Forward physics results from ATLAS

Michele Viti on behalf of the ATLAS collaboration
Hadron Structure '11

Content

- Overview of the detectors
 - Lucid
 - ZDC
 - MBTS
 - ALFA
- Luminosity measurements
- 2 ATLAS results presented
 - Inelastic pp cross section
 - Rapidity gap cross section

ATLAS forward detectors

28.06.2011

Michele Viti

MBTS: Minimum Bias Trigger Scintillator

- Each side segmented into 2 discs, each disc in ϕ in 8 scintillator counters.
- **Primary minimum bias trigger for low luminosity (rapidity gap topology).**
- Used also for relative luminosity measurement.

LUCID: LUminosity Cherenkov Integrating Detector

Forward detector using Cherenkov light.

- 2 symmetric detector at 17 m.
- 20 tubes filled with Gas.
- Sensitive to charged particle coming from the IP (tubes pointing to the IP).
- Fast response (bunch-by-bunch measurement).
- Radiation hardness.
- Online Luminosity monitor. Designed to work from $10^{27} \text{ cm}^{-2}\text{s}^{-1}$ up to $4 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$.
- It can provide also minimum bias trigger at high η .

ZDC: Zero Degree Calorimeter

- 4 modules/arm: 1 EM ($29 X_0$), 3 Had ($1.14 \lambda_{int}$), similar in composition.
- Both ZDCs reside in a slot of the TAN Absorber ~ 140 m from IP.
- Detected neutral particles.
- 11 Tungsten plates
 - + 1 mm quartz rod parallel to beam for position measurement.
 - + 1.5 mm quartz rod for energy measurement.
- Radiation hardness:
 - At $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ it survives for few years.
 - At $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ it survives for few months.

Absolute Luminosity For ATLAS

- 8 scintillating fiber detectors located in Roman Pots.
- $0.5 \times 0.5 \text{ mm}^2$ square fibers arranged in UV geometry.
- 2 Roman Pots (1 up and 1 down) form a station.
- Resolution of $30\text{--}40 \text{ }\mu\text{m}$ required.
- **Determination of the absolute luminosity for ATLAS with an accuracy of $\sim 3\%$.**

ALFA in the LHC tunnel. 2 stations are located each side of ATLAS detector at 240 m distance from the IP.

Absolute Luminosity For ATLAS

- Special optic conditions required
 - large value of betatron function at the detector and IP (small emittance).
 - 90° phase advance in the vertical plane.
 - negligible dispersion.
- Consequences
 - low bunch charge.
 - few bunches
 - → low luminosity $\sim 10^{27} \text{ cm}^{-2}\text{s}^{-1}$.

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

- Measurement of the scattering angle for elastic scattered protons.
- Determination of the absolute luminosity (plus total cross section).
- Calibration of LUCID.

Luminosity measurement

- Fundamental parameter for cross section measurement.
- Already the largest contribution to the errors for many measurements.
- At LHC start MC predictions, $\sim 20\%$ error.
- 2010/2011 luminosity determined by machine parameters using the Van der Meer (VdM) scan. An error of 3.4 % was reached in 2010.
- When sufficient statistic will be reached, W/Z production will be also used, $\sim 5\%$ error.
- In the next years, ALFA will provide a luminosity calibration with an error $\sim 3\%$.

- Recently we reached 1 fb⁻¹
- ATLAS efficiency $\sim 96\%$
- Max peak luminosity $1.26 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
- Max bunch. 1092

Soft QCD/Diffraction

- Total cross section, (in)elastic cross section, fundamental quantity
 - _ They cannot be calculated by perturbative QCD.
 - _ $\sigma_{\text{tot}} = \sigma_{\text{el}} + \sigma_{\text{inel}}$
- **Diffraction event.**
 - _ $\sigma_{\text{inel}} = \sigma_{\text{ND}} + \sigma_{\text{SD}} + \sigma_{\text{DD}}$
 - _ They represent a large fraction of the inelastic event. (~30% inelastic events).
 - _ In the theory:
 - Exchange of the quantum numbers of the vacuum.
 - Pomeron exchange in the t-channel
 - _ In the experiment:
 - Large rapidity gap and/or intact protons

→ low noise and few pile-up events
→ forward detectors as veto/triggers

Diffraction

Total Cross Section with ALFA

- August/September ALFA will perform together with TOTEM **first measurement of the total cross section.**
- Beta function ~ 90 m $\rightarrow$ measurement not in the interference region.
- **Luminosity needed as input parameter (LUCID+VdM).**
- **Expected error $< 5\%$.**

Results from ATLAS experiment

Some results from ATLAS measurements will be presented

- Measurement of the inelastic pp cross section at $\sqrt{s}=7$ TeV with the ATLAS detector (ArXiv:1104.0326 [hep-ph])
- Rapidity gap cross sections in pp Interactions at $\sqrt{s}=7$ TeV (ATLAS-CONF-2011-059)

Inelastic pp cross section

- **Fundamental detector: Minimum Bias Trigger Scintillator.**
- Coverage: $2.09 < |\eta| < 3.84$.
→ $\xi = M^2/s > 5 \times 10^{-6}$, M invariant mass of the dissociated system.
- Trigger: require at least one hit in the MBTS counters.
- Offline selection: require two counter's charge to be above 0.15 pC.

