Physics with the first 100 inverse picobarns in ATLAS and CMS

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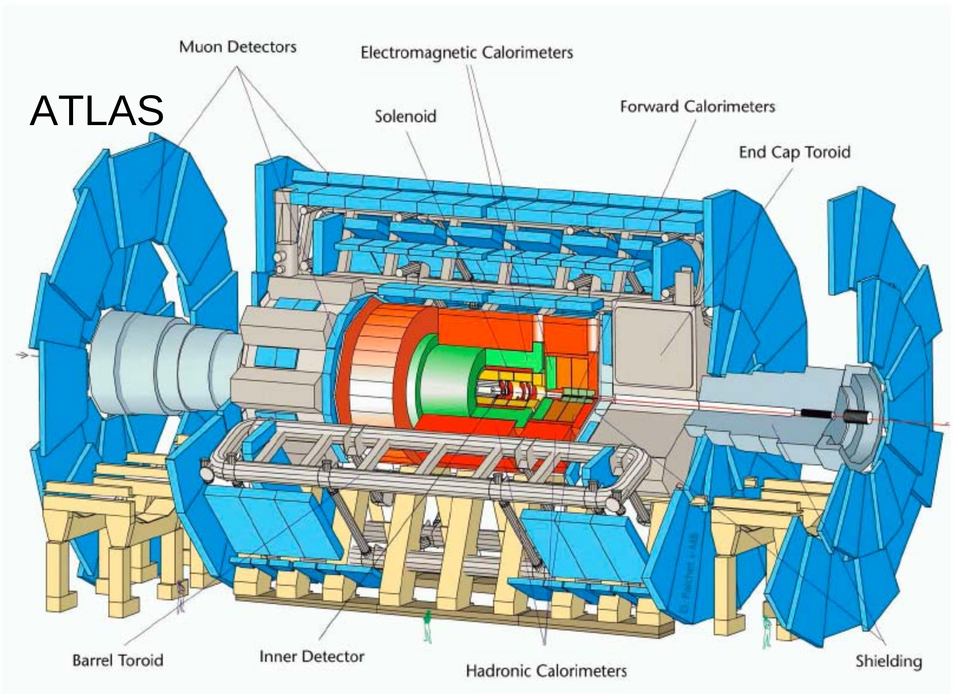
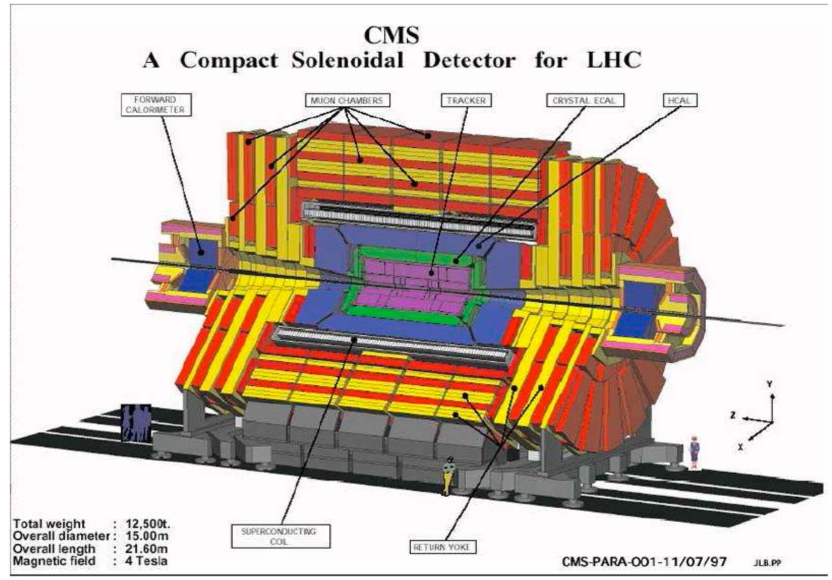
For ATLAS and CMS

Outline

- ATLAS and CMS detector overview
- Detector integration
- Strategy to new physics
- Before collisions
  - Test beams
  - Commissioning with cosmic rays
- LHC startup
  - Sanity checks
  - Commissioning
  - First discoveries
- Conclusions

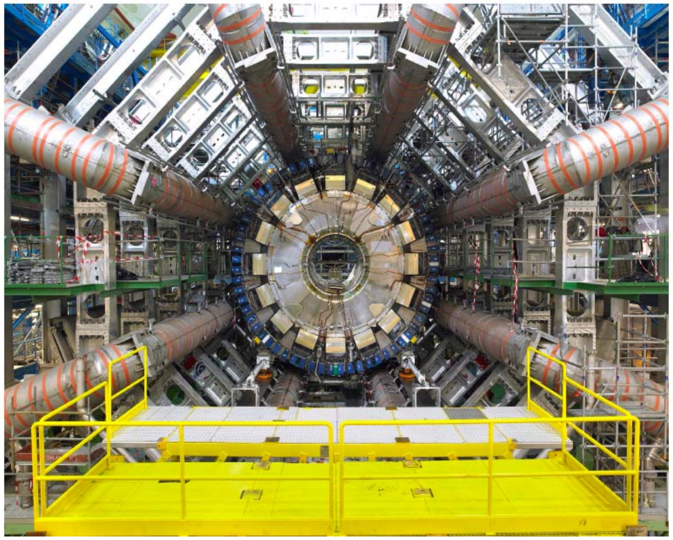
ATLAS and CMS …

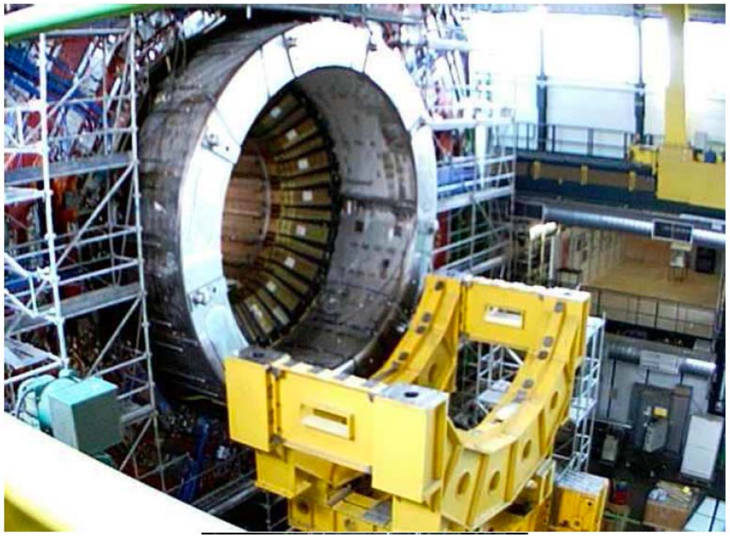


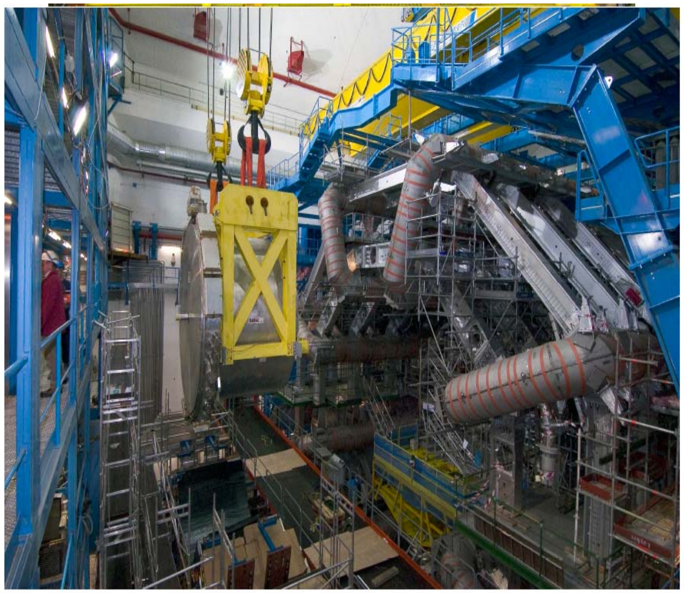


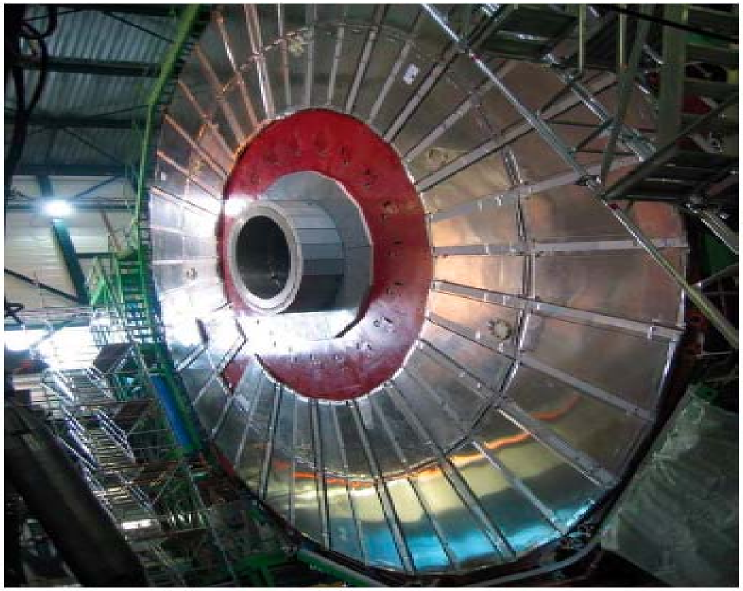
Parameter	ATLAS	CMS
Total weight (tons)	7,000	12,500
Overall diameter (m)	22	15
Overall length (m)	46	20
Magnetic field for tracking (T)	2	4
Solid angle for lepton ID or tracking ($\Delta\phi \times \Delta\eta$)	$2\pi \times 5.0$	$2\pi \times 5.0$
Solid angle for energy measurements ($\Delta\phi \times \Delta\eta$)	$2\pi \times 9.6$	$2\pi \times 9.6$
Total cost (MCHF)	550	550

Detector Integration …









Strategy to new physics discovery …

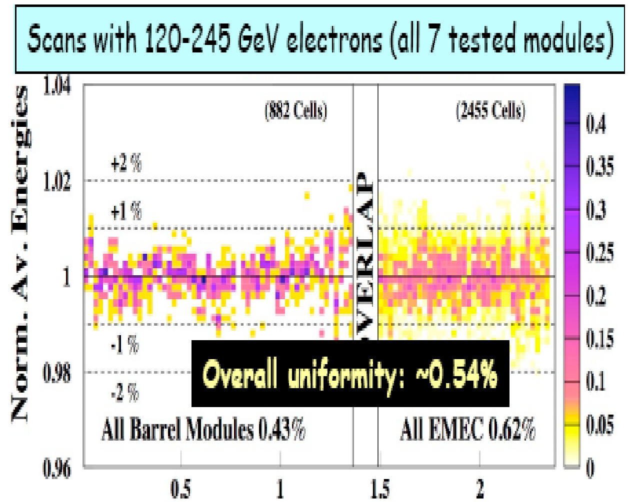
- Before data taking:
  - Quality controls of detector construction to meet physics requirements
  - Test beam: several years of activities culminating in the combined test beam of 2004/2007 to understand and calibrate sub-detectors, and to validate/tune software tools, e.g., Geant4 simulation
  - Full simulations of realistic "as-built" and "as-installed" detector (misalignments, material non-uniformity, dead channels): test and validate calibration and alignment strategies
  - Some aspects of commissioning with cosmics are being addressed now or have already been addressed:
    - Pre-alignment and calibration
    - Initial detector shake-down
    - Data processing at the Tier 0 (CERN), distributed to Tier 1's and some Tier 2's. Analysis at the Tier 2's.

now we are here

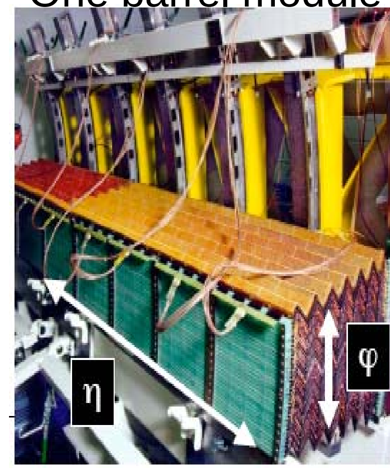
- With first data
  - Commission and calibrate detector and trigger in situ with minimum bias, $Z \rightarrow ll$, etc
  - Rediscover SM at $\sqrt{s}$ = 14 TeV (minimum bias, W, Z, tt, QCD jets, etc)
  - Validate and tune tools (MC generators)
  - Measure main backgrounds to new physics: W+jets, Z+jets, tt+jets, QCD multijets, …

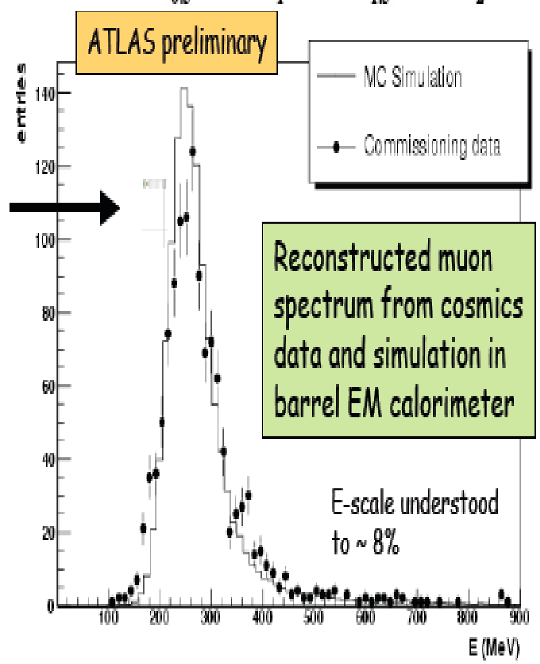
Before Collisions (ATLAS as an example)…

- Test beam measurements to understand detector components and tune simulation
- Dress rehearsals to test data acquisition, data streaming and distribution
- Calibration and alignment procedures on "as installed" simulation samples
- B-field mapping with survey data from magnetic probes
- Calibration of electronic channels, mapping of dead/noisy channels with external charge/source injections
- Cosmics run: initial detector alignment (barrel)
- Beam halo events for initial detector alignment (end-cap)

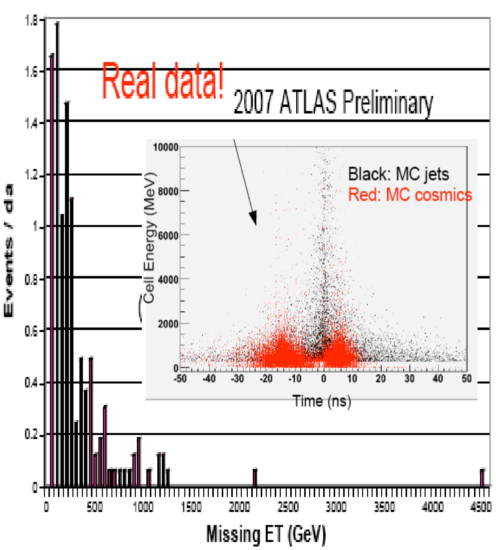


One barrel module





Missing ET from Cosmics in ATLAS 2007



CMS took test beam data up to 2007. Also, CMS had a very strong cosmic challenge in 2006

