Dimuon measurement at CBM experiment

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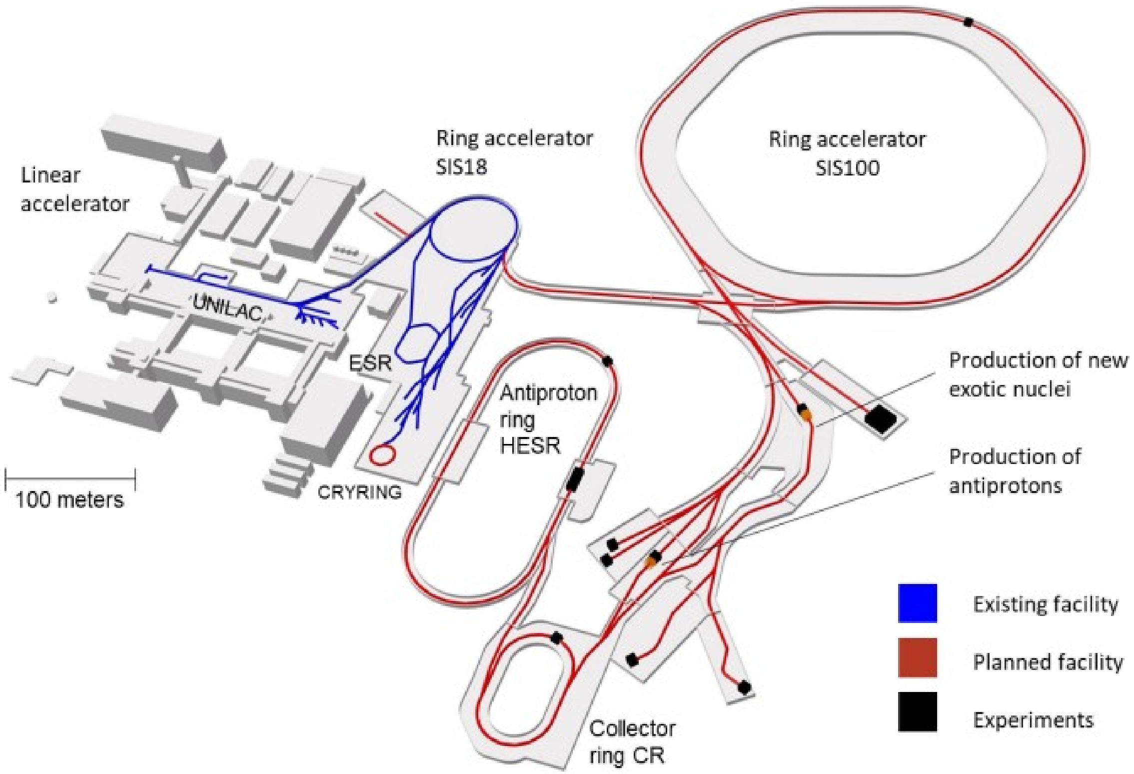
Outline

- **Introduction**
  - Facility for Antiproton and Ion Research (FAIR)
  - Compressed Baryonic Matter (CBM) experiment
    - Muon Chamber (MuCh) detector
- **Dimuon measurement at CBM**
- **Feasibility study of dimuon detection coming from**
  - Freeze-out cocktail
  - Charmonium (J/ψ)
- **Summary & outlook**

Layout of the Facility for Antiproton and Ion Research (FAIR)



Unique features:

- Intense and high energy heavy-ion beams
- Flexibility and parallel operation
- Storage rings and beam cooling: Beam quality

Experimental pillars:

- APPA (Atomic, Plasma Physics and Applications)
- PANDA (antiProton ANnihilation at DArmstadt)
- **CBM (Compressed Baryonic Matter)**
- NuSTAR (Nuclear Structure, Astrophysics and Reactions)

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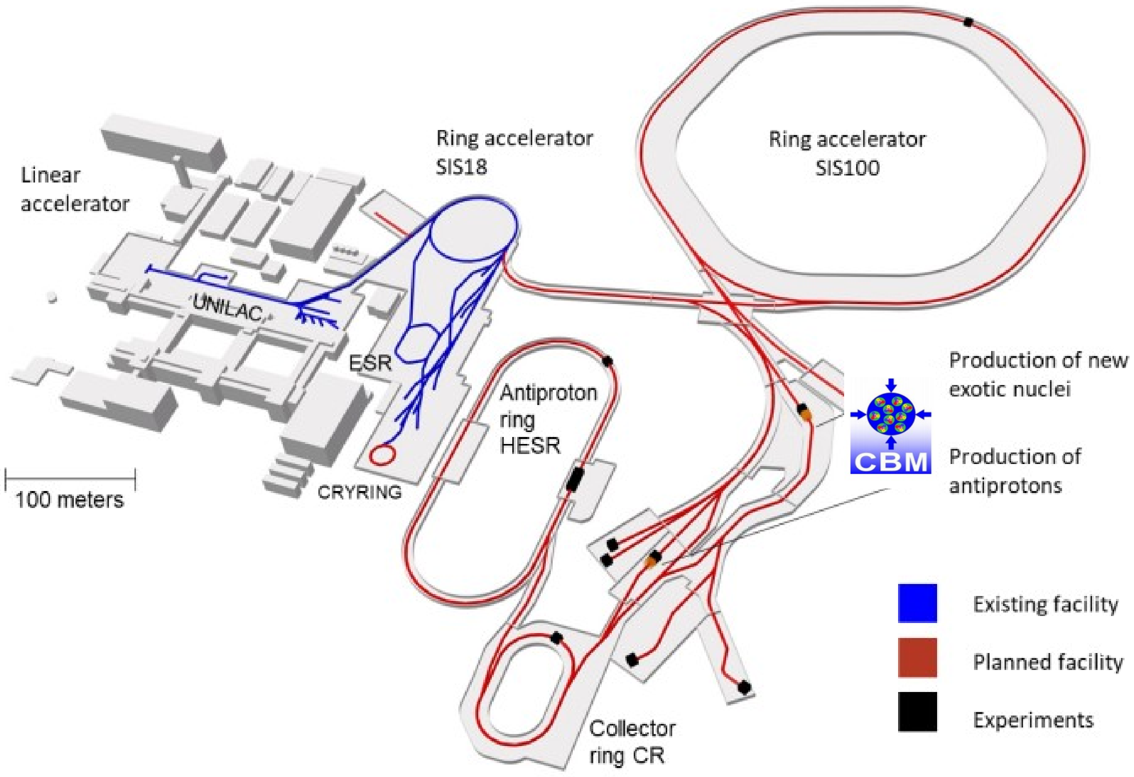

