

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

IFT meeting

Speaker: Youen Kang

# Introduction

# Nuclear matter effect & collision systems

- Collision systems

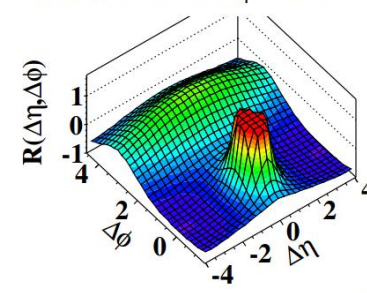
- A-A collisions: Both **Hot Nuclear Matter (HNM) effects** (related to the QGP → **Large systems** formation and evolution) and **Cold Nuclear Matter (CNM) effects** exist
- $p$ -A collisions: **CNM effects** dominate
- $pp$  collisions: **No** nuclear matter effect expected to exist

} **Small systems**

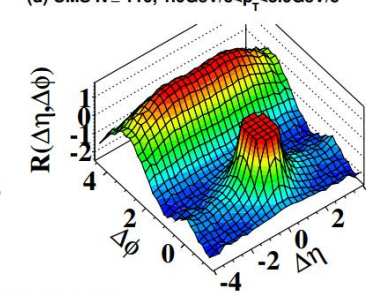
- QGP-like signatures found in high-multiplicity small system collisions:

- 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)

$pp$ : minimum bias  
(b) CMS MinBias,  $1.0\text{ GeV}/c < p_T < 3.0\text{ GeV}/c$



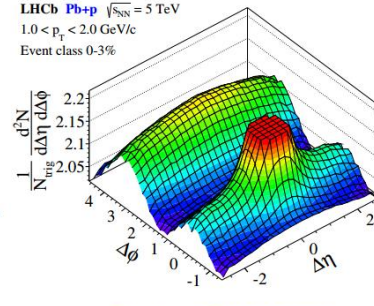
$pp$ : high multiplicity  
(d) CMS  $N \geq 110$ ,  $1.0\text{ GeV}/c < p_T < 3.0\text{ GeV}/c$



JHEP 09 (2010) 091

$p\text{Pb}$ : high multiplicity

LHCb  $\text{Pb}+p$   $\sqrt{s_{NN}} = 5\text{ TeV}$   
 $1.0 < p_T < 2.0\text{ GeV}/c$   
Event class 0-3%

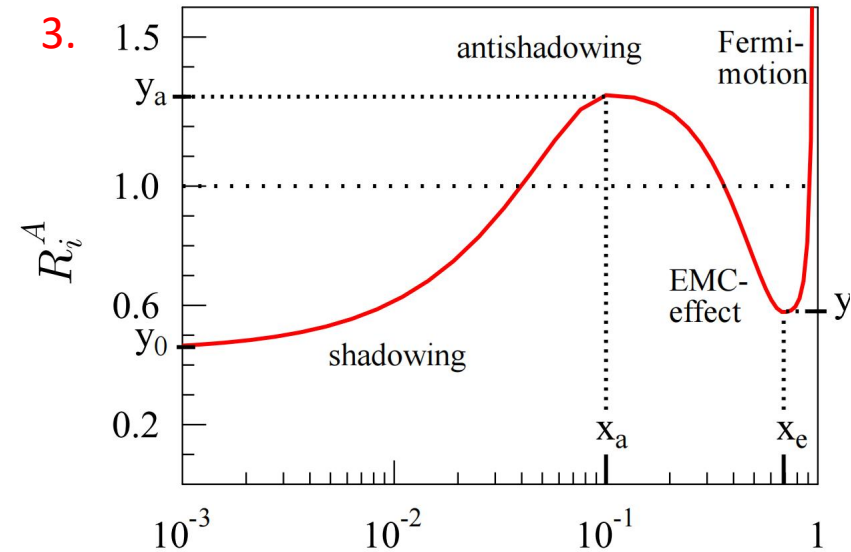
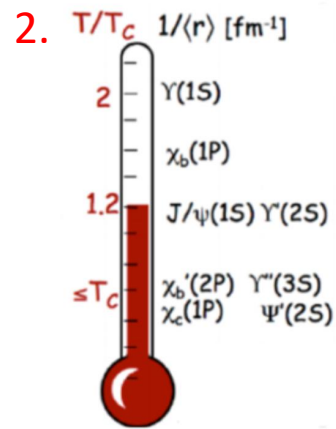
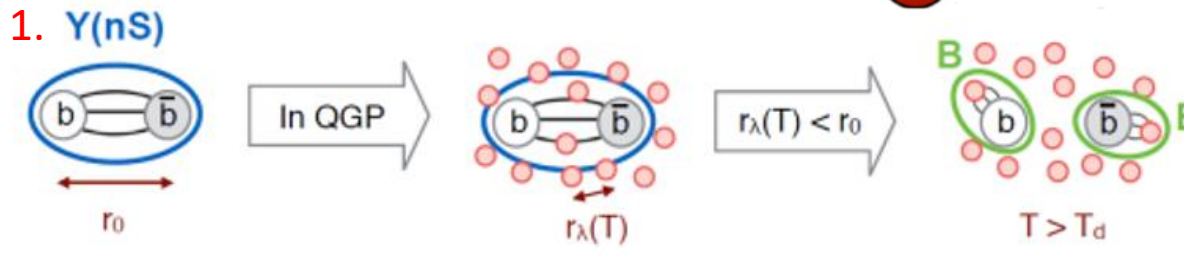


Phys. Lett. B762 (2016) 473

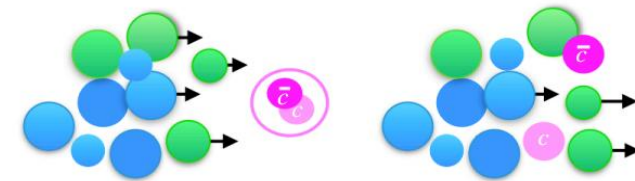
# Heavy quarkonium production

- Why  $q\bar{q}$ ?

1. Color screening in QGP
2. Sequential melting
3. Sensitive to initial-state effect
4. Probe for final-state effect



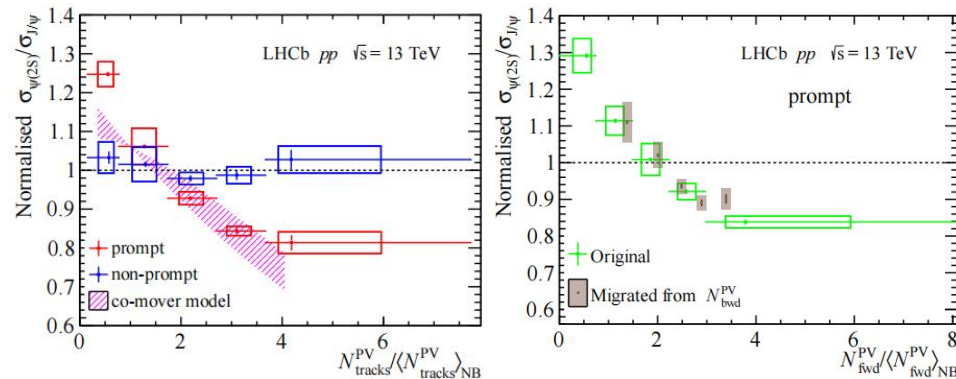
4. Co-mover effect: *Quarkonia are suppressed by interaction with the co-moving medium, constituted by particles with similar rapidities.* [JHEP 03 (2019) 063]



