Forward J/ψ in UPCs 2023

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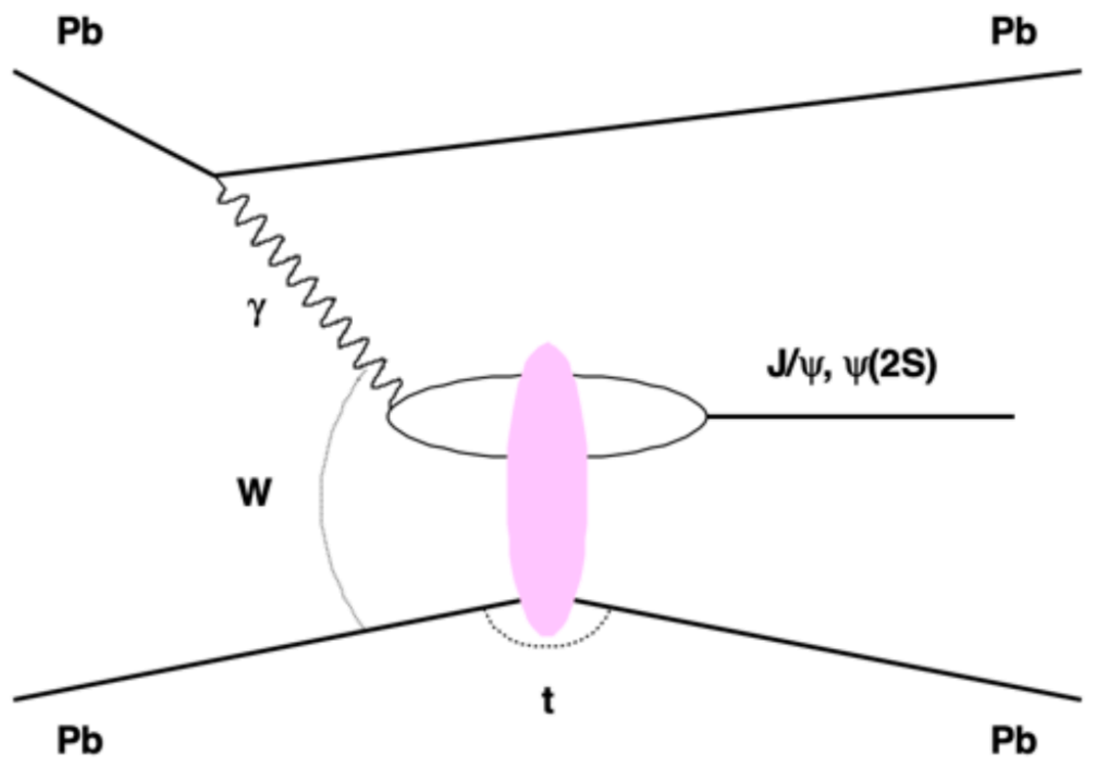
Introduction

- our goal is to measure the energy evolution of the |t|-dependence of coherent photoproduction of J/ψ in ultra-peripheral Pb–Pb collisions
  - at $\sqrt{s_{\mathrm{NN}}} = 5.36$ TeV, using 2023 Pb-Pb data
  - in dimuon channel
  - at forward rapidity $-4.0 < y < -2.5$
    - MCH and MID used only for now; MFT tracks will be included later on



Dataset used

- UPCCandidateProducer.cxx was used to produce the J/ψ candidates by running on Hyperloop over the following datasets from 2023 Pb-Pb data taking:
  - `LHC23_PbPb_pass3_fullTPC` - runs with full TPC acceptance
  - `LHC23_PbPb_pass3_I−A11` - runs without TPC sector A-11
- derived data downloaded and analyzed locally
  - some jobs were not successful, so the luminosity is slightly lower compared to the full sample
- MCH and MID information used
  - studies with MFT tracks in progress, plan to run over the full sample once we optimize the settings

Selection

- 2 MCH+MID tracks or 1 MCH+MID + 1 MCH track, unlike sign
- 17.6 < R_{abs} < 89.5 cm
- $p \times$ DCA
- $-4 < \eta < -2.5$
- V0A amplitude <100 in the same BC

Cross section for coherent photoproduction in UPCs

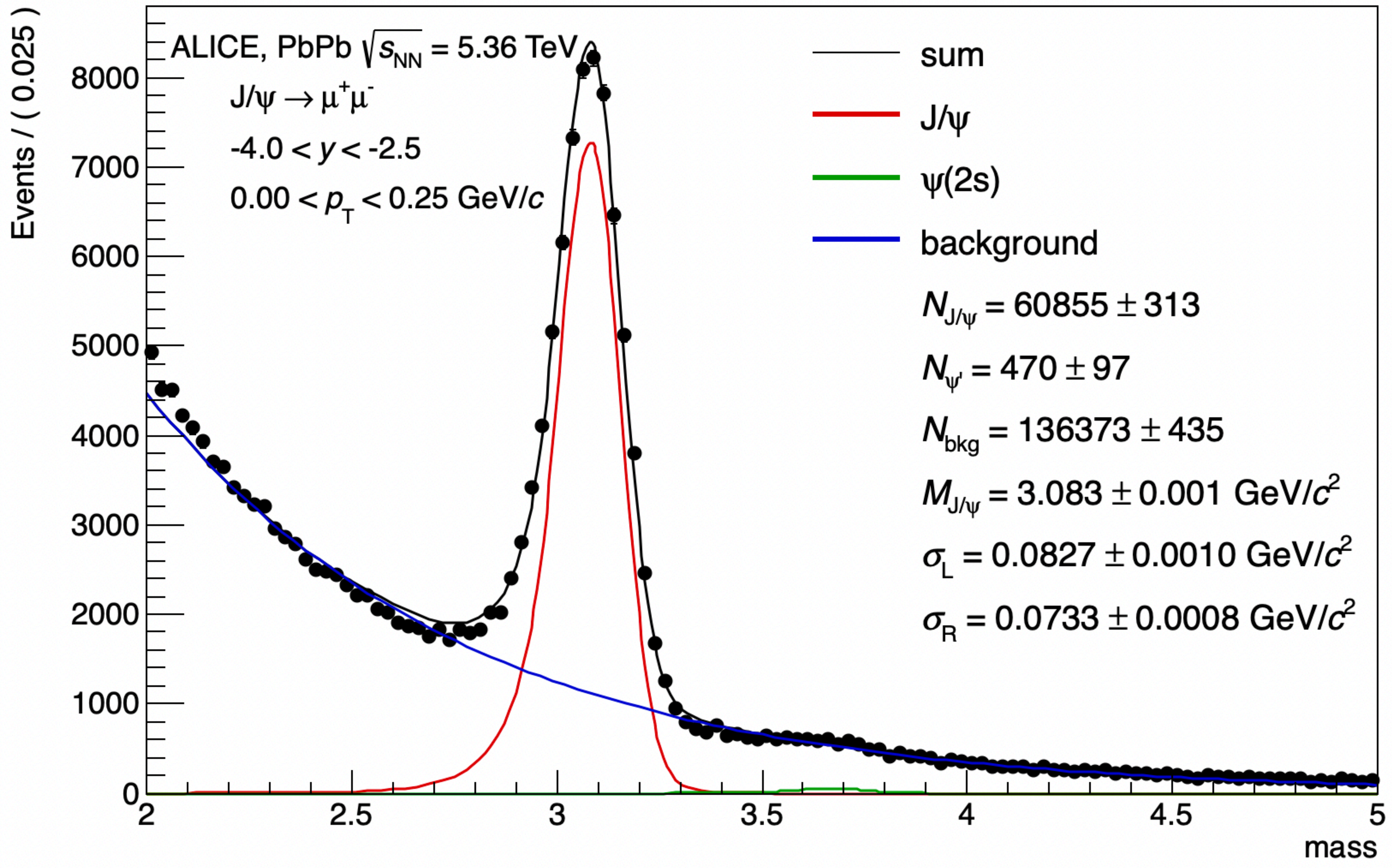
Cross section for coherent photoproduction in UPCs

$$\frac{d^2\sigma^{coh}_{J/\psi}}{dy\ dt} = \frac{N_{J/\psi}/\left(1+f_I+f_D\right)}{(A\times\varepsilon)_{J/\psi}\cdot BR\left(J/\psi\rightarrow\mu^+\mu^-\right)\cdot\mathscr{L}_{int}\cdot\Delta y\cdot\Delta|t|}$$

- yield of J/ψ measured from the invariant mass fit - see slide 8
- incoherent contamination: $\left\langle p_T^{coh}\right\rangle \sim 60$ MeV/c, $\left\langle p_T^{inc}\right\rangle \sim 300$ MeV/c
- feed-down contamination:
  - $\psi(2s)\rightarrow J/\psi + X$
    - $\psi(2s)$ coherent or incoherent
    - X charged or neutral, most often $\pi\pi$

Total yield of J/ψ candidates

- produced locally with the downloaded data from the dataset mentioned in s.3
  - some jobs were not successful, the luminosity is slightly lower (see next slide)
- using the double-sided crystal ball + an exponential for background
- ψ' parameters are fixed to the ones from the J/ψ in a standard way
- details of the fit in the back-up



	λ	$N_{\psi'}$	$N_{J/\psi}$	N_{bg}	m0	sigmaL	sigmaR
λ	1	-0.370713	-0.158658	0.19682	0.0201506	-0.0355914	-0.0827104
$N_{\psi'}$	-0.370713	1	0.118108	-0.297238	0.0158978	0.0630682	0.0262765
$N_{J/\psi}$	-0.158658	0.118108	1	-0.297463	0.0966901	0.276326	0.0210509
N_{bg}	0.19682	-0.297238	-0.297463	1	-0.0729956	-0.212559	-0.020996
m0	0.0201506	0.0158978	0.0966901	-0.0729956	1	0.777157	-0.850031
sigmaL	-0.0355914	0.0630682	0.276326	-0.212559	0.777157	1	-0.567023
sigmaR	-0.0827104	0.0262765	0.0210509	-0.020996	-0.850031	-0.567023	1

Integrated luminosity

$$\frac{\mathrm{d}^2\sigma^{\mathrm{coh}}_{\mathrm{J}/\psi}}{\mathrm{dy}\ \mathrm{dt}} = \frac{N_{\mathrm{J}/\psi}/\left(1+f_{\mathrm{I}}+f_{\mathrm{D}}\right)}{(A\times\varepsilon)_{\mathrm{J}/\psi}\cdot \mathrm{BR}\left(\ \mathrm{J}/\psi\to\mu^+\mu^-\right)\cdot\mathscr{L}_{\mathrm{int}}\cdot\Delta\mathrm{y}\cdot\Delta\,|\,\mathrm{t}\,|}$$

- `hCountersTrg` that contains count for TVX-TCE triggers used to calculate analyzed luminosity
    - stored along with produced UD tables

integral of TCE distribution

$$\sigma_{\mathrm{TCE}} = \sigma_{\mathrm{INEL}}\frac{N_{\mathrm{TCE}}}{N_{\mathrm{INEL}}}$$

from the fit

~ 4.1 b

- luminosity calculated from TVX-TCE triggers for the local dataset: $1213\ \mu\mathrm{b}^{-1}$

MC sample

$$\frac{d^2\sigma^{coh}_{J/\psi}}{dy\ dt} = \frac{N_{J/\psi}/(1+f_I+f_D)}{(A\times\varepsilon)_{J/\psi}\cdot BR(J/\psi\to\mu^+\mu^-)\cdot\mathscr{L}_{int}\cdot\Delta y\cdot\Delta|t|}$$

- for the moment:
  - sample for coherent J/ψ downloaded from grid
  - J/ψ generated in $|y| < 4.1$, then filtered to $-4.1 < y < -2.4$, using STARlight (approx. 2M events)
  - test simulation with latest MCH and MID developments
  - to be used to calculate $A\times\varepsilon$, resolution, for unfolding…
    - work in progress

