Forward detectors

the best way to measure diffractive physics at the LHC

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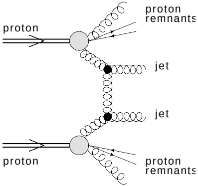
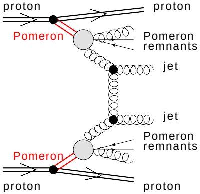
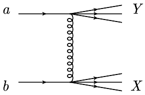
- **hard** – perturbative approach of calculating is valid; small cross-sections:
  - non-diffractive



  - diffractive

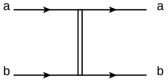


- **soft** – large cross-sections:
  - non-diffractive:

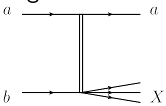


  - diffractive:

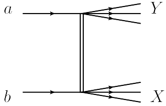
Elastic Scattering



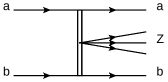
Single Diffraction



Double Diffraction



Central Diffraction



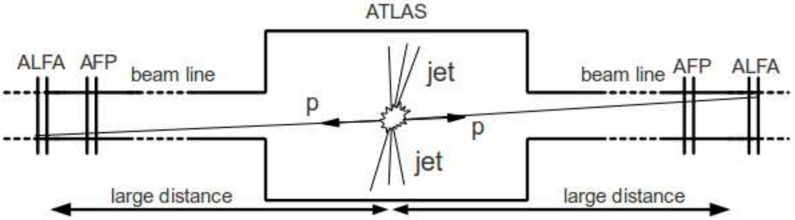
Diffraction:

- colour singlet exchanged,
- Pomeron (QCD = two gluons + ...).

Natural ways to seek for diffraction:

- rapidity gaps,
- **forward protons**.

Intact protons → natural diffractive signature → usually scattered at very small angles (μrad) → detectors must be located far form the Interaction Point.



ALFA

- **A**bsolute **L**uminosity **F**or **A**TLAS
- exist, 240 m from ATLAS IP
- soft diffraction (elastic scattering)
- special runs (high β^* optics)
- vertically inserted Roman Pots
- tracking detectors, resolution: $\sigma_x = \sigma_y = 30\ \mu$m

AFP

- **A**TLAS **F**orward **P**roton
- planned, 210 m from ATLAS IP
- hard diffraction
- nominal runs (collision optics)
- horizontally inserted Roman Pots
- tracking detectors, resolution: $\sigma_x = 10\ \mu$m, $\sigma_y = 30\ \mu$m
- timing detectors, resolution: $\sigma_t \sim 20$ ps

Similar Devices @ IP5: CMS-TOTEM.

Luminosity: $L = \frac{N_1 \cdot N_2 \cdot n \cdot f \cdot \gamma}{4 \cdot \pi \cdot \varepsilon \cdot \beta^*} F$

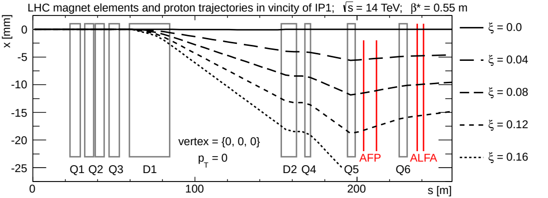
- N_1 **and** N_2 **– number of protons per bunch in beam 1 and 2,**
- n **– number of bunches per beam,**
- f – revolution frequency,
- γ – beam Lorentz factor,
- ε – beam emittance,
- β^* **– betatron function at the IP,**
- F – luminosity reduction factor due to the crossing angle at the IP.

Data collecting strategies

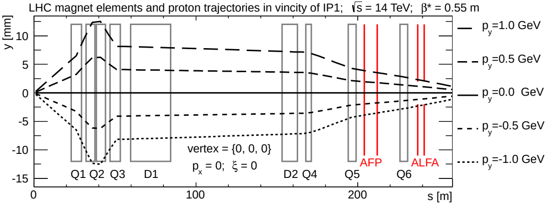
hard processes, potential discoveries	soft processes, elastic scattering
⇓	⇓
small cross sections	large cross sections
⇓	⇓
rare events	clean environment needed
⇓	⇓
much luminosity needed	minimise pile-up, pp interactions within a beam and beam divergence
⇓	⇓
maximise N_1, N_2, n, $1/\beta^*$	optimise N_1, N_2, n, β^*
forward protons: access to wide range of relative energy loss (ξ)	forward protons: access to as low t values as possible

Proton trajectory is determined by the LHC magnetic field.

