Exclusive Production at the LHC

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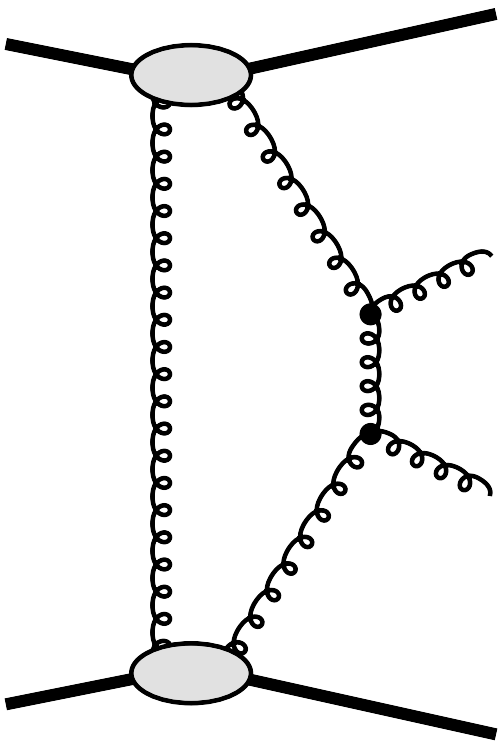
Workshop on QCD and Diffraction

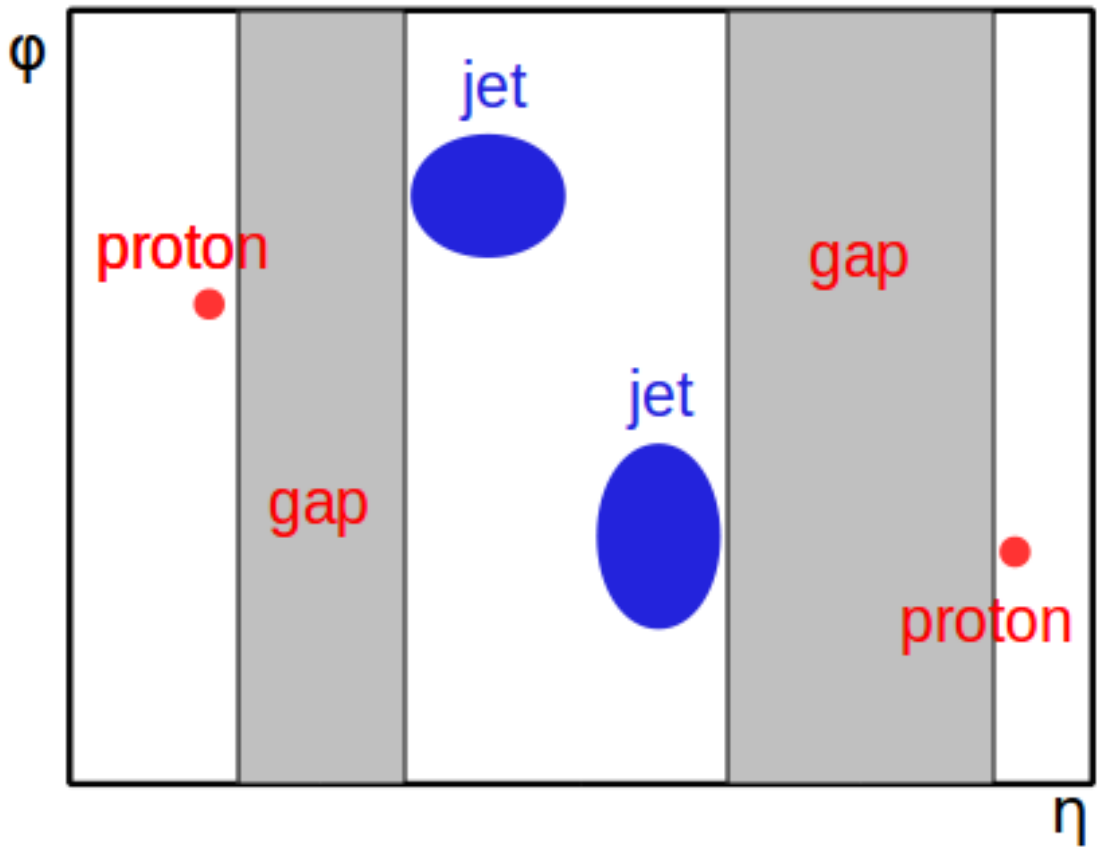
Saturation 1000+

7th December 2016

Exclusivity (for Experimentalists)



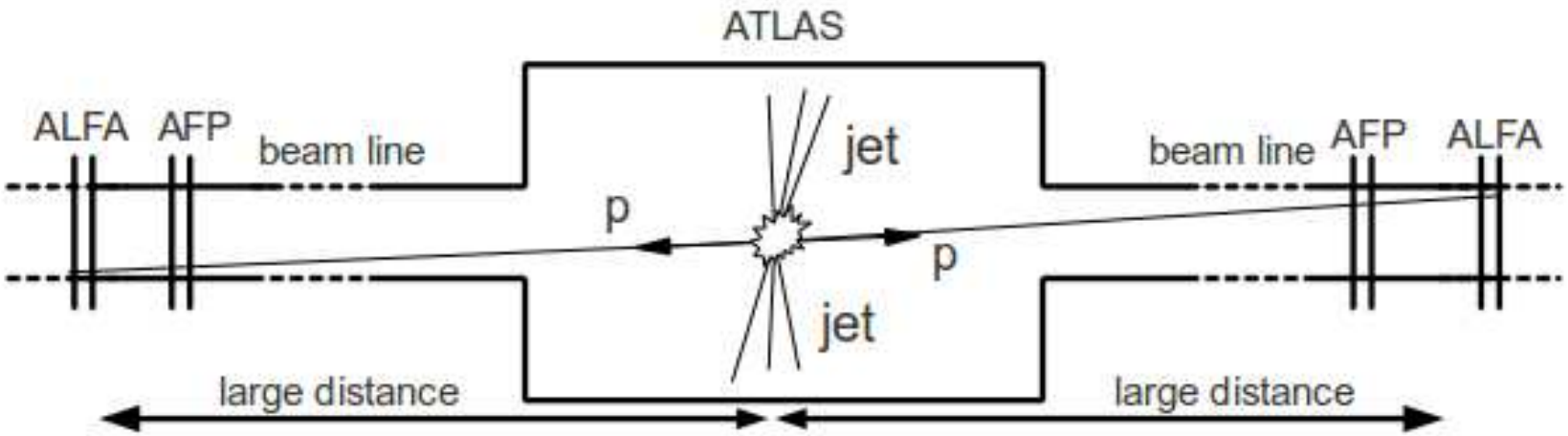
Exclusive Production



All particles produced within detector acceptance.

Forward Detectors

Intact protons – natural diffractive signature.



ALFA

- 240 m from ATLAS IP
- elastic scattering
- special runs (high β^* optics)
- position detectors
- vertically inserted Roman Pots

- soft events, pile-up background

AFP

- 210 m from ATLAS IP
- hard diffraction
- nominal runs (collision optics)
- position and timing detectors
- horizontally inserted RP

- proton detector for hard events

ATLAS was taken as an example, but the conclusions are similar for CMS/TOTEM

Geometric Acceptance

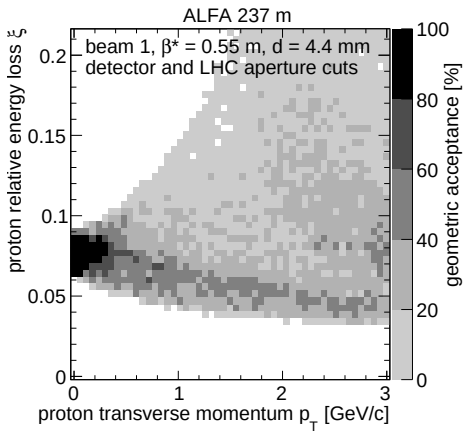
optics

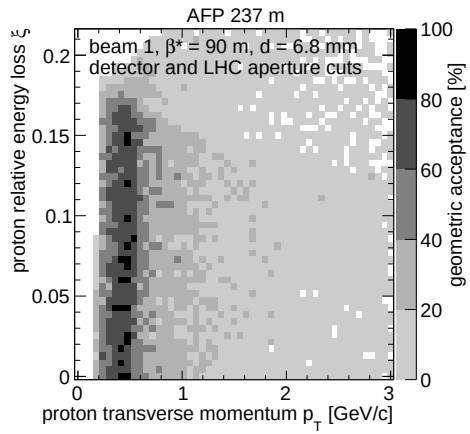
ALFA

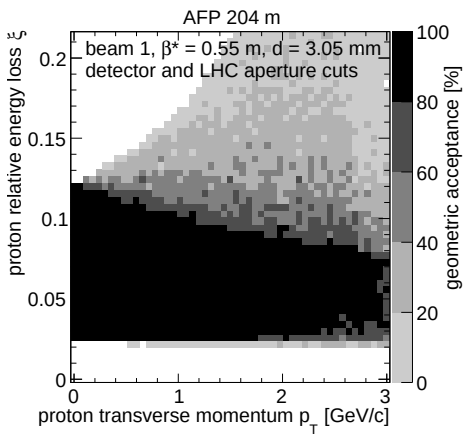
AFP

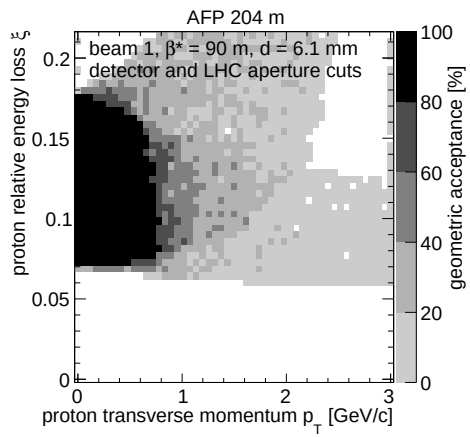
$\beta^* = 0.55$ m
nominal (*collision*)

$\beta^* = 90$ m
special (*high-β^**)







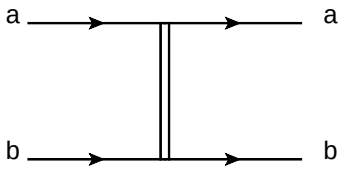


Exclusive Pion Production

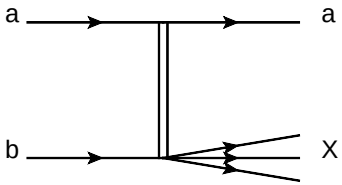
Exclusive Pion Production with Forward Proton Tagging
R. Staszewski, P. Lebiedowicz, M. Trzebinski, J. Chwastowski,
A. Szczurek, Acta Physica Polonica B **42** (2011) 1861

