Measurements of dileptons with the CBM-Experiment at FAIR

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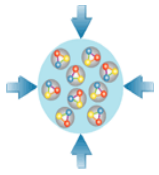
CBM collaboration

HIC for FAIR
Helmholtz International Center

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

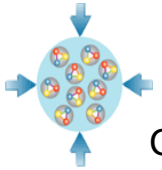
GSI



Outline

- **Introduction & motivation**
- **Detector concept of CBM**
  - overall concept
  - challenges of the dilepton measurement: electrons – muons
- **Simulations**
  - feasibility studies for di-electrons and di-muons
  - background analysis
- **Detector development**
- **Summary and Outlook**

Related Posters
- RICH detector development: M-09, M-10, M-11
- MUCH detector development: M-03
- Di-Electron simulations: G-18



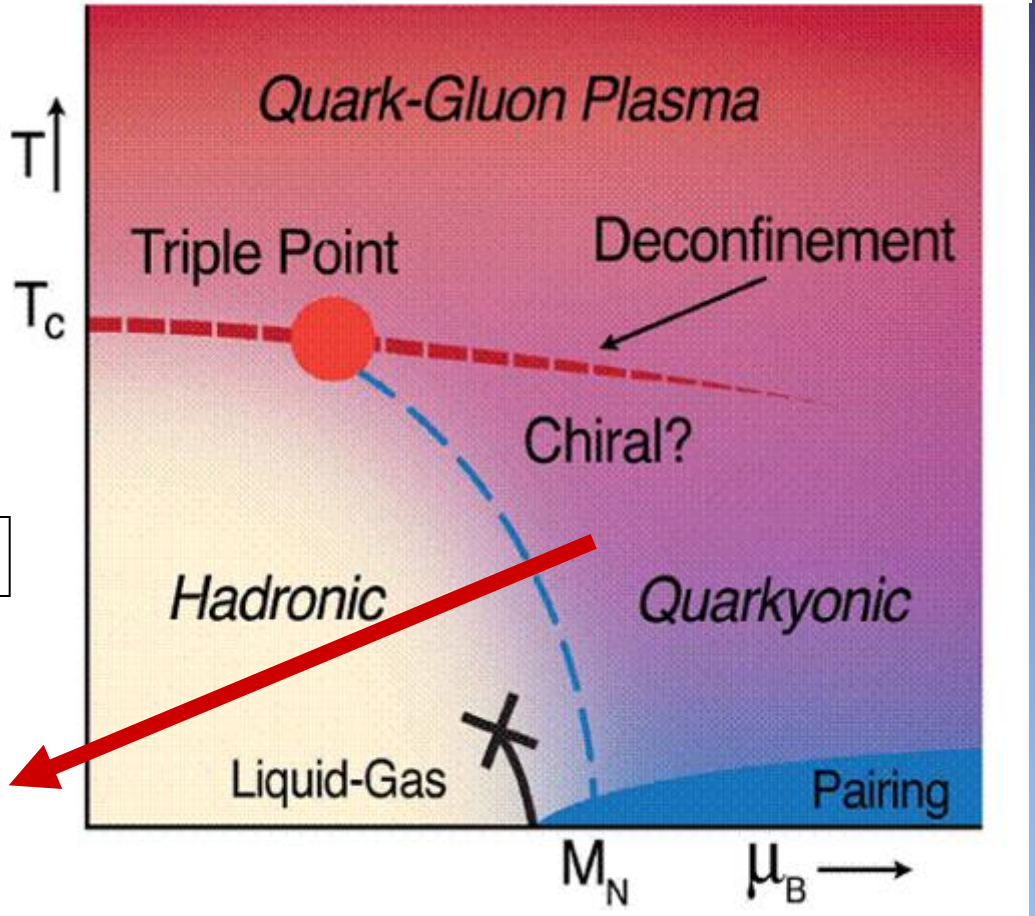
The QCD diagram at high μ_B

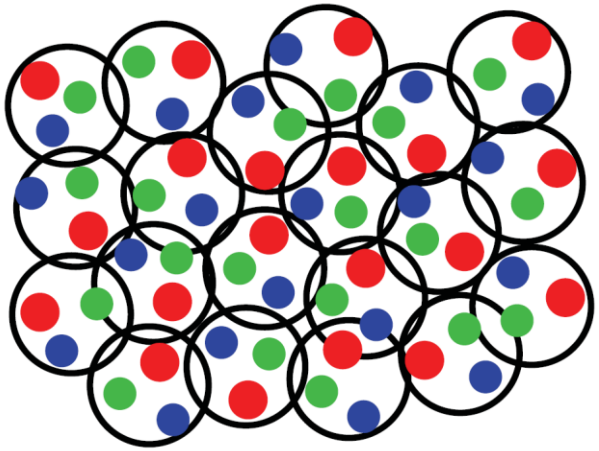
phase diagram at high μ_B ?

- quarkyonic phase?
- phase transition(s)?
- critical point/ triple point?
- **need for high precision data including rare probes!**
- **Electromagnetic probes!**

Field driven by experimental data!

[A. Andronic et al., arXiv:0911.4806]

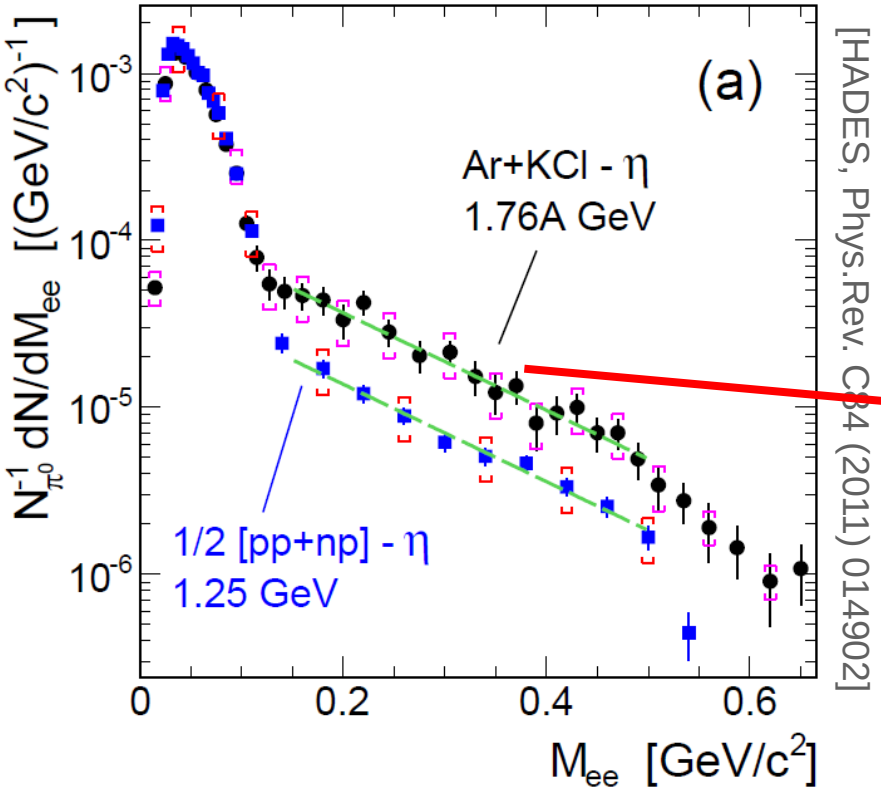


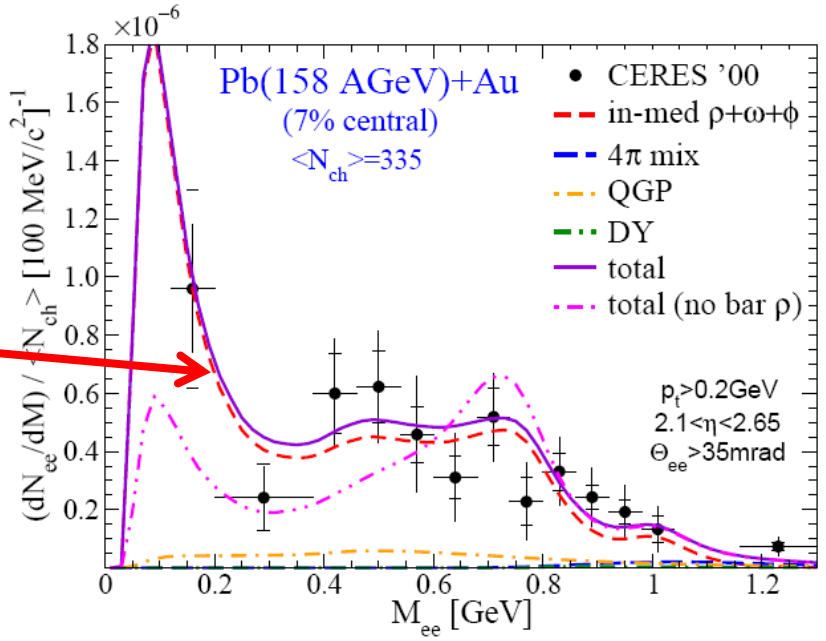


Physics case (I)

Relevance of HADES data for understanding high-energy LMVM spectra:

- strength of dilepton yield at low masses is due to coupling to baryons!
- **Dilepton yield at highest net-baryon densities?**

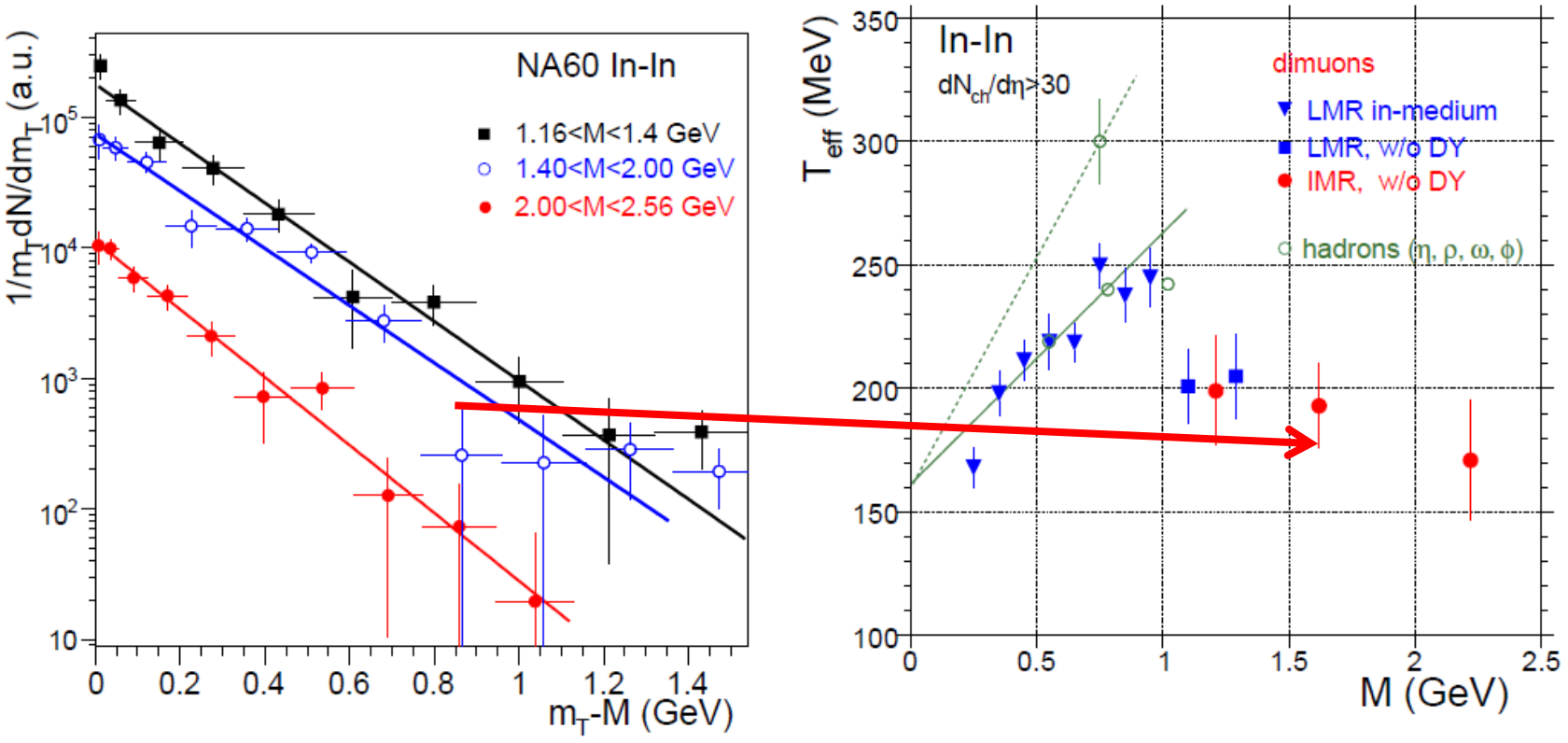




[CERES: Phys.Lett.B 666, 425 (2008)]
[calculations: H. v. Hees, R. Rapp, Nucl.Phys.A806:339,2008]

Physics case (II)

- NA60: excess dimuons in intermediate mass range give direct access to thermal radiation from an early, partonic emission source with processes like $q\bar{q} \rightarrow \mu^+\mu^-$
- **Direct radiation from (new) phases at high net-baryon densities?**

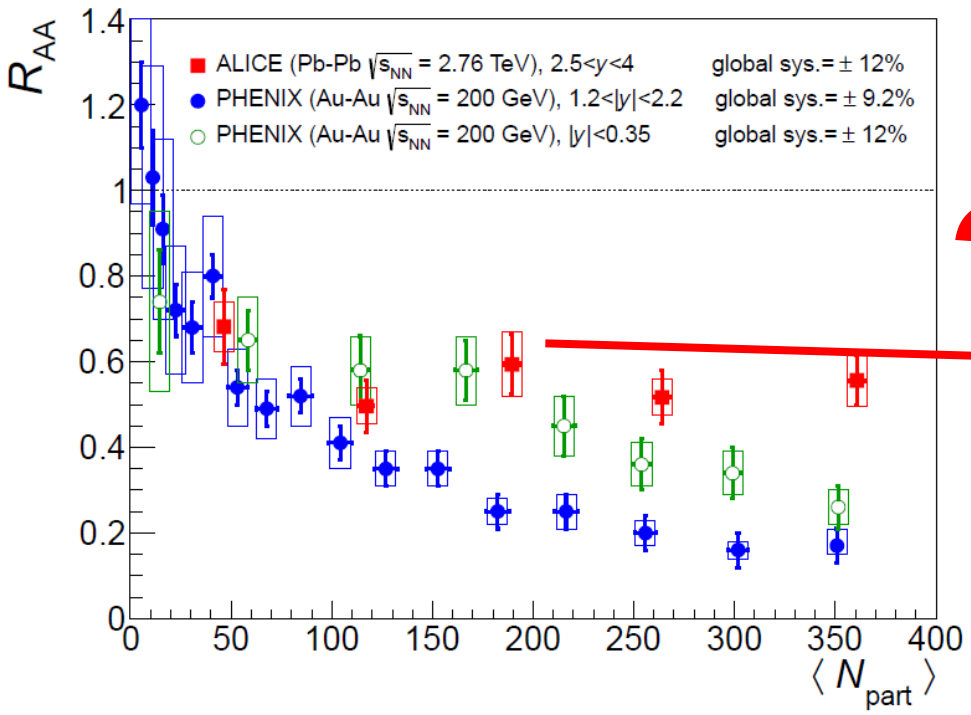


[NA60, Eur.Phys.J. C61 (2009) 711-720]

