# Di-muon Measurements with the CBM Experiment at FAIR

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VECC, Kolkata

“Advanced Detectors for Nuclear, High Energy and Astroparticle Physics”

# Outline

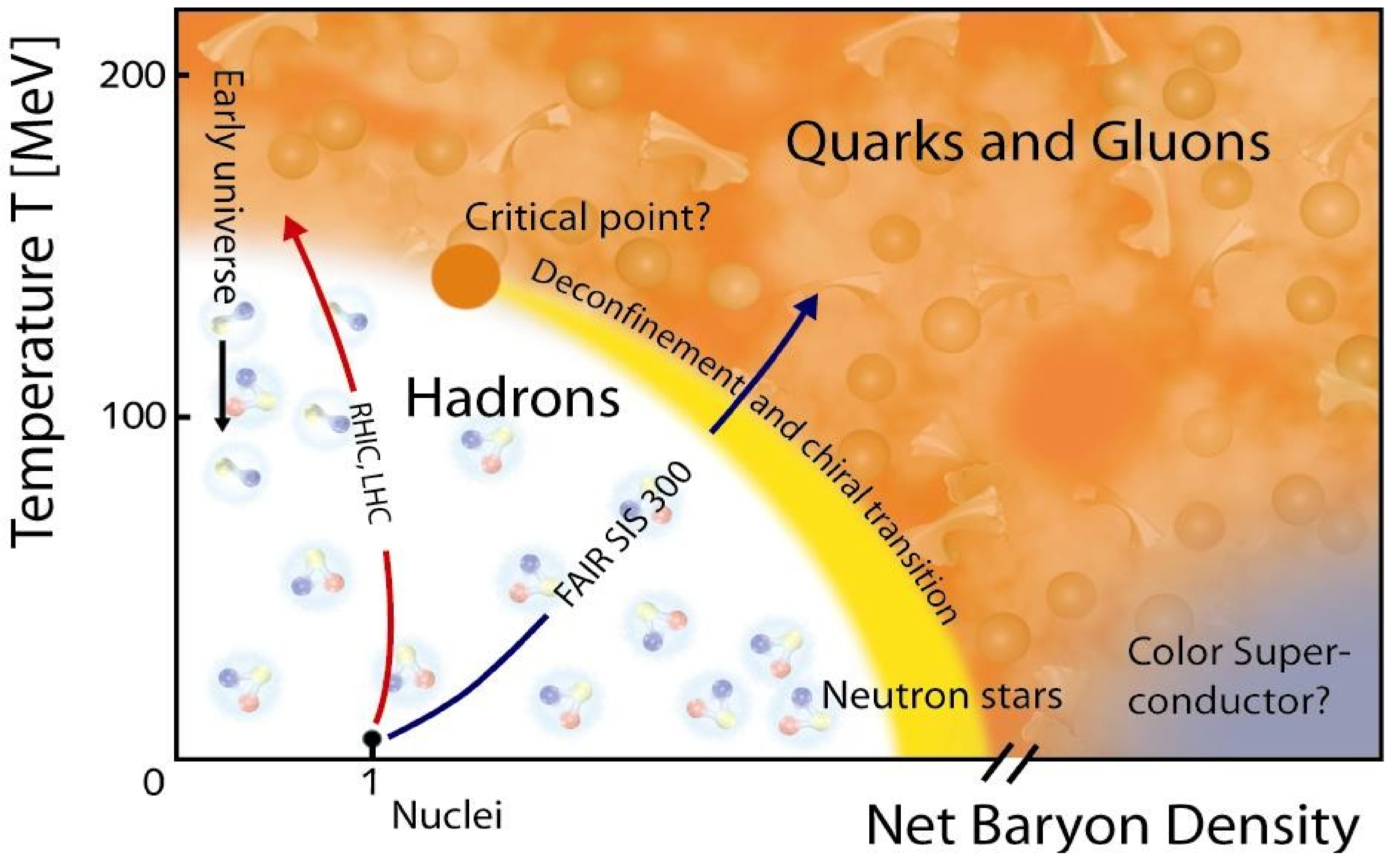
## CBM Experiment @ FAIR

- Overview of CBM experiment
- CBM Experimental set-up
- Experimental challenges

## Simulation study on Dimuon measurement at CBM

- Design of Dimuon detection system
- Dimuon measurement technique
- Feasibility of detection of low mass vector mesons which decay into dimuon channel [$\rho,\omega,\phi \rightarrow (\mu^+\mu^-)$ ].

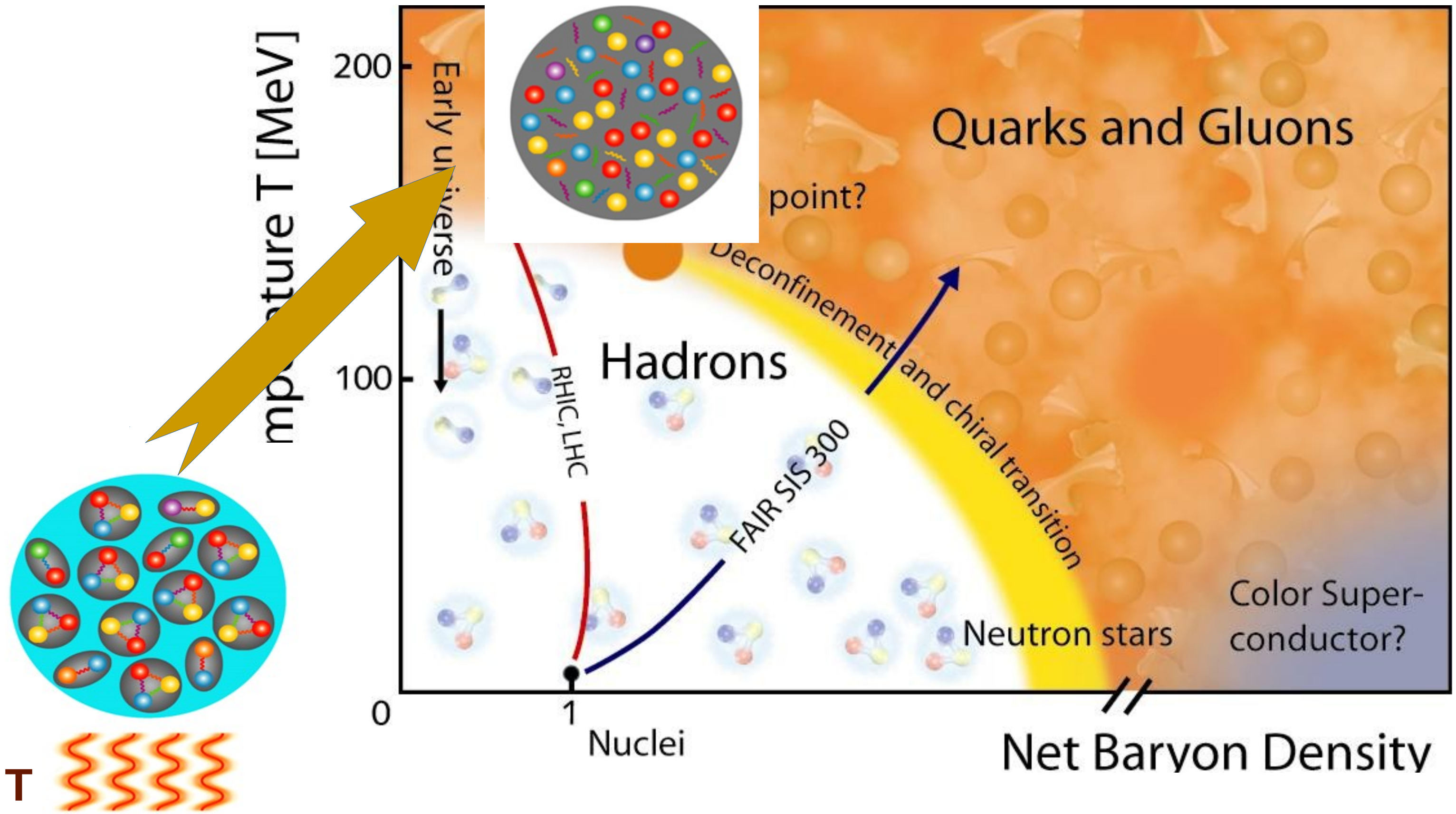
# Exploring QCD-phase diagram




- **Two regions in phase diagram hadronic phase and Quark gluon plasma phase & they are separated by a phase boundary. Lot of efforts are being made to locate this phase boundary of nuclear matter both theoretically and experimentally.**

- **There are two extremes in QCD phase diagram : High temperature /low net baryon density and low temperature /high net baryon density region.**

