Inclusive J/ψ pair production cross section measurement

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P&P meeting

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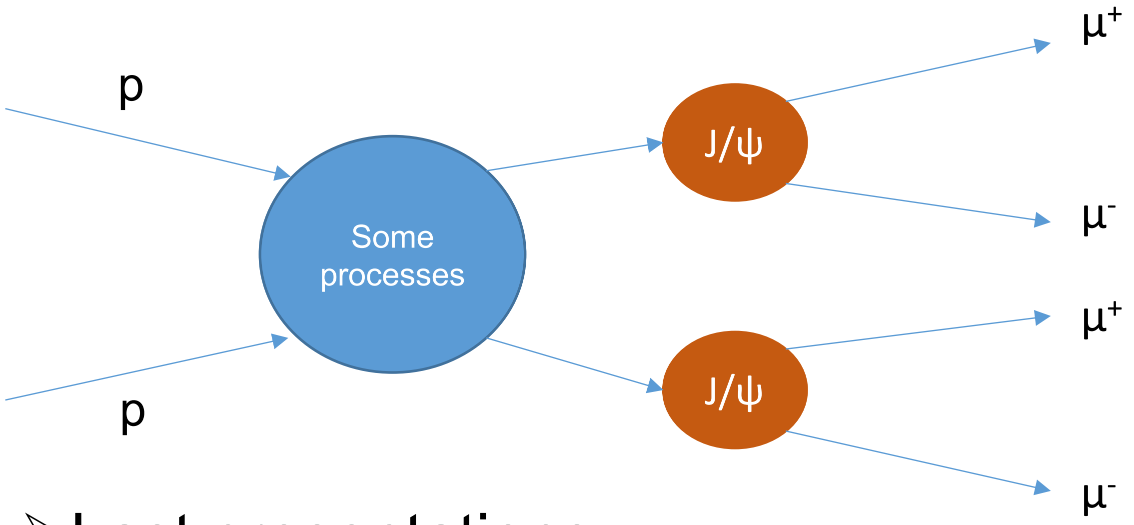
4.Nanjing Normal University, China

Introduction

- Measure the inclusive J/ψ pair production cross section using all Run2 data in CMS



$$\sigma_{fid} = \frac{N_{events}}{\varepsilon \mathcal{L} \mathcal{B}^2 (J/\psi \to \mu^+\mu^-)}$$

$$\varepsilon = acceptance \times Eff_{\mu_{RECO}} \times Eff_{\mu_{ID}} \times Eff_{\mu^+\mu^-} \times Eff_{HLT} \times Eff_{\mu^+\mu^-\mu^+\mu^-}$$

- Last presentations
  - Study different lifetime variables to distinguish prompt and non-prompt(here)
- This presentation
  - Add trigger matched in event selection
  - Do 4D fit in invariance mass and lifetime dimension to extract prompt J/ψ pair events
  - Try to separate DPS and SPS components

Dataset

/Charmonium/Run2016B-21Feb2020-ver2_UL2016_HIPM-v1/AOD	/Charmonium/Run2017C-09Aug2019_UL2017-v1/AOD
/Charmonium/Run2016C-21Feb2020_UL2016_HIPM-v1/AOD	/Charmonium/Run2017D-09Aug2019_UL2017-v1/AOD
/Charmonium/Run2016D-21Feb2020_UL2016_HIPM-v1/AOD	/Charmonium/Run2017E-09Aug2019_UL2017-v1/AOD
/Charmonium/Run2016E-21Feb2020_UL2016_HIPM-v1/AOD	/Charmonium/Run2017F-09Aug2019_UL2017-v1/AOD
/Charmonium/Run2016F-21Feb2020_UL2016_HIPM-v1/AOD	/Charmonium/Run2018A-12Nov2019_UL2018_rsb-v1/AOD
/Charmonium/Run2016F-21Feb2020_UL2016-v1/AOD	/Charmonium/Run2018B-12Nov2019_UL2018-v1/AOD
/Charmonium/Run2016G-21Feb2020_UL2016-v1/AOD	/Charmonium/Run2018C-12Nov2019_UL2018 rsb v2-v2/AOD
/Charmonium/Run2016H-21Feb2020_UL2016-v1/AOD	/Charmonium/Run2018D-12Nov2019_UL2018-v1/AOD

JSON:

2016	Cert_271036-284044_13TeV_Legacy2016_Collisions16_JSON_MuonPhys.txt
2017	Cert_294927-306462_13TeV_UL2017_Collisions17_JSON_MuonJSON.txt
2018	Cert_314472-325175_13TeV_Legacy2018_Collisions18_JSON MuonPhys.txt

Prompt/Non-prompt sample		Sample
Non-prompt sample	BBbar -> J/ψ J/ψ + X	/Pythia8_BBartoJJ/jinfeng-MC2016_SKIM_JinfengLiu_bDecay-36fd85e4f67556ca0c698512e4b68db7/USER
Prompt sample	SPS	/Pythia8_MC_SPS_Direct_TighterFilter_2016/shunlian-SKIM_v1-1180d22d2a36d93597d4befd39820c18/USER
	DPS	/Pythia8_DPStoJJ/jinfeng-MC2016_SKIM_JinfengLiu_Tight2-9b15e3a700bc0e2adf631d6ebeb85f0a/USER

Object and event selection

➢Trigger

HLT_Dimuon0_Jpsi_Muon(2016 and 2016APV)

HLT_Dimuon0_Jpsi3p5_Muon2(2017 and 2018)

➢Muon

- Standard Soft muon ID
- pT(muon)>=3.5GeV
- |η(muon)|<=2.4
- Gen match for MC
  - DeltaR(Gen muon, RECO muon)<0.03

➢J/ψ

- The J/ψ was reconstructed by two opposite sign muons
- The vertex probability of the 2 muons associated to the J/ψ is greater than 0.5%
- 2.7<m(dimuon)<3.5GeV

➢J/ψ Pair

- J/ψ1(muon12) and J/ψ2(muon34) do not share a common muon
- Assign the J/ψ randomly
- Make one J/ψ match trigger J/ψ and another muon match trigger muon

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:

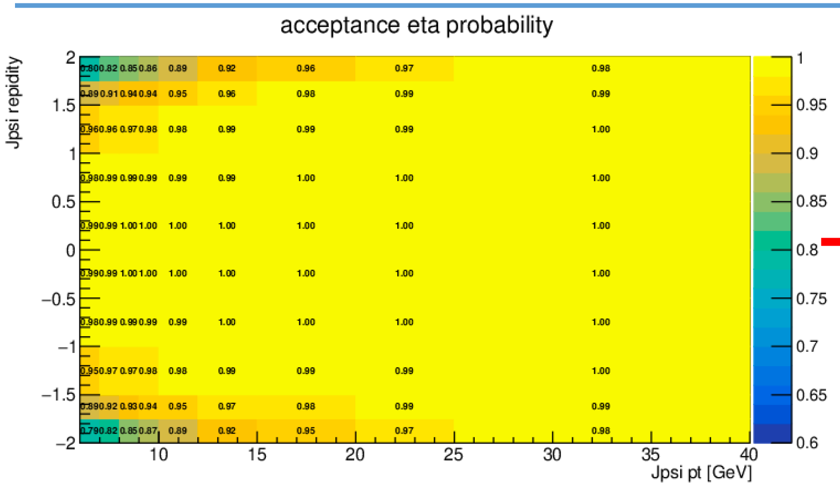
$$\sigma_{fid} = \frac{N^{corr}}{\mathcal{L}\mathcal{B}^2(J/\psi \to \mu\mu)} \qquad \mathcal{L} = 36.3 fb^{-1} \qquad \mathcal{B}^2(J/\psi \to \mu\mu) = 5.93 \pm 0.06\%$$

