Inclusive Double Jpsi cross section measurement in CMS

Taozhe Yu, Hongbo Liao

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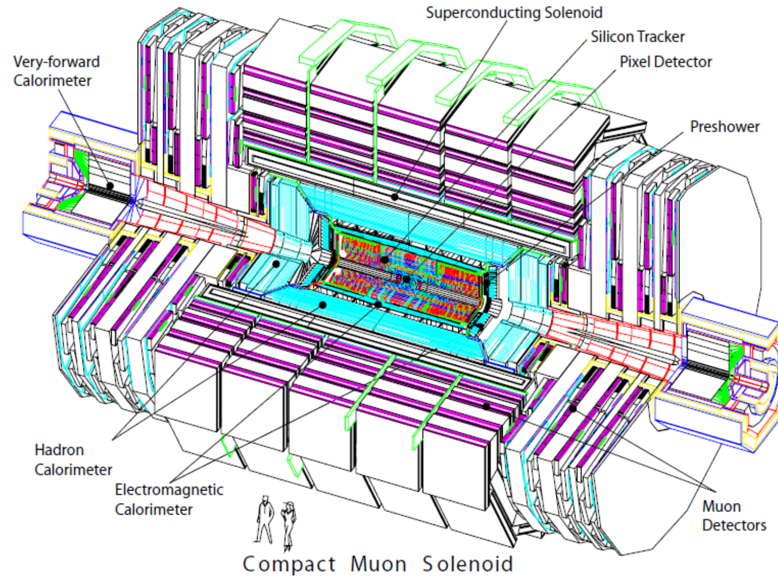
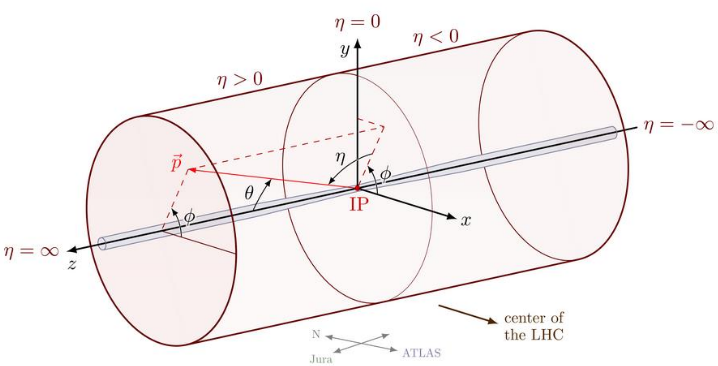
高能所博士后学术交流会

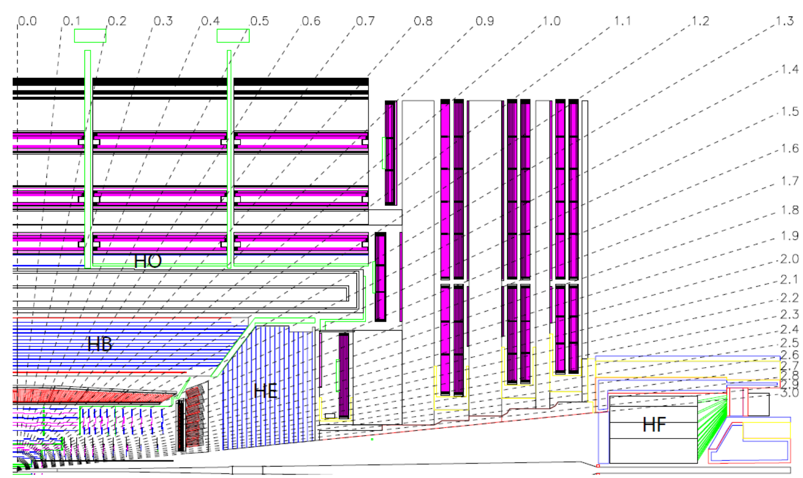
LHC and CMS

- 周长27km，跨越瑞士法国国境，总投资40亿美元
- 世界能量最高最大的加速器，质心系能量–〉7, 8, 13/14TeV（14×10^{12}eV）



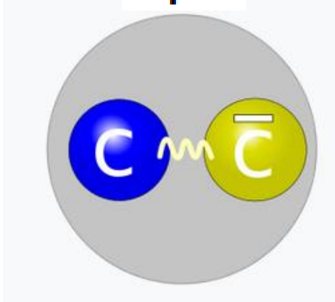


$$\eta = -\ln\tan\frac{\theta}{2}$$ 赝快度

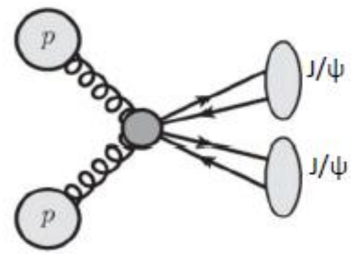


Introduce

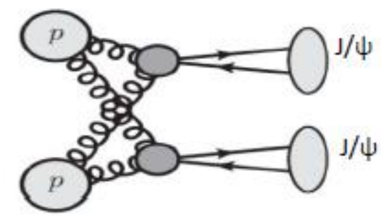
J/psi



J/psi pair produced in LHC



SPS: gg→J/ψJ/ψ



DPS: gg→J/ψJ/ψ

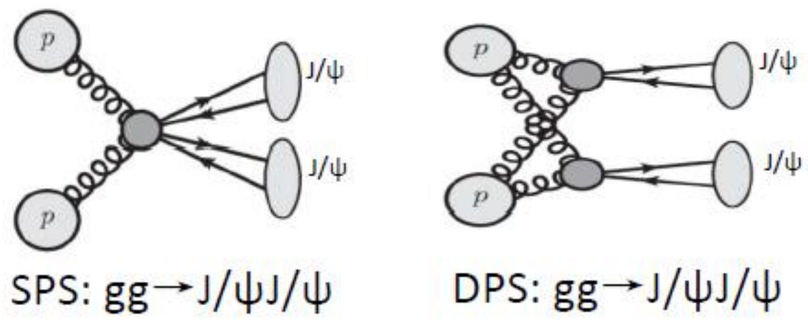
Measurement of Jpsi Pair cross section can validate perturbative quantum chromodynamics (QCD)

$c\bar{c} \rightarrow 3\,g$		$64.1\% \pm 1.0\%$
$c\bar{c} \rightarrow \gamma + 2\,g$		$8.8\% \pm 0.5\%$
$c\bar{c} \rightarrow \gamma$		~25.4%
	$\gamma \rightarrow$ hadrons	$13.5\% \pm 0.3\%$
	$\gamma \rightarrow e^{+} + e^{-}$	$5.94\% \pm 0.06\%$
	$\boxed{\gamma \rightarrow \mu^{+} + \mu^{-}}$	$\boxed{5.93\% \pm 0.06\%}$

- We choose Jpsi decay to two μ channel：
  - The physics process is cleaner
  - The lepton trigger is better to select signal
  - CMS have the best technology to identity μ

Introduce

- Measure the J/ψ pair production cross section using Run2(2016-2018) data in CMS
- Study the Fraction of DPS and SPS



➢ The J/ψ pair production measurement has been done by LHCb, ATLAS and CMS

collaboration	Sqrt(s)	luminosity	Phase space	Result	paper
LHCb	7TeV	$37.5pb^{-1}$	$2<\eta<4.5$ pt<10GeV	$5.1\pm1.0\pm1.1$nb	link
LHCb	13TeV	$279\pm11pb^{-1}$	$2<\eta<4.5$ pt<10GeV	$15.2\pm1.0\pm0.9$nb	link
ATLAS	8TeV	$11.4fb^{-1}$	$\lvert\eta\rvert<2.1$, pt>8.5GeV	$15.6\pm1.3\pm1.2\pm0.2\pm0.3$pb for $\lvert\eta\rvert<1..05$ $13.5\pm1.3\pm1.1\pm0.2\pm0.3$pb for $1.05<\lvert\eta\rvert<2.1$	link
CMS	7TeV	$4.7fb^{-1}$	pt>6.5GeV: $\lvert\eta\rvert<1.2$ pt>6.5→4.5GeV: $1.2<\lvert\eta\rvert<1.43$ pt>4.5GeV: $1.43<\lvert\eta\rvert<2.2$	$1.49\pm0.07\pm0.13$nb	link

Data and MC

Data	sample
2016	/Charmonium/Run2016B-02Apr2020_ver2-v1/NANOAOD /Charmonium/Run2016C-02Apr2020-v1/NANOAOD /Charmonium/Run2016D-02Apr2020-v1/NANOAOD /Charmonium/Run2016E-02Apr2020-v1/NANOAOD /Charmonium/Run2016F-02Apr2020-v1/NANOAOD /Charmonium/Run2016G-02Apr2020-v1/NANOAOD /Charmonium/Run2016H-02Apr2020-v1/NANOAOD
2017	/Charmonium/Run2017B-02Apr2020-v1/NANOAOD /Charmonium/Run2017C-02Apr2020-v1/NANOAOD /Charmonium/Run2017D-02Apr2020-v1/NANOAOD /Charmonium/Run2017E-02Apr2020-v1/NANOAOD /Charmonium/Run2017F-02Apr2020-v1/NANOAOD
2018	/Charmonium/Run2018A-02Apr2020-v1/NANOAOD /Charmonium/Run2018B-02Apr2020-v1/NANOAOD /Charmonium/Run2018C-02Apr2020-v1/NANOAOD /Charmonium/Run2018D-02Apr2020-v1/NANOAOD

background	sample
SPS	/SPS_ToJPsiJPsi_*-pythia8/RunII*NanoAODv7-*mcRun2*/NANOAODSIM
DPS	/DPS_ToJPsiJPsi_*-pythia8/RunII*NanoAODv7-*mcRun2*/NANOAODSIM