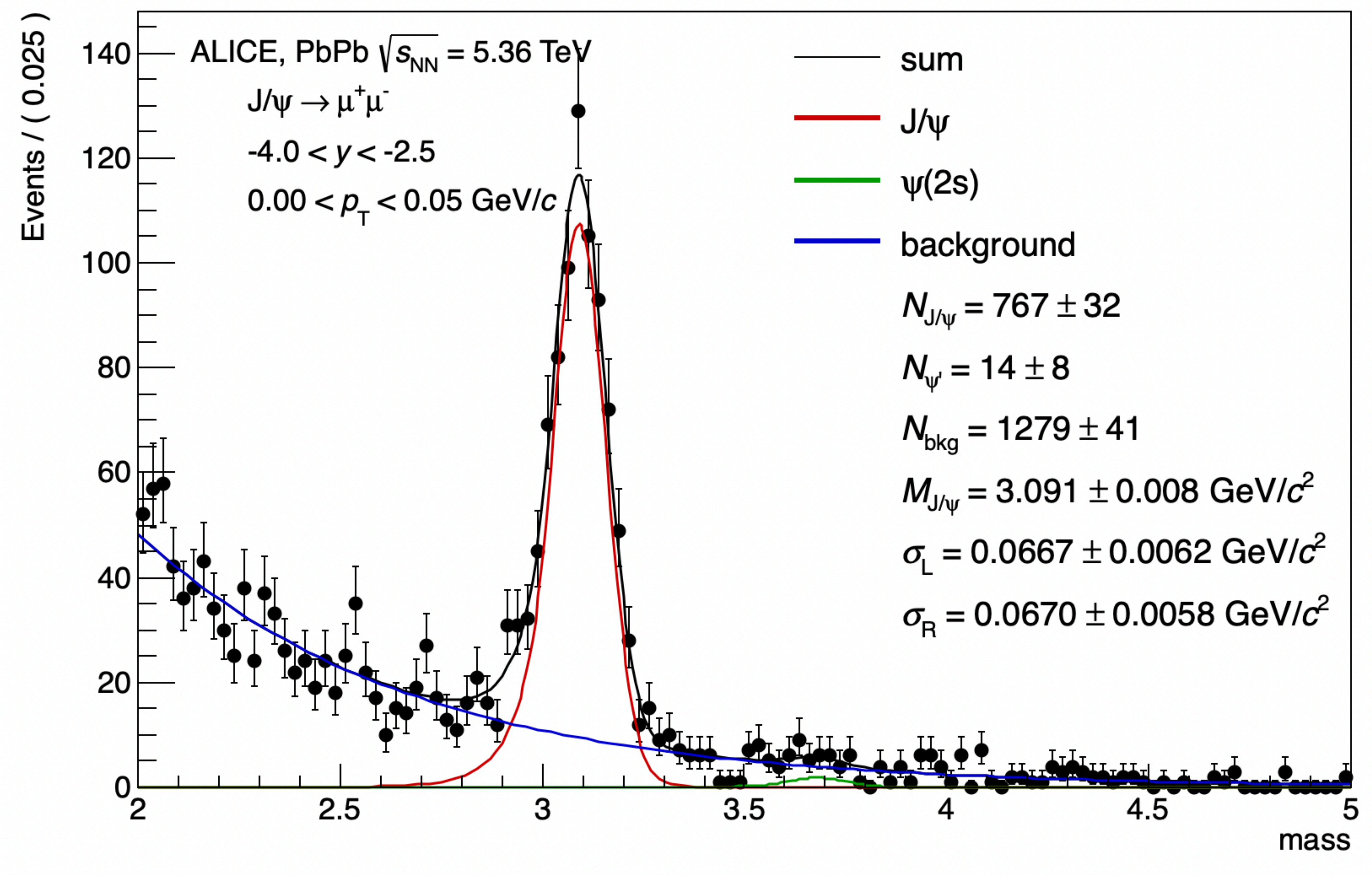
Yield of J/ψ in p_T and y bins

Choice of binning in p_T and y

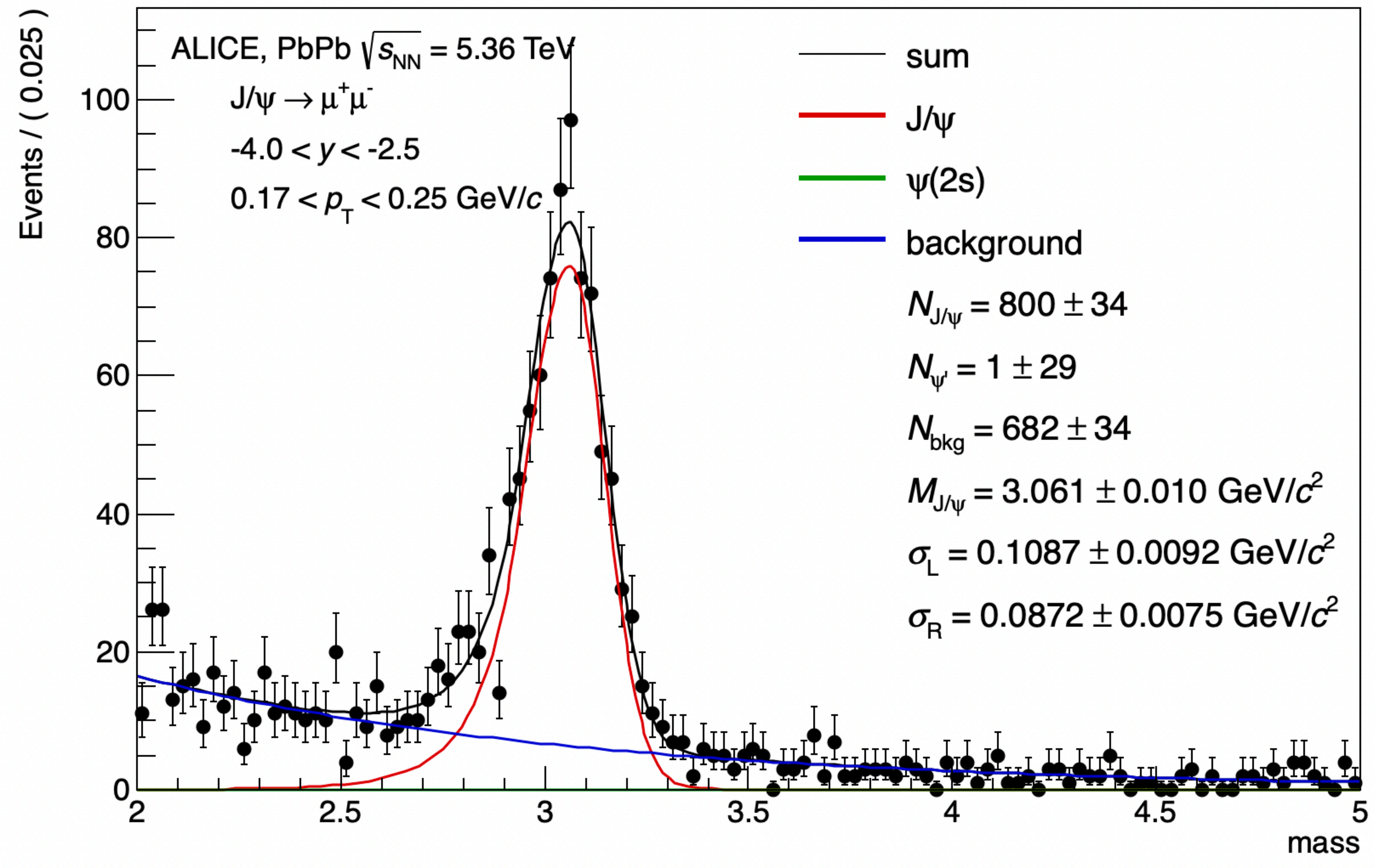
- by performing the fit of the invariant mass distribution, bins selected such that they all contain a similar number of signal events
- using the XnXn class: the sample with the fewer candidates
- 6 p_T bins defined as

p_T bin	y range	#J/ψ
(0.0, 0.05)	(-4.0, -2.5)	767 ± 32
(0.05, 0.075)	(-4.0, -2.5)	742 ± 32
(0.075, 0.10)	(-4.0, -2.5)	753 ± 32
(0.10, 0.13)	(-4.0, -2.5)	751 ± 32
(0.13, 0.17)	(-4.0, -2.5)	768 ± 32
(0.17, 0.25)	(-4.0, -2.5)	800 ± 34

1st bin



6th bin



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- further divided into 2 rapidity bins:
- (-4.0, -3.25) and (-3.25, -2.5)

p_T bin	y range	#J/ψ
(0.0, 0.05)	(-4.0, -3.25)	288 ± 20
(0.05, 0.075)	(-4.0, -3.25)	266 ± 19
(0.075, 0.10)	(-4.0, -3.25)	308 ± 20
(0.10, 0.13)	(-4.0, -3.25)	290 ± 20
(0.13, 0.17)	(-4.0, -3.25)	333 ± 21
(0.17, 0.25)	(-4.0, -3.25)	305 ± 21

p_T bin	y range	#J/ψ
(0.0, 0.05)	(-3.25, -2.5)	478 ± 25
(0.05, 0.075)	(-3.25, -2.5)	479 ± 25
(0.075, 0.10)	(-3.25, -2.5)	444 ± 25
(0.10, 0.13)	(-3.25, -2.5)	464 ± 25
(0.13, 0.17)	(-3.25, -2.5)	436 ± 24
(0.17, 0.25)	(-3.25, -2.5)	499 ± 26

Choice of binning in p_T and y

- by performing the fit of the invariant mass distribution, bins selected such that they all contain a similar number of signal events
- using the XnXn class
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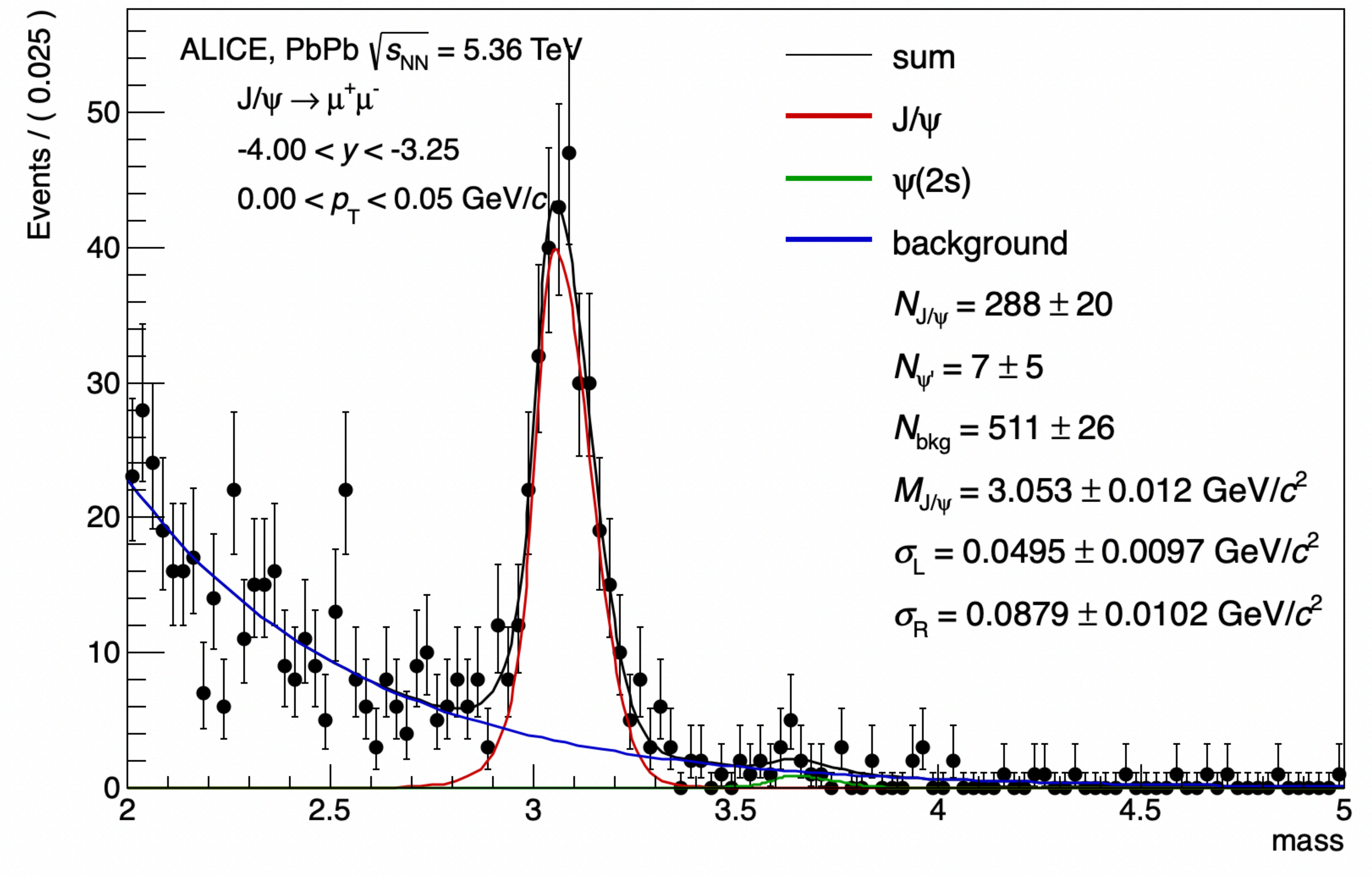
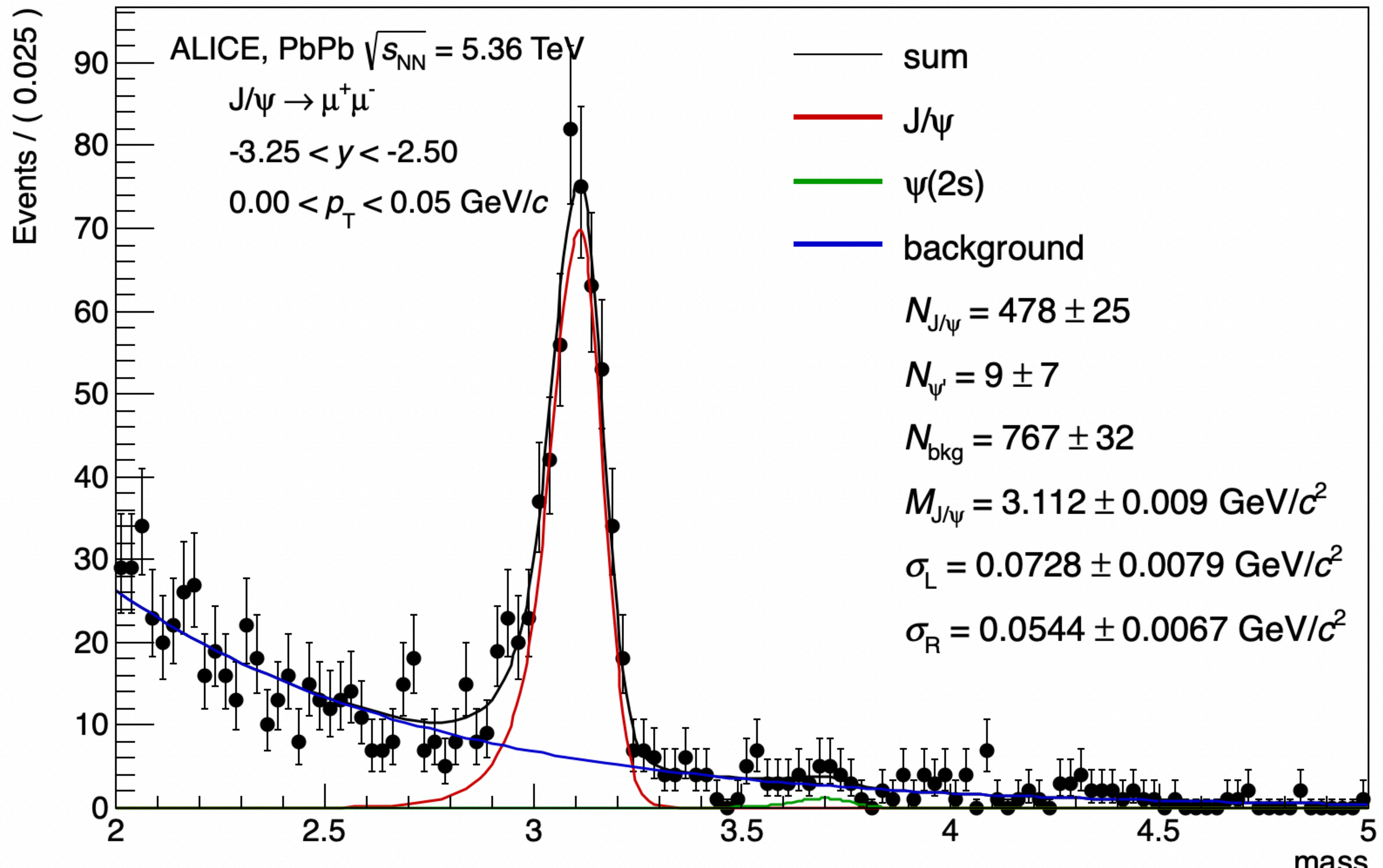
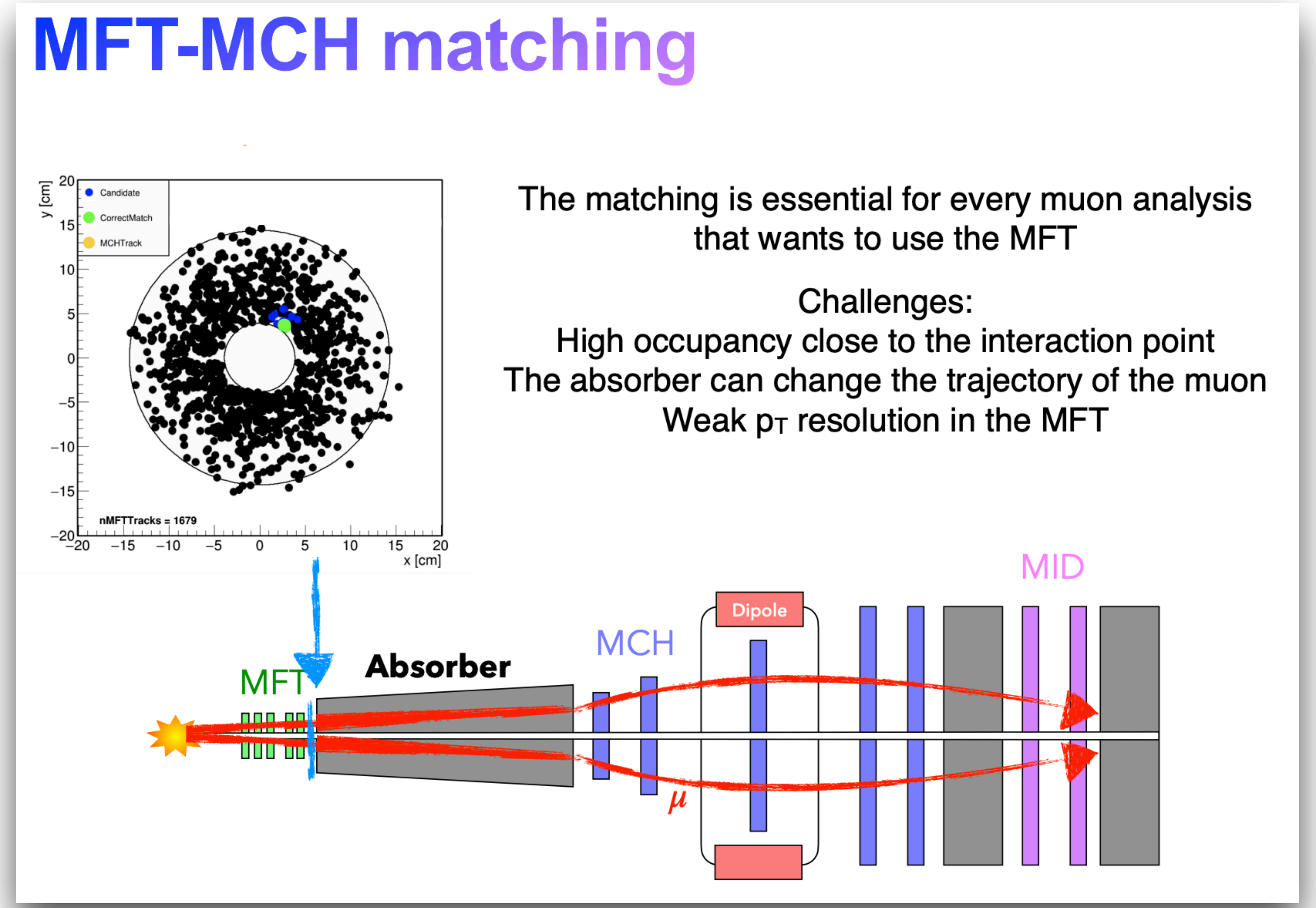




