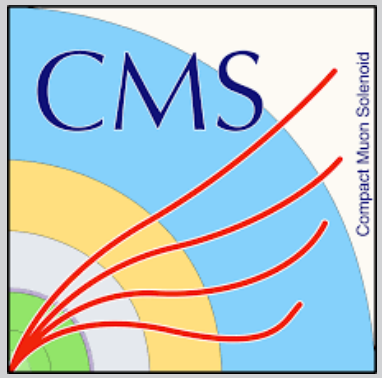


Recent CMS + TOTEM diffractive results

István Szanyi
on behalf of the CMS and TOTEM Collaborations

University of Kansas, Lawrence, USA
MATE Institute of Technology, KRC, Gyöngyös, Hungary
HUN-REN Wigner RCP, Budapest, Hungary

Zimányi School 2024

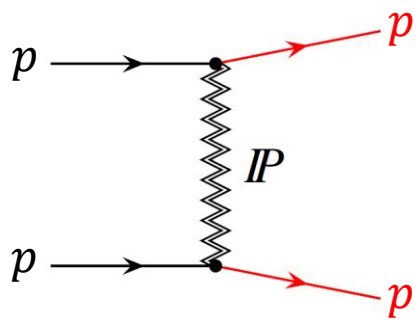
2 – 6 December 2024, Budapest, Hungary

Outline

- basic diffractive scattering events in pp collisions
- the CMS and TOTEM detectors at LHC
- nonresonant central exclusive production of charged-hadron pairs in pp collisions at $\sqrt{s}$ = 13 TeV Phys. Rev. D **109** (2024) 112013
- dijet events with hard color-singlet exchange (jet-gap-jet events) in pp collisions at $\sqrt{s}$ = 13 TeV Phys. Rev. D **104** (2021) 032009
- single-diffractive dijet production in pp collisions at $\sqrt{s}$ = 8 TeV Eur. Phys. J. C 80 (2020) 1164
- summary

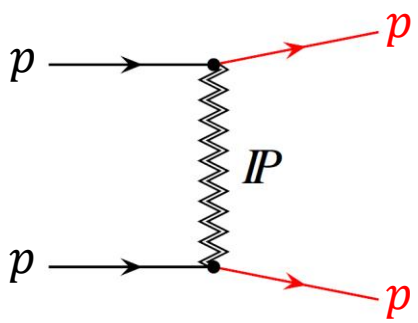
Basic diffractive scattering events in pp collisions

Basic diffractive scattering events in pp collisions



elastic

Basic diffractive scattering events in pp collisions



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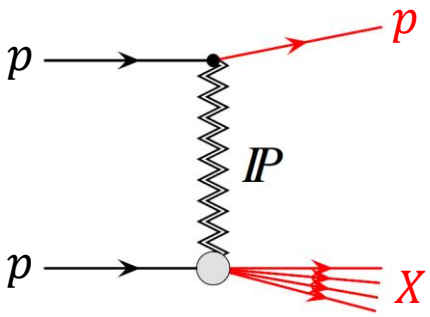

single-diffractive

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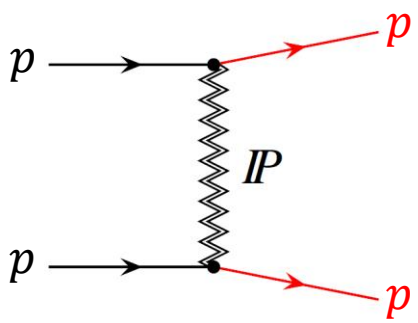

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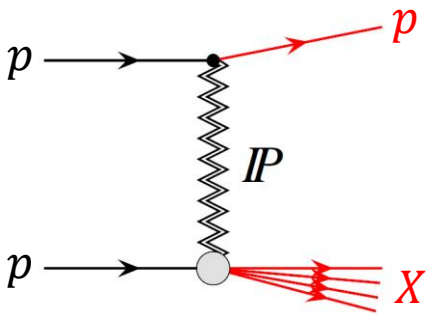

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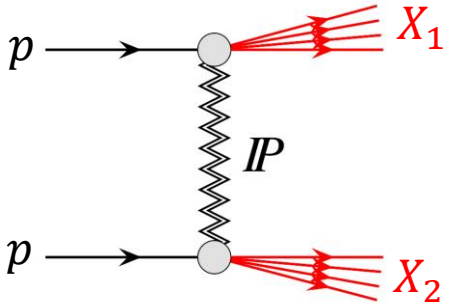

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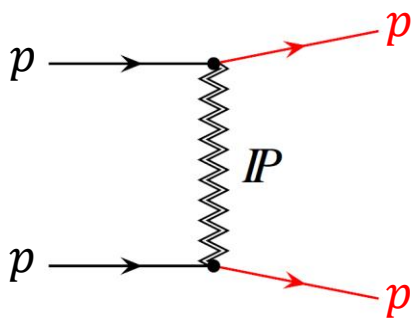

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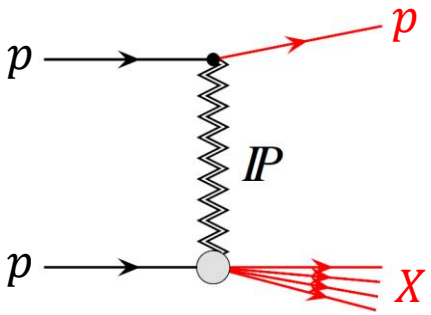

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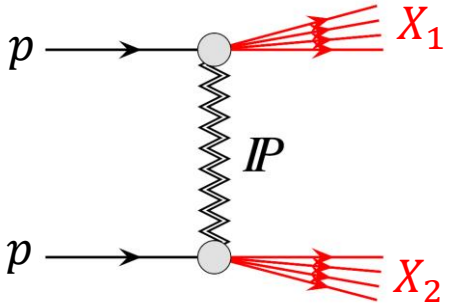

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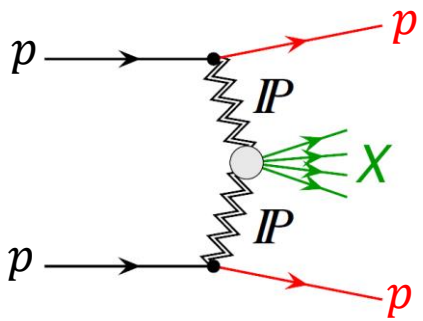

double pomeron exchange
(central exclusive production)

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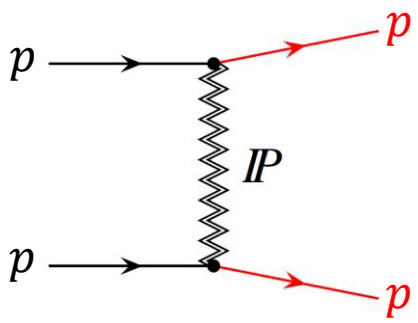

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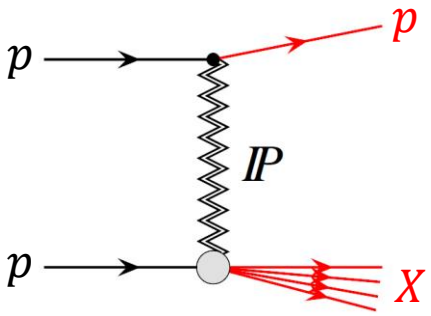

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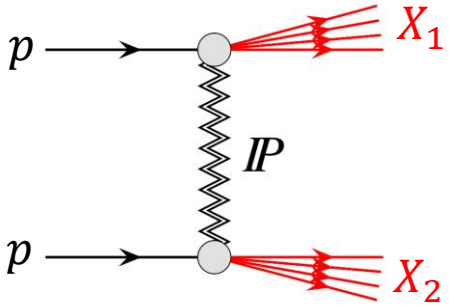

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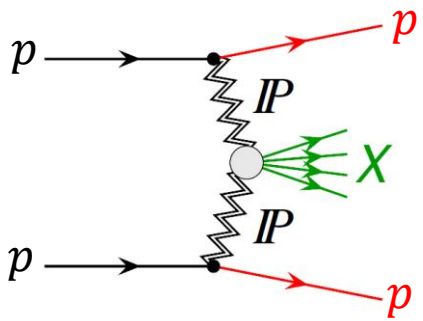

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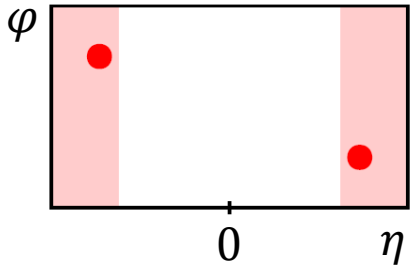

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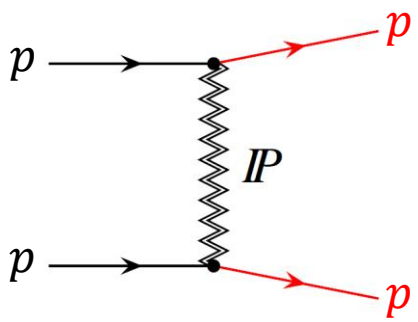

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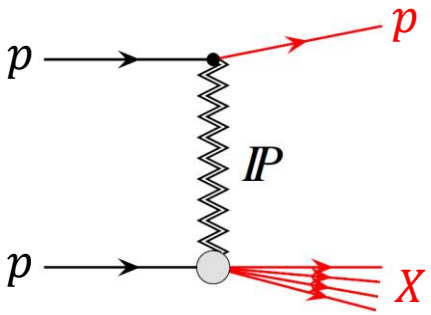

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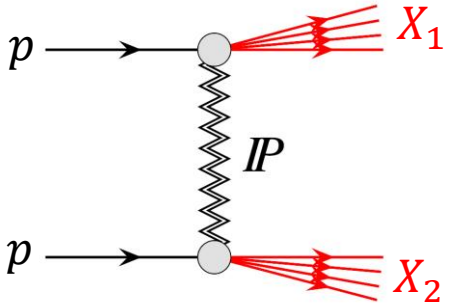

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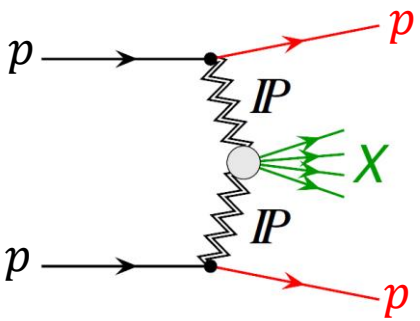

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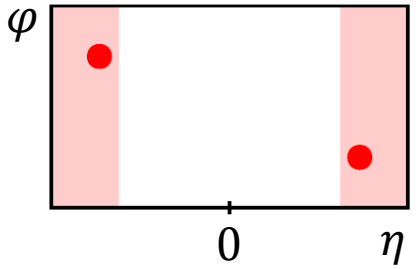

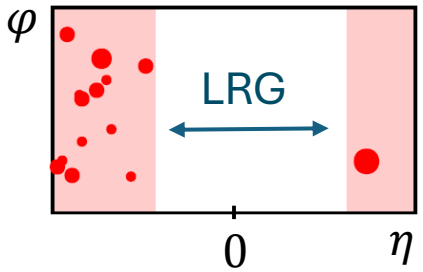

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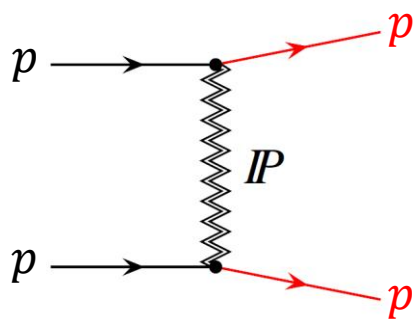
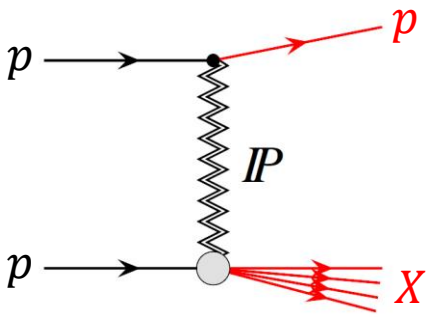


elastic



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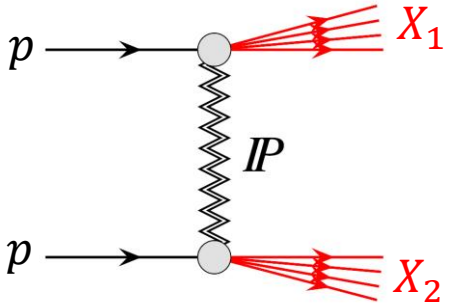

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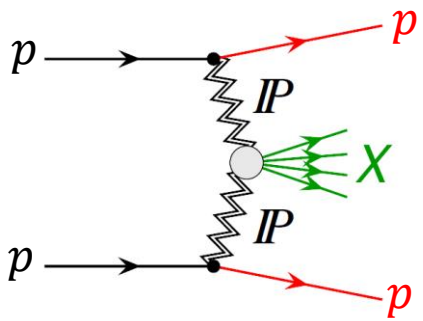

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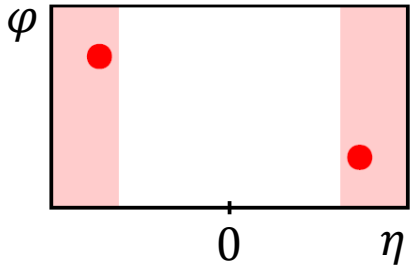

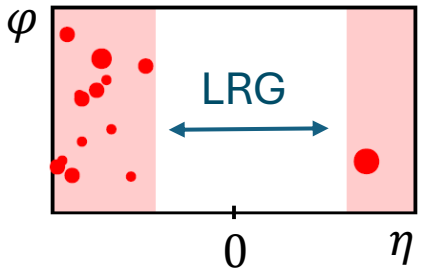

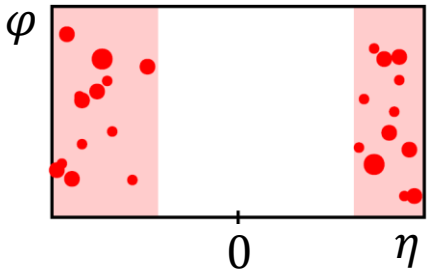

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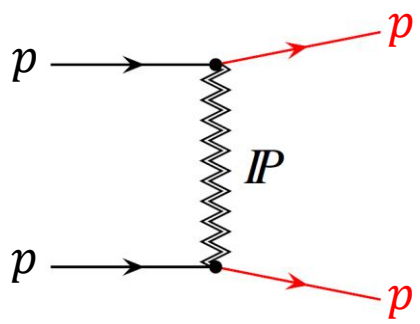
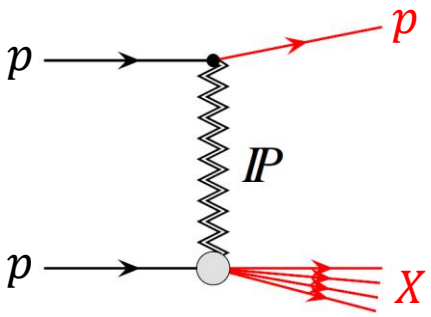


elastic



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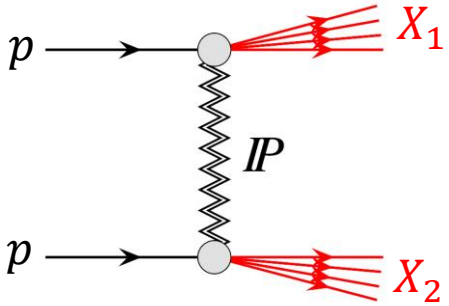

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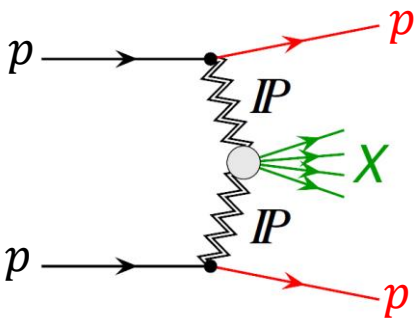

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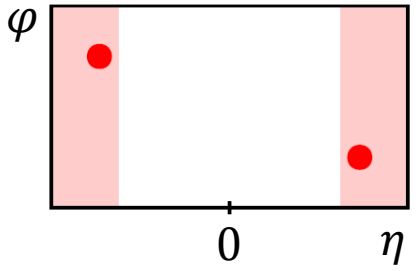

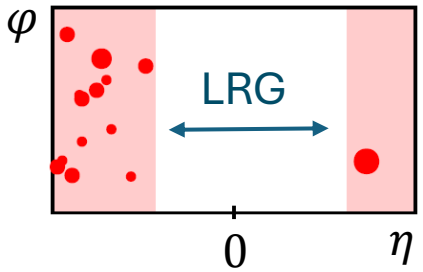

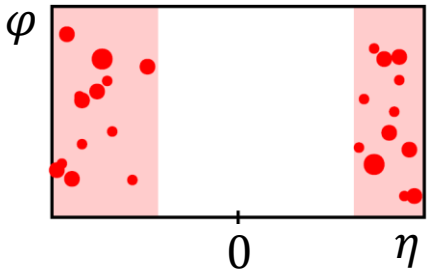

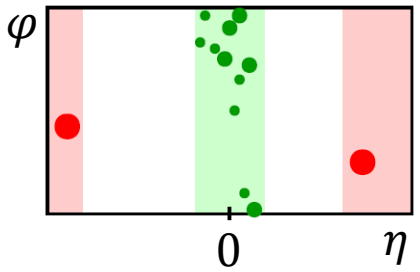

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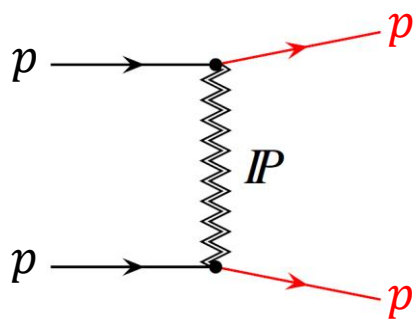
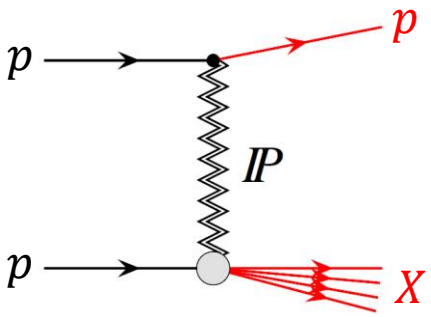


elastic



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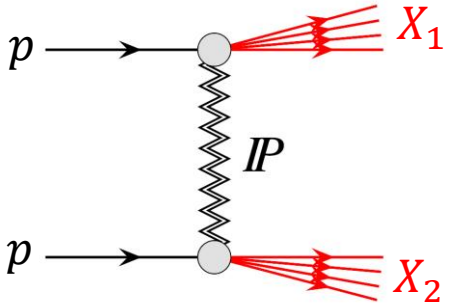

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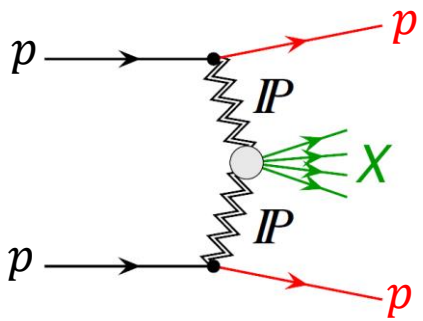

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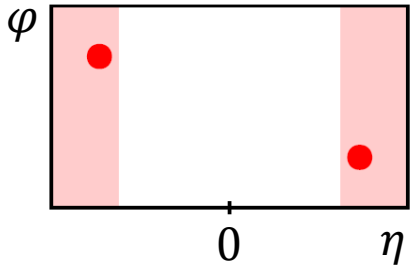
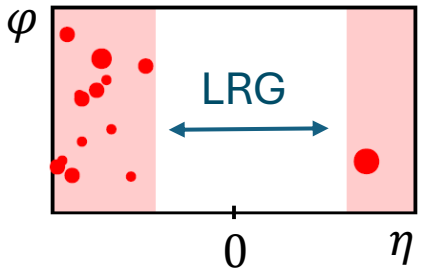
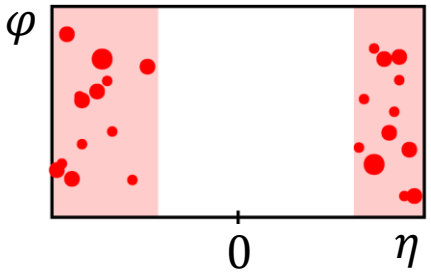
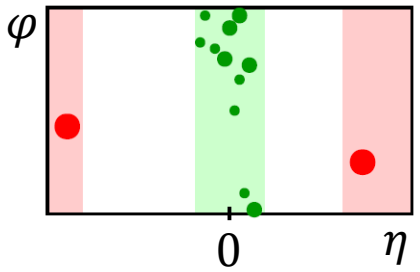


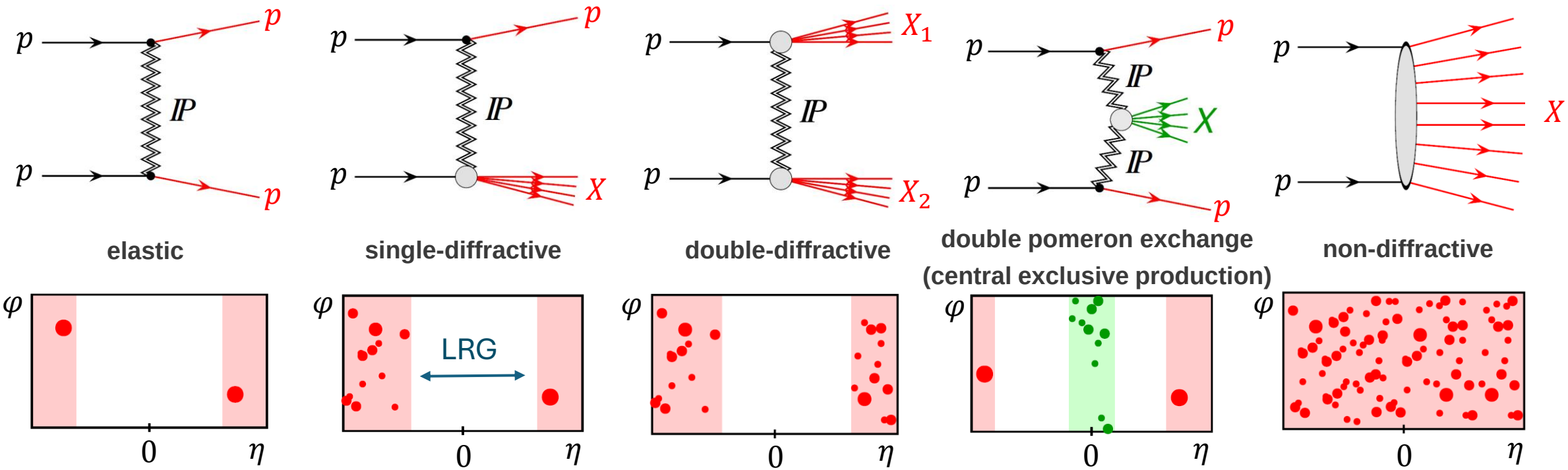






dominant **pomeron exchange** leading to a **large rapidity gap** (LRG),
a wide region devoid of particle activity

Basic diffractive scattering events in pp collisions



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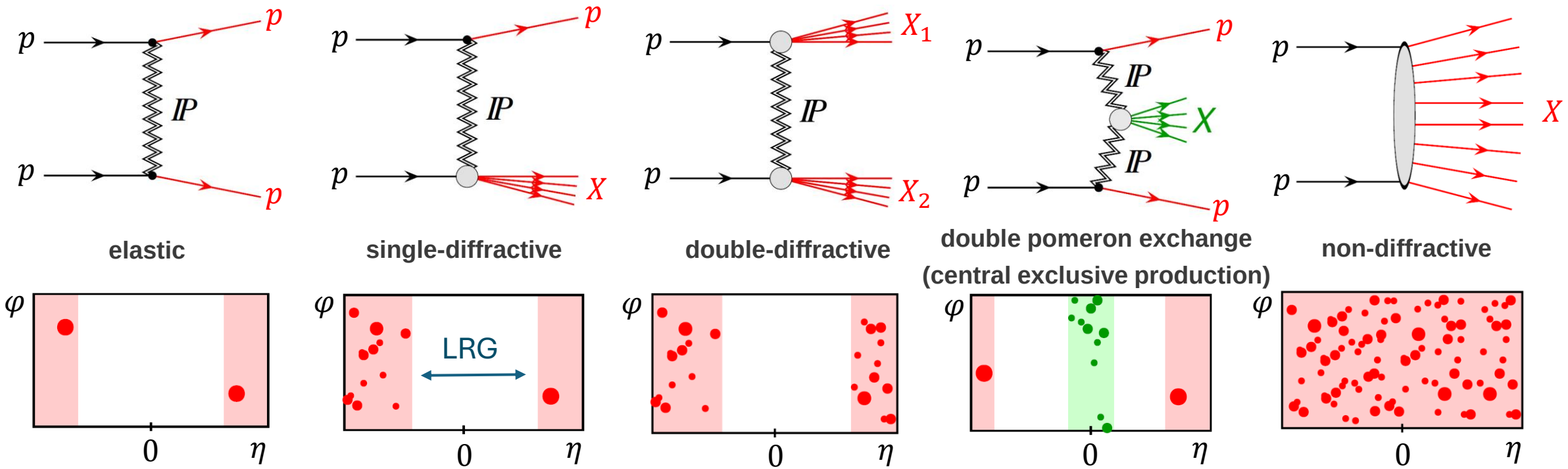

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"soft" pomeron in Regge theory: whole family of particles with vacuum quantum numbers; it accounts for the rising hadronic cross sections with rising CM energy ($\sqrt{s}$)

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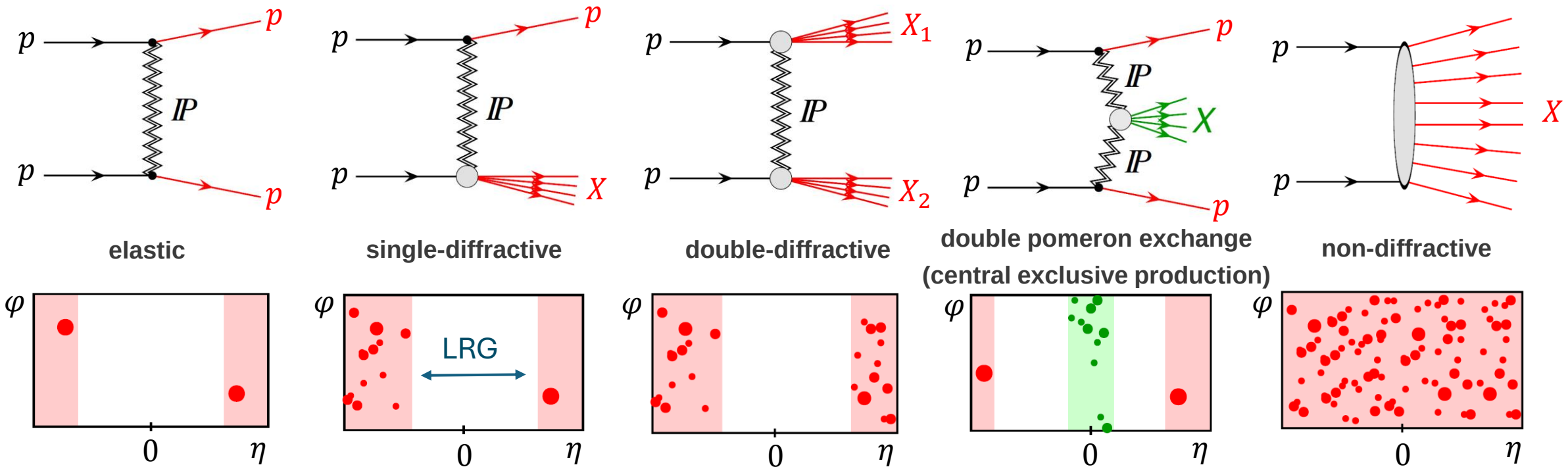

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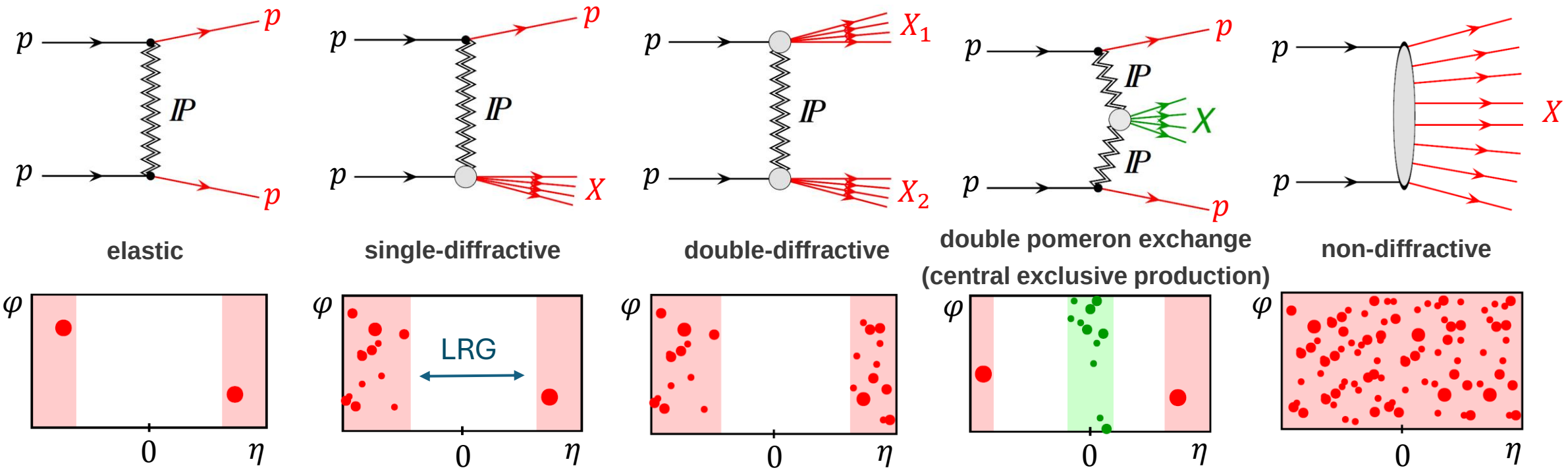

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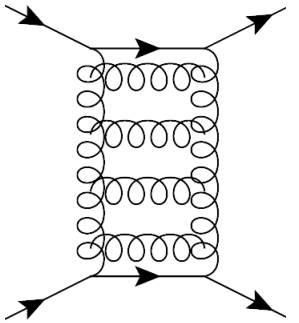

