The Pomeron structure at the LHC using proton tagging

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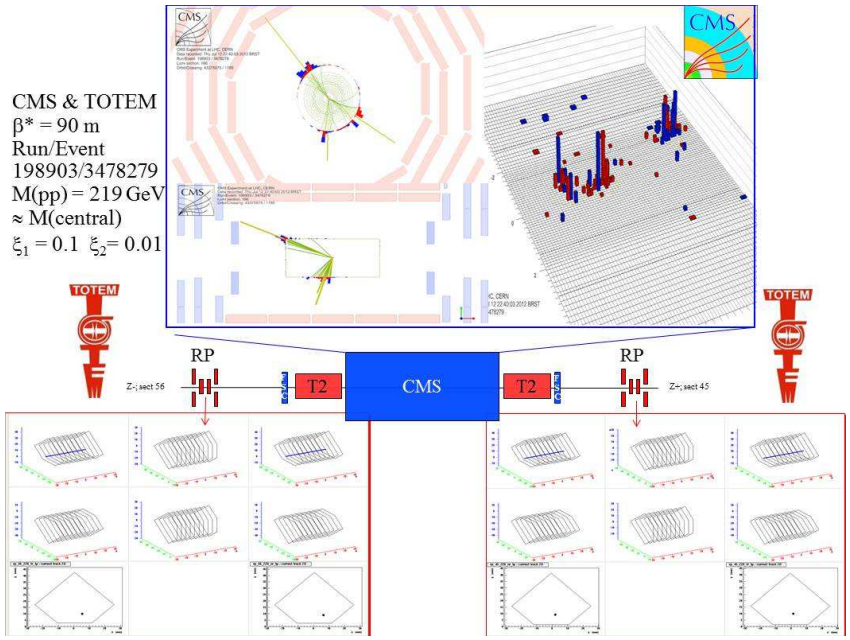
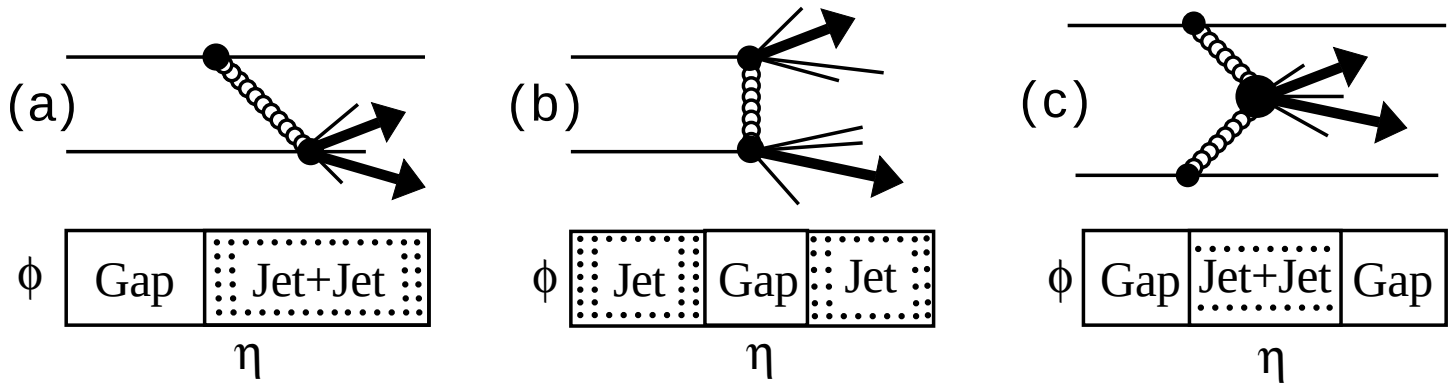


- Different optics at the LHC
- Pomeron structure in terms of quarks/gluons
- Tests of BFKL resummation
- Exclusive diffraction

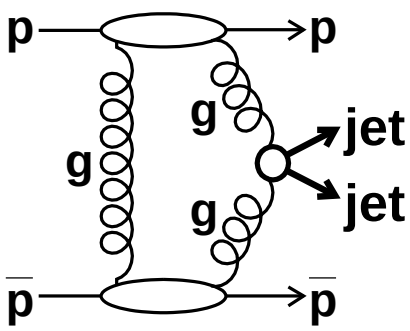
Diffraction at Tevatron/LHC

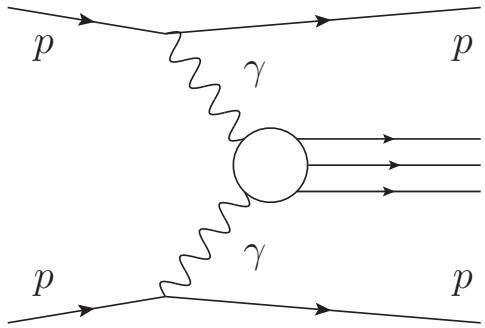


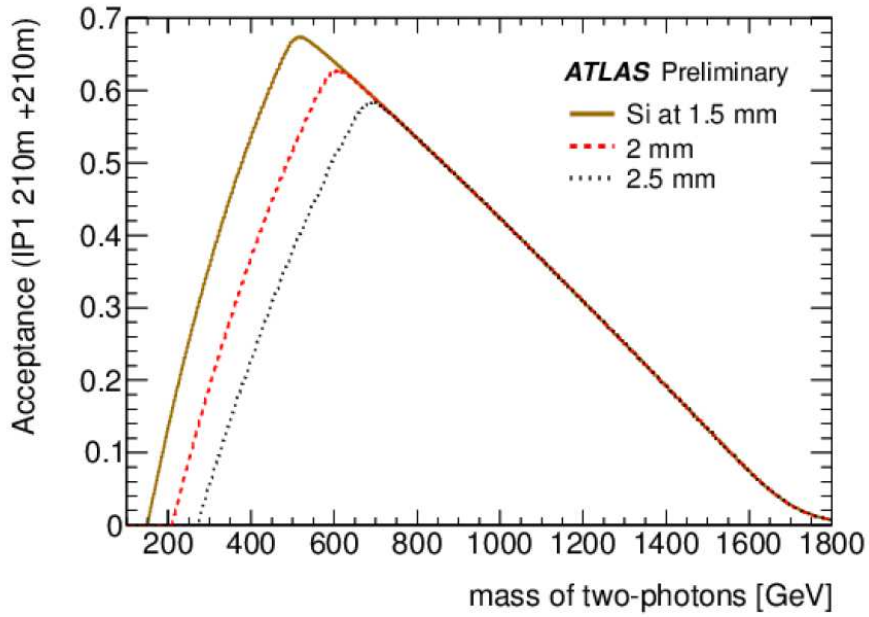
Kinematic variables

- 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
- See also the talks by Beatriz Gay-Ducati, Victor Goncalves, Sandro de Souza

What is AFP/CT-PPS?

