Observation of triple-J/Ψ production in p-p collisions at the LHC

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Details: **CMS-PAS-BPH-21-004**

N-parton scatterings in p-p collisions

- Motivation for studies of multiple production of hard/heavy particles:
  (1) Generalized PDFs (x,Q^2,b) of the proton, in particular unknown energy evolution of transverse proton profile.
  (2) Role of partonic correlations (in space, p, x, flavour, colour, spin,...) in hadronic wave functions.
  (3) Backgrounds for rare (B)SM resonance decays w/ multiple heavy particles
- Studies so far focused on double-parton scatterings (DPS):

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

"Pocket formula":

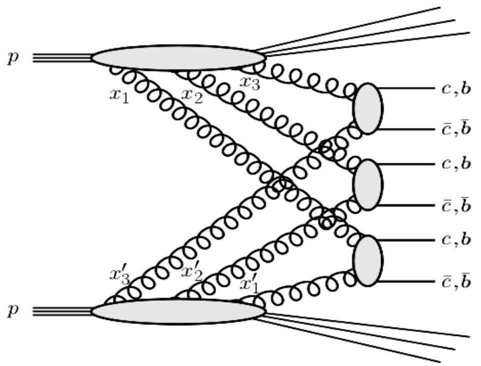
Assuming no parton correlations: $\sigma_{\rm DPS}$ is proportional to SPS x-sections normalized by effective x-section ($\sigma_{\rm eff}$, proxy to mean inter-parton transverse separation squared) derivable from p-p transverse overlap:

$\sigma_{\rm eff} \sim$ 20–30 mb expected from PYTHIA8/HERWIG proton form factors.
$\sigma_{\rm eff} \sim$ 15 mb, derived from DPS of jets, photons, EWK bosons
$\sigma_{\rm eff} \sim$ 5 mb, derived from di-quarkonia final states

- Reasons: Correlations? x- & q,g-dependent transverse proton profile?
- Can triple-parton scatterings (TPS), unobserved so far, help to clarify this?

Triple parton scattering cross sections

- Assuming that the probabilities for 3 hard collisions are independent of each other, one can write a pocket-formula for TPS x-section:



$$\sigma^{\rm TPS}_{hh'\to a_1 a_2 a_3} = \left(\frac{m}{3!}\right) \frac{\sigma^{\rm SPS}_{hh'\to a_1} \cdot \sigma^{\rm SPS}_{hh'\to a_2} \cdot \sigma^{\rm SPS}_{hh'\to a_3}}{\sigma^2_{\rm eff,TPS}}$$

normalized by the square of an eff. x-section ($\sigma^2_{\rm eff,TPS}$) plus a trivial combinatorial factor (m/3!) to avoid triple-counting in case of same particles produced: $m = 1$ if $a_1 = a_2 = a_3$;
$m = 3$ if $a_1 = a_2$, or $a_1 = a_3$, or $a_2 = a_3$; and
$m = 6$ if $a_1 \neq a_2 \neq a_3$.

- How to interpret $\sigma_{\rm eff,TPS}$? Relationship to $\sigma_{\rm eff,DPS}$?
- Most generic expression for TPS cross section:

$$\sigma^{\rm TPS}_{hh'\to a_1 a_2 a_3} = \left(\frac{m}{3!}\right) \sum_{i,j,k,l,m,n} \int \Gamma^{ijk}_h(x_1, x_2, x_3; \mathbf{b_1}, \mathbf{b_2}, \mathbf{b_3}; Q_1^2, Q_2^2, Q_3^2)$$
$$\times \hat{\sigma}^{il}_{a_1}(x_1, x_1', Q_1^2) \cdot \hat{\sigma}^{jm}_{a_2}(x_2, x_2', Q_2^2) \cdot \hat{\sigma}^{kn}_{a_3}(x_3, x_3', Q_3^2)$$
$$\times \Gamma^{lmn}_{h'}(x_1', x_2', x_3'; \mathbf{b_1} - \mathbf{b}, \mathbf{b_2} - \mathbf{b}, \mathbf{b_3} - \mathbf{b}; Q_1^2, Q_2^2, Q_3^2)$$
$$\times dx_1 dx_2 dx_3 dx_1' dx_2' dx_3' d^2b_1 d^2b_2 d^2b_3 d^2b.$$

Generalized PDFs = f(x,Q^2,**b**)

[DdE, Snigirev PRL 118(2017)122001]

Effective TPS cross section

- Assumption 1: Factorize generalized Triple-PDF into longitudinal & transverse components:

$$\Gamma_h^{ijk}(x_1, x_2, x_3; \mathbf{b_1}, \mathbf{b_2}, \mathbf{b_3}; Q_1^2, Q_2^2, Q_3^2) = D_h^{ijk}(x_1, x_2, x_3; Q_1^2, Q_2^2, Q_3^2) f(\mathbf{b_1}) f(\mathbf{b_2}) f(\mathbf{b_3}),$$

p-p transv. overlap function (mb^{-1}): $T(\mathbf{b}) = \int f(\mathbf{b_1}) f(\mathbf{b_1} - \mathbf{b}) d^2 b_1$, with $\int d^2 b T(\mathbf{b}) = 1.$

- Assumption 2: Longitudinal triple-PDF is the product of 3 single PDFs (i.e. no parton correlations in colour, momentum, flavour, spin,…)

$$D_h^{ijk}(x_1, x_2, x_3; Q_1^2, Q_2^2, Q_3^2) = D_h^i(x_1; Q_1^2) D_h^j(x_2; Q_2^2) D_h^k(x_3; Q_3^2)$$

- Then, $\sigma^2_{\rm eff,TPS}$ is simply the inverse of the cube of the transv. pp overlap:

$$\sigma^2_{\rm eff,TPS} = \left[\int d^2 b\, T^3(\mathbf{b})\right]^{-1}$$

(identical result for the effective DPS x-section, with one power less).

