Incoherent photoproduction of J/ψ mesons in ultra-peripheral collisions at ALICE

DUCD 2023

Faculty of Nuclear Sciences and Physical Engineering
CTU in Prague

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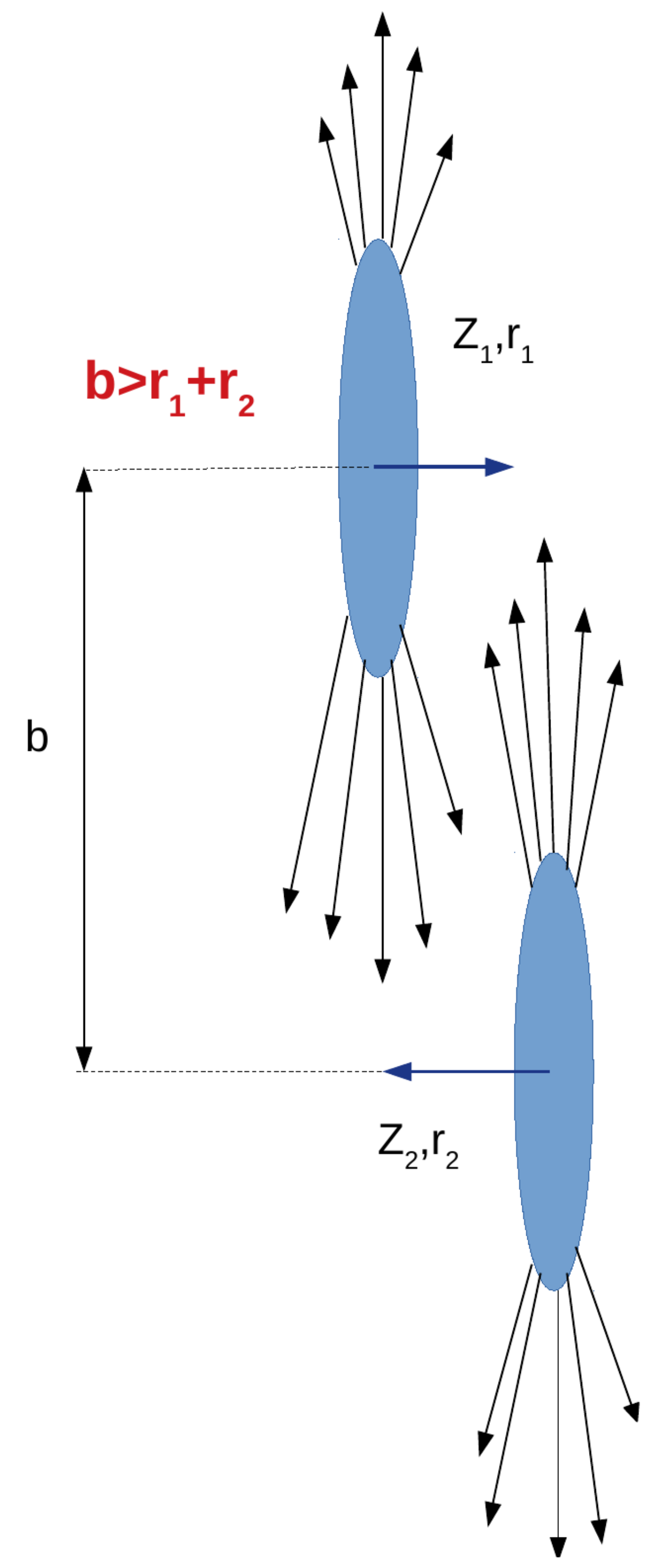
Vendulka Fílová

Photoproduction of J/Ψ

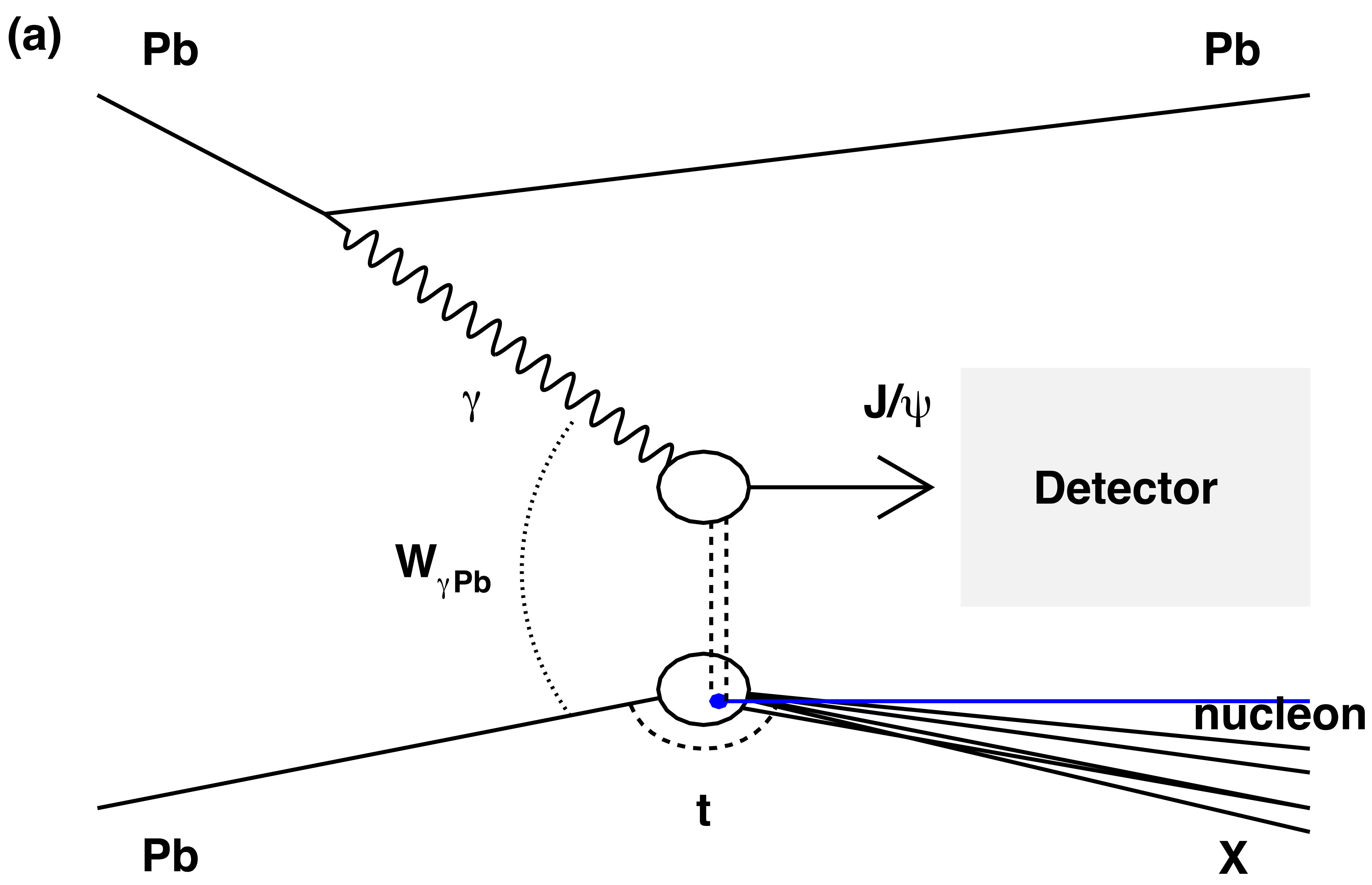
Ultra-peripheral collisions



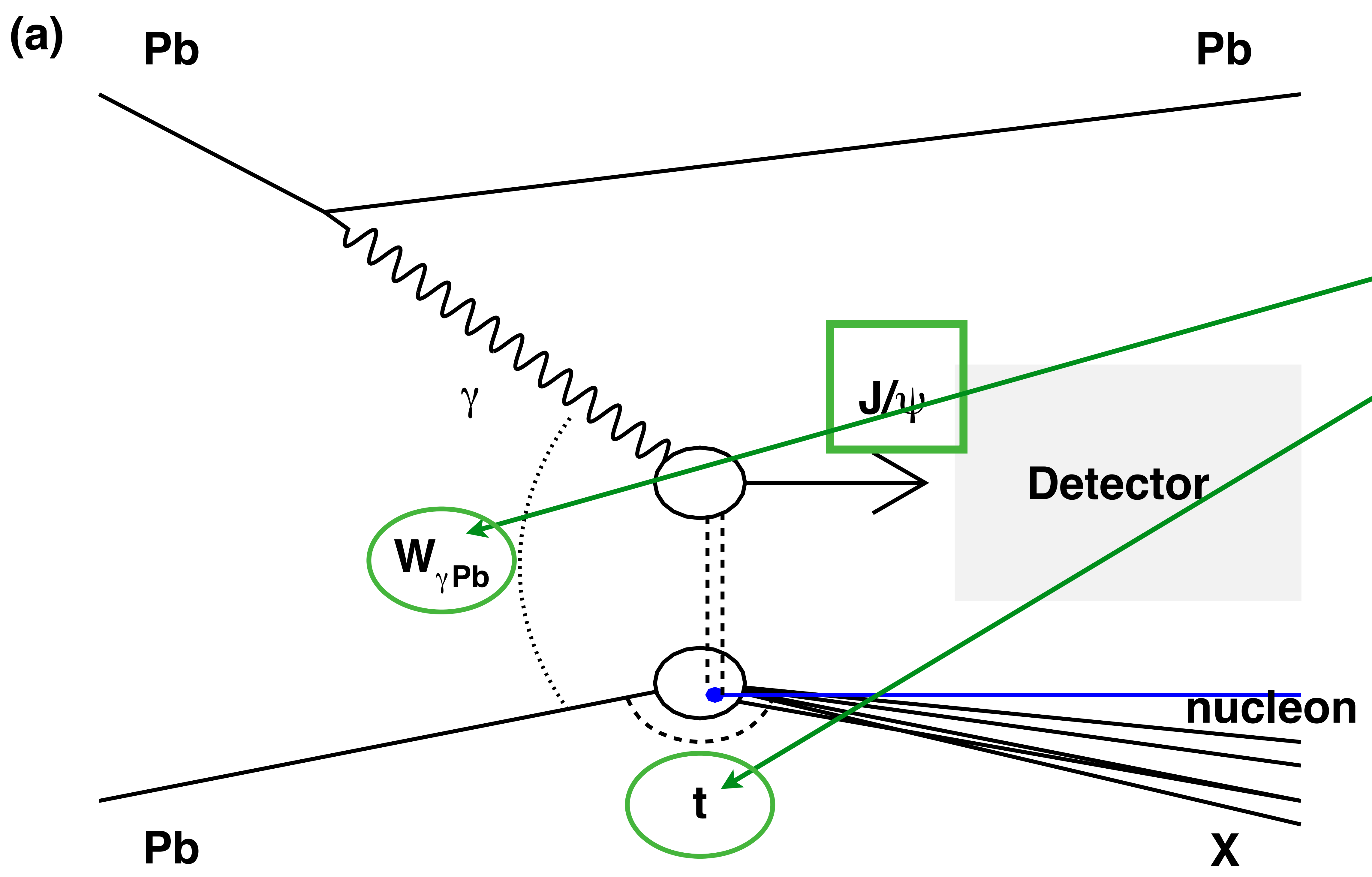
- Electromagnetic field of Lorentz-contracted nuclei can be seen as a flux of quasi real photons.
- The intensity of the photon flux is proportional to Z^2.
- For an impact parameter larger than the sum of the radii of the nuclei:
  - Strong interactions are strongly suppressed.
  - Photon induced processes remain.

These processes are called **Ultra-peripheral collisions.**

Photoproduction of J/Ψ vector mesons



Photoproduction of J/Ψ vector mesons



J/Ψ measured p_T and **y**

- Center-of-mass energy of the photon-nucleus system:

$$W^2_{\gamma \mathrm{Pb}} = \sqrt{s_{\mathrm{NN}}} M_{\mathrm{J}/\Psi} e^{-y}$$

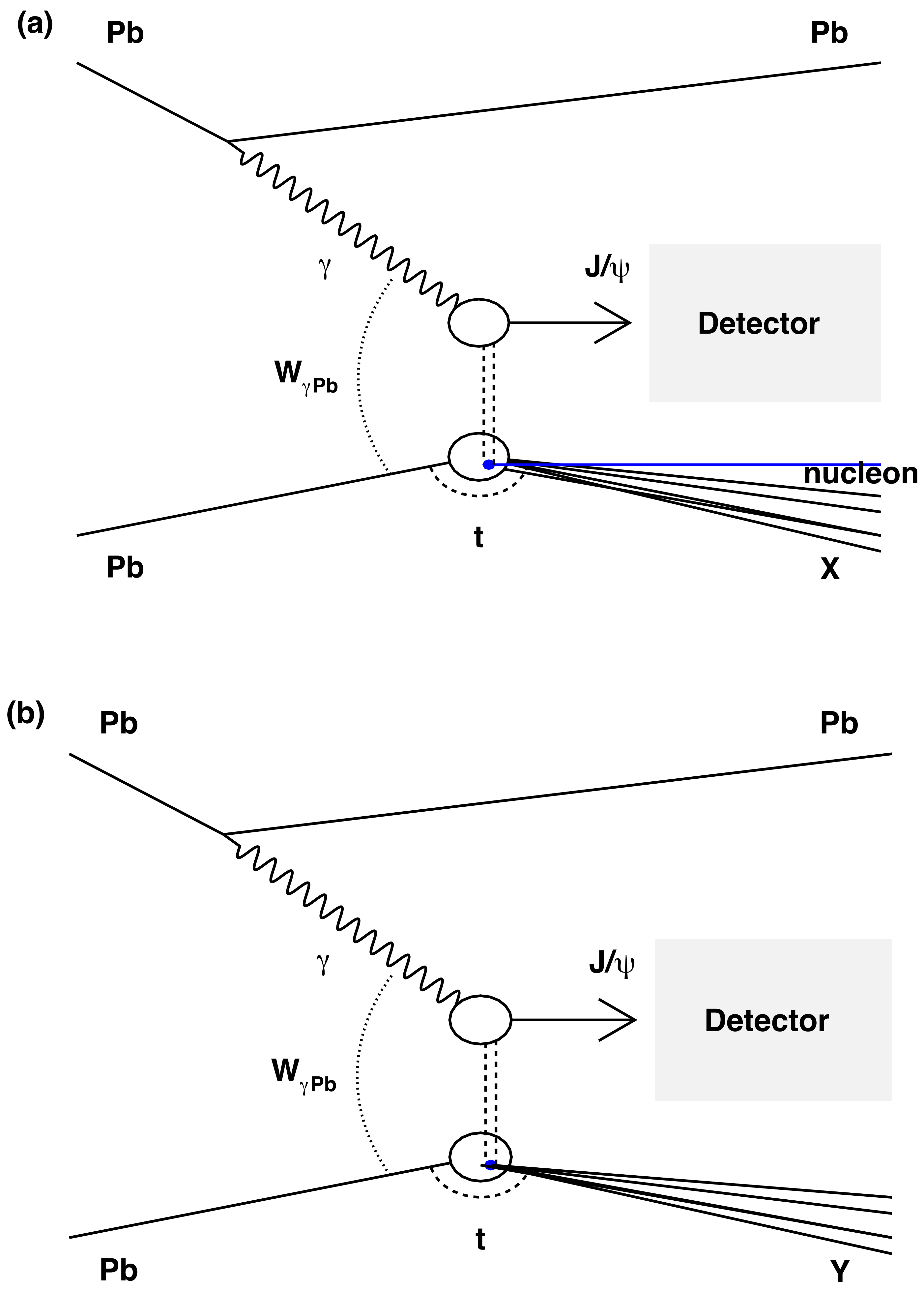
- The momentum transferred -t is related to the transverse momentum of the J/Ψ:

$$|t| = p_T^2$$

Incoherent photoproduction of J/Ψ vector mesons

- The incoherent photoproduction of a vector meson measures the interaction with one nucleon inside the target nucleus:
  - Characterized by $p_T > 300$ MeV/c of the J/Ψ
  - two cases:
    - The nucleon remains intact
    - The nucleon gets excited and dissociates after the interaction
  - In both cases the nucleus breaks up and one or more neutrons are produced at forward direction.

We can measure the p_T (equivalently $|t|$) dependence of this process for different rapidities (equivalently $W_{\gamma \mathrm{Pb}}$).



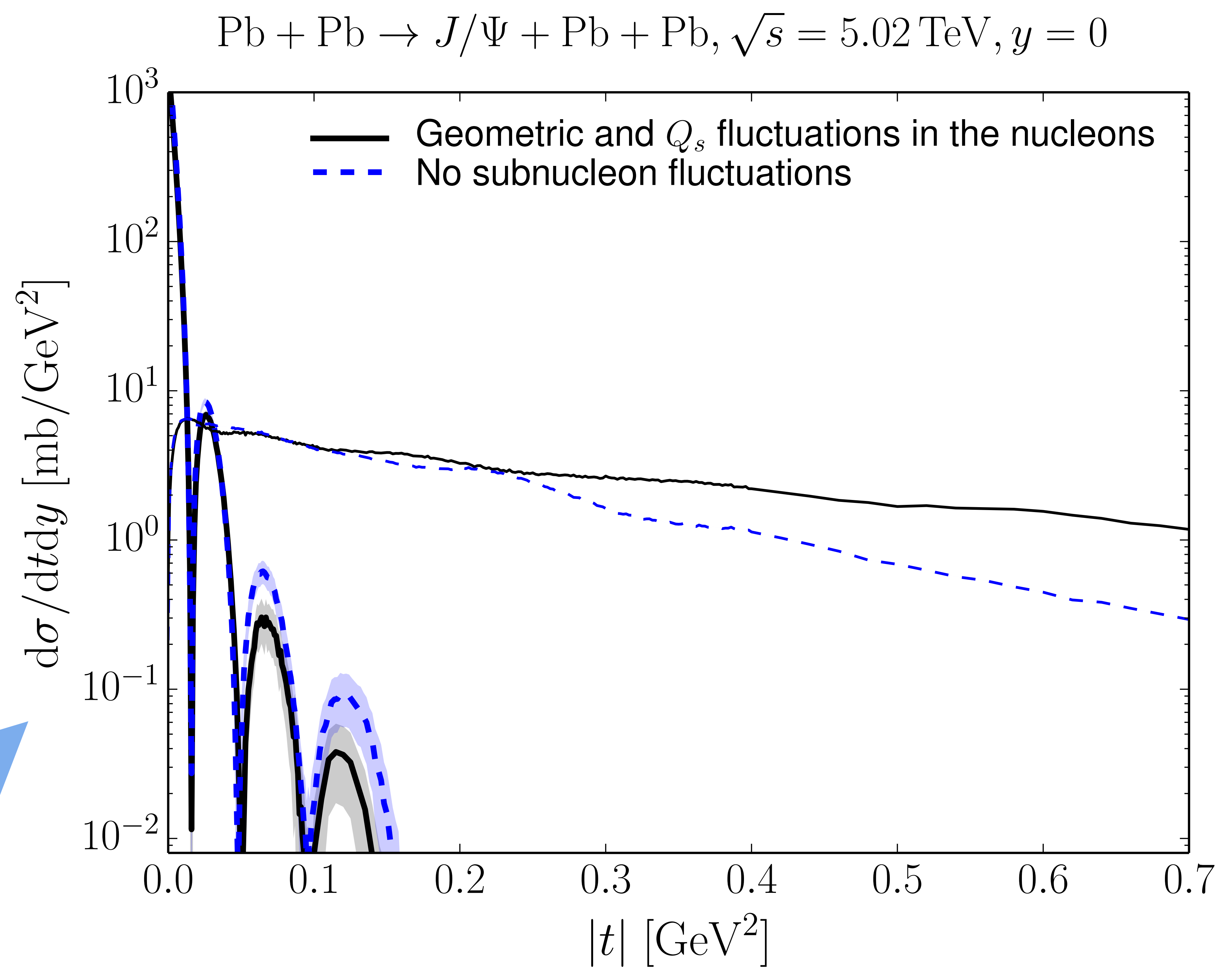
Incoherent photoproduction of J/Ψ vector mesons

- The cross section for incoherent production, in a Good-Walker approach, is proportional to the variance of the fluctuations of the gluon field.

$$\frac{d\sigma_{\gamma \mathrm{Pb}}}{dt}\Big|_{T,L}^{\mathrm{inc}} = \frac{(R_g^{T,L})^2}{16\pi}\left(\left\langle \left| A^j(x, Q^2, \vec{\Delta})_{T,L} \right|^2 \right\rangle_j - \left| \left\langle A^j(x, Q^2, \vec{\Delta})_{T,L} \right\rangle_j \right|^2 \right)$$

where the amplitude A depends on the gluon distribution of the target.

Predictions including fluctuations at the sub-nucleon scale predict a different dependence on $|t|$



Incoherent (thin lines) diffractive J/Psi production cross section as a function of |t|, with (solid) and without (dashed) sub nucleonic fluctuation.

Can be found here: http://inspirehep.net/record/1519841

UPC cross section of photo produced J/Ψ

- Either nucleus can serve as a photon emitter or as the target:

Calculated photon flux

Measured cross section

$$\frac{d\sigma_{PbPb\to J/\Psi PbPb}(y)}{dy} = N_{\gamma Pb}(y)\cdot\sigma_{\gamma Pb\to J/\Psi Pb}(y) + N_{\gamma Pb}(-y)\cdot\sigma_{\gamma Pb\to J/\Psi Pb}(-y)$$

J/Ψ cross section on range of x of order 10^{-2}

J/Ψ cross section on range of x of order 10^{-5}

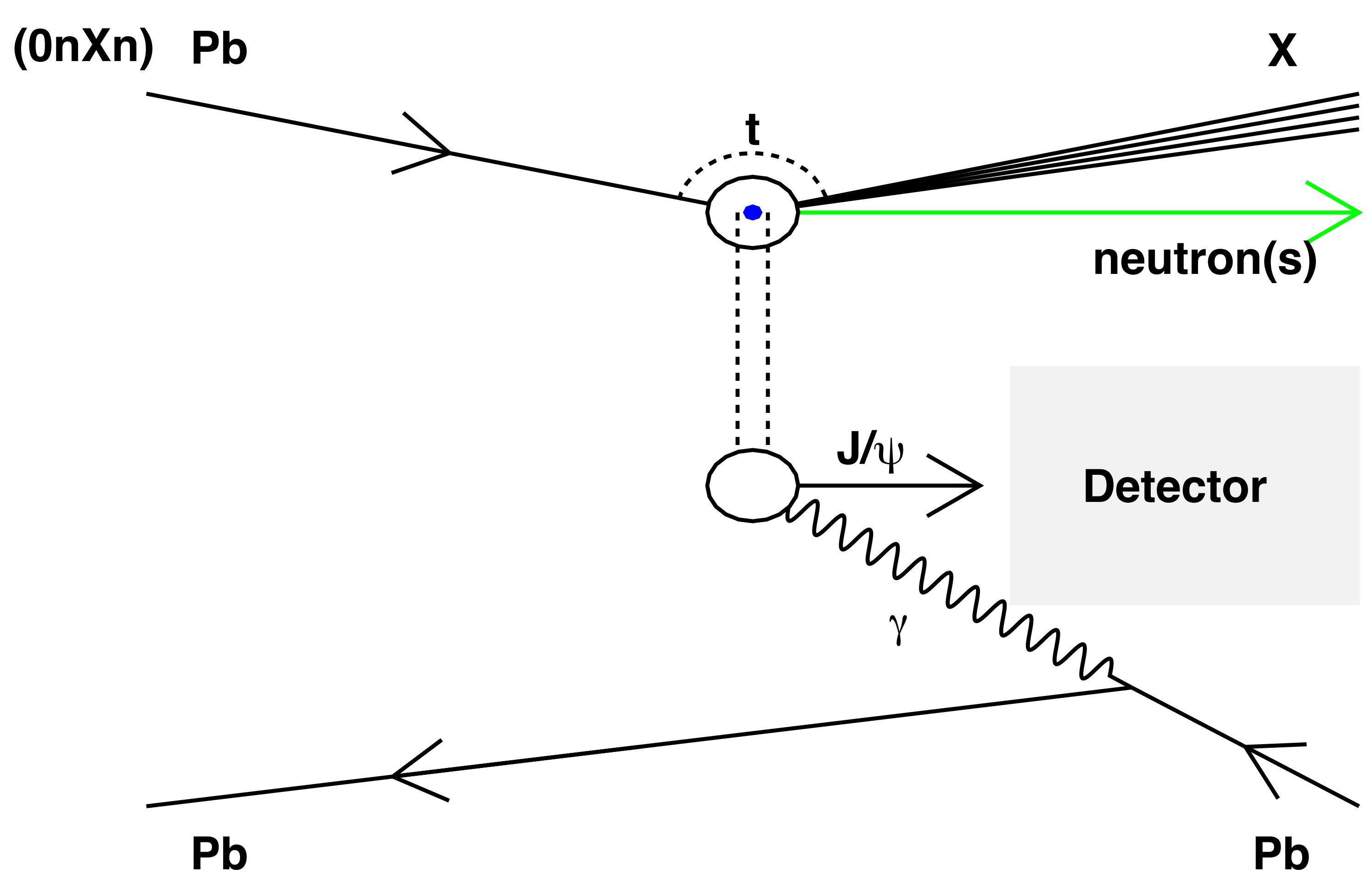
$$x = \frac{M_{J/\Psi}}{\sqrt{s_{\mathrm{NN}}}}e^{-y}$$

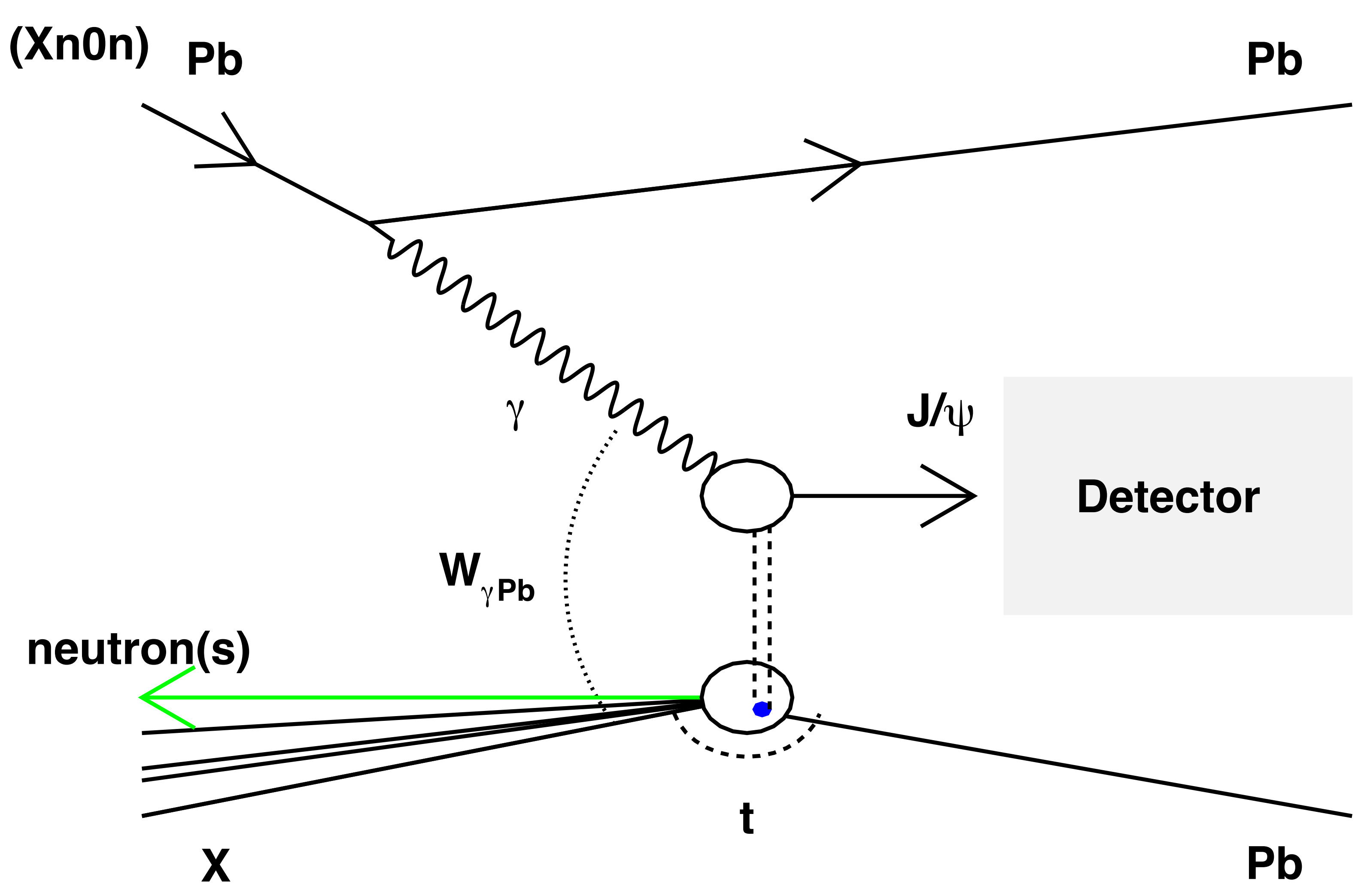
Extract the two contributions.

Disentangling low and high x contributions

- It was proposed to separate the large and small energy contributions to the cross section by tagging the production of neutrons at beam rapidities.
- Neutrons measured in Zero Degree Calorimeters
- Separation into two break-up classes: (0nXn) and (Xn0n)

Proposed here: http://inspirehep.net/record/1273593





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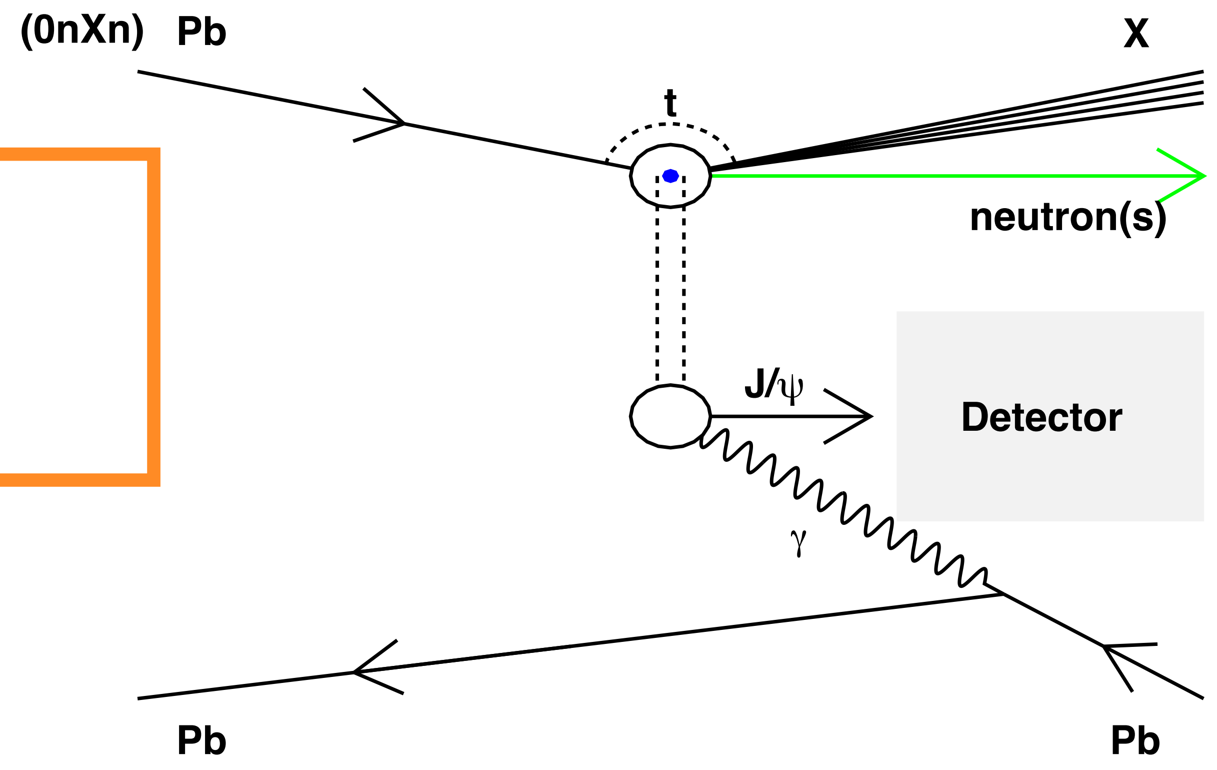
$$\frac{d\sigma_{PbPb\to J/\Psi PbPb}(y)}{dy} = N_{\gamma Pb}(y)\cdot\sigma_{\gamma Pb\to J/\Psi Pb}(y) + N_{\gamma Pb}(-y)\cdot\sigma_{\gamma Pb\to J/\Psi Pb}(-y)$$

$$\frac{d\sigma^{0nXn}_{PbPb\to J/\Psi X}(y)}{dy} = N^{0nXn}_{\gamma Pb}(y)\cdot\sigma_{\gamma Pb\to J/\Psi X}(y)$$

$$\frac{d\sigma^{Xn0n}_{PbPb\to J/\Psi X}(y)}{dy} = N^{Xn0n}_{\gamma Pb}(-y)\cdot\sigma_{\gamma Pb\to J/\Psi X}(-y)$$

→ high-x gluon

→ low energy photon



→ low-x gluon

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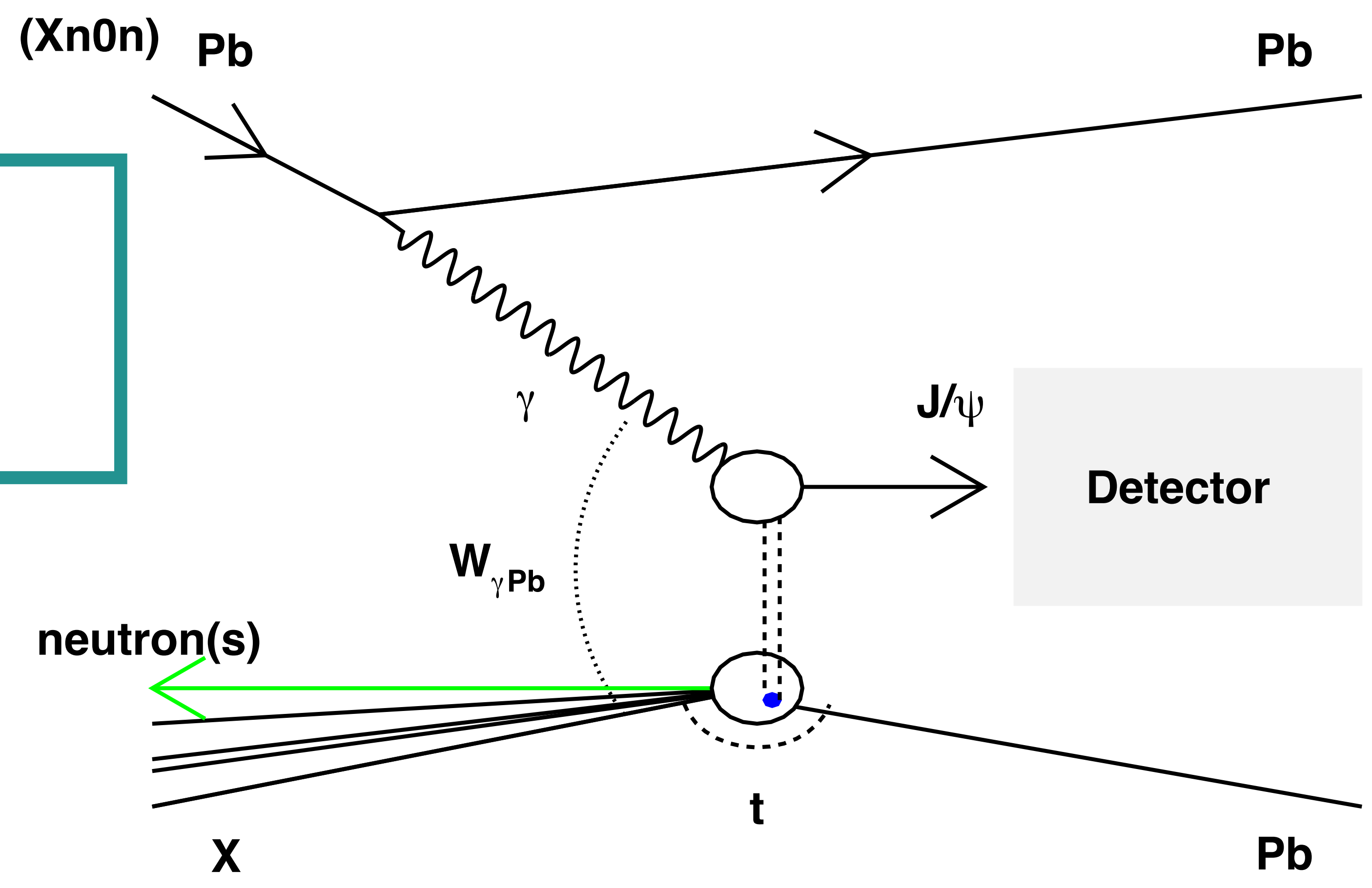


Analysis

Analyzed data

- Data sample: Muon Calo pass 3:PbPb 2018 MUON: periods q,r
- Trigger: CMUP6-NOPF-MUFAST = !0VBA & 0MUL
  - !0VBA: no signal in V0A detector with beam-beam timing
  - 0MUL: low$-p_T$ unlike sign muon trigger
- Used anchored MC LHC18q and LHC18r data periods, labeled as LHC18l7

Data selection

Cut	Number of survivors
Preselection criteria	
AOD events	92106524
Events selected in good runs	91422936
Trigger information found	85482
At least one muon track	85482
Two good muon tracks	85482
Offline selection criteria	
Selected with CMUP6 trigger	85482
General kinematics selection	64889
No SPD tracklets	49342
ADA(C) decision	48861
Empty V0A	46801
Maximum 2 cells fired and matched to muons in V0C	40339
Rapidity $-4.0 < y_{\mu^+\mu^-} < -2.5$	40339
Mass cut $2.85 < M_{\mu^+\mu^-} < 3.35$ GeV/c^2	23531
Cut $p_T > 0.3$ GeV/c	6622

This part of the selection is done in LEGO trains.

