Probing the Pomeron quark/gluon structure using γ+jet and dijet events

Workshop on QCD and Diffraction at the LHC

Matthias Saimpert,
C. Royon, D. Werder, C. Marquet

CEA Saclay - Irfu/SPP

November 18th 2013

Introduction

- Resolved (hard) Pomeron model for **Double Pomeron Exchange events** (DPE)
  - Protons interact via a **double Pomeron exchange**
  - Diffractive mass produced from the interaction of two quarks/gluons from **each of Pomerons**

Introduction

- Resolved (hard) Pomeron model for **Double Pomeron Exchange events** (DPE)
  - Protons interact via a **double Pomeron exchange**
  - Diffractive mass produced from the interaction of two quarks/gluons from **each of Pomerons**

- Pomeron structure
  - **Never been checked** experimentally at 14 TeV
  - Constraints exist on **the sum of quark density and the gluon distribution** from F_2^D measurement (HERA) assuming Pomeron is made of quarks and gluons
  - **u=d=s** and q=$\bar{q}$ have been assumed for the fits

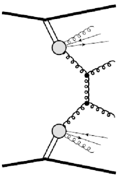
Introduction

- Resolved (hard) Pomeron model for **Double Pomeron Exchange events** (DPE)
  - Protons interact via a **double Pomeron exchange**
  - Diffractive mass produced from the interaction of two quarks/gluons from **each of Pomerons**
- Pomeron structure
  - **Never been checked** experimentally at 14 TeV
  - Constraints exist on **the sum of quark density and the gluon distribution** from F_2^D measurement (HERA) assuming Pomeron is made of quarks and gluons
  - **u=d=s** and q=$\bar{q}$ have been assumed for the fits
- With the LHC (**Proton tagging required**)
  - Possible check of **Pomeron universality** between hadronic and ep colliders
  - **New constraints** on quark densities difference

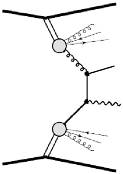
Introduction

- Resolved (hard) Pomeron model for **Double Pomeron Exchange events** (DPE)
  - Protons interact via a **double Pomeron exchange**
  - Diffractive mass produced from the interaction of two quarks/gluons from **each of Pomerons**
- Pomeron structure
  - **Never been checked** experimentally at 14 TeV
  - Constraints exist on **the sum of quark density and the gluon distribution** from F_2^D measurement (HERA) assuming Pomeron is made of quarks and gluons
  - **u=d=s** and q=$\bar{q}$ have been assumed for the fits
- With the LHC (**Proton tagging required**)
  - Possible check of **Pomeron universality** between hadronic and ep colliders
  - **New constraints** on quark densities difference
- Other models as **Soft Color Interaction (SCI)** model does not use Pomeron to describe DPE

Why γ+jet and dijet events?

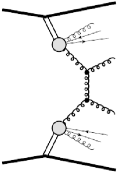


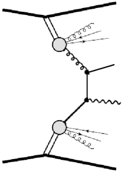
- **dijet** inclusive DPE production
  - Herwig process ID 1500
  - Main mechanism : g+g
  - High σ dependance on **gluon** PDFs
  - $\sigma \simeq$ 10,000 pb after cuts and selection



- γ**+jet** inclusive DPE production
  - Herwig process ID 1800
  - Main mechanism : q+g
  - High σ dependance on **quark** PDFs
  - $\sigma \simeq$ 1 pb after cuts and selection

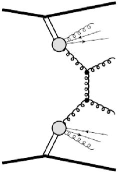
Why γ+jet and dijet events?



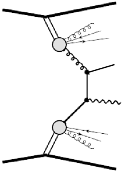


- **dijet** inclusive DPE production
  - Herwig process ID 1500
  - Main mechanism : g+g
  - High σ dependance on **gluon** PDFs
  - $\sigma \simeq$ 10,000 pb after cuts and selection
- γ**+jet** inclusive DPE production
  - Herwig process ID 1800
  - Main mechanism : q+g
  - High σ dependance on **quark** PDFs
  - $\sigma \simeq$ 1 pb after cuts and selection
- **All leading order subprocesses** implemented

Why γ+jet and dijet events?



