Hard Diffractive and Exclusive Events with Forward Proton Tag – Feasibility Studies

Maciej Trzebiński

Institute of Nuclear Physics
Polish Academy of Sciences

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joint with
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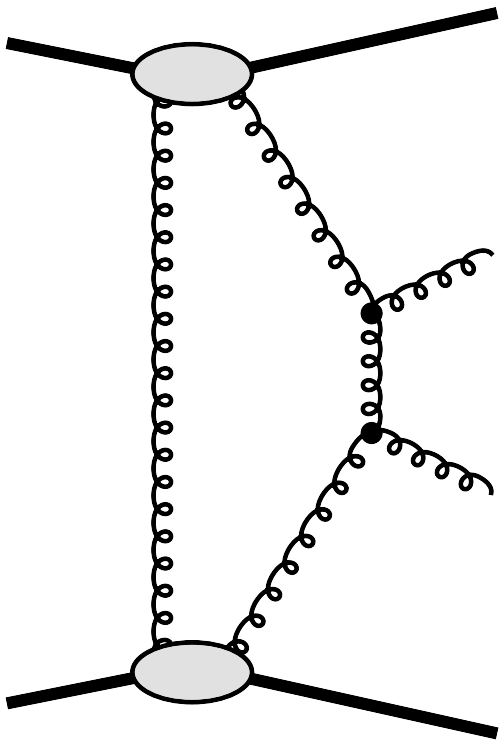
Exclusive Jet Production

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

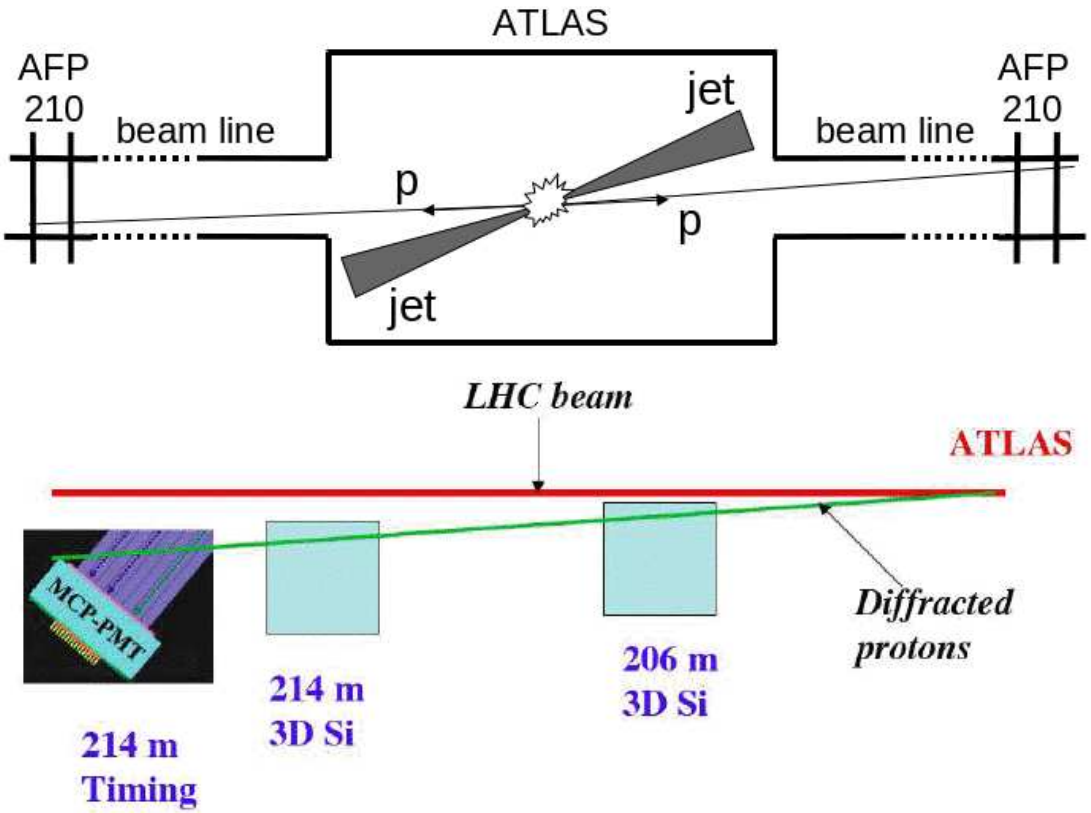


Exclusive Production

- Theoretical description – KMR model.
- No Pomeron remnants.
- Measurement constrain theoretical models.
- Limits on exclusive Higgs production.

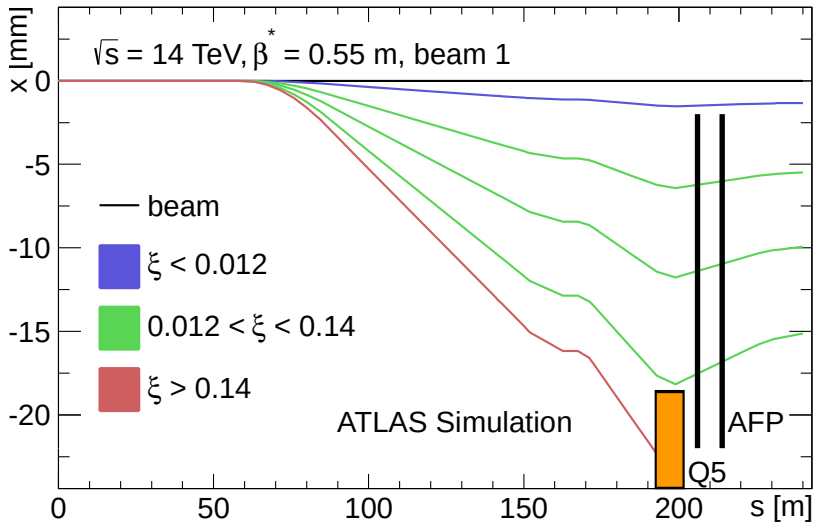
AFP Detector

- Detector located close to the beam (Roman Pots/Movable Beam Pipe).
- Protons must leave beam envelope.



