The LHC: Experiments and First Physics (Part IV)

Albert De Roeck
CERN, Geneva, Switzerland
Universiteit Antwerpen, Belgium
IPPP Durham, UK
UC Davis, USA

CERN School Thailand 2010

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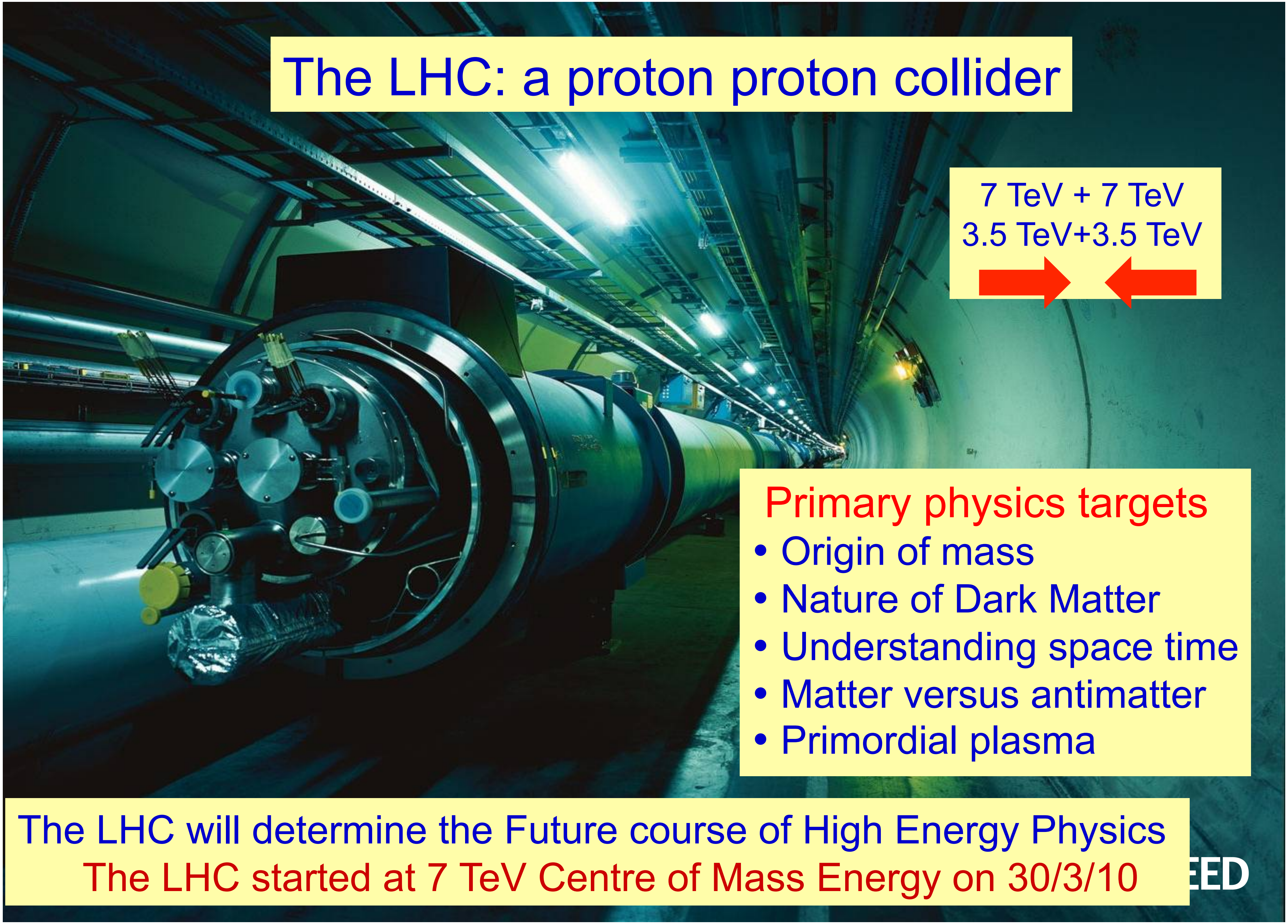
Lecture Plan

- Introduction
  - The LHC startup as seen from the experiments
- The experimental challenges at the LHC
  - The experimental solutions
- The “general purpose” experiments
  - The CMS experiment
  - The ATLAS experiment
- First performance results of ATLAS/CMS
- A tour on the other experiments and their performance
- First physics with the LHC experiments
  - QCD, B-physics
  - EWK/Searches and the outlook

The LHC: a proton proton collider



7 TeV + 7 TeV
3.5 TeV+3.5 TeV

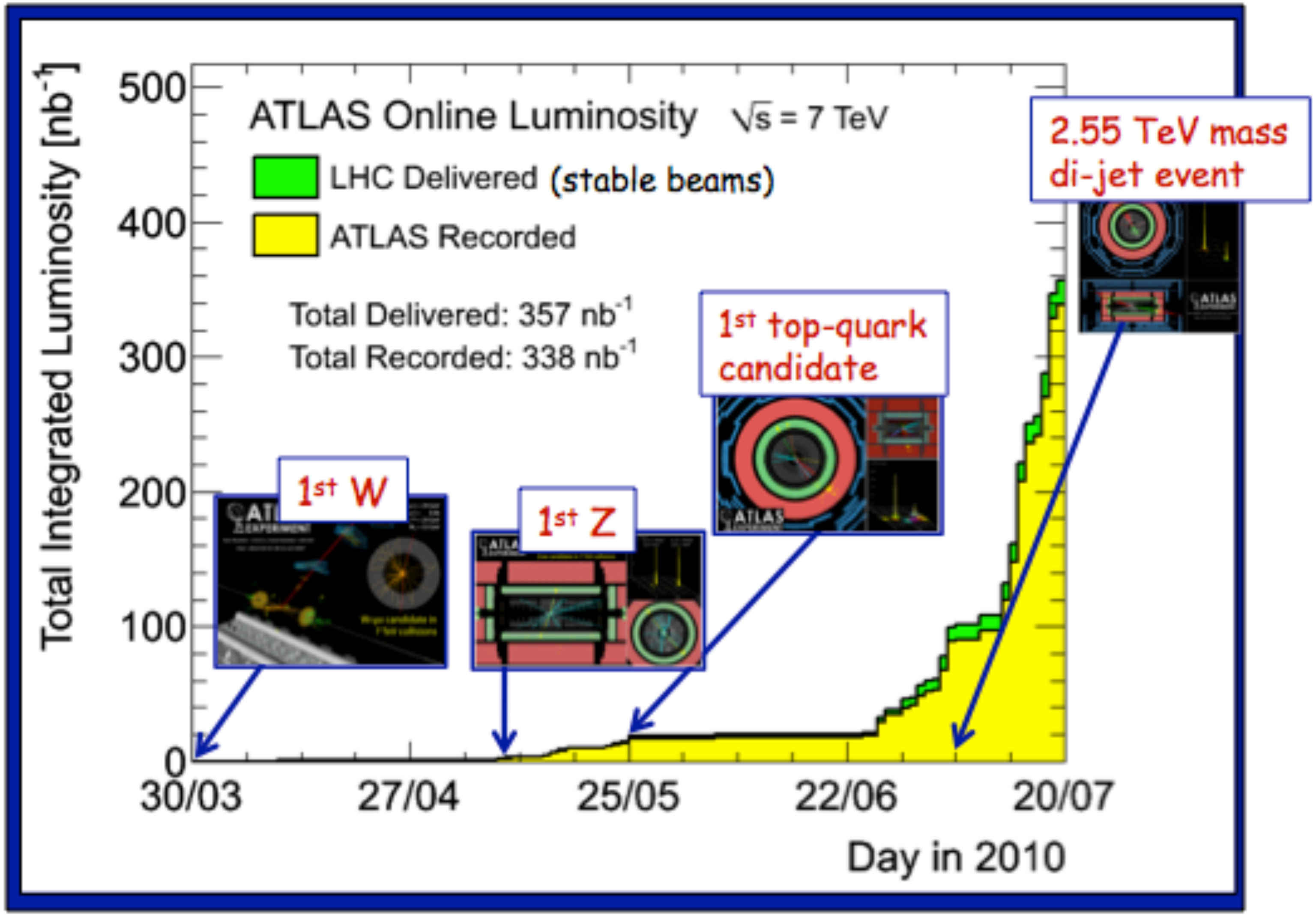
Primary physics targets

- Origin of mass
- Nature of Dark Matter
- Understanding space time
- Matter versus antimatter
- Primordial plasma

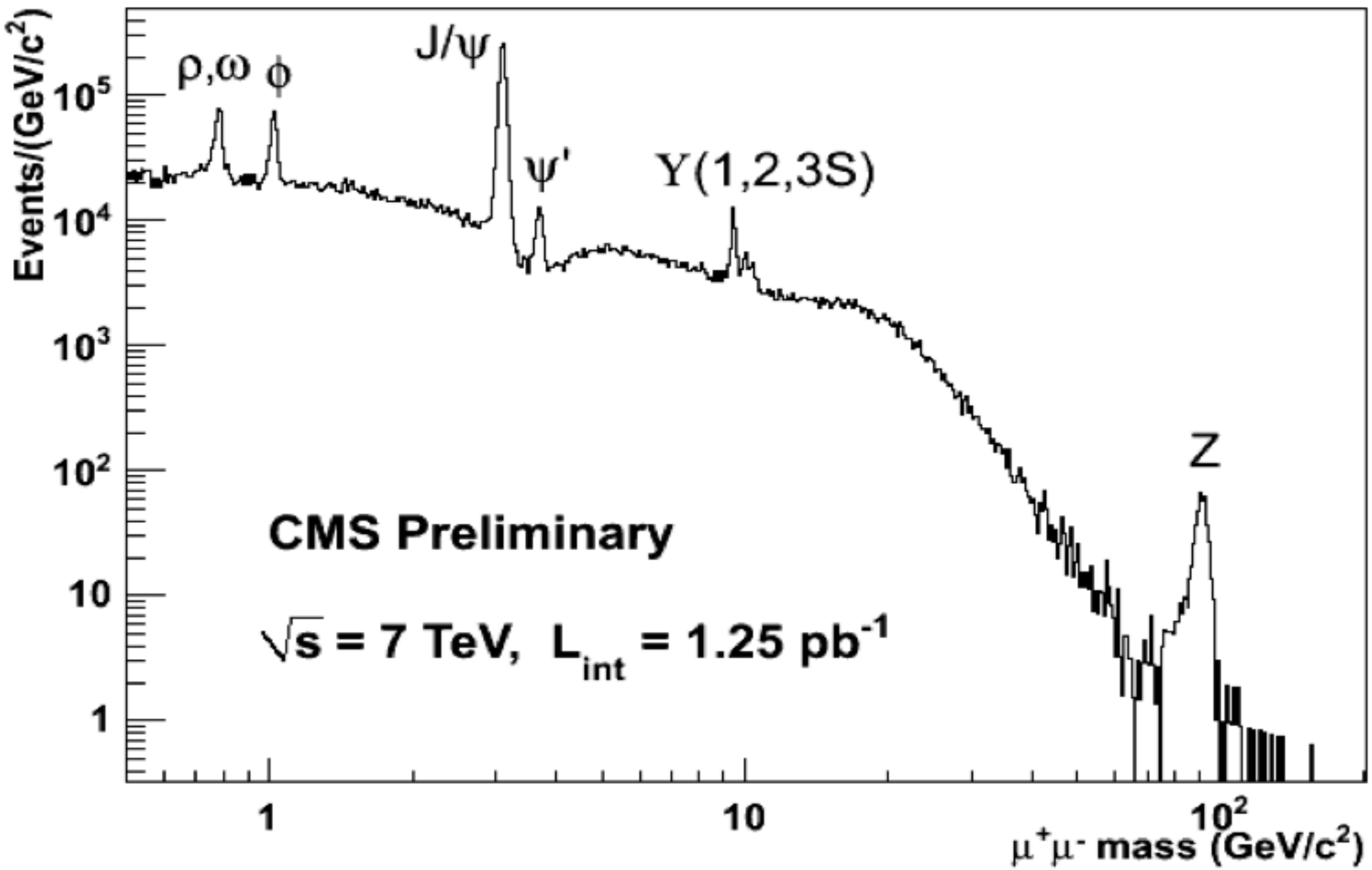
The LHC will determine the Future course of High Energy Physics

The LHC started at 7 TeV Centre of Mass Energy on 30/3/10

Luminosity & Physics

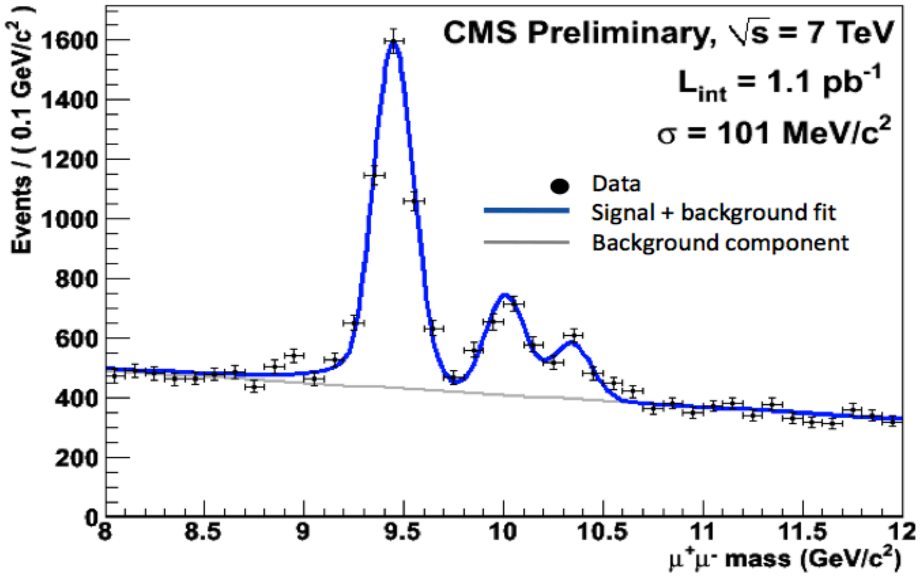


Resonances → μμ



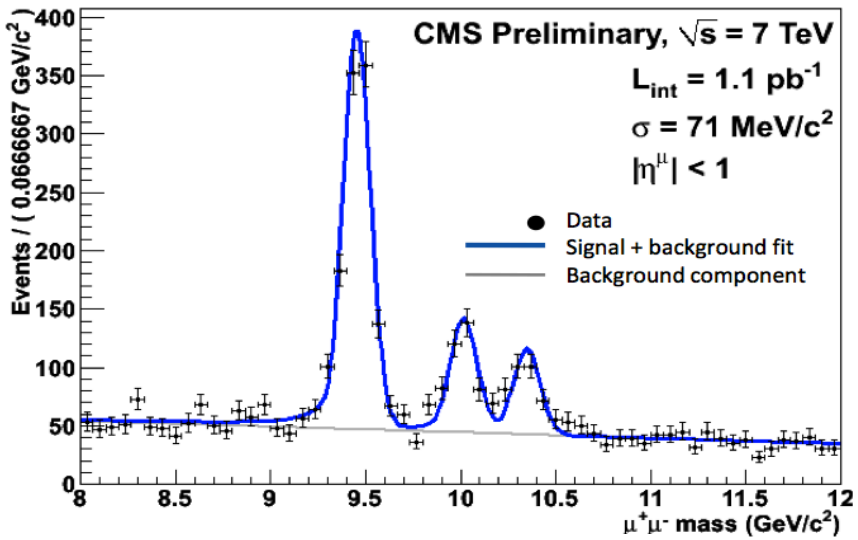
Remember: CMS = Compact Muon Solenoid!!

Υ (upsilon) → μμ



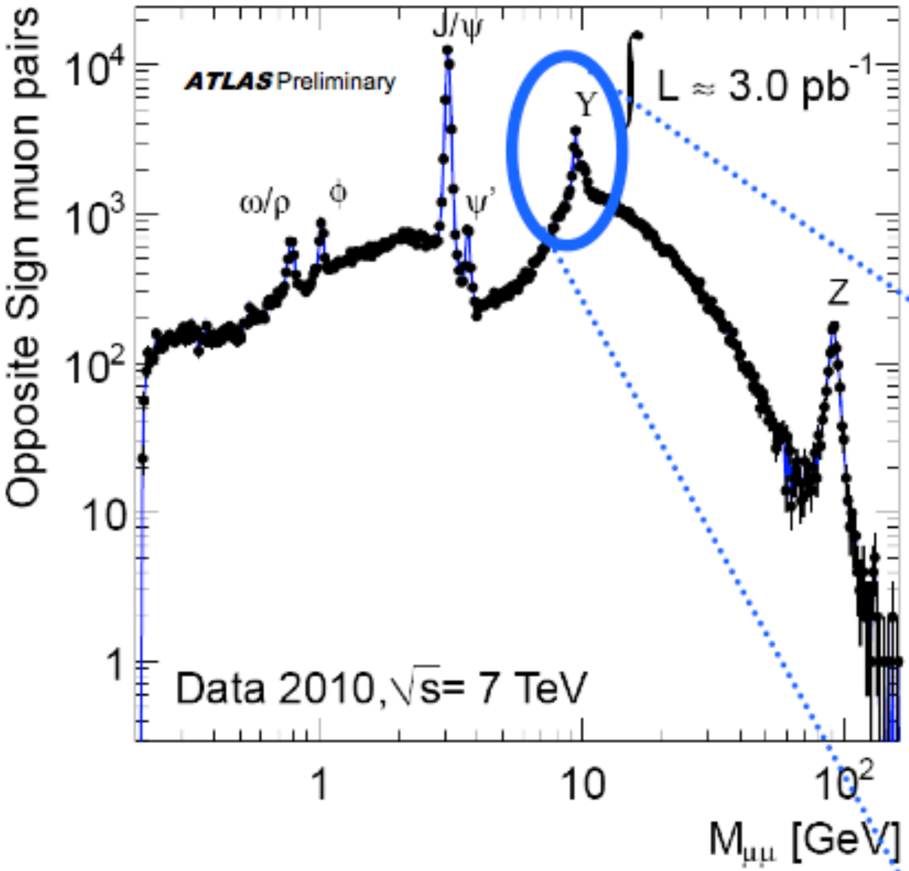
Signal events Υ(1S) = 3106 83
Signal events Υ(2S) = 893 57
Signal events Υ(3S) = 508 51

Muons in the barrel detectors only

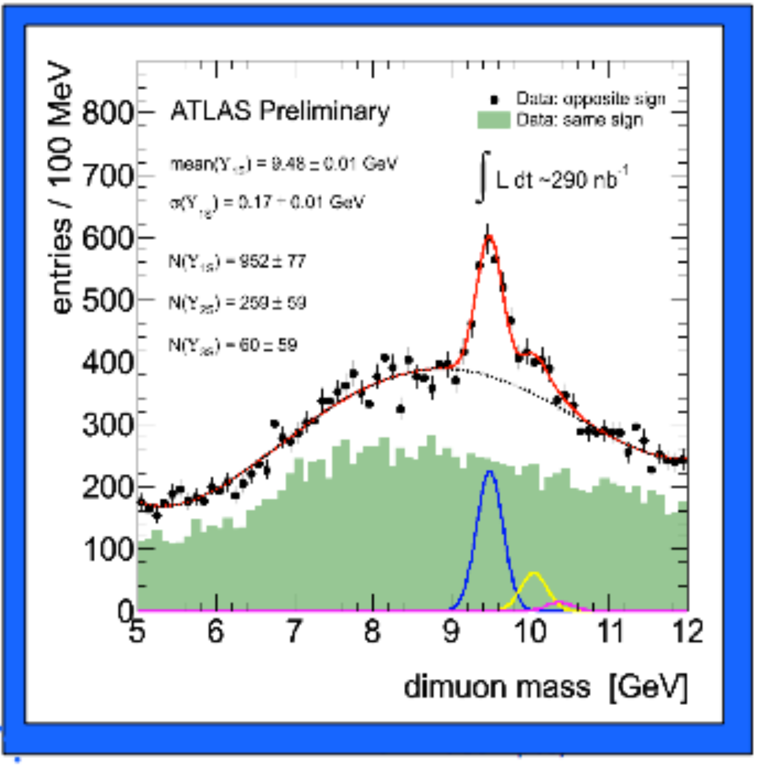


Signal events Υ(1S) = 979 38
Signal events Υ(2S) = 278 24
Signal events Υ(3S) = 212 22

Resonances → μμ



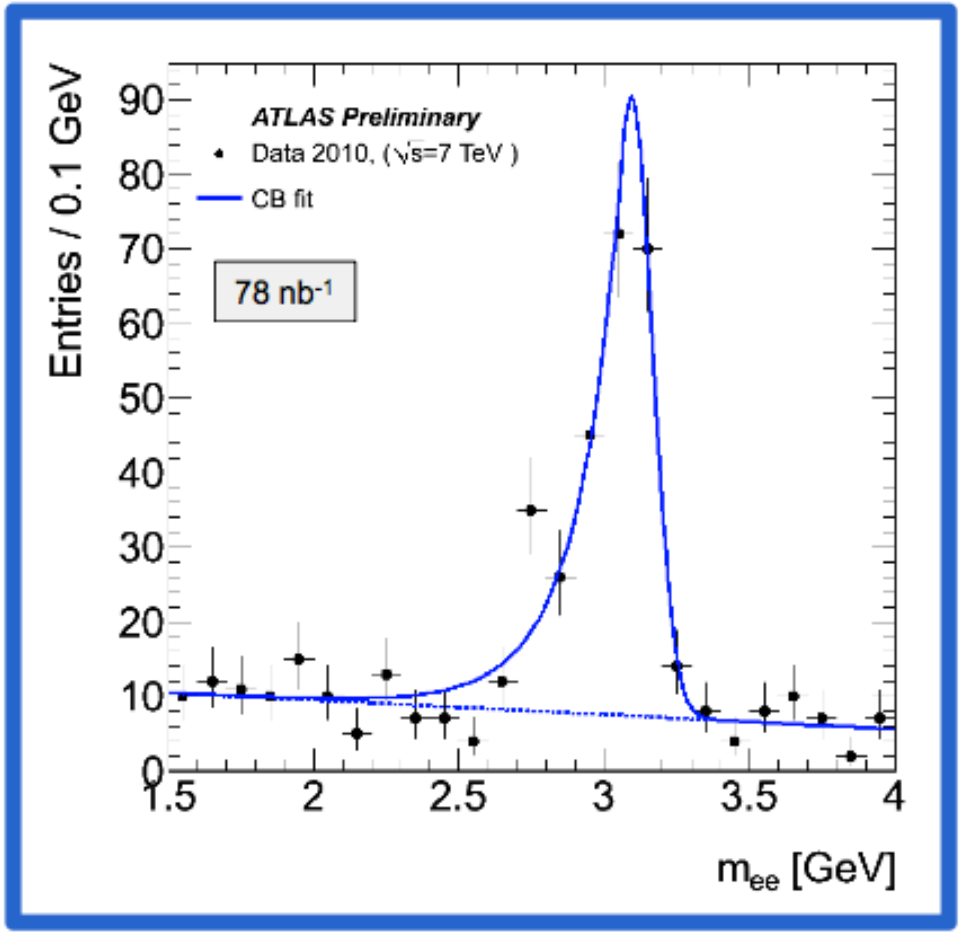
Simple analysis:
- ❑ LVL1 muon trigger with $p_T \sim 6$ GeV threshold
- ❑ 2 opposite-sign primary muons reconstructed by combining tracker and muon spectrometer



- ❑ Looser selection: includes also muons made of Inner Detector tracks + Muon Spectrometer segments
- ❑ Distances between resonances fixed to PDG values; Υ(2S), Υ(3S) resolutions fixed to Υ(1S) resolution

37

Resonances → ee

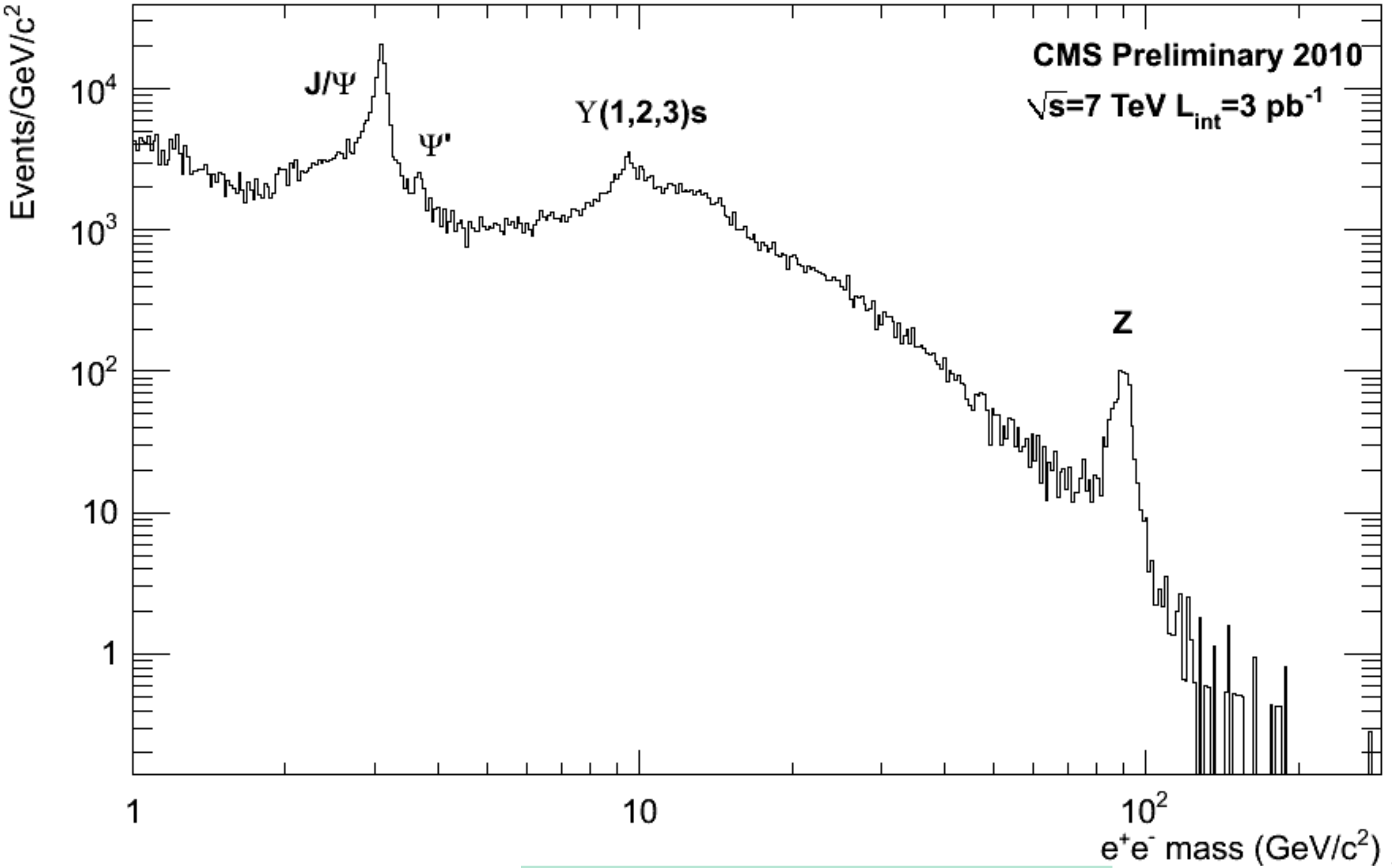


Signal	: 222 ± 11 events
Background	: 28 ± 2 events
Mass peak	: 3.09± 0.01 GeV
Mass resolution	: 0.07 ± 0.01 GeV

Requirements:

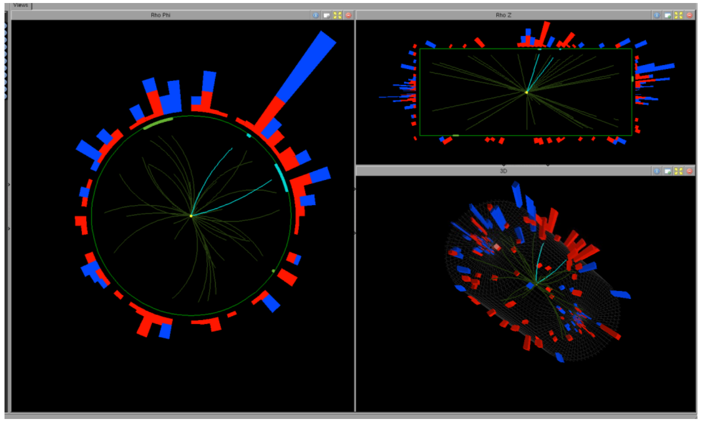
- ❑ 2 EM clusters matched to tracks
- ❑ p_T ($e^{\pm}$ tracks) > 4, 2 GeV
- ❑ track quality, calo shower shapes
- ❑ key handle: large transition radiation in TRT
- ❑ invariant mass from track parameters after Brem recovery (GSF)

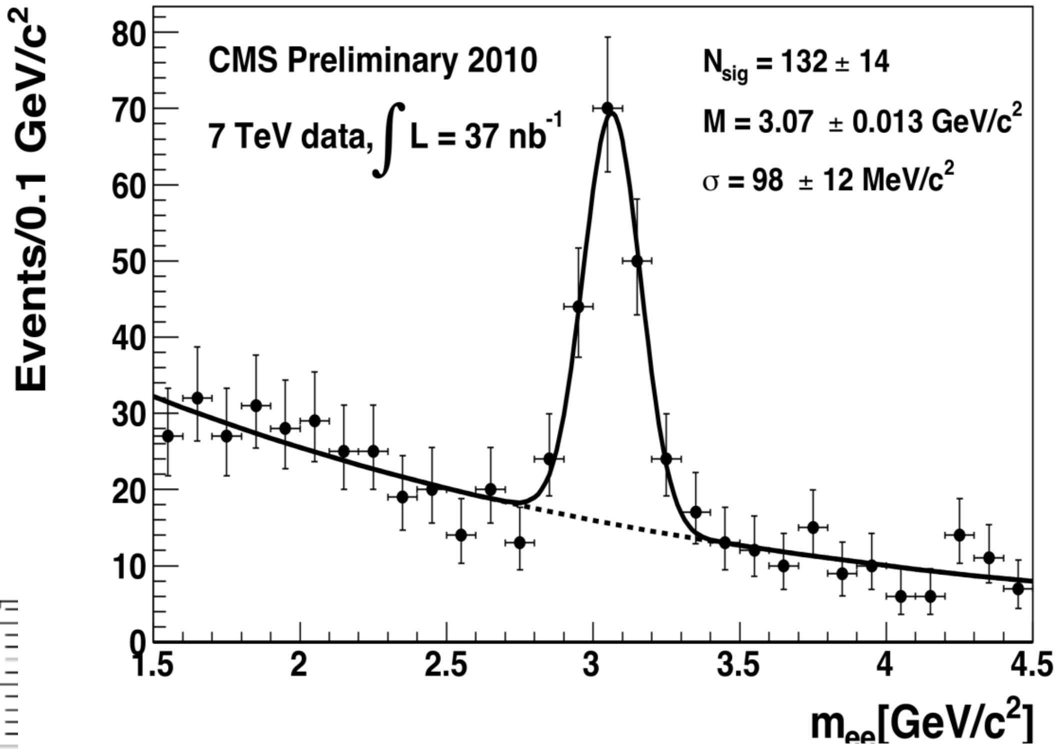
Resonances → ee



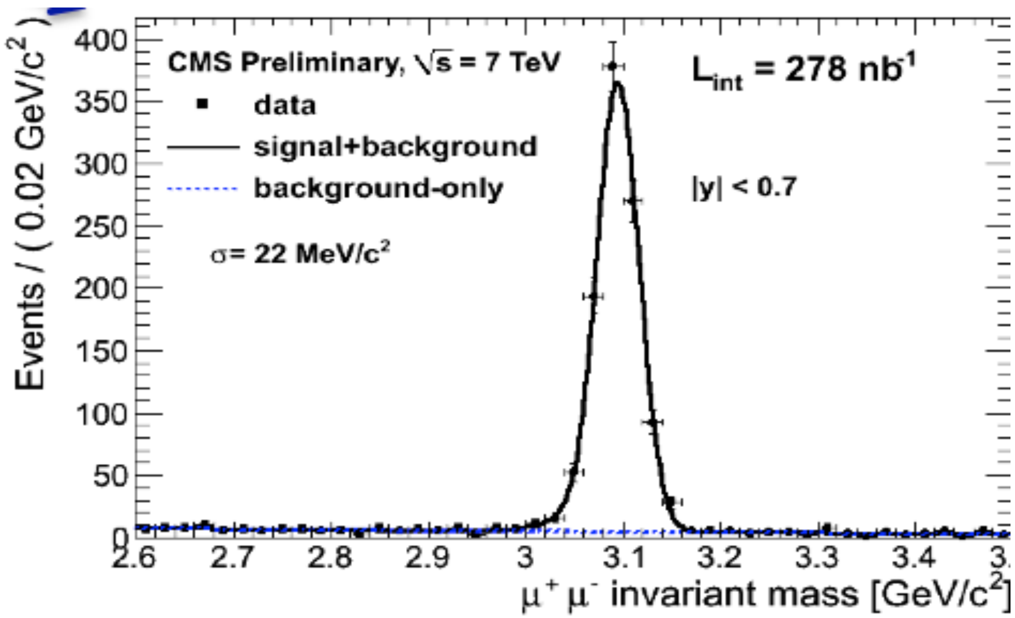
Also good for electrons!!

