J/ψ PRODUCTION VS MULTIPLICITY IN p-Pb and pp COLLISIONS WITH ALICE AT THE LHC

ALICE

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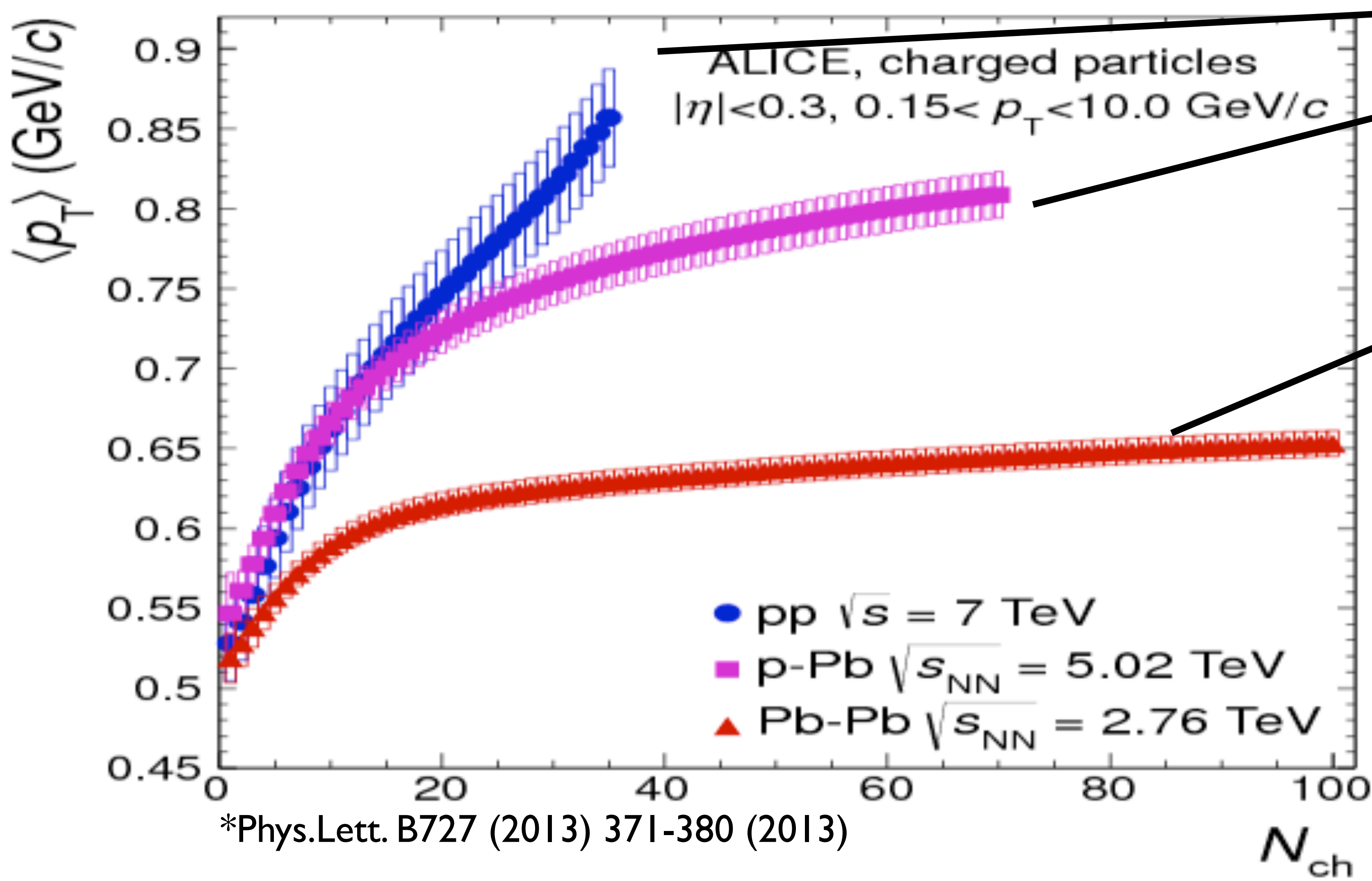
OUTLINE

- Motivation
- Analysis
  - Multiplicity study
  - Signal extraction and $< p_T >$
- Results
  - Relative yields vs charged particle multiplicity
  - Relative $<p_T>$ vs charged particle multiplicity
- Outlook

MOTIVATION

The objective of this analysis is to study the correlation of the J/Ψ yield and its <p_T> with the number of charged particles produced in the collision.

We will compare the results obtained in p-Pb, Pb-p (5.02 TeV) and p-p (8 TeV) to try to get some insight on the particle production mechanism as in* :



Collective effects at very high multiplicities?

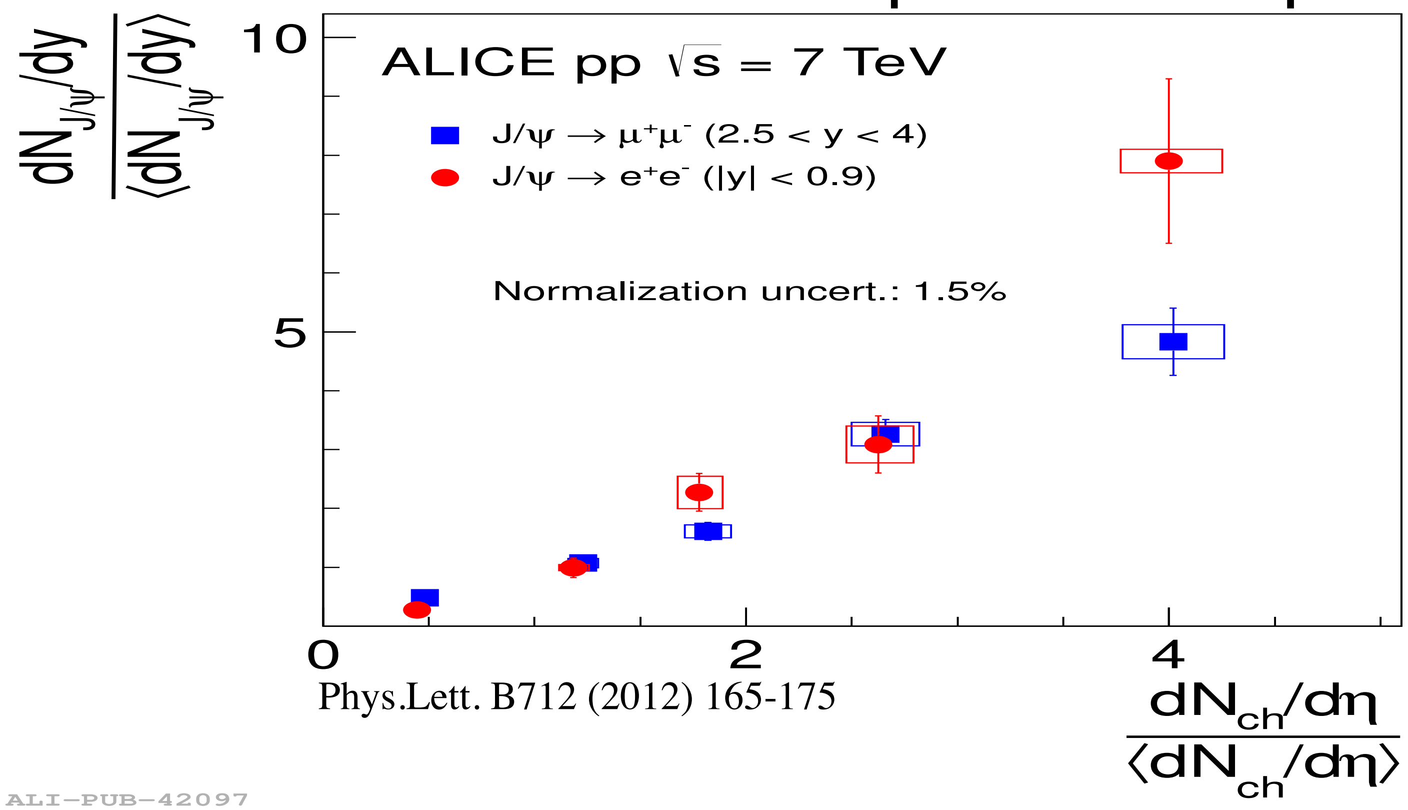
Particles thermalize in the medium

*Phys.Lett. B727 (2013) 371-380 (2013)

*Multiplicity dependence of the average transverse momentum in pp, p-Pb and Pb-Pb collisions at the LHC

MOTIVATION

Comparison with previous results:



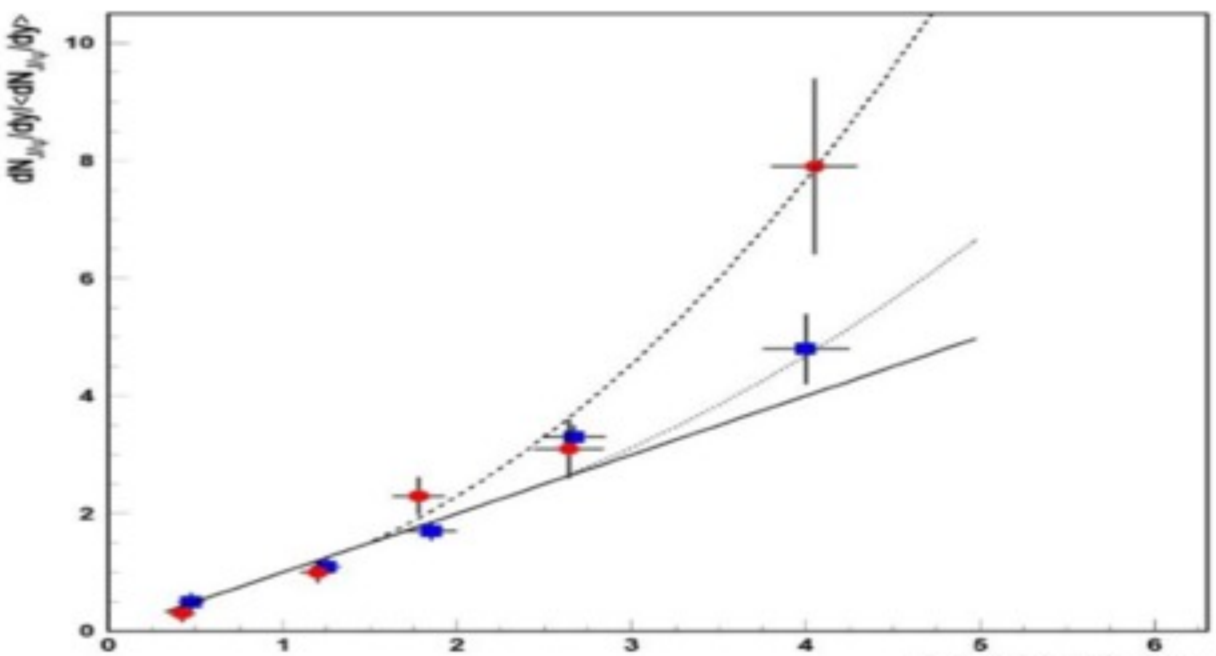
Phys.Lett. B712 (2012) 165-175

In pp at 8 TeV we are able to reach higher multiplicities, which means rarer events

Comparison with models:

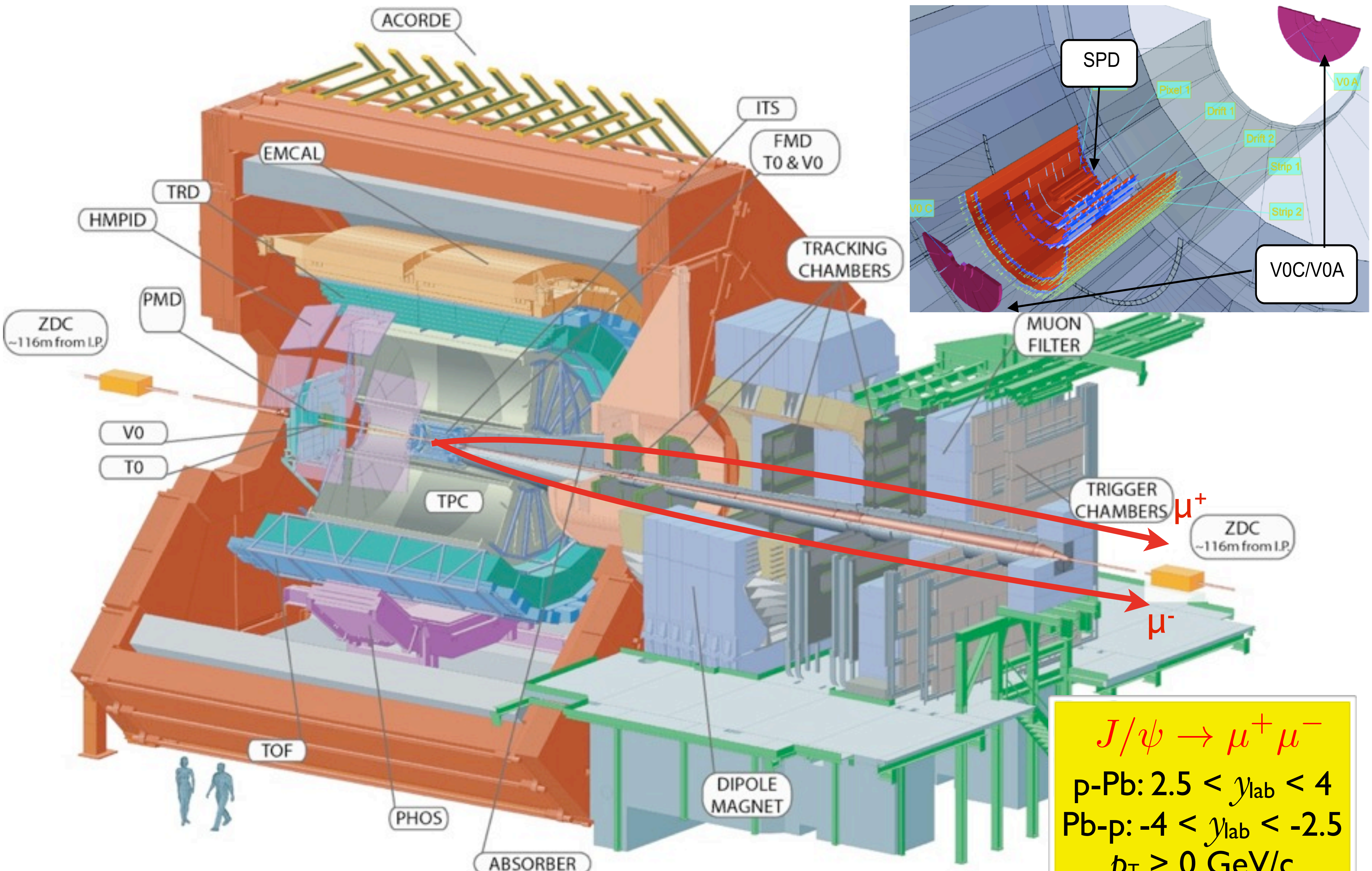
Model: Assuming proportionality of number of J/ψ with the number of initial parton-parton interactions

