Inclusive diffractive production of top quarks at the LHC

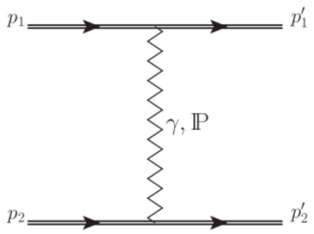
30 September 2021

C. Baldenegro, A. Bellora, M. Pitt, C. Royon

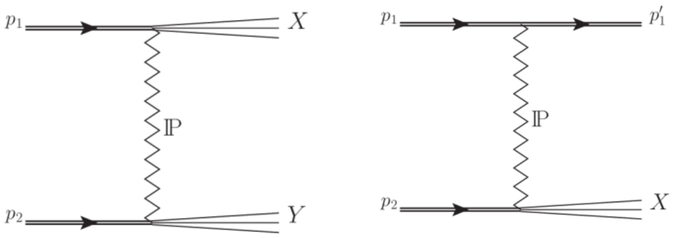
Introduction

Diffractive processes in *pp* collisions at the LHC

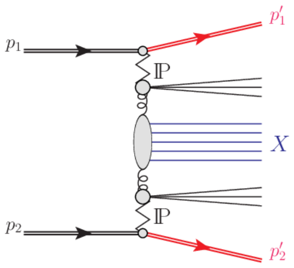
- t-channel exchange of color neutral particles (QED, QCD)
- Sometimes protons emerge intact



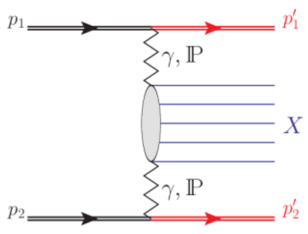
Elastic scattering



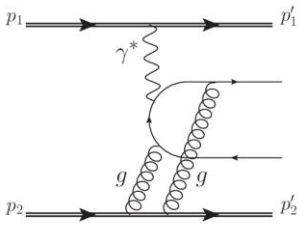
Single/double diffractive dissociation



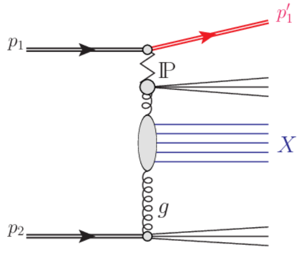
Double pomeron exchange



Central exclusive production



Exclusive photoproduction



Single-diffraction with central system

- Provide a rich scientific program for LHC experiments

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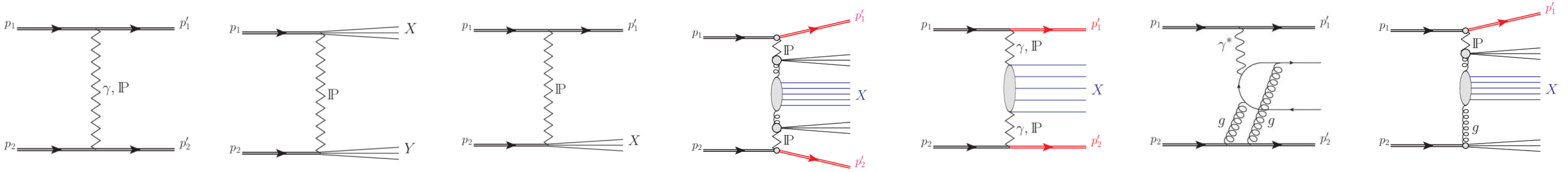

Elastic scattering | Single/double diffractive dissociation | Double pomeron exchange | Central exclusive production | Exclusive photoproduction | Single-diffraction with central system

- Provide a rich scientific program for LHC experiments
- A few examples from Run2 data:

TOTEM
Eur.Phys.J.C 79 (2019) 10, 861
Eur.Phys.J.C 79 (2019) 79, 785
Eur.Phys.J.C 79 (2019) 2, 103

LHCb
JHEP 06 (2018) 100
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CMS (+TOTEM)
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ATLAS (+LHCf)
ATLAS-CONF-2017-075
PLB 777 (2018) 303-323
PRL 125, 261801 (2020)
PLB 816 (2021) 136190

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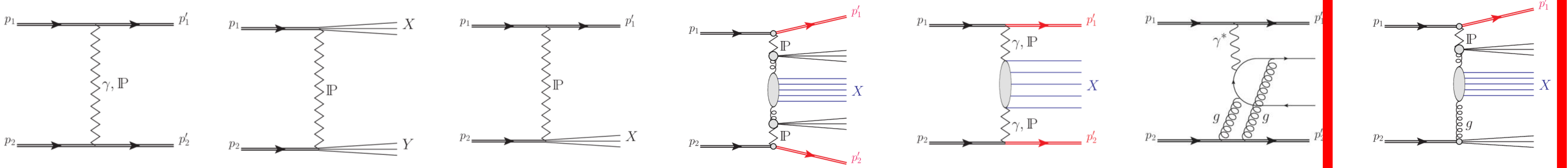

Elastic scattering

Single/double diffractive dissociation

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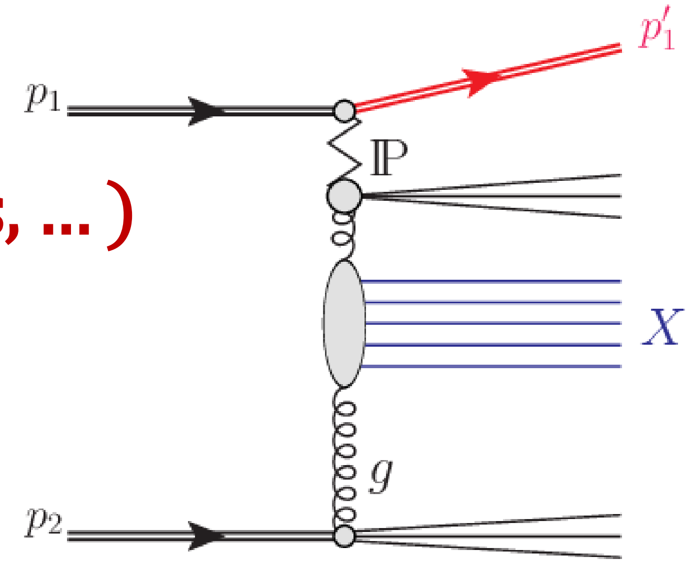
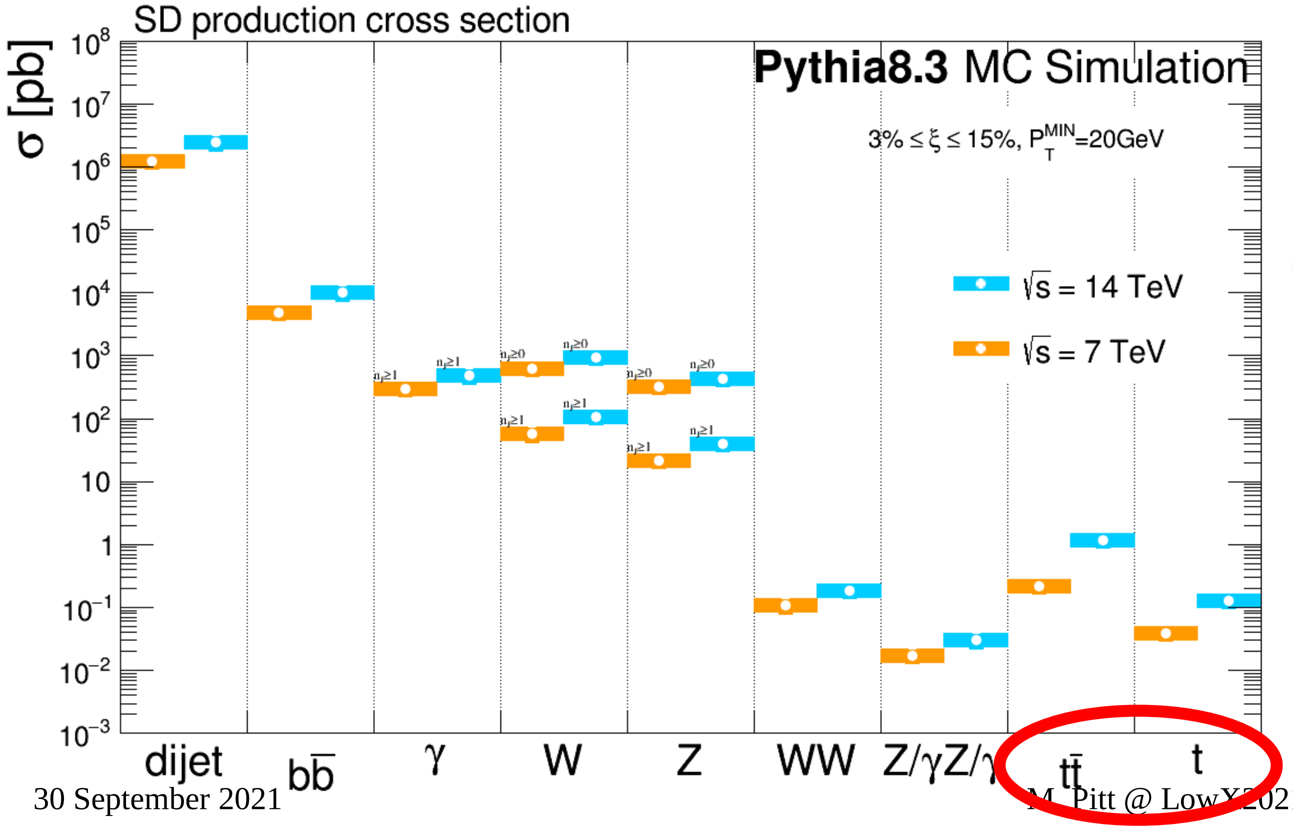
- **I'll focus on: Single-diffraction with central system**

