LEPTONS AT THE CBM EXPERIMENT

Joachim Stroth, Goethe University / GSI

3rd CBM-China Meeting

Yichang, China, April 16-18, 2018

Model: Ralf Rapp
STAR: QM2014,
NA60: EPJC 59 (2009) 607,
CERES: Phys. Lett. B 666 (2006) 425,
HADES: Phys.Rev.C84 (2011) 014902

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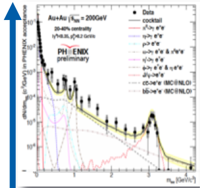
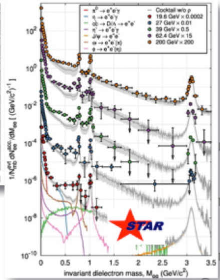
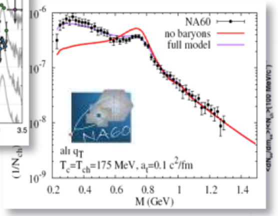
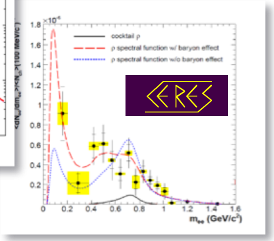


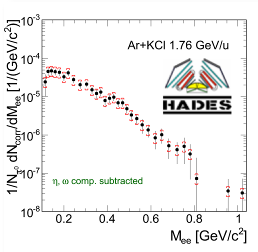




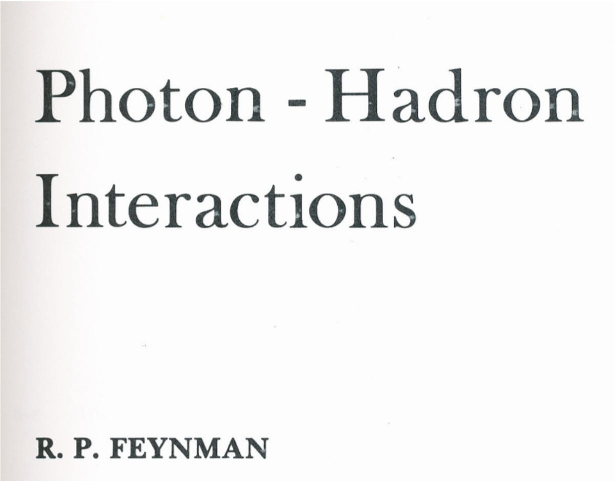


Consistent description of RHIC, SPS, SIS18 dilepton-continuum data

→ lepton pairs as true messengers of the dense phase (standard candle)



μ_B



Photon - Hadron Interactions

R. P. FEYNMAN

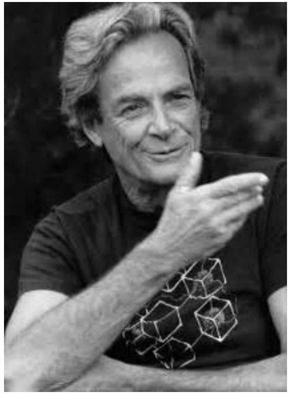
California Institute of Technology

1972

W. A. BENJAMIN, INC.

ADVANCED BOOK PROGRAM

Reading, Massachusetts

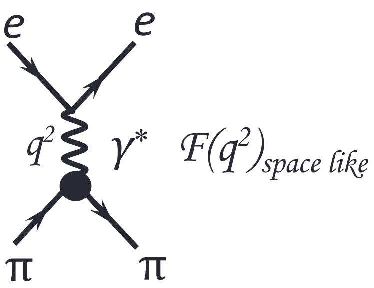


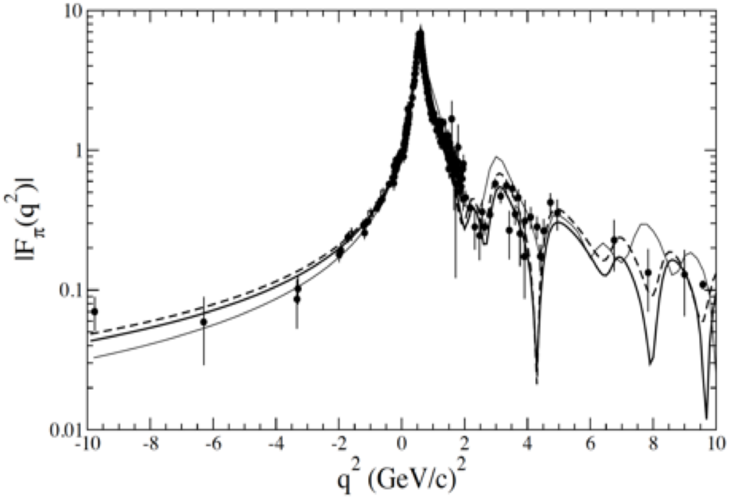
Program

- Vector Meson Dominance
- Thermal radiation
- Extracting the „signal“
- Dilepton excitation function
- CBM and dileptons

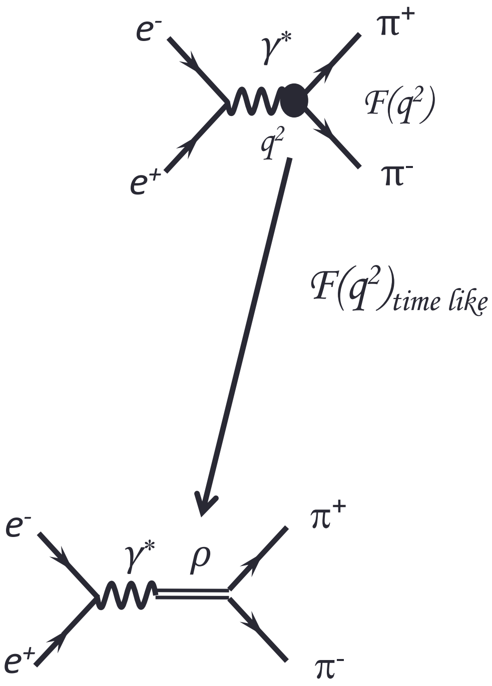
How do photons couple to hadrons - VMD

space-like photons ($q^2 < 0$)





time-like photons ($q^2 > 0$)



$$F(q^2) = \frac{d\sigma / dq^2}{\left(d\sigma / dq^2 \right)_{\text{point like}}}$$

- $J^P = 1^-$ for both γ^* and Vector Meson
- Strong coupling of γ^* to Vector Meson → Vector-Meson Dominance model (VMD)
- Observable: vector mesons (ρ,ω,ϕ)

Vector Meson Dominance

Generalized „Bremsstrahlung" – current-current correlation function $\langle j(x), j(0)\rangle$ (the imaginary part of it is called the spectral function):

$$\Pi^{\mu\nu}_{EM}(q) = \int d^4x e^{iqx}\,\Theta(x_0)\langle[j^{\mu}_{EM}(x), j^{\nu}_{EM}(0)]\rangle$$

The current on the partonic level ...

$$j^{\mu}_{EM} = \frac{2}{3}\bar{u}\gamma^{\mu}u - \frac{2}{3}\bar{d}\gamma^{\mu}d - \frac{2}{3}\bar{s}\gamma^{\mu}s$$

... and „mapped" to the hadronic world:

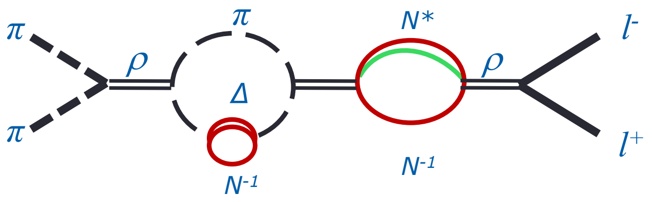
$$j^{\mu}_{EM} = \frac{1}{2}\left(\bar{u}\gamma^{\mu}u - \bar{d}\gamma^{\mu}d\right) + \frac{1}{6}\left(\bar{u}\gamma^{\mu}u + \bar{d}\gamma^{\mu}d\right) - \frac{1}{3}\bar{s}\gamma^{\mu}s$$

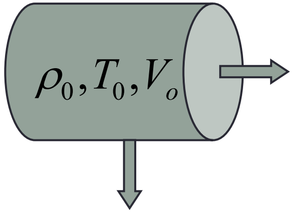
$$= \frac{1}{\sqrt{2}}j^{\mu}_{\rho} + \frac{1}{3\sqrt{2}}j^{\mu}_{\omega} - \frac{1}{3}j^{\mu}_{\phi} \quad \propto \quad j^{\mu}_{\rho} + 0.34\, j^{\mu}_{\omega} + 0.24\, j^{\mu}_{\phi}$$

If the hadronic current is saturated by the vector mesons, the correlator turns into the *VM propagator*

Dilepton Radiation in Theory

In-medium propagation of the ρ



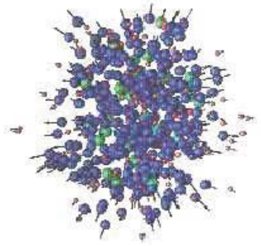


Emissivity (hadronic)

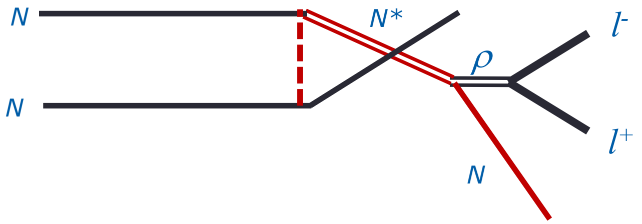
$$\frac{\mathrm{d}N_{ll}}{\mathrm{d}^4p} = -\frac{\alpha_{\mathrm{em}}^2}{\pi^3 M^2} f_B(q_0;T)\frac{1}{3} g_{\mu\nu} \mathrm{IM}\, \Pi_{em}^{\mu\nu}$$

Thermal emission rate

$$\frac{d^4N}{dM_{ee}dp_t d_Y d\alpha} \equiv \int dV \int dt\, \frac{\mathrm{d}N_{ll}}{\mathrm{d}^4p}[T(x), \mu_B(x), v_{coll}(x), \dots],$$



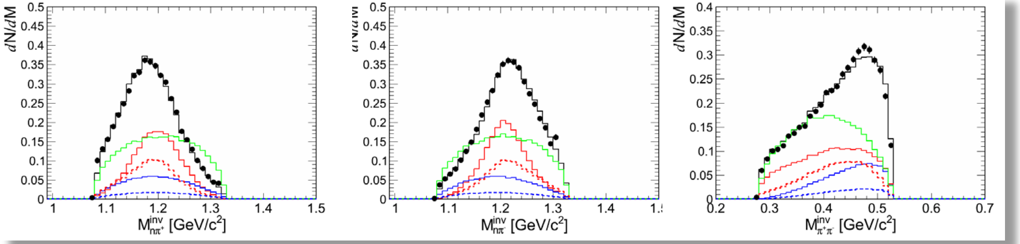
Microscopic transport approach UrQMD, HSD, iQMD



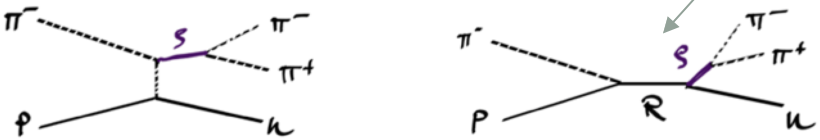
Follow up all resonances during the collision and let them (perturbatively) decay → SHINING

VMD scrutinized ($\pi^- p$ reactions)

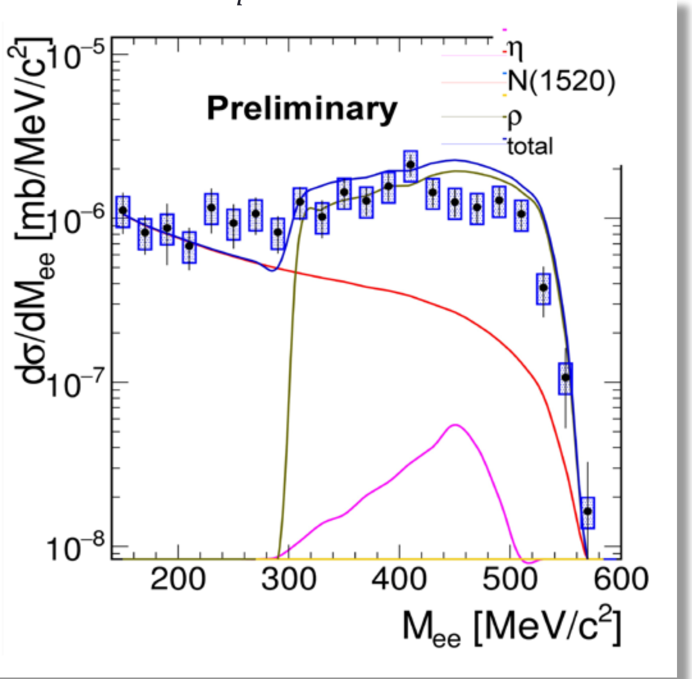
$\pi^- + p \rightarrow \pi^- + \pi^+ + n$; p_{π^-} = [656, 690, 748, 800] MeV



σN(939) Δ(1232)π ρN(939) | N(1520) ρN



$\pi^- + p \rightarrow e^- + e^+ + n$

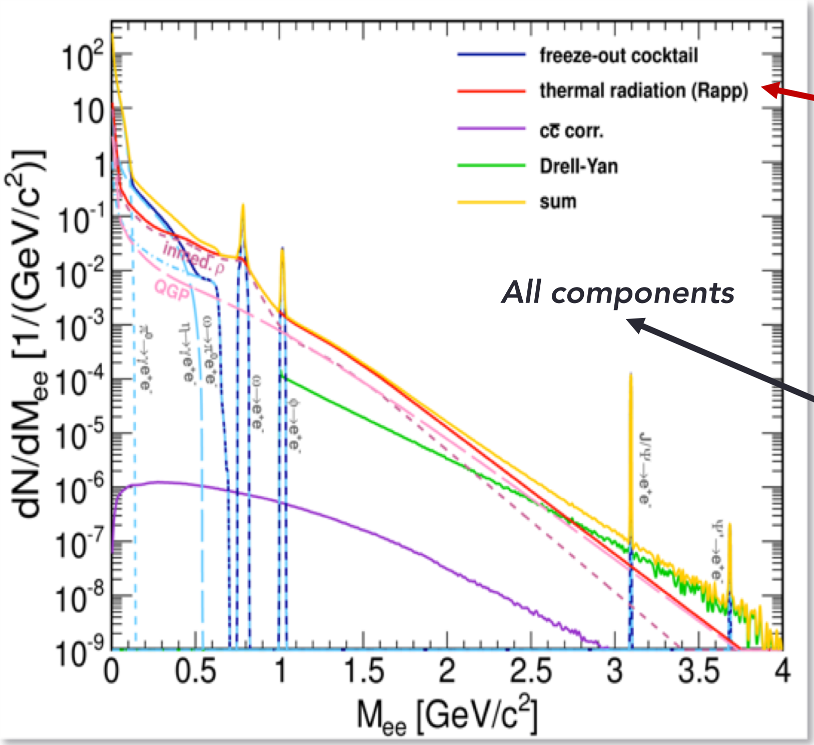


Evidence for intermediate ρ propagation (VMD) in both s and t-channel.