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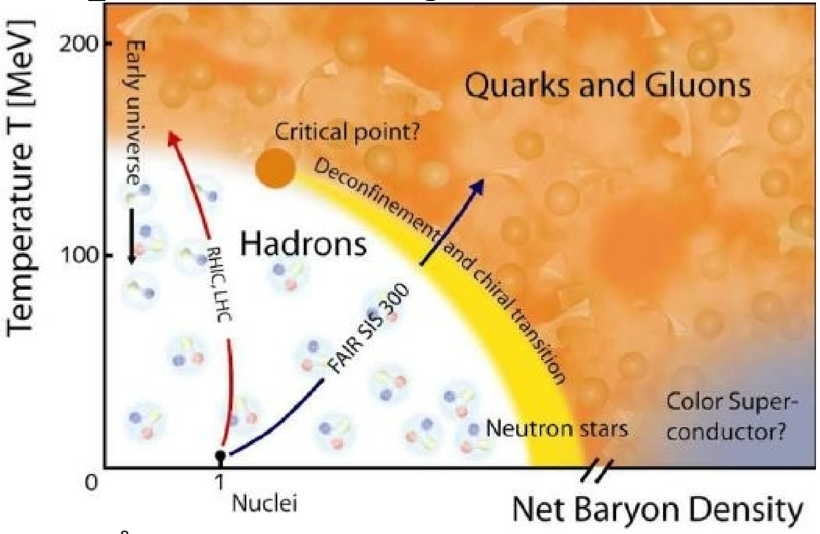
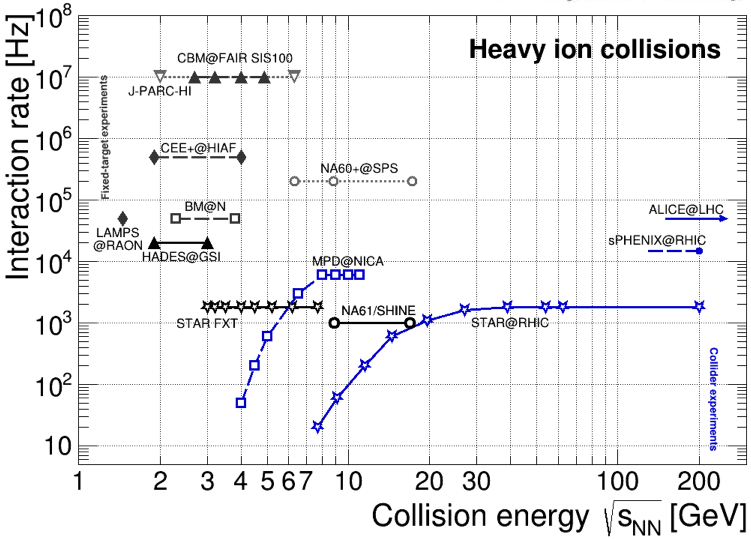
Compressed Baryonic Matter (CBM) experiment





Physics Goals :

- QCD equation of states (EOS)
- Exotic phases and order of transitions
- Location of critical point
- Chiral phase transition
- Charm production and propagation close to and below the kinematic threshold
- ...

Challenges :

- Production cross sections are dramatically small
- Requires accelerators with unprecedentedly high beam intensities
- Detectors with good resolution and high rate capabilities
- On-line event selection
- ...

Reference : T. Galatyuk, Nucl. Phys. A982 (2019) 163

Di-muon measurement at CBM-FAIR (SIS100): Uniqueness and Challenges

Uniqueness:

- No di-muon data in heavy-ion sector between 2 – 40 A GeV
- No charm data below top SPS energies (158 A GeV)
- High precision measurements

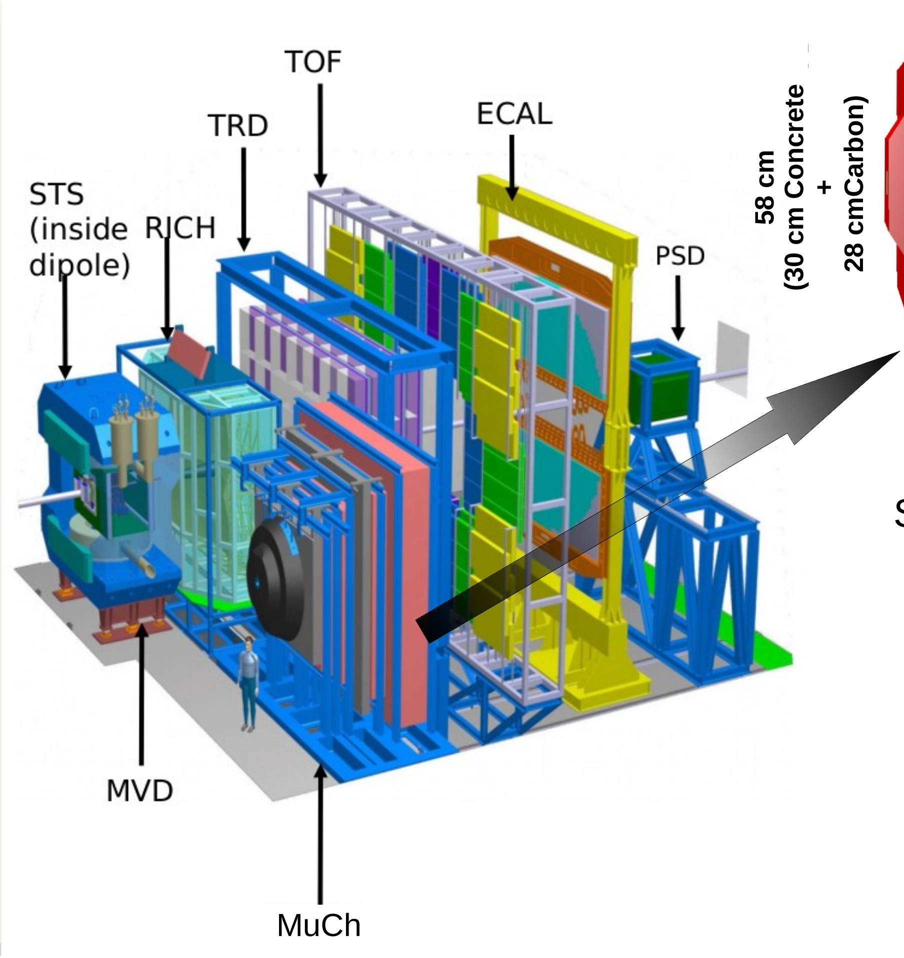
Opportunities:

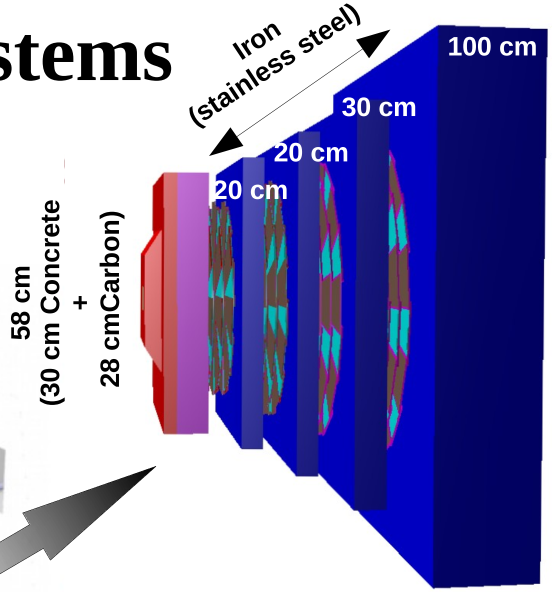
- Precision measurements of di-muon production in LMR and IMR
- Signal of first order phase transition (caloric curve)
- Detailed measurement of charm production and propagation in cold matter with beams of proton and light nuclei
- Possibility to investigate sub-threshold production of charm with heavy-ion (Au) beams

Challenges:

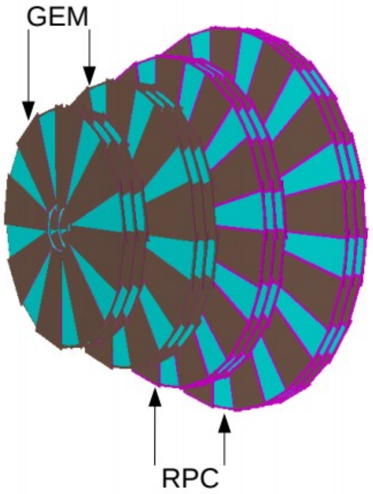
- Production cross sections/branching ratio are dramatically small
- Requires accelerators with unprecedentedly high beam intensities
- Detectors with high rate capabilities
- Large combinatorial background from weak decay of pions and kaons
- On-line event selection to reduce the raw data rate down to recordable

CBM detector sub-systems





Simulated MuCh setup



Muon Chamber (MuCh):

- MuCh Comprises of several detectors & segmented hadron absorbers
- Longitudinal segmentation of absorber & detectors are placed inside absorbers to facilitate tracking
- Angular coverage ~ 5º to 25º
- GEM will be used in the first two stations and RPC for the last two stations

Challenges:

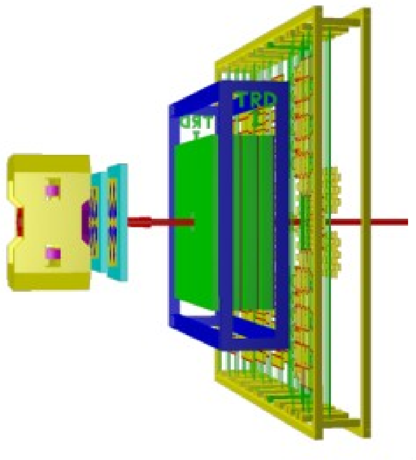
- High interaction rate (up to 10 MHz)
- High particle flux at the detector stations (~ MHz/cm^2 in the 1st station for central collisions)
- Self triggered electronics
- Detectors with high resolution and good rate handling capabilities are required

MuCh at CBM

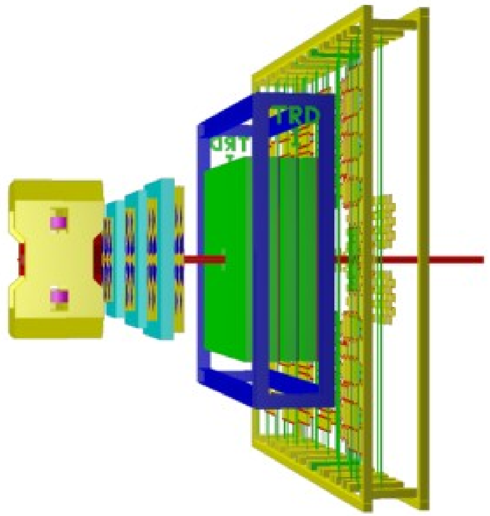
MuCh detector sub-system has three different geometry variants

- To detect the muon pairs coming from the decay of LMVM and J/ψ over the entire SIS100 energy range
- Modularised structure for hassle free comissioning of the detector sub-system

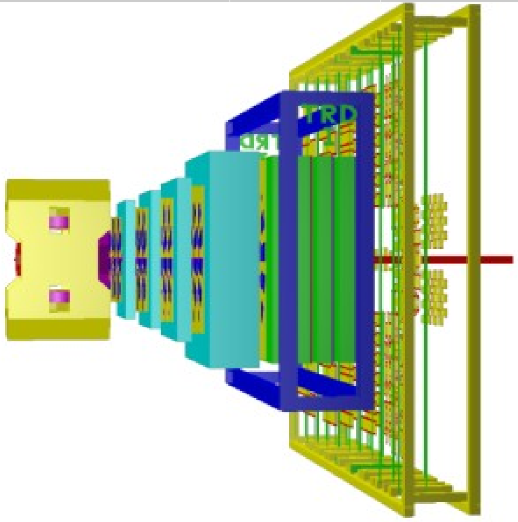
MuCh Geometry variant	No of absorbers	Configuration of the absorbers	No of detector stations	Purpose
Low energy version	3	1^{st} : 58 cm (28 C + 30 cm concrete) 2^{nd} & 3^{rd} : 20 cm Iron	2 (GEM stations)	LMVM detection E_b < 4 A GeV (Au beam)
LMVM version	4	1^{st} : 58 cm (28 C + 30 cm concrete) 2^{nd} & 3^{rd} : 20 cm Iron 4^{th} : 30 cm Iron	2 (GEM stations) 2 (RPC stations)	LMVM detection E_b > 4 A GeV (Au beam)
J/ψ version	5	1^{st} : 58 cm (28 C + 30 cm concrete) 2^{nd} & 3^{rd} : 20 cm Iron 4^{th} : 30 cm Iron 5^{th} : 100 cm Iron	2 (GEM stations) 2 (RPC stations)	J/ψ detection



Low energy version with 3 absorbers and 2 stations (E_b < 4 A GeV) for LMVM ($\mu^+\mu^-$) detection



LMVM ($\mu^+\mu^-$) detection setup with 4 absorbers and 4 stations for E_b > 4 A GeV



J/ψ detection setup with 5 absorbers and 4 stations + TRD

Simulation details

Event generators:

- UrQMD (for background):
  - Au+Au
  - Ni+Ni
  - p+Au
- PLUTO (for signal):
  - Freeze-out cocktail
  - $J/\psi \rightarrow \mu^+ + \mu^-$
- **Transport engine:** GEANT3

SIS100 energy scan:

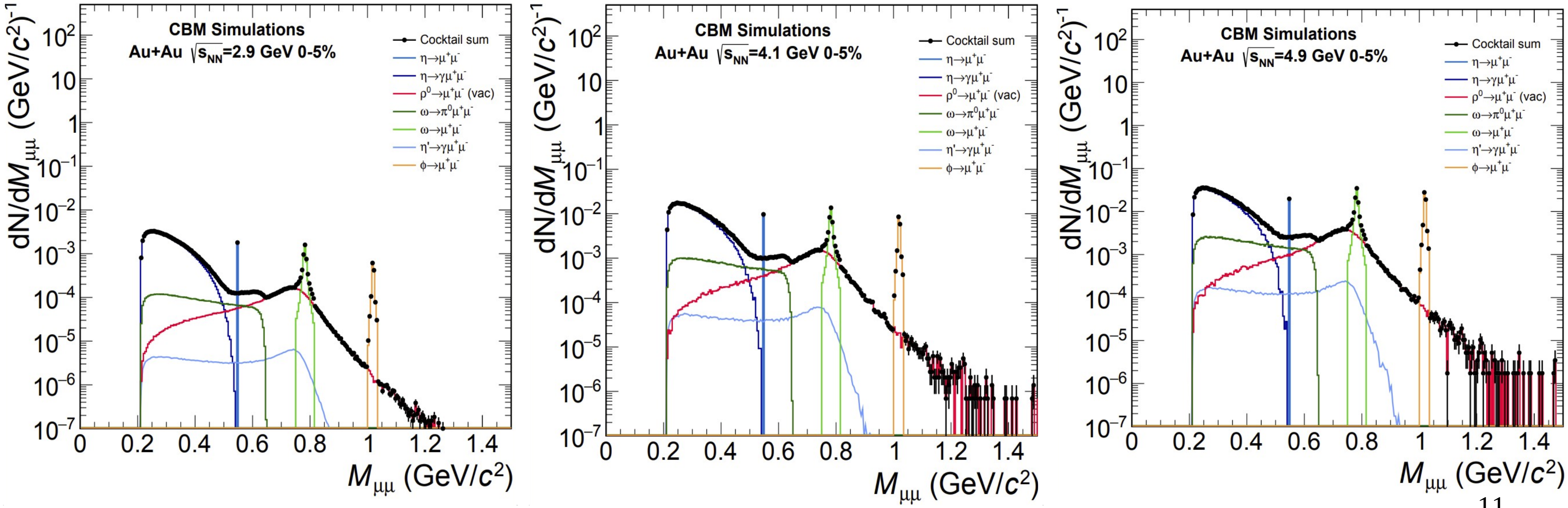
P_{beam} (A GeV/c)	E_{beam} (A GeV)	E_{kin} (A GeV)	$\sqrt{S_{NN}}$ (GeV)	Description
3.3	3.43	2.49	2.86	lowest possible for heavy-ions at SIS100
4.4	4.5	3.56	3.19	HADES@SIS100 reference energy
7.95	8.0	7.06	4.09	intermediate energy of the scan
12.00	12.04	11.1	4.93	highest possible for heavy-ions at SIS100