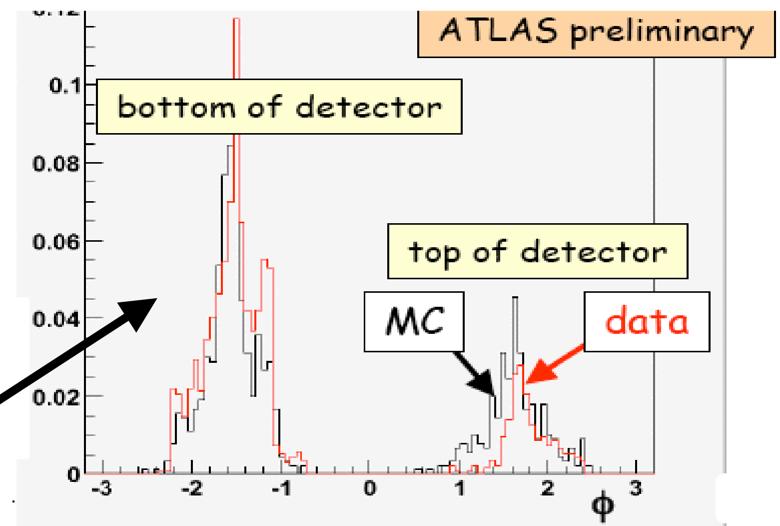
Detector and Trigger Commissioning …

Present fraction of working ATLAS:

Sub-detector	Number of Channels	% of non-working channels
Pixels	80.0 10^6	0.2
Silicon Strips (SCT)	6.0 10^6	0.3
Transition Radiation Tracker	3.5 10^5	1.0
Electromagnetic Calorimeter	1.7 10^5	0.04
Scintillator Tile Calorimeter	9800	0.8
Liquid Argon Had. End-cap Calorimeter	5600	0.09
Liquid Argon Forward Calorimeter	3500	0.2
Barrel Muon Spectrometer	7.0 10^5	0.5
End-cap Muon Spectrometer	3.2 10^5	0.02

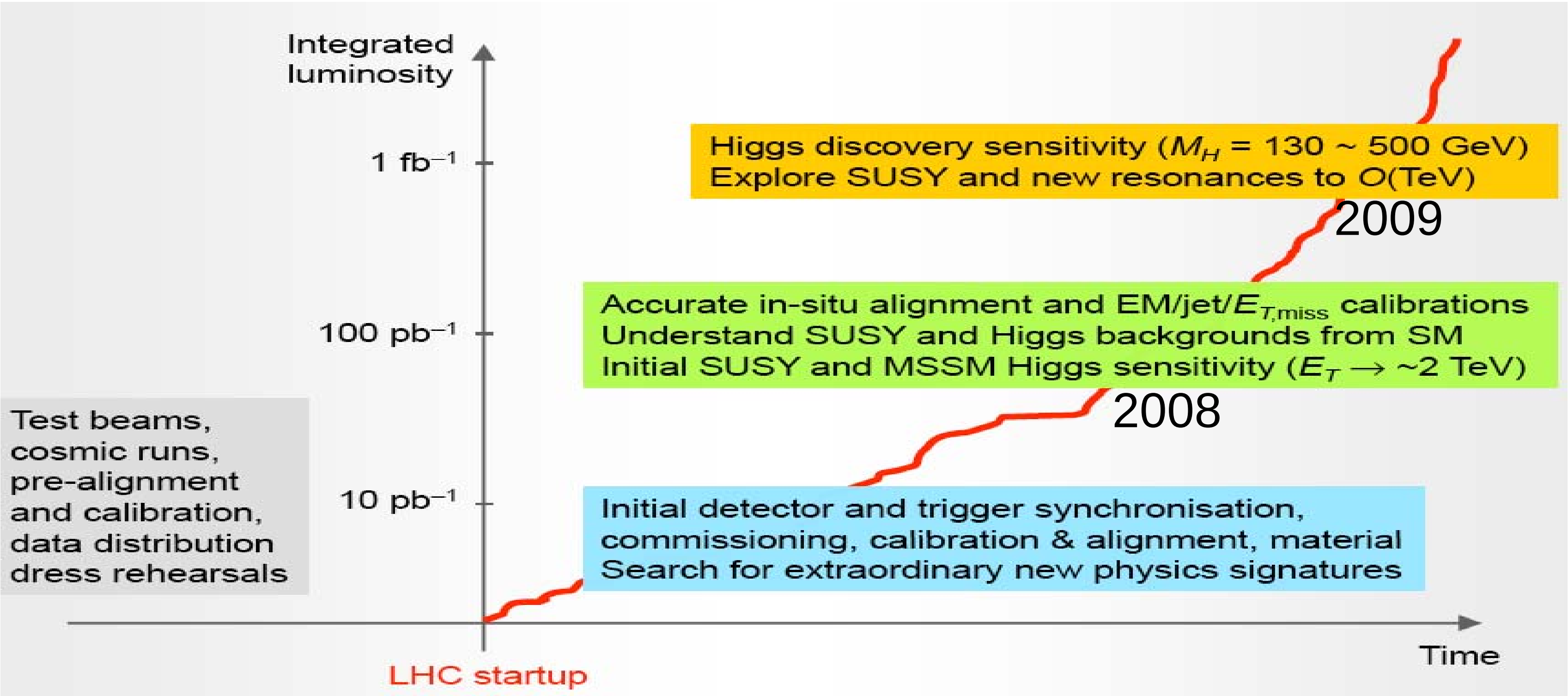
Based on measurements during sub-detector integration on surface or in the cavern

Trigger menus for initial luminosity of 10^{31} $cm^{-2}s^{-1}$ are being prepared: 200 Hz storage rate (ATLAS) out of $40x10^6$ Hz interaction rate. Can afford low thresholds w/o pre-scaling, simple selections, redundant items, calibration triggers, HLT in pass-through mode, etc: See the talk by Leonidopoulos for details



August 2007 cosmics run: muon tracks reconstructed by Trigger

LHC Startup …

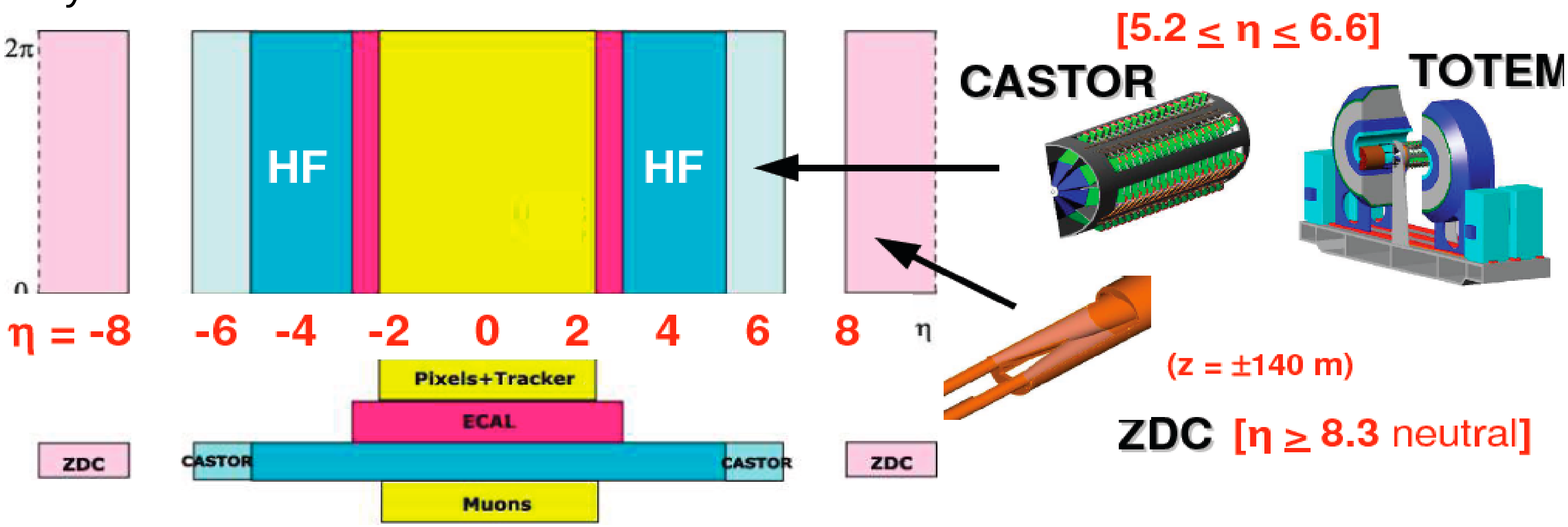


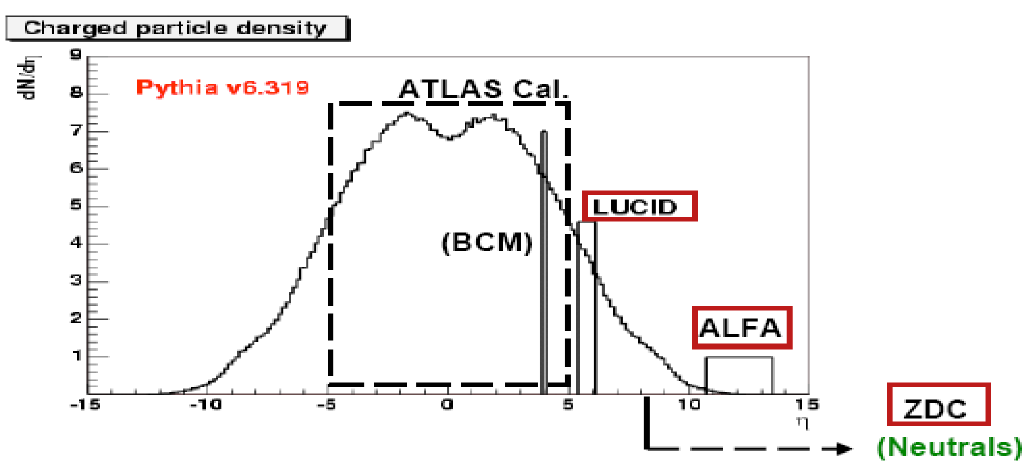
Expected data samples with only 100 pb^{-1}

Channels (examples …)	Events to tape for 100 pb^{-1} (ATLAS)	Total statistics from LEP and Tevatron
$W \to \mu\nu$	~ 10^6	~ 10^4 LEP, ~ 10^{6-7} Tevatron
$Z \to \mu\mu$	~ 10^5	~ 10^6 LEP, ~ 10^{5-6} Tevatron
$tt \to WbWb \to \mu\nu + X$	~ 10^4	~ 10^{3-4} Tevatron
QCD jets p_T > 1 TeV	> 10^3	---
$\tilde{g}\tilde{g}$ m = 1 TeV	~ 50	---

Precision on luminosity measurements …

CMS/TOTEM and ATLAS forward detectors forward physics, heavy ion, … and luminosity measurements

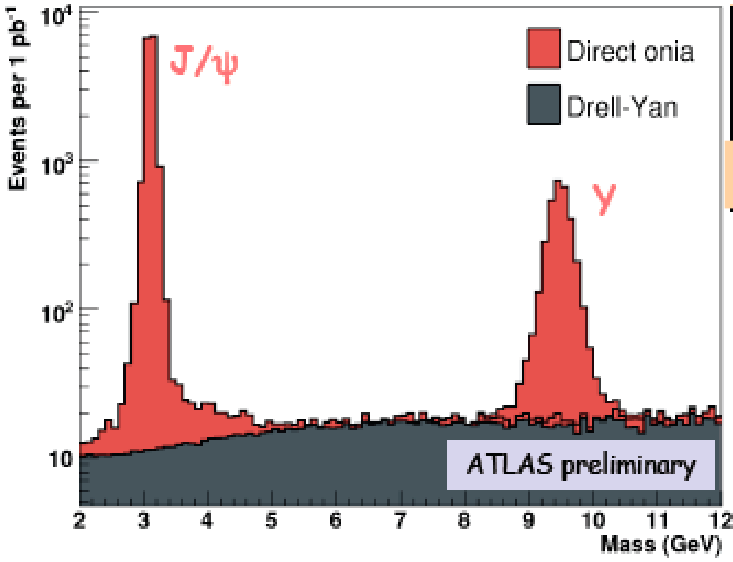




- Initially from machine parameters
  - Precision ~10-15%
- Medium term from physics processes:W/Z & μμ/ee
  - Precision ~5-10%
- 2009 from Roman Pot detectors
  - Precision ~2-3%

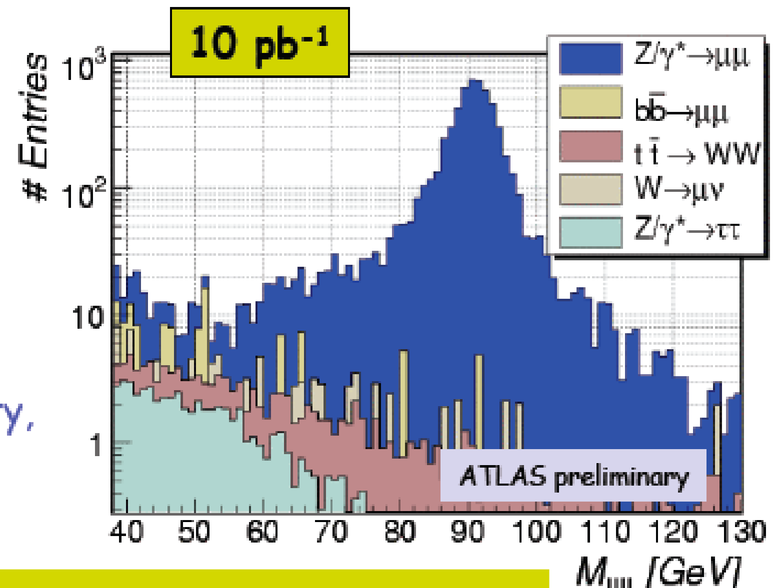
$J/\Psi(Y) \rightarrow \mu\mu$ and $Z \rightarrow \mu\mu$ ...

1 pb^{-1} = 3.85 days at 10^{31} with 30% efficiency



After all cuts:
~ 4200 (800) J/ψ (Y) → μμ evts per day at L = 10^{31}
(for 30% machine x detector data taking efficiency)
~16000 (3100) events per pb^{-1}

→ tracker momentum scale, trigger performance, detector efficiency, sanity checks, ...