# Exploring QCD-phase diagram

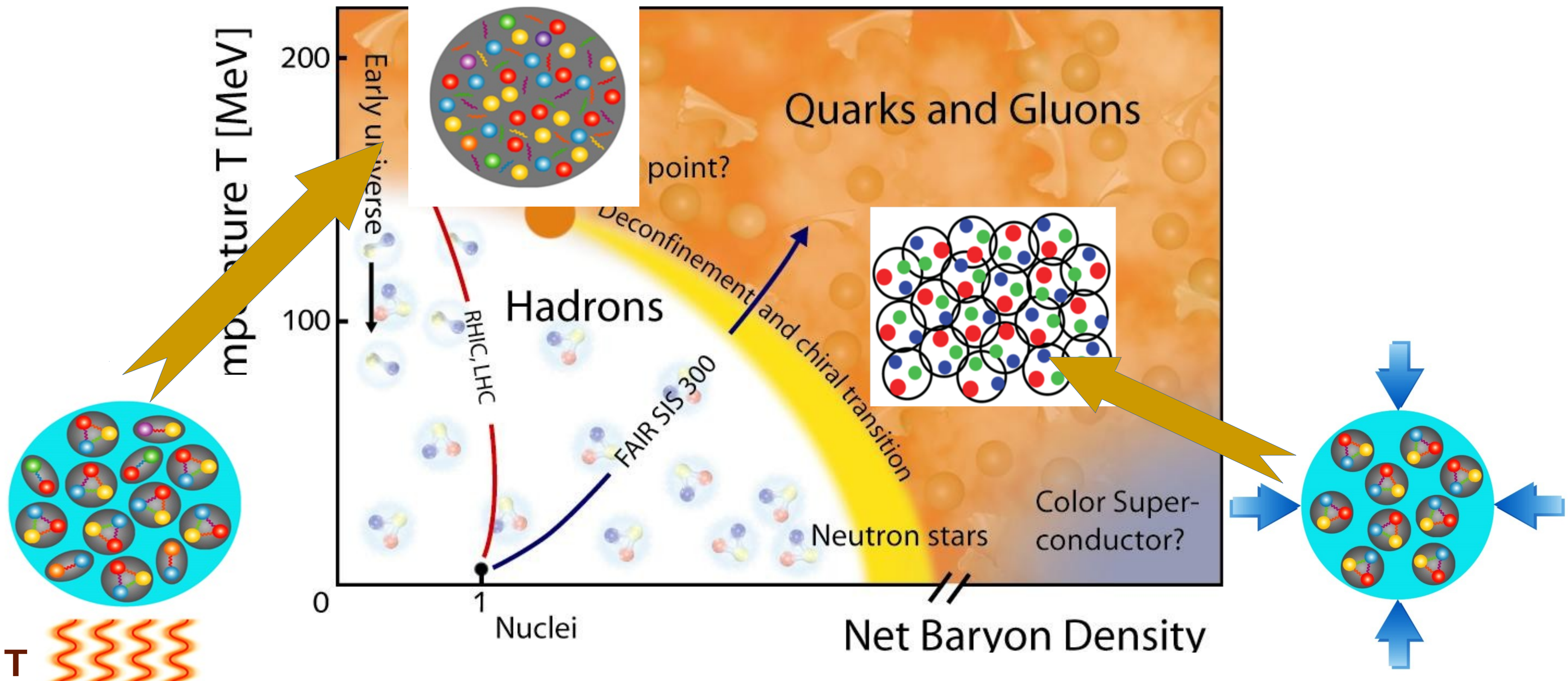



**At very high temperature:**

- **N of baryons ≈ N of antibaryons**
  **Situation similar to early universe**
- **L-QCD finds crossover transition between hadronic matter and Quark-Gluon Plasma**

- **Experiments:**
  **LHC, RHIC top energy (√s = 200 GeV)**

# Exploring QCD-phase diagram




**At very high temperature:**

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- **Experiments:**
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**At high baryon density:**

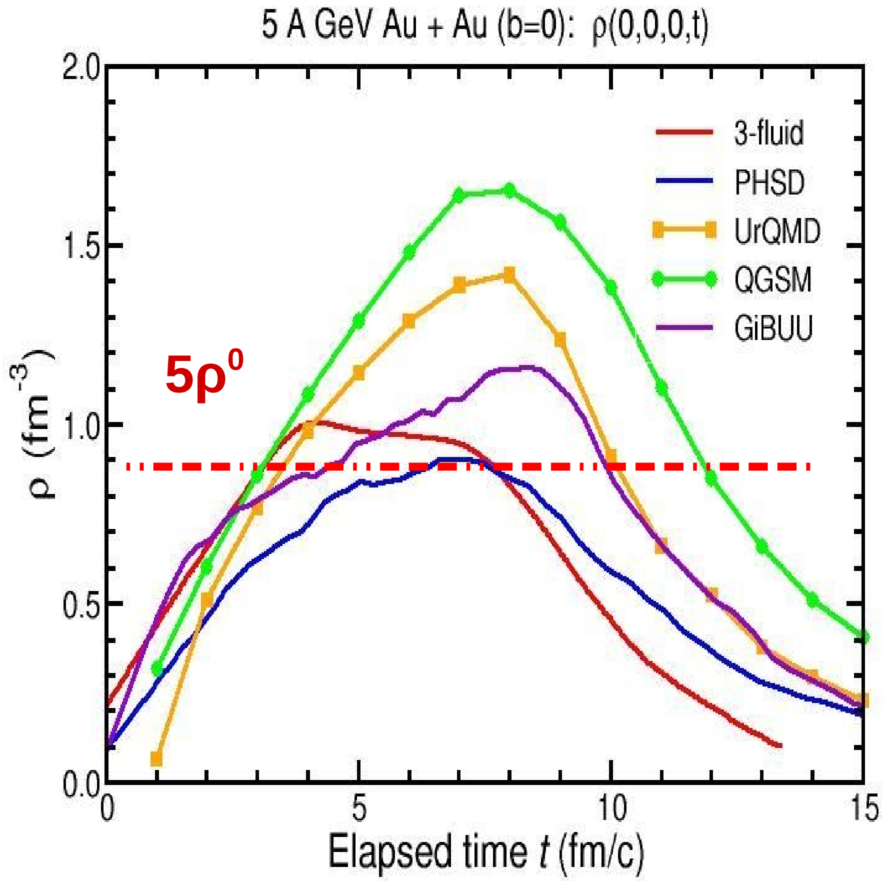
- **N of baryons >> N of anti-baryons**
  **Densities like in neutron star cores**
- **Models predict first order phase transition with possible existence of mixed phase.**

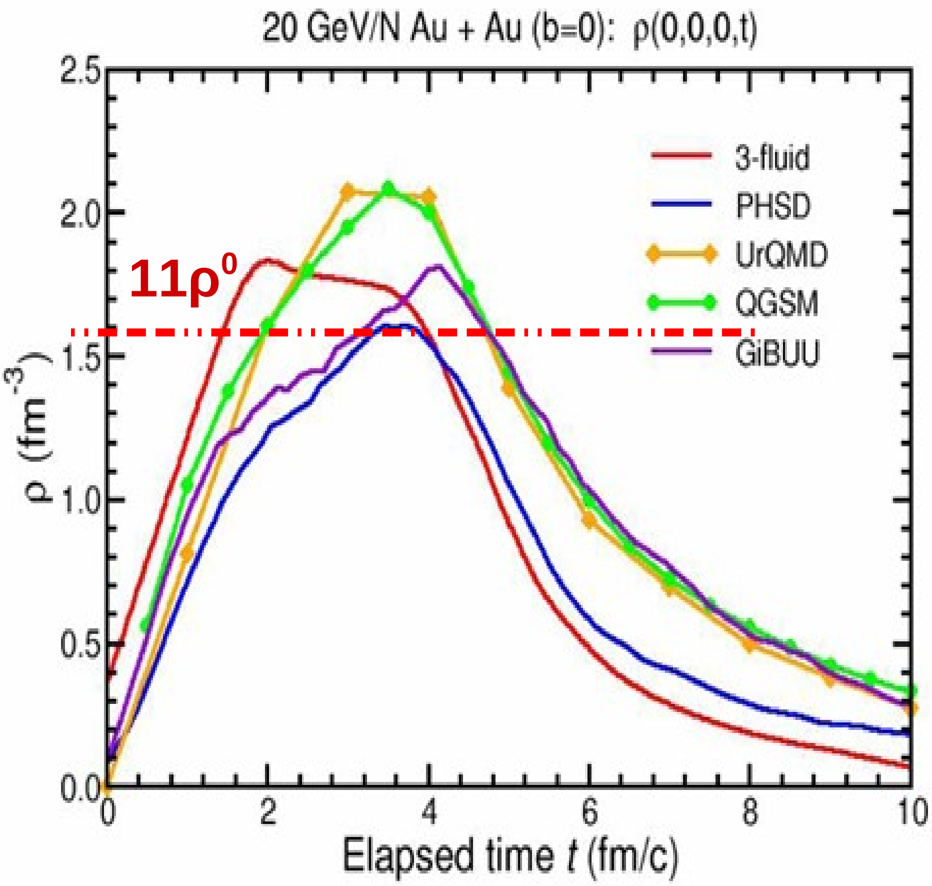
- **Experiments:**
  **BES at RHIC, NA61 CERN SPS,**
  **CBM at FAIR, NICA at JINR**


CBM is an upcoming experiment at Facility for Anti-Proton and Ion Research (FAIR) in Darmstadt, Germany .
It is a fixed target experiment using heavy-ion beams from 4-(35)45 A GeV.
Designed and dedicated to explore the QCD phase diagram in the regime of moderate temperatures and high net-baryon densities.

# Baryon density Evolution at CBM

**Model calculation predicts that Matter density may reach 5-10 times normal nuclear density ($\rho^0$~0.14 /fm$^3$ ) depending on collision energy.**

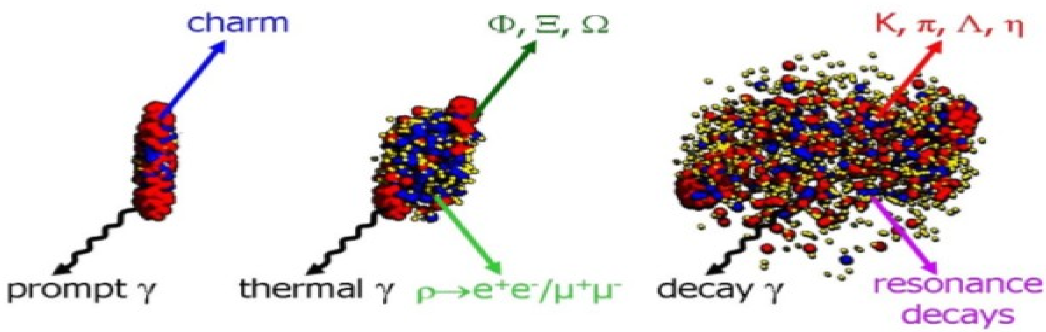



Ref : I.C. Arsene et al., Phys. Rev. C 75, 24902 (2007)

**So we can expect a baryon rich QGP at CBM energy.**

# CBM Physics cases and observables




- **The equation-of-state of high baryon density matter**
  collective flow of hadrons

- **Indication of Deconfinement phase transition at high $\rho_B$**
  –Yield ,spectra, collective flow of strange (K, Λ, Σ, Ξ, Ω), Charmed particles (J/ψ, ψ', D0, Ds, D±, Λc) and dileptons
  – Charmonium suppression, J/ψ.
  – Strangeness enhancement

- **QCD Critical End Point (CEP)**
  Event by Event fluctuations of conserved quantities and particle ratios (**K/π**, **…** **Ξ/** π**, Ω/** π)

- **Onset of chiral symmetry restoration at high $\rho_B$**
  In-medium properties of hadrons will be changed. (Mass shift and broadening in the medium).
  **(ρ,ω,ϕ →e+e-(μ+μ-)**

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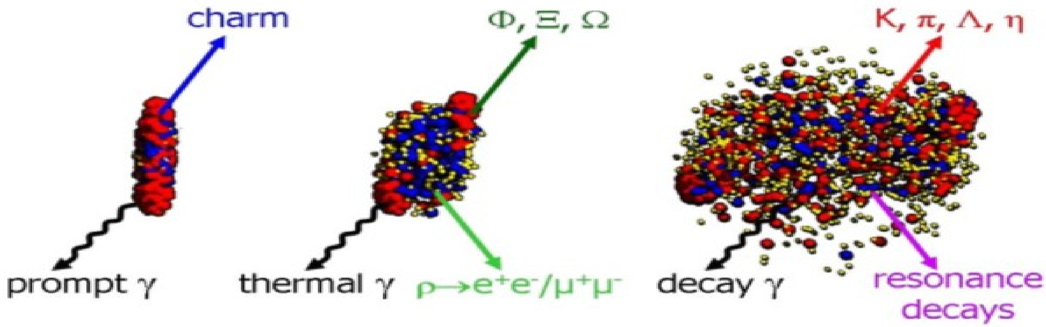


