ATLAS plans on soft and hard diffraction at the early LHC

Vojtěch Juránek

On behalf of ATLAS Collaboration

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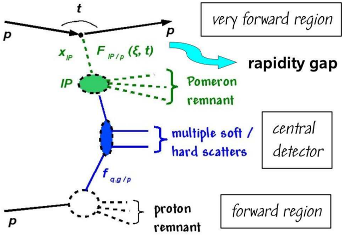
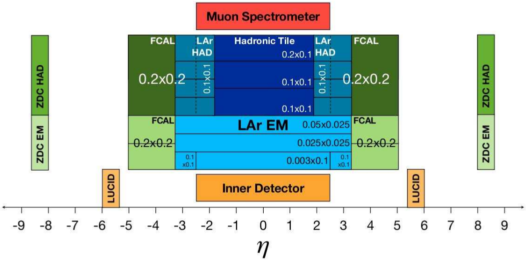
Early LHC data

- Initial physics run at 10 TeV - fall 2009.
- LHC has larger rapidity range than at the Tevatron: $\Delta y \simeq 2 \ln \frac{\sqrt{s}}{m_p} = 18.5$ for LHC at 10 TeV, 15.2 at Tevatron.
- Peak luminosity will be from $\mathcal{L} = 5 \cdot 10^{31} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ to $\mathcal{L} = 2 \cdot 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$.
- Number of interactions in bunch crossing depends on luminosity and also on bunch spacing.
- At early data luminosities and bunch spacing of 75ns is expected up to 1.8 interactions per bunch crossing.
- Total integrated luminosity during the first 100 days will be about $100\mathrm{pb}^{-1}$.
- Next 100 day of operation about $200\mathrm{pb}^{-1}$.
- **Many diffractive measurements possible with this early data!**
- **Some of these analyses can be done even with $10\mathrm{pb}^{-1}$ of data.**
- **This talk is short review, what we plan to do with early ATLAS data.**

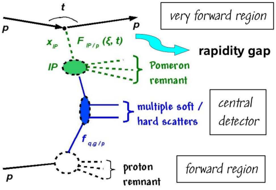
ATLAS Detector η Coverage

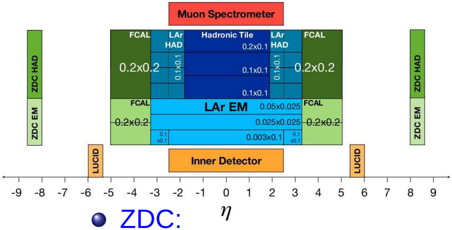




- Hadron calorimeter covers rapidity range $|\eta| < 3.2$
  - Central calorimeter (TileCal) covers rapidity $|\eta| < 1.7$.
  - Hadronic end-cup calorimeters (HEC) cover rapidity $1.5 < |\eta| < 3.2$.
  - TileCal and HEC have the same granularity of 0.1×0.1 in $\phi - \eta$.
- Forward calorimeter (FCAL) covers region $3.1 < |\eta| < 4.9$ and has granularity 0.2×0.2 in $\phi - \eta$.
- EM calorimeter has η coverage $|\eta| < 3.2$ and has fine granularity, electromagnetic coverage in region $3.1 < \eta < 4.9$ is provided by FCAL.
- Tracking covers rapidity $|\eta| < 3.2$.
- Muon spectrometer covers rapidity $|\eta| < 2.7$.

ATLAS Forward Detectors





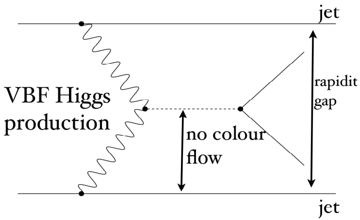
- LUCID:
  - Relative luminosity counter.
  - May be also used for triggering.
  - Covers $5.6 < |\eta| < 5.9$.
- Minimum Bias Trigger Scintillator (MBTS):
  - Just trigger.
  - Will be used by diffractive measurements for triggering.
  - Covers $2.09 < |\eta| < 3.84$.
- ZDC:
  - Covers $|\eta| > 8.3$.
  - Measures only neutral particles (n, γ, π^0).
- ALFA
  - Absolute luminosity measurement for ATLAS.
  - Roman pots at 240 m far from interaction point.
  - Only special low luminosity runs.
- Proposal for installation of forward proton detectors at 220 m and 420 m.
- More about LHC forward detectors - Alessia Tricomi's talk on Thursday.