After all cuts:
~ 160 Z → μμ evts per day at L = 10^{31}
~ 600 events per pb^{-1}

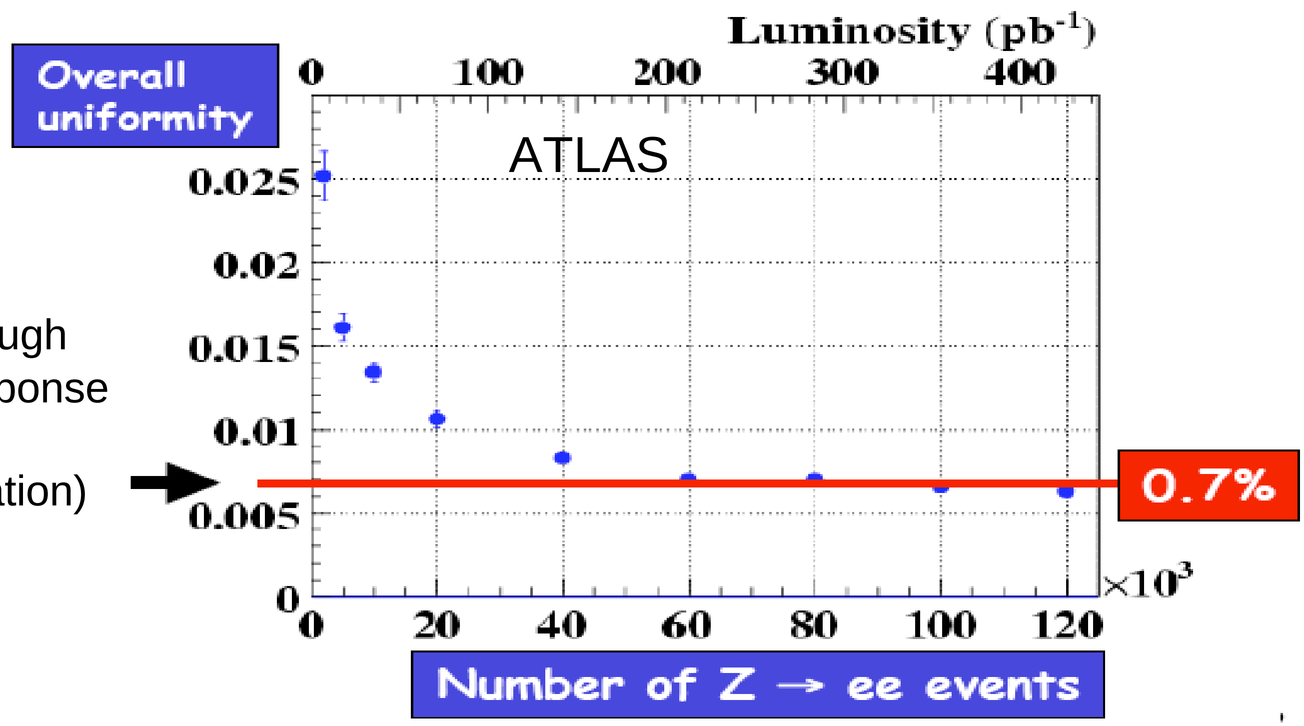
→ Muon Spectrometer alignment, ECAL uniformity, energy/momentum scale of full detector, lepton trigger and reconstruction efficiency, ...

Expected precision on σ (Z→ μμ): < 2% experimental, ~10% luminosity

EM Calorimeter uniformity…

- Use Z→ee to correct for residual long range non-uniformity due to
  - Module-to-module variation
  - Temperature effects

10^5 Z→ee would be enough to achieve a uniform response at the level of ~0.7% (from full detector simulation)



Minimum bias/Underlying Event …

Minimum bias events

- Inelastic hadron-hadron events selected with an experiment's "minimum bias trigger".
- Usually associated with inelastic non-single-diffractive events (NSD) (e.g. UA5, E735, CDF … ATLAS/CMS?)

$$\sigma_{tot} = \sigma_{elas} + \sigma_{s.dif} + \sigma_{d.dif} + \sigma_{n.dif}$$

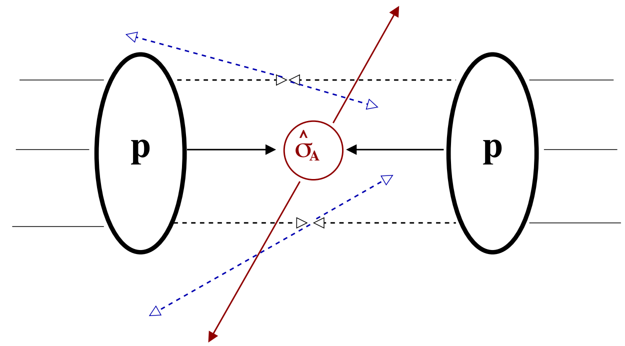
σ_{tot} ~ 102 - 118 mb (PYTHIA) (PHOJET)

σ_{NSD} ~ 65 - 73mb (PYTHIA) (PHOJET)

- Need minimum bias data to:
  - Study general characteristics of proton-proton interactions
  - Investigate multi-parton interactions and the structure of the proton etc.
  - Understand the underlying event: impact on physics analyses?

The underlying event (UE)

- The "soft part" associated with hard scatters

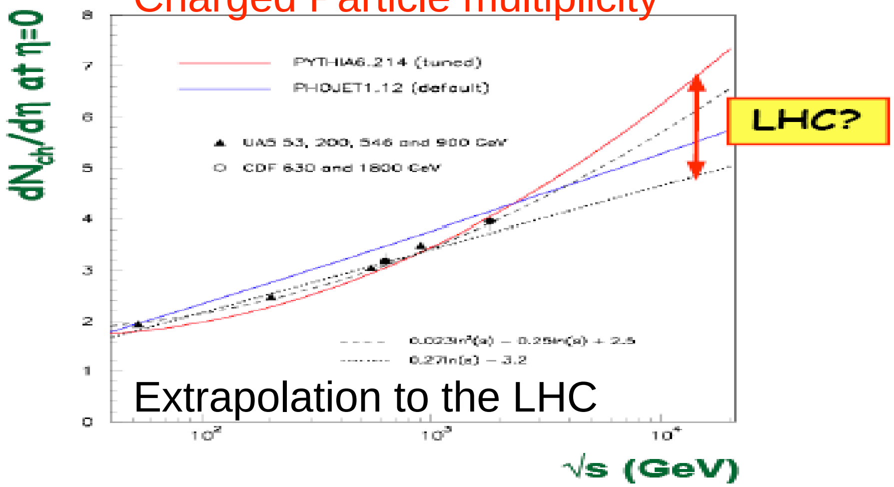


- In parton-parton scattering, the UE is usually defined to be everything except the two outgoing hard scattered jets:
  - Beam-beam remnants.
  - Additional parton-parton interactions.
  - ISR + FSR

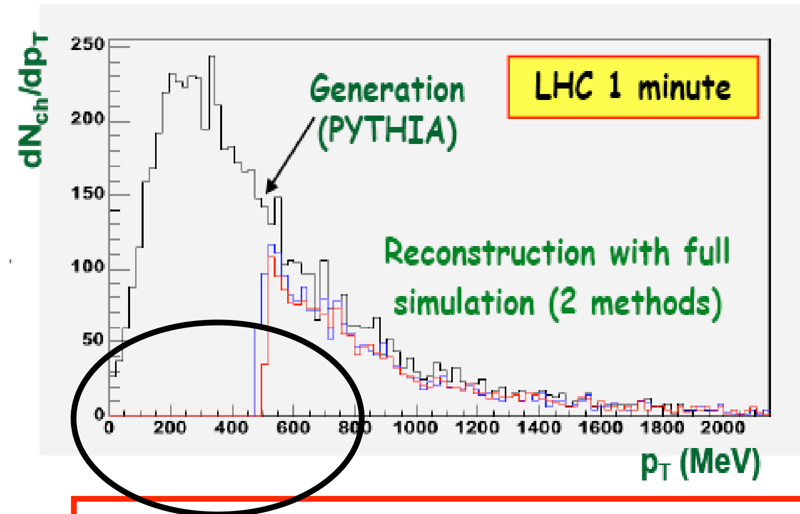
- Can we use "minimum bias" data to model the "underlying event"?
  - At least for the beam-beam remnant and multiple interactions?

Minimum bias/Underlying Event …

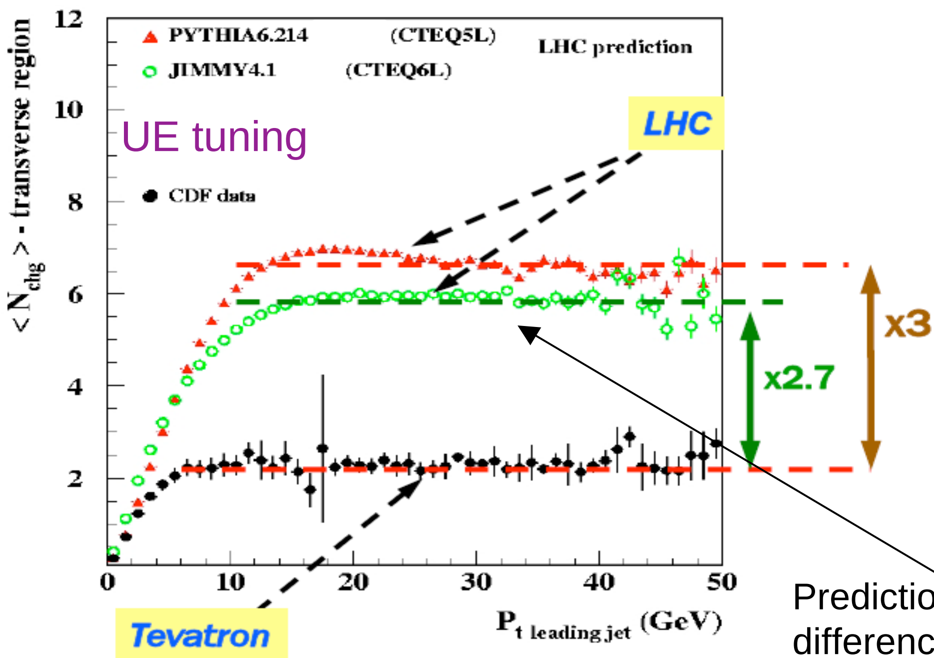
Charged Particle multiplicity



Minimum bias tuning on data



Take special run with low B field to reach p_T ~ 200 MeV.

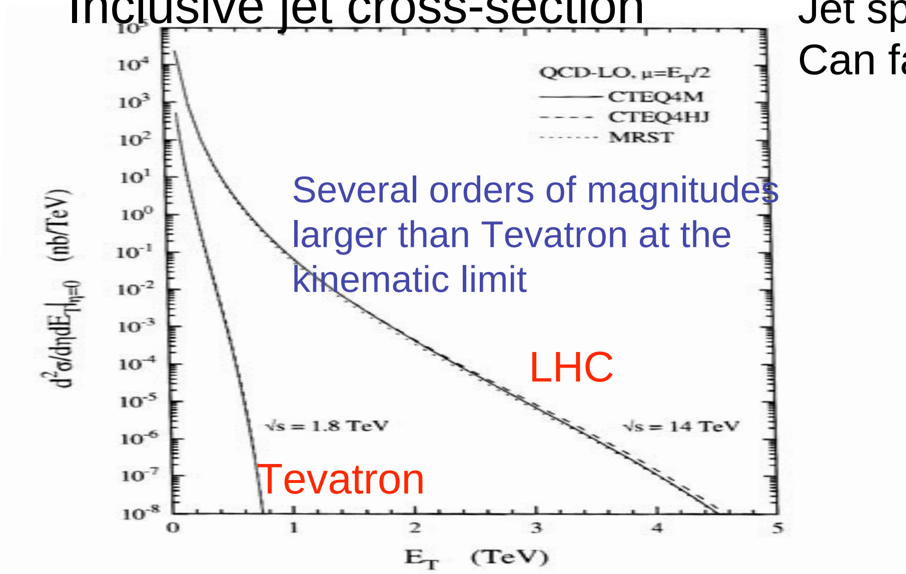


Predictions similar:
difference used to be a factor 2

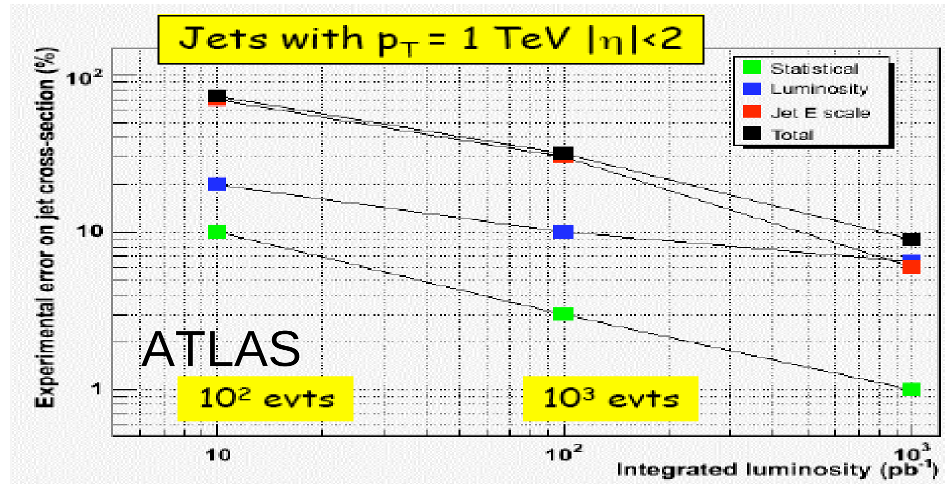
- Measurements from different LHC experiments should be complementary:
  - LHC-b tracks charged particles to higher rapidities than ATLAS or CMS
  - ALICE tracks charged particles down to lower momenta than ATLAS or CMS

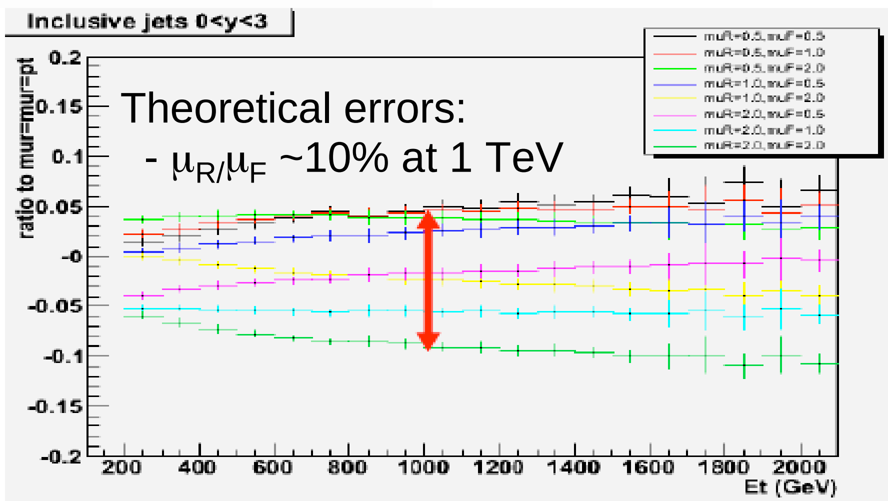
Inclusive jet cross-section …

Inclusive jet cross-section



Jet spectrum at high p_T sensitive to new physics
Can fake/mask signal if not well understood …





