DOUBLE TRIPLE MULTI

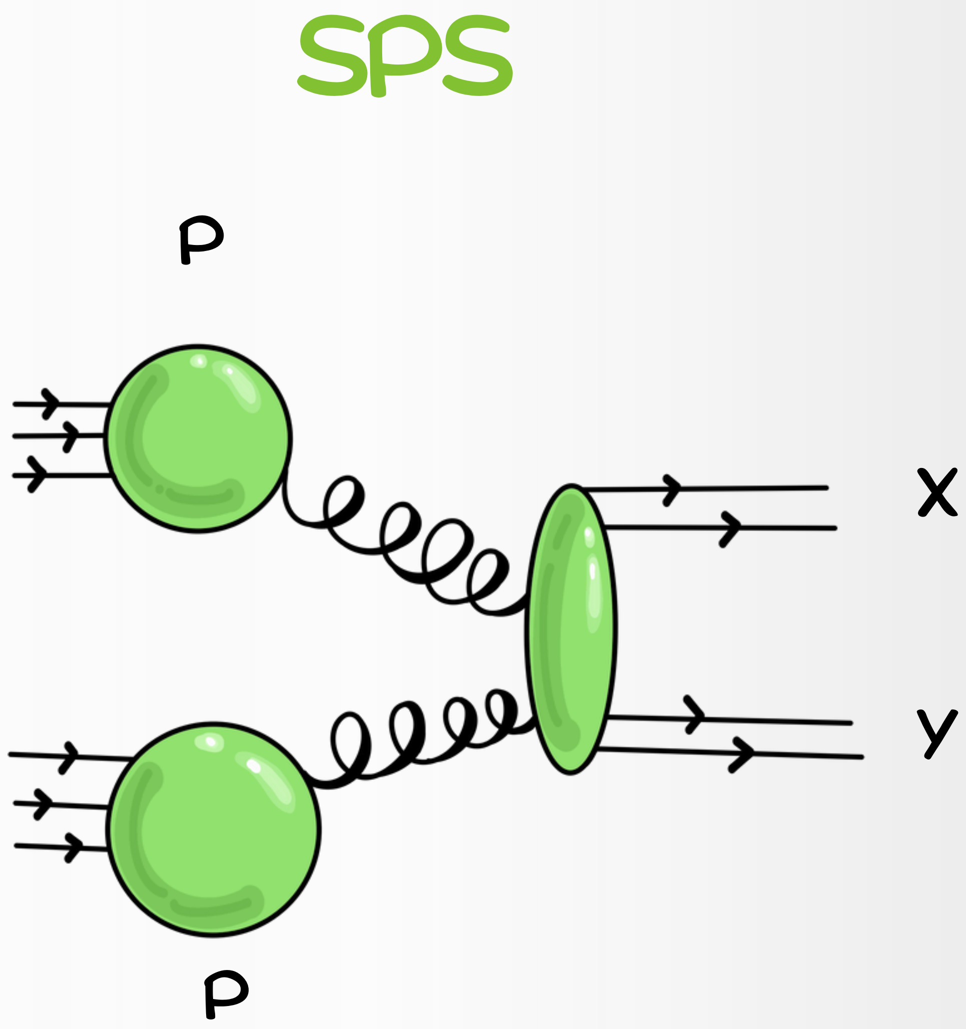
PARTON SCATTERING @ LHC

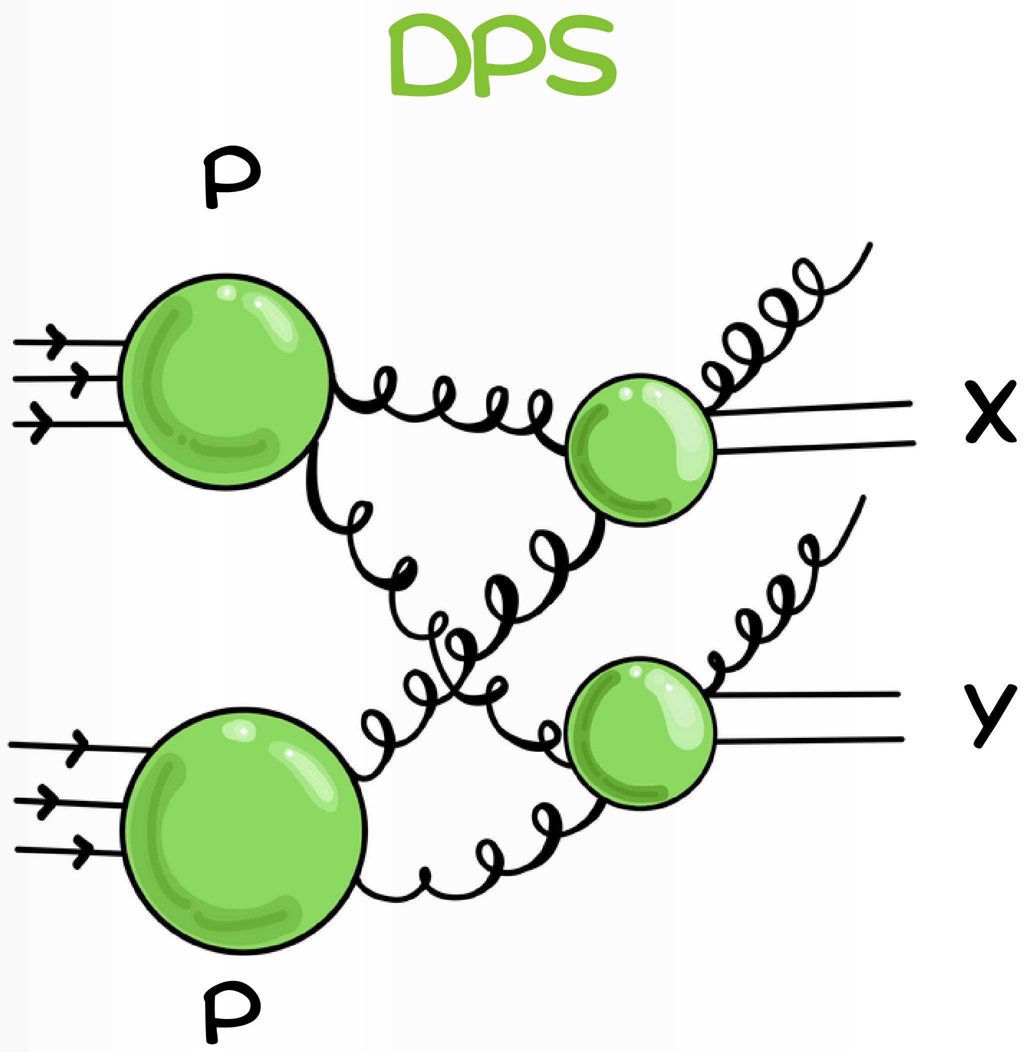
SYNERGIES BETWEEN LHC AND EIC FOR QUARKONIUM PHYSICS
JUL 8 – 12, 2024
ECT*

SPEAKER: MARIA ELENA ASCIOTI | ON BEHALF OF THE ALICE, ATLAS, CMS , AND LHCB COLLABORATIONS

CMS
A.D. 1308 unipg
DIPARTIMENTO DI FISICA E GEOLOGIA
DIPARTIMENTO DI ECCELLENZA MUR 2023/2027
INFN
CERN

Single and Double Parton Scattering





- Single-Parton Scattering (SPS) involves the production of two or more particles through a single interaction between two partons.
- The kinematics are correlated, with the neglect of additional gluon emissions.

- Double-Parton Scattering (DPS) involves the production of two particles through a double interaction between two partons from the same proton pairs.
- To simplify, the hard scattering is assumed as uncorrelated.
- Described by the pocket formula.

The pocket formula

POCKET FORMULA

$$\sigma_{\mathrm{DPS}}^{pp\to\psi_1\psi_2+X} = \left(\frac{m}{2}\right)\frac{\sigma_{\mathrm{SPS}}^{pp\to\psi_1+X}\,\sigma_{\mathrm{SPS}}^{pp\to\psi_2+X}}{\sigma_{\mathrm{eff}}}$$

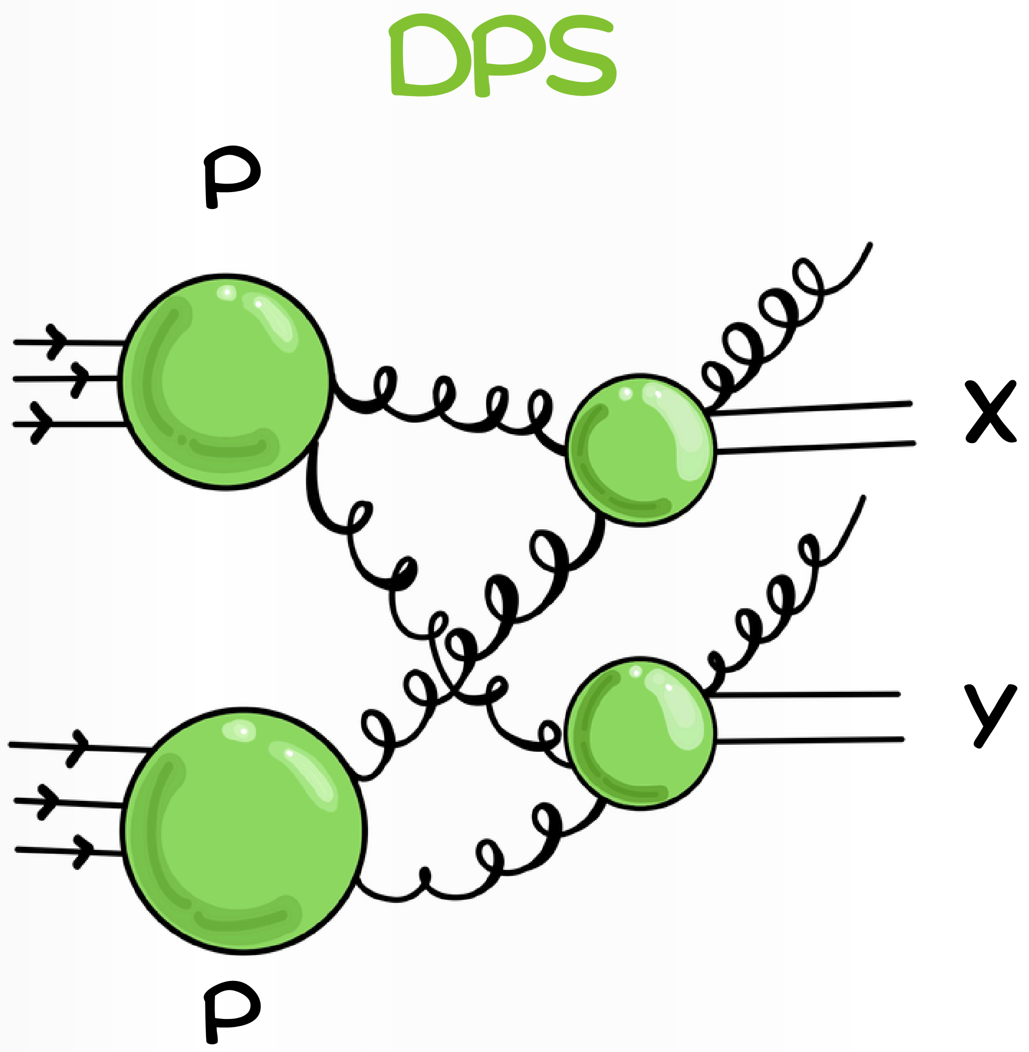
WITH

$$\sigma_{\mathrm{eff}} = \left[\int d^2b\, T^2(b)\right]^{-1}$$

WHERE

$$T(b) = \int \rho(b_1)\rho(b_1 - b)\, d^2b_1$$

IS THE PP TRANSVERSE OVERLAP FUNCTION AT COLLISION IMPACT PARAMETER B = |B|, WHICH DEPENDS ON THE TRANSVERSE PARTON DENSITY OF THE PROTON



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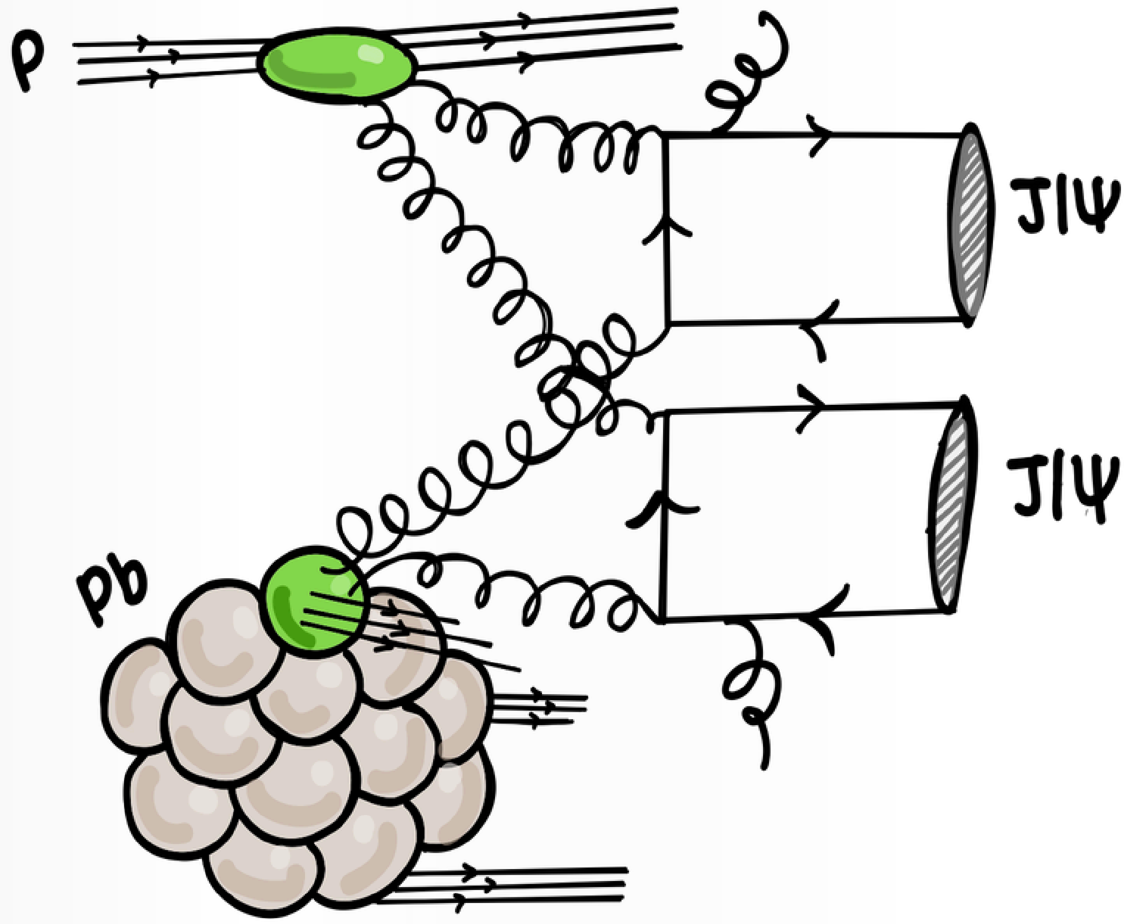
P-A POCKET FORMULA

$$\sigma_{\rm DPS}^{p{\rm Pb}\to J/\psi J/\psi+X} = \left(\frac{1}{2}\right)\frac{\sigma_{\rm SPS}^{p{\rm Pb}\to J/\psi+X}\,\sigma_{\rm SPS}^{p{\rm Pb}\to J/\psi+X}}{\sigma_{\rm eff,pA}}$$

WITH

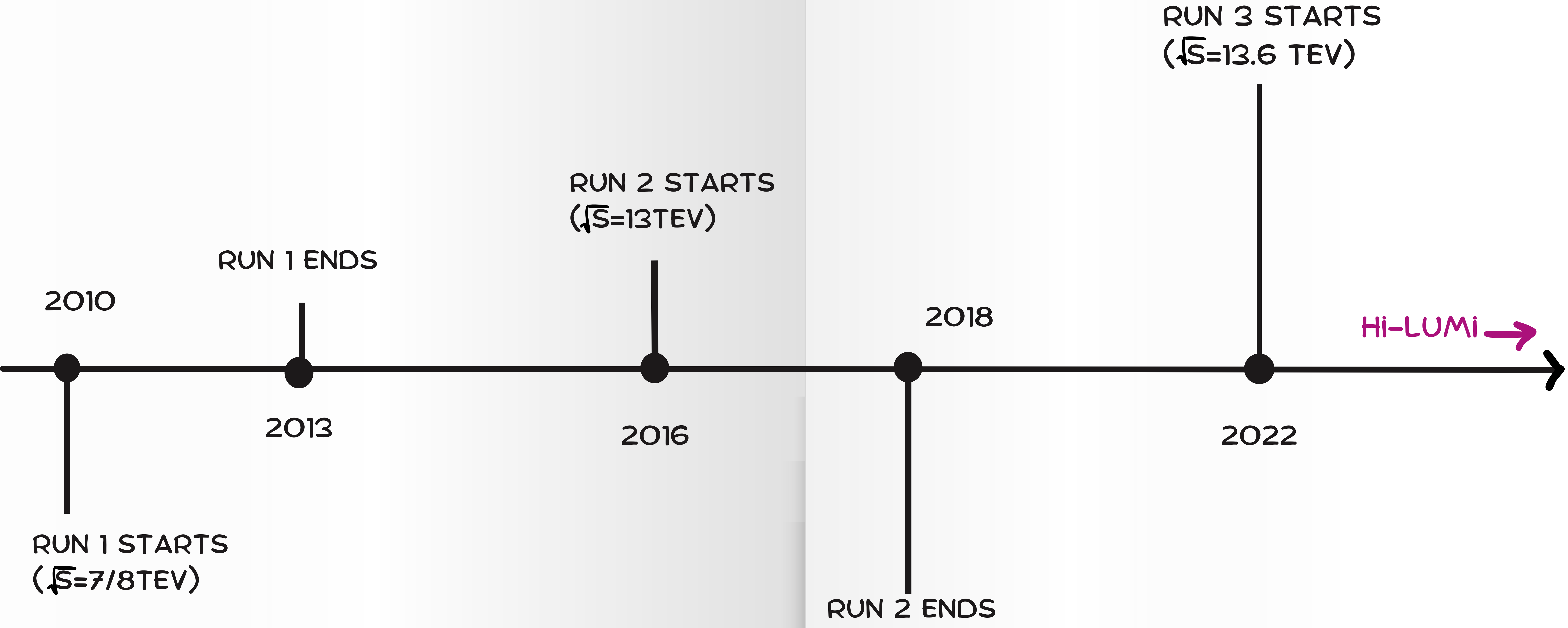
$$\sigma_{\rm eff,pA} = \frac{A\sigma_{\rm eff}}{1+\sigma_{\rm eff}F_{pA}/A'}$$



$$F_{pA} = \frac{(A-1)}{A}\int d^2b\,T^2(b)$$

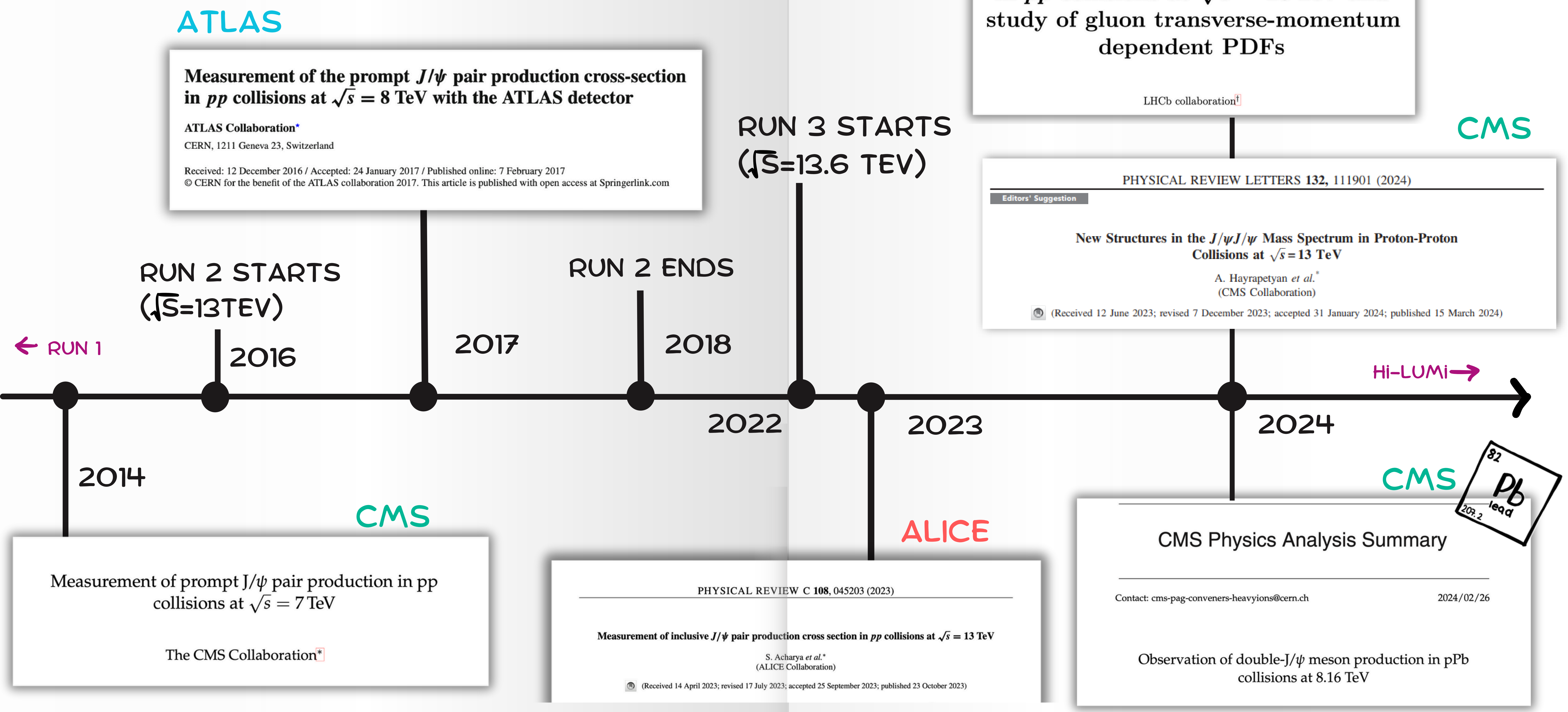
INTEGRAL OVER IMPACT PARAMETER OF THE SQUARED PA TRANSVERSE PROFILE, WHICH CAN BE DETERMINED THROUGH A GLAUBER MONTE CARLO MODEL

These last few years



Di-J/ψ

These last few years



Di-J/ψ in LHCb

LHCB

Main goals of the analysis:

- Measure the production cross-section of the di-J/ψ:
  - SPS and DPS cross-sections as well;
  - extrapolate the effective cross-section.
- Study the gluon Transverse Momentum Distribution:
  - measure the distribution of the azimuthal angle ϕ
  - pt spectrum in the Collins-Soper frame

The di-J/ψ are reconstructed in the di-muon channel and are requested to be prompt.

https://arxiv.org/abs/2311.15921

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$2.0 < y < 4.5$

$p_T < 14$ GeV/c

The di-J/ψ are reconstructed in the di-muon channel and are requested to be prompt.

The J/ψs are assumed to be uniformly distributed in ϕ.

The SPS contribution is considered negligible in the $1.8 < \Delta y < 2.5$ region.

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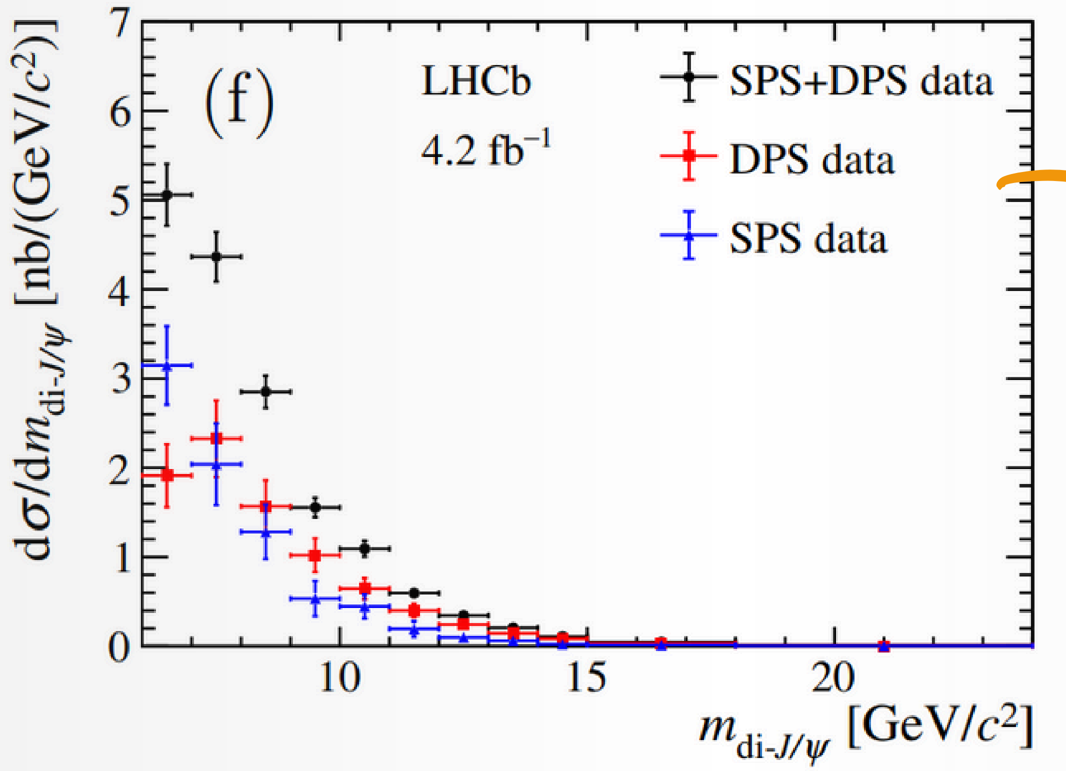
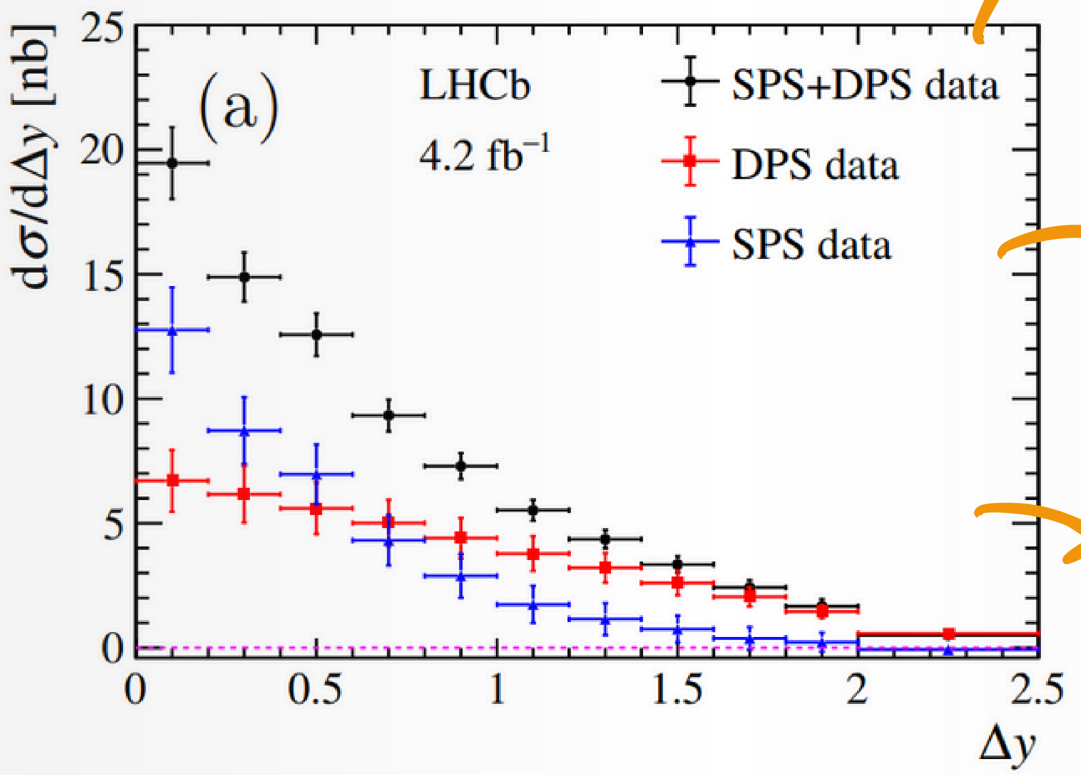
LHCB

4.2 FB^{-1}



$\sqrt{S}$= 13 TEV

IN THE DPS WE EXPECT THE J/ΨS TO BE UNCORRELATED



THE DPS CONTRIBUTION IS EXTRACTED USING A DATA-DRIVEN TEMPLATE

SPS AND DPS CONTRIBUTIONS ARE SEPARATED

Di-J/ψ in LHCb

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- Study the gluon Transverse Momentum Distribution:
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  - pt spectrum in the Collins-Soper frame

$$\sigma_{J/\psi} = 15.03 \pm 0.03\,(\text{stat}) \pm 0.94\,(\text{syst})\,\mu\text{b}$$

$$\sigma_{\text{eff}} = \frac{1}{2}\frac{\sigma^2_{J/\psi}}{\sigma^{\text{di-}J/\psi}_{\text{DPS}}} = 13.1 \pm 1.8\,(\text{stat}) \pm 2.3\,(\text{syst})\,\text{mb}$$

$$\sigma^{\text{di-}J/\psi}_{\text{DPS}} = 8.6 \pm 1.2\,(\text{stat}) \pm 1.0\,(\text{syst})\,\text{nb}$$