- **dijet** inclusive DPE production
  - Herwig process ID 1500
  - Main mechanism : g+g
  - High σ dependance on **gluon** PDFs
  - $\sigma \simeq$ 10,000 pb after cuts and selection



- γ**+jet** inclusive DPE production
  - Herwig process ID 1800
  - Main mechanism : q+g
  - High σ dependance on **quark** PDFs
  - $\sigma \simeq$ 1 pb after cuts and selection
- **All leading order subprocesses** implemented

Purpose: evaluate $\frac{\sigma^{\gamma+jet}}{\sigma^{dijet}}$ for various PDFs patterns to determine if measurement is sensitive to **Pomeron quark structure** + **test HERA fit of gluon PDF** at the LHC (σ^{dijet}).

Herwig ID 1800 and 1500: list of Subprocesses

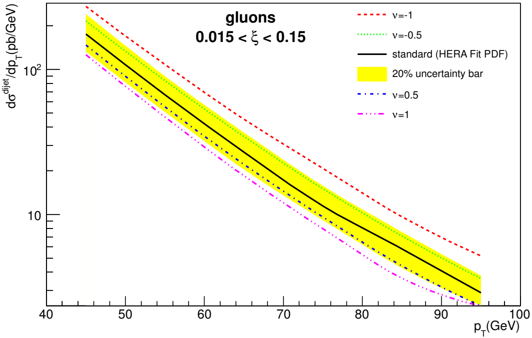
IHPRO	1 + 2	®	3 + 4	c/f conn.
41	q + q-	®	g + g	2 3 1 4
42	q + g	®	q + g	3 1 2 4
43	q- + q	®	g + g	3 1 2 4
44	q- + g	®	q- + g	2 3 1 4
45	g + q	®	q + g	2 3 1 4
46	g + q-	®	q- + g	3 1 2 4
47	g + g	®	g + g	2 3 1 4
51	g+ q	®	g+ q	1 4 2 3
52	g+ q-	®	g+ q-	1 3 4 2
53	g+ g	®	q + q-	1 4 2 3
61	q + q-	®	g+g	2 1 3 4
62	q- + q	®	g+g	2 1 3 4
63	g + g	®	g+g	2 1 3 4
71	g+ q	®	M(S=0) +q'	1 4 3 2
72	g+ q	®	$M(S{=}1)_L$+q'	1 4 3 2
73	g+ q	®	$M(S{=}1)_T$+q'	1 4 3 2
74	g+ q-	®	M(S=0)+q-'	1 4 3 2
75	g+ q-	®	$M(S{=}1)_L$+q-'	1 4 3 2
76	g+ q-	®	$M(S{=}1)_T$+q-'	1 4 3 2

Table 12: Direct photon subprocesses.

IHPRO	1 + 2	®	3 + 4	c/f conn.
1	q + q	®	q + q	3 4 2 1
2	q + q	®	q + q	4 3 1 2
3	q + q'	®	q + q'	3 4 2 1
4	q + q-	®	q'+ q-'	2 4 1 3
5	q + q-	®	q + q-	3 1 4 2
6	q + q-	®	q + q-	2 4 1 3
7	q + q-	®	g + g	2 4 1 3
8	q + q-	®	g + g	2 3 4 1
9	q + q-'	®	q + q-'	3 1 4 2
10	q + g	®	q + g	3 1 4 2
11	q + g	®	q + g	3 4 2 1
12	q- + q	®	q-' +q'	3 1 4 2
13	q- + q	®	q- + q	2 4 1 3
14	q- + q	®	q- + q	3 1 4 2
15	q- + q	®	g + g	3 1 4 2
16	q- + q	®	g + g	4 1 2 3
17	q- + q'	®	q- + q'	2 4 1 3
18	q- + q-	®	q- + q-	4 3 1 2
19	q- + q-	®	q- + q-	3 4 2 1
20	q- + q-'	®	q- + q-'	4 3 1 2
21	q- + g	®	q- + g	2 4 1 3
22	q- + g	®	q- + g	4 3 1 2
23	g + q	®	g + q	2 4 1 3
24	g + q	®	g + q	3 4 2 1
25	g + q-	®	g + q-	3 1 4 2
26	g + q-	®	g + q-	4 3 1 2
27	g + g	®	q + q-	2 4 1 3
28	g + g	®	q + q-	4 1 2 3
29	g + g	®	g + g	4 1 2 3
30	g + g	®	g + g	4 3 1 2
31	g + g	®	g + g	2 4 1 3

Table 11: QCD subprocesses.

