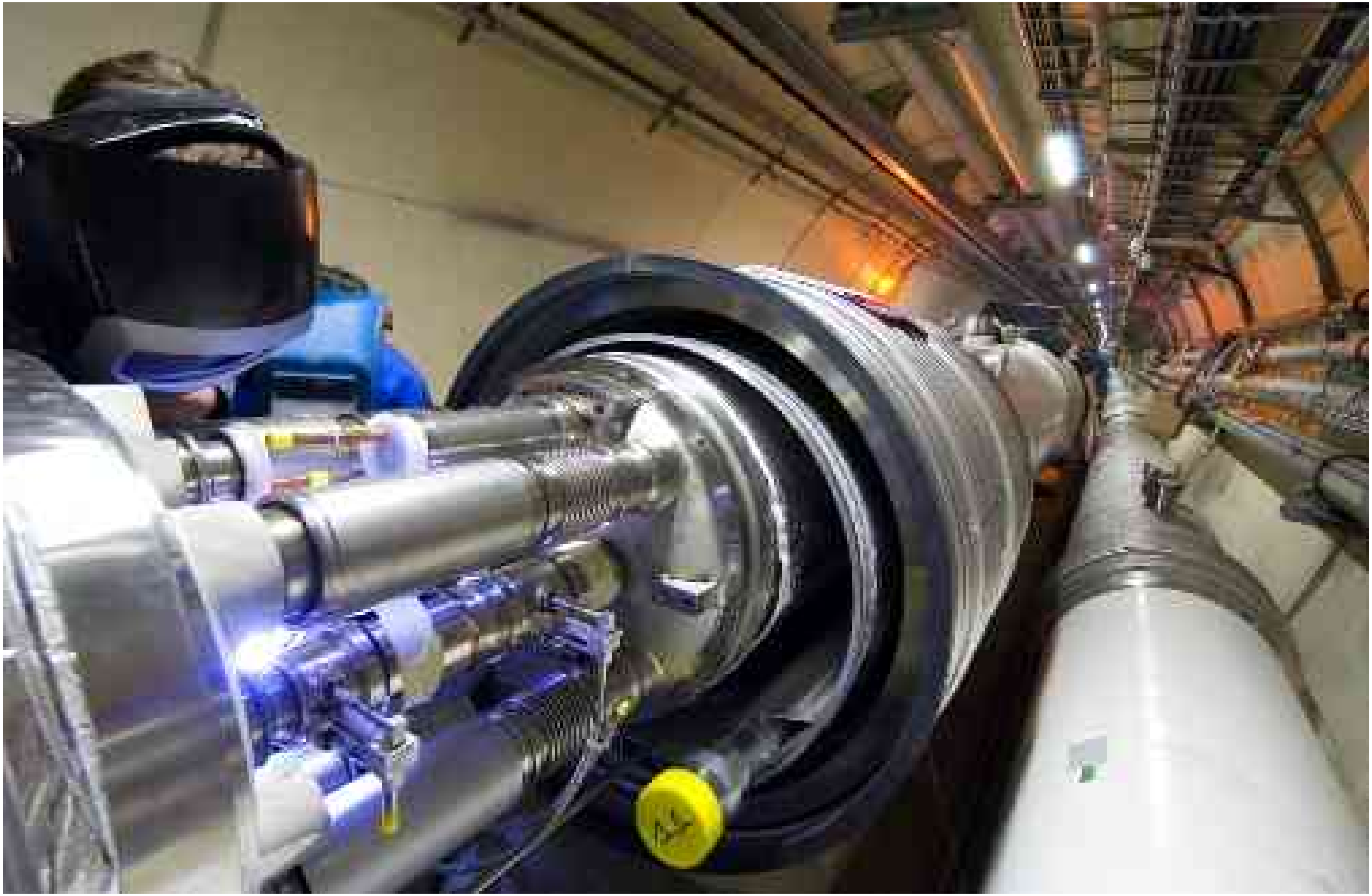
The LHC Turn-on and the Tevatron

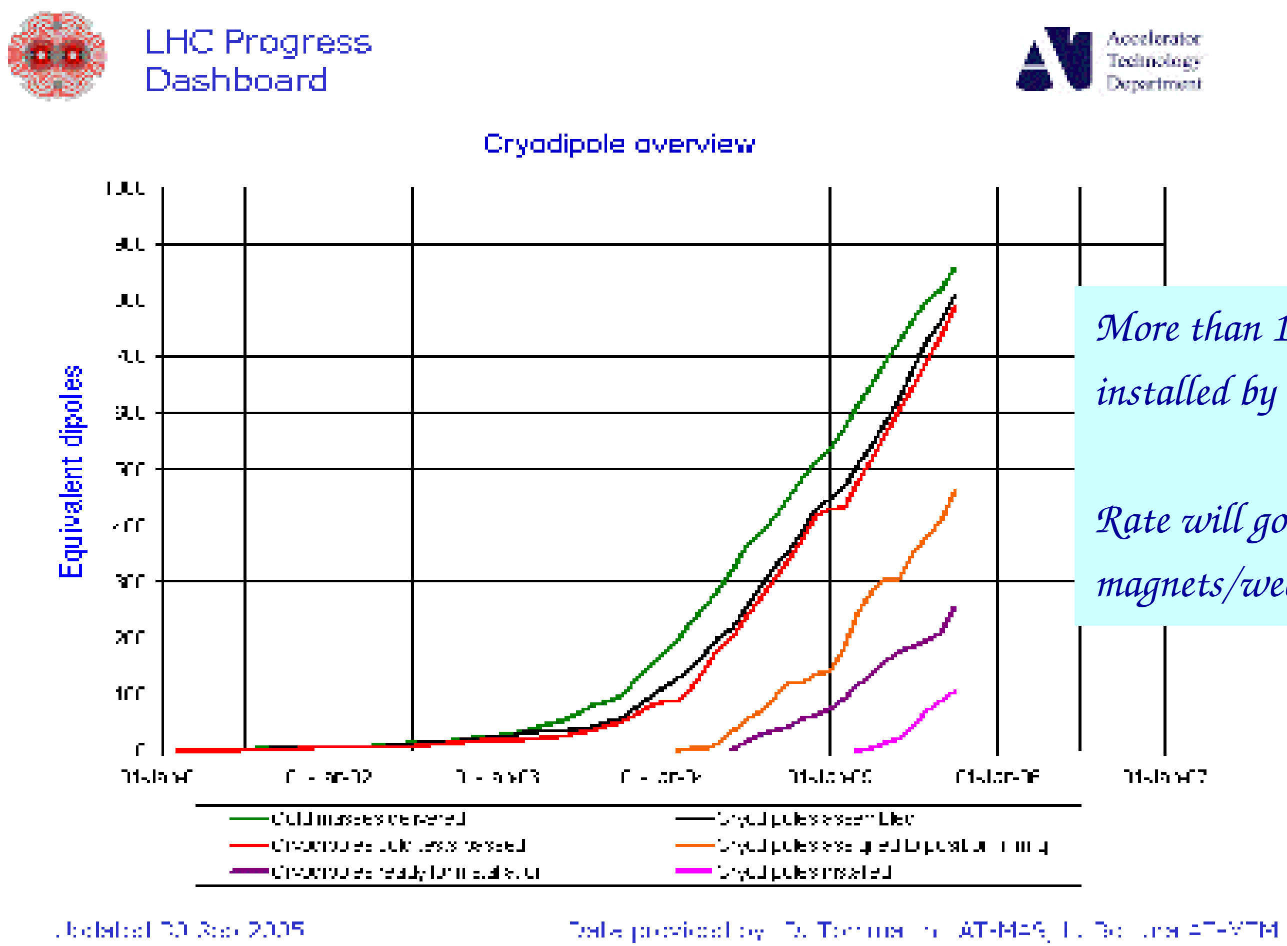
Albert De Roeck

CERN and University of Antwerp

The LHC is Coming!



The LHC Progress



More than 100 dipoles installed by now

Rate will go up to 20 magnets/week

Crucial part: 1232 superconducting dipoles

Can follow progress on the CERN web page (dashboard)

http://lhc-new-homepage.web.cern.ch/lhc-new-homepage/

When will LHC Start?

Go to the 11th floor (LPC)

You'll find: first collisions at the LHC are

617 days and 14 hours away

$\Longrightarrow$ *In other words 1 July 2007*

Close!

But not quite correct according to the latest official plan

When will LHC Start? (take two)

- When will they close the LHC/inject beams (Detector experimentalists)
- When will be first collisions in the LHC? (Analysis experimentalists)
- When will we have first physics results from the LHC? (Theorists)
- When will we have the new big discoveries at the LHC? (Politicians thinking on whether to finance an International Linear Collider)

Picture becoming more clear now after the cryogenic line problem (and solution): according to the current plan (*)

- LHC will be closed and set up for beam on 1 July 2007
- First beam in machine: August 2007
- LHC commissioning will take time!
- First collisions expected in November 2007 (739 days and 14 hrs away)
- Followed by a short pilot run
- First physics run in 2008 (starting April/May; one to a few fb^{-1}?)
- First big discovery ?? …but see last slide in this talk

(*) M. Lamont at the TeV4LHC Workshop @CERN 30/4

First Collisions: November 2007?

43 on 43 Bunches with 3 to 4 x 10^{10} ppb to 7 TeV

- *No parasitic encounters*
  - *No crossing angle, No long range beam, Larger aperture*
- *Instrumentation (testing)*
- *Good beam for RF, Vacuum…*
- *Lower energy densities*
  - *Reduced demands on beam dump system*
  - *Collimation*
  - *Machine protection*
- *Luminosity* 2×10^{31} $cm^{-2}s^{-1}$ *at a* β^* *of 1 m (ultimate)*

Achtung!! Lumi numbers are my private guess, using 10^7 sec/year. Not official numbers released by the machine Group!

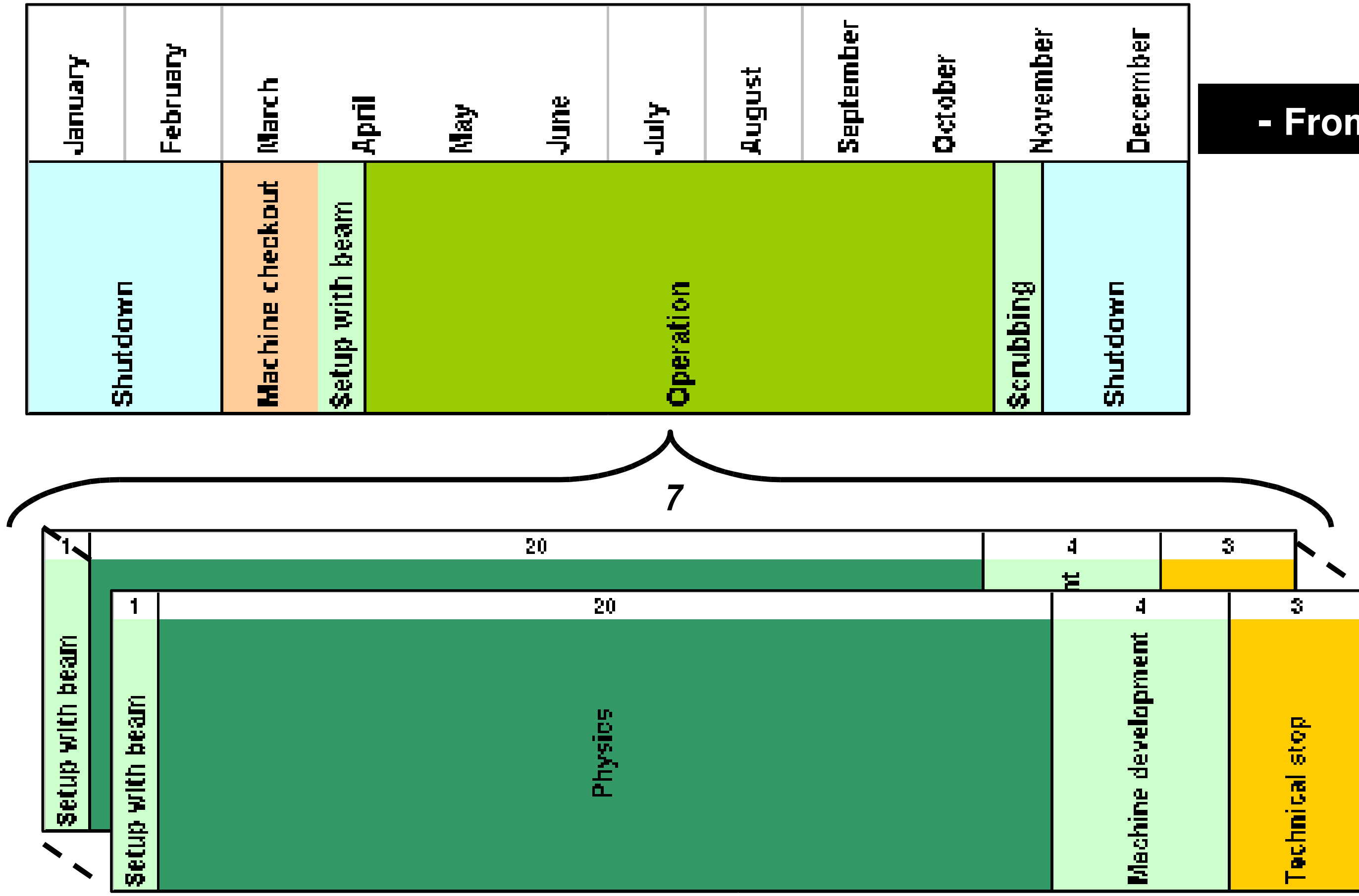
Pilot run $\Rightarrow$ *maybe a few weeks of collisions in 2007: ~10-20* pb^{-1} *?*