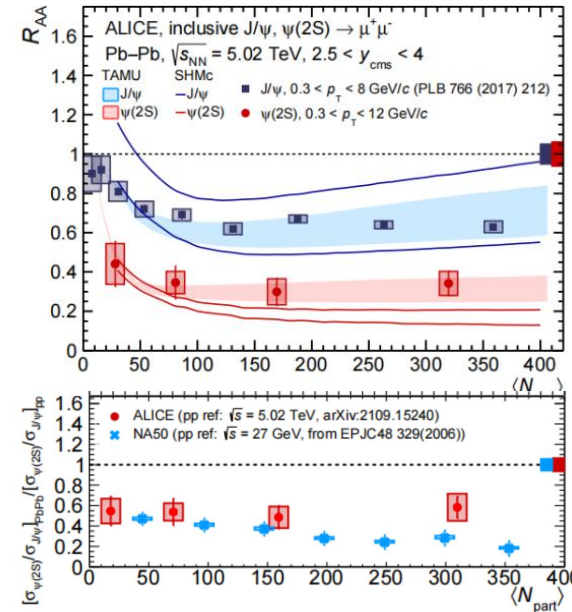
Breakup due to co-moving particles

# Experimental overview: ALLICE & CMS

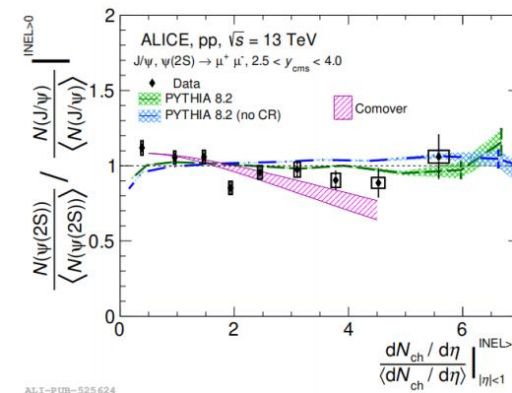
- ✓ Both  $\sigma_{\psi(2S)}$  and  $\sigma_{J/\psi}$  are strongly suppressed in PbPb collisions
- ✓  $\psi(2S)$  is **more suppressed** than  $J/\psi$  in PbPb collisions
- ✗  $\sigma_{\psi(2S)}/\sigma_{J/\psi}$  **does not** show multiplicity dependence in ALICE and CMS PbPb collisions measurements, nor in ALICE  $pp$ ,  $p$ Pb measurements



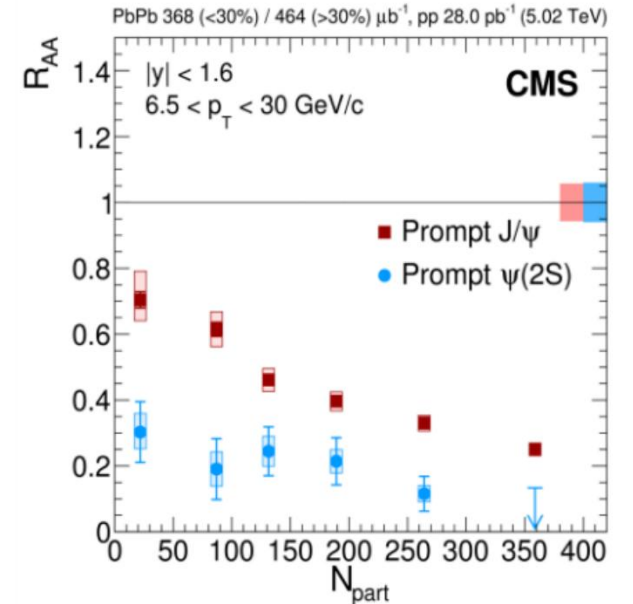
LHCb-PAPER-2023-035



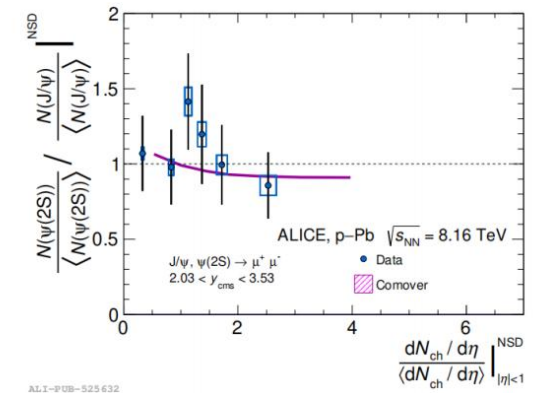
[EPI Web Conf. 276 (2023) 02002]



ALICE-PAPER-525 624



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



ALICE-PAPER-525 632

[arXiv:2207.13399 [nucl-ex]]

# Motivation

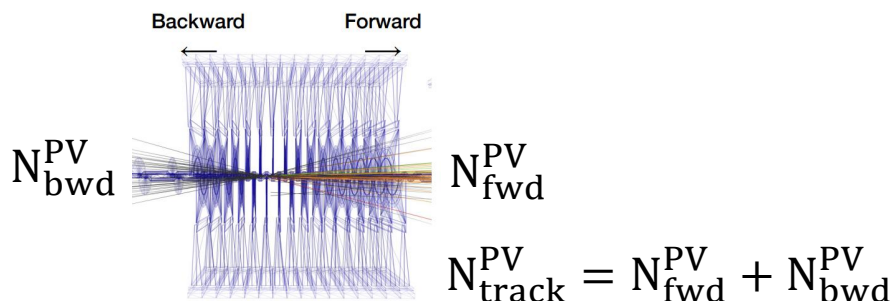
- Exploring the multiplicity dependence of  $\sigma_{\psi(2S)}/\sigma_{J/\psi}$  in  $p\text{Pb}$  collisions with different multiplicity variables
- Compare results in  $p\text{Pb}$  and  $\text{Pb}p$  collisions, in search of a transition from small system to large-system-like environment
- Compare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

