# $\pi^0$ / $\eta$ conversion analysis in CBM

## status and next steps...

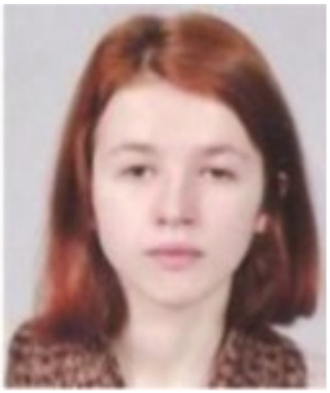
# *Two new PHD students in Wuppertal*

**Ievgenii Kres**

finished PHD in Jan. 2019
left BuW in Feb 2020

worked on $\pi^0$ / η via
double conversion in CBM

last year: HADES Ag+Ag data



**Tetiana Povar**
from Ukraine
starting - today

main focus: **HADES**
continue $\pi^0$ / η conversion
analysis in HADES
→ include simulation

**Pavish Subramani**
from India
starting ~Oct. 2020

main focus: **CBM**
continue work on photon
conversion analysis

# *Short recapitulation: status photon conversion analysis I. Kress*

- (own) UrQMD simulations Au+Au @ 8 AGeV
  no PLUTO cocktail added
- detector setup ~ 2017: STS v16g, MVD v17a_tr, RICH V17a_1e
  field map v12b
  **250 µm gold target**
  70% magnetic field (0.7 Tm)
- most of his work based on $15 \times 10^6$ simulated events (central)
- using standard RICH reconstruction for lepton ID

# *gamma reconstruction via conversion*

- **γ-reconstruction from**
  - pair of primary $e^+$ / $e^-$ tracks ( $\chi^2_{trackfit}$ <5 )
  - pair of secondary $e^+$ / $e^-$ tracks ($\chi^2_{trackfit}$ >5 )

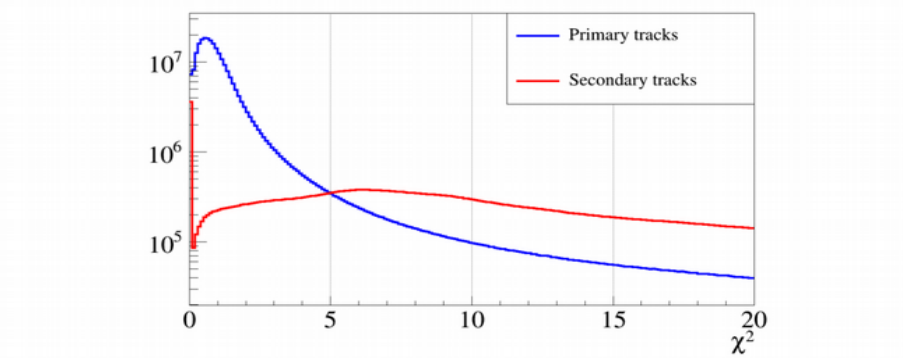


Figure 5.3: Distributions of normalized $\chi^2$ from the standard fitter, fitting all tracks to the primary vertex.

- **secondary vertex reconstruction using KFparticle (as module, not "black box")**

- **Lepton identification using RICH, 3 different cases:**
  1) all 4 leptons within RICH acceptance + "good" Cherenkov rings matched
  2) 0/1 lepton of each $\gamma \rightarrow e^+e^-$ pair allowed outside RICH acceptance (→ no ID)
  3) 0/1/2 leptons allowed outside RICH acceptance

  **2-photon reconstruction efficiency:**

  case 3 ≡ **100%,** case 2 : **55%,** case 1 : **10%**

- **additionl cuts on:**

  $\Theta^{e+e-} < 1°$ ( <2°)

  $M^{e+e-} < 10$ MeV/c² (< 20 MeV/c²)