- Proton position measurement (3-D Pixel detectors).
- Precise time of flight measurement (QUARTIC timing detector).

AFP Acceptance



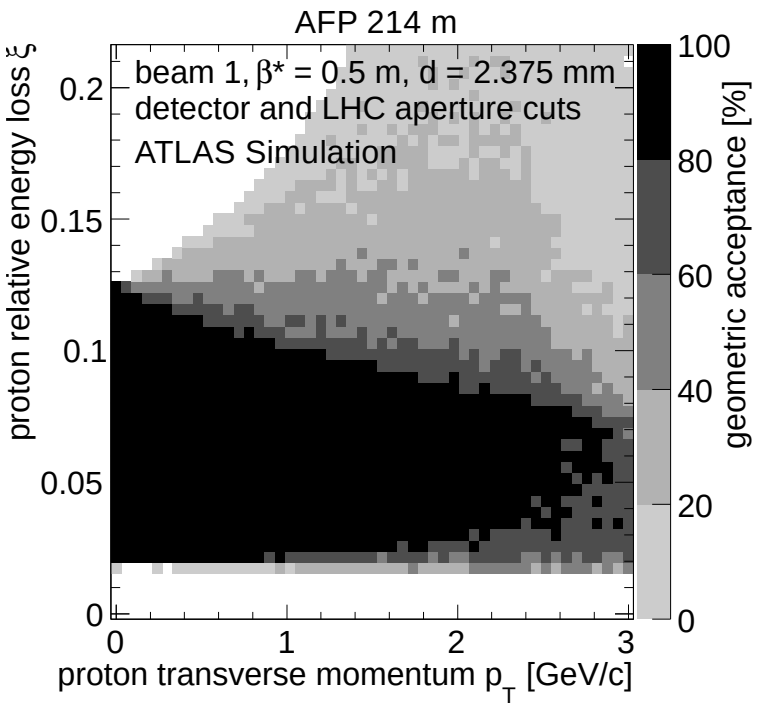
$$M_X = \sqrt{s \cdot \xi_1 \cdot \xi_2}$$

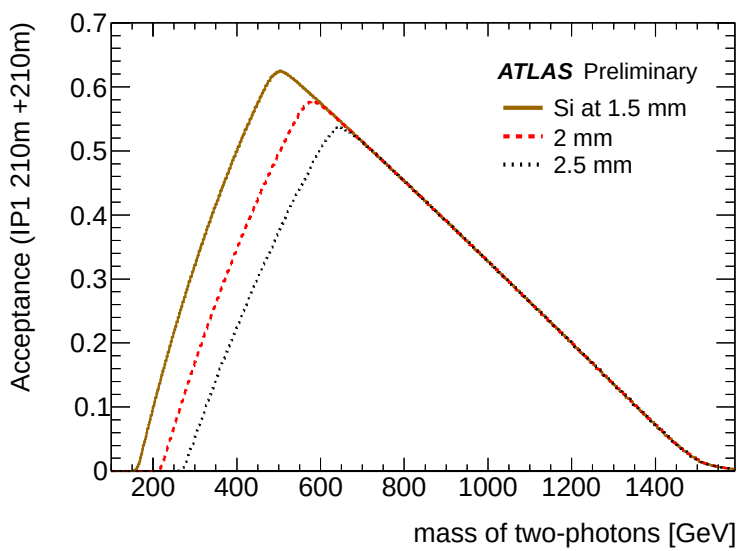
$\xi_1,\ \xi_2$ – proton relative energy loss

$$\xi = (E_{beam} - E_{proton})/E_{beam}$$

$$200\,GeV < M_X < 2000\,GeV$$

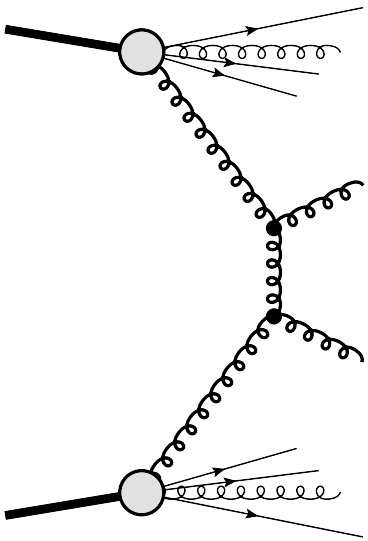
AFP acceptance could probably be improved (lower mass measurement) during special runs assuming different low-β^* optic (additional studies of LHC beam division).



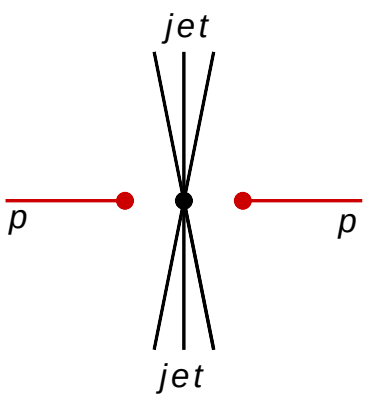


Background

Non-diffractive jets + pile-up.

