Exploring the Pomeron structure at the LHC

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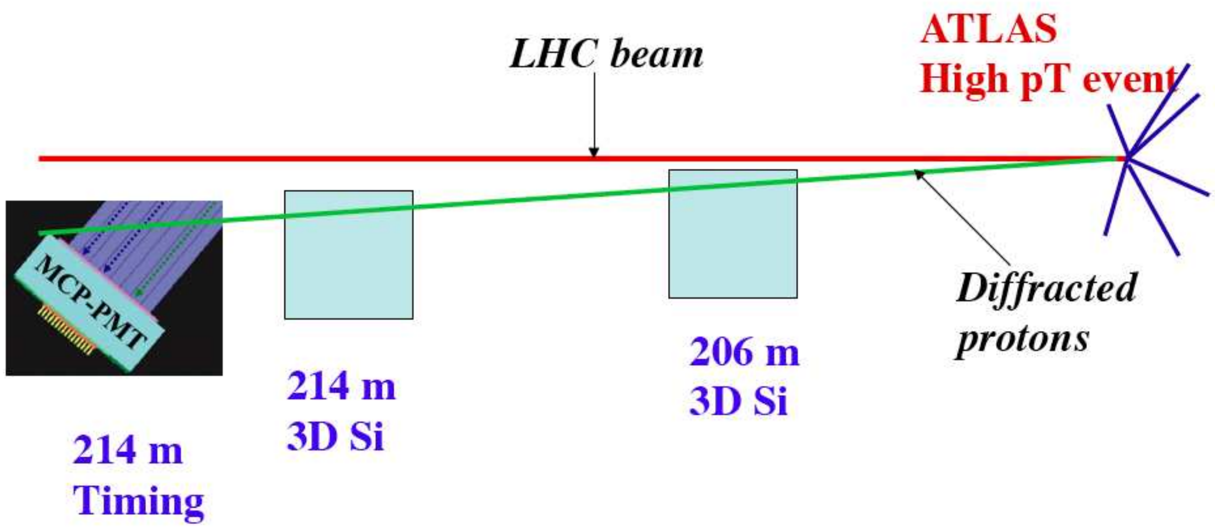
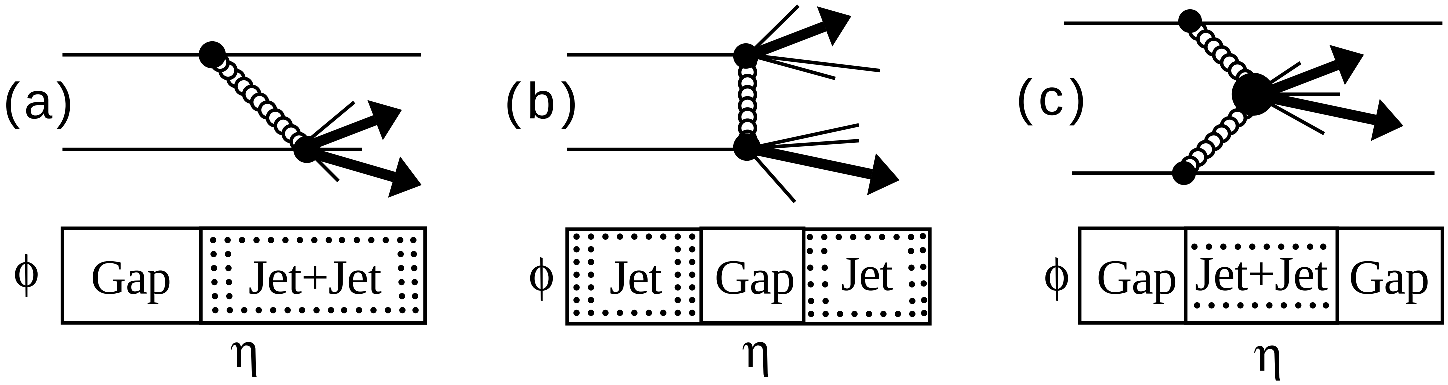
Contents:

- Pomeron structure: DPE dijets and γ+jet
- Soft colour interaction models
- BFKL tests: Jet gap jets
- Anomalous couplings: $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$: see talk by Matthias



Diffraction at Tevatron/LHC



Kinematic variables

- t: 4-momentum transfer squared
- ξ_1, ξ_2: proton fractional momentum loss (momentum fraction of the proton carried by the pomeron)
- $\beta_{1,2} = x_{Bj,1,2}/\xi_{1,2}$: Bjorken-x of parton inside the pomeron
- $M^2 = s\xi_1\xi_2$: diffractive mass produced
- $\Delta y_{1,2} \sim \Delta\eta \sim \log 1/\xi_{1,2}$: rapidity gap

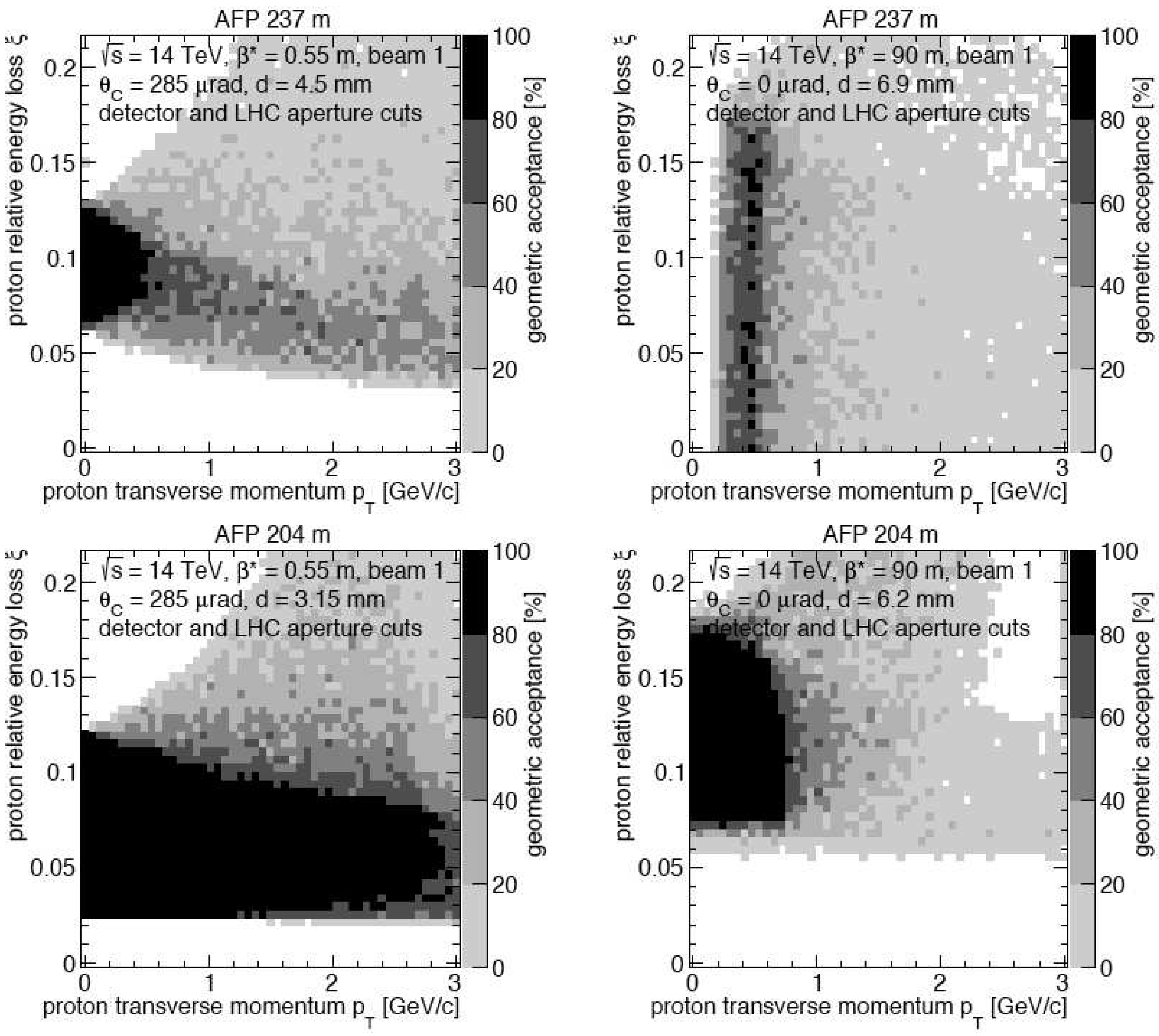
Running conditions: proton tagging

- Possibility to tag intact protons in the final state in CMS-TOTEM and in ATLAS
- High and low β^* runnings: complementarity in kinematical domain, see ξ versus t plots

optics | $\beta^* = 0.55$ m nominal (*collision*) | $\beta^* = 90$ m special (*high-β^**)

