QCD Studies in ATLAS

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On behalf of the ATLAS Collaboration

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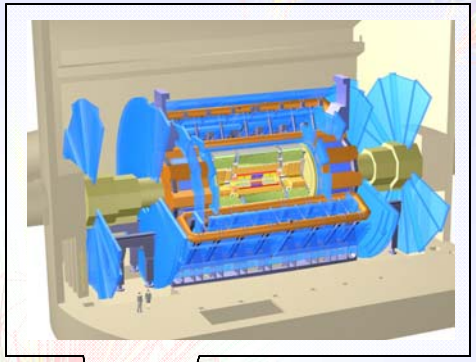
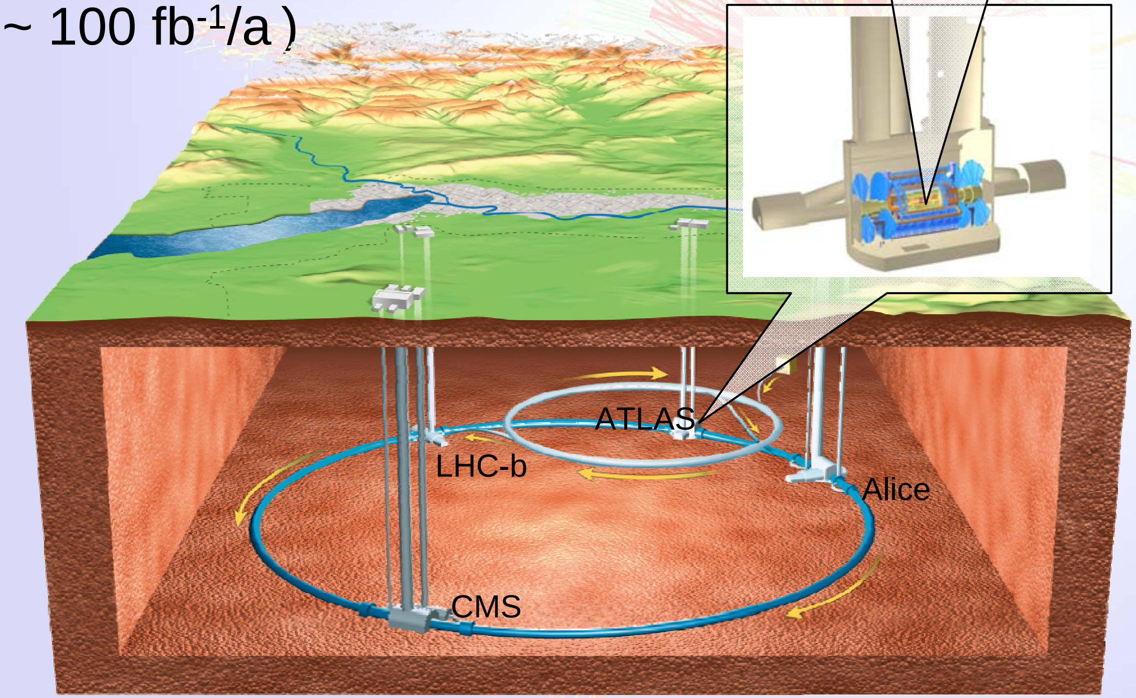
LHC and ATLAS

- Synchrotron with 27km circumference
- pp collisions at $\sqrt{s}$ = 14TeV
- Low Luminosity: $2*10^{33} cm^{-2} s^{-1}$ (~ 20 fb^{-1}/a)
- High Luminosity: $10^{34} cm^{-2} s^{-1}$ (~ 100 fb^{-1}/a)





- General purpose detector
- 42m x 25m x 25m
- Mass: 7000t

- Precision measuerments with InDet, Calo, Muons within $|\eta|< 2.5$
- Calorimetry coverage $|\eta|<5$
- Jet Energy Resolution: $50\%/\sqrt{E}+3\%$ (central)

QCD at ATLAS

- LHC is a QCD Machine
  - Properties of initial partons determined by strong interactions inside the protons (PDF)
  - Highest cross-sections for QCD processes
  - Background to most processes
  - QCD corrections to all processes
  - Final state rarely colour singlet
    - → strong interactions of FS with proton remnant

→ QCD is of utmost importance at LHC

- LHC is a discovery machine
  - Unprecedented energy range and luminosity
  - SM Higgs well within coverage
  - Many alternative scenarios:
    - SuperSymmetry
    - Technicolour
    - Contact interactions
    - Leptoquarks
    - Compositeness
    - … many more

- Exciting possibilities for new physics
- QCD (and SM) often take the back seat
- QCD (and SM) will have to be measured precisely at LHC energies

QCD at ATLAS

- Many interesting subjects, e.g.
  - PDF measurements (proton structure)
  - Jet studies (reconstruction, rates, cross sections…)
  - Fragmentation studies
  - Diffractive physics
  - α_s measurements
- Here: Discussing state of some picked examples
  - Jet reconstruction
  - Jet cross section mesurements
  - Diffractive Luminosity measurement

Jet Reconstruction

- Jets in the final state dominant signature of strong interactions
- General task: Transform calorimeter response into four-vectors representing the properties of a jet/parton
- Jet energy has to be measured as precise as possible
- Reconstruction of jets, calibration of energy measurement essential to a multitude of measurements

Jet Reconstruction

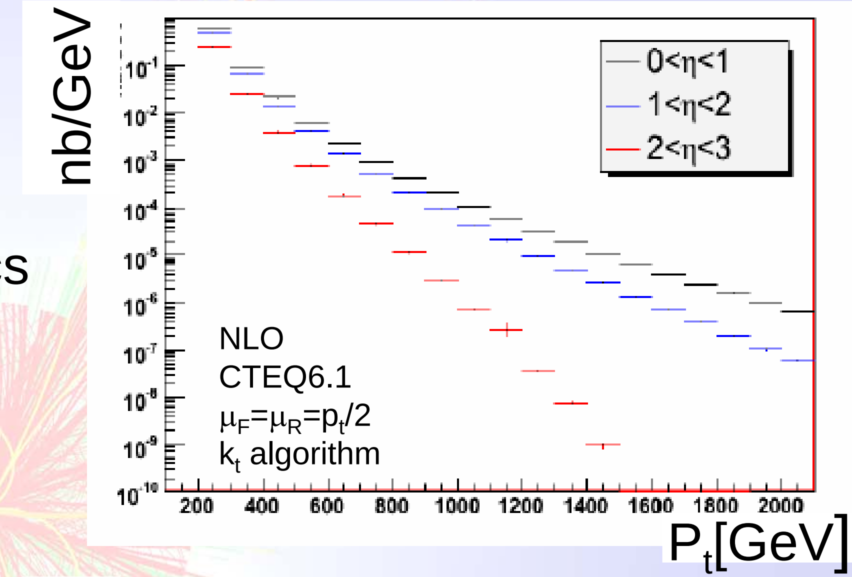
- **I Calo Reco**
  - Shower containment
  - Electronic noise
  - Pile-up
  - Particle separation and Id
- **II Jet Reconstruction**
  - Issues
    - Reco algorithm (k_t,cone) ?
    - Input (towers, clusters) ?
    - Jet size
    - Overlap
  - Used Reco Algorithms
    - Cone (w+w/o seeds), seed cut 1-2 GeV in E_t, R = 0.4 … 1
    - K_t w/o preclustering, R = 0.4 … 1
  - Typically cut E_t>20 GeV on final jets
- **III Calibration Calo$\rightarrow$ Particles:**
  - Global jet calibration
    - Reconstruct jet in calo
    - Match reco jet with true jet
    - Fit calibration function in η,E from di-jets
  - Local hadron calibration
    - Calibrate calo clusters to true particle scale
    - Form jets from calibrated clusters
    - Apply jet-based correction to particle level
- **IV Calibration Particles $\rightarrow$ Partons**
  - Out of cone corrections
    - Parton-jet matching in di-jets
    - E_t balance in γ+jet events
    - In situ corrections from W,top,… masses
  - Underlying event compensation
  - Flavour dependence (b,udsc,g)