MFT track studies for forward UPC analyses

Tracks at forward rapidity

- MCH-MID tracks:
  - muon analyses that require no vertex information
- global tracks:
  - muon analyses that need access to the vertex
- matching is done at reco level currently
  - not flexible



Forward matching

Track types:

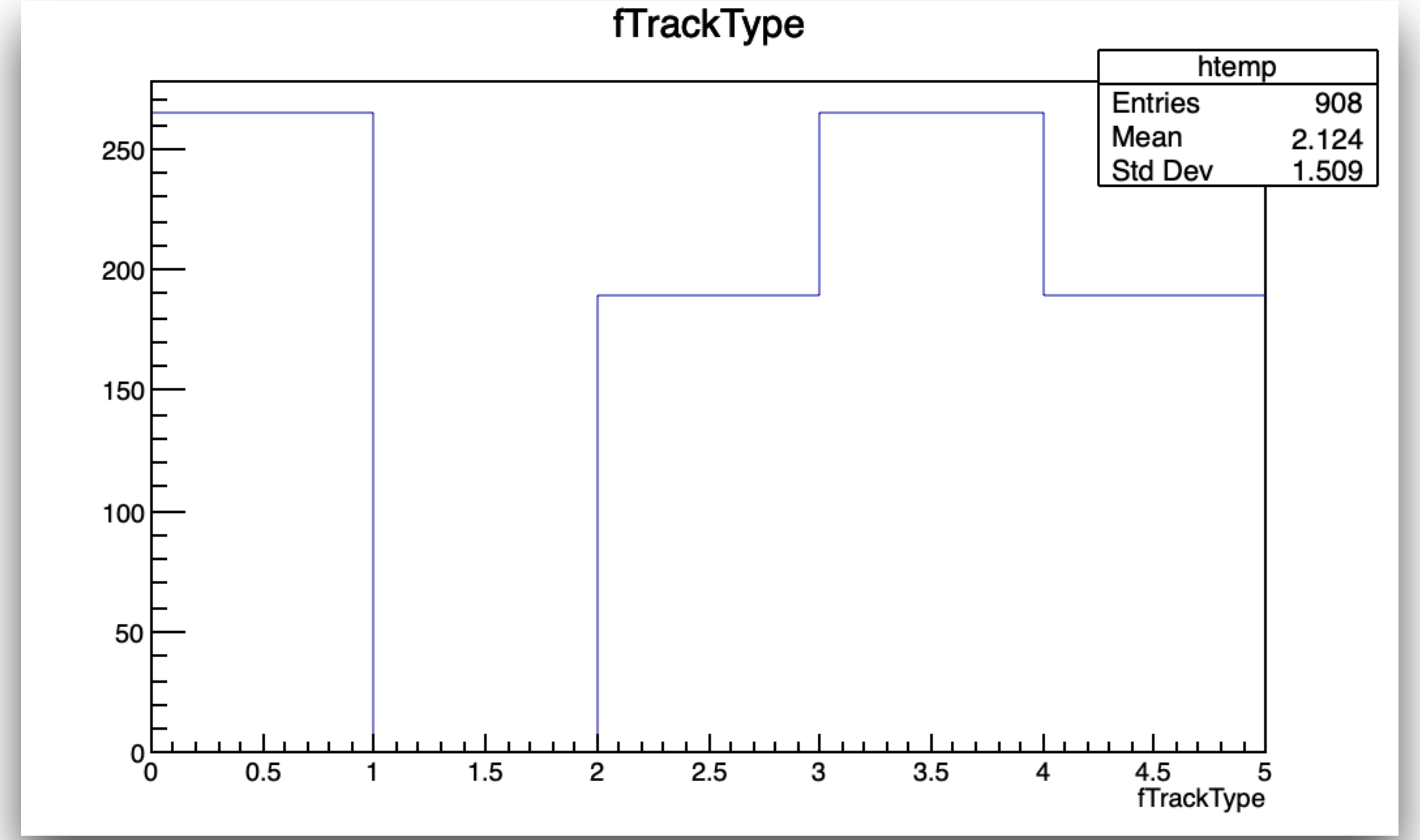
- 0: GlobalMuonTrack - MFT-MCH-MID
- 1: GlobalMuonTrackOtherMatch - MFT-MCH-MID (MCH-MID used another time)
- 2: GlobalForwardTrack - MFT-MCH
- 3: MuonStandaloneTrack - MCH-MID
- 4: MCHStandaloneTrack - MCH

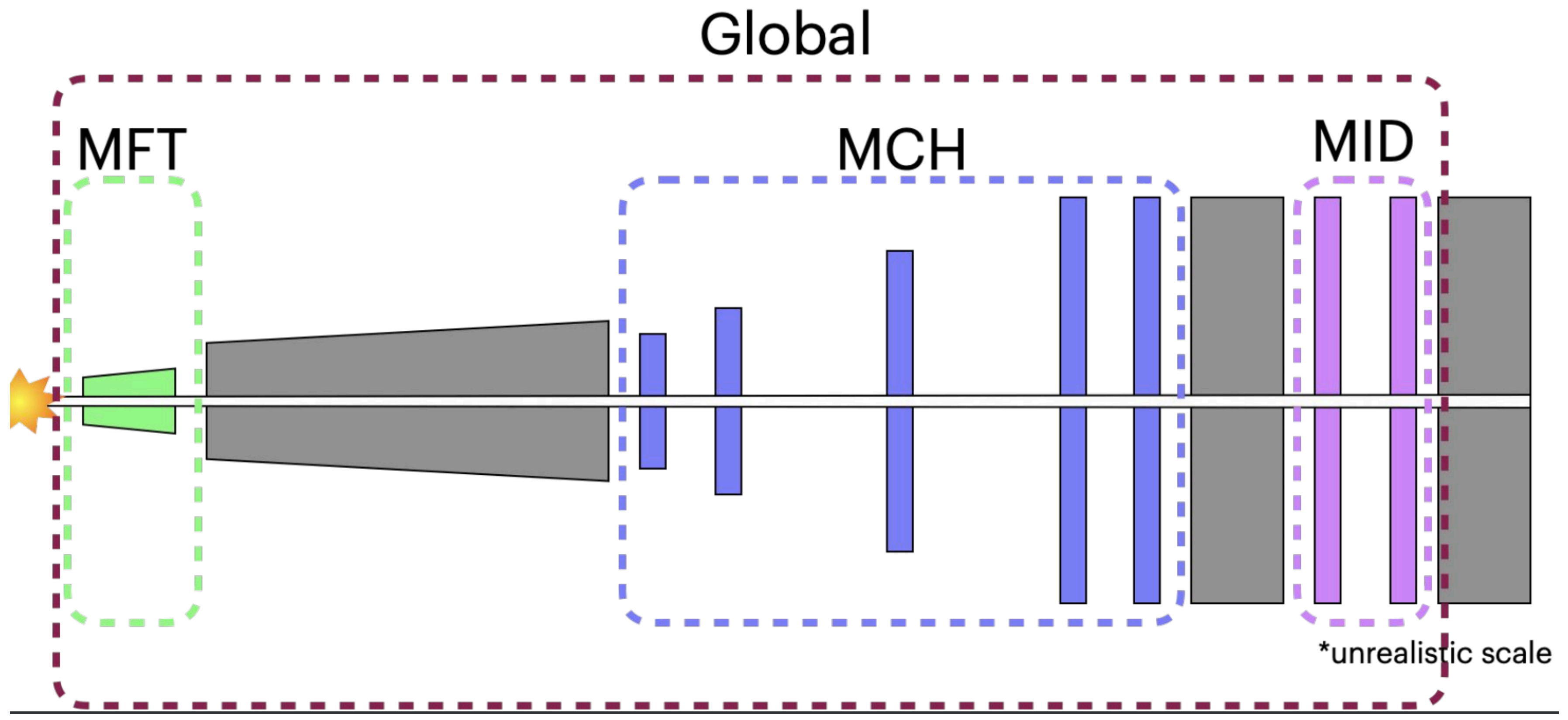
```
enum ForwardTrackTypeEnum : uint8_t {
  GlobalMuonTrack = 0,          // MFT-MCH-MID
  GlobalMuonTrackOtherMatch,    // MFT-MCH-MID (MCH-MID used another time)
  GlobalForwardTrack,           // MFT-MCH
  MuonStandaloneTrack,          // MCH-MID
  MCHStandaloneTrack            // MCH
```

example from a random AO2D file: 0+2 ≊ 3+4

(MFT-MCH-MID)+(MFT-MCH) ≊ (MCH-MID)+(MCH)

→ MCH track always gets matched with MFT





Forward tracks

MCH ~ 40 BC

MCH+MID ~ 1 BC

MFT+MCH+MID ~ 594 BC (for Pb-Pb)