J/ψ → μμ and ee



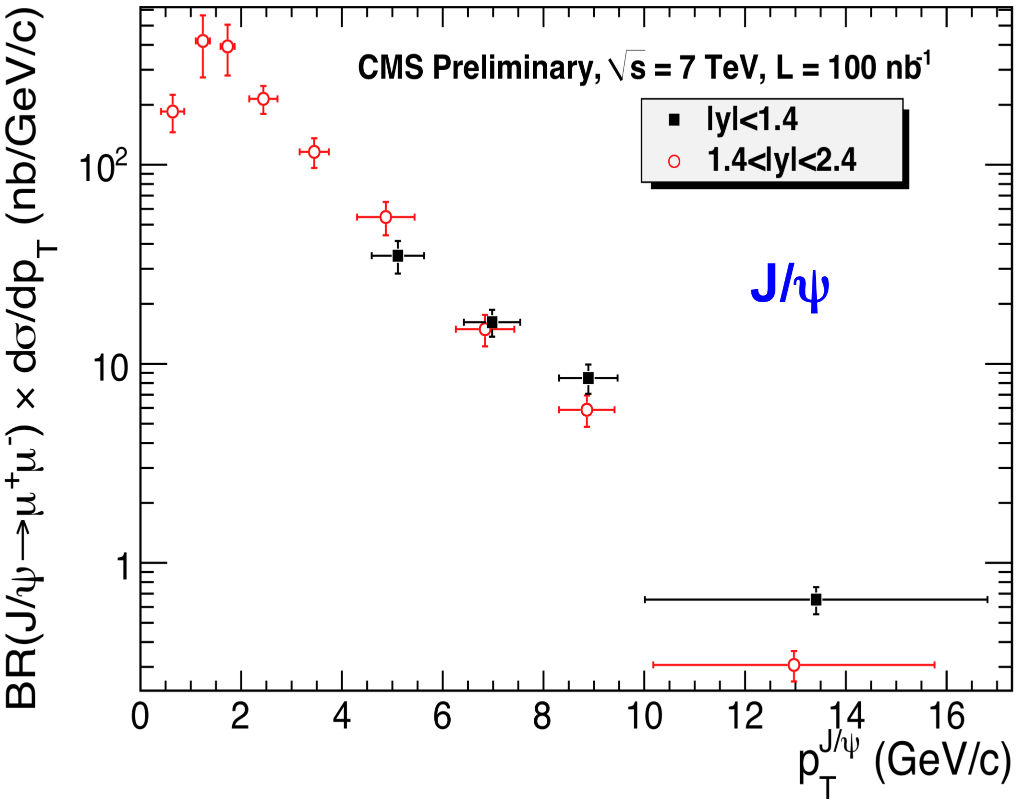


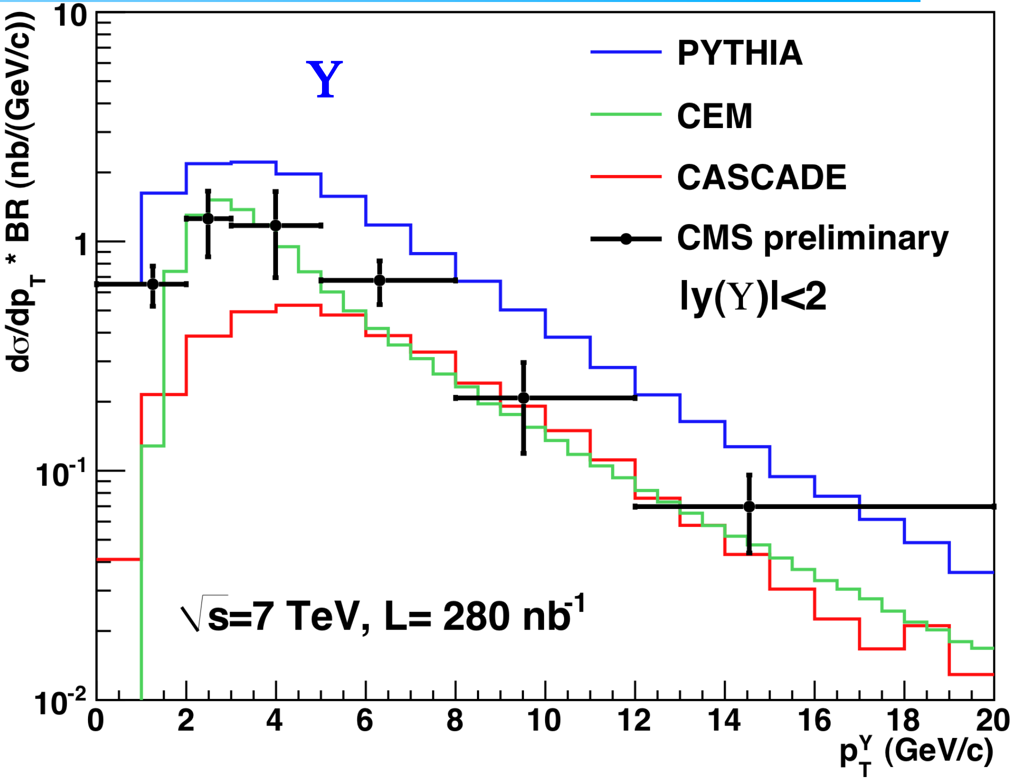
CMS Preliminary 2010
7 TeV data, ∫ L = 37 nb⁻¹
N_sig = 132 ± 14
M = 3.07 ± 0.013 GeV/c²
σ = 98 ± 12 MeV/c²
Events/0.1 GeV/c²
m_ee[GeV/c²]



CMS Preliminary, √s = 7 TeV
data
signal+background
background-only
σ= 22 MeV/c²
L_int = 278 nb⁻¹
|y| < 0.7
Events / (0.02 GeV/c²)
μ⁺ μ⁻ invariant mass [GeV/c²]

$J/\psi(\Upsilon)\rightarrow\mu^+\mu^-$ Differential/Total Cross Section





Differential cross sections as a function of p_T (in the null polarization scenario).

The total cross sections are: (p_T between 4-30 GeV and $|\eta|<2.4$)

$\sigma(pp\rightarrow J/\psi + X)\cdot BR(J/\psi\rightarrow\mu^+\mu^-) = (289.1 \pm 16.7(stat) \pm 60.1(syst))$ nb

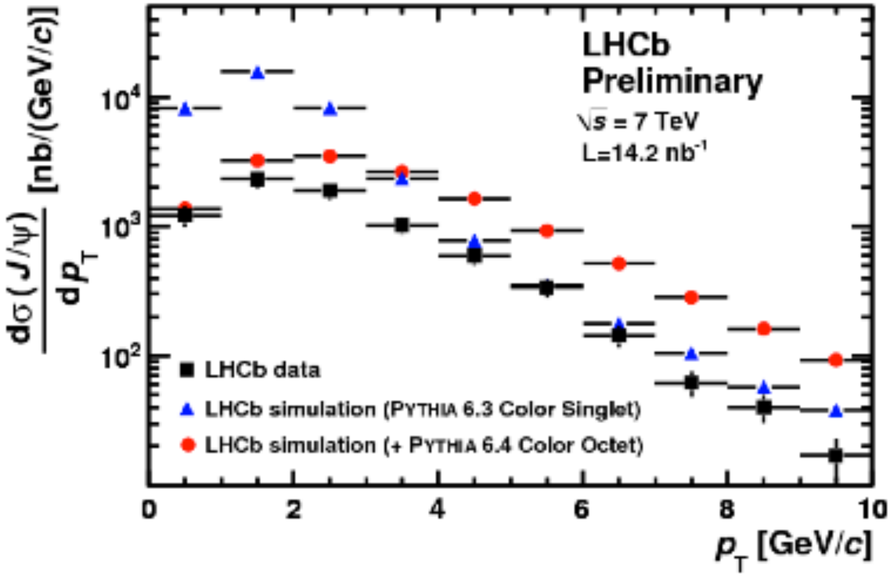
and ($|\eta|<2.0$)

$\sigma(pp \rightarrow \Upsilon(1S)+X)\cdot B(\Upsilon(1S)\rightarrow\mu^+ \mu^-)=(8.3\pm0.5(stat)\pm0.9(syst) \pm1.0(lum))$nb

The systematic uncertainties are dominated by the statistical precision of the muon efficiency determination from data and by the uncertainty on the luminosity.

$J/\psi \rightarrow \mu^+\mu^-$ Differential/Total Cross Section

- Preliminary cross section measurement with ~14 nb^{-1} (ICHEP):



- Scale and shapes not well described by colour singlet nor by octet models→ new studies are coming.

- Inclusive J/ψ production:

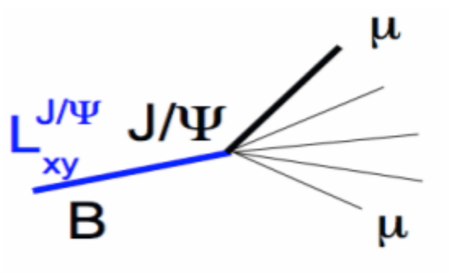
  $(2.5<y<4, p_T<10\ \mathrm{GeV}/c) = 7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27}$ b

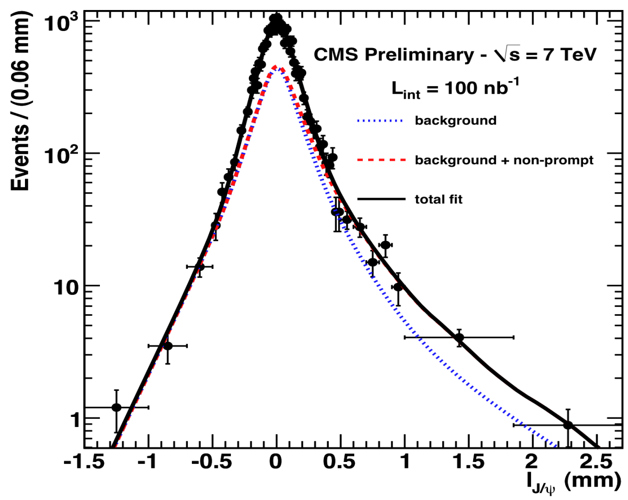
- J/ψ production from b: polarization uncertainty

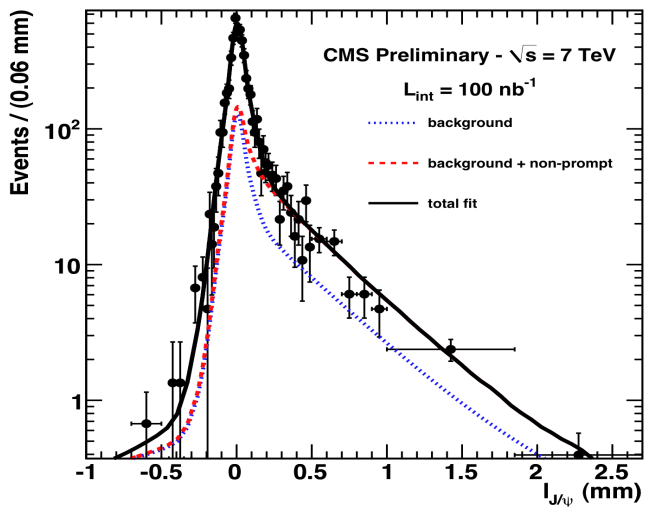
  $(2.5<y<4, p_T<10\ \mathrm{GeV}/c) = 0.81 \pm 0.06 \pm 0.13$ b

Fraction of J/ψ→μ+μ- from B Hadron decays

Traditional approach: the B transverse decay length used to separate the prompt from the non-prompt component





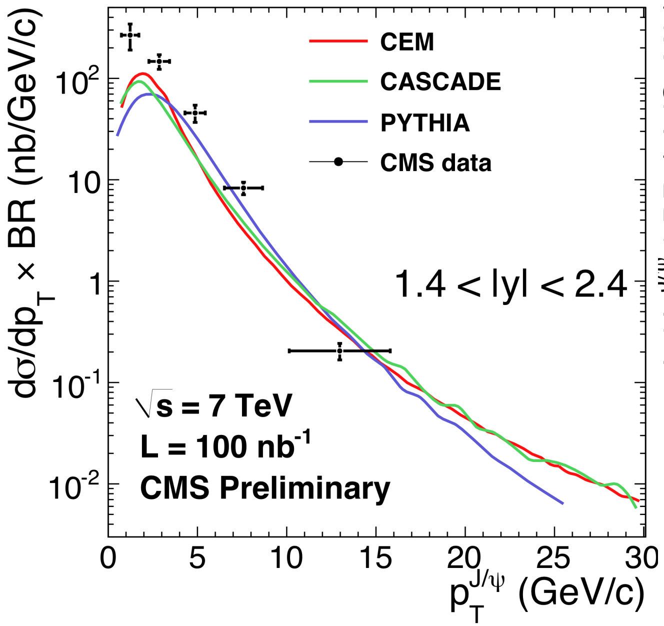


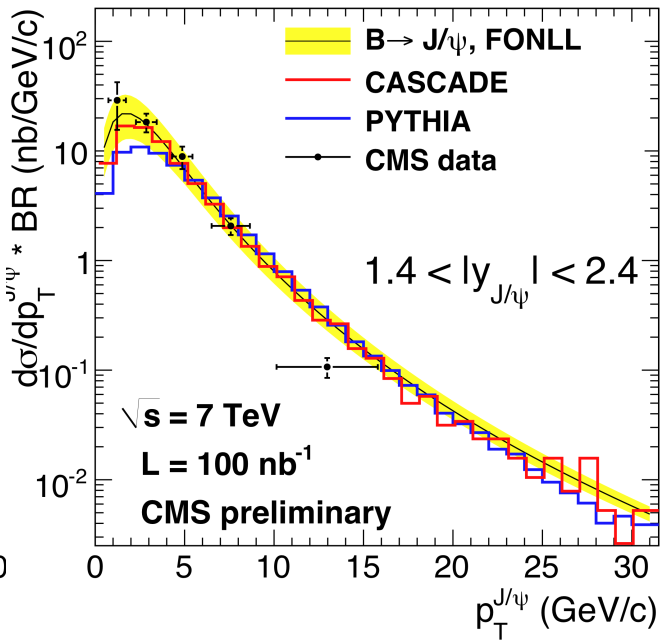
and to measure the prompt (non-prompt) differential cross section.

Non prompt cross section:

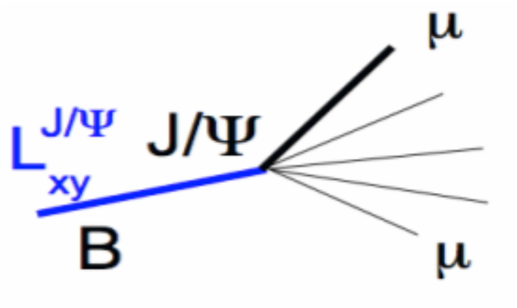
BR(J/ψ→μ+μ−)· σ(pp→bX→ J/ψ+X') = (56.1 ± 5.5(stat) ± 7.2(syst))nb

(p_T>4GeV/c and |y| <2.4)





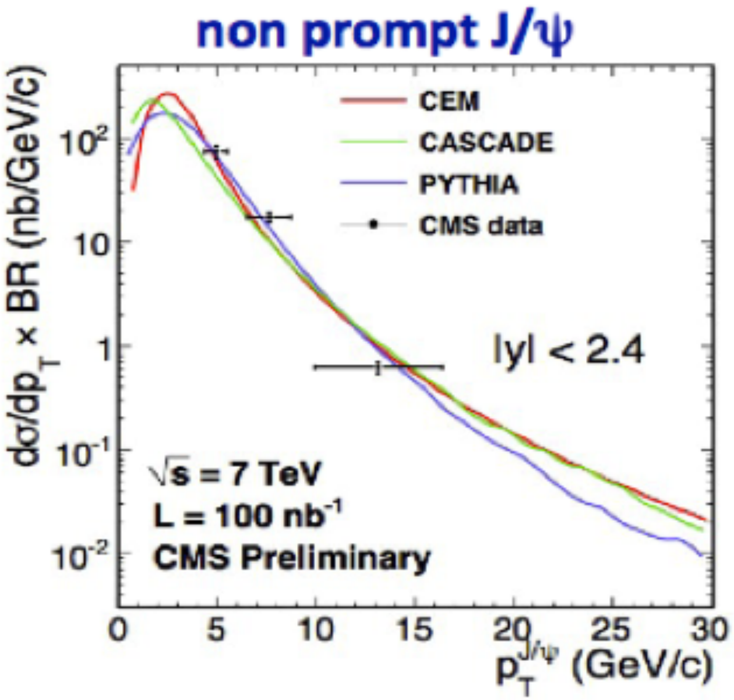
J/ψ from B-hadrons

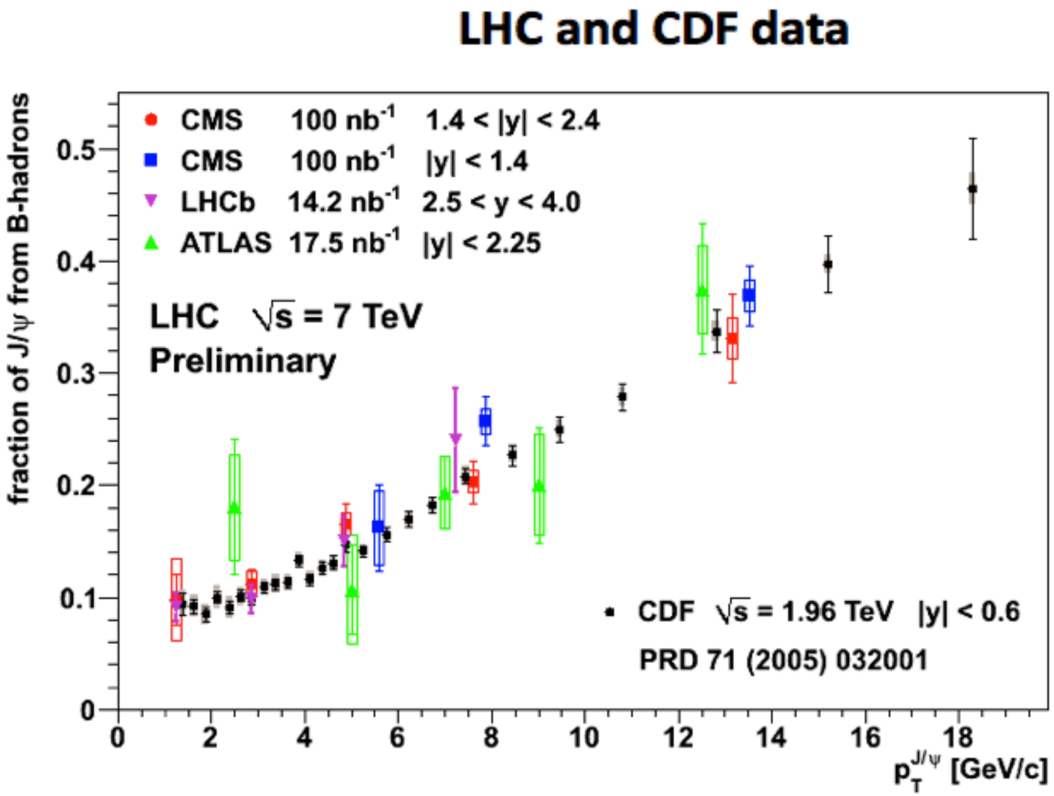


Non prompt J/ψ :

σ_{NP}* BR= **56.1±5.5(stat)±7.2(syst) nb**

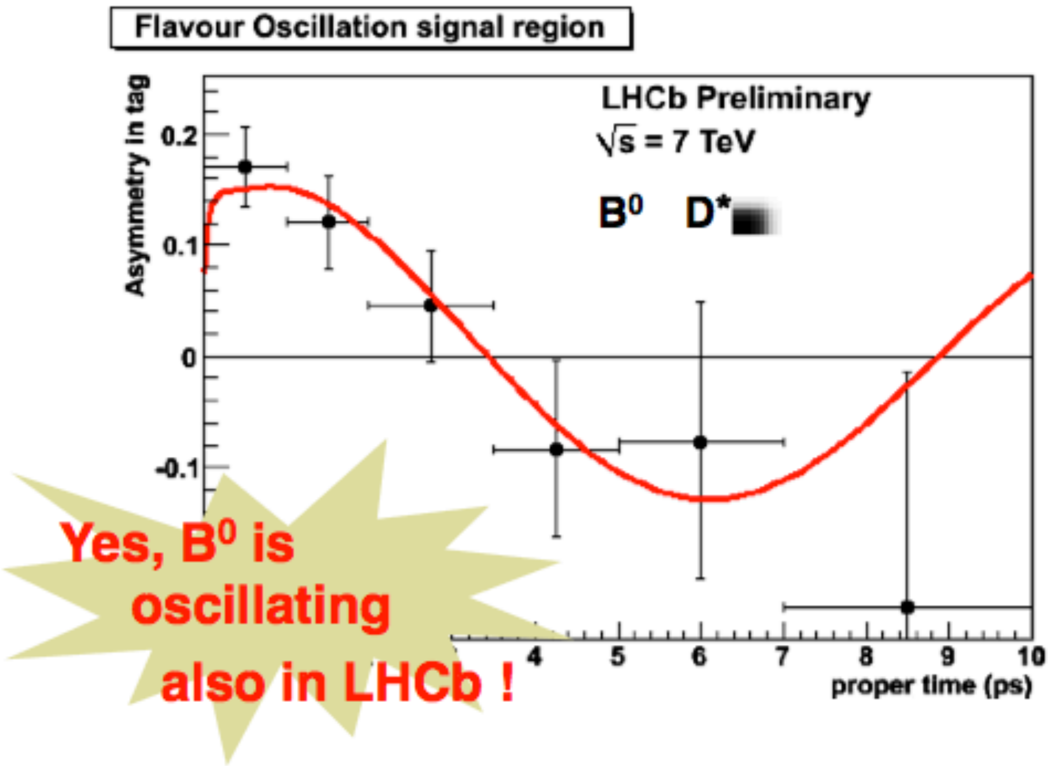
(p_T within 4-30GeV/c, |η|<2.4)

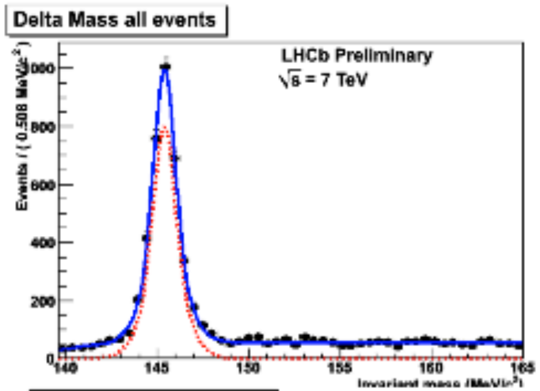


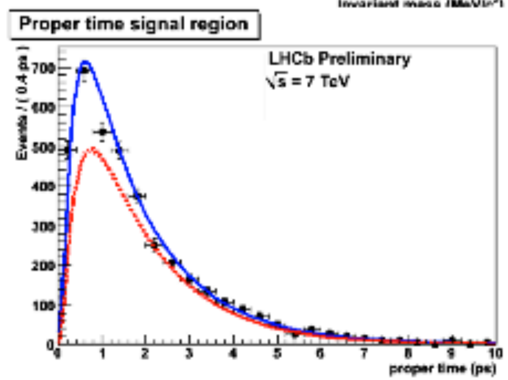


B-oscillations

- First signal of flavour oscillation from B^0_d D* (D^0) + events .







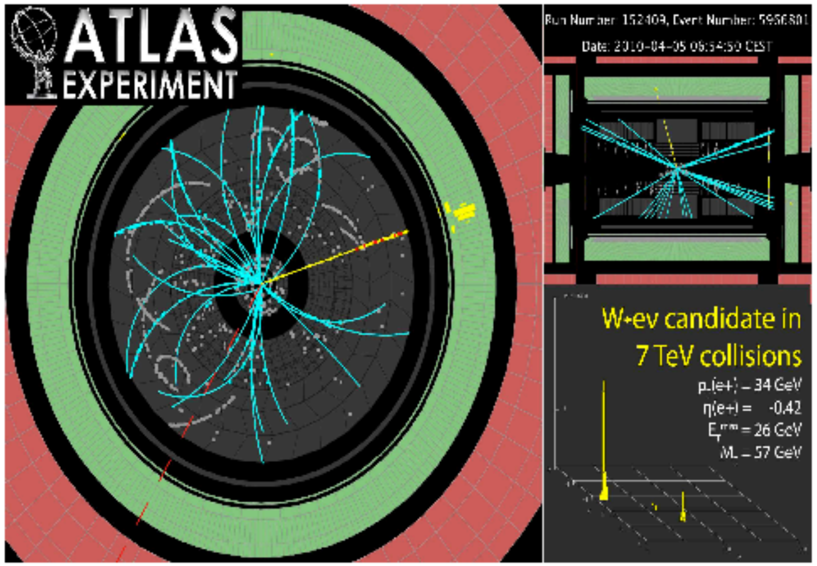
- “Out of the box” un-calibrated tagging performance (algorythm tuning, tagger combination etc..) already at 60% of expected performance.

Production of Heavy Bosons: W

W particle : ~ 90 times proton mass   Discovered in '83 at CERN

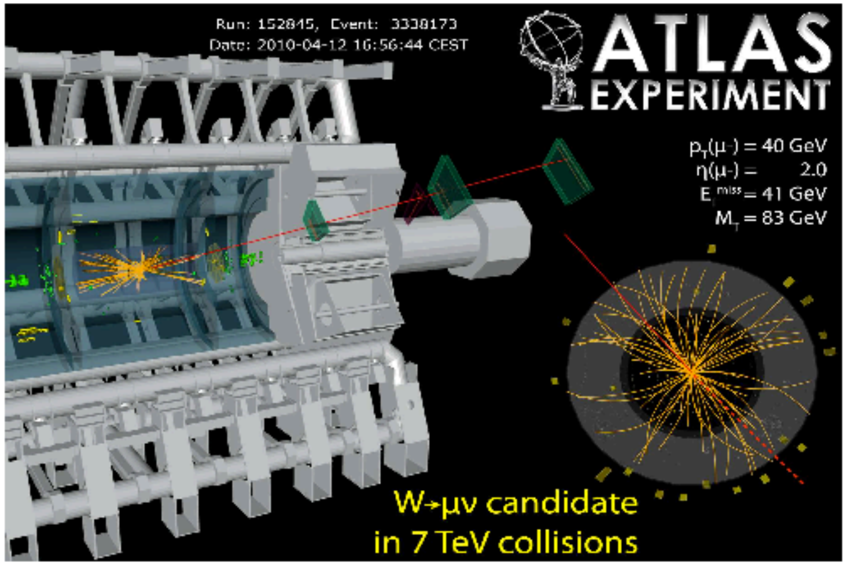
- **Fundamental milestone in the rediscovery of the Standard Model**
  - W powerfull tool to constraints the PDF
  - Among dominant source for New physics and top (W+4 jets)
  - High statistics sources of pure high pT leptons

  ➔ EM calo calibration (E/p), Muon Spectrometer aligment / Toroidal field mapping



W-> eν

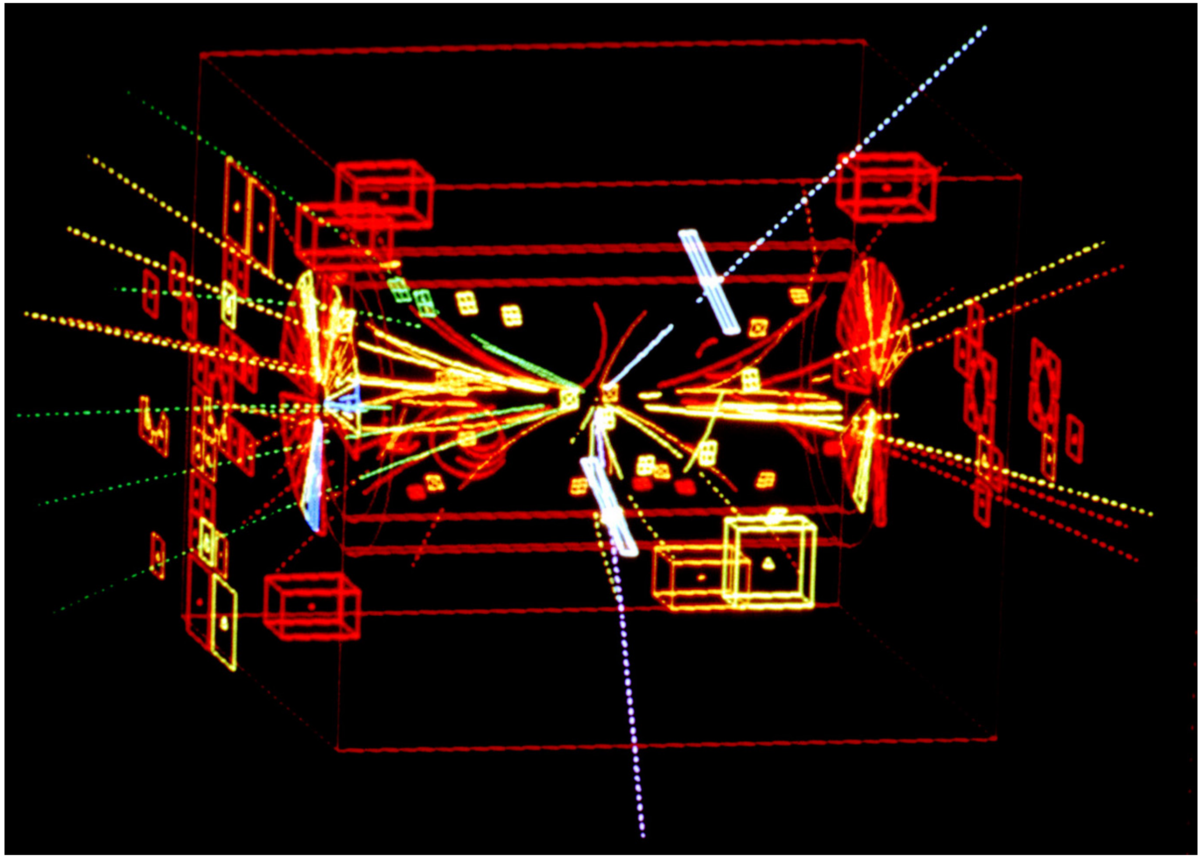
Very clean signatures !



