Early physics with ATLAS

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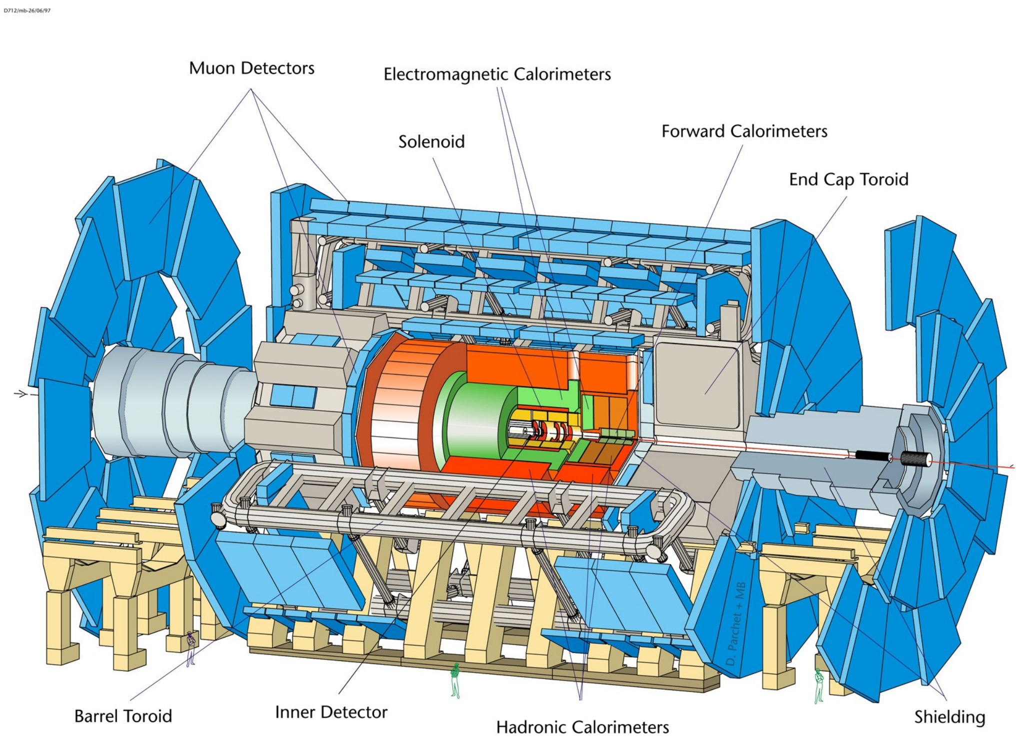
The ATLAS detector



Length ∼45 m

Radius ∼12 m

Weight ∼7000 m

Silicon pixel Detector: $\sim 1.4 \times 10^8$ Channels

SemiConductor Tracker: $\sim 6 \times 10^6$ Channels

Transition Radiation Tracker: $\sim 4 \times 10^5$ Channels

Liquid Argon Calorimeters $\sim 1.8 \times 10^5$ Channels

Tile Hadronic Calorimeter $\sim 10^5$ Channels

Muon Precision Chambers and Trigger $\sim 1.2 \times 10^6$ Channels

Many subsystems

Many readout channels

Complex commissioning

and integration

Ambitious physics program driving severe performance requirements

- Lepton measurement: $p_T \sim \mathrm{GeV} \rightarrow 5\mathrm{TeV}$ ($b \rightarrow lX$, W', Z')
- Mass Resolution (m~ 100 GeV):

  $\sim 1\%$ $(H \rightarrow \gamma\gamma, 4l)$

  $\sim 10\%$ $(W \rightarrow jj,\ H \rightarrow bb)$
- Calorimeter coverage: $|\eta| < 5$ (E_T^{miss}, forward jet tag)
- Particle identification :

  $\epsilon_b \sim 50\%$ $R_j \sim 100$ ($H \rightarrow bb$, SUSY)

  $\epsilon_\tau \sim 50\%$ $R_j \sim 100$ $(A/H \rightarrow \tau\tau)$

  $\epsilon_\gamma \sim 80\%$ $R_j \sim 10^3$ $(H \rightarrow \gamma\gamma)$

  $\epsilon_e > 50\%$ $R_j \sim 10^5$
- Trigger: 40 MHz$\rightarrow$ 100 Hz reduction

Commissioning scenarios

In summary we need to address a very difficult problem:

- Complex detector with tens of millions of channels and many different subsystems
- Ambitious performance goals

Large amount of work (and time) required to control detector at desired level

Need however to be ready to optimally exploit the very first LHC data

Final understanding of detectors only with real collisions in LHC environment

Develop strategy to exploit time from now to collisions to achieve detector understanding adequate to fully take advantage of data from the first day

Main variables: readiness of detectors, time before LHC is running at full steam, building up of integrated luminosity

Tentative LHC schedule (CERN council June 2006)

• Last magnet installed	March 2007
• Machine and experiments closed	31 August 2007
• First collisions ($\sqrt{s} = 900$ GeV, $\mathcal{L} \sim 10^{29}\ cm^{-2}s^{-1}$)	November 2007
• Commissioning run at 900 GeV (~ 30 days)	until end 2007
• Shutdown	3-4 months (?)
• First collisions at 14 TeV (followed by physics run)	2^{nd} half June 2008

Two sectors fully commissioned up to 7 TeV in 2006-2007

If other sectors commissioned to to 7 TeV no circulating beam in 2007

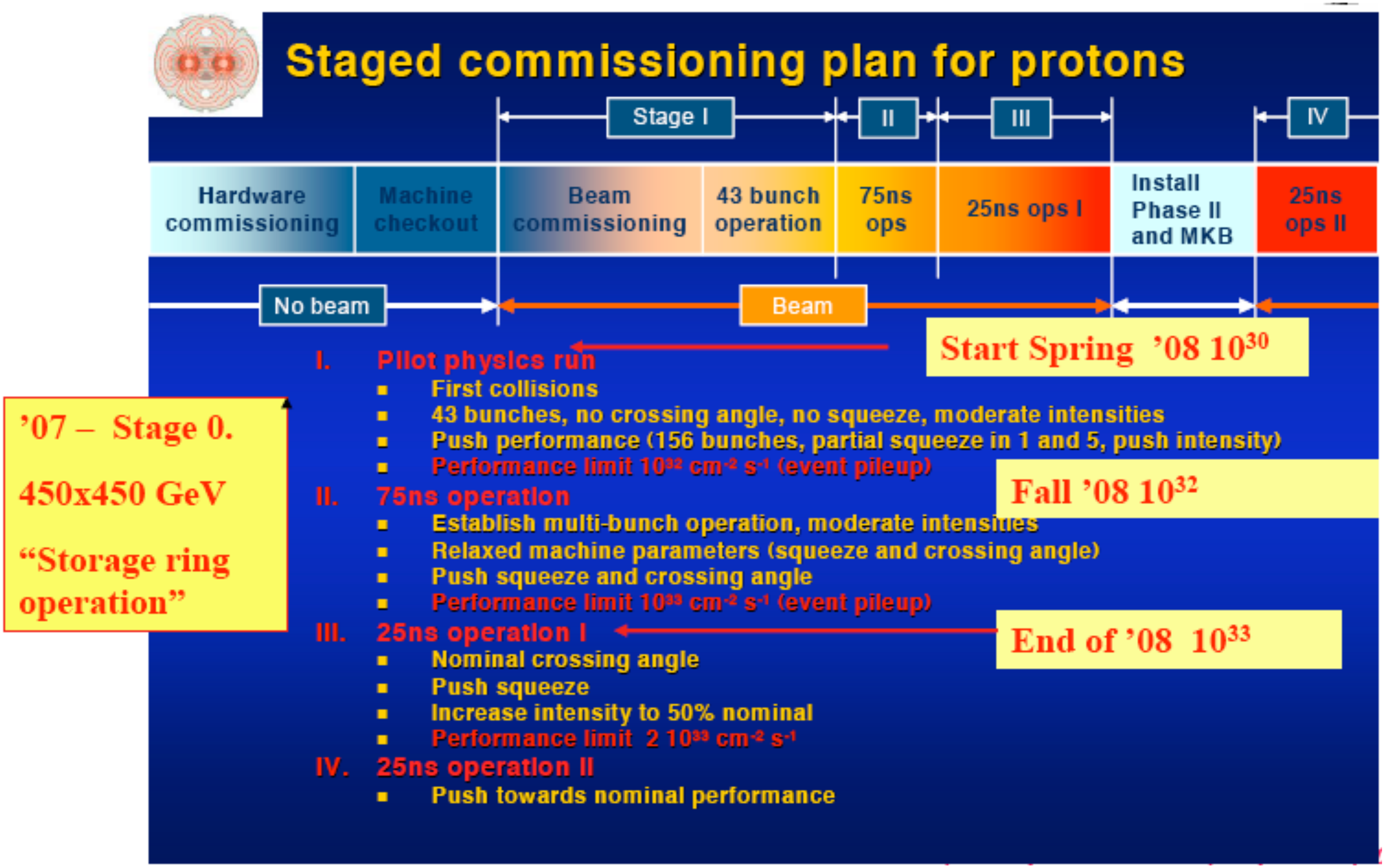
$\Rightarrow$ commission other sectors up to field needed for degaussing

Initial operation at 900 GeV (CM) with static machine (no ramp, no squeeze)