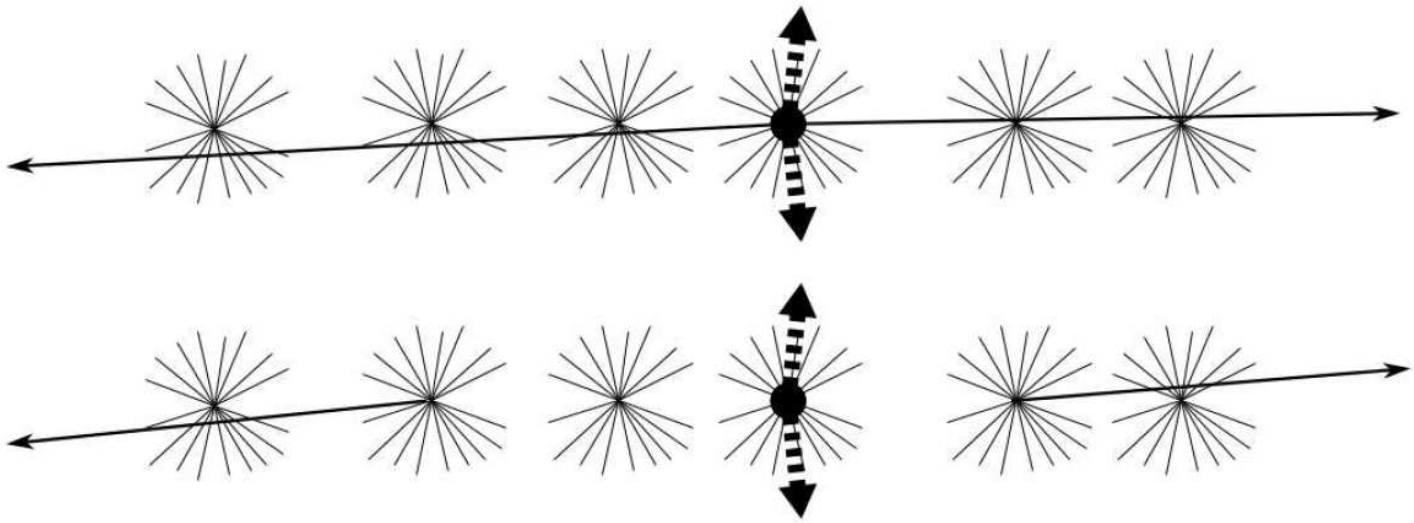






- Tag and measure protons at ± 210 m: AFP (ATLAS Forward Physics), CT-PPS (CMS TOTEM - Precision Proton Spectrometer)
- All diffractive cross sections computed using the Forward Physics Monte Carlo (FPMC)
- Sensitivity to high mass central system, X, as determined using AFP: Very powerful for exclusive states: kinematical constraints coming from AFP and CT-PPS proton measurements

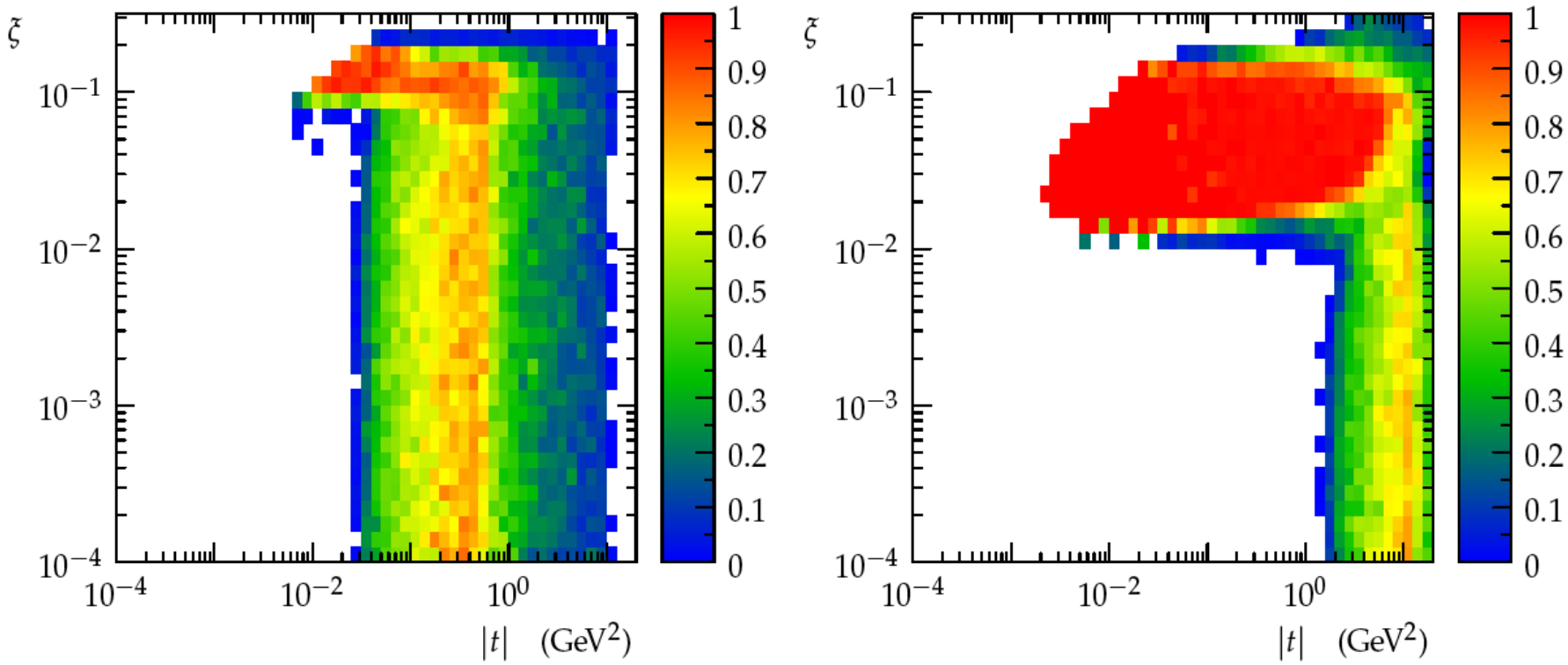
One aside: what is pile up at LHC?



