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Prompt $J/\psi J/\psi$ Cross Section Measurement

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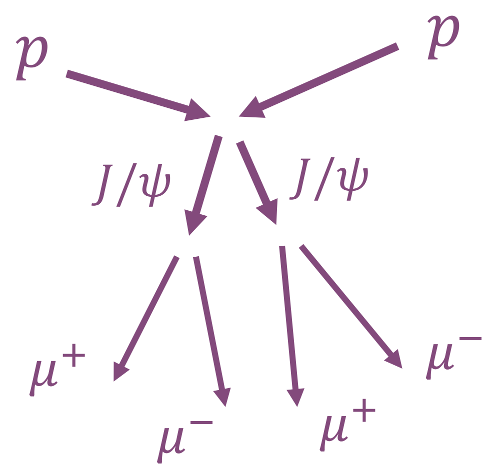
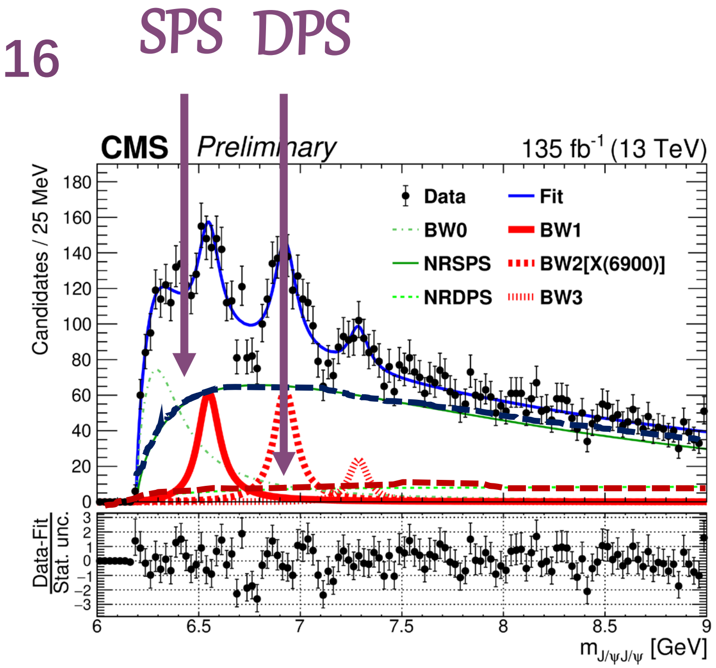
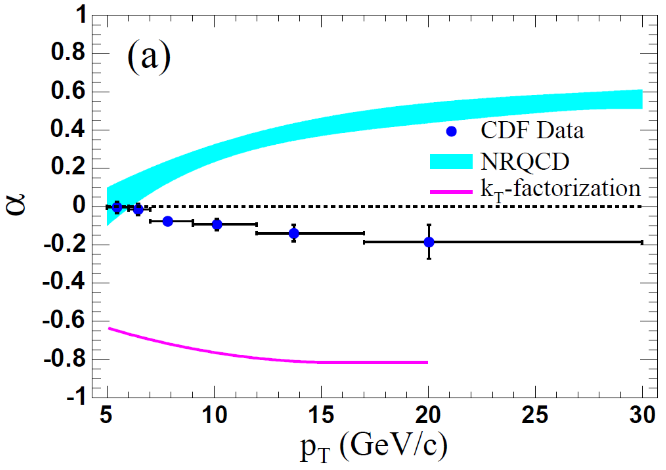
- Simultaneously produced $J/\psi J/\psi$ was first observed by NA3 group
- The main contribution of this channel is expected from parton scattering, including single parton scattering (SPS) and double parton scattering (DPS). Resonances ($cc\bar{c}\bar{c}$) are also predicted to be found in this channel.
- Aim: measure prompt cross section in $J/\psi J/\psi$ final state using 2016 dataset
  - With decay channel: $J/\psi J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-$
  - Main contribution is from SPS and DPS
  - SPS/DPS fraction can be estimated

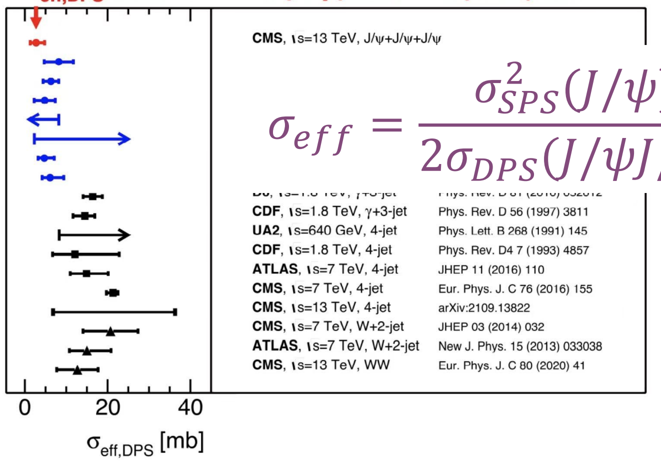




- Production cross section measurement is meaningful for QCD study:
  - Supposed to add valuable information to solve the puzzle of the production of quarkonium.
  - Provide an unique insight into the parton structure.
  - Measurement of DPS process serves as another estimation of the effective cross section.
- Measured widely in LHC:

Group	Energy	Fiducial Volume	Result
LHCb	7TeV	$2 < \eta < 4.5,\ p^T < 10\text{GeV}$	$(5.1 \pm 1.0)\text{nb}$
	13TeV	$2 < \eta < 4.5,\ p^T < 14\text{GeV}$	$(16.4 \pm 0.28)\text{nb}$
ALICE	13TeV	$2.5 < \eta < 4$	$(10.3 \pm 2.3)\text{nb}$
ATLAS	8TeV	$\lvert\eta\rvert < 2.1,\ p^T > 8.5\text{GeV}$	$(29.1 \pm 1.8)\text{pb}$
CMS	7TeV	$\lvert\eta\rvert < 1.2,\ p^T > 6.5\text{GeV}$, $1.2 < \lvert\eta\rvert < 1.43,\ 6.5\text{GeV} > p^T > 4.5\text{GeV}$, $1.43 < \lvert\eta\rvert < 2.2,\ p^T > 4.5\text{GeV}$	$(1.49 \pm 0.07)\text{nb}$





$$\sigma_{eff} = \frac{\sigma_{SPS}^2(J/\psi)}{2\sigma_{DPS}(J/\psi J/\psi)}$$

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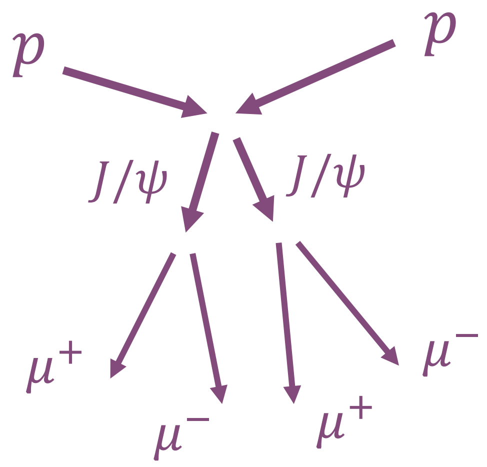
- **Event selection**