W-> μν

Proton –(anti) Proton Colliders
Discoveries are possible

Discovery of the Z and W bosons in UA1/UA2 (1983)



'Picture' of the first

$p\bar{p} \rightarrow Z + X$
$\rightarrow e^+e^- + X$

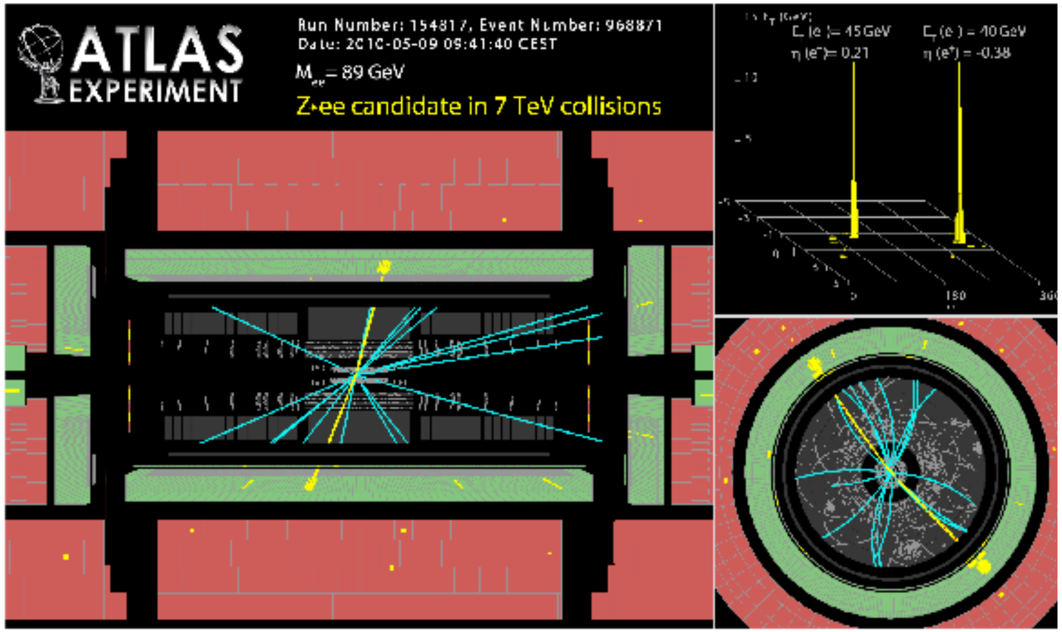
event in the UA1 detector at the $Sp\bar{p}S$, for a centre of mass energy ($\sqrt{s}$) = 630 GeV

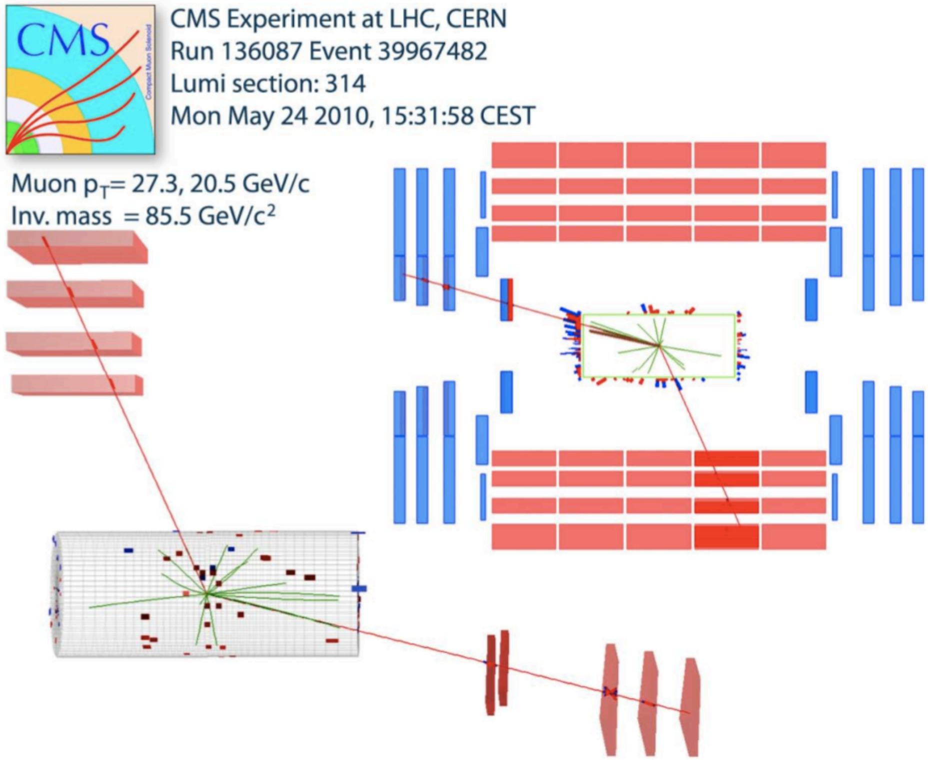
(30/4/1983)

Success story of the $Sp\bar{p}S$ machine at CERN rebuilt from a fixed target machine to a collider

Production of heavy bosons: Z

Z particle : ~ 100 times proton mass   Discovered in '83 at CERN



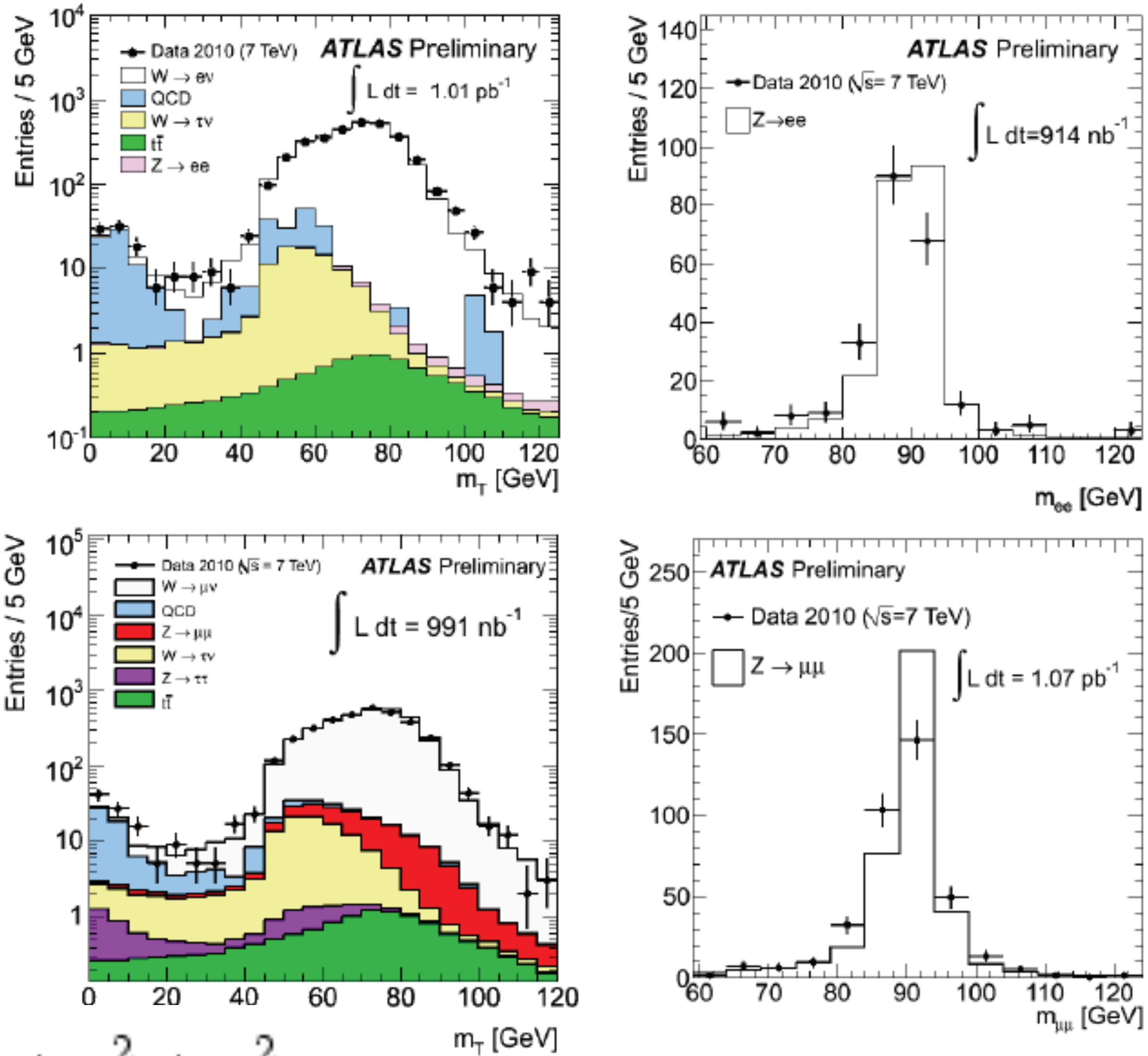


Z→μμ

ATLAS W/Z Studies

electron channel

muon channel



$$m_T^2 = m^2 + p_x^2 + p_y^2$$

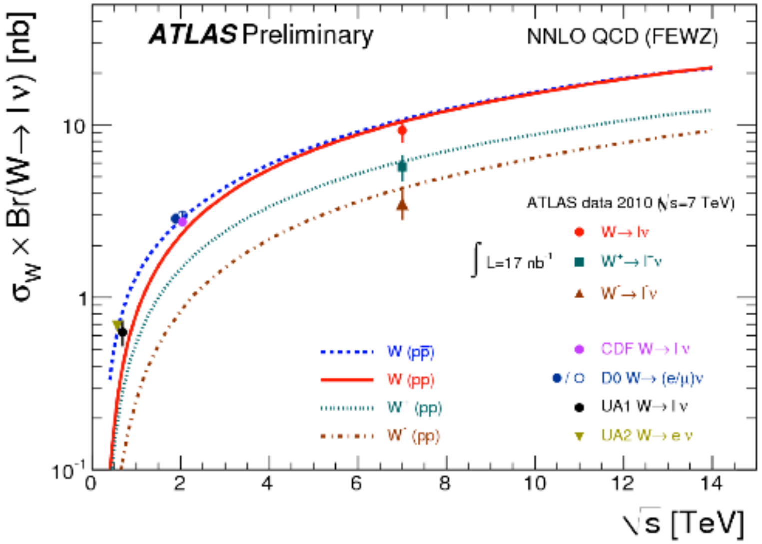
W Cross Section

❑ Total cross-section measurement at L_{int}=17 nb^{-1}: 46 (72) W→eν(μν)

- MC geometrical and kinematic acceptance: A_W~ 47±1.5%
- Systematics on reconstruction efficiency (C_W):

$$\sigma(W \to l\nu) = \frac{N_W^{sig}}{A_W C_W L_{\text{int}}}$$

Uncertainty	Electron	Muon
Trigger	<0.5%	4%
Material effect	4%	--
Identification	6%	4%
E Scale+Resolution	2%	4%
E_T^{miss} Scale+Resolution	2%	2%
Total	8%	7%
C_W	(65.6±5.3)%	(81.4±5.6)%



σ (W → lν) = 9.3 ± 0.9 (stat) ± 0.6 (syst) ± 1.0 (lumi) nb

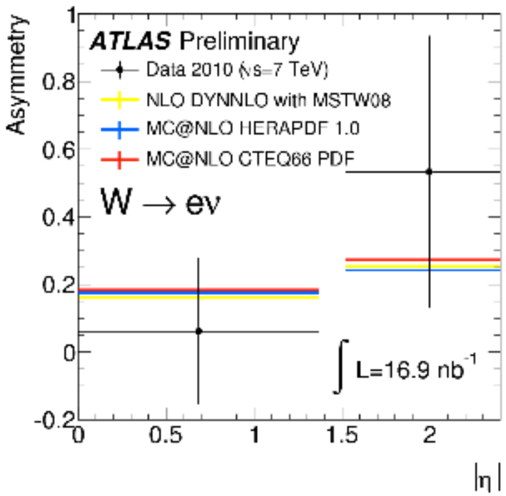
- Compatible with Standard Model expectations (10.5±0.4 nb)
- Combined measurement dominated by luminosity systematics at 17 nb^{-1} !

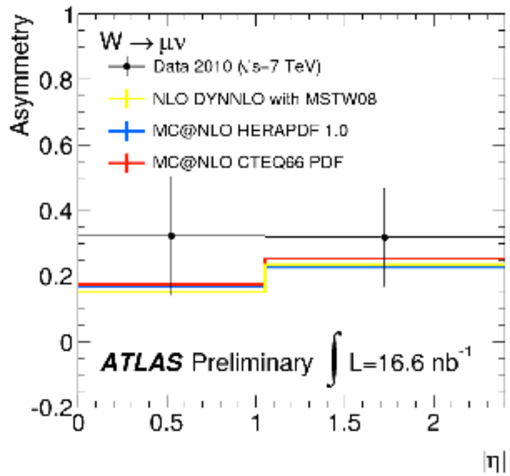
W Production Asymmetry

- **Asymmetry (A) → Measured the difference in W+/W- production**
  - Most systematics cancel in the ratio
  - Sensitive to valence quark distributions ($x \sim 10^{-3}$-10^{-1}) → A vs η to distinguish between PDF

$$A = \frac{\sigma(W \to \ell^{+}\nu) - \sigma(W \to \ell^{-}\nu)}{\sigma(W \to \ell^{+}\nu) + \sigma(W \to \ell^{-}\nu)} \neq 0$$

A (W→ eν) = 0.21 ± 0.18 (stat) ± 0.01 (syst)
A (W→ μν) = 0.33 ± 0.12 (stat) ± 0.01 (syst)
NNLO theory prediction: A~0.2





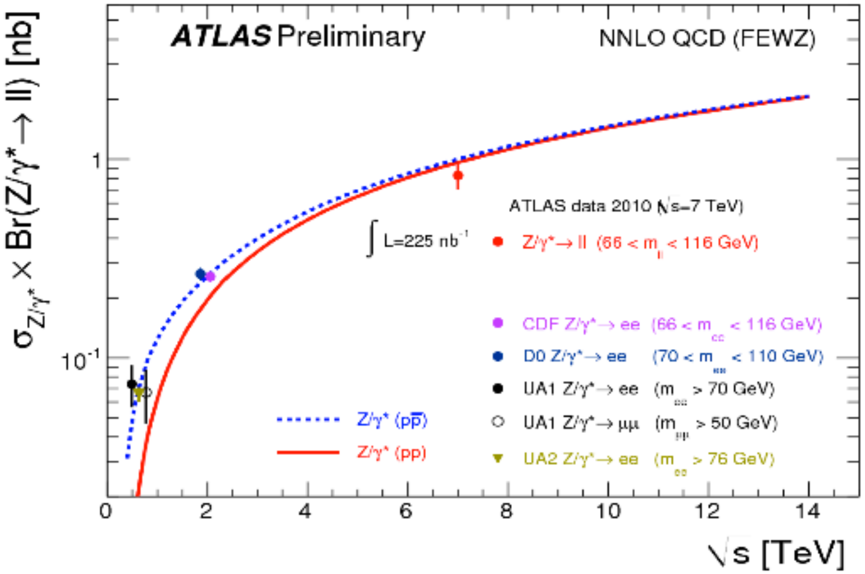
Statistically limited up to few pb^{-1}

Z Cross Section

- **Total cross-section measurement at L_{int}~225 nb^{-1}: 46 (79) Z→ee(μμ)**
  - MC geometrical and kinematic acceptance: A_Z~ 46.5±1.4%
  - Systematics on reconstruction efficiency (C_Z):

$$\sigma(Z/\gamma^* \rightarrow ll) = \frac{N_Z^{sig}}{A_Z C_Z L_{int}}$$

Uncertainty	Electron	Muon
Trigger	<0.5%	2%
Identification	10%	7%
Material effect	8%	--
E Scale+Resolution	2%	1%
Pile-up	2%	--
Total	14%	7%
C_Z	(64.5±9.0)%	(79.7±5.3)%



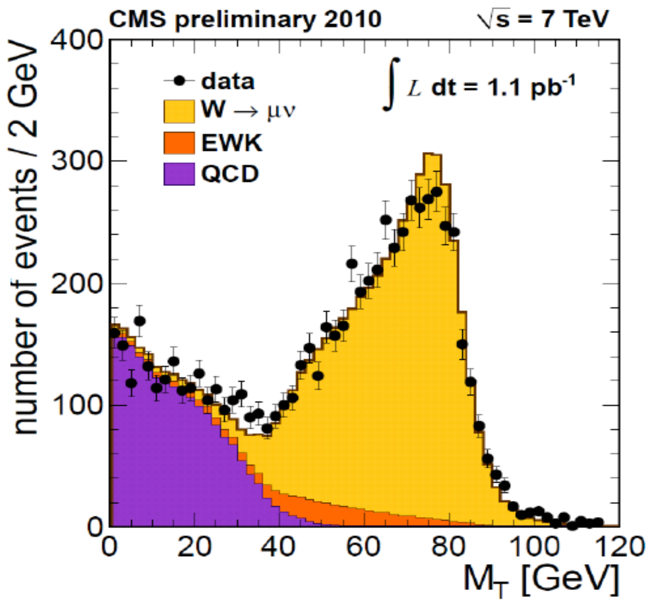
σ (Z/γ* → ll) = 0.83 ± 0.07 (stat) ± 0.06 (syst) ± 0.09 (lumi) nb
- Compatible with Standard Model expectations (0.99±0.04 nb)
- Combined measurement dominated by luminosity systematics at 225 nb^{-1} !

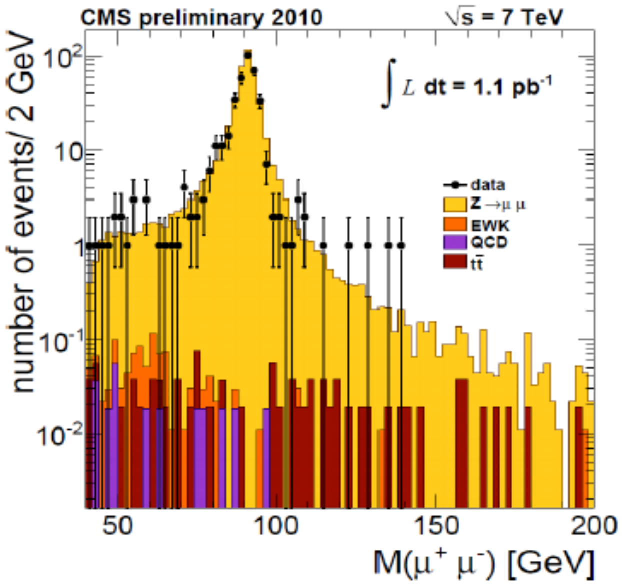
CMS: W/Z Production (muon channel)

- Kinematics
  - For W, $p_T > 9$ GeV, $|\eta| < 2.1$
  - For Z, $p_T > 20$ GeV, one $|\eta| < 2.4$
- Good quality muon track
  - Hits in pixels, strip tracker, muon system)
  - χ^2/dof < 10
- Z measurement requires only track isolation of 3 GeV in a cone
- For W measurement, use a relative isolation in a cone of $\Delta R < 0.3$:

Source	W channel (%)	Z channel (%)
Muon reconstruction/identification	3.0	2.5
Trigger efficiency	3.2	0.7
Isolation efficiency	0.5	1.0
Muon momentum scale/resolution	1.0	0.5
$\not\!\!E_T$ scale/resolution	1.0	-
Background subtraction	3.5	-
PDF uncertainty in acceptance	2.0	2.0
Other theoretical uncertainties	1.4	1.6
TOTAL (without luminosity uncertainty)	6.3	3.8
Luminosity	11.0	11.0

Simultaneous fits to backgrounds and signal contributions.
QCD background shapes obtained using data.
EWK background shapes and signal from MC.





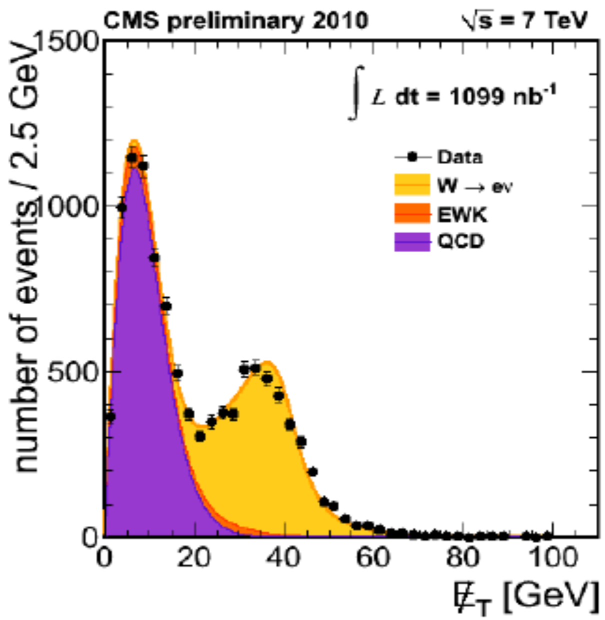
W/Z Production (electron channel)

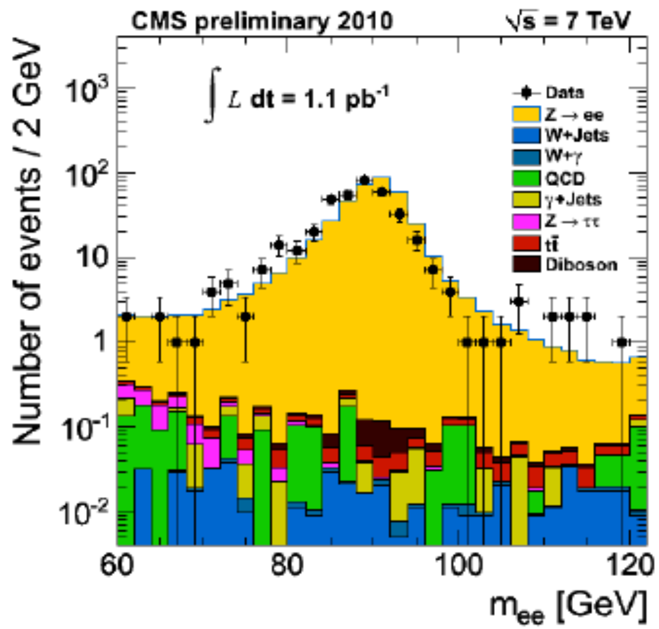
- Kinematics
  - $p_T > 20$ GeV
  - $0.0 < |\eta| < 1.442$
  - $1.566 < |\eta| < 2.5$
- Specialized track reconstruction to deal with potential large bremsstrahlung
- Electron identification requirements on shower shape variables
- Isolation requirements in tracker ECAL, HCAL

W: 75% efficiency
Z: 90% efficiency
QCD background shapes from data, EWK background and signal shapes from MC

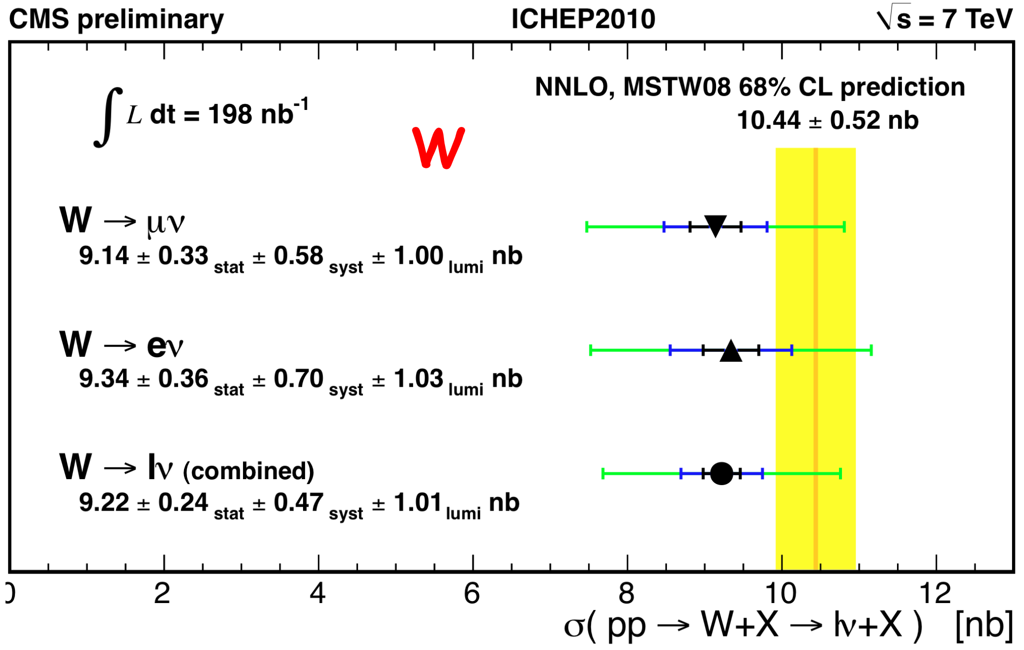
4530 W's
389 Z's

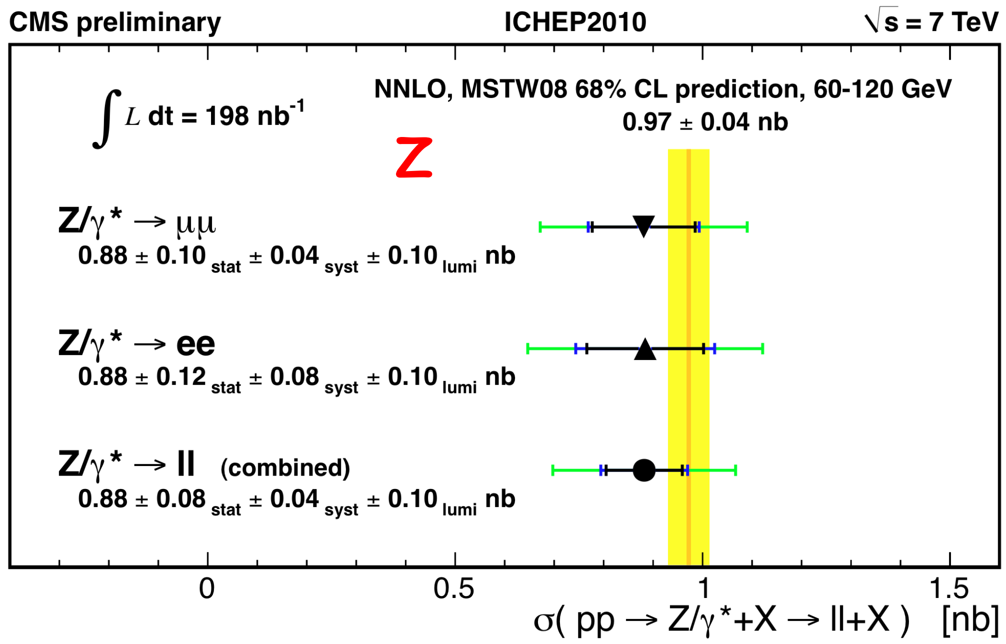
Source	W channel (%)	Z channel (%)
Electron reconstruction/identification	6.1	7.2
Trigger efficiency	0.6	-
Isolation efficiency	1.1	1.2
Electron momentum scale/resolution	2.7	-
$\not{E}_T$ scale/resolution	1.4	-
Background subtraction	2.2	-
PDF uncertainty in acceptance	2.0	2.0
Other theoretical uncertainties	1.3	1.3
TOTAL (without luminosity uncertainty)	7.7	7.7
Luminosity	11.0	11.0



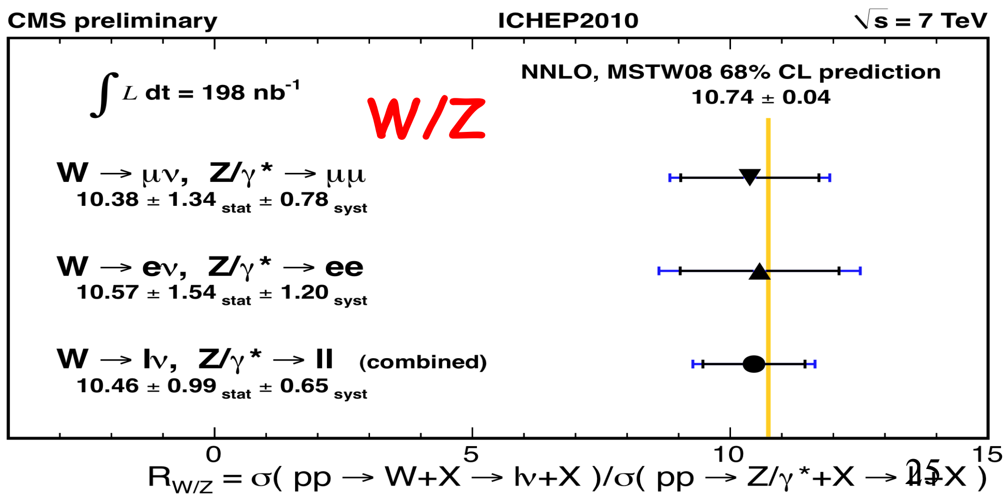


W/Z Production Cross Sections

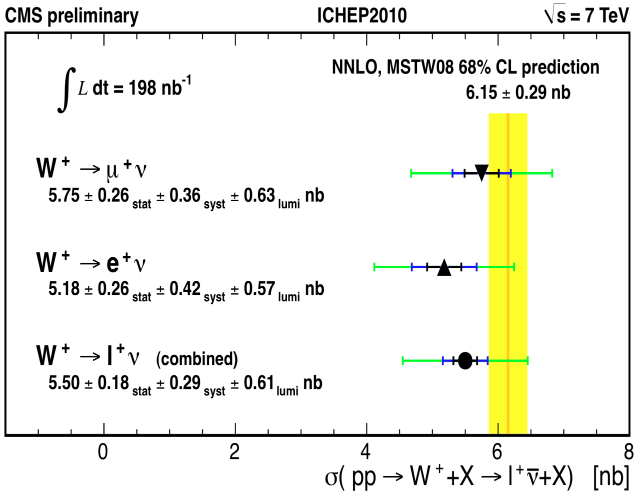


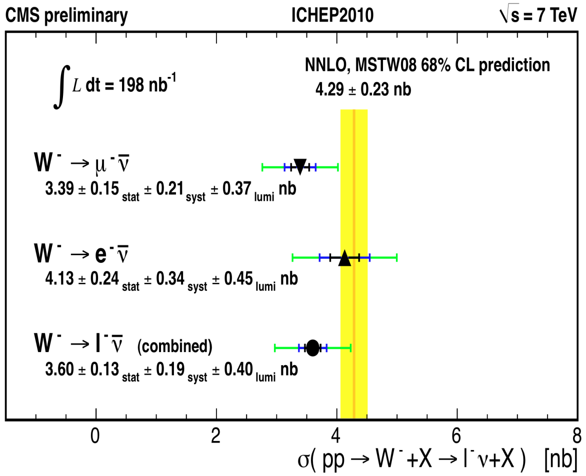


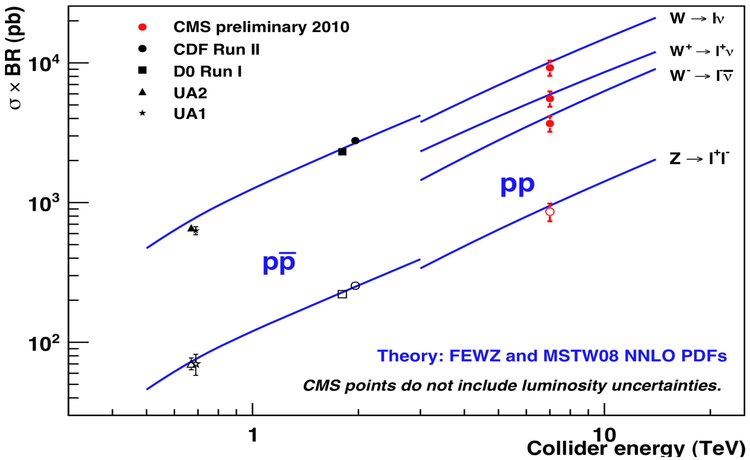
Note: ~all major components of the measurements (efficiency, background, systematic errors etc) are carefully evaluated using data driven methods.