2008: 75 nsec + low intensity 25ns $\Rightarrow$ *expect O(1)* fb^{-1}

2009: 25ns half intensity $\Rightarrow$ *expect O(10)* fb^{-1}

Breakdown of a year (startup)

R. Bailey
9/22/05
CMS week



- From Chamonix XIV -

~ 140 days for physics per year
Not forgetting ion and TOTEM operation
Leaves ~ 100 days for proton luminosity running
? Efficiency for physics 40% ?
~ 40 days ~ 1000 h ~ 4 10^6 s of colliding beams / year

Historical Perspective

1982: first run of UA1/UA2 (CMS energy 10x higher than ISR)

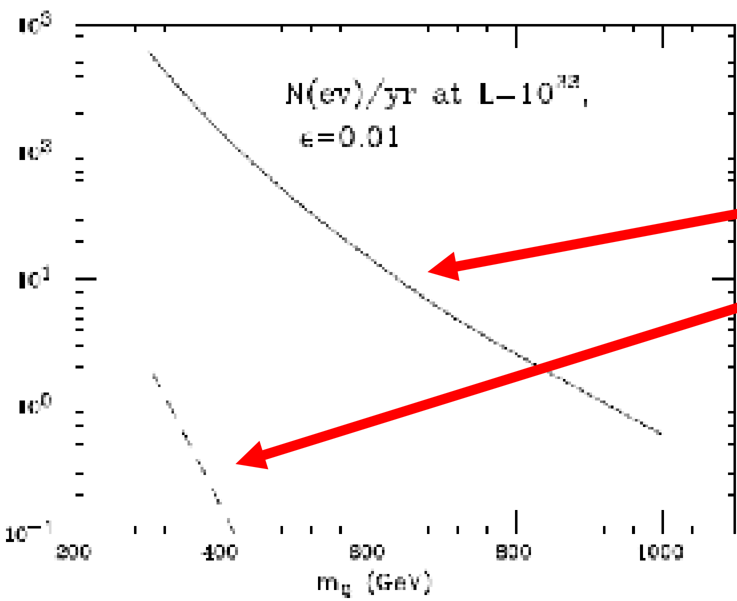
30 days with 5• 10^{28} $cm^{-2}s^{-1}$ (~ 1% of final one) ⟹ 20 nb^{-1}

⟹ *W,Z Discovery!*

1987: first run of CDF (CMS energy 3x times higher than SppS)

30 days with 5• 10^{28} $cm^{-2}s^{-1}$ (~ 1% of design one) ⟹ 20 nb^{-1}

⟹ *No Early discoveries: Top showed up in 93-94 runs*



Production rate for new heavy (s)quarks as function of mass for

LHC (14TeV)

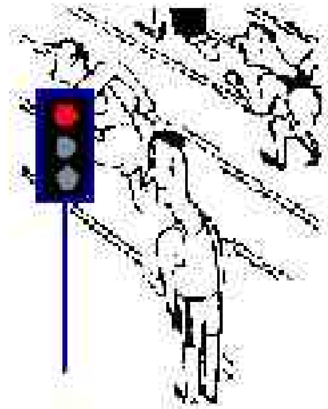
Tevatron (2TeV)

LHC energy 7 times higher than Tevatron ⟹ ???

We have to be ready for it!!

Detectors at Start-up

❷ Which detectors the first year ?



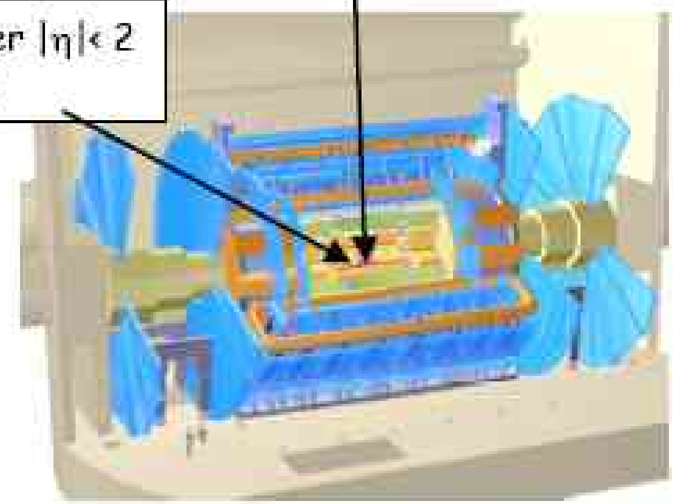
RPC over |η|<1.6 (instead of |η|< 2.1)
4th layer of end-cap chambers missing

Pixels and end-cap ECAL
installed during first shut-down

2 pixel layers/disks instead of 3 ?

Detectors will be fairly complete at start-up

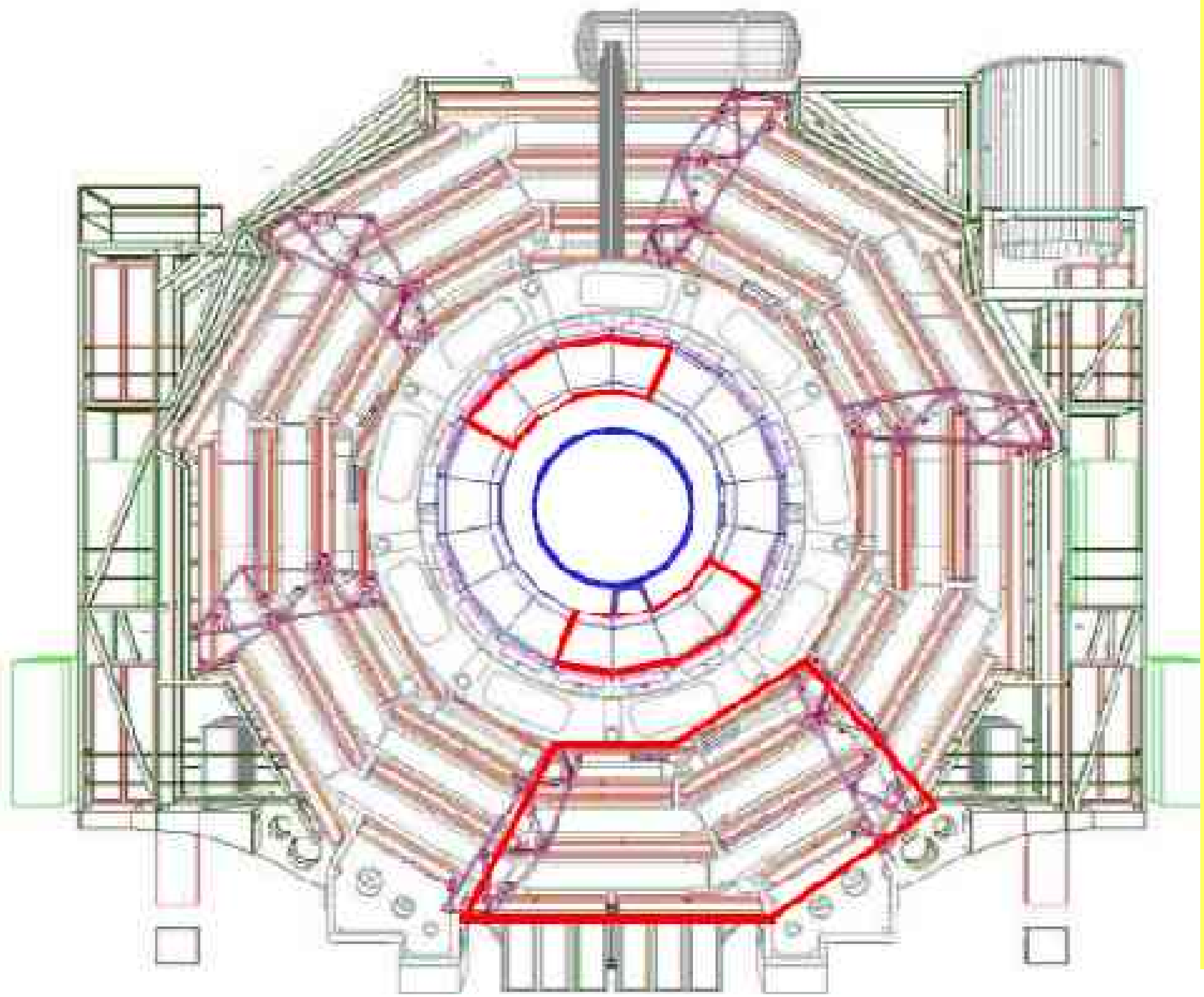
TRT acceptance over |η|< 2
(instead of |η|< 2.4)



Both experiments:
deferrals of high-level Trigger/DAQ processors
→ LVL1 output rate limited to
~ 50 kHz CMS (instead of 100 kHz)
~ 40 kHz ATLAS (instead of 75 kHz)

Impact on physics visible but acceptable
Main loss : B-physics programme strongly reduced (single μ threshold p_T ≈ 14-20 GeV)

2006: CMS Cosmic Data Challenge



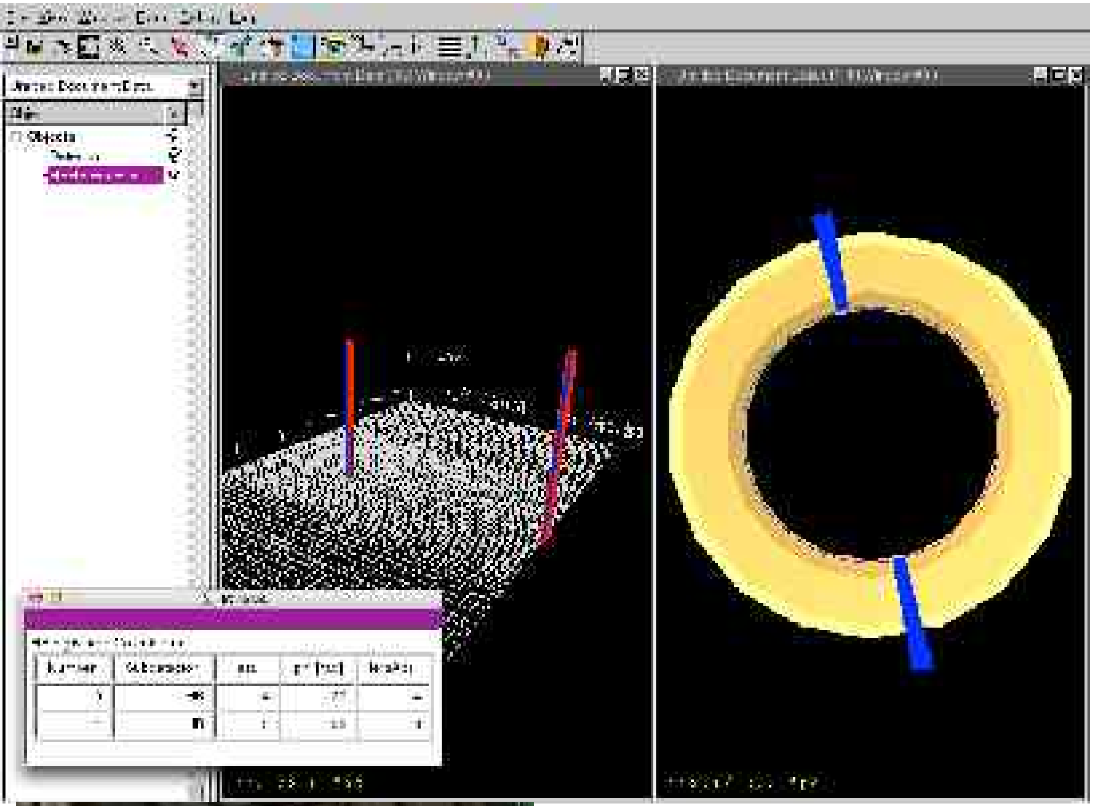
Detector readiness preparation: Important milestone for 2006⟹