The N^{corr} can be obtained as:

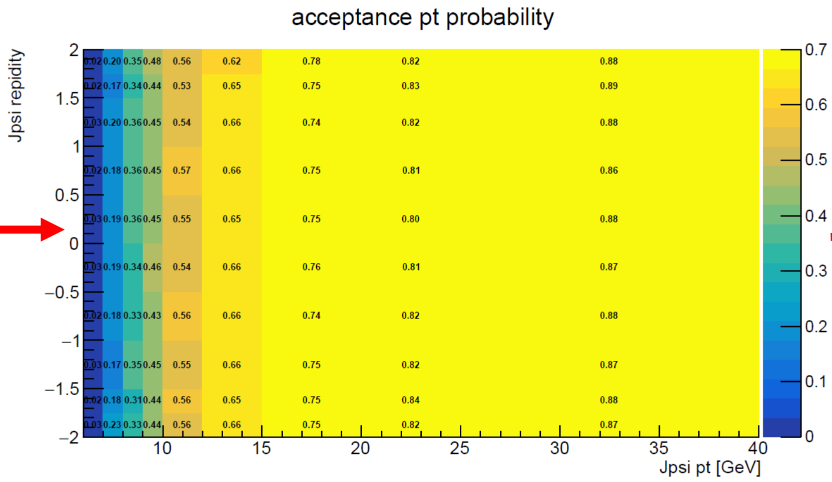
$$N^{corr} = \sum_i^{N^{obs}} [\omega_{acc}^i(J/\psi_1)\, \omega_{acc}^i(J/\psi_2)\, \omega_{reco}^i(J/\psi_1)\, \omega_{reco}^i(J/\psi_2)\, \omega_{eff}^i(J/\psi_1)\, \omega_{eff}^i(J/\psi_2)\, \omega_{vtx}^i(J/\psi_1)\, \omega_{vtx}^i(J/\psi_2) \omega_{trig}^i(J/\psi_1, J/\psi_2) \omega_{evt}^i(J/\psi_1,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

- 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)
- ω_{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 soft muon ID
- ω_{vtx} the probability for two muon from the J/ψ which pass the ω_{acc} , ω_{reco} and ω_{eff} to have a vertex probability above 0.005
- $\omega_{trigger}$ the probability of a event include a pair of J/ψ which have pass the ω_{acc} , ω_{reco}, ω_{eff} and ω_{vtx} can pass the trigger
- $\omega_{tri\_Matched}$ the probability of a event include a pair of J/ψ which have pass the ω_{acc} , ω_{reco}, ω_{eff}, ω_{vtx} and $\omega_{trigger}$ to pass the trigger Matched

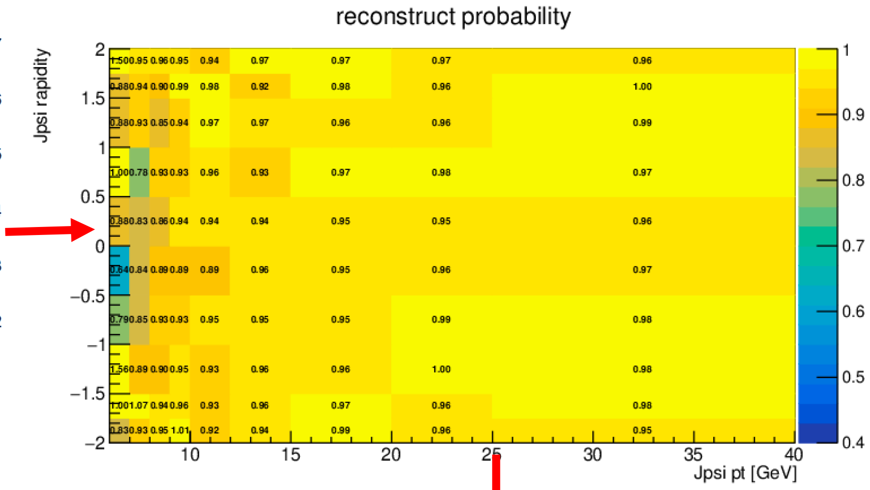
Acceptances and Efficiencies

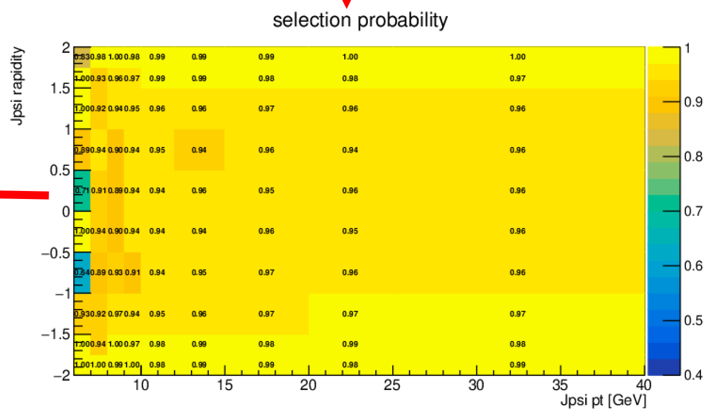


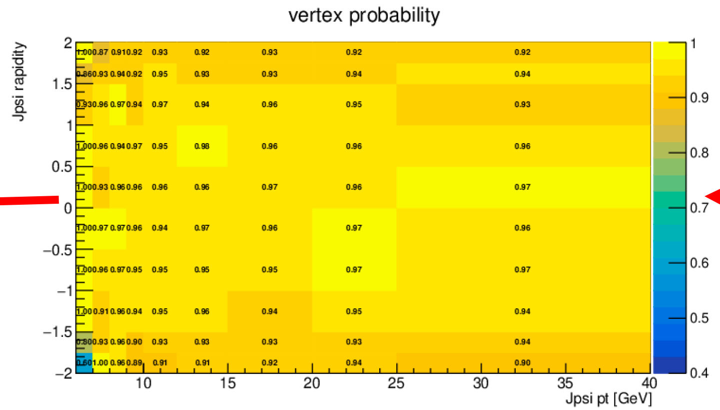
$|\eta(\mu)| < 2.4$

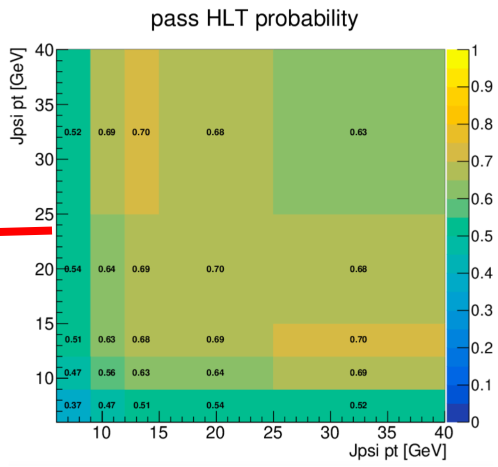


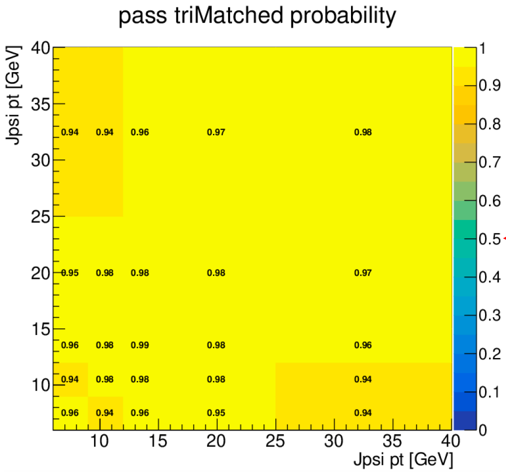
$|p_T(\mu)| > 3.5GeV$











Use SPS official sample to get weights

Extract prompt J/ψ pair strategy

- The muon pair could be J/ψ or comb. Since J/ψ maybe prompt or non-prompt, the J/ψ1 + J/ψ2 could be separate to 4 categories. So we totally have 7 components

- J/ψ1 + J/ψ2
  - prompt J/ψ1 + prompt J/ψ2
  - prompt J/ψ1 + non-prompt J/ψ2
  - non-prompt J/ψ1 + prompt J/ψ2
  - non-prompt J/ψ1 + non-prompt J/ψ2
- J/ψ1 + comb.
- Comb. + J/ψ2
- Comb. + comb.

