Possible bias in the correction

- Bias can be induced by the correction
- The way we do the correction:
  - $\epsilon = 0.3\epsilon_{SPS} + 0.7\epsilon_{DPS}$
  - $W = \frac{1}{\epsilon} = \frac{1}{0.3\epsilon_{SPS}+0.7\epsilon_{DPS}}$
- Some events have zero DPS efficiency, in this case:
  - $\epsilon = 0.3\epsilon_{SPS}$
  - $W = \frac{1}{0.3\epsilon_{SPS}} \sim 3.3\frac{1}{\epsilon_{SPS}}$
- It may overestimate the yield

Possible bias in the correction

- Propose to change the correction:

$$\epsilon = \begin{cases} 1 & (\epsilon_{DPS} = 0, \epsilon_{SPS} = 0) \\ \epsilon_{DPS} & (\epsilon_{DPS} \neq 0, \epsilon_{SPS} = 0) \\ \epsilon_{SPS} & (\epsilon_{DPS} = 0, \epsilon_{SPS} \neq 0) \\ 0.3\epsilon_{SPS} + 0.7\epsilon_{DPS} & (\epsilon_{DPS} \neq 0, \epsilon_{SPS} \neq 0) \end{cases}$$

Redo the closure test

	N^{obs}	N^{Corr}_{SPS}	N^{Corr}_{DPS}	N^{Corr}_{37Mix}	N^{Corr}_{82Mix}
$Total$	151857	148980	153623	151509	149176
$\eta(\mu)$	148365	145561	149726	148072	145944
$p^T(\mu)$	50459				

Test for acceptance

	N^{obs}	N^{Corr}_{SPS}	N^{Corr}_{DPS}	N^{Corr}_{37Mix}	N^{Corr}_{82Mix}
$Total$	13140	15500	11371	13904	14916
$RECO$	13140	14858	10982	13349	14308
$id(\mu)$	12410	14013	10450	12577	13491
$vtx(\mu^+\mu^-)$	11379	12733	9906	11572	12316
HLT	8337	9334	8899	9207	9275
evt	8160				

Test for efficiency

- SPS (2016) sample
- $37Mix$: $0.3\epsilon_{SPS} + 0.7\epsilon_{DPS}$
- $82Mix$: $0.8\epsilon_{SPS} + 0.2\epsilon_{DPS}$
- Generally good consistency

Redo the closure test

	N^{obs}	N^{Corr}_{SPS}	N^{Corr}_{DPS}	N^{Corr}_{37Mix}	N^{Corr}_{82Mix}
$Total$	77	80.1	79.2	79.4	79.9
$\eta(\mu)$	77	78.1	77.5	77.6	77.9
$p^T(\mu)$	15				

Test for acceptance

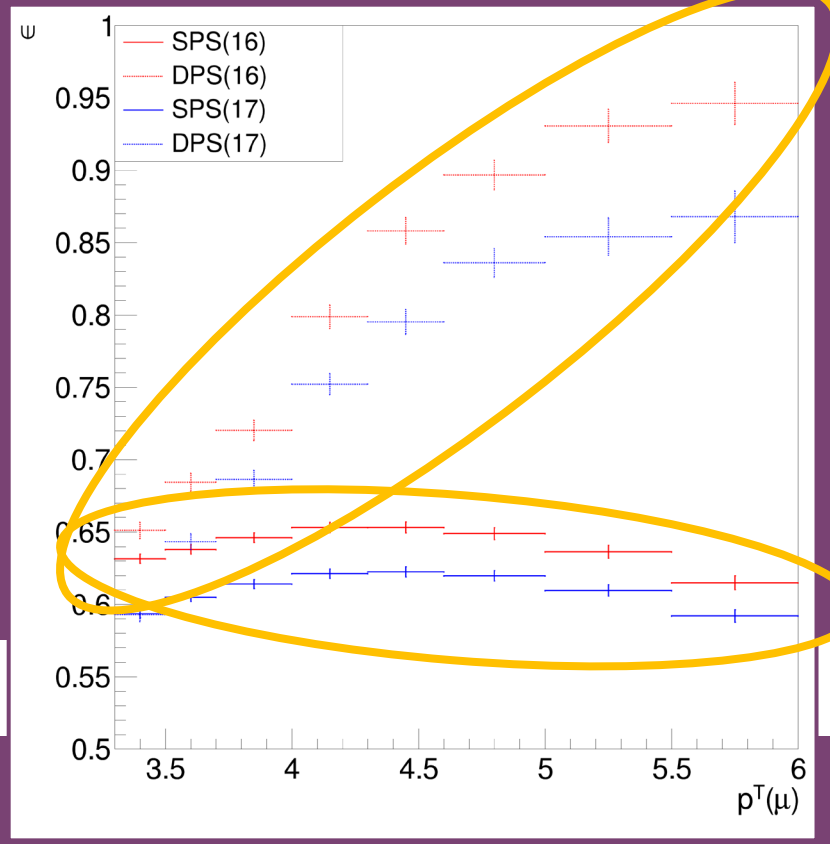
	N^{obs}	N^{Corr}_{SPS}	N^{Corr}_{DPS}	N^{Corr}_{37Mix}	N^{Corr}_{82Mix}
$Total$	1786	2547	2019	2149	2411
$RECO$	1786	2401	1919	2040	2278
$id(\mu)$	1680	2252	1801	1914	2137
$vtx(\mu^+\mu^-)$	1566	2015	1675	1761	1931
HLT	1264	1415	1372	1382	1404
evt	1257				

Test for efficiency

- DPS (2016) sample
- Poor statistic
- Generally good consistency

HLT efficiency

- Checked the HLT efficiency:
  - $\epsilon = \frac{cuts \;\&\&\; HLT}{cuts}$
  - "cuts" here include all selections before the HLT. $p^T(J/\psi) > 10\mathrm{GeV}$
- Check the dependence of $p^T(\mu)$ requirement