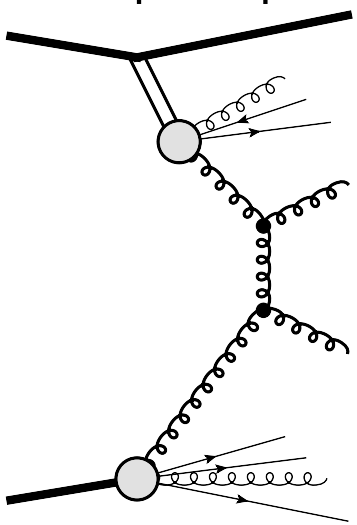


Non−difftactive Production

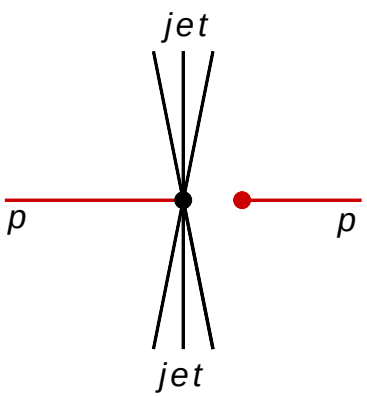


$\sigma_{ND}/\sigma_{EXC} \sim 10^6$

Single-diffractive jets + pile-up.

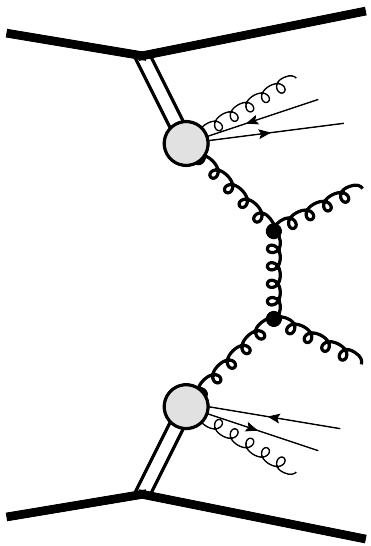


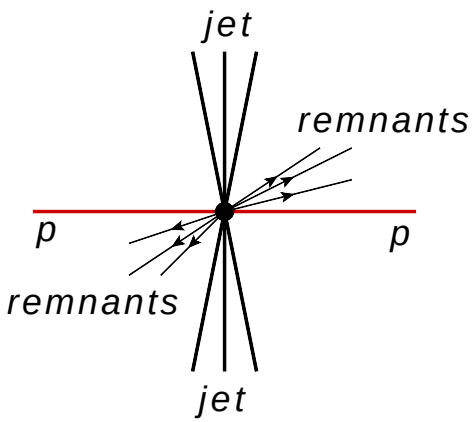
Single Diffractive Production



$\sigma_{SD}/\sigma_{EXC} \sim 10^4$

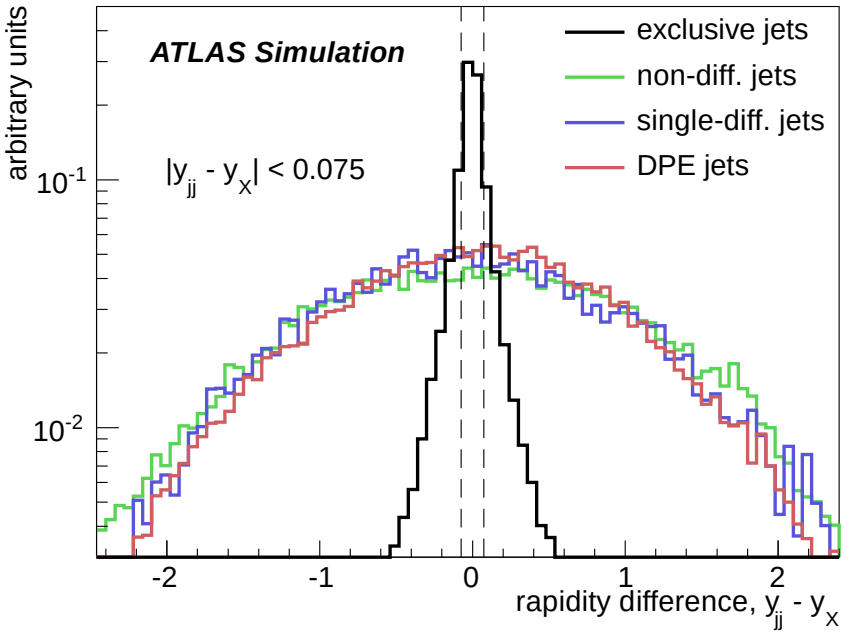
DPE jets.