- Close relationship between $\sigma_{\rm eff,TPS}$ & $\sigma_{\rm eff}$ found by testing many proton overlaps/profiles (hard sphere, Gaussian, exponential, dipole fit):

$$\sigma_{\rm eff,TPS} = k \times \sigma_{\rm eff,DPS}, \text{ with } k = 0.82 \pm 0.11$$

[DdE, Snigirev PRL 118(2017)122001]

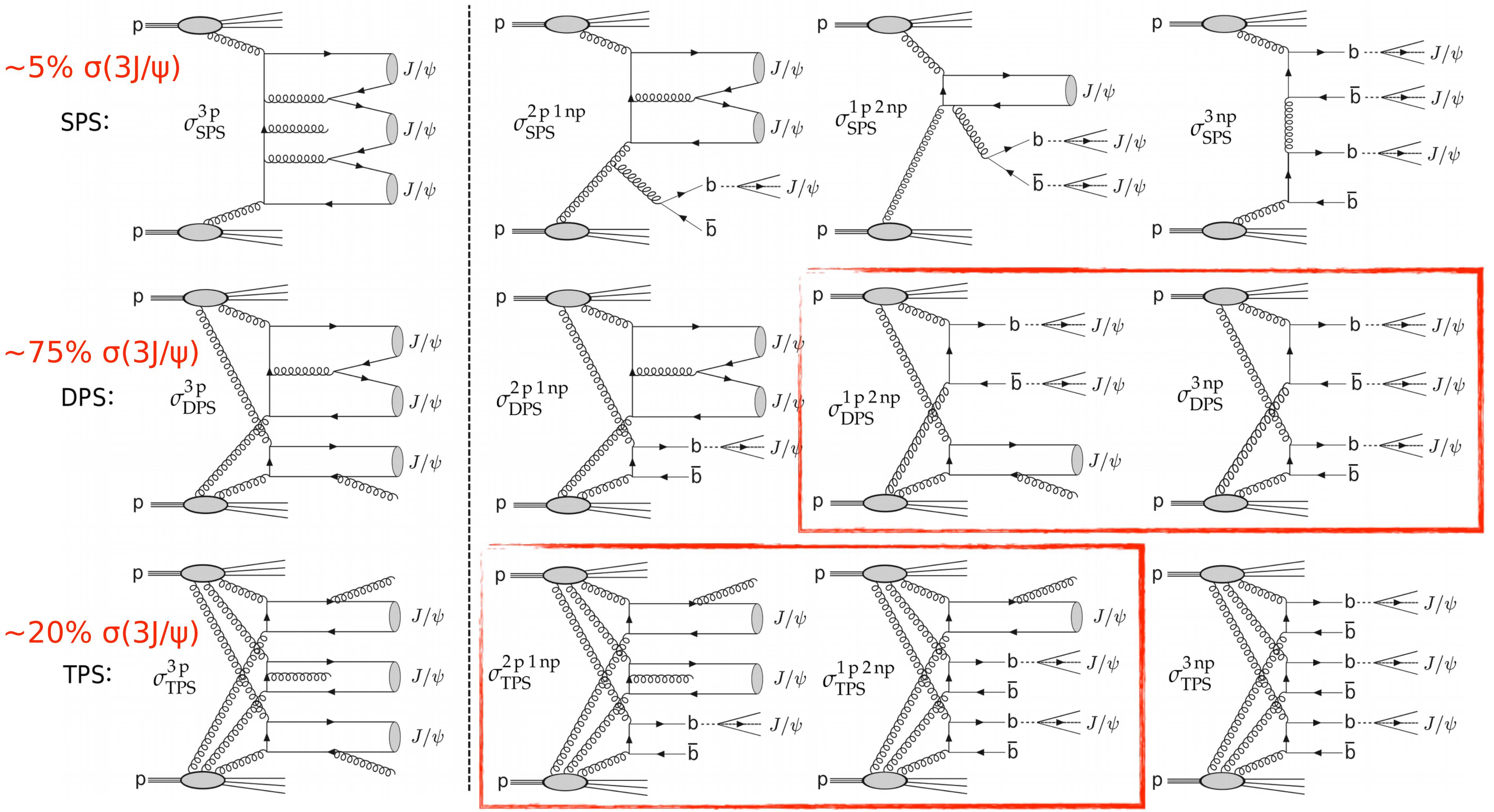
- TPS measurements: Novel NPS probe, independent $\sigma_{\rm eff}$ extraction.

Triple-J/ψ production in p-p collisions

σ(pp→J/ψ J/ψ J/ψ X) = Mix of pp→J/ψ (prompt) & pp→b→J/ψ (nonprompt)

Simple system: SPS negligible, golden-channel for DPS/TPS studies:

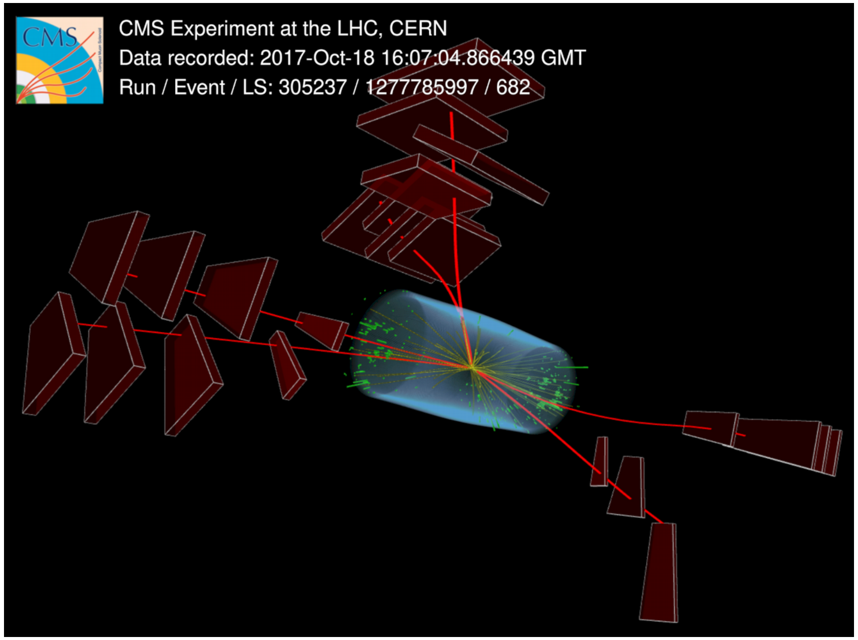
Pure prompt: Nonprompt contributions: [H-S Shao, Y-J Zhang PRL 122(2019)19]