- General kinematics:
  - $2.0 < m_{\mu^+\mu^-} < 6.0$ GeV/c^2
  - $-4.0 < y < -2.5$
  - $p_T < 5.0$ GeV/c

Signal obtained from the invariant mass fit

$$\frac{d^2\sigma_{J/\Psi}}{dydp_T} = \frac{N_{J/\Psi}}{(1+f_C+f_D)\cdot(A\times\epsilon)_{J/\Psi}\cdot BR(J/\Psi\to\mu_+\mu_-)\cdot L_{int}\cdot\Delta y\cdot\Delta p_T}$$

Coefficient of coherent contamination

Coefficient of feed-down contamination

Efficiency (Tracking from Monte Carlo, vetoes from special samples)

Branching ratio
$\mathrm{J}/\Psi \to \mu_+\mu_-$
0.05961±0.00033
here

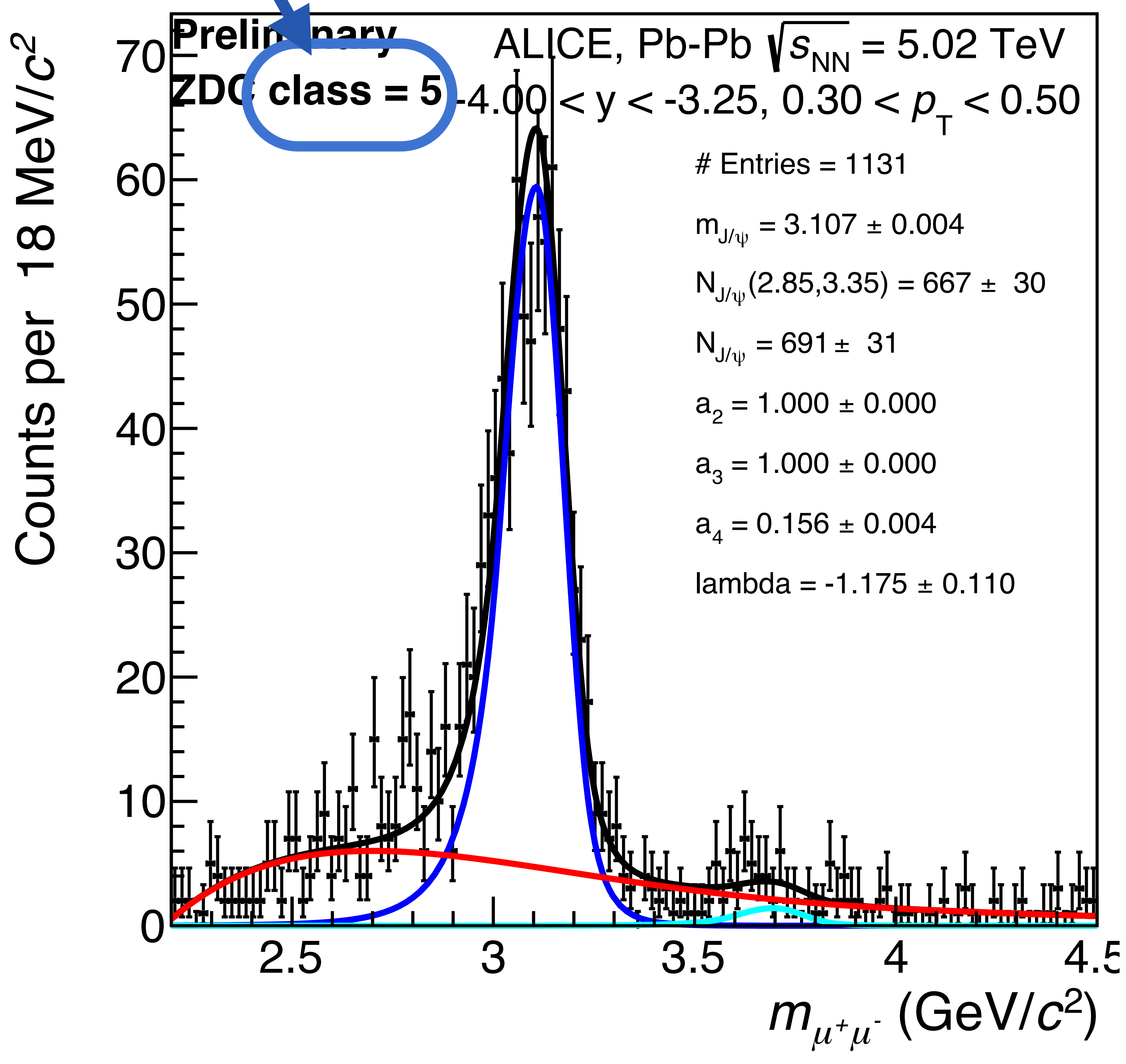
Integrated luminosity
$L_{int} = 533\ \mu b^{-1}$

Binning

Signal extraction

Signal extraction

ZDC class = 5 means there is no neutron classes separation



- Individual fits are in the backup.

bin (GeV/c)	-4.0<y<-3.25	-3.25<y<-2.5
(0.3; 0.5)	691±31	627±29
(0.5; 0.7)	533±26	476±25
(0.7; 0.9)	462±23	370±21
(0.9; 1.2)	540±24	427±22
(1.2; 1.5)	387±20	307±19

Signal obtained from the invariant mass fit

$$\frac{d^2\sigma_{J/\Psi}}{dydp_T} = \frac{N_{J/\Psi}}{(1+f_C+f_D)\cdot(A\times\epsilon)_{J/\Psi}\cdot BR(J/\Psi\rightarrow\mu_+\mu_-)\cdot L_{int}\cdot\Delta y\cdot\Delta p_T}$$

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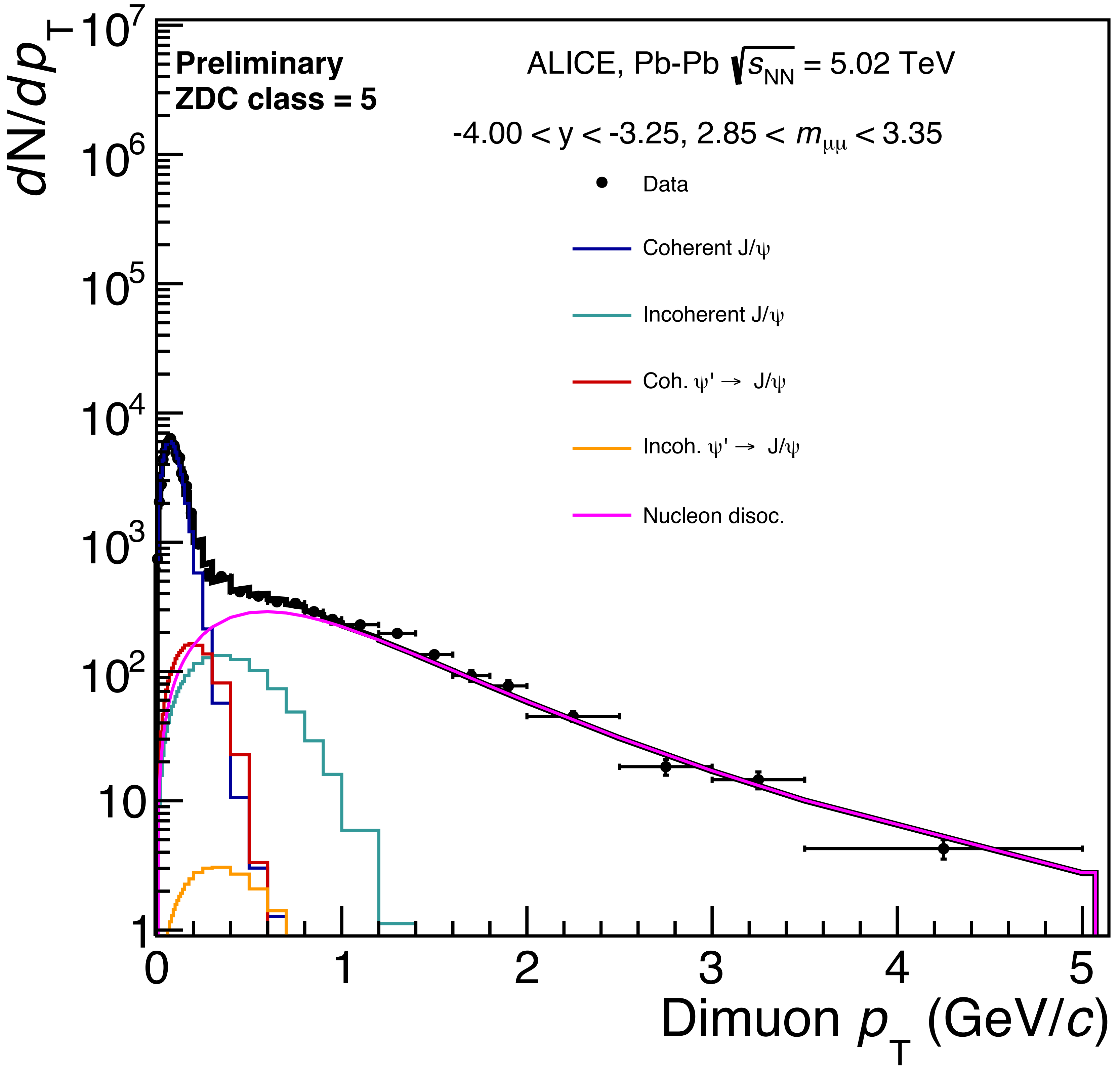
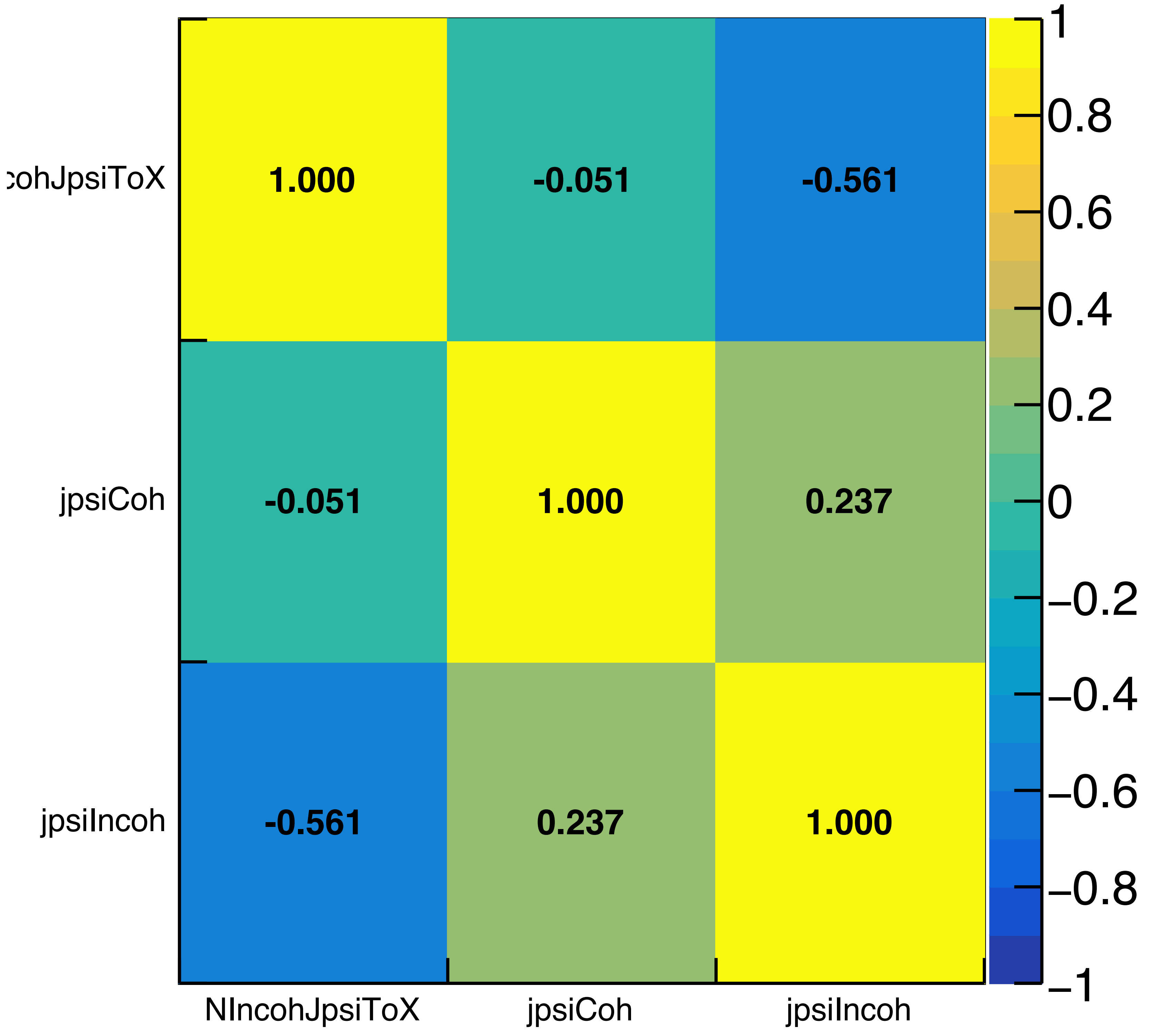
Binning

Coherent and feed-down contamination coefficients

Transverse momentum distribution

- Transverse momentum fit is used to extract the contribution from coherent production and feed-down.





Coherent and feed-down contamination coefficients

$$f_{\mathrm{DCoh}}^{\mathrm{pTbin}} = \frac{N_{\mathrm{coh}\Psi'}^{\mathrm{pTbin}}}{N_{\mathrm{incohJ/\Psi}}^{\mathrm{pTbin}} + N_{\mathrm{disocJ/\Psi}}^{\mathrm{pTbin}}}$$

$$f_{\mathrm{DIncoh}}^{\mathrm{pTbin}} = \frac{N_{\mathrm{incoh}\Psi'}^{\mathrm{pTbin}}}{N_{\mathrm{incohJ/\Psi}}^{\mathrm{pTbin}} + N_{\mathrm{disocJ/\Psi}}^{\mathrm{pTbin}}}$$

$$f_{\mathrm{C}}^{\mathrm{pTbin}} = \frac{N_{\mathrm{coh}}^{\mathrm{pTbin}}}{N_{\mathrm{incoh}}^{\mathrm{pTbin}} + N_{\mathrm{disoc}}^{\mathrm{pTbin}}}$$

$$f_{\mathrm{D}}^{\mathrm{pTbin}} = f_{\mathrm{DCoh}}^{\mathrm{pTbin}} + f_{\mathrm{DIncoh}}^{\mathrm{pTbin}}$$

Coherent contamination coefficient	**-4<y<-3.25**	**-3.25<y<-2.5**
(0.3,0.5)	0.087±0.004	0.124±0.007
(0.5,0.7)	0.006±0.000	0.008±0.000
(0.7,0.9)	0.001±0.000	0.002±0.000
(0.9,1.2)	0.001±0.000	0.001±0.000
(1.2,1.5)	0.000±0.000	0.000±0.000

Feed-down contamination coefficient	**-4<y<-3.25**	**-3.25<y<-2.5**
(0.3,0.5)	0.156±0.007	0.210±0.011
(0.5,0.7)	0.018±0.002	0.018±0.002
(0.7,0.9)	0.006±0.001	0.005±0.001
(0.9,1.2)	0.002±0.000	0.001±0.000
(1.2,1.5)	0.000±0.000	0.000±0.000

Efficiency of reconstructed events $(A \times \epsilon)_{\mathrm{MC}}$

Signal obtained from the invariant mass fit

$$\frac{d^2\sigma_{J/\Psi}}{dy dp_T} = \frac{N_{J/\Psi}}{(1 + f_C + f_D) \cdot (A \times \epsilon)_{J/\Psi} \cdot BR(J/\Psi \to \mu_+\mu_-) \cdot L_{int} \cdot \Delta y \cdot \Delta p_T}$$

Coefficient of coherent contamination

Coefficient of feed-down contamination

Efficiency (Tracking from Monte Carlo, vetoes from special samples)

In the back-up

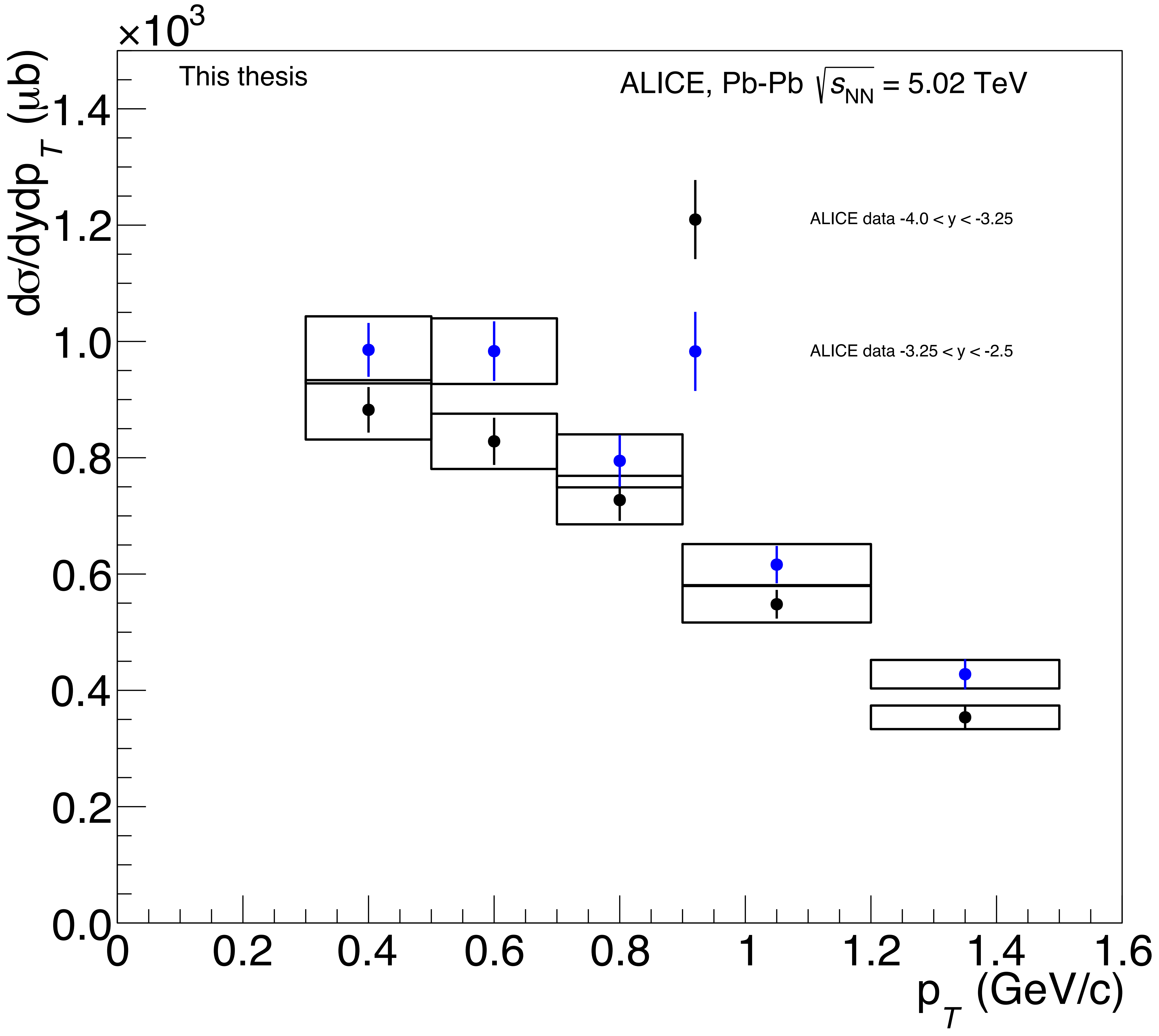
Branching ratio
$J/\Psi \to \mu_+\mu_-$
0.05961±0.00033
here

Integrated luminosity
$L_{int} = 533\ \mu b^{-1}$

Binning

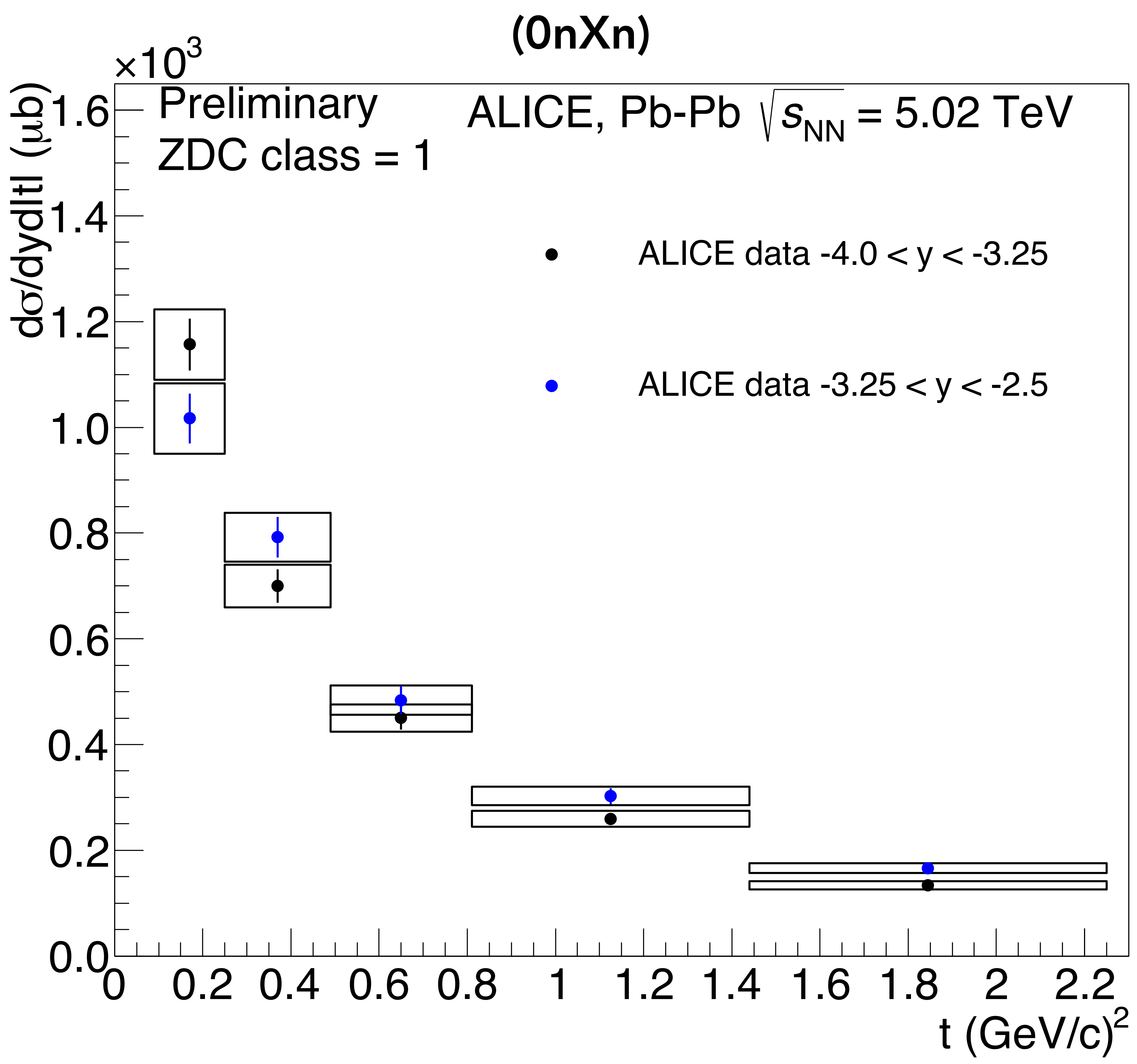
Cross section

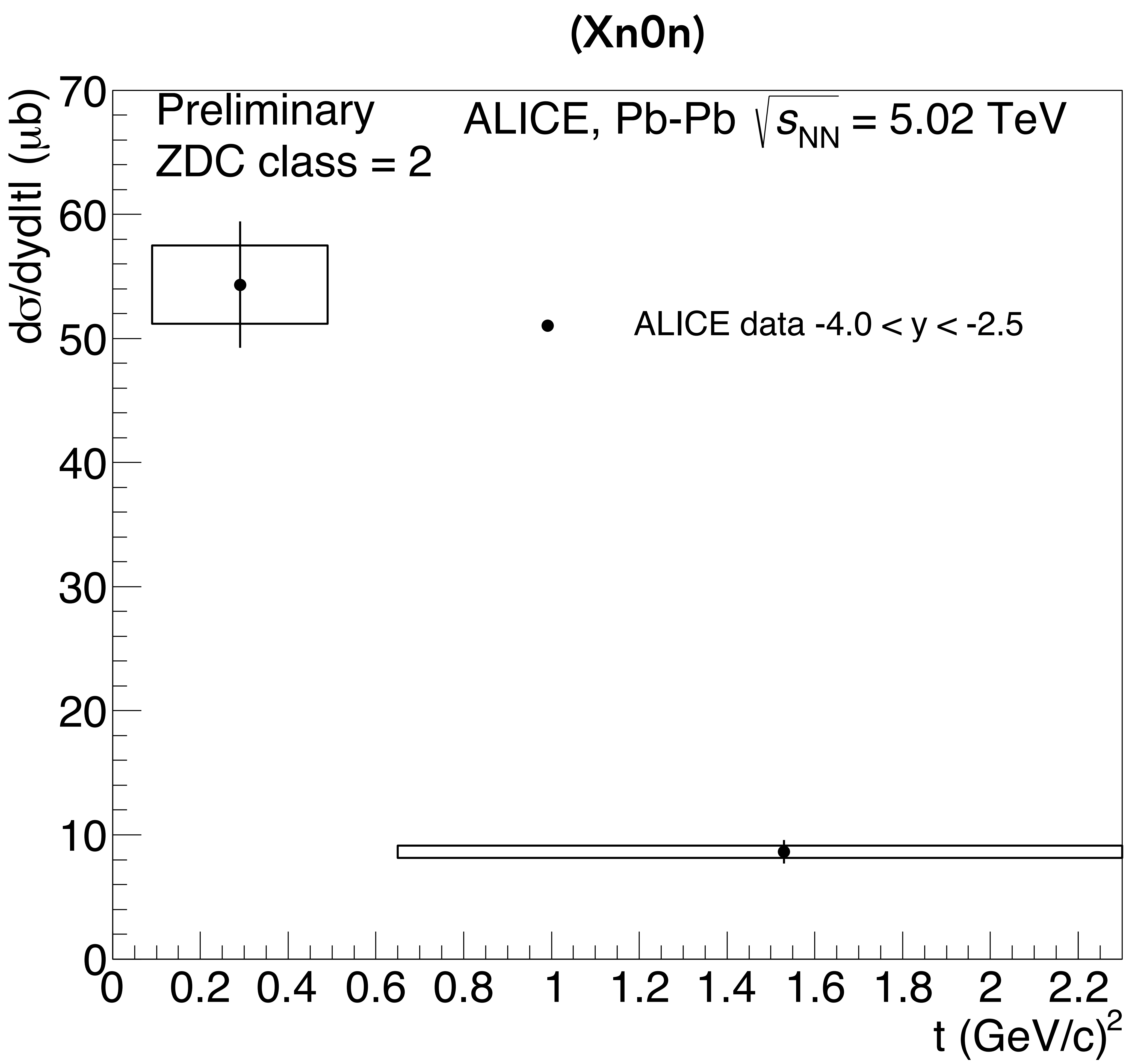
UPC cross section



Separation into neutron classes (0nXn) and (Xn0n)

UPC cross section





Photon lead cross section

(0nXn)

