Exclusive prodution in AFP at high luminosity

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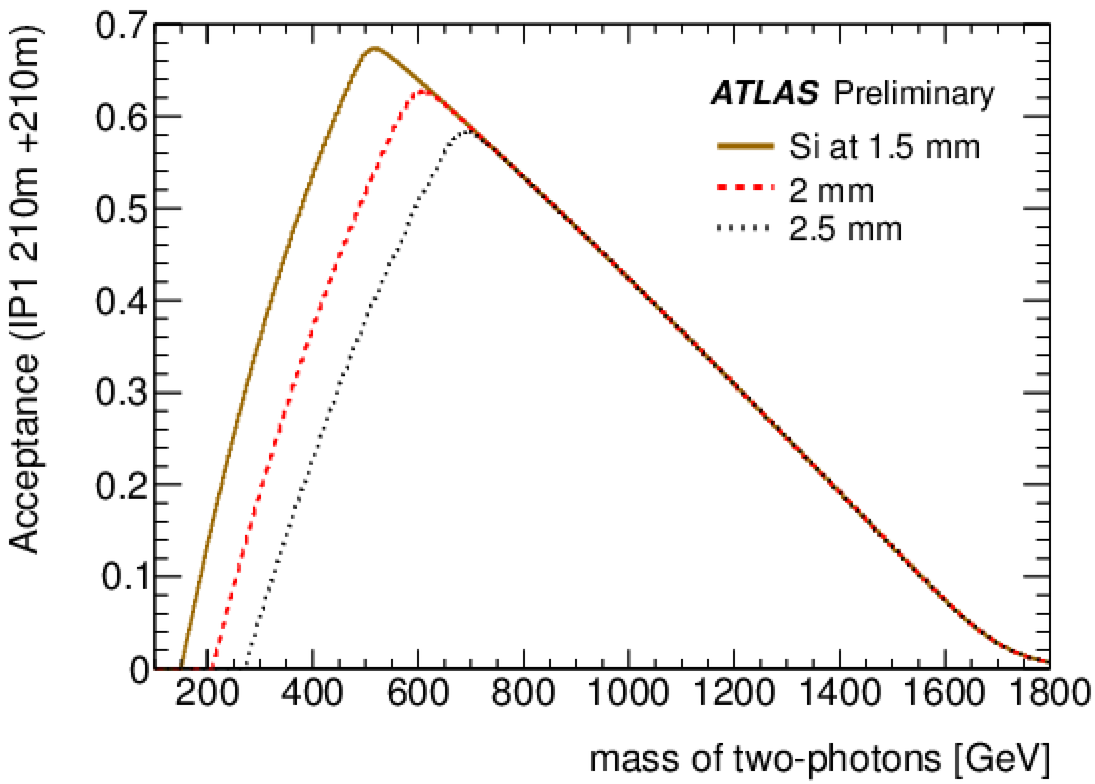
Outline

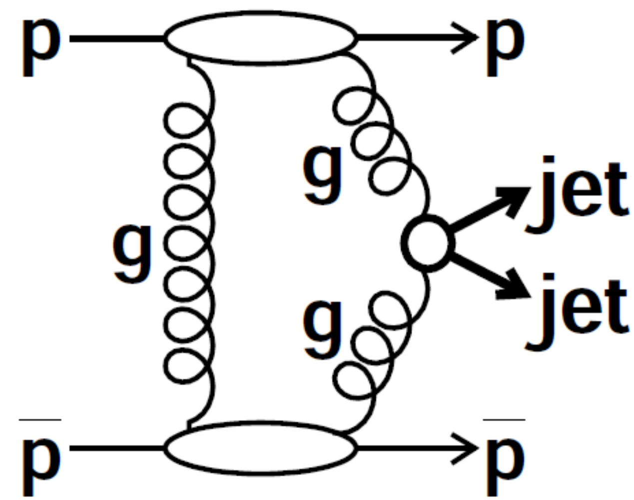
- Sensitivity to anomalous quartic gauge boson couplings
  - Analysis with no pile-up 210 + 420m
  - Analysis using full simulation of ATLAS with pile-up for 210 case
- Exclusive dijet production at high luminosity
- Summary

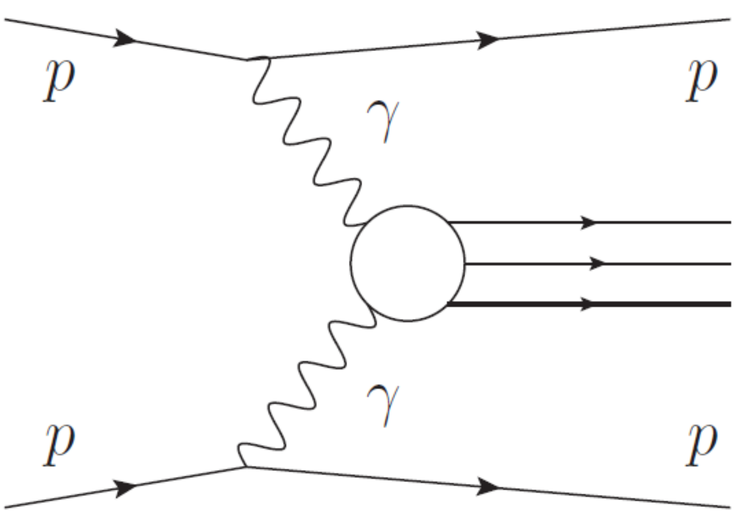
Acceptance

- Acceptance up to ~1TeV scale
- Very small acceptance below 350 GeV

$$W = \sqrt{s\xi_1\xi_2}$$



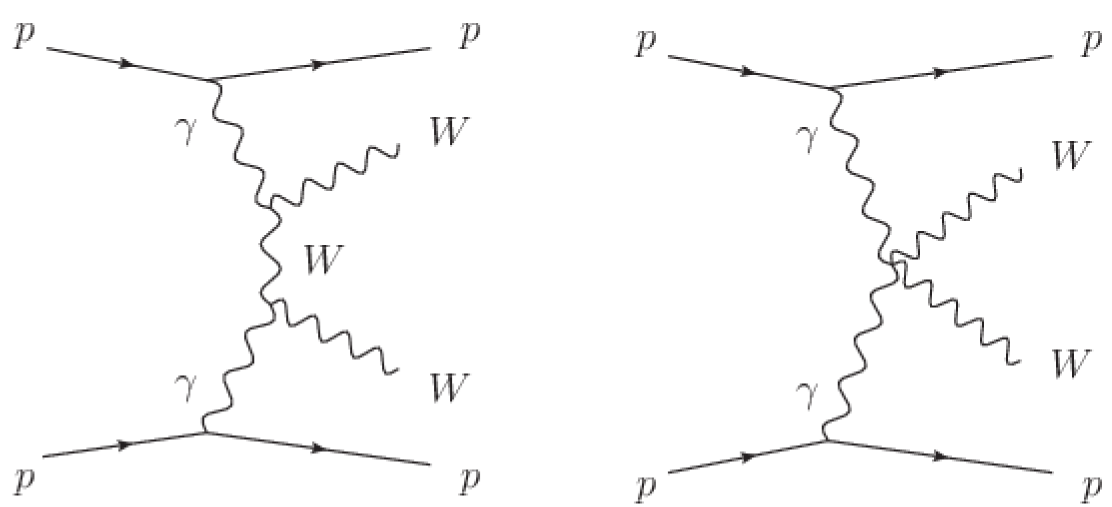


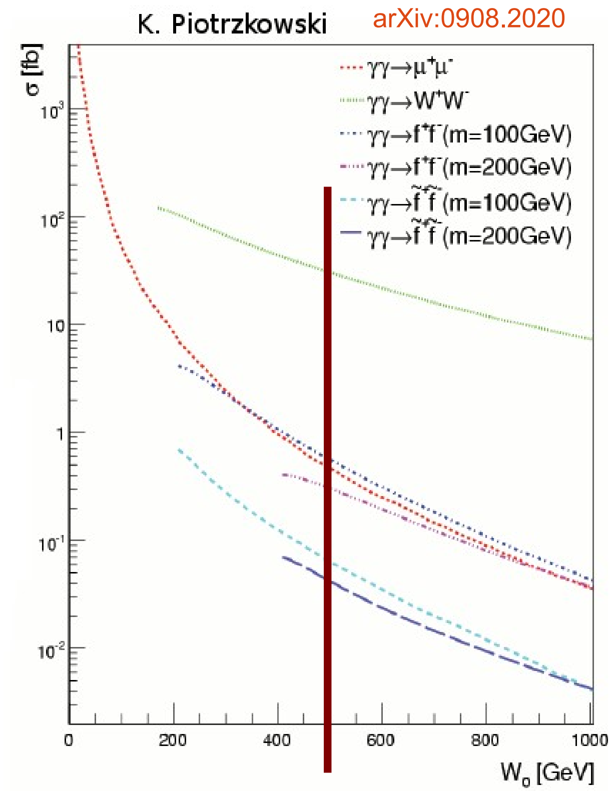


Exclusive QED production

VBS in exclusive mode

- AFP turn LHC pp machine into an effective photon-photon collider
  - But also gamma-pomeron
- Photon induced vector boson scattering process
  - No particle produced from underlying event involving MPI
  - No color flow – possible jet gaps as in VBF





Cross sections for γγ processes as a function of the minimal γγ cms energy W_0

- Improving anomalous TGC/QGC constraints showed on hadron level
  - Exciting mainly for anomalous aQGC, sensitivity to aTGC comparable with existing limits

Anomalous Quartic Gauge Coupling

- Stringent test of the electroweak symmetry breaking by proton tagging

  SM: γγWW   BSM: γγZZ, (γγγγ)

- aQGC γγ → WW can be measured very precisely looking in deviations in m(γγ), or p_T(lep) spectrum → $\sim 10^{-6}$
- 4 orders of magnitude improvement wrt. LEP
  - Hadron level analysis considering diffractive background with primary int.