Physics case (III)

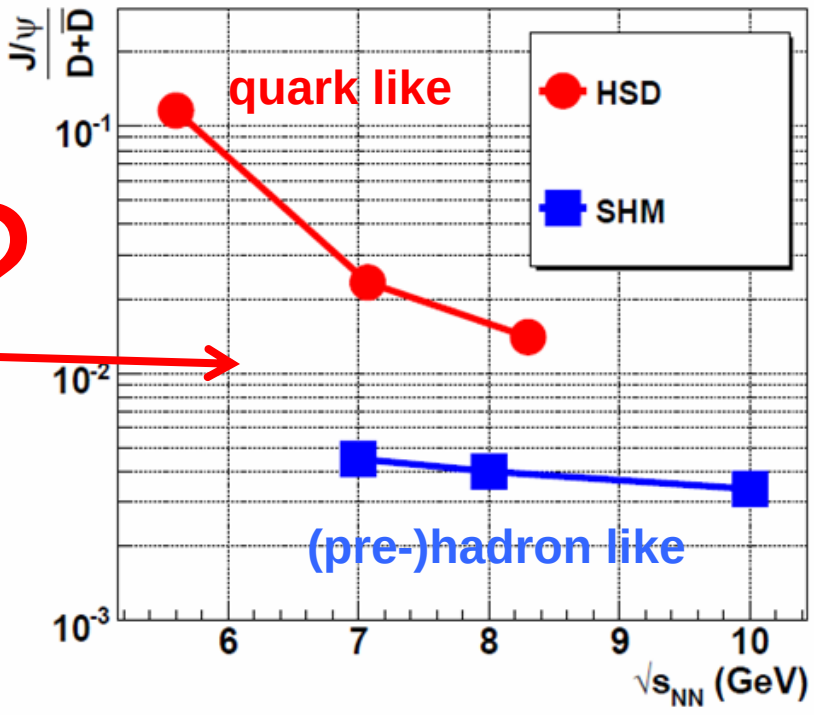
- At high energies complex pattern of J/ψ suppression observed: dissociation of $c\bar{c}$ pairs in partonic phase, statistical coalescence at freeze-out?
- **Production scenario should be visible in charm quark distribution amongst hadrons!**

[ALICE, Phys.Rev.Lett. 109 (2012) 072301]

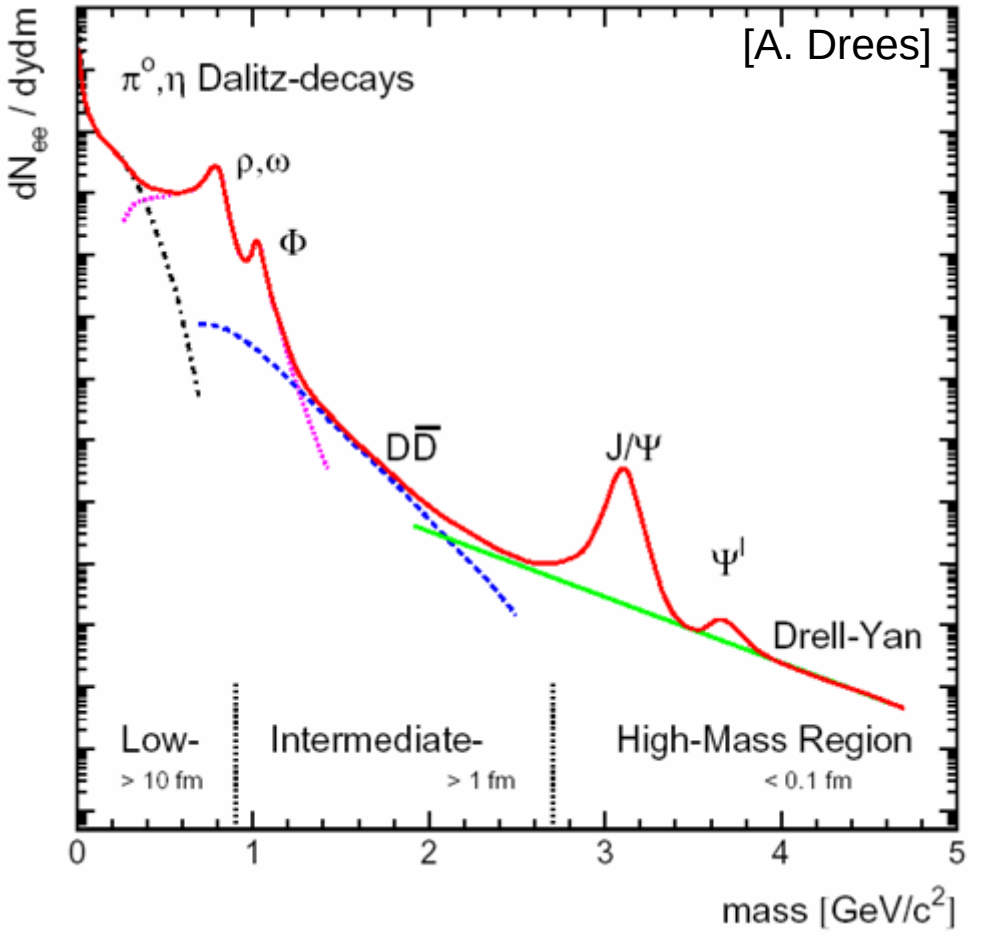


?

[CBM Physics Book]



Dileptons at FAIR - the aim



Study EM radiation (+ heavy flavor) in baryon dominated matter at moderate temperature as accessible by FAIR!

- Photons: access to early temperatures
- Low-mass vector mesons: in-medium properties of ρ
- Intermediate range: acces to fireball radiation
- J/ψ: charm as a probe for dense baryonic matter

no ρ,ω,φ → e^+e^- ($\mu^+\mu^-$) measurement between 2 and 40 AGeV
no J/ψ → e^+e^- ($\mu^+\mu^-$) measurement below 158 AGeV

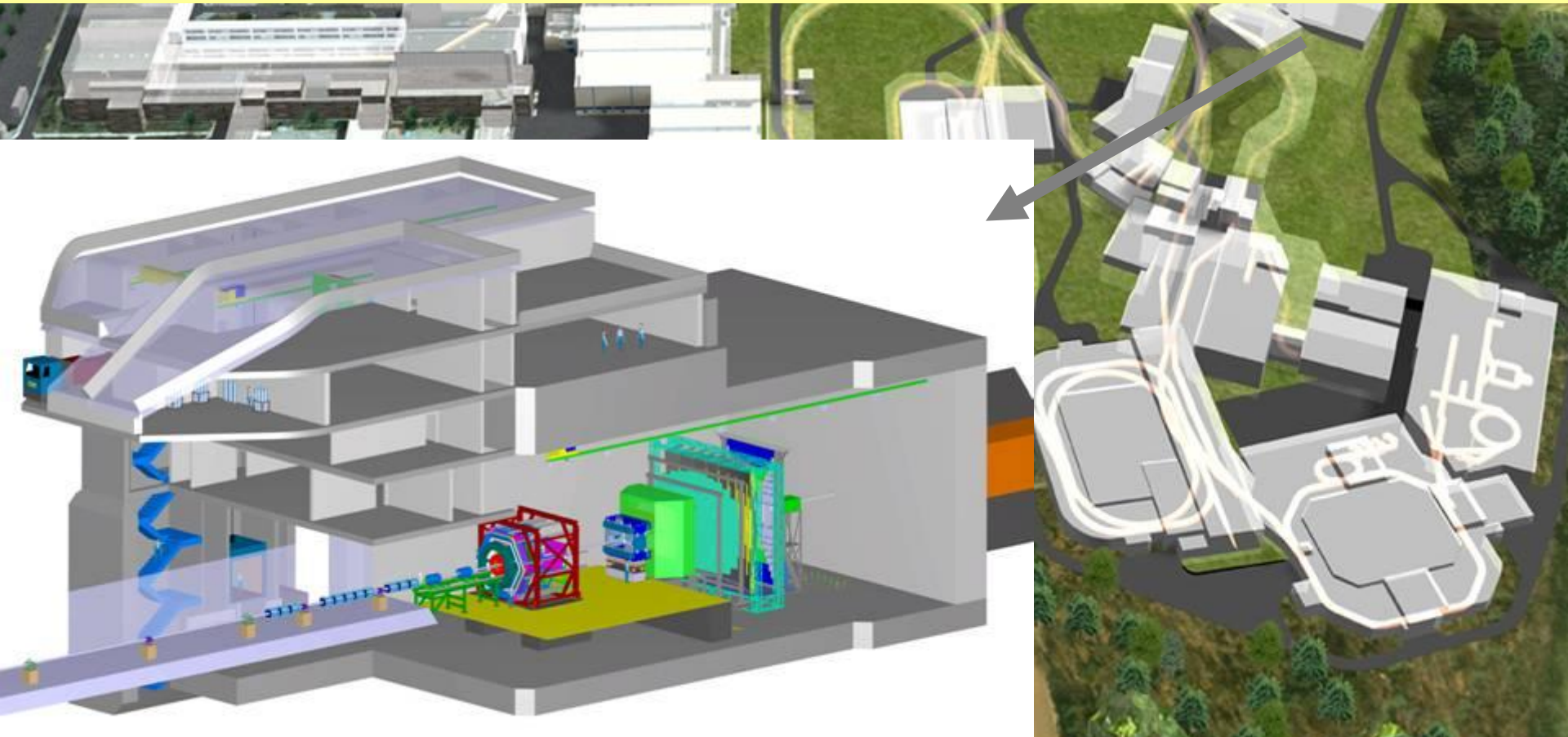
The Facility for Antiproton and Ion Research

CBM and HADES at SIS-100 and SIS-300

- systematic exploration of baryon dominated, high density matter in A+A collisions from 2 – 45 AGeV beam energy with 2nd generation experiments

HADES: Au+Au collisions 2-4 AGeV, low material budget, 20°-85° polar angle

CBM: Au+Au collisions 4-35 AGeV, larger material budget, 2.5°-25° polar angle



CBM @ SIS-100 & SIS-300

The first years of CBM operation will be at SIS-100 with a start setup

Beam	$p_{lab,\,max}$	$\sqrt{s}_{NN,\,max}$
heavy ions (Au)	11A GeV	4.7 GeV
light ions (Z/A = 0.5)	14A GeV	5.3 GeV
protons	29 GeV	7.5 GeV

CBM at SIS-300

Beam	$p_{lab,\,max}$	$\sqrt{s}_{NN,\,max}$
heavy ions (Au)	35A GeV	8.2 GeV
medium ions (In) (Cu)	38A GeV 41A GeV	8.5 GeV 8.9 GeV
light ions (Z/A = 0.5)	45A GeV	9.3 GeV
protons	90 GeV	13 GeV

…. at interaction rates up to 10 MHz (J/ψ)

CBM – detector concept

• fixed target experiment, "medium" energies

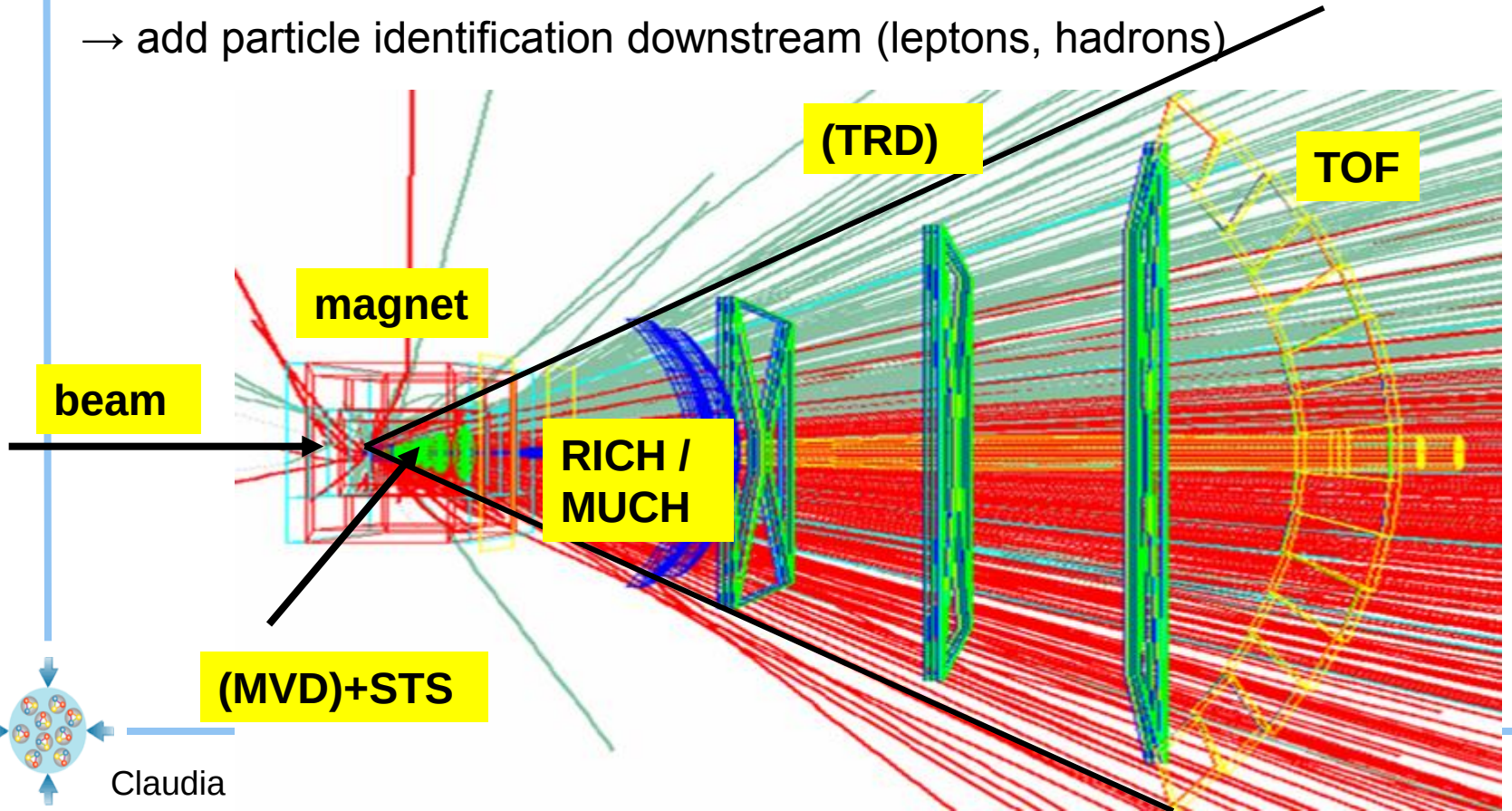
→ large solid angle to be covered

• high rate, multipurpose detector including open charm reconstruction

→ fast, excellent tracking based on silicon pixel and strip detectors directly behind the target and inside a magnetic field