We just use 2016 dataset in this presentation

Object and event selection

➢Trigger

HLT_Dimuon0_Jpsi_Muon

➢Muon

- Standard Medium muon ID
- pT(muon)>=3.0GeV
- |η(muon)|<=2.4

➢J/ψ

The J/ψ was reconstructed by two muon

- 1<|η(J/ψ)| < 2.2   pT(J/ψ) >6GeV
  |η(J/ψ)| < 1   pT(J/ψ) >7GeV

- |m(dimuon) – 3.096GeV|<0.3GeV

➢J/ψ Pair

- In one event, if the number of J/ψ candidates is larger than 2
  minimal $|\,m(J/\psi1)-3.092GeV|^2 + |\,m(J/\psi2\,)-3.092GeV|^2$ is used to select one combination

- J/ψ pairs assigned randomly as J/ψ1 and J/ψ2

- J/ψ1(muon12) and J/ψ2(muon34) do not share a common muon

J/ψ J/ψ events extraction strategy

- The process contribution to the signal region are:
  - J/ψ + J/ψ (signal)
  - J/ψ + combinatorial
  - Combinatorial + combinatorial

- Process modeling
  - J/ψ: using double-sided Crystal Ball (DSCB) function

    The parament get from DPS and SPS fit

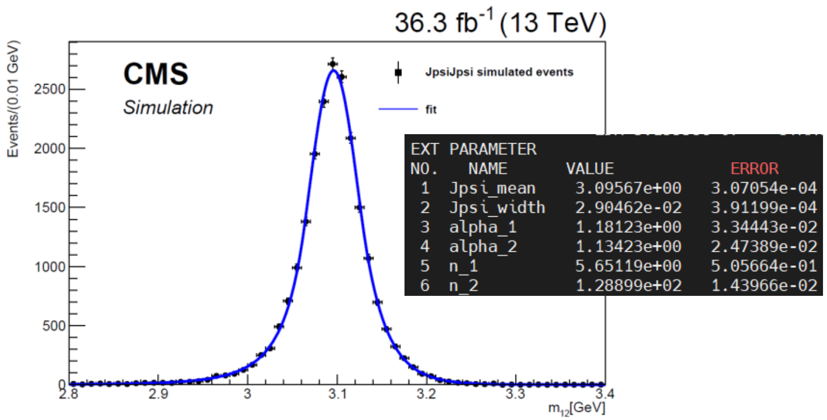
$$f_S(x;\vec{\theta}) = \begin{cases} \left(\frac{n_L}{|\alpha_L|}\right)^{n_L} \exp\left(\frac{-|\alpha_L|^2}{2}\right)\left(\frac{n_L}{|\alpha_L|} - |\alpha_L| - \frac{x-\mu}{\sigma}\right)^{-n_L}, & \text{for } \frac{x-\mu}{\sigma} \leq -\alpha_L \\ \exp(-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2), & \text{for } -\alpha_L < \frac{x-\mu}{\sigma} < \alpha_R \\ \left(\frac{n_R}{|\alpha_R|}\right)^{n_R} \exp\left(\frac{-|\alpha_R|^2}{2}\right)\left(\frac{n_R}{|\alpha_R|} - |\alpha_R| + \frac{x-\mu}{\sigma}\right)^{-n_R}, & \text{for } \frac{x-\mu}{\sigma} \geq \alpha_R, \end{cases}$$

  - Combinatorial component: use the 2nd Chebyshev Polynomial

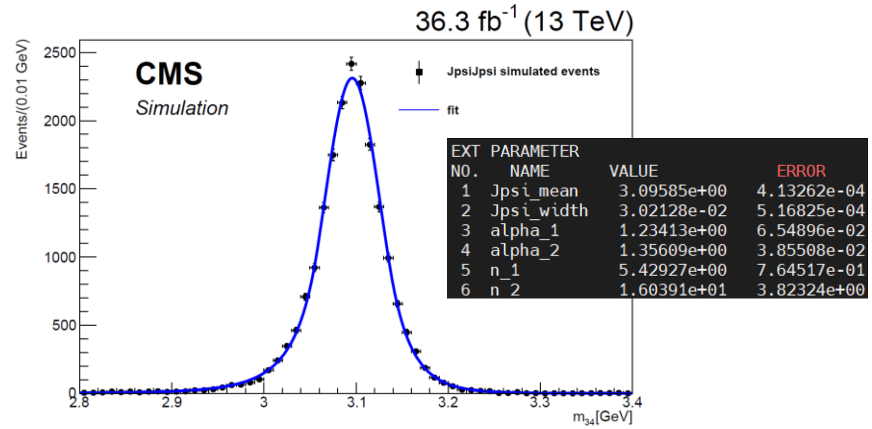
Modeling the J/ψ

- Use SPS and DPS simulation sample to get J/ψ shape

DPS

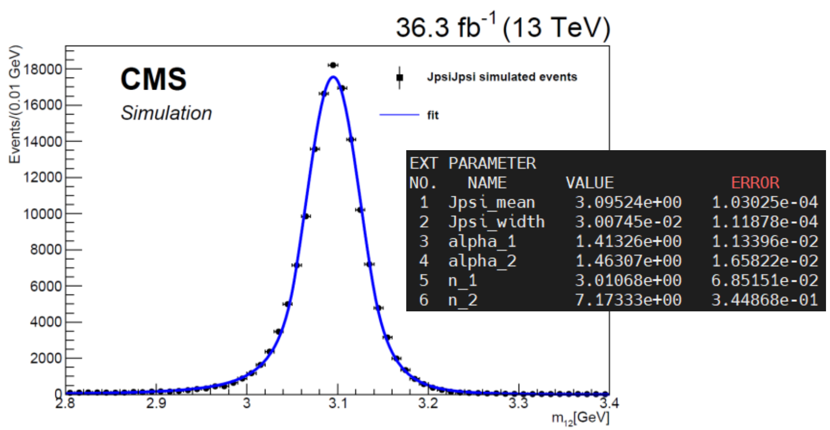


EXT NO.	PARAMETER NAME	VALUE	ERROR
1	Jpsi_mean	3.09567e+00	3.07054e-04
2	Jpsi_width	2.90462e-02	3.91199e-04
3	alpha_1	1.18123e+00	3.34443e-02
4	alpha_2	1.13423e+00	2.47389e-02
5	n_1	5.65119e+00	5.05664e-01
6	n_2	1.28899e+02	1.43966e-02

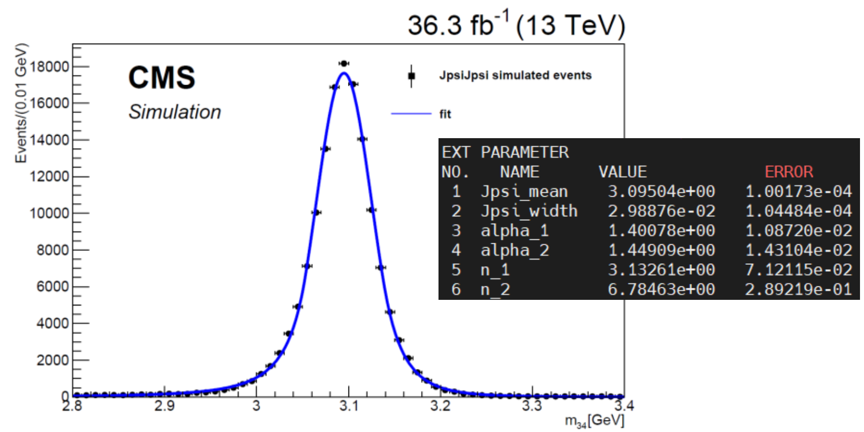


EXT NO.	PARAMETER NAME	VALUE	ERROR
1	Jpsi_mean	3.09585e+00	4.13262e-04
2	Jpsi_width	3.02128e-02	5.16825e-04
3	alpha_1	1.23413e+00	6.54896e-02
4	alpha_2	1.35609e+00	3.85508e-02
5	n_1	5.42927e+00	7.64517e-01
6	n_2	1.60391e+01	3.82324e+00

SPS



EXT NO.	PARAMETER NAME	VALUE	ERROR
1	Jpsi_mean	3.09524e+00	1.03025e-04
2	Jpsi_width	3.00745e-02	1.11878e-04
3	alpha_1	1.41326e+00	1.13396e-02
4	alpha_2	1.46307e+00	1.65822e-02
5	n_1	3.01068e+00	6.85151e-02
6	n_2	7.17333e+00	3.44868e-01