Jet Cross Sections

- Inclusive jet cross sections one of the early (low integrated luminosity) analyses at ATLAS
- Measurement of α_s possible
- Sensitive to new phenomena
- QCD jets are background to almost all interesting physics processes
- Understanding of QCD jets crucial for discovery of new phenomena
- Here:
  - Estimation of expected precision
  - Focus on low luminosity ($L \approx 10^{33}$ cm^{-2} s^{-1})

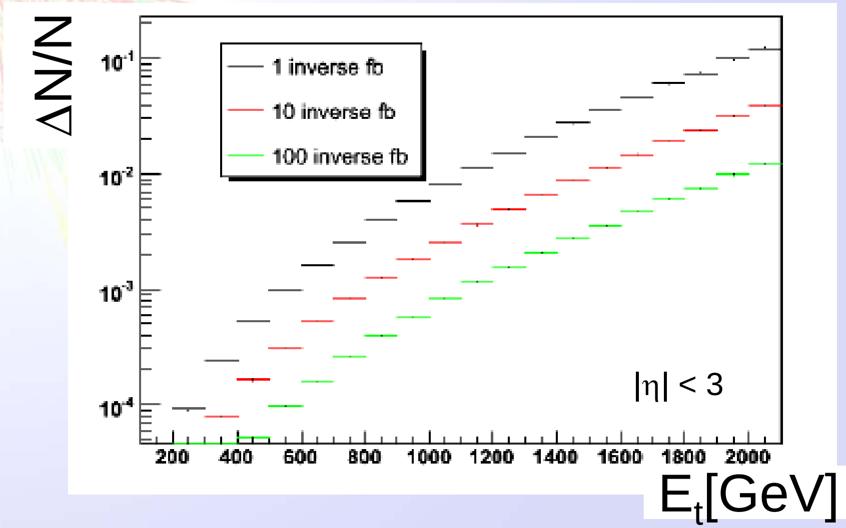
Jet Cross Sections

- Jet p_t spectra for different η
- Rapid decrease for higher p_t
- High p_t region sensitive to new physics
- Considered errors:
  - statistical
  - experimental
  - theoretical



<u>Statistical Errors</u>

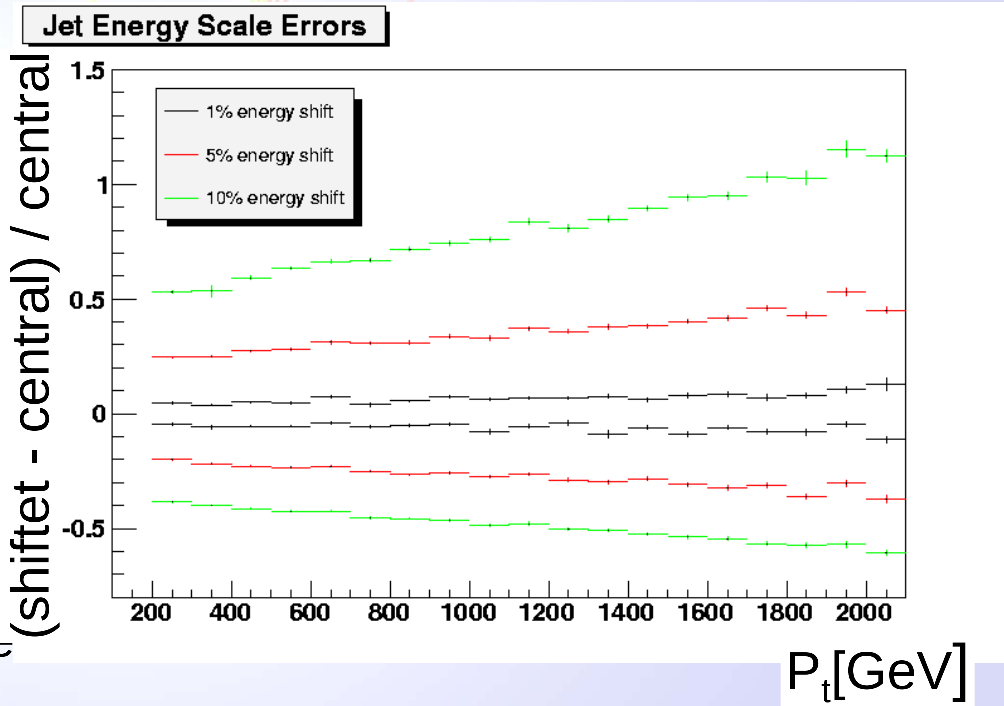
- Only jets with $|\eta| < 3$ considered
- Naïve Error Estimation $\Delta N = \sqrt{N}$
- Plotted: $\Delta N/N$ for different L
- 1% error at $p_t \approx$ 1TeV with 1 fb^{-1}
- For $3.2 < |\eta| < 5$ error up to 10%



Jet Cross Sections

Experimental Errors

- Several sources:
  - Luminosity measurement
  - Jet Energy Scale
  - Jet Resolution, UE, trigger efficiency
  - …
- Jet Energy Scale:
  - 1% uncertainty results in 10% e on σ
  - 5% uncertainty result in 30% e on σ
  - 10% uncertainty result in 70% e on σ
  - If known to 1-2%, experimental errors not dominant