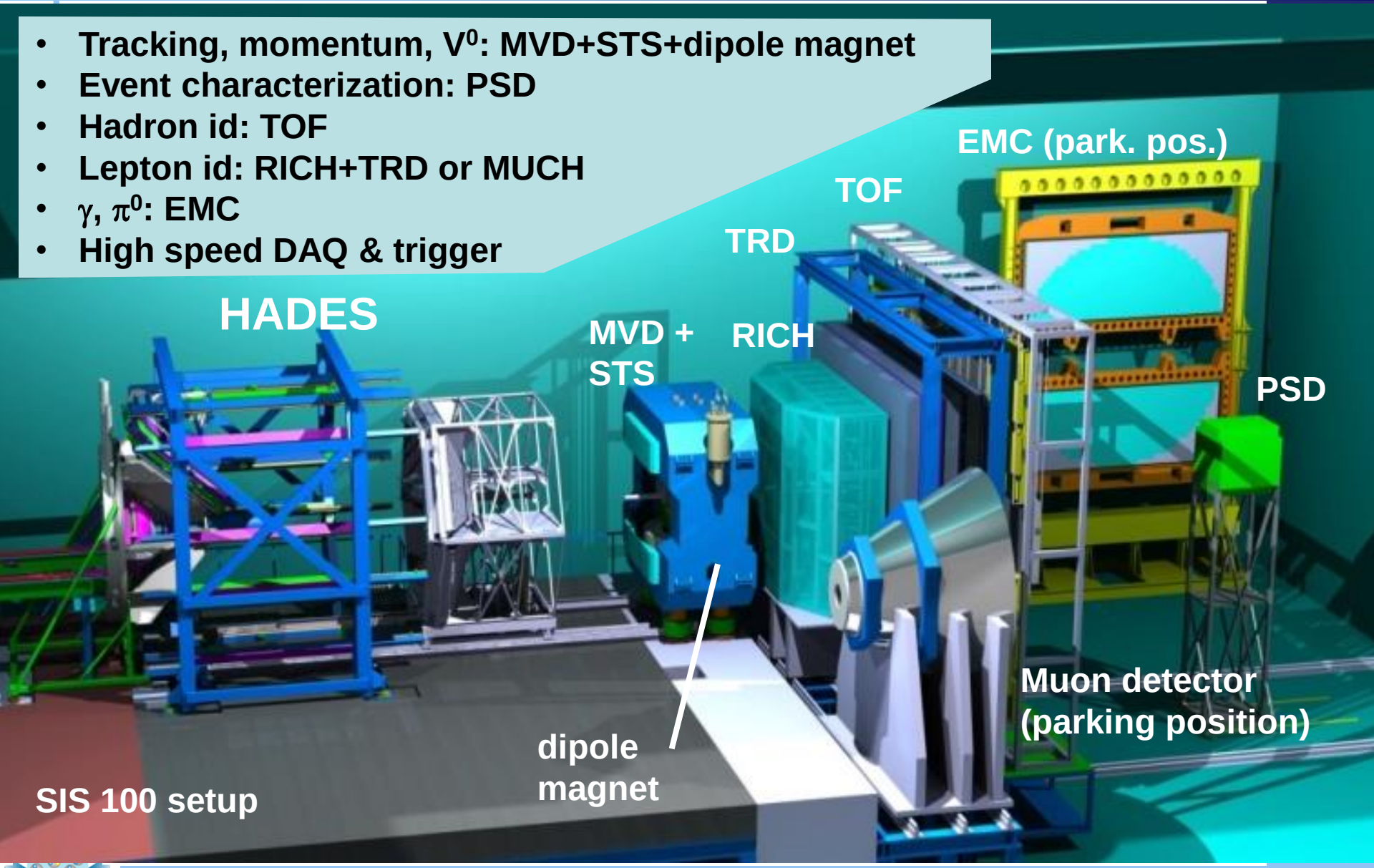
→ add particle identification downstream (leptons, hadrons)

drives layout



The CBM experiment

- Tracking, momentum, V^0: MVD+STS+dipole magnet
- Event characterization: PSD
- Hadron id: TOF
- Lepton id: RICH+TRD or MUCH
- γ, π^0: EMC
- High speed DAQ & trigger

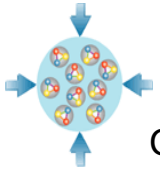


Simulation input

- CBMROOT framework, GEANT3
- Background: UrQMD v. 3.3
- Signal: PLUTO with multiplicities from HSD
- (semi-)realistic detector descriptions

- **Muons:**
  - STS: realistic detector response, clustering, material from cables…
  - MUCH: realistic detector response, clustering

- **Electrons:**
  - STS: realistic detector response, clustering, material from cables…
  - RICH: realistic detector response
  - TRD: semirealistic detector response (hit smearing)
  - TOF: semirealistic detector response (hit smearing)

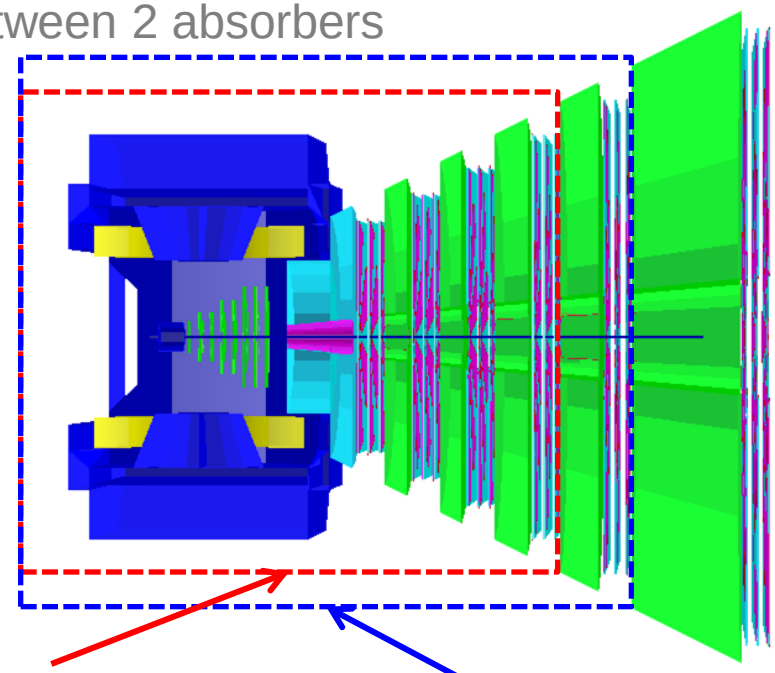


Muon detection system: MUCH

- ID after hadron absorber with intermediate tracking layers
- **major combinatorical background from π,K decays into μν, punch through of hadrons and track mismatches**

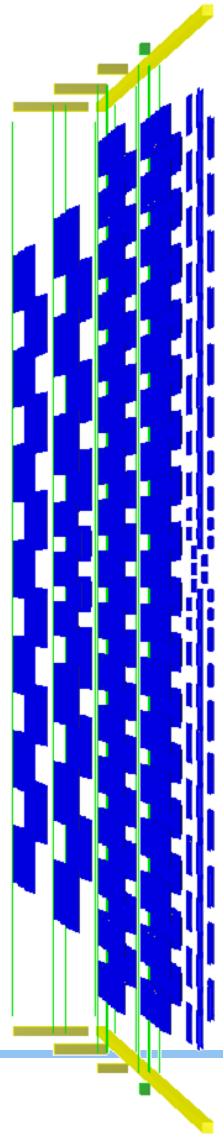
→ use excellent tracking to reject π,K decays in the STS

60 C + 20 Fe + 20 Fe + 30 Fe + 35 Fe + 100 Fe (cm)
30 cm gap between 2 absorbers



LMVM @ SIS100 + ToF

LMVM @ SIS300 + ToF

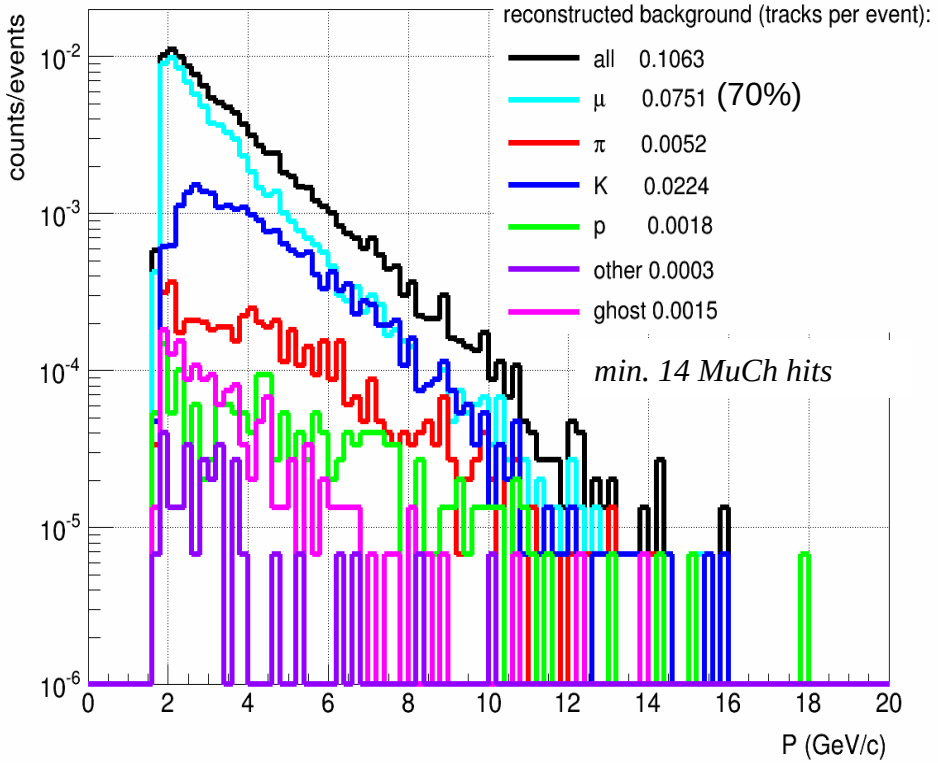


Background - muons

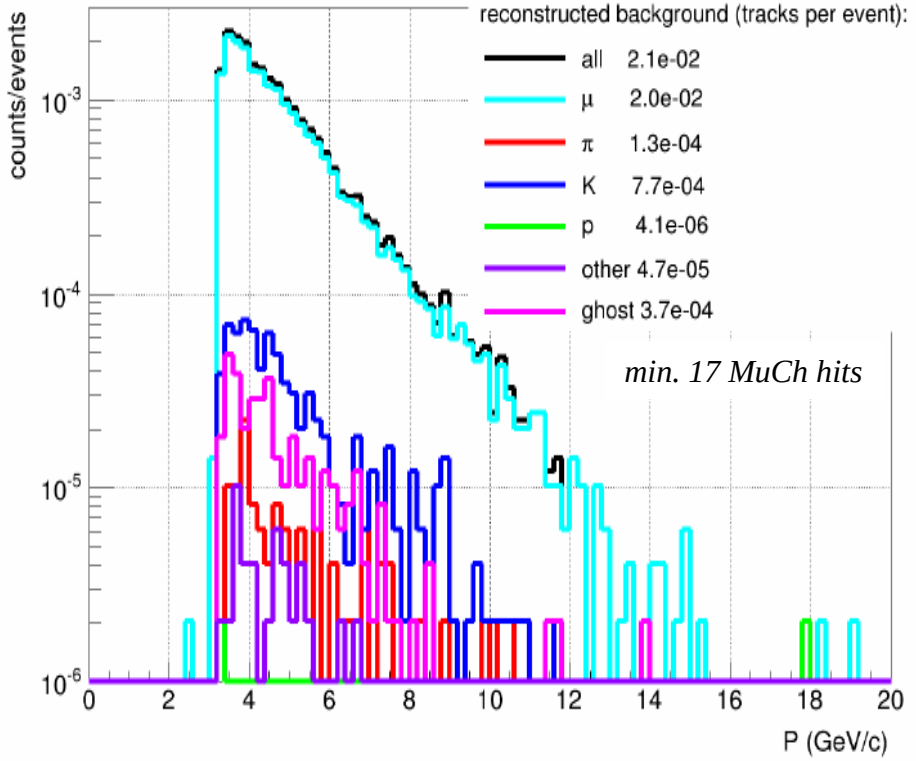
Particles identified as muons = reconstructed after MUCH (25 AGeV central Au+Au)

- Total number allows for a trigger also for LMVM

LMVM setup (no TOF)



J/ψ setup (no TOF)

