Forward physics with tagged protons at the LHC: QCD and anomalous couplings

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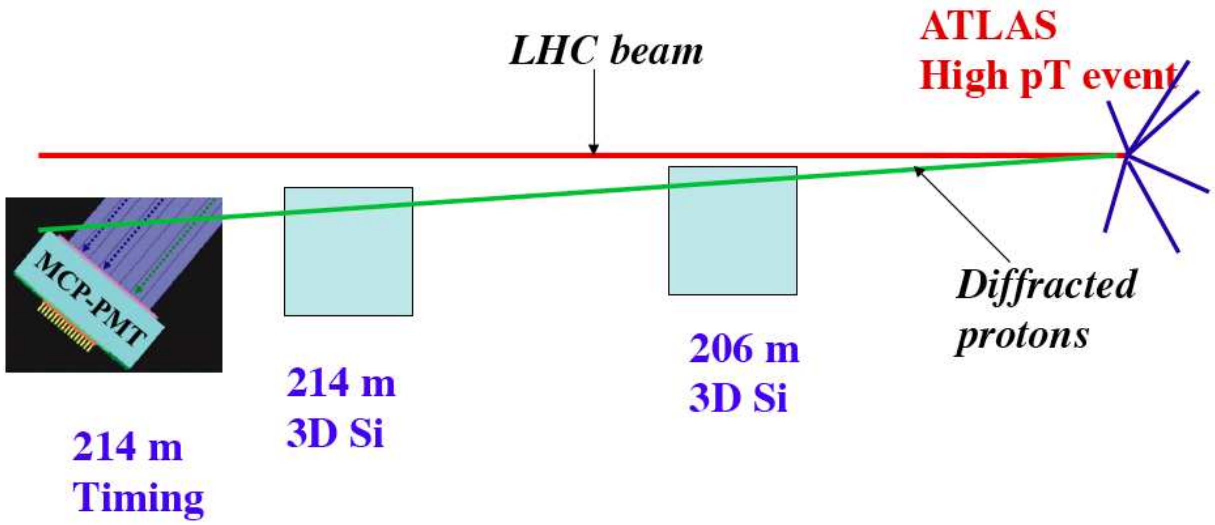
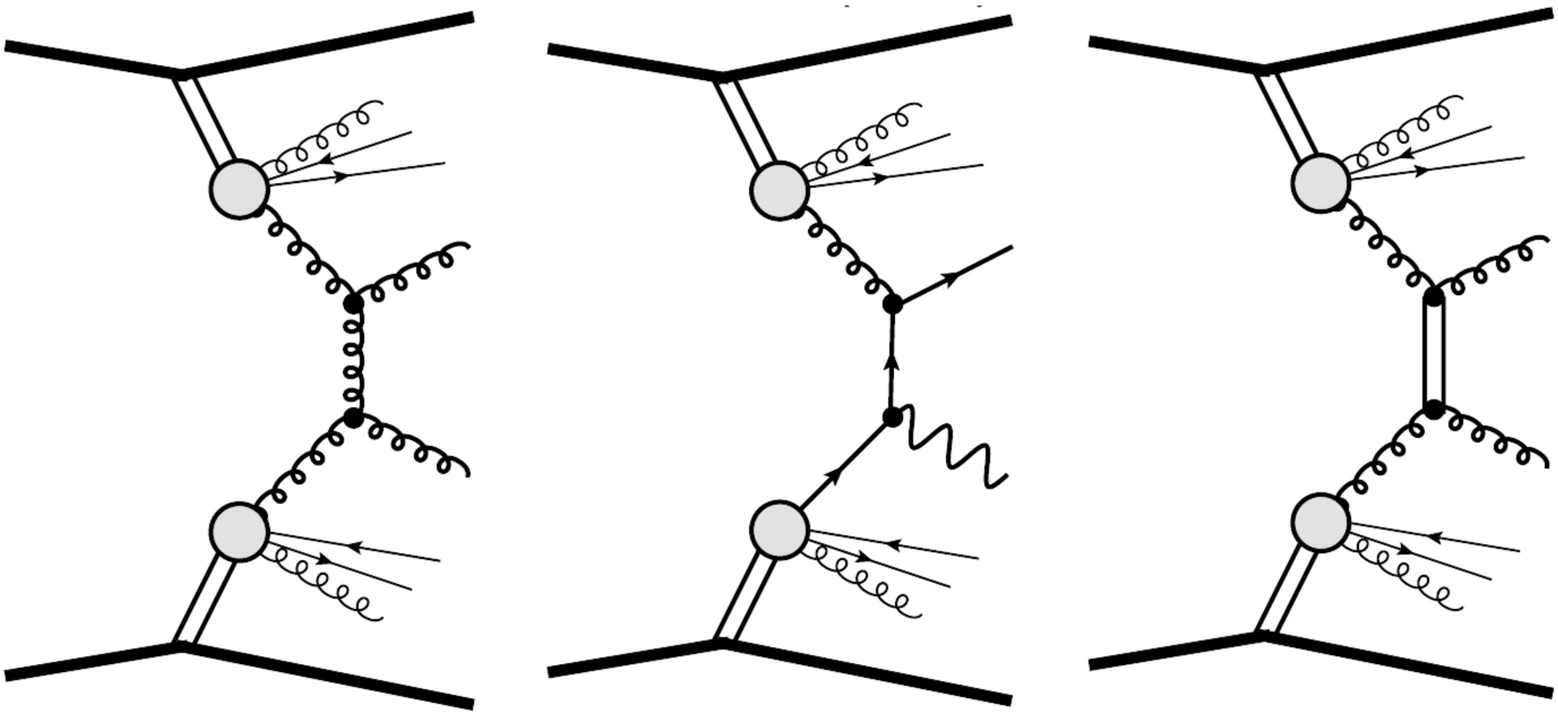
Contents:

- Constraining the Pomeron structure (DPE jets and γ+jet)
- Jet gap jet in diffraction
- Anomalous $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings
- Exclusive jets



Inclusive diffraction at the LHC

- Dijet production: dominated by gg exchanges
- γ+jet production: dominated by qg exchanges
- C. Marquet, C. Royon, M. Saimpert, D. Werder in preparation
- Jet gap jet in diffraction: Probe BFKL
- C. Marquet, C. Royon, M. Trzebinski, R. Zlebcik, Phys. Rev. D 87 (2013) 034010; O. Kepka, C. Marquet, C. Royon,, Phys. Rev. D79 (2009) 094019; Phys.Rev. D83 (2011) 034036