LHCB

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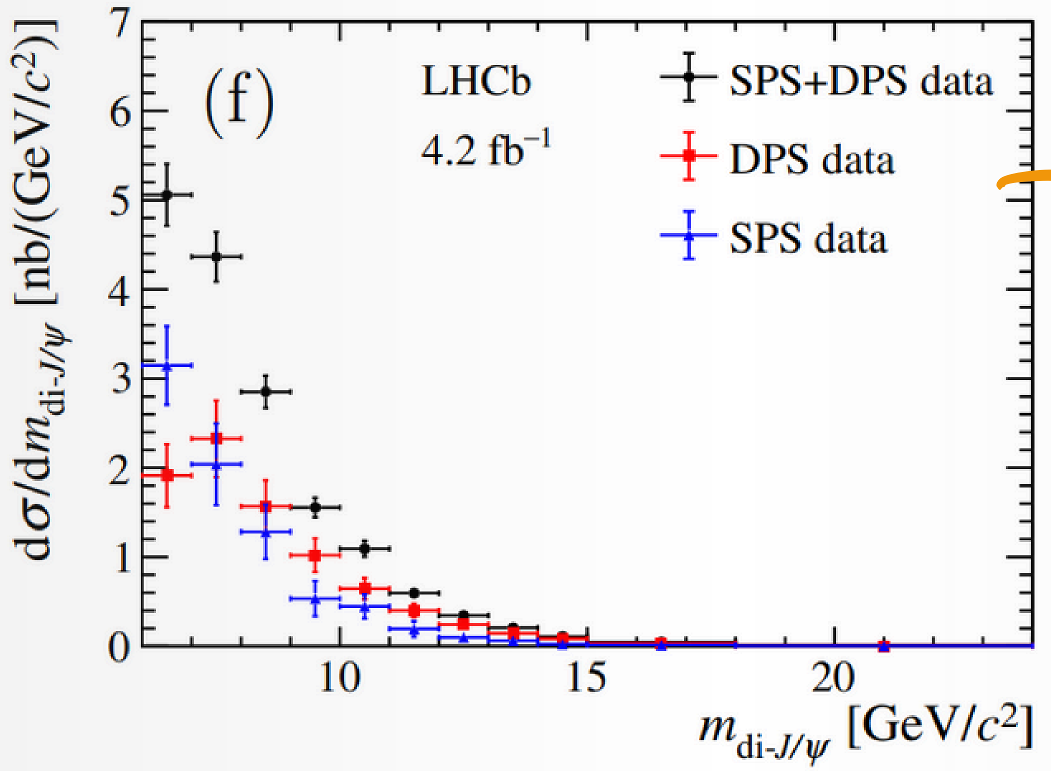

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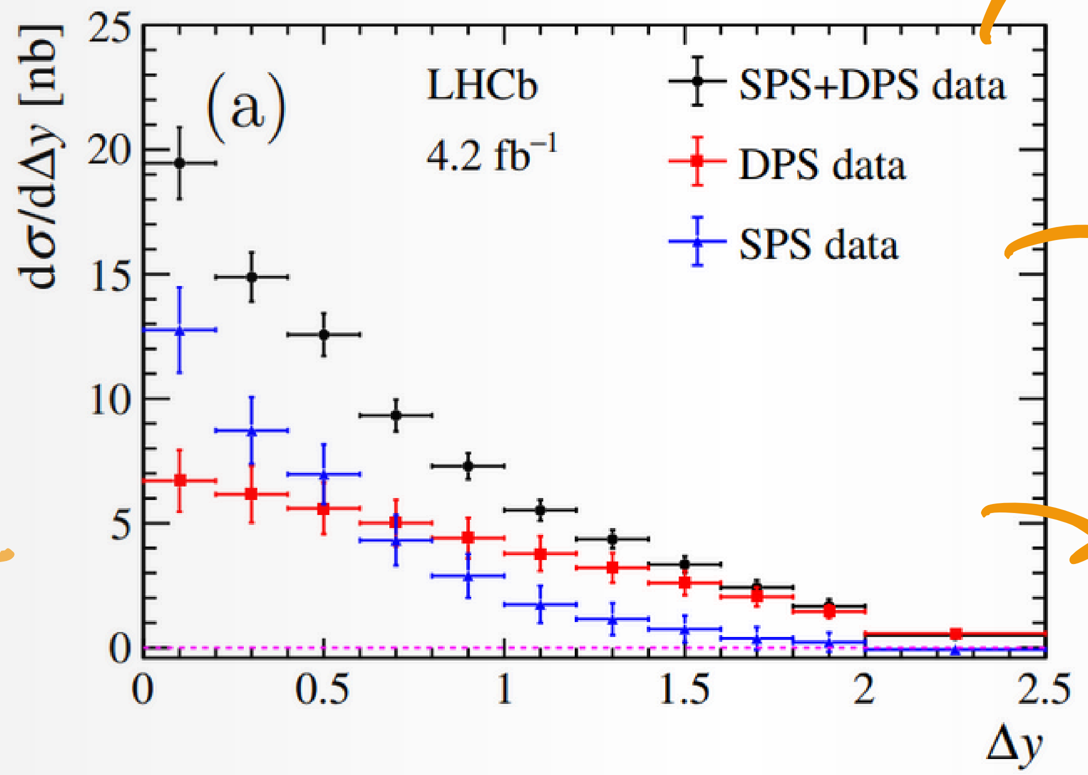

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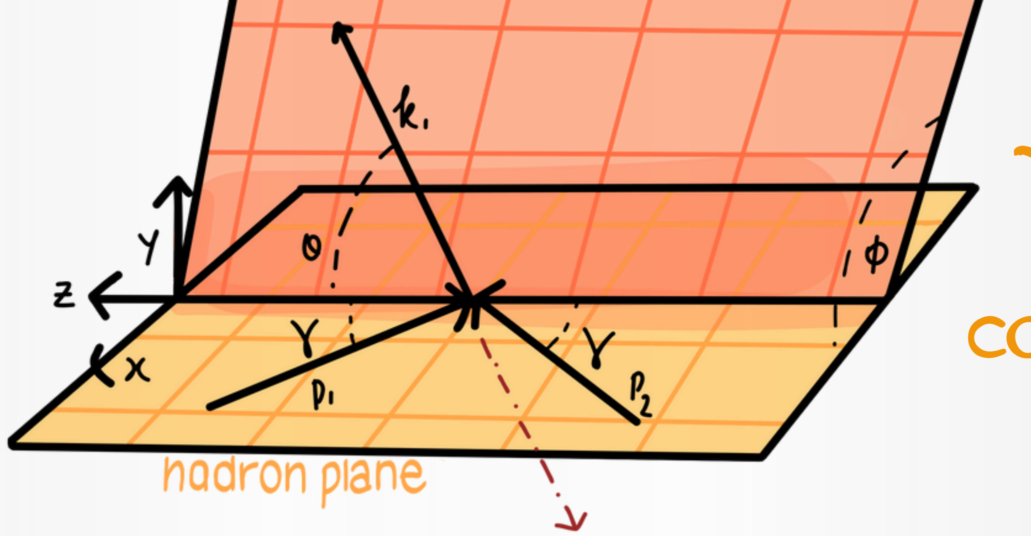
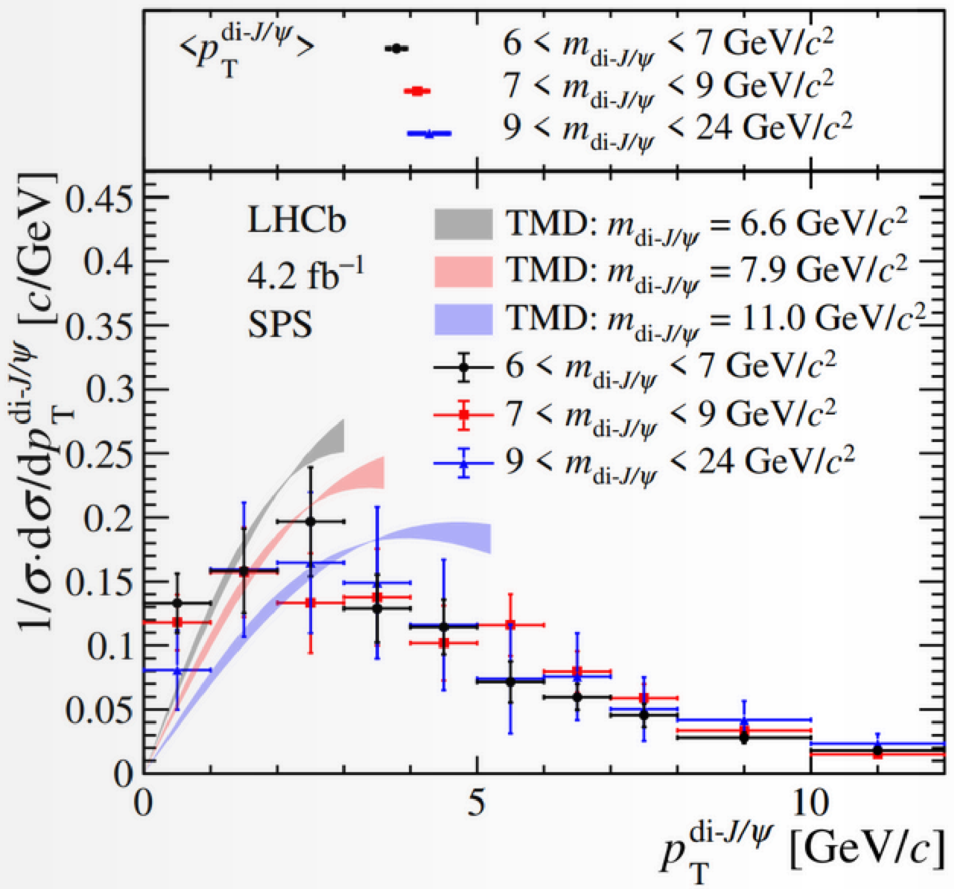
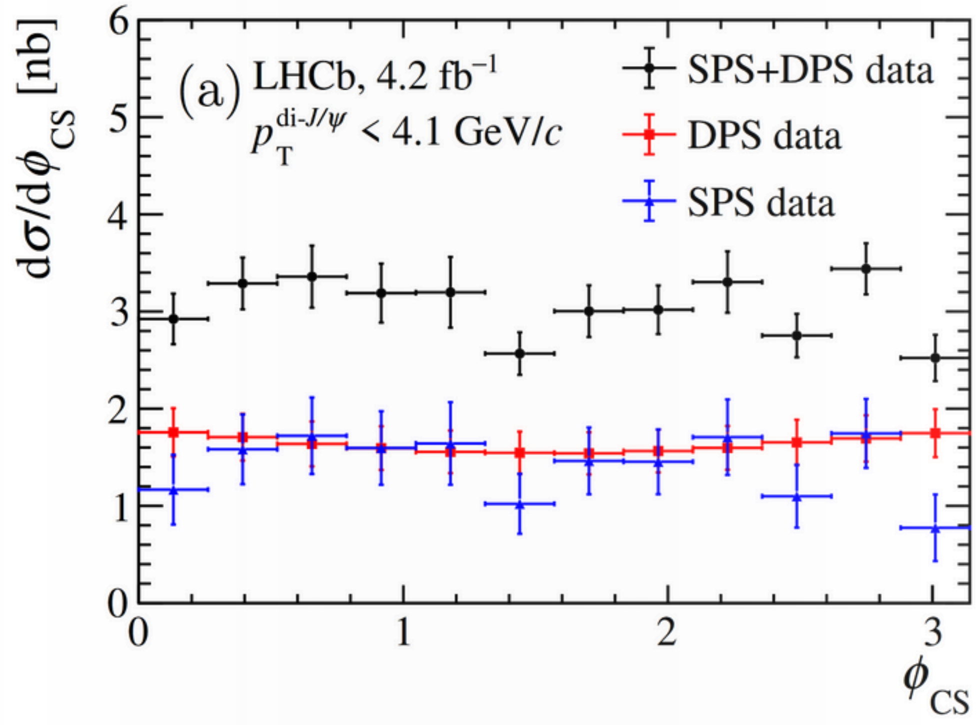
- Study the gluon Transverse Momentum Distribution:
  - measure the distribution of the azimuthal angle ϕ_{CS}
  - pt spectrum in the Collins-Soper frame



COLLINS-SOPER FRAME



THE AVERAGE PT DISTRIBUTION SHOWS A SLIGHT INCREASE WITH DI-J/Ψ MASS



The extracted values of $\langle \cos 2\phi_{CS} \rangle$ and $\langle \cos 4\phi_{CS} \rangle$ are consistent with zero, but the presence of azimuthal asymmetry at a few percent levels is allowed.

https://arxiv.org/abs/2311.15921

Di-J/ψ in ALICE

Main goals of the analysis:

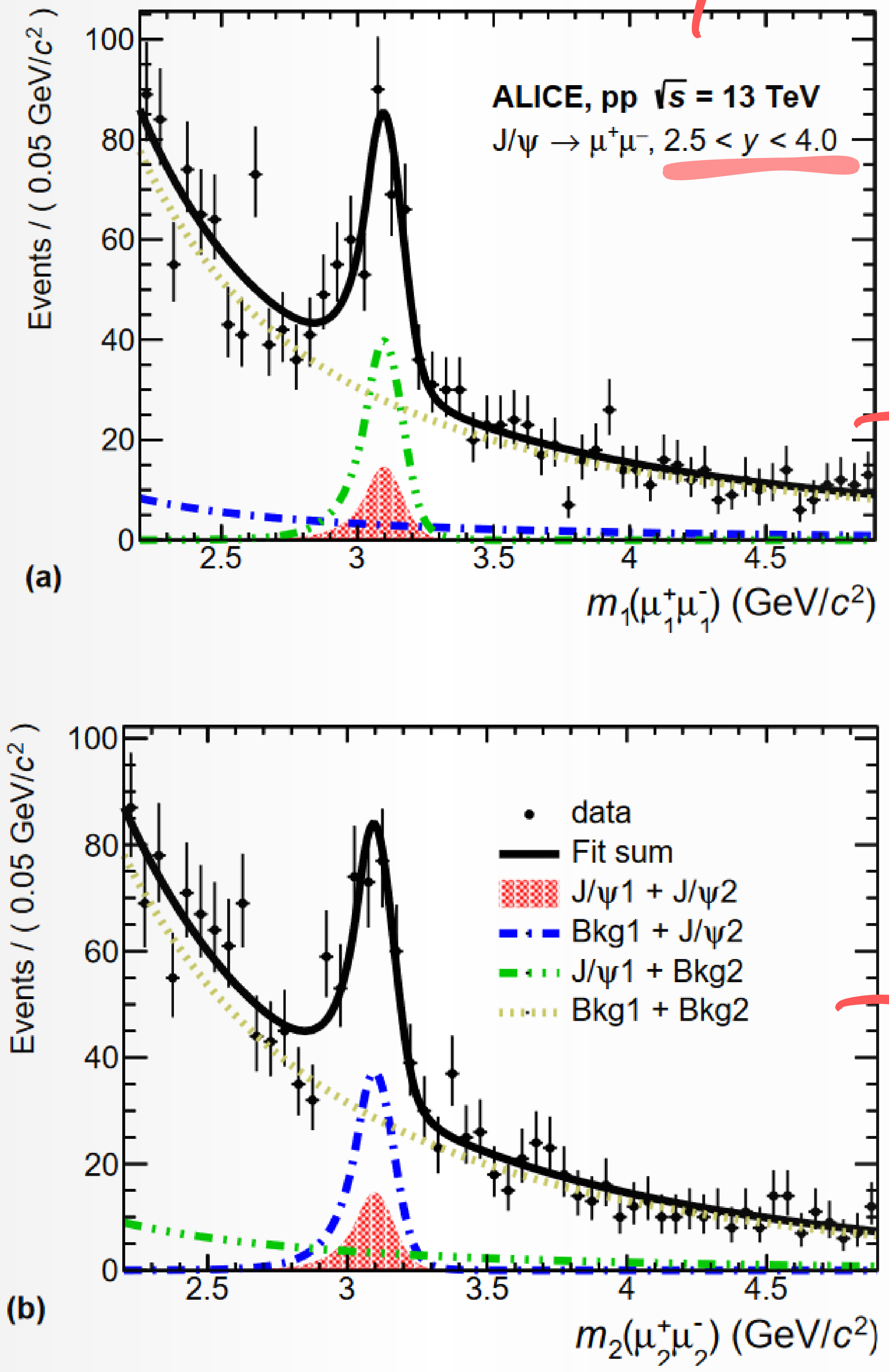
- Measure the contribution from non prompt J/ψ
- Measure the effective double-parton scattering cross section

24.11 PB^{-1}

SAME REGION OF LHCB

ALICE

THIS IS THE FIRST DOUBLE QUARKONIUM MEASUREMENT CONDUCTED BY ALICE!



√S= 13 TEV

THE LABEL 1 OR 2 IS ASSIGNED RANDOMLY

https://journals.aps.org/prc/abstract/10.1103/PhysRevC.108.045203

Di-J/ψ in ALICE

THE NON PROMPT CONTRIBUTION = J/Ψ FROM BEAUTY DECAYS

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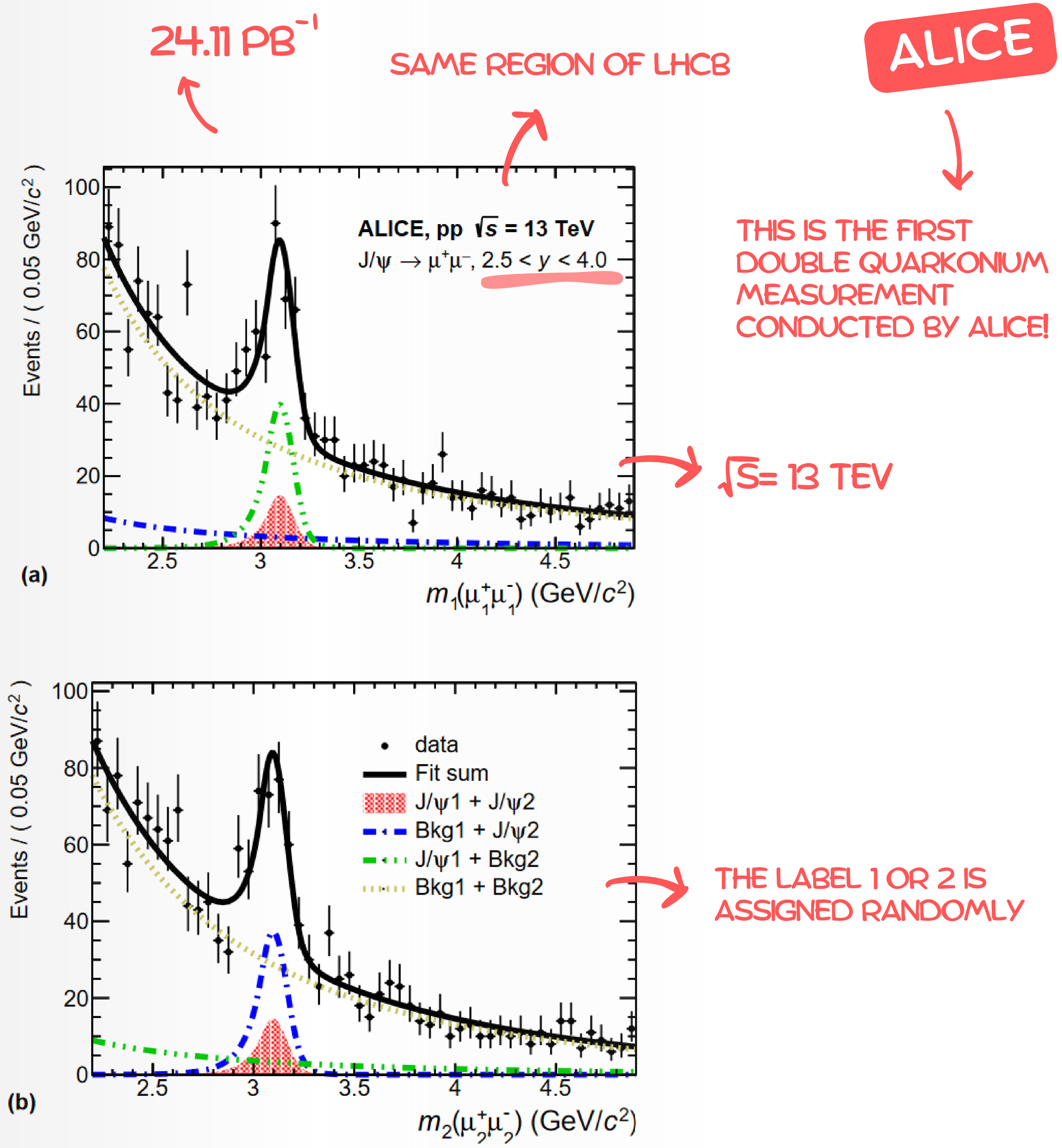

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THE NON PROMPT CONTRIBUTION = J/Ψ FROM BEAUTY DECAYS

Main goals of the analysis:

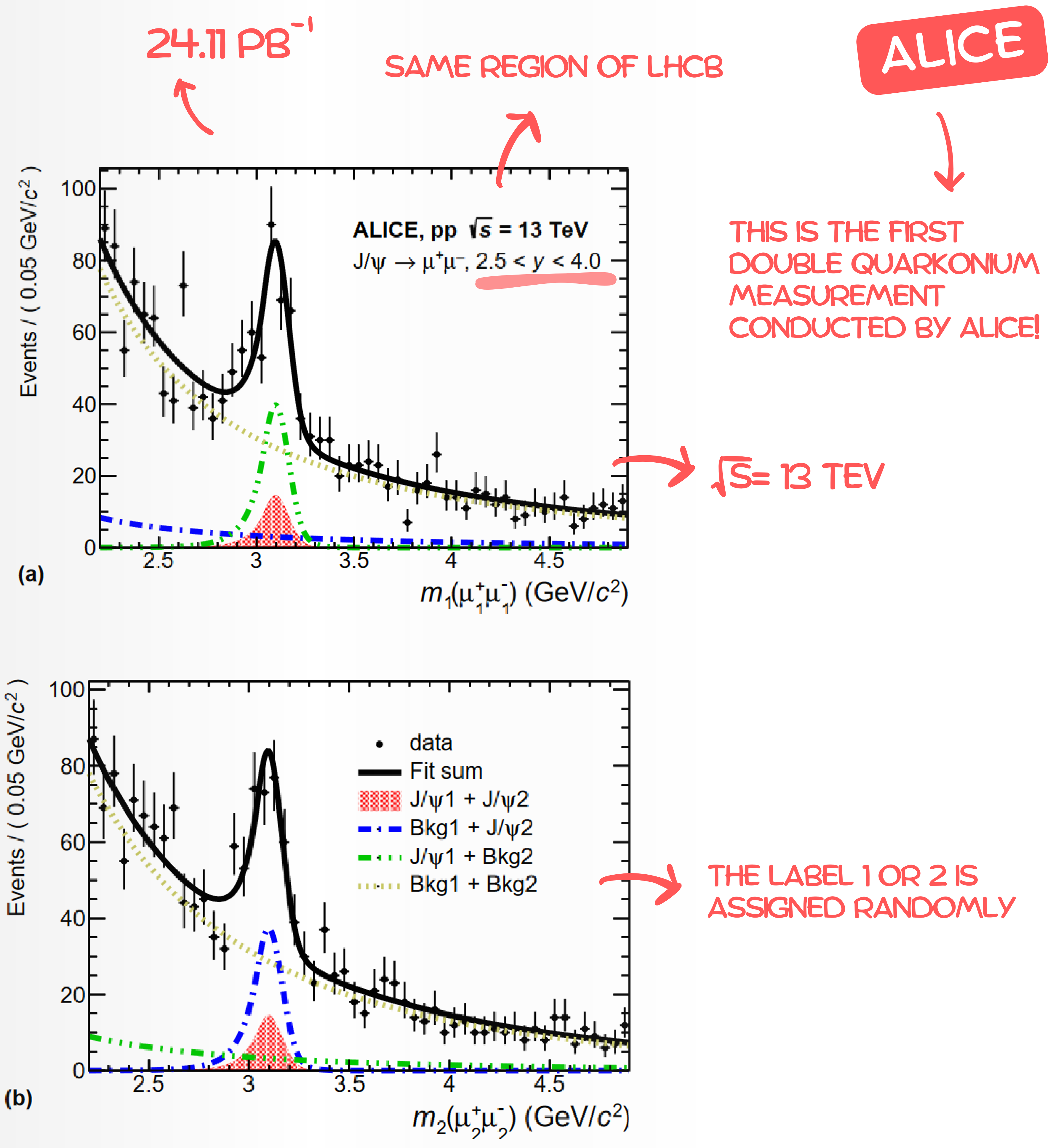
- Measure the contribution from non prompt J/ψ
- Measure the effective double-parton scattering cross section

- The di-J/ψ are reconstructed in the di-muon channel.
- The di-J/ψ inclusive cross section is:

$$\sigma(J/\psi J/\psi) = 10.3 \pm 2.3(\text{stat}) \pm 1.3(\text{syst.})\text{nb}$$

LET'S USE THIS TO EXTRAPOLATE THE SIGMA EFF

$$\sigma(J/\psi J/\psi) = \frac{N}{\mathcal{L}_{\text{int}} \times \epsilon \times \mathcal{B}^2(J/\psi \to \mu^+\mu^-)}$$



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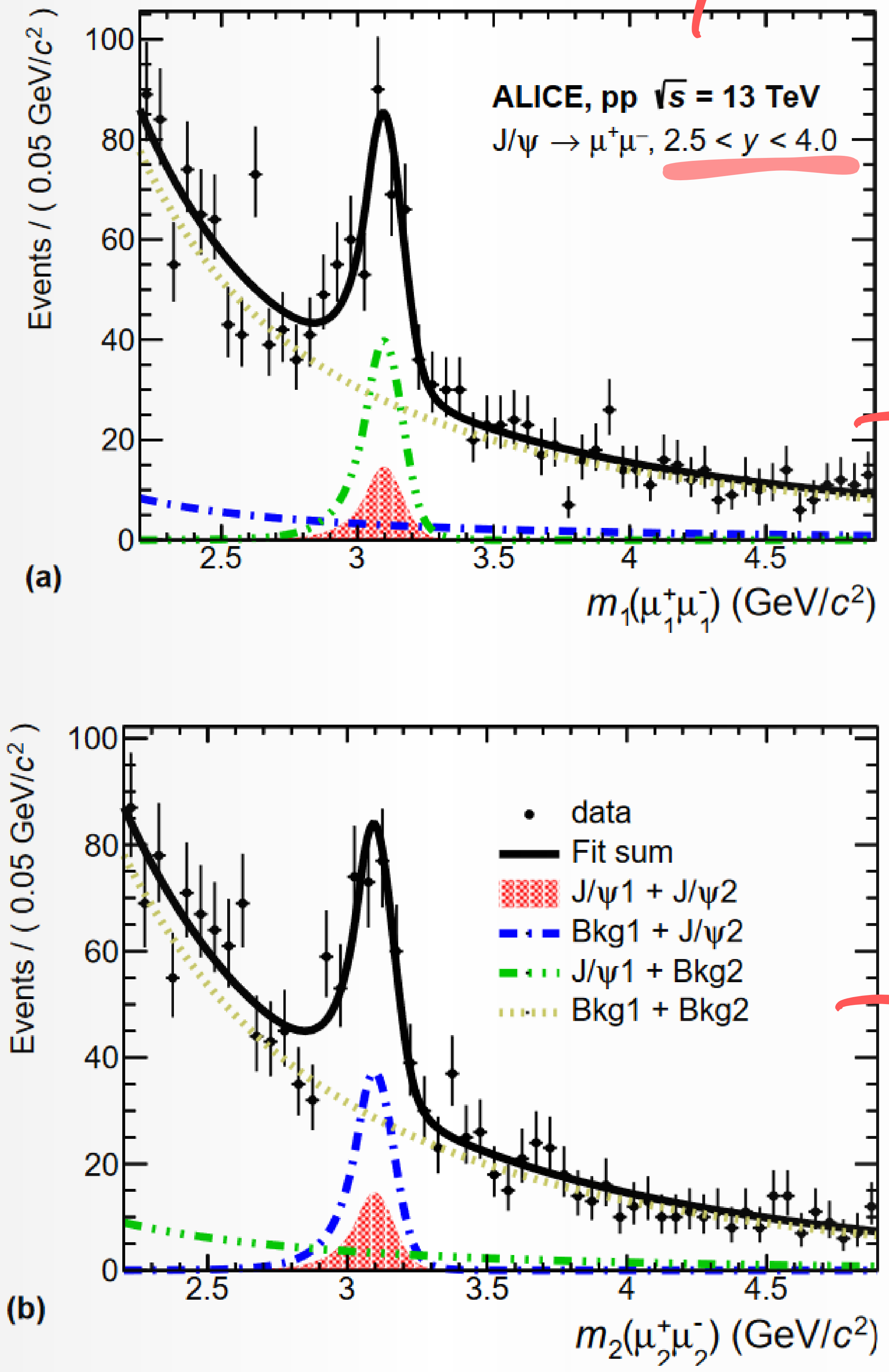

$\sqrt{S}$= 13 TEV

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$$\sigma(J/\psi J/\psi) = 10.3 \pm 2.3(\text{stat}) \pm 1.3(\text{syst.})\text{nb}$$

LET'S USE THIS TO EXTRAPOLATE THE SIGMA EFF

$$\frac{1}{2}\frac{\sigma(J/\psi)^2}{\sigma(J/\psi J/\psi)} = 6.2 \pm 1.4\,(\text{stat.}) \pm 1.1\,(\text{syst.})\,\text{mb}$$