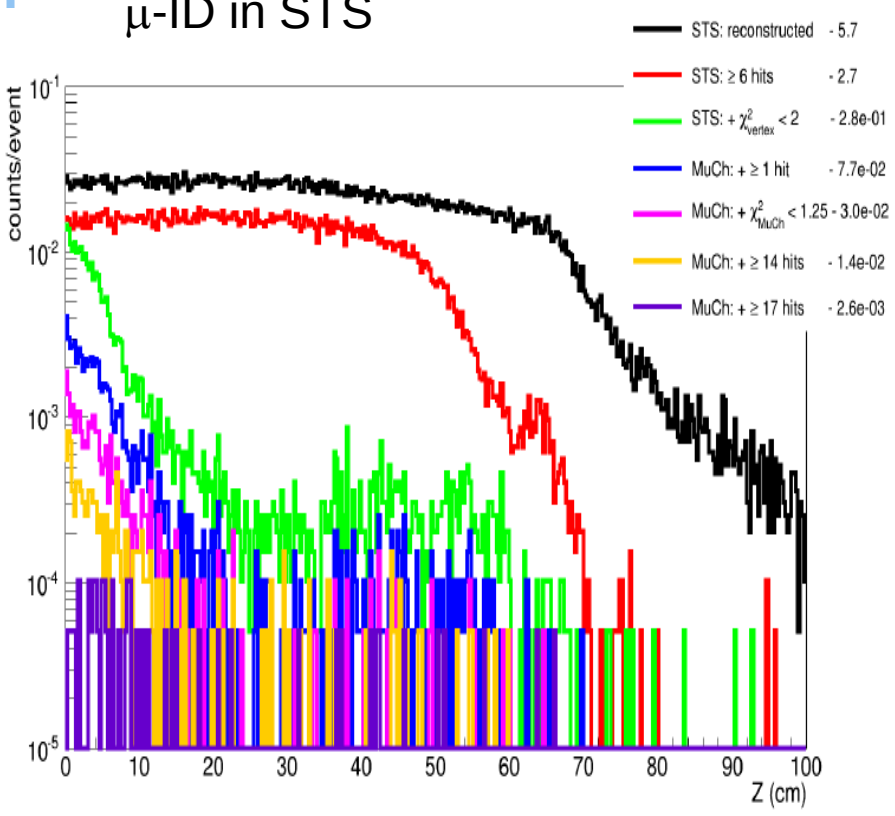


Decay muons

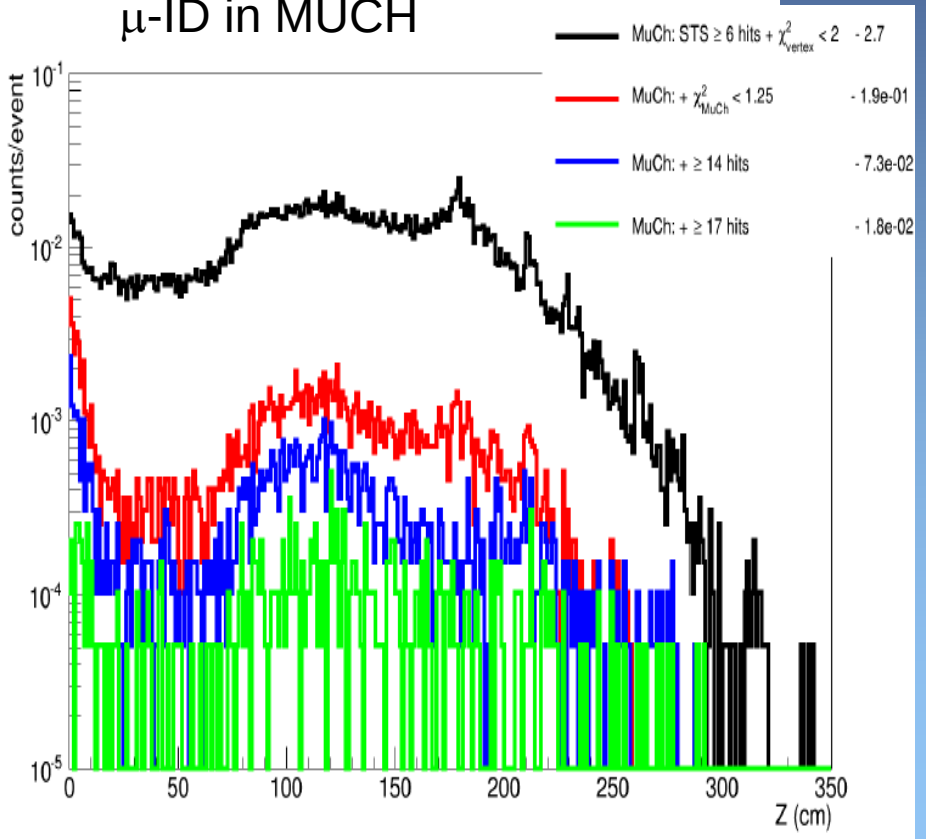
Background dominated by decay muons

- Vertex-z distribution of reconstructed μ tracks in STS/ MUCH:
  Successful reduction of decay muons by tracking cuts!

μ-ID in STS

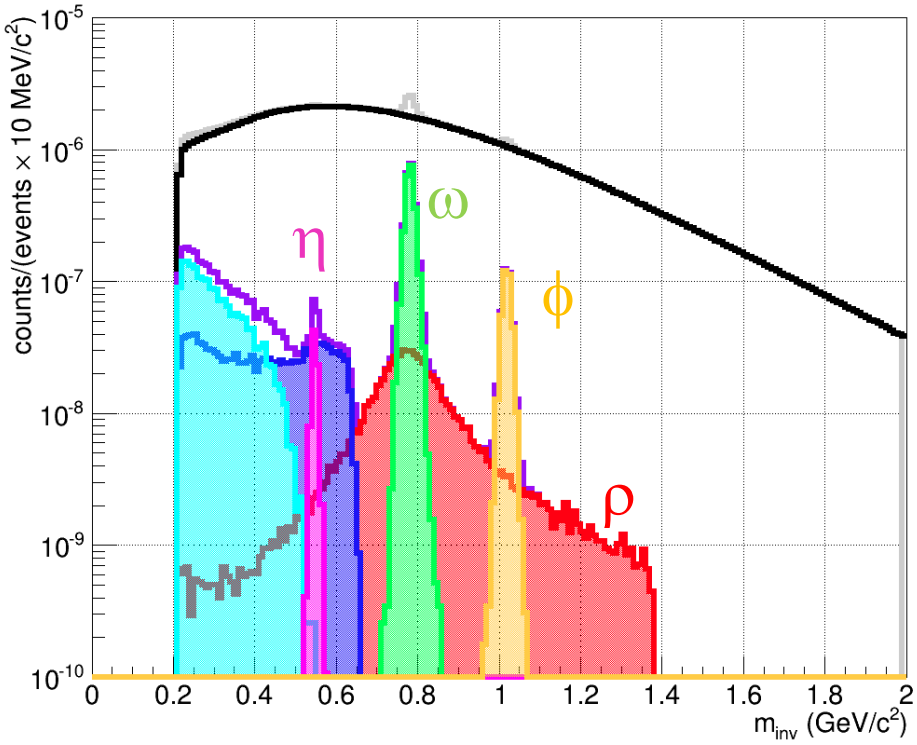


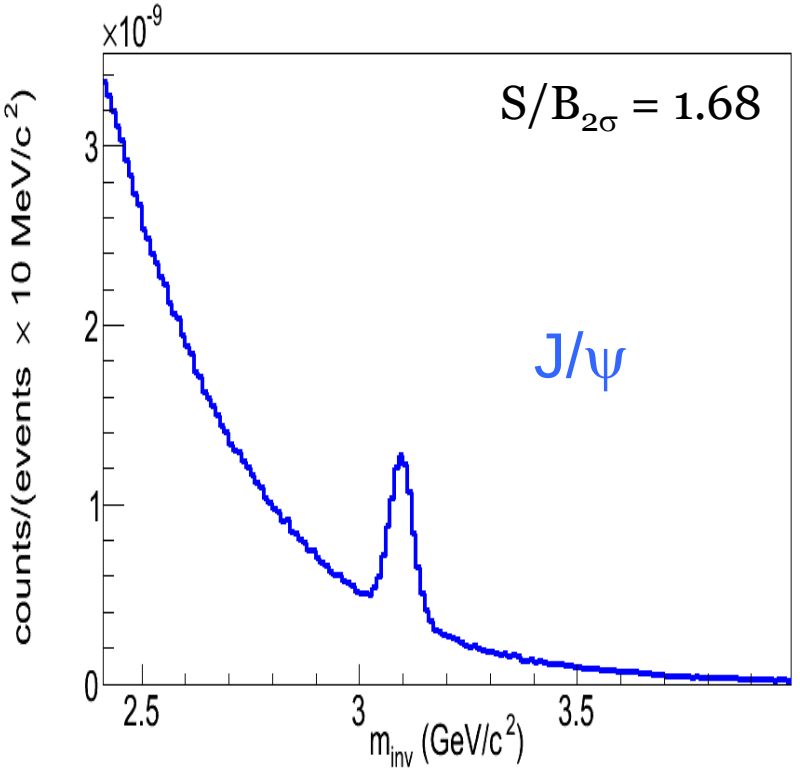
μ-ID in MUCH



Invariant mass spectra – muons

- Shown: central (b=0fm) Au+Au collisions at 25 AGeV
- Mass resolution: 12 MeV (ω) and 29 MeV (J/ψ) only due to momentum determination in STS
- LMVM spectra for SIS100 show similar quality
- J/ψ in central pAu at 30GeV with superb S/B ratio





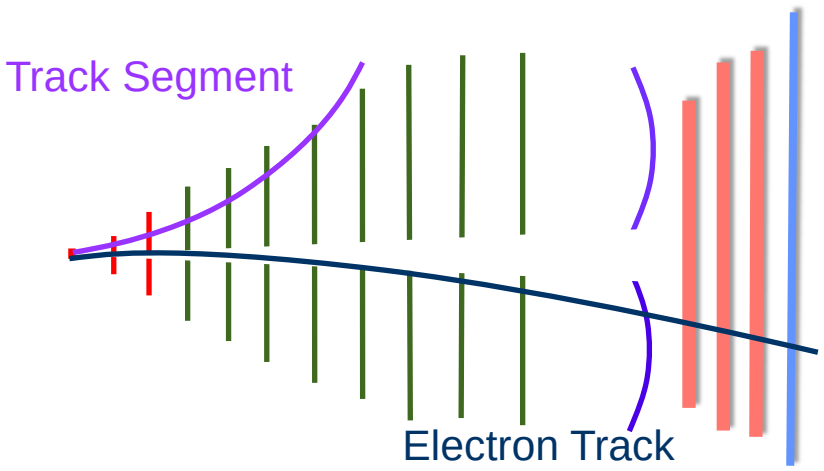
Electron ID – RICH + TRD

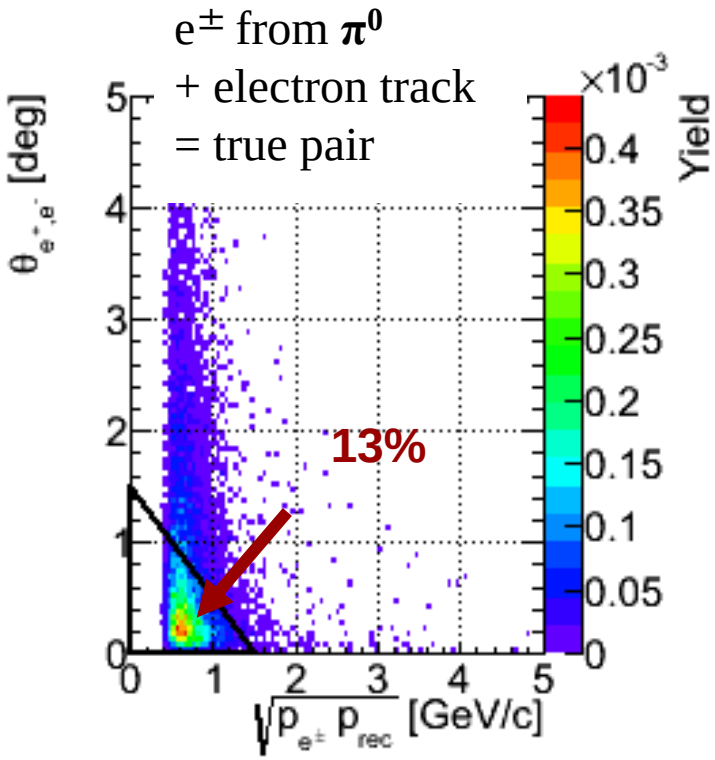
- identification: RICH, TRD and TOF – no e-ID in front of B-field
- **clean electron identification** (π suppression ≥ 10^4)
- **major combinatorial background from physical sources**

  γ-conversions in target and STS, π^0 Dalitz decays

  → use excellent tracking and topological cuts for bg rejection (LMVM)

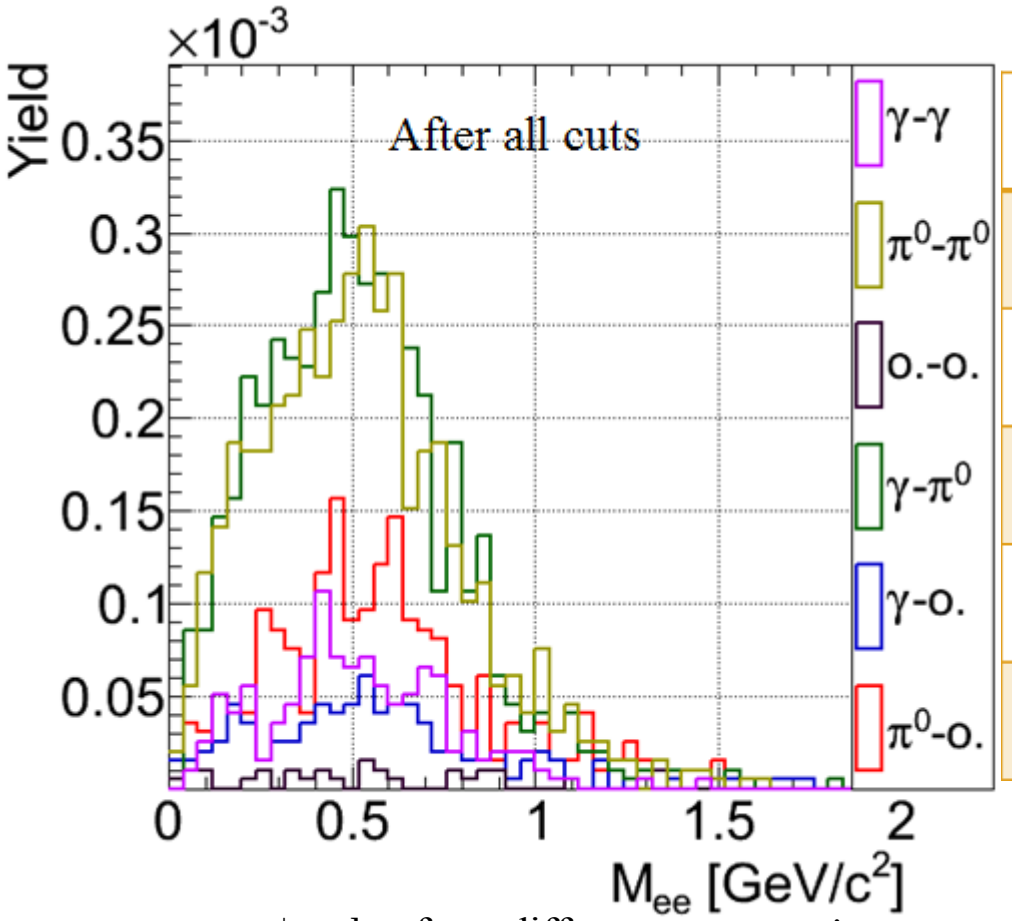
  → use (segmented) target with thin (0.1% int. length) foil(s)