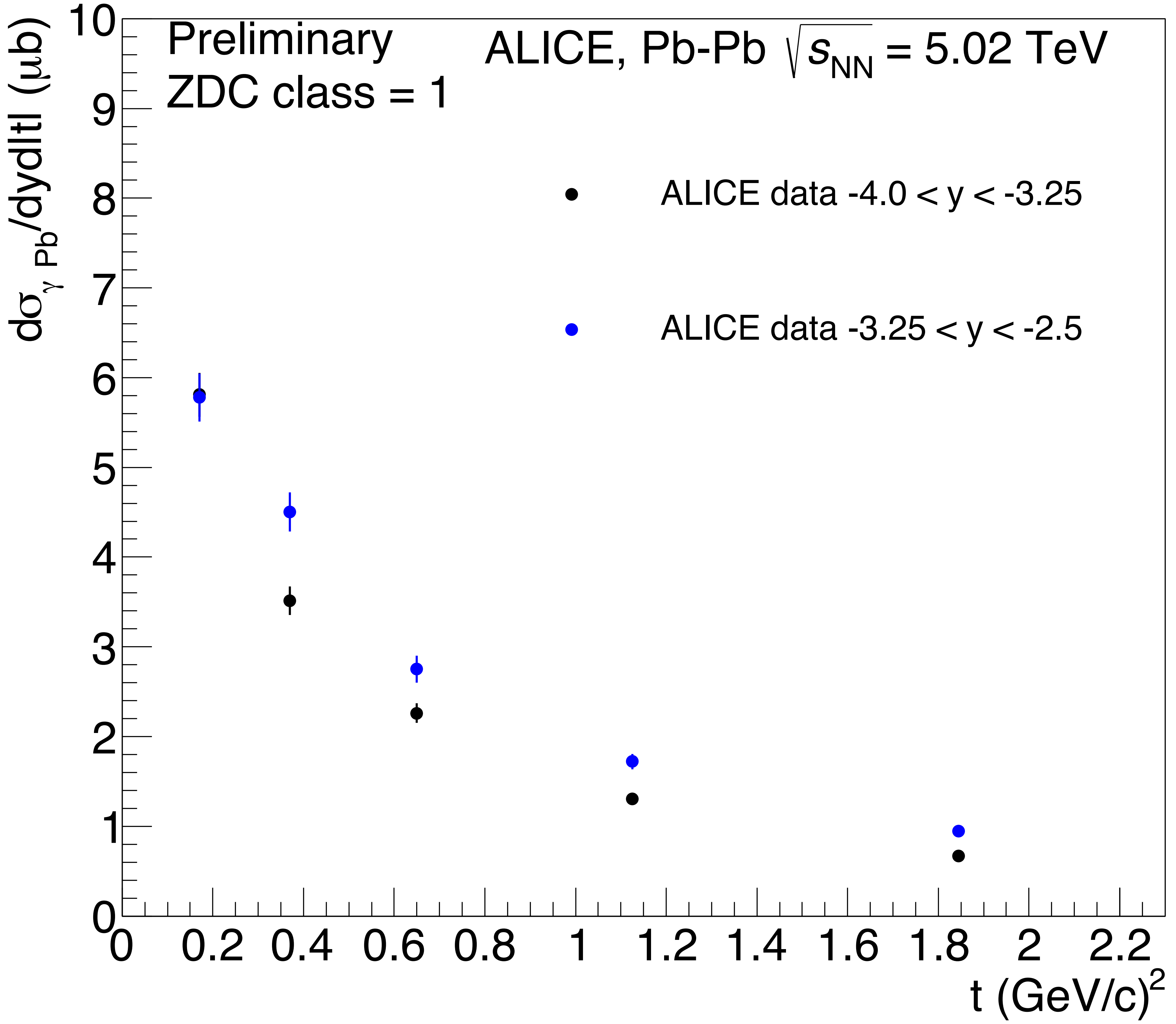
- Low energy

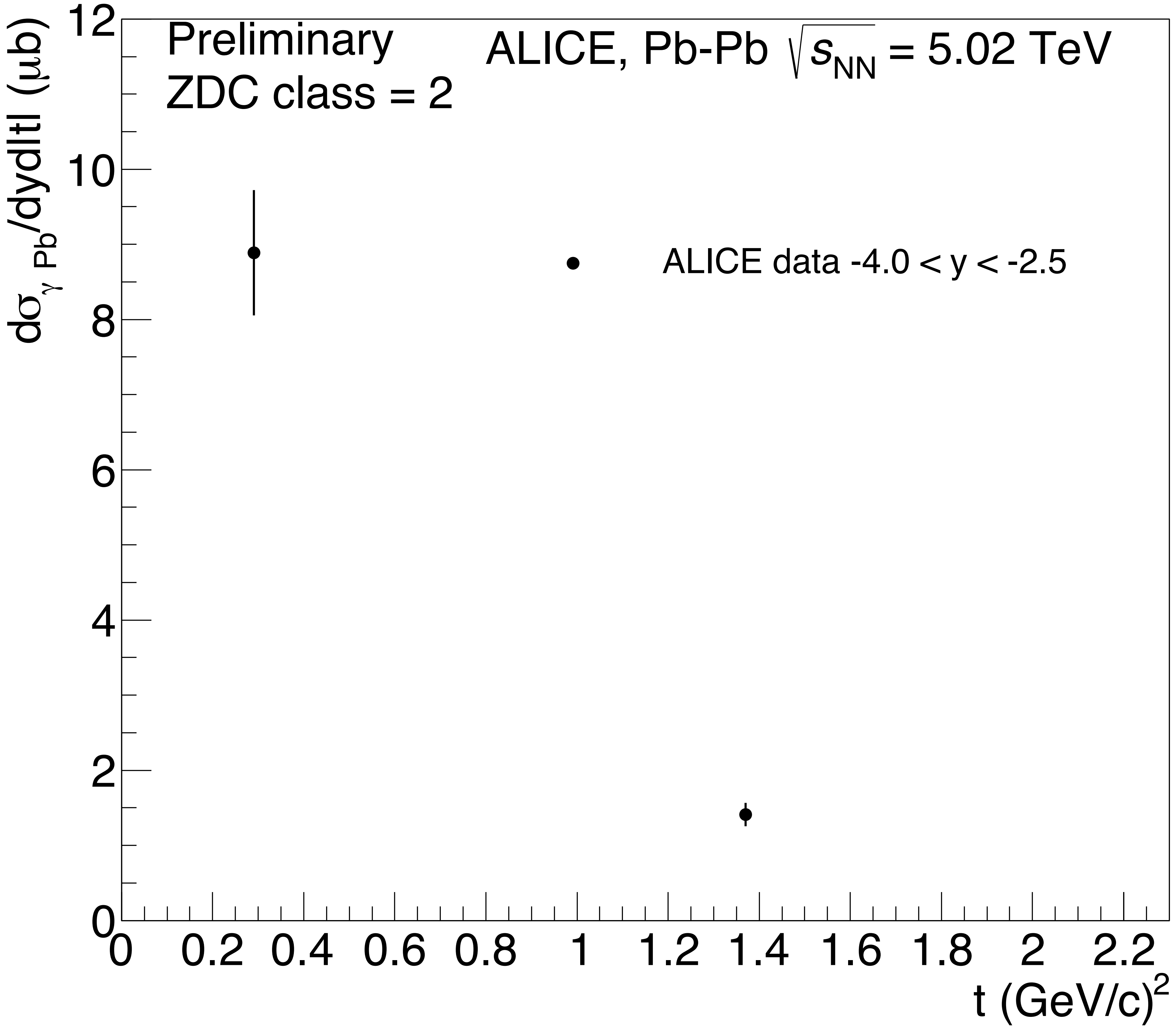
- David's measurement

|y|<0.8

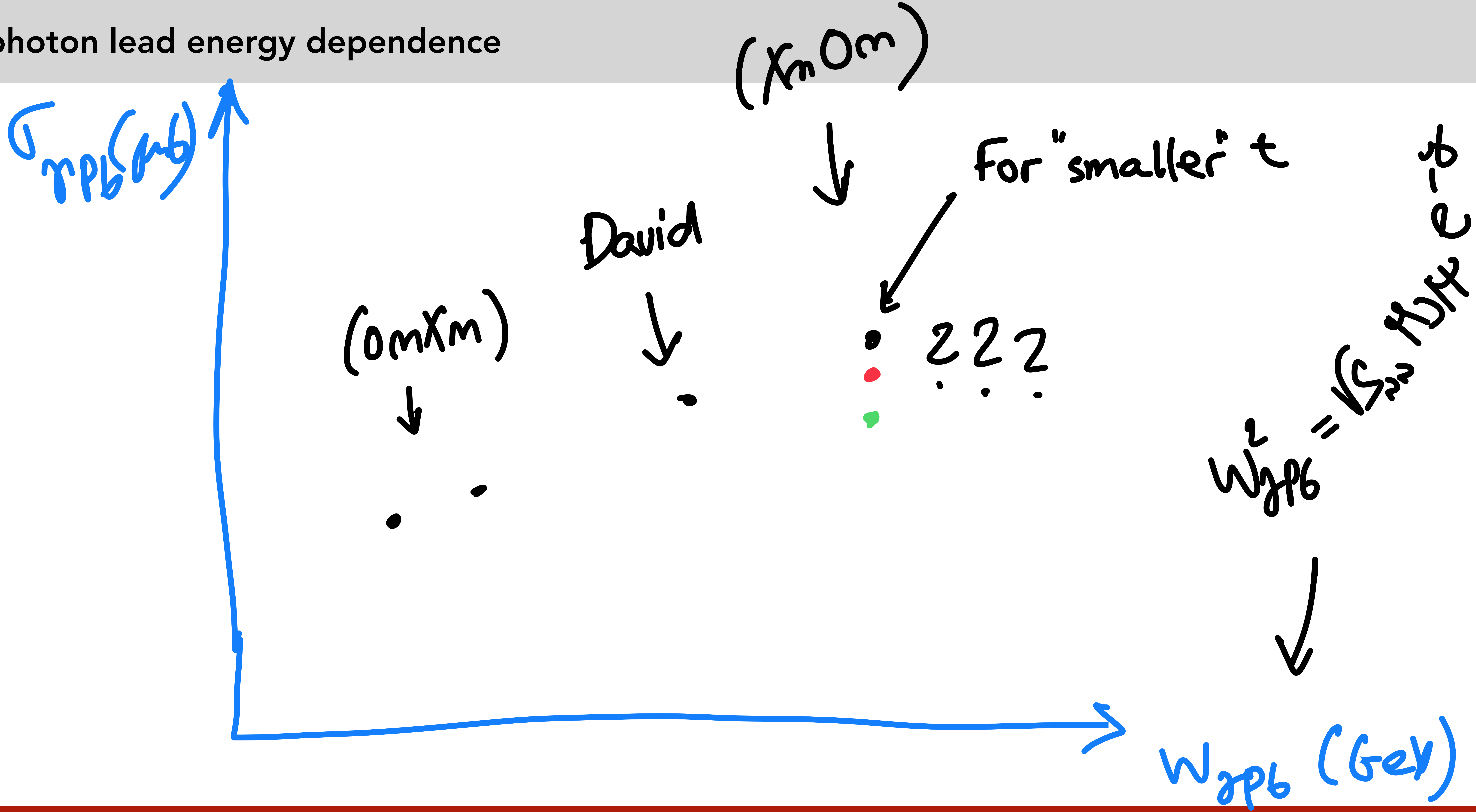
(Xn0n)

- High energy





Goal: photon lead energy dependence



Summary and outlook

- The UPC cross section for incoherent J/Ψ photoproduction in rapidity and p_T bins was reported.
- Separation into nuclear break-up classes and first results were shown.
- Still some work left: systematics, neutron migration,…

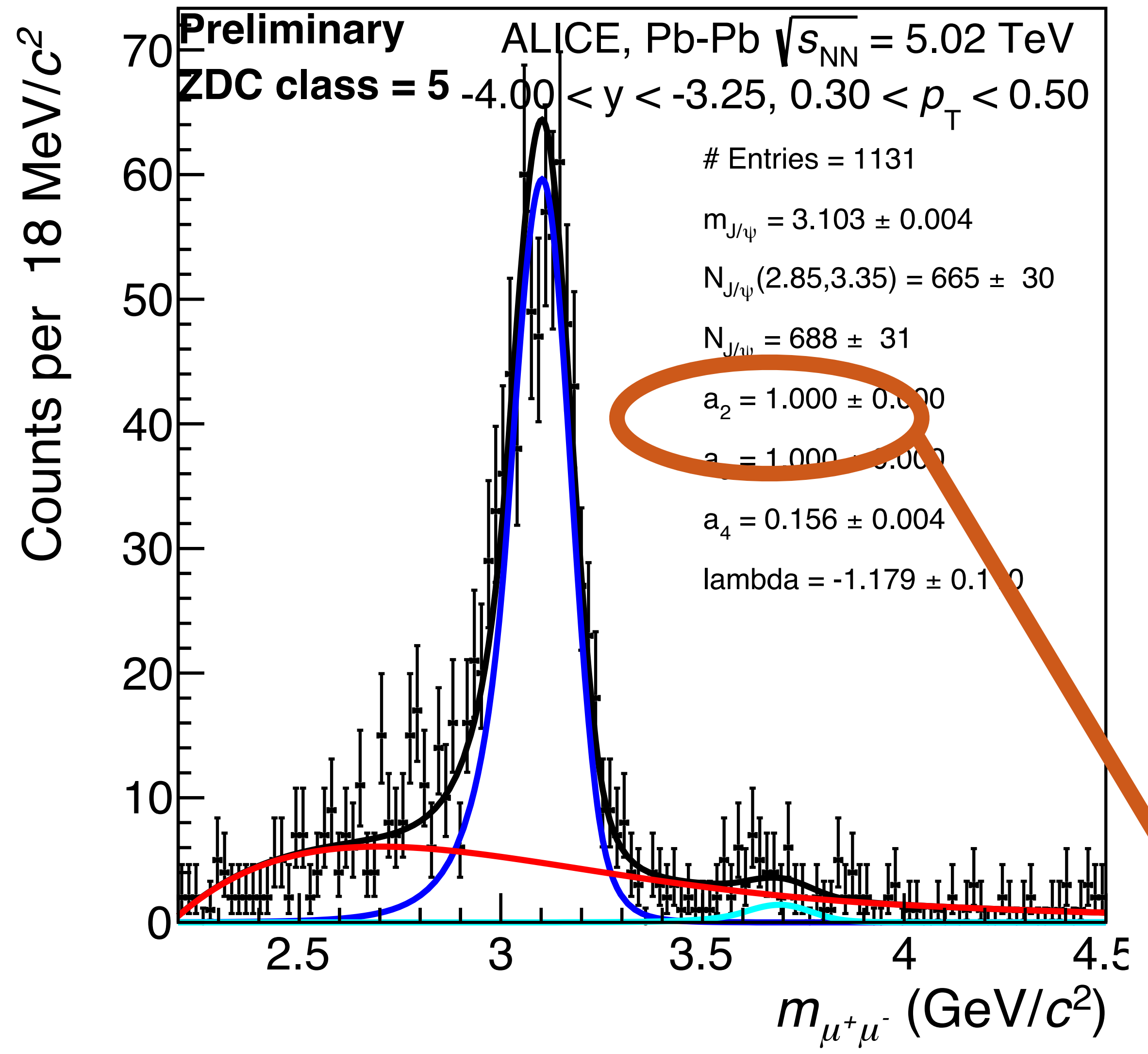
Stay tuned! And thank you for your attention!

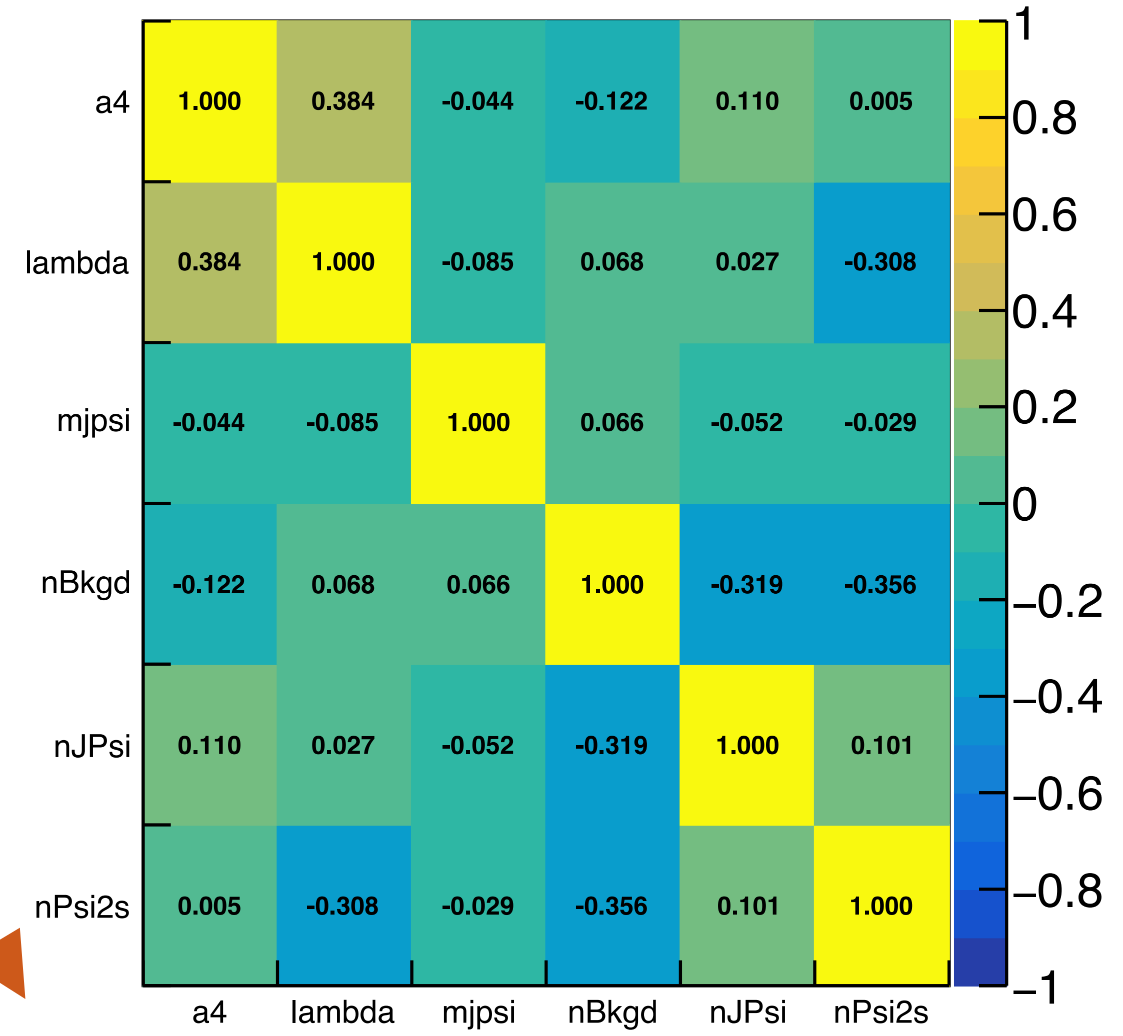
Backup

Signal extraction

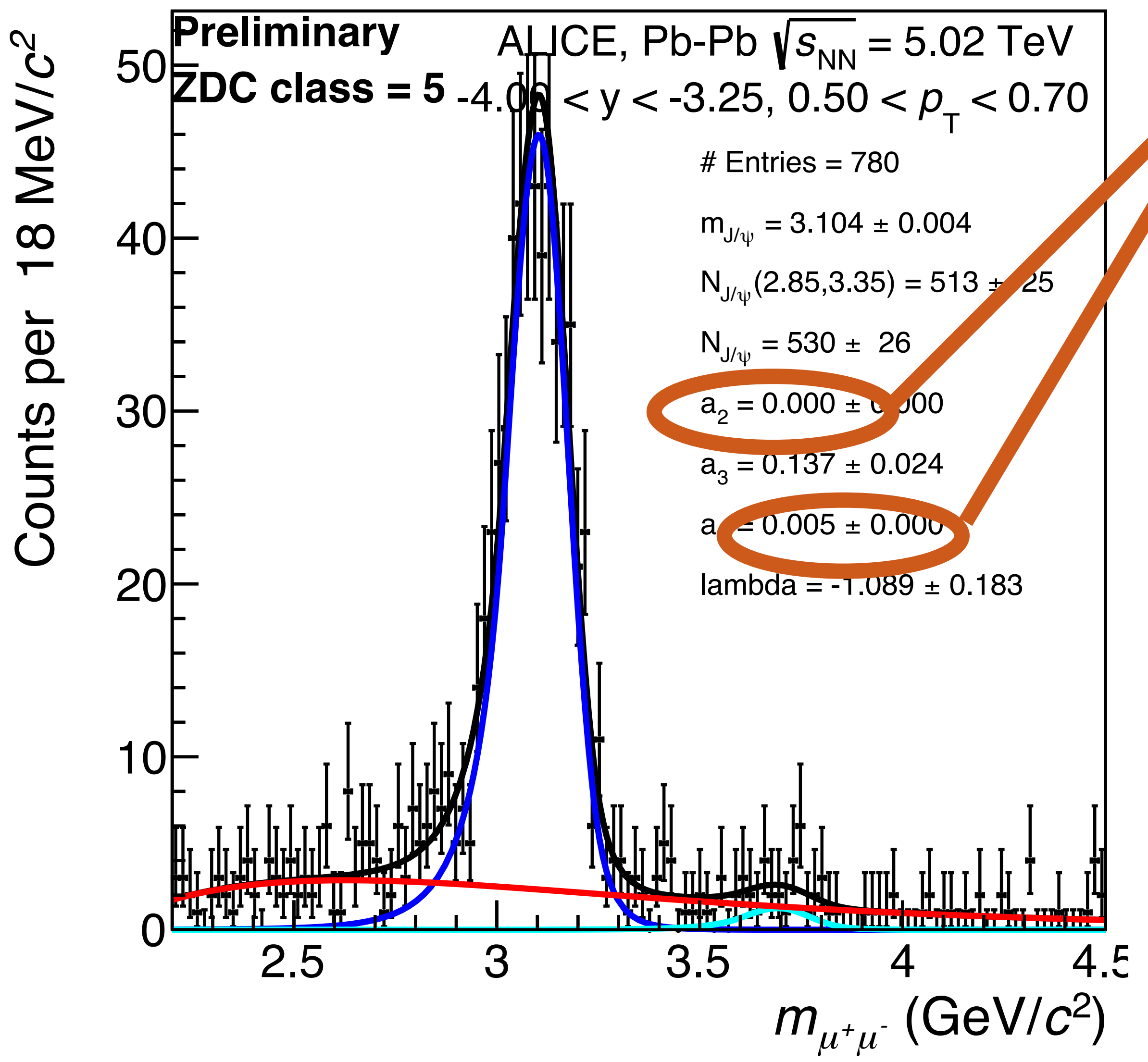
- J/Ψ signal is extracted from a fit to the invariant mass distribution of the muon pair
- Fitting function: Double-sided crystal ball
  - MC incoherent J/Ψ sample studied:
    - Parameters n are fixed to $n = 10$.
    - σ_L, σ_R fixed first, then α_L, α_R fixed.
- Background fitted with an exponential with polynomial tail in first two p_T bins
  - Some of the parameters were fixed.
- Background in last three bins was fitted with an exponential function.