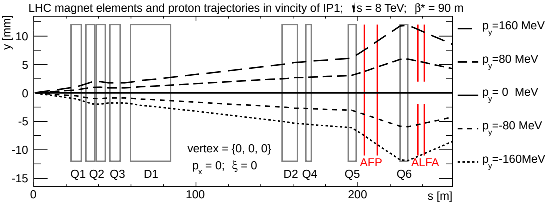
collision optics,
ALFA and **AFP**:
trajectory due to ξ
$\xi = 1 - E_{proton}/E_{beam}$



collision optics,
ALFA and **AFP**:
trajectory due to p_y



special high-β^* optics,
ALFA:
improve acceptance in
p_T



Ratio of the number of protons with a given relative energy loss (ξ) and transverse momentum (p_T) that crossed the active detector area to the total number of the scattered protons having ξ and p_T.

optics

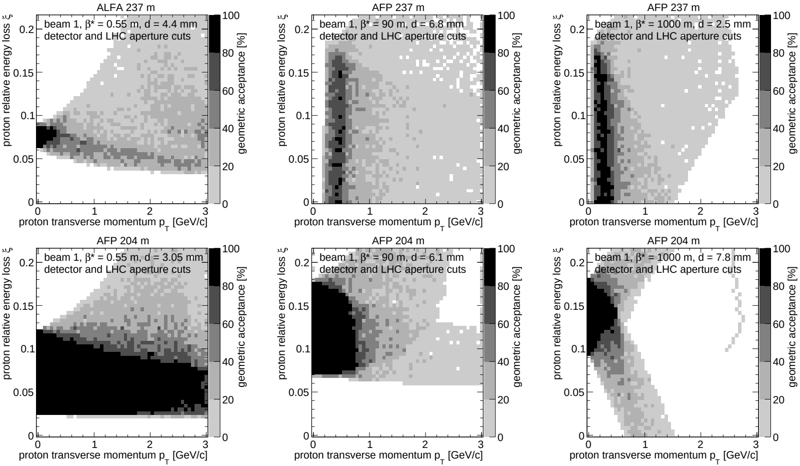
$\beta^* = 0.55$ m
nominal (*collision*)

$\beta^* = 90$ m
special (*high-β^**)

$\beta^* = 1000$ m
special (*high-β^**)

ALFA

AFP



Data Taking Scenarios

Collected data

- $\sqrt{s} = 7$ TeV, $\beta^* = 90$ m
- $\sqrt{s} = 8$ TeV, $\beta^* = 90$ m
- $\sqrt{s} = 8$ TeV, $\beta^* = 1000$ m

Future: very low pile-up scenarios ($\mu \sim 0.05$)

- detectors: ALFA or AFP
- optics: collision or high β^*, few very low intensity bunches
- goals: measure total cross-section and properties of soft diffraction

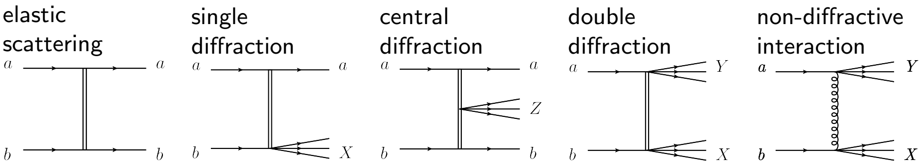
Future: low pile-up scenarios ($\mu \sim 1$)

- detectors: ALFA or AFP
- optics: collision or high β^*, low intensity bunches
- goal: measure properties of hard diffraction

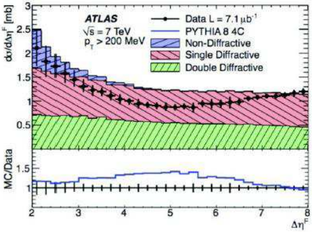
Future: high pile-up scenarios ($\mu \sim 50$)

- detectors: AFP
- optics: collision, join all ATLAS runs
- goals: measure exclusive jet production, discovery physics