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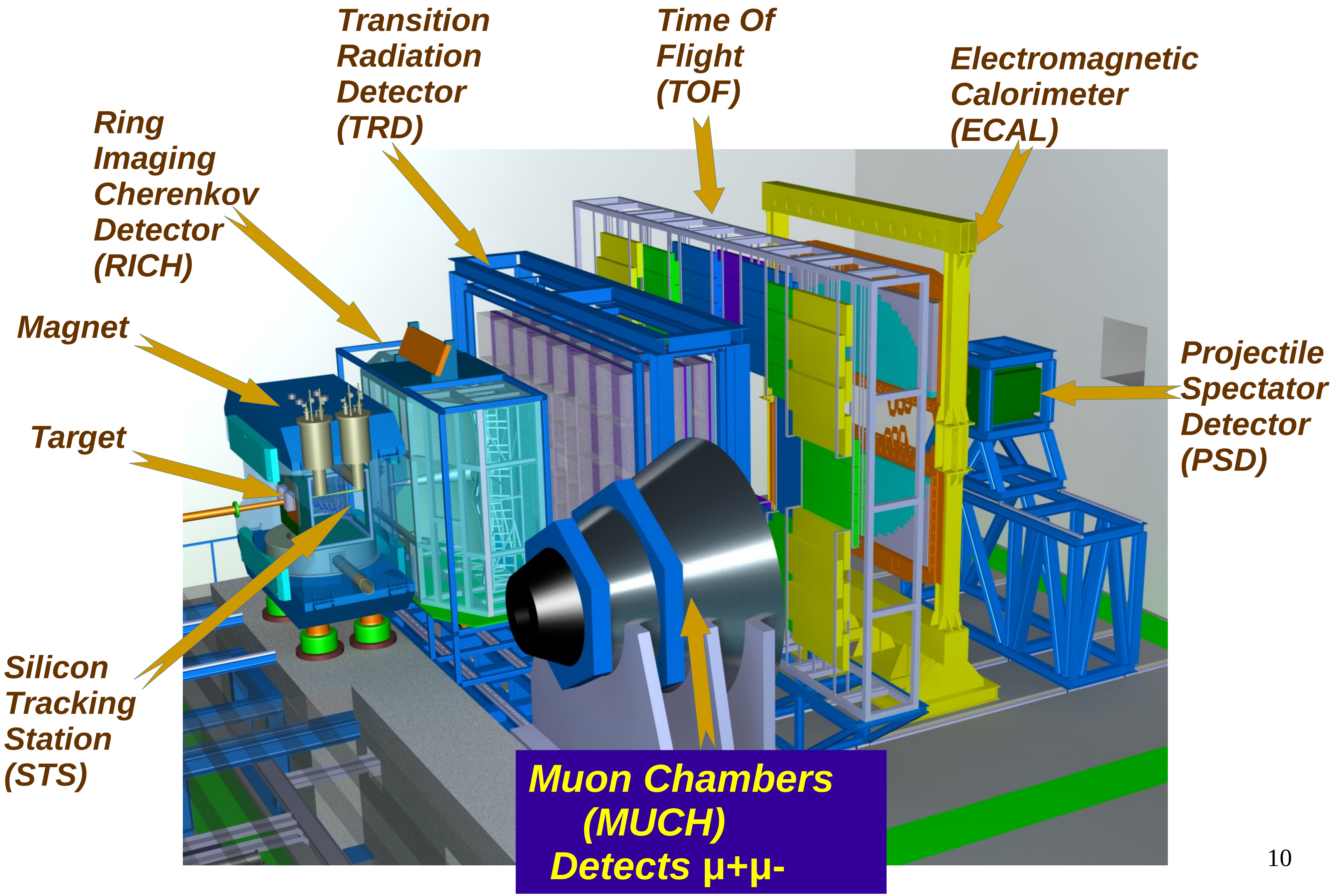
**ρ,ω,ϕ →(μ+μ-) Dimuon**
**(Low Mass Vector Mesons)**

# CBM Experimental Set-up



# Experimental Challenges

$10^5$ - $10^7$ Au+Au interactions/sec

Determination of (displaced) vertices ($\sigma \sim 50\ \mu m$)

Identification of leptons and hadrons

Fast and radiation hard detectors

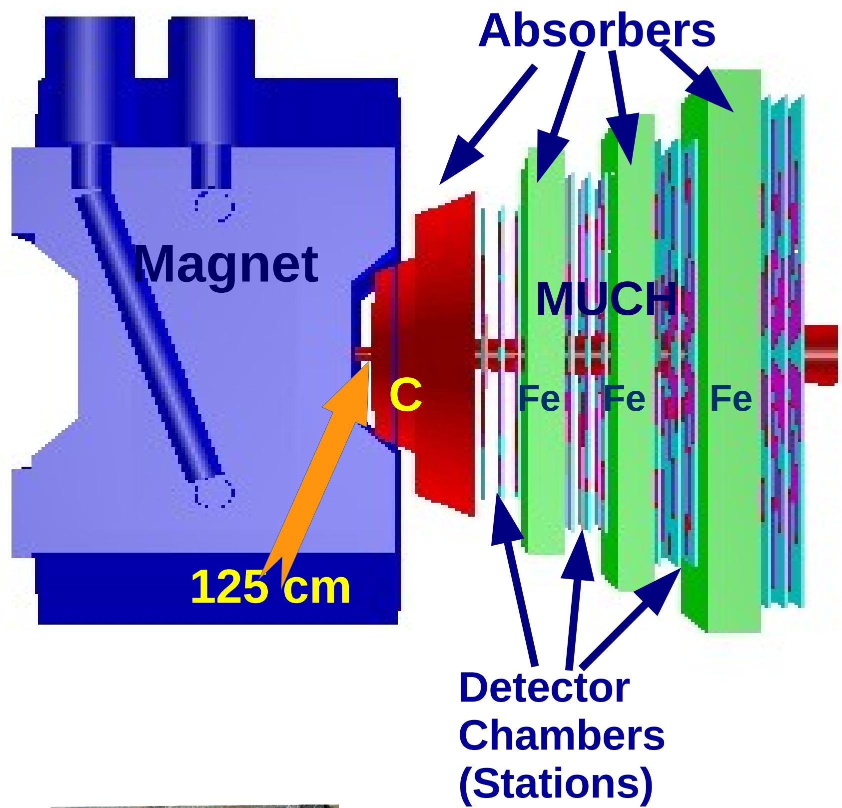
High speed data acquisition and high performance computer farm for online event selection

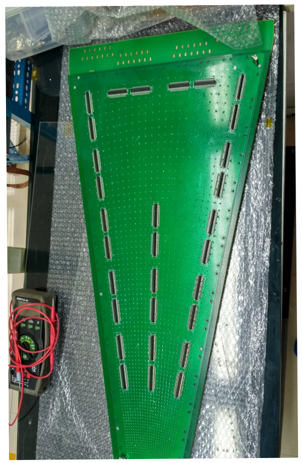
4-D (x,y,z,t) event reconstruction

# Di-muon Studies

# Muon Detector Set up ( MUCH )

- **Muon Chamber is a conical shaped set-up with detector coverage is 5.7º to 25º (1.5<η<3.0).**
- **Unique feature of CBM muon chamber is that hadron absorbers are sliced and detectors are placed in between them.**
- **Other HEP experiment use a single thick absorber for detection of muons. If a single thick absorber will be used here , then will loose information of low momentum muons which comes from low mass vector mesons.**
- **Absorbers will be used for hadron absorption.**
- **1st absorber is made of Carbon of thickness 60 cm and rest are made of Iron of 20+20+30 cm thickness.**
- **Gap between the consecutive absorbers is 30 cm and 3 detector chambers (Station) are placed in between the absorbers.**
- **Gas Electron Multiplier (GEMs) will be used in the first two stations. For the last two stations, we are planning to use Resistive Plate Chambers (RPCs).**
- **R & D is going on the feasibility study of using RPCs.**