- We can distinguish muon pair are J/ψ or comb in invariance mass dimension
- We can distinguish J/ψ1 + J/ψ2 prompt components in lifetime dimension

The 4D fit PDF

➢J/ψ + J/ψ

$$f_{Jpsi1} * f_{Jpsi2} * g_{prompt1} * g_{prompt2}$$

$$f_{Jpsi1} * f_{Jpsi2} * g_{non-prompt1} * g_{prompt2}$$

$$f_{Jpsi1} * f_{Jpsi2} * g_{prompt1} * g_{non-prompt2}$$

$$f_{Jpsi1} * f_{Jpsi2} * g_{non-prompt1} * g_{non-prompt2}$$

➢J/ψ1+ comb.

$$f_{Jpsi1} * f_{comb2} * h_{Jpsi1} * h_{comb.}$$

➢comb.+ J/ψ2

$$f_{comb1} * f_{Jpsi2} * h_{comb.} * h_{Jpsi2}$$

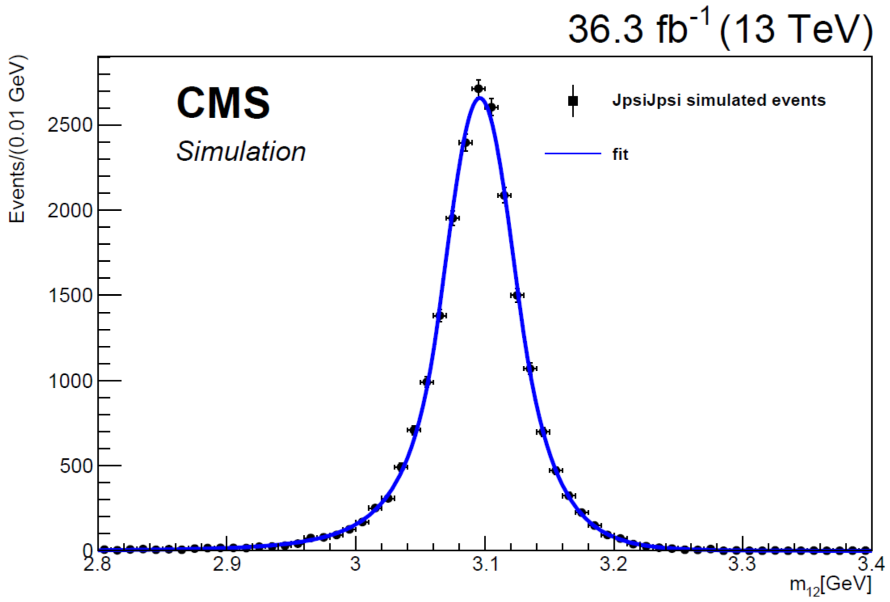
➢comb.+comb.

$$f_{comb1} * f_{comb2} * h_{comb.} * h_{comb.}$$

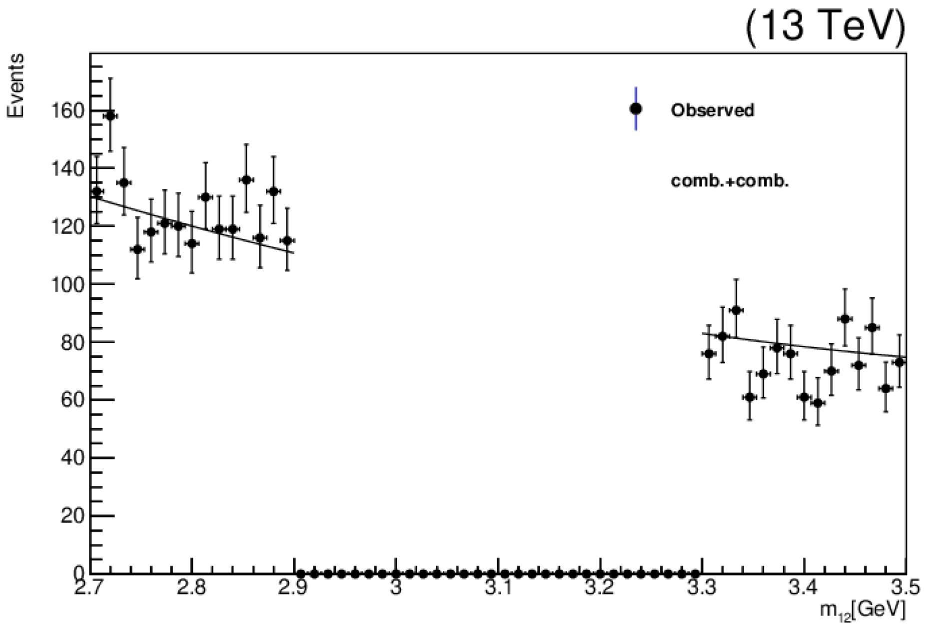
- I use f to stand for J/ψ or comb. mass PDF; use g to stand for J/ψ + J/ψ prompt and non-prompt ctau distribution; use h to stand for Jpsi + comb. or comb.+ comb. ctau distribution
- The f_{Jpsi} get from MC sample and f_{comb} get from data sideband region
- The g_{prompt} and $g_{non-prompt}$ get from MC sample
- The h_{Jpsi1} and $h_{comb.}$ get from data sideband region

The J/ψ and comb. mass PDF

- Get J/ψ invariance mass distribution from MC sample
- Get combinatorial invariance mass distribution from data sideband region



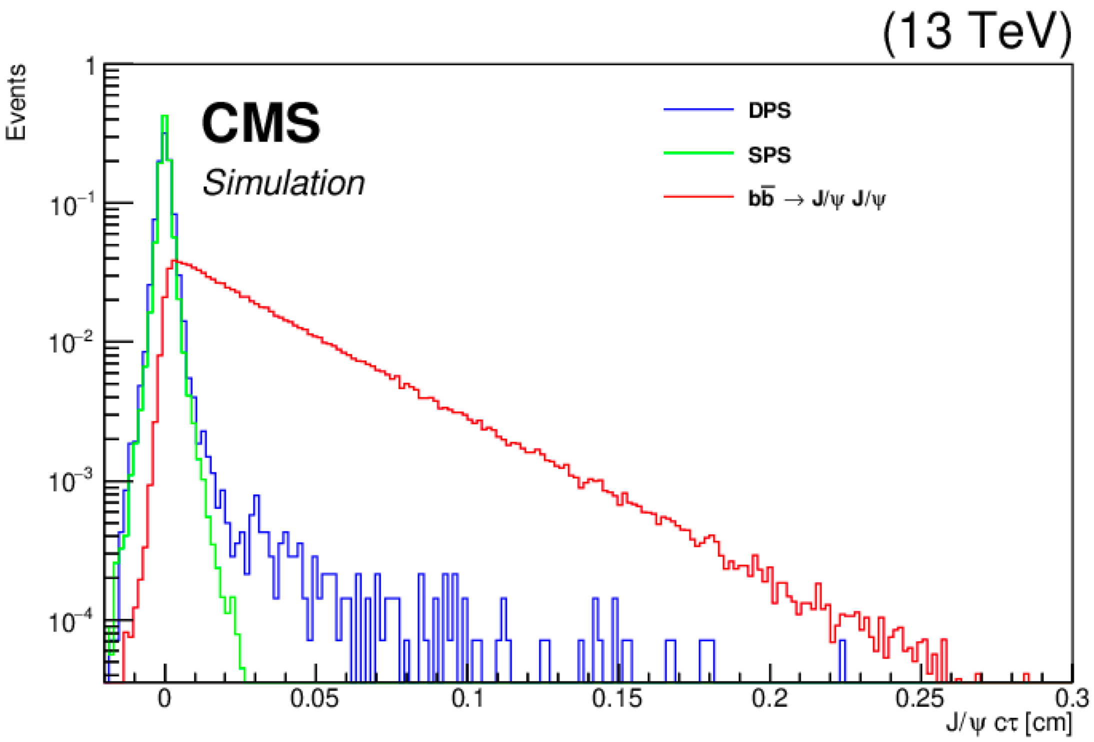
J/ψ: using double Crystal Ball (DSCB) function, the parament get from J/ψ MC fit

