Diffraction with proton tagging at the LHC

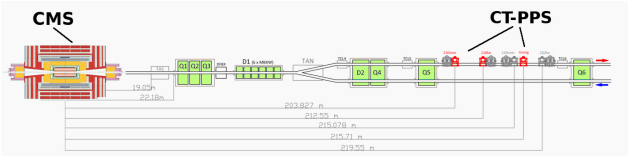
Christophe Royon
University of Kansas, Lawrence, USA
EF06 meeting, Snowmass

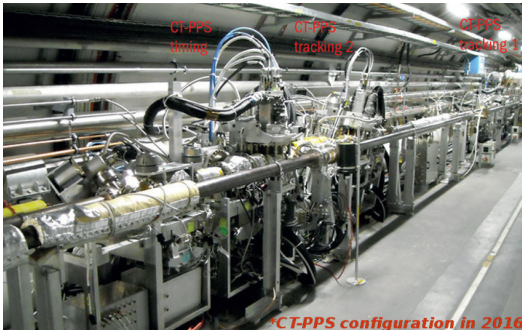
September 16 2020

Contents

- Proton tagging at the LHC
- Pomeron structure
- BFKL resummation effects

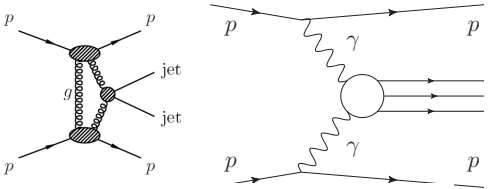
What is the CMS-TOTEM Precision Proton Spectrometer (CT-PPS)?

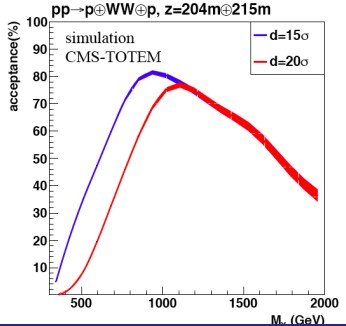




- Joint CMS and TOTEM project: https://cds.cern.ch/record/1753795
- LHC magnets bend scattered protons out of the beam envelope
- Detect scattered protons a few *mm* from the beam on both sides of CMS: 2016, first data taking ($\sim$ 15 fb^{-1})
- Similar detectors: ATLAS Forward Proton (AFP)

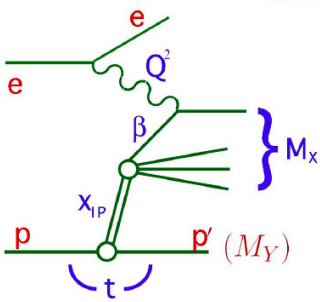
Detecting intact protons in ATLAS/CMS-TOTEM at the LHC





- Tag and measure protons at ± 210 m: AFP (ATLAS Forward Proton), CT-PPS (CMS TOTEM - Precision Proton Spectrometer)
- All diffractive cross sections computed using the Forward Physics Monte Carlo (FPMC)
- Complementarity between low and high mass diffraction (high and low cross sections): special runs at low luminosity (no pile up) and standard luminosity runs with pile up

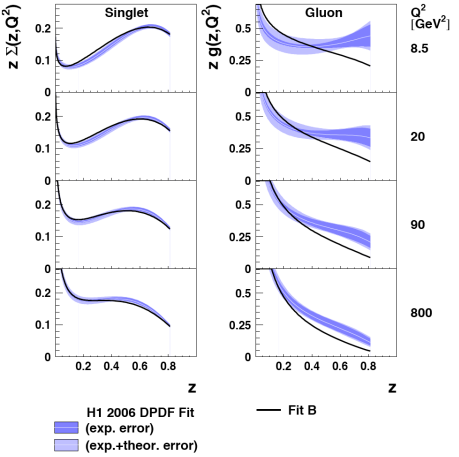
Reminder: Diffraction at HERA



Invariant mass of the diffractive final state

- Momentum fraction of the proton carried by the colourless object (pomeron): $x_p = \xi = \frac{Q^2+M_X^2}{Q^2+W^2}$
- Momentum fraction of the pomeron carried by the interacting parton if we assume the colourless object to be made of quarks and gluons: $\beta = \frac{Q^2}{Q^2+M_X^2} = \frac{x_{Bj}}{x_P}$
- 4-momentum squared transferred: $t = (p - p')^2$