Addition theoretical errors from PDF uncertainties ~15% at 1 TeV

Constraining PDF with early data …

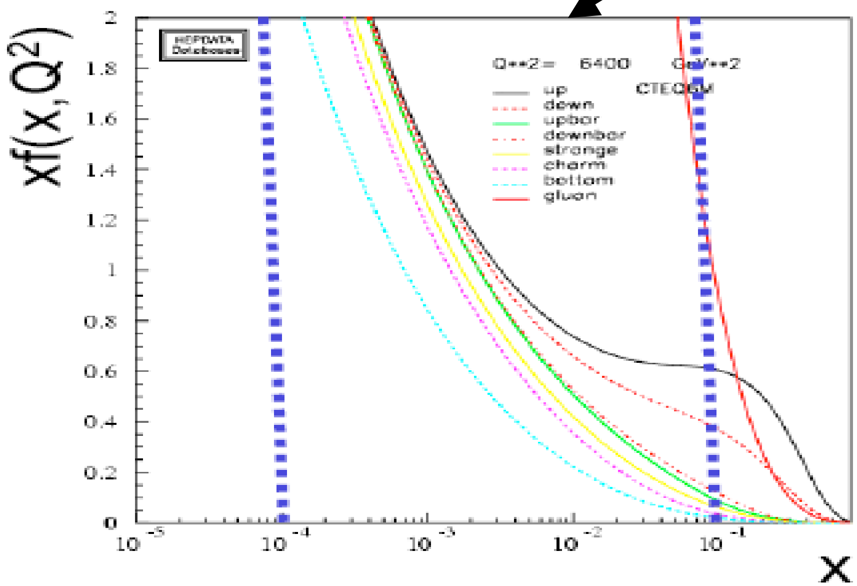
Using W→lν angular distribution

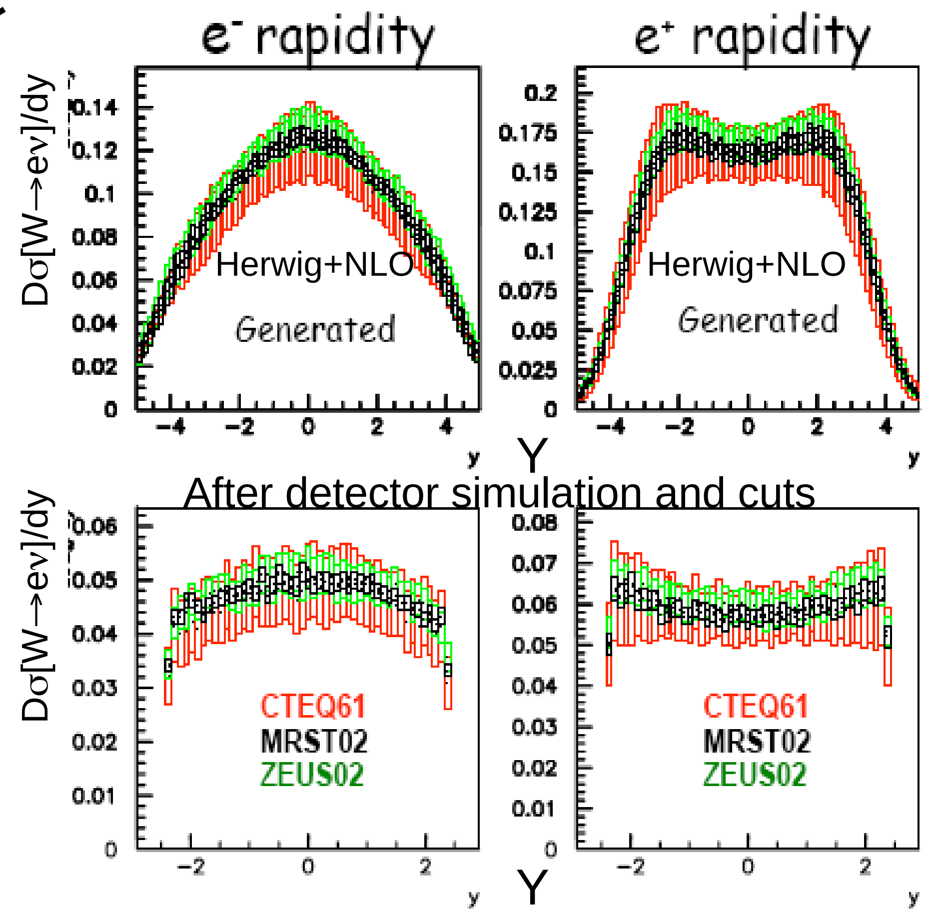
$$u\bar{d} \rightarrow W^{+} \rightarrow e^{+}\nu$$
$$d\bar{u} \rightarrow W^{-} \rightarrow e^{-}\bar{\nu}$$

A particle of mass M, at a rapidity y, produced by a pair of partons (1,2) carrying a fraction $x_{1,2}$ of the proton momentum:

$$x_{1,2} = \frac{M}{\sqrt{s}} \exp(\pm y)$$

W production at LHC over |y|<2.5 implies $10^{-4} < x_{1,2} < 0.1$: region dominated by g→qq

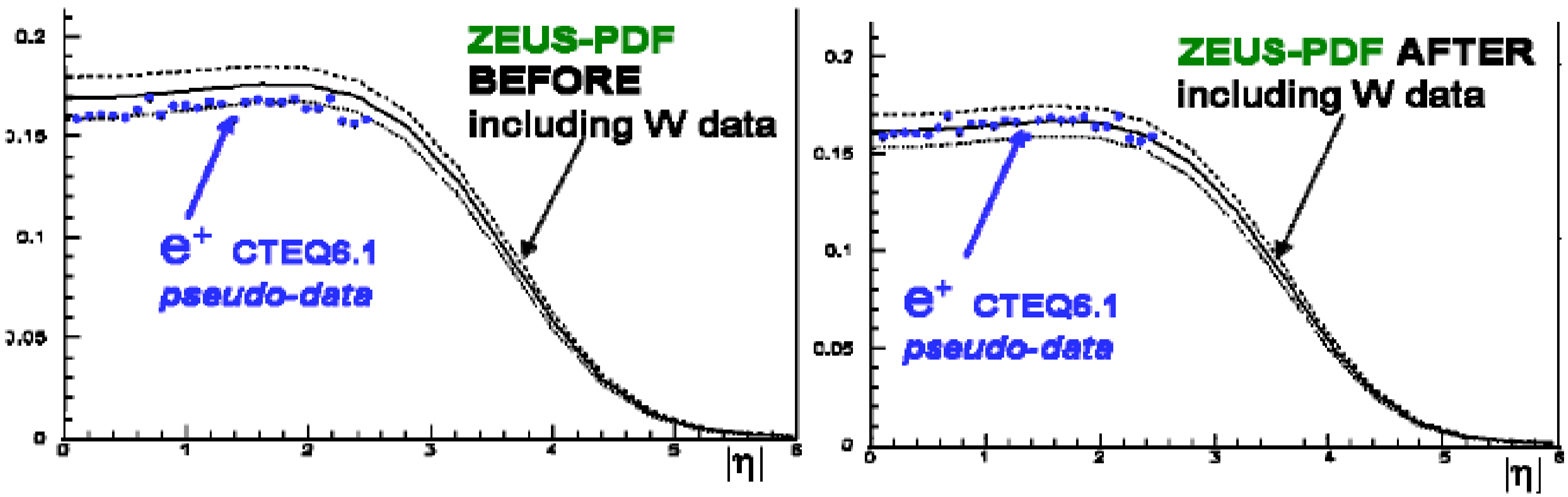




- The goal is experimental uncertainty < 5%:
  - Possibility to discriminate between PDFs

Constraining PDF with early data …

- What will be the effect of including LHC data in global PDF Fits?
  - How much can we reduce the error?
- Take 10^6 $W \rightarrow e\nu$ events generated with CTEQ6.1 PDF and ATLFAST detector simulation to probe the low-x gluon PDF at $Q^2 = m_W^2$: $W^+ \rightarrow e^+\nu$ rapidity spectrum sensitive to gluon shape parameter λ
  - The statistics corresponds to 150 pb^{-1}
  - Introduce 4% systematic errors by hand
- This "data" included in the global fit



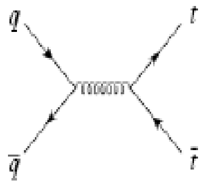
The central value of the ZEUS-PDF prediction shifts and uncertainty is reduced;
Error on low-x gluon shape parameter λ [$xg(x) \sim x^{-\lambda}$] reduced by 35%

The systematics on electron acceptance versus η, will be controlled to a few percent using $Z \rightarrow ee$ (~3 10^4 events at 100 pb^{-1})

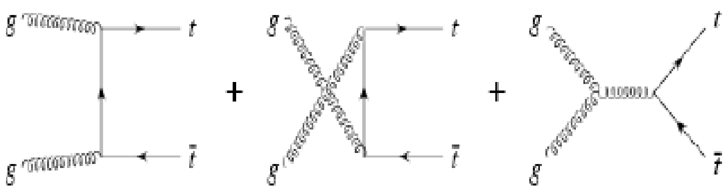
top at the LHC …

Strong Interaction → $t\bar{t}$

LHC
σ ~833 pb
10% $q\bar{q}$, 90% gg



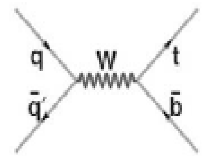
Tevatron
σ ~7 pb
85% $q\bar{q}$, 15% gg



Weak Interaction → single top*

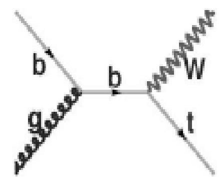
LHC
σ ~300 pb
75%Wg, 20%Wt

W*

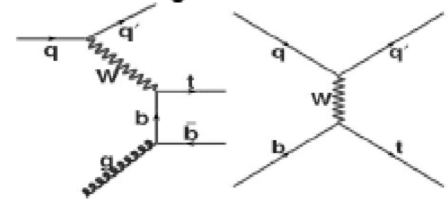


Tevatron
σ ~3 pb
65%Wg, 30%Wt

W t



W-g fusion



BR (t→Wb) ~ 100 % in SM and no top hadronisation

W→eν, μν

$t\bar{t}$ final states (LHC 100 pb^{-1})

- Full hadronic 37K : 6 jets
- Semileptonic 25K : l + ν + 4jets
- Dileptonic 4K : 2l + 2ν + 2jets

Single top final states (LHC 100 pb^{-1})

- W-g 5K : l + ν + 2jets
- Wt 2K : l + ν + 3jets
- W* 0.2K : l + ν + 2jets

Commissioning with top-events…

- A top signal can be observed quickly even with limited detector performance and simply analysis
- The easiest channel will be lepton+jets, with W+jets, tt combinatorics, QCD as the main backgrounds
- Assume b-tagging will not be available yet
  - Challenge: extract tt events without b-tagging
- In addition, excellent sample for: light jet calibration, b-jet efficiency determination, general detector performance

W =2 jets maximizing p_T W in jjj rest frame

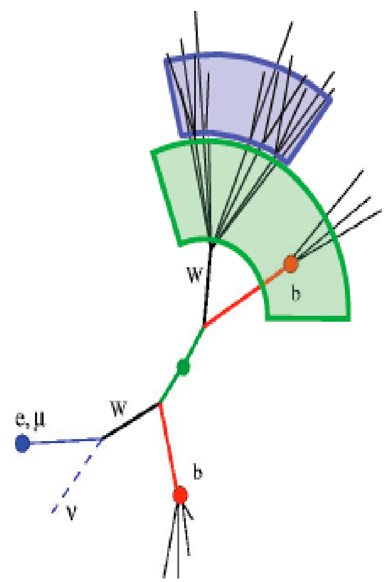
Apply simple selection:

- good isolated lepton (e,μ), p_T(lep) > 20 GeV/c

- E_T^{miss} > 20 GeV

- ≥ 4 jets, 3 with p_T(jet) > 40 GeV/c ($|\eta(1,jets)| < 2.5$)
  1 with p_T(jet) > 20 GeV/c

- quality improvement cuts

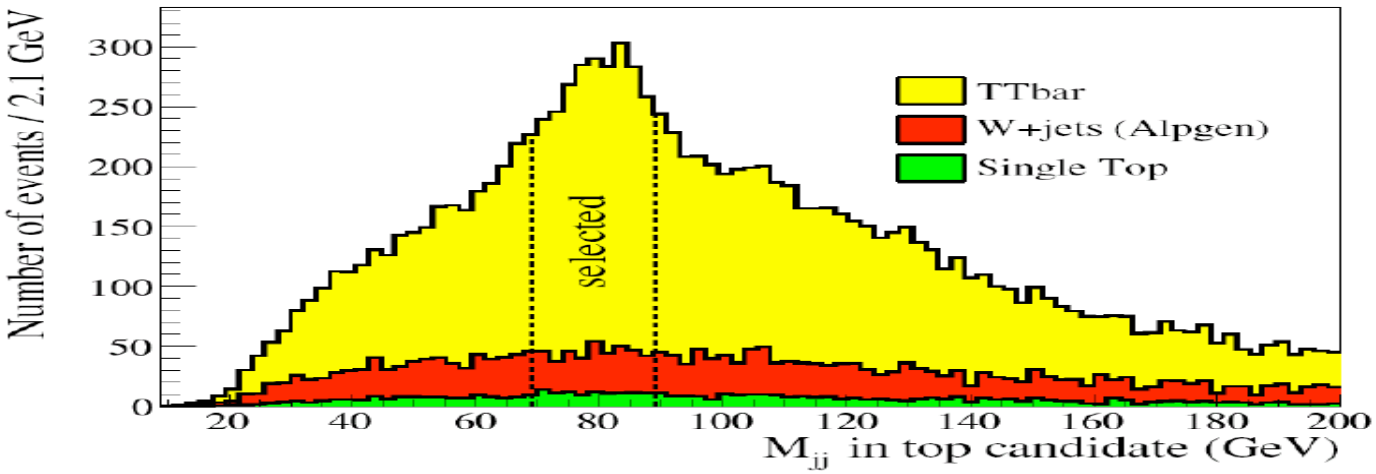


Hadronic top=3 jets maximizing p_T top

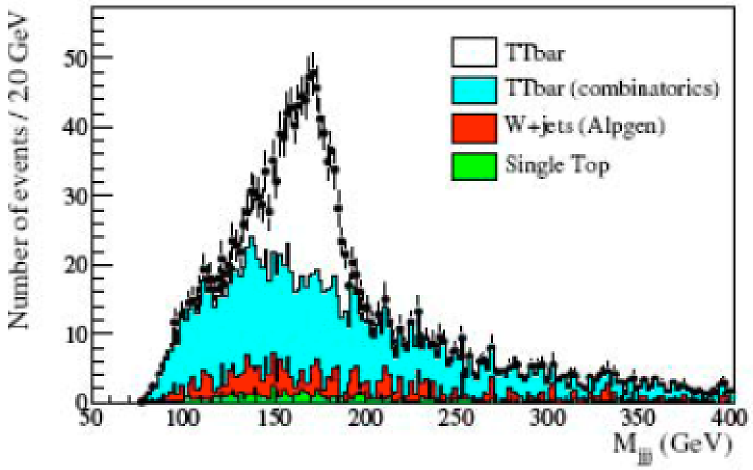
$|m_{jj}-m_W| < 10$ GeV/c^2

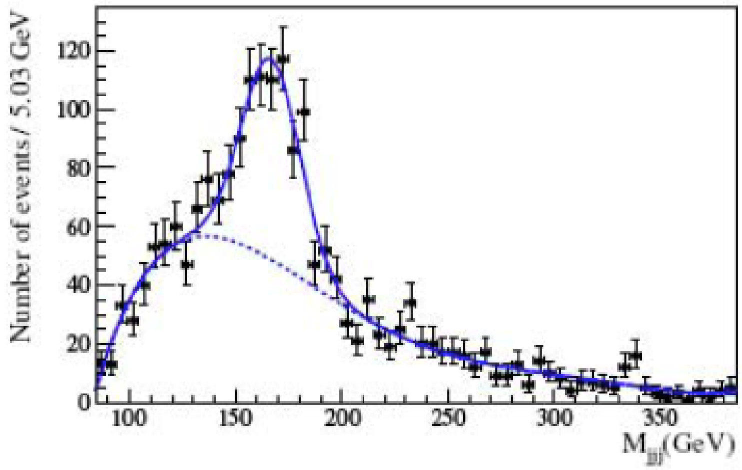
Commissioning with top-events …

- The technique seems to work:



Studies done from fast simulation: QCD is likely not well modeled

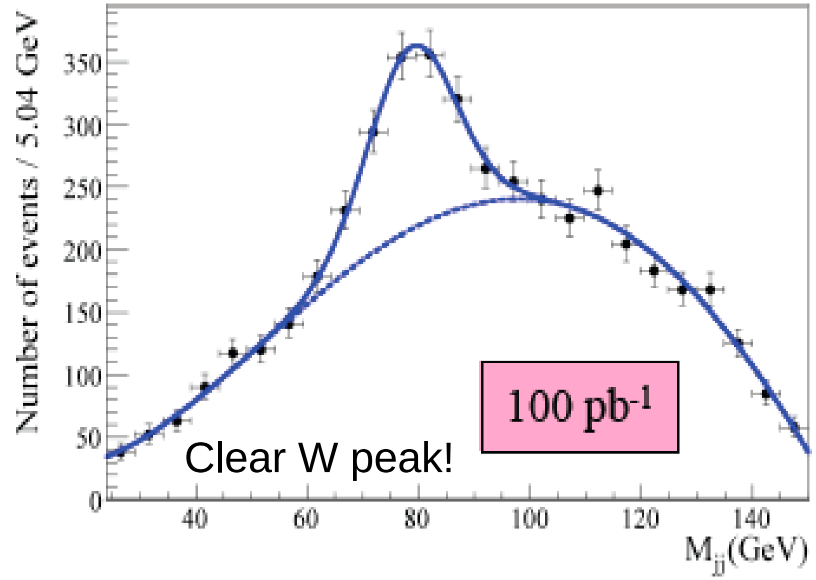




But Missing ET will be problematic at the start.
Signal can still be extracted without Missing ET requirement

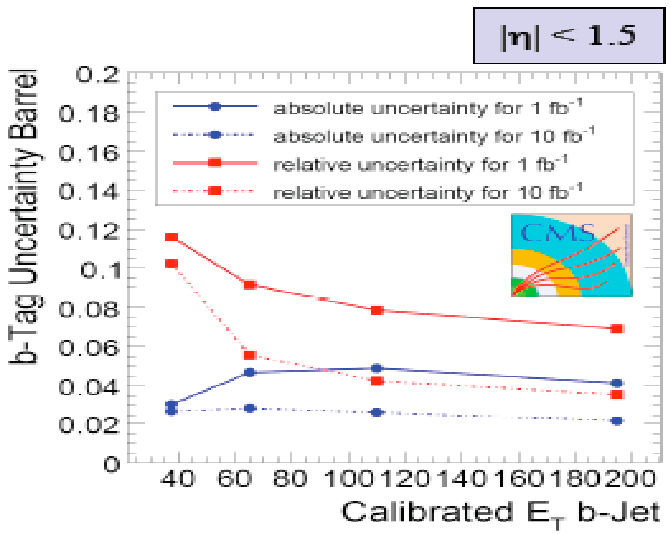
Jet Energy Scale / b-tagging Efficiency…

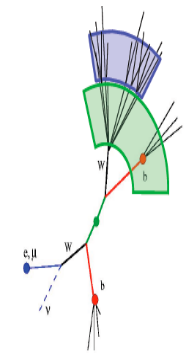
- Calibration of light jet energy scale, to complement γ+jets sample
  - Remove $|m_{jj}-m_W|<10GeV/c^2$ (bias requirement) and look at m_{jj} for all the 3jet combinations in m_t mass window
  - Still to be translated into jet energy scale correction faction



Jet E-scale:
- initially to ~ 10% from test beam + simulation (Geant4 reproduces test-beam pion response of hadronic end-cap calorimeter to ~2%)
- Then eventually from data (γ/Z+jets, W→jj in tt events) + simulation →1%

- Calibration of b-tagging efficiency
  - Select 3jets from the hadronic top
  - Perform a fit using resolution, m_t, and m_W as constraints
  - Measure the b-tag efficiency for the 4th jets a function of E_T and eta

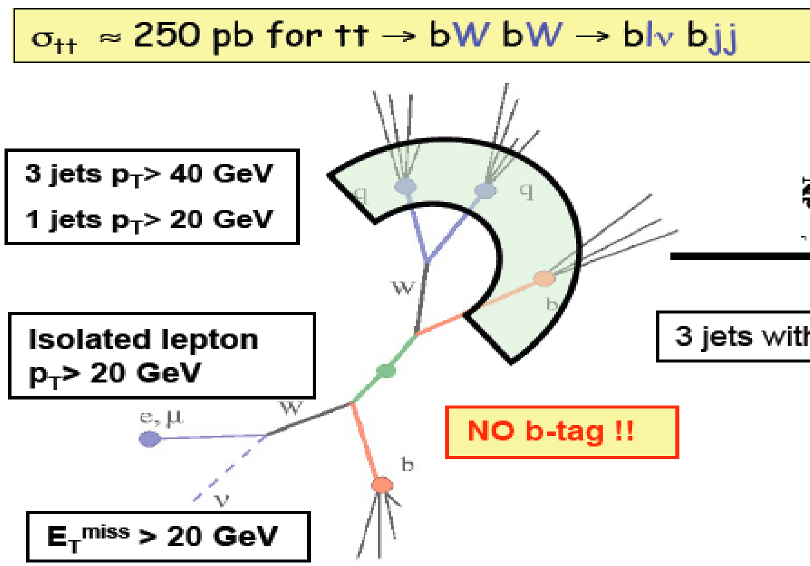


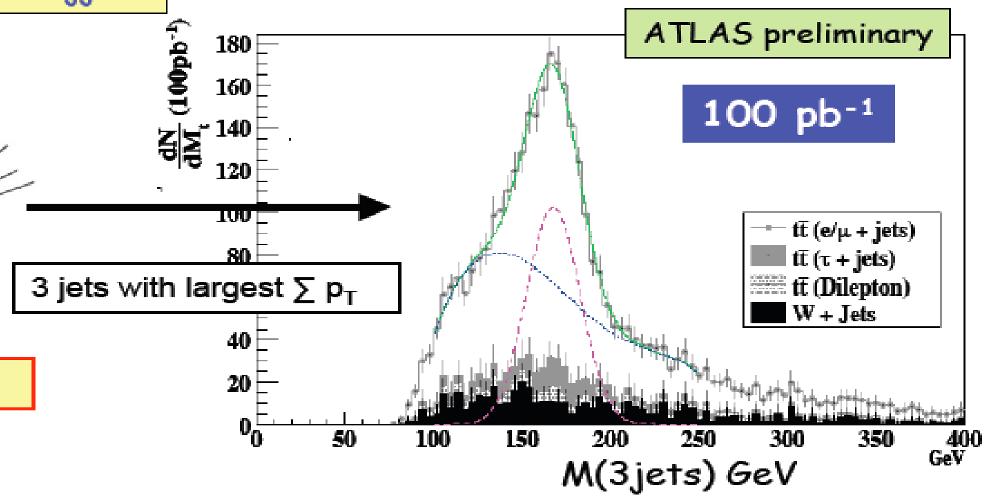


Calibration can also use dilepton events

top mass measurement …

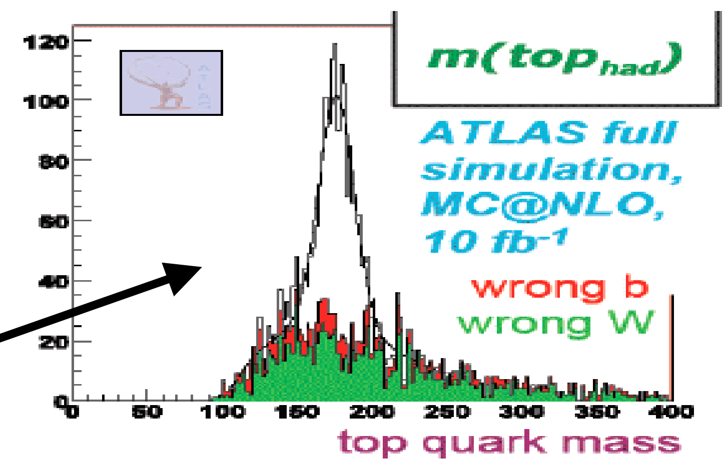
- Several methods for early top mass measurement - for example, kinematic fit to reconstruct hadronic top in lepton+jet sample



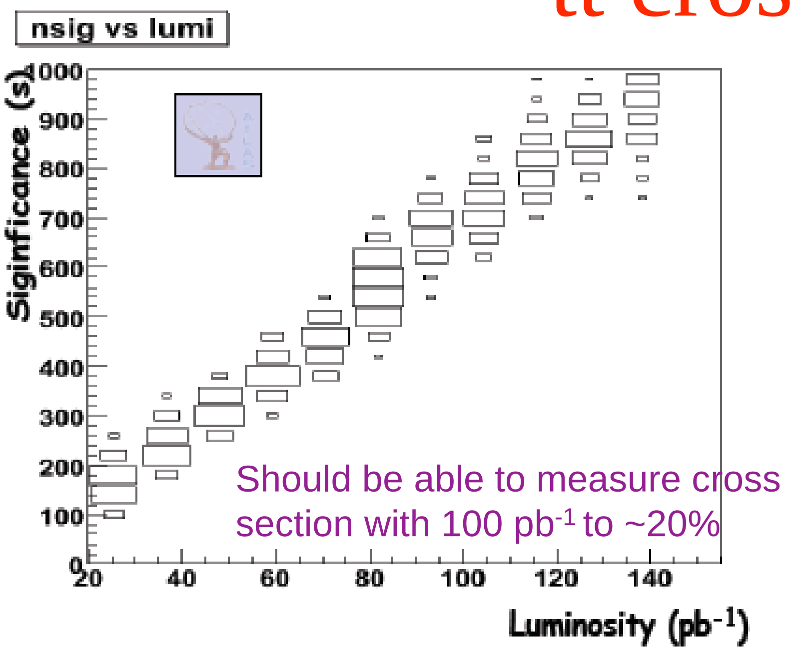


Even without b-tagging, simple analysis, expect to measure m_t to within 10 GeV with 100 pb^{-1}

Statistical errors @10fb^{-1}: 0.05-0.2 GeV
Systematics uncertainties: 0.9-1.6 GeV

