MULTI PARTON SCATTERING

FROM REMARKABLE RESULTS TO AMBITIOUS PERSPECTIVES

SPEAKER: MARIA ELENA ASCIOTI | ON BEHALF OF THE CMS COLLABORATION

CMS
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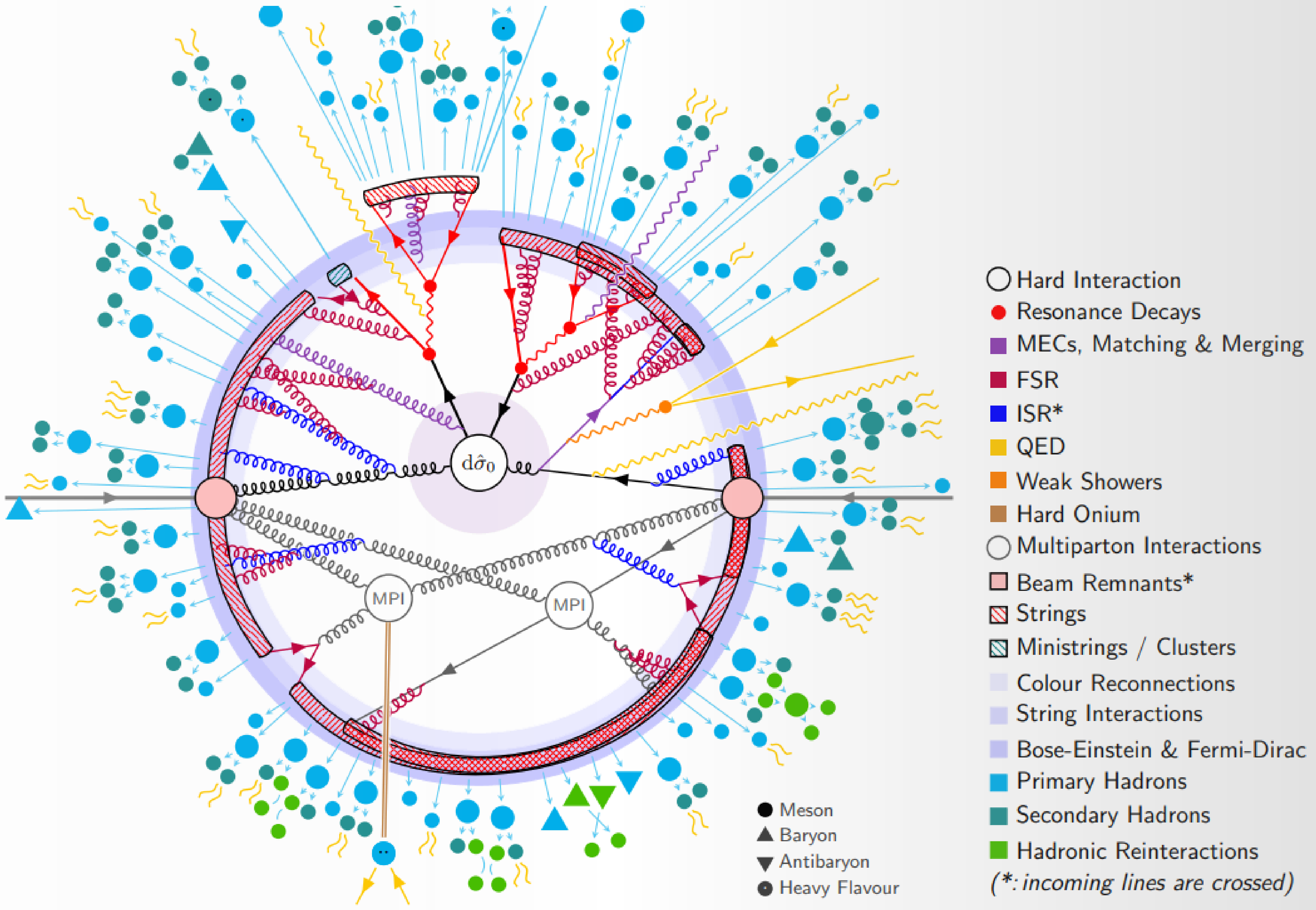
DIPARTIMENTO
DI FISICA E GEOLOGIA
DIPARTIMENTO DI ECCELLENZA
MUR 2023/2027
INFN
CERN