- **Single muon**
  - Soft muon
  - $|\eta(\mu)| < 2.4$, $p^T(\mu) > 3.5$ GeV
  - RECO level μ matches with HLT level μ
- $\mathbf{J/\psi}$ (Opposite sign muons)
  - $2.85 < M(J/\psi) < 3.35$ GeV
  - Vertex probability (dimuon) > 0.005
  - $p^T(J/\psi) > 10$ GeV
- **For MC samples, we also require:**
  - GEN level μ matches with RECO level μ
  - GEN level: $|\eta(\mu)| < 2.4$, $p^T(\mu) > 3.5$ GeV
- **Two J/ψs in one candidate are sorted randomly**

- **HLT Trigger**
  - HLT_Dimuon0_Jpsi_Muon
- $\boldsymbol{\mu^+\mu^-\mu^+\mu^-}$
  - Pass $\mu^+\mu^-\mu^+\mu^-$ vertex fit
  - $M(\mu^+\mu^-\mu^+\mu^-) > 7.5$ GeV



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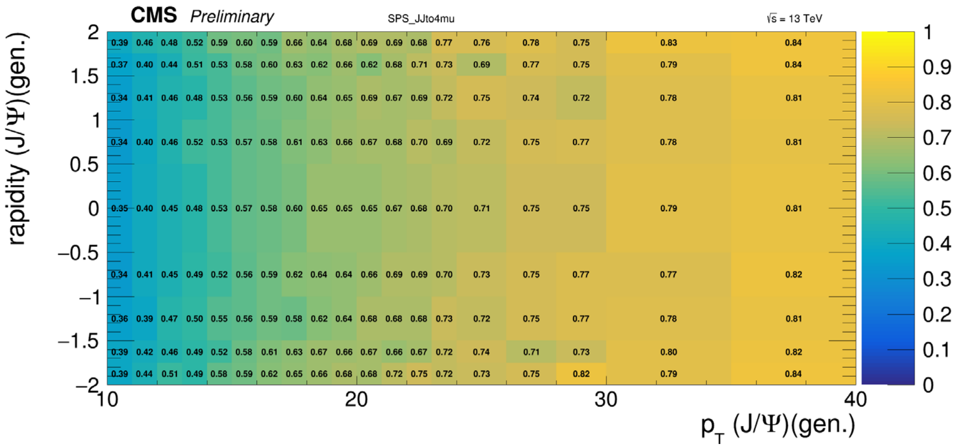
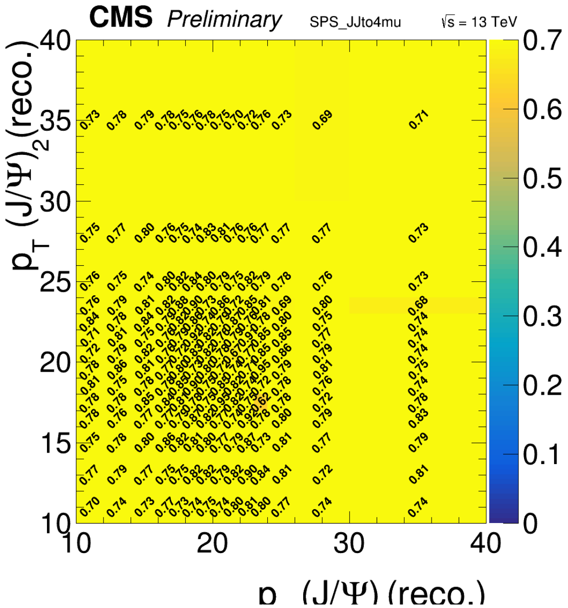
- Acceptance and efficiency are calculated sequentially against $p^T(J/\psi)$ (10, 40) and $y(J/\psi)$ (-2,2) with variable bin width
- Different acceptance and efficiency maps are calculated for different processes (SPS and DPS) using MC samples
- The dataset has been corrected by the acceptance and efficiency maps
    - Correction is carried out event-by-event
    - Correction is conducted with a weight:
        - $W = \frac{1}{(1-f_{DPS})A_{total}^{SPS}\epsilon_{total}^{SPS}+f_{DPS}A_{total}^{DPS}\epsilon_{total}^{DPS}}$



Acceptance of $p^T(\mu)$ (SPS)



Efficiency of HLT (SPS)

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- To extract the signal yield, a four dimensional fitting is conducted, with the consideration of two sets of background:
  - Combinatorial background
  - Non-prompt background (J/ψ decayed from B meson)
- The final fitting includes four dimensions: $M(J/\psi_1)$,$M(J/\psi_2)$, $c\tau(J/\psi_1)$, $c\tau(J/\psi_2)$
- And seven components:
  - J/ψ_1(prompt)+J/ψ_2(prompt) → Signal
  - J/ψ_1(non-prompt)+J/ψ_2(prompt)
  - J/ψ_1(prompt)+J/ψ_2(non-prompt)
  - J/ψ_1(non-prompt)+J/ψ_2(non-prompt)

    → Non-prompt background
  - $J/\psi_1\mu^+\mu^-$
  - $\mu^+\mu^-J/\psi_2$
  - $\mu^+\mu^-\mu^+\mu^-$

