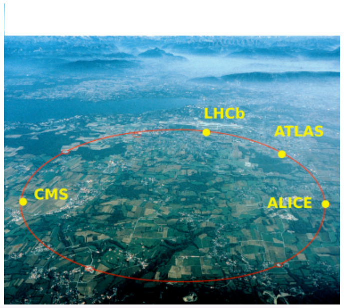
The Search for New Physics at the LHC

50 JAHRE
MPI für Physik in München
50 Years of MPI for Physics in Munich

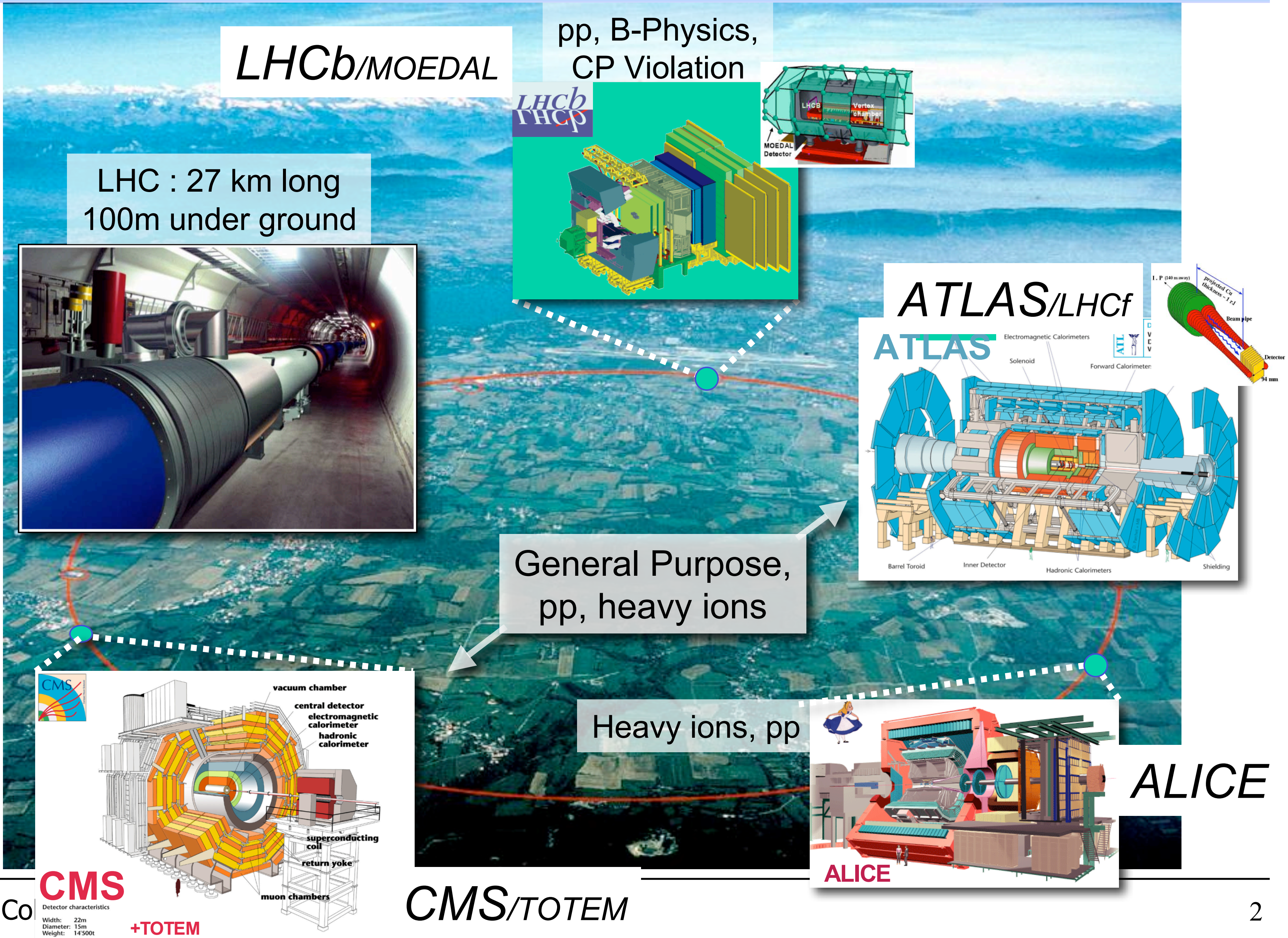
Oliver Buchmüller
CERN



- *LHC Startup and the "LHC Environment"*
  - a real challenge
- *Physics Commissioning*
  - rediscovery of the SM
- *Search for New Physics in the Early Days*
  - focus on illustrative examples from ATLAS/CMS

MPI Colloquium 02/12/2008

The Large Hardon Collider at CERN



LHCb/MOEDAL

pp, B-Physics,
CP Violation

LHC : 27 km long
100m under ground

ATLAS/LHCf

General Purpose,
pp, heavy ions

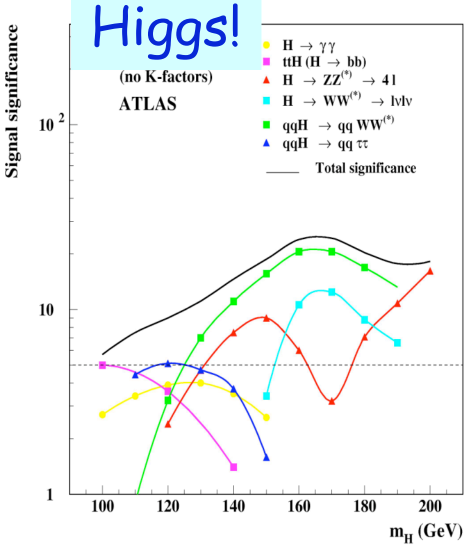
Heavy ions, pp

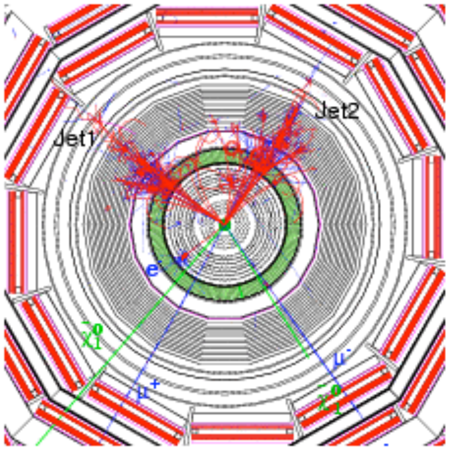
ALICE

CMS/TOTEM

A Glimpse at the LHC Physics Program

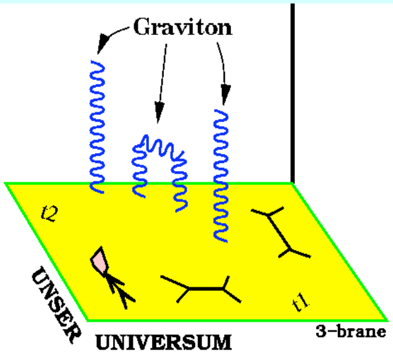
Higgs!



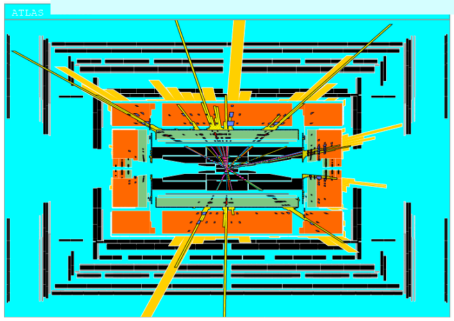


Supersymmetry?

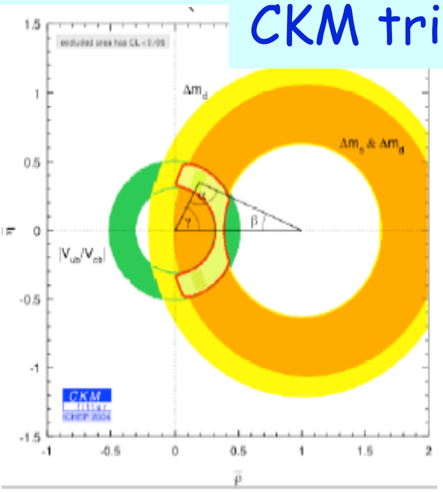
Extra Dimensions??



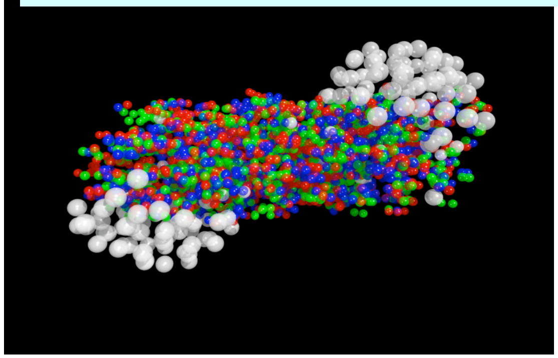
Black Holes???



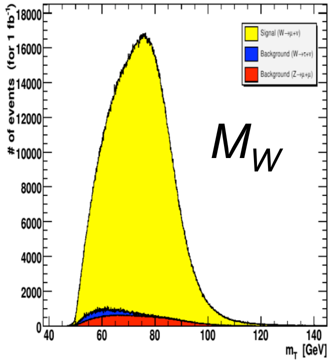
CKM triangle!

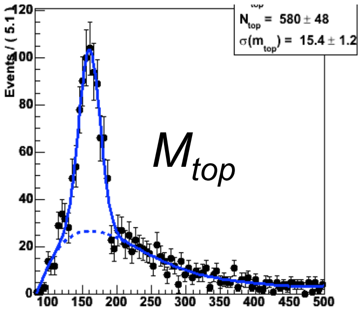


Quark Gluon Plasma?



Precision Electroweak!

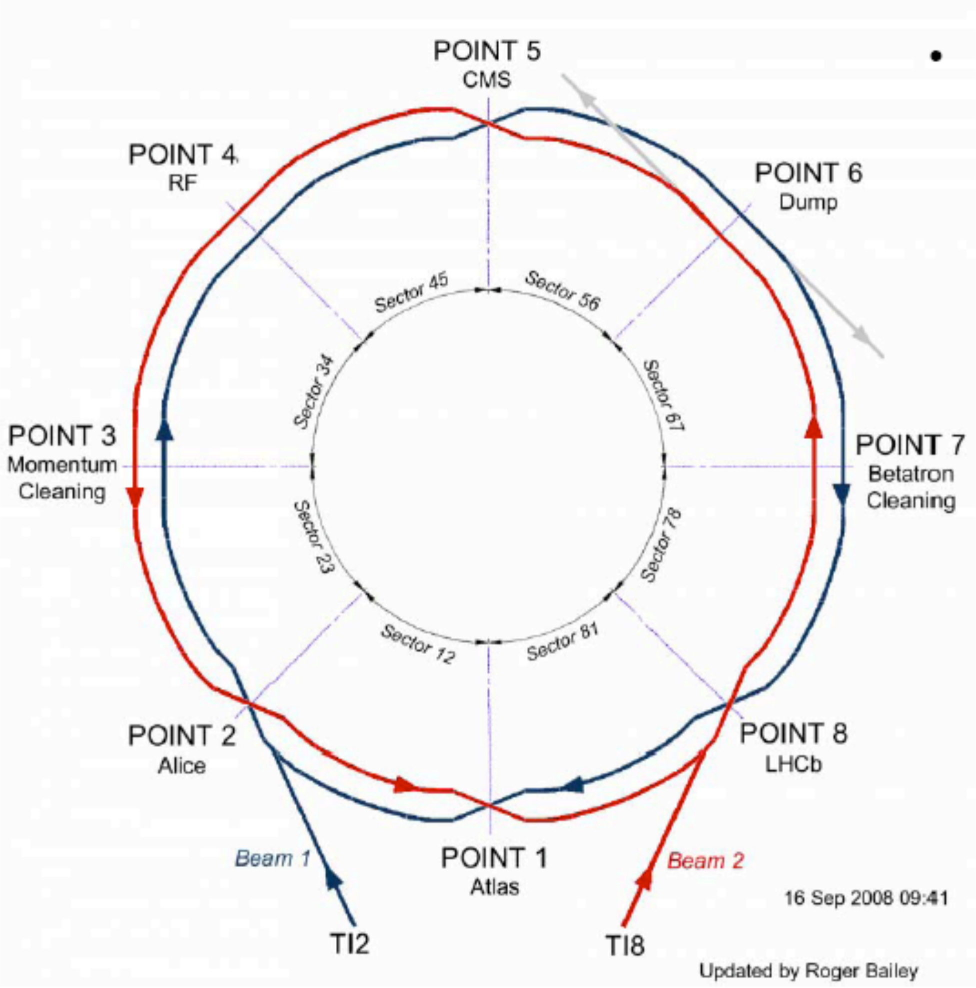




Physics at a new energy frontier!

LHC Startup - 10 September 2008

LHC Startup - 10 September 2008



16 Sep 2008 09:41

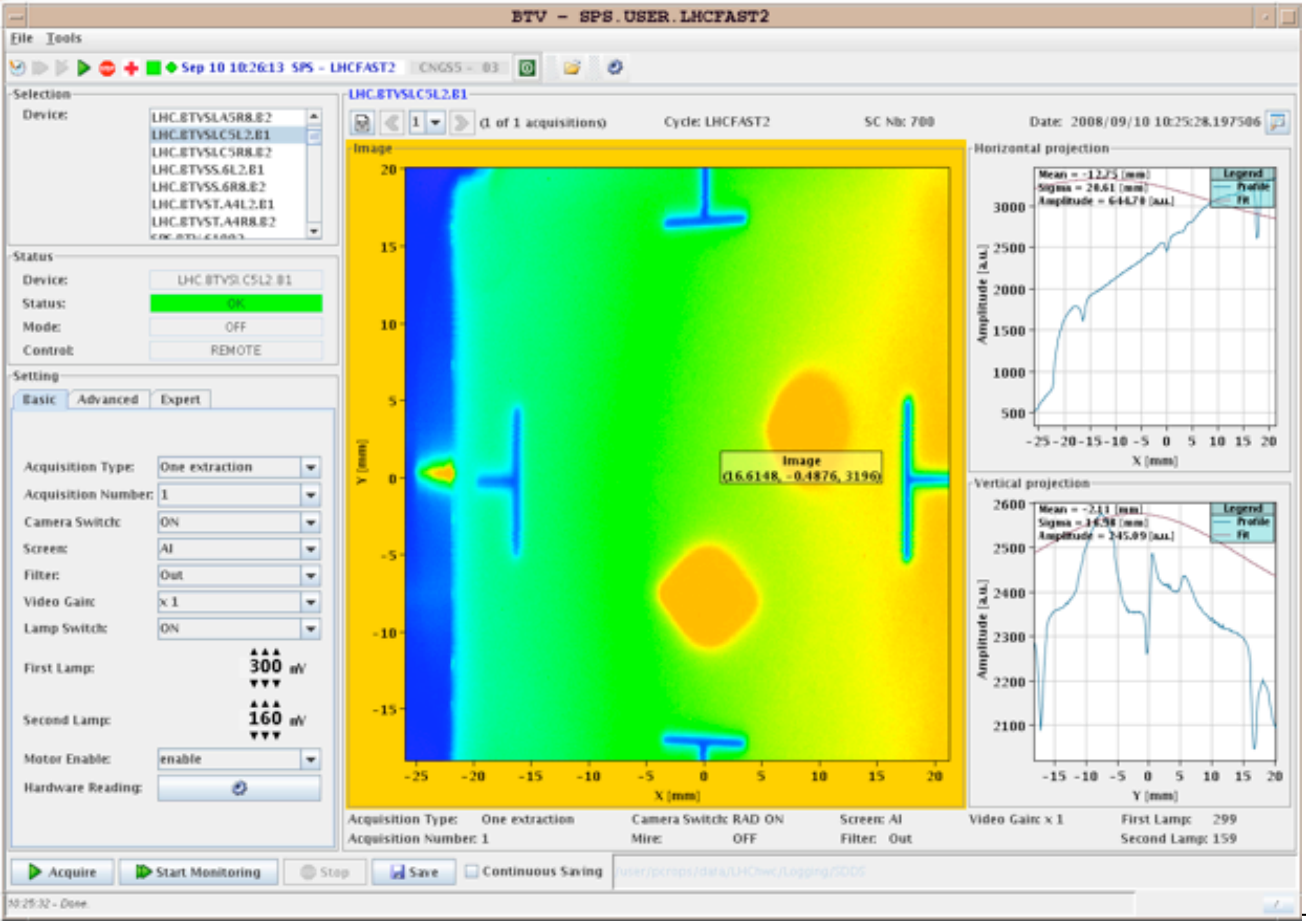
Updated by Roger Bailey

- Achieved
  - **Beam 1** injected IP2
  - Threaded around the machine in 1h
  - Trajectory steering gave 2 or 3 turns

  - **Beam 2** injected IP8
  - Threaded around the machine in 1h30
  - Trajectory steering gave 2 or 3 turns
  - Q and Q’ trims gave a few hundred turns

(R. Bailey at CMS Pleanry)

First Beam on September 10.



BTV – SPS.USER.LHCFAST2

Sep 10 10:26:13 SPS - LHCFAST2 CNGS5 - 03

Selection

Device:
- LHC.BTVSLA5R8.B2
- LHC.BTVSLC5L2.B1
- LHC.BTVSLC5R8.B2
- LHC.BTVSS.6L2.B1
- LHC.BTVSS.6R8.B2
- LHC.BTVST.A4L2.B1
- LHC.BTVST.A4R8.B2

Status

Device: LHC.BTVSLC5L2.B1
Status: OK
Mode: OFF
Control: REMOTE

Setting

Acquisition Type: One extraction
Acquisition Number: 1
Camera Switch: ON
Screen: Al
Filter: Out
Video Gain: x 1
Lamp Switch: ON
First Lamp: 300 mV
Second Lamp: 160 mV
Motor Enable: enable

LHC.BTVSLC5L2.B1

1 (1 of 1 acquisitions) Cycle: LHCFAST2 SC Nb: 700 Date: 2008/09/10 10:25:28.197506

Image (16.6148, -0.4876, 3196)

Horizontal projection

Mean = -12.75 [mm]
Sigma = 20.61 [mm]
Amplitude = 644.70 [a.u.]

Vertical projection

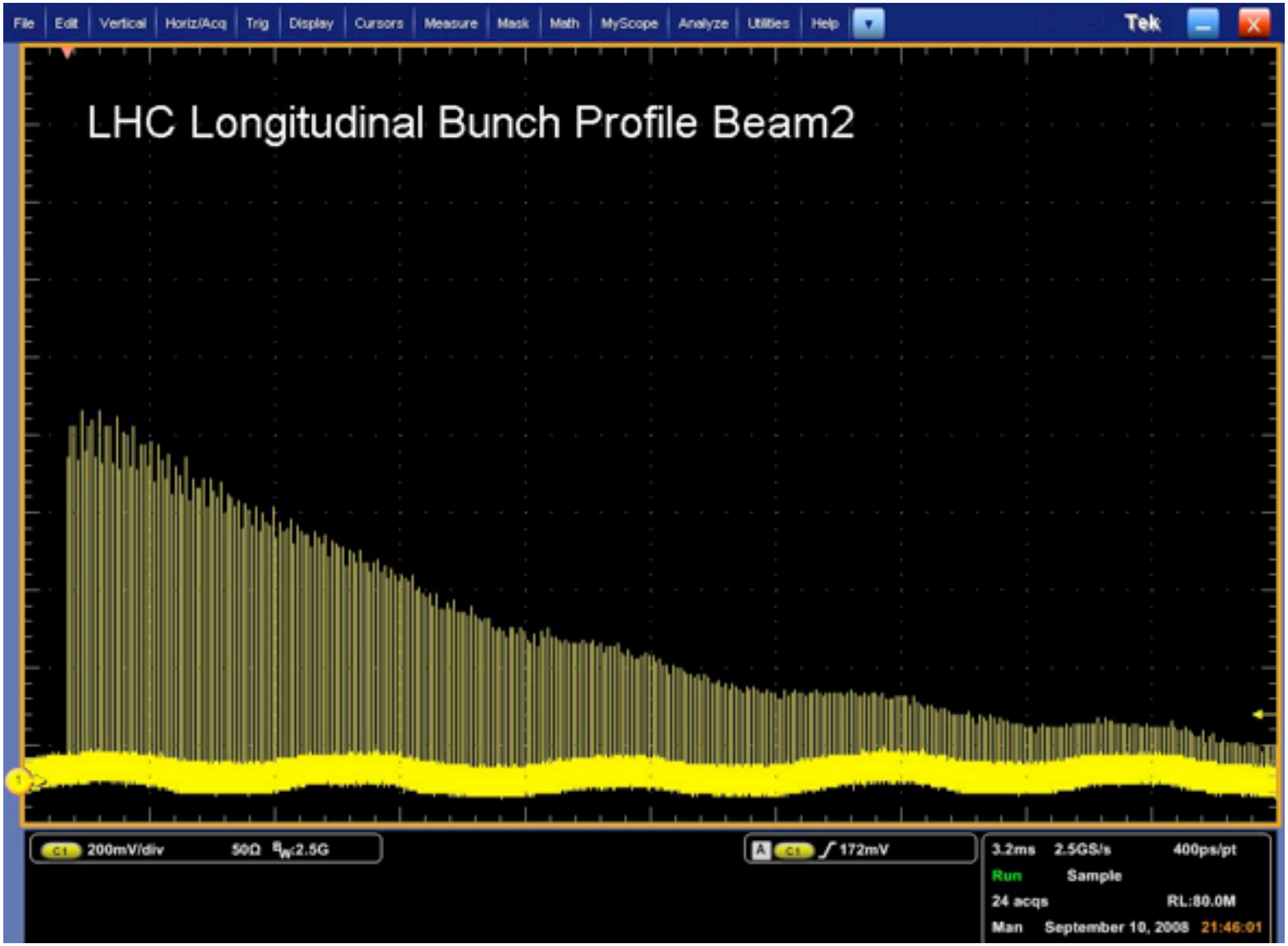
Mean = -2.11 [mm]
Sigma = 16.98 [mm]
Amplitude = 245.09 [a.u.]

Acquisition Type: One extraction
Acquisition Number: 1
Camera Switch: RAD ON
Mire: OFF
Screen: Al
Filter: Out
Video Gain: x 1
First Lamp: 299
Second Lamp: 159

☐ Continuous Saving /user/pcrops/data/LHCbwc/Logging/SDDS

10:25:32 - Done

Many Turns



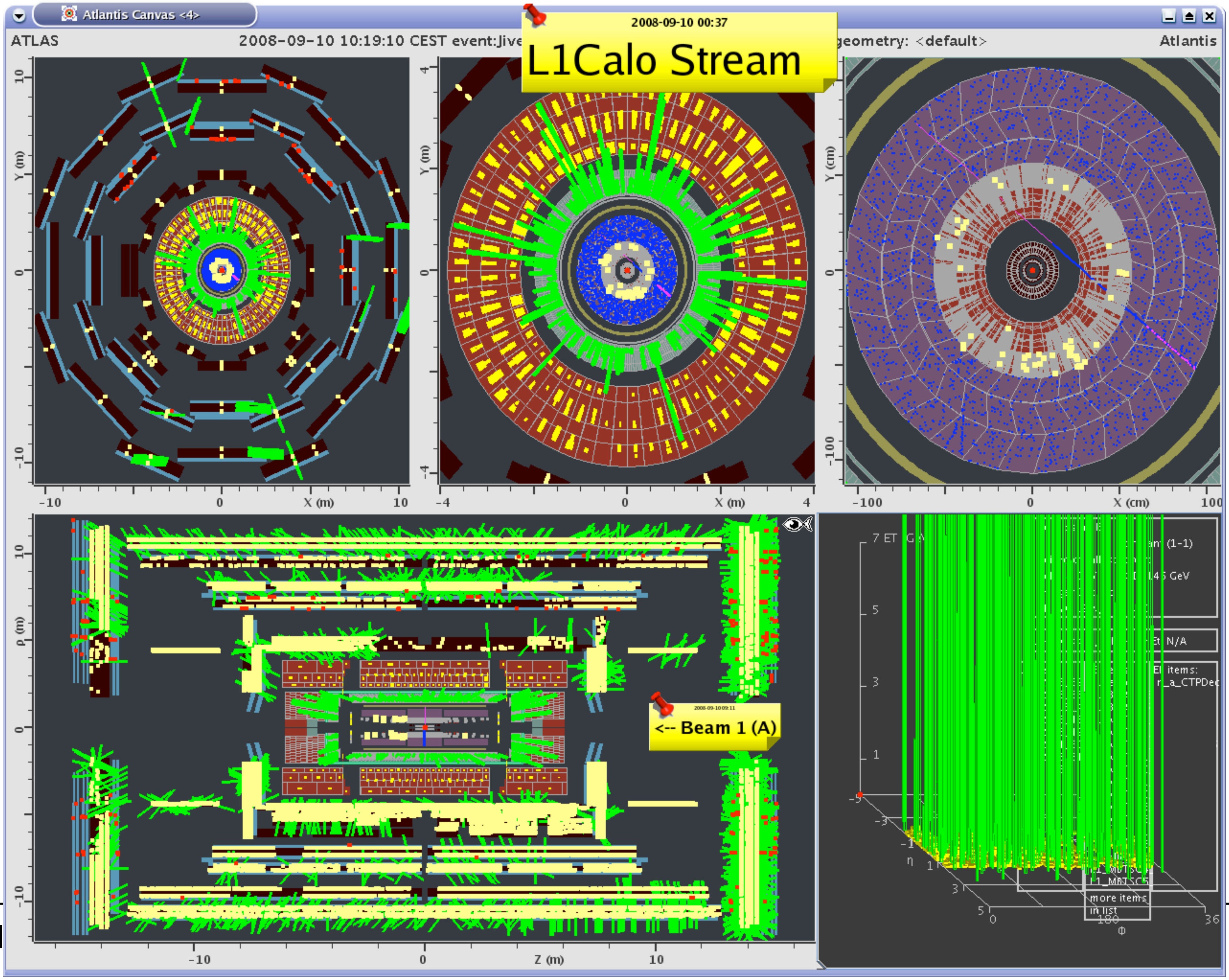
LHC Longitudinal Bunch Profile Beam2

200mV/div 50Ω B_W:2.5G

172mV

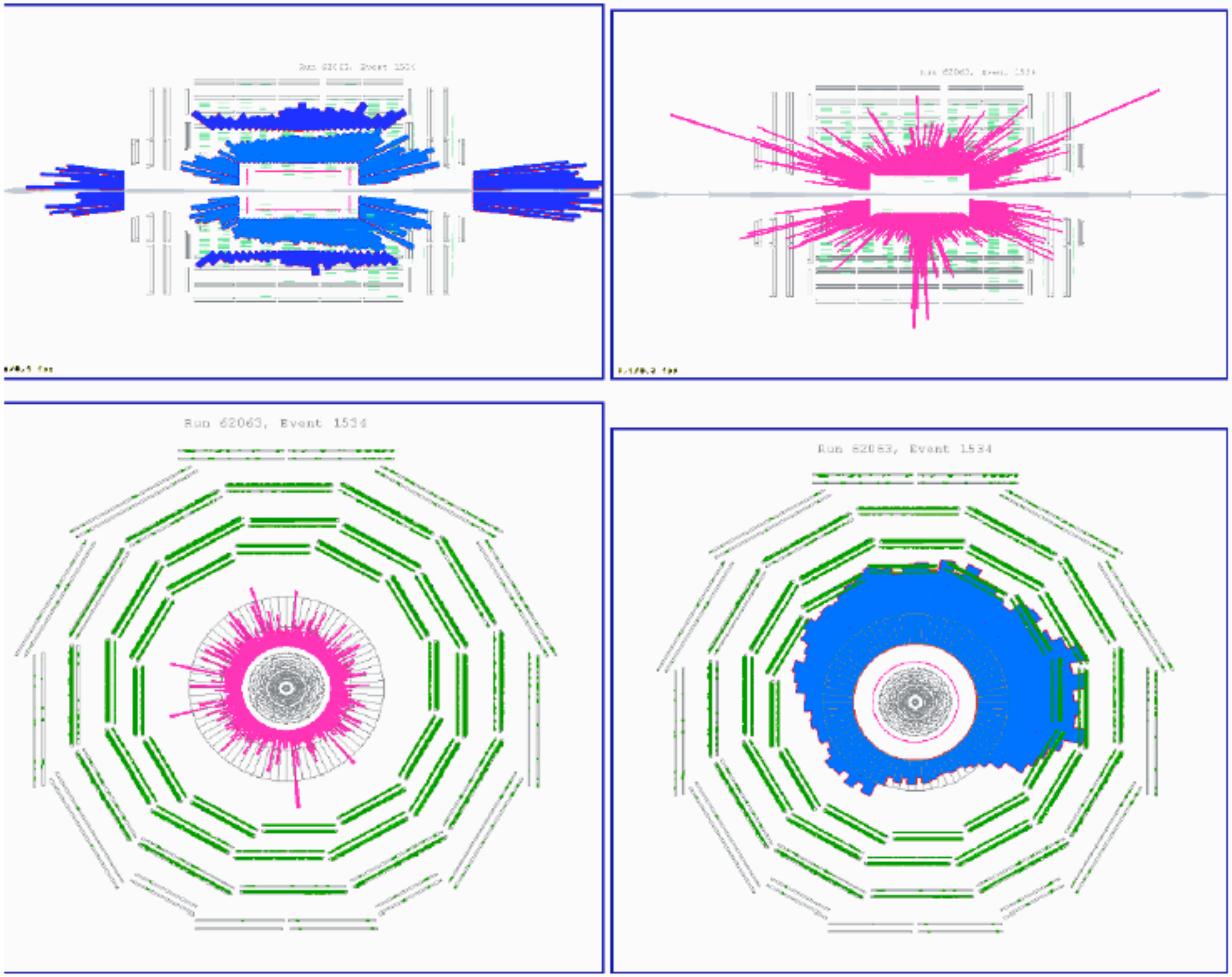
3.2ms 2.5GS/s 400ps/pt
Run Sample
24 acqs RL:80.0M
Man September 10, 2008 21:46:01

First Events in ATLAS



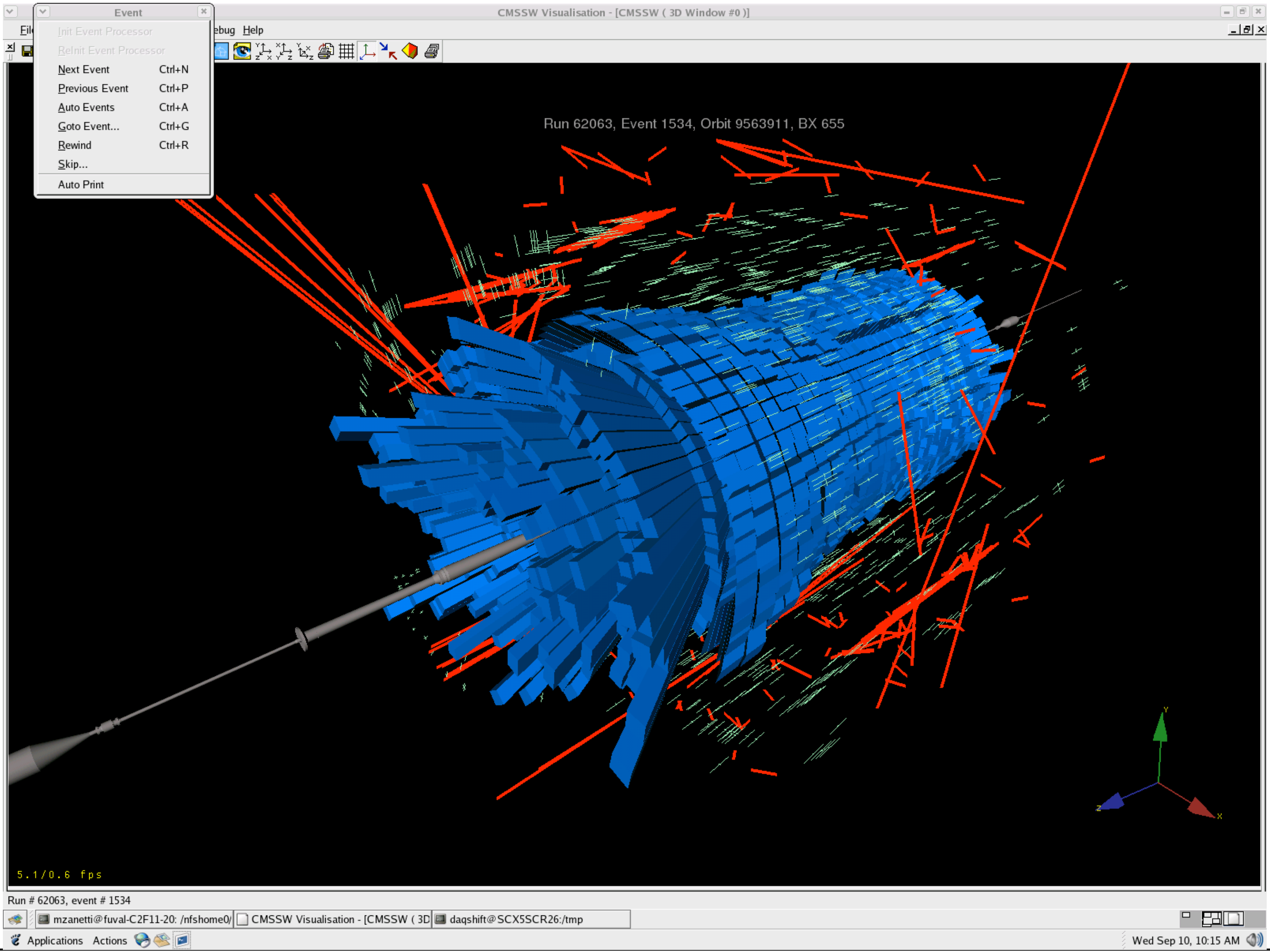
First Event in CMS

~2x10^9 protons on collimator 150 m upstream of CMS



Ecal - pink, HB,HE light blue, HO, HF dark blue,Muon DT green

Impressive Energy Deposits in CMS

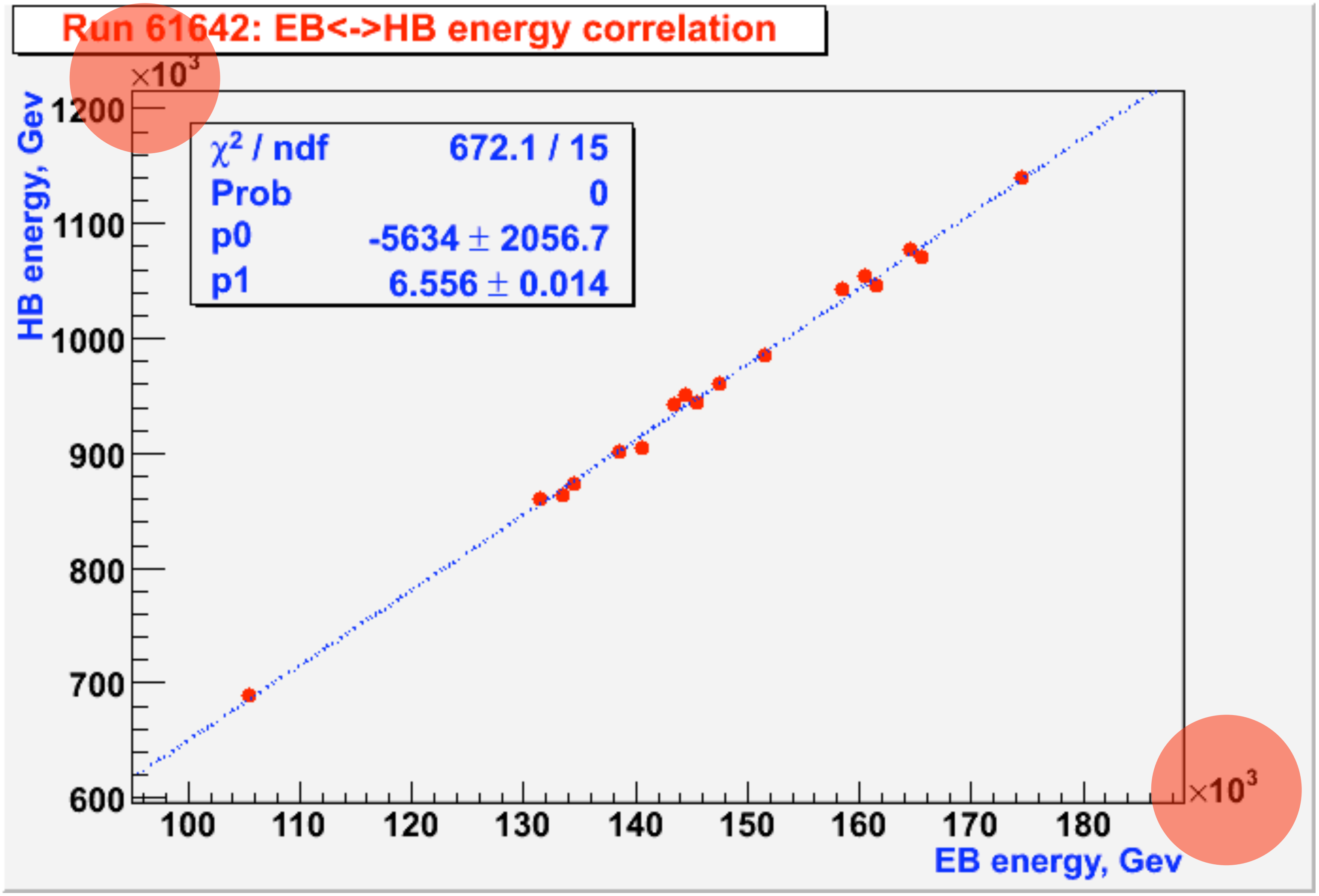


Run 62063, Event 1534, Orbit 9563911, BX 655

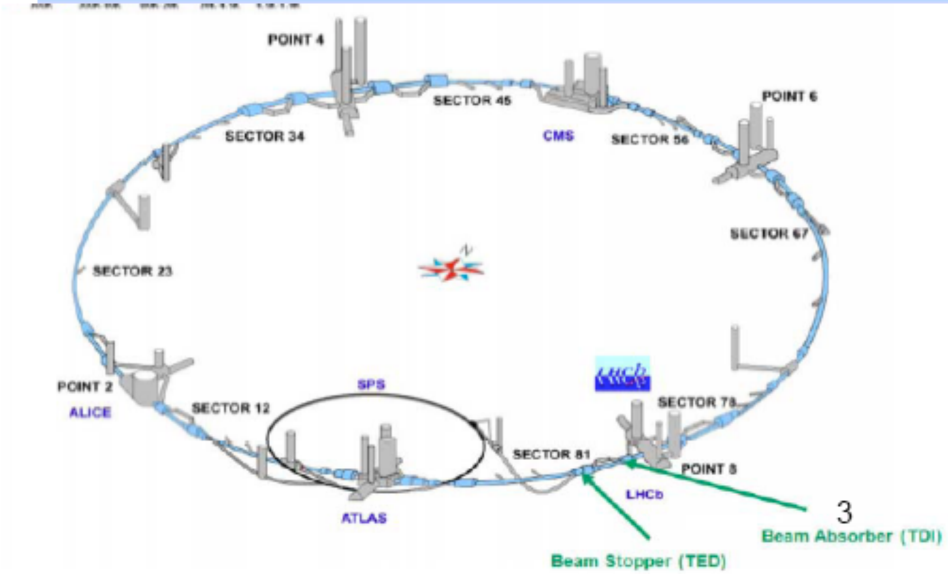
Run # 62063, event # 1534

Energy Deposits: ECAL vs. HCAL

Beam dump at collimators produces many proton collisions upstream that reach 100s and 1000s of TeV in CMS!

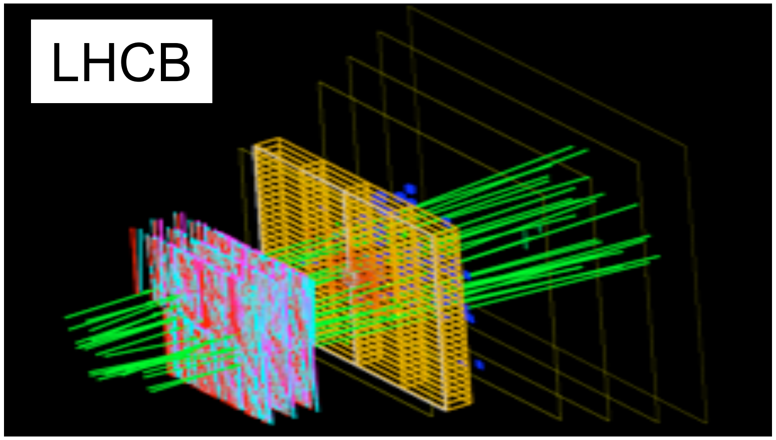


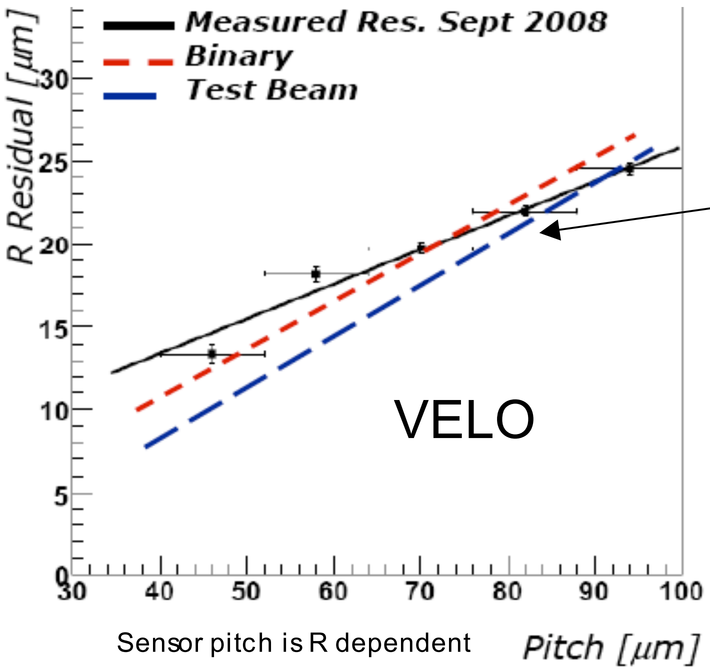
First Alignment with Beam Data



Muons originating from the beam stopping in P2 (~300 away from LHCB) are used for alignment

(e.g. injection test from August 24)



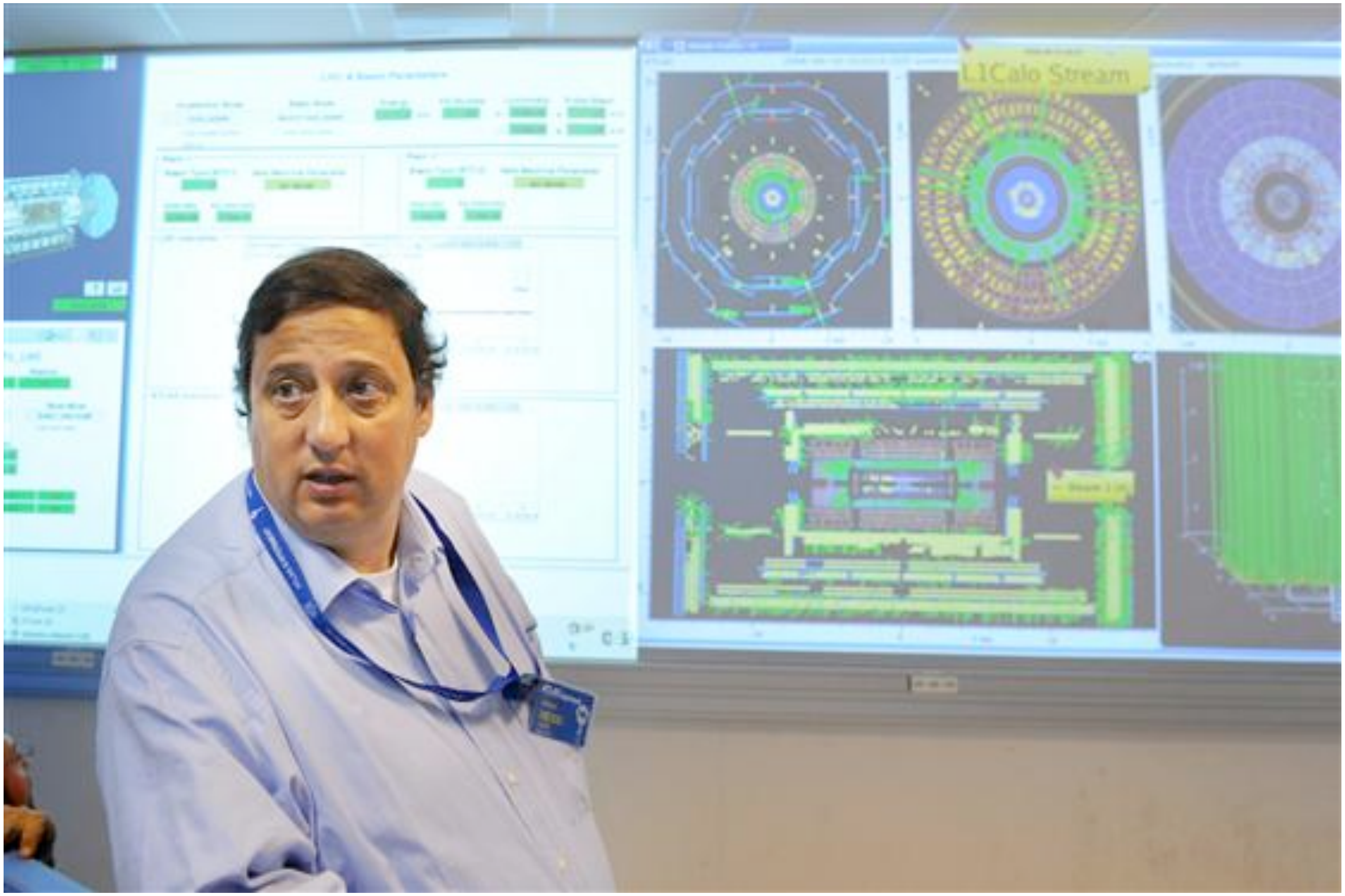


Sensor pitch is R dependent

VELO Alignment with straight muon tracks. Good agreement with test beam data for large sensor pitch values. Some disagreement at lower values - residual mis-alignment?!

Already very little beam data can be very useful for commissioning!

It Works?!



Yes, it really works!

Lets celebrate!

The 9/19 Incident

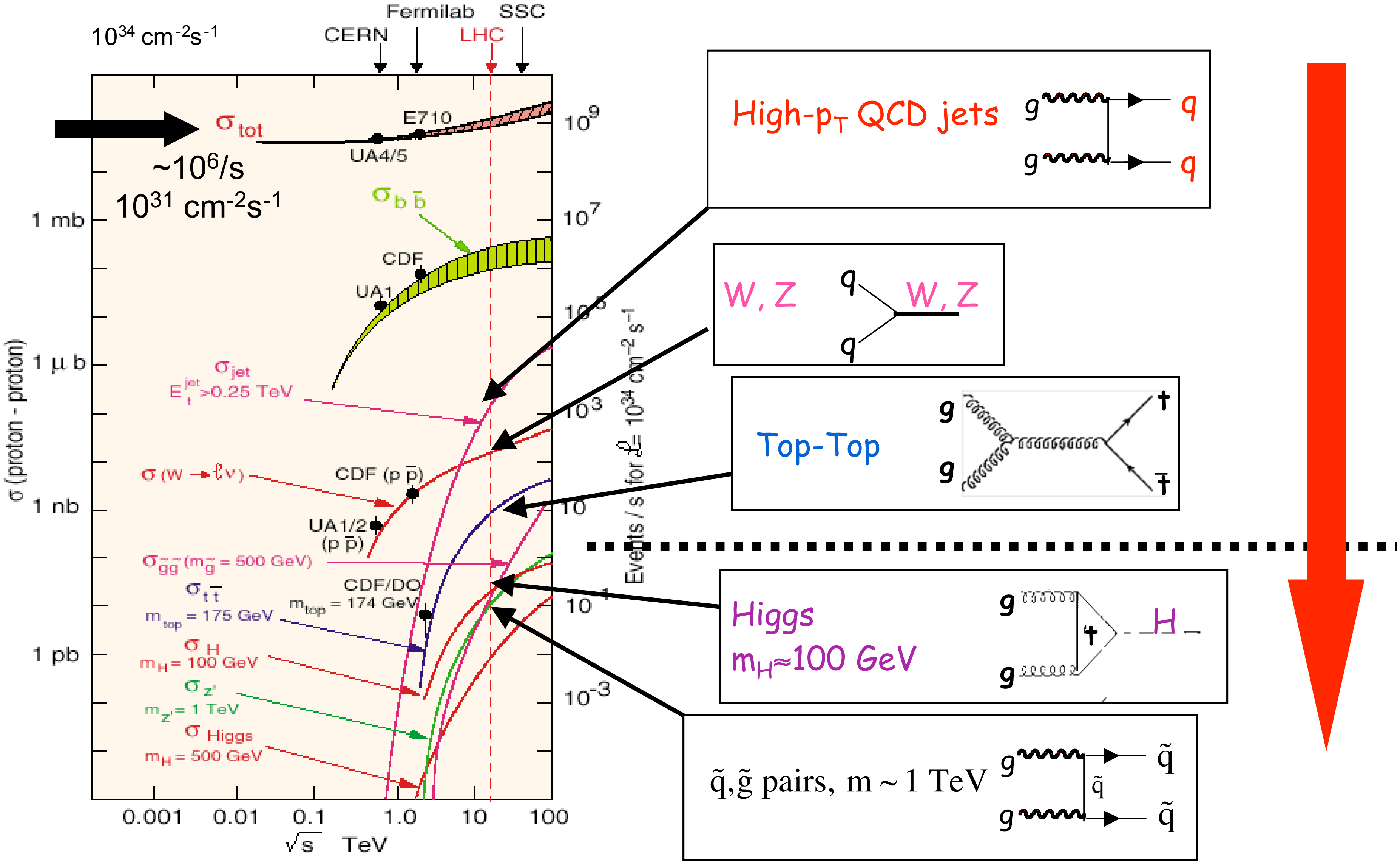
- Start-of of the LHC on 9/10 was really good
  - Beam circulating for 30 minutes within days.
- However on 9/19 an unfortunate incident happened
  - An electrical resistive zone built up and led to an electric arc in the cryogenics part in one of the 8 arcs of the LHC
  - This created a rupture in the helium enclosure of the magnets
- This created considerable damage that needs to be repaired
  - Takes several months (at least)
  - Cause and preventive measures still under study
  - 6 tons of helium were released in the tunnel…
- Planned winter shutdown (December-March) came earlier…
  - LHC back and starting physics program in 2009 after the shutdown
  - Definite schedule for 2009 not released yet

Significant Damage

Q27

The LHC Environment

Background and Signal



High-p_T QCD jets

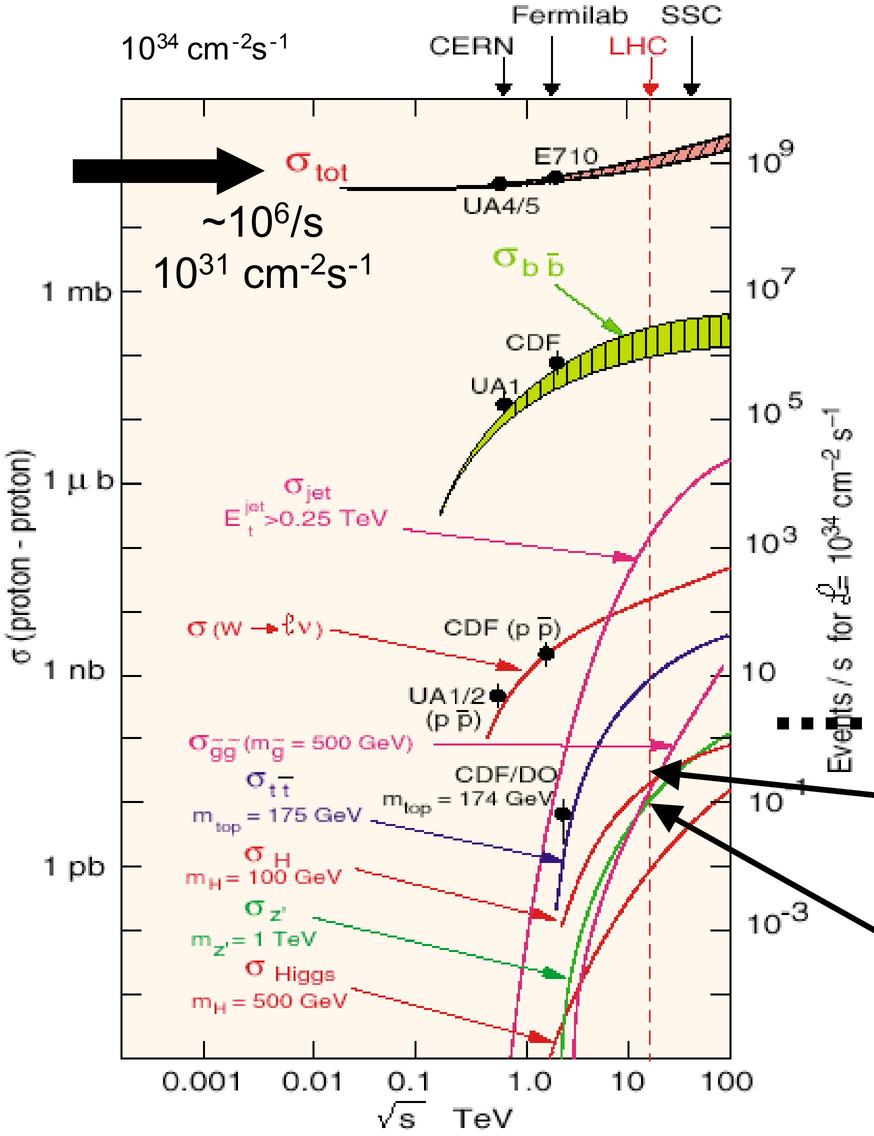
W, Z

Top-Top

Higgs
m_H≈100 GeV

q̃,g̃ pairs, m ~ 1 TeV

Background and Signal

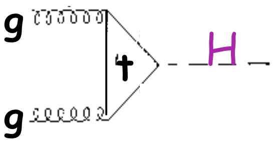


Searching for these events is like looking for a needle in a (very) big haystack:

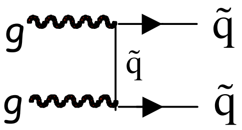
σ_{tot} ≈ 100mb
Jets w. E_T>100 GeV ≈ 1μb
ttar ≈ 800pb

In order to find the "needle", we need to understand these processes very well (don't forget, additional hard jets only cost α_s/π ~0.1)

Higgs
m_H≈100 GeV

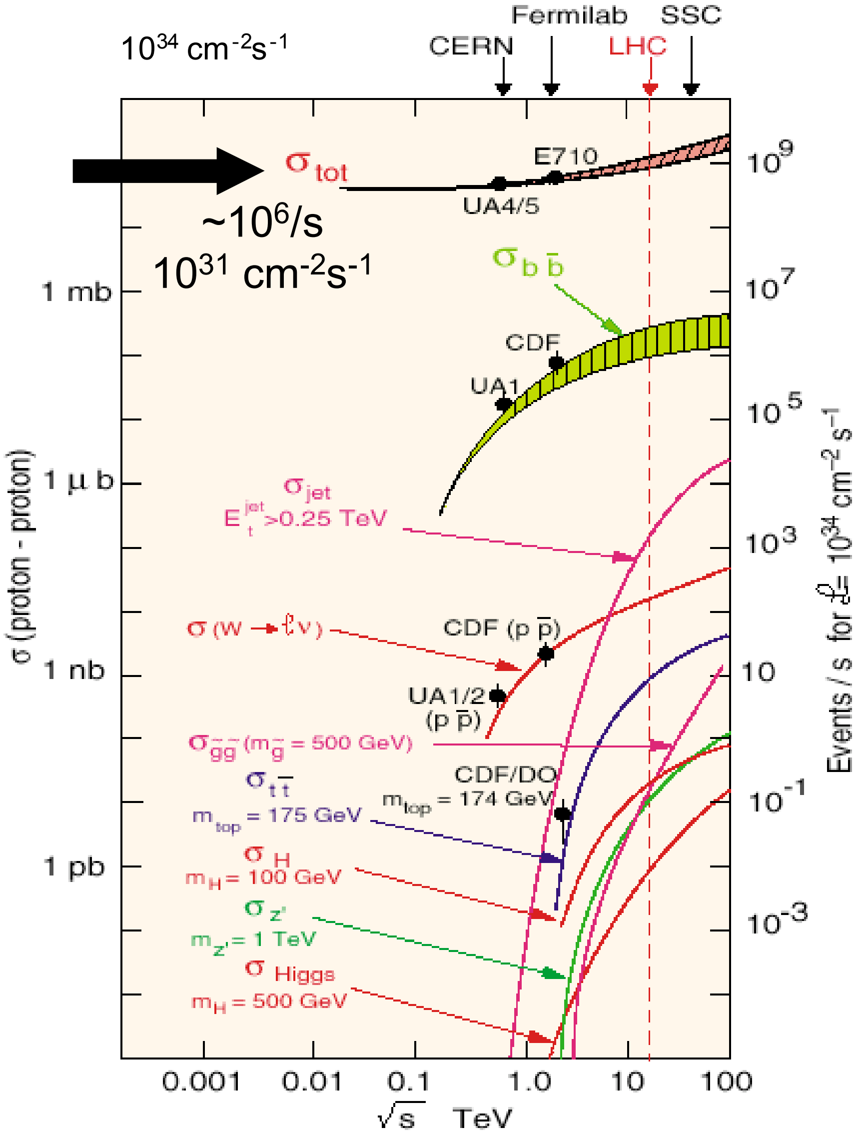


$\tilde{q},\tilde{g}$ pairs, m ~ 1 TeV



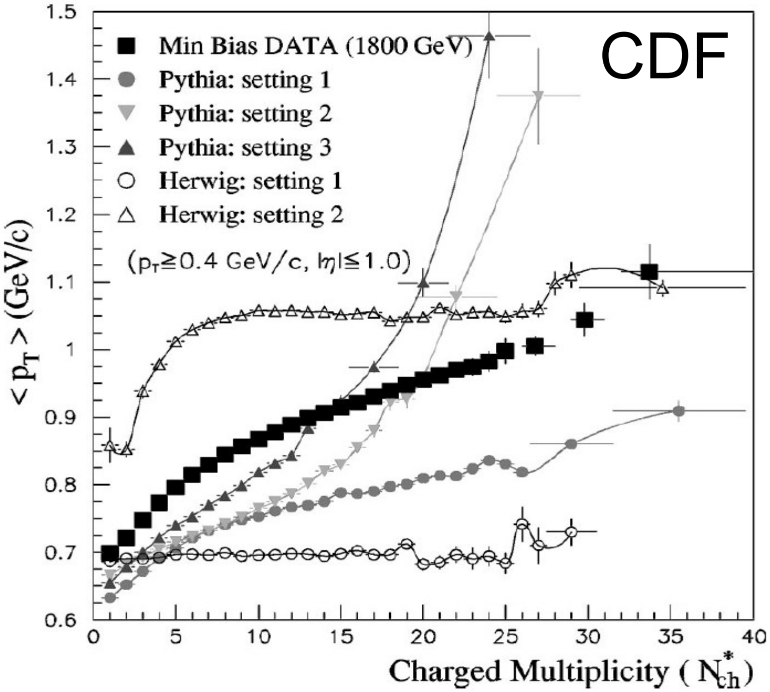
Physics Commissioning with the first collision data

First Phase



"Why":Measure Charged Particle Density

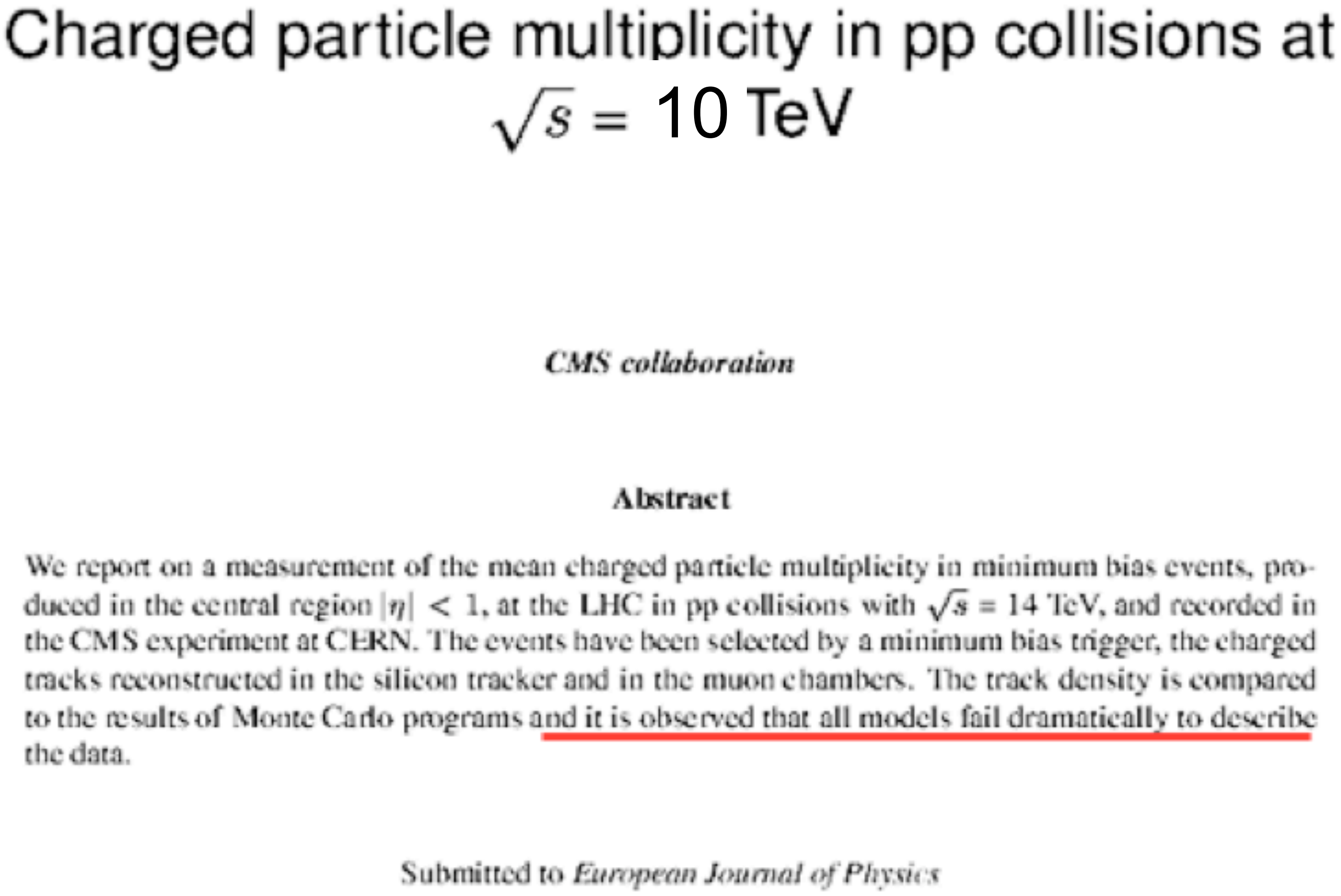
- W,Z, ttbar cross sections known to ~3 to 10%
- Large uncertainties in minimum bias **$dN_{ch}/d\eta$** known to only ~50% (or worse)



Precise knowledge of $dN_{ch}/d\eta$ very important for *MC tuning, understanding underlying event*, pile-up etc.