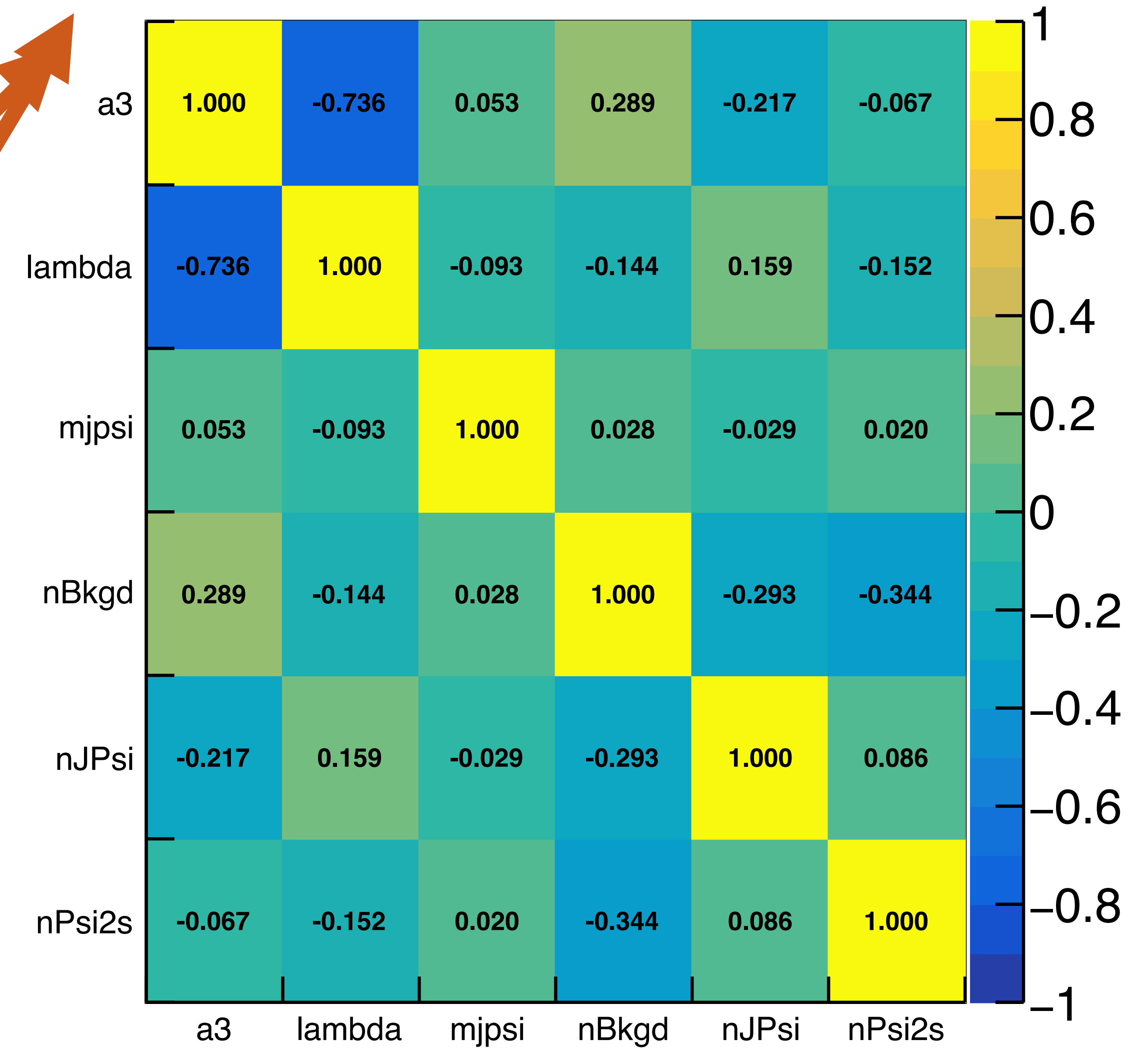
Backup: Signal extraction: -4.0<y<-3.25



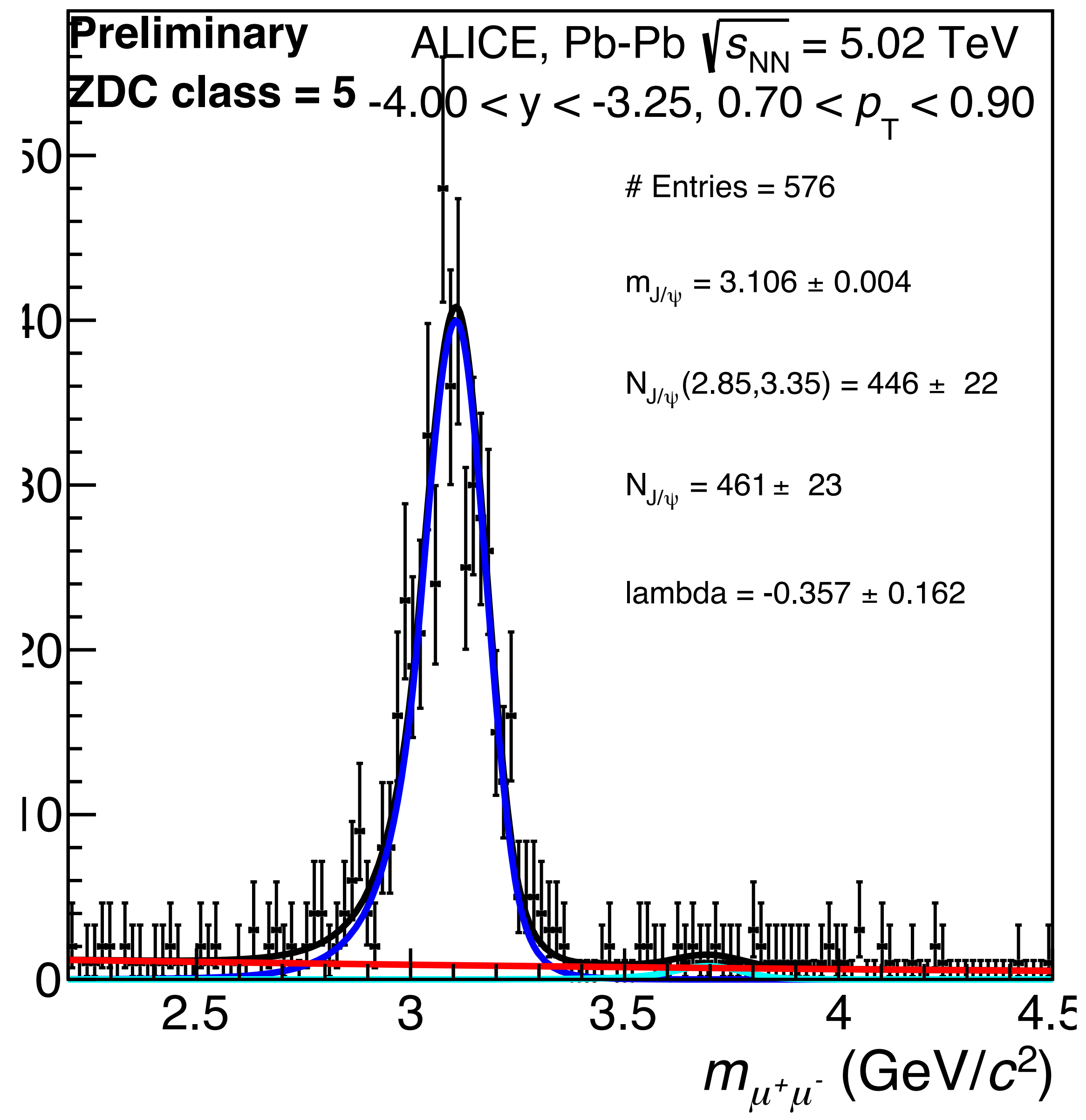


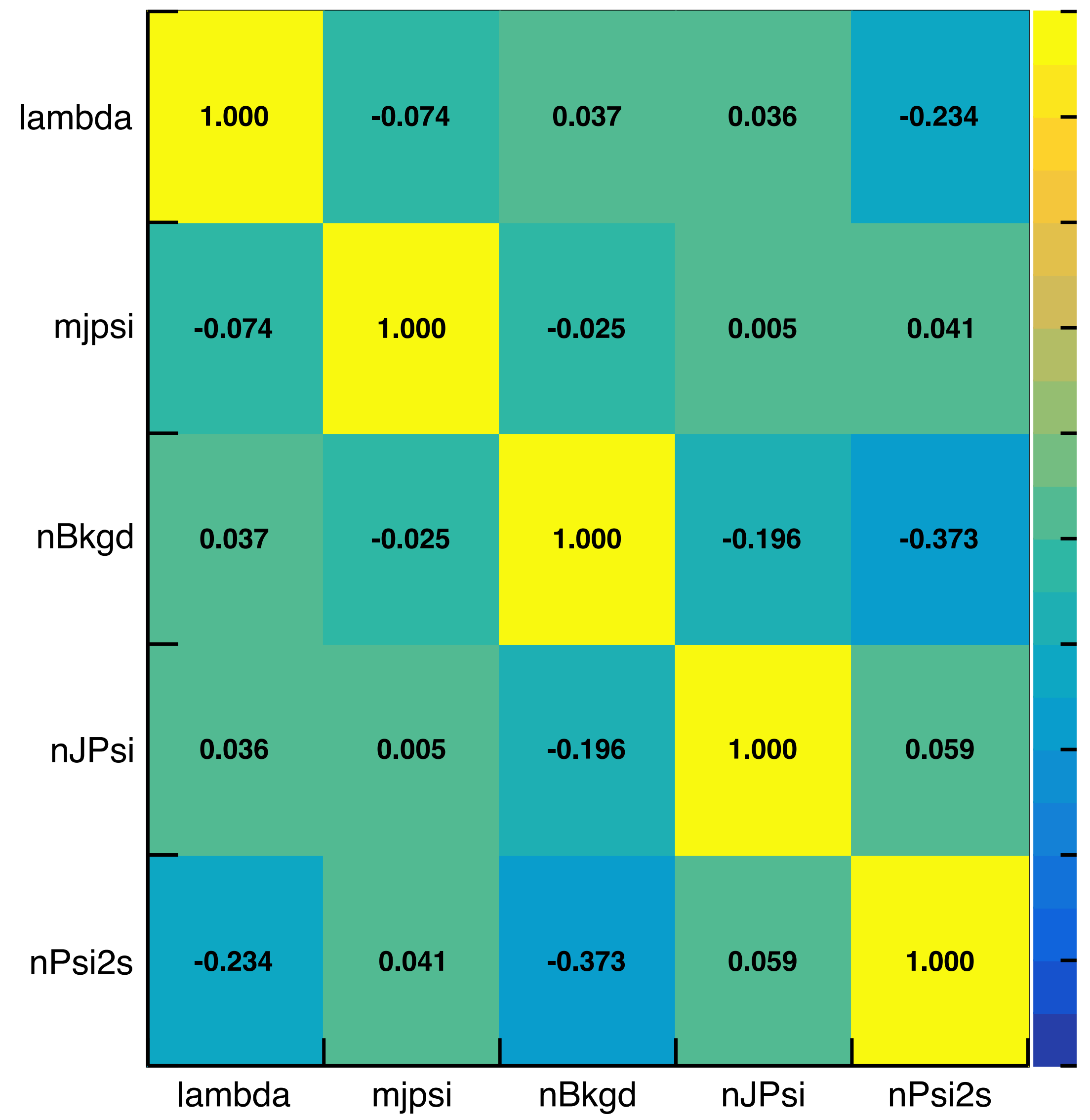
Fixed





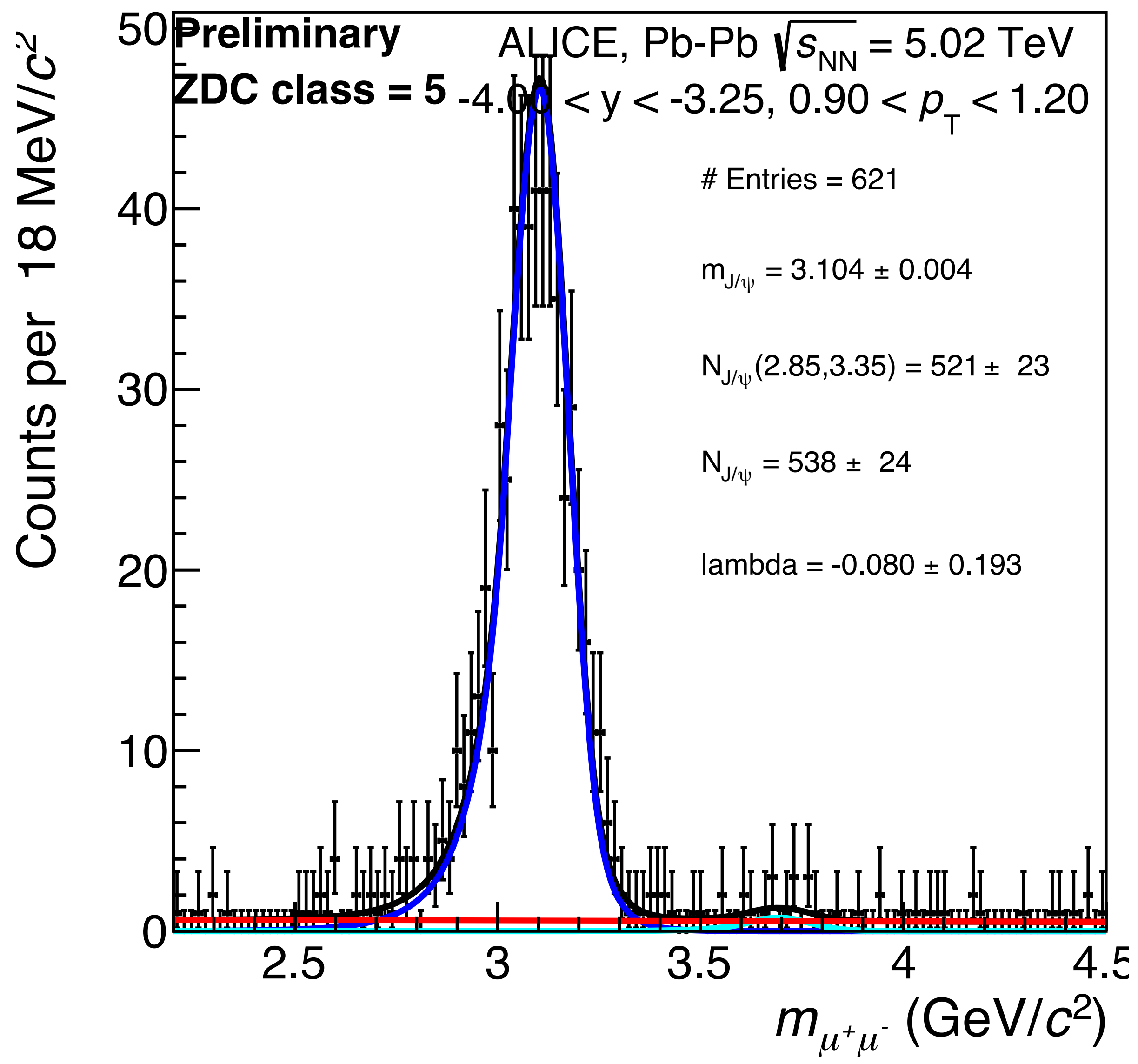
Background fitted with exponential

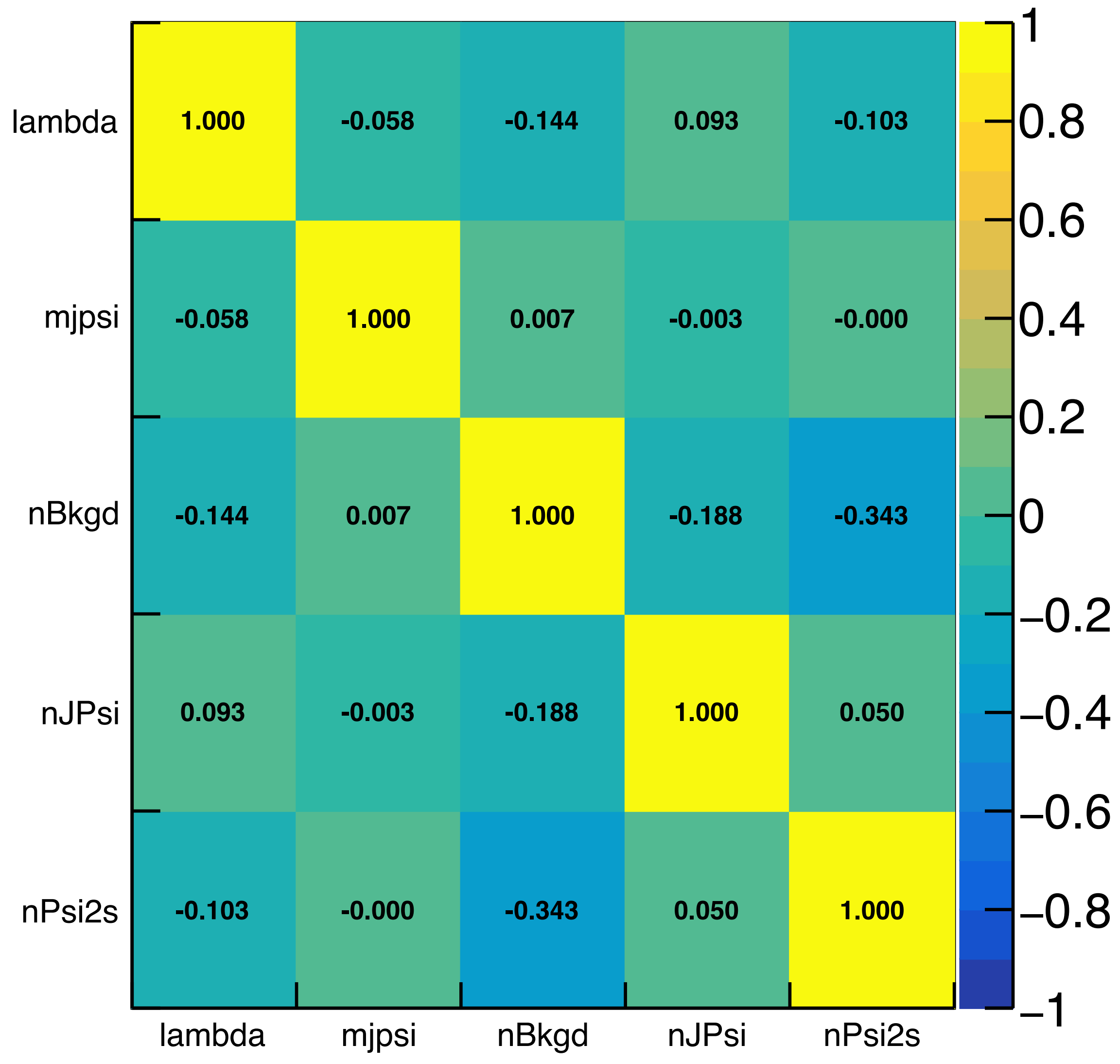


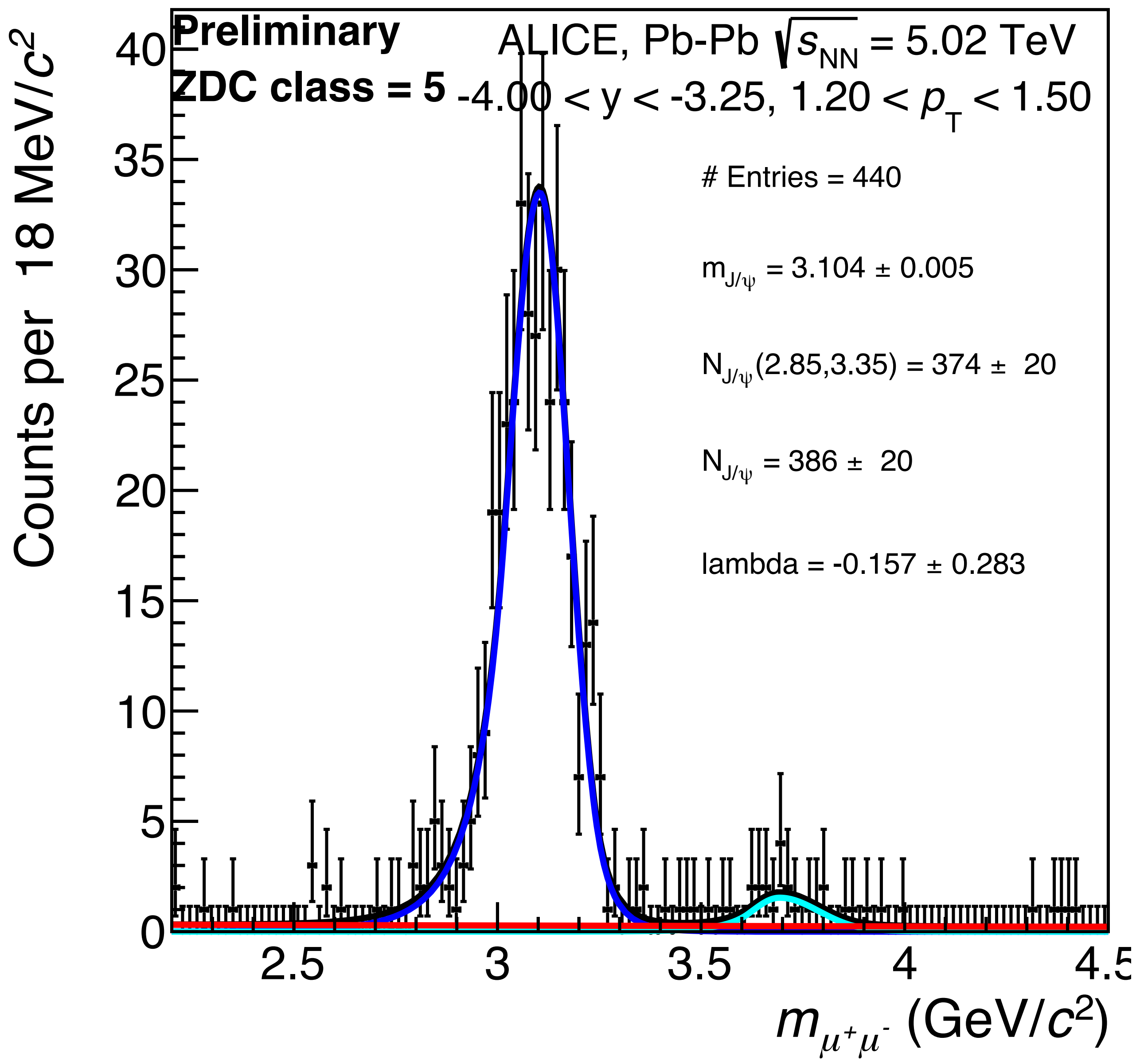


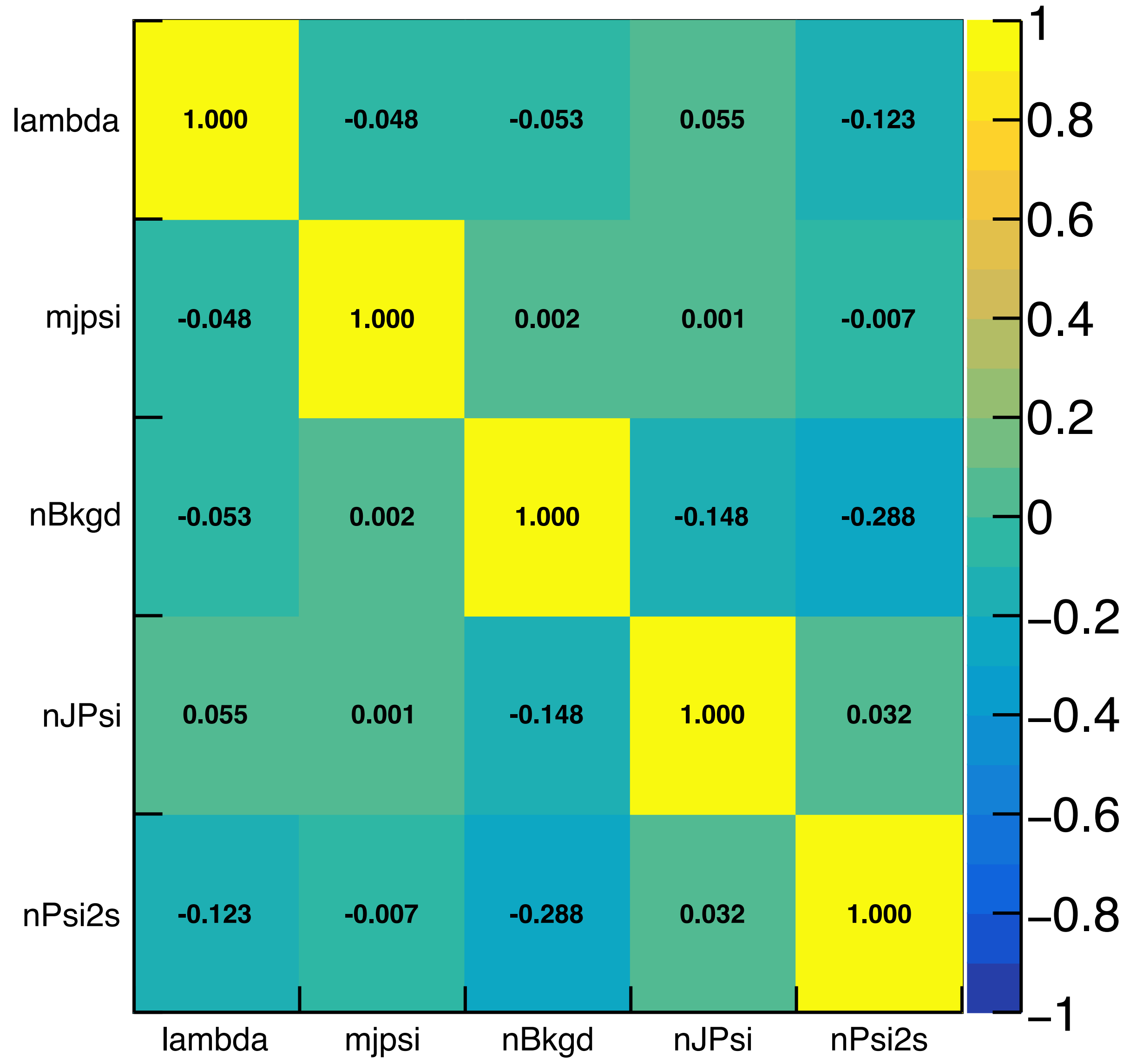
Backup: Signal extraction: -4.0<y<-3.25

Background fitted with exponential

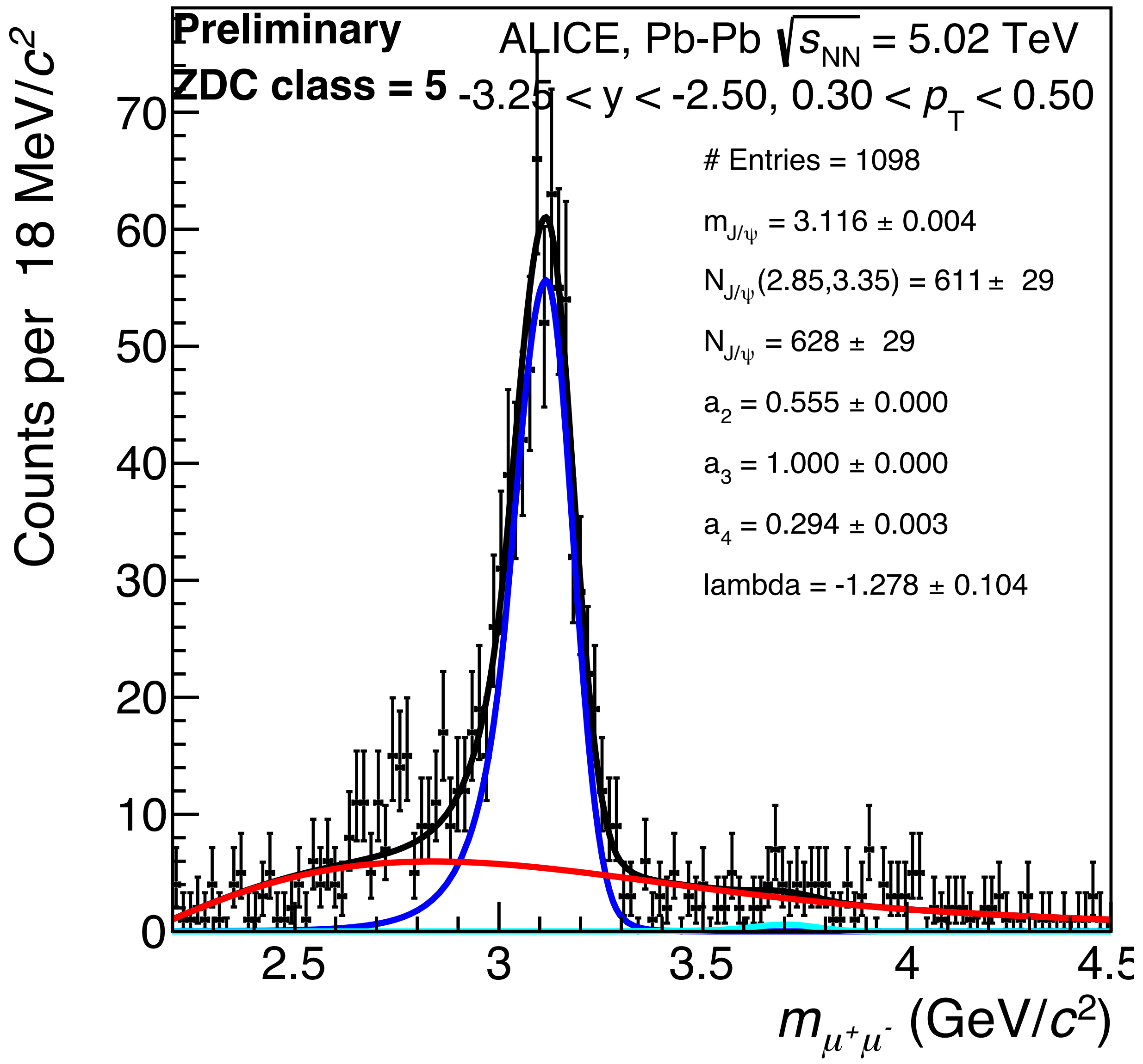


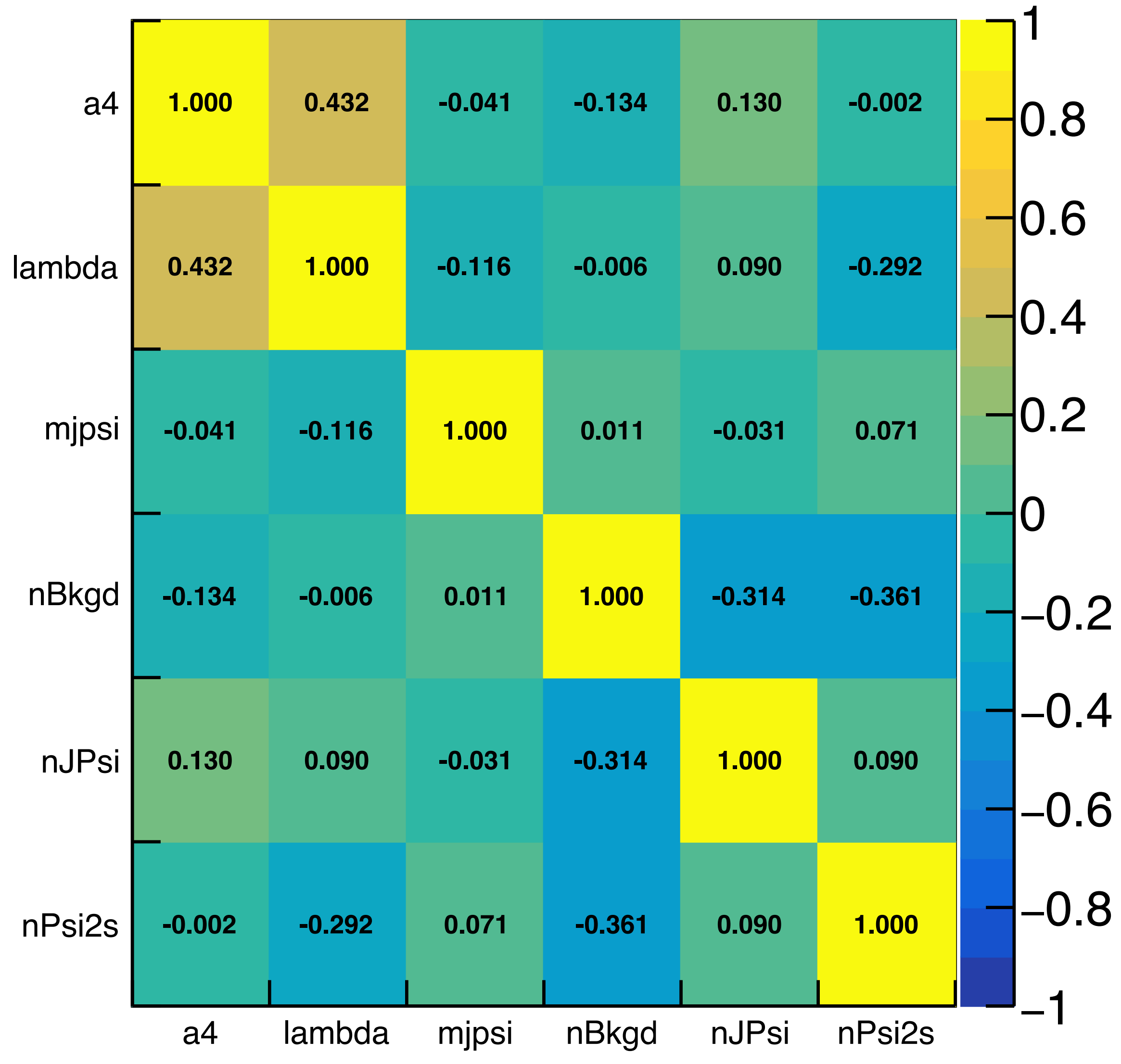


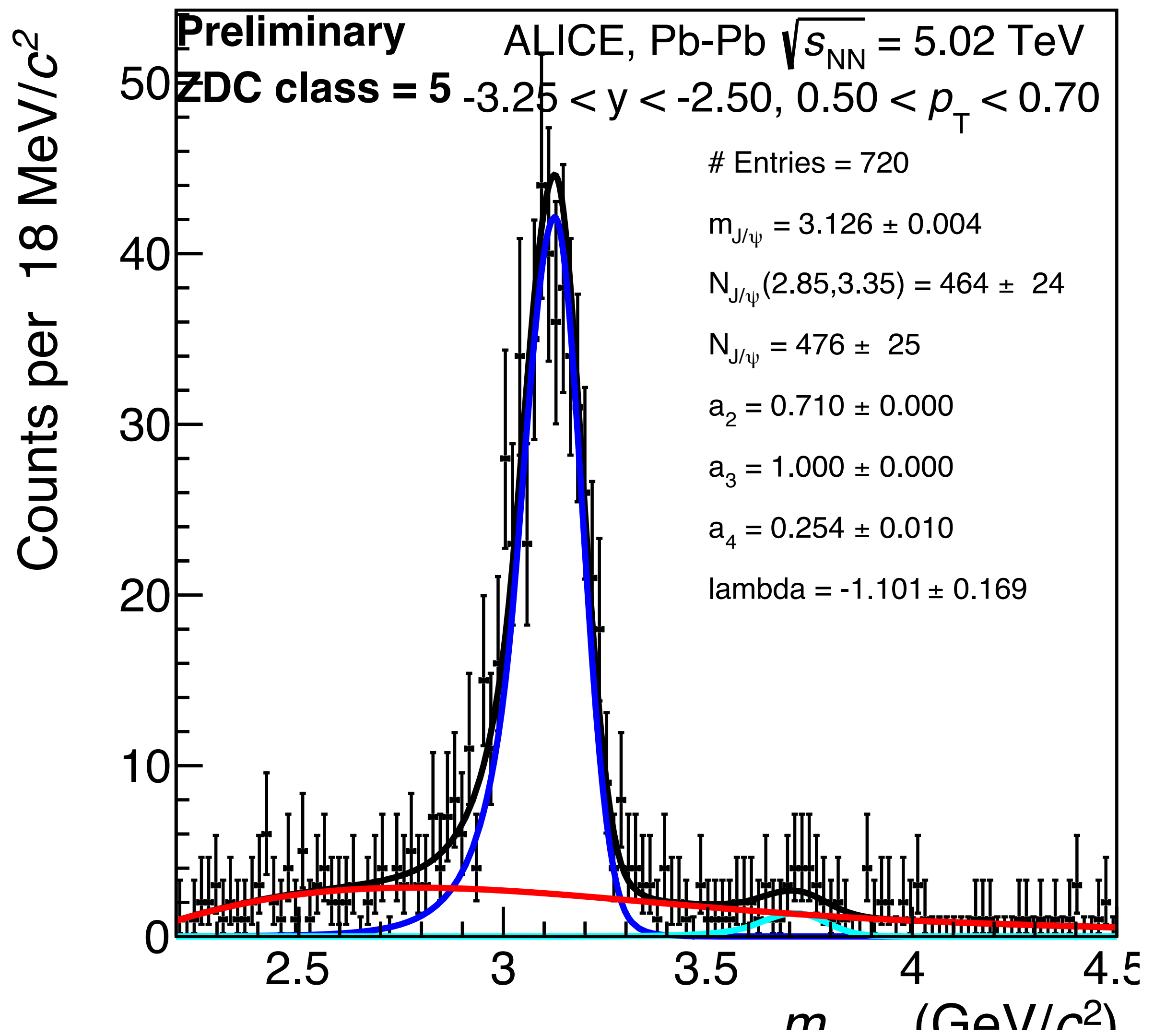


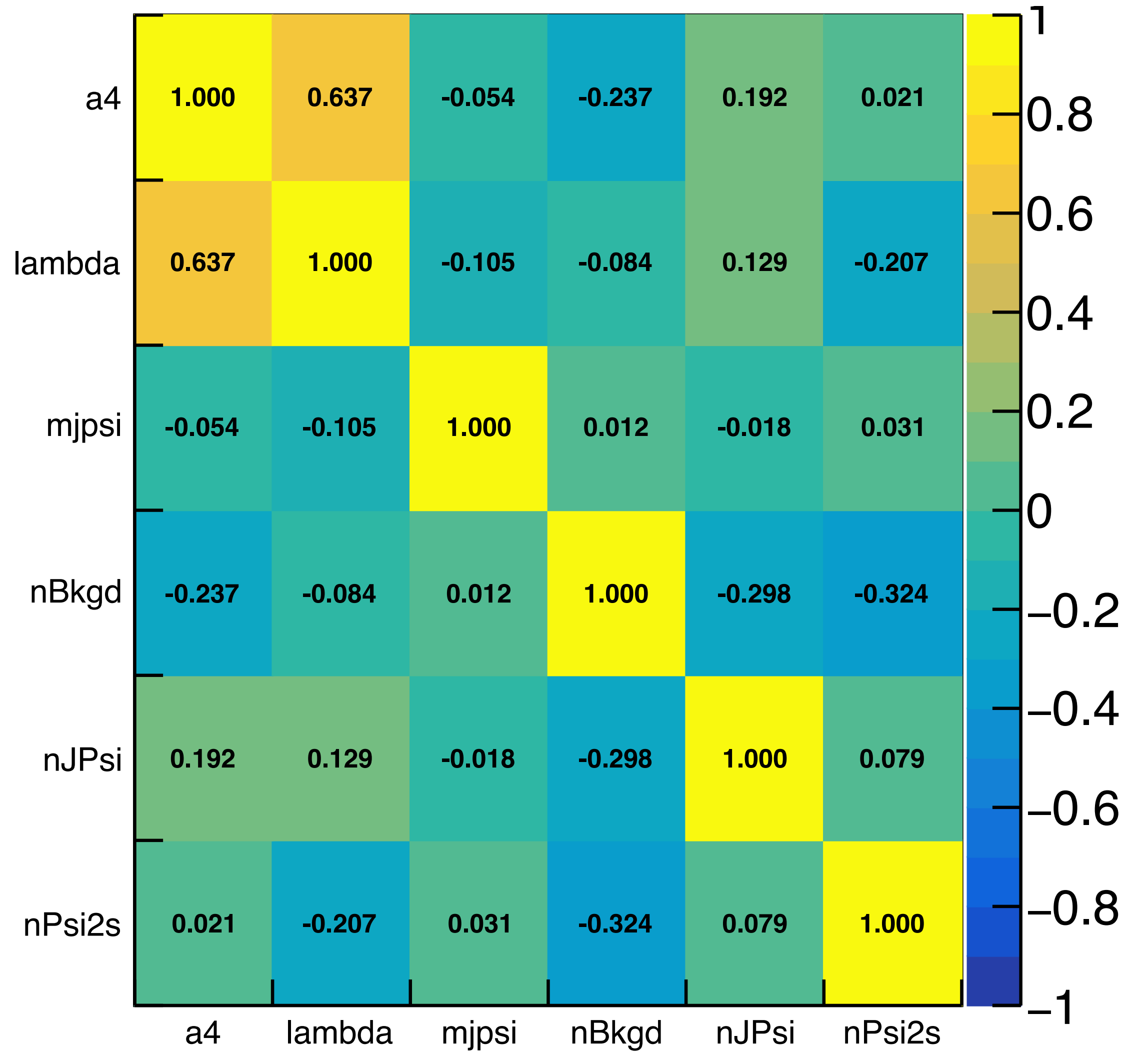


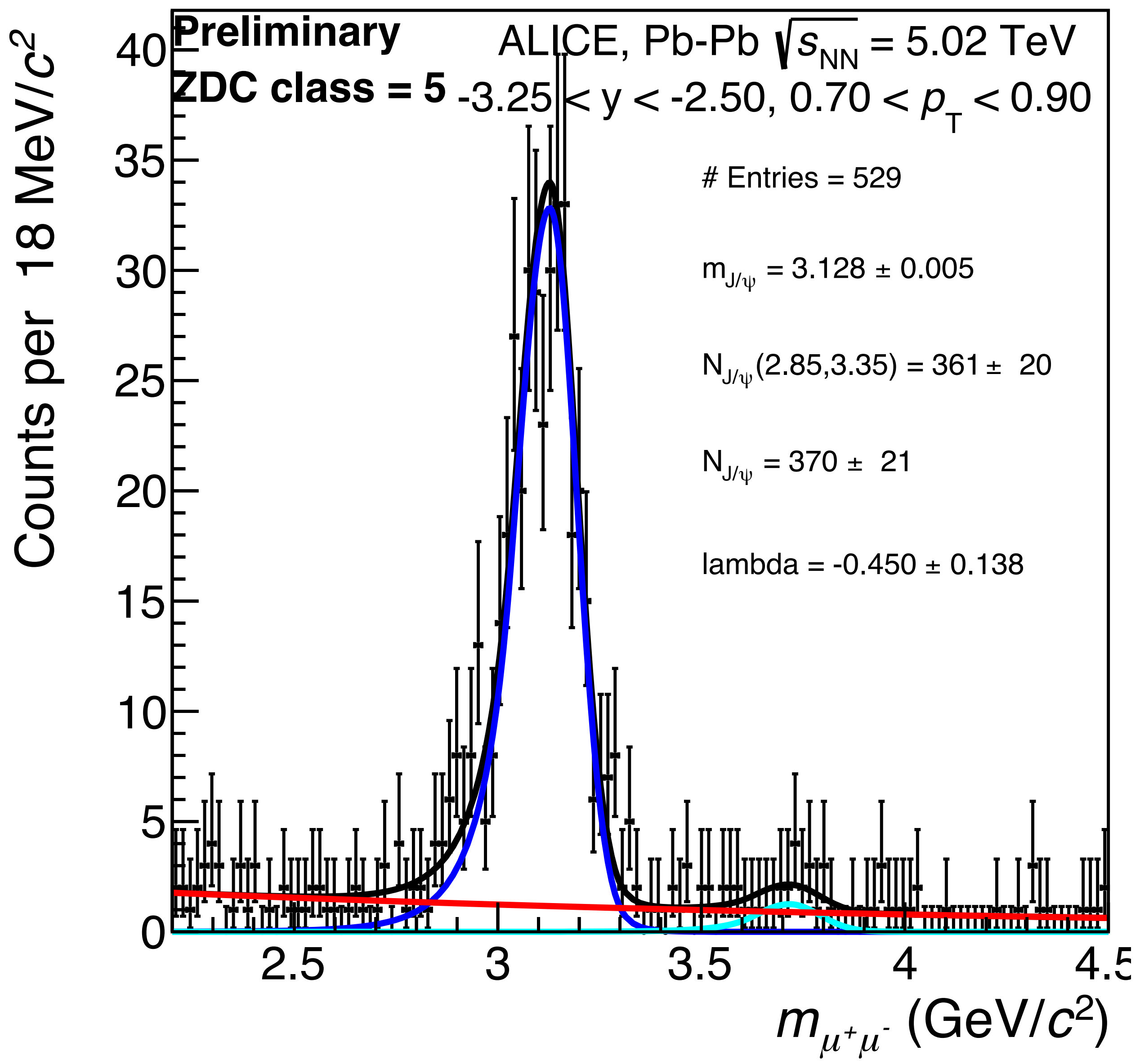
Backup: Signal extraction: -3.25<y<-2.5

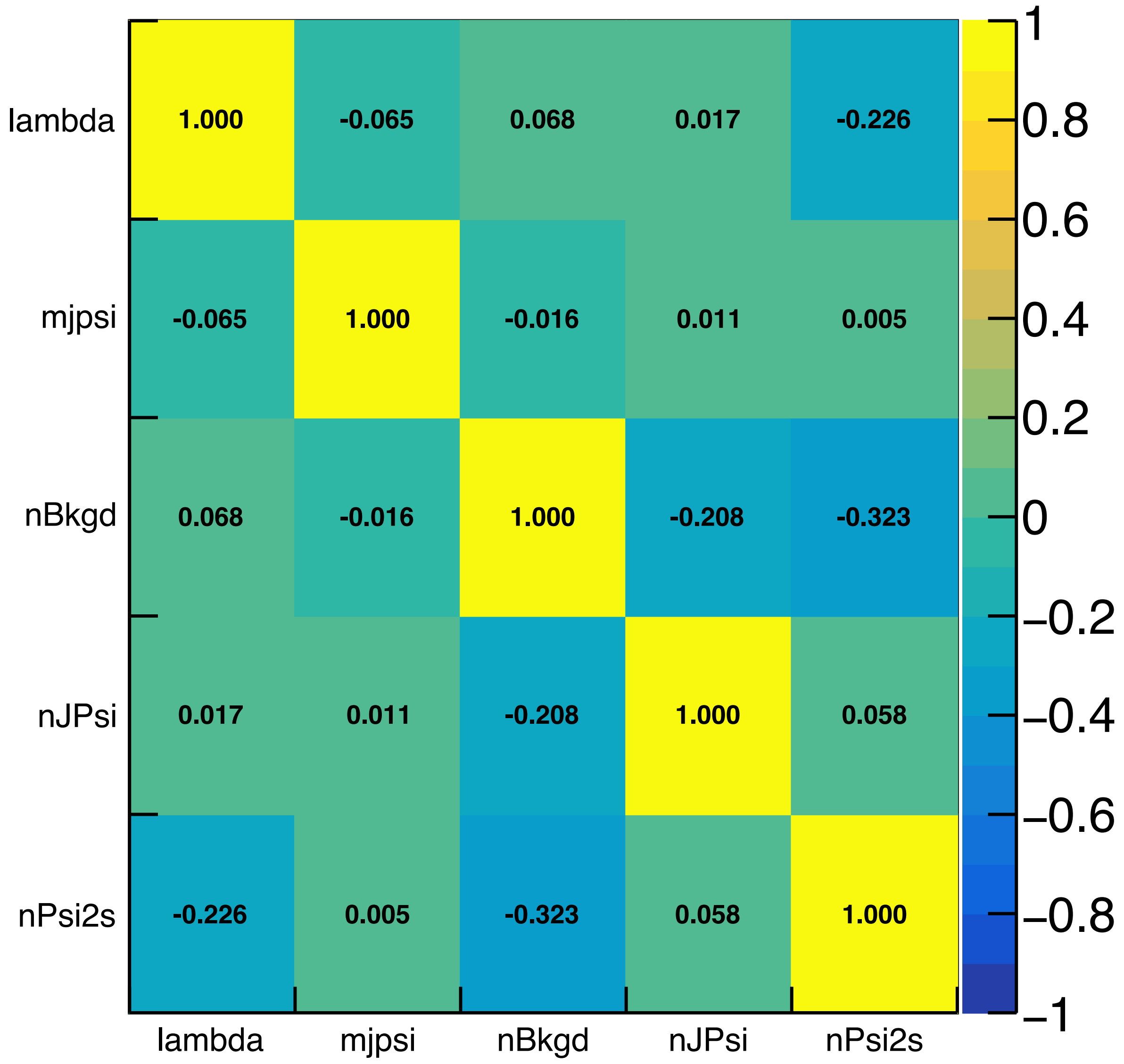




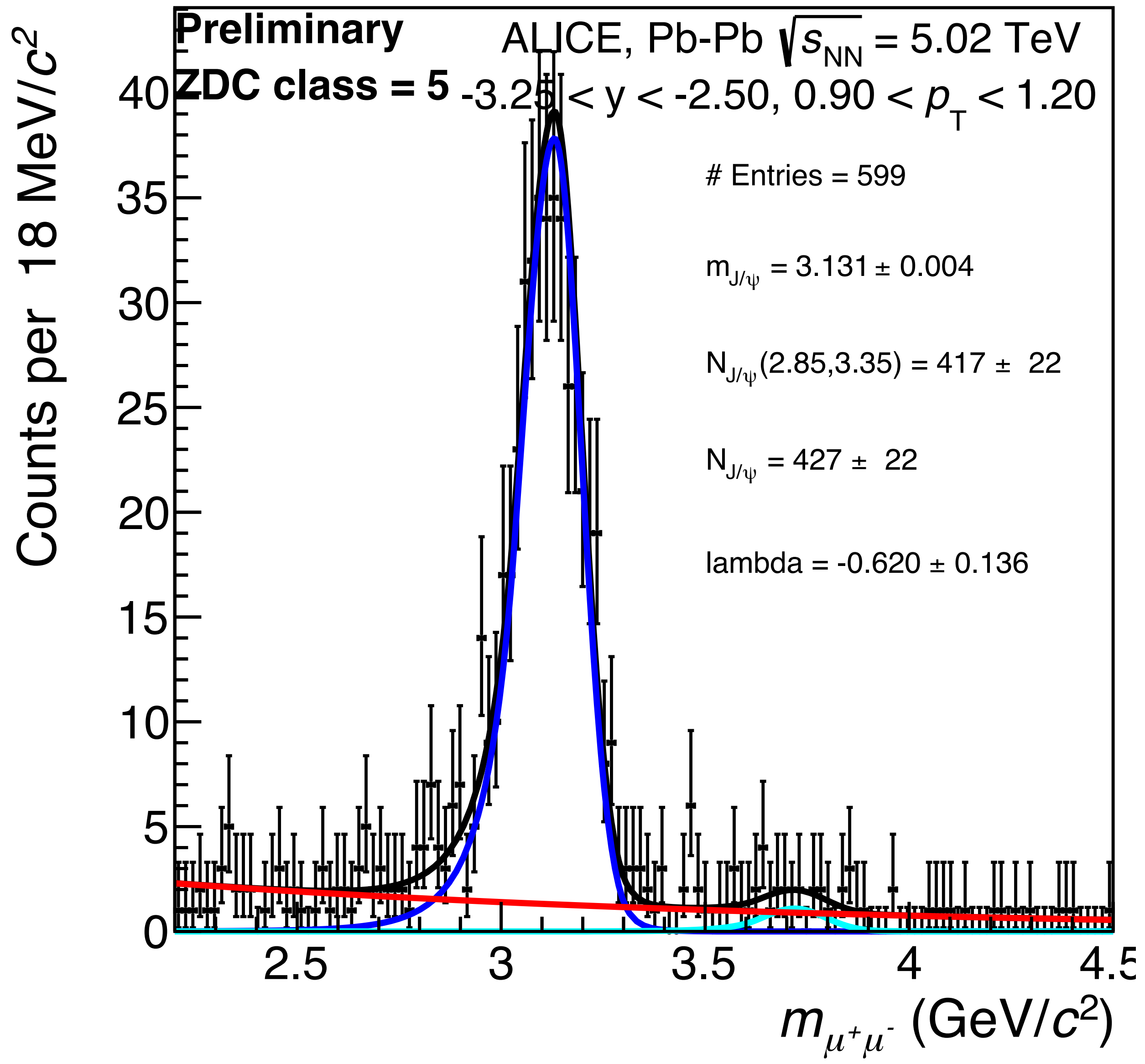


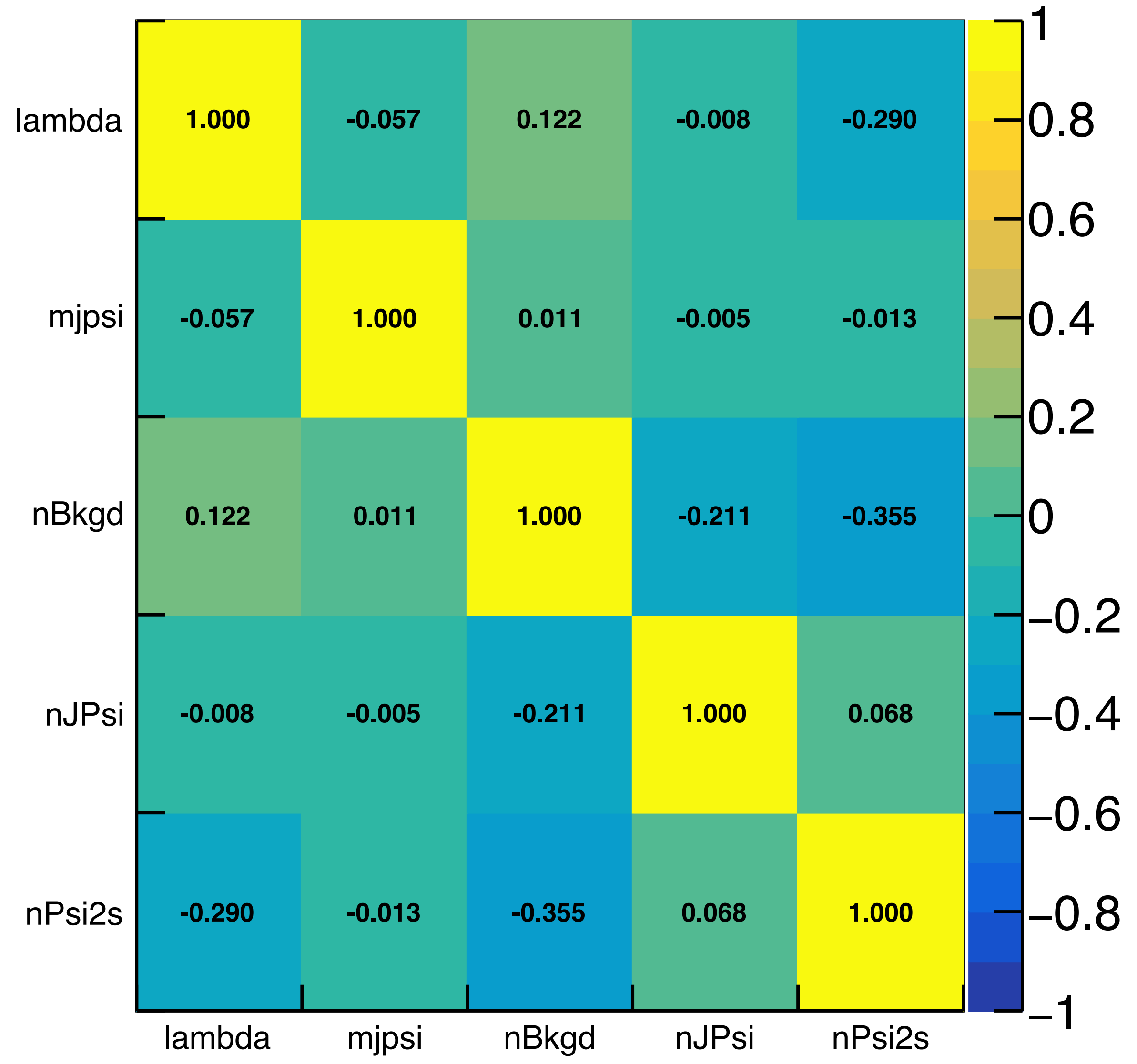


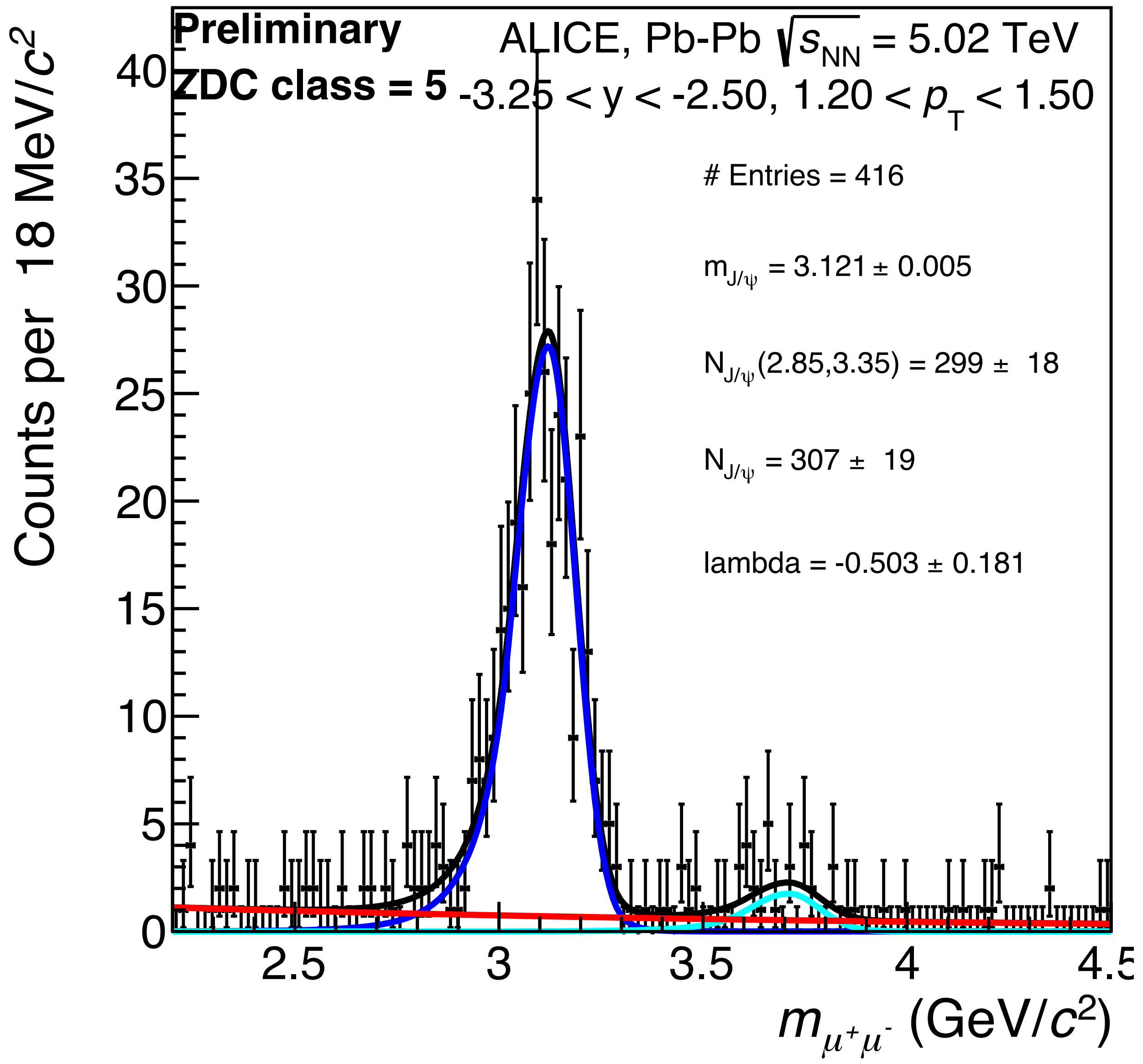


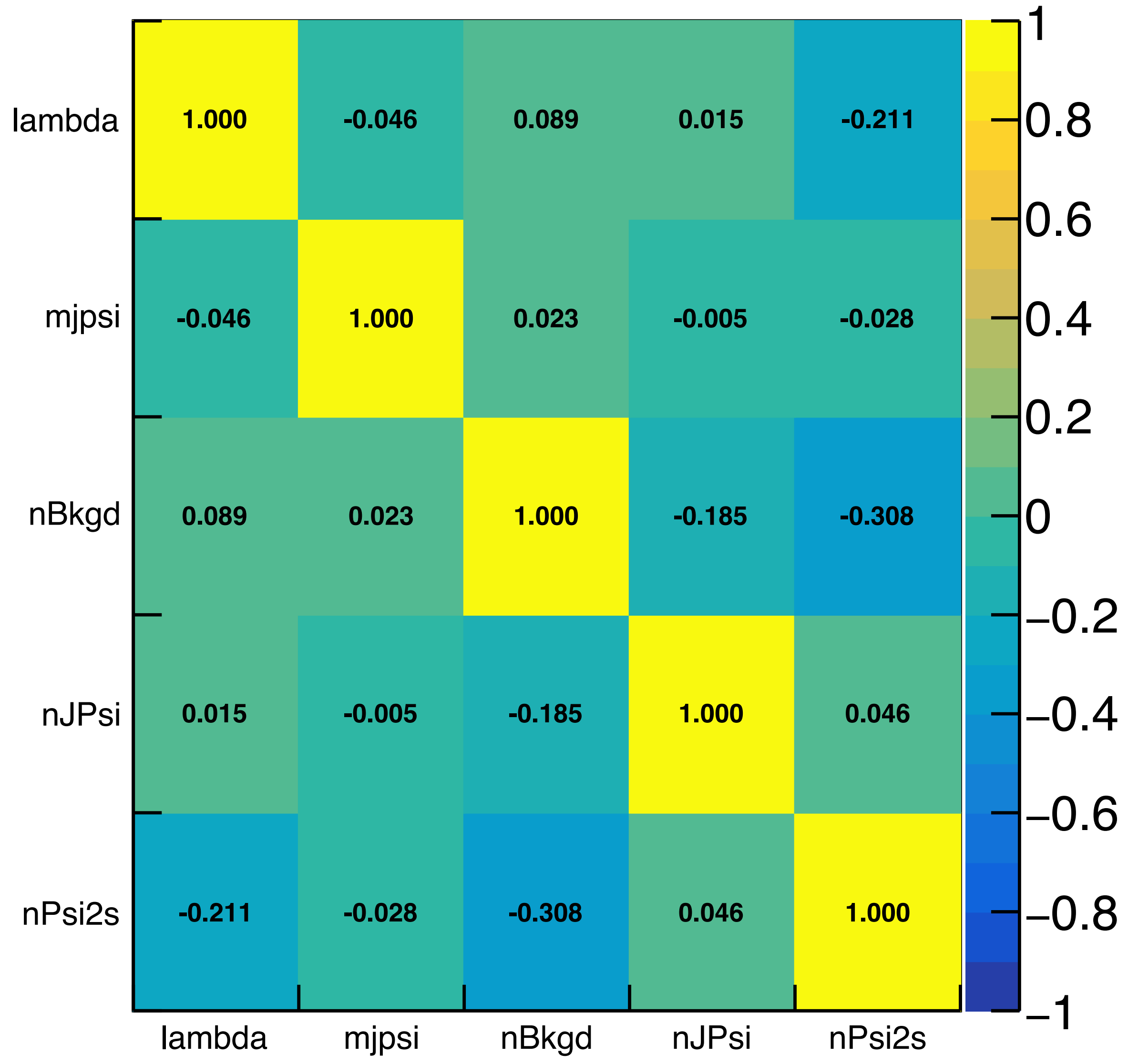


Backup: Signal extraction: -3.25<y<-2.5