Inelastic pp cross section

- R_{ss} , ratio events single side (dominated by SD and DD) and inclusive events.
- R_{ss} in function of f_D (the ratio diffractive/ total inelastic events).
- PYTHIA and PHOJET with different input parameter.
- Results for f_D between 25% and 30%.

Inelastic pp cross section

MC validation with data

- MBTS hit multiplicity for the single side and inclusive events
- Pythia based on DL model good description of the single side events (→ good description of the diffractive part)
- For the inclusive events data lie between the models at low multiplicity (important for the extrapolation).

Inelastic pp cross section

$$\sigma(\xi > 5 \cdot 10^{-6}) = 60.3 \pm 0.05 (stat.) \pm 0.5 (sys.) \pm 2.1 (lumi.) mb$$

$$\sigma_{inel} = 69.1 \pm 2.4 (exp.) \pm 6.9 (extr.) mb$$

Inelastic pp cross section

- First measurement from ATLAS of the pp inelastic cross.
- Luminosity dominant experimental error.
- Low-mass diffraction is not measured because the diffractive system is outside the acceptance. This has a large uncertainty (not easy to predict).
 - Considering prediction for several model an error of 10% was given for this extrapolation.
 - ALFA can increase the acceptance?
- Consistency with predictions from power law and logarithmic dependences from center-of-mass energy.

Inelastic pp cross section

- Possibility to measure this quantity without large extrapolation.
- Integrating the rate we have the **elastic cross section**.
- With the optical theorem we have the **total cross section**.

$$\rightarrow \sigma_{\text{inel}} = \sigma_{\text{tot}} - \sigma_{\text{el}}$$

Rapidity Gap Cross Section

- Detector used

- Liquid argon calorimeter $|\eta| < 4.9$.
- Inner detector $|\eta| < 2.5$.
- **MBTS as trigger.**

- Gap Algorithm

- Divide the calorimeter in η rings.
- One ring fired if
 - At least one track with $p_T > 200$ MeV.
 - One calorimeter cell above threshold.

- 2 definitions of rapidity gap.

MC Optim. { – **Floating gap**: largest consecutive runs of empty rings, parametrized by its size $\Delta\eta$ and $|\eta_{\text{start}}|$ (**double diffraction topology**).

Cross section determination { – **Forward gap**: largest consecutive runs of empty rings, starting from the edge of acceptance $|\eta| = 4.9$ (**single diffraction topology**) with size $\Delta\eta^F$

$$\begin{aligned}\Delta\eta &= 4 \\ \Delta\eta^F &= 4 \\ \eta_{\text{start}} &= 5\end{aligned}$$

$$\begin{aligned}\Delta\eta &= 3 \\ \Delta\eta^F &= 0 \\ \eta_{\text{start}} &= 2\end{aligned}$$

Rapidity Gap Cross Section

- $\sigma_{\text{inel}} = \sigma_{\text{ND}} + \sigma_{\text{SD}} + \sigma_{\text{DD}}$
- One template for each component.
- Since limited acceptance, **re-organization of the event in SD/DD-like events.**
- DD events with one dissociated system with $\xi = M^2/s < 5 \times 10^{-6}$ have a SD signature in the apparatus (SD-like events)
- **Use this definition in the MC.**

Rapidity Gap Cross Section

- Fit data-MC for the tuning using the likelihood method.
- In this way the parameter f_D (ratio diffractive/total inelastic events) was determined
- It was found for Pythia8 $f_D = 30 \pm 0.3(\text{stat.}) \pm 3.8(\text{sys.})$

Rapidity Gap Cross Section

Control distribution for MC

Forward rapidity gap distribution (detector level). Acceptable description at large gap size.

Pythia8 chosen for correcting the data.

Rapidity Gap Cross Section

- Measured differential cross section in function of the forward rapidity gaps, together with MC prediction.
- Contribution non diffractive events, important for gaps < 2 .
- For forward rapidity gaps > 4 SD-like events dominant.
- Plateau observed ~ 1 mb.
 - Data uncertainty typically $\sim 20\%$
- Pythia models give a better description for small rapidity gaps.
- Phojet successful at large gaps value.

Rapidity Gap Cross Section

Pythia8

Phojet

A zoom in the diffractive region and comparison with Pythia8/Phojet

→ Difference is in the DD contribution.