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Di-J/ψ in ALICE

$$\sigma_{\text{non-prompt}}(J/\psi J/\psi) = \sigma^{\text{total}}_{b\bar{b}} \times \alpha \times B^2(h_b \to J/\psi + X)$$

LET'S ALSO EXTRACT THE PROMPT CONTRIBUTION

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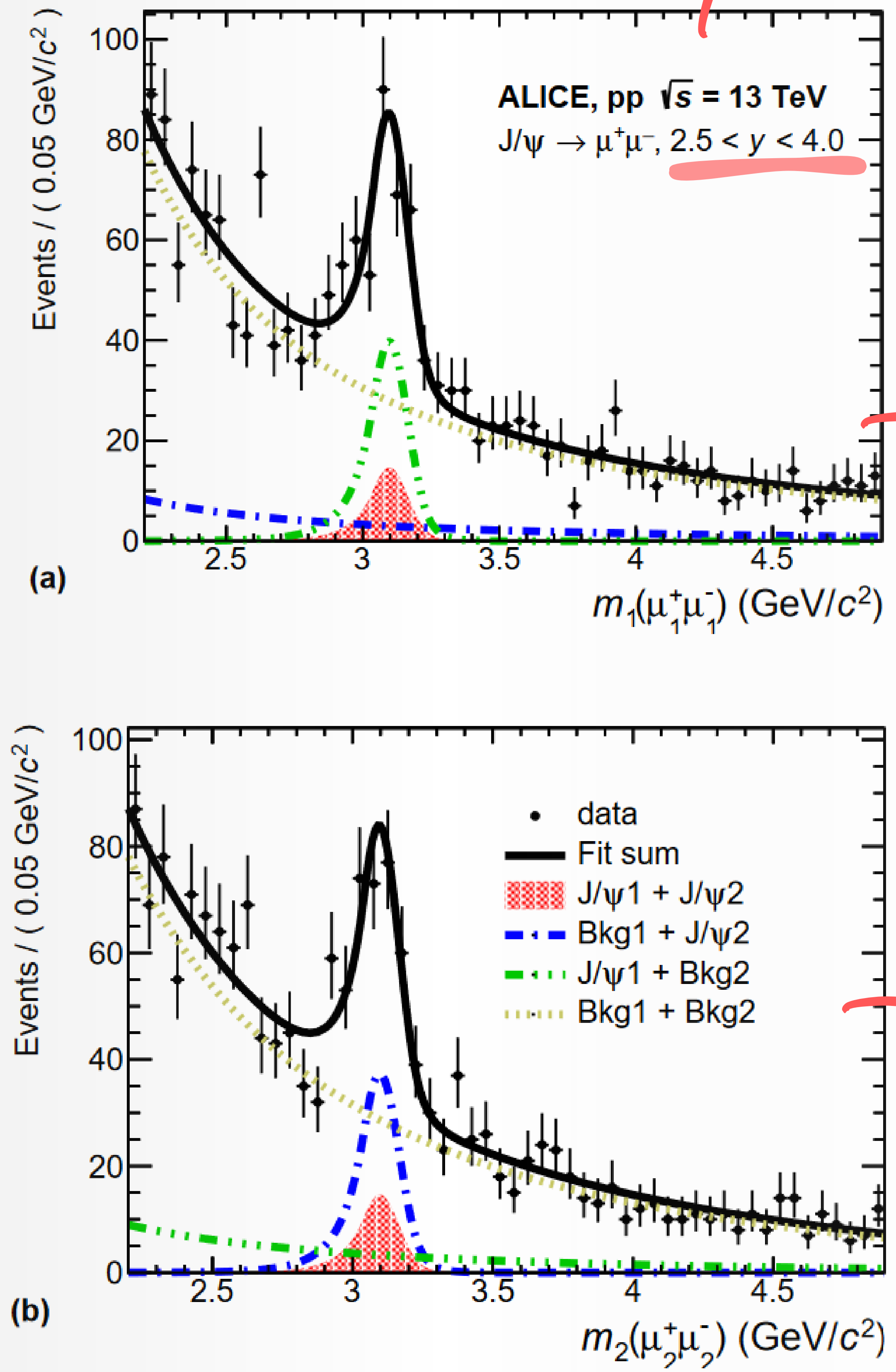

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Di-J/ψ in ALICE

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LET'S ALSO EXTRACT THE PROMPT CONTRIBUTION

$$2.97 \pm 0.09(\text{stat.})^{+0.68}_{-0.76}(\text{syst.})\text{nb}$$

$$\sigma(J/\psi J/\psi) = 10.3 \pm 2.3(\text{stat}) \pm 1.3(\text{syst.})\text{nb}$$

LET'S USE THIS TO EXTRAPOLATE THE SIGMA EFF

$$\frac{1}{2}\frac{\sigma(J/\psi)^2}{\sigma(J/\psi J/\psi)} = 6.2 \pm 1.4\,(\text{stat.}) \pm 1.1\,(\text{syst.})\,\text{mb}$$

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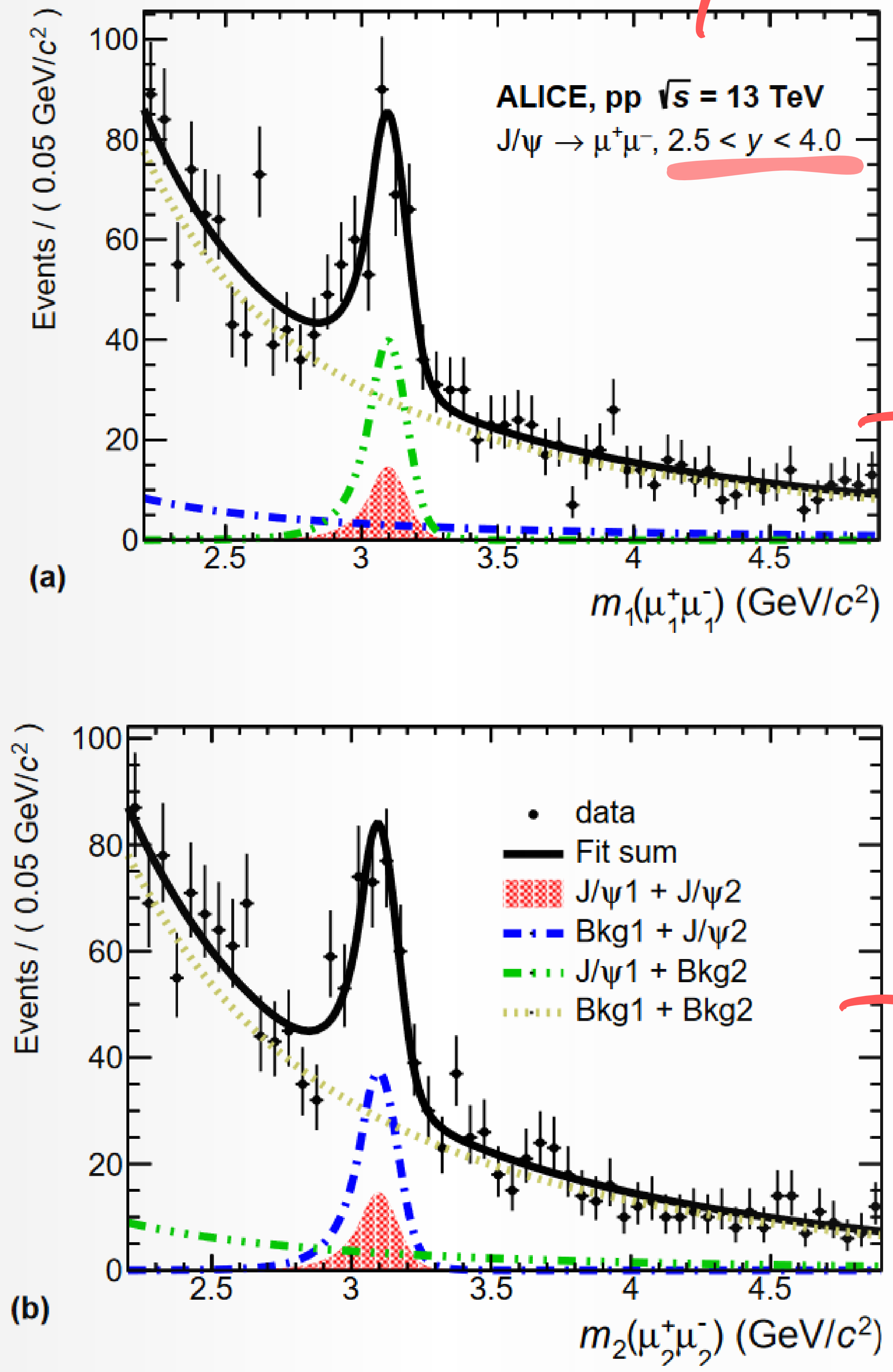

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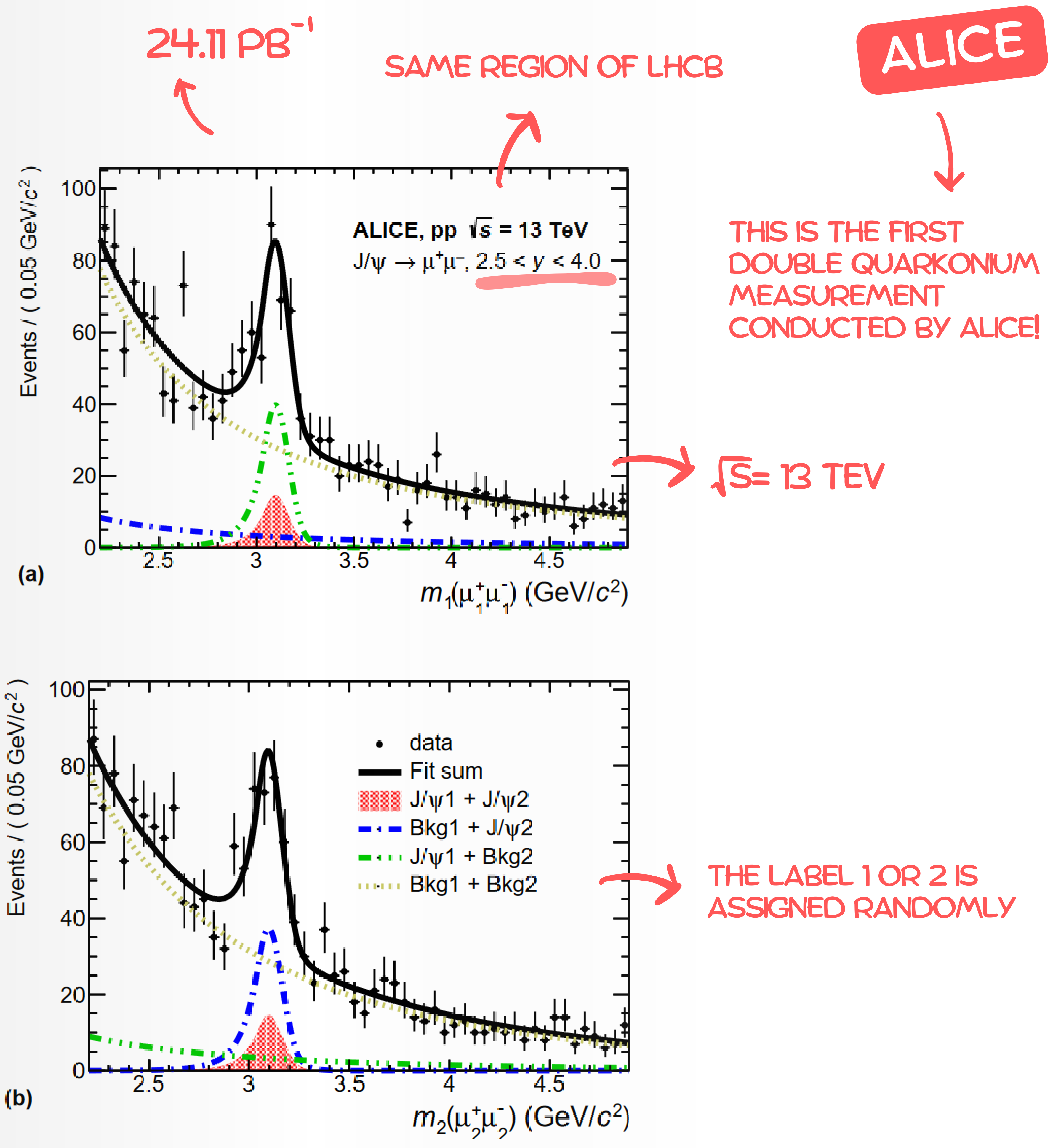

WE CAN NOW EXTRACT THE PROMPT CONTRIBUTION

$$\sigma(J/\psi J/\psi) = 10.3 \pm 2.3(\text{stat}) \pm 1.3(\text{syst.})\text{nb}$$

LET'S USE THIS TO EXTRAPOLATE THE SIGMA EFF

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Di-J/ψ in ALICE

$$\sigma_{\text{prompt}}(J/\psi J/\psi) = 7.3 \pm 1.7\,(\text{stat.})^{+1.9}_{-2.1}\,(\text{syst.})\,\text{nb}$$

WE CAN NOW EXTRACT THE PROMPT CONTRIBUTION

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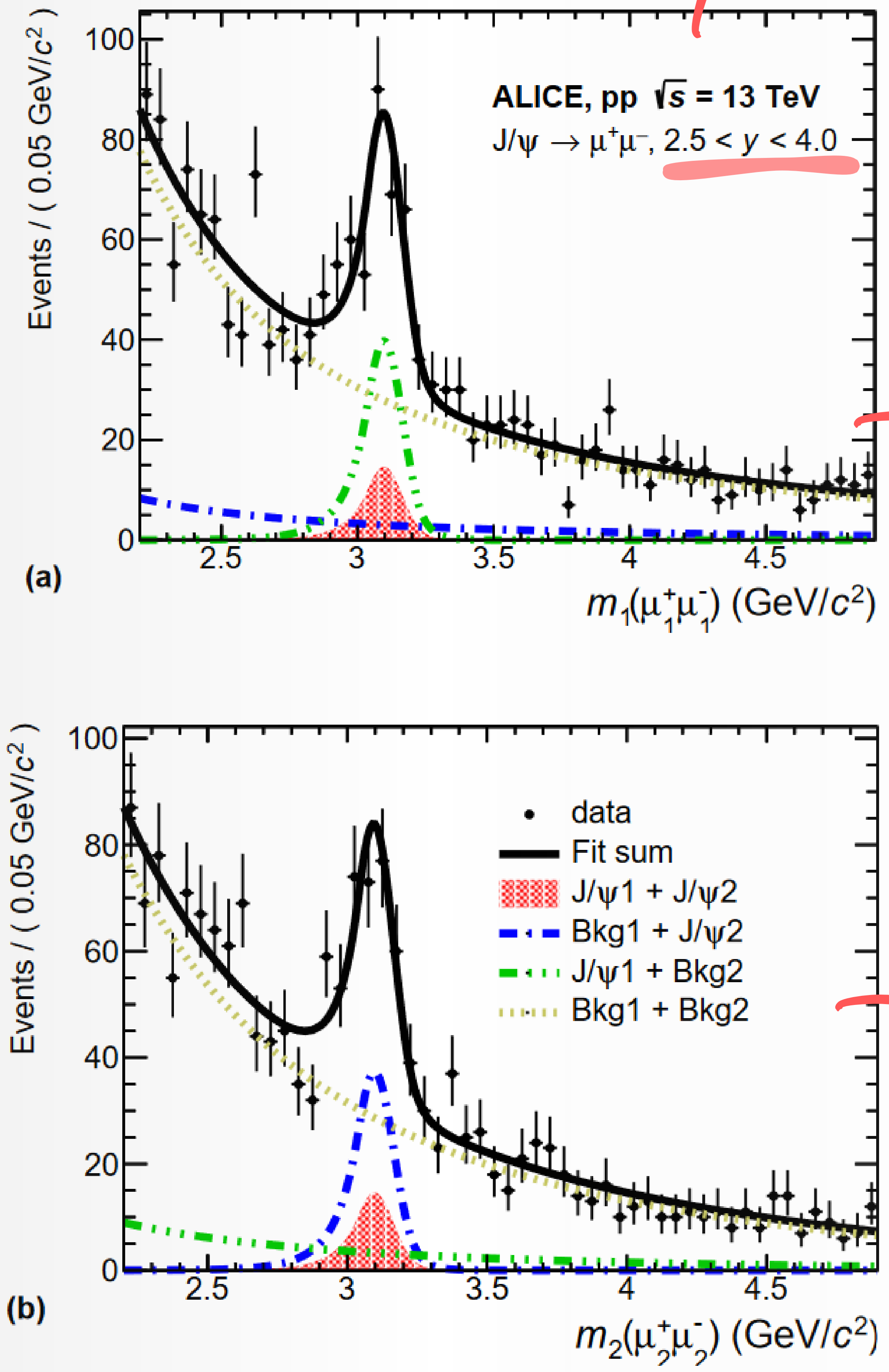

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$\sqrt{s}$= 13 TEV

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Di-J/ψ in ALICE

$$\frac{1}{2}\frac{\sigma_{\text{prompt}}(J/\psi)^2}{\sigma_{\text{prompt}}(J/\psi J/\psi)} = 6.7 \pm 1.6\,(\text{stat.}) \pm 2.7\,(\text{syst.})\,\text{mb}$$

AND EXTRAPOLATE THE SIGMA EFF FROM THE PROMPT PRODUCTION

$$\sigma_{\text{prompt}}(J/\psi J/\psi) = 7.3 \pm 1.7\,(\text{stat.})^{+1.9}_{-2.1}\,(\text{syst.})\,\text{nb}$$

WE CAN NOW EXTRACT THE PROMPT CONTRIBUTION

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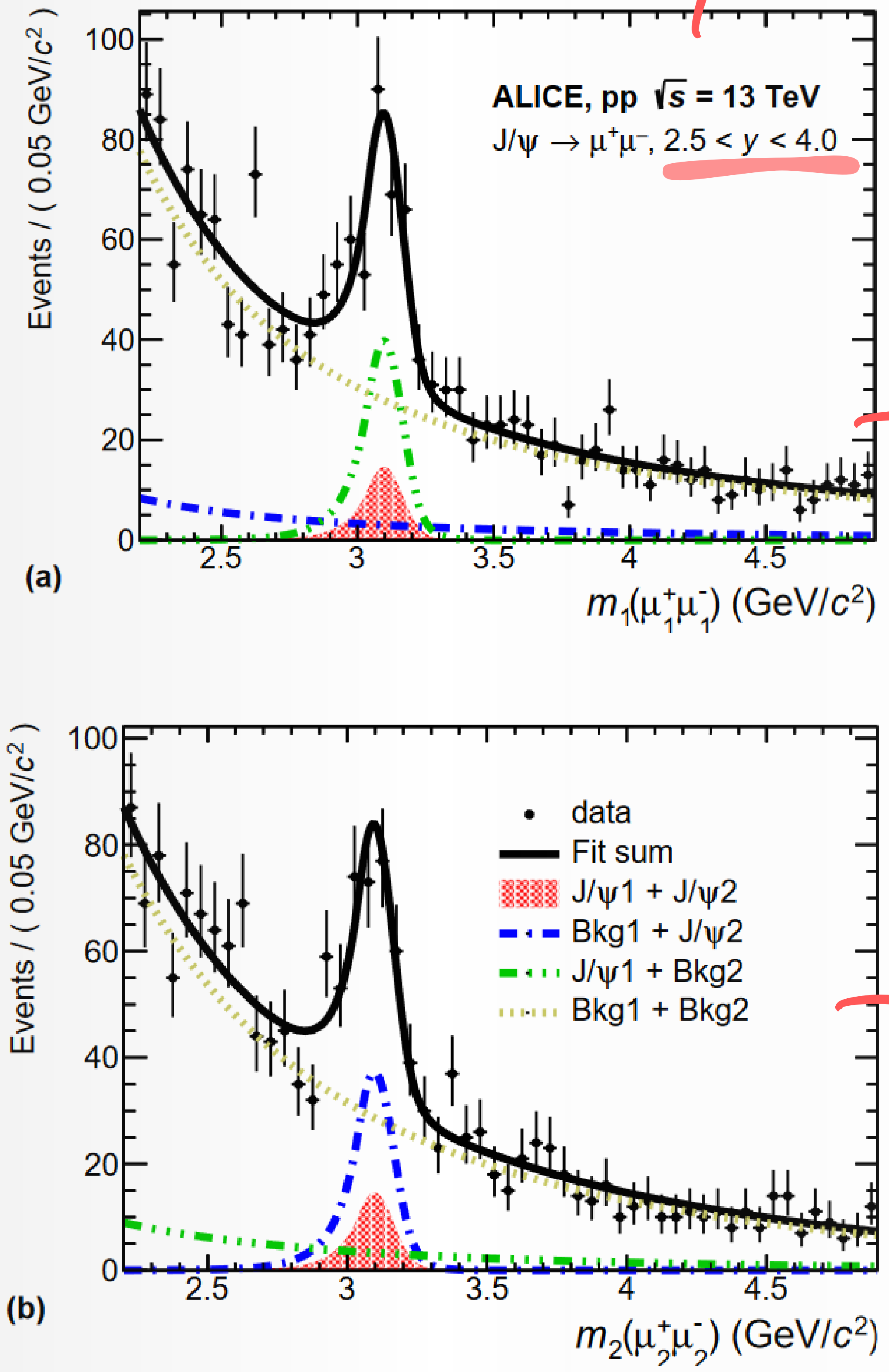


$\sqrt{S}$= 13 TEV

THE LABEL 1 OR 2 IS ASSIGNED RANDOMLY

Di-J/ψ in CMS

RUN 1

Main goals of the analysis:

- Measure the contribution from prompt di-J/ψ
- Investigate the DPS contribution

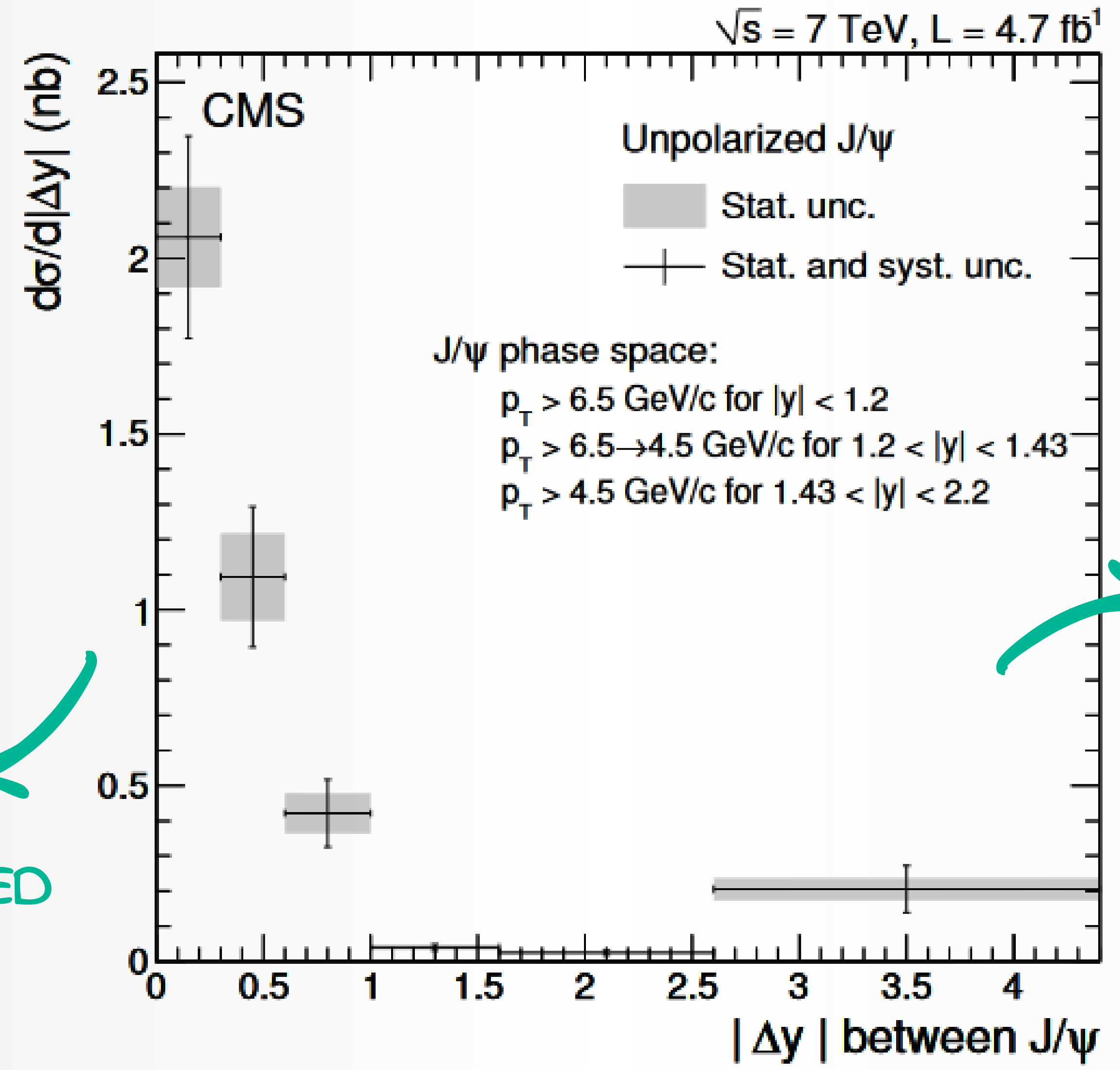
The J/ψ were reconstructed in the di-muon channel and requested to be prompt

$$\sigma_{\text{prompt}}(J/\psi J/\psi) = 1.49 \pm 0.07(\text{stat}) \pm 0.13(\text{syst.})\text{nb}$$

Then differential cross-sections in mass, |Δy| and transverse momentum were also evaluated.