Charge Asymmetry and W+jets

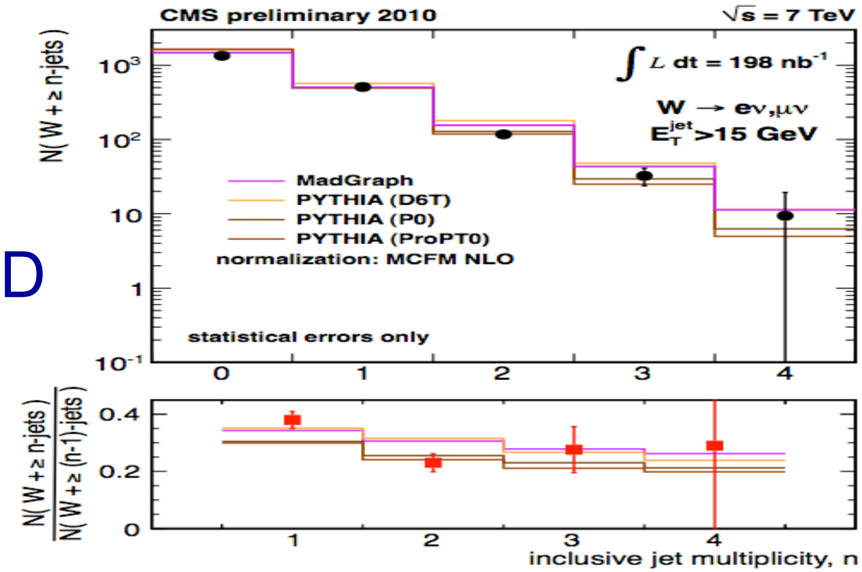






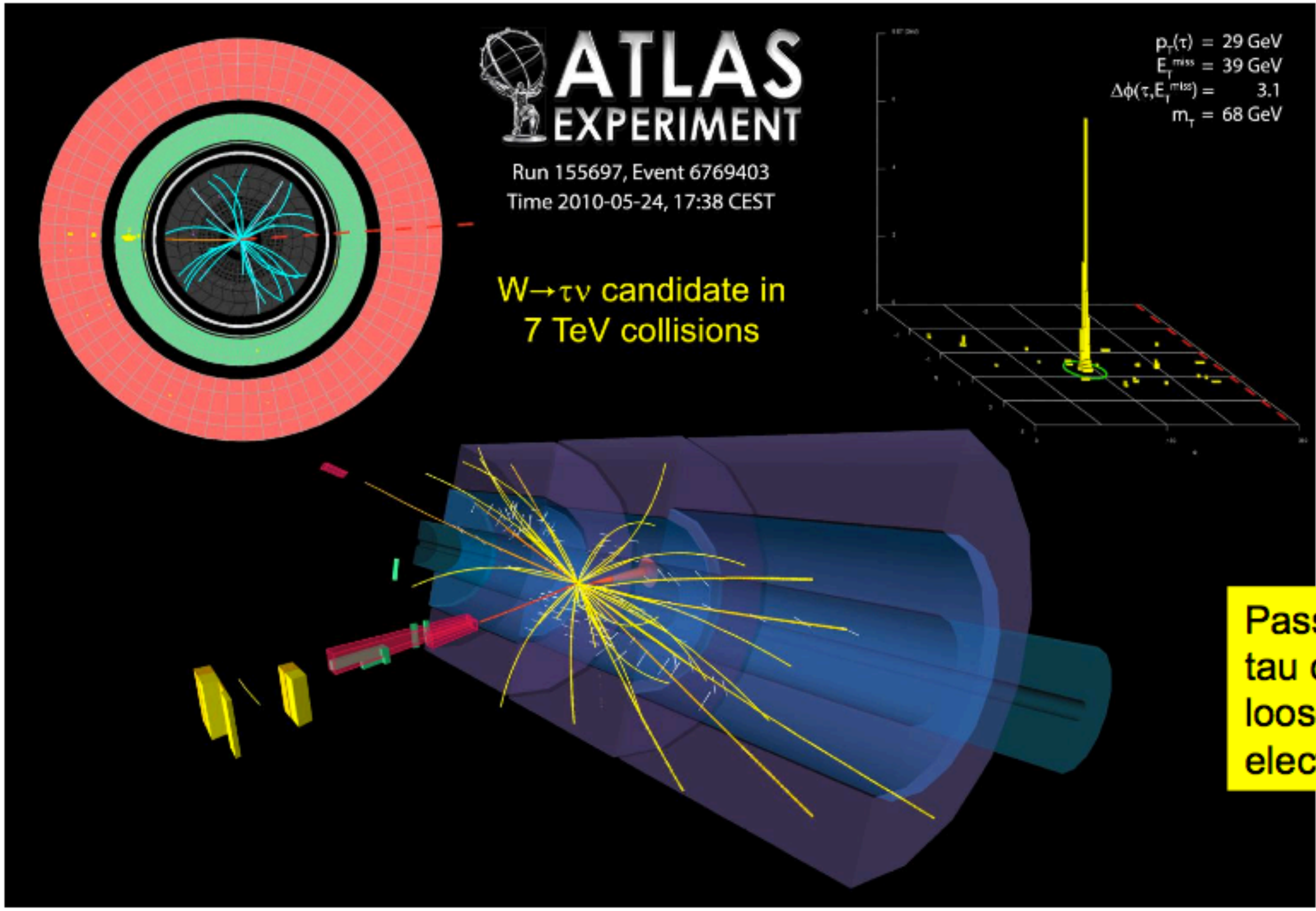
W+jets

Important for QCD



…And now we deploy everything for hunting the top

Heavy Bosons decaying to Taus

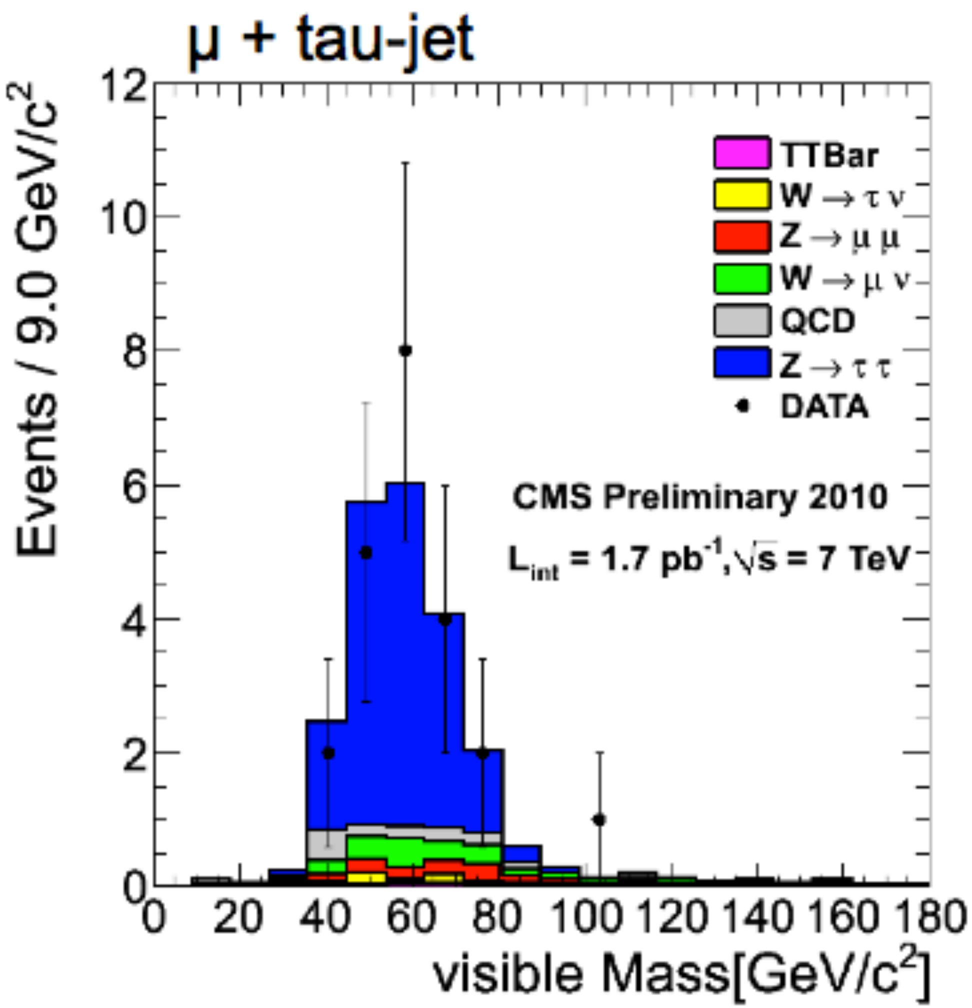


Passes tightest tau cuts; fails loosest electron cuts.

This channel has substantially more background, so it's more difficult to tell event-by-event if a given event is a real tau or background.

Heavy Bosons decaying to Taus

Z->тau тau



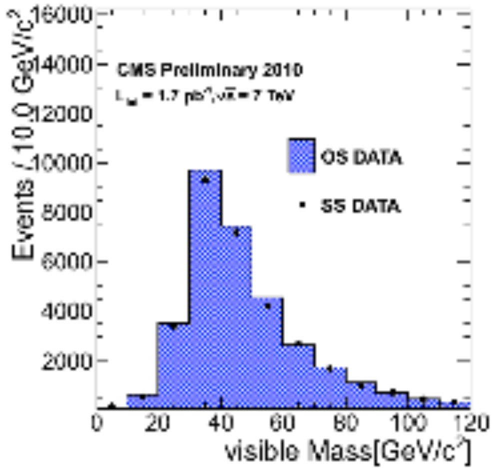
QCD Bkgr

Measured:

OS/SS = 1.03 +- 0.01(stat)

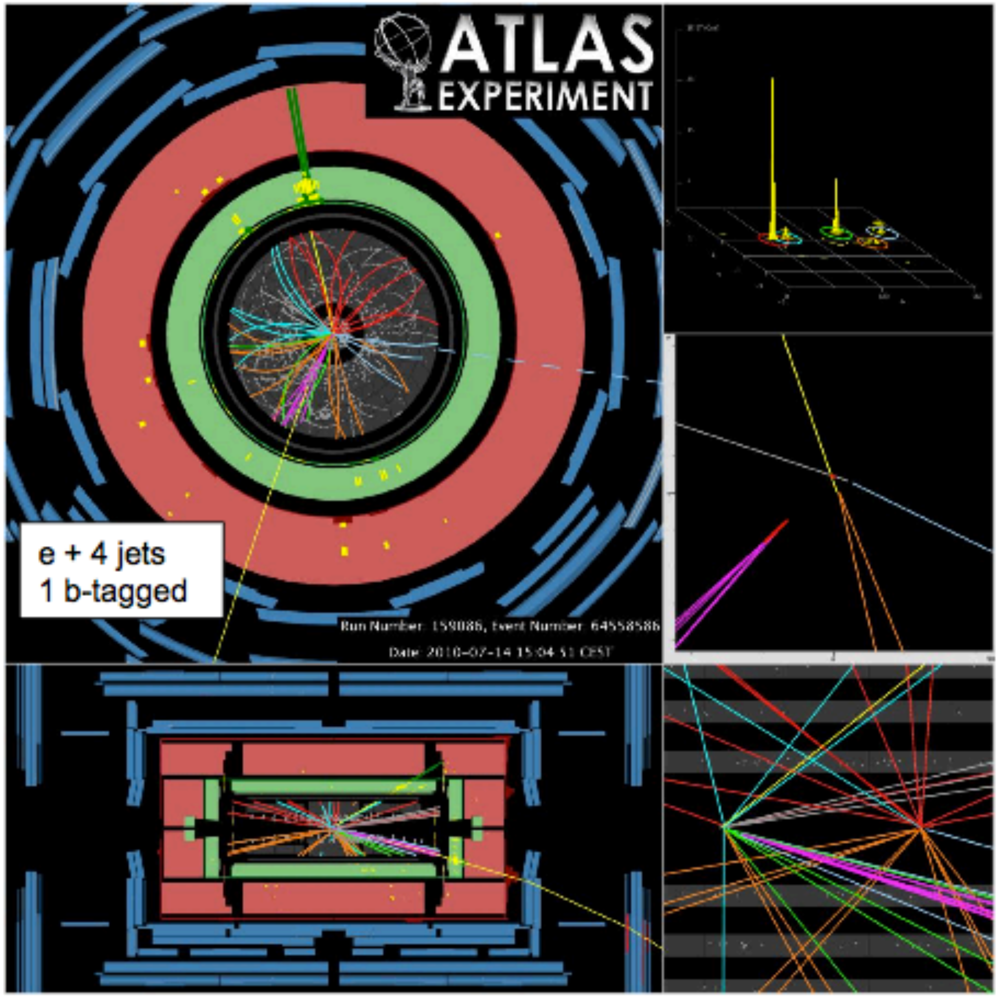
QCD MC expected value:

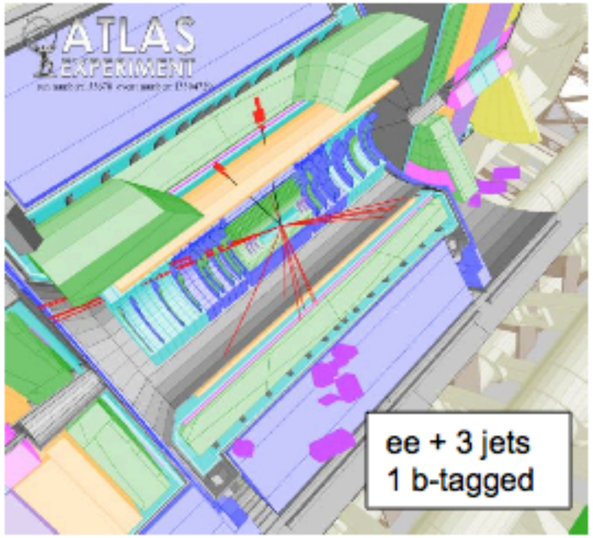
OS/LS = 1.036 +-0.002

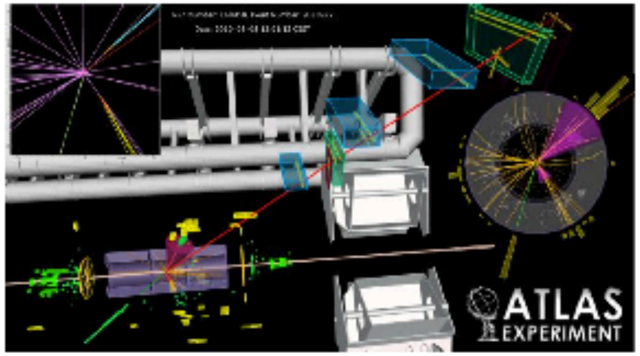


However, there is something more…

- Towards the end of May we started recording events like this





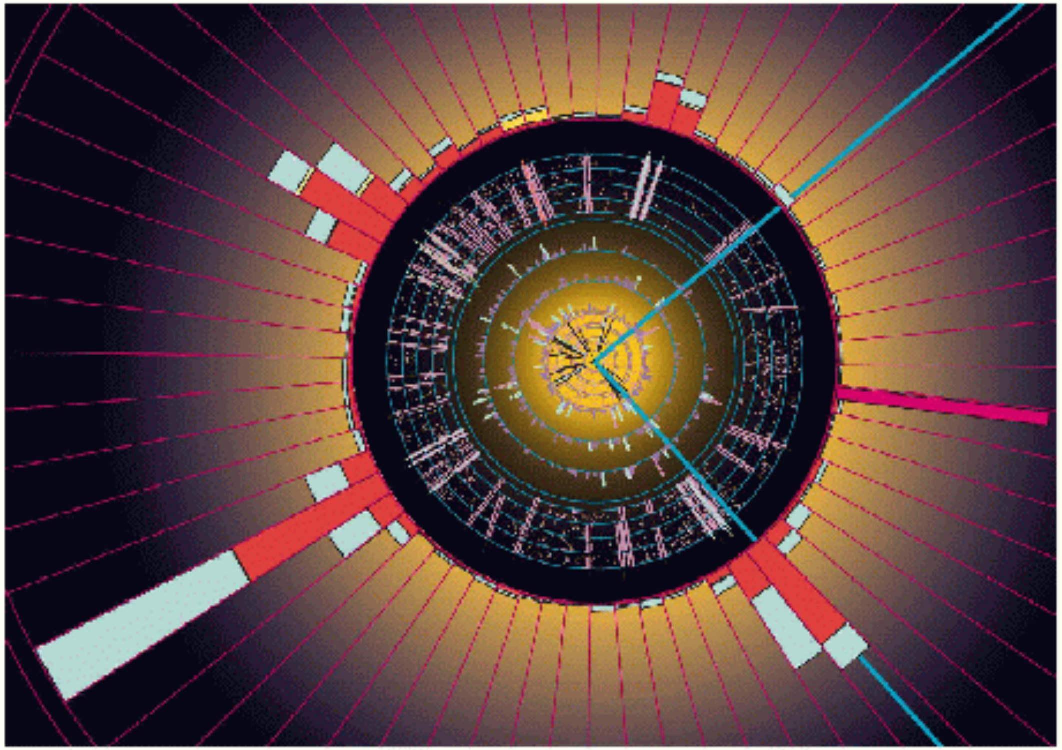


e + 3 jets
1 b-tagged

Discovery of the Top Quark

Recent Steps

The Last Quark

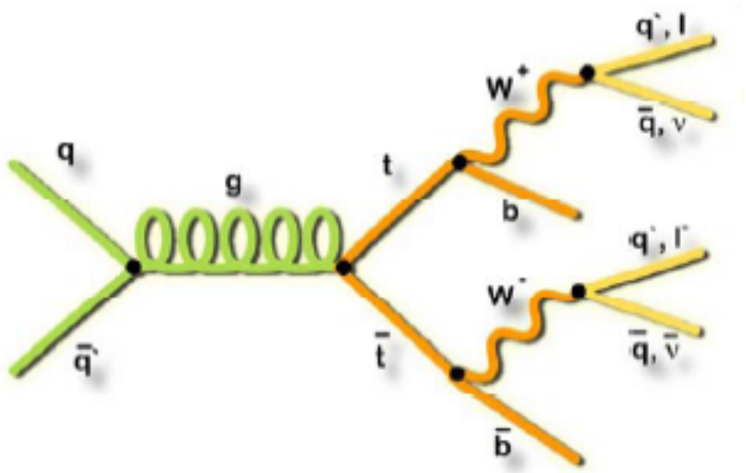


Top Quark discovered at Fermilab

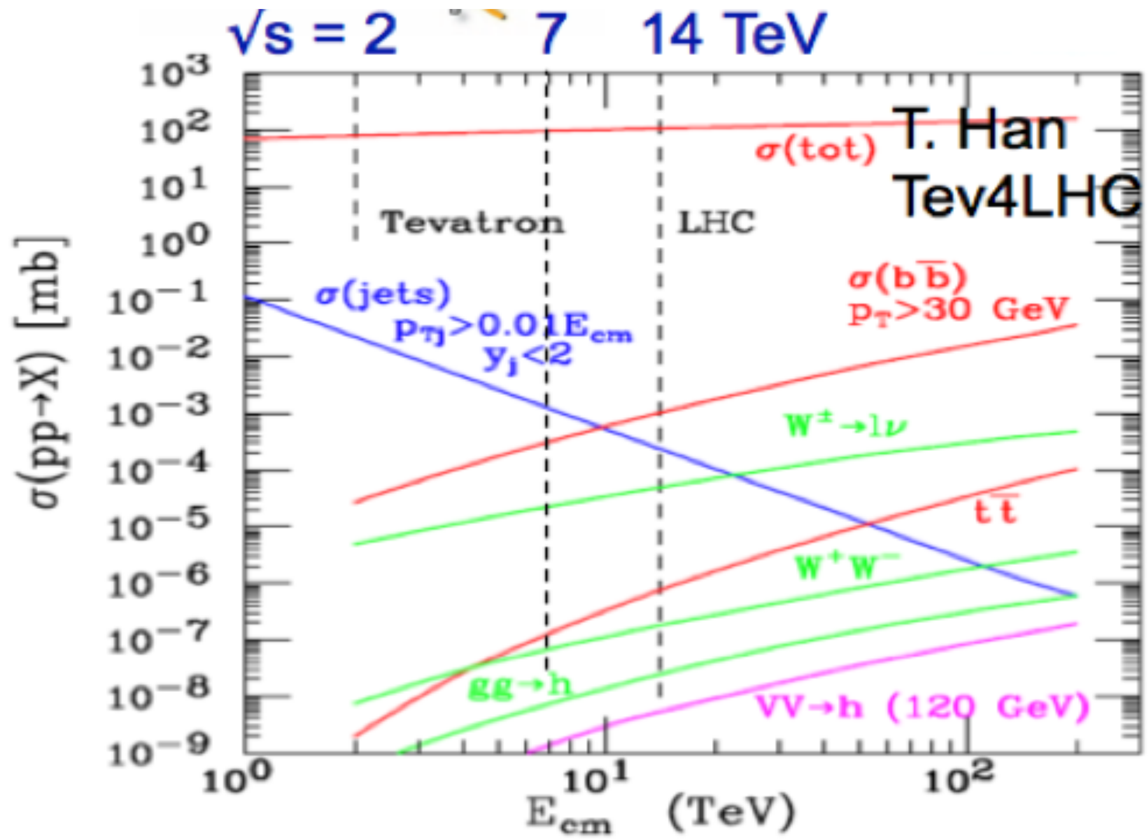
1995
Top mass
174 +/- 5 GeV

i.e. this quark
is as heavy as
a gold nucleus

Top Quarks at the LHC



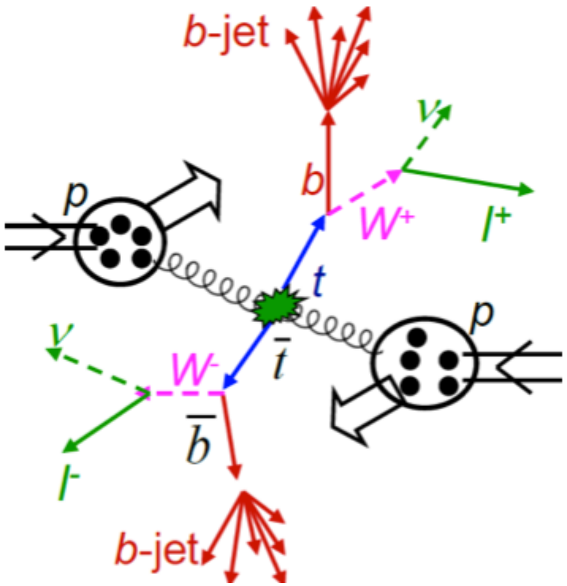
- Precise SM measurements
- A window to new physics
- In many new physics scenarios (e.g. SUSY) top is dominant BG
- Great tool to calibrate detector
  - Jet energy scale, b-jet eff.



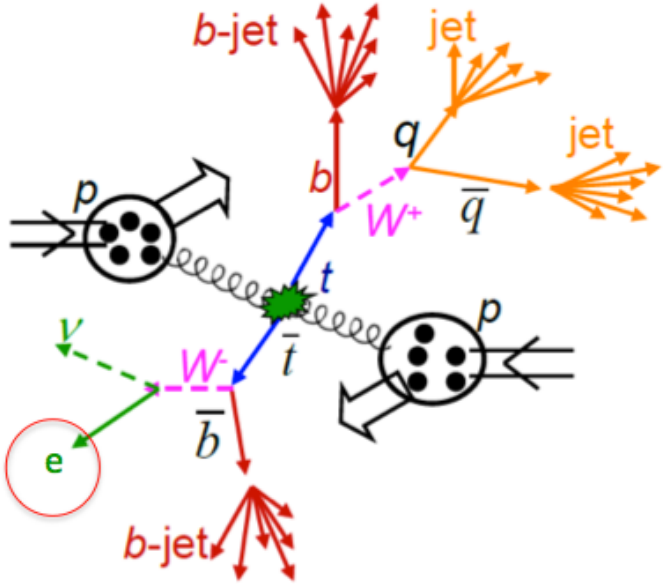
TOP is the gateway to New Physics…!!

Top Channels Studied so far

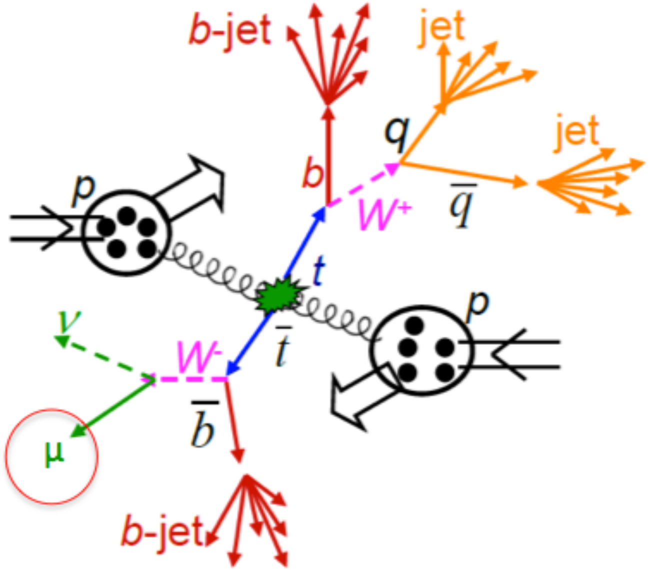
2 leptons + MET
2 (or more) jets



Electron + MET +
4 (or more) jets

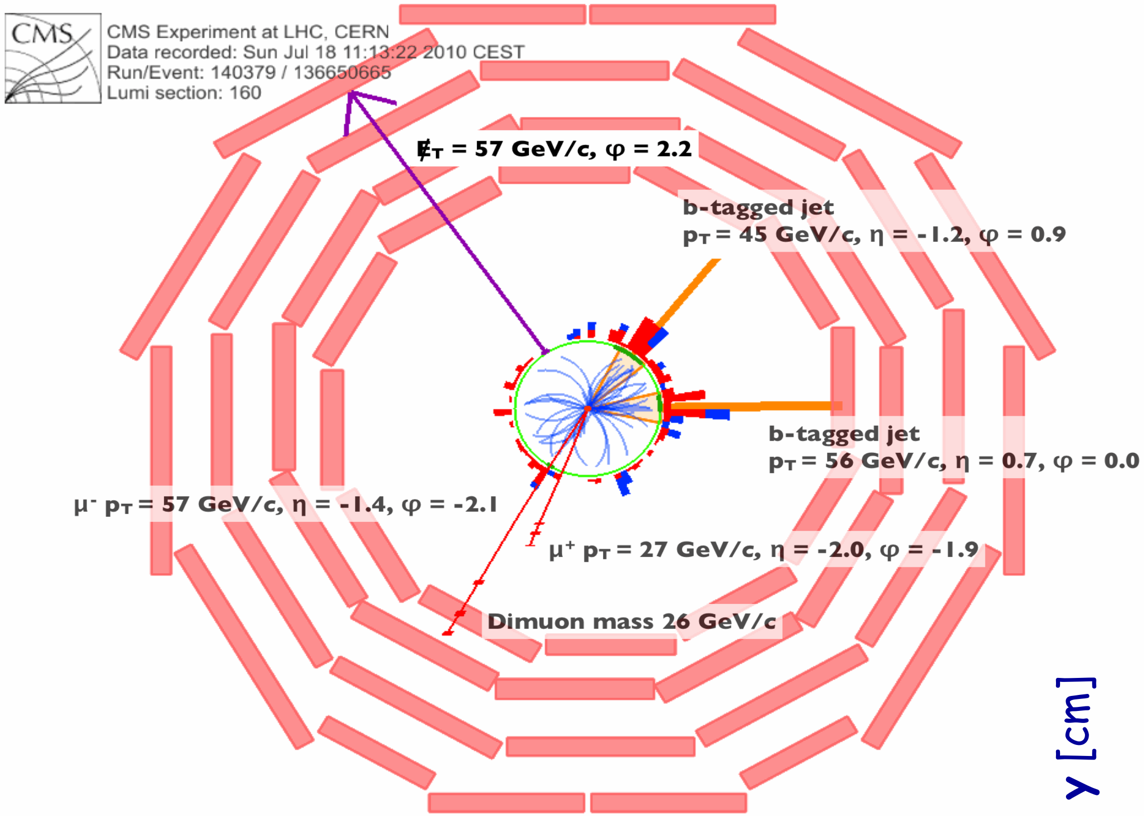


Muon + MET +
4 (or more) jets



Note: always 2 b-jets
MET = missing transverse energy

Top signals in CMS



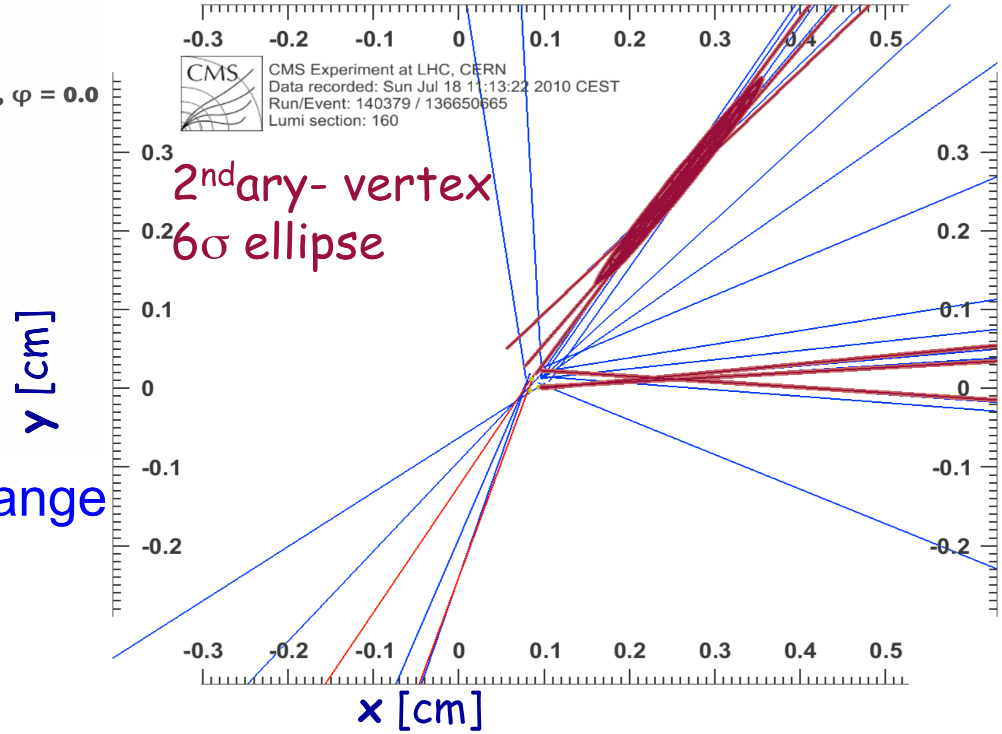
μμ +Jets candidate event.