  only for η: $\Theta^{\gamma\gamma} < 40°$

- including external conversion increased $\pi^0$ yield 4x

# *origin of conversion*

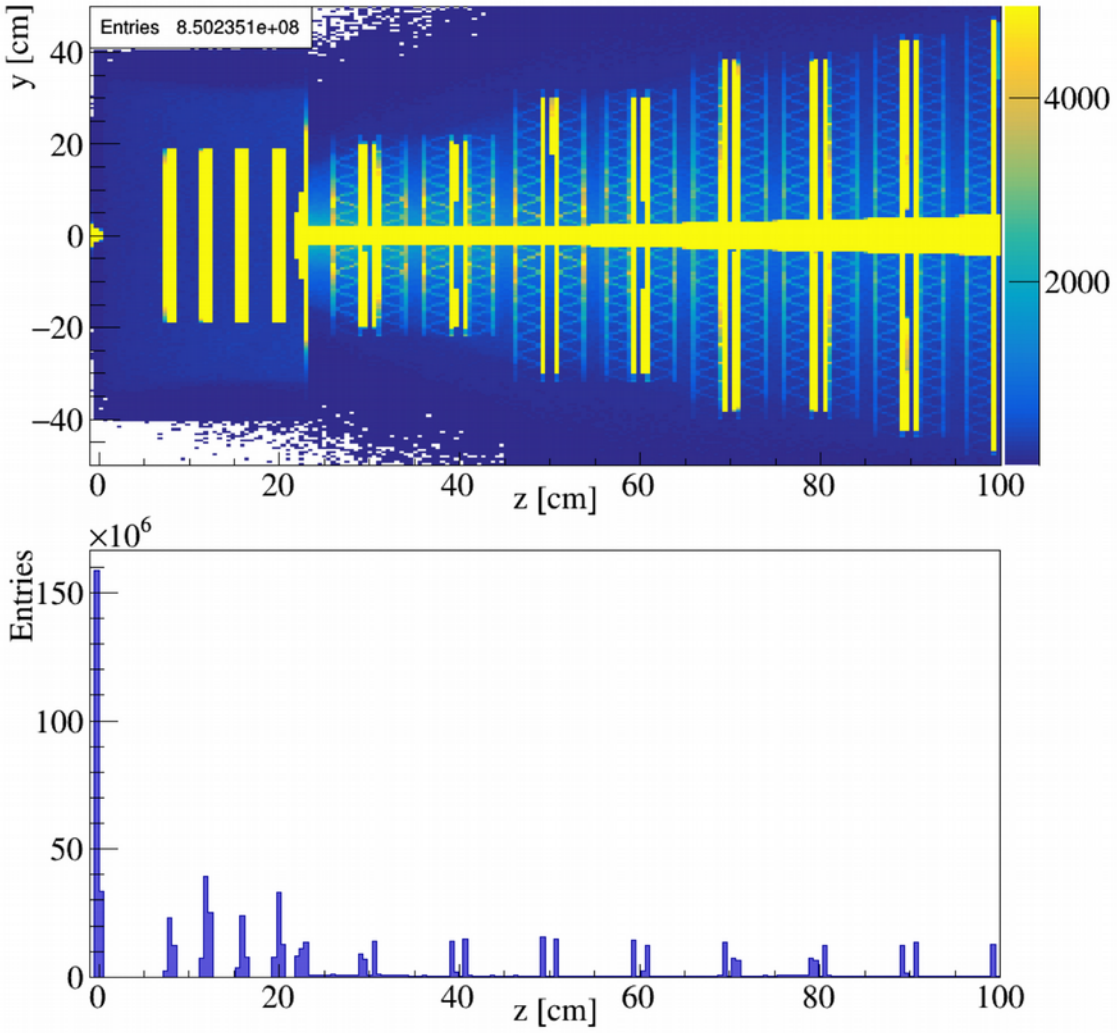



Figure 5.1: Start vertices of leptons coming from conversion of photons (taken from MCTracks array). Vertical yellow lines on top picture and blue lines on bottom picture display target position ($0-1$ cm), four MVD stations ($z = 8-20$ cm), and eight STS stations ($z = 30-100$ cm). Several additional sources of conversion are also recognizable on pictures: beam pipe inside the STS detector, carbon ladder holding structures of the STS detector, and exit window from the vacuum box of the MVD detector ($\sim 23$ cm).

conversion probability for a single photon:

28% inside target (250 µm Au)
29% inside MVD
43% in STS+beampipe

And this was in 2017 setup,
certainly less dead material (unrealistic)
than now (!)