Background contributions – LMVM

central (b=0fm) Au+Au collisions at 25 AGeV, 200k events



γ-γ	8.3%
π^0-π^0	**33.8%**
o.-o.	1.3%
γ-π^0	**35.4%**
γ-o.	6.3%
π^0-o.	14.8%

e± tracks contributing per event:

0.14 from π^0-Dalitz decay (60%)

0.07 from γ-conversion (29%)

0.007 misidentified $\pi^{\pm}$ (3.3%)

0.016 secondary $e^{\pm}$ (7%)

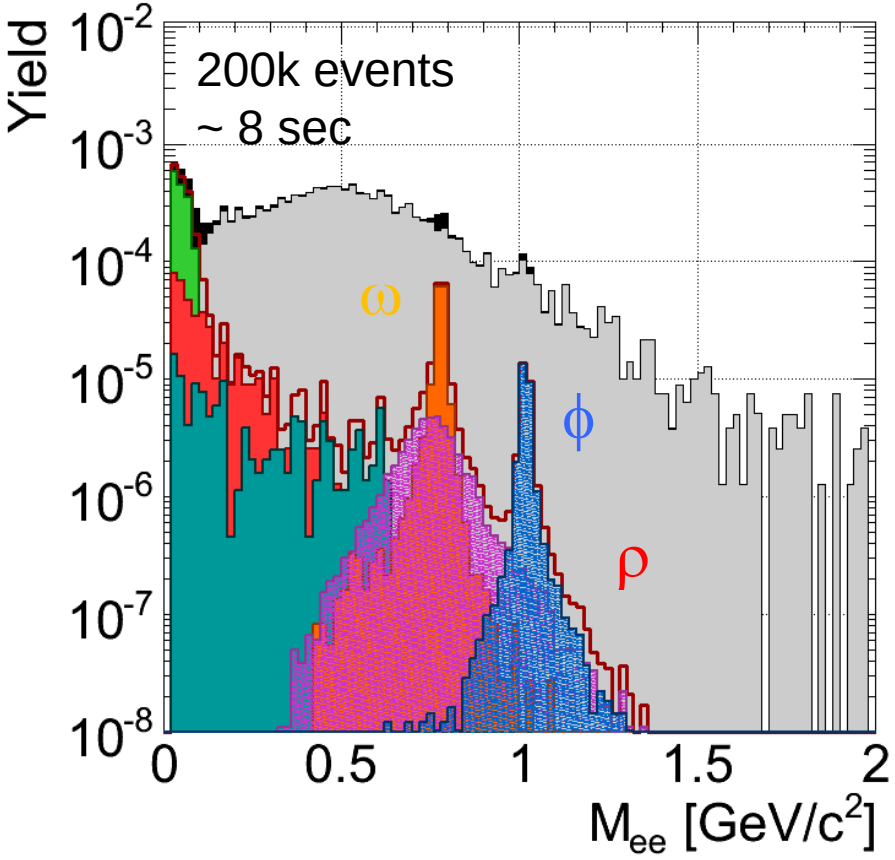
- γ-γ – e^+ and e^- from different γ-conversions
- π^0-π^0 – e^+ and e^- from different π^0-Dalitz decays
- o. - $e^{\pm}$ from other sources including misidentification

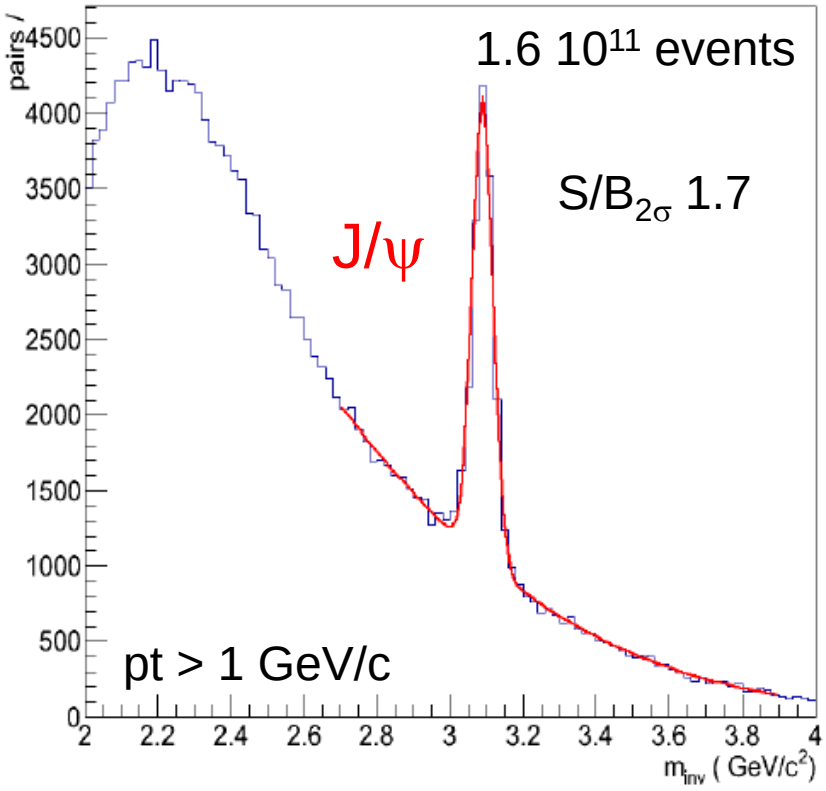
Related Poster

- Di-Electron simulations: G-18

Invariant mass spectra - electrons

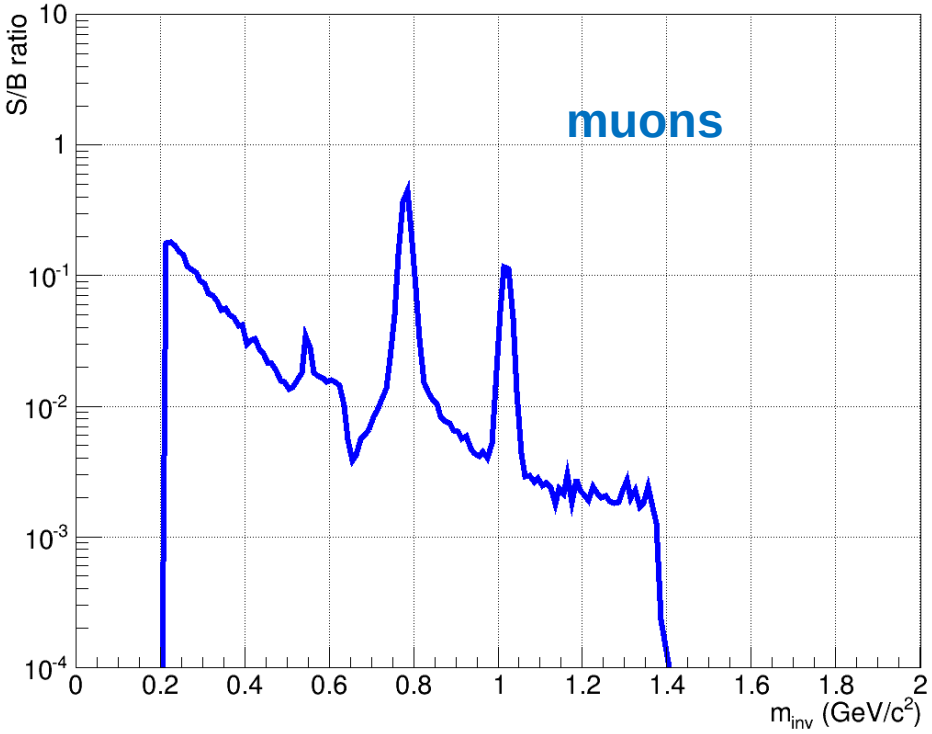
- Shown: central (b=0fm) Au+Au collisions at 25 AGeV
- Mass resolution: 13.6 MeV (ω) and 44 MeV (J/ψ)
- LMVM spectra for SIS100 show similar quality
- J/ψ in central pAu at 30GeV with S/B=1.25 („thick“ 1% int. length target)

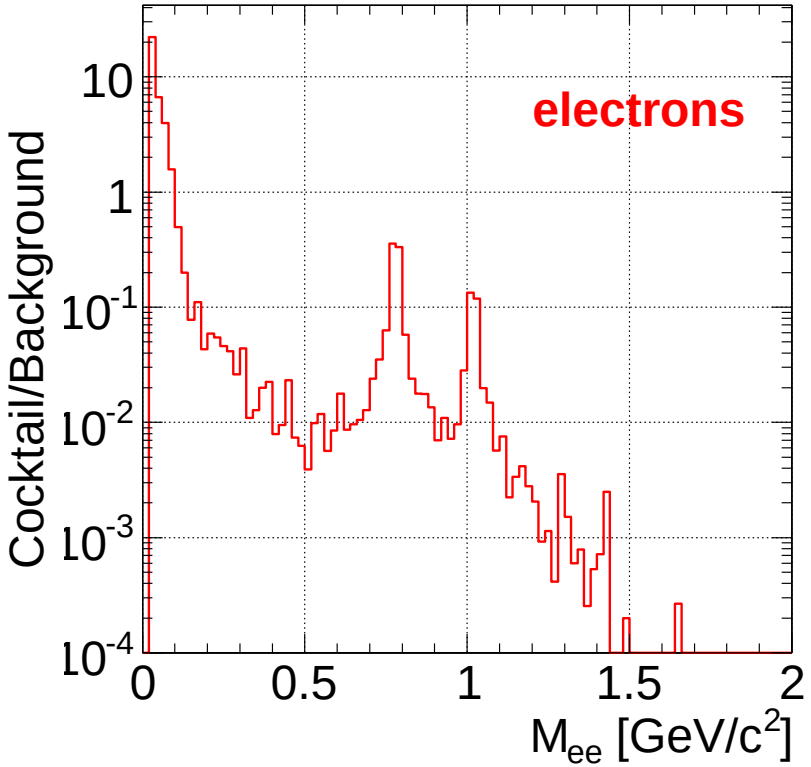




Cocktail/ Background distribution for LMVM

For both setups Cocktail/Background ratios of about 100 are reached in central Au+Au collisions at 25 AGeV for m_{inv} ~ 0.5 – 0.6 GeV/c^2