- MCH+MID acceptance
  - $-4.0 < \eta < -2.5$
- MFT acceptance
  - $-3.6 < \eta < -2.45$

UPC EVENTS SEEN IN FWD TRACKS:

- valid UPC - no background
- 2 tracks in MFT + GLOBAL
- 1 track in MFT + 1 outside
- 0 tracks in MFT + 2 outside

DOUBLE COUNTING TRACKS:

- it can happen that one MFT track gets matched with two MCH tracks
- to remove this:
  - the MCH track which is outside of MFT acceptance typically has a high χ^2 value for matching
    - applying a strict selection (e.g. $\chi^2 < 35$) should remove most of the cases
  - when analysing a matched track in AO2Ds, we could retrieve the corresponding MCH track that was used for matching, and discard the global tracks if the MCH track is outside of MFT acceptance

Vertexing

- all the tracks are propagated using fwdTrackPropagation.cxx
- MCH-MID tracks:

```cpp
if (static_cast<int>(muon.trackType()) > 2) {
  o2::dataformats::GlobalFwdTrack track;
  track.setParameters(tpars);
  track.setZ(fwdtrack.getZ());
  track.setCovariances(tcovs);
  auto mchTrack = fMatching.FwdtoMCH(track);
  o2::mch::TrackExtrap::extrapToVertex(mchTrack, vtx[0], vtx[1], vtx[2], vtxCov[0], vtxCov[1]);
  auto proptrack = fMatching.MCHtoFwd(mchTrack);
  propmuon.setParameters(proptrack.getParameters());
  propmuon.setZ(proptrack.getZ());
  propmuon.setCovariances(proptrack.getCovariances());
```

- tracks with MFT:

```cpp
} else if (static_cast<int>(muon.trackType()) < 2) {
  double centerMFT[3] = {0, 0, -61.4};
  o2::field::MagneticField* field = static_cast<o2::field::MagneticField*>(TGeoGlobalMagField::Instance()->GetField());
  auto Bz = field->getBz(centerMFT); // Get field at centre of MFT
  auto geoMan = o2::base::GeometryManager::meanMaterialBudget(muon.x(), muon.y(), muon.z(), vtx[0], vtx[1], vtx[2]);
  auto x2x0 = static_cast<float>(geoMan.meanX2X0);
  fwdtrack.propagateToVtxhelixWithMCS(vtx[2], {vtx[0], vtx[1]}, {vtxCov[0], vtxCov[1]}, Bz, x2x0);
  propmuon.setParameters(fwdtrack.getParameters());
  propmuon.setZ(fwdtrack.getZ());
  propmuon.setCovariances(fwdtrack.getCovariances());
}
```

  - propagation to vtx helix with MCS

Dataset used for the MFT track and matching studies

- using Hyperloop
- dataset `LHC23zzh_pass3_small`
- two trains
  - one with a process for MCH+MID tracks
  - one with both tracks of the MFT+MCH+MID type

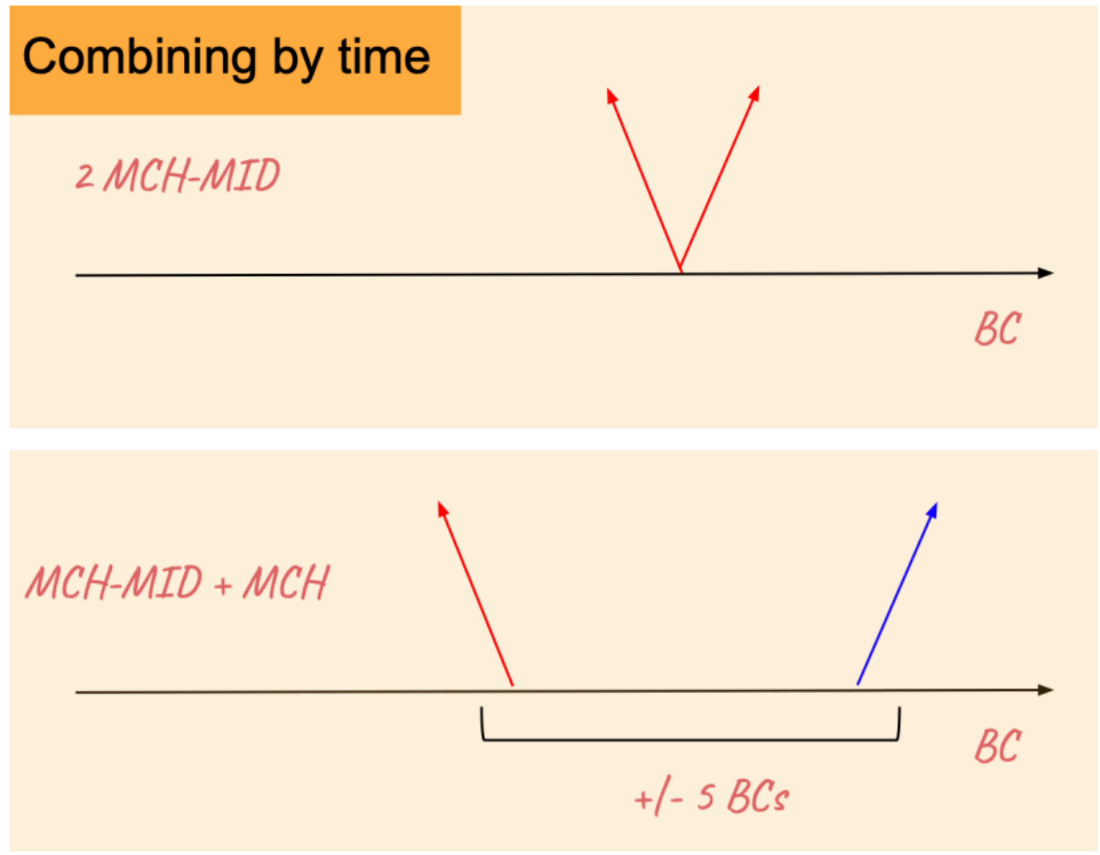
- slim derived data produced
- UDCollisions, UDCollisionsSels, UDCollisionsSelsExtra, UDCollisionsSelsFwd, UDFwdTracks, UDFwdTracksExtra, UDZdcsReduced, UDFwdIndices

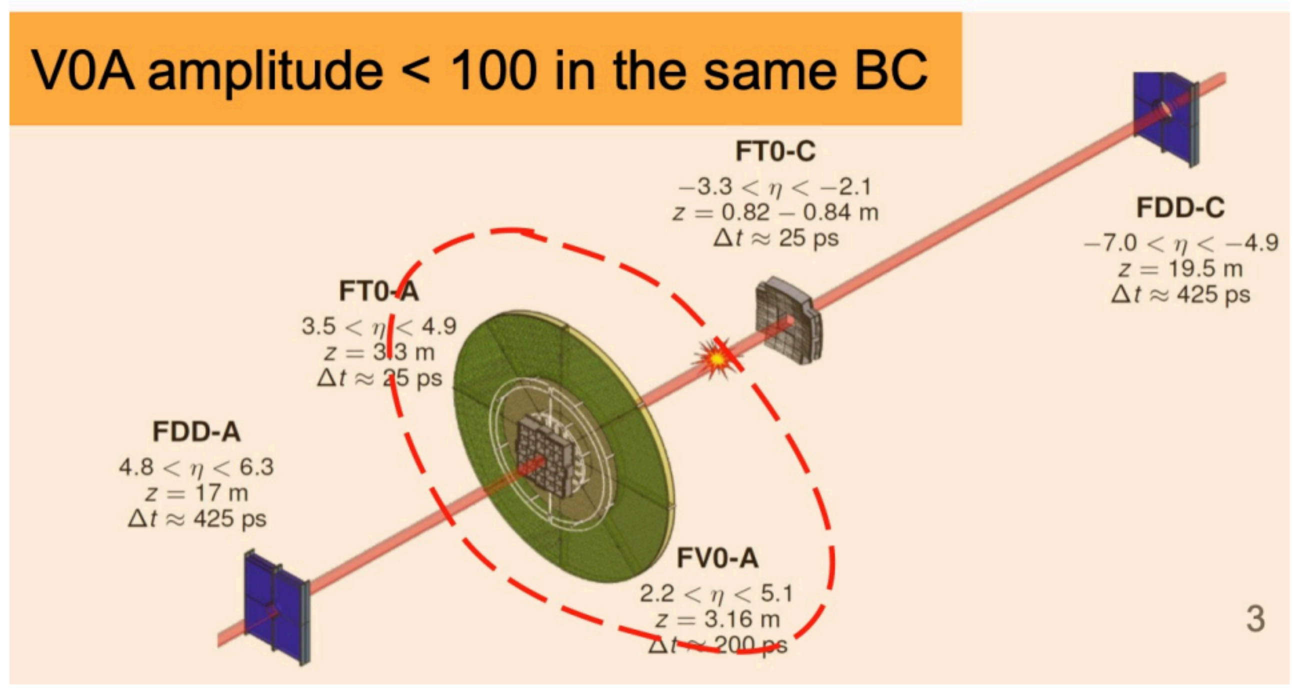
globalIndex
matchMFTTrackId
matchMCHTrackId

Event selection

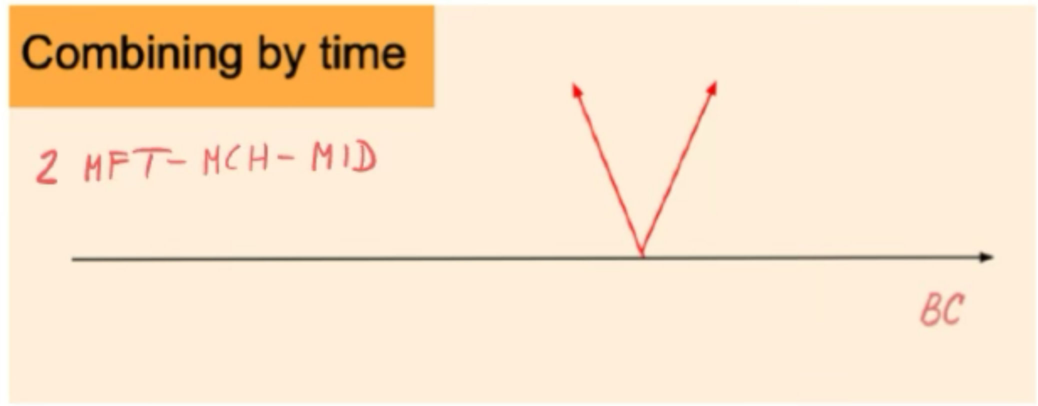
- $17.6 < R_{abs} < 89.5$ cm
- $p \times \mathrm{DCA}$
- $-4 < \eta < -2.5$
- V0A amplitude <100 in the same BC

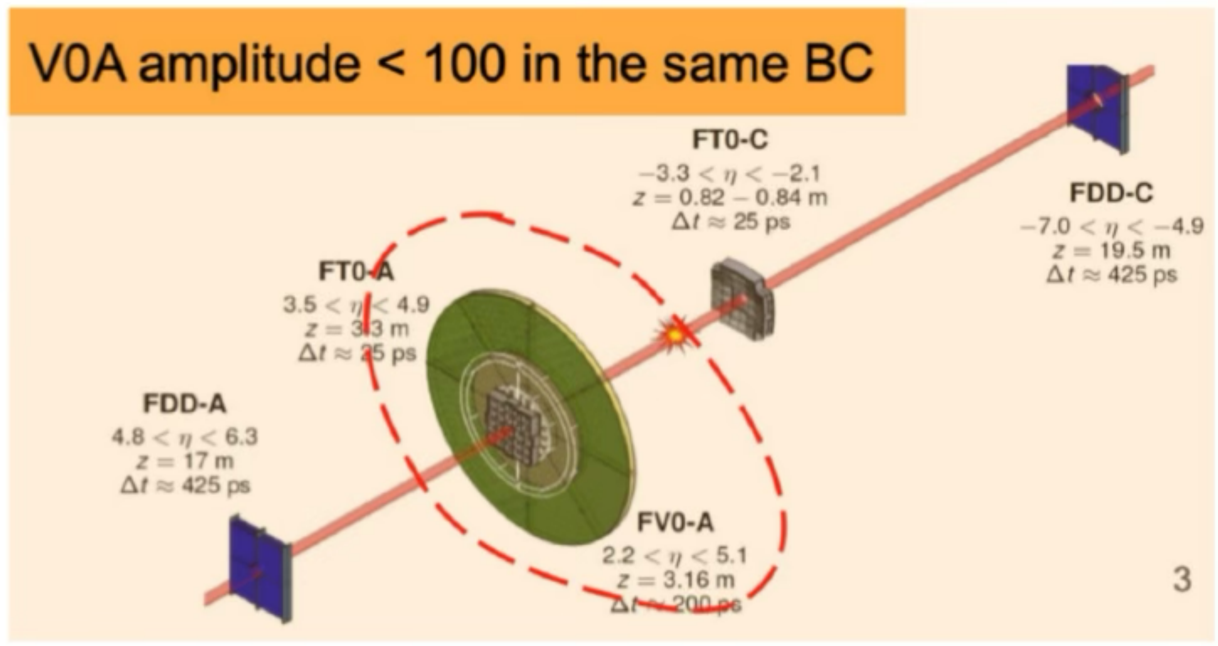
- Nazar's selection:





- our selection:





Comparison of the two datasets

- MCH-MID / MCH-MID + MCH
- total number of MCH-MID tracks: 1.23076×10^7 = 12.3 M tracks
- total number of MCH tracks: 2.093×10^6 = 2 M tracks