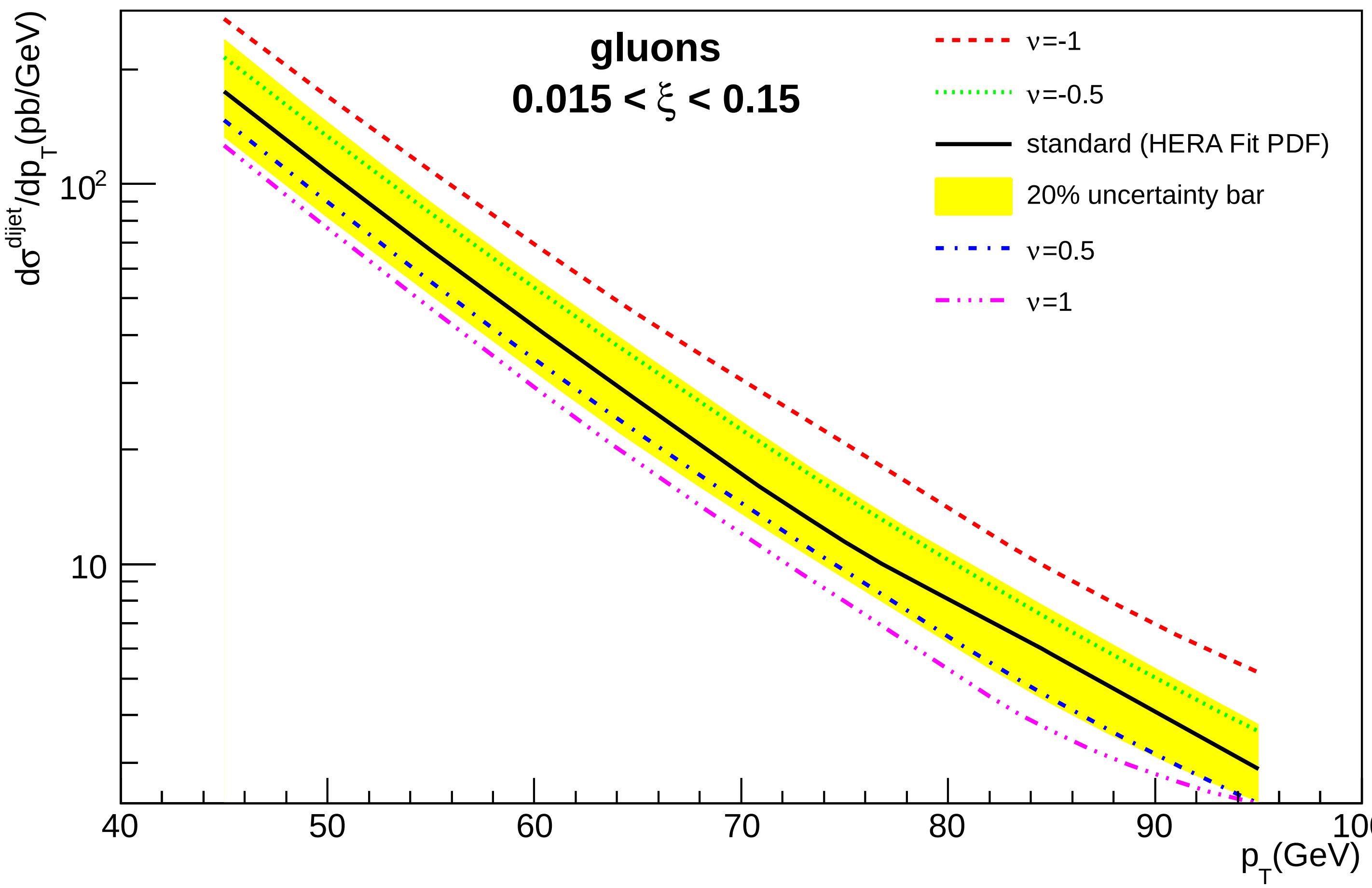


Forward Physics Monte Carlo (FPMC)

- FPMC (Forward Physics Monte Carlo): implementation of all diffractive/photon induced processes
- List of processes
  - two-photon exchange
  - single diffraction
  - double pomeron exchange
  - central exclusive production
- Inclusive diffraction: Use of diffractive PDFs measured at HERA, with a survival probability of 0.03 applied for LHC
- Central exclusive production: Higgs, jets...
- FPMC manual (see M. Boonekamp, A. Dechambre, O. Kepka, V. Juranek, C. Royon, R. Staszewski, M. Rangel, ArXiv:1102.2531)
- Survival probability: 0.1 for Tevatron (jet production), 0.03 for LHC, 0.9 for γ-induced processes
- Output of FPMC generator interfaced with the fast simulation of the ATLAS detector in the standalone ATLFast++ package

