Multiplicity dependence of $\sigma_{\psi(2S)}/\sigma_{J/\psi}$ in pPb collisions at $\sqrt{s_{NN}}$ = 8.16TeV

IFT meeting

Speaker: Youen Kang

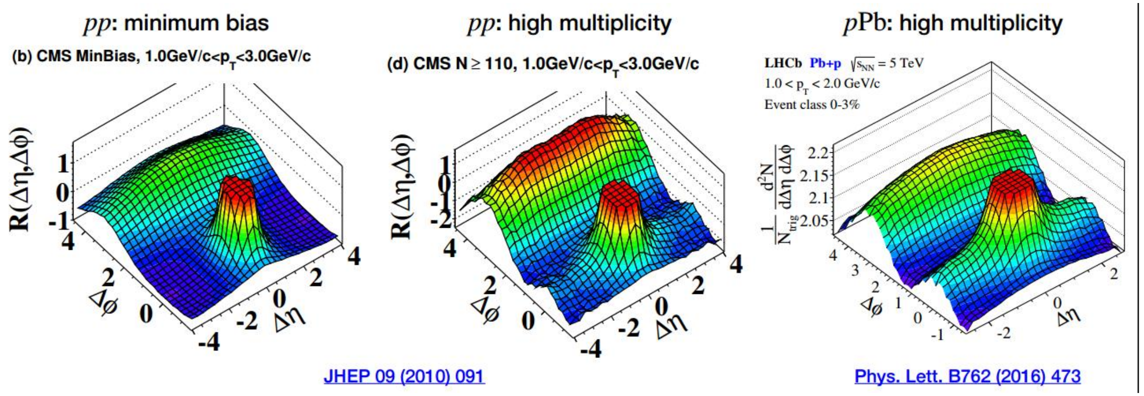
Introduction

Nuclear matter effect & collision systems

- **Collision systems**
  - A-A collisions: Both **Hot Nuclear Matter (HNM) effects** (related to the QGP formation and evolution) and **Cold Nuclear Matter (CNM) effects** exist → **Large systems**
  - *p*-A collisions: **CNM effects** dominate
  - *pp* collisions: **No** nuclear matter effect expected to exist

Small systems

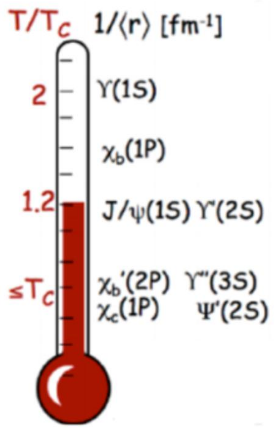
- QGP-like signatures found in high-multiplicity small system collisions:
  - Collectivity (as shown in the right figure)
  - Strangeness enhancement ([arXiv:2311.08490v1](https://arxiv.org/abs/2311.08490v1) [hep-ex])
  - Heavy quarkonium suppression (Phys.Rev.C 105 (2022) 6, 064912)



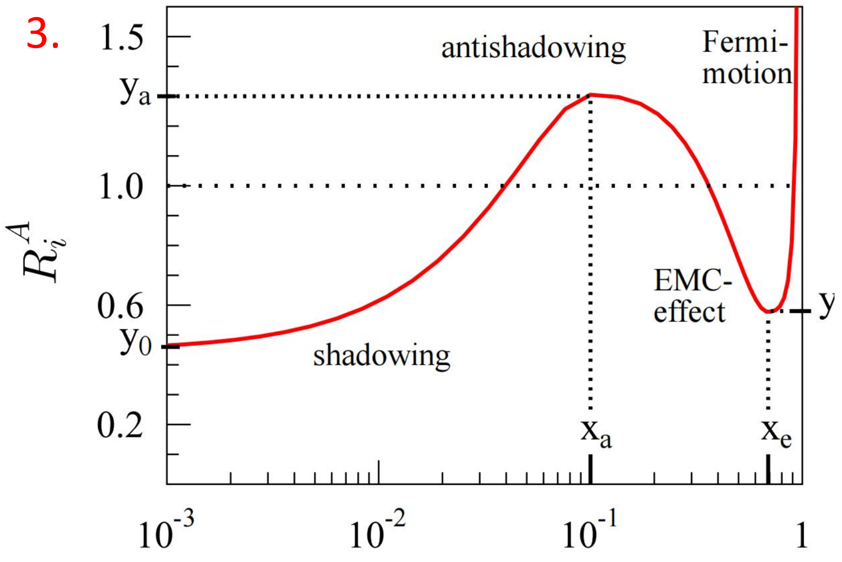
Heavy quarkonium production

- Why $q\bar{q}$? :
  1. Color screening in QGP
  2. Sequential melting
  3. Sensitive to initial-state effect
  4. Probe for final-state effect

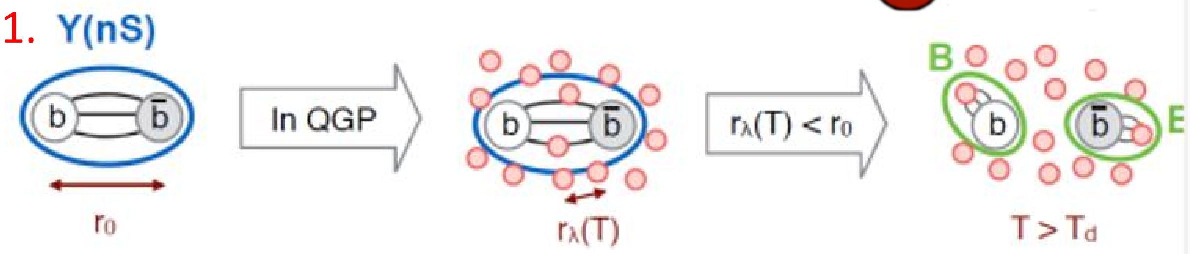
2.



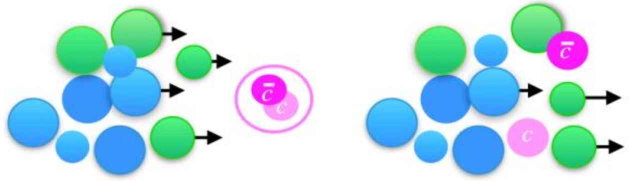
3.



1.



4. Co-mover effect: *Quarkonia are suppressed by interaction with the co-moving medium, constituted by particles with similar rapidities*.’ [JHEP 03 (2019) 063]

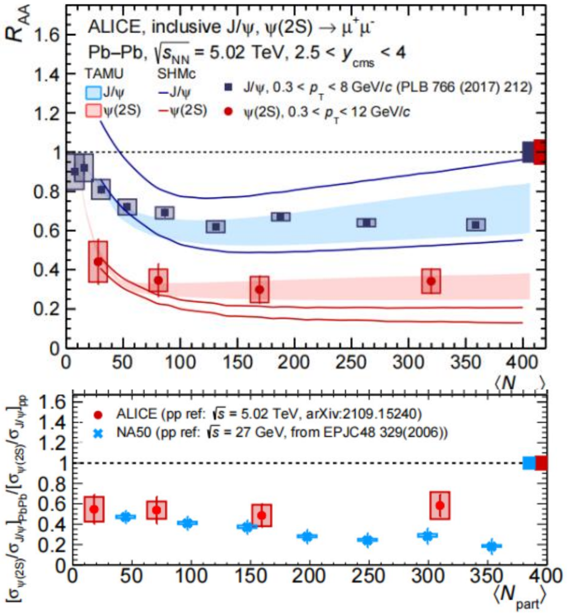


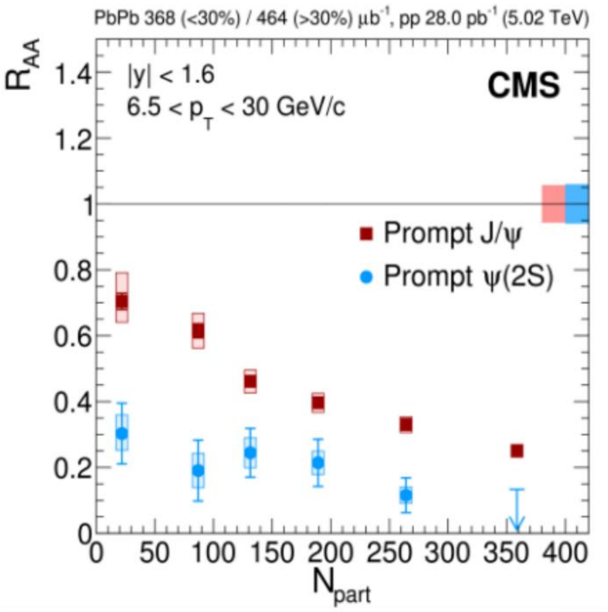
Breakup due to co-moving particles

Experimental overview: ALICE & CMS

- ✓ Both $\sigma_{\psi(2S)}$ and $\sigma_{J/\psi}$ are strongly suppressed in PbPb collisions
- ✓ $\psi(2S)$ is **more suppressed** than J/ψ in PbPb collisions