Introduction



Single diffraction with central system (jets, bosons, tops, …)

- Production of hard process + a diffractive proton
- Hard SD events comprise a few % of the inclusive production
- Could play a role in precision measurement at the HL-LHC



- **Large fraction of SM processes are accessible by the LHC experiments**

Diffractive top physics:

Goncalves et al 2007.04565

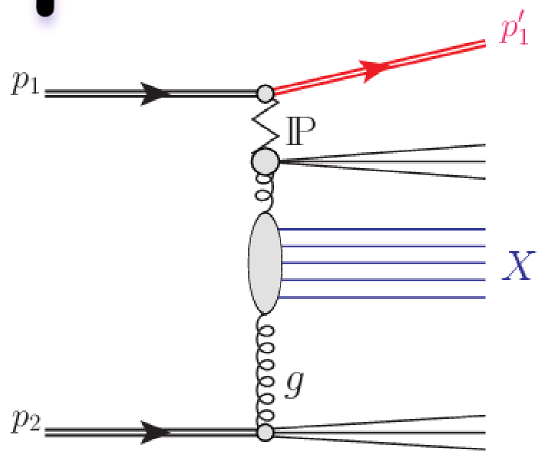
Howarth 2008.04249

Single diffraction in pp

Production cross-section of single diffractive events

$$\frac{d\sigma}{d\xi dt} = \underbrace{F_{IP/p}(\xi,t)}_{\text{Pomeron flux}} \sum_{a\,b} \int \underbrace{dx_g d\frac{x_b}{\xi} f_{b/P}(x_b,Q^2) f_{a/IP}\left(\frac{x_b}{\xi},Q^2\right)}_{\text{dPDF, PDF}} \hat{\sigma}_{ab\to X}$$

Hard-scatter Xsec



Where:

$F_{IP/p}(\xi,t)$ is the pomeron flux

ξ is proton momentum loss, and t is the scale

x_a, x_b proton momentum fraction caried by the struck partons ($x_b \equiv x_{bj}$, $\beta \equiv \frac{x_{bj}}{\xi}$)

$f_{a/P}, f_{b/IP}$ parton distribution function of proton (PDF) or pomeron (dPDF) respectively

Q^2 – factorization scale of order of transverse energy of the hard scattering

Single diffraction in pp

Production cross-section of single diffractive events

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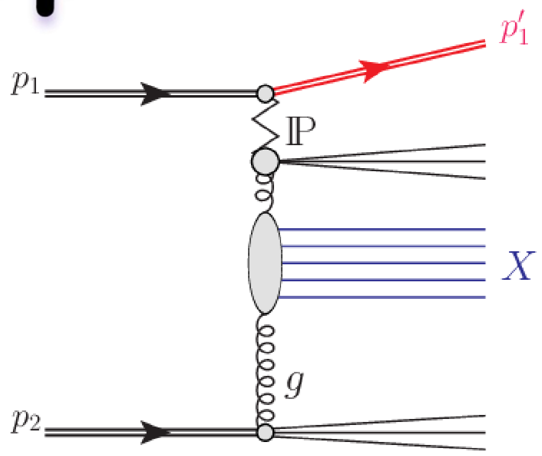
Pomeron flux

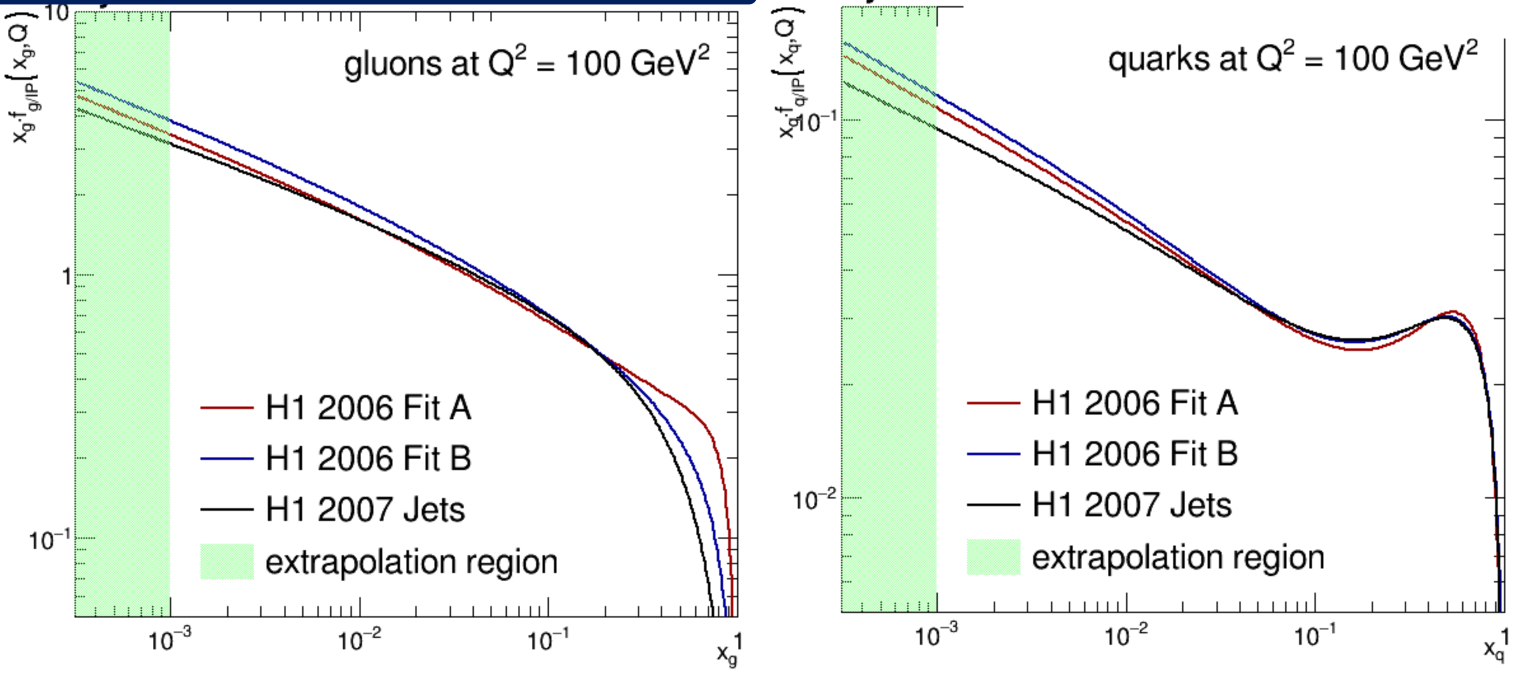
dPDF, PDF

Hard-scatter Xsec



<u>Diffractive terms</u>:

- Structure functions are fitted using H1 data[1]
- Dominated by gluons
- No fits from Tevatron/LHC
- H1 assumption of flavor universality (never tested)



[1]Eur. Phys. J. C48 (2006) 715 [hep-ex/0606004]