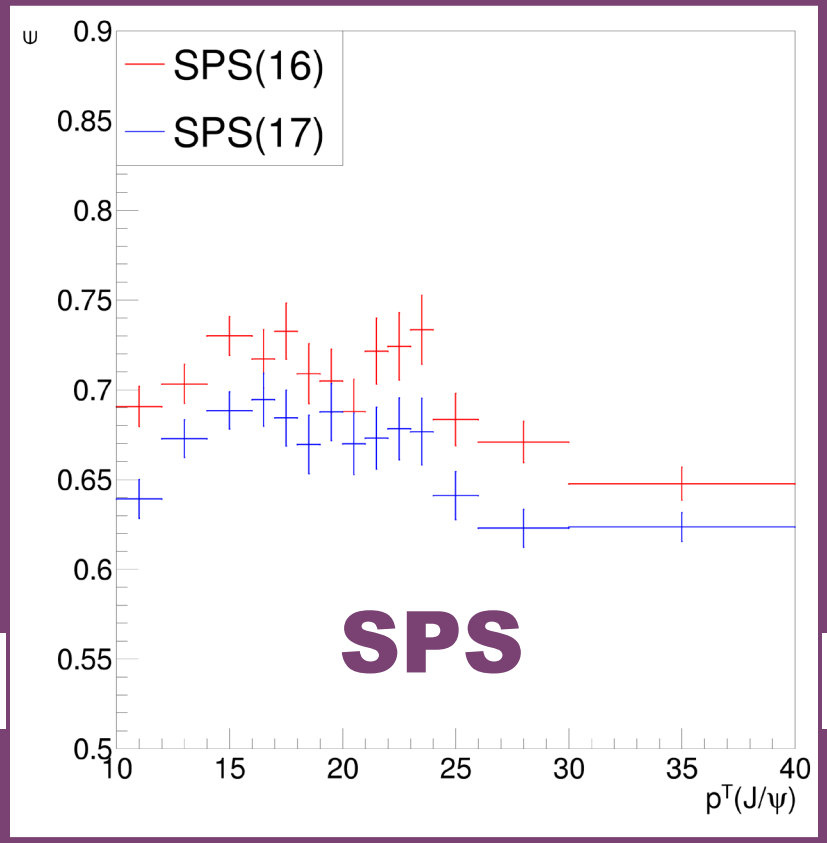


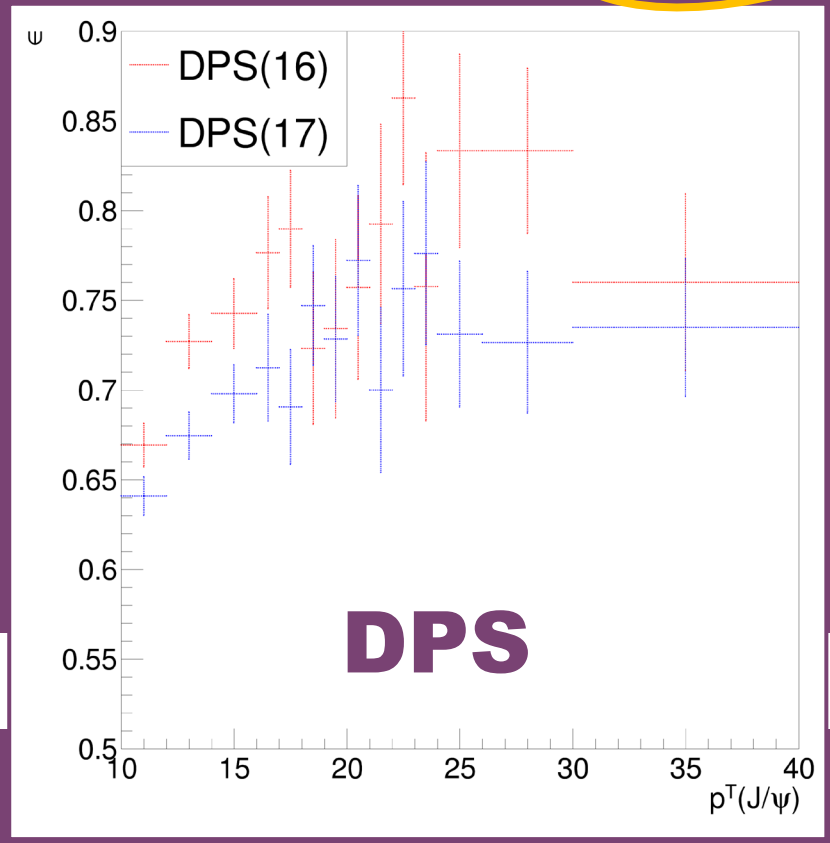
DPS

SPS

HLT efficiency

- Checked the HLT efficiency:
  - $\epsilon = \frac{cuts \;\&\&\; HLT}{cuts}$
  - "cuts" here include all selections before the HLT. $p^T(\mu) > 3.5\mathrm{GeV}$
- Check the efficiency in different $p^T(J/\psi)$ bins





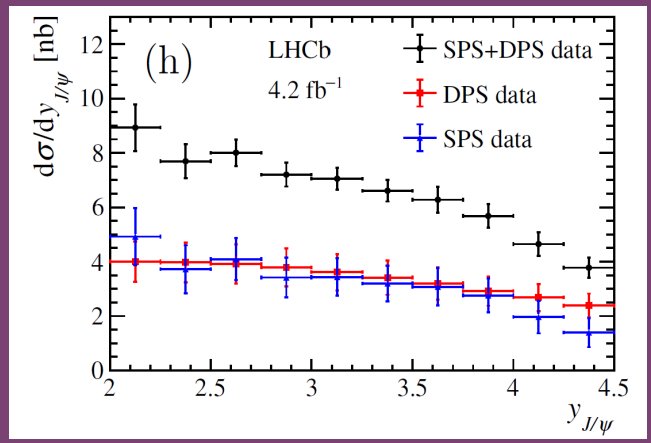
Compare with LHCb's result

$2 < y(J/\psi) < 4.5$

- Cross section is calculated as:
  - $\mathrm{d}\sigma/\mathrm{d}p^T(J/\psi) = \frac{N^{Corr}}{L \times BR^2 \times \Delta p^T(J/\psi)} \times SF_{y(J/\psi)}$
  - $SF_{y(J/\psi)} = 2.5/4$, assume uniform distribution against $y(J/\psi)$
- 10-12:
  - $\mathrm{d}\sigma/\mathrm{d}p^T(J/\psi) = \frac{2510}{36.3\mathrm{fb}^{-1} \times 0.06^2 \times 2\mathrm{GeV}} \times 2.5/4$
  - $= 6002\mathrm{fb/GeV} = 0.006\mathrm{nb/GeV}$
- 12-14:
  - $\mathrm{d}\sigma/\mathrm{d}p^T(J/\psi) = \frac{2329}{\ldots} = 0.005\mathrm{nb/GeV}$