BFKL pomeron

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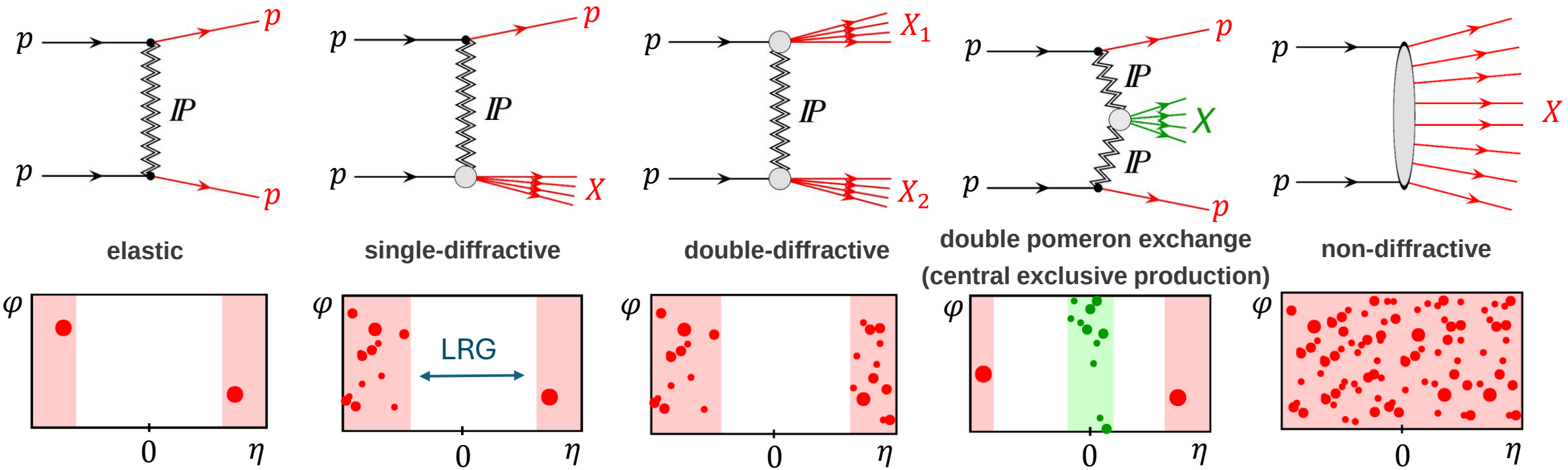

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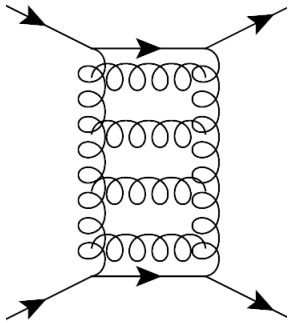
pomeron physics is an ongoing research topic both experimentally and theoretically



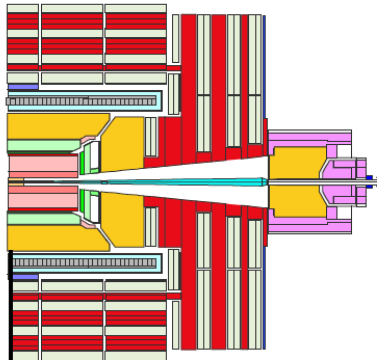
BFKL pomeron

CMS and TOTEM detectors at the LHC

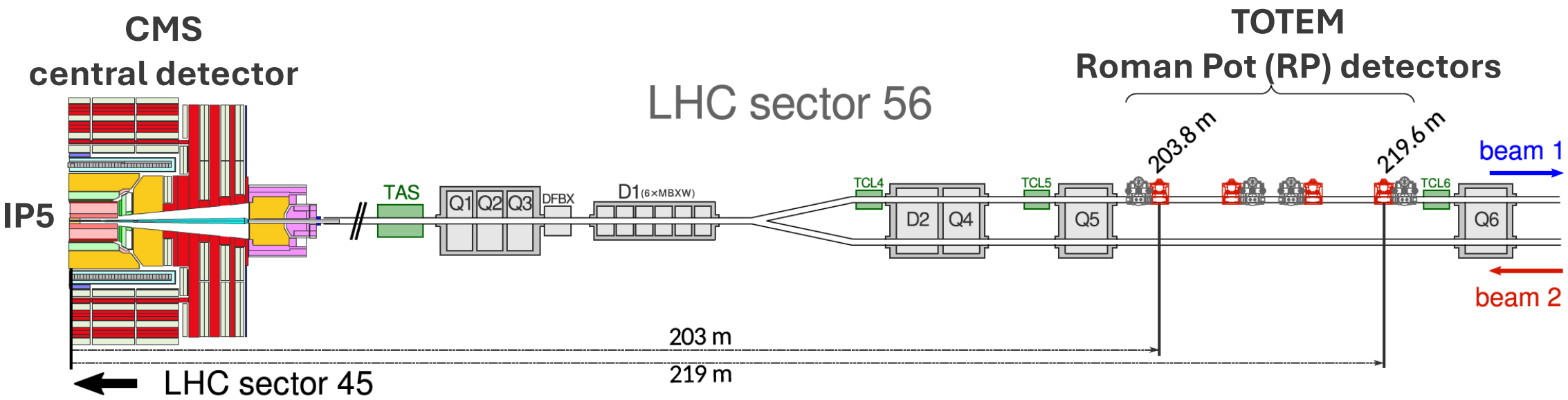
CMS and TOTEM detectors at the LHC

CMS
central detector

IP5



CMS and TOTEM detectors at the LHC



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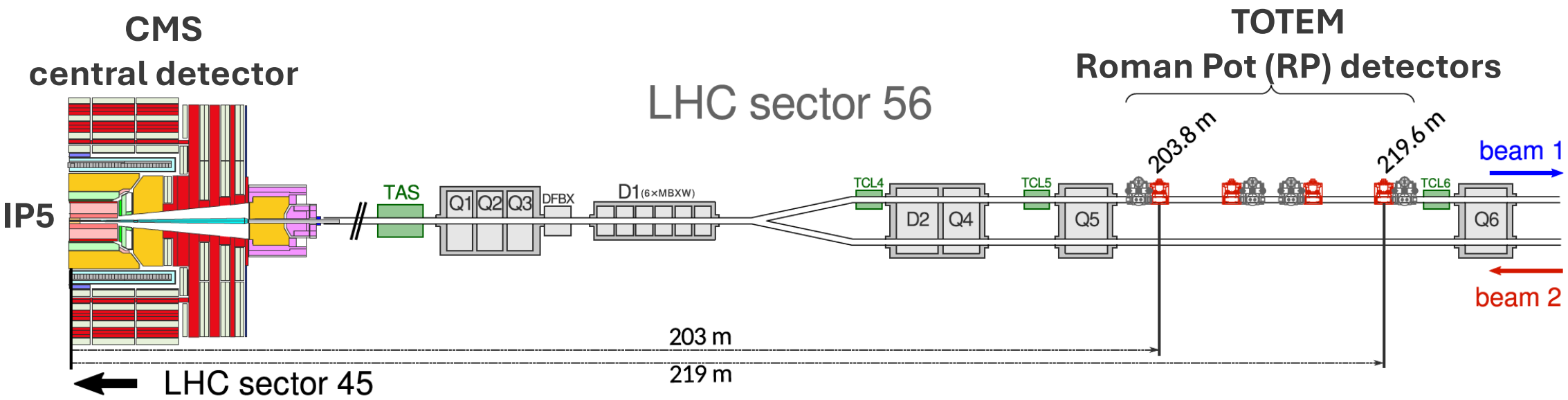

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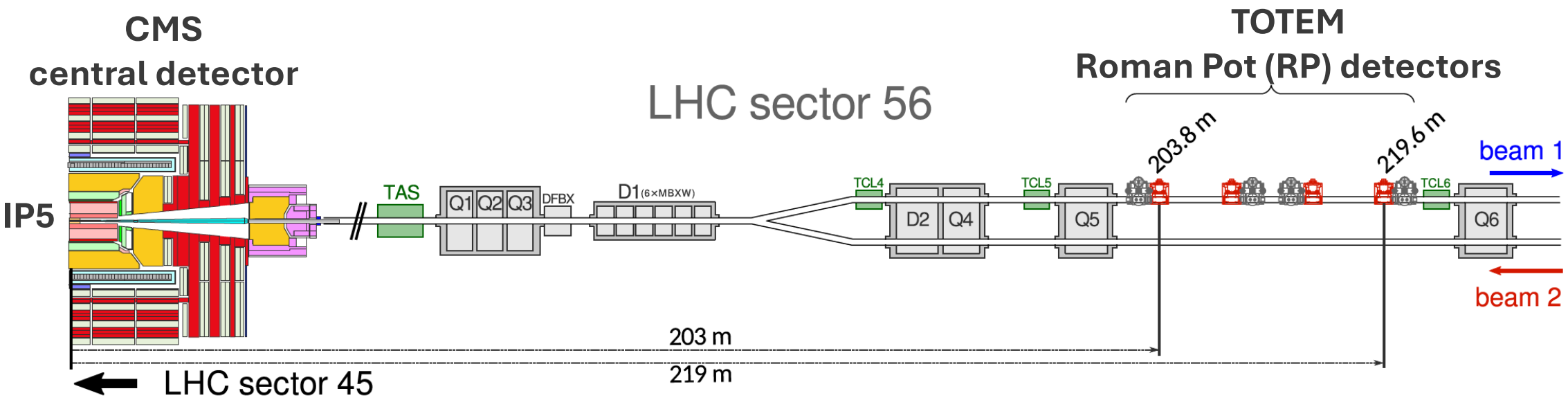

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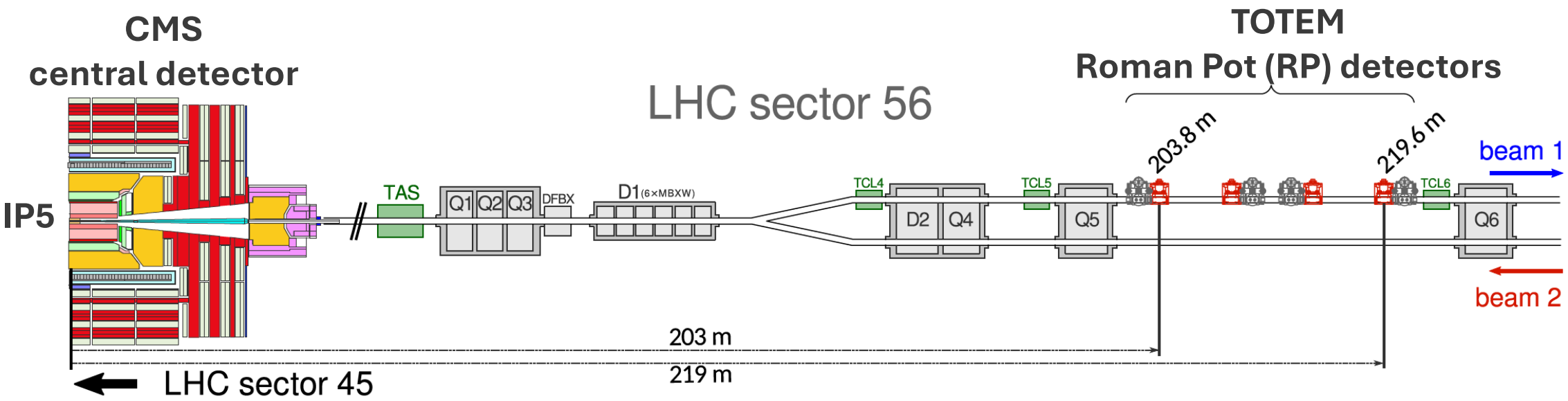

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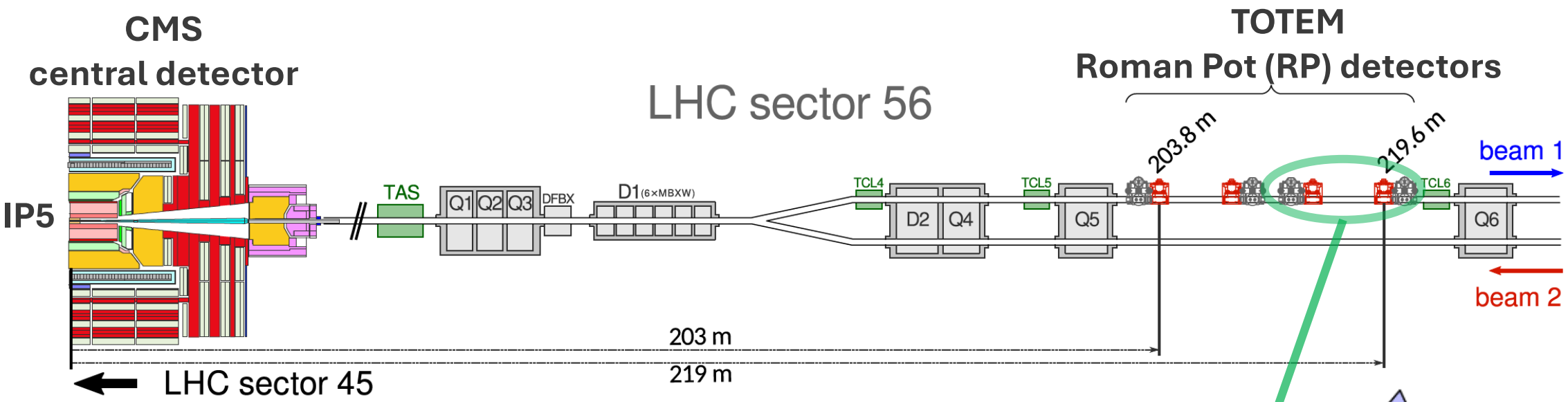

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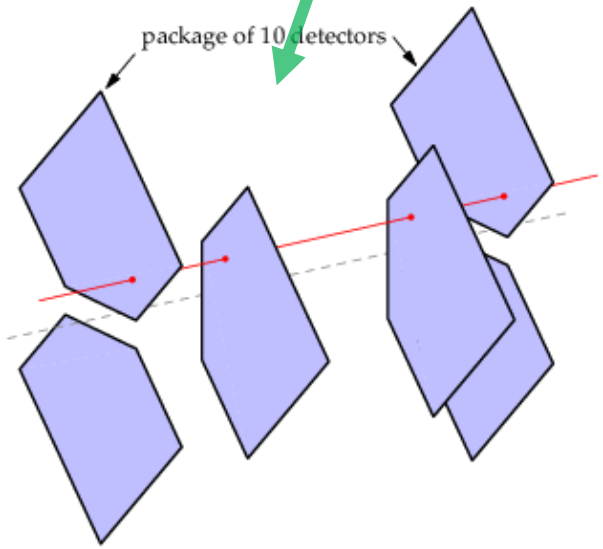

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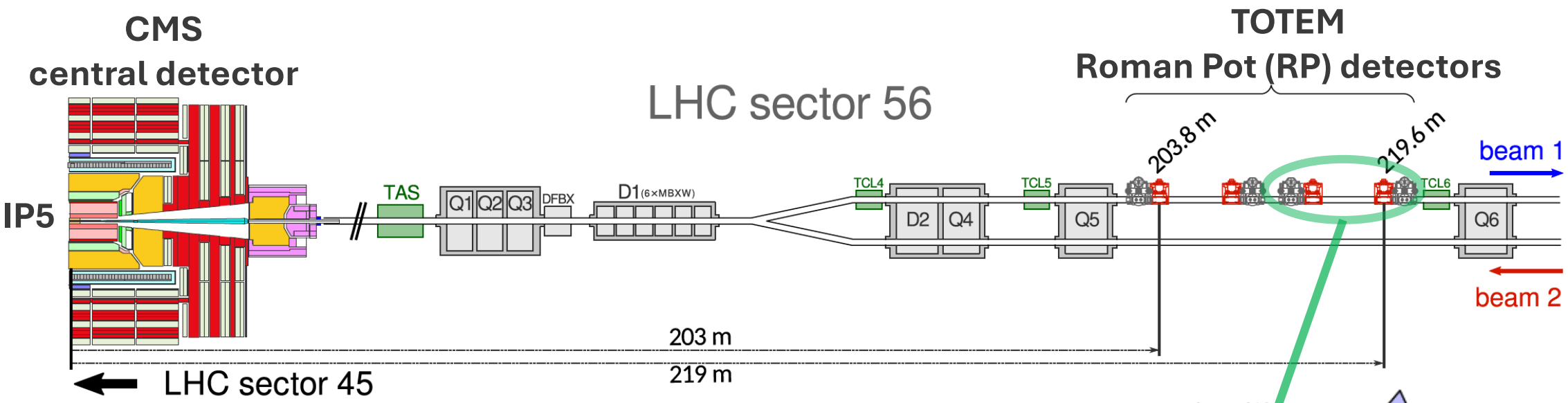

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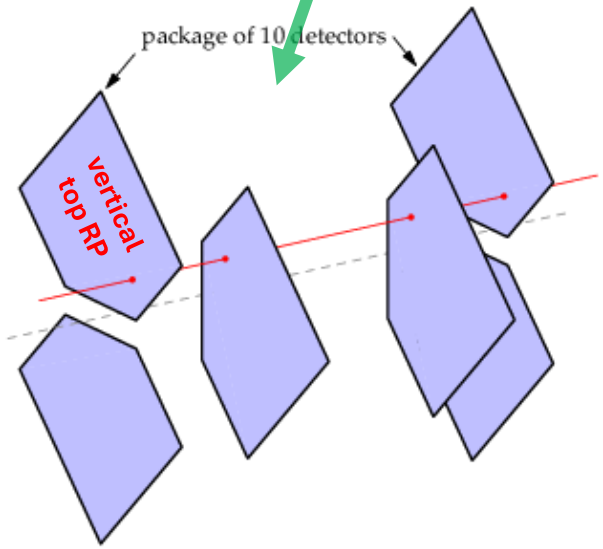

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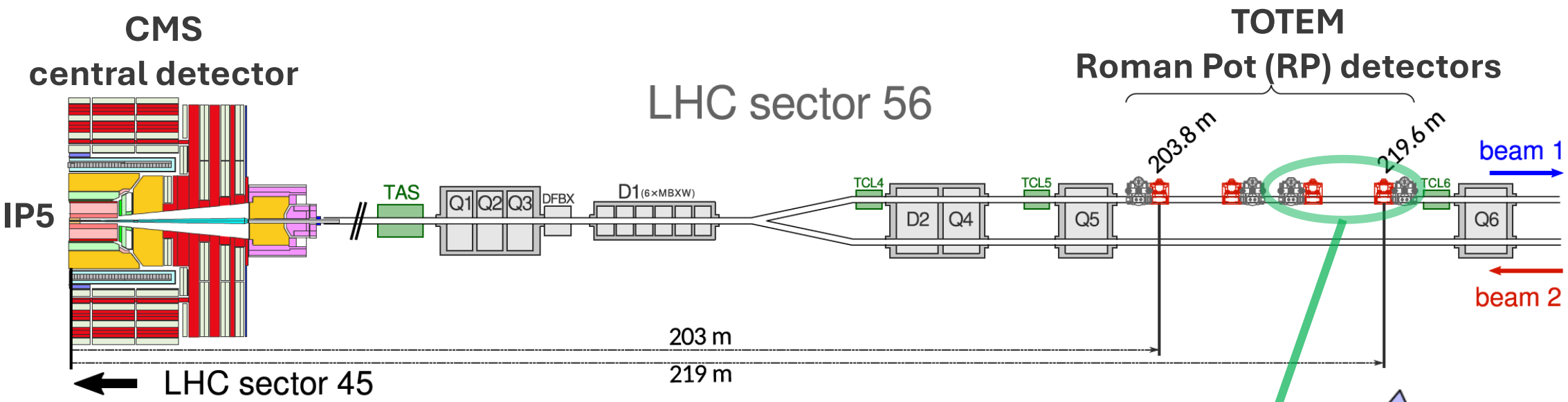

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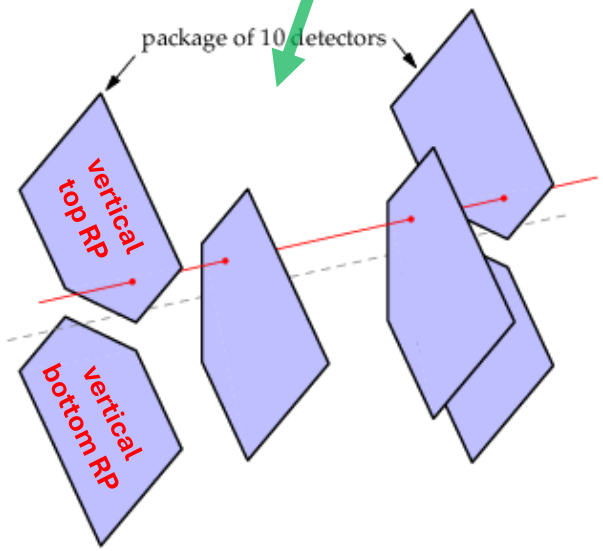

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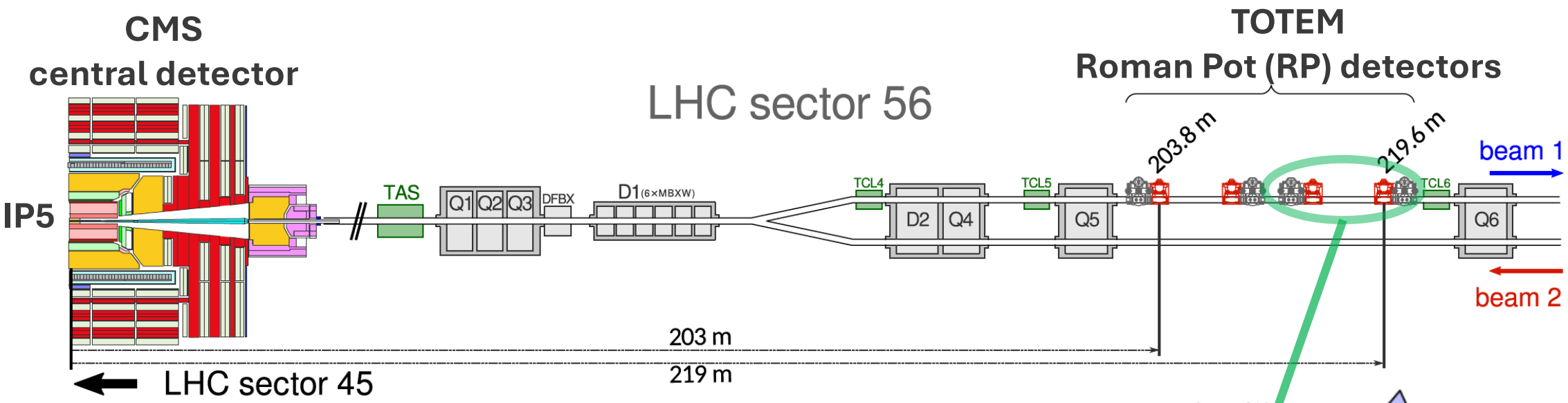

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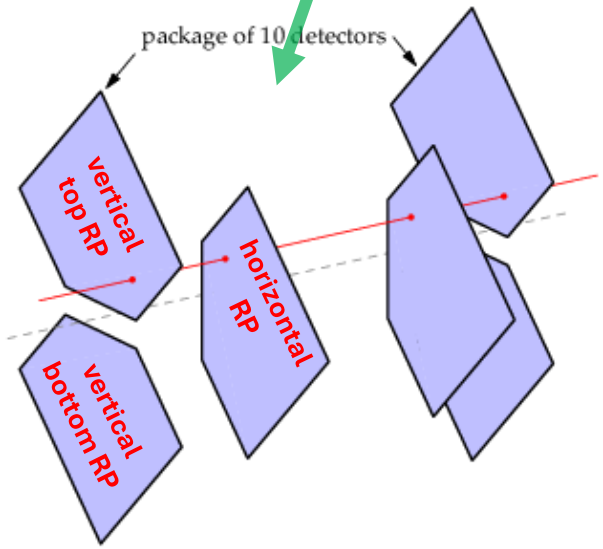

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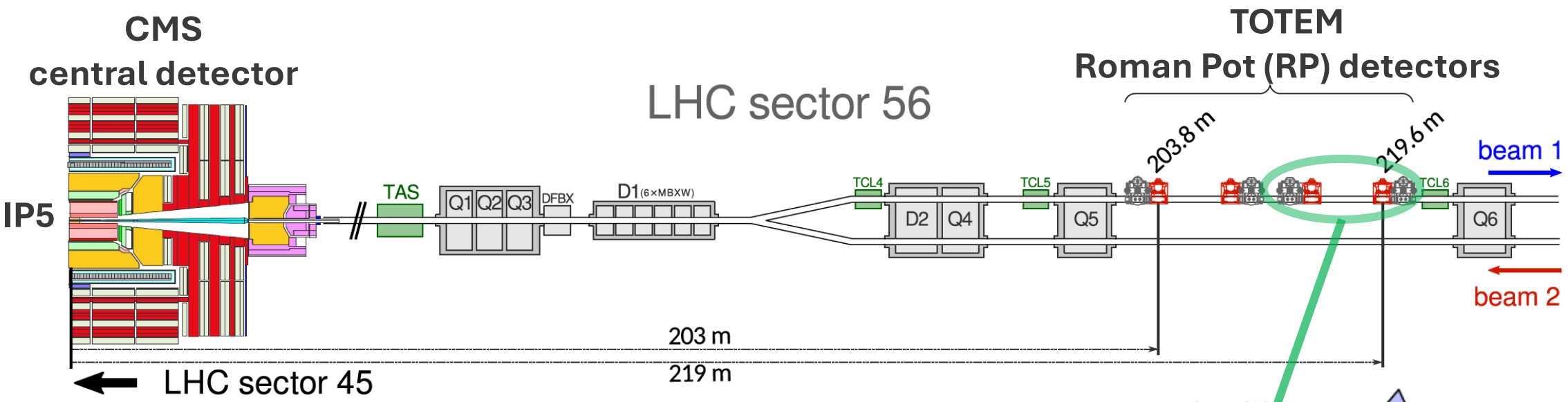

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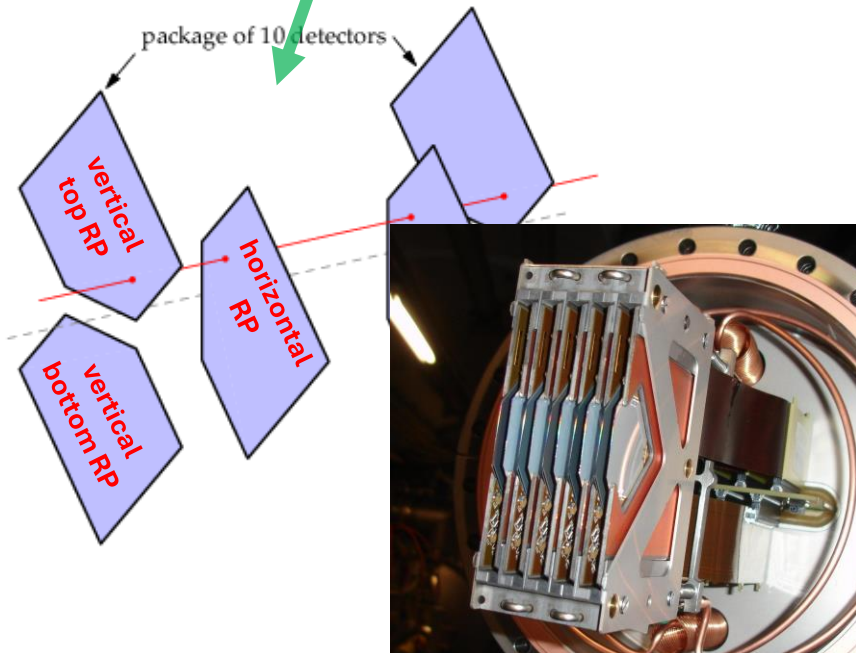

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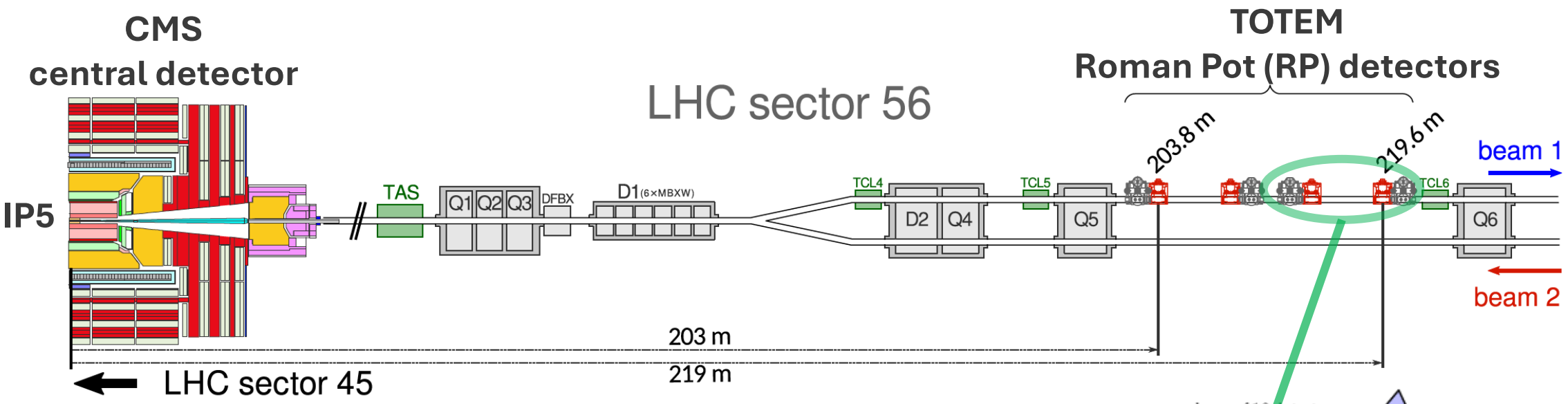

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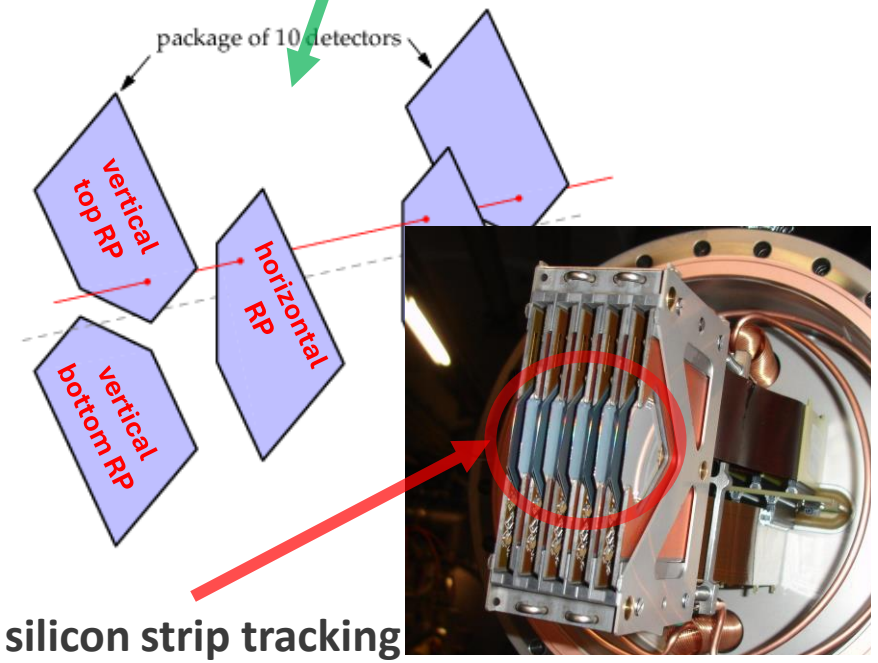