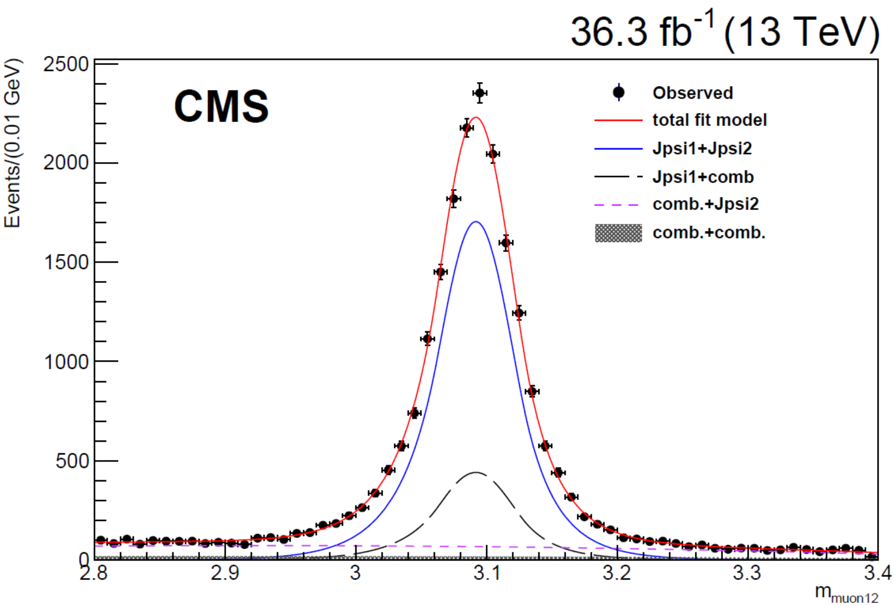


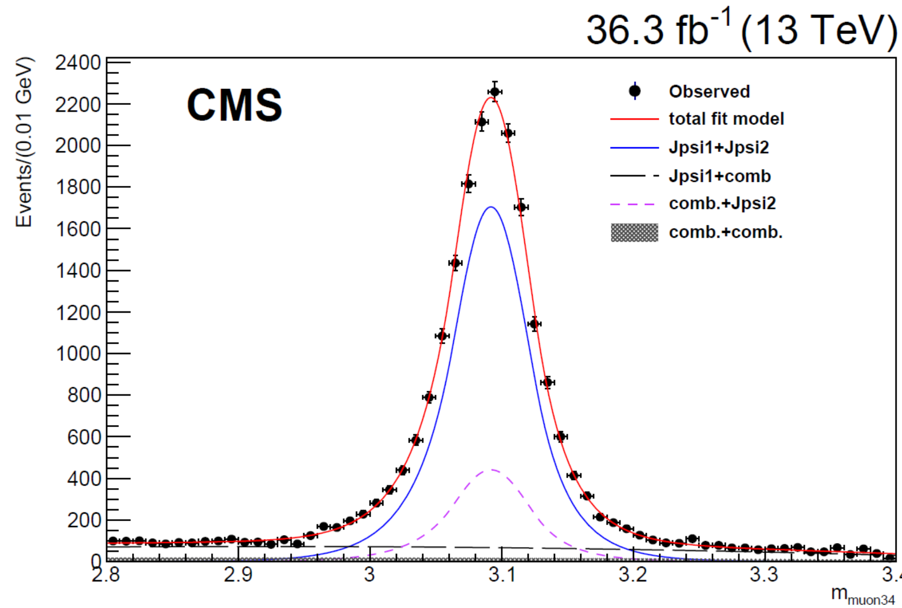
EXT NO.	PARAMETER NAME	VALUE	ERROR
1	Jpsi_mean	3.09504e+00	1.00173e-04
2	Jpsi_width	2.98876e-02	1.04484e-04
3	alpha_1	1.40078e+00	1.08720e-02
4	alpha_2	1.44909e+00	1.43104e-02
5	n_1	3.13261e+00	7.12115e-02
6	n_2	6.78463e+00	2.89219e-01

J/ψ1 (muon12) J/ψ2 (muon34)

- Use the double-sided Crystal Ball (DSCB) function to fit
- The shape are same in the SPS and DPS

Extraction of the number of J/ψ J/ψ events





- We do the 2D fit invariance mass of muon12 and muon34 of data, and show the projections of the 2D fit
- The fit function is double-sided Crystal Ball (DSCB) function + 2nd Chebyshev Polynomial

Process	fraction	Uncorrected yield
J/ψ+J/ψ	0.631±0.033	14176±754
J/ψ+Comb.	0.327±0.024	7336±550
Comb.+comb	0.042±0.008	949±195

- The J/ψ Pair fraction is f(J/ψ1 J/ψ2) = 0.631 ± 0.033
- The J/ψ Pair events observed is 14176±754

fiducial inclusive cross section

The J/ψ pair production cross section is measured in the fiducial region where both J/ψ pt>6 and absolute rapidity below 2.2 (when absolute rapidity below 1, J/ψ pt>7). The fiducial inclusive cross section can be calculate as follow formula:

$$\sigma_{fid} = \frac{N^{corr}}{\mathcal{L}\mathcal{B}^2(J/\psi \to \mu\mu)} \qquad \mathcal{L} = 36.3 fb^{-1} \qquad \mathcal{B}^2(J/\psi \to \mu\mu) = 5.93 \pm 0.06\%$$

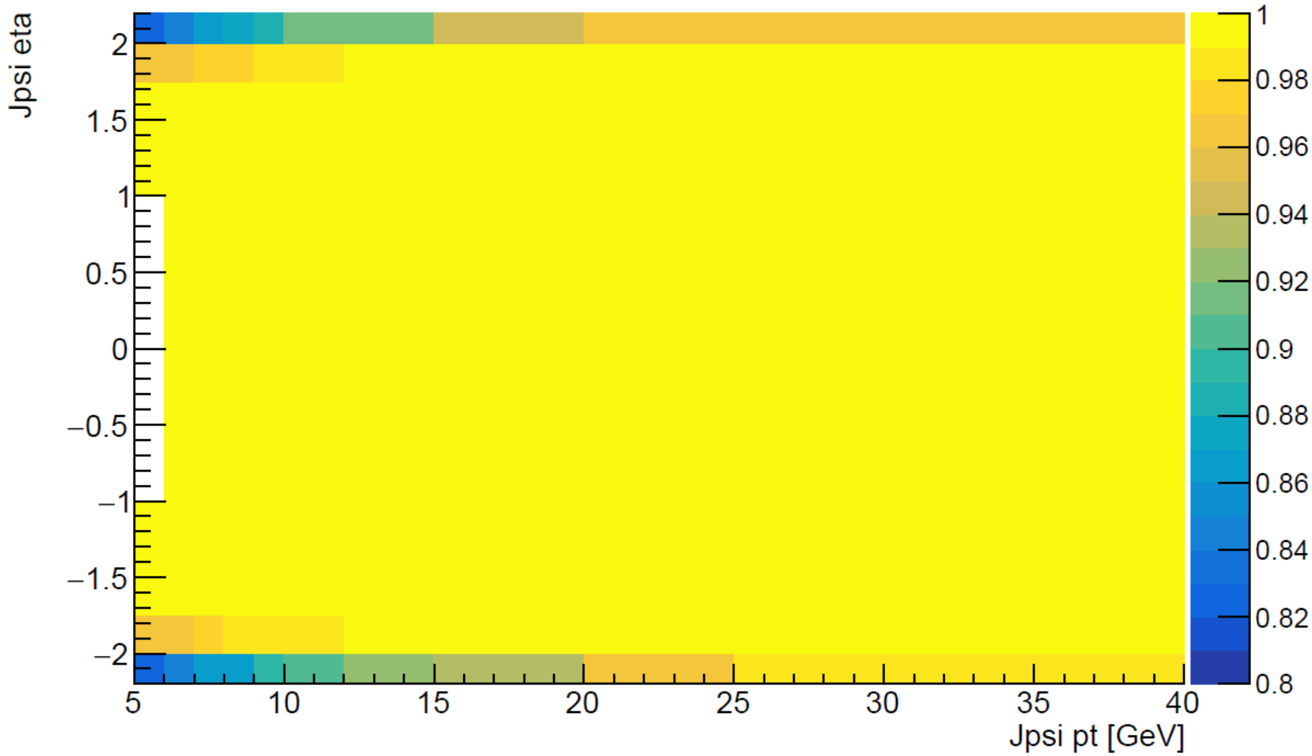
The N^{corr} can be obtained as:

$$N^{corr} = [\sum_i^{N^{obs}} \omega_{acc}^i(J/\psi_1)\, \omega_{acc}^i(J/\psi_2)\, \omega_{reco}^i(J/\psi_1)\, \omega_{reco}^i(J/\psi_2)\, \omega_{eff}^i(J/\psi_1)\, \omega_{eff}^i(J/\psi_2)\, \omega_{trig}^i(J/\psi_1, J/\psi_2)]^{-1}$$

- N^{obs} number of observed J/ψ Pair events in fiducial region
- ω_{acc} the probability for a J/ψ (|η| <2.2 and decaying to a pair of muon) decay to two muon within the geometrical acceptance of detector(muon (|η| <2.4)
- $\omega_{reco}$the probability for two muon from the J/ψ which pass ω_{acc} can be reconstructed by PF algorithm as muon
- ω_{eff} the probability for two muon from the J/ψ which pass the ω_{acc} and ω_{reco} can pass the event selection
- $\omega_{trigger}$ the probability of a event include a pair of J/ψ which have pass the ω_{acc} , ω_{reco} and ω_{eff} can pass the trigger