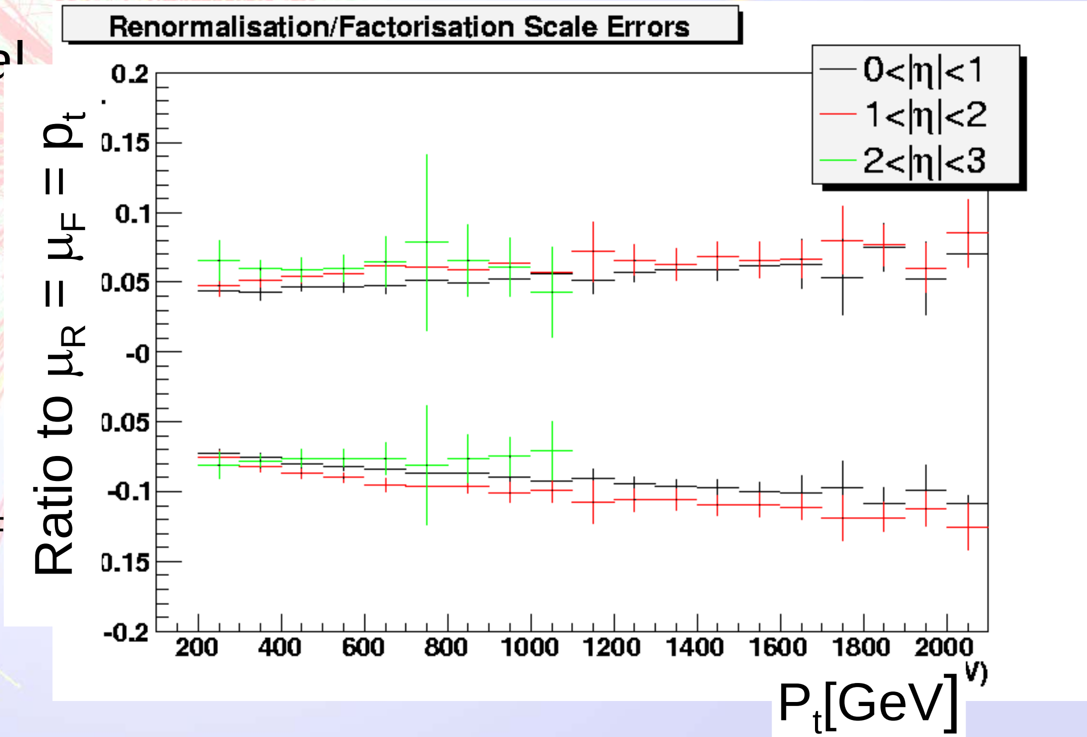
Jet Cross Sections

Theoretical Errors

- Cross section is convolution of PDF and hard interaction:

$$\sigma = \sum_{a,b} \int dx_1 dx_2 f_a(x_1, \mu_F) f_b(x_2, \mu_F) \hat{\sigma}_{a,b}(x_a, x_b, \mu_R)$$

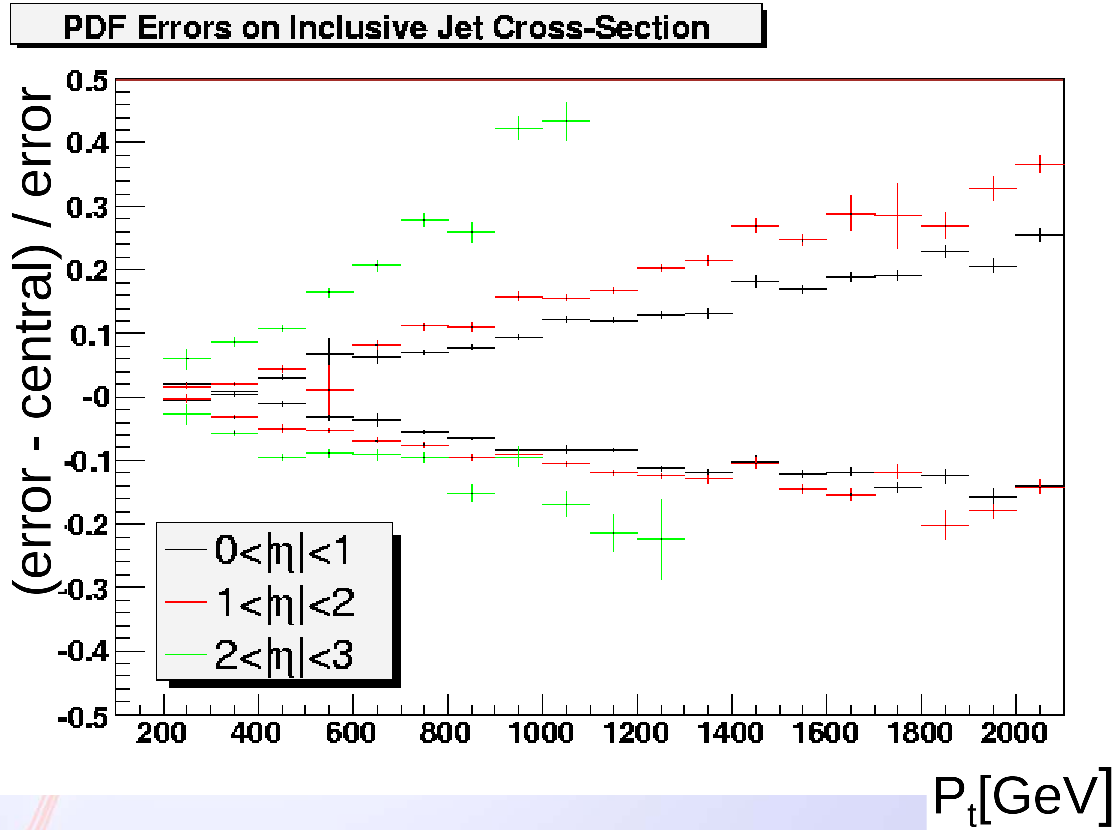
- Can be calculated in NLO
- Two main sources of theoretical errors (CDF) :
  - scale uncertainties
    - Factorisation μ_F
    - Renormalisation μ_R
  - PDF uncertainties
- Scale uncertainties:
  - independent variation of μ_F and μ_R within $p_t^{max}/2<\mu<2p_t^{max}$
  - ~ 10% uncertainty at 1TeV