- High luminosity at the LHC to look for rare (non standard events): many protons in one bunch, many interactions within the same bunch crossing in ATLAS and CMS (LHCb is different)
- Hard interaction and pile up: one hard interaction (leading to a high p_T event with jets, W/Z, top...) and many additional soft events in the detectors
- Energy flow everywhere in the event due to pile up: rapidity gap measurement works only at very low pile up ("special runs") at the LHC
- Intact protons can originate from hard events (hard diffractive production of jets for instance with intact protons) or also from additional soft interaction
- Typically 20-25 pile up events per interaction at 8 TeV, between 25 and 50 next year at 13 TeV, and 200 for the high luminosity LHC

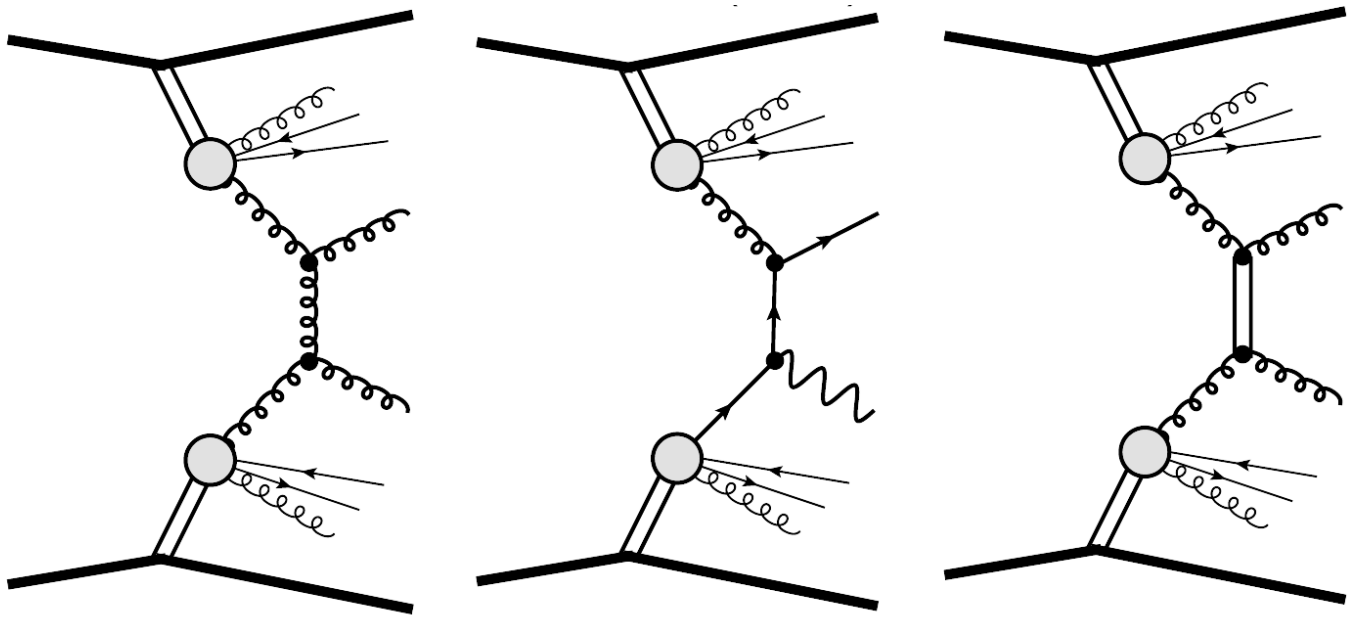
Running conditions: proton tagging

- Possibility to tag intact protons in the final state in CMS-TOTEM and in CT-PPS
- High β^* runnings using vertical pots mainly low mass diffraction (small luminosity, special runs, sensitivity to processes with high cross section)
- Low β^* runnings using horizontal pots: Standard high luminosity physics, sensitive to low cross sections and to new physics