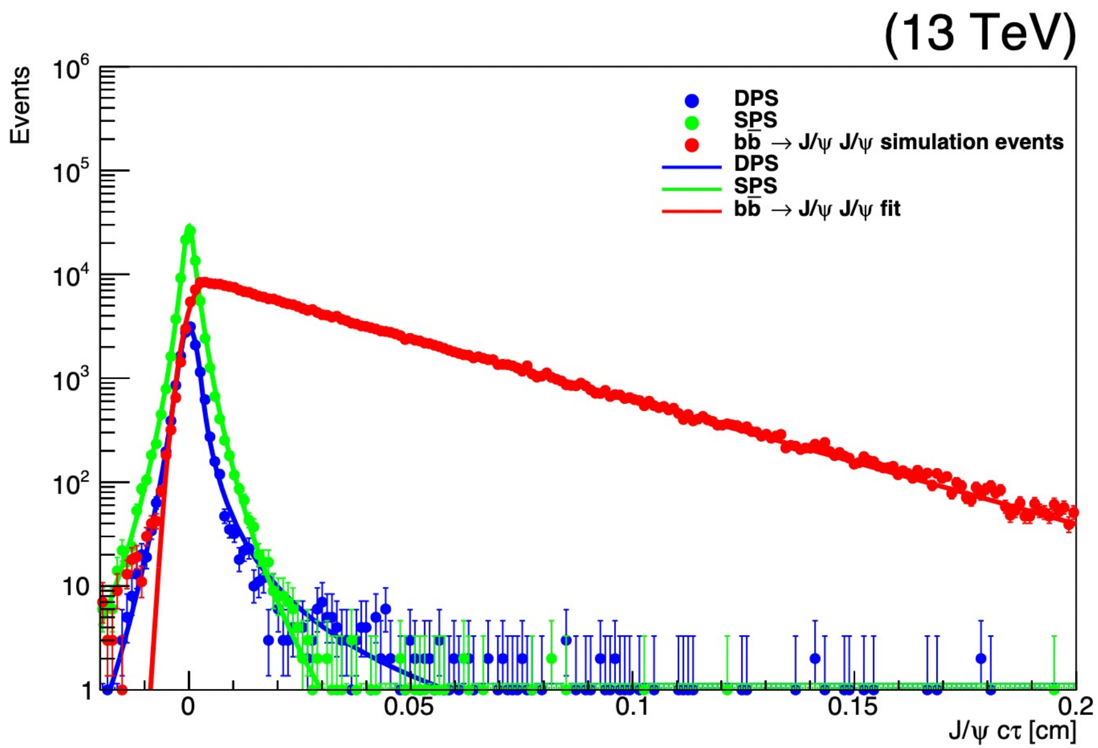


Combinatorial component: use the 2nd Chebyshev Polynomial in the data sideband region

The J/ψ prompt and non-prompt PDF

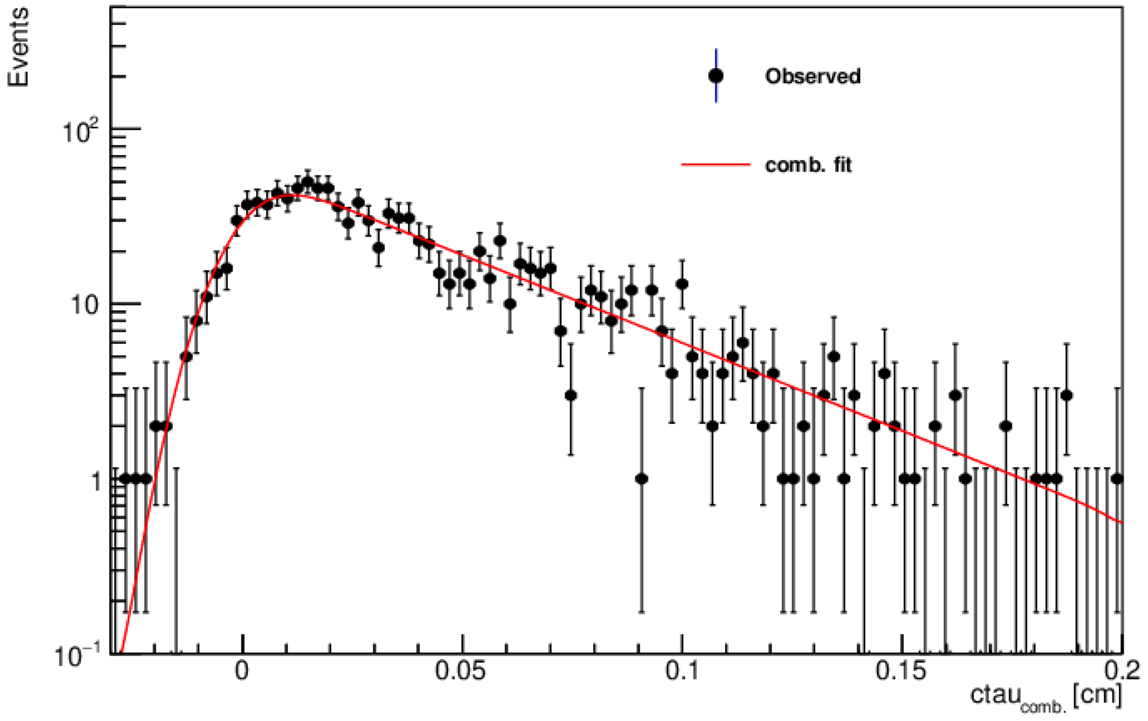
- Get prompt(DPS and SPS) and non-prompt(BBbar) distribution from MC sample