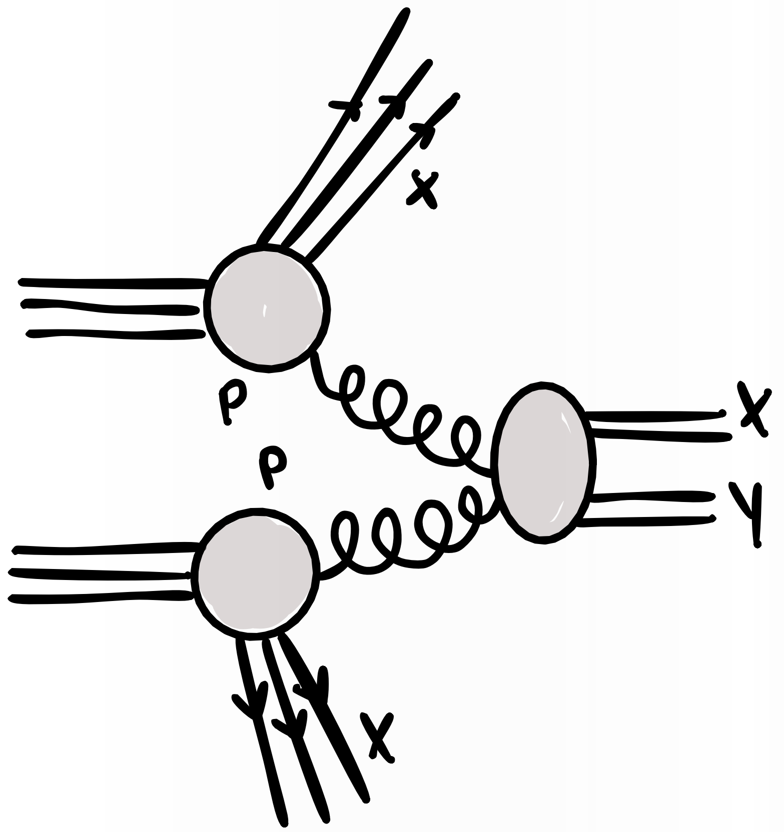


HTTPS://SCIPOST.ORG/SCIPOSTPHYSCODEB.8

Multi-parton interactions: two energy scales

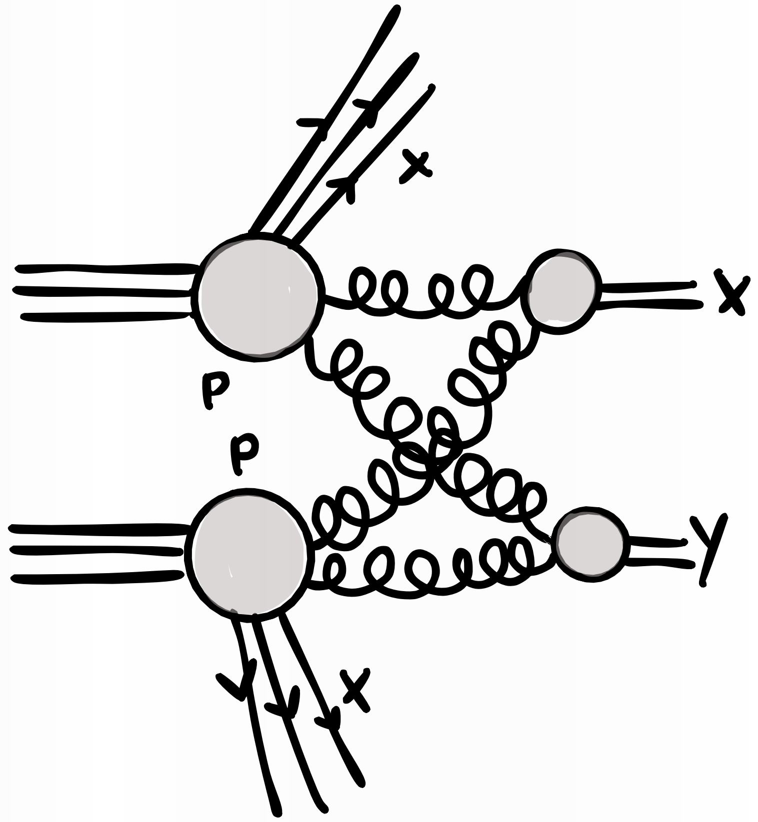
- The interaction between two protons can involve simultaneous interactions of multiple partons.
- Such interactions tend to increase with the center-of-mass energy due to the increase in partons.
- Multi-parton interactions (MPI):
  - **Soft regime (low pT):** secondary hadronic activity;
  - **Hard regime (high pT):** energetic scattering between multiple pairs of partons.

Multi Parton Scattering



Single-Parton Scattering (SPS):

Production of two or more particles through a **single interaction** between two partons. The **kinematics are correlated**, and additional gluon emissions are neglected.



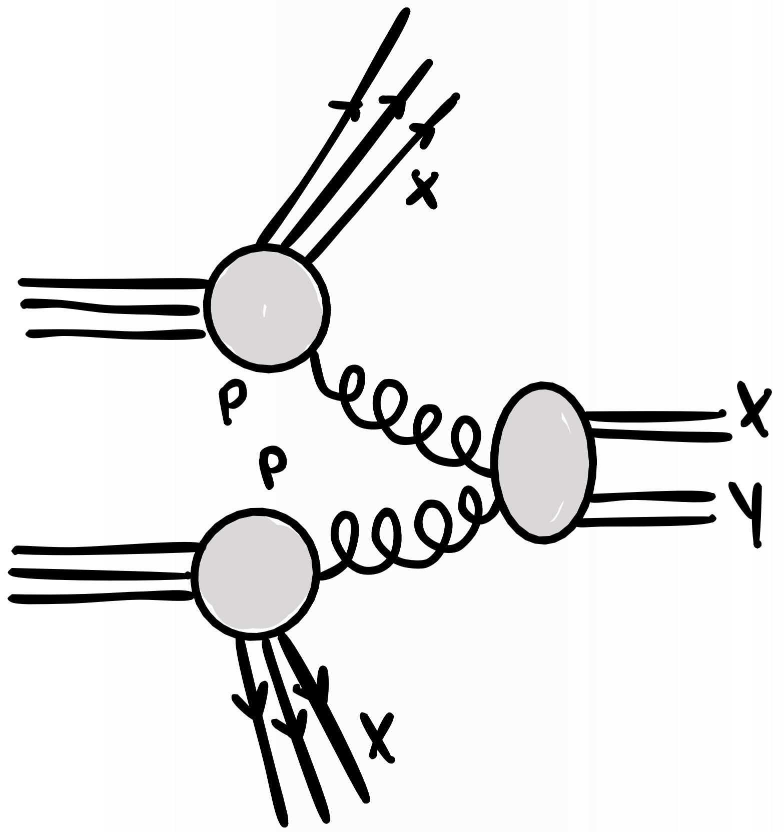
Double-Parton Scattering (DPS):

Production of two particles through a **double interaction** between two partons belonging to the same protons. It is assumed that the **scatterings are uncorrelated.**

Described by the **pocket formula**:

$$\sigma_{\text{DPS}} = \frac{1}{m!} \frac{\sigma_{\text{SPS}}^{pp\to A} \sigma_{\text{SPS}}^{pp\to B}}{\sigma_{\text{eff}}}$$

Multi Parton Scattering



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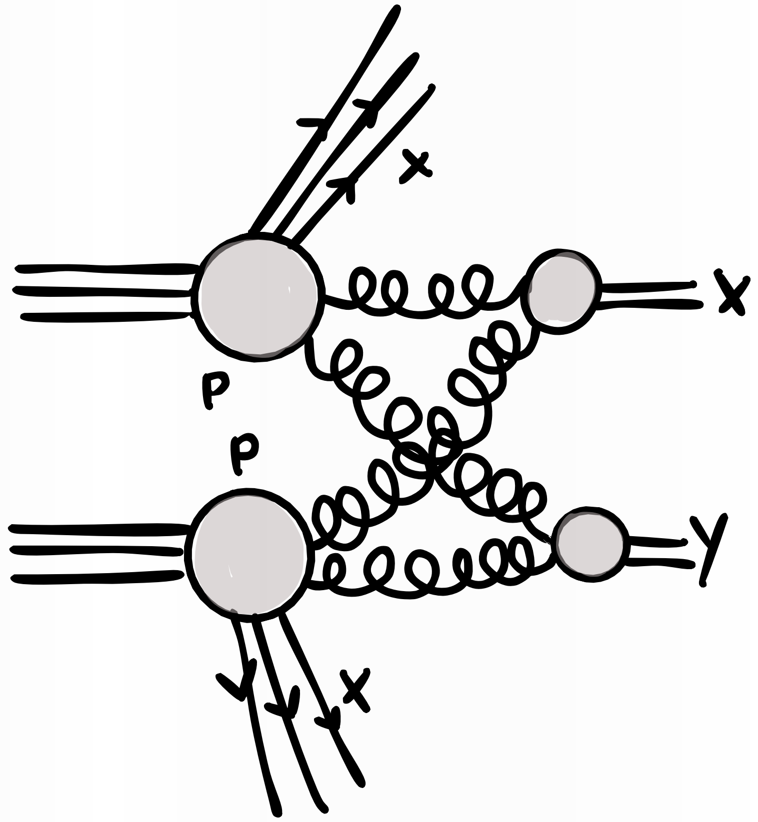