Couplings	OPAL limits $[\mathrm{GeV}^{-2}]$	Sensitivity @ $\mathcal{L} = 30$ (200) fb^{-1} 5σ	95% CL
a_0^W/Λ^2	[-0.020, 0.020]	$5.4\ 10^{-6}$ ($2.7\ 10^{-6}$)	$2.6\ 10^{-6}$ ($1.4\ 10^{-6}$)
a_C^W/Λ^2	[-0.052, 0.037]	$2.0\ 10^{-5}$ ($9.6\ 10^{-6}$)	$9.4\ 10^{-6}$ ($5.2\ 10^{-6}$)
a_0^Z/Λ^2	[-0.007, 0.023]	$1.4\ 10^{-5}$ ($5.5\ 10^{-6}$)	$6.4\ 10^{-6}$ ($2.5\ 10^{-6}$)
a_C^Z/Λ^2	[-0.029, 0.029]	$5.2\ 10^{-5}$ ($2.0\ 10^{-5}$)	$2.4\ 10^{-5}$ ($9.2\ 10^{-6}$)

O. K. et al, Phys. Rev. D 81, 074003 (2010)

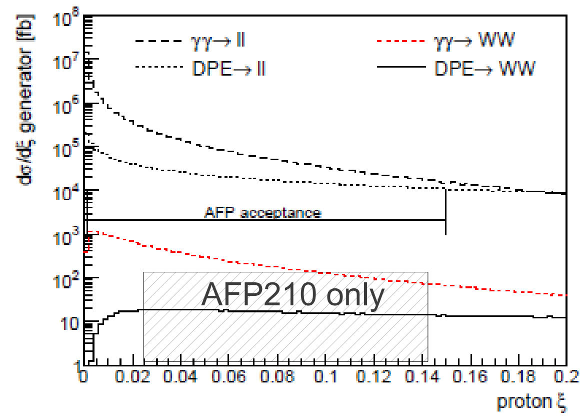
T. Pierzchala et al, Nucl. Phys. Proc. Suppl. 179-180 (2008) 257

- Effective Lagrangiang:
  - Conserve *C*, *P*, *T*, and custodial symmetries

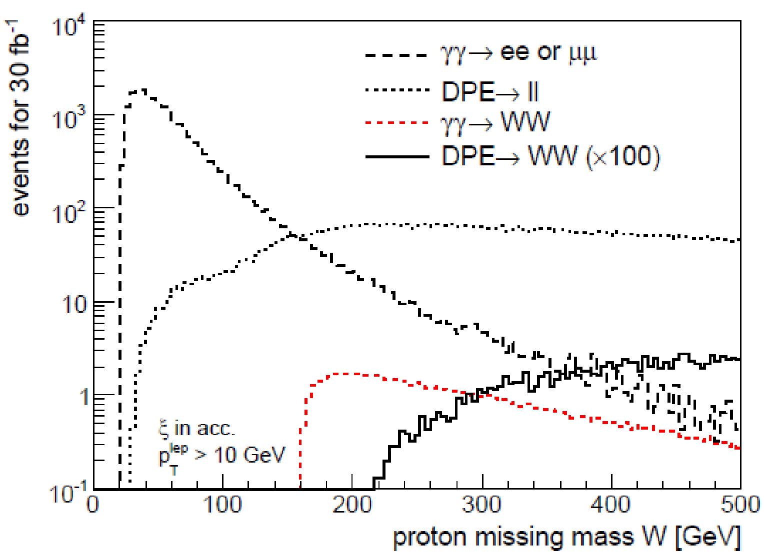
$$\mathcal{L}_{\mathrm{eff}}^{\mathrm{BSM}} = -\frac{e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha - \frac{e^2}{16}\frac{a_C^W}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W^-_\beta + W^{-\alpha}W^+_\beta) - \frac{e^2}{16\cos^2\theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha - \frac{e^2}{16\cos^2\theta_W}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta$$

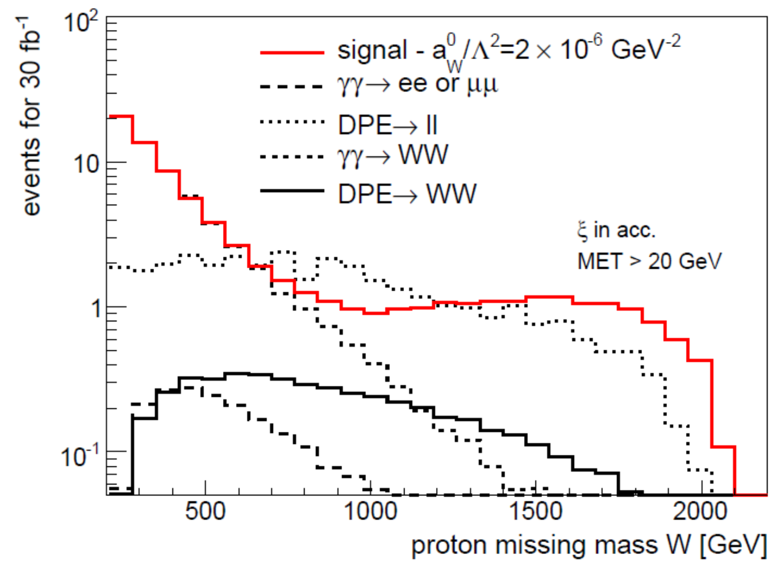
Details of the analysis

- Use both 210m and 420m detectors
- Consider: γγ and double pomeron exchanges
- Neglect pile-up



- Not a realistic scenario anymore – no 420 detector, better to avoid using MET for high-mu conditions
- Large rates of SM process at low mass





- Since anomalous shows up at high mass, 420m actually not needed …

Implementation of the aQGC

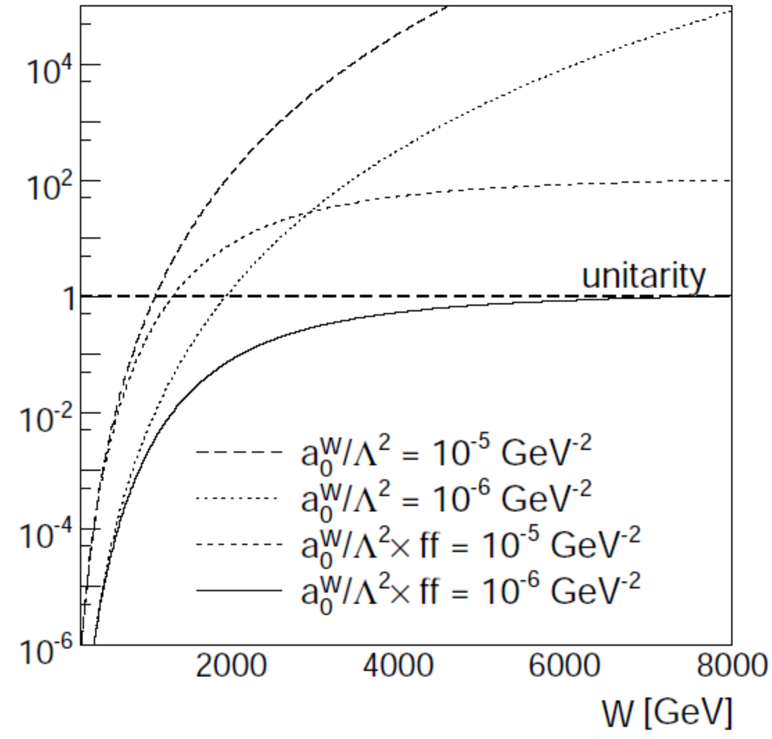
New couplings violate unitarity, couplings need to be accompanied by Form factors regularizing the effect of cross section at high mass

$$a \longrightarrow \frac{a}{[1+(W_{\gamma\gamma}/2\,\mathrm{TeV})^2]^2}$$

- Unitarity condition for anomalous coupling (J. P. Eboli) as a function of the invariant mass measured in AFP

$$\frac{1}{N}\left(\frac{\alpha a s}{16}\right)^2\left(1-\frac{4M_W^2}{s}\right)^{1/2}\left(3-\frac{s}{M_W^2}+\frac{s^2}{4M_W^4}\right)\leq 1 \text{ for } V=W$$

$$\frac{1}{N}\left(\frac{\alpha a s}{16\cos^2\theta_W}\right)^2\left(1-\frac{4M_Z^2}{s}\right)^{1/2}\left(3-\frac{s}{M_Z^2}+\frac{s^2}{4M_Z^4}\right)\leq 1 \text{ for } V=Z$$



- It shows that for coupling of the order ~10^{-6} unitarity is not violated up to very high energies

- Moreover: Acceptance of AFP serves as a natural cutoff

- Limits do NOT differ by more then factor of 2 with or without ff.