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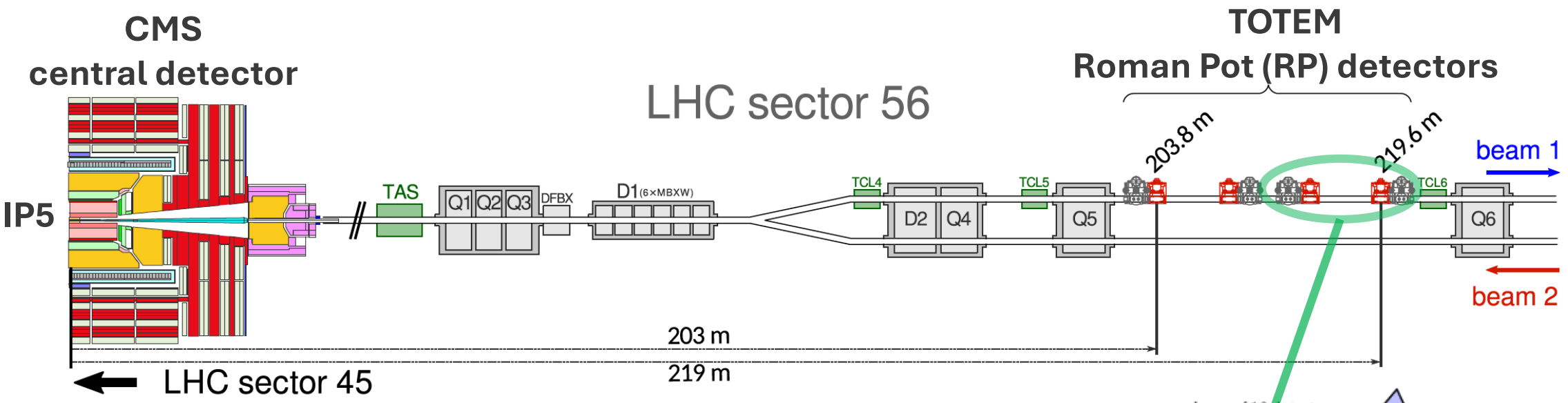

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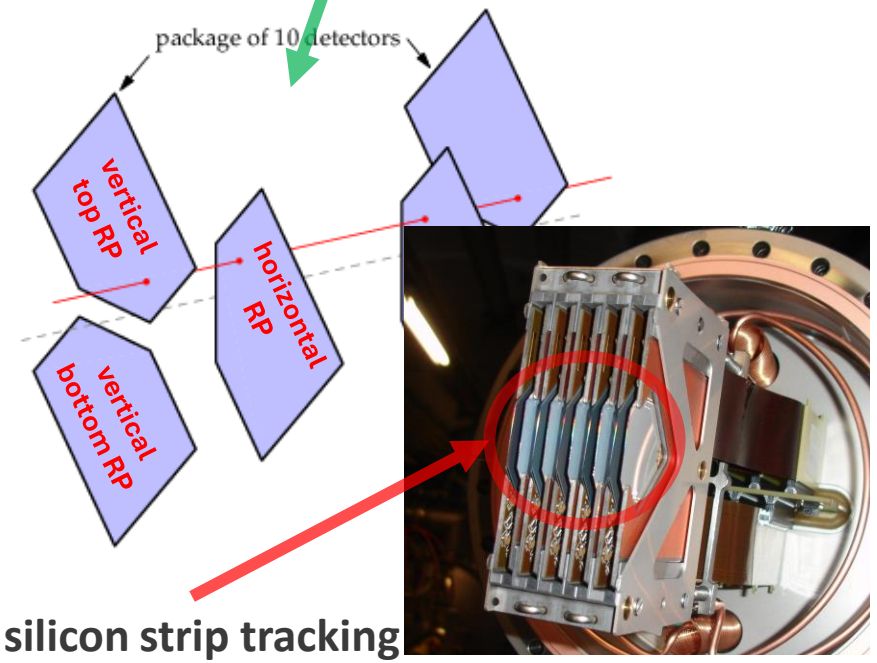
acceptance down to ~0 in fractional momentum loss (ξ) and in squared transferred 4-momentum (t), and ~0.4 GeV in mass (m)



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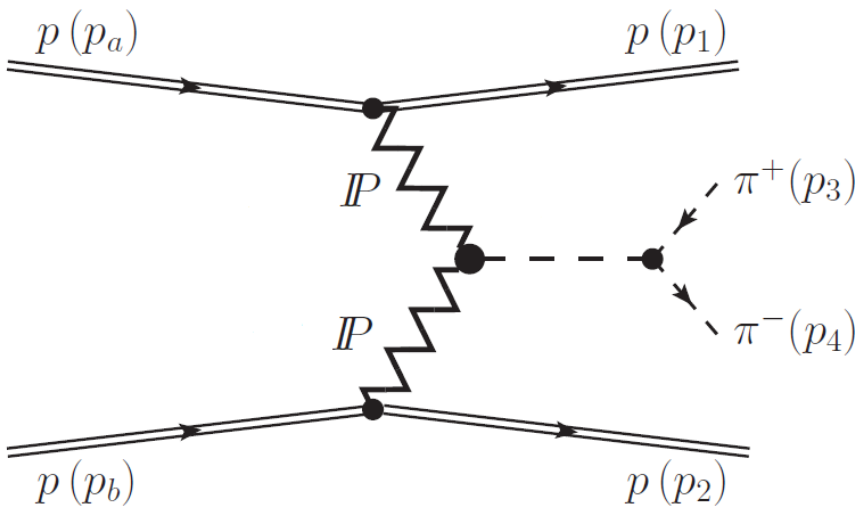

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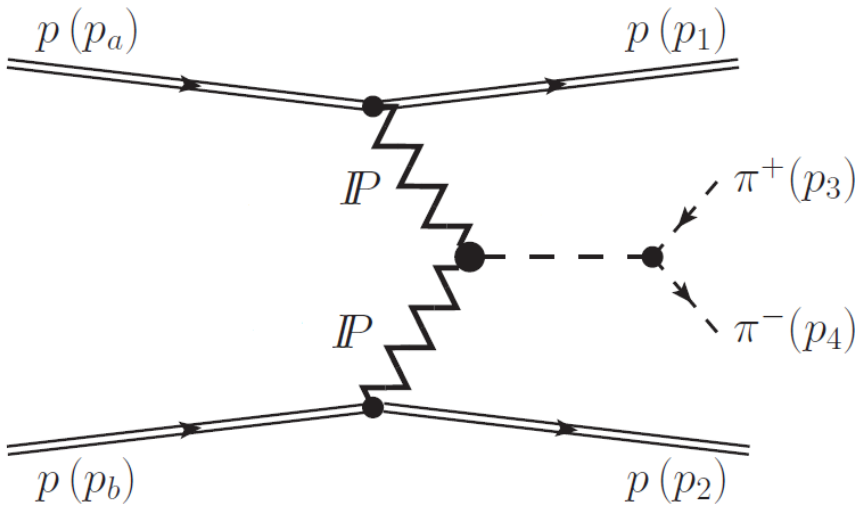

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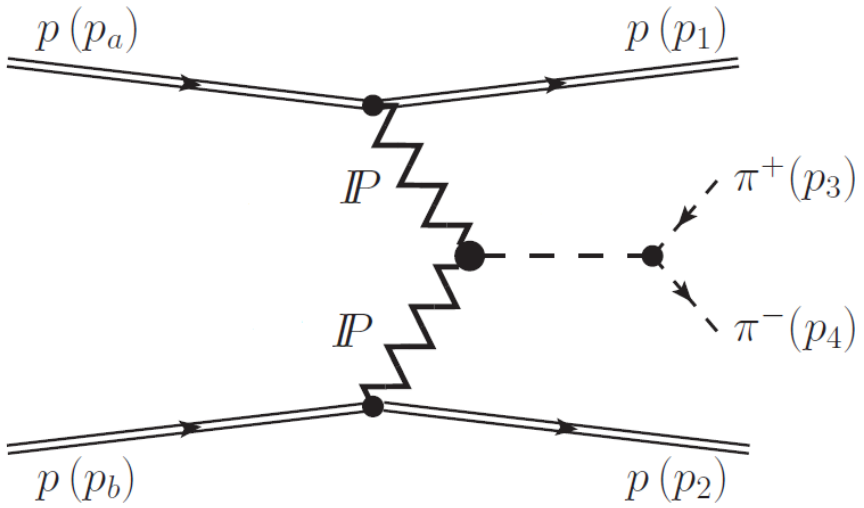

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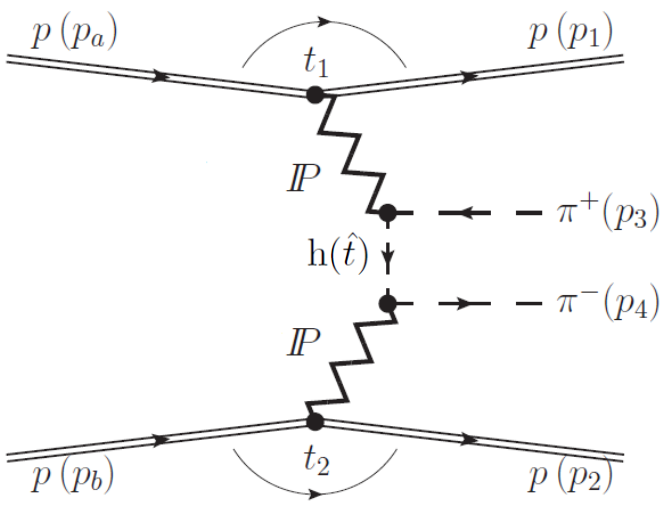

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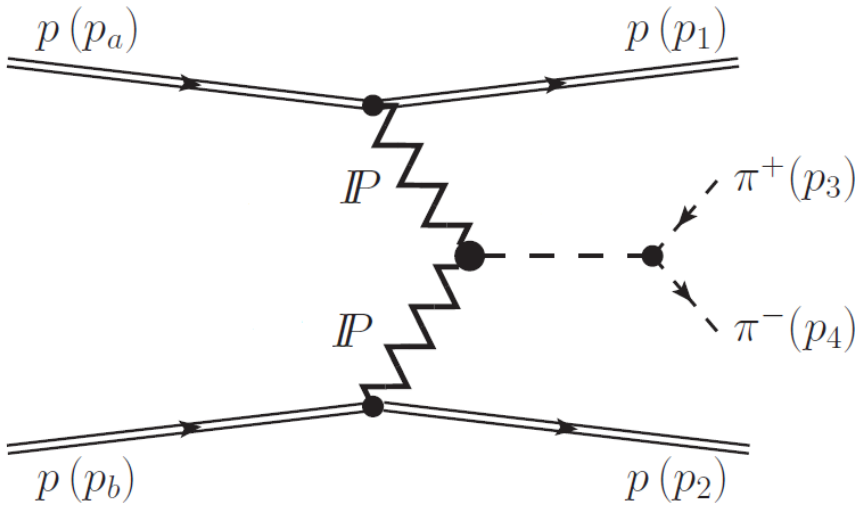

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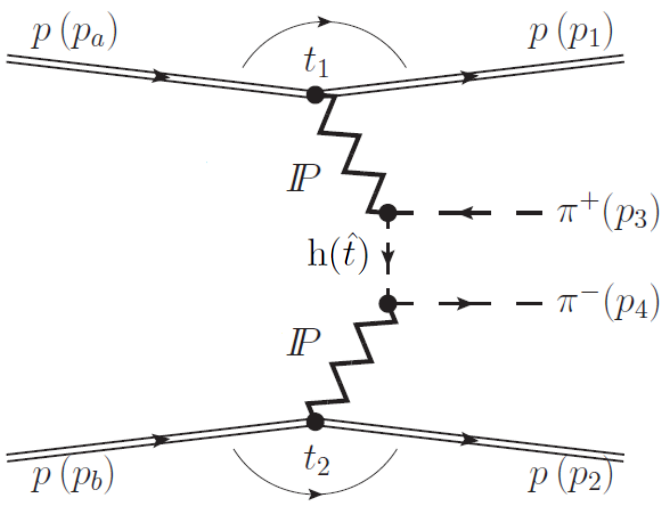

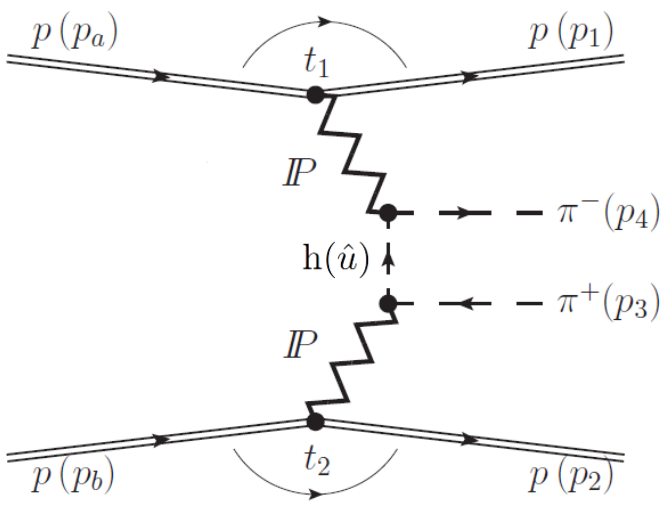

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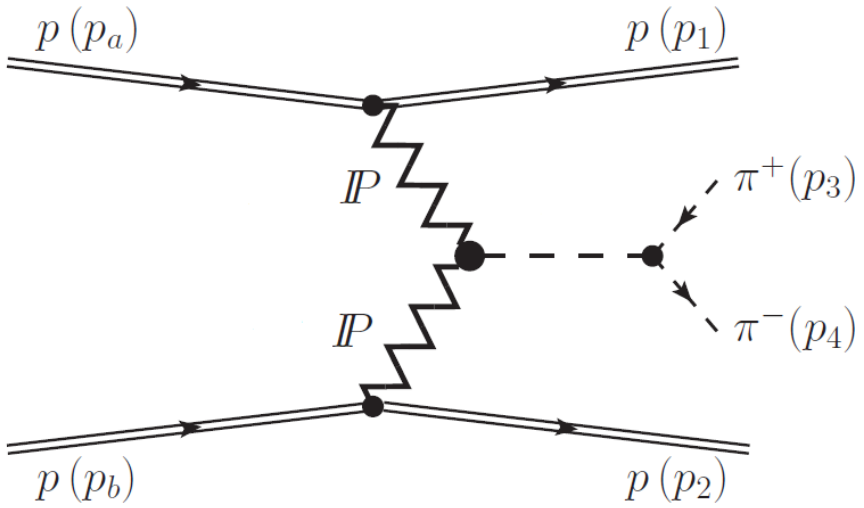

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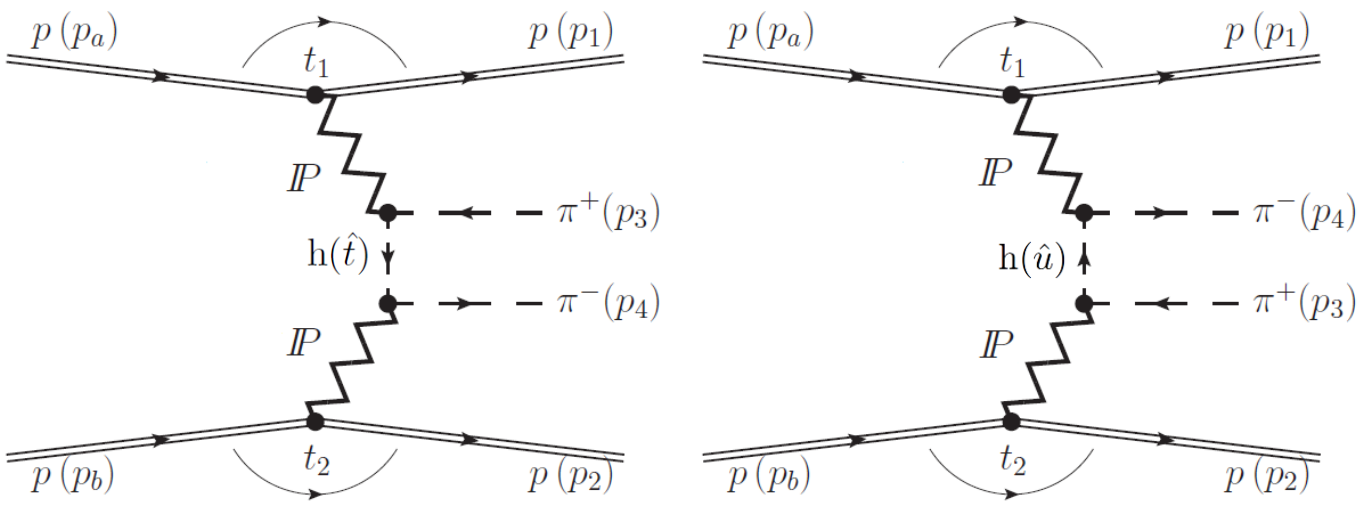

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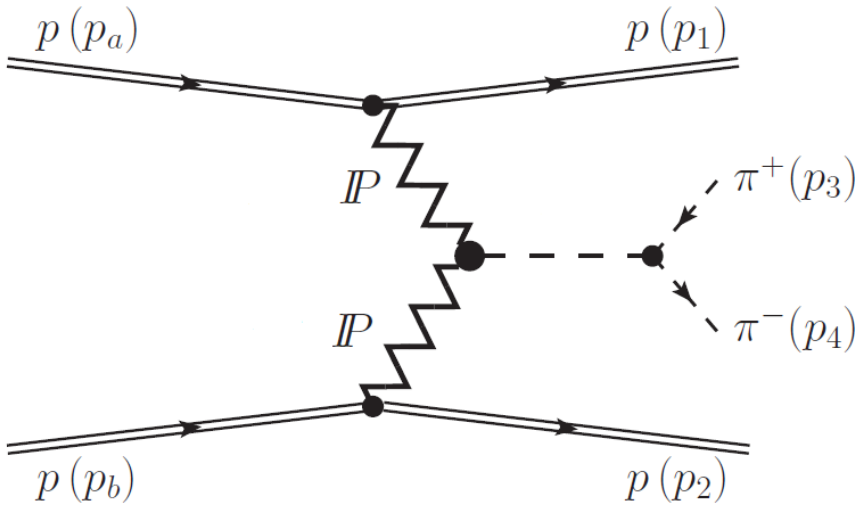

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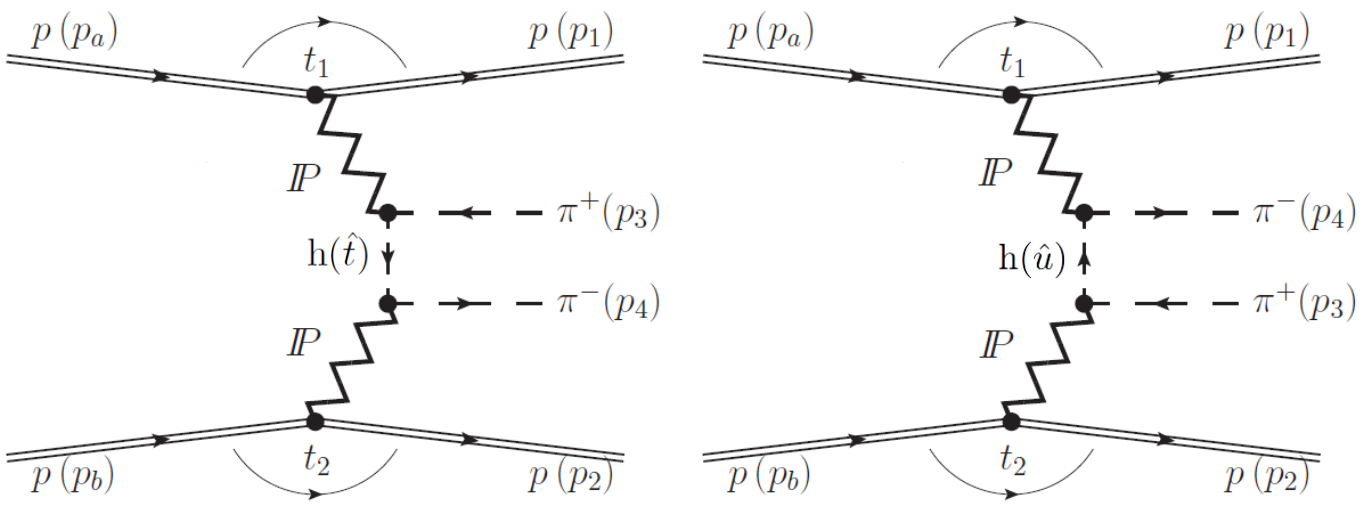

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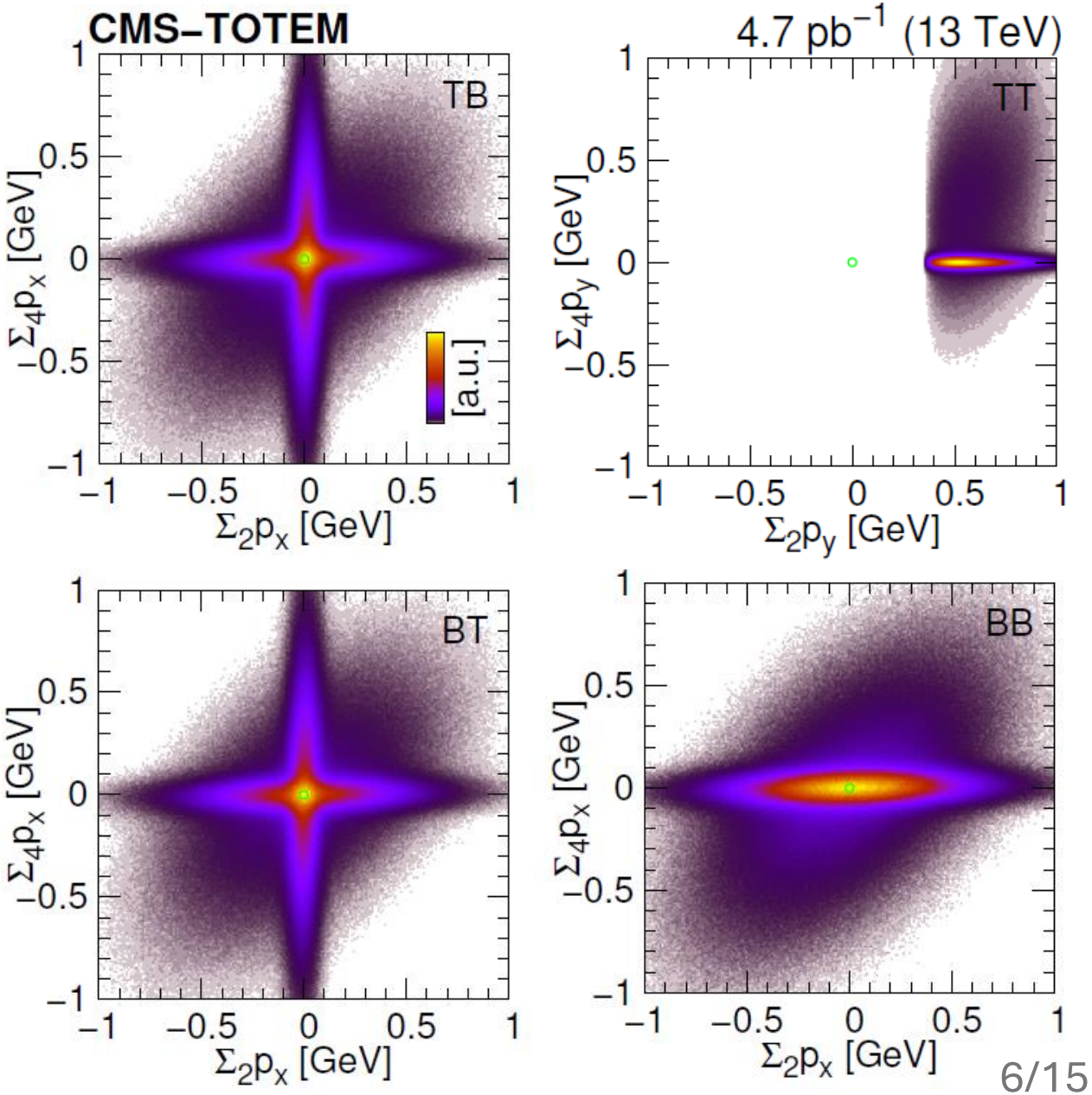

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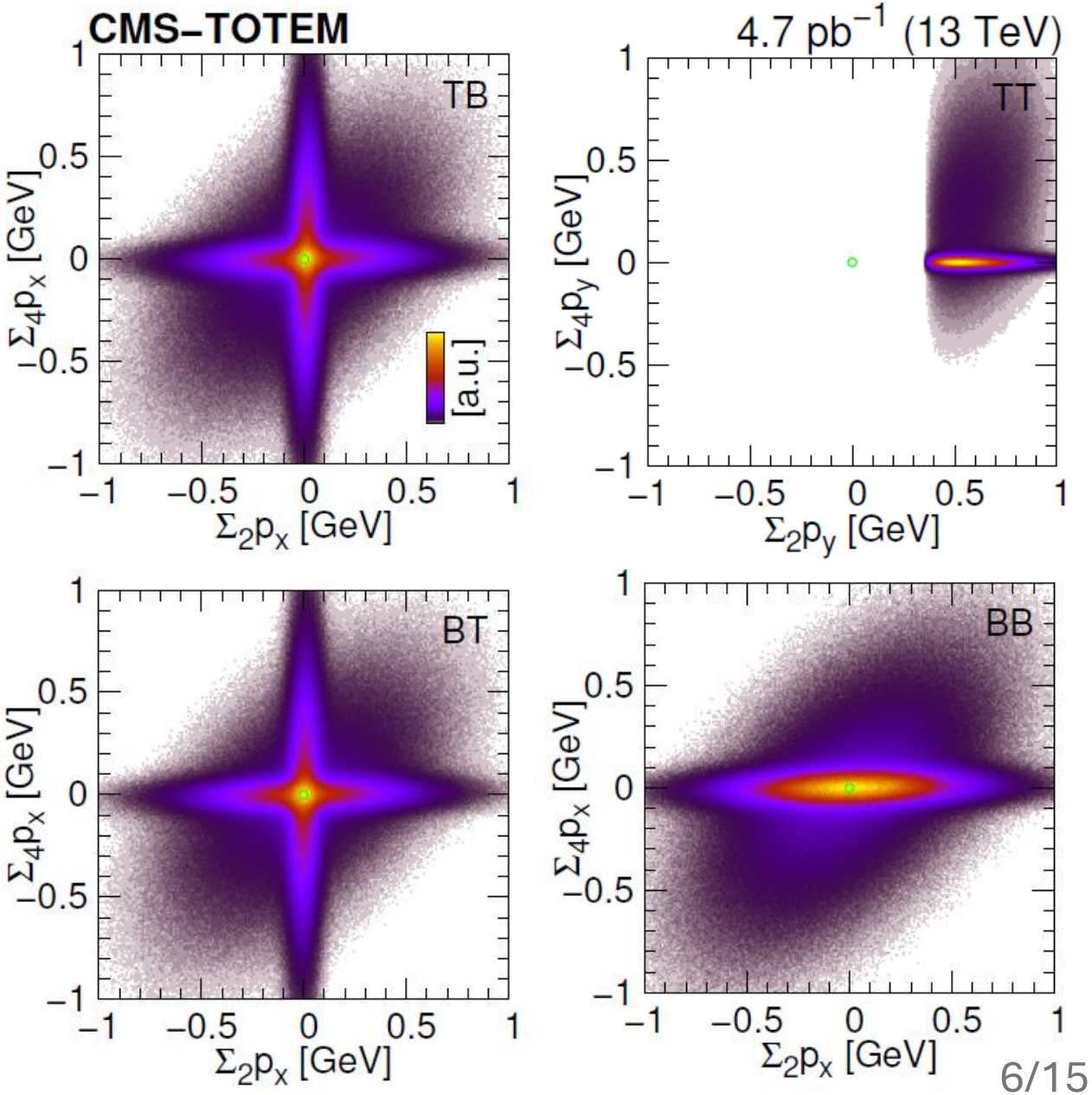

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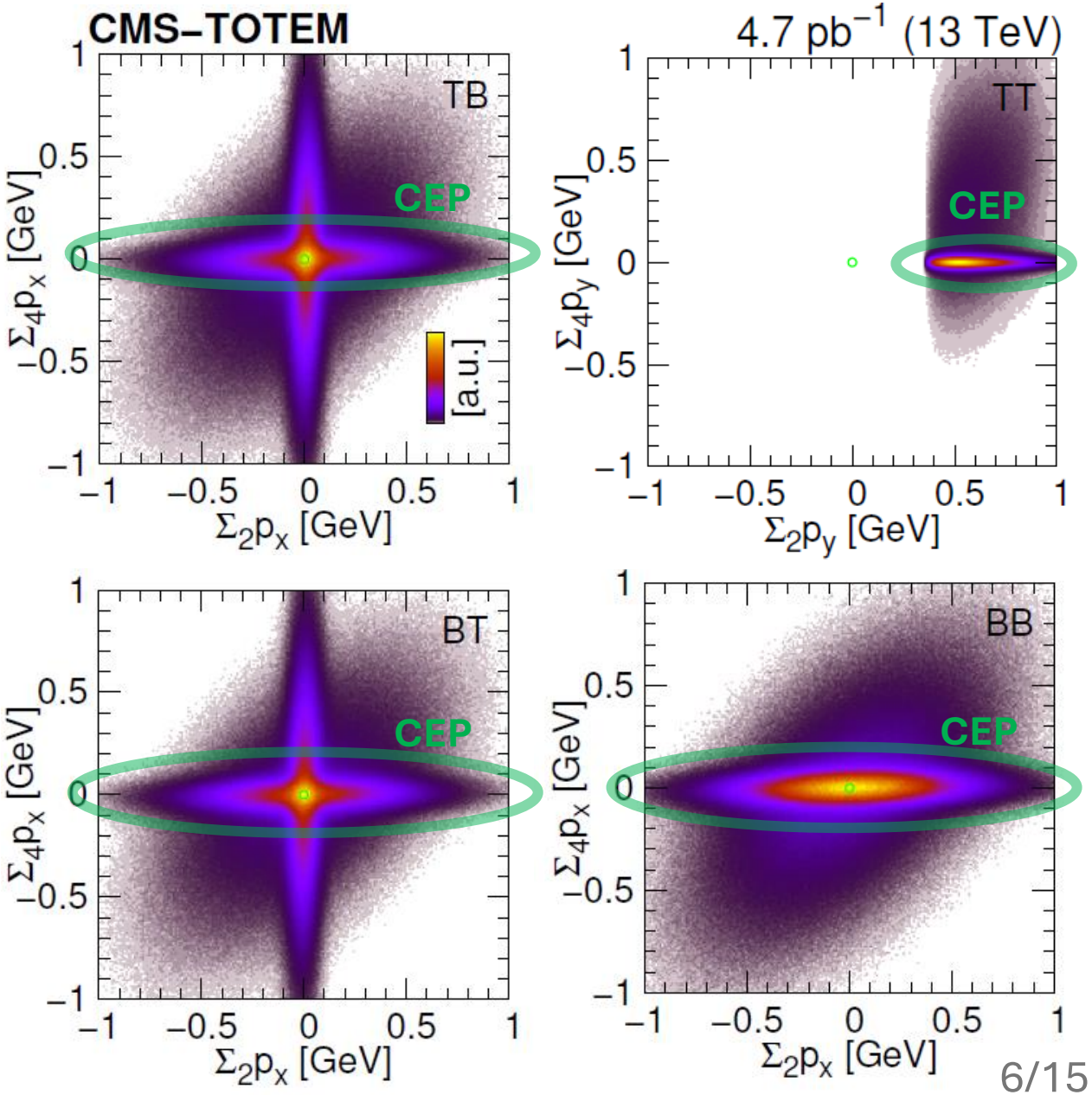