The method is similar to that used by LHCb Collaboration

Acceptance probability

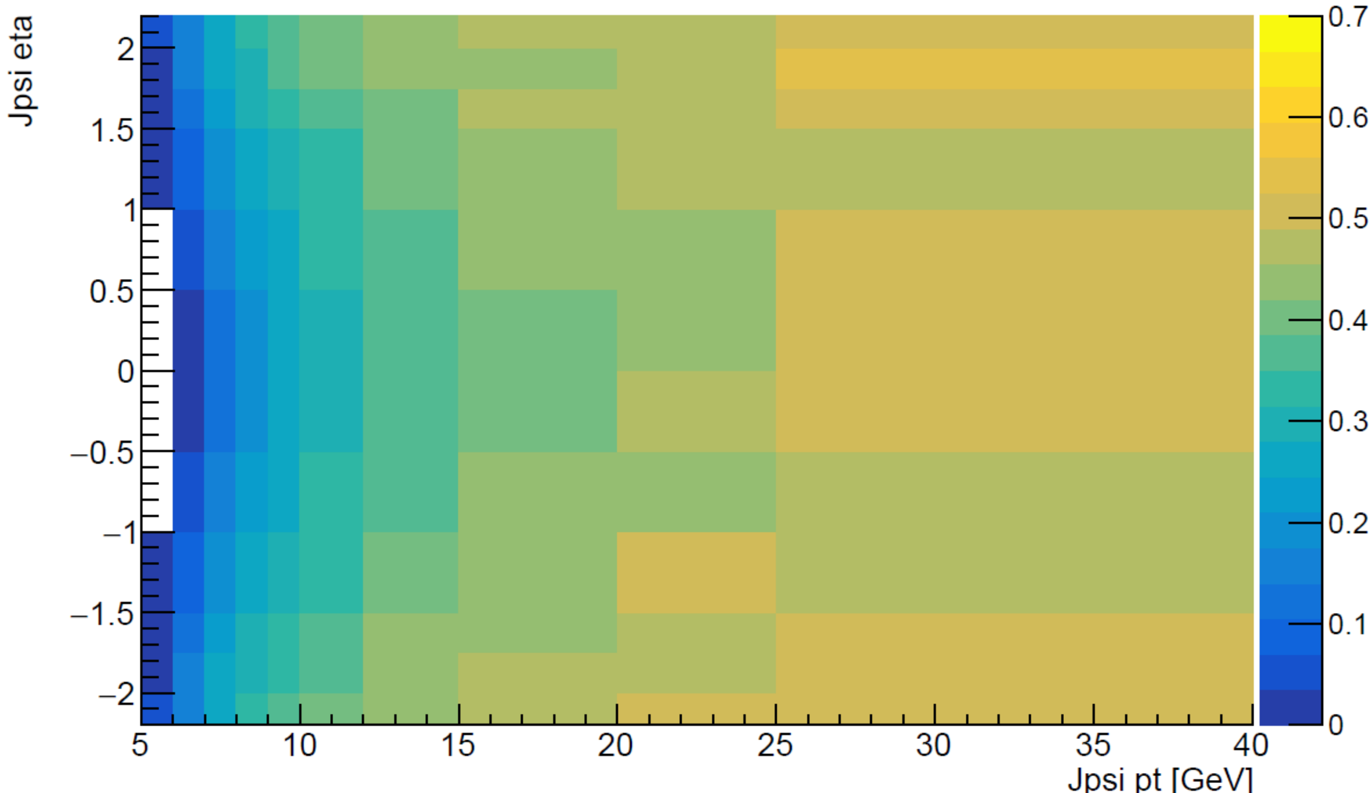


$$\omega_{acc} = \frac{NUM}{DEN}$$

DEN = Number of J/ψ with $|\eta|$ <2.2 and decaying to a pair of muons
NUM = DEN && muon $|\eta|$ < 2.4

- The ω_{acc} was calculated in the J/ψ (pt , eta) plane
- DEN and NUM were calculated in generator level

Reconstruct probability

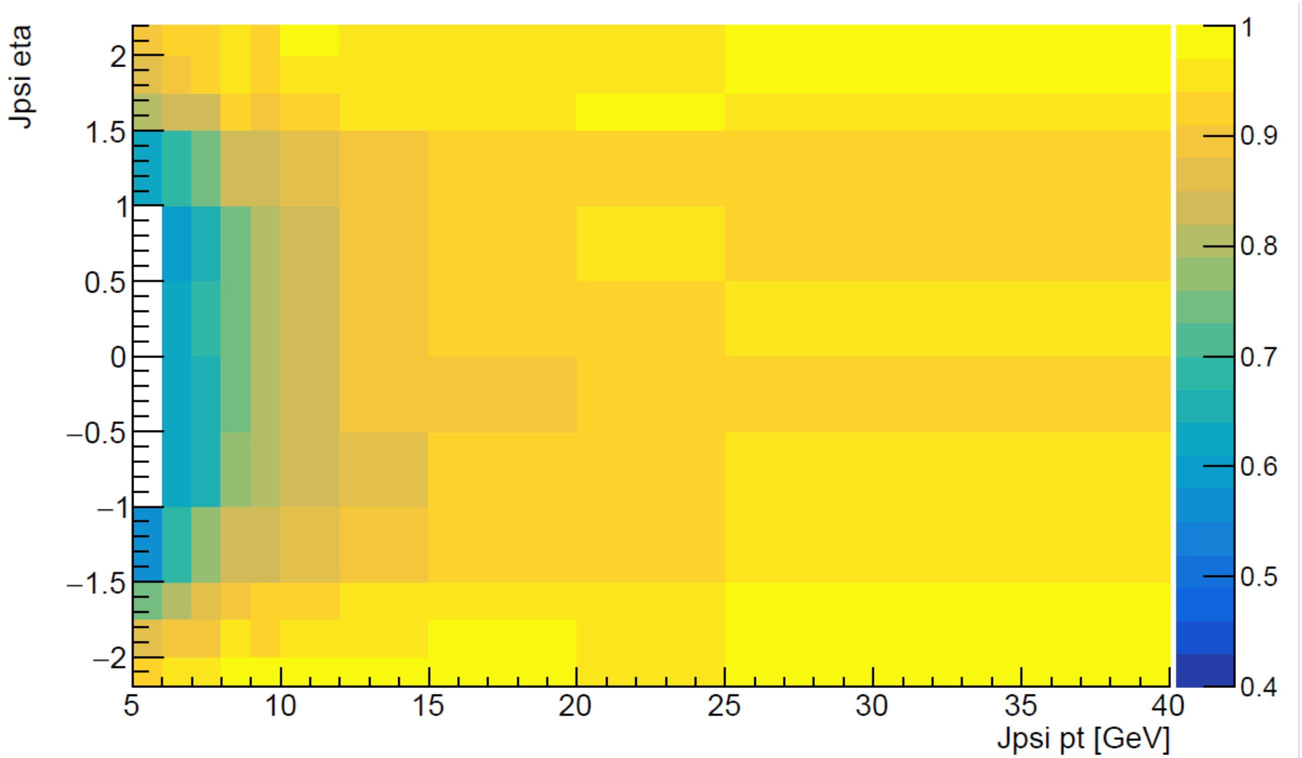


$$\omega_{reco} = \frac{NUM}{DEN}$$

DEN = Number of J/ψ with $|\eta|$ <2.2 and decaying to a pair of muons with muon $|\eta|$ <2.4(the NUM in ω_{acc})
NUM = DEN && Pair of muons reconstructed by PF algorithm as muon

- The ω_{reco} was calculated in the J/ψ (pt , eta) plane
- DEN and NUM were calculated in generator level

Selection efficiency

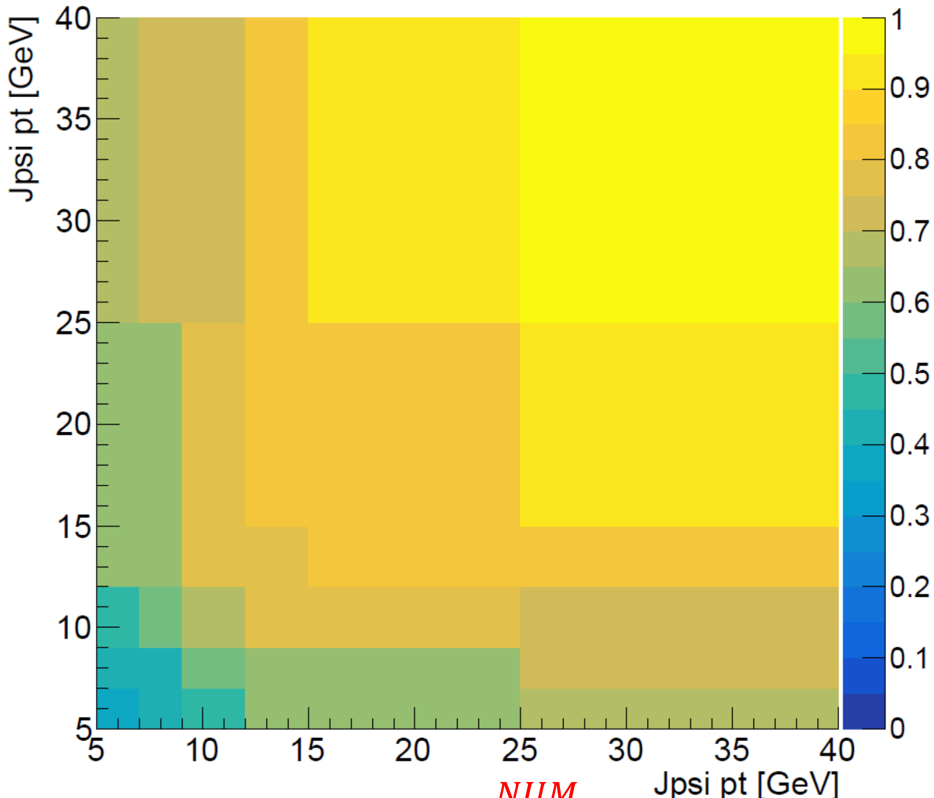


$$\omega_{eff} = \frac{NUM}{DEN}$$

DEN = The NUM in ω_{reco}
NUM = DEN && J/ψ and decayed muon pass the event selection