CMS

LOWER ENERGY AND LUMINOSITY



SPS DOMINATED

DPS DOMINATED

NOT ENOUGH TO EXTRAPOLATE THE DPS SIGNAL, BUT ENOUGH TO SAY THAT THE DPS MUST BE THERE

https://link.springer.com/article/10.1007/JHEP09(2014)094

Di-J/ψ in CMS

RUN 2

Di-J/ψ in CMS

RUN 2

CMS

SPOILER!
WE ARE WORKING ON IT!
SO STAY TUNED

Di-J/ψ in CMS

RUN 2

CMS

SPOILER!
WE ARE WORKING ON IT!
SO STAY TUNED

HOWEVER

Di-J/ψ in CMS

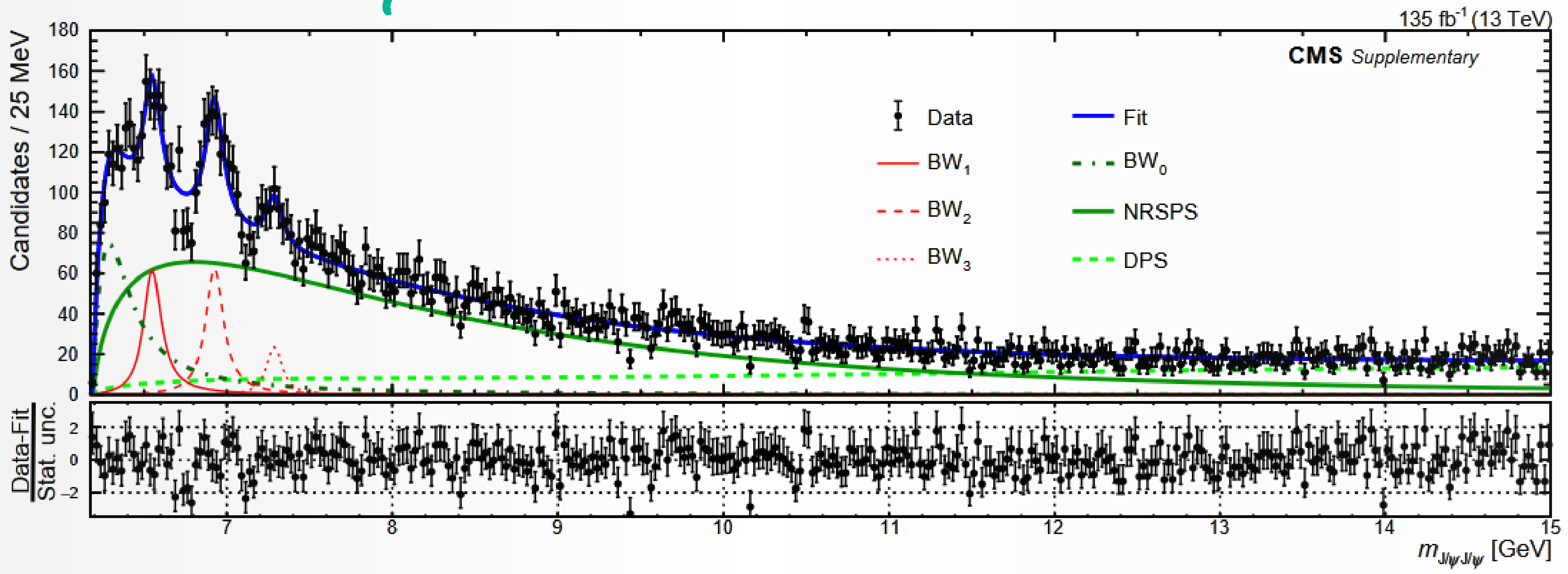
RUN 2

In this analysis the main focus was to confirm the resonances seen by LHCb:

- $6555 \pm 10(\text{stat.}) \pm 12(\text{syst.})\text{MeV}(6.5\sigma)$
- $6927 \pm 9(\text{stat.}) \pm 4(\text{syst.})\text{MeV}(9.4\sigma)$
- $7287 \pm 20(\text{stat.}) \pm 5(\text{syst.})\text{MeV}(4.1\sigma)$

√S= 13 TEV

CMS



https://arxiv.org/pdf/2306.07164.pdf

Di-J/ψ in CMS

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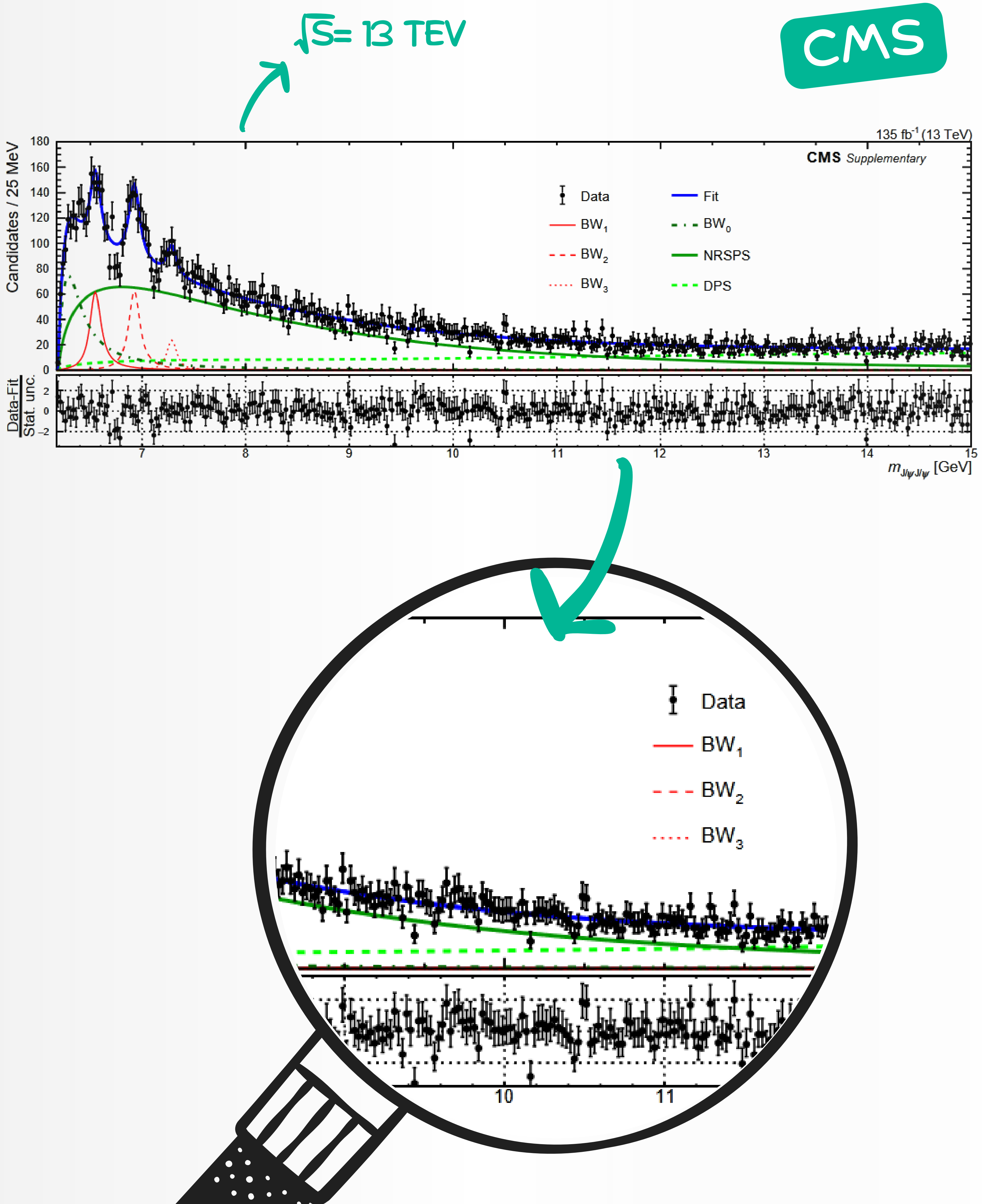
BUT

Here the DPS is a background but we learned that:

- the NR-SPS contribution is expected to dominate the DPS contribution near the J/ψJ/ψ threshold
- the DPS contribution is dominating at masses above 11 GeV.



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Di-J/ψ in CMS

Main goals of the analysis:

- Measure the production cross-section of the di-J/ψ in the di-muon (or di-electron) channel.
- Estimate the SPS/DPS contribution.

https://cds.cern.ch/record/2890161?ln=en

Di-J/ψ in CMS

82 Pb lead 207.2

CMS

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TO CLARIFY THE SPS PRODUCTION OF MULTIPLE QUARKONIUM STATES

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TO CLARIFY THE SPS PRODUCTION OF MULTIPLE QUARKONIUM STATES

TO IMPROVE OUR UNDERSTANDING OF DPS PROCESSES

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TO STUDY THE B-DEPENDENCE IN THE N-PDFS

TO CLARIFY THE SPS PRODUCTION OF MULTIPLE QUARKONIUM STATES

TO IMPROVE OUR UNDERSTANDING OF DPS PROCESSES

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CMS

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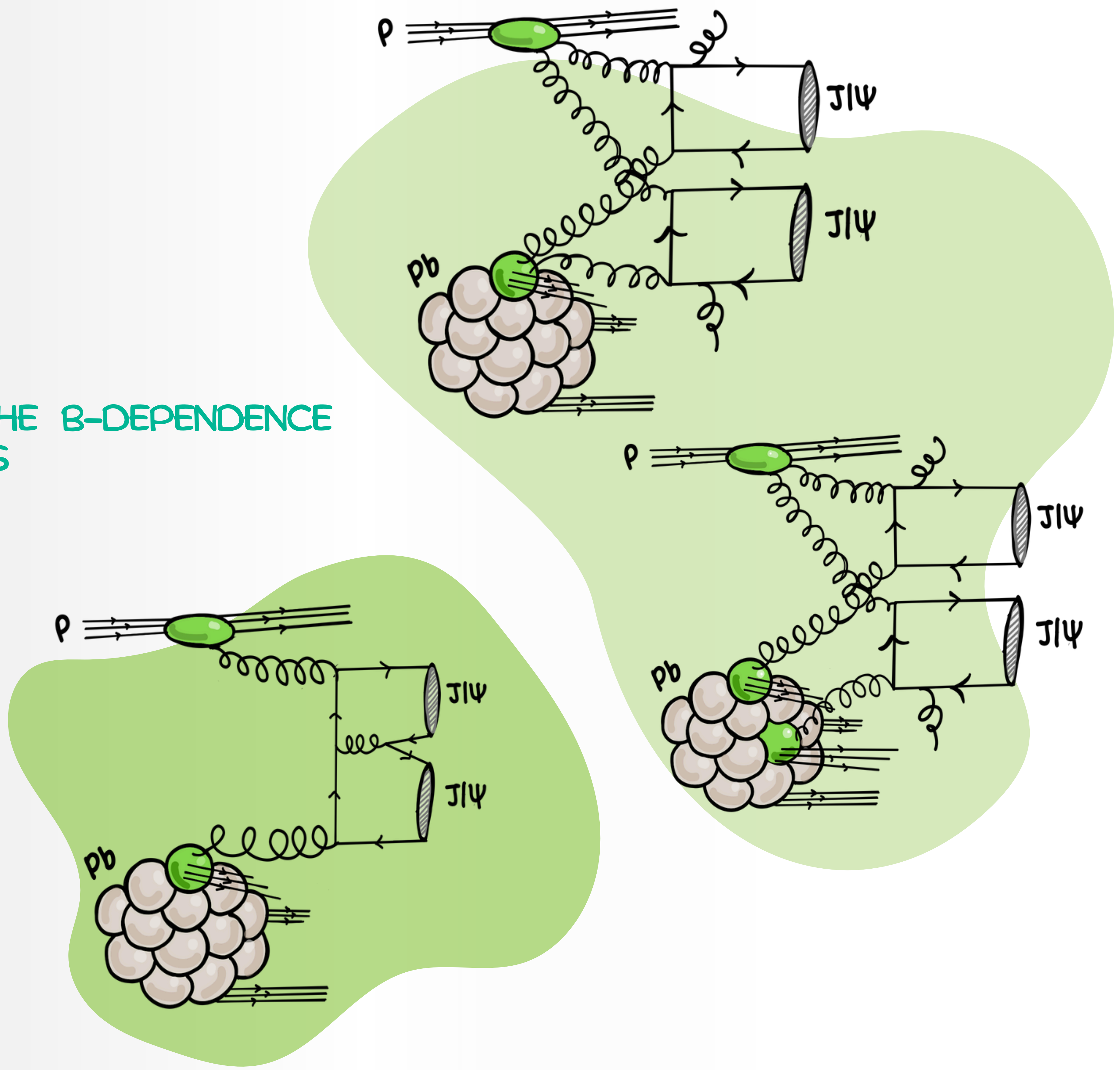
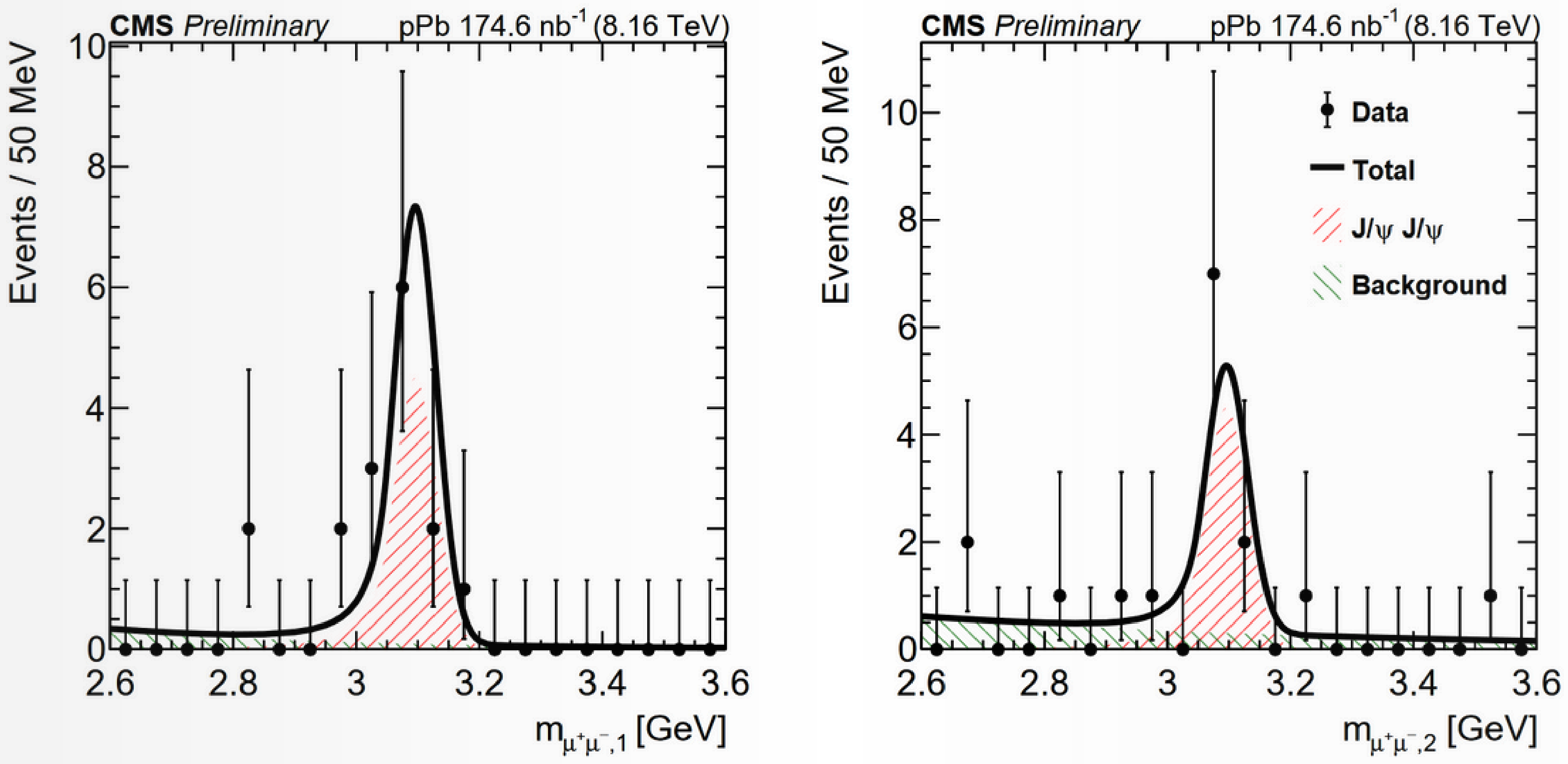
TO IMPROVE OUR UNDERSTANDING OF DPS PROCESSES



https://cds.cern.ch/record/2890161?ln=en

Di-J/ψ in CMS

The J/ψs are reconstructed in the di-muon channel. The additional request for the four muons to originate from the same vertex suppresses the non-prompt contribution.



The measured signal yield is:

$$N_{\text{sign}} \equiv N(J/\psi_1^{\text{sign}}, J/\psi_2^{\text{sign}}) = 8.5 \pm 3.4 \text{ events}$$

$$\sigma = 4.9$$

STANDARD DEVIATIONS WHEN IMPOSING N SIGNAL EVENTS = 0

$$\sigma(pPb \to J/\psi J/\psi + X) = 22.0 \pm 8.9(\text{stat}) \pm 1.5(\text{syst}) \text{ nb}$$

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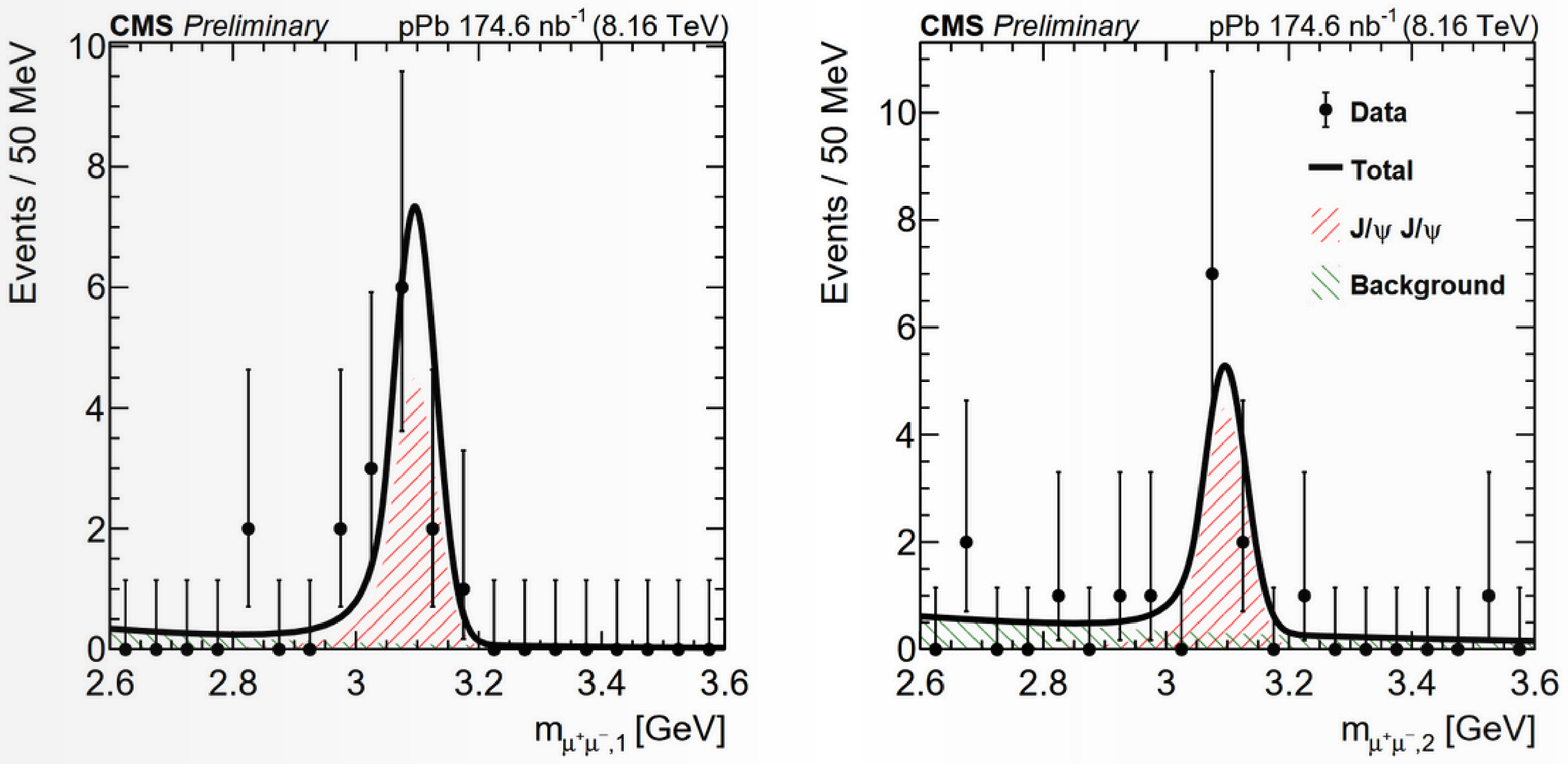

To confirm the observation were also analyzed the events where the J/ψ are reconstructed one in the di-muon channel, and the other in the di-electron channel.

The measured signal yield is:

$$N_{\text{sign}} \equiv N(J/\psi_1^{\text{sign}}, J/\psi_2^{\text{sign}}) = 5.7 \pm 4.0 \text{ events}$$

$\sigma = 2.3$ STANDARD DEVIATIONS WHEN IMPOSING N SIGNAL EVENTS = 0

https://cds.cern.ch/record/2890161?ln=en

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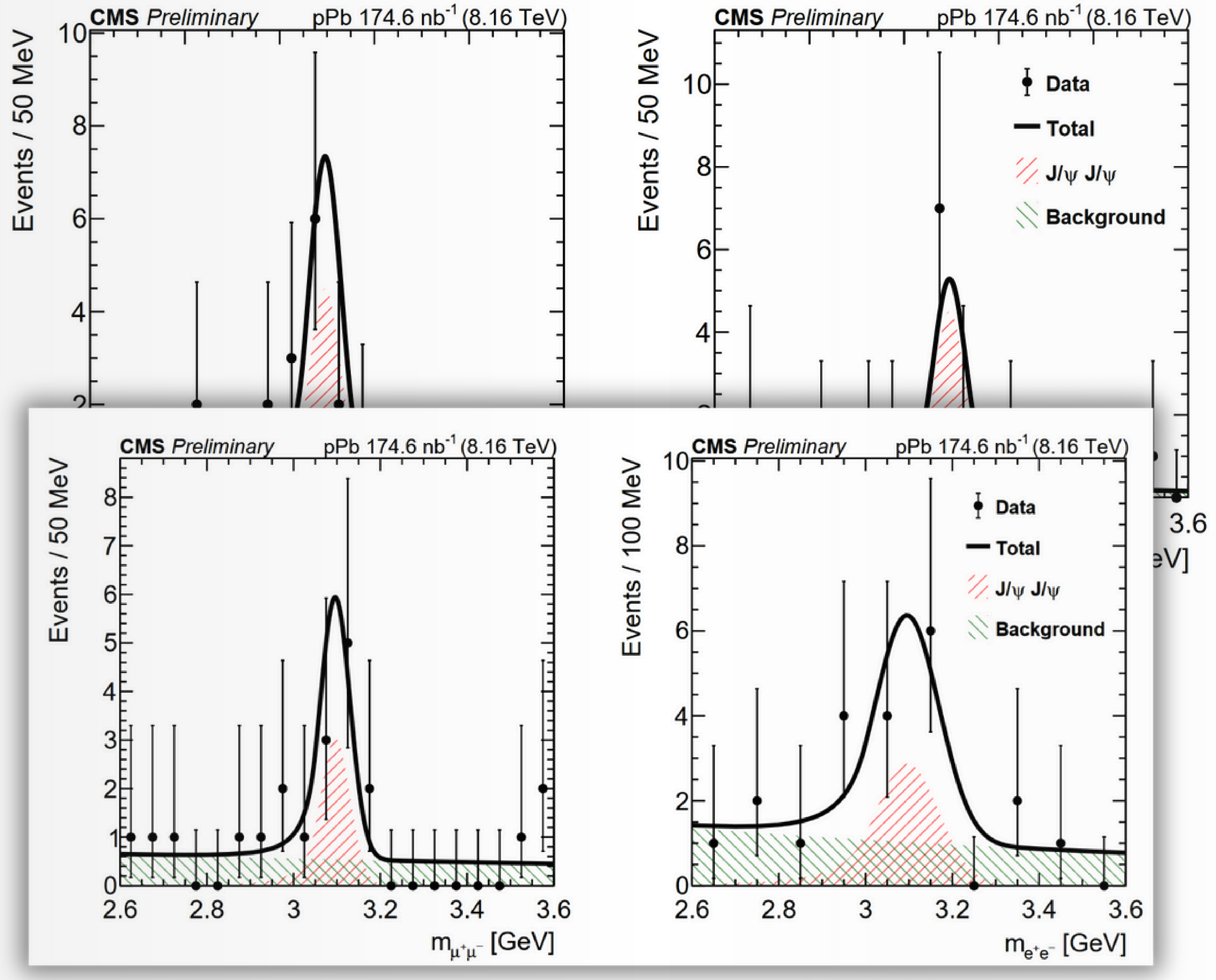

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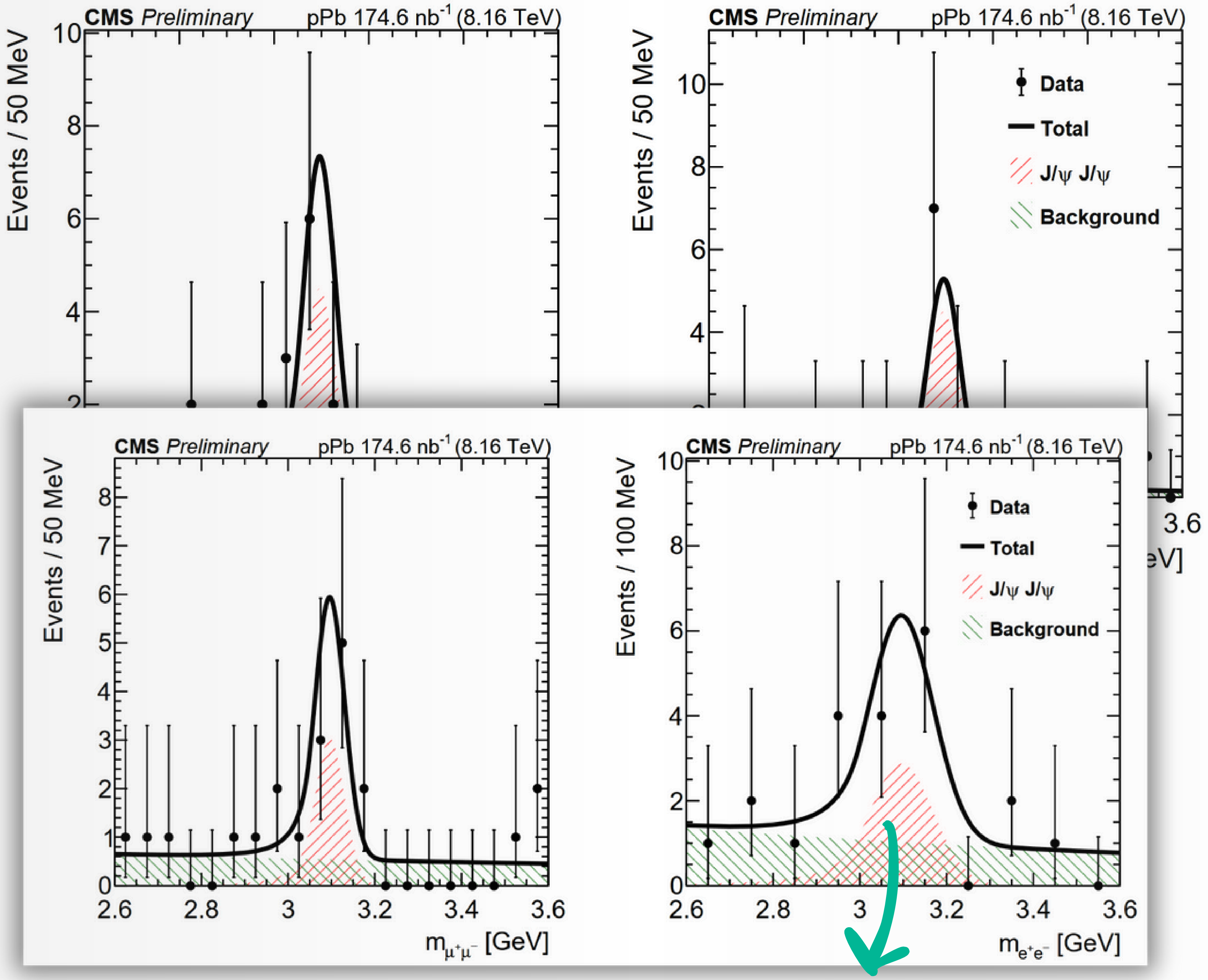


THIS LATTER CHANNEL HAS A LARGER BACKGROUND BUT INCREASES THE TOTAL SIZE OF THE DATA SAMPLE PROVIDING A CROSS-CHECK

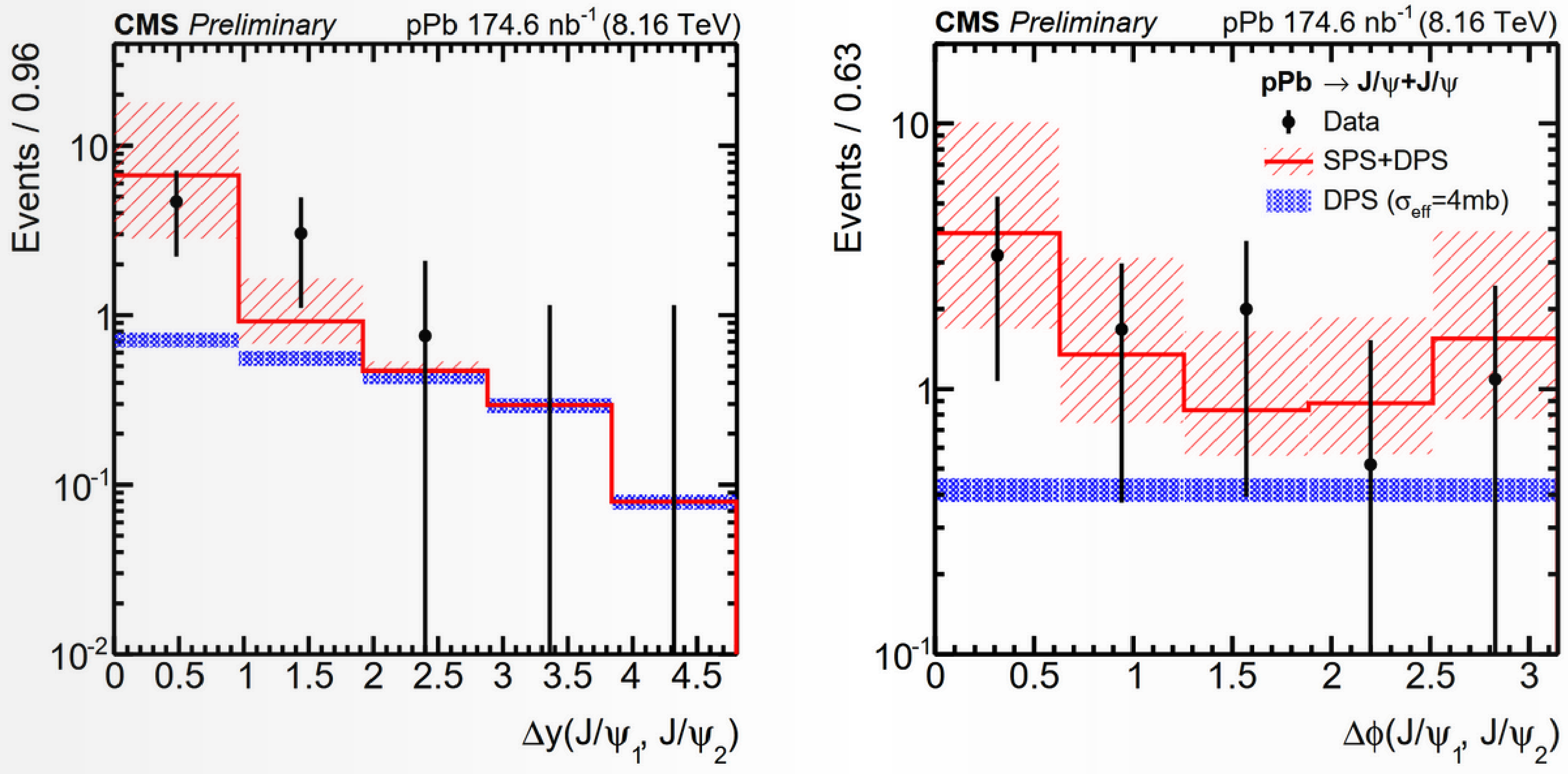
https://cds.cern.ch/record/2890161?ln=en

Di-J/ψ in CMS

Due to the limited size of our signal data sample, we cannot apply a 2D template-fit of the measured Δϕ–Δy distributions, with shapes dictated by the theoretical expectations, to extract the absolute normalization of the poorly known SPS di-J/ψ yields

INSTEAD

- We identify a phase-space region where the SPS contribution is expected to be minimal and then constrain the expected size of the DPS yield.
- We perform a 1D fit on the Δy variable. Using a data-driven DPS template we fit the weighted data in the DPS-dominated region of Δy > 1.92