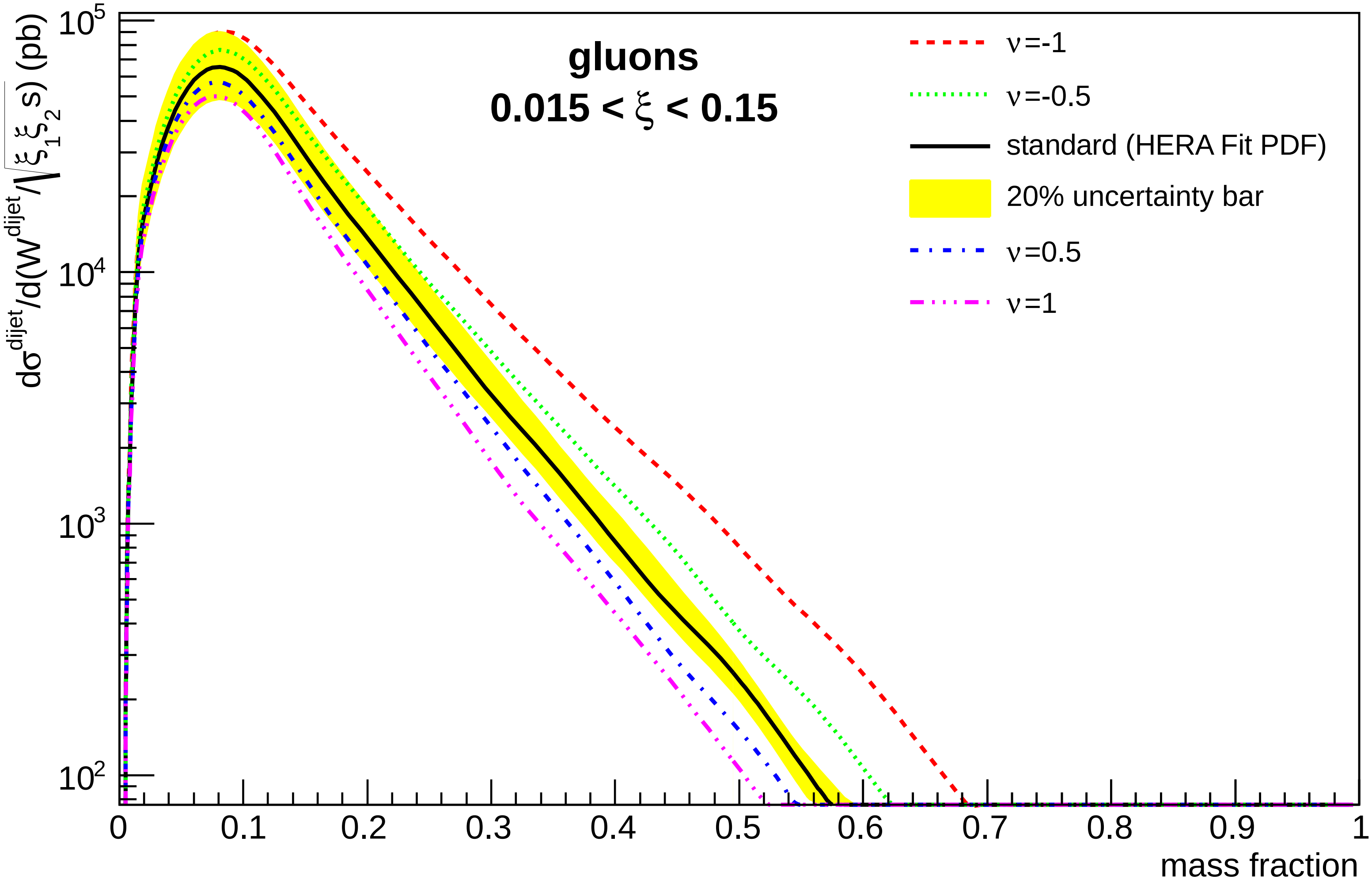
Inclusive diffraction at the LHC: sensitivity to gluon density

- Predict DPE dijet cross section at the LHC
- Sensitivity to gluon density in Pomeron especially the gluon density on Pomeron at high β: multiply the gluon density by $(1-\beta)^\nu$ with $\nu = -1, ..., 1$
- Measurement possible with 100 pb^{-1}, allows to test if gluon density is similar between HERA and LHC (universality of Pomeron model)
- If a difference is observed, it will be difficult to know if it is related to the survival probability or different gluon density



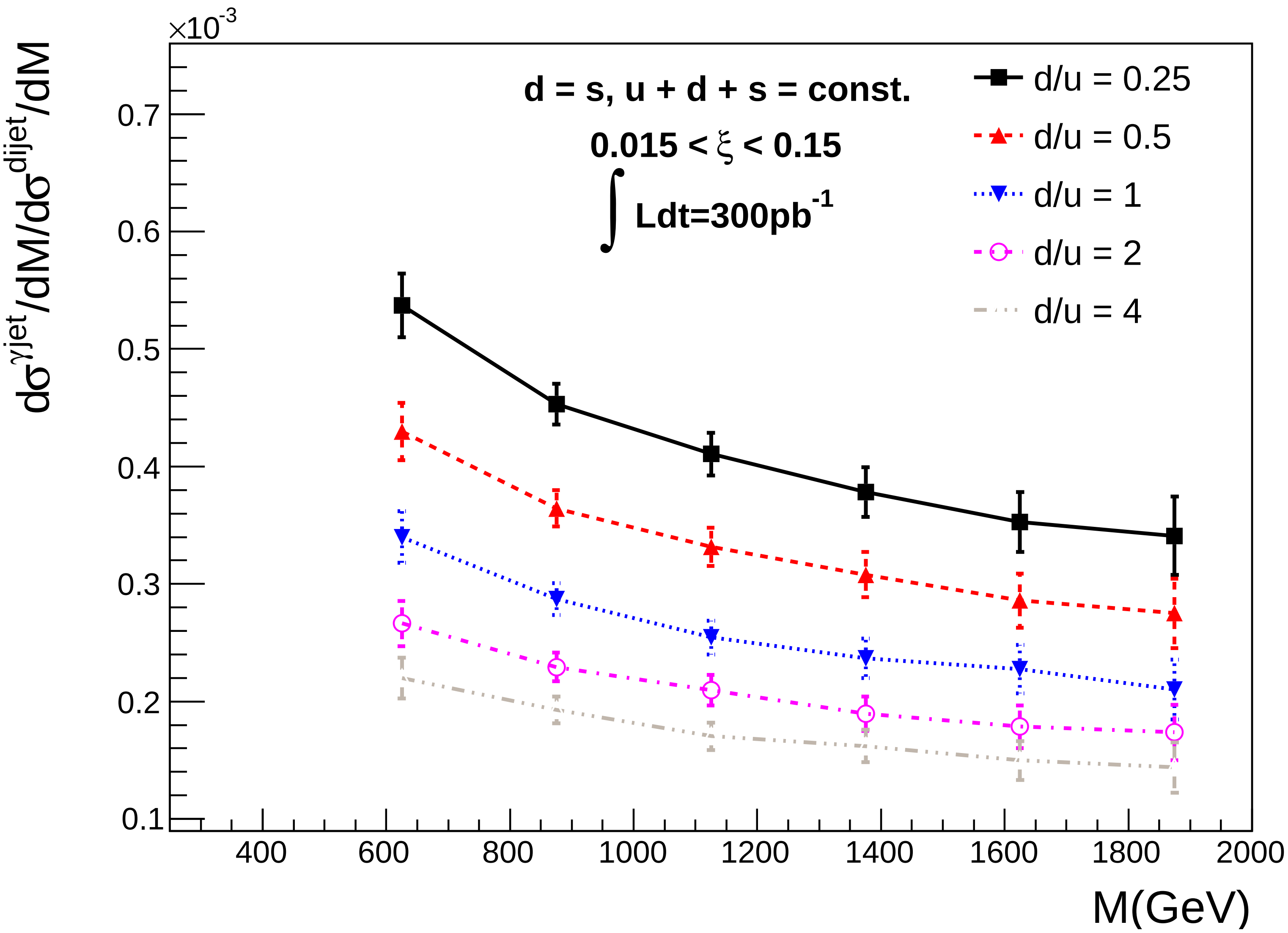
Dijet mass fraction: sensitivity to gluon density