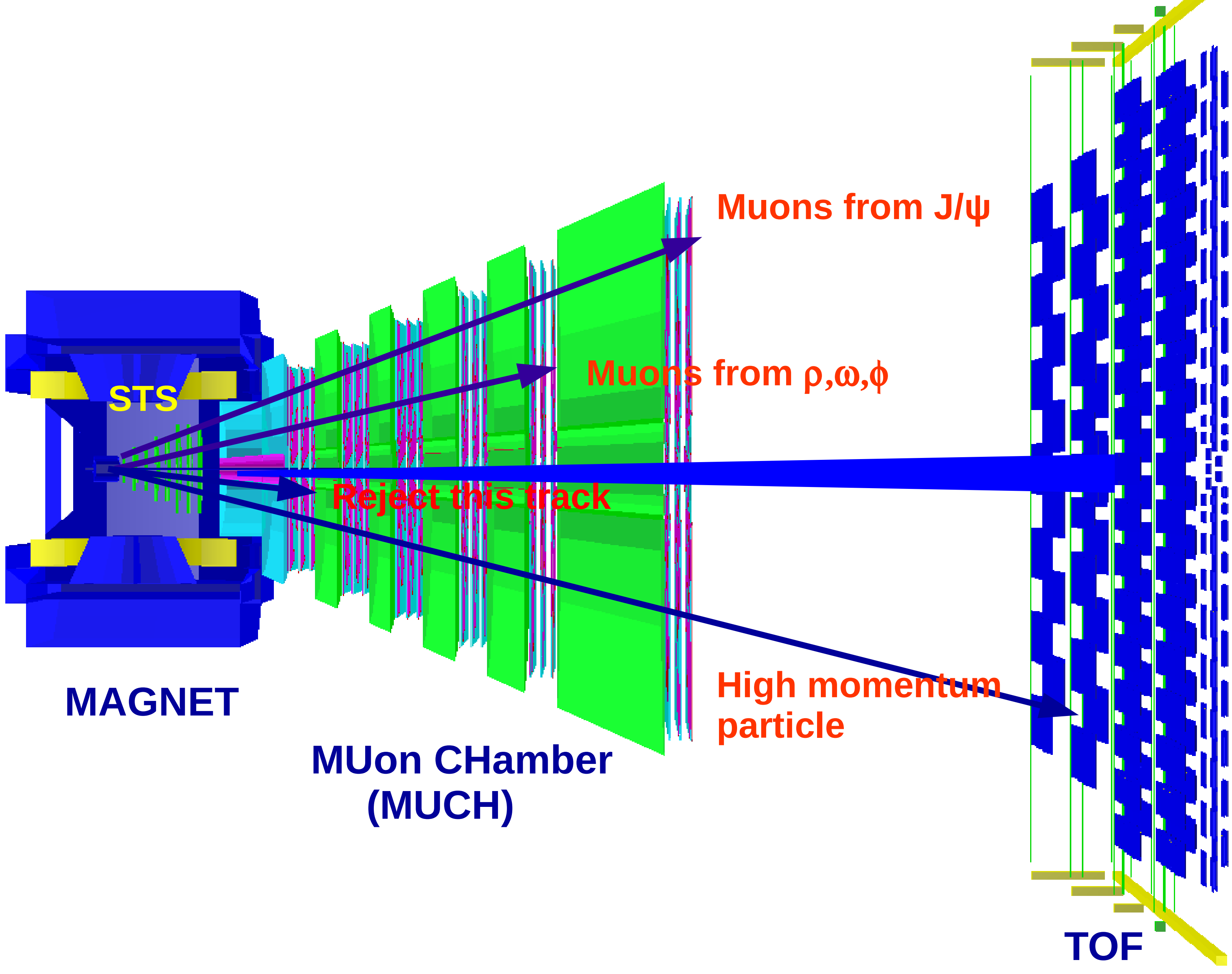


**Prototype of real GEM module**

# Muon Detection at CBM

Selection of muon tracks for low mass vector mesons (8 AGeV energy Au+Au)---
Tracks should have, MUCH hits>=11, STS hits>=7, $\chi$ 2 much <1.3, $\chi$ 2 vertex <2.0



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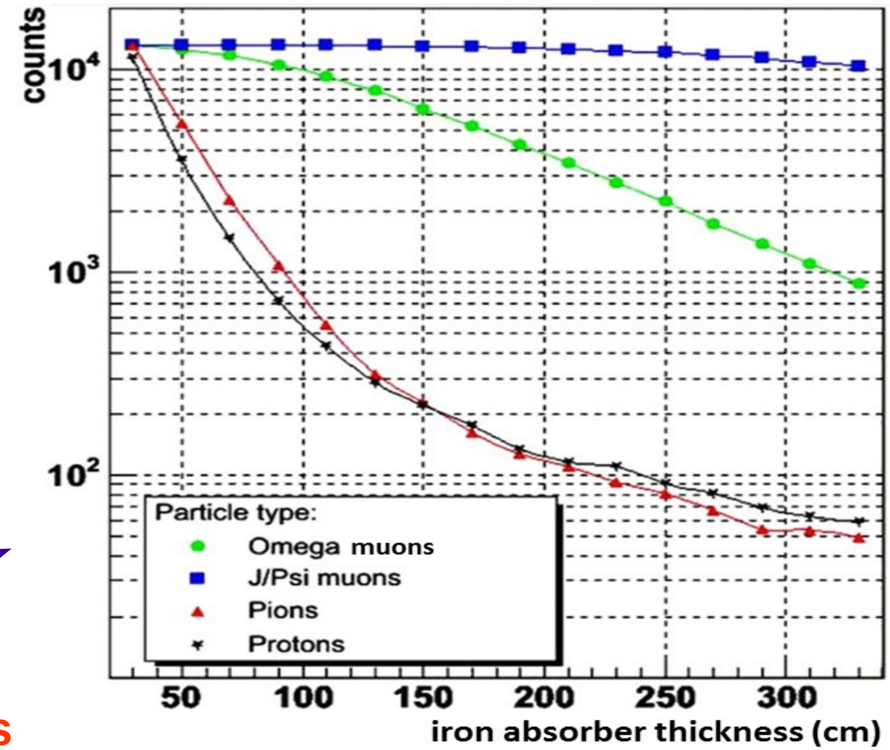
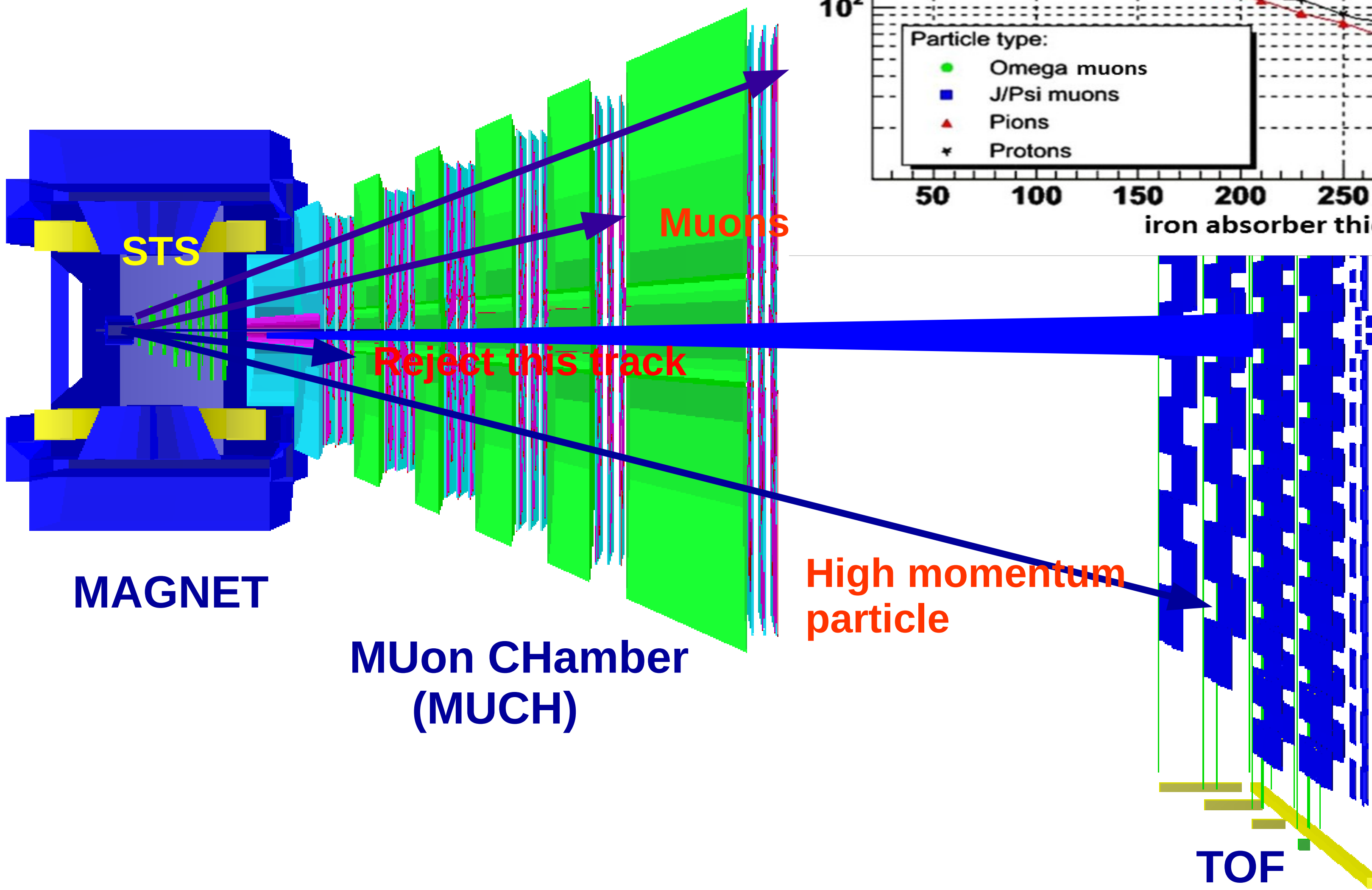


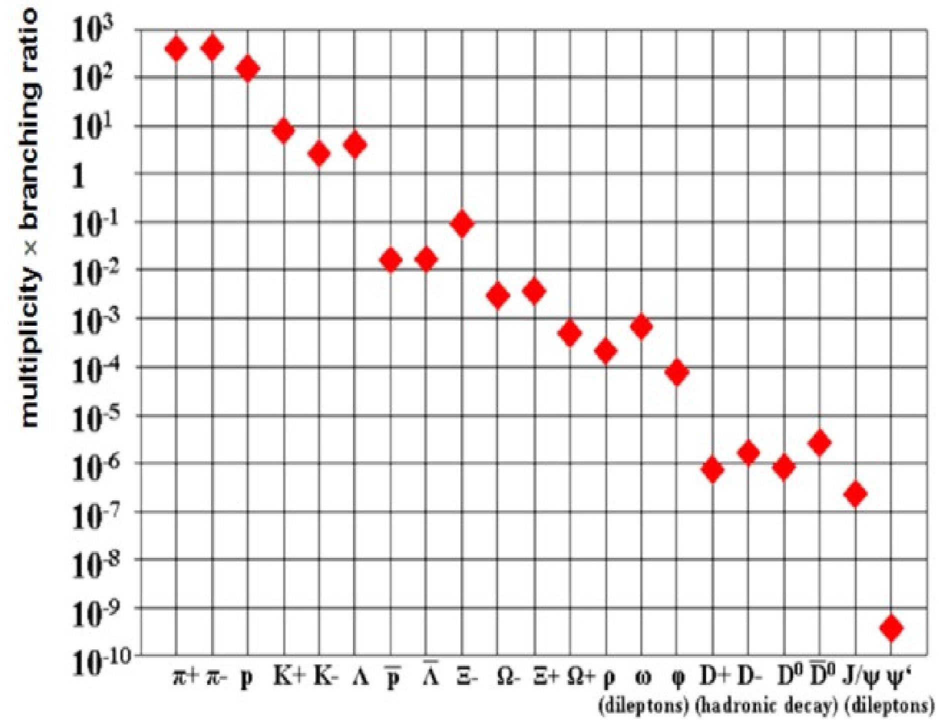
# Uniqueness and Challenges in Dimuon measurement at CBM

*Uniqueness---*

- No di-lepton measurement between 2-40 A GeV.
- For the First time CBM aims to measure precisely rarely produced dimuons in the FAIR energy range.