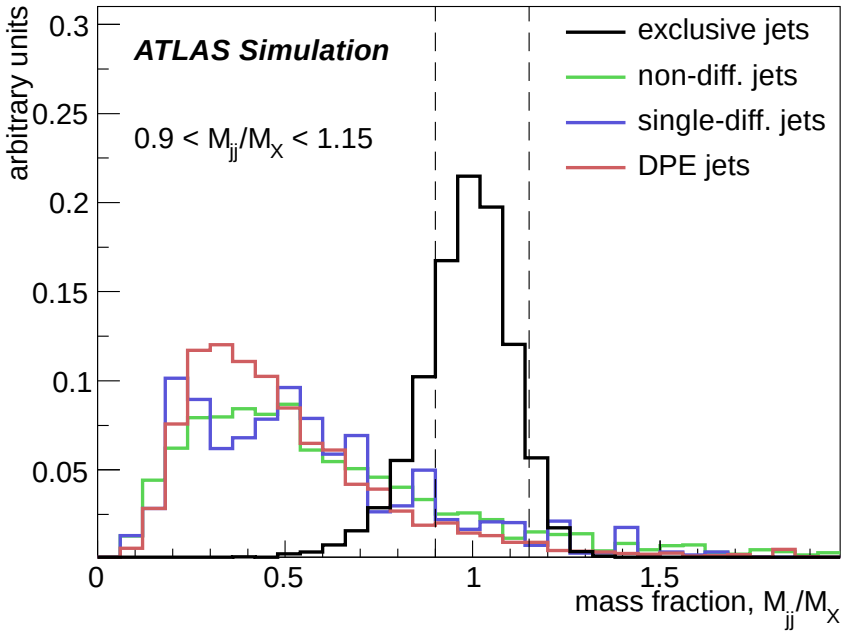




$\sigma_{DPE}/\sigma_{EXC} \sim 10^2$

Cuts: Rapidity Difference and Mass Fraction





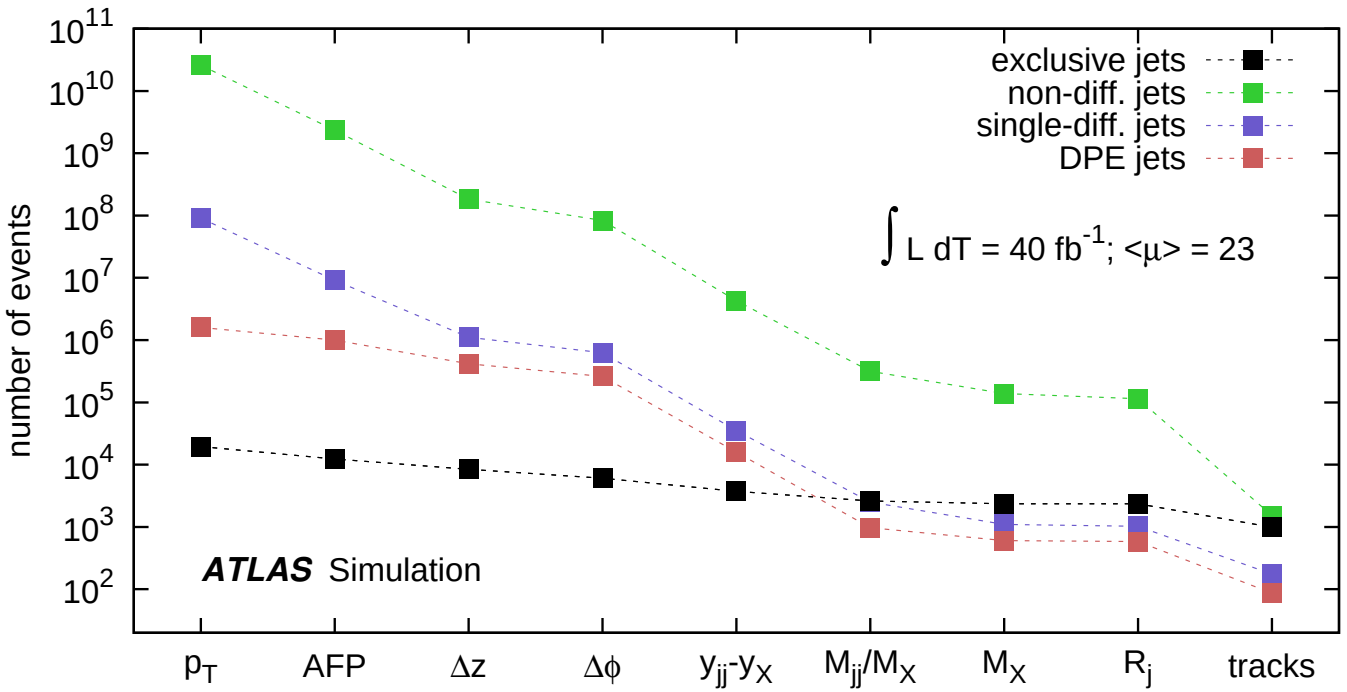
Difference, $y_{jj} - y_X$, of the rapidity of the jet system (y_{jj}) and the rapidity of the proton system $y_X = 0.5 \cdot \ln\left(\frac{\xi_1}{\xi_2}\right)$

Ratio of the jet system mass to the missing mass $M_X = \sqrt{s \cdot \xi_1 \cdot \xi_2}$