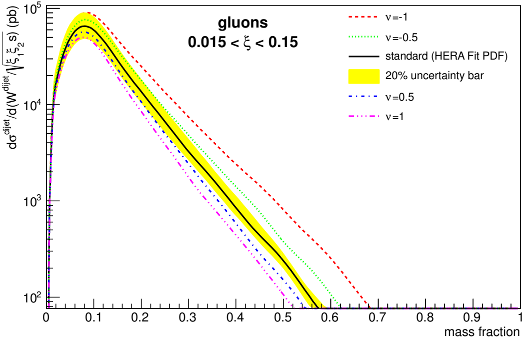
Dijet gluon PDF dependance : jet p_T observable



- "Standard case", "20% uncertainty bar" and "Standard case * $(1-\beta)^{\nu}$" scenarios

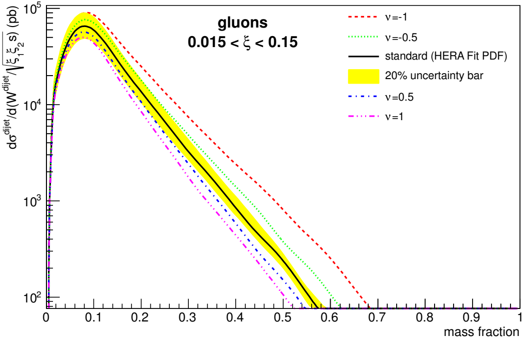
- β, Pomeron momentum fraction loss
- FPMC generator with antikT jet algorithm used, $R = 0.6$, $p_{T,min} = 20\ \mathrm{GeV}$

Dijet gluon PDF dependance : Mass fraction $W^{dijet}/\sqrt{\xi_1 \xi_2 s}$ observable



- "Standard case", "20% uncertainty bar" and "Standard case * $(1-\beta)^{\nu}$" scenarios
- β, Pomeron momentum fraction loss
- FPMC generator with antikT jet algorithm used, $R = 0.6$, $p_{T,min} = 20\ \mathrm{GeV}$

Dijet gluon PDF dependance : Mass fraction $W^{dijet}/\sqrt{\xi_1\xi_2 s}$ observable



- "Standard case", "20% uncertainty bar" and "Standard case * $(1-\beta)^{\nu}$" scenarios

- β, Pomeron momentum fraction loss
- FPMC generator with antikT jet algorithm used, $R = 0.6$, $p_{T,min} = 20$ GeV

- Mass fraction = $\sqrt{\beta_1\beta_2}$, **direct access to Pomeron gluon structure**

Quark densities, $\frac{\sigma_{\gamma+jet}}{\sigma_{dijet}}$ calculation : simulation and selection

- **FPMC generator** has been used. 2 cases considered
  - 14 TeV protons, $0.015 < \xi < 0.15$ (AFP210m)
  - 14 TeV protons, $0.0015 < \xi < 0.15$ (AFP210+420m)

Quark densities, $\frac{\sigma_{\gamma+jet}}{\sigma_{dijet}}$ calculation : simulation and selection

- **FPMC generator** has been used. 2 cases considered
  - 14 TeV protons, $0.015 < \xi < 0.15$ (AFP210m)
  - 14 TeV protons, $0.0015 < \xi < 0.15$ (AFP210+420m)

- Jet reconstruction at particle level with **antikT algorithm** (FastJet package)
  - $R = 0.6$ (ATLAS Standard)
  - $p_{T,jet(s)} > 20\ \mathrm{GeV}$

Quark densities, $\frac{\sigma_{\gamma+jet}}{\sigma_{dijet}}$ calculation : simulation and selection

- **FPMC generator** has been used. 2 cases considered
  - 14 TeV protons, $0.015 < \xi < 0.15$ (AFP210m)
  - 14 TeV protons, $0.0015 < \xi < 0.15$ (AFP210+420m)

- Jet reconstruction at particle level with **antikT algorithm** (FastJet package)
  - $R = 0.6$ (ATLAS Standard)
  - $p_{T,jet(s)} > 20$ GeV
- Photon selection: $p_{T,\gamma} > 20$ GeV

Quark densities, $\frac{\sigma_{\gamma+jet}}{\sigma_{dijet}}$ calculation : simulation and selection

- **FPMC generator** has been used. 2 cases considered
  - 14 TeV protons, $0.015 < \xi < 0.15$ (AFP210m)
  - 14 TeV protons, $0.0015 < \xi < 0.15$ (AFP210+420m)
- Jet reconstruction at particle level with **antikT algorithm** (FastJet package)
  - $R = 0.6$ (ATLAS Standard)
  - $p_{T,jet(s)} > 20\ \mathrm{GeV}$
- Photon selection: $p_{T,\gamma} > 20\ \mathrm{GeV}$
- Photons and jets are central in ATLAS ($\eta < 2.5$)