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Improvments of the analysis

- Consider multiple proton – proton collisions
- Aim at higher luminosities, and up to 46 interactions per bunch crossings
- Try to avoid missing energy
- I this possible? Yes, the crucial points are:
  - Timing detectors
  - Counting tracks in the inner detector

Suppression of pile-up

- Require difference between proton arrival times compatible with primary vertex

$$z_0 = \frac{c}{2}(t_1 - t_2) \qquad \Delta t_{1,2} = 10\,\text{ps} \rightarrow \Delta z_0 = 2.1\,\text{mm}$$

- Smearing both in time and position - rejection at 1σ level (2.1mm)

Summary:

- Acceptance

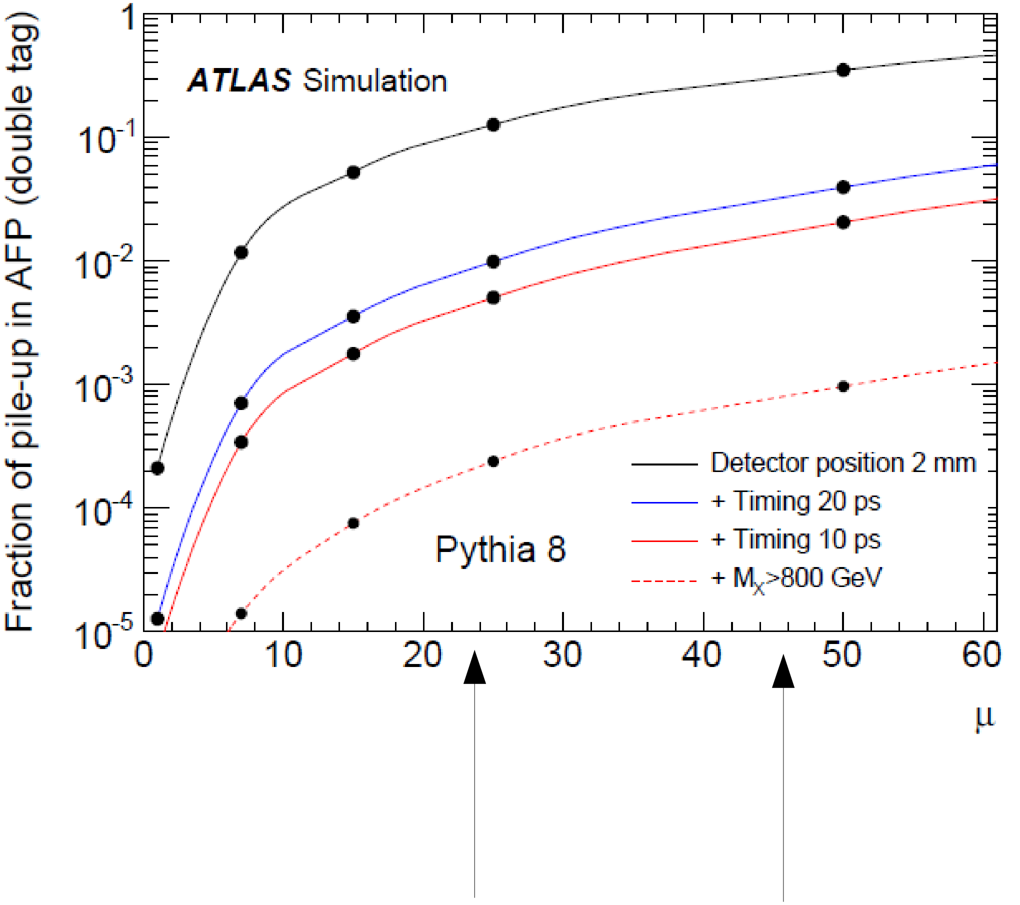
  μ = 23: 10^{-1} μ = 46: 3×10^{-1}

- +10ps timing

  μ = 23: 4×10^{-3} μ = 46: 2×10^{-2}

- +High mass W>800GeV

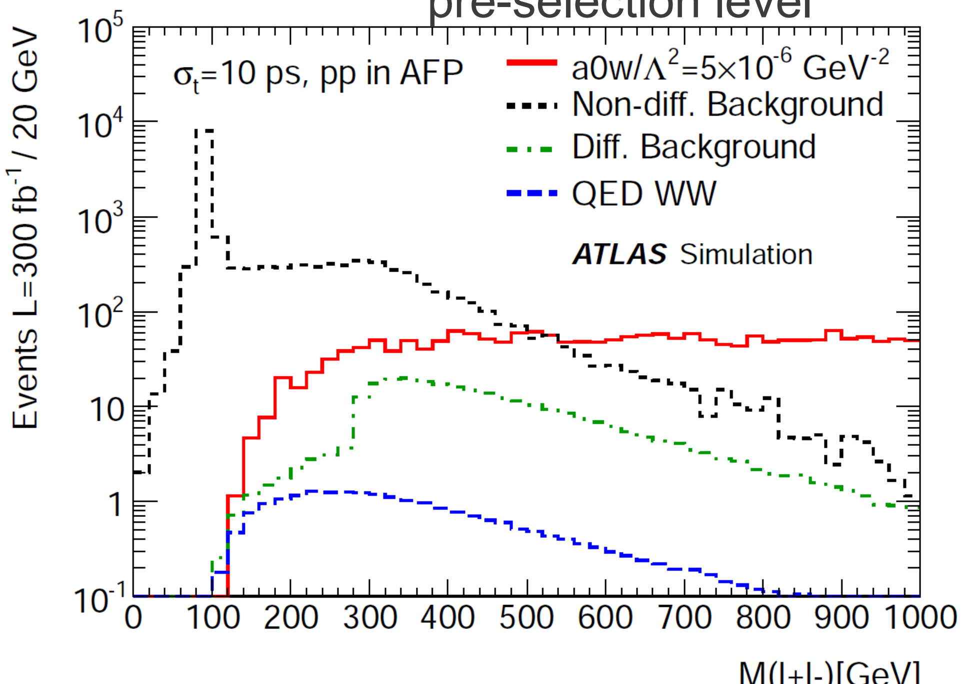
  μ = 23: 2×10^{-4} μ = 46: 10^{-3}



Event selection

- Protons tracked through magnetic field of LHC, detector position at 206, 214m @ 1.5 mm from the beam (FPTracker), AFP approximate acceptance $0.02 < \xi < 0.14$
- Analysis for medium pile-up μ=23
  - p_T(lead lep) > 150 GeV p_T(sub-lead lep) > 20GeV
  - m(ll)>300 GeV
  - N_{tracks} <=3
  - Δφ(ll) < 3.1rad
  - m_X > 800 GeV
- Analysis for high pile-up μ=46
  - increase lepton threshold
  - p_T(lead lep) > 300 GeV

pre-selection level

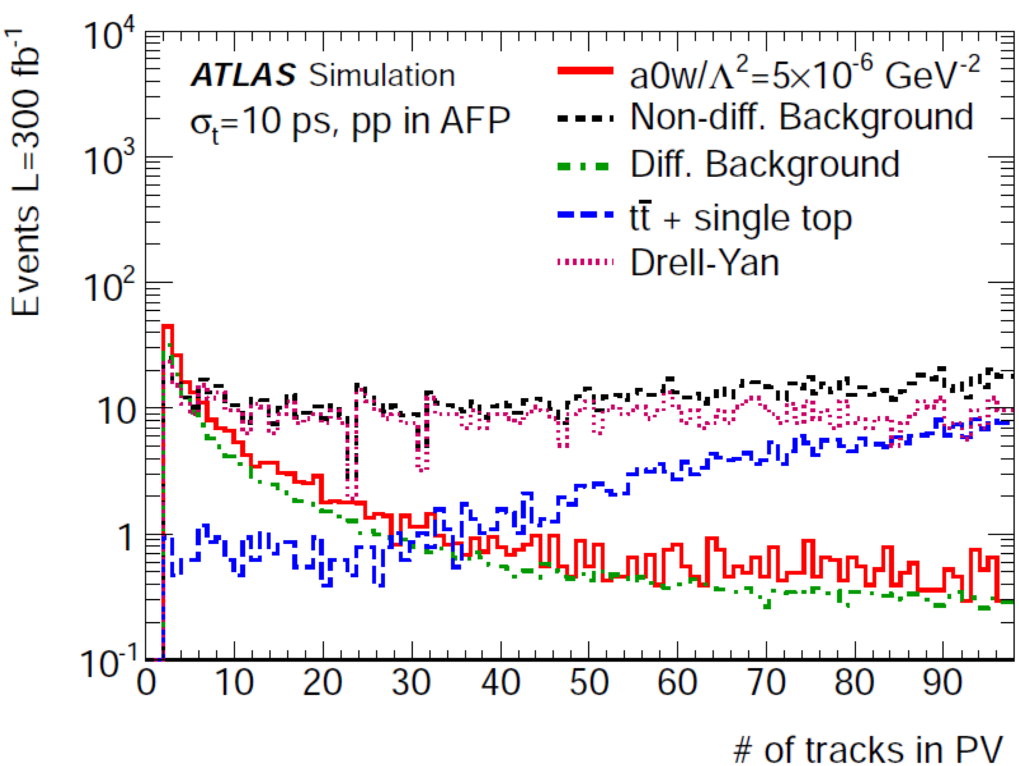


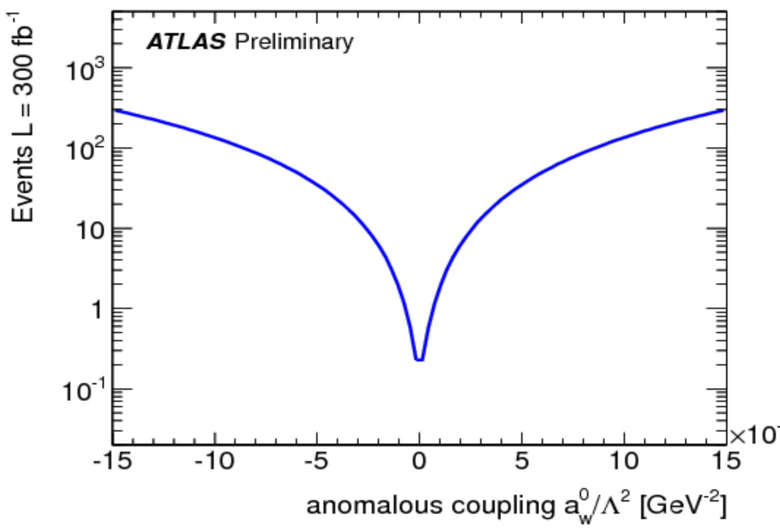
x50

- Considering complete physics background set as in ATLAS/CMS WW analyses with central detector (see backup). Signal protons appear at high ξ, less affected by beam background