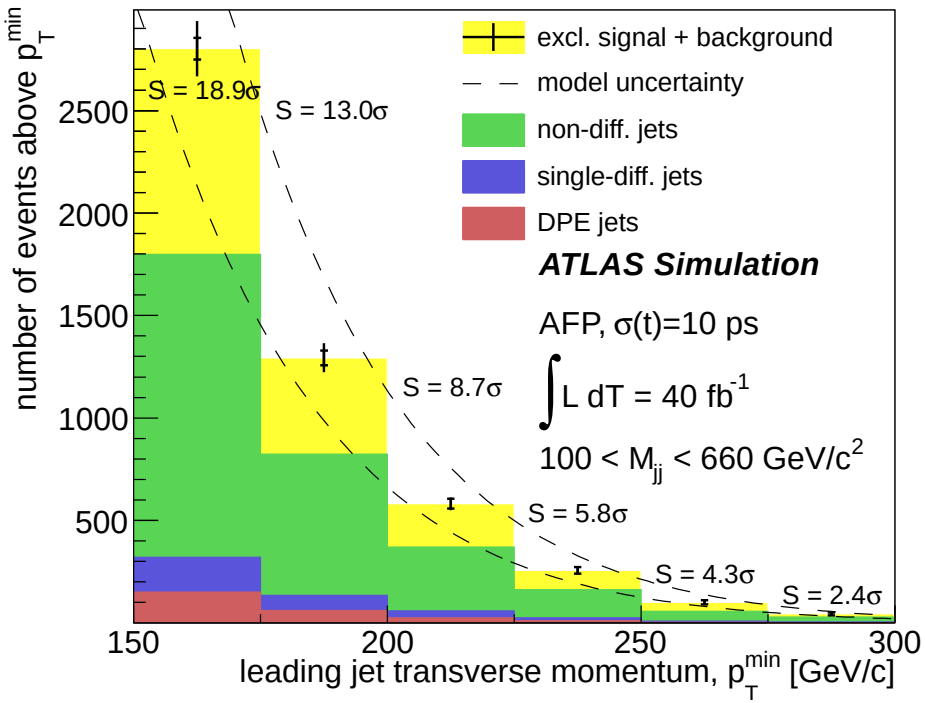
Discriminating Power

Event selection:

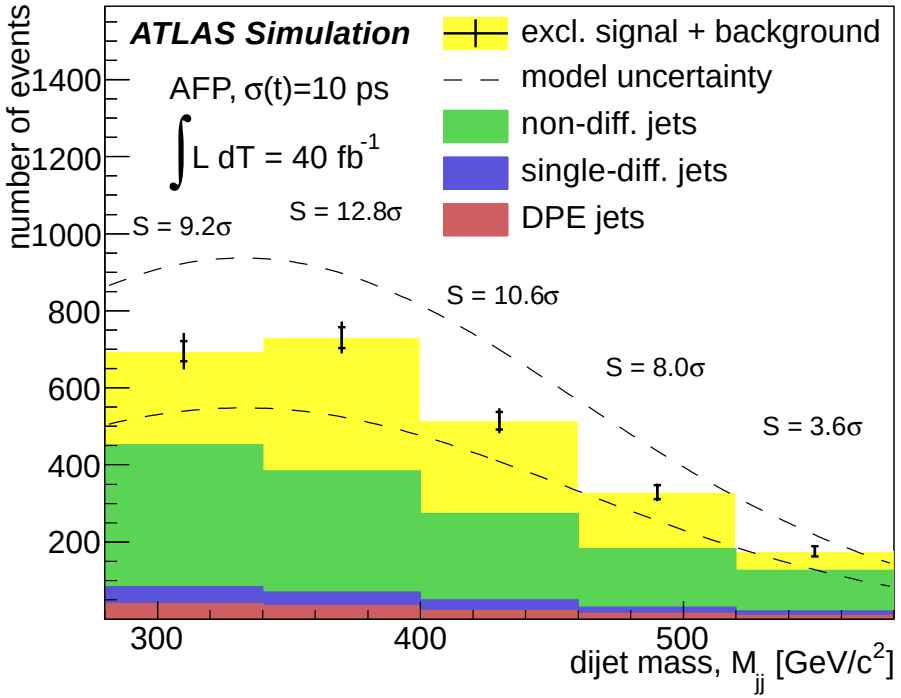
- At least one proton tagged in each AFP station.
- Rapidity Difference $|y_{jj} - y_X| < 0.075$ and Mass Fraction $0.9 < M_{jj}/M_X < 1.15$.
- Number of tracks outside the jet system < 4.
- Angle between two leading jets $2.9 < \Delta\phi < 3.3$.
- Missing mass $M_x < 550$ GeV$/c^2$.
- The distance between hard vertex reconstructed by ATLAS and from the AFP time measurement $|\Delta z| < 3.5$ mm.



Number of Events ($< \mu >= 23$)



leading jet transverse momentum distribution above a given threshold



mass of the jet system distribution

- Double tag requirement $\rightarrow$ central mass $>$ 300 GeV $\rightarrow$ leading jet $p_T >$ 150 GeV $\rightarrow$ relatively small cross section $\rightarrow$ inverse femtobarns of data needed $\rightarrow$ high pileup environment is a must
- Very challenging measurement.
- Impossible without forward proton detectors.
- Improvement of uncertainties coming from the Tevatron CDF measurements by about one order of magnitude.

Exclusive Jets with One Tag

- one tag $\rightarrow$ leading jet $p_T > 20$ GeV $\rightarrow$ higher cross sections
- medium luminosity runs ($\mu \sim 1$)

Probability of Single Tag

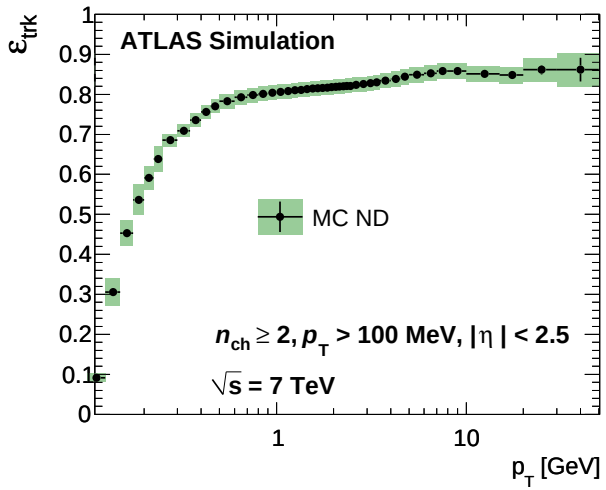
Single Tag (ST) Interactions					
probability					
default	0.18	0.045	–	0.0055	0.038
MBR	0.12	0.040	0.42	0.0054	0.030
cross section [mb]					
default	2.3	0.40	–	0.32	3.0
MBR	1.3	0.38	0.34	0.30	2.3
	SD	DD	CD	ND	MB