$\longrightarrow$ use for debugging of machines and detectors

Full commissioning up to 7 TeV during winter 2008 shutdown

Possible scenario for machine startup (machine presentation)



Integrated luminosities and dates: presentation by H. van der Schmitt

Based on this information develop start-up strategy

- Last few years: extensive test-beam activities with final detector components
  - Standalone Detector test beams: Basic calibration of calorimeter modules, test of electronics and alignment procedures
  - ATLAS combined test-beam of full slice of detector: test in real life particle ID algorithms, procedures of inter-detector alignment, validation of detailed simulation
- Now, extending up to most of 2007:
  - Computing System Commissioning (CSC), Calibration Data Challenge (CDC): Develop software tools for performing calibration and alignment and perform analysis on non-ideal detector: asymmetric, misaligned, miscalibrated.
  - Cosmics data taking: detector timing and alignment

- From first injections: beam-halo and beam-gas interactions. More specialised alignment work
- 900 GeV interactions: First shake-down of detector with real collisions, some physics measurements (Minimum bias, jets)
- First 14 TeV interactions:
  - Understand and calibrate detector and trigger in situ using well-known physics samples:
    - $Z \to ee, \mu\mu$: tracker, ECAL, muons system
    - $tt \to b\ell\nu bjj$: Jets scale, b-tag performance, $\not{E}_T$
  - Understand basic SM physics at 14 TeV: first checks of MonteCarlo
    - jets and W, Z cross-section top mass and cross-section
    - Event features: Min. bias, jet distributions, PDF constraints
  - Prepare road to discovery: background to discovery from tt, W/Z + jets.

Physics with early data

Realistic approach: assume low selection efficiency for interesting events

Process	$\sigma \times BR$		Events selected for 100 pb^{-1}
$W \to \ell\nu$	20 nb	$\sim 20\%$	~ 400000
$Z \to \mu\mu$	2 nb	$\sim 20\%$	~ 40000
$\bar{t}t$ (semileptonic)	370 pb	$\sim 1.5\%$	< 1000

Jets and minimum bias statistics only limited by allocated trigger bandwidth

Already in autumn 2008 probably enough statistics for physics studies

Already in this workshop talks highlighting the early use of SM processes in ATLAS both as calibration tools and for physics studies: e.g M. Cobal, A. Tricoli.

It is mandatory to demonstrate that we understand LHC physics through SM measurement before going for discovery physics

I will try here to give a rapid overview of the main results of these studies, referring to the specific talks for details

Caveat: all preliminary work mostly not yet documented

Minimum bias and Underlying Event studies

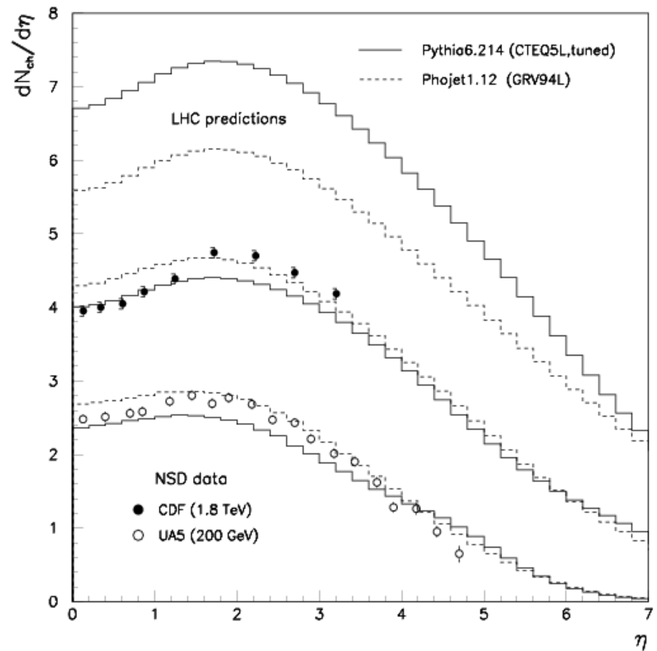
Hadronic interactions:

- Hard processes (high p_T): well described by PQCD
- Soft interactions (low p_T): require non-perturbative phenomenological models:
  - Minimum bias: non single-diffractive events: $\sigma \sim 60 - 70$ mb
  - Underlying event: everything except two outgoing hard scattered jets

First physics available at the LHC

Interesting *per se*

Modeling of minimum bias pile-up and underlying event necessary tool for high P_T physics



Large uncertainty in prediction of track multiplicity when extrapolating from Tevatron data

Measuring minimum bias with early data (ATLAS preliminary)

Number of charged tracks N_{ch} as a function of η $(dN_{ch}/d\eta)$ and p_T $(dN_{ch}/d\eta)$

On fully simulated events compare reconstructed to generated distributions

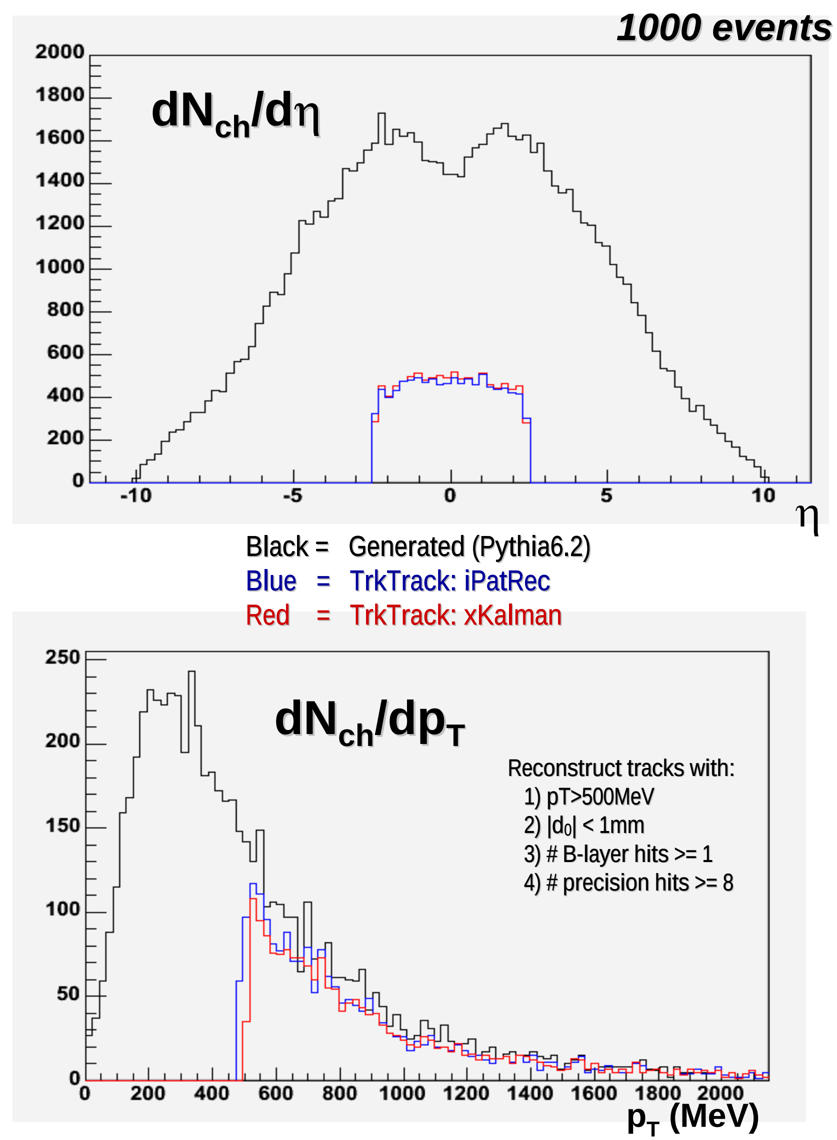
Very few events required

Only a fraction of tracks reconstructed:

- Limited rapidity coverage
- Can only reconstruct track p_T with good efficiency down to ∼500 MeV

Need to apply correction factor from MonteCarlo to subtract minimum bias: systematic uncertainty