1 December 2009??

- *Probably one of the first papers:*
  not Higgs, not SUSY,
  but rather “boring bread-and-butter” stuff



Charged particle multiplicity in pp collisions at $\sqrt{s}$ = 10 TeV

CMS collaboration

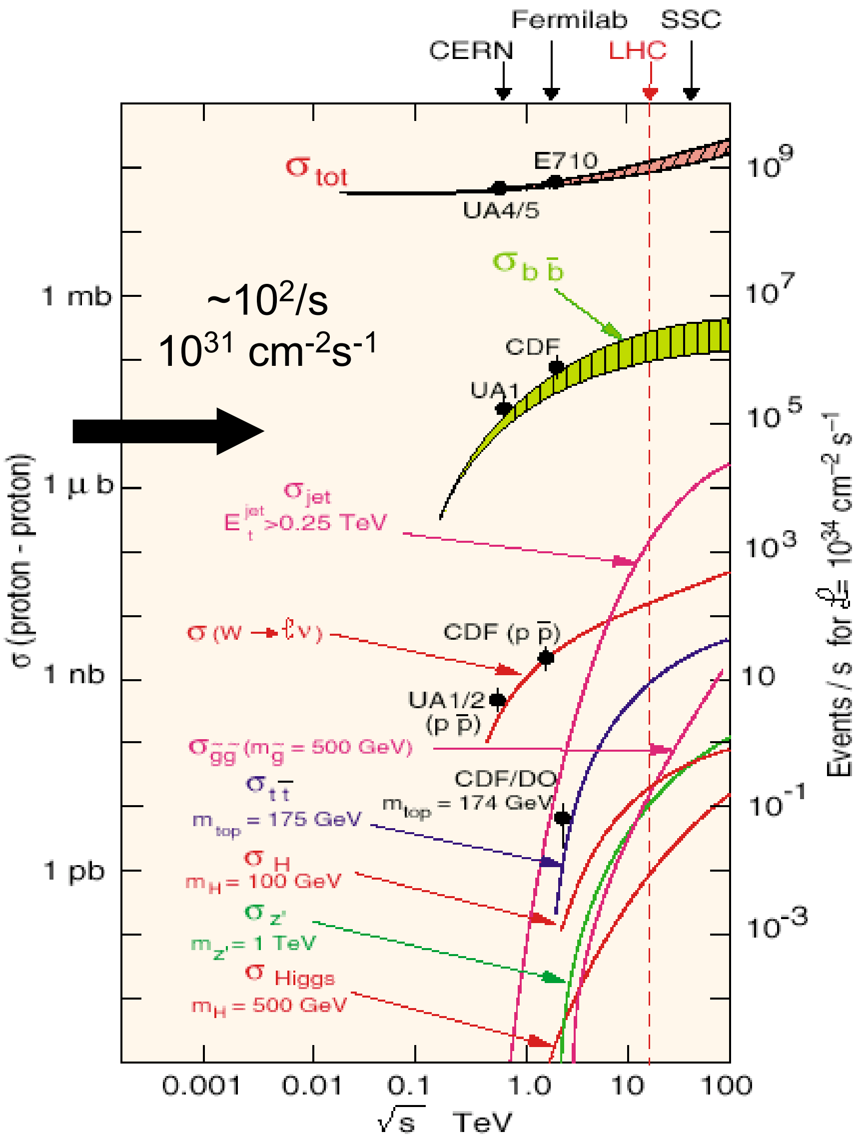
Abstract

We report on a measurement of the mean charged particle multiplicity in minimum bias events, produced in the central region $|\eta| < 1$, at the LHC in pp collisions with $\sqrt{s}$ = 14 TeV, and recorded in the CMS experiment at CERN. The events have been selected by a minimum bias trigger, the charged tracks reconstructed in the silicon tracker and in the muon chambers. The track density is compared to the results of Monte Carlo programs and it is observed that all models fail dramatically to describe the data.

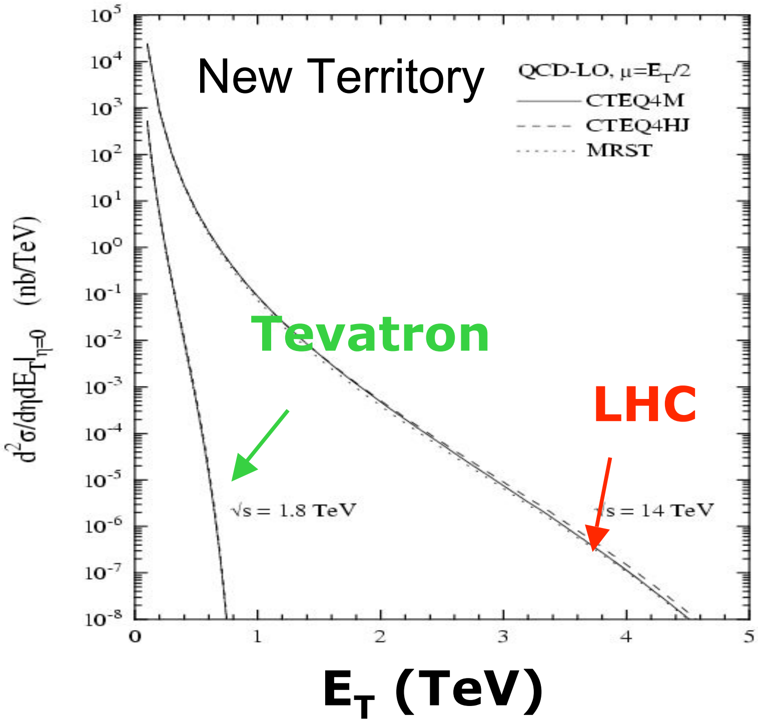
Submitted to *European Journal of Physics*

Second Phase

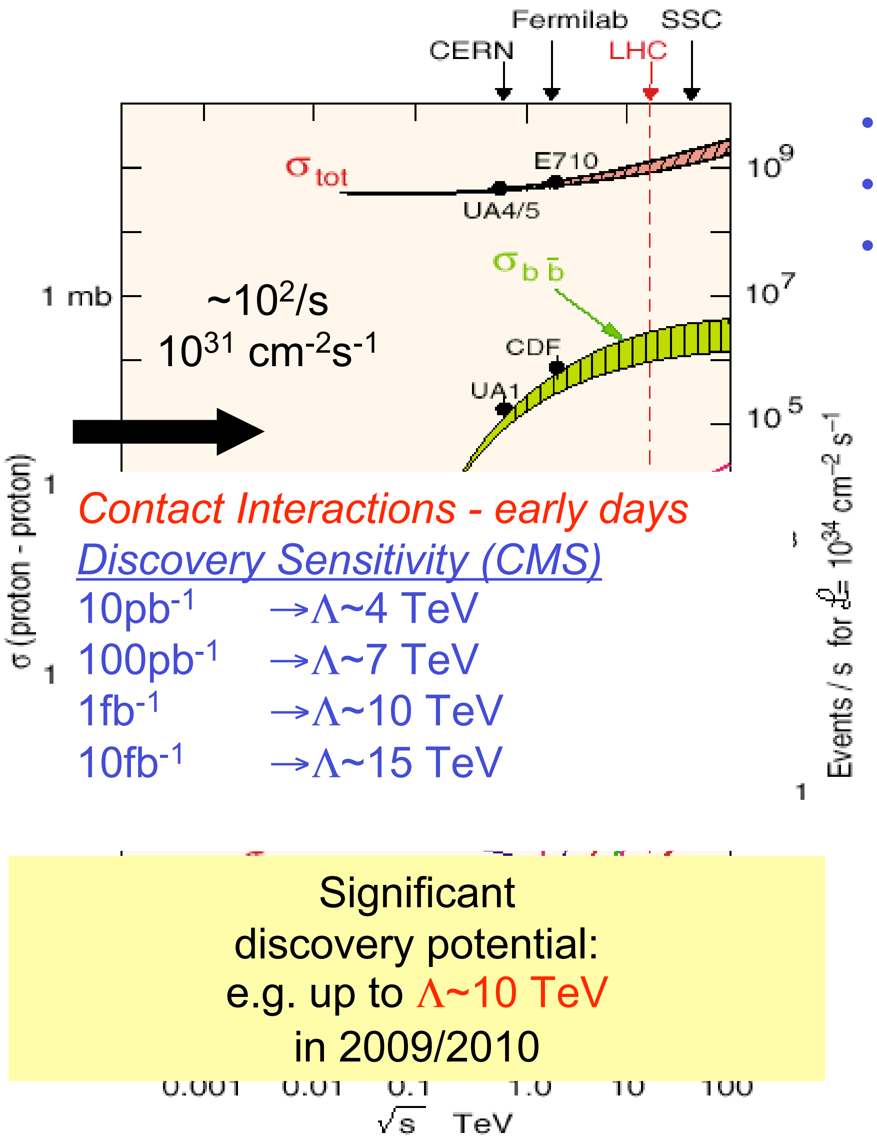
Measure Jet Cross Section



- E_T^{Jet} > 500 GeV after a few weeks at 10^{31}cm^{-2}s^{-1}
- Going fast beyond the reach of the Tevatron
- Early sensitivity to compositeness requires understanding of the jet energy scale, PDF's, …



Second Phase



~10^2/s
10^{31} cm^{-2}s^{-1}

Contact Interactions - early days

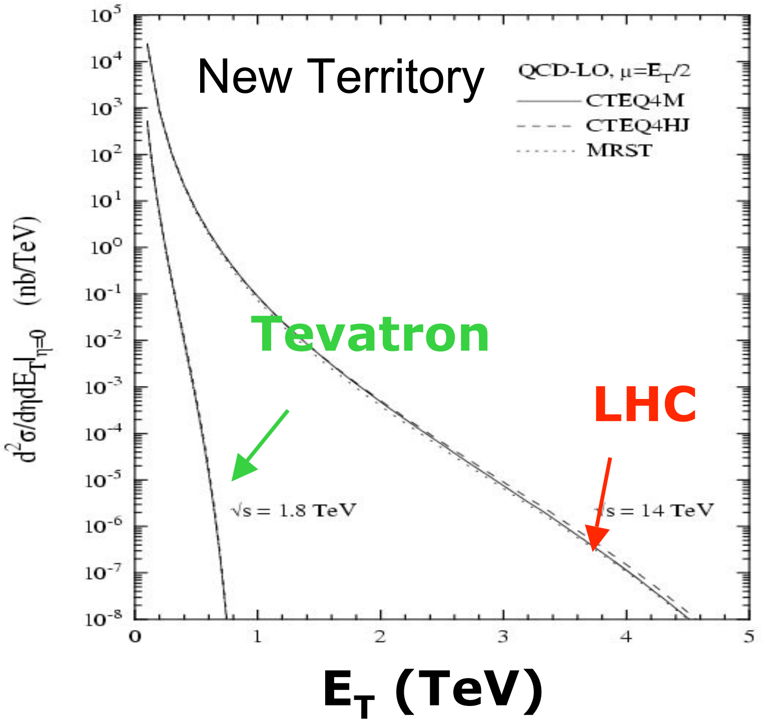
Discovery Sensitivity (CMS)

10pb^{-1}	→Λ~4 TeV
100pb^{-1}	→Λ~7 TeV
1fb^{-1}	→Λ~10 TeV
10fb^{-1}	→Λ~15 TeV

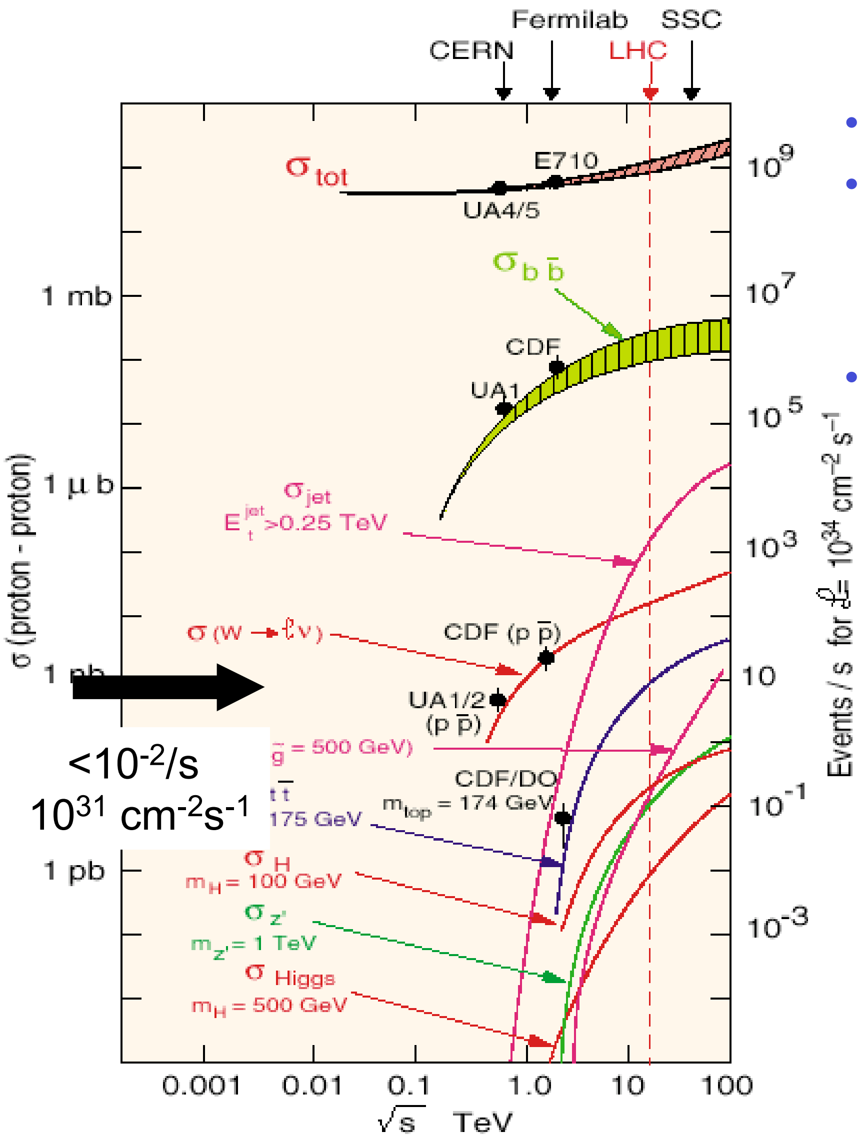
Significant
discovery potential:
e.g. up to Λ~10 TeV
in 2009/2010

Measure Jet Cross Section

- E_T^{Jet} > 500 GeV after few weeks at 10^{31}cm^{-2}s^{-1}
- Going fast beyond the reach of the Tevatron
- Early sensitivity to compositeness; requires understanding of the jet energy scale, PDF's, …



Third Phase



<10^{-2}/s

10^{31} cm^{-2}s^{-1}

Rediscover the SM

- Reestablish the Standard Model
- Most SM cross sections are significantly higher than at the Tevatron
  e.g. σ_{ttbar} (LHC)> 100 x σ_{ttbar} (Tevatron)
- Crucial for final Detector and Physics Commissioning

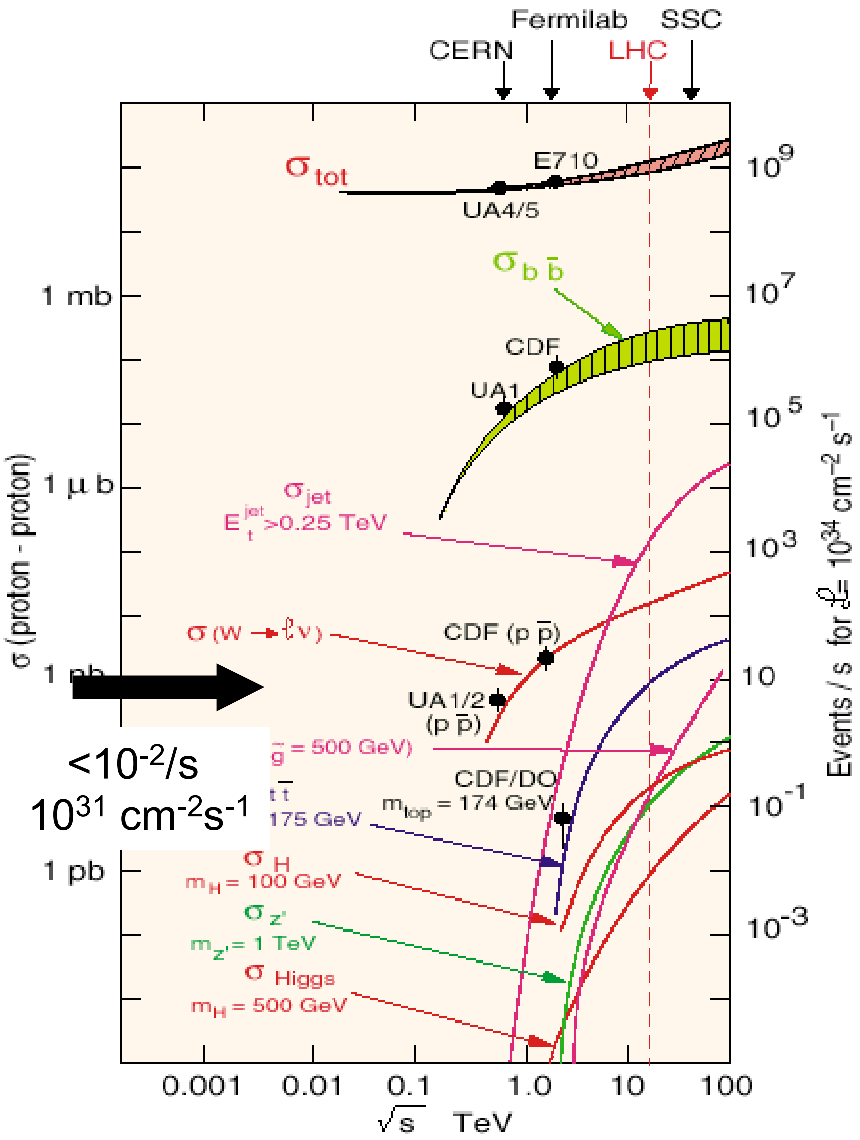
THE path to new physics! 14 TeV

At Luminosity 10^{31}cm^{-2}s^{-1}

bb production:	→ 10^3 Hz
W→ ℓ ν:	→0.1 Hz
Z→ ℓ ℓ:	→0.01 Hz
t t production:	→0.01 Hz
SM Higgs	→0.0001 Hz

At this stage the LHC becomes a real SM Factory!

Third Phase



$<10^{-2}$/s

10^{31} cm^{-2}s^{-1}

Rediscover the SM

For L=10/pb @ 10 TeV

W→ ℓ ν:	→300K Events
Z→ ℓ ℓ:	→30K Events
t t production:	→10K Events

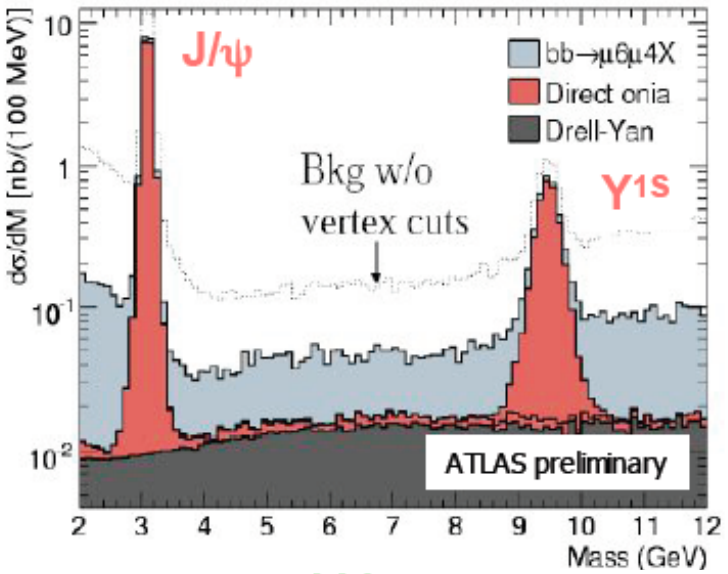
Rather large data samples already expected for 2009!

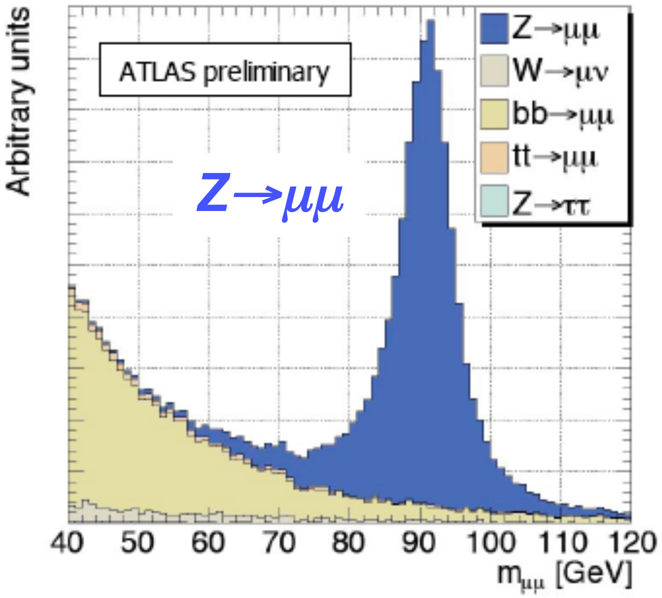
Production Rate: 10 vs.14 TeV:
- W/Z ~70%
- ttbar ~50%
- Higgs (200) ~50%

"Rediscovery" of the Standard Model @ 14 TeV (10 TeV)

Rediscovery of the SM

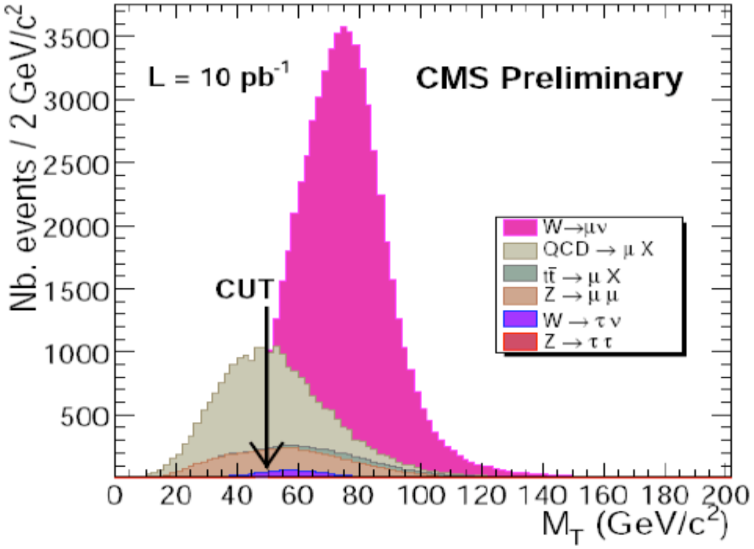
J/ϕ→μμ and Υ→μμ

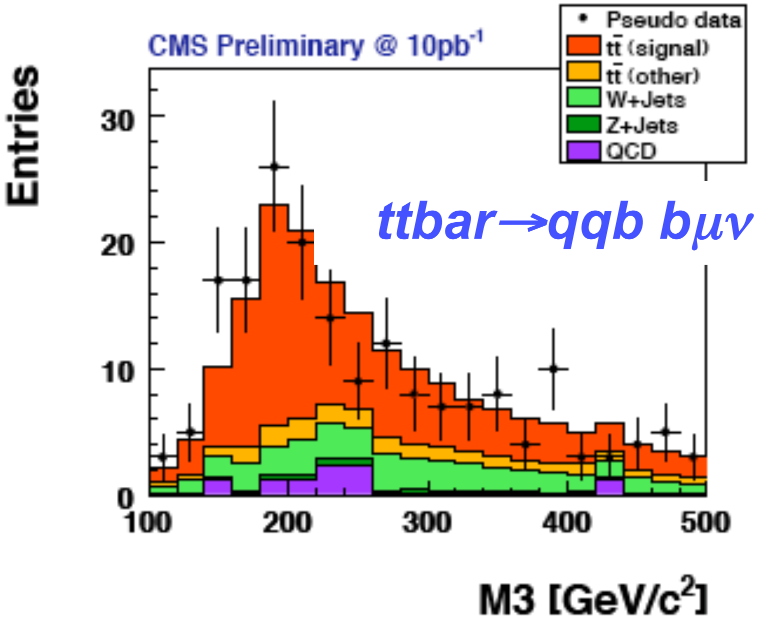




Z→μμ

W→μν





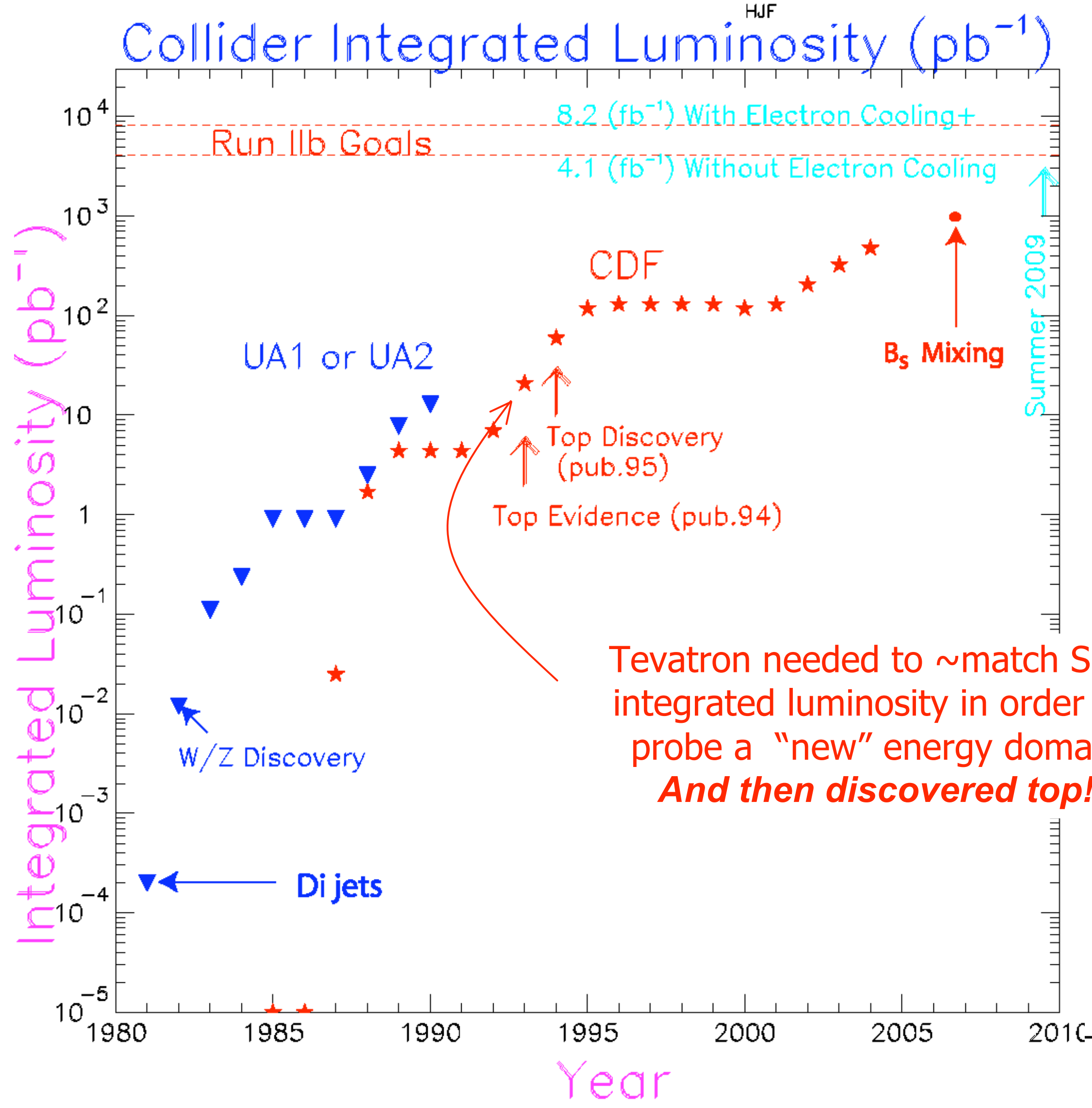
ttbar→qqb bμν

New Physics
What to expect?

Good Things Come Early … and Late

J. Incandela

Hadron Collider History

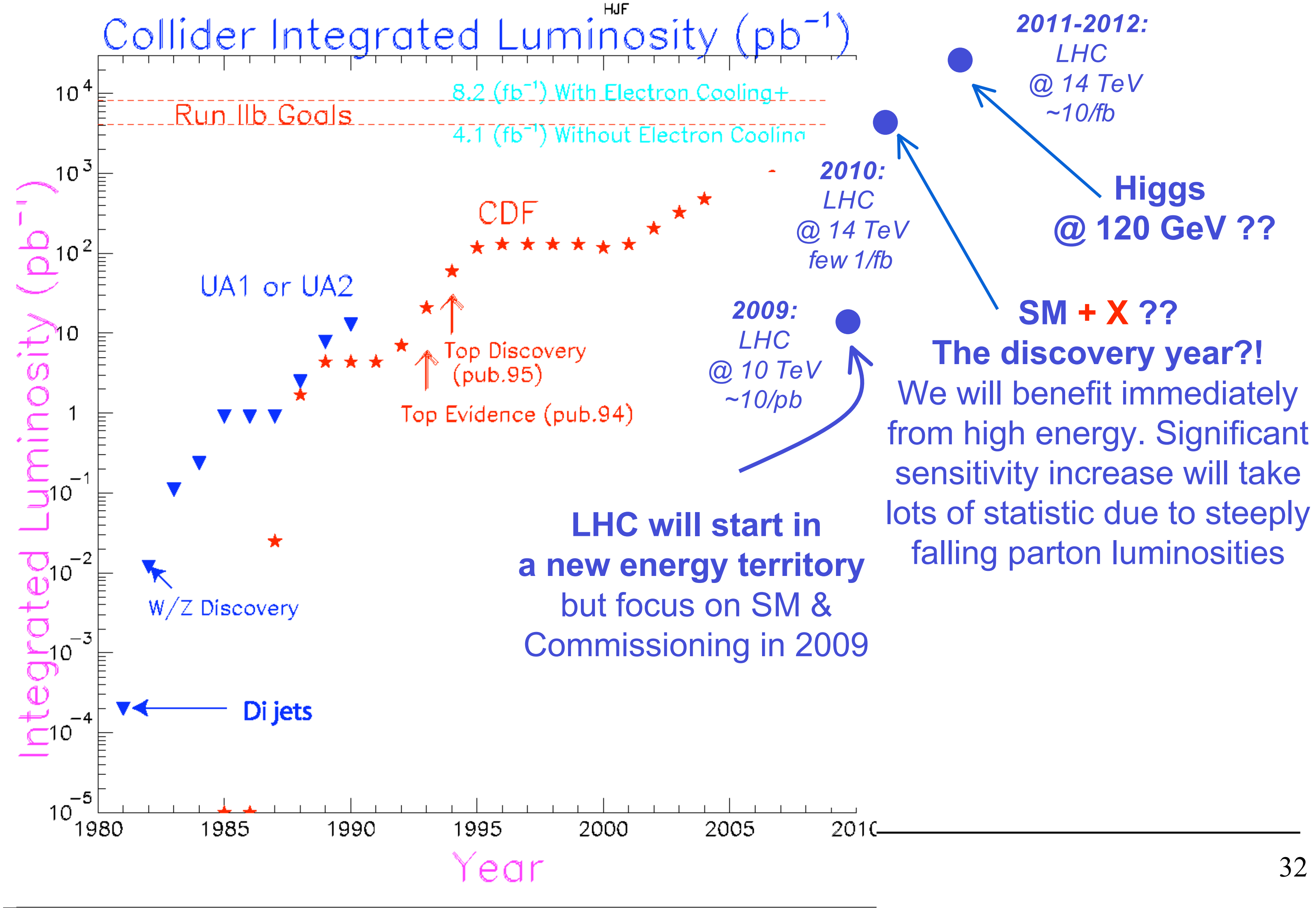


Tevatron needed to ~match SPS integrated luminosity in order to probe a “new” energy domain
And then discovered top!

Good Things Come Early … and Late

J. Incandela

Hadron Collider History … and its potential Future



2011-2012:
LHC
@ 14 TeV
~10/fb

2010:
LHC
@ 14 TeV
few 1/fb

2009:
LHC
@ 10 TeV
~10/pb

Higgs
@ 120 GeV ??

SM + X ??
The discovery year?!
We will benefit immediately from high energy. Significant sensitivity increase will take lots of statistic due to steeply falling parton luminosities

LHC will start in
a new energy territory
but focus on SM & Commissioning in 2009

Another Way to Look at It …

Many people now ask:

Will the LHC discover the Higgs boson?

My answer is …

Another Way to Look at It …

Many people now ask:

Will the LHC discover the Higgs boson?

My answer is …

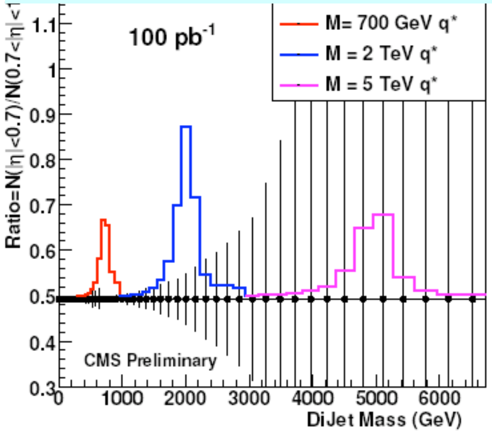
By the time the LHC discovers the Higgs boson, that discovery will no longer be considered interesting.

M.E. Peskin - Tools 2008

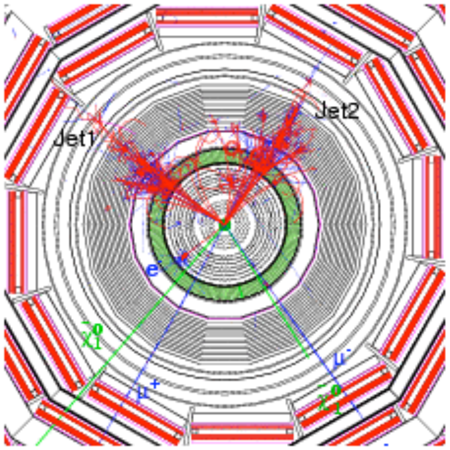
SM + X: New Physics Potential of the LHC

What could make a Higgs discovery "uninteresting"?

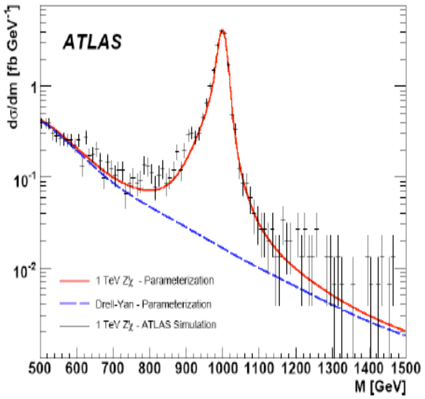
Contact Interaction /Excited Quarks?



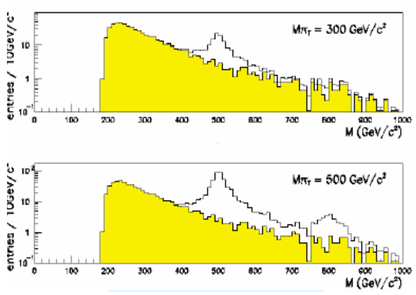
Supersymmetry?



New Gauge Bosons?



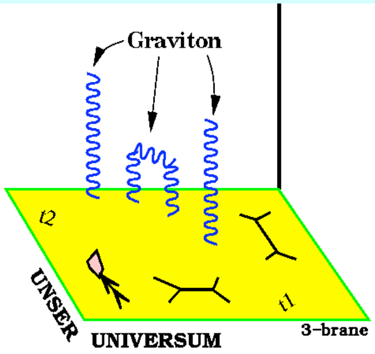
Technicolor?



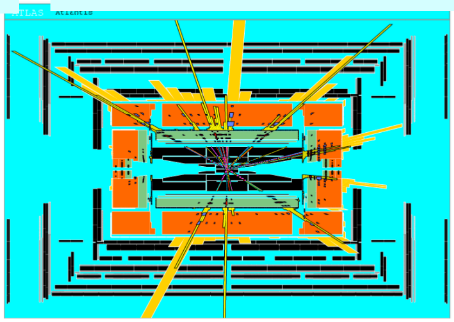
Little Higgs?

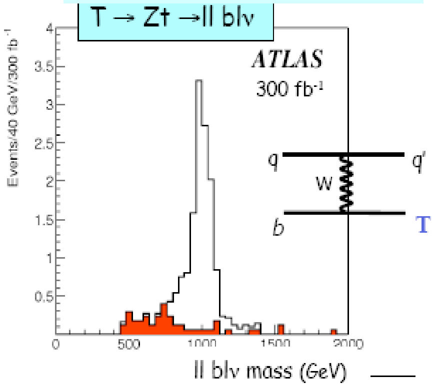
Split Susy?

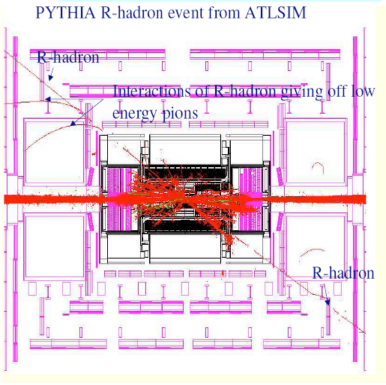
Extra Dimensions?



Black Holes???







New Physics Potential - Early Days

Model	Mass reach	Luminosity (fb^{-1})	Early Systematic Challenges
Contact Interaction	$\Lambda < 3$ TeV	0.01	Jet Eff., Energy Scale
Z' W'	M ~ 1 TeV M ~ 1 TeV	0.01-0.1 0.01	Alignment Alignment/MET
Black Holes	M_D~ 2.0 TeV	0.01	MET/ Jet Energy Scale
Excited Quark	M ~0.7 – 3.6 TeV	0.1	Jet Energy Scale
Axigluon or Colouron	M ~0.7 – 3.5 TeV	0.1	Jet Energy Scale
E6 diquarks	M ~0.7 – 4.0 TeV	0.1	Jet Energy Scale
Technirho	M ~0.7 – 2.4 TeV	0.1	Jet Energy Scale
ADD Virtual G_{KK}	M_D~ 4.3 - 3 TeV, n = 3-6 M_D~ 5 - 4 TeV, n = 3-6	0.1 1	Alignment
ADD Direct G_{KK}	M_D~ 1.5-1.0 TeV, n = 3-6	0.1	MET, Jet/photon Scale
SUSY Jet+MET+0 lepton Jet+MET+1 lepton	M ~1.5 – 1.8 TeV M ~0.5 TeV M ~0.5 TeV	1 0.01 0.1	MET, Jet Energy Scale, Multi-Jet backgrounds, Standard Model backg.
mUED	M ~0.3 TeV M ~ 0.6 TeV	0.01 1	Lepton ID
HSCP	M ~ 0.3 TeV M ~ 1.0 TeV	0.1 1	TOF, dE/Dx
RS1 di-jets di-muons	 M_{G1}~0.7- 0.8 TeV, c=0.1 M_{G1}~0.8- 2.3 TeV, c=0.01-0.1	 0.1 1	 Jet Energy Scale Alignment

Not an exhaustive list!!

Understood data - of course!

Courtesy of R. Cavanaugh

New Physics Potential - Early Days

Model	Mass reach	Luminosity (fb^{-1})	Early Systematic Challenges
Contact Interaction	Λ < 3 TeV	0.01	Jet Eff., Energy Scale
Z’	M ~ 1 TeV	0.01-0.1	Alignment
W’	M ~ 1 TeV	0.01	Alignment/MET
Black Holes	M_D~ 2.0 TeV	0.01	MET/ Jet Energy Scale
Excited Quark	M ~0.7 – 3.6 TeV	0.1	Jet Energy Scale
Axigluon or Colouron	M ~0.7 – 3.5 TeV	0.1	Jet Energy Scale
E6 diquarks	M ~0.7 – 4.0 TeV	0.1	Jet Energy Scale
Technirho	M ~0.7 – 2.4 TeV	0.1	Jet Energy Scale
ADD Virtual G_{KK}	M_D~ 4.3 - 3 TeV, n = 3-6 M_D~ 5 - 4 TeV, n = 3-6	0.1 1	Alignment
ADD Direct G_{KK}	M_D~ 1.5-1.0 TeV, n = 3-6	0.1	MET, Jet/photon Scale
SUSY	M ~1.5 – 1.8 TeV	1	MET, Jet Energy Scale, Multi Jet backgrounds, Standard Model backg.
Jet+MET+0 lepton	M ~0.5 TeV	0.01	
Jet+MET+1 lepton	M ~0.5 TeV	0.1	
mUED	M ~0.3 TeV M ~ 0.6 TeV	0.01 1	Lepton ID

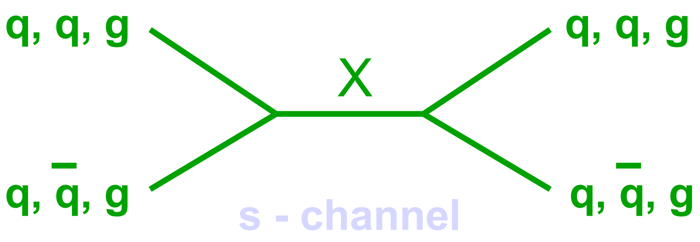
Not an exhaustive list!!

Rather than presenting the generic reach plots for each scenario (we have seen them so many times already), I will discuss a few illustrative examples in more detail.

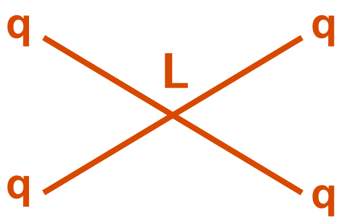
Courtesy of R. Cavanaugh

New Physics Search with Di-jets

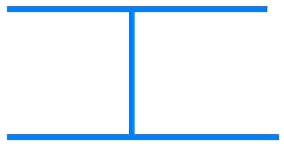
Dijet Resonance



Contact Interaction

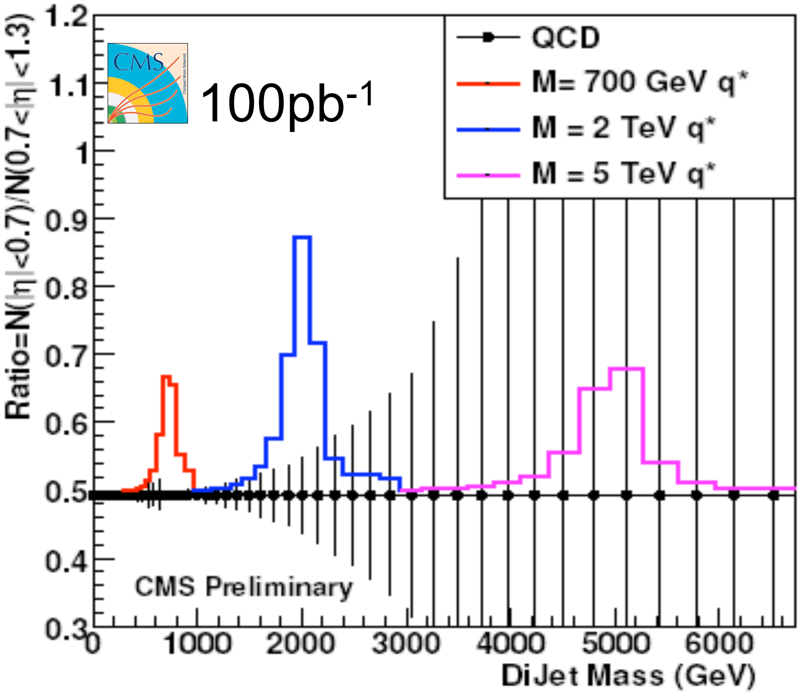


QCD

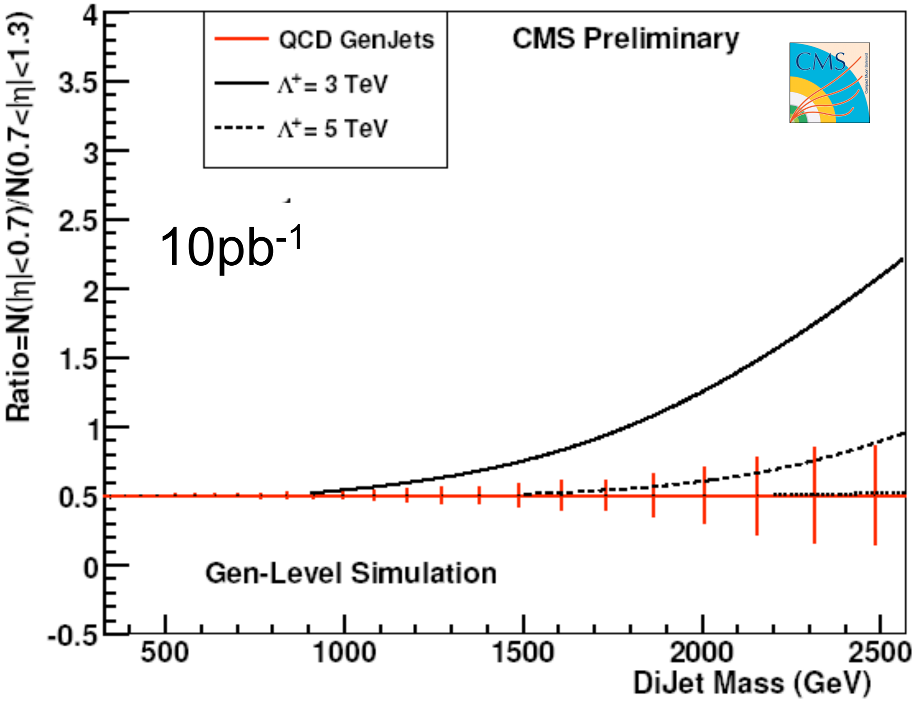


mainly t - channel

Exited Quarks

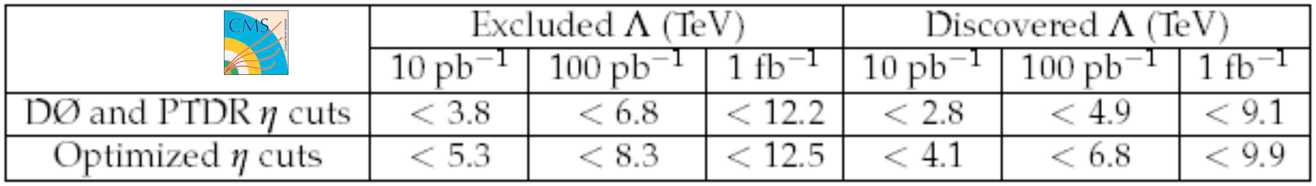


Contact Interaction



New Physics Search with Di-jets

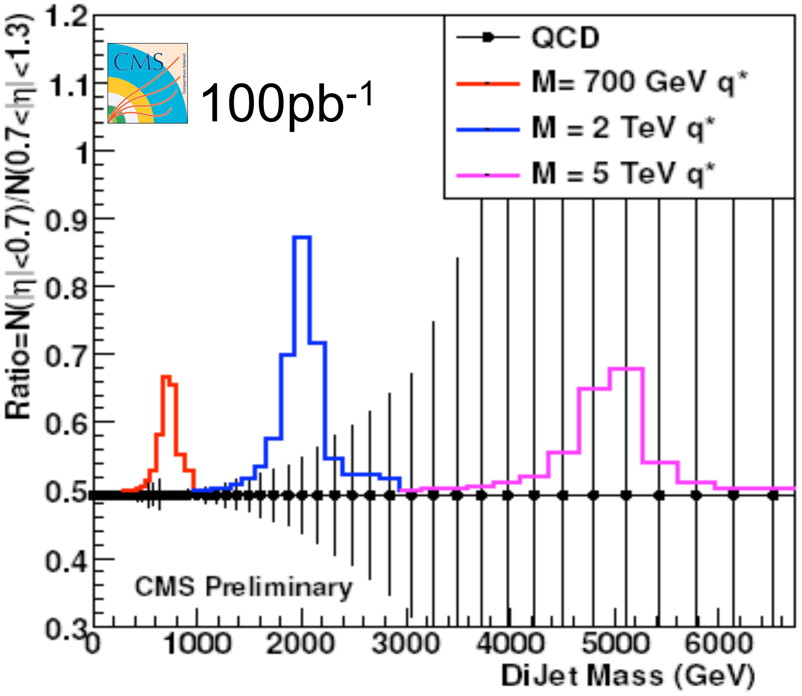
Small systematic due to use of ratio:
Di-jet Ratio = N(|η|<0.7) / N(0.7<|η|<1.3)



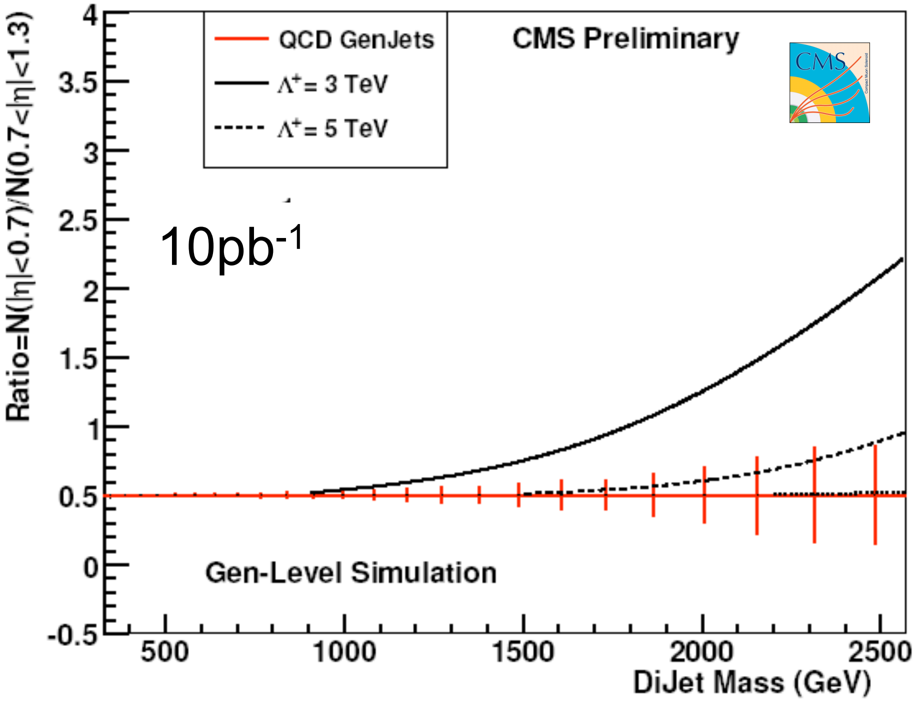
	Excluded Λ (TeV)			Discovered Λ (TeV)		
	$10\ \mathrm{pb}^{-1}$	$100\ \mathrm{pb}^{-1}$	$1\ \mathrm{fb}^{-1}$	$10\ \mathrm{pb}^{-1}$	$100\ \mathrm{pb}^{-1}$	$1\ \mathrm{fb}^{-1}$
DØ and PTDR η cuts	< 3.8	< 6.8	< 12.2	< 2.8	< 4.9	< 9.1
Optimized η cuts	< 5.3	< 8.3	< 12.5	< 4.1	< 6.8	< 9.9

Significant discovery potential: e.g. up to Λ~10 TeV in 2009/2010

Exited Quarks



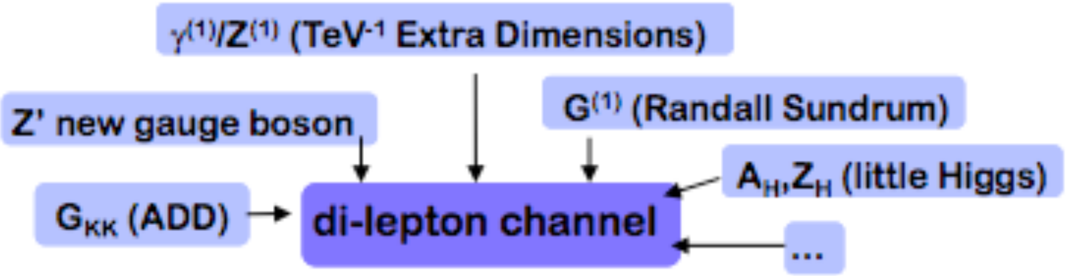
Contact Interaction



Di-lepton Resonances

Because of their clear signature di-lepton resonances have always been the subject of new physics searches.