Minimum bias processes at the LHC

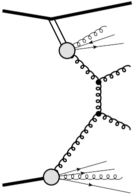


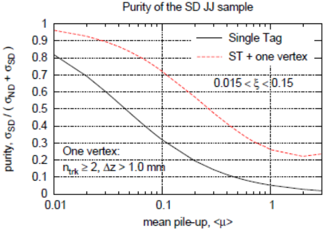
- Gap measurement in ATLAS does not distinguish SD from DD.
- Possible with forward proton tagging.
- High cross sections → low lumi needed → low pile-up possible.
- Properties of SD – central and forward.
- Central diffraction (DPE – double Pomeron exchange).

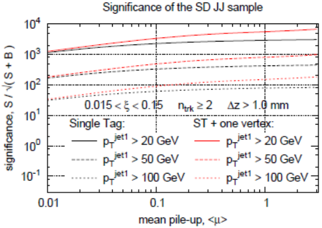


Motivation: gap survival probability, gluon distribution in Pomeron.

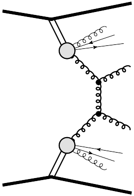
Single diffractive jets

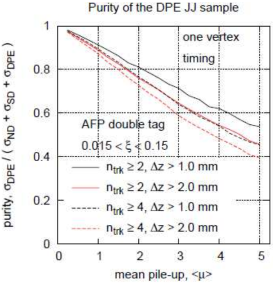


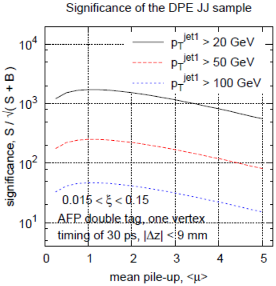




Central diffractive (double Pomeron exchange) jets

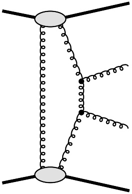






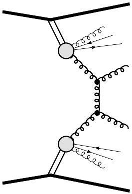
Exclusive jets

- Two intact protons
- No Pomeron remnants
- All particles measured

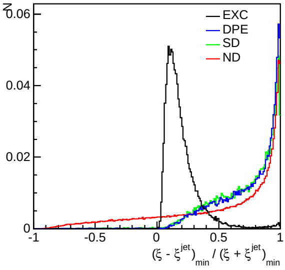


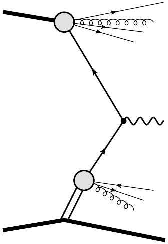
For comparison: CD (DPE) jets

- Two intact protons
- Pomeron remnants
- Remnants escape



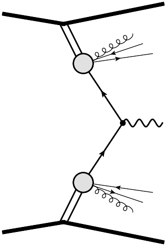
- **Motivation: verification of QCD production models, unintegrated gluon PDFs.**
- Small cross section for exclusive processes → measurement with two proton tags needs high luminosity.
- Low luminosity – use only single tag events, but less pile-up background.
- All particles measured → strong kinematic constraints between central state and each of the forward protons.





SD W

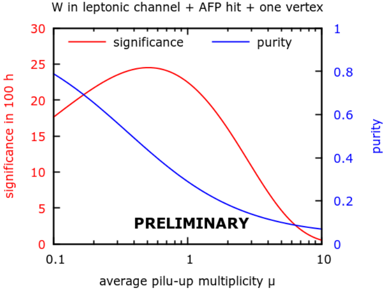
- One intact proton
- One quark from proton, one from Pomeron

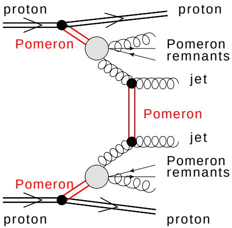


CD (DPE) W

- Two intact protons
- Both quarks from Pomeron

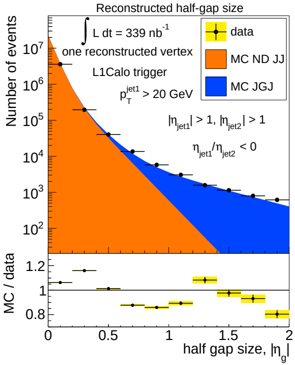
- Sensitivity to quarks in Pomeron.
- SD W – sensitivity to Pomeron flavour composition (via charge asymmetry).
- CD/DPE W – long running at low luminosity needed – unlikely.