Single diffraction in pp

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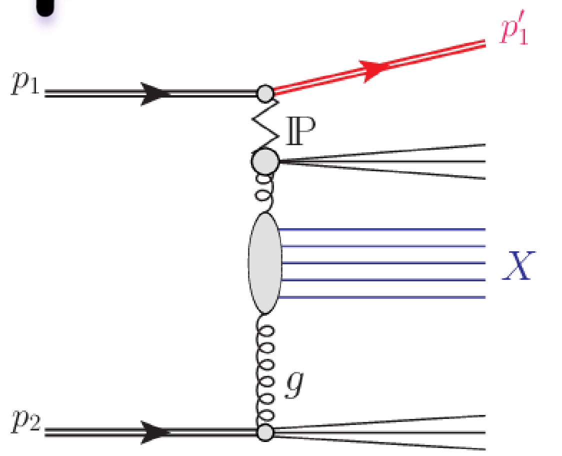
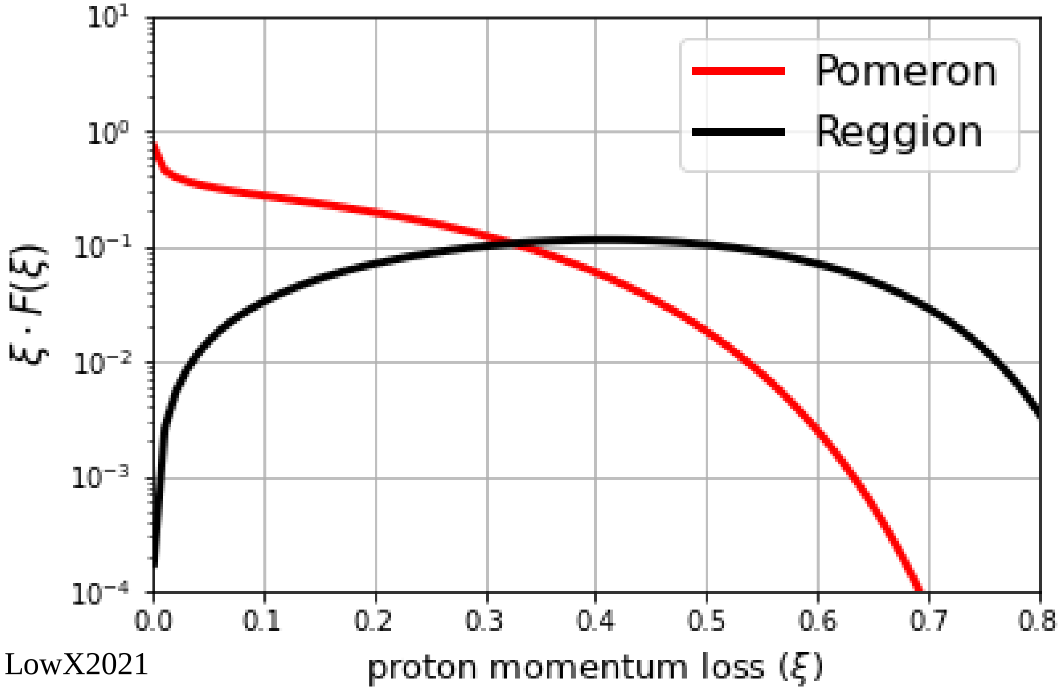
Pomeron flux — dPDF, PDF — Hard-scatter Xsec



Fluxes:

- H1 parametrized fluxes: $A_{IP} \frac{e^{B_{IP}t}}{\xi^{2\alpha_{IP}(t)-1}}$
- Reggeon contributions are not constrained at LHC/Tevatron
- Testing the fluxes at ξ>10% could give a first hint on the Reggion contributions at LHC (?)



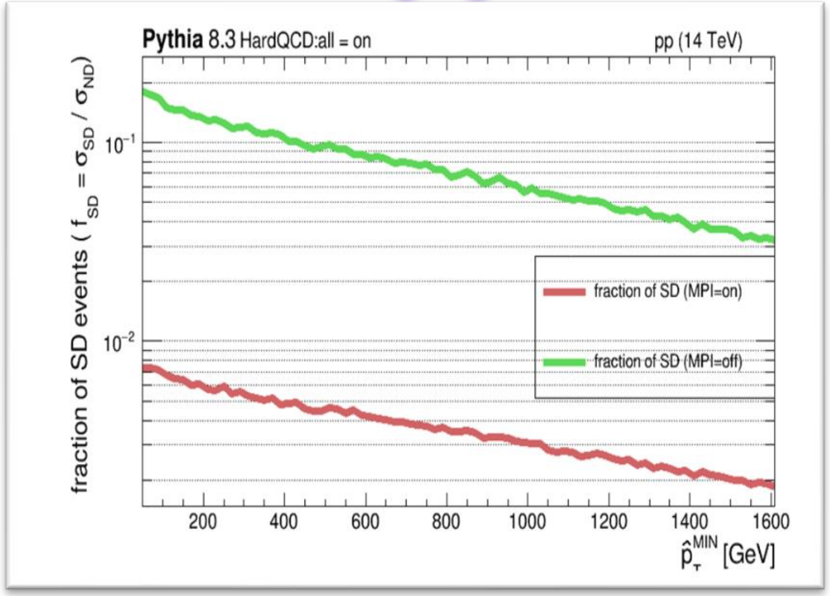
Single diffraction in pp

Experimental challenges

- Obtaining a pure sample of SD events
- Tradeoff between lowPU (high purity) and high integrated luminosity (high scales)

Experimental goals

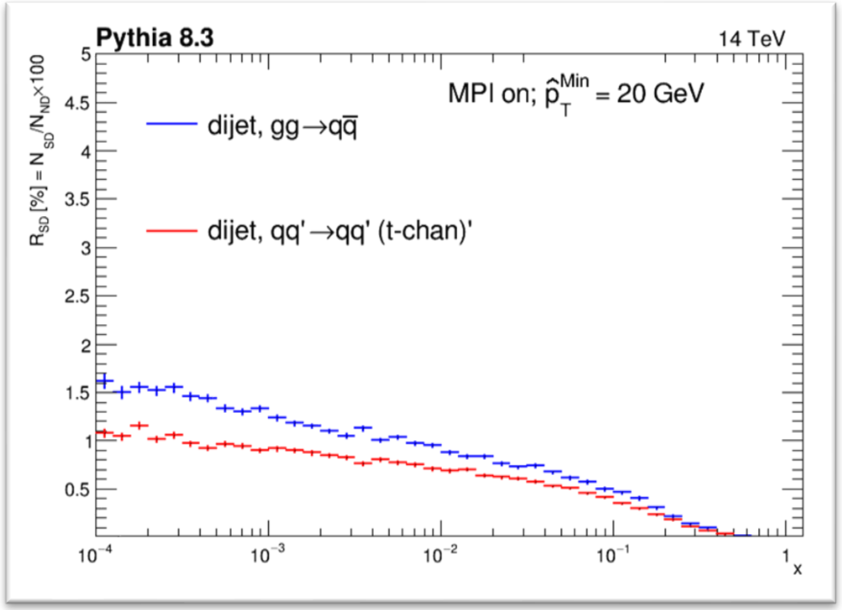
1. Constraining the fraction of SD events
2. Constraining the model parameters



Process of study:

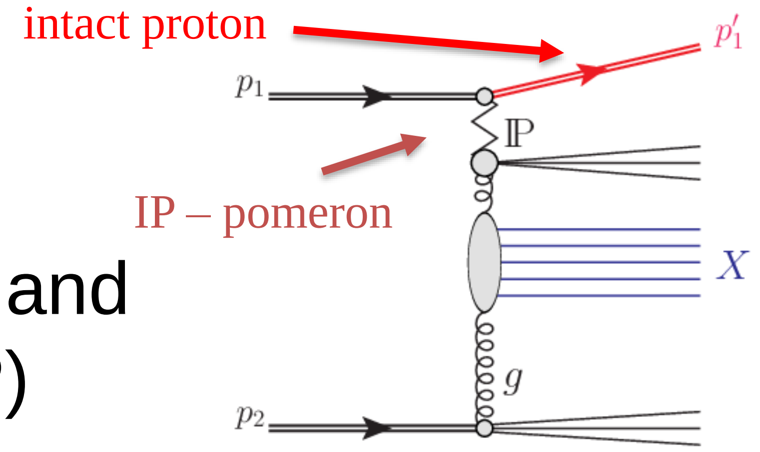
SD tops (tt and t) with tagged protons

- Sensitive to PDFs (gluons, heavy-flavor)
- High scale ($\sqrt{\hat{s}}$)
- Use proton kinematics to test model parameters

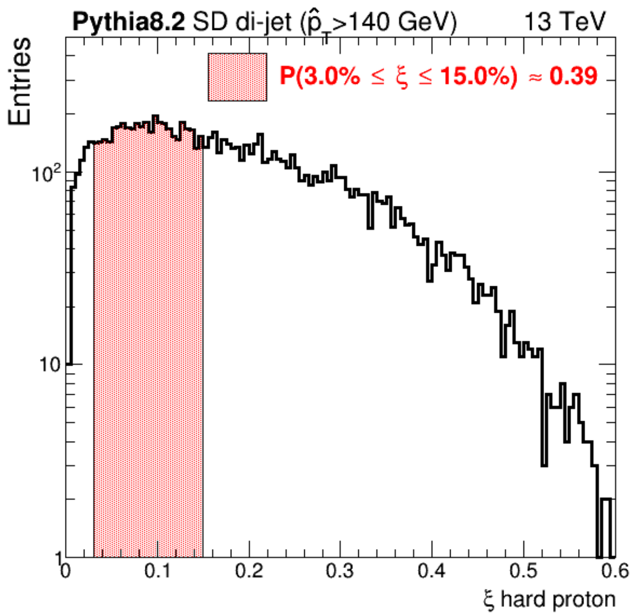


SD with tagged protons

- Occasionally in diffractive events proton emerge intact from the pp collisions
- Intact protons are deflected away from the beam and measured by forward proton detectors (PPS/AFP)