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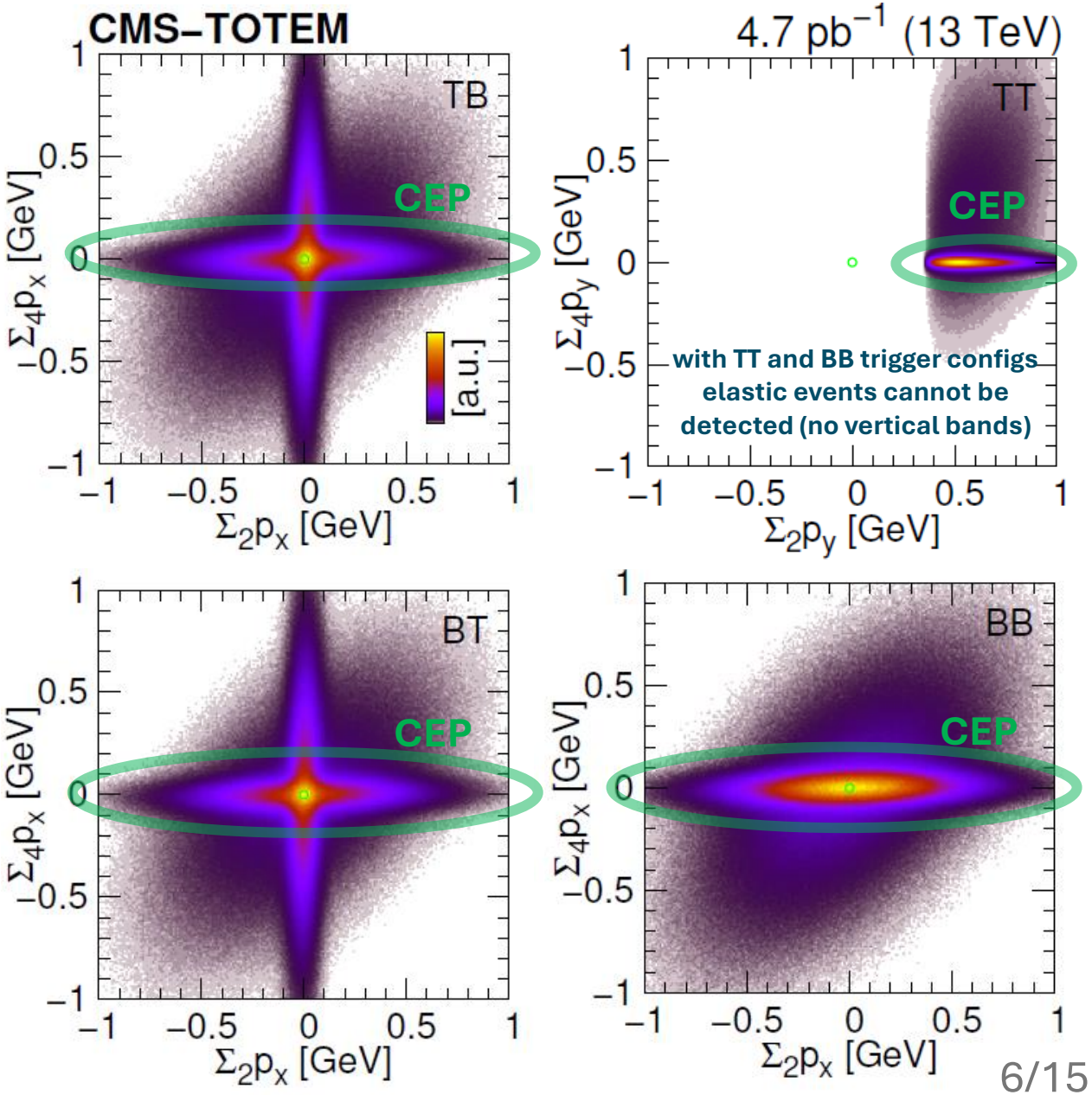

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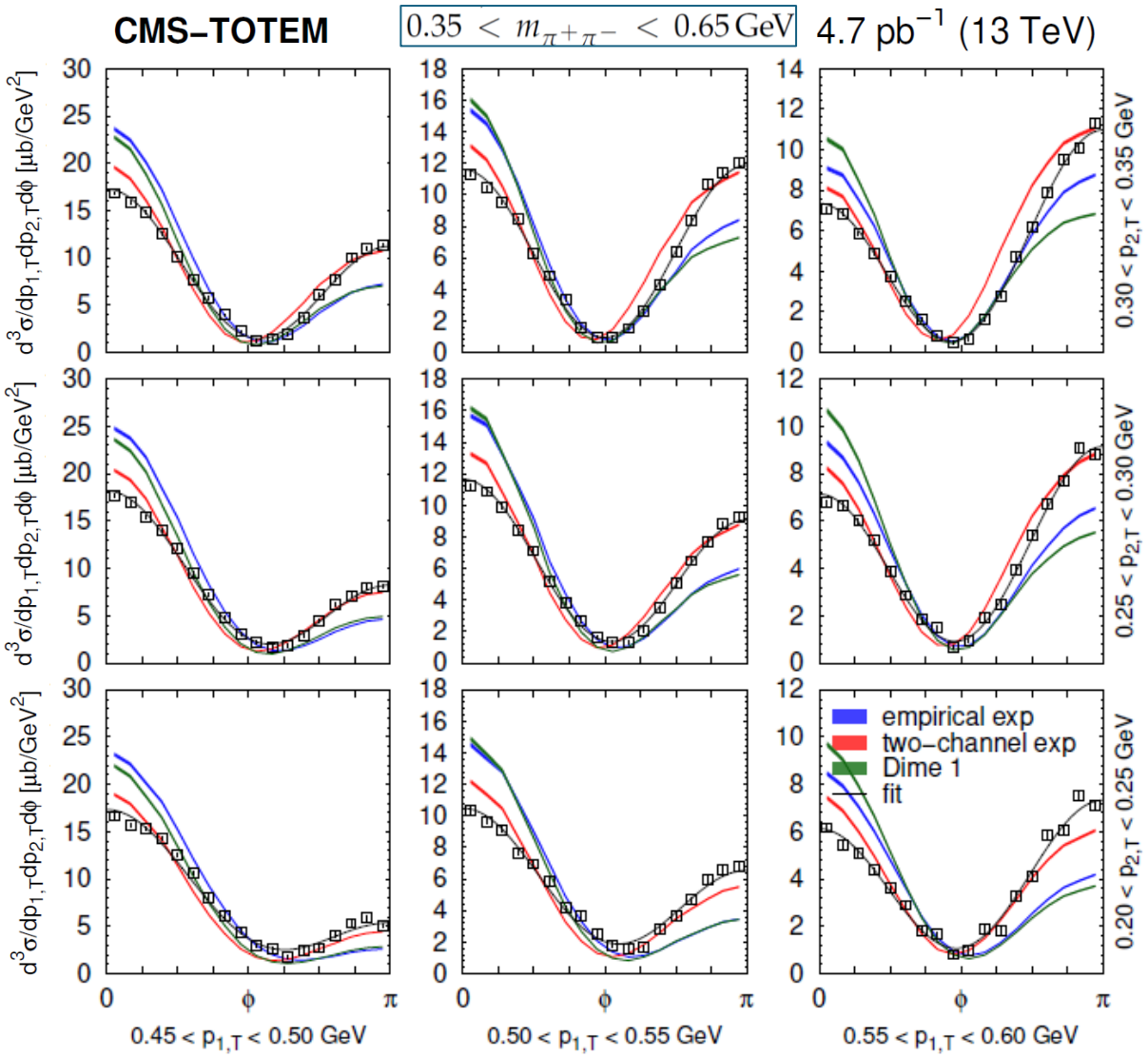

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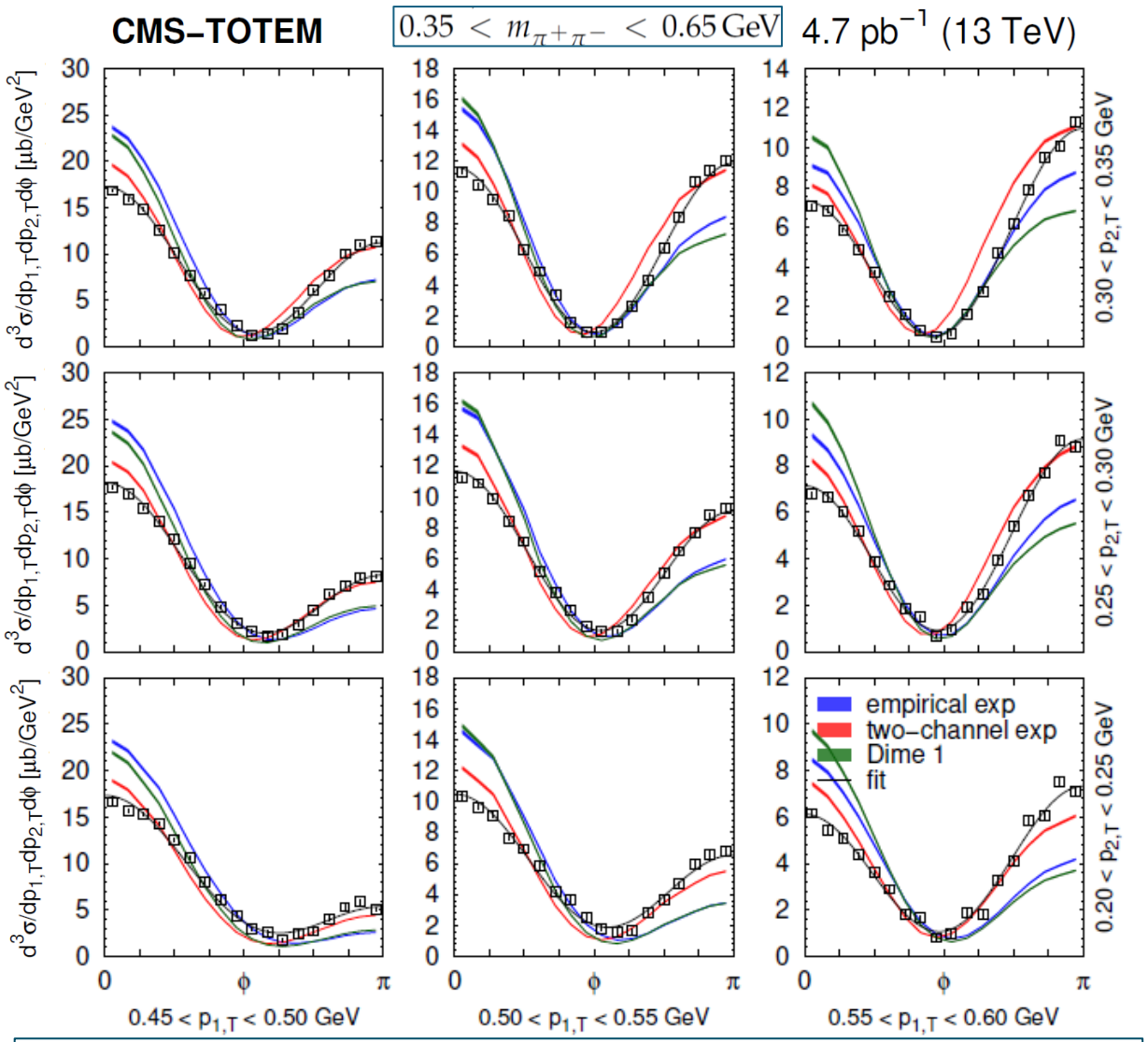

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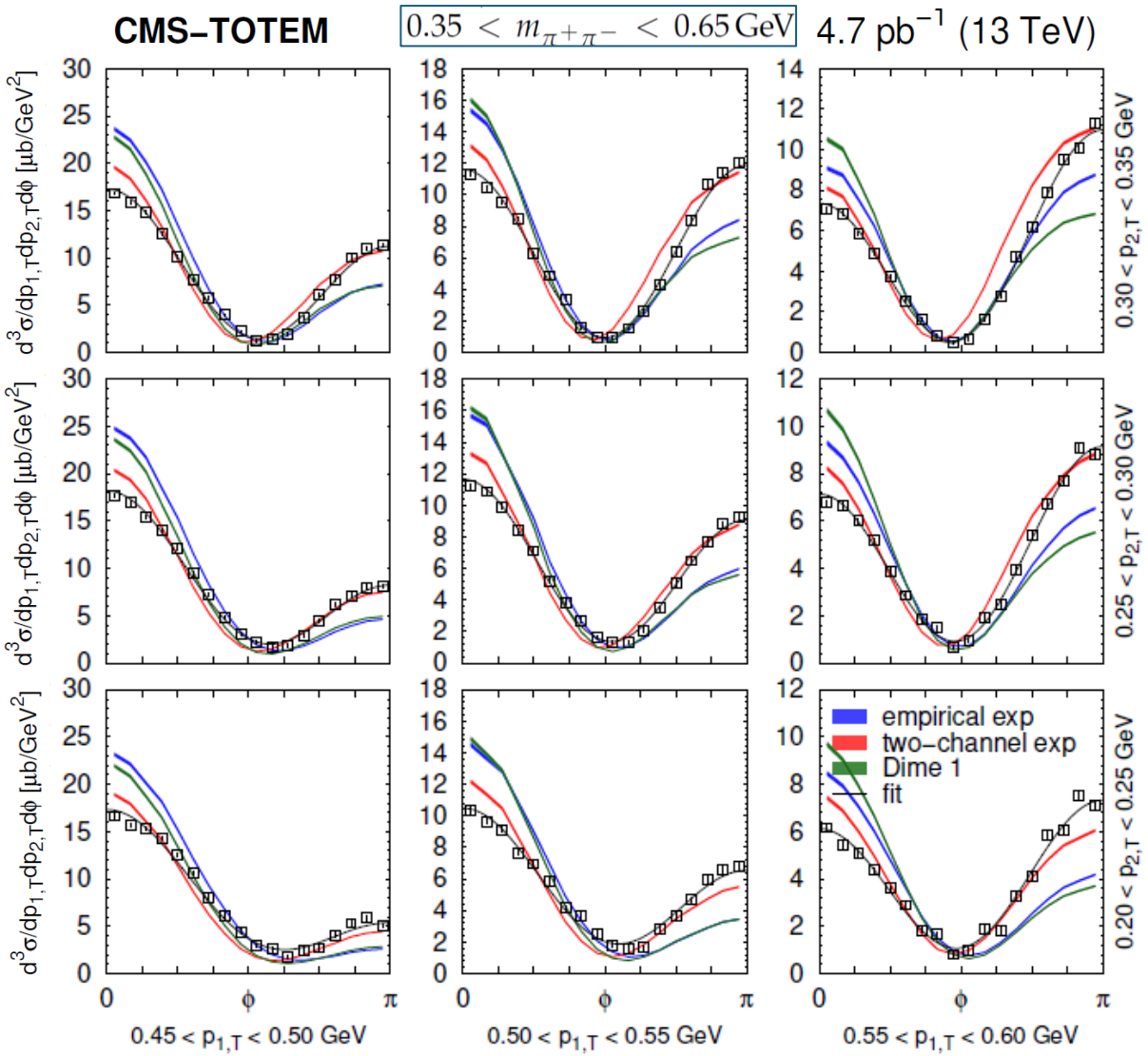

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$\max(t, u)$ squared four momentum of the virtual meson

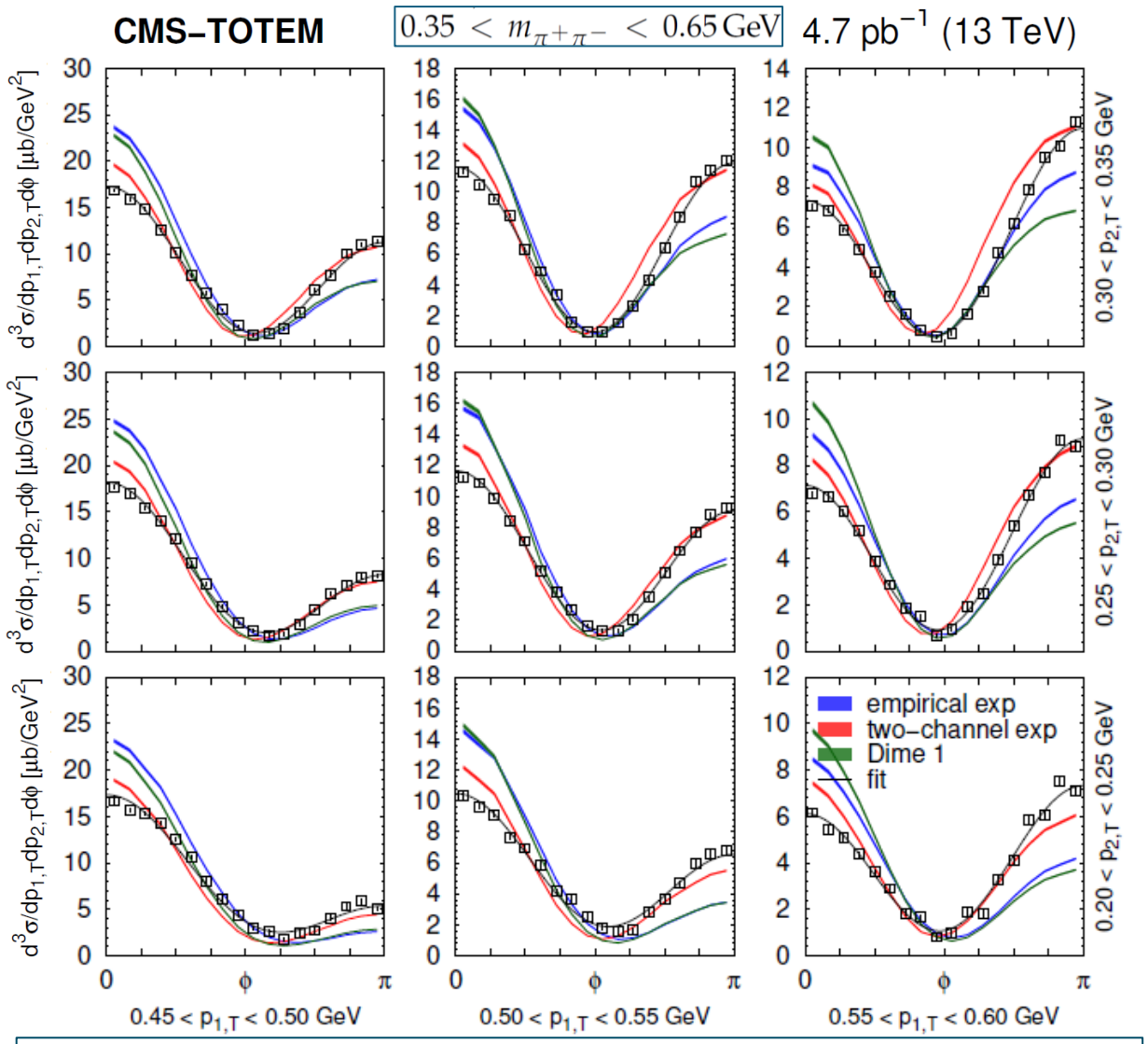
triple differential cross sections:

in ranges of $p_{1,T}$ and $p_{2,T}$, distributions of ϕ, m, and $\max(t, u)$

a parabolic minimum in the distribution of ϕ is observed for the first time

the minimum can be interpreted as an effect due to rescattering (absorption) corrections

Harland-Lang, Khoze, Ryskin, Eur. Phys. J. C 74 (2014) 2848



models after tuning give better descriptions but still need for further theoretical developments

$d^3\sigma/dp_{1,T}\,dp_{2,T}\,dm$ and $d^3\sigma/dp_{1,T}\,dp_{2,T}\,d\max(t,u)$

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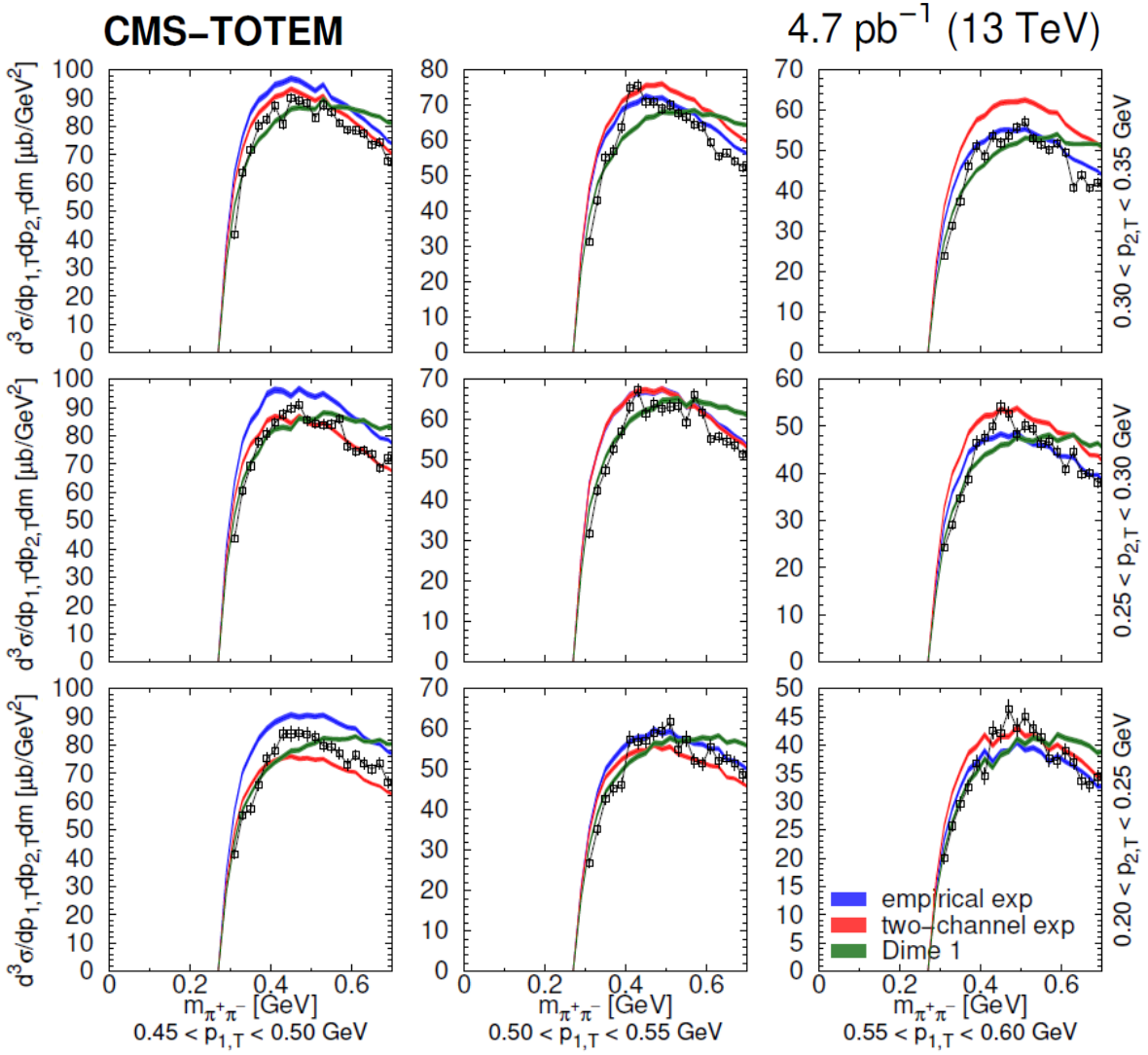

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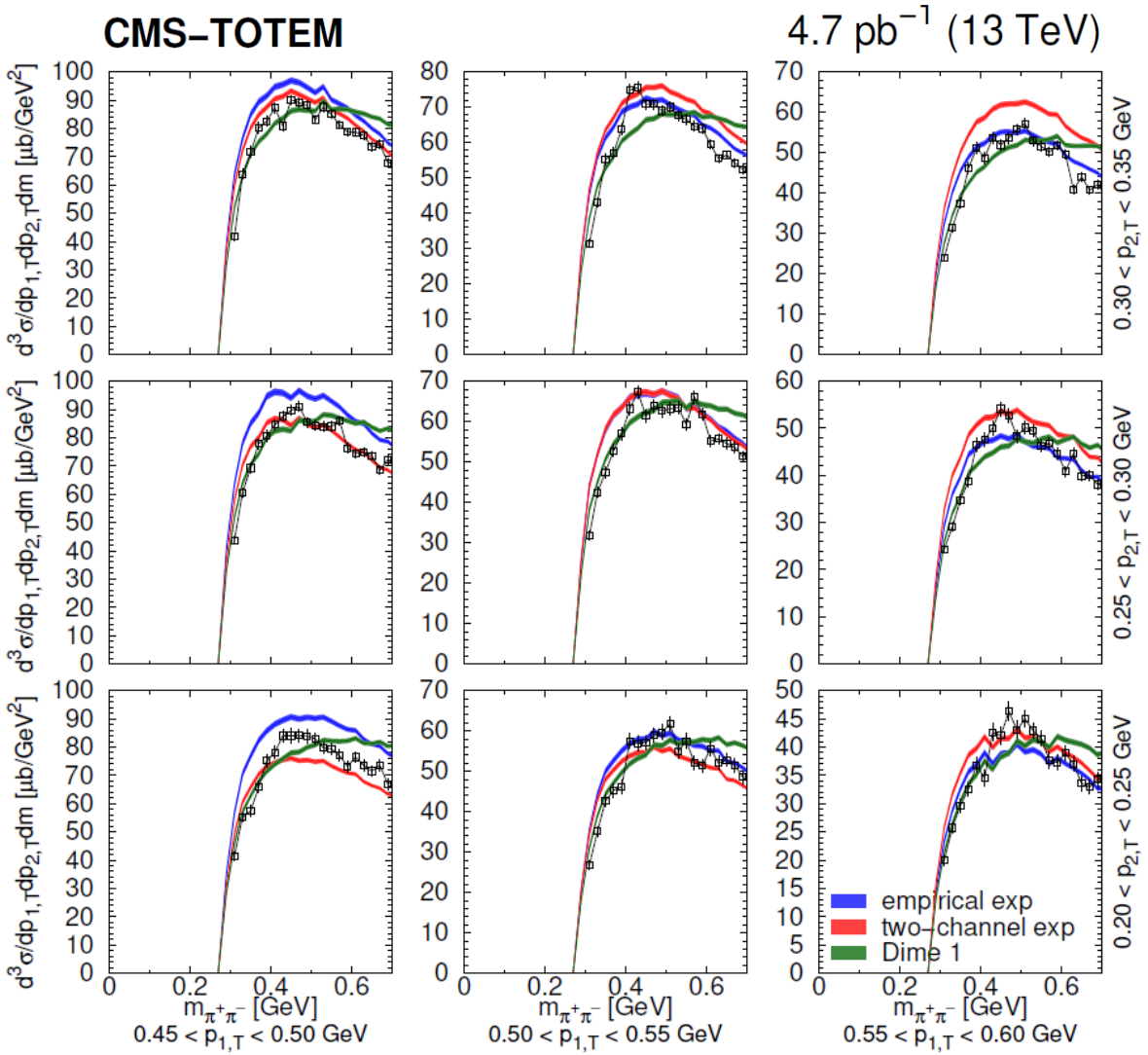