The cosmic data challenge

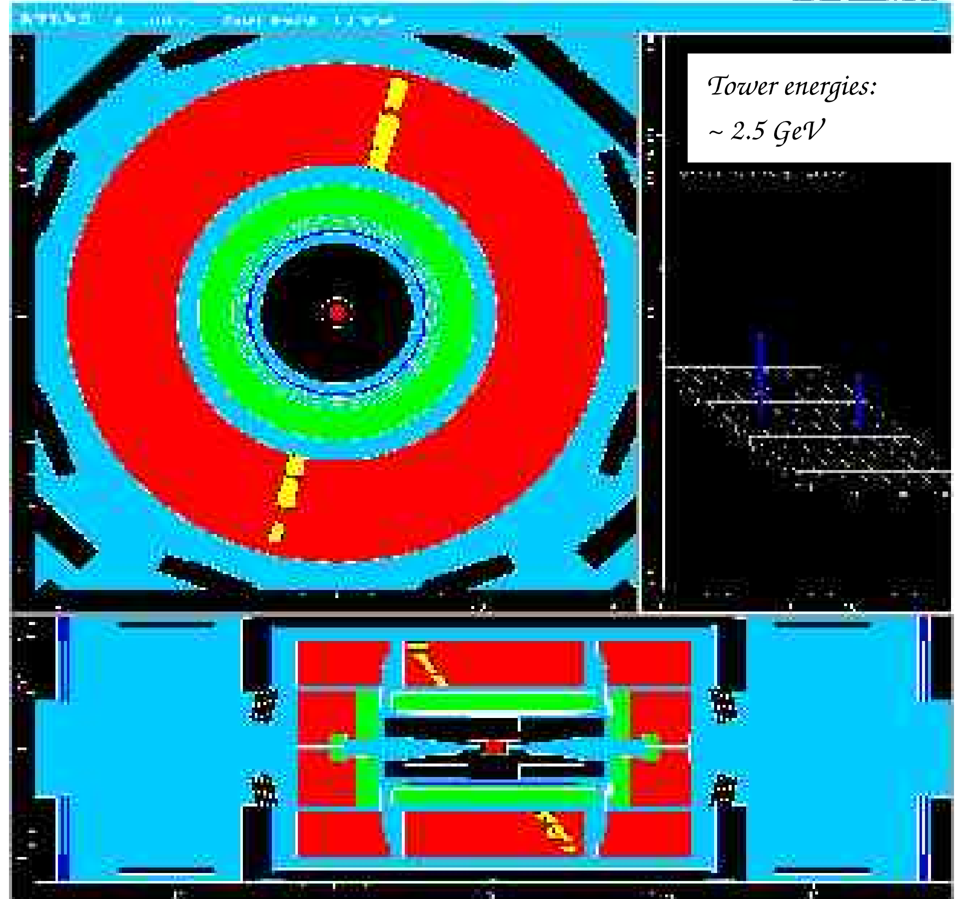
Combined operation of the subdetector systems (on surface)

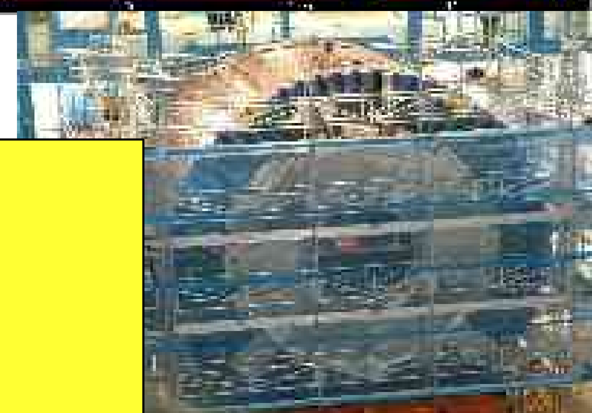
Similar to the combined beamtest of ATLAS in 2004 (a lot of sweat!!)

Include experience in Vol2.1 of PTDR



Cosmic muons observed by CMS at IP5 (recorded by hadron barrel calorimeter)

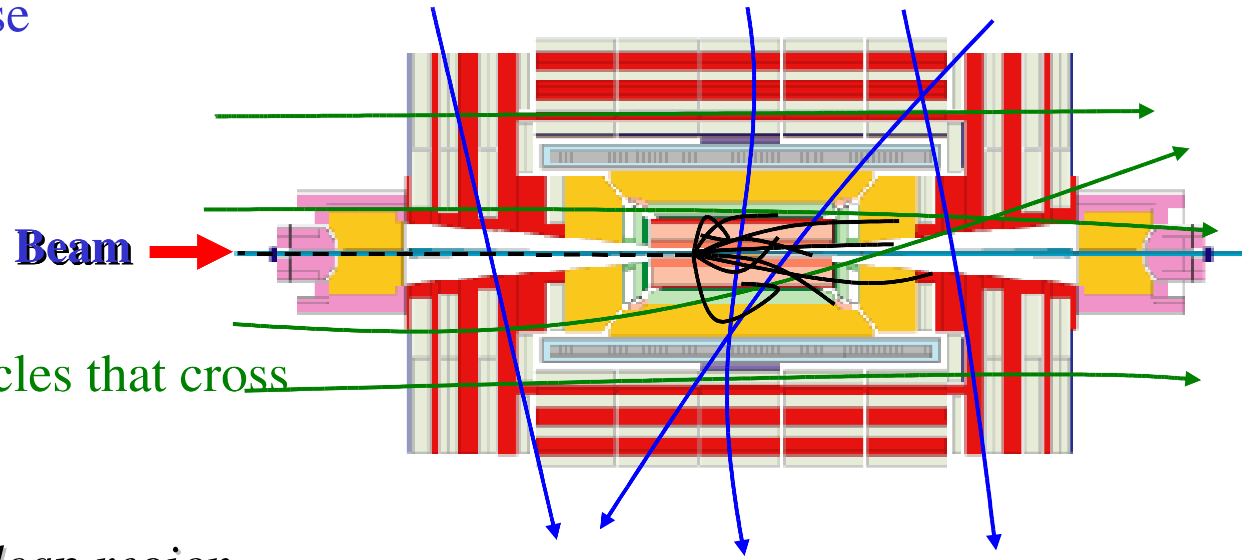




Cosmic muons observed by ATLAS in the pit (recorded by hadron Tilecal calorimeter)

Calibrating/Alignment Before Collisions

Experiments will have ~3-4 months before collisions



Cosmic Muons

High energetic muons that traverse the detector vertically

→particular useful for alignment and calibration - *barrel region.*

Beam Halo Muons (Hadrons)

Machine induced secondary particles that cross the detector almost horizontally

→particular useful for alignment and calibration - *endcap region.*

Beam Gas Interactions

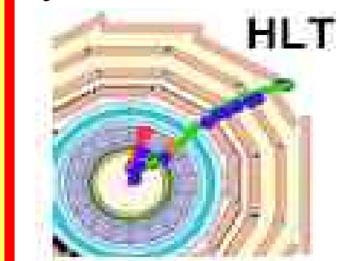
Proton-nucleon interaction in the active detector volume (7TeV →E_{cm}=115 GeV)

→resemble collision events but with a rather soft p_T spectrum (p_T<2 GeV)

All three physics structures are interesting for alignment, calibration, gain operational experience, dead channels, debug readout, etc …

Major Commissioning Challenges

Efficient op… System

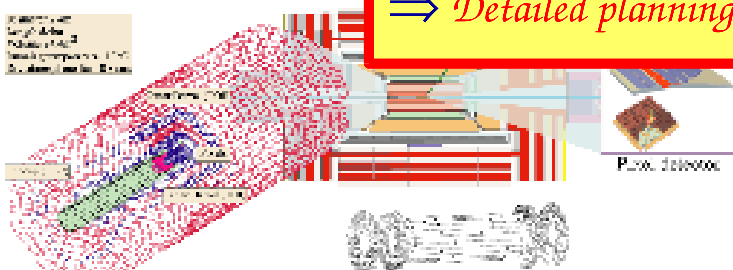


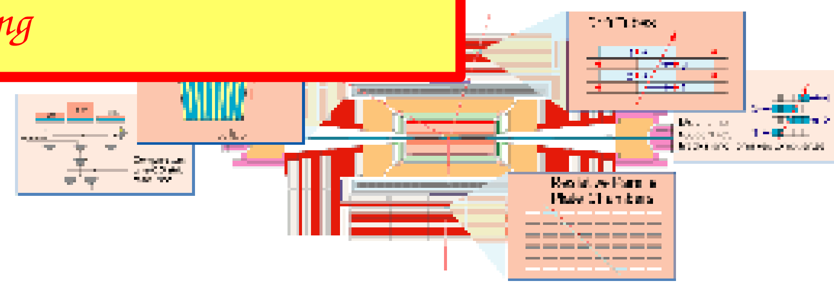
Important Run II reminder/lesson
(TeV4LHC Sep 2004)

Experiments will need to give priority to detector commisioning at the start (triggers, special data samples, etc.)

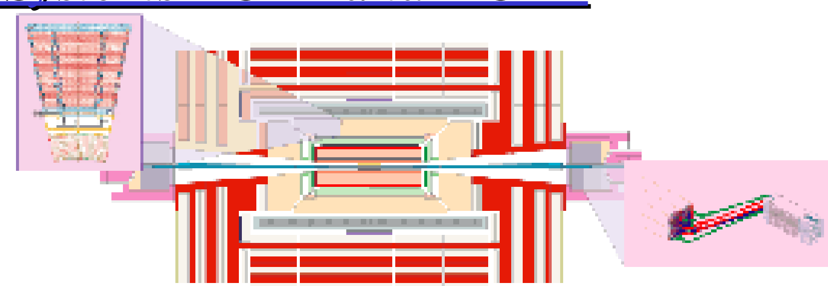
$\Rightarrow$ *Detailed planning starting*

Alignment of the … d Muon System





Calibration of the Calorimeter Systems ECAL and HCAL



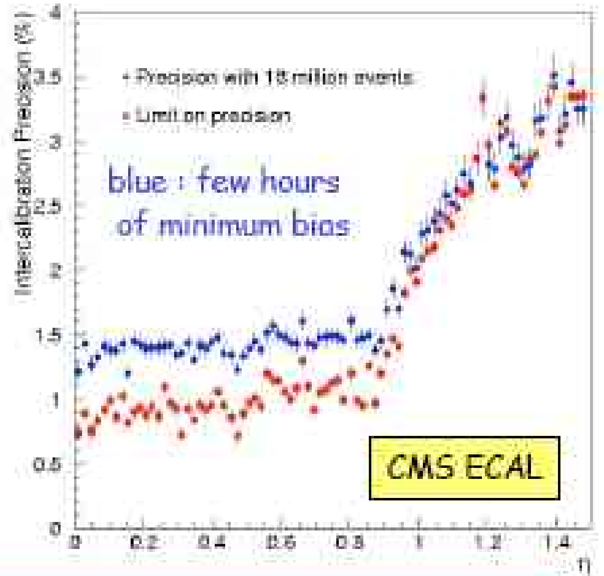
→form the base for the "commissioning of physics tools" like b and τ tagging, jets, missing E_T …

Detectors at Start-up for Physics

Which detector performance on day one ?

A few examples and educated guesses
based on test-beam results and simulation studies

Gianotti, Mangano hep-ph/0504221



	Expected performance day 1	Physics samples to improve (examples)
ECAL uniformity e/γ scale	~ 1% (ATLAS), 4% (CMS) 1-2 % ?	Minimum-bias, Z→ ee Z → ee
HCAL uniformity Jet scale	2-3 % < 10%	Single pions, QCD jets Z (→ ll) +1j, W → jj in tt events
Tracking alignment	20-500 μm in Rφ ?	Generic tracks, isolated μ , Z → μμ

Ultimate statistical precision achievable after few days of operation. Then face systematics ....
E.g. : tracker alignment : 100 μm (1 month) → 20μm (4 months) → 5 μm (1 year) ?