At the LHC they are predicted to arise in many BSM models:



$\gamma^{(1)}/Z^{(1)}$ (TeV^{-1} Extra Dimensions)

Z' new gauge boson

$G^{(1)}$ (Randall Sundrum)

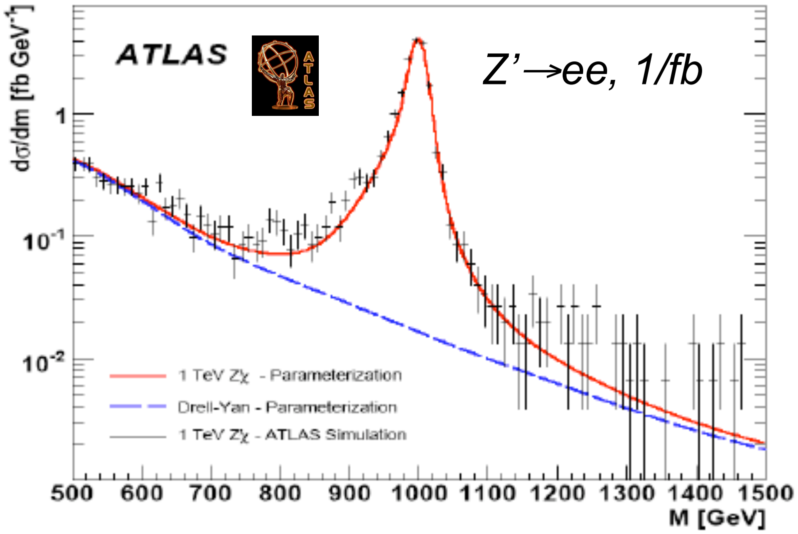
A_H,Z_H (little Higgs)

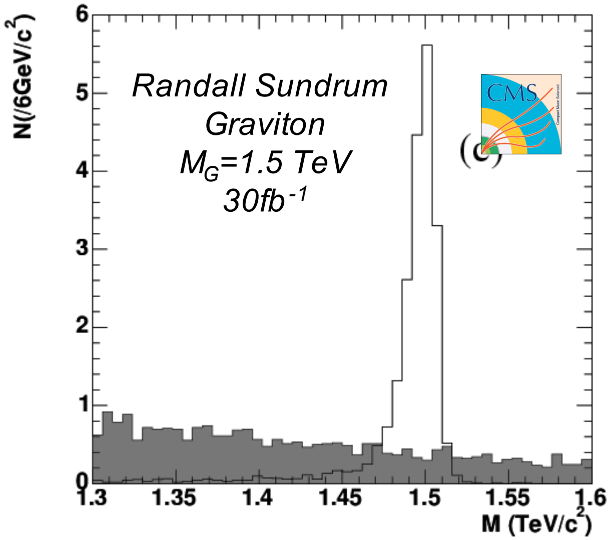
G_{KK} (ADD)

di-lepton channel

...

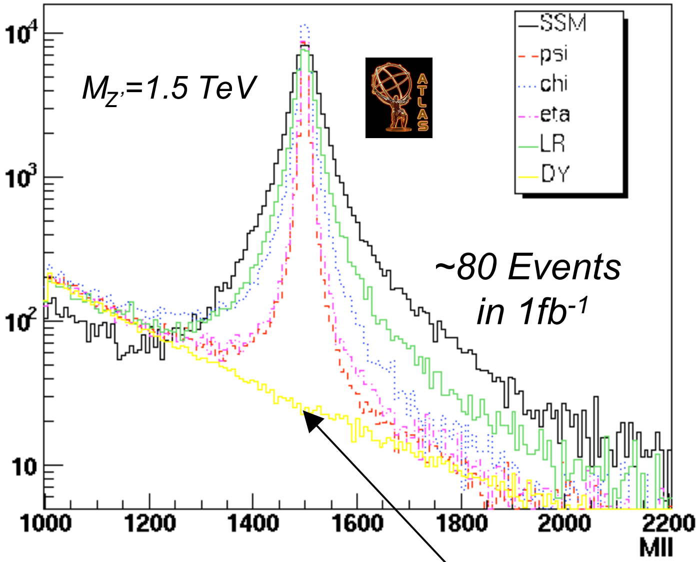
Clear signatures: $\mu^+\mu^-$ *and* e^+e^- *final state*





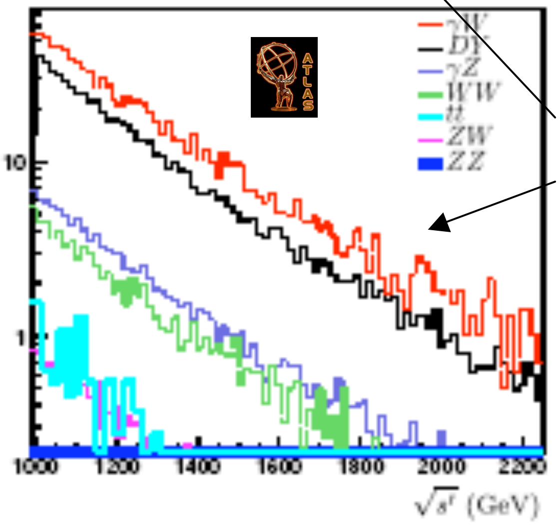
Di-lepton Resonances (Example Z')

has always been the subject of (clean) searches …



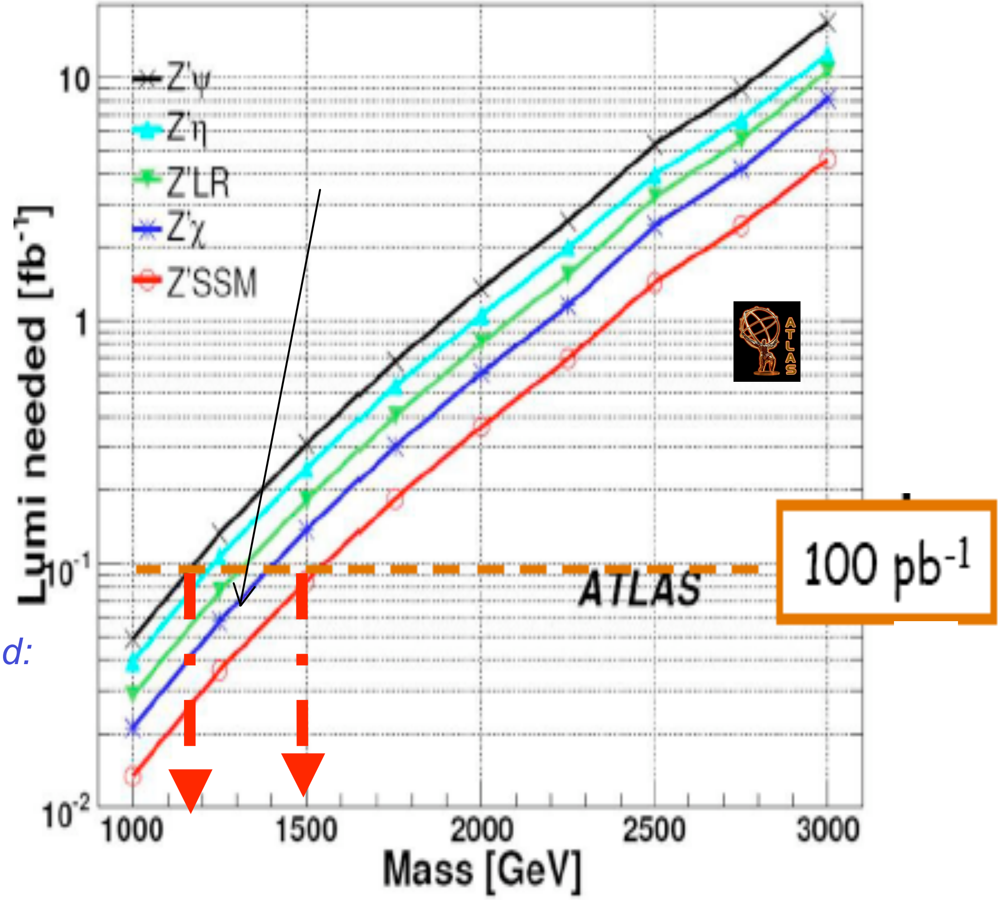
$M_{Z'}$=1.5 TeV

~80 Events in $1fb^{-1}$



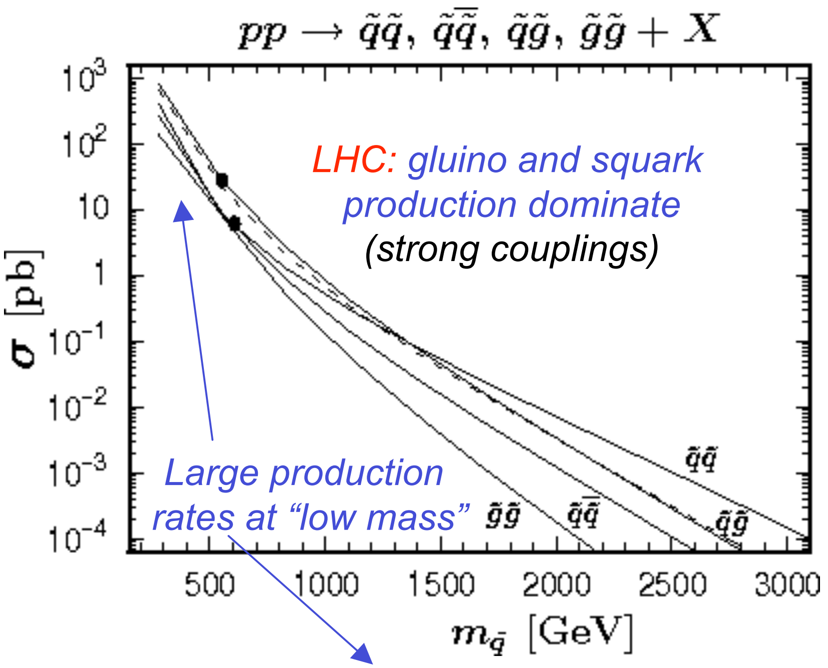
Main background:
Drell-Yan:
<1 event for
M>1.5 TeV
in $1fb^{-1}$

$Z'\rightarrow e^+e^-$ Discovery Potential



Very early discovery potential with clean signatures!

SUSY Searches @ LHC



LHC: gluino and squark production dominate *(strong couplings)*

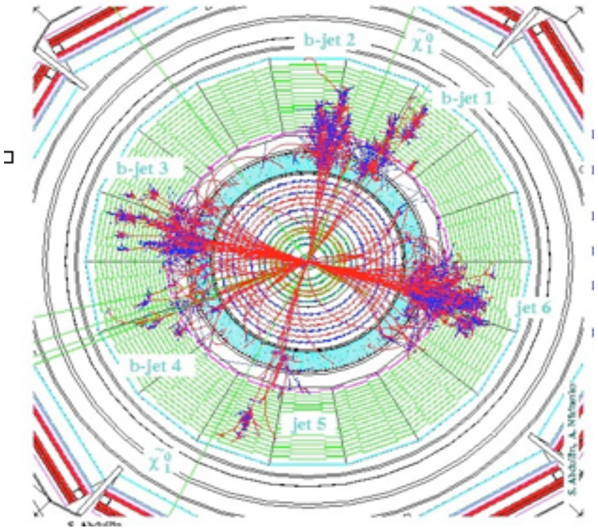
Large production rates at “low mass”

M_{sp}(GeV)	*σ (pb)*	*Evts/yr*
500	100	10^6-10^7
1000	1	10^4-10^5
2000	0.01	10^2-10^3

For low masses the LHC becomes a real ***SUSY factory***

Huge number of theoretical models

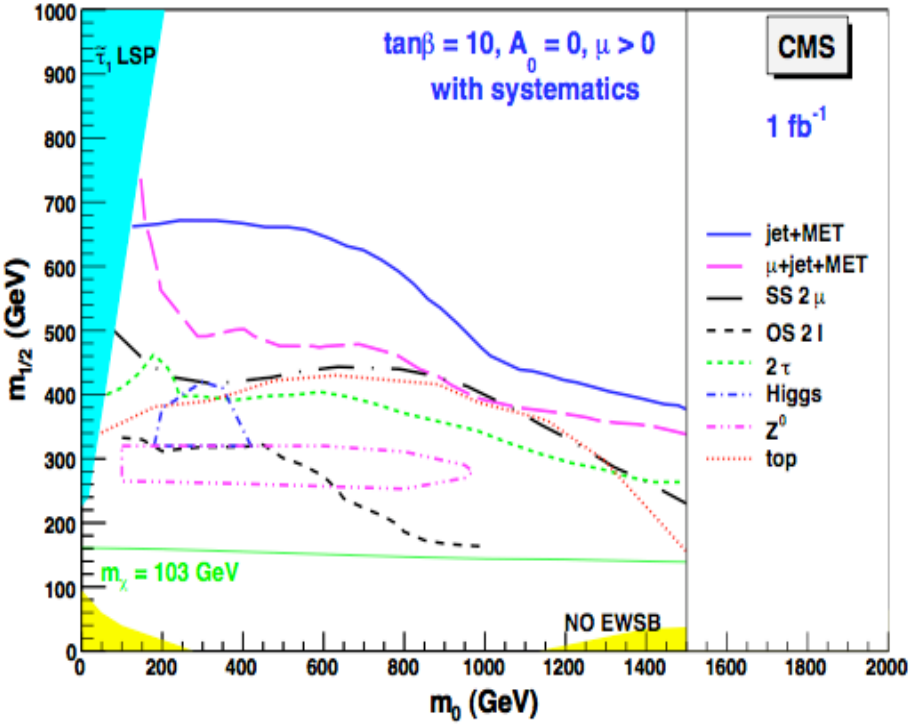
- Very complex analysis; MSSM >100 parameter
- To reduce complexity we have to choose some “reasonable”, “typical” models; use a theory of dynamical SUSY breaking
  - mSUGRA (main model)
  - GMSB (studied in less detail)
  - AMSB (studied in less detail)
- Use models to study different SUSY signatures in the detector.

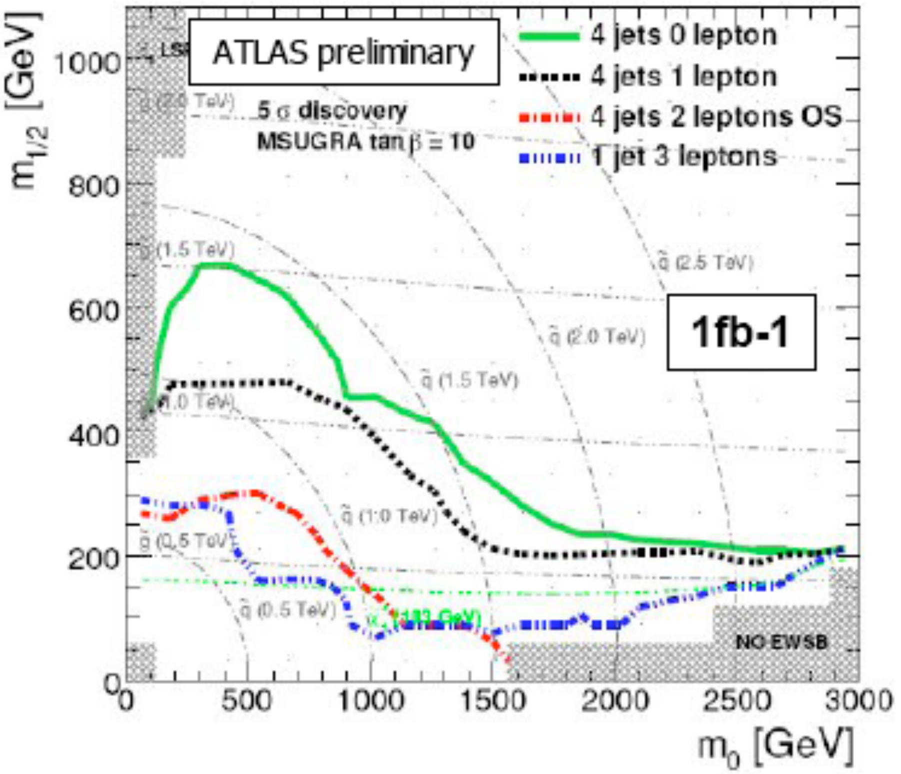


Clear signatures of large missing energy, hard jets and many leptons!
(assume R-Parity)

Could be very spectacular!

SUSY Discovery Potential - CMSSM





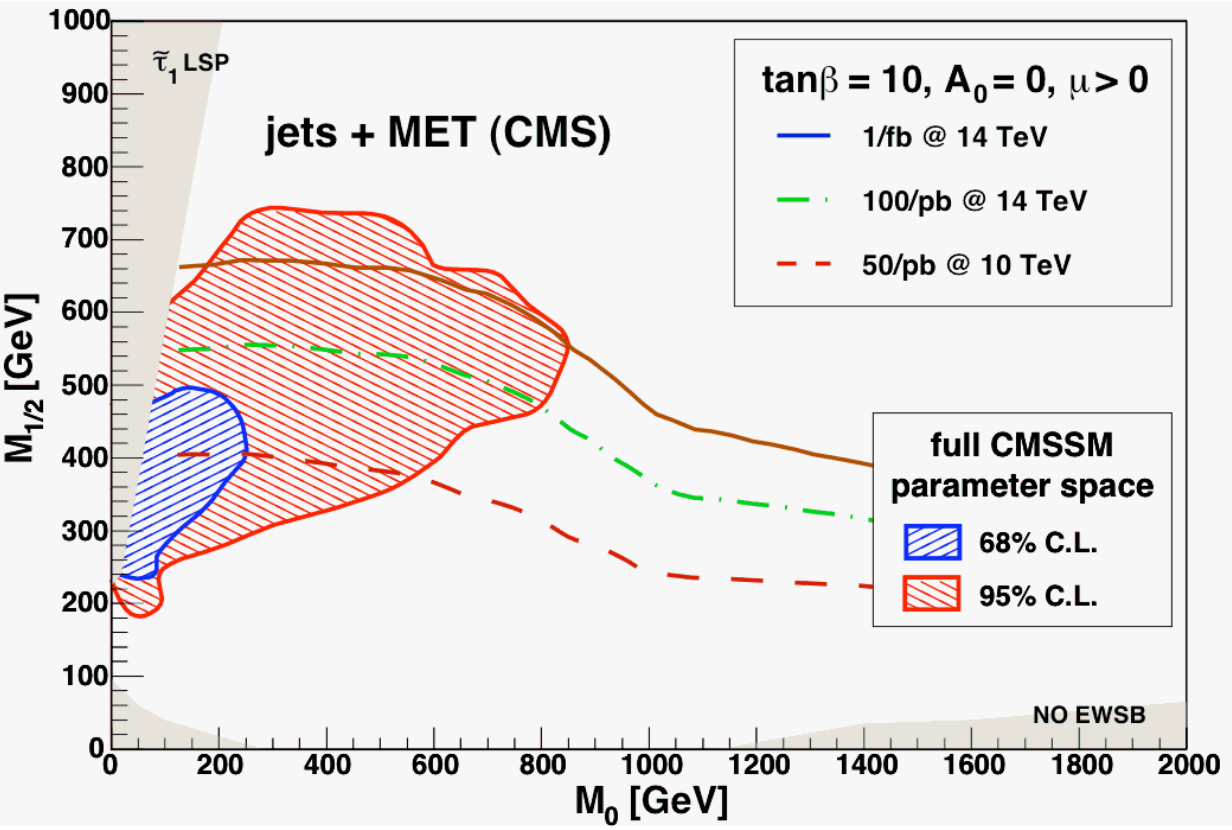
Discover Potential for "muli-jet, multi-lepton and missing energy search" is described in the CMSSM.
Both ATLAS and CMS have very similar performance (as expected).

Preferred CMSSM Parameter Space

"LHC Weather Forecast"

JHEP 0809:117,2008

OB, R.Cavanaugh, A.De Roeck,
J.R.Ellis, H.~Flaecher, S.~Heinemeyer,
G.Isidor, K.A.Olive, P.Paradisi,
F.J.Ronga, G.Weiglein



Simultaneous fit of CMSSM parameters m_0, $m_{1/2}$, A_0, $\tan\beta$ (μ>0) to more than 30 collider and cosmology data (e.g. M_W, M_{top}, g-2, BR($B \to X\gamma$), relic density)

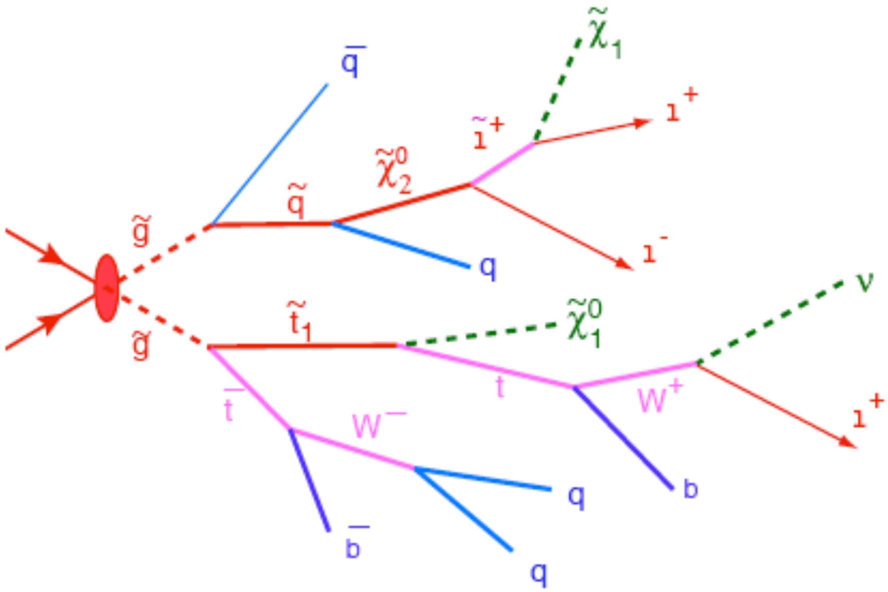
"CMSSM fit clearly favors low-mass SUSY - Evidence that a signal might show up very early?!"

What do we call a “SUSY search”?

The definition is purely derived from the experimental signature.

Therefore, a “SUSY search signature” is characterized by

Lots of missing energy, many jets, and possibly leptons in the final state



Missing Energy:
- *from LSP*

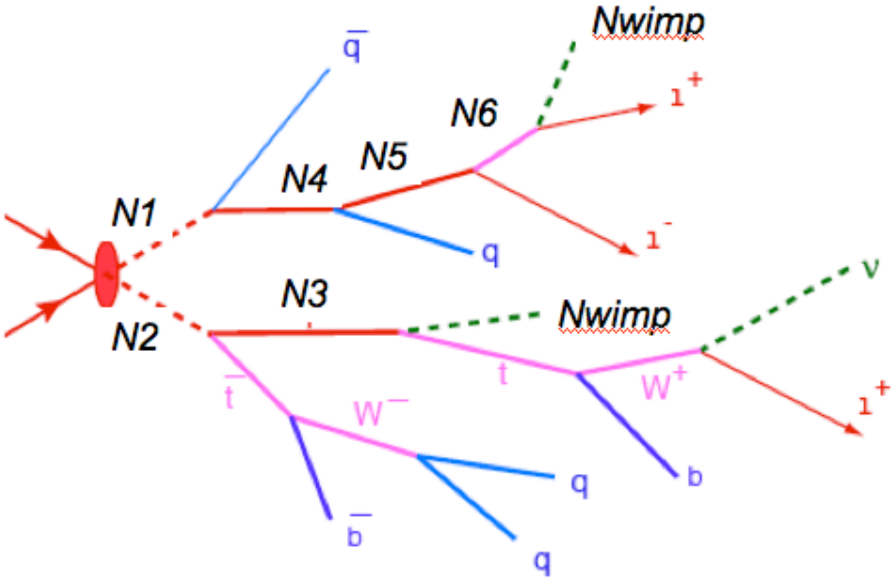
Multi-Jet:
- *from cascade decay (gaugino)*

Multi-Leptons:
- *from decay of charginos/neutralios*

RP-Conserving SUSY is a very prominent example predicting this famous signature but …

What is its experimental signature?

… by no means is it the only New Physics model predicting this experimental pattern. Many other NP models predict this genuine signature



Missing Energy:

- *Nwimp - end of the cascade*

Multi-Jet:

- *from decay of the Ns (possibly via heavy SM particles like top, W/Z)*

Multi-Leptons:

- *from decay of the N's*

Model examples are Extra dimensions, Little Higgs, Technicolour, etc but a more generic definition for this signature is as follows.

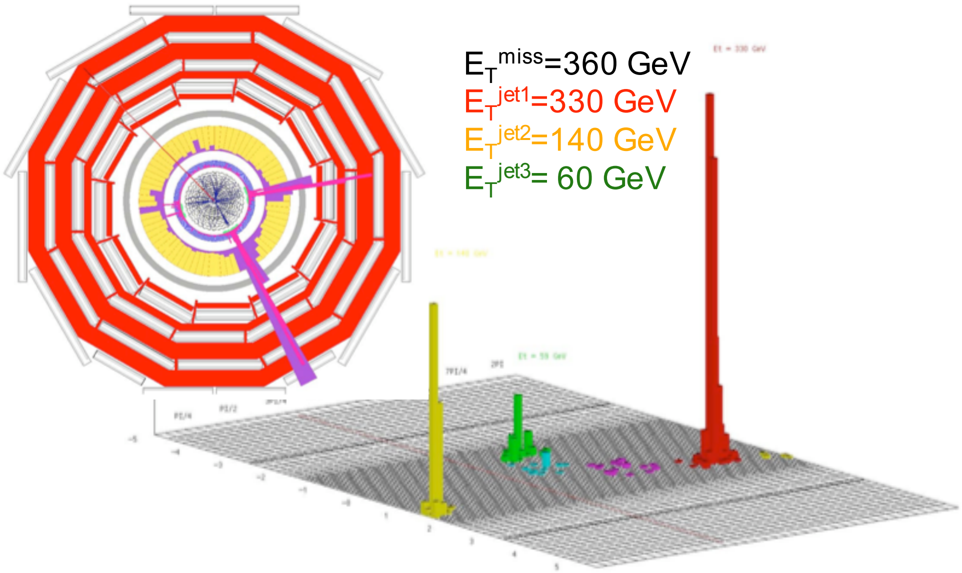
“SUSY Searches” - What are we searching for?

- Pair-produced new particles N with a colour charge and a mass of O(TeV/2)
- N decays via a cascade into other new particles as well as SM particles like bosons, leptons and quarks
- At the end of the cascade decay is a weakly interacting new particle - i.e. a dark matter candidate

In other words, a “SUSY search” is a search for a weakly interacting (stable) particle that was produced in the cascade decay of a heavy new particle.

Use “SUSY” as a convenient tool to characterize this search!

Jets + E_T^{miss} - Inclusive Search

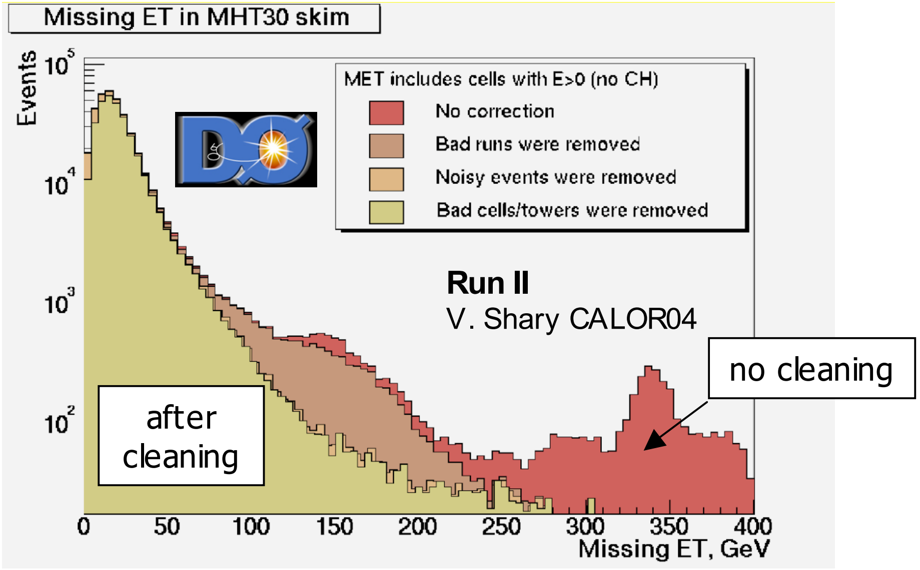


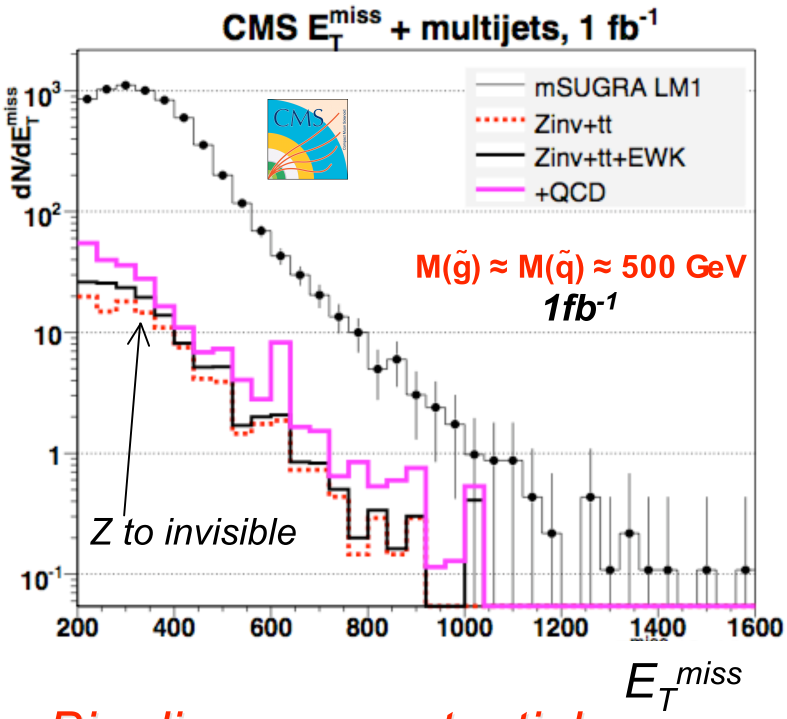
E_T^{miss}=360 GeV

E_T^{jet1}=330 GeV

E_T^{jet2}=140 GeV

E_T^{jet3}= 60 GeV





Big discovery potential

But requires a very good detector understanding and background control:

Analysis Strategy:

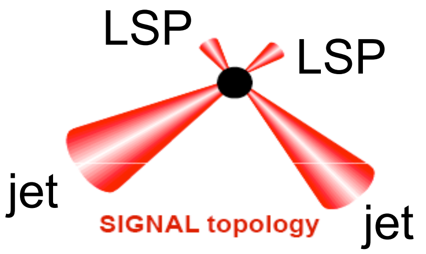
- Be brave
- Fight background and noise
- Use data control samples
- Estimate background from data

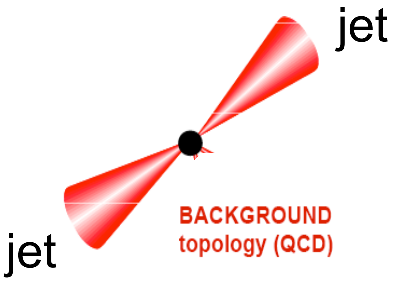
SUSY search with dijet events

Idea:

Search for squark-squark production with squark decay directly to quark + LSP

Exp. signature: 2 jets + missing ET





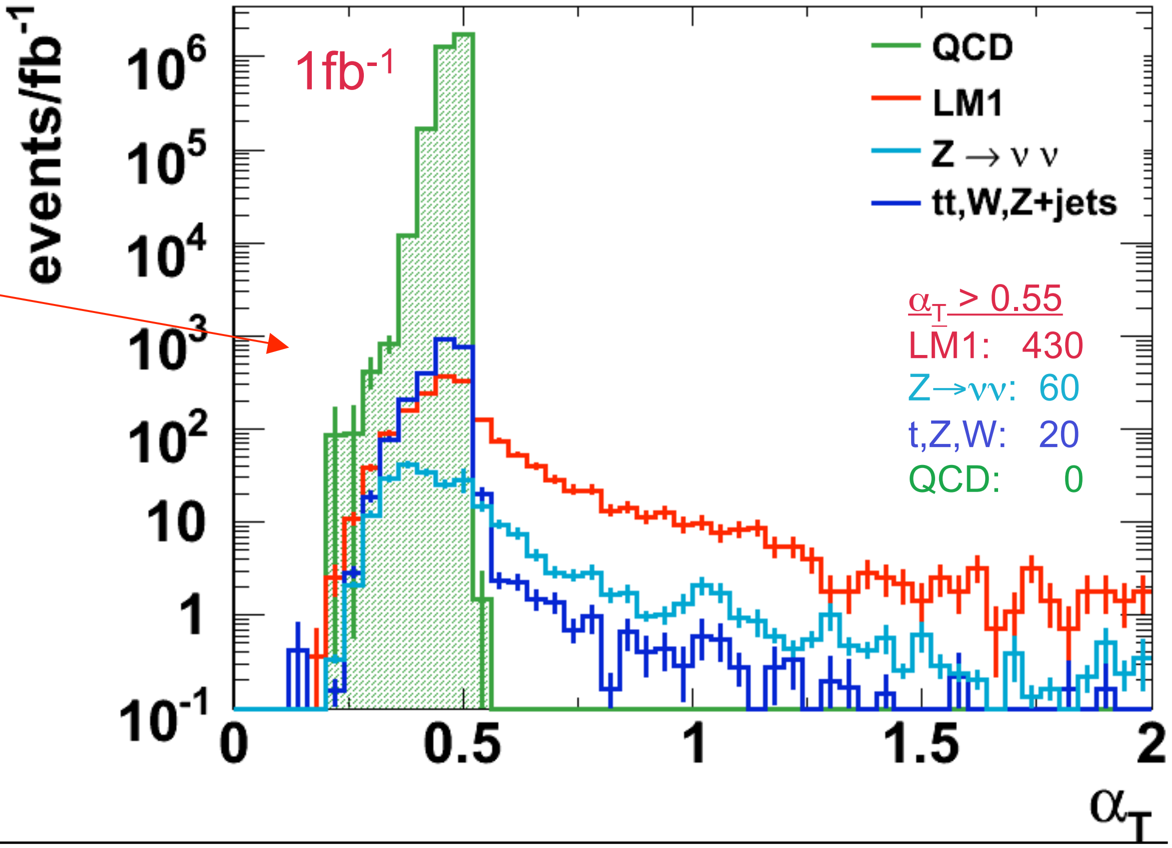
Important analysis properties:

- Trigger: HLT2jet
- $\Delta\Phi < 2/3\pi$
- **$\alpha_T = E_{Tj2}/M_{Tj1,j2} > 0.55$**

(inspired by arXiv0806.1049)

Analysis only relies on kinemtaic of dijet system:

- no direct calorimetric missing Energy dependence
- idea can be extended to generic n-jet system

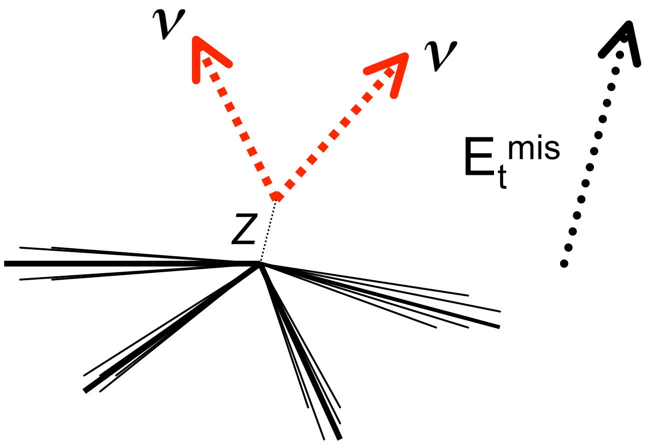


Data Driven Background Estimations

An illustrative example: Z→νν+jets
Irreducible background for Jets+E_t^{mis} search

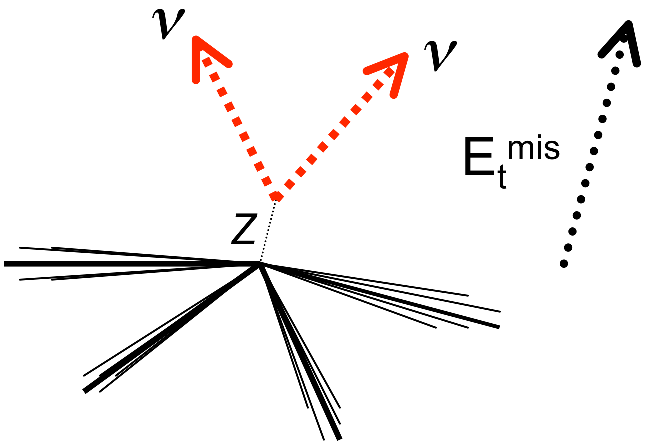
Data-driven strategy:

- *define control samples and understand their strength and weaknesses:*



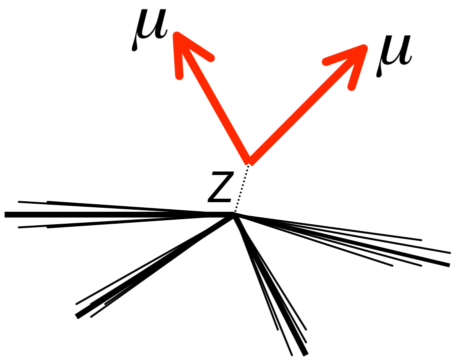
Data Driven Background Estimations

An illustrative example: $Z \rightarrow \nu\nu$+jets
Irreducible background for Jets+E_t^{mis} search



Data-driven strategy:

- *define control samples and understand their strength and weaknesses:*



$Z \rightarrow \mu\mu$+jets

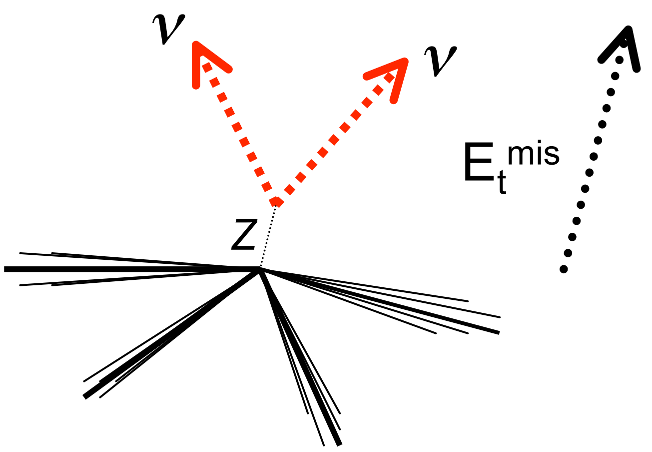
Strength:
- *very clean, easy to select*

Weakness:
- *low statistic: factor 6 suppressed w.r.t. to $Z \rightarrow \nu\nu$*

Data Driven Background Estimations

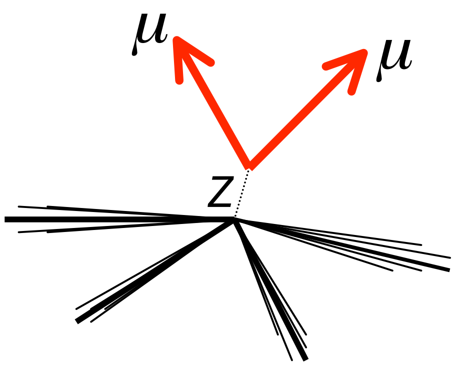
An illustrative example: $Z \rightarrow \nu\nu$+jets

Irreducible background for Jets+E_t^{mis} search



Data-driven strategy:

- *define control samples and understand their strength and weaknesses:*



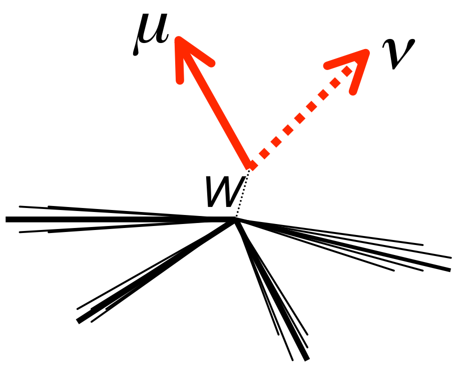
$Z \rightarrow \mu\mu$+jets

Strength:

- *very clean, easy to select*

Weakness:

- *low statistic: factor 6 suppressed w.r.t. to $Z \rightarrow \nu\nu$*



$W \rightarrow \mu\nu$+jets

Strength:

- *larger statistic*

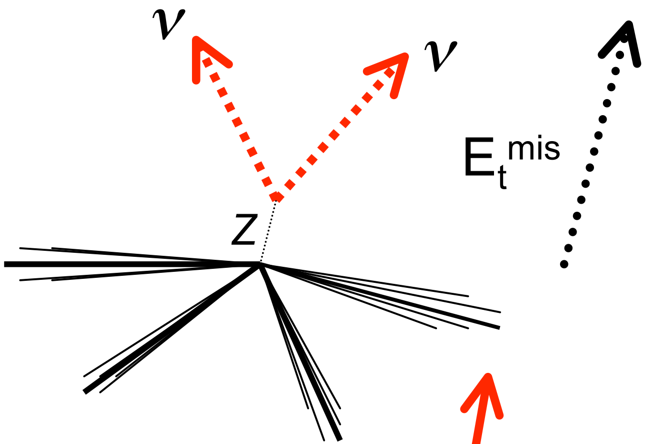
Weakness:

- *not so clean, SM and signal contamination*

Data Driven Background Estimations

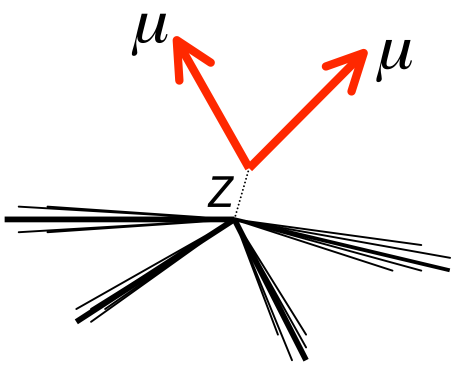
An illustrative example: Z→νν+jets

Irreducible background for Jets+E_t^{mis} search



Data driven strategy:

- *define control samples and understand their strength and weaknesses:*



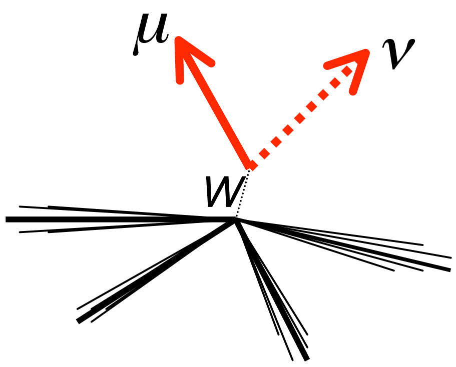
Z→ll+jets

Strength:

- *very clean, easy to select*

Weakness:

- *low statistic: factor 6 suppressed wrt. to Z →νν*



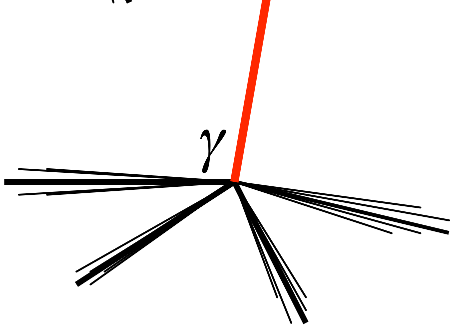
W→lν+jets

Strength:

- *larger statistic*

Weakness:

- *not so clean, SM and signal contamination*



γ+jets

Strength:

- *large stat, clean for high E_γ*

Weakness:

- *not clean for E_γ<100 GeV, possible theo. issues for normalization (u. investigation)*

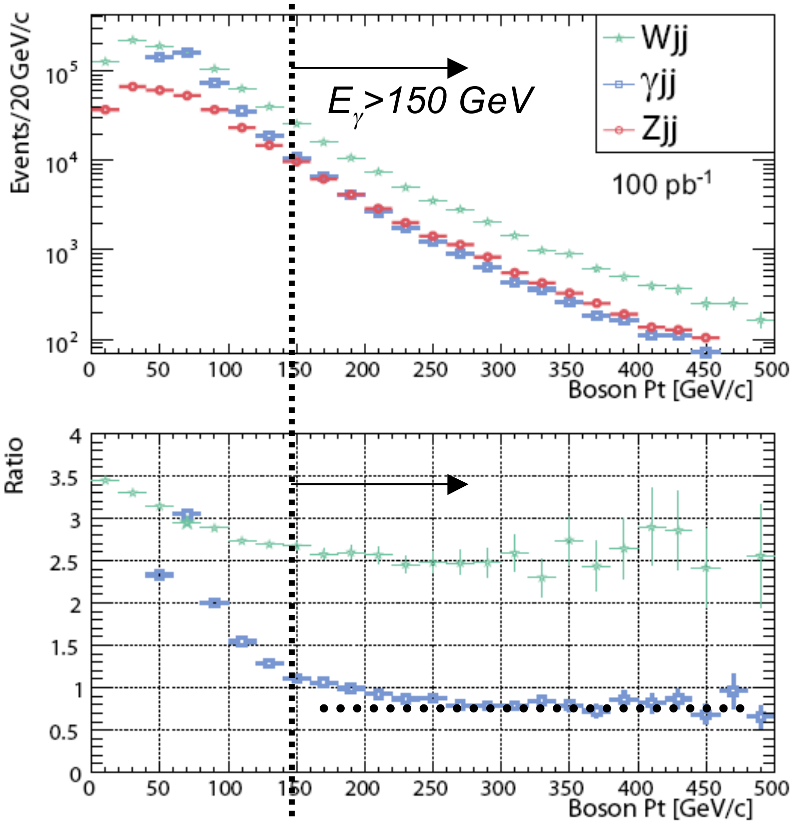
γ+jets: Estimate Z to invisible

γ+jets selection & properties:

- $E_\gamma > 150$ GeV

→ clean sample: S/B>20

→ ratio $\sigma(Z+jet)/\sigma(\gamma+jet)$ constant

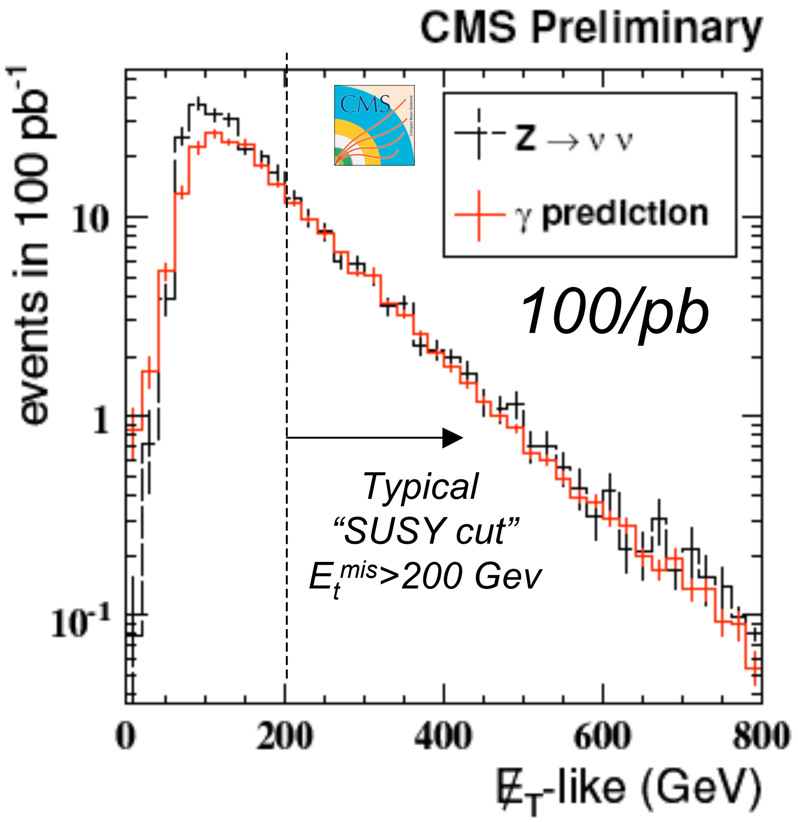


γ+jets: Strategy:

- remove γ from the event:

→ γ becomes E_T^{mis}

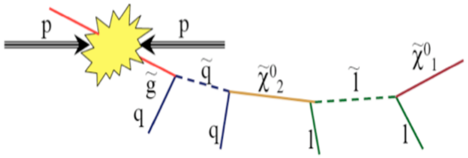
- take $\sigma(Z+jet)/\sigma(\gamma+jet)$ for $E_\gamma > 200$ GeV from MC or measure in data



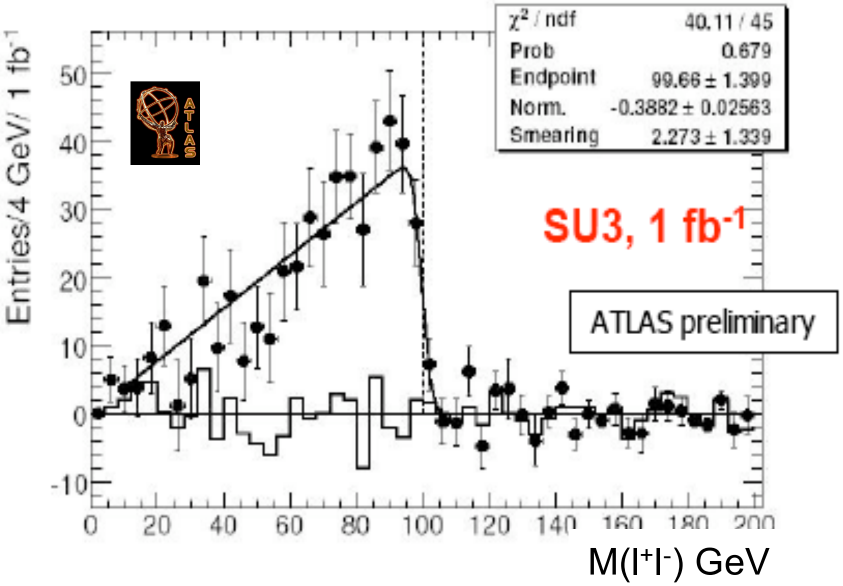
First Kinematic Measurements

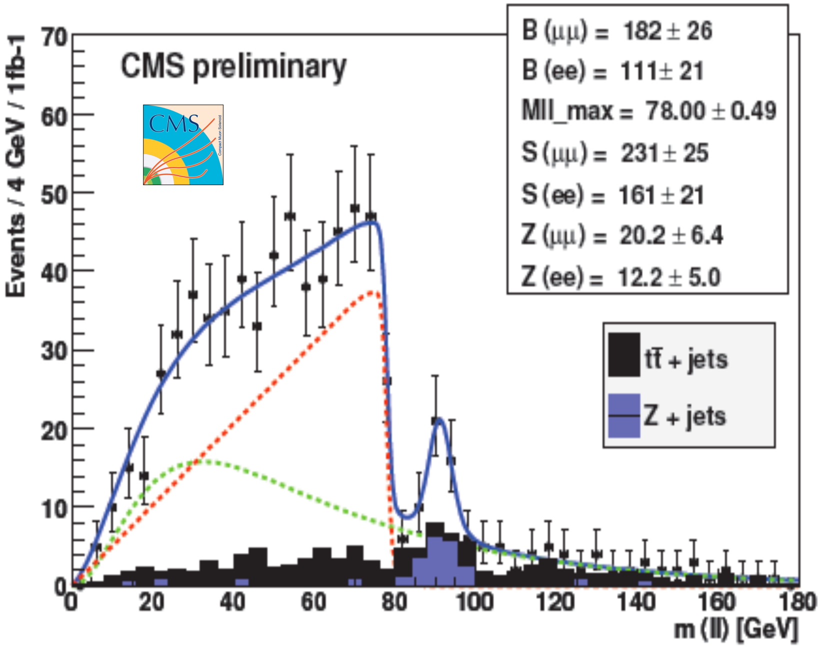
...and if we are a bit lucky we might see such spectacular signals already in the early days!

Look for generic signatures of cascade decays:



Jets + E_t^{miss}
+SFOS di-leptons



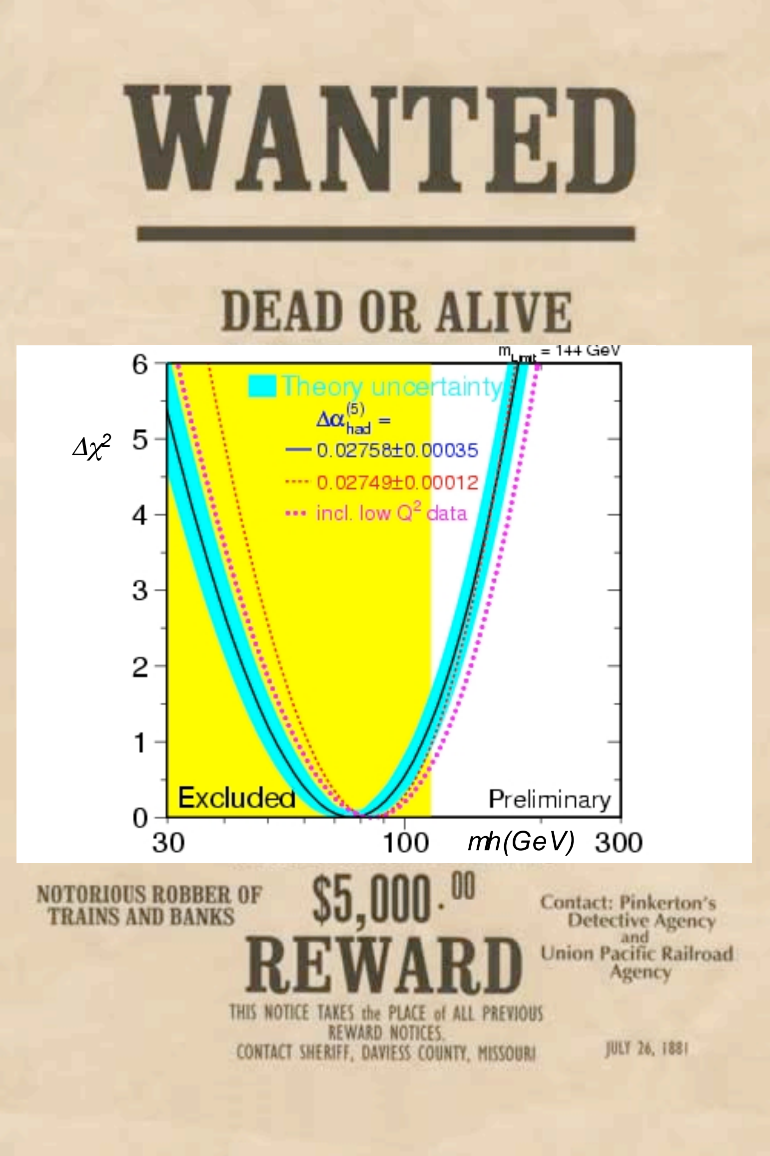


Extract: $$M_{\ell\ell}^{max} = M(\tilde{\chi}_2^0)\sqrt{1-\frac{M^2(\tilde{\ell}_R)}{M^2(\tilde{\chi}_2^0)}}\sqrt{1-\frac{M^2(\tilde{\chi}_1^0)}{M^2(\tilde{\ell}_R)}}$$

from a fit to the "edge distribution".

