J/ψ and ψ(2S) studies in p-p collisions at $\sqrt{s}$ = 7 TeV and in p-Pb collisions at $\sqrt{s}$ = 5.02 TeV using ALICE-MS

Saha Institute of Nuclear Physics

India-ALICE meeting
28th April, 2013

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On behalf of Jpsi2mumu PAG.

Outline

p-p analysis

- The analysis of the p-p (LHC11c+LHC11d periods).
- Integrated and differential (p_T,y) cross sections of J/ψ.
- Integrated and differential (p_T,y) cross sections of ψ(2S).
- ψ(2S) / J/ψ ratio vs p_T.

p-Pb and Pb-p analysis

- The analysis of the p-Pb (LHC13d+LHC13e periods) and Pb-p (LHC13f period).
- ψ(2S) / J/ψ ratio both integrated and in p_T bins for Pb-p.
- ψ(2S) / J/ψ ratio (integrated) for p-Pb.

p-p analysis

Invariant mass spectrum (LHC11c+LHC11d)

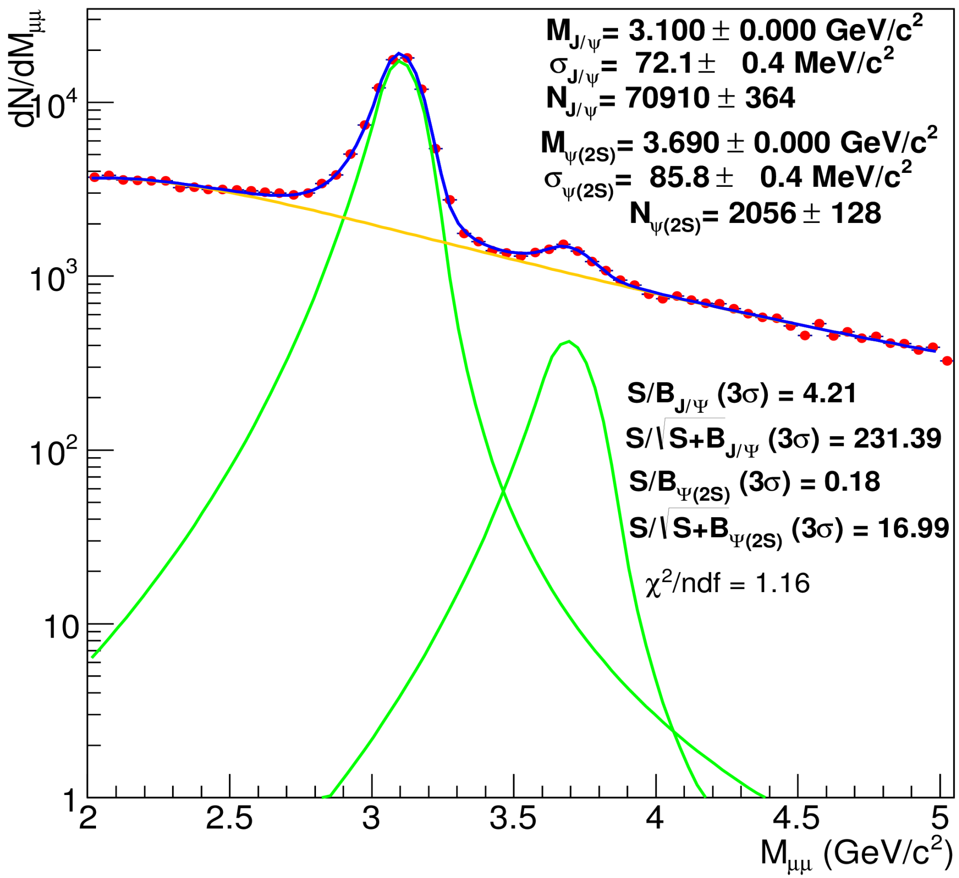
Data set :

- Very recent AOD set (AOD118) based on pass2 reconstruction (with an update alignment) + refit (improves tracking resolution) have been used.
- All runs are QA checked.

Analysis cuts :

1. Only opposite sign dimuon triggers (CMUU7-B-NOPF-ALLNOTRD and CMUU7-B-NOPF-MUON) have been selected.
2. Both muons Match Lpt Trigger.
3. $-4 \leq \eta_{\mu} \leq -2.5$.
4. $-4 \leq y_{\mu\mu} \leq -2.5$.
5. 17.6 cm < R_{abs} < 89.5 cm.

- We have a large statistics: ~71000 J/ψ and ~2100 ψ(2S). Previously published results in arXiv:1105.0380 was based on ~2000 J/ψ.
- Due to large statistics, differential cross section studies in high p_T is possible.



Fitting functions: CB2+VWG(Variable Width Gaussian function)

Signal extraction

- Fitting functions :
  - CB2+VWG
  - CB2+Pol4 X Exp
  - NA60+VWG
  - NA60+POL4 X Exp

- For each test, two fitting ranges are chosen (2-5 and 2.2-4.5).
  The default bin size is 50 MeV.

- The position of ψ(2S) is fixed to the J/ψ one $m_{\psi(2S)} = m_{J/\psi} + \left(m_{J/\psi}^{PDG} - m_{\psi(2S)}^{PDG}\right)$

- The width of ψ(2S) is fixed to the J/ψ one in two ways (number of test double)

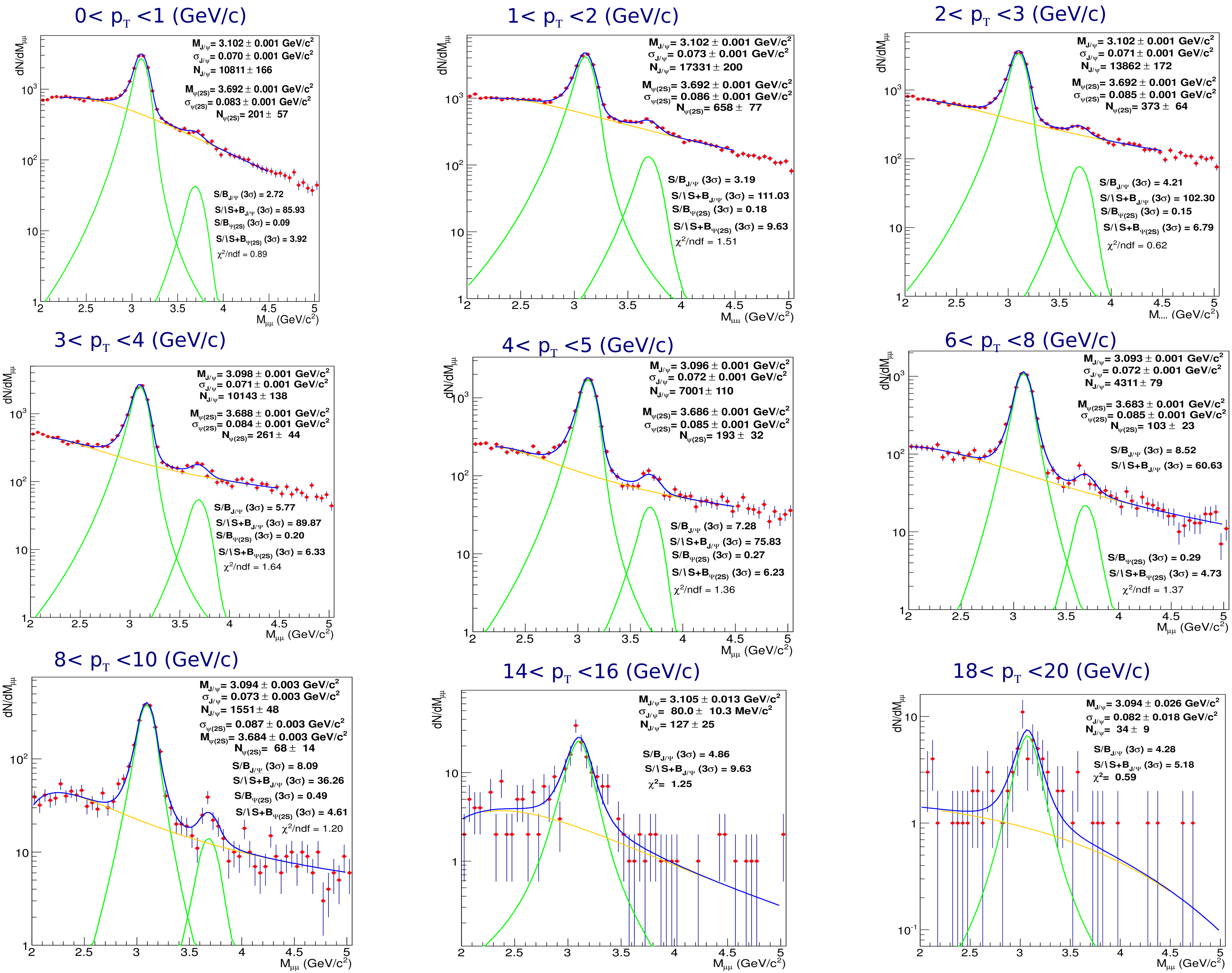
$$\sigma_{\Psi(2S)} = \sigma_{J/\Psi} . \frac{m_{\psi(2S)}}{m_{J/\psi}}$$

$$\sigma_{\Psi(2S)} = \sigma_{J/\Psi} . \frac{\sigma_{\Psi(2S)}^{MC}}{\sigma_{J/\Psi}^{MC}}$$

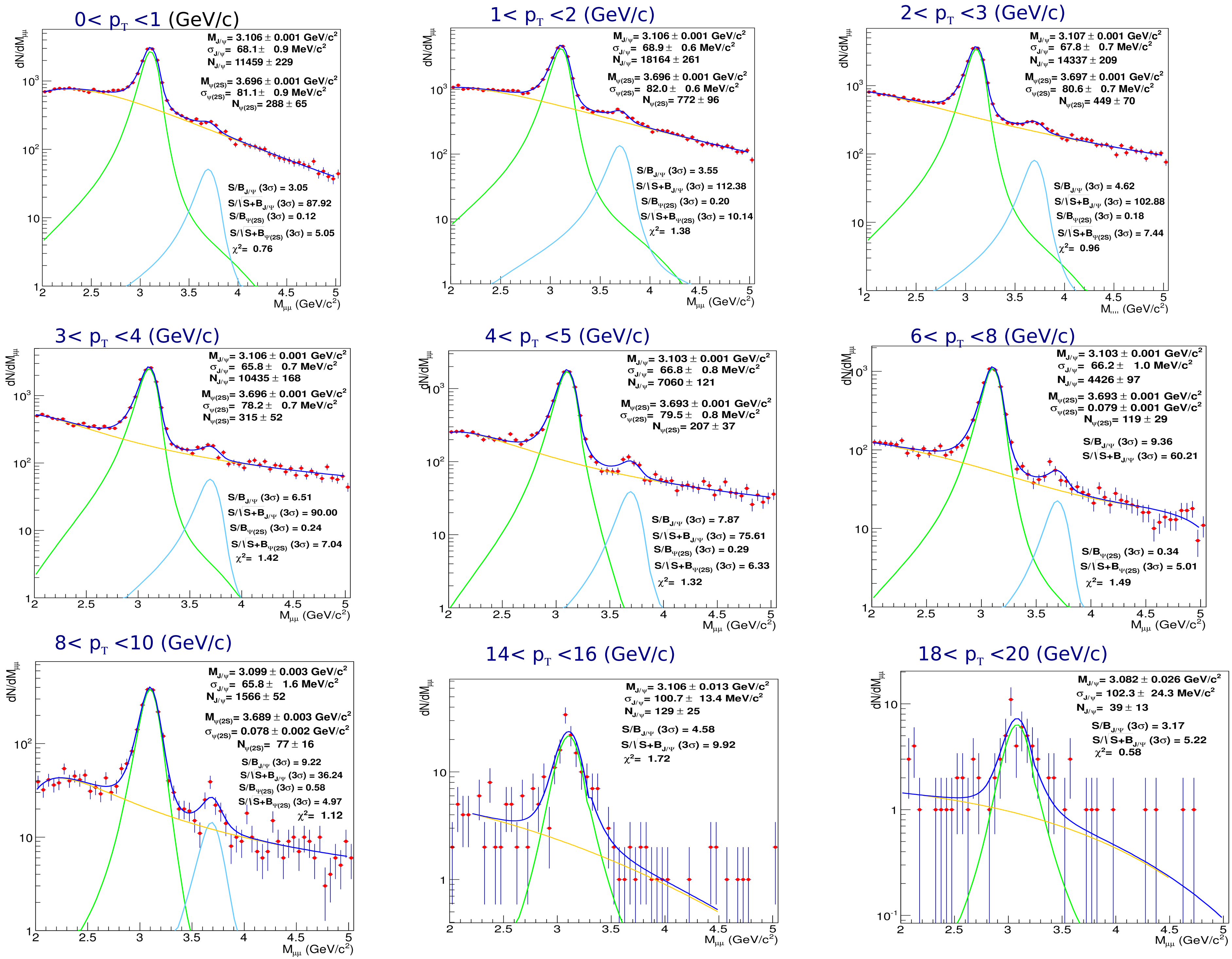
- Two different tail parameters have been used for each test: (number of test double)
  - Tails obtained by fitting pt and y integrated spectrum from MC.
  - Tails of the bin under consideration obtained by fitting the invariant mass from MC of that bin.

- The weighted average of results from these fitting approaches gives the yield of J/ψ and ψ(2S) .
- Systematic uncertainty on the signal extraction is given by the RMS of the distributions.

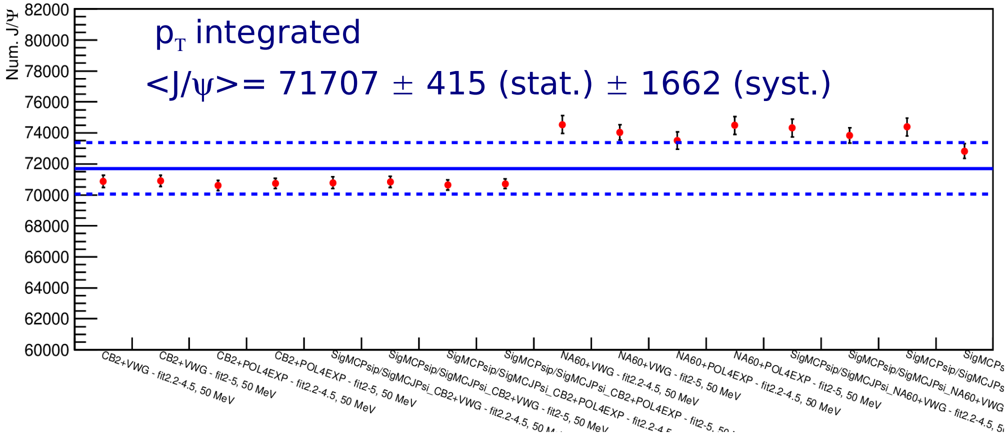
$N_{\psi(2S)}$ and $N_{J/\psi}$ in different p_T(dimuon) bins (CB2)