- Dijet mass fraction: dijet mass divided by total diffractive mass $(\sqrt{\xi_1 \xi_2 S})$
- Sensitivity to gluon density in Pomeron especially the gluon density on Pomeron at high β
- Exclusive jet contribution will appear at high dijet mass fraction



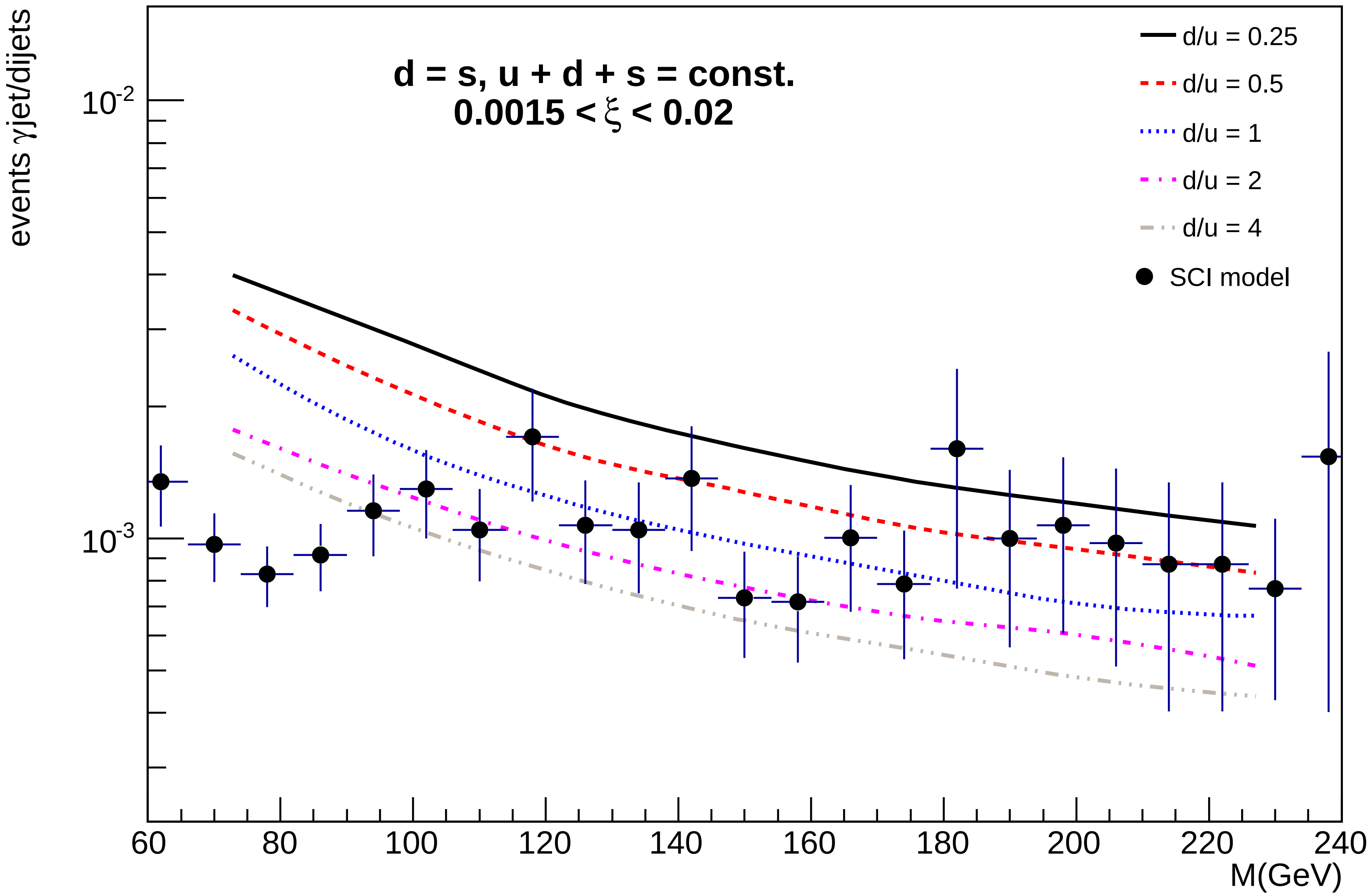
Inclusive diffraction at the LHC: sensitivity to quark densities

- Predict DPE γ+jet divided by dijet cross section at the LHC
- Sensitivity to universality of Pomeron model
- Sensitivity to gluon density in Pomeron, of assumption: $u = d = s = \bar{u} = \bar{d} = \bar{s}$ used in QCD fits at HERA
- C. Marquet, C. Royon, M. Saimpert, D. Werder, in preparation



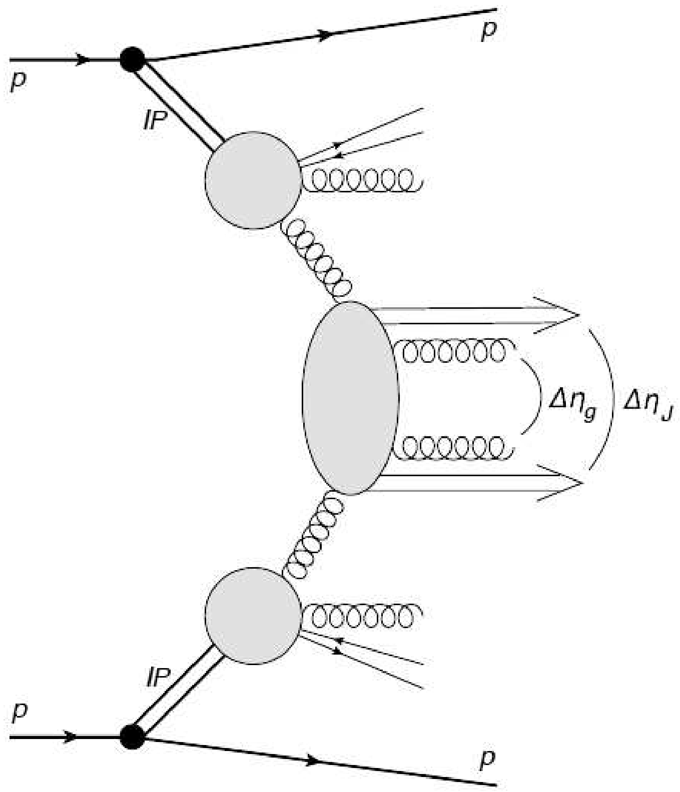
Inclusive diffraction at the LHC: sensitivity to soft colour interaction m