*Challenges---*

Previous experiments at AGS and SPS has overlap with CBM energy but due to low luminosity and detector limitations they could not measure rare particles.




| Experiment | Energy range | Reaction rate (Hz) |
|---|---|---|
| STAR-BES @ RHIC BNL | $\sqrt{s} = 7 - 200$ GeV | 1 - 800 |
| NA61 @ SPS CERN | $E_k = 20 - 160$ A GeV | 80 |
| MPD @ NICA Dubna | $\sqrt{s} = 4 - 11$ GeV | 1000 |
| CBM @ FAIR Darmstadt | $E_k = 2 - 35$ A GeV | $10^5 - 10^7$ |

- CBM will be operated at very high interaction rate (~10 MHz).
- This is a prerequisite for collecting high statistics data of rarely produced particles (eg. J/ψ, ρ, ω, φ)

# Simulation for Dimuon measurement at CBM

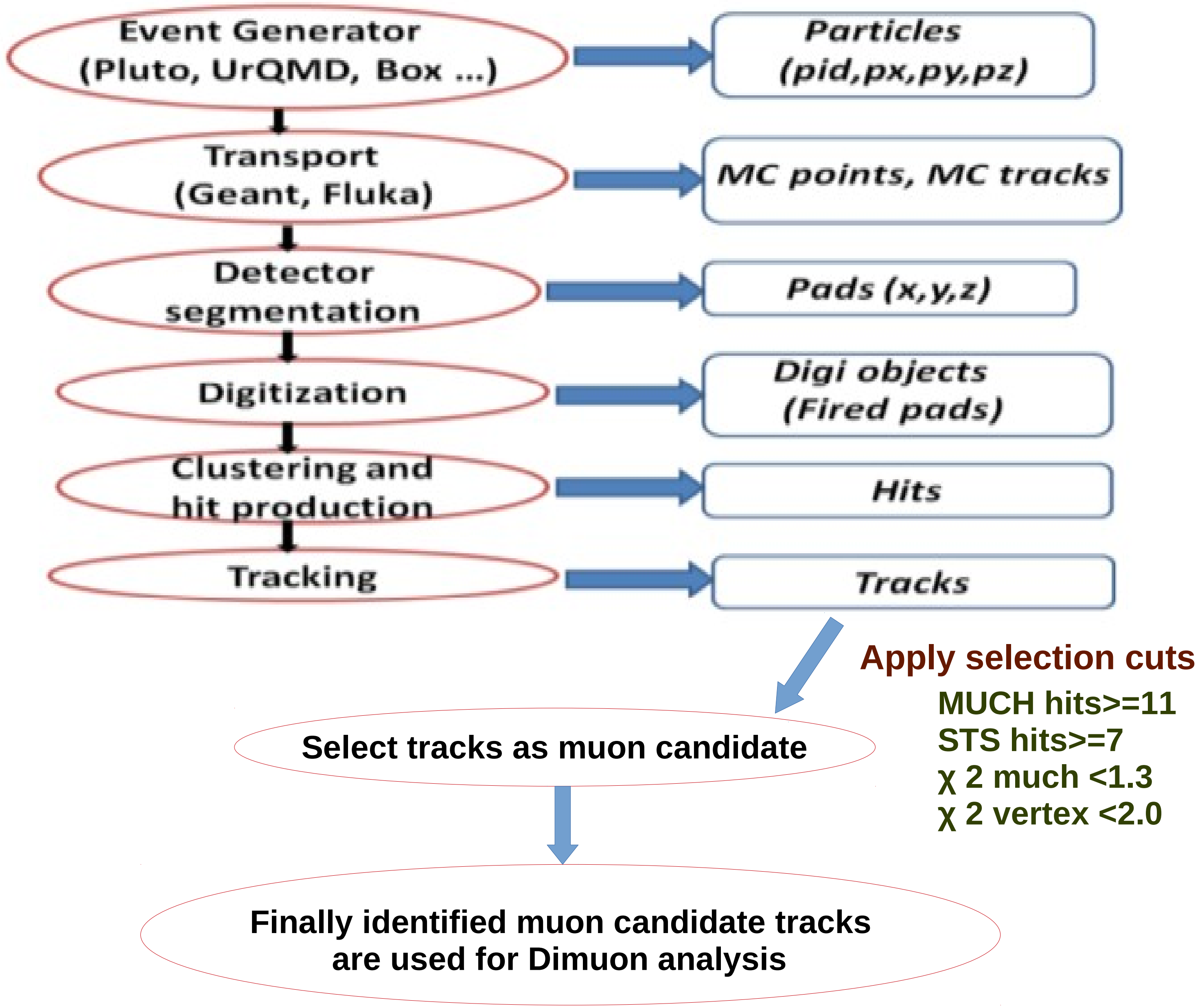
## Tools Used

- **CBM Frame -Work**
  **CBMROOT (environment)**

- **Event Generators**
  **PLUTO -- To generate signal particles ($\rho$, $\omega$, $\phi$) & decay them into dimuons.**
  **URQMD – To generate other background events.**

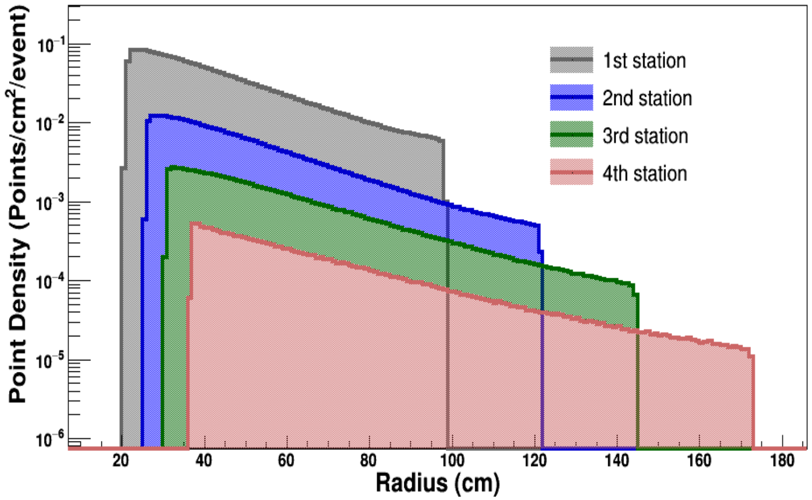
- **GEANT3 - Transport the particles through the CBM set-up**