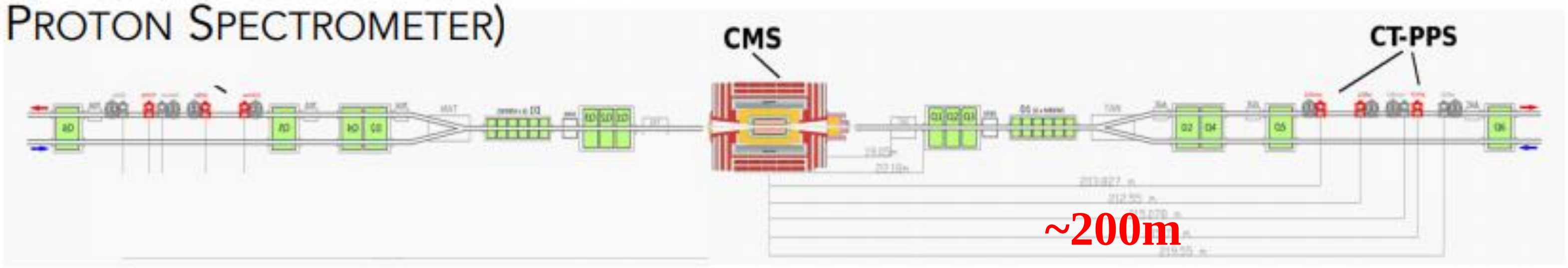


Displacement of the protons from the beam determines the proton momentum loss $\xi = \frac{\Delta p}{p}$ and p_T, can be measured by LHC detectors in the range of ξ ~ 3 – 15% and p_T up to a few GeV



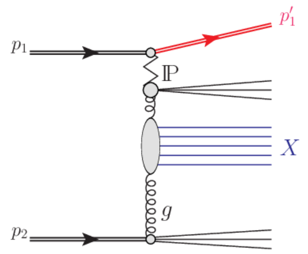
One of the examples of proton tagging at LHC – PPS:

(Precision Proton Spectrometer)



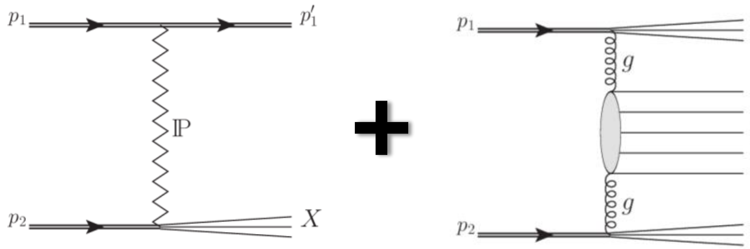
SD with tagged protons

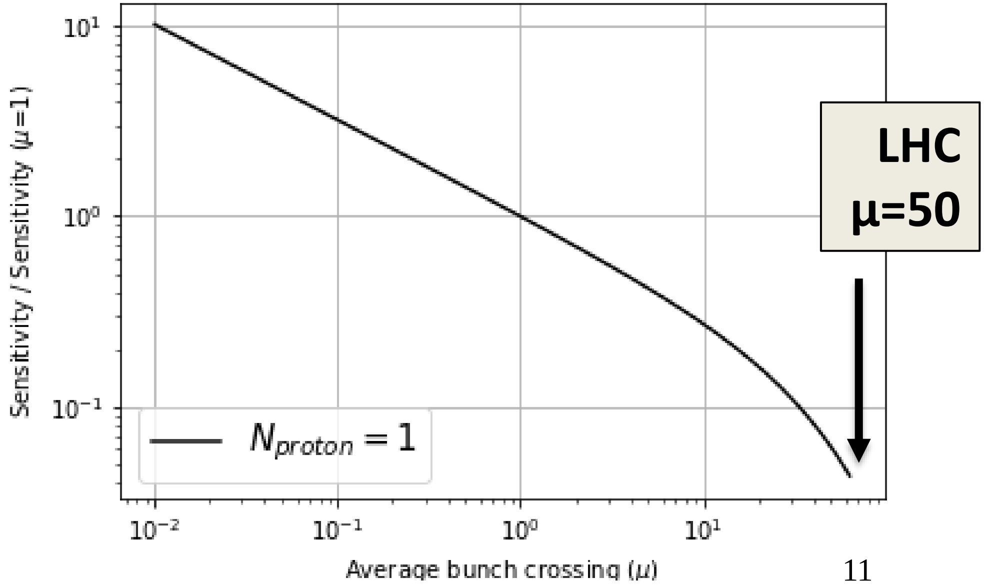
- Processes of an order of a few pb can be probed by LHC experiments benefiting from proton tagging



Backgrounds:

- SD events: ~10% of pp collisions
- Simultaneously produced with hard non-diffractive collisions cam mimic hard diffractive scattering
- Hard to distinguish at high PU rates



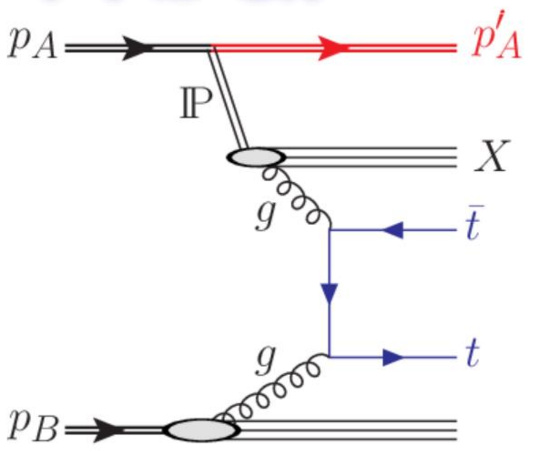


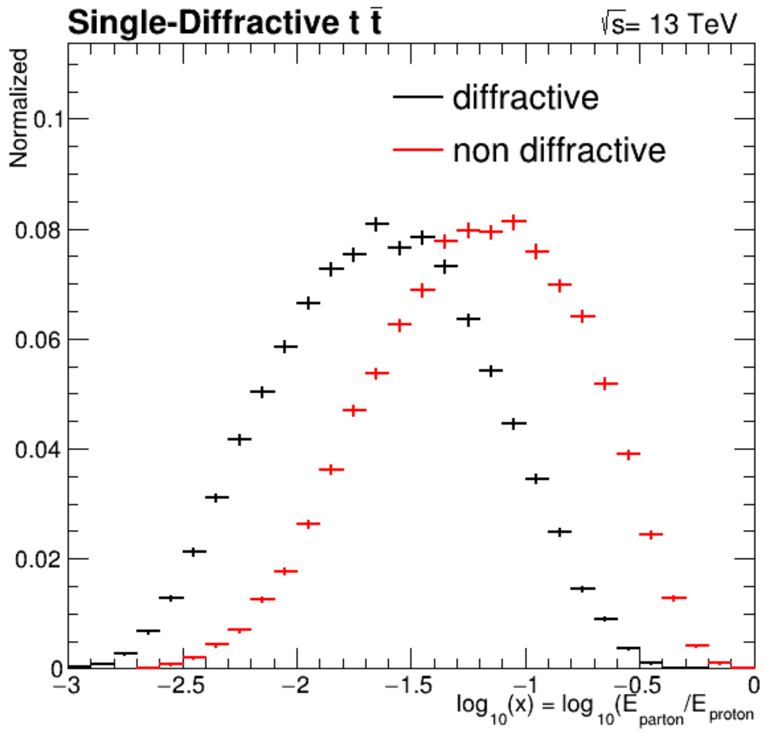
Probability to measure n protons, for PU=μ and proton acceptance p is:

$$P(n) = \Sigma_{k \geq n} Poi(k|\mu) B(n|k,p)$$

Probing diffractive ttbar

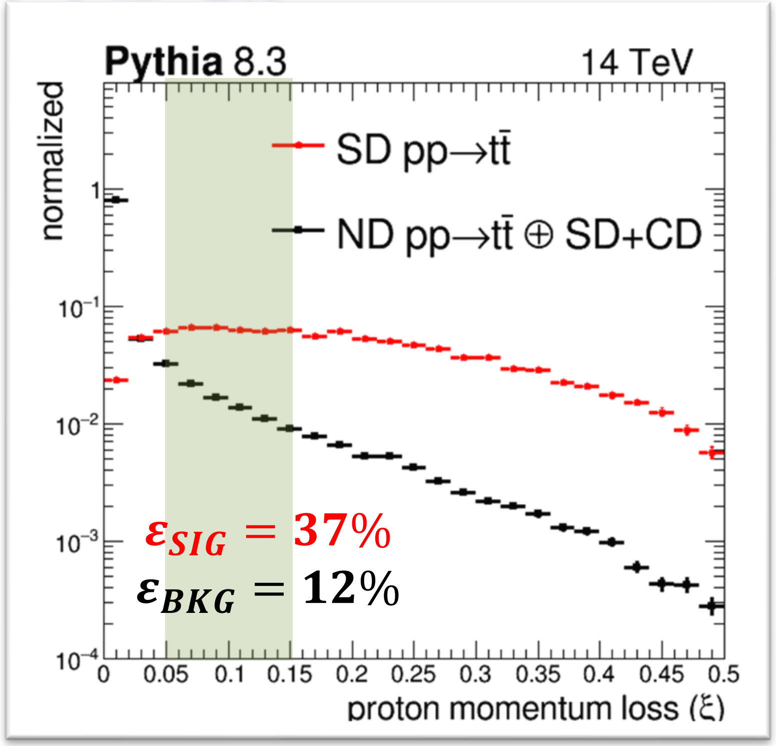
- ttbar is a common SM process produced at the largest scale (σ~800pb, $\sqrt{\hat{s}} > m_{tt} \approx$ 350 GeV)
- SD ttbar is expected to be of the order of a few pb
- Dominated by gluon-fusion
- Can have visible effects near the m_{tt} threshold
- Different structure functions manifest in different event topologies (true for all SD processes)





