Physics with tagged protons at the LHC: understanding the Pomeron structure and anomalous coupling studies

Christophe Royon
IRFU-SPP, CEA Saclay

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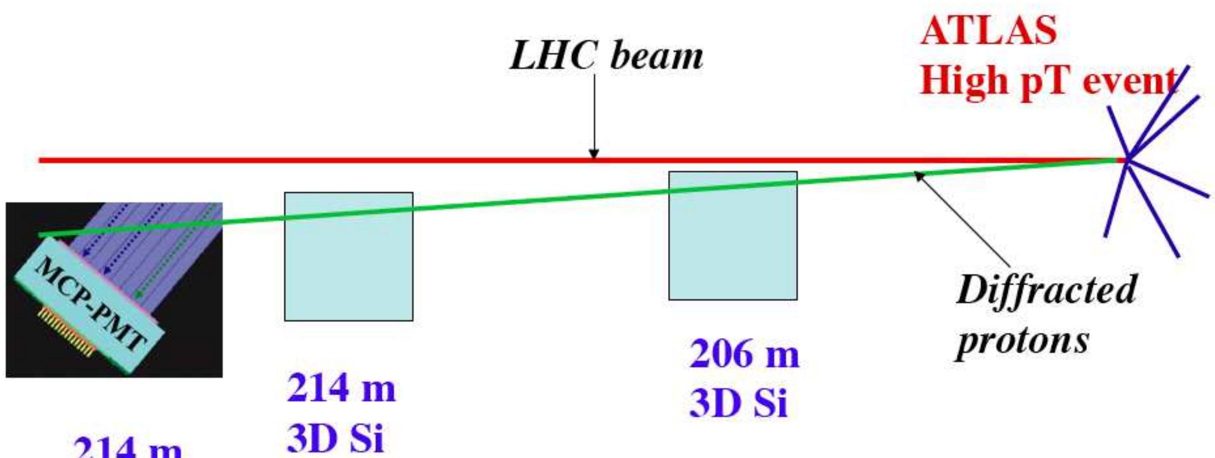
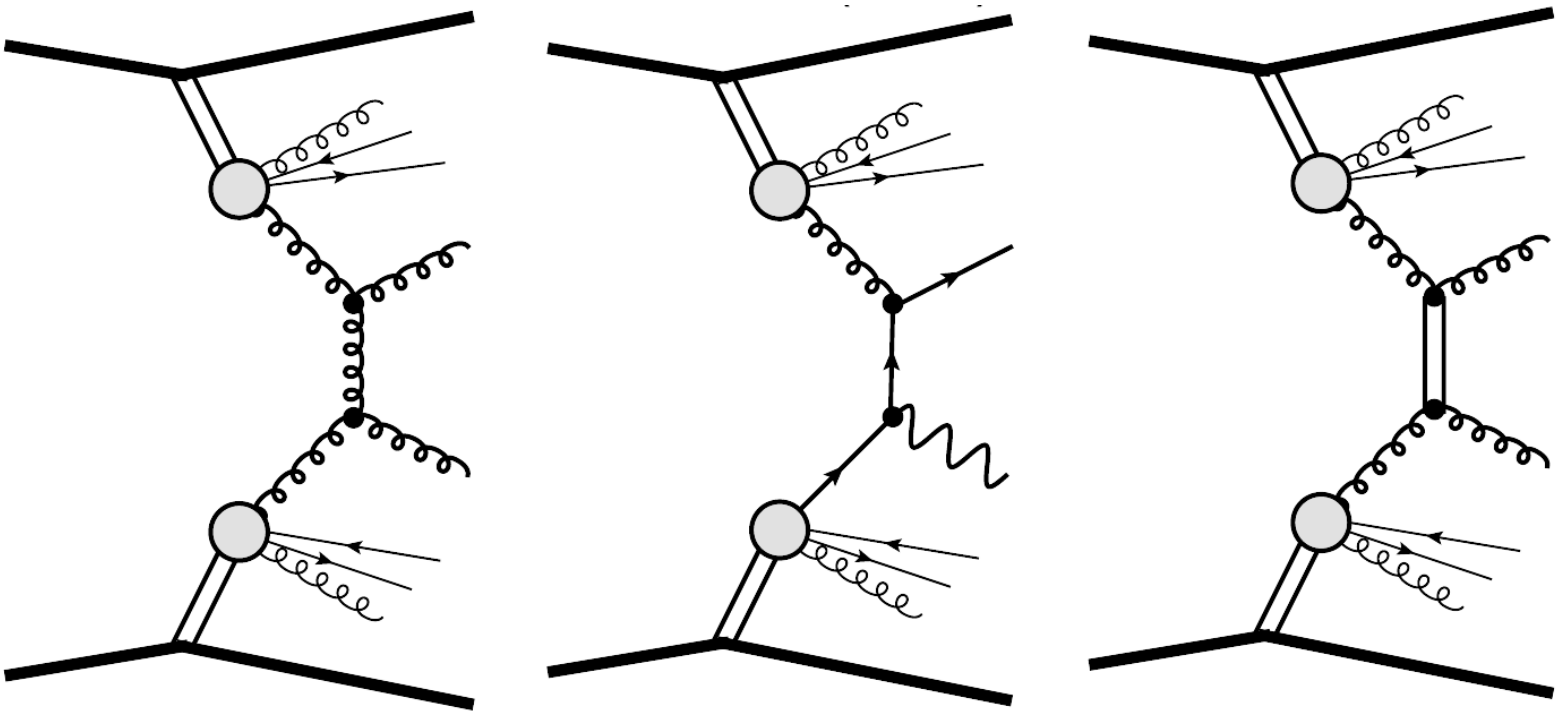
Contents:

- DPE dijets
- DPE γ+jet
- Soft colour interaction models
- Jet gap jets
- Anomalous couplings (short discussion)



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, arXiv:1306.4901
- 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

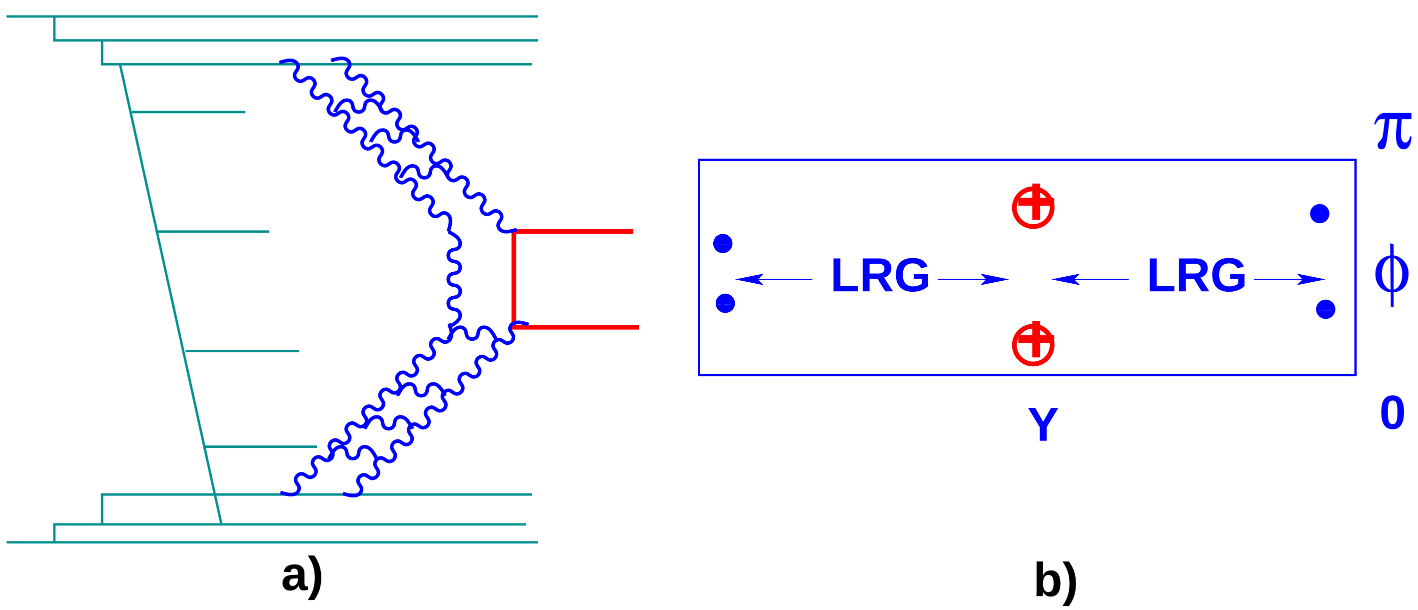


Forward Physics Monte Carlo (FPMC)