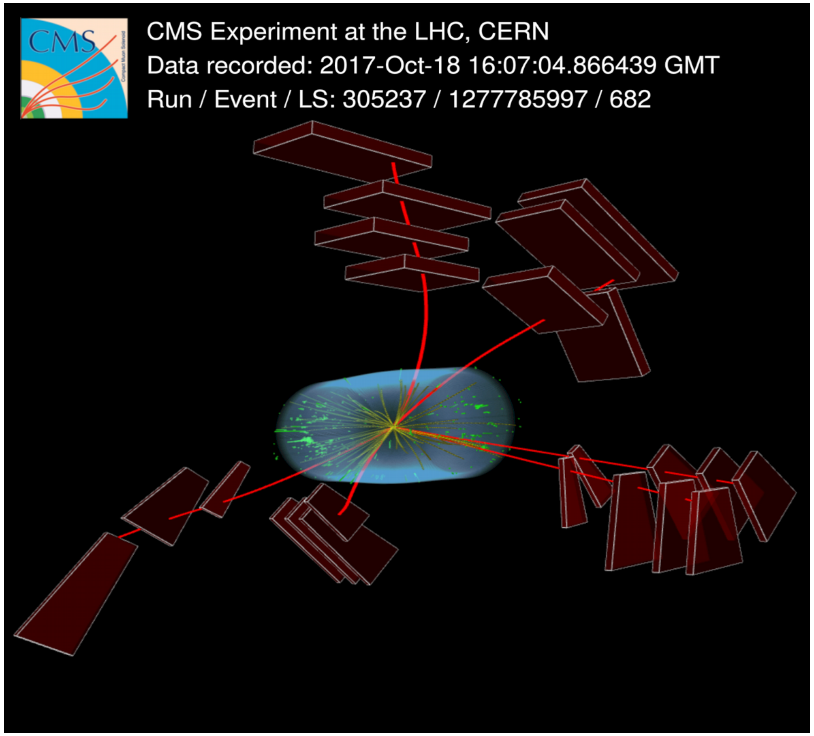


HELAC-ONIA MG5@NLO+PYTHIA8

p-p @ 13 TeV: Data selection & reconstruction

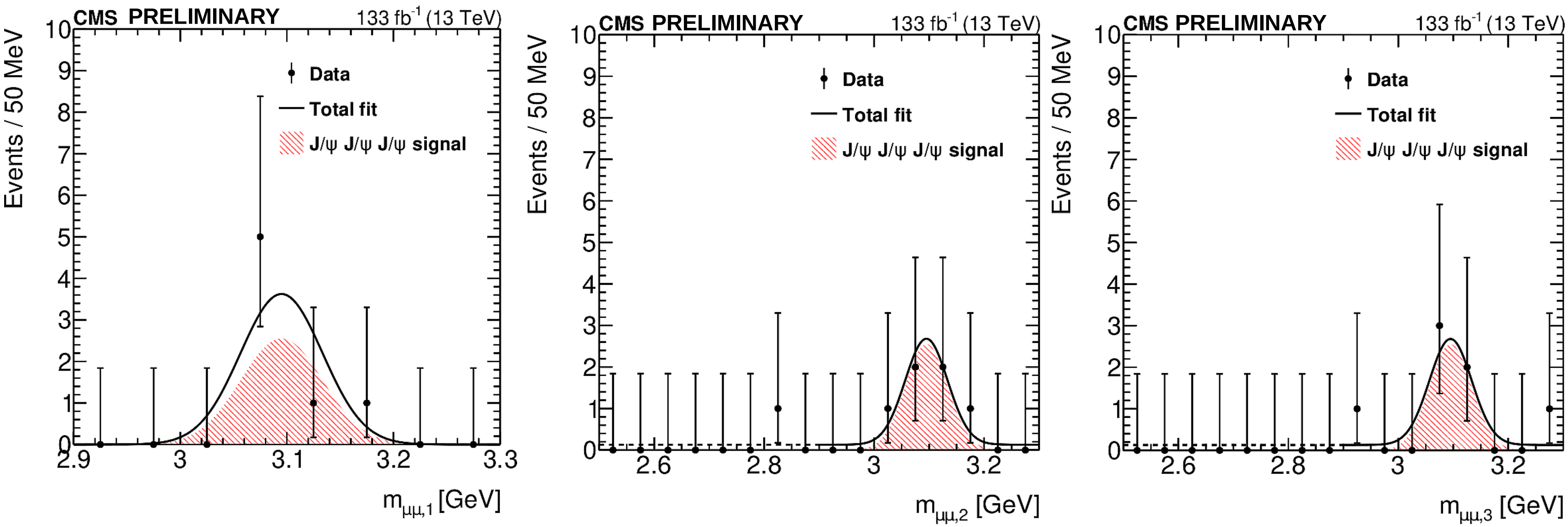
- Full Run-2 dataset: p-p collisions at 13 TeV, $\mathcal{L}_{int}$ = 133 fb^{-1}
- HLT trigger:
  – 3 muons with p_T > 3.5 GeV (|η|<1.2), p_T > 2.5 GeV (1.2<|η|<2.4).
  – 2 opp.-charge muons with 2.8<m_{inv}<3.35 GeV and common vertex.
- Offline:
  – 6+ muons, opp.-charge dimuons 2.9<m_{inv}<3.3 GeV, shared primary vtx.
  – Dimuon p_T > 6.5 GeV and |y| < 2.4
- Data yield: **6 events**





Triple-J/ψ signal extraction

- Yield extracted using 3D unbinned extended maximum likelihood fit
  - Signal: Gaussian w/ resolution fixed to MC and mean to PDG J/ψ mass
  - Background: exponential (polynomials for systematics)



- Yield accounting for all combinations of signals & bckgd dimuon pairs: N(3J/ψ,signal) = $5.0^{+2.6}_{-1.9}$, N(backgd) = $1.0^{+1.4}_{-0.8}$

  Extended mass region, down to 2.3 GeV: consistent result, no backgd.
- Significance: 6.7 std.dev. (likelihood ratio of bckgd-only/signal+backgd fits)

  5.8 std.dev. (Poisson counting exp.)

  5.5 std. dev. (MC pseudoexperiments).

Triple-J/ψ cross section & systematics

- Fiducial cross section:

  $\sigma(pp \to 3J/\psi) = N(3J/\psi) / [\varepsilon \times \mathcal{L}_{int} \times B^3(J/\psi \to \mu\mu)] = 272^{+141}_{-104}$ (stat) ± 17 (syst) fb

  - Efficiency: $\varepsilon = \varepsilon_{trig} \times \varepsilon_{id} \times \varepsilon_{reco} = 0.84 \times 0.78$ (from MC simulation, tag & probe)
  - $B^3_{(J/\psi \to \mu\mu)} = (5.96\% \pm 0.03\%)^3$

Fiducial requirement	
For all muons	$p_T > 3.5$ GeV for $\lvert\eta\rvert <= 1.2$ $p_T > 2.5$ GeV for $1.2 < \lvert\eta\rvert < 2.4$
For all J/ψ mesons	$p_T > 6$ GeV and $\lvert y\rvert < 2.4$ $2.9 < m_{\mu^+\mu^-} < 3.3$ GeV

- Systematic uncertainties: ±6.2%

- Signal shape fit: Change Gaussian to Crystal-Ball and to Gaussian w/ free widths.
- Background shape fit: Change exp. to pol0 & pol1
- Muon reconstruction efficiency: Vary tag&probe (p_T, η) correction factors within their uncertainties.
- Trigger efficiency: Change DPS/TPS fraction in MC sample.