2 muons with opposite charge

2 jets, both with good/clear b-tags

(and secondary vertices!)

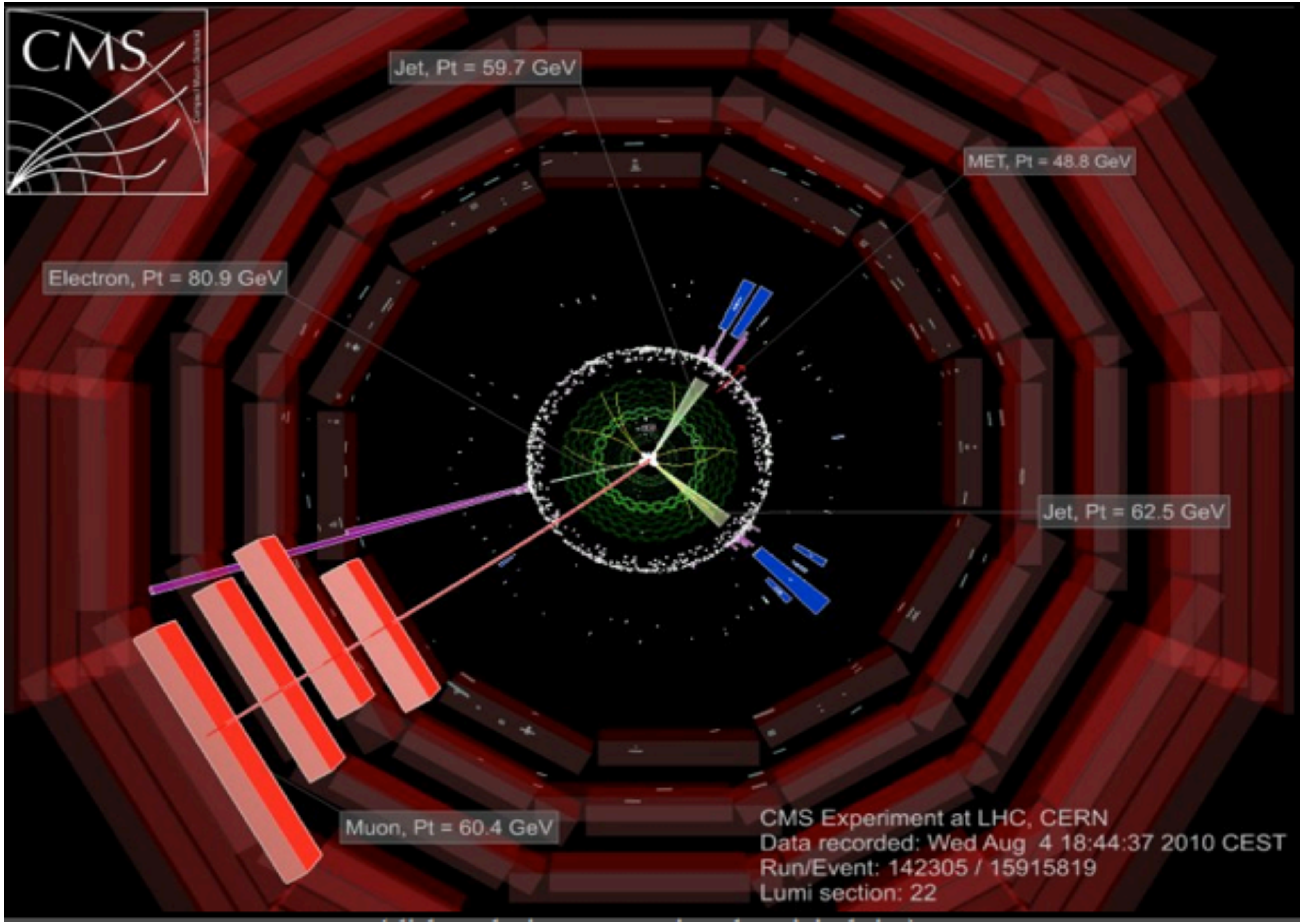
significant MET (>50 GeV)



Preliminarily reconstructed mass is in the range 160–220 GeV/c^2 (consistent with m_{top}).

0.84 pb^{-1} of data analyzed

Top candidate (muon+electron+ 2 jets)



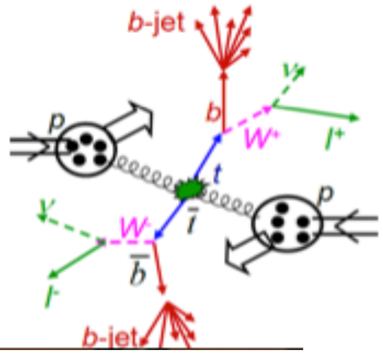
Top Selections

DILEPTON

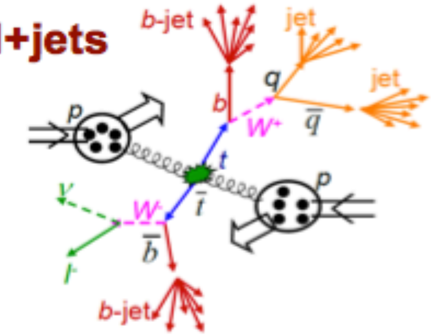
- Single lepton triggers
  - μ+X (Pt>9 GeV,) e+X (Pt>15 GeV)
- Two isolated, opposite charge leptons (ee,mumu,emu)
  - Pt>20 GeV, |eta|<2.5(mu),2.4(e)
  - Rel. isolation < 0.15

$$\text{Rel.isol.} = \frac{\sum_{R<0.3} p_T^{\text{track}} + \sum_{R<0.3} p_T^{\text{ECAL}} + \sum_{R<0.3} p_T^{\text{HCAL}}}{p_T(\text{lepton})}$$

- Z-boson veto
  - |M(ll)-M(Z)|>15 GeV
- Missing Et (MET)
  - Using calorimeter & tracking
  - MET>30(20) GeV in ee,mumu (emu)
- Jets
  - Anti-Kt (R=0.5)
  - Using calorimeter & tracking
  - Pt>30 GeV, |eta|<2.4
  - Expect >=2 jets for ttbar



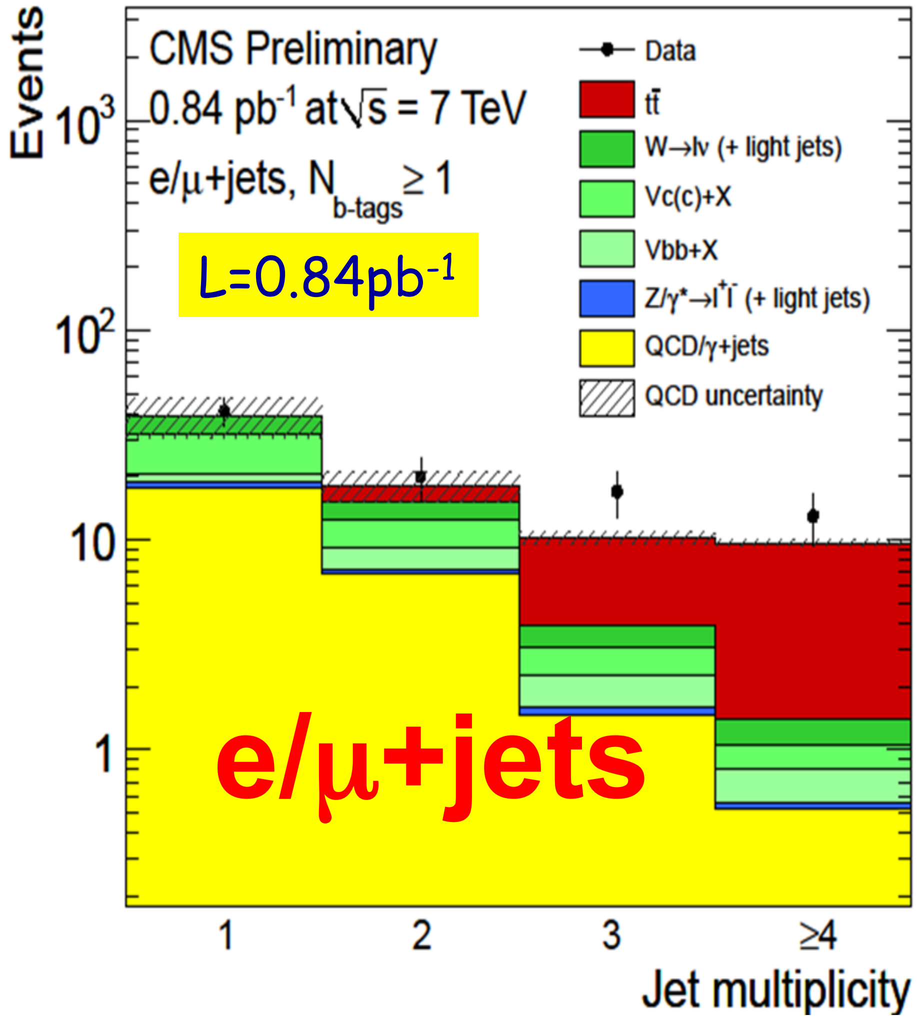
LEPTON+jets



- Considered modes:
  - e+jets
  - mu+jets
- Single lepton triggers
- Exactly one isolated lepton
  - Muons: Pt>20 GeV,|eta|<2.1
  - Electrons: Pt>30 GeV, |eta|<2.4
- Missing Et (MET)
- Not used in event selection, but to reconstruct transverse Mass
- Jets
  - Anti-Kt (R=0.5)
  - Pt>30 GeV, |eta|<2.4
  - Expect >=4 jets for ttbar
  - No b-tagging in baseline selection

Lepton+ Jets Top Selection

Using the full statistics currently validated (0.84pb^{-1}) and **requiring at least 1 jet b-tagged** (secondary vertex tagger with ≥2 tracks; high efficiency with ~1% fake rate)



For N(jets)≥3 we count

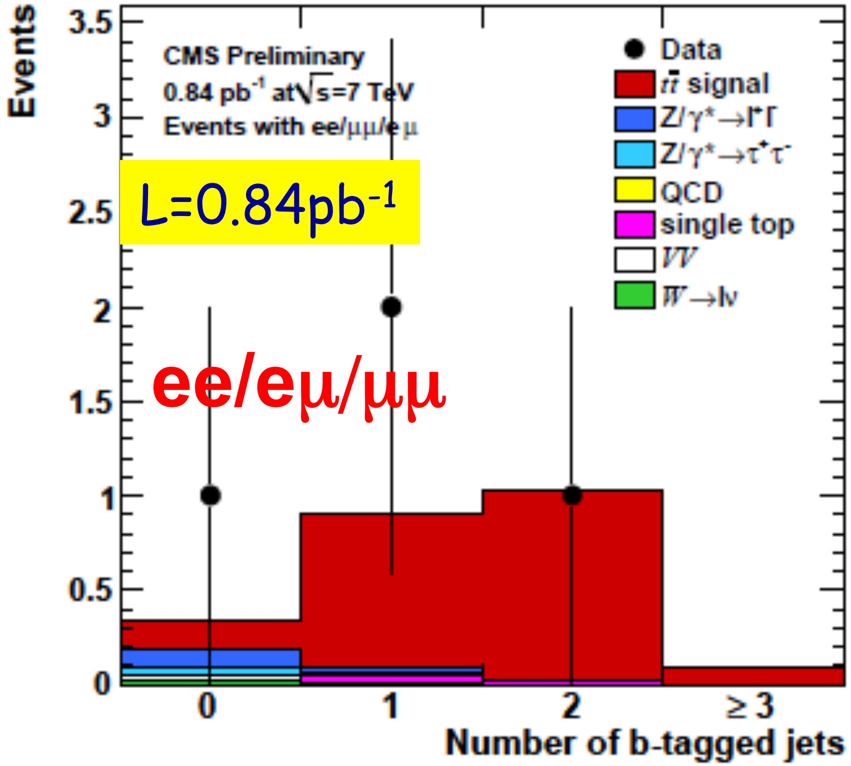
30 signal candidates over a predicted background of 5.3

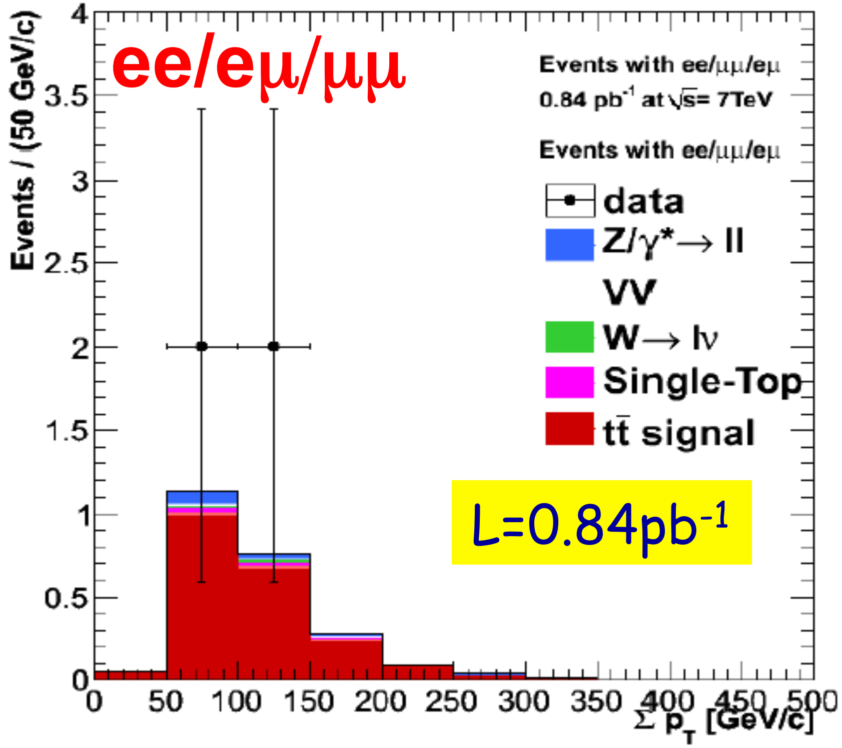
15 expected signal event

t-tbar events are observed in CMS at a rate consistent with NLO cross section, considering experimental (JES, b-tagging) and theoretical (scale, PDF, HF modelling, …) uncertainties.

Di-Lepton+ Jets Top Selection

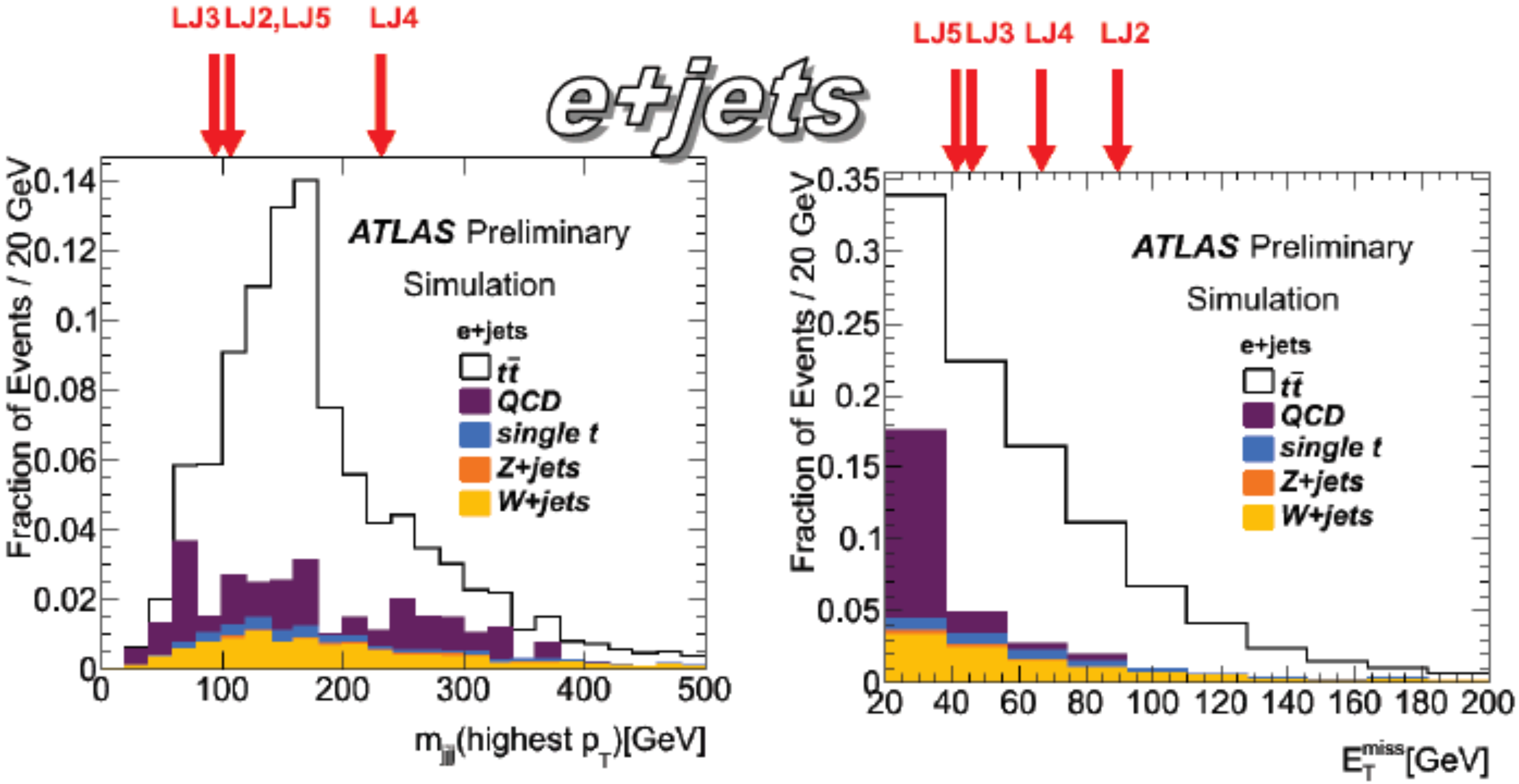
- Full selection applied: Z-bosonVeto, |M(ll)-M(Z)|>15 GeV
- MET >30 (20) GeV in ee,μμ, (eμ); N(jets)≥2



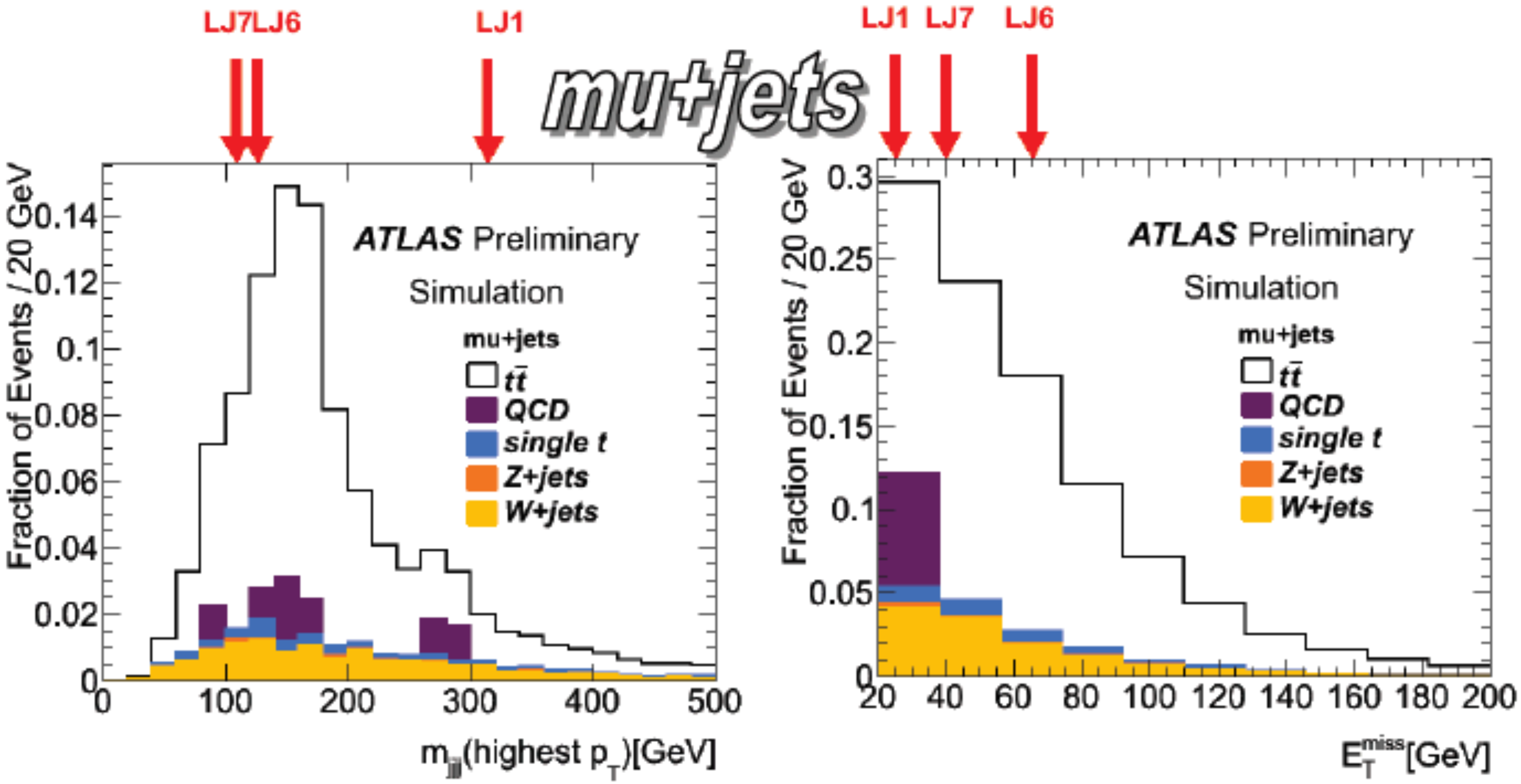


4 ttbar candidates (1eμ, 1ee, 2μμ) over a negligible background.
Top signal at LHC established.
First cross sections will come soon!

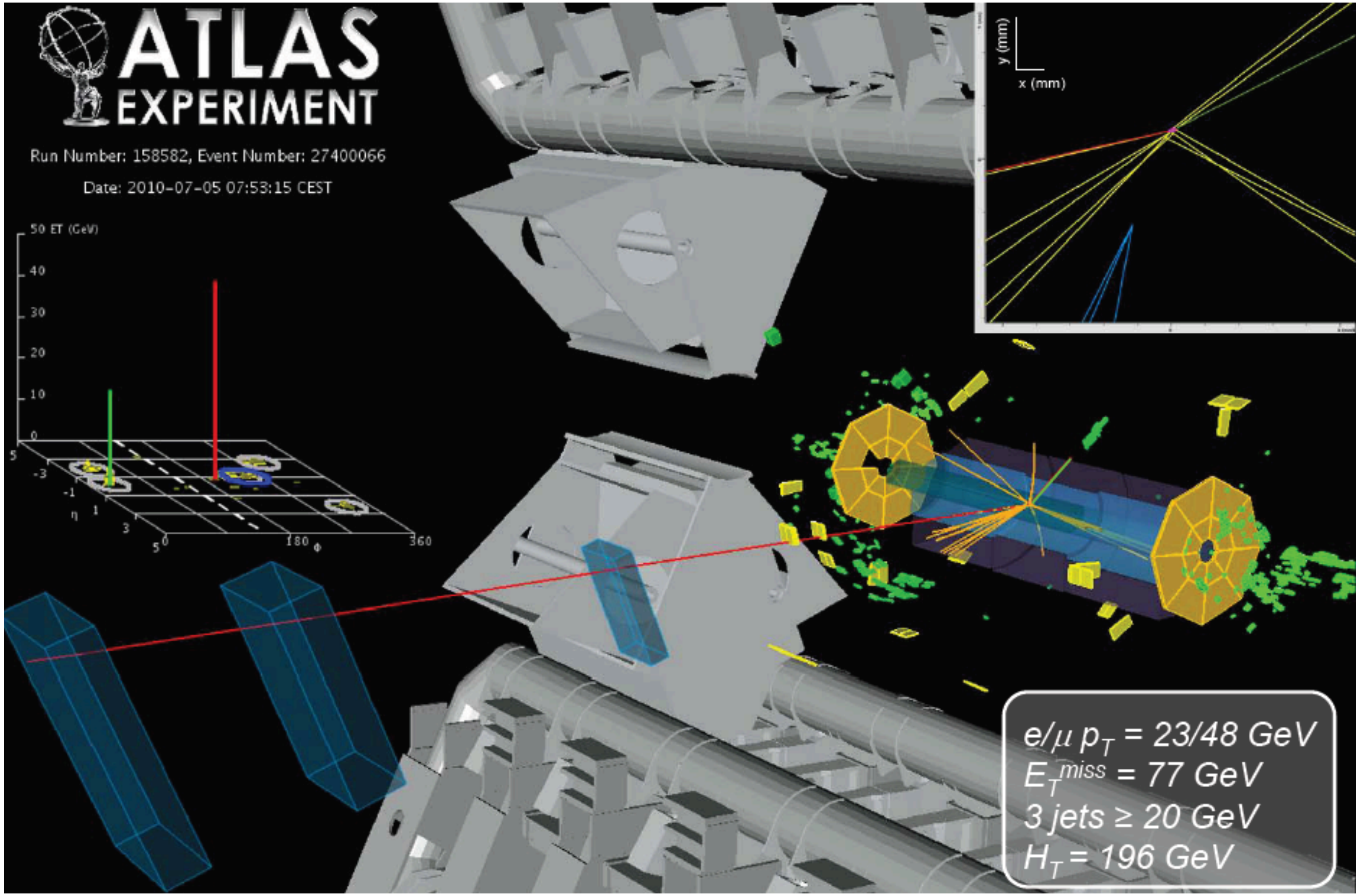
Top candidates: e+ jets



Top candidates: muon+ jets



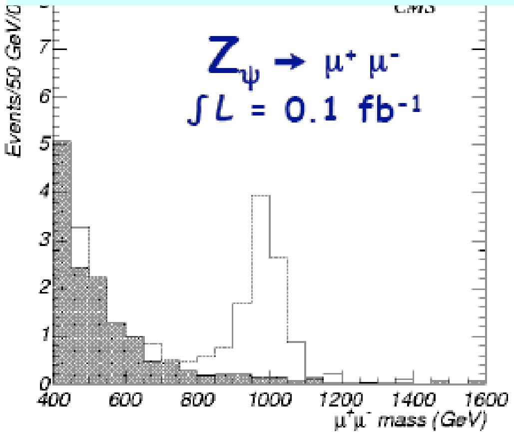
Muon + Electron + Jets Candidate



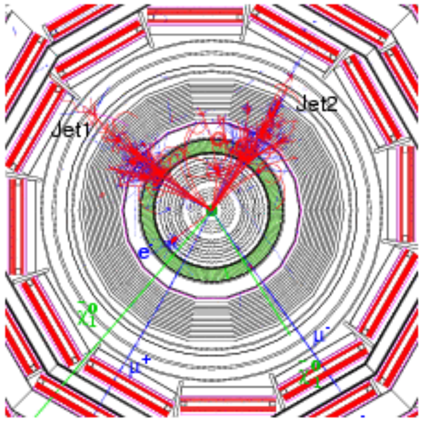
In all,Top observed in CMS and ATLAS: first top in Europe!!

New Physics at the LHC?

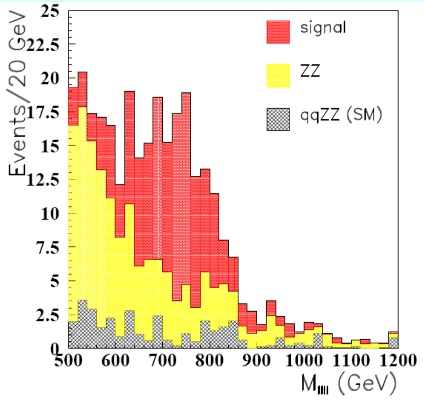
New Gauge Bosons?



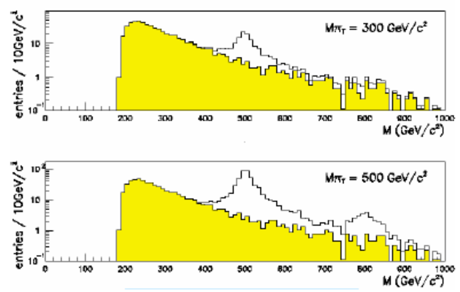
Supersymmetry



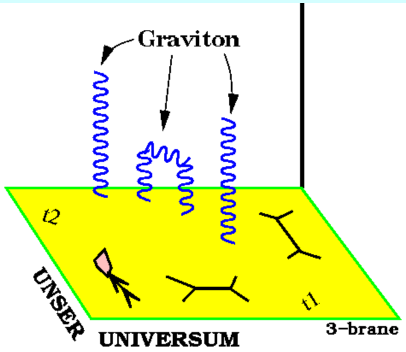
ZZ/WW resonances?



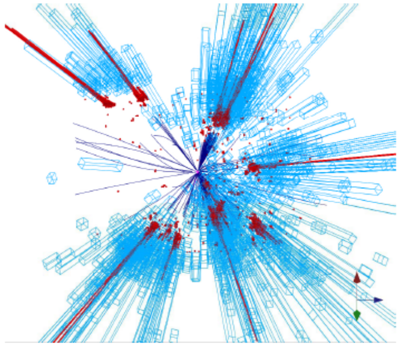
Technicolor?