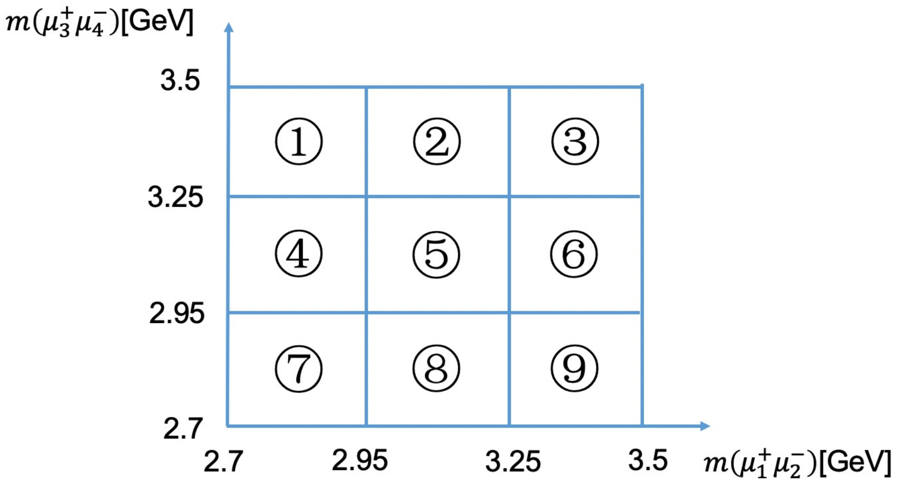




- Use double gauss function to fit prompt (DPS and SPS) distribution
- Use the Gauss⊗Exp function to fit non-prompt(BBbar) distribution

Comb. lifetime PDF

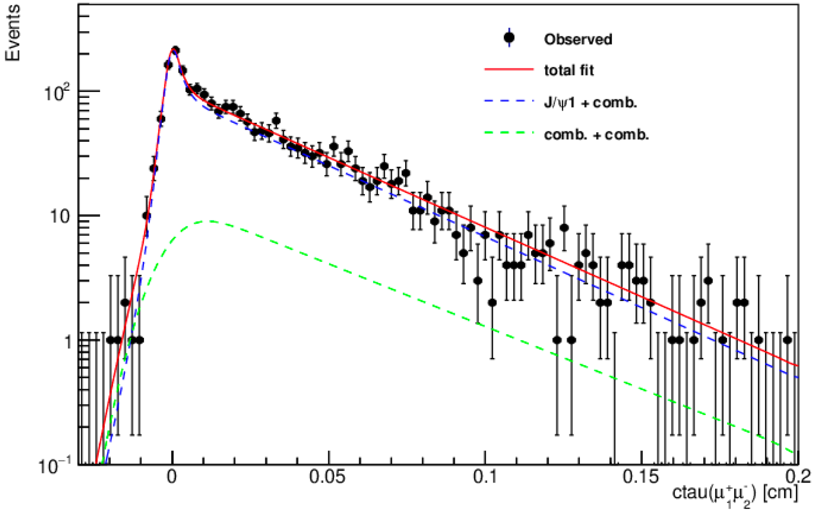


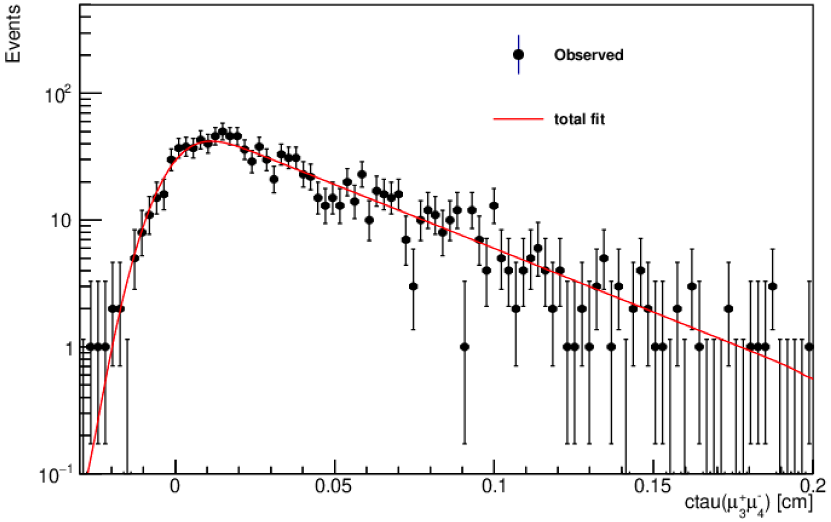


$ctau(\mu_1^+\mu_2^-)$ distribution in ①+④+⑦+③+⑥+⑨ region
or
$ctau(\mu_3^+\mu_4^-)$ distribution in ①+②+③+⑦+⑧+⑨ region

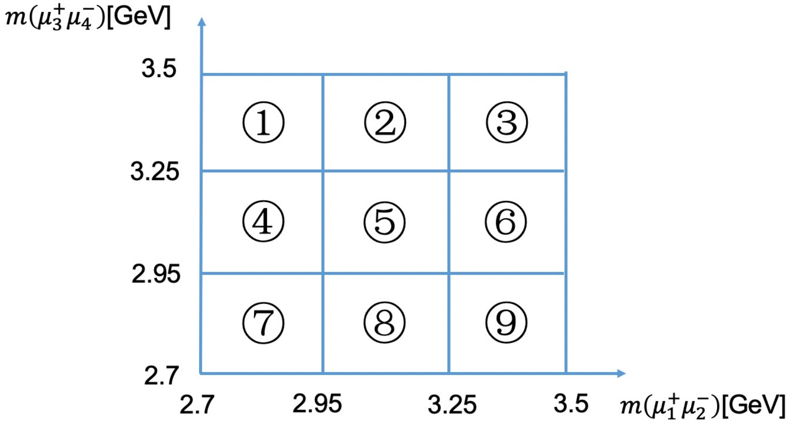
- We expected to get comb. distribution in two dimension ①+③+⑦+⑨ region, but these region have very little number of events, so we get the comb. ctau distribution in one dimension mu pair mass ∈ [2.7, 2.95]∪[3.25, 3.5]GeV region
- The comb. ctau can use Exp⊗Gauss function to fit.

J/ψ + comb. Lifetime PDF





②+⑧ region ctau fit plots



②+⑧ or ④+⑥ region

- J/ψ + comb. background region is ②+⑧ or ④+⑥.
- The ②+⑧ or ④+⑥ region include J/ψ + comb. and comb. + comb. two components.
- We have get the comb. + comb. ctau shape from last slides
- The J/ψ + comb. background J/ψ ctau can use Exp⊗Gauss + DSCB function to fit.

Fit validation

- Before fitting data, we should produce the pseudo data to do the Fit validation

- How to produce each components of pseudo data
  - Prompt J/ψ + Prompt J/ψ: use SPS or DPS MC sample
  - Prompt J/ψ + Non-prompt J/ψ: no MC sample, we generate the events by PDF
  - Non-Prompt J/ψ + Non-prompt J/ψ: use BBbar sample
  - J/ψ + comb.: no MC sample, we generate the events by PDF
  - Comb. + comb.: no MC sample, we generate the events by PDF

- We will produce two types of pseudo data to do test:
  - Mix data and pseudo data
  - Pure pseudo data

- We use pseudo to do fit to see if we can extract each components successfully

Fit validation result(1)

We mix data and pseudo data to do fit

In this table, “0” mean the data, “1-9” mean the input pseudo data

		0	1	2	3	4	5	6	7	8	9	10
J/ψ_1 J/ψ_2	SPS	-	1000	-	1000	-	-	-	-	1000	1000	1000
	DPS	-	-	500	500	-	-	-	-	500	500	500
	P+NP	-	-	-	-	500	-	-	-	500	-	500
	B decay	-	-	-	-	-	2000	-	-	2000	-	2000
$J/\psi\mu^+\mu^-$		-	-	-	-	-	-	1000	-	-	1000	1000
$\mu^+\mu^-\mu^+\mu^-$		-	-	-	-	-	-	-	100	-	100	100