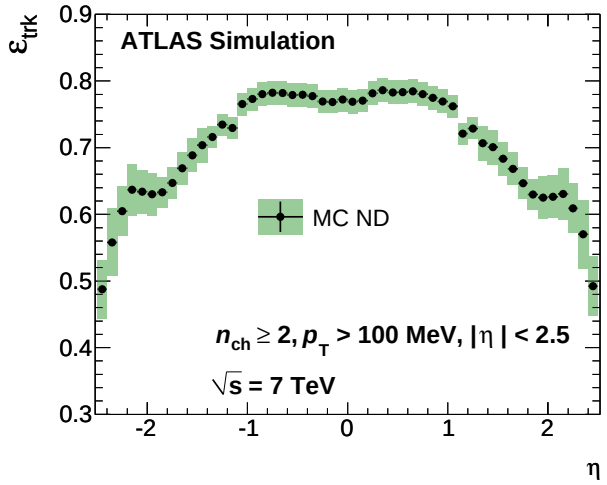
default – Schuler and Sjöstrand (PomFlux = 1)

MBR (PomFlux = 5)

One Vertex Requirement

- ATLAS track reconstruction efficiency:



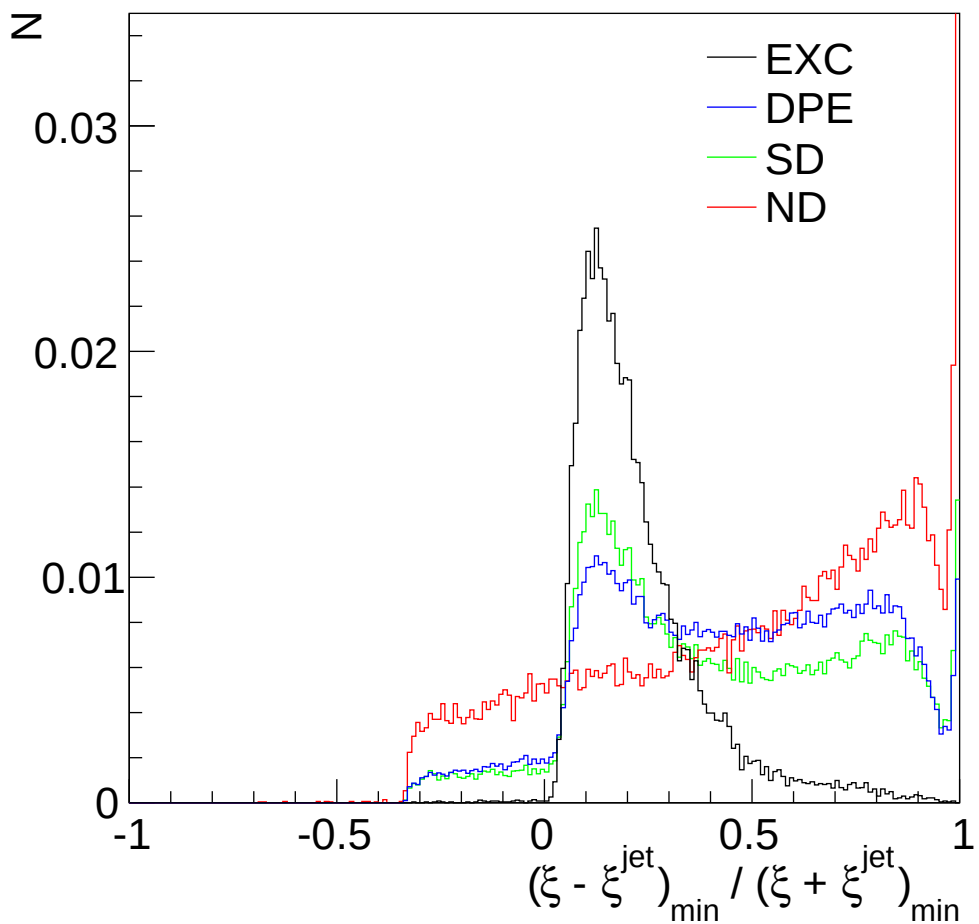


- **table**: prob. of the vertex reco. for a given number of tracks,
- last column contains a weighted sum of all listed processes,
- weight considers cross sections and probabilities of having a proton with $0.015 < \xi < 0.15$

Min. number of tracks	Probability SD	DD	ND	min-bias
2	0.917	0.546	0.987	0.870
3	0.909	0.498	0.967	0.855
4	0.894	0.450	0.932	0.833
5	0.870	0.404	0.881	0.803