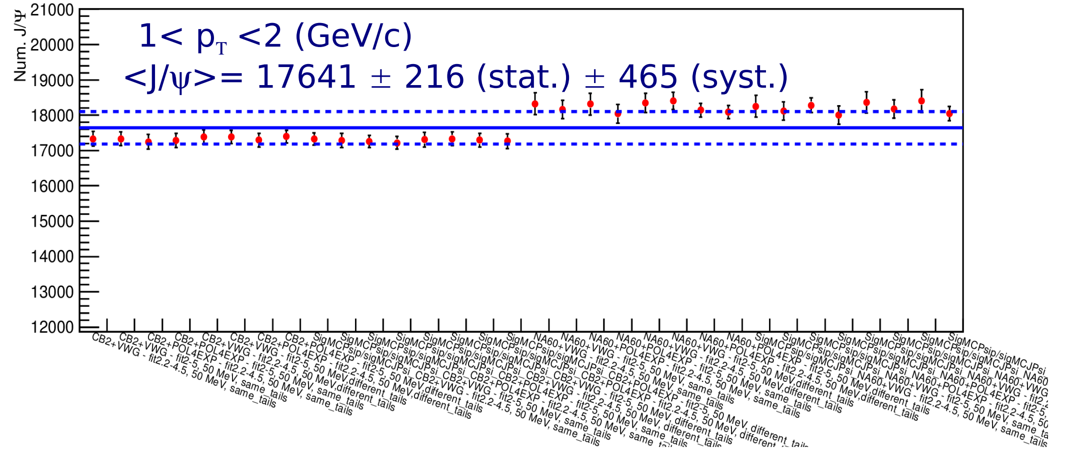


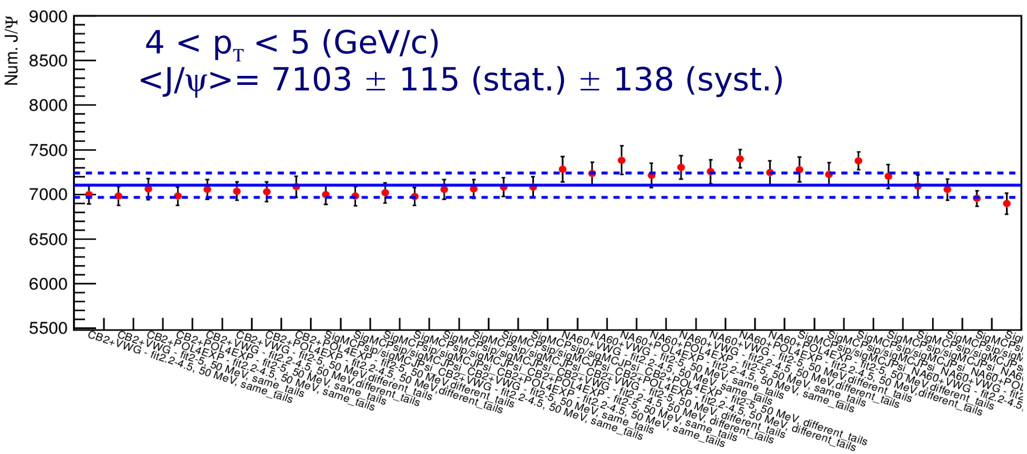
$N_{\psi(2S)}$ and $N_{J/\psi}$ in different p_T(dimuon) bins (NA60)

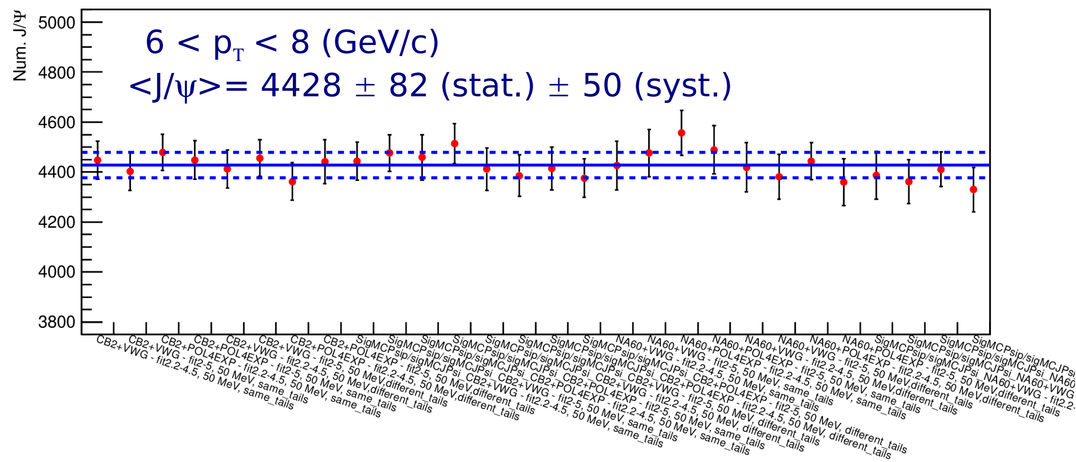


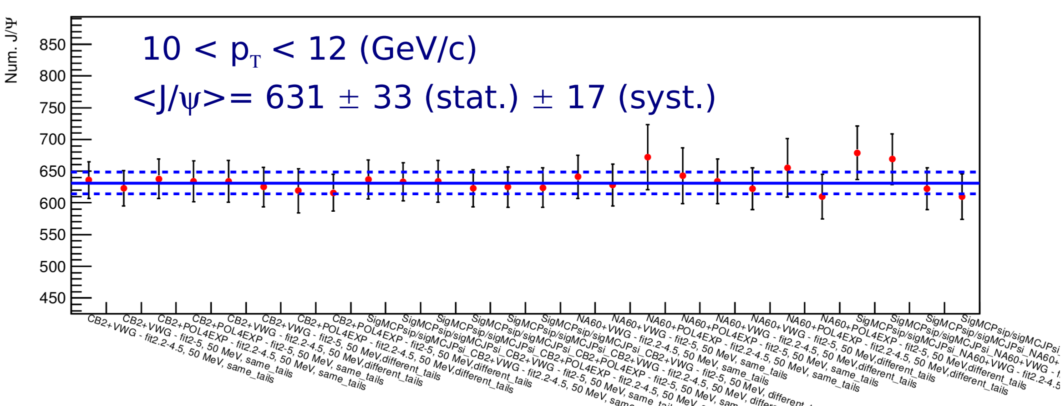
Signal extraction (J/ψ)

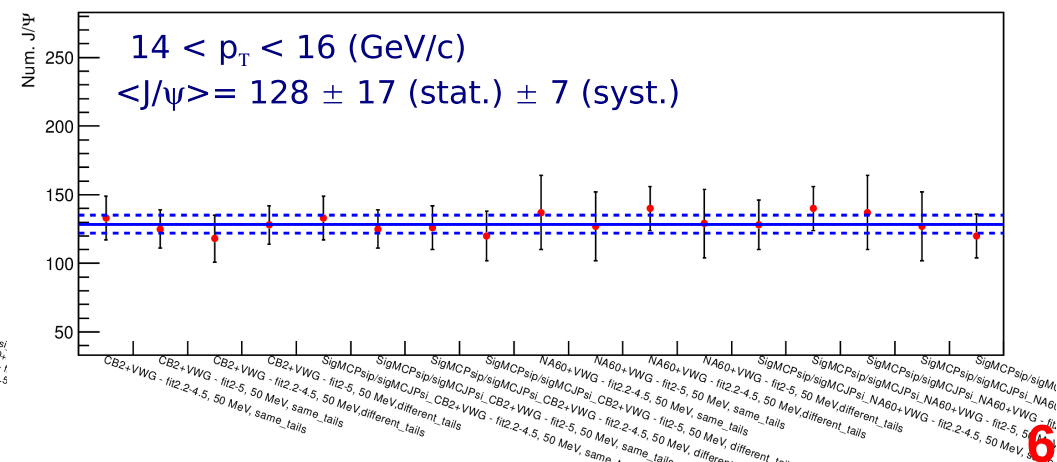




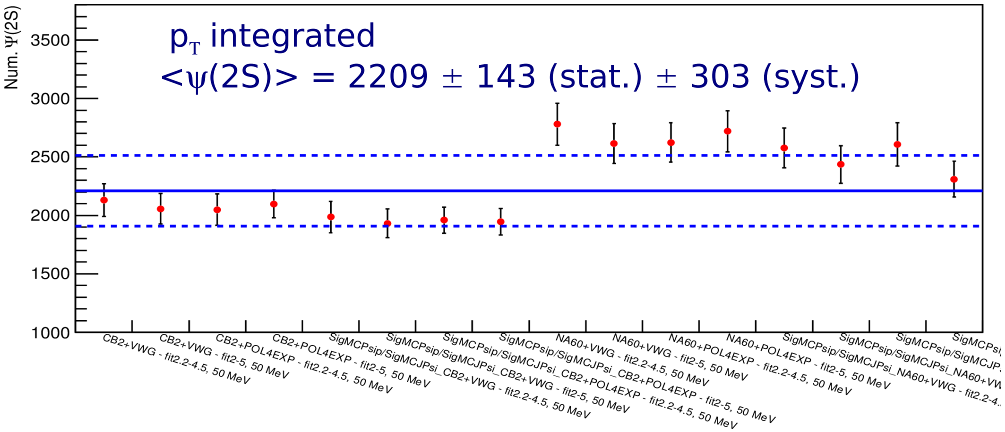


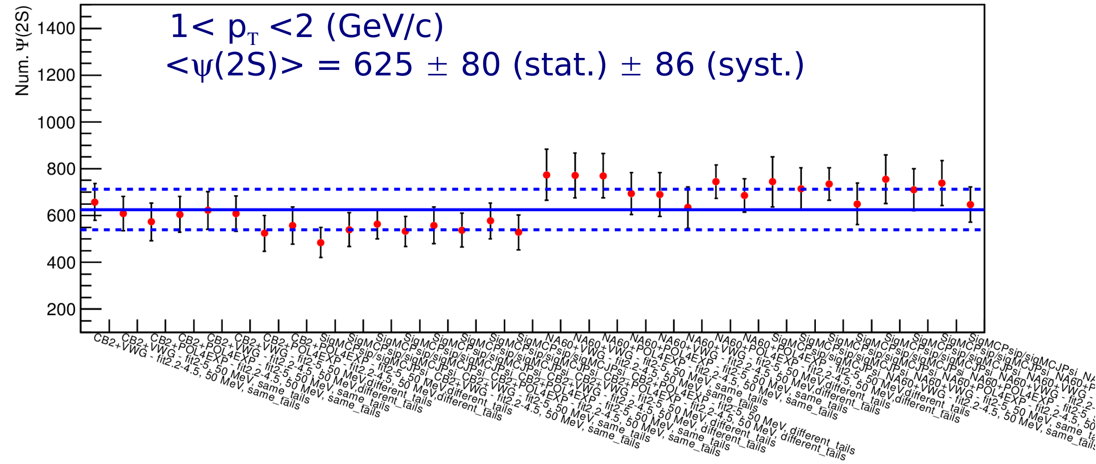


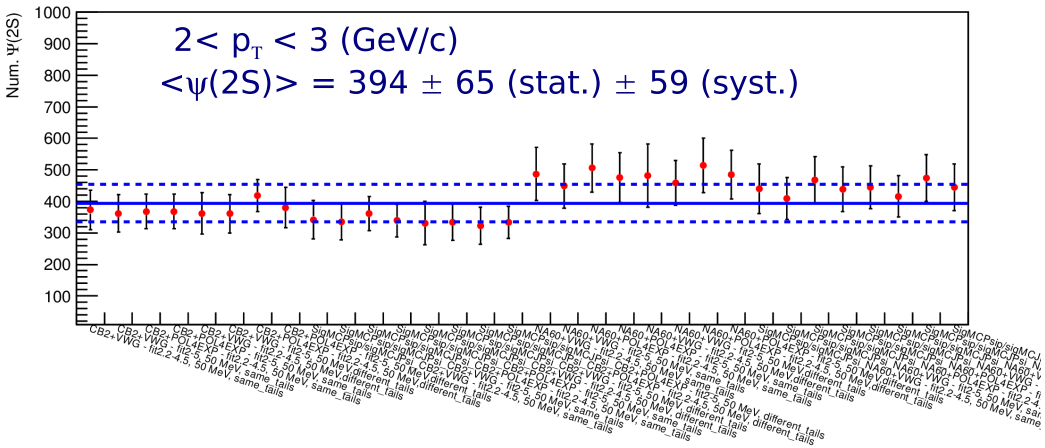


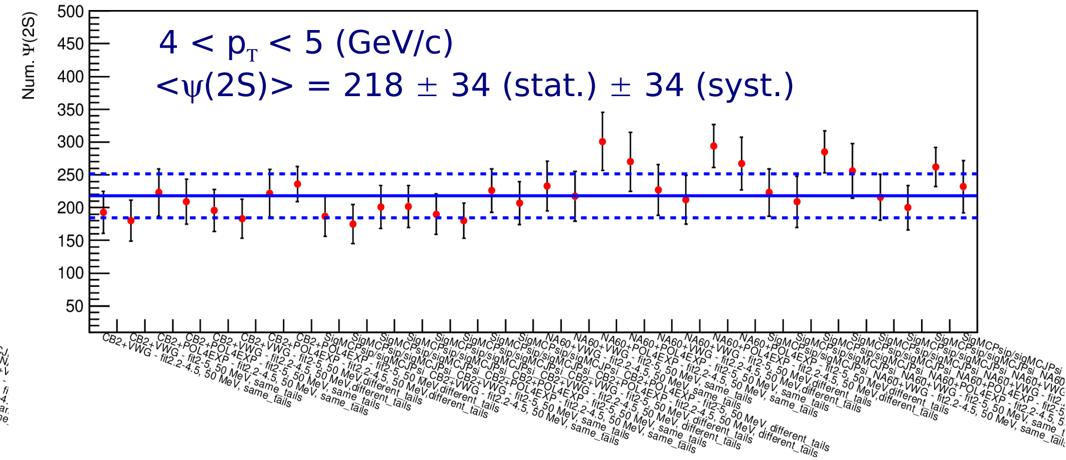


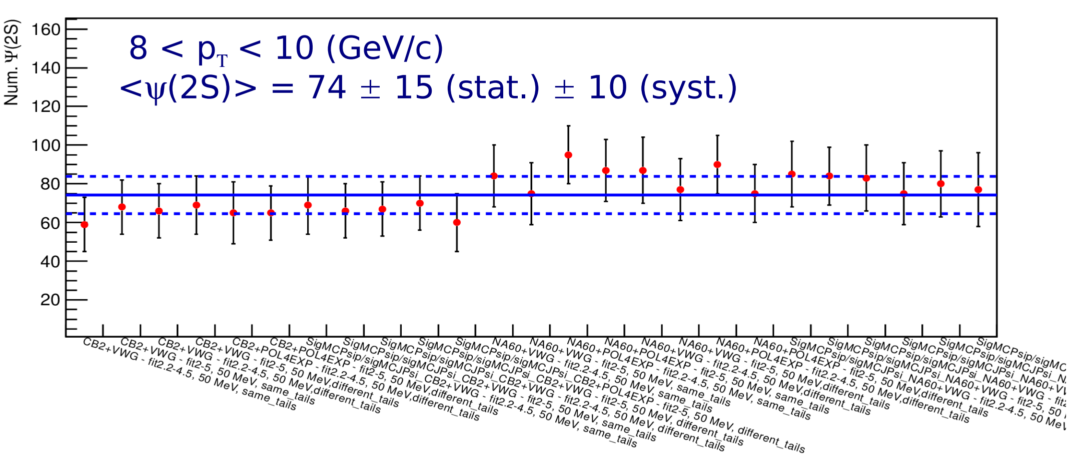
Signal extraction (ψ(2S))

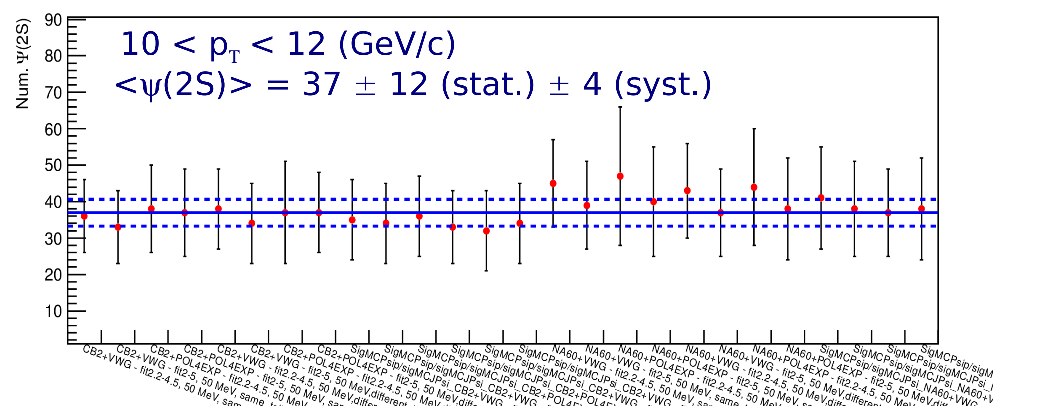












Acceptance X Efficiency calculation from MC Simulation

- AliGenParam generator: AliGenMUONlib::kJpsi for J/ψ.
- J/ψ are generated in the rapidity range $-4.5 \leq y \leq -2.0$.
- J/ψ are forced to decay in dimuons.
- 2011 raw OCDB.
- Run by run realistic simulation.
- Number of simulated events proportional to the number of unlike sign dimuon trigger (CMUU).