Soft Diffractive Production

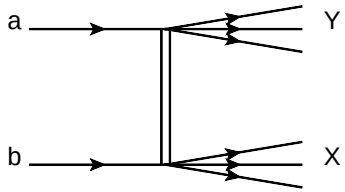
Elastic Scattering



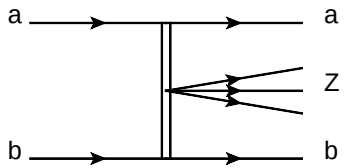
Single Diffraction



Double Diffraction

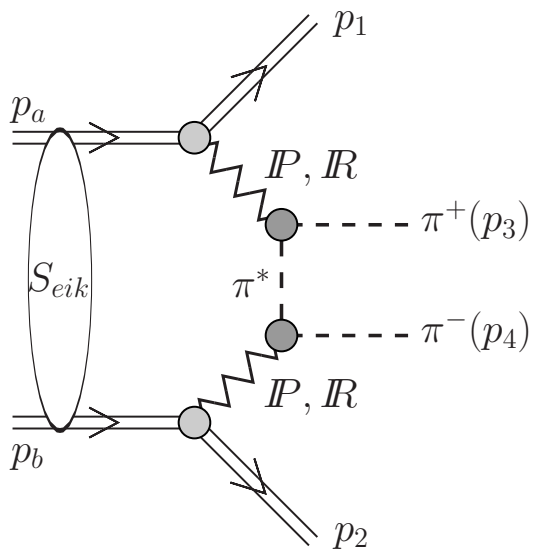


Central Diffraction



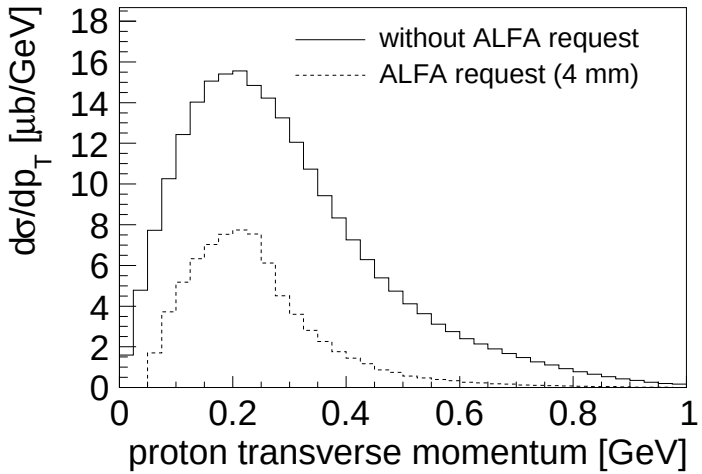
Exclusive $\pi^+\pi^-$ Production

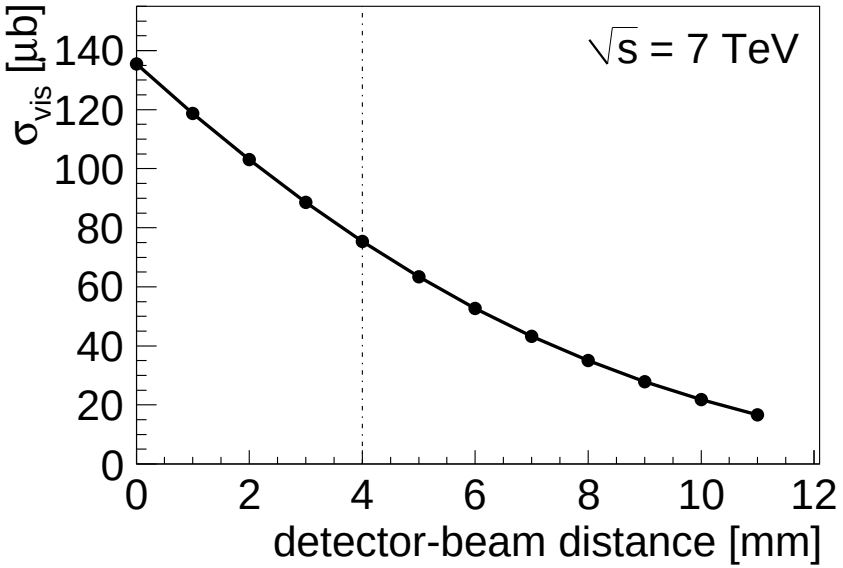
- both outcoming protons tagged in ALFA,
- pions measured in ATLAS detector.

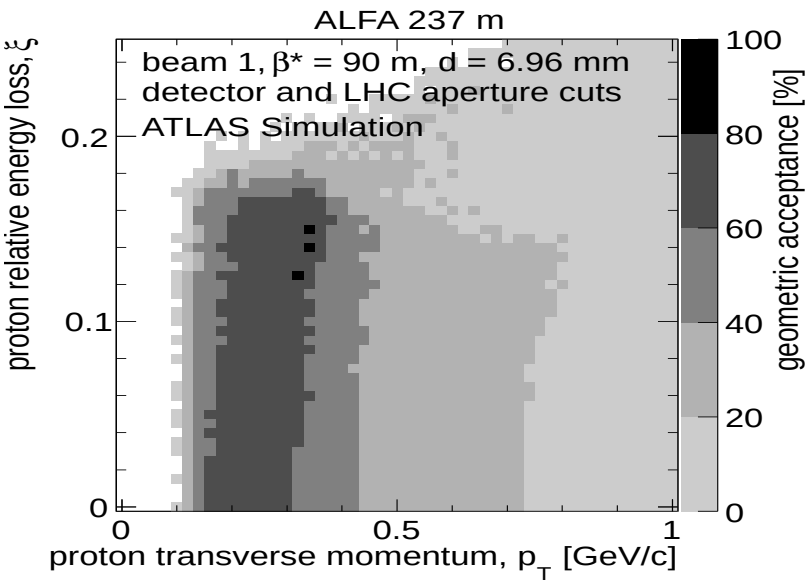


soft process $\rightarrow$ relatively large cross-section:
$\sigma(\mathbf{pp} \rightarrow \mathbf{p}\pi^+\pi^-\mathbf{p}) \approx \mathbf{230}\ \mu\mathbf{b}$

Forward Protons



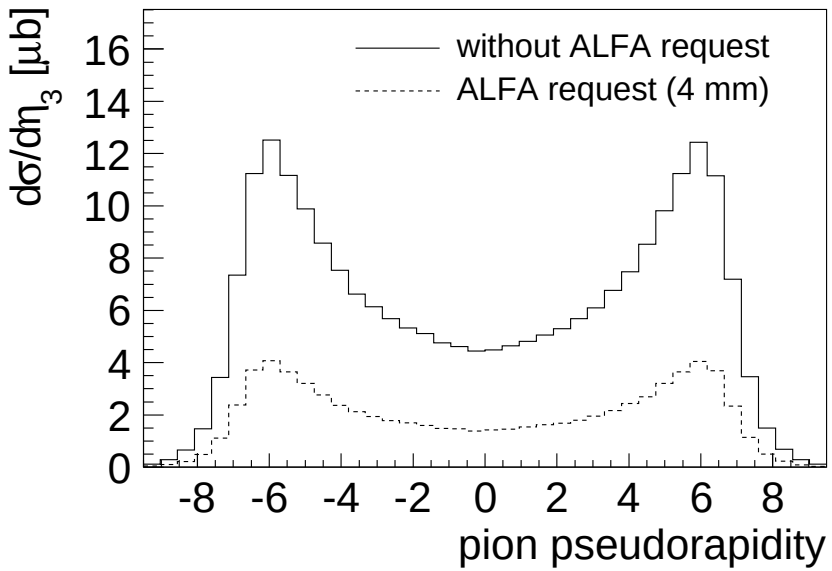


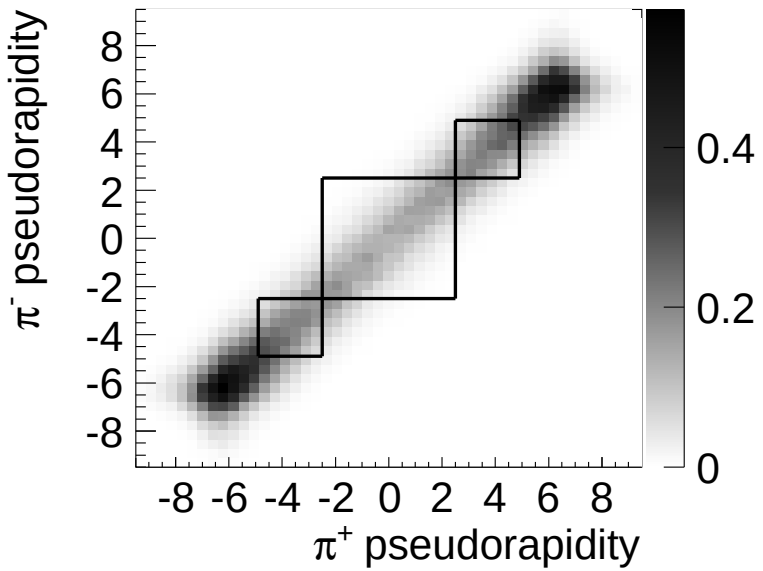


Cross section visible in the ALFA detectors (both protons tagged) as a function of the distance between the detectors and the beam centre.

Majority of outgoing protons are in ALFA acceptance region!

Central Pions





Total cross section as a function of pion pseudorapidity.

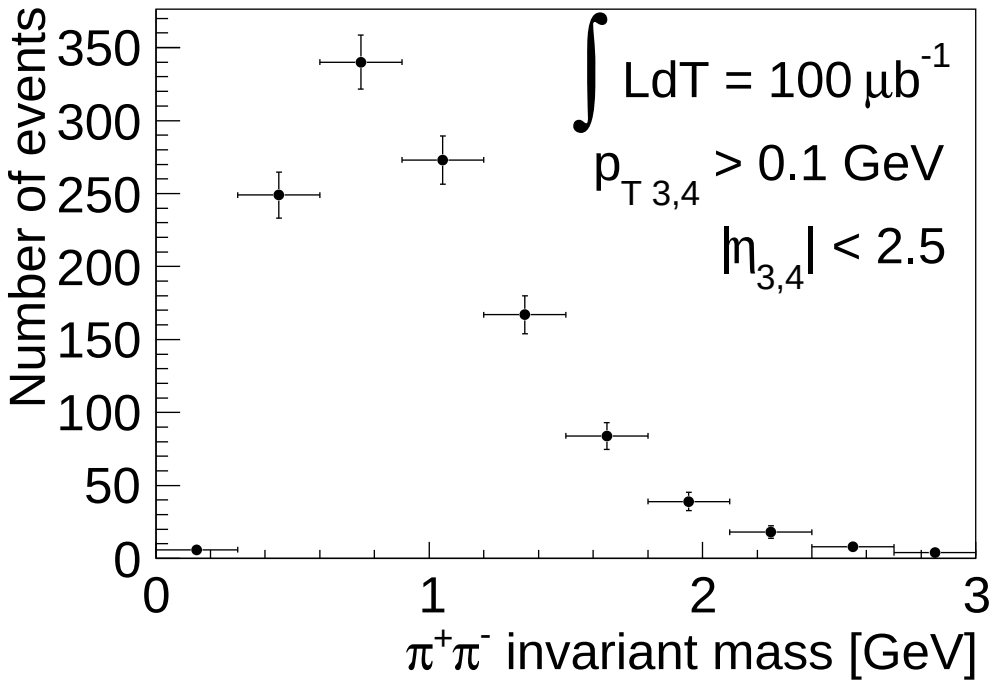
Distribution peaked around $|\eta| \sim 6$.

Large correlation between pions pseudorapidity.

Measurements possible in:

- tracker,
- FCAL.

Possible Measurement



Possible measurement of the $\pi^+\pi^-$ invariant mass distribution for $L = 100\ \mu\text{b}^{-1}$ (luminosity: $10^{27}\ \text{cm}^{-2}\text{s}^{-1}$, data collecting time: 30 h.).