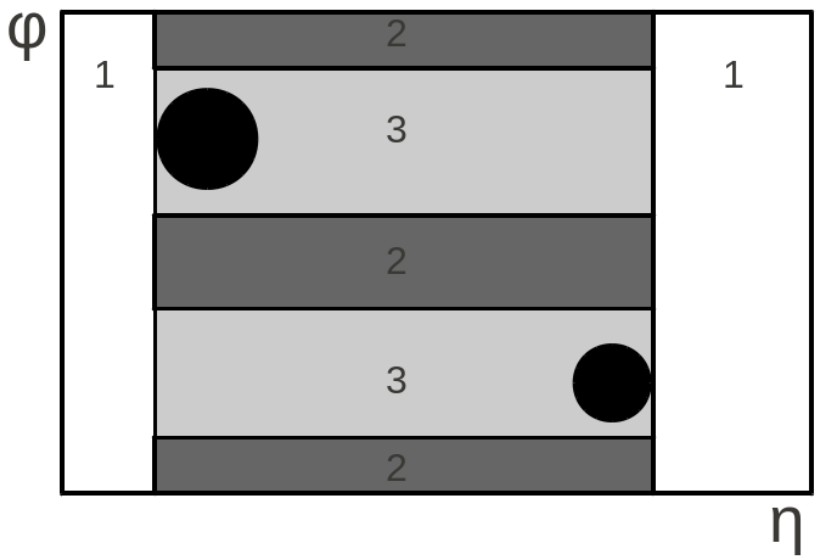
Cuts: Rapidity Difference

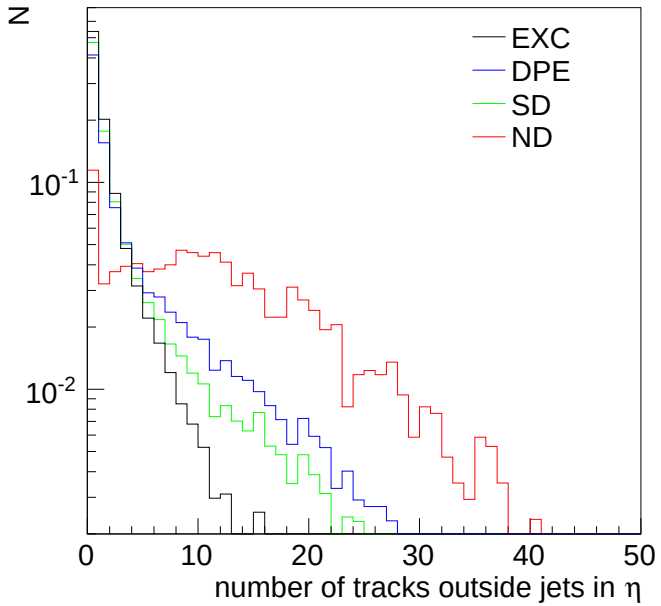
$$\xi_1^{jet} = exp(-y_{JJ}) \cdot \sqrt{\frac{M_{JJ}^2}{s}}, \quad \xi_2^{jet} = exp(y_{JJ}) \cdot \sqrt{\frac{M_{JJ}^2}{s}}$$

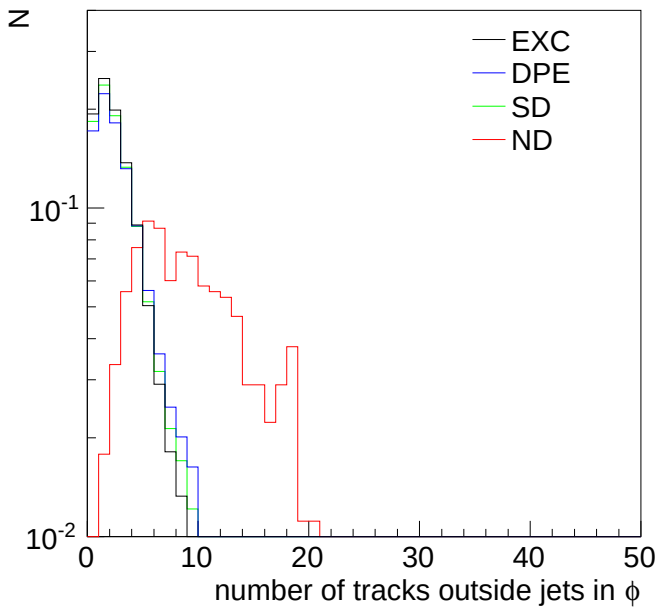


(Smallest) difference between forward proton(s) and jet system rapidity.