- *$\Delta M_{ee}^{max}=1.07_{stat}\pm0.36_{sys}$ GeV for 1/fb (CMS)*
- *$\Delta M_{\mu\mu}^{max}=0.75_{stat}\pm0.18_{sys}$ GeV for 1/fb (CMS)*
- *Estimate same flavour top and di-boson bkg directly from eμ data*
- *Relatively precise extraction of M_{ll}^{max} in the first few hundred pb^{-1} is still possible.*

SM-like Higgs Boson

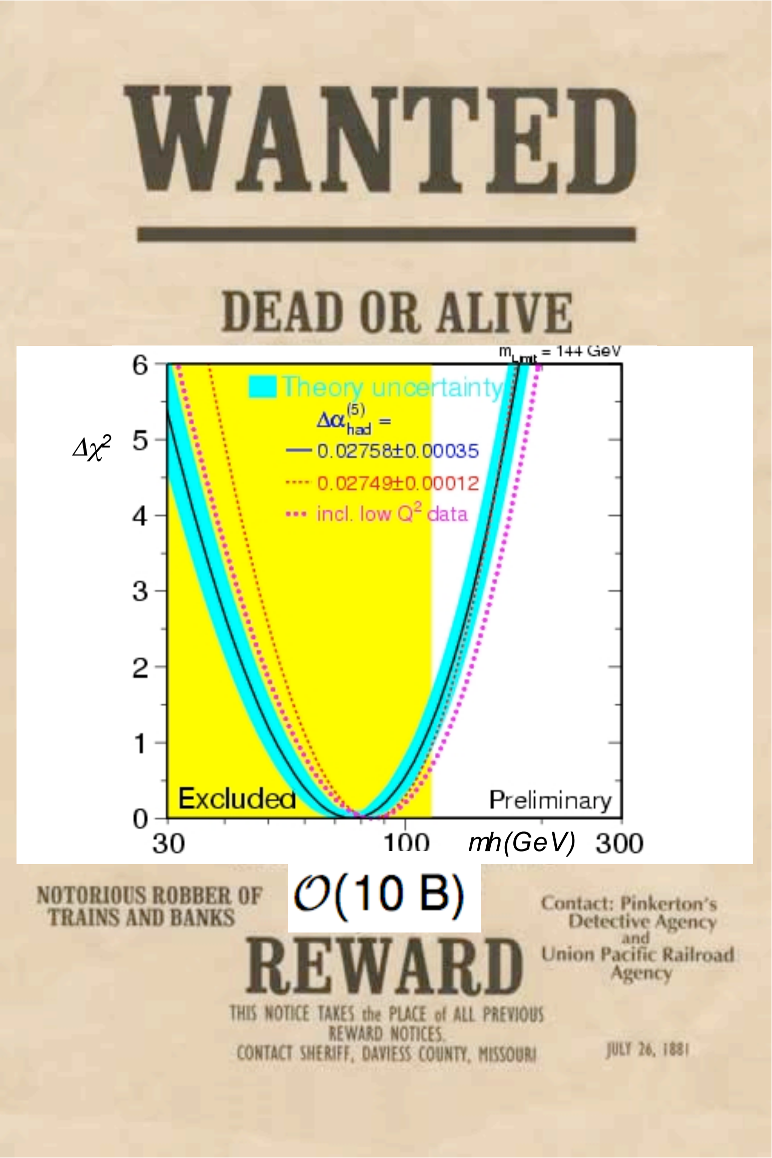


Good things come early … and late(r)

Although it may come "late" and therefore may not be the first major discovery of the LHC - we still need to find it (or exclude it).

No reason to discount it … it will be a major event for the LHC & Particle Physics in any case!

SM-like Higgs Boson



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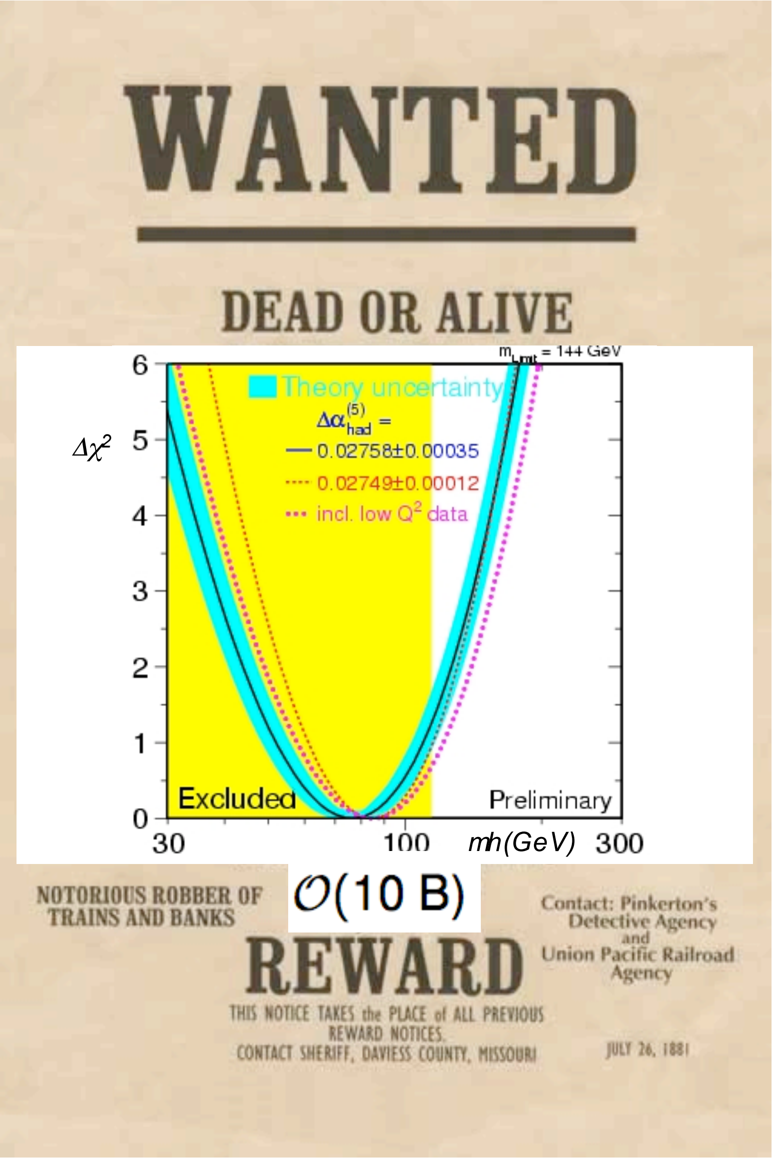
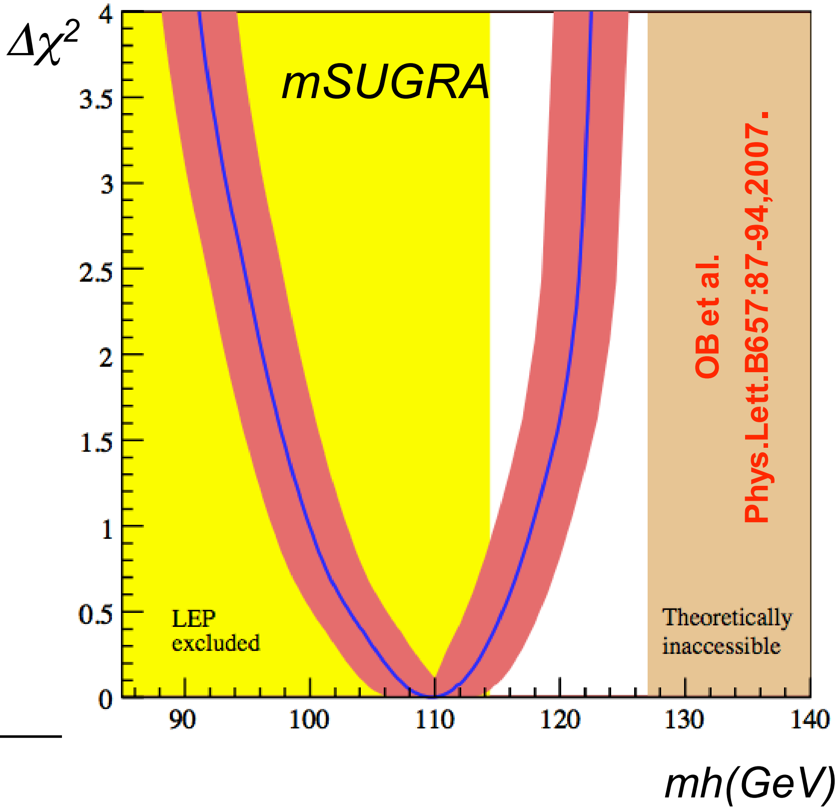


Precision electroweak data tightly constrain the allowed region of m_h in the SM.

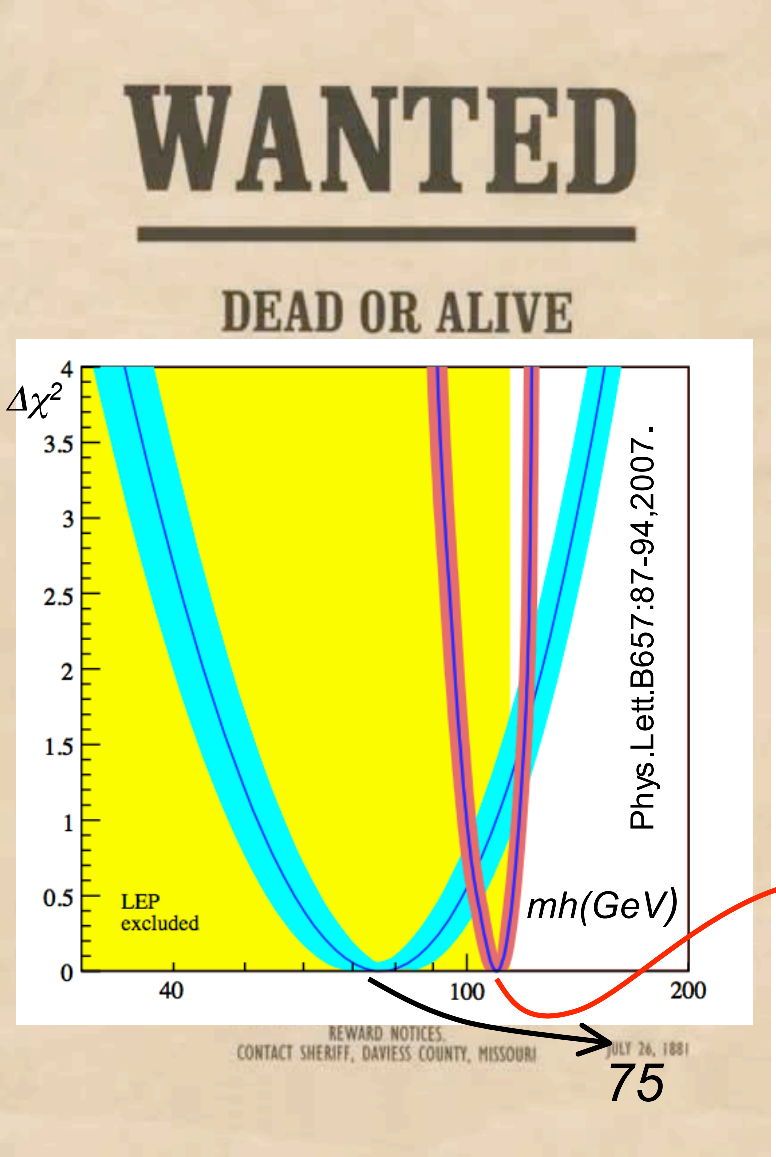
Yet, also other important models like mSUGRA are constrained by these data:

mSUGRA fit to flavour, electroweak and cosmology data:

mh(mSUGRA)=110^{+8}_{-10} (exp)±3(theo) GeV



SM-like Higgs Boson

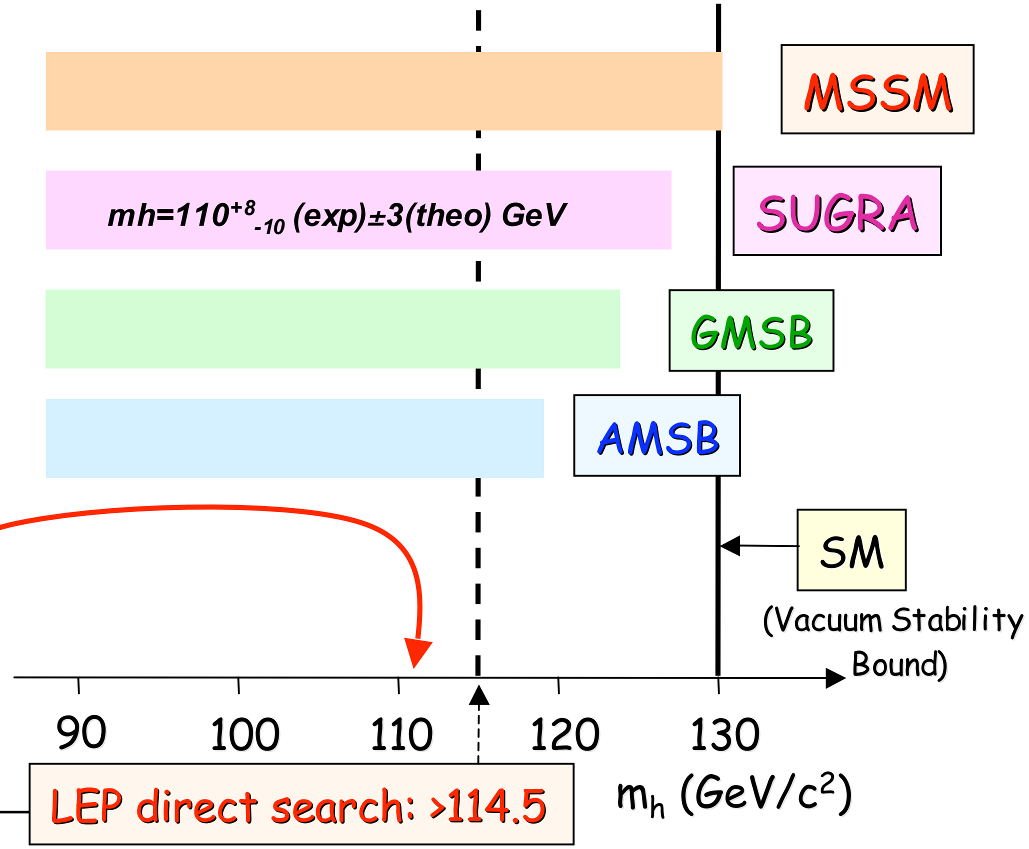


SM: Constrained Phase Space

mh(SM)=76^{+33}_{-24} GeV

mh(SM)<144 GeV @ 95% CL

SUSY: Accessible Phase Space



mh=110^{+8}_{-10} (exp)±3(theo) GeV

SM (Vacuum Stability Bound)

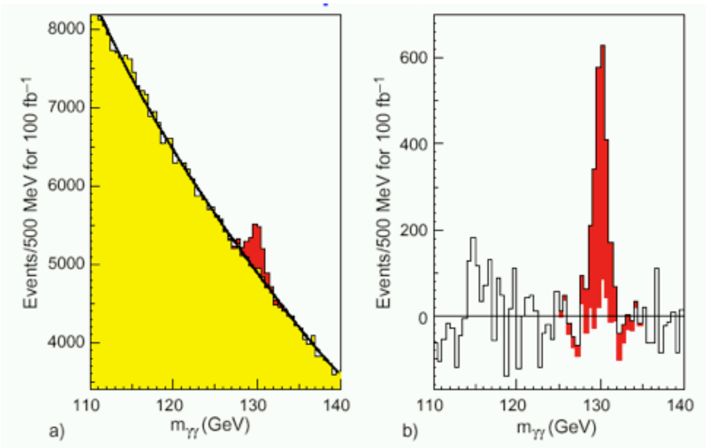
m_h (GeV/c^2)

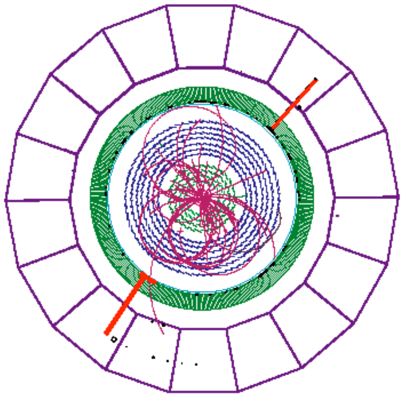
LEP direct search: >114.5

Higgs Mass below 200 GeV

Low M_H < 140 GeV

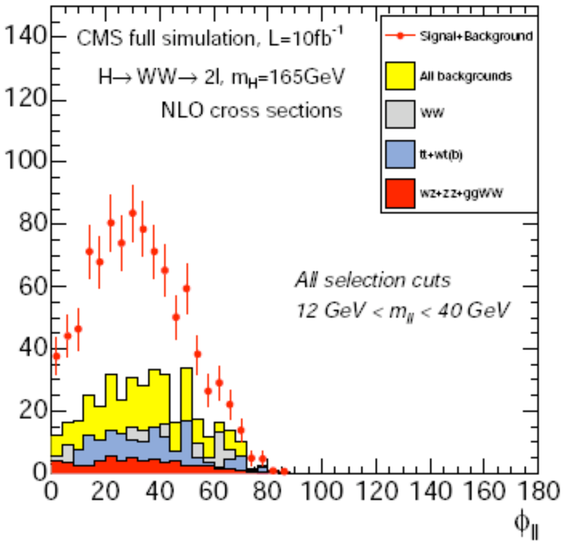
$H \rightarrow \gamma\gamma$

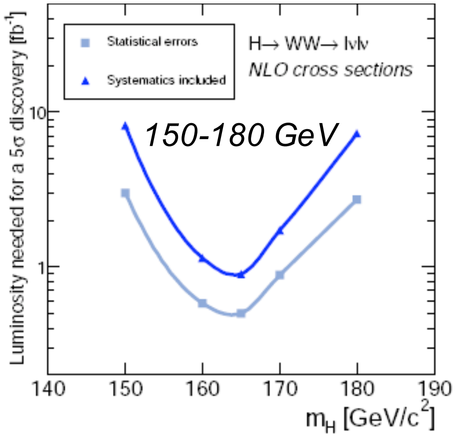




$2M_w$ < M_h <$2M_Z$

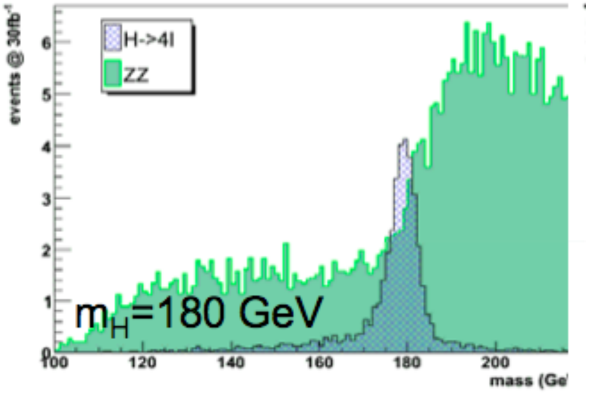
$H \rightarrow WW^{(*)} \rightarrow 2l$

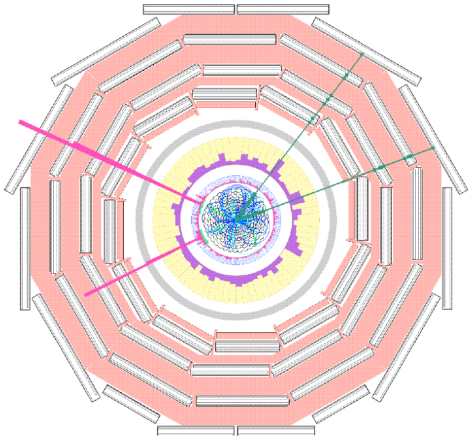




130<M_H<~600 GeV

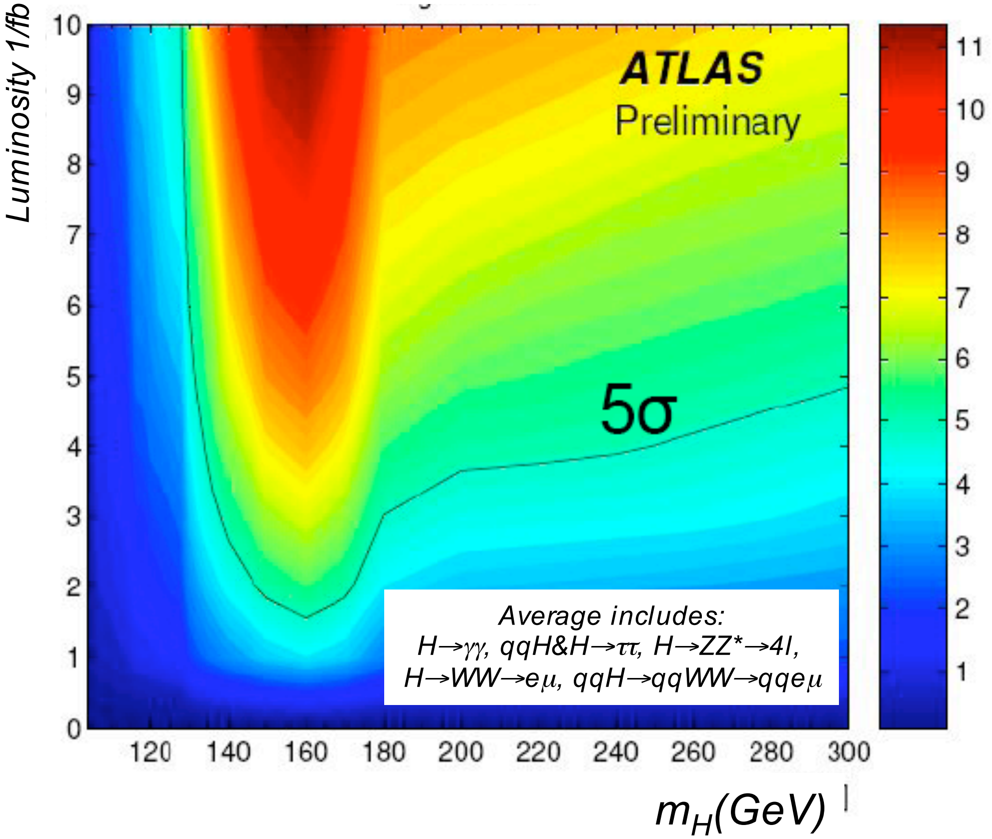
$H \rightarrow ZZ^{(*)} \rightarrow 4l$

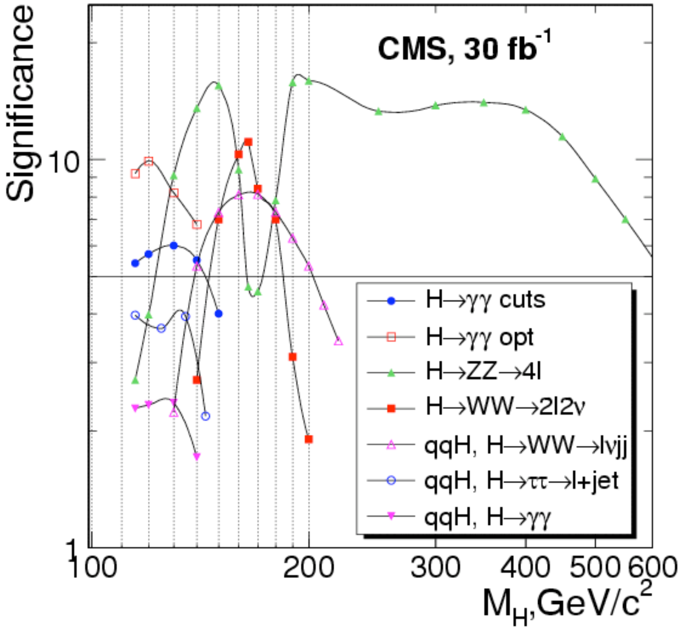




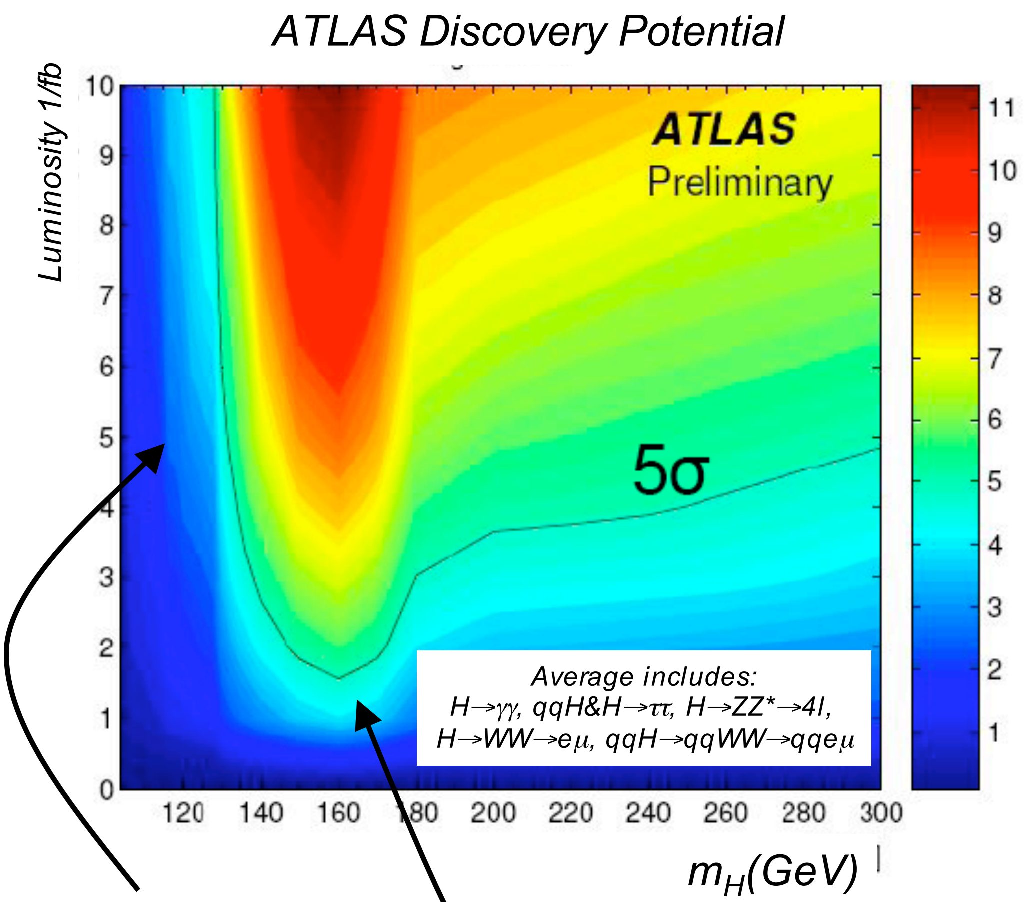
SM Higgs Reach

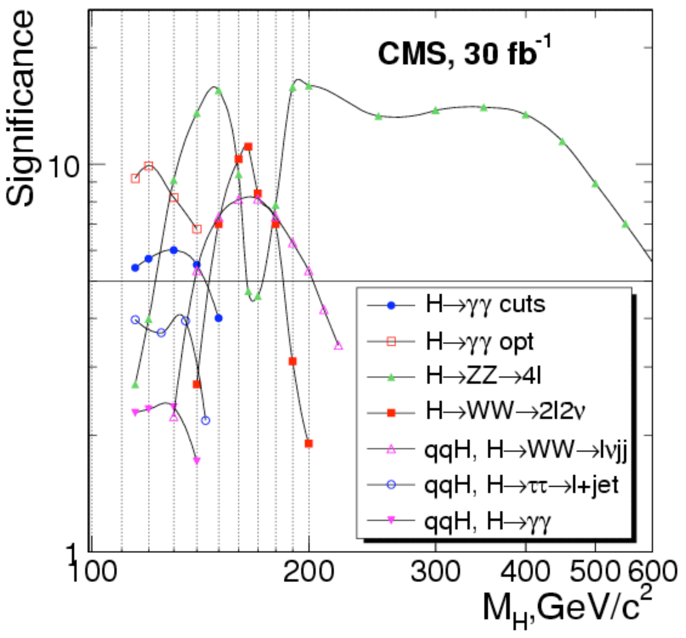
ATLAS Discovery Potential





SM Higgs Reach





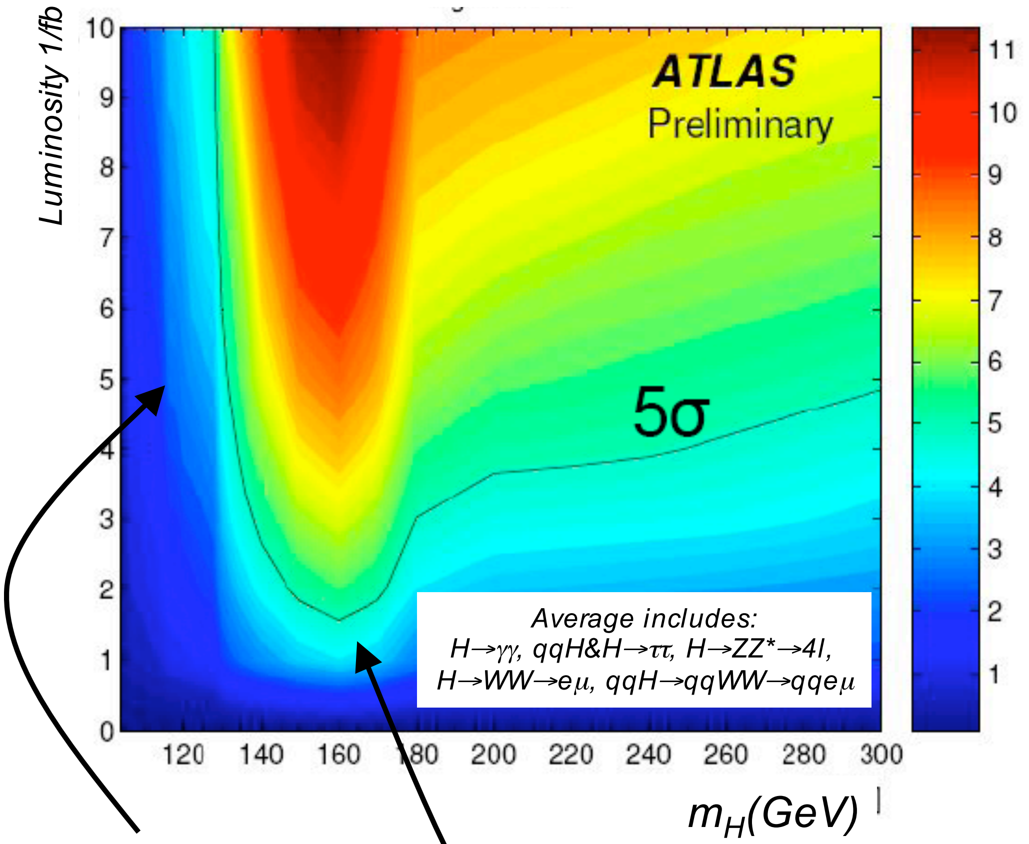
Most difficult part is M_h~115 to 120 GeV

ttH→ttbb more difficult than originally expected

Early discovery already possible with 1fb^{-1}
$H\to WW^{(*)}\to 2l$

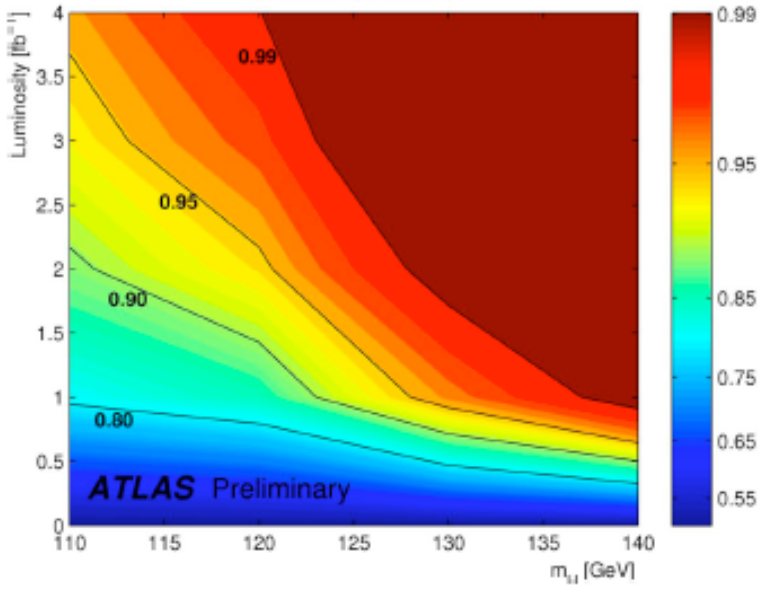
SM Higgs Reach

ATLAS Discovery Potential



Average includes:
$H \to \gamma\gamma$, $qqH\&H \to \tau\tau$, $H \to ZZ^* \to 4l$,
$H \to WW \to e\mu$, $qqH \to qqWW \to qqe\mu$

ATLAS 95% CL Exclusion



With $1fb^{-1}$ of understood data:

- *potential to exclude a very large mass range*
- *potential to discover higgs with m_h~165 GeV*

(m_h~170 GeV recently excluded by Tevatron)

LHC will give us an answer!

Most difficult part is
M_h~115 to 120 GeV
$ttH \to ttbb$ more difficult
than originally expected

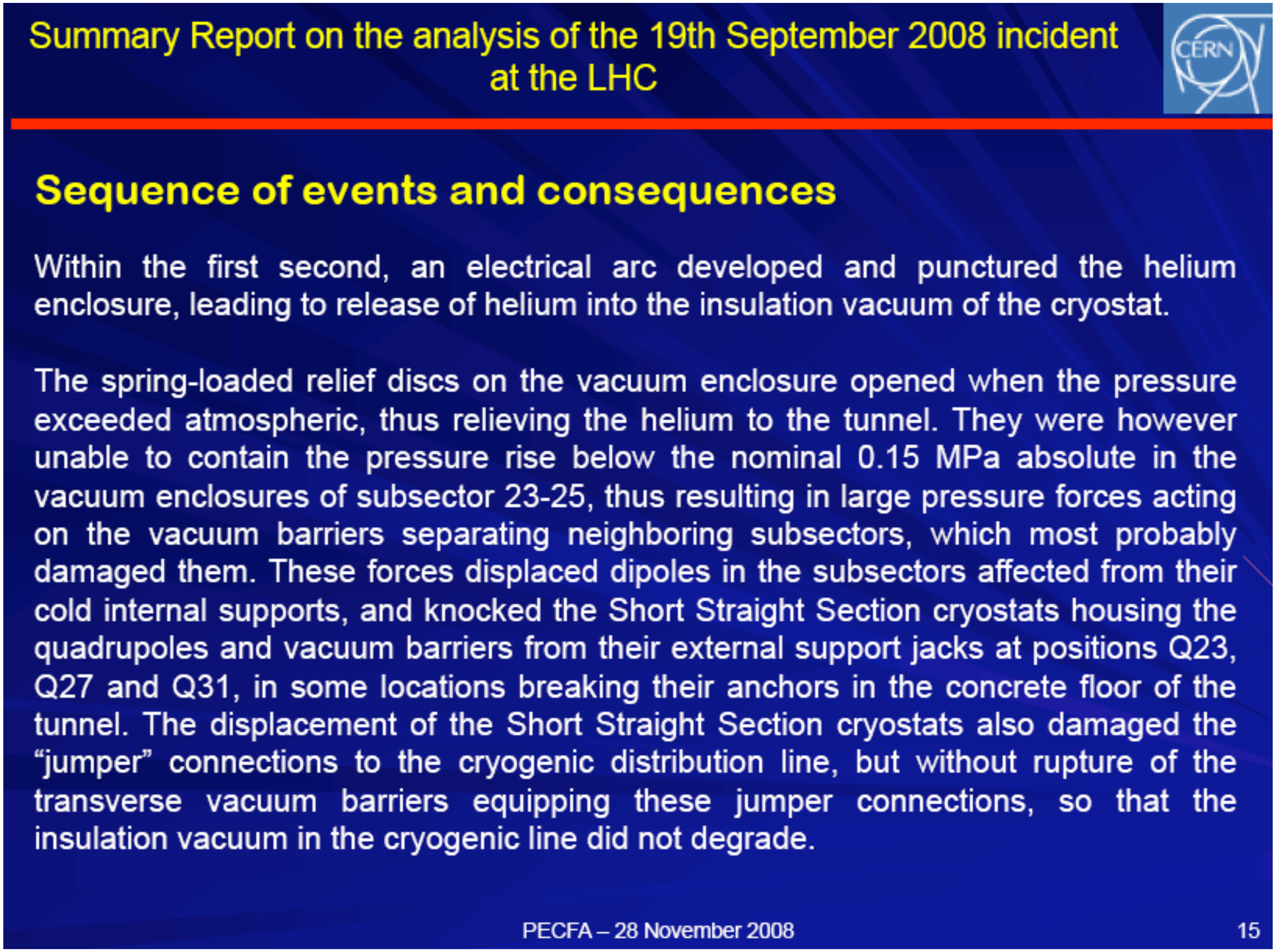
Early discovery already
possible with $1fb^{-1}$
$H \to WW^{(*)} \to 2l$

Summary

- 2009 will be the year of machine, detector, and physics analysis commissioning - i.e. intense preparation for the physics year 2010.
  - Challenge: commissioning of machine and detectors of unprecedented complexity, technology, and performance
  - Re-discover the Standard Model at 10 TeV, understand the "LHC environment"
- The LHC will discover (or exclude) the Higgs by ~2011-2012 [~10/fb].
  - We will get an answer!
  - Large phase space can already be excluded with only ~1fb^{-1} (i.e. 2009/2010)
- The LHC will discover low energy SUSY (if it exists).
  - 2009/2010 could become the year(s) of "SUSY" but it could also take more time and ingenuity before we can claim a discovery
  - First signals might emerge already in the first data but do we understand them?!
- The LHC will cover a new physics scale of 1-3 TeV.
  - Many new physics models; Black hole, Extra Dimensions,Little Higgs, Split Susy, New Bosons, Technicolour, etc …

In other words; the next years will be a very exciting time for particle physics . . .

Accident on 19th September

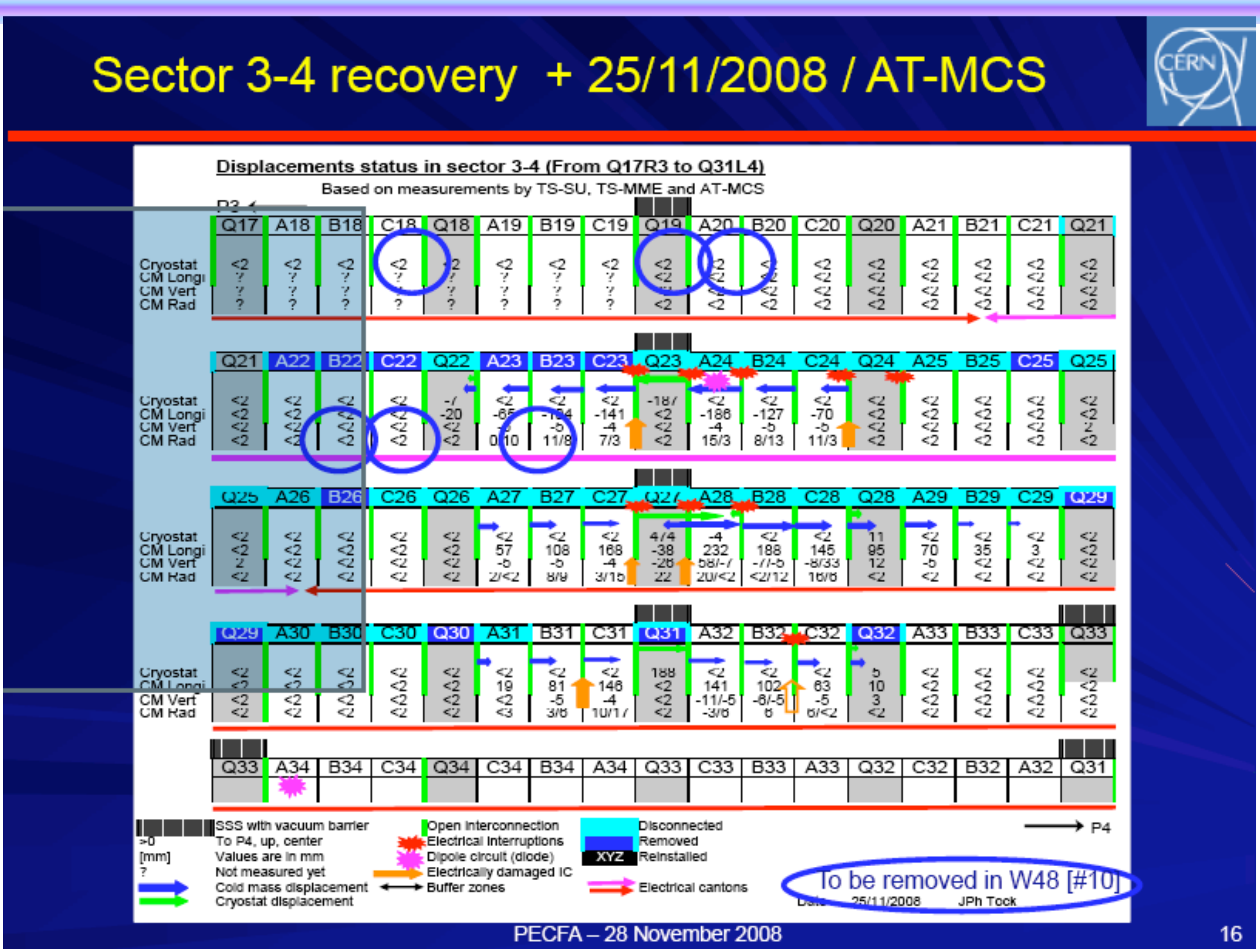


Summary Report on the analysis of the 19th September 2008 incident at the LHC

Sequence of events and consequences

Within the first second, an electrical arc developed and punctured the helium enclosure, leading to release of helium into the insulation vacuum of the cryostat.

The spring-loaded relief discs on the vacuum enclosure opened when the pressure exceeded atmospheric, thus relieving the helium to the tunnel. They were however unable to contain the pressure rise below the nominal 0.15 MPa absolute in the vacuum enclosures of subsector 23-25, thus resulting in large pressure forces acting on the vacuum barriers separating neighboring subsectors, which most probably damaged them. These forces displaced dipoles in the subsectors affected from their cold internal supports, and knocked the Short Straight Section cryostats housing the quadrupoles and vacuum barriers from their external support jacks at positions Q23, Q27 and Q31, in some locations breaking their anchors in the concrete floor of the tunnel. The displacement of the Short Straight Section cryostats also damaged the "jumper" connections to the cryogenic distribution line, but without rupture of the transverse vacuum barriers equipping these jumper connections, so that the insulation vacuum in the cryogenic line did not degrade.



Sector 3-4 recovery + 25/11/2008 / AT-MCS

Displacements status in sector 3-4 (From Q17R3 to Q31L4)

Based on measurements by TS-SU, TS-MME and AT-MCS

P3 ←

	Q17	A18	B18	C18	Q18	A19	B19	C19	Q19	A20	B20	C20	Q20	A21	B21	C21	Q21
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
CM Longi	?	?	?	?	?	?	?	?	<2	<2	<2	<2	<2	<2	<2	<2	<2
CM Vert	?	?	?	?	?	?	?	?	<2	<2	<2	<2	<2	<2	<2	<2	<2
CM Rad	?	?	?	?	?	?	?	?	<2	<2	<2	<2	<2	<2	<2	<2	<2

	Q21	A22	B22	C22	Q22	A23	B23	C23	Q23	A24	B24	C24	Q24	A25	B25	C25	Q25
Cryostat	<2	<2	<2	<2	-7	<2	<2	<2	-187	<2	<2	<2	<2	<2	<2	<2	<2
CM Longi	<2	<2	<2	<2	-20	-65	-154	-141	<2	-186	-127	-70	<2	<2	<2	<2	<2
CM Vert	<2	<2	<2	<2	<2	-5	-5	-4	<2	-4	-5	-5	<2	<2	<2	<2	2
CM Rad	<2	<2	<2	<2	<2	0/10	11/8	7/3	<2	15/3	8/13	11/3	<2	<2	<2	<2	<2

	Q25	A26	B26	C26	Q26	A27	B27	C27	Q27	A28	B28	C28	Q28	A29	B29	C29	Q29
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	474	-4	<2	<2	11	<2	<2	<2	<2
CM Longi	<2	<2	<2	<2	<2	57	108	168	-38	232	188	145	95	70	35	3	<2
CM Vert	2	<2	<2	<2	<2	-5	-5	-4	-26	58/-7	-7/-5	-8/33	12	-5	<2	<2	<2
CM Rad	<2	<2	<2	<2	<2	2/<2	8/9	3/15	22	20/<2	<2/12	16/6	<2	<2	<2	<2	<2

	Q29	A30	B30	C30	Q30	A31	B31	C31	Q31	A32	B32	C32	Q32	A33	B33	C33	Q33
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	188	<2	<2	<2	5	<2	<2	<2	<2
CM Longi	<2	<2	<2	<2	<2	19	81	146	<2	141	102	63	10	<2	<2	<2	<2
CM Vert	<2	<2	<2	<2	<2	<2	-5	-4	<2	-11/-5	-8/-5	-5	3	<2	<2	<2	<2
CM Rad	<2	<2	<2	<2	<2	<3	3/6	10/17	<2	-3/6	6	6/<2	<2	<2	<2	<2	<2

Q33	A34	B34	C34	Q34	C34	B34	A34	Q33	C33	B33	A33	Q32	C32	B32	A32	Q31

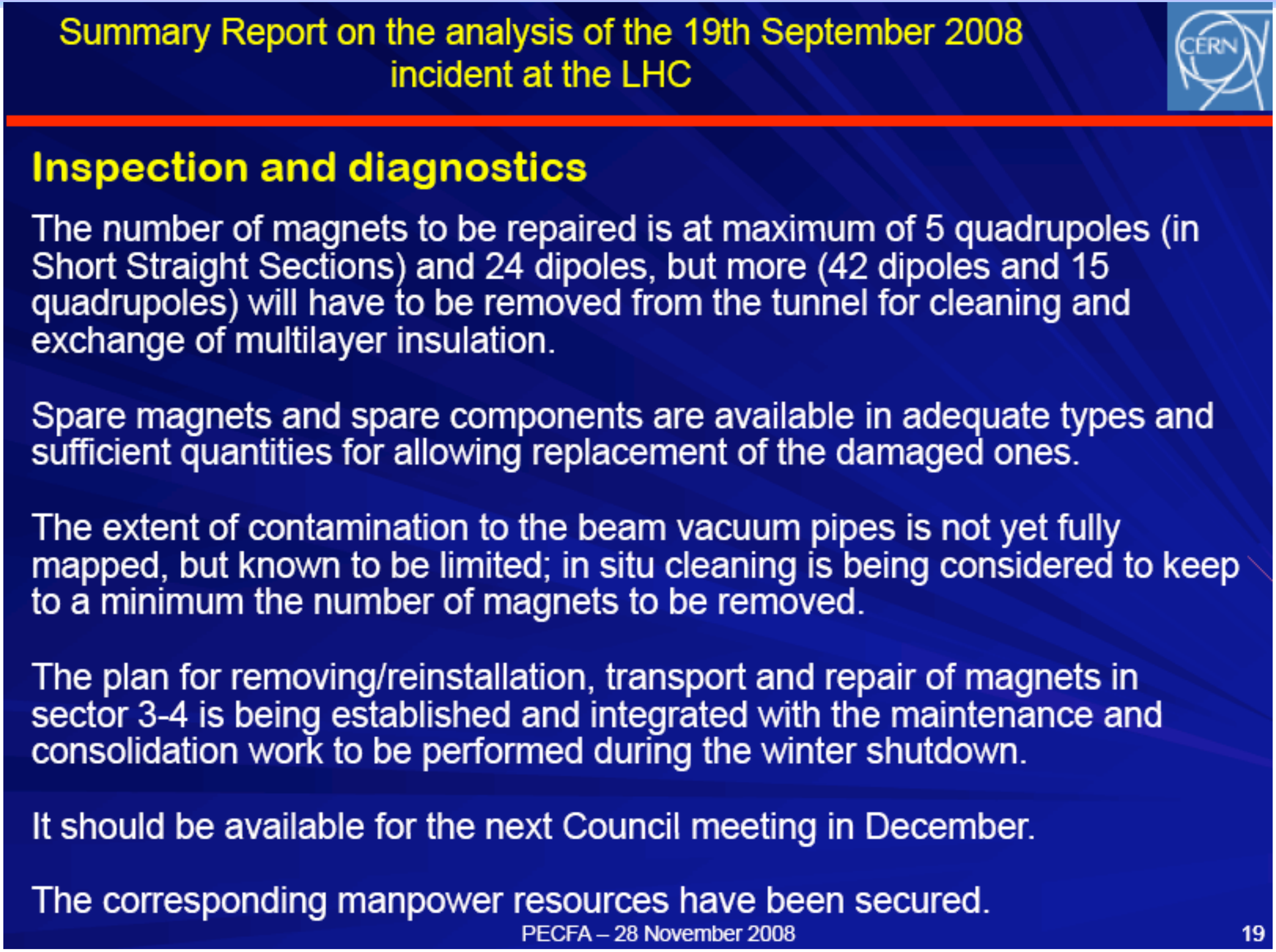
▮▮▮▮	SSS with vacuum barrier
>0	To P4, up, center
[mm]	Values are in mm
?	Not measured yet
➡	Cold mass displacement
➡	Cryostat displacement
▮	Open interconnection
✸	Electrical interruptions
✸	Dipole circuit (diode)
➡	Electrically damaged IC
↔	Buffer zones
🟦	Disconnected
🟦	Removed
XYZ	Reinstalled
⇉	Electrical cantons

→ P4

To be removed in W48 [#10]

Date 25/11/2008 JPh Tock

Q27R3



Summary Report on the analysis of the 19th September 2008 incident at the LHC

Inspection and diagnostics

The number of magnets to be repaired is at maximum of 5 quadrupoles (in Short Straight Sections) and 24 dipoles, but more (42 dipoles and 15 quadrupoles) will have to be removed from the tunnel for cleaning and exchange of multilayer insulation.

Spare magnets and spare components are available in adequate types and sufficient quantities for allowing replacement of the damaged ones.

The extent of contamination to the beam vacuum pipes is not yet fully mapped, but known to be limited; in situ cleaning is being considered to keep to a minimum the number of magnets to be removed.

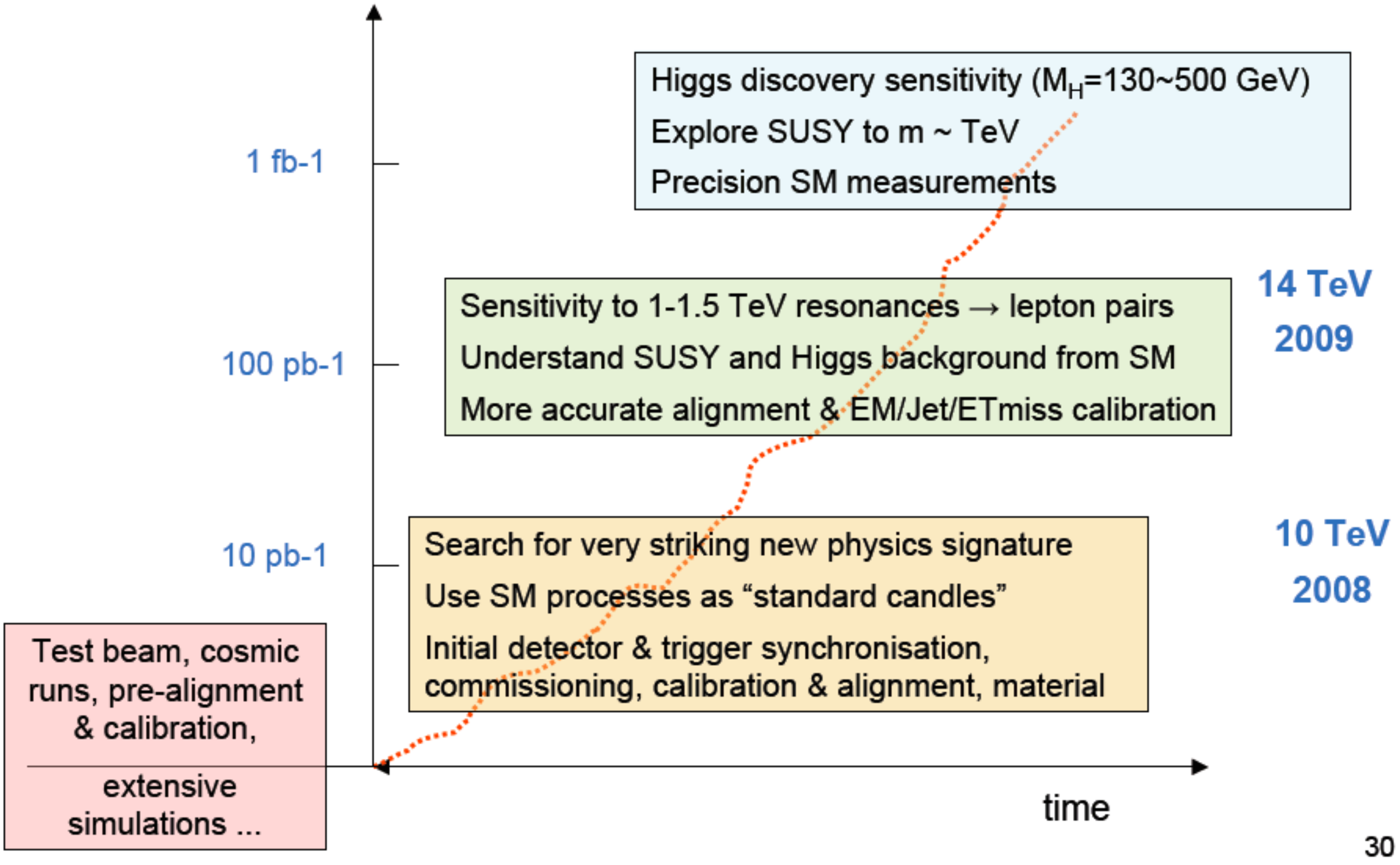
The plan for removing/reinstallation, transport and repair of magnets in sector 3-4 is being established and integrated with the maintenance and consolidation work to be performed during the winter shutdown.

It should be available for the next Council meeting in December.

The corresponding manpower resources have been secured.

PECFA – 28 November 2008 19

Timeline: Near-term Prediction



Higgs discovery sensitivity (M_H=130~500 GeV)
Explore SUSY to m ~ TeV
Precision SM measurements

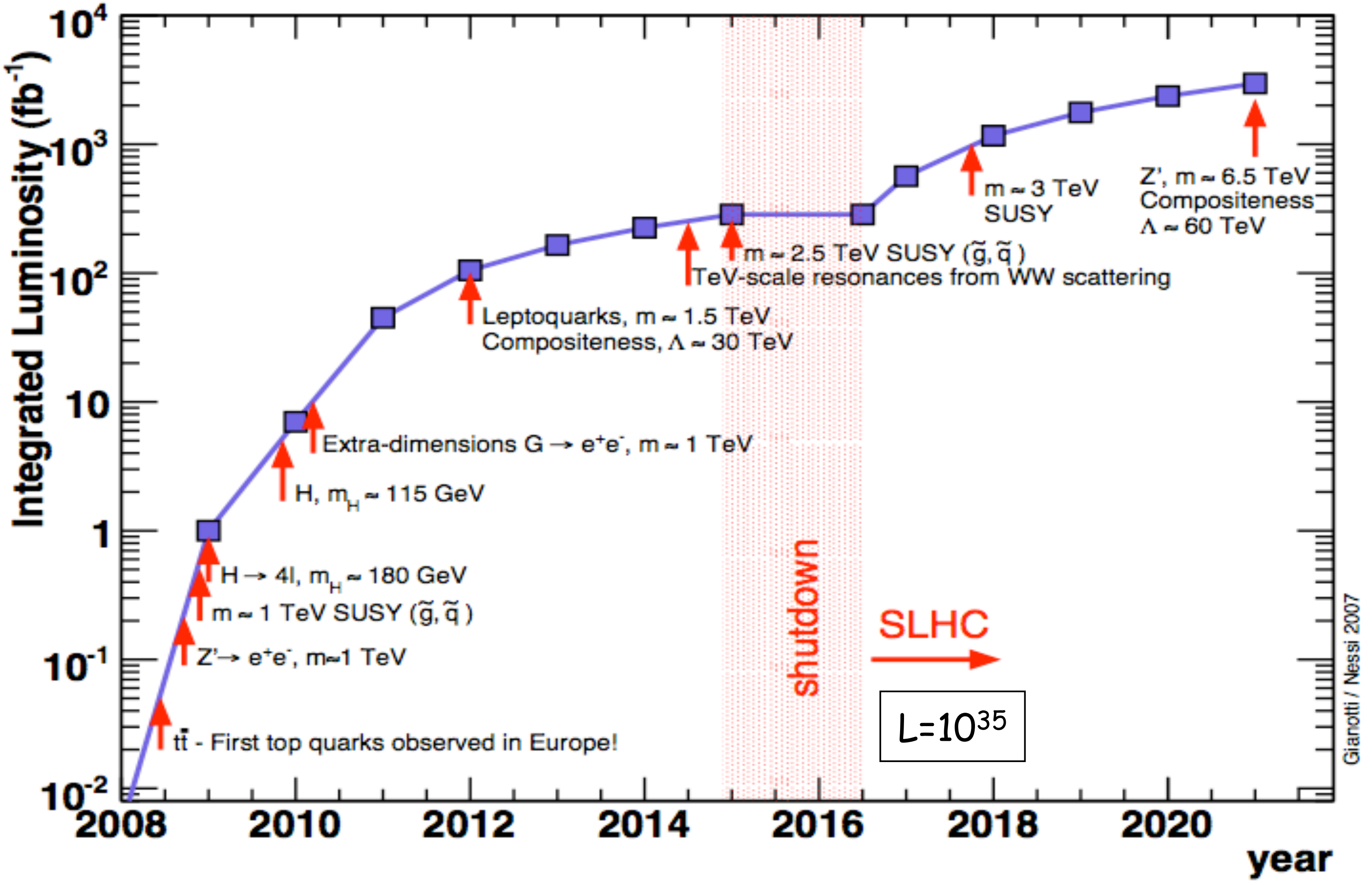
Sensitivity to 1-1.5 TeV resonances → lepton pairs
Understand SUSY and Higgs background from SM
More accurate alignment & EM/Jet/ETmiss calibration

Search for very striking new physics signature
Use SM processes as "standard candles"
Initial detector & trigger synchronisation, commissioning, calibration & alignment, material

Test beam, cosmic runs, pre-alignment & calibration,

extensive simulations ...