- 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

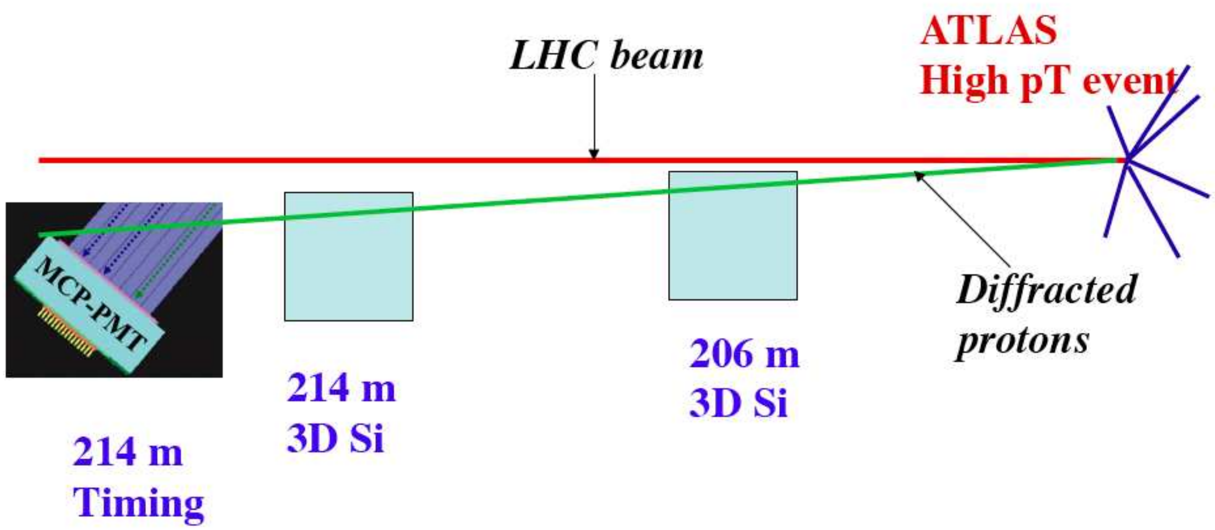
Factorisation at Tevatron/LHC?

- 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)

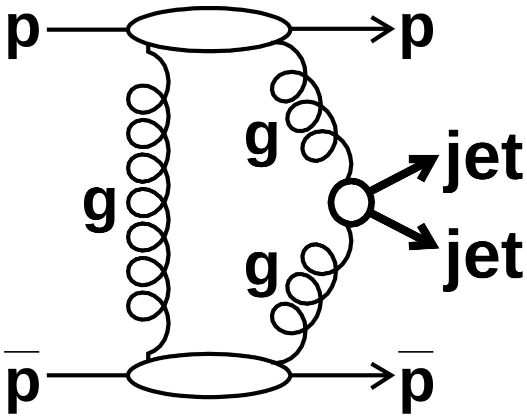


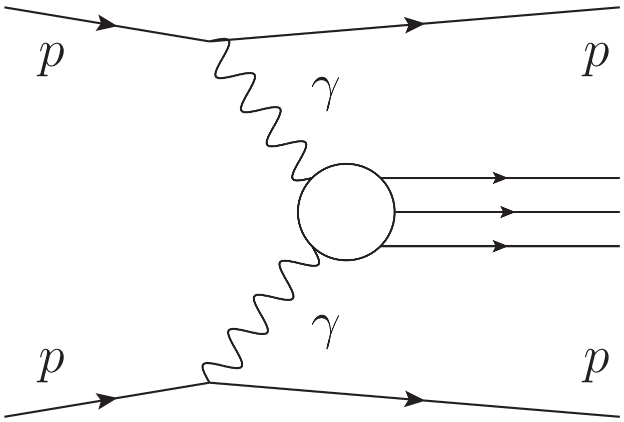
AFP detectors

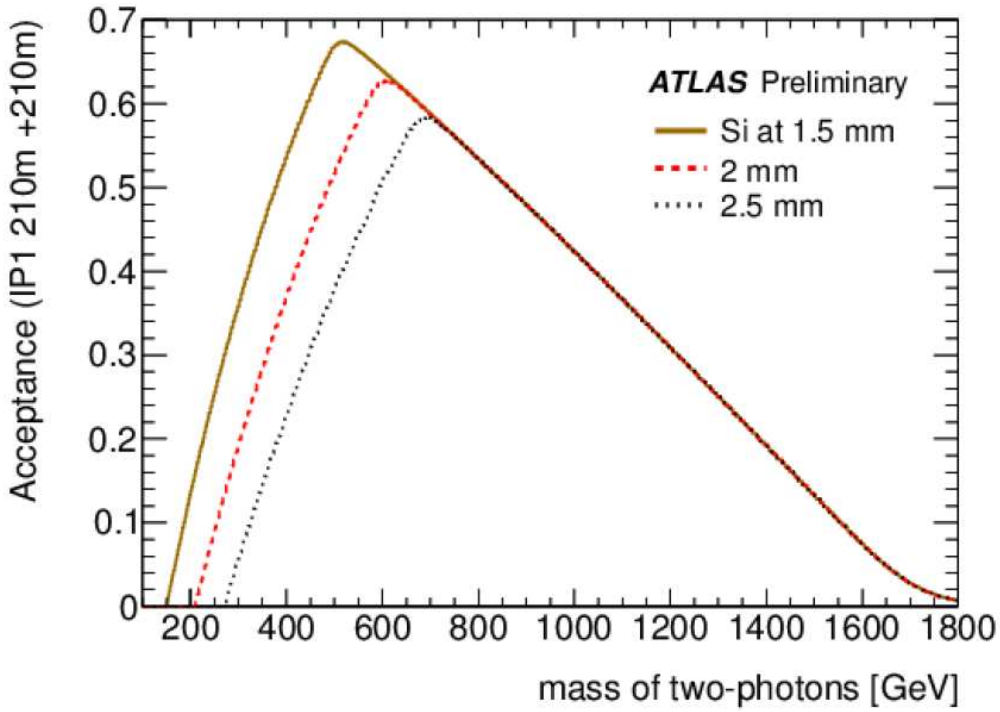
- In the following, we assume protons to be tagged in AFP:
  - 210 m detectors: $0.015 < \xi < 0.15$
  - 210 and 420 m detectors: $0.0015 < \xi < 0.15$
- No reggeon exchange was introduced in this study, only Pomeron; Reggeons are assumed to dominate only above $\xi > 0.1$
- Measurement assumed to be performed at low luminosity, no pile up was introduced: possibility of using low pile up runs (3-5)?
- Trigger possibilities:
  - For $\gamma +$ jet, trigger on γ in central detector
  - For dijets, trigger on leading jet and on protons in AFP (timing detector gives the trigger)