The table shows the fit result of different input

		0	1	2	3	4	5	6	7	8	9	10
J/ψ_1 J/ψ_2	P+P	2650 ± 60	3660 ± 70	3080 ± 60	4090 ± 70	2630 ± 60	2650 ± 60	2630 ± 60	2640 ± 60	4080 ± 70	4070 ± 70	4050 ± 70
	NP+P	780 ± 30	770 ± 30	800 ± 30	790 ± 30	1290 ± 40	780 ± 40	780 ± 40	770 ± 30	1300 ± 40	790 ± 40	1300 ± 40
	NP+NP	4420 ± 100	4410 ± 100	4390 ± 100	4390 ± 100	4290 ± 100	6220 ± 110	4360 ± 110	4390 ± 100	6180 ± 110	4340 ± 100	6120 ± 120
$J/\psi\mu^+\mu^-$		1500 ± 50	1510 ± 50	1520 ± 50	1520 ± 50	1510 ± 50	1500 ± 50	2540 ± 60	1530 ± 50	1520 ± 50	2560 ± 60	2560 ± 60
$\mu^+\mu^-\mu^+\mu^-$		80 ± 20	80 ± 20	80 ± 20	80 ± 30	80 ± 20	90 ± 20	70 ± 30	180 ± 30	100 ± 20	180 ± 30	190 ± 30

Compare the two tables, we can extract the input pseudo data successfully

Fit validation result(2)

➢We only use pseudo data to do fit

In this table, “1-9” mean different input pseudo data

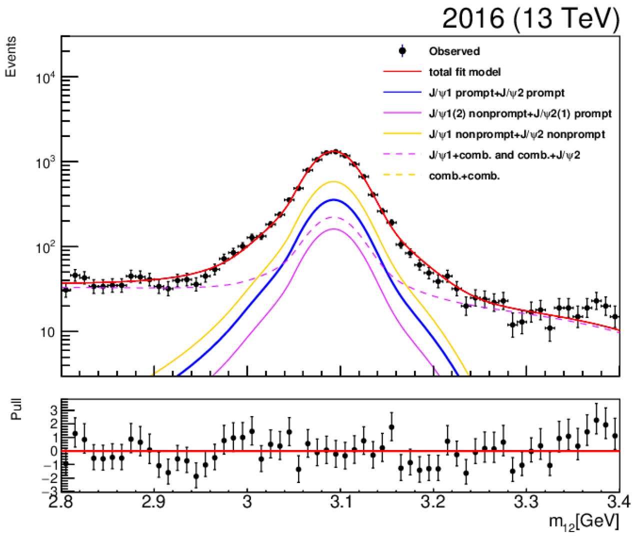
		1	2	3	4	5	6	7	8	9	10
J/ψ_1 J/ψ_2	SPS	1000	2000	1000	2000	1000	1000	1000	1000	2000	2000
	DPS	500	500	1000	1000	500	500	500	500	1000	1000
	P+NP	500	500	500	500	1000	500	500	500	1000	500
	B decay	2000	2000	2000	2000	2000	4000	2000	2000	4000	2000
$J/\psi\mu^+\mu^-$		1000	1000	1000	1000	1000	1000	2000	1000	1000	2000
$\mu^+\mu^-\mu^+\mu^-$		100	100	100	100	100	100	100	200	200	200

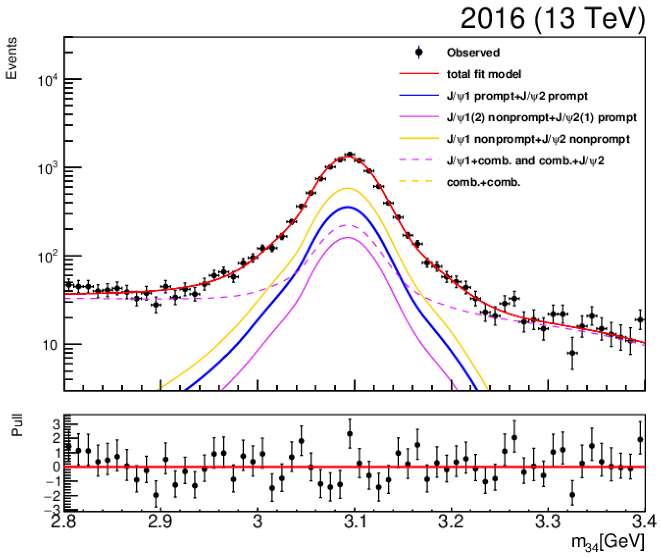
The table shows the fit result of different input

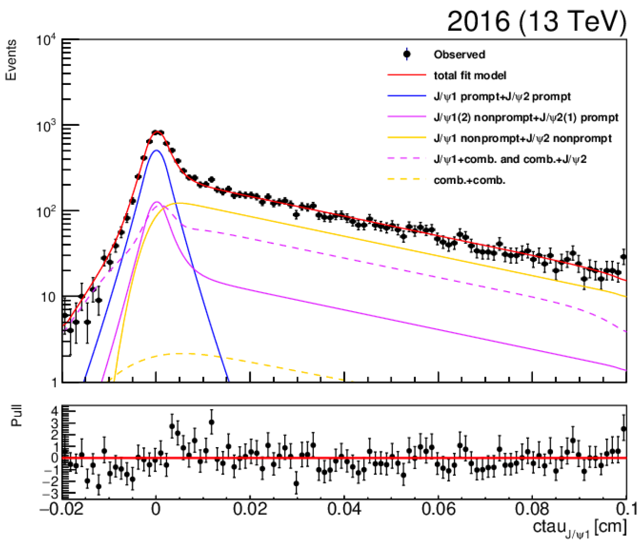
J/ψ_1 J/ψ_2	P+P	1410 ± 40	2400 ± 50	1860 ± 50	2850 ± 60	1470 ± 50	1420 ± 40	1430 ± 40	1410 ± 40	2900 ± 60	2860 ± 60
	NP+P	530 ± 30	520 ± 30	550 ± 30	540 ± 30	1020 ± 30	520 ± 30	530 ± 30	530 ± 30	1020 ± 30	540 ± 30
	NP+NP	1760 ± 60	1760 ± 60	1760 ± 60	1760 ± 60	1780 ± 70	3510 ± 80	1860 ± 70	1760 ± 60	3520 ± 80	1850 ± 70
$J/\psi\mu^+\mu^-$		1030 ± 40	1040 ± 30	1030 ± 40	1040 ± 30	1000 ± 40	1060 ± 40	1960 ± 40	1030 ± 30	1040 ± 40	1970 ± 40
$\mu^+\mu^-\mu^+\mu^-$		100 ± 20	100 ± 20	100 ± 20	100 ± 20	100 ± 20	100 ± 20	130 ± 30	190 ± 20	110 ± 20	230 ± 30

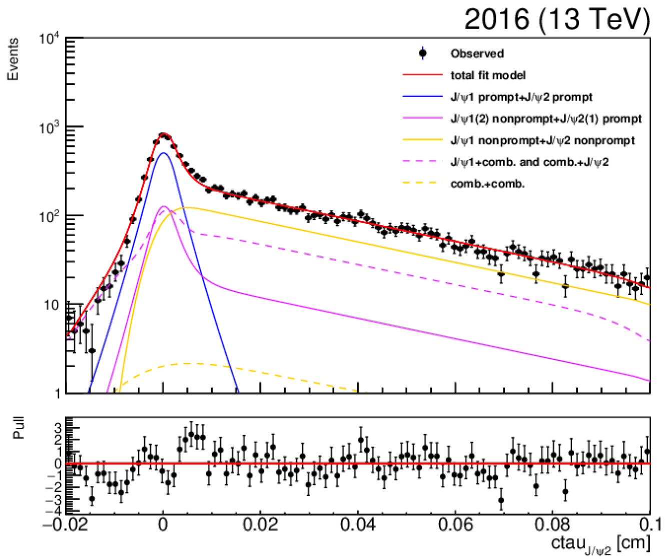
Compare the two tables, we can extract the input pseudo data successfully