Explore extending tracking down to lower p_T

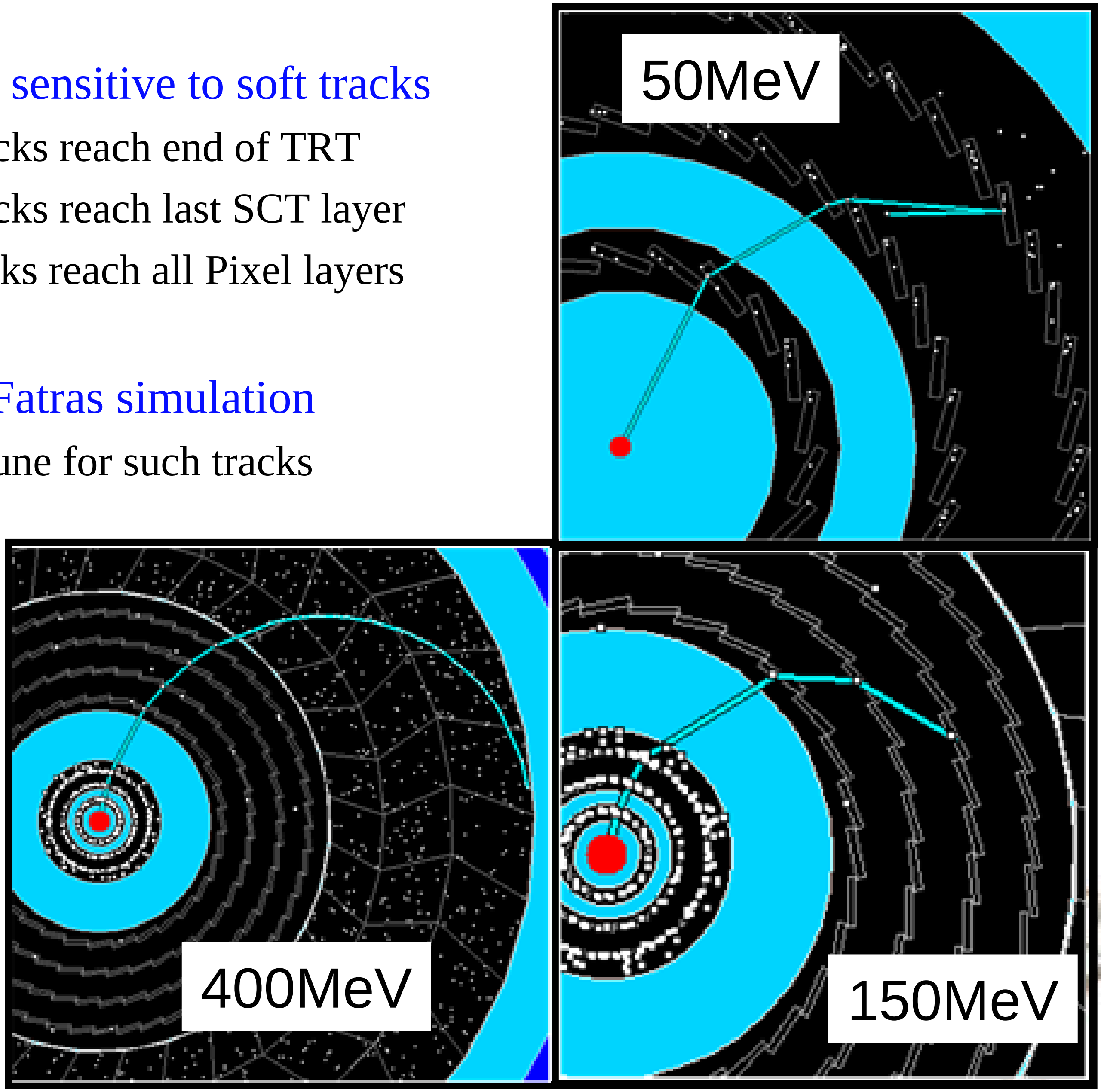


Preliminary exploration of low-pt track reconstruction in ATLAS ID

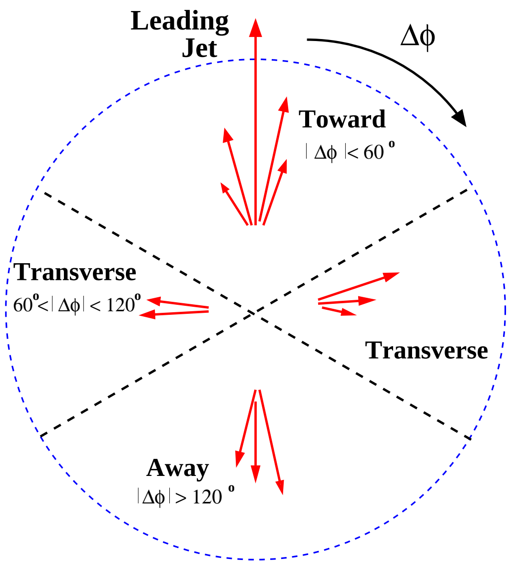
- Tracker is in principle sensitive to soft tracks
  - Pt = 400 MeV - tracks reach end of TRT
  - Pt = 150 MeV - tracks reach last SCT layer
  - Pt = 50 MeV - tracks reach all Pixel layers

- Event graphics using Fatras simulation
  - Tools are there to tune for such tracks

A.Salzburger



Measuring Underlying Event at the LHC



Perform measurement by looking at tracks in the "transverse" region with respect to jet activity

On fully simulated events compare reconstructed and generated multiplicity

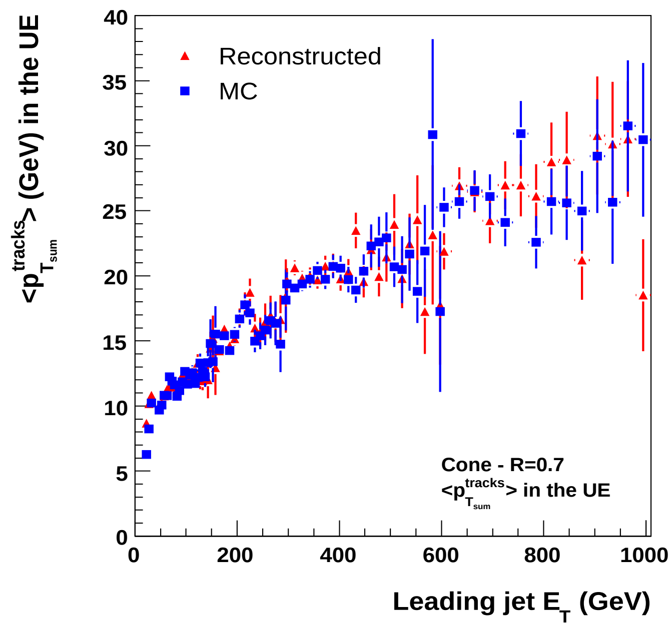
Select:

$N_{jet} > 1 \quad p_T^{jet} > 10 \text{ GeV} \quad |\eta_{jet}| < 2.5$

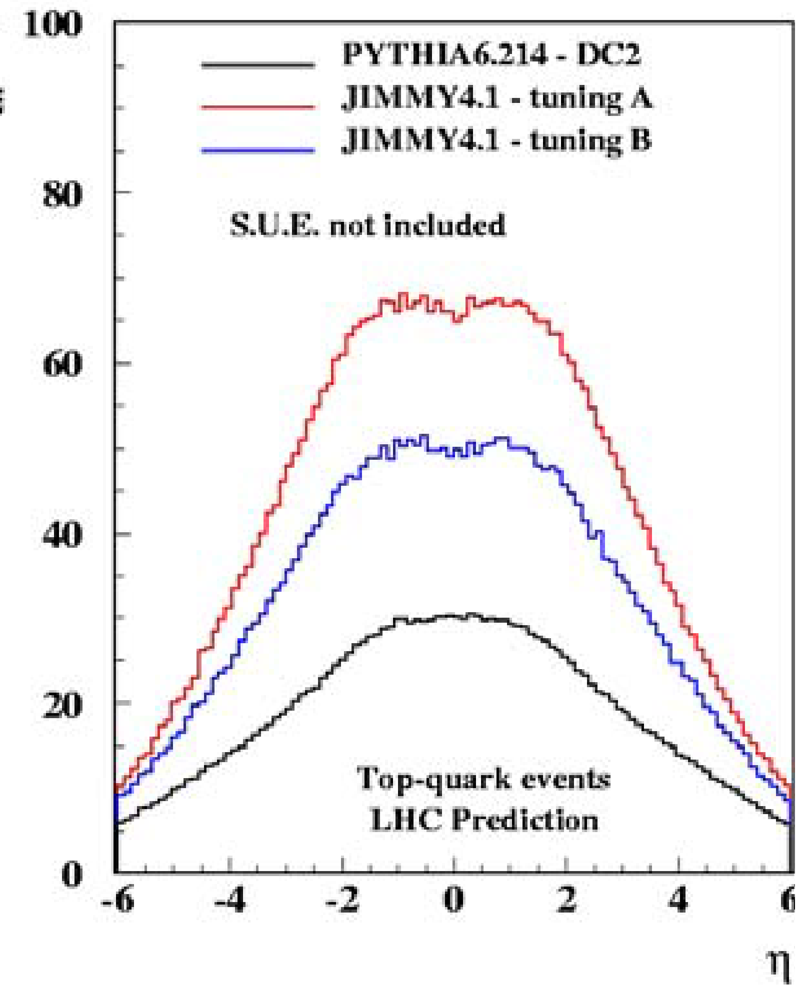
$p_T^{track} > 1.0 \text{ GeV} \quad |\eta_{track}| < 2.5$