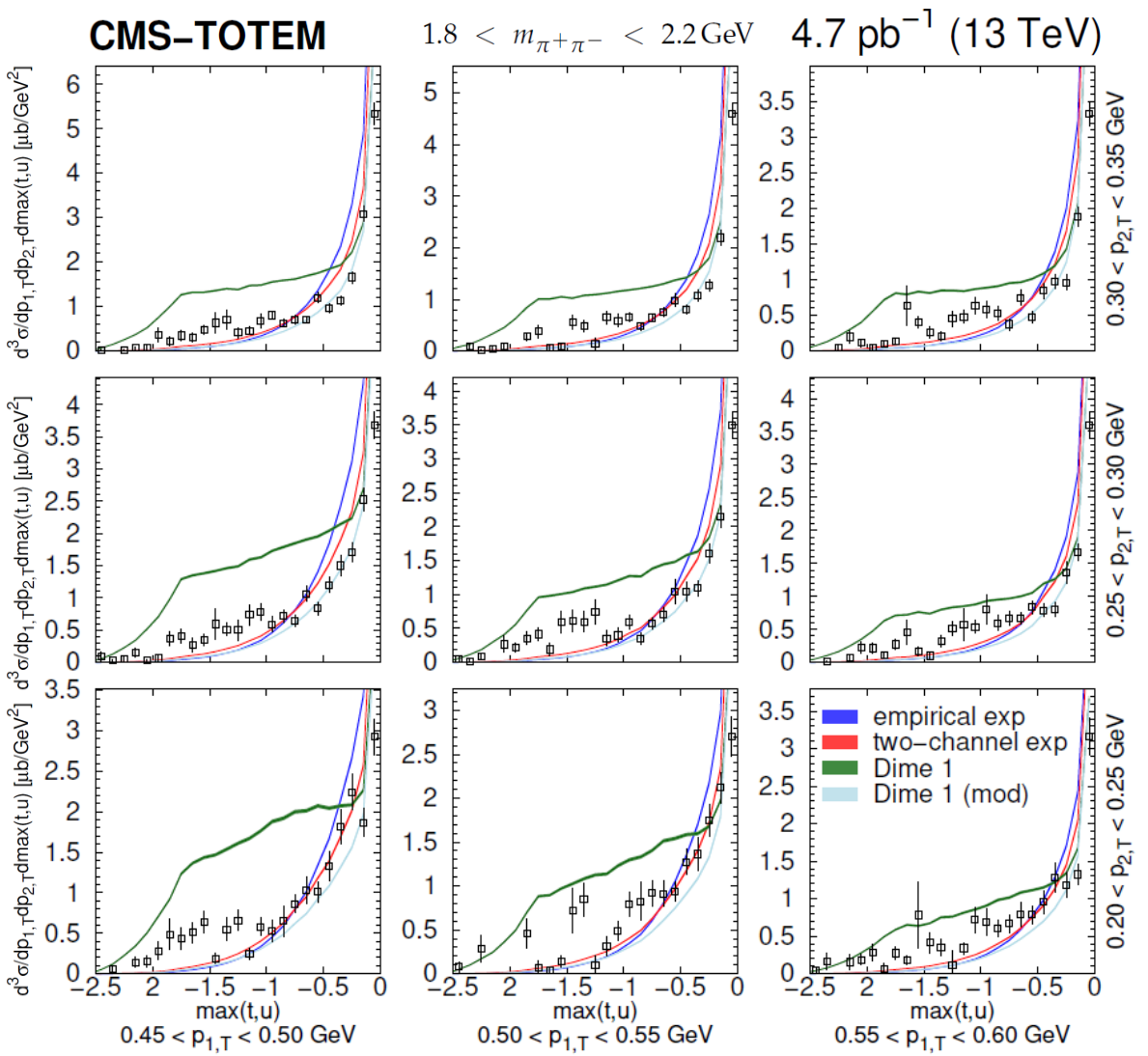

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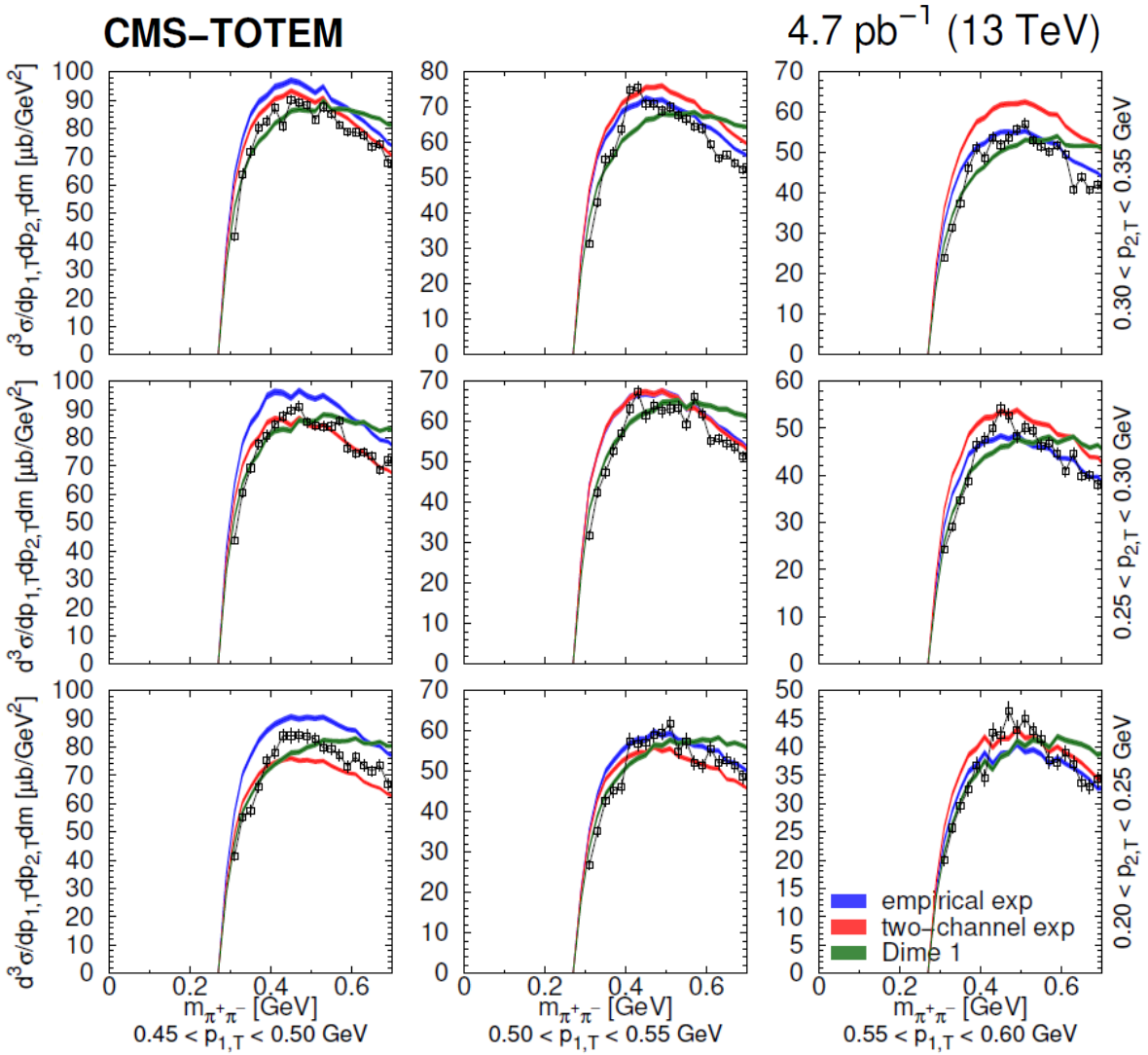
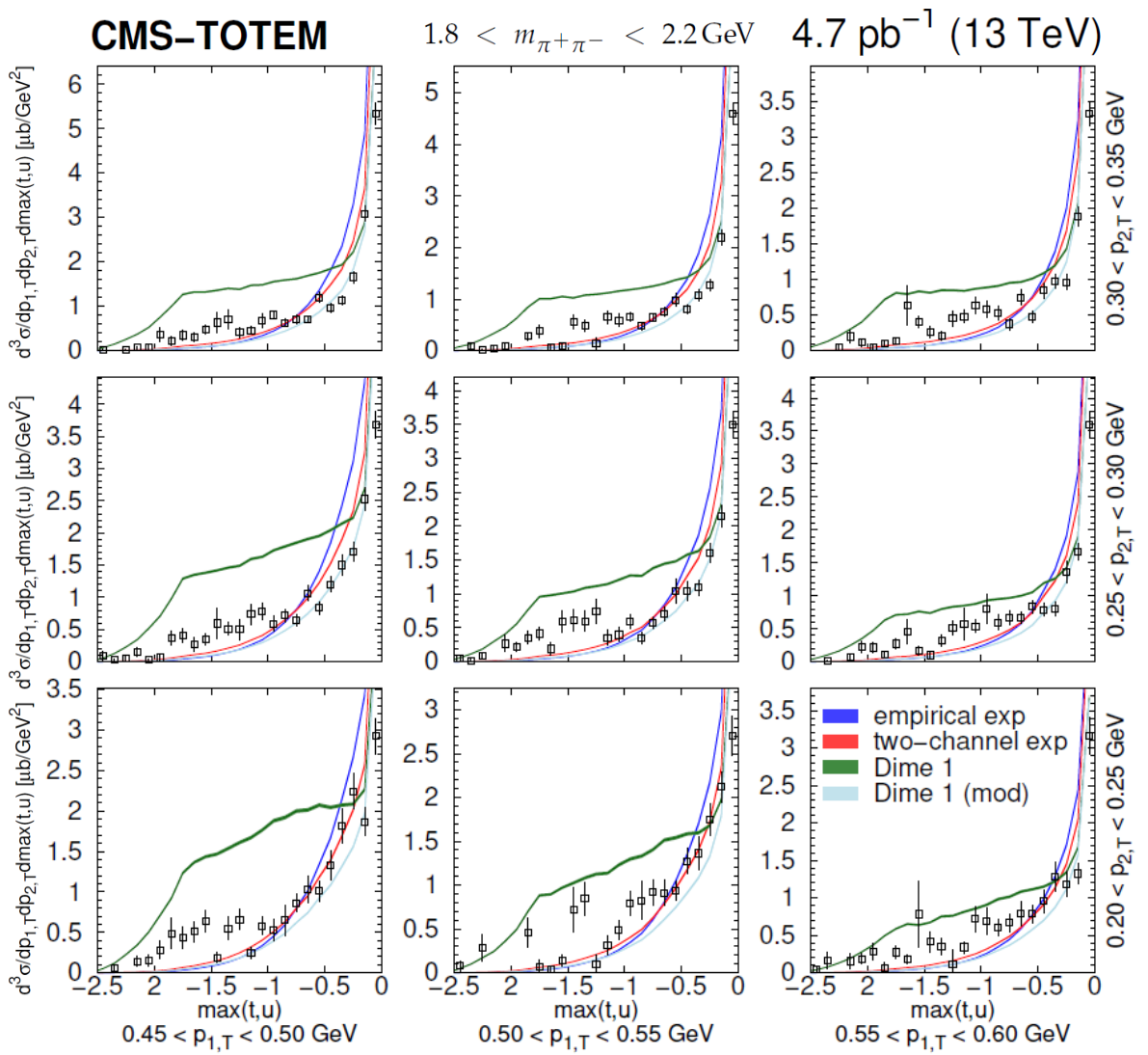
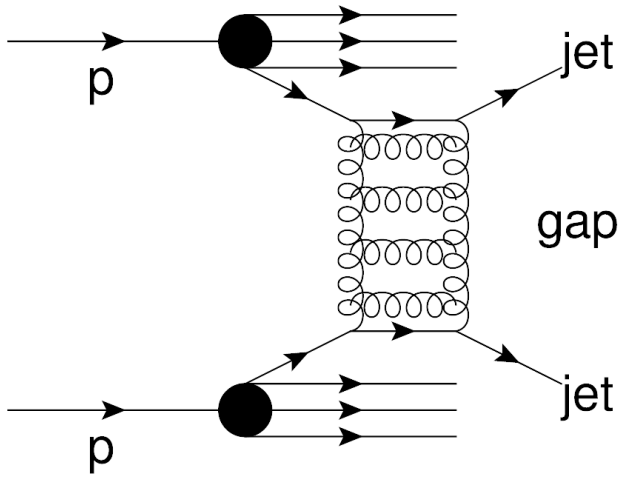




based on the measured distributions, models are tuned and various physical parameters related to pomeron physics are determined

Dijet events with hard color-singlet exchange

Dijet events with hard color-singlet exchange



jet-gap-jet event
by hard color-singlet exchange

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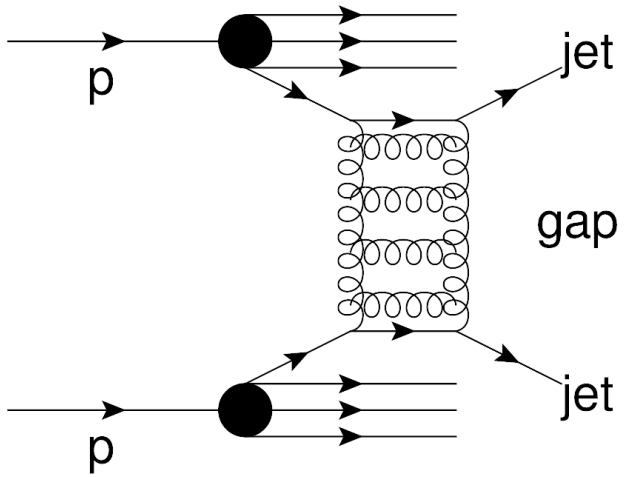

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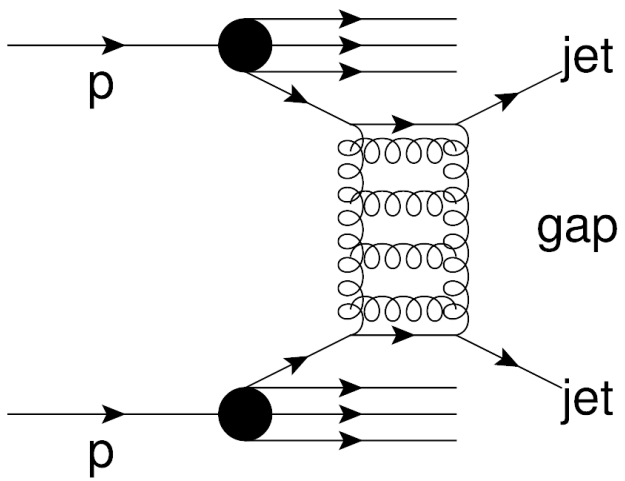
devoid of particle activity between the final-state jets due to **BFKL pomeron exchange**

Dijet events with hard color-singlet exchange



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tool to study BFKL dynamics

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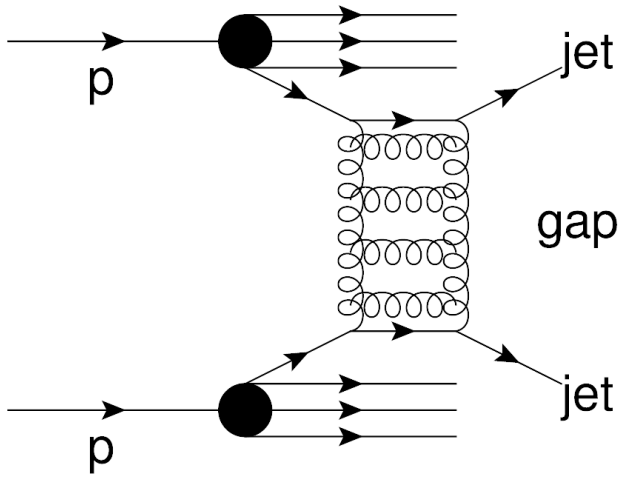

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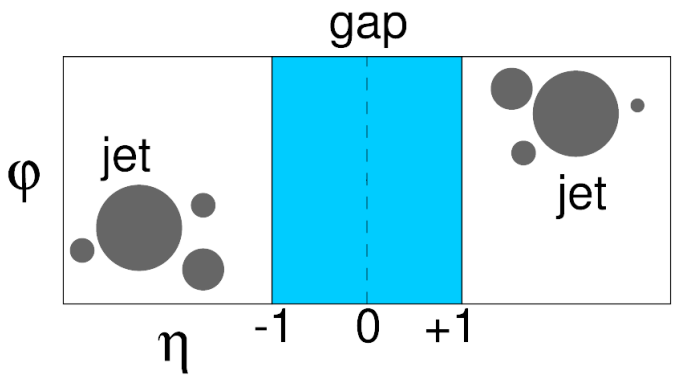
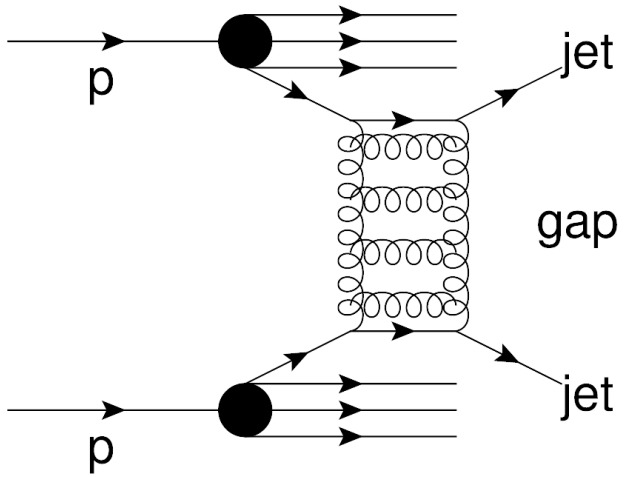


jet-gap-jet event signature in the φ-η plane

measured by CMS

Dijet events with hard color-singlet exchange



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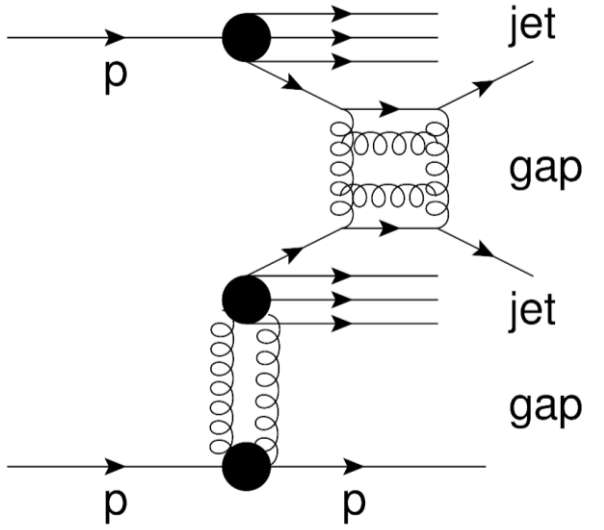
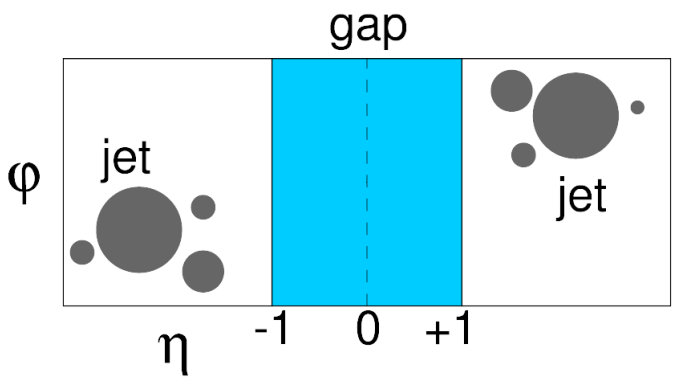


jet-gap-jet with intact proton event
by hard color-singlet exchange



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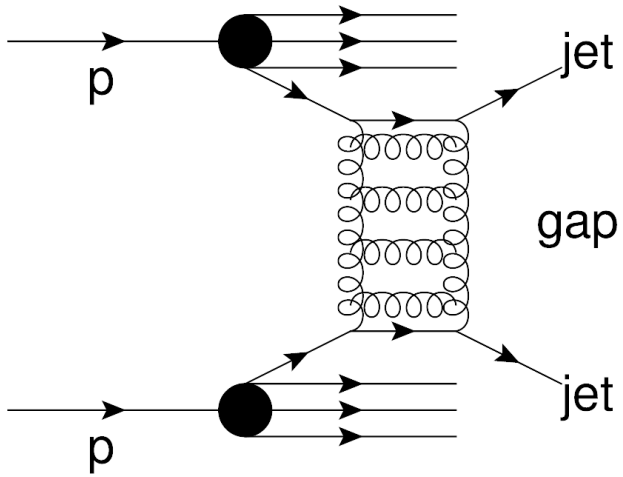

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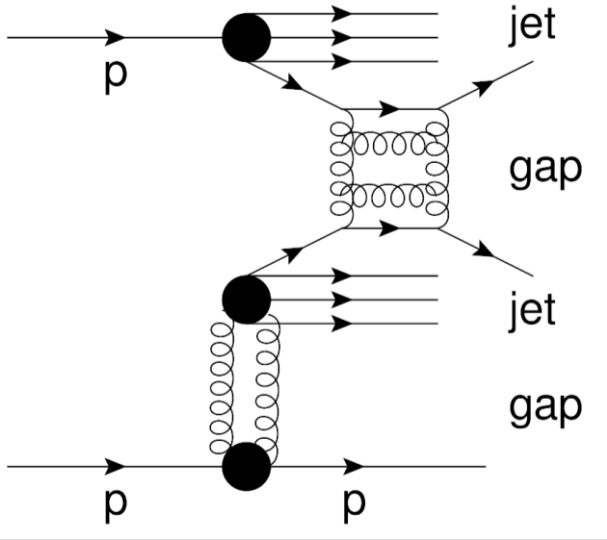

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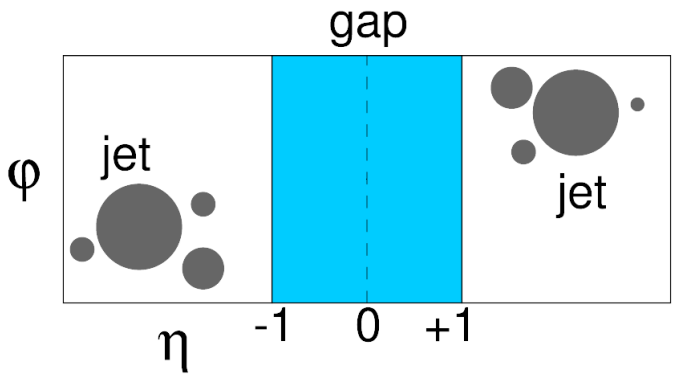

jet-gap-jet event signature in the
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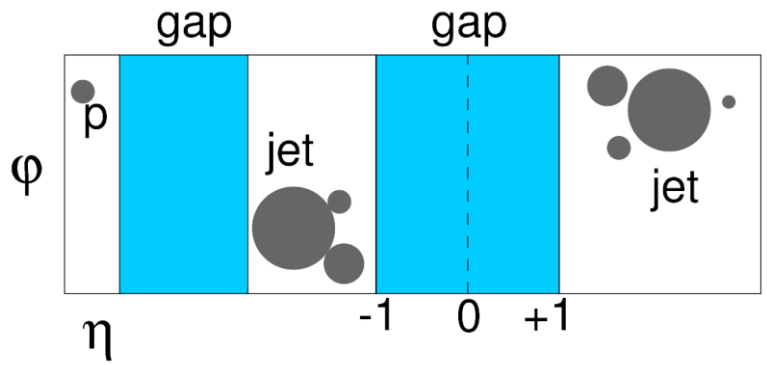

jet-gap-jet + intact proton event
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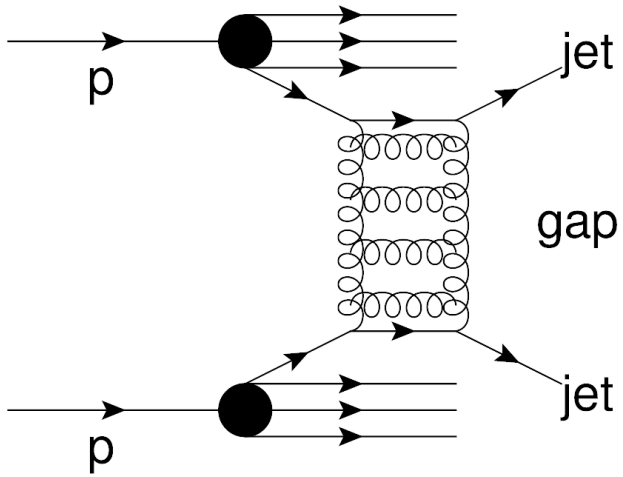

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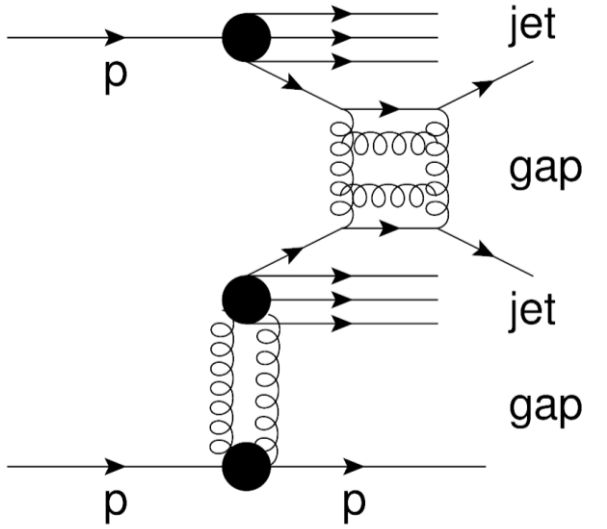

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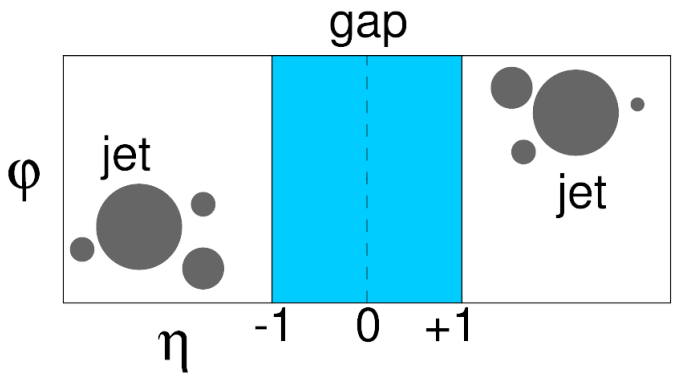

jet-gap-jet event signature in the
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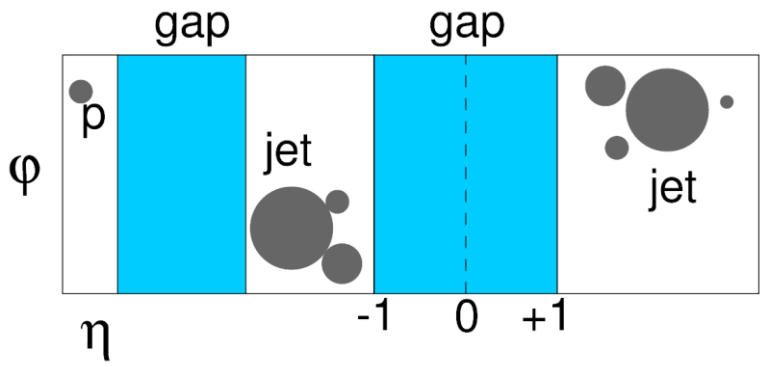
measured by CMS+TOTEM



jet-gap-jet + intact proton event
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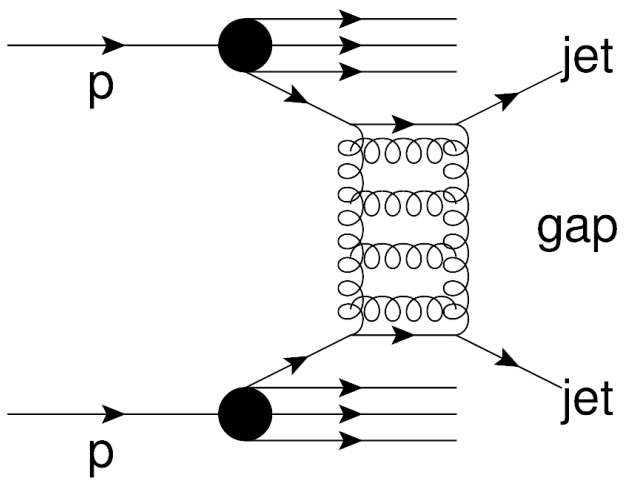
Dijet events with hard color-singlet exchange



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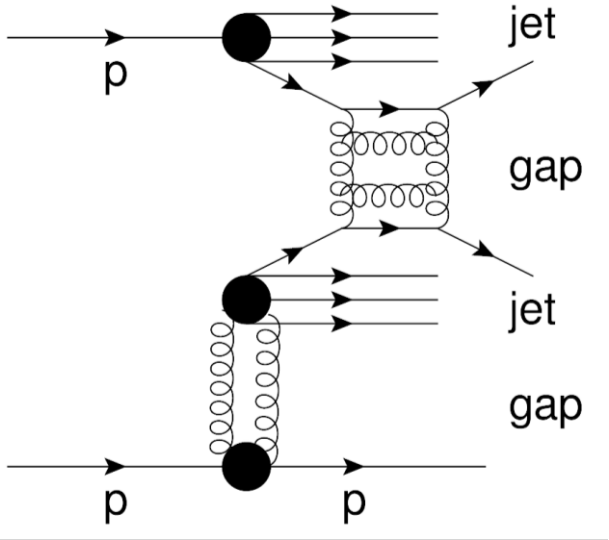

jet-gap-jet with intact proton event
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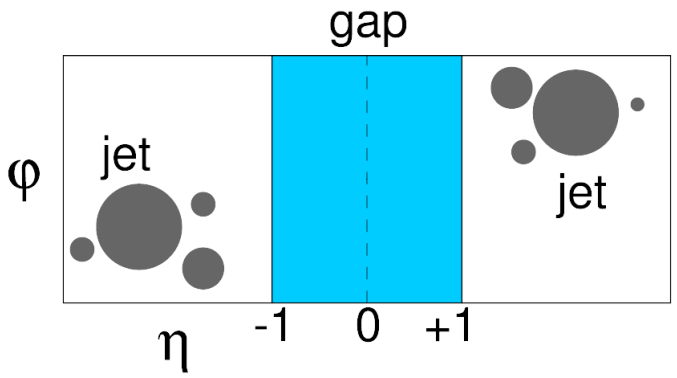

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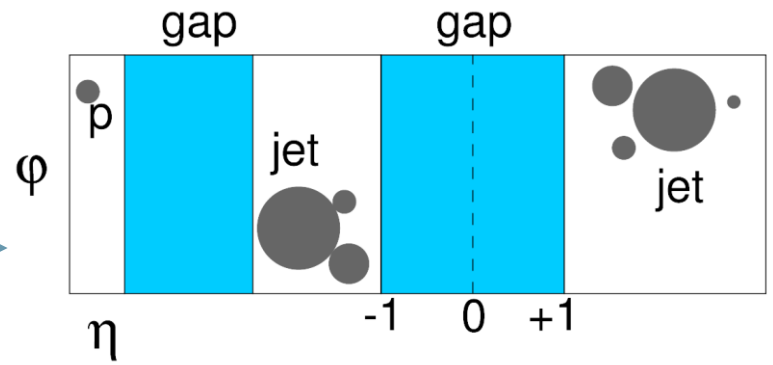

jet-gap-jet + intact proton event
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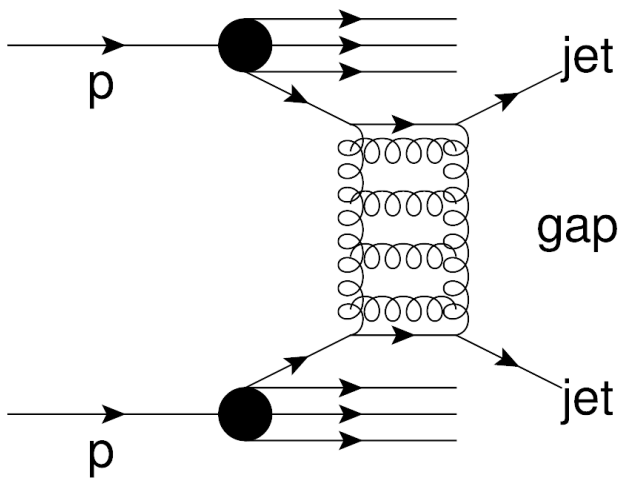

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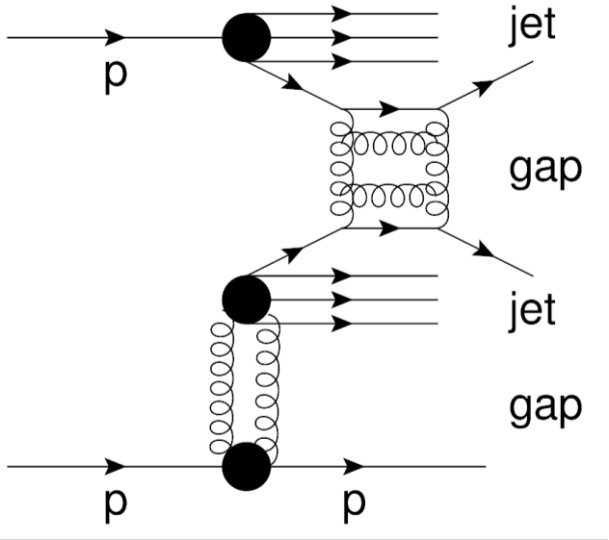
tool to study BFKL dynamics



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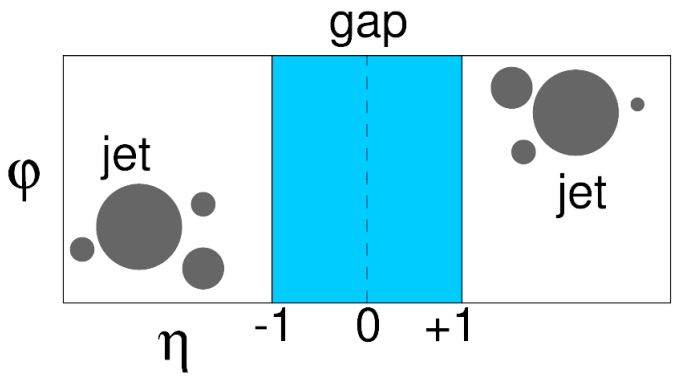