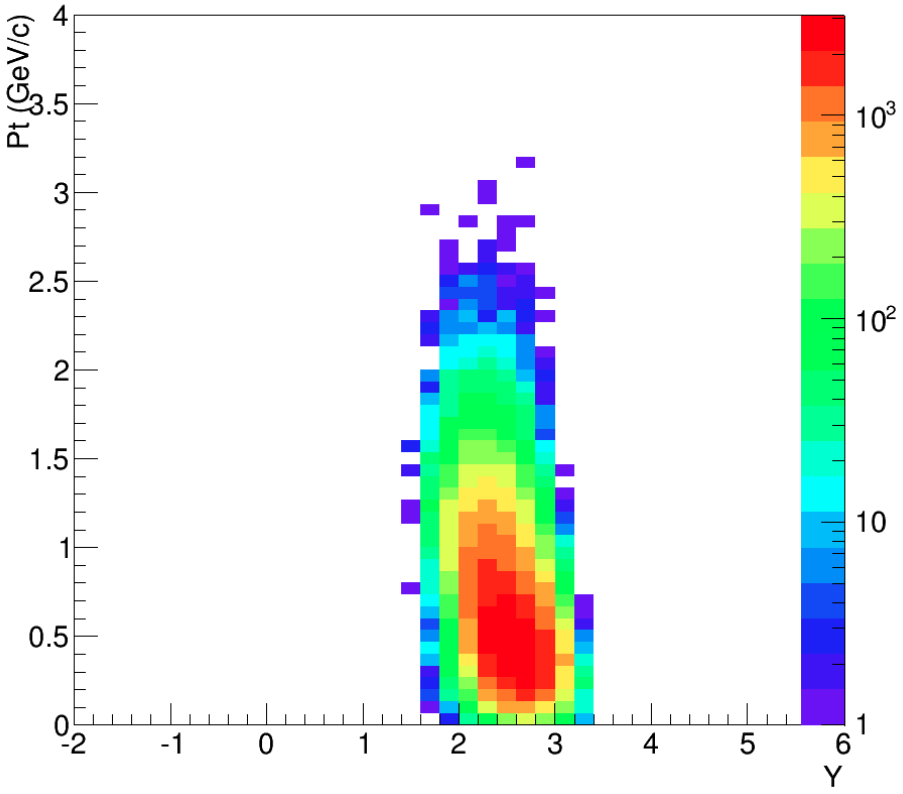




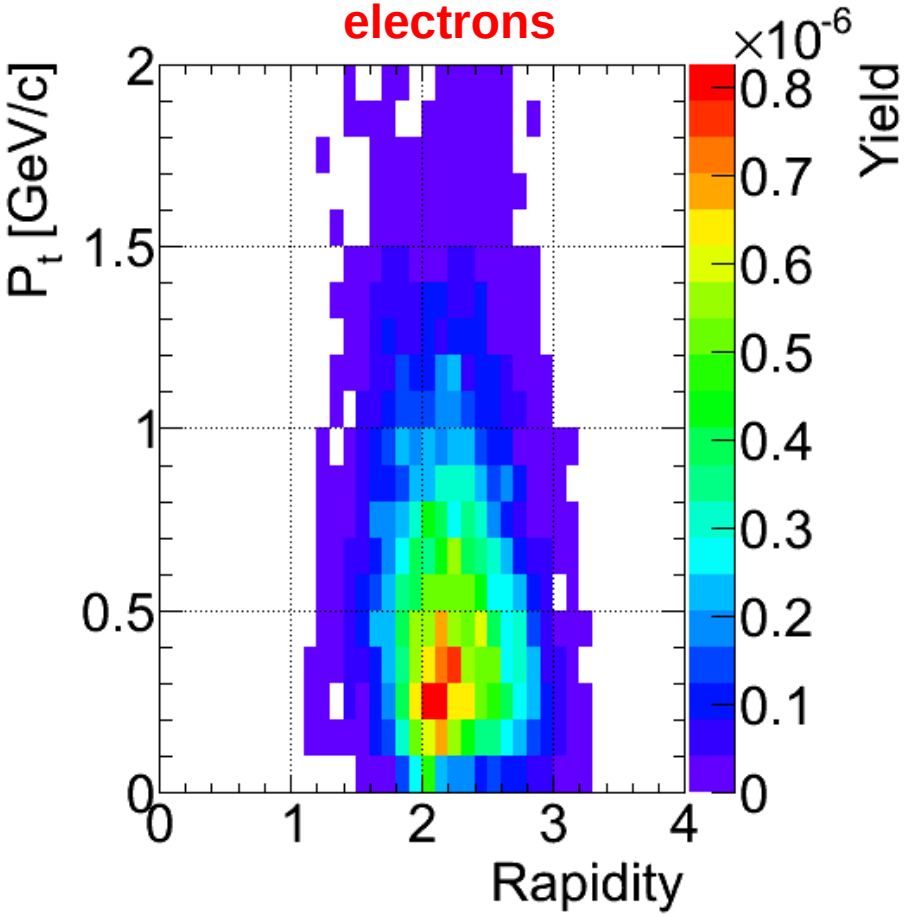
Acceptance – ρ-meson

Central (b=0fm) Au+Au collisions at 25 AGeV
Midrapidity at 2

muons



electrons

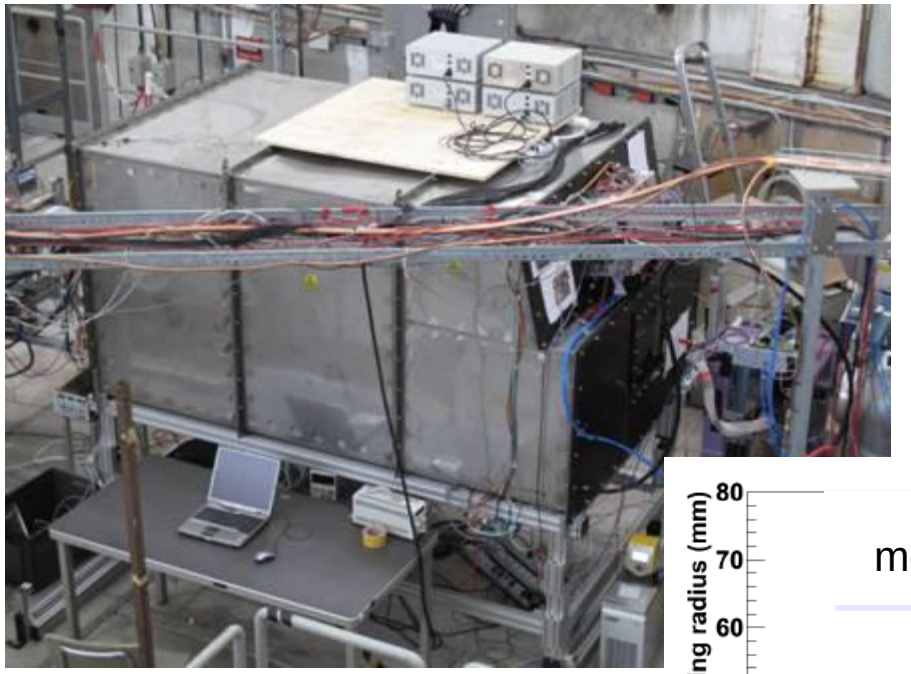


RICH Detector

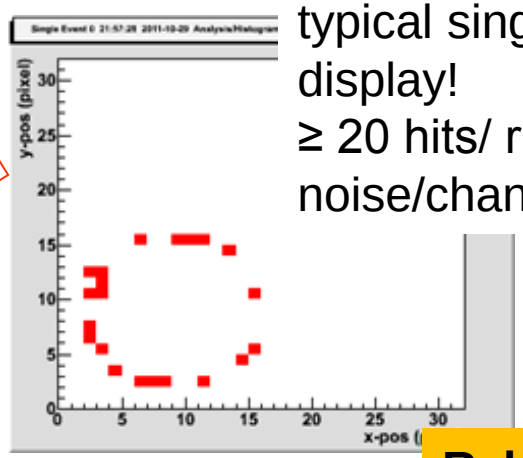
RICH radiator box filled with CO_2

elaborated gas system

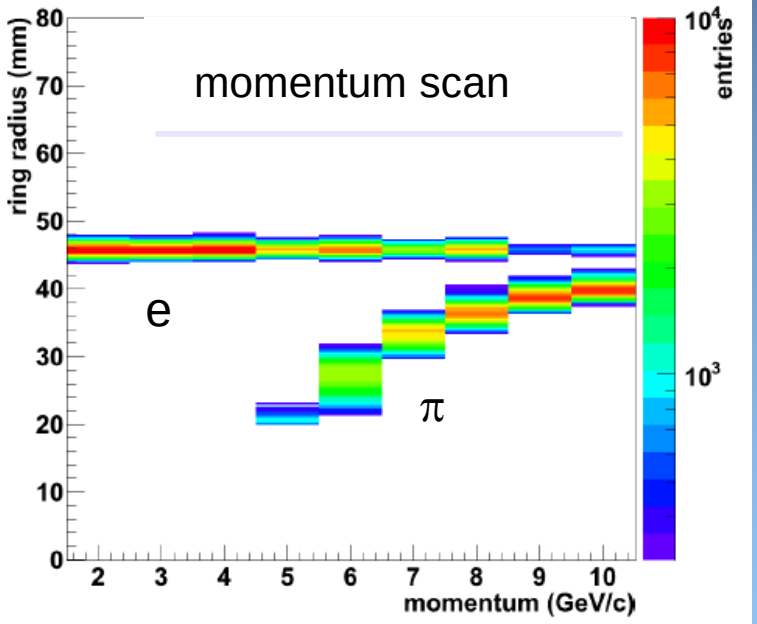
test with mixed e-π beam from 2-10 GeV/c



real dimension prototype in test beam at CERN, October 2011, 2012



typical single event display!
≥ 20 hits/ ring
noise/channel ~10Hz



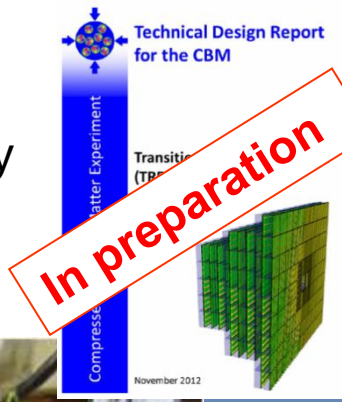
Related Posters

- RICH detector development: M-09, M-10, M-11

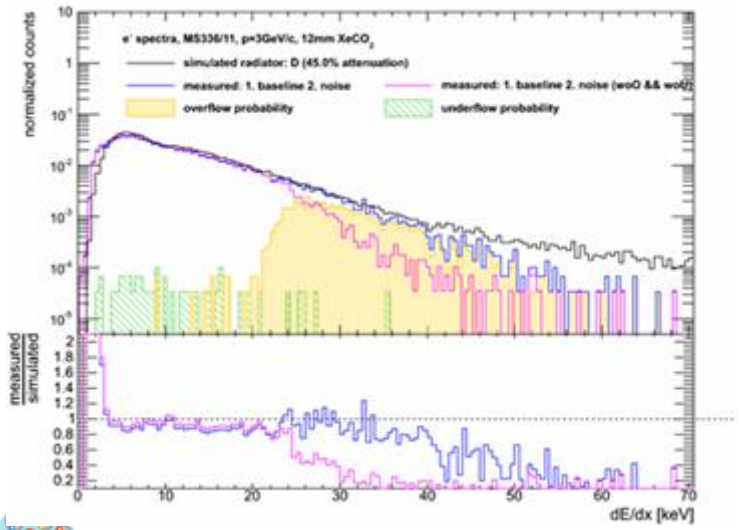
TRD detector

beamtest at CERN, October 2011, 2012:

- 2011: test 12 different chamber types (w & w/o drift, distances…)
- test different radiator types (fibers, foils, foams)
- very nice agreement of simulated and measured data for the energy spectra
- 2012: real dimension chambers succesfully tested (59x59)cm^2

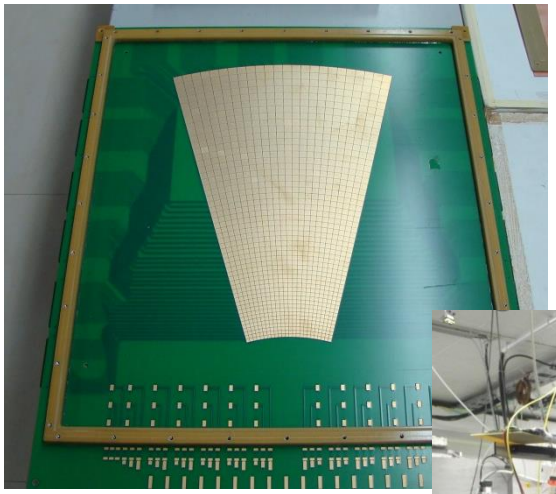


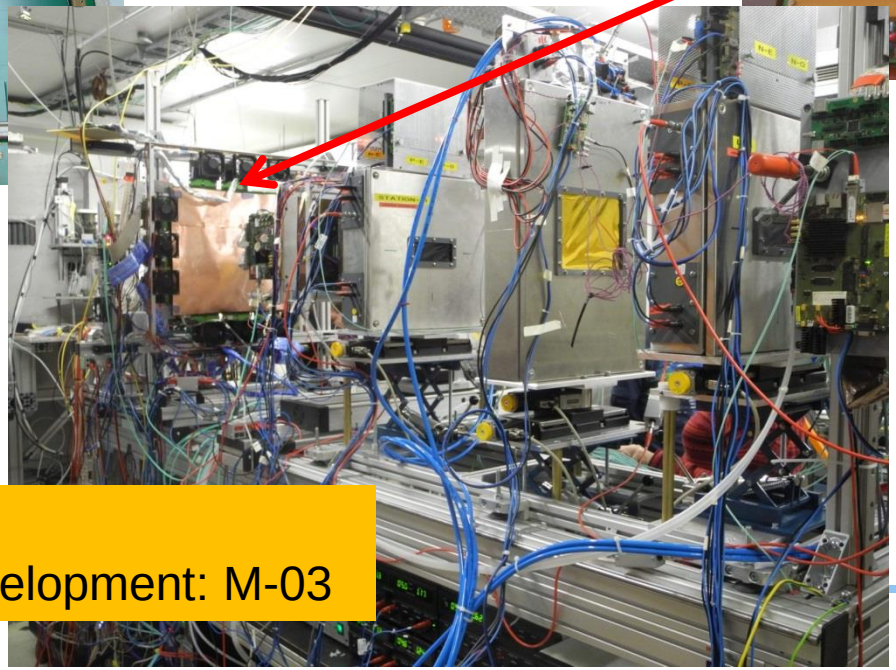
e-spectrum



MUCH detector

- Several succesful testbeam campaigns at CERN and COSY including a „mini-MUCH“ setup with absorbers
- > 90% efficiency, rate capability ok
- Large triple GEM chamber built (31x31 cm^2), sector based readout



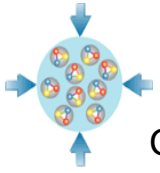


Related Poster

- MUCH detector development: M-03

Summary

- **FAIR** construction progressing well: first beams 2018
- **CBM**
  - Status of experiment preparation: Prototype detector performances fulfill CBM requirements, TDRs!
  - Funding: Substantial part of the CBM start version for SIS100 is financed (incl. planned applications)
- **Di-Lepton feasibility studies in CBM:**
  - Di-Muons: simulations based on realistic assumptions on signal cocktail, background and detector responses; next step: Implementation of straw-tube detectors for the stations 4 and 5
  - Di-Electrons: detailed investigation of background performed; next step: realistic detector description (TRD, TOF), further optimization (MVD)
  - Photons (not shown): Proof of principle ok, more details soon
  - All measurements well feasible with very good S/B ratios; di-electrons and di-muons complementary for detailed investigation of baryon dominated matter



CBM collaboration

China:
Tsinghua Univ., Beijing
CCNU Wuhan
USTC Hefei

Croatia:
University of Split

Czech Republic:
CAS, Rez
Techn. Univ. Prague

France:
IPHC Strasbourg

Hungaria:
Wigner IPNP, Budapest
Eötvös Univ. Budapest

Germany:
TU Darmstadt
Univ. Gießen
Univ. Heidelberg, Phys. Inst.
Univ. Heidelberg, ZITI
Univ. Frankfurt
FIAS Frankfurt
Univ. Münster
FZ Rossendorf
GSI Darmstadt
FAIR Darmstadt
Univ. Tübingen
Univ. Wuppertal

India:
Aligarh Muslim Univ., Aligarh
IOP Bhubaneswar
Panjab Univ., Chandigarh
Gauhati Univ., Guwahati
Univ. Rajasthan, Jaipur
Univ. Jammu, Jammu
IIT Kharagpur
SAHA Kolkata
Univ Calcutta, Kolkata
VECC Kolkata
Univ. Kashmir, Srinagar
Banaras Hindu Univ., Varanasi
Inst. of Tech., Indore, India

Korea:
Pusan National Univ.

Poland:
Krakow Univ.
Warsaw Univ.
Warsaw Univ. of Tech.
Silesia Univ. Katowice
Nucl. Phys. Inst. Krakow

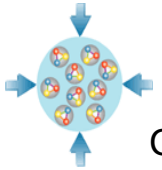
Romania:
NIPNE Bucharest
Bucharest University

Russia:
IHEP Protvino
INR Moscow
ITEP Moscow
KRI, St. Petersburg
Kurchatov Inst. Moscow
VBLHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP, Moscow State Univ.
St. Petersburg Polytec. U.