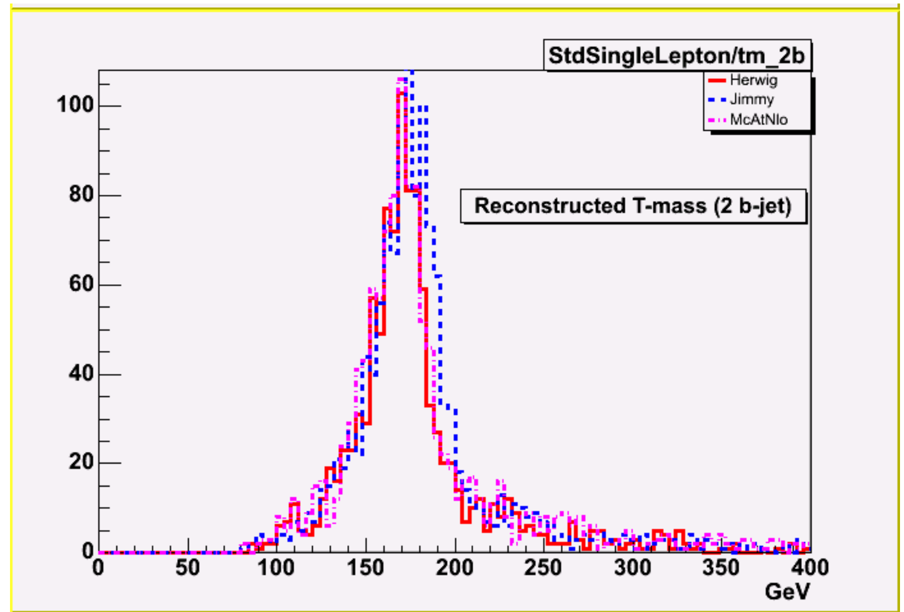
Good agreement reconstructed/generated

Can use to tune MonteCarlo



Example: Impact on top mass measurement





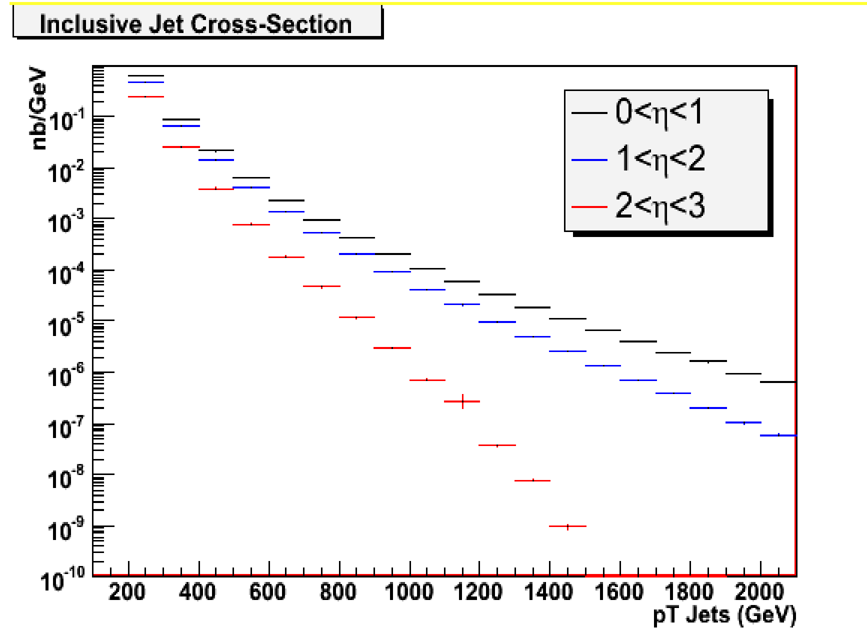
Different UE models can shift top mass by up to 5 GeV

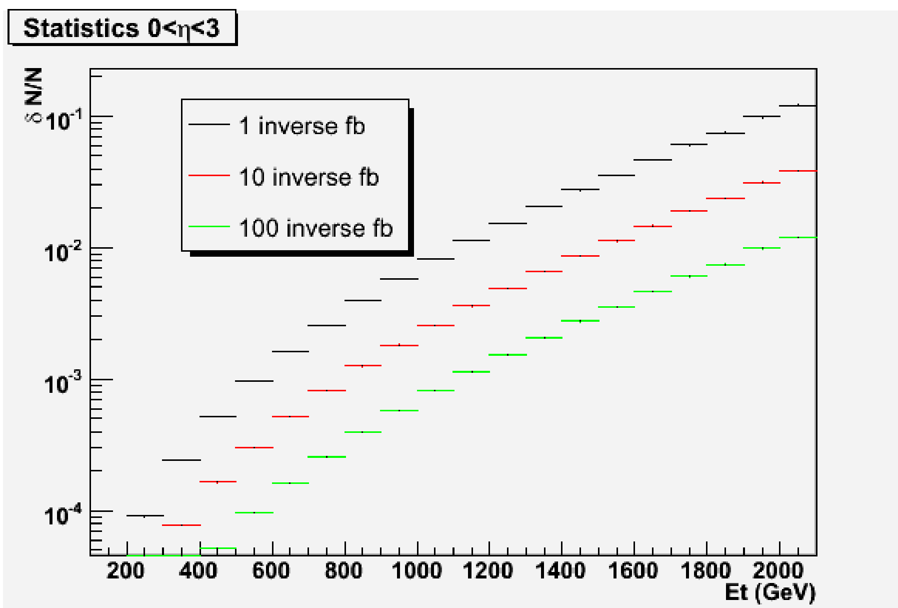
Need excellent UE modeling to perform subtraction

Inclusive Jet cross-section measurement

Concerns all events containing jets, the bulk of high p_T events at the LHC

Show preliminary investigation of ATLAS Glasgow group assessing relative weight of possible error sources





Statistical error

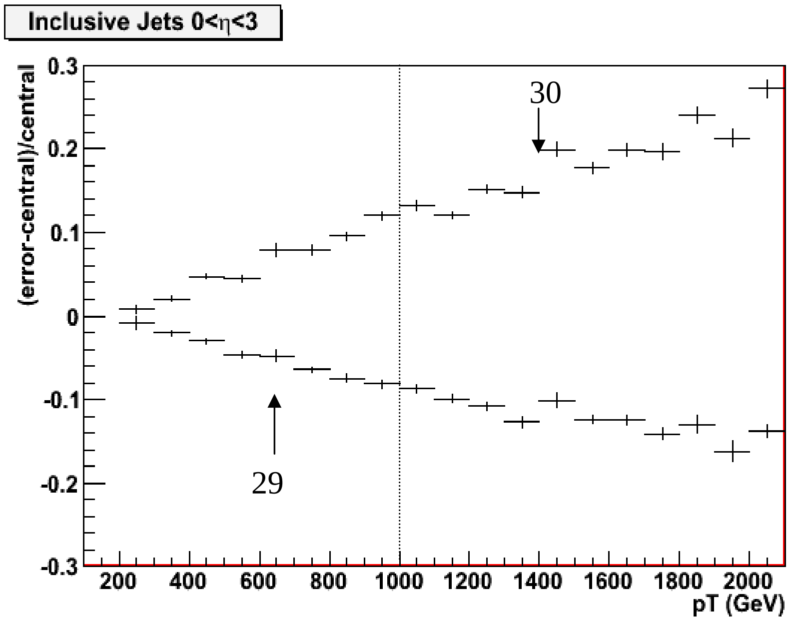
Naive estimate: take error as $\sqrt{N}$, with N number of events for a given integrated luminosity

Plot relative error $\sqrt{N}/N$

For 1 fb^{-1} 1% error for $P_T(jet) \sim 1$ TeV

For 100 pb^{-1} 1% error for $P_T(jet) \sim 0.8$ TeV

Theoretical uncertainties



Use LHAPDF error estimate

Study relative change of NLOJET X-S for the extreme sets of the CTEQ6 PDF

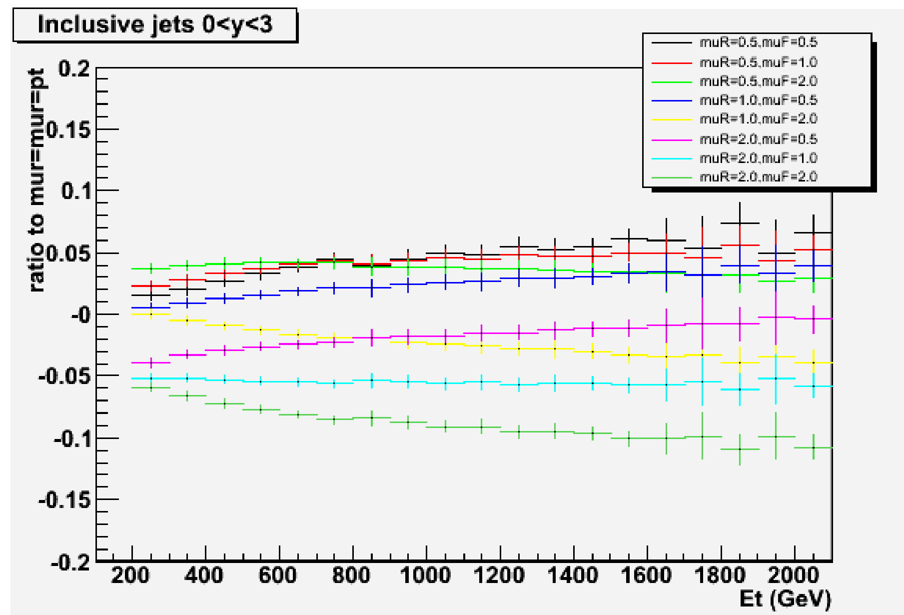
For a jet p_T of 1 TeV errors are approx 10 to 15%

Dominated by high-x gluon uncertainty

Vary renormalisation (μ_R) and factorisation scale (μ_F) between $0.5E_T$ and $2E_T$