Backup

Extraction of signal in small p_T bins for the fits of p_T distribution

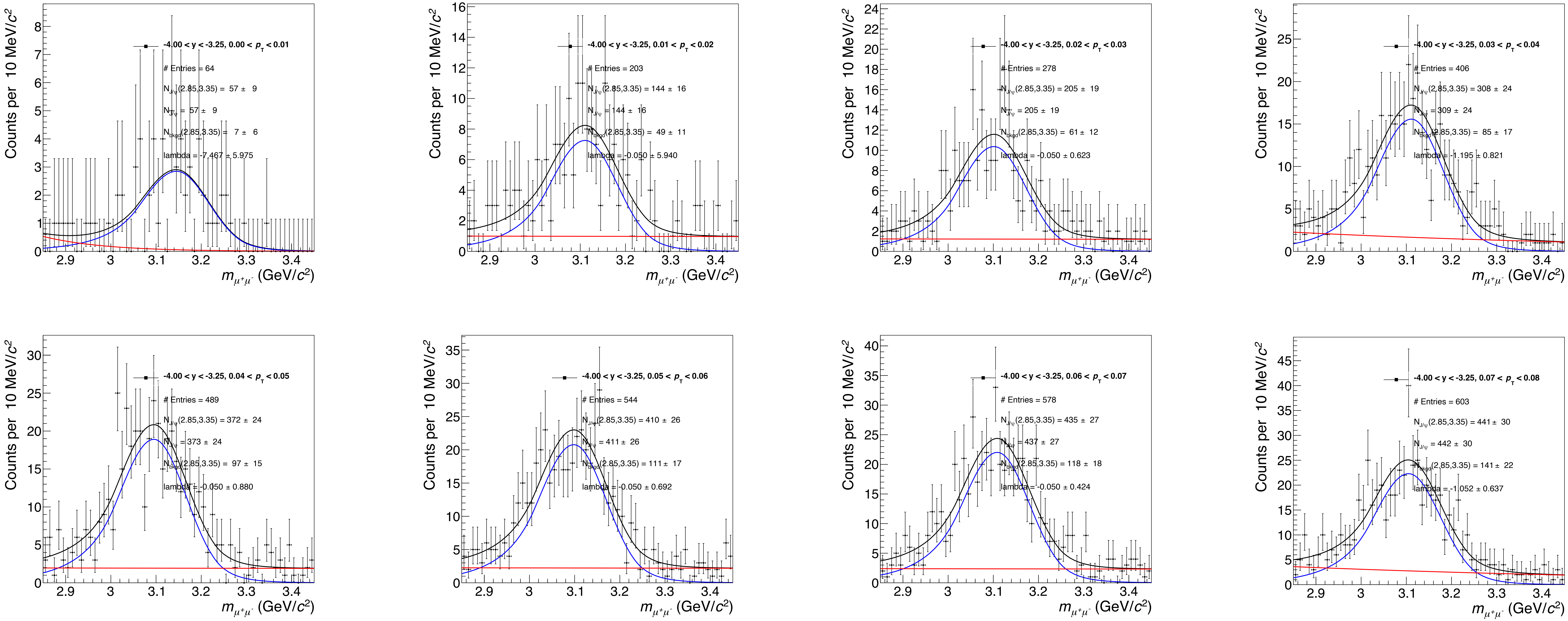
- Signal for p_T distribution obtained by fitting $\mu_+\mu_-$ invariant mass in range $2.85 < m_{\mu\mu} < 3.45\ \mathrm{GeV/c^2}$ in small p_T bins
  - DSCB was used, parameters were fixed, except the mass.
  - Background fitted with exponential.

	Pt bin (GeV/c)	Pt step
1.	(0.,0.15)	0.01
2.	(0.15,0.2)	0.025
3.	(0.2,0.3)	0.05
4.	(0.3,1.0)	0.1
5.	(1.0,2.0)	0.2
6.	(2.0,3.5)	0.5
7.	(3.5,5.0)	1.5

Backup: Signal for p_T distribution: Invariant mass fits in small p_T bins

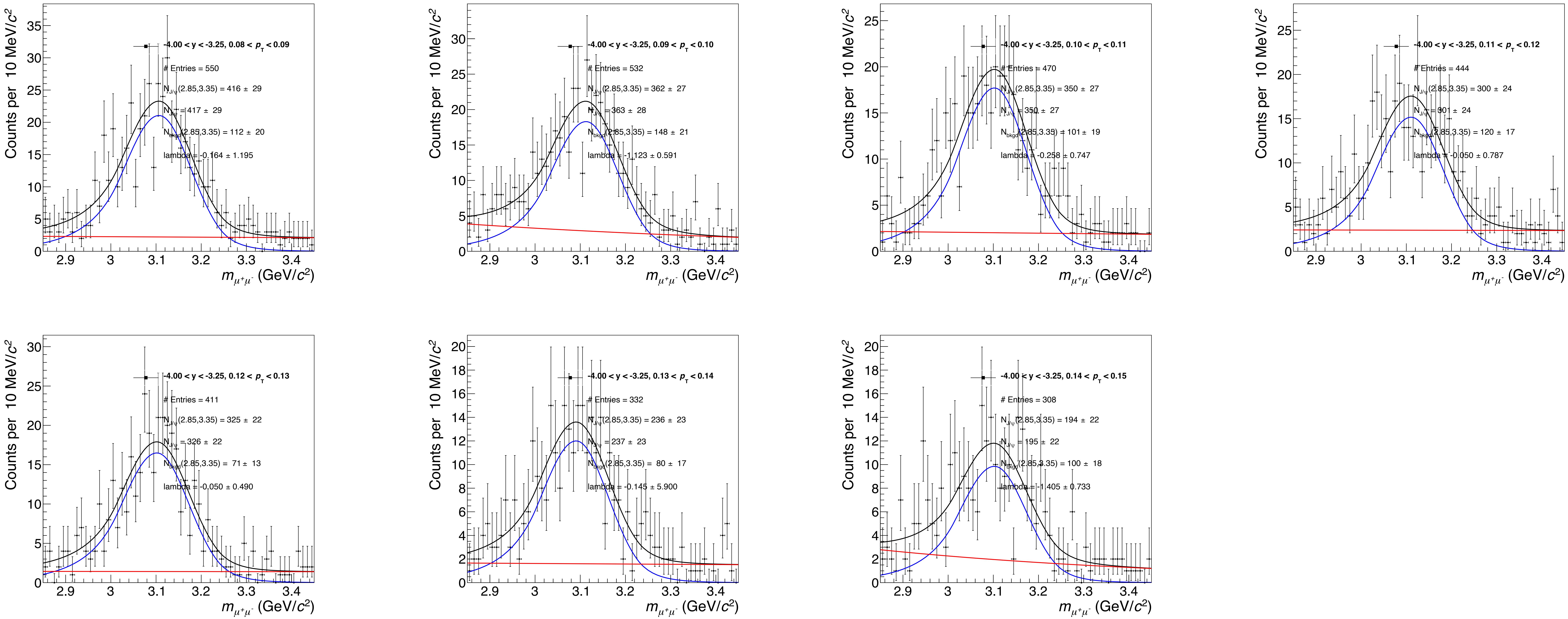
-4.0<y<-3.25

Pt Bin1



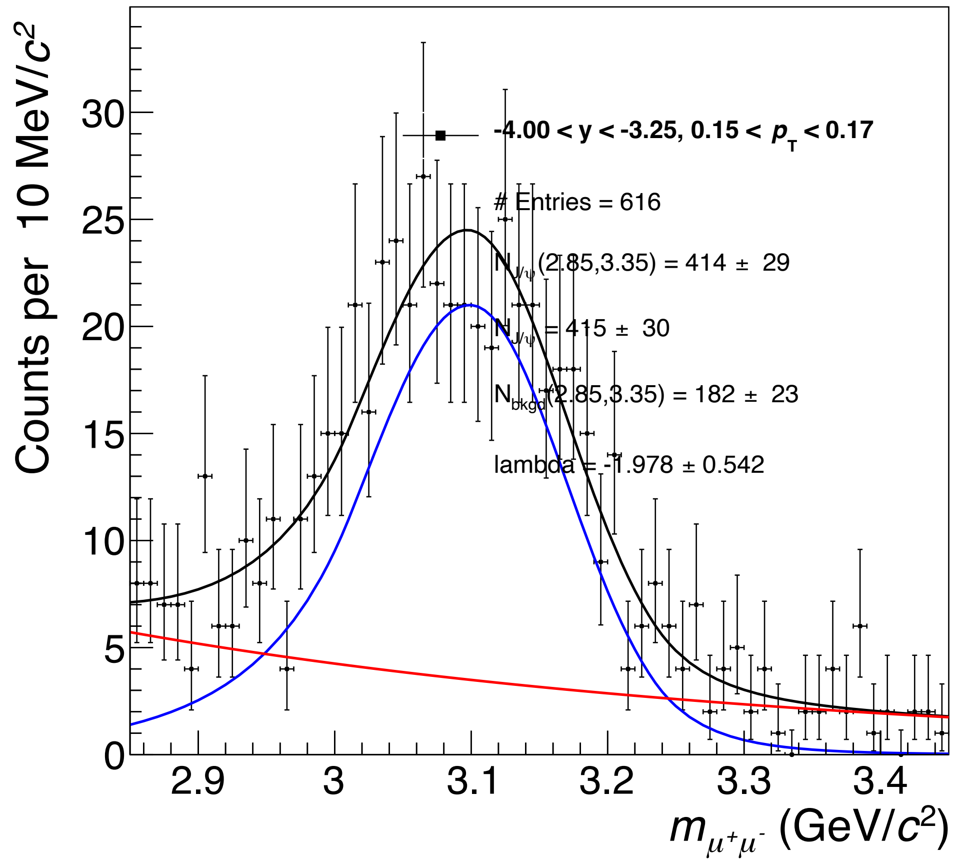
Backup: Signal for p_T distribution: Invariant mass fits in small p_T bins

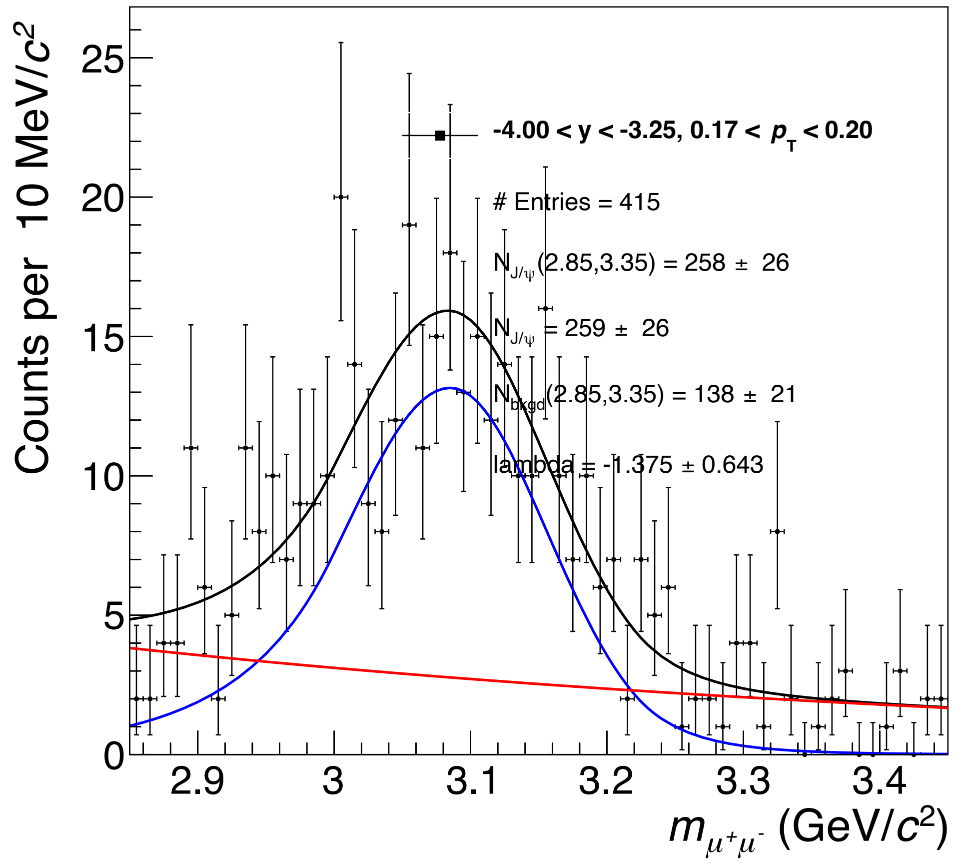
Pt Bin1



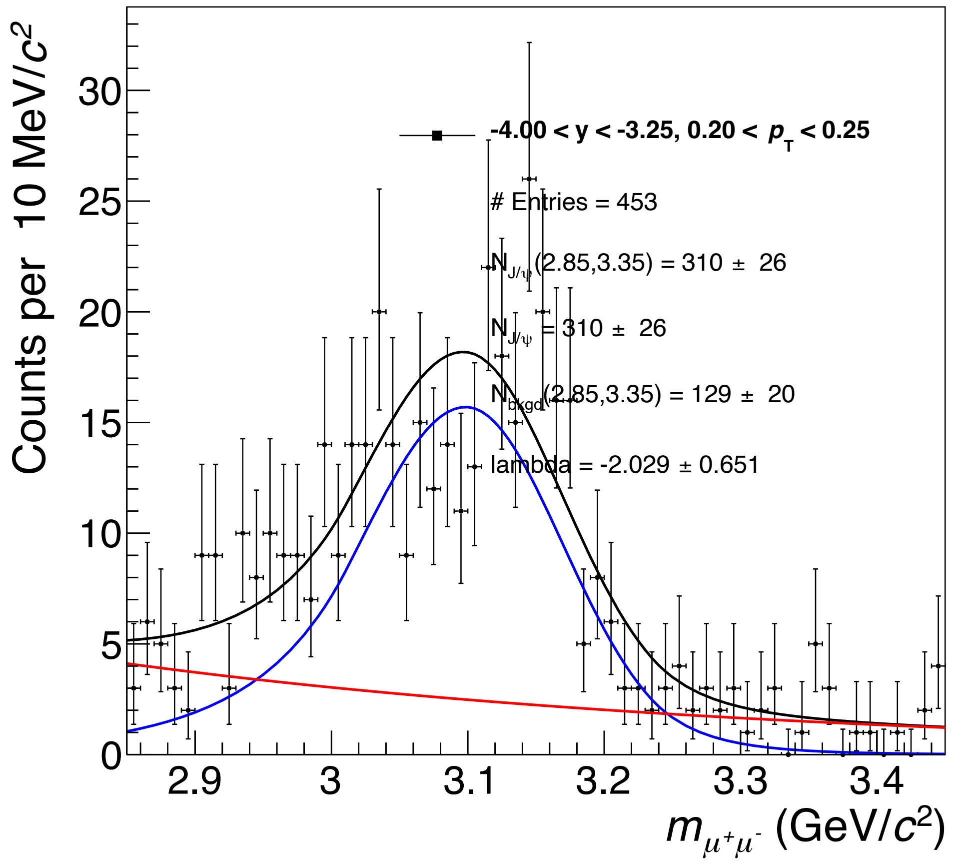
Backup: Signal for p_T distribution: Invariant mass fits in small p_T bins