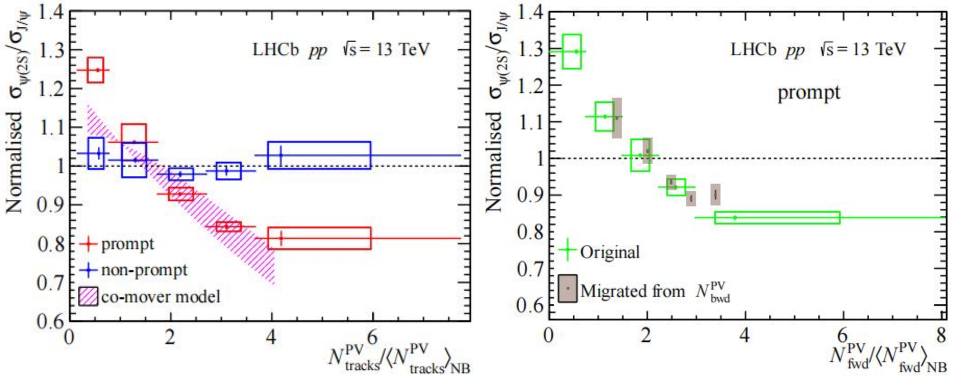
× $\sigma_{\psi(2S)}/\sigma_{J/\psi}$ **does not** show multiplicity dependence in ALICE and CMS PbPb collisions measurements, nor in ALICE *pp*, *p*Pb measurements



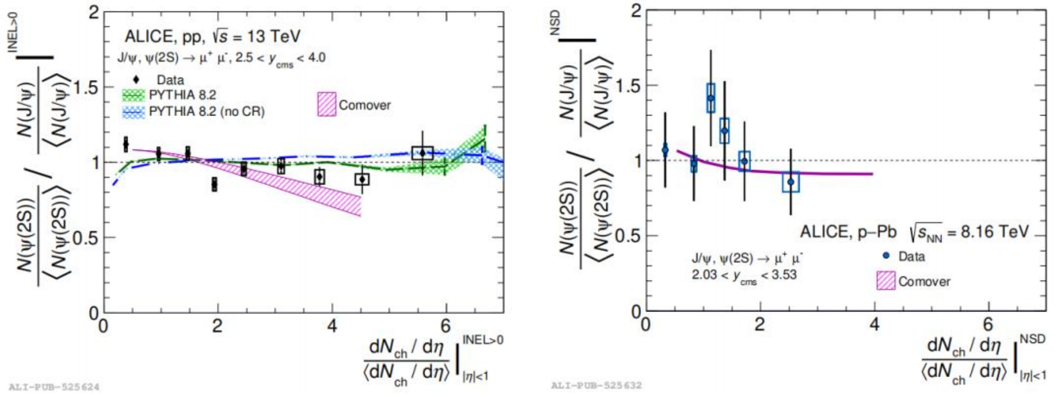


[EPJ Web Conf. 276 (2023) 02002]

[J.Phys.Conf.Ser. 1258 (2019) 1, 1]



LHCb-PAPER-2023-035



[arXiv:2207.13399 [nucl-ex]]

Motivation

- Exploring the multiplicity dependence of $\sigma_{\psi(2S)}/\sigma_{J/\psi}$ in *p*Pb collisions with different multiplicity variables
- Compare results in *p*Pb and Pb*p* collisions, in search of a transition from small system to large-system-like environment
- Compare with other measurements

LHCb detector

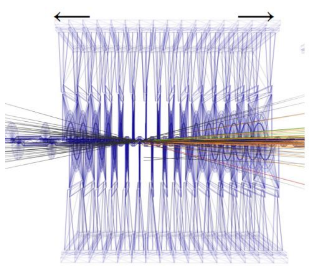
- The LHCb detector is a single-arm forward spectrometer covering the pseudorapidity range 2 < η < 5
- Designed primarily for the study of particles containing *b* or *c* quarks.

Velo:

- Time resolution ~ 50fs $\ll \tau_b$
- PV resolution ~ 13μm

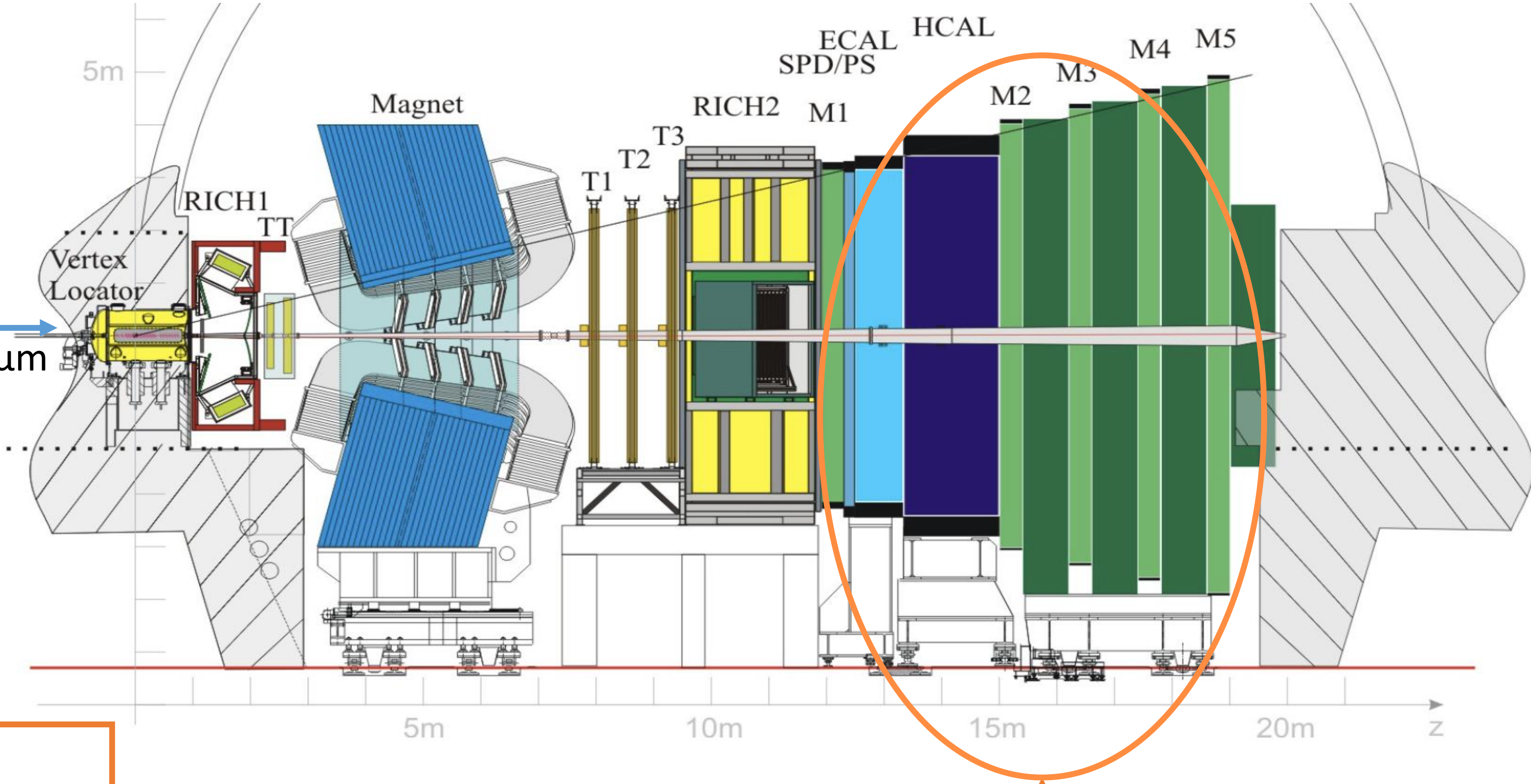
→ prompt and non-prompt separation

- Impact parameter resolution:(15 + 29/p_{T})[GeV])μm



$\mathrm{N}^{\mathrm{PV}}_{\mathrm{bwd}}$ $\mathrm{N}^{\mathrm{PV}}_{\mathrm{fwd}}$

$$\mathrm{N}^{\mathrm{PV}}_{\mathrm{track}} = \mathrm{N}^{\mathrm{PV}}_{\mathrm{fwd}} + \mathrm{N}^{\mathrm{PV}}_{\mathrm{bwd}}$$