Quark densities, $\frac{\sigma_{\gamma+jet}}{\sigma_{dijet}}$ calculation : simulation and selection

- **FPMC generator** has been used. 2 cases considered
  - 14 TeV protons, $0.015 < \xi < 0.15$ (AFP210m)
  - 14 TeV protons, $0.0015 < \xi < 0.15$ (AFP210+420m)
- Jet reconstruction at particle level with **antikT algorithm** (FastJet package)
  - $R = 0.6$ (ATLAS Standard)
  - $p_{T,jet(s)} > 20\ \mathrm{GeV}$
- Photon selection: $p_{T,\gamma} > 20\ \mathrm{GeV}$
- Photons and jets are central in ATLAS ($\eta < 2.5$)
- Data normalized for $L = 300pb^{-1}$ (3 weeks low luminosity dedicated run)

Quark densities, $\frac{\sigma_{\gamma+jet}}{\sigma_{dijet}}$ calculation : simulation and selection

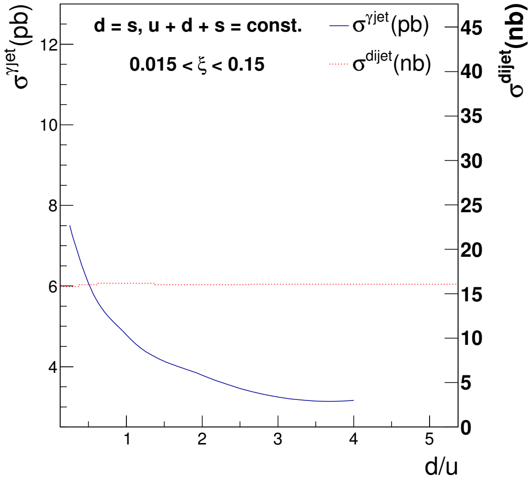
- **FPMC generator** has been used. 2 cases considered
  - 14 TeV protons, $0.015 < \xi < 0.15$ (AFP210m)
  - 14 TeV protons, $0.0015 < \xi < 0.15$ (AFP210+420m)

- Jet reconstruction at particle level with **antikT algorithm** (FastJet package)
  - $R = 0.6$ (ATLAS Standard)
  - $p_{T,jet(s)} > 20$ GeV
- Photon selection: $p_{T,\gamma} > 20$ GeV

- Photons and jets are central in ATLAS ($\eta < 2.5$)
- Data normalized for $L = 300pb^{-1}$ (3 weeks low luminosity dedicated run)

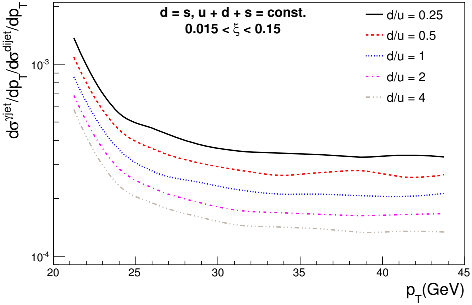
- u+d+s = constant, d=s and d/u $\in \{0.25, 0.5, 1, 2, 4\}$
- u+d+s = constant, d=u and d/s $\in \{0.25, 0.5, 1, 2, 4\}$

d/u results : cross-section ratio

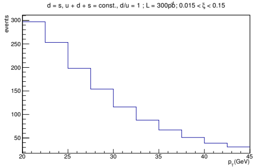


- Cross-sections **after** jet and γ selection ($p_T > 20\ \mathrm{GeV}$)
- Cross-sections ratio varies by **a factor 2.5**

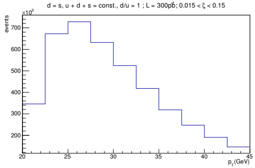
d/u results : $p_{T,jet}$ differential cross-section ratio, $\sqrt{s} = 14$ TeV