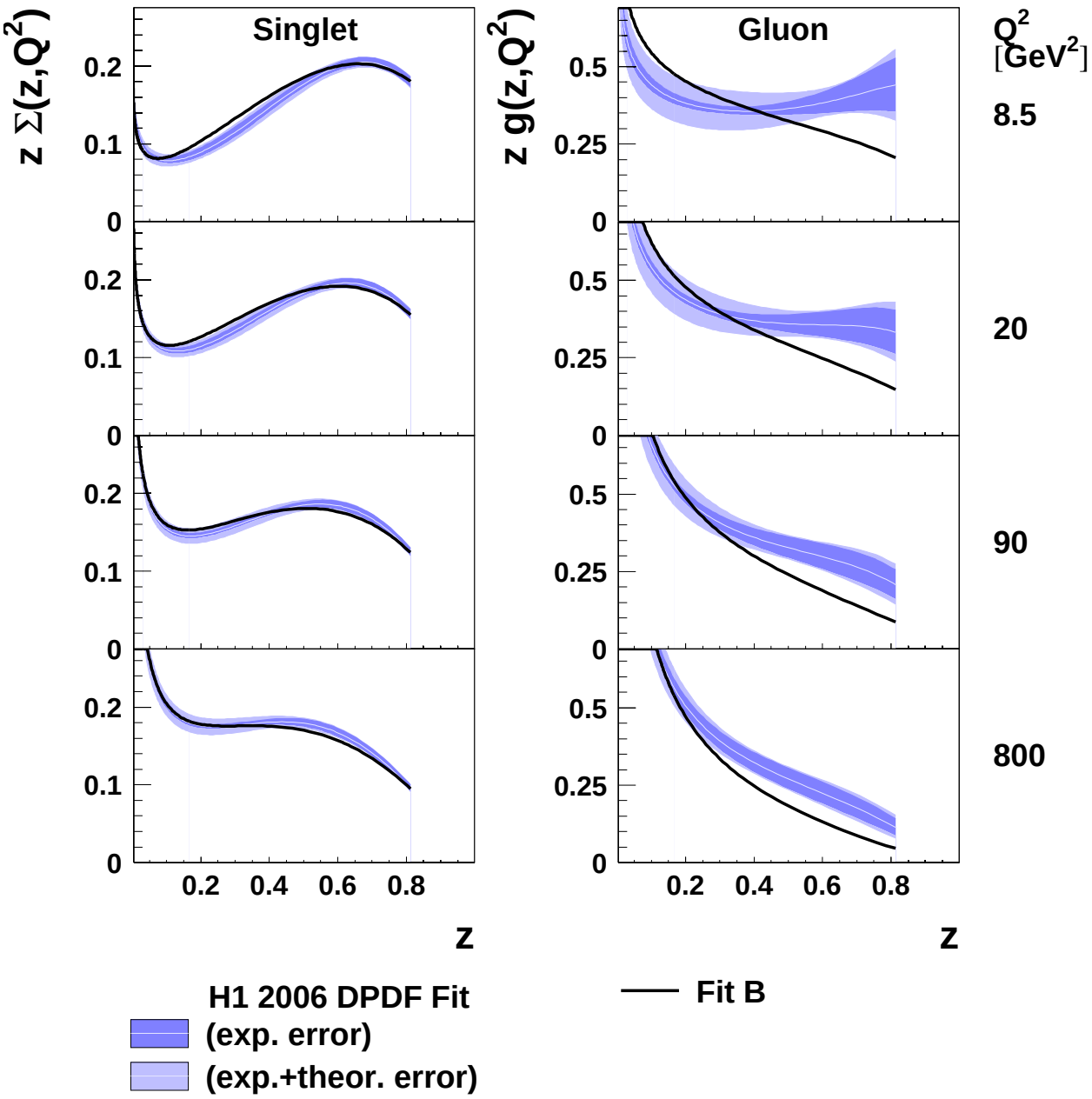
Hard diffraction at the LHC

- 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



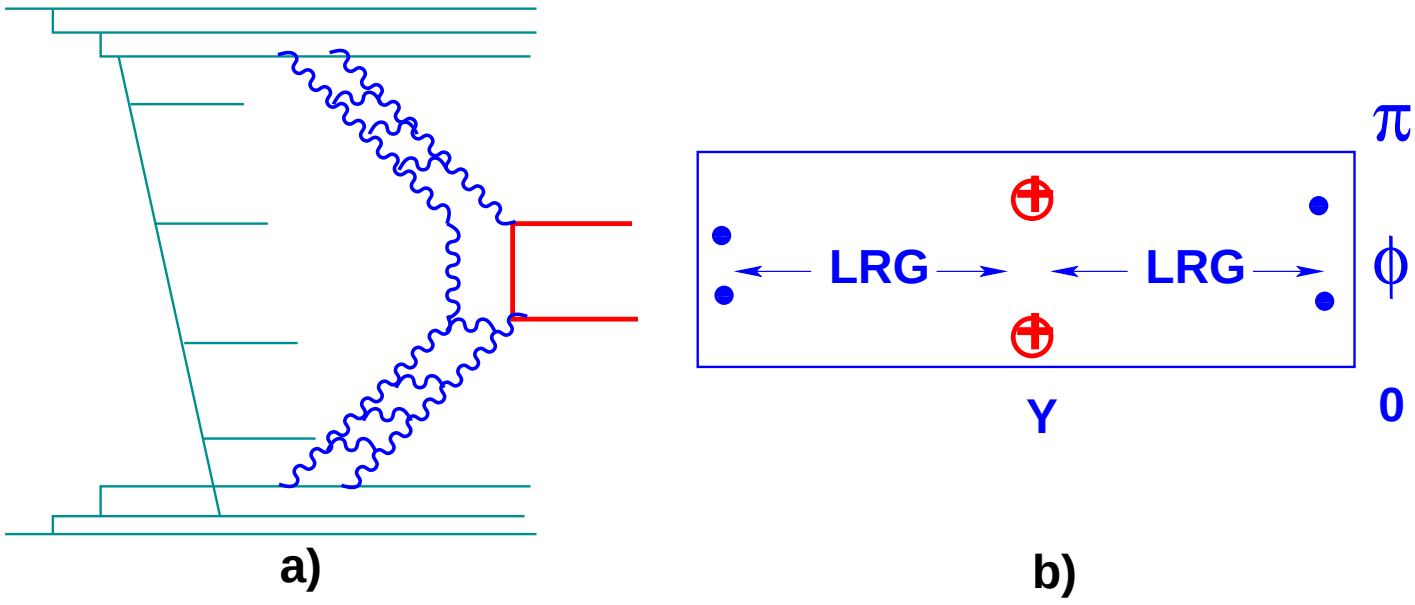
Parton densities in the pomeron (H1)

- Extraction of gluon and quark densities in pomeron: gluon dominated
- Gluon density poorly constrained at high β



Hard diffraction: A difficulty to go from HERA to LHC: 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)

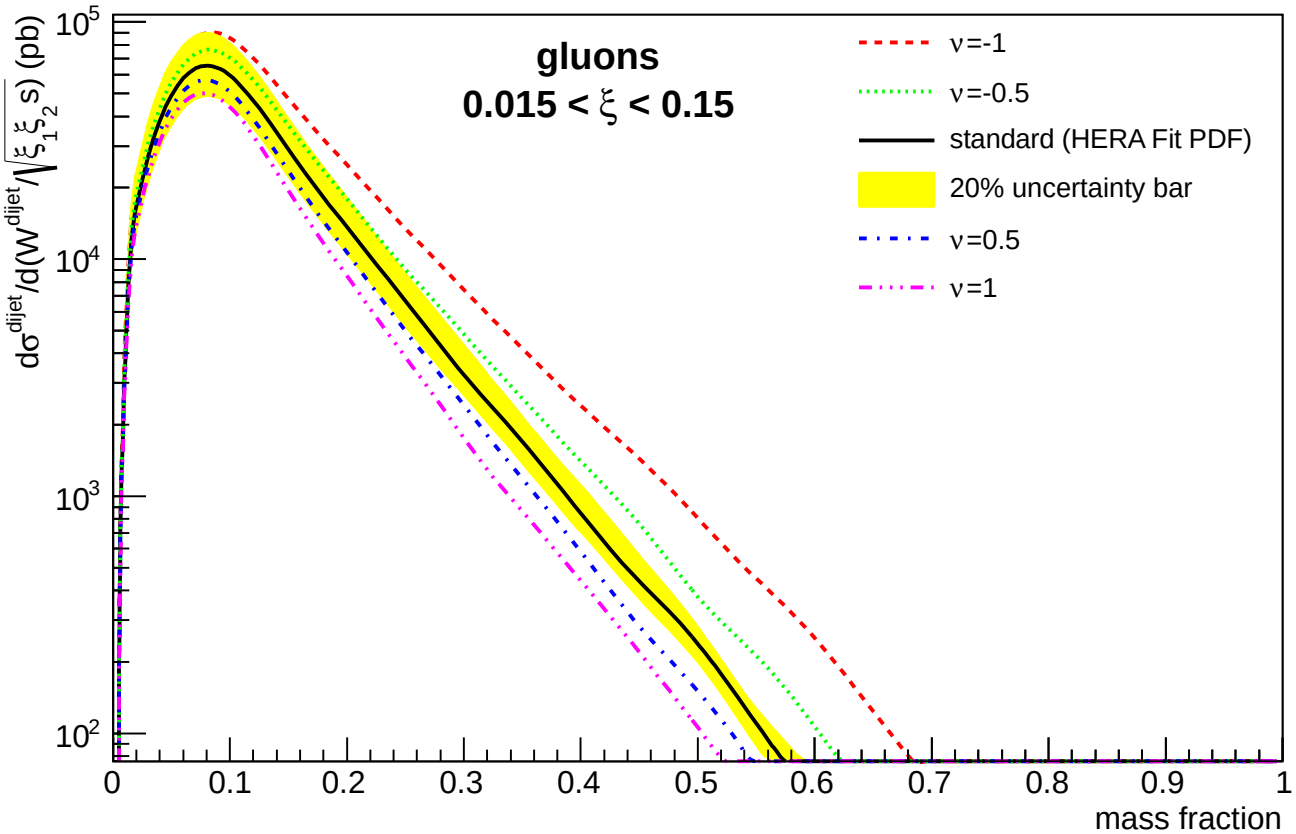


Forward Physics Monte Carlo (FPMC)