Rapidity gaps definitions

- Almost all diffractive analysis will have to use (and somehow define) rapidity gaps.
- One of the most important objects in the diffractive analyses.
- Several definitions of rapidity gap based on different objects like minijets, topoclusters, cells of calorimeter.
- Dependence on calorimeter noise.
- Two types of gaps:
  - Gaps in forward region of the detector (CEP, SD, DPE).
    - Define so called visible energy limit.
    - Rings in rapidity with cells of calorimeter under visible energy limit.
  - Gaps in central calorimeter (jet-gap-jet events).
    - Cuts on total E_T in given $\Delta\eta$ region.
    - Several slightly different definitions.
- How to define gaps and studying gaps still ongoing.

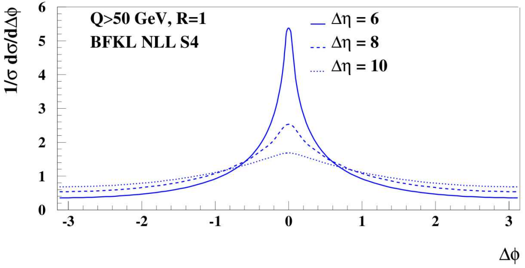
Forward jets

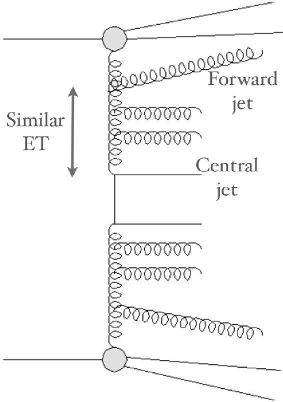
- Many interesting processes will have jets in ATLAS forward calorimeter, e.g. Higgs production in vector boson fusion (VBF).
- Good exercise for VBF processes, which can be studied after a substantial amount of data has been collected (VBF Higgs need about 30 fb^{-1}).
- Understand ATLAS forward calorimeter and forward jet reconstruction in clean environment without almost no additional $p-p$ interactions.



Jet Evolution and Mueller-Navelet jets

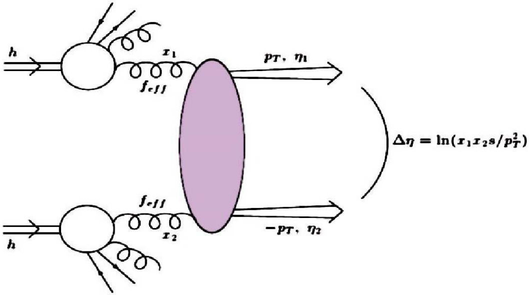
- BFKL predicts different shower evolution to DGLAP.
- Gluon splitting is not ordered in E_T - BFKL predicts open leader which leads to jets in central region with similar E_T as in forward regions.
- Also predicts decorrelation in $\Delta\Phi(= \pi - \phi_1 + \phi_2)$ between the jets.
- Azimuthal decorrelation increases with $\Delta\eta$.



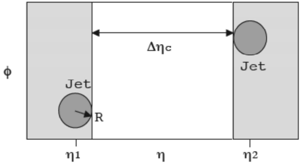


Marquet, Royon, Phys.Rev.D79:034028

Colour singlet exchange

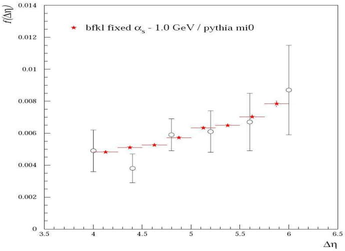


- Events with two forward jets.
- Jets are separated by large central rapidity gap.
- Observed at Tevatron and HERA.
- Colour singlet can be BFKL pomeron, $\Delta\eta \simeq \ln \frac{x_1 x_2 s}{Q_1 Q_2}$, $Q_i \approx E_{T,i}$.

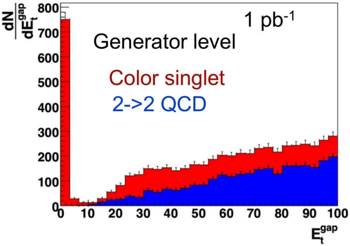


- Measure this process in kinematics regime of the ATLAS detector.
- Study nature of colour singlet exchange.
- Also good opportunity to study jet reconstruction and trigger in forward calorimeter.