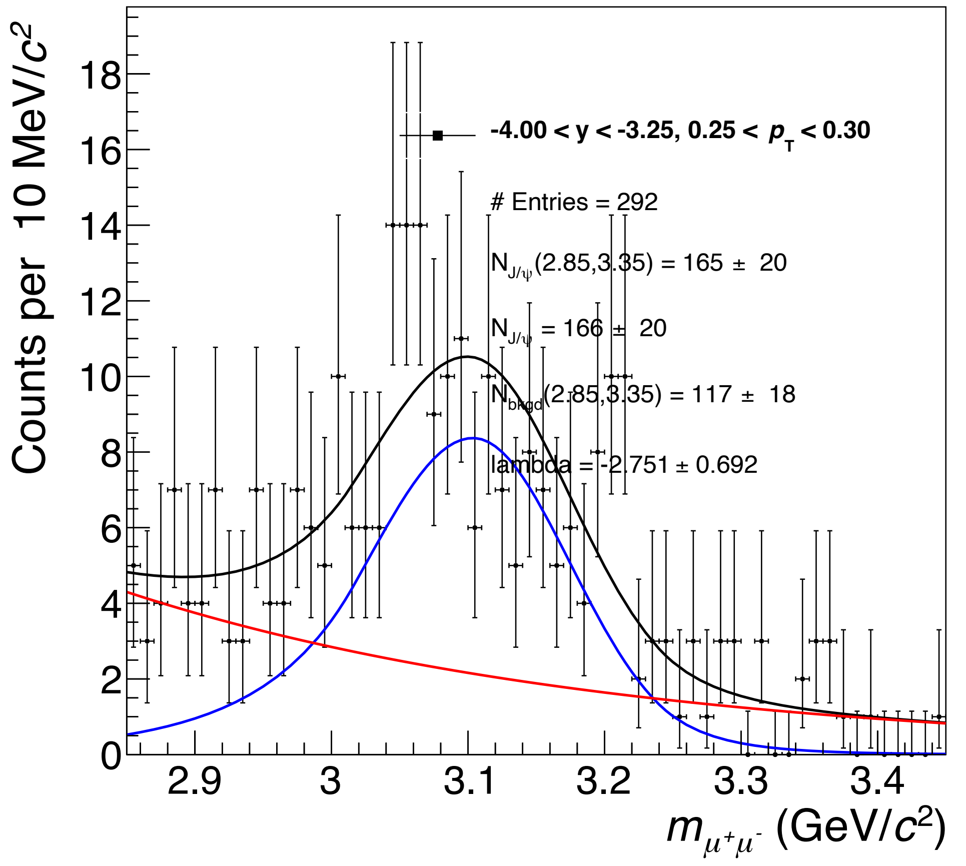
Pt Bin2



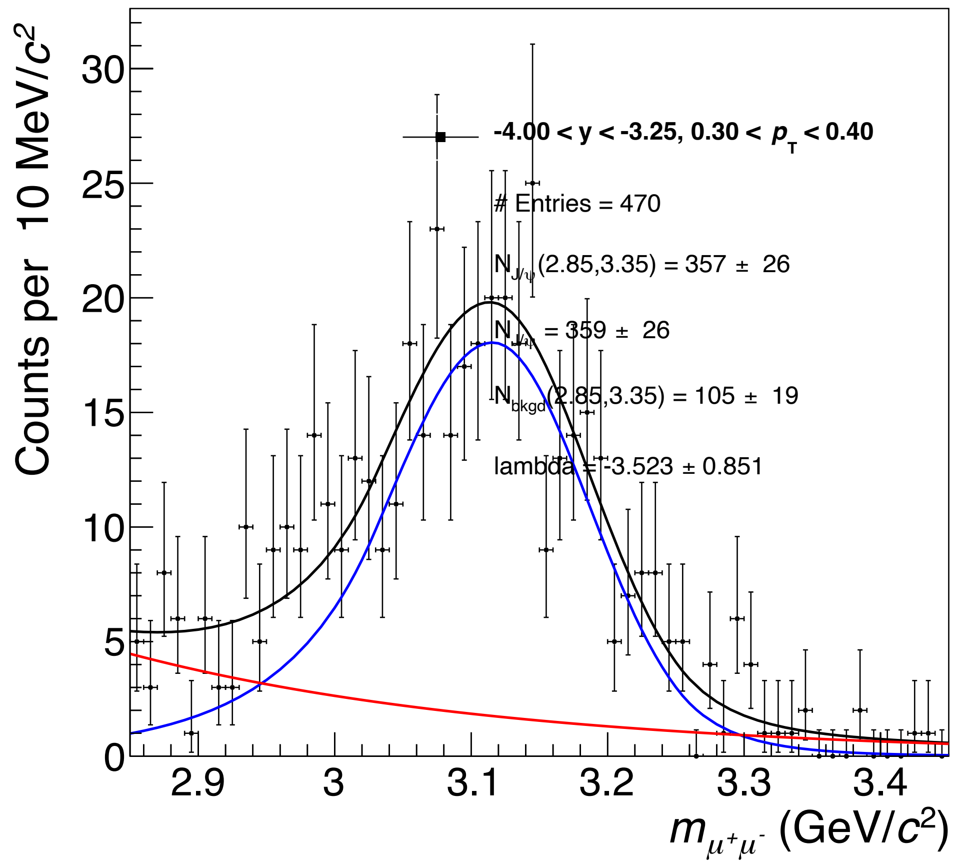


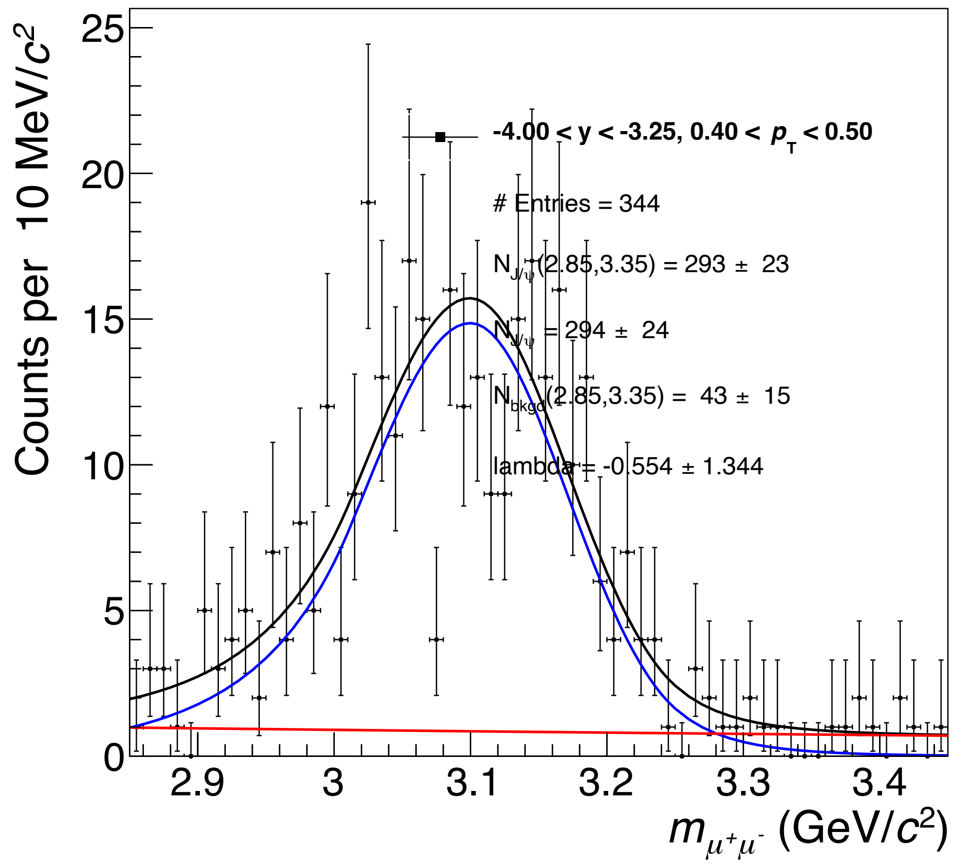
Pt Bin3

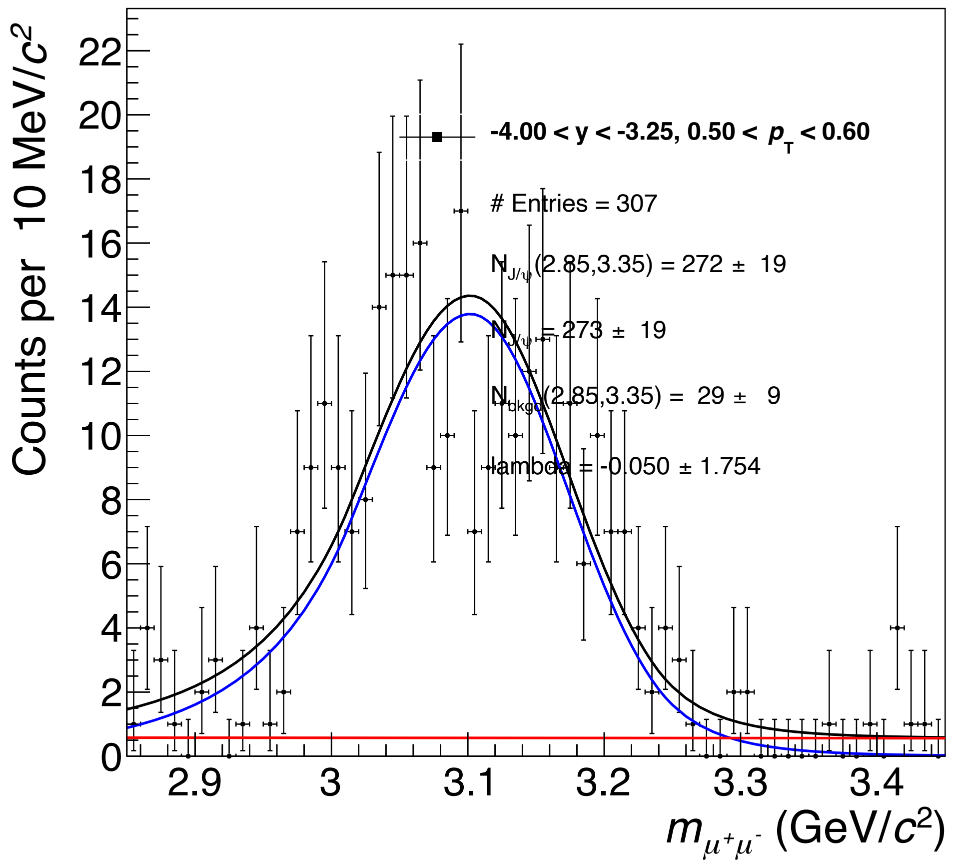


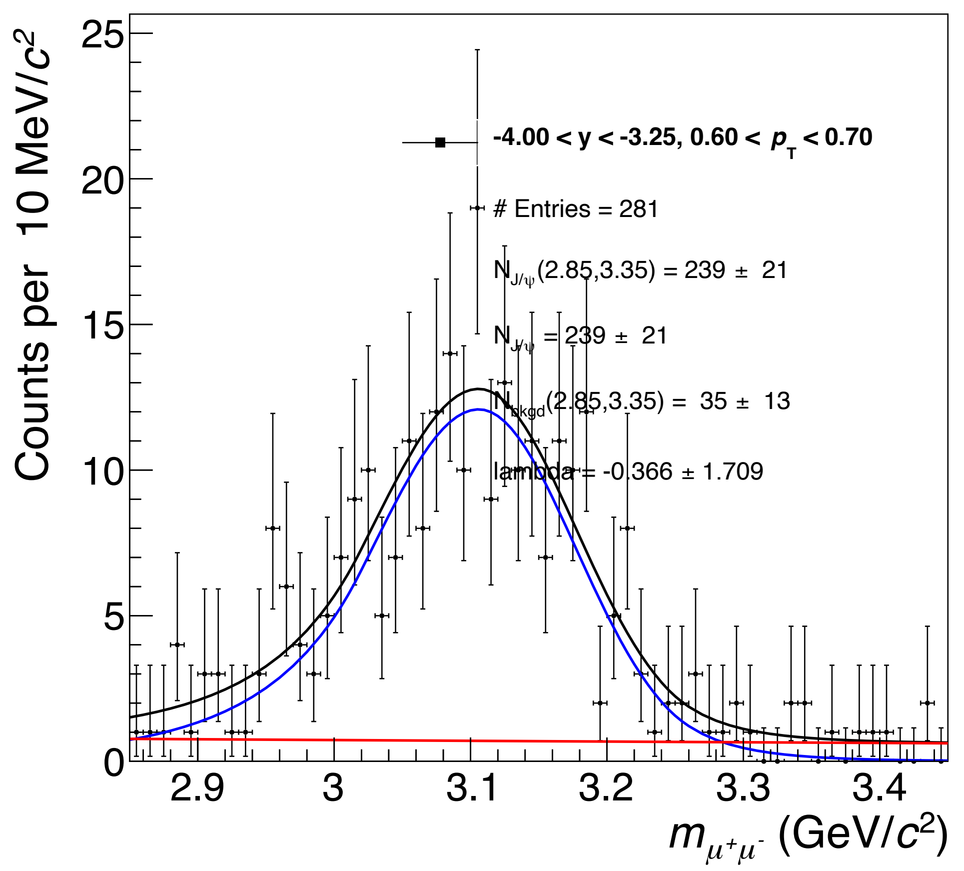


Pt Bin4





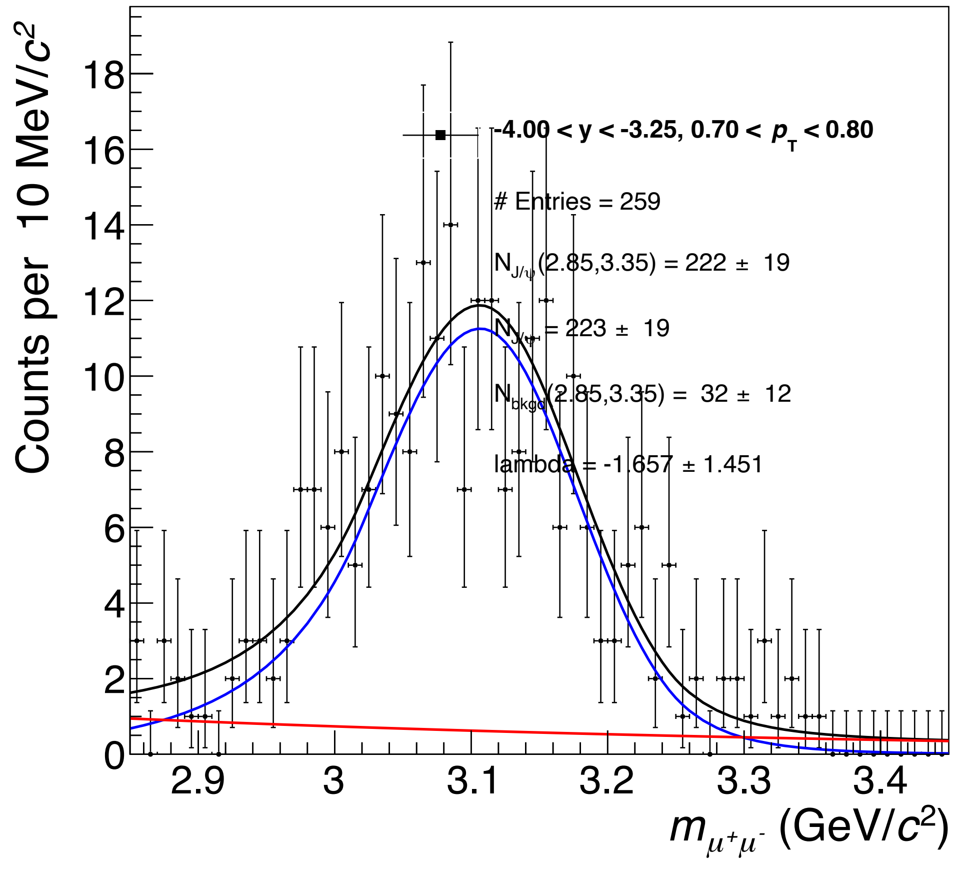


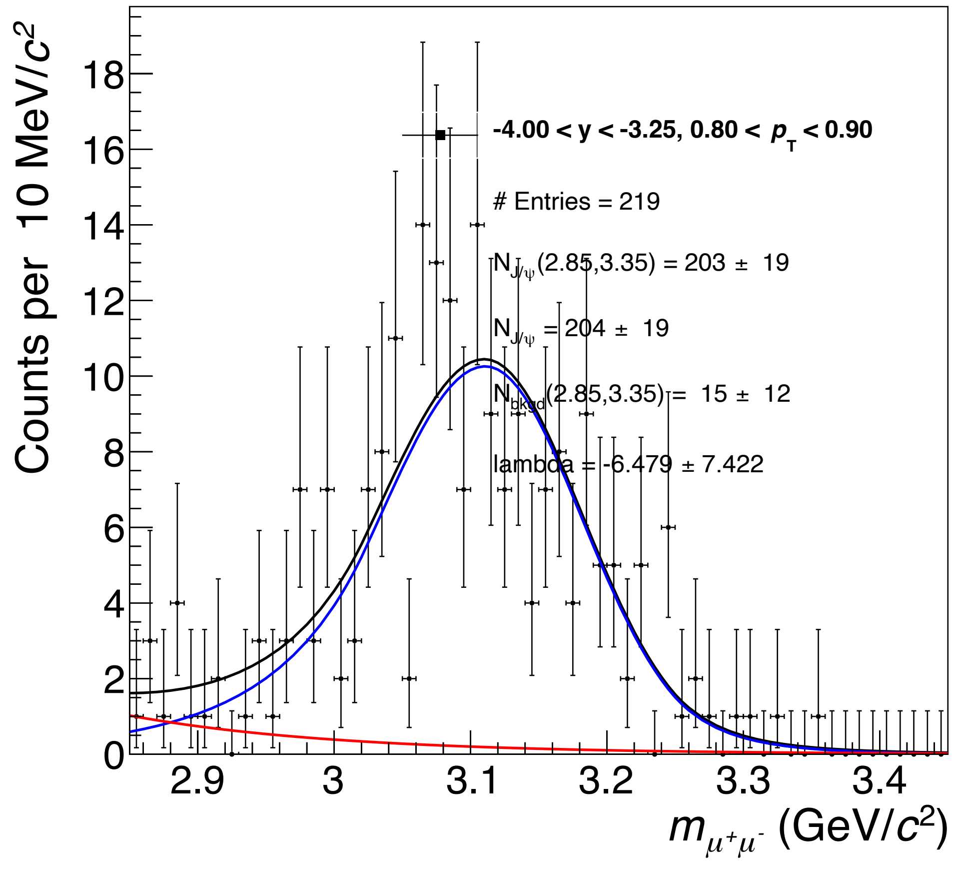


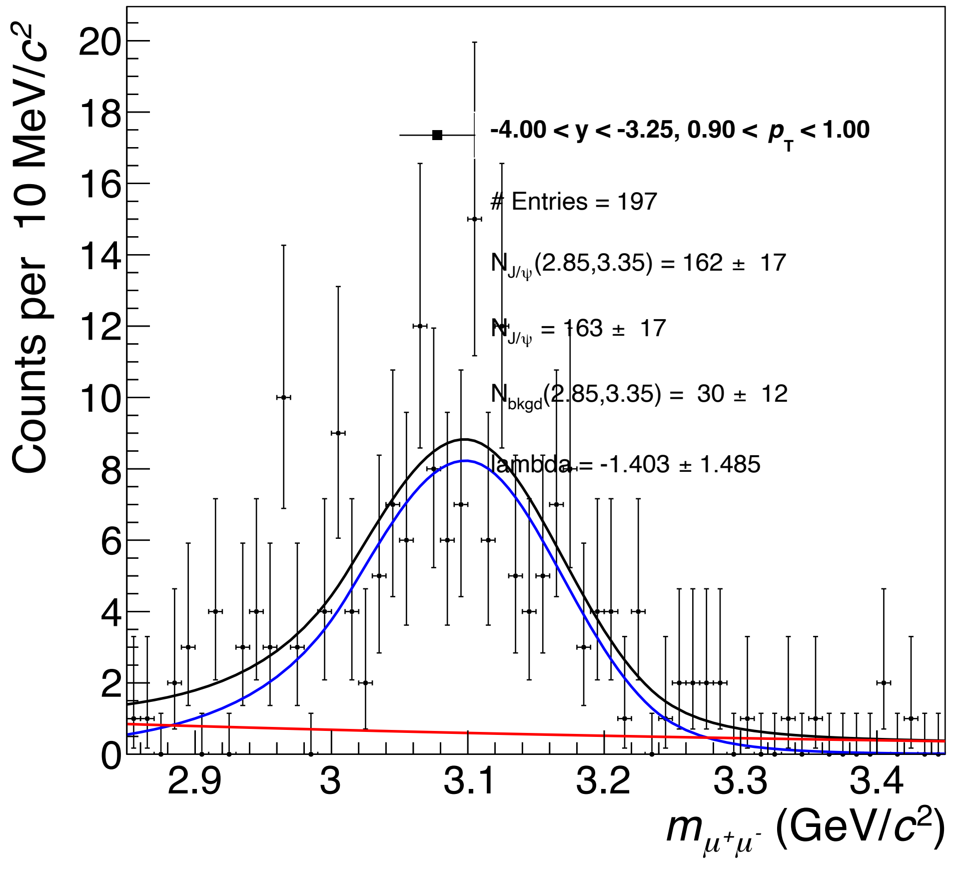
Backup: Signal for p_T distribution: Invariant mass fits in small p_T bins