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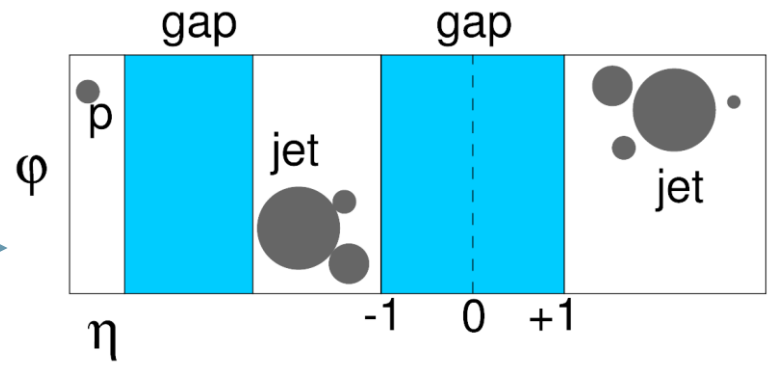

jet-gap-jet + intact proton event
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CMS color-singlet exchange (CSE) dijet event fractions

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the fraction of dijet events produced via color-singlet exchange, f_{CSE}, is measured in bins of $\Delta\eta_{jj} = |\eta^{jet1} - \eta^{jet2}|$, p_T^{jet2} (subleading jet p_T) and $\Delta\phi_{jj} = |\phi^{jet1} - \phi^{jet2}|$

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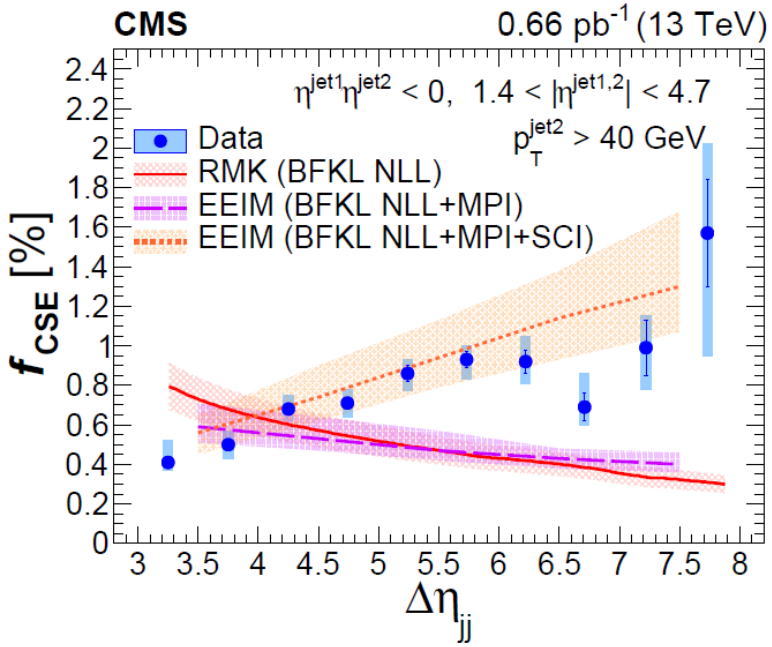

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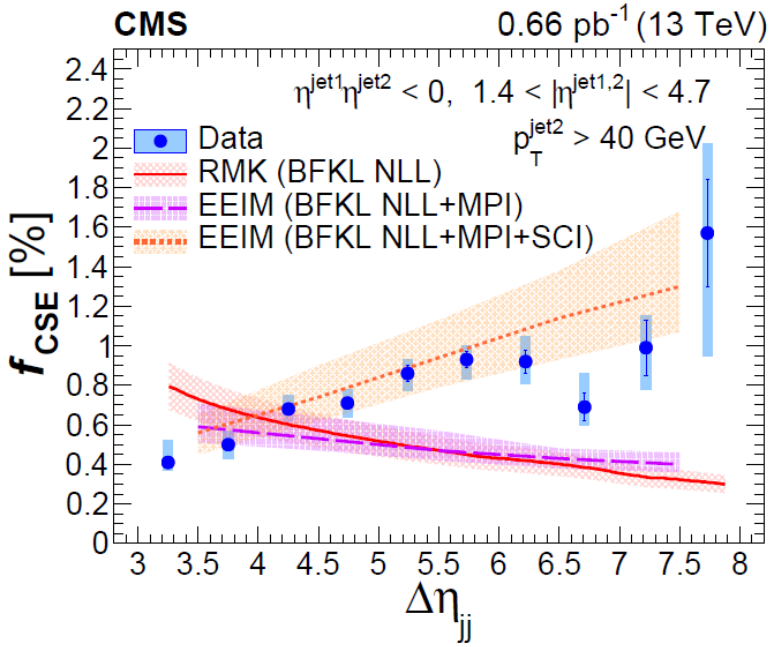

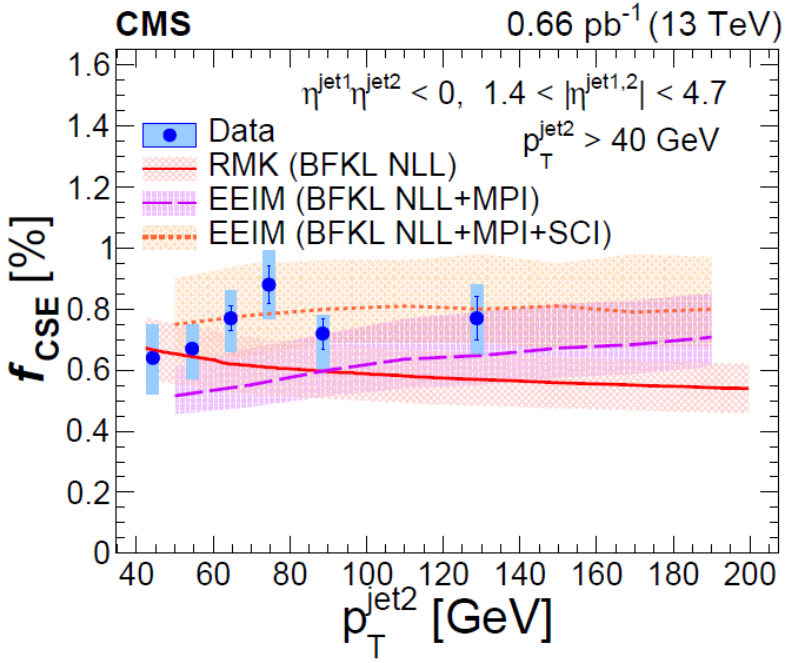

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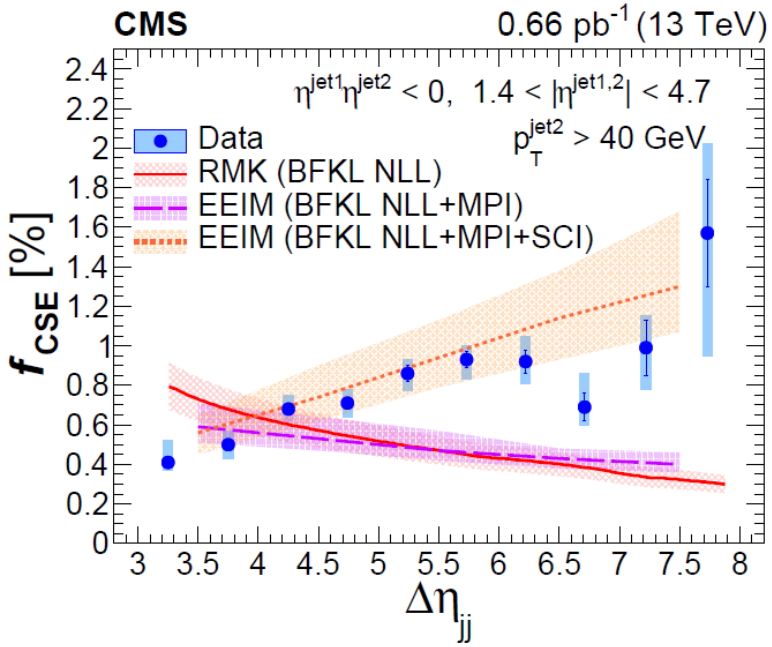

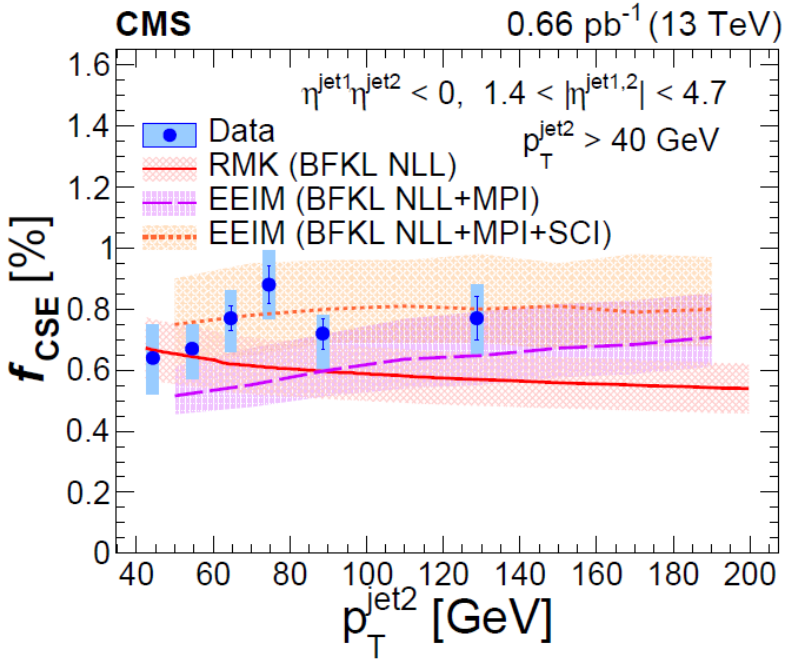

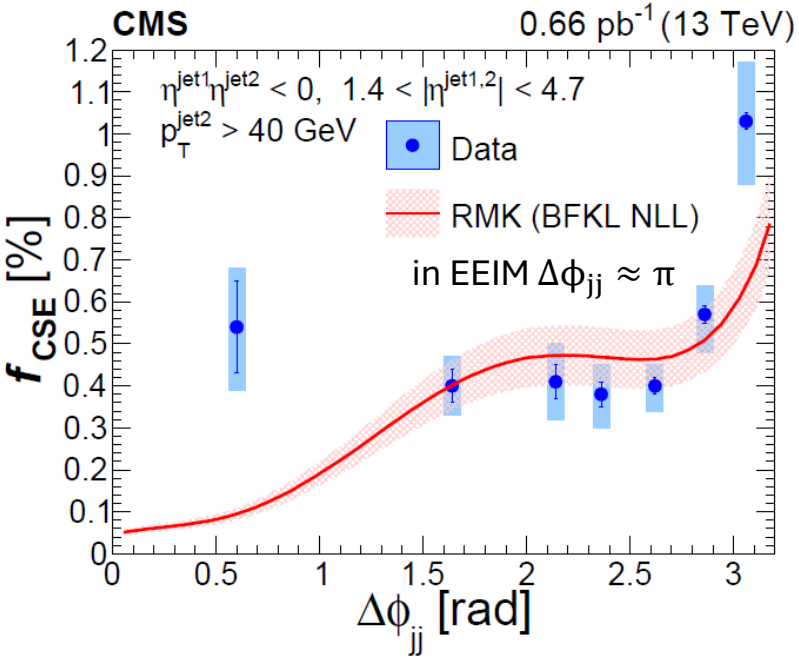

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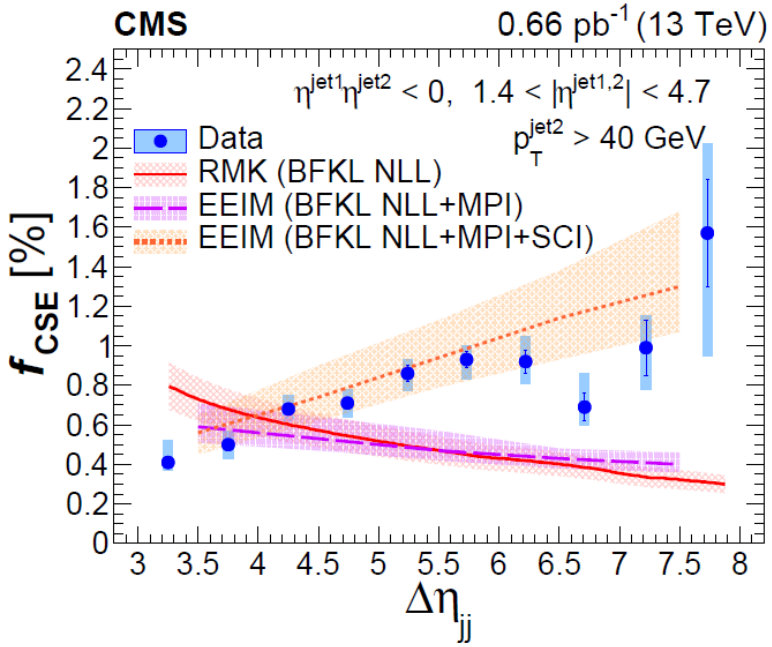

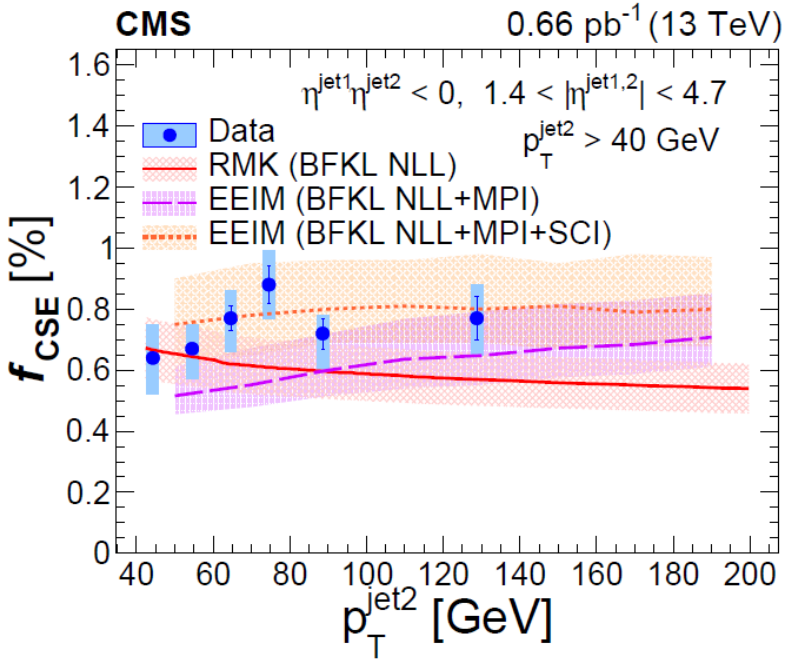

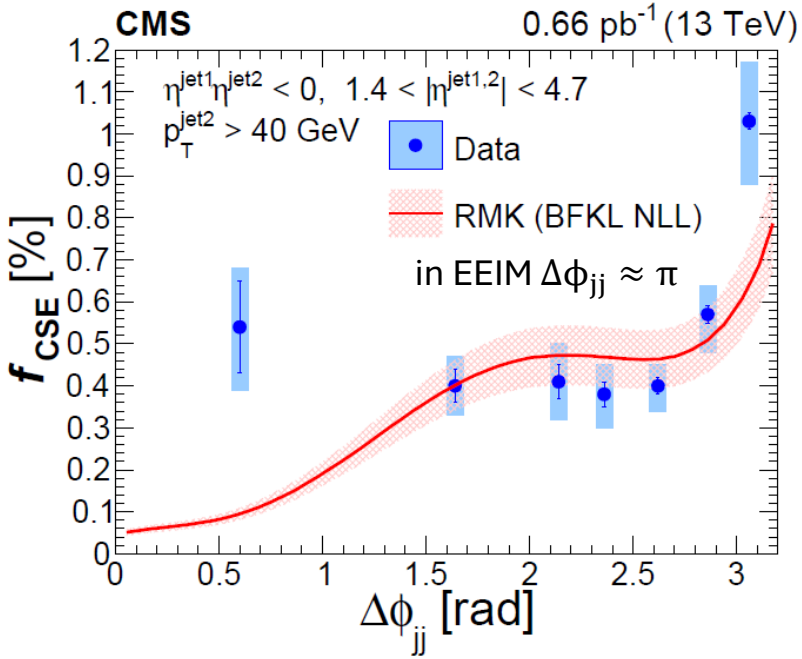

results are compared with BFKL-based calculations by Royon, Marquet, Kepka (RMK) and Ekstedt, Enberg, Ingelman, Motyka (EEIM) in NLL accuracy implemented in PYTHIA (the latter includes soft color interaction (SCI) and/or multi-parton interaction (MPI) contributions)

CMS-TOTEM CSE dijet event fractions

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dominant background: uncorrelated forward protons from pile up or beam halo activity

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background removal based on matching between the fractional momentum losses ξ_p^{TOTEM} and ξ_p^{CMS}

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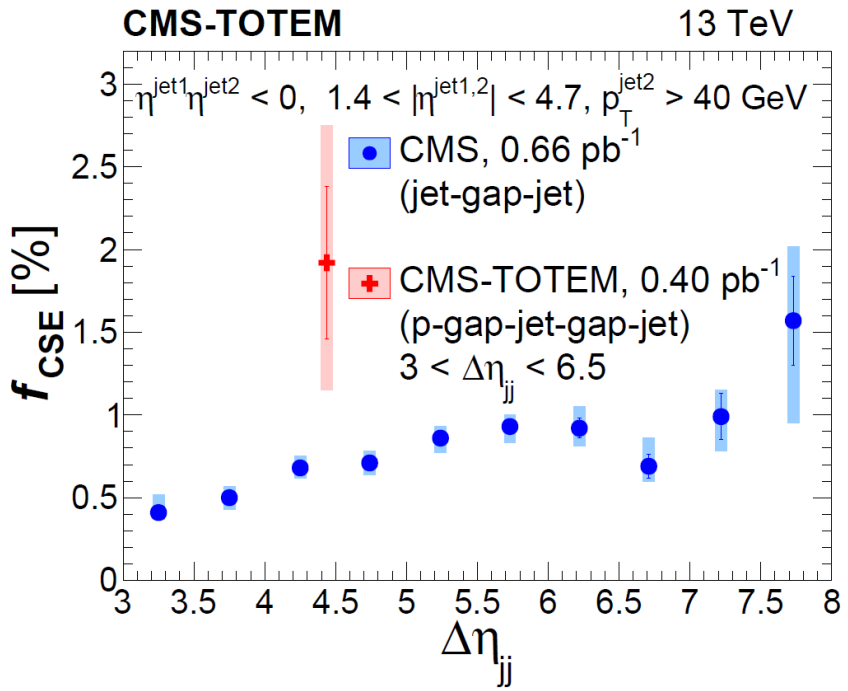

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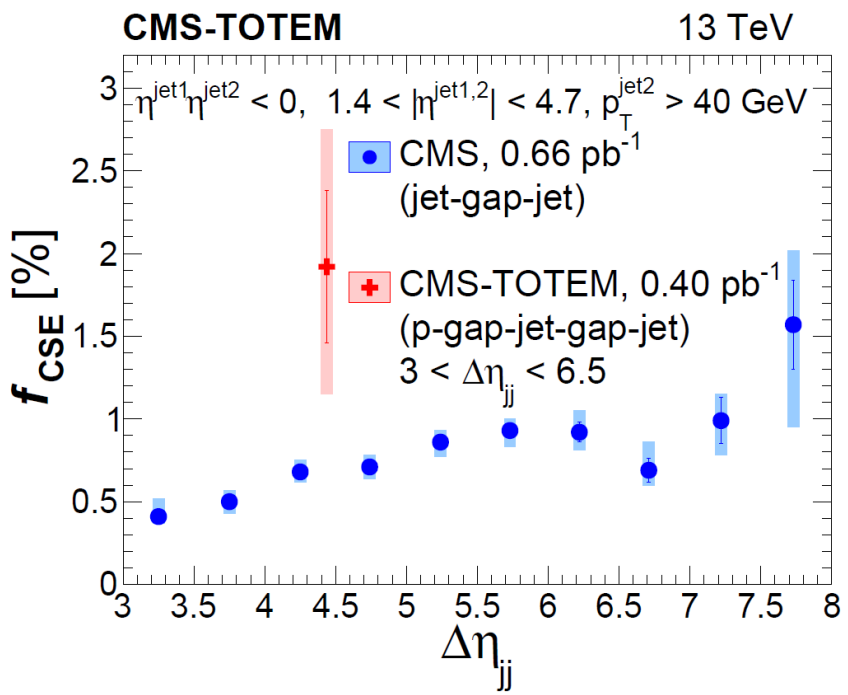

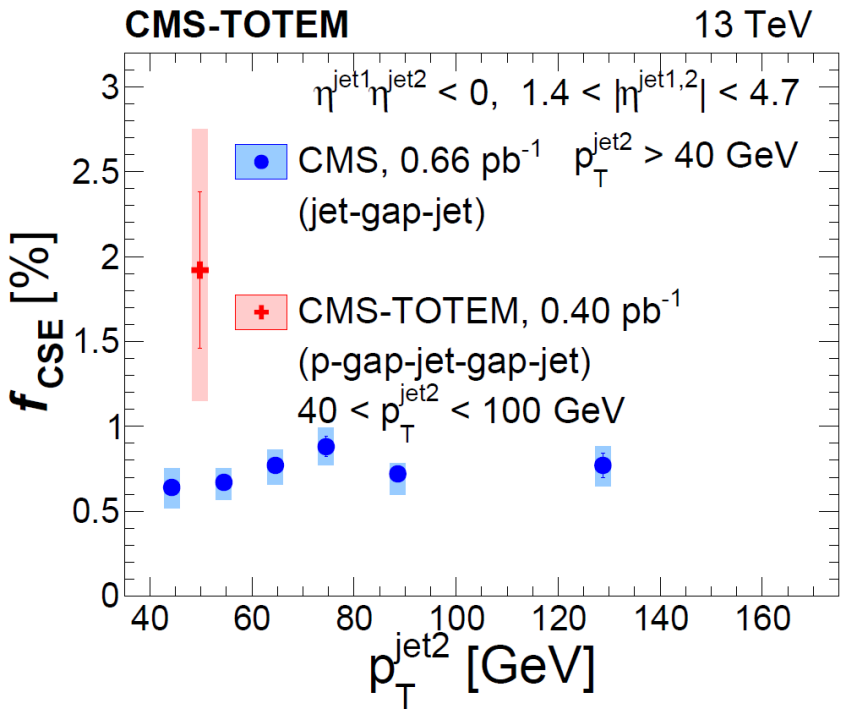

Single-diffractive (SD) dijet production

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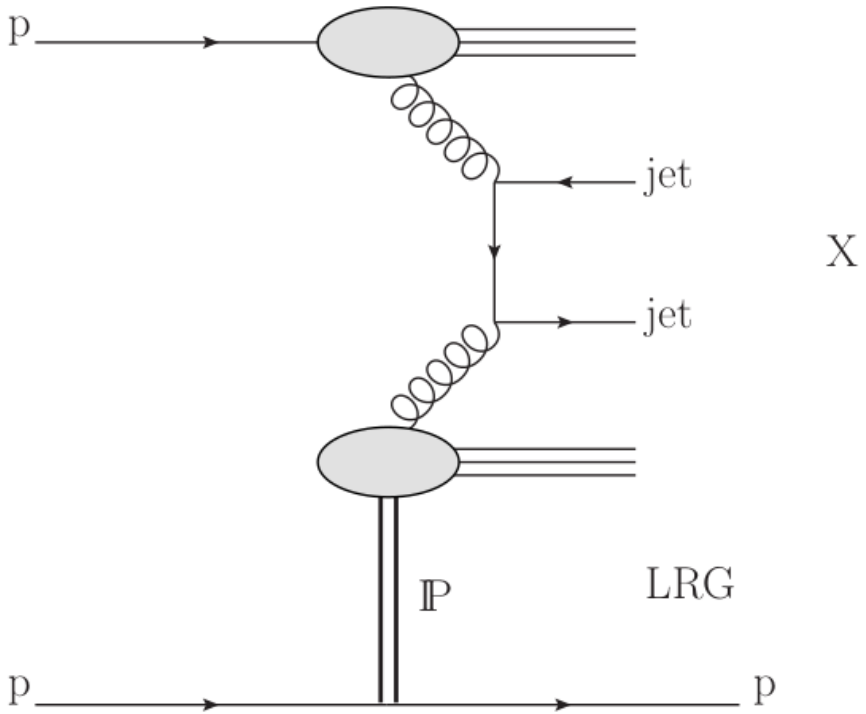

Schematic diagram of single-diffractive dijet production with hard gg → dijet scatteing process; the qq and gq initial states also contribute

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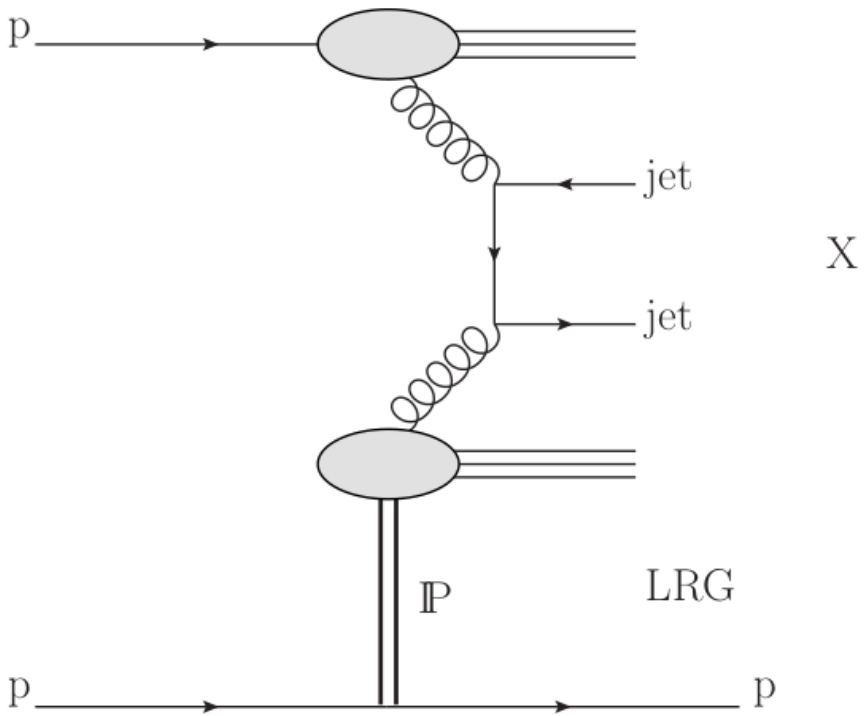

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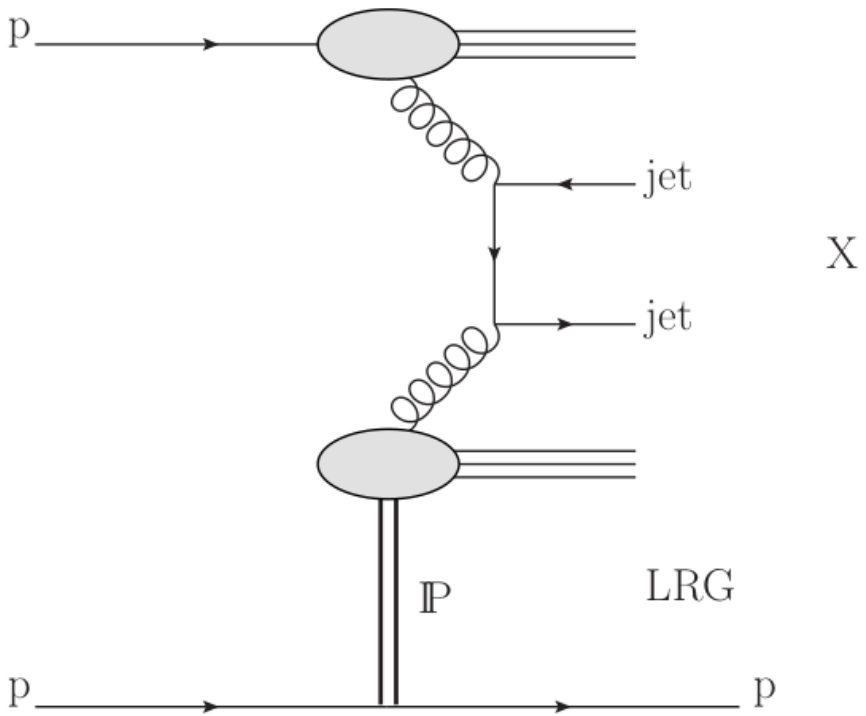

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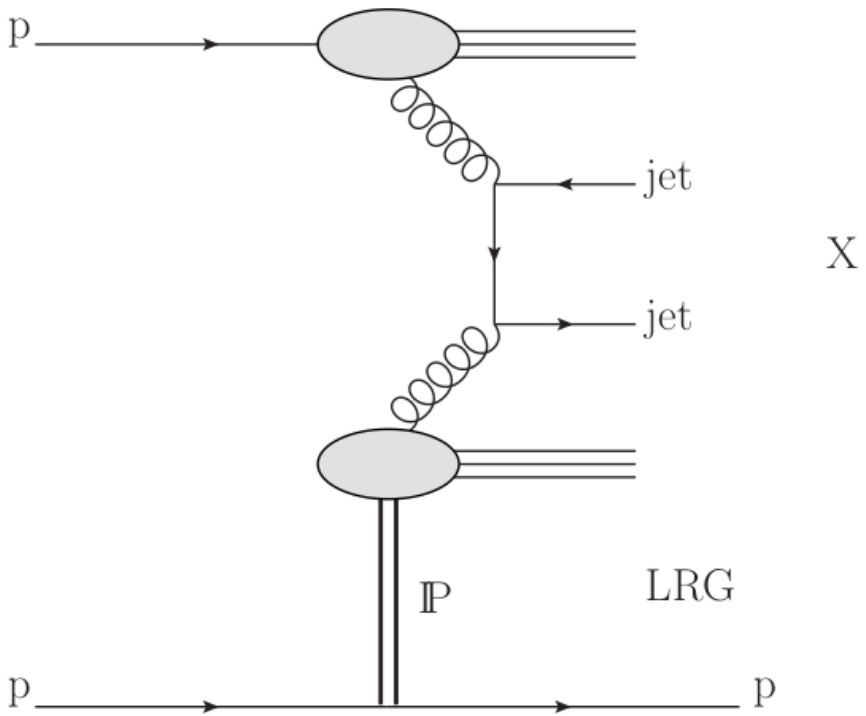

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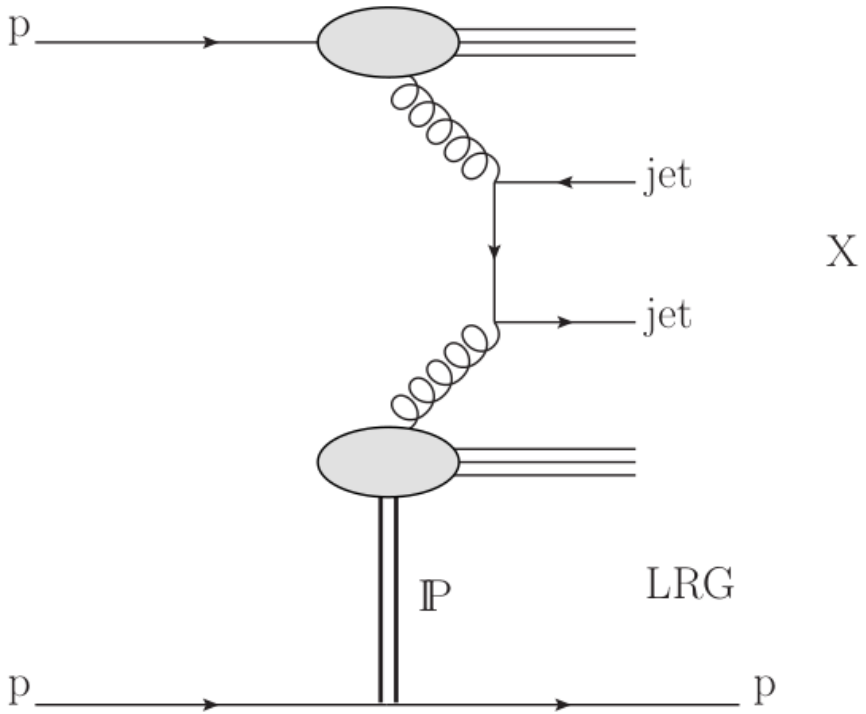