# Simulation chain

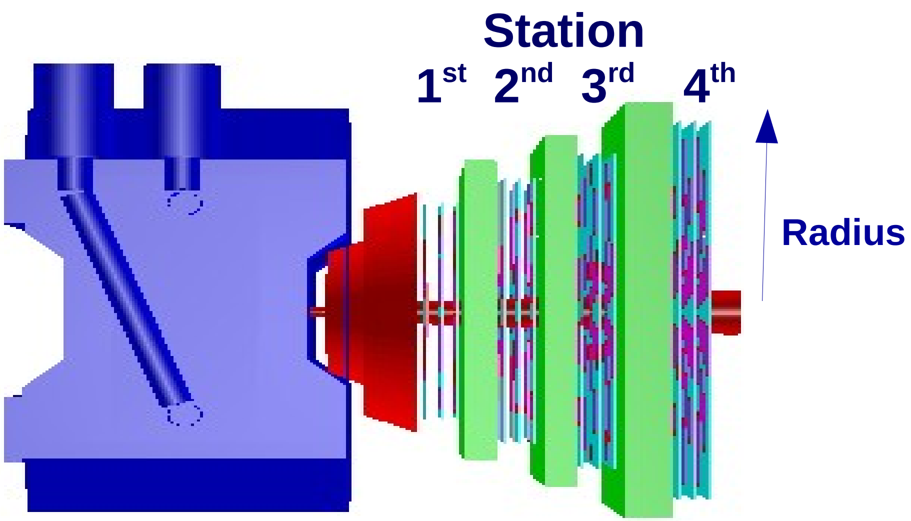


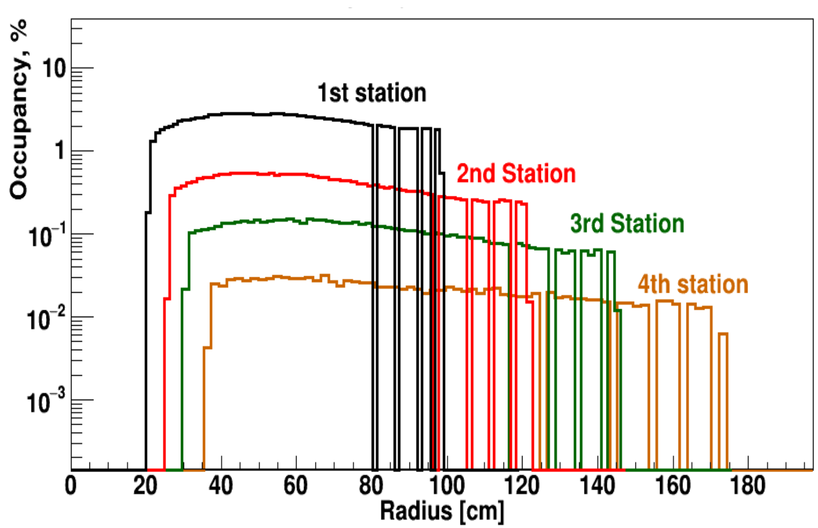
# Simulation Results

**[ 8 AGeV central Au+Au ]**

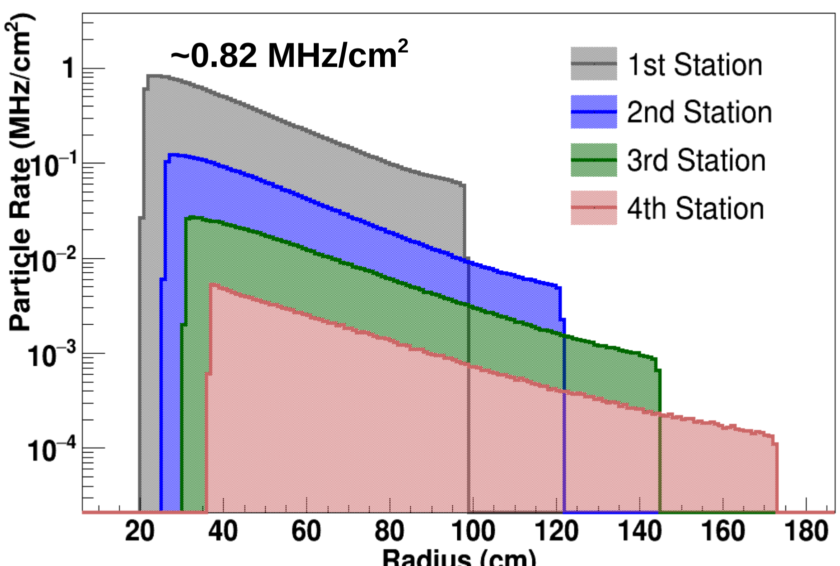



**Point Density Distribution**




**Occupancy : Fraction of total no of pads fired per event**



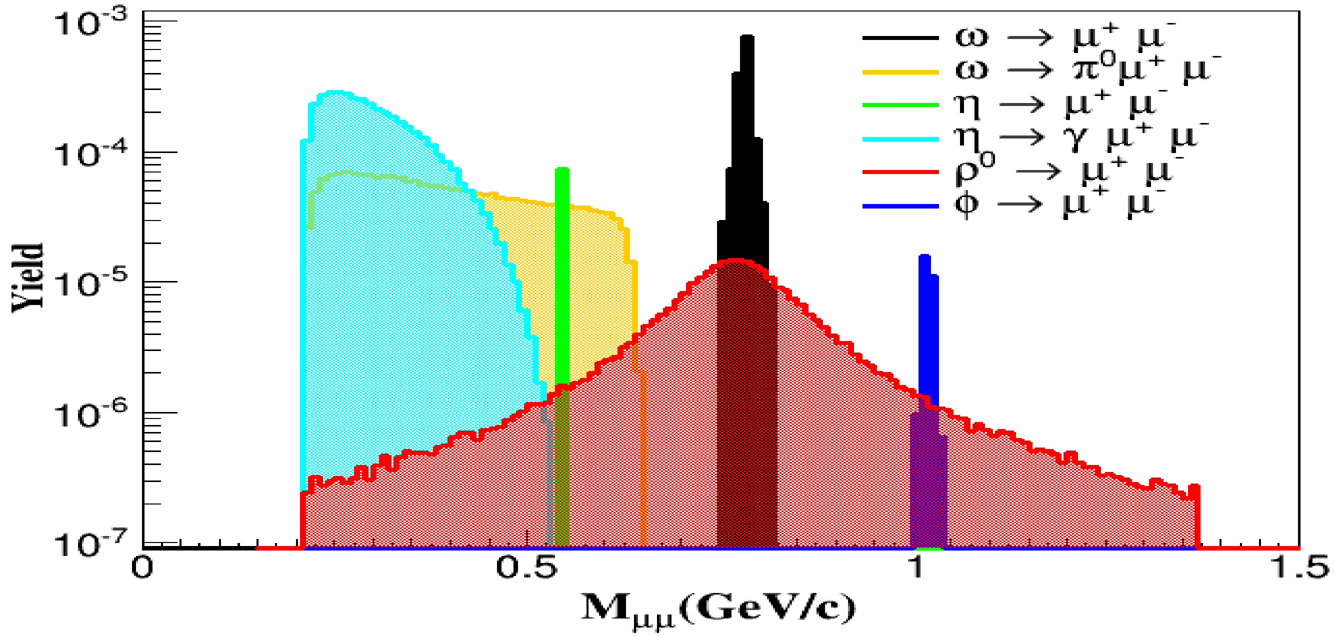



**Particle rate (Scaled by 10 MHz interaction rate)**

# Simulation Results

**[ 8 AGeV central Au+Au ]**

**Raw input cocktail (From pluto)**

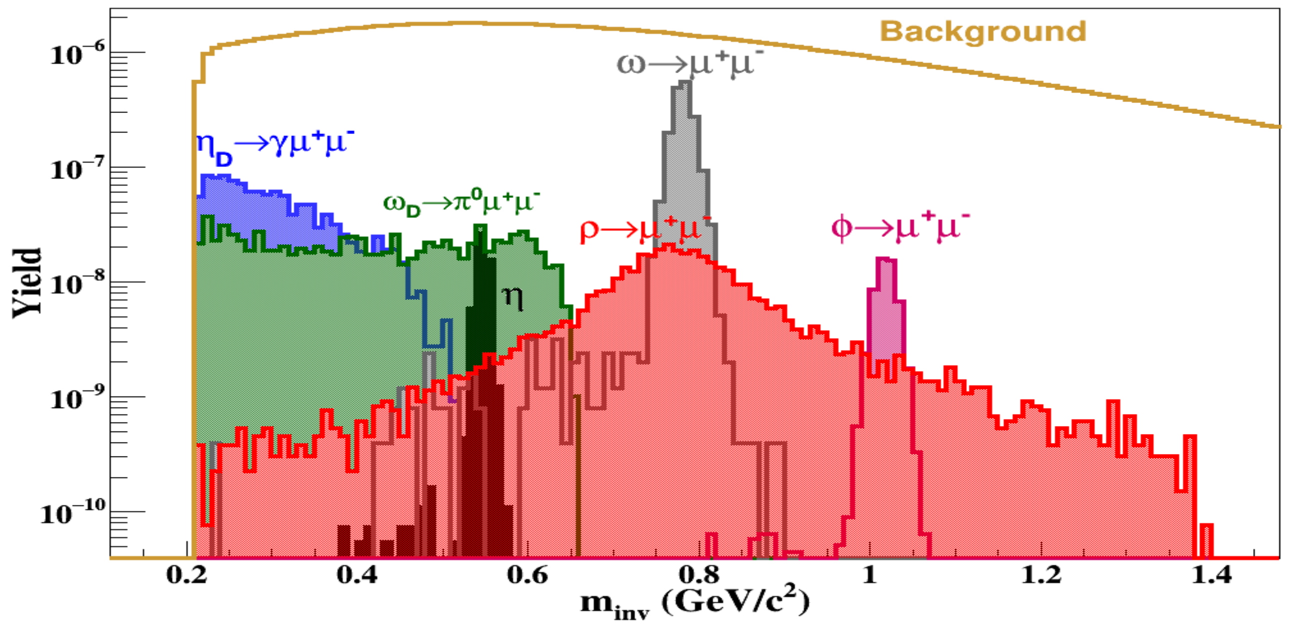



**Invariant mass--**

$$P^2_{\rho,\omega,\phi} = (P_{\mu+} + P_{\mu+})^2$$

**P- Four momentum**

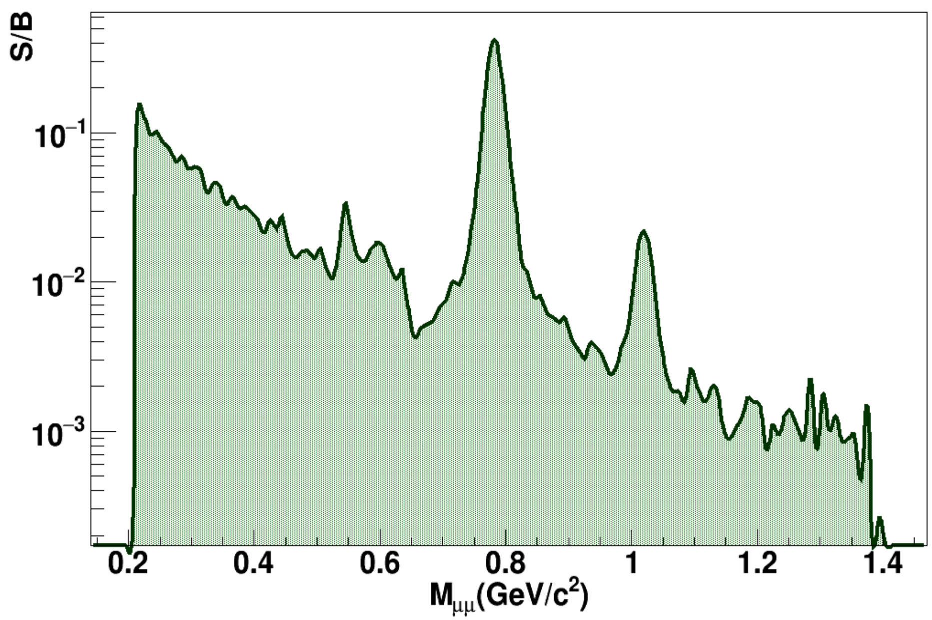
**Reconstructed cocktail (After passing through detector)**



# Simulation Results
**[ 8 AGeV central Au+Au ]**

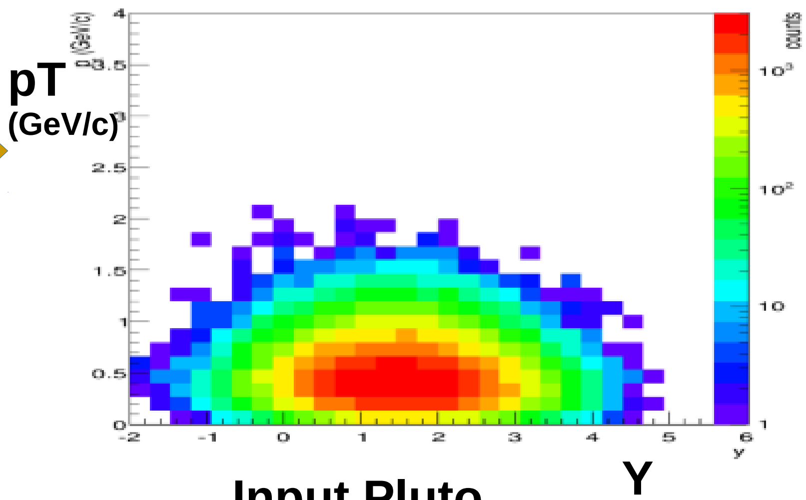
| Particle | Eff (%) | S/B |
|---|---|---|
| ρ | 1.03 | 0.005 |
| ω | 1.01 | 0.287 |
| φ | 1.53 | 0.005 |
| η | 0.56 | 0.004 |
| ηD | 0.23 | 0.092 |
| ωD | 0.37 | 0.004 |