Relatively small variation due to use of NLO cross-sections

Uncertainty of 5 to 10% on inclusive jet cross-section for jet p_T of 1 TeV

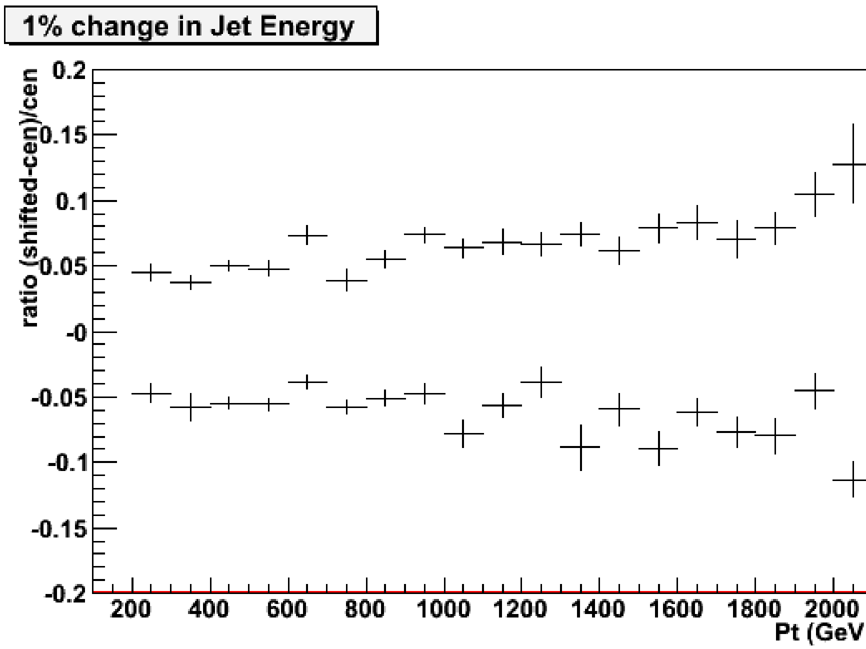


Experimental errors

Many possible sources of experimental errors:

- Jet energy scale,
- Linearity of calo response
- Jet resolution, UE subtraction, trigger efficiency....
- Luminosity determination

Focus on jet energy scale, dominant in Tevatron analyses



Uncertainty on jet scale of 1% yields error on σ(jet) X-s of 6%

Uncertainty on jet scale of 5% yields error on jet σ(jet) of 30%

Jet scale must be known to $\sim 1\%$ in the TeV region: $\Rightarrow$ control of linearity to carry to high energy scale established at 100 GeV.

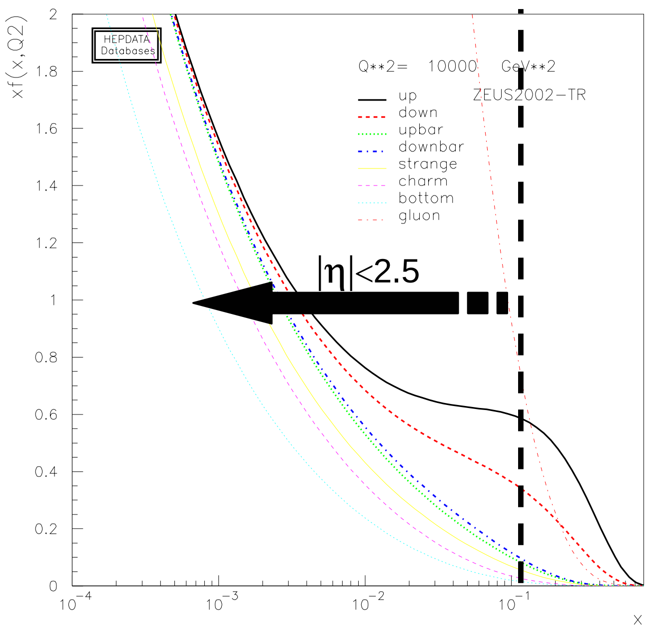
Requires studies of many control samples: tt, γ+jets, Z+jets,... likely to be the dominant factor in determining the time of publication

Studies of W and Z production (see talk by A.Tricoli last meeting

W and Z production cross-section precisely predicted by QCD

Measuring them is one of first basic physics checks at the LHC

Eventually can be used as a luminosity measuring device if theoretical and experimental uncertainties down to ∼3%



Main theoretical uncertainty: PDF parametrisation

For W and Z production at the LHC:

- Dominant sea-sea parton interactions at low x
- At $Q^2 = M_Z^2$ sea distributions driven by gluon
- Low x gluon has large uncertainty

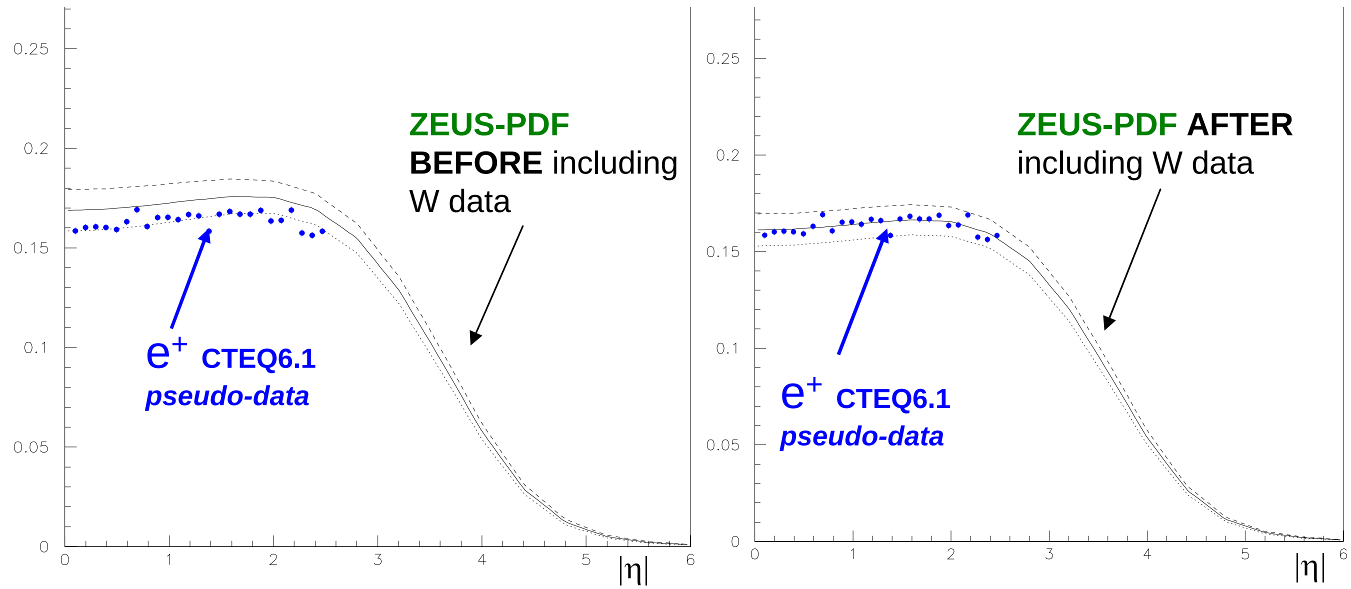
Studying W and Z production can increase our knowledge of gluon SF

Show study performed by ATLAS Oxford group (see talk by A. Tricoli)

PDF constraining potential of ATLAS

Exercise: generate 1M ATLAS pseudo-data (ATLFAST) with CTEQ6.1 PDF's, correct back for acceptance effects, and include in ZEUS PDF fit

Statistics corresponds to $\sim$100-200 pb^{-1}



To simulate experimental uncertainties impose a 4% random error on data points

Low-x gluon distribution determined by shape parameter λ ($xg(x) \sim x^{-\lambda}$)

Observe 35% error reduction λ when ATLAS pseudo-data included in fit

Early top physics in ATLAS (see talk by M. Cobal in first meeting)

Top production is ideal laboratory for initial studies

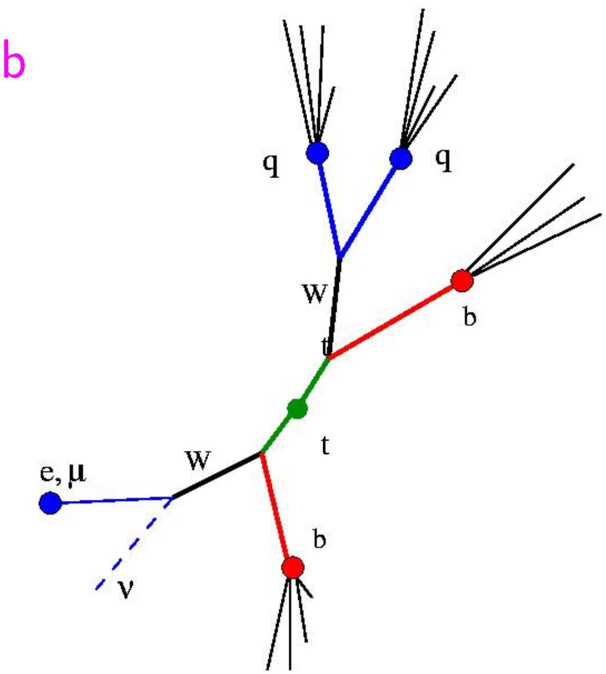
Very high cross-section at the LHC: $\sigma_{\bar{t}t} = 830$ pb

Semi-leptonic signature: $\bar{t}t \rightarrow b\ell\nu bqq$:

Easy to trigger on and to extract

involves many detector signatures:

lepton-id, $\not{E}_T$, Jet reconstruction and calibration, b-tagging



Three main aspects of early top studies:

- Initial measurements of mass, σ_{tt}, possible deviations due to new physics
- Use as a calibration tool
- Learn how to control top as a background