Jet Cross Sections

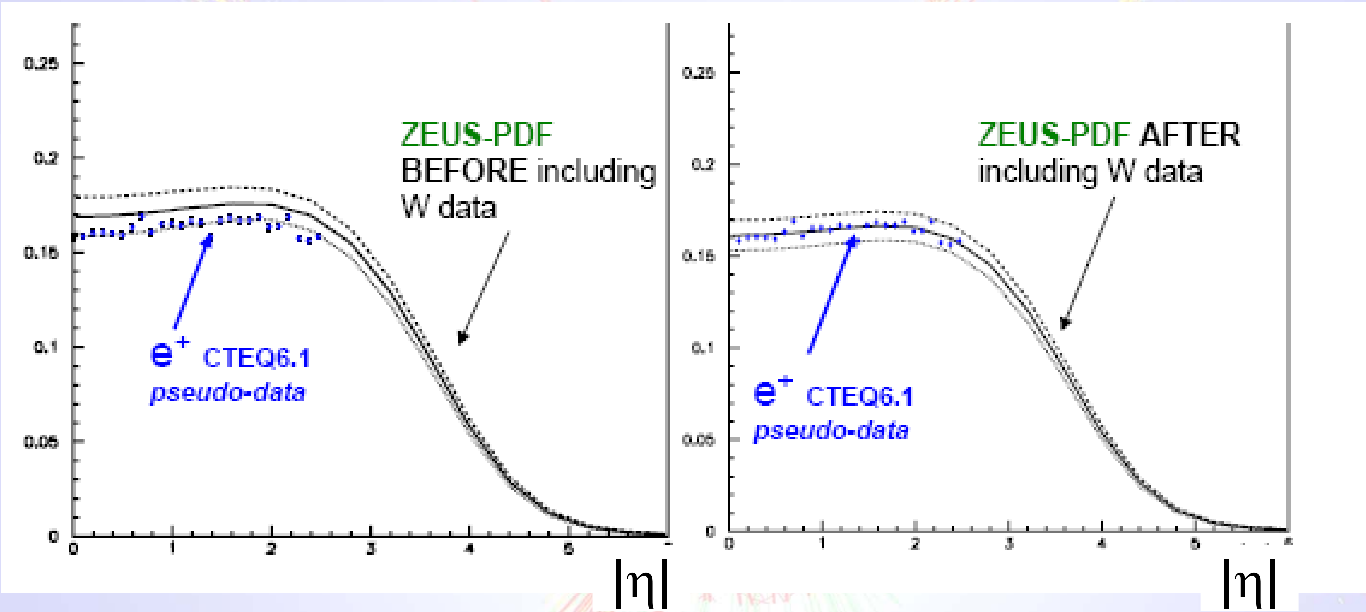
Theoretical Errors

- PDF uncertainties dominant
- Uncertainty evaluation using CTEQ6, 6.1
- Largest uncertainty: high x gluons, in DIS only indirectly accessible
- Related error sets: 29, 30
- Comparison: Best fit with 29 30
- k_t clustering algorithm
- At $p_t \approx 1$ TeV around 15% uncertainty



Jet Cross Sections

Constraining the PDF at LHC



- W and Z cross section predicted precisely
- Main uncertainty: At $Q^2 \approx M_Z^2$ with $x \approx 10^{-2}$-10^{-4} gluon PDF relevant
- Asymmetry is gluon PDF independent → benchmark test
- 1M W events (~200pb^{-1}) generated, CTEQ6.1, ATLFAST, 4% exp. error
- 'Measurements' detector corrected and entered into Zeus PDF fit
- Error on λ parameter ($x \cdot g(x) \sim x^{-\lambda}$) reduced by 35%

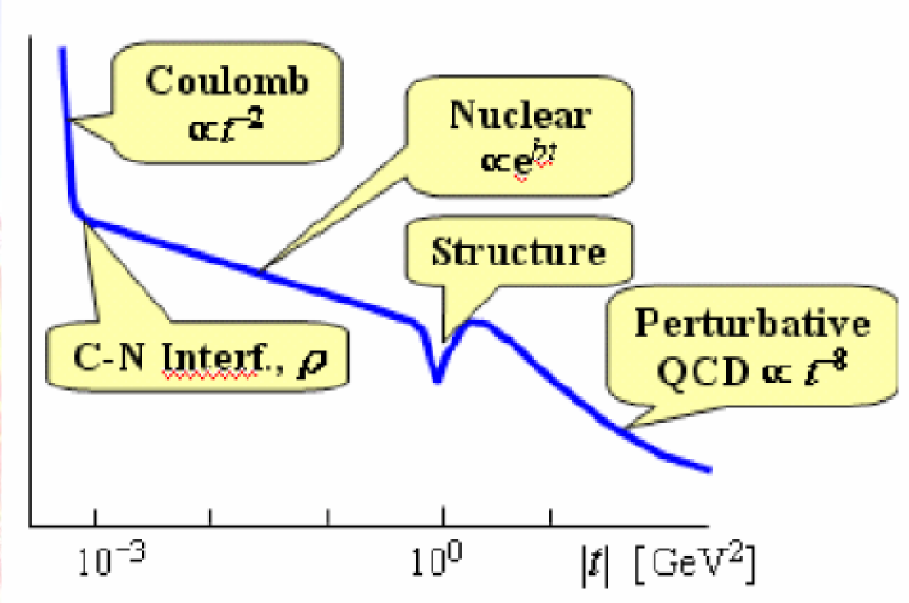
Luminosity Measurement

- Luminosity determination: Leading uncertainty for many cross section measurements
- QCD processes can be used to determine LHC luminosity
- Aim: 2-3% precision of Luminosity measurement
- Options:
  - LHC beam parameter measurements outside the experimental areas, 5-10% accuracy, improving
  - QED cross sections (lepton pair production via $\gamma\gamma$), low event rate, theoretical uncertainties (PDF, fixed order calculation), >5% accuracy
  - Elastic scattering via QED and QCD, requires coverage at very high η-values (Roman Pots), planned for ATLAS

    $\rightarrow$ UA4: Absolute measurements with 3% accuracy achieved

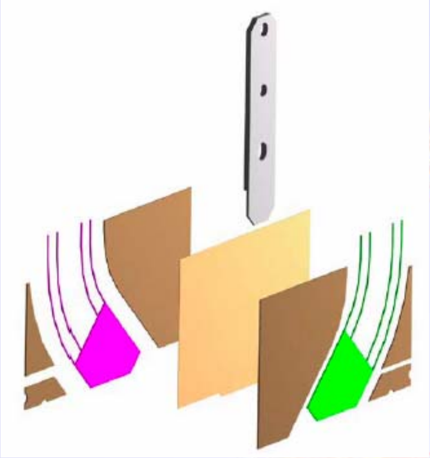
Luminosity Measurement

- t dependence of the cross section
- Fit of measured event rate in C-N interference region yields L,σ_{tot}, ρ, b
- Requires measurements down to t ~ 6.5 10^{-4} GeV^2 (θ ~ 3.5 10^{-6})
- Detectors necessary which
  - Are close to the beam (1.5mm for z=240m)
  - Have a resolution well below 100 μm
  - Have no significant inactive edge