**S/B plot**

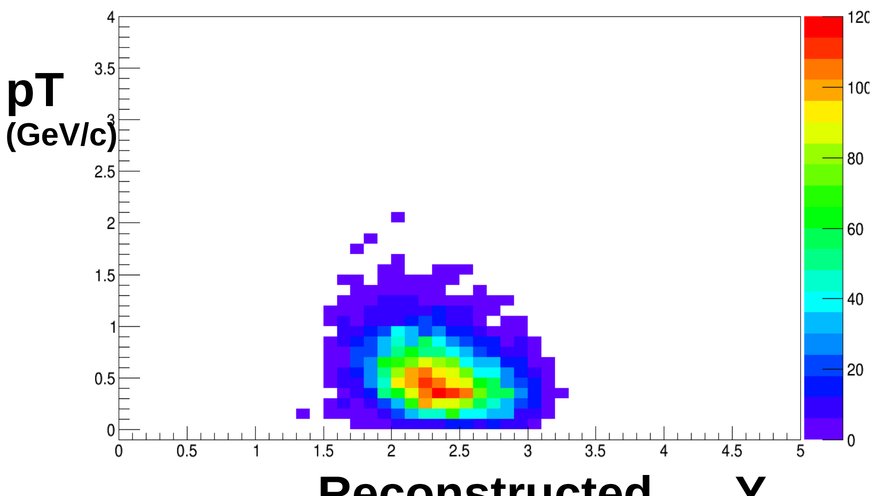



**Background comes mainly from decays of pions and kaons, and punched through hadrons**

**Y-pT acceptance (ρ)**




**Input Pluto**




**Reconstructed**

# Summary

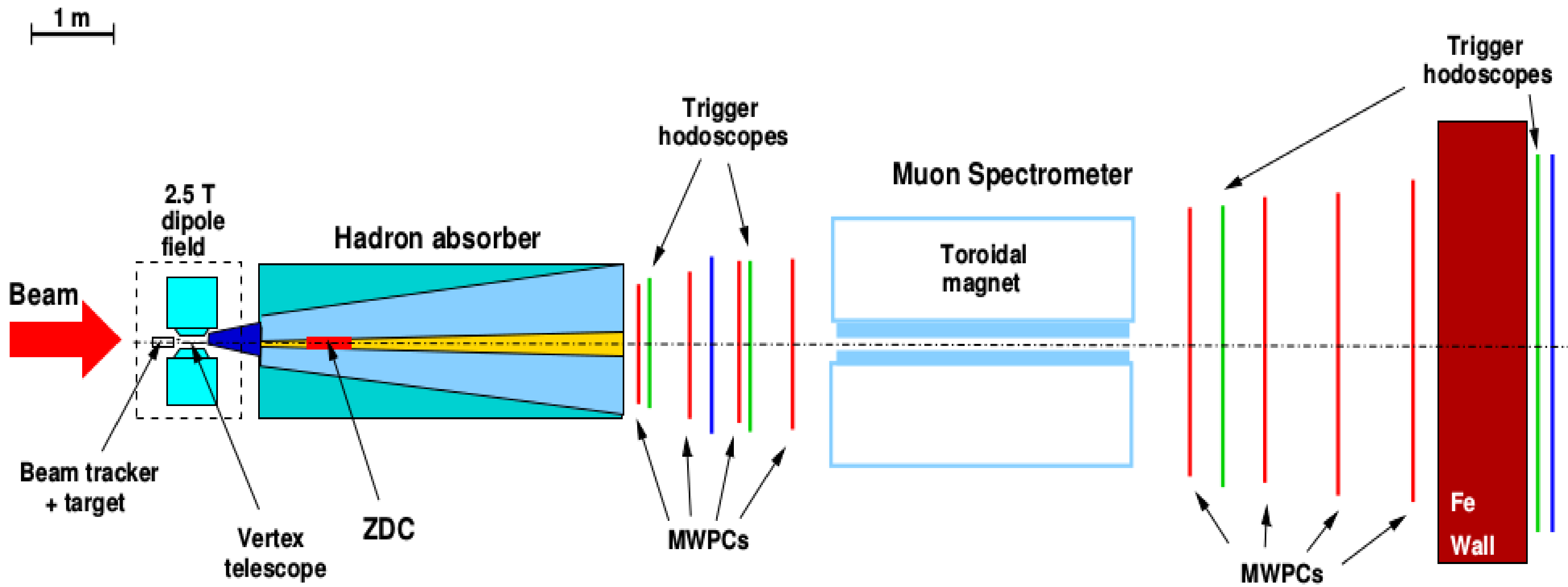
- Dilepton measurements is an integral part of the physics program at CBM. They are believed to be penetrating probes carrying undistorted information of the dense collision zone.
- Till now there is no dilepton data in 2-40 AGeV, so CBM will make pioneering measurements in this energy region.
- A muon detector set up using novel concept of segmented hadron absorber has been designed & realistic simulations via dimuon channel will establish the feasibility of such measurements.

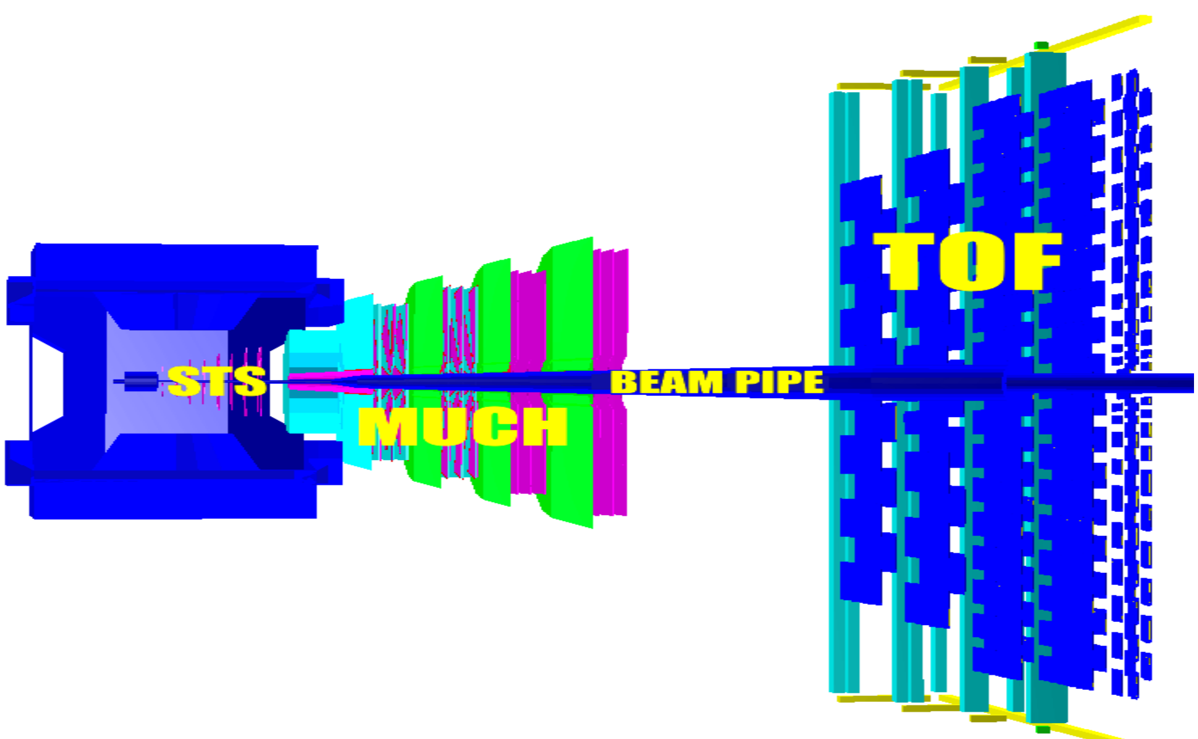
# Acknowledgement

**Prof. Subhasis Chattopadhyay**
**Dr. Partha Pratim Bhaduri**
**All CBM collaborators**


# Thank You

# Back up


1 m
Beam
2.5 T
dipole
field
Hadron absorber
Trigger
hodoscopes
Muon Spectrometer
Toroidal
magnet
Trigger
hodoscopes
Beam tracker
+ target
Vertex
telescope
ZDC
MWPCs
MWPCs
Fe
Wall


TOF
STS
BEAM PIPE
MUCH

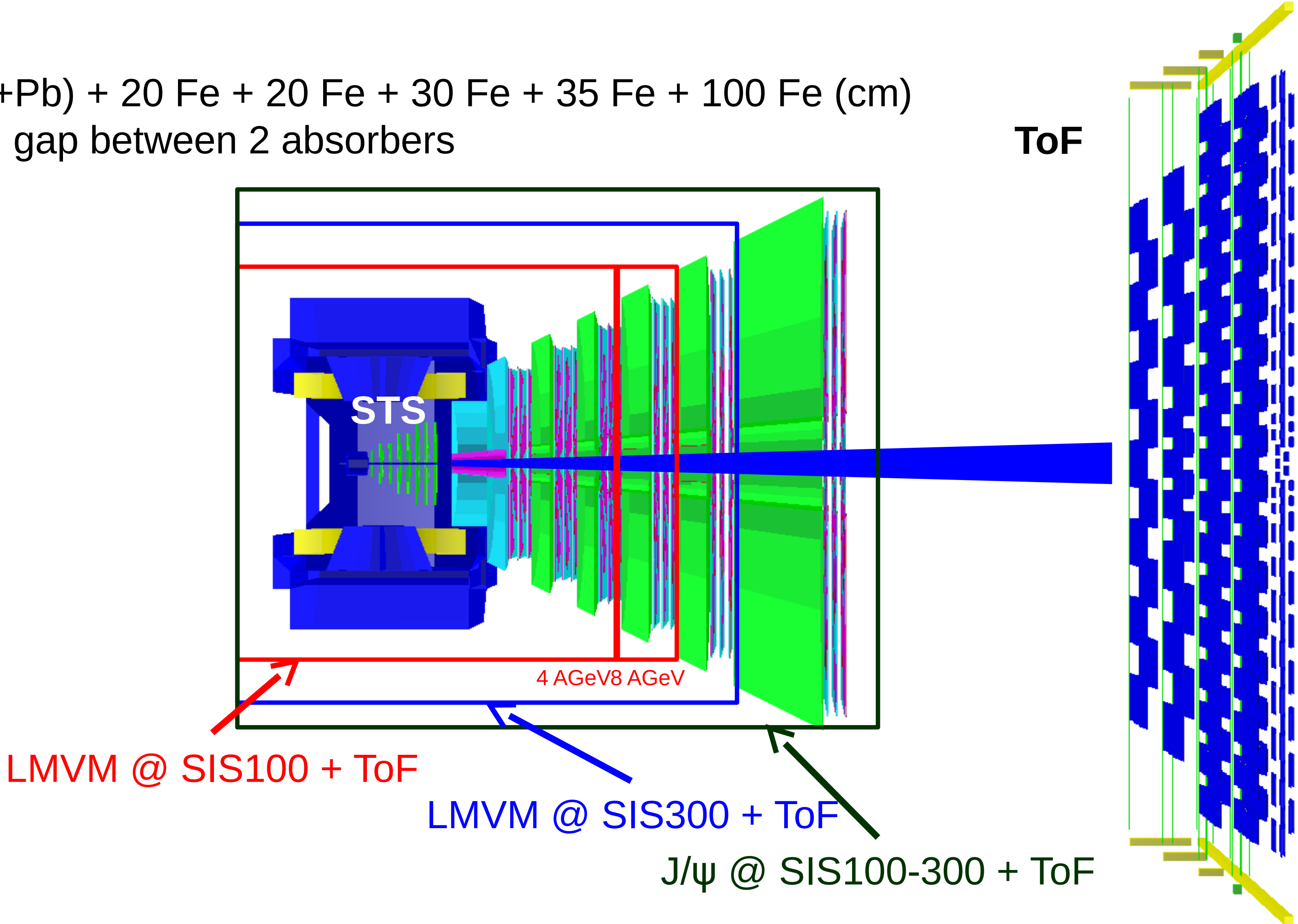
# Combinatorial Background/Signal in Dilepton Experiments