Early Physics at the LHC and Tevatron

- *Important asset: Tevatron has data!!*
  - *Physics studies at LHC are monte carlo exercises*
- *Topics where the Tevatron can help*
  - *MC tuning/validation: starting point for the LHC*
    - *Eg. Underlying events, minimum bias tune*
  - *Measurements of cross sections and validation of the theoretical estimates (K Factors, NLO MCs,…)*
  - *Optimum measurements to compare with theory: eg jets algorithms*
  - *Systematic errors for studies: experience/procedures: eg. ISR/FSR*
  - *Precision measurements:* M_{top}, M_{W},…
  - *Experience with luminosity measurement techniques*
  - *Techniques to deal with event pile-up*
  - *B-tagging techniques*
  - *Demonstrate that certain measurements can be done/methods can be applied: eg* $Z \rightarrow \tau\tau$ *measurements*

Note: plan to organize a second MC4LHC workshop mid July 2006 (17-26?)

Expected Event Rates

Process	Events/s	Events/year	Other machines
$W \rightarrow e\nu$	15	10^8	10^4 LEP / 10^7 Tev
$Z \rightarrow ee$	1.5	10^7	10^7 LEP
$t\bar{t}$	0.8	10^7	10^4 Tevatron
$b\bar{b}$	10^5	10^{12}	10^8 Belle/BaBar
$\tilde{g}\tilde{g}$ (m=1 TeV)	0.001	10^4	—
H (m=130 GeV)	0.02	10^5	—
QCD jets $p_T > 200$ GeV	10^2	10^9	10^7

1 day at LHC = several years at other machines

10 fb^{-1}

Huge event rates:

($10^{33} cm^{-2} s^{-1}$)

The LHC will be a W-factory, a Z-factory, a top factory, a Higgs factory etc..

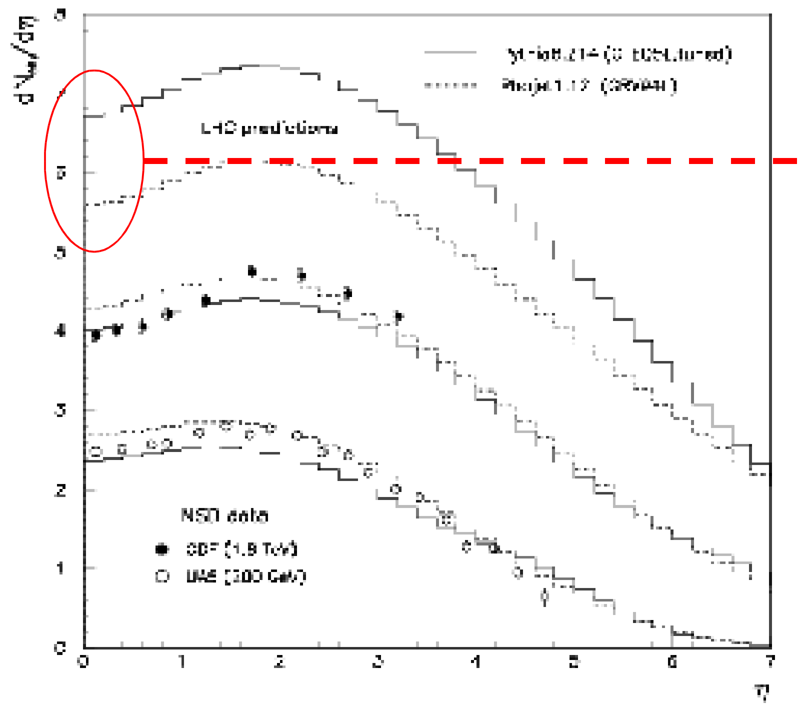
Precision physics will be limited by systematics

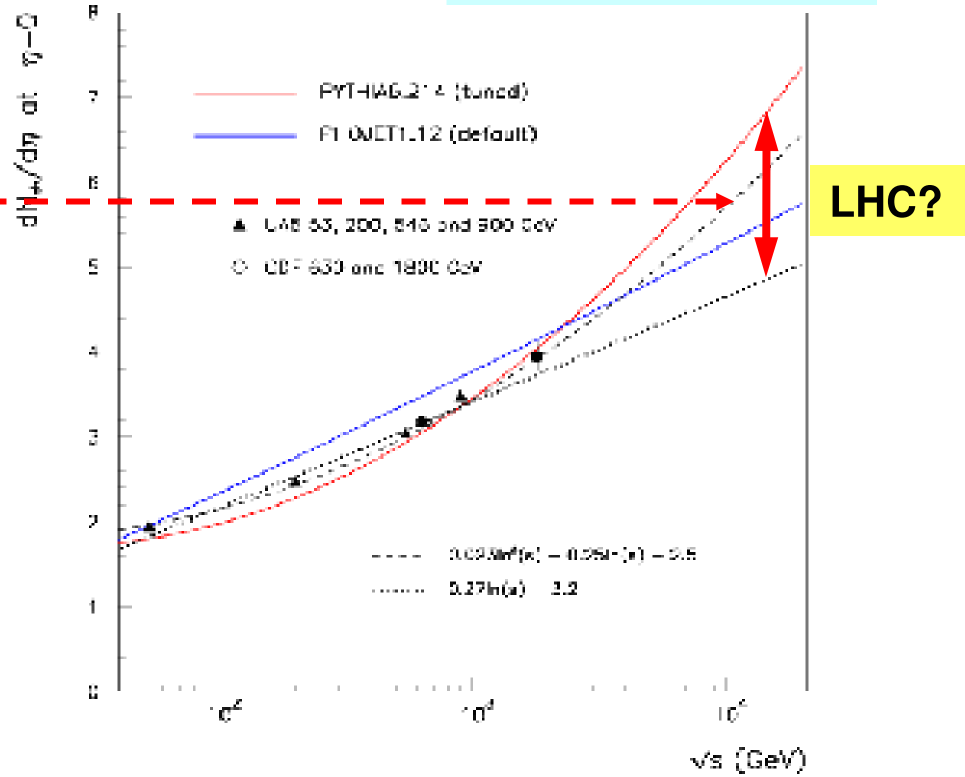
Note: pilot run
10^4 top pairs,
10^6 QCD jets

Early Minimum-Bias Measurements

E.g. charged particle density

The pile-up for the future



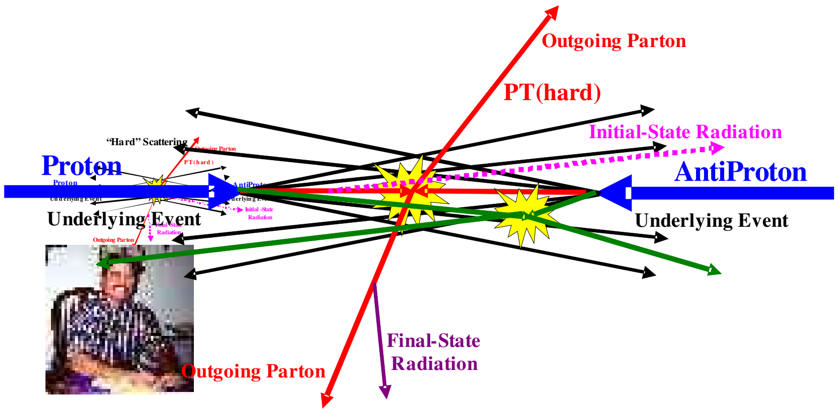


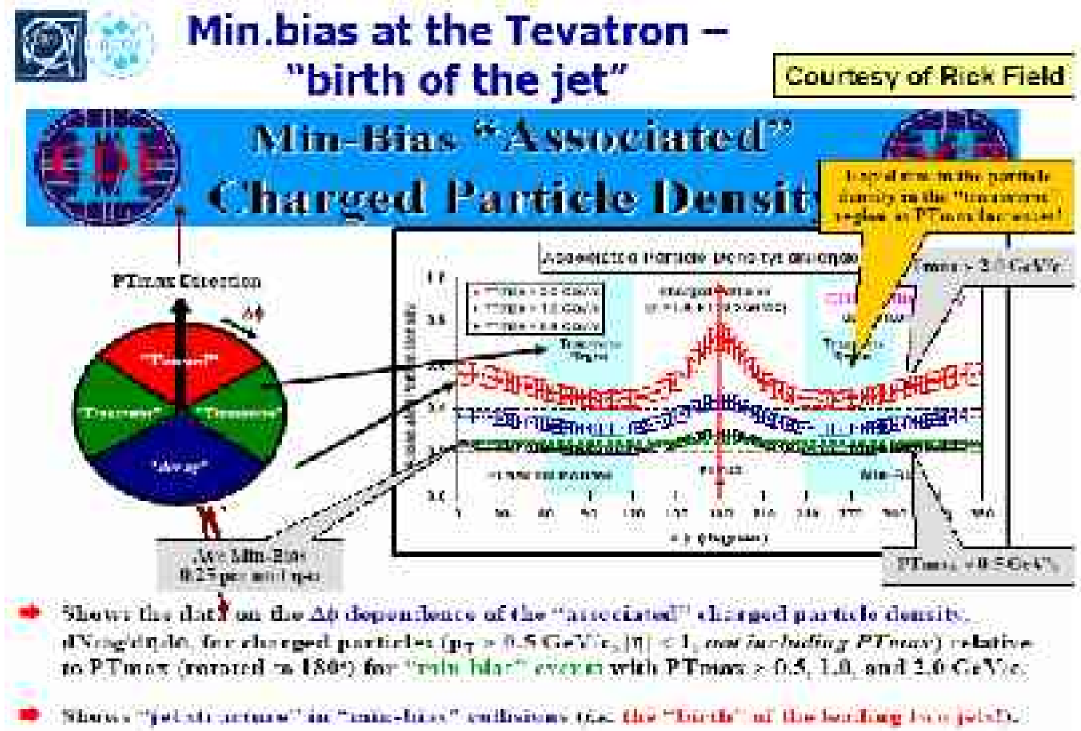
- *Energy dependence of dN/dη ?*
- *Vital for tuning Underlying Event model*
- *Only requires a few thousand events.*

• PYTHIA models favour ln²(s);
• PHOJET suggests a ln(s) dependence

We need to be ready for such measurements (particle spectra etc,…)

Minimum Bias and Underlying Event





Being studied in great detail at the Tevatron

This is very important!

New developments (this workshop)

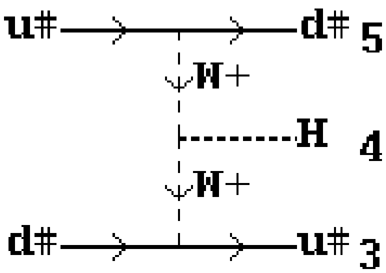
- *Corrected data! Important for future comparisons*
- *Include also energy flows*
- *Other processes, such as Drell-Yan*
- *New models to compare to (PYTHIA 3.2, Jimmy…)*

Systematic uncertainty!

These studies will have to be repeated at the LHC early on.