- MFT-MCH-MID
- total number of MFT-MCH-MID tracks: 1.04021×10^7 = 10.4 M tracks

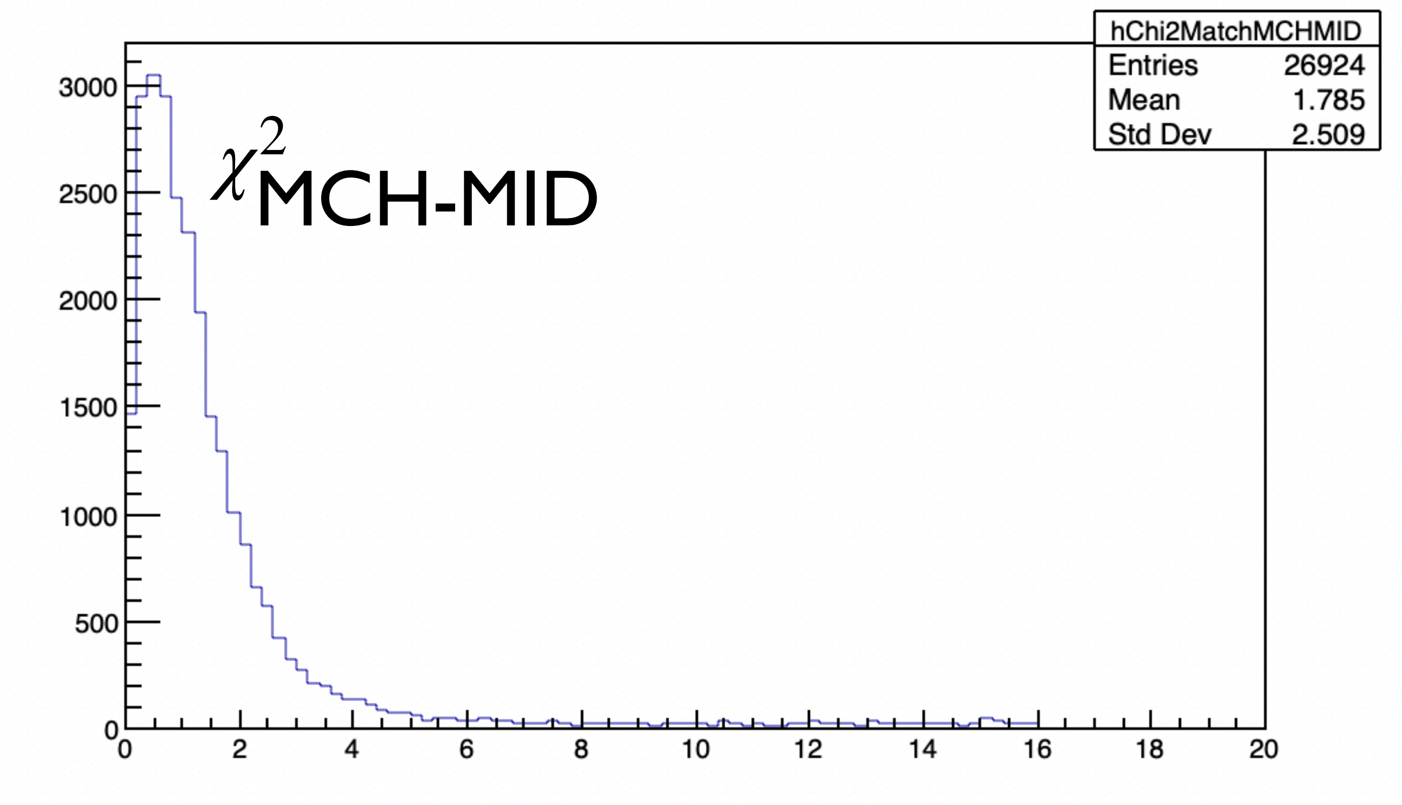
After the selection

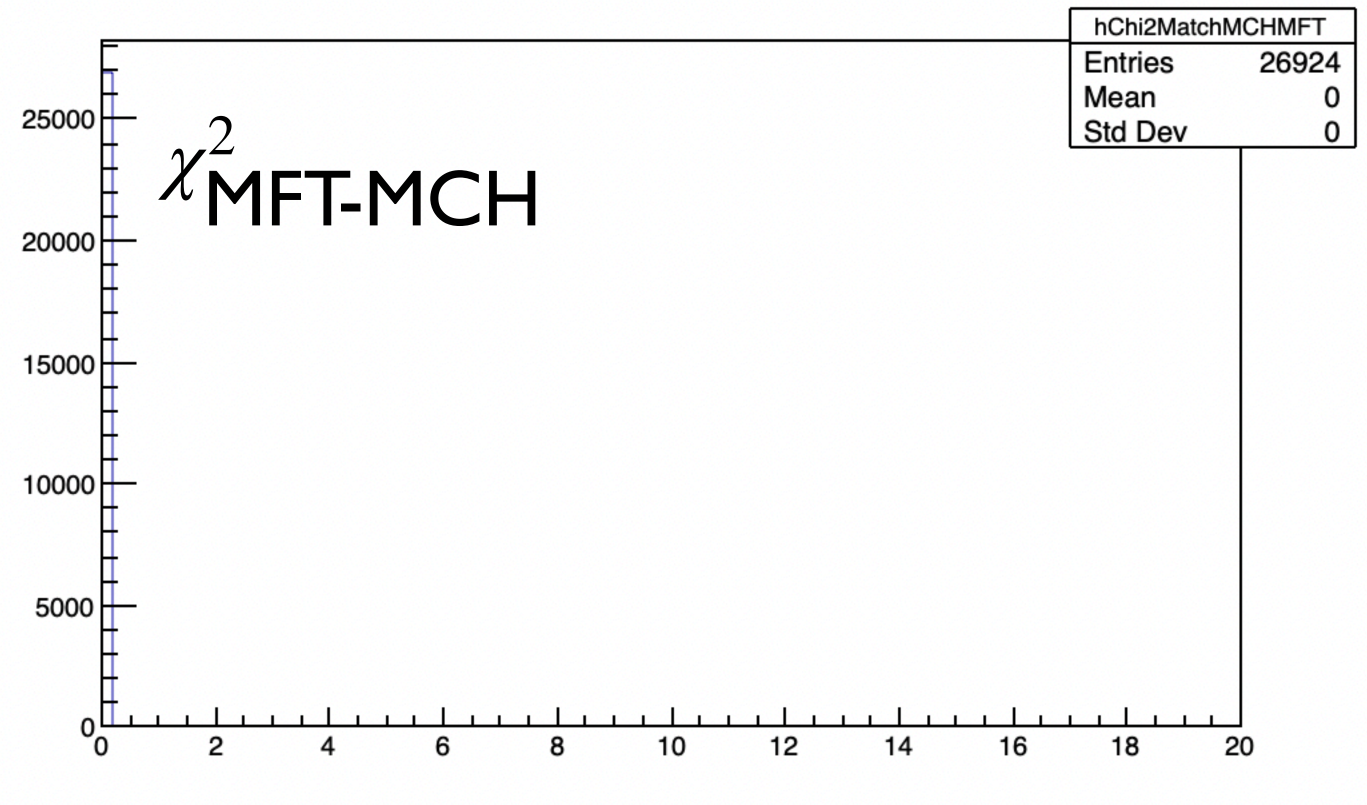
see next slides

Comparison of the two samples

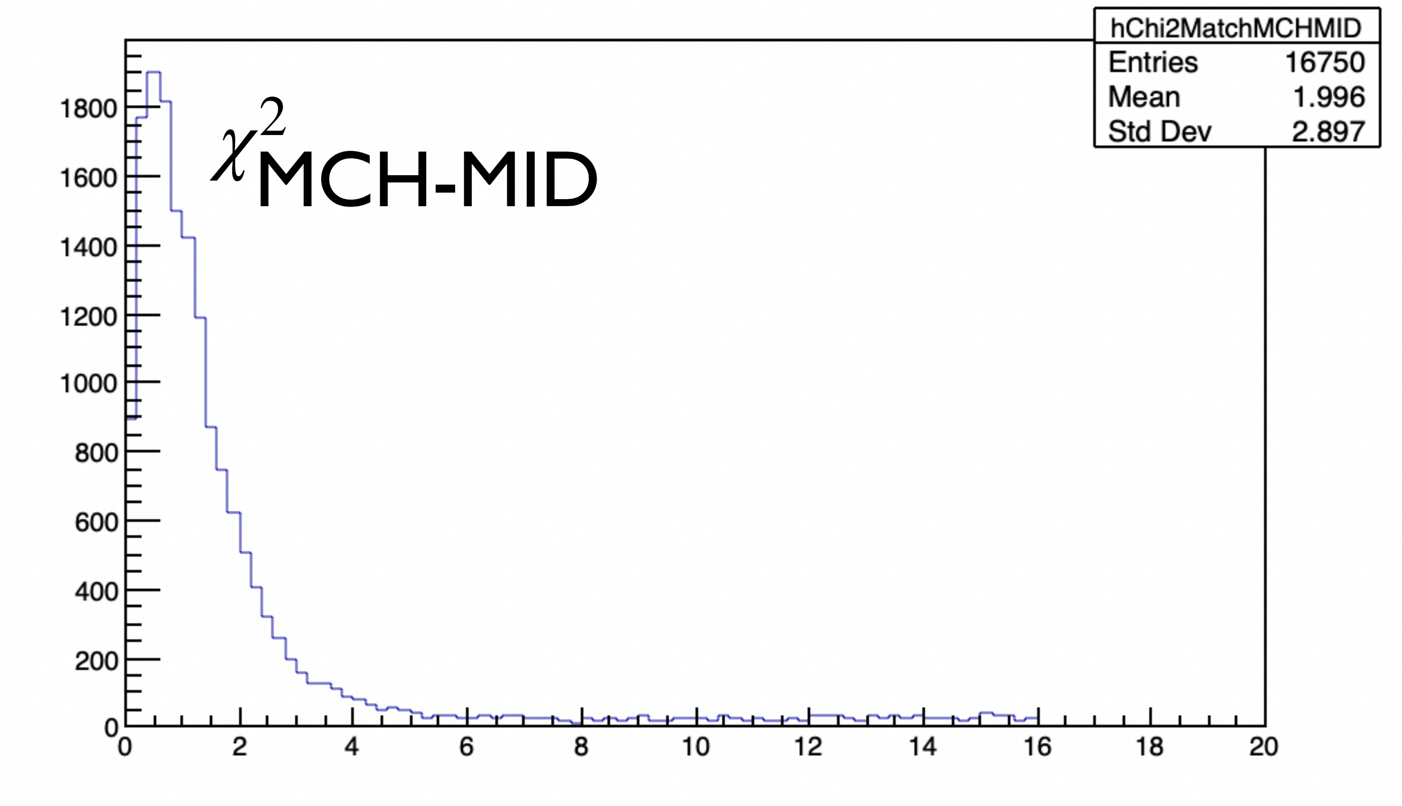
After the selection

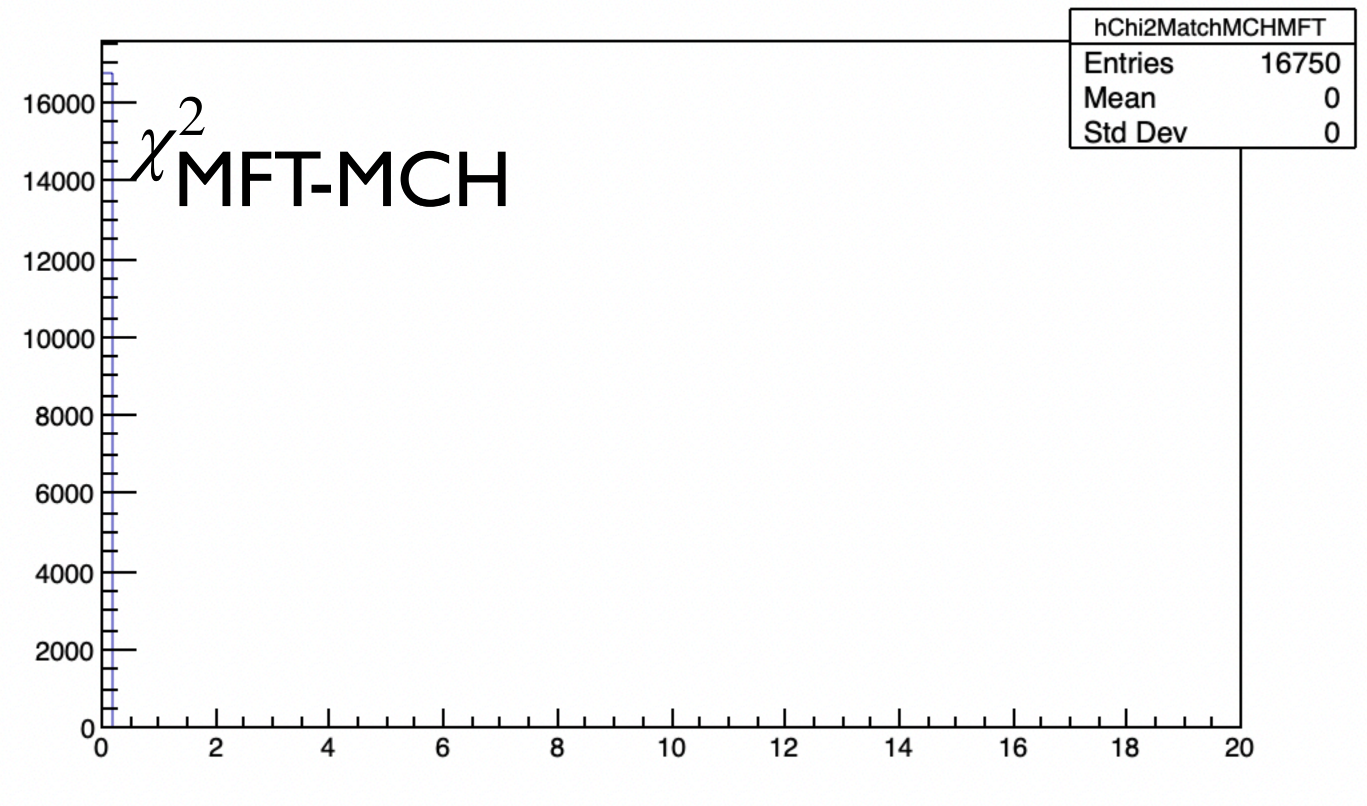
- 2 MCH-MID tracks / 1 track MCH-MID + 1 MCH track