- The ω_{eff} was calculated in the J/ψ (pt , eta) plane
- DEN were calculated in generator level but NUM were calculated in reconstruct level

Events pass trigger probability

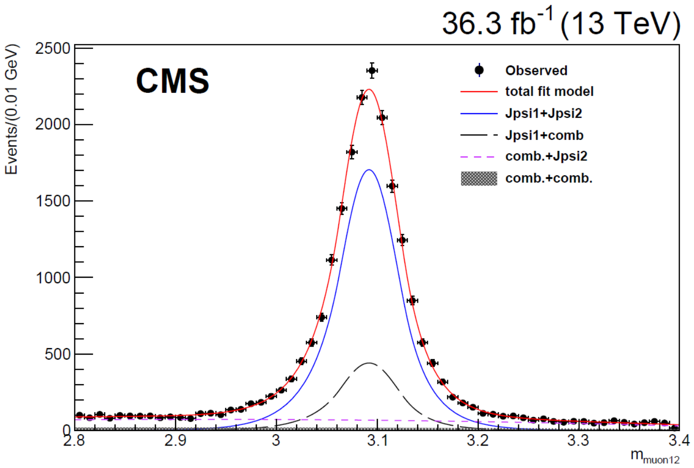


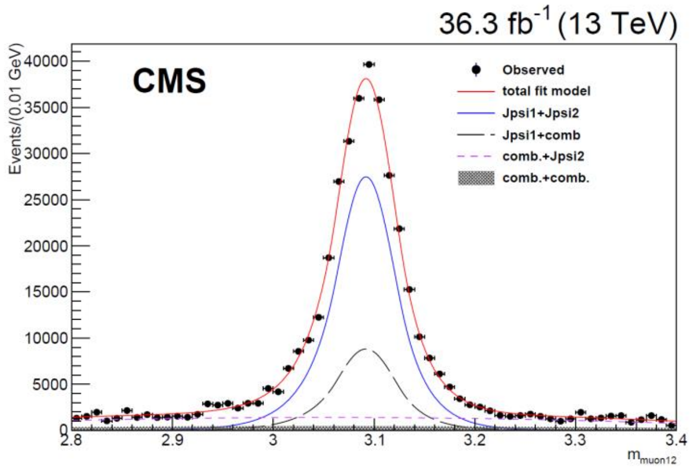
$$\omega_{trig} = \frac{NUM}{DEN}$$

DEN = event included a pair of muons which pass the ω_{acc} ,ω_{reco} and ω_{eff}
NUM = DEN && event pass trigger

- The ω_{eff} was calculated in the(J/ψ_1 pt , J/ψ_2 pt) plane
- DEN and NUM were calculated in reconstruct level
- Since J/ψ pairs assigned randomly, ω_{trig} should be symmetric for J/ψ_1 and J/ψ_2

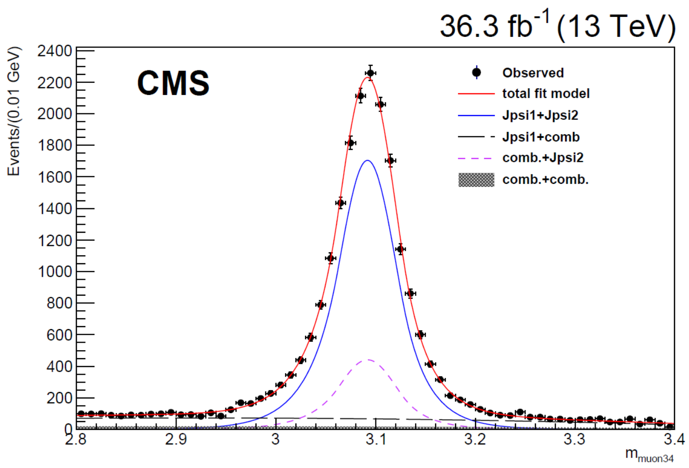
Fit of corrected events

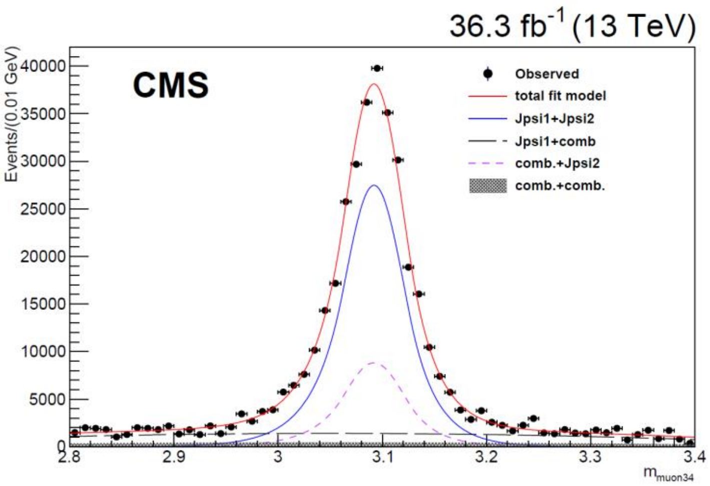




$$1/\prod \omega^i$$

The weights are computed event-by-event



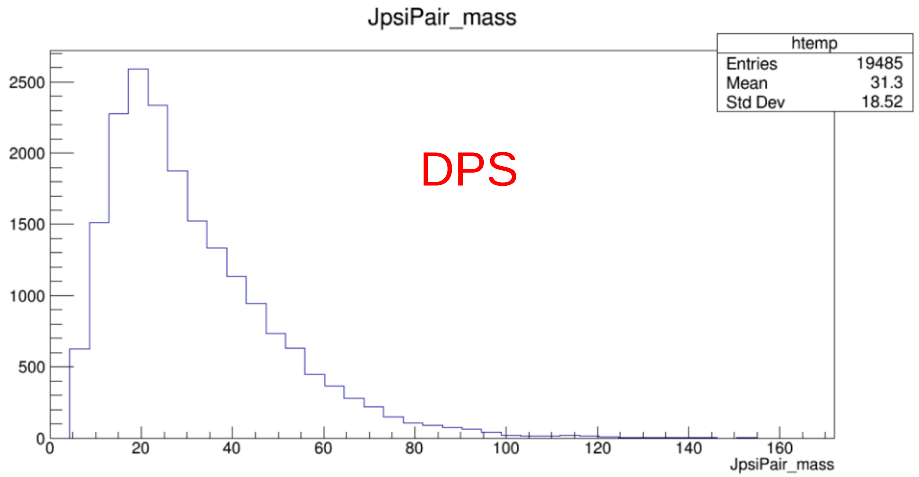


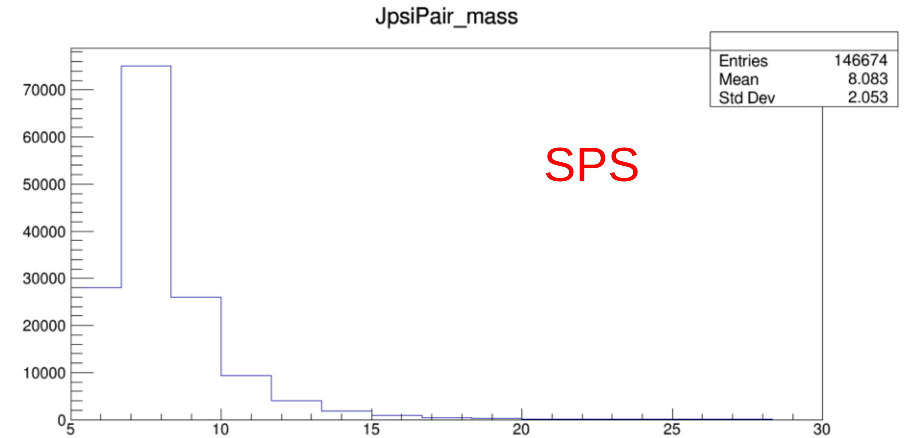
Process	Fraction	Corrected yield
J/ψ+J/ψ	0.5732±0.0010	229234±501
J/ψ+Comb.	0.3678±0.0009	147101±372
Comb.+comb	0.0590±0.0004	23599±161