Analysis cuts:

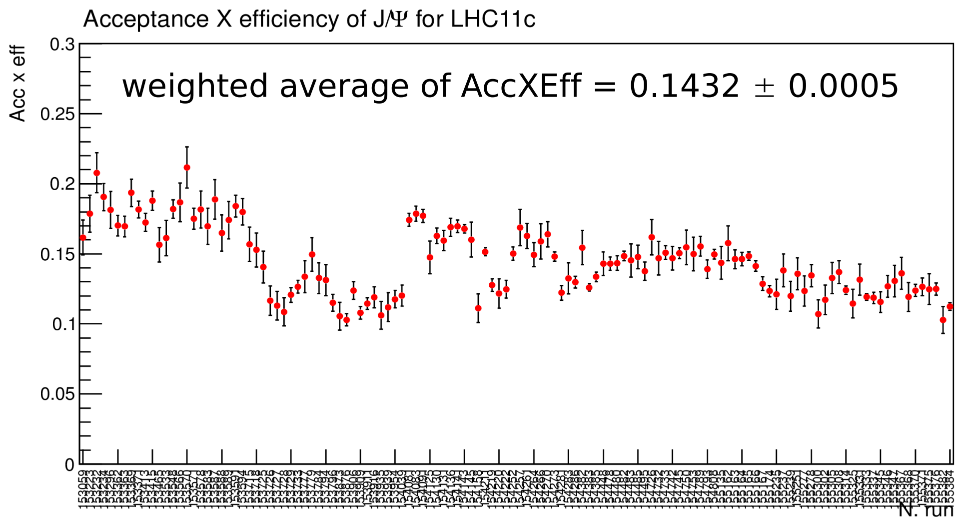
- Both muons Match Lpt Trigger.
- $-4 \leq \eta_{\mu} \leq -2.5$.
- $-4 \leq y_{\mu\mu} \leq -2.5$.
- 17.6 cm $< R_{abs} <$ 89.5 cm.

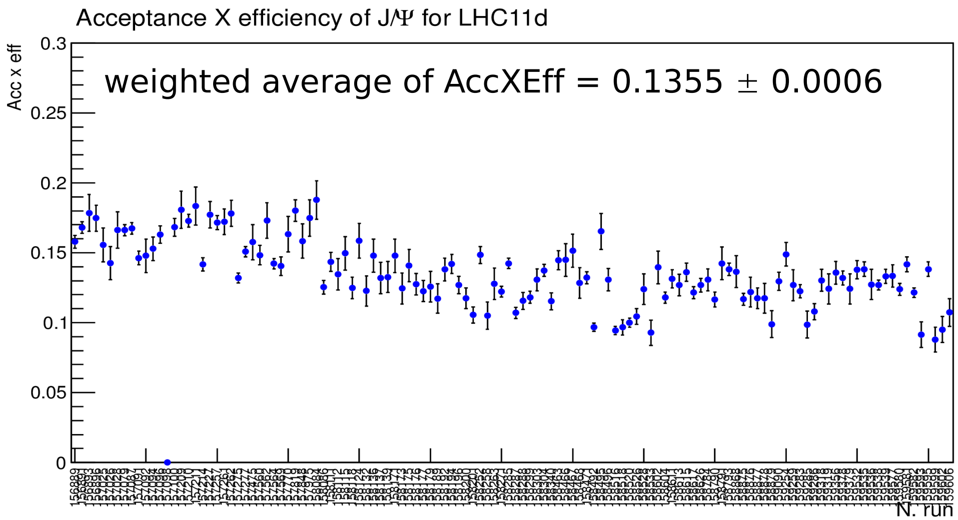
- Acc X Eff:

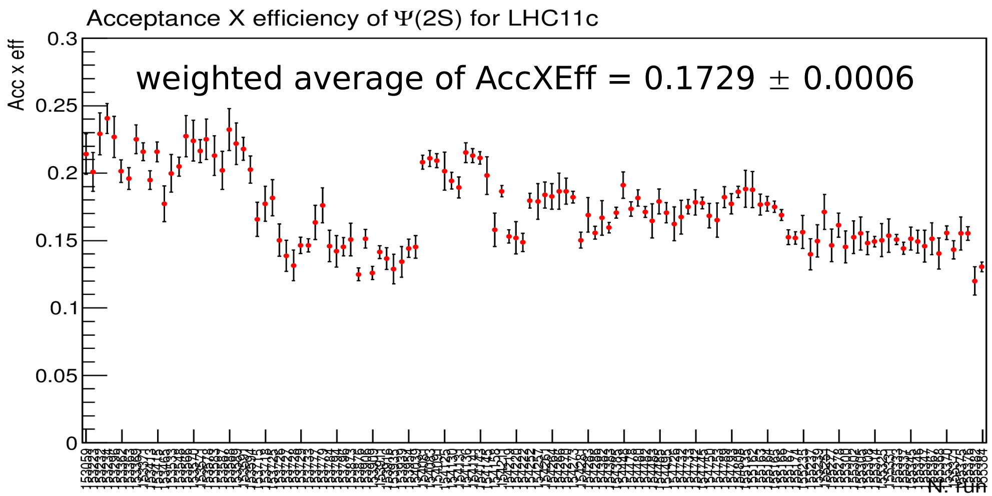
$$\frac{N^{rec}_{J/\Psi}(analysis\ cuts)}{N^{sim}_{J/\Psi}(-4 \leq y \leq -2.5)}$$

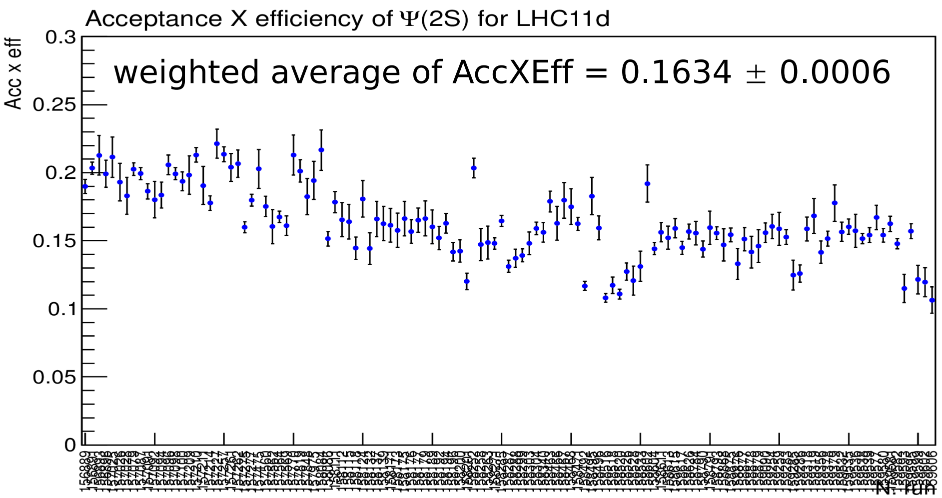
- Same frame work has been used for ψ(2S).
  Only difference is the generator, for ψ(2S) it is AliGenMUONlib::kPsiP

Run per run Acceptance X Efficiency of J/ψ and ψ(2S)



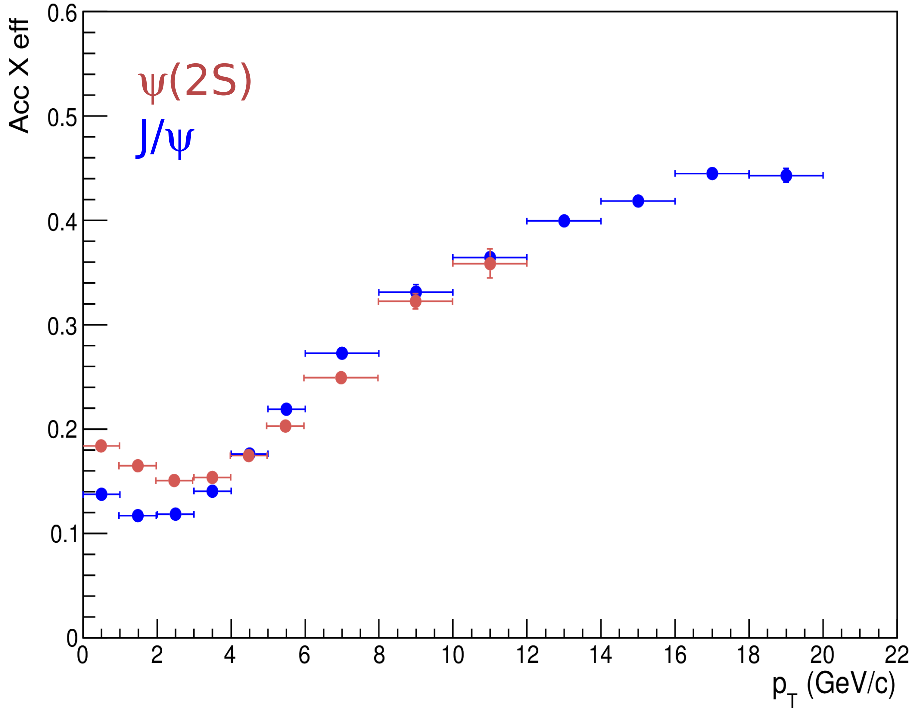


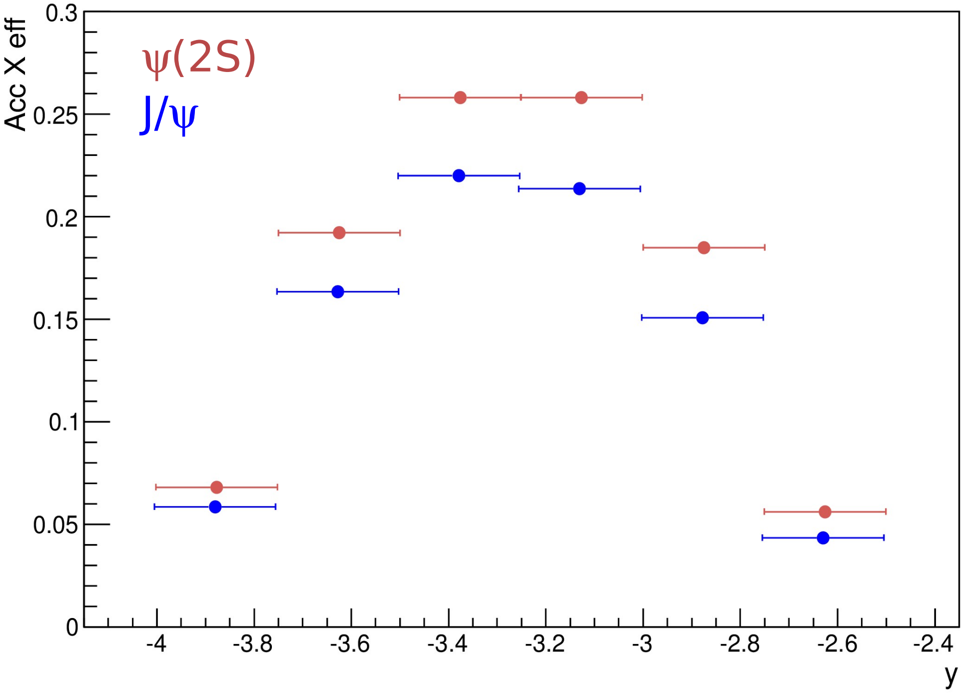




- Weighted average of AccXEff of J/ψ (LHC11c+LHC11d) = 0.1400 ± 0.0004
- Weighted average of AccXEff of ψ(2S)(LHC11c+LHC11d) = 0.1700 ± 0.0004
- Not just the average of LHC11c and LHC11d.

Acceptance X Efficiency of J/ψ and ψ(2S) in p_T(dimuon) bins and y(dimuon) bins for LHC11c+LHC11d





Simulated J/ψ signal

- CB2 function or Extended Crystal Ball function : A Gaussian core convoluted with two power-law tails.

$$f(x;\bar{x},\sigma,\alpha,n,\alpha',n') = N\cdot\begin{cases}\exp(-\frac{(x-\bar{x})^2}{2\sigma^2}), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha\\ A\cdot(B-\frac{x-\bar{x}}{\sigma})^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leqslant -\alpha\\ C\cdot(D+\frac{x-\bar{x}}{\sigma})^{-n'}, & \text{for } \frac{x-\bar{x}}{\sigma} \geqslant \alpha'\end{cases}$$

$$A = \left(\frac{n}{|\alpha|}\right)^{n}\cdot\exp\left(-\frac{|\alpha|^2}{2}\right)$$

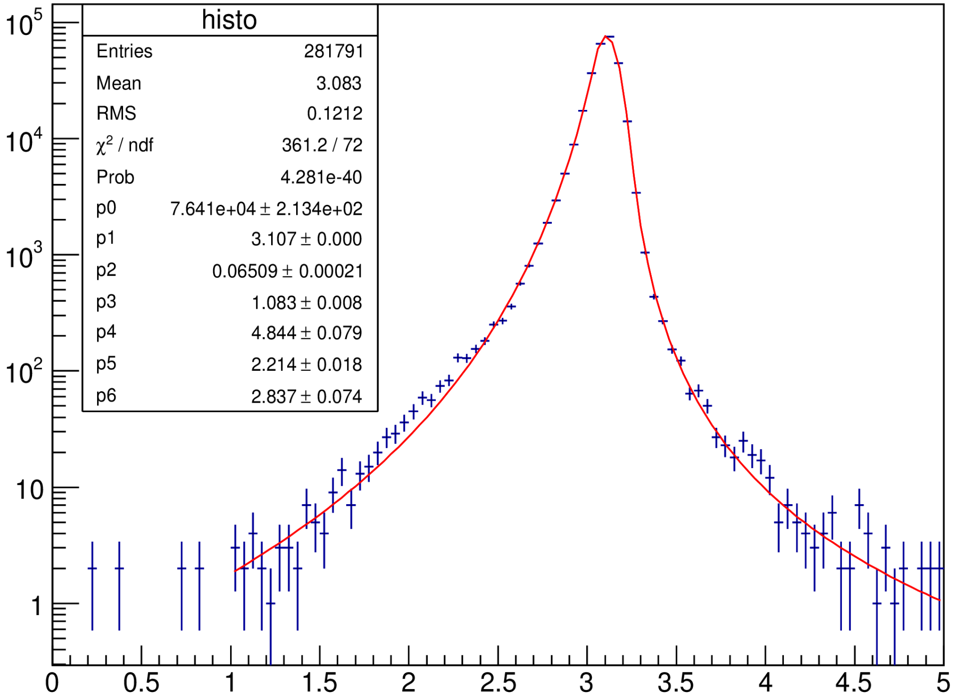
$$B = \frac{n}{|\alpha|} - |\alpha|$$

$$C = \left(\frac{n'}{|\alpha'|}\right)^{n'}\cdot\exp\left(-\frac{|\alpha'|^2}{2}\right)$$

$$D = \frac{n'}{|\alpha'|} - |\alpha'|$$

- The function has 7 parameters.

- CB2 function fits the invariant mass from MC simulation very well.



Simulated J/ψ signal (2)

- "NA60" function: This is a function adopted for charmonia in NA50 and NA60 experiments.