- 2 MFT-MCH-MID tracks: $\chi^2_{\text{MFT-MCH}}$ is 0 everywhere



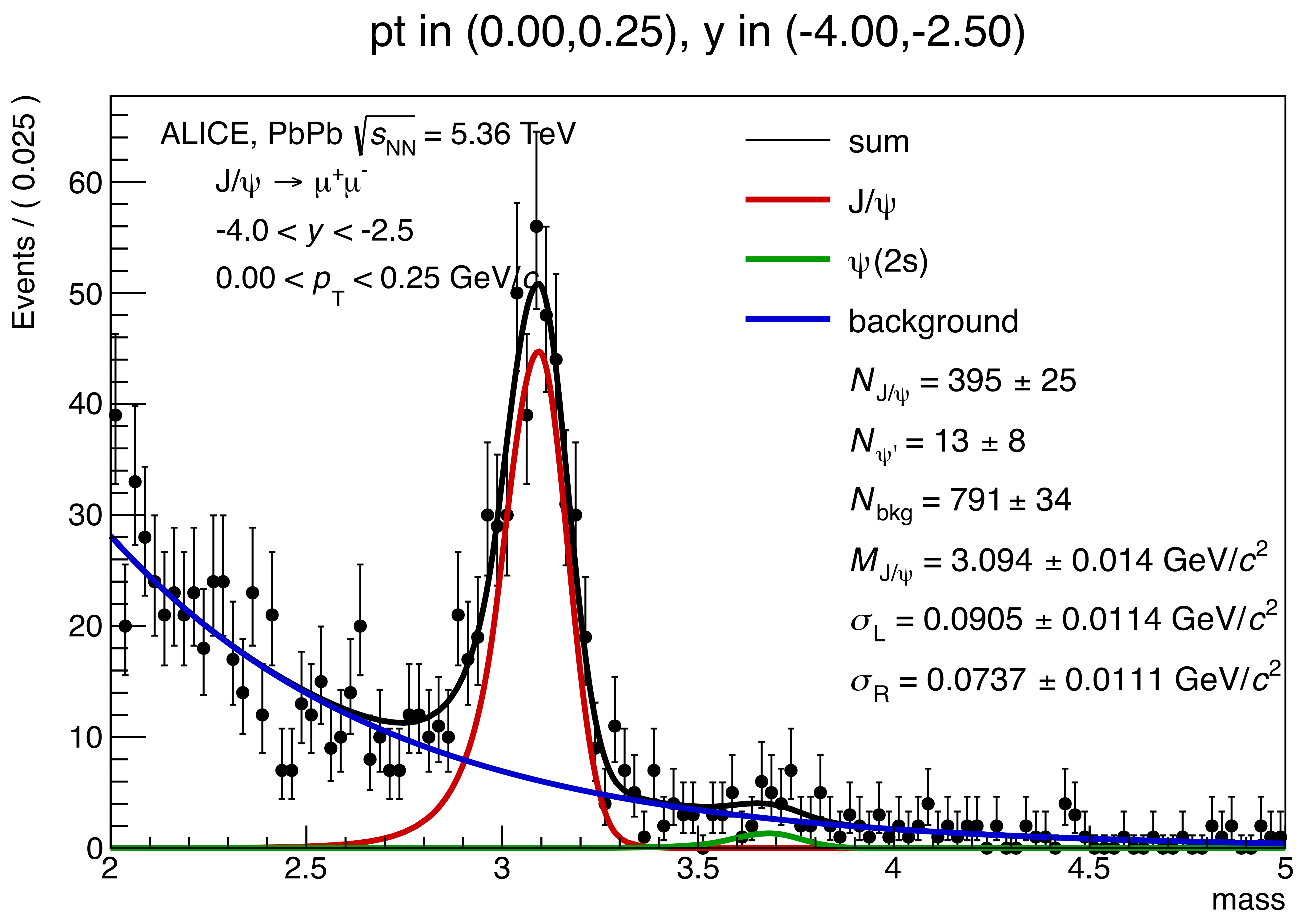


→ **the idea of using a χ^2 fit is not possible ?**

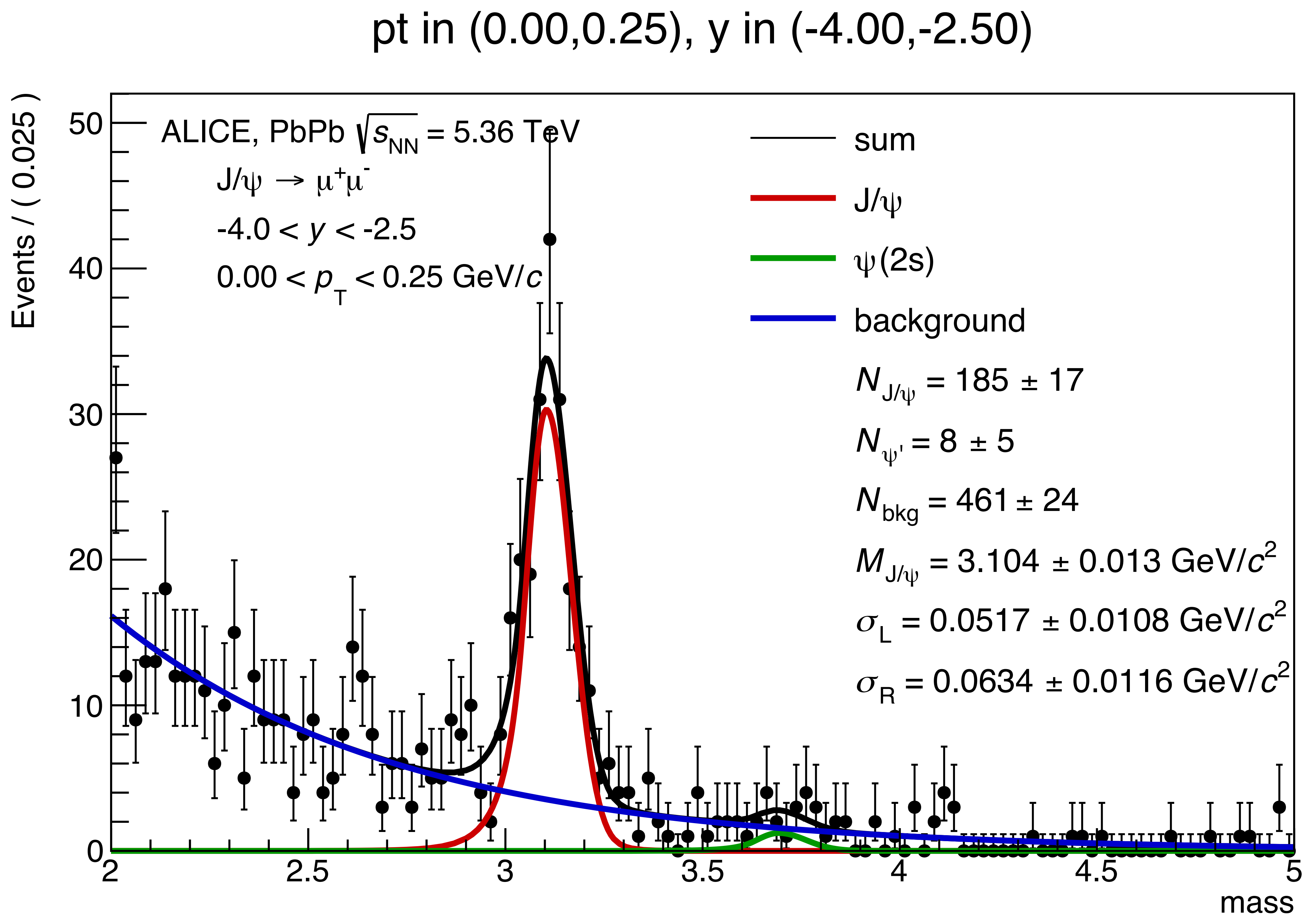
Invariant mass fits

- MCH+MID acceptance
  - $-4.0 < \eta < -2.5$
- MFT acceptance
  - $-3.6 < \eta < -2.45$

without MFT tracks



both tracks with MFT



Invariant mass fits

- MCH+MID acceptance
  - $-4.0 < \eta < -2.5$
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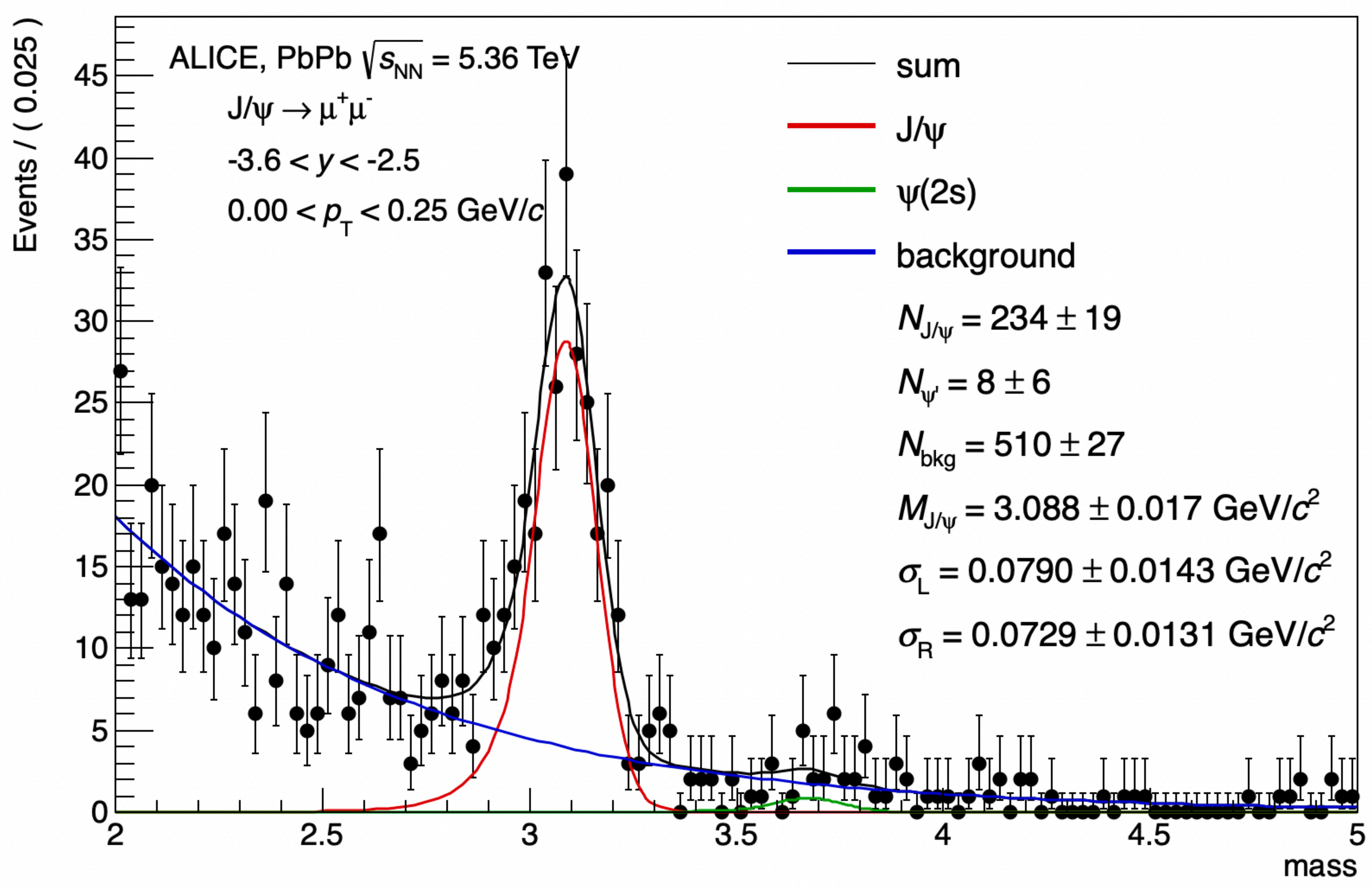
  - $-3.6 < \eta < -2.45$