THE Δy > 2 REGION IS FREE FROM SPS CONTRIBUTIONS AND THEREFORE ANY SIGNAL COUNT MEASURED THERE IS DOMINATED BY DPS PRODUCTION

https://cds.cern.ch/record/2890161?ln=en

Di-J/ψ in CMS

82
Pb
lead
207.2

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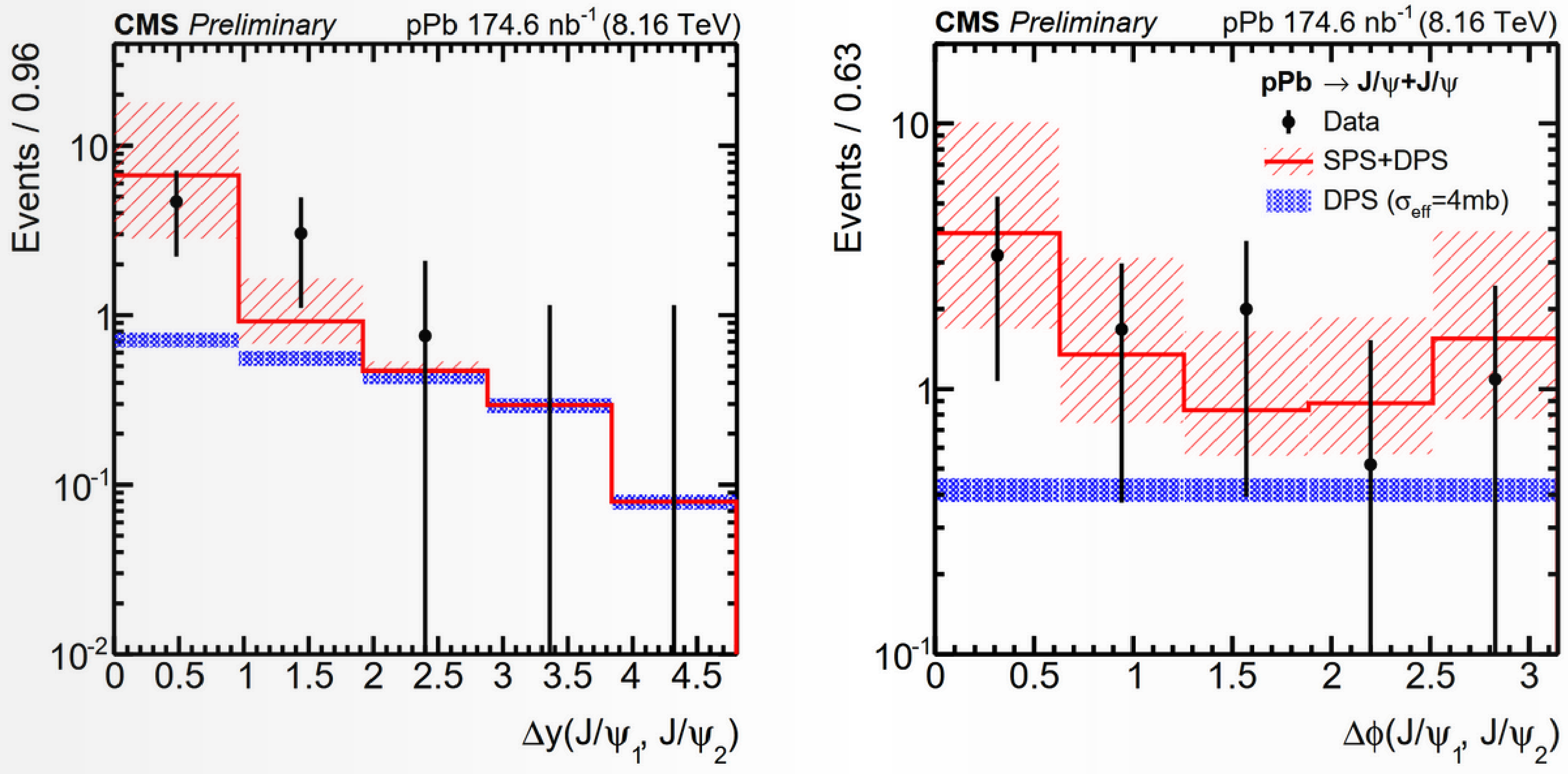
$$N_{\mathrm{DPS}} = 2.1 \pm 2.4 \quad \text{et} \quad N_{\mathrm{SPS}} = 6.4 \pm 4.2$$

$$\sigma_{\mathrm{DPS}}^{p\mathrm{Pb}\to J/\psi J/\psi+X} = 5.4 \pm 6.2\,(\mathrm{stat}) \pm 0.4\,(\mathrm{syst})\,\mathrm{nb}$$

$$\sigma_{\mathrm{SPS}}^{p\mathrm{Pb}\to J/\psi J/\psi+X} = 16.5 \pm 10.8\,(\mathrm{stat}) \pm 0.1\,(\mathrm{syst})\,\mathrm{nb}$$

https://cds.cern.ch/record/2890161?ln=en

CMS



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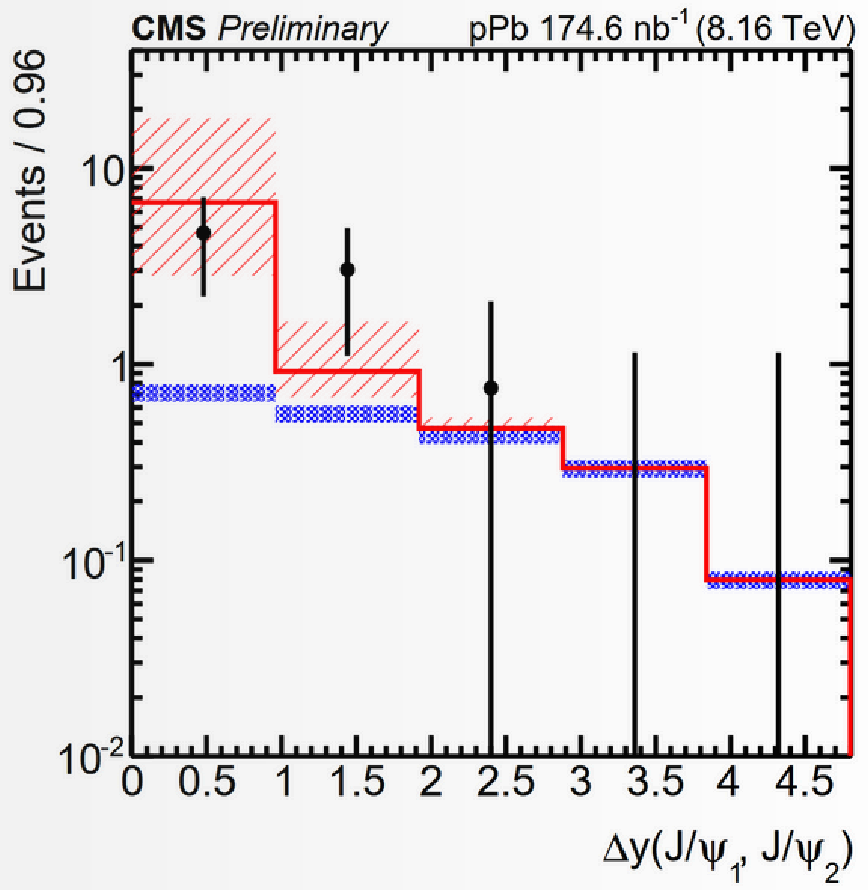

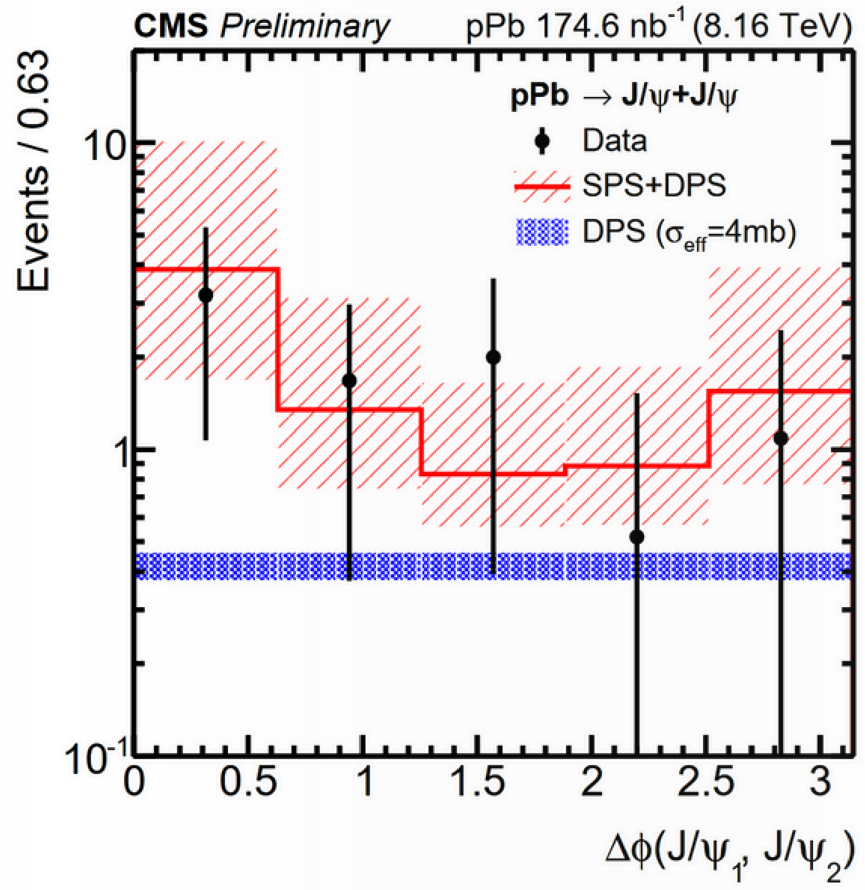

THE ARBITRARILY LARGE UPPER UNCERTAINTY THAT INDICATES THAT THE SPS YIELD ALONE WOULD BE COMPATIBLE WITH THE DATA, AND THEREFORE THAT DPS CONTRIBUTIONS COULD BE IN PRINCIPLE ABSENT

$$\sigma_{\rm eff,pA} = \left(\frac{1}{2}\right) \frac{\sigma_{\rm SPS}^{p{\rm Pb}\to J/\psi+X}\,\sigma_{\rm SPS}^{p{\rm Pb}\to J/\psi+X}}{\sigma_{\rm DPS}^{p{\rm Pb}\to J/\psi J/\psi+X}} = 0.53^{+\infty}_{-0.2}\,{\rm b}$$

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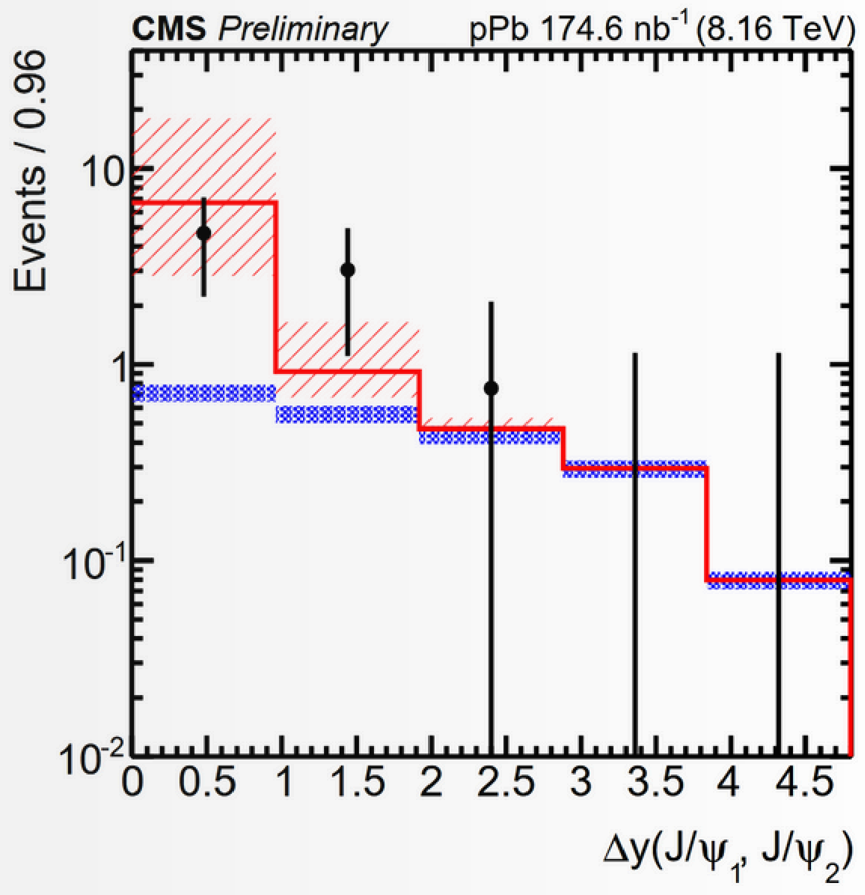

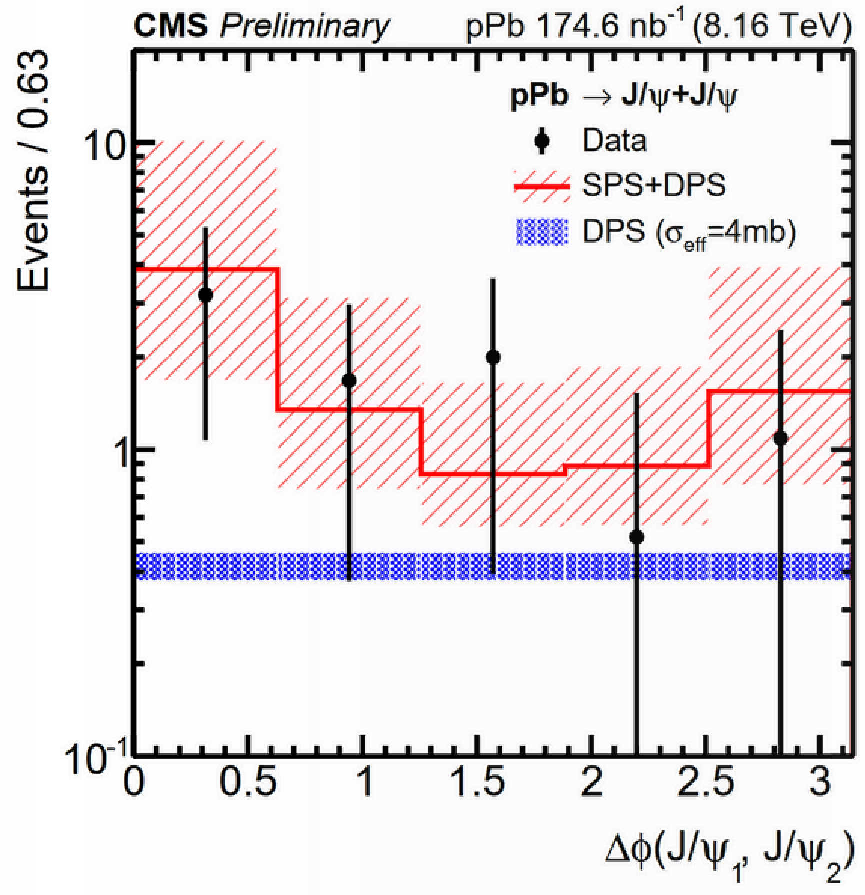

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$$\sigma_{\text{eff}} = \frac{\sigma_{\text{eff,pA}}}{A - \sigma_{\text{eff,pA}}F_{\text{pA}}/A} = 4.0^{+\infty}_{-1.5}\ \text{mb}$$

$$A = 208 \qquad F_{\text{pA}} = 29.5\,\text{mb}^{-1}$$

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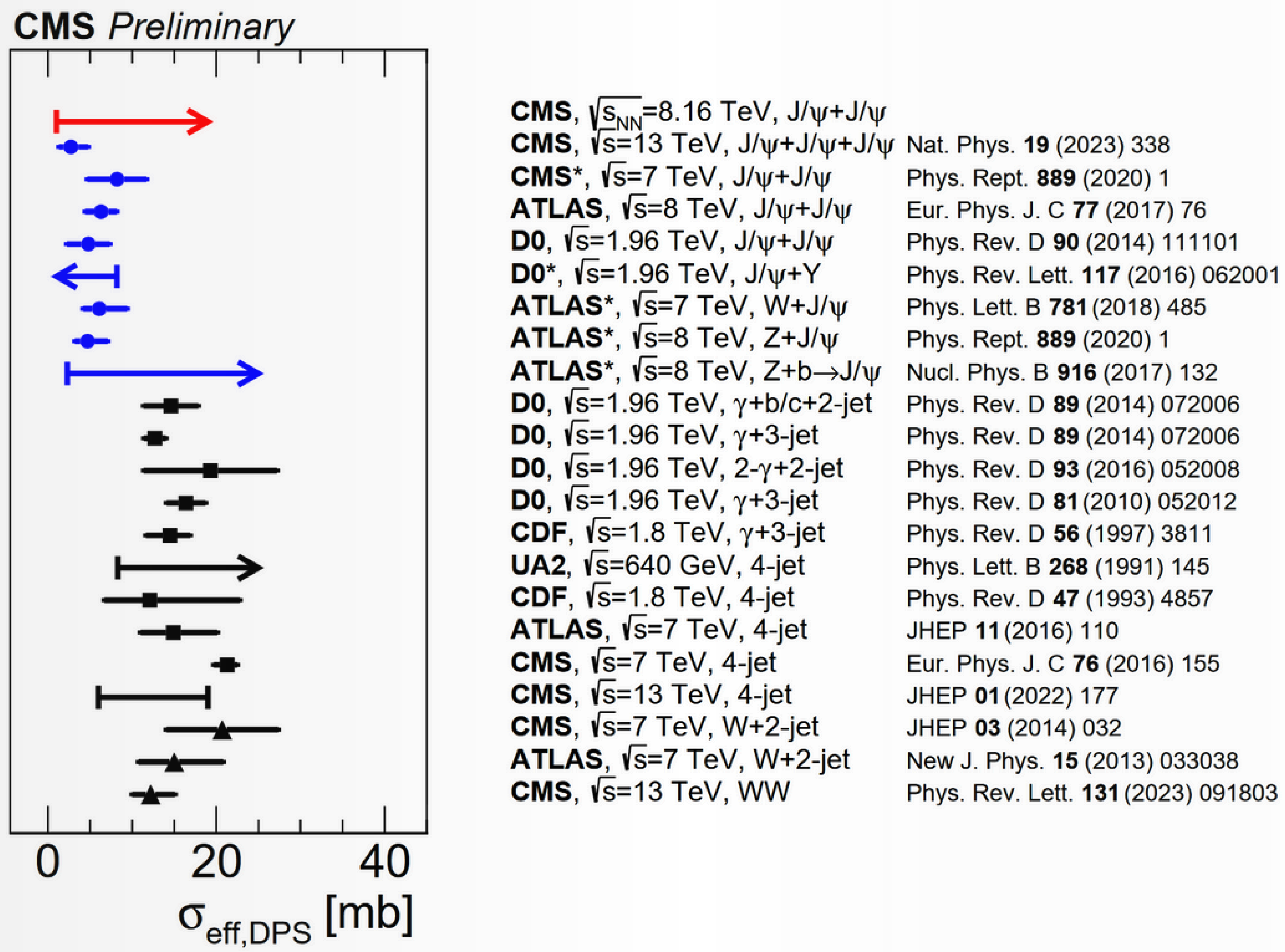

https://cds.cern.ch/record/2890161?ln=en

Di-J/ψ in ATLAS

RUN 1

ATLAS

Main goals of the analysis:

- Measure the production cross-section of the di-J/ψ:
  - SPS and DPS cross-sections as well;
  - extrapolate the effective cross-section.

THE CROSS-SECTION IS MEASURED IN TWO REGIONS

RECONSTRUCTED IN THE DI-MUON CHANNEL

https://link.springer.com/article/10.1140/epjc/s10052-017-4644-9

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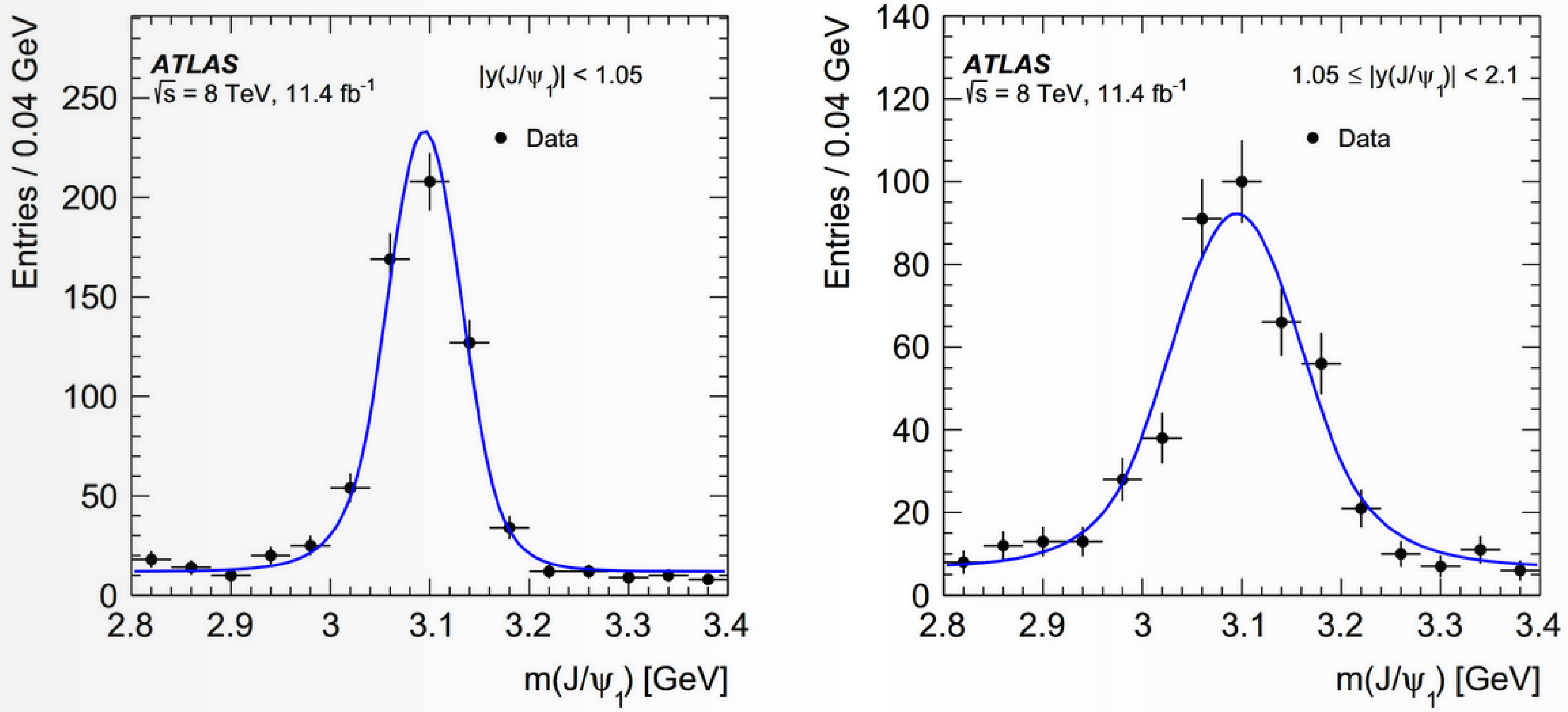
CENTRAL REGION |Y| < 1.05

$$\sigma_{\text{Fid}}(pp \to J/\psi J/\psi + X) = 15.6 \pm 1.3\,(\text{stat}) \pm 1.2\,(\text{syst}) \pm 0.2\,(\text{BF}) \pm 0.3\,(\text{lumi})\,\text{pb}$$

FOWARD REGION 1.05 < |Y| < 2.1

$$\sigma_{\text{Fid}}(pp \to J/\psi J/\psi + X) = 13.5 \pm 1.3\,(\text{stat}) \pm 1.1\,(\text{syst}) \pm 0.2\,(\text{BF}) \pm 0.3\,(\text{lumi})\,\text{pb}$$



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MEASURE THE FRACTION OF DPS EVENTS F_DPS

ONE METHOD INVOLVES FITTING THE DPS AND SPS TEMPLATES TO DATA.

UNDER THE FACTORIZATION ASSUMPTION WE CREATE A DATA-DRIVEN SAMPLE COMBINING TWO RANDOM J/Ψ/ EVENTS FROM THE DATA (OBVIOUSLY, THE KINEMATICS MUST PASS THE REQUIREMENTS)

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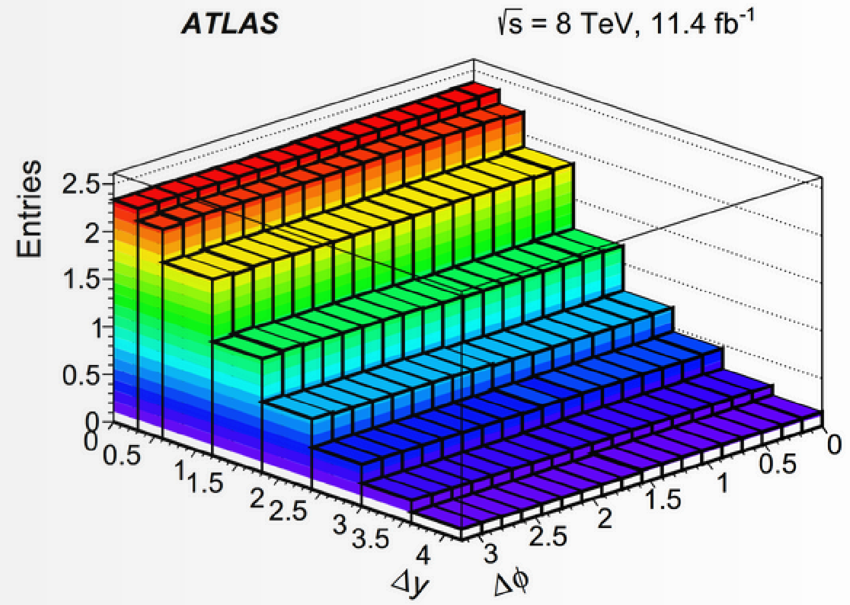
ATLAS

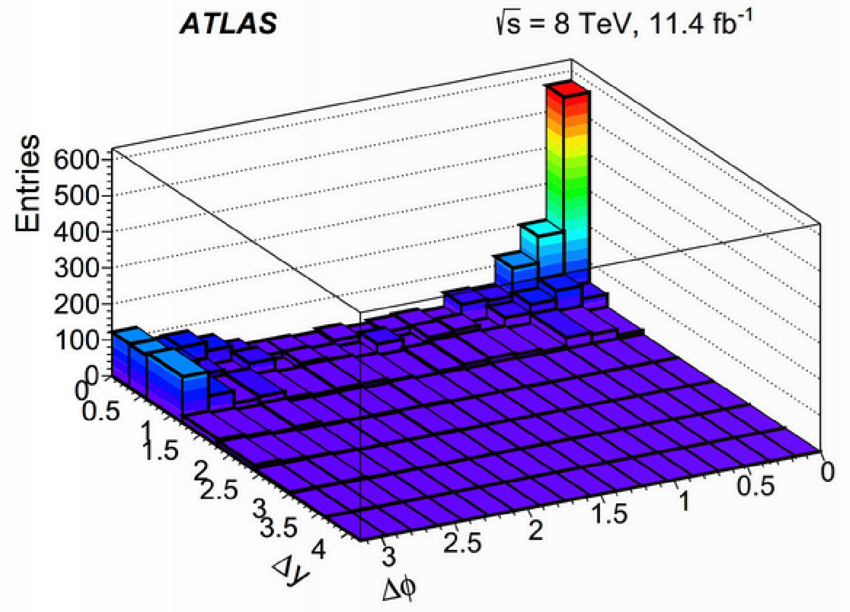
THE DPS CONTRIBUTION IS NORMALISED IN A REGION WHERE THE SPS IS CONSIDERED NEGLIGIBLE

$$w_{\text{DPS}}(\Delta\phi,\ \Delta y) = \frac{N_{\text{DPS}}(\Delta\phi,\ \Delta y)}{N_{\text{Data}}(\Delta\phi,\ \Delta y)}$$

$$w_{\text{SPS}}(\Delta\phi,\ \Delta y) = \frac{N_{\text{SPS}}(\Delta\phi,\ \Delta y)}{N_{\text{Data}}(\Delta\phi,\ \Delta y)}$$

$$f_{\text{DPS}} = (9.2\ \pm\ 2.1\ (\text{stat}) \pm 0.5(\text{syst}))\%$$





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ONCE WE HAVE F_DPS WE CAN MEASURE THE DPS C.S.

$$\sigma_{DPS}^{J/\psi,J/\psi} = 14.8 \pm 3.5(\text{stat}) \pm 1.5(\text{syst}) \pm 0.2(\text{BF}) \pm 0.3(\text{lumi})\text{pb}$$

$$\sigma_{\text{eff}} = \frac{1}{2}\frac{\sigma^2_{J/\psi}}{\sigma^{J/\psi,J/\psi}_{\text{DPS}}} \; \frac{1}{2}\frac{\sigma^2_{J/\psi}}{f_{\text{DPS}} \times \sigma_{J/\psi J/\psi}} = $$

$$= 6.3 \pm 1.6\ (\text{stat}) \pm 1.0\ (\text{syst}) \pm 0.1\ (\text{BF}) \pm 0.1\ (\text{lumi})\ \text{mb}$$