AFP acceptance in total mass



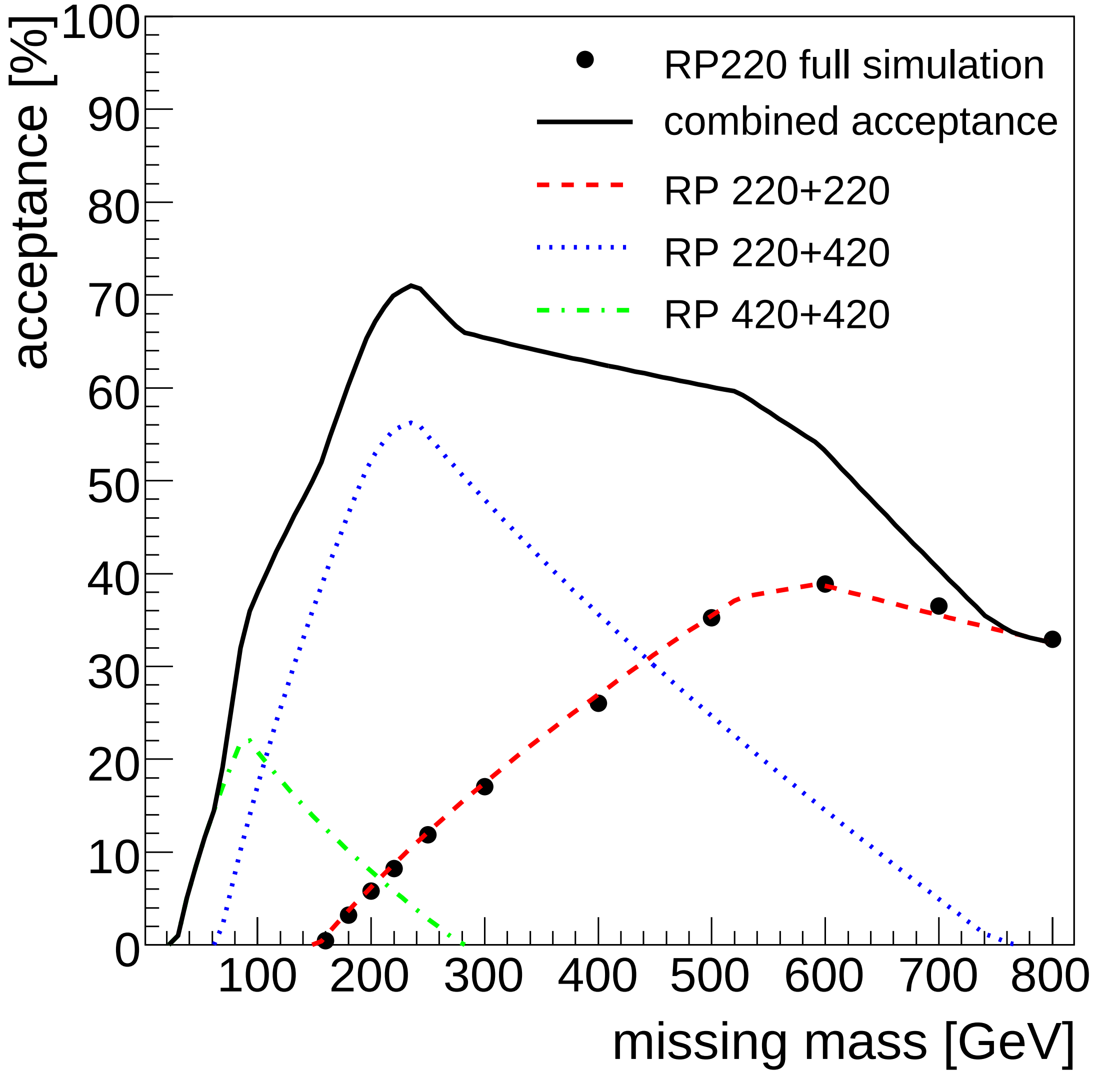




- Increase sensitivity to (new) physics in ATLAS due to color singlet or photon exchanges
- Sensitivity to high mass central system, X, as determined using AFP
- Very powerful for exclusive states: kinematical constraints coming from AFP proton measurements

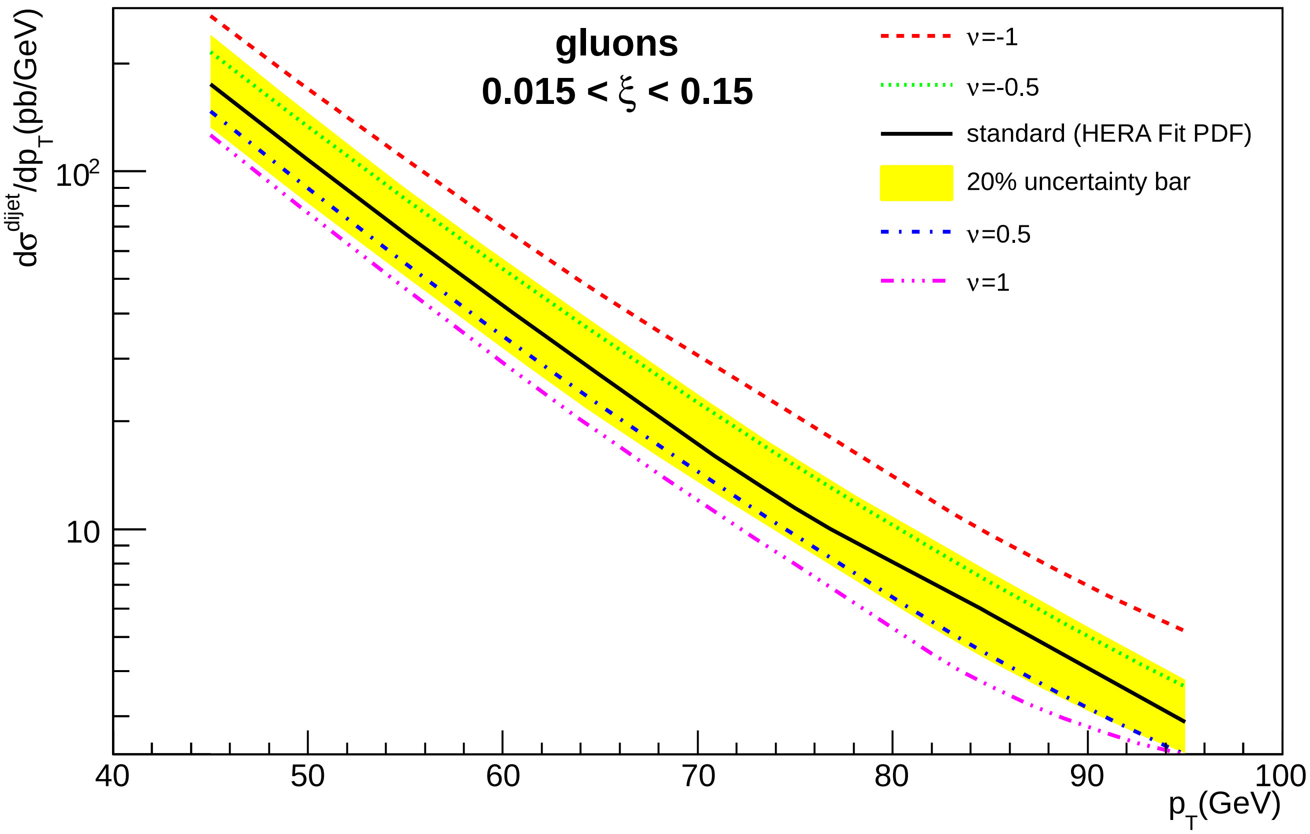
Possible upgrades of AFP

- Detectors at 420 and 220 allow to increase the acceptance at low masses (NB: acceptance slightly smaller in CMS than in ATLAS)
- Possibility to increase the acceptance at high mass by having additional detectors close to ATLAS



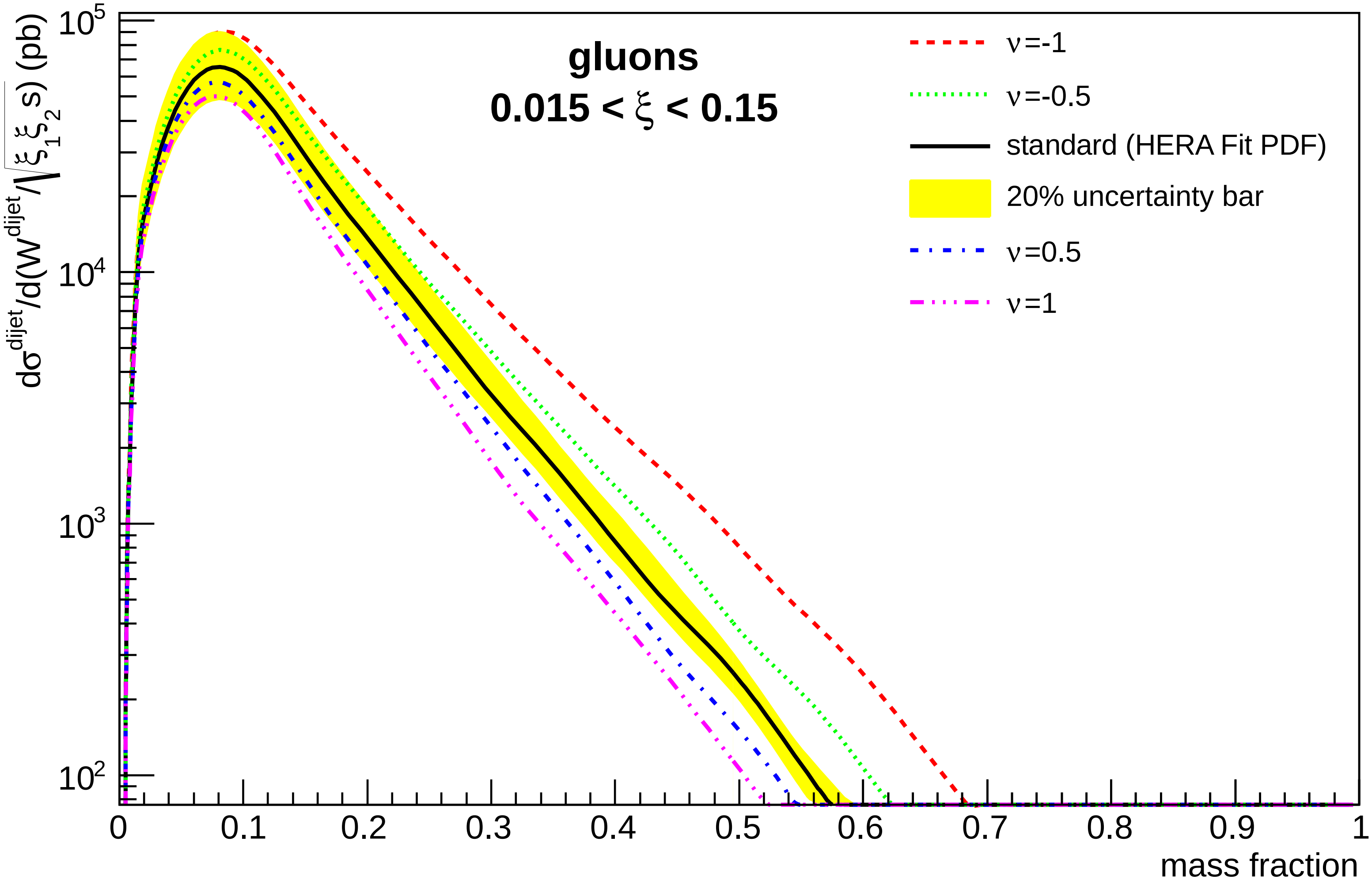
Inclusive diffraction at the LHC: sensitivity to gluon density