    → Combinatorial background

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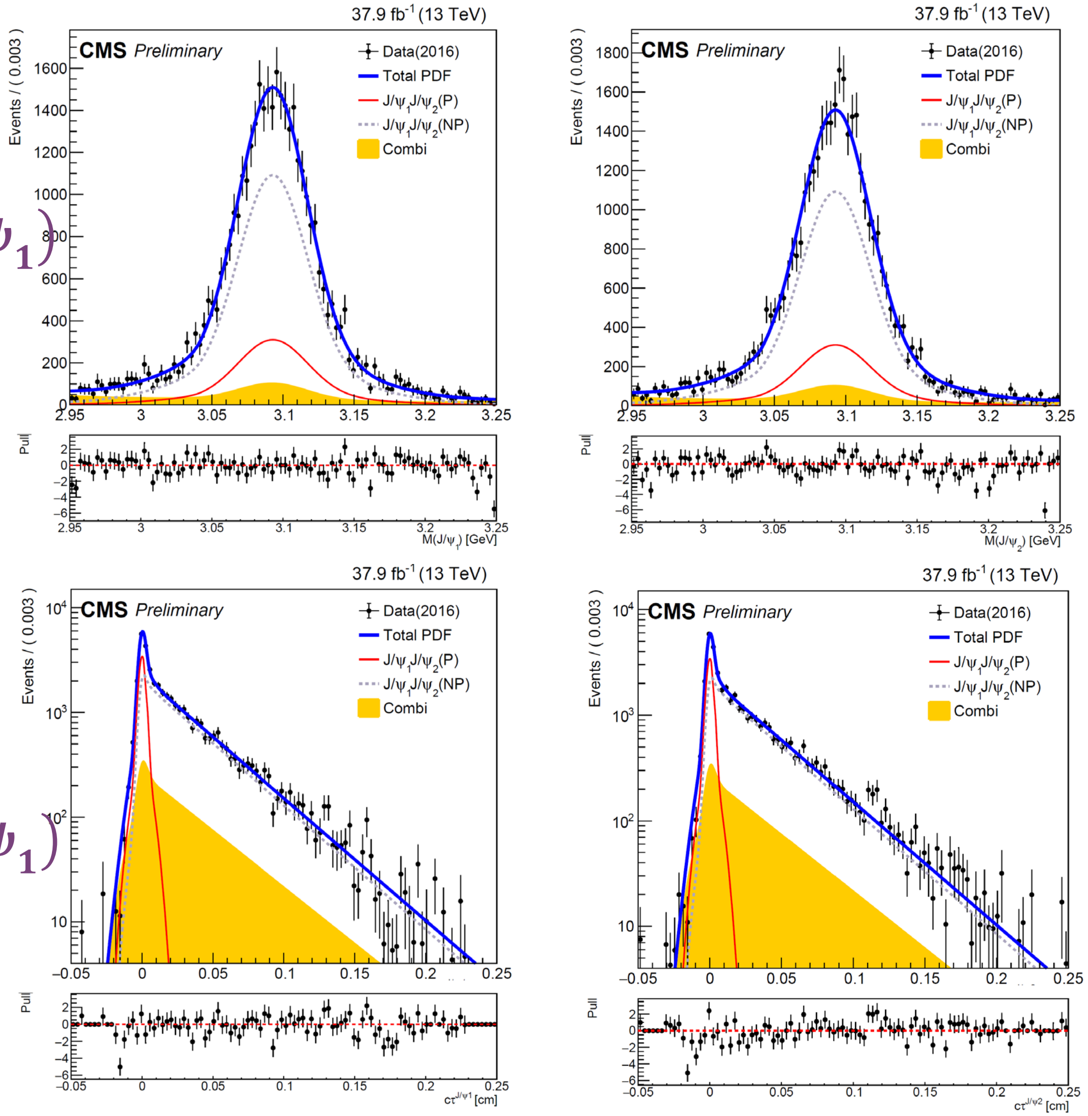
- The fitter has been employed on 2016 dataset

$M(J/\psi_1)$ $M(J/\psi_2)$



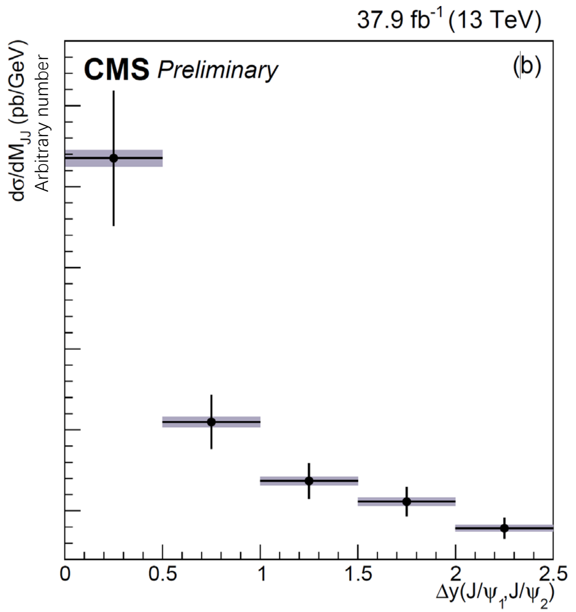
$c\tau(J/\psi_1)$ $c\tau(J/\psi_2)$

- Fitting quality is satisfactory

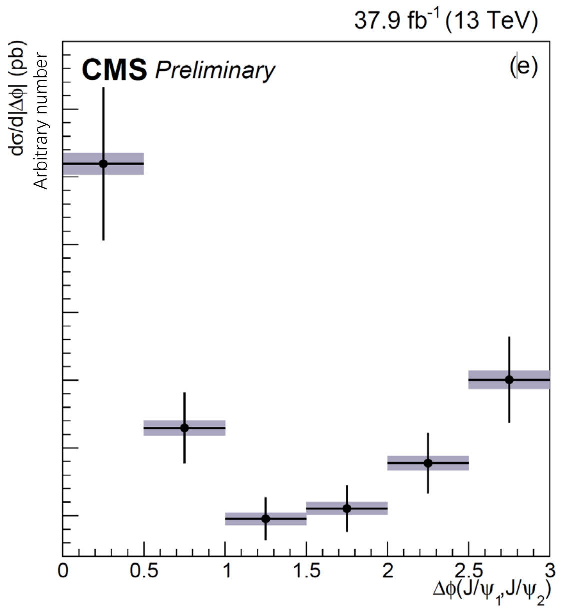
Component		Yield
J/ψ_1 J/ψ_2	P+P	**7340 ± 100**
	P+NP	2540 ± 70
	NP+P	
	NP+NP	21300 ± 200
$J/\psi_1\mu^+\mu^-$		2530 ± 120
$\mu^+\mu^- J/\psi_2$		
$\mu^+\mu^-\mu^+\mu^-$		10 ± 40

- Cross section is calculated:
  - $\sigma = \frac{N^{corr}}{L \times BR^2(J/\psi \to \mu^+\mu^-)}$
    - N^{corr}: Yield of signal acquired from fitting with corrected dataset
    - L: Integral luminosity (for 2016, 36.303 fb^{-1})
    - BR: Branch ratio $(5.961 \pm 0.033)\%$
- A preliminary result has been acquired with 2016 dataset (under review)

- Differential cross section is calculated similarly against $M(J/\psi_1 J/\psi_2)$, $p^T(J/\psi_1 J/\psi_2)$, $y(J/\psi_1 J/\psi_2)$, $\Delta(y_1, y_2)$ and $\Delta(\phi_1, \phi_2)$ (under review)