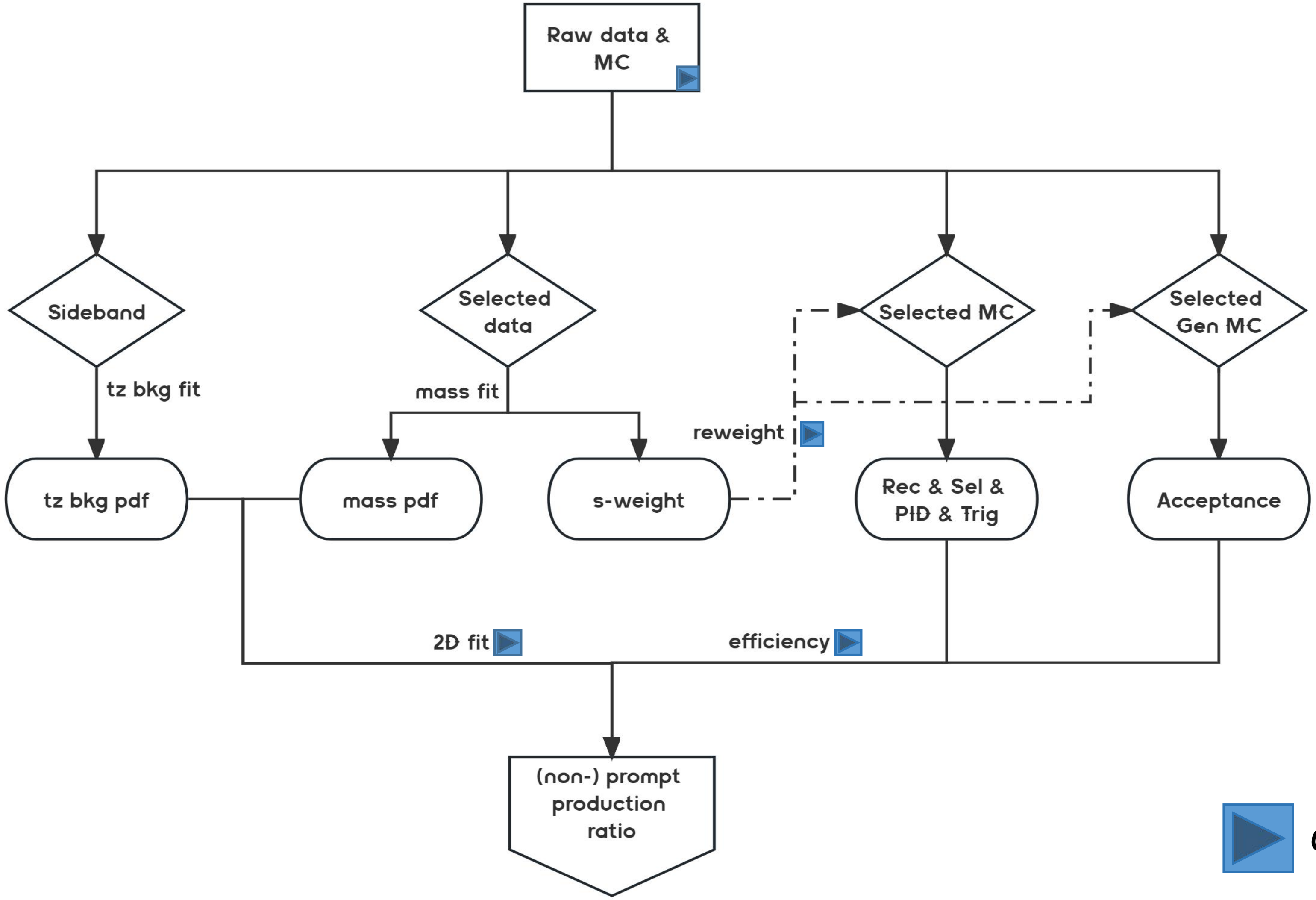


Muon detector:

- High Muon ID ~ 97 %,
- Mis ID for Pion to Muon 1%~3%

Analysis

Analysis



Go to uncertainties

Data set

- **Data**:
  - **Data taking period:** 2016
  - **Collision type:** pPb(Pbp) collisions
  - **Integrated Lyminosity:** 13.6 (20.8) nb^{-1}
  - **TCK:** 0x1138160F and 0x11381612
  - **TriggerLine:**
    - L0: L0Muon
    - Hlt1: Hlt1DiMounHighMass

- **MC:**
  - **EventType:** 24142001(J/ψ) 28142001(ψ(2S))
  - **Sample size:** 4M for each type in pPb and Pbp
  - **Generator:** EPOS
  - **Sim. Version:** Sim09l

- **Offline selection**
  - nPVs: = 1
  - vertex chi2/dof: < 7.8794
  - mass Window: $\pm$ 120 MeV/c^2
  - muon η: [2, 5]
  - TrackGhostProb.: < 0.4
  - z_{PV}: Different in each type
  - IsMuon: = 1
  - ProbNNmu: > 0.9

- **Decay Channel:**
  - $J/\psi \to \mu^+ + \mu^-$
  - $\psi(2S) \to \mu^+ + \mu^-$

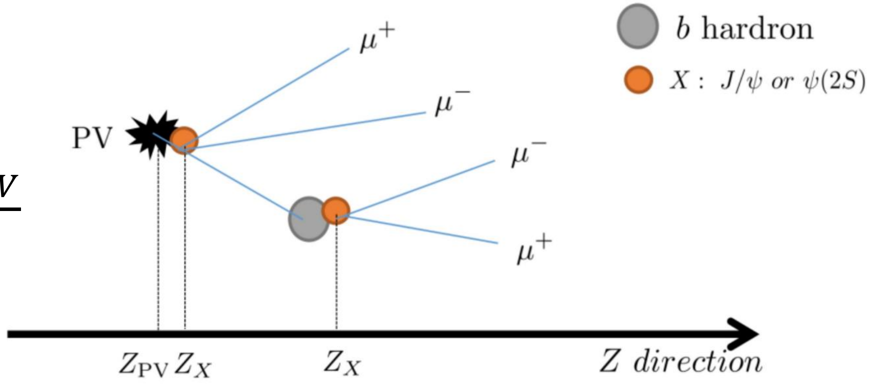
- **Bookkeeping path:**
  - pPb /LHCb/Protonion16/Beam6500GeV-VeloClosed-MagDown/Real Data/Turbo03pLead/94000000/TURBO.MDST
  - Pbp /LHCb/Ionproton16/Beam6500GeV-VeloClosed-MagDown/Real Data/Turbo03pLead/94000000/TURBO.MDST
  - pPb /MC/2016/pPb-Beam6500GeV-2560GeV-2016-MagDown-Fix1-Epos/Sim09l/Trig0x61421621/Reco16pLead/Turbo03/eventType/DST
  - Pbp /MC/2016/Pbp-Beam2560GeV-6500GeV-2016-MagDown-Fix1-Epos/Sim09l/Trig0x61421621/Reco16pLead/Turbo03/eventType/DST