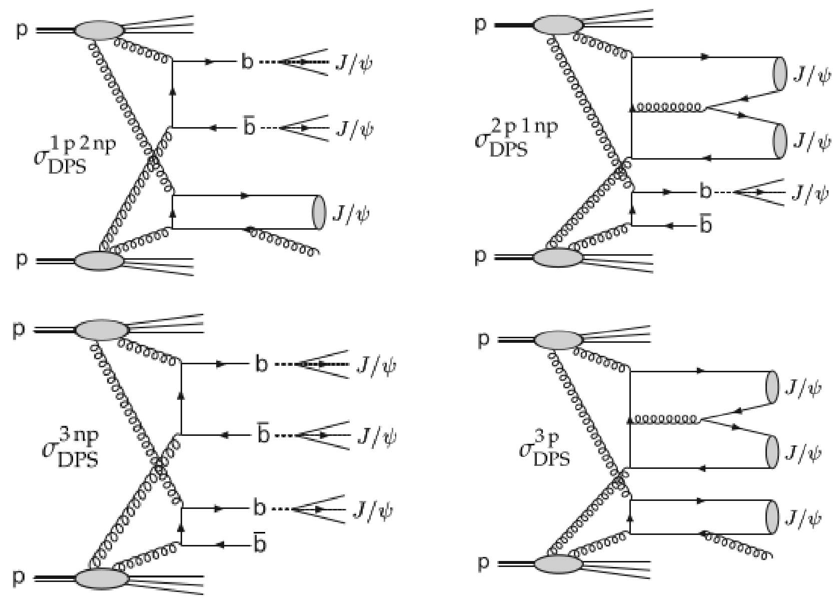
Source	Relative uncertainty
J/ψ meson signal shape	0.8%
Dimuon continuum background shape	3.4%
Muon reconstruction efficiency	1.0%
Trigger efficiency measurement	3.4%
MC sample size	3.0%
Integrated luminosity	1.6%
Branching fraction	1.7%
Total	6.2%

Prompt & non-prompt J/ψ contributions

- 2 approaches to identify prompt & non-prompt J/ψ:
  1) Cut on J/ψ proper decay length distributions at L=60µm
  2) Fit proper decay length distributions:
     - Fit all individual distributions with prompt and nonprompt templates derived from MC.
     - Unbinned maximum likelihood fit with 2 variables
     - Compare sPlot prompt and nonprompt weights per event.

  Same answer from both methods.

- N(3J/ψ) = 5 signal events consistent with:
  - 2 events: 2 nonprompt + 1 prompt
  - 1 event: 1 nonprompt + 2 prompt
  - 1 event: 3 nonprompt
  - 1 event: 3 prompt



Triple-J/ψ x-section: SPS, DPS, TPS contributions

- The theoretical total triple-J/ψ cross section expected to correspond to the sum of the contributions from SPS, DPS, and TPS processes:

$$\sigma_{\text{tot}}^{3J/\psi} = \sigma_{\text{SPS}}^{3J/\psi} + \sigma_{\text{DPS}}^{3J/\psi} + \sigma_{\text{TPS}}^{3J/\psi} =$$
$$= \left(\sigma_{\text{SPS}}^{3\,\text{p}} + \sigma_{\text{SPS}}^{2\text{p}1\text{np}} + \sigma_{\text{SPS}}^{1\text{p}2\text{np}} + \sigma_{\text{SPS}}^{3\,\text{np}}\right) +$$
$$+ \left(\sigma_{\text{DPS}}^{3\,\text{p}} + \sigma_{\text{DPS}}^{2\text{p}1\text{np}} + \sigma_{\text{DPS}}^{1\text{p}2\text{np}} + \sigma_{\text{DPS}}^{3\,\text{np}}\right) + \left(\sigma_{\text{TPS}}^{3\,\text{p}} + \sigma_{\text{TPS}}^{2\text{p}1\text{np}} + \sigma_{\text{TPS}}^{1\text{p}2\text{np}} + \sigma_{\text{TPS}}^{3\,\text{np}}\right)$$

- In the factorized approach, the DPS and TPS triple-J/ψ cross sections derivable from the single- and double-J/ψ SPS cross sections via:

$$\sigma_{\text{DPS}}^{3J/\psi} = \frac{m_1 \left(\sigma_{\text{SPS}}^{2\text{p}}\sigma_{\text{SPS}}^{1\text{p}} + \sigma_{\text{SPS}}^{2\text{p}}\sigma_{\text{SPS}}^{1\text{np}} + \sigma_{\text{SPS}}^{1\text{p}}\sigma_{\text{SPS}}^{1\text{p}1\text{np}} + \sigma_{\text{SPS}}^{1\text{p}1\text{np}}\sigma_{\text{SPS}}^{1\text{np}} + \sigma_{\text{SPS}}^{1\text{p}}\sigma_{\text{SPS}}^{2\text{np}} + \sigma_{\text{SPS}}^{2\text{np}}\sigma_{\text{SPS}}^{1\text{np}}\right)}{\sigma_{\text{eff,DPS}}}$$

$$\sigma_{\text{TPS}}^{3J/\psi} = \frac{m_3 \left(\left(\sigma_{\text{SPS}}^{1\text{p}}\right)^3 + \left(\sigma_{\text{SPS}}^{1\text{np}}\right)^3\right) + m_2 \left(\left(\sigma_{\text{SPS}}^{1\text{p}}\right)^2 \sigma_{\text{SPS}}^{1\text{np}} + \sigma_{\text{SPS}}^{1\text{p}} \left(\sigma_{\text{SPS}}^{1\text{np}}\right)^2\right)}{\sigma_{\text{eff,TPS}}^2},$$

with m_1=1, m_2=1/2, m_3=1/6, and effective DPS & TPS x-sections.