ALFA

AFP



LHC running conditions vs experiments

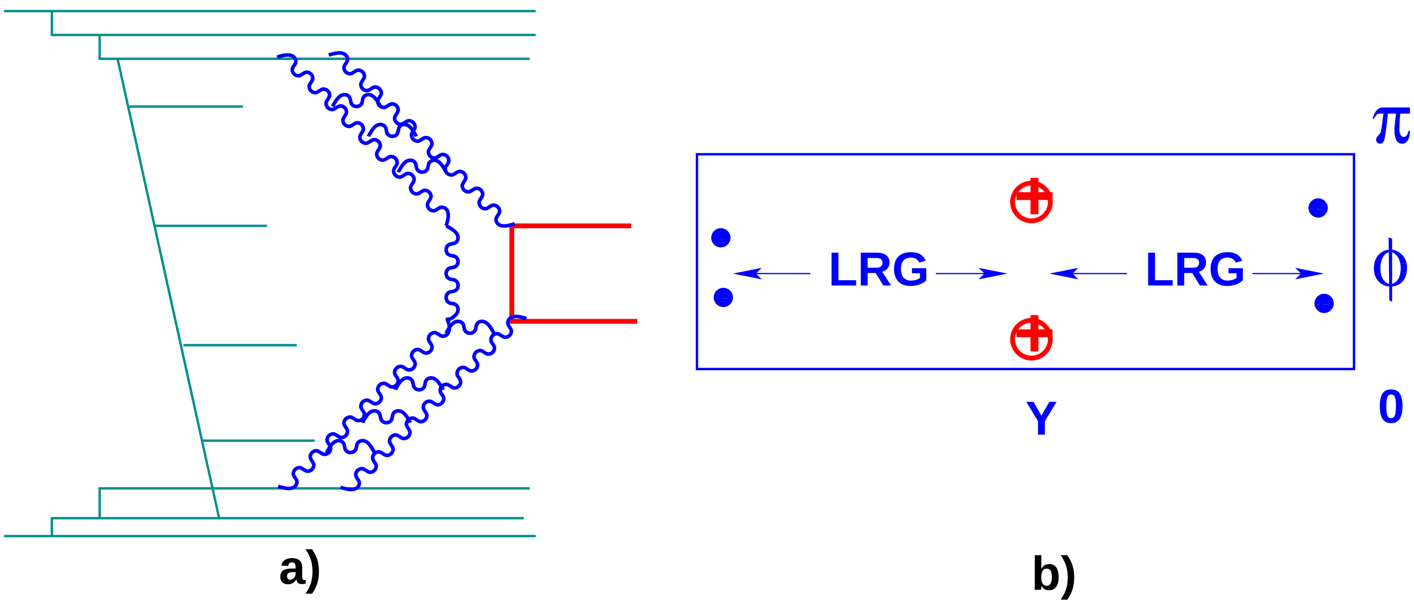
- Low luminosity runs
  - No pile up ($\mu << 1$) (very low luminosity) - dedicated to multiplicity, energy flow measurements (dediacted to LHC f, together will all other LHC experiments)
  - No pile up high β^*, total cross section (ALFA and TOTEM)
  - Very low pile up with proton tagged or not (soft physics): 0.1 to 1 pb^{-1}, a few days are needed
- Medium luminosity runs: QCD studies, Pomeron structure, exclusive diffraction...
  - LHCb runs with little pile up, a few fb^{-1} accumulated
  - Alice, ATLAS, CMS runs at low pile up, rapidity gap measurements
  - CMS-TOTEM and ALFA/AFP special runs at high β^*, $\mu \sim$1, a few days needed to accumulate 1 to 10 pb^{-1}
  - AFP and CMS/TOTEM running at low β^*, low pile up ($\mu = 2, ..., 5$), between one and two weeks of data taking, 10 to 100 pb^{-1}
- High pile up (μ =20,...,100) (high luminosity) with proton tagging; Possibility to collect data with high pile up (50 and above) and also at $\mu \sim$25 by restricting to end of store data taking and tails of the vertex distribution: 40% of total luminosity can be collected

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 and also to the full simulation including pile up

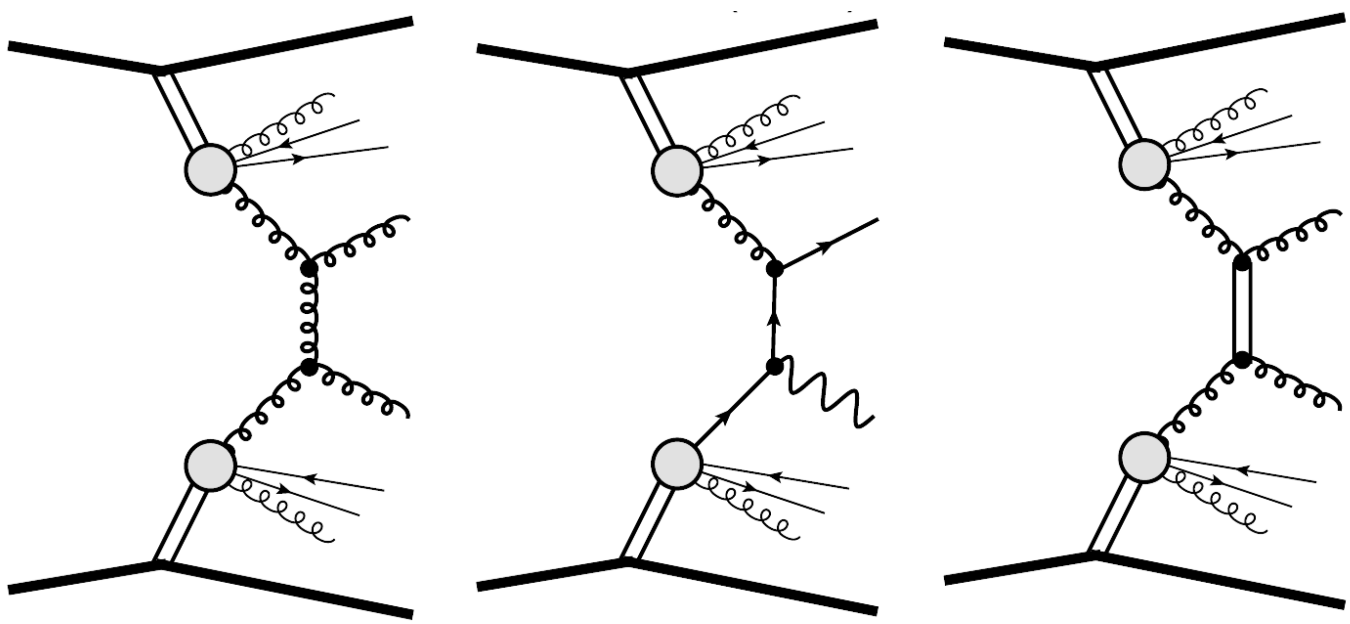
Going from HERA to Tevatron: survival probability

- Use parton densities measured at HERA to predict diffractive cross section at the 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)