Event selection

- Exclusivity cut – number of tracks >= 3 (p_T> 500MeV)
  - Main improvement wrt. hadron level studies, which couldn't use tracks without a realistic simulation of tracker and pile-up
- Non-diffractive productions has larger tails
  - Tracker and vertexing performs extremely well in pile-up
- Fully simulated samples for 4 couplings, dependence fitted with a formula including polynomial and exponential distribution





Final limits

- Fully simulated samples for 4 couplings, dependence fitted with a formula including polynomial and exponential distribution
- Background of the order of ~0.5 events in both μ=23 and 46 scenarios

Cuts	Top	Dibosons	Drell-Yan	W/Z+jet	Diffr.	$a_0^W/\Lambda^2 = 5 \cdot 10^{-6}$ GeV^{-2}
timing < 10 ps $p_T^{lep1} > 150$ GeV $p_T^{lep2} > 20$ GeV	5198	601	20093	1820	190	282
M(ll)>300 GeV	1650	176	2512	7.7	176	248
nTracks ≤ 3	2.8	2.1	78	0	51	71
$\Delta\phi < 3.1$	2.5	1.7	29	0	2.5	56
$m_X > 800$ GeV	0.6	0.4	7.3	0	1.1	50
$p_T^{lep1} > 300$ GeV	0	0.2	0	0	0.2	35

- Final obtained limits

	a_0^W/Λ^2 Sensitivity	
	5σ	95% C.L.
$\mathscr{L} = 40\ fb^{-1}, \mu = 23$	$5.5\ 10^{-6}$	$2.4\ 10^{-6}$
$\mathscr{L} = 300\ fb^{-1}, \mu = 46$	$3.2\ 10^{-6}$	$1.3\ 10^{-6}$

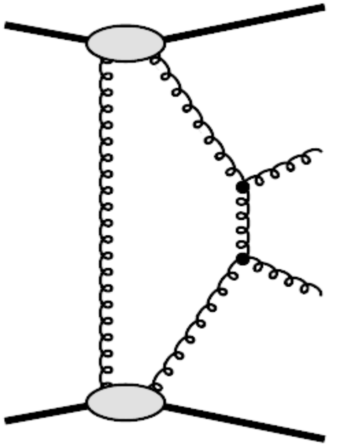
- Precision of ~10^{-6} GeV^{-2} where the BSM effect could show-up maintained
- Mainly due to exclusivity requirement

Exclusive dijet production

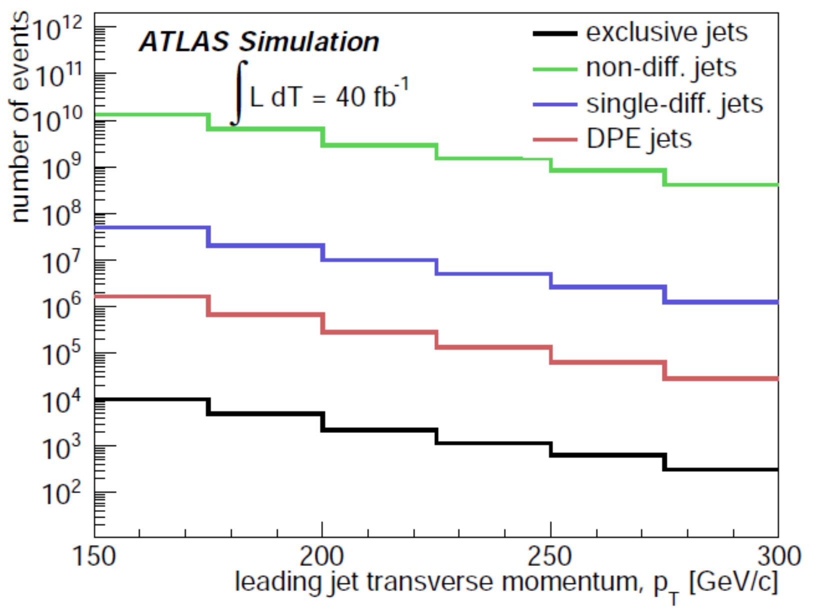
Exclusive production

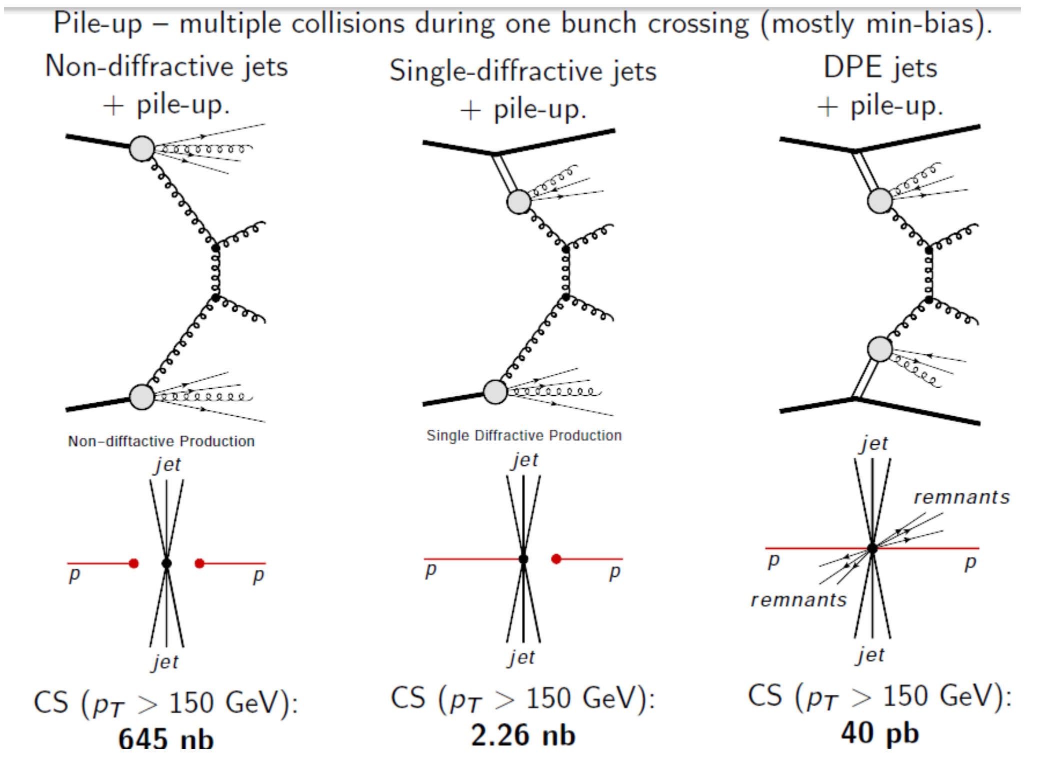
ATL-PHYS-SLIDE-2012-618

- Full analysis of exclusive dijets – a prove that we can do measurements using medium mass
- Previously measured at CDF
- Important to gauge the the exclusive production of Higgs
  - σ(Higgs)/σ(dijets) known precisely theoretically