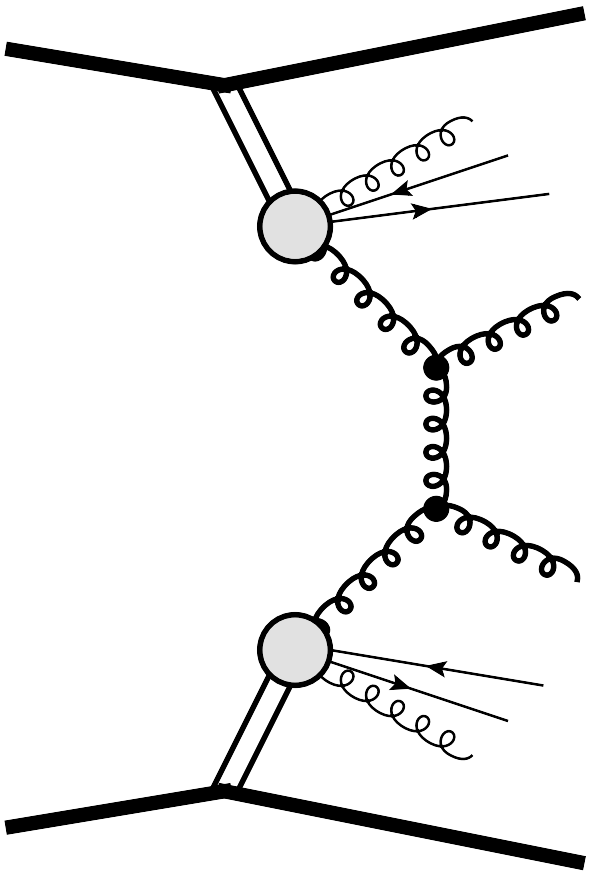
Conclusions

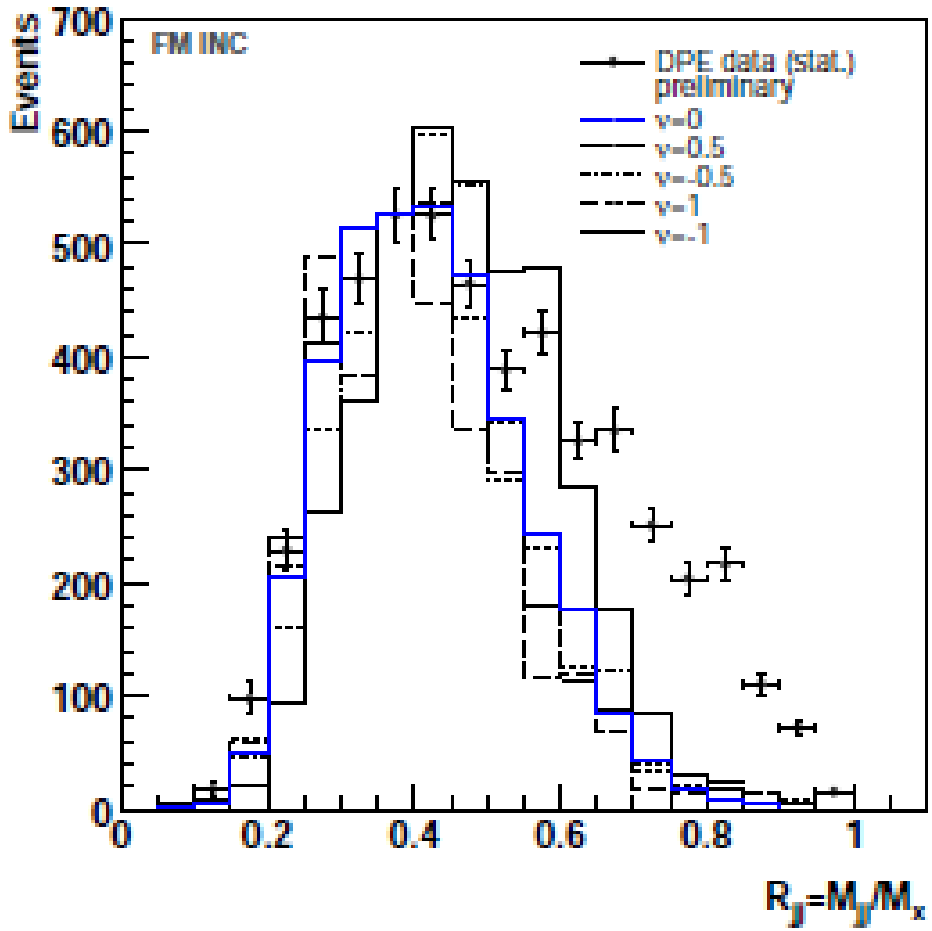
- Measurement of Exclusive $\pi^+\pi^-$ is possible using ALFA data.
- Motivated joint ALFA-ATLAS data taking.
- It requires ALFA trigger and low-p_T tracking.
- Measurements at LHC are on the way. So far the only measurements were performed at:
  - $\sqrt{s} = 62$ GeV and $\sqrt{s} = 63$ GeV by the ABCDHW Collaboration,
  - $\sqrt{s} = 200$ GeV STAR,
  - $\sqrt{s} = 1.96$ TeV Tevatron.
- GenEx – exclusive meson generator.

Exclusive Jets

DPE – Double Pomeron Exchange

Signature: two jets in central region + two intact protons.





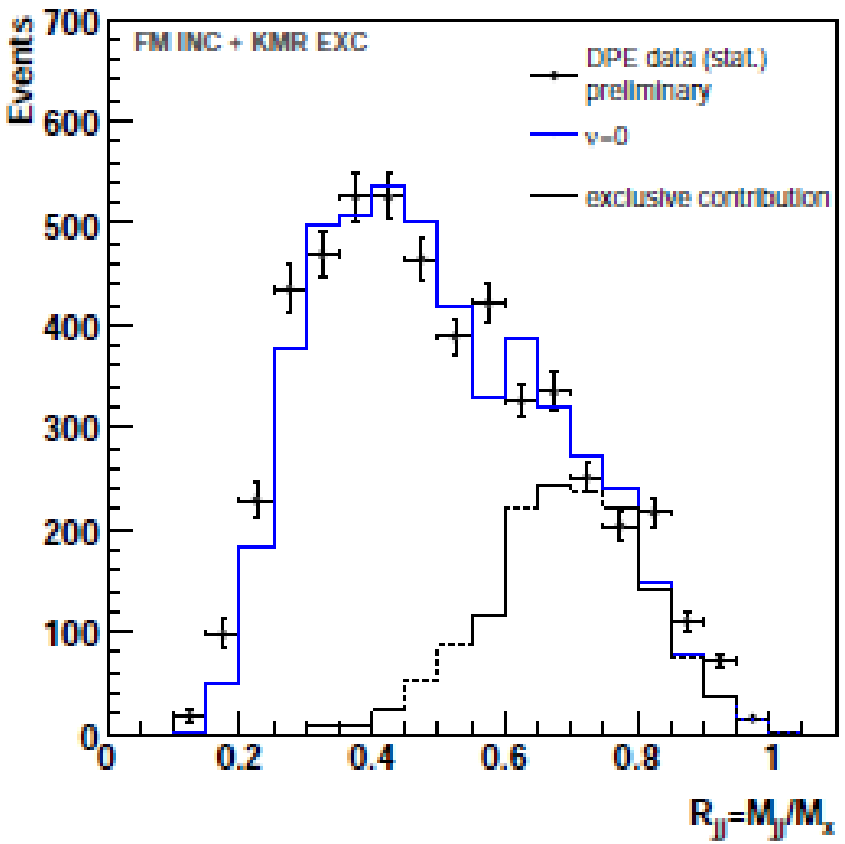
Goal: to probe the Pomeron Density Function.

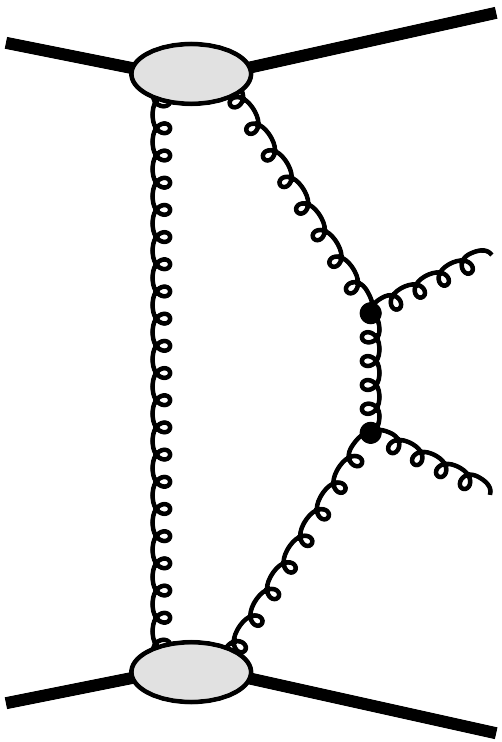
Too much events in the high mass ratio (M_{jj}) region.

Mass ratio is defined as the ratio of mass of the dijet system to missing mass.

Exclusive Jet Production at the Tevatron

Signature: two jets in central region + two intact protons
+ **gap in rapidity between jet and proton** (no remnants).

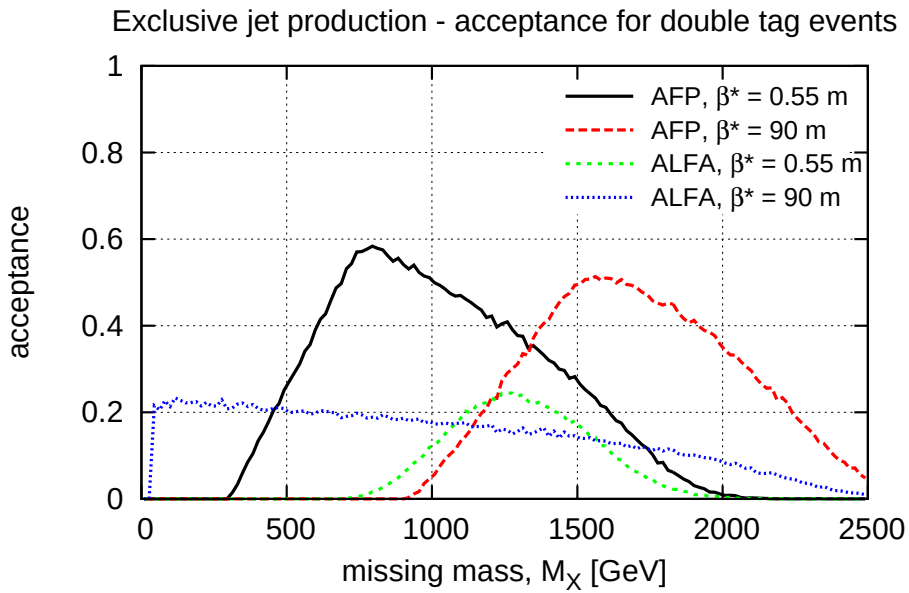


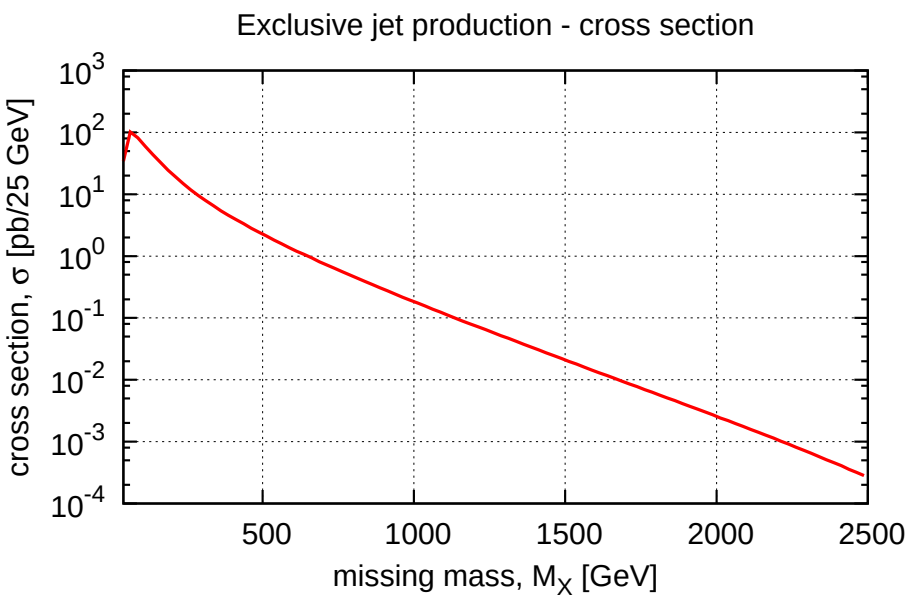


Exclusive Production

KMR model explains additional contribution in high mass ratio region. In such process there are no Pomeron remnants (in theory ratio = 1, smearing due to the detector effects).

Mass Acceptance

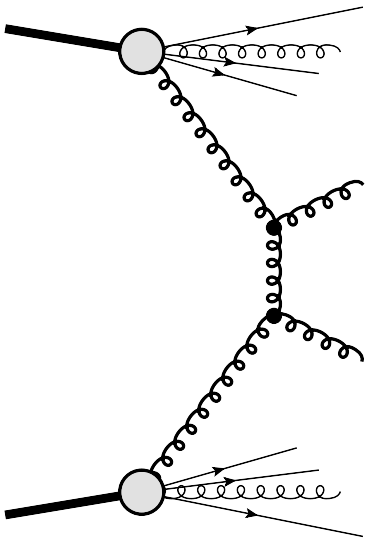


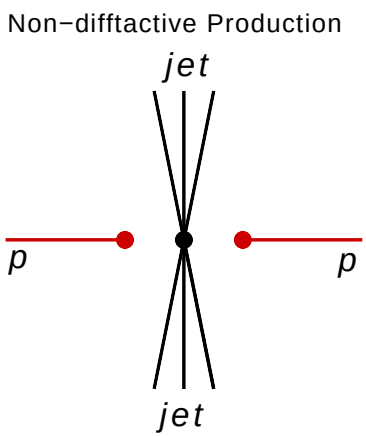


Background

Pile-up – multiple collisions during one bunch crossing (mostly min-bias).

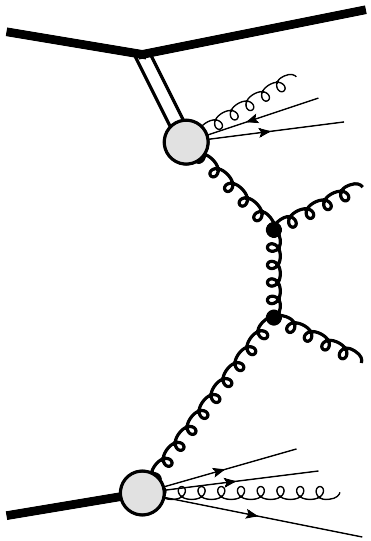
Non-diffractive jets + pile-up.