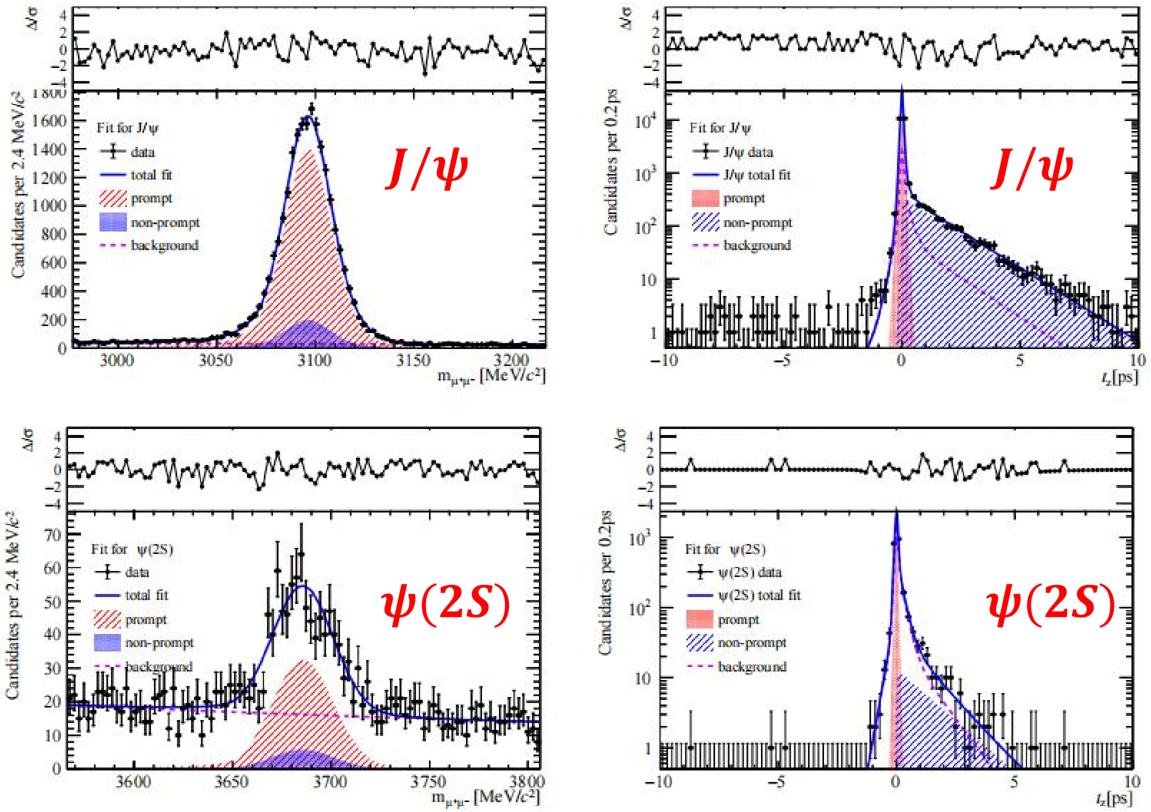
back to analysis

Signal Extration

- 2-D fit on mass and t_z spectrum:
  - mass:
    - signal: (double) CB function
    - bkg: exponential decay
  - Pseudo decay time t_z:
    - signal:
      - prompt: δ function $\otimes$ resolution function
      - non-prompt: exponential decay
    - bkg: extacted from sideband

$$t_z = \frac{Z_X - Z_{PV}}{p_z/M_X}$$





back to analysis

Efficiency

$\epsilon_{\mathrm{tot}} = \epsilon_{\mathrm{acc}} \times \epsilon_{\mathrm{MuonID}} \times \epsilon_{\mathrm{Reco\&Sel}} \times \epsilon_{\mathrm{Trigger}}$

where,

$$\epsilon_{\mathrm{acc}} \equiv \frac{\mathrm{N}(p_{\mathrm{T}},\mathrm{y}) \text{ with both } \mu \text{ in LHCb acceptance}}{\mathrm{N}(p_{\mathrm{T}},\mathrm{y})}$$

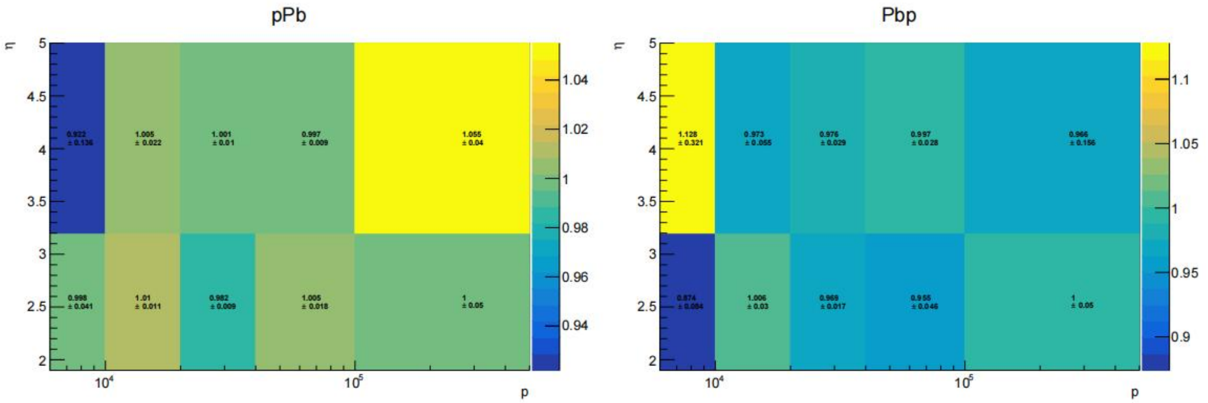
$$\epsilon_{\mathrm{Reco\&Sel}} \equiv \frac{\mathrm{N}(p_{\mathrm{T}},\mathrm{y}) \text{ reconstructed and selected (w/o } \mu \text{ ID)}}{\mathrm{N}(p_{\mathrm{T}},\mathrm{y}) \text{ with both } \mu \text{ in LHCb acceptance}}$$

$$\epsilon_{\mathrm{MuonID}} \equiv \frac{\mathrm{N}(p_{\mathrm{T}},\mathrm{y}) \text{ selected including } \mu\text{ID requirement}}{\mathrm{N}(p_{\mathrm{T}},\mathrm{y}) \text{ reconstructed and selected (w/o } \mu\text{ID)}}$$

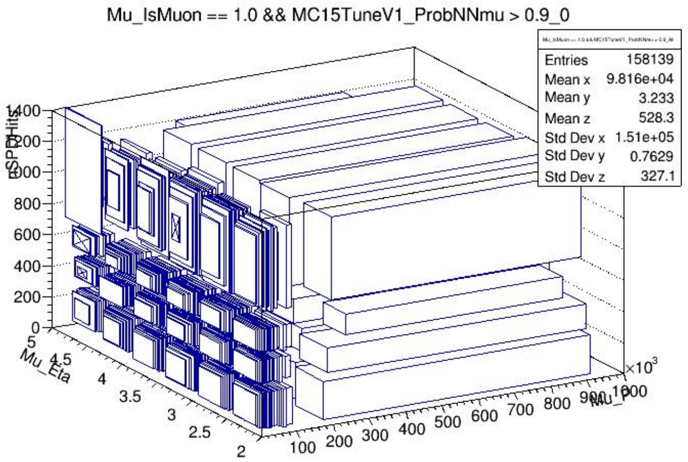
$$\epsilon_{\mathrm{Trigger}} \equiv \frac{\mathrm{N}(p_{\mathrm{T}},\mathrm{y}) \text{ triggered}}{\mathrm{N}(p_{\mathrm{T}},\mathrm{y}) \text{ selected including } \mu\text{ID requirement}}$$

All the efficiency are calculated from Monte-Carlo simulation.

Tracking correction table:



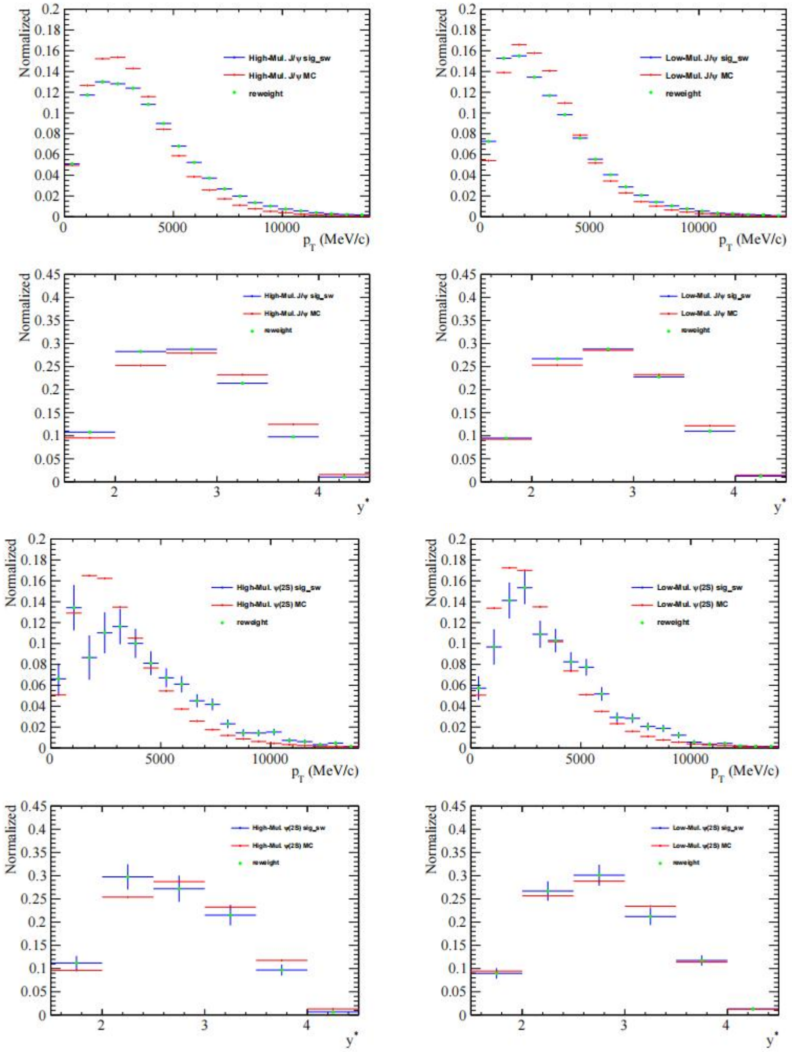
Visualization of PID table from PIDCalib:



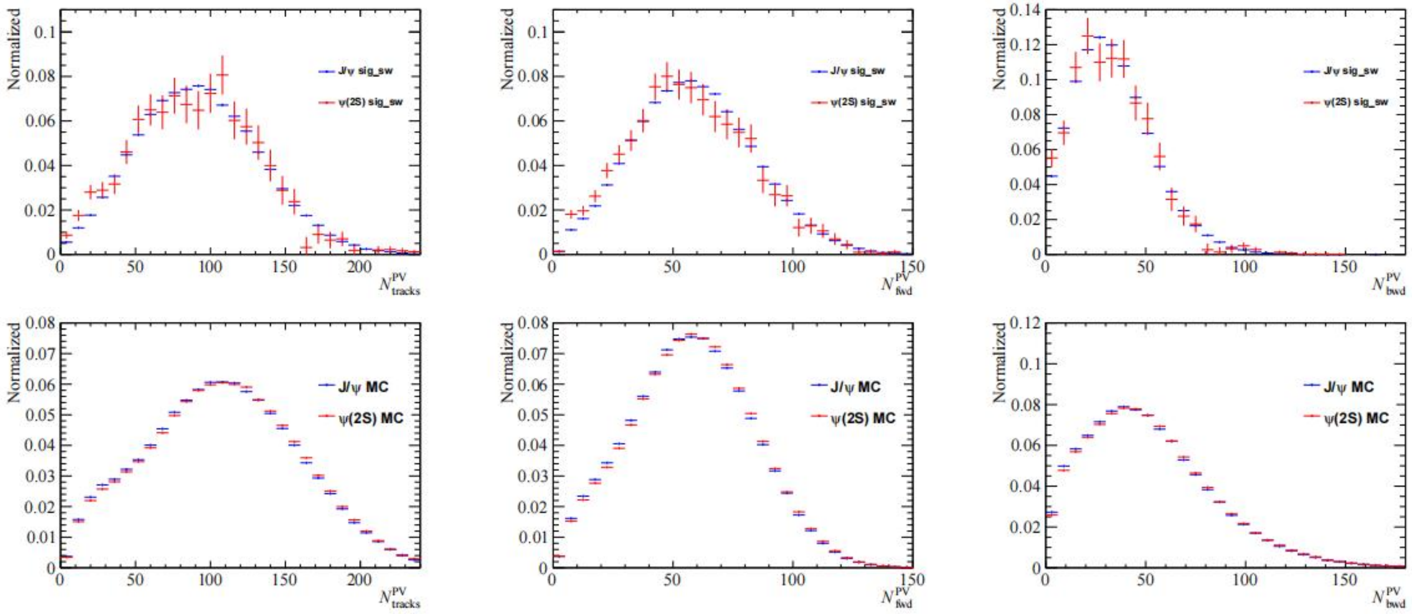
back to analysis

Reweight

p_{T} and y^{*} distribution for high- and low-multiplicity samples



Multiplicity distribution for s-weight data (first row) and MC (second row)



1. Multiplicity distribution for J/ψ and $\psi(2S)$ are almost the same in both s-weight data and MC, so no re-weight is performed for multiplicity.

2. p_{T} and y^{*} distribution are reweighted by high- and low-multiplicity s-weight data samples (> or < mean multiplicity).

(details seen Systematic Uncertainties)

back to analysis

Systematic uncertainties

part I

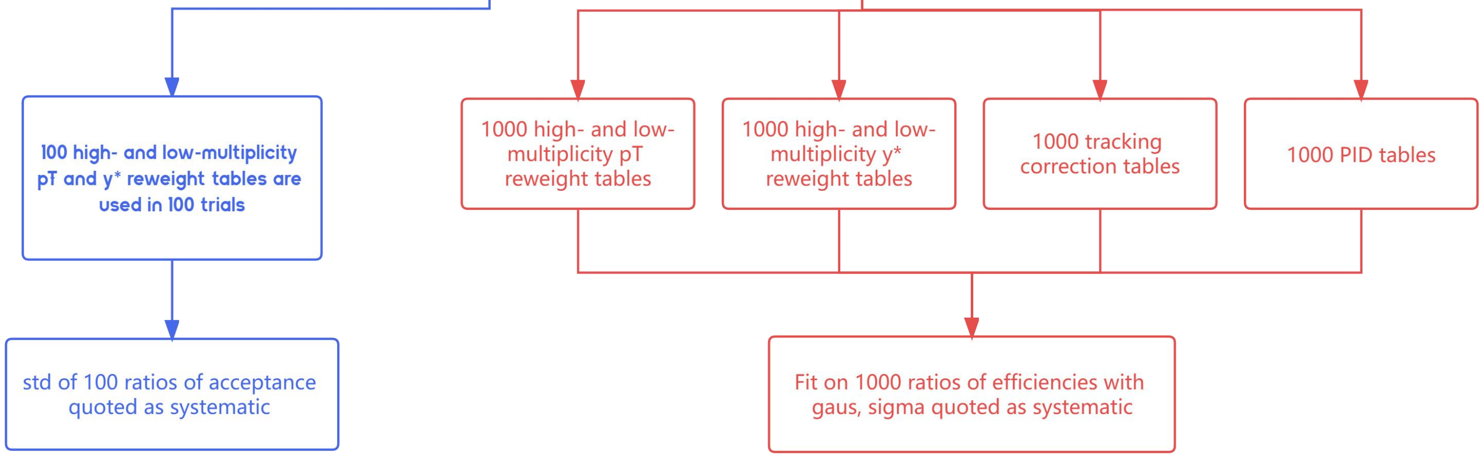
The rest

source	p**Pb**	**Pb**p
L0&HLT	3.2%-3.9%	3.6%-4.1%
Tracking Table Uncertainty& PID Table Uncertainty& p_{T} spectrum& y spectrum	1.7%-3.6%	2.1%-3.6%
PID Table scheme	0.4%-1.7%	0.1%-1.8%
Imperfectly simulating acceptance	0.8%-1.2%	0.9%-1.3%
$\frac{\mathcal{B}(J/\psi\to\mu^+\mu^-)}{\mathcal{B}(\psi(2S)\to\mu^+\mu^-)}$(canceled if normalized)	2.2%	2.2%
Fit model	negligible	negligible
MC sample size	negligible	negligible
Multiplicity global cut	negligible	negligible

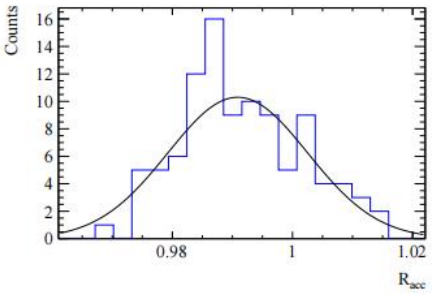
Go to Results

Systematic uncertainties

$$R_{\epsilon_{tot}} = \boxed{\frac{\epsilon_{Acc,J/\psi}}{\epsilon_{Acc,\psi(2S)}}} \times \boxed{\frac{\epsilon_{RecSel,J/\psi} \times \epsilon_{PID,J/\psi} \times \epsilon_{tri,J/\psi}}{\epsilon_{RecSel,\psi(2S)} \times \epsilon_{PID,\psi(2S)} \times \epsilon_{tri,\psi(2S)}}}$$

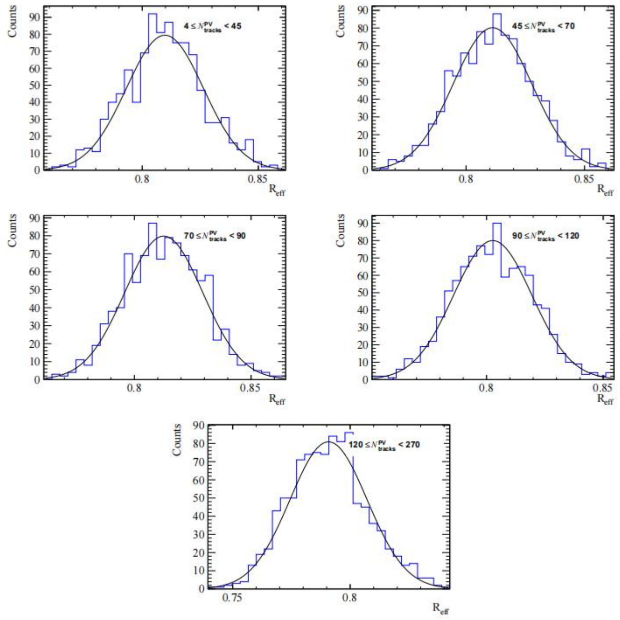


$$R_{acc} = \frac{\epsilon_{\mathrm{acc},J/\psi}}{\epsilon_{\mathrm{acc},\psi(2S)}} = 0.991 \pm 0.012.$$



R_{eff} in different $N_{\mathrm{tracks}}^{\mathrm{PV}}$ regions in pPb configuration.