- Gap fraction is fraction of events containing no radiation in the center of the detector.
- Fraction of events with suppressed activity in the gap should rise with energy of jets and rapidity gap between jets.
- Simulated with Herwig with fixed α_S (suggested by Cox et al., see JHEP 9910,23) which better fits Tevatron data.
- Process signature:
  - Two jets in forward calorimeter (one in each calorimeter).
  - Gap in central calorimeter.

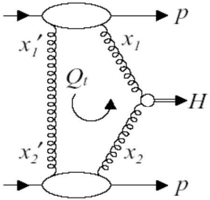


Gap fraction as predicted by Herwig with fixed α_S compared with D0 data



Central exclusive production

- pp→p+gap+X+gap+p (X is central system).
- Central system can be di-jet system, WW pair …or e.g. Higgs boson.
- Central system is produced exclusively, i.e. suppression of radiation from incoming gluons.
- At higher luminosities there will be no rapidity gaps because of pile-up.



- Outgoing protons remain intact, no multiple parton interactions.
- Protons are scattered on very small angle, can not be detected by ATLAS forward detectors.
- To detect diffractive protons, very forward detectors are needed - installation of forward protons detectors is intended as part of ATLAS upgrade - proton taggers at 220 m and 420 m far from interaction point (ATLAS Forward Physics project).
- See also talk by Marek Taševský on Thursday.

CEP di-jets, exclusive variables

- ξ: fractional momentum loss of the interaction proton:

$$\xi = 1 - \frac{|p'_z|}{|p_z|} \tag{1}$$

- No proton taggers during the first data - ξ has to be reconstructed from calorimeter

$$\xi_{1,2} = \frac{1}{\sqrt{s}} \sum_{clus} E_T^i \exp(\pm\eta_i) \tag{2}$$

- Not so precise measurement as using forward proton detectors.
- Fraction of proton momentum contained in di-jet:

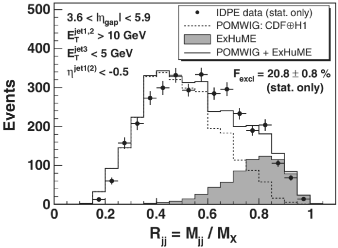
$$x_{1,2} = \frac{1}{\sqrt{s}} \sum_{jets} E_T^i \exp(\pm\eta_i) \tag{3}$$

- Di-jet mass fraction

$$R_{jj} = \frac{M_{jj}}{M_{calo}} \simeq \sqrt{\frac{x_1 x_2}{\xi_1 \xi_2}} \tag{4}$$

- In case of exclusive events all proton energy loss is used to create di-jet - R_{jj} should be peaked around 1.

CEP di-jets

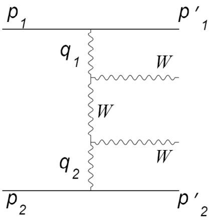


Exclusive di-jets as observed by CDF collaboration

- Observed by Tevatron (Phys. Rev D 77, 05, 2004).
- In good agreement with KMR calculations, but there are still big uncertainties.
- $\sigma \sim \mathcal{O}(10)$ pb at LHC energies.

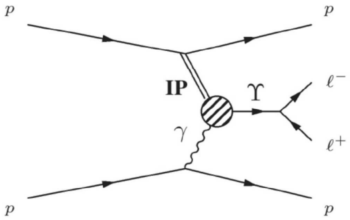
- Early measurements to constrain the factor three uncertainty in theoretical calculation.
- Process signature:
  - Two central jets ($|\eta| < 2.5$).
  - Large rapidity gaps in FCAL and even no activity in MBTS (MBTS veto).
- With first data central two and three jet production can be also used to constrain Sudakov factor T (another source of uncertainty in KMR model).

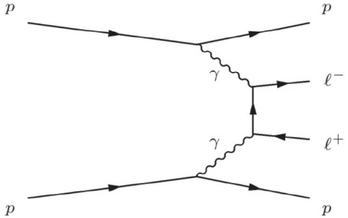
Central exclusive WW and anomalous coupling



- Exclusive production of W pairs via photon exchange: QED process, cross section perfectly known.
- Two steps: CEP WW measurement, anomalous coupling study with this process.
- Modified SM Lagrangian: added anomalous triple gauge coupling or quartic anomalous coupling.
- LHC is more sensitive to quartic anomalous coupling than to anomalous triple gauge coupling.
- $\sigma \sim \mathcal{O}(100)$ fb at LHC energies (for a L=$200\mathrm{pb}^{-1}$ it's expected to observe about 6 CEP WW pair events and background to be less then 0.4 events).
- See Oldřich Kepka's talk about anomalous coupling on Wednesday.
- See also O. Kepka, C. Royon, arXiv:0808.0322.