with the acceptance reduced to $-3.6 < \eta < -2.5$

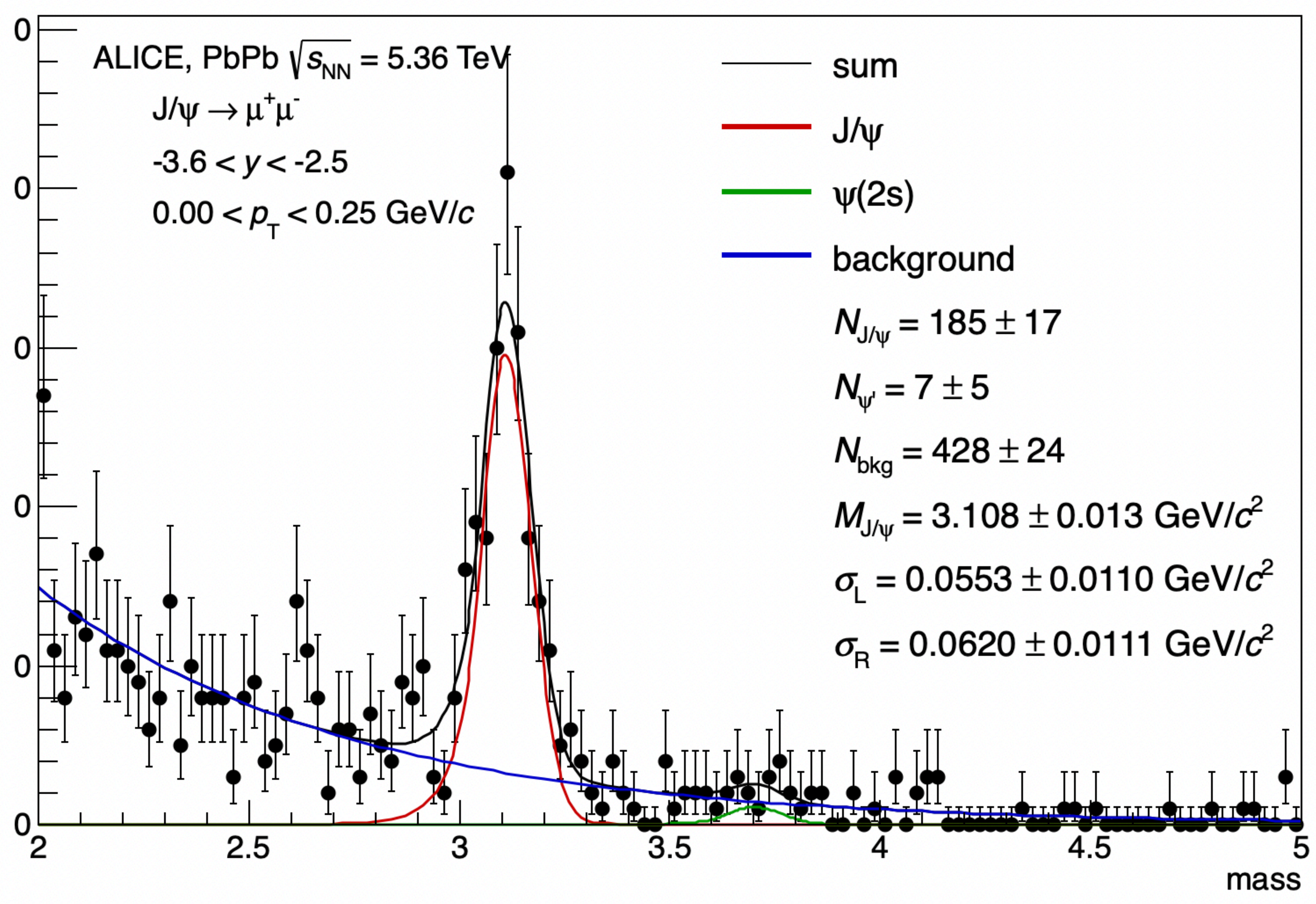
without MFT tracks

pt in (0.00,0.25), y in (-3.60,-2.50)



both tracks with MFT

pt in (0.00,0.25), y in (-3.60,-2.50)



A different approach

- retrieve the corresponding MCH track which was used in the matching and discard the global track if the MCH track is outside the MFT acceptance

- MCH+MID acceptance
  - $-4.0 < \eta < -2.5$
- MFT acceptance
  - $-3.6 < \eta < -2.45$

Further modification of FwdTracks in UDTables.h

- we had the following:

```
// Muon track kinematics
DECLARE_SOA_TABLE(UDFwdTracks, "AOD", "UDFWDTRACK",
                  o2::soa::Index<>,
                  udfwdtrack::UDCollisionId,
                  udfwdtrack::Px,
                  udfwdtrack::Py,
                  udfwdtrack::Pz,
                  udfwdtrack::Sign,
                  udfwdtrack::GlobalBC,
                  udfwdtrack::TrackTime,
                  udfwdtrack::TrackTimeRes);

// Muon track quality details
DECLARE_SOA_TABLE(UDFwdTracksExtra, "AOD", "UDFWDTRACKEXTRA",
                  fwdtrack::NClusters,
                  fwdtrack::PDca,
                  fwdtrack::RAtAbsorberEnd,
                  fwdtrack::Chi2,
                  fwdtrack::Chi2MatchMCHMID,
                  fwdtrack::Chi2MatchMCHMFT,
                  fwdtrack::MCHBitMap,
                  fwdtrack::MIDBitMap,
                  fwdtrack::MIDBoards);
```

- what was added:

- trackType
- MCHTrackID
- MFTTrackID

```
// Details about FWD indices
DECLARE_SOA_TABLE(UDFwdIndices, "AOD", "UDFWDINDEX",
                  o2::soa::Index<>,
                  udfwdmatchindex::UDCollisionId,
                  udfwdmatchindex::GlobalIndex,
                  udfwdmatchindex::MCHTrackId,
                  udfwdmatchindex::MFTTrackId);
```

```
// Version with global tracks
DECLARE_SOA_TABLE_VERSIONED(UDFwdTracksExtra_001, "AOD", "UDFWDTRACKEXTRA", 1,
                  fwdtrack::TrackType,
                  fwdtrack::NClusters,
                  fwdtrack::PDca,
                  fwdtrack::RAtAbsorberEnd,
                  fwdtrack::Chi2,
                  fwdtrack::Chi2MatchMCHMID,
                  fwdtrack::Chi2MatchMCHMFT,
                  fwdtrack::MCHBitMap,
                  fwdtrack::MIDBitMap,
                  fwdtrack::MIDBoards);
```

Outlook

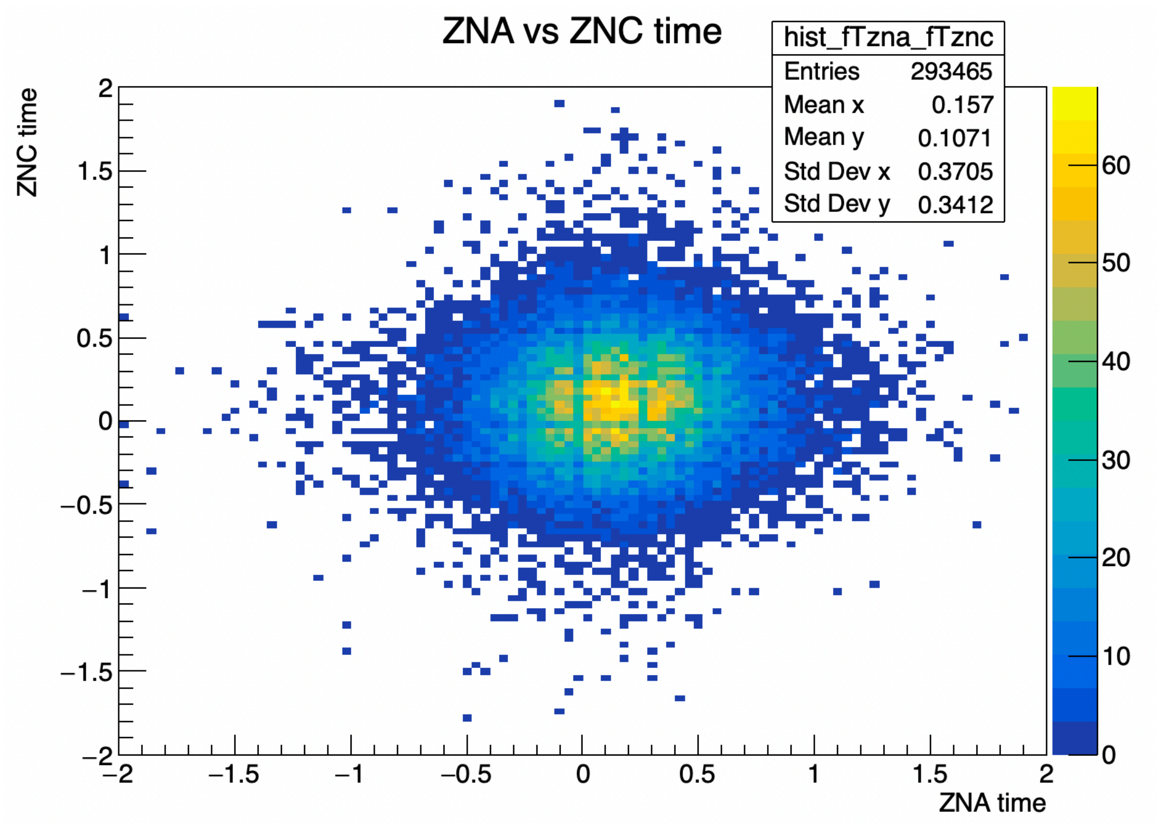
Next steps

- acceptance and efficiency in p_T bins
  - veto efficiency, acceptances, unfolding
- calculation of feed-down and incoherent contamination
- further studies with MFT tracks
  - still many aspects to be understood (matching, χ^2 distributions, IDs)
- inclusion of MFT tracks looks promising for forward UPC analyses
  - better mass resolution when MFT tracks are included
- UPCCandidateProducer to be modified with an option to include the 1 MFT track

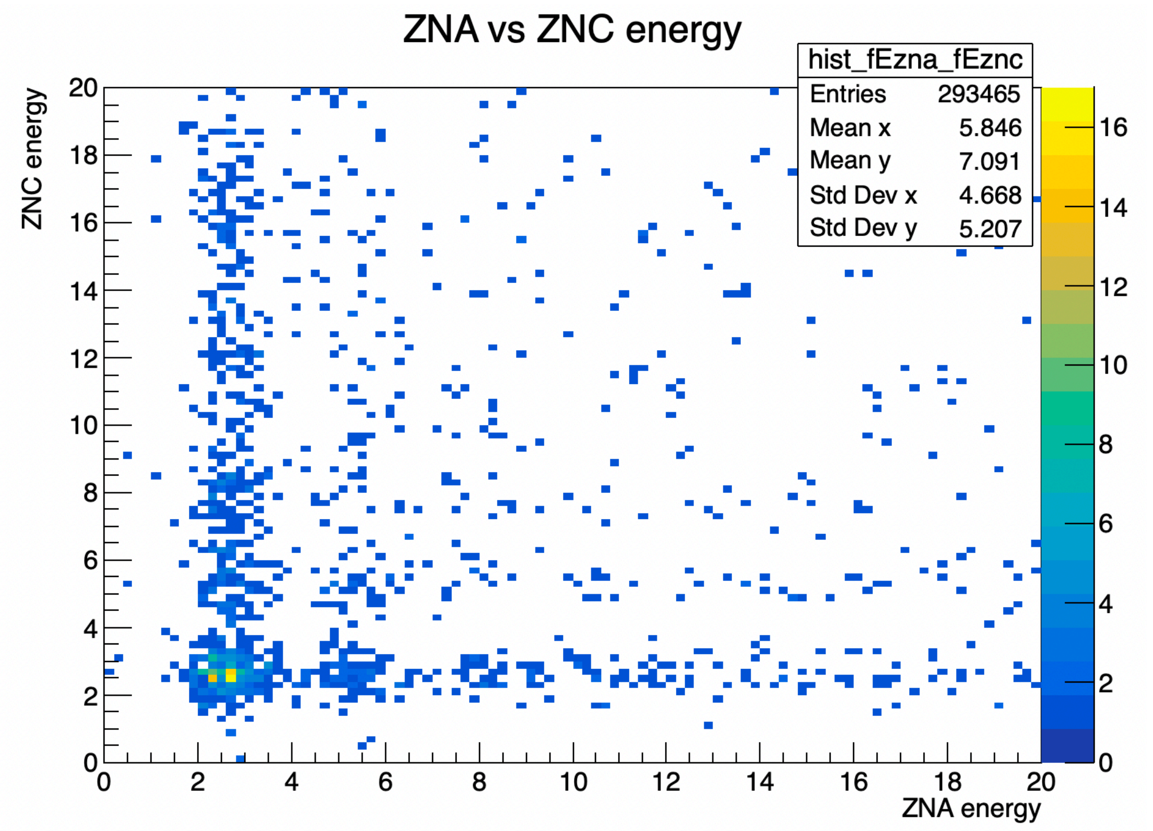
ALICE

Back-up

ZN classes



- total number of events in ZN classes
- ZNA and ZNC time information will be used to separate the events into the 4 classes: 0n0n, 0nXn, Xn0n, XnXn