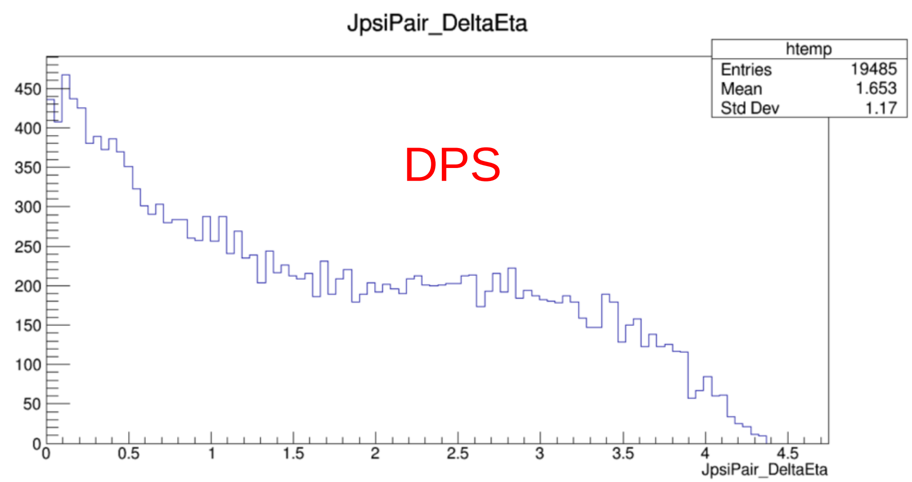
- The J/ψ Pair fraction is 0.5731± 0.0010
- Number of J/ψ Pair events is 229234±501, the cross section is 1.80±0.02 nb

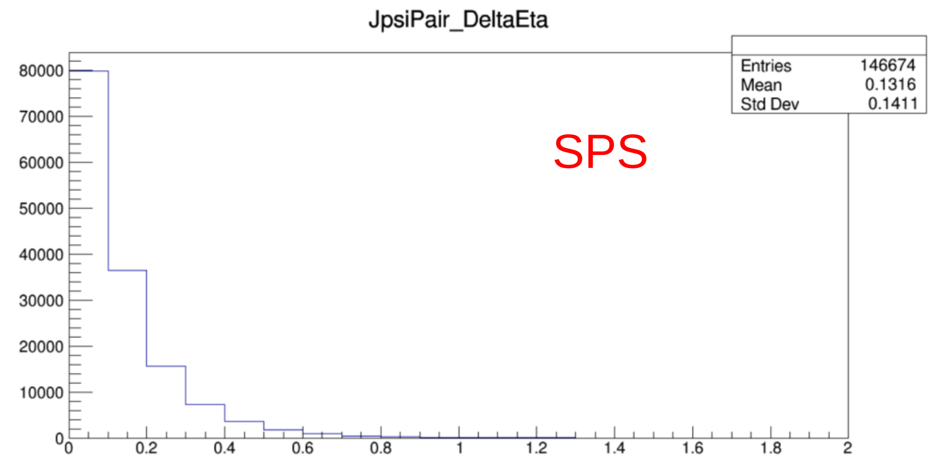
Fraction of DPS

Extracting the DPS fraction strategy







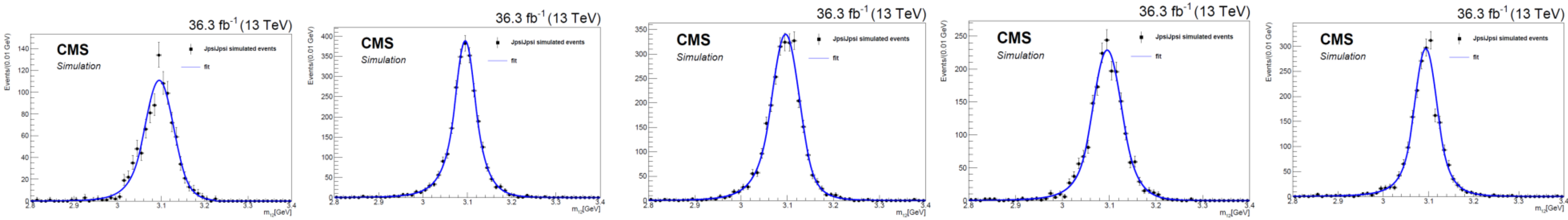


- The SPS and DPS contribution can be separated because of their different kinematics
- The fiducial cross section is measured in individual bins of the rapidity difference or invariant mass

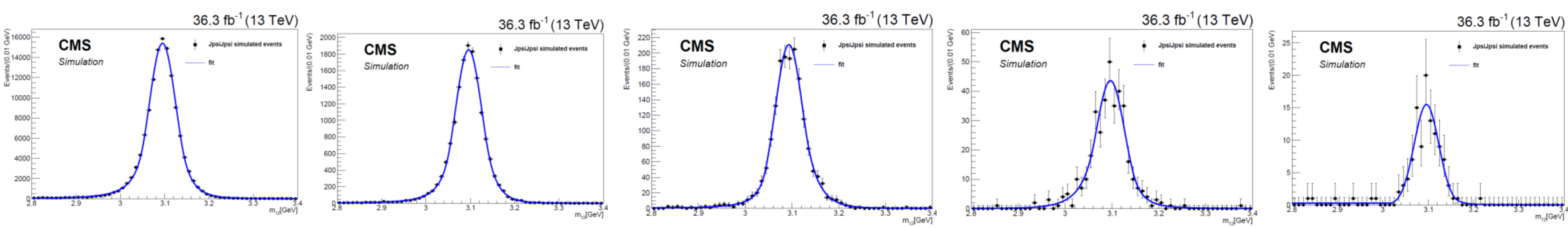
Modeling the J/ψ(1)

The individual bins of two J/ψ invariance mass are [5, 10, 15, 20, 25, 30] GeV

DPS



SPS



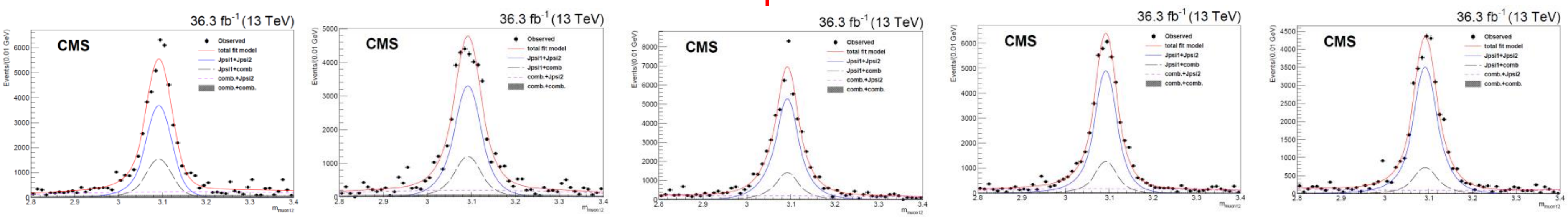
[5,10] [10,15] [15,20] [20,25] [25,30]

- Use the double-sided Crystal Ball (DSCB) function to fit DPS and SPS shape in individual bins of two J/ψ invariance mass

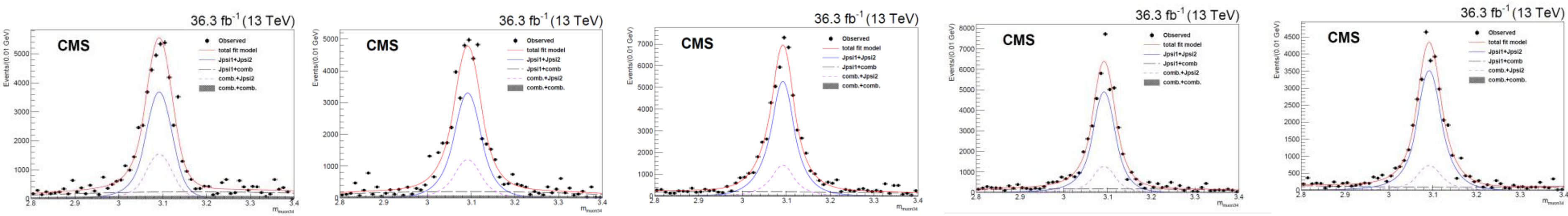
Extracting the DPS fraction

The individual bins of two J/ψ invariance mass are [5, 10, 15, 20, 25, 30] GeV

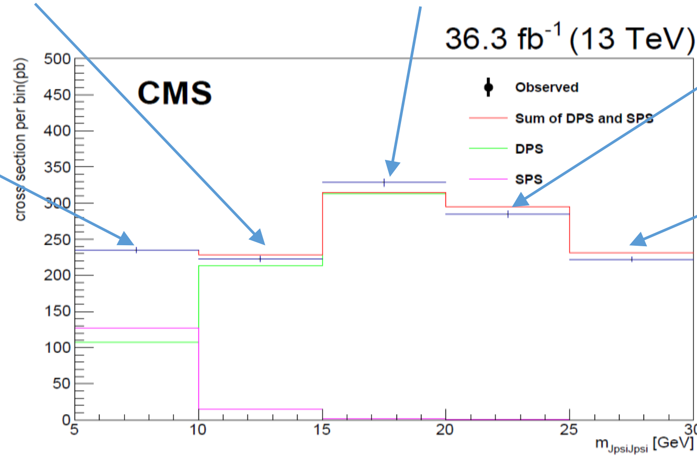
Jpsi1



Jpsi2



[5,10] [10,15] [15,20] [20,25] [25,30]



- The SPS and DPS templates are obtained from MC
- The SPS and DPS normalization are freely floating