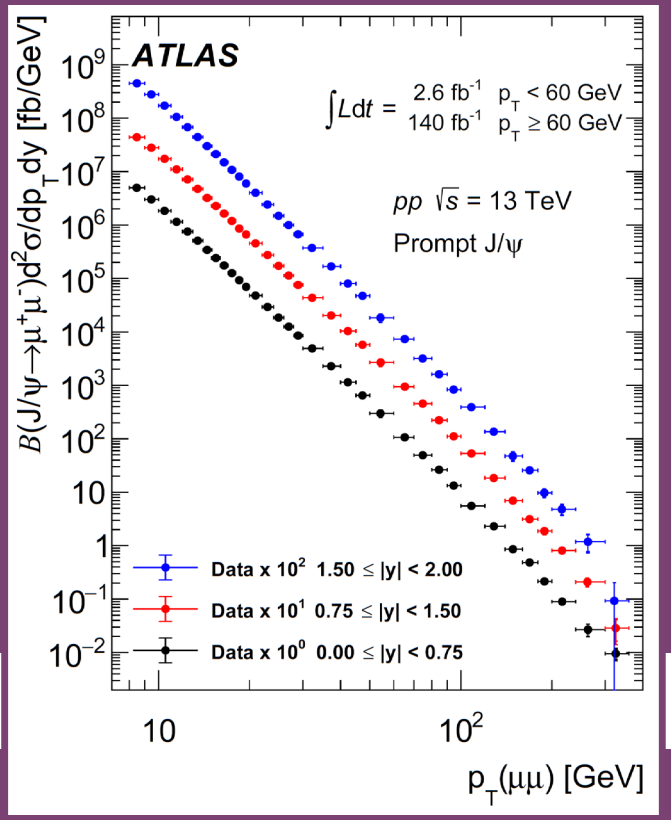
$p^T(J/\psi)$GeV	$\mathrm{d}\sigma/\mathrm{d}p^T(J/\psi)$ nb/GeV
$10-12$	0.048
$12-14$	0.016

LHCb's result



Effective cross section

- It seems there is almost no DPS candidate in the range: $M(J/\psi J/\psi) < 7.5\ \mathrm{GeV}$
  - 2 compared to 1026 in DPS (2016) MC sample
  - Safe to estimate $\sigma_{DPS\to J/\psi J/\psi}$ with the fiducial requirement
  - $\boldsymbol{\sigma_{DPS\to J/\psi J/\psi} = (65.7 \times 0.671)\ \mathrm{pb} = 44.1\ \mathrm{pb}}$
- $\sigma_{SPS\to J/\psi}$ is from ATLAS's result (2309.17177v2)
  - CMS's result has small volume (1710.11002v2)
  - $\sigma_{SPS\to J/\psi} \sim 0.37\ \mu\mathrm{b}$
- $\sigma_{eff} = \dfrac{\sigma^2_{SPS\to J/\psi}}{2\sigma_{DPS\to J/\psi J/\psi}} = \dfrac{(0.37\ \mu\mathrm{b})^2}{2\times 44.1\ \mathrm{pb}} = \mathbf{1.55\ mb}$