Probing diffractive ttbar

- Analysis at μ=3, $\sqrt{s}$=14 TeV, L_{int}=0.5fb^{-1}
- Event selection (semi-leptonic ttbar decays)
  1 lepton with pT>15 GeV
  2 b-jet with pT>20 GeV, |η|<2.5, TR=60%
  2 light jets with pT>20, |η|<4.5
- Backgrounds: ttbar + PU proton (MinBias events)

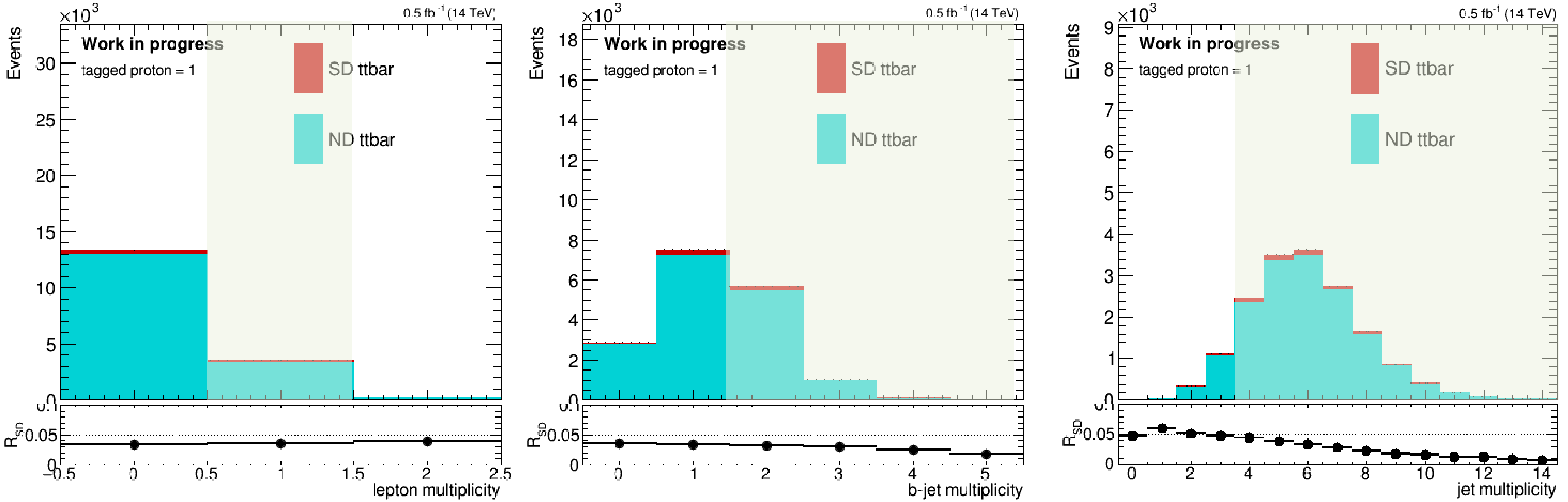


Cut	Signal	Background	$N_S/\sqrt{N_B}$
1 lepton	22.03%	20.56%	1.46
&& 2 bjets	7.64%	7.48%	0.84
&& 2 light jets	6.04%	6.41%	0.72
1 proton	2.28%	0.40%	1.09

Proton acceptance (ξ in 3 – 15%):
Signal = 37%
Bkg =(18%*12%)=2.2% / collision

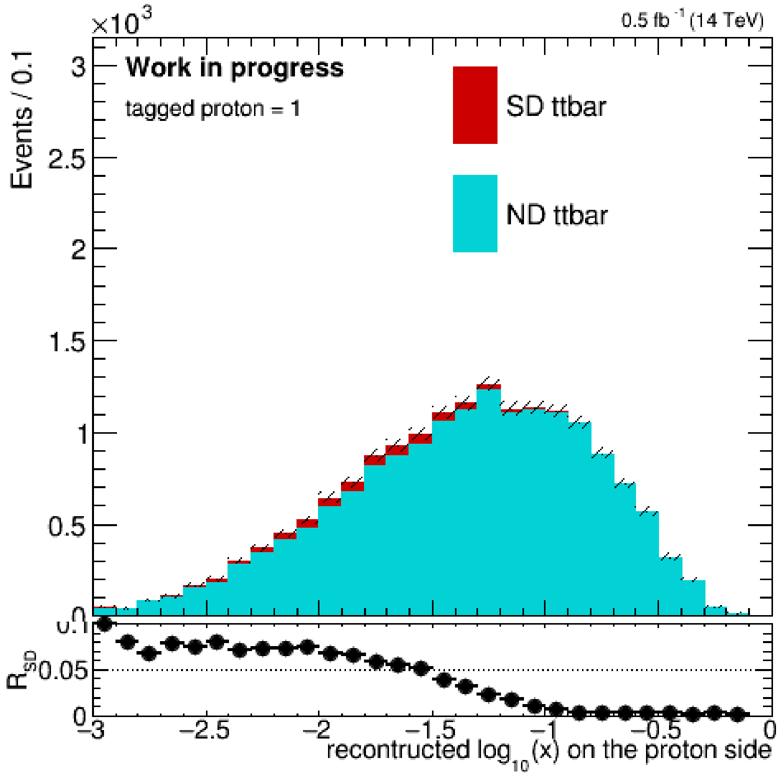
Probing diffractive ttbar

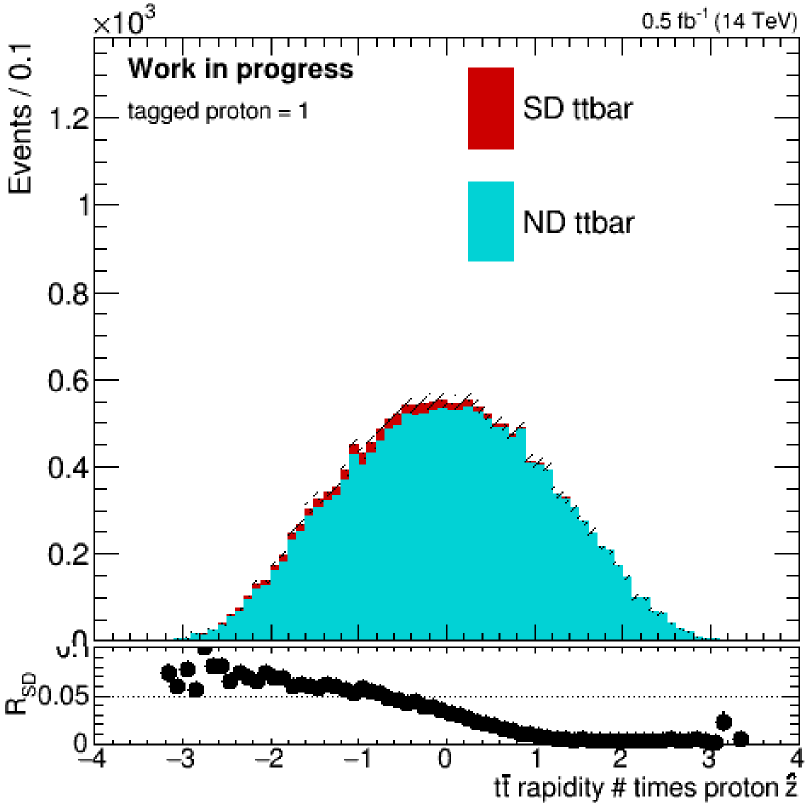
- Kinematic distributions – selection cuts



Probing diffractive ttbar

- Kinematic distributions – discriminating variables





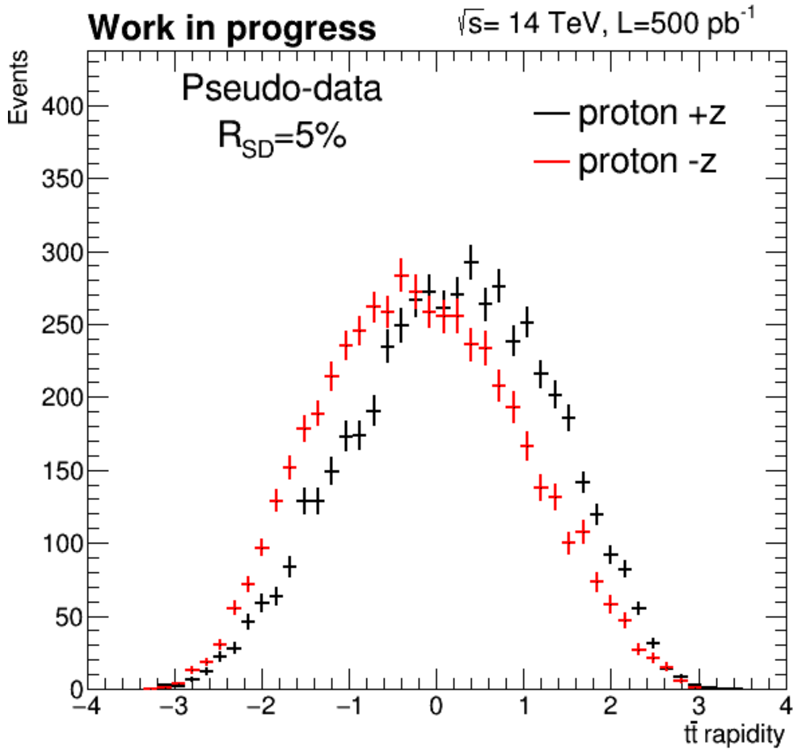
- Goal to measure R_{SD} inclusively and as a function of ξ (unbiased with x)