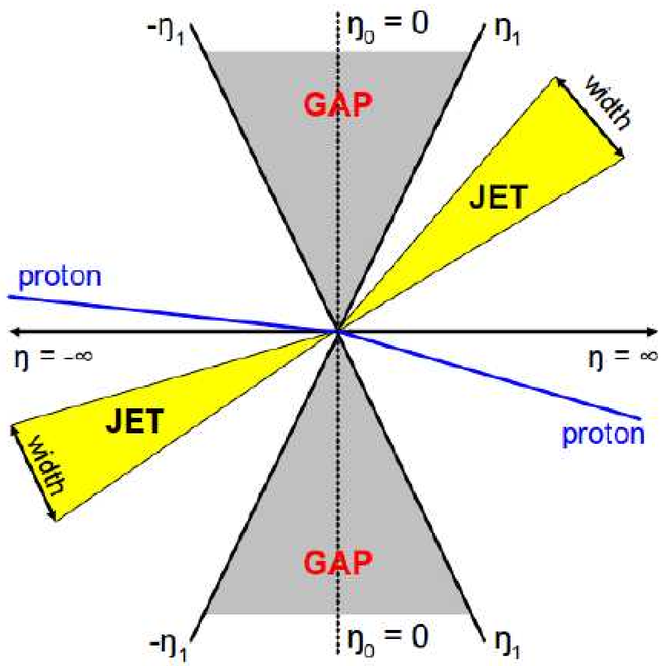
- Predict DPE γ+jet divided by dijet cross section at the LHC for pomeron like and SCI models
- SCI models: alternative model to explain diffraction, fluctuation in the hadronic final state (strings) to obtain "recombined" protons



Jet gap jet events in diffraction

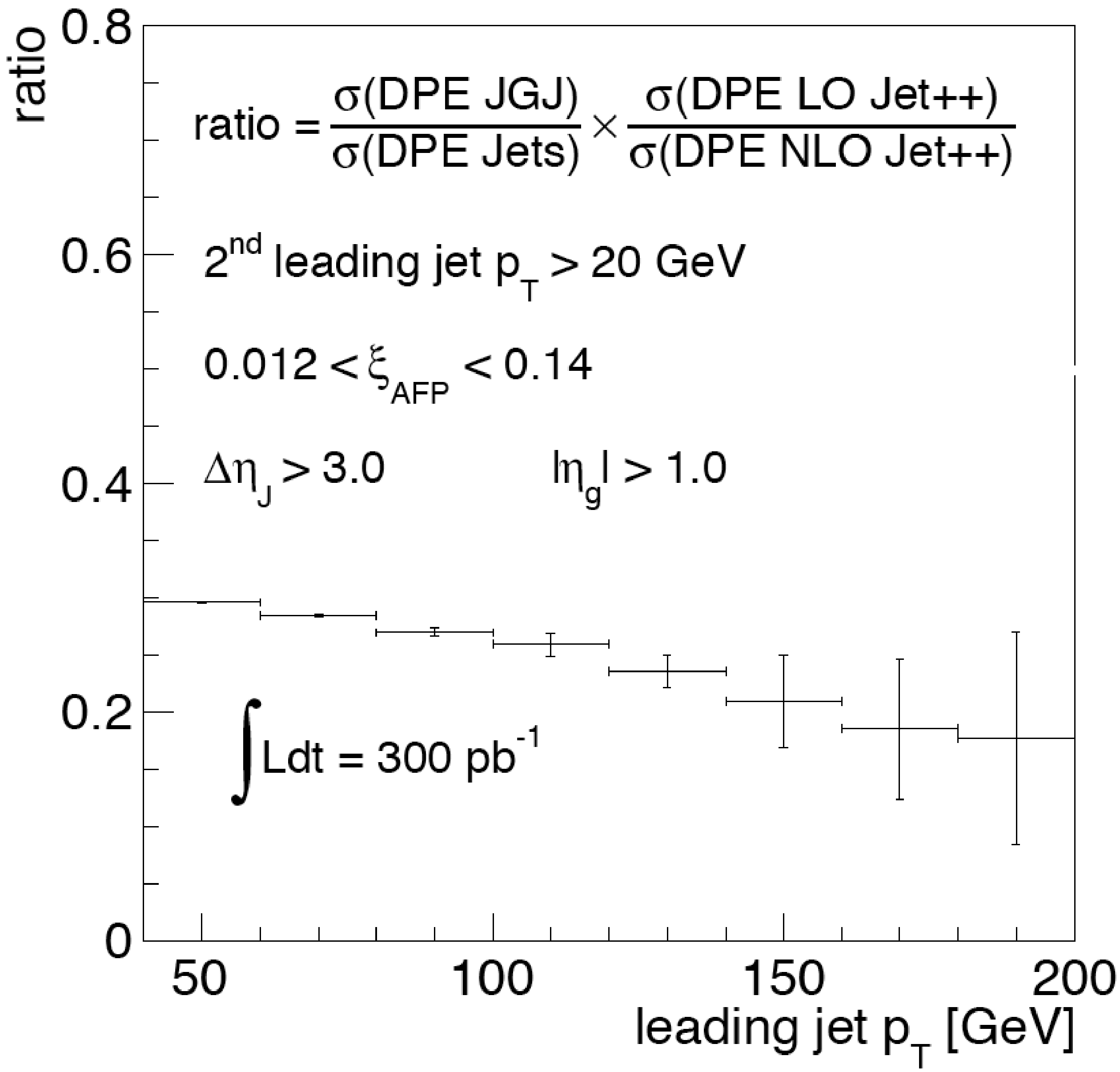
- Study BFKL dynamics using jet gap jet events
- Jet gap jet events in DPE processes: clean process, allows to go to larger $\Delta\eta$ between jets
- See: Gaps between jets in double-Pomeron-exchange processes at the LHC, C. Marquet, C. Royon, M. Trzebinski, R. Zlebcik, ArXiv:1212:2059, accepted by Phys. Rev. D