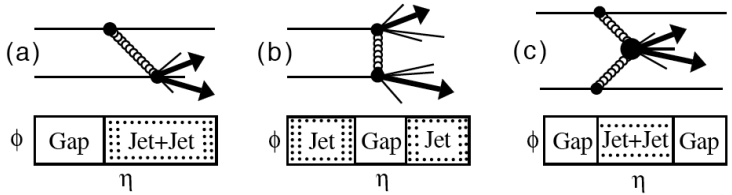
Reminder: Diffraction at HERA



- Measurement of the diffractive cross section using the rapidity gap selection
- Perform QCD fits using NLO Dokshitzer Gribov Lipatov Altarelli Parisi evolution equation
- At low β: evolution driven by $g \to q\bar{q}$, at high β, $q \to qg$ becomes important

$$\frac{dF_2^D}{d\log Q^2} \sim \frac{\alpha_S}{2\pi}\left[P_{qg} \otimes g + P_{qq} \otimes \Sigma\right]$$

Diffraction at LHC: kinematical variables



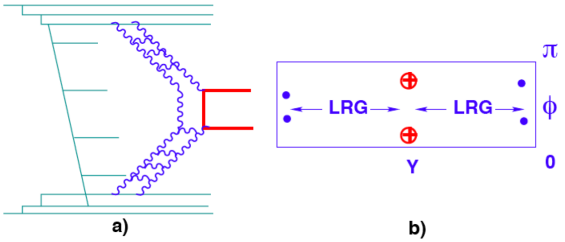
- t: 4-momentum transfer squared
- ξ_1, ξ_2: proton fractional momentum loss (momentum fraction of the proton carried by the pomeron)
- $\beta_{1,2} = x_{Bj,1,2}/\xi_{1,2}$: Bjorken-x of parton inside the pomeron
- $M^2 = s\xi_1\xi_2$: diffractive mass produced
- $\Delta y_{1,2} \sim \Delta\eta \sim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

The Forward Physics Monte Carlo (FPMC)

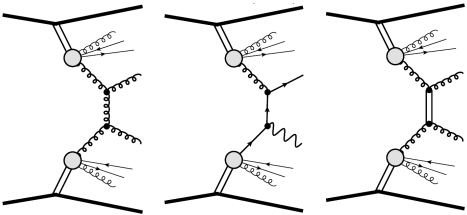
- FPMC (Forward Physics Monte Carlo): implementation of all diffractive/photon induced processes
- List of processes
  - single diffraction
  - double pomeron exchange
  - central exclusive production
  - photon induced processes (and anomalous couplings)
- Inclusive diffraction: Use of diffractive PDFs measured at HERA, with a survival probability of 0.03 applied for LHC
- FPMC manual (see M. Boonekamp, A. Dechambre, O. Kepka, V. Juranek, C. Royon, R. Staszewski, M. Rangel, ArXiv:1102.2531)
- Output of FPMC generator interfaced with fast simulation of ATLAS/CMS detectors

Hard diffraction at the LHC: A difficulty to go from HERA to LHC, Survival probablity

- 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)

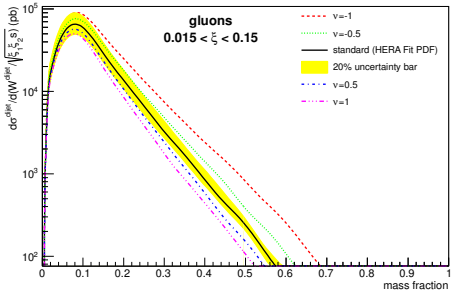


Hard diffraction at the LHC



- Understanding better the structure of the exchanged colorless object, the Pomeron
- Dijet production: dominated by gg exchanges
- γ+jet production: dominated by qg exchanges
- Jet gap jet in diffraction: Probe proton structure at high gluon densities