Theoretical Approaches to Fireball Radiation

Medium radiation from Thermal Emission Rates:

$$\frac{d^3\dot{N}}{dMdydp_td\alpha} \equiv \int_{t=0}^{\infty} \frac{d^4\epsilon}{d\boldsymbol{p}} [T(\boldsymbol{x}), \mu_B(\boldsymbol{x}), \vec{v}(\boldsymbol{x})]\, d\boldsymbol{x}$$



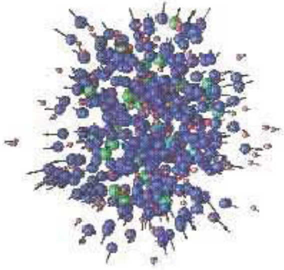
All components

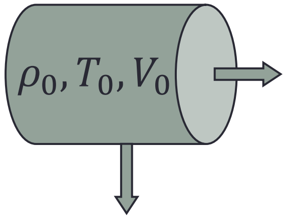
shining

coarse graining

isentropic expansion

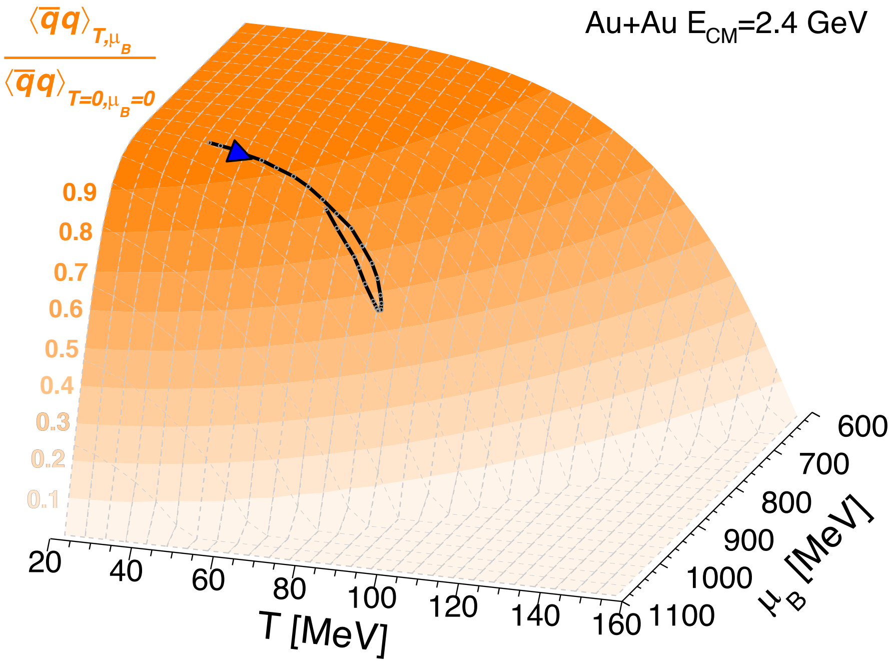
UrQMD

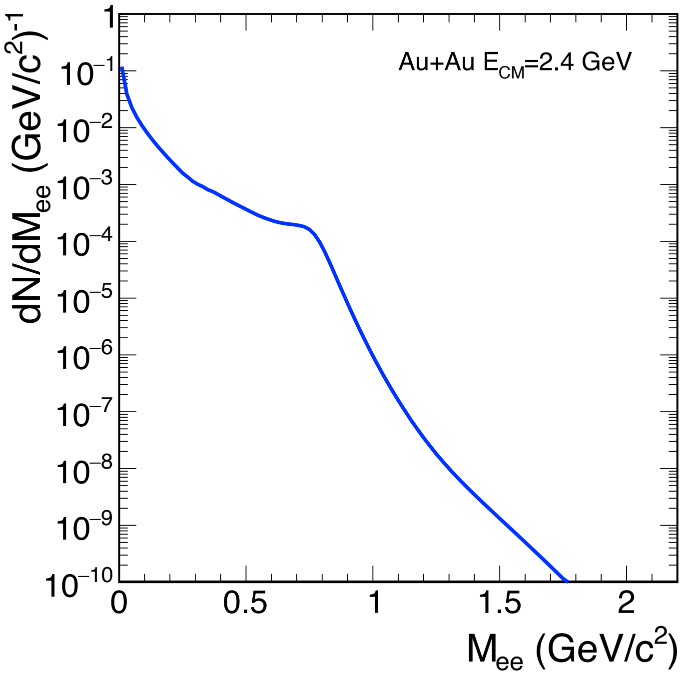




Dilepton emission from Microscopic Transport (pHSD, UrQMD, SMASH).

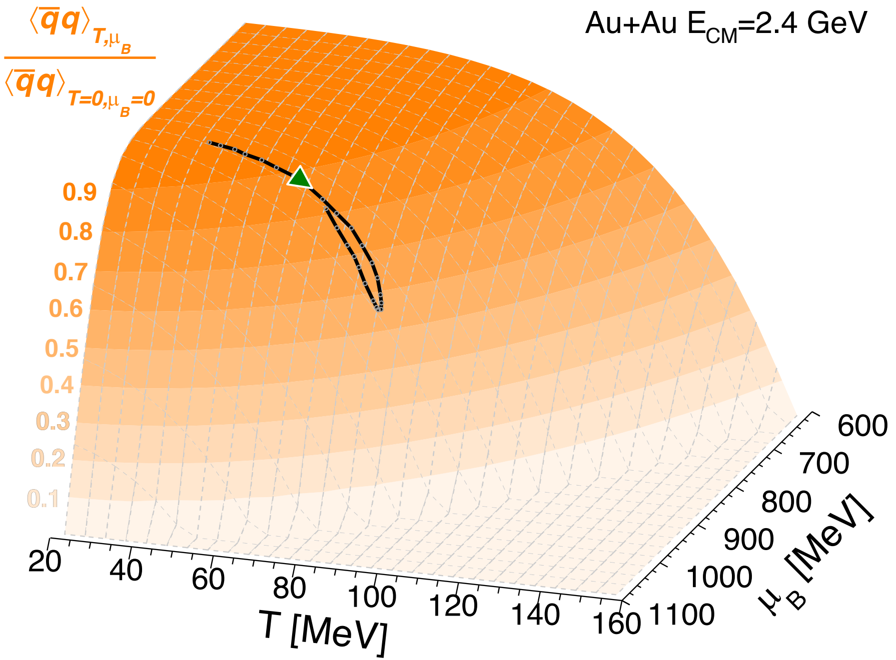
Dependence of the Emissivity (Standard Candle)