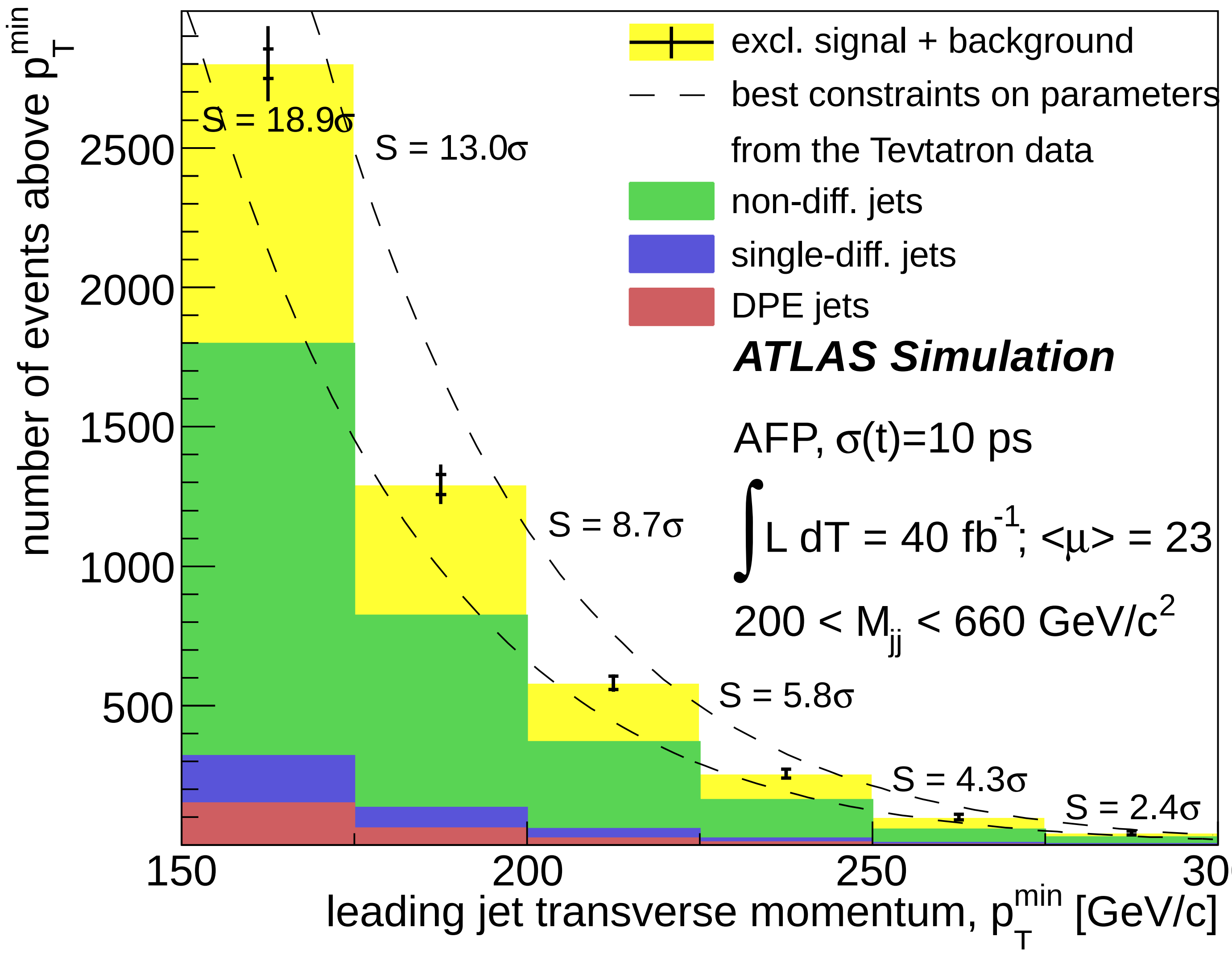
Jet gap jet events in diffraction

- Measure the ratio of the jet gap jet to the dijet cross sections: sensitivity to BFKL dynamics
- As an example, study as a function of leading jet p_T



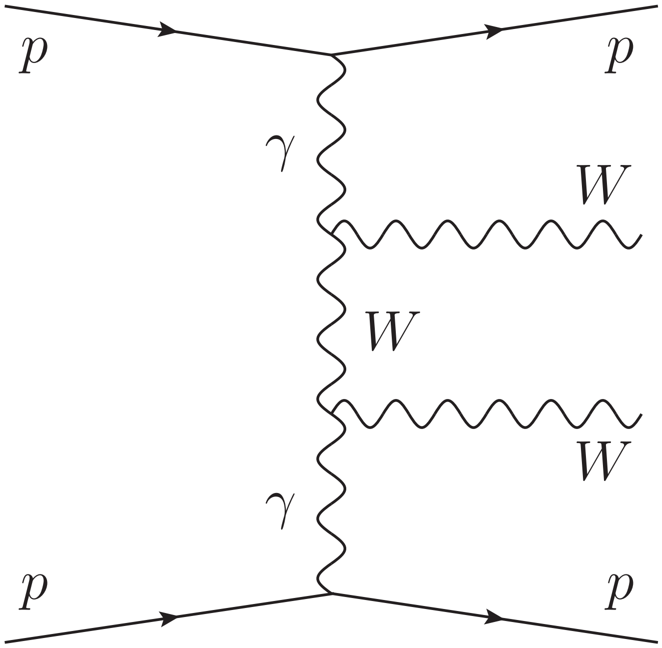
Exclusive jet production at the LHC

- Jet cross section measurements: up to 18.9 σ for exclusive signal with 40 fb^{-1} ($\mu = 23$): highly significant measurement in high pile up environment, improvement over measurement coming from Tevatron (CDF) studies using $\bar{p}$ forward tagging by about one order of magnitude



- Important to perform these measurements to constrain exclusive Higgs production: background/signal ratio close to 1 for central values at 120 GeV

Search for $\gamma\gamma WW$ quartic anomalous coupling



- Study of the process: $pp \to ppWW$
- Standard Model: $\sigma_{WW} = 95.6$ fb, $\sigma_{WW}(W = M_X > 1TeV) = 5.9$ fb
- Process sensitive to anomalous couplings: $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$; motivated by studying in detail the mechanism of electroweak symmetry breaking, predicted by extradim. models
- Many anomalous couplings to be studied (dimension 6 and 8 operators) if Higgs boson is discovered; $\gamma\gamma$ specially interesting
- Rich $\gamma\gamma$ physics at LHC: see E. Chapon, O. Kepka, C. Royon, Phys. Rev. D78 (2008) 073005; Phys. Rev. D81 (2010) 074003

Quartic anomalous gauge couplings

- Quartic gauge anomalous $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings parametrised by a_0^W, a_0^Z, a_C^W, a_C^Z