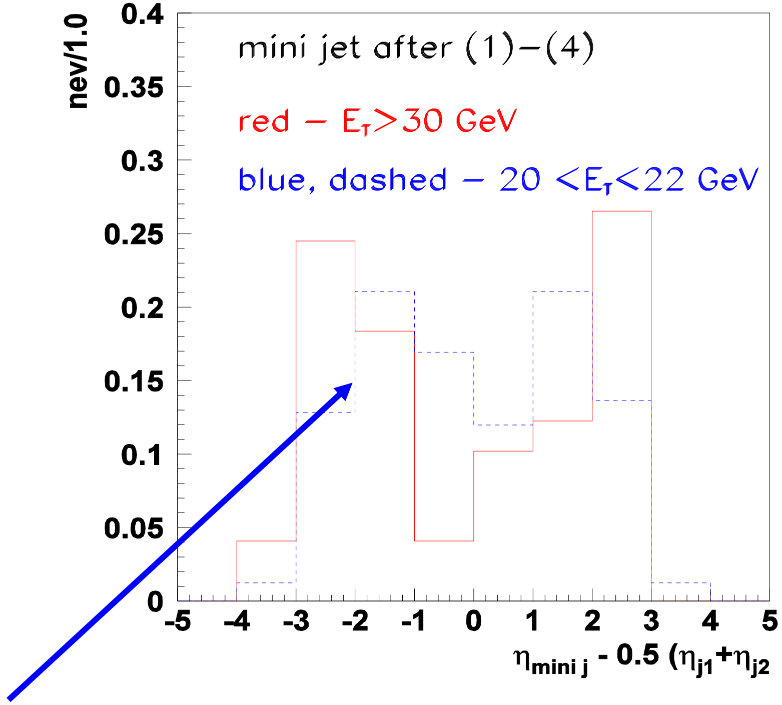
Energy dependence will help to understand the PHYSICS of the UE

Effect of underlying event on central jet veto in VBF Higgs



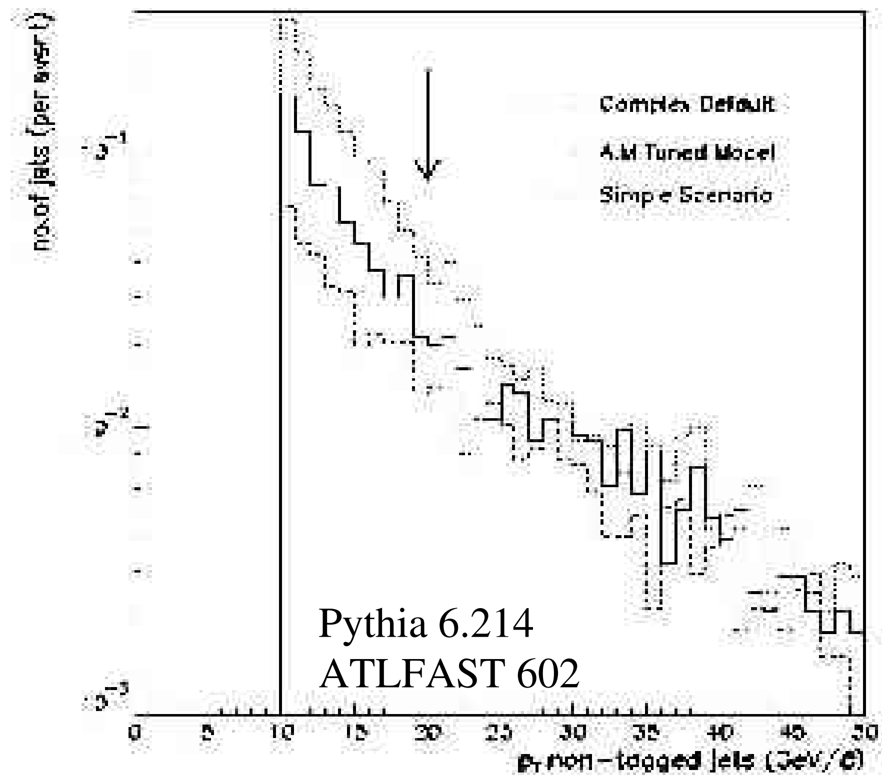
H->WW*->2l in qqH prod.

Rapidity of the central jet in Higgs events; CMS; full simulation, $L=2x10^{33} cm^{-2}s^{-1}$



"bkg. like" behaviour for soft jets; fake jets: pile up+UE+detector

Uncertainty of the central jet veto efficiency due to UE model; ATLAS.

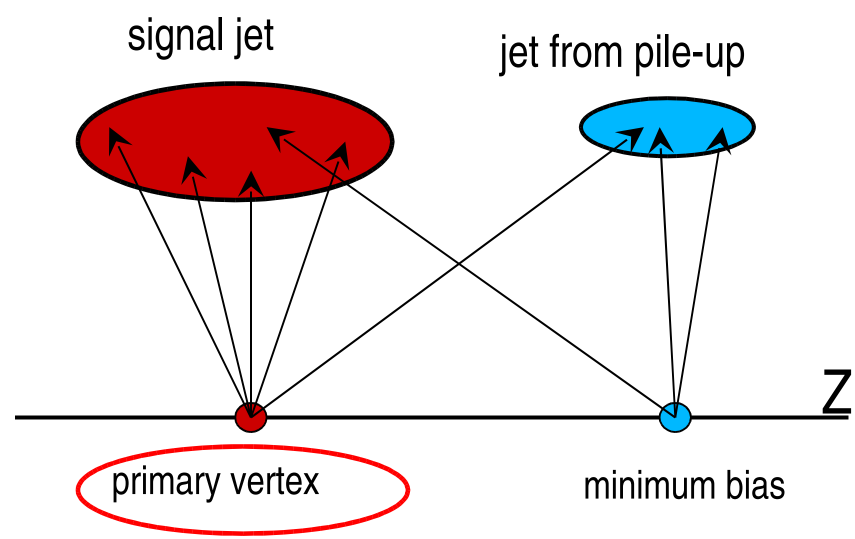


Model	CJV efficiency	Significance
Default pythia	85%	**8.2**
Default DG	75%	**7.7**
AM tuning	79%	7.9

S. Nikitenko

Dealing with Pile-up

Eg. Identifying jets from the signal vertex



At Tevatron: $1.5 \bullet 10^{32}$ $cm^{-2}s^{-1}$

⟹ 5 pile up events on average

⟹ similar to $2 \bullet 10^{33}$ $cm^{-2}s^{-1}$ at the LHC

Can learn from the techniques used and developed at the Tevatron

Eg. Estimators based on fraction of tracks belonging to the true primary vertex

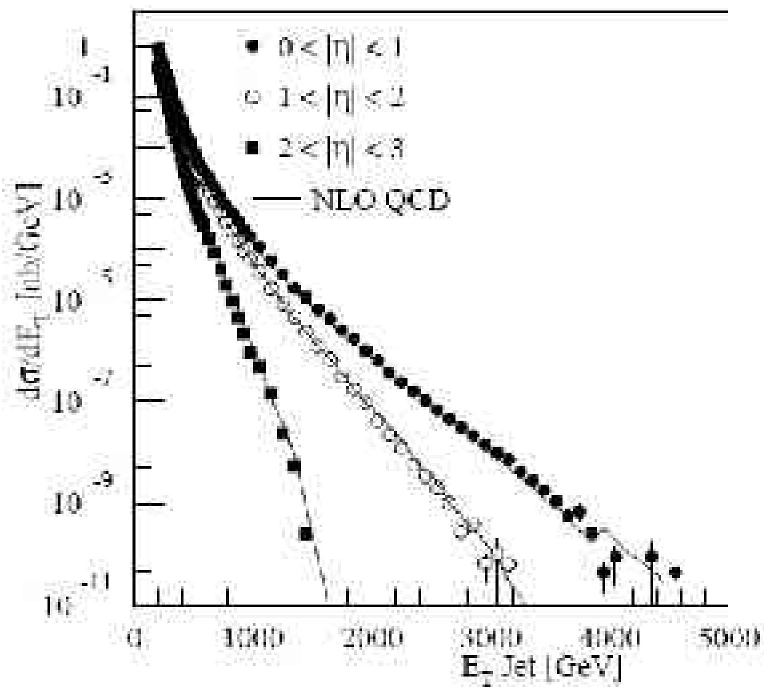
QCD Studies

E.g. Jet Physics

Huge cross sections:

Eg for 1 fb^{-1} ~ 10000 events with E_T> 1 TeV

100 events with E_T> 2 TeV



- *PDFs*
- *Jet shape*
- α_s
- *Diffraction*
- *BFKL studies*
- *New physics?*
- …

Tevatron:

Optimal jet algorithm to compare with theory: debate ongoing

- *Understanding QCD at 14 TeV will be one of the first topics at LHC*
- *Then: precise measurements of W,Z, tt, Drell-Yan production*
- *Then: W,Z+1 jet; W,Z+2 jets etc*

⟹ *Use to tune Monte Carlos*

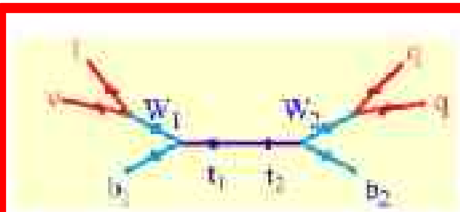
Top Quarks

Example of initial measurement : top signal and top mass

- Use gold-plated $t\bar{t} \to bW\ bW \to bl\nu\ bjj$ channel
- Very simple selection:
  - isolated lepton (e, μ) p_T > 20 GeV
  - -- exactly 4 jets p_T > 40 GeV
  - -- no kinematic fit
  - -- no b-tagging required (pessimistic, assumes trackers not yet understood)
- Plot invariant mass of 3 jets with highest p_T

Time	Events at 10^{33}	Stat. error δM_{top} (GeV)	Stat. error $\delta\sigma/\sigma$
1 year	3×10^5	0.1	0.2%
1 month	7×10^4	0.2	0.4%
1 week	2×10^3	0.4	2.5%

- top signal visible in few days also with simple selection and no b-tagging
- cross-section to ~ 20% (10% from luminosity)
- top mass to ~7 GeV (assuming b-jet scale to 10%)
- get feedback on detector performance : m_{top} wrong → jet scale ? gold-plated sample to commission b-tagging



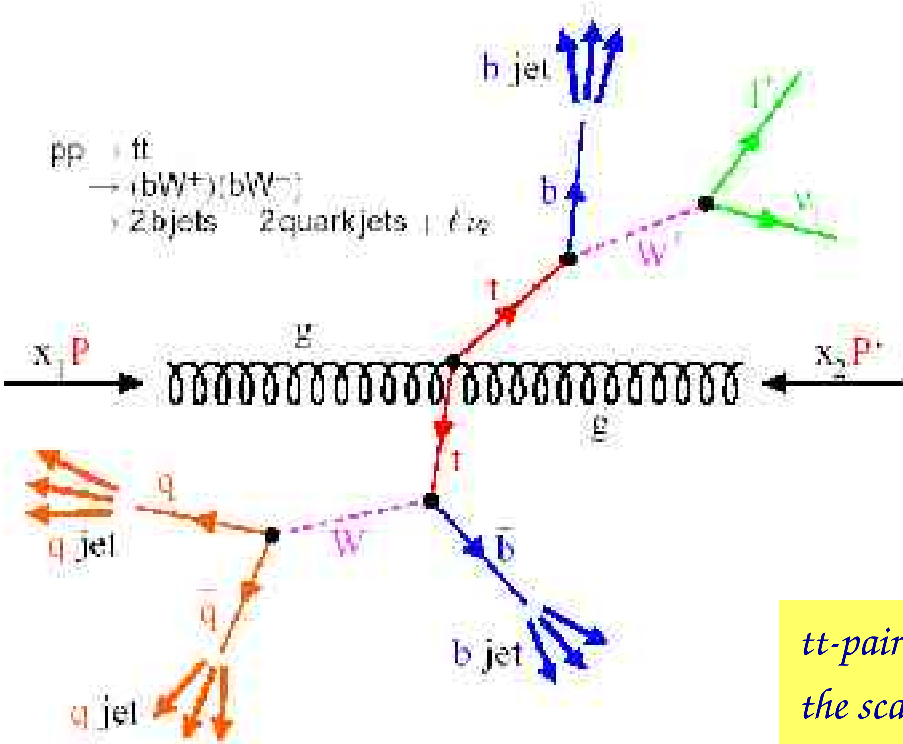
But most precise measurement will be from Tevatron for some time to come

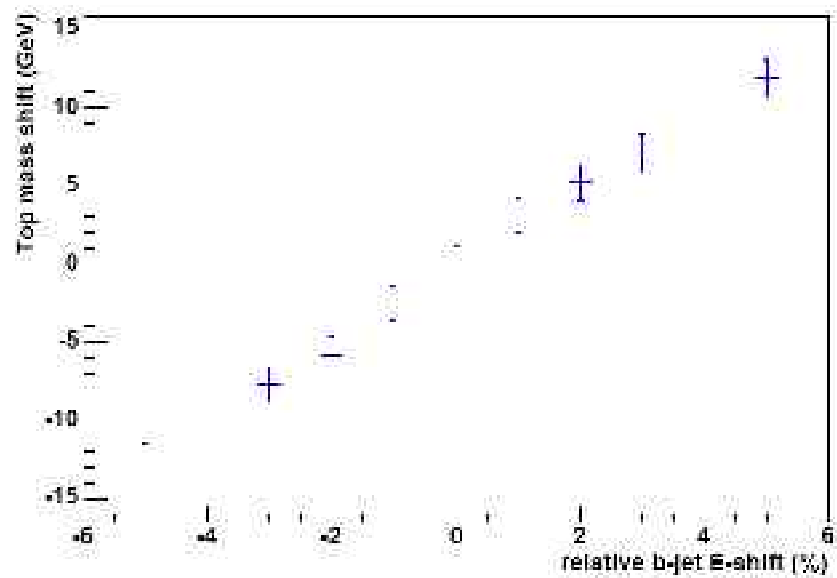
Top Quarks

Light Quark jet energy scale calibration using tt-pairs

Aim: reach 1-2 % precision with 1 fb^{-1}

Also b-tag efficiency etc.