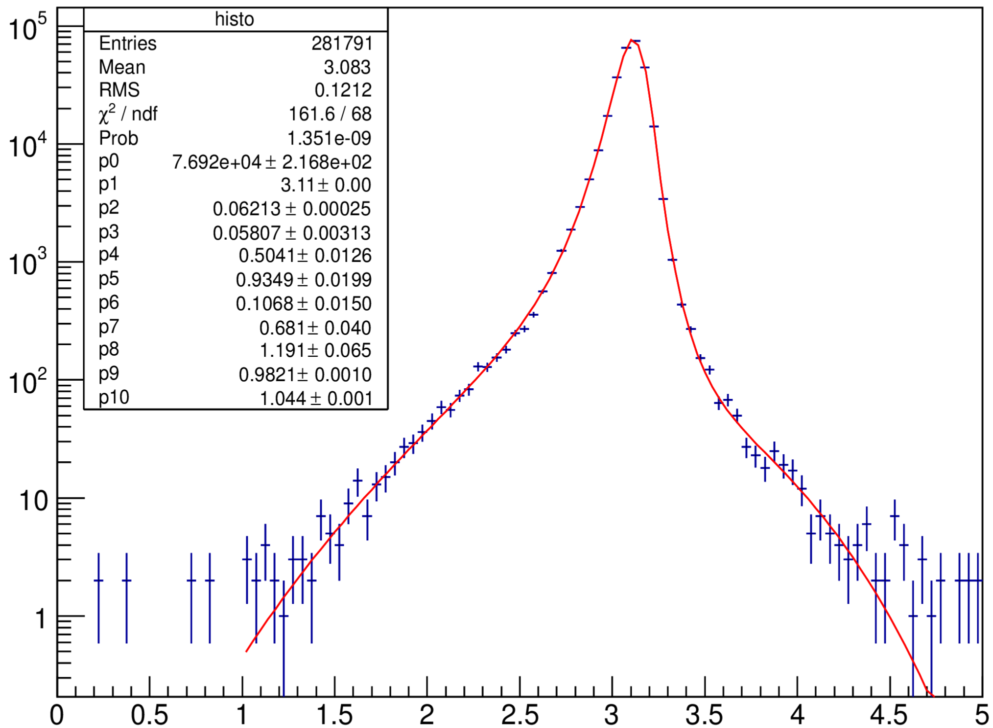
- Gaussian shape with variable sigma:

$$\sigma = \begin{cases} p_3 & M_1 < M < M_2 \\ p_3 \times \left\{ 1 + \left[p_4 \times (M_1 - M) \right]^{\left[p_5 - p_6 \times (M_1 - M) \right]} \right\} & M < M_1 \\ p_3 \times \left\{ 1 + \left[p_7 \times (M - M_2) \right]^{\left[p_8 - p_9 \times (M - M_2) \right]} \right\} & M > M_2 \end{cases}$$

- Right and left asymmetric tails are allowed.

- The function has many parameters (11).

- "NA60" function seems to better describe both right and left sides of the spectrum.



Cross section of J/ψ

The inclusive J/ψ production cross section for LHC11c+LHC11d period:

$$\sigma_{J/\Psi} = \frac{N_{J/\Psi}}{AX\varepsilon} \cdot \frac{1}{BR(J/\Psi \rightarrow l^+l^-)} \cdot \frac{1}{L_{int}}$$

$\sigma_{J/\Psi}$ = 6.41 ± 0.04 (stat.) ± 0.35 (syst.) μb

Using, $N_{J/\Psi}$ = 71707 ± 415 (stat.) ± 1662 (syst.)

$AX\varepsilon$ = 0.1400 ± 0.0004

$BR(J/\Psi \rightarrow l^+l^-)$ = (5.94 ± 0.06)%

$L_{int} = \sum_{run} N^{CMUU}_{Trigger,run} / (\sigma_{MB} * R_{run})$ = Integrated luminosity =1346 nb-1 ± 5%

Martino Gagliardi (Torino)

- Good agreement with the published ALICE result (arXiv:1105.0380): Sigma_J/ψ (2.5 < y < 4) = 6.31 ± 0.25 (stat.) ± 0.76 (syst.) μb.

$d\sigma_{J/\Psi}/dy$ for LHCb = 11.66 ± 0.04 ± 1.40 μb/2.5 = 4.66 ± 0.016 ± 0.56 μb

$d\sigma_{J/\Psi}/dy$ for ALICE =6.41 ± 0.04 ± 0.35 μb/1.5 = 4.30 ± 0.027 ± 0.23 μb

- In good agreement with LHCb as well.
- Systematic uncertainty on the cross section is due to luminosity+uncertainty on signal extraction. Other systematic will be included.

Cross section of ψ(2S)

The integrated ψ(2S) production cross sections for LHC11c+LHC11d period:

$$\sigma_{\Psi(2S)} = \frac{N_{\Psi(2S)}}{AX\varepsilon} \cdot \frac{1}{BR(\Psi(2S) \to l^+l^-)} \cdot \frac{1}{L_{int}}$$

$\sigma_{\Psi(2S)}$ = 1.25 ± 0.08 (stat.) ± 0.18 (syst.) μb

Using, $N_{\Psi(2S)}$ = 2209 ± 143 (stat.) ± 303 (syst.)

$AX\varepsilon$ = 0.1700 ± 0.0004

$BR(\Psi(2S) \to l^+l^-)$ = 0.77%

$L_{int} = \sum_{run} N^{CMUU}_{Trigger,run} / (\sigma_{MB} * R_{run})$ = Integrated luminosity =1346 nb-1 ± 5%

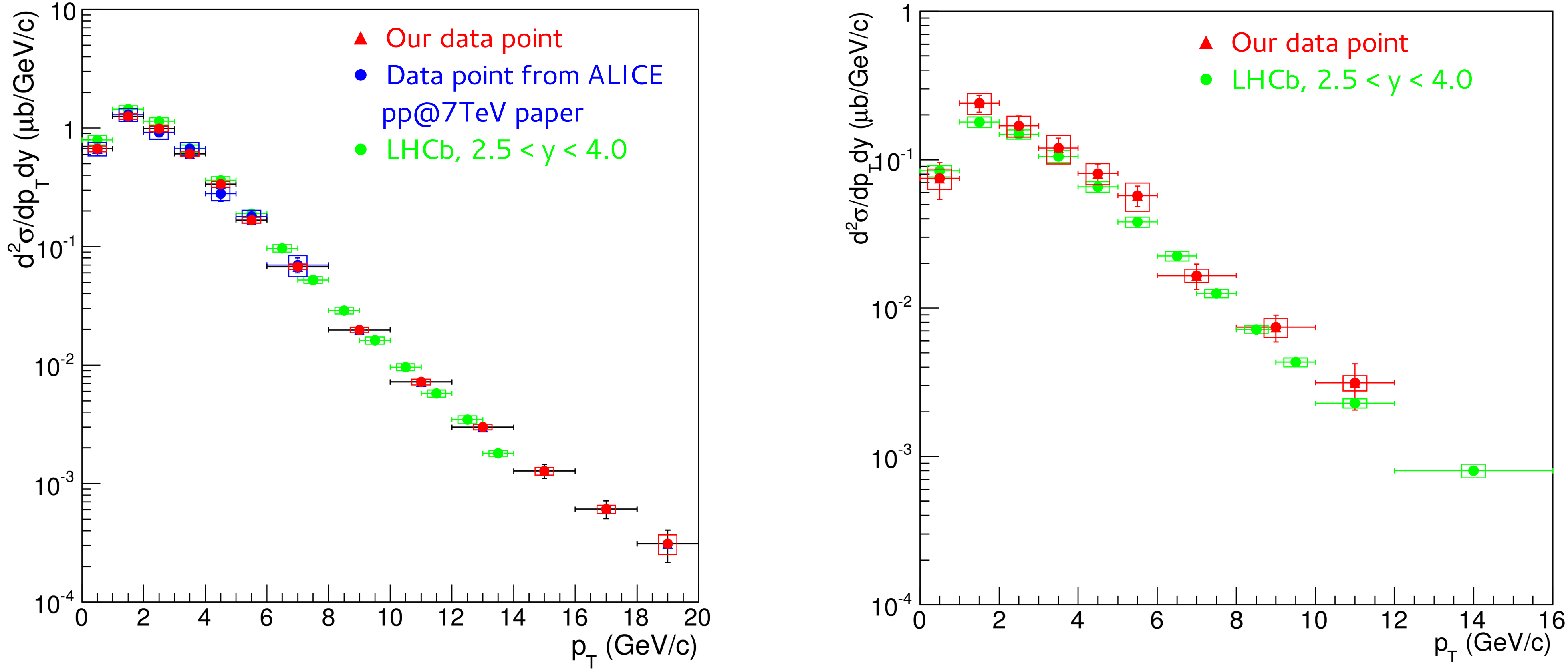
- Comparison with LHCb:

  $d\sigma_{\Psi(2S)}/dy$ for LHCb = 1.69 ± 0.01 ± 0.12 μb/2.5 = 0.68 ± 0.004 ± 0.048 μb

  $d\sigma_{\Psi(2S)}/dy$ for ALICE =1.25 ± 0.08 ± 0.18 μb/1.5 = 0.83 ± 0.05 ± 0.12 μb

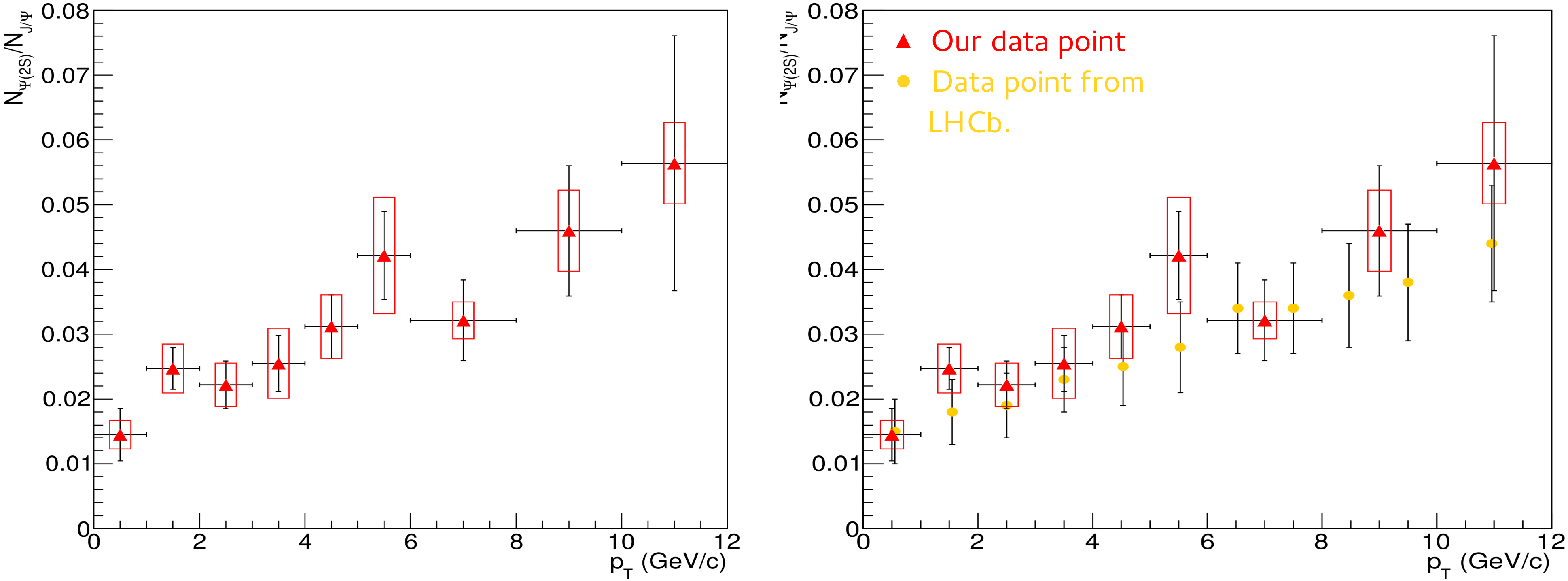
- $d\sigma_{\Psi(2S)}/dy$ of ALICE is slightly higher than LHCb one but it is within the error, (for the moment only luminosity and signal extraction uncertainties are included).

p_T differential cross section of J/ψ and ψ(2S)



- We have reached upto 20 GeV/c in p_T for J/ψ and upto 12 GeV/c in p_T for ψ(2S).
- Our result of p_T differential cross section is in good agreement with previous pp result @7TeV (arXiv:1105.0380) and also with LHCb.
- Systematic uncertainty on the differential cross section is due to luminosity + uncertainty on signal extraction. Other systematics will be included.

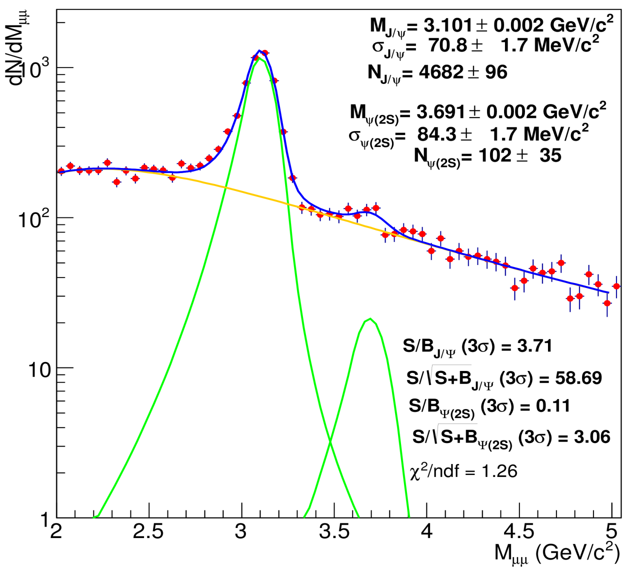
ψ(2S)/ψ ratio



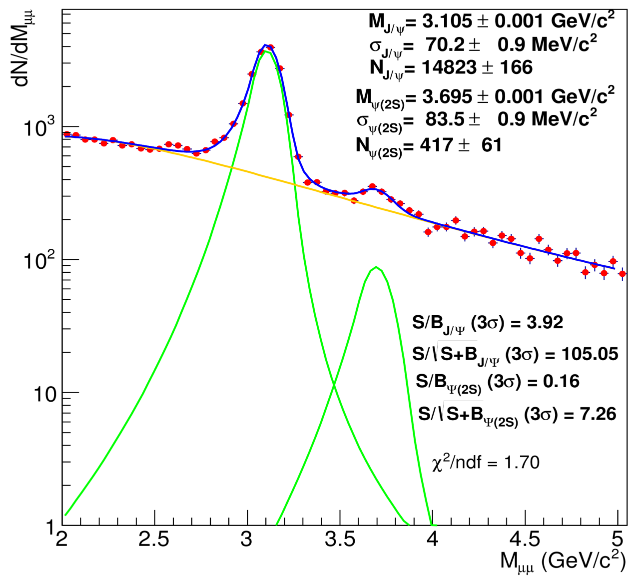
- ψ(2S)/ψ (Acc. Cor.) = 0.025 ± 0.002 ± 0.004
- The ratio is between inclusive ψ(2S) and J/ψ, while for LHCb, the ratio is between prompt ψ(2S) and J/ψ.
- No polarization uncertainty has been included (only uncertainty on signal extraction). In LHCb, polarization uncertainty of ψ(2S) and J/ψ is also included along with the systematic and statistical errors.