Ukraine:
KINR, Kiev
Shevchenko Univ. , Kiev

56 institutions, > 400 members

Backup



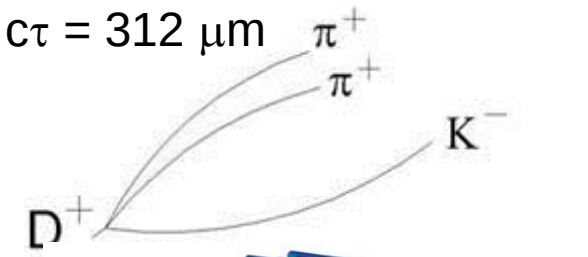
STS tracking – heart of CBM

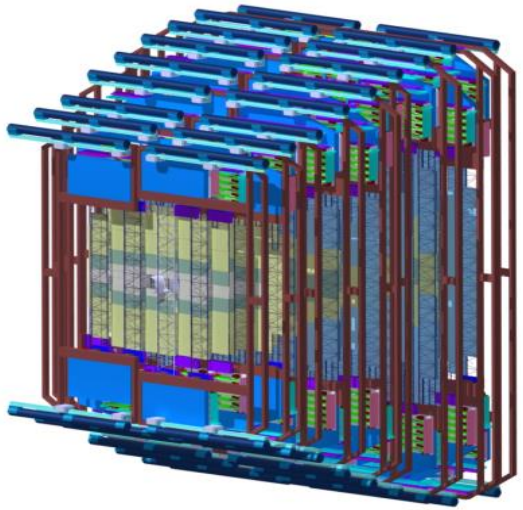
Challenge: high track density: ≈ 600 charged particles in ± 25° @ 10MHz

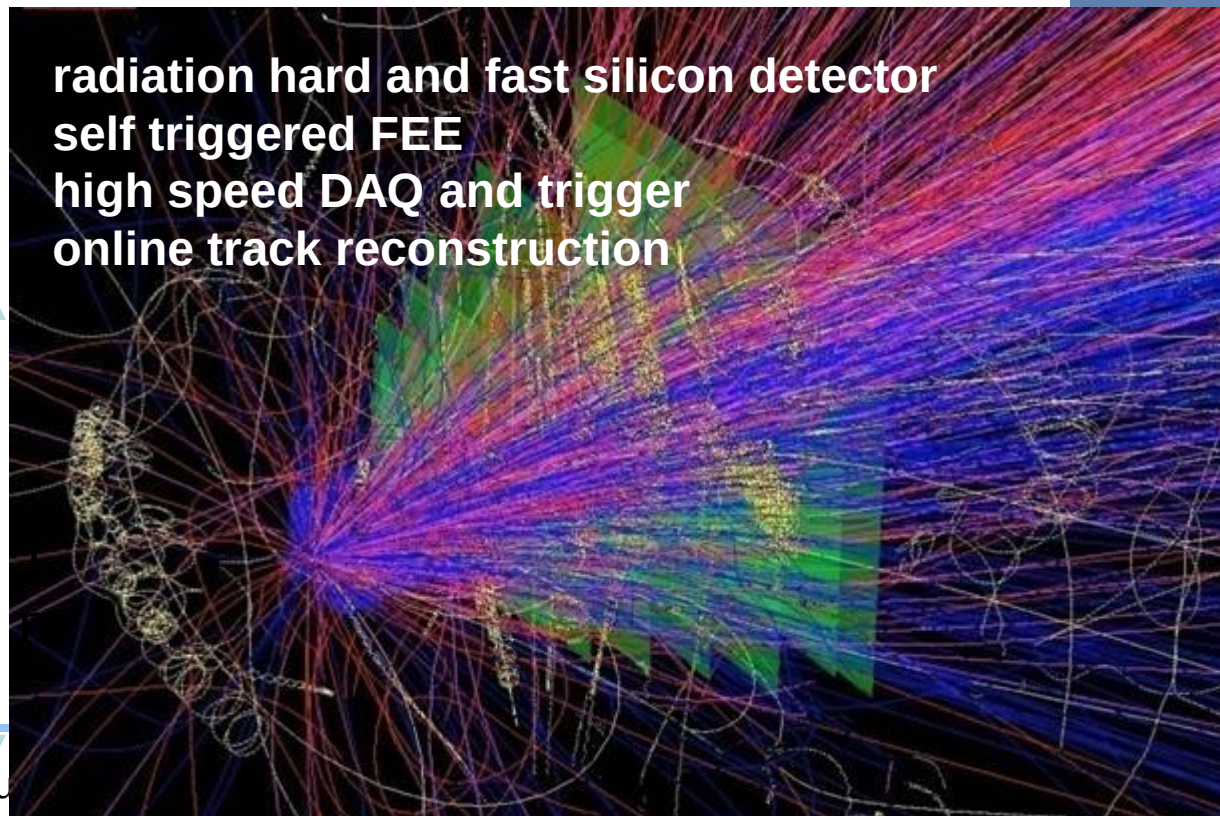
Task

- track reconstruction: 0.1 GeV/c < p ≤ 10-12 GeV/c $\Delta p/p$ ~ 1% (p=1 GeV/c)
- primary and secondary vertex reconstruction (resolution ≤ 50 μm)
- V_0 track pattern recognition

→ make use of excellent tracking for background suppression and momentum determination for dileptons



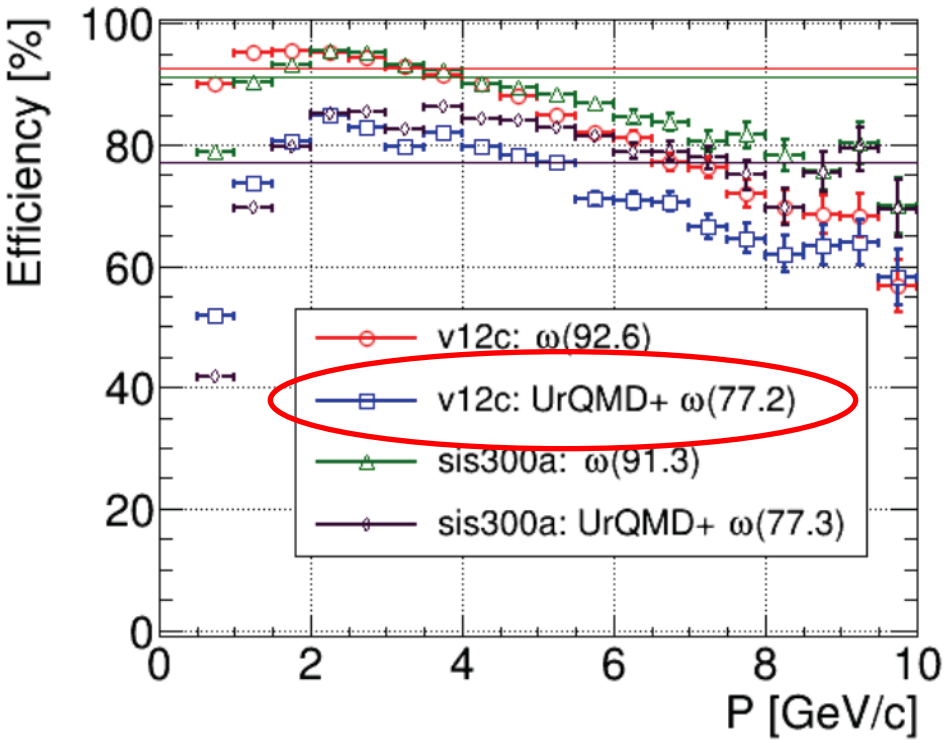




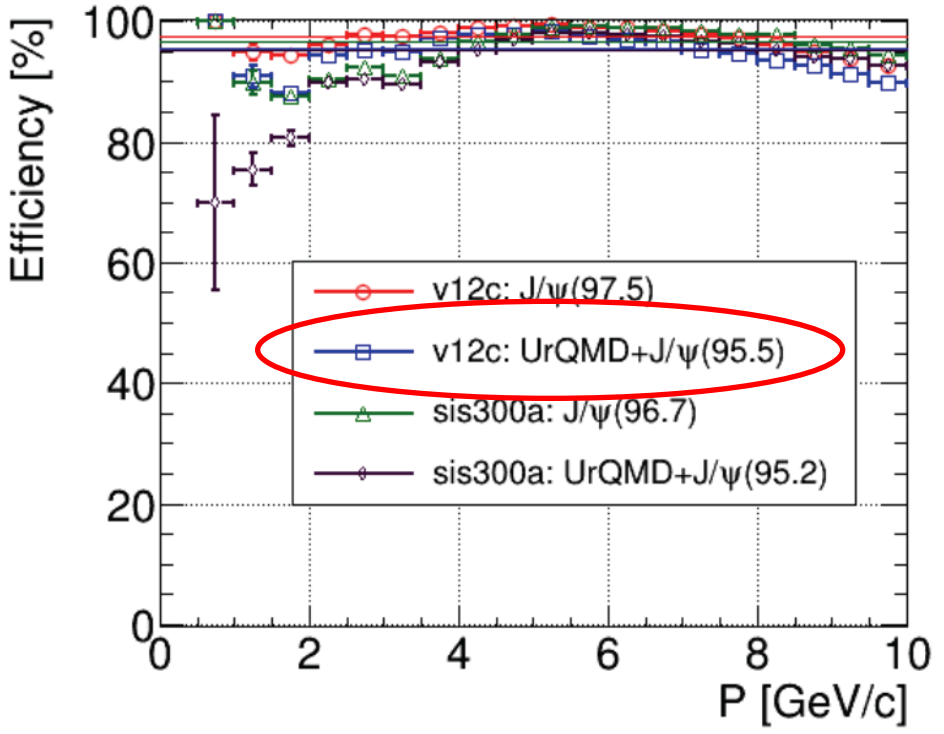
MUCH – tracking performance

- Tracking performance for μ from ω and J/ψ embedded in central Au+Au events (UrQMD) at 25 AGeV of 77% and 95% respectively

LMVM setup (reduced absorber length)



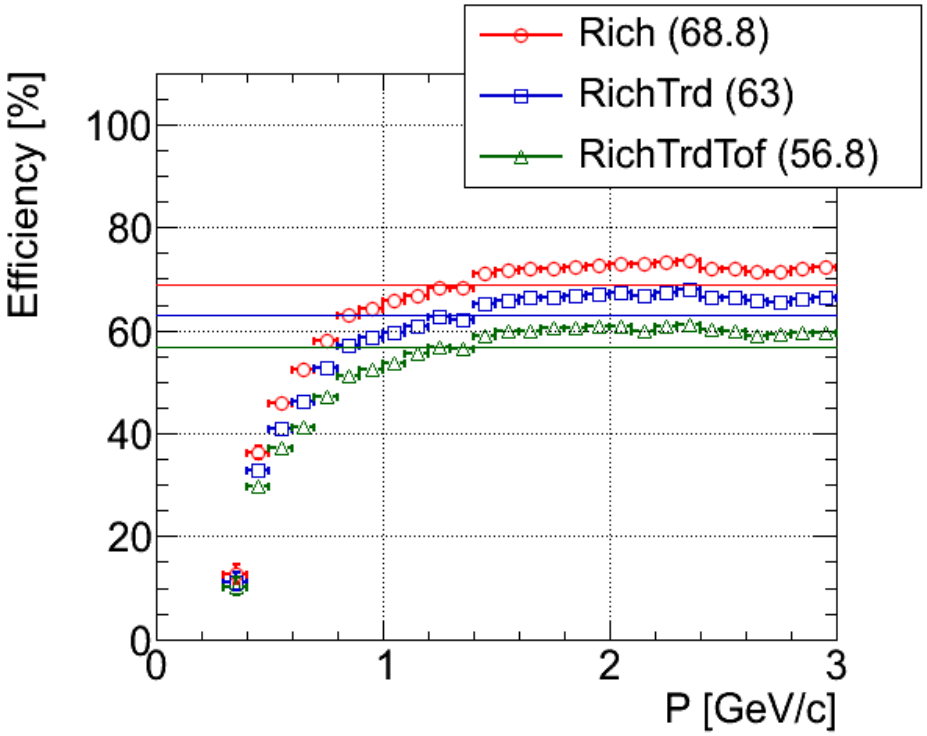
J/ψ setup (full absorber length)

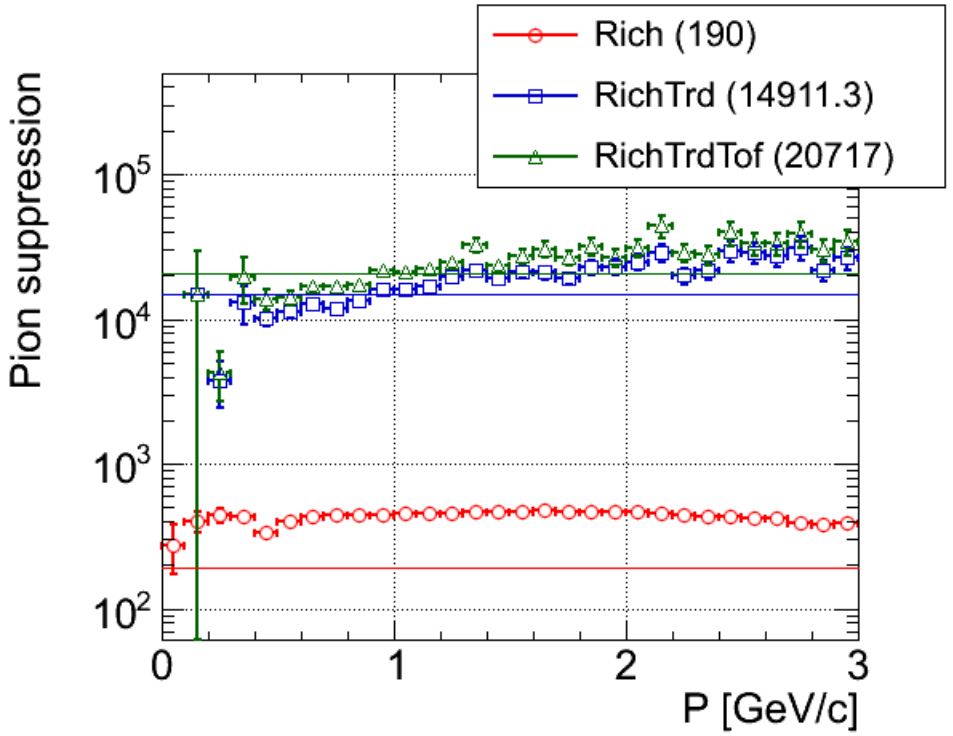


Electron identification

- global tracking + matching efficiency (STS, RICH, TRD, TOF) ~ 68% for p = 2 GeV/c
- e-ID in all detectors required: RICH, TRD, TOF