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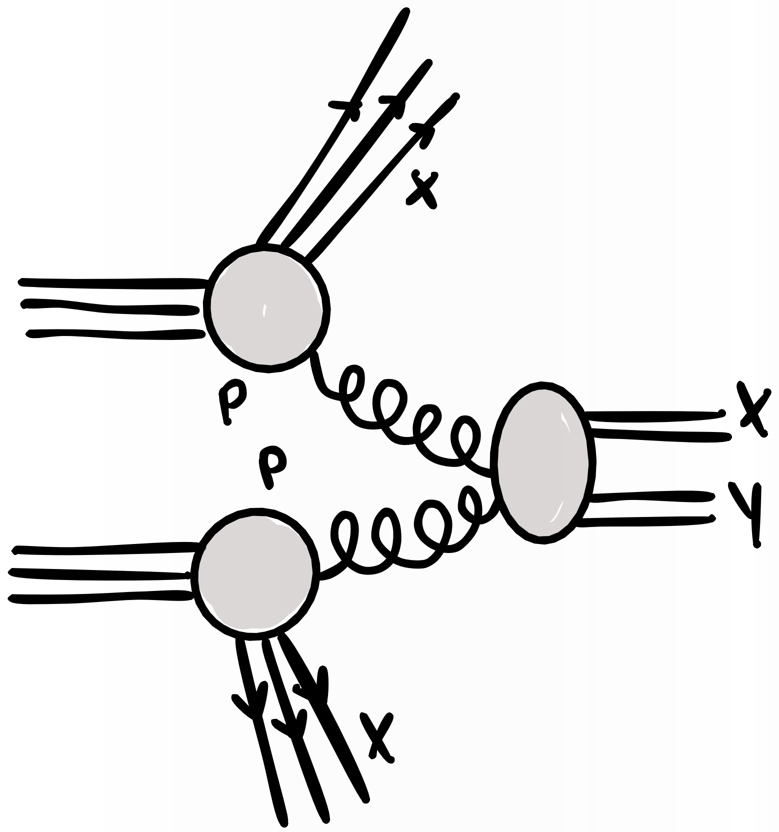
COMBINATORIAL FACTOR

Multi Parton Scattering



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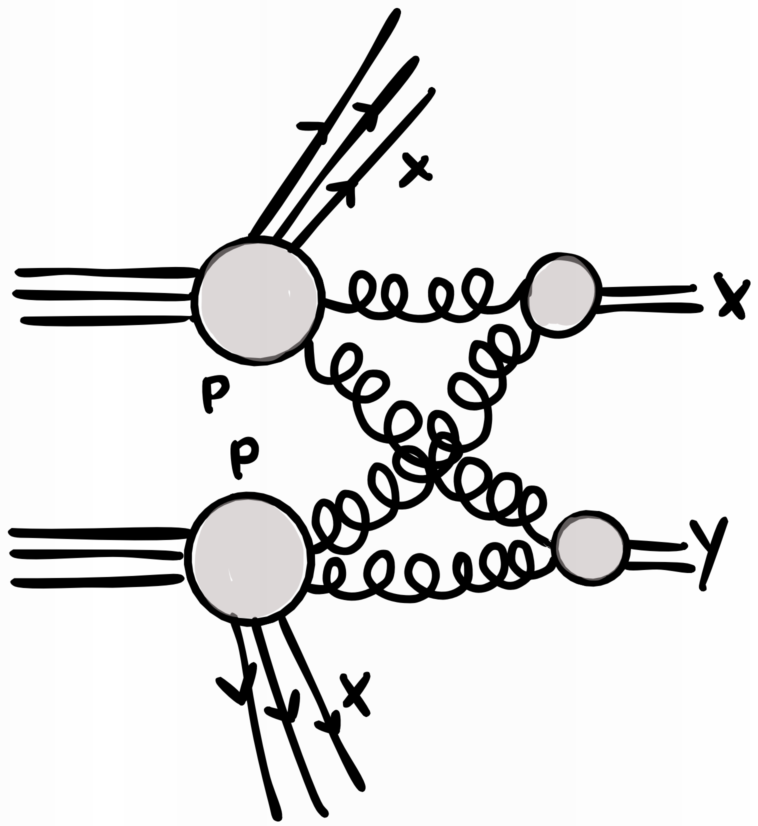

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SINGLE CROSS SECTIONS

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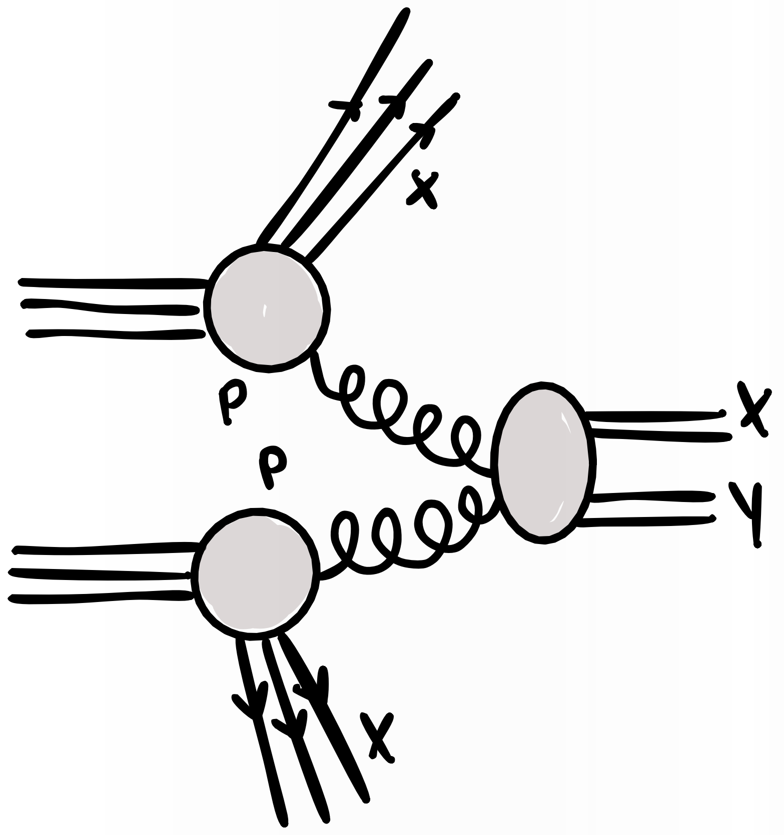

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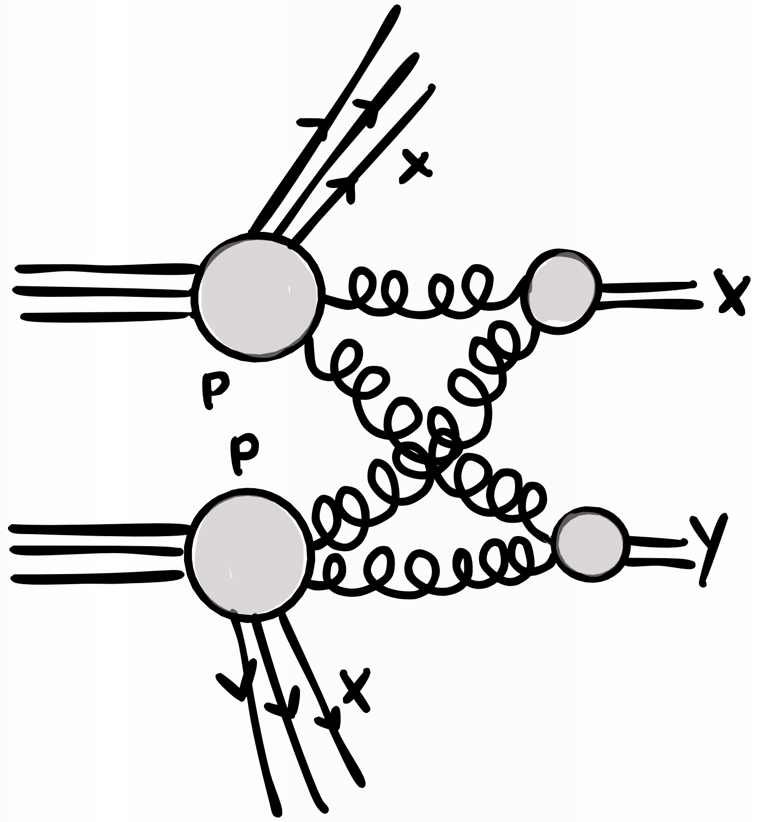