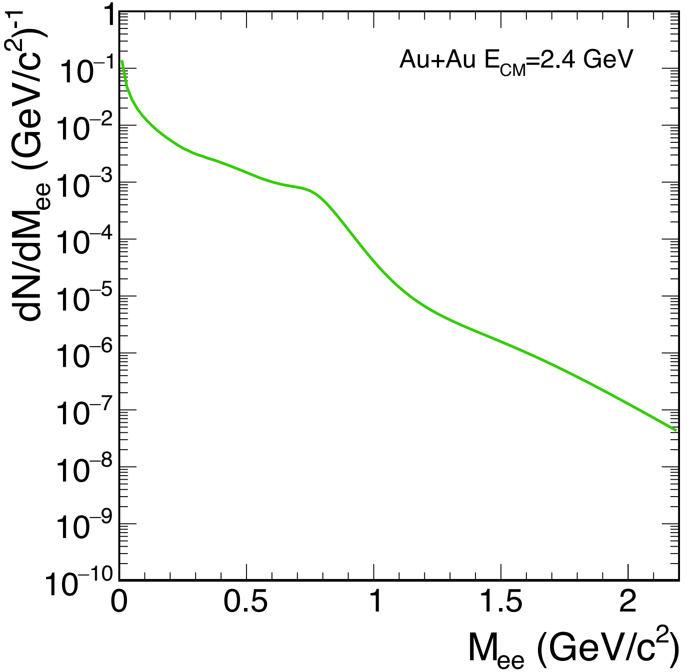




Chiral condensate a.f.o. temperature T and chemical potential μ_B. Shown is the ecpected trajectory of the central region of the heavy-ion collision.

Dependence of the Emissivity (Standard Candle)





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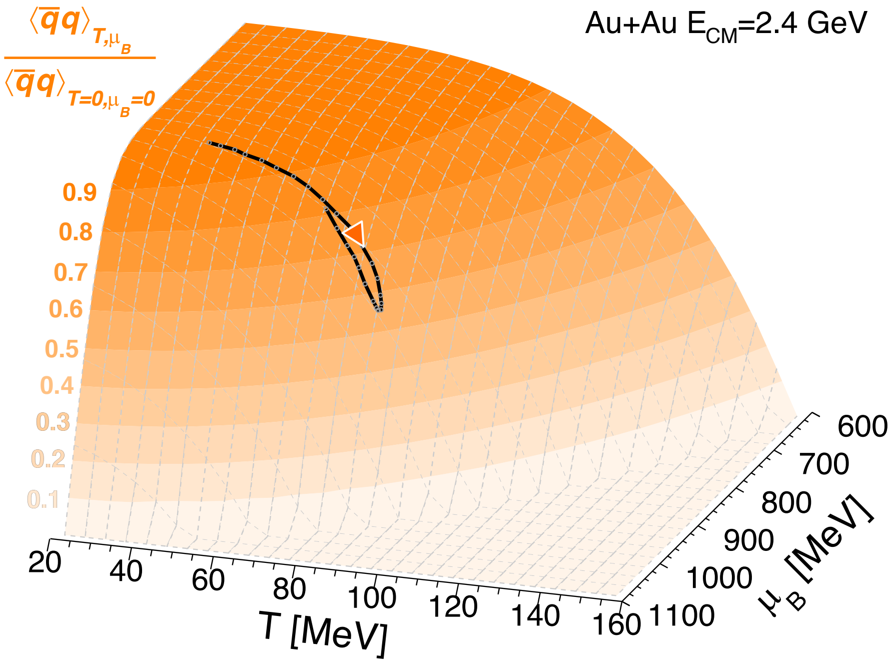