γ+jet



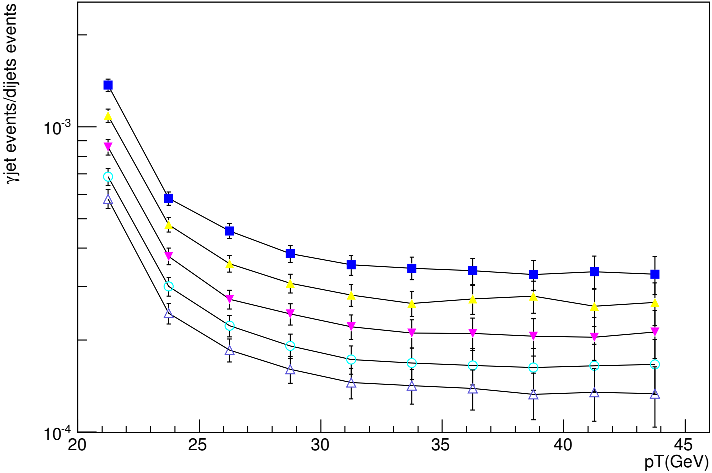
Dijet



- Cross-sections integrated on **2.5 GeV bins**
- Cross-sections ratio varies by **a factor 4**
- Jet Energy Scale (JES) systematics should compensate (but not resolution)
- Statistical uncertainty driven by γ+jet

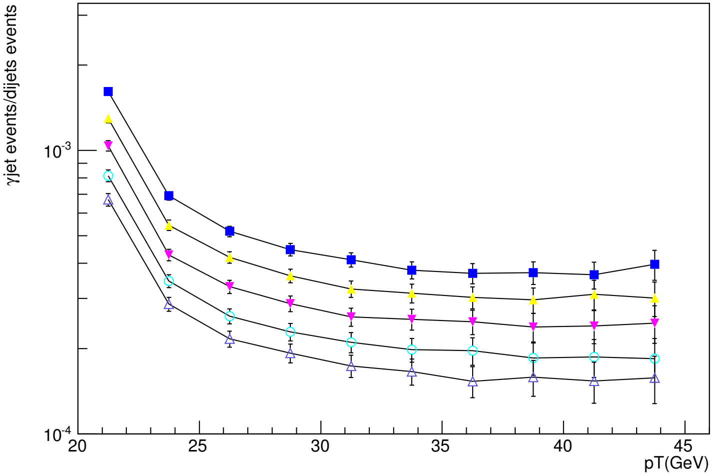
d/u results : $p_{T,jet}$ differential cross-section ratio, $\sqrt{s} = 14$ TeV

Statistical uncertainty ($L = 300\ pb^{-1}$, AFP 210m)

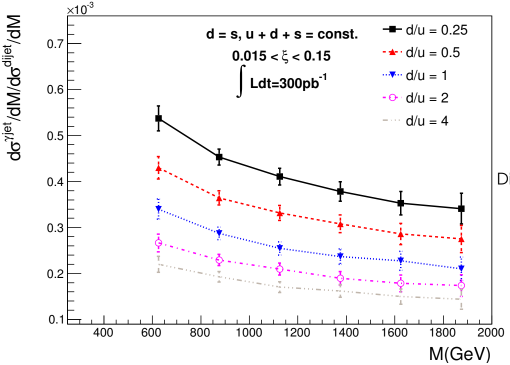


d/u results : $p_{T,jet}$ differential cross-section ratio, $\sqrt{s} = 14$ TeV

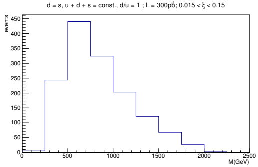
Statistical uncertainty ($L = 300\ pb^{-1}$, AFP 210+420m)



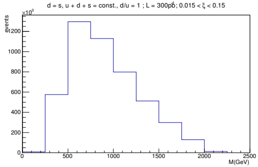
d/u results : $M_{p-p}(=\sqrt{\xi_1\xi_2 s})$ differential cross-section ratio, $\sqrt{s} = 14\ \mathrm{TeV}$



γ+jet

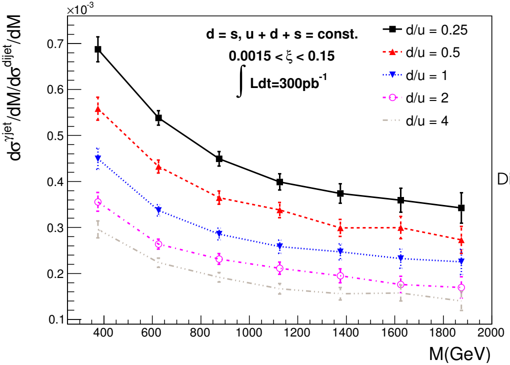


Dijet

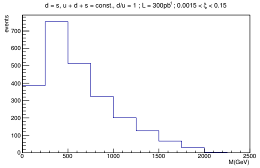


- Cross-sections integrated on **250 GeV bins**
- Cross-sections ratio varies by **a factor 1.5**
- Systematics should almost compensate (AFP measurement)
- Statistical uncertainty driven by γ+jet