- 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

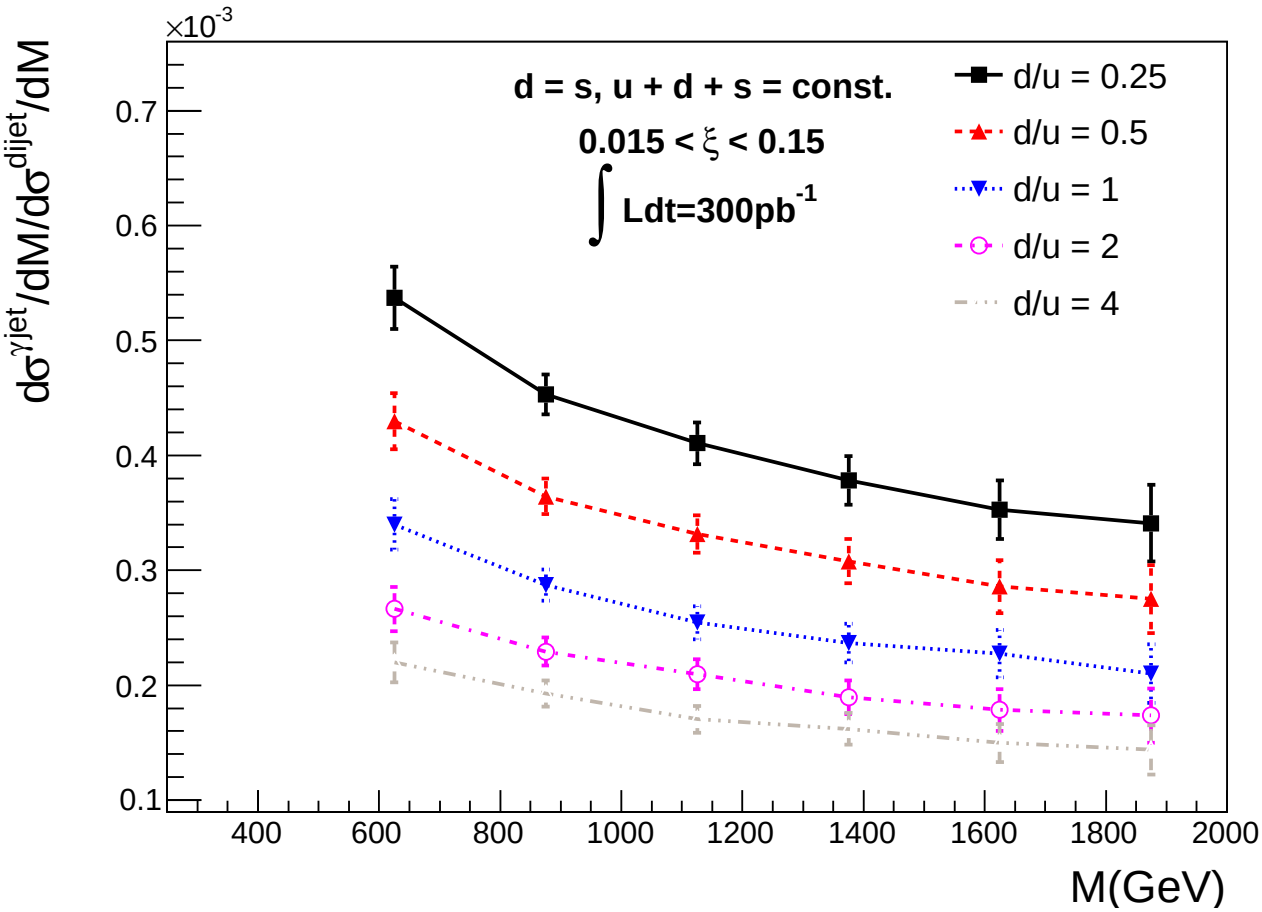
Inclusive diffraction at the LHC: sensitivity to gluon density

- Predict DPE dijet cross section at the LHC 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)
- Dijet mass fraction: dijet mass divided by total diffractive mass $(\sqrt{\xi_1 \xi_2 S})$



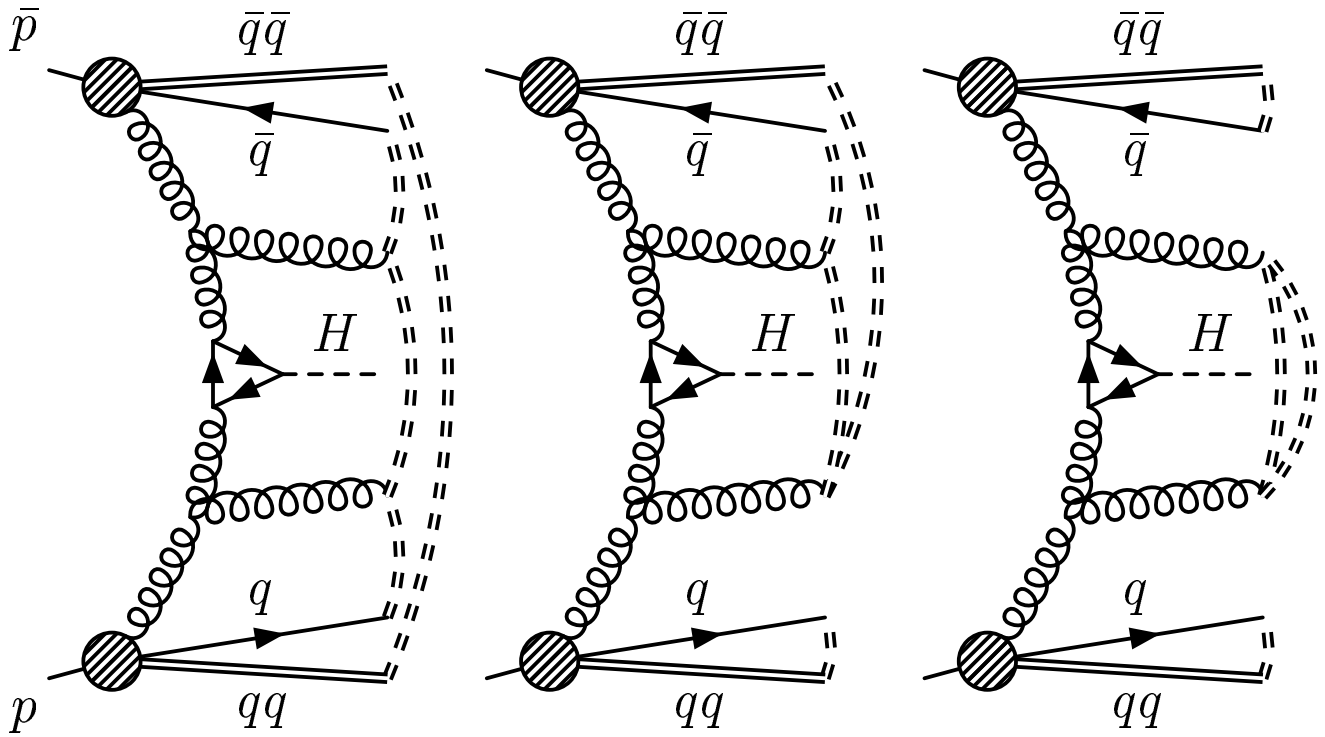
Inclusive diffraction at the LHC: sensitivity to quark densities