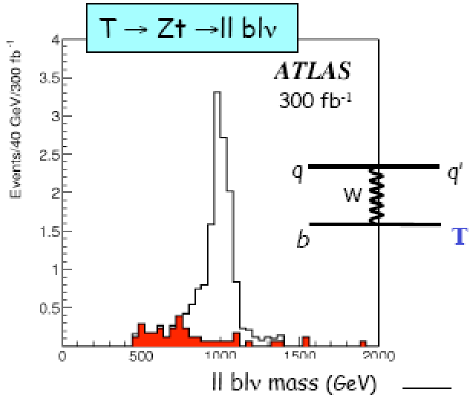
Extra Dimensions?



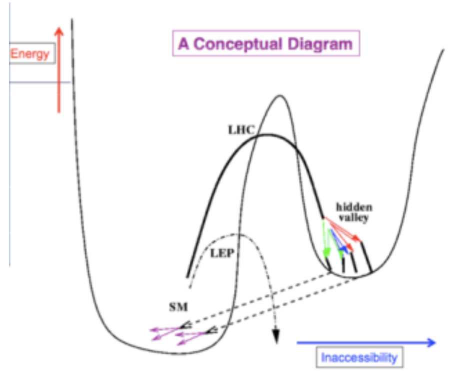
Black Holes???



Little Higgs?

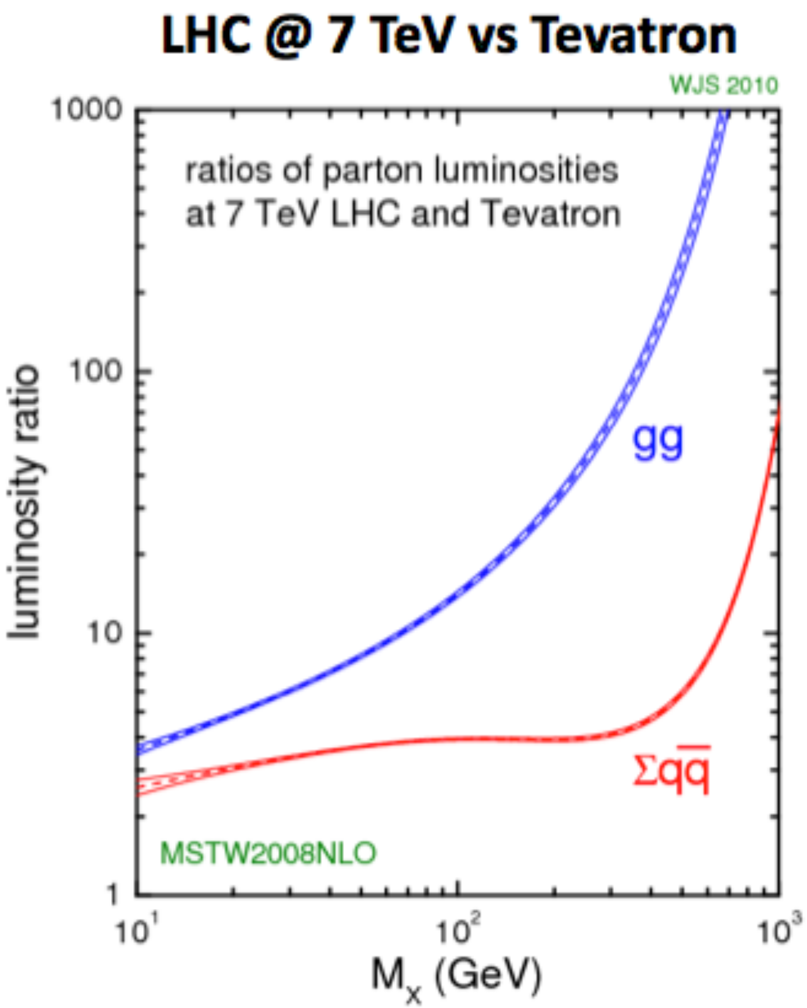


Hidden Valleys?



We do not know what is out there for us…
A large variety of possible signals. We have to be ready for that

Searches for New Physics



How fast can we expect the LHC to take over from the Tevatron?
(2 TeV CM)

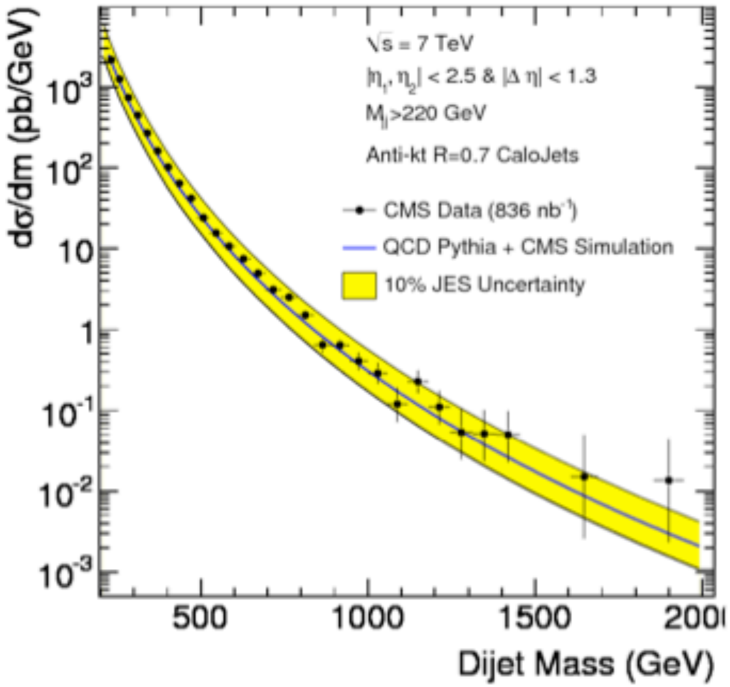
Look at the parton luminosities

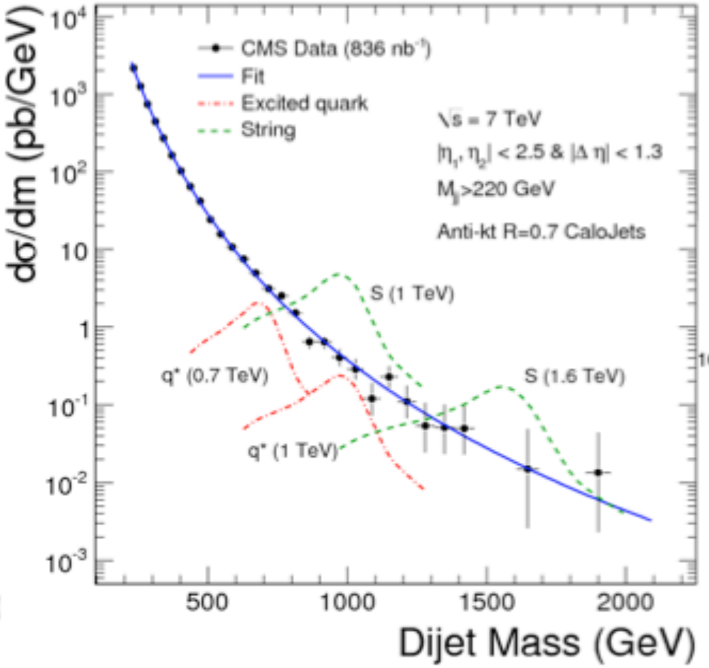
The power of the higher energy!!!

Much more in
Steve Worm's talks

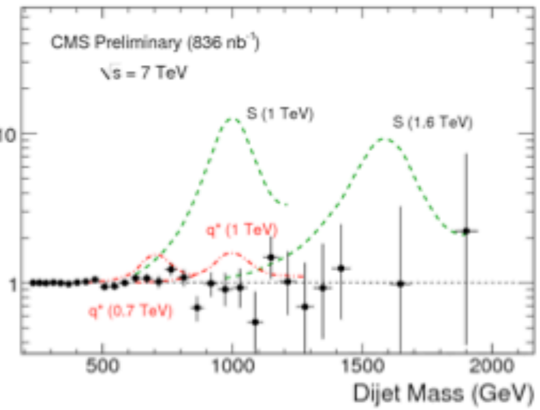
Exploring New Territory: Di-jets

Measured dijet mass differential cross section for $|h_1,h_2|<2.5$ and $|\eta_1,\eta_2|<1.3$.
The distribution is sensitive to the coupling of any new massive object to quarks and gluons.





L=0.84pb^{-1}



95% CL mass limits:

String resonances >2.1TeV **Excited quarks >1.14TeV**

Axigluons/Colorons >1.06TeV **E_6 Diquarks>0.58 TeV.**

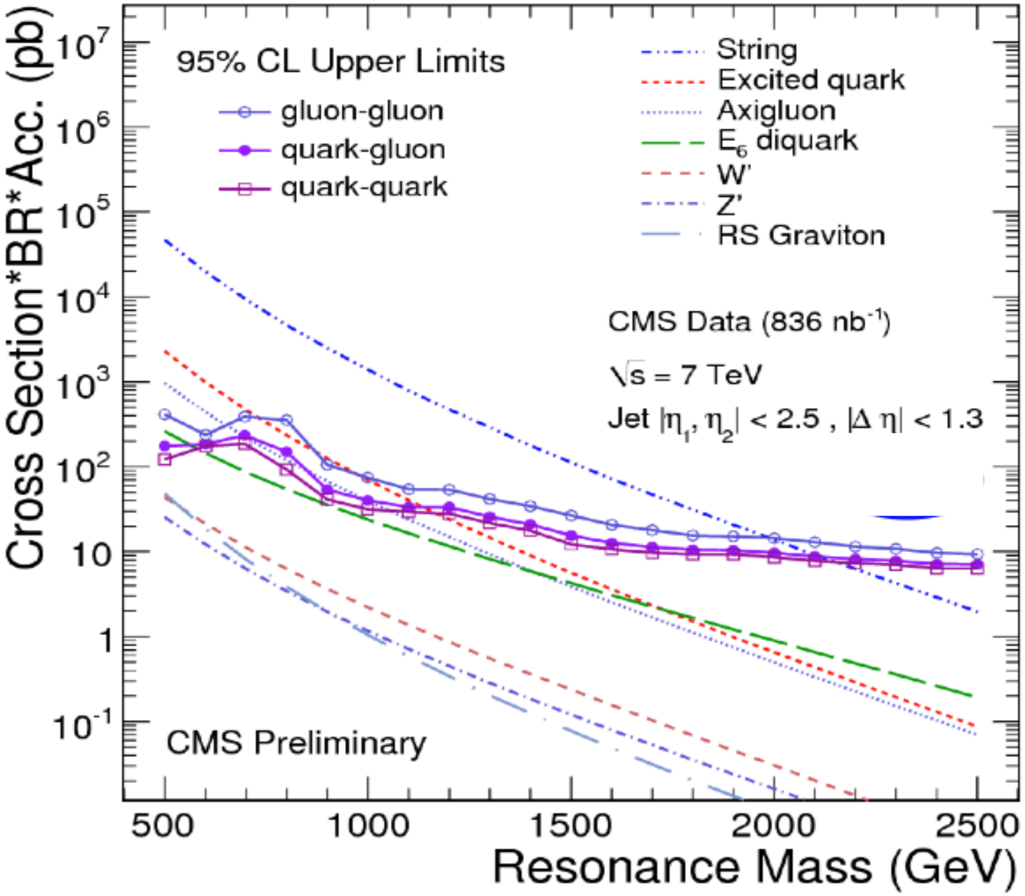
Exploring New Territory: Di-jets

new massive objects that couple to quarks (q) and gluons (g) → di-parton resonance
qq, qg, gg → resonant structures in the di-jet

Several model of quark compositeness:

Model Name	X	Color	J^P	$\Gamma/(2M)$	Final-state Partons
String	S	mixed	mixed	0.003-0.037	qq, $q\bar{q}$, gg and qg
Axigluon	A	Octet	1^+	0.05	$q\bar{q}$
Coloron	C	Octet	1^-	0.05	$q\bar{q}$
Excited Quark	q*	Triplet	$1/2^+$	0.02	qg
E_6 Diquark	D	Triplet	0^+	0.004	qq
RS Graviton	G	Singlet	2^+	0.01	$q\bar{q}$, gg
Heavy W	W'	Singlet	1^-	0.01	$q\bar{q}$
Heavy Z	Z'	Singlet	1^-	0.01	$q\bar{q}$

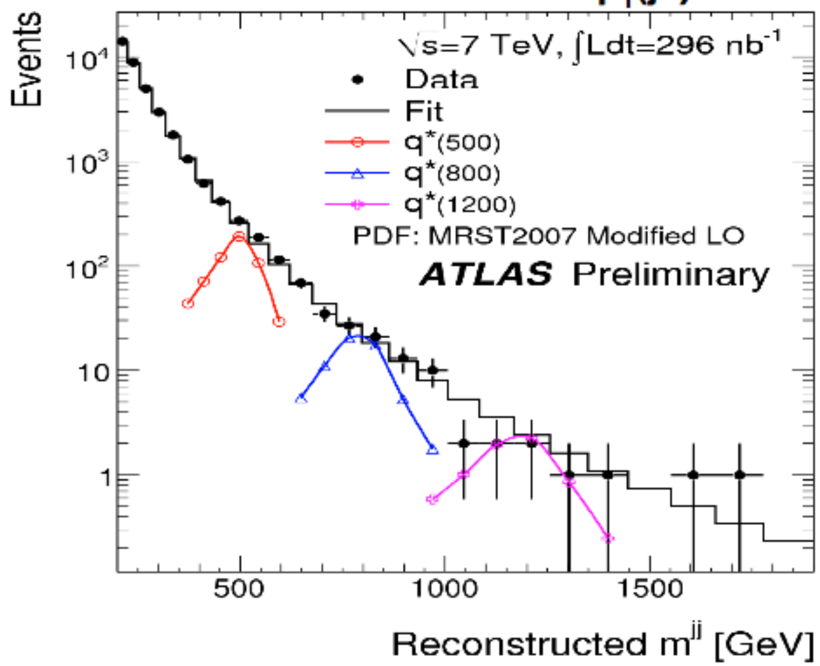
Model	95% C.L. Mass Limit (TeV) using CTEQ6L	
	CMS (836 nb⁻¹)	CDF (1.13 fb⁻¹)
String	2.10	1.4
q*	1.14	0.87
Axigluon/ Coloron	1.06	1.25
E_6 Diquark	0.58	0.63

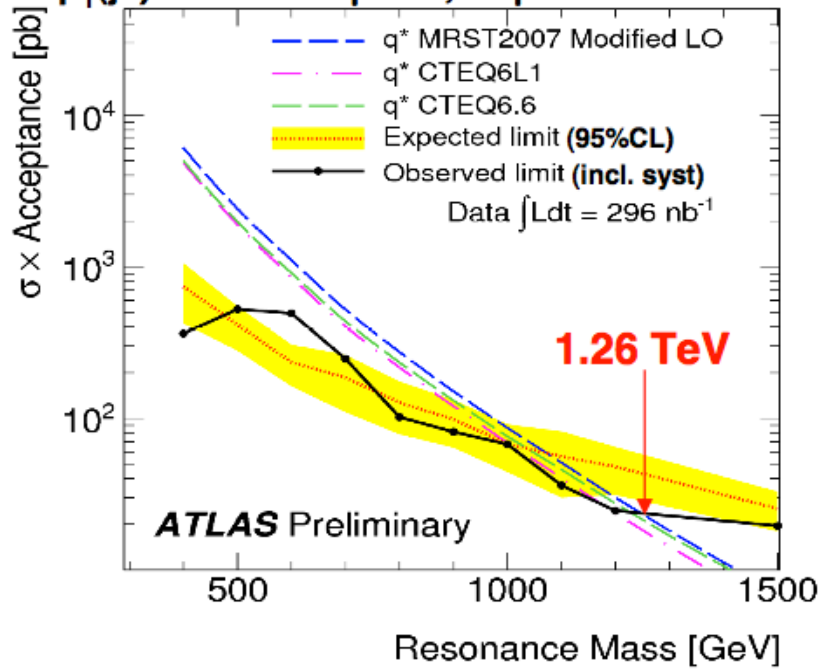


Exploring New Territory: Di-jets

- **Search for excited quarks ($q^* \rightarrow jj$) on full ICHEP data sample**
  - Signal is searched as deviation from smooth monotonic function
  - Systematics considered: luminosity, Jet Energy scale, background fit

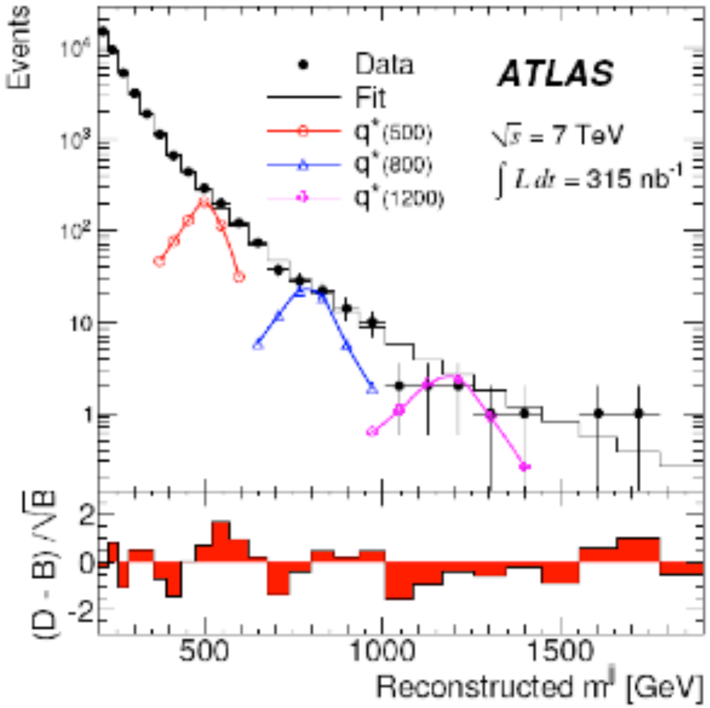
To enhance $S/\sqrt{B}$: $p_T(j1)>80$ GeV and $p_T(j2)>30$ GeV: $|\eta|<2.5$, $|\Delta\eta|<1.3$

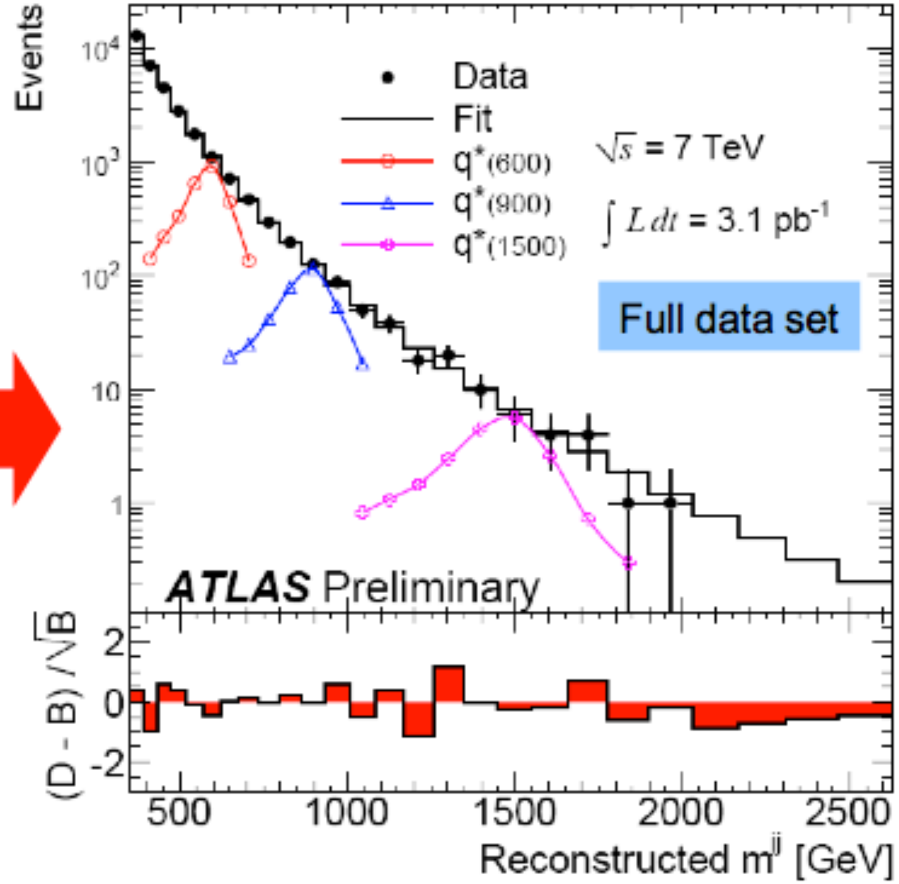




0.4< M(q*) <1.26 TeV excluded at 95% CL (*CDF latest: 0.26 < M(q*)<0.87 GeV*)

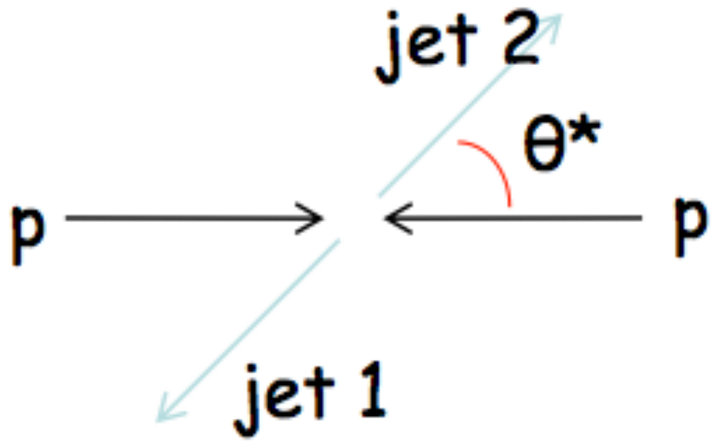
Exploring New Territory: Di-jets

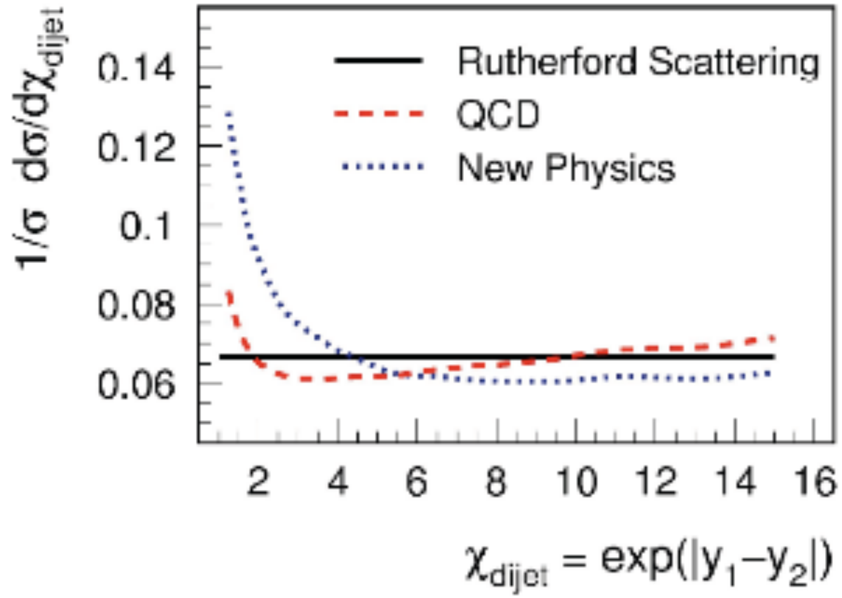


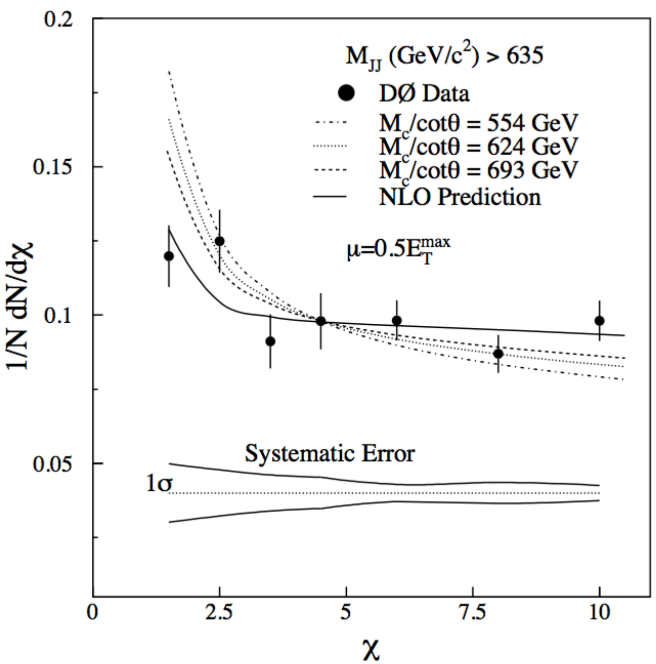


- With 10x as much data the expected limit moves from 1.06 TeV to 1.51 TeV and the observed limit moves from 1.26 TeV to **1.53 TeV**.
  - We raised the jet requirement to $p_T(j_1)$ > 150 GeV to match the evolving trigger.

Di-jet Angular Distributions







$$\chi = e^{2y^*} = \exp(|y_1 - y_2|)$$

$$\chi_{dijet} = \exp(2y^*) = (1 + \cos\theta^*)/(1 - \cos\theta^*)$$

Eg searches for contact interactions at the Tevatron

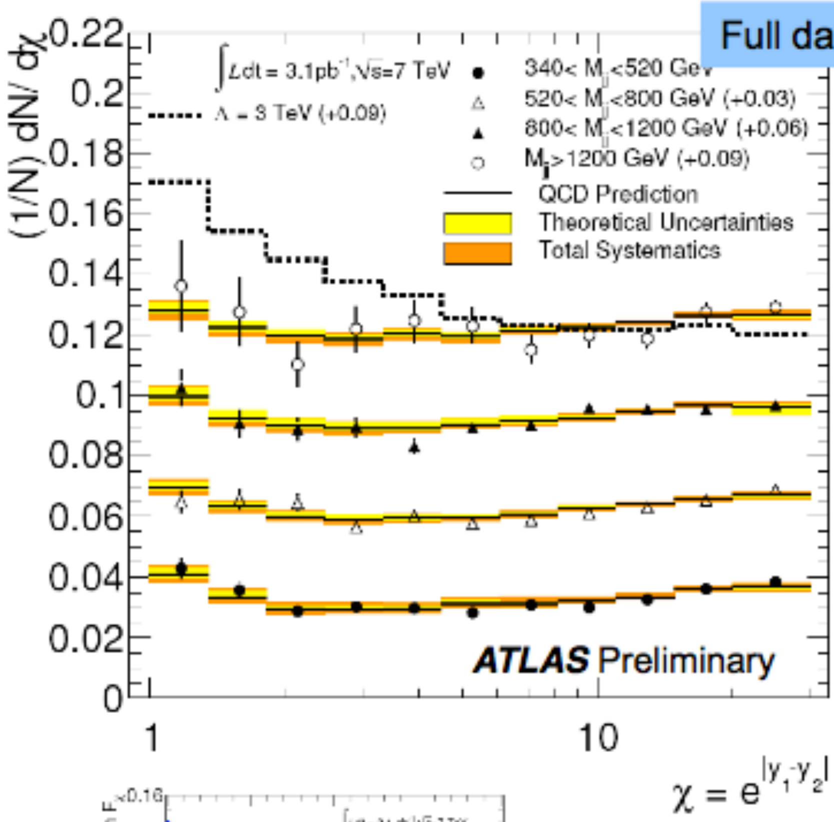
Λ < 2.8 TeV - 3 TeV

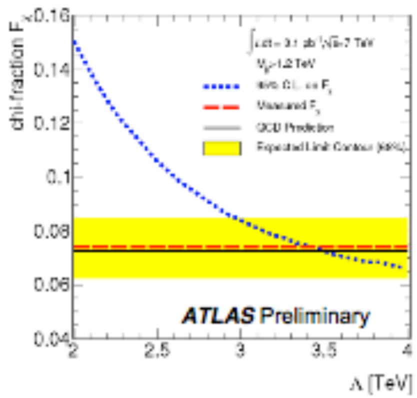
Di-jet Angular Distributions

- Angular distributions are sensitive to s-channel vs. t-channel (QCD) production of dijets
  - The variable ■ is convenient – it's flat for Rutherford scattering, and almost flat for QCD
  - s-channel exchange peaks at low ■.
- We require (depending on mass bin)
  - $p_T(j_1) > 80\text{-}150$ GeV (trigger)
  - $p_T(j_2) > 30$ GeV (reconstruction)
  - $|y_1 + y_2| < 1.5$
  - $|y_1 - y_2| < 4.9$

  } Makes acceptance in ■ relatively flat.
- No significant deviation from QCD is observed
  - Expressed as our benchmark, a contact interaction , this works out to **> 3.4 TeV** (at 95%), with an expected sensitivity of 3.5 TeV
  - Previous best limit is from D0, > 2.8 TeV

Full data set





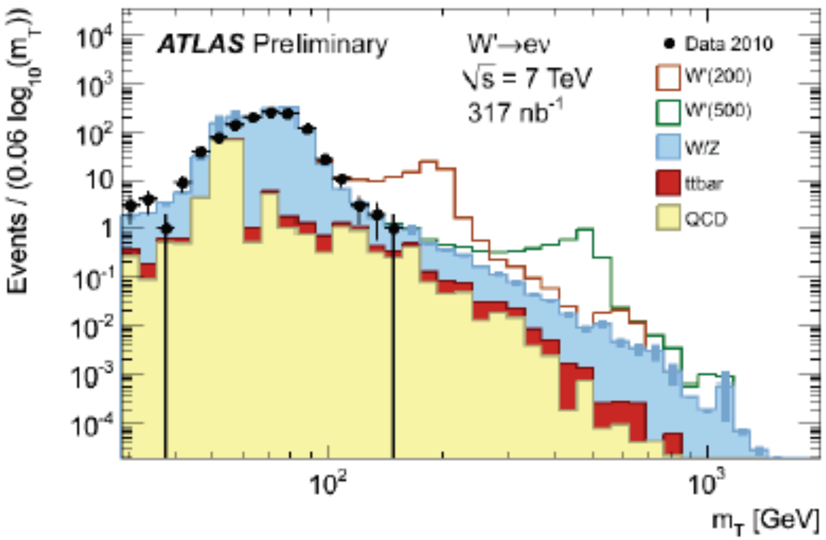
qqqq 3.4 TeV

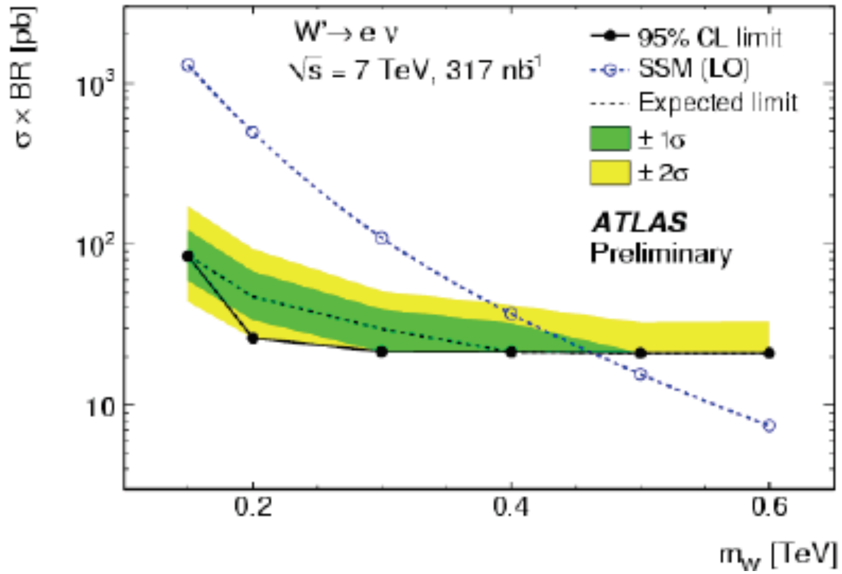
Search for new heavy W' Bosons

- Analysis exercised with 317 nb-1 of data
- Data consistent with SM predictions
- Current limit that can be set (electrons): 465 GeV