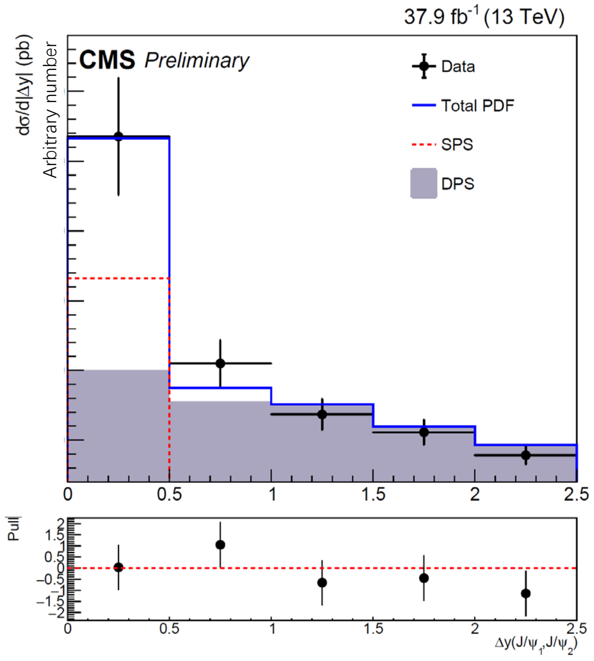


$\Delta(y_1, y_2)$

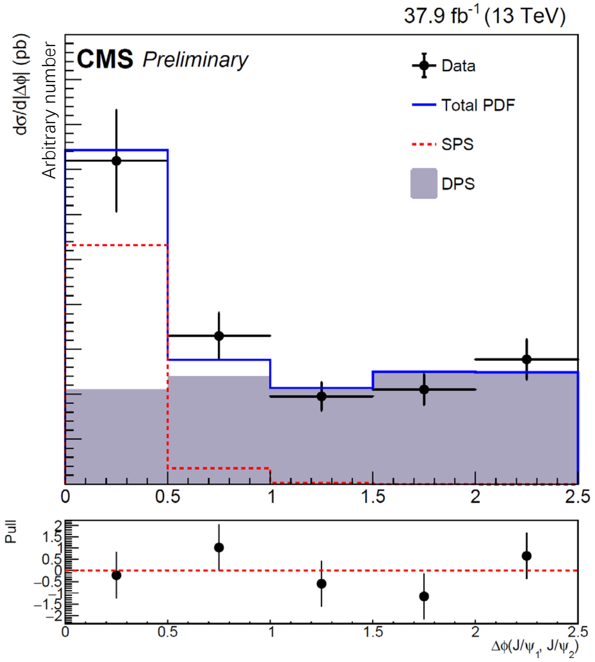


$\Delta(\phi_1, \phi_2)$

- A template fit can be conducted on the distribution of differential cross section to acquire the fraction of DPS component (f_{DPS})
  - The distributions of SPS/DPS can be extracted from MC samples
  - These distributions are employed as templates
  - These template PDFs are utilized to fit the distribution of differential cross section
  - The fit is conducted simultaneously on Δy and $\Delta\phi$ dimensions



$\Delta(y_1, y_2)$



$\Delta(\phi_1, \phi_2)$

- The result is under review

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- Systematic uncertainty
- Several sources of systematic error are considered:
  1. Branch ratio($J/\psi \to \mu^+\mu^-$): Acquired from PDG
  2. Integral luminosity: Provided by CMS
  3. Acceptance and efficiency correction:
     - Using different correction (different f_{DPS}) causes different yield estimation
  4. Model of prompt J/ψ:
     - The $\boldsymbol{c\tau}$ distribution of promptly produced J/ψ is extracted from a SPS/DPS mixing MC sample
     - Different mixing fraction causes different shape
  5. Stability of the fitter:
     - The feasibility and robustness of the fitter is tested

- Systematic uncertainty
- Several sources of systematic error are considered:

6. Lifetime variables selection:
   - Another fitting is conducted with an alternative lifetime variables ($Sig_{Lxy1} + Sig_{Lxy2}$), the difference between two fits is taken as an error

	Error [%]
Branch ratio	1.5
Luminosity	2.6
Correction	13.1
$c\tau$ shape	4.2
Stability of the fitter	6.0
Lifetime variables	0.3
Total	15.5

- **Summary**
- **We present the cross section measurement for prompt $J/\psi J/\psi$ at 13TeV**

1. **Acceptance and efficiency** are calculated with MC samples
   - The datasets are **corrected with a mixed SPS/DPS** acceptance and efficiency
2. **Fitter** is developed $[M(J/\psi_1), M(J/\psi_2), c\tau(J/\psi_1), c\tau(J/\psi_2)]$
   - Fitting to the **2016 dataset** is satisfactory
   - The fitting is employed in different **kinematic bins** to acquire **differential cross section**
   - A template fit is conducted and $\boldsymbol{f_{DPS}}$ **is acquired**
4. **Systematic error** is estimated
5. A **preliminary result** is acquired
   - Including **total cross section, differential cross section and** $\boldsymbol{f_{DPS}}$

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Thank You

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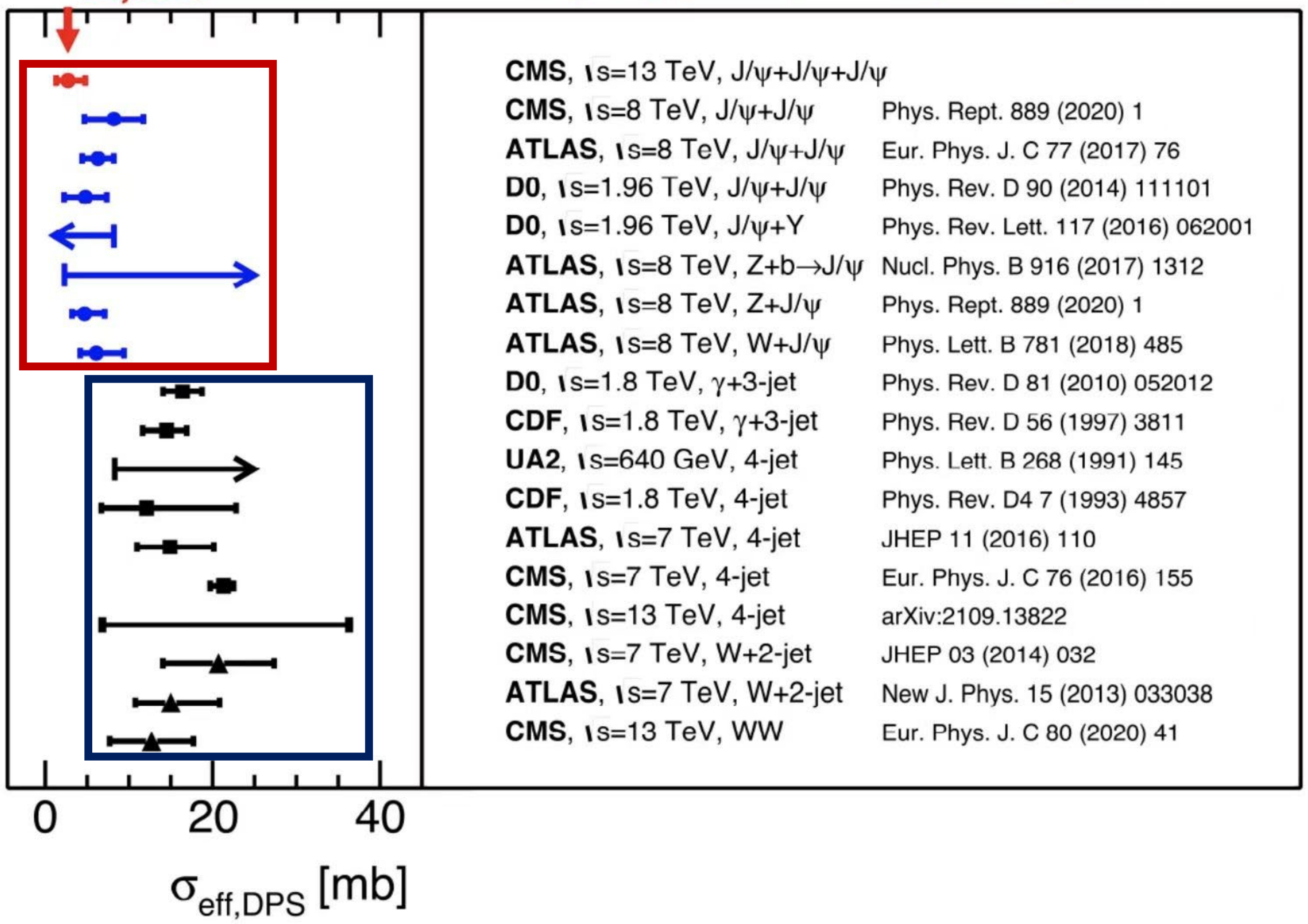
$\sigma_{eff,DPS}$ = 2.7+1.4–1.0 (exp)+1.5–1.0 (theo) mb