("sum pocket formula")

Triple-J/ψ x-section: SPS, DPS, TPS contributions

- Theoretical single-, double-, and triple-J/ψ SPS cross sections from HELACONIA(data-based,LO,NLO*)+PYTHIA8, MG5@NLO+PYTHIA8:

SPS single-J/ψ production		SPS double-J/ψ production			SPS triple-J/ψ production			
HO(DATA)	MG5NLO+PY8	HO(NLO*)	HO(LO)+PY8	MG5NLO+PY8	HO(LO)	HO(LO)+PY8	HO(LO)+PY8	MG5NLO+PY8
σ^{1p}_{SPS}	σ^{1np}_{SPS}	σ^{2p}_{SPS}	σ^{1p1np}_{SPS}	σ^{2np}_{SPS}	σ^{3p}_{SPS}	σ^{2p1np}_{SPS}	σ^{1p2np}_{SPS}	σ^{3np}_{SPS}
570 ± 57 nb	600^{+130}_{-220} nb	40^{+80}_{-26} pb	24^{+35}_{-16} fb	430^{+95}_{-130} pb	<5 ab	$5.2^{+9.6}_{-3.3}$ fb	14^{+17}_{-8} ab	12 ± 4 fb

Nonprompt cross sections scaled to NNLO (x1.15).
Uncertainties dominated by scale variations, then PDF.

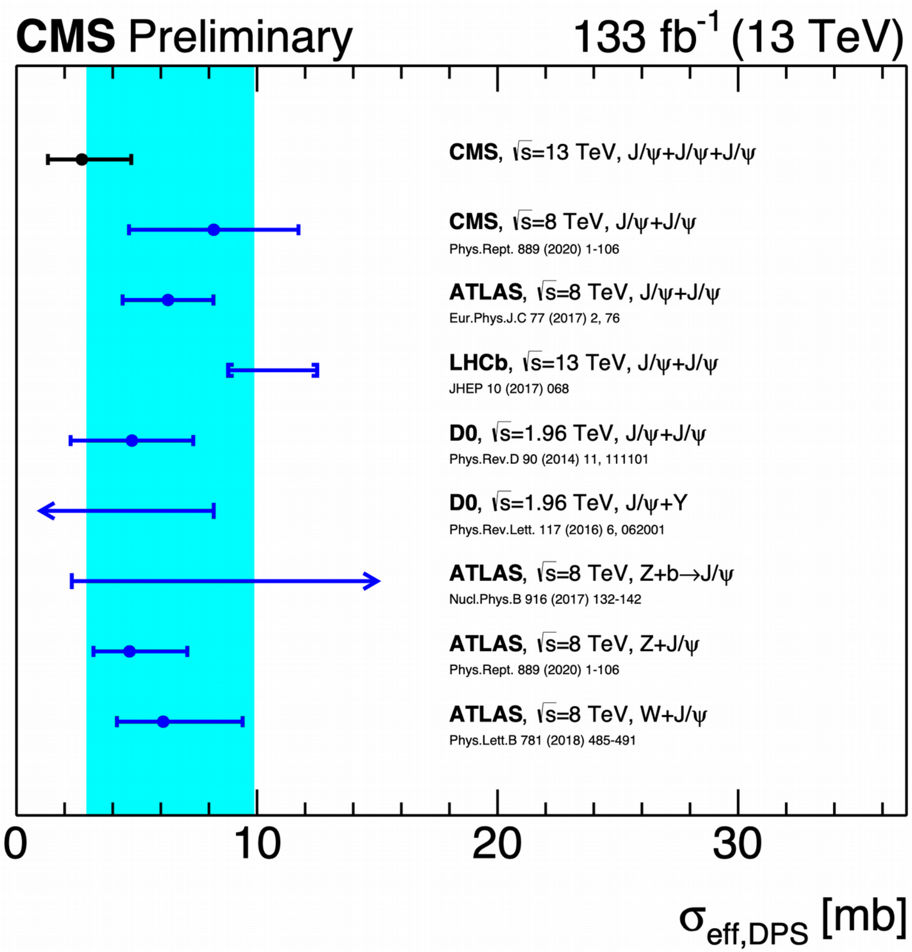
- Using "sum pocket formula" with $\sigma_{eff,TPS} = (0.82 \pm 0.11)\ \sigma_{eff,DPS}$, value of free $\sigma_{eff,DPS}$ = 2.7 mb extracted by requiring $\sigma(pp \to 3J/\psi)_{th} = \sigma(pp \to 3J/\psi)_{exp}$

Process:	3 prompt	2 prompt+1 nonprompt	1 prompt+2 nonprompt	3 nonprompt	total
SPS:					
$\sigma^{3J/\psi}_{SPS}$ (fb)	$<5\,10^{-3}$	5.7	0.014	12	18
$N^{3J/\psi}_{SPS}$	0.0	0.1	0.0	0.22	0.32
DPS:					
$\sigma^{3J/\psi}_{DPS}$ (fb)	8.4	8.9	90	95	202
$N^{3J/\psi}_{DPS}$	0.15	0.16	1.7	1.7	3.7
TPS:					
$\sigma^{3J/\psi}_{TPS}$ (fb)	6.1	19.4	20.4	7.2	53
$N^{3J/\psi}_{TPS}$	0.11	0.36	0.38	0.13	1.0
SPS+DPS+TPS:					
$\sigma^{3J/\psi}_{tot}$ (fb)	15	34	110	114	272
$N^{3J/\psi}_{tot}$	0.3	0.6	2.0	2.1	5.0

Effective DPS cross section ($\sigma_{eff,DPS}$)

- Derived effective DPS cross section:
  $\sigma_{eff,DPS} = 2.7\ ^{+1.4}_{-1.0}\ (exp)\ ^{+1.5}_{-1.0}\ (theo)$ mb
- Expected fractions from SPS, DPS, TPS processes amount to:
  SPS: 6%, DPS: 74%, TPS: 20%
  (triple-J/ψ is a golden channel to study DPS/TPS).
- Derived $\sigma_{eff,DPS}$ consistent with world-data of effective DPS cross sections obtained so far from quarkonium-related DPS measurements at midrapidity:

  $\sigma_{eff,DPS} \approx 3 – 10$ mb



Effective DPS cross section ($\sigma_{eff,DPS}$)

- Derived effective DPS cross section:

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

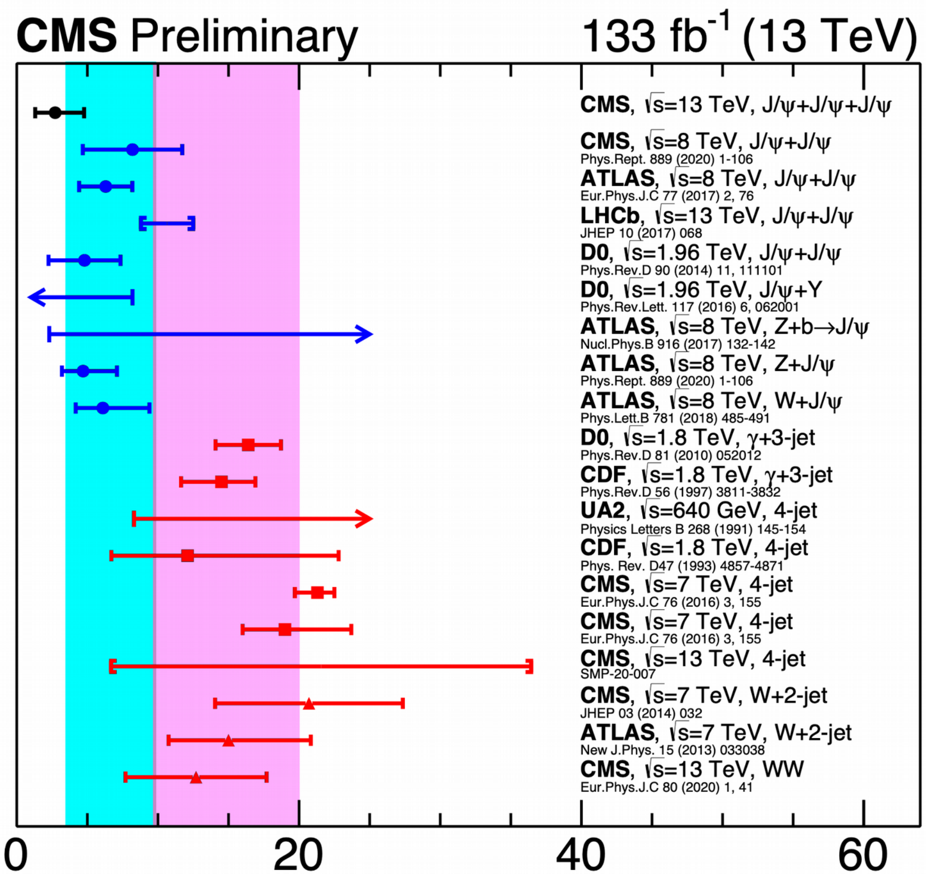
- Expected fractions from SPS, DPS, TPS processes amount to:

  SPS: 6%, DPS: 74%, TPS: 20%

  (triple-J/ψ is a golden channel to study DPS/TPS).

- Derived $\sigma_{eff,DPS}$ much smaller than world-data of effective DPS cross sections obtained using double- jets, γ, W, Z bosons measurements:

  $\sigma_{eff,DPS} \approx 10 – 20$ mb



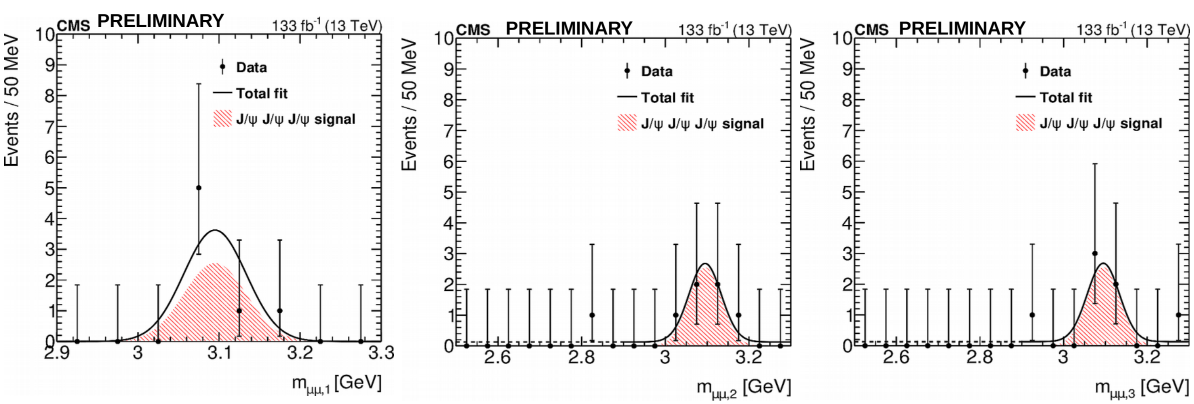
- Differences suggestive of a $\sigma_{eff,DPS}$ dependence on different transverse density/correlations for gluon- ($x \sim 10^{-4}$) or quark- ($x \sim 10^{-2}$) dominated processes

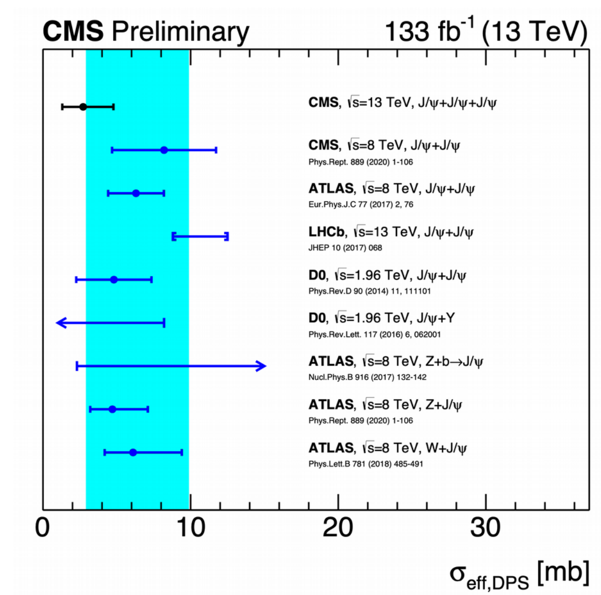
$\sigma_{eff,DPS}$ [mb]

Summary

- <u>First</u> observation of triple J/ψ meson production in pp collisions.
- <u>First</u> experimental study of TPS.
- <u>First</u> extraction of $\sigma_{eff,DPS}$ in non-doubly-produced final states.

- Measurement of fiducial cross section
  $\sigma(pp \rightarrow 3J/\psi) = 272^{+141}_{-104}$ (stat) ± 17 (syst) fb
- Theoretical interpretation assuming factorized NPS ansatz, based on (N)NLO SPS estimates for single-, double-, triple-J/ψ cross sections:
  - Triple-J/ψ fractions: ~6% SPS, ~74% DPS, ~20% TPS
  - Extraction of $\sigma_{eff,DPS} = 2.7\ ^{+1.4}_{-1.0}$ (exp) $^{+1.5}_{-1.0}$ (theo) mb
  - Confirmation of lower $\sigma_{eff,DPS} \approx 3 - 10$ mb values for quarkonia-based wrt. jet/γ/W/Z DPS studies:
  - ▶ q/g x-dependent transverse profile & correlations

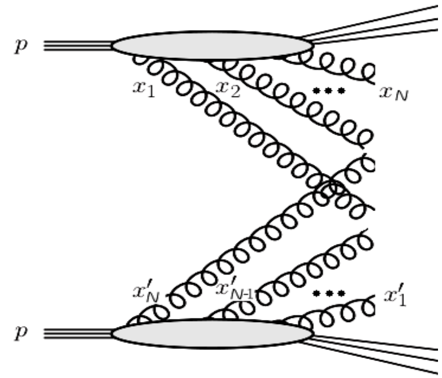




Backup slides

N-parton scatterings x-sections in p-p colls.