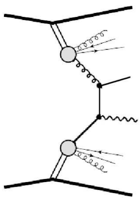




DPE jet-gap-jet

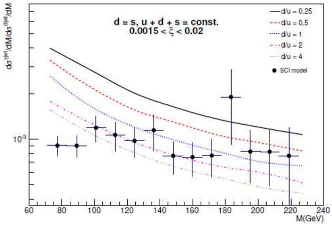
- Two intact protons and gap between jets.
- Never measured before.
- BFKL dynamics.
- Cleaner than JGJ without forward protons.





DPE photon+jet

- Two intact protons.
- Never measured before.
- Sensitivity to quark in Pomeron and to mechanism of diffraction.



Anomalous couplings of gauge bosons: $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$

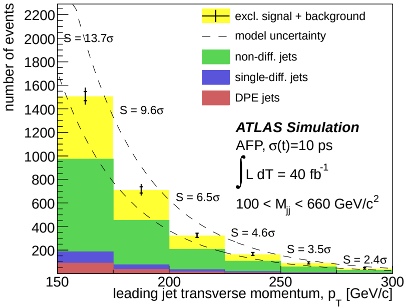
$\gamma\gamma WW$ and $\gamma\gamma ZZ$

Coupling	OPAL limits [GeV2]	Sensitivity for 200 fb1 5σ	95% CL
a_0^W/Λ^2	[-0.020, 0.020]	$2.7 \cdot 10^{-6}$	$1.4 \cdot 10^{-6}$
a_C^W/Λ^2	[-0.052, 0.037]	$9.6 \cdot 10^{-6}$	$5.2 \cdot 10^{-6}$
a_0^Z/Λ^2	[-0.007, 0.023]	$5.5 \cdot 10^{-6}$	$2.5 \cdot 10^{-6}$
a_C^Z/Λ^2	[-0.029, 0.029]	$2.0 \cdot 10^{-5}$	$9.2 \cdot 10^{-6}$

$\gamma\gamma\gamma\gamma$

Coupling (GeV^{-4})	1 conv. γ 5σ	1 conv. γ 95% CL	all 95% CL
ζ_1 f.f.	$1 \cdot 10^{-13}$	$7 \cdot 10^{-14}$	$4 \cdot 10^{-14}$
ζ_1 no f.f.	$3 \cdot 10^{-14}$	$2 \cdot 10^{-14}$	$1 \cdot 10^{-14}$
ζ_2 f.f.	$3 \cdot 10^{-13}$	$1.5 \cdot 10^{-13}$	$8 \cdot 10^{-14}$
ζ_2 no f.f.	$7 \cdot 10^{-14}$	$2 \cdot 10^{-14}$	$2 \cdot 10^{-14}$

Excusive jets



- Quartic Gauge Couplings – testing BSM models.
- Constrained kinematics $\rightarrow$ low background.
- Reaching limits predicted by string theory and grand unification models (10^{-14} – 10^{-13} for $\gamma\gamma\gamma\gamma$).
- Exc. jets – high p_T, double tag.

Summary

- Intact protons → natural diffractive signature → usually scattered at very small angles (μrad) → detectors must be located far form the IP.
- Two forward detectors systems in ATLAS (similar situation in CMS):
  - ALFA – existing vertical RPs located 240 m from IP1 (soft diffraction),
  - AFP – planned horizontal RPs located 210 m from IP1 (hard diffraction).
- **Various data taking strategies (LHC optics):**
  - very low pile-up ($\mu \sim 0.05$):
    - detectors: ALFA or AFP,
    - optics: collision or high β^*, few very low intensity bunches,
    - measure total cross section and properties of soft diffraction,
  - low pile-up ($\mu \sim 1$):
    - detectors: ALFA or AFP,
    - optics: collision or high β^*, low intensity bunches,
    - measure properties of hard diffraction: SD JJ, SD JGJ, SD W, SD Z, DPE JJ, DPE JGJ, DPE γ+jet,
  - high pile-up ($\mu \sim 50$):
    - detectors: AFP,
    - optics: collision, join all ATLAS runs,
    - measure exclusive production, discovery physics: EXC JJ, anomalous couplings: $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$.

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