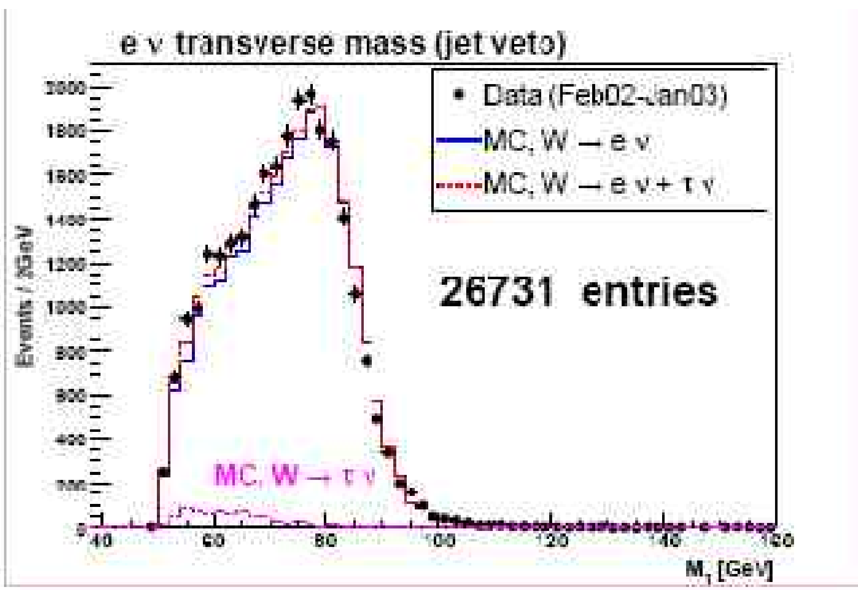


tt-pair events can also be used to determine the scale of b-jets. Constraint: top quark mass

Changing the top mass from, say 178 GeV to 172.7 changes the b-jet scale by >2%

Luminosity Techniques

Luminosity measurement is an challenging problem at the LHC
Similar techniques will be used as for previous colliders,
notable the Tevatron



New luminosity methods will be deployed as well,
Example: measuring W and Z rates

Expected O(3%) precision, dominant uncertainty will be the PDFs

Tevatron could already demonstrate that this works (Dittmar et al.)

What about early discoveries ?

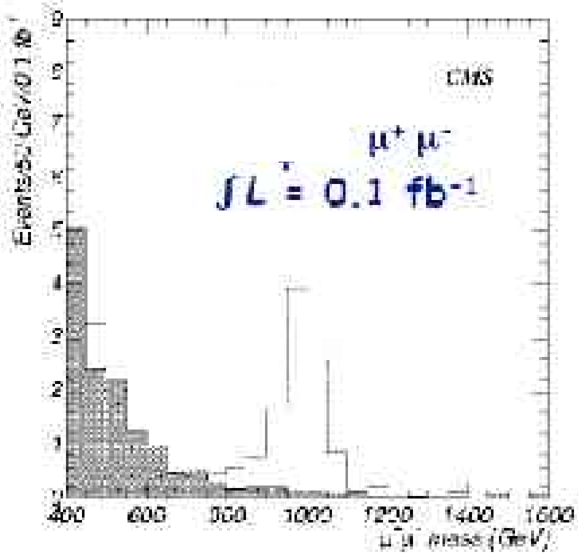
An easy case : a new resonance decaying into e+e-, e.g. a Z ' → ee of mass 1-2 TeV

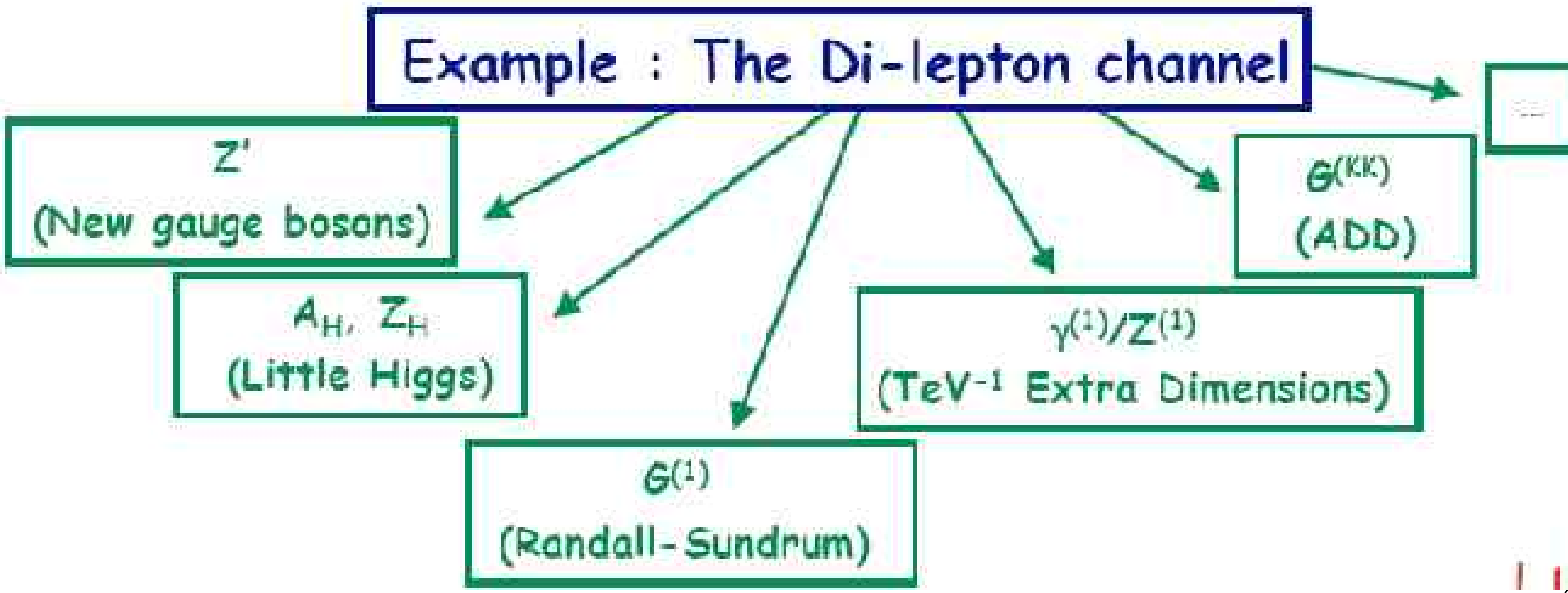
An intermediate case : SUSY

A difficult case : a light Higgs (m ~ 115 GeV)

Example: Di-lepton Resonance

May be seen very early: first weeks



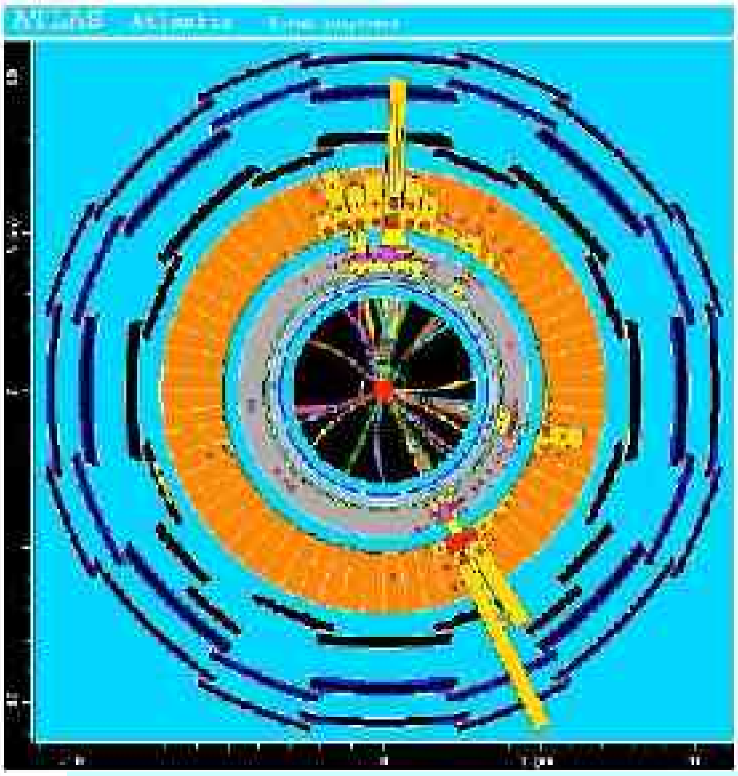


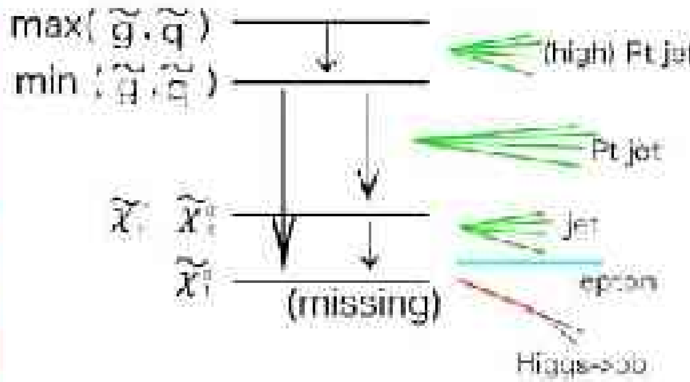
Supersymmetry

SUSY could be at the rendez-vous very early on!

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

10fb^{-1}





event topologies of SUSY

multi leptons
$\not{E}_T$ + High P_T jets + b-jets
τ-jets

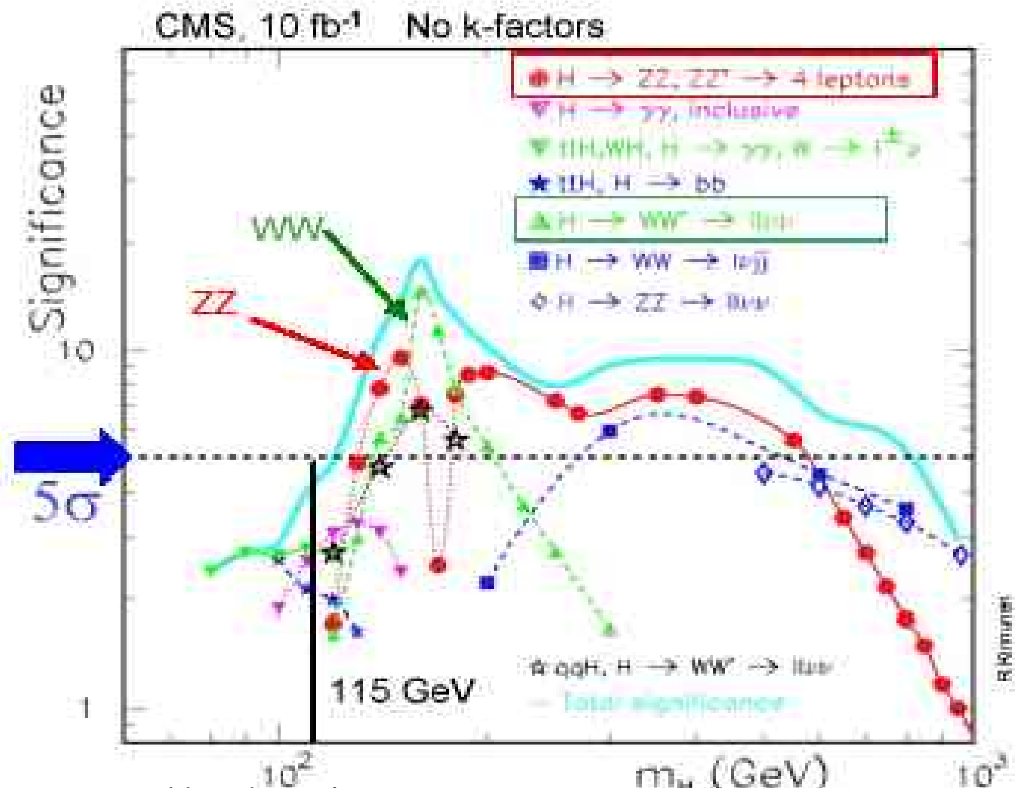
Therefore:
SUSY one of the priorities of the "search" program

Main signal: lots of activity (jets, leptons, taus, missing E_T)

Needs however good understanding of the detector & SM processes!!