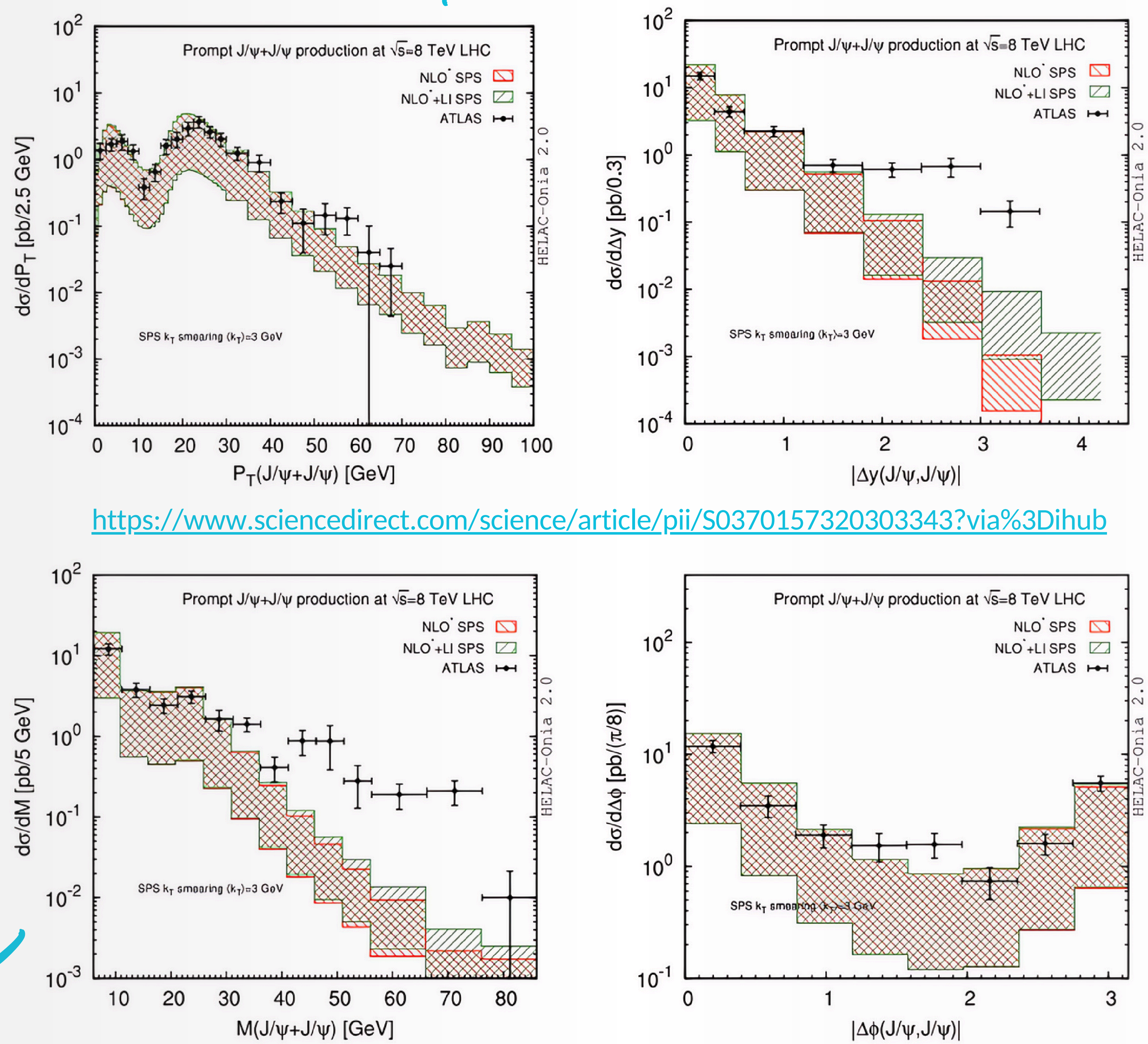
THE DISCREPANCIES MAY ARISE FROM THE FEED-DOWN CONTRIBUTIONS WHICH COULD CHANGE THE KINEMATIC PROPERTIES OF THE SPS CONTRIBUTION

https://link.springer.com/article/10.1140/epjc/s10052-017-4644-9

ATLAS

11.4 FB $^{-1}$

$\sqrt{S}$ = 8 TEV



https://www.sciencedirect.com/science/article/pii/S0370157320303343?via%3Dihub

(c)

(d)

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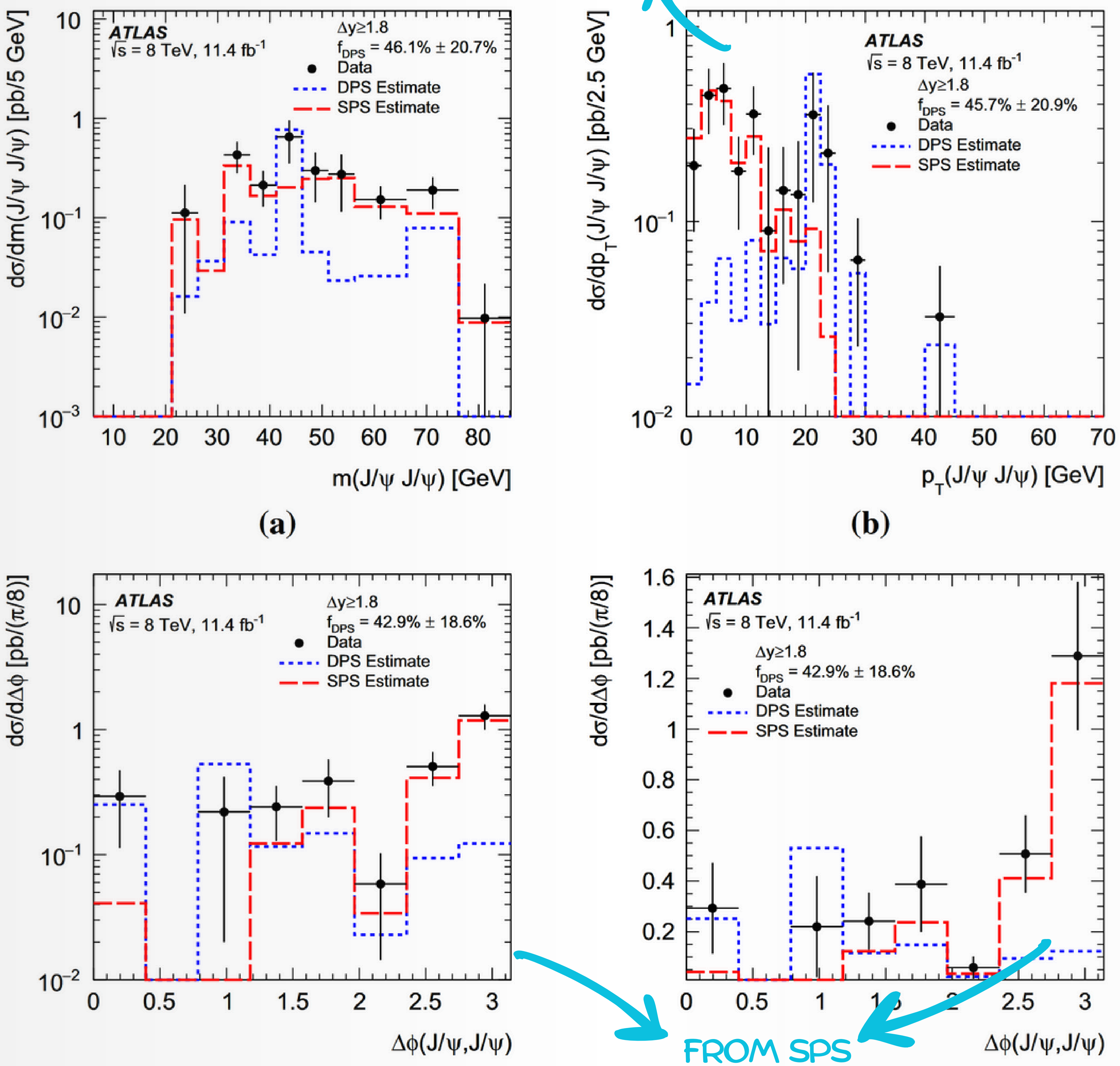
$$= 6.3 \pm 1.6\,(\text{stat}) \pm 1.0\,(\text{syst}) \pm 0.1\,(\text{BF}) \pm 0.1\,(\text{lumi})\text{ mb}$$

ATLAS

PRODUCED IN AN AWAY TOPOLOGY



FROM SPS

BACK-TO-BACK FROM FEED-DOWN

https://link.springer.com/article/10.1140/epjc/s10052-017-4644-9

Di-J/ψ in ATLAS

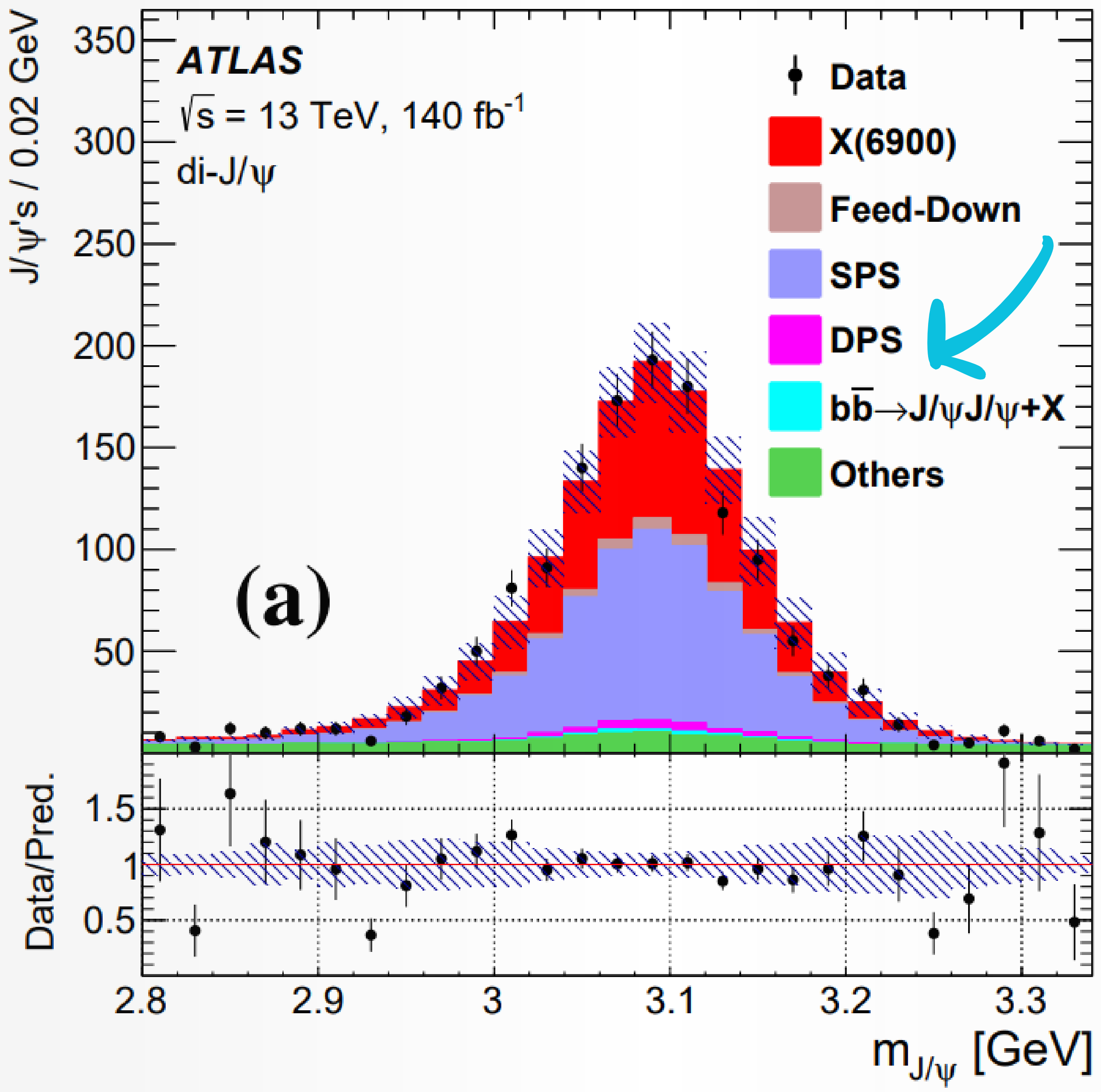
RUN 2

ATLAS

Like CMS, ATLAS has reproduced the di-J/ψ analysis to confirm the new resonances over 6.9 GeV.

But, differently from the other experiments, ATLAS has also investigated the J/ψ + Υ(1S) channel.

BUT...WHAT ABOUT DPS?



Phys. Rev. Lett. 131 (2023) 151902

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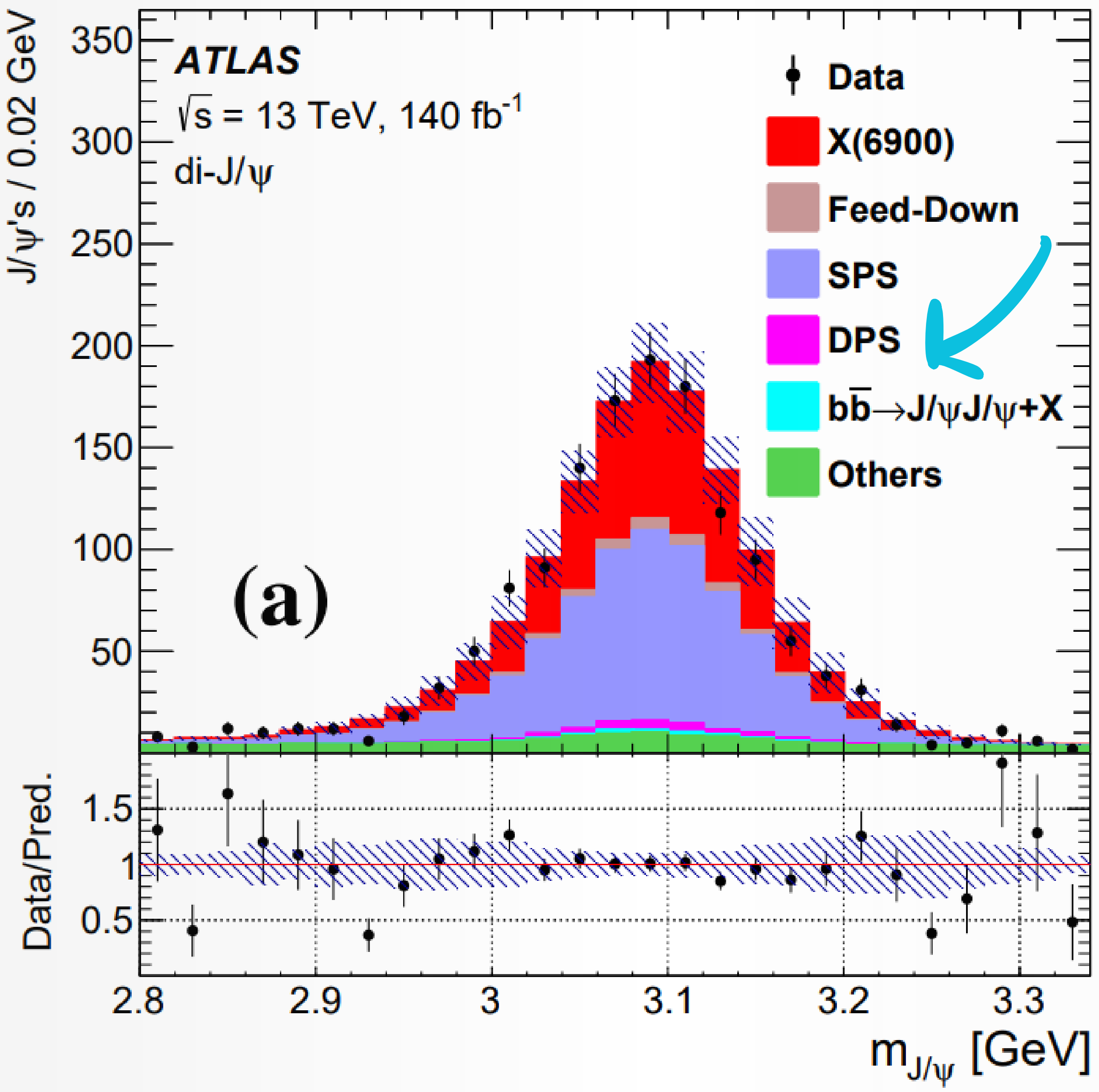

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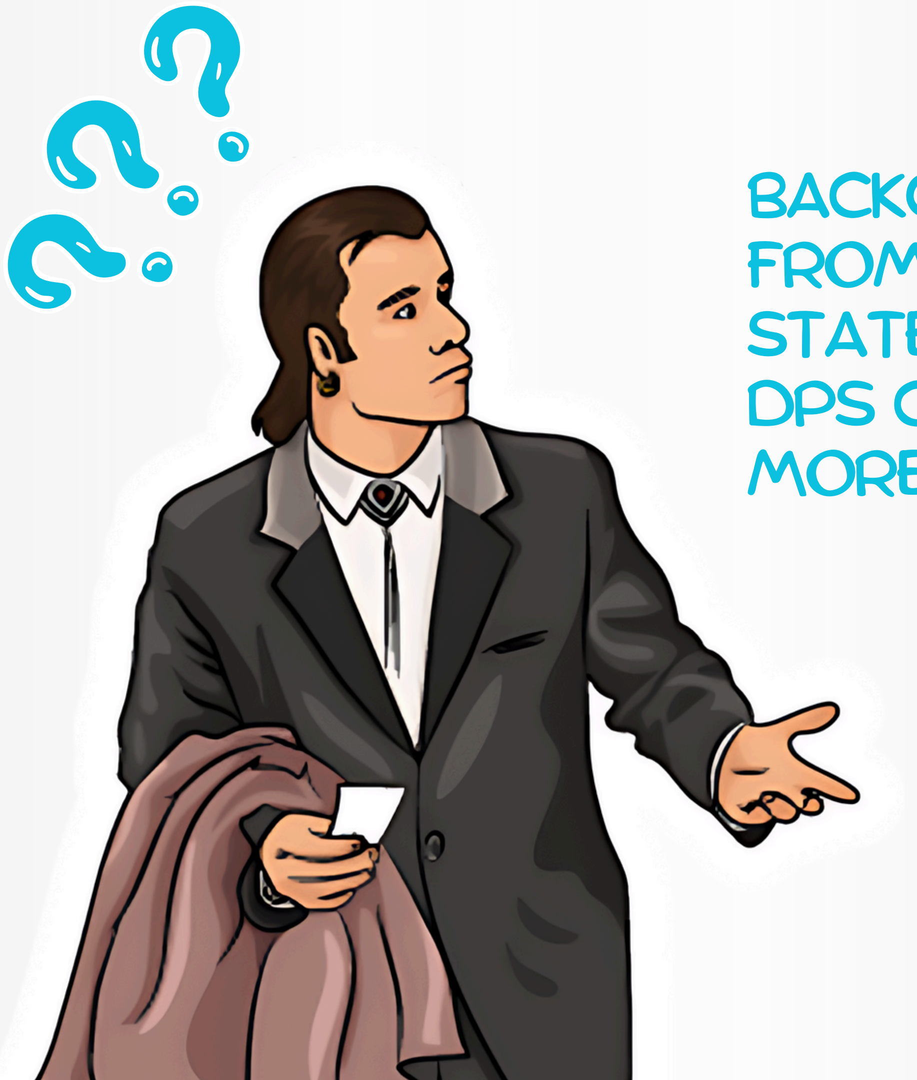
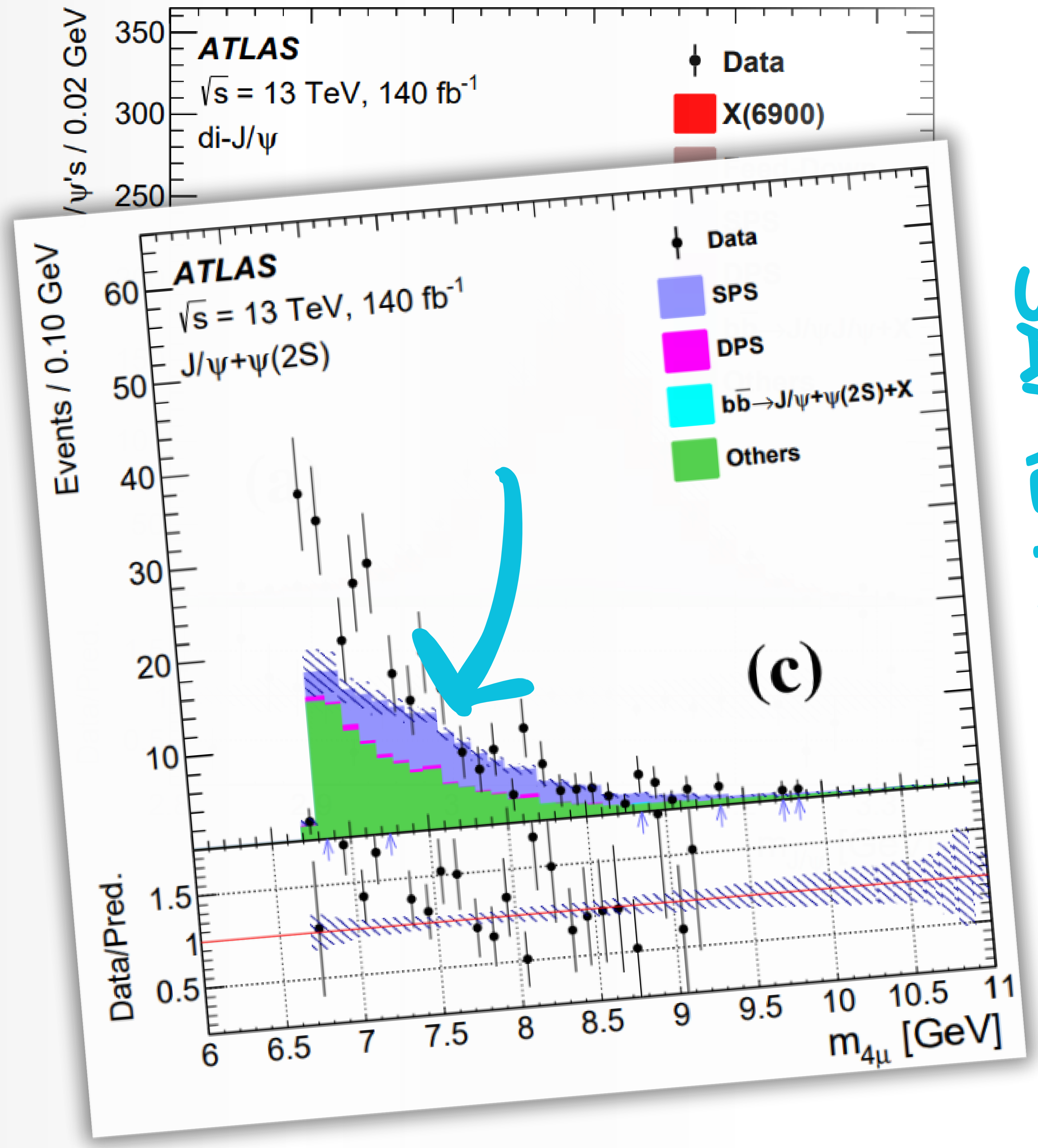


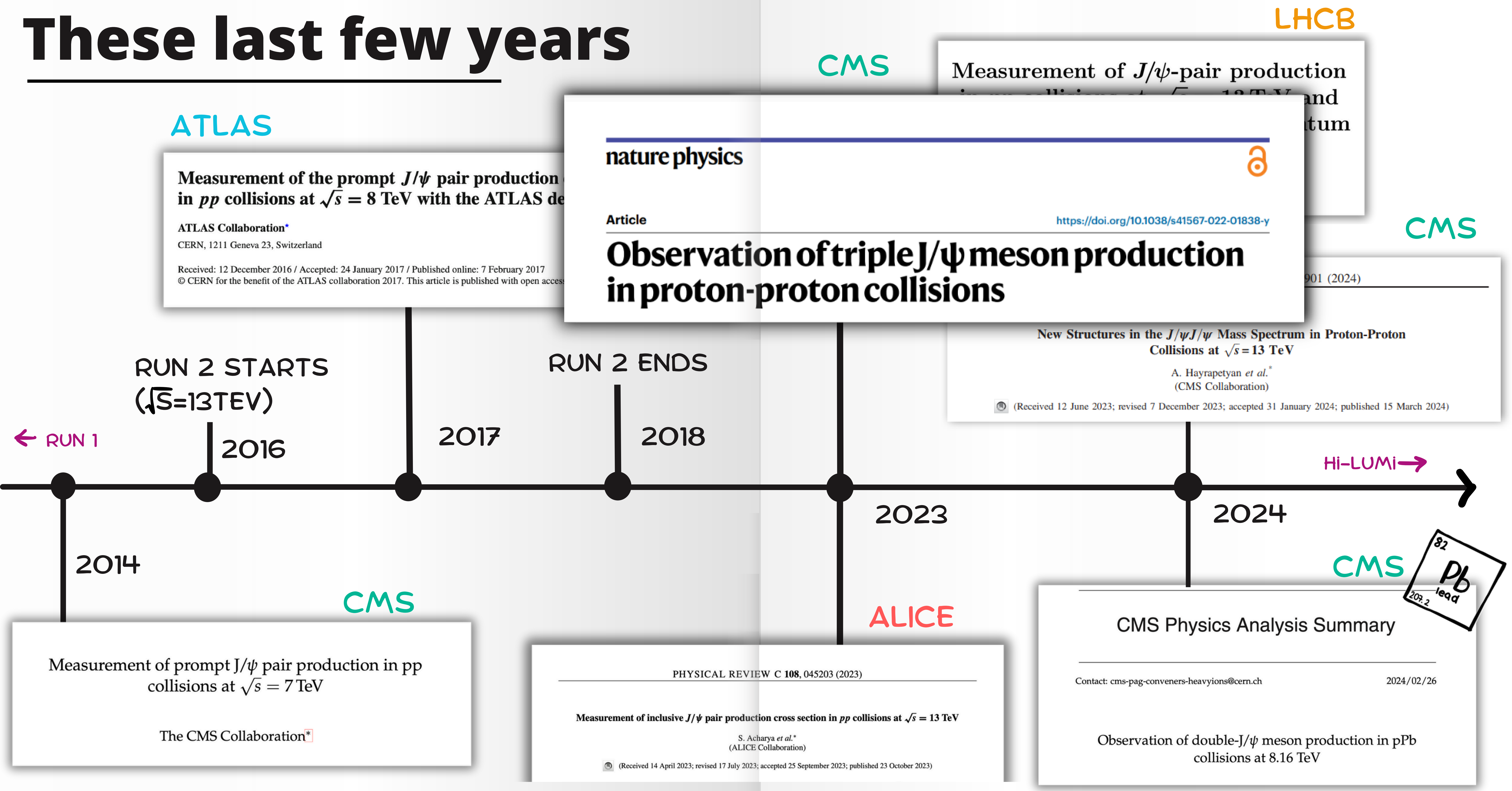
BACKGROUND DOMINATED FROM SPS IN BOTH THE FINAL STATES: J/ΨJ/Ψ AND J/Ψ + Ψ(2S). DPS CONTRIBUTION MAY BE MORE PRESENT IN J/Ψ + Ψ(2S)?



SAME PAPER!!!

Triple-J/ψ

These last few years



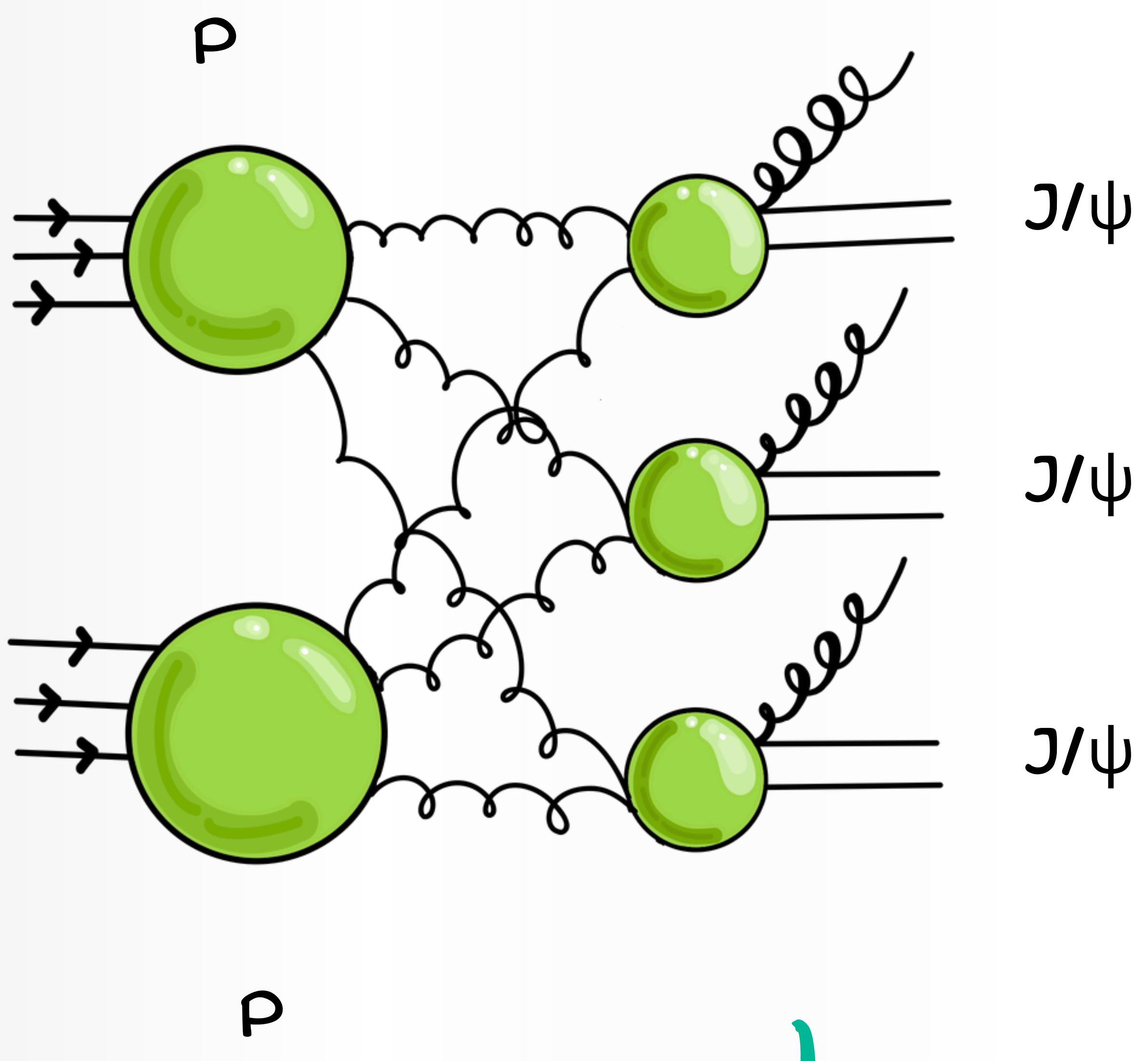
Triple-J/ψ in CMS

CMS

M = 1, 3, OR 6 (DEPENDING ON WHETHER ALL THREE, TWO, OR NONE OF THE ψ STATES ARE IDENTICAL).