$N_{\psi(2S)}$ and $N_{J/\psi}$ in different y (dimuon) bins (CB2)

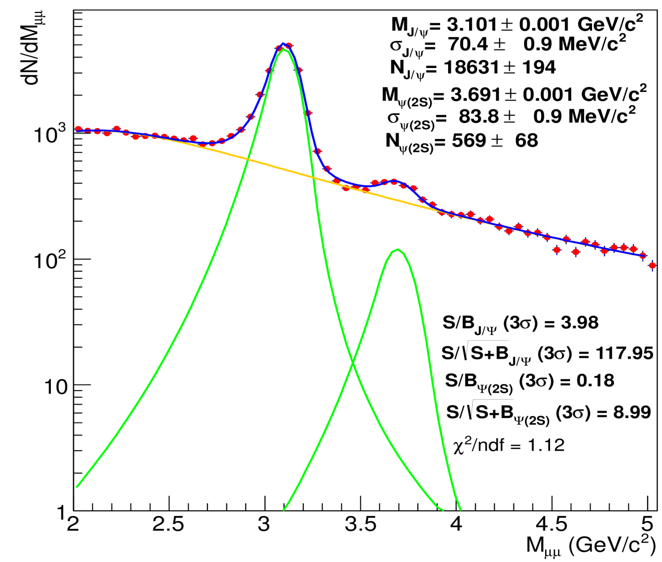
2.5 < y < 2.75



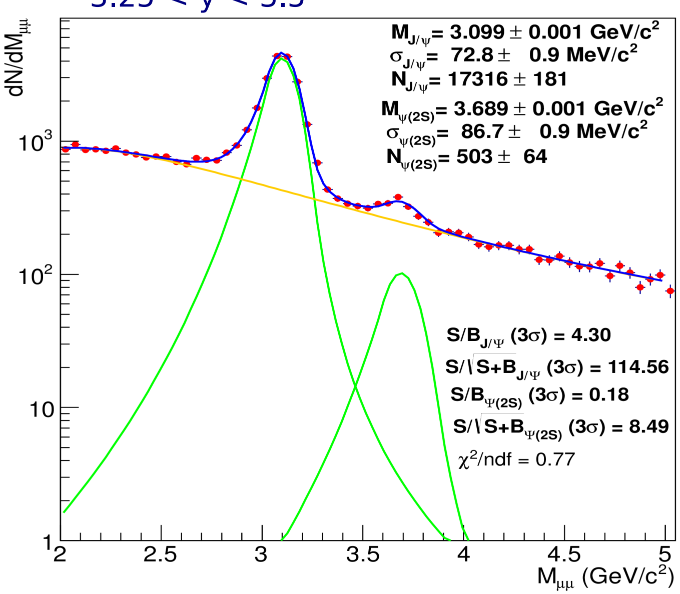
2.75 < y < 3.0



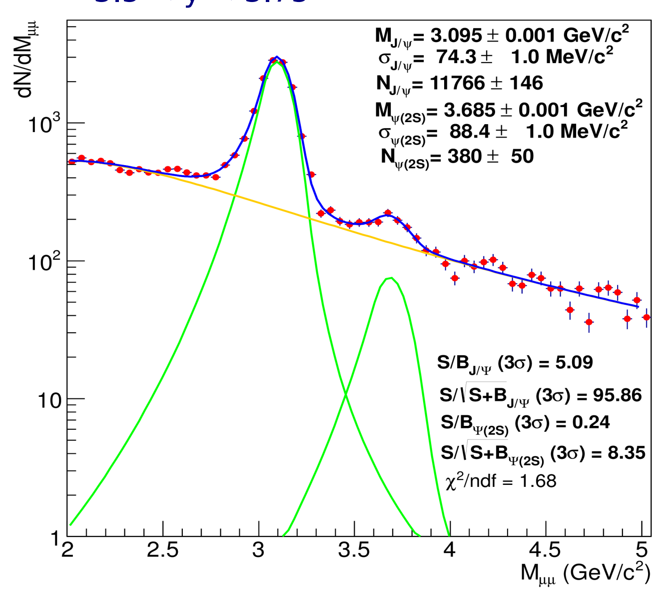
3.0 < y < 3.25



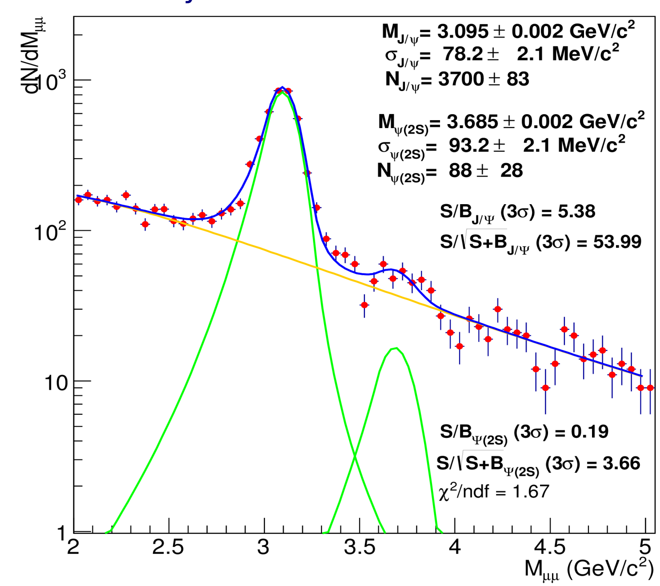
3.25 < y < 3.5



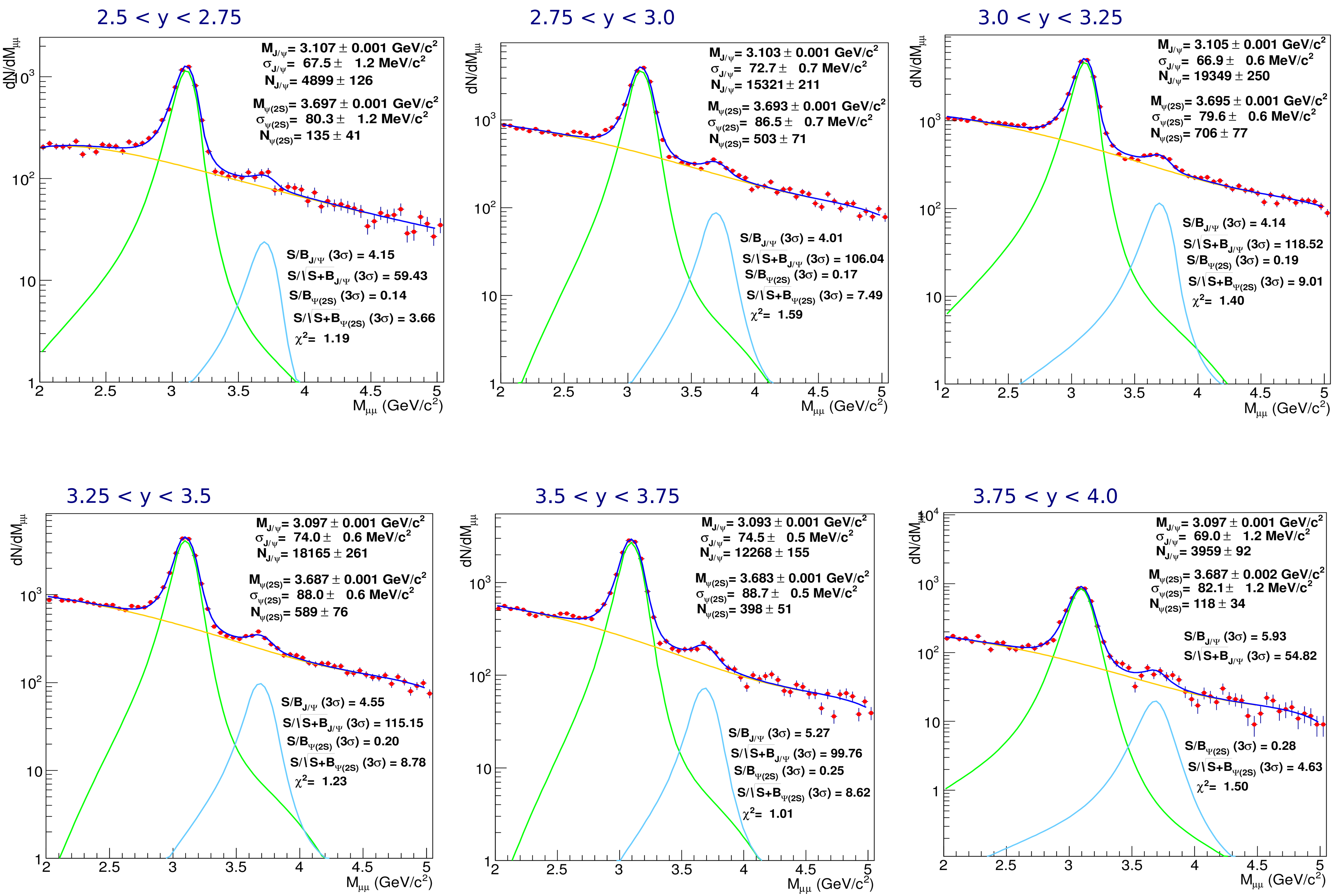
3.5 < y < 3.75



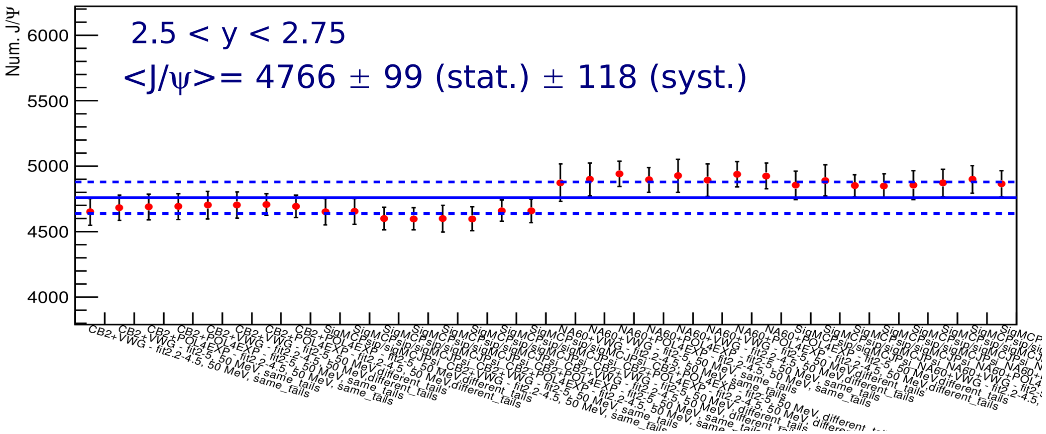
3.75 < y < 4.0

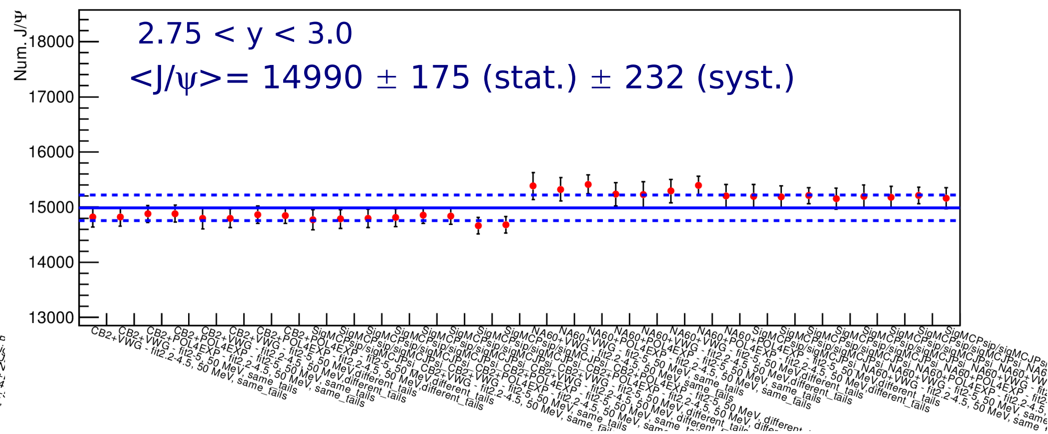


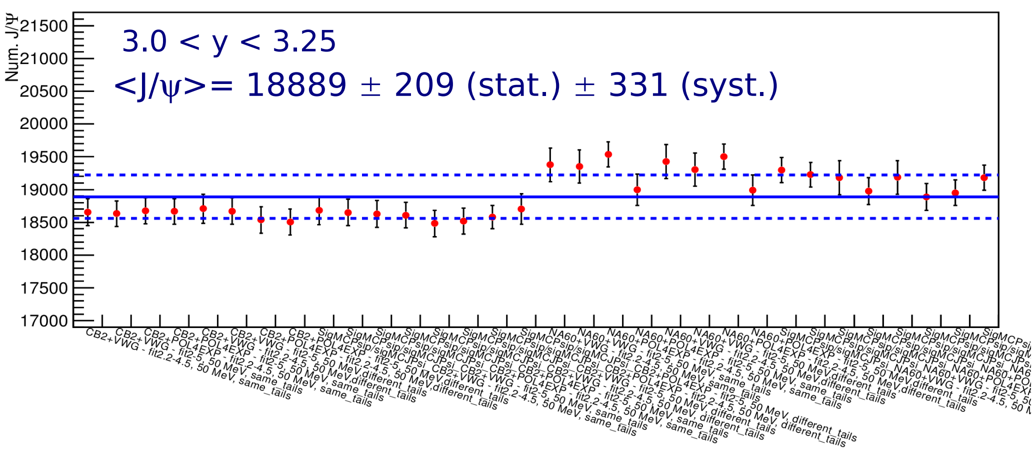
$N_{\psi(2S)}$ and $N_{J/\psi}$ in different y (dimuon) bins (NA60)

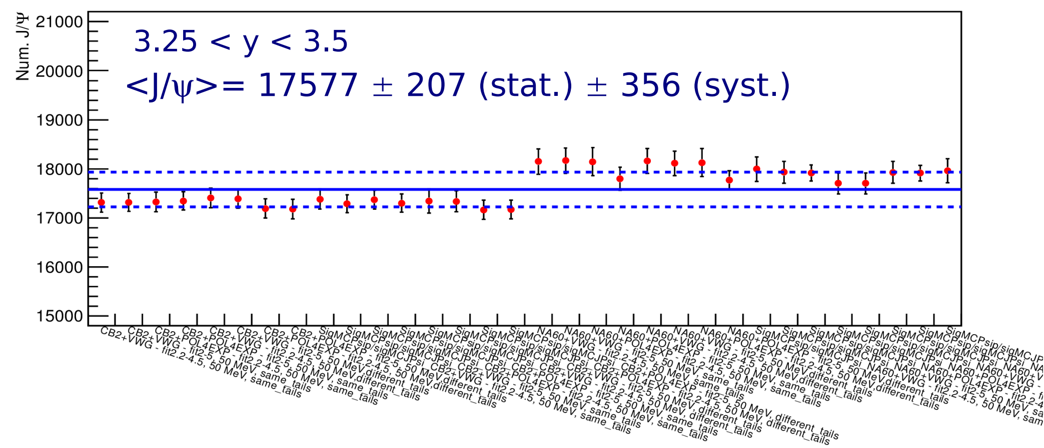


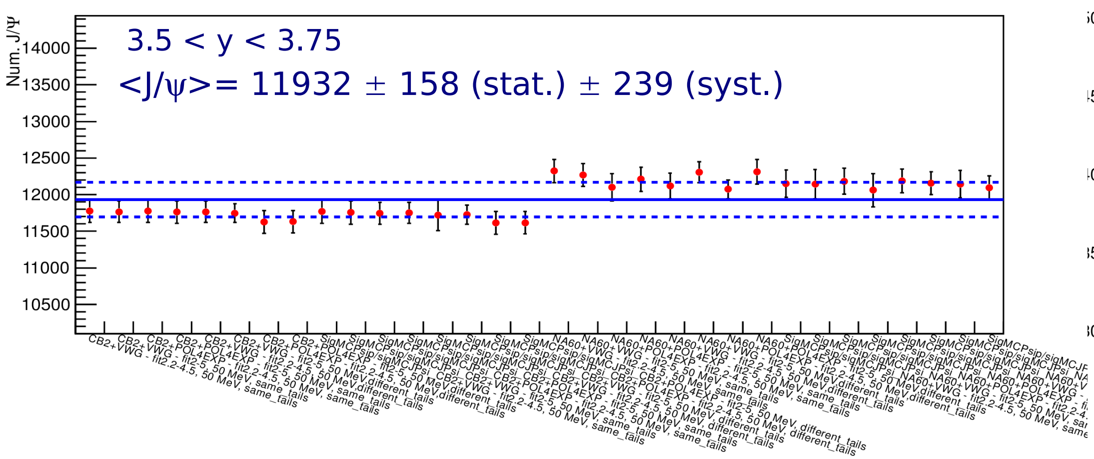
Signal extraction (J/ψ)