# LHCb detector

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

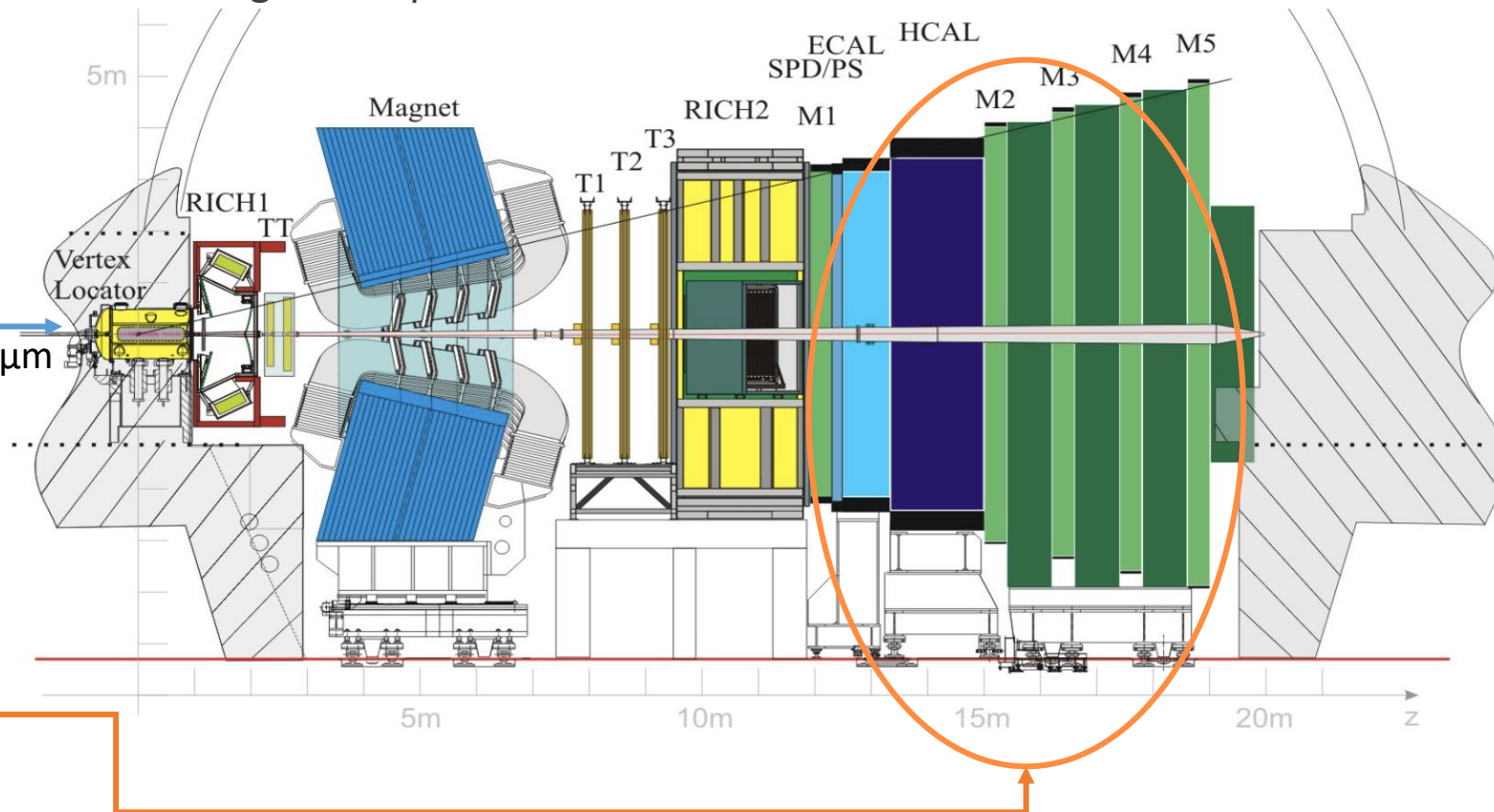
## Velo:

- Time resolution  $\sim 50\text{fs} \ll \tau_b$
- PV resolution  $\sim 13\mu\text{m}$
- prompt and non-prompt separation
- Impact parameter resolution:  $(15 + 29/p_T)[\text{GeV}]\mu\text{m}$



## Muon detector:

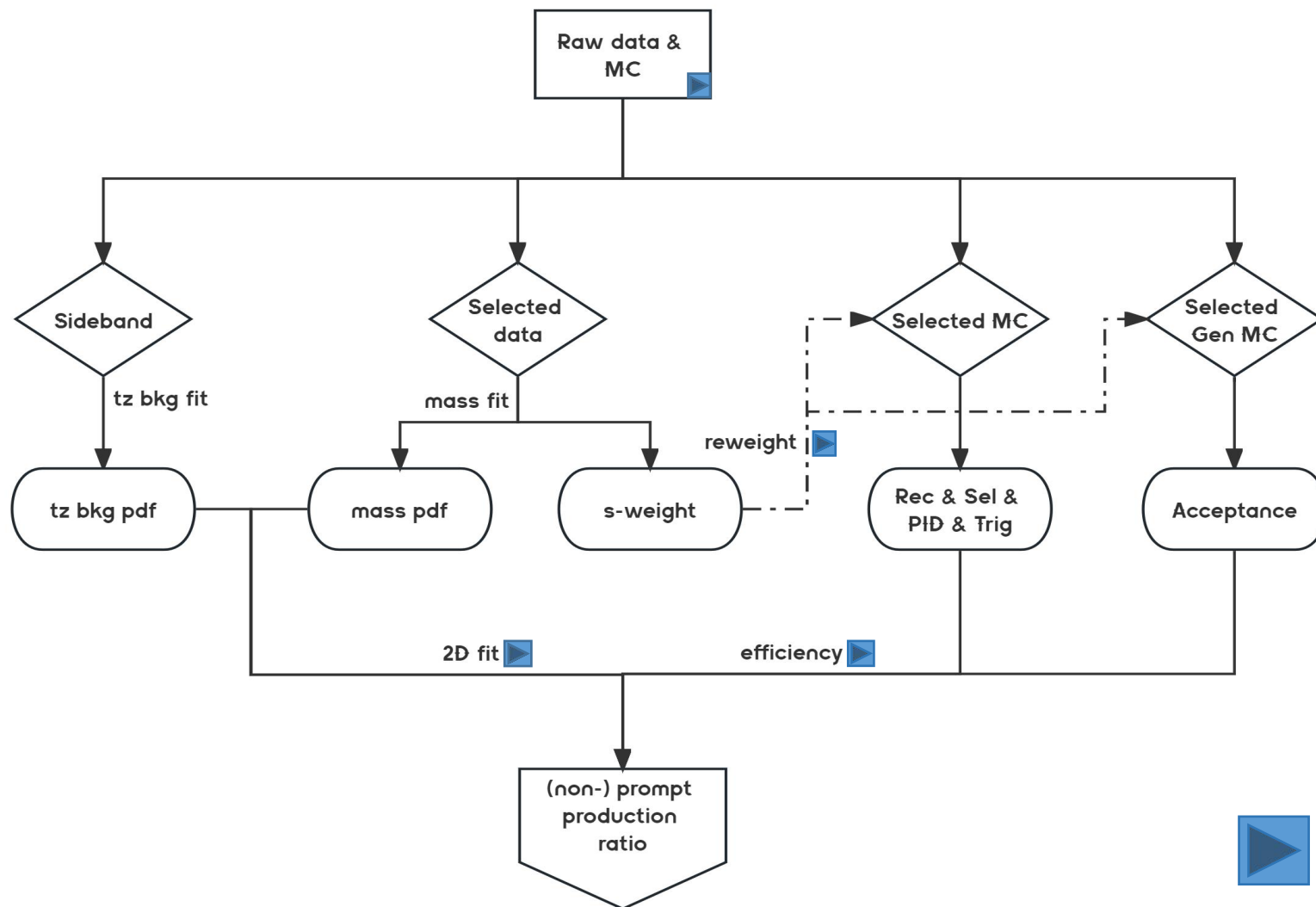
- High Muon ID  $\sim 97\%$ ,
- Mis ID for Pion to Muon  $1\% \sim 3\%$




# Analysis



# Analysis



 *Go to uncertainties*

# Data set

- **Data:**

- **Data taking period:** 2016
- **Collision type:**  $p\text{Pb}(\text{Pb}p)$  collisions
- **Integrated Luminosity:** 13.6 (20.8)  $\text{nb}^{-1}$
- **TCK:** 0x1138160F and 0x11381612
- **TriggerLine:**
  - LO: LOMuon
  - Hlt1: Hlt1DiMounHighMass

- **MC:**

- **EventType:** 24142001( $J/\psi$ ) 28142001( $\psi(2S)$ )
- **Sample size:** 4M for each type in  $p\text{Pb}$  and  $\text{Pb}p$
- **Generator:** EPOS
- **Sim. Version:** Sim09l