Redo the closure test

	N^{obs}	N^{Corr}_{SPS}	N^{Corr}_{DPS}	N^{Corr}_{37Mix}	N^{Corr}_{82Mix}
$Total$	508103	497806	504856	501302	498182
$\eta(\mu)$	496209	486518	493069	489661	486741
$p^T(\mu)$	171957				

Test for acceptance

	N^{obs}	N^{Corr}_{SPS}	N^{Corr}_{DPS}	N^{Corr}_{37Mix}	N^{Corr}_{82Mix}
$Total$	16343	19487	13663	15959	18154
$RECO$	16343	18524	13049	15193	17270
$id(\mu)$	15510	17560	12483	14440	16391
$vtx(\mu^+\mu^-)$	13684	15401	11423	12932	14488
HLT	9678	10862	9888	10280	10673
evt	9312				

Test for efficiency

- SPS (2017) sample

Redo the closure test

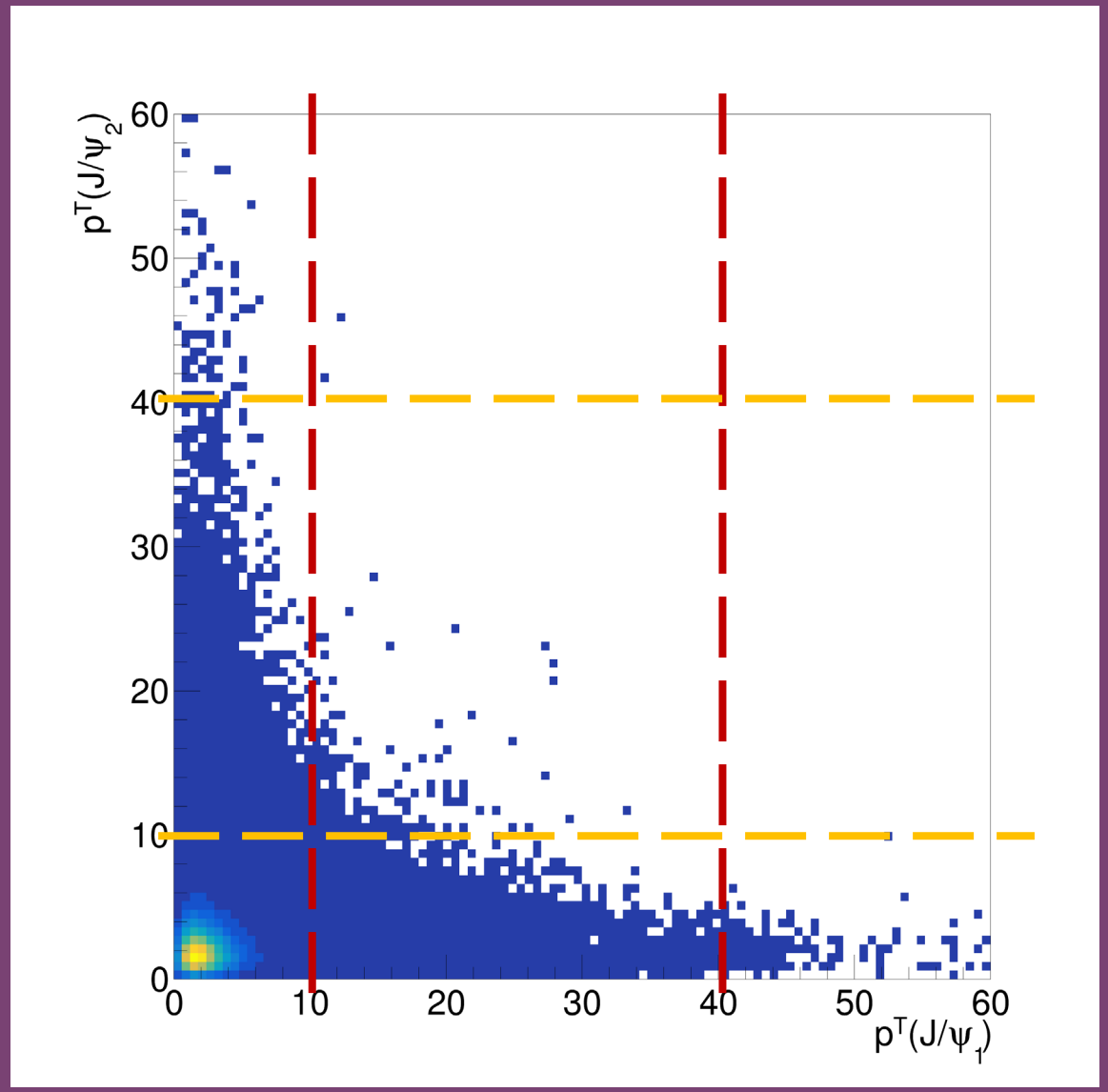
	N^{obs}	N^{Corr}_{SPS}	N^{Corr}_{DPS}	N^{Corr}_{37Mix}	N^{Corr}_{82Mix}
$Total$	276	221.5	225.1	223.8	222.1
$\eta(\mu)$	270	211.4	214.4	213.3	211.9
$p^T(\mu)$	48				