The results of this analysis can help us to put more constrains in this kind of models



Phys. Rev. C 86, 034903 (2012)

THE ALICE DETECTOR



$J/\psi \to \mu^+\mu^-$

p-Pb: 2.5 < y_{lab} < 4

Pb-p: -4 < y_{lab} < -2.5

p_T > 0 GeV/c

DATA SELECTION

- **Event selection**
  - Dimuon trigger = Minimum Bias (MB) trigger (Coincidence of the two VZERO ($2.8 < \eta^{lab} < 5.1$ and $-3.7 < \eta^{lab} < -1.7$)) & two opposite sign muon tracks in the trigger chambers
  - Rejection of beam-gas and electromagnetic interactions
  - SPD used for vertex determination and charged particle multiplicity measurement
    - SPD vertex Quality Assurance (QA):
      - ✓ Z_v^{SPD} resolution < 0.25 cm
      - ✓ $|\text{Primary } Z_v^{SPD} - \text{Primary } Z_v^{TPC+ITS}| < 0.5$ cm
      - ✓ Number of contributors $n_{contr} > 0$
  - $|Z_{vertex}| < 10$ cm (due to SPD acceptance for multiplicity estimation)
- **Dimuon analysis cuts**
  - Muon trigger matching
  - $-4 < \eta_{\mu}^{lab} < -2.5$
  - 17.6 cm < R_{abs} < 89.5 cm (R_{abs} is the track radial position at the end of the absorber)
  - $2.5 < y_{\mu\mu}^{lab} < 4$

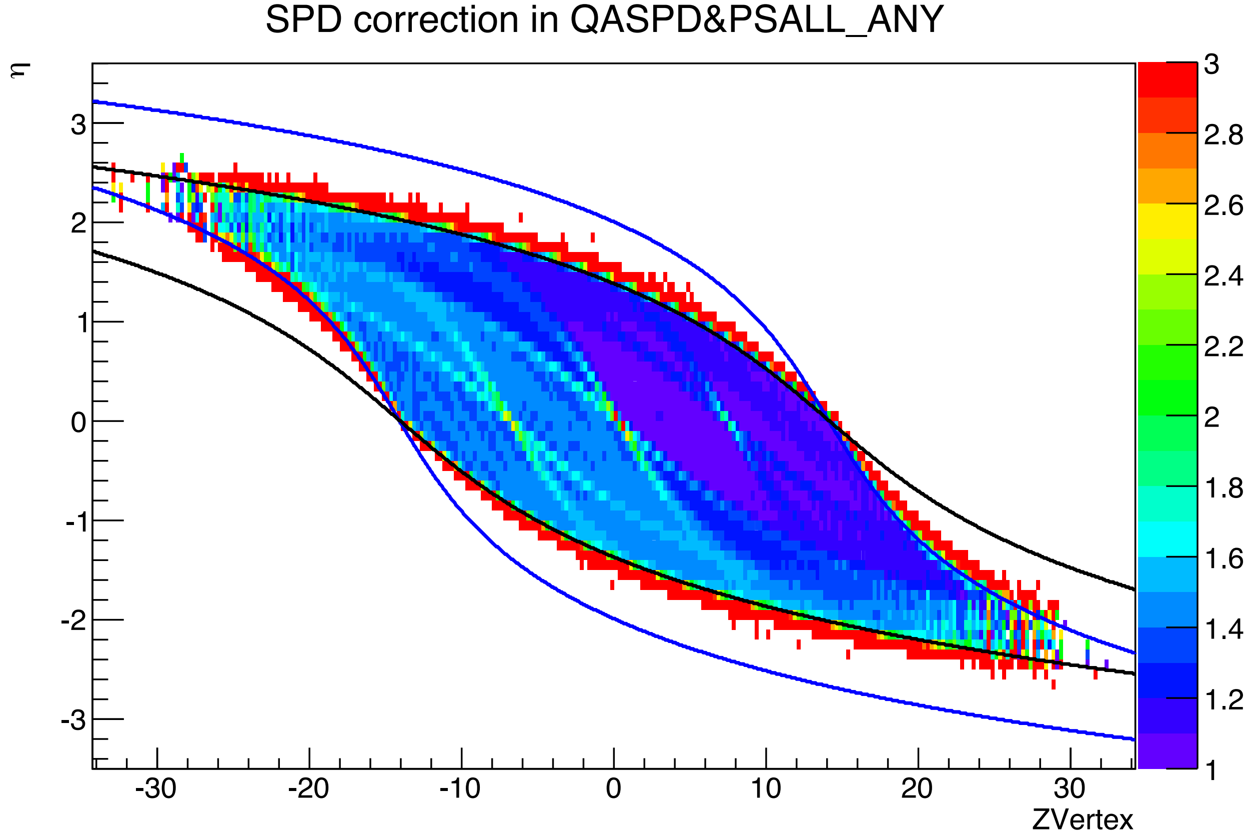
MULTIPLICITY DETERMINATION

We have two different methods to estimate the **charged particle multiplicity** from the **number of tracklets measured in the SPD**:

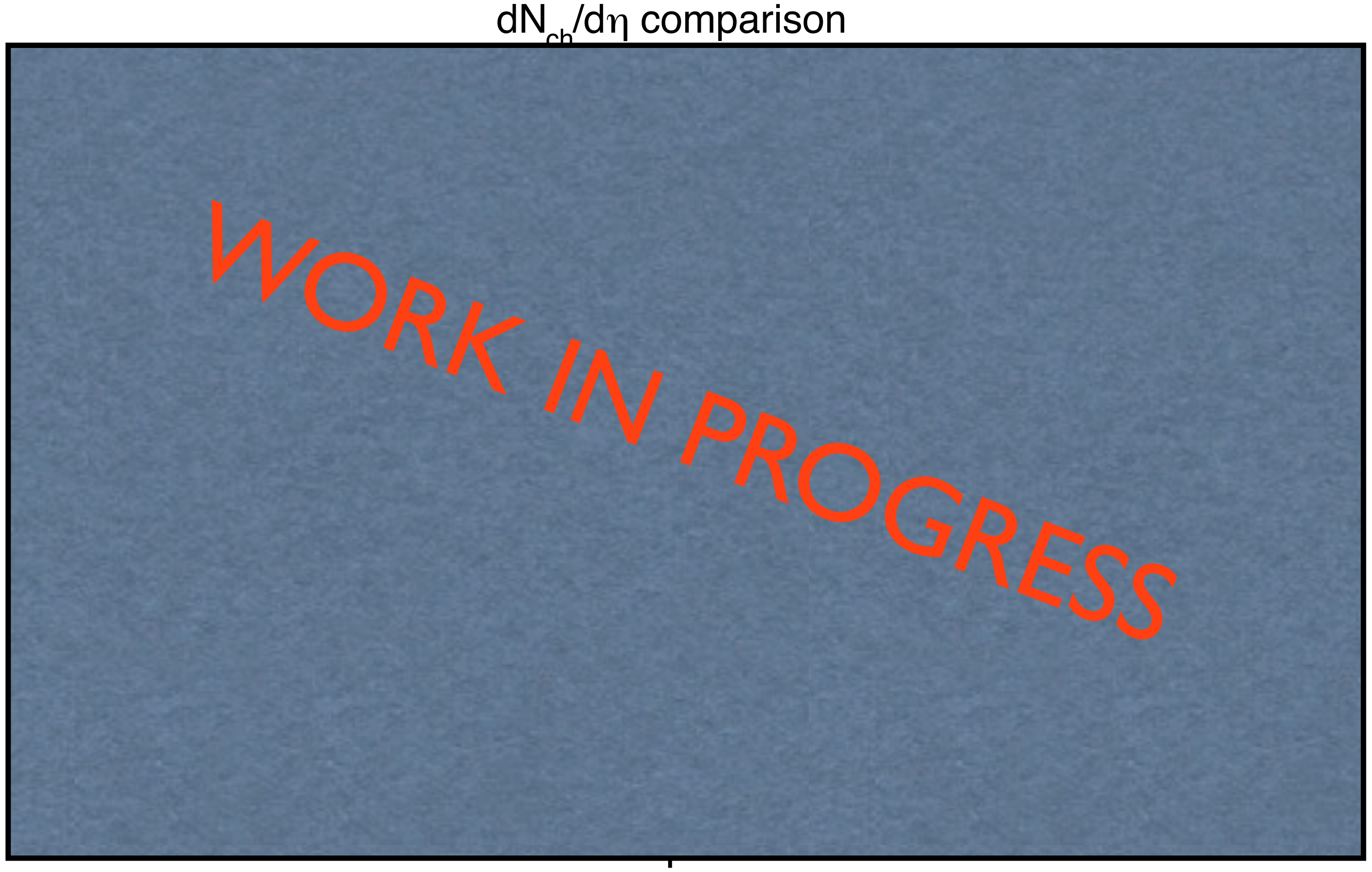
- **SPD AccxEff correction** of the number of tracklets :
  - Allows to correlate J/Ψ with the absolute multiplicity $dN_{ch}/d\eta$
  - Restricted to $|\eta_{tracklets}| < 0.5$ to be within the acceptance of the detector.
  - Need MC simulations to get the SPD AccxEff and to deal with the N_{ch} inelastic efficiency corrections.
- **"Mean corrected"** number of tracklets. Data-driven correction :
  - Allows to correlate J/Ψ only with the relative multiplicity $dN_{ch}/d\eta / \langle dN_{ch}/d\eta \rangle$
  - We can go to $|\eta_{tracklets}| < 1$, direct to compare with previous publications
  - Need also MC simulations

SPD AccxEff CORRECTION

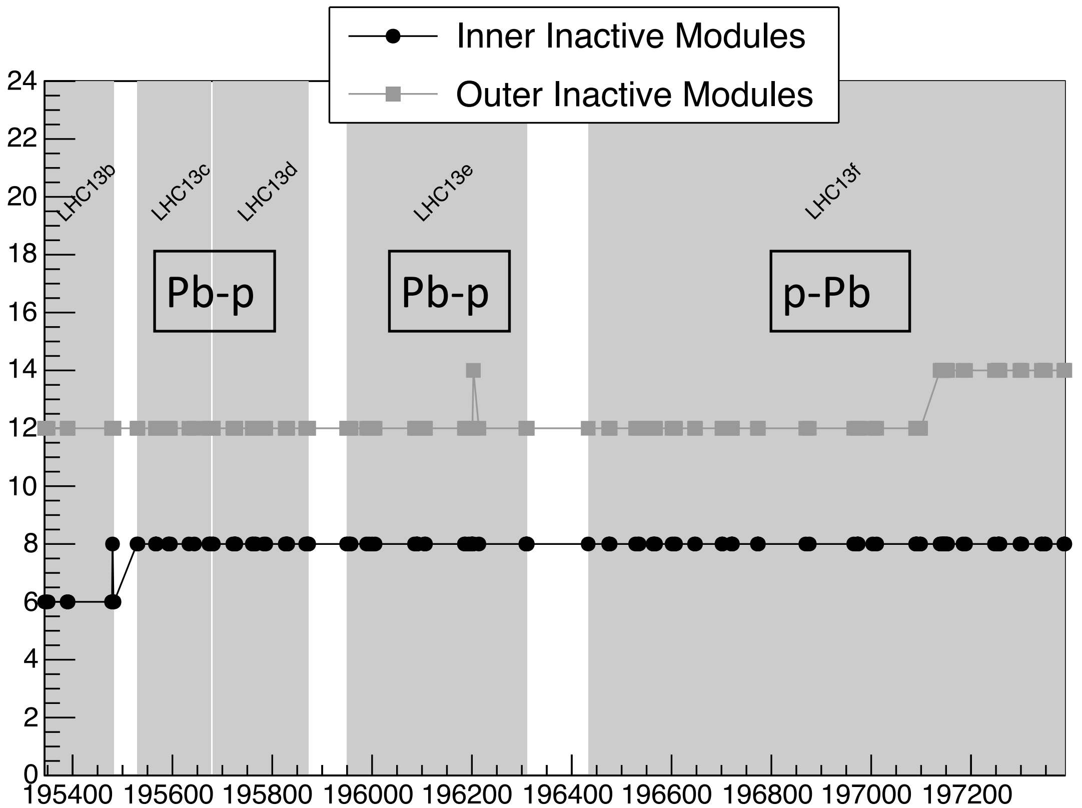
generated charged particles / detected tracklets