- **Offline selection**

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

- **Decay Channel:**

- $J/\psi \rightarrow \mu^+ + \mu^-$
- $\psi(2S) \rightarrow \mu^+ + \mu^-$

- **Bookkeeping path:**

- $p\text{Pb}$  /LHCb/Protonion16/Beam6500GeV-VeloClosed-MagDown/Real Data/Turbo03pLead/94000000/TURBO.MDST
- $\text{Pb}p$  /LHCb/Ionproton16/Beam6500GeV-VeloClosed-MagDown/Real Data/Turbo03pLead/94000000/TURBO.MDST

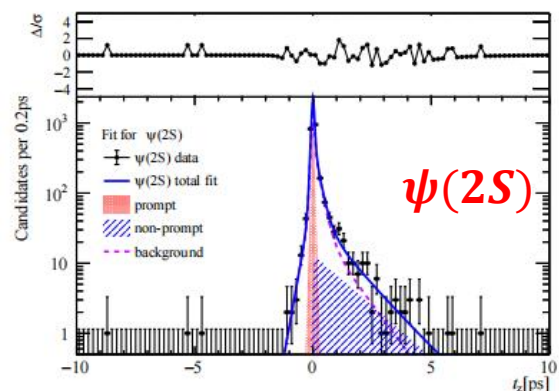
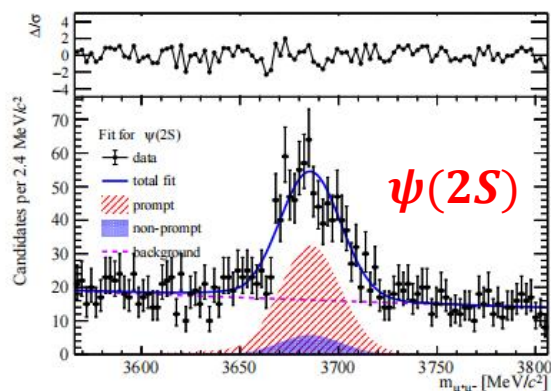
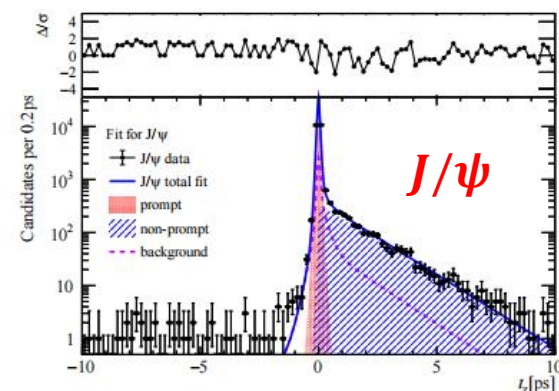
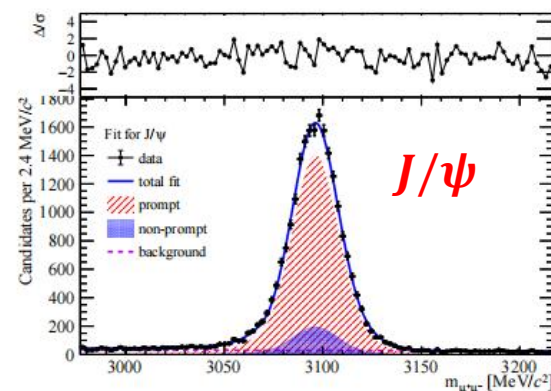
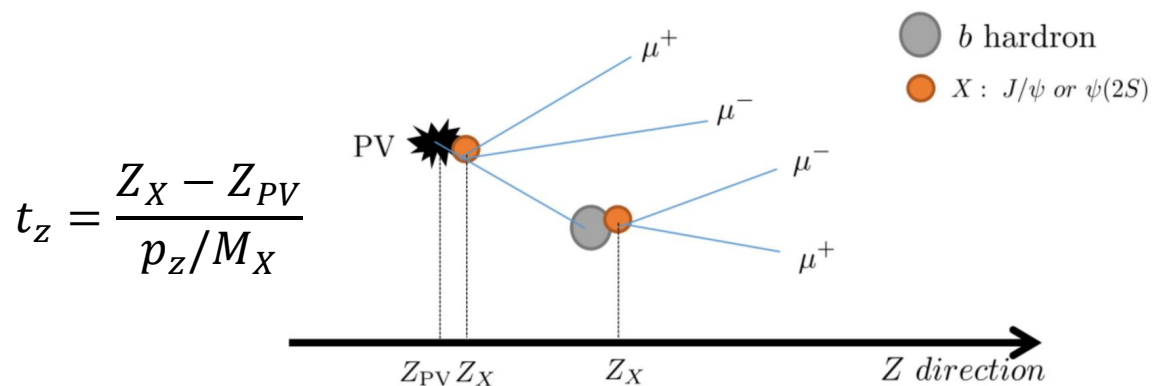
- $p\text{Pb}$  /MC/2016/pPb-Beam6500GeV-2560GeV-2016-MagDown-Fix1-Epos/Sim09l/Trig0x61421621/Reco16pLead/Turbo03/eventType/DST
- $\text{Pb}p$  /MC/2016/Pbp-Beam2560GeV-6500GeV-2016-MagDown-Fix1-Epos/Sim09l/Trig0x61421621/Reco16pLead/Turbo03/eventType/DST



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# 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:  $\delta$  function  $\otimes$  resolution function
      - non-prompt: exponential decay
    - bkg: extacted from sideband



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# Efficiency

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

where,

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

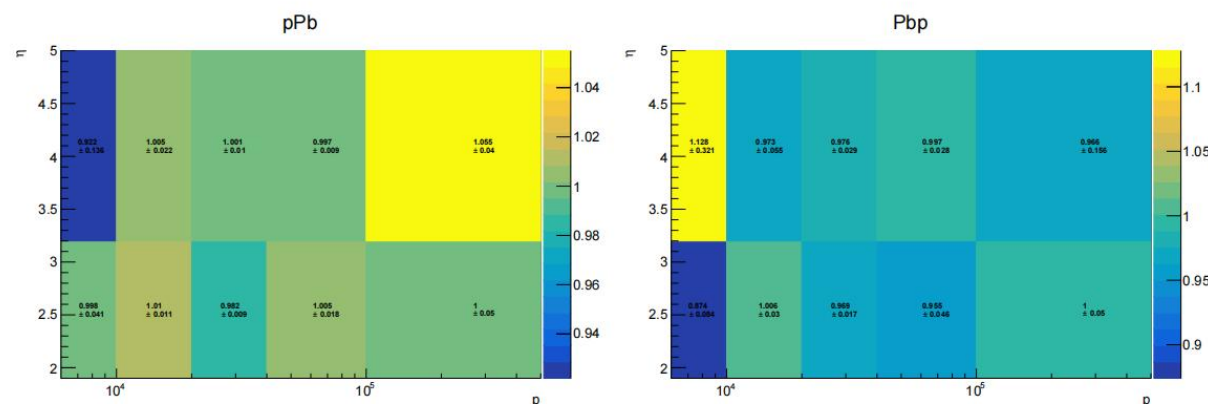
$$\epsilon_{\text{Reco\&Sel}} \equiv \frac{N(p_{\text{T}}, y) \text{ reconstructed and selected (w/o } \mu \text{ ID)}}{N(p_{\text{T}}, y) \text{ with both } \mu \text{ in LHCb acceptance}}$$

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

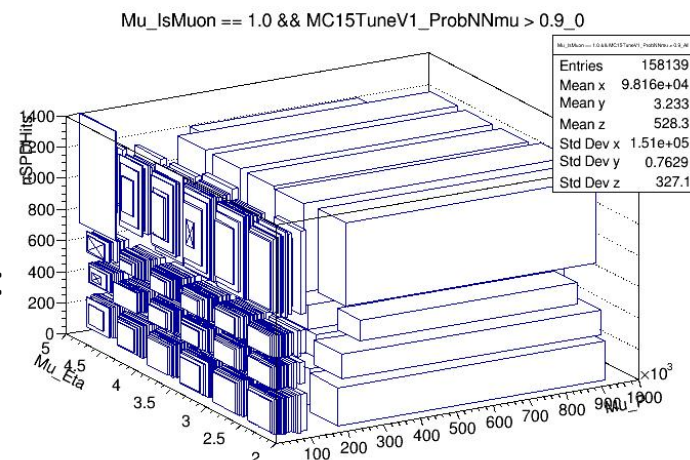
$$\epsilon_{\text{Trigger}} \equiv \frac{N(p_{\text{T}}, y) \text{ triggered}}{N(p_{\text{T}}, y) \text{ selected including } \mu \text{ID requirement}}$$

All the efficiency are calculated from Monte-Carlo simulation.