- Assuming that the probabilities for N hard collisions to be independent of each other, one can write a generic pocket-formula for NPS x-section:



$$\sigma^{\rm NPS}_{hh'\to a_1\ldots a_n} = \left(\frac{m}{n!}\right) \frac{\sigma^{\rm SPS}_{hh'\to a_1} \cdots \sigma^{\rm SPS}_{hh'\to a_n}}{\sigma^{n-1}_{\rm eff,NPS}}$$

normalized by the N^th-1 power of an effective x-section ($\sigma_{\rm eff,NPS}$) plus a trivial combinatorial factor (m/n!) to avoid double,triple,N-counting in case of same particles produced:

- DPS: $m = 1$ if $a_1 = a_2$; and $m = 2$ if $a_1 \neq a_2$.
- TPS: $m = 1$ if $a_1 = a_2 = a_3$; $m = 3$ if $a_1 = a_2$, or $a_1 = a_3$, or $a_2 = a_3$; and $m = 6$ if $a_1 \neq a_2 \neq a_3$.

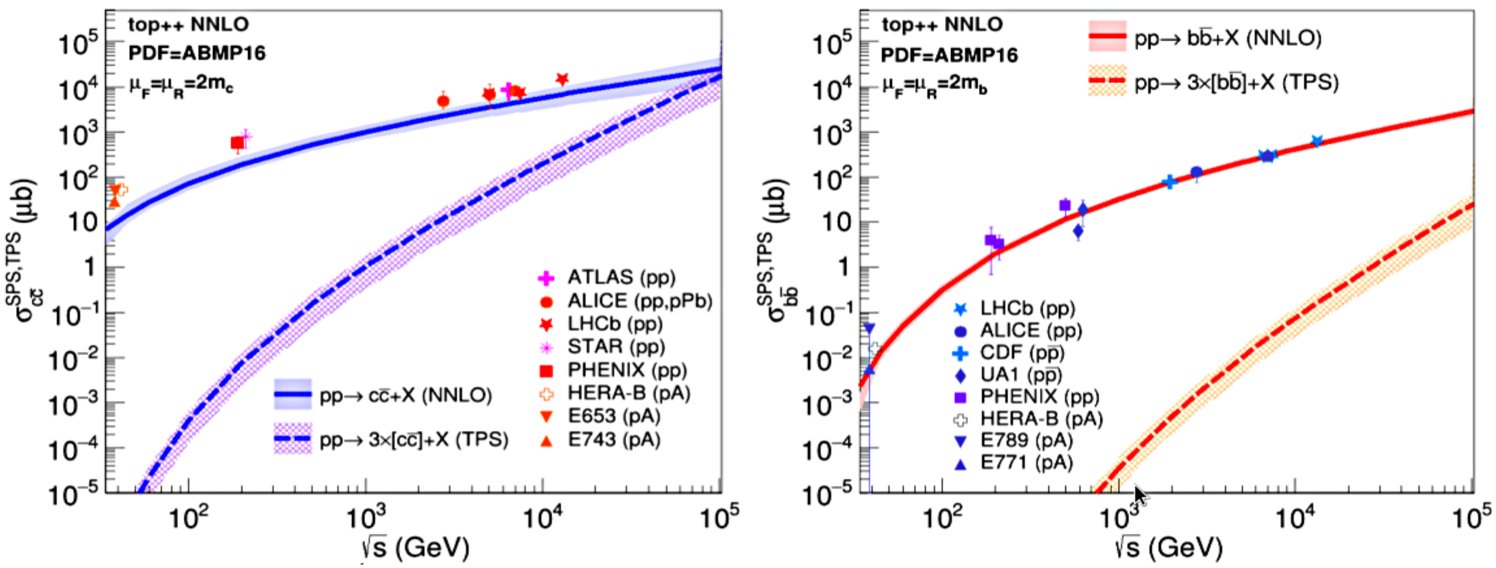
- Ignoring all parton correlations, $\sigma_{\rm eff,NPS}$ is the inverse N^{th}-1 power of the integral of the N^{th} power of the pp overlap function:

$$\sigma_{\rm eff,NPS} = \left\{\int d^2b\, T^n(\mathbf{b})\right\}^{-1/(n-1)}$$

- Most economical (geometrical) expressions for N-parton scattering x-sections as a function of SPS x-sections & overlap function.

Triple charm & beauty production (p-p)

- TPS x-sections are small: $\sigma(\text{SPS})^3/\sigma(\text{eff})^2 \approx 1$ fb for $\sigma(\text{SPS}) \approx 1$ μb, but rise fast (cube of SPS) with c.m. energy.
- Charm & beauty have large enough σ(SPS) to attempt TPS observation:

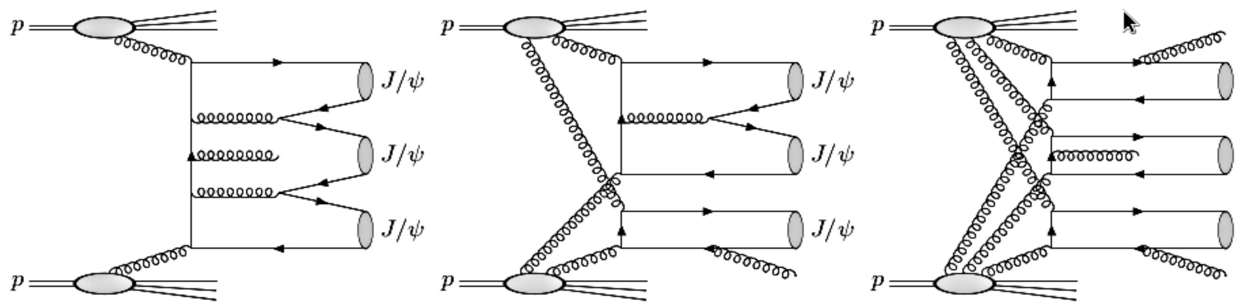


Final state	$\sqrt{s} = 14$ TeV	$\sqrt{s} = 100$ TeV
$\sigma^{\rm SPS}_{c\bar{c}+X}$	$7.1 \pm 3.5_{\rm sc} \pm 0.3_{\rm PDF}$ mb	$25.0 \pm 16.0_{\rm sc} \pm 1.3_{\rm PDF}$ mb
$\sigma^{\rm TPS}_{c\bar{c}\,c\bar{c}\,c\bar{c}+X}$	$0.39 \pm 0.28_{\rm tot}$ mb	$16.7 \pm 11.8_{\rm tot}$ mb
$\sigma^{\rm SPS}_{b\bar{b}+X}$	$0.56 \pm 0.09_{\rm sc} \pm 0.01_{\rm PDF}$ mb	$2.8 \pm 0.6_{\rm sc} \pm 0.1_{\rm PDF}$ mb
$\sigma^{\rm TPS}_{b\bar{b}\,b\bar{b}\,b\bar{b}+X}$	$0.19 \pm 0.12_{\rm tot}$ μb	$24 \pm 17_{\rm tot}$ μb

- Triple charm amounts to ~15% (50%) of inclusive charm x-sections at LHC (FCC). Contribution from triple-SPS, double-SPS processes?