Reference: hadron cocktail at masses of 0.5-0.6 GeV H.J.Specht

| Experiment | Centrality | Lepton flavor | B/S as meas. or simul. | B/S rescaled to $dN_{ch}/dy=300$ |
|---|---|---|---|---|
| HADES-SIS100 | semicentr | $e^+e^-$ | 20 | 60 |
| CERES DR | semicentr | $e^+e^-$ | 80 | 100 |
| CERES SR/TPC | central | $e^+e^-$ | 110 | 100 |
| PHENIX with HBD | central | $e^+e^-$ | 250 | 100 |
| PHENIX w/o HBD | central | $e^+e^-$ | 1300 | 600 |
| STAR | central | $e^+e^-$ | 400 | 200 |
| ALICE Upg ITS | central | $e^+e^-$ | 1200 | 200 |
| CBM-SIS100 | central | $e^+e^-$ | 80 | 100 |
| CBM-SIS300 | central | $e^+e^-$ | 100 | 100 |
| NA60 (InIn) | semicentr | $\mu^+\mu^-$ | 35 | 80 |
| NA60-like (20AGeV) | central | $\mu^+\mu^-$ | 90 | 110 |
| CBM | | $\mu^+\mu^-$ | | |
| central Au+Au @ 25 A GeV : | | | | |
| 5 stations | | | 30 | 30 |
| 6 stations *(NA60-like acceptance)* | | | 20 | 20 |
| central Au+Au @ 8 A GeV: | | | | |
| 4 stations | | | 50 | 50 |

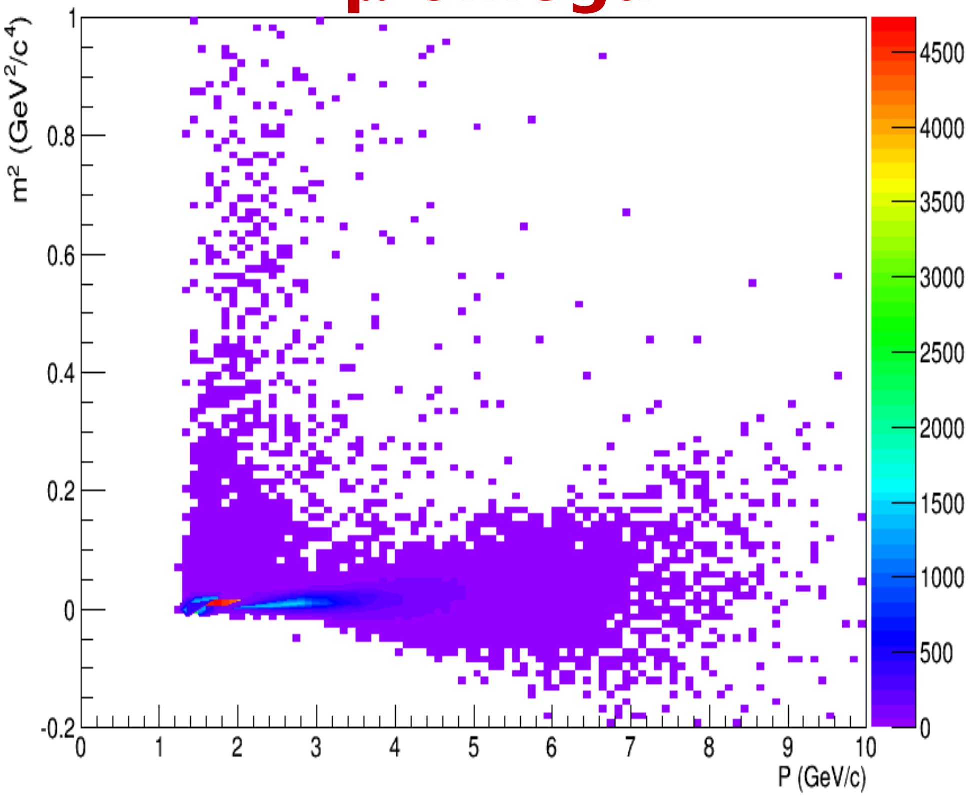
# Much  setup (SIS100/300)

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

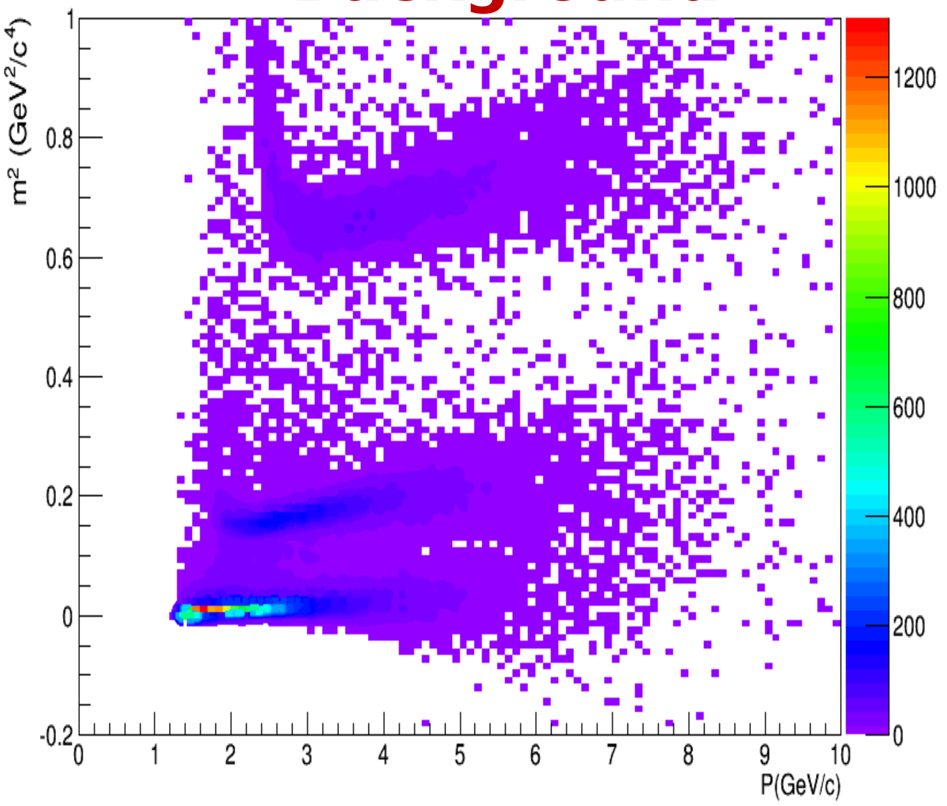


# TOF information

## μ omega

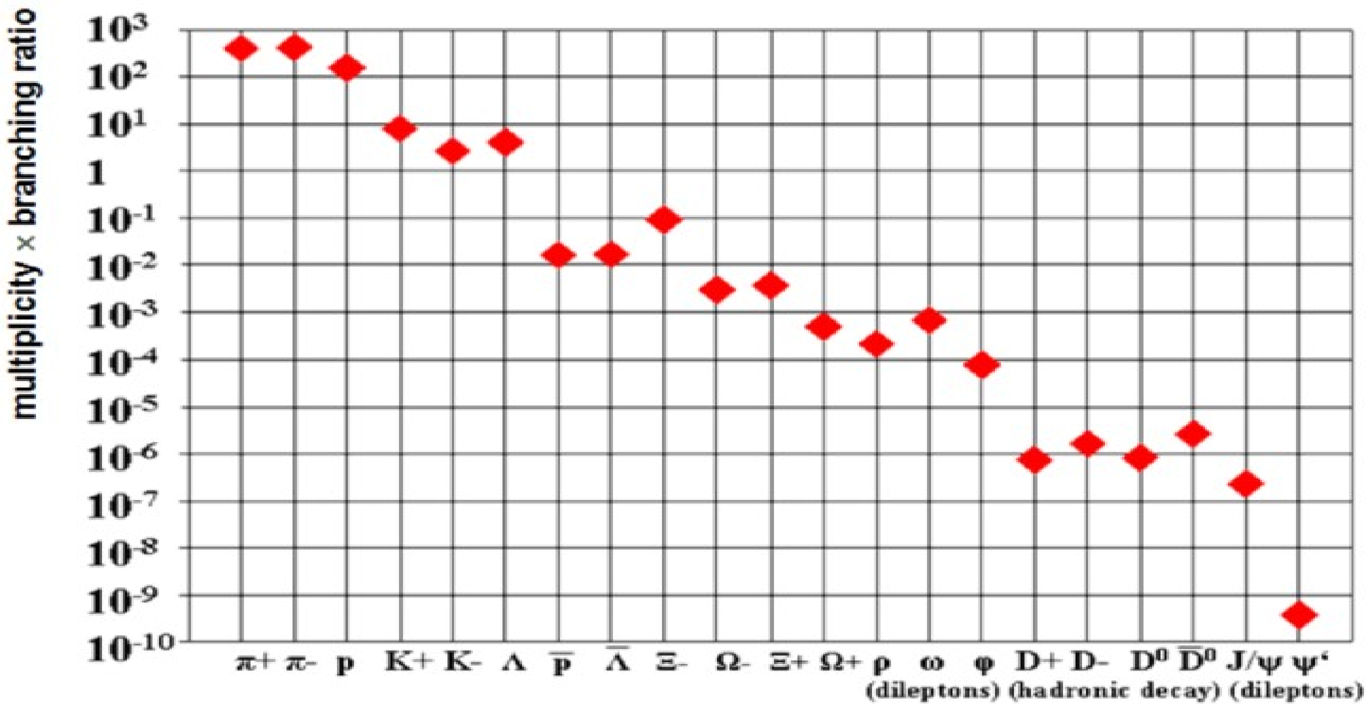



## Background




**TOF is used to reduce background ($m^2$ >=0.05 $GeV^2/C^4$)**

# Challenges in Dimuon mesurement at CBM




**Particle multiplicities times branching ratio for central Au+Au collisions at 25 AGeV as calculated with the HSD transport code**

| particles | $\rho^0$ (775MeV) | $\omega$ (783 MeV) | $\varphi$ (1020 MeV) | $\eta$ (550 MeV) | $\eta_D$ (550 MeV) | $\omega$ (783 MeV) |
|---|---|---|---|---|---|---|
| Multiplicity (HSD) | 9 | 19 | 0.12 | 16 | 16 | 19 |
| BR(μμ channel) | 4.55*10-5 | 9*10-5 | 2.87*10-5 | 5.6*10-6 | 3.1*10-4 | 1.3*10-4 |
| Per event yield | 4.09*10-4 | 1.71*10-3 | 3.44*10-6 | 8.96*10-5 | 4.96*10-3 | 2.47*10-3 |