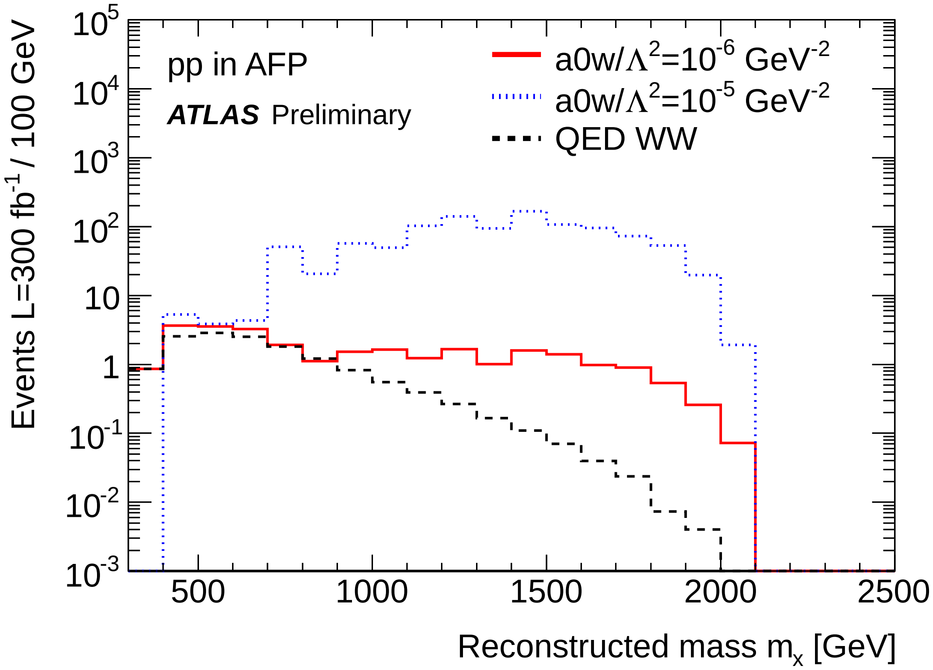
$$\mathcal{L}_6^0 \sim \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W_\alpha^- - \frac{e^2}{16\cos^2(\theta_W)}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

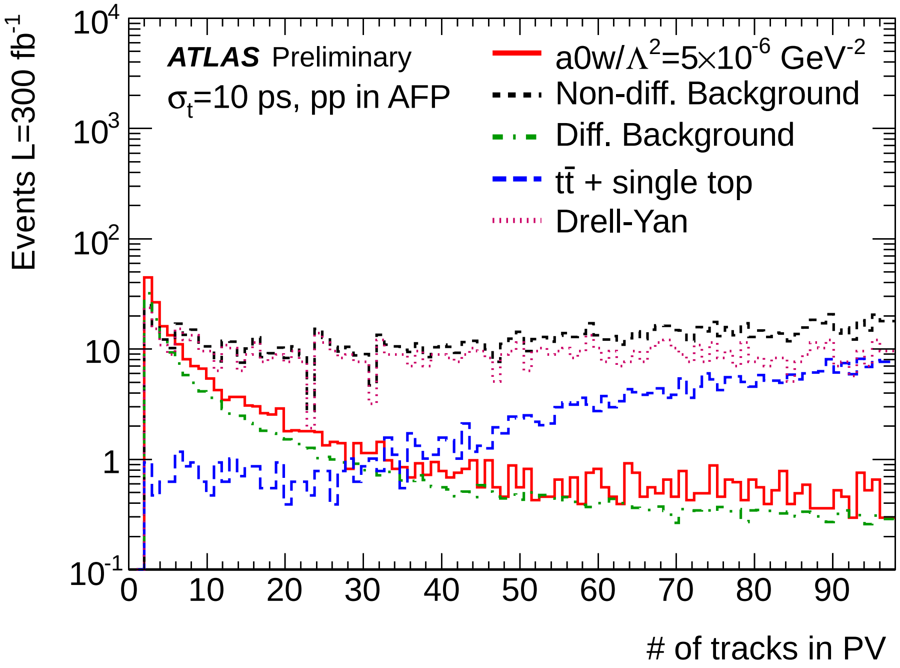
$$\mathcal{L}_6^C \sim \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W_\beta^- + W^{-\alpha}W_\beta^+) - \frac{e^2}{16\cos^2(\theta_W)}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta$$

- Anomalous parameters equal to 0 for SM
- Best limits from LEP, OPAL (Phys. Rev. D 70 (2004) 032005) of the order of 0.02-0.04, for instance $-0.02 < a_0^W < 0.02$ GeV^{-2}
- Dimension 6 operators $\rightarrow$ violation of unitarity at high energies
- Introducing form factors to avoid quadratical divergences of scattering amplitudes due to anomalous couplings in conventional way: $a_0^W/\Lambda^2 \rightarrow \frac{a_0^W/\Lambda^2}{(1+W\gamma\gamma/\Lambda_{cutoff})^2}$ with $\Lambda_{cutoff} \sim 2$ TeV, scale of new physics

Anomalous couplings studies in WW events

- Reach on anomalous couplings studied using a full simulation of the ATLAS detector, including all pile up effects; only leptonic decays of Ws are considered
- Signal appears at high lepton p_T and dilepton mass (central ATLAS) and high diffractive mass (reconstructed using forward detectors)
- Cut on the number of tracks fitted to the primary vertex: very efficient to remove remaining pile up after requesting a high mass object to be produced (for signal, we have two leptons coming from the W decays and nothing else)





Results from full simulation

- Reaches the values expected for extradim models (C. Grojean, J. Wells)

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

Table 9.5. Number of expected signal and background events for 300 fb^{-1} at pile-up $\mu = 46$. A time resolution of 10 ps has been assumed for background rejection. The diffractive background comprises production of QED diboson, QED dilepton, diffractive WW, double pomeron exchange WW.

- **Improvement of "standard" LHC methods by studying $pp \to l^\pm \nu\gamma\gamma$ (see P. J. Bell, ArXiV:0907.5299) by more than 2 orders of magnitude with 40/300 fb^{-1} at LHC**

	5σ	95% CL	LEP limit
$\mathcal{L} = 40\ fb^{-1}, \mu = 23$ $\mathcal{L} = 300\ fb^{-1}, \mu = 46$	5.5 10^{-6} 3.2 10^{-6}	2.4 10^{-6} 1.3 10^{-6}	0.02