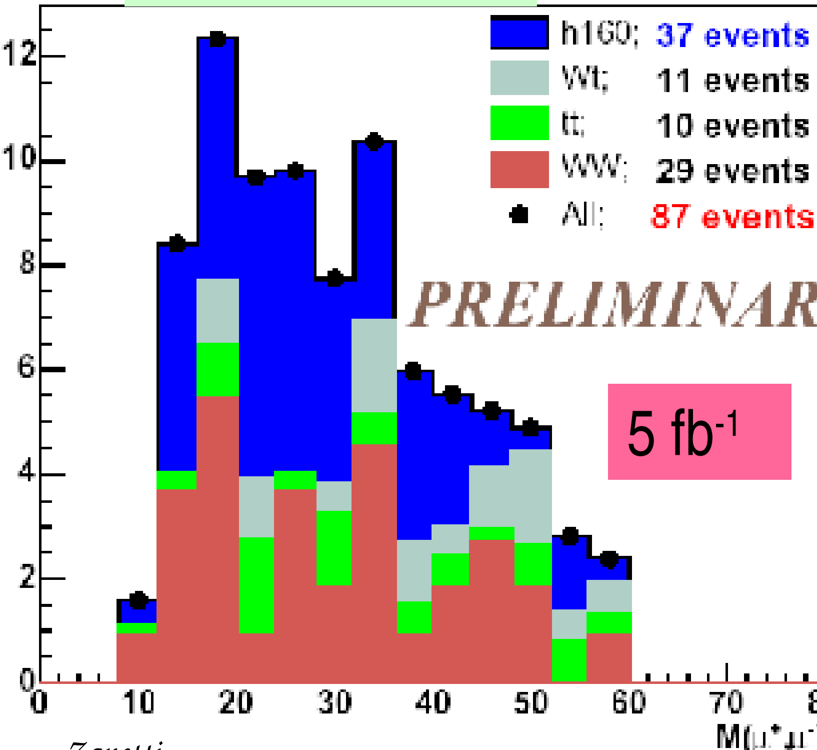
Note: establishing that the new signal is SUSY will be more difficult!

SM Higgs Discovery Prospects



Nikitenko et al

H→WW→μμνν



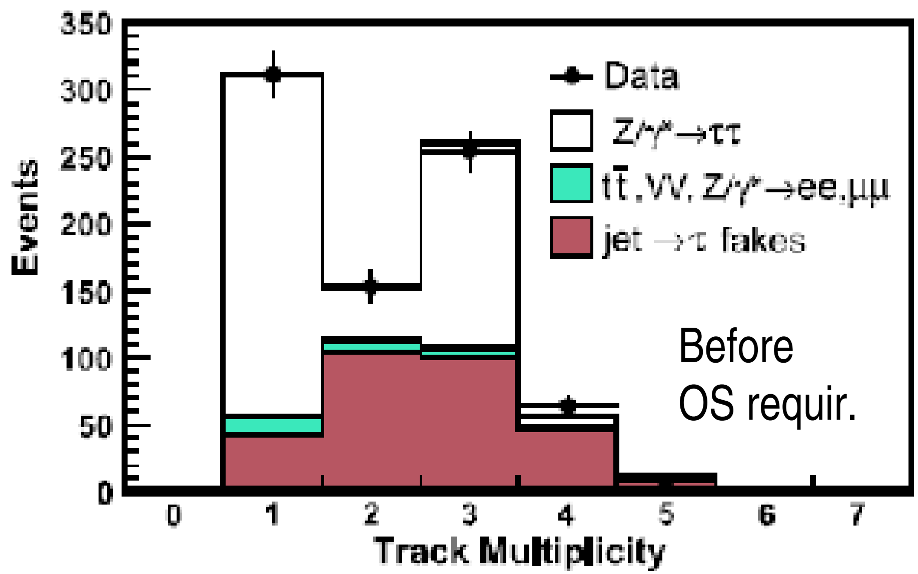
Zanetti

- *Generally need O(10) fb^{-1} for 5σ discovery*
- *Possible exception WW⟶ll νν at ~ 155-180 GeV (systematics?)*
- *Exclusion limits on large region of SM Higgs (H ⟶ZZ,WW)*

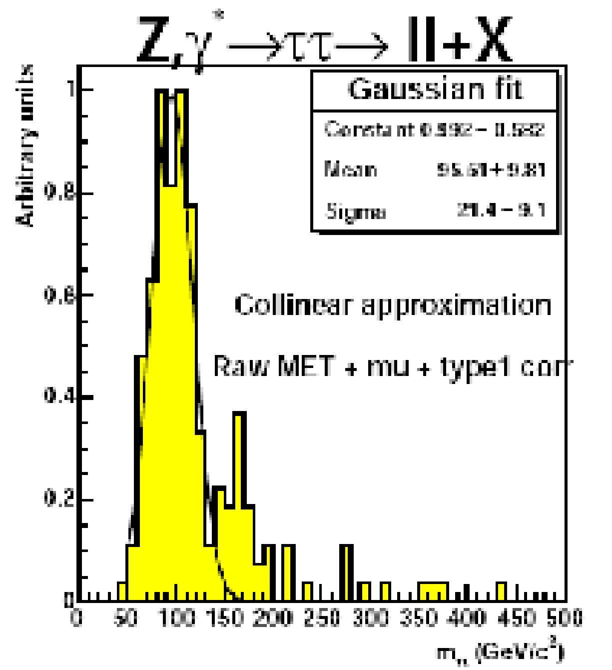
  MSSM Higgs (A ⟶ττ)

Measurement of Z→ττ

CDF Run II analysis of MSSM H->ττ with 310 pb^{-1} of data; hep-ex/0508051



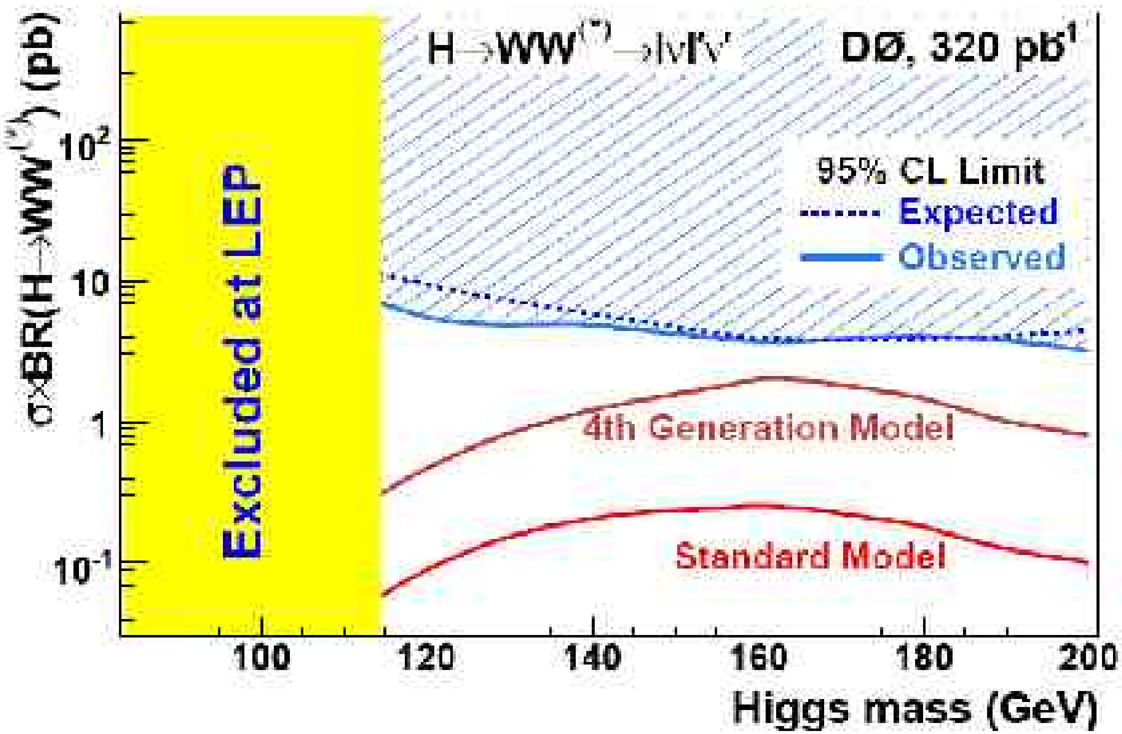
LHC



Eg: important cross check channel for A→ττ analyses at the LHC

The demonstration that this can be measured at Tevatron is important

Measurement of $H\to WW\to l l \nu\nu$



Important discovery channel at the LHC

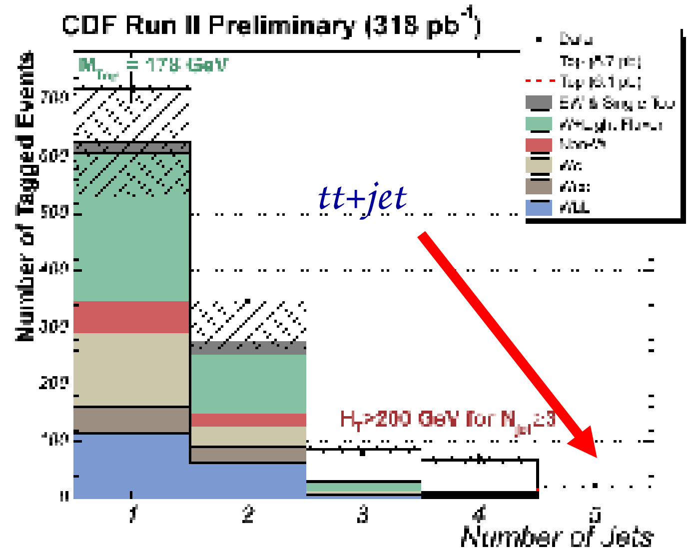
Techniques and systematics control achieved at the LHC are an important demonstration of the feasibility

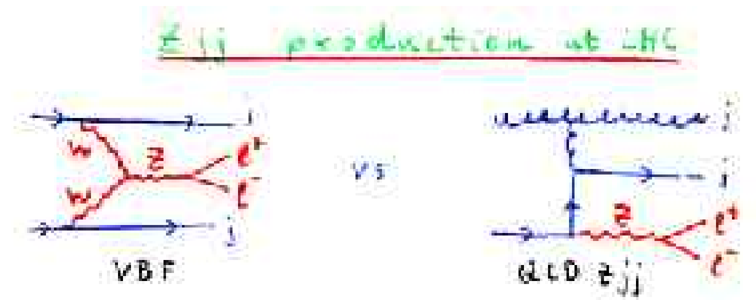
MC/Theory Calculation Validation

- *To discover new physics or discover the Higgs we need to understand the SM processes*
- *Measurements at the LHC and comparisons with MCs/calculations will be made early on (10-20% level)*
- *Important that these MCs/calculations are already well understood from comparison and validation with Tevatron data.*
- *In particular:*

QCD jets, tt, tt+ jet, ttjj, ttbb, single top, W and Z, W and Z + njets, WW, WZ, ZZ, Wbb, Zbb, Wcc, Zcc, VBF production of Z…

- *Some of these are being studied or can be reached with O(4) fb^{-1} (Tevatron 2007)*