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EFFECTIVE CROSS SECTION

These last few years

2020

Physics Letters B 808 (2020) 135578

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

ELSEVIER

Measurement of the Υ(1S) pair production cross section and search for resonances decaying to $\Upsilon(1S)\mu^+\mu^-$ in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration *

CERN, Switzerland

2023

PHYSICAL REVIEW LETTERS **131,** 091803 (2023)

Observation of Same-Sign *WW* Production from Double Parton Scattering in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV

A. Tumasyan *et al.**
(CMS Collaboration)

(Received 6 June 2022; accepted 18 August 2022; published 1 September 2023)

2023

nature physics

Article

https://doi.org/10.1038/s41567-022-01838-y

Observation of triple J/ψ meson production in proton-proton collisions

2024

PHYSICAL REVIEW LETTERS **132,** 111901 (2024)

Editors' Suggestion

New Structures in the $J/\psi J/\psi$ Mass Spectrum in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV

A. Hayrapetyan *et al.**
(CMS Collaboration)

(Received 12 June 2023; revised 7 December 2023; accepted 31 January 2024; published 15 March 2024)

OBSERVATION OF SAME-SIGN WW PRODUCTION FROM DOUBLE PARTON SCATTERING

Golden channel for studying **Double Parton Scattering (DPS):**

- The experimental signature of this final state is **extremely clean**;
- The contribution from **Single Parton Scattering** (SPS) is strongly **suppressed.**

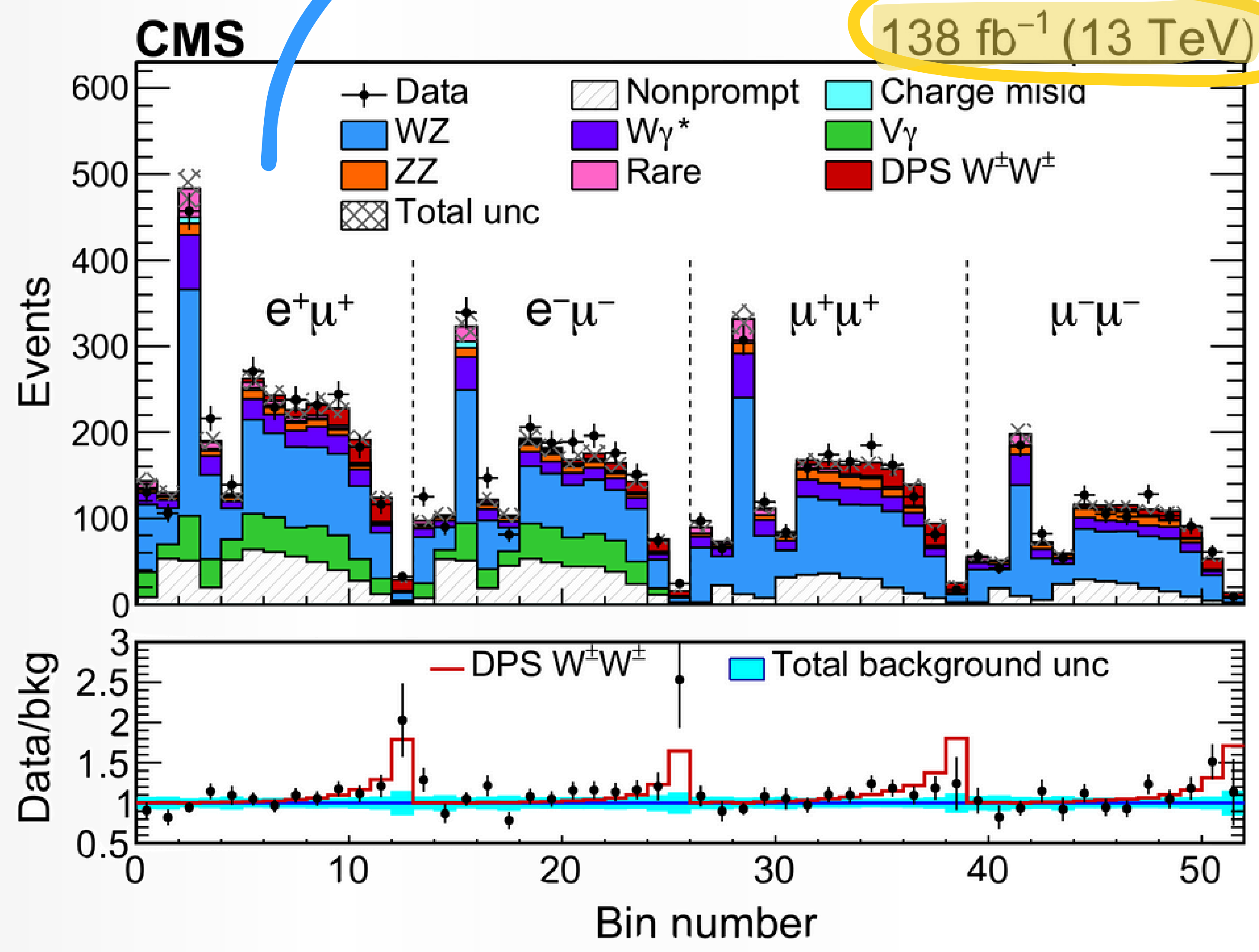
The **exclusive cross-section** is:

$$\sigma_{\text{exc}} = (6.28 \pm 0.81(\text{stat}) \pm 0.69(\text{sys}) \pm 0.37(\text{model}))\text{fb}$$

Effective cross-section for DPS was extracted, equal to:

$$\sigma_{\text{eff}} = (12.2^{+2.9}_{-2.2})\text{mb}$$

4 DIFFERENT CHANNELS ANALYZED



A STANDARD DEVIATION OF 6.2 SIGMA FROM THE ONLY- BACKGROUND HYPOTHESIS

HTTPS://JOURNALS.APS.ORG/PRL/ABSTRACT/10.1103/PHYSREVLETT.131.091803

MEASUREMENT OF PAIR PRODUCTION: Υ(1S)Υ(1S) AND Υ(1S) + $\mu\mu$

The **kinematics** of the **DPS** process **is different compared to the SPS:** greater |Δy(Υ(1S), Υ(1S))| between the mesons and a greater invariant mass.