# *pi0 reconstruction (15mio central events) for the 3 RICH el.ID cases (full / partial / no)*

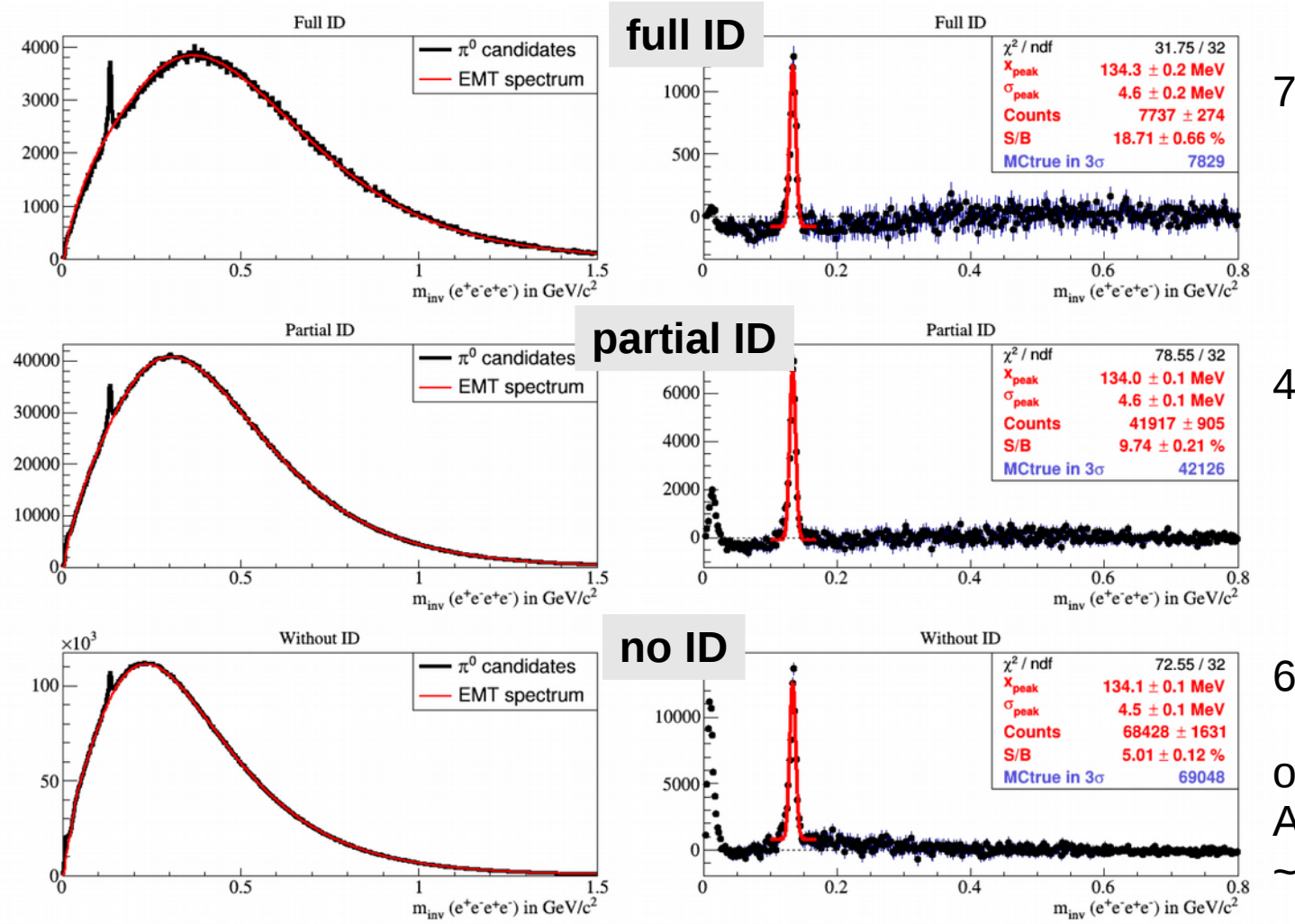



Figure 6.6: Resulting invariant mass spectra of $\pi^0$ candidates (left) and background-subtracted spectra (right) reconstructed by applying double conversion method with cuts on invariant mass of photons $m_{inv}(e^+e^-) < 10$ MeV/c$^2$ and opening angle of photons $\Theta_{e^+e^-} < 1°$ using different identification approaches: full (upper row), partial (middle row), without (bottom row).