4D fit for data





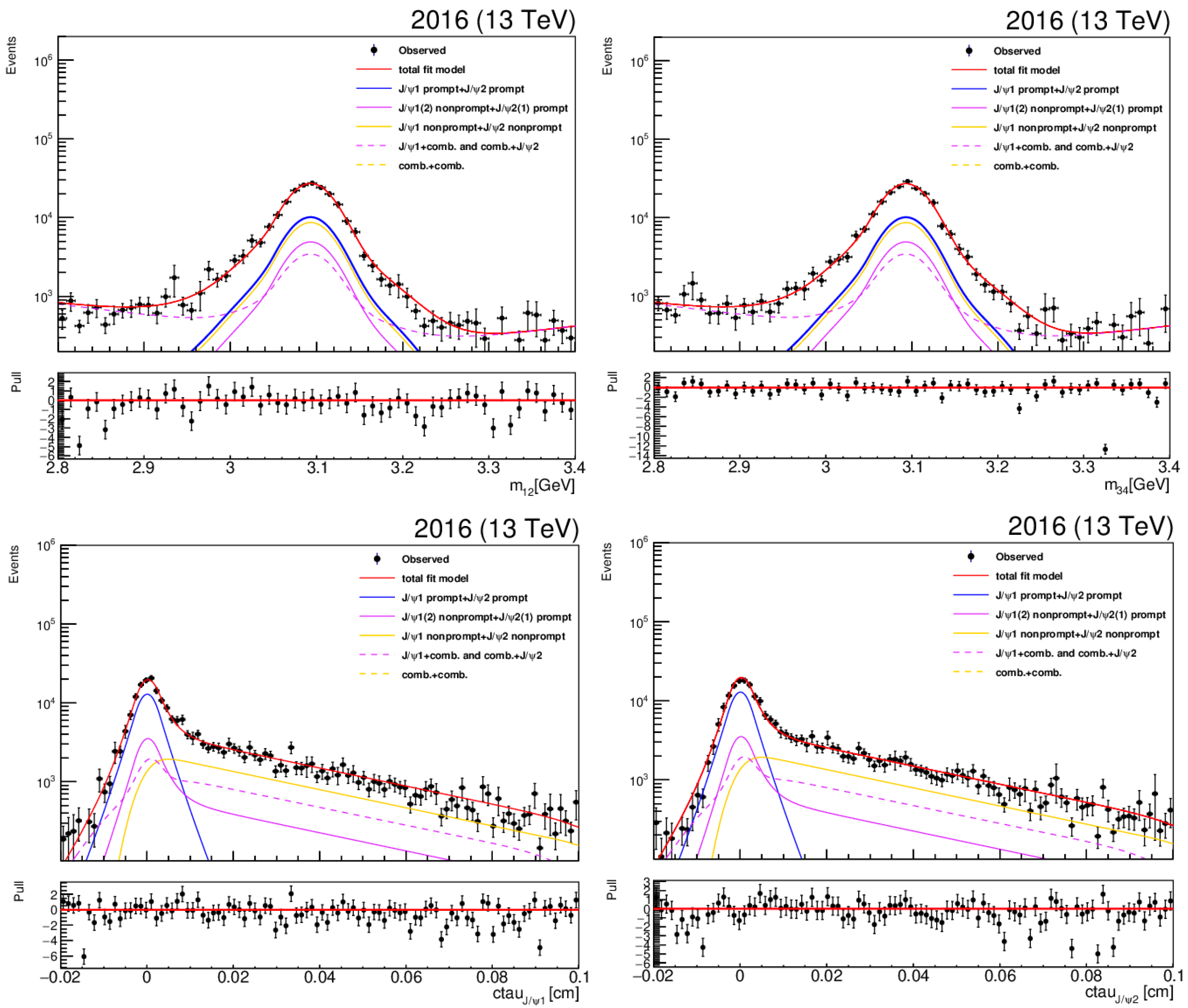




➢ 4D fit

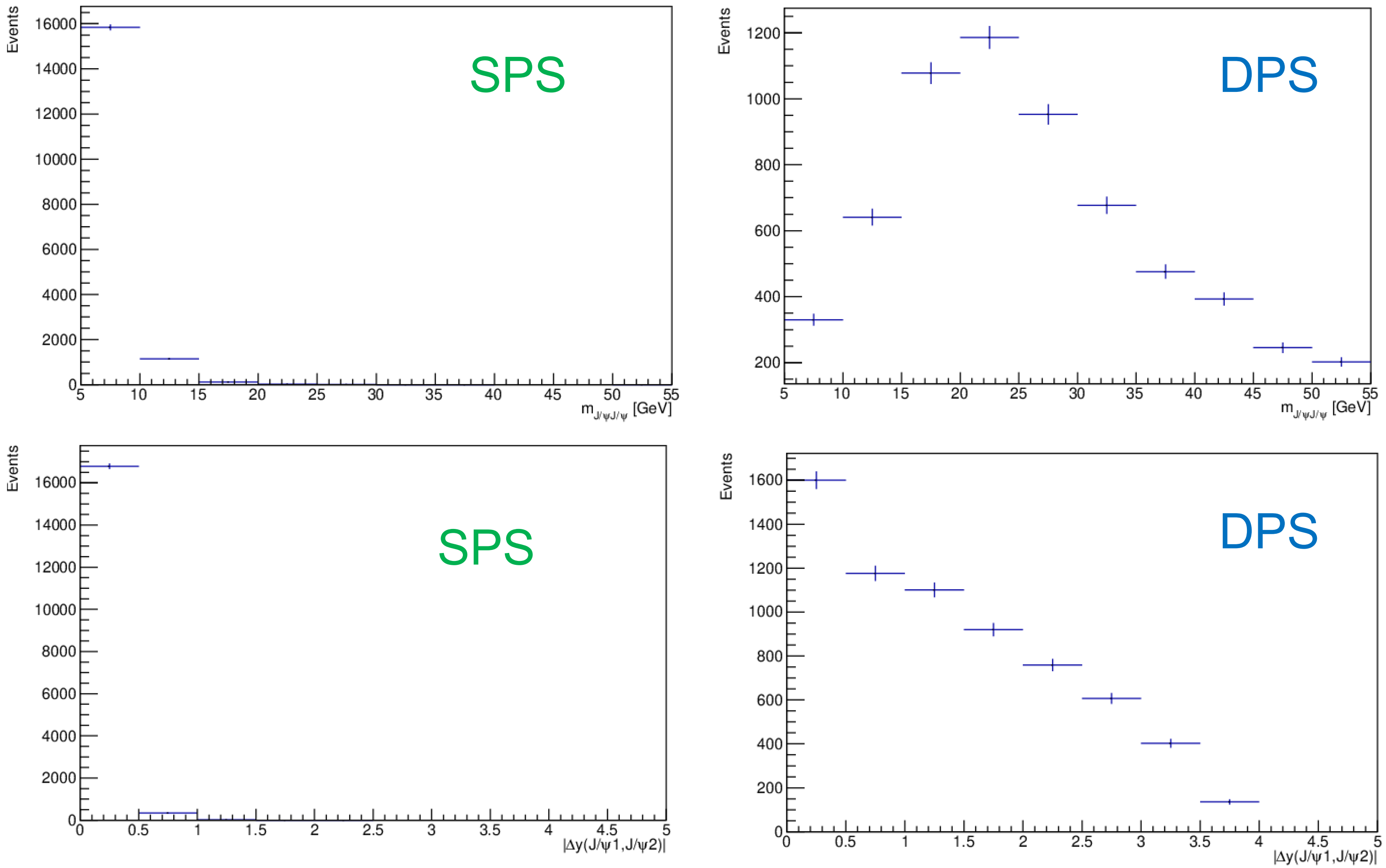
- we merge some components in the plots, the legend in the plots:
  - ☐ J/ψ1 prompt + J/ψ2 prompt
    - The two muon pair are all prompt J/ψ, this component are signal
  - ☐ J/ψ1(2) non-prompt + J/ψ2(1) prompt
    - The two muon pairs are all J/ψ, but one of them is non-prompt
  - ☐ J/ψ1 non-prompt + J/ψ2 non-prompt
    - The two muon pairs are all non-prompt J/ψ
  - ☐ J/ψ1(comb.) + comb. (J/ψ2)
    - One muon pair is J/ψ and another is comb.
  - ☐ comb. + comb.
    - All these two muon pairs are comb