Tracking correction table:



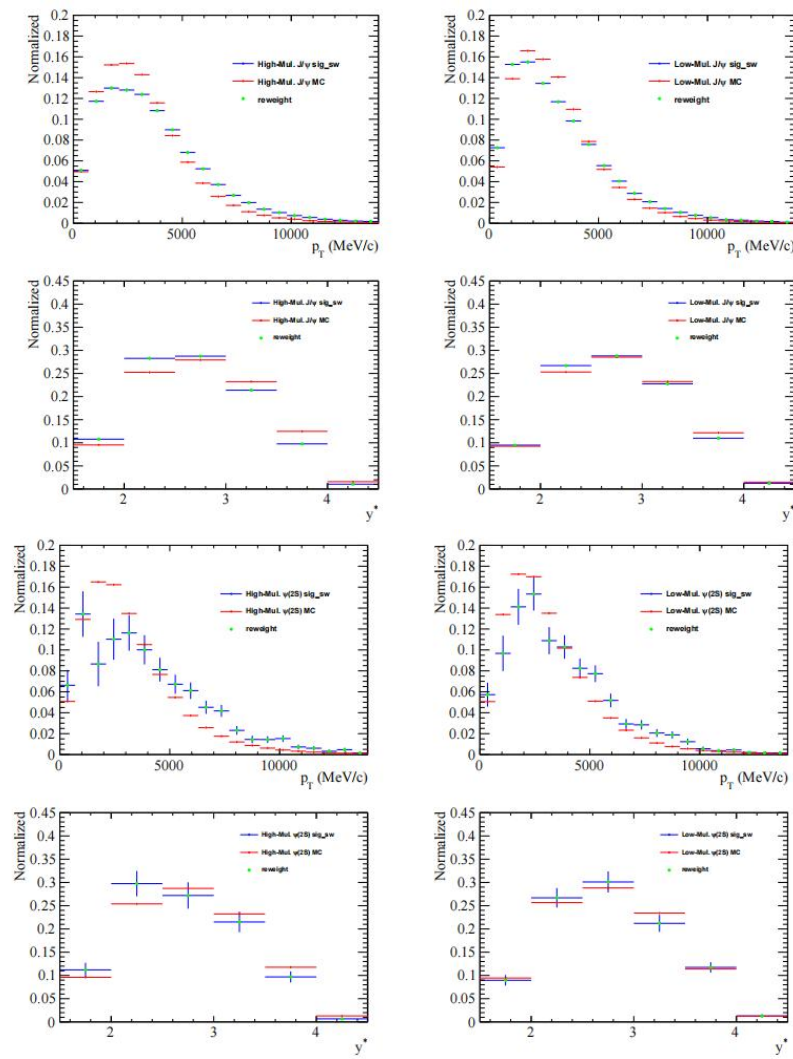
Visualization of PID table from PIDCalib:



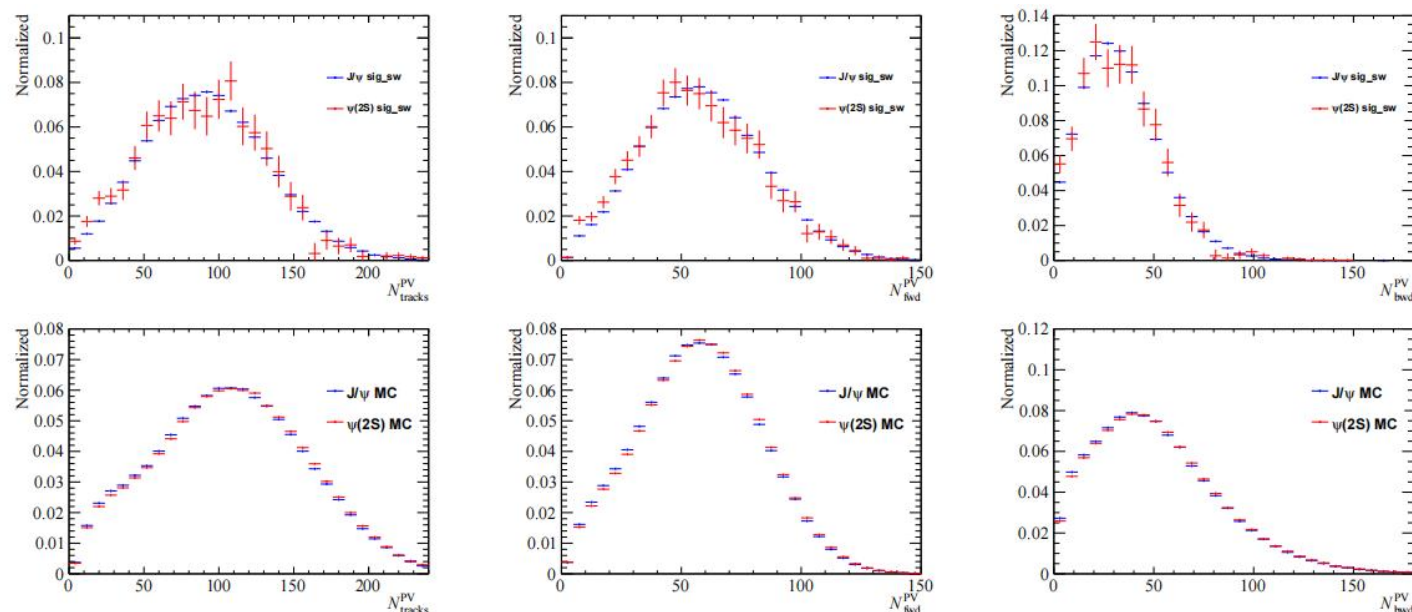
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# Reweight

$p_T$  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  $J/\psi$  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)