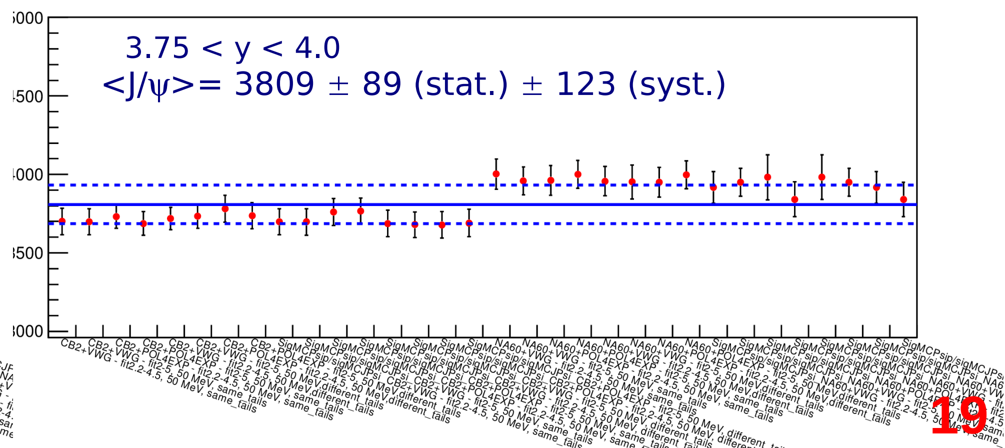




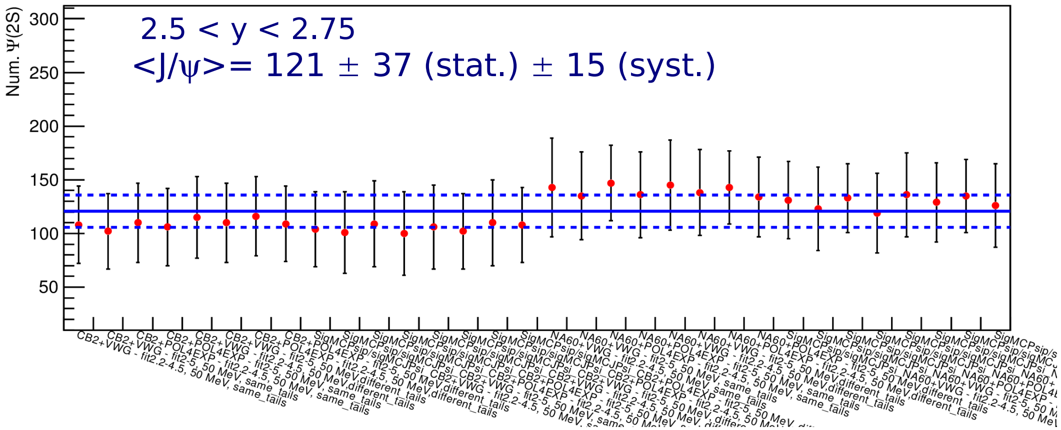


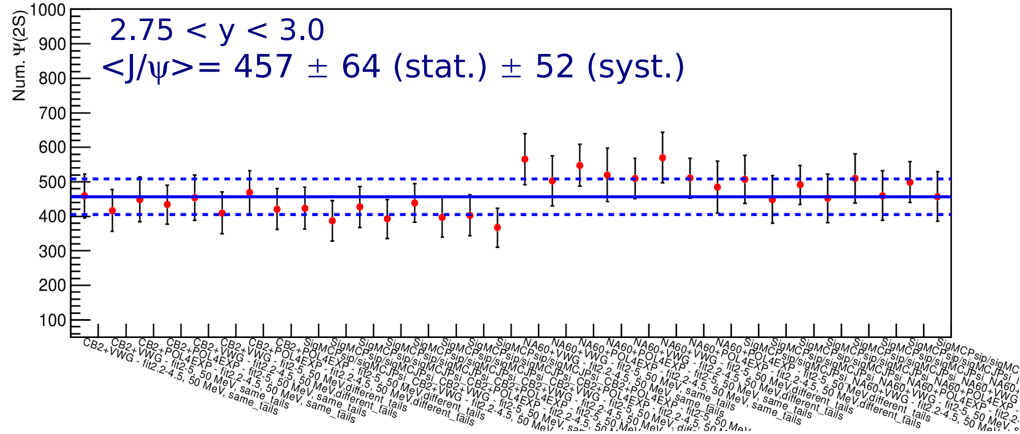


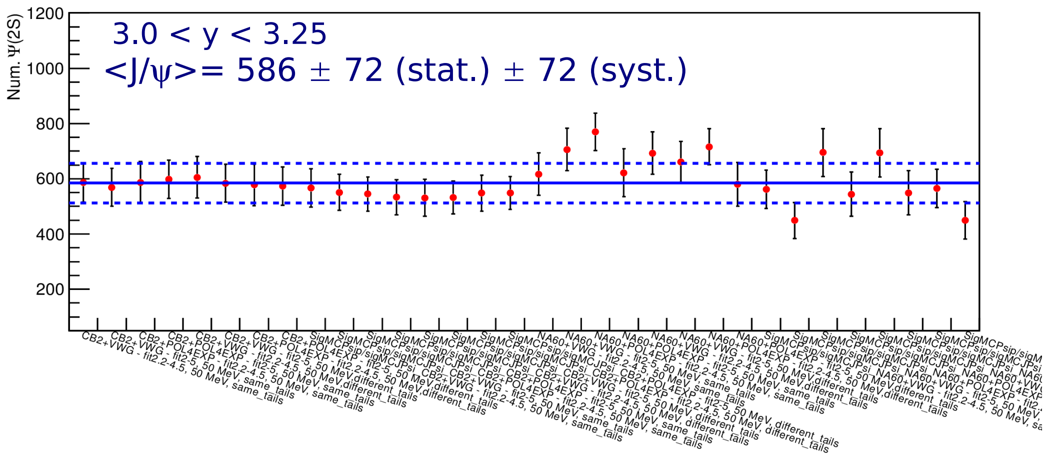


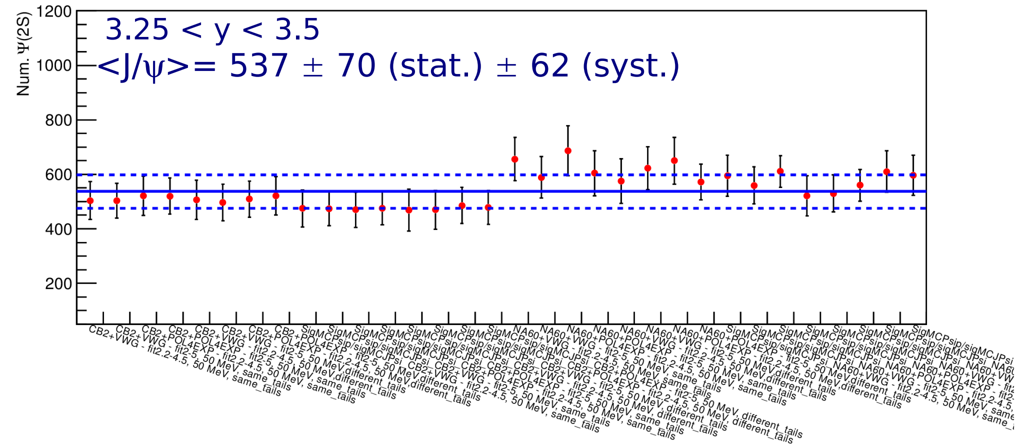


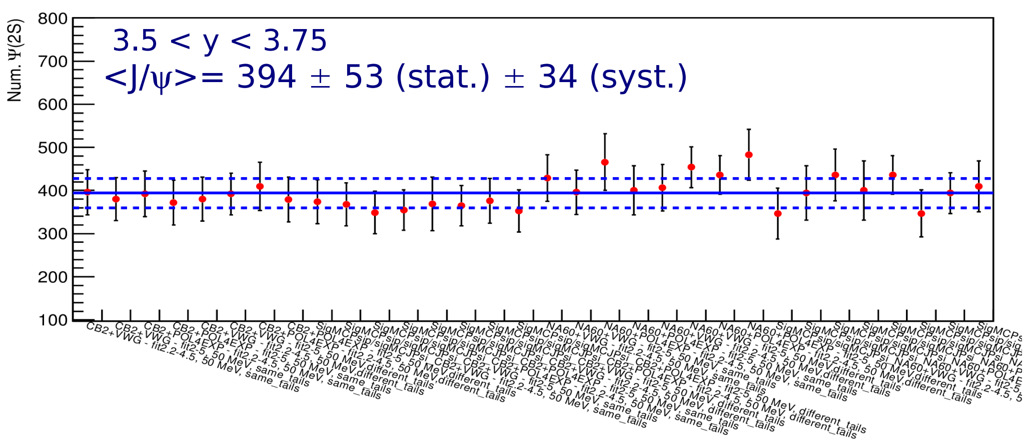
Signal extraction (ψ(2S))

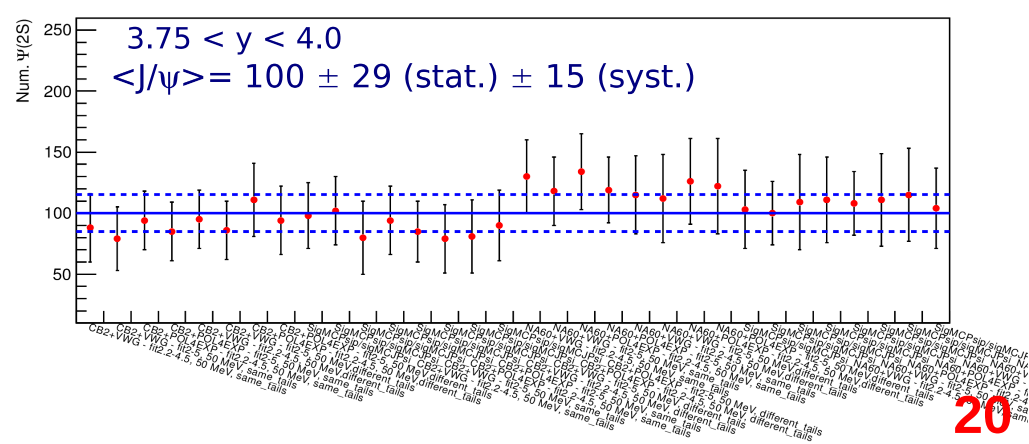




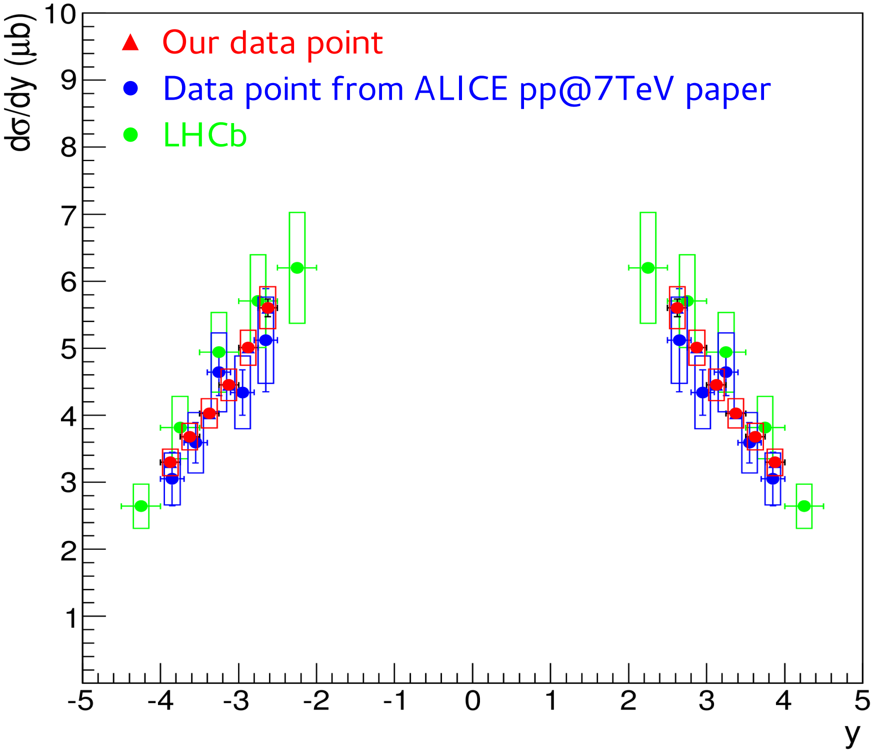


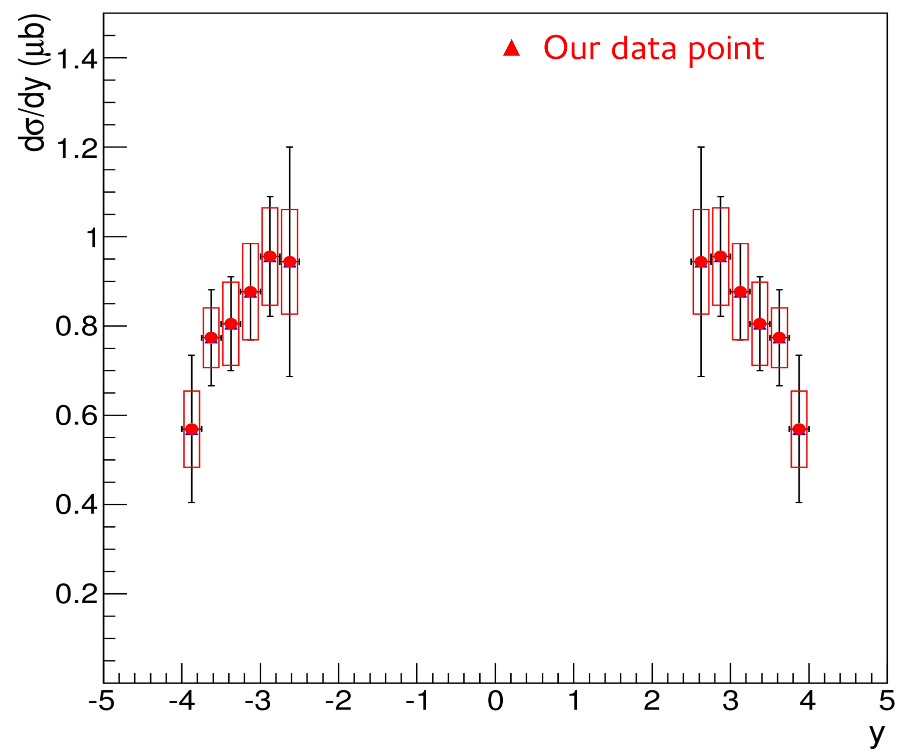






y differential cross section of J/ψ and ψ(2S)





- We have 6 bins in rapidity both for J/ψ and ψ(2S).
- Our result of y differential cross section is in good agreement with previous pp result @7TeV (arXiv:1105.0380) and also with LHCb.
- LHCb did not measure the y differential cross section of ψ(2S).
- Systematic uncertainty on the differential cross section is due to luminosity + uncertainty on signal extraction.

Outlook

1) Analysis of the AOD118 (LHC11c+d):

- Integrated and differential cross section of J/ψ production are in very good agreement with the ALICE published one.
- Much higher p_T values have been reached with respect to first publication: differential cross section now computed up to 20 GeV/c.
- y differential cross section of J/ψ has been evaluated.
- Integrated and p_T and y differential cross section of ψ(2S) production have been evaluated. p_T differential cross section has been computed up to 12 GeV/c.
- Ratio of ψ(2S) and J/ψ have an increasing trend with the increase of p_T .

2) Next steps:

- Work in progress to calculate the systematic uncertainties on tracking and trigger efficiencies.
- Analysis note will be completed soon.
- A paper named "Quarkonia production in p-p collisions at $\sqrt{s}$ = 7 TeV" will be published.