- 6 orders of magnitude to select signal





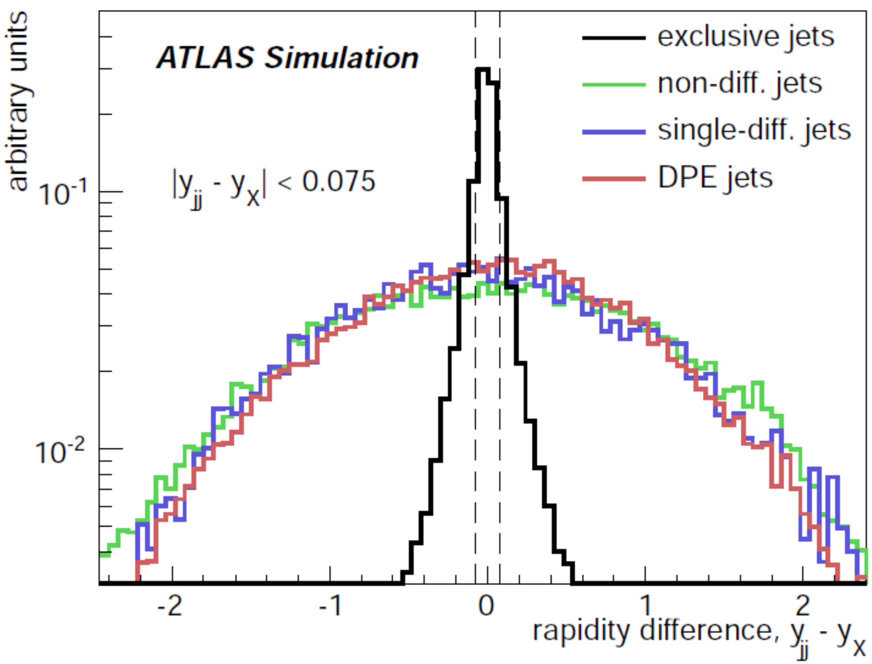
Kinematic constraints

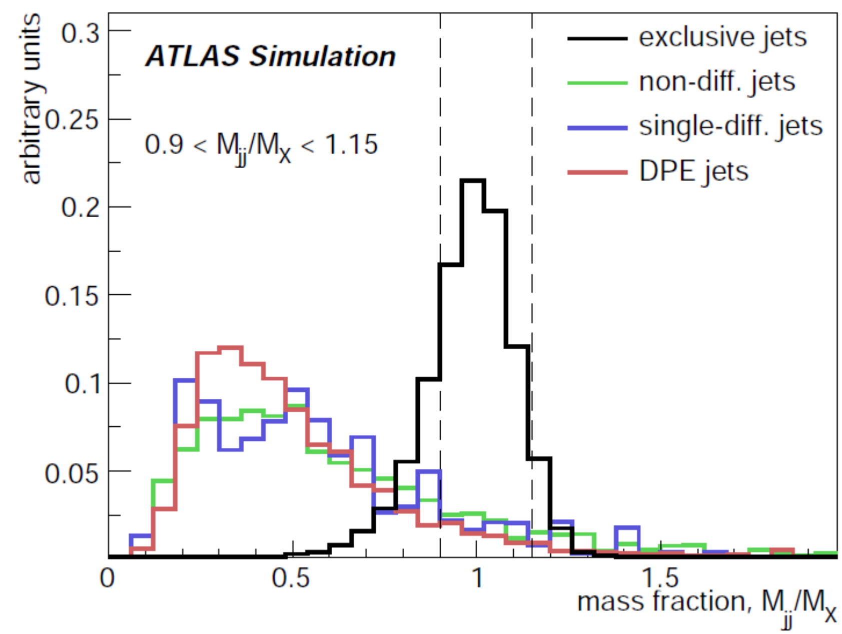
- Important AFP addition
  - Kinematic correlation between central detector and AFP
- Difference y_{jj}-y_X of rapidity of the jet system and rapidity of proton system

$$y_X = 0.5 \cdot \ln\left(\frac{\xi_1}{\xi_2}\right)$$

- Ratio of the jet system mass to the missing mass calculated in AFP

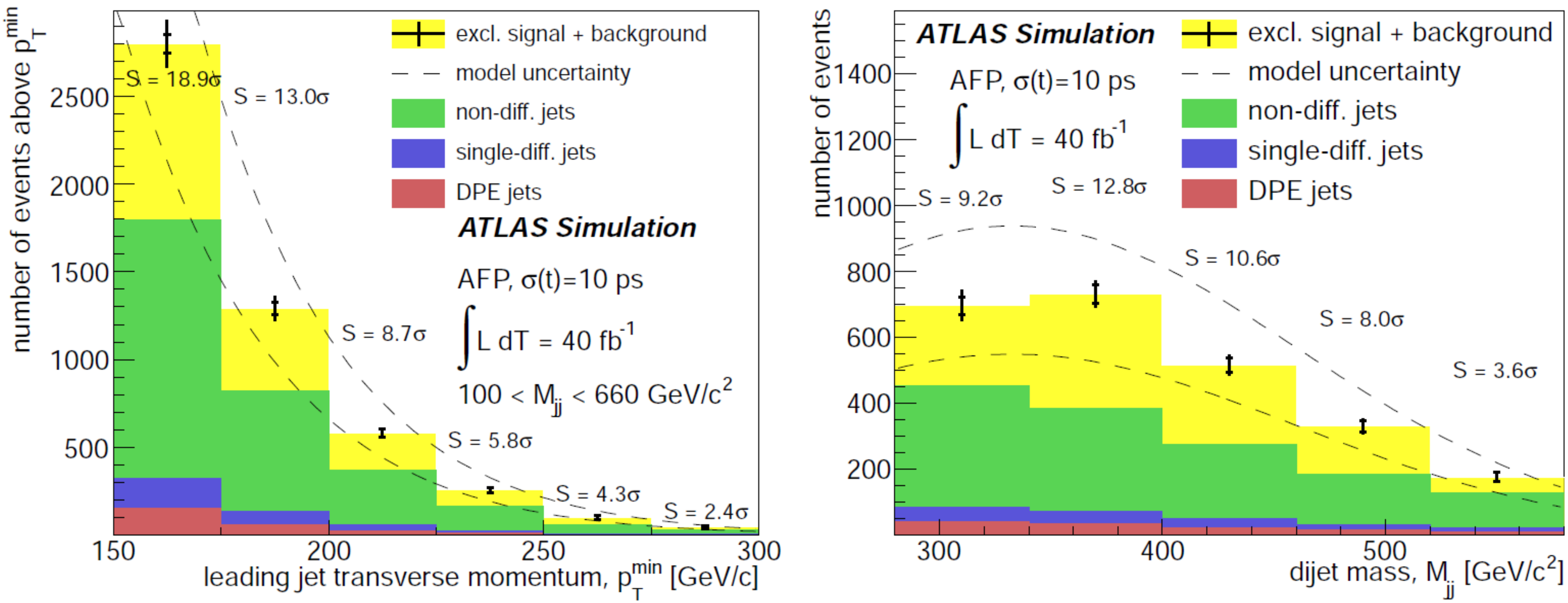
$$M_X = \sqrt{s \cdot \xi_1 \cdot \xi_2}$$





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

Maciej Trzebinski



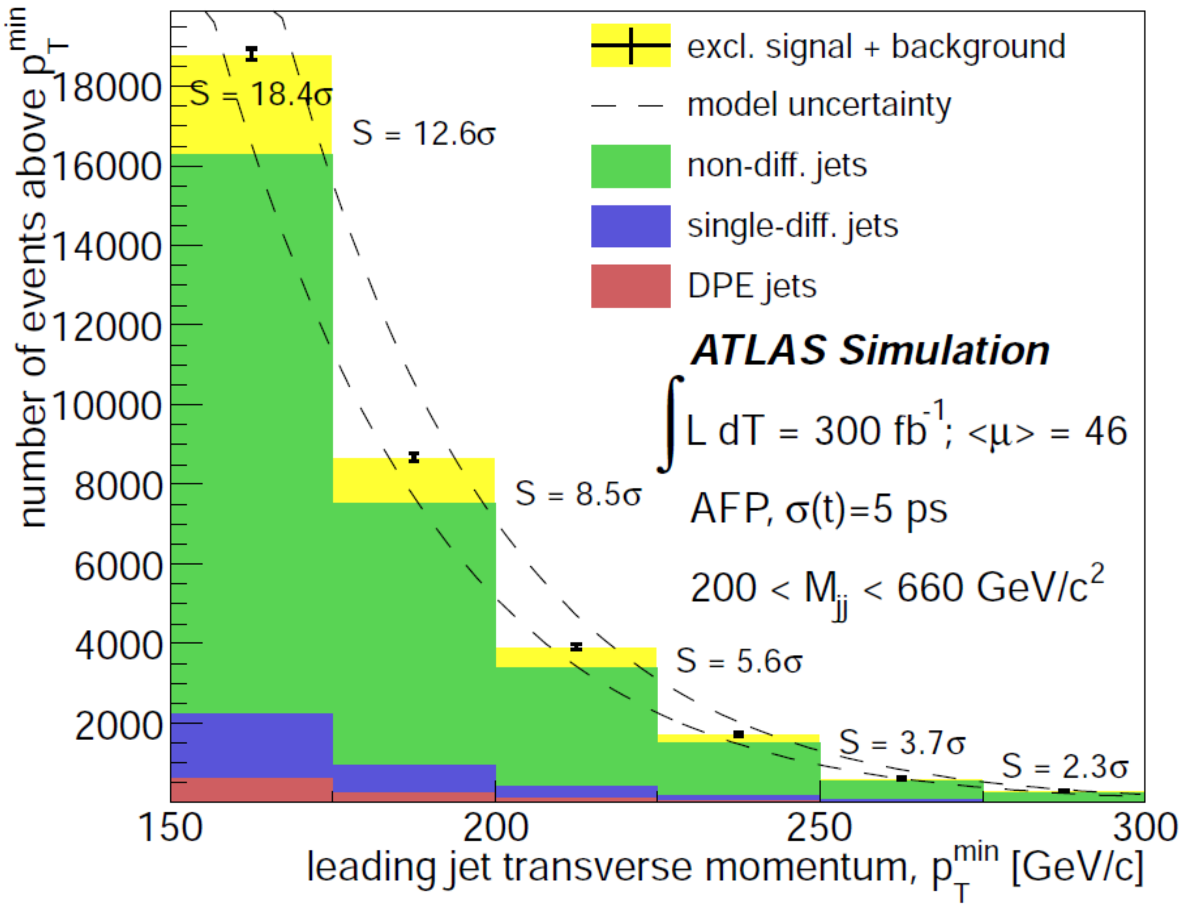
The leading jet transverse momentum distribution above a given threshold (left) and mass of the jet system distribution (right) for the accepted signal and background events for the integrated luminosity $L = 40$ fb^{-1} at pile-up $\mu = 23$.

The error bars show the statistical and systematic uncertainties.

The dashed line represents the theoretical model uncertainty (best constraints on parameters from the Tevtatron data).

For each bin the significance (S) is presented.

Number of Events ($< \mu >= 46$)



The leading jet transverse momentum distribution above a given threshold for the accepted signal and background events for the integrated luminosity $L = 300\ \text{fb}^{-1}$ at pile-up $\mu = 46$.
The error bars show the statistical uncertainty.
The dashed line represents the theoretical model uncertainty (best constraints on parameters from the Tevtatron data).

For each bin the significance (S) is presented.