- Current results support estimates from previous MC sensitivity studies

electron channel

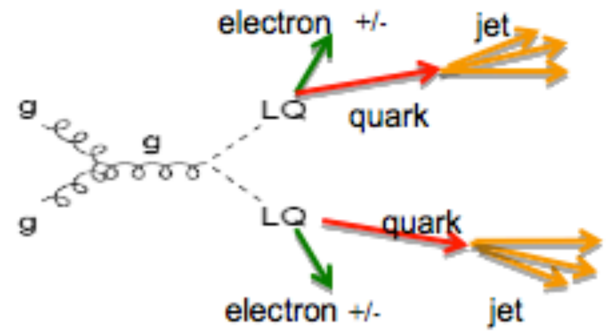


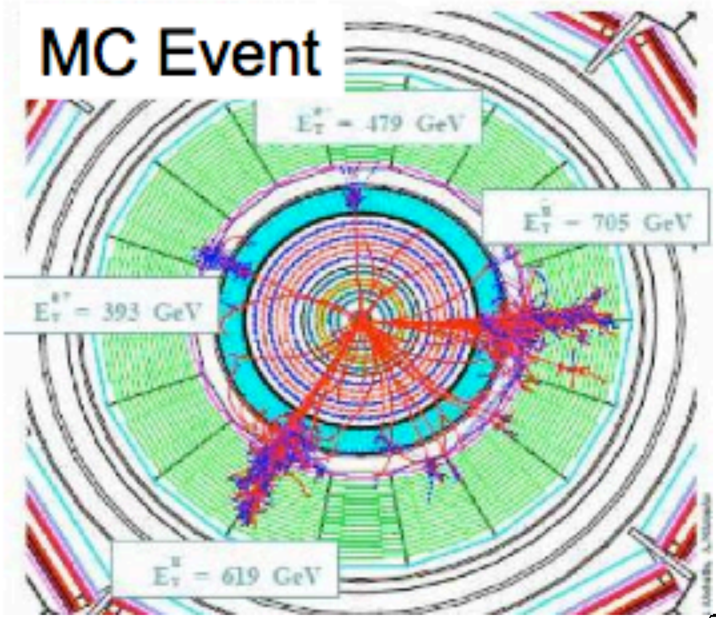


First Generation Lepto-quarks

- Search for 1st generation scalar LQ in the eejj channel (goes as ^{2})
- HEEP (High Energy e & photon) selection
- Optimize to minimize limit xsec
  - 2 isolated high-p_T electrons, 2 high-p_T jets
  - Z Veto
  - $S_T = p_T(e_1) + p_T(e_2) + p_T(j_1) + p_T(j_2) > f(M_{LQ})$
- Background estimation:
  - Data-driven techniques developed for 100 pb^{-1} cannot yet be applied
  - MC for main backgrounds (Z+jets and tt)
    - Data-driven/MC strategy for the uncertainty
  - Small QCD background est. from data

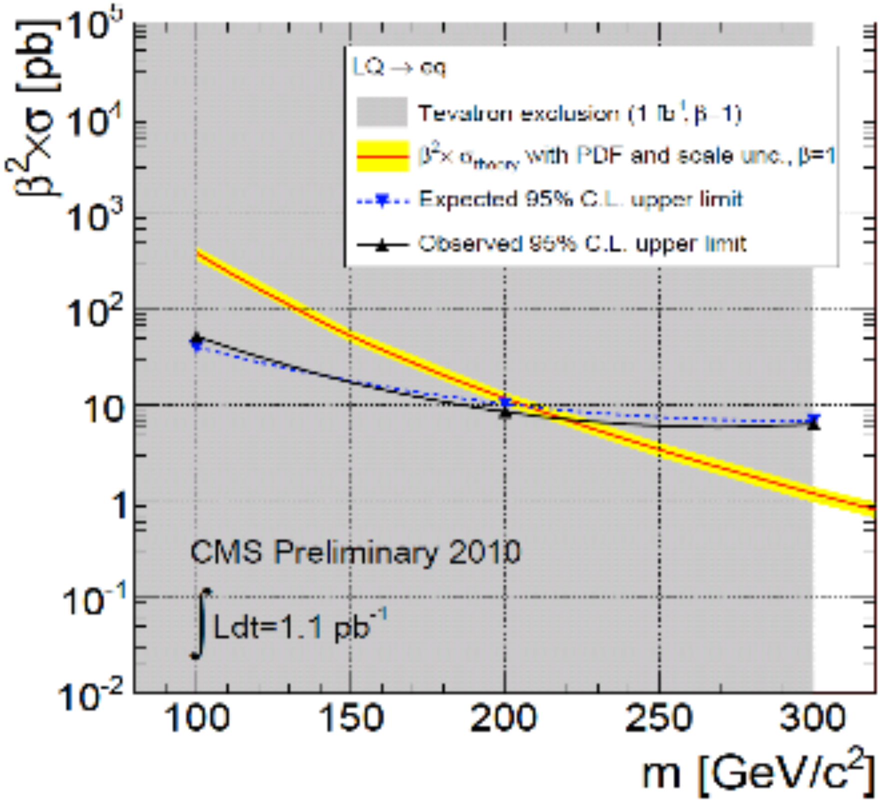
$= BR(LQ \rightarrow l^{+/-} + q)$ is unknown

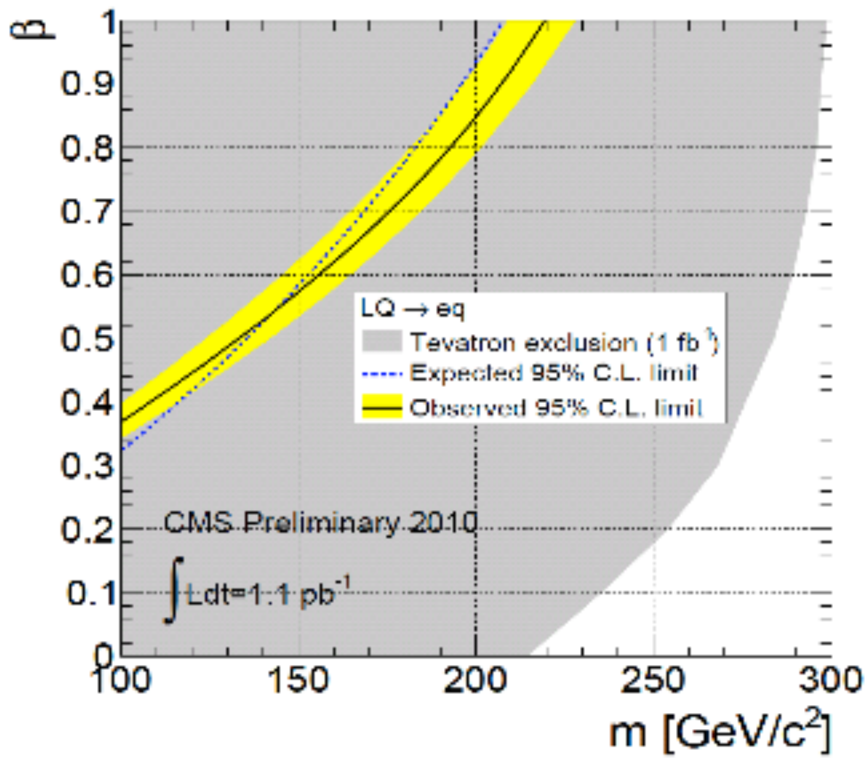




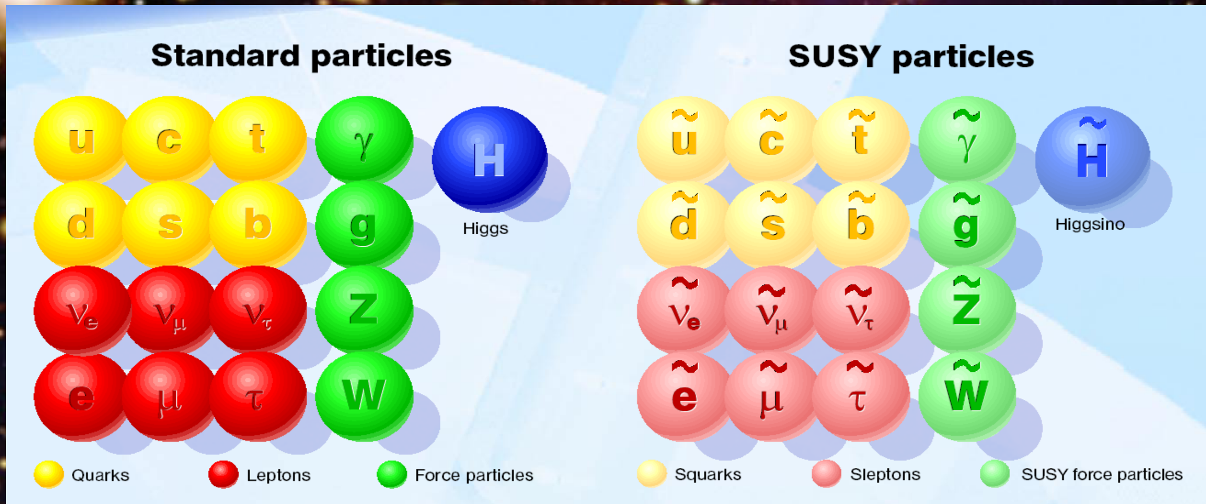
First Generation Lepto-quarks

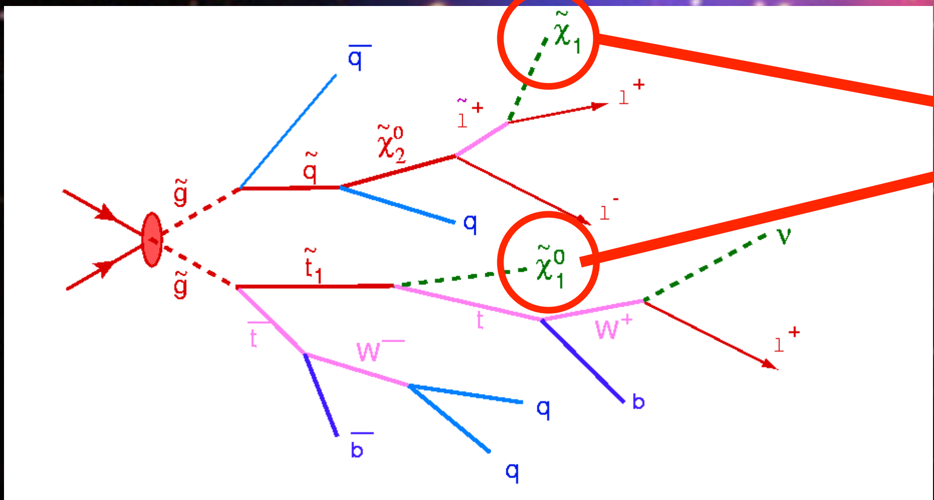
- Observation from data are consistent with SM bkg expectations
  - Set \upper limit on the LQ cross section (using a Bayesian approach)
  - Systematic uncertainties are included in the upper limit calculation
- A lower limit on the LQ mass is 220 GeV for β=1
  - The Tevatron limit is 299 GeV





Supersymmetry: a new symmetry in Nature



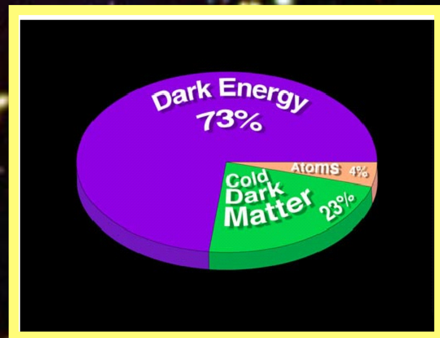


SUSY particle production at the LHC

+ 2 b-jets
+ 4 jets

Candidate particles for Dark Matter

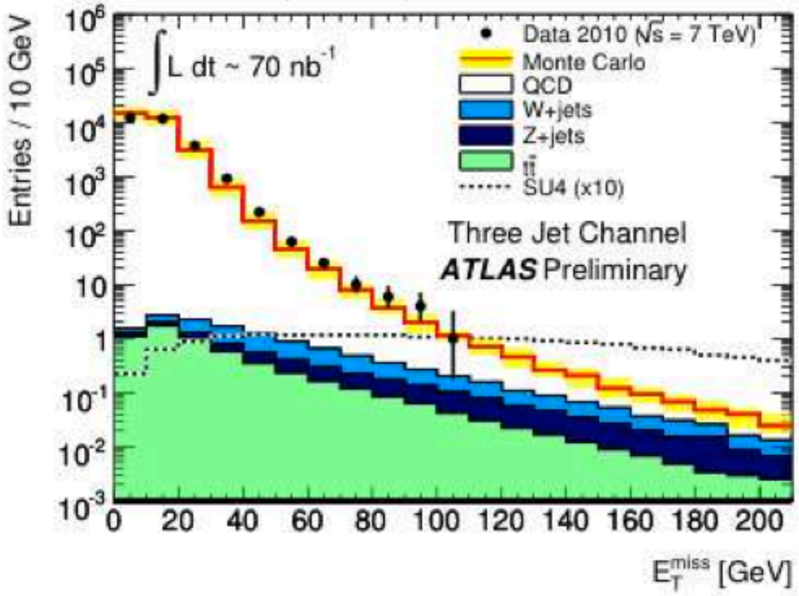
⇒ Produce Dark Matter in the lab



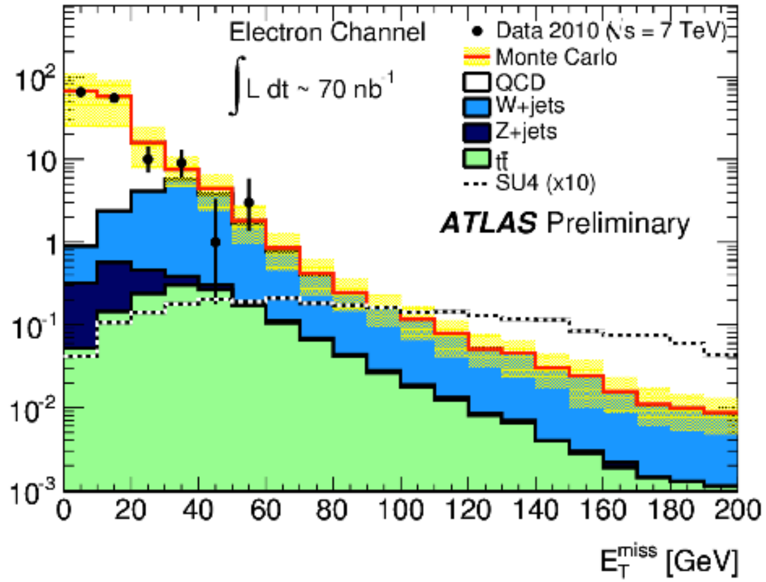
Searches for Supersymmetry

- **First task: Understand backgrounds !**
  - Some examples in SUSY-like searches

Jets + E_T^{miss} channel:
$\geq$ 3 high-p_T jets, p_T (j1) > 70 GeV



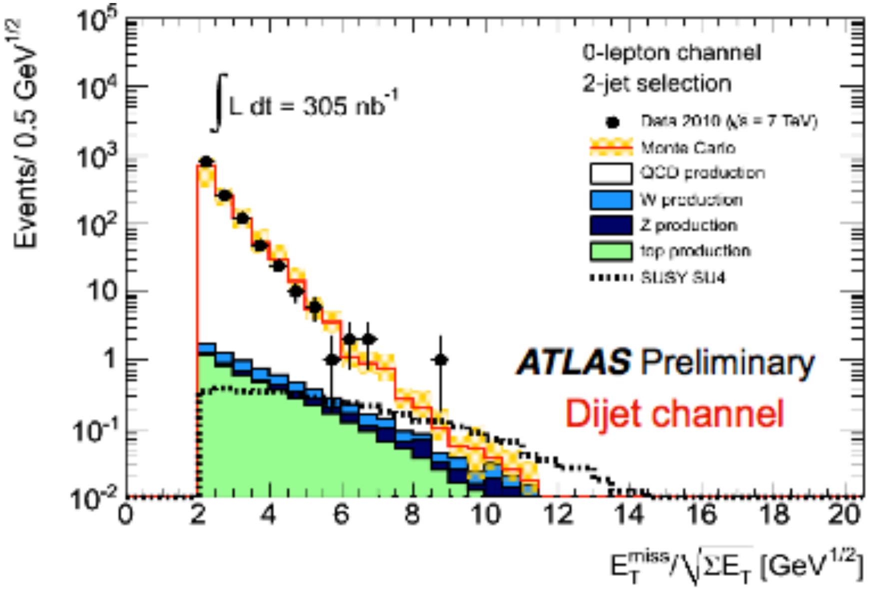
1 electron + Jets + ETmiss channel:
p_T (el) > 20 GeV, $\geq$ 2 high-p_T jets



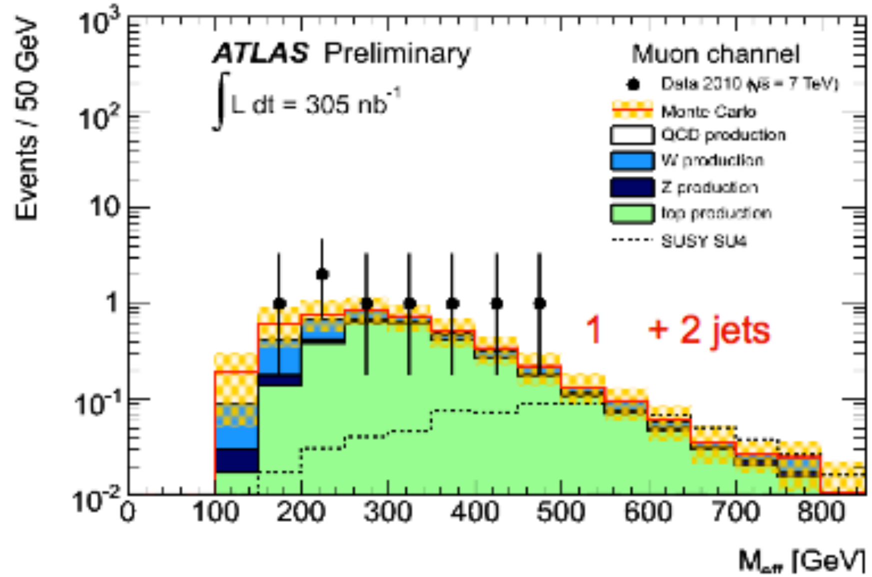
Meanwhile be prepared to set competitive limits with > 1pb^{-1} data

Searches for Supersymmetry

- Secondary vertex b-tagging algorithm:
  - Decay length significance: L/ > 6
  - $\varepsilon_{b\text{-tagging}}$ ~ 50%
- Event selection (305 nb^{-1}):
  - channels: "≥2-j (70,30)", "≥1 lep (20) + 2 j (30,30)"
  - $E_{Tmiss}/\sqrt{\Sigma E_T} > 2\sqrt{\text{GeV}}$, at least one b-jet

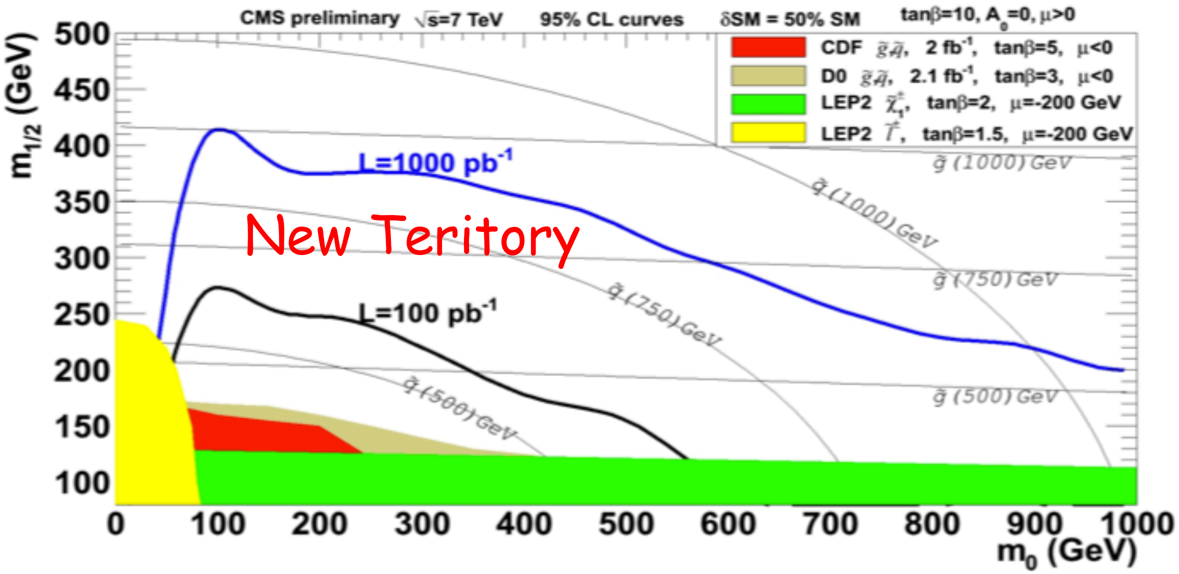


- Two things to take away from these plots:
  - The data are consistent with background
  - SUSY is not on this plot with the "x10" any more: a sign our sensitivity is getting close to where it needs to be to make a discovery..

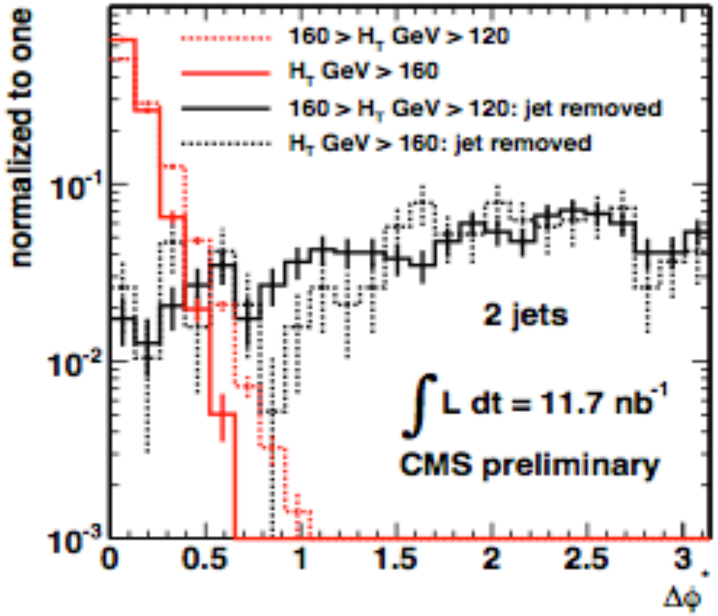


Preparing for SUSY Searches

Sensitivity to SUSY will come soon



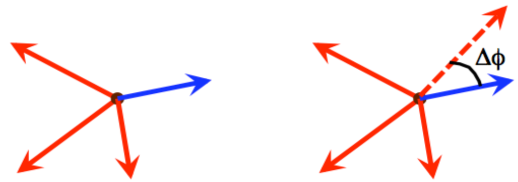
Data driven methods in place



m_0 amd $m_{1/2}$ are universal scalar and gaugino masses at the GUT scale

$$\Delta\phi^* \equiv \min_k(|\Delta\phi((\sum_{i=0}^{i=n} -\vec{j}_i) + \vec{j}_k, \vec{j}_k)|)$$

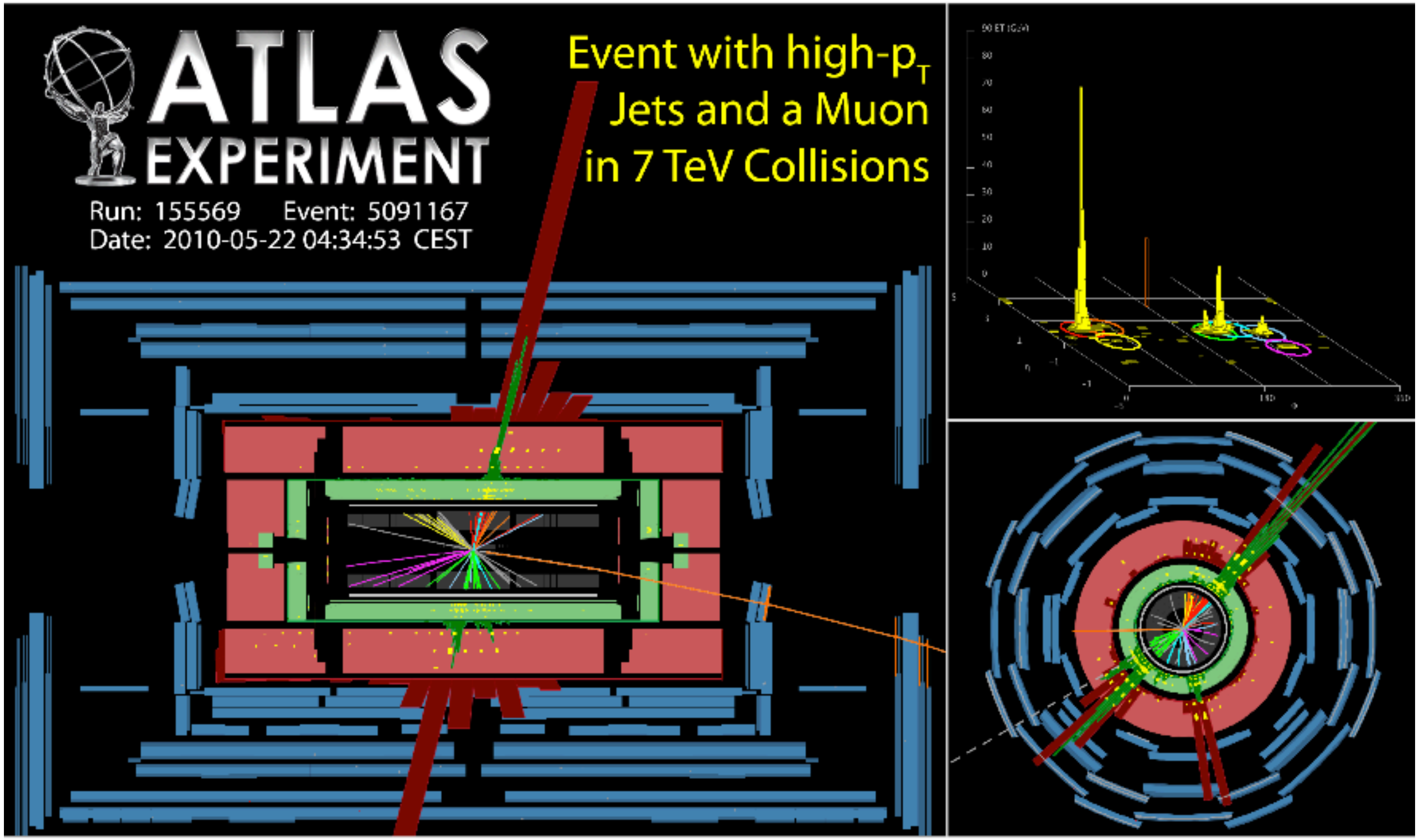
$\Delta\phi^*$ is min over all jet partitions



100 pb^{-1} = end of 2010
1000 pb^{-1} = end of 2011

A Higgs discovery will likely need more data…

An Interesting Event…



A few weeks back…

It's On: Early Interpretations of ATLAS Results in Jets and Missing Energy Searches

Daniele S. M. Alves,[1,2] Eder Izaguirre,[1,2] and Jay G. Wacker[1]

[1] *Theory Group, SLAC National Accelerator Laboratory, Menlo Park, CA 94025*
[2] *Physics Department, Stanford University, Stanford, CA 94305*

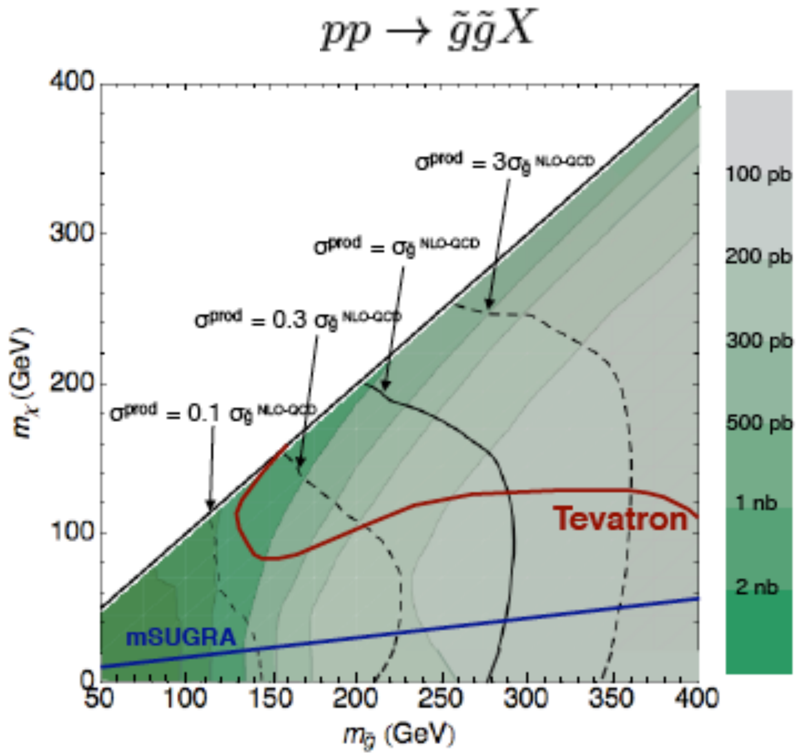
4/8/2010

The first search for supersymmetry from ATLAS with 70 nb^{-1} of integrated luminosity sets new limits on colored particles that decay into jets plus missing transverse energy. For gluinos that decay directly or through a one step cascade into the LSP and two jets, these limits translate into a bound of $m_{\tilde{g}} \geq 205$ GeV, regardless of the mass of the LSP. In some cases the limits extend up to $m_{\tilde{g}} \simeq 295$ GeV, already surpassing the Tevatron's reach for compressed supersymmetry spectra.