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



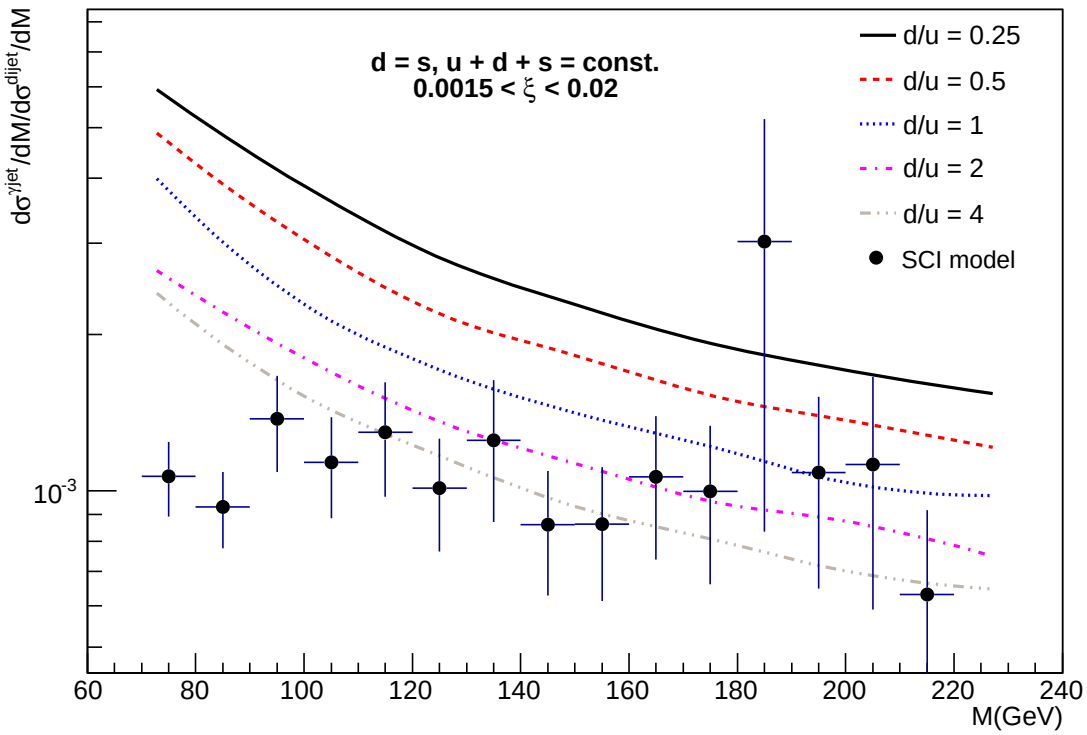
Soft Colour Interaction models

- 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

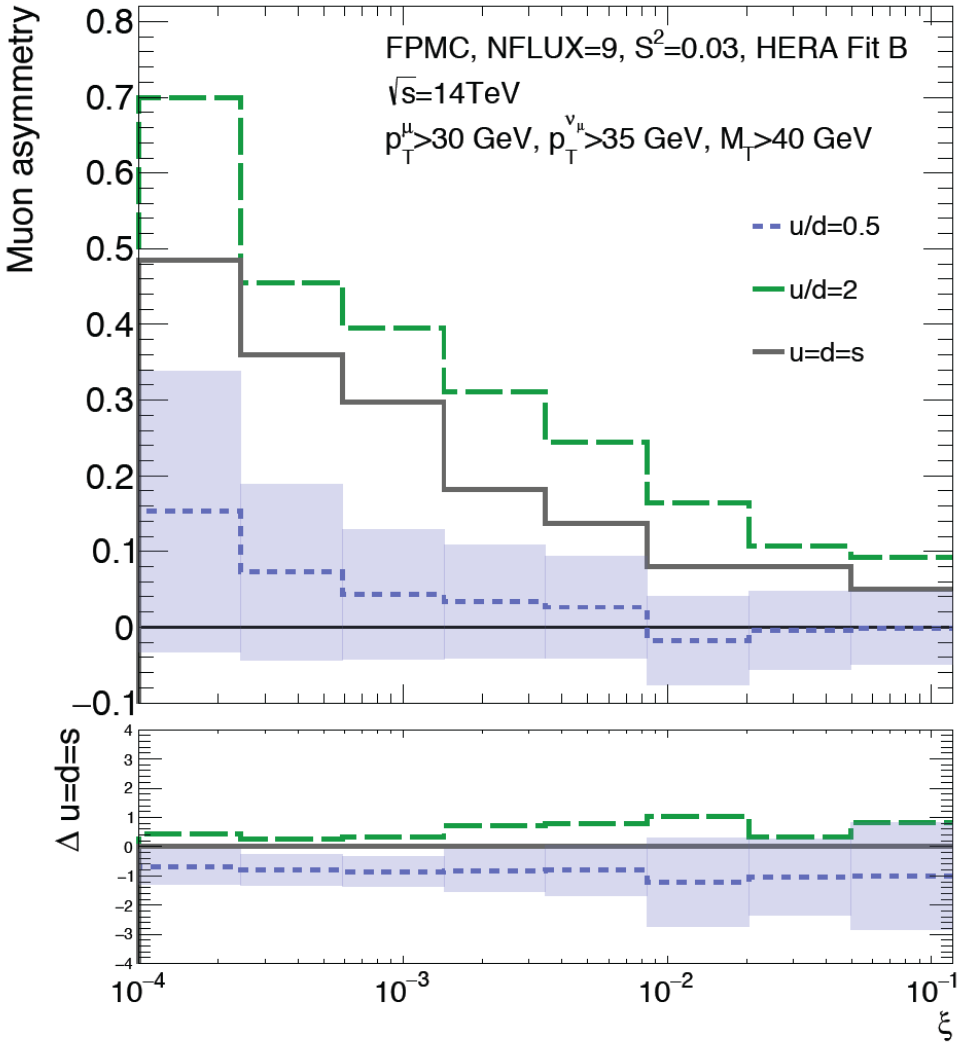


Inclusive diffraction at the LHC: sensitivity to soft colour interaction

- 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



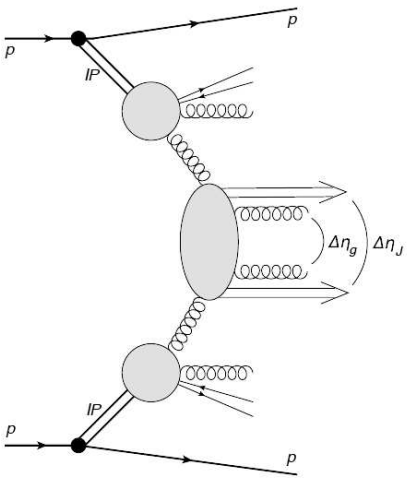
Medium lumi: W charge asymmetry
Sensitivity to quark densities