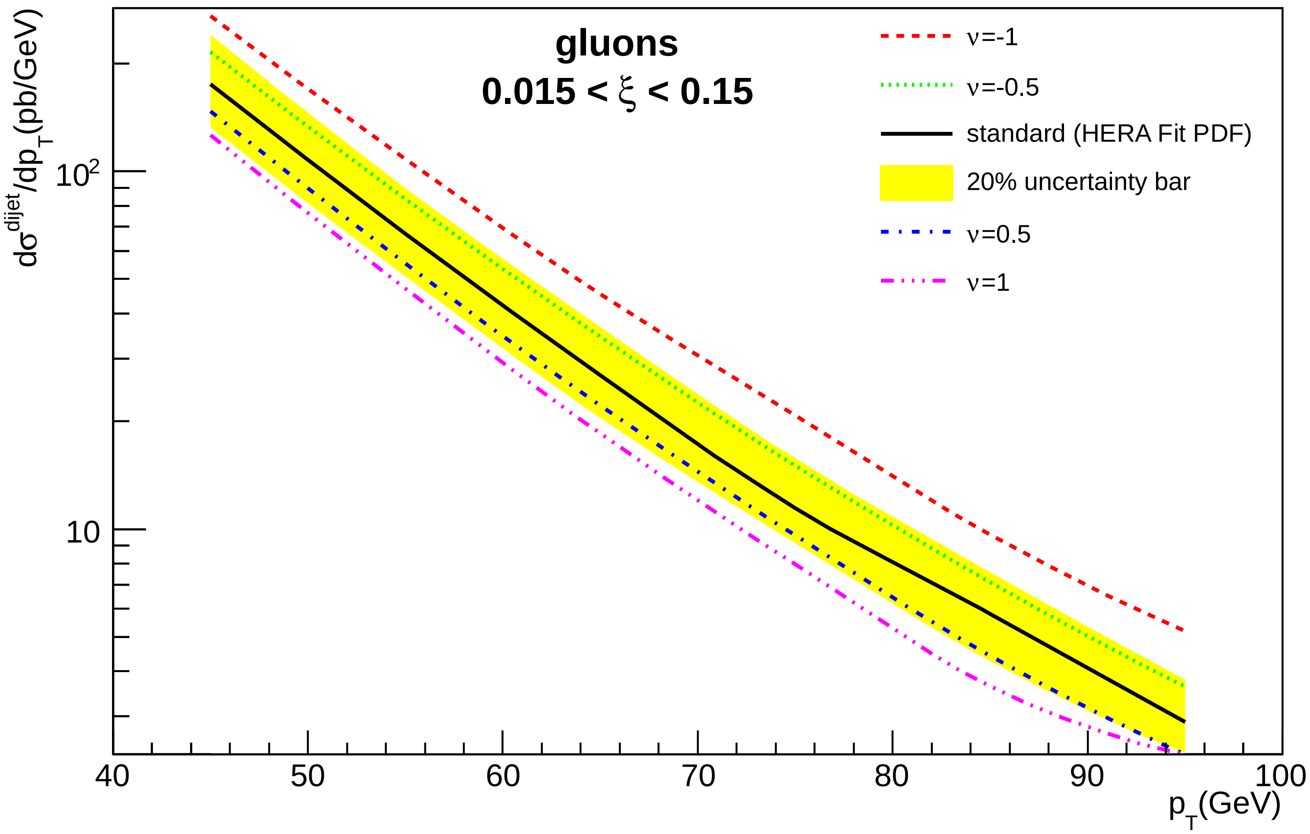
Hard diffraction at the LHC

- 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)
- Three aims
  - Is it the same object which explains diffraction in pp and ep?
  - Further constraints on the structure of the Pomeron as was determined at HERA
  - Survival probability: difficult to compute theoretically, needs to be measured, inclusive diffraction is optimal place for measurement



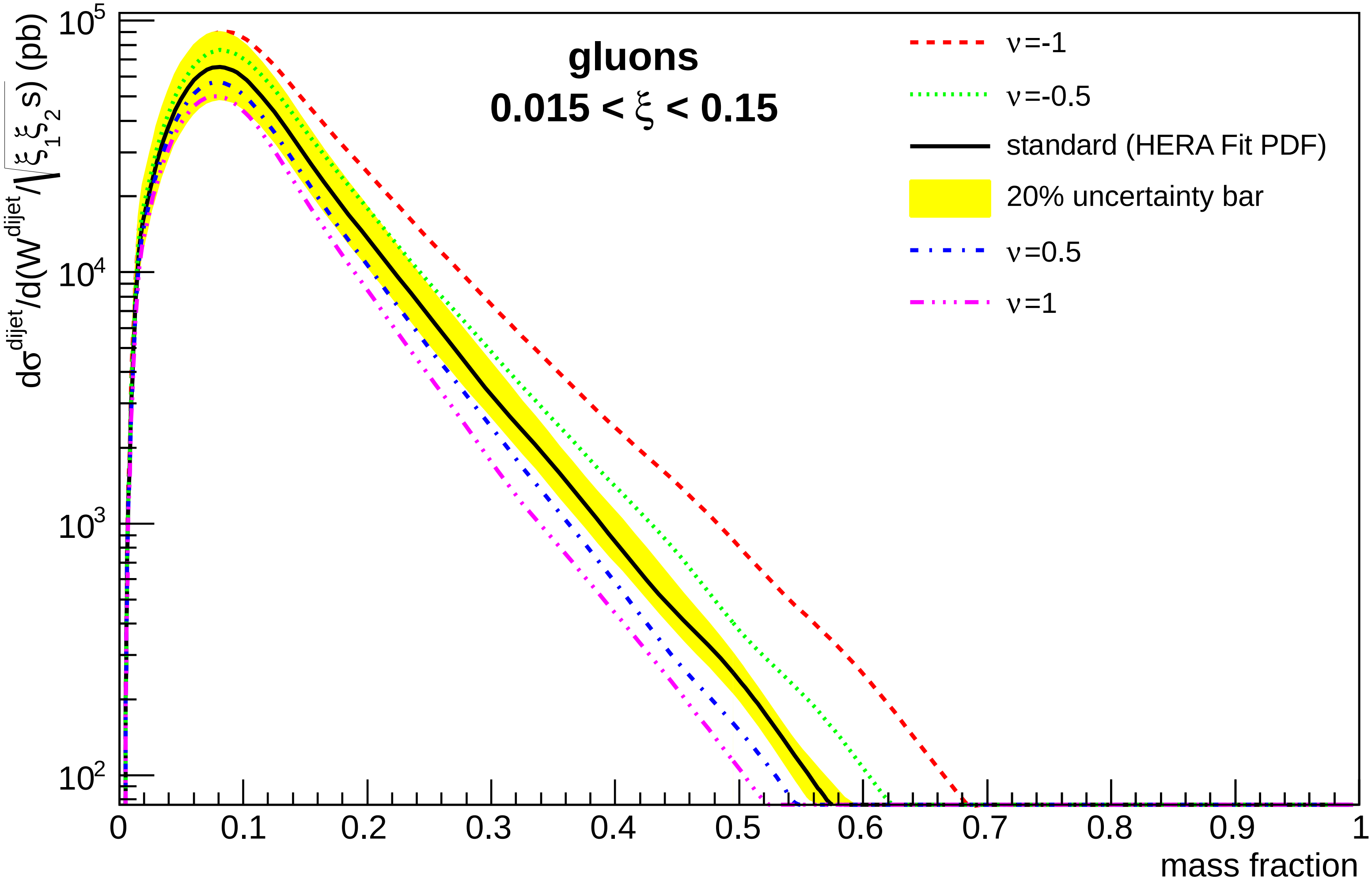
Inclusive diffraction at the LHC: sensitivity to gluon density

- 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

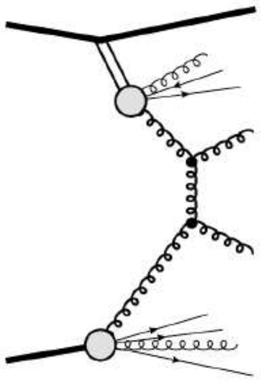
- Dijet mass fraction: dijet mass divided by total diffractive mass ($\sqrt{\xi_1 \xi_2 S}$)
- Sensitivity to gluon density in Pomeron especially the gluon density on Pomeron at high β
- Exclusive jet contribution will appear at high dijet mass fraction

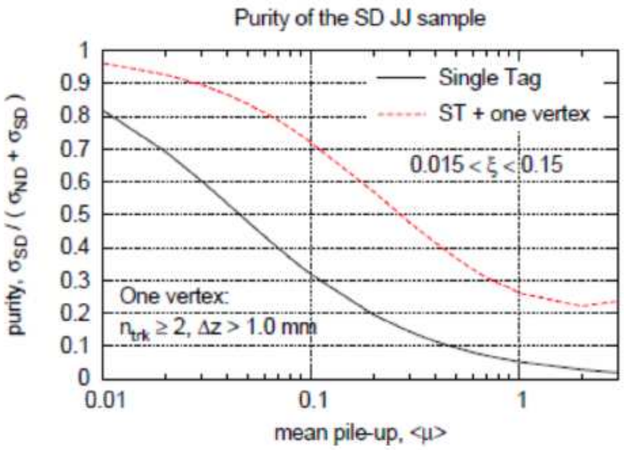


Single Diffraction and Double Diffractive jets: feasibility studies

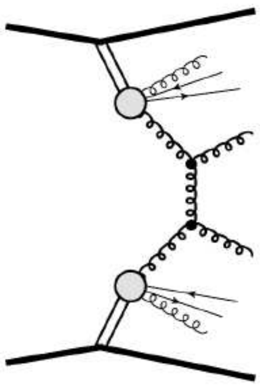
- Study by ATLAS including pile up (CMS-TOTEM at 8 TeV on data)
- Low Pile up runs (0.1) to get a sample of high purity for SD events
- Moderate pile up for DPE jet measurements (2-3)
- Possibility also to run at high β^* with less pile up, low masses