Central exclusive J/Ψ, Υ and di-lepton production



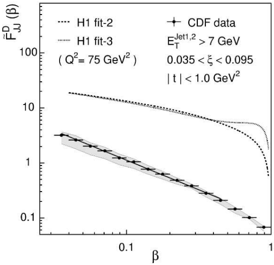


- $p - \gamma$ physics.
- $\gamma\gamma \rightarrow \Upsilon \rightarrow l^+l^-$, $\sigma \sim \mathcal{O}(10)$pb.
- Measurement can be used to constrain unintegrated gluon distribution function f_g (important e.g. in KMR model).
- Studies in the beginning.

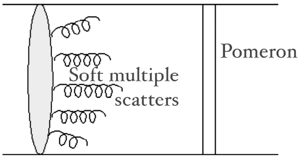
- $\gamma - \gamma$ physics - LHC can be used also as photon collider.
- $\gamma\gamma \rightarrow l^+l^-$, $\sigma \sim \mathcal{O}(10)$pb ($p_T > 2.5$GeV).
- $\gamma\gamma \rightarrow \tau\tau$

- Similar techniques (trigger etc.) will be used as in case of anomalous

Rapidity gap survival probability

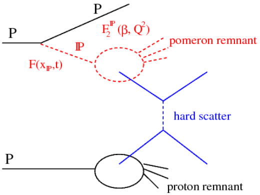


- CDF results suppressed by factor $\sim$ 10 relative to HERA - QCD factorization breaking.
- Could be explained by color exchange (soft interaction) between protons.
- Multiple soft interaction between proton - not to be confused with pile-up.

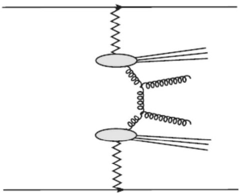


- These interactions typically exchange colour and spoil the gap.
- Only small fraction of events survive the soft radiation into gap - soft survival probability S^2.
- Large uncertainty on soft survival probability at LHC: $S^2 \sim 0.02$ - 0.05

Single Diffraction and Double Pomeron Exchange



- $\sigma \sim \mathcal{O}(1)\mu$b at LHC energies.
- Process signature:
  - Two central jets ($|\eta| < 2.5$).
  - Gap on one side in forward region.



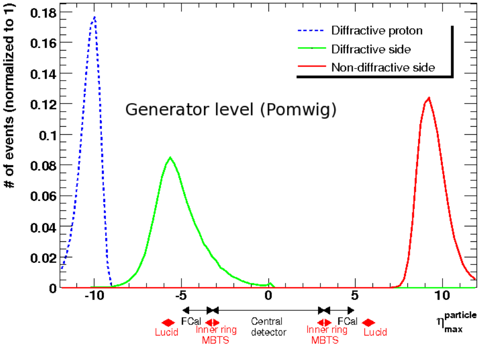
- $\sigma \sim \mathcal{O}(10)$nb at LHC energies.
- Process signature:
  - Two central jets ($|\eta| < 2.5$).
  - Gap on both sides in forward regions.
- Background to CEP di-jets.

Aims:

- Diffractive structure functions from $\frac{\sigma(SD_{jj})}{\sigma(ND_{jj})} = \frac{F^D_{jj}(x)}{F_{jj}(x)}$
- soft-hard factorization: R(SD/ND).

- R(DPE/SD) and diffractive structure function from DPE (CDF observed restoring of factorization).

Single Diffraction and Double Pomeron Exchange



- In both cases gaps are not very large (as in CEP case) because of pomeron remnants and gaps are more in forward region.
- Bigger gaps are in case of lower p_T jets ($\eta_{max} \sim \ln(\frac{2p_T}{m_p})$), but low p_T jets are heavily prescaled.