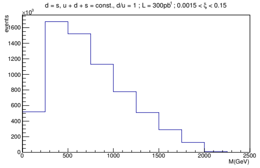
d/u results : $M_{p-p}(= \sqrt{\xi_1 \xi_2 s})$ differential cross-section ratio, $\sqrt{s} = 14$ TeV



γ+jet

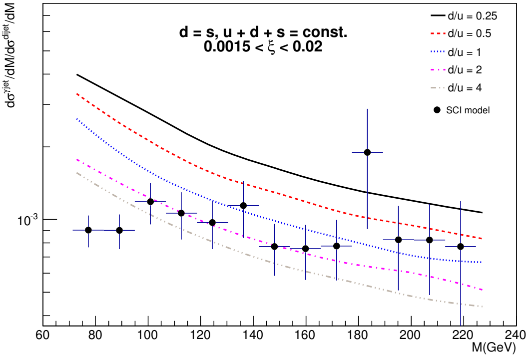


Dijet



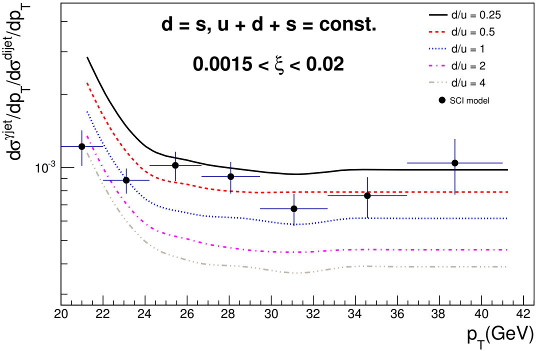
- Cross-sections integrated on **250 GeV bins**
- Cross-sections ratio varies by **a factor 2.5**
- Systematics should almost compensate (AFP measurement)
- Statistical uncertainty driven by γ+jet

$M_{p-p}(=\sqrt{\xi_1\xi_2 s})$ observable : A way to discriminate Pomeron from SCI model?



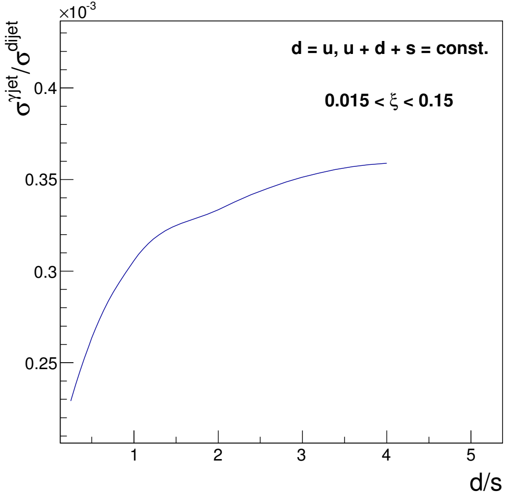
- Need to be out of the SCI **background** : $\xi < 0.02$ (probably overestimated)
- SCI : **flat** distribution

$p_{T,jet}$ observable : A way to discriminate Pomeron from SCI model?



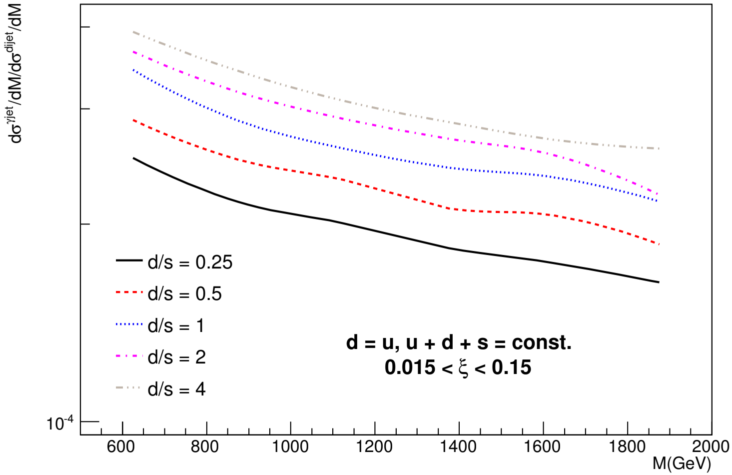
- Need to be out of the SCI **background** : $\xi < 0.02$ (probably overestimated)
- SCI : **flat** distribution

d/s results : cross-section ratio



- Cross-sections **after** jet and γ selection ($p_T > 20\ \mathrm{GeV}$)
- Cross-sections ratio varies by **a factor 1.5**

d/s results : $M_{p-p}(=\sqrt{\xi_1\xi_2 s})$ differential cross-section ratio, $\sqrt{s} = 14$ TeV



Experimental issues

- **No reggeons exchange** was introduced in this study, it is expected to dominate for $\xi > 0.1$ only.