- Predict DPE dijet cross section at the LHC in AFP acceptance, jets with $p_T >$20 GeV, reconstructed at particle level using anti-k$_T$ algorithm
- 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 10 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



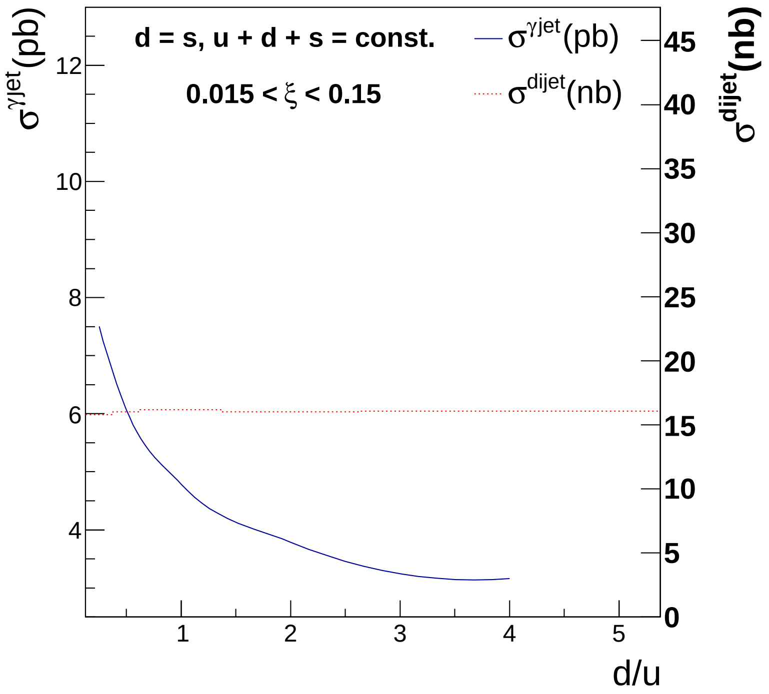
Dijet mass fraction: sensitivity to gluon density

- 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



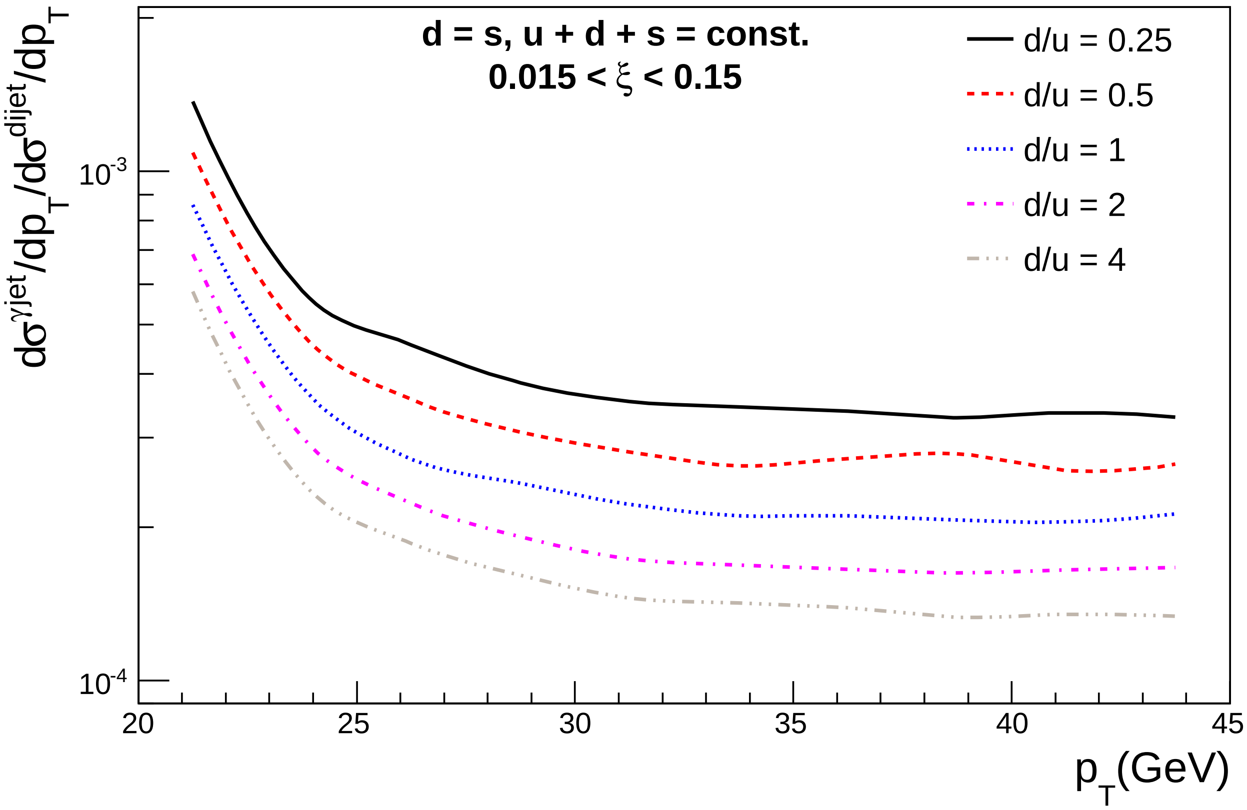
Inclusive diffraction at the LHC: sensitivity to quark densities

- γ+jet and dijet cross sections as a function of d/u in the acceptance of AFP (210 and 210+420 m detectors)
- As expected, the dijet cross section remains constant, whereas the $\gamma+$ jet cross section varies by a factor 2.5
- Jets and photon at particle level with $p_T >$20 GeV



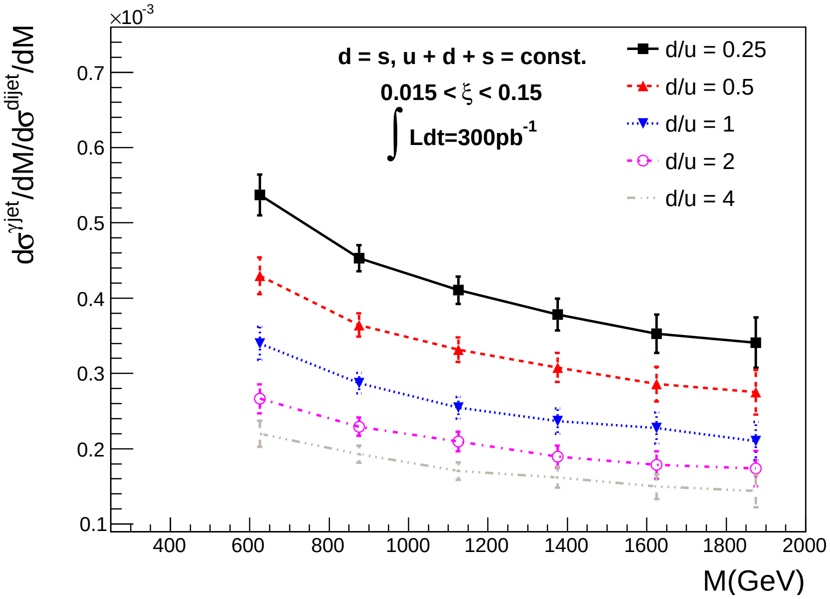
Inclusive diffraction at the LHC: sensitivity to quark densities