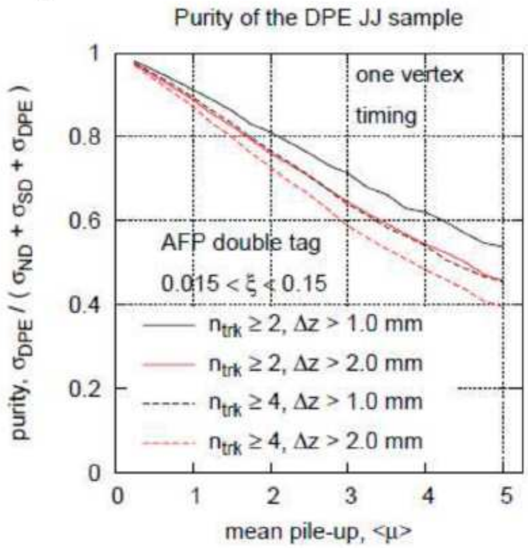
Single diffractive jets





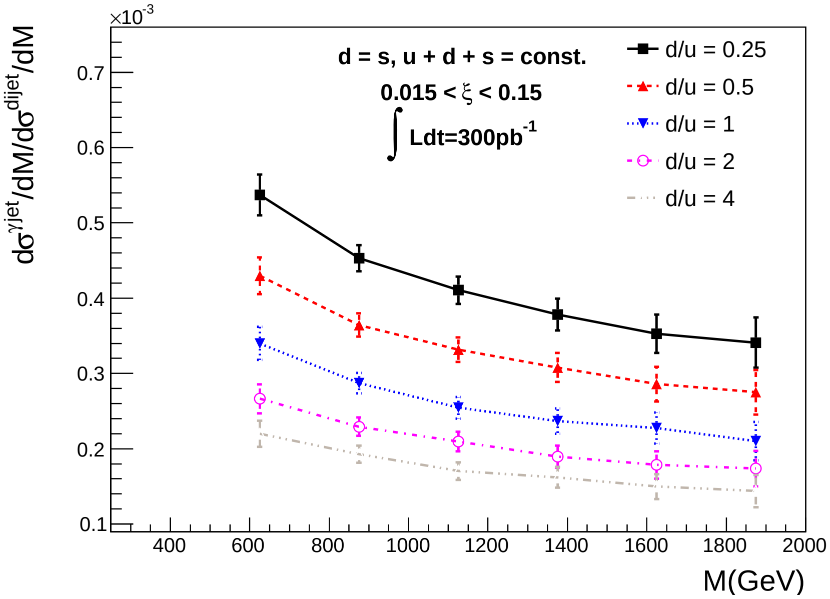
Central diffractive (double Pomeron exchange)

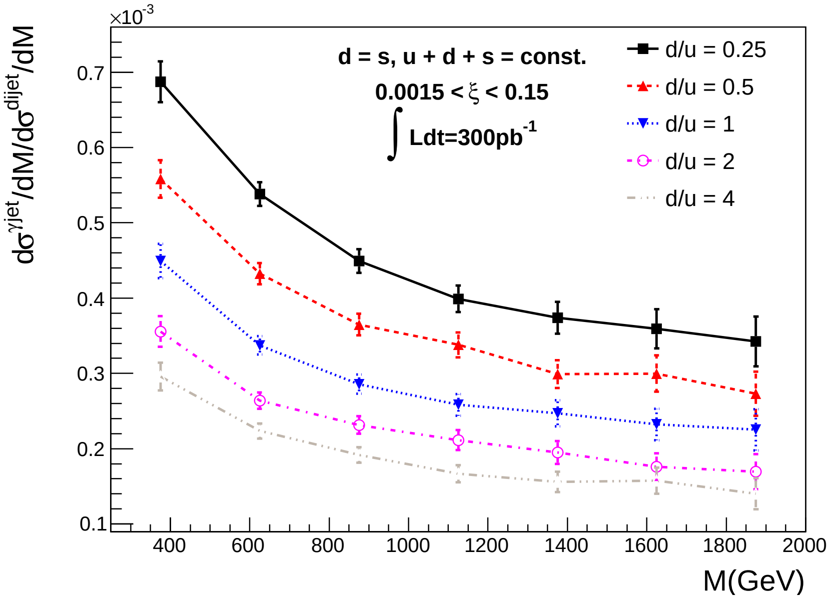




Inclusive diffraction at the LHC: sensitivity to quark densities

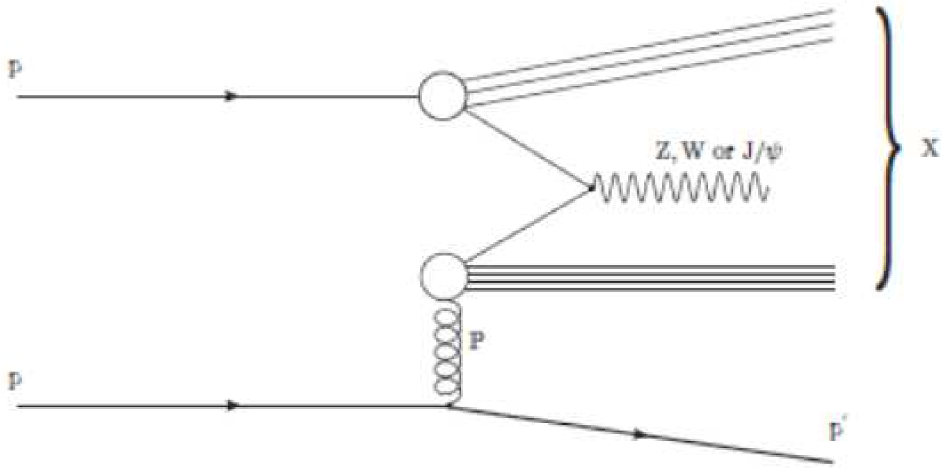
- Predict DPE γ+jet divided by dijet cross section at the LHC
- Sensitivity to universality of Pomeron model
- Sensitivity to gluon density in Pomeron, of assumption: $u = d = s = \bar{u} = \bar{d} = \bar{s}$ used in QCD fits at HERA





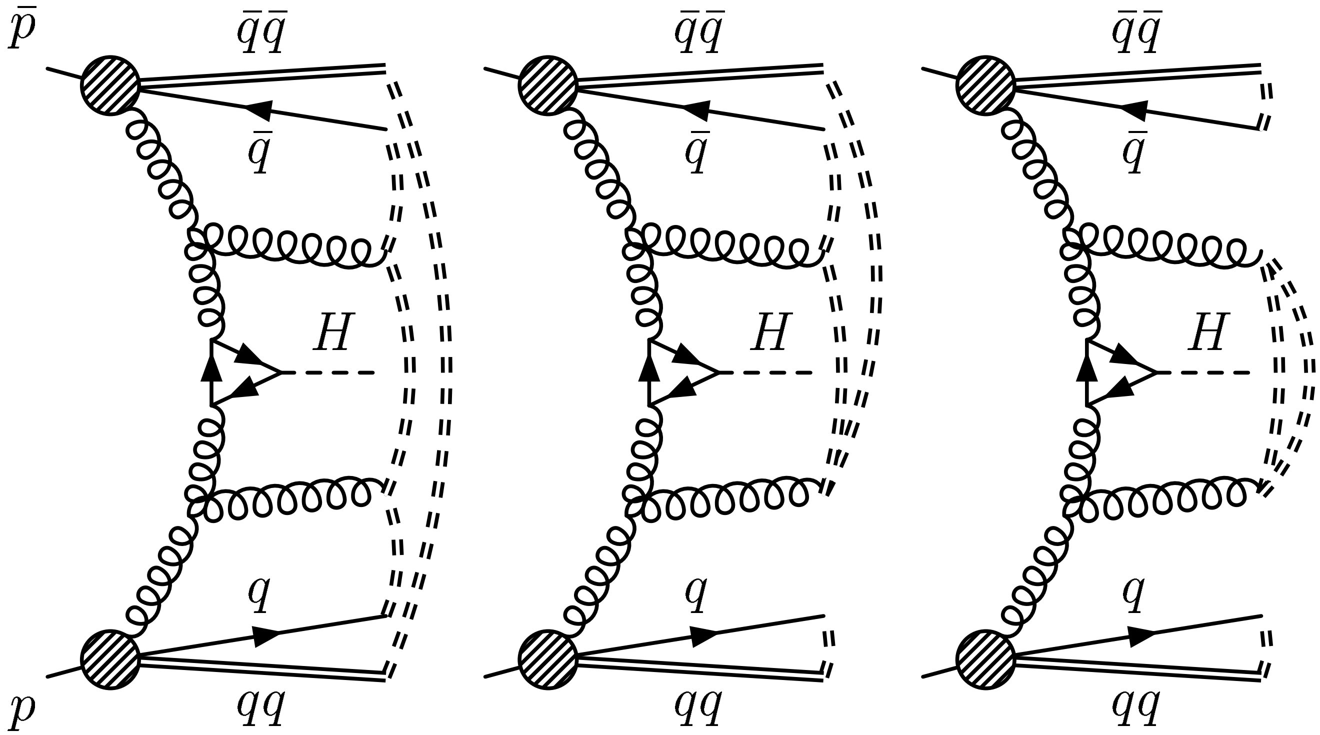
Single diffraction with proton tagging at high β^*

- Run at high β^* (no ξ cut)
- Study different single diffractive processes with low pile up
  - J/Ψ production: Two muons with opposite charge, $3.05 < M_{\mu\mu} < 3.15$ GeV, 3080±90 for 10 pb^{-1}
  - W production: leading lepton p_T >20 GeV, $60 < M_T < 110$, about 340±10 events for 10 pb^{-1}
  - Z production: same cuts, 30±1 events for 10 pb^{-1}
- SD jet production...