$|\eta| < 2.0$ & $|Z_v| < 18.0$ in run 195644 (LHC13c) MB

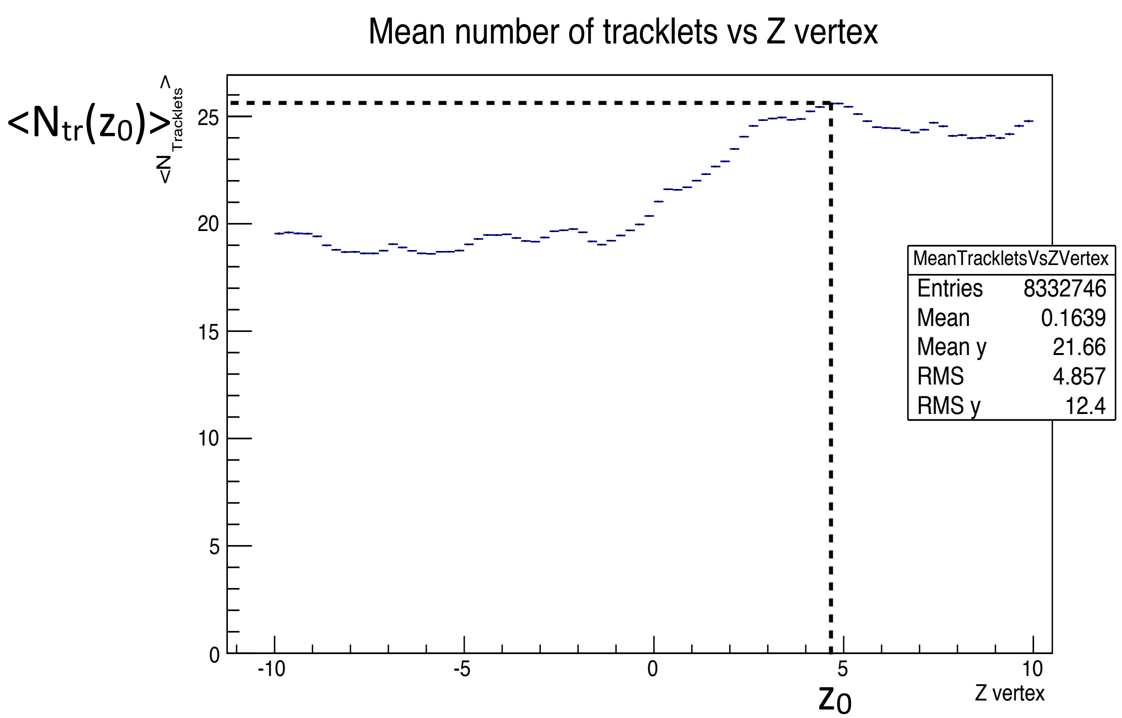


Our estimation is correct => **we can rely on our $dN_{ch}/d\eta$ computation**



Need a specific MC production for each period. Tests have been made (see backup) but still resolving some issues

"MEAN CORRECTION"



Note: for this method we use also $|\eta_{\text{tracklets}}| < 0.5$

- $<N_{tr}(z_0)>$ is a reference value, the maximum value of the $<N_{tr}>$ vs Z_v^{SPD} distribution
- $<N_{tr}(z)>$ is the $<N_{tr}>$ for the Z_v^{SPD} of the event
- $N_{tr}(z)$ is the number of tracklets of the event

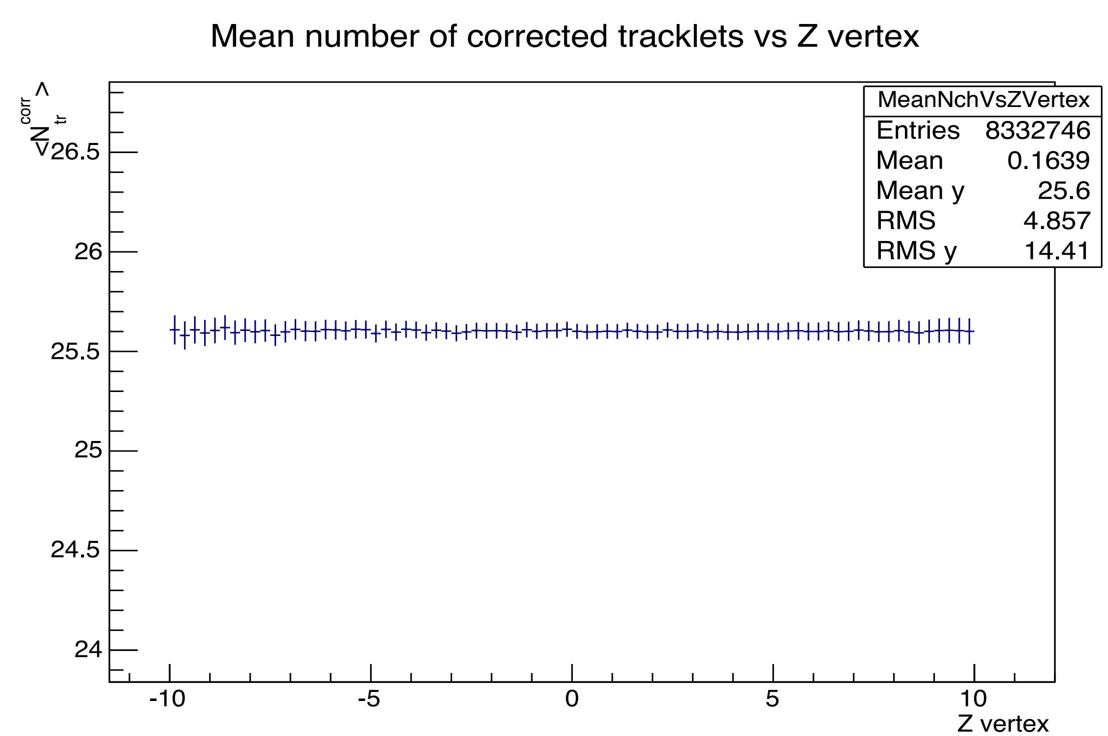
$$N_{tr}^{corr}(z) = N_{tr}(z)\frac{< N_{tr}(z_0) >}{< N_{tr}(z) >}$$

The correction is the same for each Z_v^{SPD}. We need to introduce the natural fluctuations to the correction:

$$\Delta N = N_{tr}(z)\frac{< N_{tr}(z_0) > - < N_{tr}(z) >}{< N_{tr}(z) >}$$

The correction is generated randomly with a Poissonian distribution centered at ΔN, so:

$$\boxed{N_{tr}^{corr} = N_{tr} + \Delta N_{rand}}$$



CORRECTION TO $<N_{tr}>$

From simulations we know that

$N_{ch} \propto N^{corr}_{tr}$ $\Rightarrow$ $$\frac{N^{corr}_{tr}}{< N^{corr}_{tr} >} = \frac{dN_{ch}/d\eta}{< dN_{ch}/d\eta >}$$

We need to have into account the mean number of tracklets of events w/o reconstructed SPD vertex (0) and the mean number of tracklets of events not seen by the MB trigger condition:

$$< N^{corr}_{tracklets} > = \epsilon_{MB} \underbrace{\left((1-\epsilon_{\overline{SPDQA}})\cdot < N^{corr}_{tracklets} >_{measured} + \epsilon_{\overline{SPDQA}} \cdot < N^{corr}_{tracklets} >_{\overline{SPDQA}}\right)}_{< N^{corr}_{tracklets} >_{MB}} + (1-\epsilon_{MB})\cdot < N^{corr}_{tracklets} >_{\overline{MB}}$$

ϵ_{MB} → ~ 0.96 for pA

ϵ_{MB} → ~ 0.74 for pp @ 7TeV

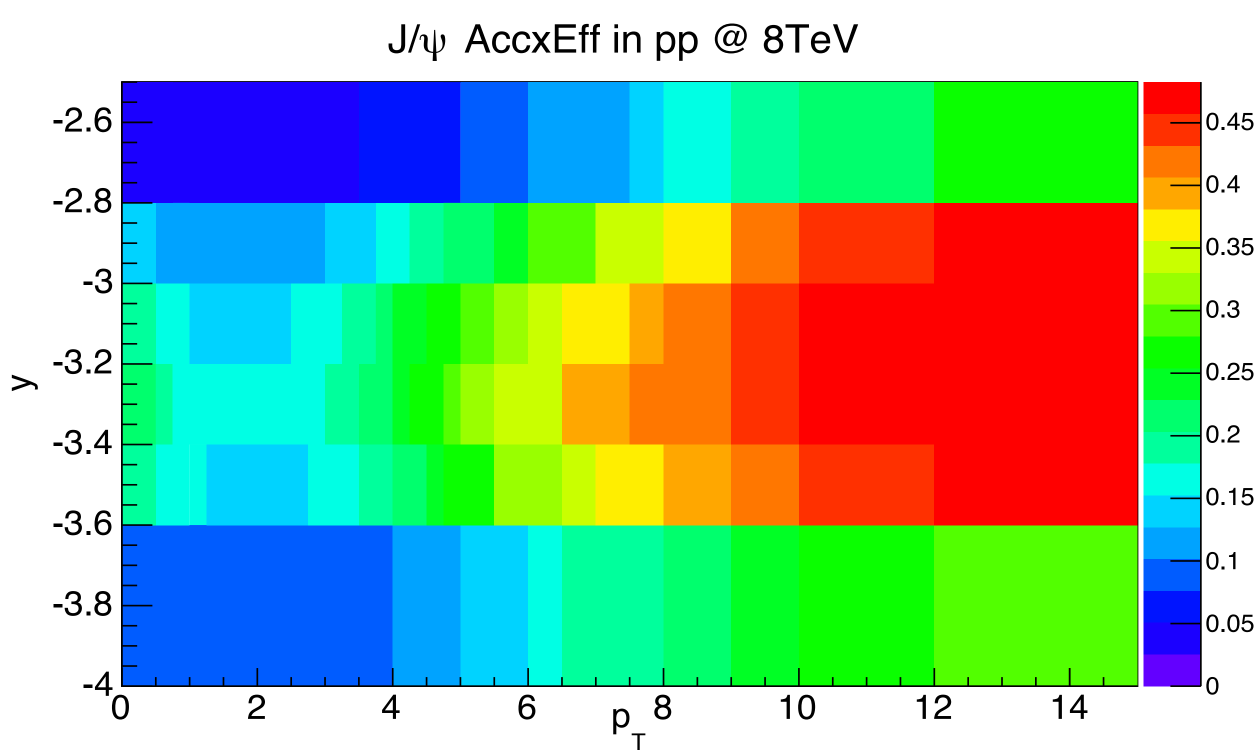
Since we don't know yet the mean number of tracklets for events not seen by the MB we take this as a source of systematic uncertainty by taking the two extreme situations:

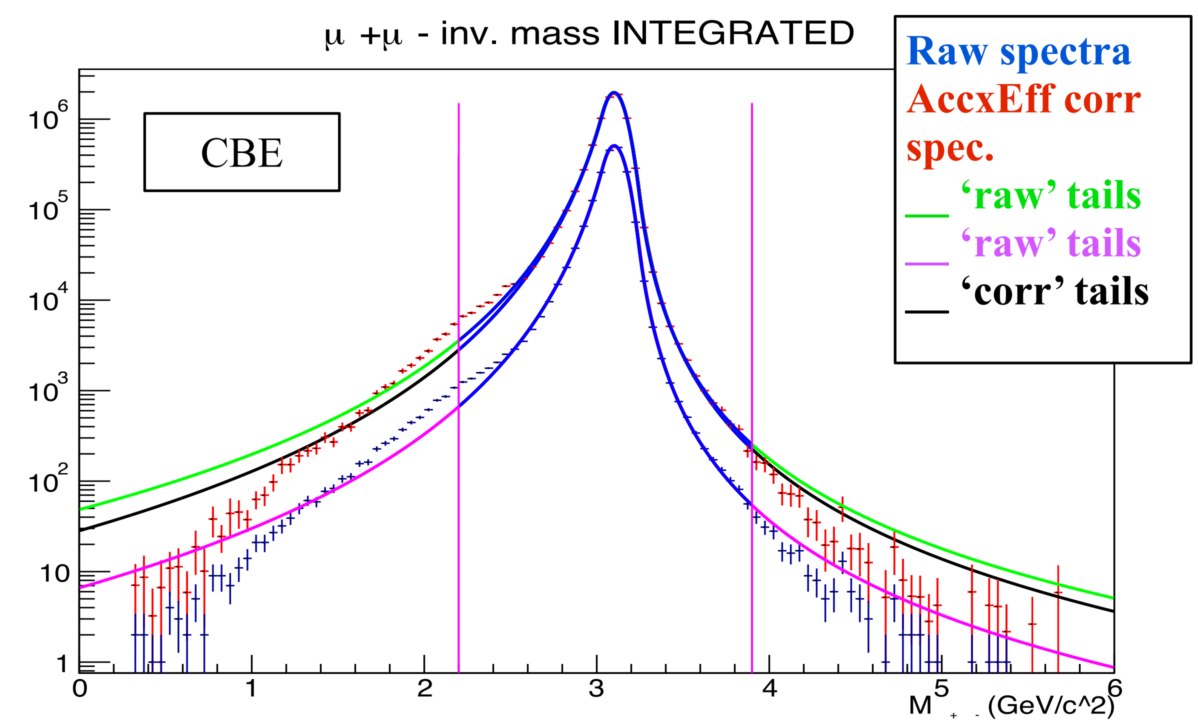
$$\boxed{< N^{corr}_{tracklets} >_{\overline{MB}} \longrightarrow 0 \text{ - } < N^{corr}_{tracklets} >_{MB}}$$

J/ψ SIGNAL EXTRACTION

Need the Muon Spectrometer's AccxEff corrected J/Ψ and Ψ' signals to fit the $<p_T>$ distributions :
To get the M_{inv} spectra we **weight each dimuon pair with J/Ψ 1/Acc×Eff(p_T,y)**

- **Fitting functions for signal :** Crystal ball extended (CBE) and NA60
  - **Tails parameters :** Fixed from the J/Ψ AccxEff corrected MC
- **Fitting function for background :** VWG, POL2xEXP.
- **Fitting range :** 2 - 5 , 2.2- 4.7 GeV/c^2