Experimental issues

- **No reggeons exchange** was introduced in this study, it is expected to dominate for $\xi > 0.1$ only.
- **Need dedicated low luminosity runs**. 300 $pb^{-1} \simeq 3$ weeks at no pile-up

Experimental issues

- **No reggeons exchange** was introduced in this study, it is expected to dominate for $\xi > 0.1$ only.
- **Need dedicated low luminosity runs**. 300 $pb^{-1} \simeq 3$ weeks at no pile-up
- **Possible low pile-up measurements** (μ = 2,3) would decrease significantly required dedicated runtime

- **No reggeons exchange** was introduced in this study, it is expected to dominate for $\xi > 0.1$ only.
- **Need dedicated low luminosity runs**. 300 $pb^{-1} \simeq 3$ weeks at no pile-up
- **Possible low pile-up measurements** (μ = 2,3) would decrease significantly required dedicated runtime
- **Trigger possibilities:** for $\gamma + jet$, trigger on γ in the central detector, for *dijet* trigger on leading jet and on protons with AFP timing detectors.

Conclusion

- γ+jet/dijet DPE events study is a good probe of **Pomeron structure**
  - Requires dedicated **low luminosity runs**
  - Measurement would be relevant as of $\boldsymbol{L = 300\ pb^{-1}}$ ($\simeq$ 3 weeks of data) with AFP 210 m to probe **quark densities**
  - Statistical uncertainty driven by γ+jet

Conclusion

- γ+jet/dijet DPE events study is a good probe of **Pomeron structure**
  - Requires dedicated **low luminosity runs**
  - Measurement would be relevant as of $\boldsymbol{L = 300\ pb^{-1}}$ ($\simeq$ 3 weeks of data) with AFP 210 m to probe **quark densities**
  - Statistical uncertainty driven by γ+jet

- Test of the **Pomeron model**
  - **Universality of the Pomeron** between ep (HERA) and hadronic (LHC) colliders
  - **New constrains** on quark PDFs are possible with the LHC

Conclusion

- γ+jet/dijet DPE events study is a good probe of **Pomeron structure**
  - Requires dedicated **low luminosity runs**
  - Measurement would be relevant as of $\boldsymbol{L = 300\ pb^{-1}}$ ($\simeq$ 3 weeks of data) with AFP 210 m to probe **quark densities**
  - Statistical uncertainty driven by γ+jet

- Test of the **Pomeron model**
  - **Universality of the Pomeron** between ep (HERA) and hadronic (LHC) colliders
  - **New constrains** on quark PDFs are possible with the LHC

- Possible way to discriminate Pomeron model from **Soft Color Interaction model**

Conclusion

- γ+jet/dijet DPE events study is a good probe of **Pomeron structure**
  - Requires dedicated **low luminosity runs**
  - Measurement would be relevant as of $\boldsymbol{L = 300\ pb^{-1}}$ ($\simeq$ 3 weeks of data) with AFP 210 m to probe **quark densities**
  - Statistical uncertainty driven by γ+jet
- Test of the **Pomeron model**
  - **Universality of the Pomeron** between ep (HERA) and hadronic (LHC) colliders
  - **New constrains** on quark PDFs are possible with the LHC
- Possible way to discriminate Pomeron model from **Soft Color Interaction model**
- Paper published 24/10/13, Phys.Rev.D **88**, 074029

Published paper

PHYSICAL REVIEW D **88**, 074029 (2013)

Probing the Pomeron structure using dijets and γ + jet events at the LHC

C. Marquet,[1,*] C. Royon,[2,†] M. Saimpert,[2,‡] and D. Werder[3,§]
[1] *Centre de Physique Théorique, École Polytechnique, CNRS, 91128 Palaiseau, France*
[2] *IRFU/Service de Physique des Particules, CEA/Saclay, 91191 Gif-sur-Yvette Cedex, France*
[3] *Department of Physics and Astronomy, Uppsala University, Box 516, SE-751 20 Uppsala, Sweden*
(Received 20 June 2013; published 24 October 2013)