Commissioning scenarios

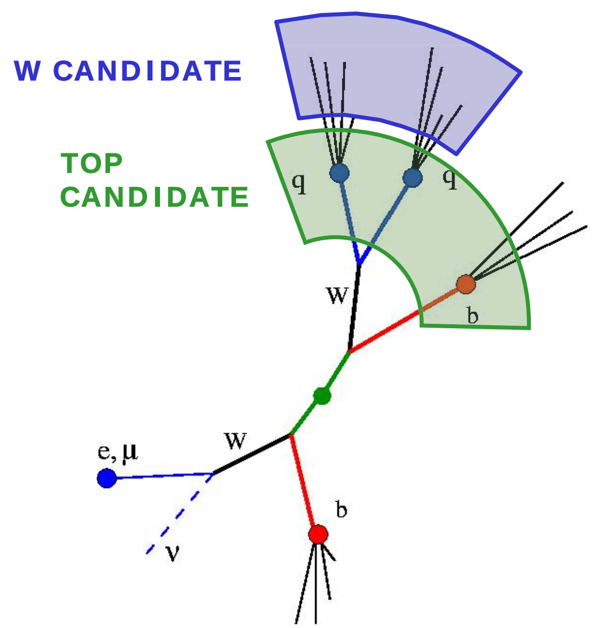
Several months to achieve pixel alignment necessary for nominal b-tagging

Study separation of sample of top events from background without b-tagging

- Use high multiplicity in final state
- hard p_T cuts to clean sample and minimize contribution of additional jets

Even with a 5% selection efficiency still have ∼10 events/hour at 10^{33}

Full simulation study by the ATLAS NIKHEF group



Jet assignment:

Hadronic top:

Three jets with highest $\sum \vec{p}_T$ as top decay products

W boson:

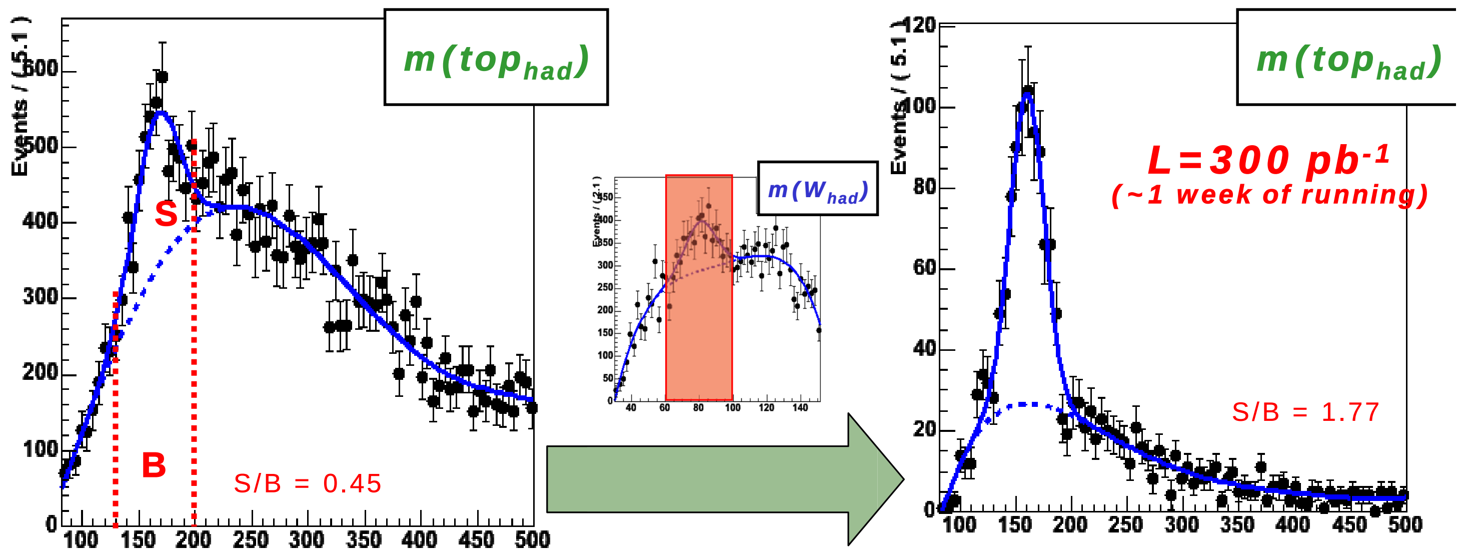
Two jets in hadronic top with highest momentum

in reconstructed jjj C.M. frame

Signal + W+jets background

Exploit correlation between $m(top_{had})$ and $m(W_{had})$ to clean top signal

Show $m(top_{had})$ only for events with $|m(jj) - m(W)| < 10$ GeV



A clear top signal can be observed even at low statisitcs

Expect a statistical error on cross-section between 5 and 10%, depending on cuts

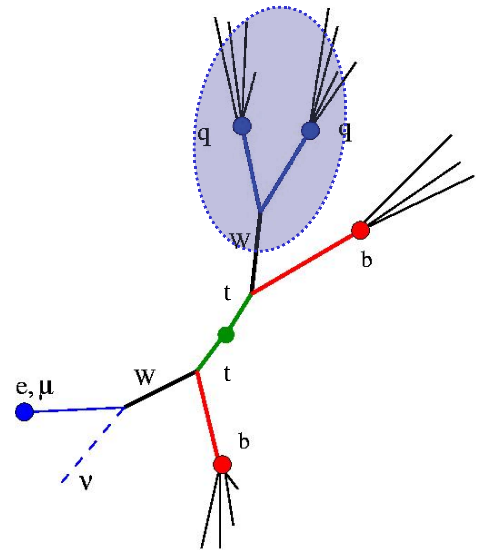
Error on $m(top)$ already dominated by systematic effects

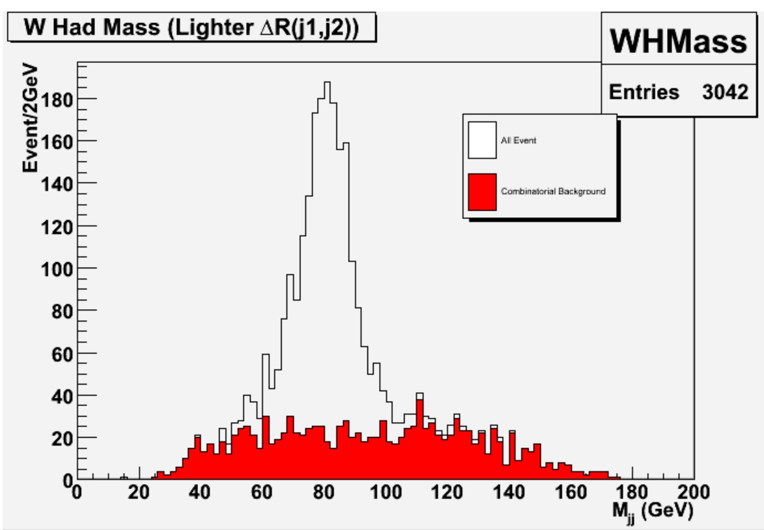
Using ttbar events: jet energy scale from W

Preliminary exercise on ATLAS full simulation (D. Pallin)

Use top semileptonic decay: select two light jets from W decay, and calibrate to W mass

Selection with 1 or 2 b tags Typically 3000(6000) W/fb^{-1} for 2(1) b-tag, $\epsilon_{btag} = 60\%$





W mass distribution ATLAS full sim, 500 pb^{-1}.

Using both b-tagging and kinematic constraints achieve purity of 80-90%

Cover jet energies from 40 to 400 GeV

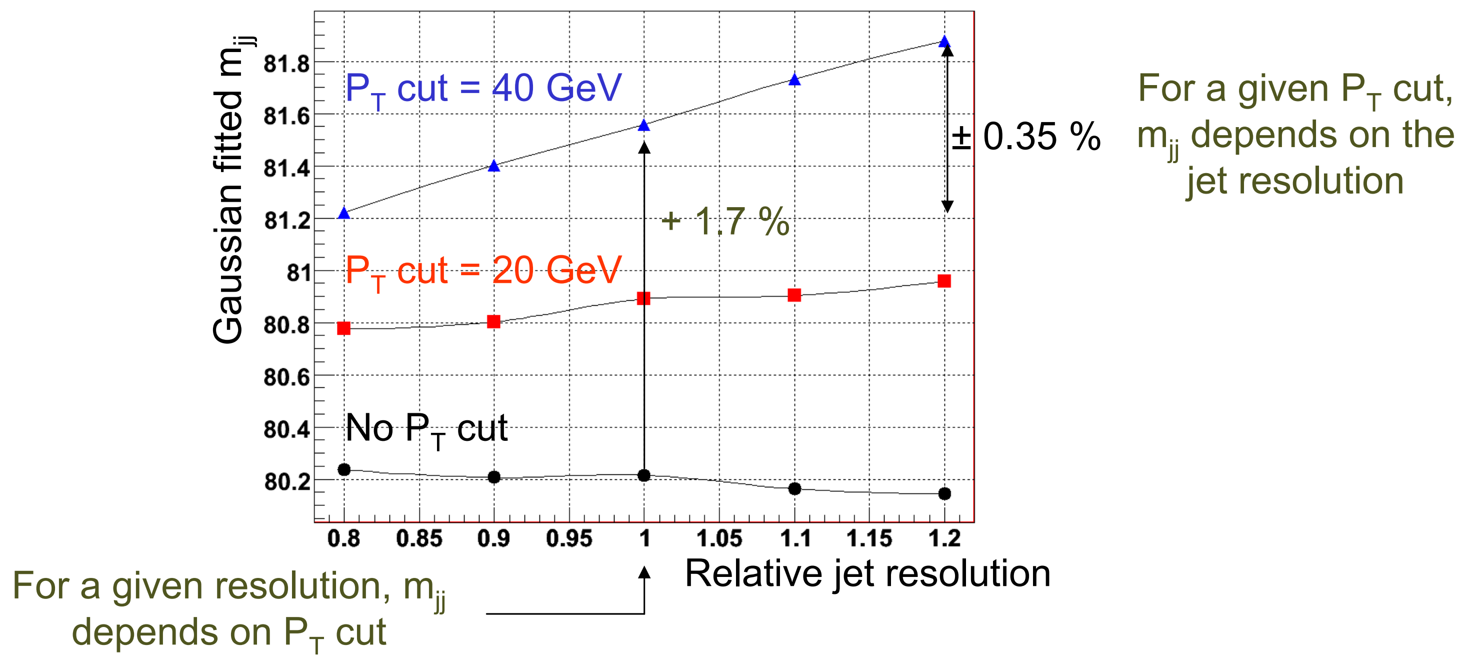
Use a naive jet scaling method for equating the peak position to the nominal W mass