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

N THE ABSENCE OF PARTON CORRELATIONS, THE EFFECTIVE CROSS-SECTION σEFF,TPS IS CLOSELY RELATED TO ITS DPS COUNTERPART



THE SIGNAL FOR US IS FROM PROMPT CONTRIBUTION AND ALL THE POSSIBLE MIXED PROMPT+ NON-PROMPT STATES

https://www.nature.com/articles/s41567-022-01838-y#citeas

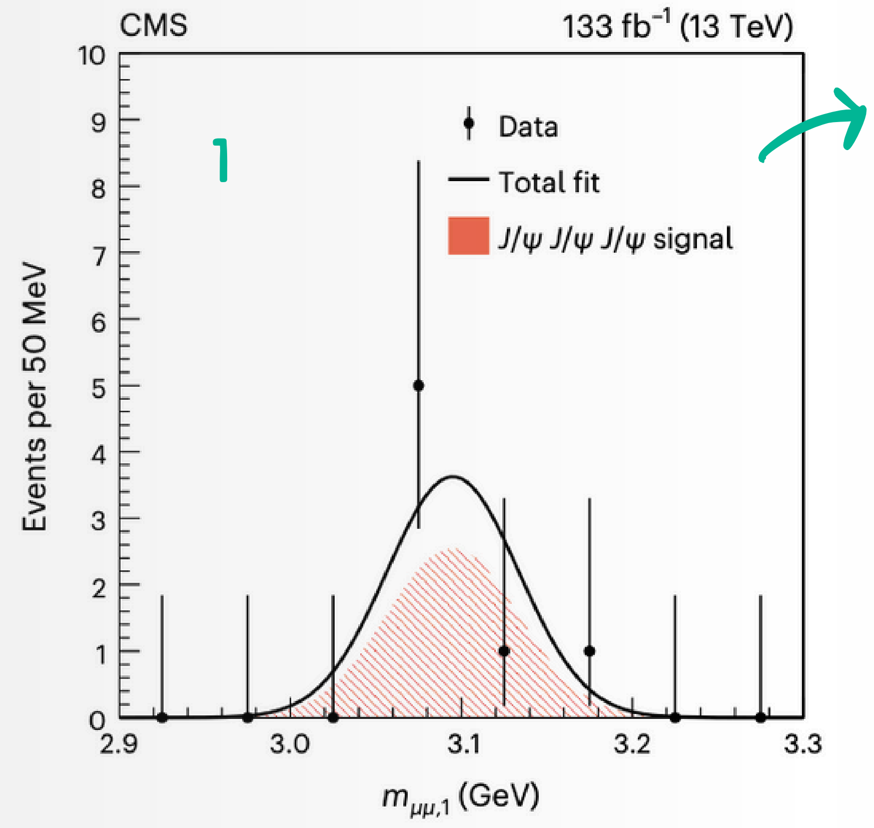
Triple-J/ψ in CMS

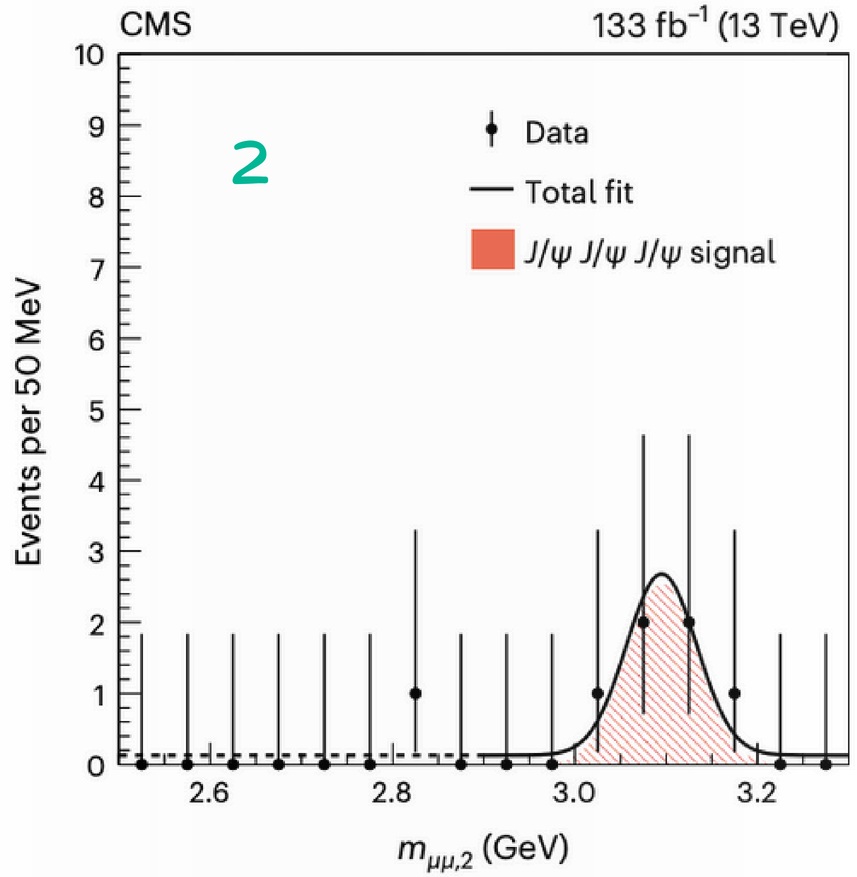
The goals of this analysis are:

- To measure the production cross-section of the triple J/ψ
- Interpret the result in terms of SPS, DPS, and TPS cross-sections

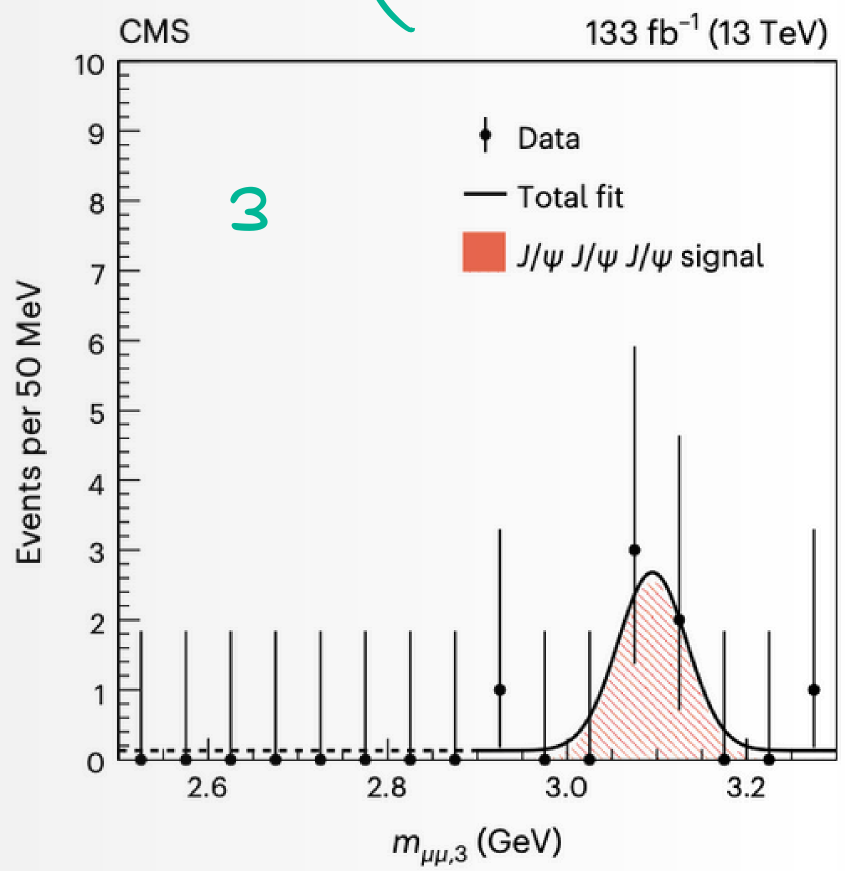
√S= 13 TEV

CMS





133 FB $^{-1}$



THE J/Ψ WERE RECONSTRUCTED IN THE DI-MUON CHANNEL

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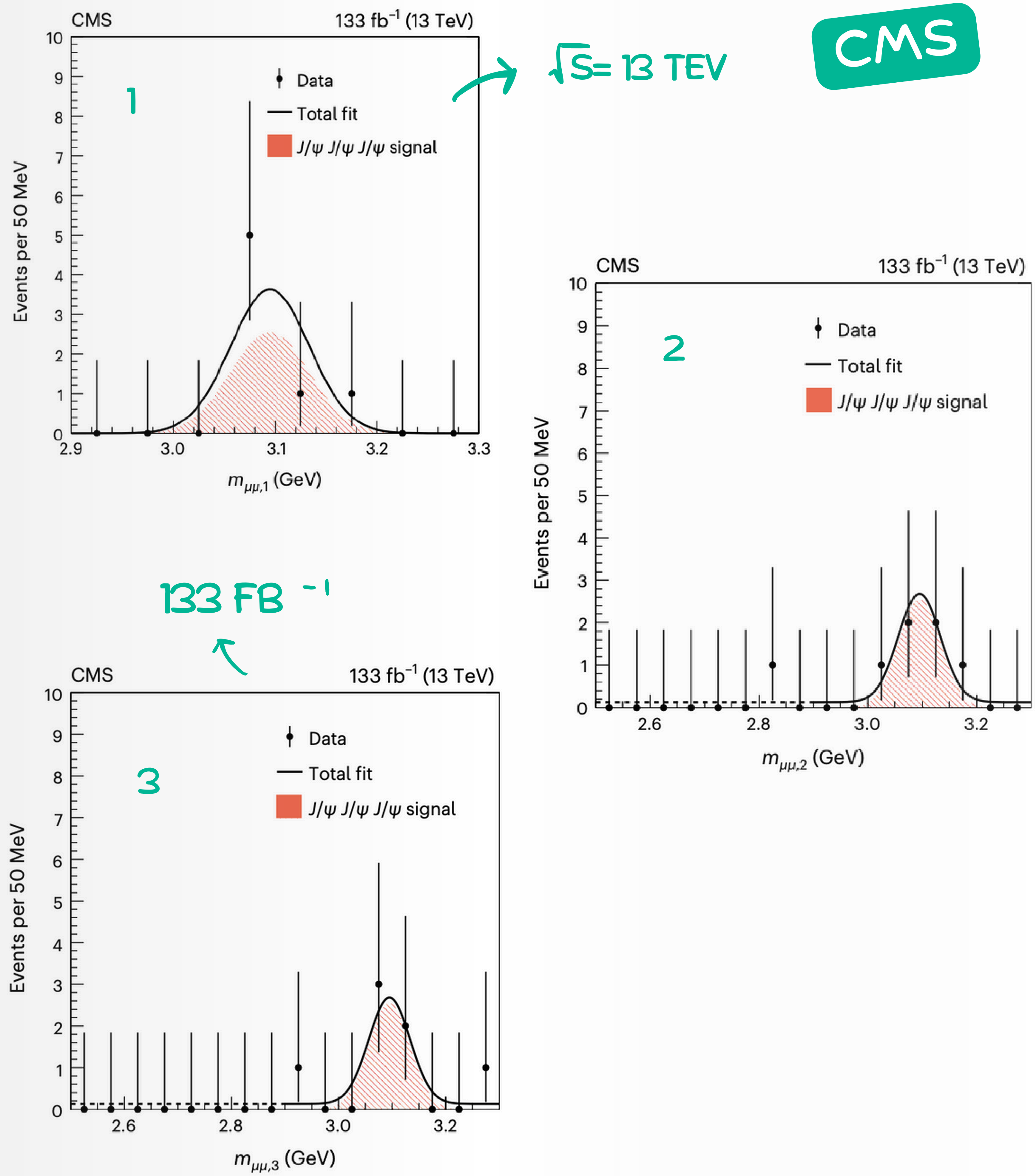
$$N_{\text{sign}}^{3J/\psi} = 5.0^{+2.6}_{-1.9} \quad + \quad N_{bkg} = 1^{+1.4}_{-0.8}$$

6.7 STD. DEV. FROM THE NULL HYPOTESIS

↓

$$\sigma(pp \to J/\psi J/\psi J/\psi X) = 272 + 141(\text{stat}) \pm 17(\text{syst})\text{fb}$$



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$$N^{3J/\psi}_{\text{sign}} = 5.0^{+2.6}_{-1.9} \quad + \quad N_{bkg} = 1^{+1.4}_{-0.8}$$

6.7 STD. DEV. FROM THE NULL HYPOTESIS

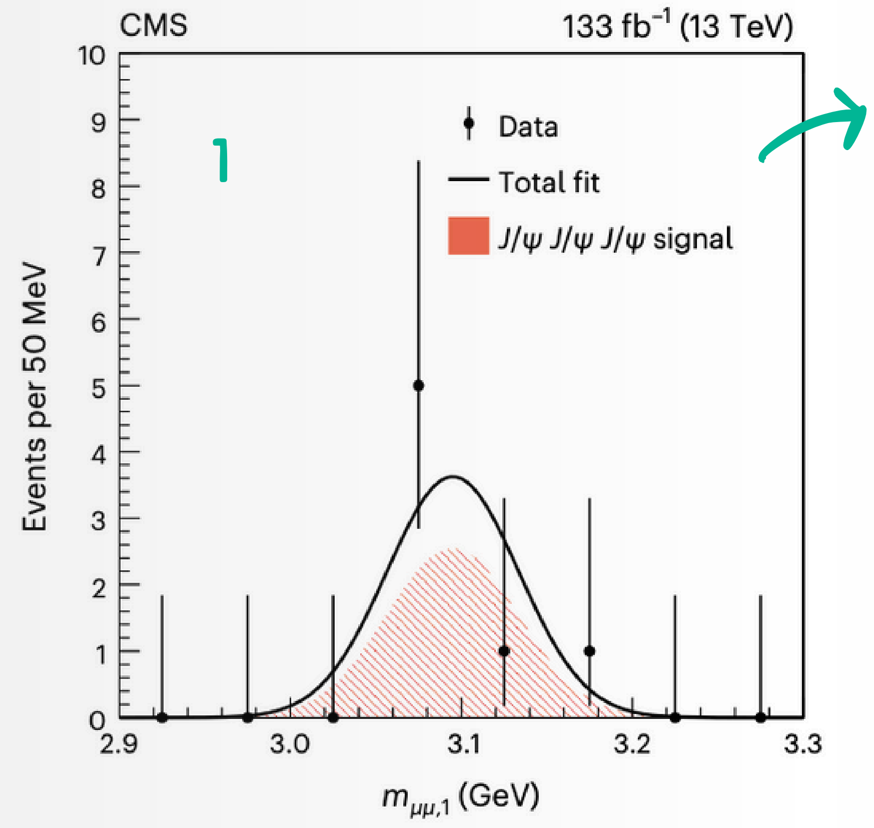
↓

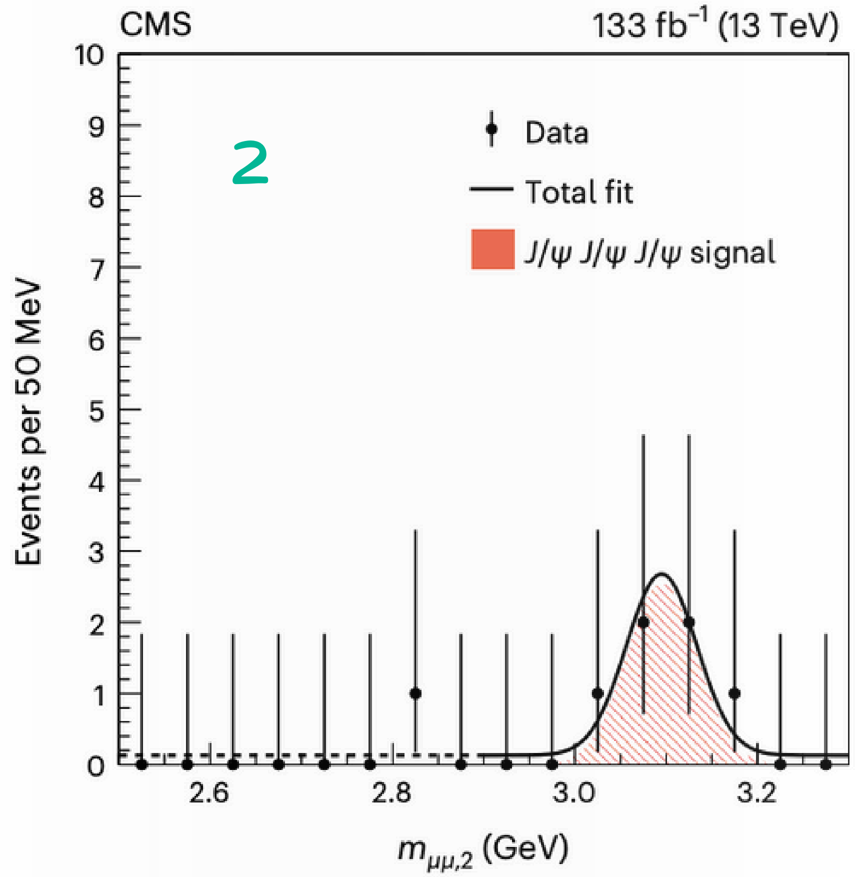
$$\sigma(pp \to J/\psi J/\psi J/\psi X) = 272 + 141(\text{stat}) \pm 17(\text{syst})\text{fb}$$

https://www.nature.com/articles/s41567-022-01838-y#citeas

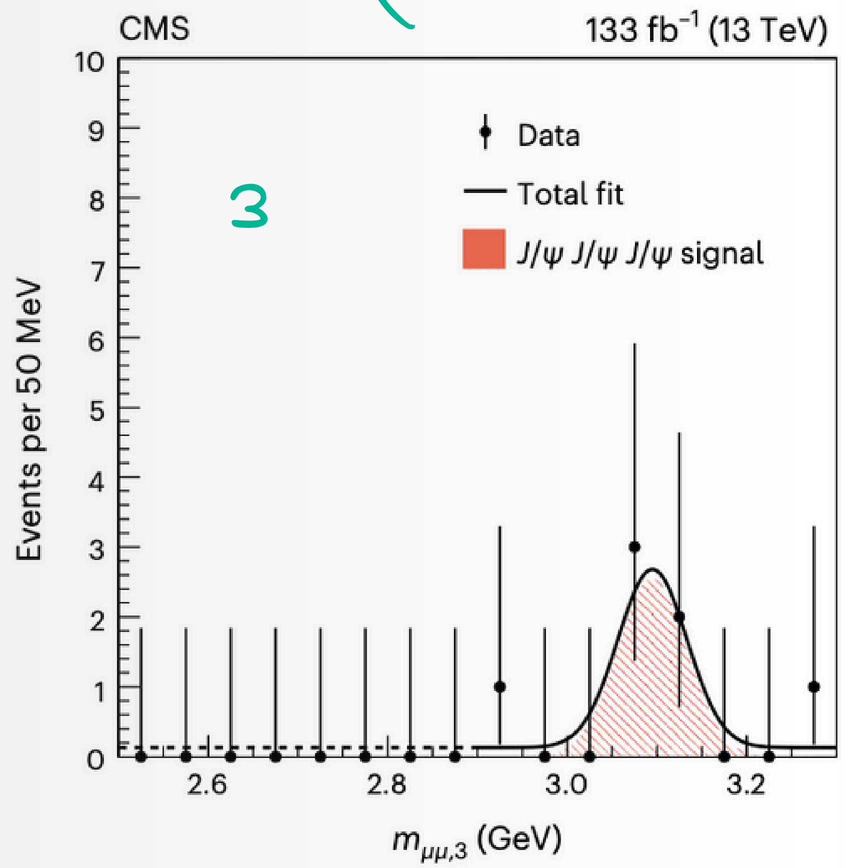
√S= 13 TEV

CMS





133 FB $^{-1}$



6 % SPS
70% DPS
20% TPS

Triple-J/ψ in CMS

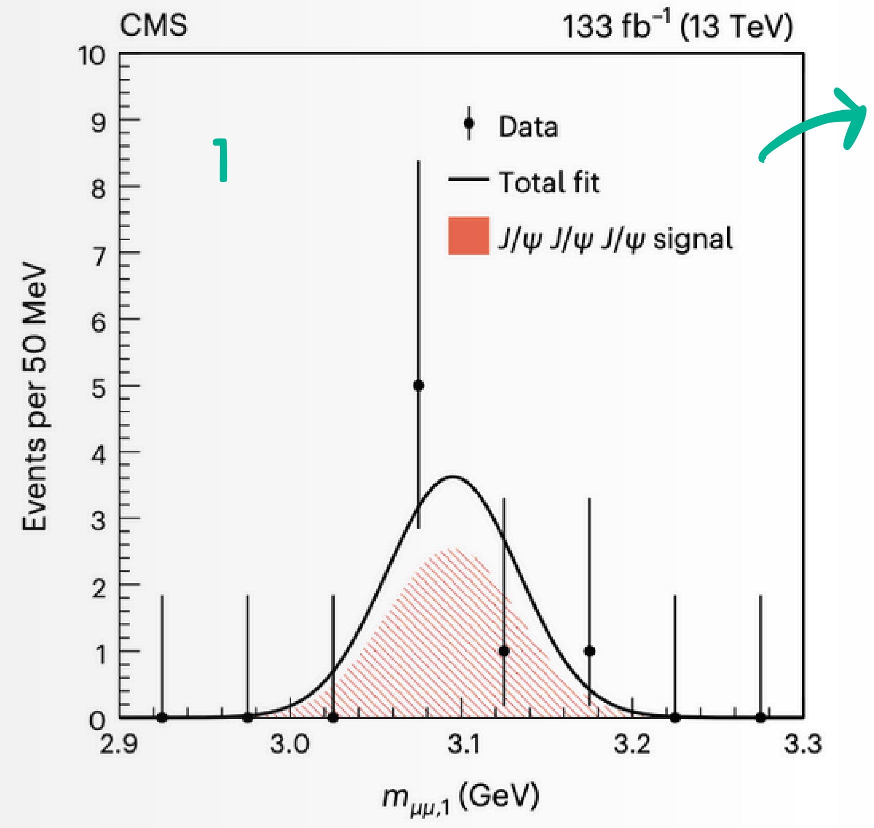
The goals of this analysis are:

- To measure the production cross-section of the triple J/ψ
- Interpret the result in terms of SPS, DPS, and TPS cross-sections

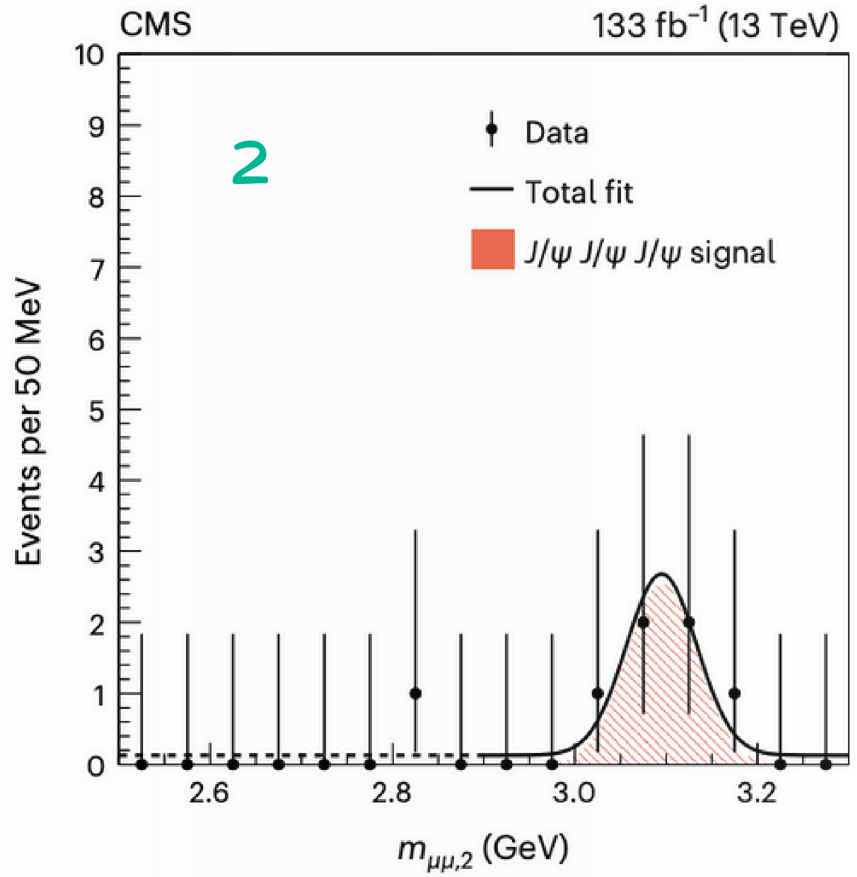
$$\sigma_{\text{eff, DPS}} = 2.7^{+1.4}_{-1.0}(\text{exp}) \pm^{1.5}_{-1.0} (\text{theo})\ \text{mb}$$

$$\sigma_{\text{eff,TPS}} = 0.82\sigma_{\text{eff,DPS}} = 2.2\ \text{mb}$$

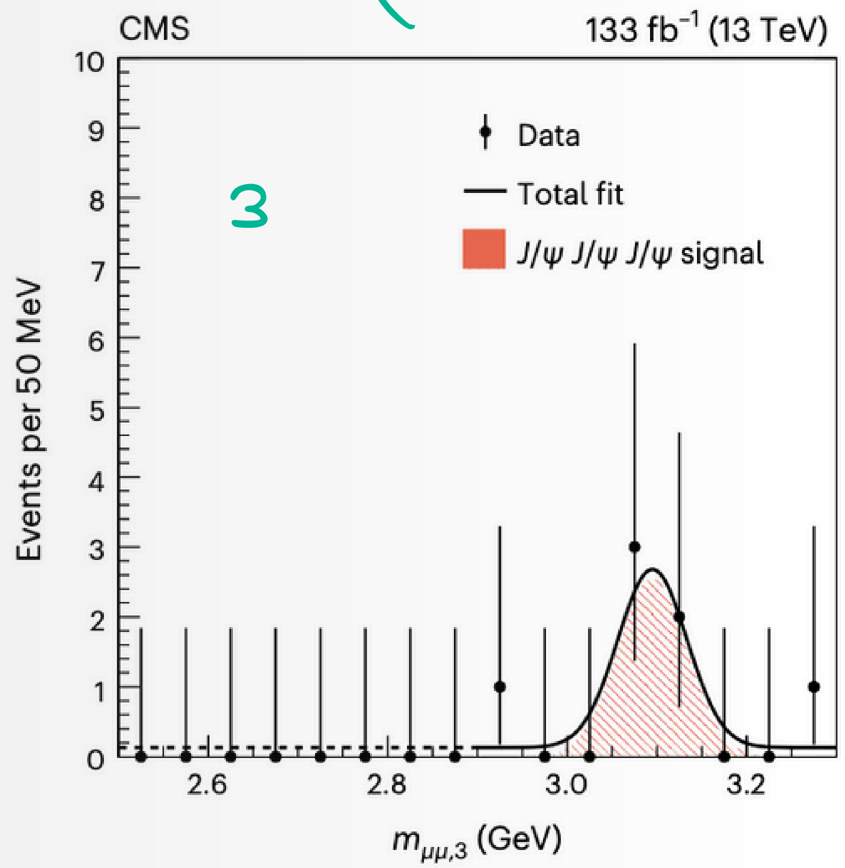
https://www.nature.com/articles/s41567-022-01838-y#citeas