- **Total number of events simulated:** $\sim 10^6$
- **Simulation framework**: CbmRoot (APR20 release)
- **Mode of simulation** : Event by Event mode
- **Multiplicities:** Thermal FIST model (LMVM) (https://cbm-wiki.gsi.de/foswiki/bin/view/PWG/)
  UrQMD (J/ψ) (J. Steinheimer *et al.*, Phys. Rev. C 95, 014911, 2017)

Freeze-out cocktail

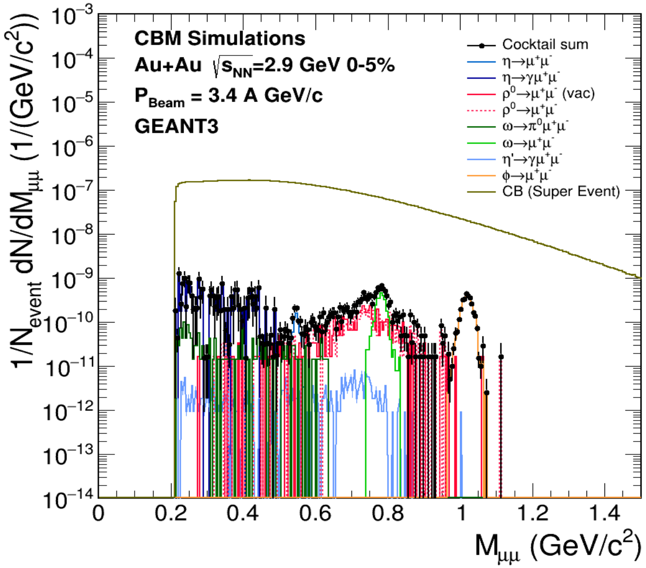
Freeze-out cocktail (Pluto)

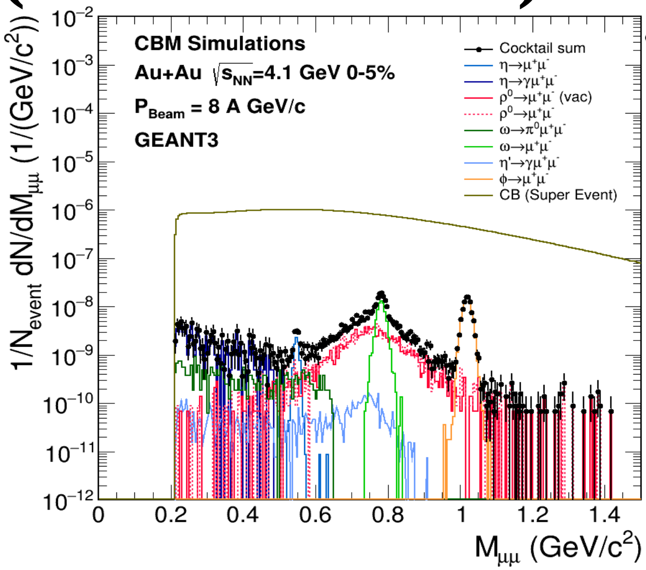
- The input distribution of the signals are taken from Pluto based on thermal fireball model for Au+Au collisions
- Thermal transverse distribution following $dN/dp_T \sim p_T m_T K_1(m_T/T)$
- Gaussian rapidity distribution

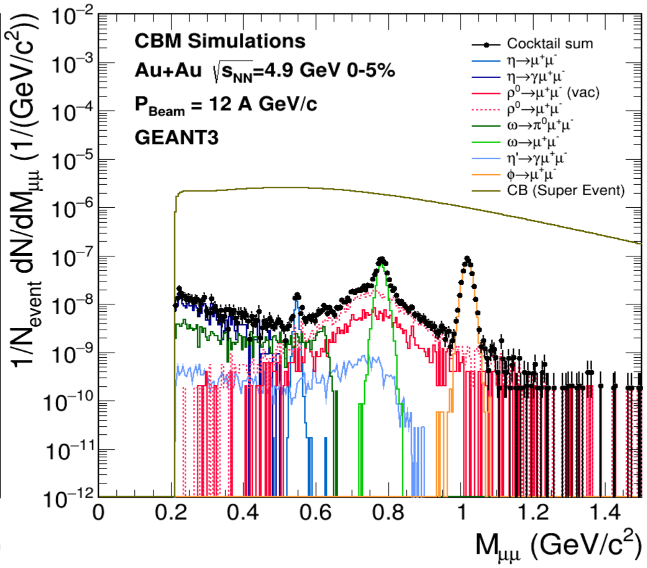


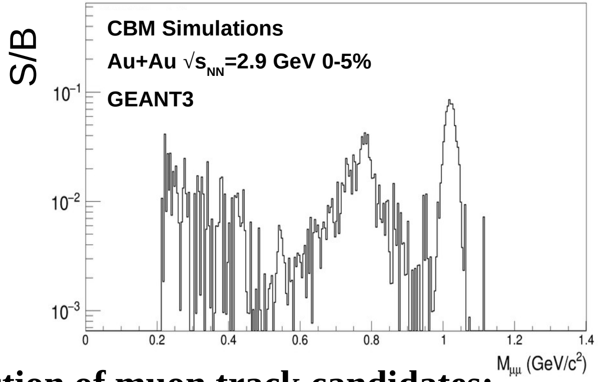
Ref: https://cbm-wiki.gsi.de/foswiki/bin/view/PWG/CbmDileptonInfoFiles
I Fröhlich et al 2010 J. Phys.: Conf. Ser. 219 032039 (arXiv:0905.2568v1)

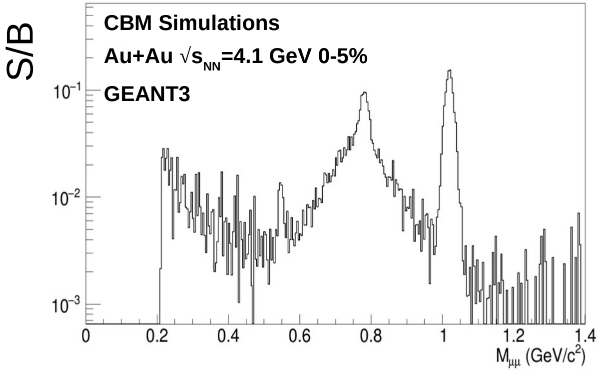
Freeze-out cocktail (Reconstructed)