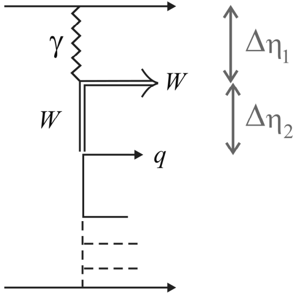
- η coverage of ATLAS detectors is not ideal for SD and DPE.
- LUCID is well placed, but the acceptance is quite low (bad rejection of non-diffractive events makes impossible to lower jet trigger prescale).
- ZDC could work well (not yet in full simulation)

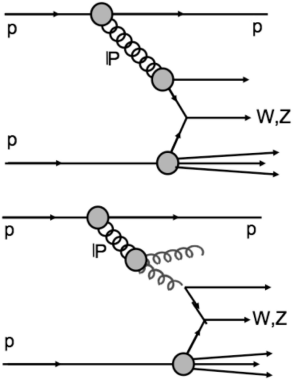
Single Diffraction and Double Pomeron Exchange

Expected number of events:

- Expected number of SD di-jet events (after applying trigger efficiencies etc.) in 10 $\mathrm{pb}^{-1} \sim \mathcal{O}$(1000) with cut $\Delta\eta > 0.4$.
- Expected number of DPE di-jet events (after trigger efficiencies etc.) in 10 $\mathrm{pb}^{-1} \sim \mathcal{O}$(10) with cut $\Delta\eta > 0.4$.
- $\Delta\eta$ is size of rapidity gap measured from and of calorimeter.

Diffractive W/Z production

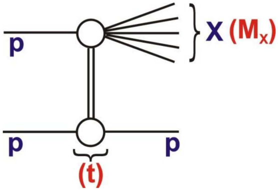




- This measurement will be very usefull for studying soft survival factor S^2.
- Also for pomeron distribution functions - quark content of the pomeron.
- Production by gluon (Fig. on right bottom) is suppressed by α_S, additional jet present.
- $\sigma \sim \mathcal{O}(100)$pb for W production and $\sim \mathcal{O}(10)$pb for Z production at LHC energies.

Soft diffraction

- Will be measured by ALFA, but also using ATLAS detector (using track asymmetry etc.), Lucid and ZDC in normal runs.
- Fundamental process for which the cross section and distributions should be measured.
- Large model and Monte Carlo (Pythia, Phojet) uncertainties.
- Background to other processes.



- Aims to measure total cross section for soft single diffraction.
- Differential spectra of t and ξ.
- Diffractive mass distribution.
- One of the first measurements in ATLAS.
- In case of ALFA is expected 1.2-1.8 M accepted events in 100 hours at $10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ with overall acceptance is about 40-45%.

Triggers for diffractive physics

- A lot of effort devoted to the diffractive triggers in recent period.

Main triggers for diffractive analyses:

- Mueller-Navelet jets, color singlet exchange:
  - Forward jet trigger (2 jets of $E_T > 18$ GeV in both forward calorimeters with $|\eta| > 3.2$).
  - Expected rate $\sim$ 1Hz.
- Central exclusive di-jet production:
  - Jet trigger (jet $E_T > 18$GeV with $|\eta| < 2.5$, unprescaled), combined with veto in MBTS on both sides.
  - Expected rate < 0.5 Hz.
- Single diffraction and double pomeron exchange:
  - Only jet trigger J18 (veto in MBTS kills to much signal, veto in Lucid is not effective in background suppression - too high trigger rate).
  - Expected rate $\sim$ 0.5 Hz.

Expected feasible analyses with given amount of data

Amount of collected data	Analysis
10 pb^{-1}	Forward jets studies (BFKL evolution, colour singlet exchange) Soft single diffraction Single diffractive di-jets
10 - 100 pb^{-1}	CEP di-jets Single diffractive W
100 - 200 pb^{-1}	CEP WW CEP $\tau\tau$ Anomalous coupling

Summary

- A lot of measurement could be done with early ATLAS data.
- More precise measurements at regime of LHC energies.
- Constraint theoretical models (soft survival probability, unintegrated gluon distribution functions, BFKL . . .).
- Understand the detector and prepare for other measurement (like diffractive Higgs).

- Ongoing studies:
  - Mueller-Navelet jets, colour singlet exchange . . . (target on BKFL and BFKL pomeron)
  - Central exclusive di-jet production
  - Single diffractive and double pomeron exchange di-jet production
  - Anomalous coupling studies
  - Soft diffraction
  - Central exclusive $\tau\tau$ production

- Startup studies:
  - Diffractive W and Z production
  - Central exclusive Υ production