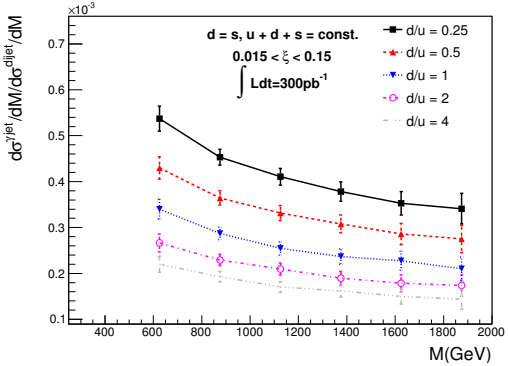
Inclusive diffraction at the LHC: sensitivity to gluon density



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

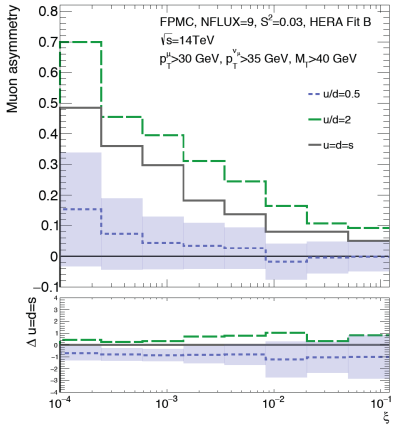
- Sensitivity to gluon density in Pomeron especially the gluon density on Pomeron at high β: multiply the gluon density by $(1-\beta)^\nu$ with $\nu = -1, ..., 1$
- Measurement possible with 10 pb^{-1}, allows to test if gluon density is similar between different accelerators (HERA and LHC) (universality of Pomeron model)
- Dijet mass fraction: dijet mass divided by total diffractive mass ($\sqrt{\xi_1 \xi_2 S}$)
- C. Marquet, C.R., M. Saimpert, Phys.Rev. D88 (2013) no.7, 074029

Inclusive diffraction at the LHC: sensitivity to quark densities



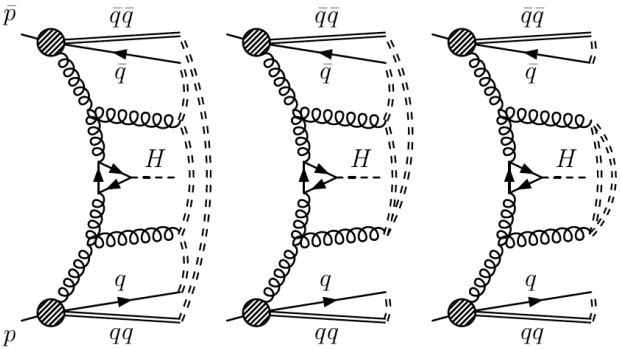
- Predict DPE γ+jet divided by dijet cross section at the LHC
- Sensitivity to universality of Pomeron model
- Sensitivity to quark density in Pomeron, and of assumption:
  $u = d = s = \bar{u} = \bar{d} = \bar{s}$ used in QCD fits at HERA

W asymmetry: sensitivity to quark densities



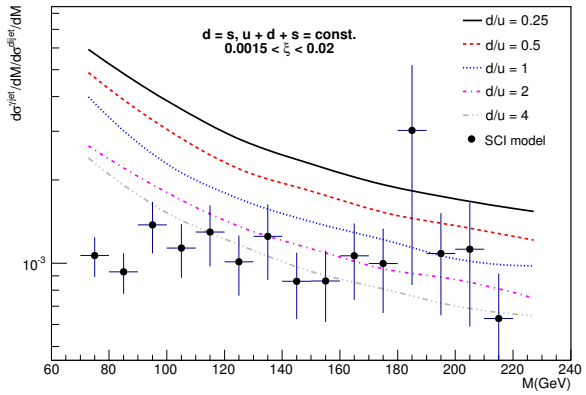
- Measure the average W charge asymmetry in ξ bins to probe the quark content of the proton: $A = (N_{W^+} - N_{W^-})/(N_{W^+} + N_{W^-})$
- Test if u/d is equal to 0.5, 1 or 2 as an example
- A. Chuinard, C. R.,R. Staszewski, JHEP 1604 (2016) 092