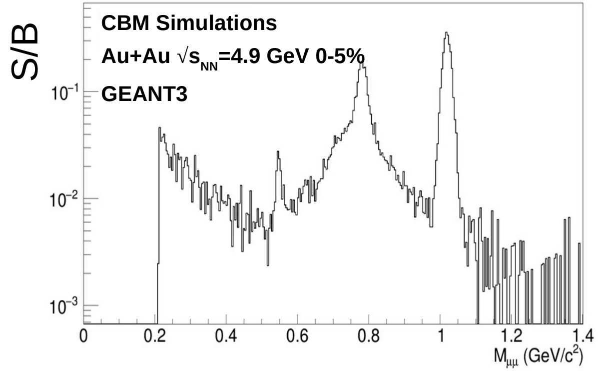










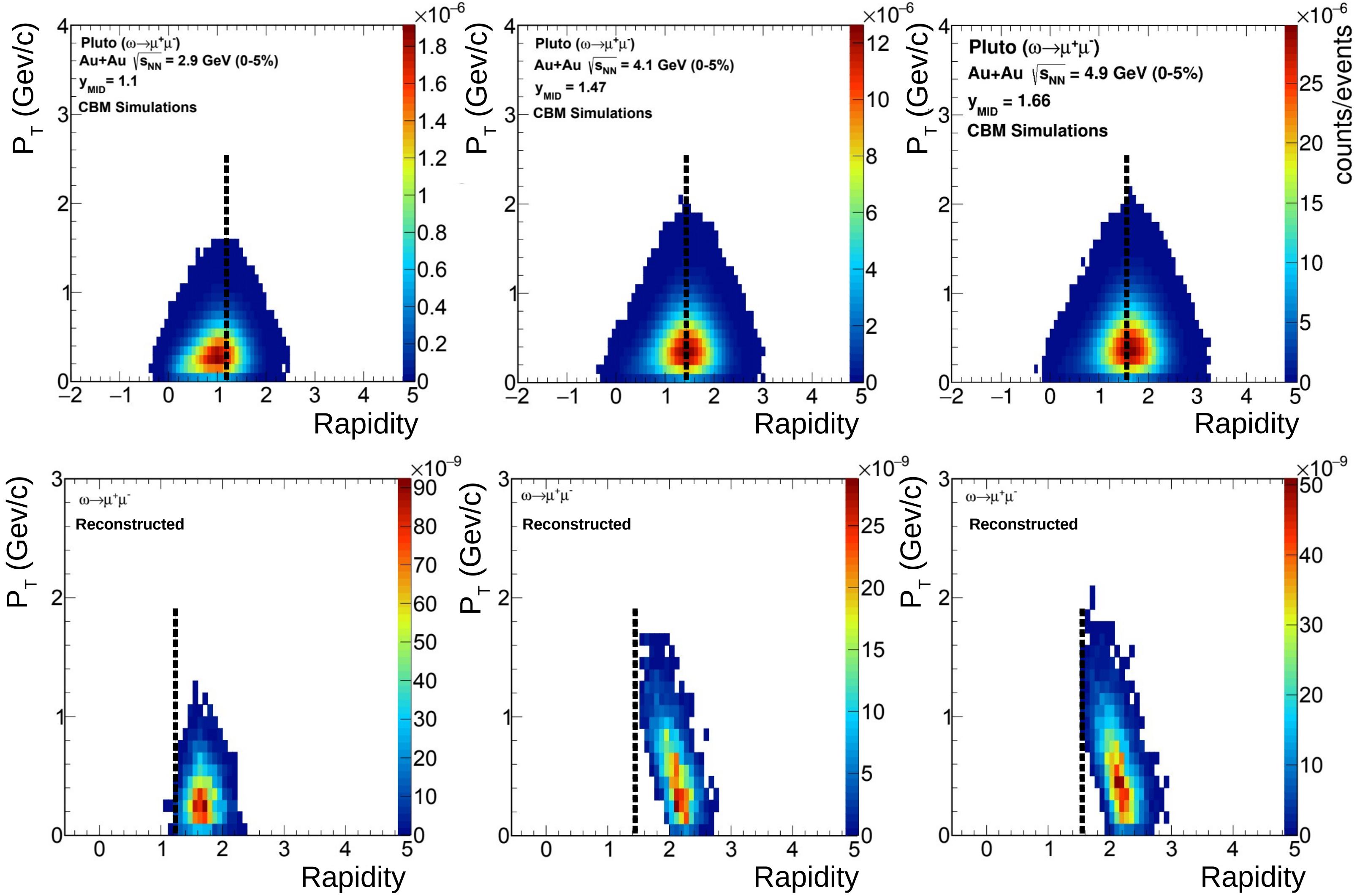


Selection of muon track candidates:

Accepted tracks: STS hit ≥ 7, MuCh hit ≥ 11, 5 ($\sqrt{s_{NN}}$ = 2.9 GeV), TOF hit ≥ 1; **Reconstructed tracks:** $\chi^2_{VERTEX} \leq 2.0$, $\chi^2_{STS} \leq 2.0$, $\chi^2_{MuCh} \leq 4.5$

Ref: S. Chatterjee QM2022 Poster (https://indico.cern.ch/event/895086/contributions/4707020/)

Phase space distribution ($\omega \rightarrow \mu^+\mu^-$)



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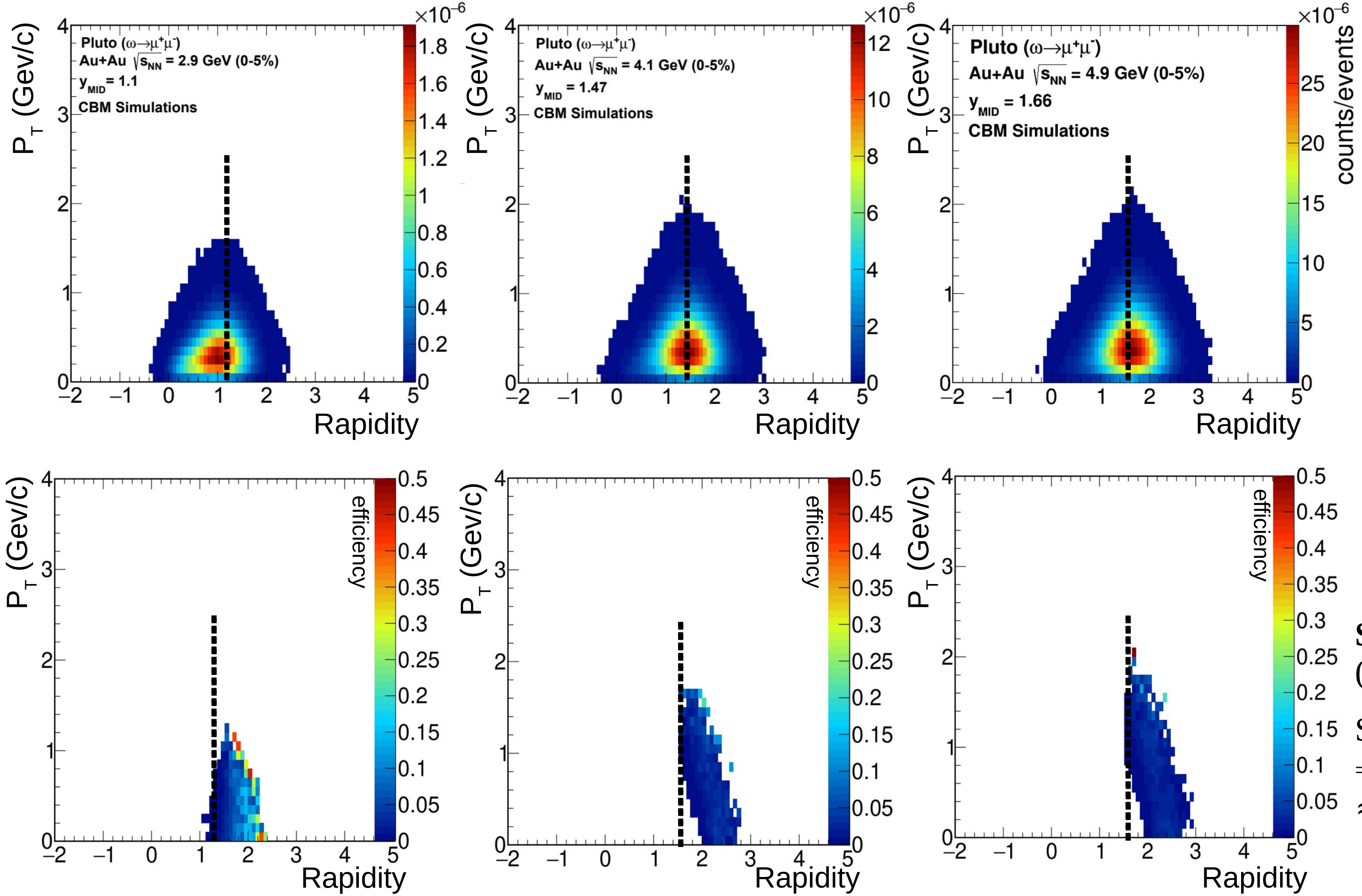
Reconstructed tracks:

$\chi^2_{VERTEX} \leq 2.0$, $\chi^2_{STS} \leq 2.0$, $\chi^2_{MuCh} \leq 4.5$

No mid-rapidity coverage!!!

Reconstruction efficiency ($\omega \rightarrow \mu^+\mu^-$)



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Signal counts per week:

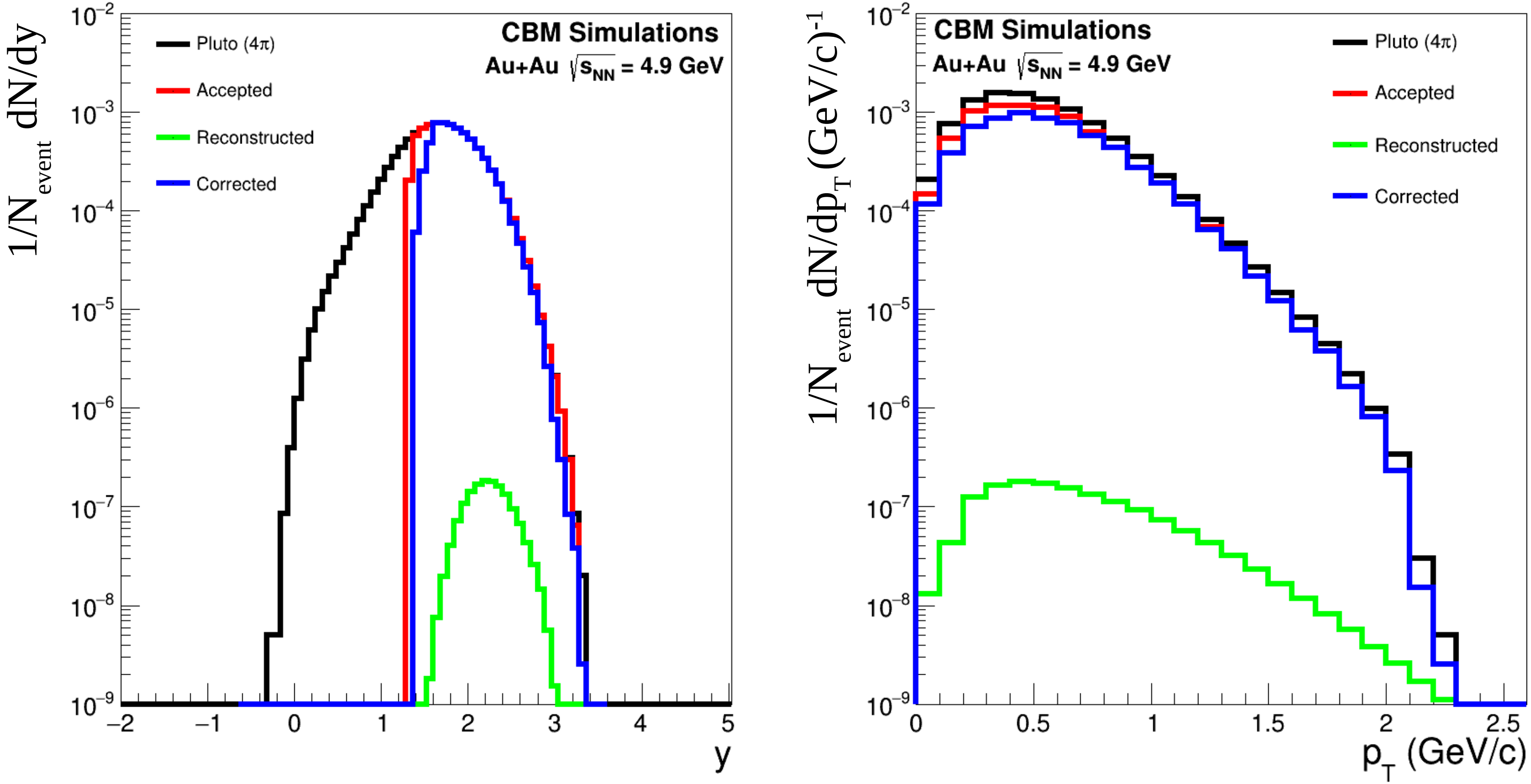
(At $\sqrt{s_{NN}} = 4.9$ GeV)

$$S_w = R_{peak} e_{duty} P_{prod} BR f_{mb/cen} \varepsilon_{reco} \Delta T$$

$$= 10^5 \times 0.7 \times 5.8 \times 7.4 \times 10^{-5} \times 0.25 \times 0.02 \times 6 \times 10^5$$

$$\approx 1 \times 10^5$$

Efficiency × Acceptance correction ($\omega \rightarrow \mu^+\mu^-$)



After the correction, the corrected spectra matches well with the accepted spectra