7800 $\pi^0$

42000 $\pi^0$

69000 $\pi^0$

out of 15mio central events
Au+Au 8 AGeV
~200 $\pi^0$ (10 η) per event

**eff x acc. ~ $10^{-5}$ !!!**

2x more
using less strict cuts

# 2-dim. efficiency for $\pi^0$

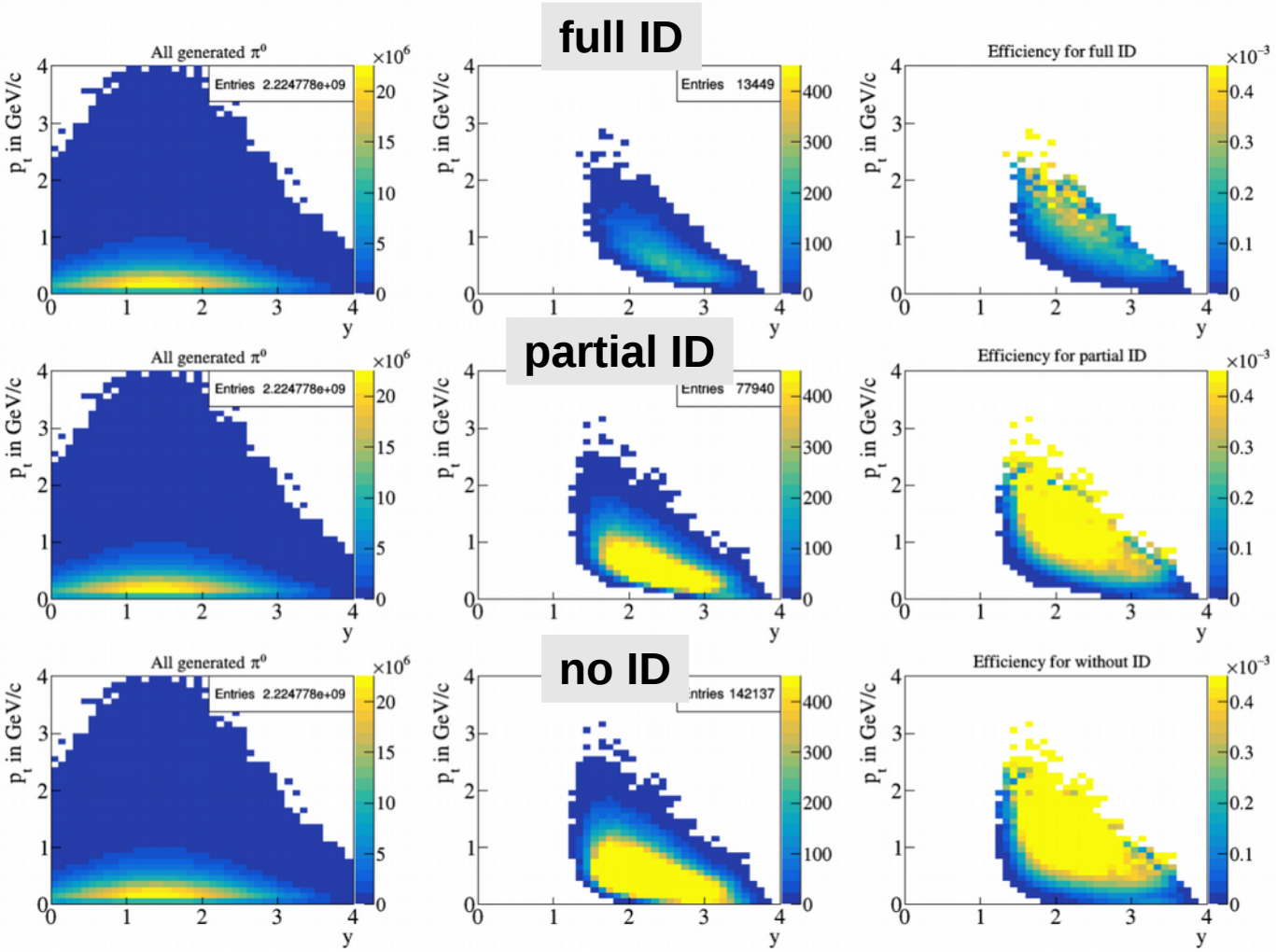



Figure 6.5: Reconstruction efficiency of $\pi^0$ as function of transverse momentum $p_t$ and rapidity $y$ for all 3 discussed analysis approaches: full (upper row), partial (middle row), without (bottom row).