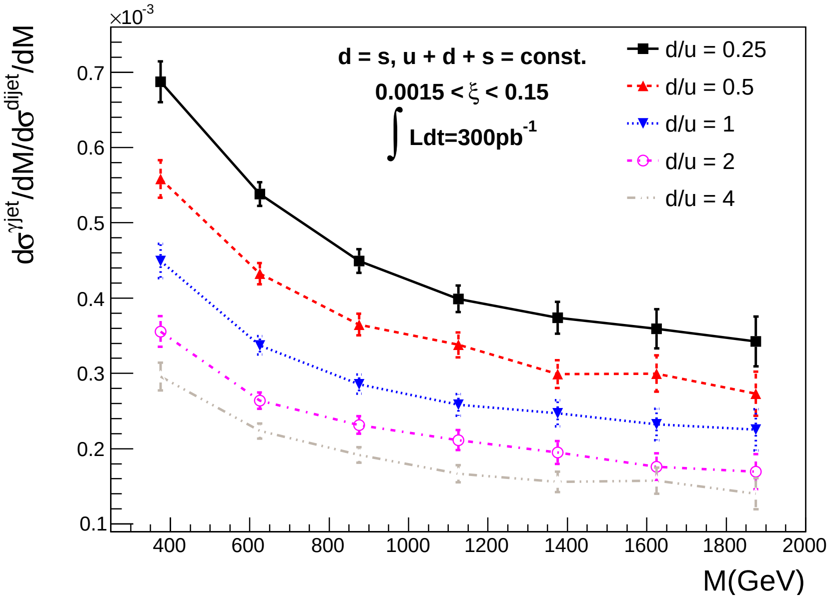
- γ+jet to dijet cross section ratio as a function of leading jet p_T for different d/u quark contents in the Pomeron: factor 2.5 between different quark densities
- Similar results in 210 or 210+420 m AFP detectors



Inclusive diffraction at the LHC: sensitivity to quark densities

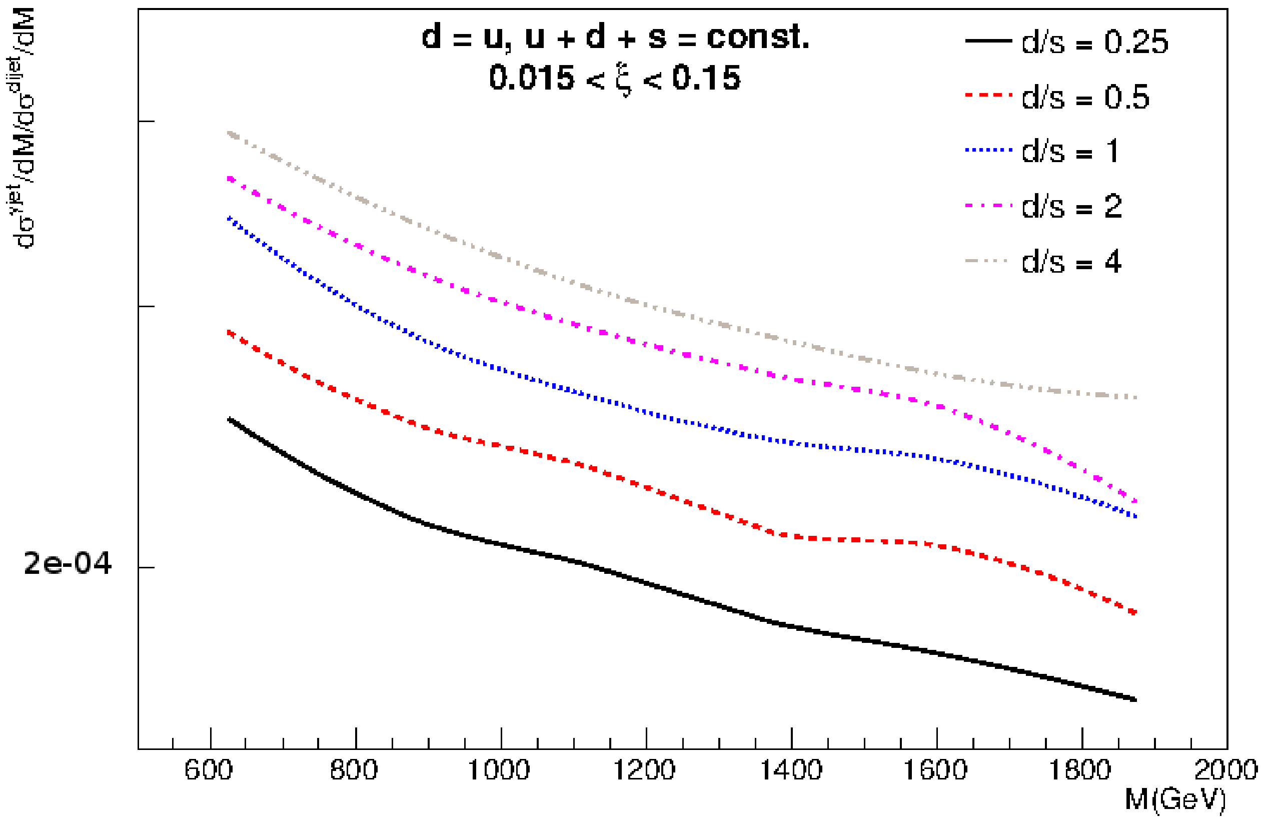
- Predict DPE γ+jet divided by dijet cross section at the LHC
- Sensitivity to universality of Pomeron model
- Sensitivity to gluon density in Pomeron, of assumption: $u = d = s = \bar{u} = \bar{d} = \bar{s}$ used in QCD fits at HERA





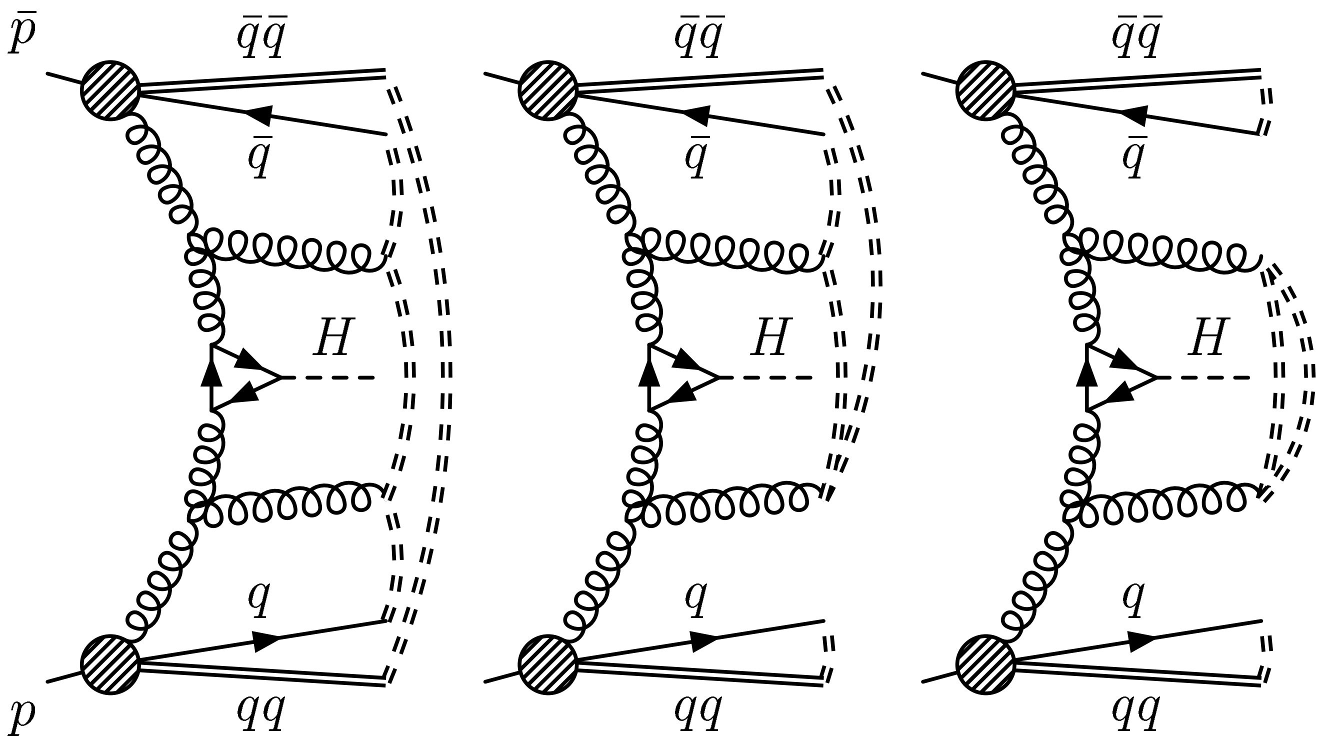
Inclusive diffraction at the LHC: sensitivity to quark densities