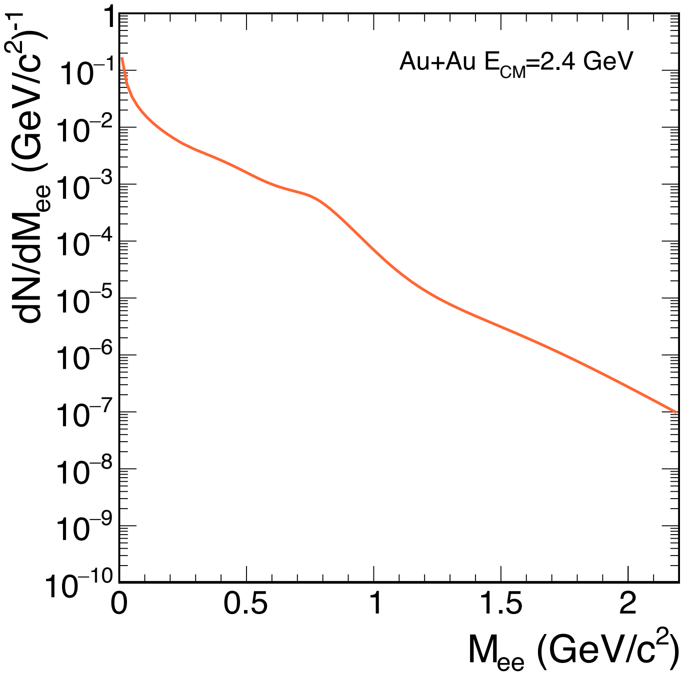

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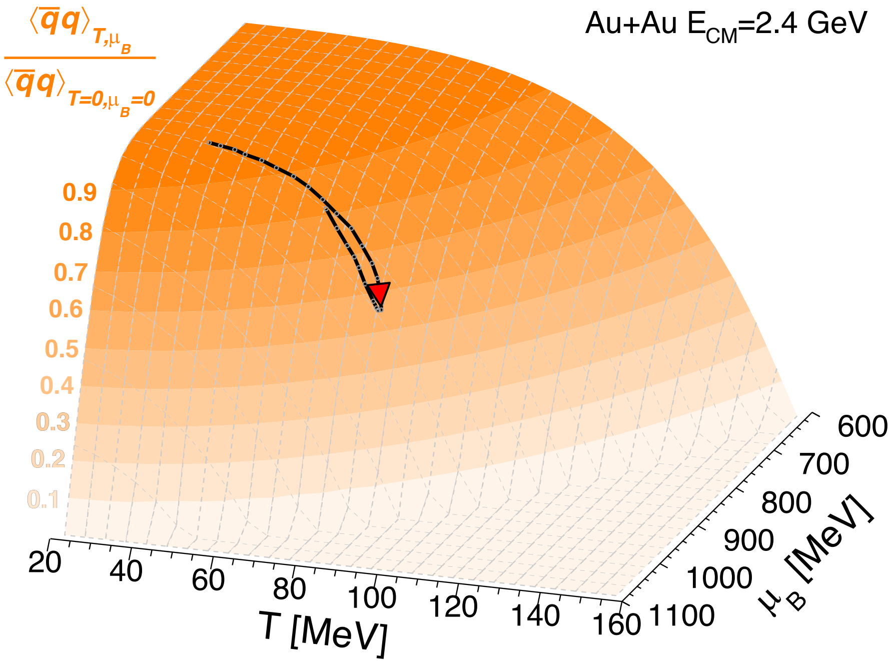
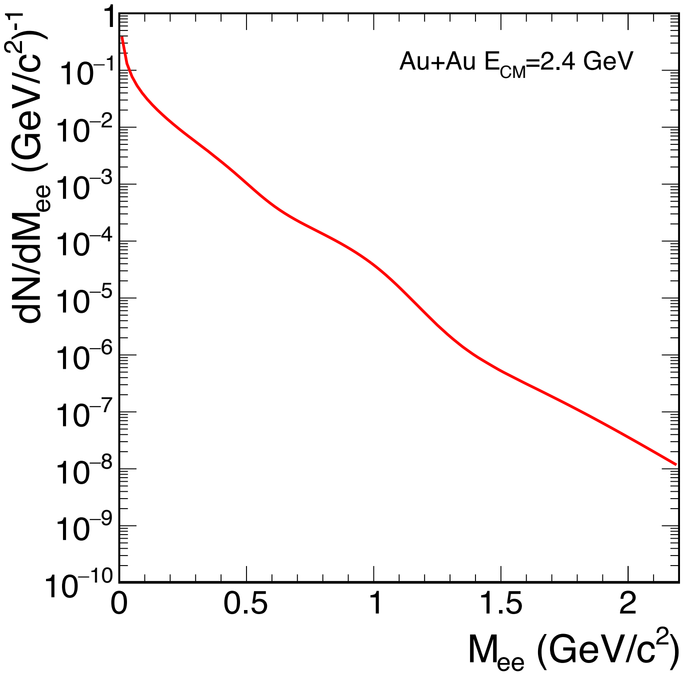
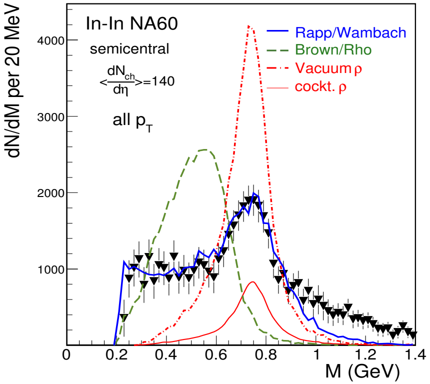


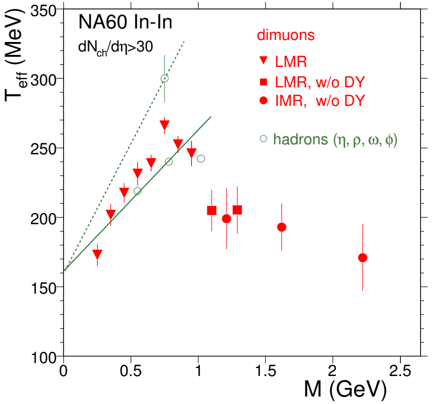


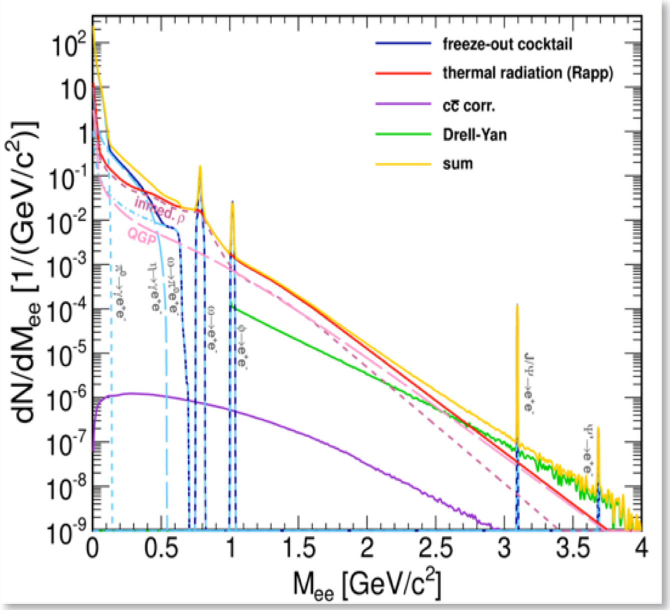
Chiral condensate a.f.o. temperature T and chemical potential μ_B. Shown is the ecpected trajectory of the central region of the heavy-ion collision.

Spectrometer



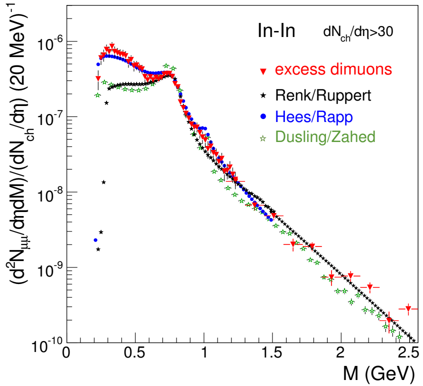
Barometer ($d_N/dp_\perp$)