ATLAS ~ 6mb
LHCb ~ 13mb

/Charmonium/Run2016B-21Feb2020-ver2_UL2016_HIPM-v1/AOD
/Charmonium/Run2016C-21Feb2020_UL2016_HIPM-v1/AOD
/Charmonium/Run2016D-21Feb2020_UL2016_HIPM-v1/AOD
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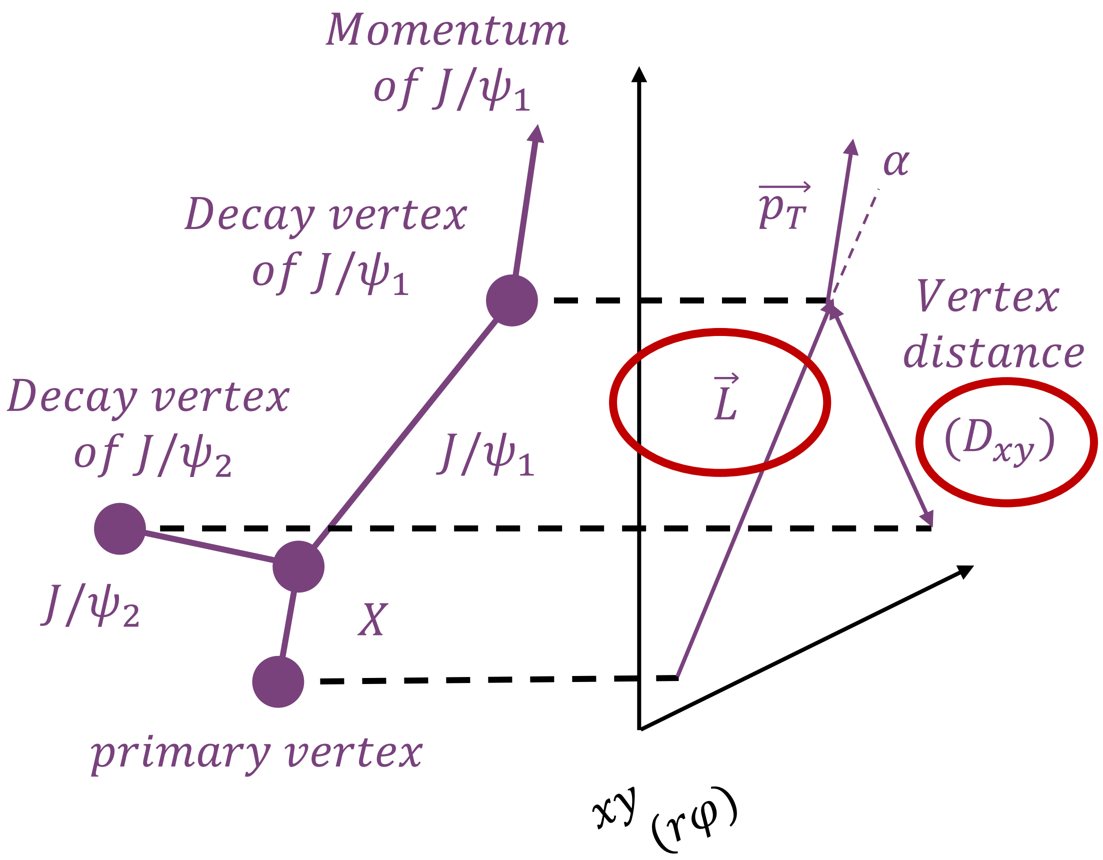
/Charmonium/Run2016H-21Feb2020_UL2016-v1/AOD