- γ+jet to dijet cross section ratio as a function of leading jet p_T for different d/s quark contents in the Pomeron: factor 1.5 between different quark densities
- Similar results in 210 or 210+420 m AFP detectors



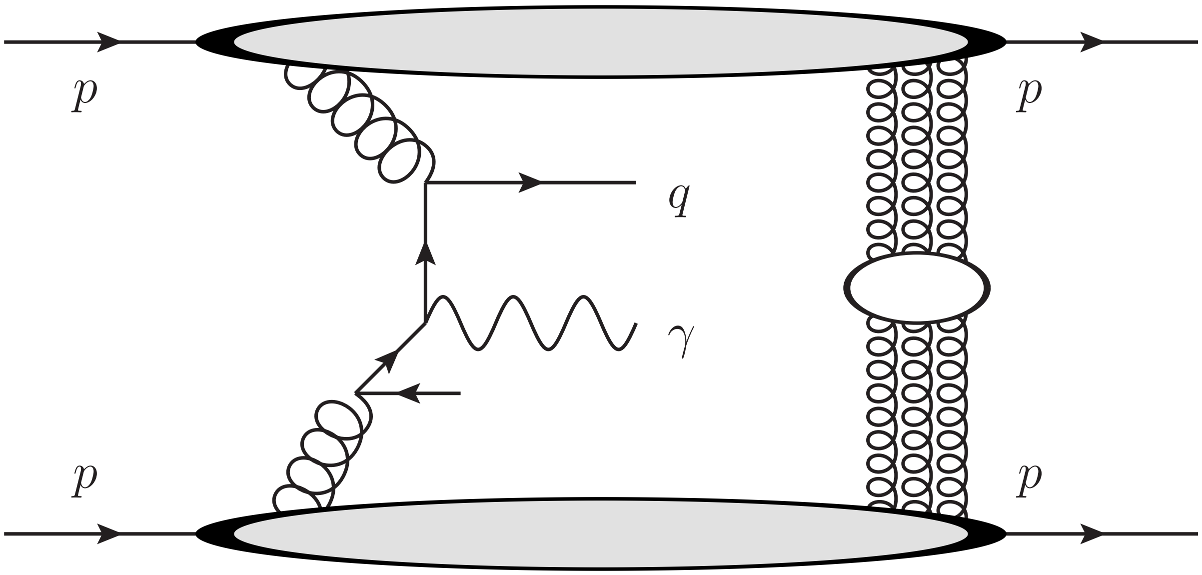
Soft Colour Interaction models

- A completely different model to explain diffractive events: Soft Colour Interaction (R.Enberg, G.Ingelman, N.Timneanu, hep-ph/0106246)
- Principle: Variation of colour string topologies, giving a unified description of final states for diffractive and non-diffractive events
- No survival probability for SCI models



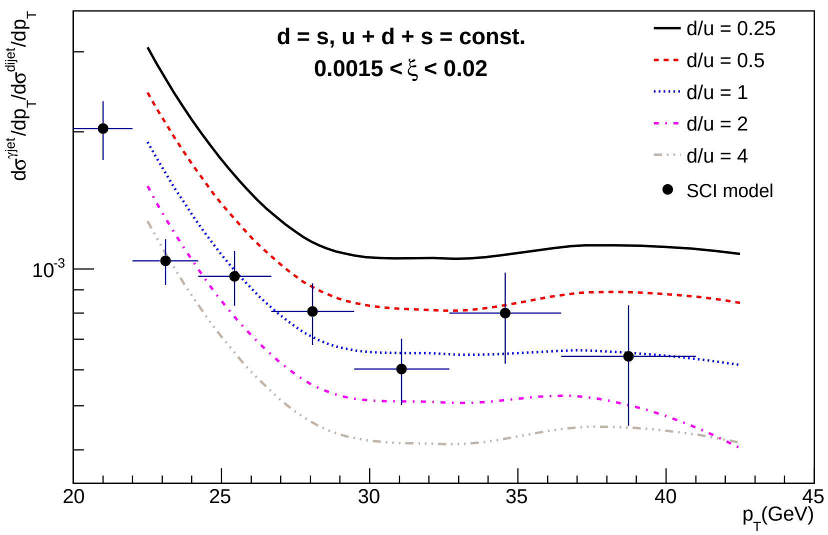
Soft colour interaction

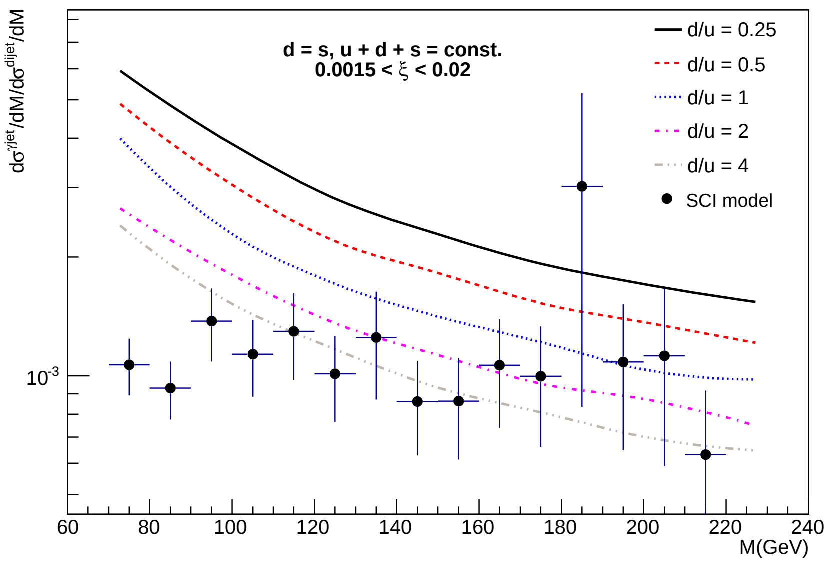
- Scheme of SCI production of γ+jet event as an example
- The advantage of SCI events is that they do not any additional factors sur as survival probability to explain the differences between HERA and Tevatron/LHC
- Very interesting to know if some observables allow to distinguish between both models at the LHC



Inclusive diffraction at the LHC: sensitivity to soft colour interaction

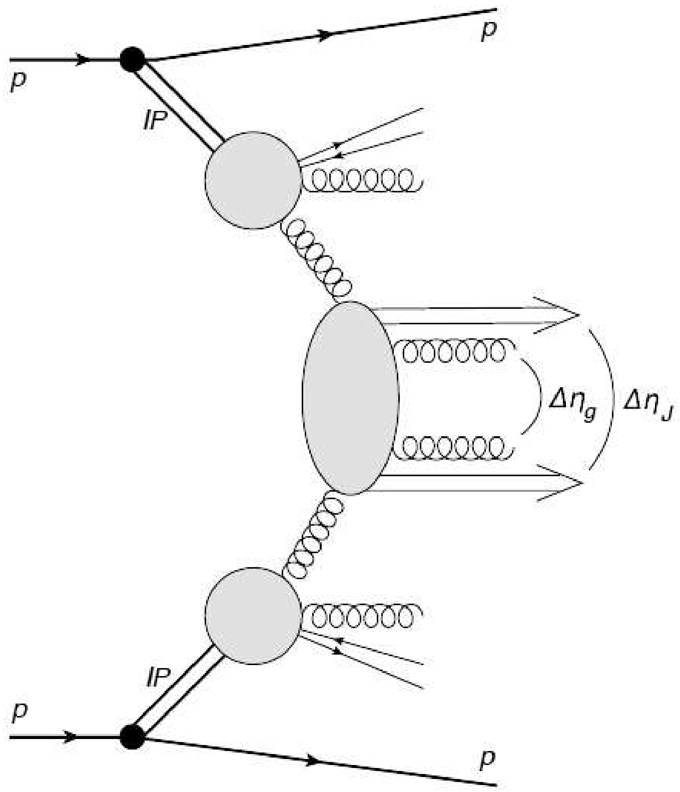
- Predict DPE γ+jet divided by dijet cross section at the LHC for pomeron like and SCI models
- In particular, the diffractive mass distribution (the measurement with lowest systematics) allows to distinguish between the two sets of models: flat distribution for SCI