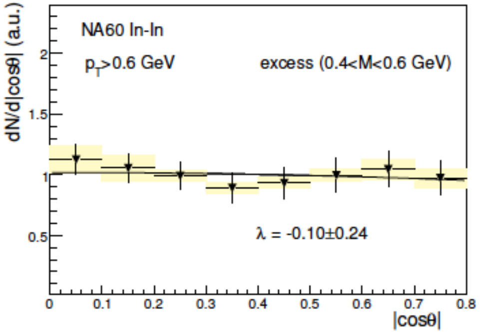


All data from NA60

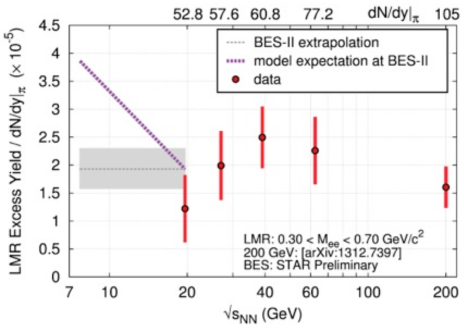
Thermometer

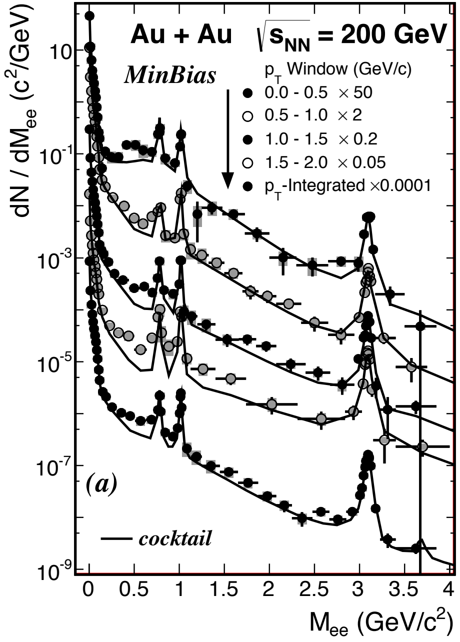


Polarimeter



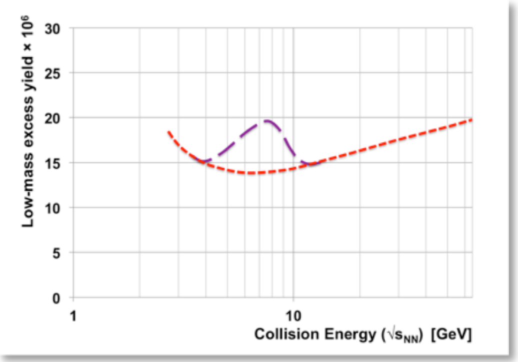
Excitation Functions



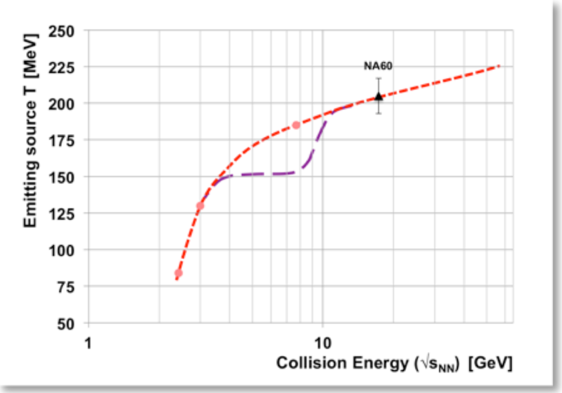


All data from STAR

Ecess yield



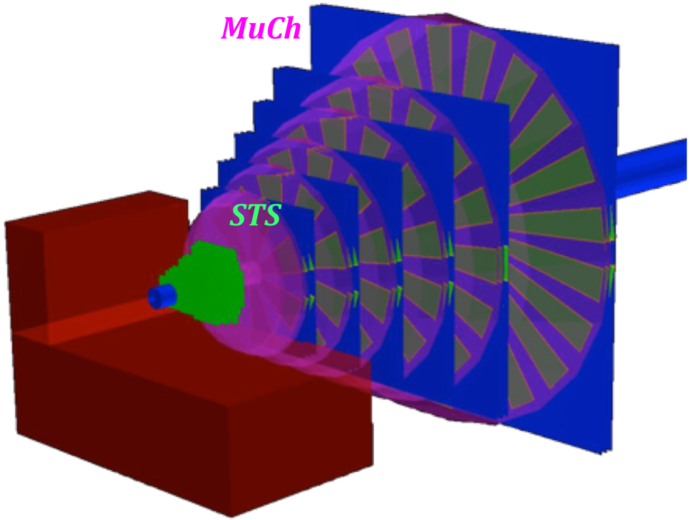
Mean temperature



Conjecture (very suggestive) for the case of a 1st order phase transition ☛

THE MUON SETUP

CBM μ setup

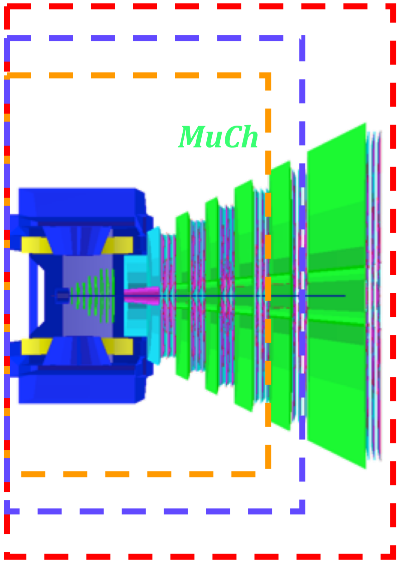


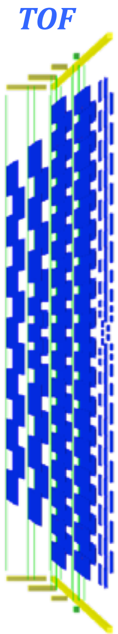
- Instrumented hadron absorber & time-of-flight
- 60 (C+Pb) + 20 Fe + 20 Fe + 30 Fe + 35 Fe + 100 Fe (cm)
- 30 cm gap between 2 absorbers

- Goal:
  - Clean dilepton signal for low- and intermediate mass pairs.
  - "Trigger" on high-mass pairs (J/ψ)
- Challenge:
  - Muon detection at low energies.
  - Efficient weak decay rejection.
  - High areal particle rates in first detector: 0.7 hit/cm2 ≅ 0.4 mA/cm2 (full intensity)
- Strategy:
  - Identification in/after hadron absorber with intermediate tracking layers
  - Triple GEM detectors with pad read-out

VECC , Kolkata

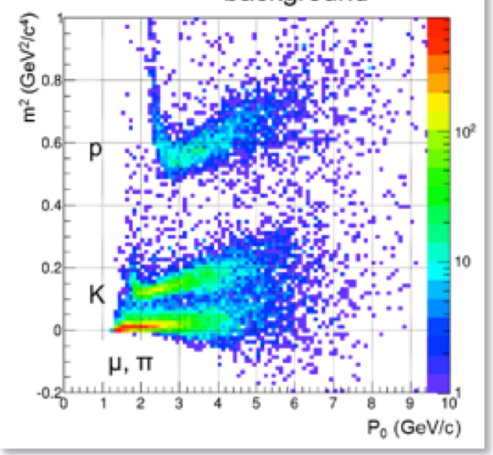
Muon background rejection



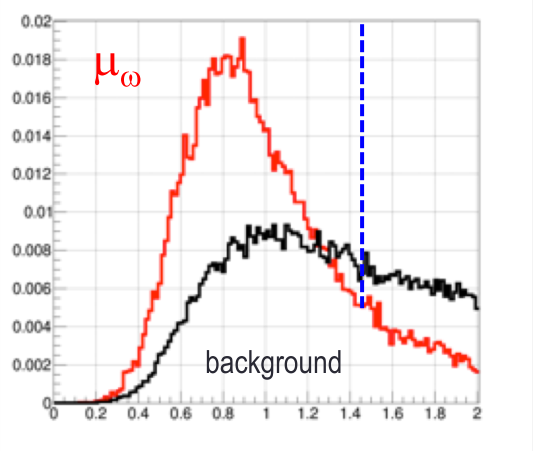


LMR-IMR @ SIS100
LMR-IMR @ SIS300
J/ψ at SIS100/300

Punched through hadrons in ToF



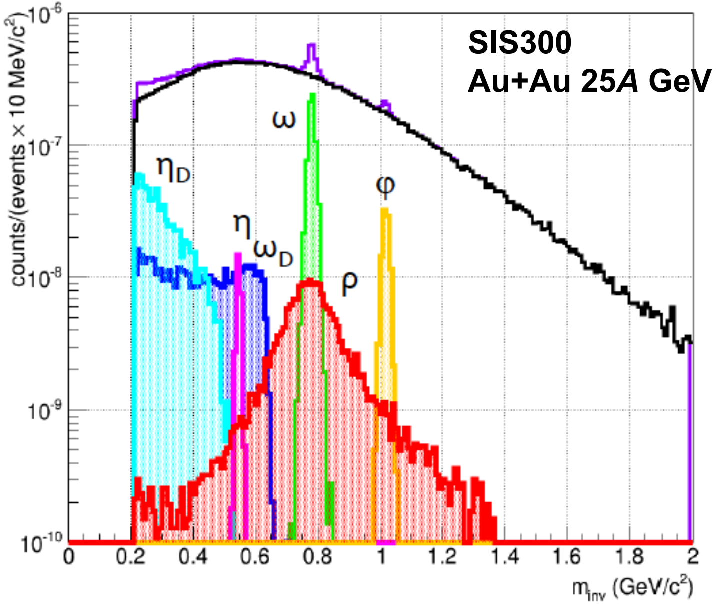
Quality of the muon track (χ^2_{MuCh})