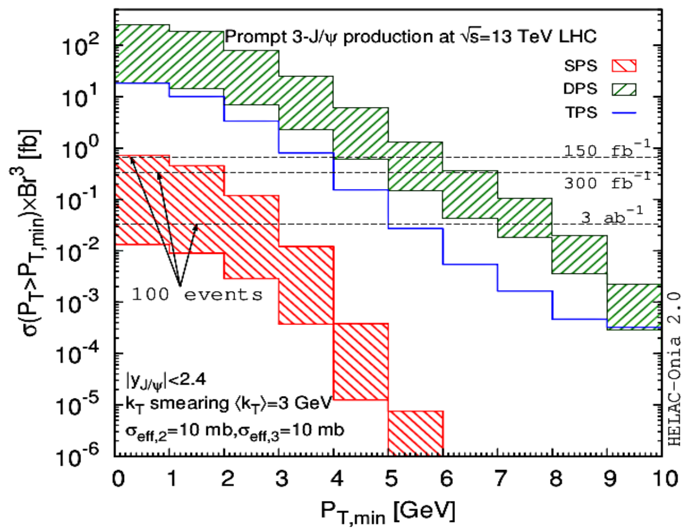
Triple-J/ψ from SPS production (p-p)

- H.-S. Shao et al. [arXiv:1902.04949, PRL 122(2019)192002] computed all triple-J/Ψ x-sections with SPS HELAC-ONIA plus pocket formulas:



(a) SPS (b) DPS (c) TPS

		inclusive	$2.0 < y_{J/\psi} < 4.5$	$\lvert y_{J/\psi}\rvert < 2.4$
13 TeV	SPS	$0.41^{+2.4}_{-0.34} \pm 0.0083$	$(1.8^{+11}_{-1.5} \pm 0.18) \times 10^{-2}$	$(8.7^{+56}_{-7.5} \pm 0.098) \times 10^{-2}$
	DPS	$(190^{+501}_{-140}) \times \frac{10\text{ mb}}{\sigma_{\text{eff},2}}$	$(7.0^{+18}_{-5.1}) \times \frac{10\text{ mb}}{\sigma_{\text{eff},2}}$	$(50^{+140}_{-37}) \times \frac{10\text{ mb}}{\sigma_{\text{eff},2}}$
	TPS	$130 \times \left(\frac{10\text{ mb}}{\sigma_{\text{eff},3}}\right)^2$	$1.3 \times \left(\frac{10\text{ mb}}{\sigma_{\text{eff},3}}\right)^2$	$18 \times \left(\frac{10\text{ mb}}{\sigma_{\text{eff},3}}\right)^2$
27 TeV	SPS	$0.46^{+2.9}_{-0.39} \pm 0.022$	$(3.2^{+22}_{-2.8} \pm 0.21) \times 10^{-2}$	$(5.8^{+39}_{-5.1} \pm 0.29) \times 10^{-2}$
	DPS	$(560^{+2900}_{-480}) \times \frac{10\text{ mb}}{\sigma_{\text{eff},2}}$	$(19^{+97}_{-16}) \times \frac{10\text{ mb}}{\sigma_{\text{eff},2}}$	$(120^{+630}_{-100}) \times \frac{10\text{ mb}}{\sigma_{\text{eff},2}}$
	TPS	$570 \times \left(\frac{10\text{ mb}}{\sigma_{\text{eff},3}}\right)^2$	$5.0 \times \left(\frac{10\text{ mb}}{\sigma_{\text{eff},3}}\right)^2$	$57 \times \left(\frac{10\text{ mb}}{\sigma_{\text{eff},3}}\right)^2$
75 TeV	SPS	$0.59^{+4.4}_{-0.52} \pm 0.016$	$(3.0^{+25}_{-2.7} \pm 0.23) \times 10^{-2}$	$(7.2^{+63}_{-6.5} \pm 0.38) \times 10^{-2}$
	DPS	$(1900^{+11000}_{-1600}) \times \frac{10\text{ mb}}{\sigma_{\text{eff},2}}$	$(57^{+340}_{-50}) \times \frac{10\text{ mb}}{\sigma_{\text{eff},2}}$	$(310^{+2000}_{-270}) \times \frac{10\text{ mb}}{\sigma_{\text{eff},2}}$
	TPS	$3900 \times \left(\frac{10\text{ mb}}{\sigma_{\text{eff},3}}\right)^2$	$27 \times \left(\frac{10\text{ mb}}{\sigma_{\text{eff},3}}\right)^2$	$260 \times \left(\frac{10\text{ mb}}{\sigma_{\text{eff},3}}\right)^2$
100 TeV	SPS	$1.1^{+8.4}_{-1.0} \pm 0.044$	$(4.5^{+33}_{-4.0} \pm 0.72) \times 10^{-2}$	$(36^{+290}_{-32} \pm 1.8) \times 10^{-2}$
	DPS	$(3400^{+19000}_{-2900}) \times \frac{10\text{ mb}}{\sigma_{\text{eff},2}}$	$(100^{+550}_{-86}) \times \frac{10\text{ mb}}{\sigma_{\text{eff},2}}$	$(490^{+3000}_{-430}) \times \frac{10\text{ mb}}{\sigma_{\text{eff},2}}$
	TPS	$6500 \times \left(\frac{10\text{ mb}}{\sigma_{\text{eff},3}}\right)^2$	$45 \times \left(\frac{10\text{ mb}}{\sigma_{\text{eff},3}}\right)^2$	$380 \times \left(\frac{10\text{ mb}}{\sigma_{\text{eff},3}}\right)^2$



- SPS negligible, DPS (TPS) dominates at low (high) p_T.

Clear sensitivity to σ_{eff}!