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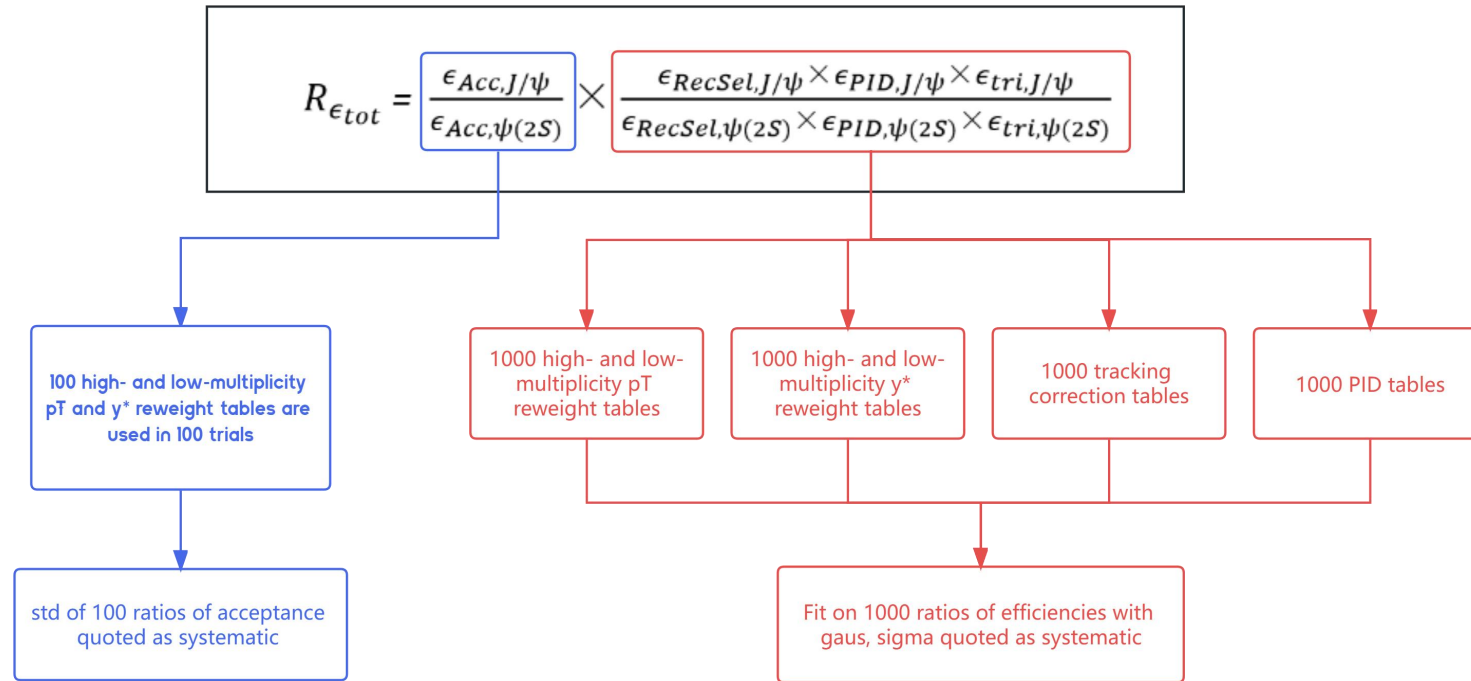


# Systematic uncertainties

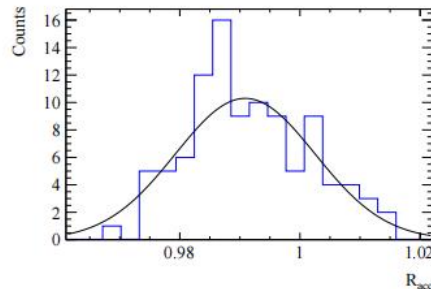
source		$p\text{Pb}$	$\text{Pb}p$
L0&HLT		3.2%-3.9%	3.6%-4.1%
part I 	Tracking Table Uncertainty& PID Table Uncertainty& $p_T$ spectrum& $y$ spectrum	1.7%-3.6%	2.1%-3.6%
	PID Table scheme	0.4%-1.7%	0.1%-1.8%
	Imperfectly simulating acceptance	0.8%-1.2%	0.9%-1.3%
	$\frac{\mathcal{B}(J/\psi \rightarrow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

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# Systematic uncertainties

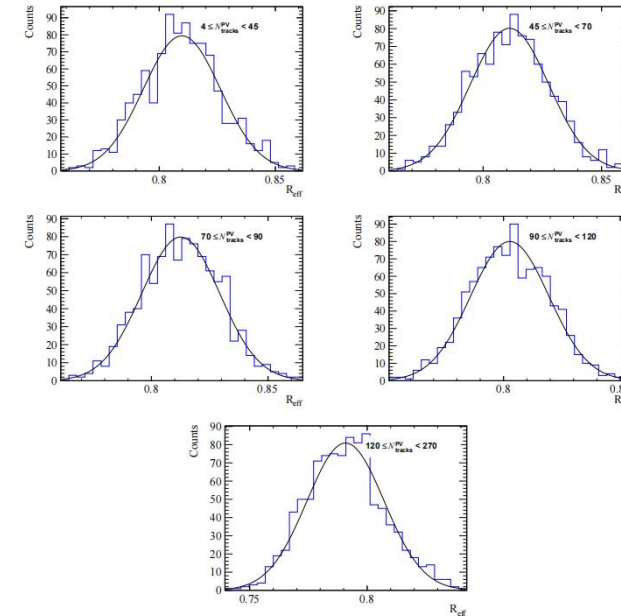


$$R_{acc} = \frac{\epsilon_{acc,J/\psi}}{\epsilon_{acc,\psi(2S)}} = 0.991 \pm 0.012.$$



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

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

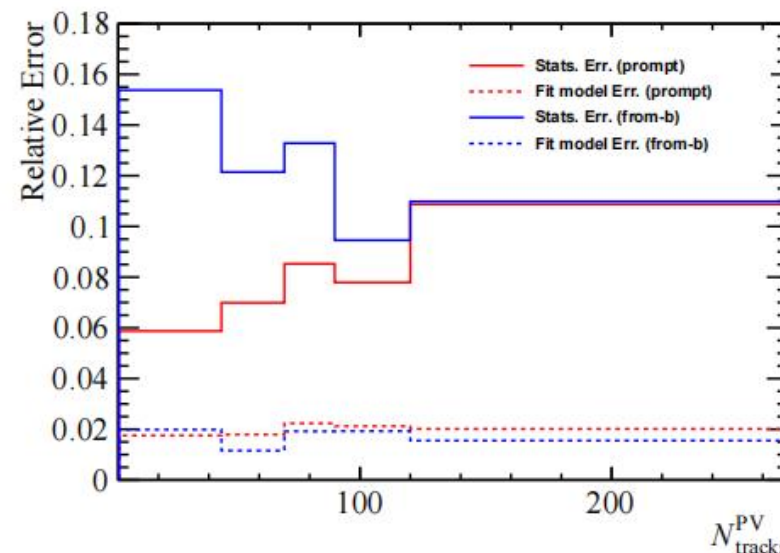


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# Systematic uncertainties

1. Fit model: variation due to different models v.s. stats. uncertainty.
2. Systematic uncertainty due to limit MC sample size  $\sim 0.1\%$ .
3. Systematic uncertainty due to global cut on multiplicity ( $n_{\text{VeloCluster}} < 8000$ )  $< 0.1\%$ .
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
$p\text{Pb}$	$N_{\text{tracks}}^{\text{PV}}$	2.7%	3.9%	3.9%
$p\text{Pb}$	$N_{\text{fwd}}^{\text{PV}}$	3.2%	3.0%	3.2%
$p\text{Pb}$	$N_{\text{bwd}}^{\text{PV}}$	2.7%	3.9%	3.9%
$\text{Pb}p$	$N_{\text{tracks}}^{\text{PV}}$	2.0%	3.8%	3.8%
$\text{Pb}p$	$N_{\text{fwd}}^{\text{PV}}$	1.7%	3.6%	3.6%
$\text{Pb}p$	$N_{\text{bwd}}^{\text{PV}}$	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:  $\mathcal{B}_{\psi(2S)}\sigma_{\psi(2S)}/\mathcal{B}_{J/\psi}\sigma_{J/\psi}$ :