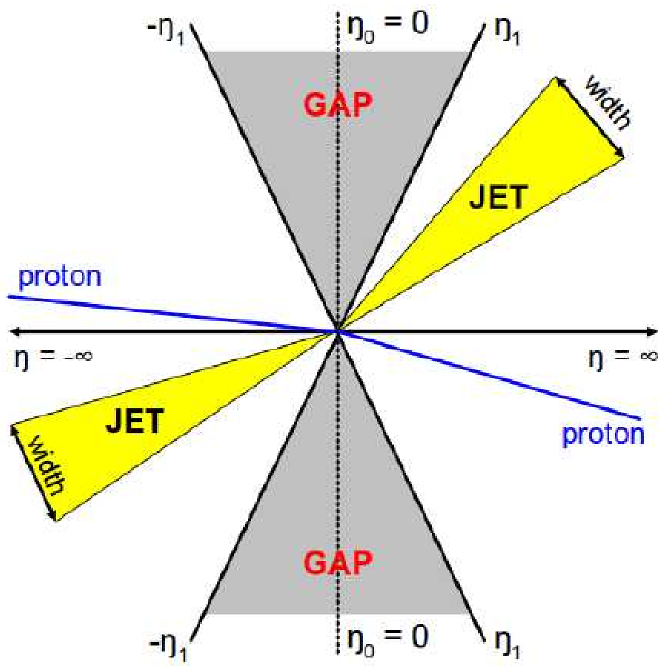




Jet gap jet events in diffraction

- 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

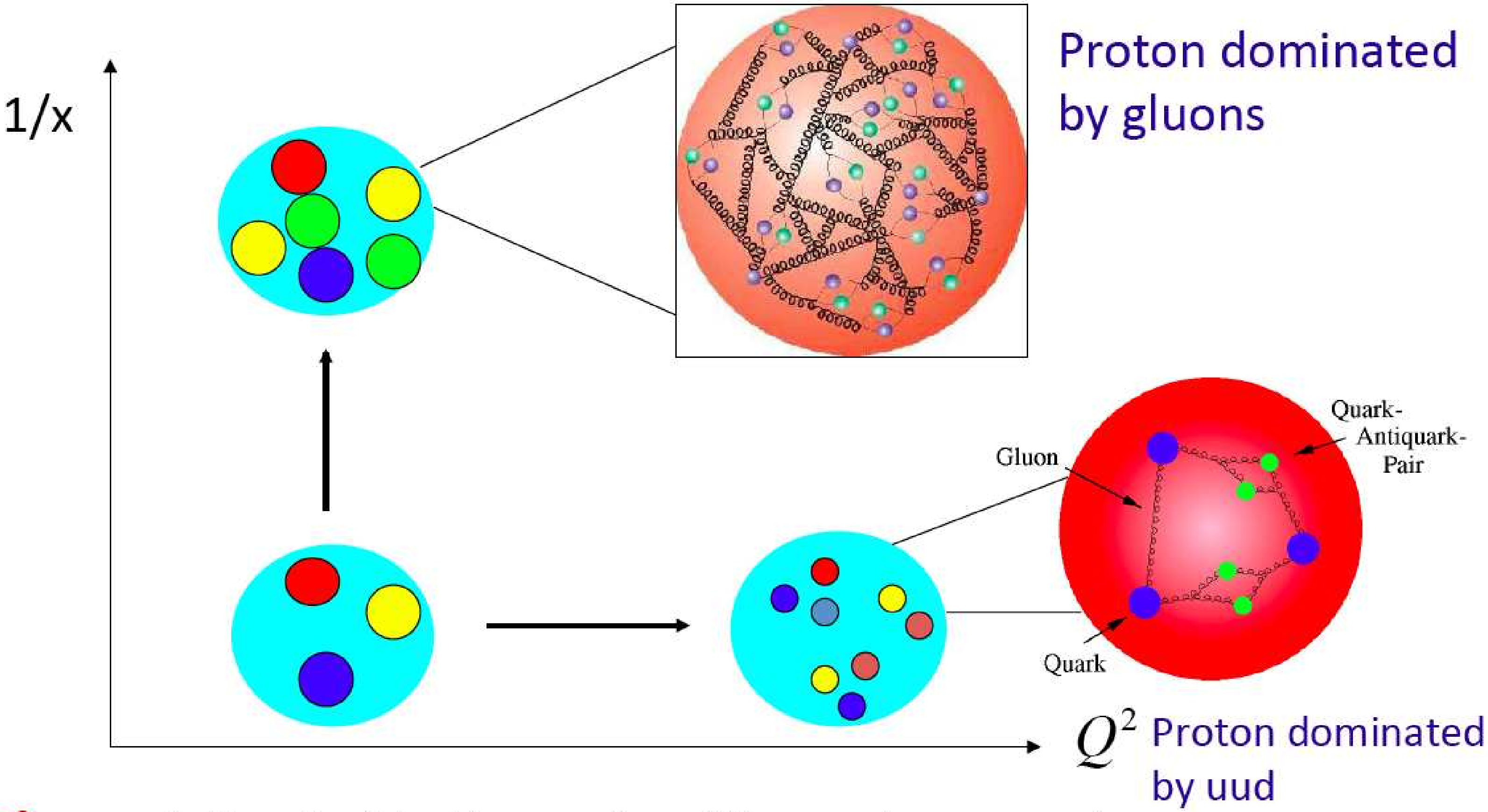




Looking for BFKL effects

- Dokshitzer Gribov Lipatov Altarelli Parisi (DGLAP): Evolution in Q^2
- Balitski Fadin Kuraev Lipatov (BFKL): Evolution in x

Aim: Understanding the proton structure (quarks, gluons)

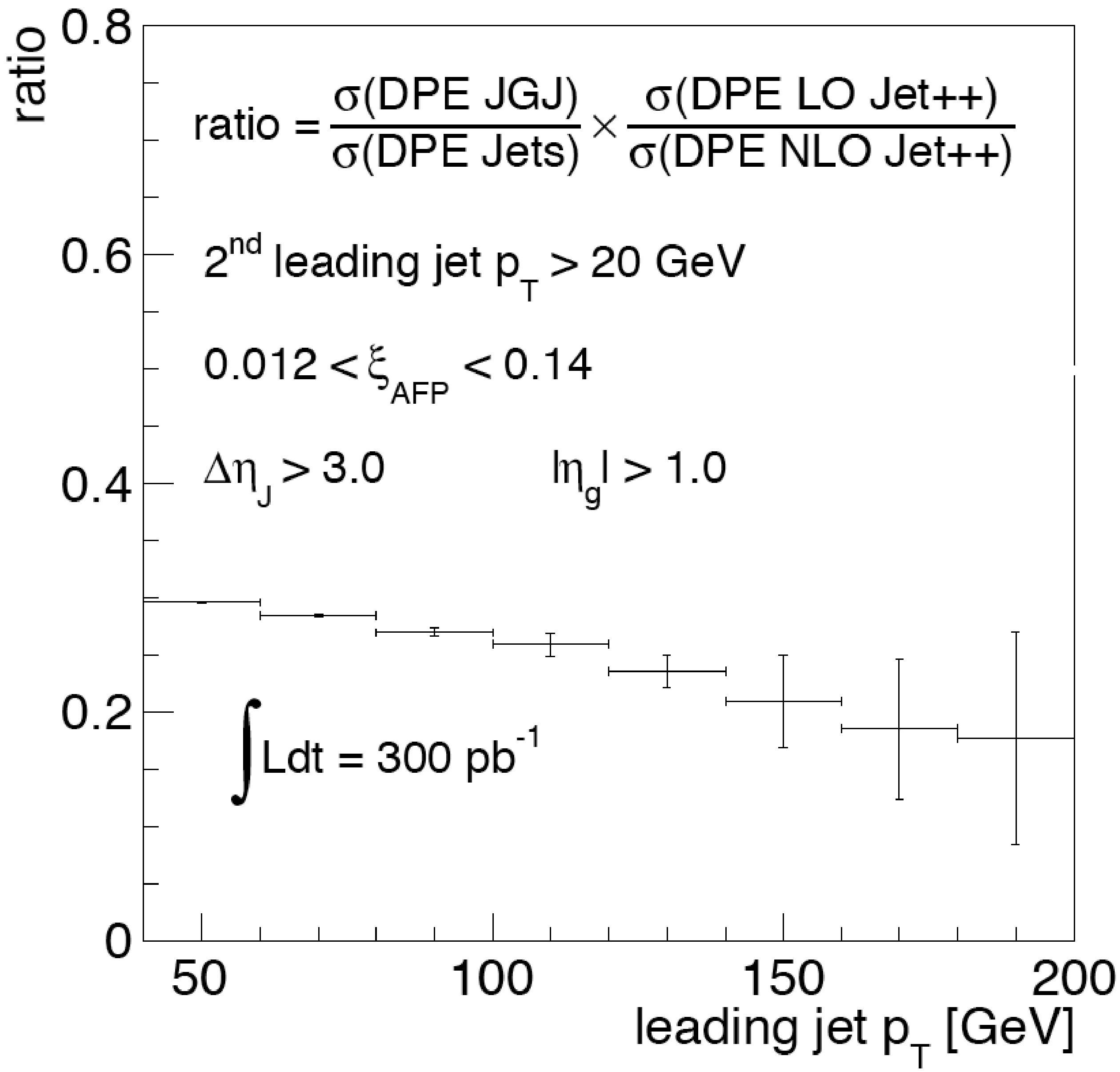


Q^2 : resolution inside the proton (like a microscope)