pi$^0$ efficiency
inside acceptance
~ $10^{-3}$

single photon conversion prob:
in target : 2.9%
in MVD +STS1-4: 2.7%

better phase space coverage
for less strict electron-ID

rapidity range: 3.8 > y > 1.5
due to acceptance: 2.5° < θ < 25°

# *reconstruction of η - based on sample of 15 mio events*

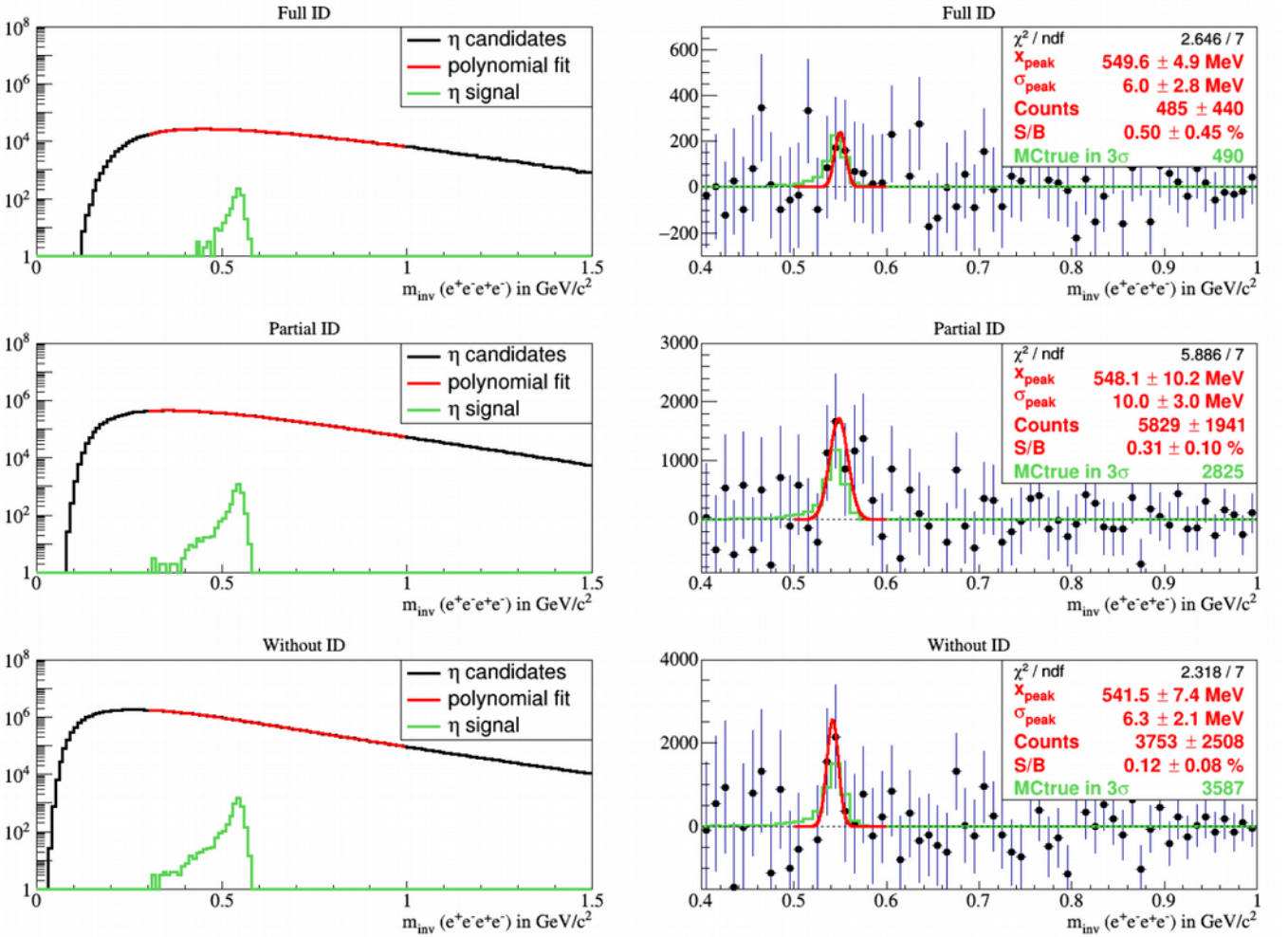



Figure 7.3: Reconstructed (left column) and background-subtracted (right column) invariant mass spectra of η meson from the $\eta \rightarrow \gamma + \gamma/\gamma^*$ decay channel using different lepton identification approaches: full (upper row), partial (middle row), without (bottom row). Green line at all graphs shows correctly reconstructed η signal contained in spectra.