Test for acceptance

	N^{obs}	N^{Corr}_{SPS}	N^{Corr}_{DPS}	N^{Corr}_{37Mix}	N^{Corr}_{82Mix}
$Total$	2879	4137.6	3254.2	3471.2	3908.4
$RECO$	2879	3874	3064.6	3263.4	3664.6
$id(\mu)$	2732	3671.8	2908.4	3096.41	3474.9
$vtx(\mu^+\mu^-)$	2455	3162.1	2615.9	2753.6	3025.1
HLT	1915	2184.4	2053.1	2088.9	2154.5
evt	1892				

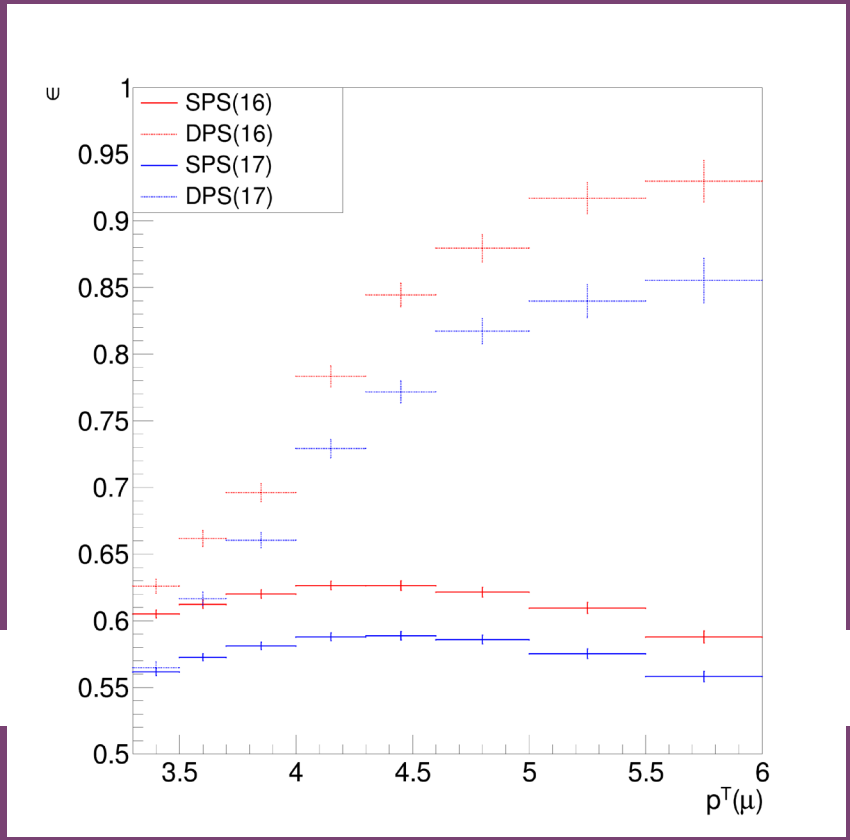
Test for efficiency

- DPS (2017) sample

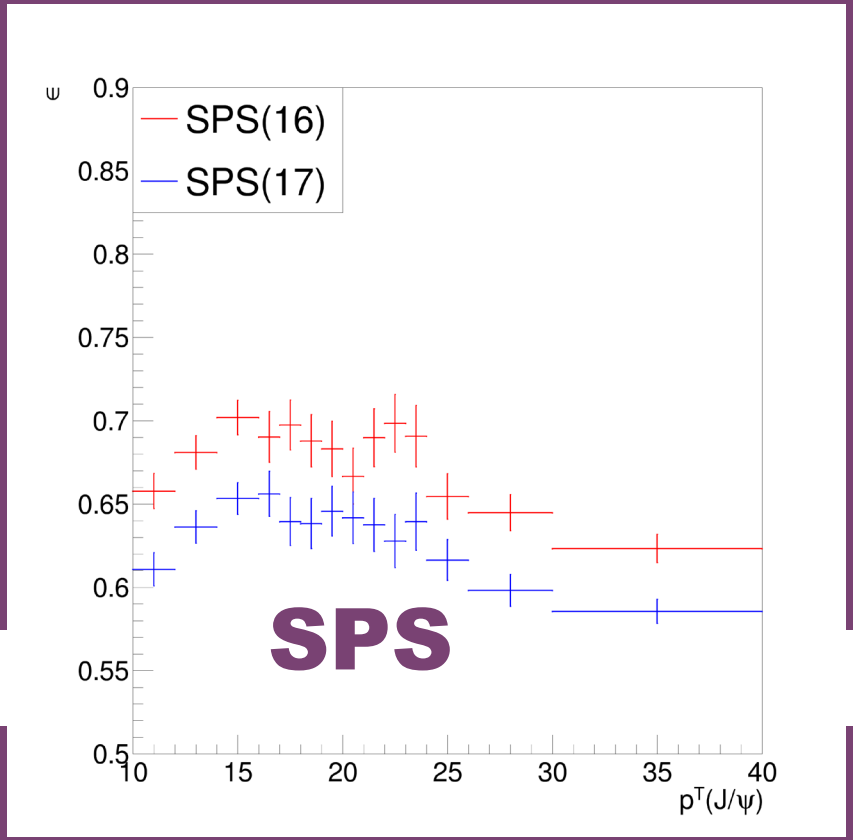


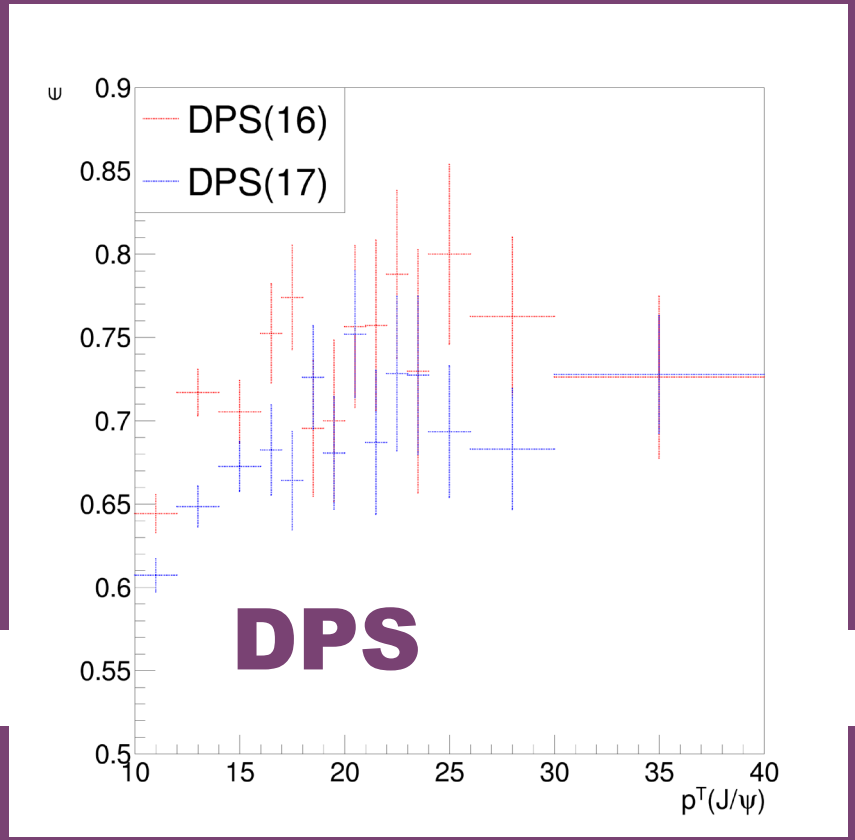
- DPS (2016), no GEN filter, GEN only sample

- Another HLT efficiency is checked:
  - $\epsilon = \frac{acc \,\&\&\, HLT}{acc}$
  - “acc” here only includes acceptance cut for single muon
- Check the dependence of $p^T(\mu)$ requirement