Probing diffractive ttbar

- Method (Measurement of R_{SD}):

In data, the ND and SD components are mixed using the following formula:

$$P^{data,RP\pm}(\eta) = N\left(\frac{\varepsilon_B^{\pm} f^{ND}(\eta) + R_{SD}\varepsilon_S^{\pm} f^{SD\pm}(\eta)}{\varepsilon_B^{\pm} + R_{SD}\varepsilon_S^{\pm}}\right)$$



Were:

R_{SD} - SD fraction

$f^{ND}(\eta)$ rapidity distribution of ND component

$f^{SD}(\eta)$ rapidity distribution of SD component

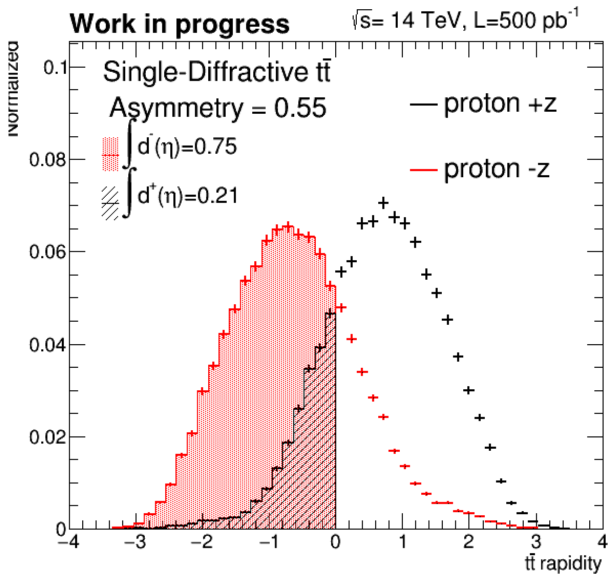
ϵ_S signal efficiency (proton acceptance)

ϵ_B background efficiency (PU proton rate)

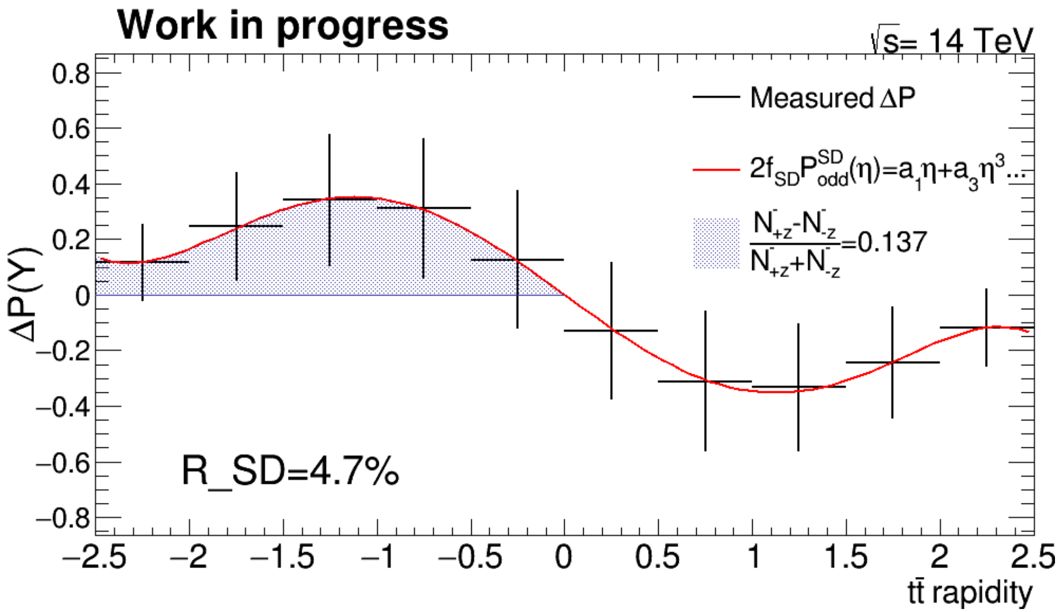
+/- denote proton in positive/negative direction

Probing diffractive ttbar

- Method (Measurement of R_{SD}):
  - The difference $\Delta P(\eta) = P^{data,RP+}(\eta) - P^{data,RP-}(\eta)$, depends only on the SD component, signal/background efficiency and the asymmetry A factor
  - A fit using an asymmetric function can constrain the asymmetry measurement.



$\mathrm{A} = 0.54$



$$\Delta = \int_{-\infty}^{0} \Delta P(\eta) = \frac{R_{SD}\varepsilon_S A}{\varepsilon_B + R_{SD}\varepsilon_S}$$

Using the following inputs:

Efficiency: $\varepsilon_S = 22\%, \varepsilon_B = 3\%$

Max Asymmetry: $\mathrm{A} = 0.54$

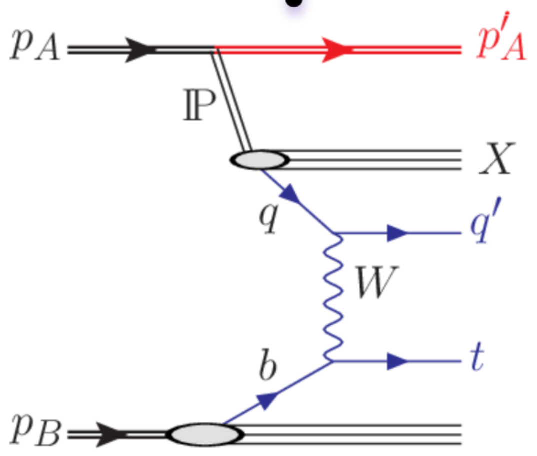
Asymmetry: Δ =0.137

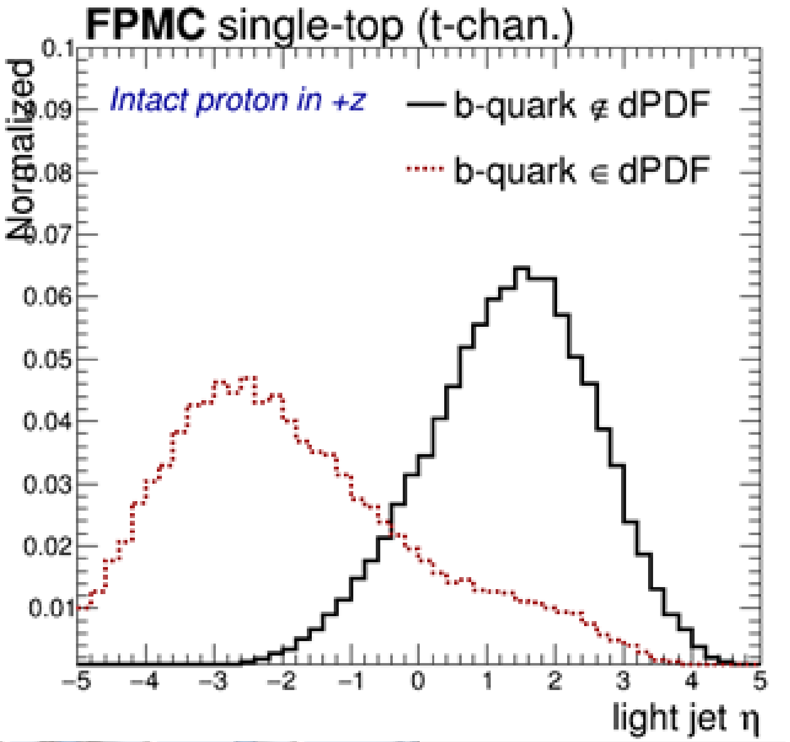
Obtain:

$$R_{SD} = \frac{\Delta \cdot \varepsilon_B}{\varepsilon_S(A - \Delta)} = 4.7\%$$

Probing diffractive single top

- Non-diffractive production of the single top is common at LHC (160pb), diffractive single top expect to have a low fraction (0.3pb)
- Although the low cross-section, single top production is sensitive to b-quark content of proton/pomeron
- Strong asymmetry in the light jet kinematics
- **The process can be used to probe pomeron b-quark content**