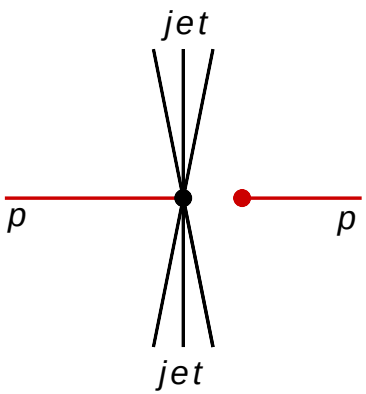




CS ($p_T > 150$ GeV):
645 nb

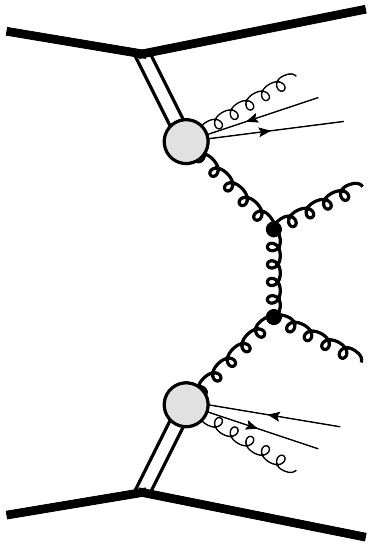
Single-diffractive jets + pile-up.

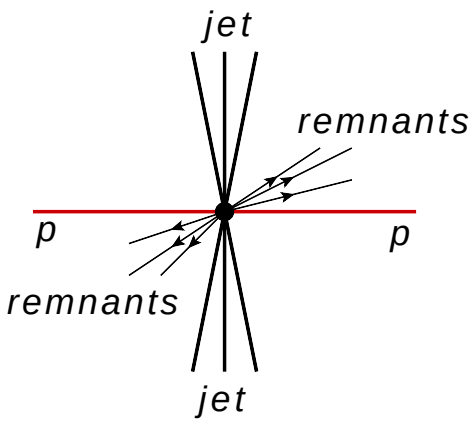




CS ($p_T > 150$ GeV):
2.26 nb

DPE jets + pile-up.



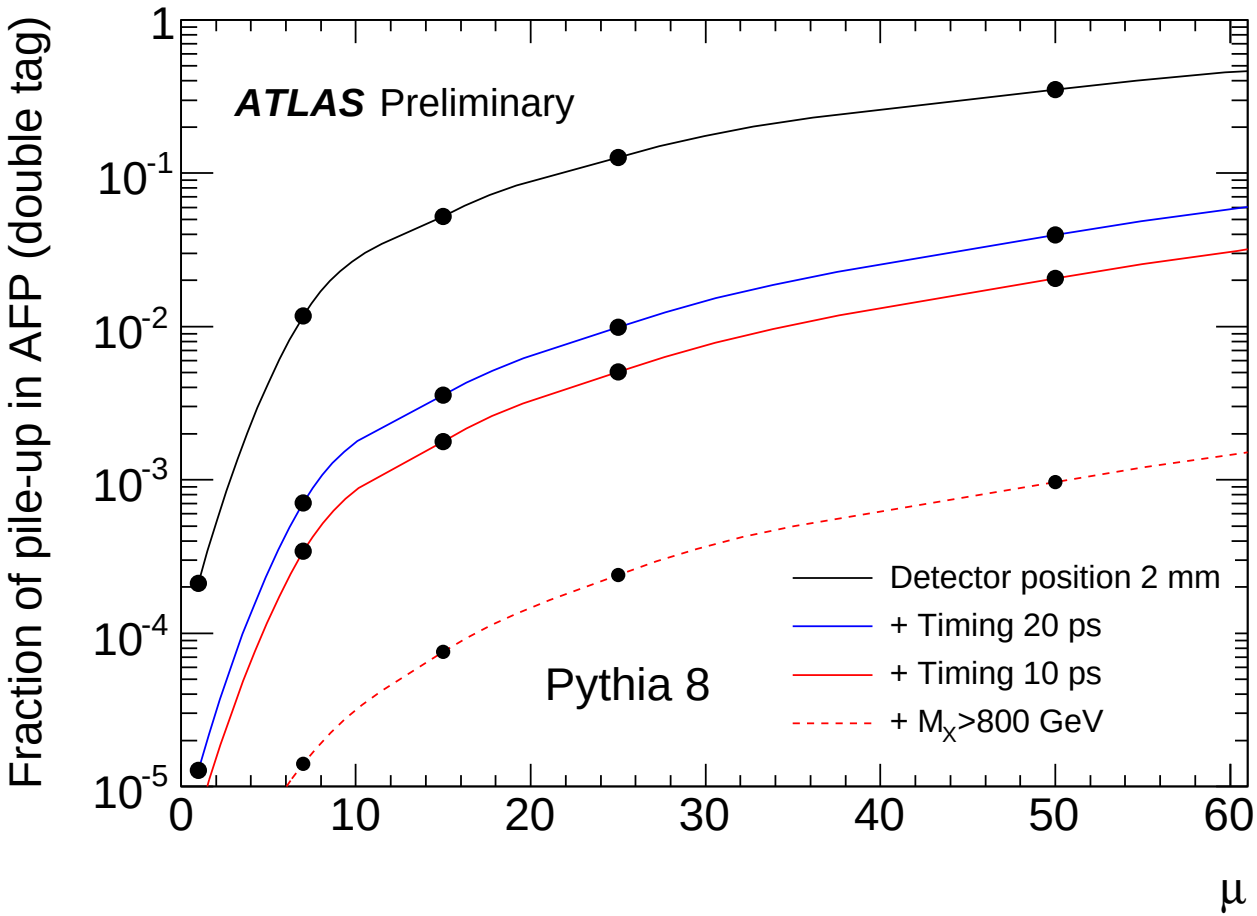


CS ($p_T > 150$ GeV):
40 pb

Double Tagged Events

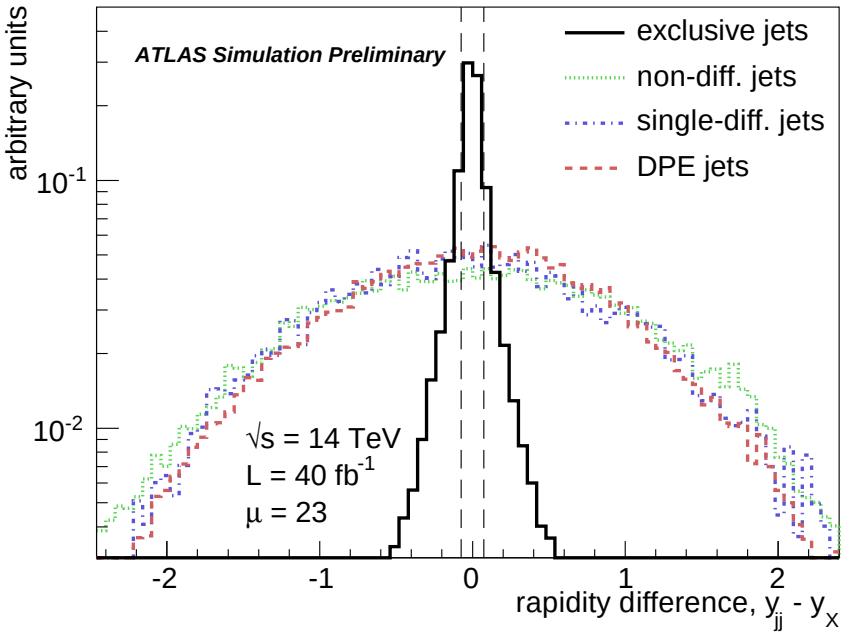
Exclusive Jet Production with Forward Proton Tagging
ATL-PHYS-PUB-2015-003

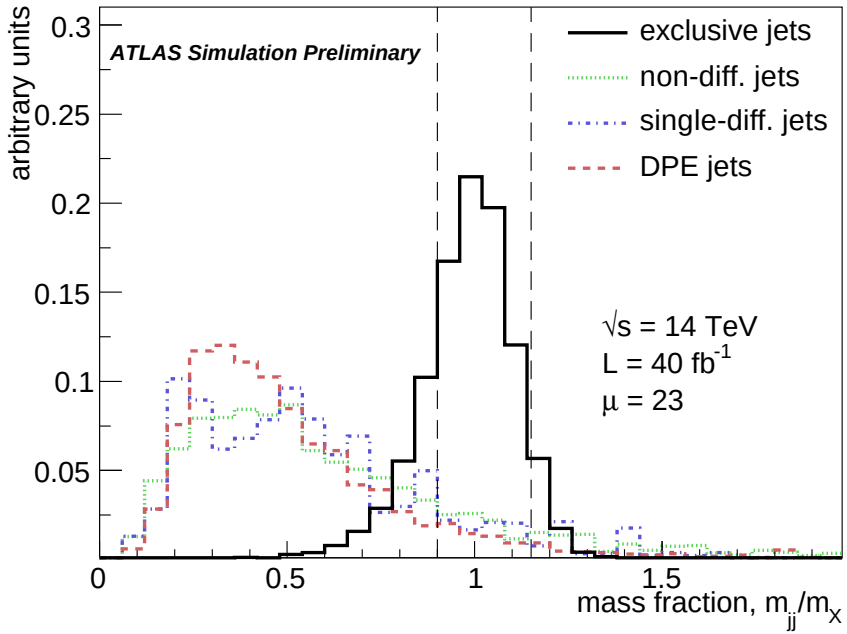
Cuts – AFP Acceptance



Fraction of pile-up events in AFP (double tagged events) as a function of the average number of interactions with a timing resolution of 20, 10 ps, and for a diffractive mass greater than 800 GeV.
Exclusive jet studies for pile-up $\mu = 23$ end $\mu = 46$.