JSON: Cert_271036-284044_13TeV_Legacy2016_Collisions16_JSON_MuonPhys.txt

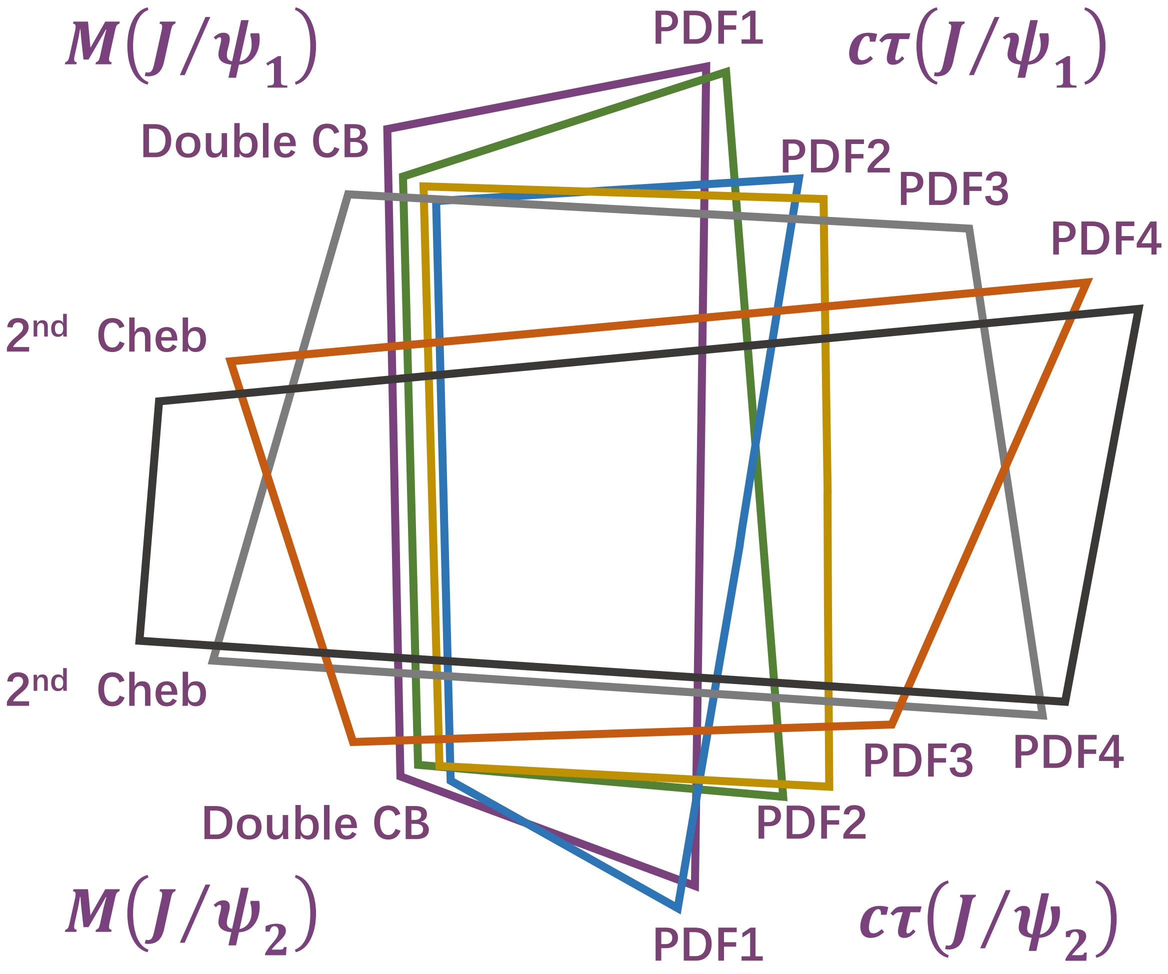
- $A_{\eta(\mu)} = N(|\eta(\mu)|<2.4) / N_{total}$
- $A_{p^T(\mu)} = N(|\eta(\mu)|<2.4 \&\& p^T(\mu) > 3.5\ \text{GeV}) / N(|\eta(\mu)|<2.4)$
- $\epsilon_{RECO(\mu)} = N(GEN_{matched} \&\& |\eta(\mu)|<2.4 \&\& p^T(\mu) > 3.5\ \text{GeV}) / N(|\eta(\mu)|<2.4 \&\& p^T(\mu) > 3.5\ \text{GeV})$
- $\epsilon_{ID(\mu)} = N(\mu_{soft} \&\& GEN_{matched} \&\& \dots) / N(GEN_{matched} \&\& |\eta(\mu)|<2.4 \&\& p^T(\mu) > 3.5\ \text{GeV})$
- $\epsilon_{\mu^+\mu^-} = N(cut(\mu^+\mu^-) \&\& \mu_{soft} \&\& \dots) / N(\mu_{soft} \&\& GEN_{matched} \&\& \dots)$
- $\epsilon_{HLT} = N(HLT \&\& cut(\mu^+\mu^-) \&\& \dots) / N(cut(\mu^+\mu^-) \&\& \mu_{soft} \&\& \dots)$
- $\epsilon_{\mu^+\mu^-\mu^+\mu^-} = N(cut(\mu^+\mu^-\mu^+\mu^-) \&\& HLT \&\& \dots) / N(HLT \&\& cut(\mu^+\mu^-) \&\& \dots)$

- In $J/\psi J/\psi$ final state, candidate with one or both J/ψ decayed from a B meson is considered as a main background (non-prompt background)
- Lifetime variables are extracted from the event to exclude this background



- $L_{xy}PV(J/\psi_1) = \overrightarrow{L(J/\psi_1)} \cdot \overrightarrow{p^T(J/\psi_1)} \Big/ \left|\overrightarrow{p^T(J/\psi_1)}\right|$
- $c\tau(J/\psi_1) = L_{xy}PV(J/\psi_1) \cdot M(J/\psi_1) \Big/ \left|\overrightarrow{p^T(J/\psi_1)}\right|$
- $Sig_{Lxy}(J/\psi_1)$: Significance of $L_{xy}PV(J/\psi_1)$
- $d^{J/\psi}$: Significance of the vertex distance (D_{xy})

- **Double CB** for J/ψ mass peak (float)
- **2nd Cheb** for $\mu^+\mu^-$ mass (float)
- **Double Gaus (PDF1)** for prompt J/ψ $c\tau$ (in $J/\psi J/\psi$ pair)
- **Exp⊗Gaus (PDF2)** for non-prompt J/ψ $c\tau$ (in $J/\psi J/\psi$ pair)
- **Gaus+Exp⊗Gaus (PDF3)** for J/ψ $c\tau$ (in combinatorial background)
- **Exp⊗Gaus (PDF4)** for $\mu^+\mu^-$ $c\tau$ (in combinatorial background)
- **PDF1/2 are fixed by MC**
- **PDF3/4 are fixed by side band**



J/ψ_1(P)+J/ψ_2(P)

J/ψ_1(P)+J/ψ_2(NP)

J/ψ_1(NP)+J/ψ_2(P)

J/ψ_1(NP)+J/ψ_2(NP)