J/ψ SIGNAL EXTRACTION

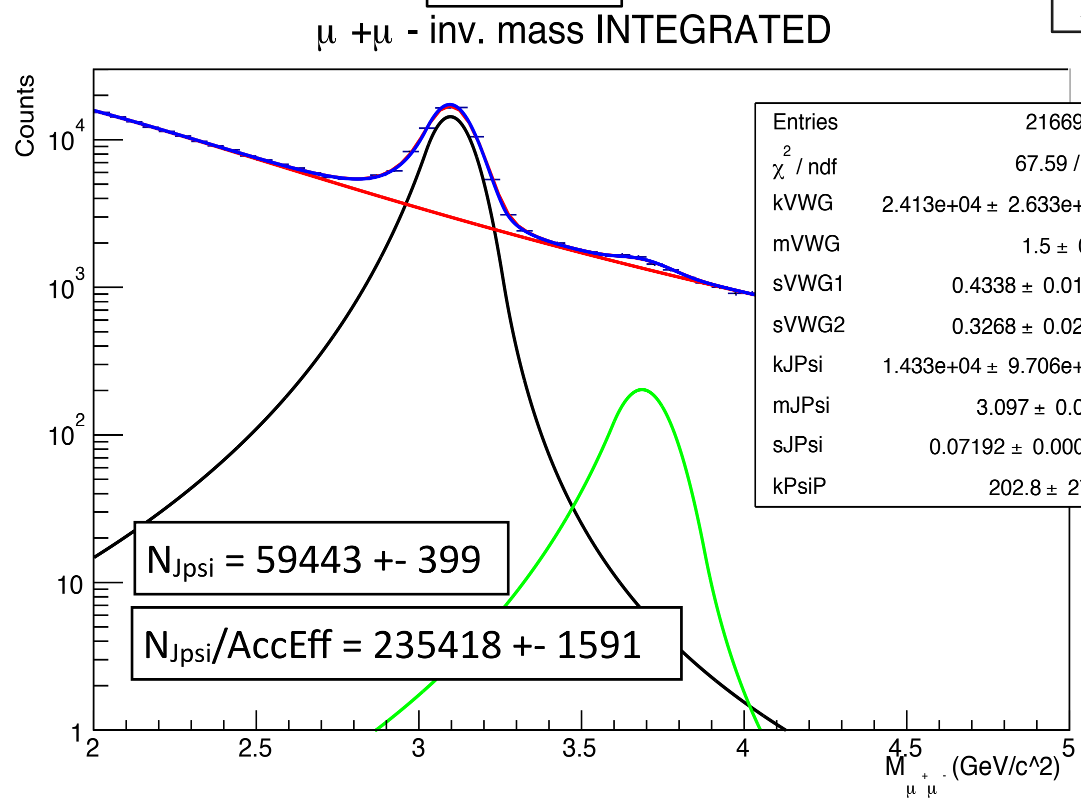
$$Y_{J/\psi} = \frac{N_{J/\psi\rightarrow\mu^+\mu^-}}{N_{MB} B.R.(J/\psi \rightarrow \mu^+\mu^-)}$$

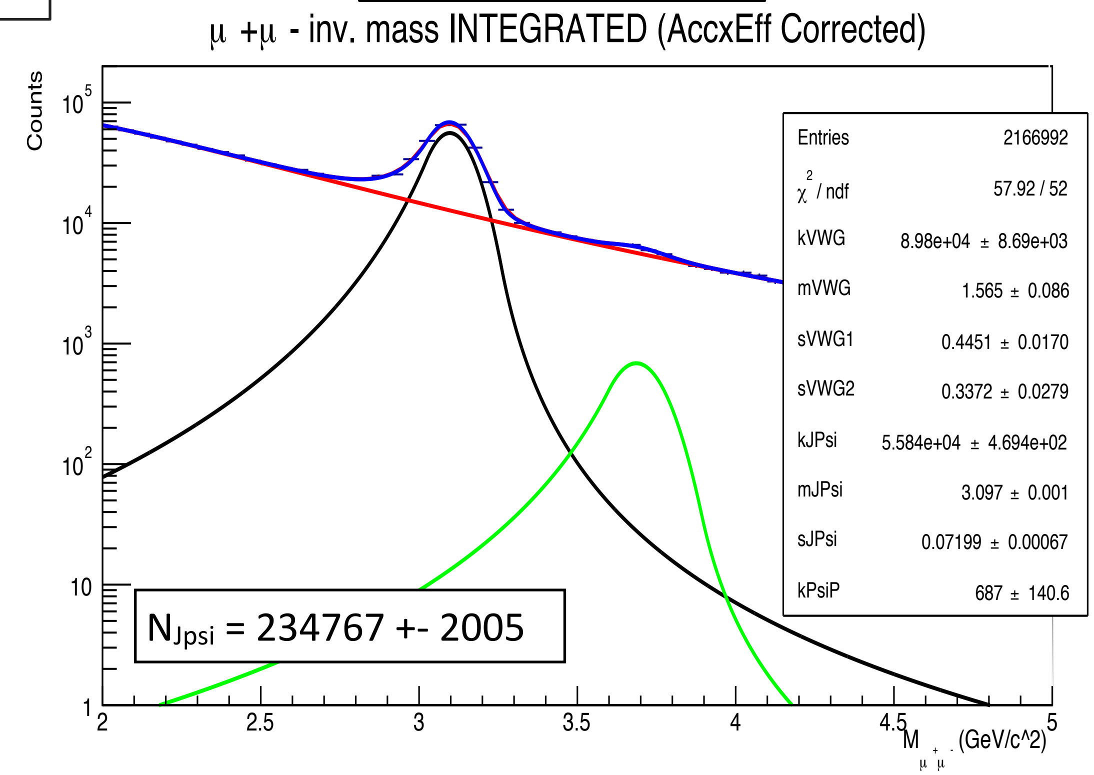
$$N_{MB} = F_{norm} N_{CMUL}$$

Raw

p-Pb example

AccxEff corrected





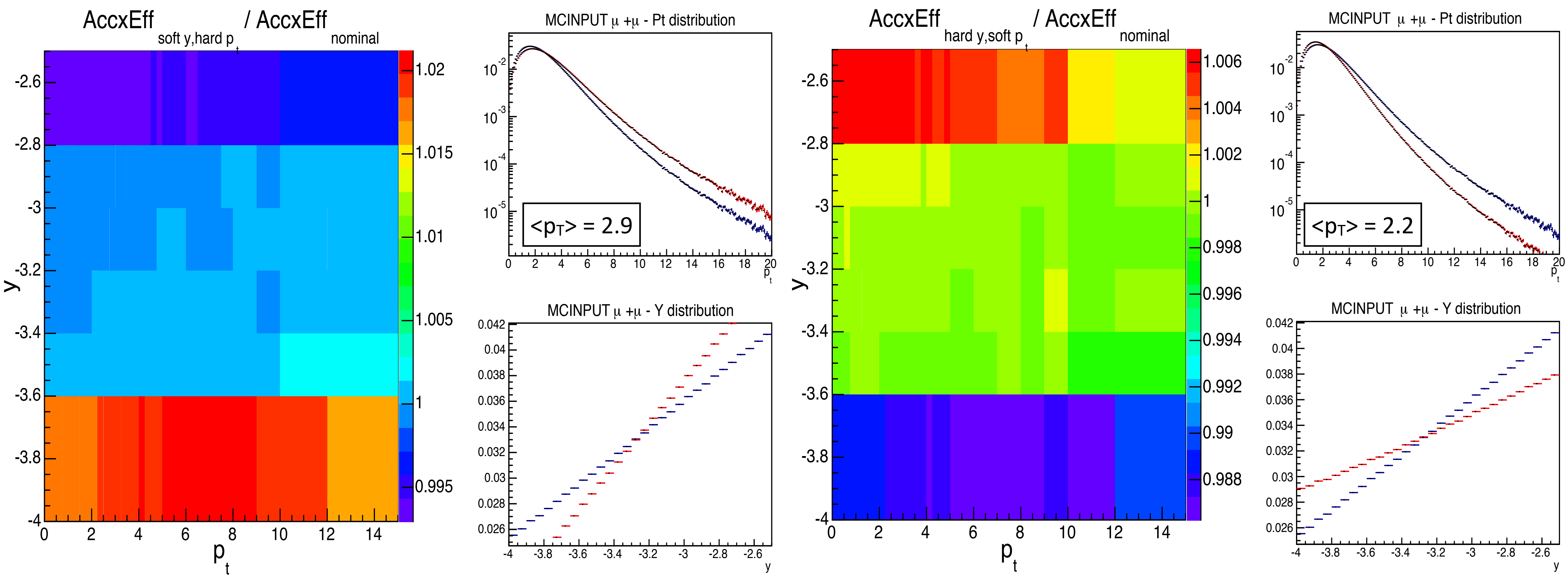
System	Yields(analysis)	$\sigma_{J/\psi}$(analysis)	$\sigma_{J/\psi}$(publi)
p-Pb (5.02 TeV)	4.24E-4	883 μb	886 +- 48 (uc.sys) μb*
Pb-p (5.02 TeV)	4.58E-4	971 μb	966 +- 70 (uc.sys)μb*
pp (8 TeV)	1.34E-4	7.52 μb	7.59 +- 0.55 (sys)μb**

Integrated cross section in agreement with the publications

J/ψ SIGNAL EXTRACTION: SOME SYSTEMATICS

Does Muon Spectrometer J/Ψ AccxEff change with multiplicity ?

J/Ψ simulations with extreme p_T and y distributions have been performed. Input nominal distributions are modified to reproduce <p_T> in the low and high multiplicity bins in pp



Very small changes in 2D AccxEff correction (just on the rapidity bin -3.6 to -4, the difference ~2% is because is a big bin.)

Negligible changes expected in 2D AccxEff corrected results

J/ψ SIGNAL EXTRACTION: SOME SYSTEMATICS

The 2D Acc$\times$Eff correction barely changes with the input MC distributions, nevertheless, differences up to 6.5% were found in the integrated Acc$\times$Eff

Same integrated Acc$\times$Eff in multiplicity bins

Acc$\times$Eff$_{nominal}$ = 12.44%

Mult(N_{tr} corr)	$N_{J/\psi}$ raw	$N_{J/\psi}$ 2Dcorr spec.	$N_{J/\psi}$ raw/Acc$\times$eff	rel. dif
0-4	5278+-92	43921+-893	42428+-740	3.4 %
30-60	666+-42	4894+-364	5354+-338	-9.4%

Different integrated Acc$\times$Eff in multiplicity bins

Acc$\times$Eff$_{soft\ p_T}$ = 11.80%

Acc$\times$Eff$_{hard\ p_T}$ = 13.25%

Mult(N_{tr} corr)	$N_{J/\psi}$ raw	$N_{J/\psi}$ 2Dcorr spec.	$N_{J/\psi}$ raw/Acc$\times$eff	rel. dif
0-4	5278+-92	43921+-893	44728+-780	-1.8%
30-60	666+-42	4894+-364	5026+-317	-2.7%

The changes in the integrated Acc$\times$Eff with the p_T and y distributions (multiplicity) explains the difference between the $N_{J/\psi}$ extracted with the two methods

J/ψ <p_T> EXTRACTION

To compute the dimuon <p_T> vs M_{inv}, we **weight each dimuon pair with J/Ψ 1/Acc×Eff(p_T,y)**

$$\langle p_T \rangle^{\mu^+\mu^-}(M_{\mu^+\mu^-}) = \alpha^{J/\psi}(M_{\mu^+\mu^-}) \times \langle p_T \rangle^{J/\psi} + \alpha^{\psi'}(M_{\mu^+\mu^-}) \times \langle p_T \rangle^{\psi'} + (1 - \alpha^{J/\psi}(M_{\mu^+\mu^-}) - \alpha^{\psi'}(M_{\mu^+\mu^-})) \times \langle p_T \rangle^{bkg}$$

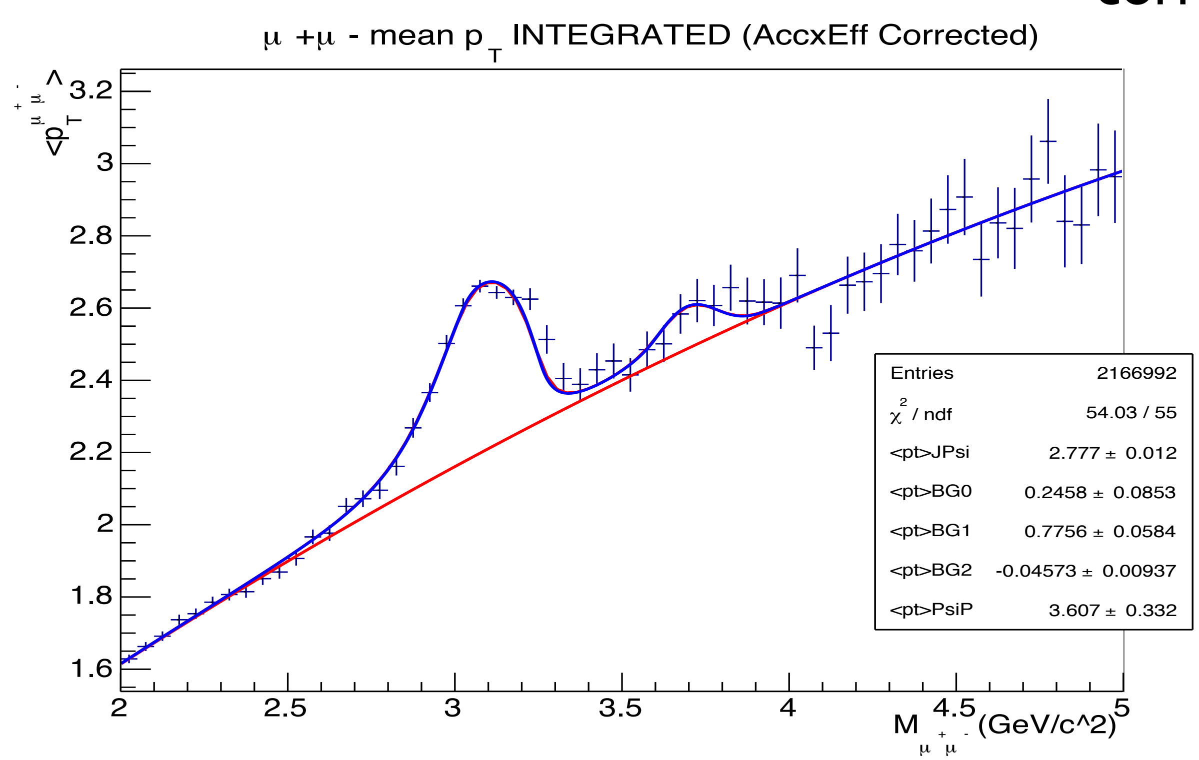
$$\alpha(M_{\mu^+\mu^-}) = \frac{S(M_{\mu^+\mu^-})}{S(M_{\mu^+\mu^-}) + B(M_{\mu^+\mu^-})}$$