Cuts: Tracks Outside Jets





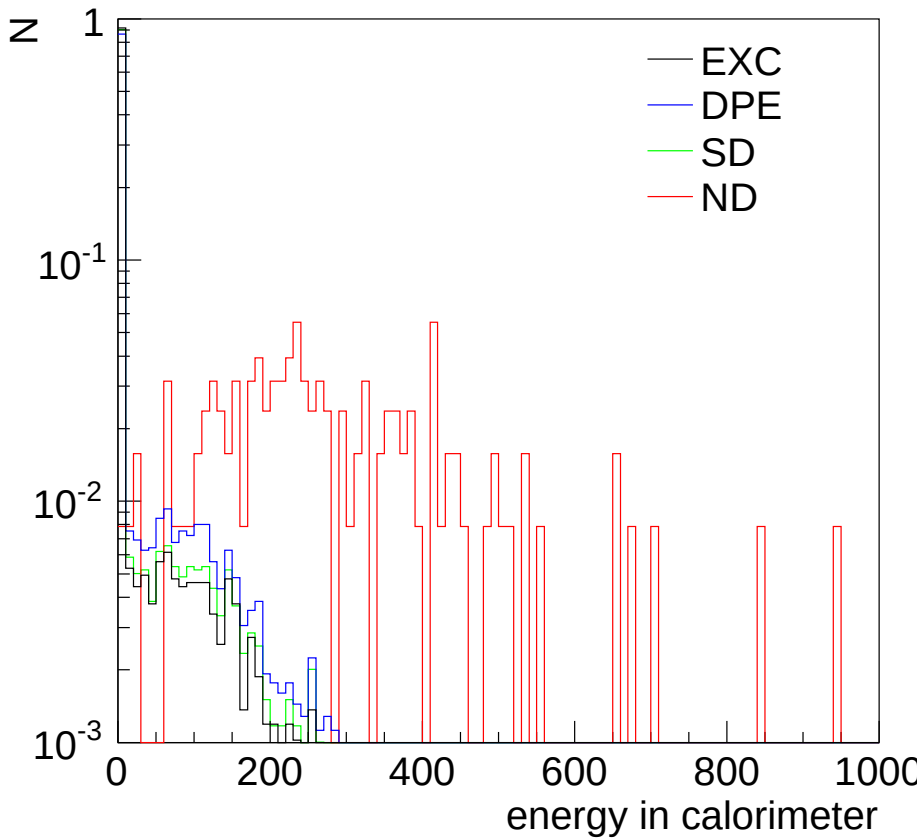


Number of tracks outside the jet system in η (region 1, top) and the number of tracks perpendicular to the leading jet in ϕ (region 2, bottom).

Cuts: Forward Energy

Energy of particles produced at:

- $3 < \eta < 4.9$,
- $\eta_{JJ}/\eta_{particle} < 0$.



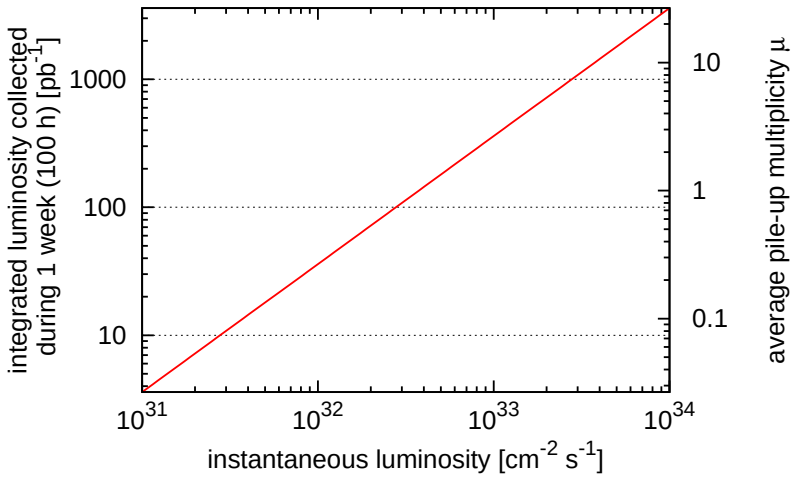
Cuts – Summary

$\mu = 0.5$

cut	σ_{EF} [pb] ND	SD	DPE	EXC
$p_T > 20$ GeV	$5.7 \cdot 10^8$	$1.0 \cdot 10^6$	$5.2 \cdot 10^4$	1800
vtx & ST	$2.4 \cdot 10^6$	$7.4 \cdot 10^5$	$3.9 \cdot 10^4$	1350
ξ correlation	$1.1 \cdot 10^5$	$2.9 \cdot 10^4$	$2.7 \cdot 10^3$	340
tracks	$8.6 \cdot 10^3$	$2.6 \cdot 10^3$	410	285
calo energy	860	1000	240	280

$S/B \sim 0.13$

$S/\sqrt{B}\ (100\ h) \sim 65$



$\mu = 1.0$

cut	σ_{EF} [pb] ND	SD	DPE	EXC
$p_T > 20$ GeV	$5.7 \cdot 10^8$	$1.0 \cdot 10^6$	$5.2 \cdot 10^4$	1800
vtx & ST	$4.7 \cdot 10^6$	$5.6 \cdot 10^5$	$2.9 \cdot 10^4$	1000
ξ correlation	$2.2 \cdot 10^5$	$2.2 \cdot 10^4$	$2.0 \cdot 10^3$	250
tracks	$1.6 \cdot 10^4$	$1.9 \cdot 10^3$	310	210
calo energy	1450	640	160	200

$S/B \sim 0.09$

$S/\sqrt{B}\ (100\ h) \sim 45$

Summary

- **Exclusive Jets with double tag:**
  - Double tag requirement $\rightarrow$ central mass > 300 GeV $\rightarrow$ leading jet $p_T > 150$ GeV $\rightarrow$ relatively small cross section $\rightarrow$ inverse femtobarns of data needed $\rightarrow$ high pileup environment is a must
  - Very challenging measurement.
  - Impossible without forward proton detectors.
  - Improvement of uncertainties coming from the Tevatron CDF measurements by about one order of magnitude.
- **Exclusive Jets with single tag:**
  - **Preliminary results.**
  - Measurement possible in medium luminosity runs.
  - Forward proton detectors $\rightarrow$ improvement wrt. standard methods (proton tag, correlation between rapiditiy of forward proton and jet system).
  - For 100 h at $\mu = 0.5$: $S/B \sim 0.13$, $S/\sqrt{B} \sim 65$.
    Main background: Single Diffractive jets.
  - For 100 h at $\mu = 1.0$: $S/B \sim 0.09$, $S/\sqrt{B} \sim 45$.
    Main background: Non-diffractive jets.

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