Reach at LHC

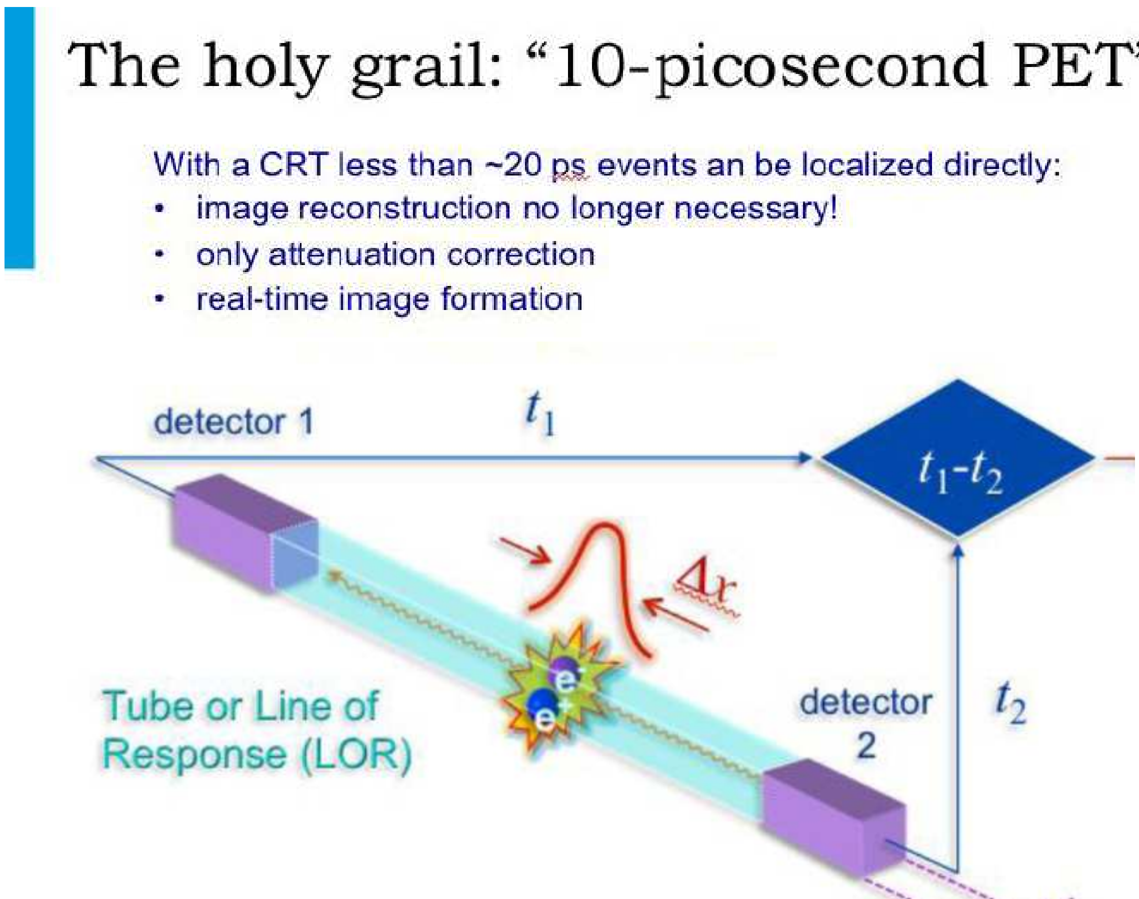
Reach at high luminosity on quartic anomalous coupling using fast simulation (study other anomalous couplings, ZZ...)

Couplings	OPAL limits $[\text{GeV}^{-2}]$	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]	$5.2\ 10^{-5}$ ($2.0\ 10^{-5}$)	$2.4\ 10^{-5}$ ($9.2\ 10^{-6}$)

- Improvement of LEP sensitivity by more than 4 orders of magnitude with 30/200 fb^{-1} at LHC
- Reaches the values predicted by Higgsless/extradimension models
- Semic leptonic decays under study: looks promising, 1 order of magnitude gain with respect to pure leptonic decays, full simulation study under progress

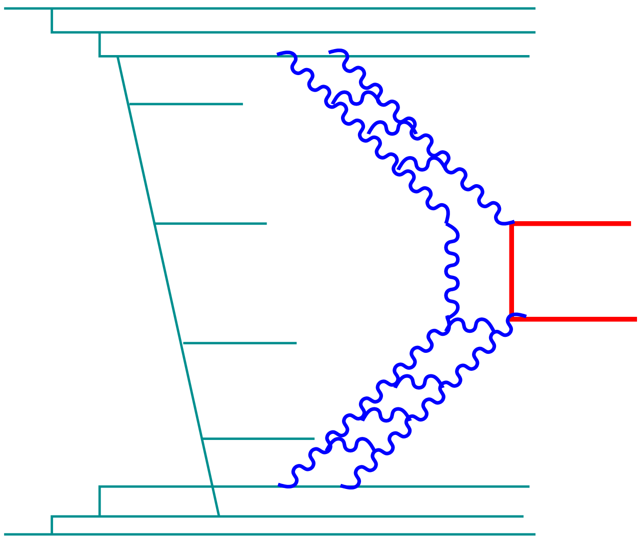
Conclusion

- Detecting intact protons at the LHC: increases the physics potential of LHC experiments
- QCD: understanding the Pomeron structure in terms of quarks and gluon (constrain for the first time the quark densities in Pomeron), universality of Pomeron between ep and pp colliders
- Jet gap jets in diffraction: probe BFKL dynamics
- Search for anomalous couplings between γ, W, Z: best sensitivity reachable at the LHC
- Many applications of the detector itself (see AFP talk by Maciej) especially in PET imaging detectors and measurement of doses

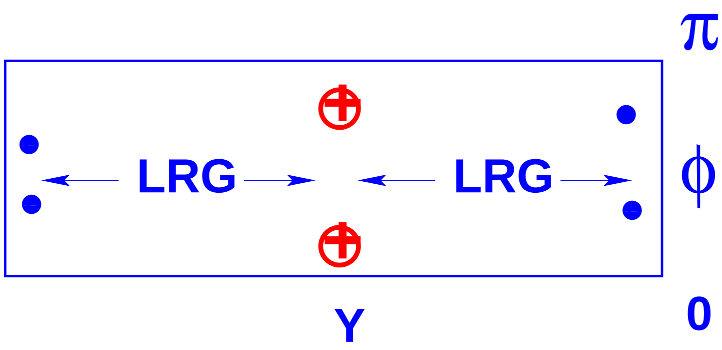


Factorisation at Tevatron/LHC?

- Is factorisation valid at Tevatron/LHC? Can we use the parton densities measured at HERA to use them at the Tevatron/LHC?
- Factorisation is not expected to hold: soft gluon exchanges in initial/final states
- Survival probability: Probability that there is no soft additional interaction, that the diffractive event is kept
- Value of survival probability assumed in these studies: 0.1 at Tevatron (measured), 0.03 at LHC (extrapolated)



a)



b)