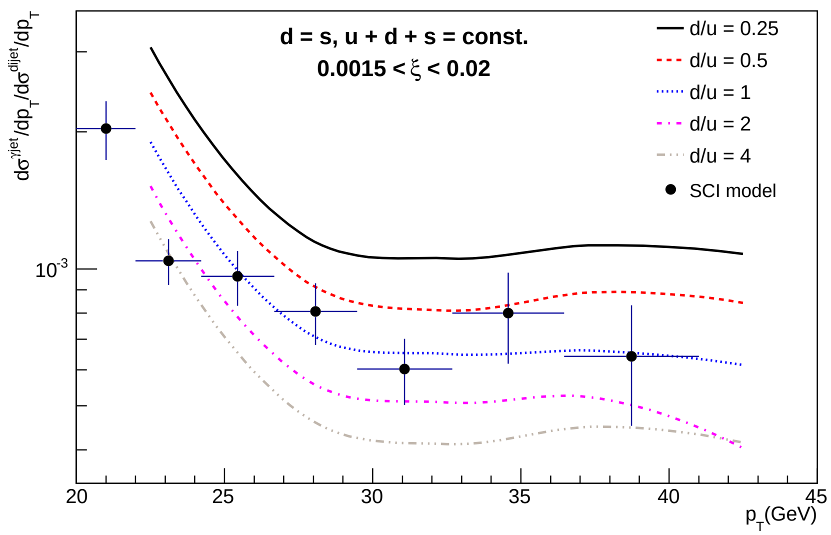
Soft Colour Interaction models

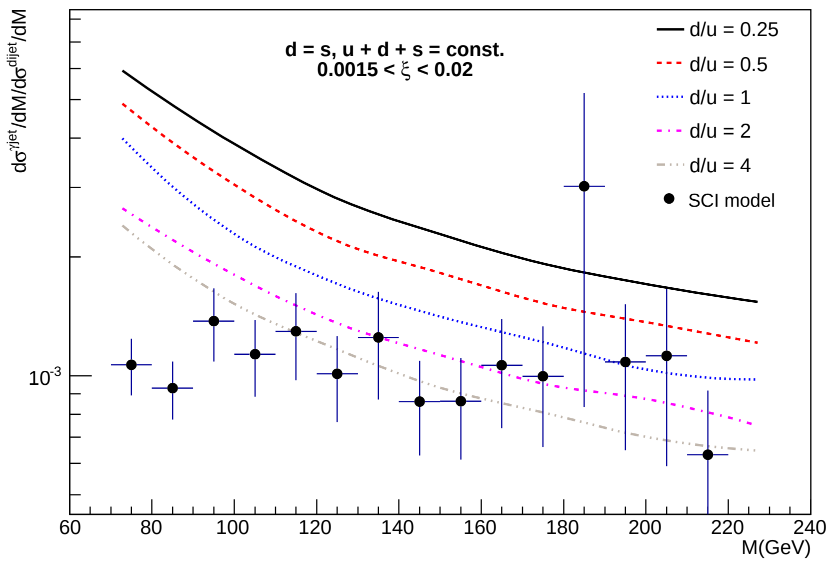
- A completely different model to explain diffractive events: Soft Colour Interaction (R.Enberg, G.Ingelman, N.Timneanu, hep-ph/0106246)
- Principle: Variation of colour string topologies, giving a unified description of final states for diffractive and non-diffractive events
- No survival probability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



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

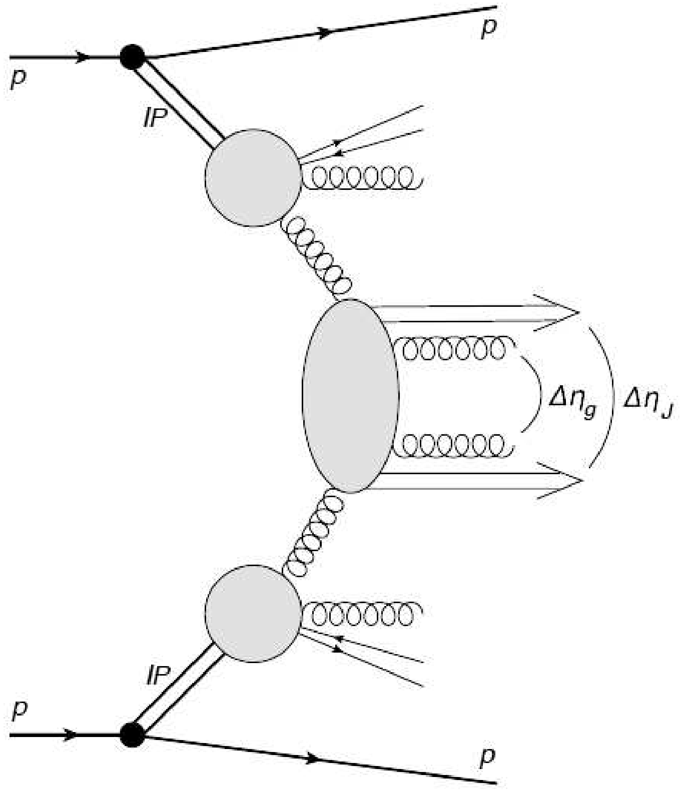
- Predict DPE γ+jet divided by dijet cross section at the LHC for pomeron like and SCI models
- In particular, the diffractive mass distribution (the measurement with lowest systematics) allows to distinguish between the two sets of models: flat distribution for SCI

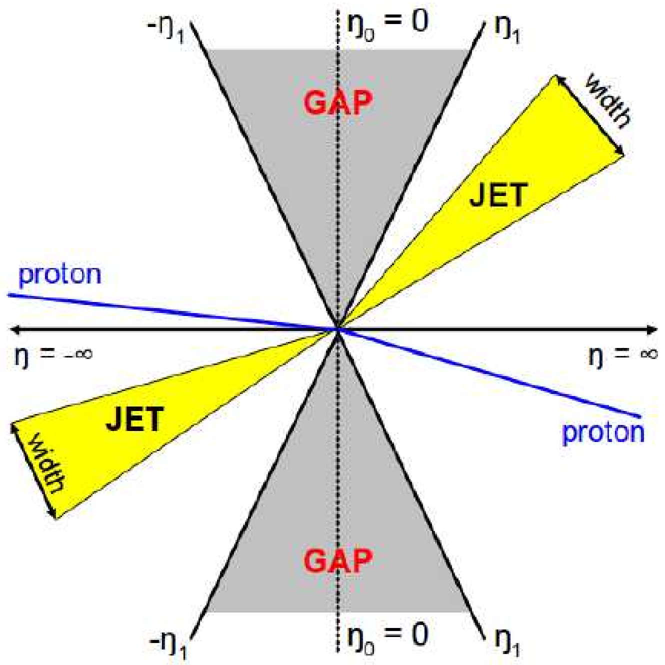




Jet gap jet events in diffraction

- 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, Phys. Rev. D 87 (2013) 034010