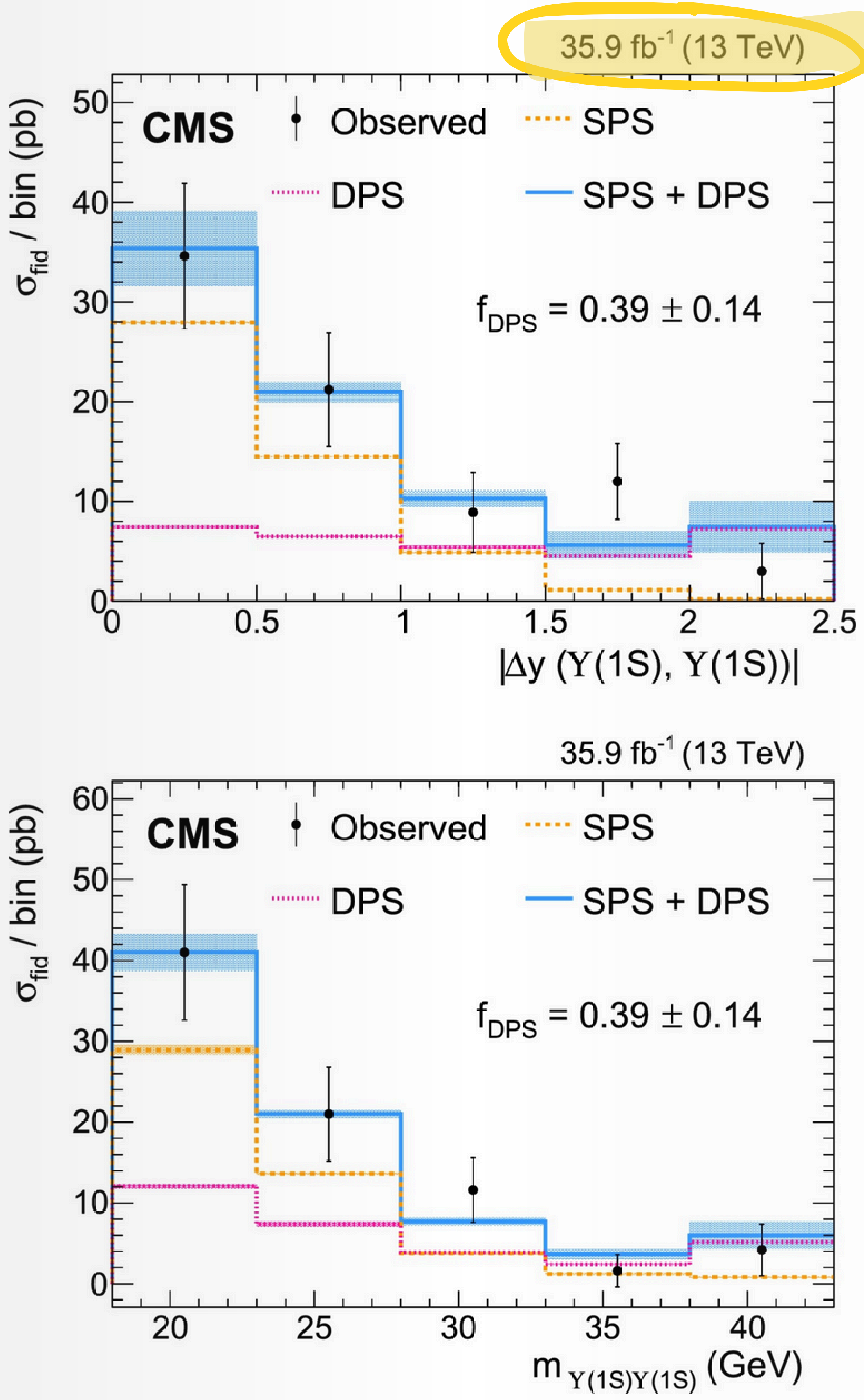
By calculating the differential cross sections, we can obtain the **fraction of DPS events** as:

$$f_{DPS} = \frac{\sigma_{fid}^{DPS}}{\sigma_{fid}^{SPS}+\sigma_{fid}^{DPS}}$$

The results obtained are:

$$f_{DPS}(|\Delta(Y(1S),Y(1S))|) = 0.39 \pm 0.14$$

$$f_{DPS}(m(Y(1S),Y(1S)) = 0.27 \pm 0.22$$



NB: IN THE DPS TWO THE PP SCATTERING ARE UNCORRELATED, THIS CAN BE SEEN IN DIFFERENT KINEMATICS CORRELATIONS OF THE FINAL OBJECT

HTTPS://WWW.SCIENCEDIRECT.COM/SCIENCE/ARTICLE/PII/S0370269320303828

NEW STRUCTURES IN THE DOUBLE J/Ψ PRODUCTION

In the past, CMS published an analysis of the **di-J/Ψ channel** that examines the data collected **during Run 1** with a centre-of-mass energy of 7 TeV.

Even in this case, the importance of including the **DPS contribution was evident**.

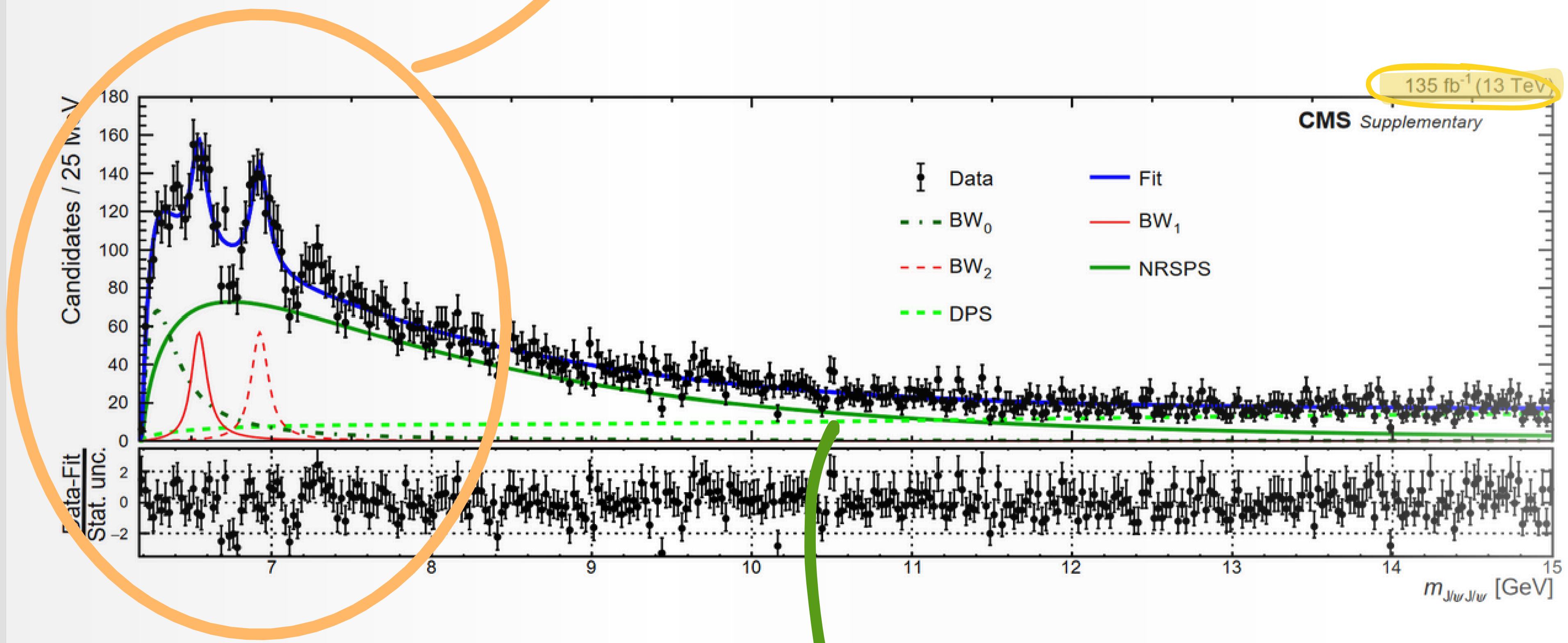
One of the main background sources in the di-J/Ψ analysis of **Run 2 is DPS**, which is expected to account for **about 25% of the background**.