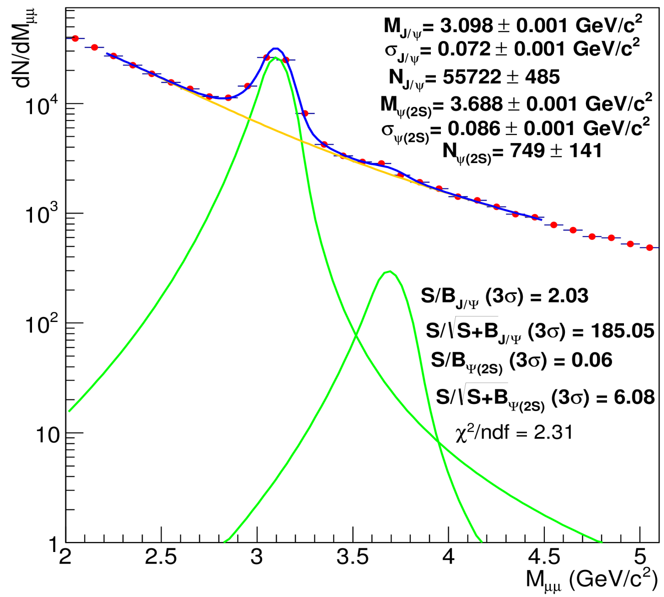
p-Pb and Pb-p analysis

Signal extraction and ψ(2S)/ψ in Pb-p (LHC13f)

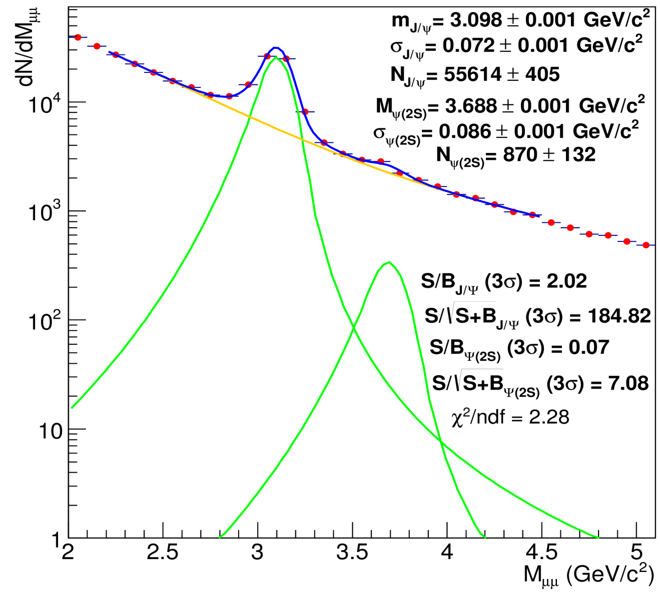
muon_pass1,
AliAOD.Muons.root

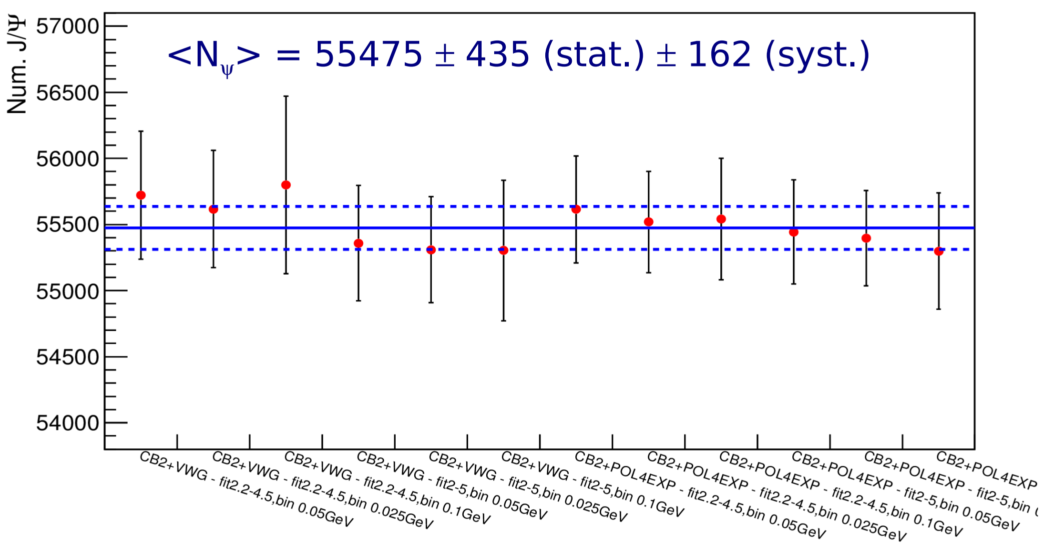
1. Only unlike sign dimuon trigger(CMUL7-B-NOPF-MUON) is selected.
2. Both muons matching the Apt trigger.
3. $-4 < \eta_{\mu} < -2.5$.
4. $-4 < y_{\mu\mu} < -2.5$.
5. $17.6 \text{ cm} < R_{abs} < 89.5 \text{ cm}$.

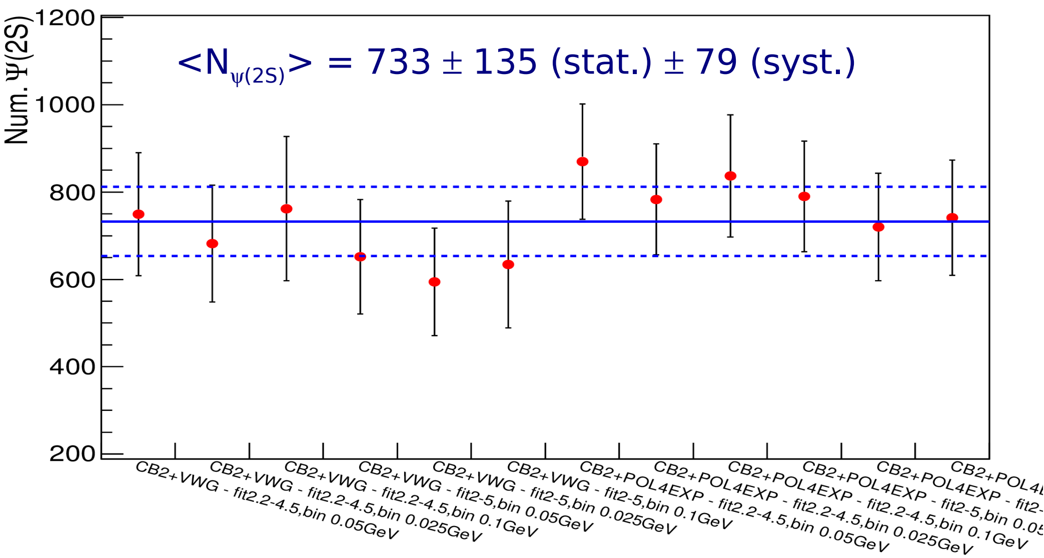
CB2 + VWG



CB2 + Pol4 X Exp



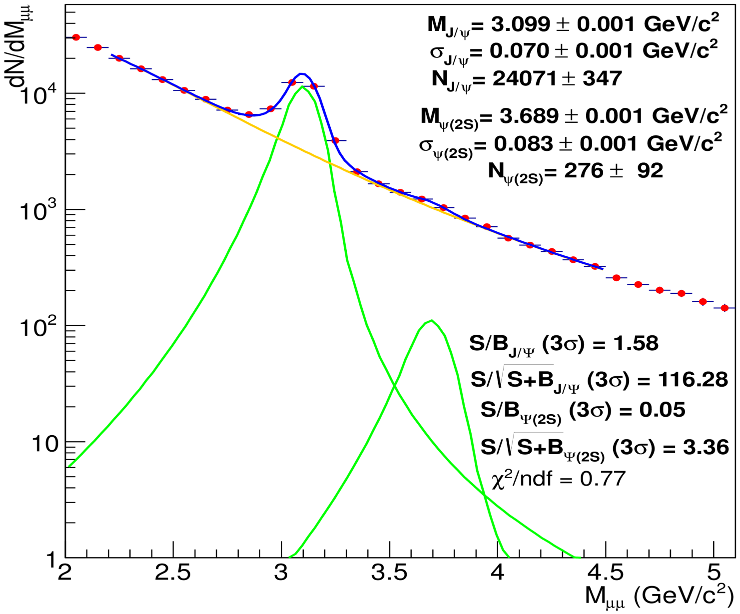




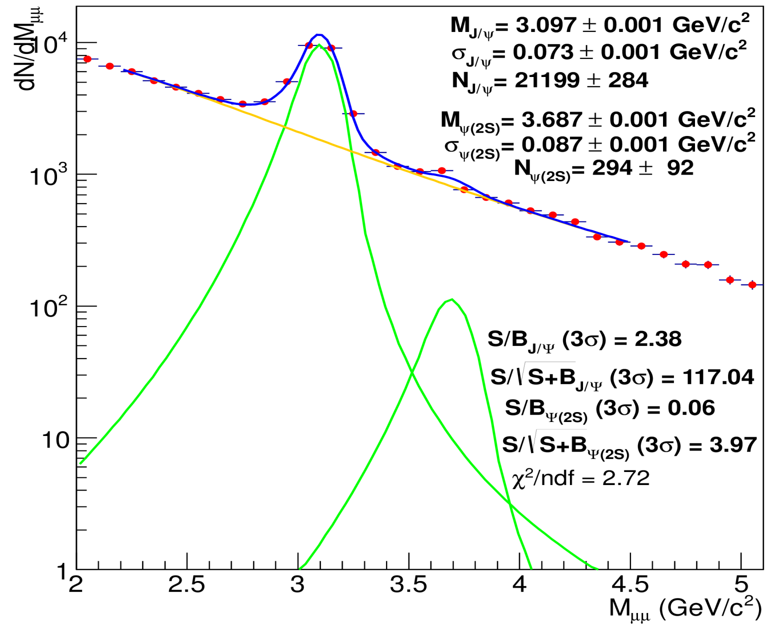
$\langle \psi(2S)/\psi \text{ (Acc. Cor.)} \rangle = 0.0127 \pm 0.0024 \pm 0.0014$ (sign. Extr).

J/ψ and ψ(2S) in p_T bins in Pb-p (LHC13f)

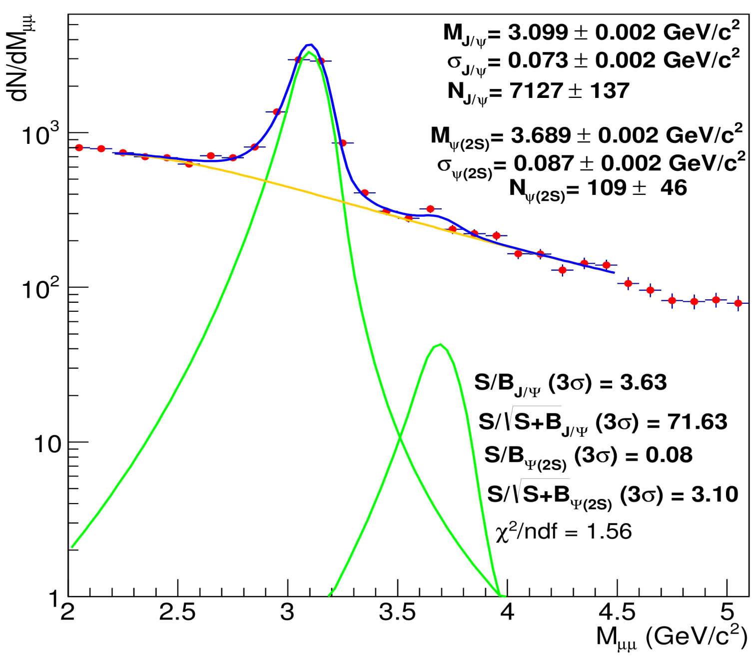
0< p_T <2 (GeV/c)



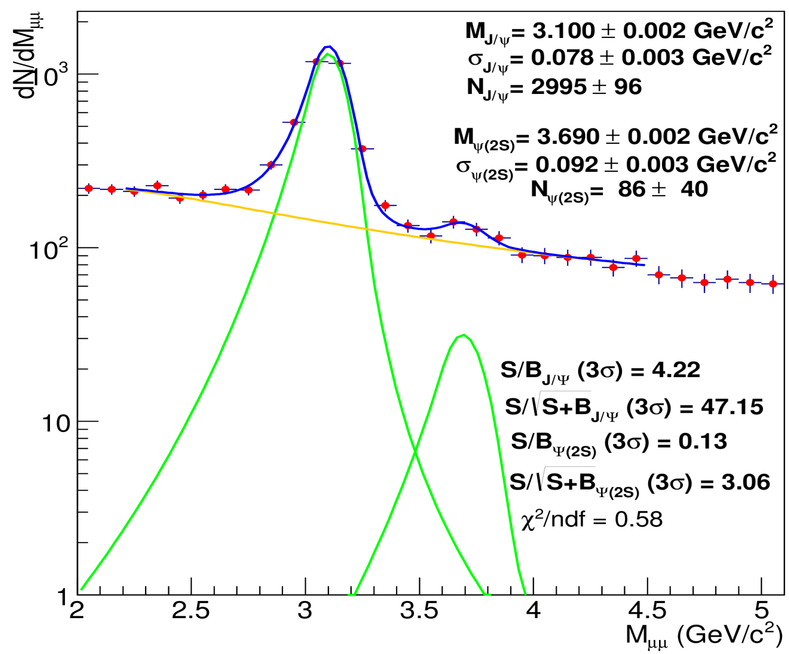
2< p_T <4 (GeV/c)



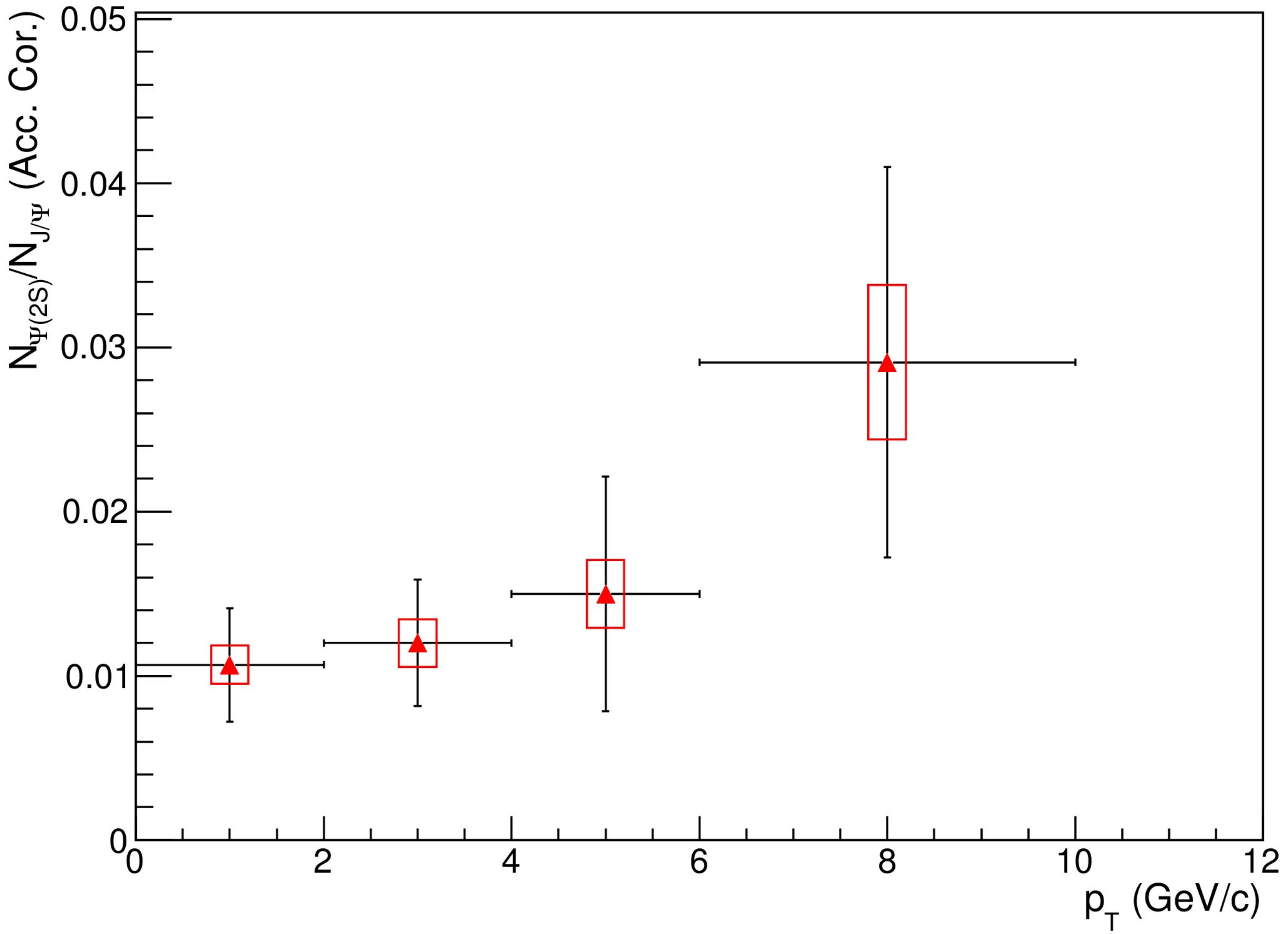
4< p_T <6 (GeV/c)



6< p_T <10 (GeV/c)



ψ(2S)/ψ in p_T bins in Pb-p (LHC13f)