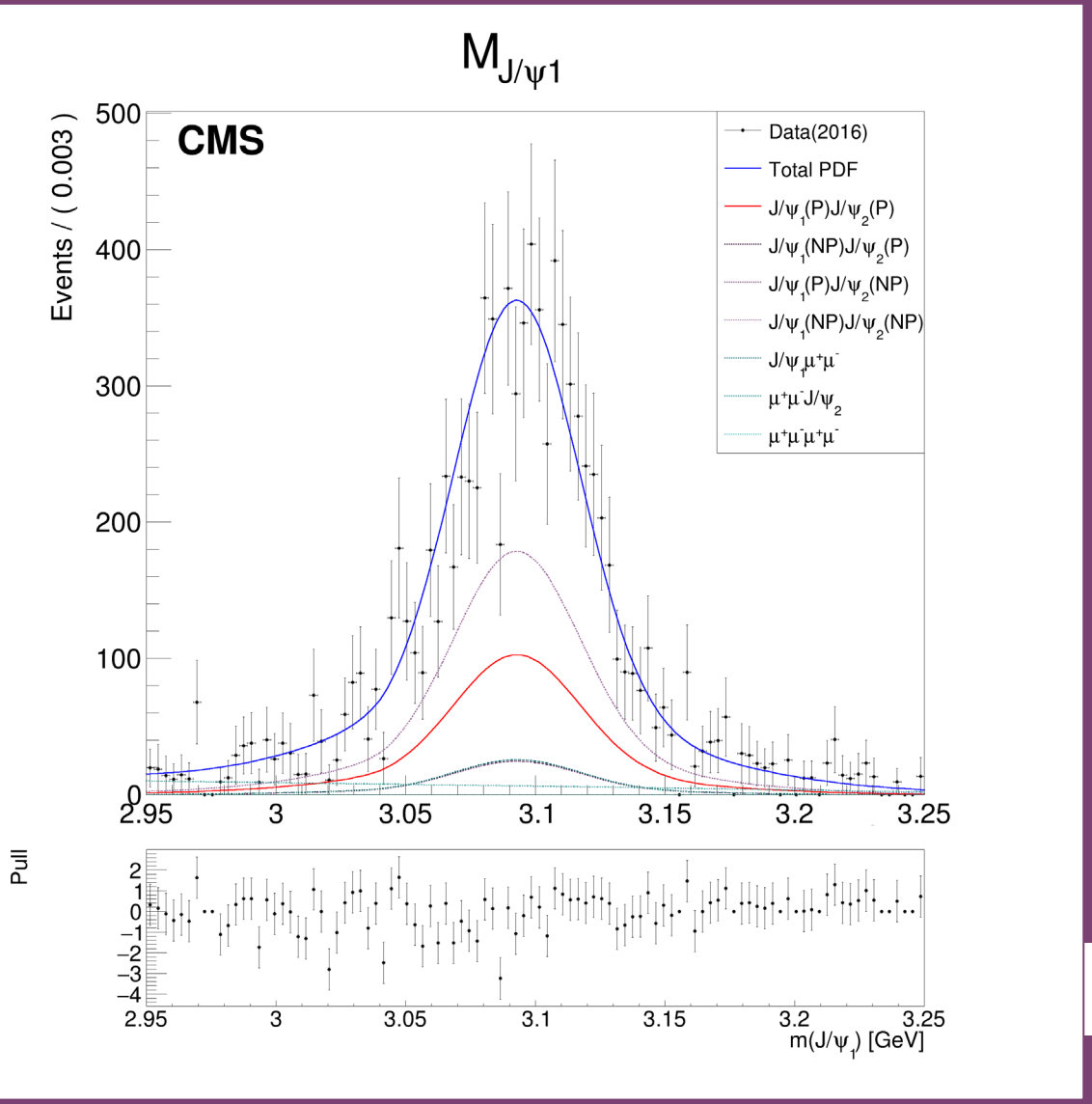


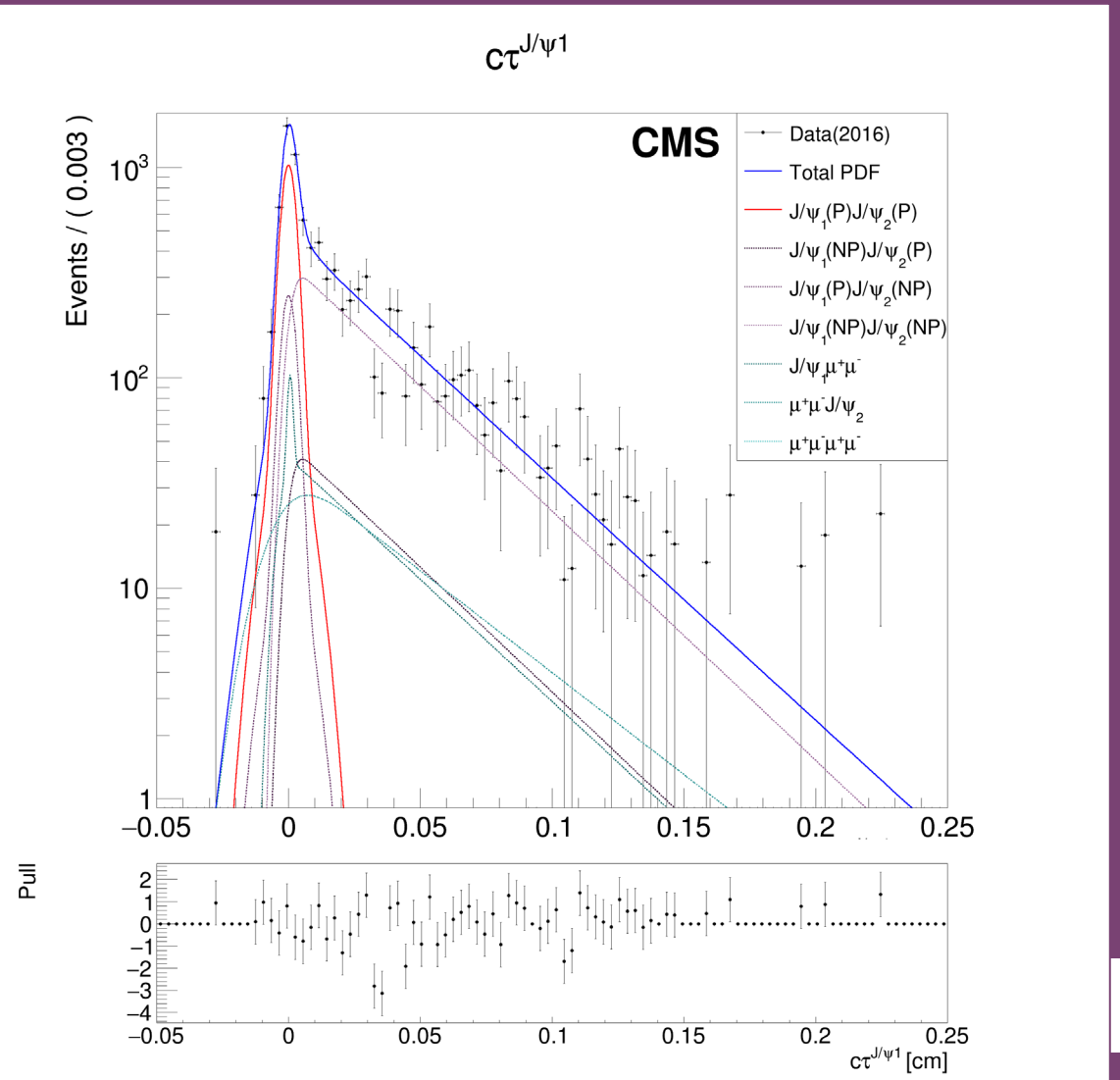
- Another HLT efficiency is checked:
  - $\epsilon = \frac{acc \,\&\&\, HLT}{acc}$
  - “acc” here only includes acceptance cut for single muon
- Check the efficiency in different $p^T(J/\psi)$ bins