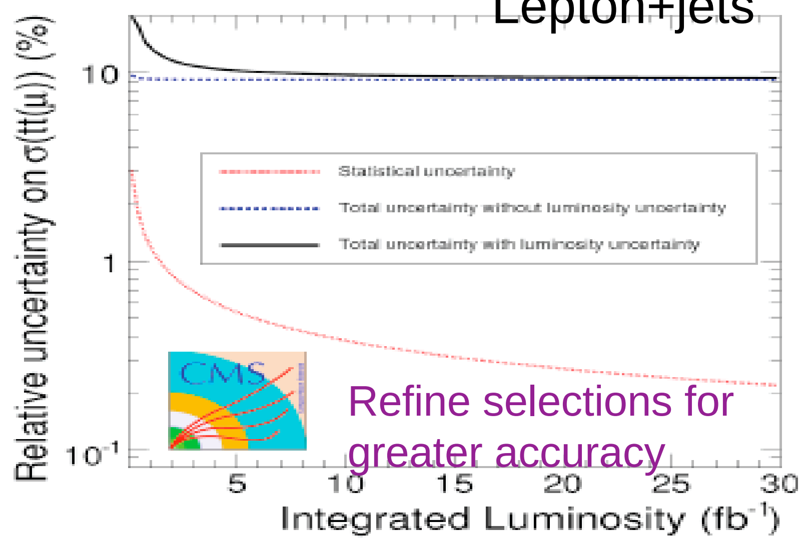


tt cross section …



Should be able to measure cross section with 100 pb^{-1} to ~20%

Lepton+jets

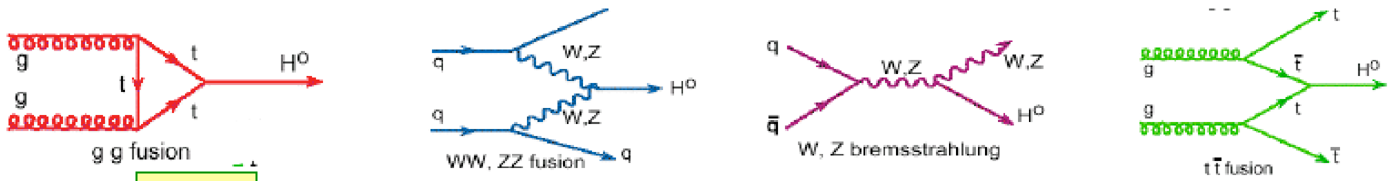


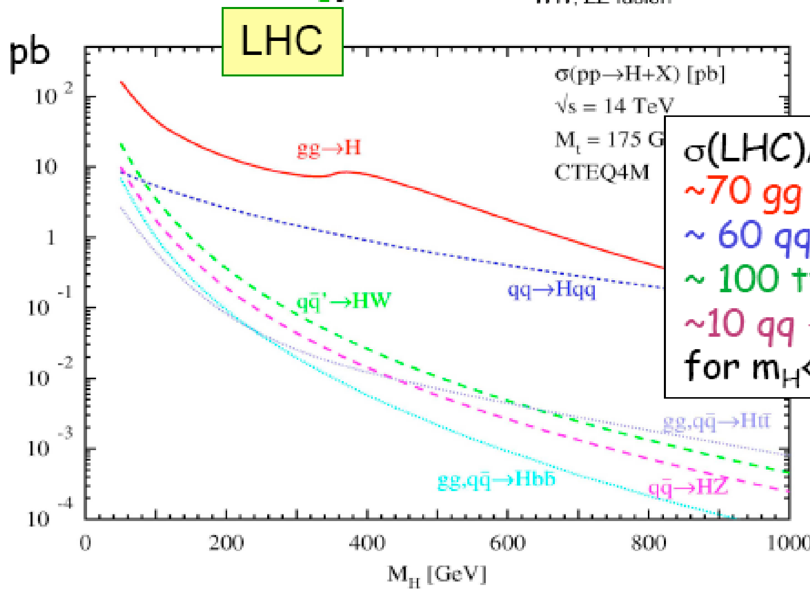
Refine selections for greater accuracy

The systematics will be important

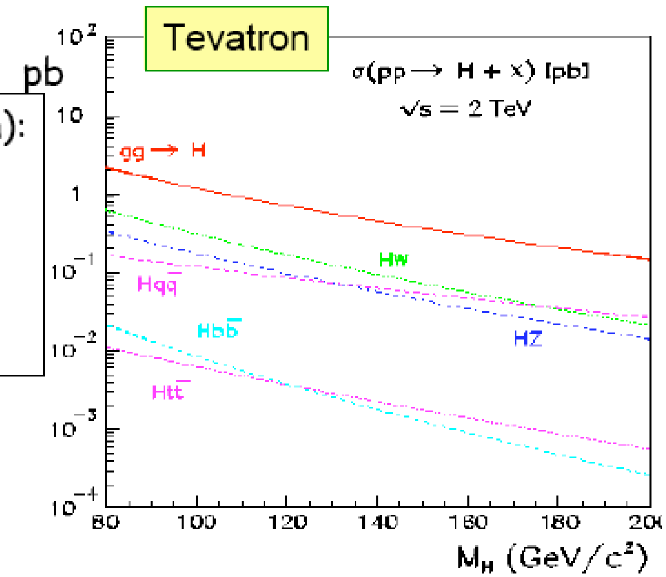
	$\Delta\sigma_{tt}/\sigma_{tt}$ syst (%)	$\Delta\sigma_{tt}/\sigma_{tt}$ stat (%)	$\Delta\sigma_{tt}/\sigma_{tt}$ lumi (%)	Main syst (%)	Main bkg	Eff (%)	S/B
10 fb^{-1} l+jets	9.7	0.4	3	Btag 7 PDF 3.4 PileUp 3.2	$t\bar{t}$ W+j	6.3	26.7
10 fb^{-1} dilep	11	0.9	3	PDF 5 Btag 4 JES 4	tt_{ll} with ($W\rightarrow\tau\nu_\tau$, $\tau\rightarrow l$)	5	5.5
1fb^{-1} hadronic	20	3	5	JES 11 PileUp 10	QCD	1.6	1/9

Light Higgs Boson …





σ(LHC)/σ(Tevatron):
~70 gg → H
~ 60 qqH → qqH
~ 100 ttH
~10 qq →WH/ZH
for m_H<200 GeV



	Tevatron Main Search Channels	LHC Main Search Channels
m_H ~115 GeV	WH→ lνbb ZH → ννbb, llbb	H → γγ, qqH → qqττ ttH→ lνbbX
m_H ~ 160 GeV	H →WW → lνlν	H → WW→ lνlν,H→ZZ*→4l, qqH→ qqWW→ qqlνlν

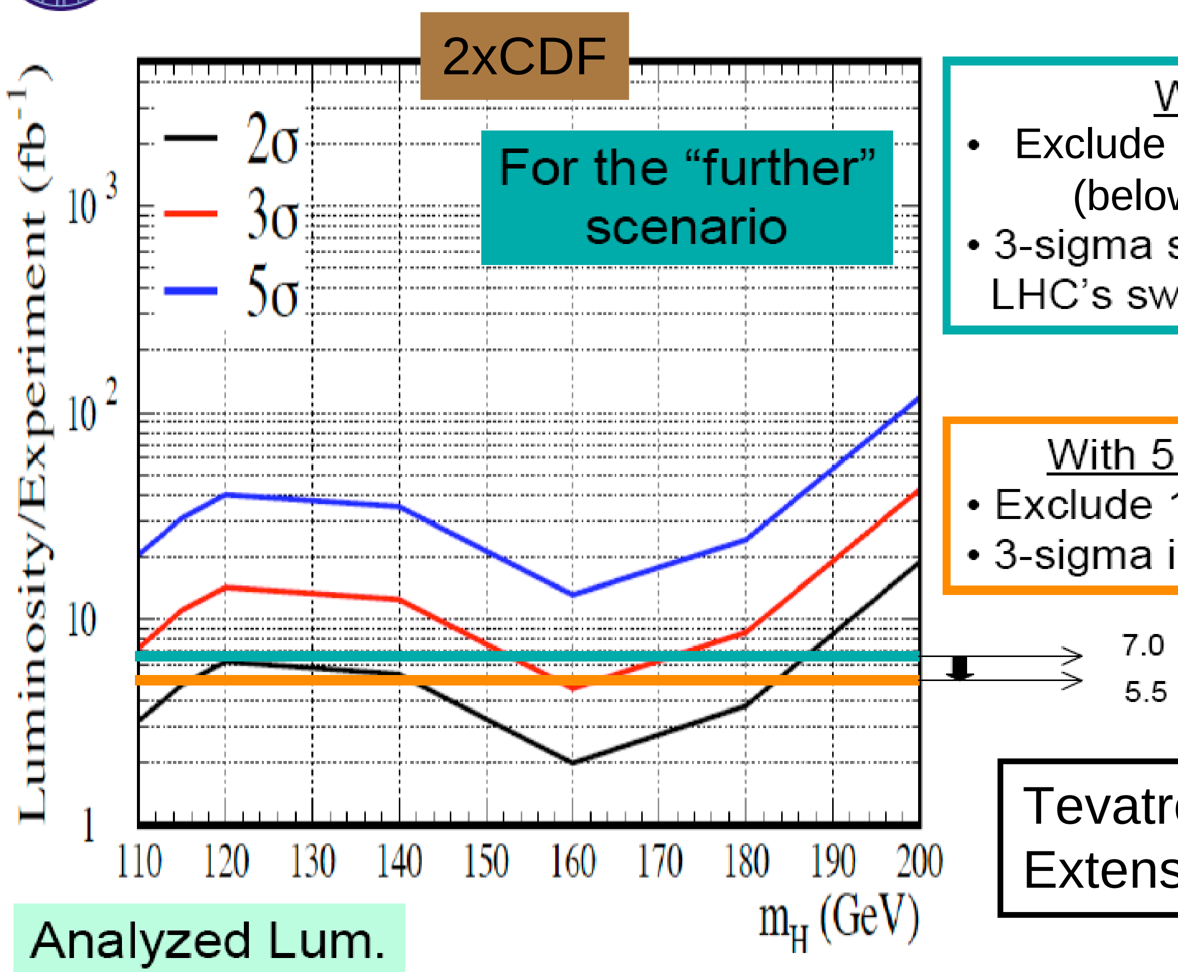
Large backgrounds at the LHC

Cross-sections too small at the Tevatron

Light Higgs Boson …

J. Konigsberg, R. Roser & D. Glenzinski, Sept 2007

An exclusion region growing



2010

With 7 fb^{-1}
- Exclude a large region (below 190 GeV)
- 3-sigma sensitivity 150:170 LHC's sweet spot

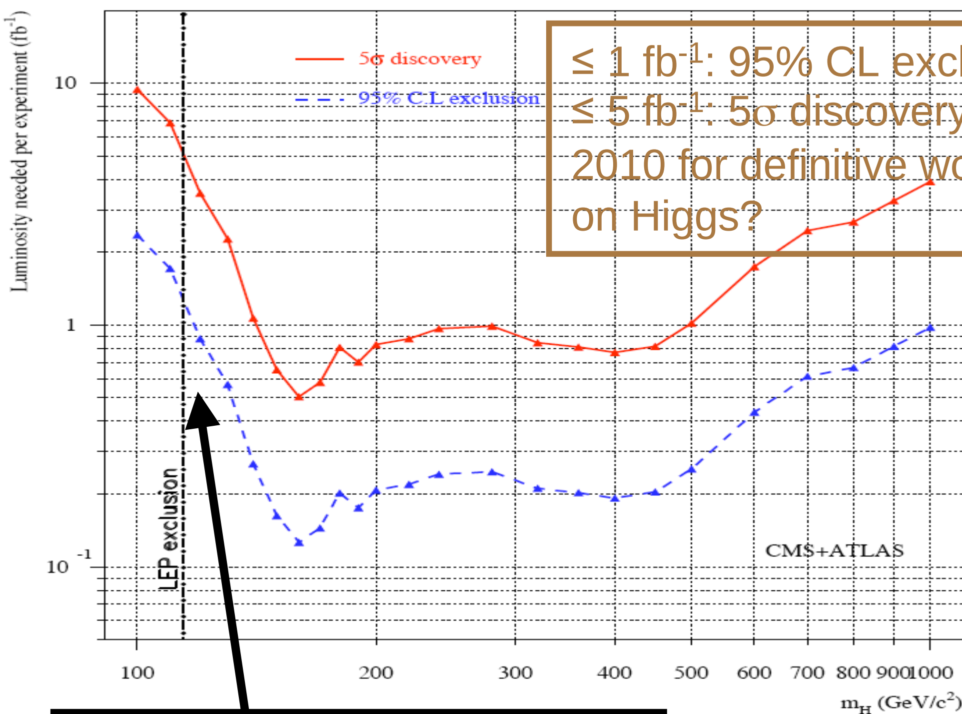
2009

With 5.5 fb^{-1} tougher:
- Exclude 140:180 range
- 3-sigma in one point: 160

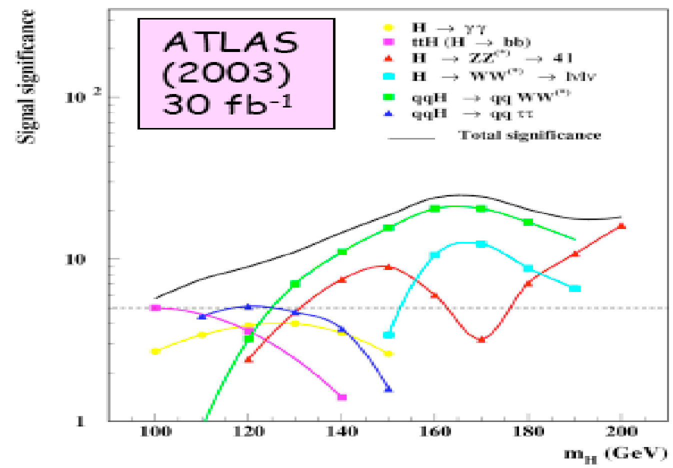
Tevatron will run until 2009
Extension to 2010?

Light Higgs Boson …

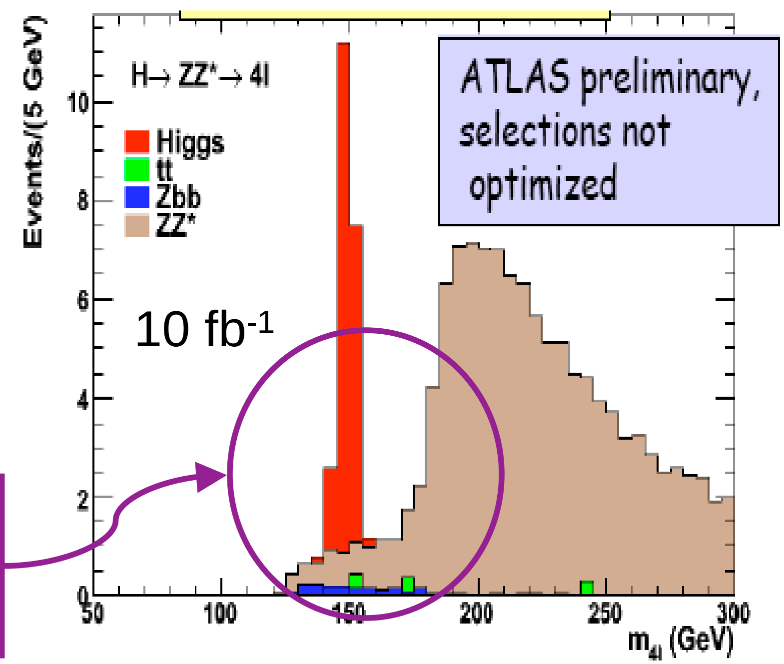
Need ~ fb^{-1} of well-understood data per experiment



≤ 1 fb^{-1}: 95% CL exclusion
≤ 5 fb^{-1}: 5σ discovery
2010 for definitive word on Higgs?