Expect to achieve a 1% calibration level with 1 fb^{-1}

Systematic effects

Two main sources of systematics being studied (Saclay group):

- Dependence on selection cuts applied to define the W sample
- Dependence on assumed jet resolution, skewing the lower energy jets



More sophisticated methods being developed to take into account these effects

Conclusions

LHC startup will require a long period of development and understanding for both machine and detectors

Detailed commissioning plan for detectors: plan to achieve baseline 'reasonable' calibration and alignment before collisions using cosmics and machine development periods

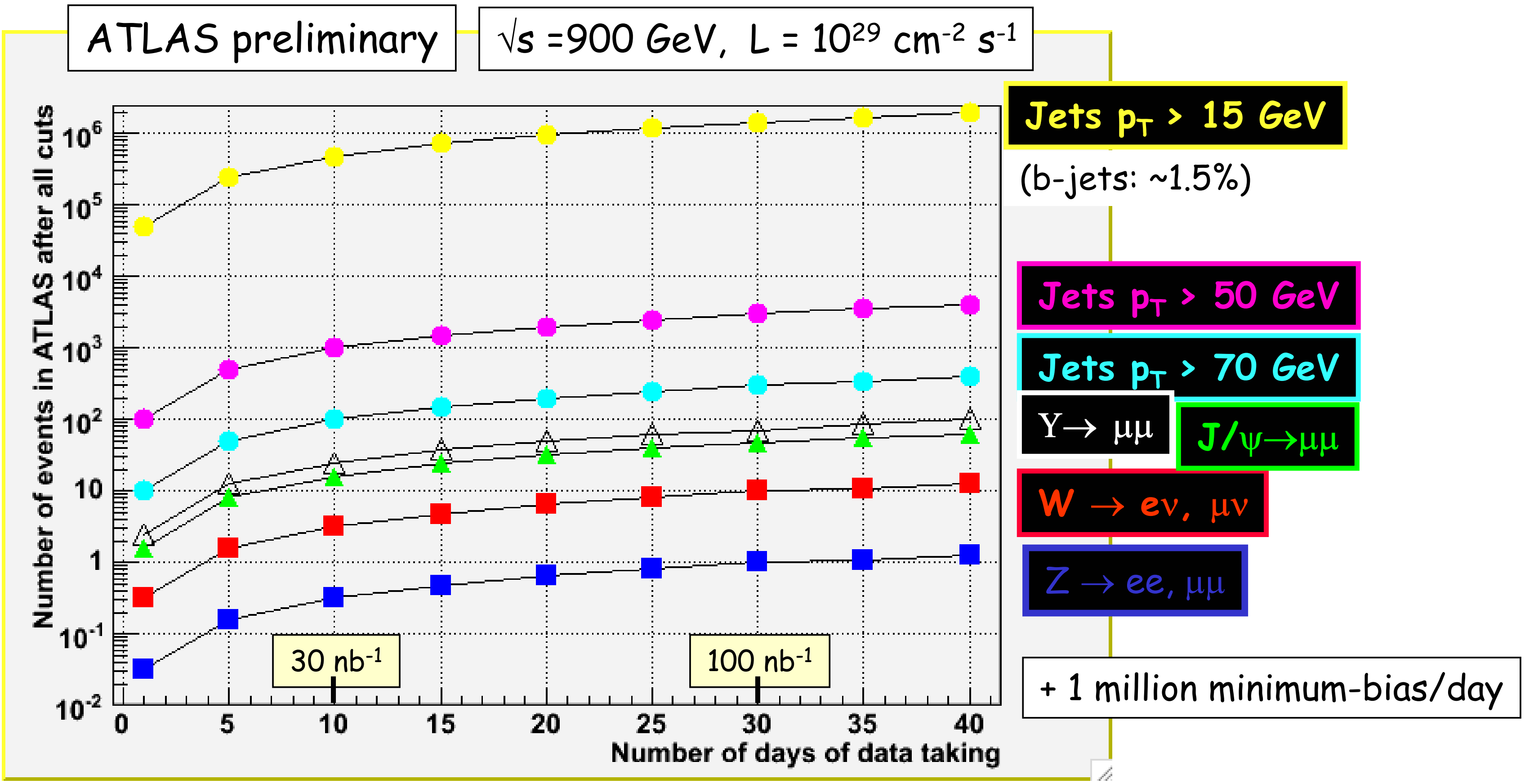
As soon as interactions at 14 TeV happen, interesting physics available in data

Parallel processes of using data to further 'technical' detector understanding and to perform benchmark SM physics measurements

Goal is to arrive at high statistics (few fb^{-1}) data-taking ready to go for early discovery physics

Backup

900 GeV run: which data samples?



30% data taking efficiency included

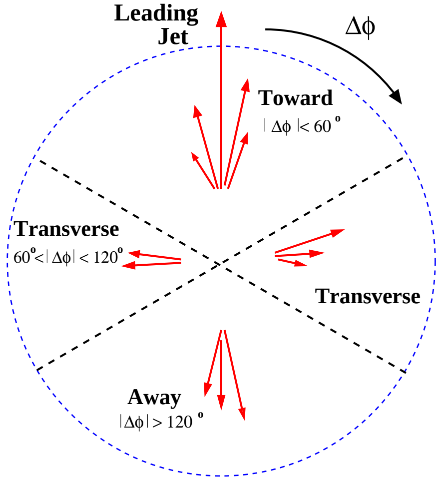
Start to commission trigger and detectors with collision data

Possibly first physics measurements (minimum bias, underlying event, jets)

Observe a handful of $W \to \ell\nu$, $Y \to \mu\mu$, $J/\psi \to \mu\mu$

Few thousand muons from b semileptonic decays

Underlying event at 900 GeV

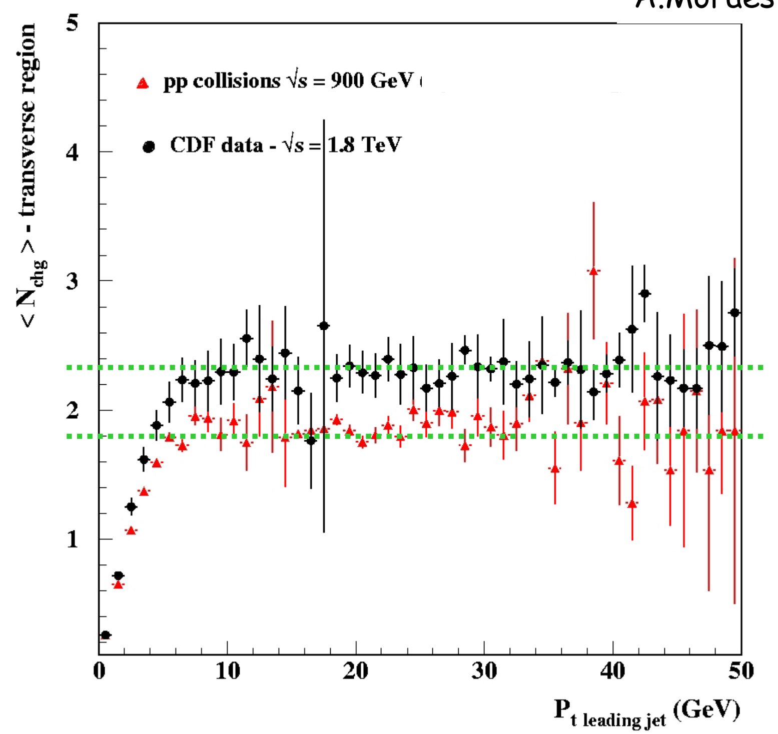


Study multiplicity of charged particles with $p_T > 0.5$ GeV and $|\eta| < 1$ in region transverse to leading jet