Summary

- Feasibility study of search for high mass object decaying into leptons in exclusive events using detector stations at 210m from IP
  - Key points – tracking, timing of protons (do not need very precise timing resolution)
- By 1-2 orders of magnitude better sensitivity than the conventional method
  - Conventional methods expect sensitivity ~10^{-4} only, competition sensitivity on exclusive WW with 8TeV data to be seen
- Anomalous γγZZ not mentioned, but experimentally simpler then WW – employ correlation of Mx in forward detectors and 4 leptons

- Exclusive dijets – prove of principle for medium-mass analysis, but suppressing background involve many detailed topological cuts whose efficiency might be difficult to estimate from data
  → Investigating feasibility for medium-mu scenario

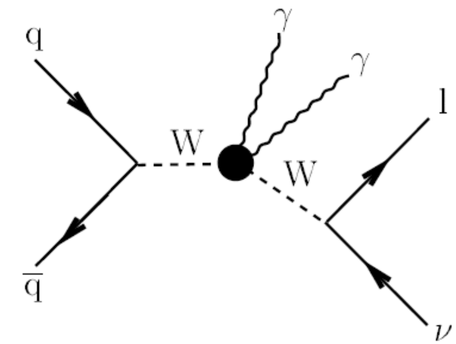
- More studies to be done:
  - Exclusive production of di-photons as a probe of anomalous coupling
  - Investigation of semi-leptonic decays of WW to improve limits

- Most important to know the impact of beam induced background on the analyses!

Backup

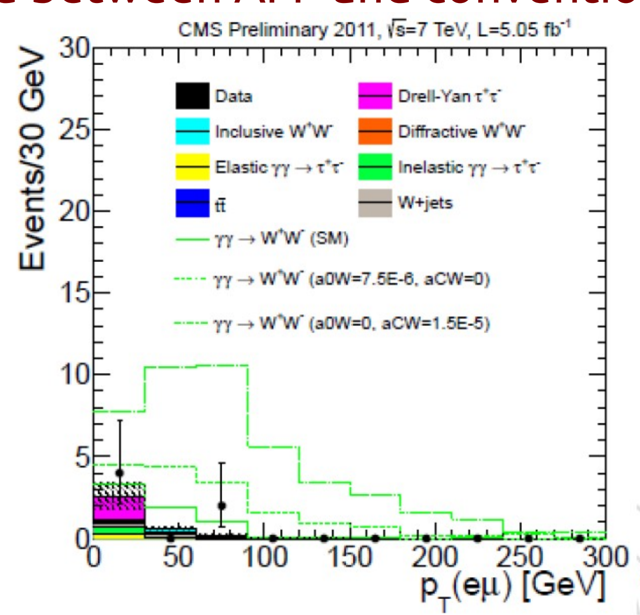
Comparison with existing methods

- $W\gamma\gamma$ – binned maximum likelihod fit of $M\gamma\gamma$ distribution
  - Unitary safe limits improve lep results by two orders of magnitude
  - Background from mis-identified W+jets events
  - AFP adds 1-2 orders better sensitivity



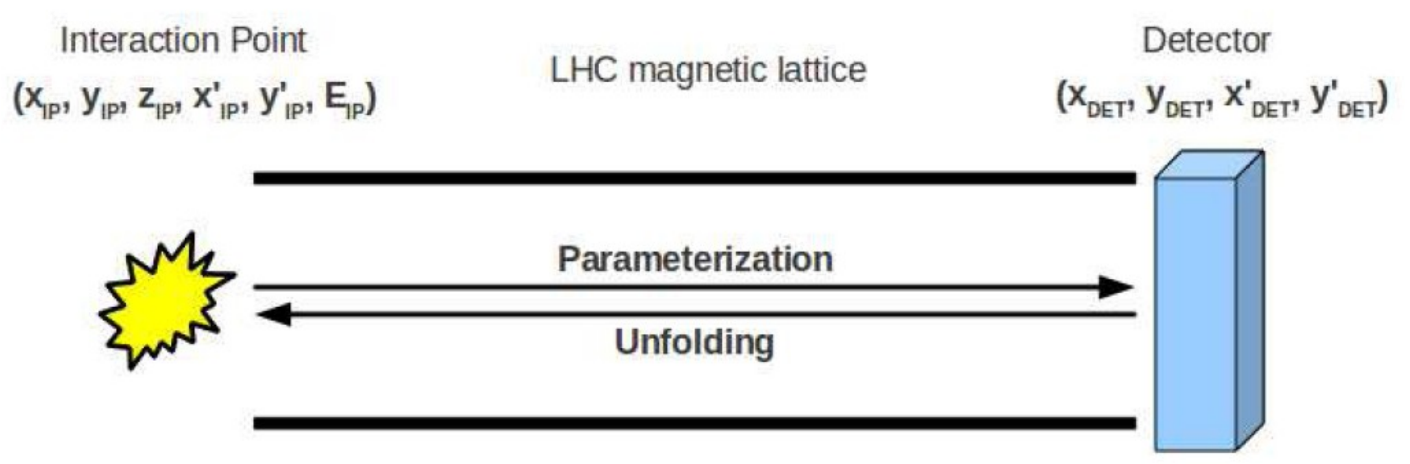
P. J. Bell, Eur.Phys.J.C64:25, 2009

- New CMS preliminary result
  - Exclusive production without tagging, results very promising, exact sensitivity to be determined ..
  - Same models should be compared between AFP and conventional method
  - Improving LEP limits by 2 orders of magnitude



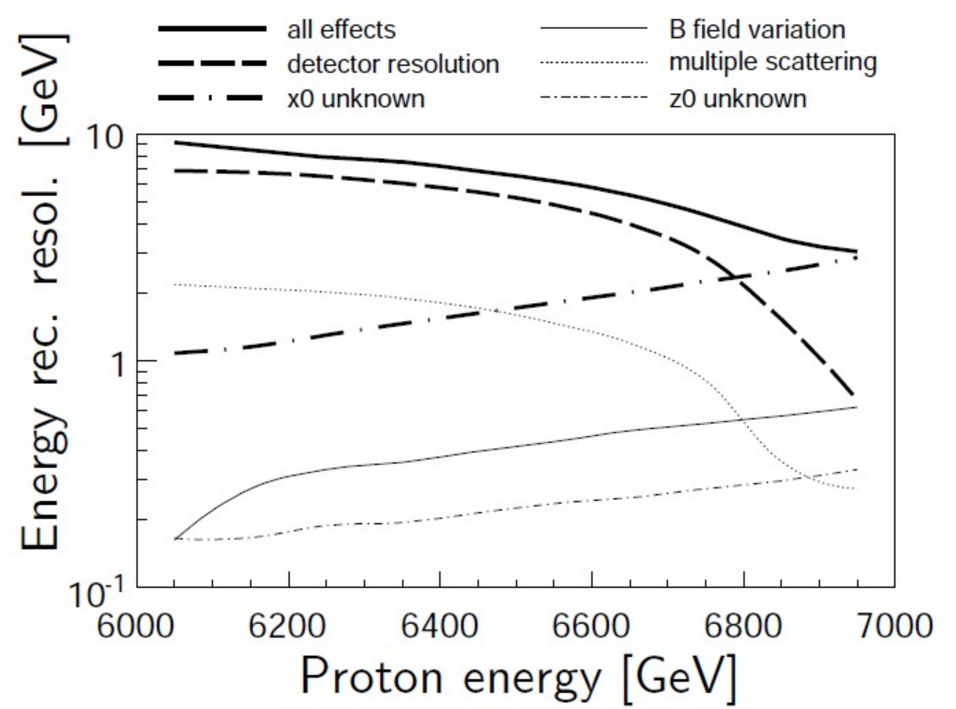
CMS PAS FSQ-12-010

Proton kinematic reconstruction



Knowing proton position at both AFP stations one can reconstruct energy and momentum at the Interaction Point.

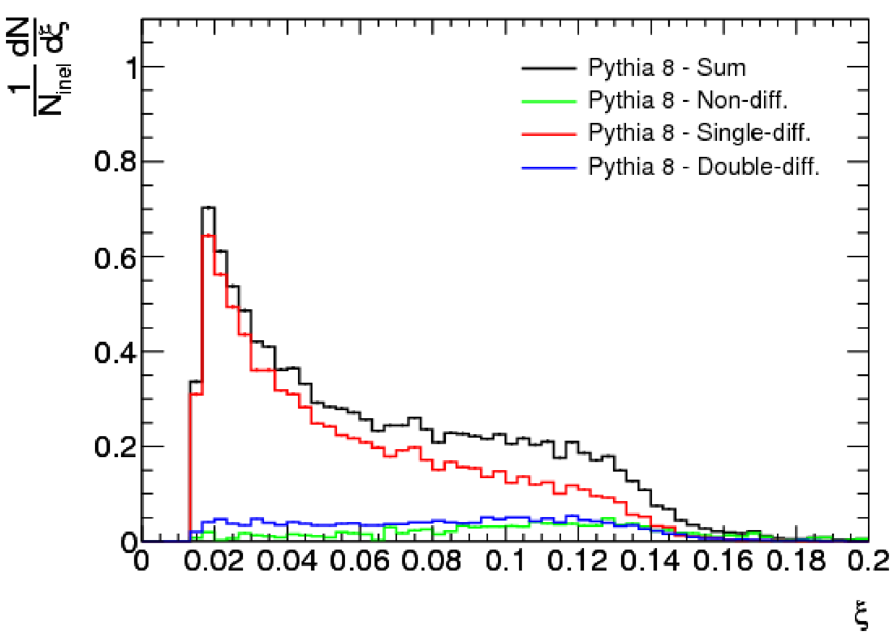
The energy reconstruction resolution is **better than 10 GeV**!