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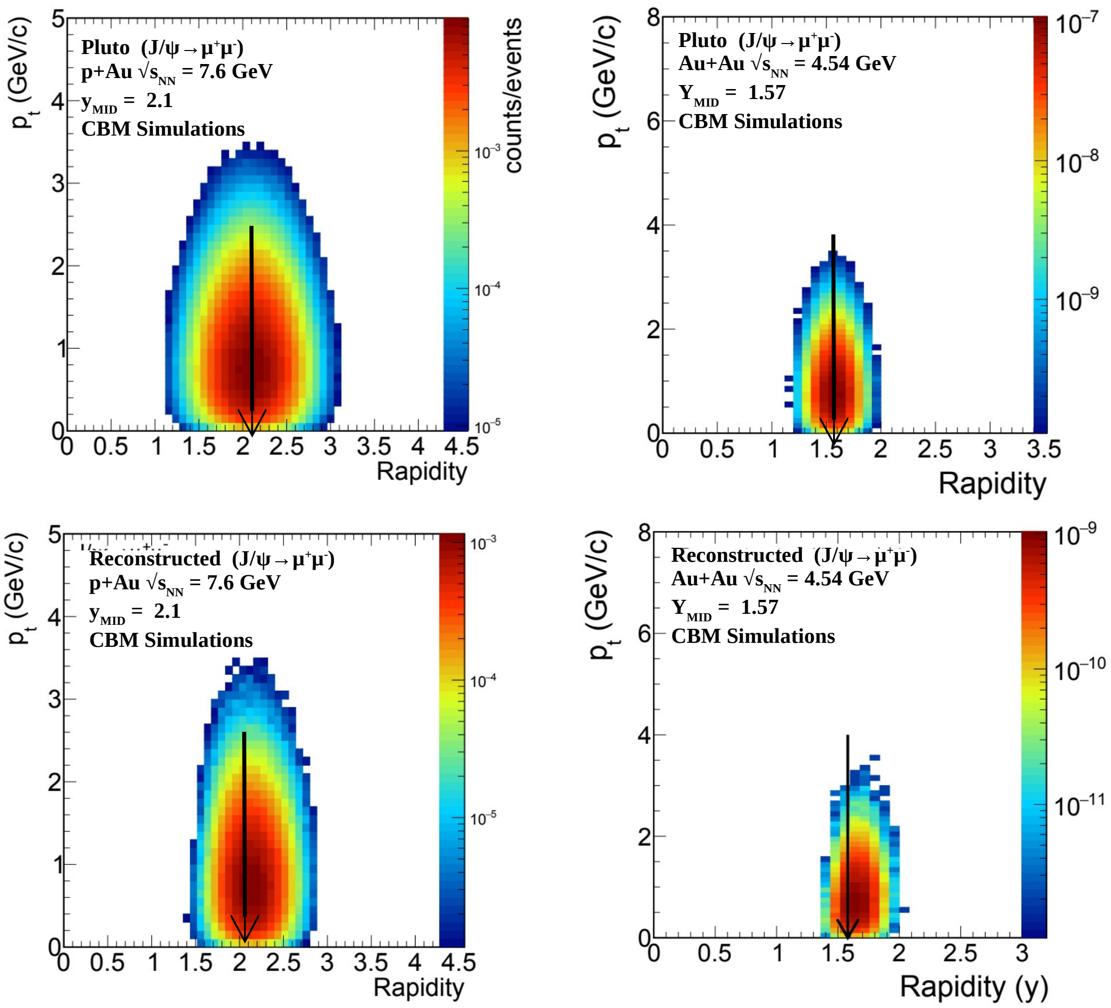
Charmonium (J/ψ)

Phase space distribution (J/Ψ → $\mu^+\mu^-$)



- Shift in pair rapidity distribution due to absorption of low momentum muons by the hadron absorbers
- Good mid-rapidity coverage

Track selection cuts:

Accepted tracks:

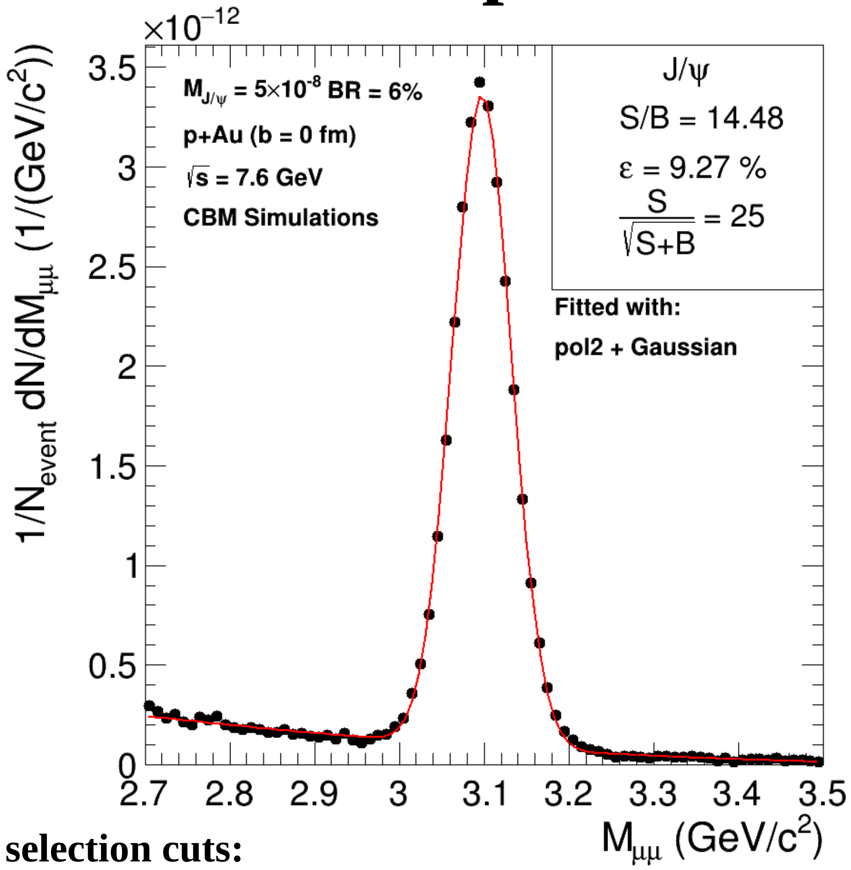
STS hit ≥ 7; MuCh hit ≥ 11; TRD hit ≥ 3; TOF hit ≥ 1;

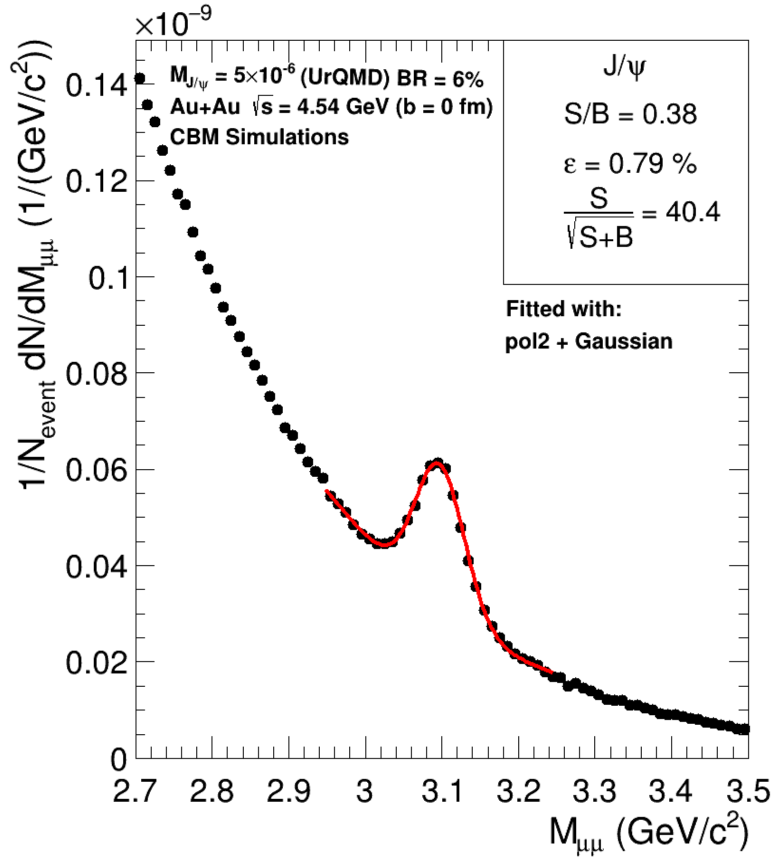
Reconstructed tracks:

$\chi^2_{VERTEX} \leq 2.2$; $\chi^2_{STS} \leq 3.4$; $\chi^2_{MuCh} \leq 2.6$; $\chi^2_{TRD} \leq 6.0$ (Au+Au)

$\chi^2_{VERTEX} \leq 3.0$; $\chi^2_{STS} \leq 4.0$; $\chi^2_{MuCh} \leq 2.5$; $\chi^2_{TRD} \leq 6.0$ (p+Au)

Invariant mass spectra





Track selection cuts:

Detection of J/ψ is found to be feasible with the model predicted multiplicity values!