$4 \leq N_{\mathrm{tracks}}^{\mathrm{PV}} < 45$	0.810 ± 0.021
$45 \leq N_{\mathrm{tracks}}^{\mathrm{PV}} < 70$	0.811 ± 0.020
$70 \leq N_{\mathrm{tracks}}^{\mathrm{PV}} < 90$	0.813 ± 0.021
$90 \leq N_{\mathrm{tracks}}^{\mathrm{PV}} < 120$	0.803 ± 0.021
$120 \leq N_{\mathrm{tracks}}^{\mathrm{PV}} < 270$	0.791 ± 0.021



back to systematic

Systematic uncertainties

1. Fit model: variation due to different models v.s. stats. uncertainty.

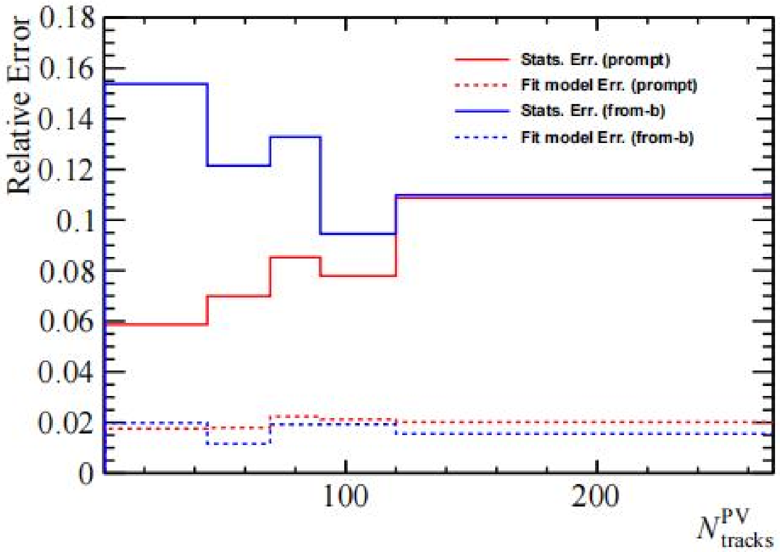
2. Systematic uncertainty due to limit MC sample size ~ 0.1%.

3. Systematic uncertainty due to global cut on multiplicity (nVeloCluster<8000) < 0.1%.

4. Systematic uncertainty from branching fraction is 2.2%, it is canceled when ratio in different multiplicity bin is divided by the ratio in total multiplicity range.

5. Uncertainty for trigger efficiency is estimated by data-driven method (TISTOS method), the larger one of variation between data and MC and the stats. error from fit in TIS(TOS) sampe is quoted as systematic.

Fit model: Stats. v.s. Sys.



TISTOS method:

Configuration	Mult. Variable	Variation	Stats. Err.	Syst. Err. quoted
pPb	N^{PV}_{tracks}	2.7%	3.9%	3.9%
pPb	N^{PV}_{fwd}	3.2%	3.0%	3.2%
pPb	N^{PV}_{bwd}	2.7%	3.9%	3.9%
Pbp	N^{PV}_{tracks}	2.0%	3.8%	3.8%
Pbp	N^{PV}_{fwd}	1.7%	3.6%	3.6%
Pbp	N^{PV}_{bwd}	2.7%	4.1%	4.1%

back to systematic

Results

1. Prompt ratio decreases in *p*Pb collisions.

2. No trend for non-prompt ratio found in *p*Pb or Pb*p* collisions.

3. Prompt ratio with Br: $\mathcal{B}_{\psi(2S)}\sigma_{\psi(2S)}/\mathcal{B}_{J/\psi}\sigma_{J/\psi}$:

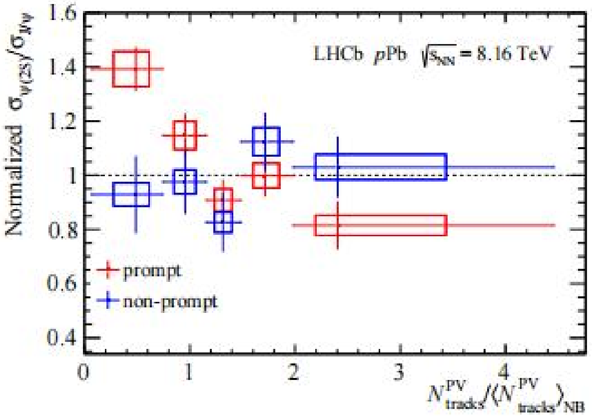
Pb*p*: $(1.353 \pm 0.090)\%$

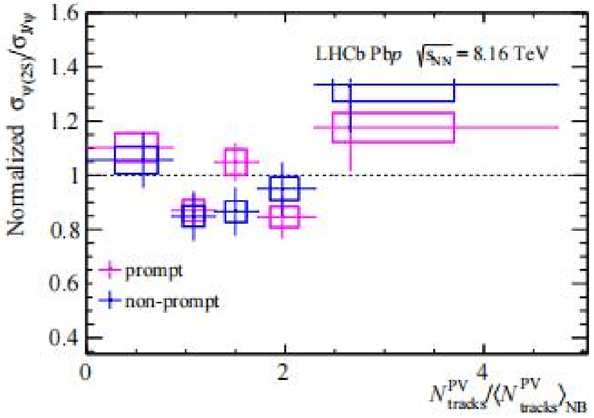
*p*Pb: $(1.705 \pm 0.098)\%$

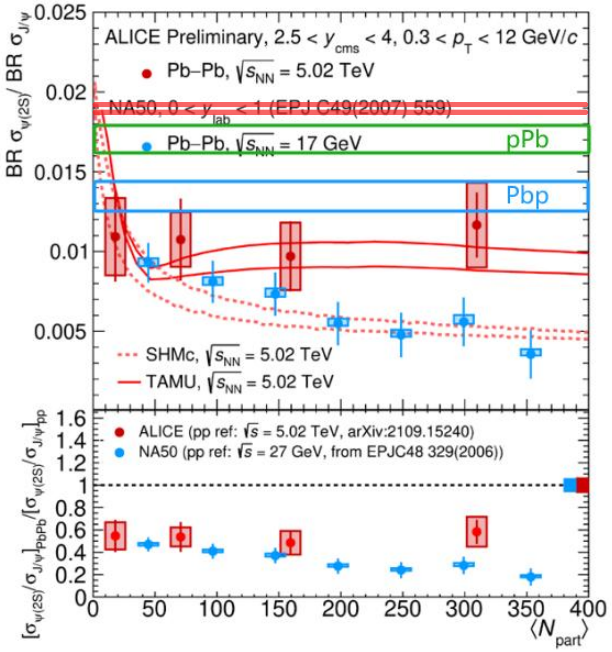
However, no decreasing trend is found for prompt ratio in Pb*p* collisions.