Timeline: Long-term Guess



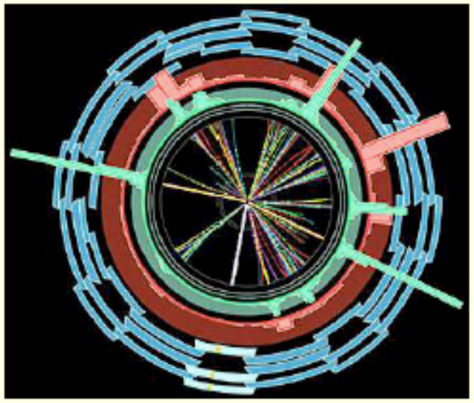
Many Thanks to:

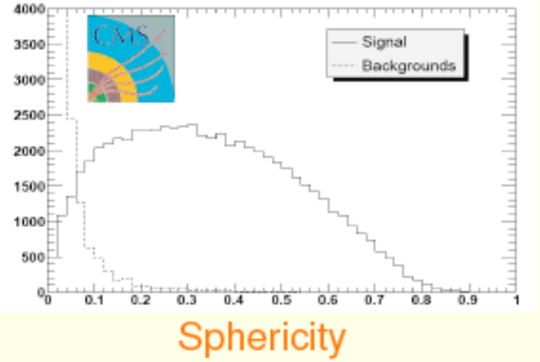
A. De Roeck, F. Gianotti, G. Giudice, J. Incandela, K.Jakobs and many others …

Backup

Black Holes at LHC:

- With Large Extra Dimensions micro Black Holes (BH) could be produced at LHC energy scale, *in (4+n) dimensional spacetime*
  - Schwarzschild radius $r_{s(4+n)}$ function of the reduced Plank scale M_D
- BH is formed if the p-p impact parameter is less than $r_{s(4+n)}$
  - from semiclassical approach $\sigma(M_{BH}) = \pi r^2_{s(4+n)}$
  - In case of $M_D \sim$ TeV then $\sigma(M_{BH}) \sim$ pb
- Could be discovered with 1 fb^{-1} if $M_D < 5$ TeV
- BH with short life time, of the order of 10^{-12} fs
- BH is expected to evaporate by emission of all particle types
  - source of new particles
  - possibility to probe quantum gravity in lab
- Signature
  - High track multiplicity, hadrons:leptons = 5:1
  - spherical event



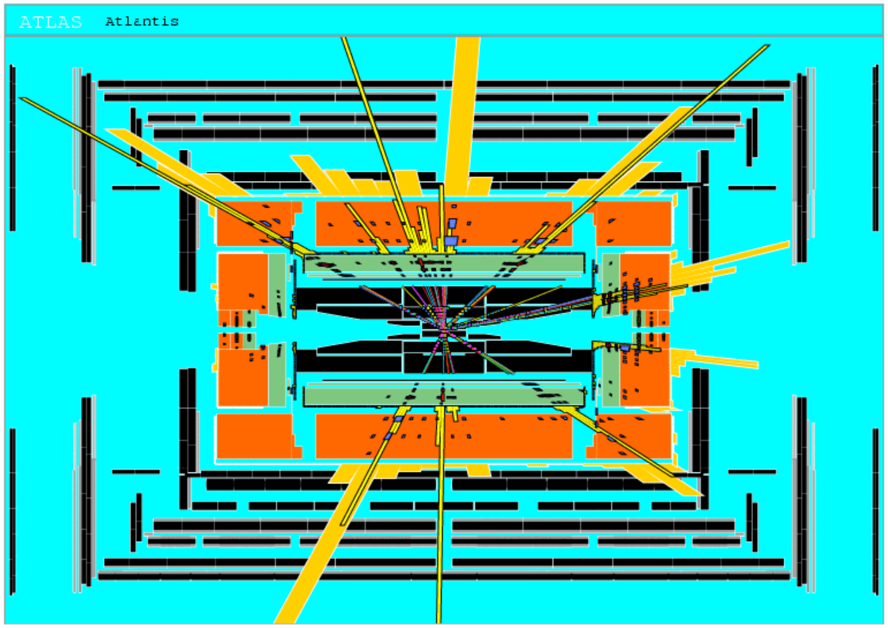


Quantum Black Holes at the LHC?

Black Holes are a direct prediction of Einstein’s general theory on relativity

If the Planck scale is in ~TeV region:
can expect Quantum Black Hole production

4 dim. : $R_s \rightarrow \ll 10^{-35}$ m
4+n dim. : $R_s \rightarrow \sim 10^{-19}$ m
R_S = schwartzschild radiu



Quantum Black Holes are harmless for the environment: they will decay within less than 10^{-27} seconds

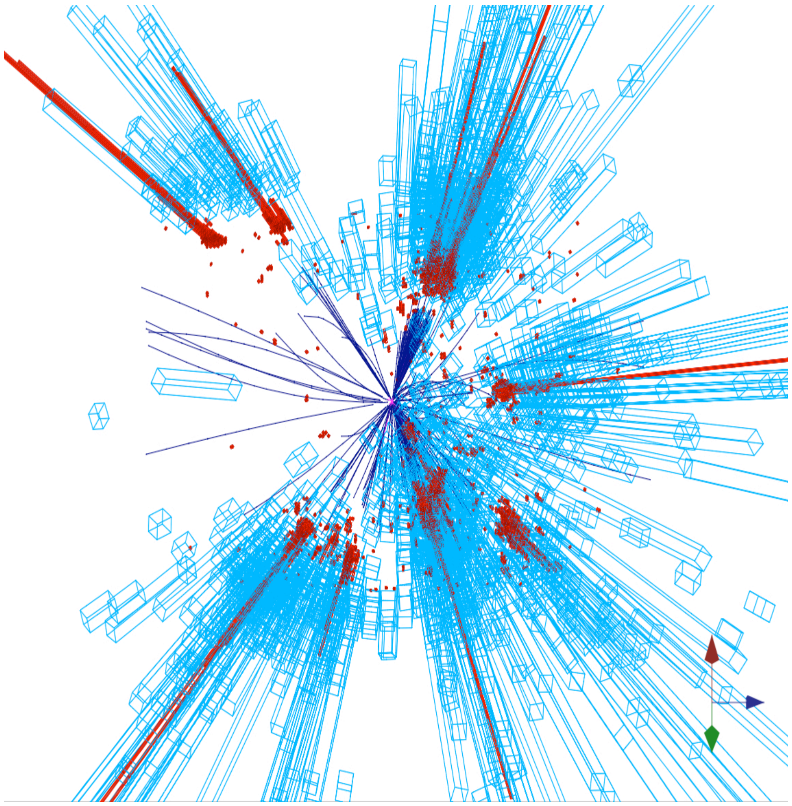
Quantum Black Holes open the exciting perspective to study Quantum Gravity in the lab!

Simulation of a Quantum Black Hole event

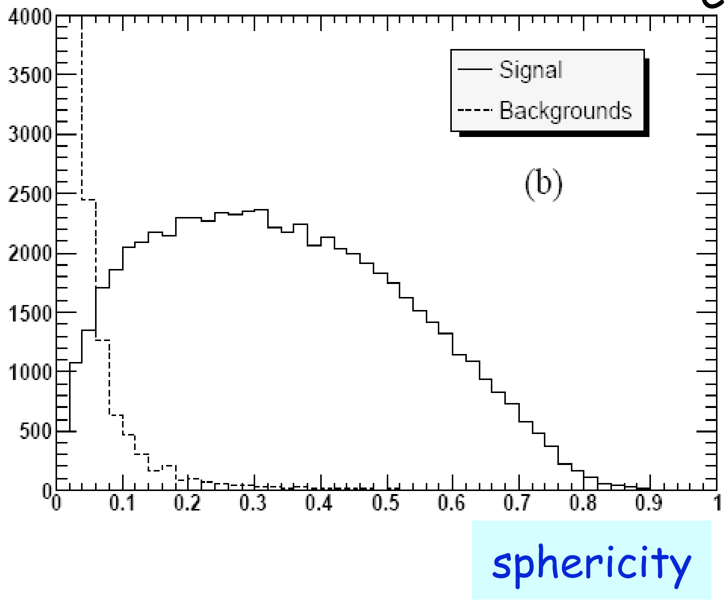
Black Holes Production

If the Planck scale in ~TeV region: can expect Black Hole production

CMS PTDR



Simulation of a black hole event with M_{BH} ~ 8 TeV in CMS



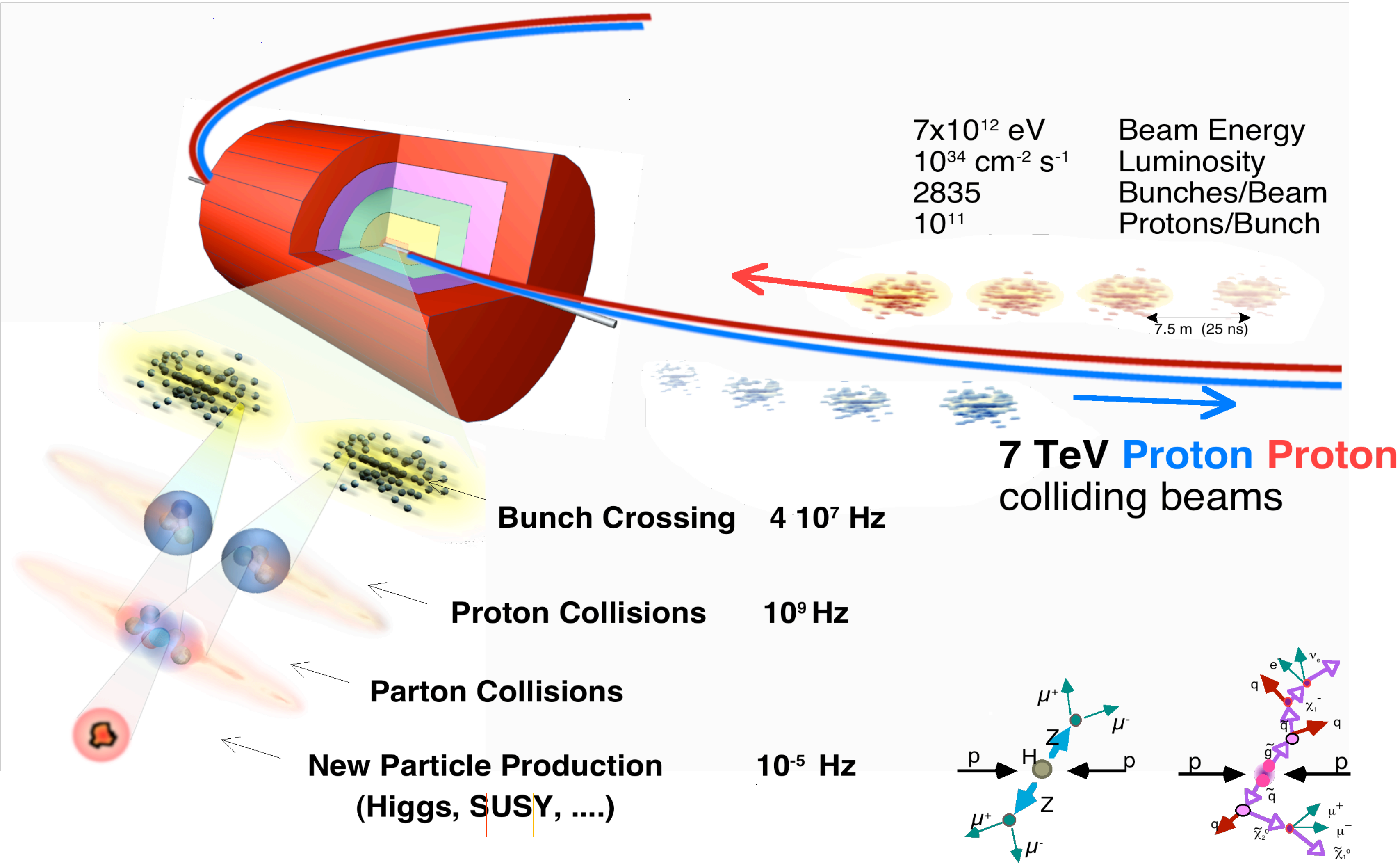
~ Spherical events: Many high energy jets leptons, photons etc.

Ecological comment: BH's will decay within ~ 10^{-27} secs

Detectors, electronics (and rest of the world) are safe!!

The LHC Environment

Collisions at the LHC



7×10^{12} eV	Beam Energy
10^{34} cm^{-2} s^{-1}	Luminosity
2835	Bunches/Beam
10^{11}	Protons/Bunch

7 TeV Proton Proton
colliding beams

Bunch Crossing	**$4\ 10^7$ Hz**
Proton Collisions	**10^9 Hz**
Parton Collisions	
New Particle Production (Higgs, SUSY, ...)	**10^{-5} Hz**

Selection of 1 event in 10,000,000,000,000

pp collisions at 14 TeV at 10^{34} cm^{-2}s^{-1}

A very difficult environment …

20 min bias

events overlap

&

H→ZZ

with Z → 2 muons

: H→ 4 muons:

the cleanest

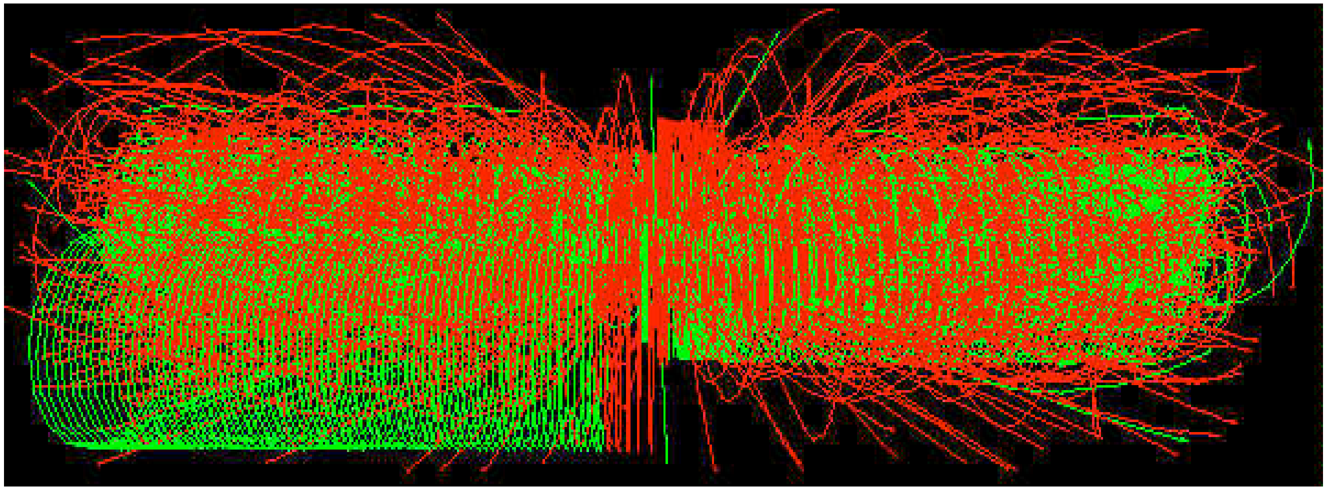
(“golden”)

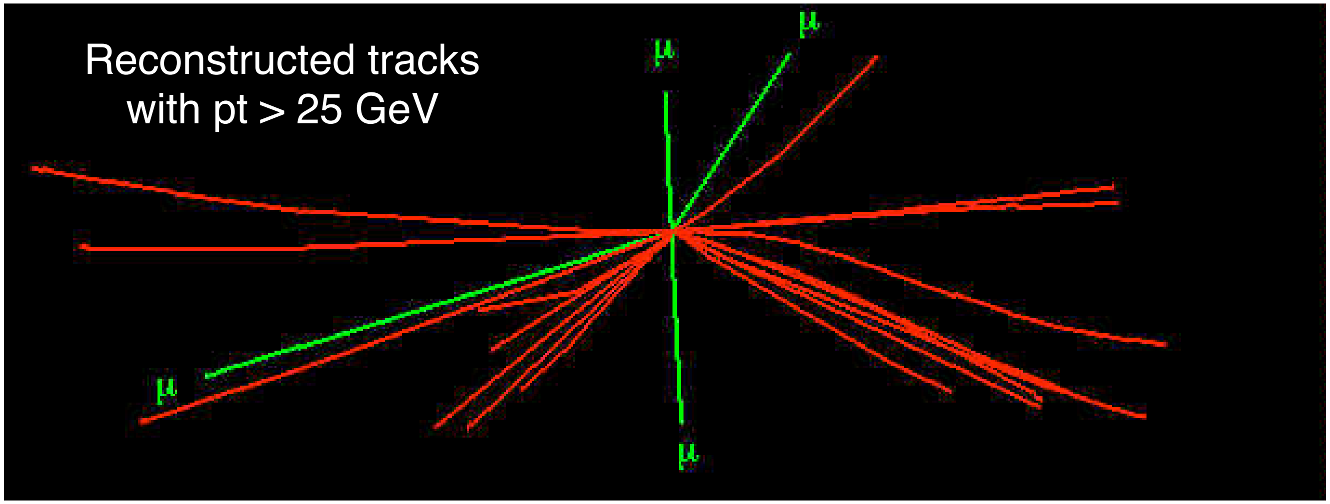
signature

And this (not the

H though…) repeats

every 25 ns…

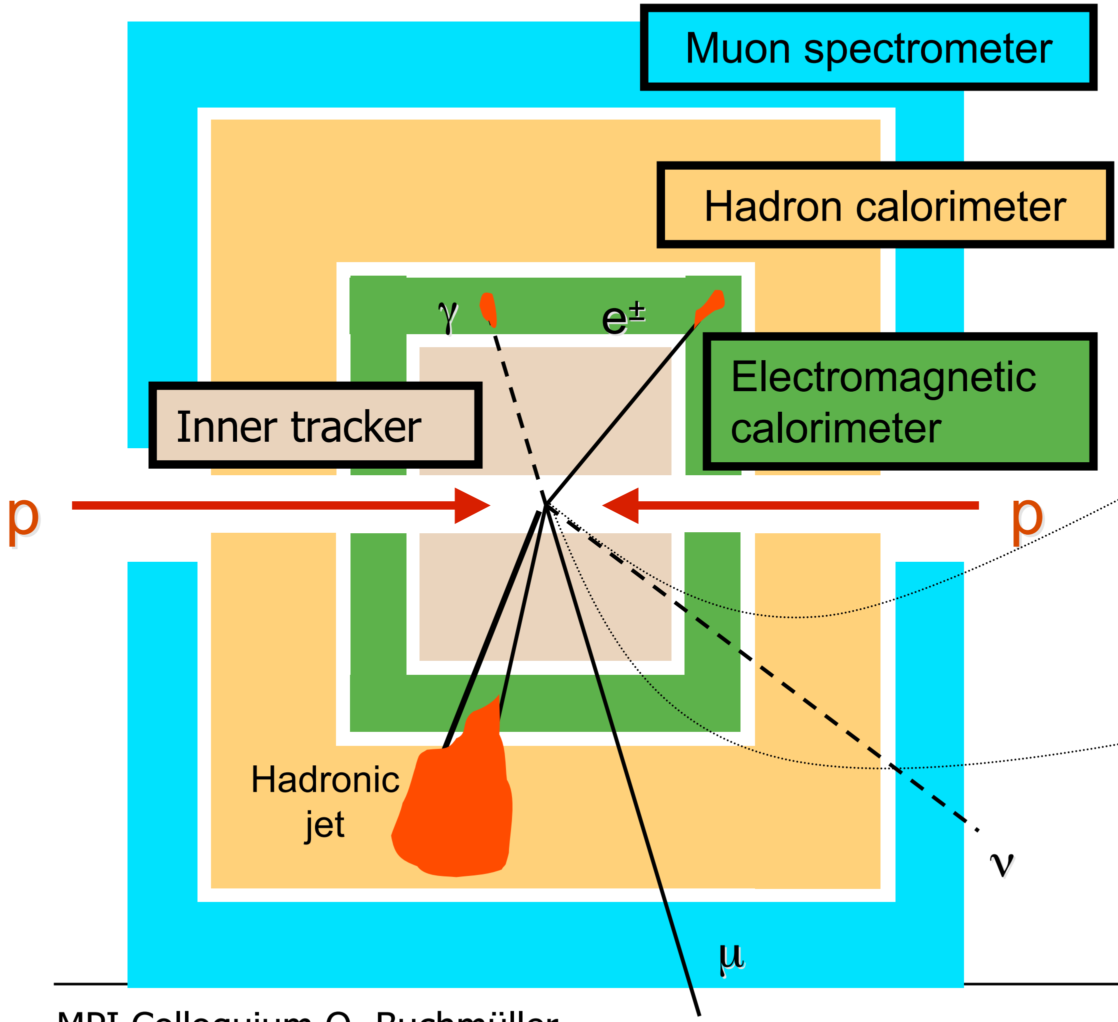




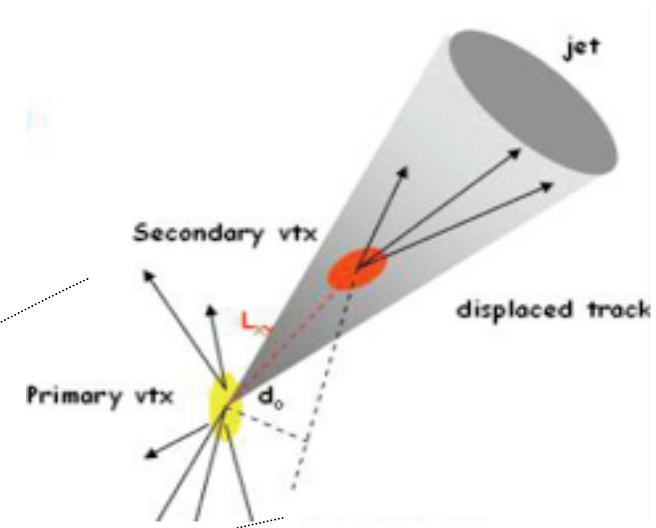
High Performance Detectors

We don't know how New Physics will manifest itself

→ detectors must be able to detect as many particles and signatures as possible: e, μ, τ, ν, γ, jets, b-quarks, ….

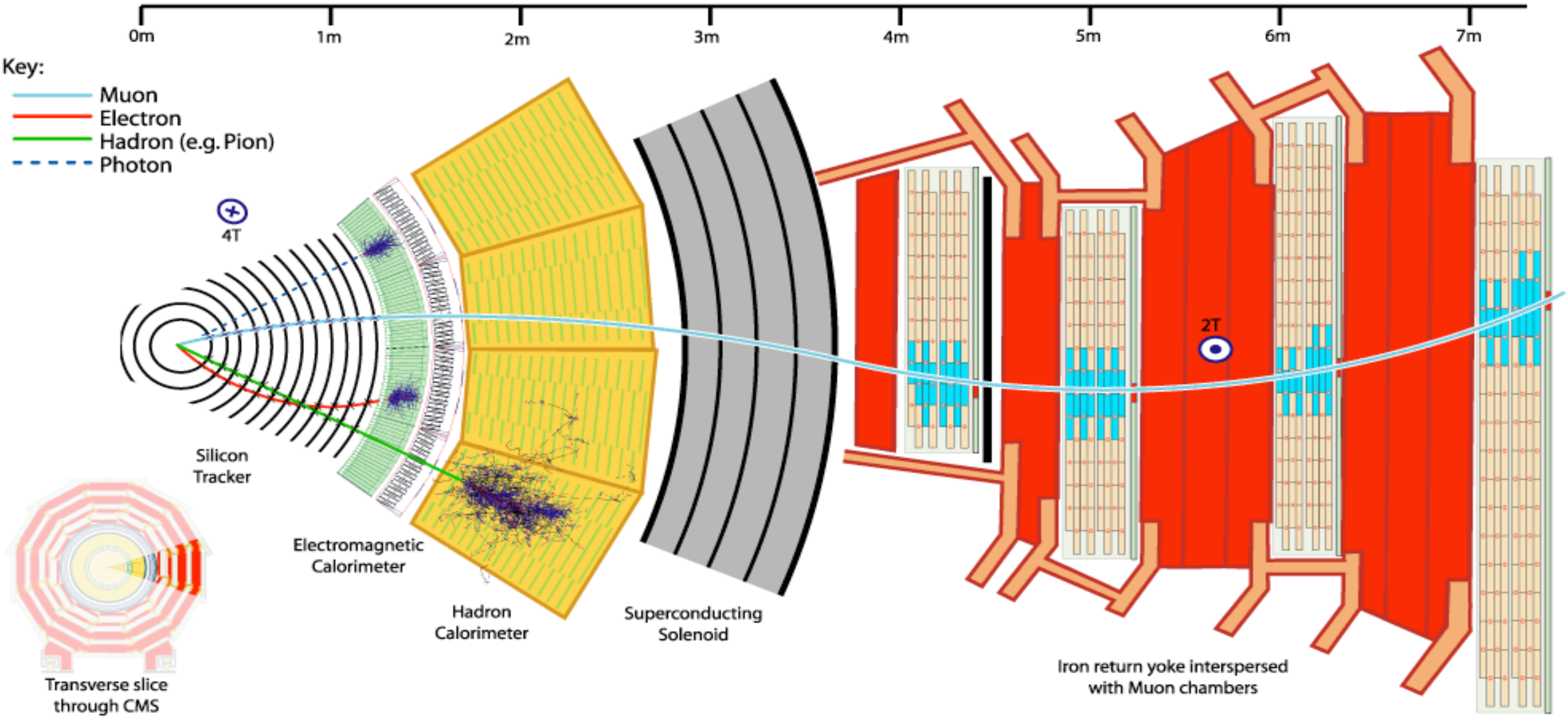


Very precise vertex reconstruction of secondary particle decays (e.g. b quarks)



Excellent performance over unprecedented energy range :
few GeV → few TeV

High Performance Detectors

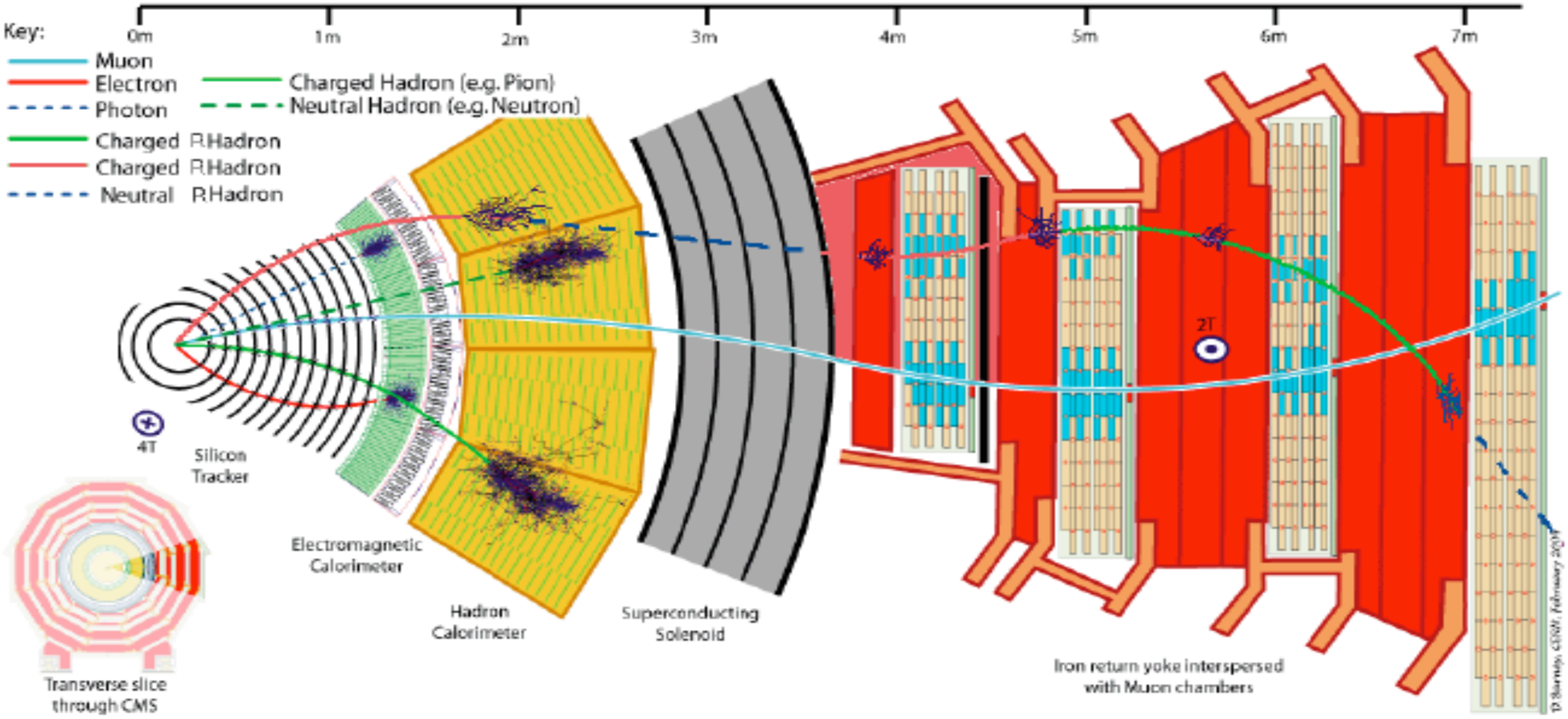


We don't know how New Physics will manifest itself.

→ Detectors must be able to detect as many particles and signatures as possible: e, μ, τ, ν, γ, jets, b-quarks, ….

High Performance Detectors

Even for exotic particles like R-Hadrons (if they exist)



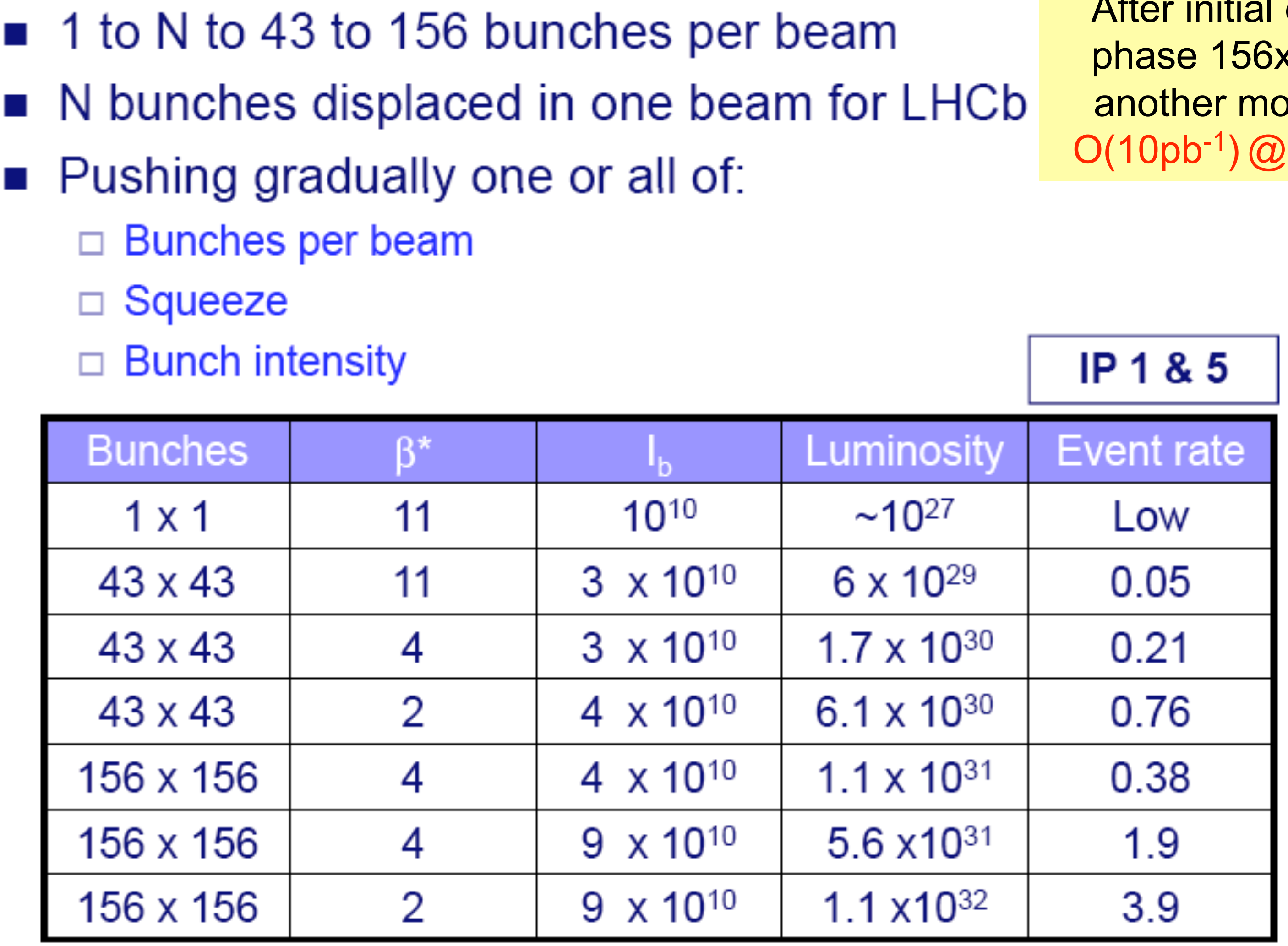
We don't know how New Physics will manifest itself.

→ Detectors must be able to detect as many particles and signatures as possible: e, μ, τ, ν, γ, jets, b-quarks, ….

LHC Startup

Slide from Mike Lamont

After initial commissioning phase 156x156 running of another month could yield O(10pb^{-1}) @ 10 TeV in 2008



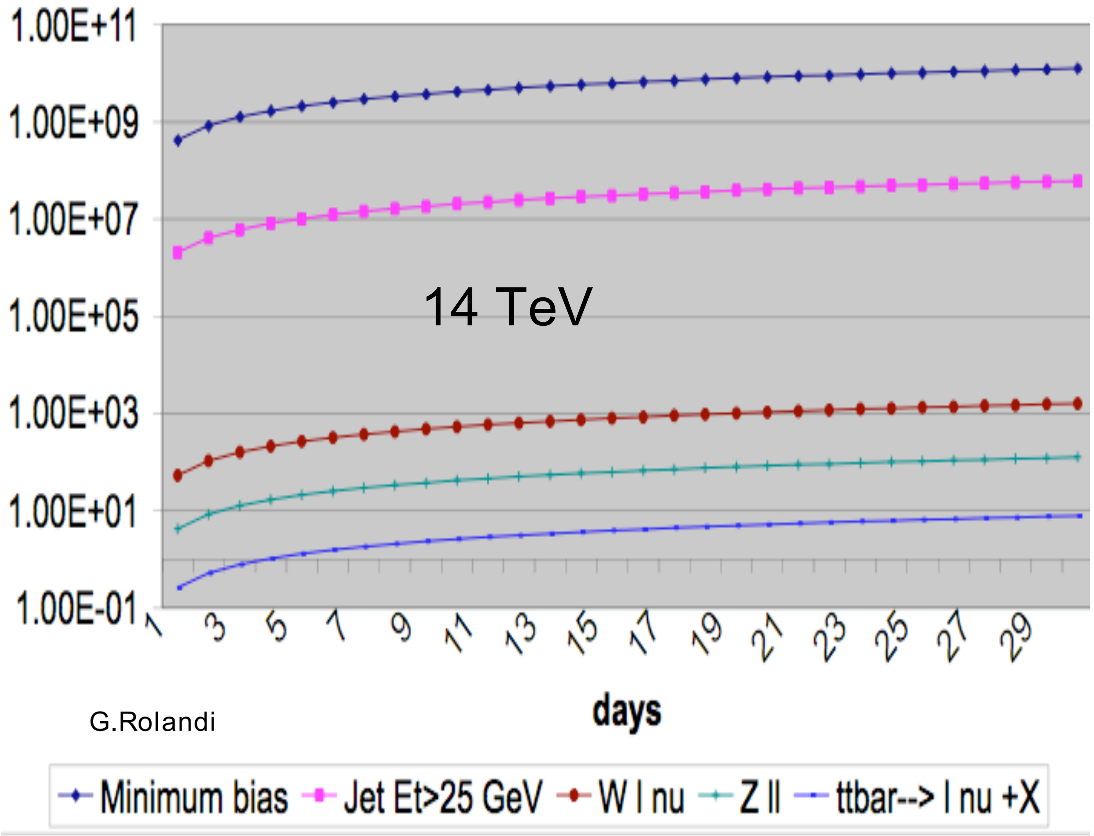
- 1 to N to 43 to 156 bunches per beam
- N bunches displaced in one beam for LHCb
- Pushing gradually one or all of:
  - ☐ Bunches per beam
  - ☐ Squeeze
  - ☐ Bunch intensity

IP 1 & 5

Bunches	β^*	I_b	Luminosity	Event rate
1 x 1	11	10^{10}	~10^{27}	Low
43 x 43	11	3×10^{10}	6×10^{29}	0.05
43 x 43	4	3×10^{10}	1.7×10^{30}	0.21
43 x 43	2	4×10^{10}	6.1×10^{30}	0.76
156 x 156	4	4×10^{10}	1.1×10^{31}	0.38
156 x 156	4	9×10^{10}	5.6×10^{31}	1.9
156 x 156	2	9×10^{10}	1.1×10^{32}	3.9

Produced Events in the very First Days

30 days at 3x10^{29} with efficiency 20% =0 .15 pb^{-1}



G.Rolandi

Assumed Efficiencies

ε(W) =0.3 ε(Z)=0.5 ε(ttbar)=0.02

Events after one Month

Min Bias :	~10^{10}
$Jet_{Et>25}$:	~10^8
$W \to \ell\nu$:	~10^3
$Z \to \ell\ell$:	~10^2
$tt \to \ell\nu + X$:	~10^1

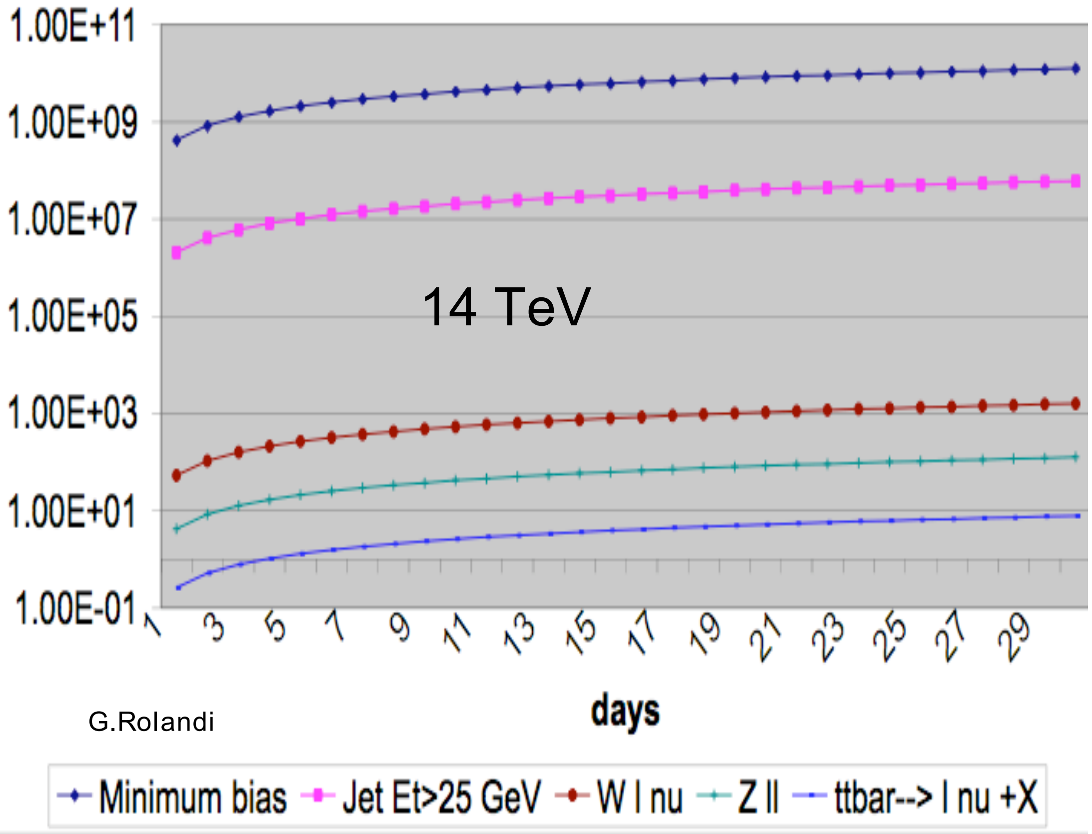
14 TeV

Mainly used for general commissioning and detector alignment & calibration.

Produced Events in the very First Days

Production Rate: 10 vs.14 TeV:
- W/Z ~70%
- ttbar ~50%
- Higgs (200) ~50%

30 days at $3x10^{29}$ with efficiency 20% =0 .15 pb^{-1}



G.Rolandi

Assumed Efficiencies

$\varepsilon(W)=0.3$ $\varepsilon(Z)=0.5$ $\varepsilon(ttbar)=0.02$

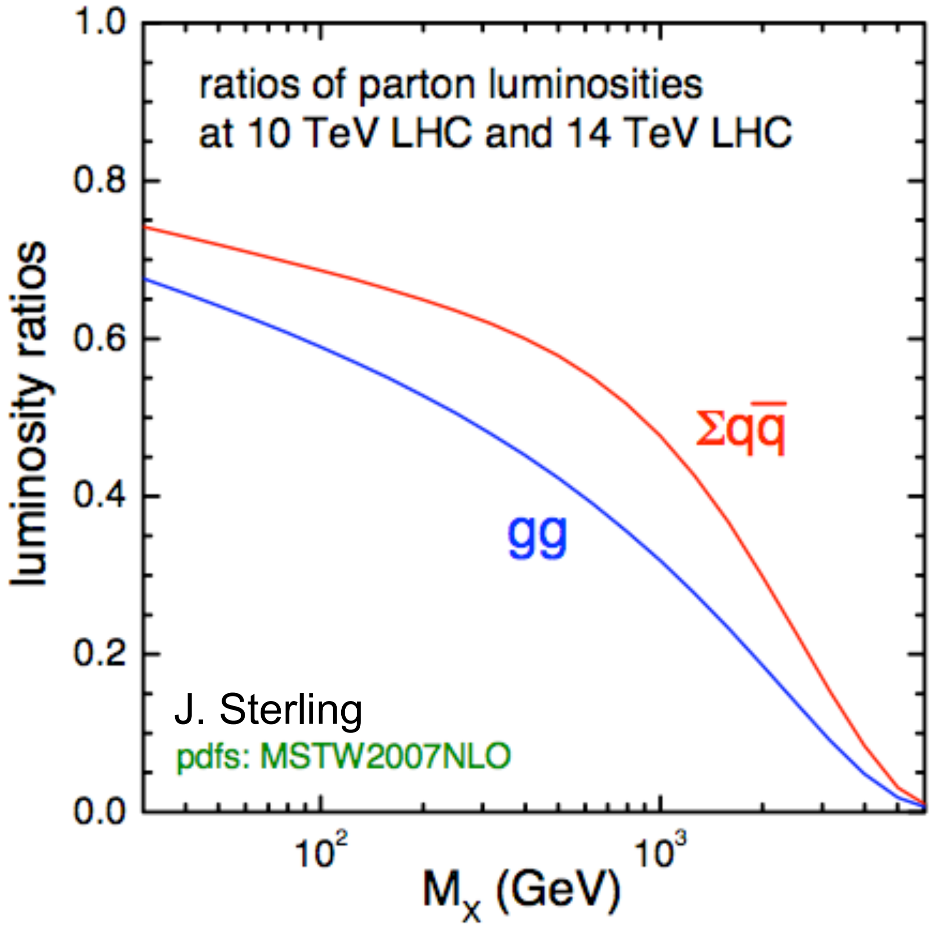
Events after one Month

Min Bias :	$\sim 10^{10}$
$Jet_{Et>25}$:	$\sim 10^{8}$
$W \rightarrow \ell\nu$:	$\sim 10^{3}$
$Z \rightarrow \ell\ell$:	$\sim 10^{2}$
$tt \rightarrow \ell\nu + X$:	$\sim 10^{1}$

14 TeV

Mainly used for general commissioning and detector alignment & calibration.

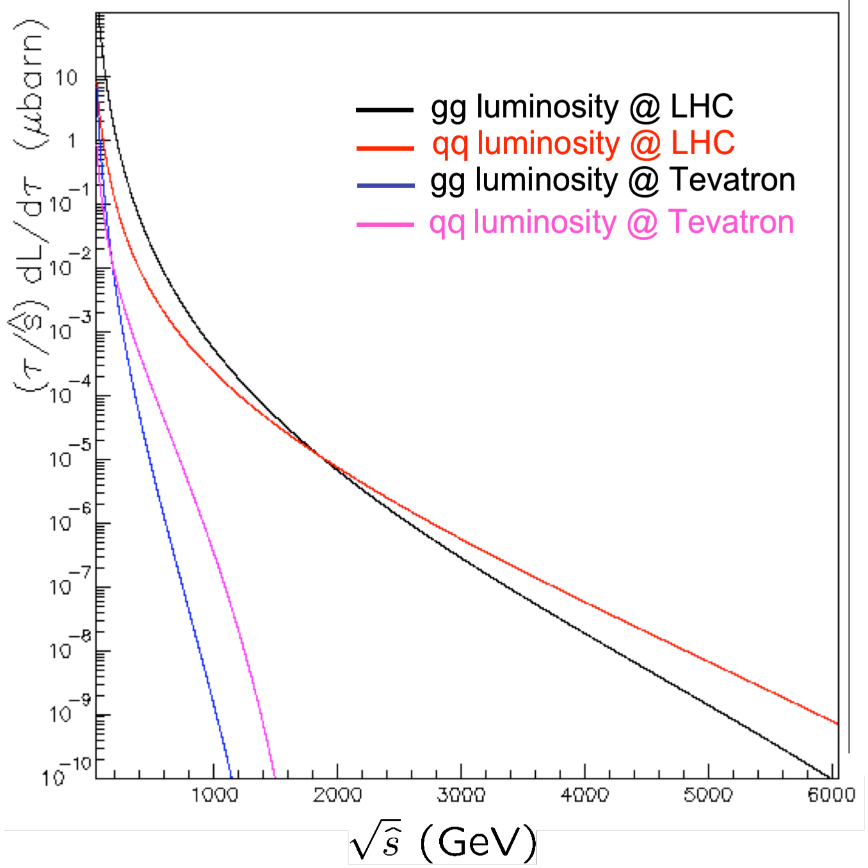
Production Rates: 14 TeV vs. 10 TeV

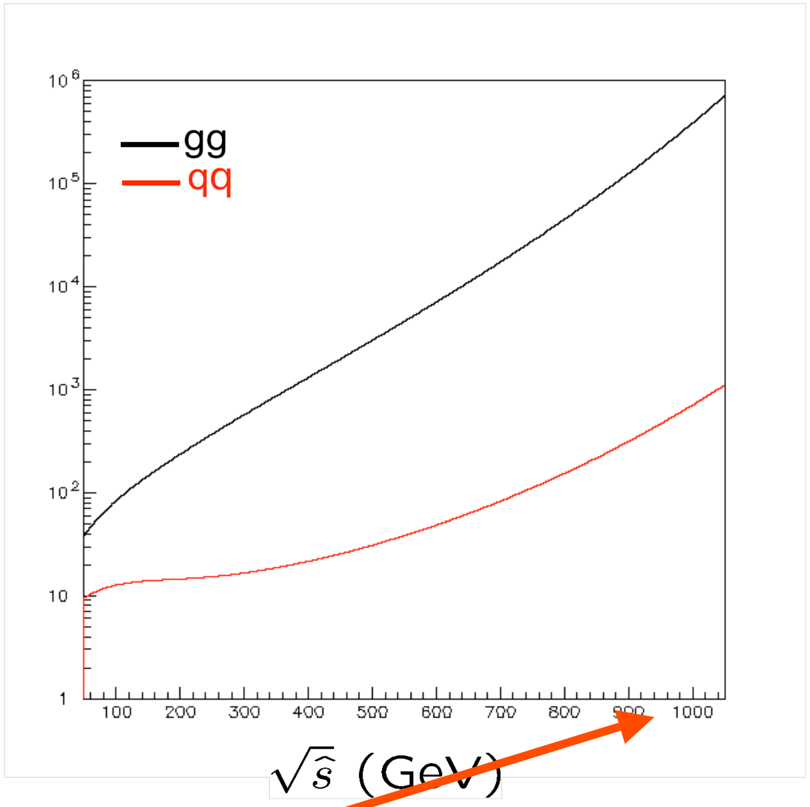


Production Rate wrt 14 TeV:

- W/Z ~70%
- ttbar ~50%
- Higgs (200) ~50%

LHC *will* startup in new territory



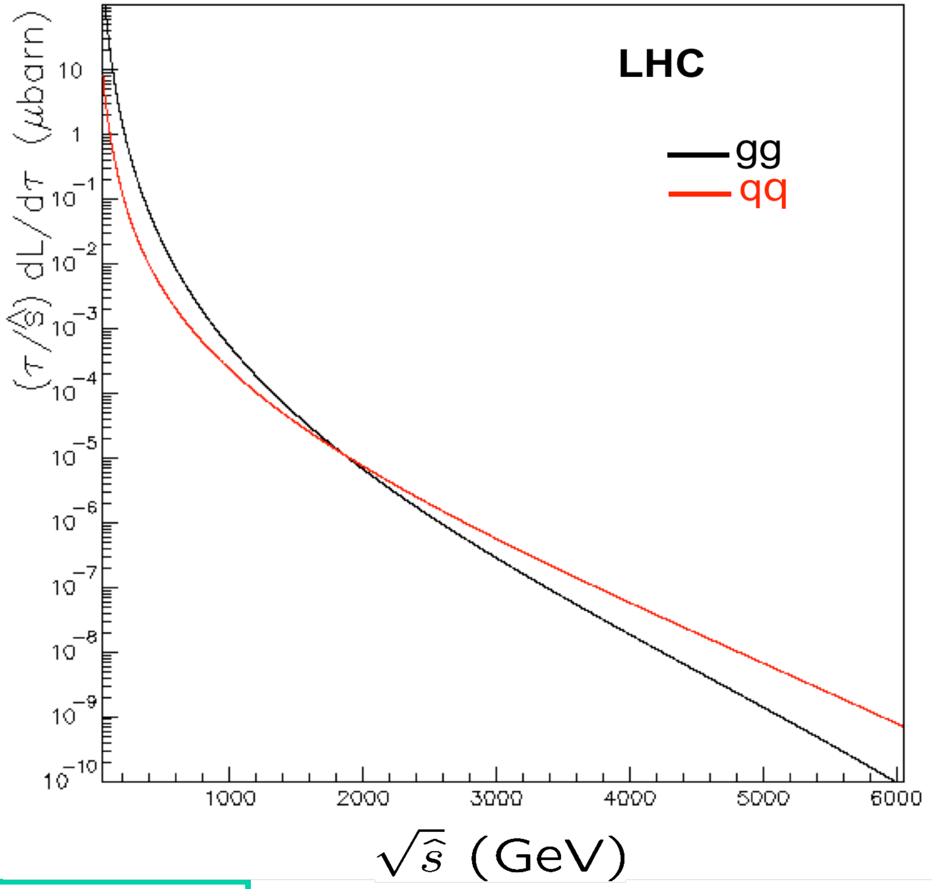


At 1 TeV constituent com energy

- → ***gg: 1 fb^{-1} at Tevatron is like 1 nb^{-1} at LHC***
- → ***qq: 1 fb^{-1} at Tevatron is like 1 pb^{-1} at LHC***

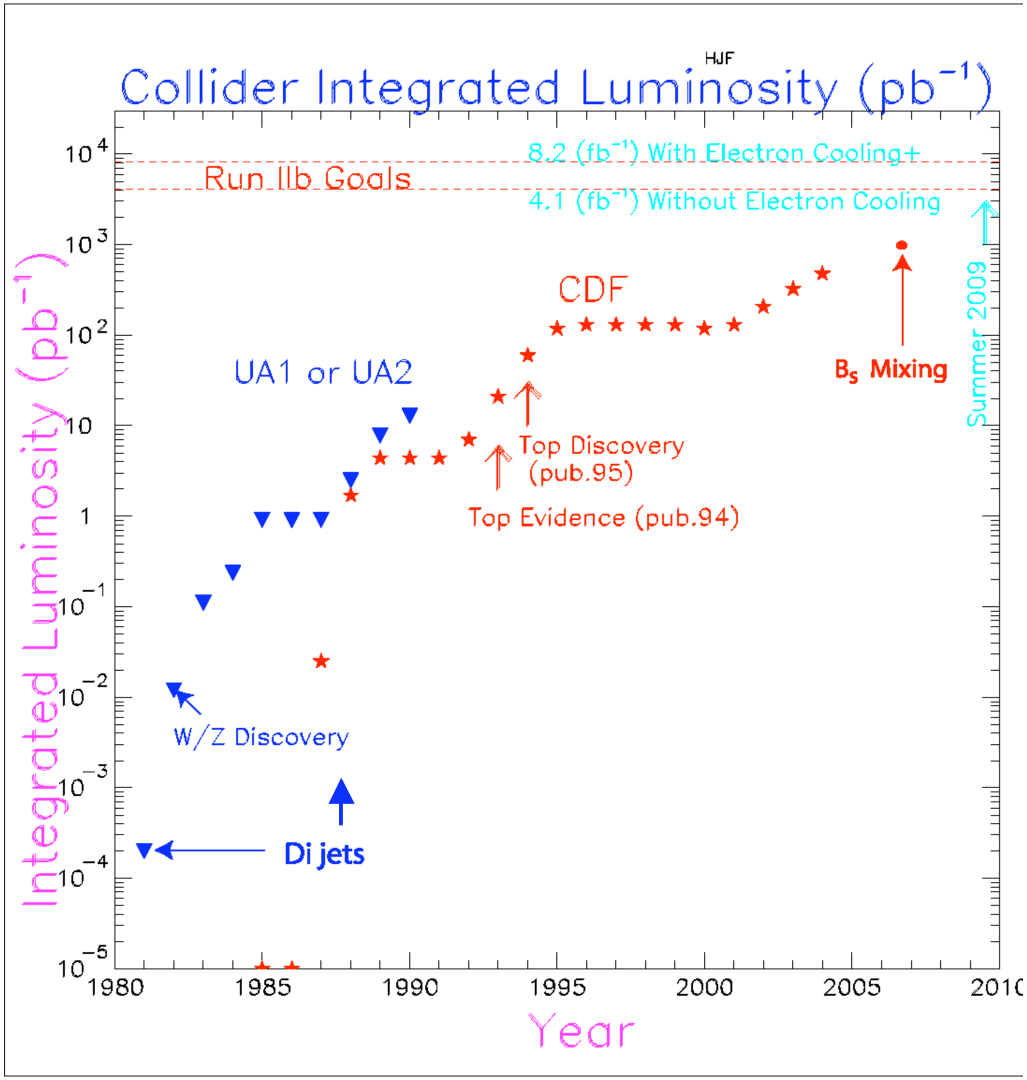
Early and Late

- Parton Luminosity falls steeply
  - In multi-TeV region, ~ by factor 10 every 600 GeV
- New states produced near threshold
  - Suppose you have a limit on some pair-produced object, M > 1 TeV. How does your sensitivity improve with more data?
    - *By ~ (600/2)=300 GeV = 30% for 10 times more integrated luminosity*



Improving sensitivity is tough....
but you can turn evidence into an observation

Good stuff comes early…and late.