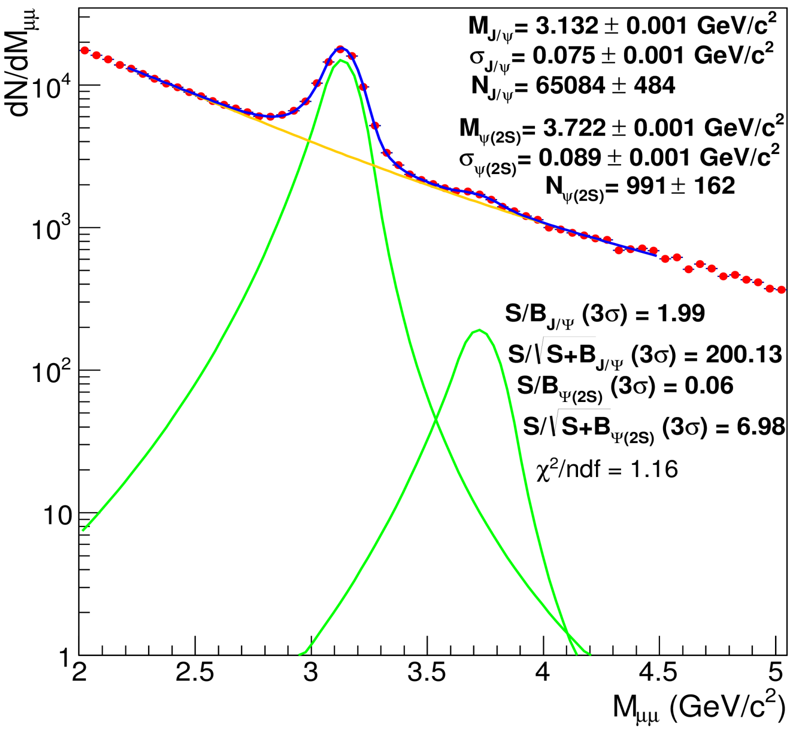
J/ψ and $\psi(2S)$ in p-Pb (LHC13d + LHC13e)

AliAOD.Muons.root

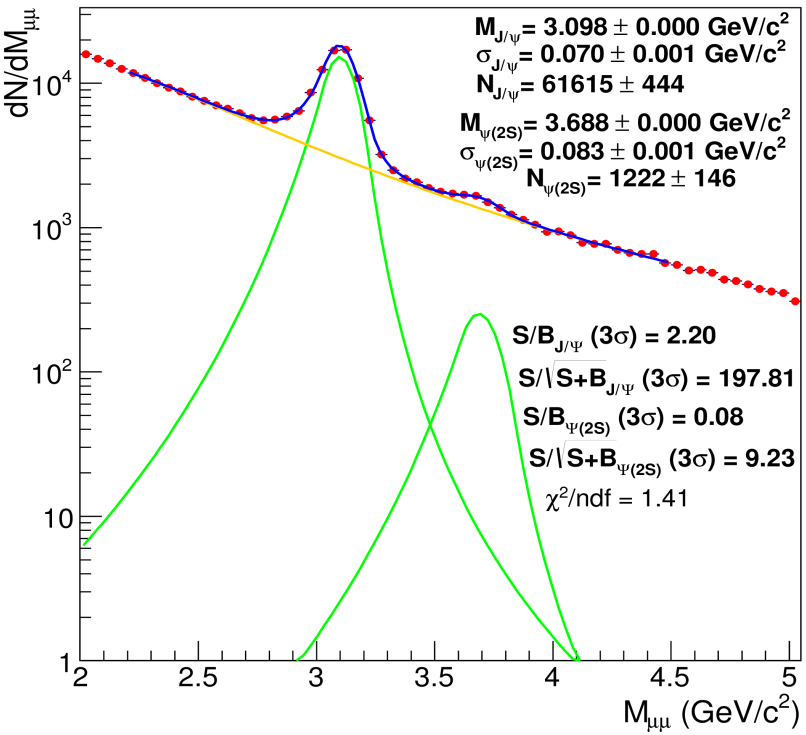
1. Only unlike sign dimuon trigger(CMUL7-B-NOPF-MUON) is selected.
2. Both muons matching the Apt trigger.
3. $-4 < \eta_{\mu} < -2.5$.
4. $-4 < y_{\mu\mu} < -2.5$.
5. $17.6 \text{ cm} < R_{abs} < 89.5 \text{ cm}$.

Fit: Double Crystal Ball + Variable Width Gausian with tails fixed and tuned on MonteCarlo

pass1



Pass2 + refit



- Improvement in mass resolution: Sigma of J/ψ from 75 ± 1 MeV to 70 ± 1 MeV.
- Improvement in mass position: from 3.132 GeV to 3.098 GeV, very close to the PDG value.

ψ(2S)/ψ in p-Pb with pass2

		ψ(2S)/ψ	ψ(2S)/ψ (Acc. Cor)
LHC13f	pass1	---------------	0.0127 ± 0.0024 ± 0.0014
LHC13d+e	pass1	0.0155 ± 0.0026(stat)	0.0148 ± 0.0025(stat.)
LHC13d+e	pass2	0.0198 ± 0.0024(stat)	0.0189 ± 0.0023(stat.)

For pp @ 7 TeV:
ψ(2S)/ψ (Acc. Cor.)= 0.025 ± 0.002 ± 0.004 (sign. Extr).

Outlook

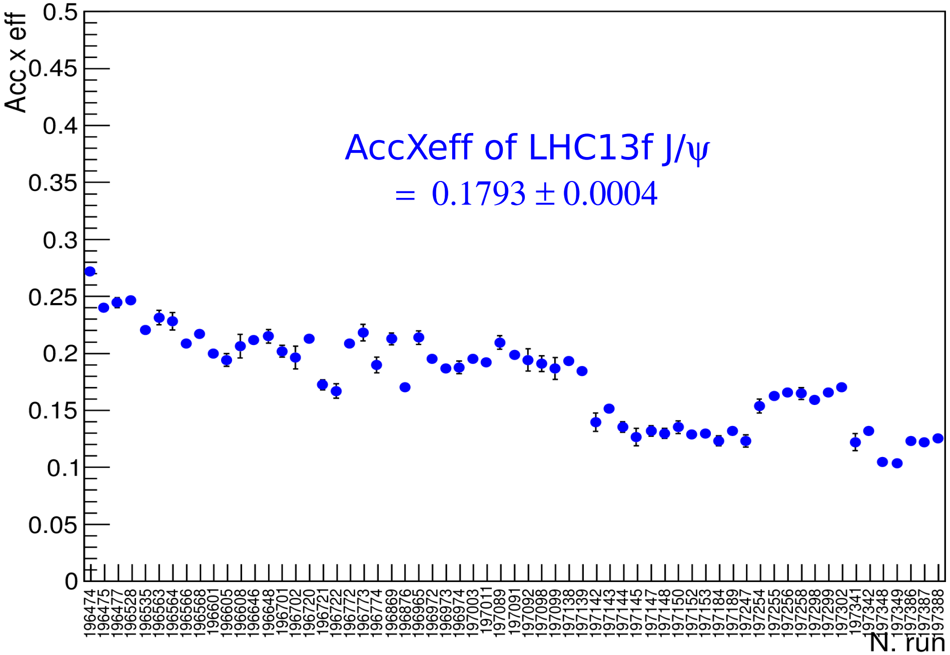
- ψ(2S) / J/ψ have been calculated for p-Pb (integrated) using pass1 and pass2.
- ψ(2S) / J/ψ have been calculated for Pb-p, both integrated and in p_T bins using pass1.

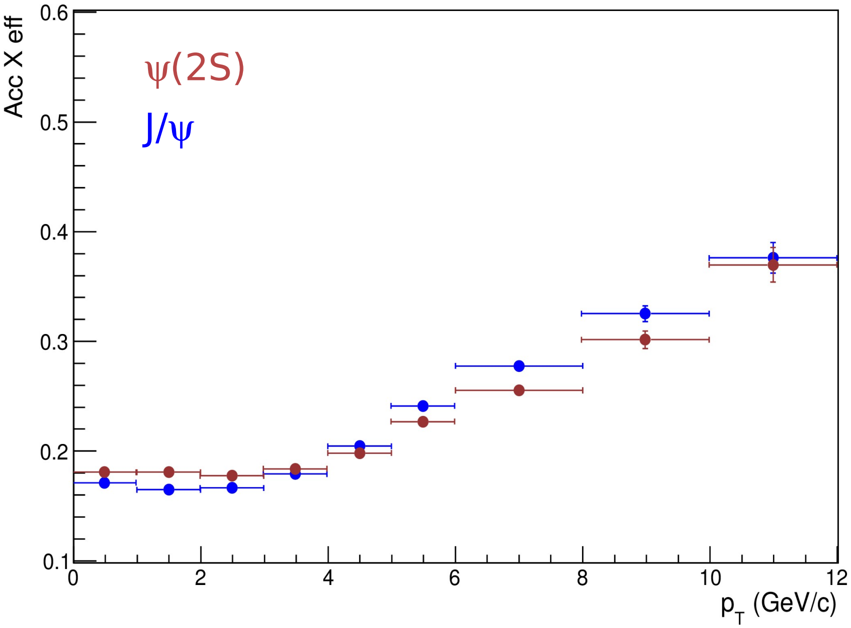
Next steps:

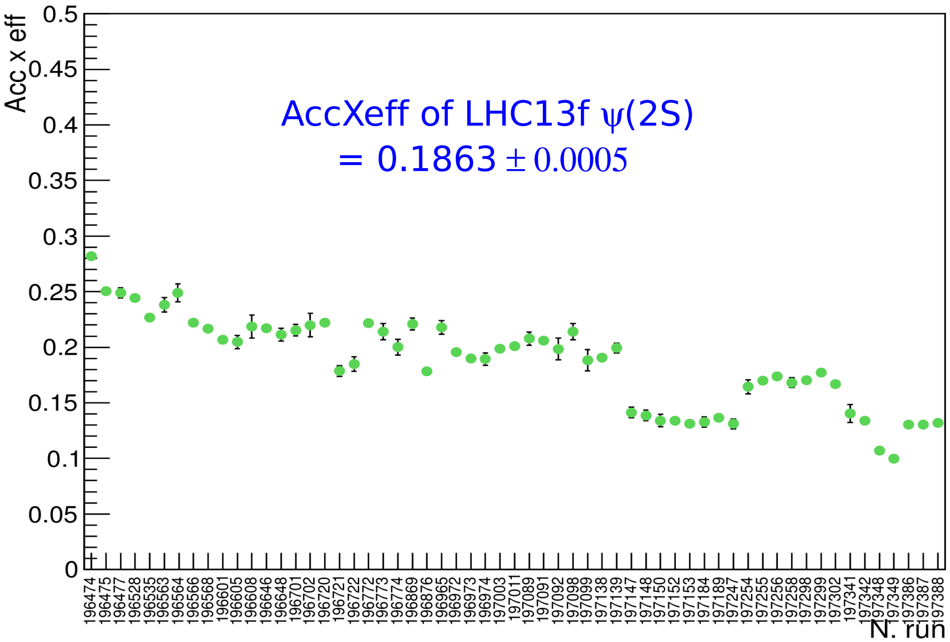
- All analysis will be repeated using pass2 reconstruction.
- Work is in progress. Stay tune....

Thank you

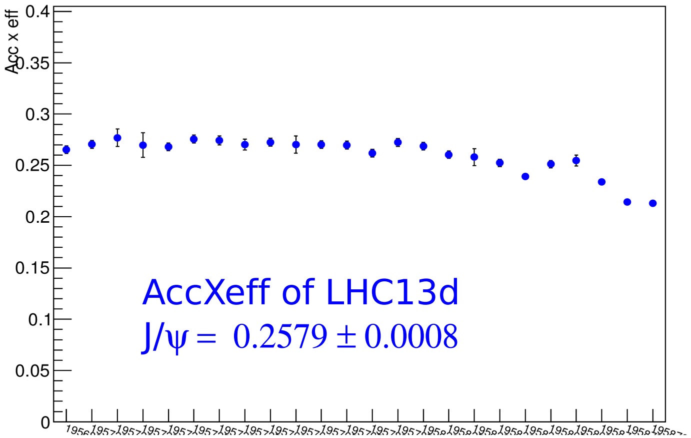
Acceptance X Efficiency of J/ψ and ψ(2S) for LHC13f

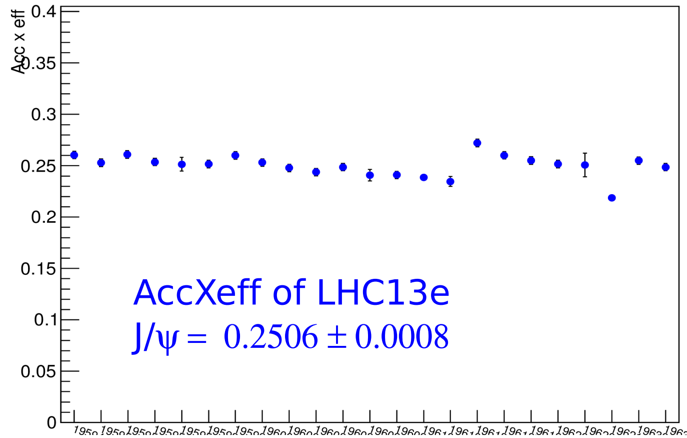


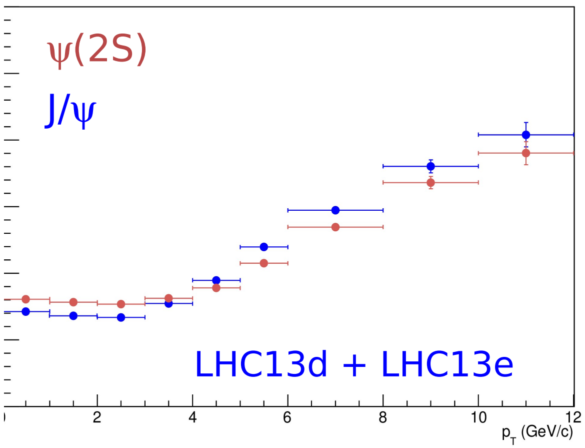


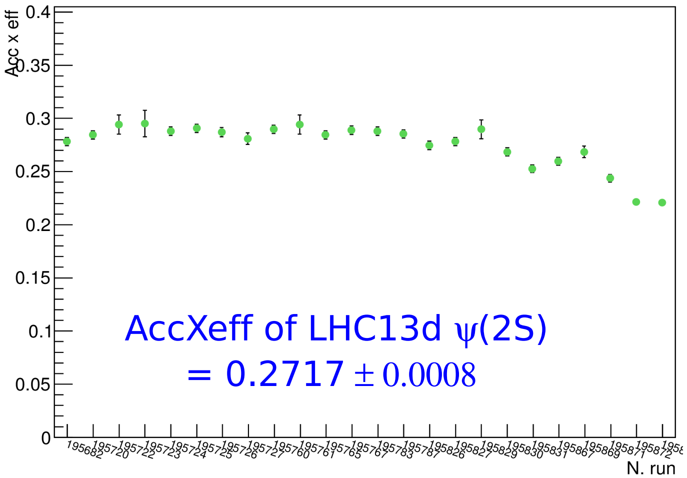


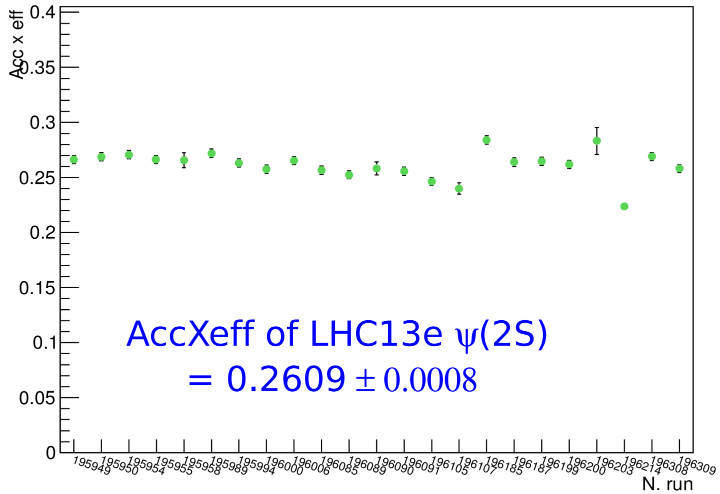
Acceptance X Efficiency of J/ψ and ψ(2S) for p-Pb (LHC13d+LHC13e)











```
 Double_t  VWG(Double_t *x, Double_t *par){
 Double_t sigma = par[2]+par[3]*((x[0]-par[1])/par[1]);
 Double_t FitBck = par[0]*TMath::Exp(-(x[0]-par[1])*(x[0]-par[1])/(2.*sigma*sigma));
 return FitBck;
 }
```

```
Double_t  POL4XEXP(Double_t *x, Double_t *par){
  Double_t FitBck =
par[0]*TMath::Exp(x[0]/par[1])*(1.+par[2]*x[0]+par[3]*x[0]*x[0]+par[4]*x[0]*x[0]*x[0]+
par[5]*x[0]*x[0]*x[0]*x[0]);
  return FitBck;
}
```