Fixed from Acc×Eff(p_T,y) corrected M_{inv} spectra

$\langle p_T \rangle^{J/\psi} \rightarrow constant$

$\langle p_T \rangle^{\psi'} \rightarrow constant$

$\langle p_T \rangle^{bkg} = pol2$



System	$\langle p_T \rangle$(this analysis)	$\langle p_T \rangle$ (other analysis)
pp	2.61 ± 0.01 (stat.)	2.60 ± 0.08 ± 0.06 *
p-Pb	2.78 ± 0.01 (stat.)	2.77 ± 0.01 ± 0.03 **
Pb-p	2.47 ± 0.01 (stat.)	2.47 ± 0.01 ± 0.03 **

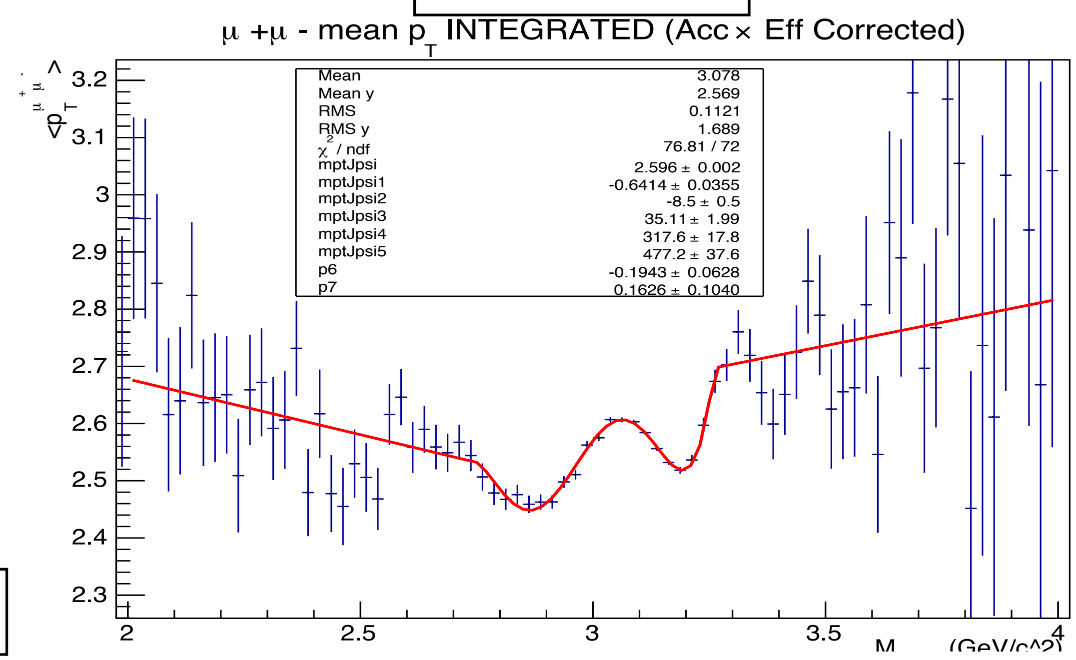
** ALICE: "Multiplicity dependence of Jpsi production in p-Pb collisions at 5.02 TeV"

The advantage of this method respect to the usual one is that we divide the event sample just in multiplicity bins. This allows to reach **higher multiplicities with a thinner binning.**

J/ψ $\langle p_T \rangle$ EXTRACTION: SOME SYSTEMATICS

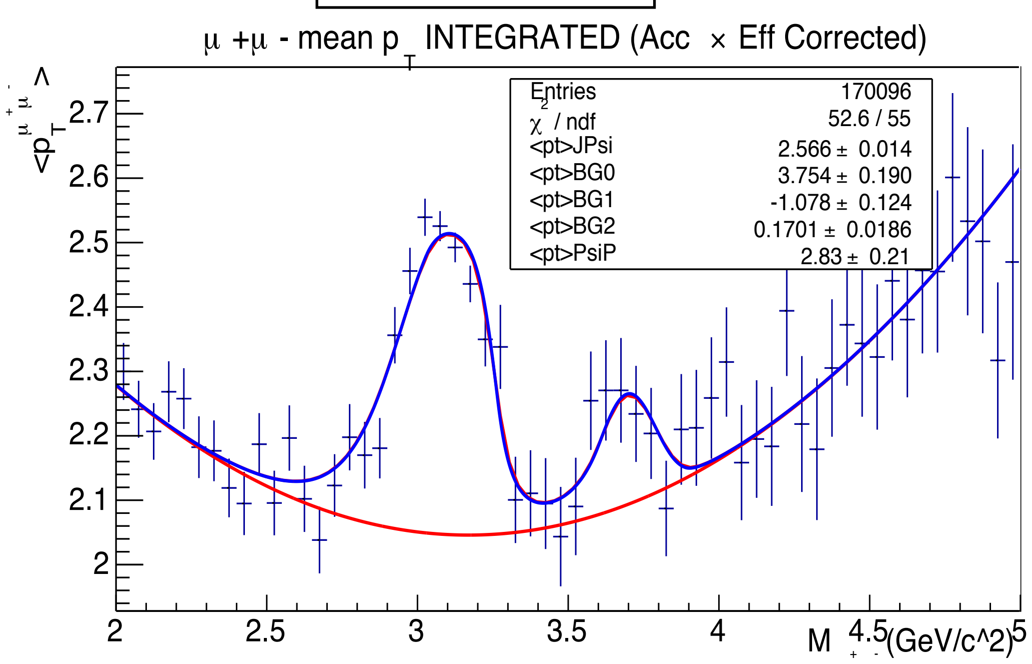
Variations of the J/Ψ $\langle p_T \rangle$ with M_{inv} have been found in the J/Ψ simulation (detector effects), while we consider it as constant in the fits.

Reco MC J/Ψ $\langle p_T \rangle$

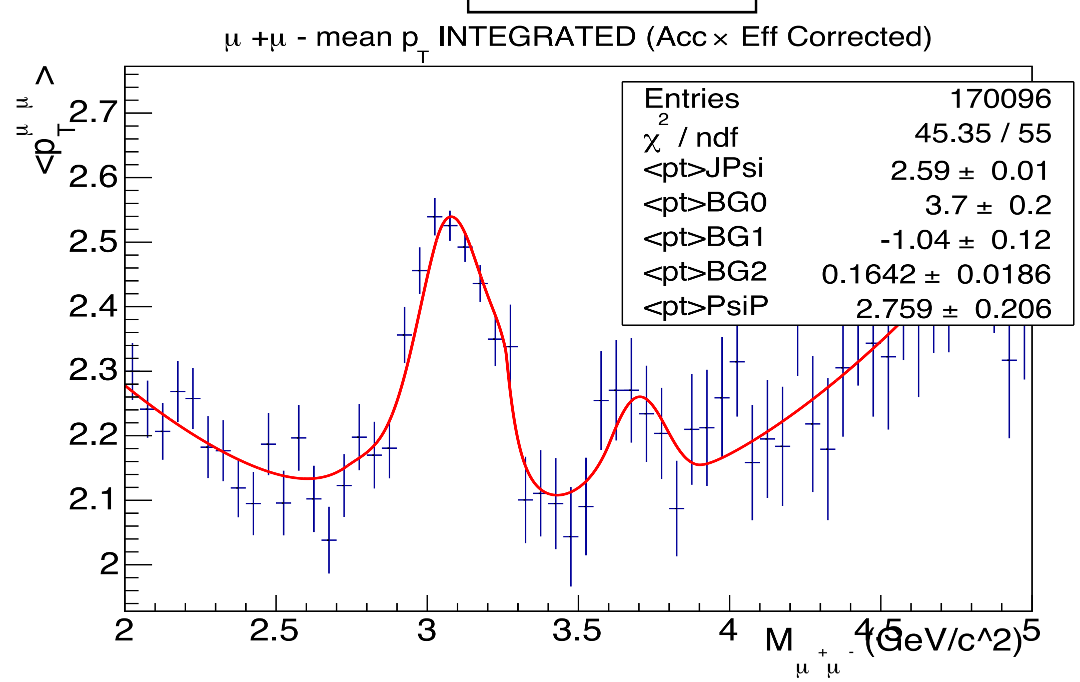


Parametrize the J/Ψ $\langle p_T \rangle$ variation in the simulation and use it in the data $\langle p_T \rangle$ fits

Constant J/Ψ $\langle p_T \rangle$



J/Ψ $\langle p_T \rangle$ (M_{inv})



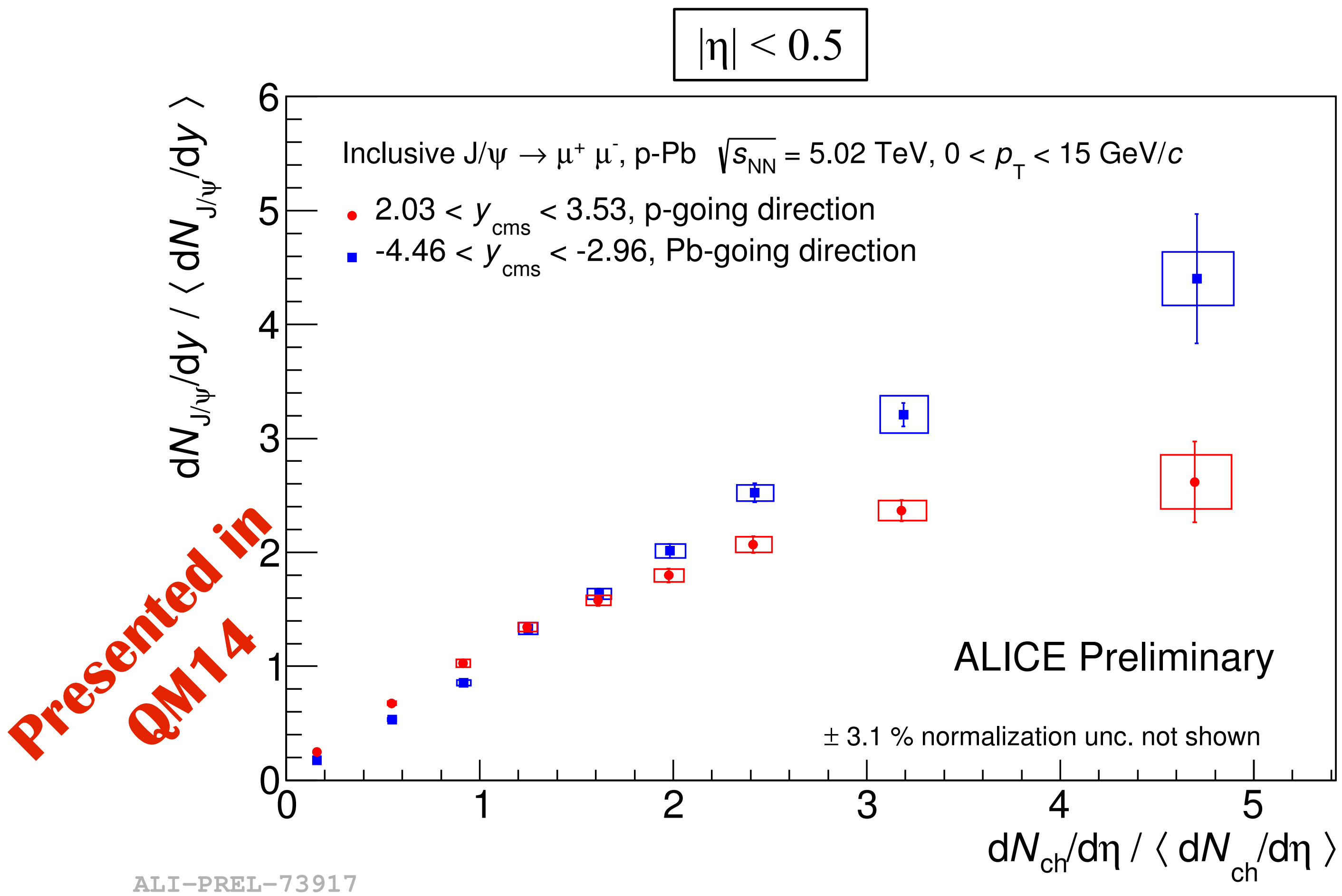
Improvement of the peak shape description, but $\langle p_T \rangle$ difference is ~1%. Treated as syst. uncertainty and we keep the constant J/Ψ $\langle p_T \rangle$ fits.

RESULTS

Comparison of the results for pp at 8TeV (V0 runs) and pp at 7 TeV (Phys.Lett. B712 (2012) 165-175)

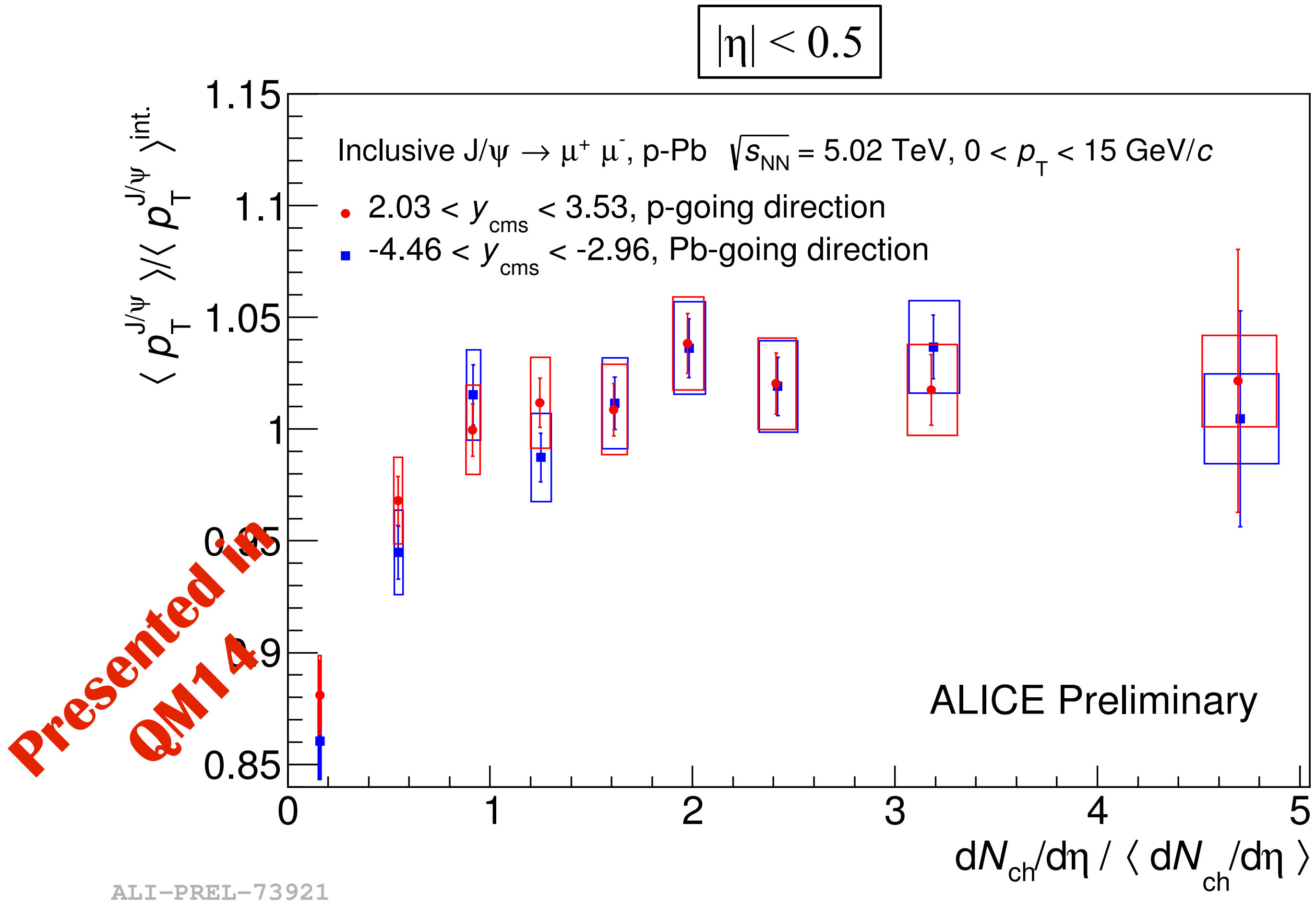
WORK IN PROGRESS

RESULTS



- **Strong increase** of relative J/ψ yields at forward and backward rapidity with relative multiplicity
- At backward rapidity similar behavior as found in pp collisions at 7 TeV, deviation at forward rapidity