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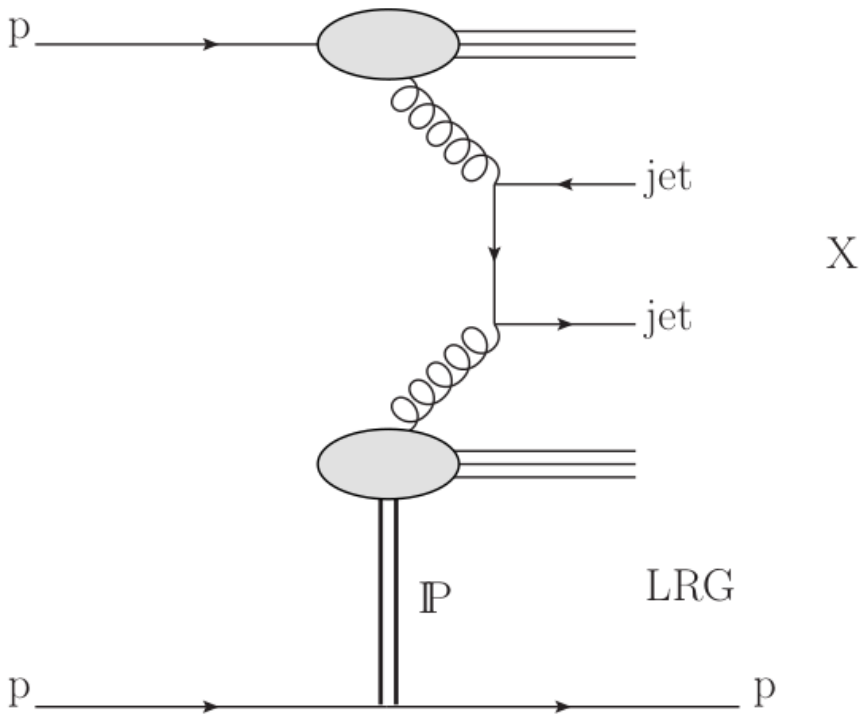

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Eur. Phys. J. C 80 (2020) 1164

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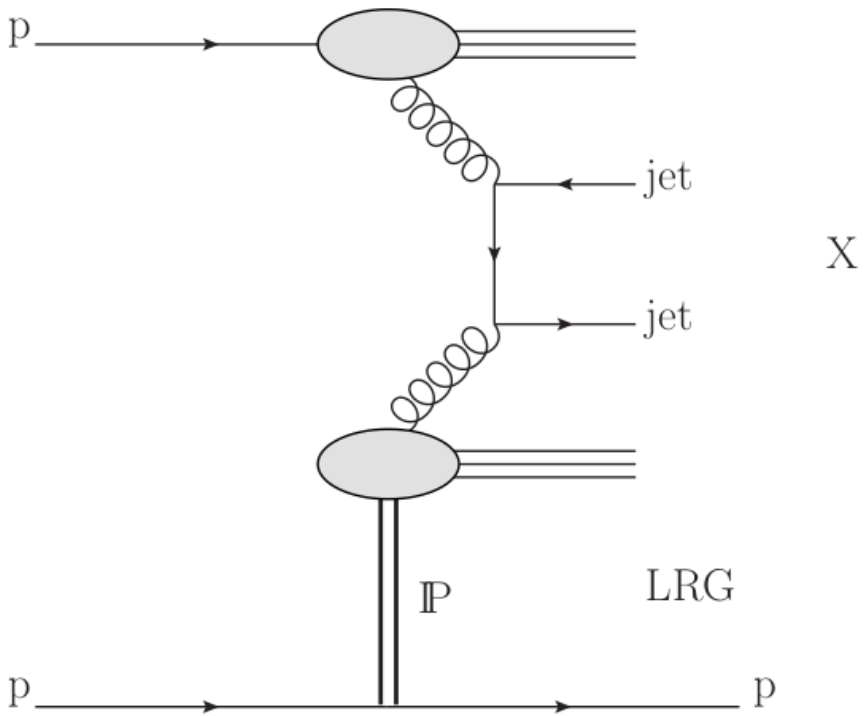

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hard diffractive processes are described in terms of a convolution of diffractive parton distribution functions (dPDFs, measured at HERA) and hard scattering cross sections (calculated in pQCD)

SD dijet results

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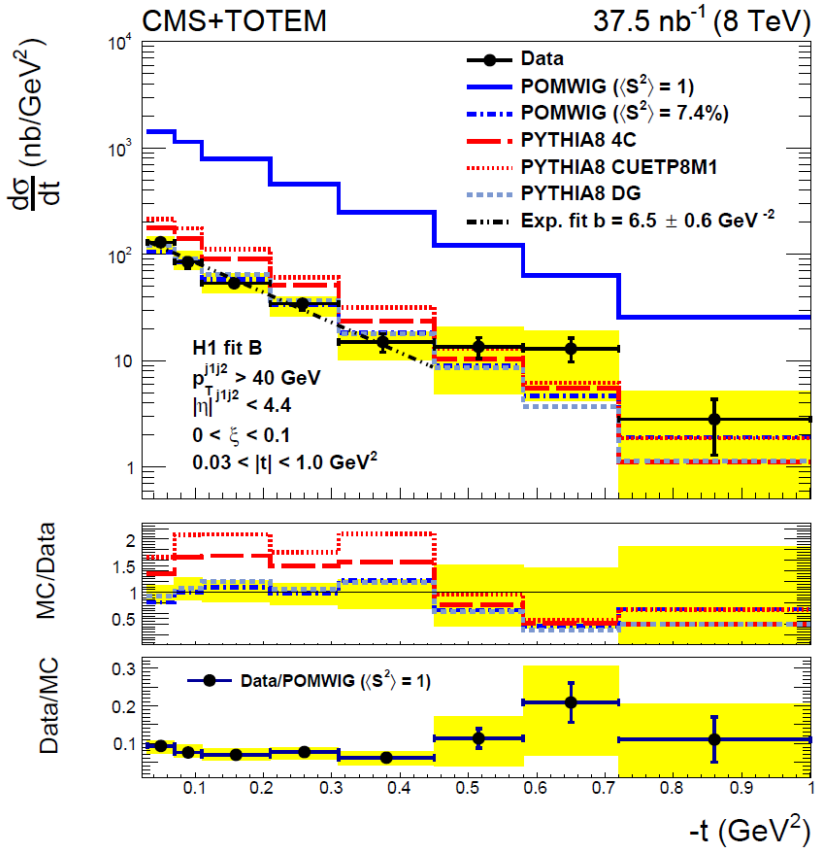

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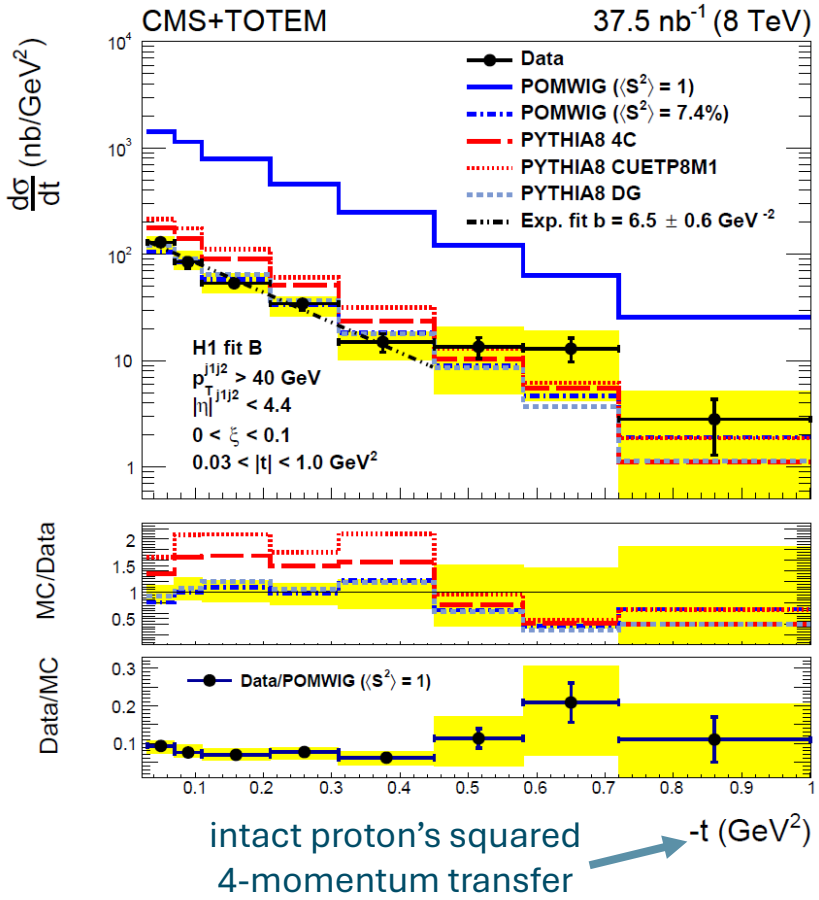

intact proton's squared 4-momentum transfer

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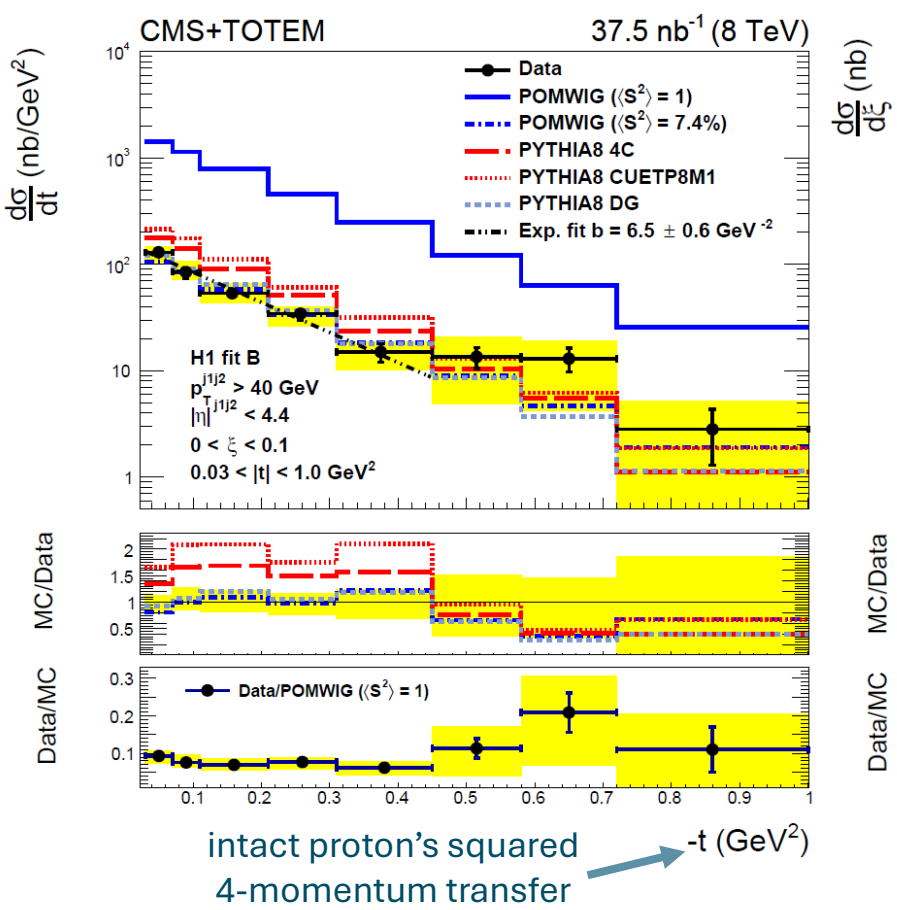

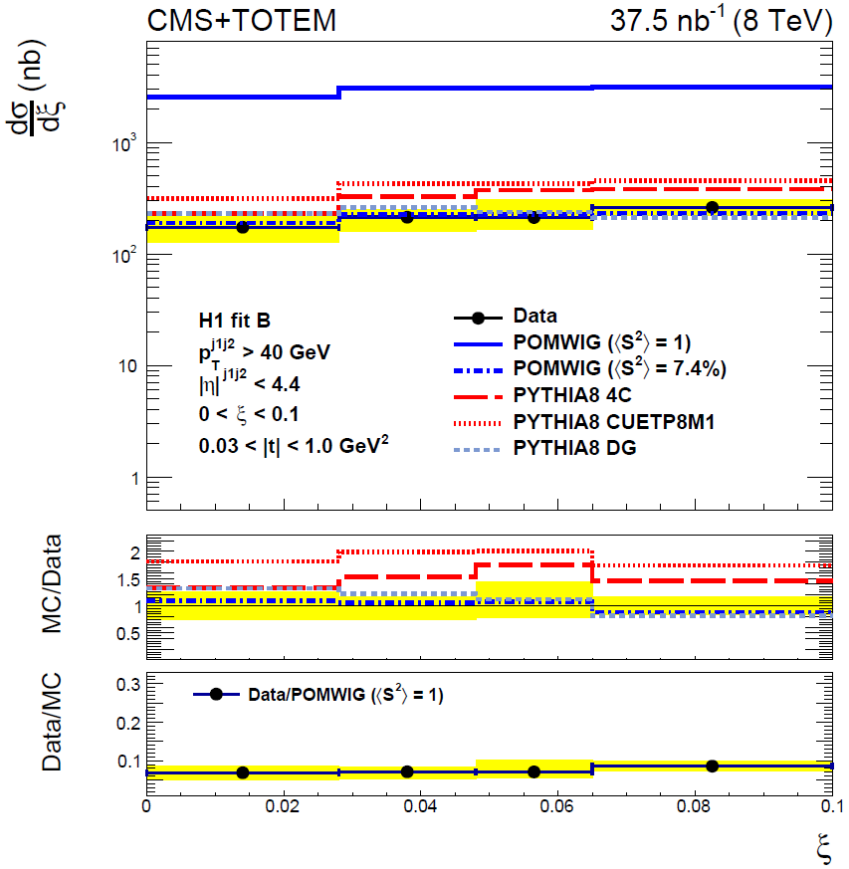

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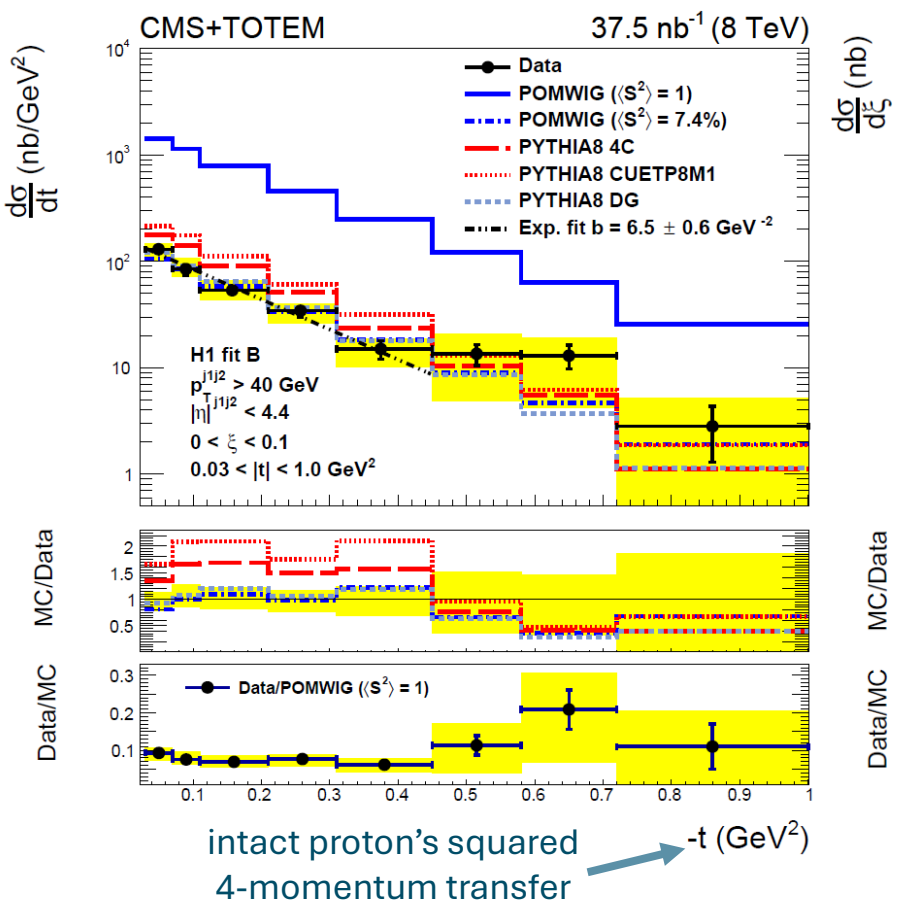

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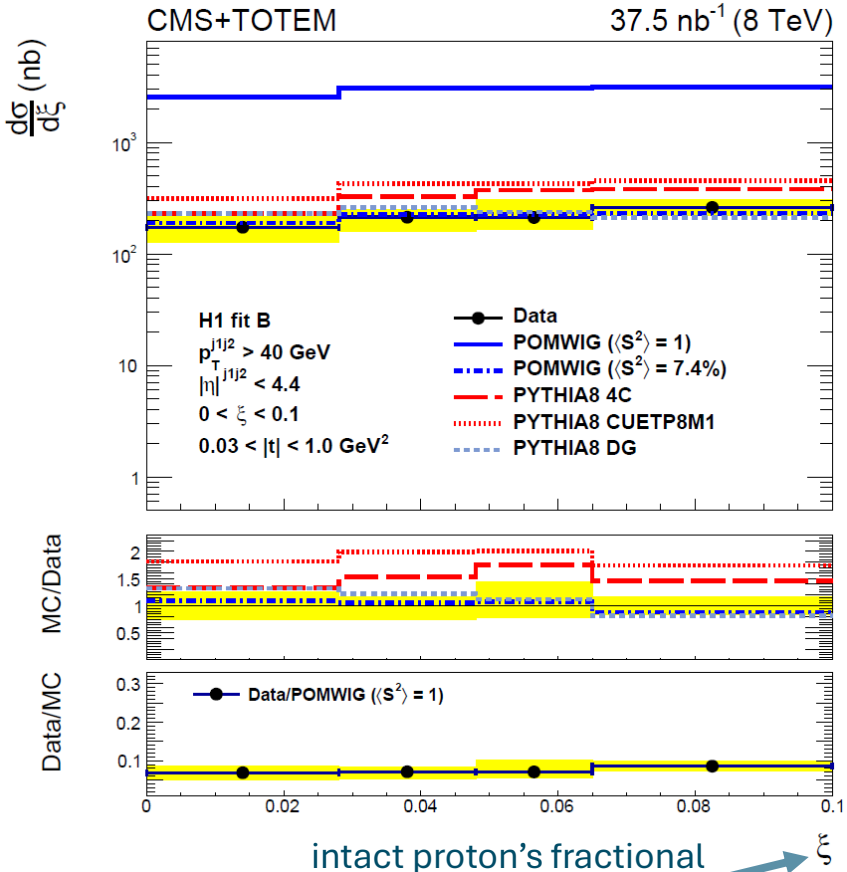

intact proton's fractional momentum loss

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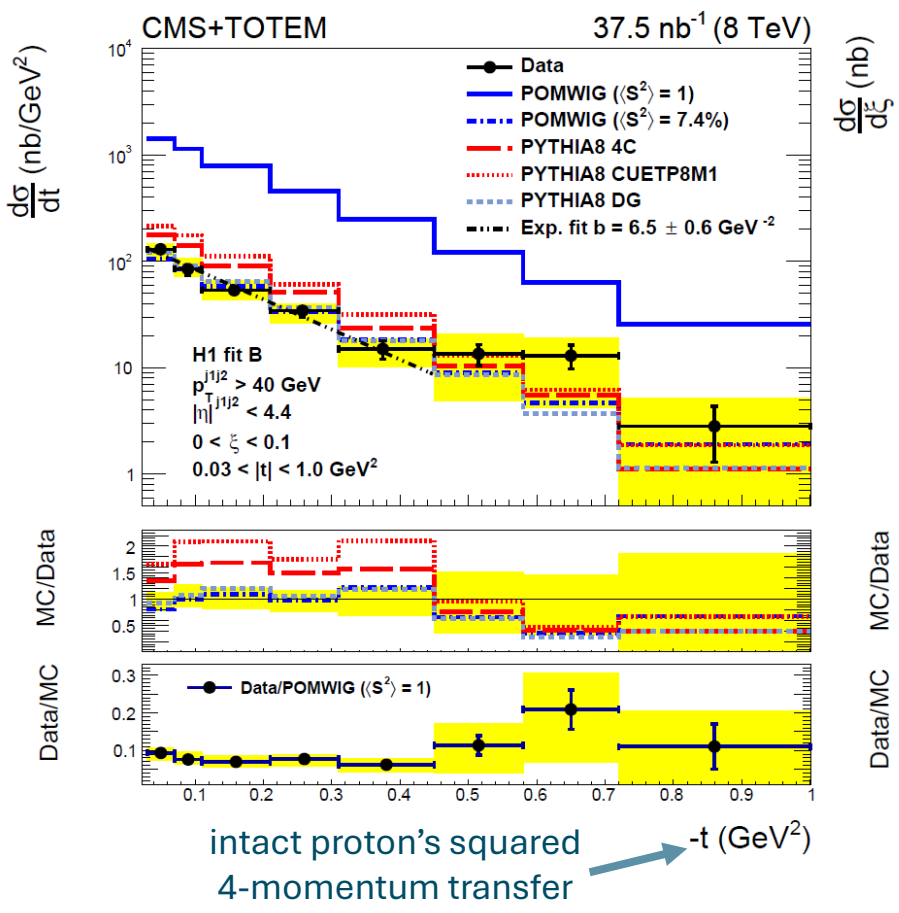

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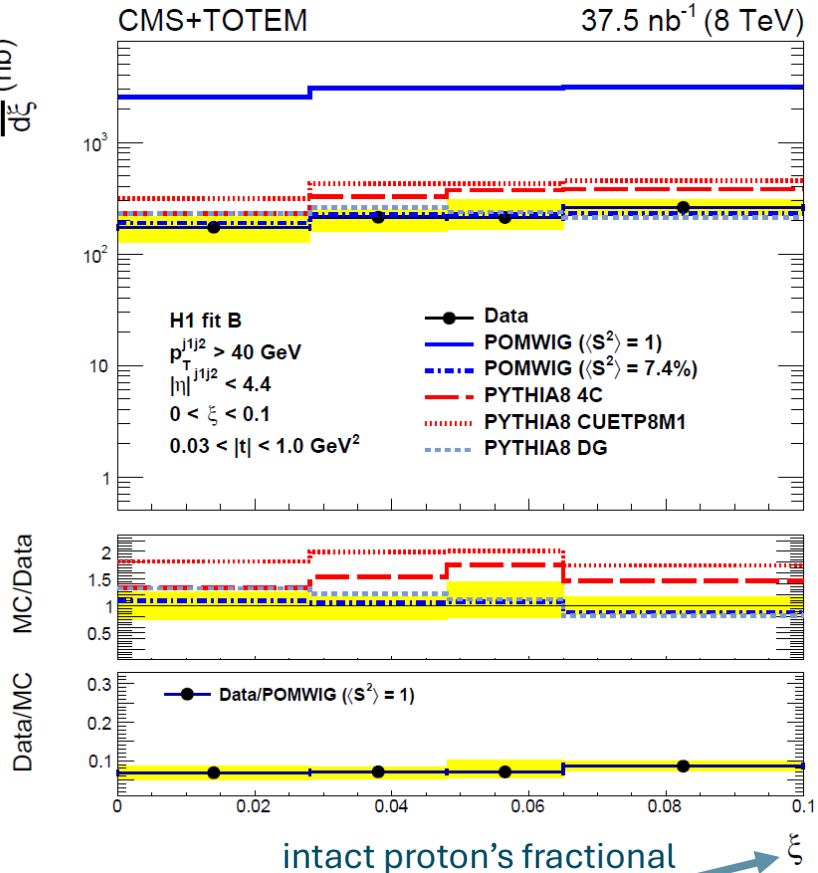

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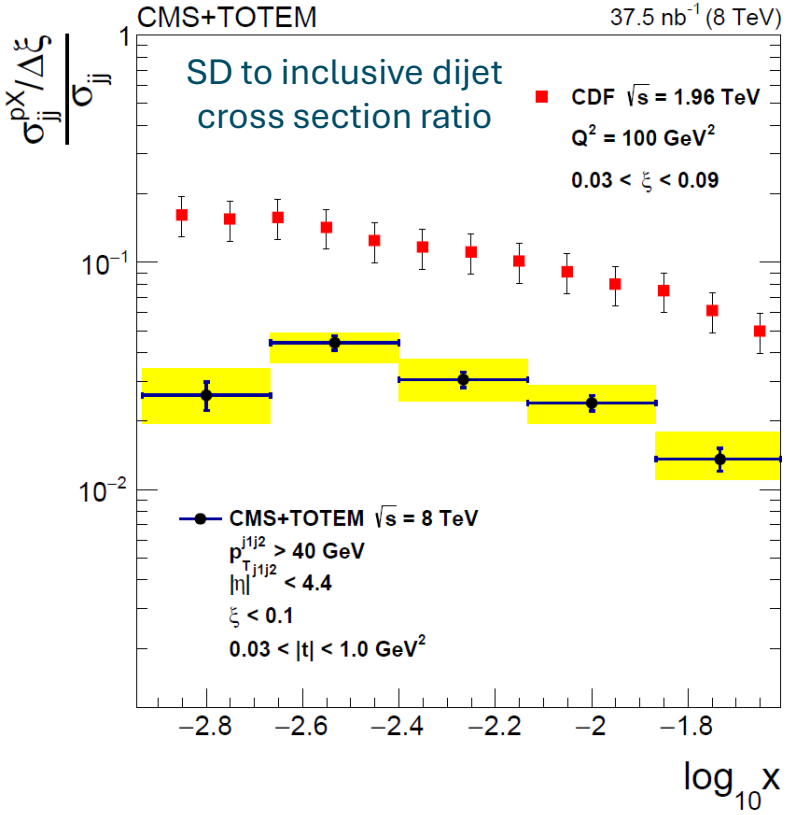

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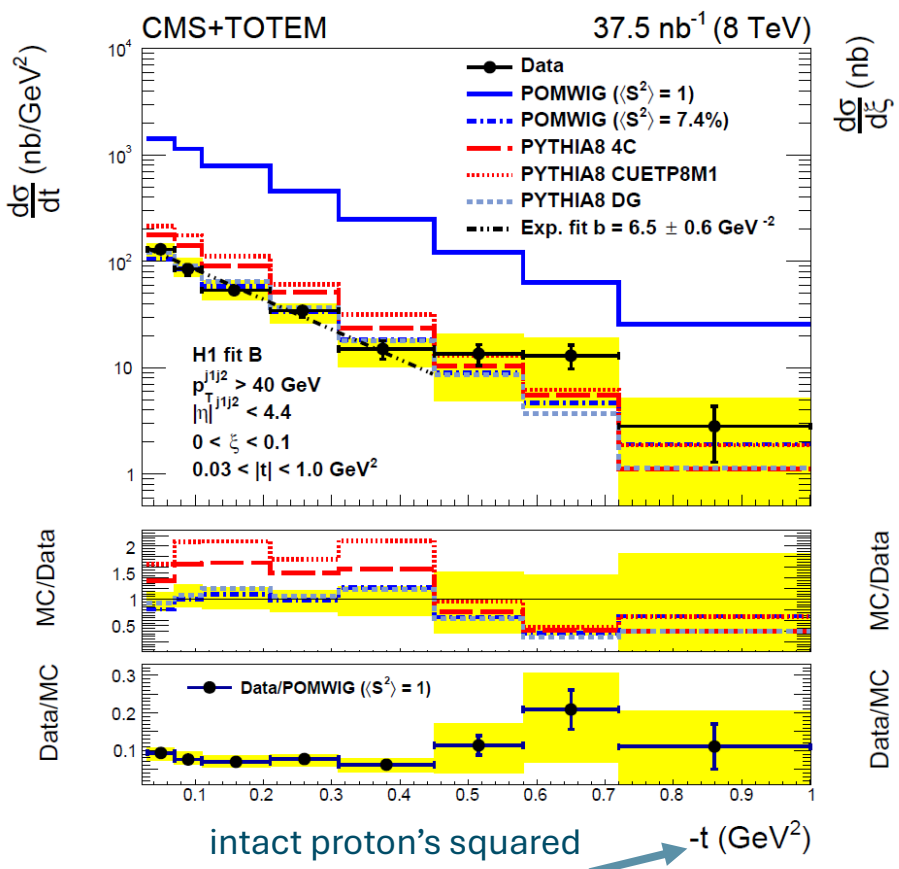

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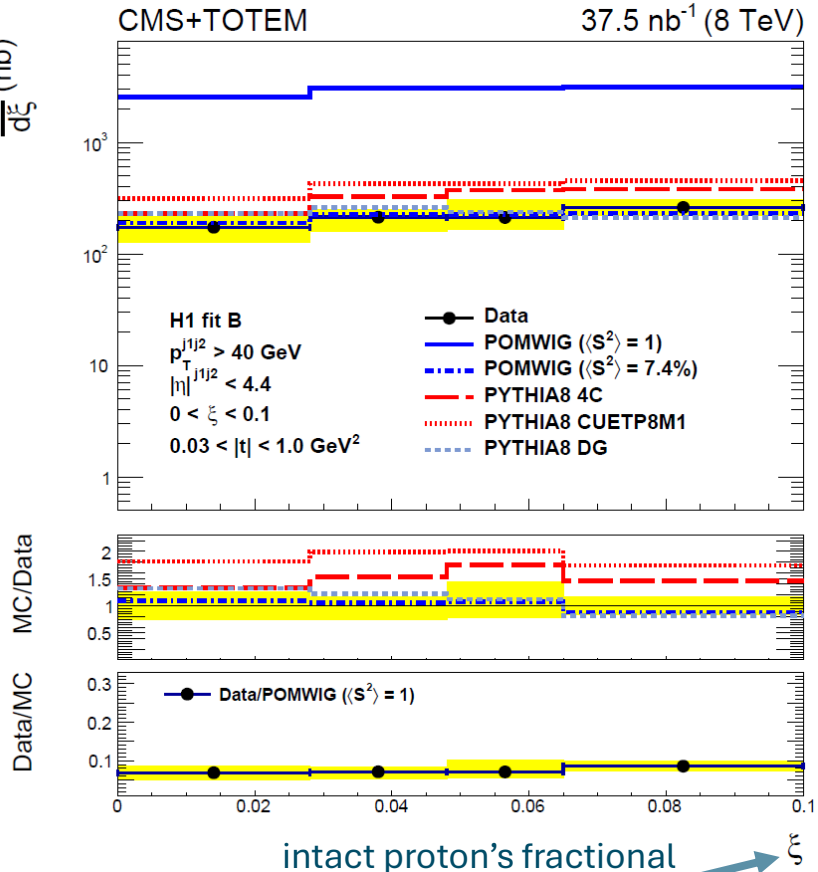