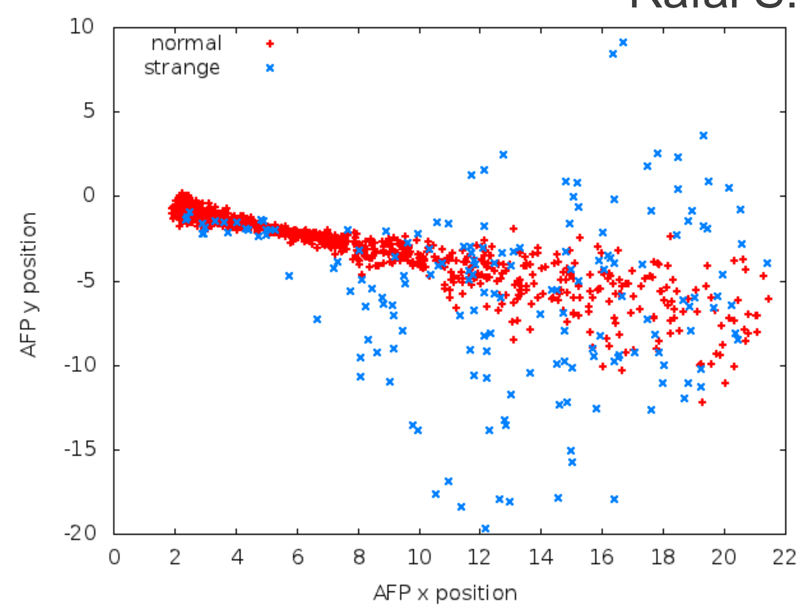


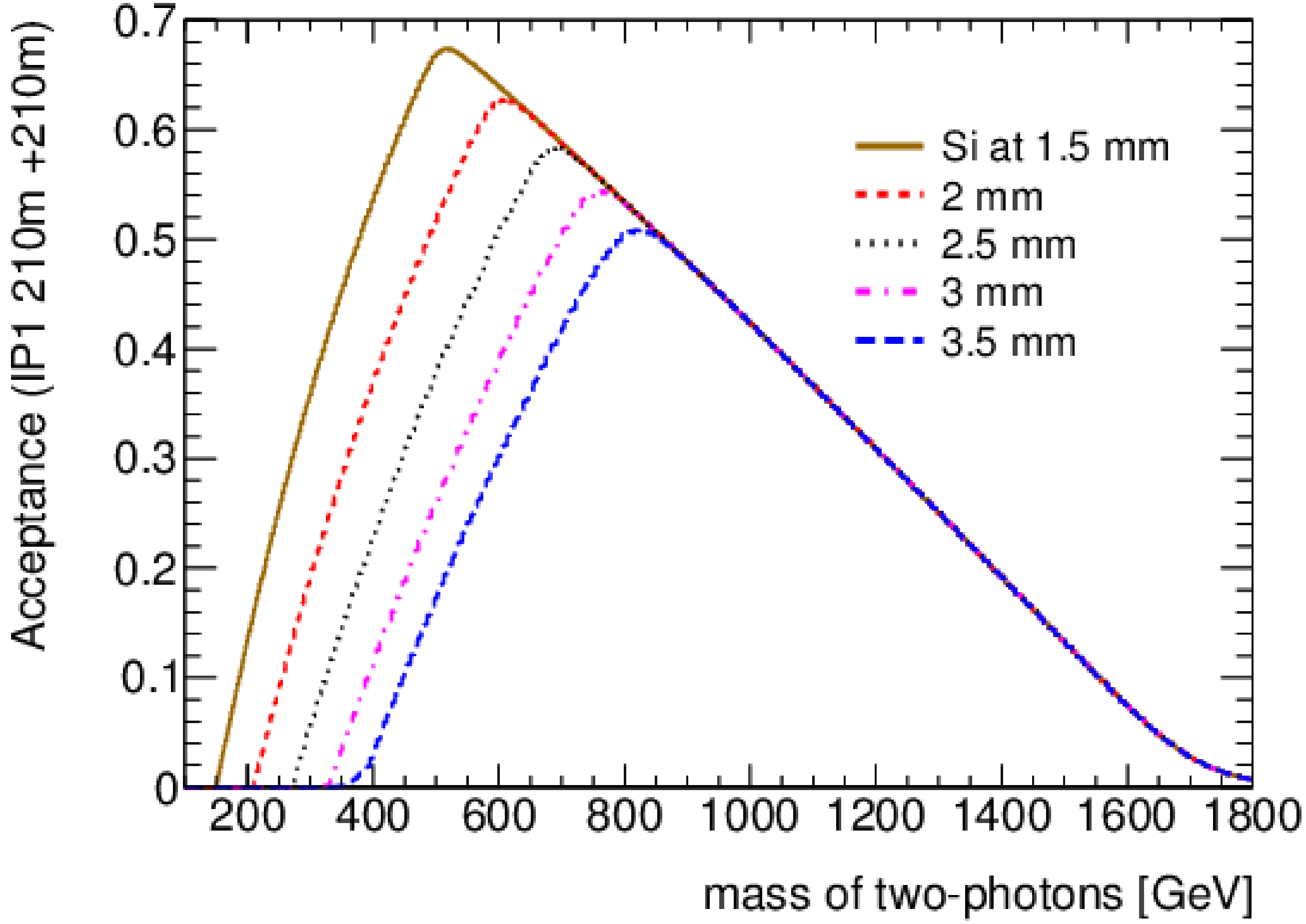
Momentum fraction loss profiles

- Intact protons in non-diffractive and double-diffractive sample make about 50% of intact protons hitting AFP
- Right: single diffractive events
  - Comparing side with forward proton and the side with dissociated system
  - Rejection power could be increased by cutting on particular XxY patterens
- Needs to be measured!
  - Starting ALFA diffractive program can provide important constraints to pile-up in AFP

Rafal S.

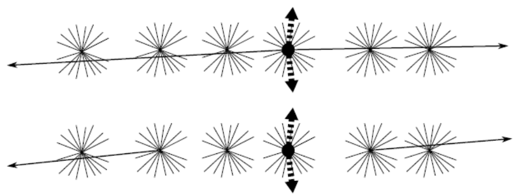




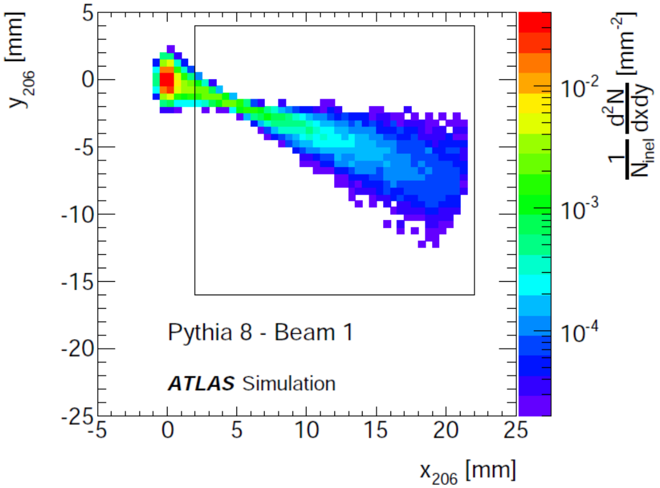


Acceptance (IP1 210m +210m)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
200
400
600
800
1000
1200
1400
1600
1800
mass of two-photons [GeV]
Si at 1.5 mm
2 mm
2.5 mm
3 mm
3.5 mm

Multiple p-p collisions (Pile-up)



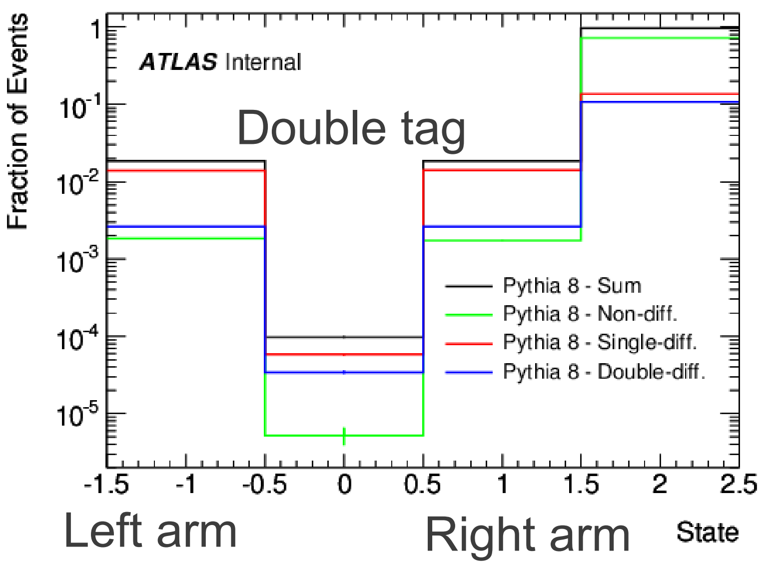
- Non-diffractive event in coincidence with two SD protons from MB events fake signal



- MB interaction hits one detector in 2% cases
- Fake double tag in 0.01% cases

- ND/DD events (and SD on the side of broken proton) also show intact protons especially at high ξ

- Pythia 6 predicts by about factor 10 higher rates than Pythia8



- Starting ALFA diffractive program can provide important constraints to pile-up in AFP

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Study with Full Simulation

Signal:

- QED WW SM, with QGC, semi-leptonic decays

Backgrounds

- non-diffractive (+pile-up)
  - WW, WZ, ZZ, Drell-Yan, W/Z+jet, ttbar, single top
- diffractive
  - QED ll, SD WW, DPE WW, DPE ll