We consider hard diffractive events in proton-proton collisions at the LHC, in which both protons escape the collision intact. In such double Pomeron exchange processes, we propose to measure dijets and photon-jet final states, and we show that it has the potential to pin down the Pomeron quark and gluon contents, a crucial ingredient in the standard QCD description of hard diffraction. By comparing with predictions of the soft color interaction approach, we also show that more generally, the measurement of the photon-jet to dijet cross section ratio can put a stringent test on the QCD dynamics at play in diffractive processes in hadronic collisions.

DOI: 10.1103/PhysRevD.88.074029 PACS numbers: 13.60.Hb, 12.38.Bx, 12.38.Lg

Back-up slides

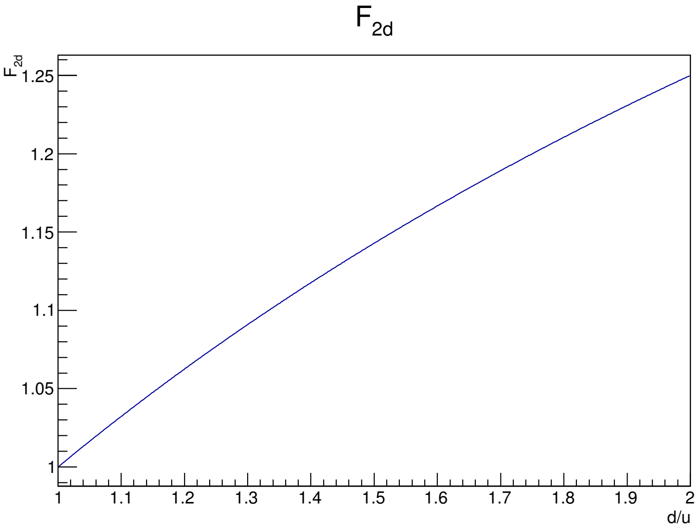
Workshop on QCD and Diffraction at the LHC

Matthias Saimpert,
C. Royon, D. Werder, C. Marquet

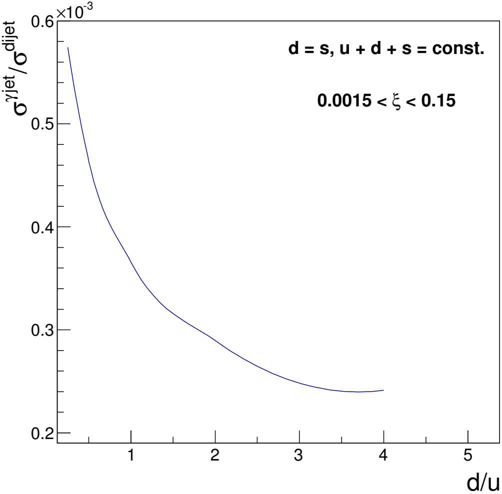
CEA Saclay - Irfu/SPP

November 18th 2013

F_2^D variations

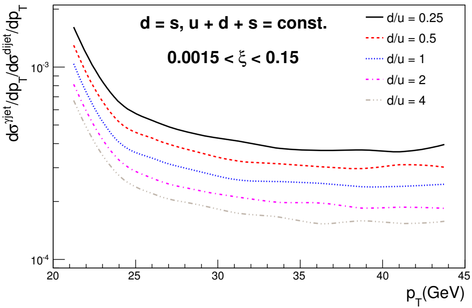


d/u results : cross-section ratio, AFP210+420

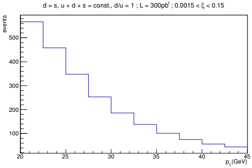


- Cross-sections **after** jet and γ selection ($p_T > 20$ GeV)
- Cross-sections ratio varies by **a factor 2.5**

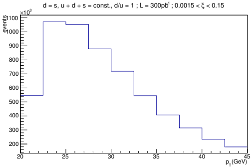
d/u results : $p_{T,jet}$ differential cross-section ratio, AFP210+420



γ+jet



Dijet



- Cross-sections integrated on **2.5 GeV bins**
- Cross-sections ratio varies by **a factor 4**
- Jet Energy Scale (JES) systematics should compensate (but not resolution)
- Statistical uncertainty driven by γ+jet