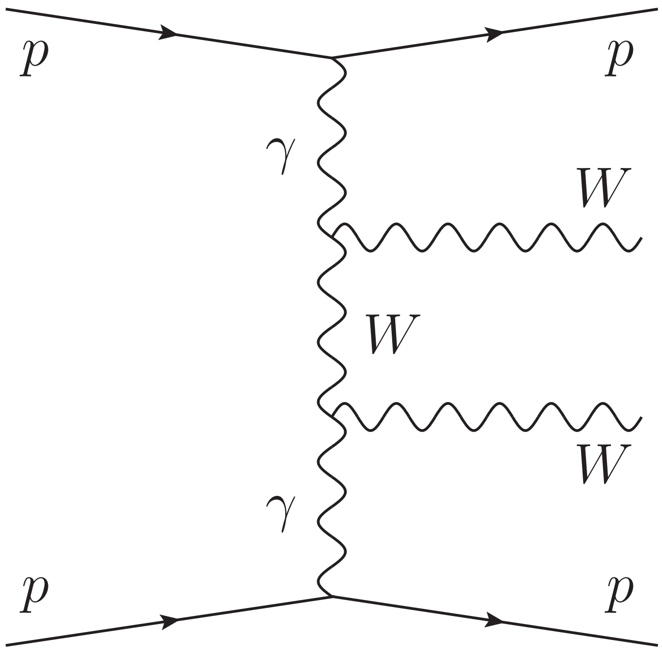
x :Proton momentum fraction carried away by the interacting quark

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



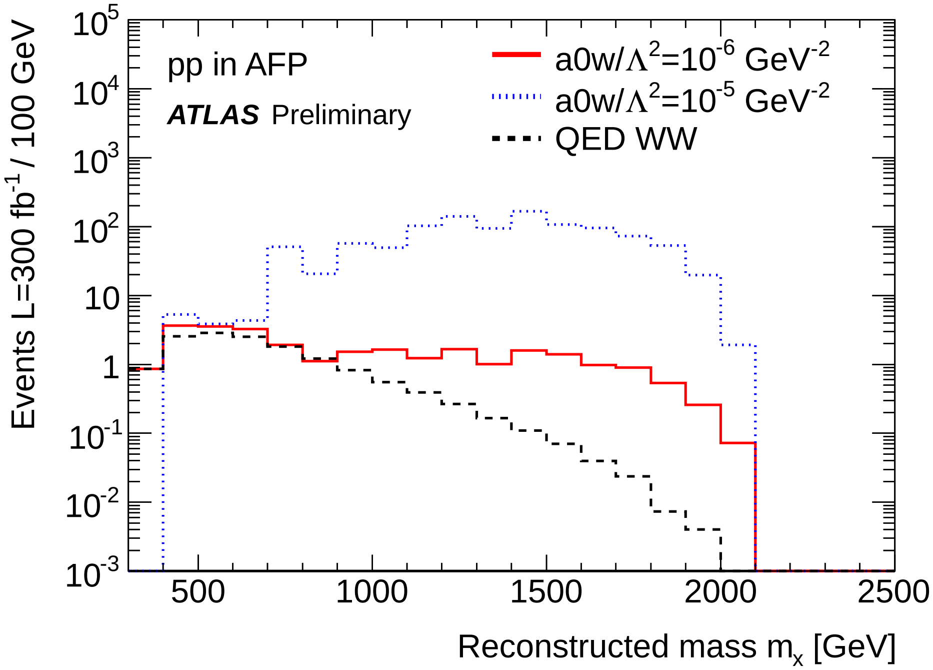
Search for $\gamma\gamma WW$ quartic anomalous coupling

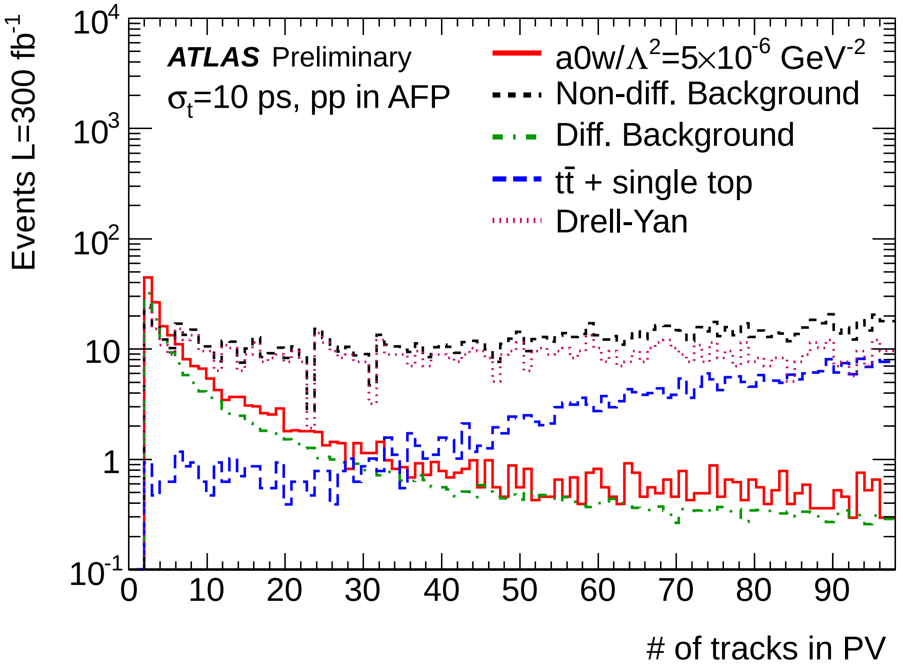


- Study of the process: $pp \to ppWW$
- Standard Model: $\sigma_{WW} = 95.6$ fb, $\sigma_{WW}(W = M_X > 1TeV) = 5.9$ fb
- Process sensitive to anomalous couplings: $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$; motivated by studying in detail the mechanism of electroweak symmetry breaking,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

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 $pp \rightarrow l^{\pm}\nu\gamma\gamma$ (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 [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

- Study in detail the Pomeron structure at hadronic colliders and compare with results obtained at HERA/Tevatron: it might be that hard diffractive events are due to Pomeron and also to soft exchanges (combination of the two)
- Dijet data and especially dijet mass fraction sensitive to the gluon density in Pomeron
- Ratio γ+jet to dijet cross sections sensitive to quark structure in the Pomeron, especially as a function of diffractive mass computed using forward detectors (smallest systematics)
- Strategy: Measure dijet and $\gamma +$ jet cross section, compare with HERA expectations; if differences are observed, redo HERA QCD fits with new assumptions; if incompatible, different Pomerons at ep and pp colliders
- Possibility to distinguish between SCI and Pomeron like models
- For more information: C. Marquet, C. Royon, M. Saimpert, D. Werder, arXiv:1306.4901
- Study jet gap jet events in DPE exchanges: clean test of BFKL evolution
- Clean test of electroweak symmetry breaking mechanism: measurement of $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$ couplings

Soft colour interaction

- ξ distribution of DPE jet events (similar distributions for SD and production of W/Z, min. bias events...
- SCI events dominate at LHC energies below 2-3 10^{-2} and "background" originating from Pythia above
- We choose to compare SCI and DPE models applying a cut on $\xi \leq 0.02$ to be in a "safe" region for SCI
- The exact value of ξ when the transition from SCI to "background" occurs needs some tuning: For CDF, SCI models predict this transition to occur also at $\xi \sim 0.02$ whereas the data show a transition at $\xi \sim 0.08$-0.1; it means that this measurement can be performed using AFP 210 and not only with AFP 210+420