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

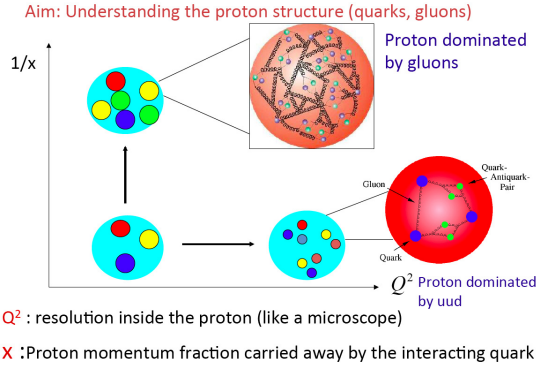
Inclusive diffraction at the LHC: sensitivity to soft colour interaction



- 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

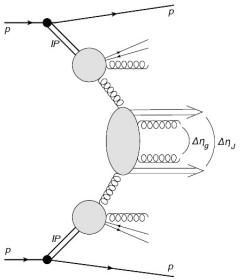
Looking for low x resummation effects effects

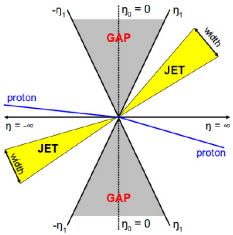
- Dokshitzer Gribov Lipatov Altarelli Parisi (DGLAP): Evolution in Q^2
- Balitski Fadin Kuraev Lipatov (BFKL): Evolution in x

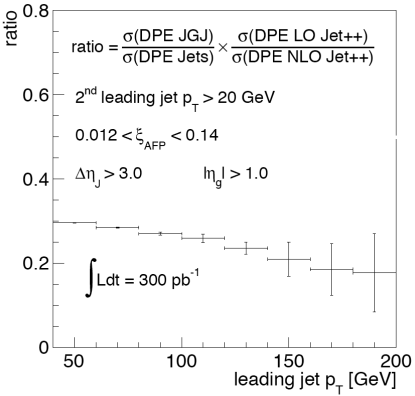


Jet gap jet events in diffraction

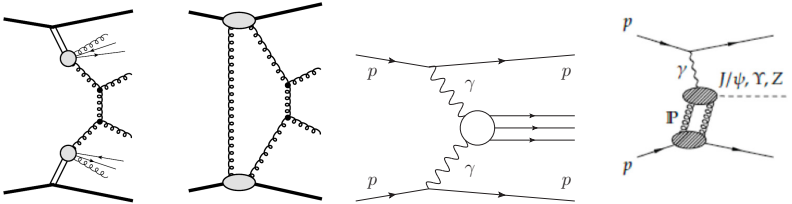
- Study BFKL dynamics using jet gap jet events in DPE
- See: C. Marquet, C. Royon, M. Trzebinski, R. Zlebcik, Phys. Rev. D 87 (2013) 034010







Exclusive diffraction



- Many exclusive channels can be studied: 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
- CMS/TOTEM has the possibility to discover/exclude glueballs at low masses: Check the $f_0(1500)$ or $f_0(1710)$ glueball candidates

Conclusion

- Better understanding of diffraction in QCD using LHC data: constrain pomeron structure in terms of quarks/gluons
- Difficulty to distinguish between partonic structure of Pomeron and survival probability
- Looking for BFKL resummation using jet gap jet events in diffraction (first measurement performed recently by CMS, see talks by Cristian Baldenegro)
- Exclusive diffraction: Important also for physics program at the EIC