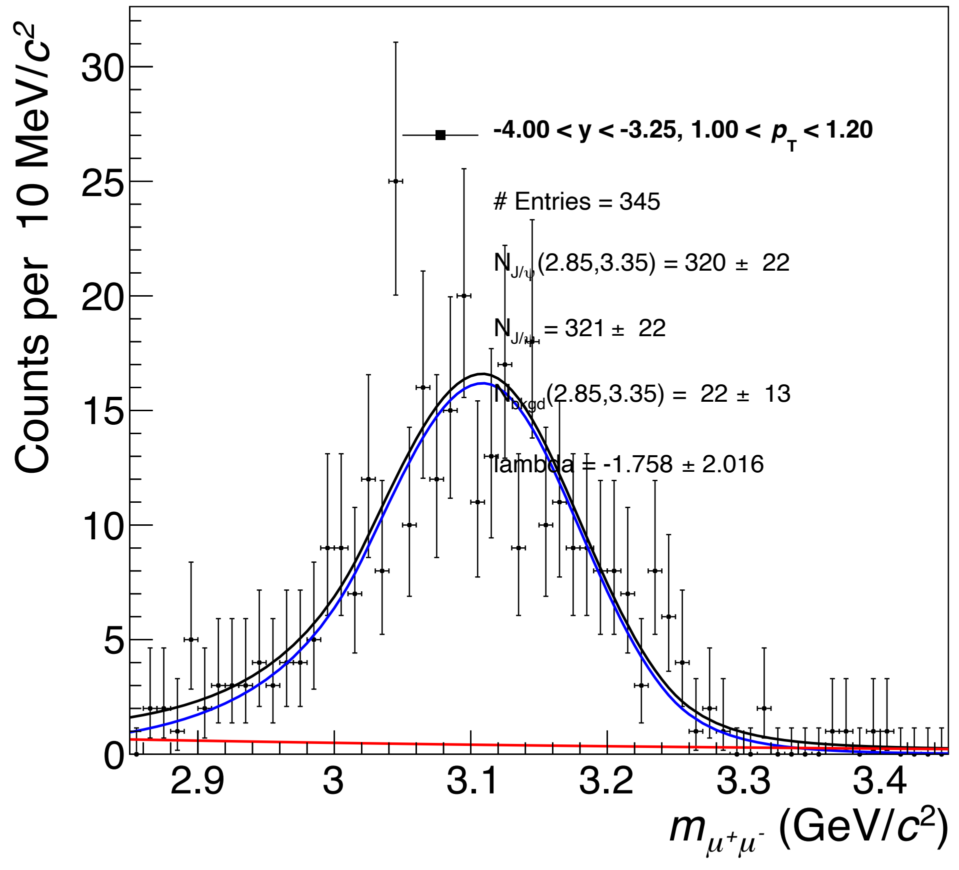
Pt Bin4

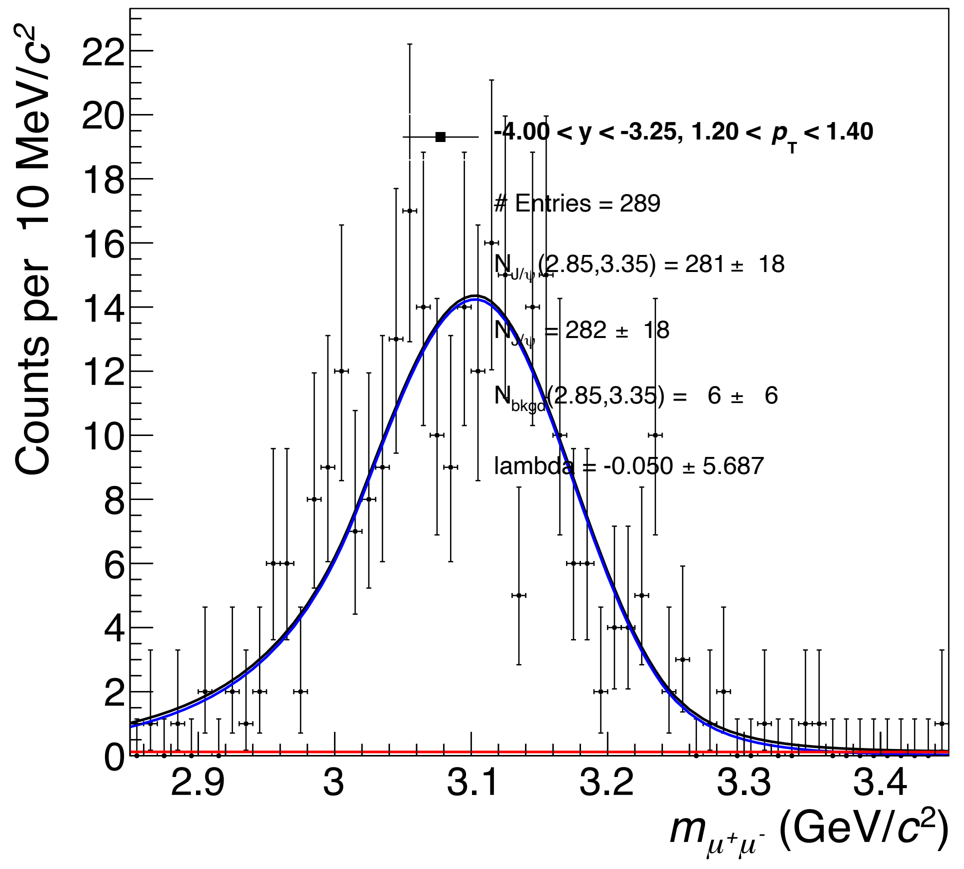
Pt Bin5

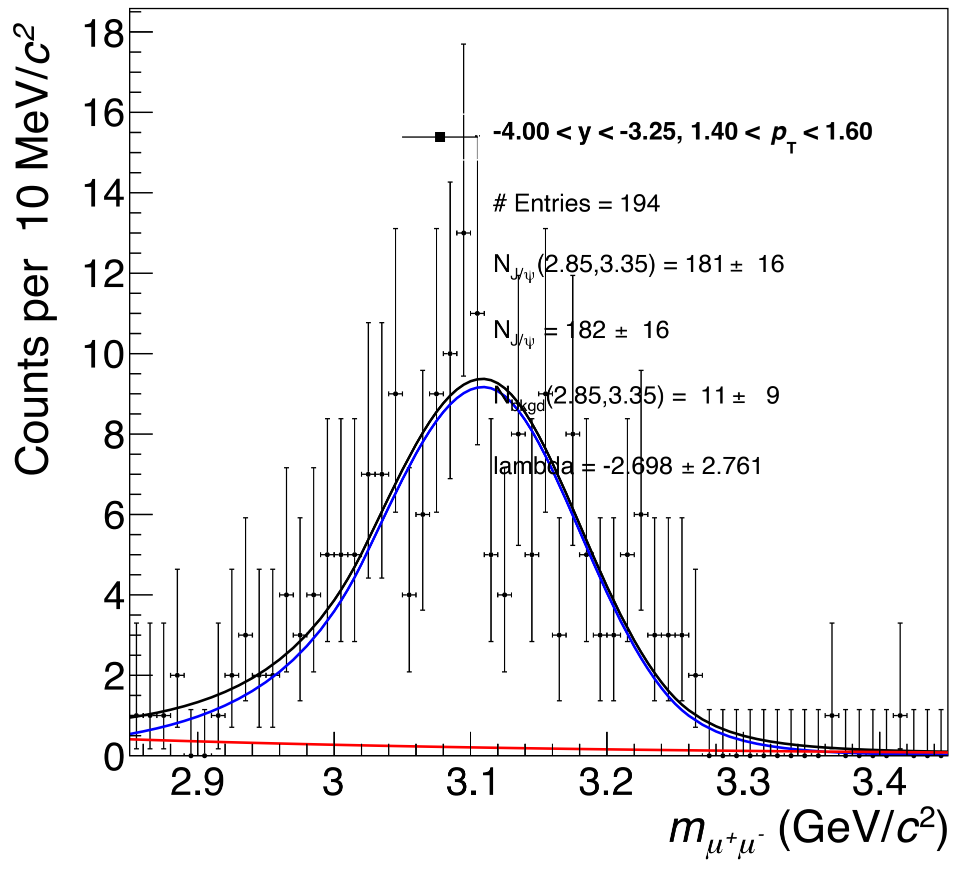


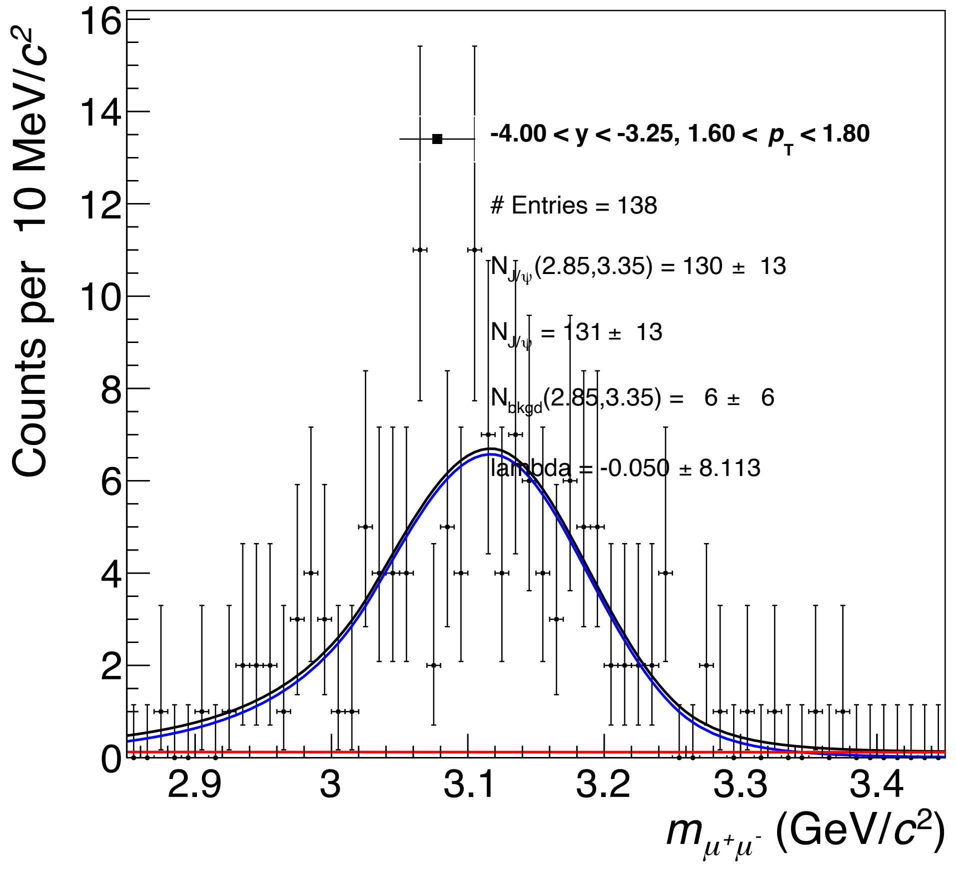


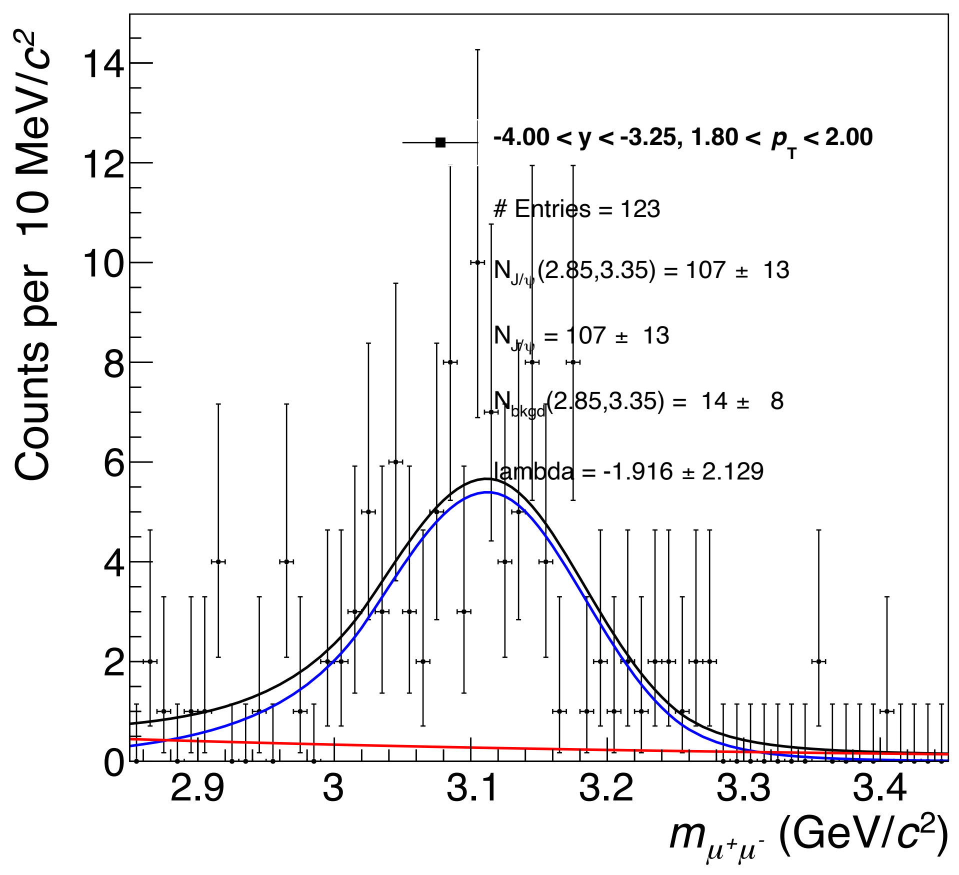






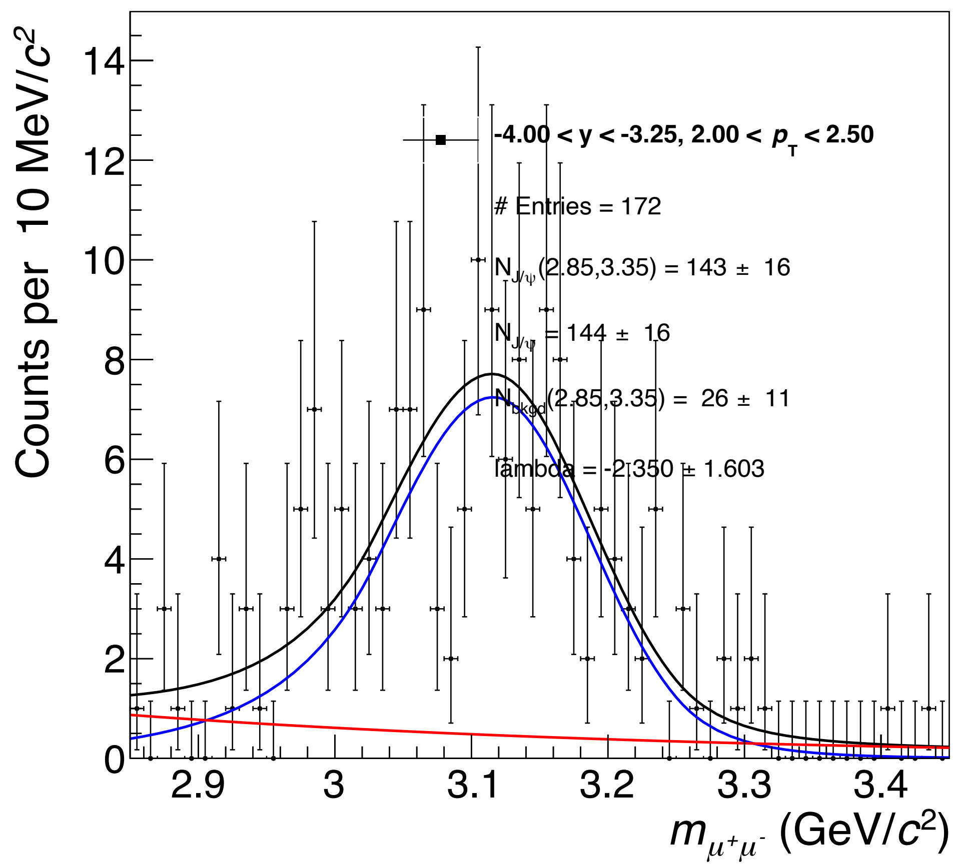


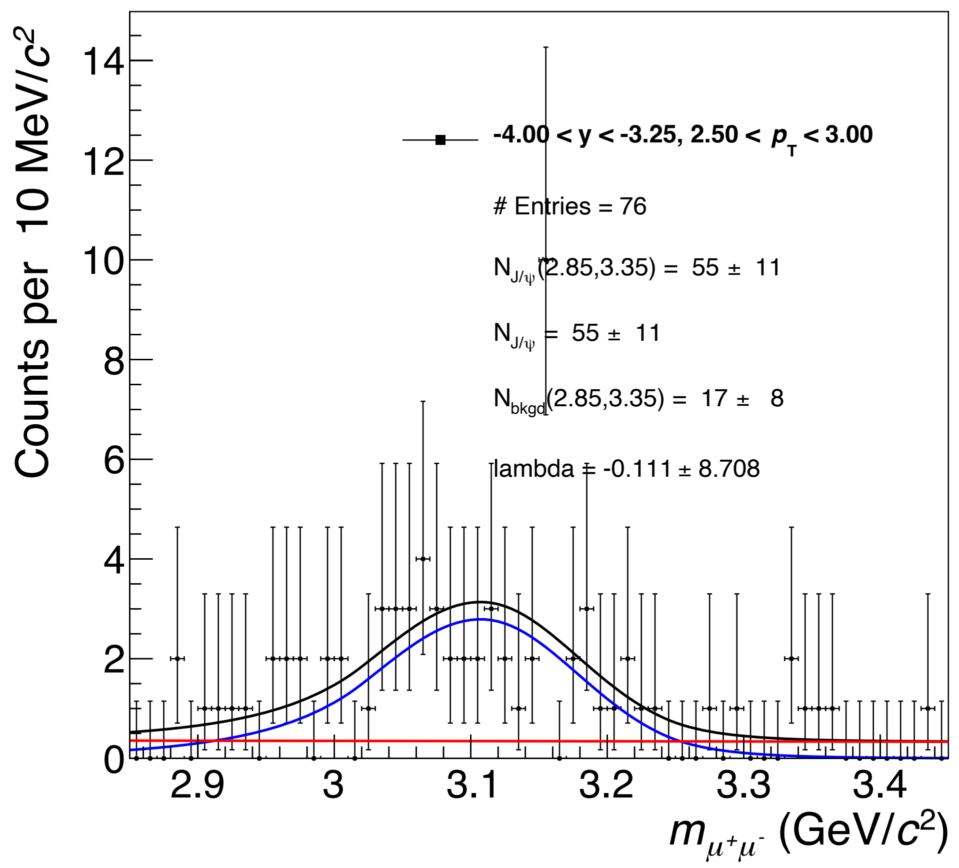


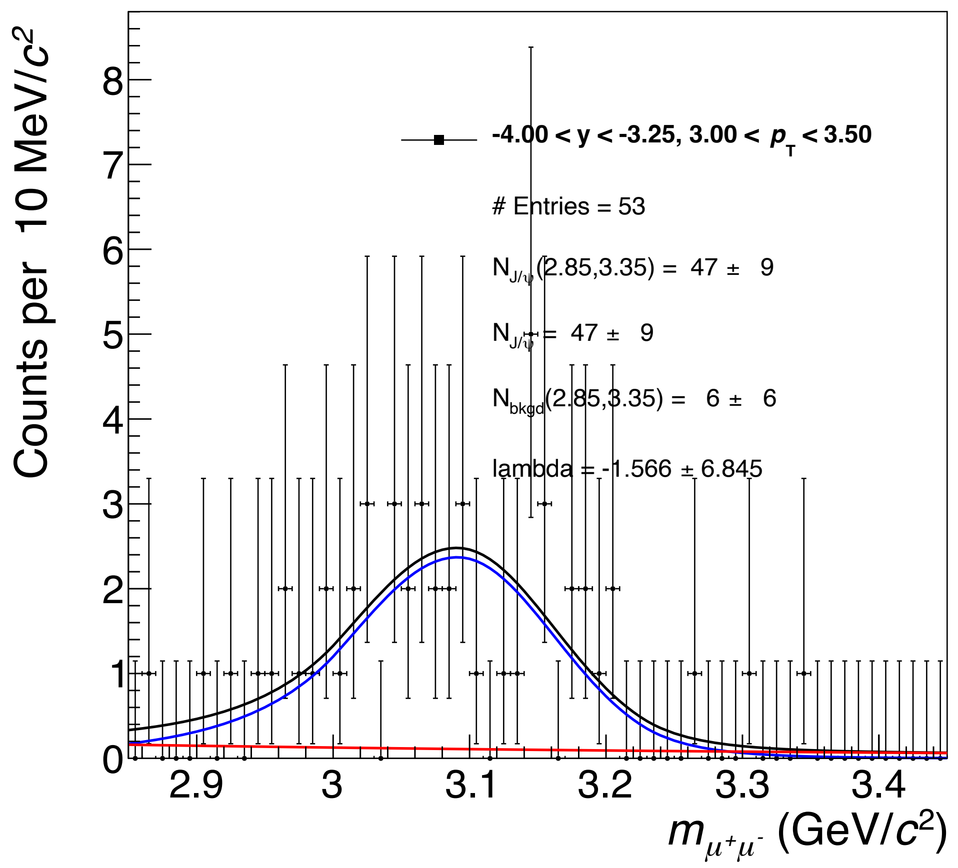


Backup: Signal for p_T distribution: Invariant mass fits in small p_T bins

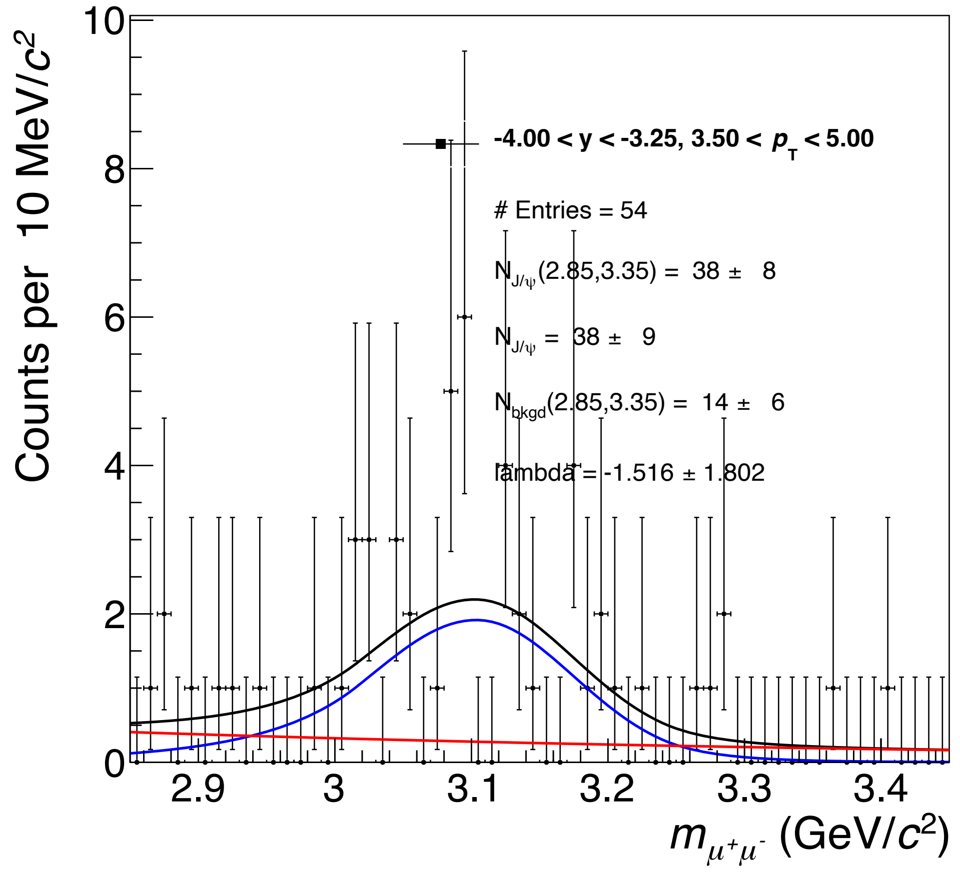
Pt Bin6







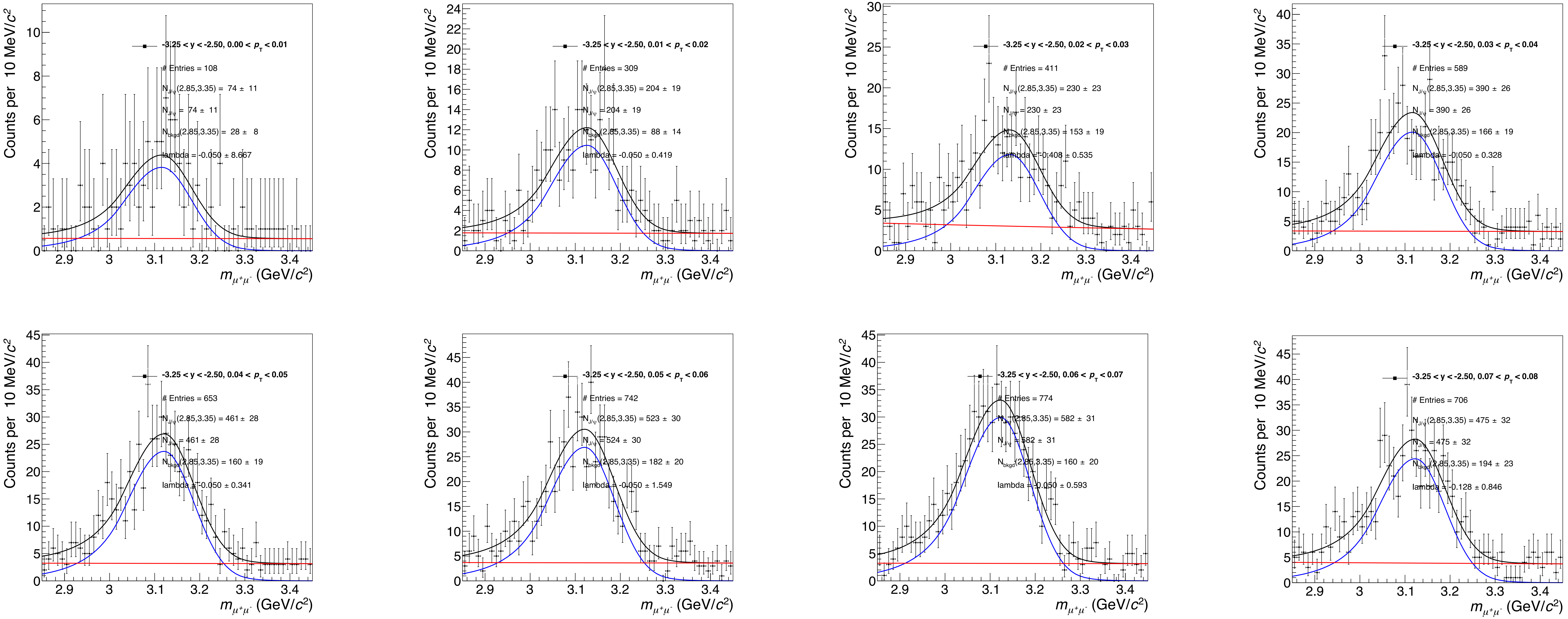
Pt Bin7



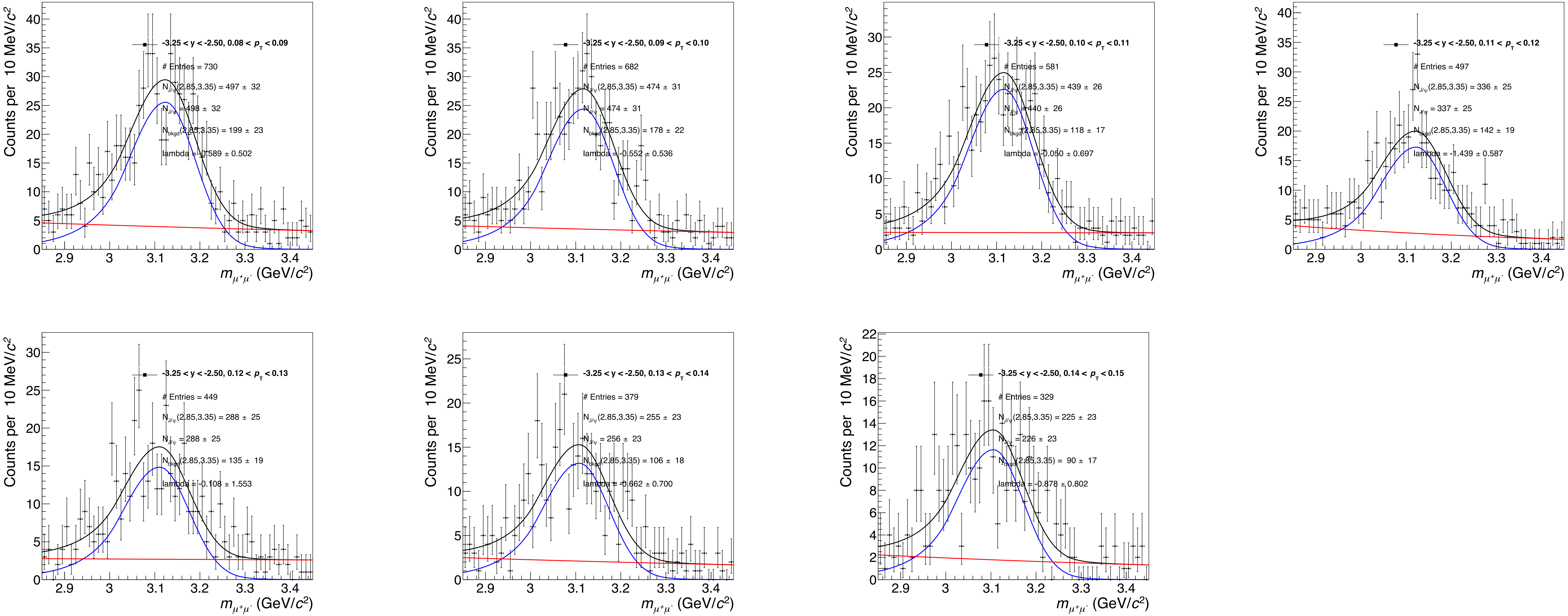
Backup: Signal for p_T distribution: Invariant mass fits in small p_T bins

-3.25<y<-2.5

Pt Bin1

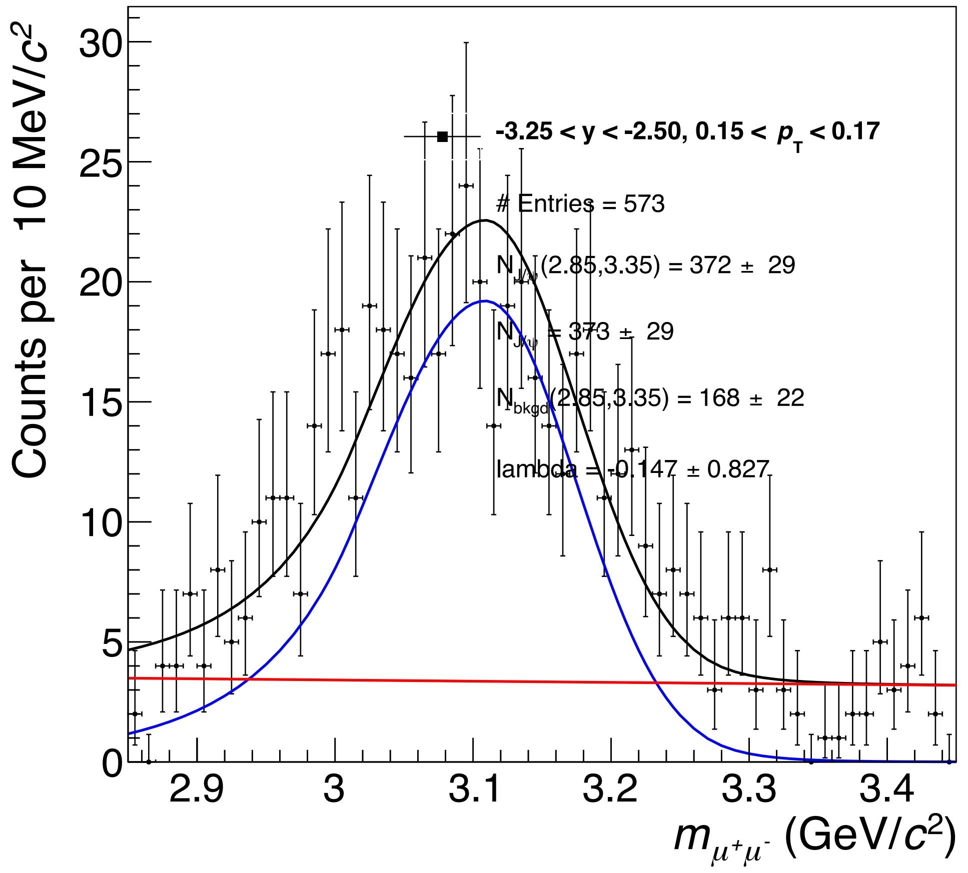


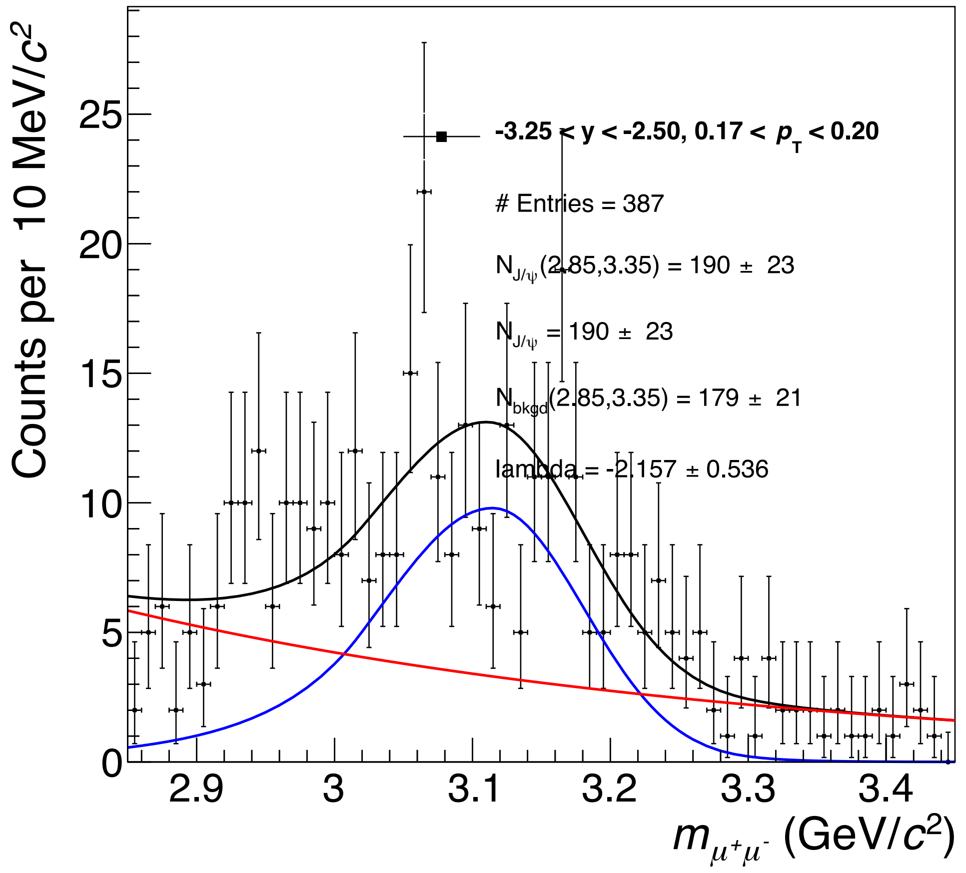
Backup: Signal for p_T distribution: Invariant mass fits in small p_T bins