only 500 – 3500 reconstr.
eta out of 15 mio central events

S/B ratio 0.1 – 0.3 %

# *how to get larger statistics*

- **at time of analysis (2018), 15 mio sample already 30 Tb of disk space**
  - despite no TRD, TOF, ECAL, PSD included !

  only 0.3 Tb of these contain events with eta undergoing conversion

- **larger statistics only possible using tricks (at that time):**
  - discard all events without eta conversion, adjust Event-Mixing background accordingly
  - or: only add histograms, discard all simulation files again during simulation

# *100 mio event sample for eta conversion analysis*

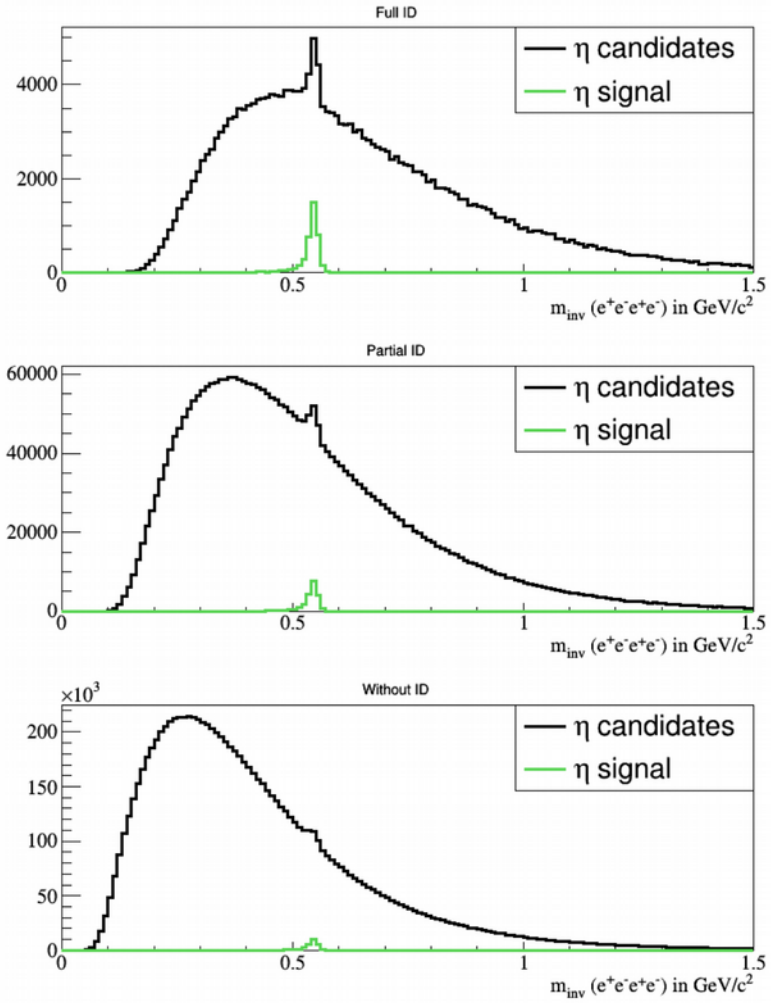



Figure 7.5: Reconstructed invariant mass spectrum of η from "signal-enriched" simulated sample using three analysis approaches: full (upper), partial (middle), without (bottom).