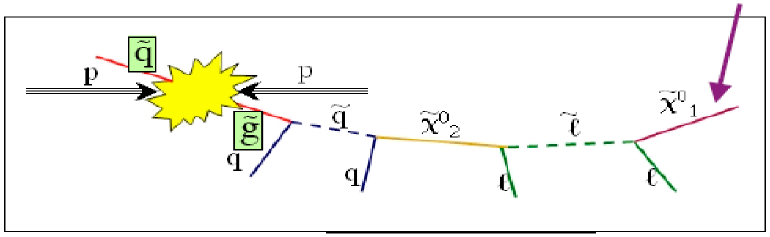
Most difficult region: combine many channels with small S/B

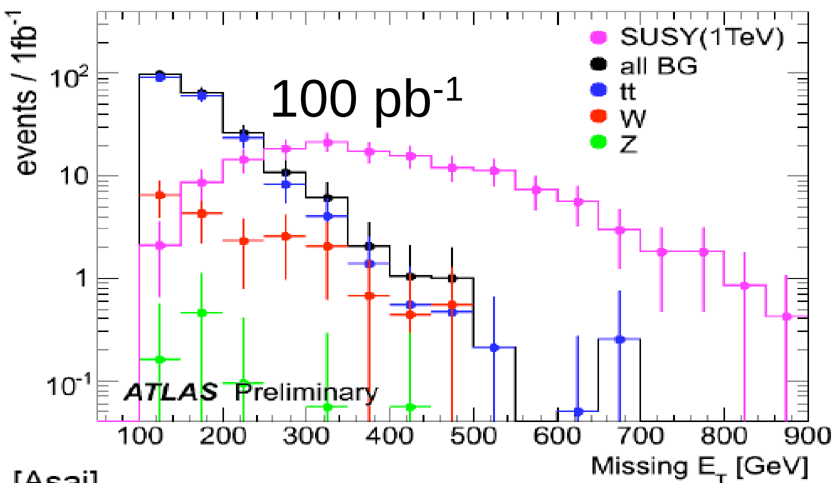


m_H > 140 GeV, easier discovery with H→ZZ*→4l
H→WW→lνlν dominates at 160 but no mass peak (counting experiment)

SUSY as excess number of events in tails…

Lepton(e or μ) +multijets+MET analysis

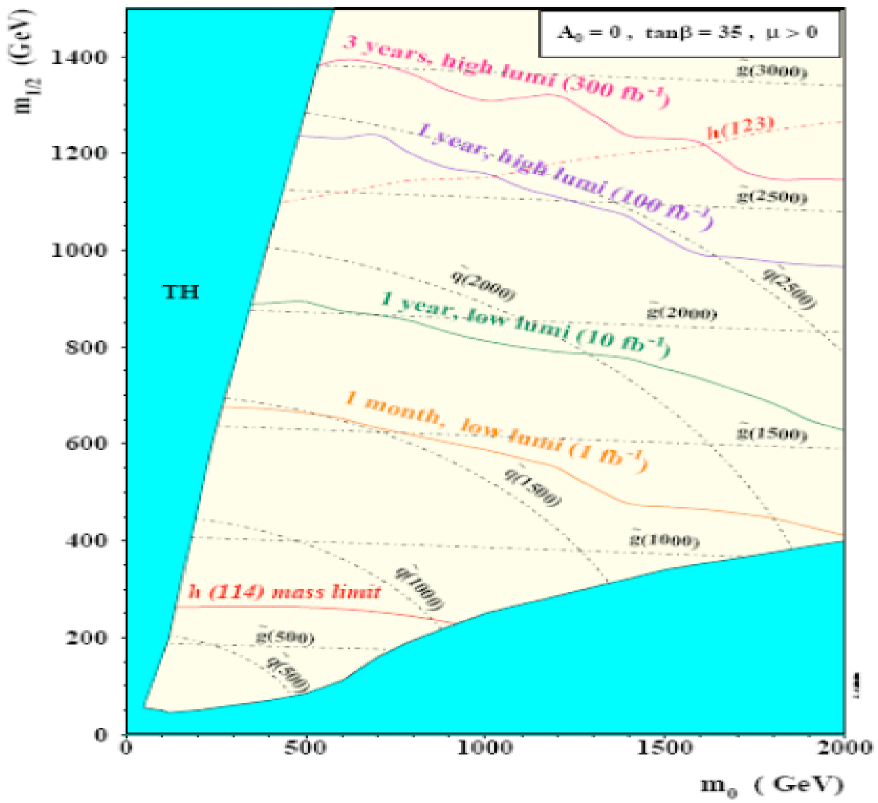




[Asai]

Luminosity	Deviation from SM (90% CL exclusion)
0.1-1 fb^{-1}(2009)	~1.1(1.5) TeV
≥ 1 fb^{-1}(2009-10)	~1.7 (2.2) TeV
300 fb^{-1}(ultimate)	Up to 3 TeV

Deviation from the SM could be seen quickly: but need time to demonstrate that it is SUSY

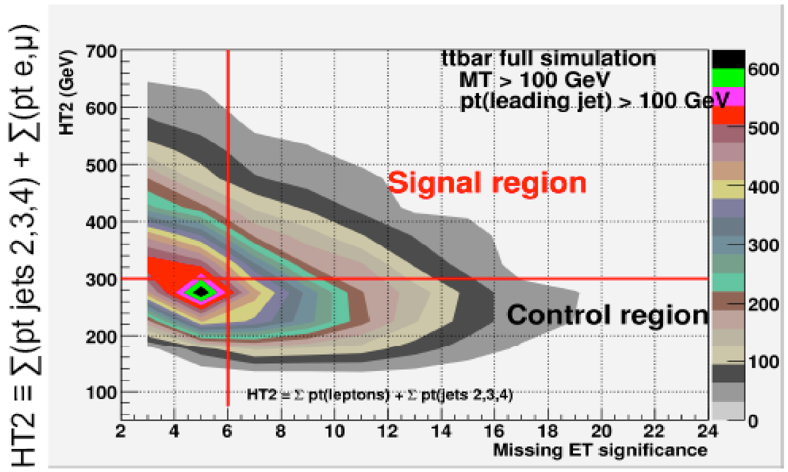


With only 100 pb^{-1}, deviation from the SM up to ~ 1 TeV. But understanding backgrounds would require 1 fb^{-1}

Understanding the tail …

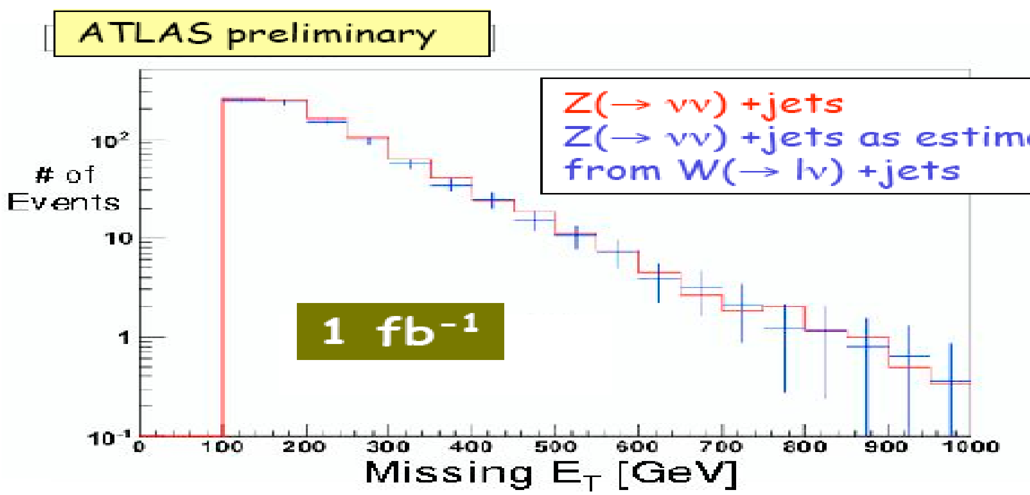
tt is the dominant background to several new physics (SUSY, etc)

- One should not rely on un-tuned MC to estimate this background
- Best is to estimate this background from data: work on constraining backgrounds from data is new - what is possible depends on SUSY parameters
- Take METsig as best discriminant: look for another discriminant X uncorrelated to METsig; one choice is HT2



METsig = MET/σ(MET) where σ(MET) = 0.49 · sqrt(ΣEt)

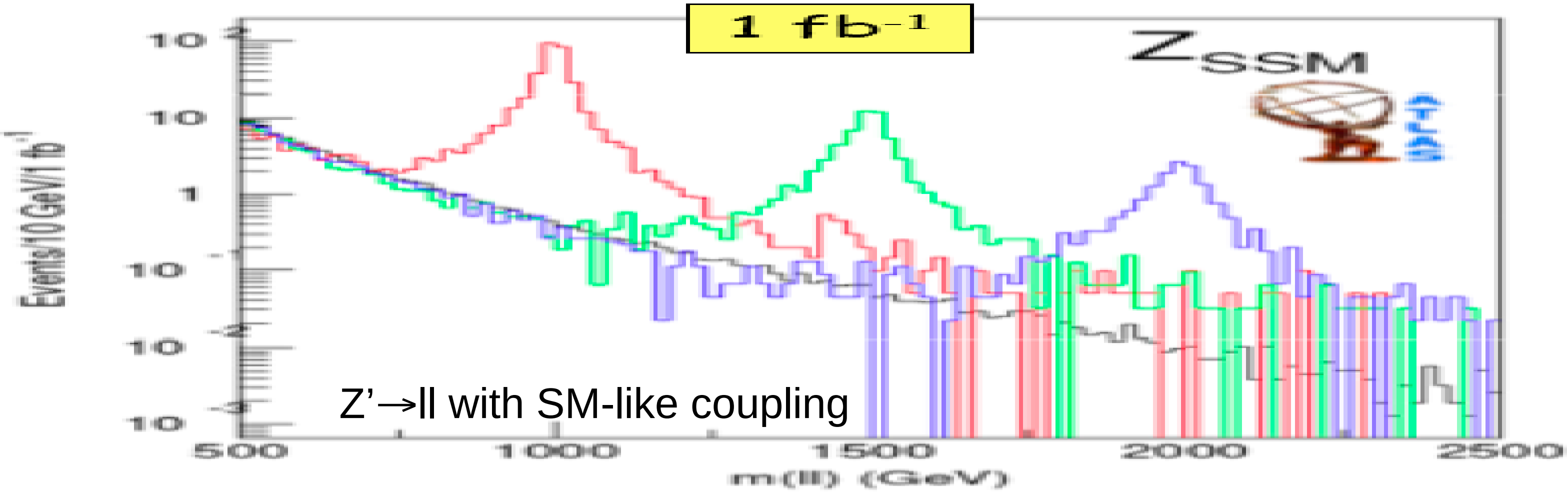
Measure MET significance in "control band" (e.g. HT2 < 300 GeV)
Normalize to the "signal band" (e.g. HT2 > 300 GeV), using the events at low MET (e.g. MET significance < 6)



Allows a prediction of the background in large-HT2, large-MET signal box

Most physics backgrounds can be constrained to 10-20% in the region of E_T^{miss}> 300GeV with 1 fb^{-1}

Narrow Resonance→ll at ~ 1TeV…



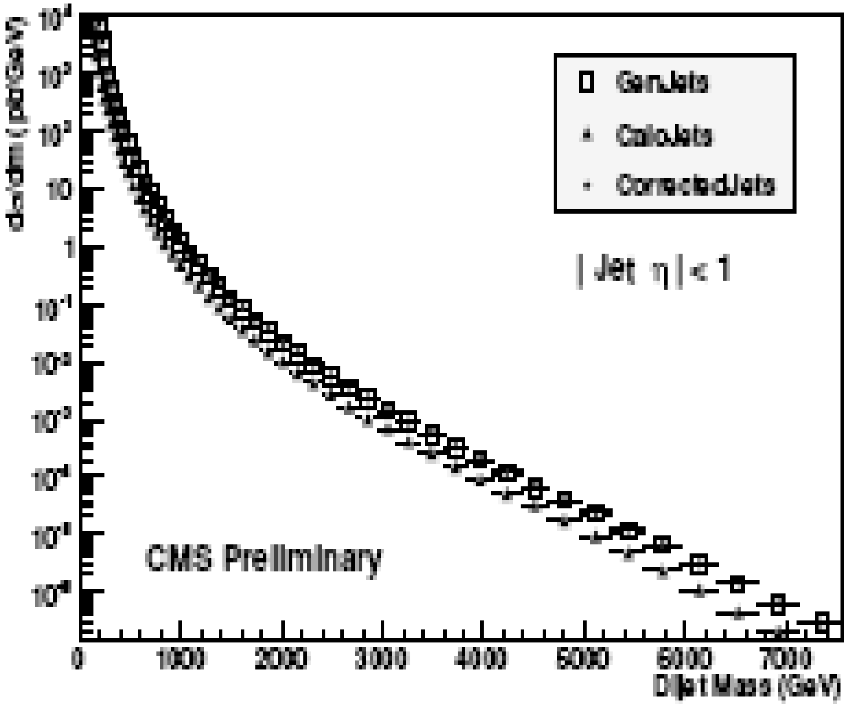
Mass (TeV)	Expected Events for $1fb^{-1}$ after cuts	Luminosity needed for discovery (corresponds 10 observed events)
1.0	~ 160	~ 70 pb^{-1}
1.5	~ 30	~ 300 pb^{-1}
2.0	~ 7	~ 1.5 fb^{-1}

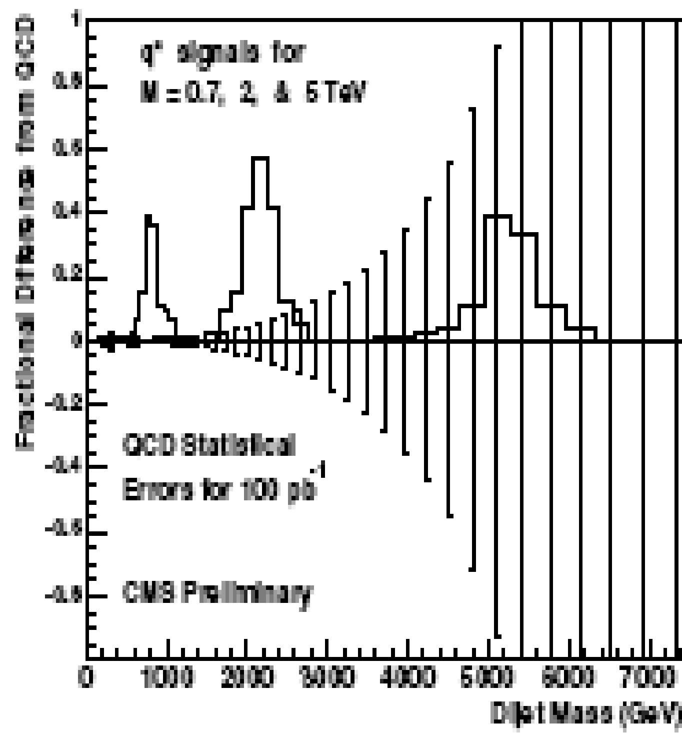
- With 100 pb^{-1}, signal large enough for discovery up to m>1 TeV
- Signal is a narrow resonance on top of a small Drell-Yan background
- Ultimate calorimeter performance not needed

Discovery likely in the e+e- channel but μ+μ- channel needed for couplings, asymmetry, etc

Di-jet Resonances …

- Physics interest is in the high mass tail:
  - Sensitivity to excited quarks, W’, Z’, etc.
  - Limits from CDF and D0 are in the range **< 0.78 TeV**
  - With **few pb^{-1}** at **14 TeV** we can extend the range
  - **Crucial** experimental parameter is the **energy resolution** in measuring jet energy (**They are narrow resonances**)





Convincing signal for a 2 TeV excited quark with 100 pb^{-1}

Conclusions

- With first data, up to 100 pb^{-1} (2008)
  - Detector and Trigger commissioning and calibration in situ
  - Simulation/reconstruction software tuning
  - "Re-discover" the SM: W, Z, top, jets
  - Help constrain PDF uncertainties
  - Could discovery some new physics
    - ~ TeV scale resonance $X \rightarrow ll$
    - Narrow resonance in di-jet mass tail
    - Hint for SUSY
    - Hint for a light neutral scalar
- With more data ($\geq$ 1 fb^{-1}: 2009 -)
  - Discover a TeV scale SUSY
  - Discover at least one Higgs boson
  - Understand deviation, excess as signal for new physics