$\sqrt{S}$= 13 TEV



133 FB $^{-1}$



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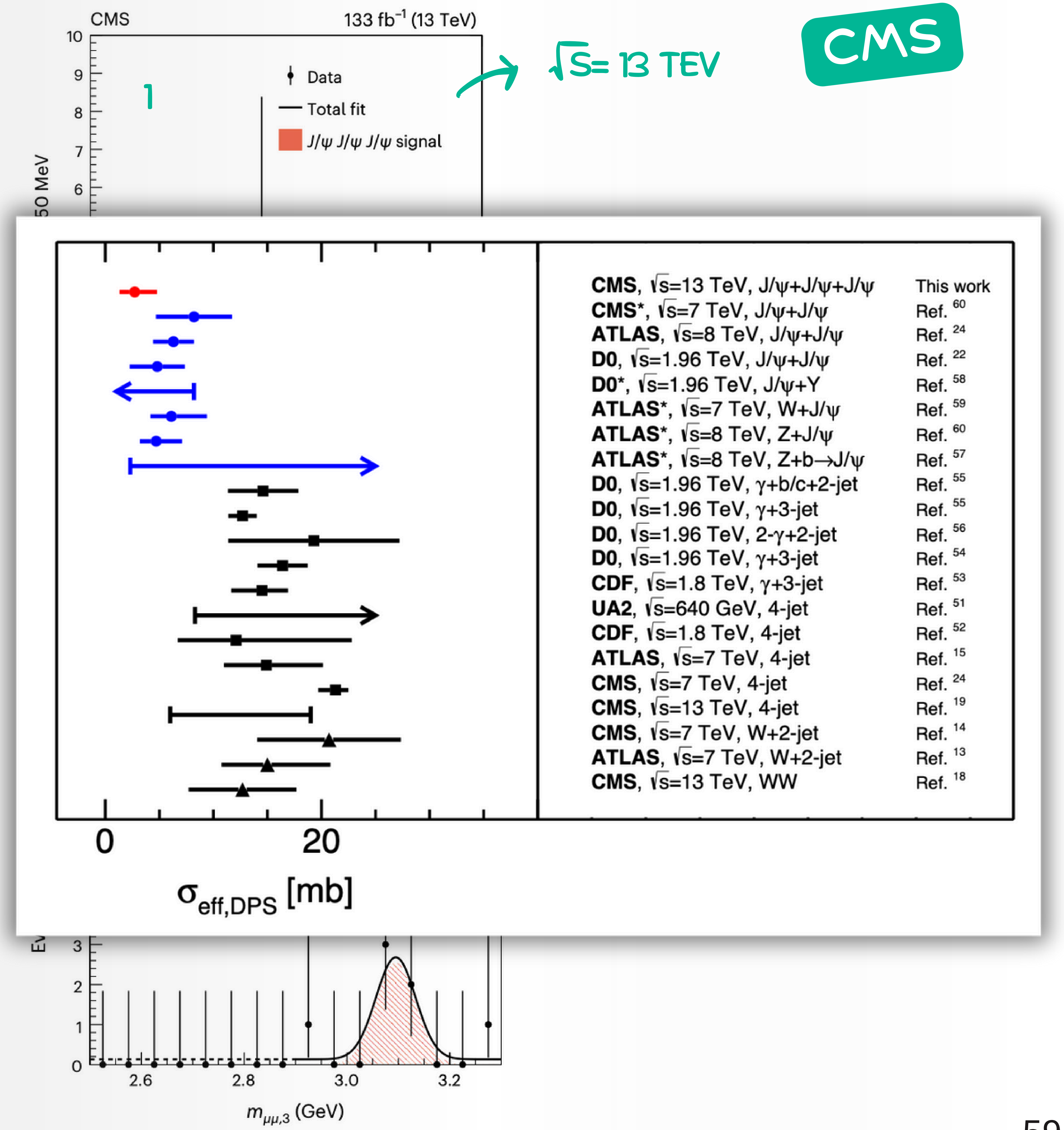


https://www.nature.com/articles/s41567-022-01838-y#citeas

Di-J/ψ

Di-~~J/ψ~~

$\Upsilon(1S)$

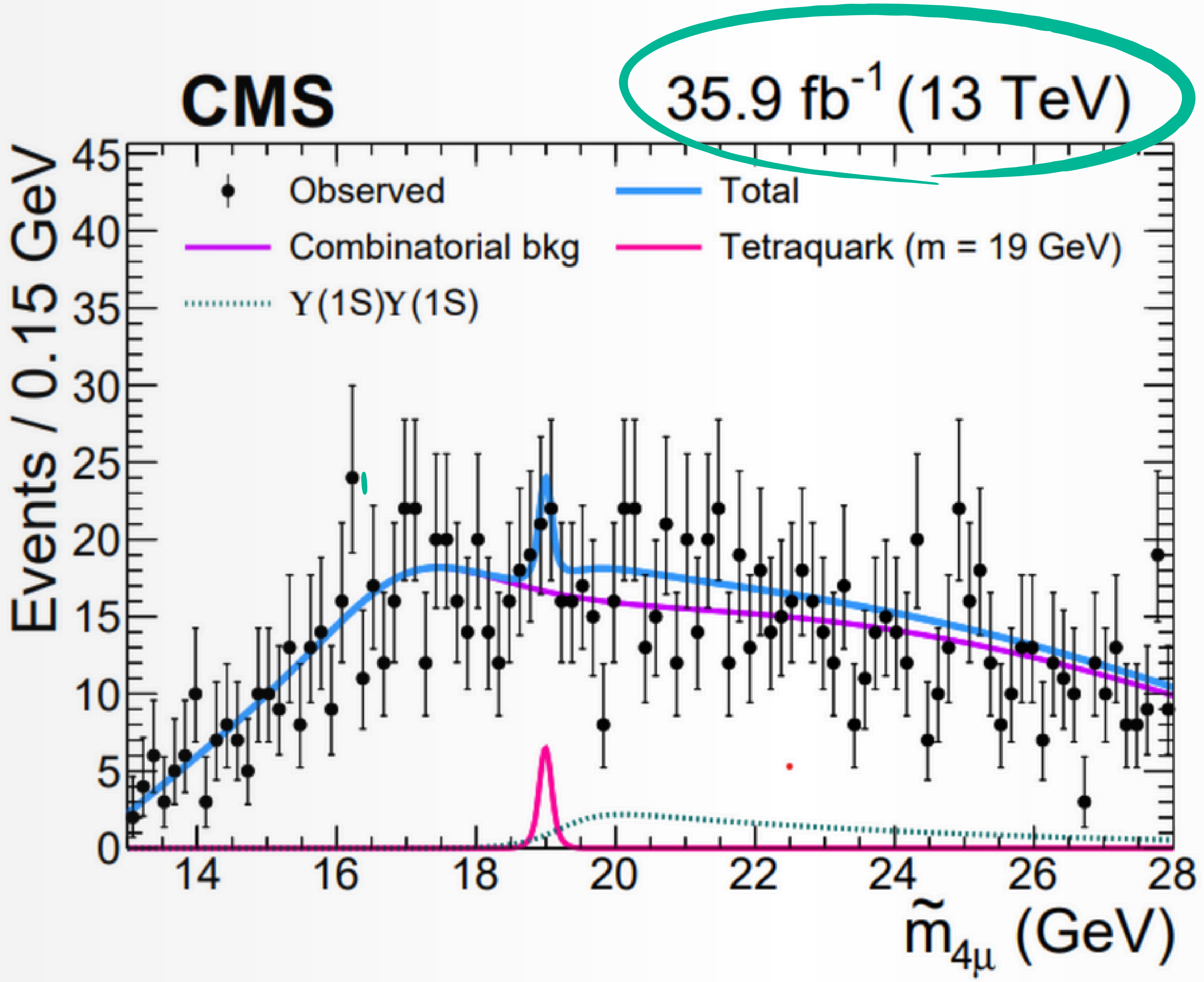
Di-Υ(1S) in CMS

The goals of the analysis are:

- Measure the Υ(1S) pair production cross section and search for resonances decaying to 4 muons
- Observe the existence of a tetraquark
- Measure the DPS contribution in this channel

$$\sigma = 79 \pm 11(\mathrm{stat}) \pm 6(\mathrm{syst}) \pm 3(\mathcal{B})\mathrm{pb}$$

FIDUCIAL CROSS-SECTION



https://doi.org/10.1016/j.physletb.2020.135578

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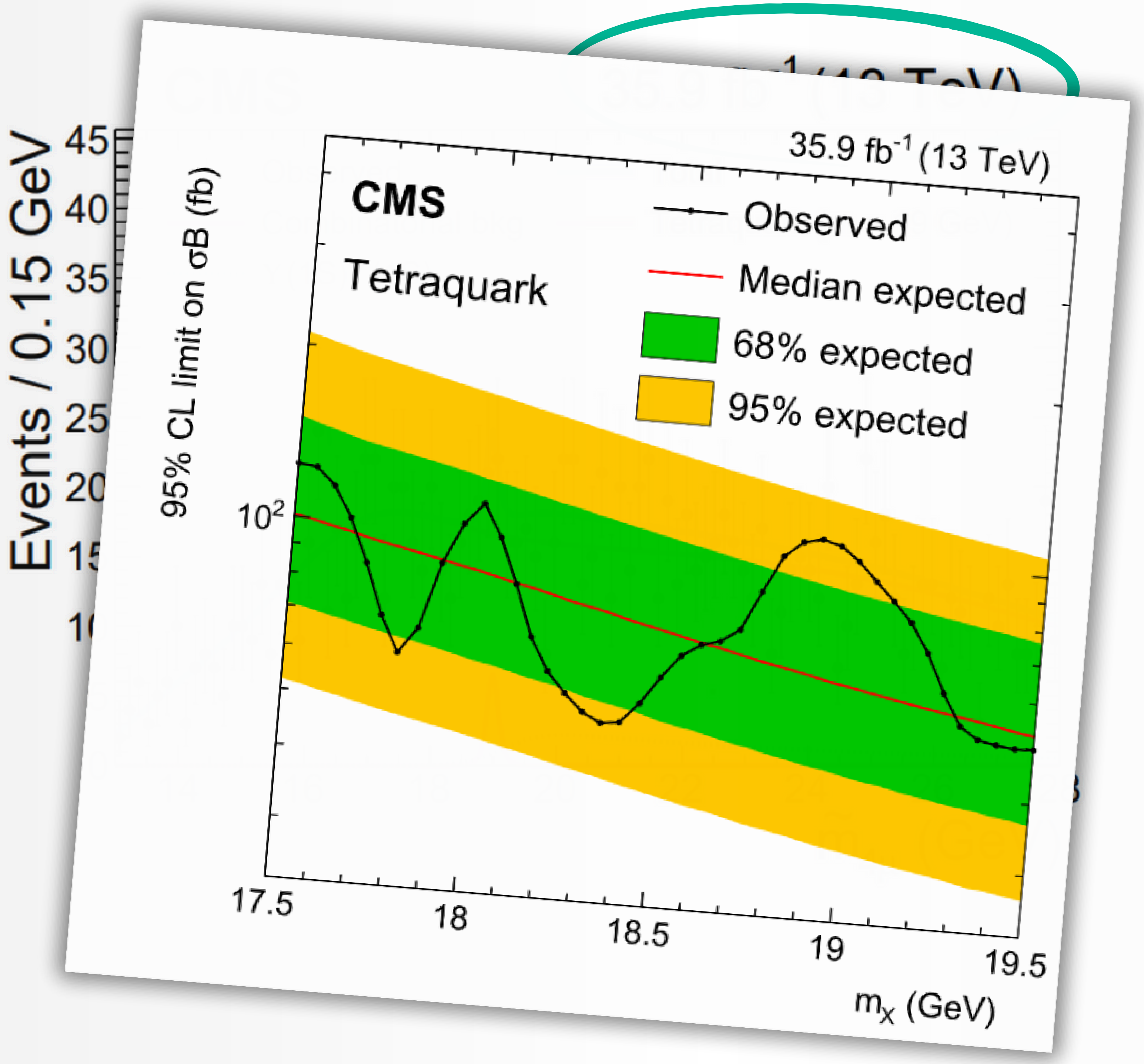
- Measure the DPS contribution in this channel

UNFORTUNATELY, NO SIGNIFICANT EXCESS OF EVENTS COMPATIBLE WITH A NARROW RESONANCE IS OBSERVED IN THE DATA



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Di-Υ(1S) in CMS

CMS

The goals of the analysis are:

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WE CAN USE CROSS-SECTION Υ(1S)Υ(1S) CROSS SECTIONS DIFFERENTIAL IN RAPIDITY AND MASS TO DETERMINE THE DPS FRACTION

MEASURED WITH A BINNED MAXIMUM-LIKELIHOOD FIT OF THESE TWO SIMULATED DISTRIBUTIONS WITH FLOATING NORMALIZATIONS TO THE MEASURED FIDUCIAL CROSS SECTIONS IN BINS

https://doi.org/10.1016/j.physletb.2020.135578

Di-Υ(1S) in CMS

The goals of the analysis are:

- Measure the Υ(1S) pair production cross section and search for resonances decaying to 4 muons
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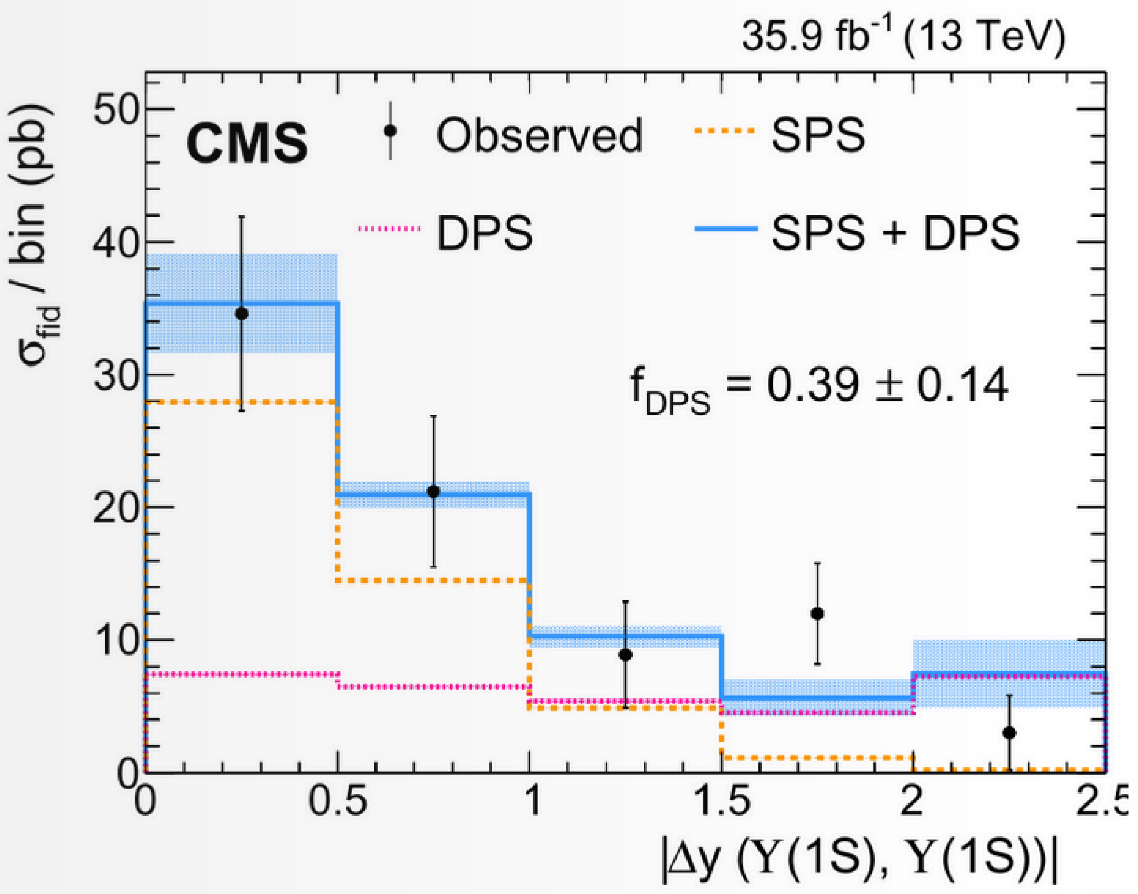
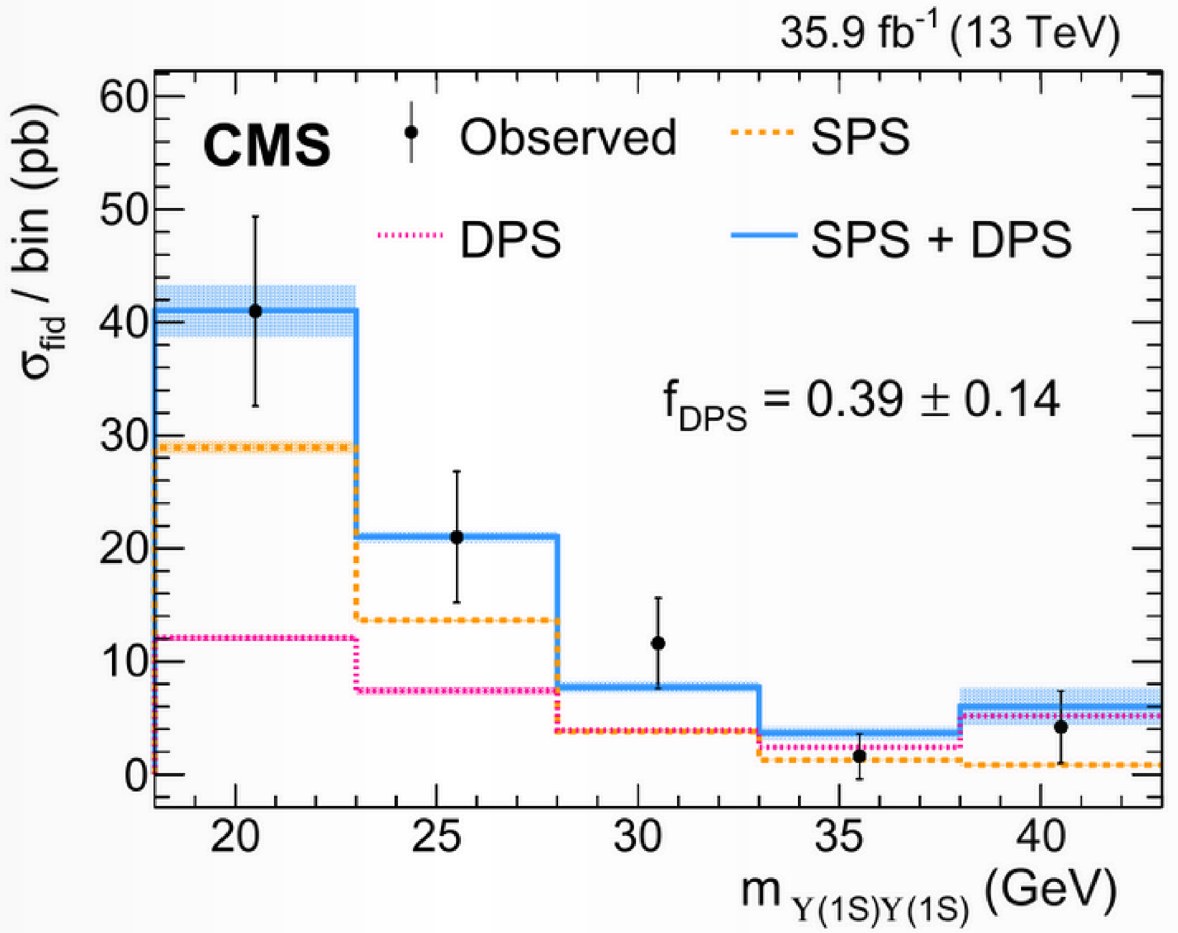
$$f_{\mathrm{DPS}} = \frac{\sigma_{\mathrm{fid}}^{\mathrm{DPS}}}{\sigma_{\mathrm{fid}}^{\mathrm{SPS}} + \sigma_{\mathrm{fid}}^{\mathrm{DPS}}}$$

$$f_{DPS}(|\Delta y(Y(1S), Y(1S))|) = (39 \pm 14)\%$$

$$f_{DPS}(m(Y(1S), Y(1S))) = (27 \pm 22)\%$$





https://doi.org/10.1016/j.physletb.2020.135578

Measurement of the prompt J/ψ pair production cross-section in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector

ATLAS Collaboration*
CERN, 1211 Geneva 23, Switzerland

Received: 12 December 2016 / Accepted: 24 January 2017 / Published online: 7 February 2017
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...ment of J/ψ-pair productio... in pp collisions at $\sqrt{s} = 13$ TeV and study of gluon transverse-momentum dependent PDFs

LHCb collaboration†

nature physics

Article

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

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

Summary

- Building on the data collected during Run 1, numerous analyses have focused on multiple hard scatterings.
- Each major experiment at the LHC has contributed to this effort.
- However, there is still much work to be done:
  - We need deeper insights into the non-universality of the effective cross-section;
  - There are likely many interesting final states produced via DPS still awaiting discovery.
- We expect new results from both pp and p-A collisions in the coming years.
- By the end of Run 3, we expect to achieve an integrated luminosity of 420 fb^{-1}, providing significantly more statistics for our analyses.

Measurement of prompt J/ψ pair production in pp collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration*

PHYSICAL REVIEW LETTERS 132, 111901 (2024)

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

A. Hayrapetyan et al.*
(CMS Collaboration)

...2023; revised 7 December 2023; accepted 31 January 2024; published 15 March 2024)

...cs Analysis Summary

...s@cern.ch 2024/02/26

...vation of double-J/ψ meson production in pPb collisions at 8.16 TeV

PHYSICAL REVIEW C 108, 045203 (2023)

Measurement of inclusive J/ψ pair production cross section in pp collisions at $\sqrt{s} = 13$ TeV

S. Acharya et al.*
(ALICE Collaboration)

(Received 14 April 2023; revised 17 July 2023; ...

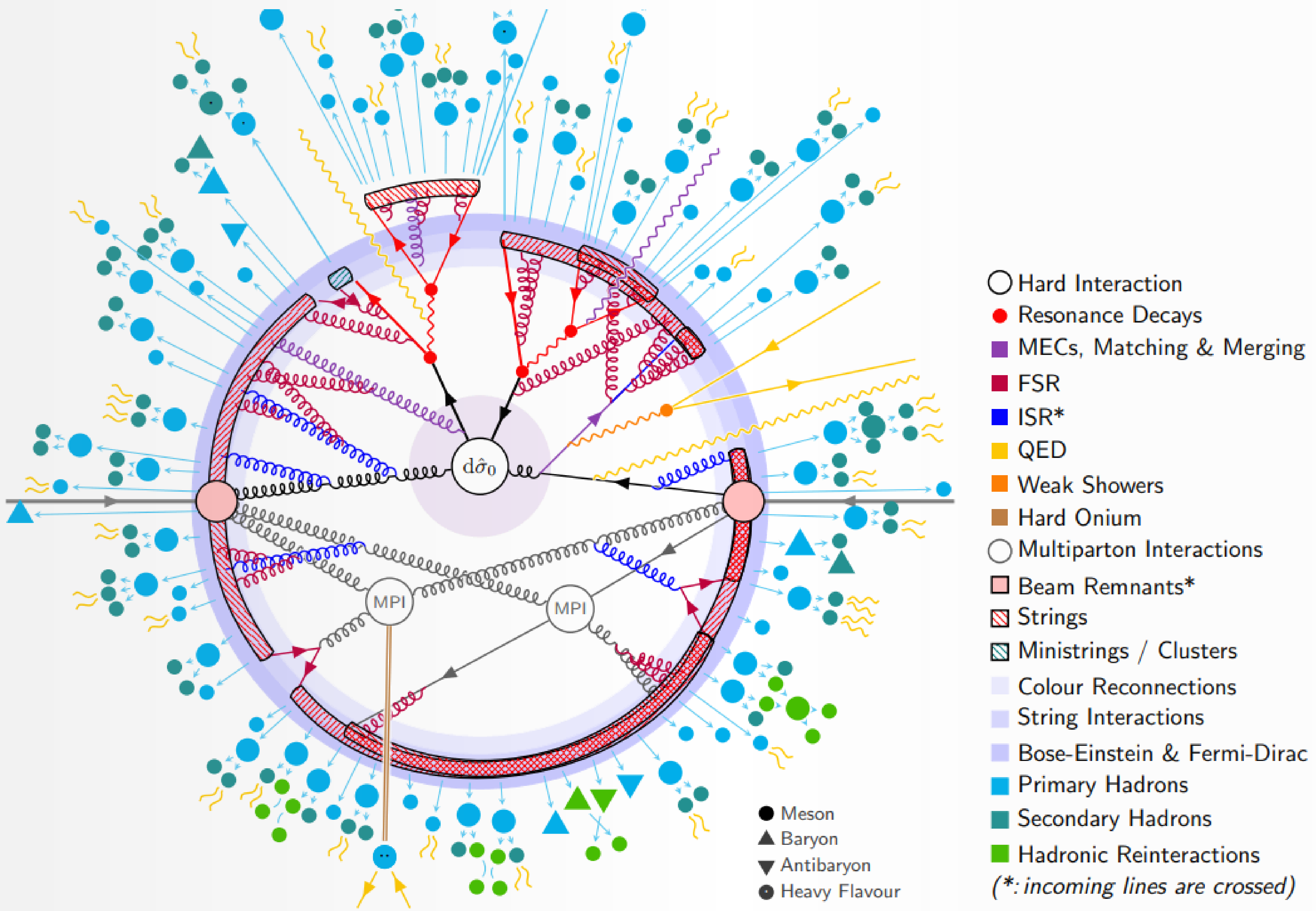
THANK YOU

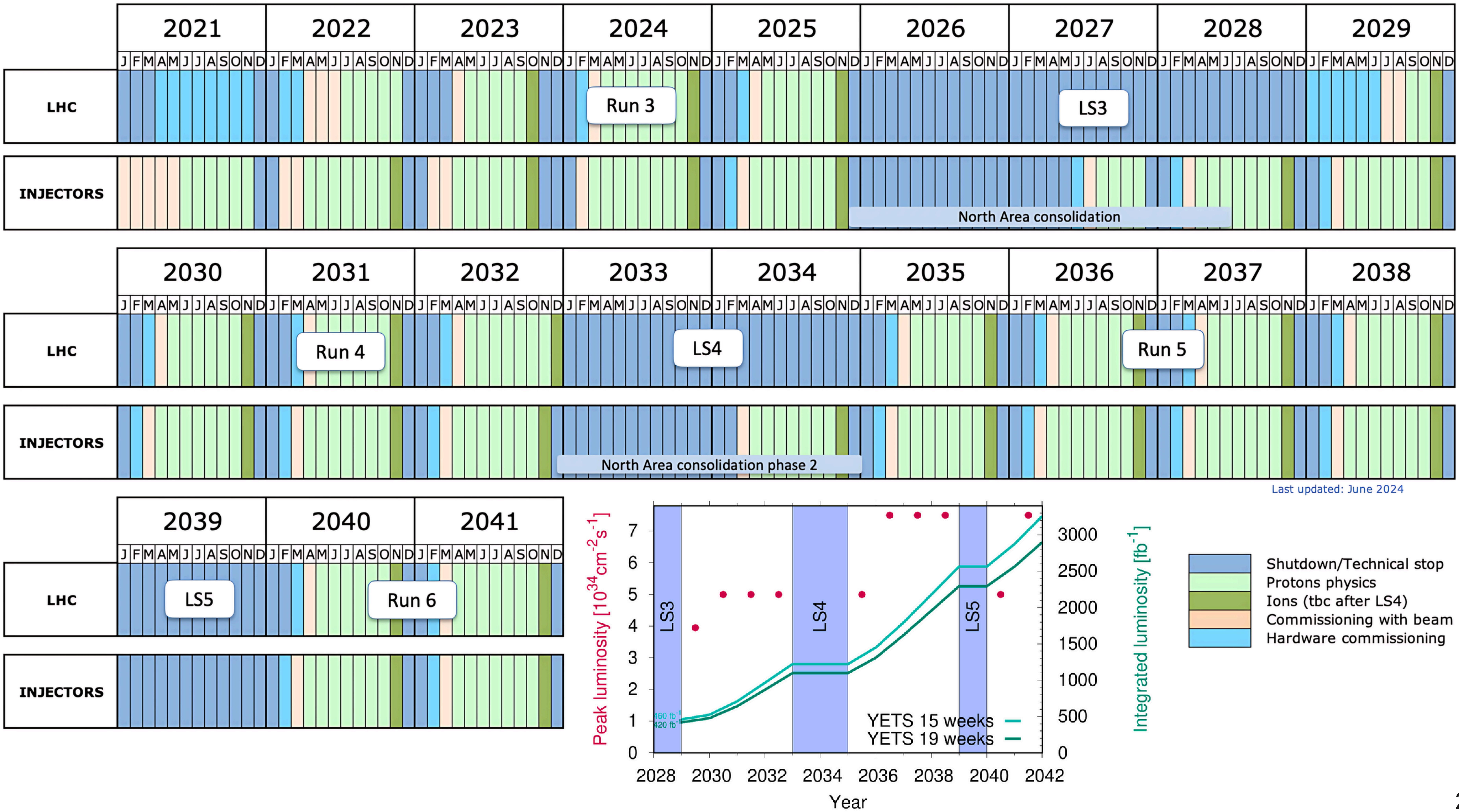
ON BEAHALF OF CMS COLLABORATION

MARIA ELENA ASCIOTI | PHD STUDENT
UNIVERSITY OF PERUGIA
MARIA.ELENA.ASCIOTI@CERN.CH
MARIAELENA.ASCIOTI@PG.INFN.IT

Multi-parton interactions:

- 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.




2021 2022 2023 2024 2025 2026 2027 2028 2029
LHC
INJECTORS
Run 3
LS3
North Area consolidation
2030 2031 2032 2033 2034 2035 2036 2037 2038
Run 4
LS4
Run 5
North Area consolidation phase 2
2039 2040 2041
LS5
Run 6
Last updated: June 2024
Peak luminosity [10^34 cm^-2 s^-1]
Integrated luminosity [fb^-1]
Year
YETS 15 weeks
YETS 19 weeks
460 fb^-1
420 fb^-1
Shutdown/Technical stop
Protons physics
Ions (tbc after LS4)
Commissioning with beam
Hardware commissioning