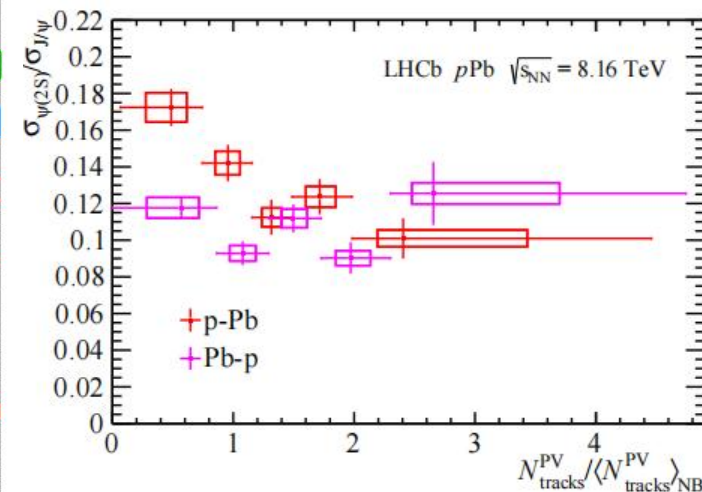
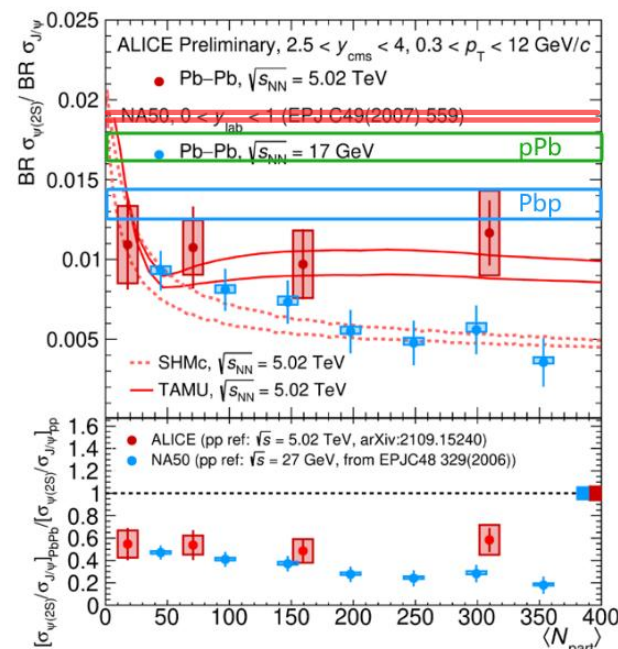
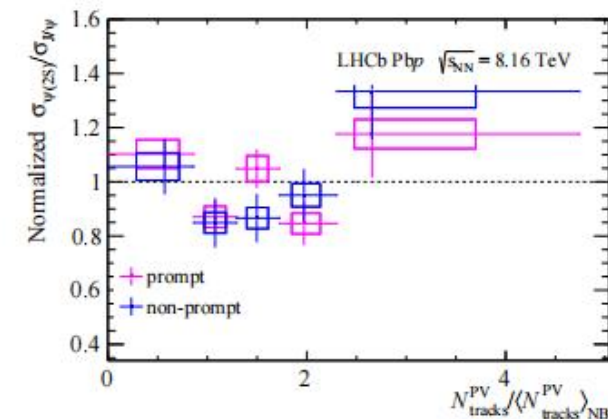
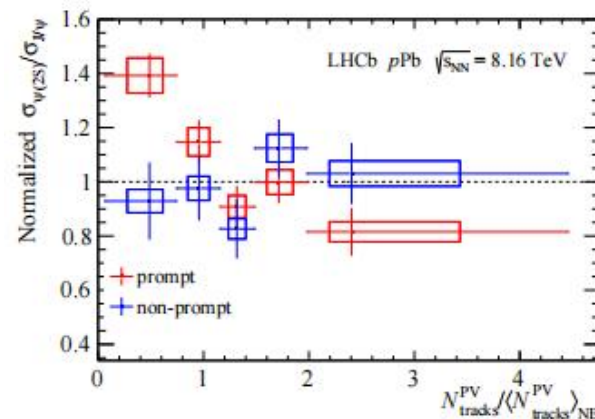
Pbp:  $(1.353 \pm 0.090)\%$

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

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

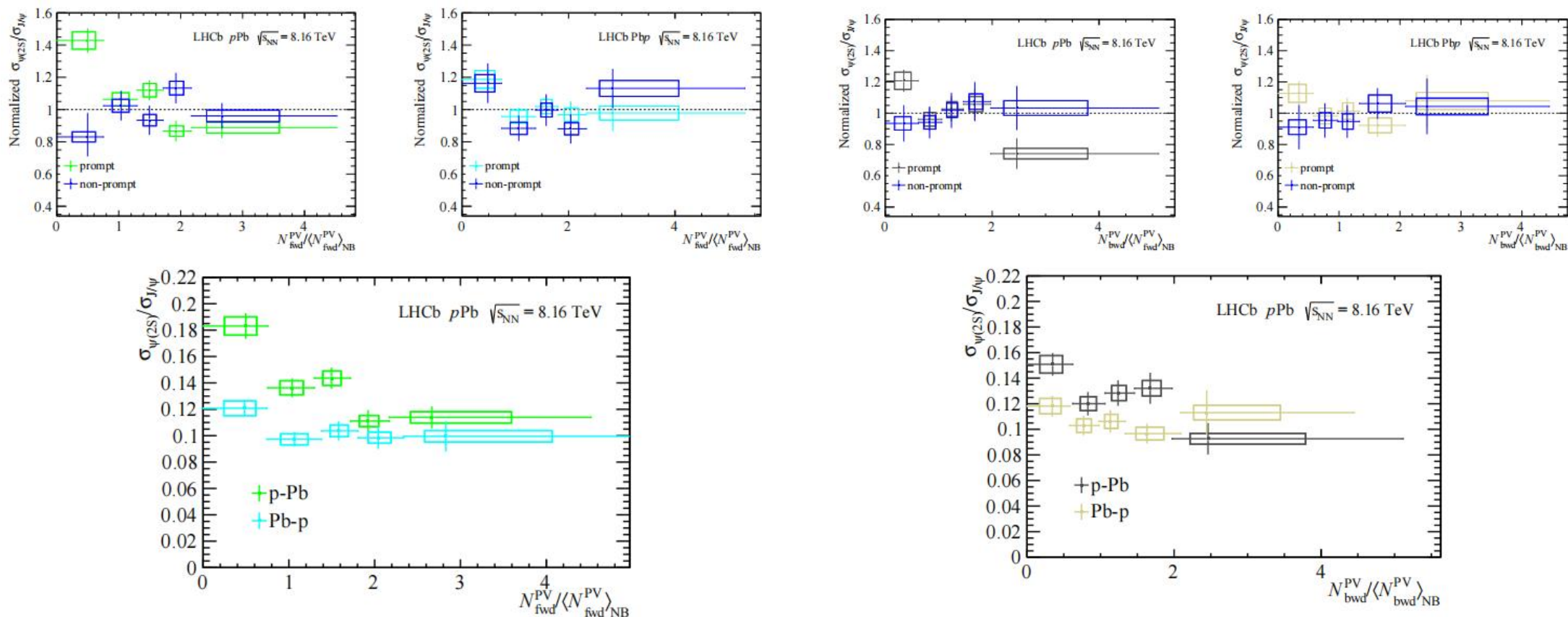
4. From the perspective of prompt ratio v.s. multiplicity:

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



# Results

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



One more conclusion: prompt ratio decrease slower with  $N_{\text{bwd}}^{\text{PV}}$  than  $N_{\text{fwd}}^{\text{PV}}$  in pPb, similar to pp collisions

# Resources

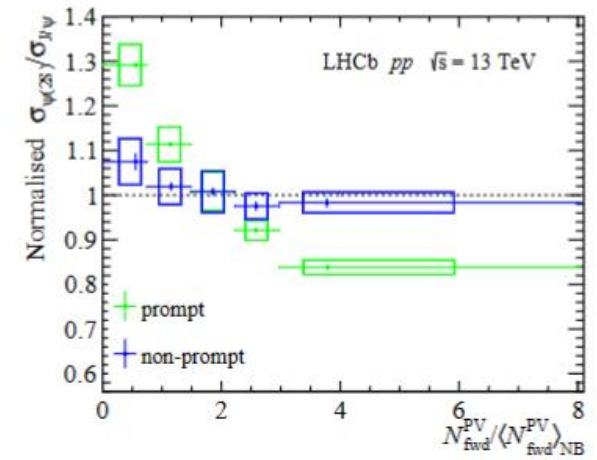
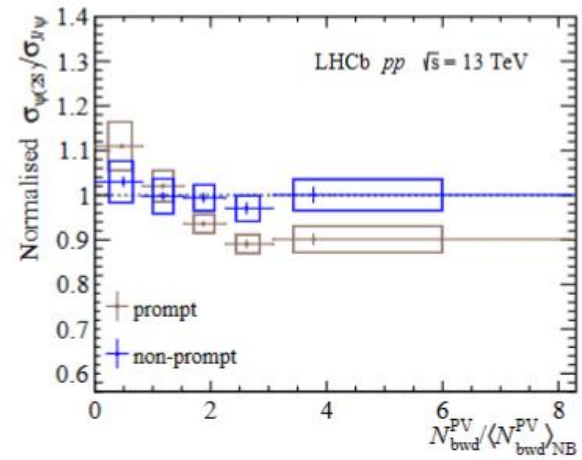
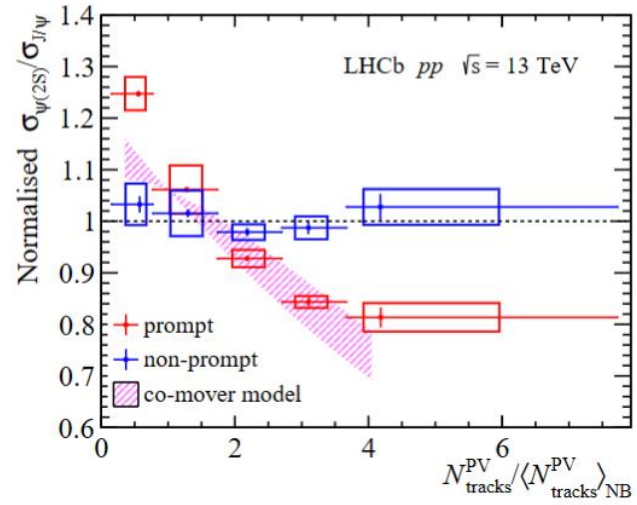
- Twikipage: <https://twiki.cern.ch/twiki/bin/viewauth/LHCbPhysics/Psi2StoJpsiRatio8TeVpPb>
- AnaNote: <https://www.overleaf.com/read/mfpgrjgmdxwj#45ea55>
- Tuple in EOS: `/eos/lhcb/wg/IonPhysics/analyses/psi2S_over_jpsi_vs_MuL_pPb_8TeV`
- gitlab for analysis code: [https://gitlab.cern.ch/lhcb-ift/psi2s\\_over\\_jpsi\\_vs\\_mul\\_p\\_pb8tev](https://gitlab.cern.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 same 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



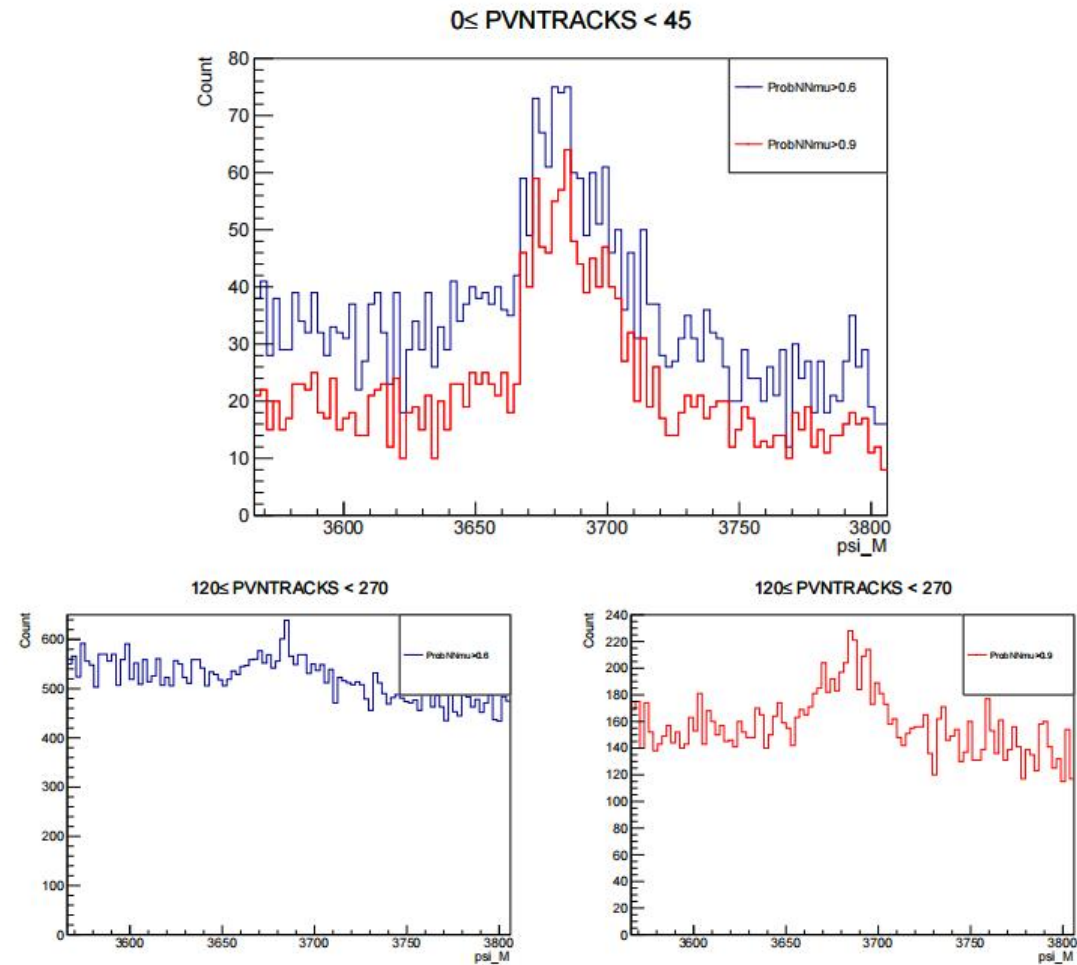
# Good runs

Table 1: List of good runs

$p\text{Pb}$	
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
$\text{Pb}p$	
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, 187337, 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



# binning for mul

Table 8: Binning schemes for different multiplicity variables.

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



# PVZ