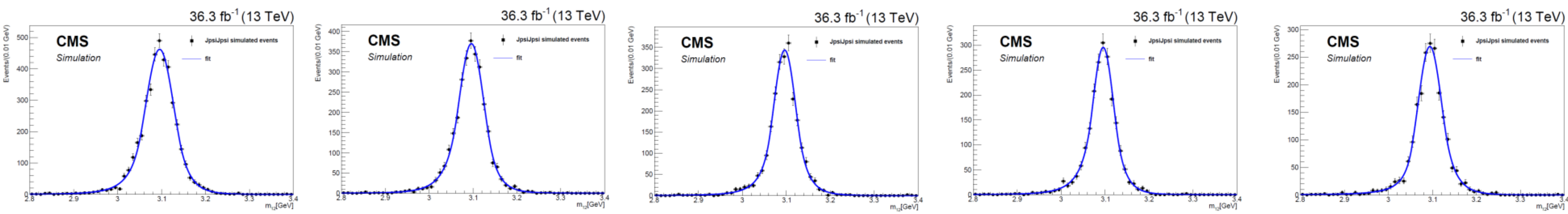
Using the invariant mass of two Jpsi:

$$f_{DPS} = \frac{\sigma_{DPS}^{fid}}{\sigma_{DPS}^{fid} + \sigma_{SPS}^{fid}} = 89.0 \pm 11.0\%$$

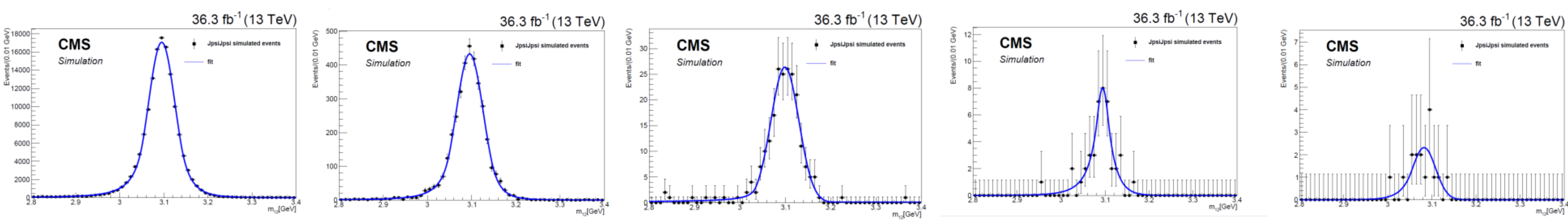
Modeling the J/ψ(2)

The individual bins of two J/ψ rapidity difference are [0, 0.5, 1.0, 1.5, 2.0, 2.5]

DPS



SPS



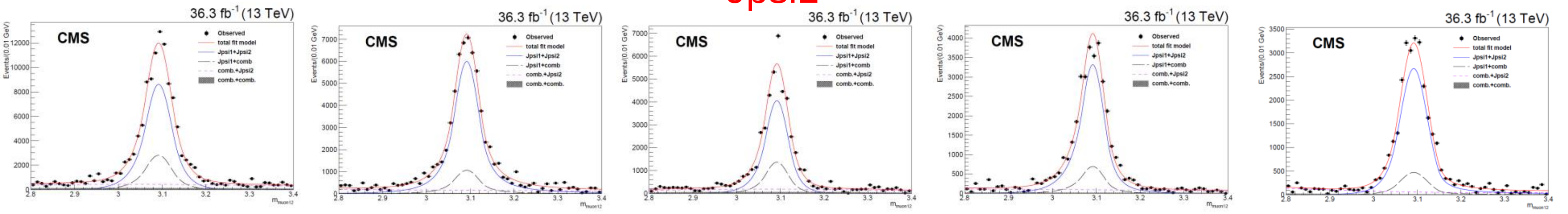
[0, 0.5] [0.5, 1.0] [1.0, 1.5] [1.5, 2.0] [2.0, 2.5]

- Use the double-sided Crystal Ball (DSCB) function to fit DPS and SPS shape in individual bins of two J/ψ rapidity difference

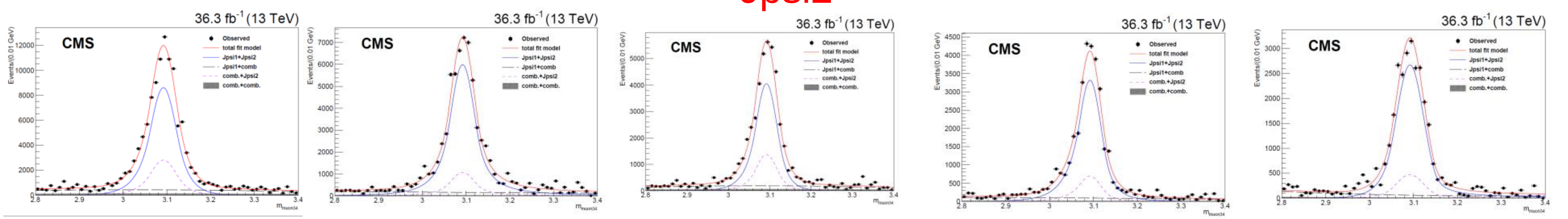
Extracting the DPS fraction

The individual bins of two J/ψ rapidity difference are [0, 0.5, 1.0, 1.5, 2.0, 2.5] GeV

Jpsi1

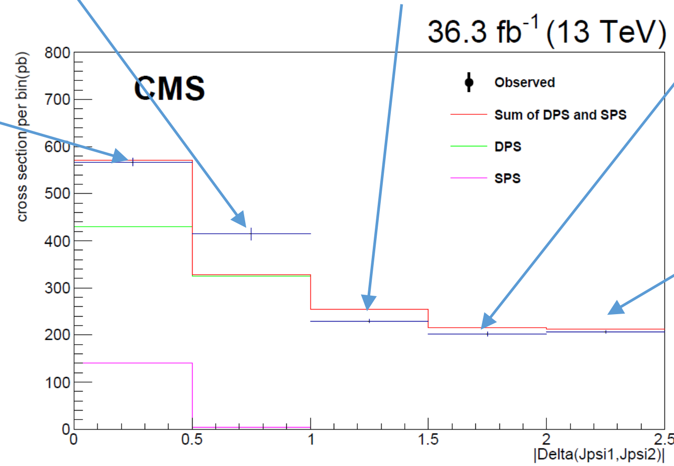


Jpsi2



[0, 0.5] [0.5, 1.0] [1.0, 1.5] [1.5, 2.0] [2.0, 2.5]

- The SPS and DPS templates are obtained from MC
- The SPS and DPS normalization are freely floating



Using the rapidity difference between Jpsi:

$$f_{DPS} = \frac{\sigma_{DPS}^{fid}}{\sigma_{DPS}^{fid} + \sigma_{SPS}^{fid}} = 90.9 \pm 9.1\%$$

Summary

- Use the CMS 2016 data measure the J/ψ Pair production cross section in this phase space

|η(J/ψ)| < 1	**pT(J/ψ) >7GeV**
1<|η(J/ψ)| < 2.2	pT(J/ψ) >6GeV

- The cross section is 1.80±0.02 nb

- Use the SPS and DPS MC sample to do the J/ψ shape fit

- Study the fraction of DPS
  - $f_{DPS} = 89.0 \pm 11.0\%$ for $m_{JpsiJpsi}$
  - $f_{DPS} = 90.9 \pm 9.1\%$ for |Delta(Jpsi1, Jpsi2)|

➢ Next step
  - Use the full Run2 data, add the systematics
  - Use the vertex information in event selection