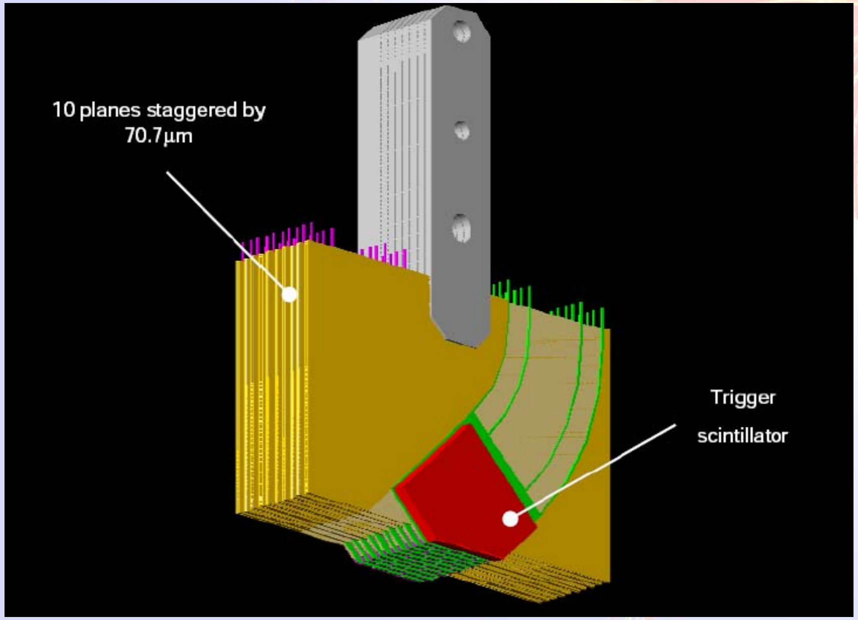
$$\frac{dN}{dt}(t \to 0) = L\pi \left(\frac{-2\alpha}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)e^{-b|t|/2} \right)^2$$

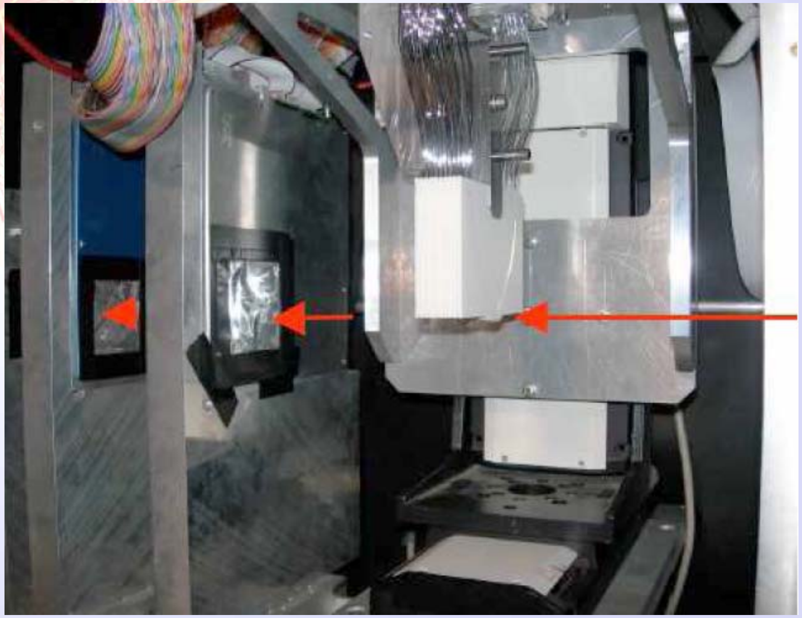
Luminosity Measurement



Roman pot design: scintillating fibres

- Square fibres 0.5mm x 0.5mm
- 2 x 64 fibres on ceramic substrate
- U/V - gemeometry with 90º tilt
- 10 double sided modules

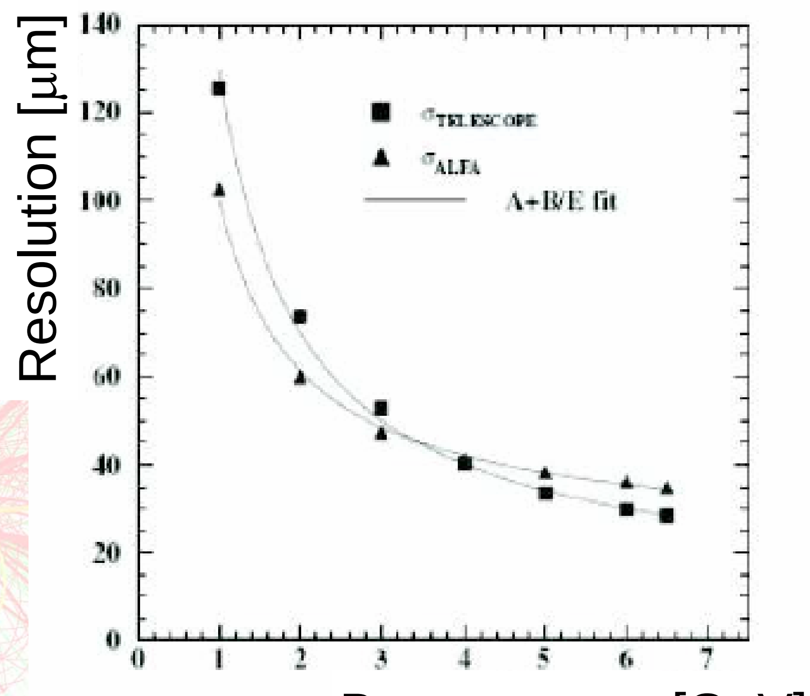




Luminosity Measurement

Performed Tests

Spatial resolution
- scales with 1/E
- For LHC Energies ~ 20 μm
- Insensitive edges < 30 μm



Luminosity Fit
- 10M events FullSim
- Fit of t dependence
- Comparison with input parameters:
  - excellent agreement
  - error on L 1.5%
  - large correlations between parameters