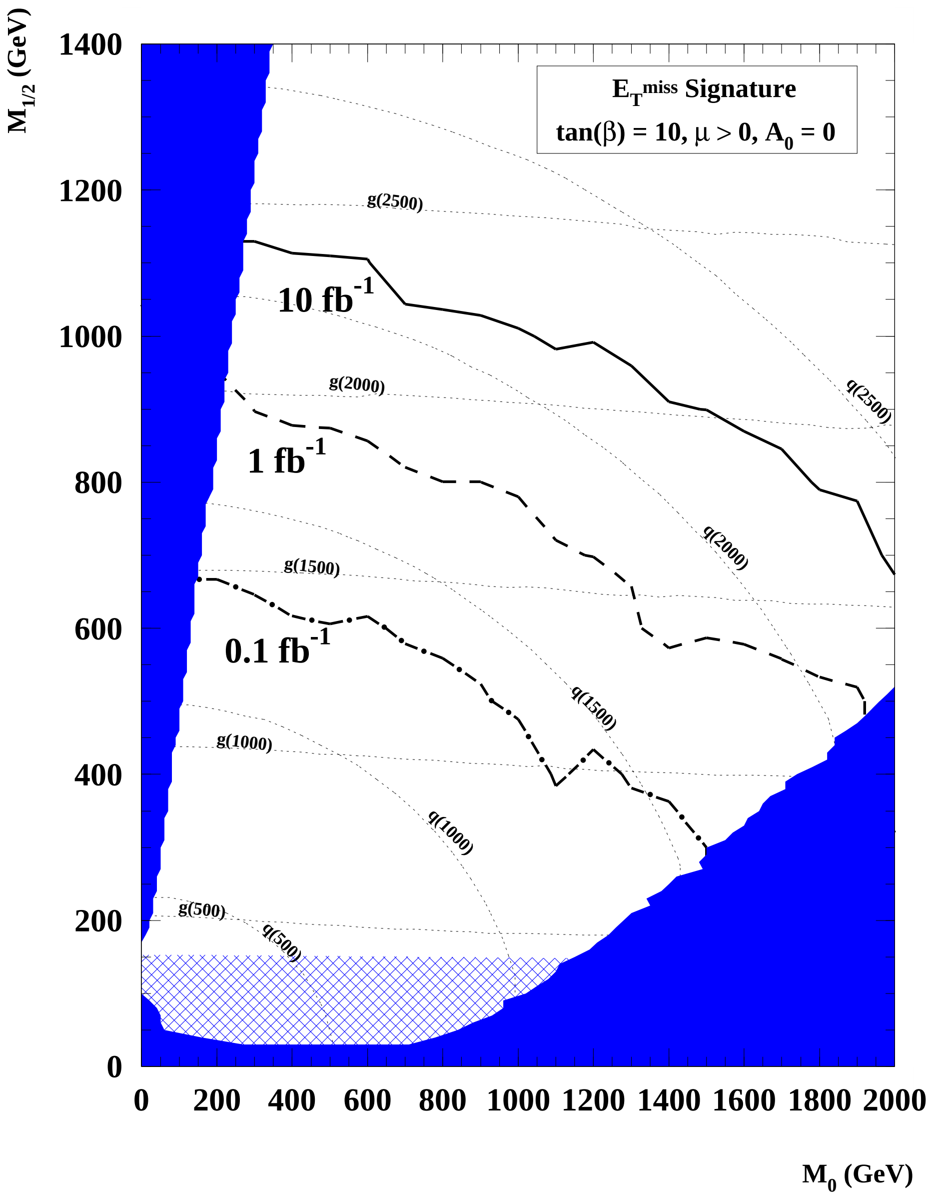
Comparison of plateau between LHC and Tevatron will tell if detector performance, reconstruction tools and physics are under control

∼15 days of data-taking enough to cover up to p_T(leading jet)∼40 GeV

A.Moraes



Early discovery of new physics: the SUSY case



- ~1300 GeV in 100 pb^{-1}
- ~1800 GeV in 1 fb^{-1}
- ~2200 GeV in 10 fb^{-1}

Fast discovery from signal statistics

Time for discovery determined by:

- Time to understand detector performance ($\not{E}_T$ tails, lepton id, jet scale)
- Time to collect sufficient statistics of SM control samples: W, Z+jets, $\bar{t}t$

Two main background classes:

- Instrumental $\not{E}_T$
- Real $\not{E}_T$ from neutrinos

Backgrounds to $\not\!\!E_T+$ jets analysis

Instrumental $\not\!\!E_T$ from mismeasured multi-jet events:

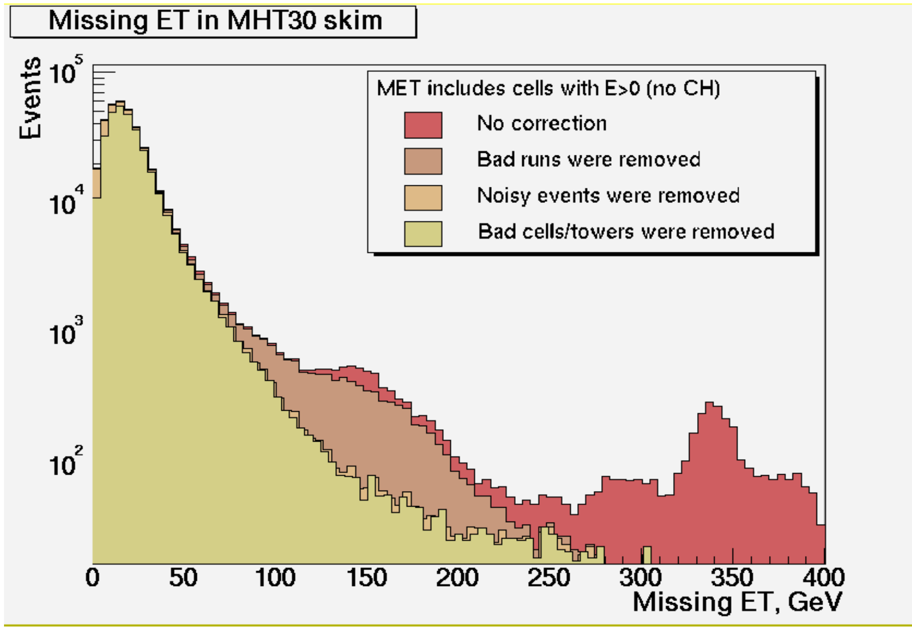
Many sources: gaps in acceptance, dead/hot cells, non-gaussian tails, etc.

Require detailed understanding of tails of detector performance.

Reject events where fake $\not\!\!E_T$ likely.

- beam-gas and machine backgrounds
- displaced vertexes
- hot cells
- $\not\!\!E_T$ pointing along jets
- jets in regions of poor response

See effect of $\not\!\!E_T$ cleaning in D0



All detector and machine garbage will end up in $\not\!\!E_T$ trigger Long and painstaking work before all the sources of instrumental $\not\!\!E_T$ are correctly identified

Control of $\not{E}_T$ from Standard Model processes

Dominant SM background to $\not{E}_T$+jets is $Z \to \nu\nu$+jets.

Use well-reconstructed $Z \to ee$ events to evaluate this background

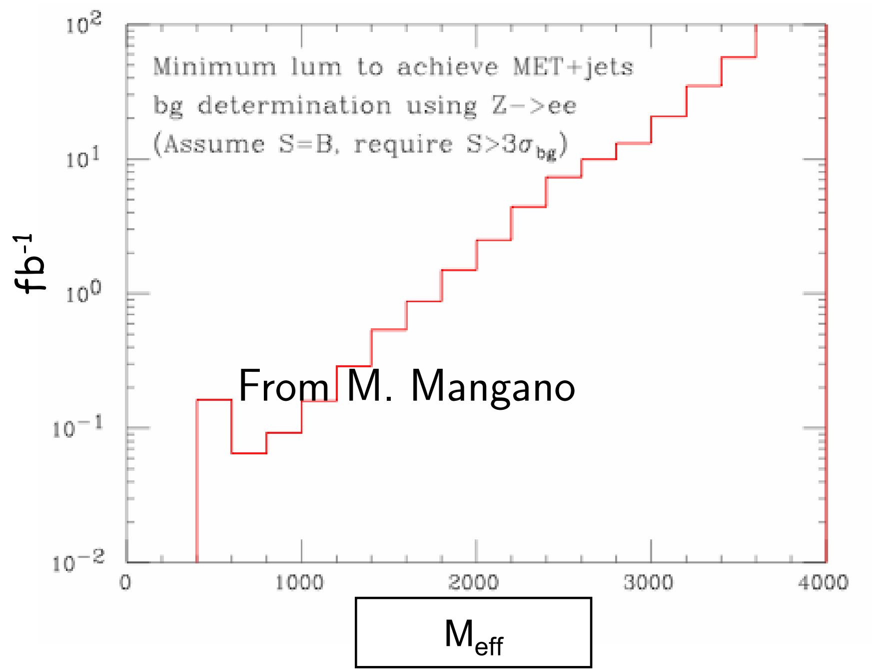
Normalisation needs to be multiplied by $BR(Z \to \nu\nu)/BR(Z \to ee) \sim 6$

Assuming SUSY signal $\sim Z \to \nu\nu$ bg, evaluate luminosity necessary for having $N_{SUSY} > 3 \times \sigma_{bg}$

Stat error on background:

$$\sigma_{bg} = \sqrt{N(Z \to ee)} \times \frac{BR(Z \to \nu\nu)}{BR(Z \to ee)}$$

For each bin where normalisation required, need ~ 10 reconstructed $Z \to \ell\ell$ events. Need to consider acceptance/efficiency factors as well



Several hundred pb^{-1} required. Attempts on $W \to \mu\nu$ ongoing to improve statistics