- SPS
  - 683 GeV com and ~100 GeV mean com partons
- Tevatron I
  - 1800 GeV com and ~270 GeV mean com partons
- SPS & Tevatron Discoveries
  - SPS turn-on led to quick major discoveries
  - Not true at the Tevatron
- SPS had a lot of data
  - Already probed quite a bit higher than the mean constituent com energy (~100 GeV)
  - Tevatron needed to ~match SPS integrated luminosity to in order to probe a "new" energy domain
    - *And then discovered top!*
- Early discoveries have been followed by other important results at hadron colliders – but these have generally come late

“Re-discovery” of the Standard Model @ 14 TeV (10 TeV)

W/Z Production

Expected rate uncertainties:

W	ATLAS 50/pb	ATLAS 1/fb	CMS 1/fb
Statistical:	0.2%	0.04%	0.04%
Systematic:	3.1% – 5.2%	2.4%	3.3%

Experimental systematic error dominated by missing energy determination

Z	ATLAS 50/pb	ATLAS 1/fb	CMS 1/fb
Statistical:	0.8%	0.2%	0.13%
Systematic:	3.2% – 3.6%	1.3%	2.3%

W/Z theoretical systematic error dominated by PDFs (1-2%) and boson Pt

Luminosity uncertainty: 10% (at startup), 5% (long-term)

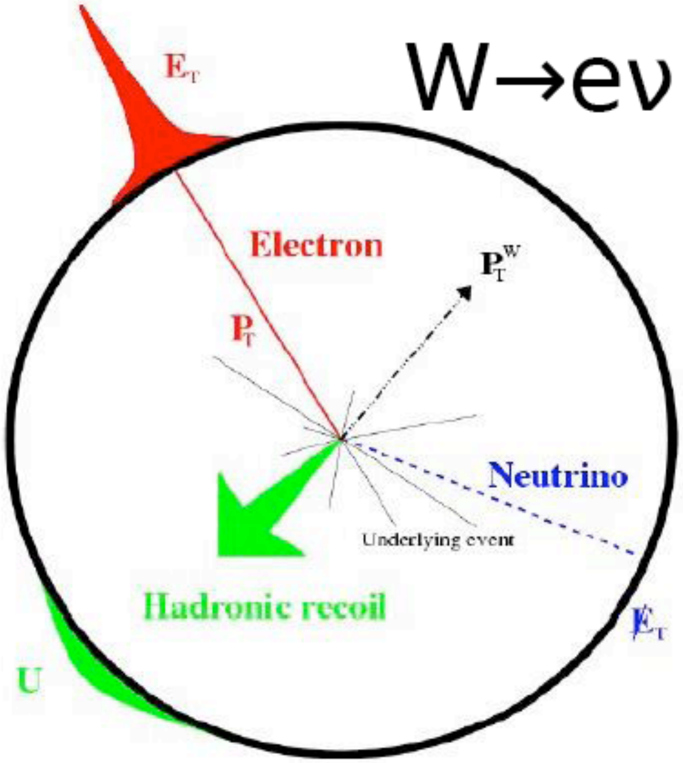
Use W (Z) production as luminosity reaction:

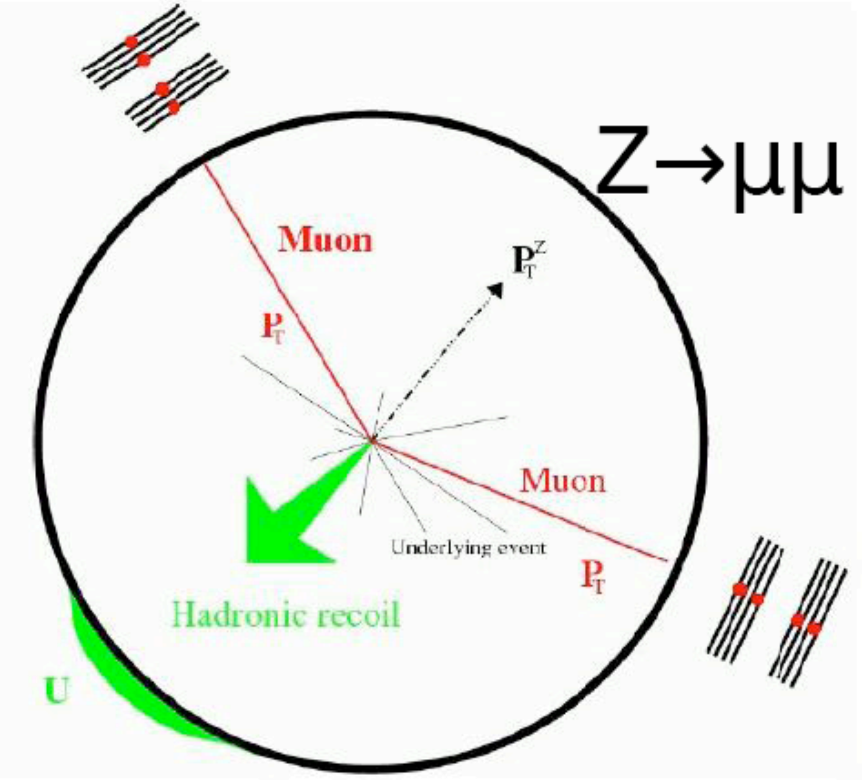
- High Q^2 – similar to other reactions (tT, SUSY, ...)
- PDF effects cancel to a large extend in ratio of rates

W/Z Production

Inclusive W→lν:

Single high-energy lepton (e, μ)
Missing (transverse) energy (ν)
Hadronic recoil, possibly jet(s)





Inclusive Z→l^+l^-:

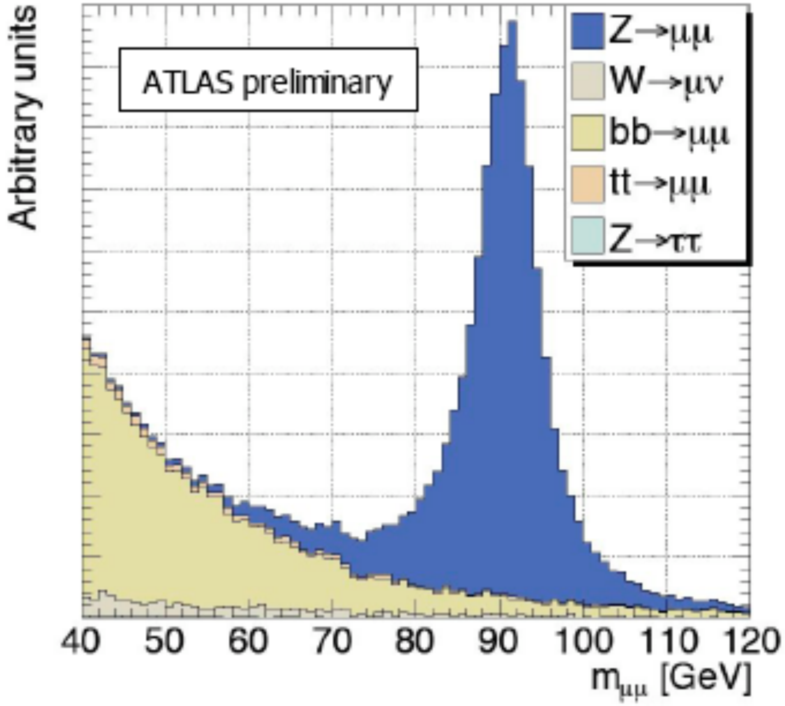
Pair of high-energy leptons of opposite electric charge
No missing transverse energy
Hadronic recoil, possibly jet(s)

Example: J/ϕ, Υ and Z

$Z \rightarrow \mu\mu$

26K Z and 0.1K backg. @ 50/pb

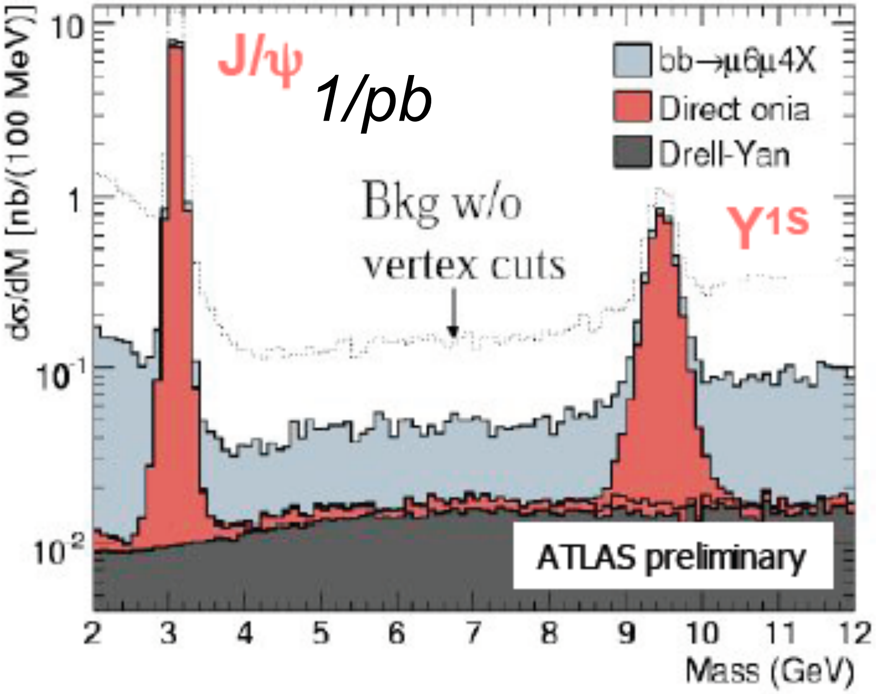
~200/day **$Z \rightarrow \mu\mu$** @ 10^{31}



$J/\phi \rightarrow \mu\mu$ and $\Upsilon \rightarrow \mu\mu$

5000/day J/ϕ and

800/day Υ @ 10^{31}

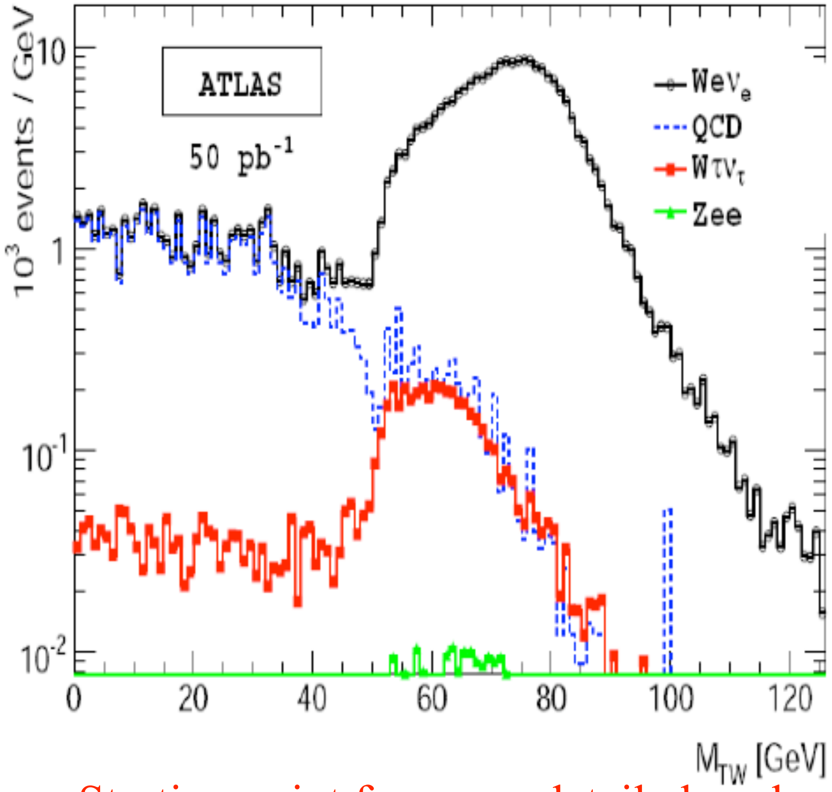


1/pb

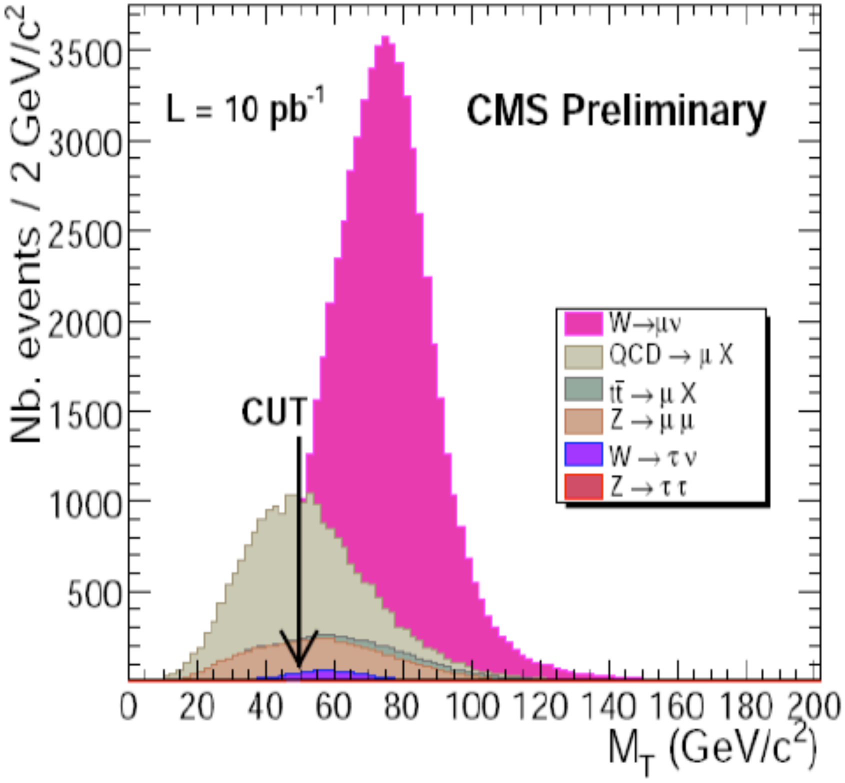
Crucial data samples for the commissioning of the experiments (alignment, momentum scale, efficiencies, etc) but also for physics.

Example: W Production

W→eν



W→μν

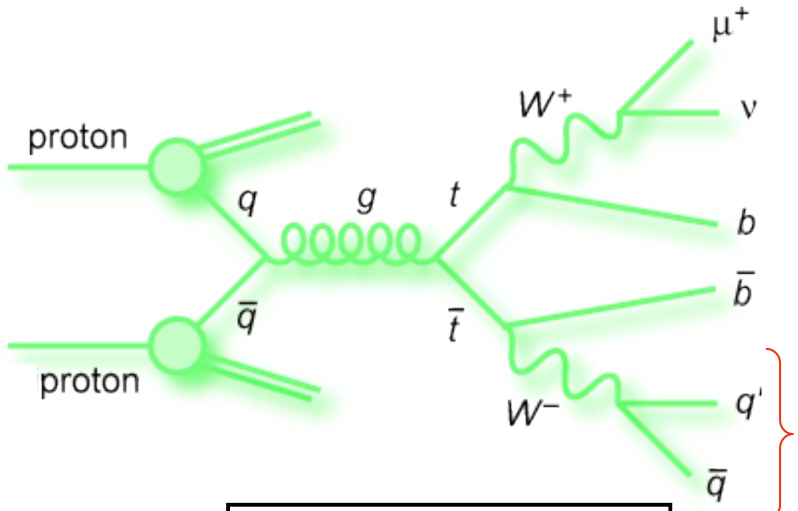


Starting point for many detailed analyses:

- p_T boson spectrum
- W(and Z) + multi-jets (important for searches)
- Asymmetries
- W mass and width
- Calibration candles (in particular Z)
- etc

Very rich program of work starting already at day one. Very relevant for searches!

Ttbar re-discovery & Ttbar as a tool



Tag and Lepton study tool

Missing E_T study tool

B tag study tool

Light quark
jet energy
scale from
M_W constraint

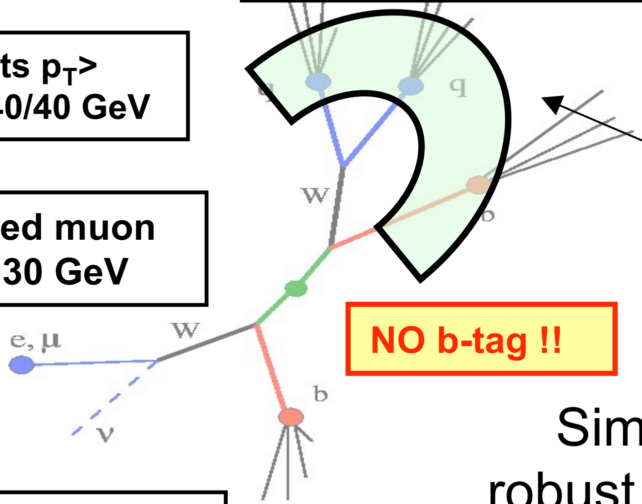
b quark
jet energy
scale from
M_{top} constraint

3 jets with largest $\sum p_T$

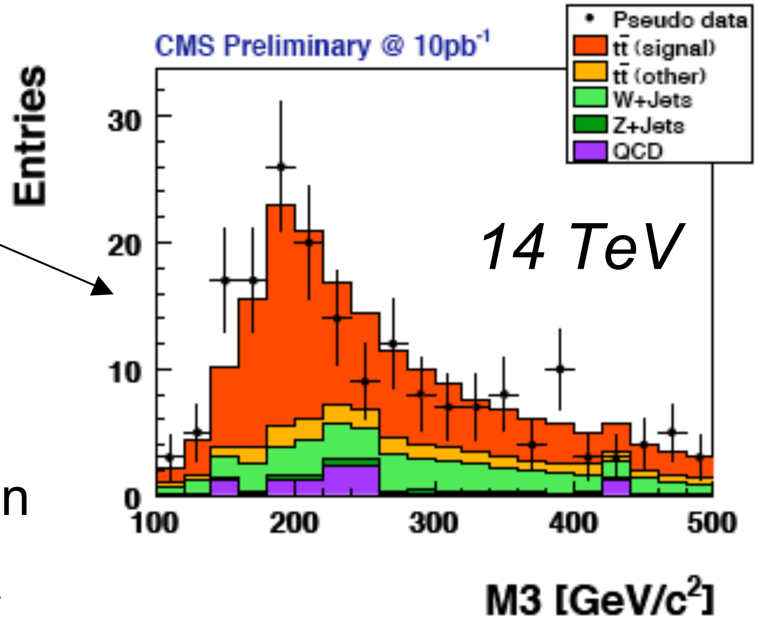
**4 jets p_T>
65/40/40/40 GeV**

**Isolated muon
p_T> 30 GeV**

No E_t^{miss} cut



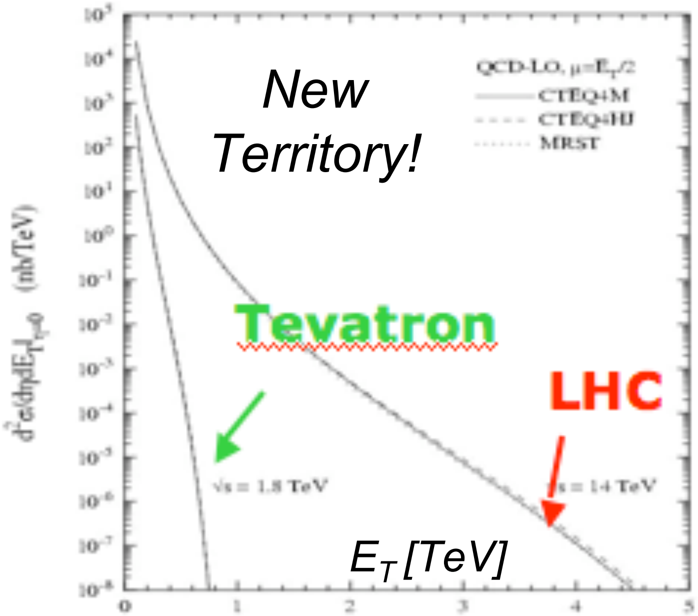
NO b-tag !!



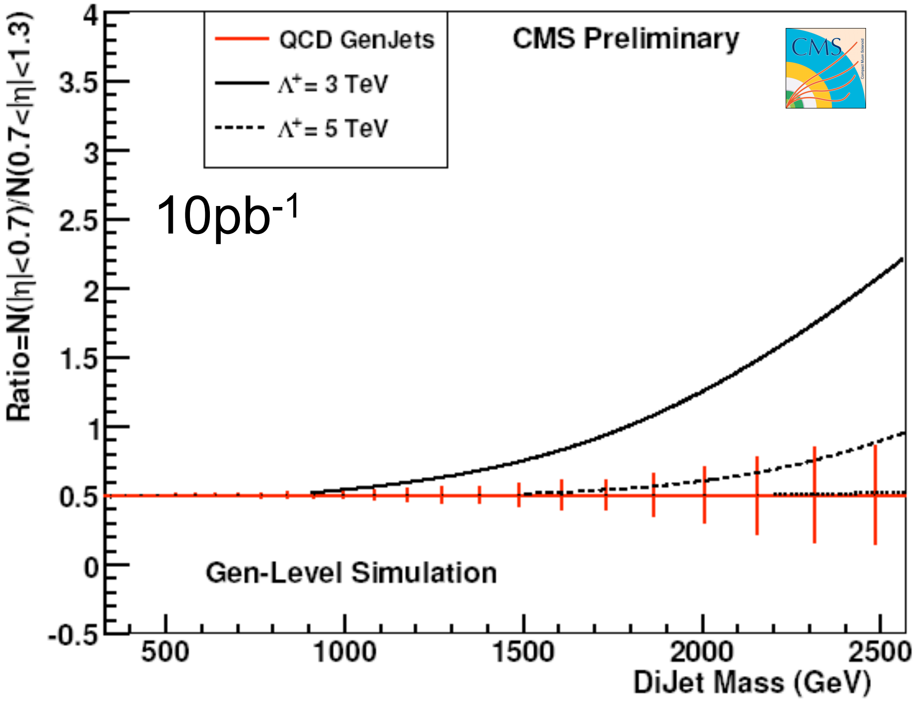
Simple and
robust tt selection
for start-up

New Physics

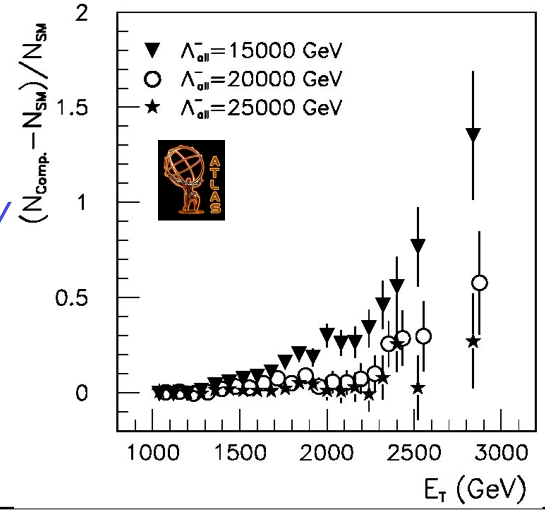
Contact Interactions with Di-jets



Signal "over QCD"



ATLAS:
Probe Λ>20 TeV
already
with $30fb^{-1}$



Small systematic due to use of ratio:

Di-jet Ratio = N(|h|<0.5) / N(0.5<|h|<1)

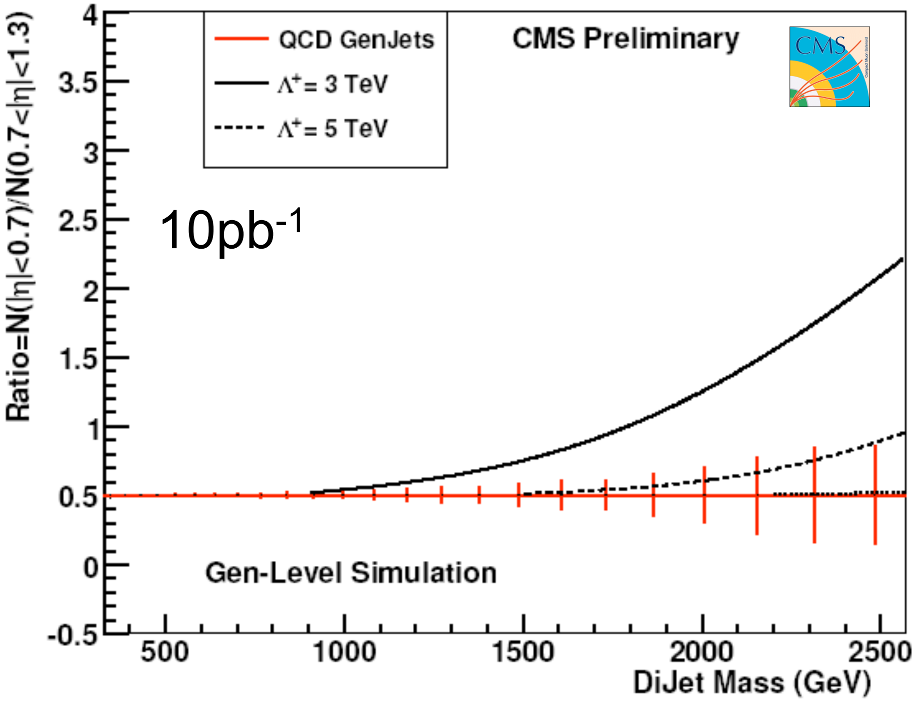
Discovery Sensitivity (CMS)

$10pb^{-1}$	→Λ~4 TeV
$100pb^{-1}$	→Λ~7 TeV
$1fb^{-1}$	→Λ~10 TeV
$10fb^{-1}$	→Λ~15 TeV

Significant
discovery potential:
e.g. up to Λ~10 TeV
in 2008/2009

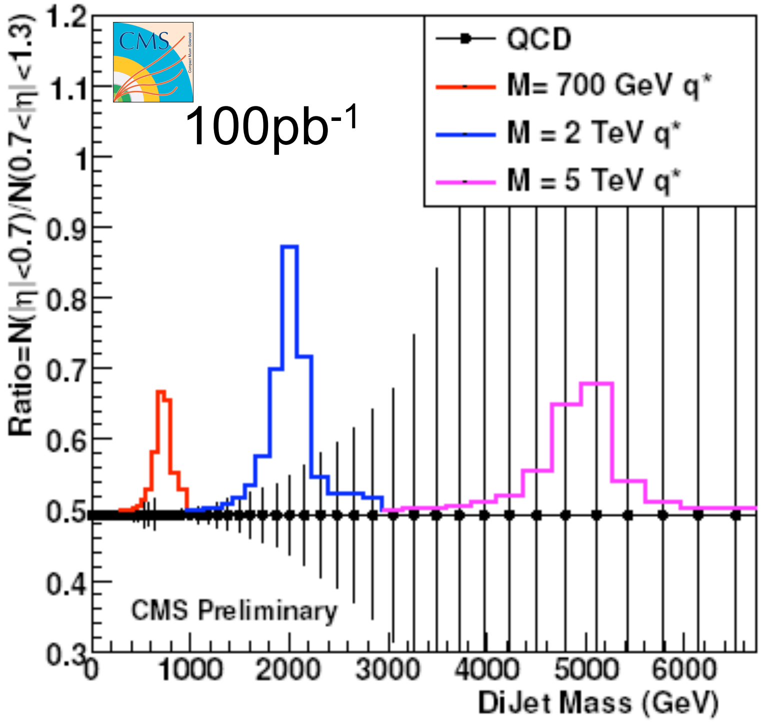
New Physics Search with Di-jets

Contact Interaction



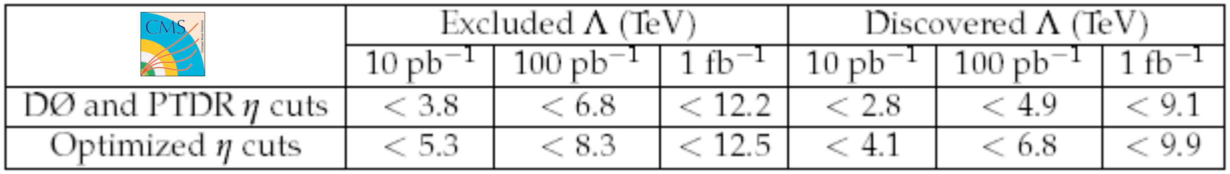
$10pb^{-1}$

Exited Quarks



$100pb^{-1}$

Small systematic due to use of ratio:
Di-jet Ratio = N(|η|<0.7) / N(0.7<|η|<1.3)

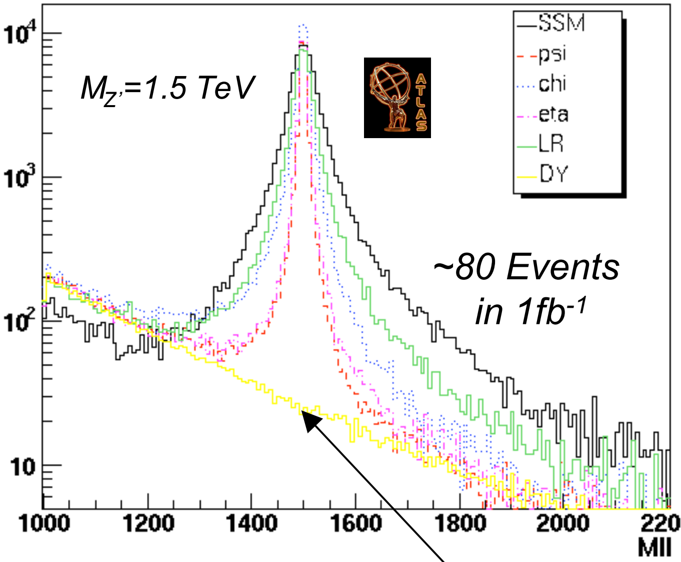


	Excluded Λ (TeV)			Discovered Λ (TeV)		
	$10\ pb^{-1}$	$100\ pb^{-1}$	$1\ fb^{-1}$	$10\ pb^{-1}$	$100\ pb^{-1}$	$1\ fb^{-1}$
DØ and PTDR η cuts	< 3.8	< 6.8	< 12.2	< 2.8	< 4.9	< 9.1
Optimized η cuts	< 5.3	< 8.3	< 12.5	< 4.1	< 6.8	< 9.9

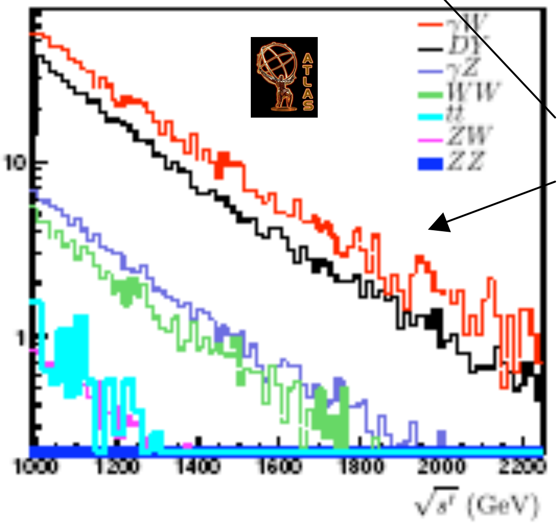
Significant discovery potential: e.g. up to Λ~10 TeV in 2008/2009

Di-lepton Resonances (Example Z')

has always been the subject of (clean) searches …



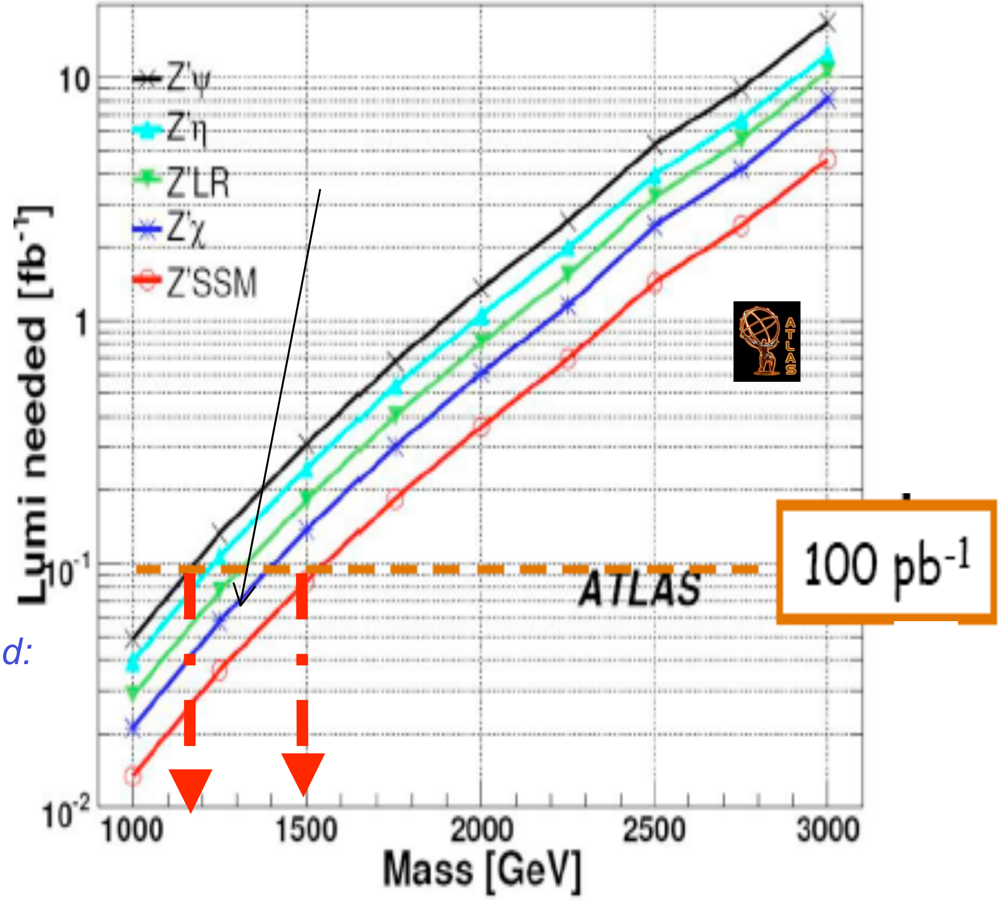
~80 Events in $1fb^{-1}$



Main background:

Drell-Yan:
<1 event for
M>1.5 TeV
in $1fb^{-1}$

$Z' \to e^+e^-$ Discovery Potential



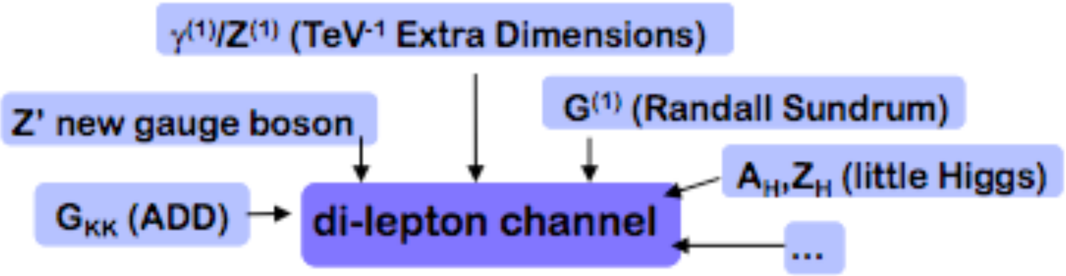
100 pb^{-1}

Very early discovery potential with clean signatures!

Di-lepton Resonances

Because of their clear signature di-lepton resonances have always been the subject of new physics searches.

At the LHC they are predicted to arise in many BSM models:



$\gamma^{(1)}/Z^{(1)}$ (TeV^{-1} Extra Dimensions)

Z' new gauge boson

$G^{(1)}$ (Randall Sundrum)

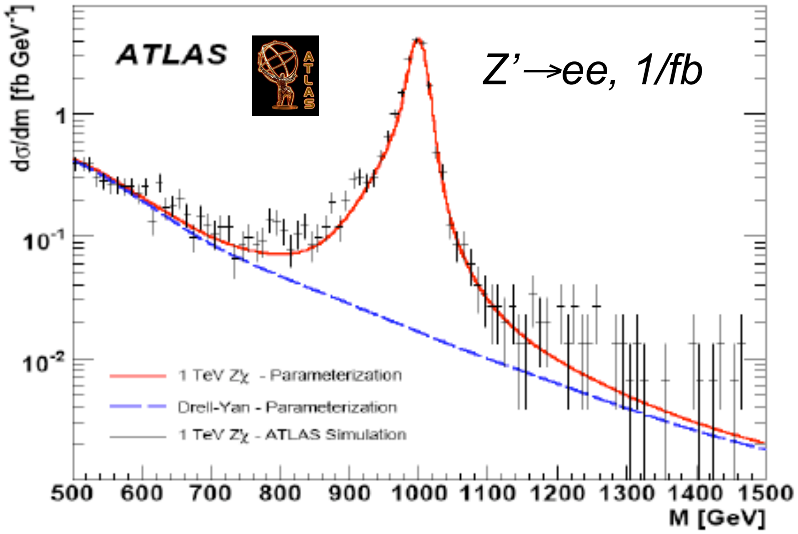
A_H,Z_H (little Higgs)

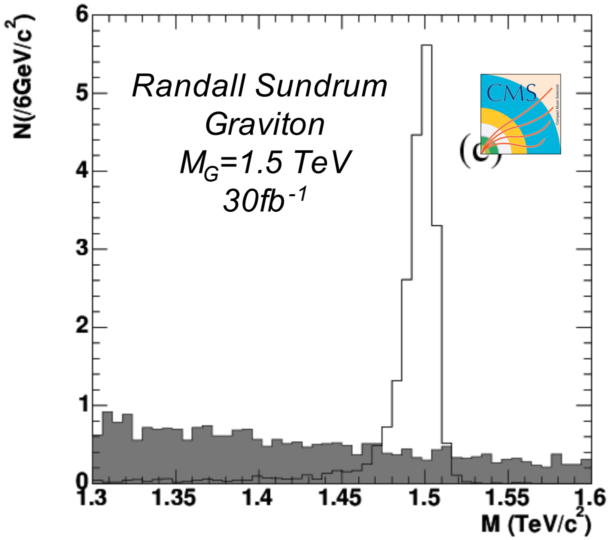
G_{KK} (ADD)

di-lepton channel

...

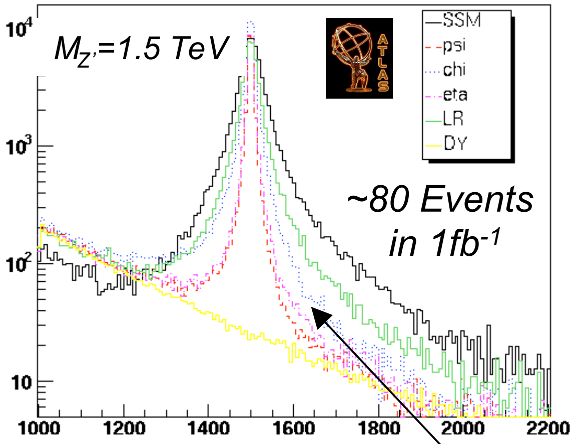
Clear signatures: $\mu^+\mu^-$ and e^+e^- final state



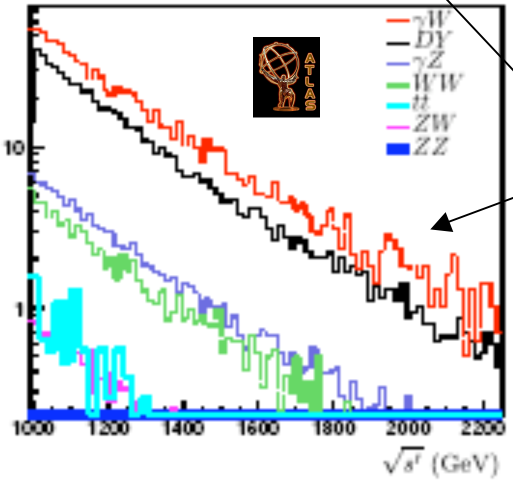


Di-lepton Resonances (Example Z')

Because of their clear signature di-lepton resonances have always been subject of new physics searches

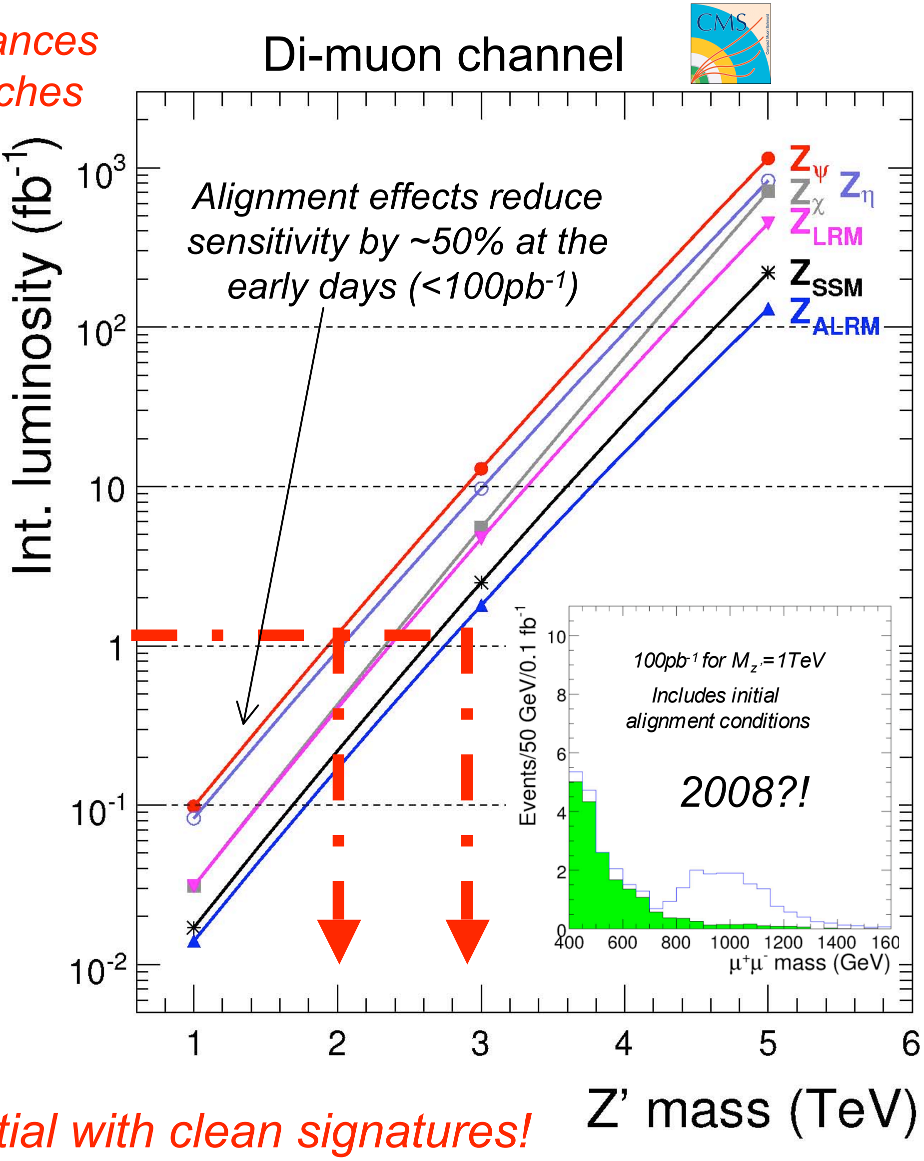


~80 Events in $1fb^{-1}$



Main background:
Drell-Yan:
<1 event for
M>1.5 TeV in $1fb^{-1}$

Di-muon channel



Alignment effects reduce sensitivity by ~50% at the early days (<$100pb^{-1}$)

$100pb^{-1}$ for $M_{Z'}$=1TeV

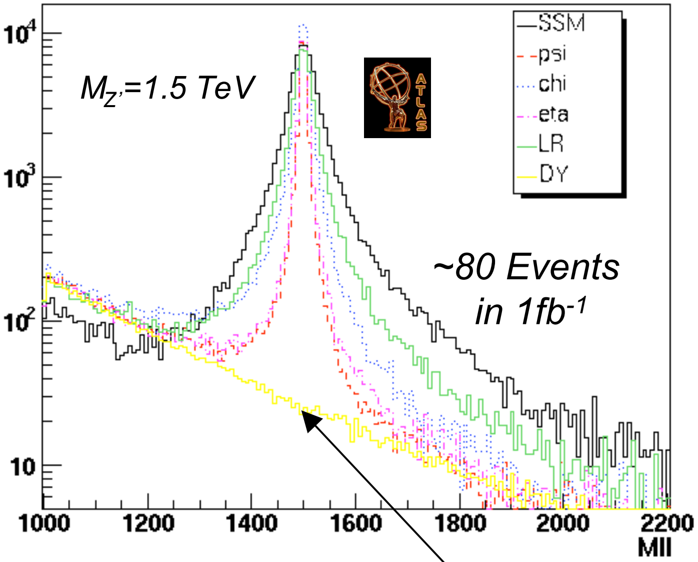
Includes initial alignment conditions

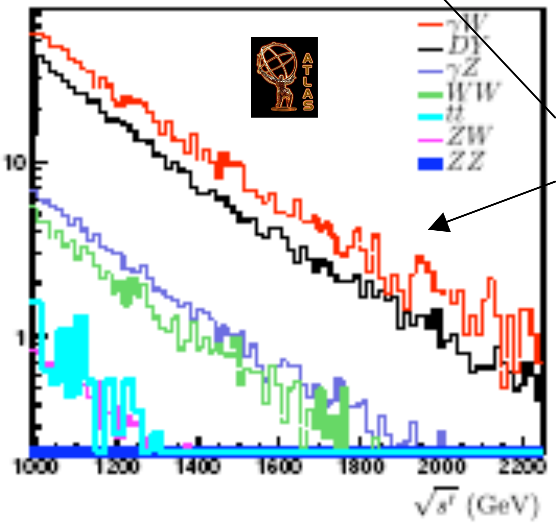
2008?!

Very early discovery potential with clean signatures!

Di-lepton Resonances (Example Z')

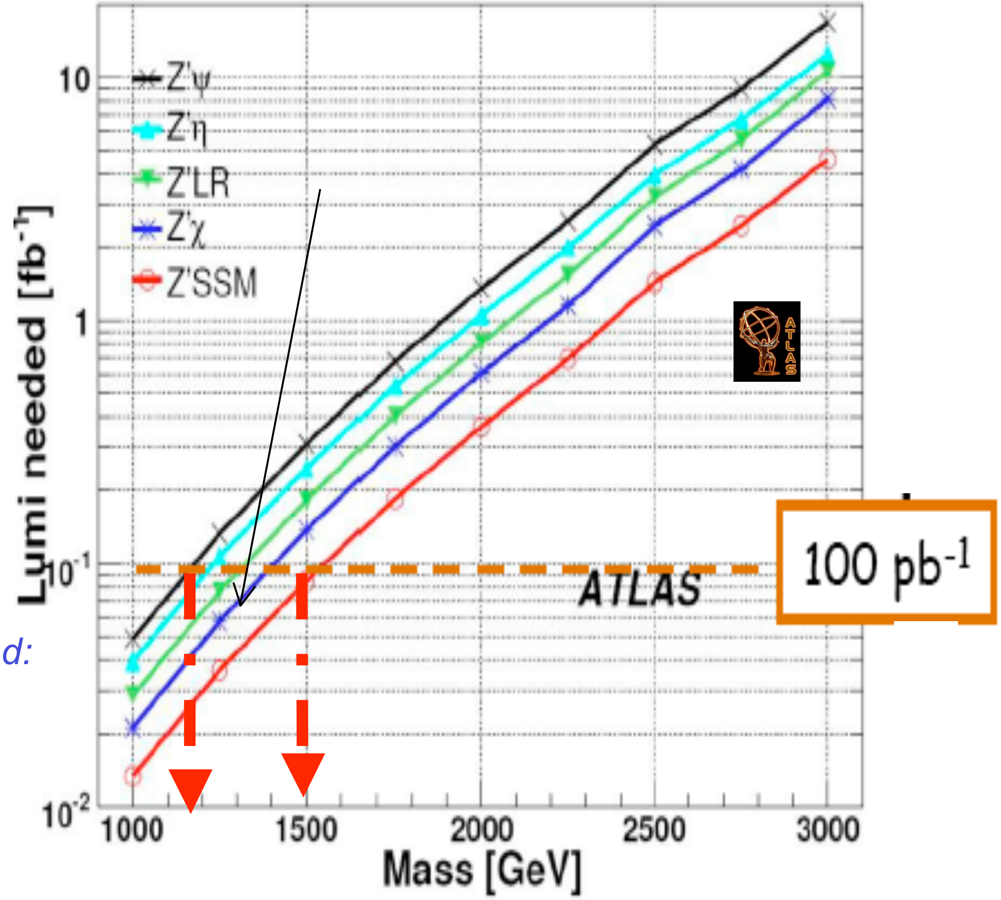
has always been the subject of (clean) searches …





Main background:
Drell-Yan:
<1 event for
M>1.5 TeV
in 1fb^{-1}

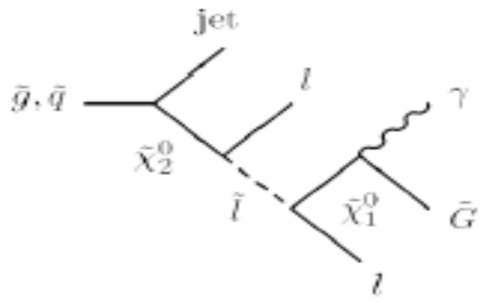
Z'→e^+e^- Discovery Potential



Very early discovery potential with clean signatures!

SUSY: GMSB

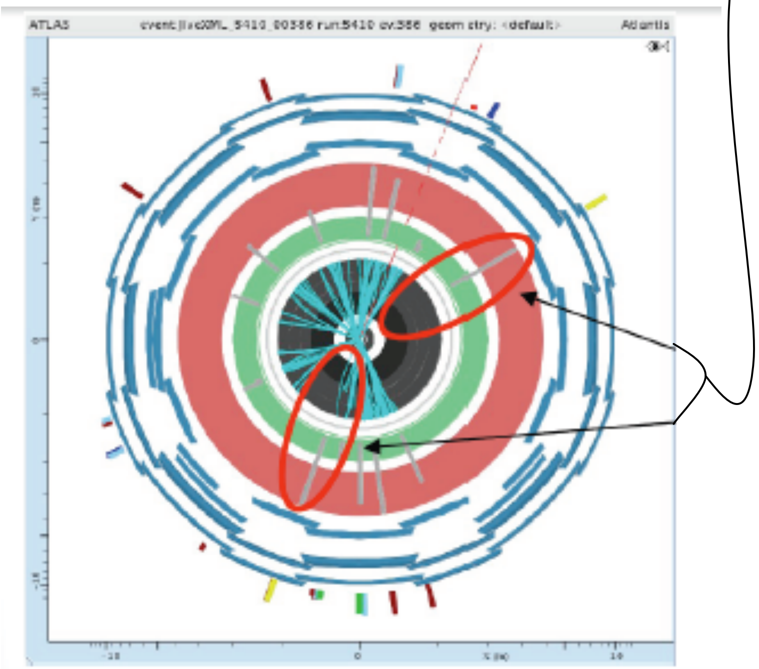
SUSY breaking mediated via gauge interactions:

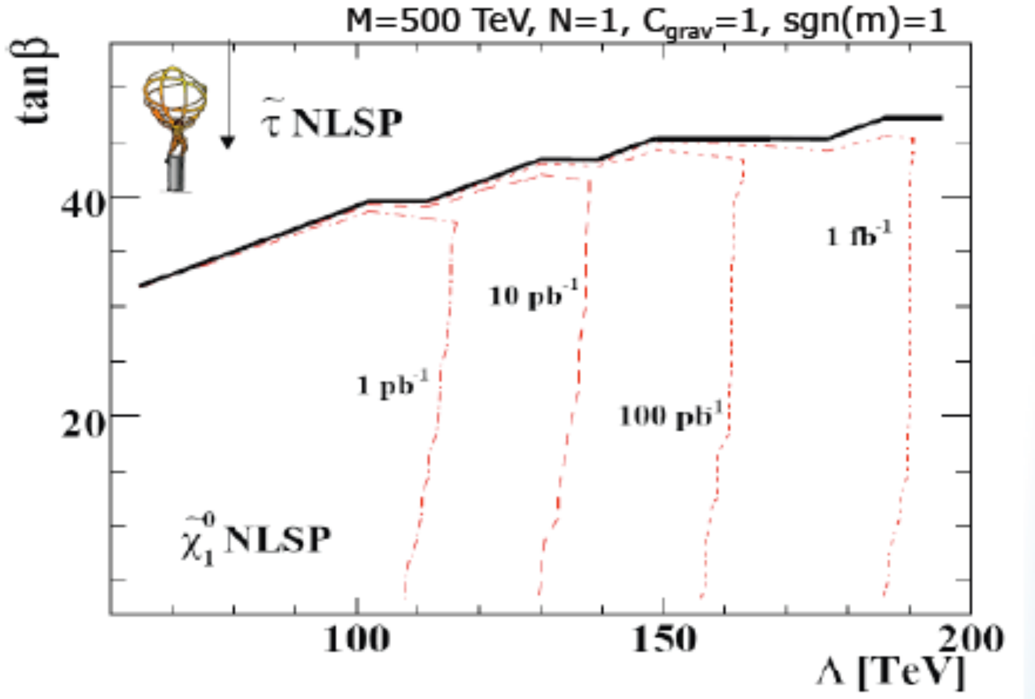


Experimental Signature:

- *lepton and jets*
- *missing energy from gravition*
- *hard photons pointing or non-pointing or long lived staus*

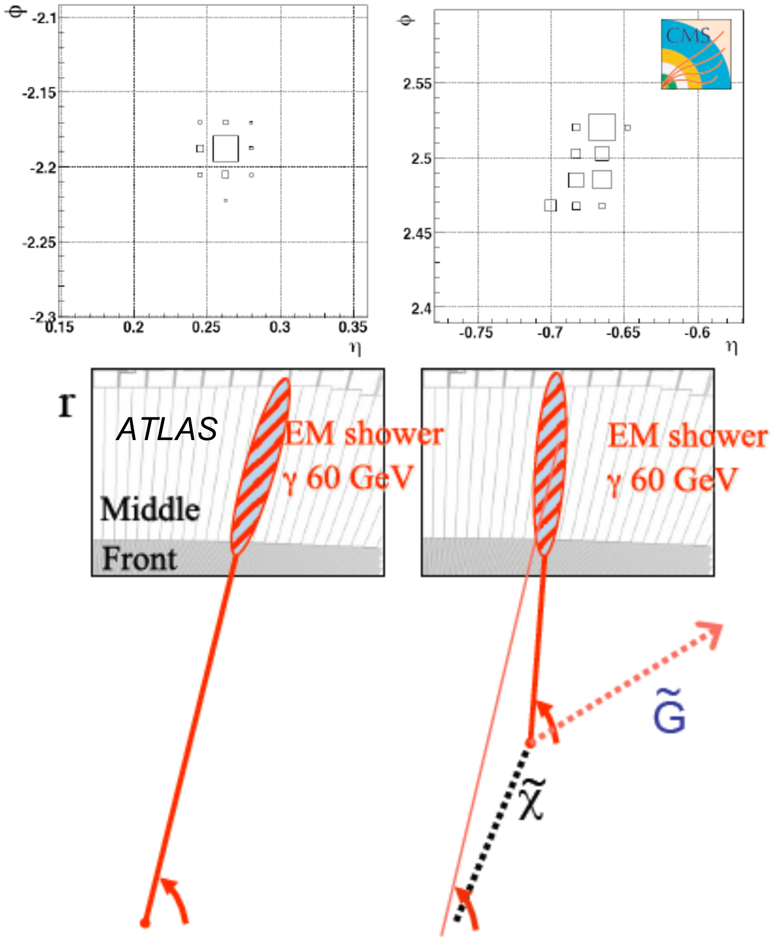
Example:
2 Photons & “Standard” SUSY cuts



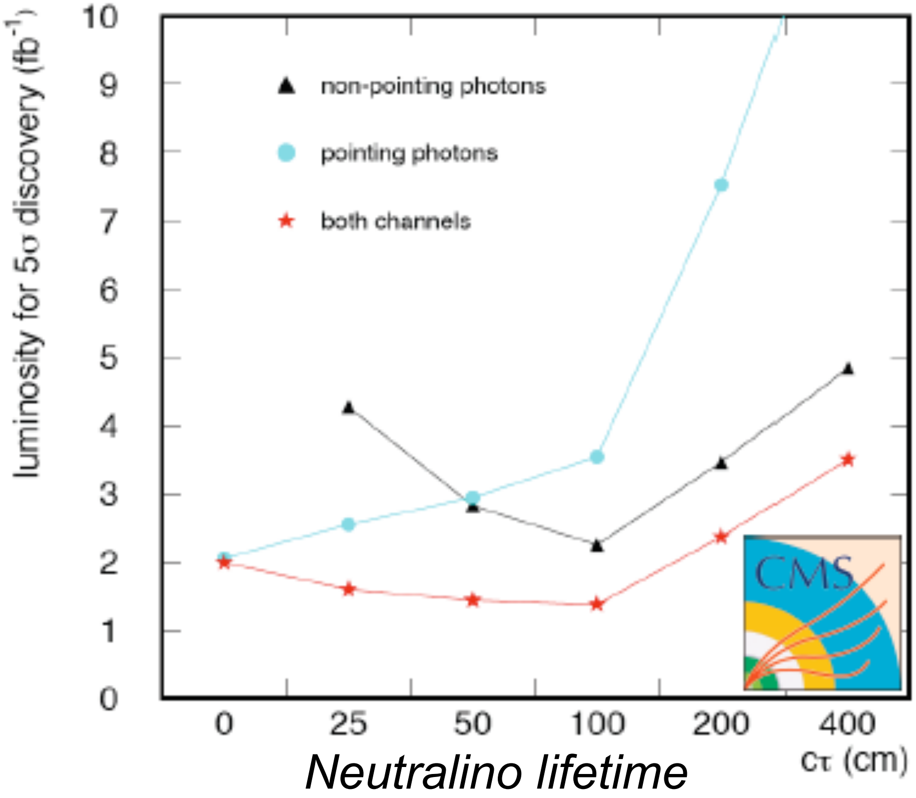


SUSY: GMSB

Separate pointing from non-pointing photons by looking at the ECAL cluster shape

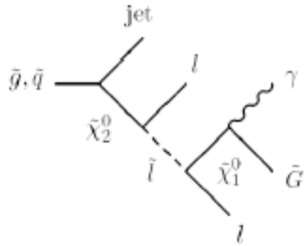


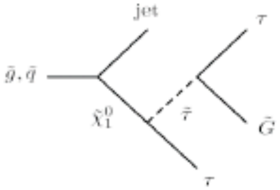
Discovery potential already with 1/fb

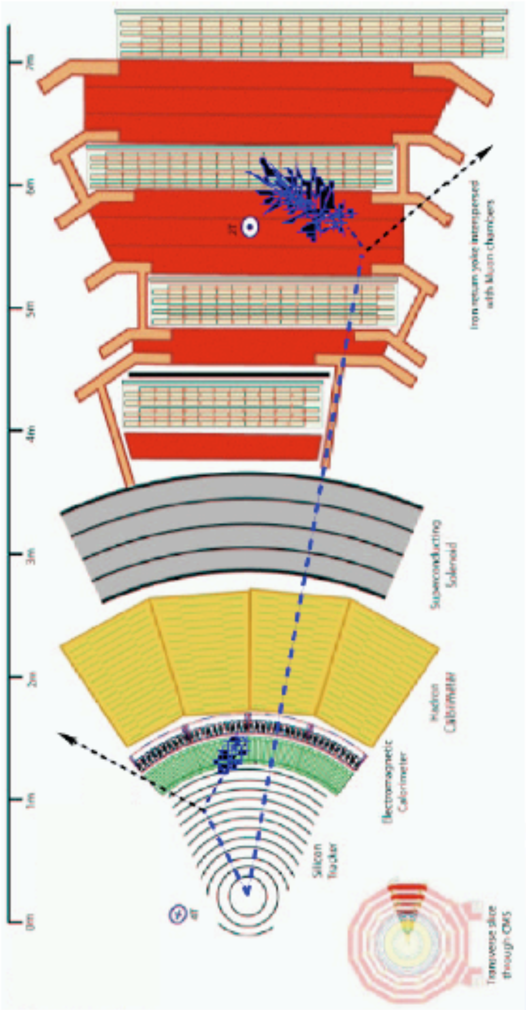


GMSB

- Theoretical framework
  - renormalizable local supersymmetry including gravity
  - SUSY breaking mediated via gauge interactions
  - depends on 6 parameters
  - spin 3/2 gravitino superpartner of the graviton
- Phenomenological consequences
  - production as in MSSM
    - can have large cross section (squarks and gluinos produced)
  - decay chains
  - LSP: gravitino, mass<KeV
  - neutralino or stau NLSP decaying to a gravitino ($\chi_1^0 \rightarrow G\gamma$)
    - decay time can be long
- Final states:
  - leptons and jets
  - MET from gravitino
  - hard photons (pointing or not-pointing)
  - or
  - long lived stau



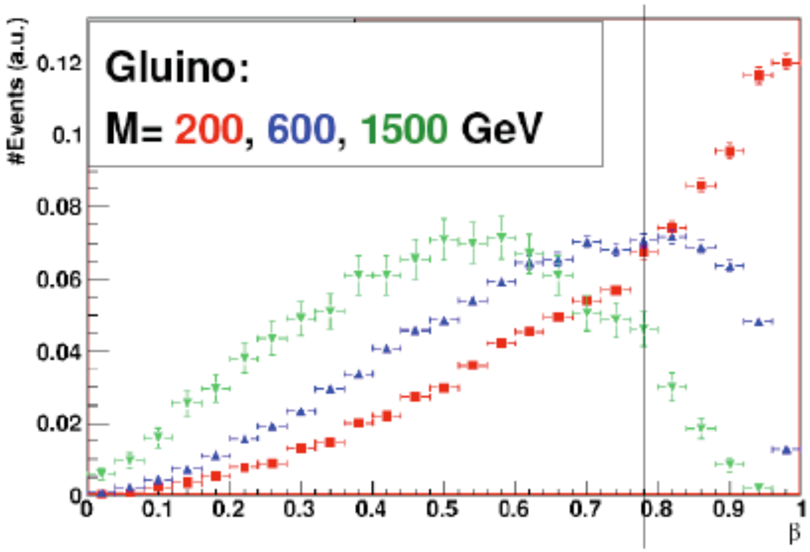


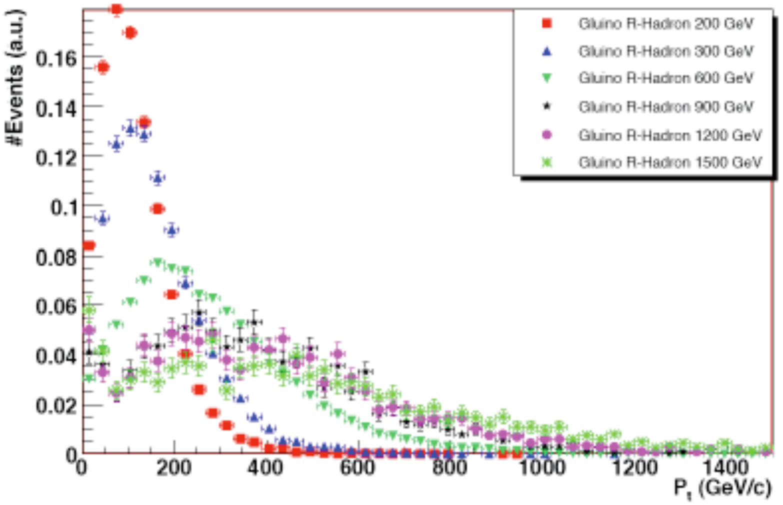


Heavy Stable (Charged) Particles

- Heavy:
  - hundreds of GeV
  - β < 1
- Stable:
  - cτ few meters
  - can decay in the detector or can cross it
  - we show results about particles crossing the detector
- Charged:
  - electrical or colour charge

- Models:
  - lepton like particles:
    - GMSB staus
    - Kaluza-Klein tau resonances in UED
  - R-hadrons:
    - long lived stops in SUSY
    - long lived gluino in Split-SUSY
- Many model considered, but model independent analysis
  - no assumption, just observation of a heavy object crossing the detector





Heavy Stable Particles: GMSB

Gauge Mediated Supersymmetry Breaking. Models for SUSY breaking, alternative to mSUGRA

SUSY breaking transmitted from Hidden sector to visible sector via gauge interactions (“messengers”)

Lightest supersymmetric particle (LSP) is the Gravitino (m≤keV)
light, stable and weakly interacting, possible candidate for Dark Matter

Par.	Description
Λ	SUSY breaking scale
M_m	Messenger mass scale
tanβ	Ratio of Higgs vev
N_m	Number of SU(5) messenger multiplets
sign(μ)	μ from Higgs sector
C_{grav}	Sets NLSP lifetime

τ mass	156	247
N_m	3	3
Λ(TeV)	50	80
M_m(TeV)	100	160
Tanβ	10	10
sign(μ)	1	1
C_{grav}	10^4	10^4

If $N_m>3$ NLSP is the stau
quasi-stable due to the smallness of the coupling constant

- production: ISASUGRA 7.69
  - 2 points from SPS line 7
    - stau(156): N=3, Λ=50 TeV, M = 100 TeV, tanβ=10, sgn(μ)=1, C_{grav}=10000
    - stau(247): N=3, Λ=80 TeV, M = 160 TeV, tanβ=10, sgn(μ)=1, C_{grav}=10000
  - for both points:
    - larger squark and gluino cross section than direct stau production
    - cτ ~ 200 m
- Generation: PYTHIA 6.409

Table 2: Summary of the slepton NLSP sample. $N_5 = 3, \tan\beta = 5, \mathrm{sgn}(\mu) = +$, and no decay of slepton is assumed.