4. From the perspective of prompt ratio v.s. multiplicity:

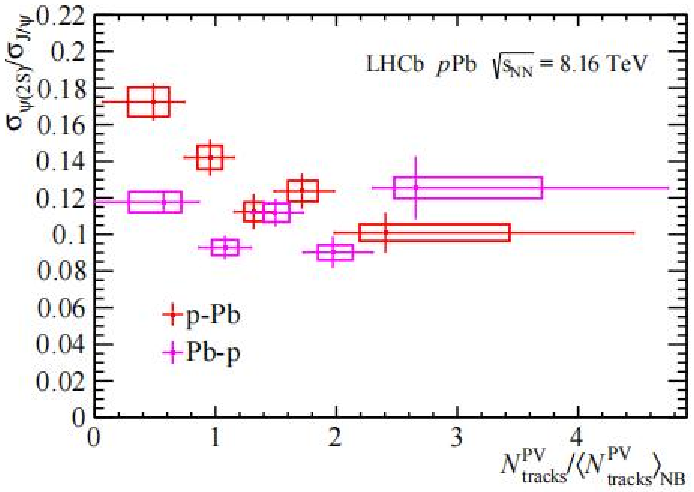
- *p*Pb collisions is more like *pp* collisions
- Pb*p* collisions is more like PbPb collisions (measured by ALICE and CMS)





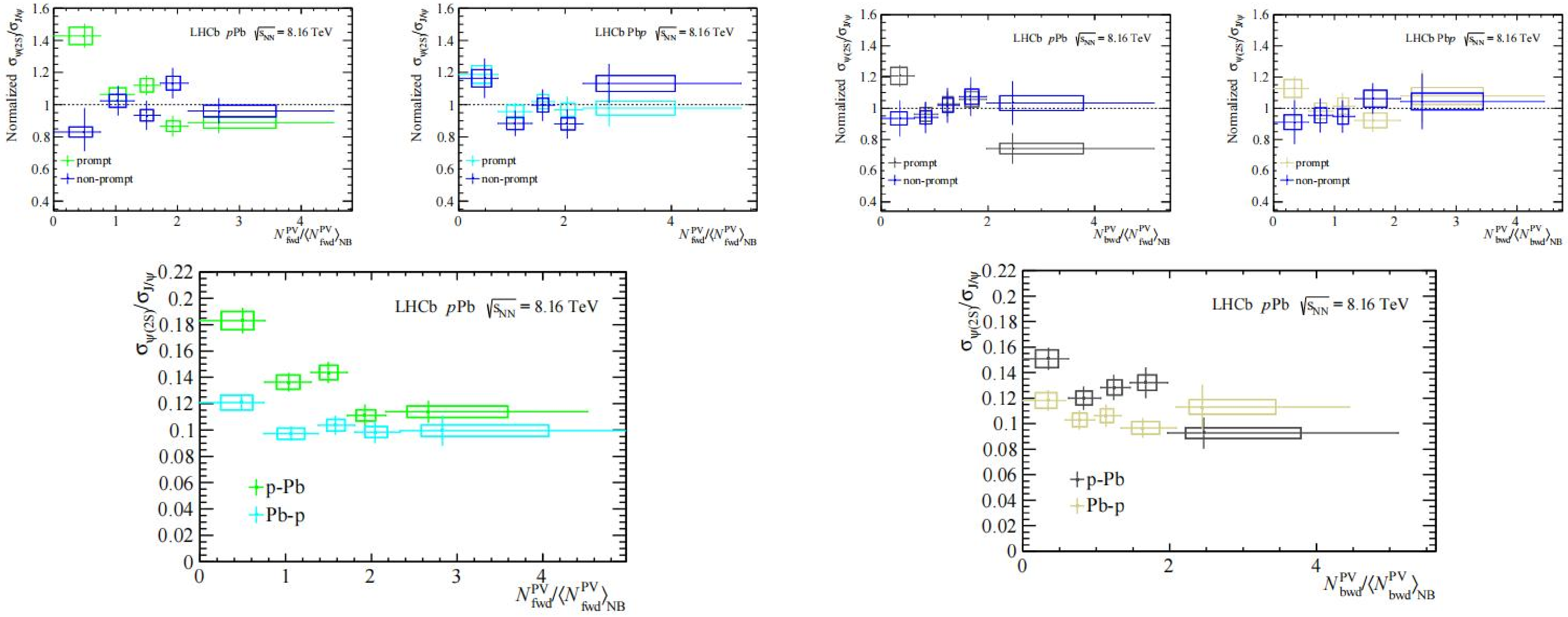


[EPJ Web Conf. 276 (2023) 02002]



Results

- Same conclusions holds for $N_{\mathrm{fwd}}^{\mathrm{PV}}$ and $N_{\mathrm{bwd}}^{\mathrm{PV}}$:



One more conclusion: prompt ratio decrease slower with $N_{\mathrm{bwd}}^{\mathrm{PV}}$ yhan $N_{\mathrm{fwd}}^{\mathrm{PV}}$ in *p*Pb, similar to *pp* collisions

Resources

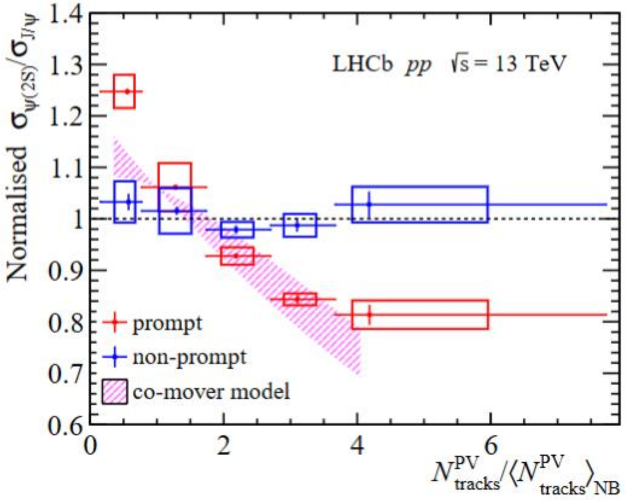
- Twikipage: https://twiki.cern.ch/twiki/bin/viewauth/LHCbPhysics/Psi2StoJpsiRatio8TeVpPb
- AnaNote: https://www.overleaf.com/read/mfpgrjgmdxwj#45ea55
- Tuple in EOS: /eos/lhcb/wg/IonPhysics/analyses/psi2S_over_jpsi_vs_Mul_pPb_8TeV
- gitlab for analysis code: https://gitlab.cern.ch/lhcb-ift/psi2s_over_jpsi_vs_mul_p_pb8tev

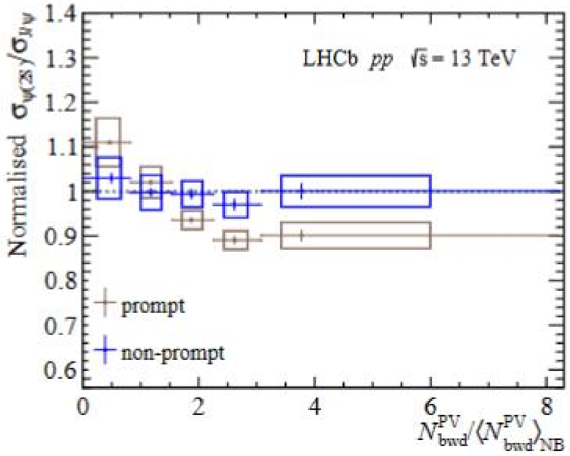
One can reproduce the result by:

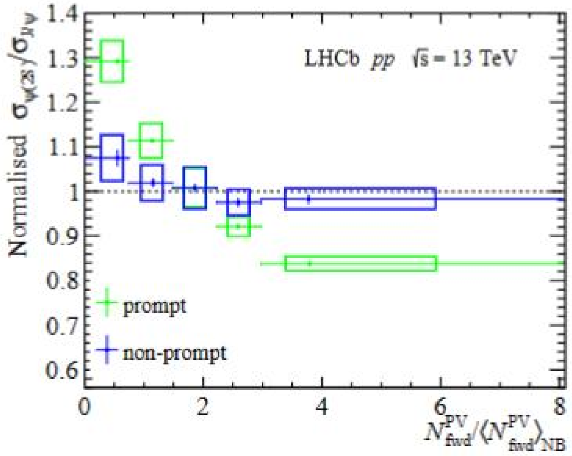
0. Download directory '0_File' from /eos/lhcb/wg/IonPhysics/analyses/psi2S_over_jpsi_vs_Mul_pPb_8TeV
1. Download all the directories in the sample place you save 0_File (DO NOT CHANGE NAMES)
2. cd 3_Scripts
3. source zTotal.sh (better run in background, it might take one or two hours)

Back Up

pp results


LHCb pp √s = 13 TeV
Normalised σψ(2S)/σJ/ψ
prompt
non-prompt
co-mover model
$N^{\mathrm{PV}}_{\mathrm{tracks}}/\langle N^{\mathrm{PV}}_{\mathrm{tracks}}\rangle_{\mathrm{NB}}$


LHCb pp √s = 13 TeV
Normalised σψ(2S)/σJ/ψ
prompt
non-prompt
$N^{\mathrm{PV}}_{\mathrm{bwd}}/\langle N^{\mathrm{PV}}_{\mathrm{bwd}}\rangle_{\mathrm{NB}}$