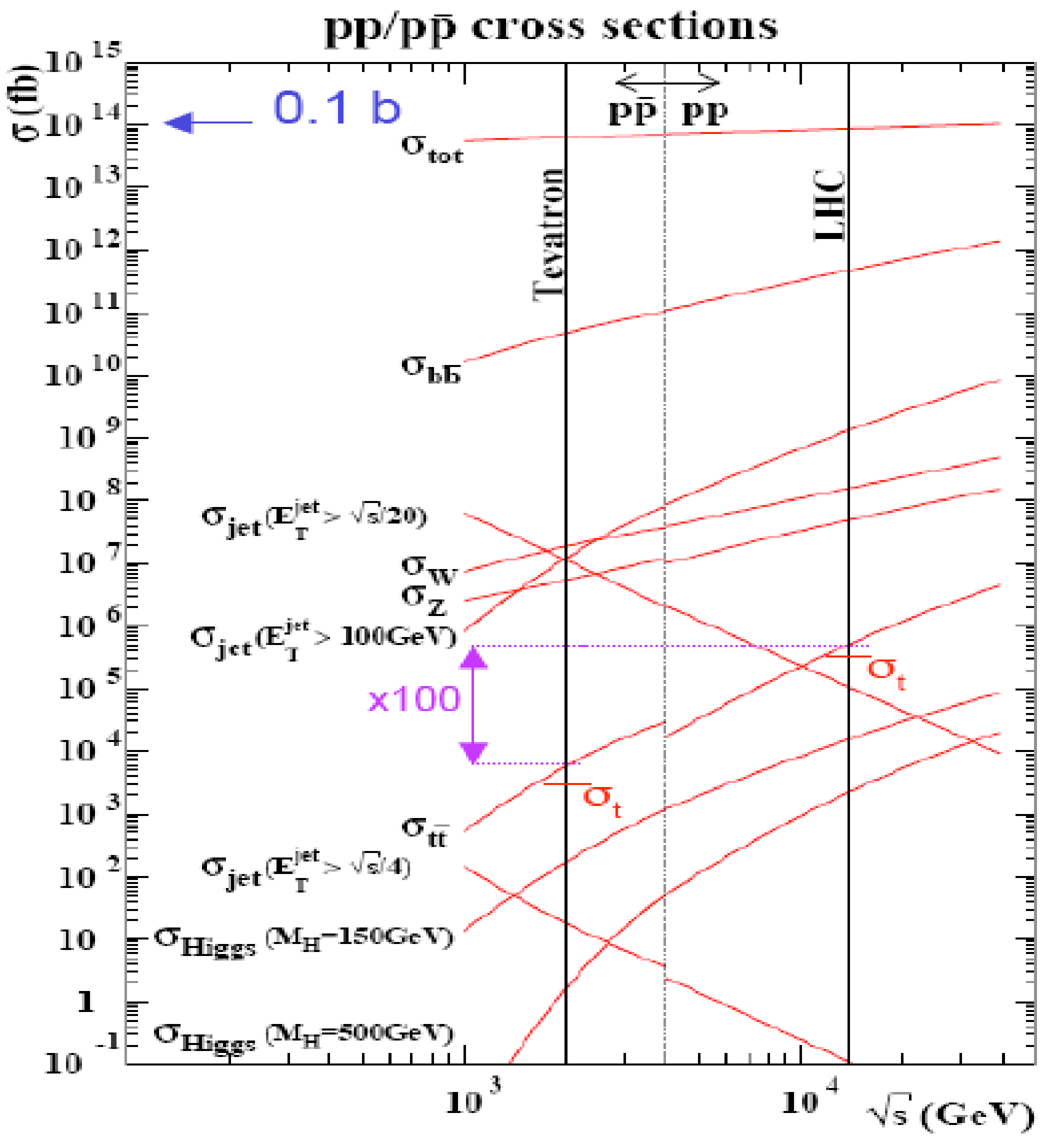
BACKUP

Conclusions (I) …

- There have bean test-beam experiments for several years
  - Understand the performance of sub-detector components
  - Validate software tools for simulation, reconstruction
- Detector installation/integration in the underground caverns almost finished
- Computing infrastructure being tested for taking/distributing data
- Commissioning using cosmic rays, with almost complete detectors in the caverns, currently in progress
- Detector performance and discovery prospects reviewed with “as-built” and “as-installed” detectors

LHC is truly a top-factory

At low luminosity,
LHC will produce ~2 $t\bar{t}$/sec,
~8M/year, compared to a
Total of 10,000 $t\bar{t}$ events
at the Tevatron



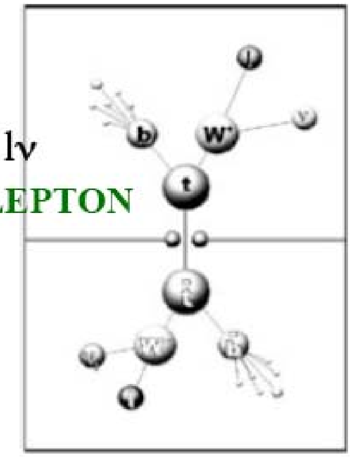
top-quark decays

Top quark decay modes

•BR(t → Wb) @ 100 %

– Both W's decay via W → lν

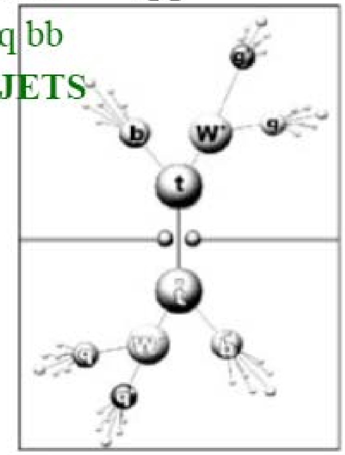
•final state: lνlν bb - **DILEPTON**



– Both W's decay via W → qq

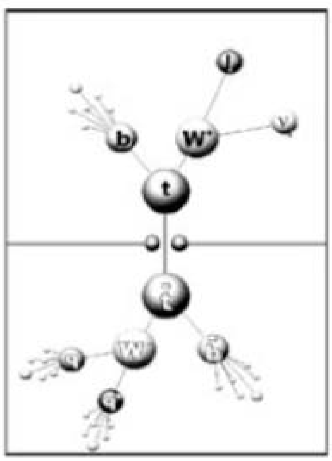
• final state: qq qq bb

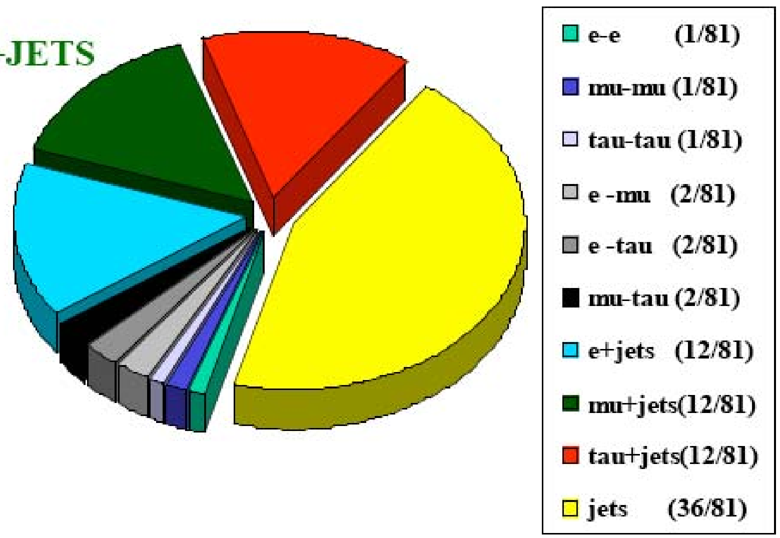
ALL JETS



– One W decays via W → lν

• final state: lν qq bb - **LEPTON+JETS**





Performance Overview

	ATLAS	CMS
INNER TRACKER	• Silicon pixels + strips • TRT with particle identification • B = 2T • $\sigma(p_T)$ ~ 3.8% (at 100 GeV, η = 0)	• Silicon pixels + strips • No dedicated particle identification • B = 4T • $\sigma(p_T)$ ~ 1.5% (at 100 GeV, η = 0)
MAGNETS	• Solonoid + Air-core muon toroids • Calorimeters outside field • 4 magnets	• Solenoid • Calorimeters inside field • 1 magnet
EM CALORIMETER	• Pb / Liquid argon accordion • $\sigma(E)$ ~ 10–12% / $\sqrt{E}$ $\oplus$ 0.2–0.35% • Uniform longitudinal segmentation • Saturation at ~ 3 TeV	• $PbWO_4$ scintillation crystals • $\sigma(E)$ ~ 3–5.5% / $\sqrt{E}$ $\oplus$ 0.5% • No longitudinal segmentation • Saturation at 1.7 TeV
HAD CALORIMETER	• Fe / Scint. & Cu-liquid argon • $\sigma(E)$ ~ 45% / $\sqrt{E}$ $\oplus$ 1.3% (Barrel)	• Brass / scint. • $\sigma(E)$ ~ 100% / $\sqrt{E}$ $\oplus$ 8% (Barrel)
MUON	• Monitored drift tubes + CSC (fwd) • $\sigma(p_T)$ ~ 10.5 / 10.4% (1 TeV, η = 0) (standalone / combined with tracker)	• Drift tubes + CSC (fwd) • $\sigma(p_T)$ ~ 13 / 4.5% (1 TeV, η = 0) (standalone / combined with tracker)

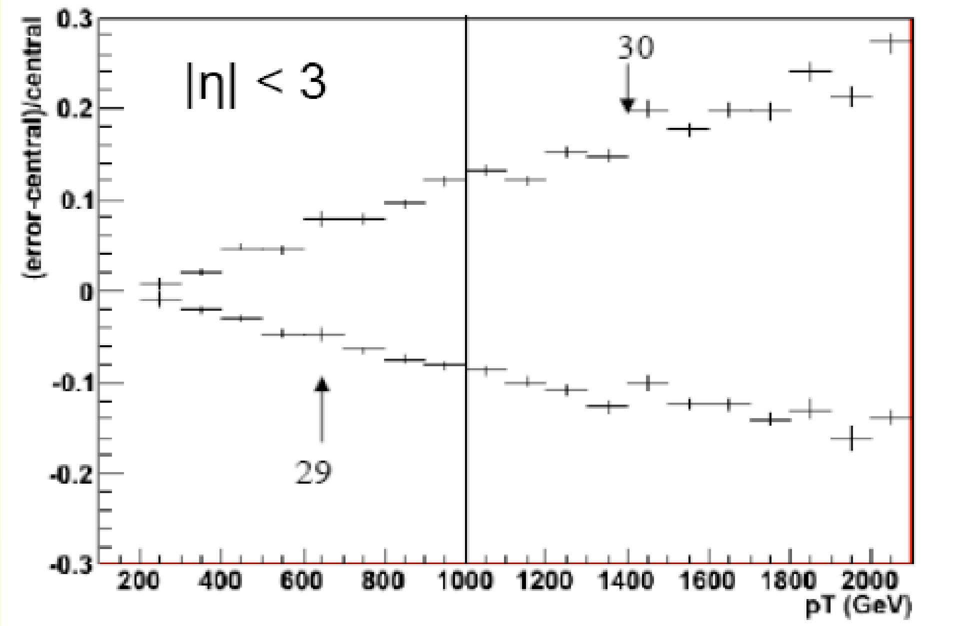
Source: Froidevaux-Sphicas, Ann Rev 56, 375 (2006)

Theoretical Errors (2)

- The PDF uncertainty has been evaluated using CTEQ6, 6.1 (CDF RUN 2 not included). They come together with a number of error sets.
- Out of all the error sets, two (namely 29 and 30) are dominant in the uncertainty of the inclusive cross section in the ~TeV region. They are related to the high x gluon (relatively large uncertainty from DIS)

K_T algorithm has been used with the best fit PDF and with set 29 and 30.

At P_T=1 TeV, the error is approximately 15%

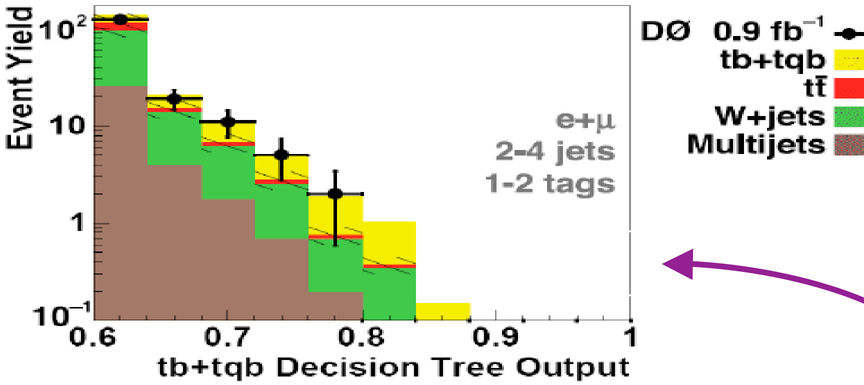


Expected detector performance on day 1…

ATLAS	Expected performance day-1
ECAL uniformity	1-2% (~0.5% locally)
e/γ E-scale	~ 2 %
HCAL uniformity	~ 3 %
Jet E-scale	< 10%
Tracking alignment	10-200 μm in Rϕ Pixels/SCT
Muon alignment	~ 1 mm

- Performance to improve with the following data
  - $Z \to ee$
  - QCD jets
  - γZ+jet, $W \to jj$ in tt
  - Isolated muons in $Z \to \mu\mu$
  - $Z \to \mu\mu$

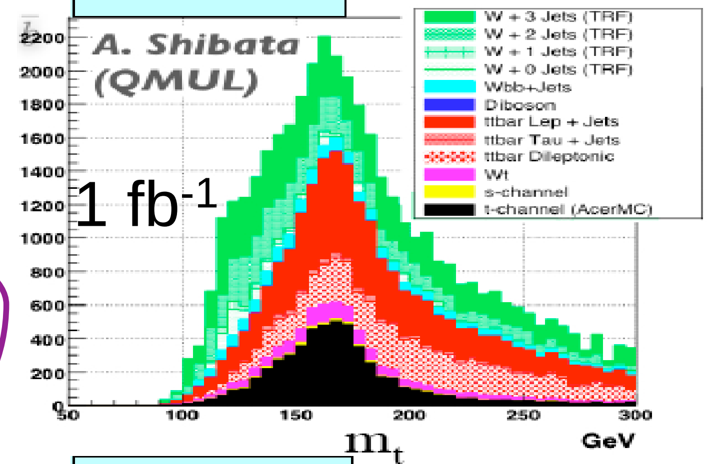
Single top …



- Discovery at the Tevatron before LHC turn-on
- Direct measurement of $|V_{tb}|$, and window on new physics
- All channels have large backgrounds and "issues" with background modeling: tt, W+jets, QCD
- Same general approach in each channel
  - Loose initial selections
  - Multivariate discriminants
    (for s-channel and Wt-channel)

Efficiency = 1%, S/B = 0.47
(after tighter selection)

t-channel



s-channel

S/B=0.18 (MV sel.)