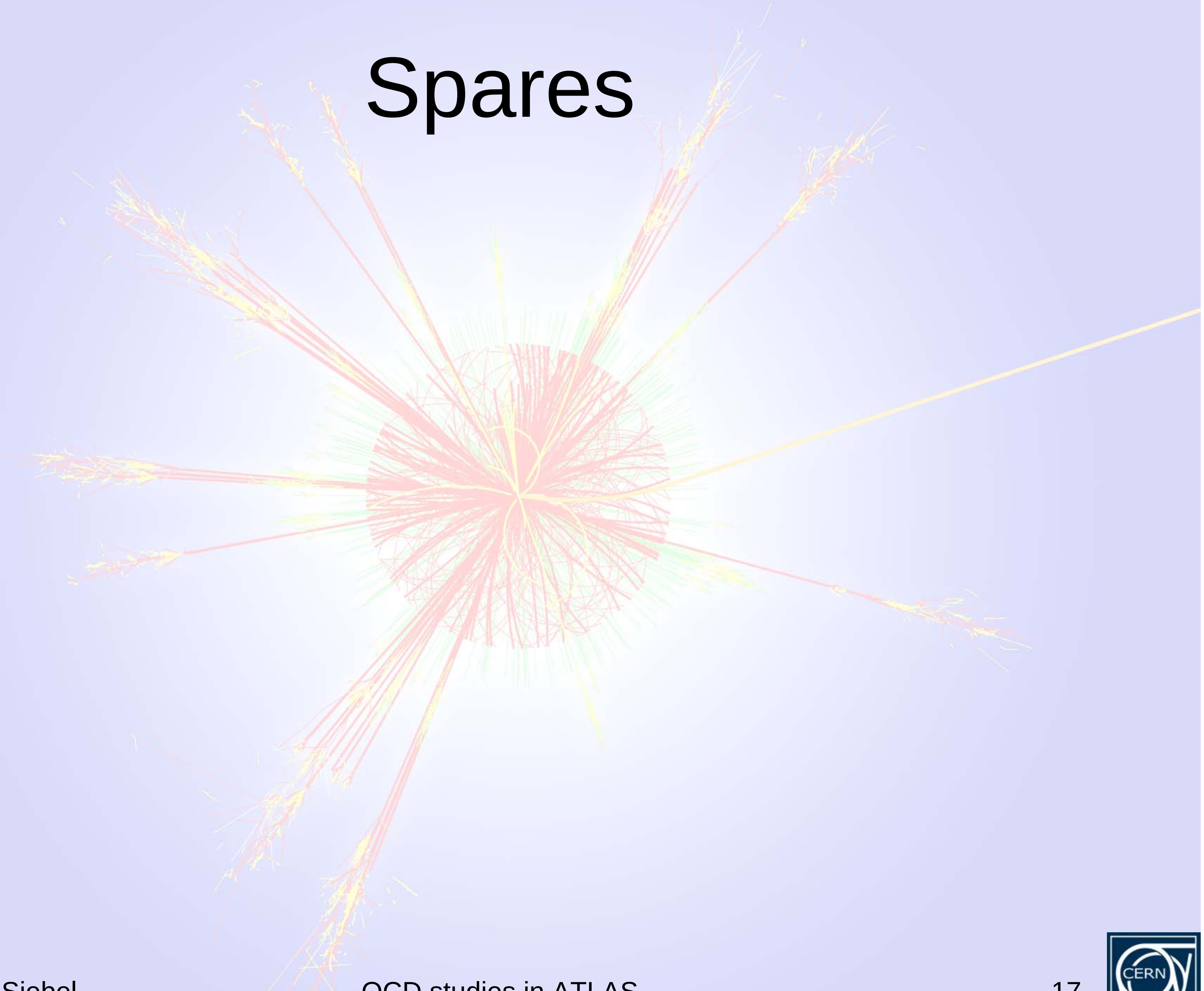
Parameters	input	fitted	error	correlation
L	$8.124\ 10^{26}$	$8.162\ 10^{26}$	1.5%	
σ_{tot}	100 mb	101.1 mb	0.74%	99%
b	18 GeV^{-2}	17.95 GeV^{-2}	0.59%	64%
ρ	0.15	0.1502	4.24%	92%

→ **Goals achievable**

Conclusions

- QCD is a central field at LHC that requires attention
- Preparations to understand Jet Energy Scale well on the way
  - Complex task
  - All options left open to see what works best on data
- Inclusive jet cross sections require good control of experimental and theoretical errors
  - Experimental error dominated by JES
  - Theoretical error dominated by high x gluon PDF
  - Contributions to PDF from LHC data worthwhile
- Absolute LHC luminosity measurement via proton diffraction
  - Promises high precision
  - Roman pot detectors required
  - Design and testing well on the way