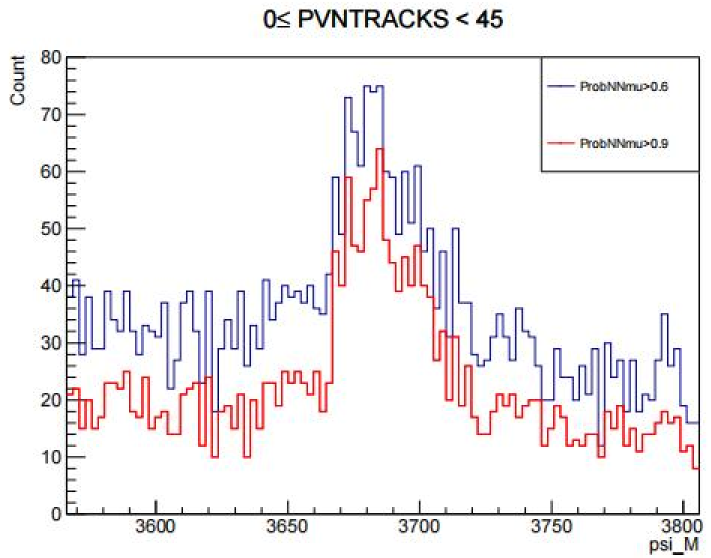

LHCb pp √s = 13 TeV
Normalised σψ(2S)/σJ/ψ
prompt
non-prompt
$N^{\mathrm{PV}}_{\mathrm{fwd}}/\langle N^{\mathrm{PV}}_{\mathrm{fwd}}\rangle_{\mathrm{NB}}$

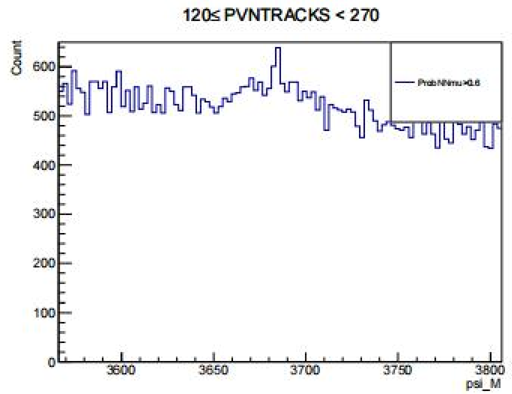
Good runs

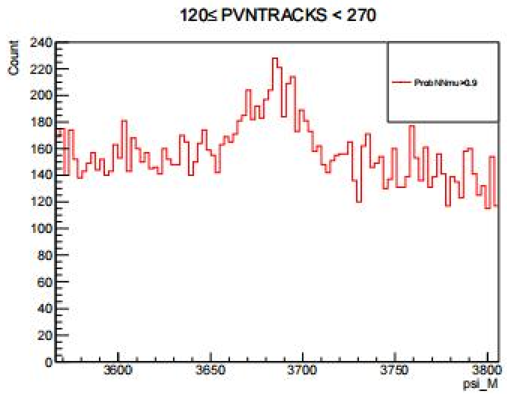
Table 1: List of good runs

pPb	
5519	186555, 186557, 186558, 186564, 186565
5520	186583, 186584, 186585, 186587, 186588, 186590
5521	186601, 186602, 186603, 186604, 186608, 186609, 186610, 186611, 186612, 186613
5522	186614, 186615, 186616, 186626, 186628, 186629, 186631, 186632, 186633, 186634, 186635, 186636, 186637, 186638, 186639
5523	186647, 186650, 186651, 186652, 186653, 186654, 186655, 186656
5524	186670, 186673
5526	186718, 186721, 186722, 186723, 186724, 186725, 186726, 186727
5527	186735, 186737, 186739, 186740, 186741, 186744, 186745, 186746
5533	186782, 186783, 186785, 186798, 186799, 186802, 186806, 186807
5534	186818, 186819, 186823, 186824
5538	186920, 186915, 186914, 186907, 186903, 186896,186890, 186884, 186879, 186876
Pbp	
5545	186989, 186990, 186991, 186992, 186993
5546	187002, 187005, 187007
5547	187015, 187018, 187019, 187020, 187021, 187023, 187025, 187026
5549	187038, 187040, 187042, 187043, 187044, 187045, 187047, 187048, 187049, 187050, 187051
5550	187058, 187061, 187062, 187063, 187064, 187065
5552	187074, 187078, 187080, 187082, 187083, 187083, 187084, 187085, 187086
5553	187106, 187109, 187110, 187111, 187112, 187113, 187115
5554	187123, 187124, 187127, 187128, 187129
5558	187178, 187182, 187183, 187184
5559	187198, 187199, 187202, 187203, 187204
5562	187229, 187230, 187232, 187233, 187234
5563	187244, 187247, 187248, 187249, 187250, 187251, 187252, 187253, 187254, 187255
5564	187266
5565	187282, 187283, 187289, 187290, 187291, 187292
5568	187325, 187328, 187329, 187330, 187331, 187332, 187333, 187334, 187335, 187336,
1873	37, 187339, 187340
5569	187348, 187349, 187350, 187351, 187355, 187357, 187358
5570	187372, 187375, 187376, 187377, 187378, 187380, 187381
5571	187389, 187392, 187393, 187394, 187395
5573	187406, 187409, 187410

cut


0≤ PVNTRACKS < 45
Count
psi_M
ProbNNmu>0.6
ProbNNmu>0.9


120≤ PVNTRACKS < 270
Count
psi_M

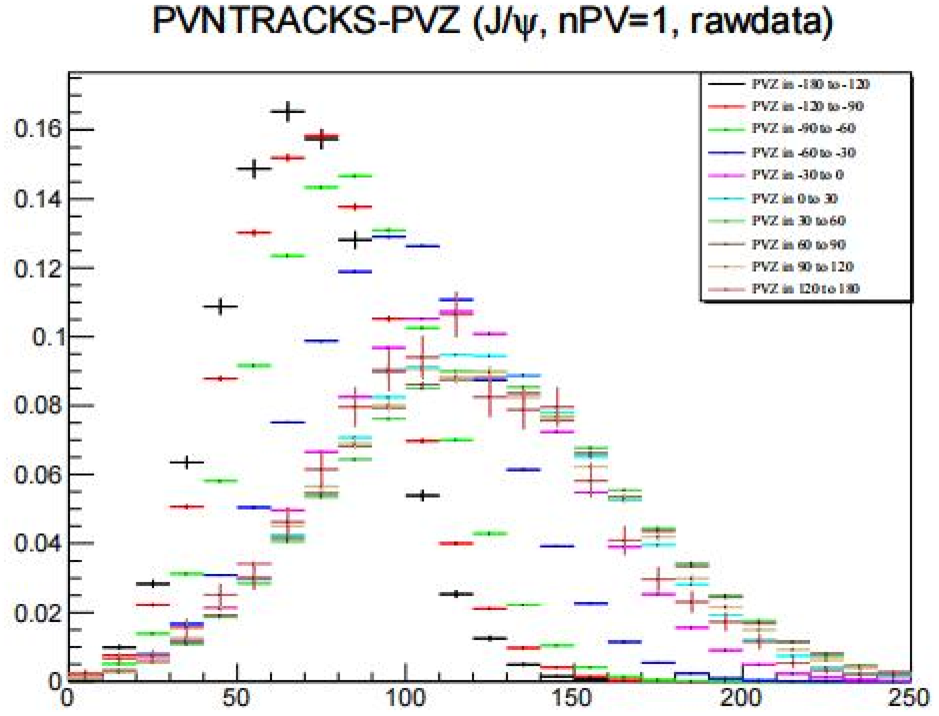

120≤ PVNTRACKS < 270
Count
psi_M

binning for mul

Table 8: Binning schemes for different multiplicity variables.

Configurations	Mult. Variables	Schemes	Mean (NoBias)
pPb	$N^{\mathrm{PV}}_{\mathrm{tracks}}$	4, 45, 70, 90, 120, 270	60.54
pPb	$N^{\mathrm{PV}}_{\mathrm{fwd}}$	0, 25, 43, 57, 72, 150	33.17
pPb	$N^{\mathrm{PV}}_{\mathrm{bwd}}$	0, 17, 29, 40, 54, 140	27.37
Pbp	$N^{\mathrm{PV}}_{\mathrm{tracks}}$	4, 60, 90, 120, 160, 330	69.54
Pbp	$N^{\mathrm{PV}}_{\mathrm{fwd}}$	0, 35, 65, 85, 110, 250	47.07
Pbp	$N^{\mathrm{PV}}_{\mathrm{bwd}}$	0, 13, 22, 30, 47, 120	22.47

PVZ


PVNTRACKS-PVZ (J/ψ, nPV=1, rawdata)
PVZ in -180 to -120
PVZ in -120 to -90
PVZ in -90 to -60
PVZ in -60 to -30
PVZ in -30 to 0
PVZ in 0 to 30
PVZ in 30 to 60
PVZ in 60 to 90
PVZ in 90 to 120
PVZ in 120 to 180
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
50
100
150
200
250