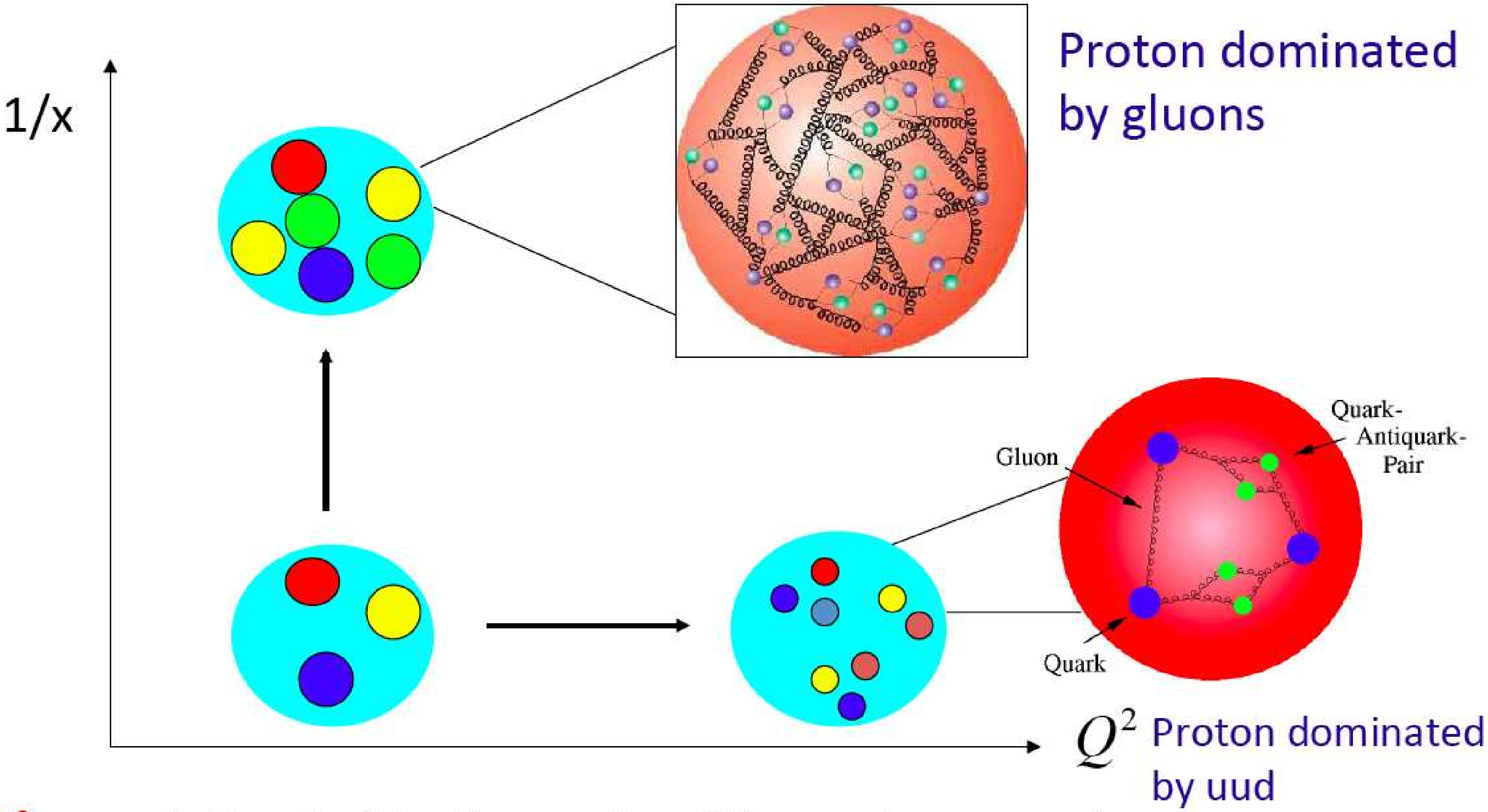




Looking for BFKL effects

- 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)

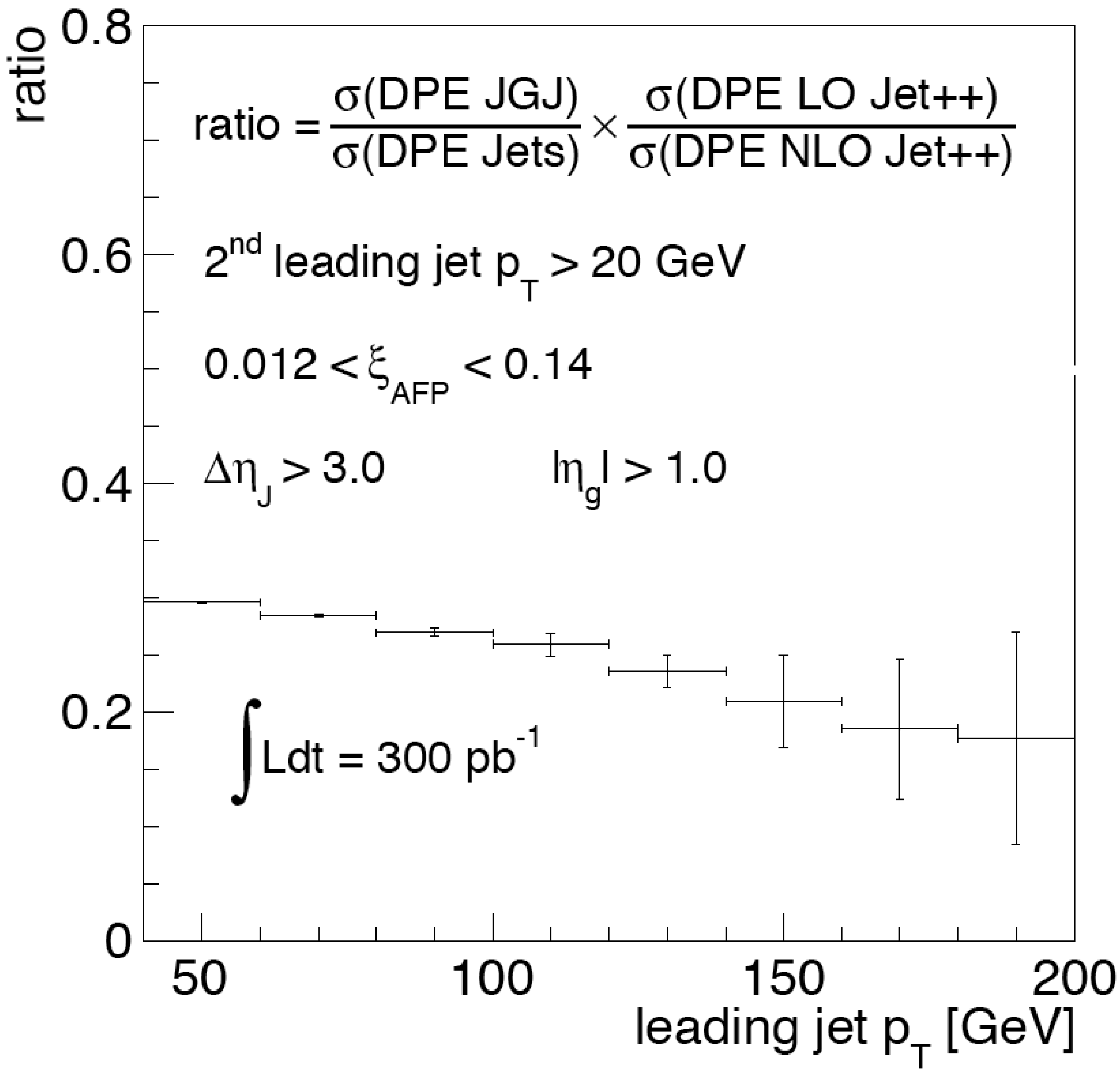


Q^2 : resolution inside the proton (like a microscope)

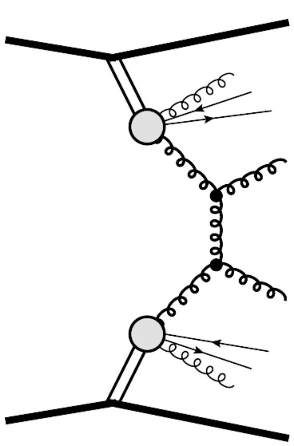
X :Proton momentum fraction carried away by the interacting quark

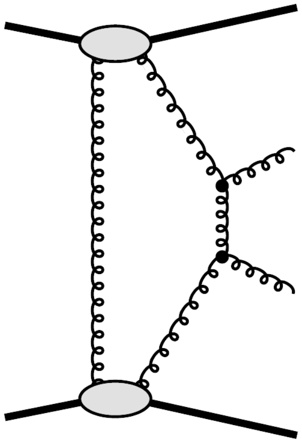
Jet gap jet events in diffraction

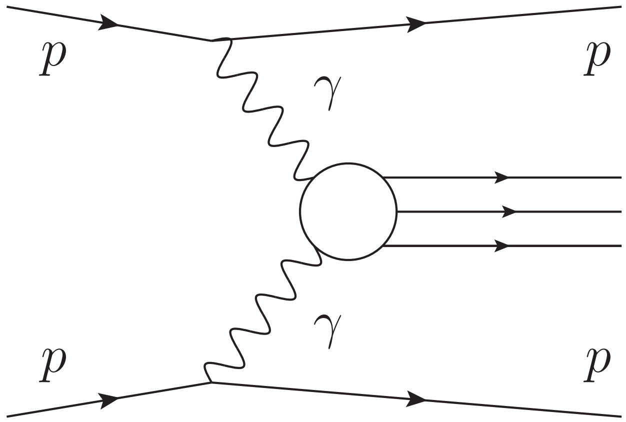
- Measure the ratio of the jet gap jet to the dijet cross sections: sensitivity to BFKL dynamics
- As an example, study as a function of leading jet p_T