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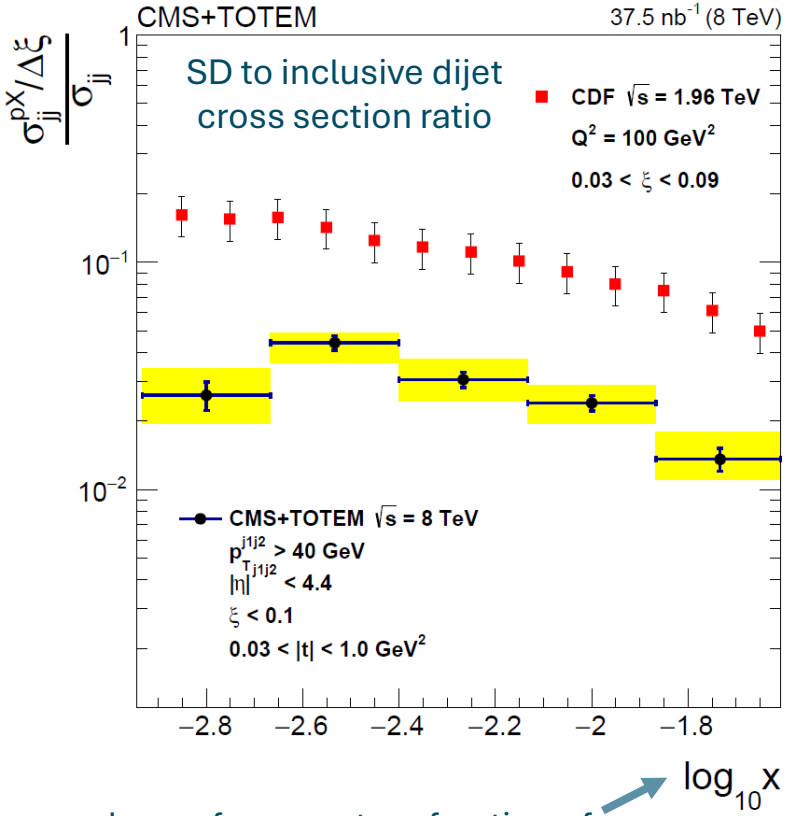

$\log_{10}$ of momentum fraction of partons initiating the hard scattering

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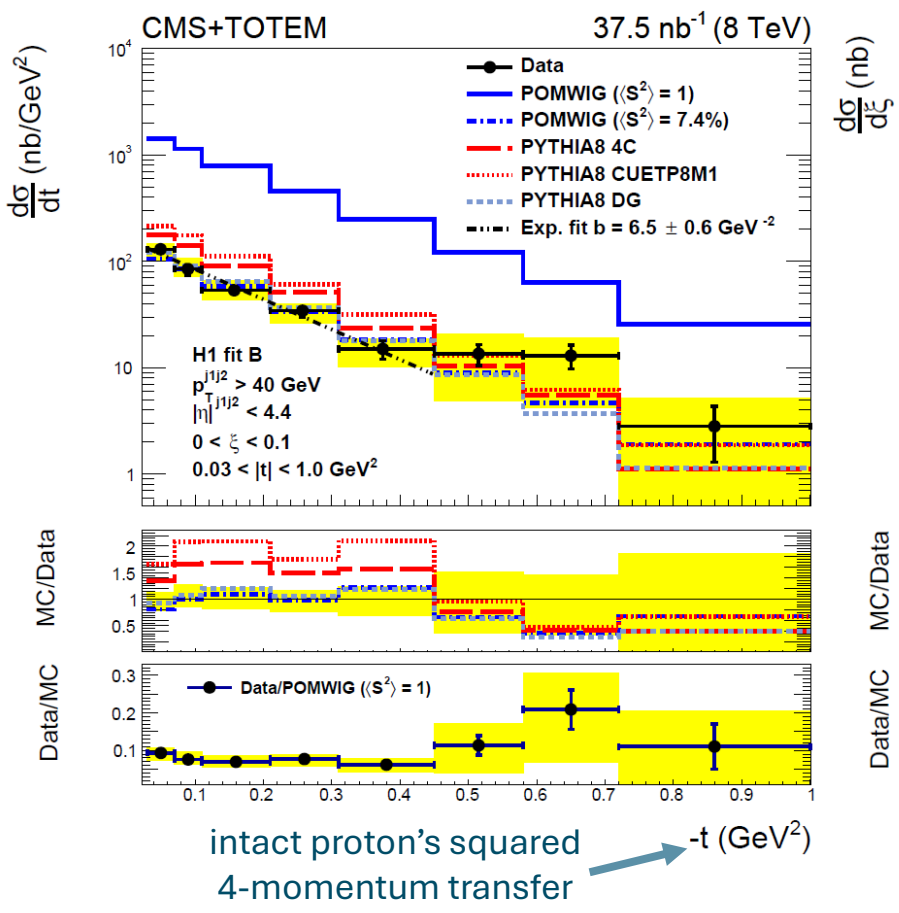

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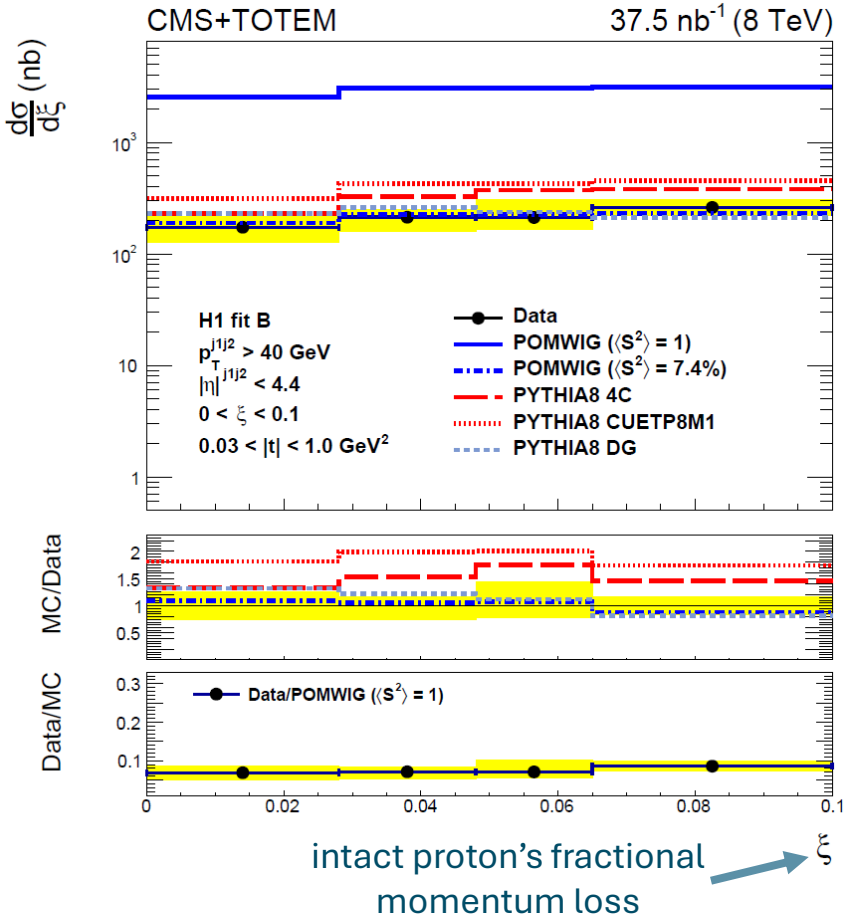

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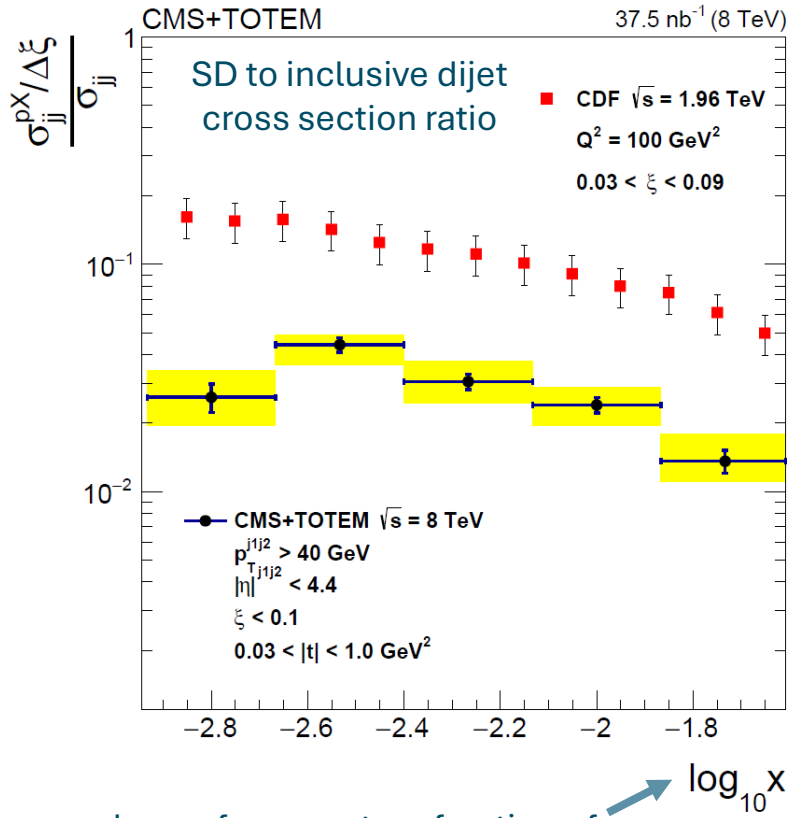

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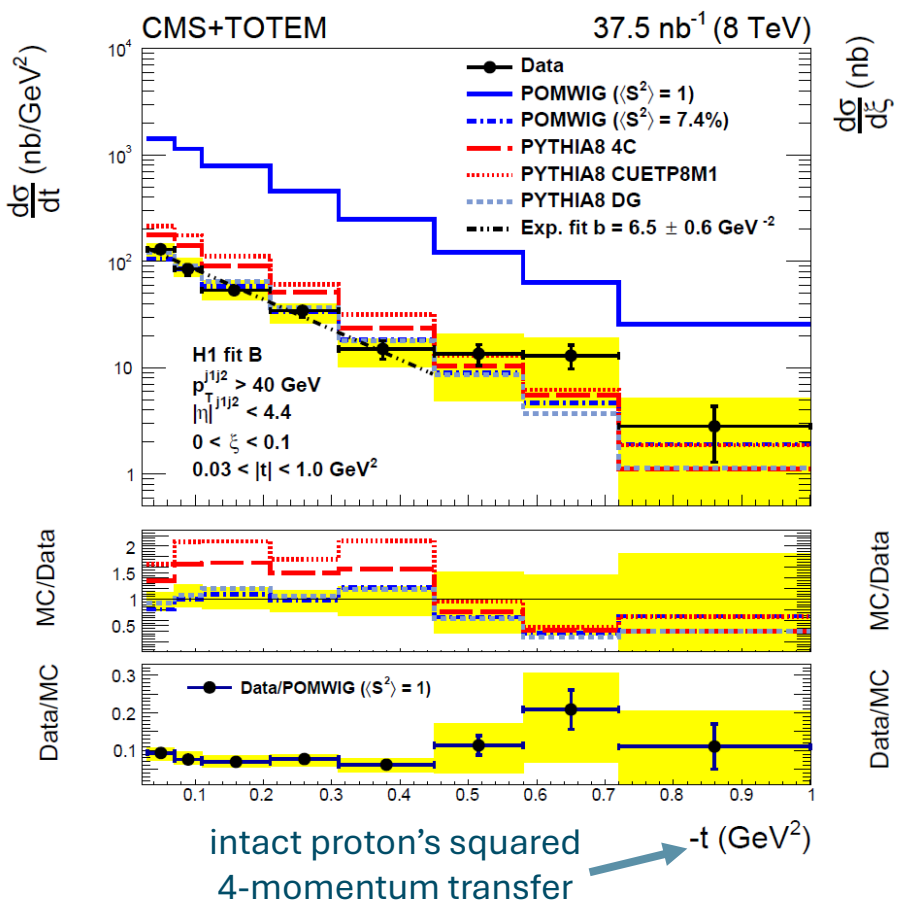

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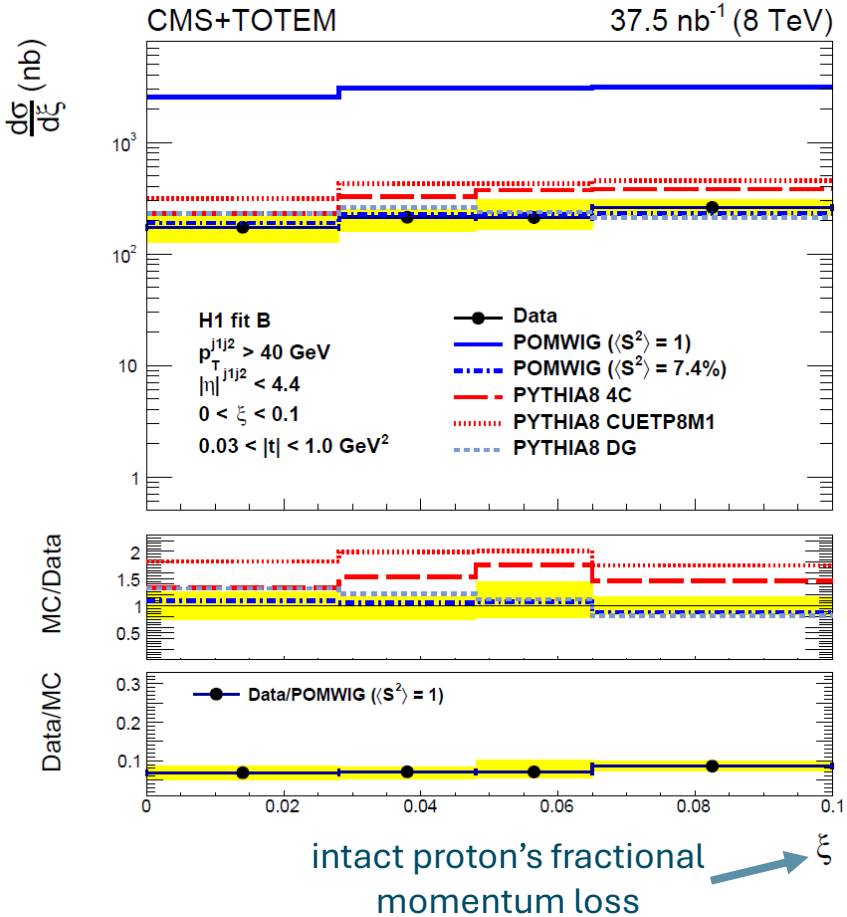

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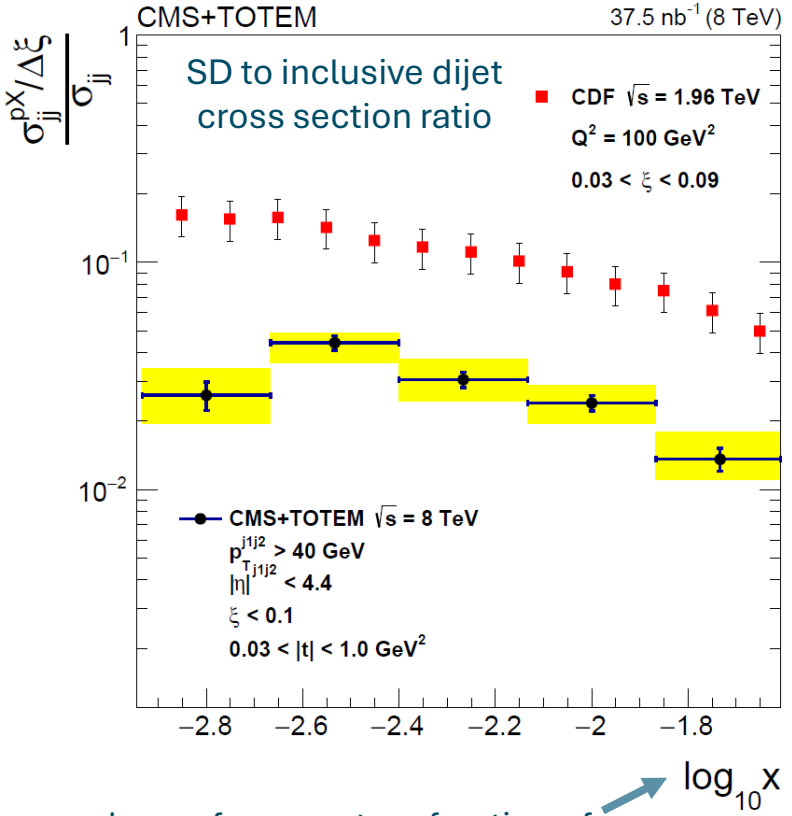

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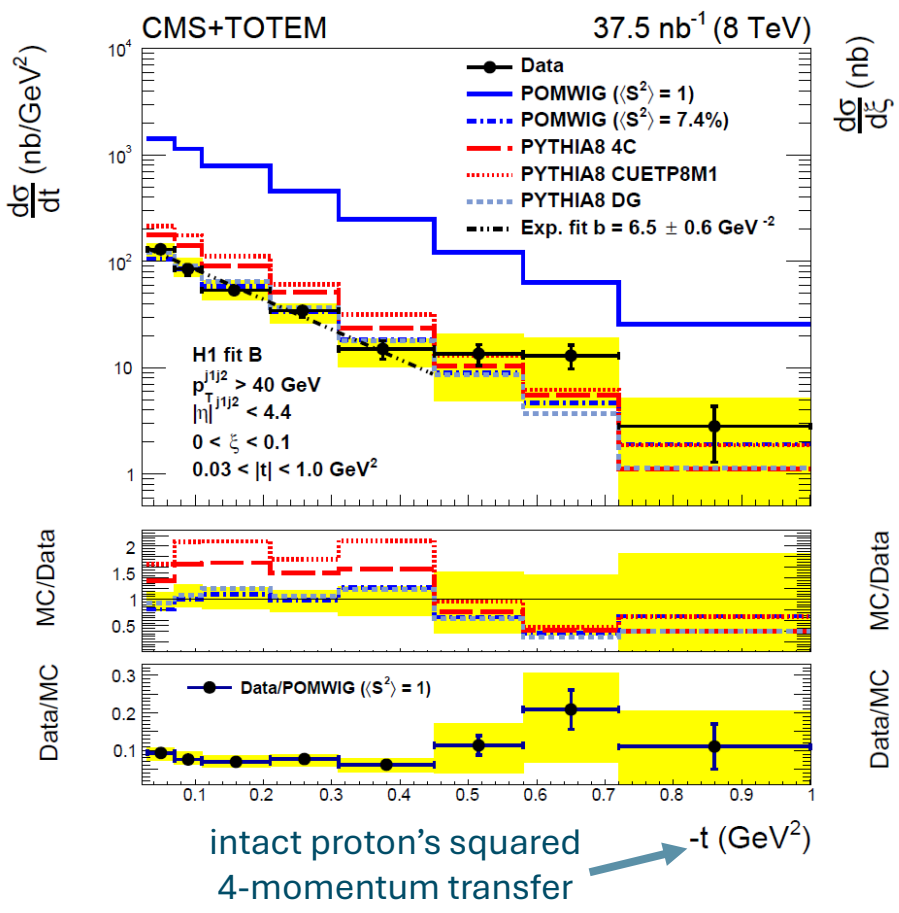

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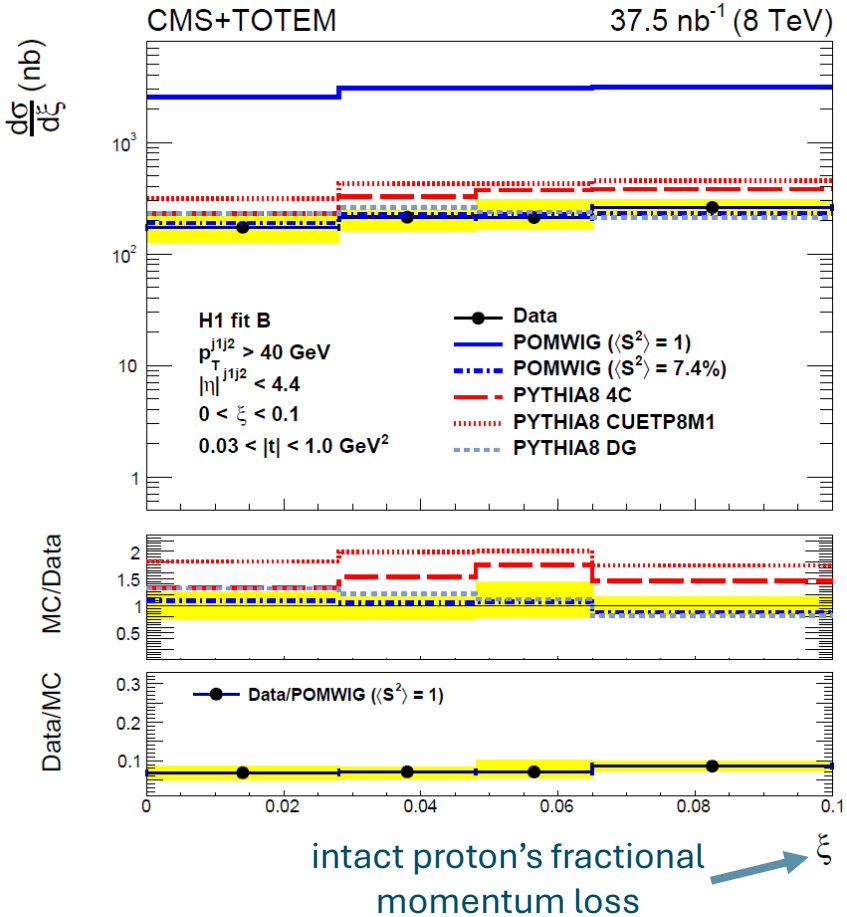

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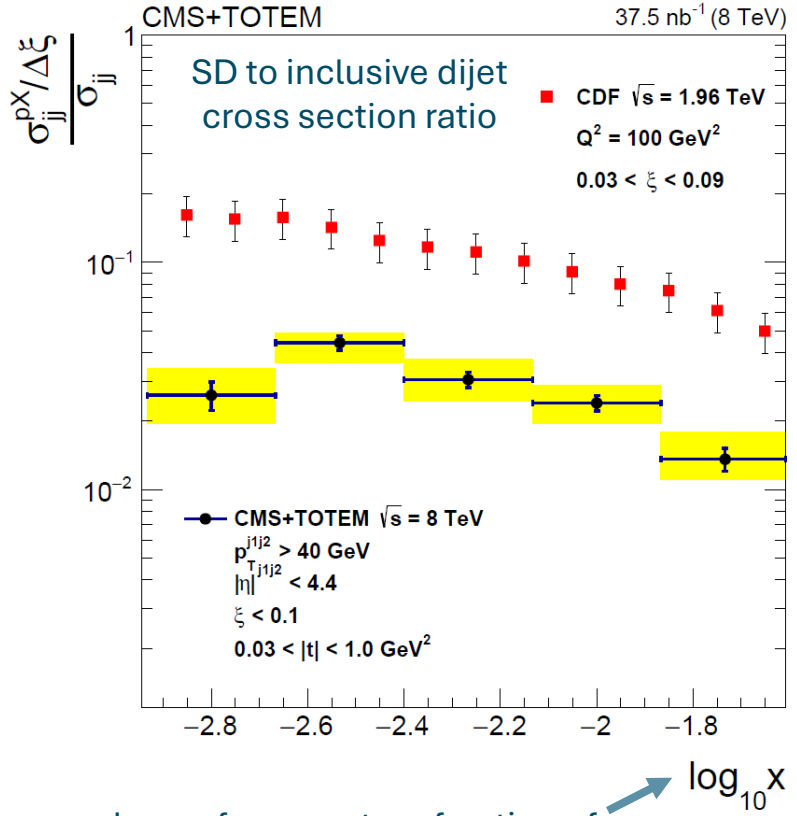

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as compared to the Tevatron CDF results, SD dijet production is further suppressed at the LHC

Summary

- various diffractive processes measured jointly by CMS and TOTEM in pp collisions
- first time observation of a parabolic minimum in the distribution of the azimuthal angle difference of the final state protons in central exclusive production;
- various physical parameters related to pomeron physics extracted/tuned
- good agreement between BFKL and jet-gap-jet measurements
- first measurement of hard diffraction with a measured intact proton at LHC

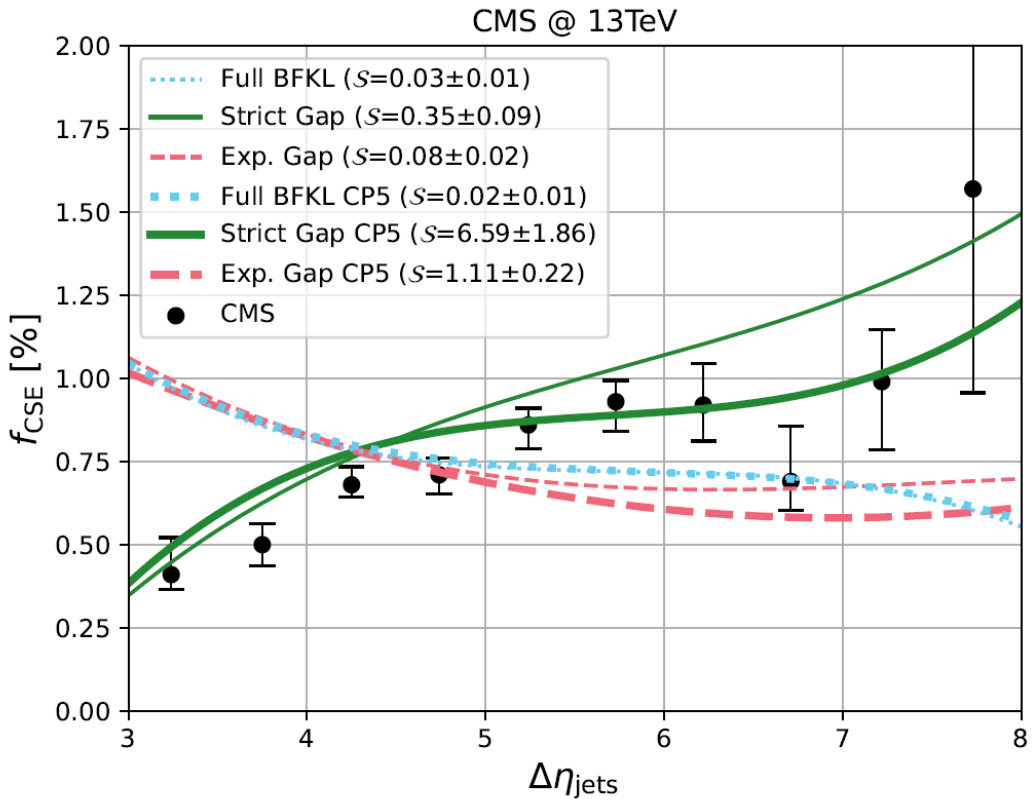
Thank you for your attention!

Supported by the
NKFIH grants K147557 and **2020-2.2.1-ED-2021-00181**; and
by the **Research Excellence Programme and the Flagship Research Groups Programme of the Hungarian University of Agriculture and Life Sciences**.

Backup slides

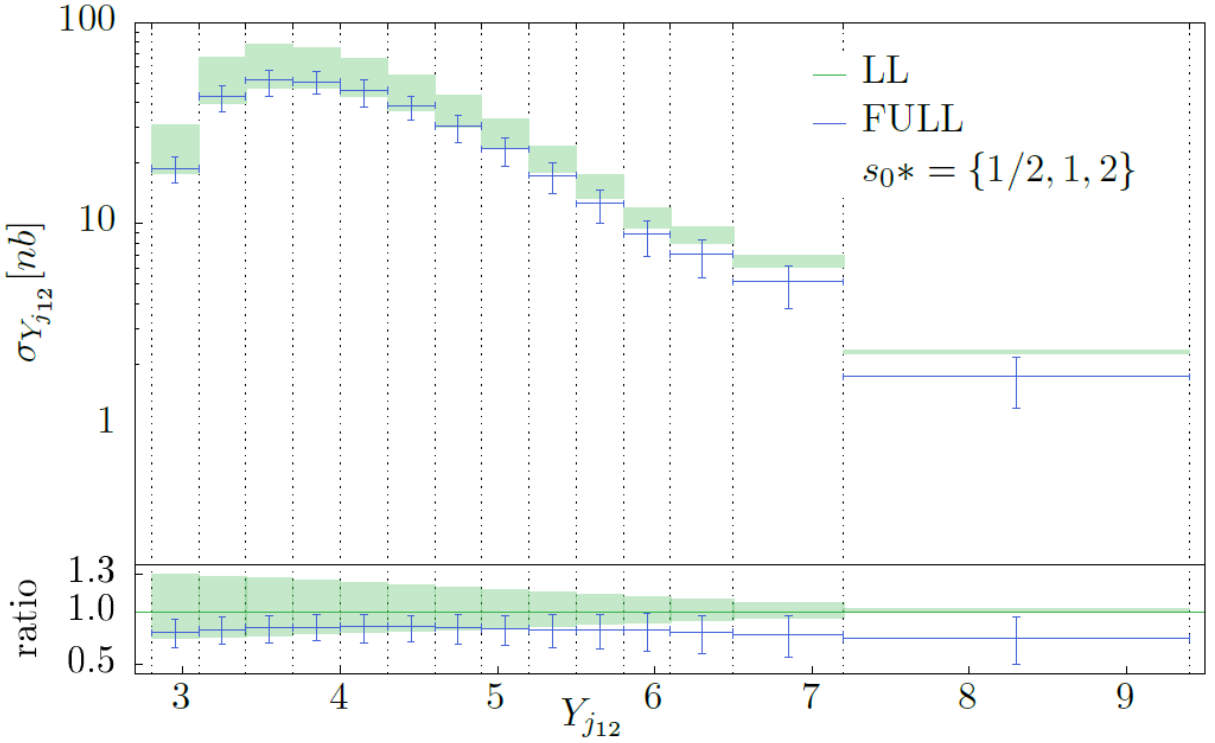
BFKL tests with jet-gap-jet events

Baldenegro, González Durán, Klasen, Royon, Salomon, JHEP 2022, 250



good agreement between BFKL and data but the gap definition is different in theory and data
(theory: no particles at all; experiment: no particles with p_T>200 MeV; explanation: too much ISR generated by PYTHIA)

Colferai, Deganutti, Raben, Royon, JHEP 2023, 91



the full BFKL NLL prediction for the jet-gap-jet cross section is below the BFKL LL estimate in the whole rapidity separation range (15-20% decrease)