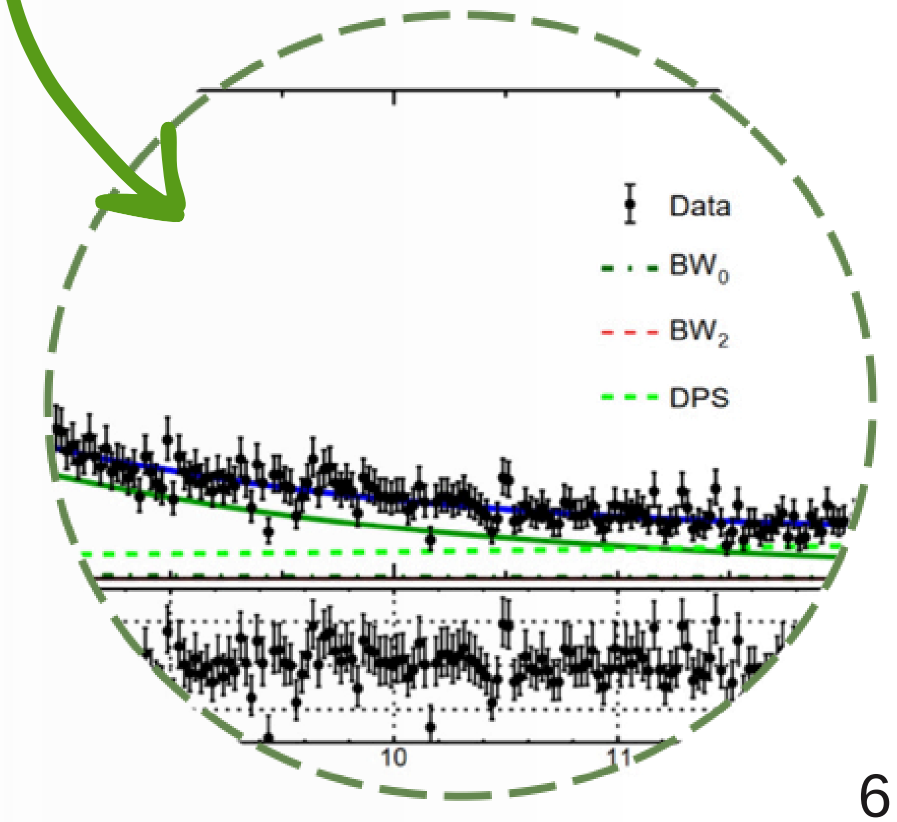
In the region **above 11 GeV**, we expect the **DPS contribution to be dominant.**

So, we just have to look for DPS here as well!
(Spoiler: we are working on it!)

HTTPS://ARXIV.ORG/ABS/2306.07164 HTTPS://ARXIV.ORG/PDF/1406.0484.PDF

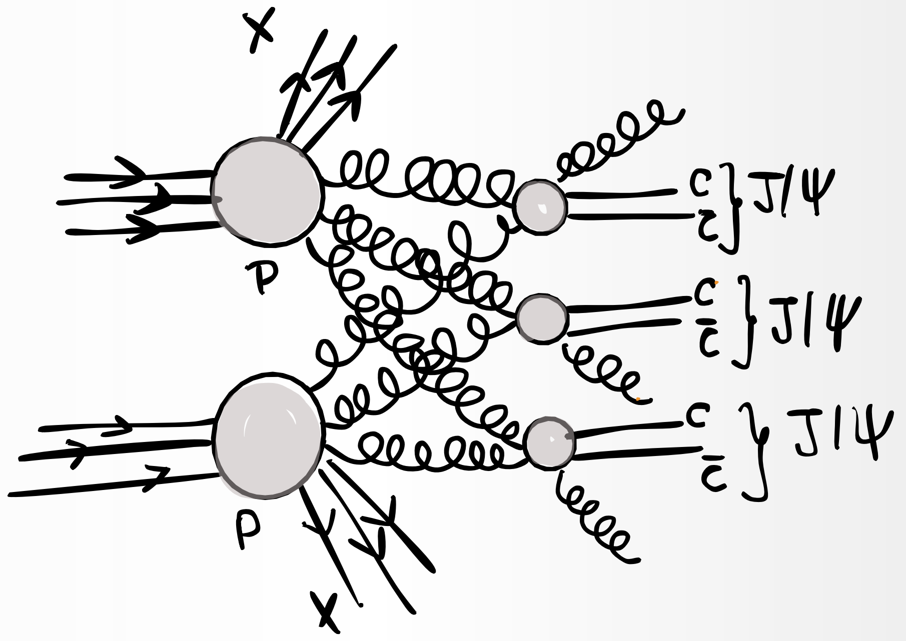
NEW NICE RESONANCES X(6600) AND X(6900) PREVIOUSLY SEEN BY LHCB... TETRAQUARKS?





SINCE THE DPS CONTRIBUTION HERE SEEMS TO BE PREDOMINANT... IT'S WORTH A TRY

THREE J/Ψ IN ONE GO



SINGLE CROSS SECTIONS

$$\sigma_{\text{TPS}}^{pp\to\psi_1\psi_2\psi_3+X} = \left(\frac{m}{3!}\right)\frac{\sigma_{SPS}^{PP\to\psi_1+X}\,\sigma_{SPS}^{PP\to\psi_2+X}\,\sigma_{SPS}^{PP\to\psi_3+X}}{\sigma^2_{\text{eff,TPS}}}$$

COMBINATORIAL FACTOR

EFFECTIVE CROSS SECTION

HTTPS://WWW.NATURE.COM/ARTICLES/S41567-022-01838-Y#CITEAS

By analyzing all the data collected during RUN 2, **5 signal events** and one background event were found.

The expected contributions from **SPS**, **DPS**, and **TPS** to the cross-section measurement of triple-J/ψ are **6%**, **74%**, and **20%**, respectively.