Exclusive and inclusive diffraction



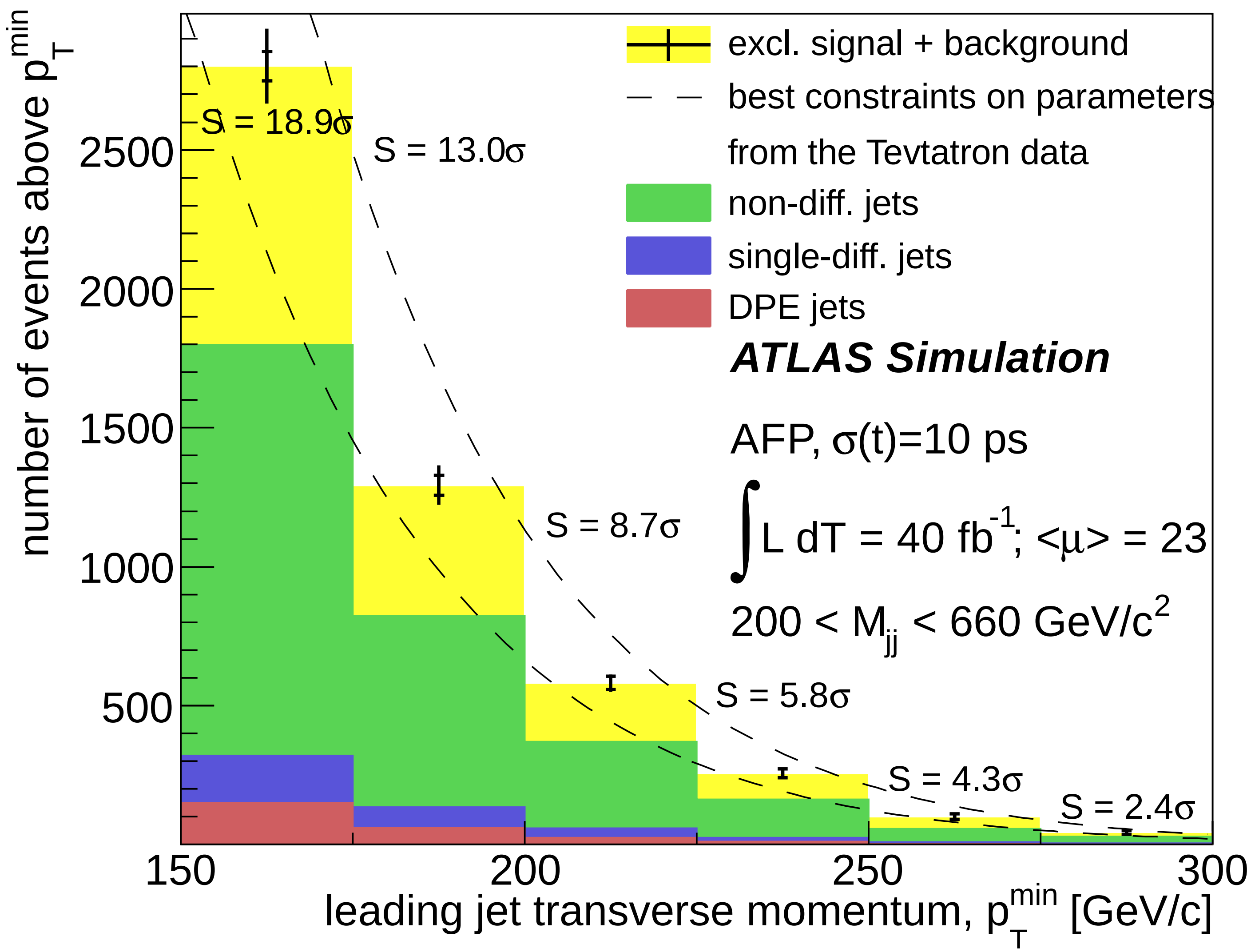




- Exclusive diffraction: All the energy is used to produce the dijets, namely $xG \sim \delta$
- Possibility to reconstruct the properties of the object produced exclusively (via photon and gluon exchanges) from the tagged proton: system completely constrained
- Possibility of constraining the background by asking the matching between the information of the two protons and the produced object

Exclusive jet production at the LHC

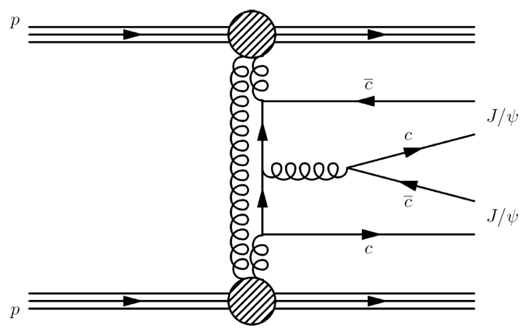
- Jet cross section measurements: up to 18.9 σ for exclusive signal with 40 fb^{-1} ($\mu = 23$): highly significant measurement in high pile up environment, improvement over measurement coming from Tevatron (CDF) studies using $\bar{p}$ forward tagging by about one order of magnitude

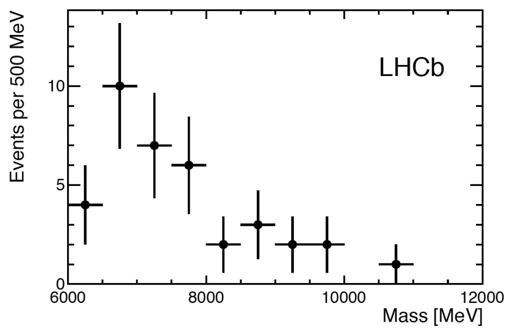


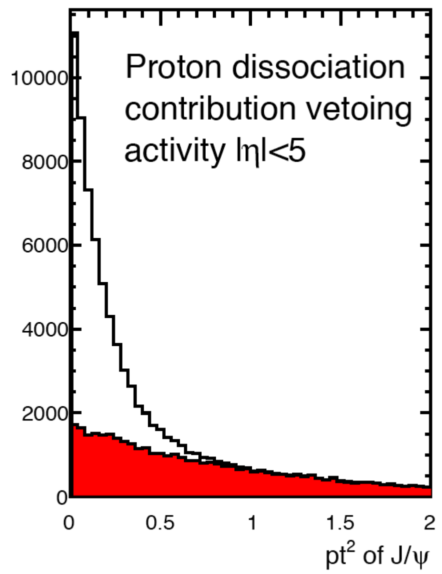
- Important to perform these measurements to constrain exclusive Higgs production: background/signal ratio close to 1 for central values at 120 GeV

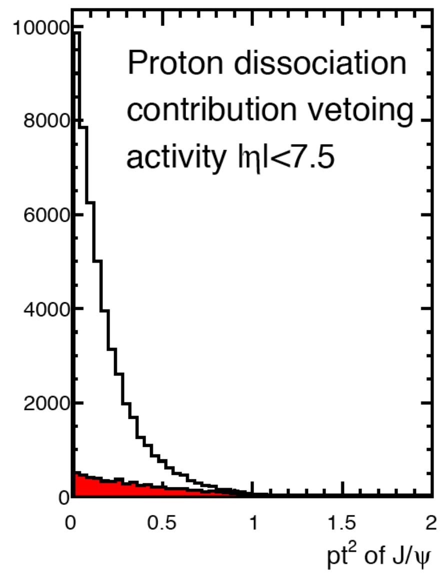
Exclusive vector mesons - LHCb

- Measurement of vector mesons: very clean sample, example of LHCb, no proton tagging (charmonium with 3 fb^{-1})
- Measurement performed in parallel with theory developments
- Herschel: Scintillators being installed in LHCB in order to get a better control of non exclusive background (some scintillators in the forward region already installed in CMS as well as CASTOR)
- Such channels are sensitive to new physics: if one has a medium mass resonance, (glueball or tetraquark state or exotic), it could lead to a bump in such a spectrum