Conclusions

- Intense program for the forward physics with the ATLAS detector.
- **ALFA detector installed recently, it will take soon data**
 - Measurement of the total cross section will be performed in September/October.
- Measurement of the inelastic pp cross section
 - $\sigma(\xi > 5 \times 10^{-6}) = 60.3 \pm 0.05(\text{stat.}) \pm 0.5(\text{sys.}) \pm 2.1(\text{lumi.}) \text{ mb}$
 - Ratio diffractive / inelastic events **between 24% and 30%.**
- Rapidity gap studies performed
 - $f_D = 30.2 \pm 0.3(\text{stat.}) \pm 3.8(\text{sys.})$
 - Diffractive cross section for forward rapidity gap > 3.5 **was found to be $\sim 1 \text{ mb}$.**

Backup

LUCID: LUminosity Cherenkov Integrating Detector

ZDC: Zero Degree Calorimeter

HI collision

- Minimum bias trigger.
- Information about the collision centrality (number of “spectator neutrons”, 20% energy resolution required).
- Tag hard photon-production and quasi elastic vector meson production (ultra-peripheral collisions).

pp collision

- Measurement of many production cross section.
- Luminosity monitor.
- Beam tuning.
- Increase the acceptance of the central detector (important for diffractive processes).

ZDC: Zero Degree Calorimeter

π^0 reconstruction with the first hadronic module for ZDC. The resolution is dominated by the energy resolution.

Distribution of events in module 2 time minus that in module 1 in ZDC-A, divided by $\sqrt{2}$.

Luminosity measurement

- ATLAS efficiency $\sim 95\%$
- Max peak lum. 3.04×10^{25}
- Max bunch. 129

VdM Scan luminosity calibration

- 5 dedicated runs in 2010, no physics runs
- Beam displaced $\pm 6 \sigma$, register activity from all luminosity monit

With the Scan we obtain

$$\Sigma_{x,y} = \frac{1}{\sqrt{2\pi}} \frac{\int R_{x,y}(\delta) d\delta}{R_{x,y}}$$

$R_{x,y}$ is the curve describing the data, this case a double Gaussian
 δ separation for x, y, for a normal Gaussian, trivially $\Sigma_{x,y} = \sigma_{x,y}$

Luminosity calculated through the formula

$$L = \frac{f_r n_b I_1 I_2}{2\pi \Sigma_x \Sigma_y}$$

n_b number of bunches

f_r frequency revolution

Σ Determined by the VdM Scan

I bunch current

Scans April / Mai 2010 $\frac{\delta L}{L} = 11 \%$

(*Eur. Phys. J. C* (2011) 71:1630)

Scan October 2010 $\frac{\delta L}{L} = 3.4 \%$

(ATLAS – CONF – 2011 – 011)

Errors dominated by the bunch current

28.06.2011

Michele

Forward physics

- Inelastic cross section $\sim 75\%$ total cross section.
- Diffractive events are 20-30% of the inelastic cross section.
- Importance of measurement total/inelastic/elastic cross sections: test of quantum mechanics at high energy.

Froissart bound $\sigma_{tot} < Const \cdot \ln^2(s)$

Optical theorem $\sigma_{tot} \approx \text{Im } f_{el}(t=0)$

Dispersion relation $\text{Im } f_{el}(t=0) \approx \text{Re } f_{el}(t=0)$

Soft/Hard Diffraction

- Hard processes where one or two protons remains + production of a high p_T ($|\eta| < 2.5$) central colorless systems (jets, W, Z).
- Central detector needed + trigger (veto) by LUCID, ZDC, MBTS.

Central Exclusive Production

- Reaction of the form $p+p \rightarrow p+X+p$.
- X is fully measured and no other particles are produced.
- Tagging the outgoing protons, **these processes can provide a clean environment even with high luminosity (large pile-up).**
- For the moment, we do not have a dedicated detector for this.
- Possible studies on Dijets, W^+W^- , Higgs and much more...

Soft Single Diffraction with ALFA

- LUCID/ZDC as trigger.
- ALFA detector to reconstruct the momentum loss $\xi = (p - p_0)/p_0$ of the remaining proton.
- Measurement performed at high beta (luminosity runs).

Inelastic pp cross section

- Fundamental quantity.
- It cannot be calculated with QCD (many approaches...).
- Measurement at lower energy, large uncertainty to extrapolation at higher energy.
- Several models
 - $S^{(\alpha-1)}$, where α is the pomeron trajectory intercept.
 - Logarithmic behavior.
- Froissart bound: the (inelastic) cross section cannot rise faster than $\text{Const} \times \ln^2(s)$.

Rapidity Gap Cross Section

Control distribution for MC

Probability for detecting activity in the most central ring of the calorimeter in function of highest p_T track.

Forward rapidity gap distribution (detector level). Acceptable description at large gap size.

Pythia8 chosen for correcting the data.

Rapidity Gap Cross Section

Formula used for the measurement :

$$\frac{d\sigma(\Delta\eta^F)}{d\Delta\eta^F} = \frac{A(\Delta\eta^F)}{\Delta\eta_{\text{ring}}} \frac{N(\Delta\eta^F) - N_{\text{BG}}(\Delta\eta^F)}{\varepsilon(\Delta\eta^F) \times \mathcal{L}}$$

Migration Matrix between hadron and detector levels.