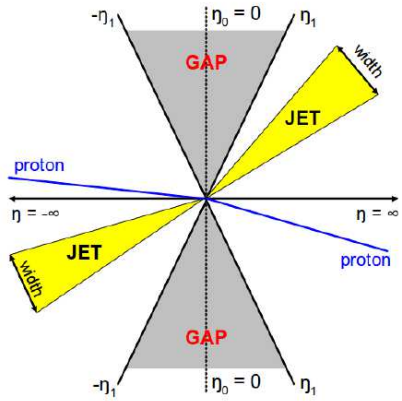


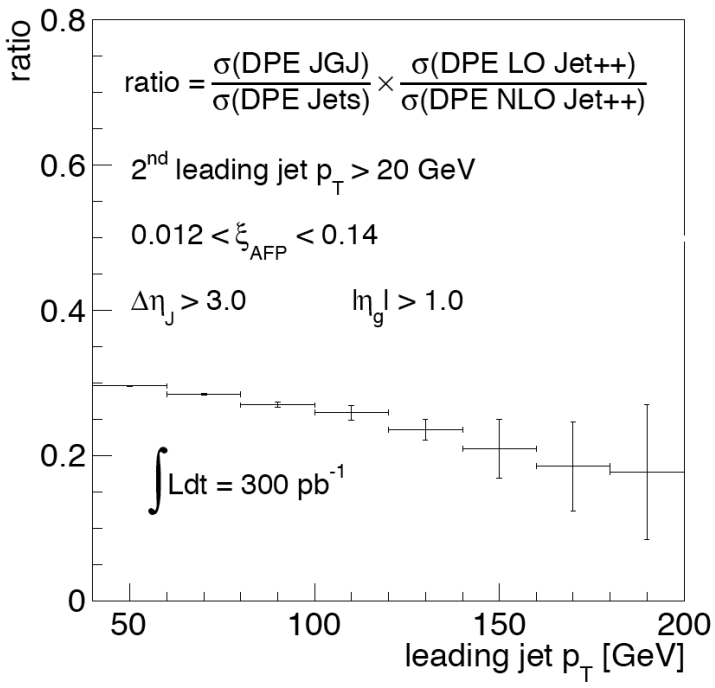
- Measure the average W charge asymmetry in ξ bins to probe the quark content of the proton: $A = (N_{W^+} - N_{W^-})/(N_{W^+} + N_{W^-})$
- Test if u/d is equal to 0.5, 1 or 2 as an example
- A. Chuinard, C. R..,R. Staszewski, JHEP 1604 (2016) 092

Jet gap jet events in diffraction

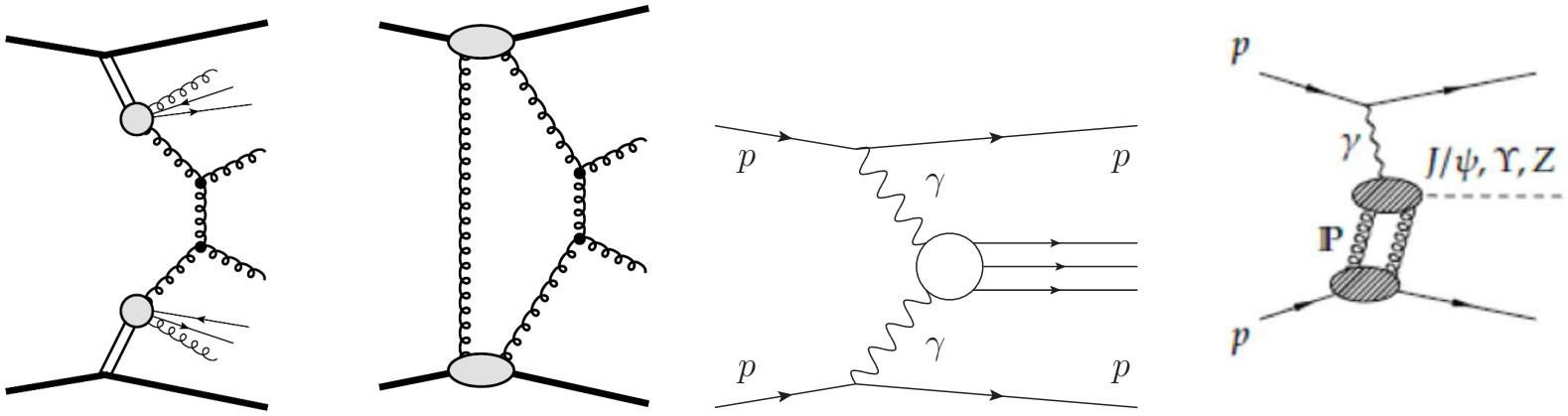
- Study BFKL dynamics using jet gap jet events in DPE
- See talk by Cristian
- Saturation in pA colliaions: see talk by Cole