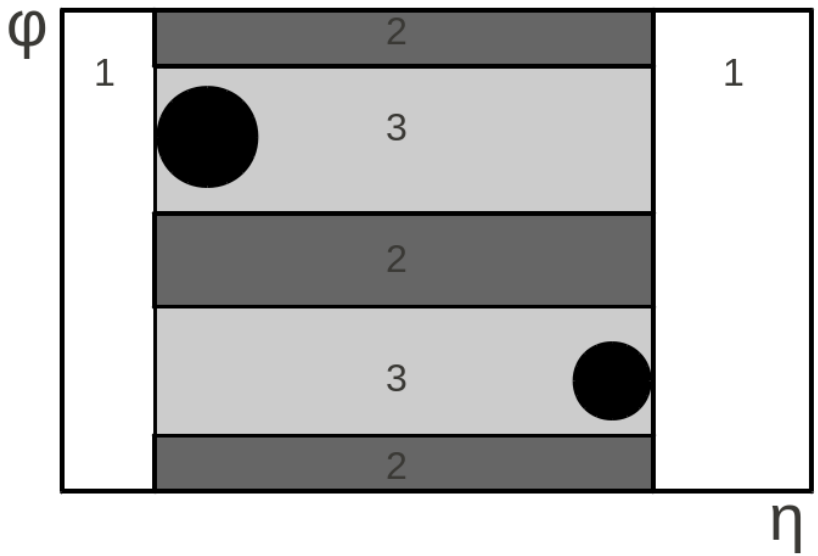
Cuts – Rapidity Difference



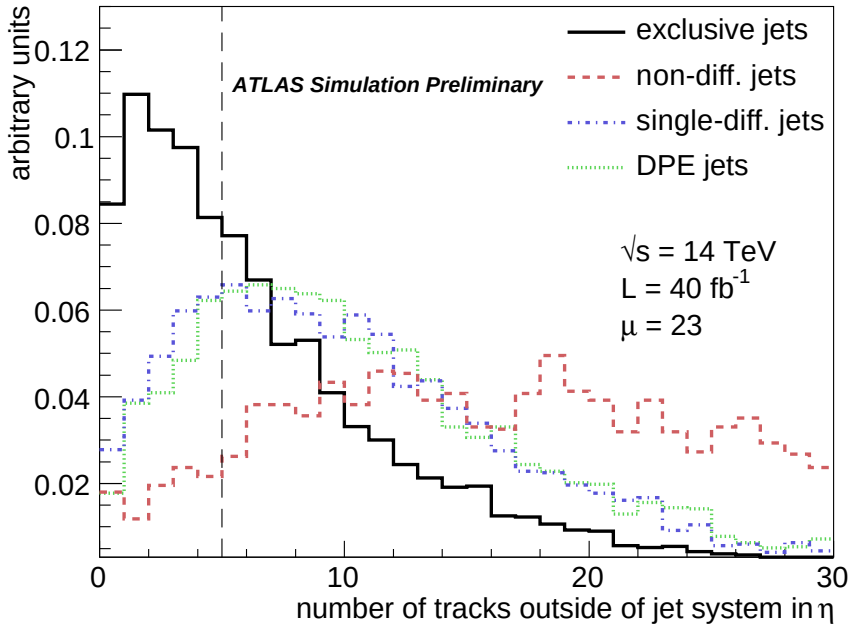


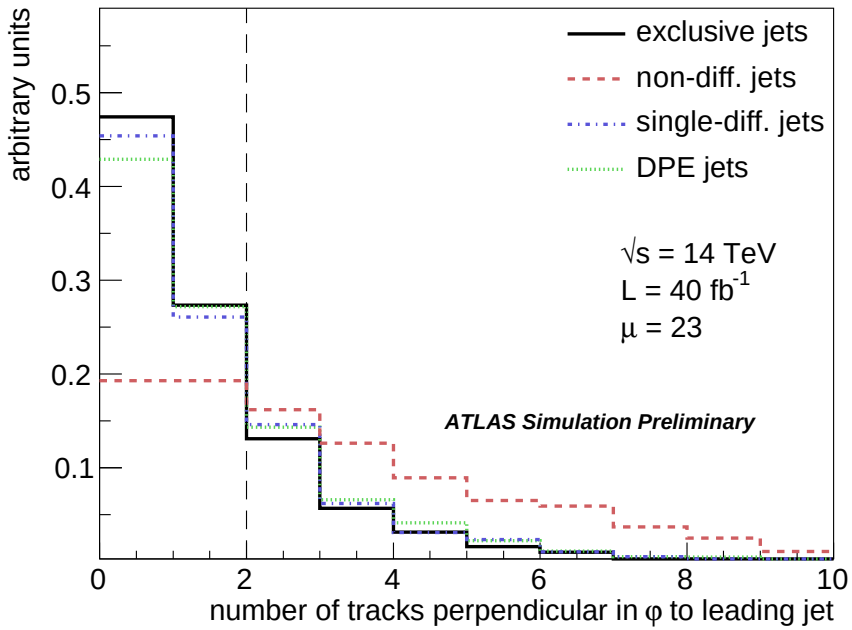
Left: Difference, $y_{jj} - y_X$, of the rapidity of the jet system (y_{jj}) and the rapidity of the proton system $y_X = 0.5 \cdot \ln\left(\frac{\xi_1}{\xi_2}\right)$, where ξ_1 and ξ_2 are relative energy losses of the tagged in the AFP C and A stations.
Right: The ratio of the jet system mass to the missing mass $M_X = \sqrt{s \cdot \xi_1 \cdot \xi_2}$.

Cuts – Tracks Outside Jets

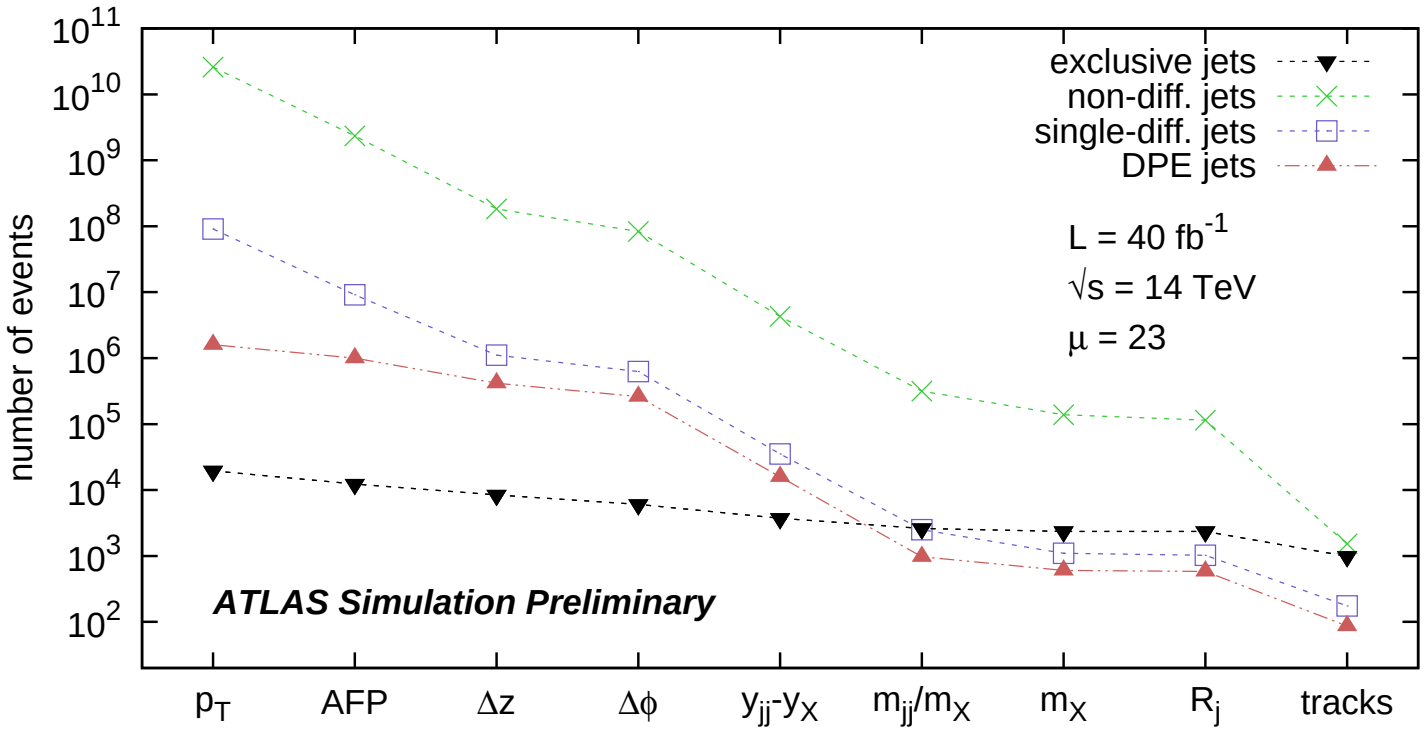


The number of tracks (fitted to the primary vertex) outside the jet system in η (region 1, top) and the number of tracks perpendicular to the leading jet in ϕ (region 2, bottom) for the signal and background events at pile-up $\mu = 23$.
The dashed line represents the value of the applied cut.



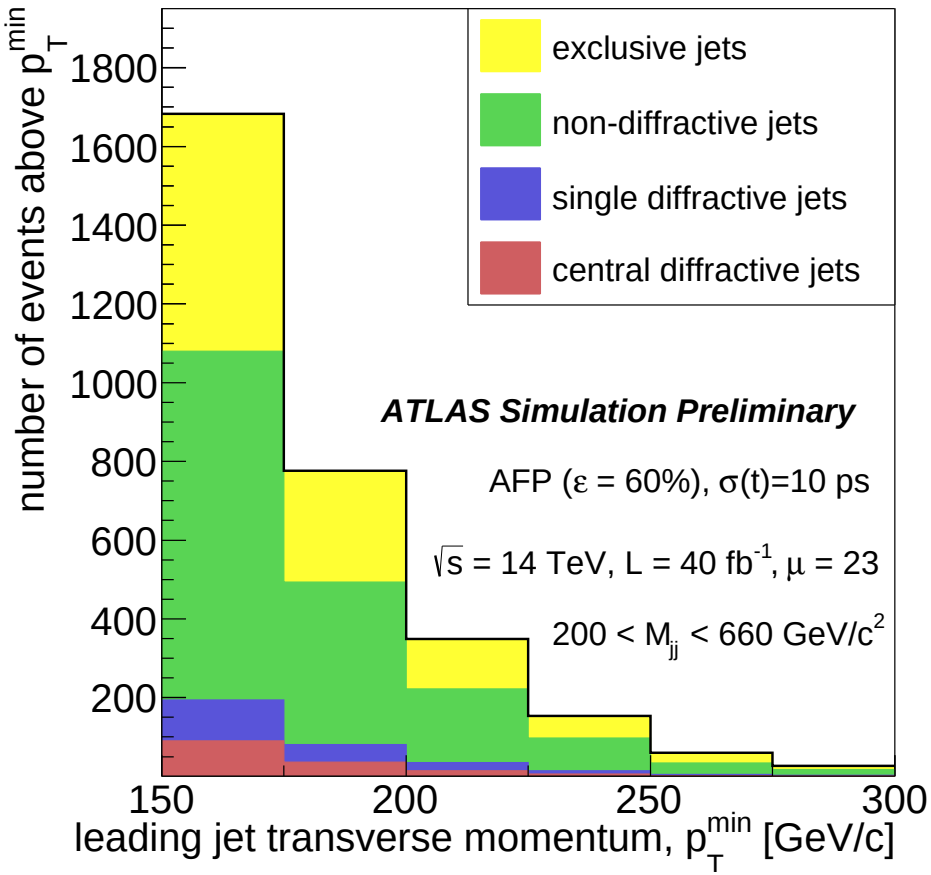


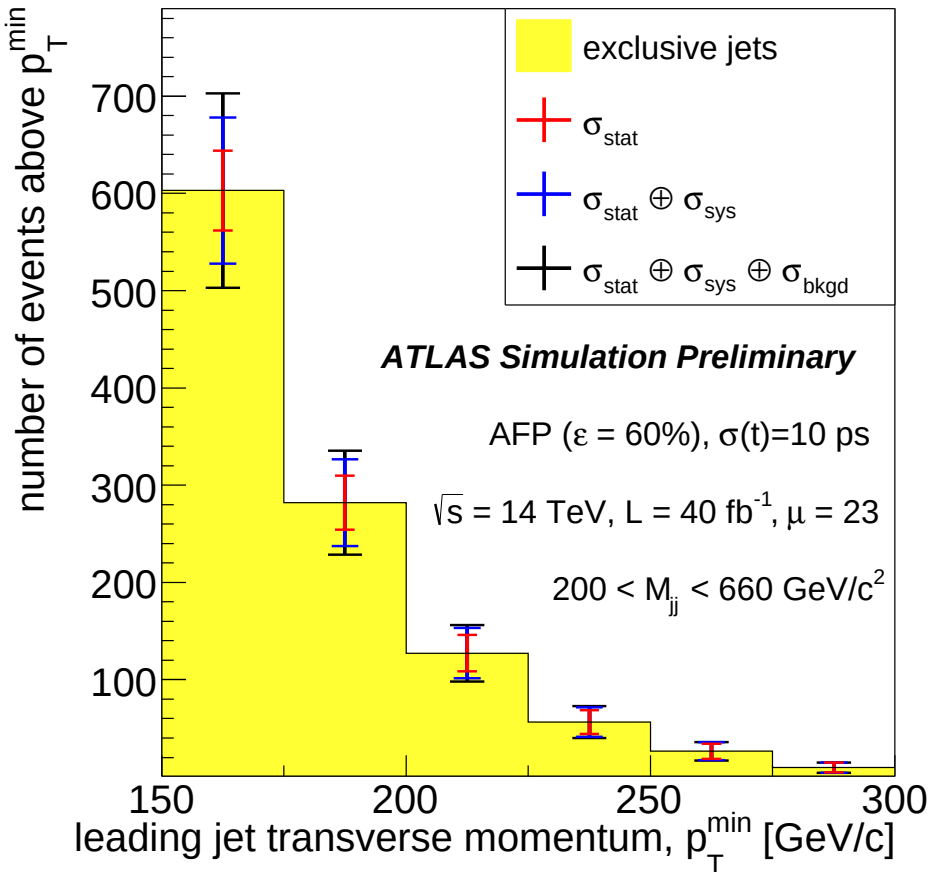
Discriminating Power



The number of events accepted after a particular cut for signal and background processes for the integrated luminosity of 40 fb^{-1} at pile-up $\mu = 23$ as a function of the applied consecutive cuts.