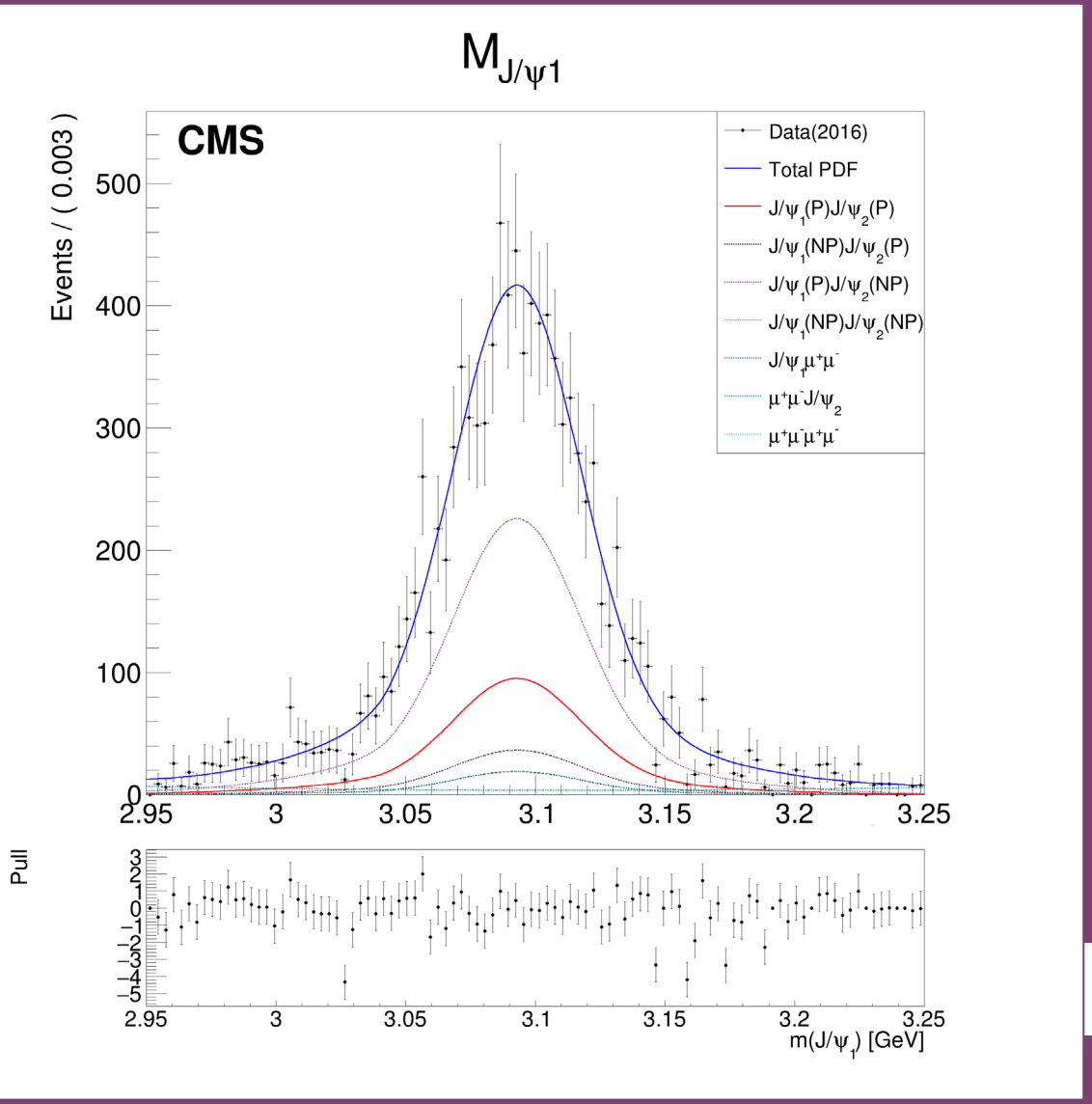


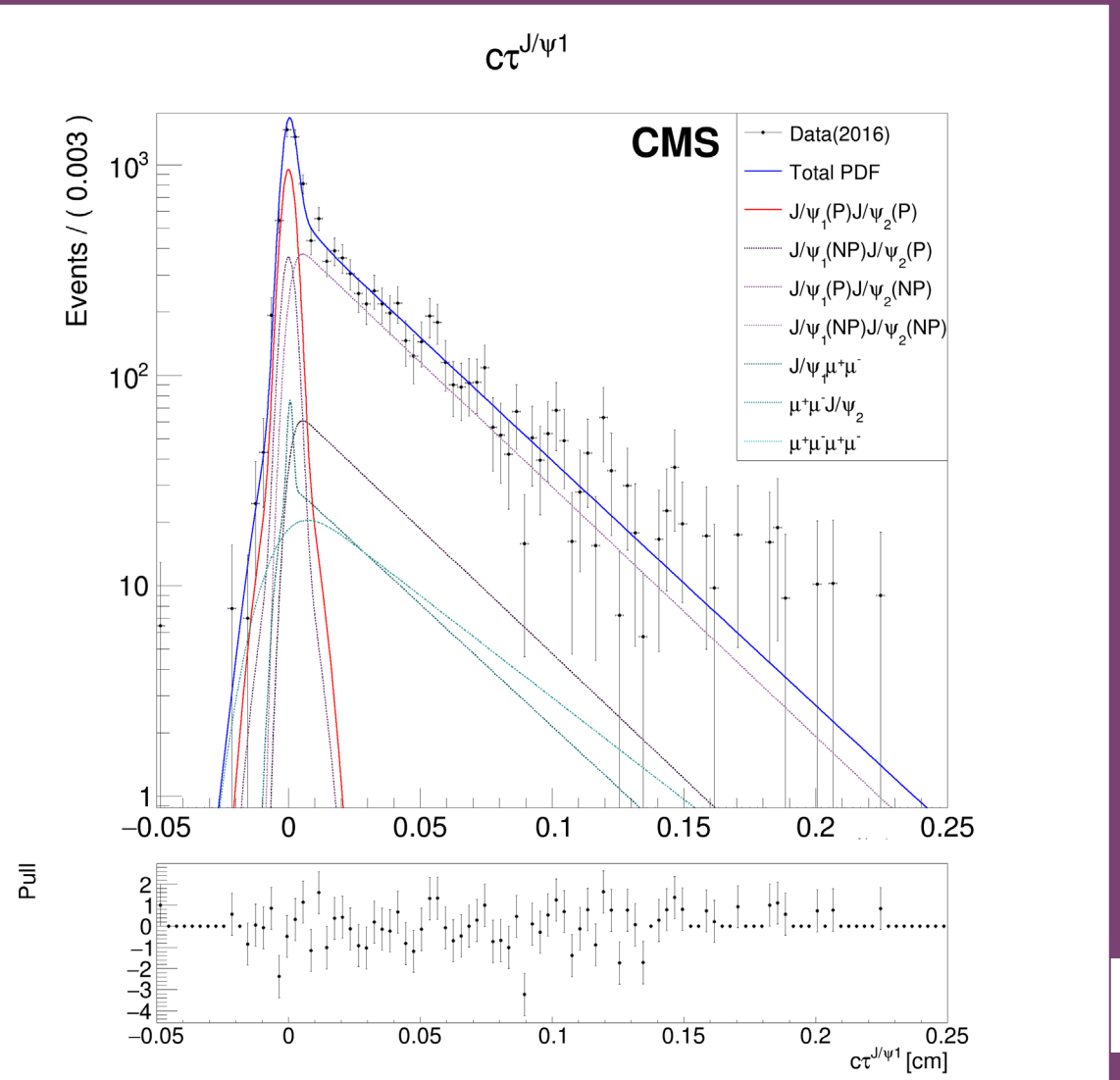
10-12

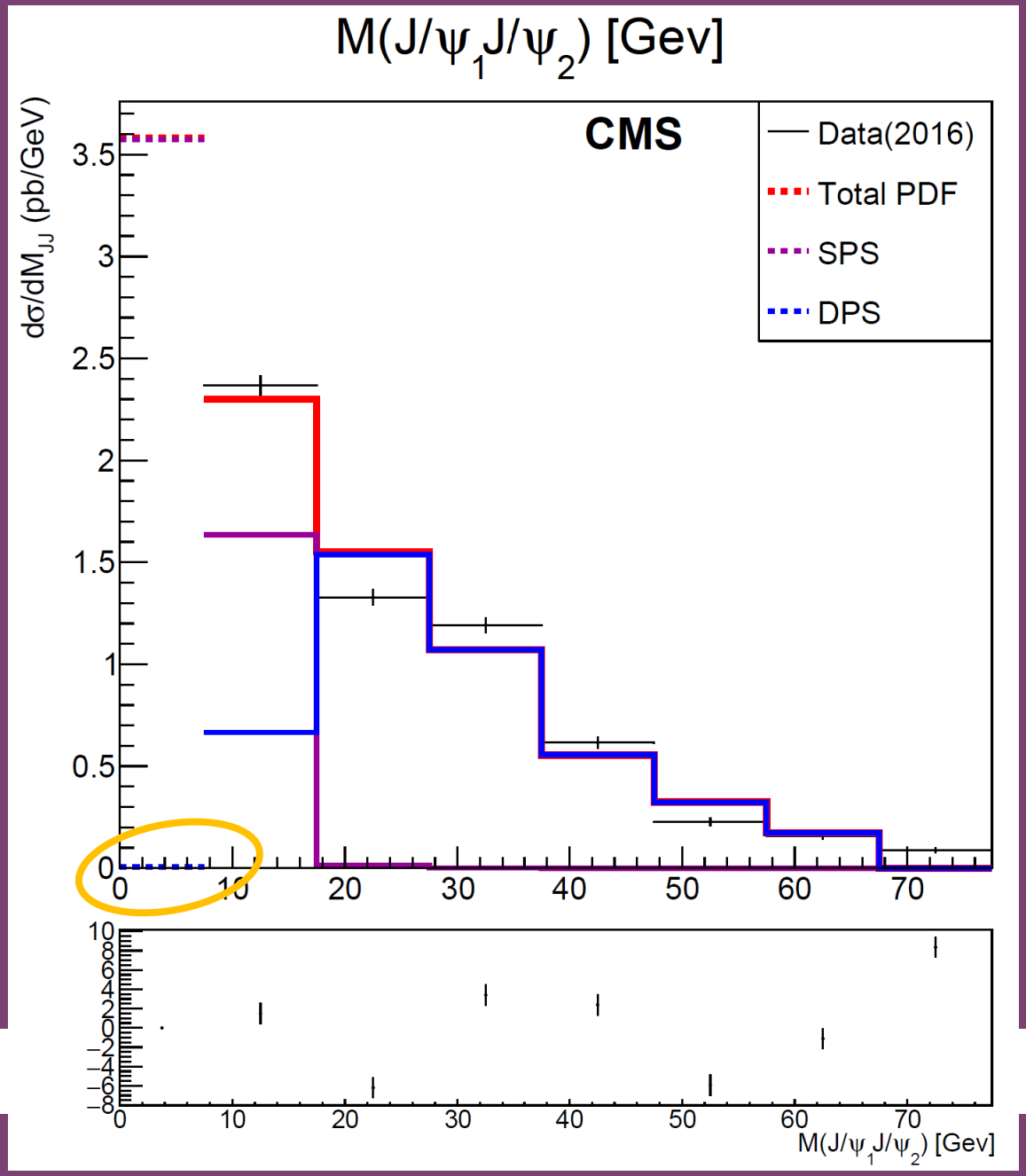

$M_{J/\psi 1}$
CMS
Data(2016)
Total PDF
$J/\psi_1(P)J/\psi_2(P)$
$J/\psi_1(NP)J/\psi_2(P)$
$J/\psi_1(P)J/\psi_2(NP)$
$J/\psi_1(NP)J/\psi_2(NP)$
$J/\psi_1\mu^+\mu^-$
$\mu^+\mu^- J/\psi_2$
$\mu^+\mu^-\mu^+\mu^-$
Events / (0.003)
Pull
$m(J/\psi_1)$ [GeV]


$c\tau^{J/\psi 1}$
CMS
Data(2016)
Total PDF
$J/\psi_1(P)J/\psi_2(P)$
$J/\psi_1(NP)J/\psi_2(P)$
$J/\psi_1(P)J/\psi_2(NP)$
$J/\psi_1(NP)J/\psi_2(NP)$
$J/\psi_1\mu^+\mu^-$
$\mu^+\mu^- J/\psi_2$
$\mu^+\mu^-\mu^+\mu^-$
Events / (0.003)
Pull
$c\tau^{J/\psi 1}$ [cm]

12-14


$M_{J/\psi 1}$
CMS
Data(2016)