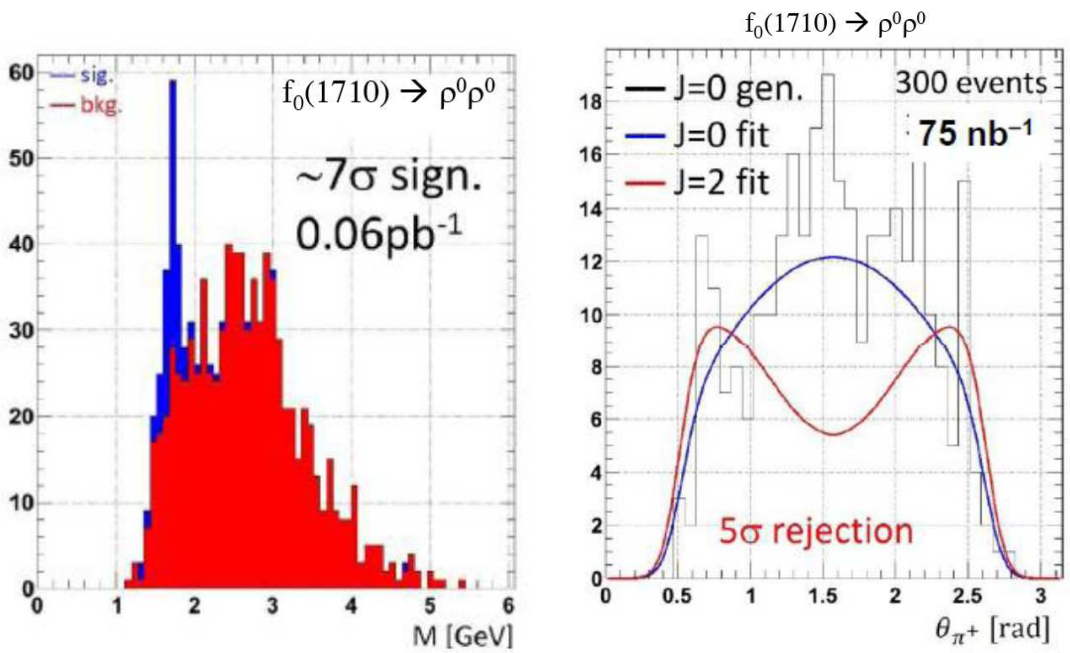
Exclusive diffraction



- Many exclusive channels can be studied at medium and high luminosity: jets, χ_C, charmonium, J/Ψ....
- 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
- Check the $f_0(1500)$ or $f_0(1710)$ glueball candidates
- Central exclusive production is a potential channel for BSM physics: sensitivity to high masses up to 1.8 TeV (masses above 400 GeV, depending how close one can go to the beam)

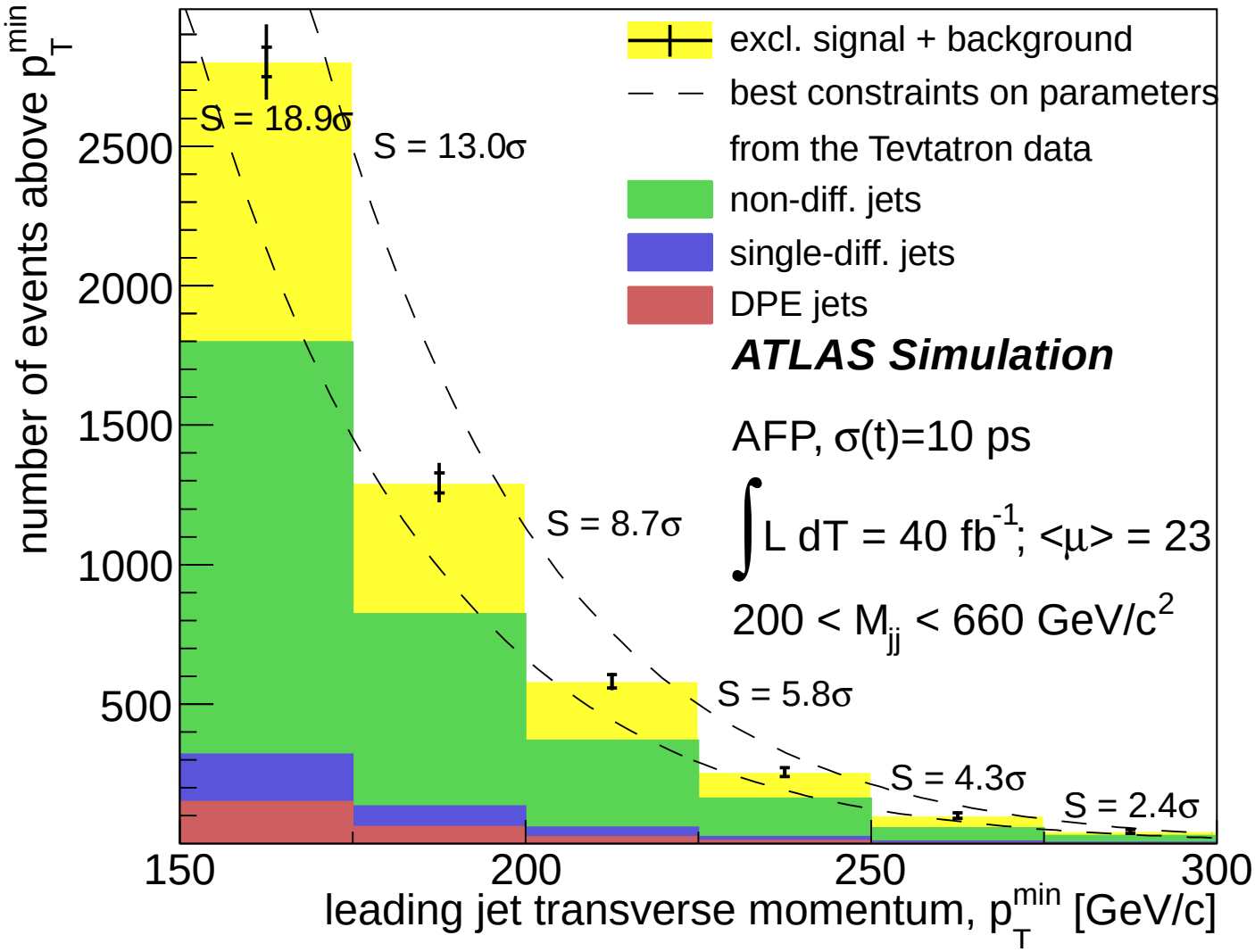
Glueball?

- Possibility to discover/exclude glueballs at low masses
- 1-10 GeV masses can be probed diffractively ($\xi \sim 10^{-4} - 10^{-3}$), ensuring pure gluonic exchanges
- About 5-10 pb^{-1} needed: 1 week of data taking
- Complementarity between forward proton and central detectors: ATLAS/CMS can reconstruct masses of 4 charged particles in the tracker with a resolution of 20-30 MeV (observing for instance $f_0(1710) \to \rho\rho$)
- Check the $f_0(1500)$ or $f_0(1710)$ glueball candidates (in excess of the meson SU(3) multiplet and resonances compatible with glueball in terns of mass, spin, parity, decay channels)
- Lattice calculations predict a $0++$ glueball at 1.7 GeV with a ∼100 MeV uncertainty, favoring the $f_0(1710)$ candidate



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



Conclusion

- Different beam lattices allow exploring different region of phase space for diffraction: soft diffraction, low and medium masses, high masses (full luminosity)
- Better constraints on gluon distribution in Pomeron especially at high β
- Sensitivity to differences in quark distributions in Pomeron: γ+jet and W/Z assymetry
- Jet gap jet events in diffraction: sensitivity to BFKL resummation effects, $\sim$15-20% of DPE jets are jet gap jet events, see talk by Cristian
- Study of exclusive diffraction: vector mesons, jets...
- Search for glueballs