The fiducial cross-section is:

$$\sigma_{fid} = 272^{+141}_{-104}(\text{stat}) \pm 17(\text{syst})\text{fb}$$

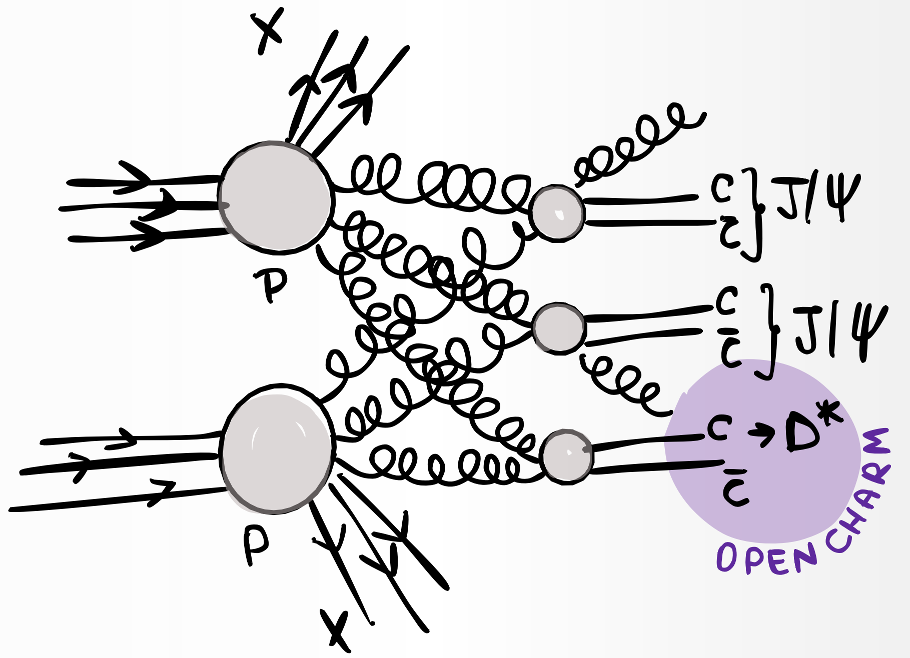
The **effective DPS cross section** is:

$$\sigma_{\text{eff, DPS}} = 2.7^{+1.4}_{-1.0}(\text{exp})^{+1.5}_{-1.0}(\text{theo})\text{mb}$$

while the **effective TPS cross section** is:

$$\sigma_{\text{eff, TPS}} = (0.82 \pm 0.11)\sigma_{\text{eff, DPS}}$$

TRIPLE PARTON SCATTERING WITH ONE OPEN CHARM MESON



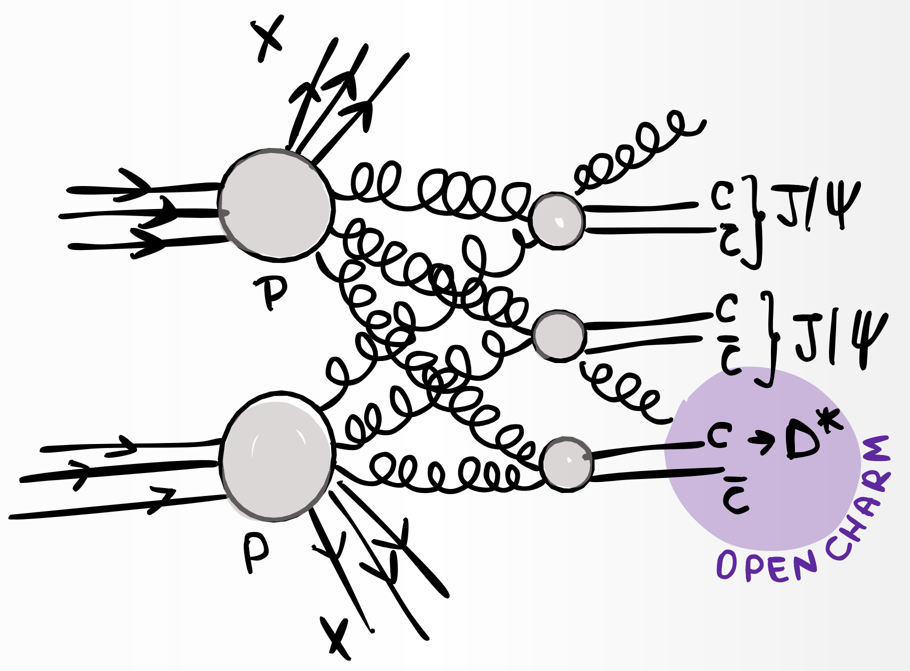
$J/\psi \to \mu^+\mu^-$

$D^{*\pm} \to D^0\pi^{\pm}_{\text{slow}} \to K^-\pi^+\pi^{\pm}_{\text{slow}}$

- The open charm mesons have a larger cross section than the J/ψ
- **Measurement of open-charm** mesons is possible in **CMS**;
- The **D* meson** is the one that can be reconstructed with the **highest purity**;
- The presence of a **slow pion** in its decay allows us to identify the **charge of the D* meson**.

HTTP://CDS.CERN.CH/RECORD/2825713/FILES/CERN-THESIS-2022-114.PDF

TRIPLE PARTON SCATTERING WITH ONE OPEN CHARM MESON



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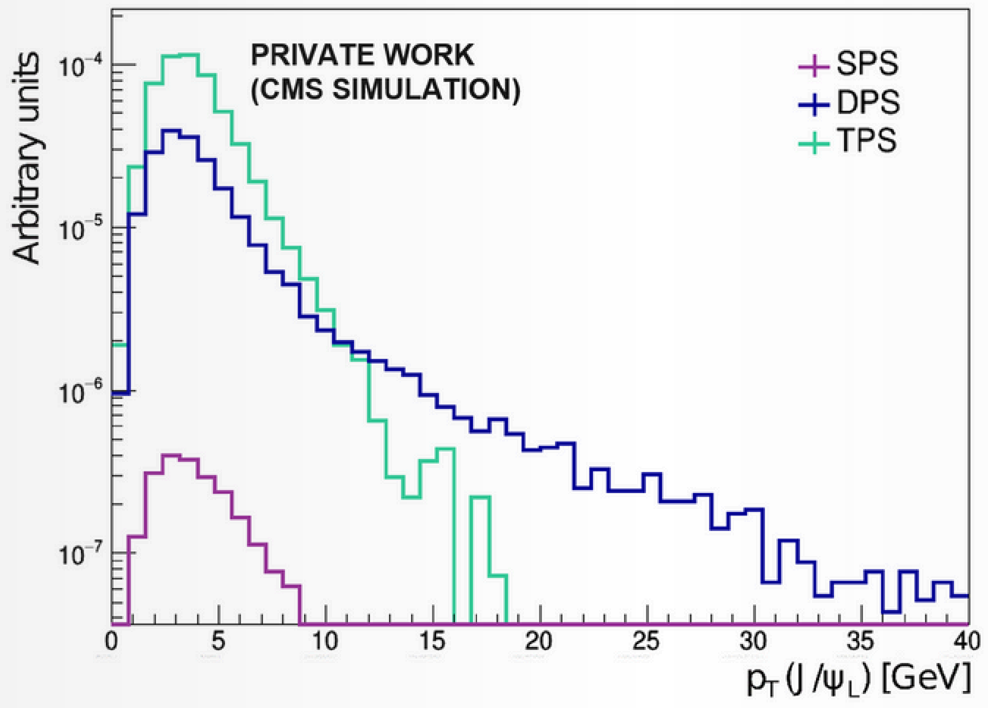
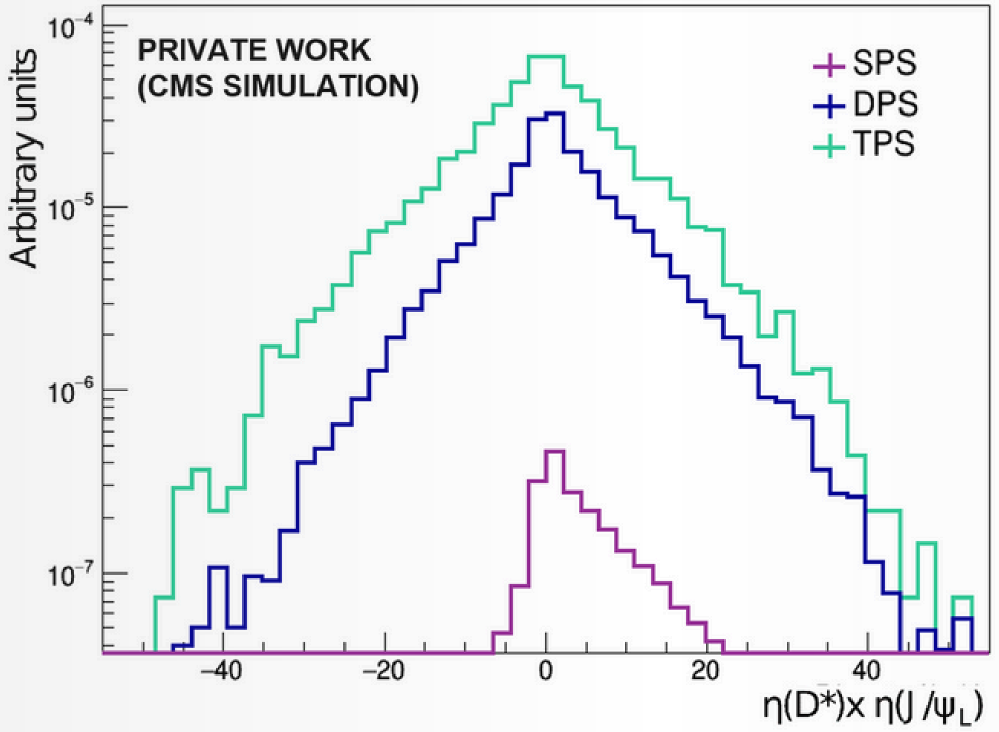
A PRELIMINARY STUDY SEEMS TO SUGGEST THAT THIS FINAL STATE IS INDEED PROMISING.