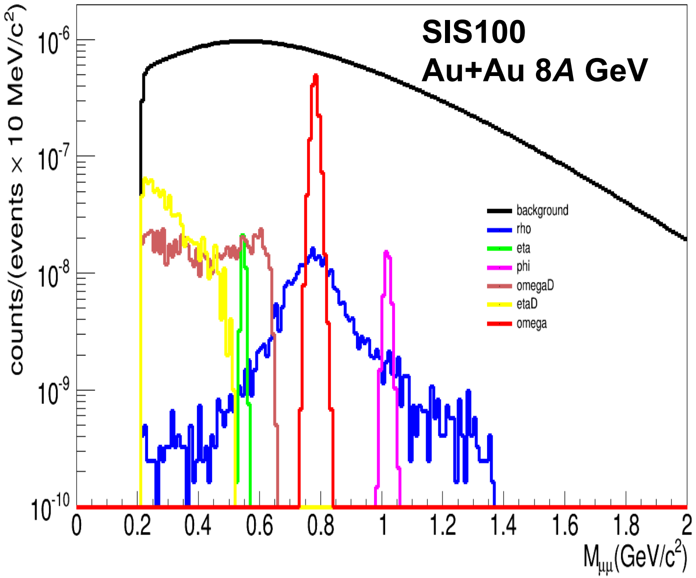
Rejection strategy

1. Tracking: $\chi^2_{vertex} < 2$ and 6 STS hits
2. MuCh: $\chi^2_{MuCh} < 1.25$ and 14 MuCh hits
3. TOF: $m^2 < 0.01$

Dimuon results



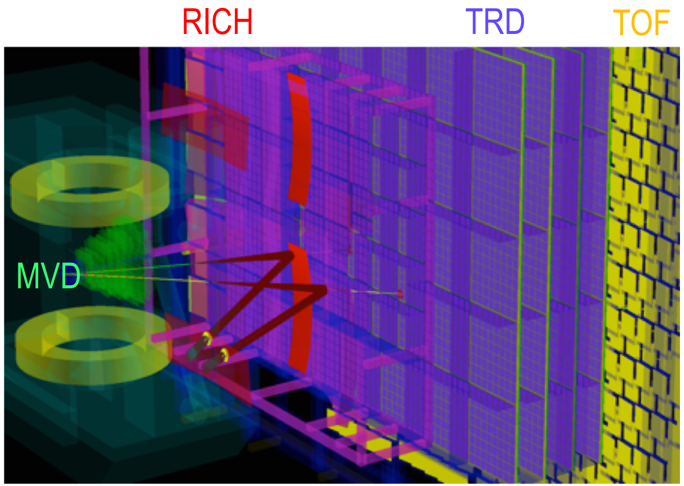
Anna Senger, GSI



Ekata Nandy, VECC

THE ELECTRON SETUP

CBM electron setup

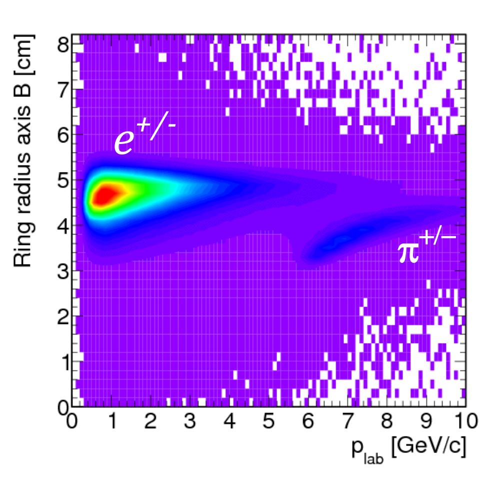


- MVD + STS: MAPS pixel sensors + silicon strip
- RICH: conventional design based on commercial products (Germany, Russia, Korea)
- TRD: thin gap design based on ALICE TRD (Germany, Romania)

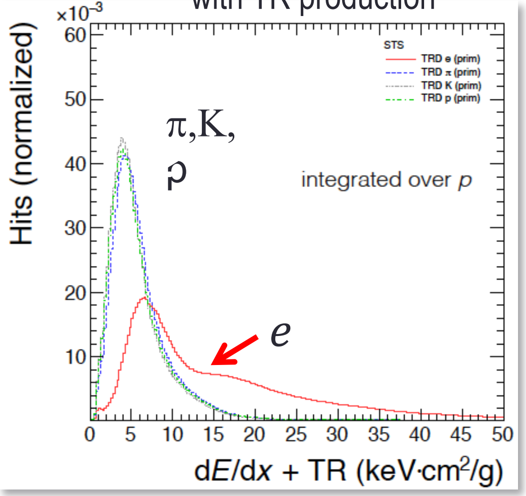
- Goal:
  - Clean dilepton signal for low- and intermediate mass pairs
- Challenge:
  - No electron identification before tracking (close pair detection)
  - Background due to material budget of the tracking system
  - Abundant singles from incomplete detection of Dalitz pairs
- Strategy:
  - Sufficient π discrimination
  - Reduction of background by reconstructing pairs from g-conversion and p0 Dalitz decay

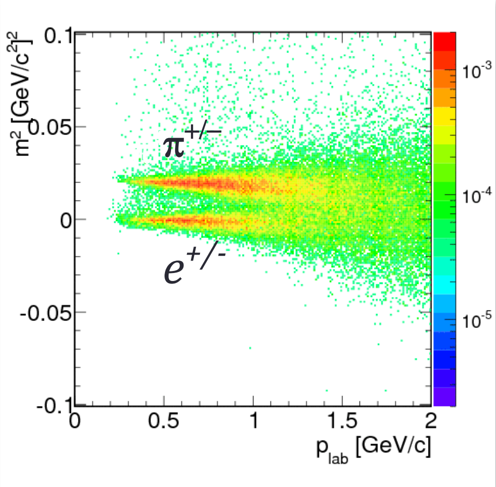
Electron identification: Discriminating input variables