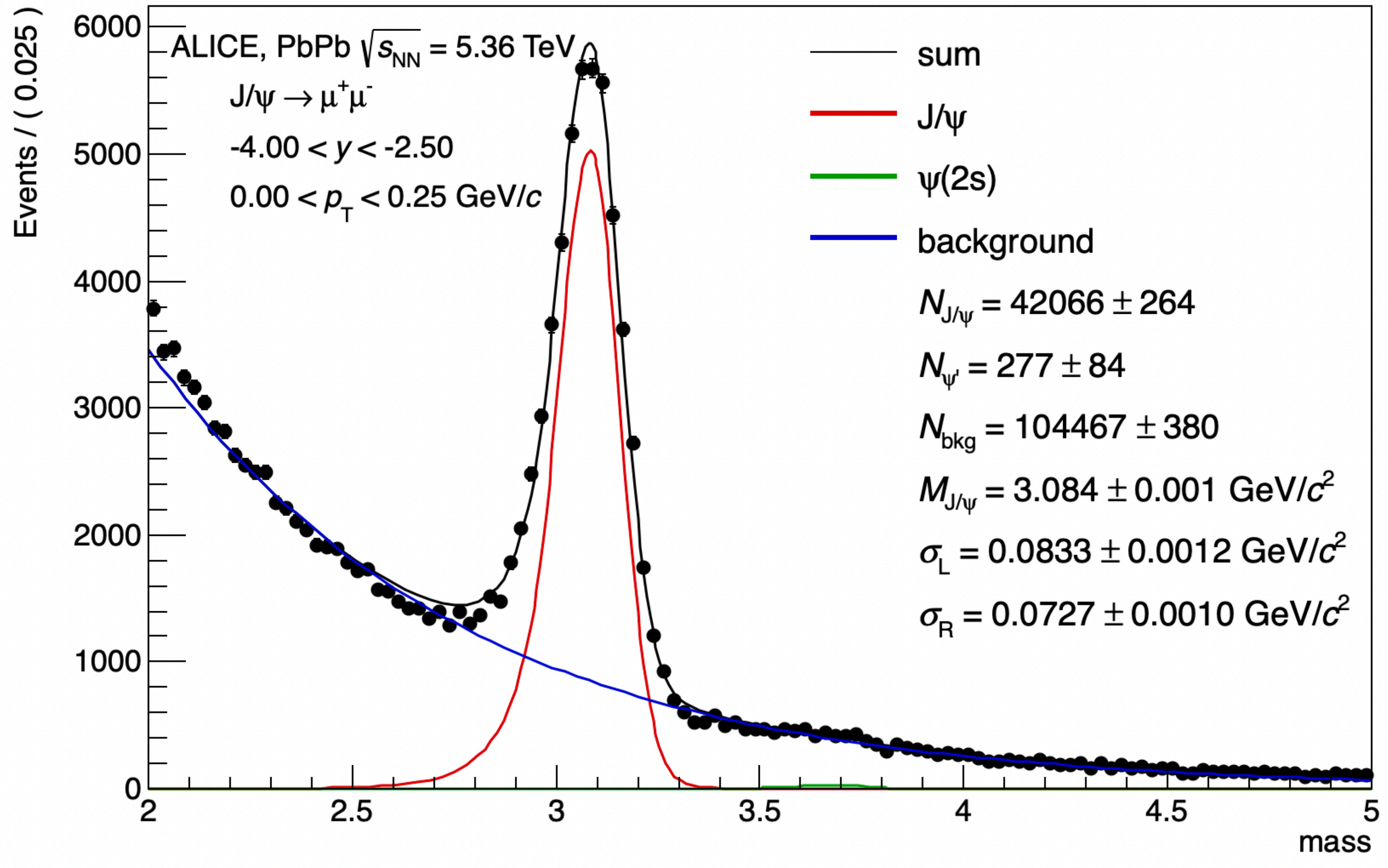
- approx. number of J/ψ candidates in each ZN class:
  - 44k in 0n0n
  - 6k in Xn0n
  - 9k in 0nXn
  - 5k in XnXn

More details on the mass fit

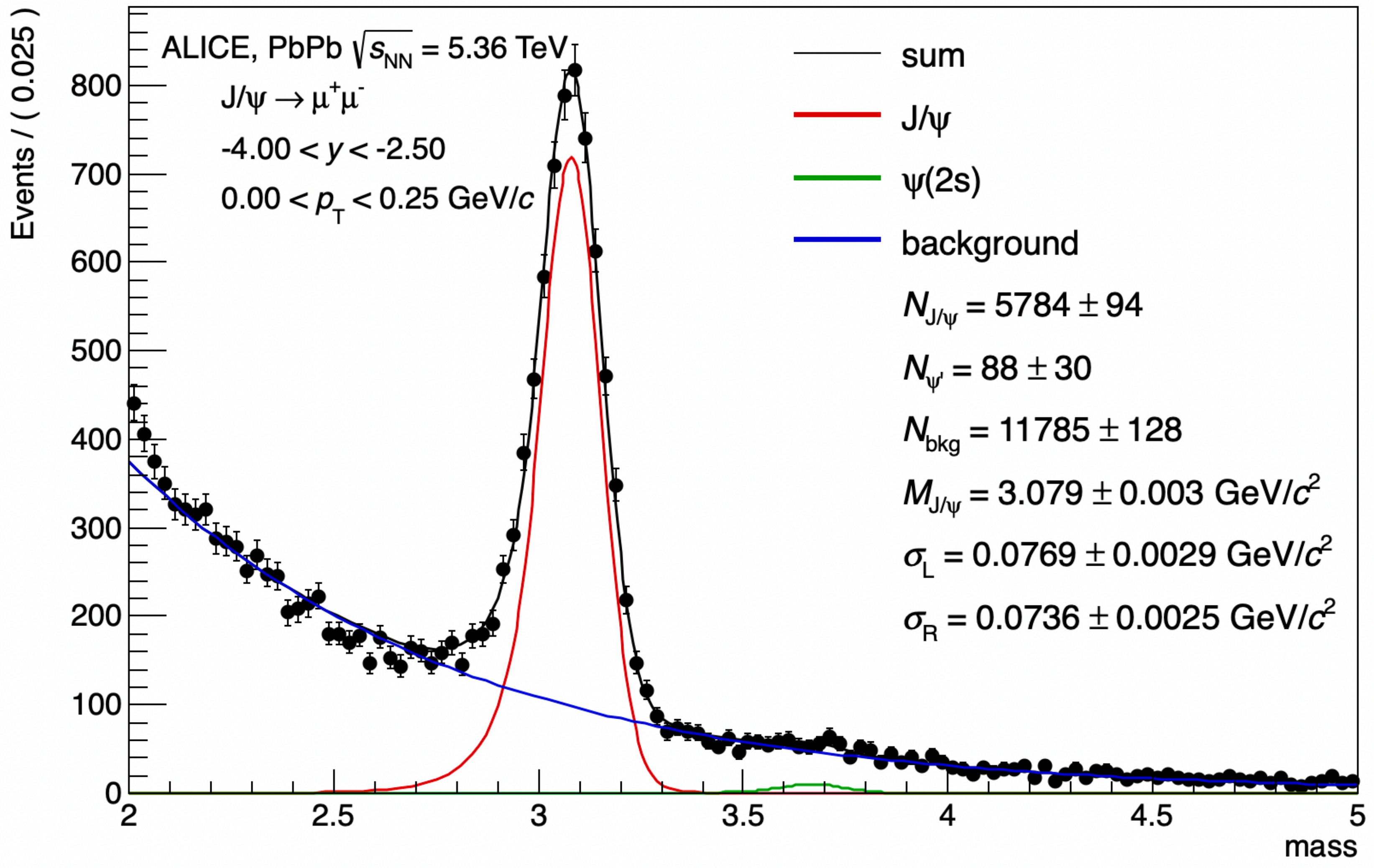
- fitting function for the J/ψ peak: double-sided crystal ball
  - tail parameters n_L, n_R fixed to 10
  - tail parameters $\alpha_L = 1.2,\ \alpha_R = 2.5$ fixed
  - $\sigma_L = 0.08,\ \sigma_R = 0.07$
- fitting function for the ψ' peak: double-sided crystal ball
- background fitted with an exponential function
  - parameter λ was left free

Mass fits in all ZN classes

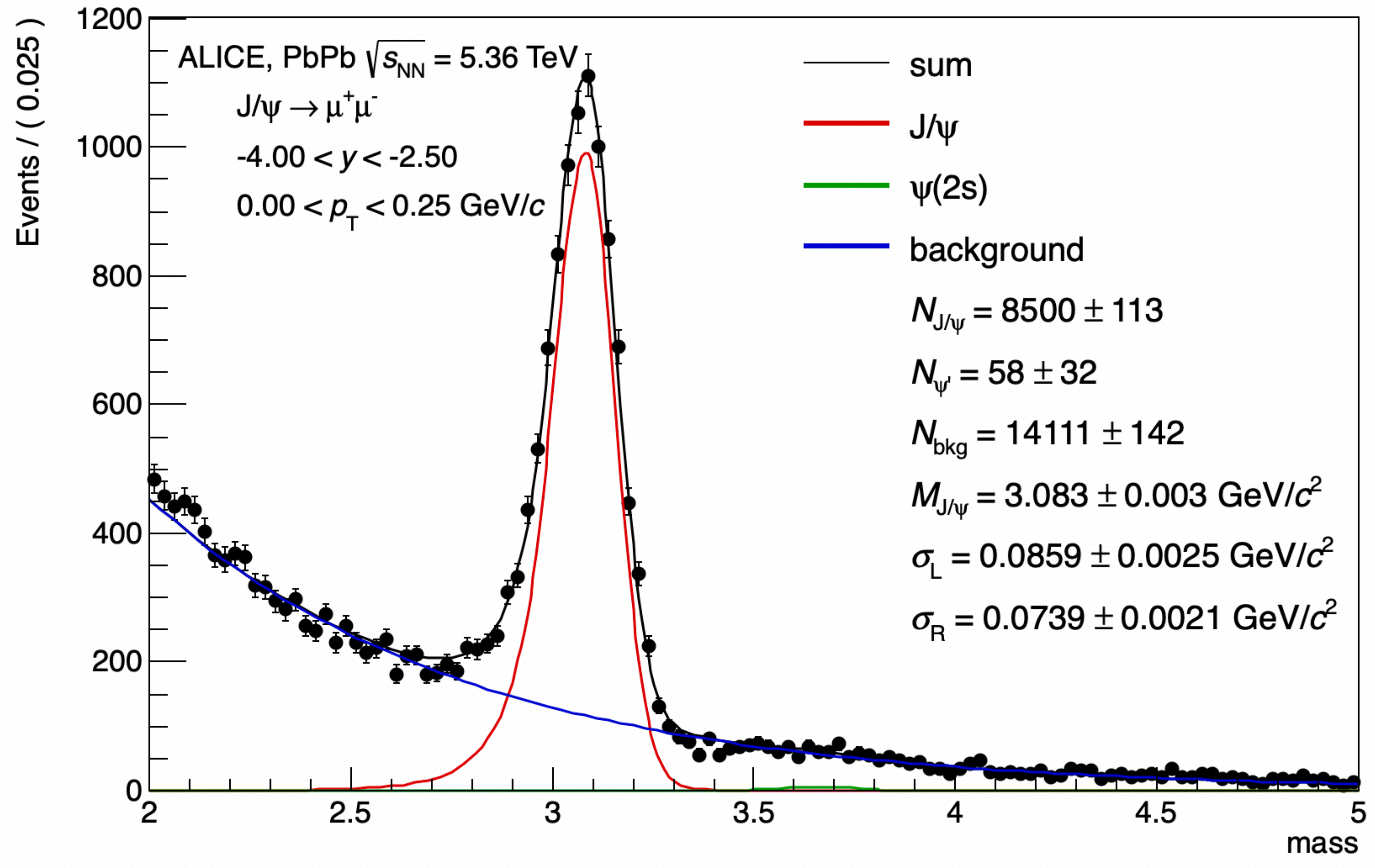
0n0n



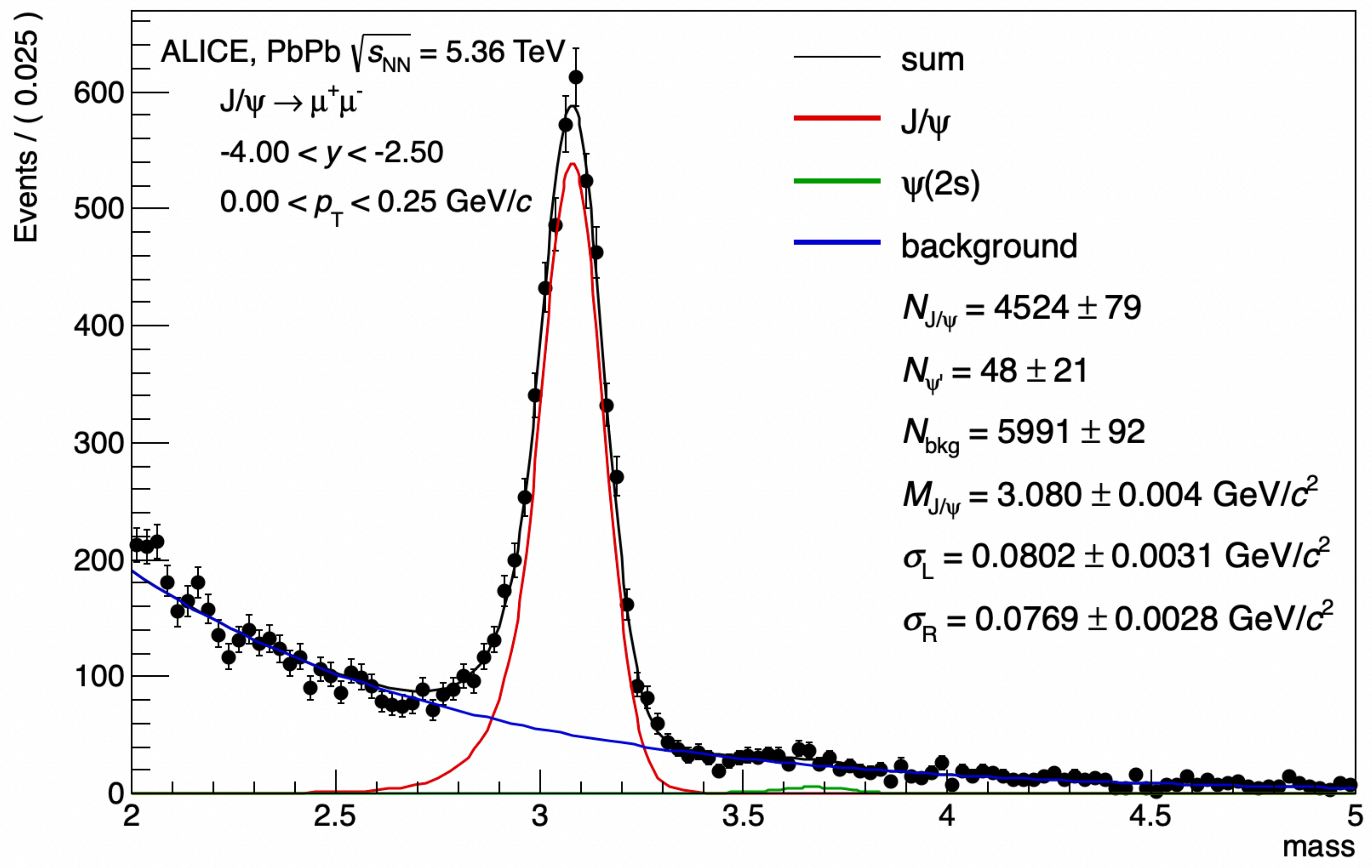
Xn0n



0nXn



XnXn



ALICE