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- Event selection (semi-leptonic top decays)
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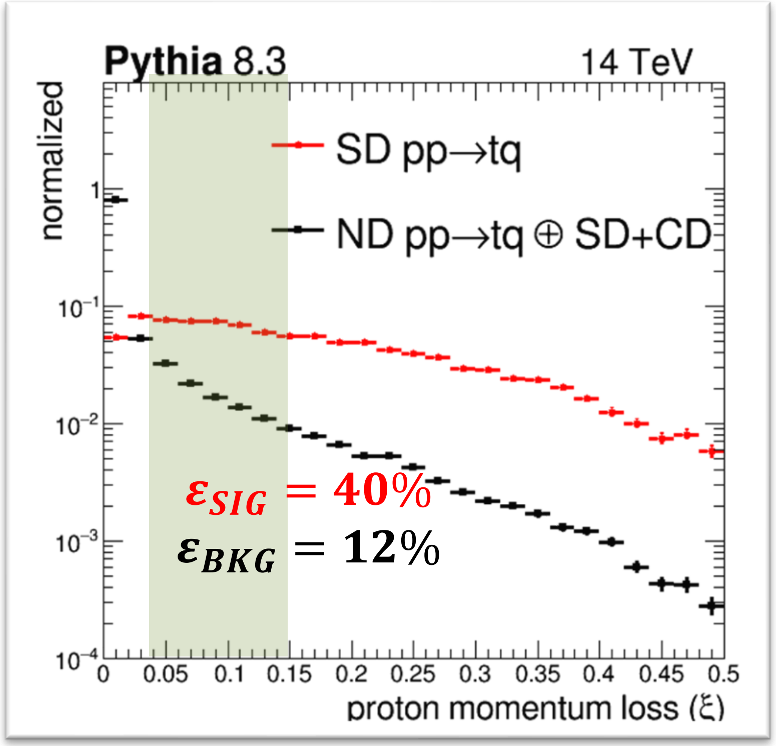
  1 forward jet with pT>20, |η|>2.5
- Backgrounds: top/ttbar/W + PU proton

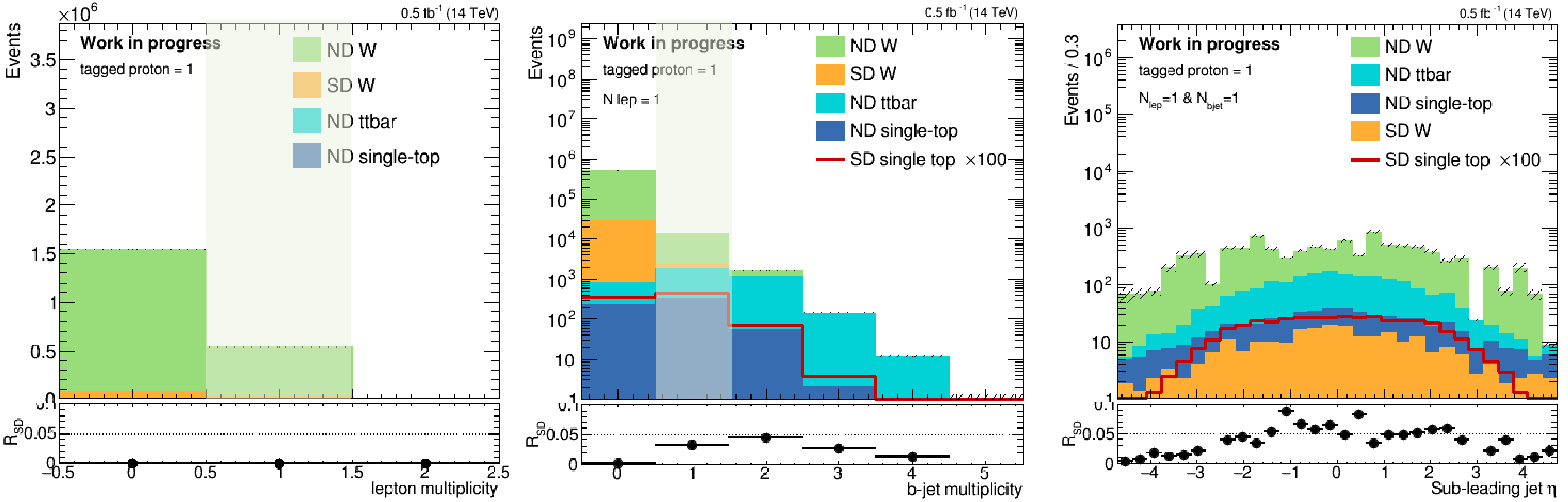


Cut	Signal	Background	$N_S/\sqrt{N_B}$
1 lepton	13.68%	12.39%	1.13
&& 1 bjet	8.27%	7.63%	0.87
&& 1 forward jet	3.08%	4.30%	0.43
1 proton	0.92%	0.27%	0.51

Proton acceptance (ξ in 3 – 15%):
Signal = 40%
Bkg =(18%*6%)=2.2% / collision

Probing diffractive single top

- Kinematic distributions – selection cuts



Not easy distinguish single top + forward jet from the background processes

Expect O(5) events for L=0.5ifb and μ=3

Summary

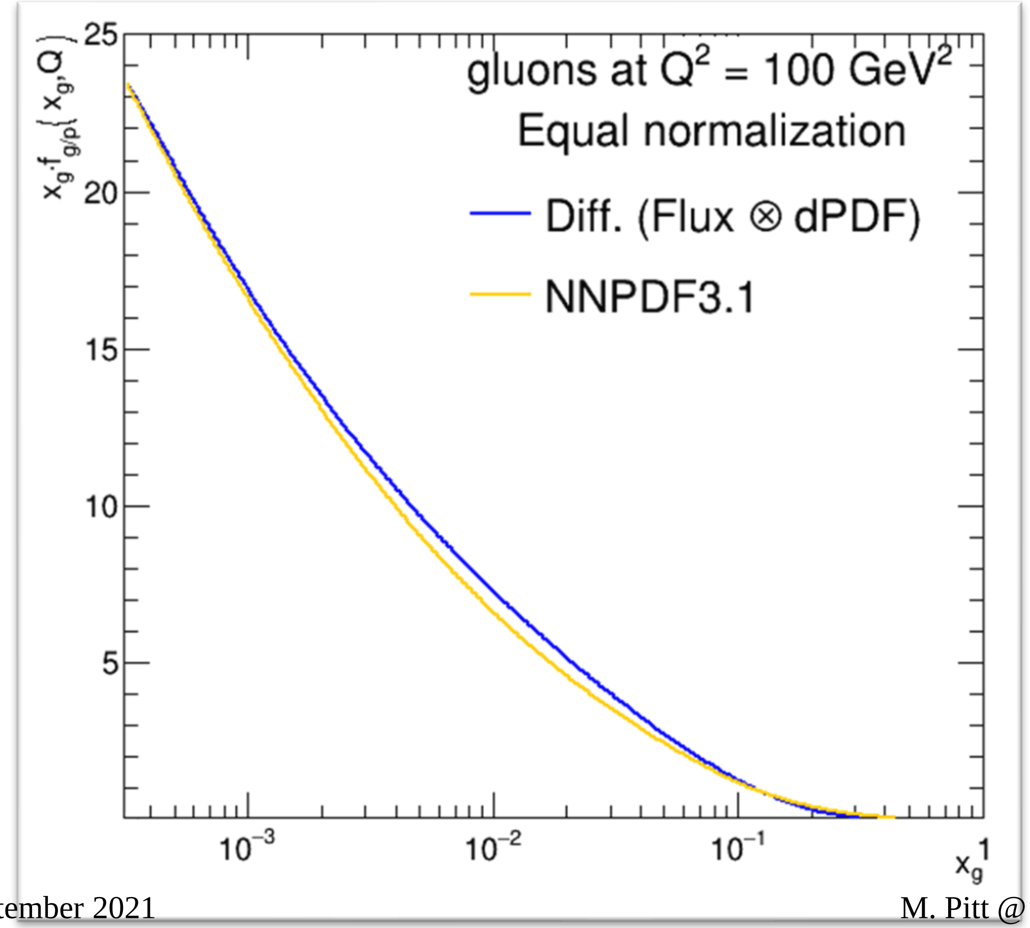
- Hard SD production processes can be used to constrain diffractive models at LHC
- Low-PU data is required to measure SD events
- Asymmetry method to measure R_{SD} was introduced
- In view of future low-PU runs, for the scenario of μ=3, Lint=0.5ifb:
  - Diffractive ttbar can be measure with good precision
  - Diffractive top: O(5) events expected, optimized selection needed