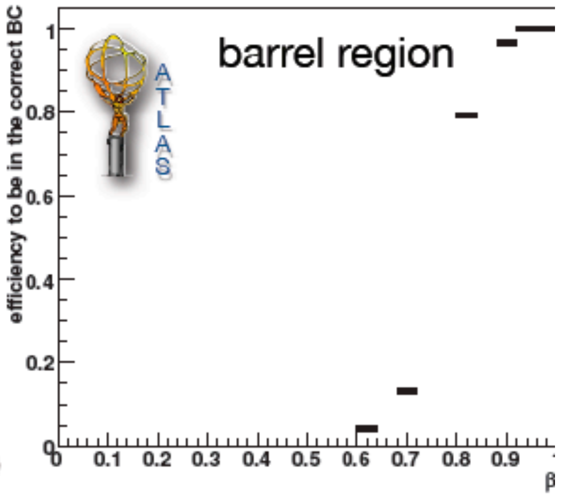
name	NLO (LO) σ [pb]	Λ [TeV]	M_m [TeV]	$M_{\tilde{\tau}_1}$ [GeV]
GMSB5	21.0 (15.5)	30	250	102.3

Heavy Stable Particles

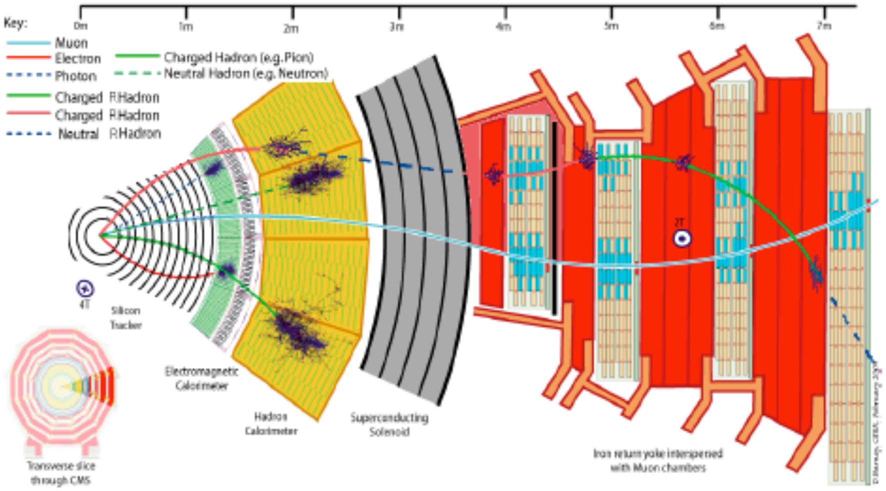
- Muon-like signature but:
  - due to particle slowness, trigger and data acquisition efficiency may be affected:

if β<<1 the event may be associated with the wrong bunch crossing

Efficiency in the correct bunch-crossing



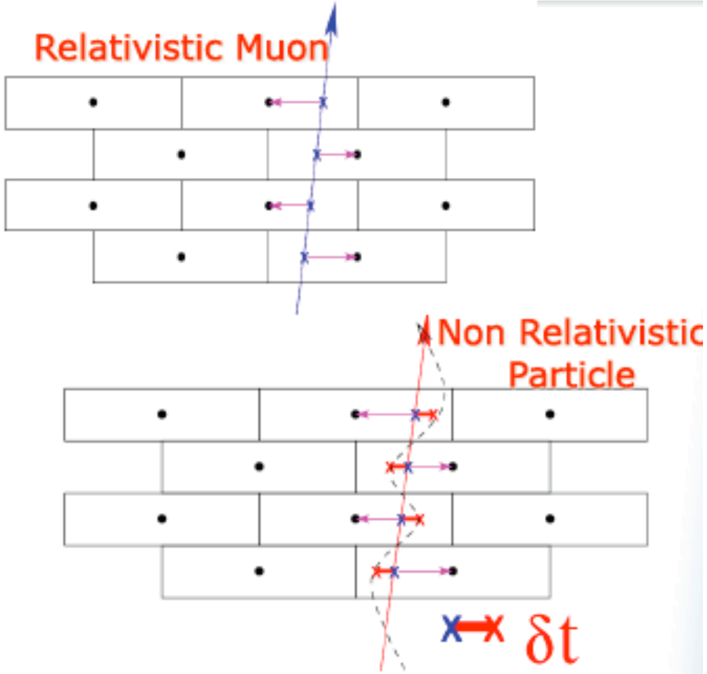
- R-hadrons most demanding case
  - direct pair production → must relies on the two R-hadrons only
  - both particles can be slow
  - charge flipping (trajectory modified and neutral R-hadrons not visible)

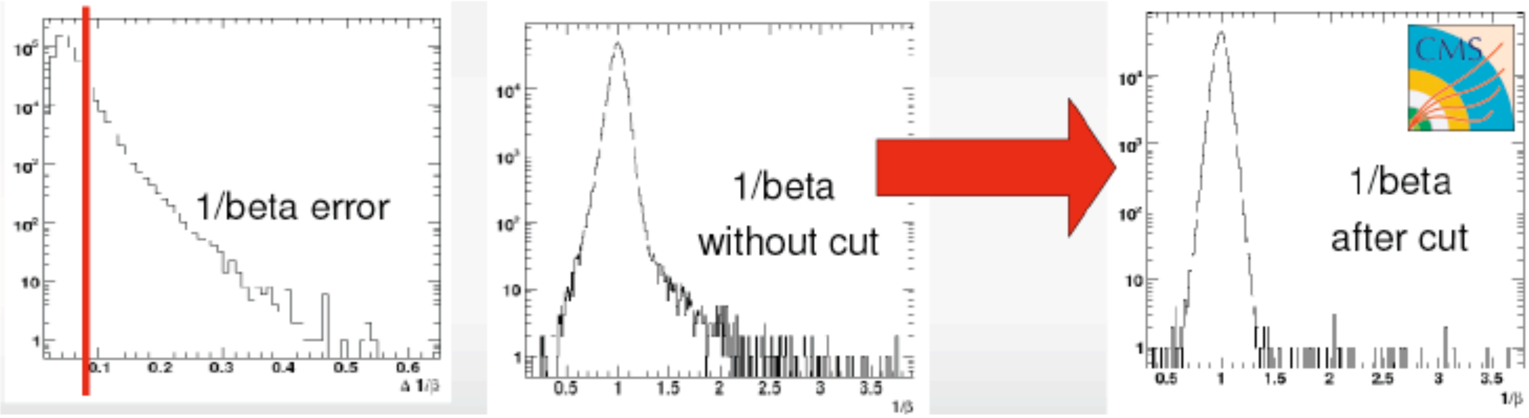


	HLT Trigger Path Efficiencies [%]				
	MU	MET	$\sum E_T$	JET	Total
$\tilde{\tau}$ 150-250 GeV	~97	~80	~90	~70	>99
$\tilde{g}$ 200-1500 GeV	~15	~30-60	~40-95	~10-50	~60-95
$\tilde{t}$ 130-800 GeV	~20	~20-40	~20-60	~4-20	~40-70

Heavy Stable Particles: beta

- Drift tubes time resolution (~1 ns in ATLAS and CMS) allows the distinction of relativistic and non-relativistic particles
  - drift time as parameter of the fit
  - realignment of the hits to give an estimate of the delay
- Main bkg:
  - tails in true muons
    - will be estimated with real data using Z→μμ
  - cosmics
    - strongly suppressed if DT combined with tracker





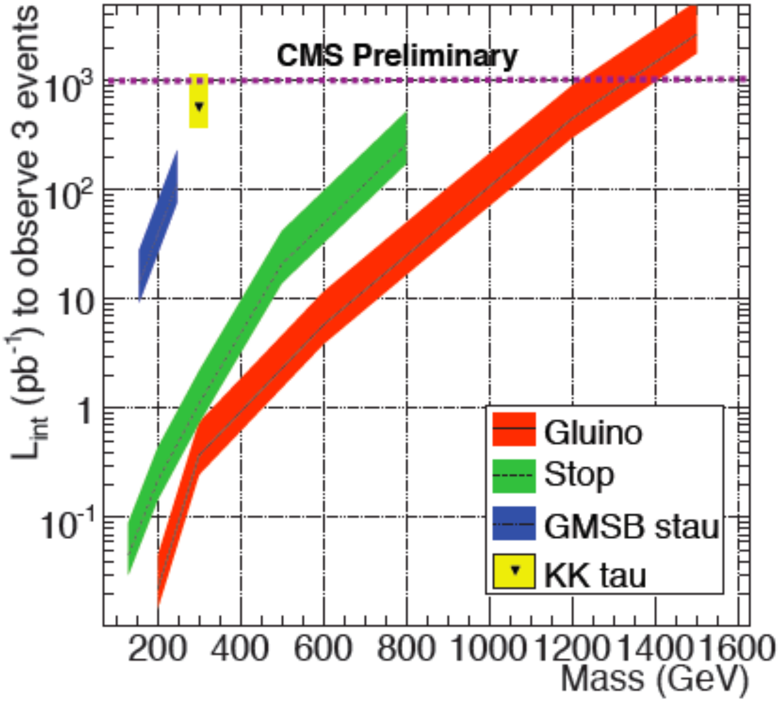
Heavy Stable Charged Particles

Predicted by several models:

- *lepton like*
  - *GMSB staus*
  - *Kaluza-Klein tau's in UED*
- *R-Hadrons*
  - *long lived stop in SUSY*
  - *long lived gluino in split-susy*

Properties:

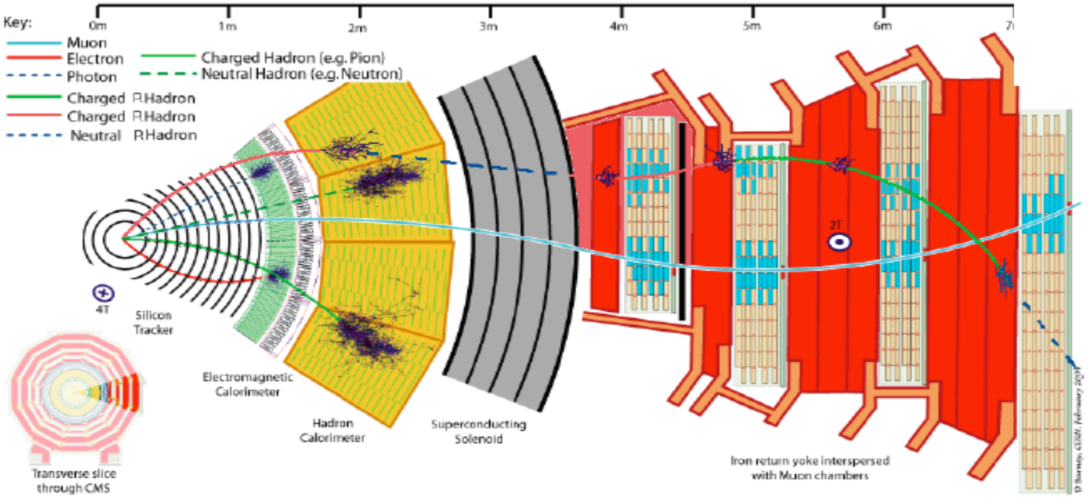
- *O(100 GeV), β<1*
- *$c\tau$ few meters*
- *electrical or colour charge*

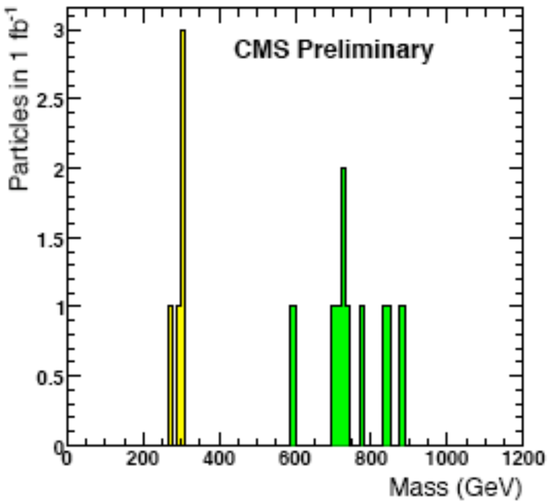


Measurement

- *momentum in Tracker&Muon*
- *β TOF in Muon DT & dE/dx in Tracker*

ATLAS similar





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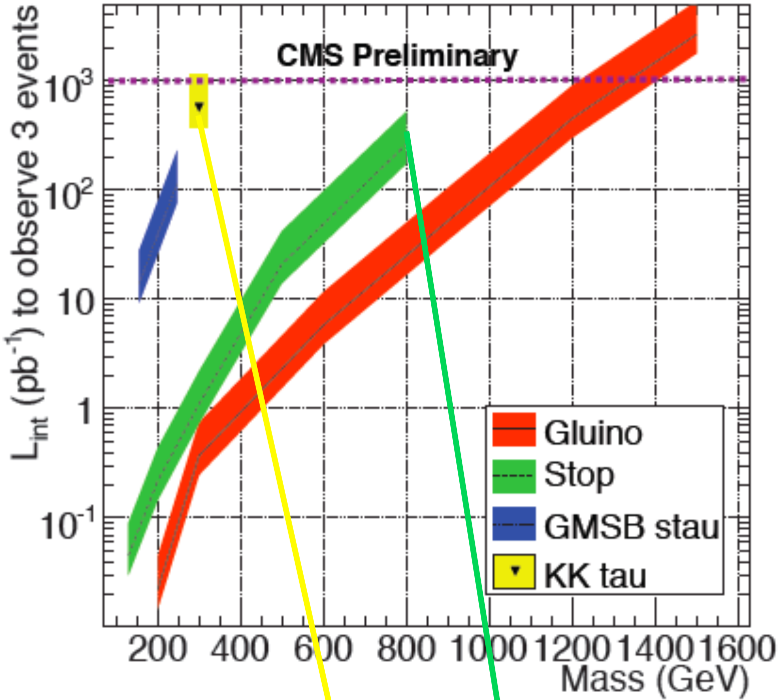

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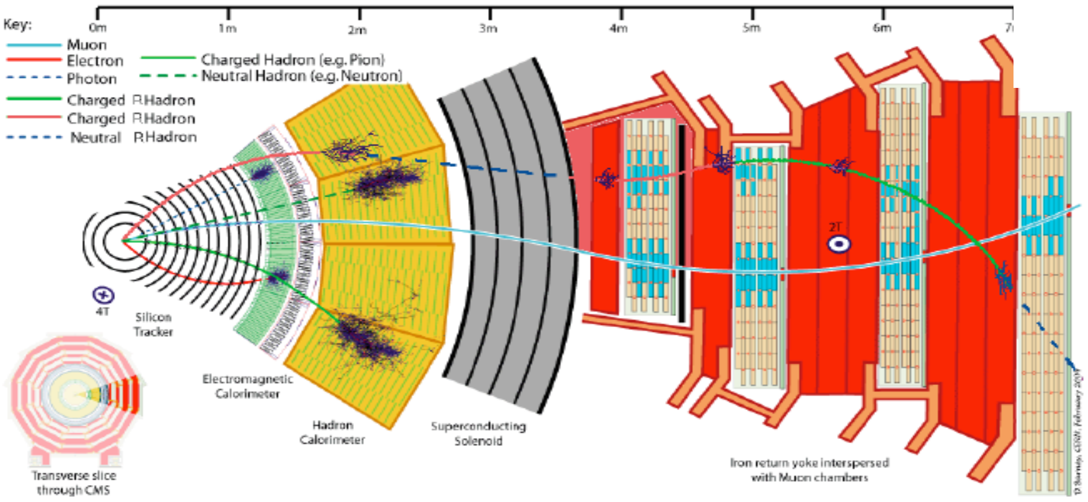
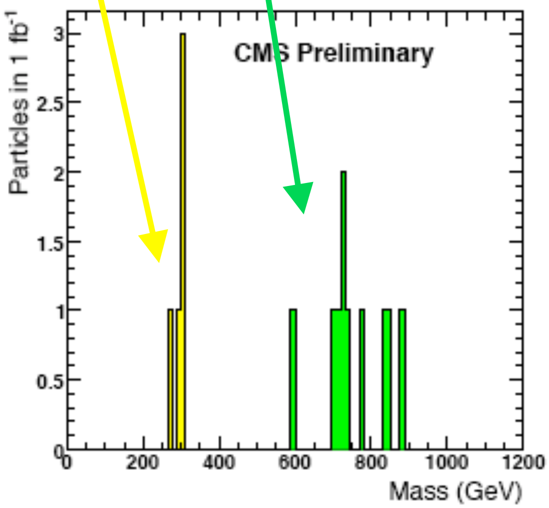
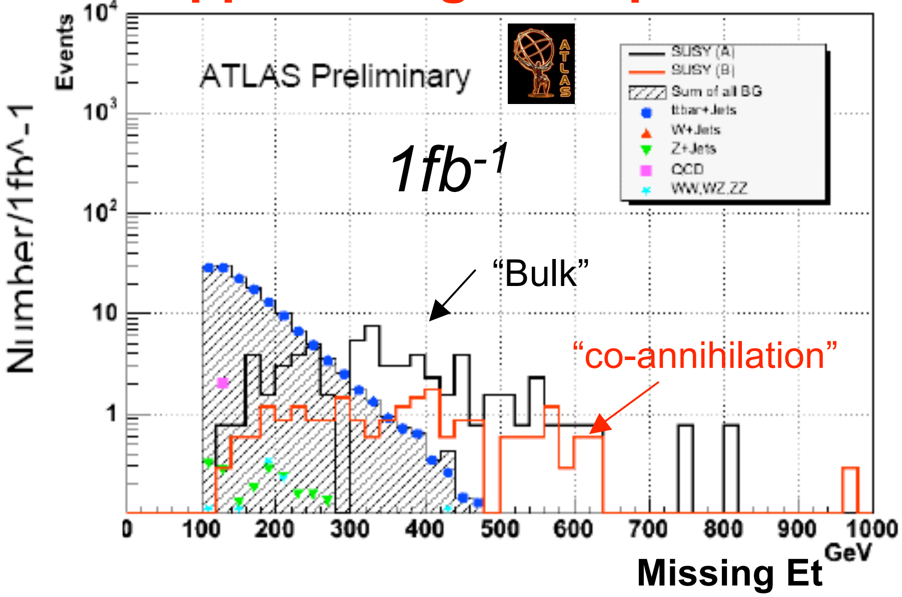


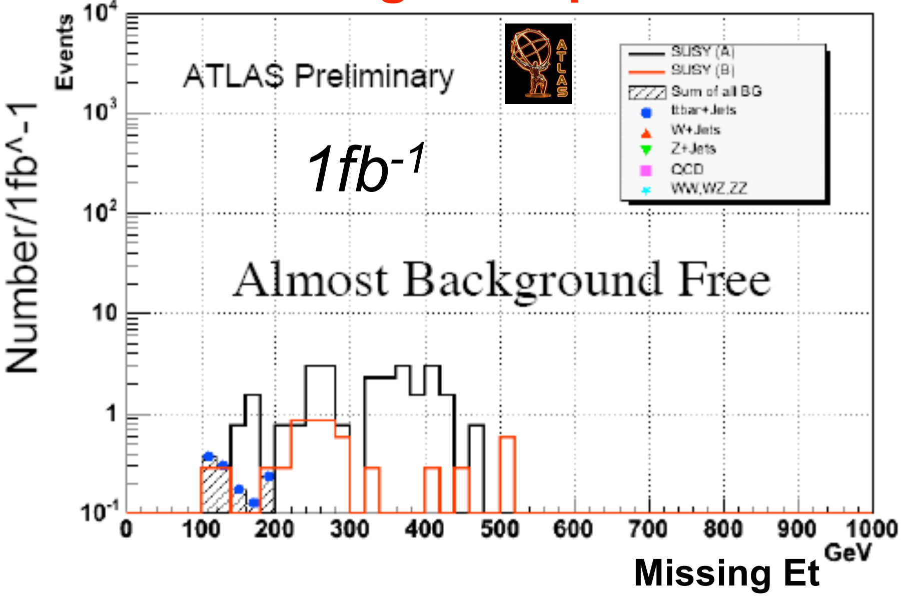


Jets+E_t^{miss}+(1,2) l - Inclusive Search

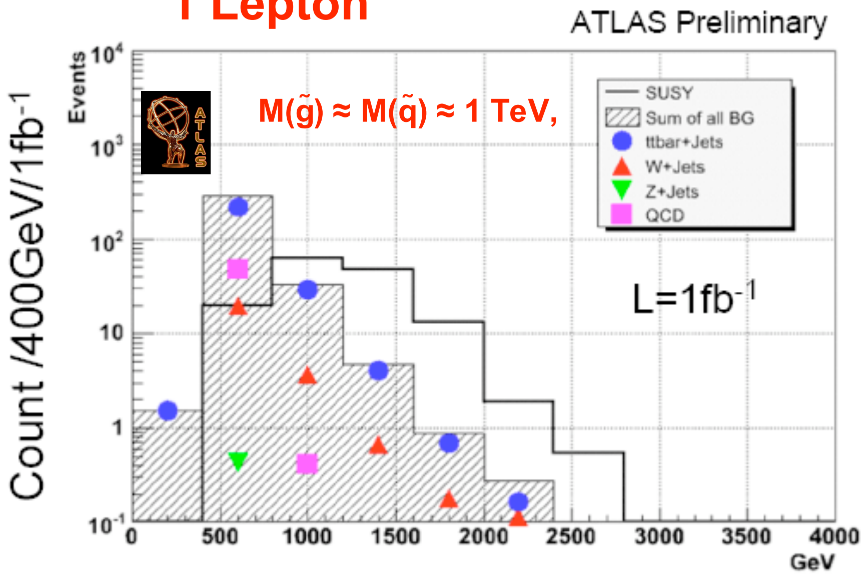
Opposite sign di-leptons



Same sign di-leptons



1 Lepton



Good discovery potential

Lower statistic but cleaner than "0 lepton".

Analysis Strategy:

- Still worry about ttbar, W/Z jets and QCD
- Use data control samples
- get lepton reconstruction/selection under control

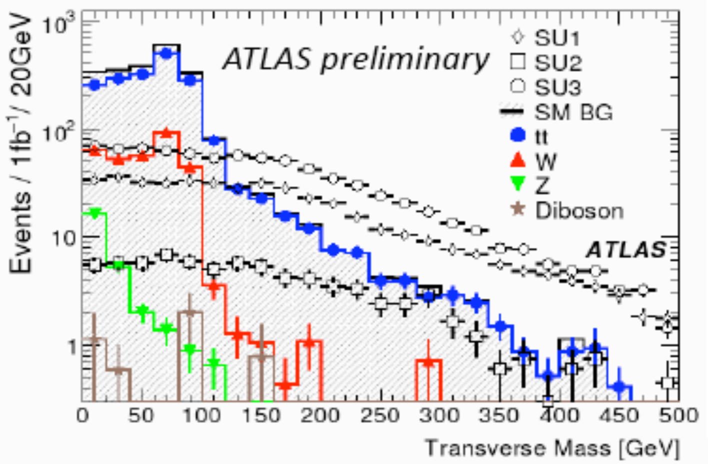
SM Background: Jets+MET+(1Lepton)

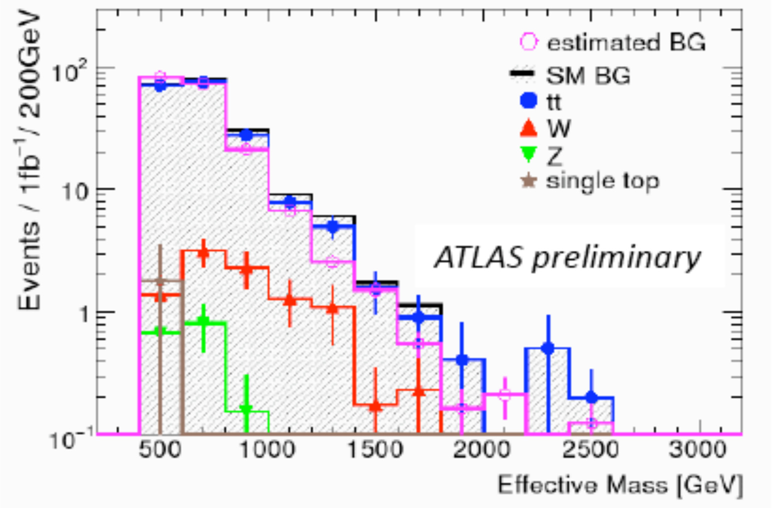
jets + 0 and 1 lepton channel

Estimate top and W background from data

ATLAS:
control region with M_T < 100 GeV
Here we have more SM events than new physics signal

effective mass distribution in control region can be used to predict distribution in signal region (M_T > 100 GeV)





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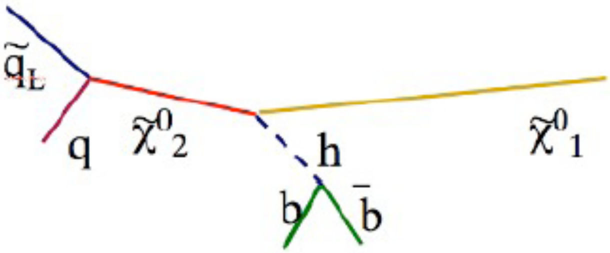
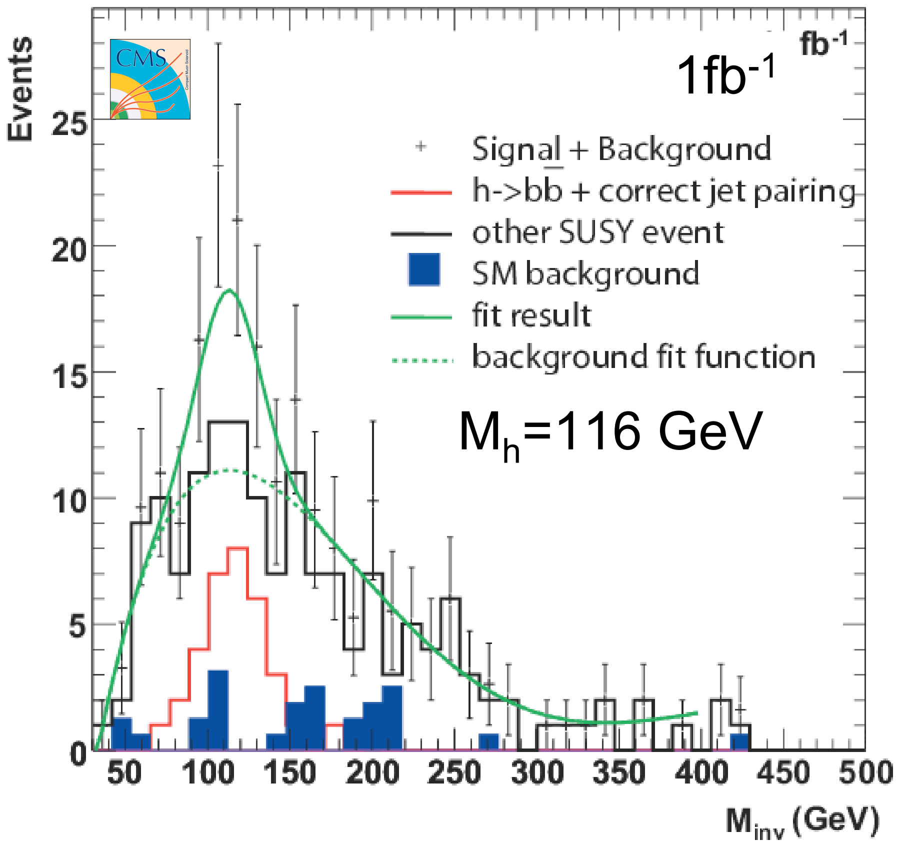
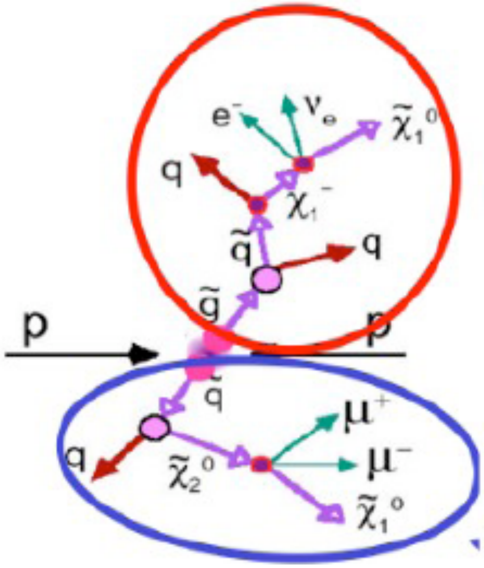
"Low Mass M_h" in SUSY Decays



Depending on the SUSY parameter space the h→bb production is possible



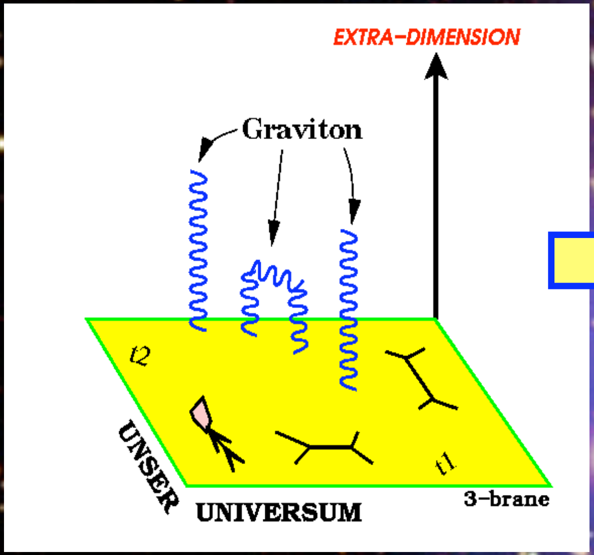


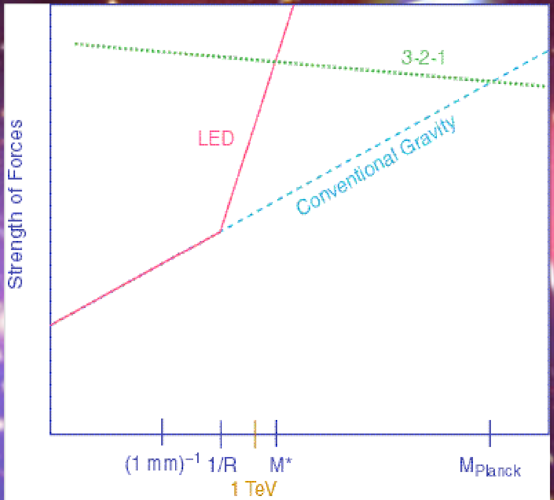
Replace μ's with b's

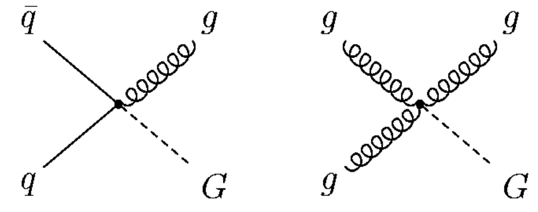
- Separate cascade decay chain in two hemispheres and require two b's in one.
- 5σ Signal (M_h=115 GeV) already with~$2fb^{-1}$

Could be the first sign of a light higgs but b-tagging is crucial!

Extra space dimensions?







Signatures

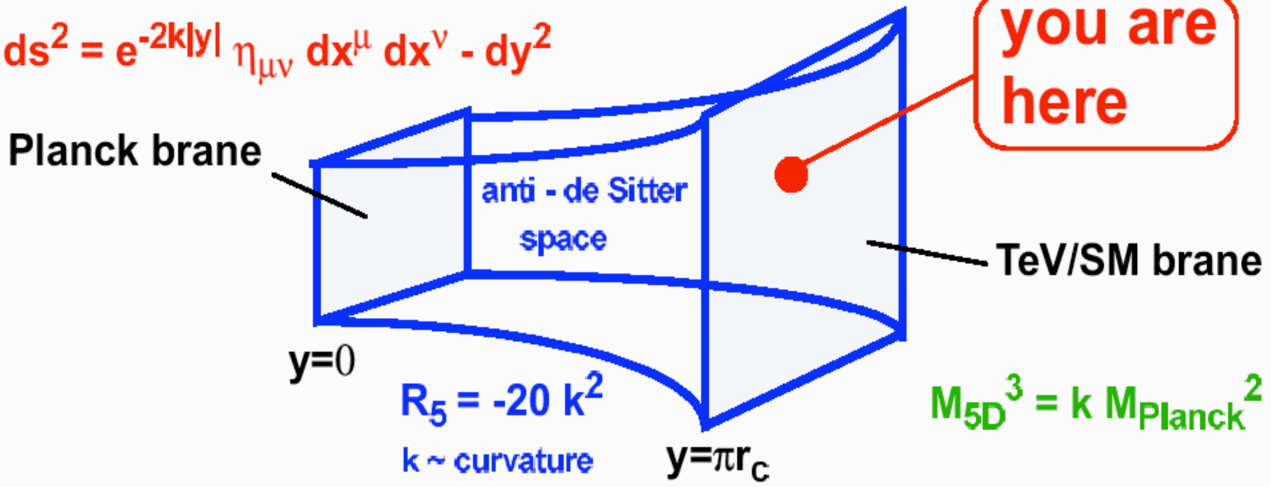
Eg monojet events
monophoton event
Z' like resonances
KK excitations
…

The Gravity force becomes strong!

Curved Space: RS Extra Dimensions

Randall, Sundrum, PRL 83, 3370 (1999)

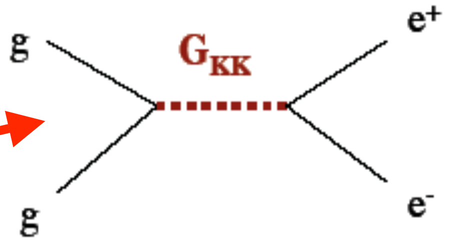
$ds^2 = e^{-2k|y|} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$



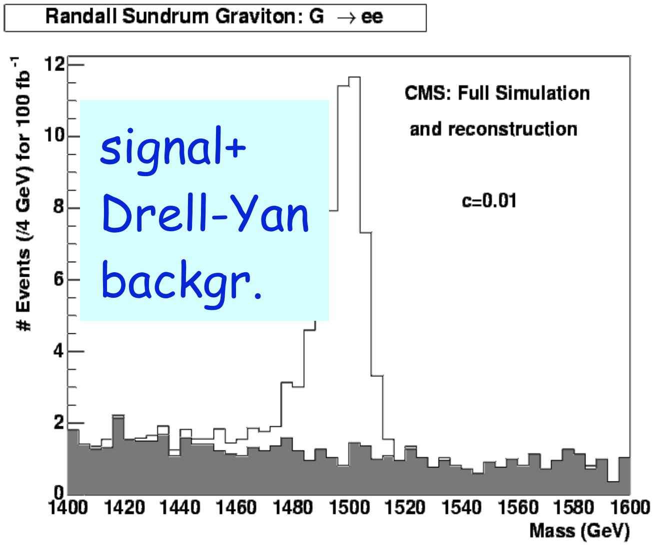
$R_5 = -20\, k^2$

$M_{5D}^3 = k\, M_{Planck}^2$

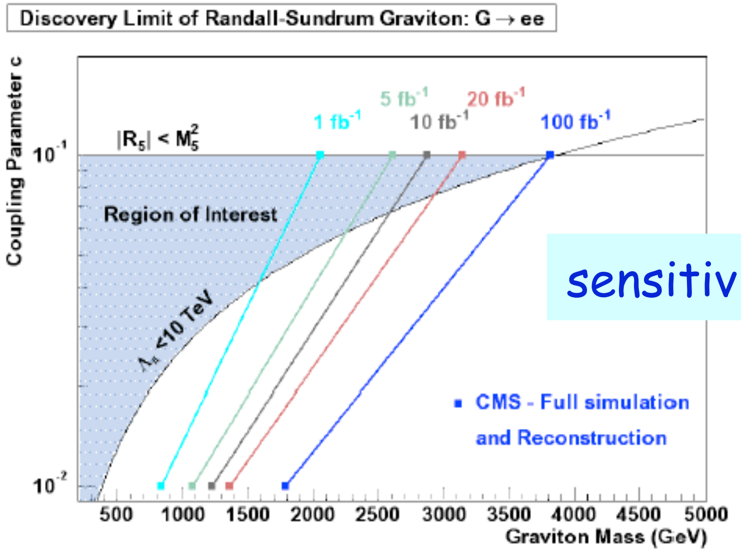
phenomenology



Study the channel pp→Graviton→ e+e-



signal+
Drell-Yan
backgr.



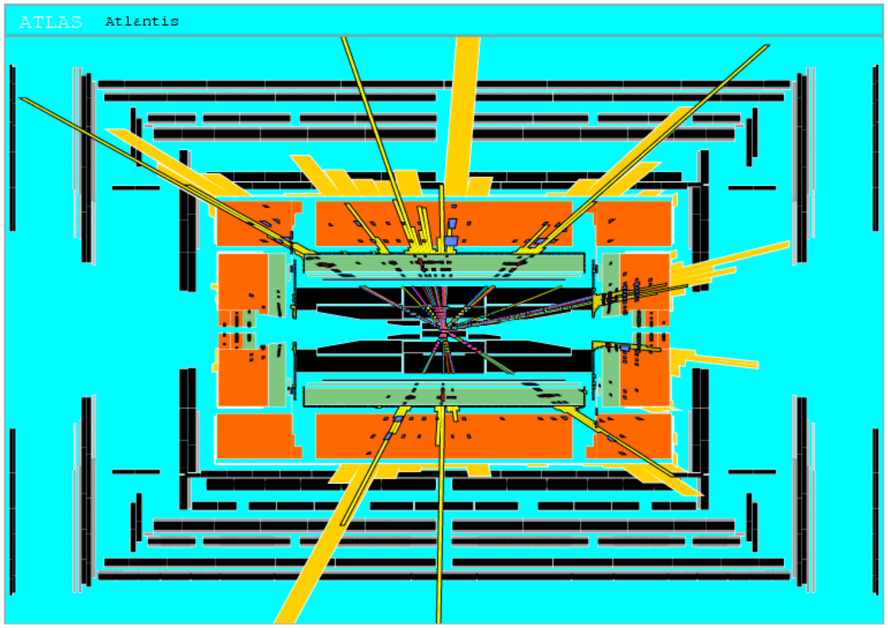
sensitivity

Quantum Black Holes at the LHC?

Black Holes are a direct prediction of Einstein's general theory on relativity

4 dim. : $R_s \rightarrow \ll 10^{-35}$ m
4+n dim. : $R_s \rightarrow \sim 10^{-19}$ m
R_S = schwartzschild radiu

If the Planck scale is in ~TeV region:
can expect Quantum Black Hole production



Simulation of a Quantum Black Hole event

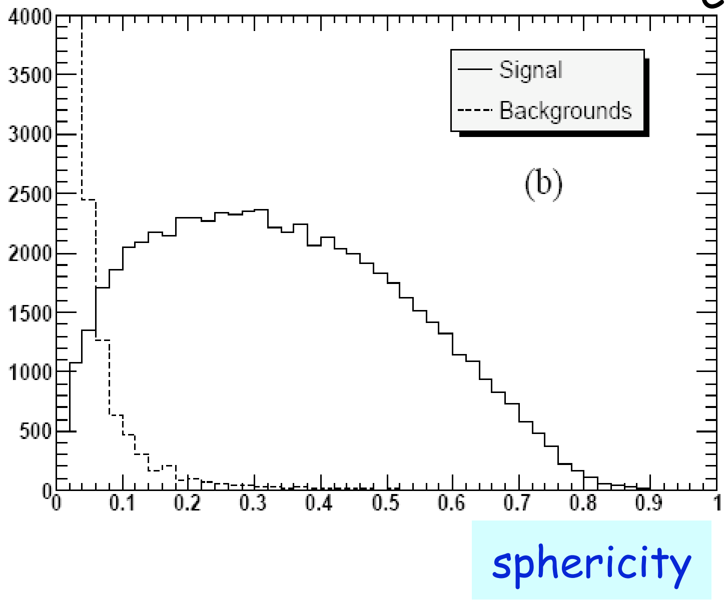
Quantum Black Holes are harmless for the environment: they will decay within less than 10^{-27} seconds

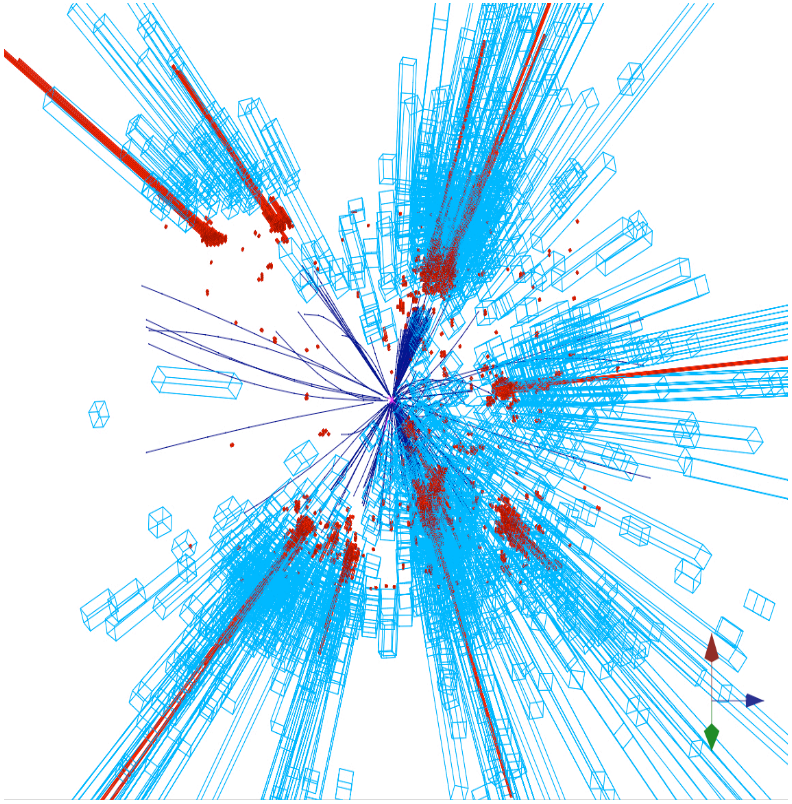
Quantum Black Holes open the exciting perspective to study Quantum Gravity in the lab!

Black Holes Production

If the Planck scale in ~TeV region: can expect Black Hole production

CMS PTDR





Simulation of a black hole event with M_{BH} ~ 8 TeV in CMS

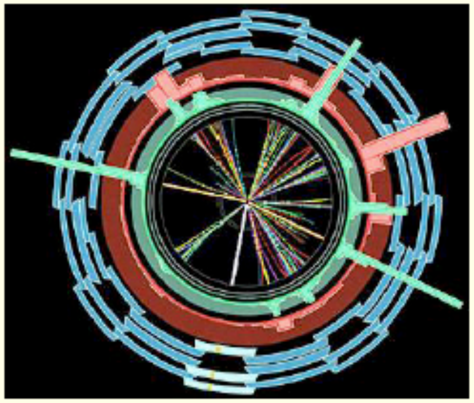
~ Spherical events: Many high energy jets leptons, photons etc.

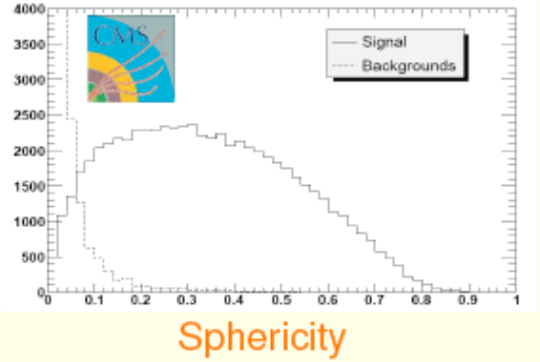
Ecological comment: BH's will decay within ~ 10^{-27} secs

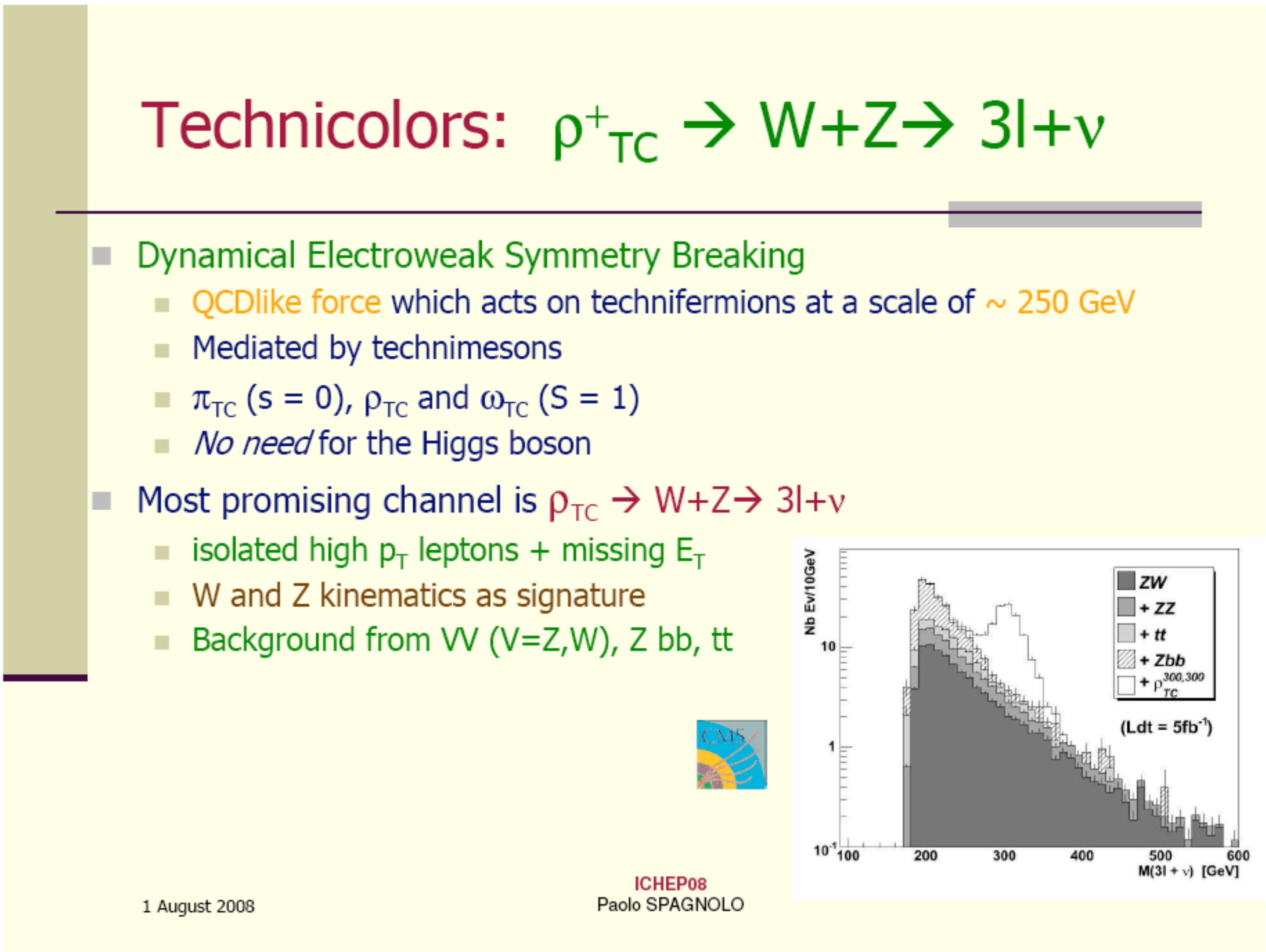
Detectors, electronics (and rest of the world) are safe!!