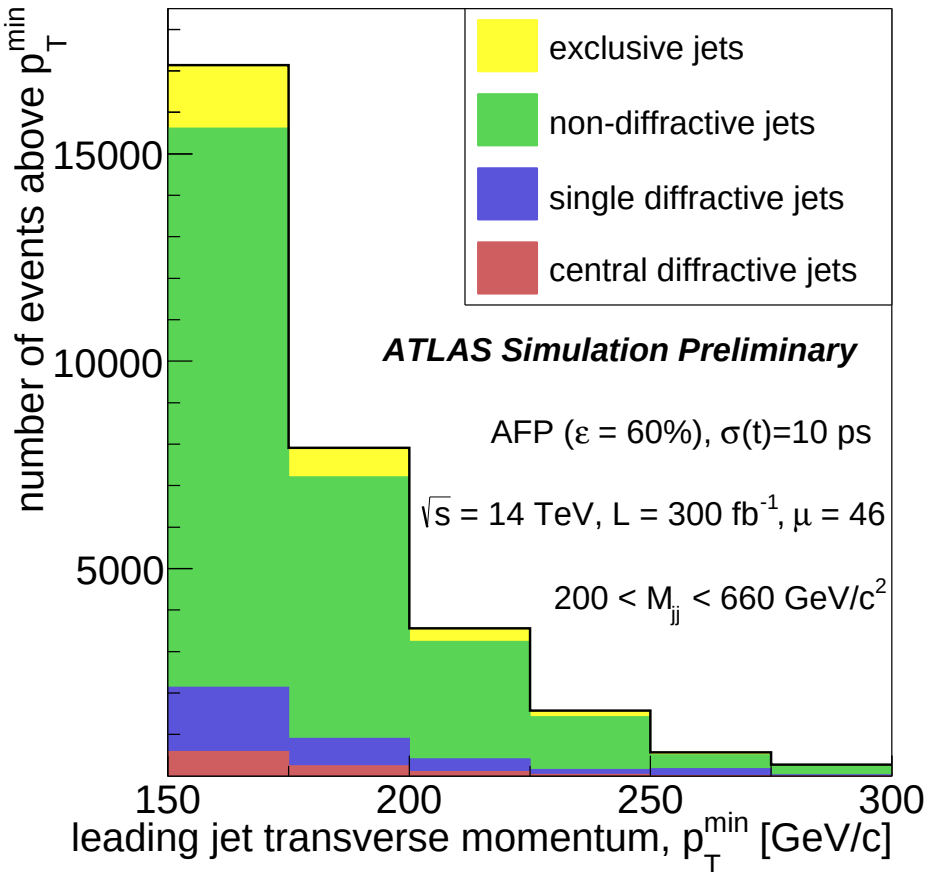
Number of Events ($\mu = 23$)

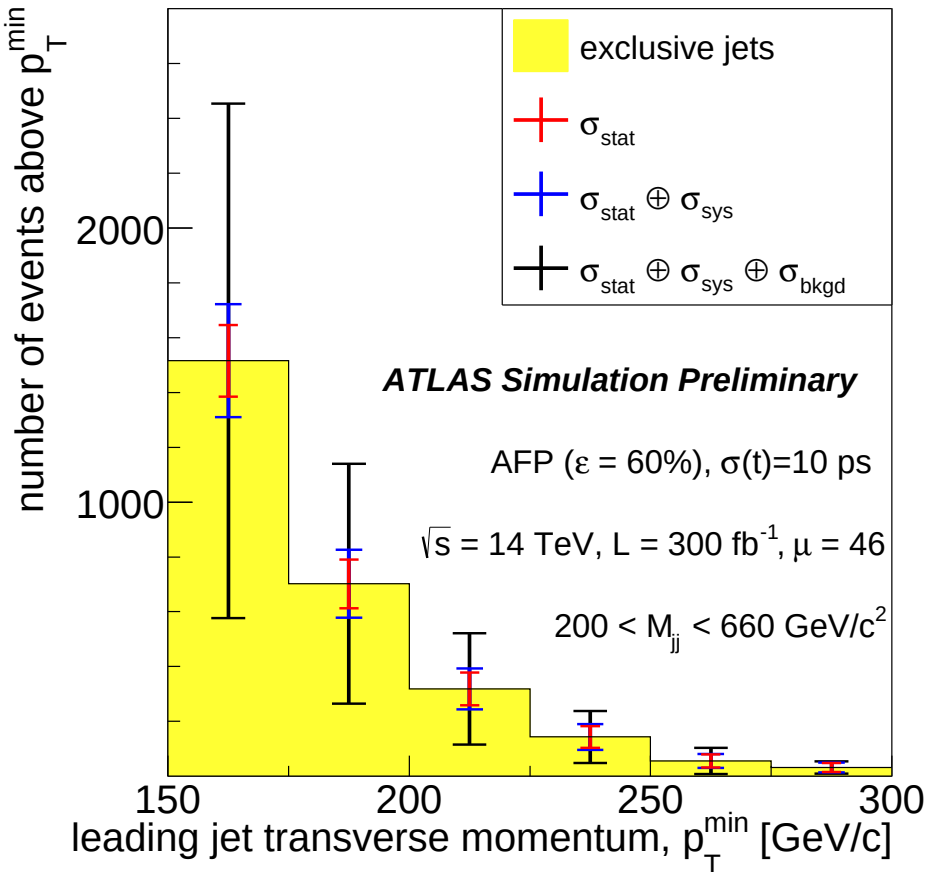




Left: The number of accepted events as a function of the leading jet pT threshold for the integrated luminosity L = 40 fb^{-1} and average number of interactions of $\mu = 23$. Right: the number of signal events, marked as yellow bar, with statistical ($\sigma stat$), systematic (σsys) and background ($\sigma bkgd$) uncertainties. The $\oplus$ sign means that given errors are added in quadrature.

Number of Events ($\mu = 46$)



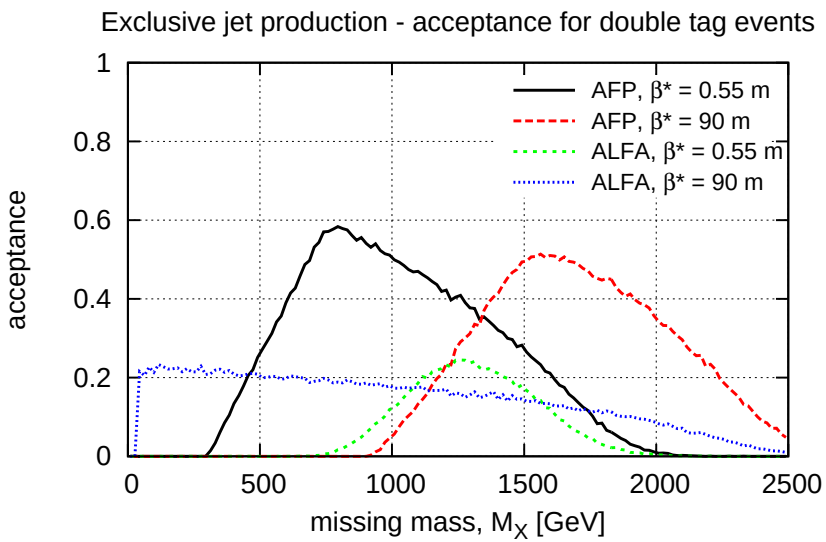


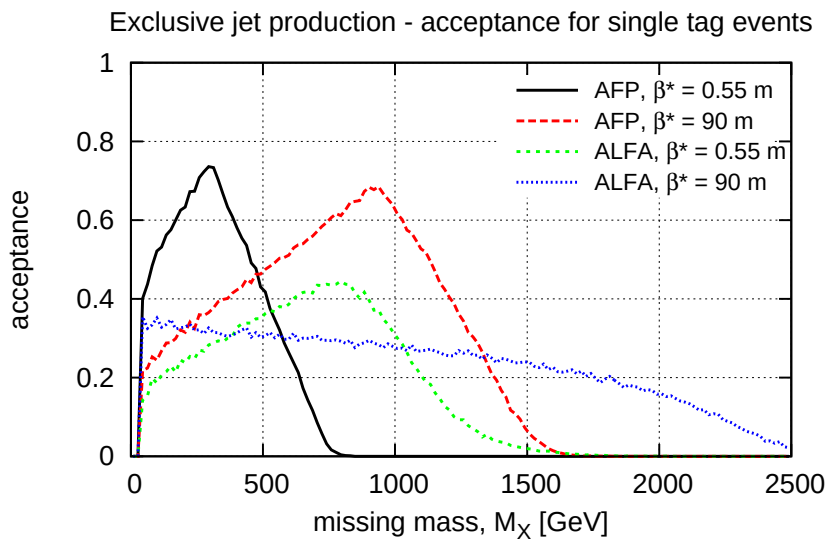
Left: The number of accepted events as a function of the leading jet pT threshold for the integrated luminosity L = 300 fb^{-1} and average number of interactions of $\mu = 46$. Right: the number of signal events, marked as yellow bar, with statistical ($\sigma stat$), systematic (σsys) and background ($\sigma bkgd$) uncertainties. The $\oplus$ sign means that given errors are added in quadrature.

Single Tagged Events

On the Possibility of Measuring the Single-tagged Exclusive Jets at the LHC
Eur. Phys. J. C **75** (2015) 320, arXiv:1503.00699

Motivation


Exclusive jet production - acceptance for double tag events
acceptance
missing mass, M_X [GeV]
AFP, β* = 0.55 m
AFP, β* = 90 m
ALFA, β* = 0.55 m
ALFA, β* = 90 m


Exclusive jet production - acceptance for single tag events
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AFP, β* = 0.55 m
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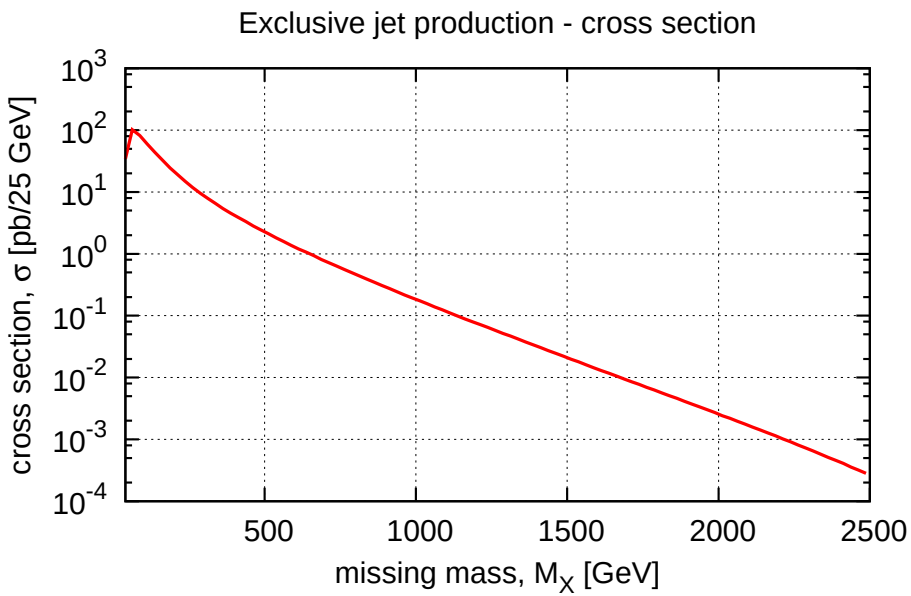
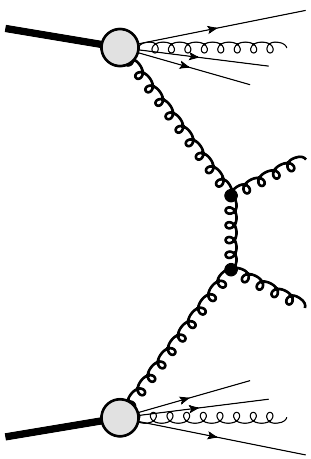
ALFA, β* = 90 m


Exclusive jet production - cross section
cross section, σ [pb/25 GeV]
missing mass, M_X [GeV]

Non-diffractive Backgrounds

Non-diffractive jets
+ pile-up

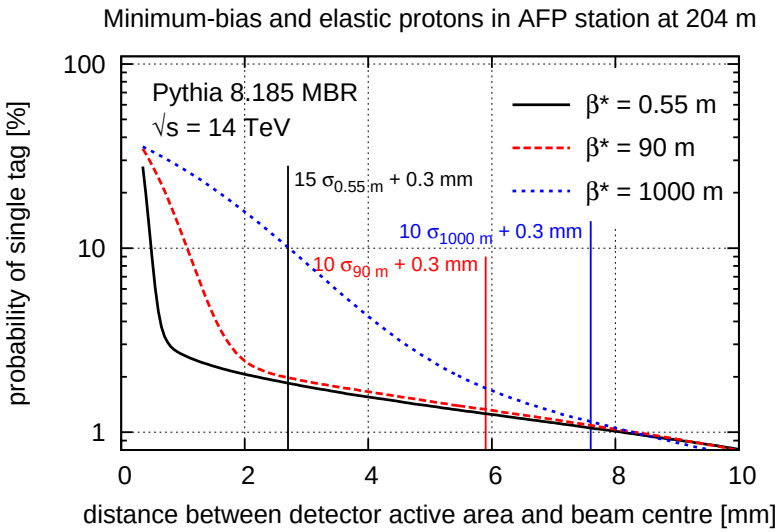


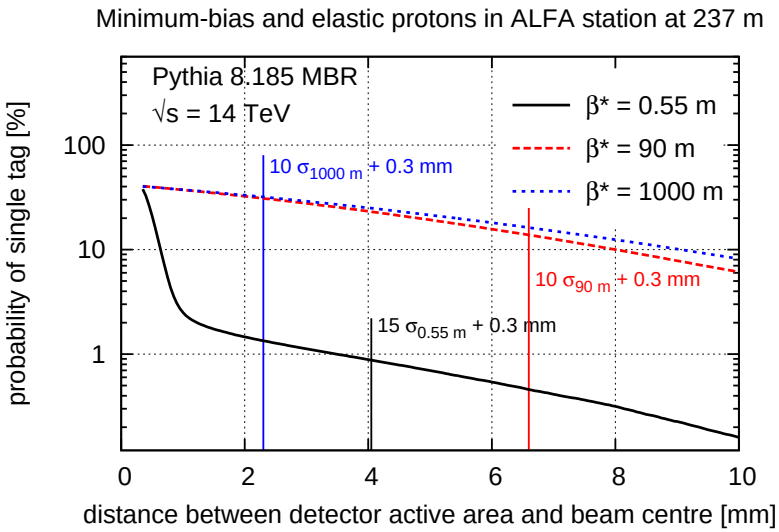
Non−difftactive Production

Cuts:

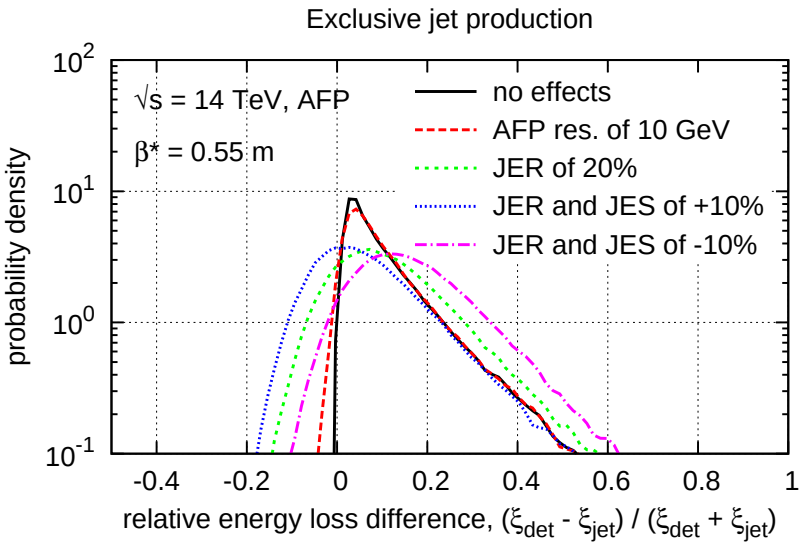
- proton in AFP/ALFA,
- one reconstructed vertex.