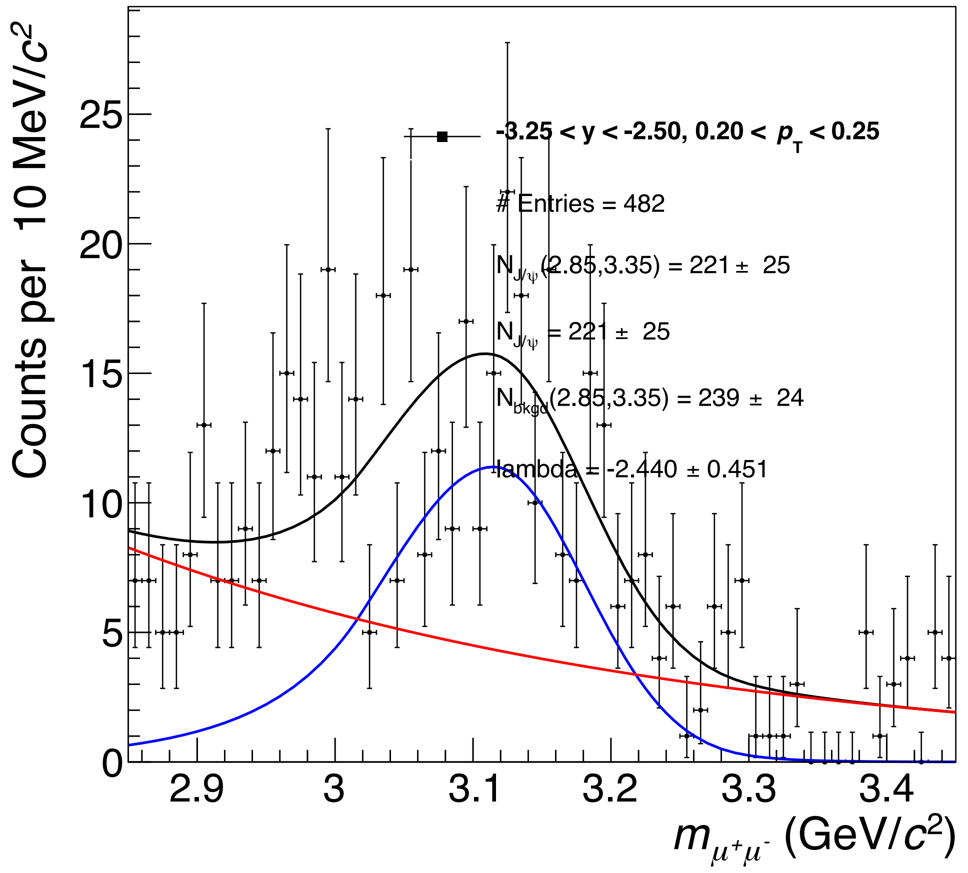


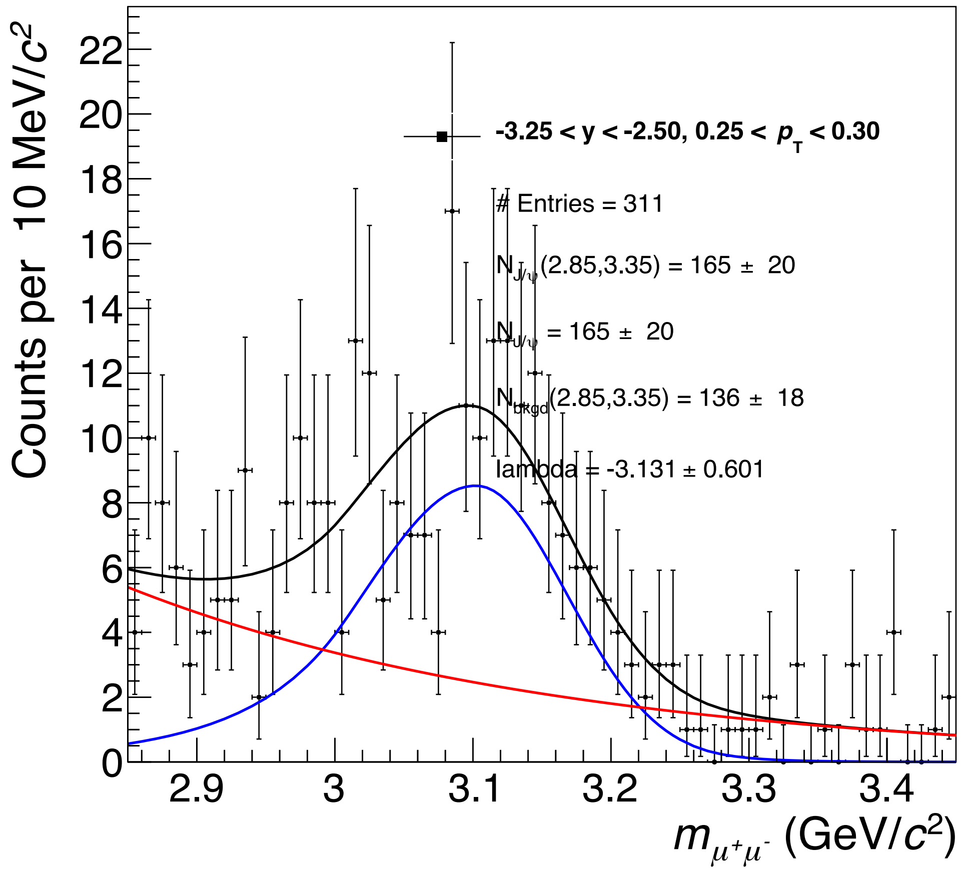
Pt Bin2

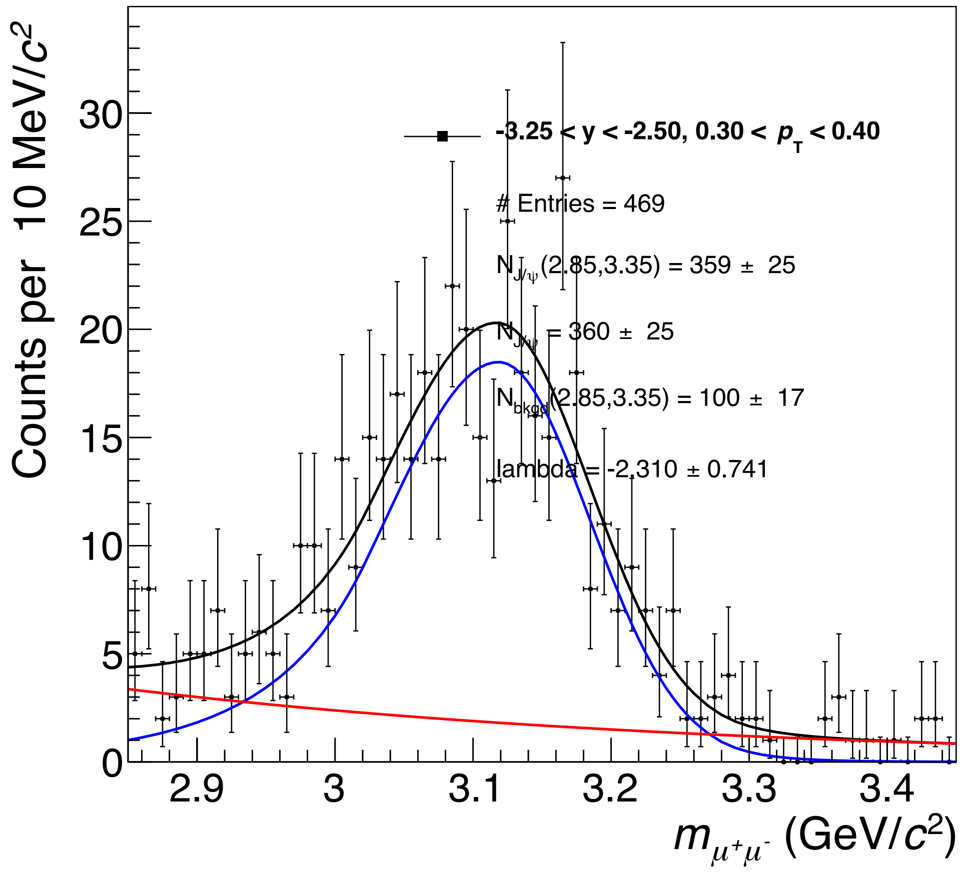
Pt Bin3

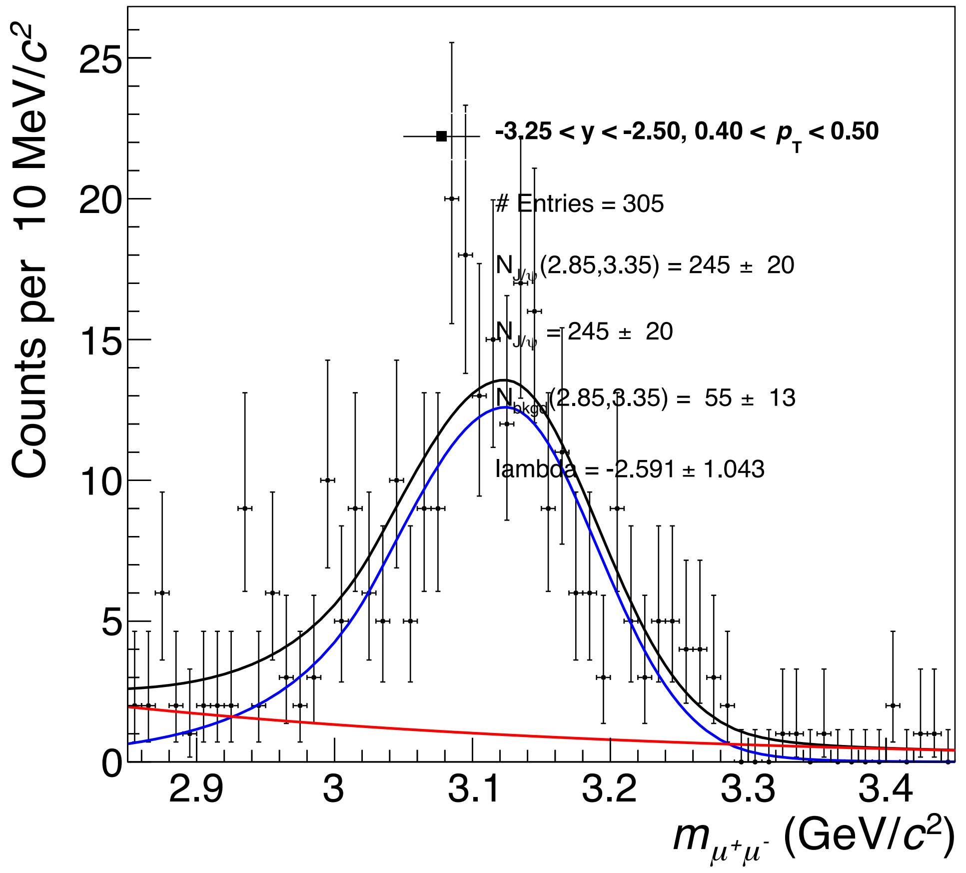


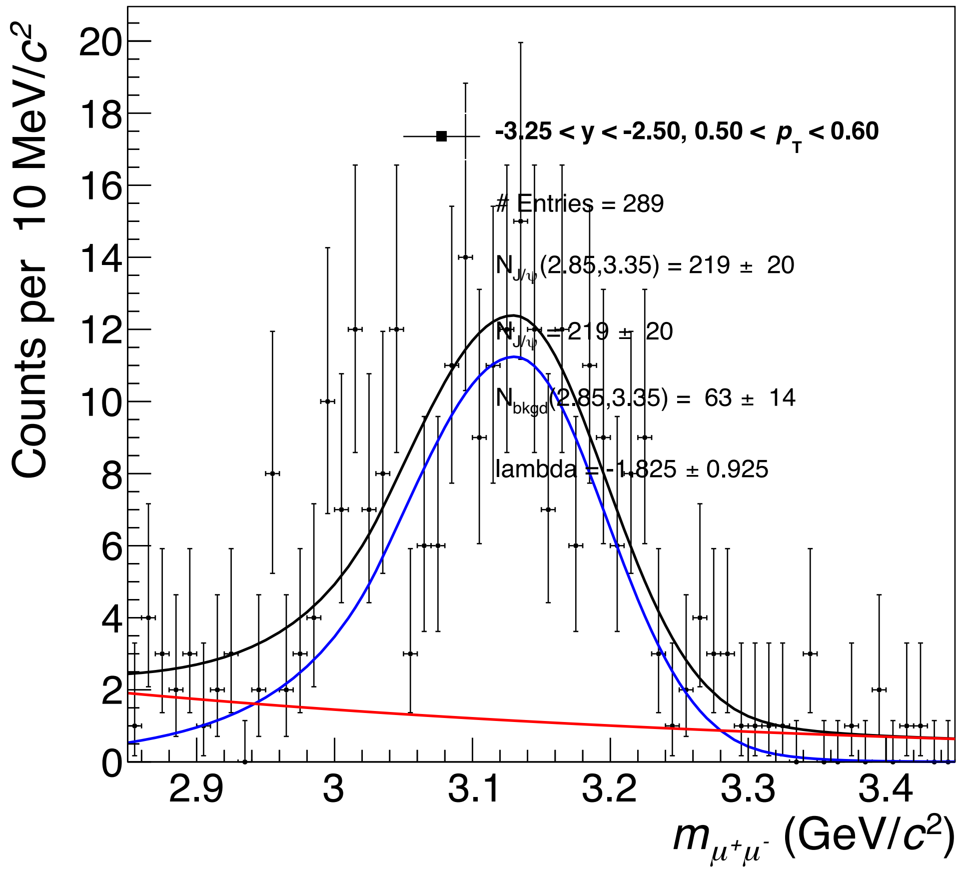


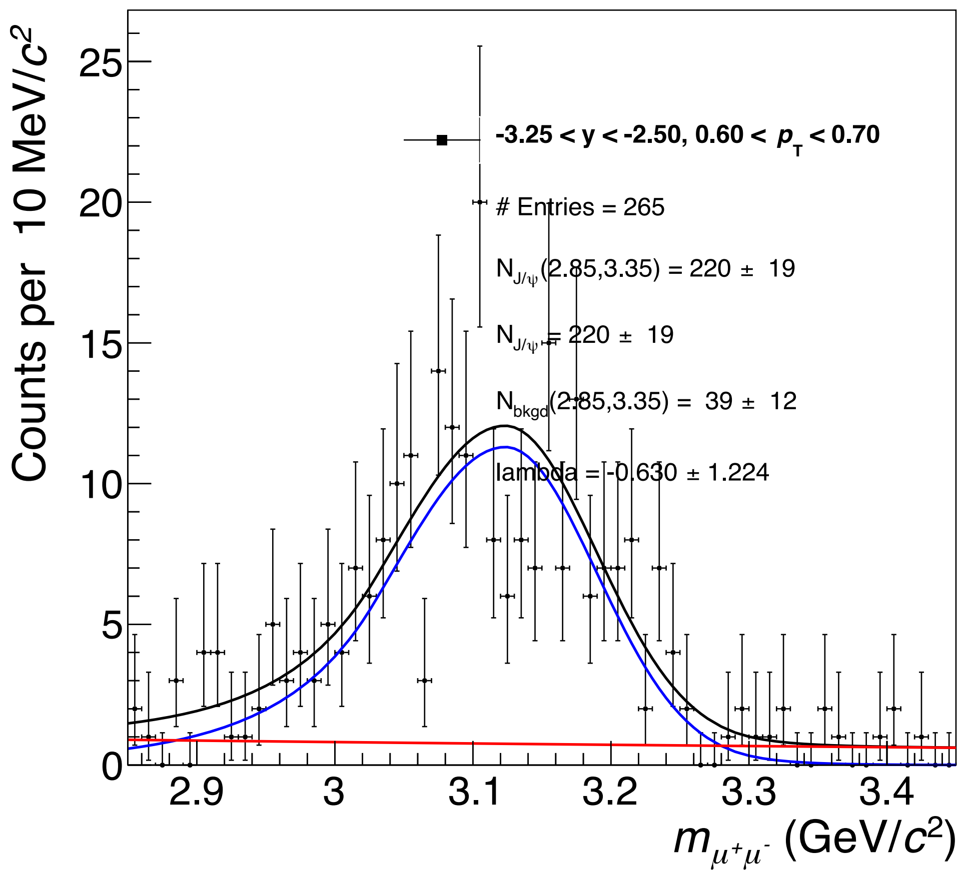








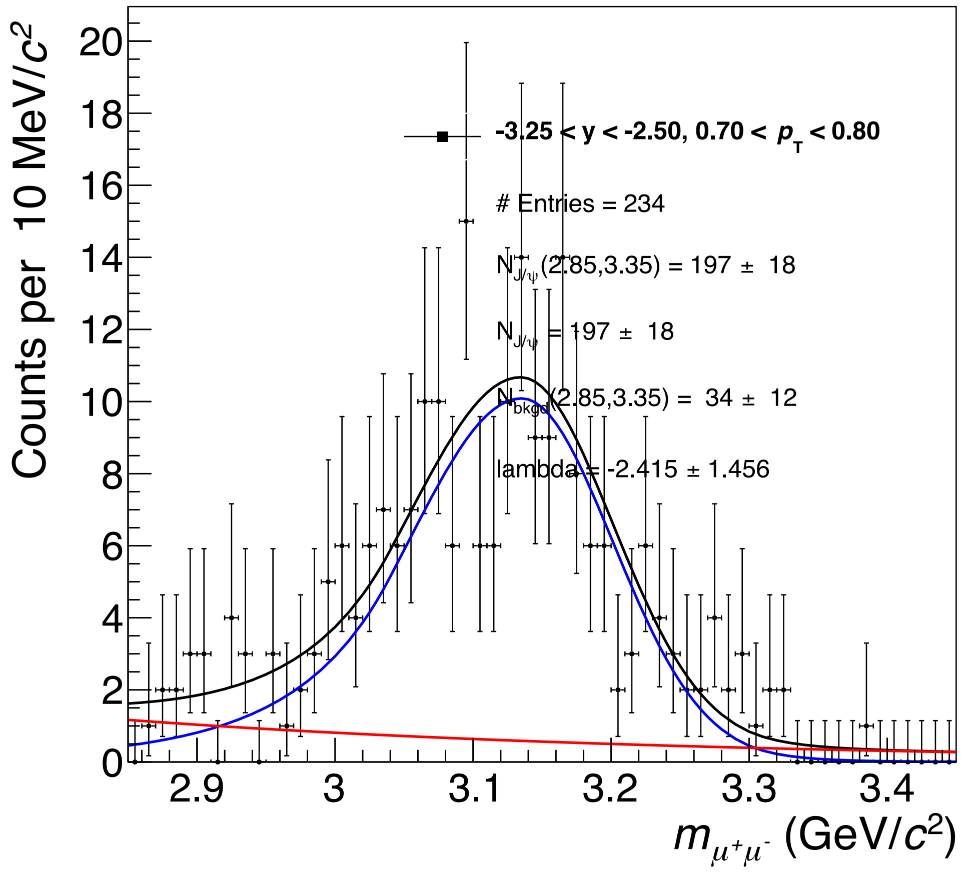


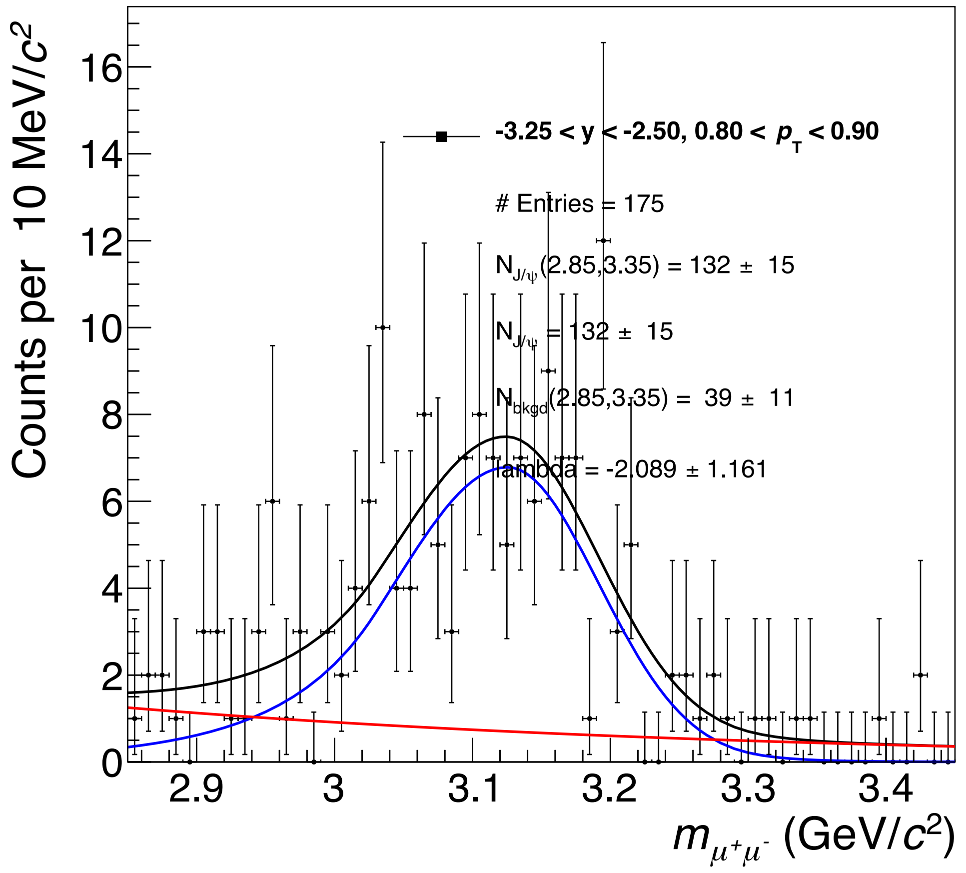


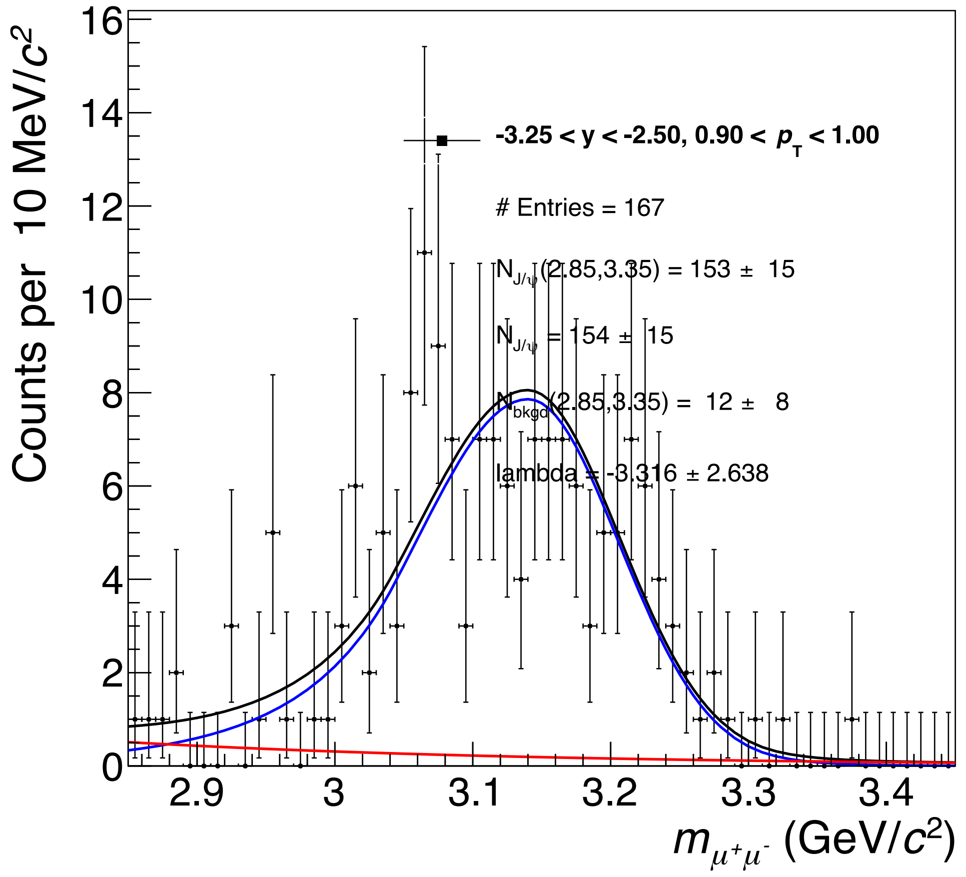
Backup: Signal for p_T distribution: Invariant mass fits in small p_T bins

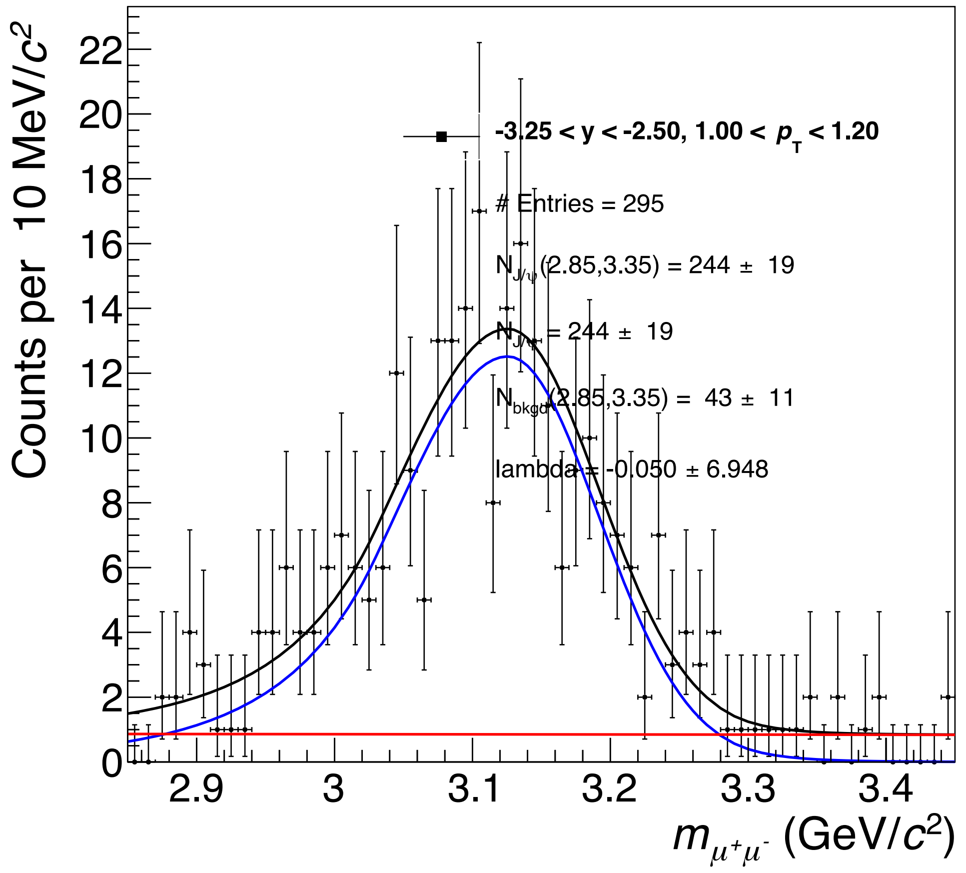
Pt Bin4

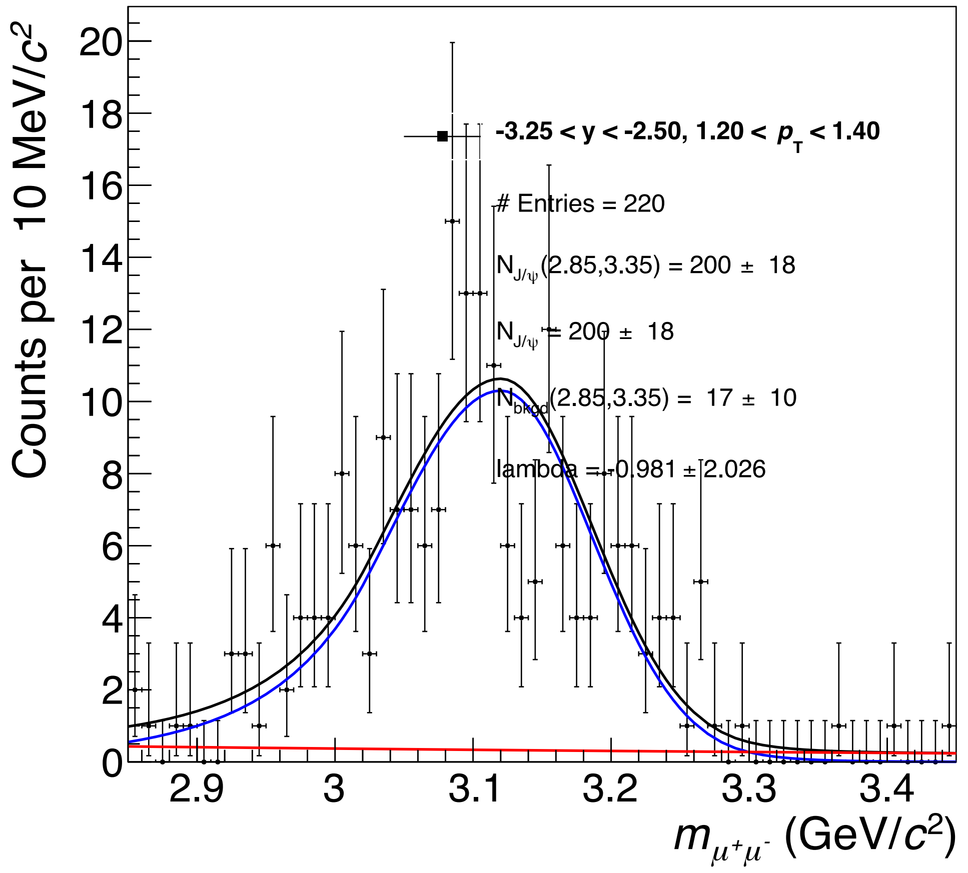
Pt Bin5

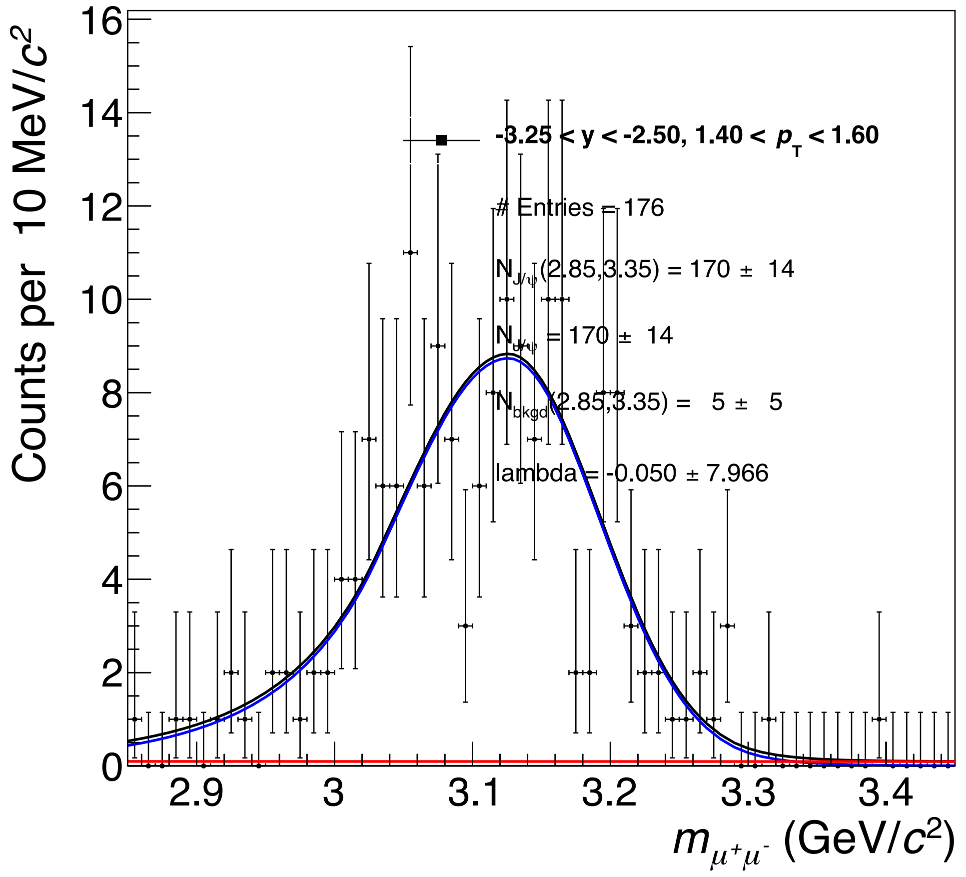


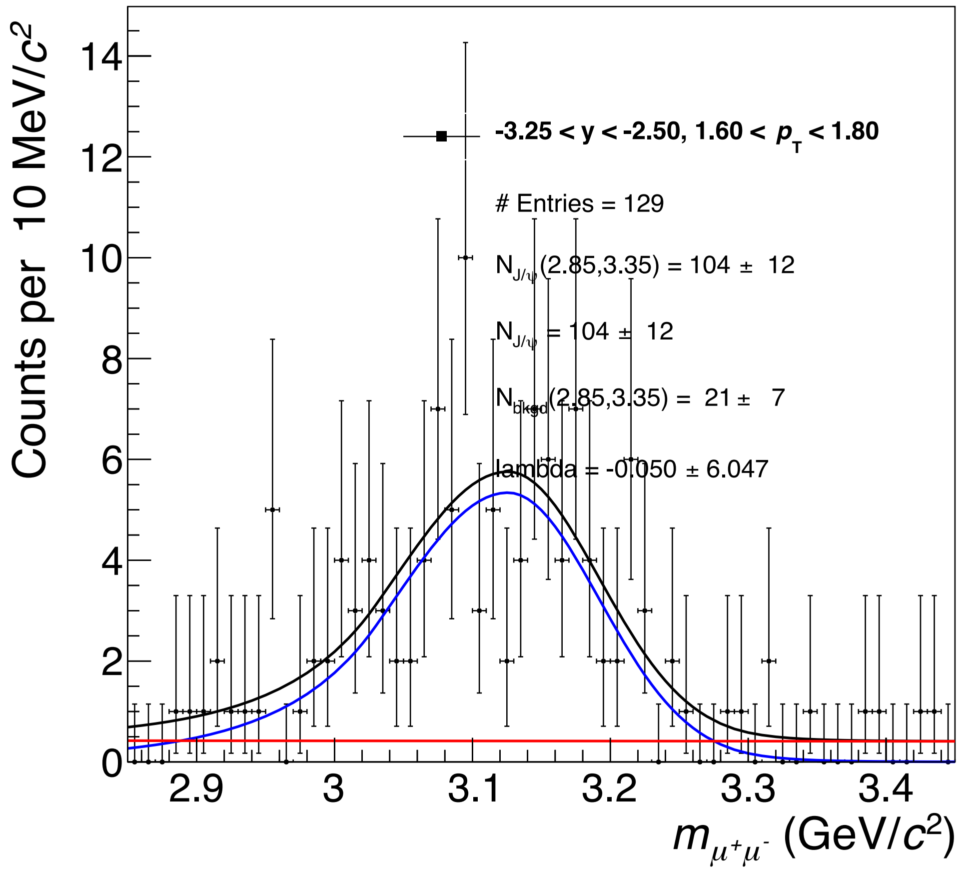


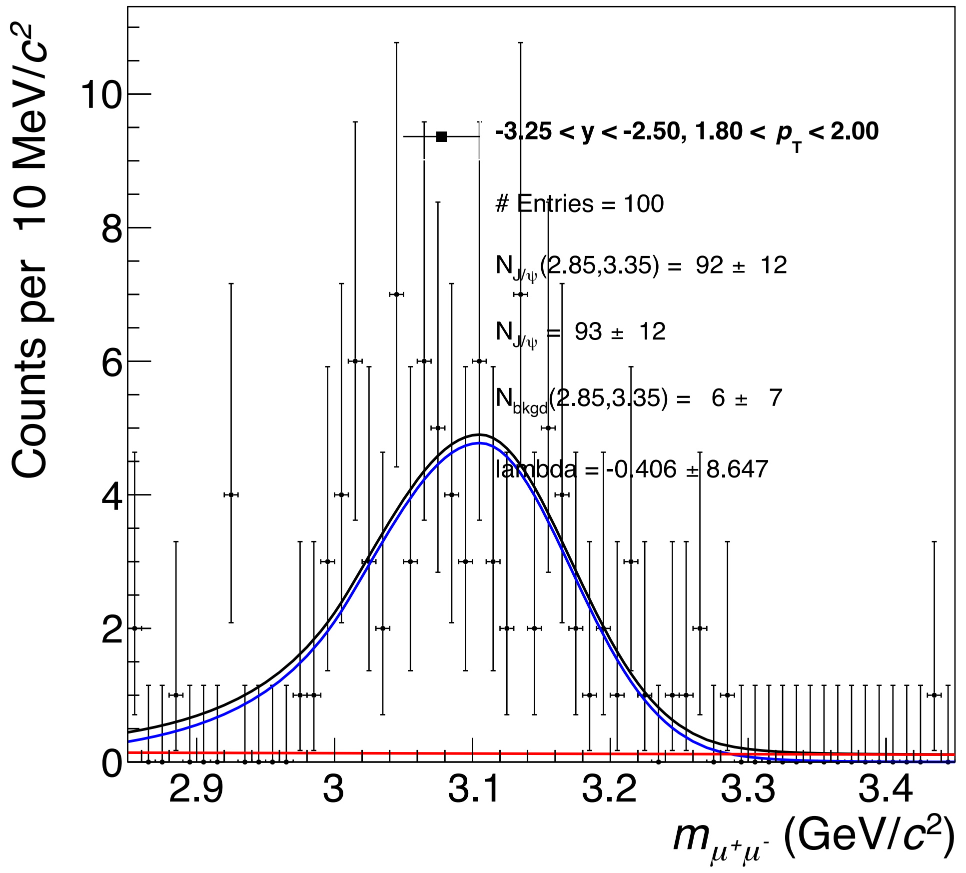




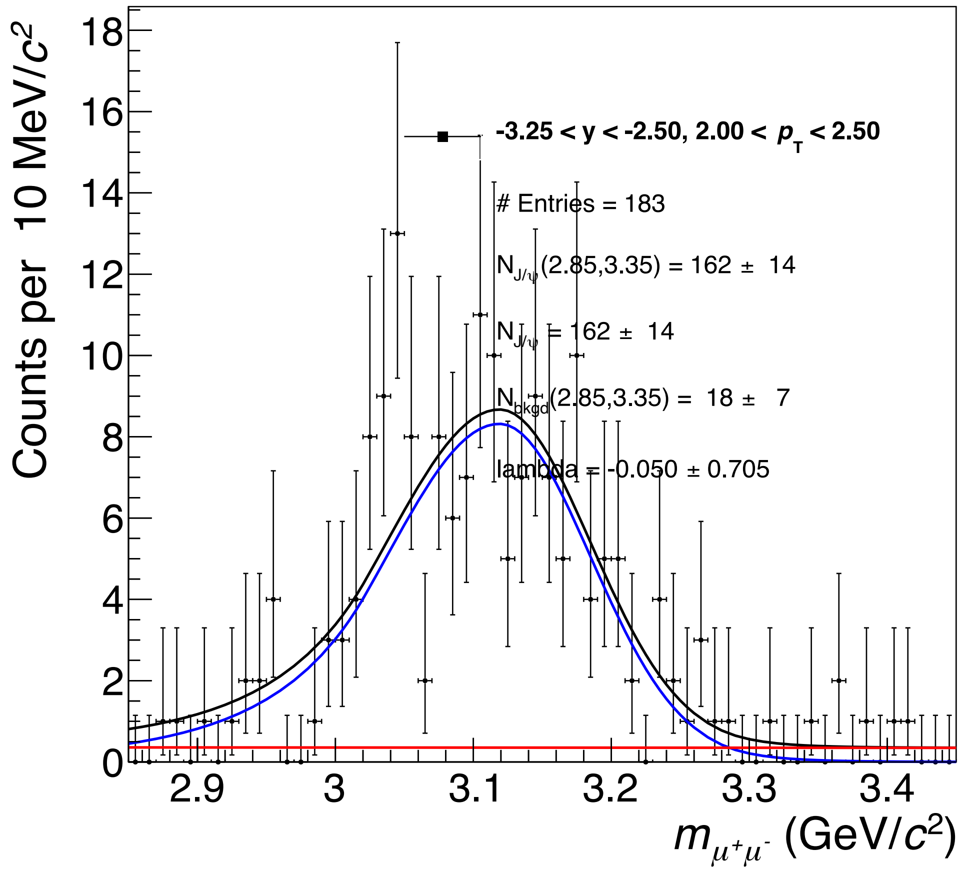


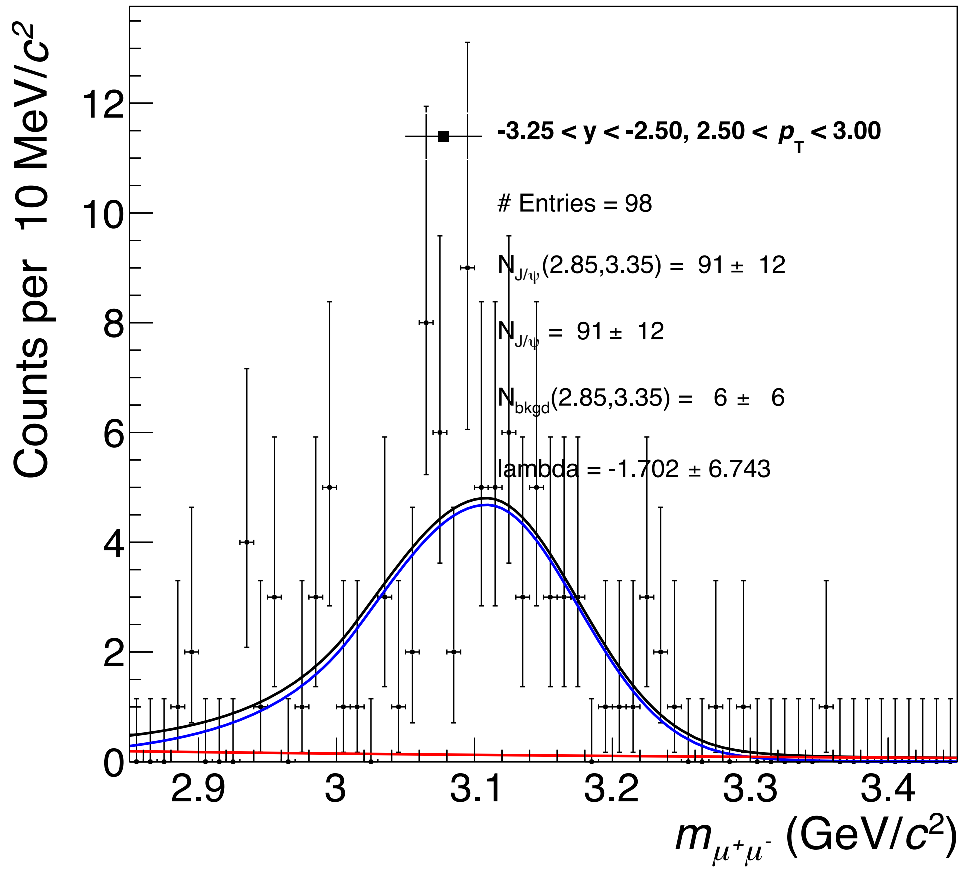


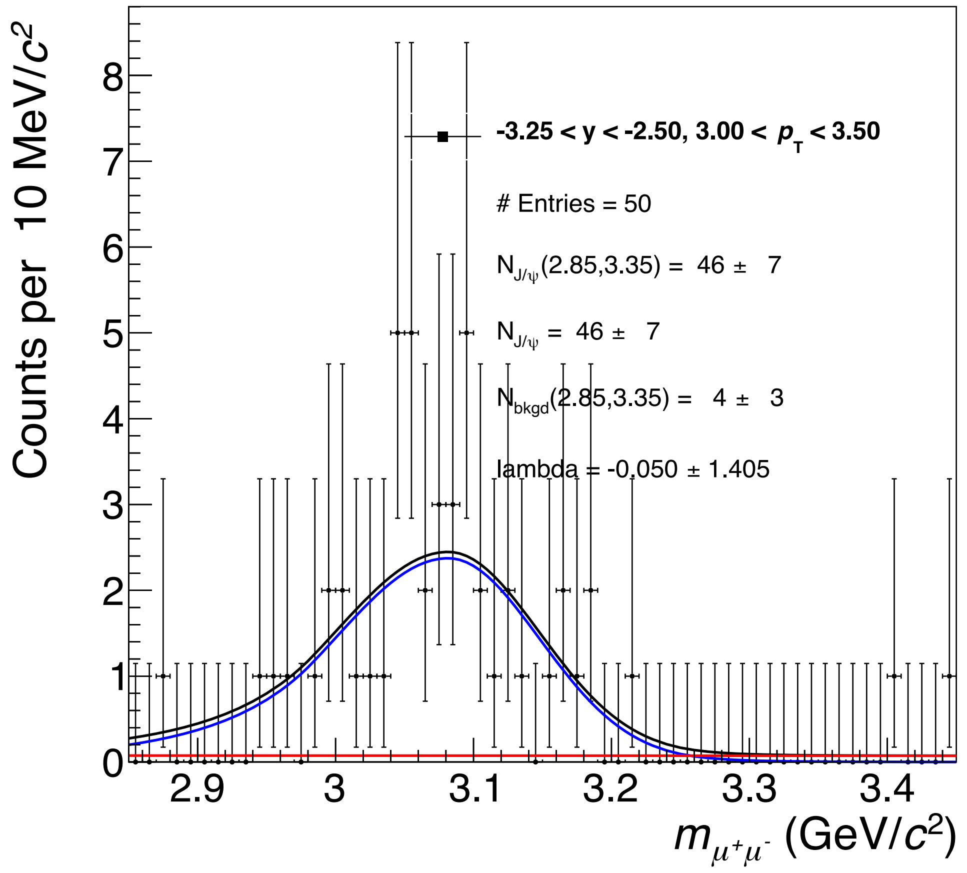




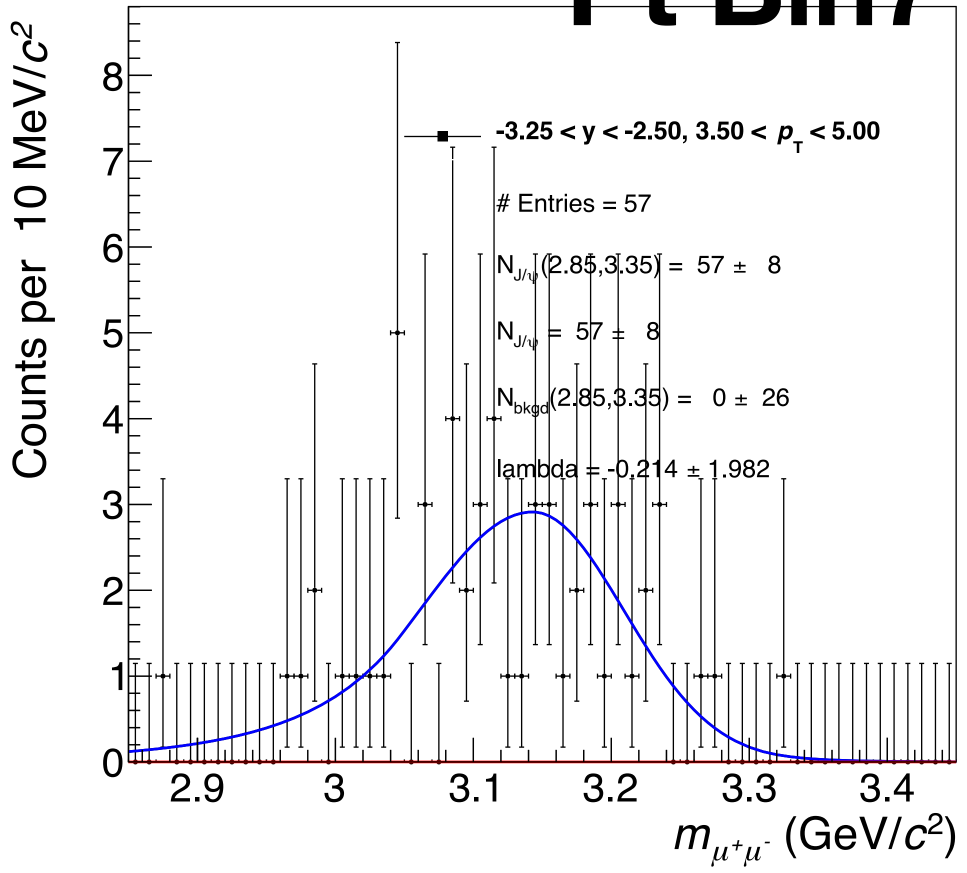
Pt Bin6







Pt Bin7



Backup

Acceptance and efficiency

Efficiency of reconstructed events $(A \times \epsilon)_{\mathrm{MC}}$

- Give with $(A \times \epsilon)_{\mathrm{MC}} = \frac{N_{\mathrm{MC}}^{\mathrm{rec}}}{N_{\mathrm{MC}}^{\mathrm{gen}}}$
- The Monte Carlo data sample: kIncohJpsiToMu: incoherent $J/\Psi \rightarrow \mu_{+}\mu_{-}$
- $N_{\mathrm{MC}}^{\mathrm{rec}}$: number of events that fulfilled the same selection as the selection for the J/Ψ
- $N_{\mathrm{MC}}^{\mathrm{gen}}$: number of events within the rapidity range and p_T bin
- Plots are in the backup.

	-4<y<-3.25	**-3.25<y<-2.5**
(0.3,0.5)	0.1330	0.1014
(0.5,0.7)	0.1326	0.1005
(0.7,0.9)	0.1333	0.0987
(0.9,1.2)	0.1382	0.0983
(1.2,1.5)	0.1540	0.1018
Total (0.3,1.5)	0.1332	0.1006

Backup: Acceptance and efficiency