Spares



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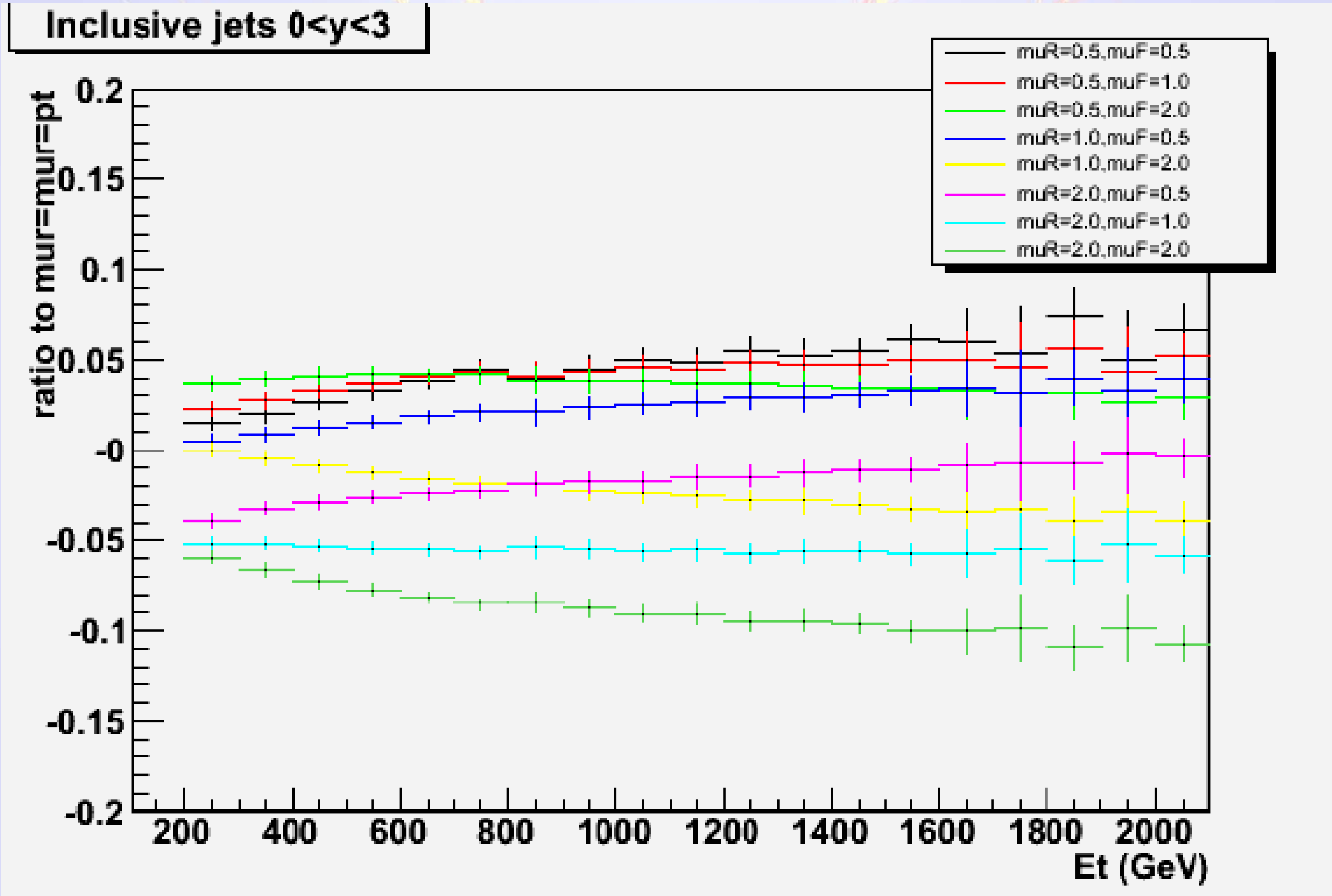
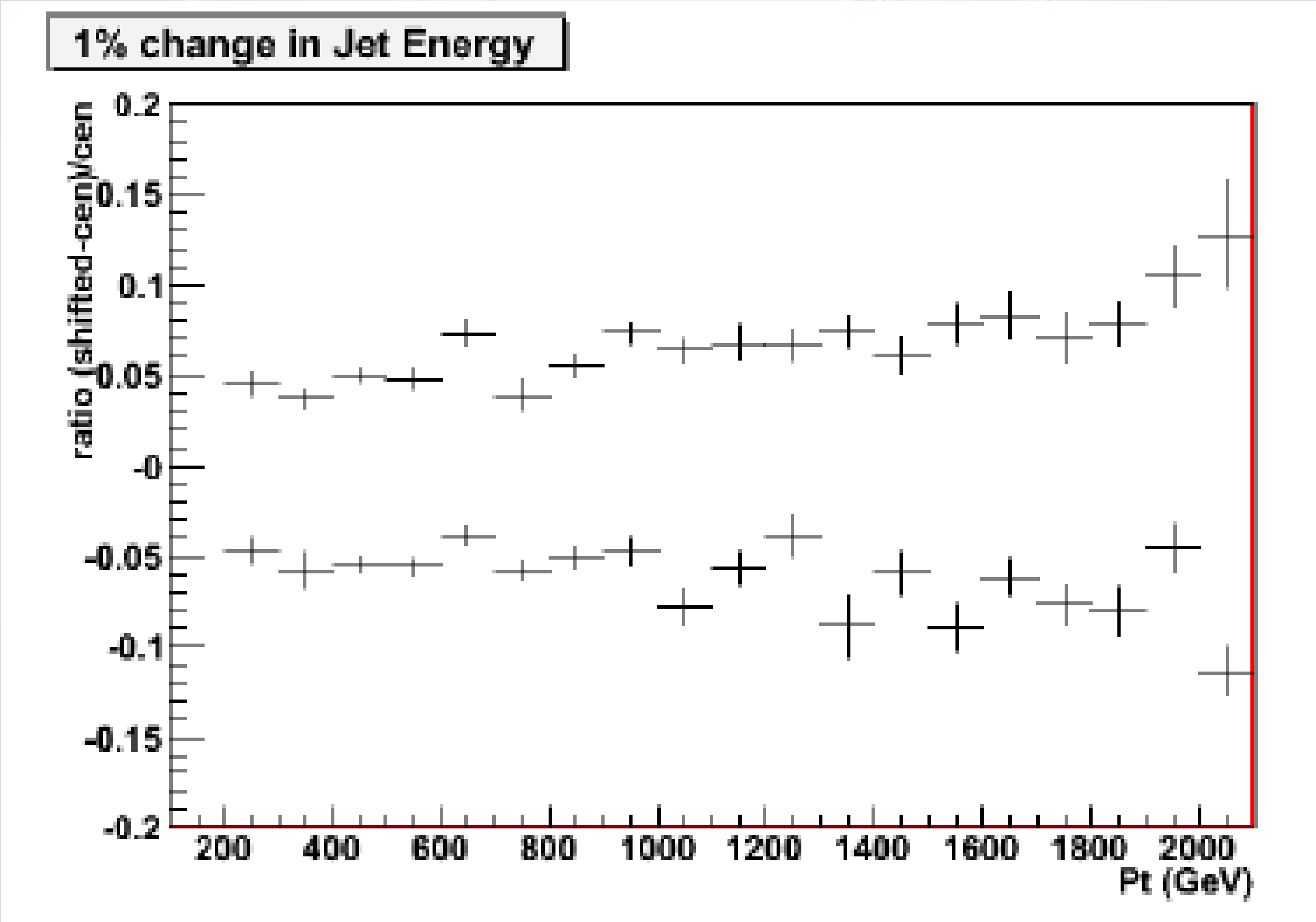
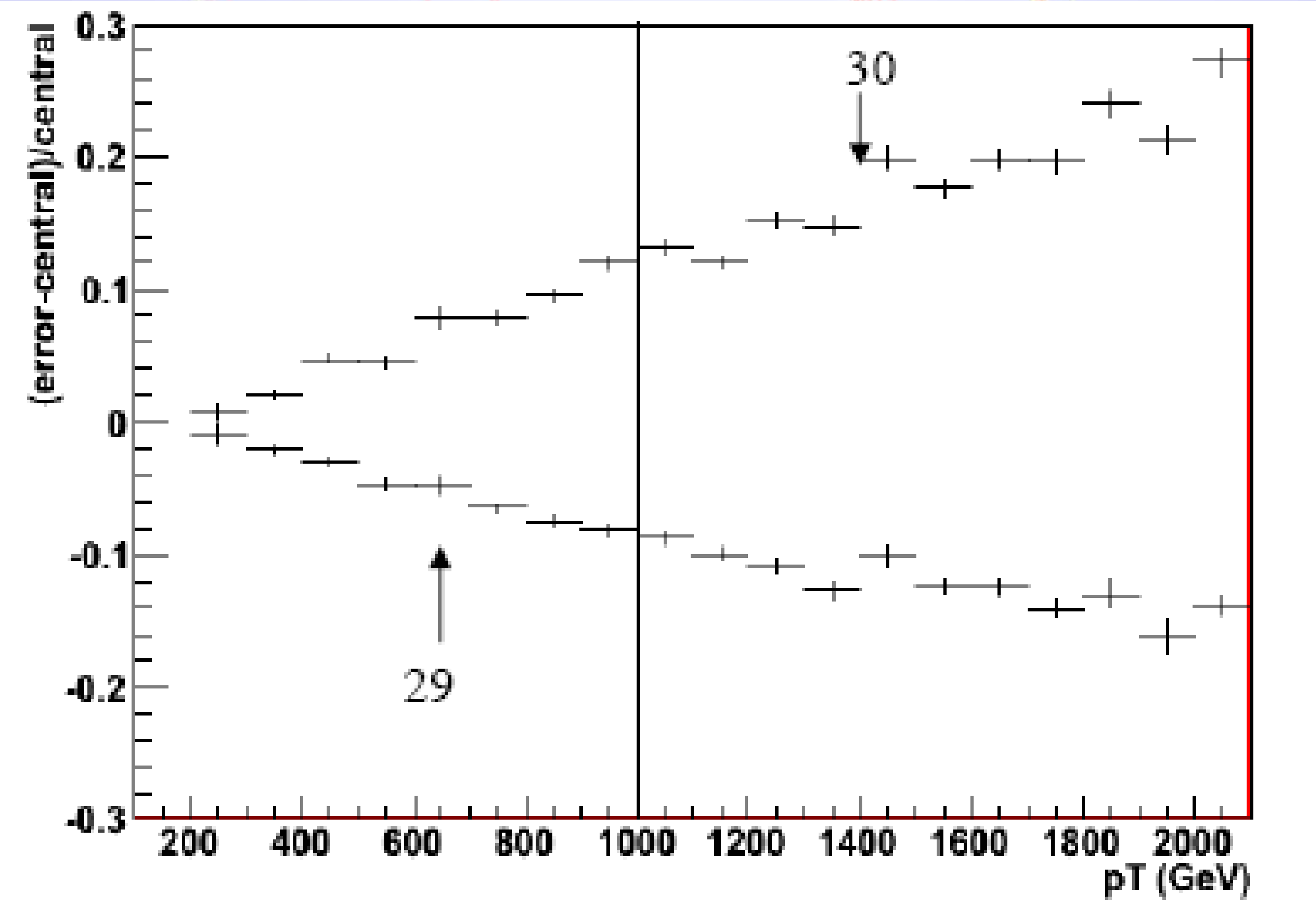