Total PDF
$J/\psi_1(P)J/\psi_2(P)$
$J/\psi_1(NP)J/\psi_2(P)$
$J/\psi_1(P)J/\psi_2(NP)$
$J/\psi_1(NP)J/\psi_2(NP)$
$J/\psi_1\mu^+\mu^-$
$\mu^+\mu^- J/\psi_2$
$\mu^+\mu^-\mu^+\mu^-$
Events / (0.003)
Pull
$m(J/\psi_1)$ [GeV]


$c\tau^{J/\psi 1}$
CMS
Data(2016)
Total PDF
$J/\psi_1(P)J/\psi_2(P)$
$J/\psi_1(NP)J/\psi_2(P)$
$J/\psi_1(P)J/\psi_2(NP)$
$J/\psi_1(NP)J/\psi_2(NP)$
$J/\psi_1\mu^+\mu^-$
$\mu^+\mu^- J/\psi_2$
$\mu^+\mu^-\mu^+\mu^-$
Events / (0.003)
Pull
$c\tau^{J/\psi 1}$ [cm]


M(J/ψ1J/ψ2) [Gev]
CMS
Data(2016)
Total PDF
SPS
DPS
dσ/dMJJ (pb/GeV)
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
70
10
8
6
4
2
0
−2
−4
−6
−8
0
10
20
30
40
50
60
70
M(J/ψ1J/ψ2) [Gev]