Black Holes at LHC:

- With Large Extra Dimensions micro Black Holes (BH) could be produced at LHC energy scale, *in (4+n) dimensional spacetime*
  - Schwarzschild radius $r_{s(4+n)}$ function of the reduced Plank scale M_D
- BH is formed if the p-p impact parameter is less than $r_{s(4+n)}$
  - from semiclassical approach $\sigma(M_{BH}) = \pi r^2_{s(4+n)}$
  - In case of $M_D \sim$ TeV then $\sigma(M_{BH}) \sim$ pb
- Could be discovered with 1 fb^{-1} if $M_D < 5$ TeV
- BH with short life time, of the order of 10^{-12} fs
- BH is expected to evaporate by emission of all particle types
  - source of new particles
  - possibility to probe quantum gravity in lab
- Signature
  - High track multiplicity, hadrons:leptons = 5:1
  - spherical event







Technicolors: $\rho^{+}_{TC} \rightarrow W+Z \rightarrow 3l+\nu$

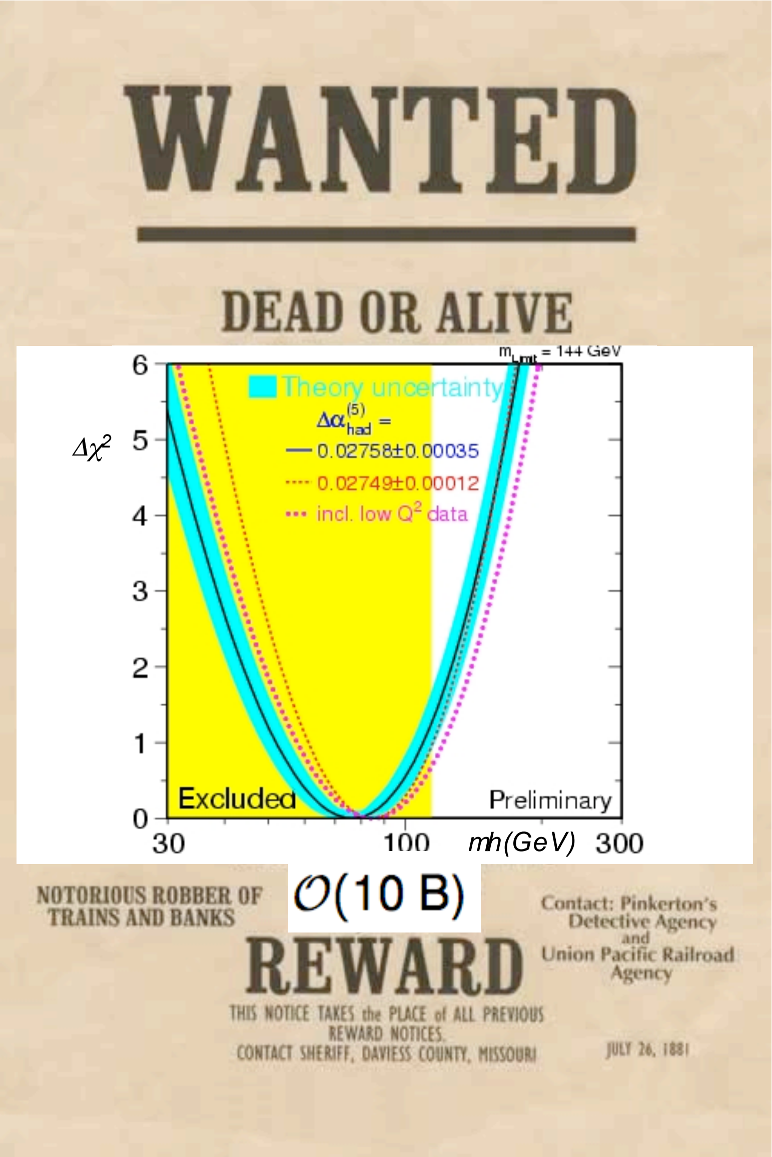
- Dynamical Electroweak Symmetry Breaking
  - QCDlike force which acts on technifermions at a scale of ~ 250 GeV
  - Mediated by technimesons
  - π_{TC} (s = 0), ρ_{TC} and ω_{TC} (S = 1)
  - *No need* for the Higgs boson
- Most promising channel is $\rho_{TC} \rightarrow W+Z \rightarrow 3l+\nu$
  - isolated high p_T leptons + missing E_T
  - W and Z kinematics as signature
  - Background from VV (V=Z,W), Z bb, tt

1 August 2008

ICHEP08
Paolo SPAGNOLO

Higgs

SM-like Higgs Boson

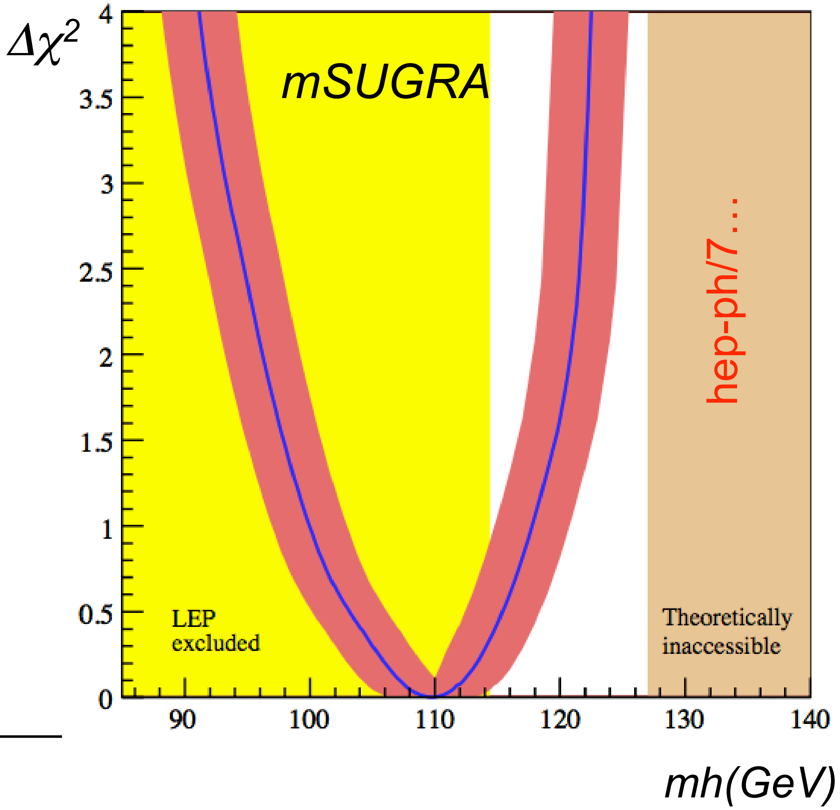


Precision electroweak data tightly constrain the allowed region of m_h in the SM.

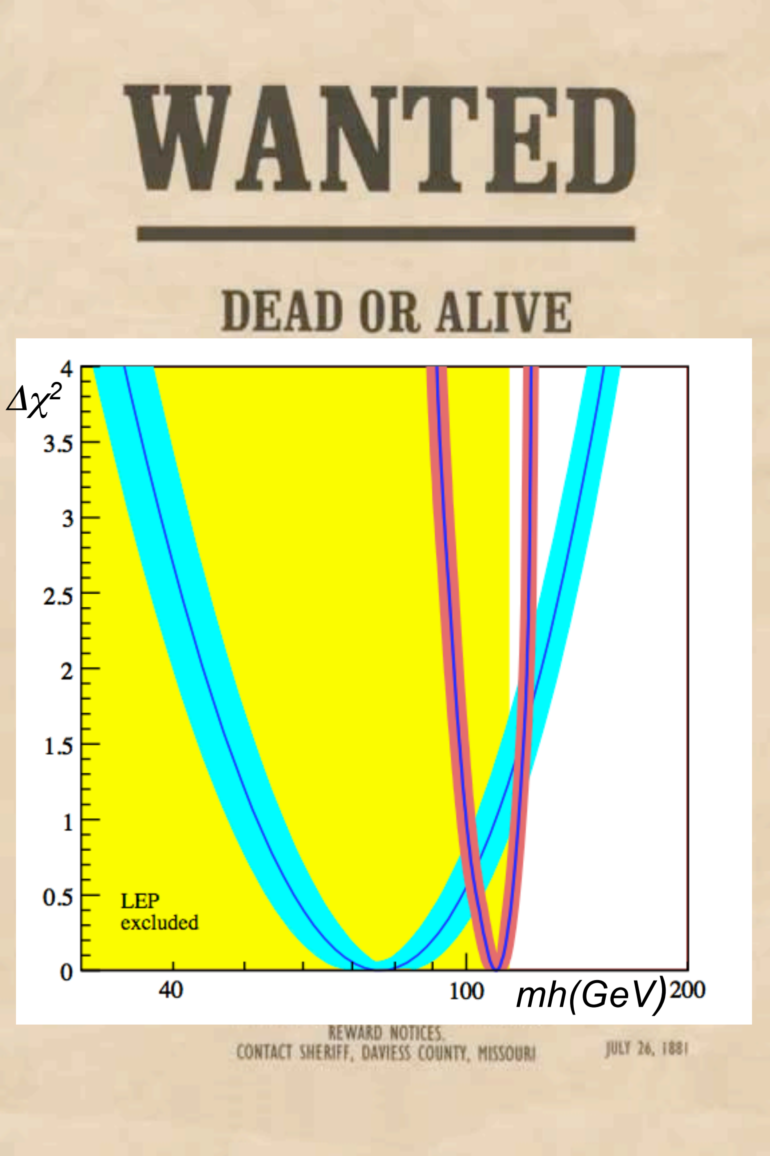
Yet, also other important models like mSUGRA are constrained by these data:

mSUGRA fit to flavour, electroweak and cosmology data:

mh(mSUGRA)=110^{+8}_{-10} (exp)±3(theo) GeV



SM-like Higgs Boson



Many of the popular models (e.g SM or MSSM) require the lightest higgs boson mass to be significantly below 200 GeV.

If the higgs boson really exist, it is probably just around the corner!

Concentrate on SM-like higgs search for mh<200 GeV but the LHC covers full phase space up to 1 TeV.

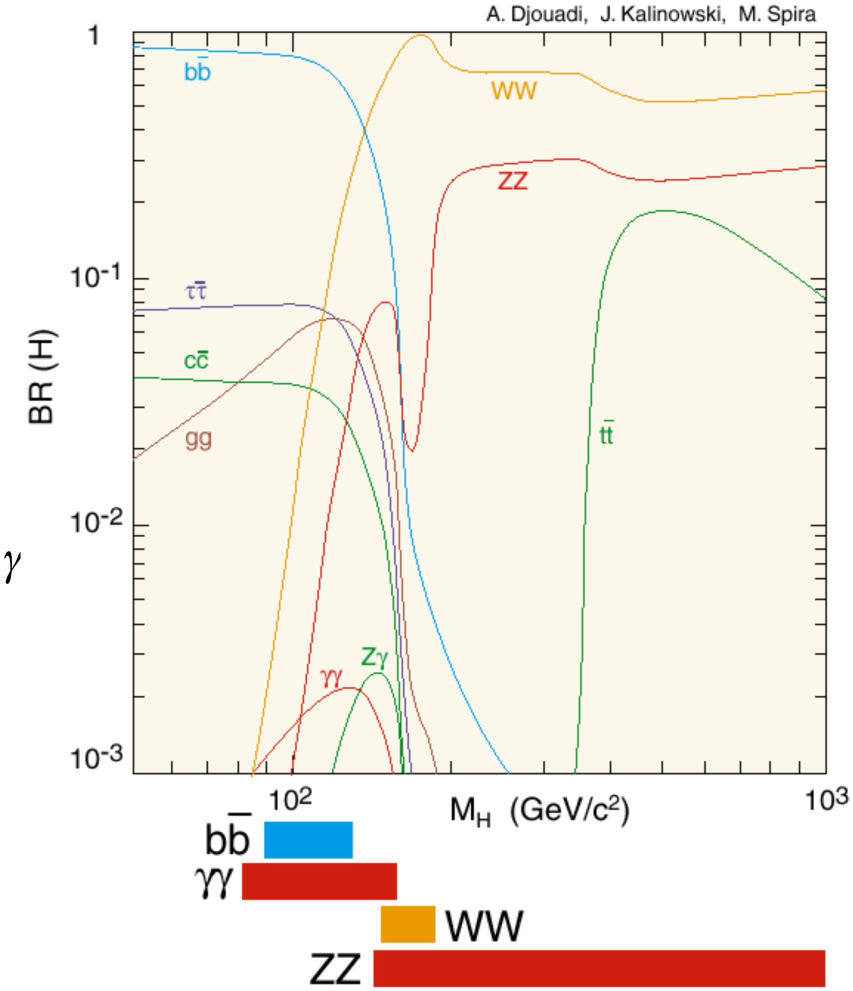
$\Rightarrow$ *We will get an answer!*

Not covered in this talk:
Search for heavy higgs (e.g. MSSM)

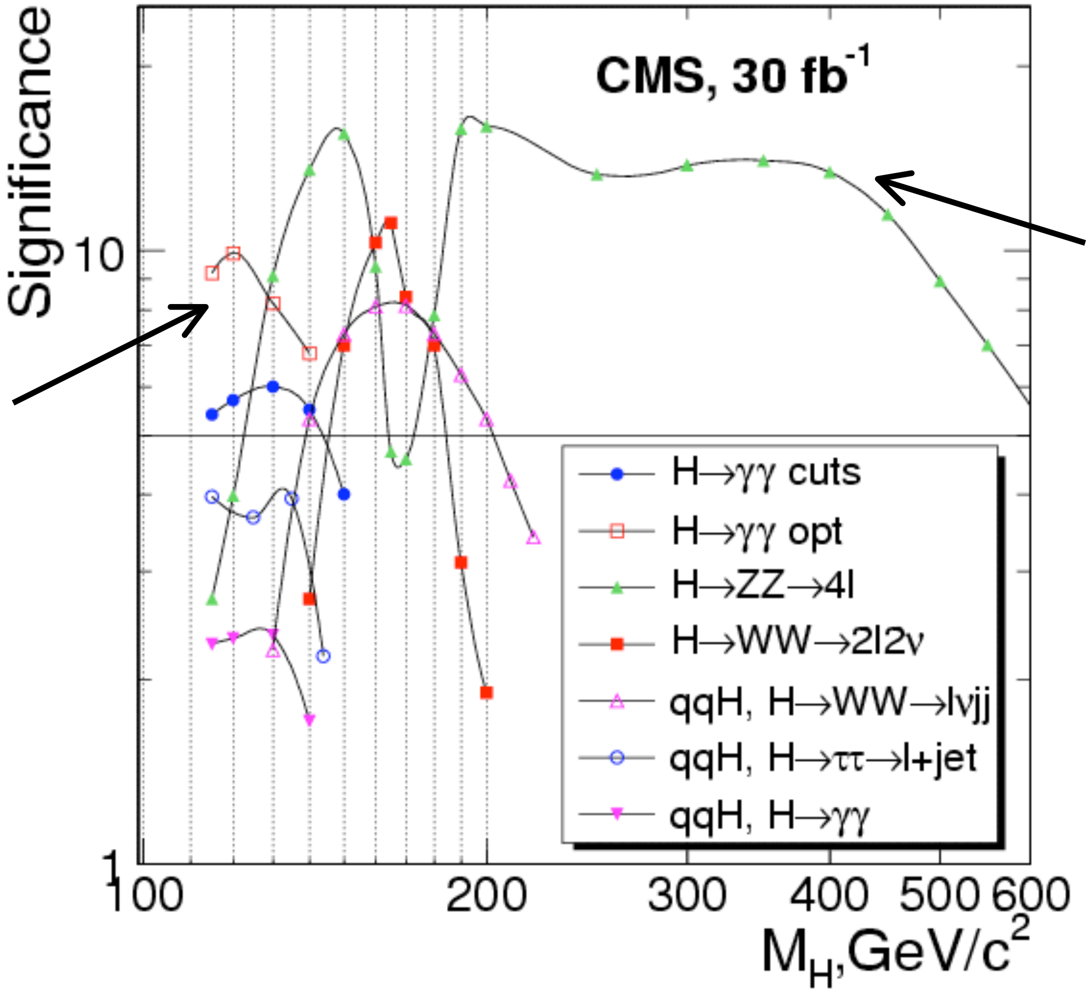
SM Higgs (or lightest Higgs)

Higgs Decay channels

- Higgs couples to m_f^2
  - *Heaviest available fermion (b quark) always dominates*
  - *Until WW, ZZ thresholds open*
- Low mass: b quarks→ jets; resolution ~ 15%
  - *Only chance is EM energy (use γ decay mode)*
- Once $M_H > 2M_Z$, use this
  - *W decays to jets or lepton+neutrino (E_T^{miss})*



CMS: Higgs Discovery Potential



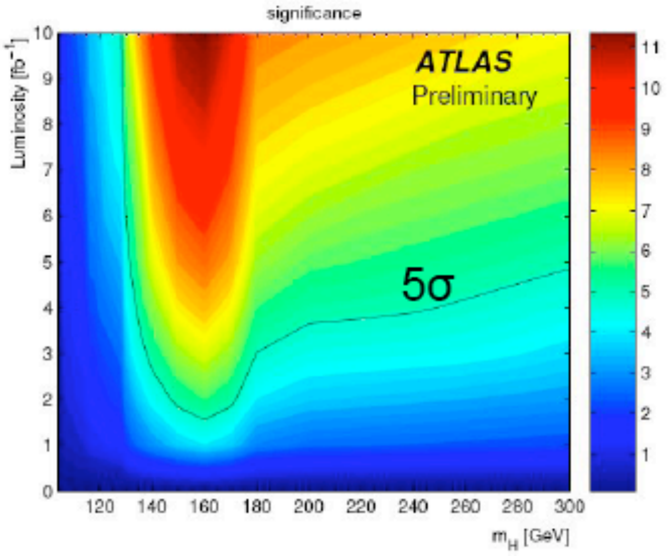
H→γγ

ATLAS is similar

H→ZZ→4l

Bottom line: We will find the Higgs (or exclude it)!

SM Higgs Reach - New ATLAS update



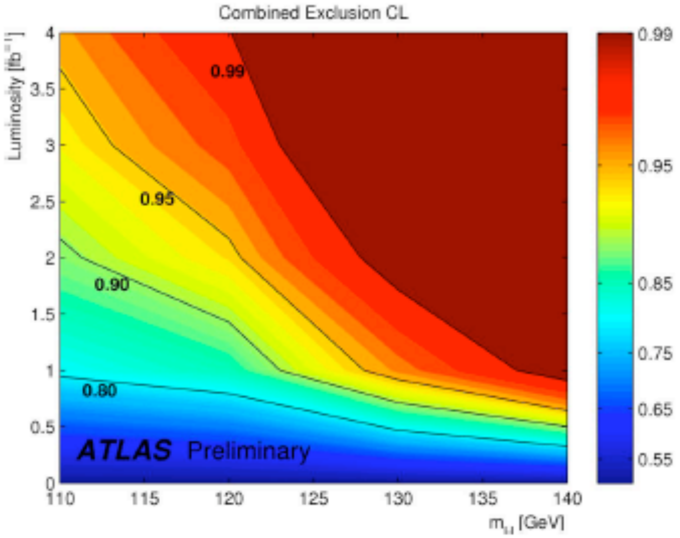
For 5σ discovery, one needs

~20 fb^{-1} to probe down to m_H=115 GeV

10 fb^{-1} for m_H range 127 – 440 GeV

3.3 fb^{-1} for m_H range 136 – 190 GeV

Just under 2 fb^{-1} for $m_H \approx 2m_W$



For 95% CL exclusion, one needs

2.8 fb^{-1} for m_H = 115 GeV/c^2

2 fb^{-1} for m_H range 121– 460 GeV

Less than 2 fb^{-1} to exclude $m_H \approx 2m_W$

Important Higgs Channels

- **H→ZZ*→4l**
- **H→WW*→lnln**

"early" discovery channels
measure Higgs properties (mass, width, xsec)
already with 30 fb^{-1} !!

- **H→WW*→jjln / lnln in VBF**
- **H→t t in VBF**

significance > 5(3) with 30 fb^{-1}
but good comprehension of detector needed
(jet, MET, t in lept. and hadr. decay)

- **H→gg** very difficult analysis with still quite unpredictable background
- **ttH→ttbb** at least 60 fb^{-1} (many jets also with low p_T (<30 GeV) → bad reso/eff)
- other channels (mainly **associated production**) can help EXCLUDING Higgs (e.g. WH→WWW*→Wlnln)

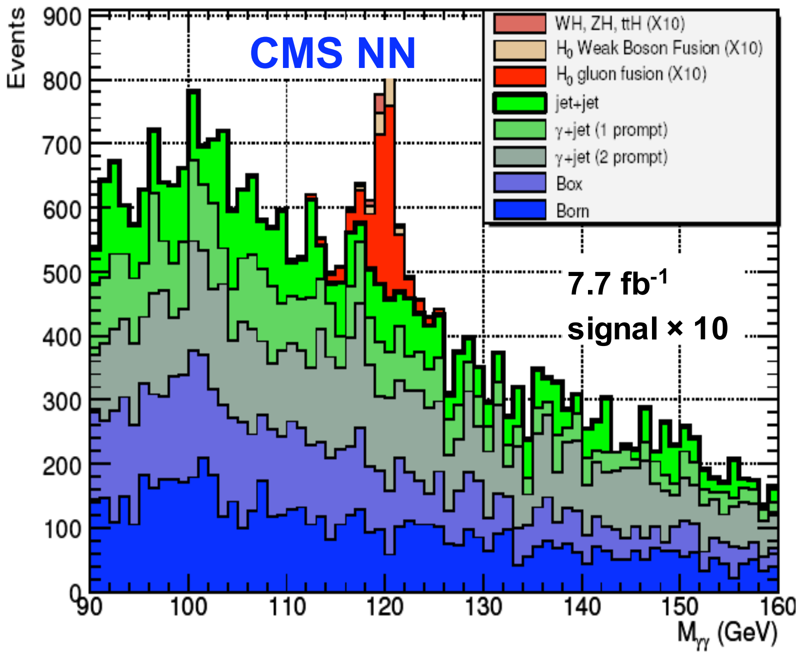
	channel	XS	**studied M_H**
	H→ ZZ*→4l	5-100 fb	130-500 GeV
	H→ WW*→lnln	0.5-2.5 pb	120-200 GeV
VBF	**H→ WW*→jjln**	200-900 fb	120-250 GeV
	H→ WW*→lnln	50-250 fb	120-200 GeV
	H→t t	50-150 fb	115-145 GeV
	H → gg	50-100 fb	115-150 GeV

❑ **Analysis focusing on**

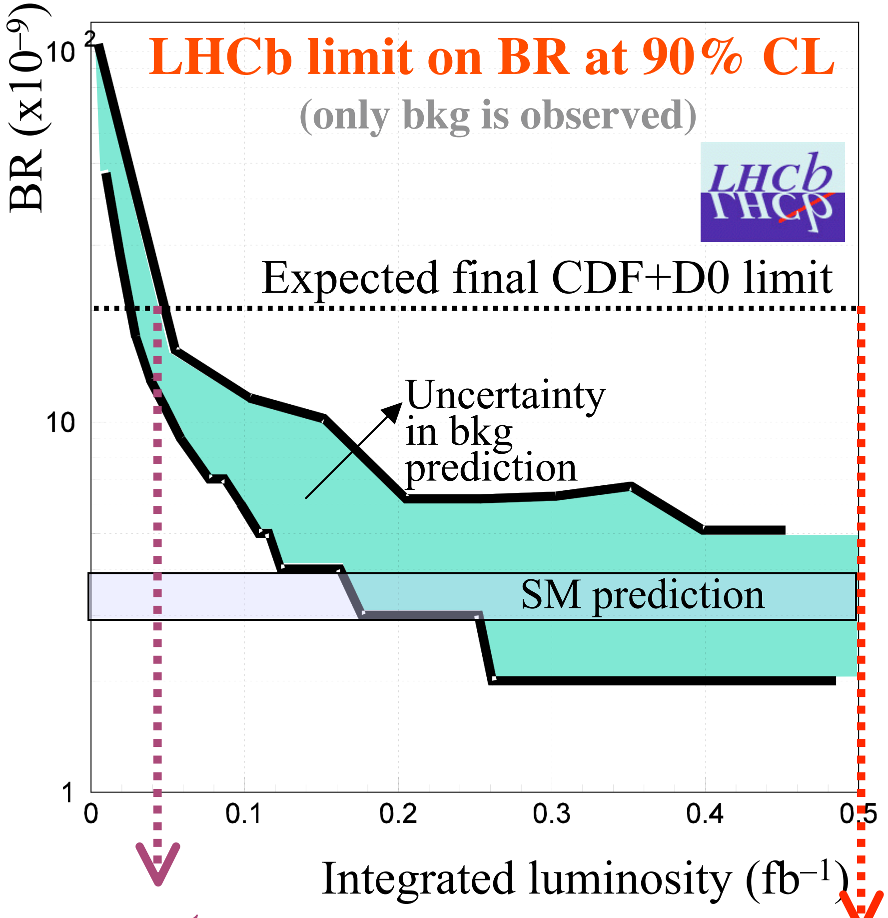
- improvement of the reconstruction
- backgr. and syst. from data

$H \rightarrow \gamma\gamma$

- Photon conversions are important, due to material balance in inner detectors
  - **42%** in the barrel, **59.5%** in the endcap
- Energy Resolution
  - **0.3%** in the barrel, **1%** in the endcap
- Associated production allows to improve s/b ratio. Both ATLAS and CMS are studying several channels
- "Advanced" analyses (NN, Likelihood, categories) allow to improve results with low statistics



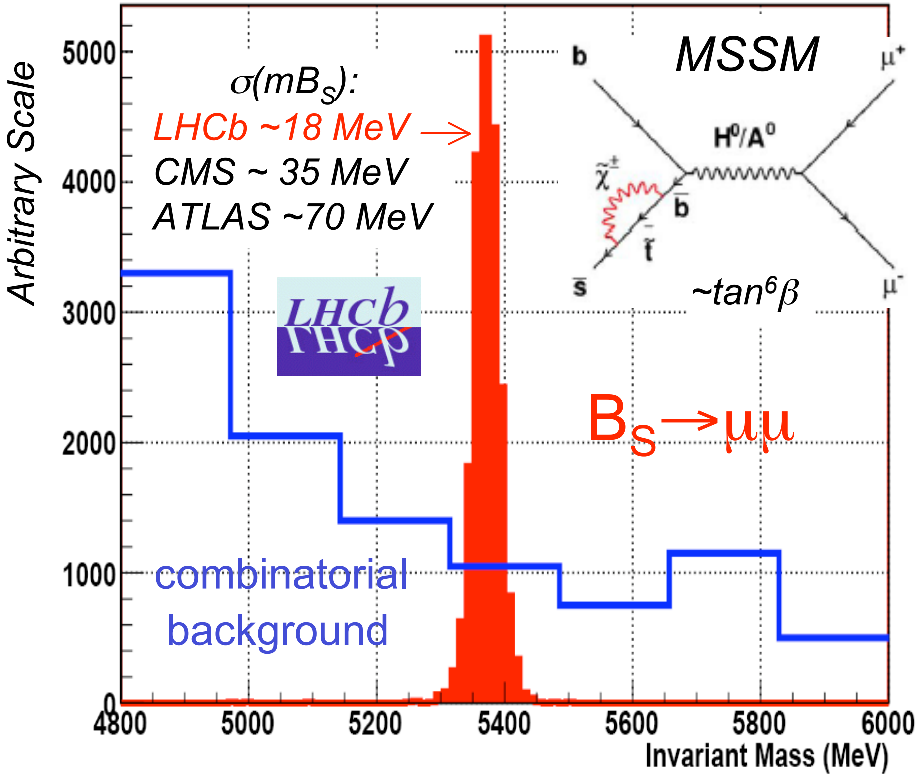
Indirect NP Search: $B_S \to \mu\mu$



0.05fb^{-1} to overtake CDF&D0

0.5fb^{-1} for 90% exclusion at SM value

Early discovery possible!



Integral LHC Luminosity	Signal ev. after cuts	BG ev. after cuts	ATLAS upper limit at 90% CL	CDF&D0 upper limit at 90% CL
100 pb^{-1}	~0	~0.2	6.4×10^{-8}	8×10^{-8}
10 fb^{-1}	~7	~20	7.0×10^{-9}	
30 fb^{-1}	~21	~60	6.6×10^{-9}	

CMS comparable sensitivity (or even a bit better)

LHC & Strings

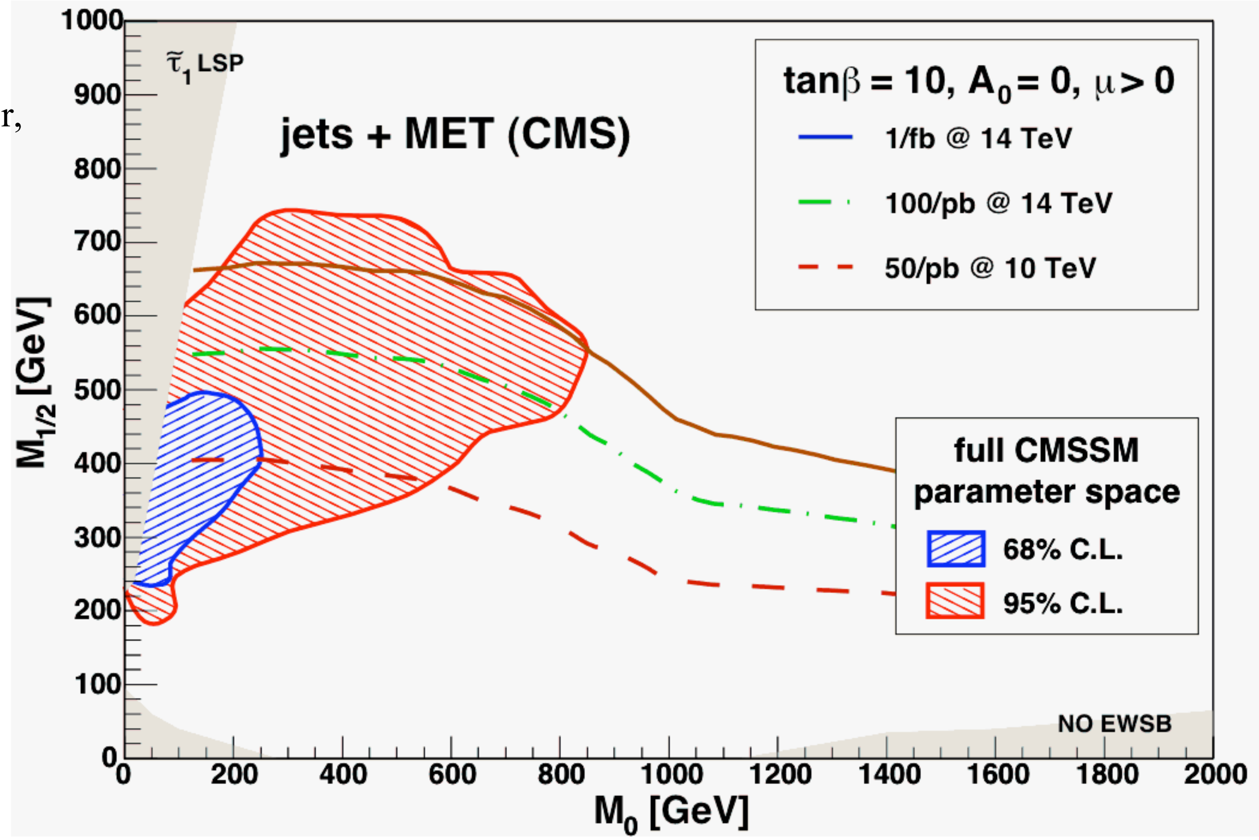
String Theory ⇔ LHC

- The LHC can discover
  - Supersymmetry in Nature
  - Extra dimensions at the Terascale
  - Black holes → Study quantum gravity in the lab
- Recent developments
  - String theory inspired models to predict SUSY phenomenology at the LHC
    - *G2-MSSM models ⇒unusual signatures* *(B Acharya, G. Kane et al)*
    - *String/M theory vacua with a visible MSSM sector (Kane, Kumar and Shao arXiv:0709.4259)*
  - New models inspired from string theoretical observations e.g. hidden valley models
  - AdS/CFT correspondence to calculate properties in heavy ion collisions
  - Pomeron as a messenger from the string world?

Preferred CMSSM Parameter Space

“LHC Weather Forecast”

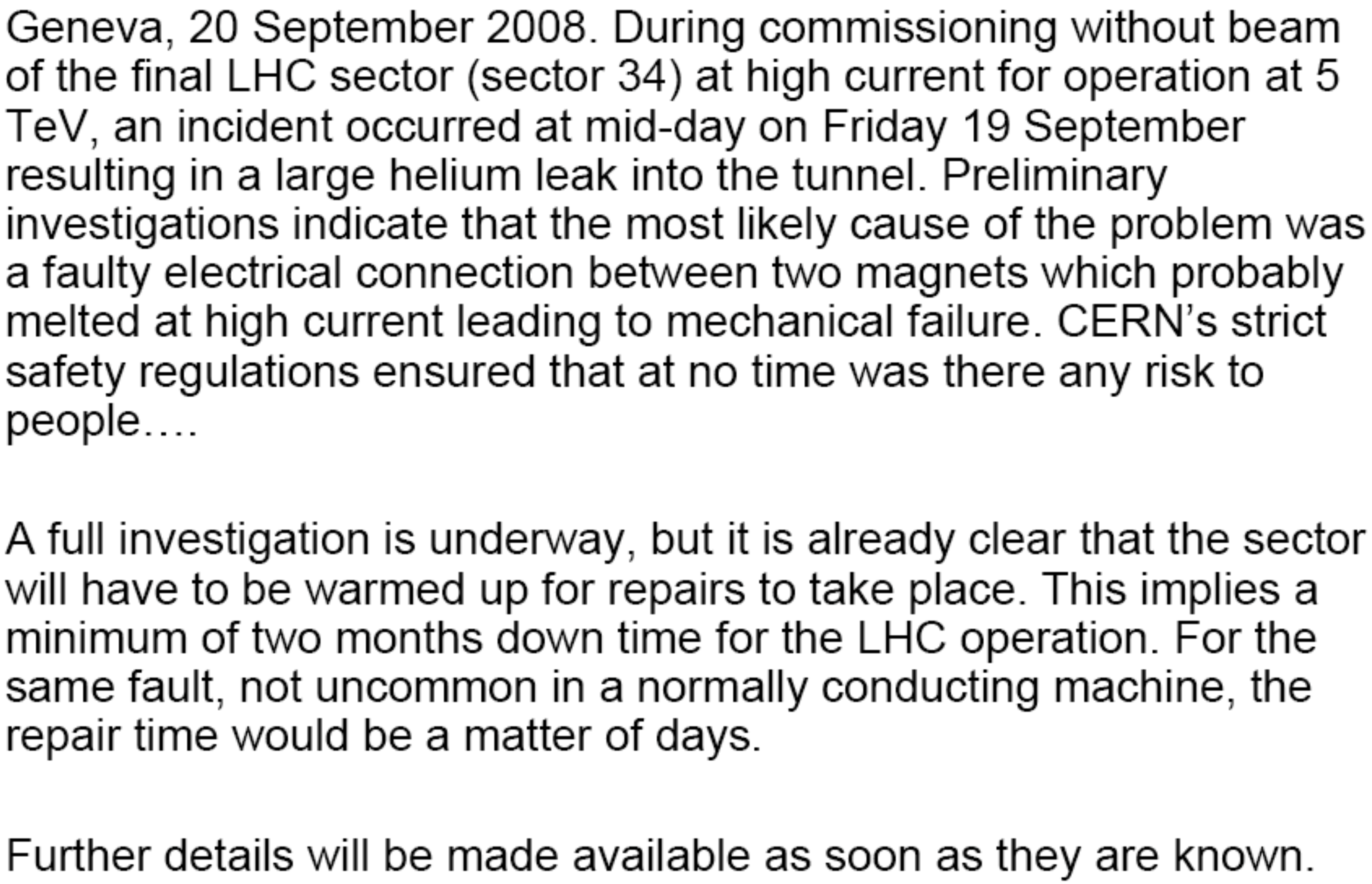
OB, R.Cavanaugh, A.De Roeck,
J.R.Ellis, H.~Flaecher, S.~Heinemeyer,
G.Isidor, K.A.Olive, P.Paradisi,
F.J.Ronga, G.Weiglein



Simultaneous fit of CMSSM parameters m_0, $m_{1/2}$, A_0, $\tan\beta$ (μ>0) to more than 30 collider and cosmology data (e.g. M_W, M_{top}, g-2, BR($B \rightarrow X\gamma$), relic density)

“CMSSM fit clearly favors low-mass SUSY - Evidence that a signal might show up very early?!”

Accident on September 19th



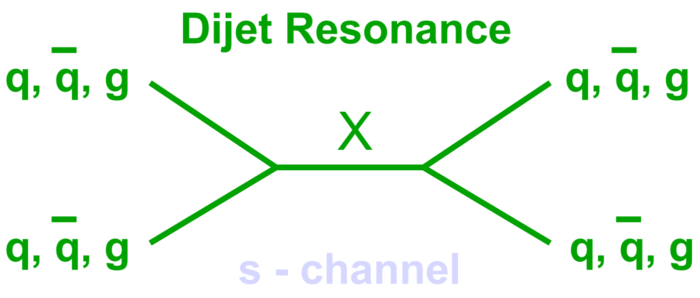
Geneva, 20 September 2008. During commissioning without beam of the final LHC sector (sector 34) at high current for operation at 5 TeV, an incident occurred at mid-day on Friday 19 September resulting in a large helium leak into the tunnel. Preliminary investigations indicate that the most likely cause of the problem was a faulty electrical connection between two magnets which probably melted at high current leading to mechanical failure. CERN’s strict safety regulations ensured that at no time was there any risk to people….

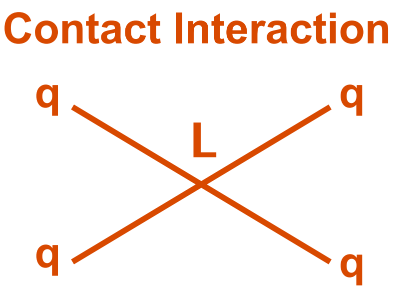
A full investigation is underway, but it is already clear that the sector will have to be warmed up for repairs to take place. This implies a minimum of two months down time for the LHC operation. For the same fault, not uncommon in a normally conducting machine, the repair time would be a matter of days.

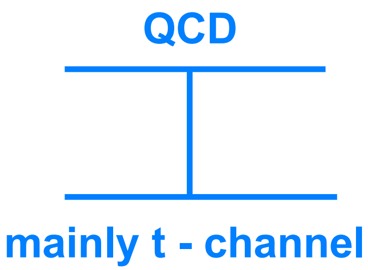
Further details will be made available as soon as they are known.

Introduction

- CMS AN-2007/039 summarizes dijet work since PTDR including
  - AN-2007/015: Dijet Ratio from QCD and Contact Interactions
  - AN-2007/016: Dijet Resonance Analysis
- Complementary to the PTDR sensitivity estimates
  - Explores how we do analysis, finds optimal and data-driven h cuts.
- Discusses two new analysis topics since PTDR
  - Contact Interaction search using jet P_T (joint with QCD group).
  - Dijet resonance search using dijet ratio.
- More discussion on angular distribution of dijet resonances than in PTDR

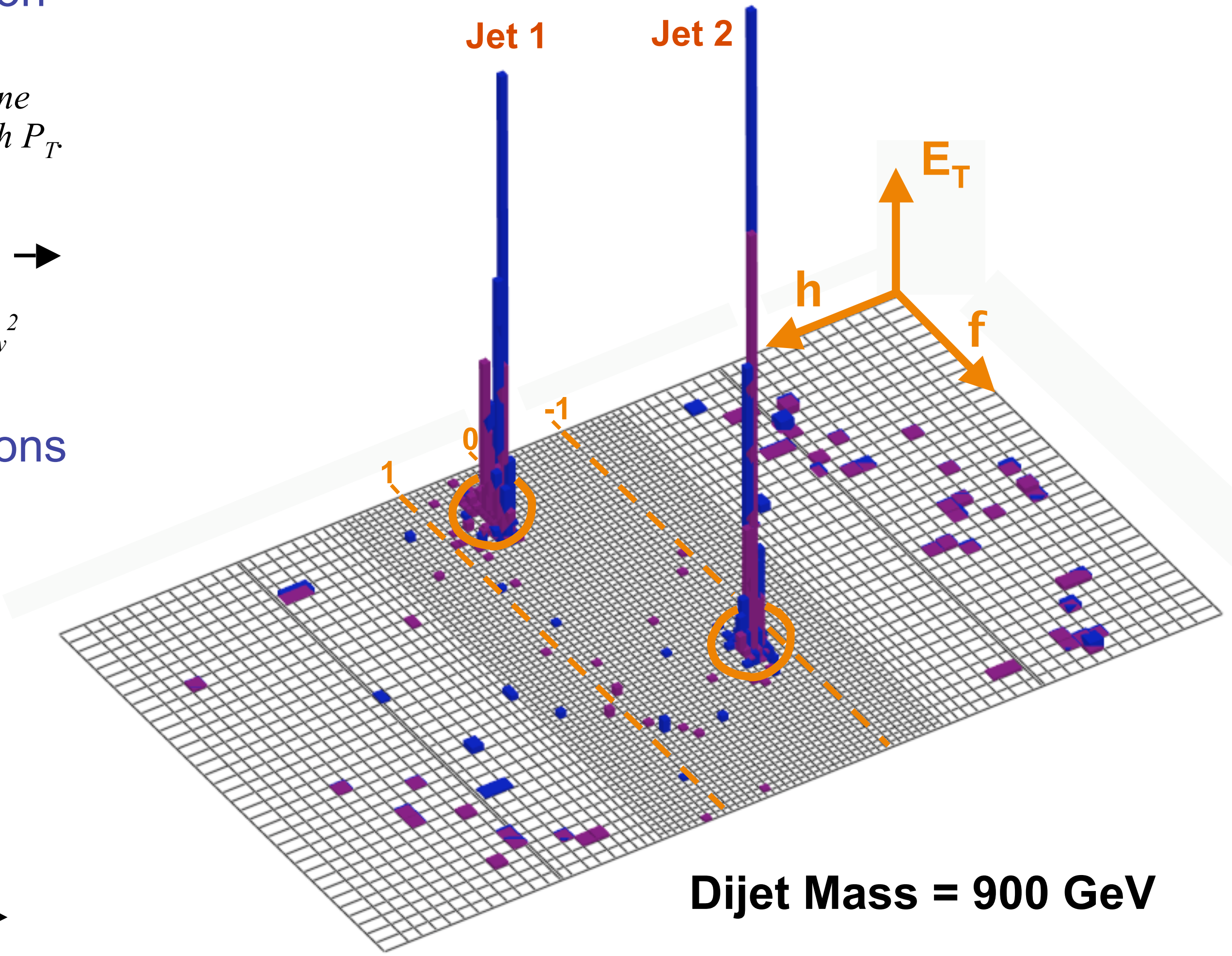






Jet Reconstruction & Correction

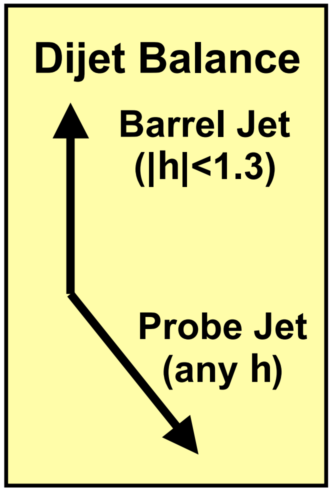
- Standard jet reconstruction
  - Cone algorithm R=0.5
    - → *Midpoint & iterative cone indistinguishable at high* P_T.
  - Standard jet kinematics
    - → Jet $E = SE_i$, Jet $p = Sp_i$
    - → $q = \tan^{-1}(p_y/p_x)$
    - → $E_T = E\sin q$, $p_T = \sqrt{p_x^2+p_y^2}$
- Standard MC jet corrections
  - Scales Jet (E,p_x,p_y,p_z) by
    - → ~1.5 at E_T = 70 GeV
    - → ~1.1 at E_T = 3 TeV
    - → *for jets in barrel region*
- Dijet is two leading jets.
  - $m=\sqrt{(E_1+E_2)^2 - (p_1+p_2)^2}$



Dijet Mass = 900 GeV

Jet Eta Region

- Barrel jets have uniform response & sensitive to new physics
  - Jet response changes smoothly and slowly up to | jet h | = 1.3
    - *CaloTowers with |h|<1.3 are in barrel with uniform construction.*
    - *CaloTowers with 1.3<|h|<1.5 are in barrel / endcap transition region*
  - Some of our analyses use | jet h |<1.3, others still use | jet h |<1
    - *All are migrating to | jet h |<1.3 which is optimal for dijet resonances*
- Measure relative response vs. jet h in data with dijet balance
  - Data will tell us what is the region of response we can trust.

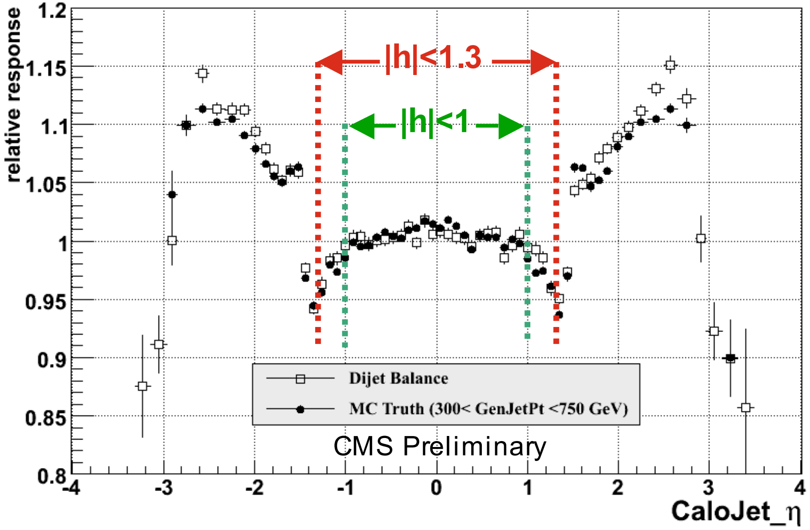


Dijet Balance

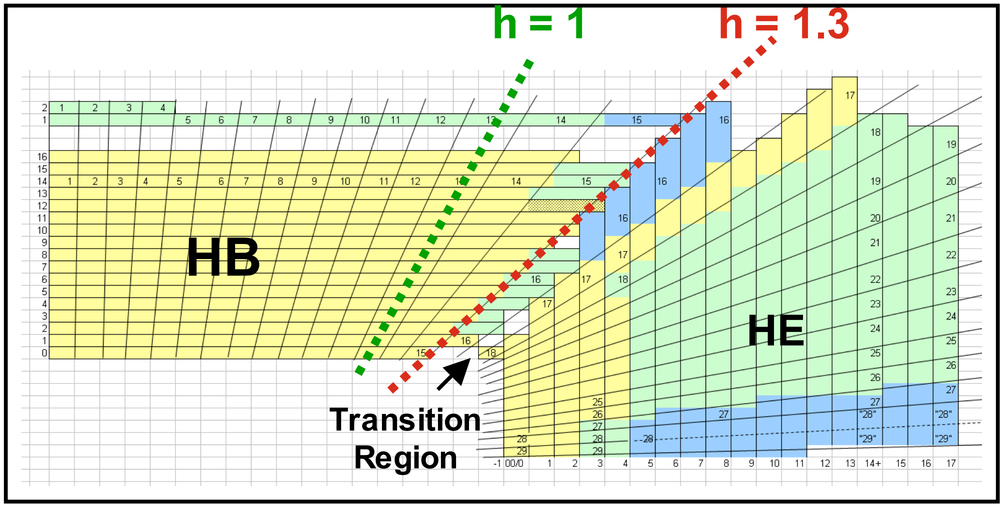
Barrel Jet (|h|<1.3)

Probe Jet (any h)

Jet response vs h relative to |h|<1.3

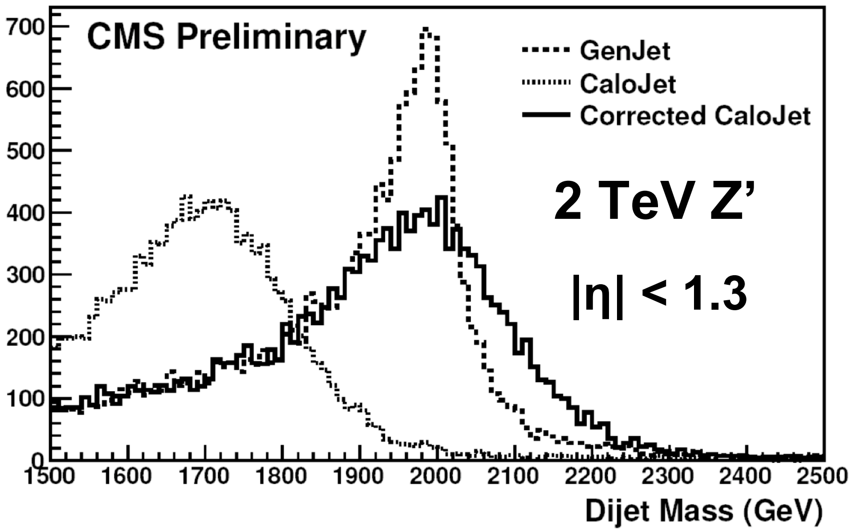


Hcal towers and h cuts

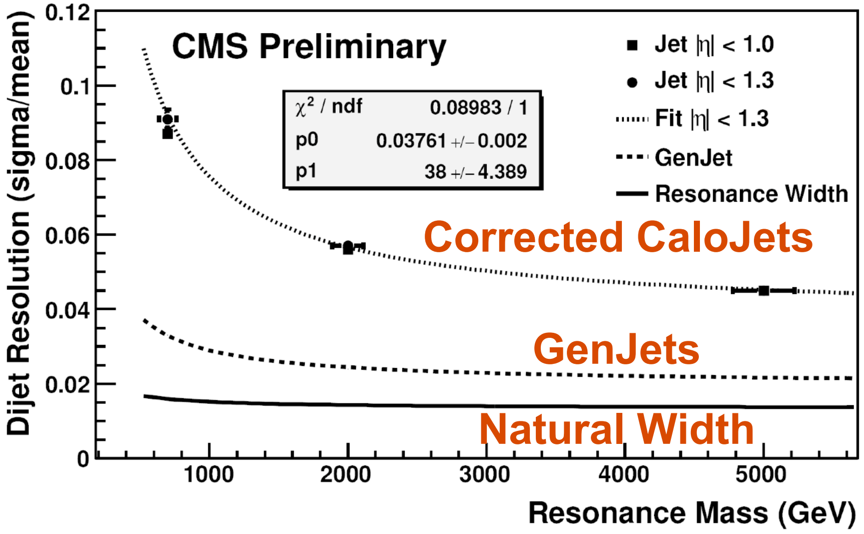


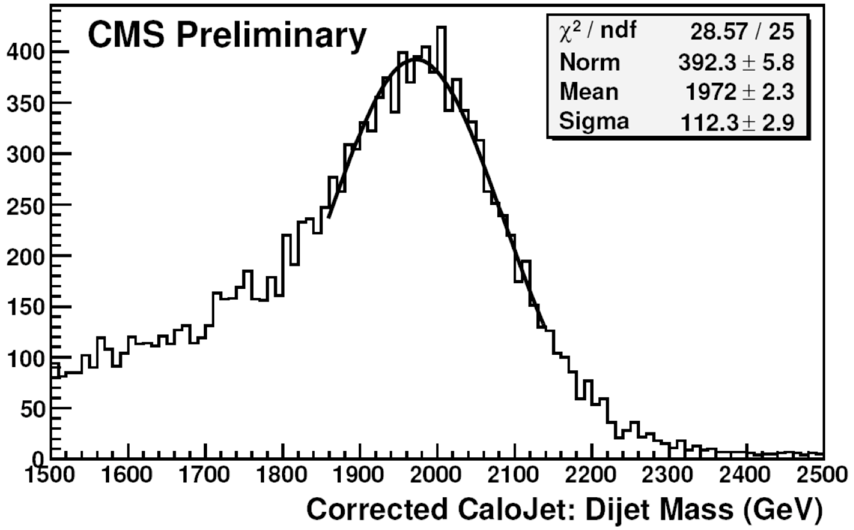
Dijet Mass Resolution

- First high statistics study of dijet resonance mass resolution.
- Gaussian core of resolution for |h|<1 and |h|<1.3 is similar.
- Resolution for corrected CaloJets
  - 9% at 0.7 TeV
  - 4.5% at 5 TeV
  - Better than in PTDR 2 study.



Resolution



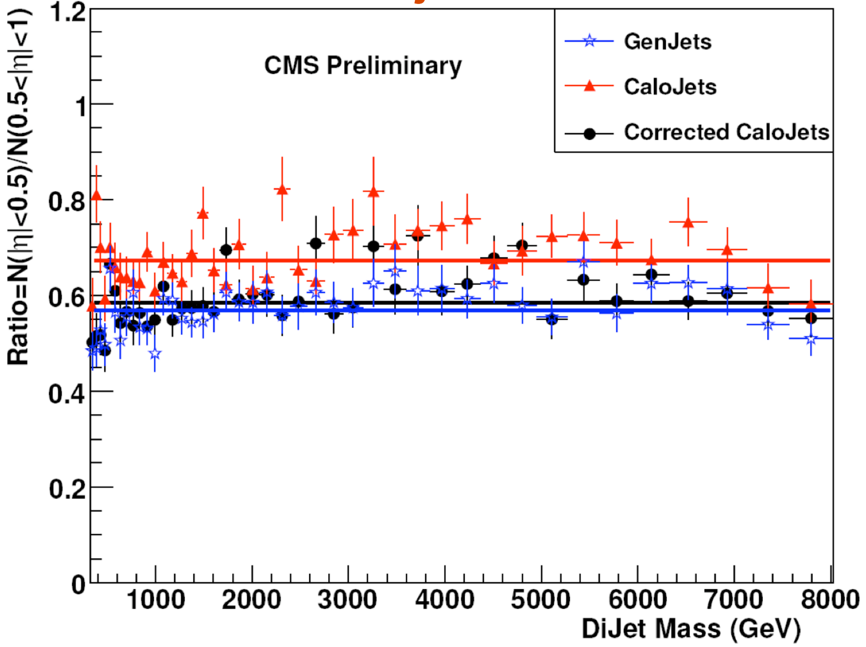


Dijet Ratio from QCD

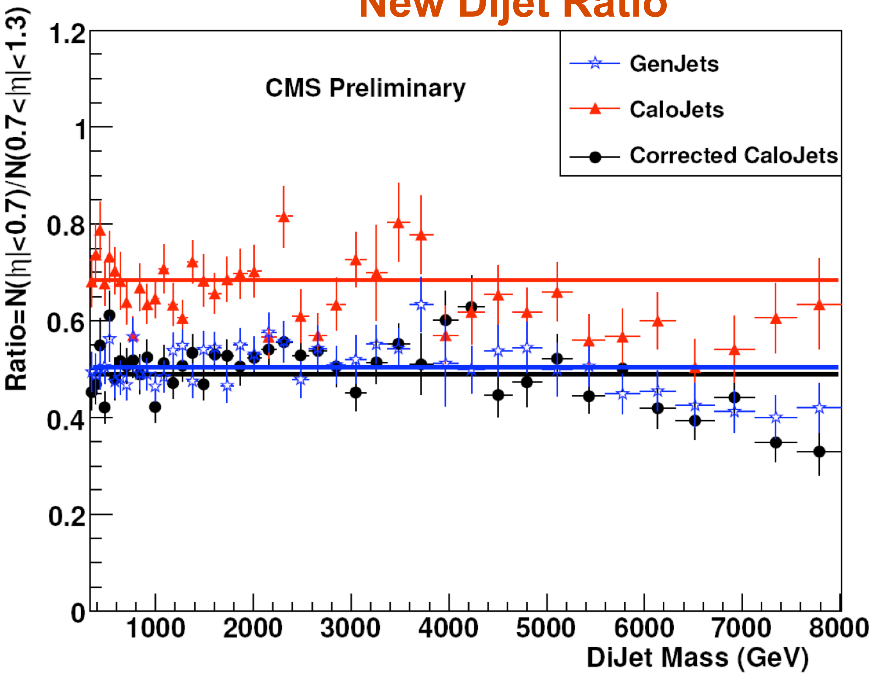
- We have optimized the dijet ratio for a contact interaction search in barrel
  - Old dijet ratio used by D0 and PTDR was N(|h|<0.5) / N(0.5<|h|<1.0)
  - New dijet ratio is N(|h|<0.7) / N(0.7<|h|<1.3)

- Dijet ratio from QCD agrees for GenJets and Corrected CaloJets
  - Flat at 0.6 for old ratio, and flat at 0.5 for new ratio up to around 6 TeV.

Old Dijet Ratio



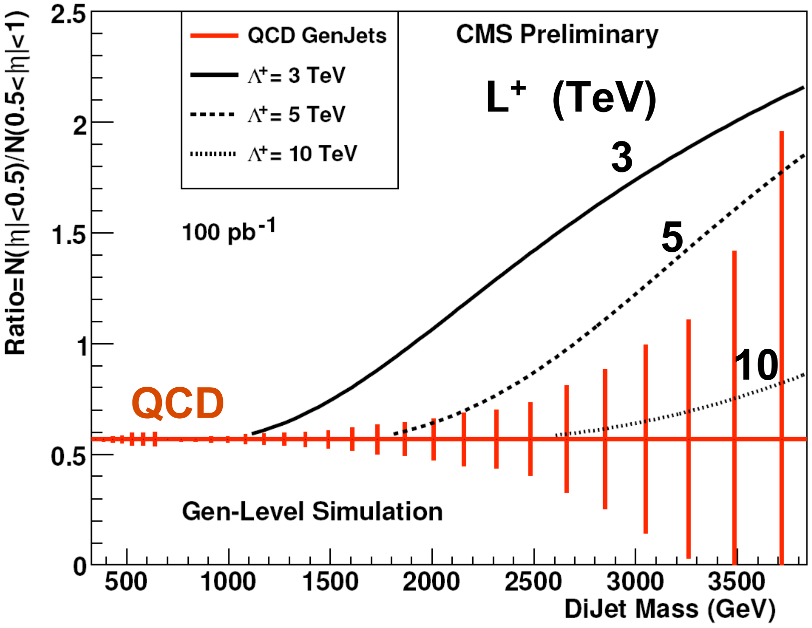
New Dijet Ratio



Dijet Ratio from QCD & Contact Interactions

- Optimization dramatically increases sensitivity to contact interactions.
  - Raising the signal and decreasing the QCD error bars.
  - Value of L^+ we can discover is increased by 2 TeV for 100 pb^{-1}
    - *From $L^+ \approx 5$ TeV with old dijet ratio (PTDR) to $L^+ \approx 7$ TeV with new dijet ratio.*

Old Dijet Ratio



New Dijet Ratio