RESULTS



- The relative J/ψ <p_T> increases with the mid-rapidity relative event multiplicity and then saturates beyond $dN_{ch}/d\eta/<dN_{ch}/d\eta>$ ~1.5 in p-Pb

OUTLOOK

- Presented two methods to estimate the event multiplicity. For now we use the data-driven method for the p-Pb preliminaries.
- Finalizing the analysis of the preliminaries and working on the SPD Acc$\times$Eff method.
- Signal extraction and $<p_T>$ with 2D J/ψ Acc$\times$Eff gives similar results that the standard method but have additional advantages.
- Relative yields in p-Pb at forward and backward rapidity show a strong increase with charged particle multiplicity. Similar behavior as in pp at 7 TeV.
- Relative J/ψ $<p_T>$ increases at low multiplicity and saturates in p-Pb.

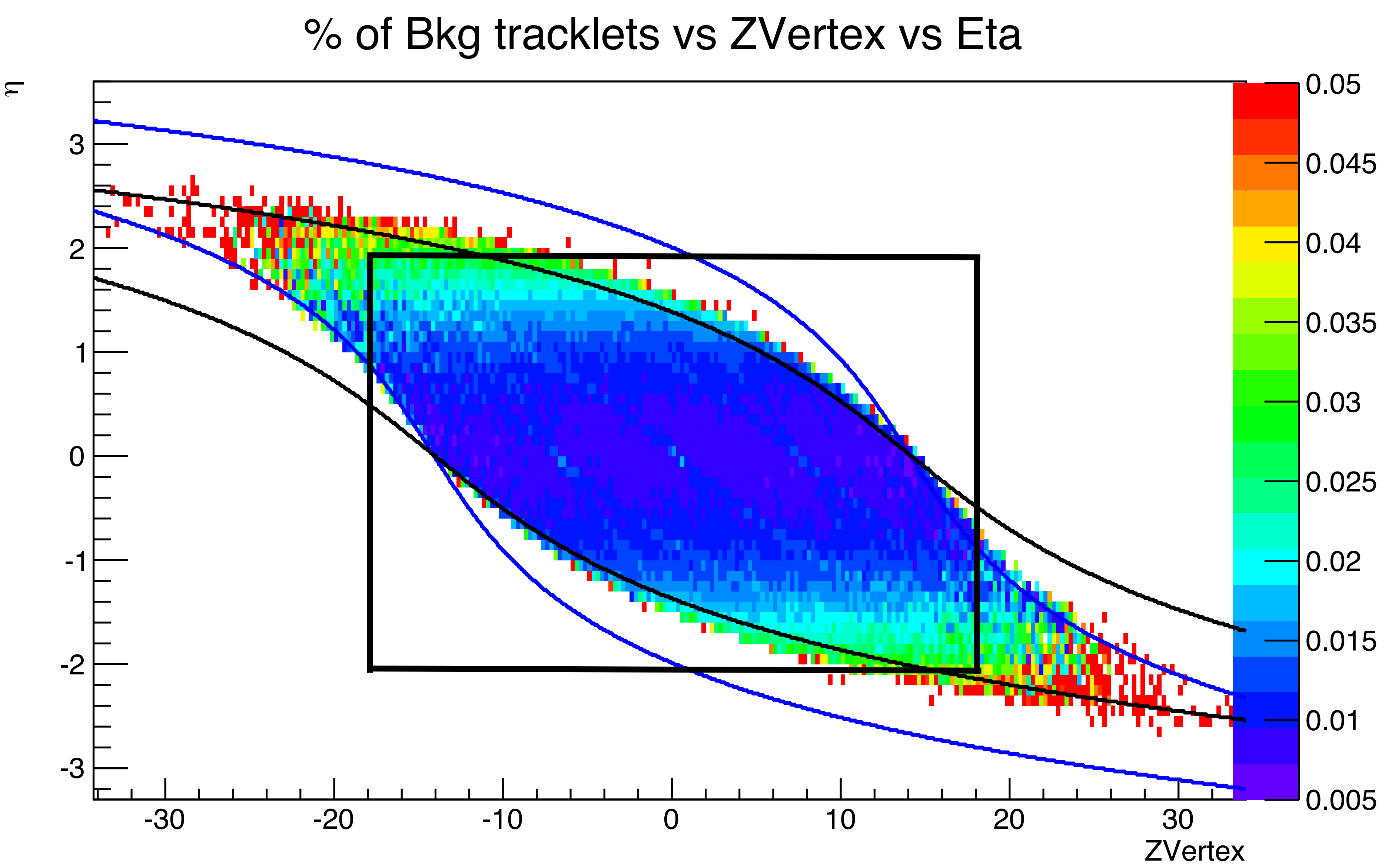
THANK YOU FOR YOUR ATTENTION

BACKUP

CHECKS SPD CORRECTION

Background estimation

In the simulation the tracklets with different labels in the 2 SPD layers (they do not come from the same MC particle) are considered as combinatorial background.



Always < 3% in our window of interest

CHECKS SPD CORRECTION

Comparison of <$dN_{ch}/d\eta$> in $|\eta| < 0.5$ $|Z_v| < 10$ vs V0A multiplicity with **Phys.Lett. B728 (2014) 25-38***

Event Class	V0A multiplicity	<dNch/deta> p-Pb*	<dNch/deta> (LHC13d&e) p-Pb	<dNch/deta> (1 run LHC13c) p-Pb
0-5%	> 227	45+-1	45.0	45.1
5-10%	187-227	36.2+-0.8	36.3	36.1
10-20%	142-187	30.5+-0.7	30.6	30.3
20-40%	89-142	23.2+-0.5	23.4	23.2
40-60%	52-89	16.1+-0.4	16.2	16.0
60-80%	22-52	9.8+-0.2	9.9	9.8
80-100%	<22	4.4+-0.1	4.5	4.4

Our estimation is correct => **we can rely on our $dN_{ch}/d\eta$ computation**

SIGNAL EXTRACTION SYSTEMATICS

We compute relative quantities so the uncertainties are estimated from the variations of:

$$\frac{N^{bin_i}_{J/\psi}}{N^{tot}_{J/\psi}} \quad \text{and} \quad \frac{< p_T >^{bin_i}}{< p_T >^{int}}$$

Since the signal shape does not change with multiplicity, we make the tests with the same signal for the integrated and bin, varying the bkg parametrization, fitting range and Ψ(2S) σ

Relative $N_{J/\Psi}$:

- 2 signal shapes: CB and NA60
- 2 bkg parametrizations: VWG and Pol2Exp
- 2 fitting ranges: 2-5, 2.2-4.7
- 3 $\sigma_{\Psi(2S)}$: 1.1, 1.0, 0.9 x $\sigma_{J/\Psi}$

$\boxed{\text{24 fits per bin}}$ ⟶ $\boxed{\text{288 tests per bin}}$

Relative $<p_T>$:

- All the variations of M_{inv} fits from the Relative $N_{J/\Psi}$ tests
- 2 bkg parametrizations: Pol2 and Pol2Exp
- 2 fitting ranges: 2-5, 2.2-4.7

$\boxed{\text{96 fits per bin}}$ $\boxed{\text{4608 tests per bin}}$

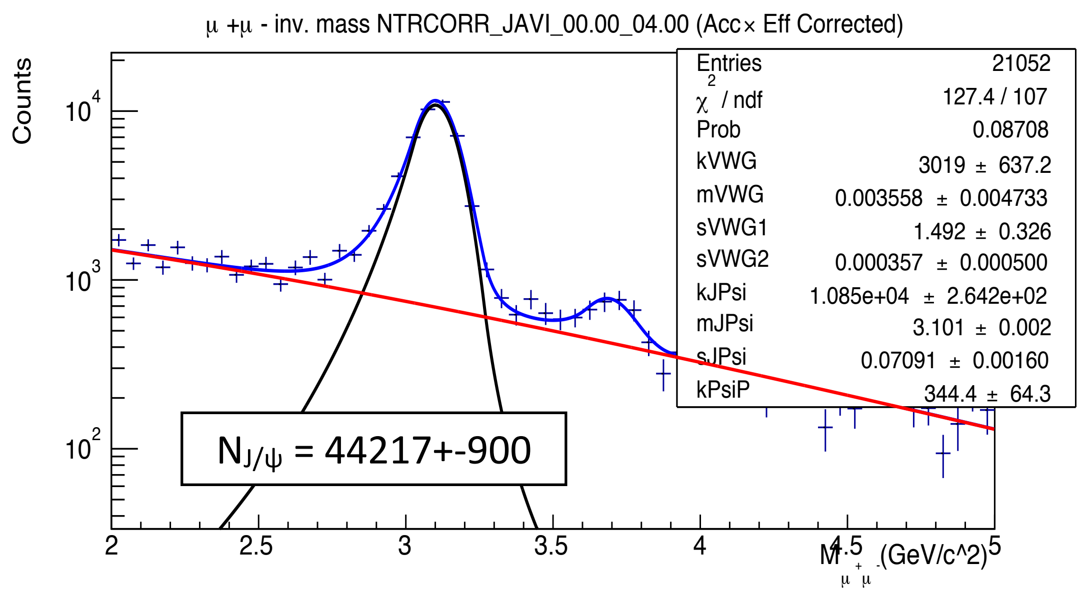
SYSTEMATIC UNCERTAINTIES

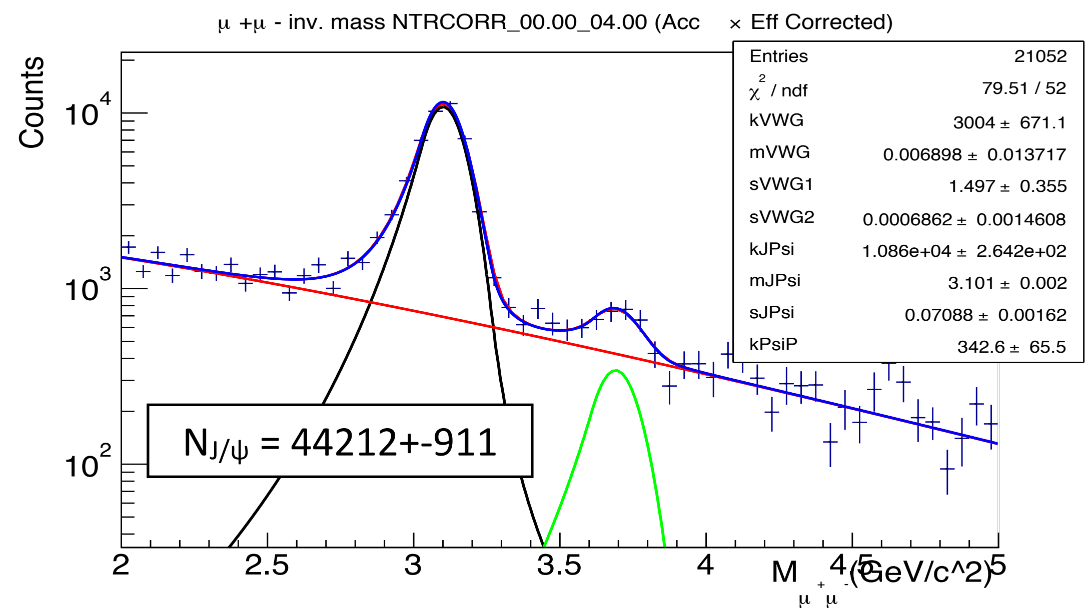
Propagation of M_{inv} fit statistical unc. to $<p_T>$

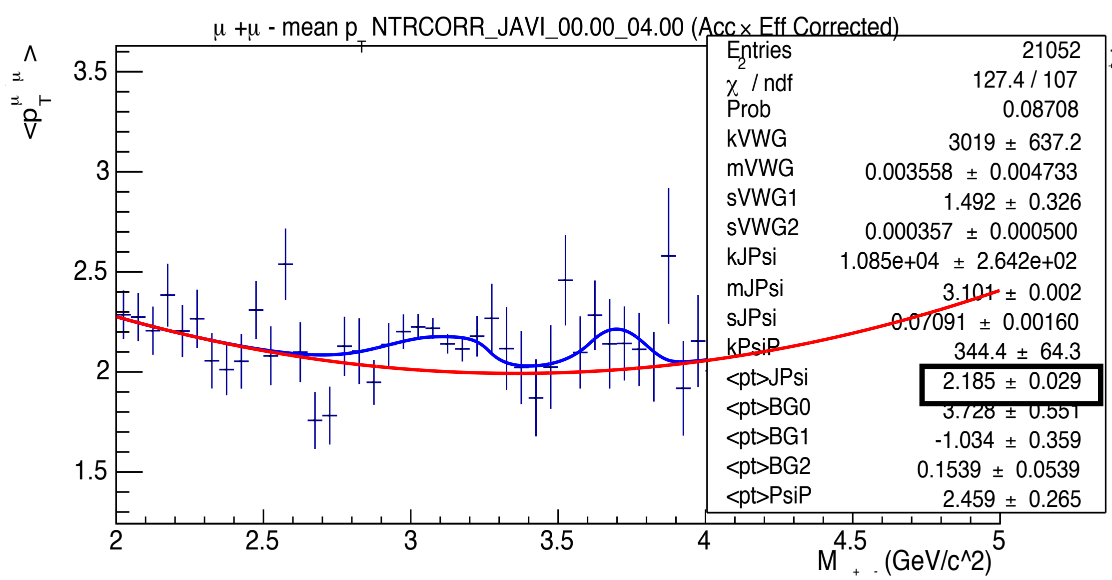
The M_{inv} and $<p_T>$ fits have been done independently, fixing the signal parameters in the $<p_T>$. In order to check the effect of the errors of the M_{inv} fit on the $<p_T>$, a simultaneous fit of the $<p_T>$ and M_{inv} has been tried.