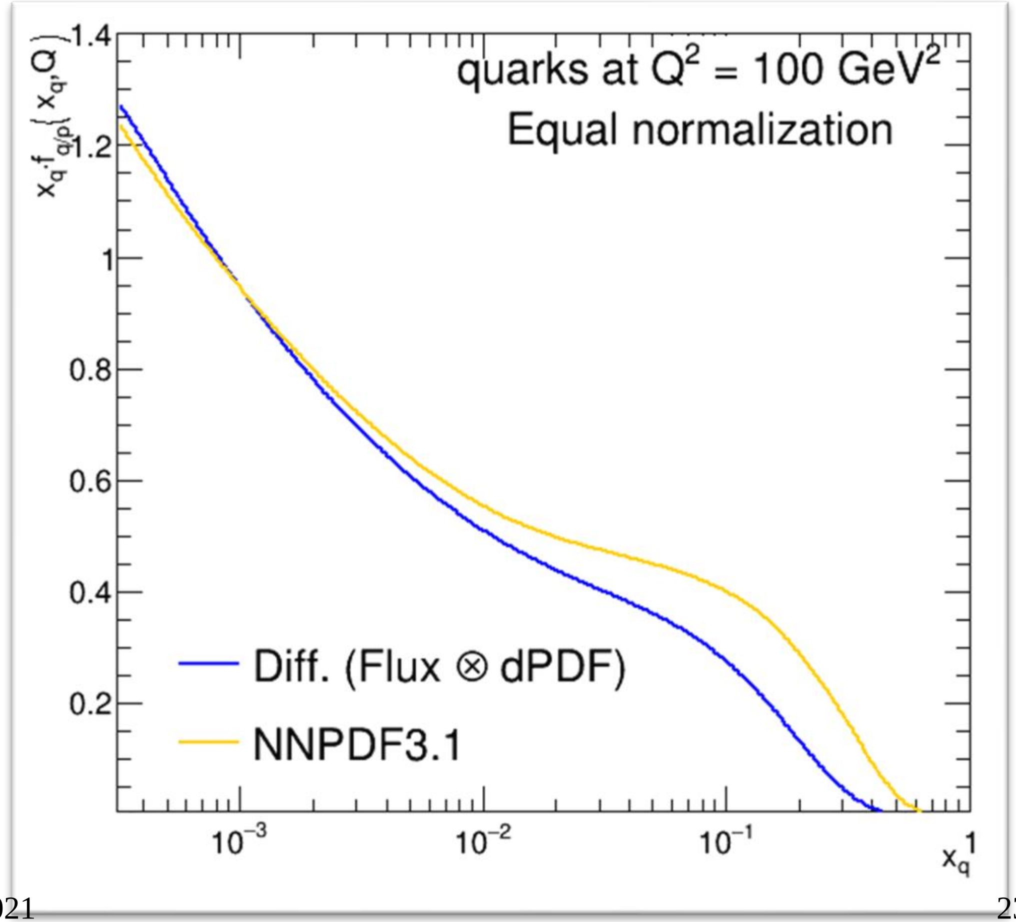
Backup

Single diffraction in pp

Structure function

- Different kinematics of colliding partons





Single diffraction in pp

Production cross-section of single diffractive events

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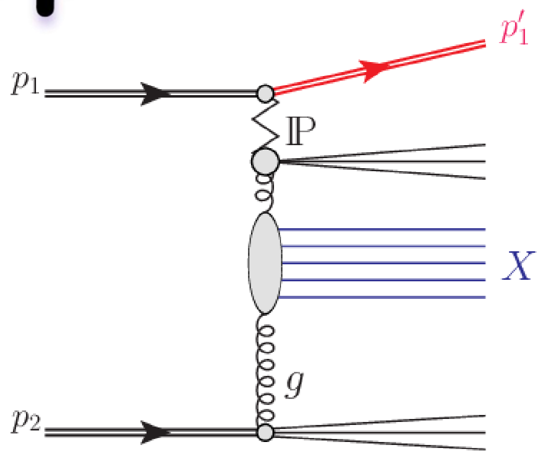
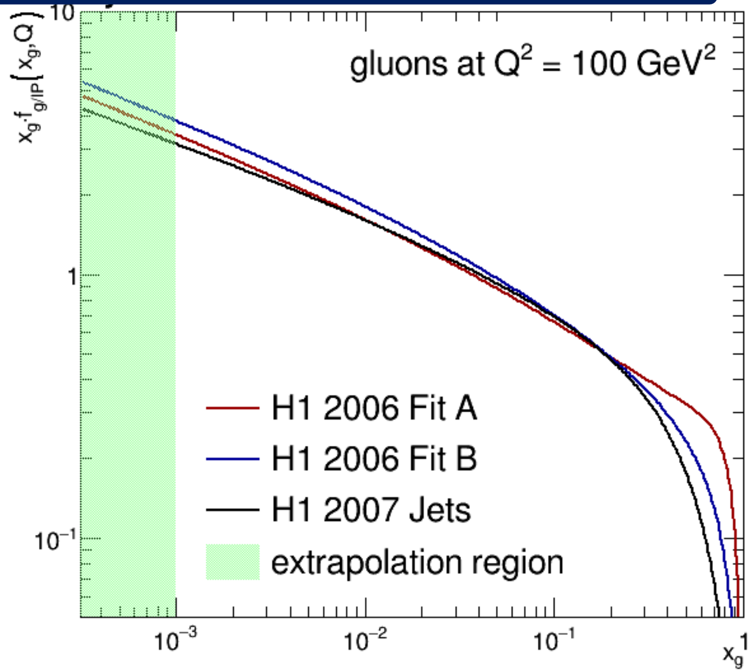
Pomeron flux — $F_{IP/p}(\xi, t)$

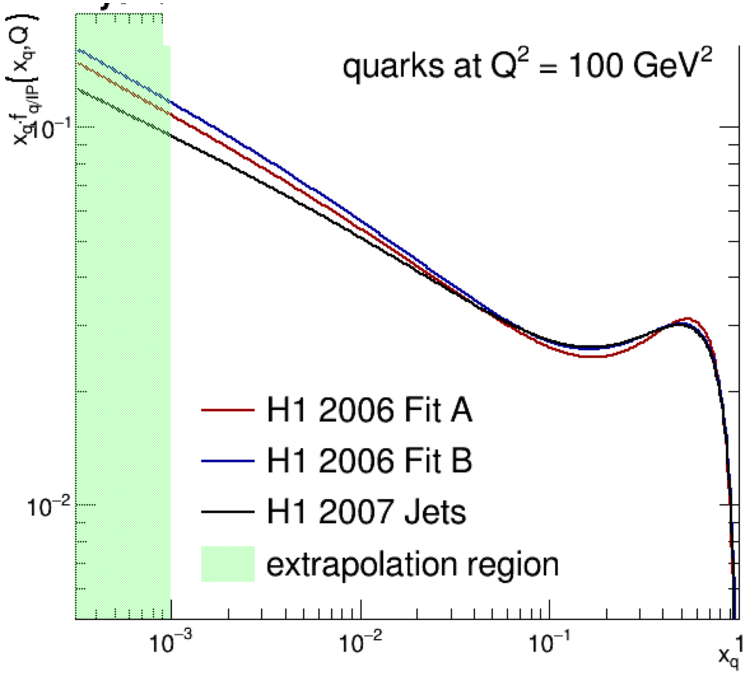
dPDF, PDF — $f_{b/P}(x_b, Q^2) f_{a/IP}\left(\frac{x_b}{\xi}, Q^2\right)$

Hard-scatter Xsec — $\hat{\sigma}_{ab \to X}$



Fit Parameter	Fit A	Fit B
$\alpha_{\mathbb{P}}(0)$	1.118±0.008	1.111±0.007
$n_{\mathbb{R}}$	$(1.7\pm0.4) \times 10^{-3}$	$(1.4\pm0.4) \times 10^{-3}$
A_q	1.06±0.32	0.70±0.11
B_q	2.30±0.36	1.50±0.12
C_q	0.57±0.15	0.45±0.09
A_g	0.15±0.03	0.37±0.02
C_g	−0.95±0.20	0 (fixed)





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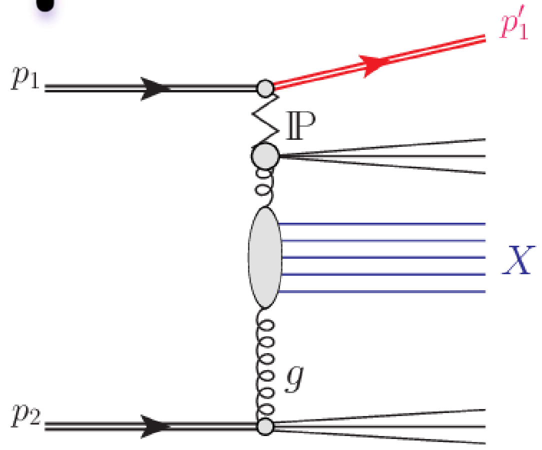
Pomeron flux

dPDF, PDF

Hard-scatter Xsec



Parameter	Value	Source
$\alpha'_{I\!P}$	$0.06\,^{+0.19}_{-0.06}$ GeV^{-2}	[6]
$B_{I\!P}$	$5.5\,^{-2.0}_{+0.7}$ GeV^{-2}	[6]
$\alpha_{I\!R}(0)$	0.50 ± 0.10	[5]
$\alpha'_{I\!R}$	$0.3\,^{+0.6}_{-0.3}$ GeV^{-2}	[6]
$B_{I\!R}$	$1.6\,^{-1.6}_{+0.4}$ GeV^{-2}	[6]

[5] C. Adloff *et al.* [H1 Collaboration], Z. Phys. C **76** (1997) 613 [hep-ex/9708016].

[6] H1 Collaboration, *"Diffractive Deep-Inelastic Scattering with a Leading Proton at HERA"*, DESY 06-048, submitted to Eur. Phys. J. C.