Eg: QCD backgrounds

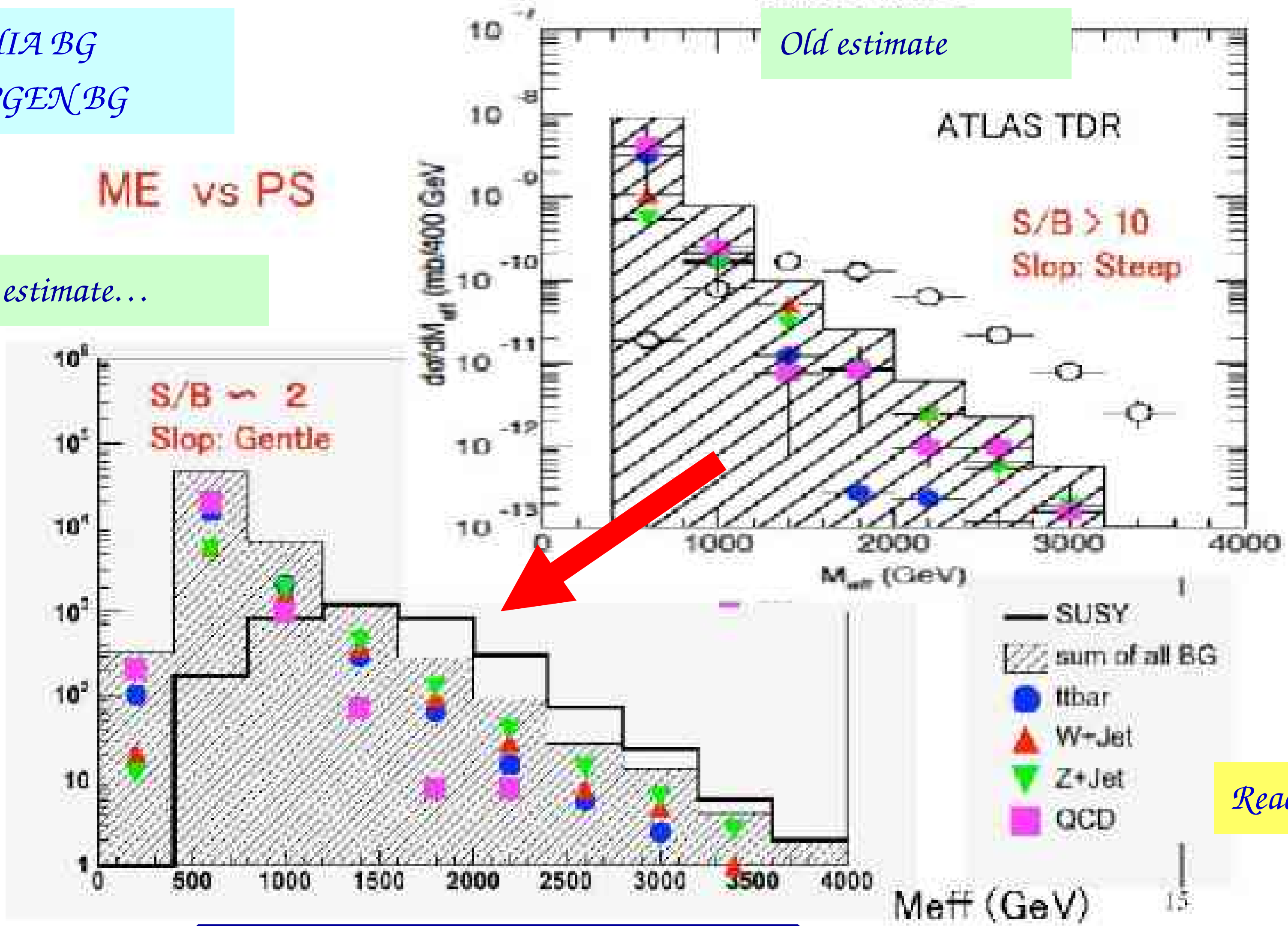
Old PYTHIA BG
New ALPGEN BG

ME vs PS

Old estimate

New estimate…

All jets
Final state



Reach lower?

$$M_{\text{eff}} = \Sigma_i \left| p_{T(i)} \right| + \not{E}_T$$

Effective mass

Summary

- LHC promises first collisions in 2007, but expect low luminosity:
  - Commissioning of detectors; QCD physics? Watch out for large signal new phenomena…
- First physics run in 2008: expect of O(1) to a few fb^{-1}.
  - Low mass SUSY reach extended far beyond Tevatron reach. Top quark/W mass measurements already dominated by systematics.
- Physics run in 2009: expect O(10) fb^{-1}.
  - SM Higgs mass range fully covered

    high mass SUSY…
- Tevatron can play a siginificant role in the

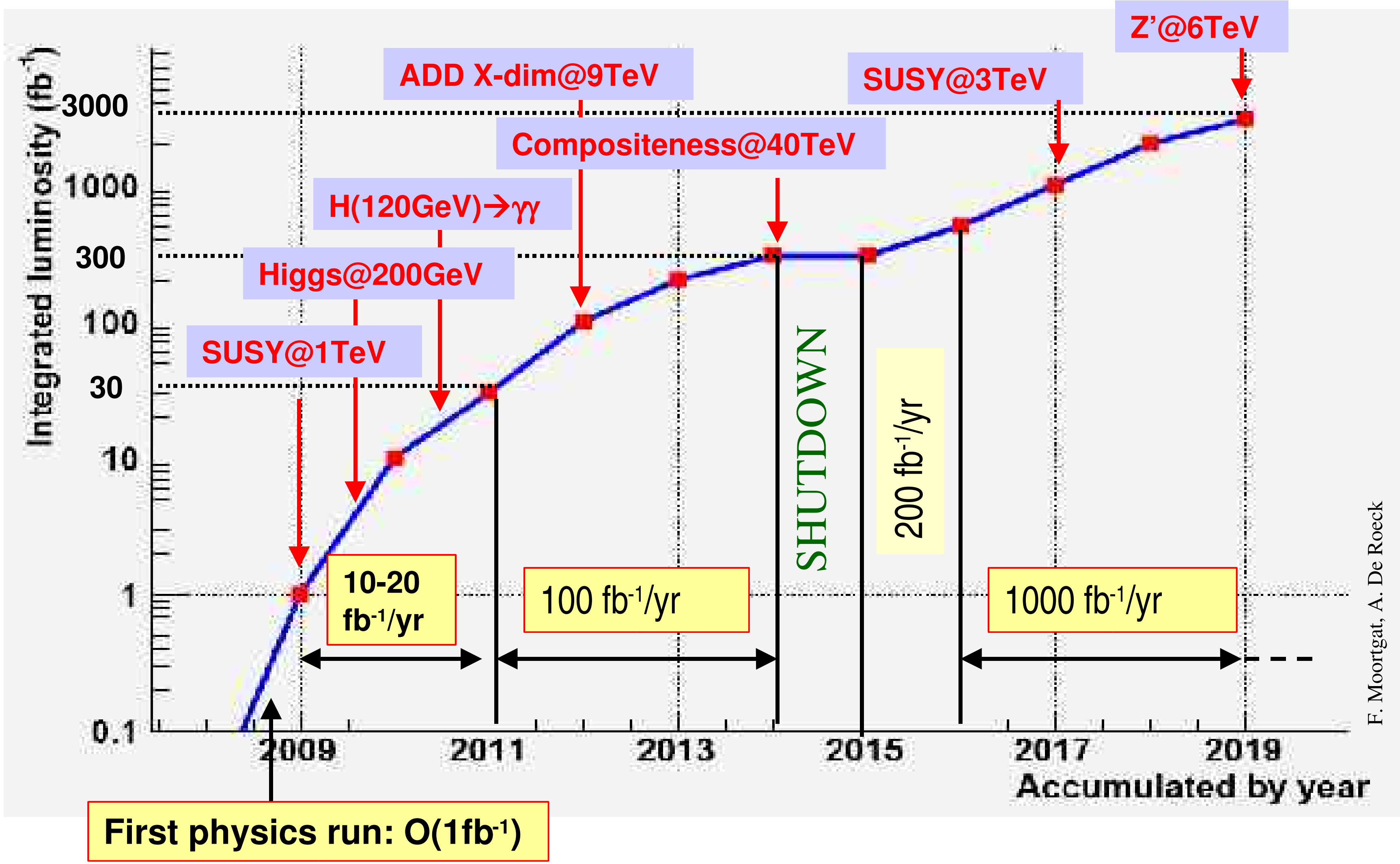
  successful startup of the LHC physics program.

  A lot to measure and techniques to validate
- Schedules are tight/lots of work ahead

  for us in the next two years

⇒ But it will be rewarding at the end

Discoveries?

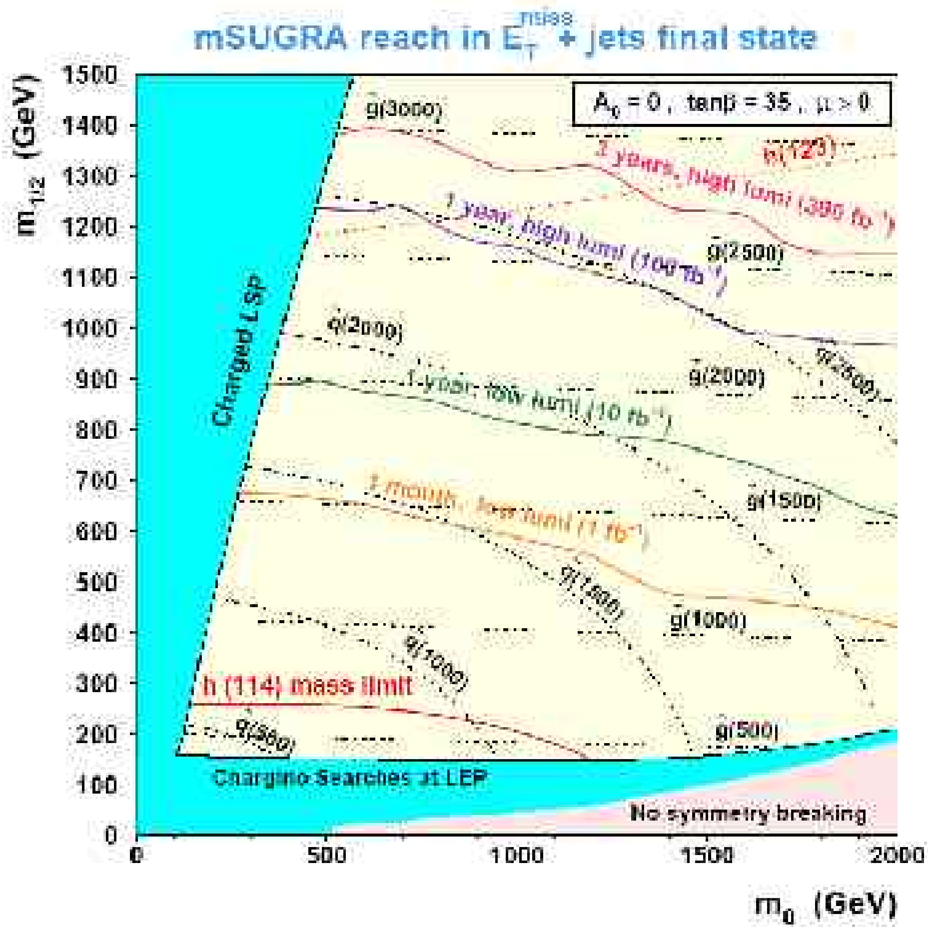


Backup

Contents

- *The current LHC schedule*
- *Preparing for physics in CMS and ATLAS*
- *First physics at the LHC*
- *Summary*

SUSY Reach vs Integrated Luminosity



* LM9

- *SUSY detectable for squarks & gluino masses up to 1-1.5TeV with 1 fb^{-1} $\longrightarrow$ all LM points are in that region. Good understanding of detector (e.g. E_{Tmiss}!) and Standard Model processes is needed.*

Dipoles: Waiting to be lowered after QRL repair

Transport in the tunnel

7th of March 2005

Lowering of the first dipole

Installing the dipole

Strategy at Start-up

Goal # 1

Understand and calibrate detector and trigger in situ using well-known physics samples

e.g. - $Z \to ee, \mu\mu$ — tracker, ECAL, Muon chambers calibration and alignment, etc.

- $tt \to bl\nu\ bjj$ — 10^3 evts/day after cuts → jet scale from $W \to jj$, b-tag perf., etc.

Understand basic SM physics at $\sqrt{s}$ = 14 TeV → first checks of Monte Carlos (hopefully well understood at Tevatron and HERA)

e.g. - measure cross-sections for e.g. minimum bias, W, Z, tt, QCD jets (to ~ 10-20 %), look at basic event features, first constraints of PDFs, etc.

- measure top mass (to 5-7 GeV) → give feedback on detector performance

Note : statistical error negligible after few weeks run

Goal # 2

Prepare the road to discovery:

-- measure backgrounds to New Physics : e.g. tt and W/Z+ jets (omnipresent ...)

-- look at specific "control samples" for the individual channels:

e.g. ttjj with j ≠ b "calibrates" ttbb irreducible background to ttH → ttbb

Goal # 3

Look for New Physics potentially accessible in first year (e.g. SUSY, some Higgs ? ...)

Detector Commisioning

Remember…

The only place where you will find
success before work is in the dictionary

May B. Smith

We will have to take this at heart in the next 3(+) years!