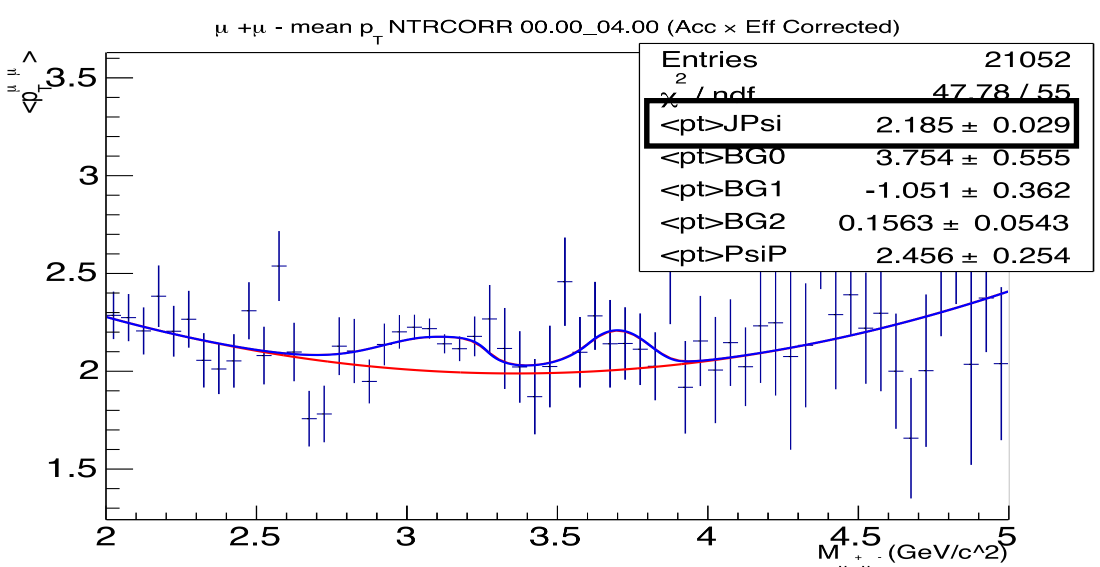
Simultaneous Fit

Independent









This has been tested on several bins in pp and pA resulting in a 0.5% difference on the $<p_T>$ and negligible on the $N_{J/\psi}$

SYSTEMATIC UNCERTAINTIES

Systematic uncertainties

Since we compute relative quantities, just uncorrelated uncertainties remain at first order

$$\frac{Y^{bin_i}_{J/\psi}}{< Y_{J/\psi} >} = \frac{N^{bin_i}_{J/\psi \to \mu^+\mu^-}}{N^{tot}_{J/\psi \to \mu^+\mu^-}} \times \frac{F_{norm}}{F^i_{norm}} \times \frac{N^{tot}_{CMUL}}{N^{bin_i}_{CMUL}} \quad ; \quad \frac{< p^{bin_i}_T >}{< p_T >}$$

-AccxEff
-Signal extraction

- 2 methods

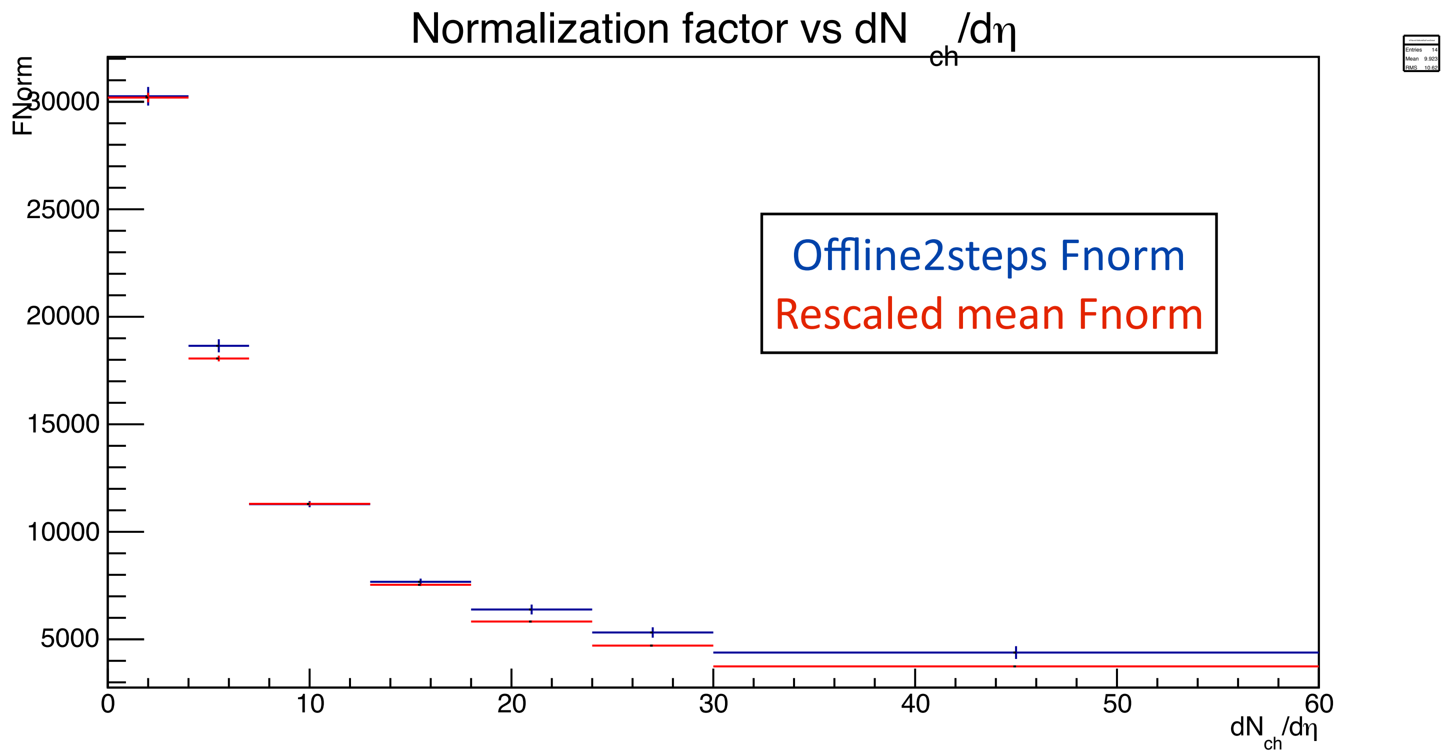
- AccxEff
- Signal extraction
- Method effects

- AccxEff MC input: Tests with different input distributions
- Signal extraction: Systematics tests on the relative $N_{J/\Psi}$ and relative $<p_T>$
- F_{norm}: Difference between the offline method and rescaled bin by bin global F_{norm}
- $<p_T>$ extraction method effects:
    - Difference between input $<p_T>$ and reconstructed in the simulation
    - Variation of the J/Ψ $<p_T>$ with the M_{inv} due to detector effects
    - Propagation of the signal parameters uncertainties with a combined fit
- Multiplicity: Uncertainty in V0AND efficiency correction, and systematic uncertainty on the multiplicity determination from Pseudorapidity density of charged particles in p-Pb paper.

F_{norm} SYSTEMATICS

Two methods have been used to compute the F_{norm}

$$F_{norm} = \frac{CMSL}{CMSL\&0MUL} \times \frac{CINT7}{CINT7\&0MSL} \quad ; \quad F_{norm}^{bin_i} = F_{norm}^{mean} \times \frac{N_{MB}^{bin_i}/N_{MB}}{N_{CMUL}^{bin_i}/N_{CMUL}}$$



We take the mean value of the two methods and the difference of the mean to the values as systematic uncertainty

SYSTEMATIC UNCERTAINTIES

Correction to mean N_{tr}

Corrections to the measured MB mean number of corrected tracklets:

$$< N^{corr}_{tracklets} > = \epsilon_{MB}\left((1-\epsilon_{\overline{SPDQA}})\cdot < N^{corr}_{tracklets} >_{measured} + \epsilon_{\overline{SPDQA}}\cdot < N^{corr}_{tracklets} >_{\overline{SPDQA}}\right) + (1-\epsilon_{MB})\cdot < N^{corr}_{tracklets} >_{\overline{MB}}$$

ϵ_{MB} → MB trigger efficiency
- → ~ 1 for pA
- → ~ 0.74 for pp @ 7TeV

$\epsilon_{\overline{SPDQA}}$ → Fraction of events w/o SPD vertex or not passing vertex QA
- → ~ 1.8% for pA
- → ~ 4.7% for pp @ 8TeV

$< N^{corr}_{tracklets} >_{\overline{SPDQA}}$ → <N_{tr}> of events w/o SPD vertex or not passing vertex QA
- → 0 for ev. w/o Vtx_{SPD}
- → >1 for ev no Vtx QA
  - Small η window
  - σ_{vtx} ↓ with N_{tr}

  → considered as 0

$< N^{corr}_{tracklets} >_{\overline{MB}}$ → <N_{tr}> of events not seen by the MB trigger condition
- → ~ 0 for V0OR ?
- → not known yet for V0AND

SYSTEMATIC UNCERTAINTIES

SUMMARY SYSTEMATIC UNCERTAINTIES

	pPb (5.02 TeV)	Pbp (5.02 TeV)	pp (8 TeV)	
$N_{J/\psi}$	1.5%	1.5%	1.7 %	→ pA and pp 7TeV papers
$N_{J/\psi}^{\ bin}$	1.5-7%	1.5-7%	1.7-8%(2-5%)*	→ rel. dif. $N_{J/\Psi}$
$N_{J/\psi}^{\ bin}/N_{J/\psi}$	0.8-3.3%	0.4-1.6%	0.2-1.4%(0.2-2.2%)*	→ s. extraction
F_{norm}	1 %	1 %	1 %	→ pA paper
F_{norm}^{bin}	0.1-7 %	0.2-4%	0.4-8%(0.2-12%)*	→ 2 methods
$<p_T>$ & $<p_T>^{bin}$	2 %	2 %	2 %	→ extraction method and MC input
$<p_T>^{bin}/<p_T>$	0.1-0.4%	0.1-1.2%	0.1-0.5%	→ s. extraction
$dN_{ch}/d\eta/< dN_{ch}/d\eta >$	3.9%	3.9%	~15%	→ corr. extremes and MB eff
Pile up	1-4%	1-2%	-	→ Toy MC

*() pp $|\eta| < 1$

$\epsilon_{MB}(pp@7TeV) = 0.742$ +-5%

PILE UP STUDY

To study the effect of the pile-up in the multiplicity determination we use a **toy MC :**

- Generate N_{events} MC (bunch crossings)
- For each event generate $n_{Collisions}$ (interactions) with Poisson(μ) (if $n_{Collisions} > 0$ -> MB event)
- Assign randomly to each collision in the event (Z_v,$N_{traklets}$,$n_{J/\Psi}$)
  - ✳ Ntracklets: Using the corrected CINT7 N_{tr} distribution for LHC13c (low PU)
  - ✳Z_v: Zvtx distribution of LHC13de
  - ✳$n_{J/\Psi}$: LHC13de yield vs $N_{tr,corr}$ (x100 enhanced), Poisson(yield($N_{tr,corr}$))
- Search of pile up events ($| Z_v^{col_i} - Z_v^{col_j} | < 2,1,0.2$ cm)
  - ✳ if PU the tracklets are summed
  - ✳We take all the Jpsi in the event
- Main Z_v = collision with higher $N_{tracklets}$ (This will be the event multiplicity)
- $|Z_v|$ cut < 10 cm

With this ingredients we compute the resulting N_{tr} distribution and **J/***Ψ* yield, and compare with the data(LHC13c) results