Inclusive jets 0<y<3
ratio to mur=mur=pt
0.2
0.15
0.1
0.05
-0
-0.05
-0.1
-0.15
-0.2
200
400
600
800
1000
1200
1400
1600
1800
2000
Et (GeV)
muR=0.5,muF=0.5
muR=0.5,muF=1.0
muR=0.5,muF=2.0
muR=1.0,muF=0.5
muR=1.0,muF=2.0
muR=2.0,muF=0.5
muR=2.0,muF=1.0
muR=2.0,muF=2.0

Spares



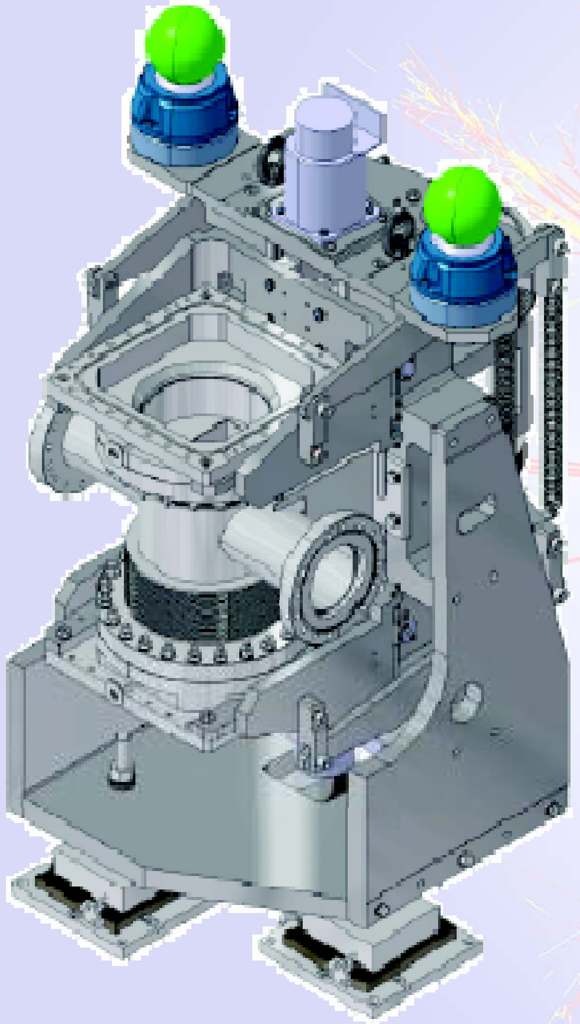
1% change in Jet Energy
ratio (shifted-cen)/cen
0.2
0.15
0.1
0.05
-0
-0.05
-0.1
-0.15
-0.2
200
400
600
800
1000
1200
1400
1600
1800
2000
Pt (GeV)

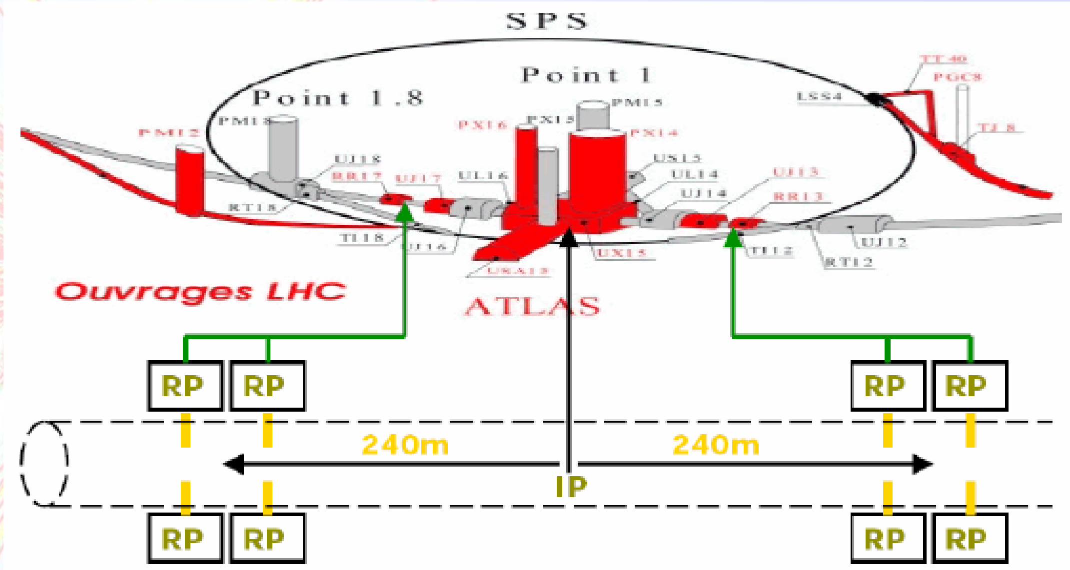
Spares



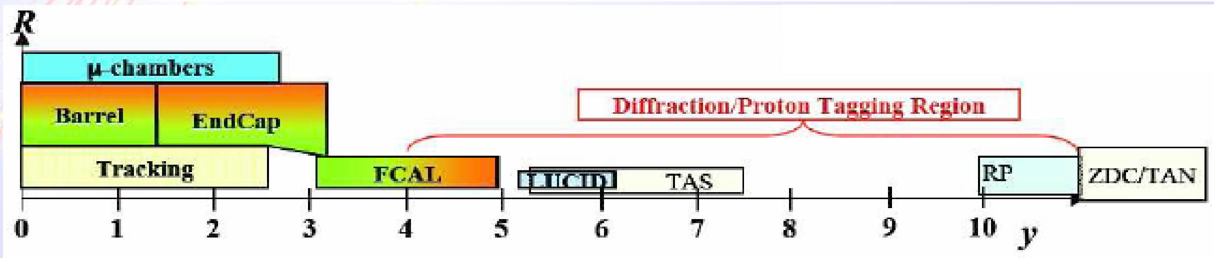
(error-central)/central
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
200
400
600
800
1000
1200
1400
1600
1800
2000
pT (GeV)
30
29

Spares





SPS
Point 1.8
Point 1
Ouvrages LHC
ATLAS
RP
RP
RP
RP
240m
240m
IP
RP
RP
RP
RP



R
μ-chambers
Barrel
EndCap
Tracking
FCAL
LUCID
TAS
Diffraction/Proton Tagging Region
RP
ZDC/TAN
0
1
2
3
4
5
6
7
8
9
10
y