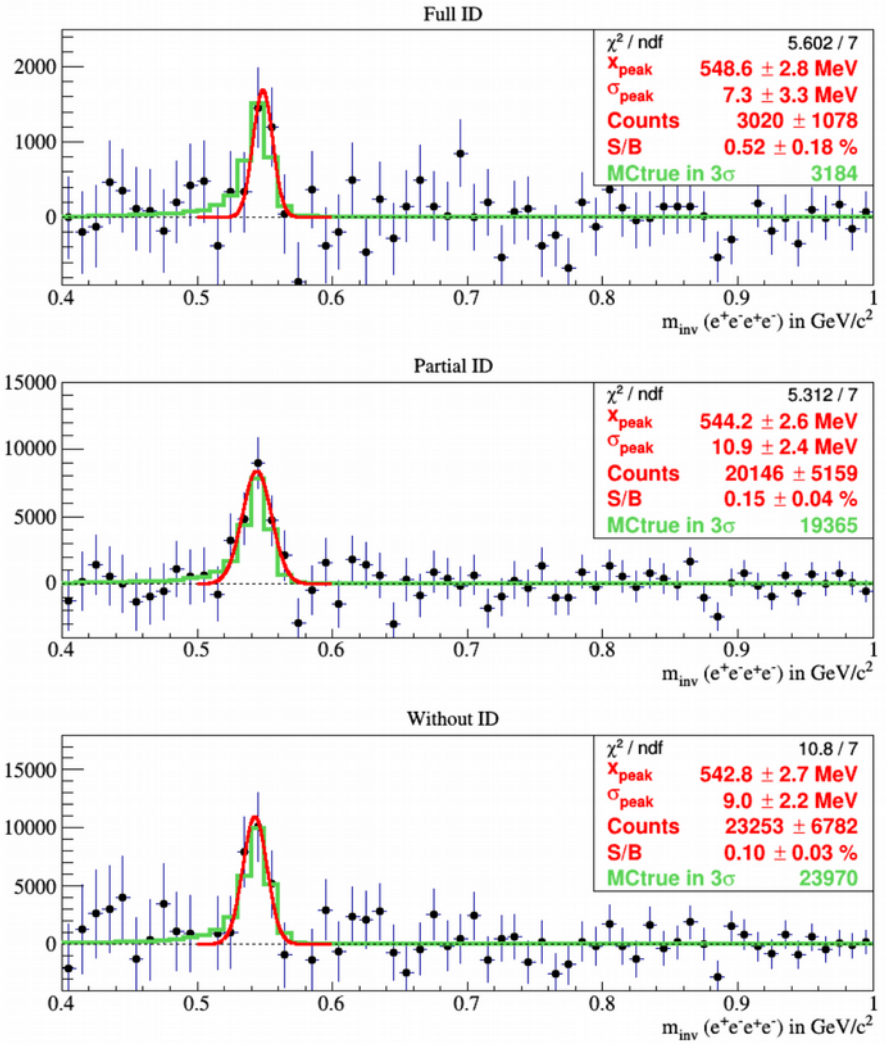



Figure 7.6: Reconstruction results for the $\eta \to \gamma + \gamma/\gamma*$ decay channel using combined invariant mass spectra corresponding to 100 million central Au+Au events. Three cases of particle identification are listed: full (upper), partial (middle), without (bottom).

100 mio central events ~~ 30h data taking at 100 kHz !

# *how to continue...*

- **The work shown here on conversion analysis is status 2018**
  - outdated detector geometry
  - probably underestimated material budget (in particular STS, MVD)
  - unrealistic beam pipe

- progress in CBMROOT software
  - **sparsification of event storage**
  - **GEANT3 → GEANT4**

- Common Monte Carlo production (large statistics ?)
  - not only UrQMD, also other event generators
  - η (into photon decay) added from PLUTO

- Analysis so far only based on RICH for el ID
  - only using standard Hough-transfrom ringfinding approach
  - not using TRD

# *next steps and some ideas*

- **Get existing conversion analysis running again ...**
  - with up to date CBMROOT and geometry
  - using MC common production samples

- **Based on the available MC common production:**
  - check double-conversion reconstruction at lower energies (p=3.3 / 4.5 / 8 / 12 GeV/c )
  - influence of reduced magnetic field on reconstruction efficiency ?
  - double conversion reconstruction using standard 25 μm target possible ?
    (might be more than compensated by additional material budget...)
  - how to properly normalize to η-enriched MC samples ? η reconstruction possible with 10 mio ?
  - influence GEANT3 / GEANT4

- **Optimize electron-ID in the RICH…**
  - investigate "backtracking" approach for el-ID.
    Use projected track to check hits in RICH, maybe pattern-matching instead of Hough transform
  - make digitizer more realistic (cross talk ! experience from HADES), check how el-ID performs
  - first look into timing / time cuts ?
  - maybe include TRD into electron identification ?

- **Maybe**: Combined analysis RICH+ECAL, 1γ via conversion, 1γ direct
- **Maybe:** look into proton-induced reactions : p+N
  - $\pi^0$ / η produced in pp / pn scattering
  - maybe reconstruction of rare eta decays ? $\eta \rightarrow e^+ e^-$ ???
    (Still, HADES has one of the best limits measured in p+p and p+Nb )

# *further ideas ?*

- **further ideas, suggestions and advice always welcome !**

- some support might be needed since right now no experienced CBM-ROOT user in our group.