Central Au+Au, 25 AGeV

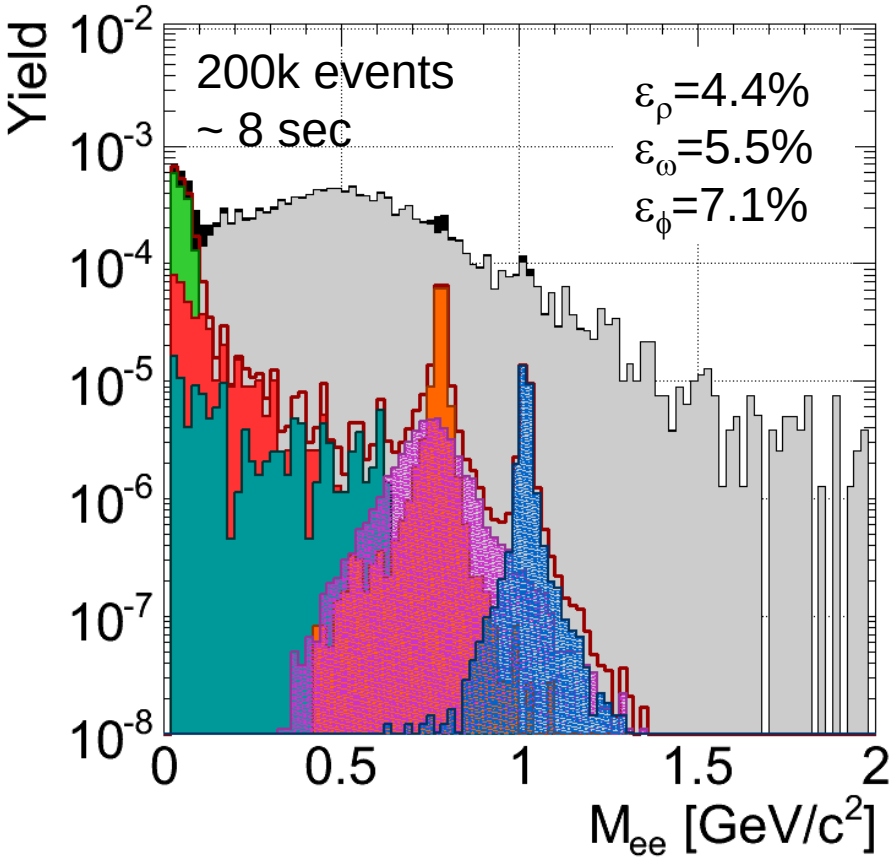


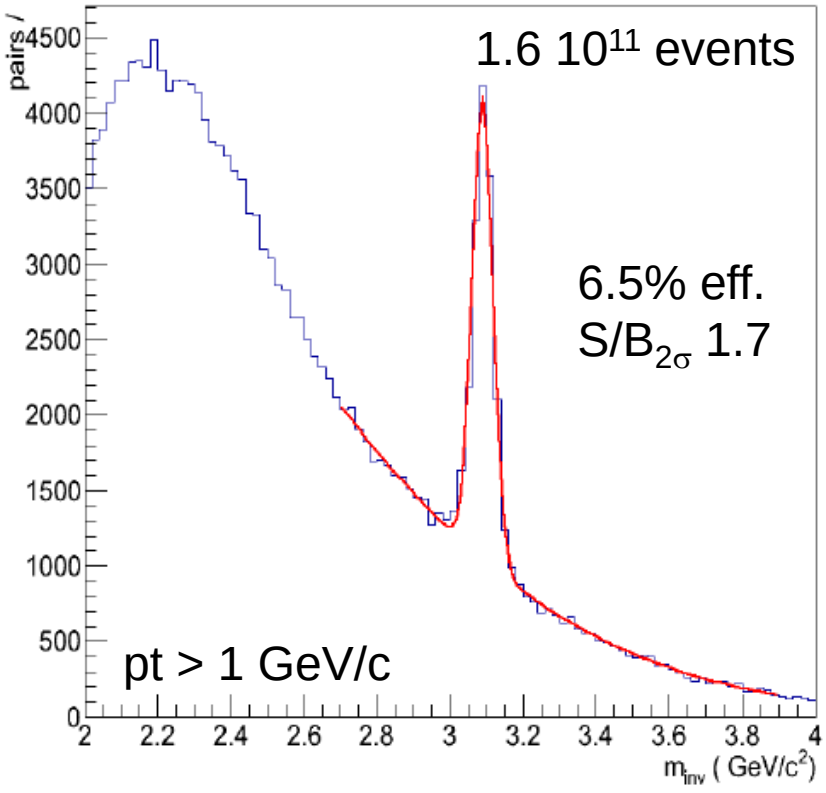


integrated numbers in brackets are for full momentum range

Invariant mass spectra - electrons

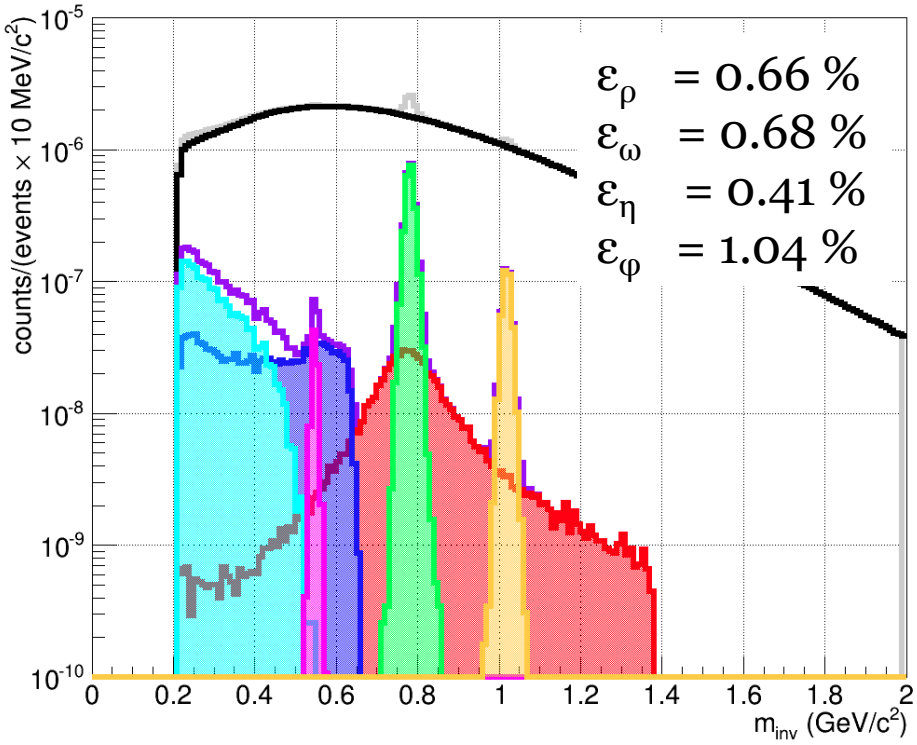
- Shown: central (b=0fm) Au+Au collisions at 25 AGeV
- Mass resolution: 13.6 MeV (ω) and 44 MeV (J/ψ)
- LMVM spectra for SIS100 show similar quality
- SIS100: J/ψ in central pAu at 30GeV

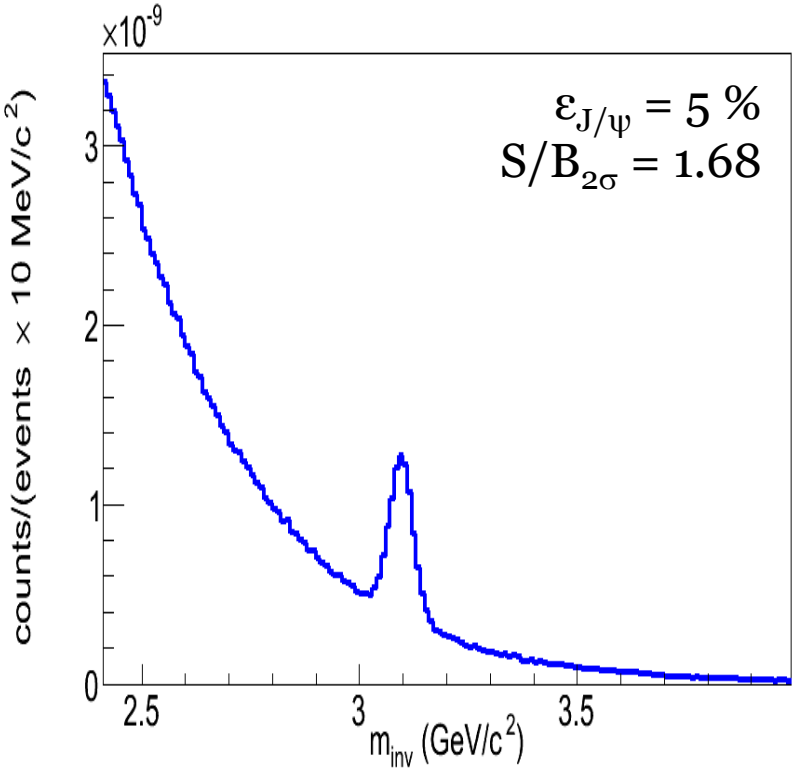




Invariant mass spectra – muons

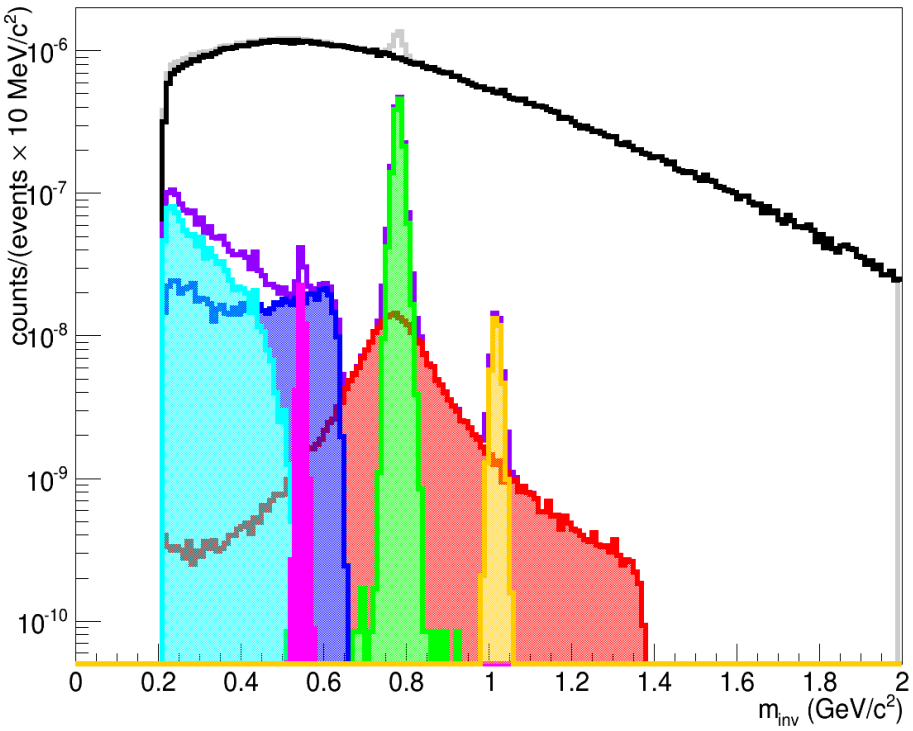
- Shown: central (b=0fm) Au+Au collisions at 25 AGeV
- Mass resolution: 12 MeV (ω) and 29 MeV (J/ψ) only due to momentum determination in STS
- LMVM spectra for SIS100 show similar quality
- J/ψ in central pAu at 30GeV with superb S/B ratio



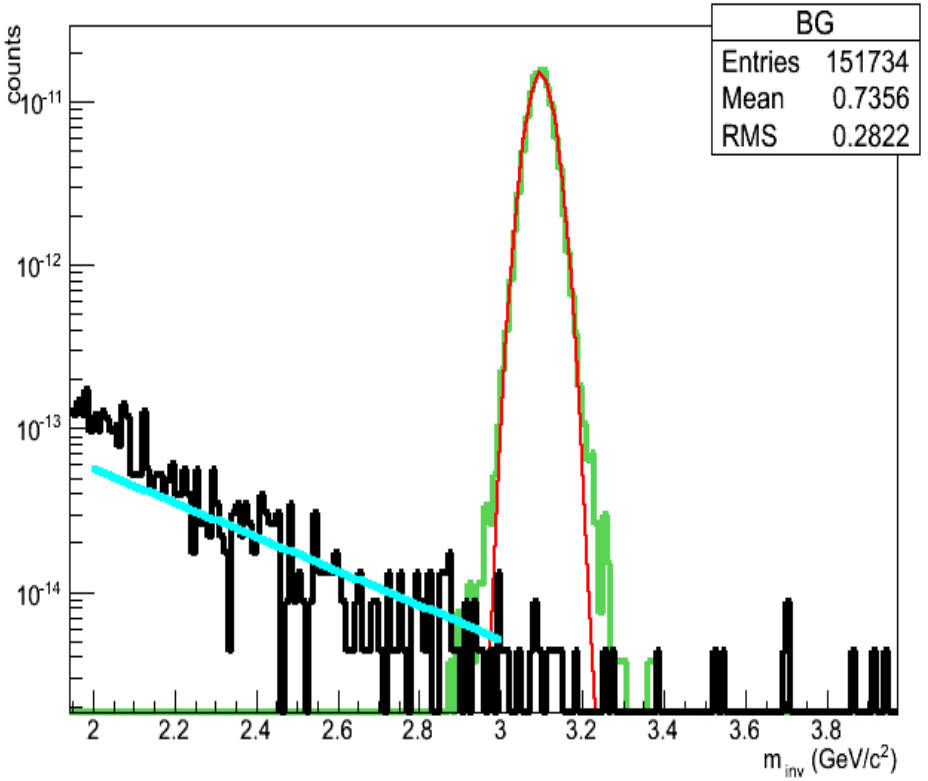


SIS 100 – muons

Central Au+Au, 8AGeV

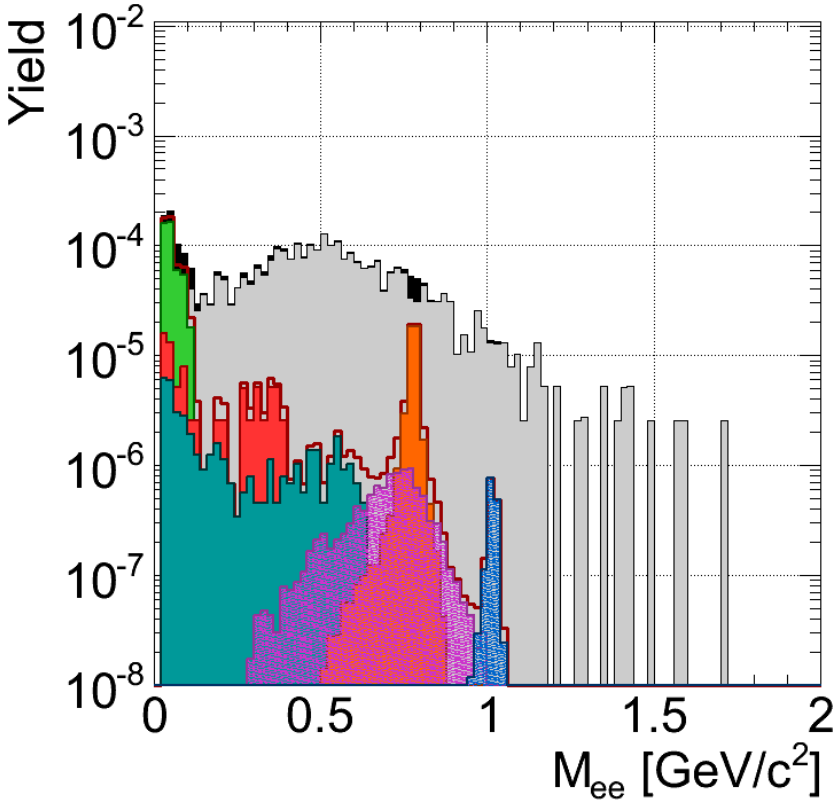


pAu, 30 GeV



SIS 100 – electrons

Central Au+Au, 8AGeV



pAu, 30 GeV