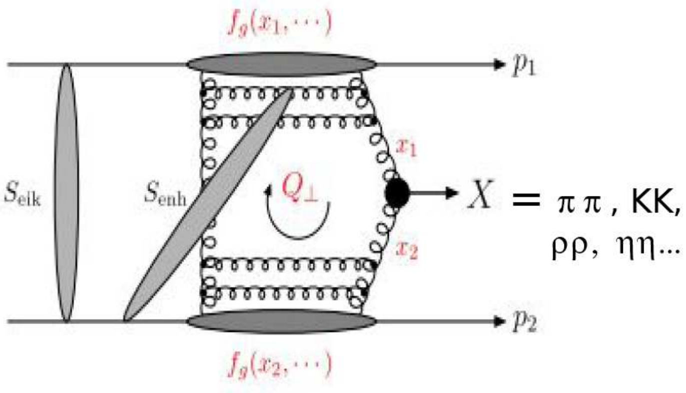


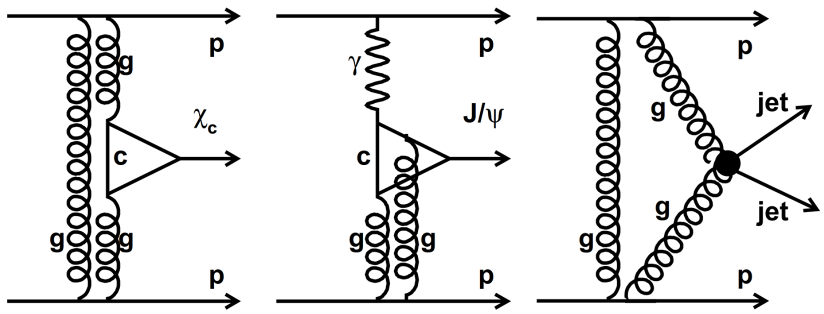




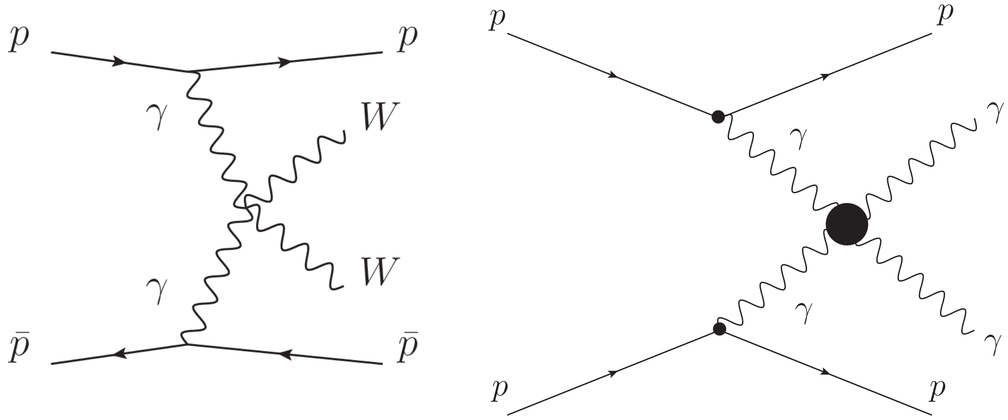
Exclusive state measurements

- Many exclusive states can be measured in high β^* runs in ALFA-CMS/TOTEM, and in standard runs in LHCb
- ALFA-CMS/TOTEM: Detect both protons, information from central detector, particle Id (pions, kaons with tracker), timing detectors
- Search for glueball states and probing low x gluon down to $x \sim 10^{-4}$
- With 1 pb^{-1}: confirmation of unobserved possible $f_0(1710)$ and $f_0(1500)$ decay modes and first cross-section $\times$ branching ratio estimates
- With 5-10 pb^{-1}: cross-section $\times$ branching ratio estimates for all three $\chi_{C,0,1,2}$ states, comparison with perturbative QCD
- Low mass exclusive dijet production: M_X >60 GeV, cross section of $\sim$ 100 pb



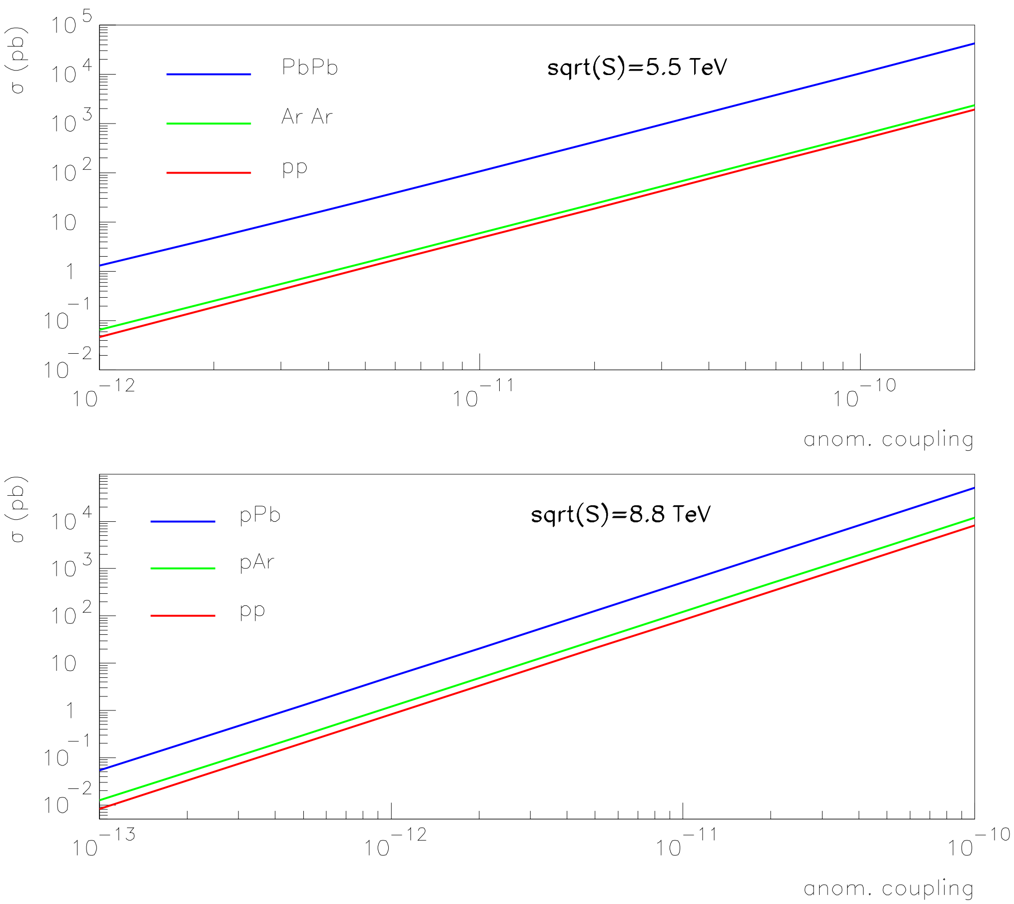


Search for $\gamma\gamma WW$, $\gamma\gamma\gamma\gamma$ quartic anomalous coupling



- Study of the process: $pp \rightarrow ppWW$, $pp \rightarrow ppZZ$, $pp \rightarrow pp\gamma\gamma$
- 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
- See talk by Matthias

$\gamma\gamma WW$, $\gamma\gamma\gamma\gamma$ quartic anomalous coupling in heavy ion mode



- UPCs: Cross section in the heavy ion case increased by Z^4
- High mass flux cut off because of impact parameter condition to be greater than the heavy ion size
- Typical luminosity of 10 nb^{-1} (1 pb^{-1}) for Pb Pb (p-Pb) runs: not such a good reach on anomalous coupling as in the pp case but interesting to study further

Conclusion

- QCD: structure of Pomeron: constrain the gluon density in Pomeron in a new kinematical domain using especially the dijet mass fraction
- QCD: structure of Pomeron: constrain for the first time the quark densities in Pomeron using γ+jet events
- Test alternative models of diffraction: soft colour interaction models leading to a flat dependence of the γ+jet to dijet cross section ratios as a function of diffractive mass
- Probe BFKL resummation effects: using jet gap jet in diffraction
- Exclusive diffraction: Jets, vector mesons
- Explaratory physics: look for $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$ anomalous couplings, see talk by Matthias
- Double complementarity:
  - Between experiments: LHCb/Alice without proton tagging (rapidity gap methods) and ALFA/AFP, CMS-TOTEM/CT-PPS
  - Within experiments between high β^* and low β^* measurements (resp. low and high mass diffraction using vertical pots in ALFA-CMS/TOTEM and hotizontal pots in CT-PPS/AFP