Accepted tracks: STS hit ≥ 7; MuCh hit ≥ 11; TRD hit ≥ 3; TOF hit ≥ 1;

Reconstructed tracks: $\chi^2_{VERTEX} \leq 2.2$; $\chi^2_{STS} \leq 3.4$; $\chi^2_{MuCh} \leq 2.6$; $\chi^2_{TRD} \leq 6.0$ (Au+Au)
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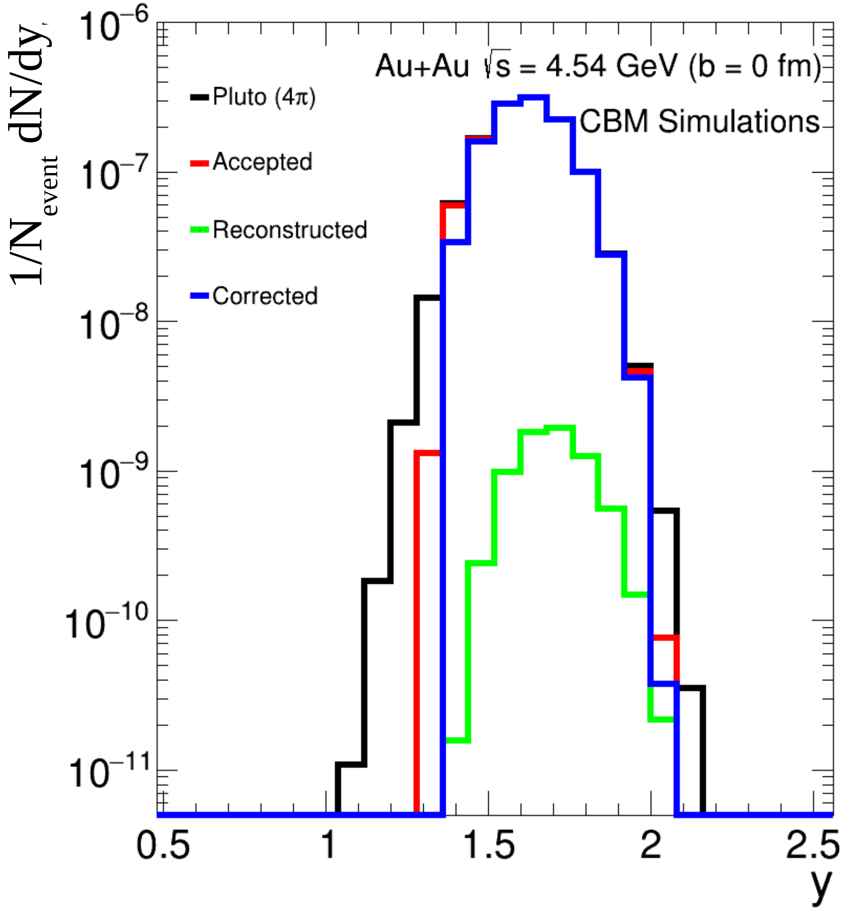
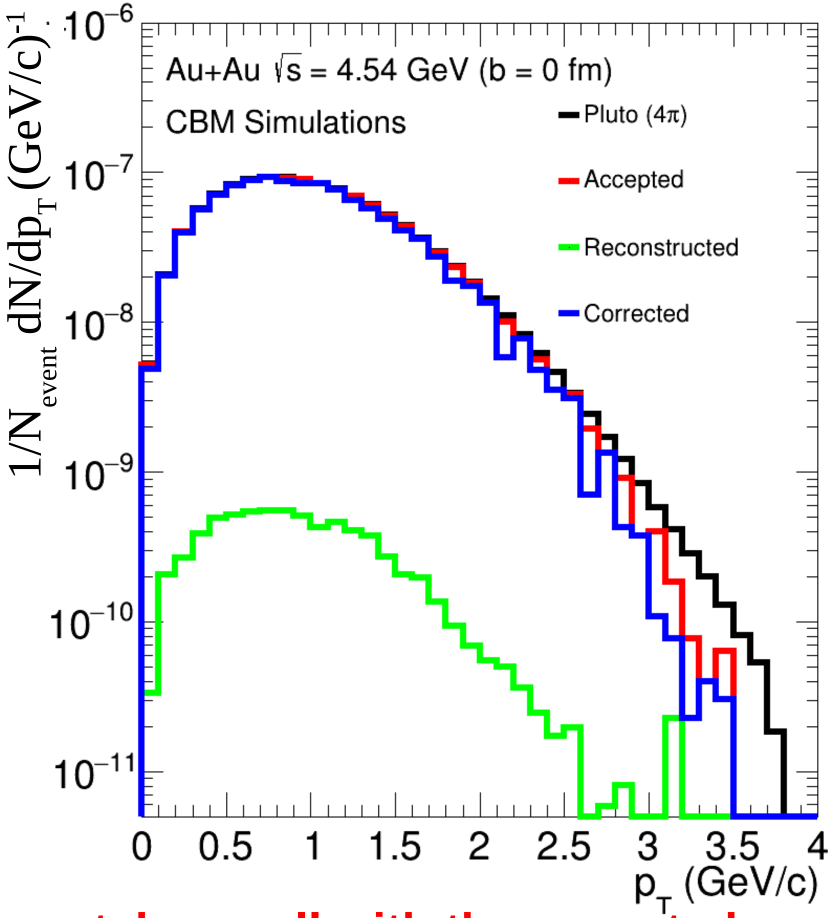
Efficiency × Acceptance correction ($J/\psi \rightarrow \mu^+\mu^-$)





After the correction, the corrected spectra matches well with the accepted spectra

Ref: S. Chatterjee DAE-BRNS HEP symposium (https://www.niser.ac.in/daehep2020/talkposter/Sayak_Chatterjee_TLK_172_508.pdf)

Summary & Outlook

- The performance of LMVM detection at three different SIS-100 energies ($\sqrt{s_{NN}}$ = 4.9, 4.1 & 2.9 GeV) are investigated with Au+Au collisions of 0-5% centrality
- The performance of J/ψ detection at FAIR SIS-100 energies is investigated with realistic detector sub-system for Au+Au ($\sqrt{s_{NN}}$ = 4.54 GeV) and p+Au ($\sqrt{s_{NN}}$ = 7.6 GeV) collisions and with predicted charmonium yields, the measurement of J/ψ is found to be feasible with MuCh subsystem
- The reconstructed spectra can be fitted with a symmetric Gaussian distribution with good mass resolution (~ 35 MeV), thanks to low material budget of STS
- Efficiency × acceptance correction is performed and the corrected spectra matches well with the input spectra

- Input signal from different event generators and comparison with the existing results
- Investigation of the different analysis techniques (e.g. Artifical Neural Network) to improve the signal to background ratios
- Simulation of thermal di-muon excess and extraction of fireball temperature
- Time based simulation

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THANK YOU!