- Neglecting: Photon+Pomeron exchanges

- Generators: FPMC, Herwig++, Pythia8

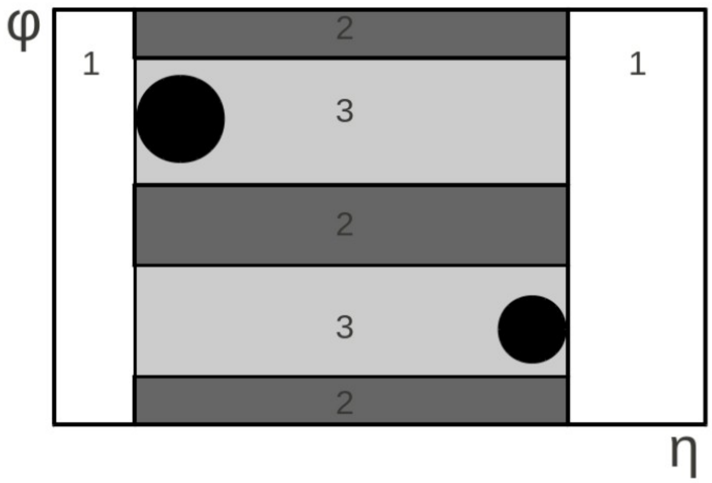
- Fully simulated samples in Athena rel. 16
  - μ=23, 46 – corresponding to 40 and 300 fb^{-1}

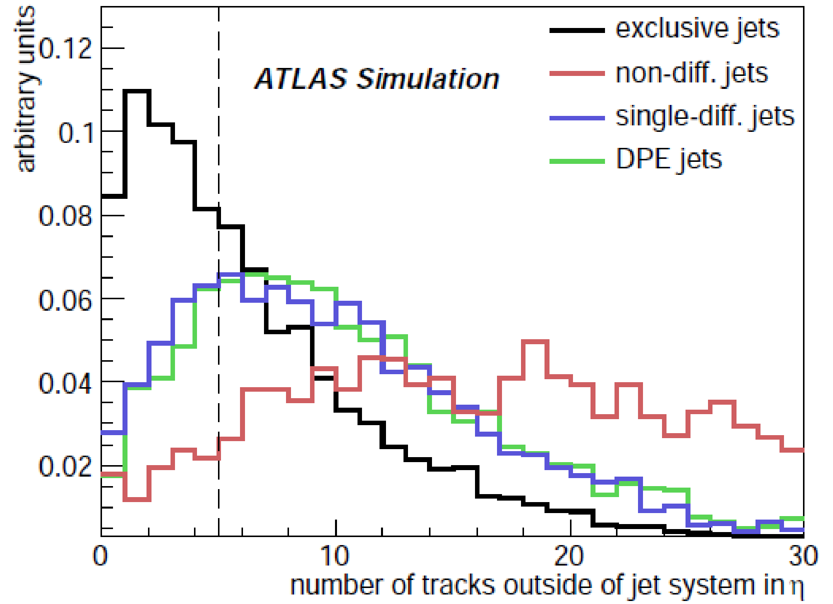
Cuts

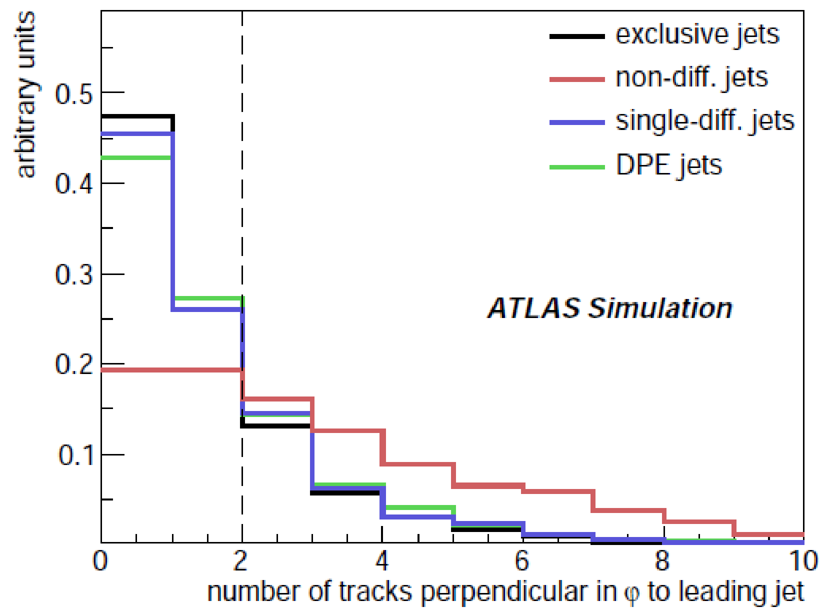
- Two leading jets must be with good quality (not reconstructed as bad nor ugly), transverse momentum of the leading jet $p_T > 150$ GeV/c.
- At least one proton should be tagged in each AFP station.
- Angle between two leading jets $2.9 < \Delta\phi < 3.3$.
- Difference between rapidity of the jet system and rapidity of the proton system $|y_{jj} - y_x| < 0.075$.
- Ratio of mass of the jet system to missing mass $0.9 < \frac{M_{jj}}{M_x} < 1.15$.
- Missing mass $M_x < 550$ GeV/c^2.
- Number of tracks outside jet system:
  - number of tracks outside of jet system (in η) $tracks_{out} < 5$,
  - number of tracks perpendicular to leading jet (in ϕ) $tracks_{phi} < 2$.
- The distance between hard vertex reconstructed by ATLAS and from the AFP time measurement $|\Delta z| < 3.5$ mm; assuming 10(5) ps AFP timing resolution for $< \mu >= 23(46)$.

- Detailed cut flow in backup

Exclusivity requirement





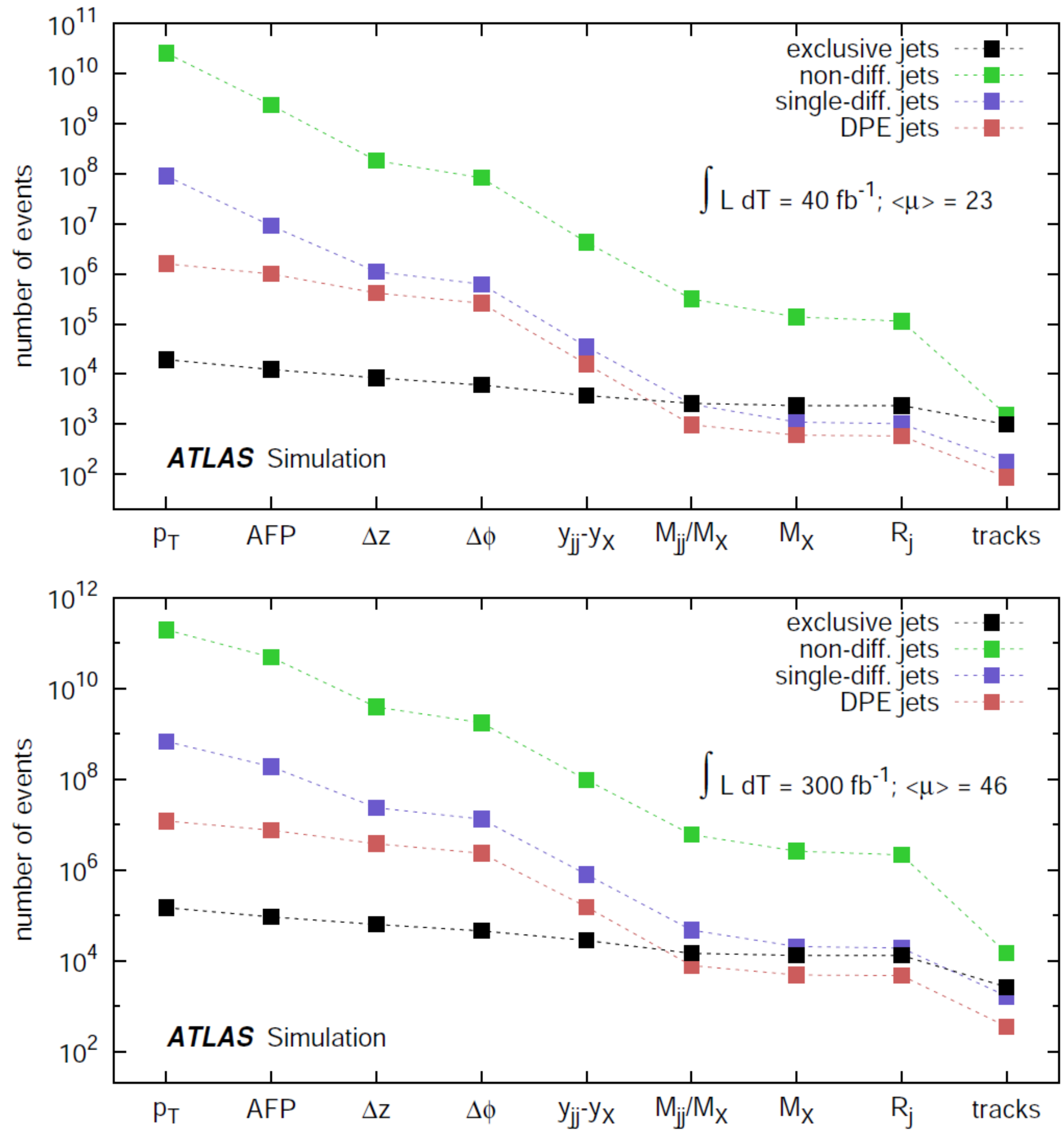


- Exclusivity requirement is more complicated than in QED case, but can bring S/B separation power
- Number of tracks fitted to the PV outside jet system in η (region1)
- Number of tracks perpendicular to leading jet in φ (region 2) for μ=23

Discriminating Power

The number of events accepted after a particular cut for signal and background processes for the integrated luminosity of 40(300) fb^{-1} at pile-up $\mu = 23(46)$ as a function of the applied consecutive cuts.

The AFP time resolution of 10(5) ps has been assumed for background rejection.



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