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

backup

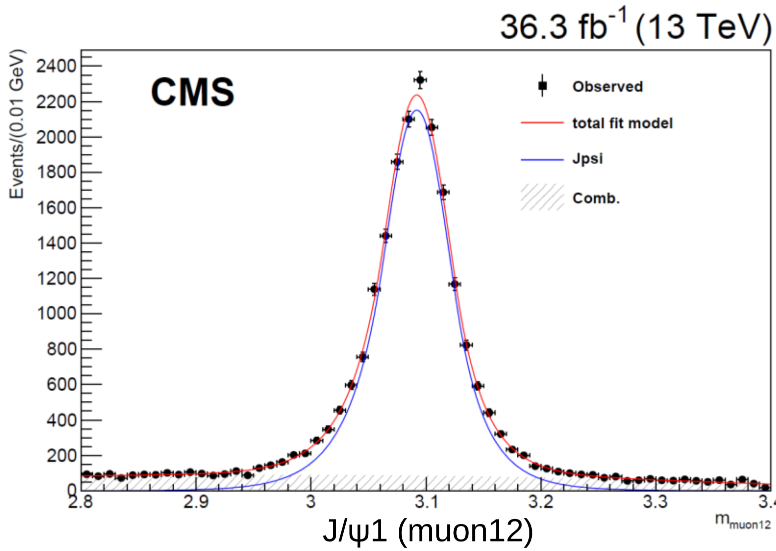
Data and MC

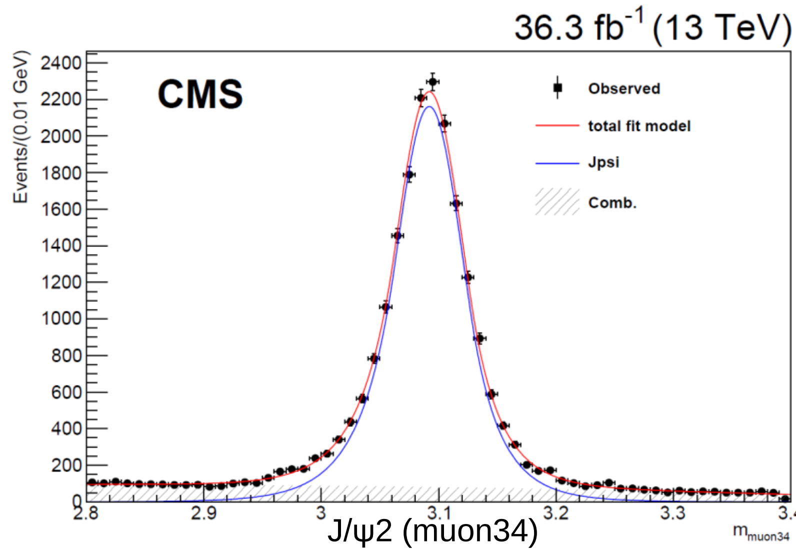
Data	sample
2016	/Charmonium/Run2016B-02Apr2020_ver2-v1/NANOAOD /Charmonium/Run2016C-02Apr2020-v1/NANOAOD /Charmonium/Run2016D-02Apr2020-v1/NANOAOD /Charmonium/Run2016E-02Apr2020-v1/NANOAOD /Charmonium/Run2016F-02Apr2020-v1/NANOAOD /Charmonium/Run2016G-02Apr2020-v1/NANOAOD /Charmonium/Run2016H-02Apr2020-v1/NANOAOD
2017	/Charmonium/Run2017B-02Apr2020-v1/NANOAOD /Charmonium/Run2017C-02Apr2020-v1/NANOAOD /Charmonium/Run2017D-02Apr2020-v1/NANOAOD /Charmonium/Run2017E-02Apr2020-v1/NANOAOD /Charmonium/Run2017F-02Apr2020-v1/NANOAOD
2018	/Charmonium/Run2018A-02Apr2020-v1/NANOAOD /Charmonium/Run2018B-02Apr2020-v1/NANOAOD /Charmonium/Run2018C-02Apr2020-v1/NANOAOD /Charmonium/Run2018D-02Apr2020-v1/NANOAOD

background	sample
SPS	/SPS_ToJPsiJPsi_*-pythia8/RunII*NanoAODv7-*mcRun2*/NANOAODSIM
DPS	/DPS_ToJPsiJPsi_*-pythia8/RunII*NanoAODv7-*mcRun2*/NANOAODSIM

We just use 2016 dataset in this presentation

Extraction of the number of J/ψ J/ψ events



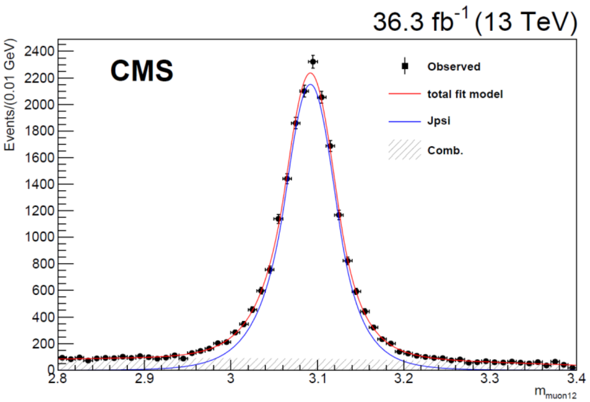


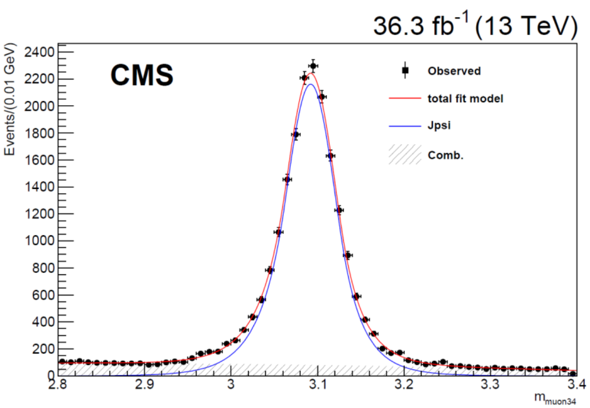
Process	fraction	Uncorrected yield
J/ψ1	0.796±0.009	17941±207
Comb.	0.204±0.009	4596±207

Process	fraction	Uncorrected yield
J/ψ2	0.798±0.013	17987±302
Comb.	0.202±0.013	4563±302

- We do the 1D fit separately for the invariance mass of muon12 and muon34 of data
- The fit function is double-sided Crystal Ball (DSCB) function + 2nd Chebyshev Polynomial
- From the fit we can get f(J/ψ1) = 0.796±0.009 and f(J/ψ2) = 0.798±0.013
- The J/ψ Pair fraction is f(J/ψ1 J/ψ2) = f(J/ψ1) * f(J/ψ2) = 0.635 ± 0.011
- The J/ψ Pair events observed is 14324 ±284

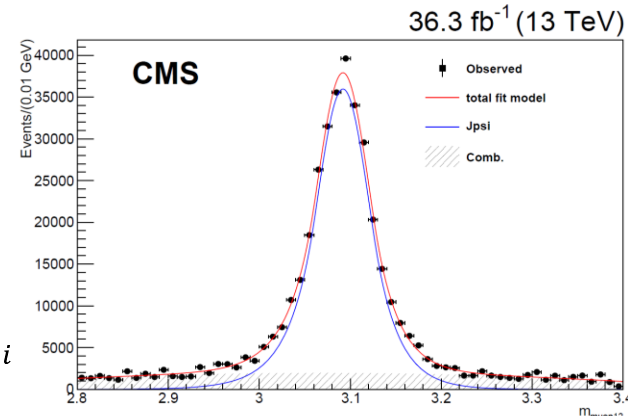
Fit of corrected events

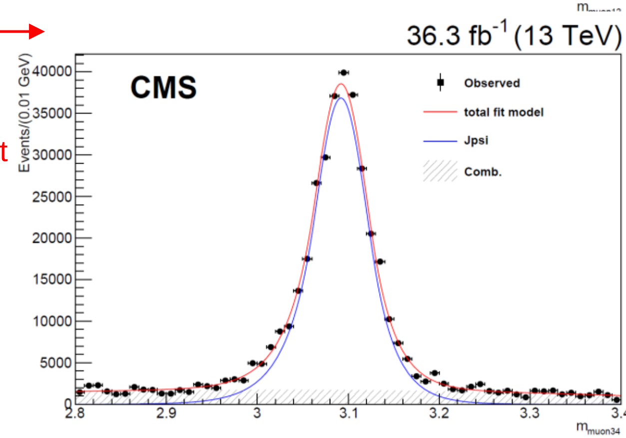




$$1/\prod \omega^i$$

The weights are computed event-by-event





Process	fraction	corr yield
J/ψ1	0.750±0.002	300772±911
Comb.	0.250±0.002	100430±911

Process	fraction	corr yield
J/ψ2	0.765±0.005	307202±1909
Comb.	0.235±0.005	94454±1909

- The J/ψ Pair fraction is f(J/ψ1 J/ψ2) = f(J/ψ1) * f(J/ψ2) = 0.574 ± 0.004
- Number of J/ψ Pair events is 230427±1626.59，the cross section is 1.80±0.02 nb

Closure test (DPS private sample)

Use DPS private sample to do test

cut	N_{obs}	N_{corr}(DPS)	N_{corr}(SPS)	N_{corr}(Mix)
$\lvert\eta(\mu)\rvert < 2.4$	2197	2201.1 ± 115.3	2196.6 ± 33.5	2197.1 ± 31.3
$\lvert p_T(\mu)\rvert > 3.5$	118	126.8 ± 21.0	117.6 ± 3.3	118.0 ± 3.2
$reco.(\mu)$	110	110.7 ± 33.6	102.3 ± 7.4	102.5 ± 6.8
$id.(\mu)$	104	108.6 ± 43.0	100.3 ± 9.9	100.4 ± 9.1
$vtx(\mu\mu)$	83	96.8 ± 45.6	85.7 ± 10.3	86.0 ± 9.5
HLT	60	73.0 ± 63.2	54.8 ± 6.6	55.1 ± 6.3
$4\ \mu\ cut$	52	56.3 ± 61.3	48.0 ± 6.4	48.2 ± 6.1

- The DPS weights error are big
- Observed events and corrected events have good agreement

Closure test (SPS private sample)

Use SPS private sample to do test

cut	N_{obs}	N_{corr}(DPS)	N_{corr}(SPS)	N_{corr}(Mix)
$\|\eta(\mu)\| < 2.4$	394844	394514±40222	394696±6190	394717±5973
$\|p_T(\mu)\| > 3.5$	75251	81903±18613	75619±1974	75776±1941
$reco.(\mu)$	66964	75576±28854	68178±3924	68321±3779
$id.(\mu)$	65756	74173±36255	66816±5188	66950±4983
$vtx(\mu\mu)$	53772	65585±37371	57180±5349	57428±5146
HLT	40733	57159±59898	39898±3992	40079±3882
$4\ \mu\ cut$	36320	43496±56847	35053±3850	35201±3761

- The DPS weights error are big
- Observed events and corrected events have good agreement