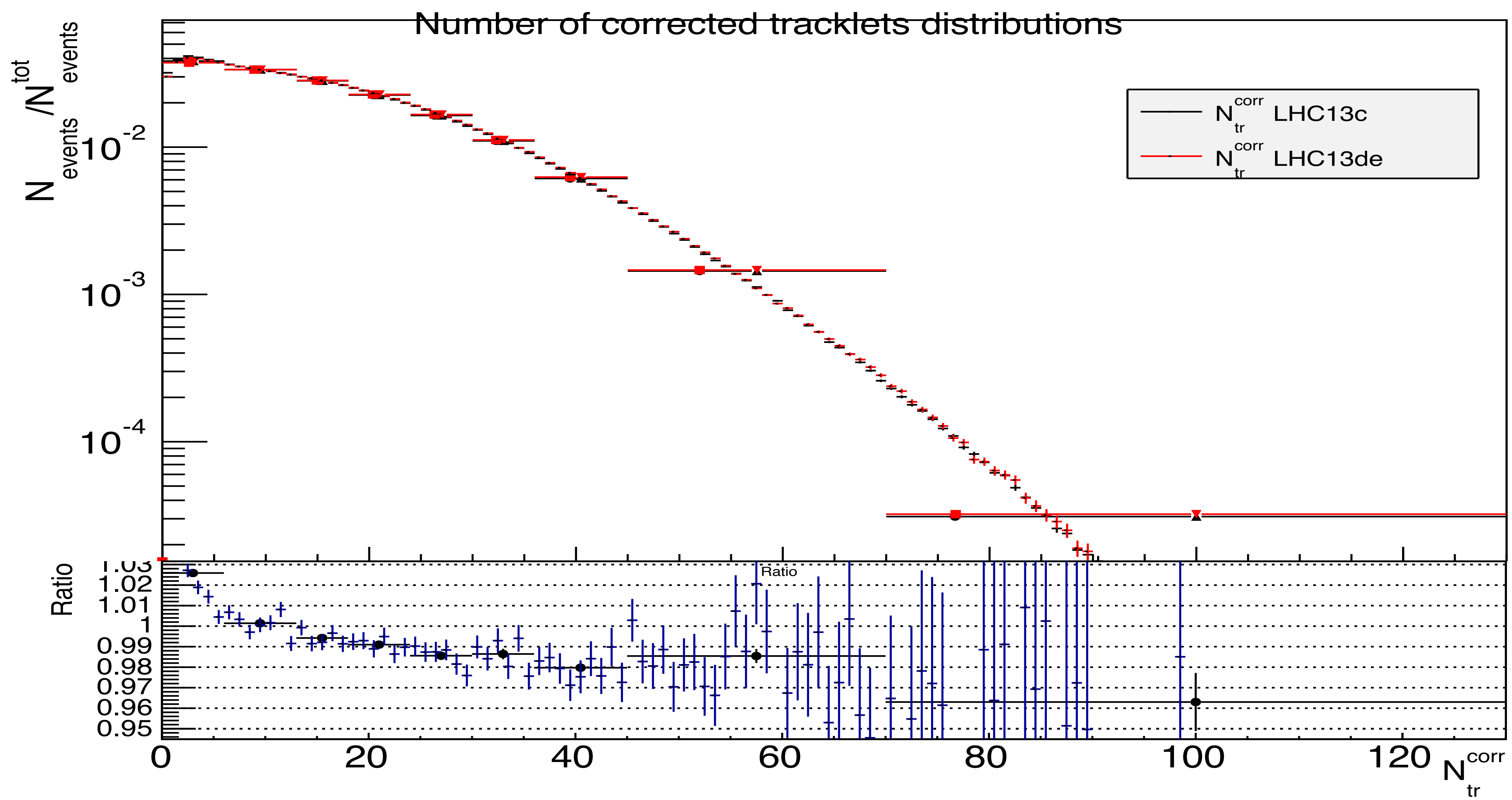
PILE UP STUDY

To study the effect of the pile-up in the tracklets multiplicity determination we use a **toy MC.**

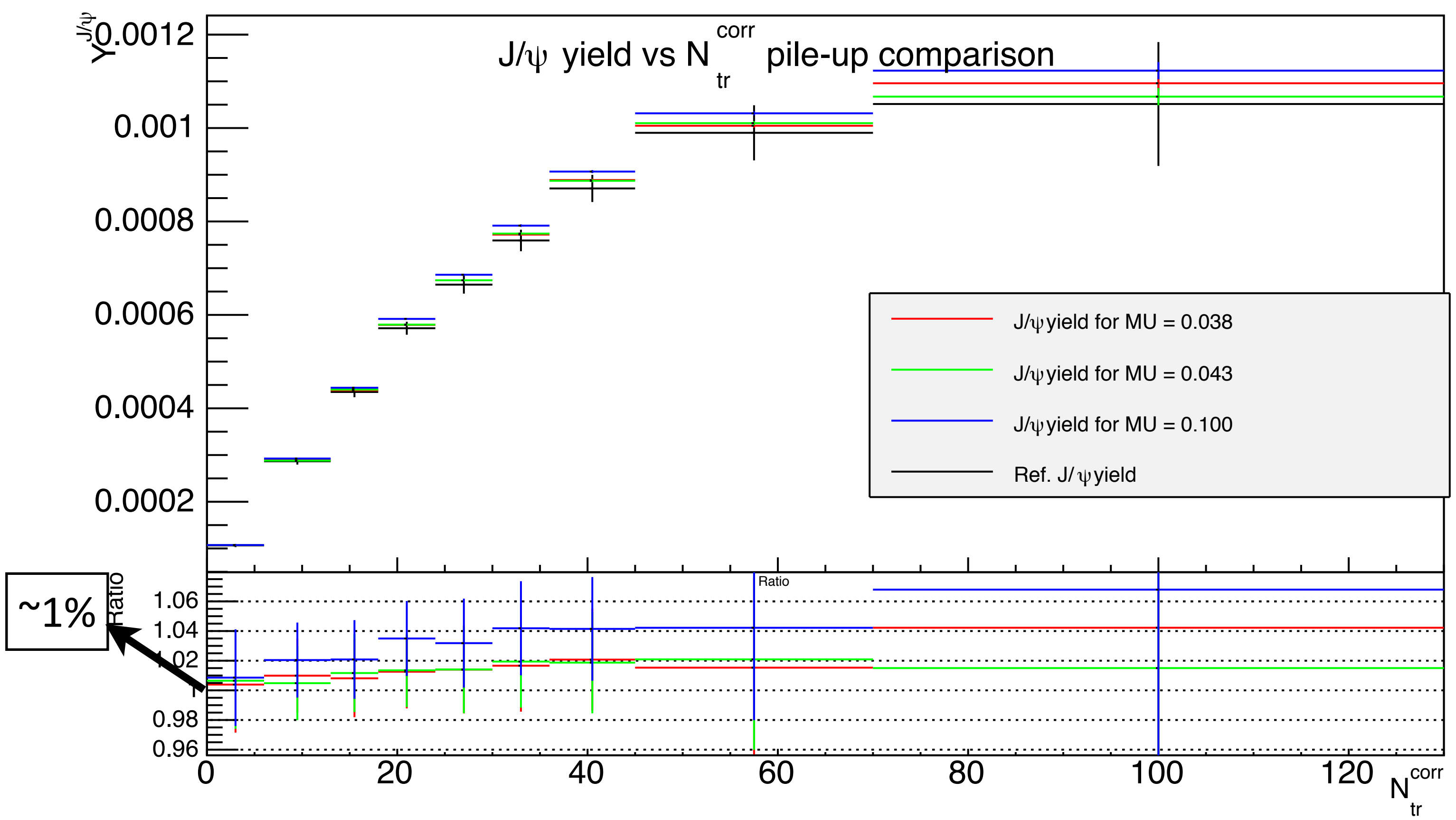
Mean Nof collisions per bunch crossing →

$< \mu >$(LHC13de) = 0.038
$< \mu >$(LHC13f) = 0.043
$< \mu >$(LHC13hi) = 0.009

Comparison of corrected tracklets distribution between a low pile up period (LHC13c) and one of the periods under study

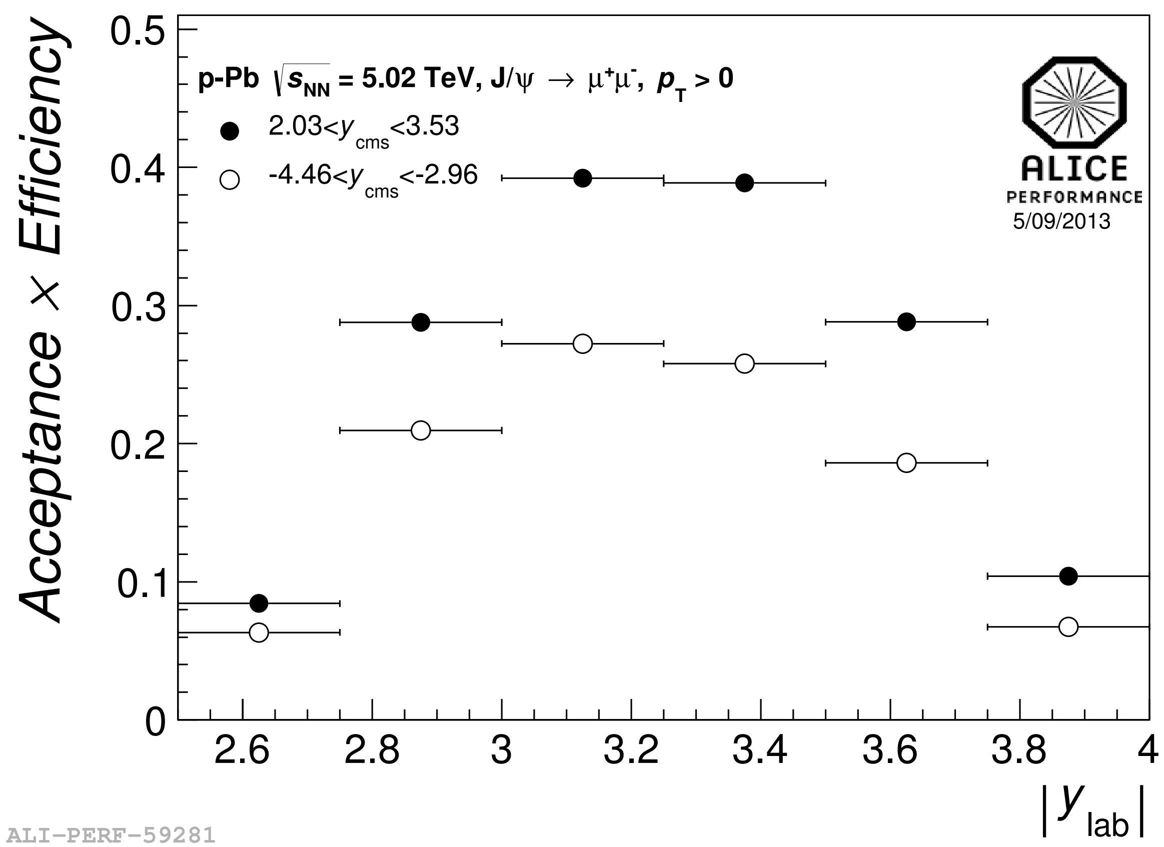


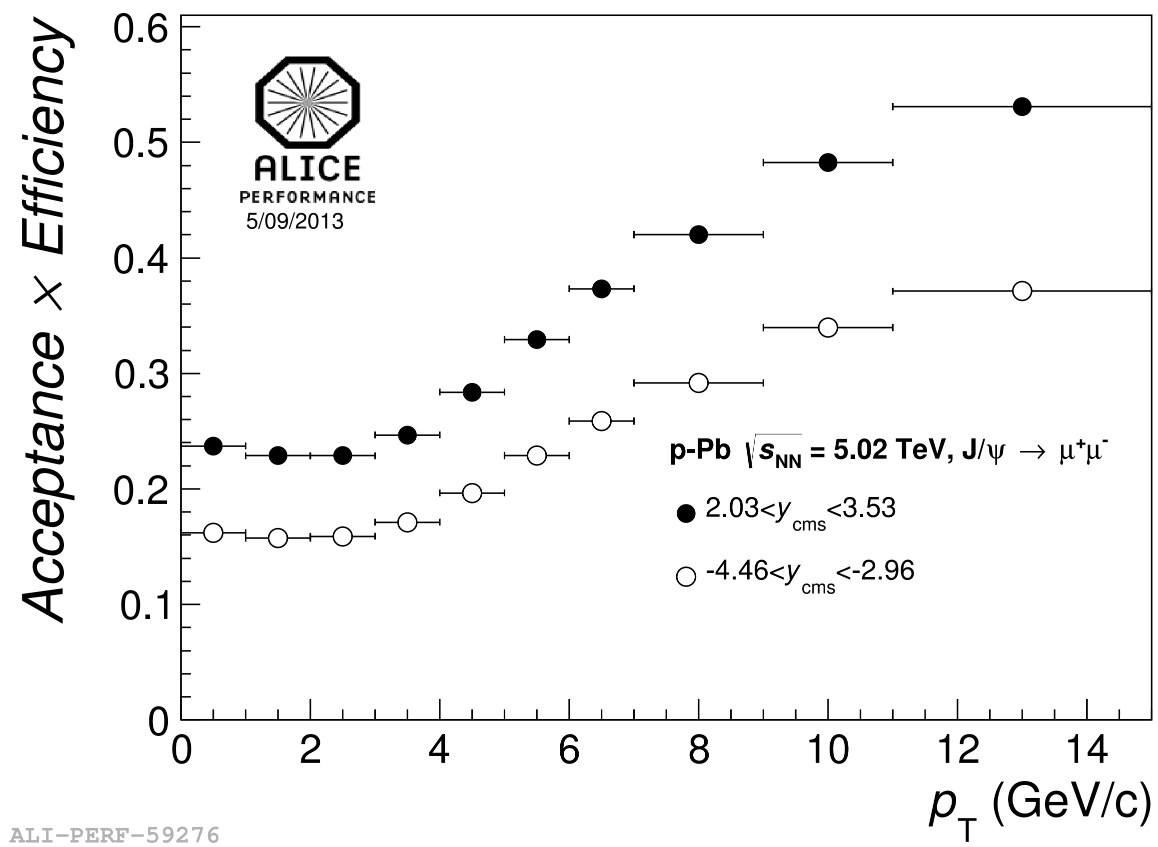
PILE UP STUDY



We take as systematic uncertainty the maximum difference in each bin (for μ = 0.043 or 0.038)

ACCEPTANCE × EFFICIENCY





RELATIVE YIELD AND <p_T> vs MID-y RELATIVE MULTIPLICITY UNCERTAINTIES

Only uncorrelated systematic uncertainties remains at first order in relative quantities

	Forward-y	Backward-y
Extraction method $N_{J/\psi}{}^{bin}$	1.5-7 %	1.5-7 %
S. Extraction $N_{J/\psi}{}^{bin}/N_{J/\psi}$	1.5-3.3 %	1.5-4.6 %
$\langle p_T \rangle$ MC input	2 %	2 %
Extraction $\langle p_T \rangle / \langle p_T \rangle^{int.}$	0.1-0.4 %	0.1-1.2 %
F	1-7 %	1-4%
$\langle dN_{ch}/d\eta \rangle$	3.9%	3.9%
Pile up	1-4%	1-2%