THIS WAS NOT FOR FREE SINCE THERE AREN'T MC GENERATORS ABLE TO PRODUCE TPS SAMPLES



I HAVE DEVELOPED A STRATEGY USING TWO GENERATORS: HELAC-ONIA AND PYTHIA*

*IF YOU WANT MORE DETAILS ON THIS FEEL FREE TO REACH ME OUT

WHY WE CARE SO MUCH? AND WHAT CAN WE DO?

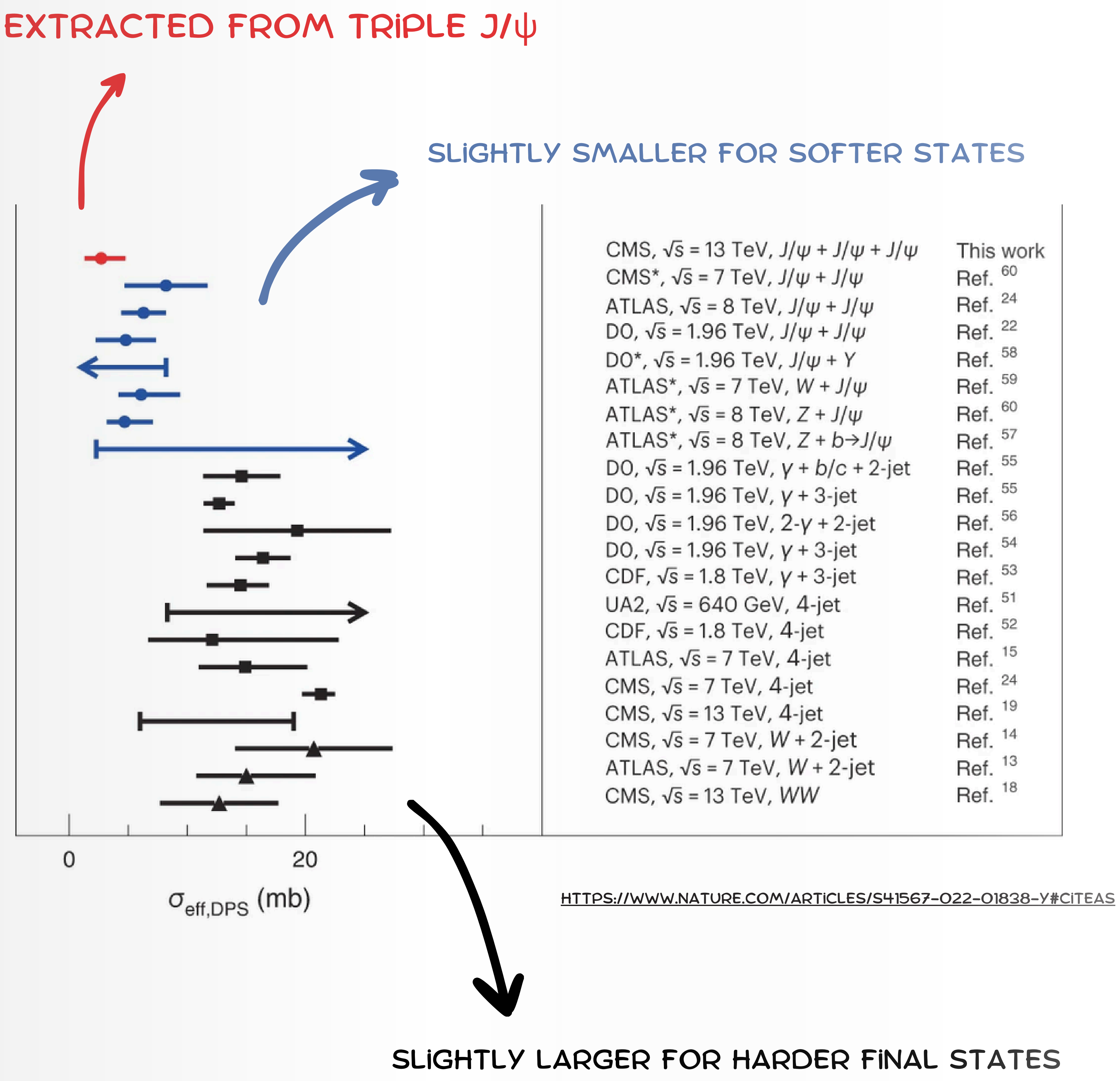
The study of multi-parton interactions should be of interest because:

- It can give us important insights into the **structure of hadrons**.
- It provides **information** in a sector that is difficult to probe, such as **parton interactions.**

The **DPS contribution is becoming increasingly significant** thanks to the increasing luminosity and center-of-mass energy.

Questions remain **open** about the **effective cross-section:**

- **Why** does it vary?
- **How dependent** is it on the **type of process**, **kinematics**, and **energy**?



THANK YOU

ON BEAHALF OF CMS COLLABORATION

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