RICH ring radius vs. momentum



TRD signal for single hits with TR production

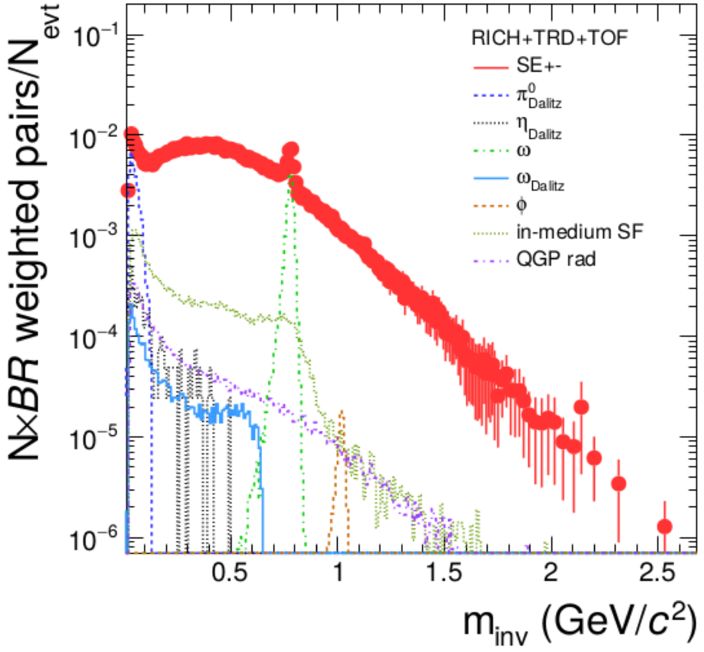




Nonlinear Analysis: Artificial Neural Networks are used to identify leptons

Invariant mass spectrum after *e*-ID Cuts

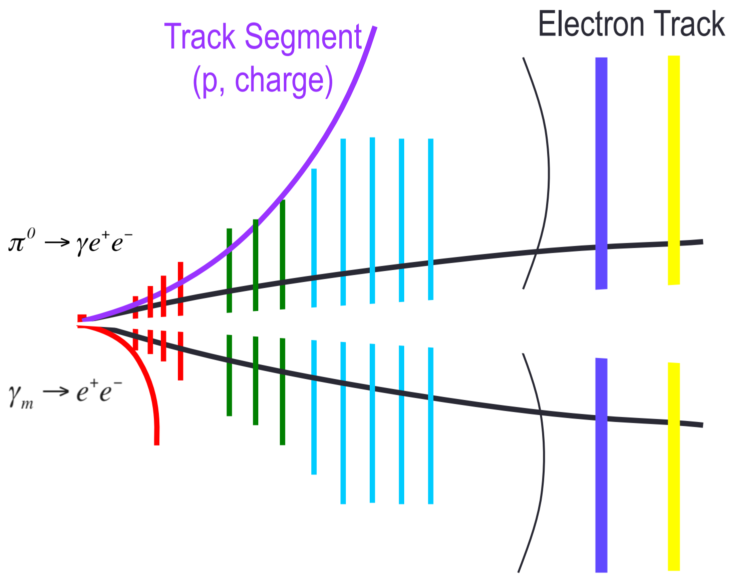
CBM Simulation, Au-Au $8\ A\ \mathrm{GeV}$, $N_{evt} = 9\ \mathrm{M}$



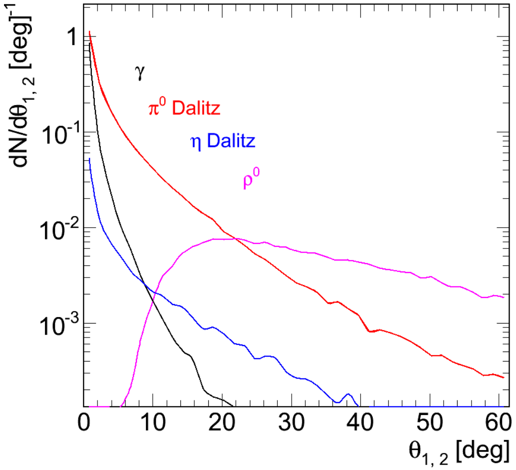
- Major combinatorial background from physical sources
  - Partially reconstructed γ-conversions in target and tracking system, π^0 Dalitz decays
- Strategy:
  - Use topological cuts in order to reject this background

Track topology

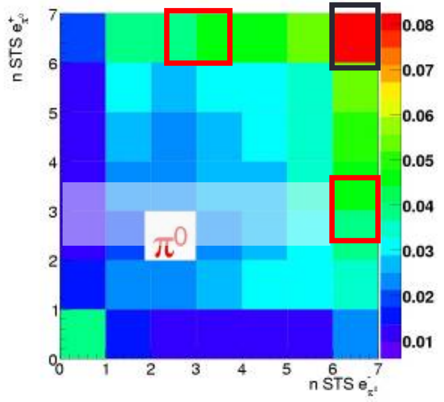
Erik Krebs



Opening angle distribution between e^+e^-

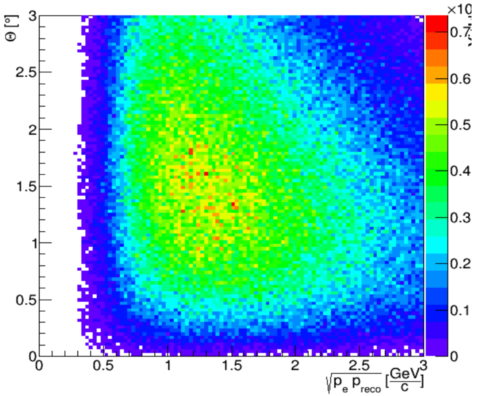


Correlation of the number of STS traversed by e^+e^- pairs from π^0-Dalitz

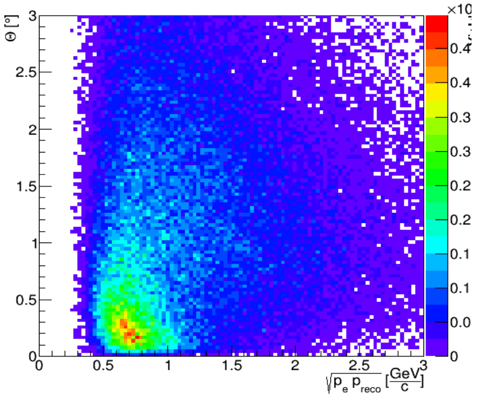


Background rejection strategy

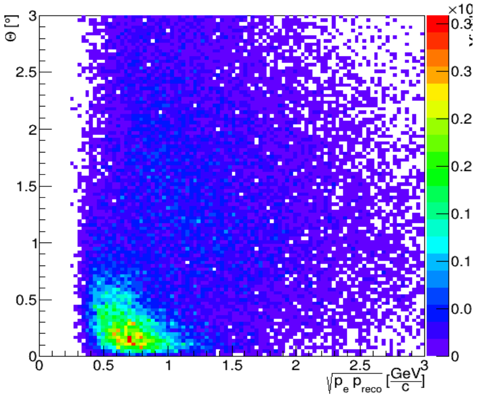
- Select closest neighbor track and plot opening angle θ versus $\sqrt{p_e p_{reco}}$
- Primary track cut
  - Extrapolate tracks to primary vertex and cut on deviation to the vertex
  - Tracks must have a hit in the first MVD station or be in its acceptance
- Track topology cut
  - Cut on opening angle and product of momenta



Signal



π^0-Dalitz



γ-conversions

Summary

CBM scientific program at SIS100:

- Exploration of the QCD phase diagram in the region of neutron star core densities
  $\rightarrow$ large discovery potential.

Goals for the dilepton program:

- Establish a full excitation function of dilepton radiation
- Extract excess yields, temperatures and flow
- Search vor non-monotonic behavior of these observables
- Study in detail the spectral distribution around 1 GeV to learn about the chiral symmetry restoration

FAIR Phase 0:

- HADES with CBM RICH photon detector
- Focus in particular on baryon transition form factors using pion-beam induced reactions
- Electromagnetic decays of hyperons

THANK YOU