$J/\psi_1\mu^+\mu^-$

$\mu^+\mu^-J/\psi_2$

$\mu^+\mu^-\mu^+\mu^-$

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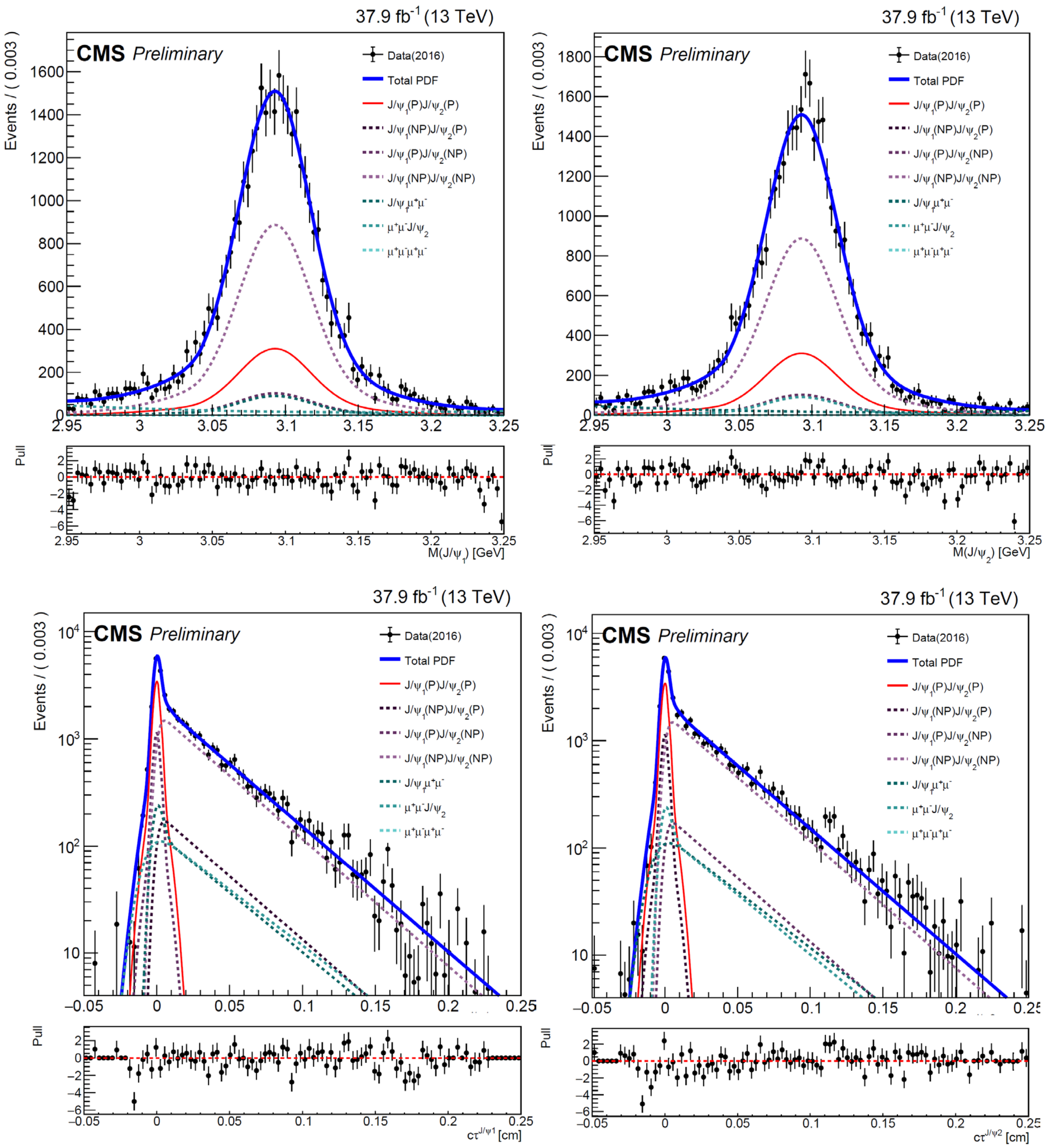
$M(J/\psi_1)$

$M(J/\psi_2)$

$c\tau(J/\psi_1)$

$c\tau(J/\psi_2)$



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SPS

	M_2	$c\tau_1$	$c\tau_2$
M_1	-0.010	-0.004	-0.010
M_2	-	-0.047	-0.072
$c\tau_1$	-	-	-0.007

DPS

	M_2	$c\tau_1$	$c\tau_2$
M_1	-0.011	-0.075	0.010
M_2	-	-0.050	-0.032
$c\tau_1$	-	-	0.066

	$N_{corr}(Mix)$	$N_{corr}(SPS)$	$N_{corr}(DPS)$
Corrected number	37259	32391	40981
Pass all selections	8160		

		1	2	3	4	5
J/ψ_1 J/ψ_2	SPS+DPS	1000+500	2000+500	1000+1000	2000+1000	1000+500
	P+NP	500	500	500	500	1000
	B decay	2000	2000	2000	2000	2000
$J/\psi\mu^+\mu^-$		1000	1000	1000	1000	1000
$\mu^+\mu^-\mu^+\mu^-$		100	100	100	100	100

J/ψ_1 J/ψ_2	P+P	1430 ± 40	2430 ± 50	1880 ± 50	2880 ± 60	1480 ± 50
	NP+P	530 ± 30	520 ± 30	540 ± 30	540 ± 30	1020 ± 30
	NP+NP	1960 ± 60	1960 ± 60	1960 ± 60	1960 ± 60	1980 ± 70
$J/\psi\mu^+\mu^-$		1030 ± 40	1040 ± 30	1030 ± 40	1040 ± 30	1000 ± 40
$\mu^+\mu^-\mu^+\mu^-$		100 ± 20	100 ± 20	100 ± 20	100 ± 20	100 ± 20