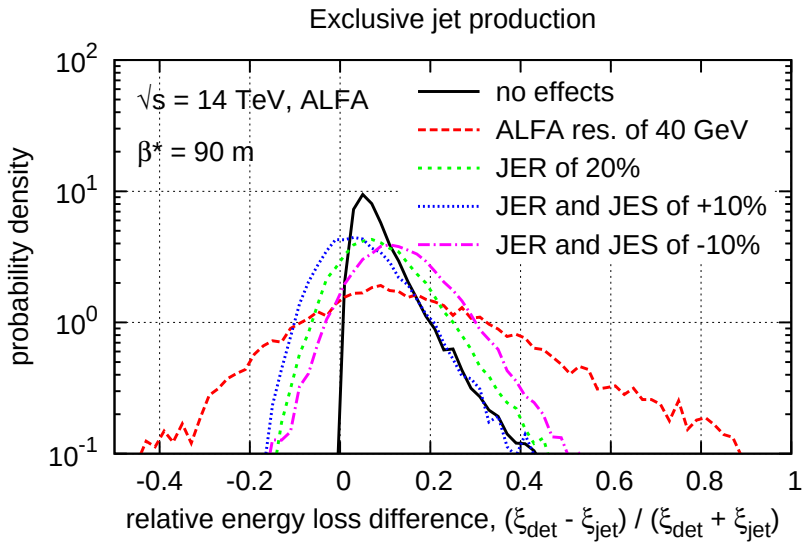
Soft single tag probability

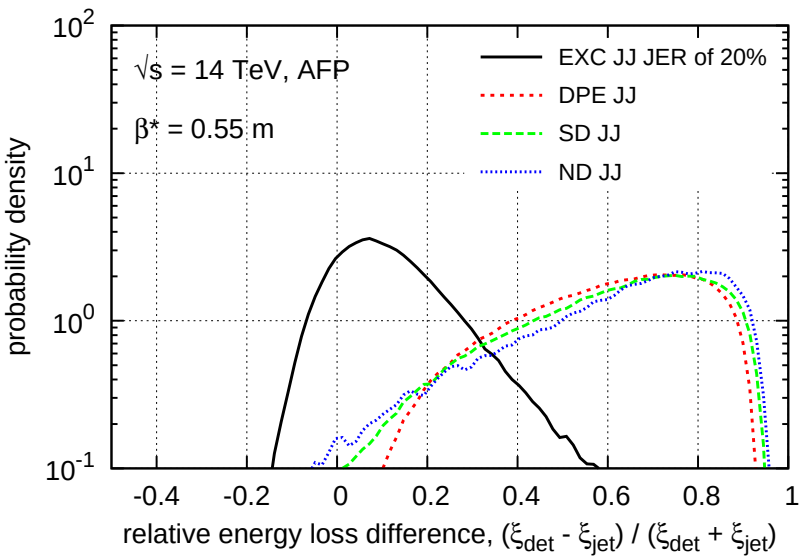


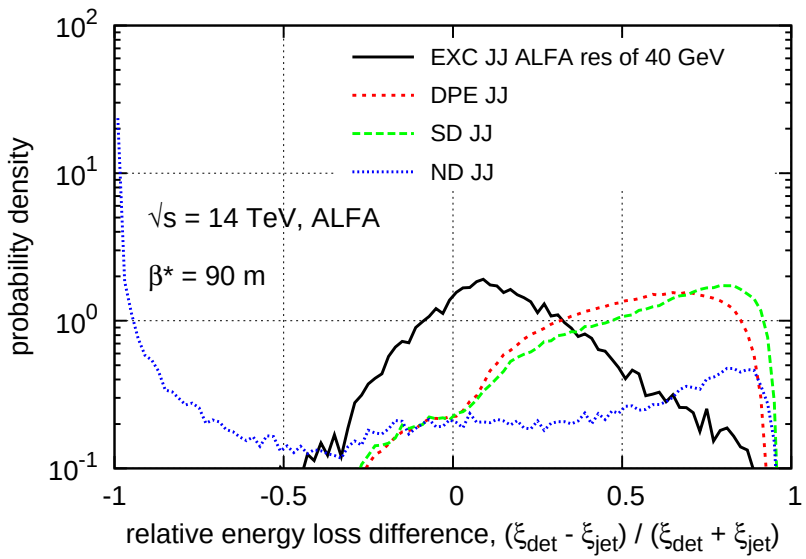


Relative Energy Loss Difference



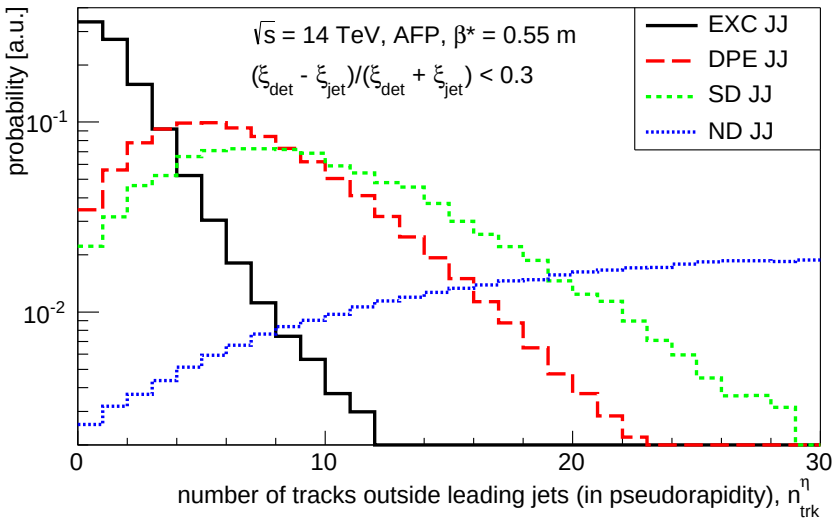


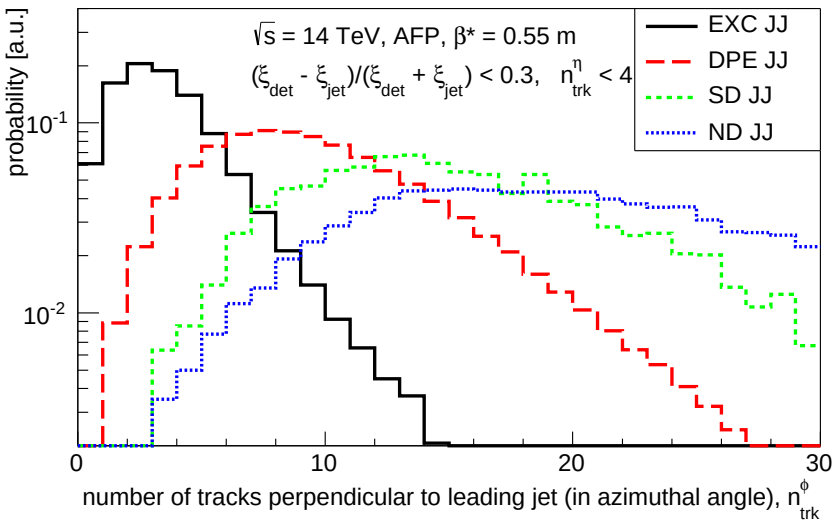


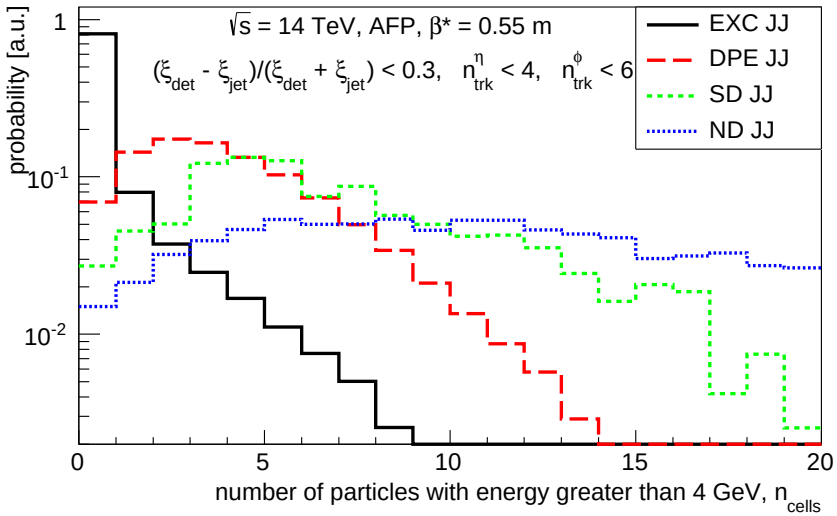


$$\xi^{jet} = \exp(\pm y_{jj}) \frac{M_{jj}}{\sqrt{s}}$$

Veto on Additional Activity

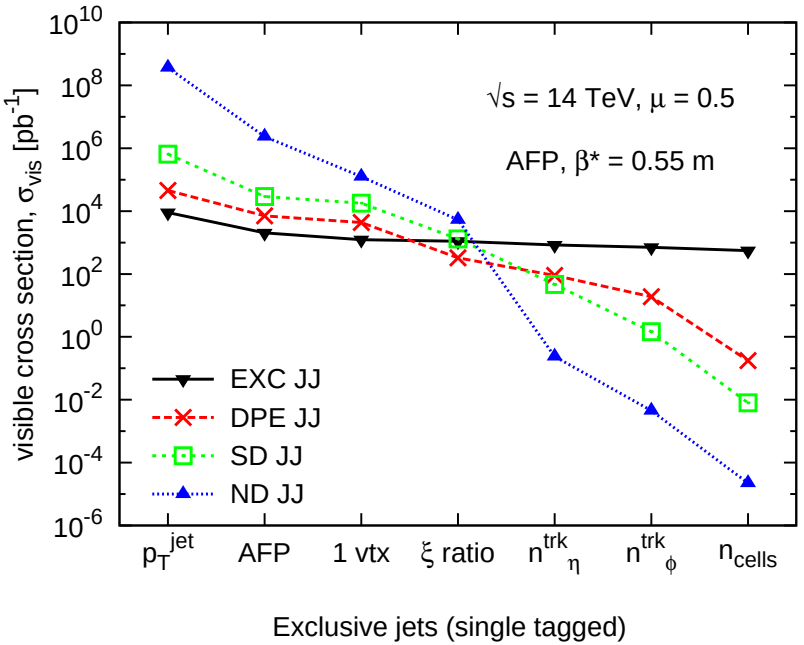


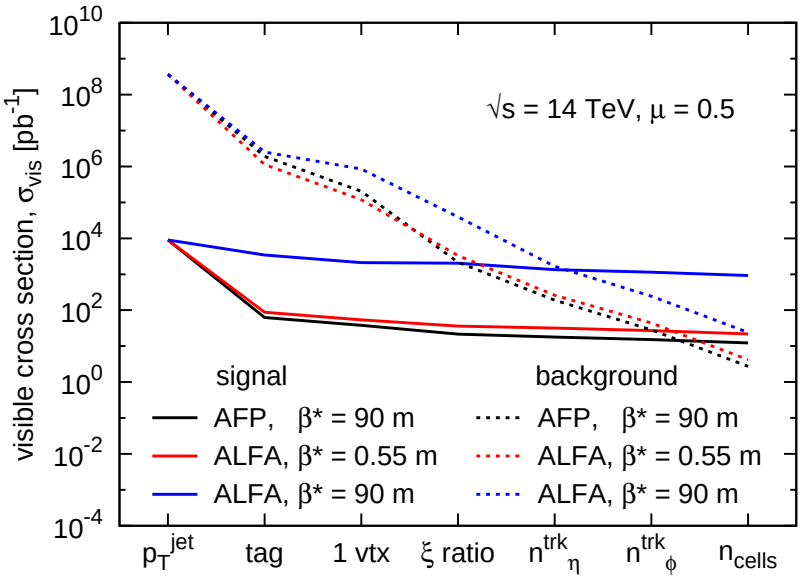


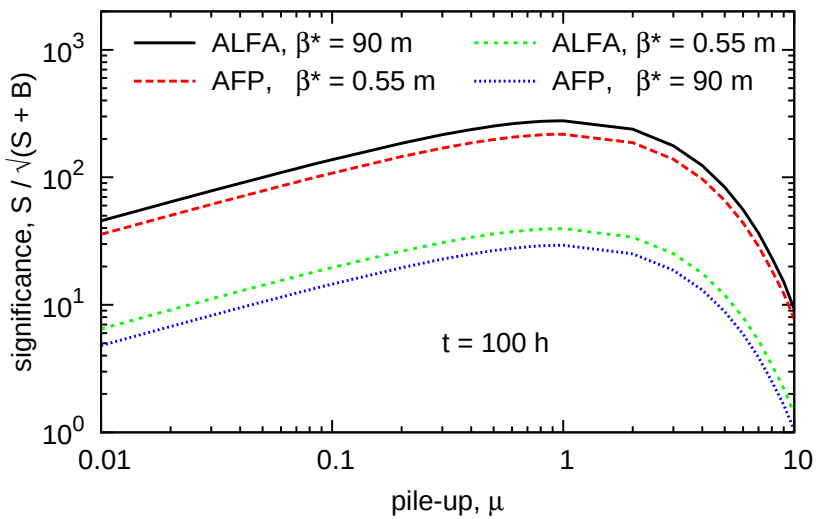


- number of tracks outside jet system (in η): $n_{trk} < 4$,
- number of tracks perpendicular to the leading jet (in ϕ): $n_{phi} < 6$,
- number of particles with energy greater than 4 GeV, $n_{cells} < 2$.

Veto on Additional Activity







- Top: cutflow.
- Bottom: statistical significance $(\frac{S}{\sqrt{S+B}})$ for 100 hours.

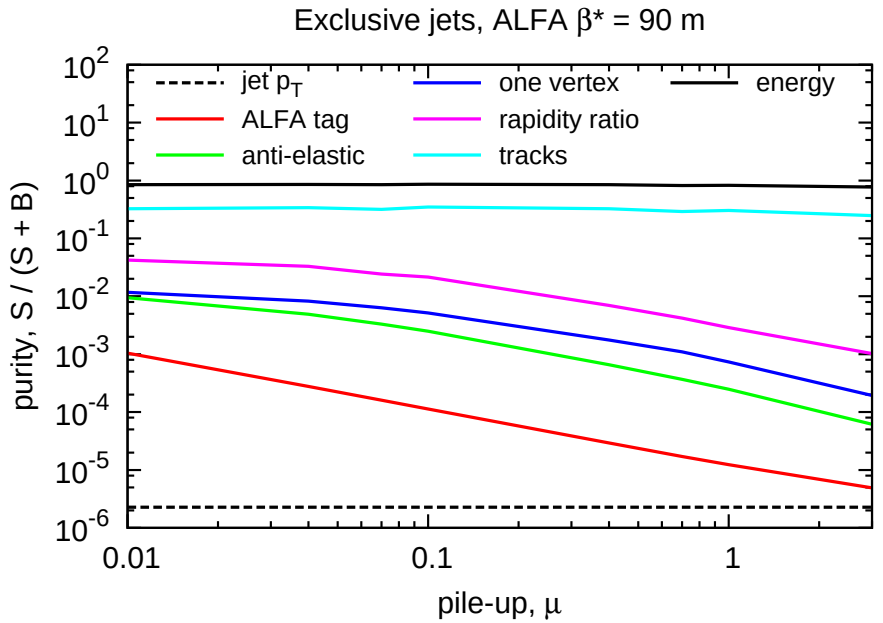
Double Tagged Events

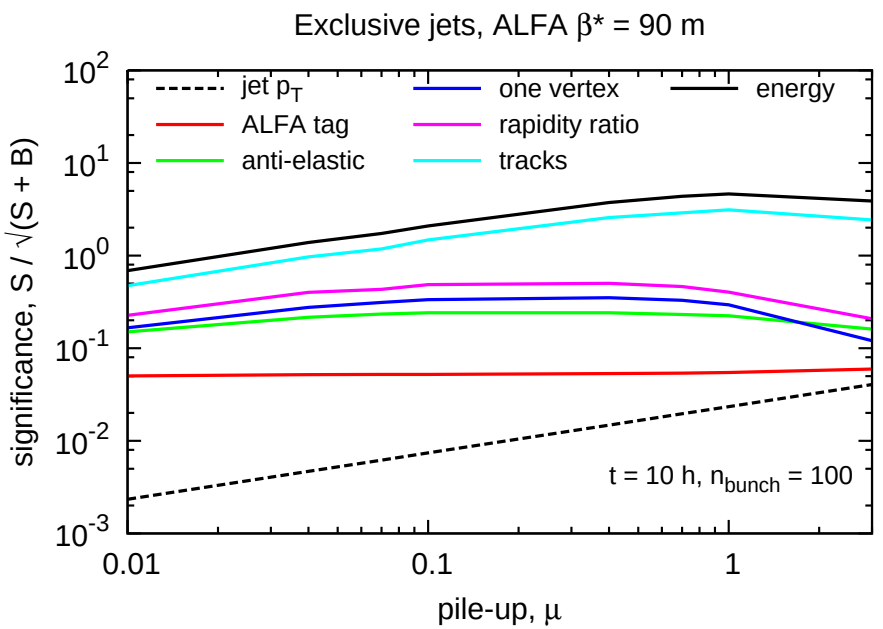
Exclusive Jet Measurement in Special LHC Runs – Feasibility Studies
Acta Phys. Pol. B **47** (2016) 1745, arXiv:1604.03855

Results

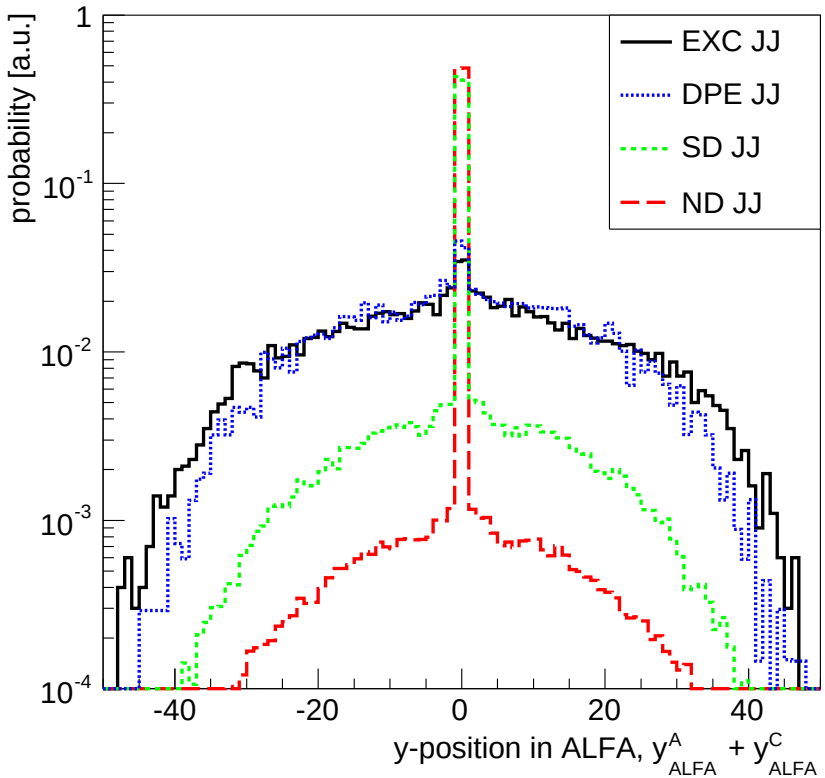
- low-p_T jets,
- double tag in ALFA,
- anti-elastic cut,
- one reconstructed vertex,
- proton-jet correlation: relative energy loss,
- number of tracks outside the jet system,
- amount of energy in forward calorimeters.

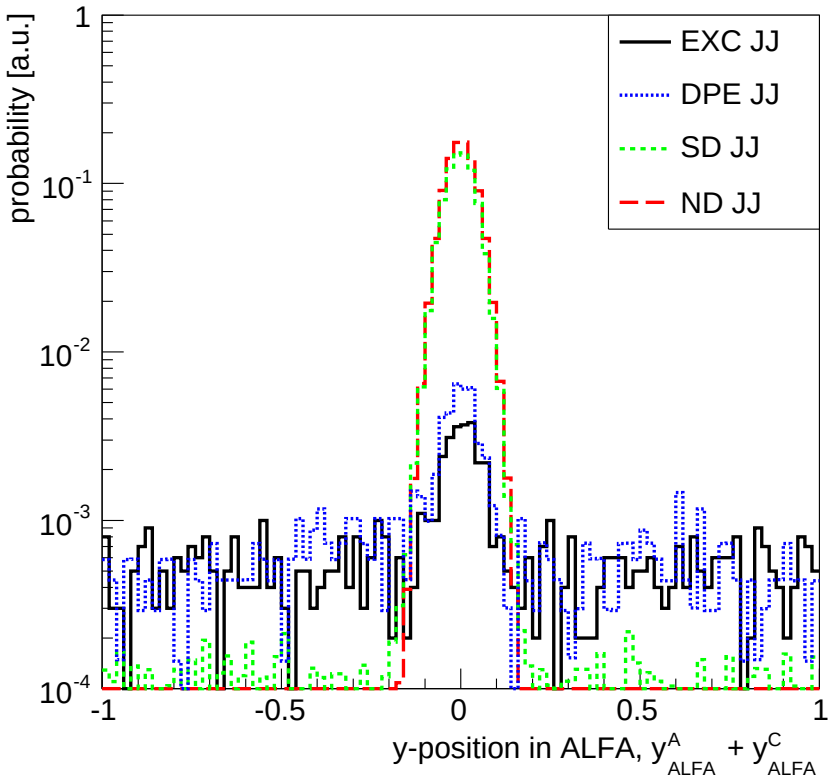
Pure ($> 90\%$) and statistically significant measurement should be feasible with data collected by ALFA during Run II.





Anti-elastic Cut





Summary

High-p_T jets (double tag)

- Measurement of the exclusive jet production will be possible in the ATLAS detector during normal runs (low beta, high pile-up) using the AFP detectors.
- Very challenging measurement – difference of six orders of magnitude between signal and background cross-sections (impossible to measure without AFP)!
- Results published in: ATL-PHY-PUB-2015-003

Low-p_T jets (single tag)

- Smaller masses $\rightarrow$ larger cross-sections $\rightarrow$ smaller pile-up $\rightarrow$ cleaner events.
- High signal-to-background ratio.
- High statistical significance.
- Results published in: Eur. Phys. J. C **75** (2015) 320.

Low-p_T jets (double tag)

- Pure ($> 90\%$) and statistically significant measurement should be feasible with data collected by ALFA during Run II.
- Results published in: Acta Phys. Pol. B **47** (2016) 1745.

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