ATLAS Data for the summer conference

Cut	Topology	$1j + \not{E}_T$	$2^+j + \not{E}_T$	$3^+j + \not{E}_T$	$4^+j + \not{E}_T$
1	p_{T1}	> 70 GeV	> 70 GeV	> 70 GeV	> 70 GeV
2	p_{Tn}	≤ 30 GeV	> 30 GeV $(n = 2)$	> 30 GeV $(n = 2, 3)$	> 30 GeV $(n = 2 - 4)$
3	$\not{E}_{T\text{EM}}$	> 40 GeV	> 40 GeV	> 40 GeV	> 40 GeV
4	$\Delta\phi(j_n, \not{E}_{T\text{EM}})$	none	$[> 0.2, > 0.2]$	$[> 0.2, > 0.2, > 0.2]$	$[> 0.2, > 0.2, > 0.2, \text{none}]$
5	$\not{E}_{T\text{EM}}/M_{\text{eff}}$	none	> 0.3	> 0.25	> 0.2
	N_{Pred}	46^{+22}_{-14}	6.6 ± 3.0	1.9 ± 0.9	1.0 ± 0.6
	N_{Obs}	73	4	0	1
	$\sigma(pp \to \tilde{g}\tilde{g}X)\epsilon\vert_{95\%\ \text{C.L.}}$	663 pb	46.4 pb	20.0 pb	56.9 pb

70 nb^{-1} only!!



Low luminosity but can already exclude some special SUSY regions with LHC

Search for New Physics in Heavy Flavor

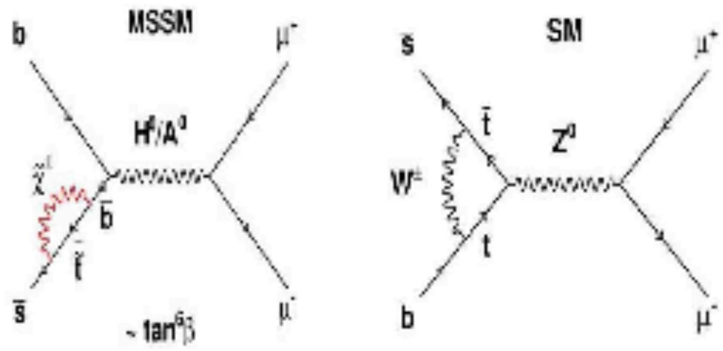
The golden mode: $B_s \to \mu\mu$

B physics rare decay par excellence:

$$BR(B_s \to \mu\mu)_{SM} = (3.35 \pm 0.32) \times 10^{-9}$$

(Blanke et al., JHEP 0610:003,2006)

Precise prediction (which will improve) !



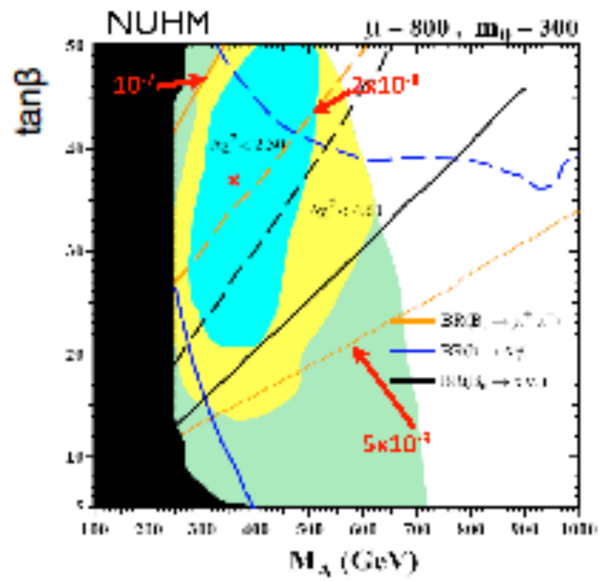
Very high sensitivity to NP, eg. MSSM:

$$Br^{MSSM}(Bq \to l^+ l^-) \propto \frac{m_b^2 m_l^2 \tan^6 \beta}{M_{A0}^4}$$

One example (Ellis et al., JHEP 0710:092,2007) with NUHM (= generalised version of CMSSM)

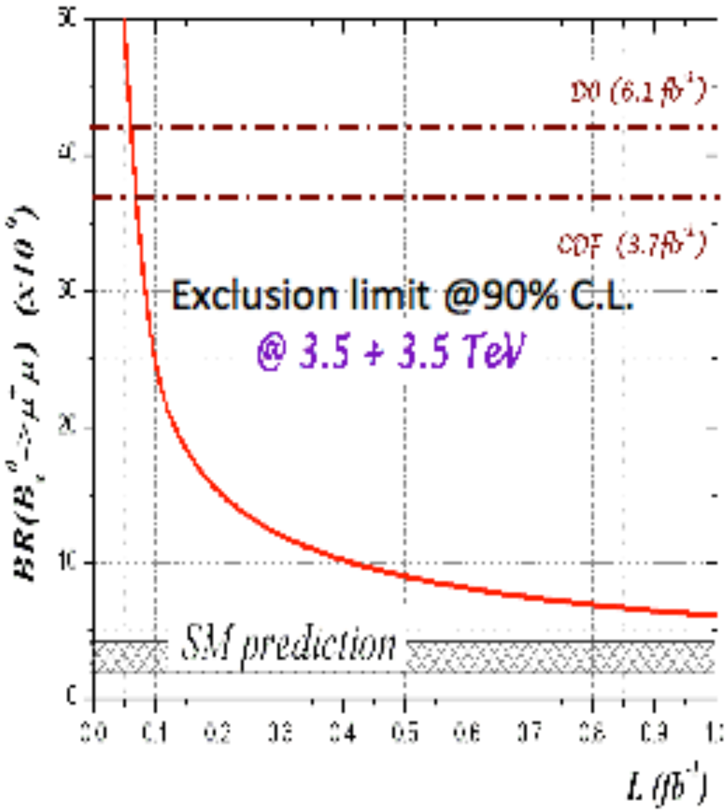
- $b \to s\gamma$ and Higgs > 114.4 GeV
  - ➡ M_A > ~ 300 GeV & $\tan\beta$ < ~50
- $(g_\mu - 2)$ is 3.4σ from SM
  - ➡ M_A < ~ 500 GeV & $\tan\beta$ > ~20

} $BR(B_s \to \mu\mu) \approx 2 \times 10^{-8}$

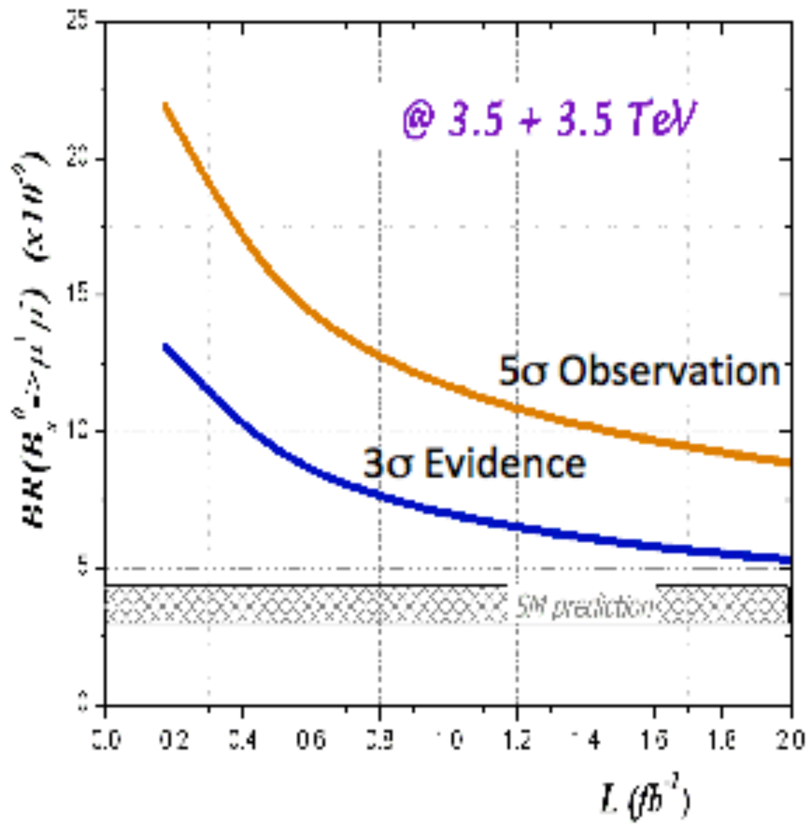


Search for New Physics in Heavy Flavor

$B_s \to \mu\mu$ prospects at LHCb in 2010



50 pb-1



But maybe the "New World" is far more weird than what we thought sofar…

Recent developments in many models lead to the possible existence of heavy particles that have unusual long lifetimes

These can decay in the middle of the detector (nanoseconds) or live even much longer eg seconds, hours, days…

This leads to very special detector signatures!

Long Lived Particles in Supersymmetry

Split Supersymmetry

- Assumes nature is fine tuned and SUSY is broken at some high scale
- The only light particles are the Higgs and the gauginos

  - Gluino can live long: sec, min, years!

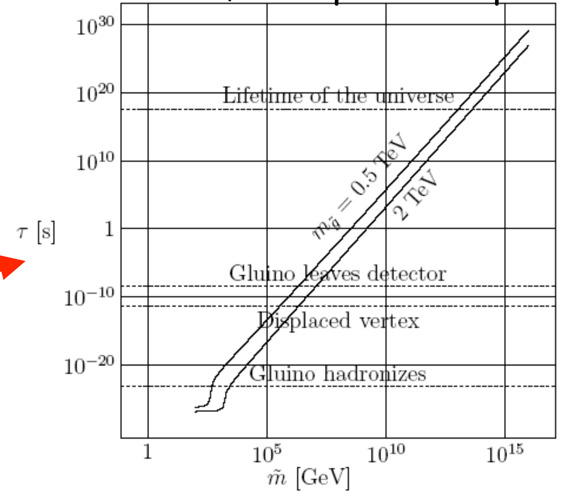
  - R-hadron formation (eg: gluino+ gluon): slow, heavy particles containing a heavy gluino. Unusual interactions with material eg. with the calorimeters of the experiments!

Gravitino Dark Matter and GMSB

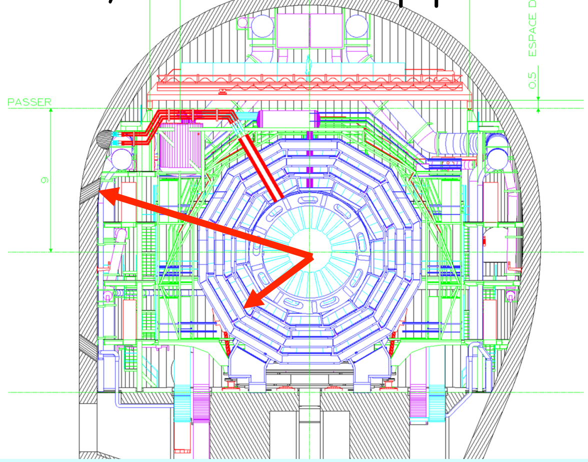
- In some models/phase space the gravitino is the Lightest supersymetric particle (LSP)
- ⇒ NLSP (neutralino, stau lepton) can live 'long'
- ⇒ non-pointing photons

⇒Challenge to the experiments!

Arkani-Hamed, Dimopoulos hep-th/0405159



K. Hamaguchi,M Nijori,ADR hep-ph/0612060
ADR, J. Ellis et al. hep-ph/0508198

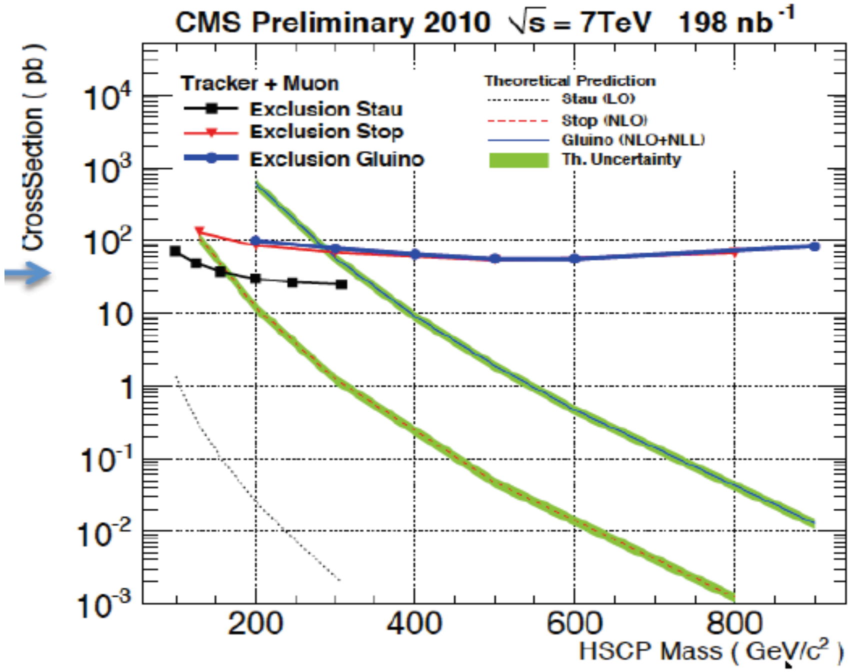


Sparticles stopped in the detector,walls of the cavern, or dense 'stopper' detector. They decay after hours---months…

Searches for Heavy Stable Charged Particles

Example:
Heavy Stable
Charged Particles

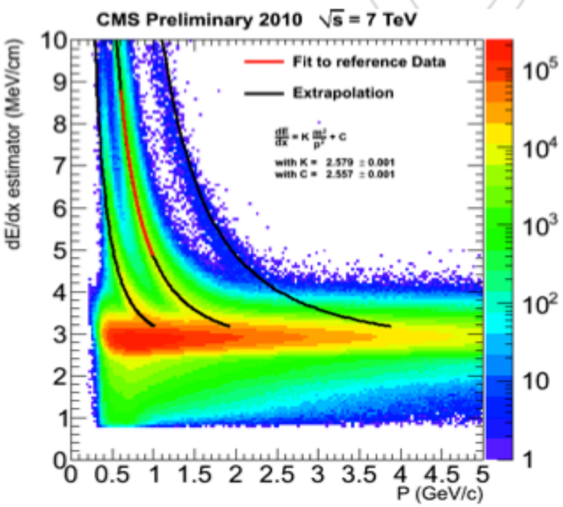
Eg heavy stable
gluino (R-hadron)
or stop/stau

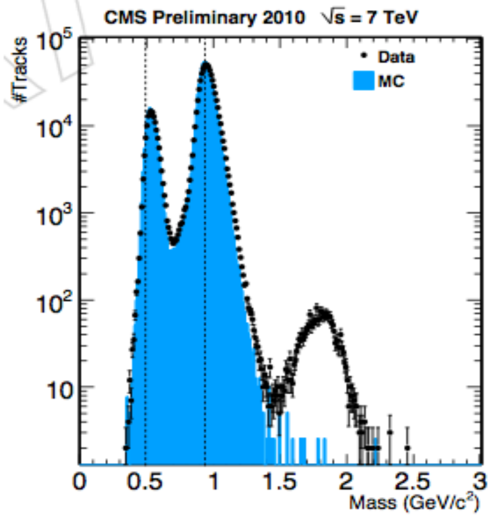


First search limits
using tracker de/dx
and muon
identification

Result for 198 nb^{-1}
0 events after cuts

95% CL limits
on production cross
sections of a few
100 pb in the 200-300
GeV mass range
Eg. Gluinos> 284 GeV





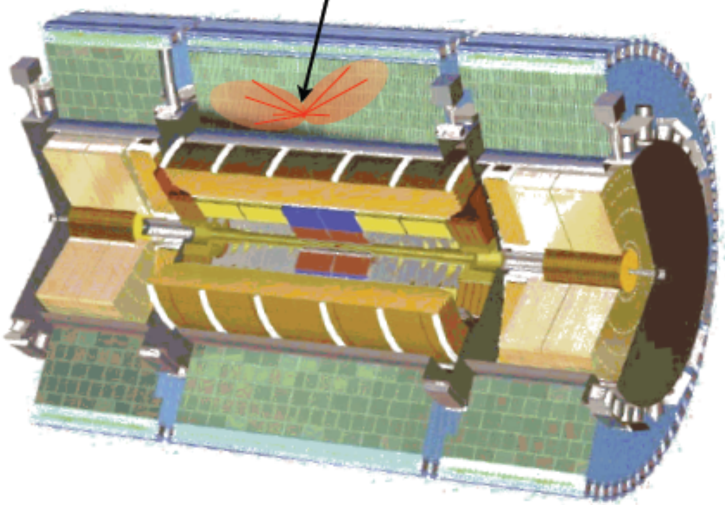
Stopped R-hadrons or Gluinos!

Long Lived Gluinos

$\tau_{\tilde{g}} > 100$ ns

looking for stopped gluinos that later decay

100s GeV Unbalanced $= \not{E}_T$



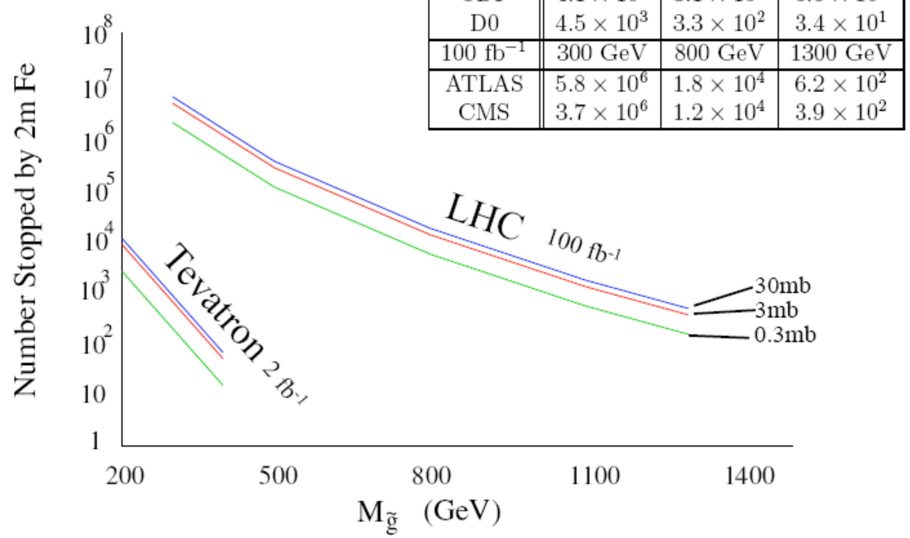
Uncorrelated with any beam crossing
No tracks going to or from activity

The R-hadrons may loose so much energy that they simply stop in the detector

Total Number of Stopped Gluinos

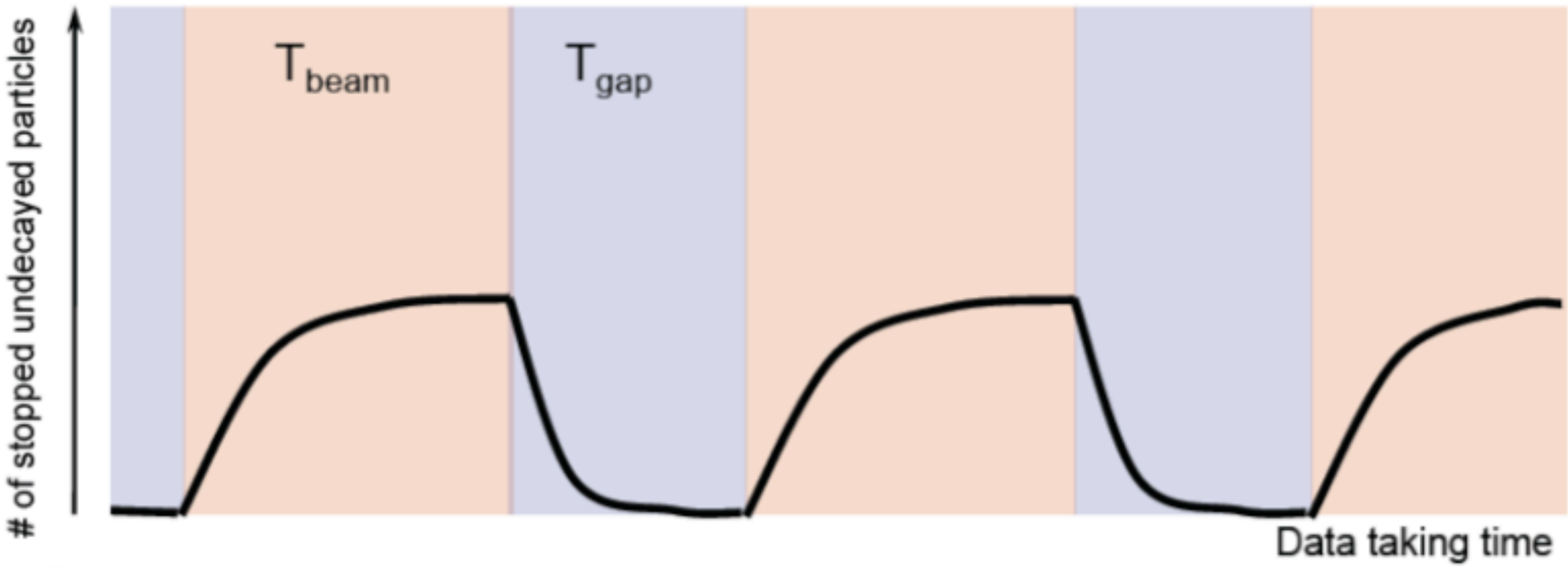
Arvanitaki, Dimopoulos, Pierce, Rajendran, JW hep-ph/0506242

$2\ fb^{-1}$	200 GeV	300 GeV	400 GeV
CDF	4.1×10^3	3.1×10^2	3.3×10^1
D0	4.5×10^3	3.3×10^2	3.4×10^1
$100\ fb^{-1}$	300 GeV	800 GeV	1300 GeV
ATLAS	5.8×10^6	1.8×10^4	6.2×10^2
CMS	3.7×10^6	1.2×10^4	3.9×10^2



⇒ Special triggers needed, asynchronous with the bunch crossing

Stopped gluinos



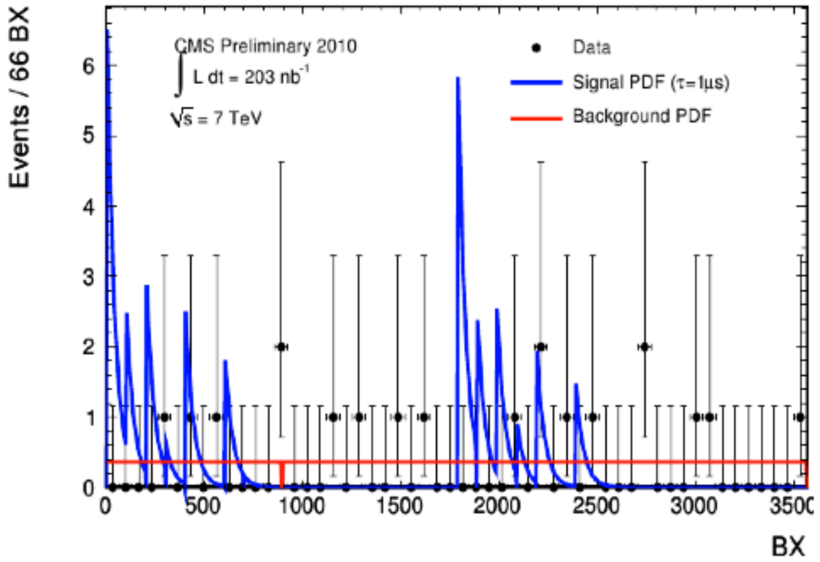
- Basic idea: R-hadrons can loose enough energy in the detector to stop somewhere inside (usually calorimeters)
- Sooner or later they must decay Eg when there is no beam!
- Trigger: (jet) && !(beam)
- Only possible backgrounds: cosmics and noise

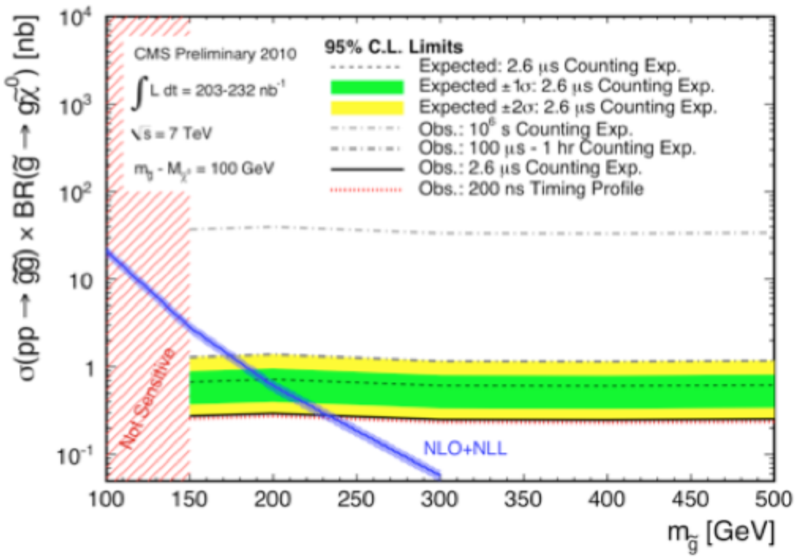
Can be studied in the experiments with cosmic data

Stopped Gluinos

Search for HSCP that stop in the detectors
and decay a long time afterwards (nsec, sec, hrs…)

Searches for Stopped Gluino





- gluino, hadronized into a charged R-hadron, can stop and decay in the calorimeter
- trigger on large “out-of-collision” energy depositions
- sensitive to the large lifetimes
- assume $BR(\tilde{g} \to g\tilde{\chi}^0) = 100\%,\ M_{\tilde{g}} - M_{\tilde{\chi}^0} > 100\ GeV$
- CMS'2010 95% CL limits on gluino lifetime $\tau_{\tilde{g}}$:
  - counting experiment excludes $\tau_{\tilde{g}}$ within [120ns, 6μs]
  - time profile analysis improves low limit down to 75ns

Gluino masses are excluded:

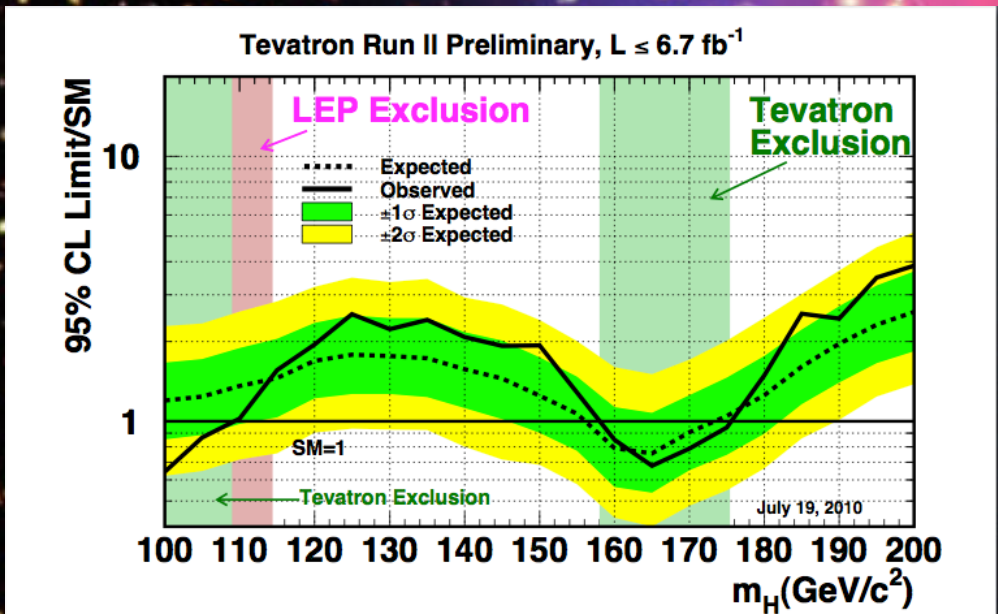
<229GeV (τ=200ns)
<225GeV (τ=2.6μs).

The Origin of Mass

Some particles have mass, some do not

Where do the masses
come from ?

Explanation of Profs P. Higgs
R. Brout en F. Englert
⇒ A new field and particle

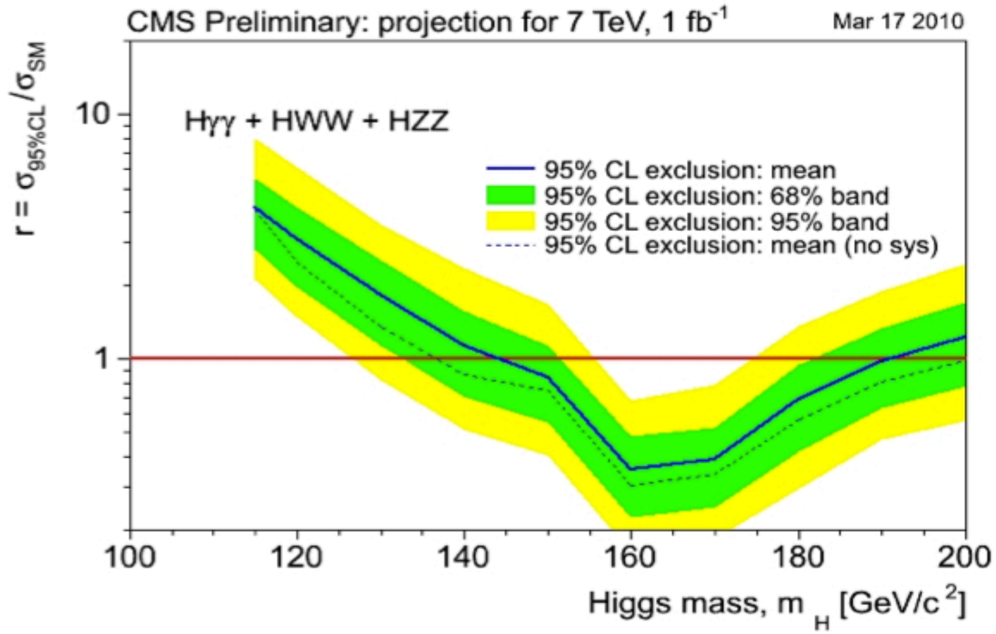


The key question:
Where is the Higgs?

…And the Search for the Higgs

- Sizeable integrated luminosity is needed before significant insights can be made in SM Higgs search.
- However, even with moderate luminosity per experiment, Higgs boson discovery is possible in particular mass regions.
- Better if CM energy would be increased: 8TeV? 9TeV?

Example Reach by end of 2011



- If the Higgs exist: LHC will discover it after 3-4 years of operation
- If the Higgs does not exist: LHC should see other new effects

Summary

- CMS and ATLAS are very well advanced with the detector commissioning and calibration
- The experiments records physics data, following a well defined scheme, evolving with luminosity, for triggers and datasets and data distribution.
- Physics papers being completed on the 7 TeV collisions. Lots of results for ICHEP2010 on QCD, EWK, B-physics, and observation of the top. The first searches for new physics have started, and some go already beyond the limits of the Tevatron.
- CMS and ATLAS are ready for the ‘real game’ ie searches for new physics, and for the Higgs

and maybe soon…

END