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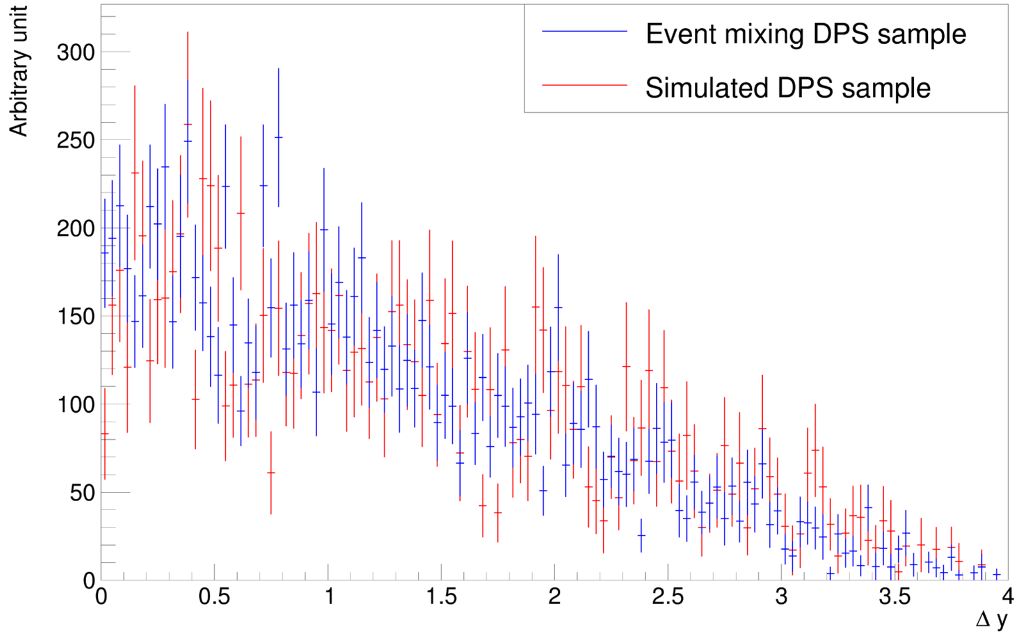
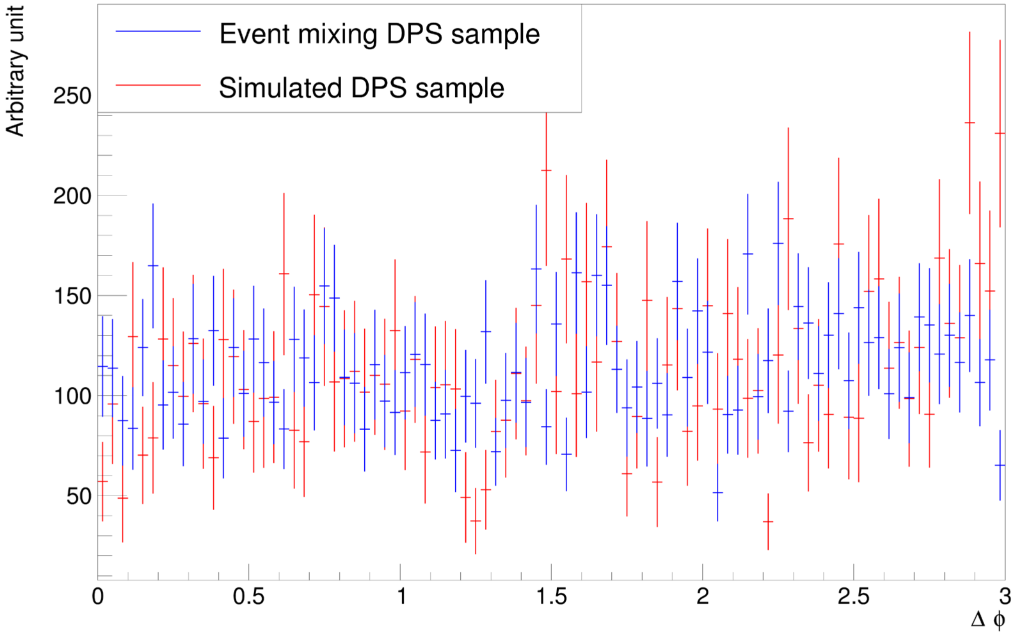
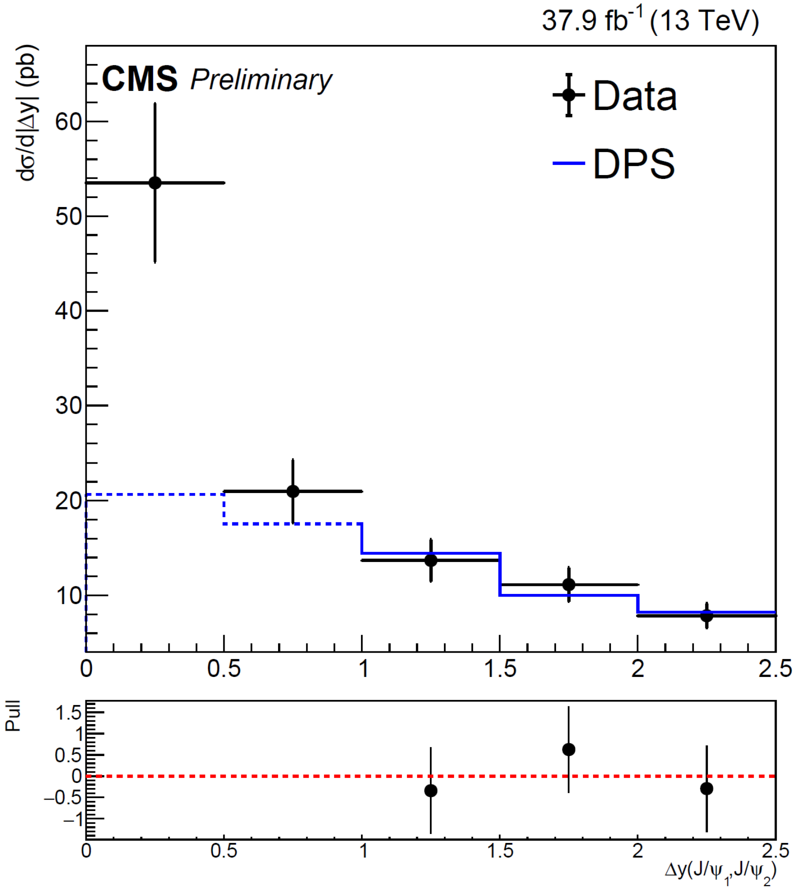


$\Delta(y_1, y_2)$



$\Delta(\phi_1, \phi_2)$



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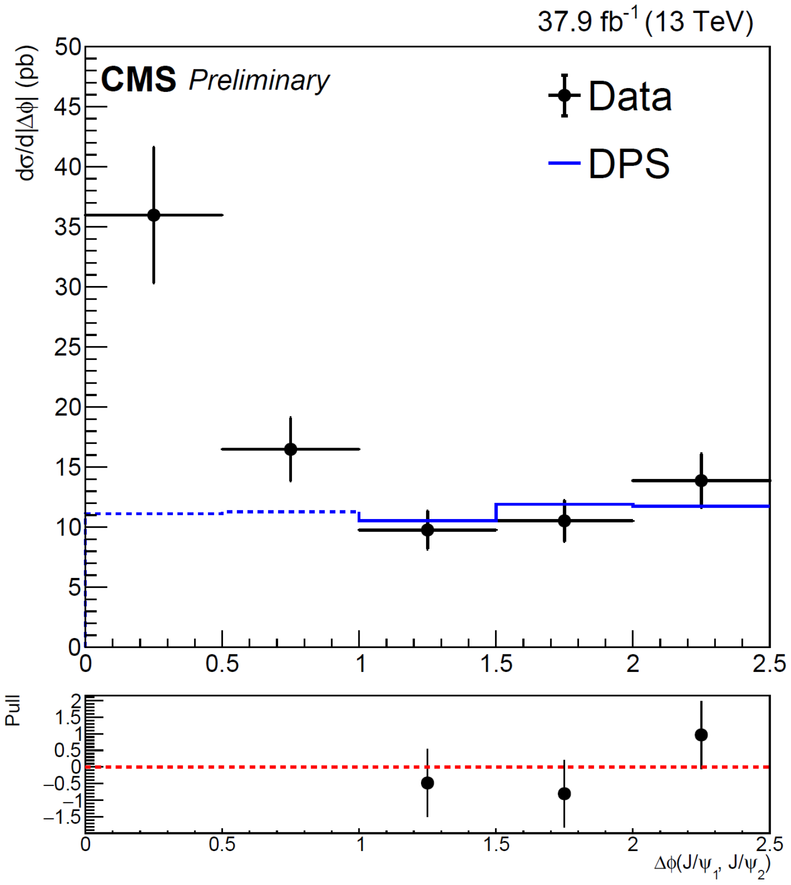

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