Add mapping Fit



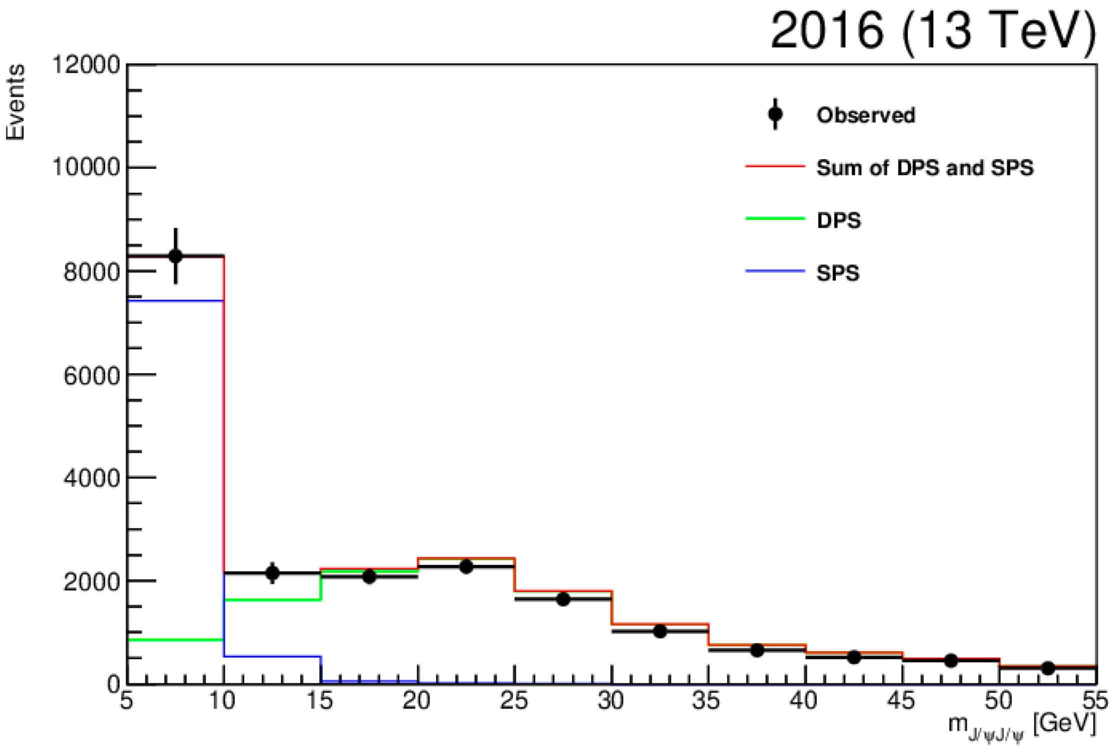
- Total number of events in this region is 251293
- Prompt Jpsi pair events are 80300 ± 3130
- Prompt Jpsi + Non-prompt Jpsi events are 38960 ± 3075
- Non-prompt Jpsi pair events are 68655 ± 4285
- Jpsi + comb. events are 49542 ± 4852
- Comb. + comb. Events are 119 ± 1078

Extracting the DPS fraction strategy

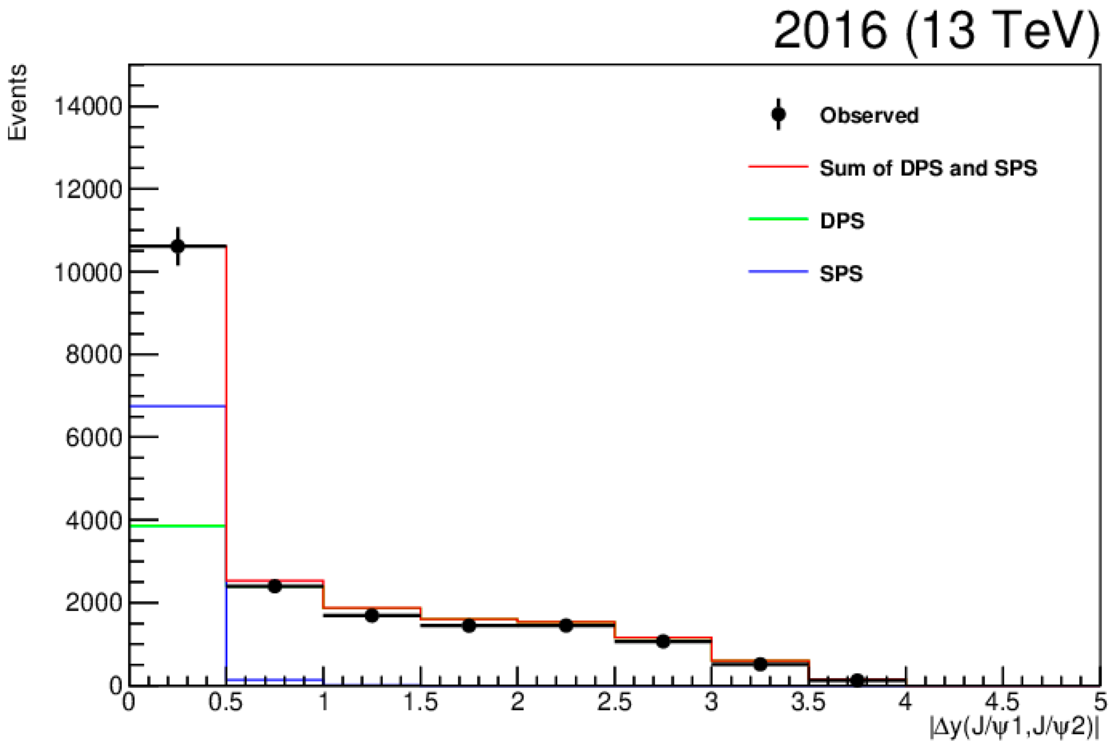


- The SPS and DPS contribution can be separated because of their different kinematics
- We get SPS and DPS templates of invariance mass and delta rapidity

DPS fraction



DPS fraction: 0.60±0.01



DPS fraction: 0.65±0.01

The definition of DPS $f_{DPS} = N_{DPS}/(N_{DPS}+N_{SPS})$

- We extract prompt J/ψ pair events in each invariance mass and delta rapidity bin.
- Use the SPS and DPS templates to fit data

Summary

- We add trigger Matched in event selection and get the corresponded efficiency
- We distinguish J/ψ and comb. in invariance mass dimension and distinguish J/ψ prompt component in lifetime dimension
- We do the fit validation first and then do four dimension fit for two muon pairs to distinguish all 7 components
- We try to separate SPS and DPS according to their different kinematics
- Next step
  - We will write analysis note and get the CADI line