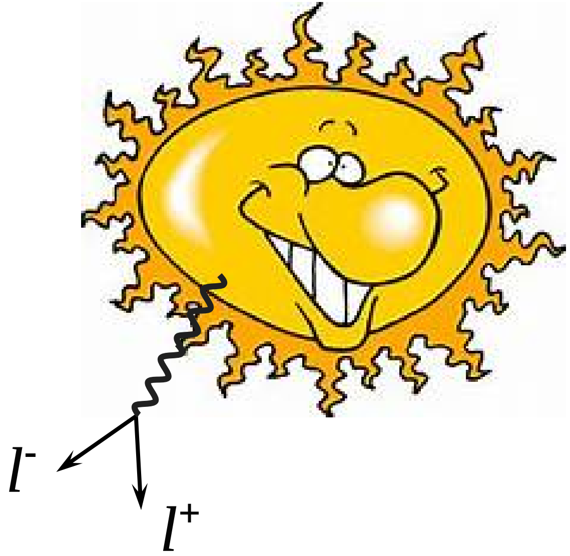
CBM Day-1 program with dileptons

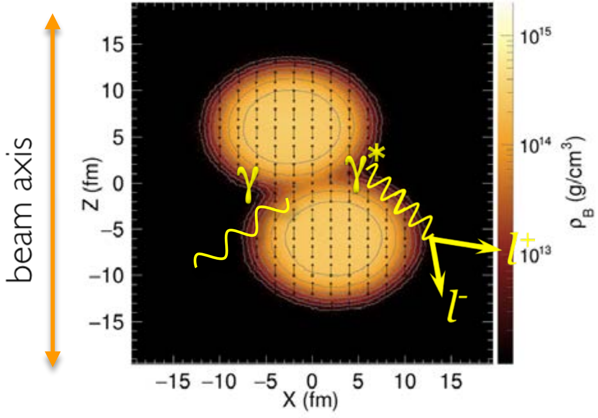


Tetyana Galatyuk
for the CBM PWG Dileptons

Physics Symposium, 32nd CBM Week, 3 Oct 2018

Electromagnetic radiation

… probe the interior of fireballs – "PET" of the fireball



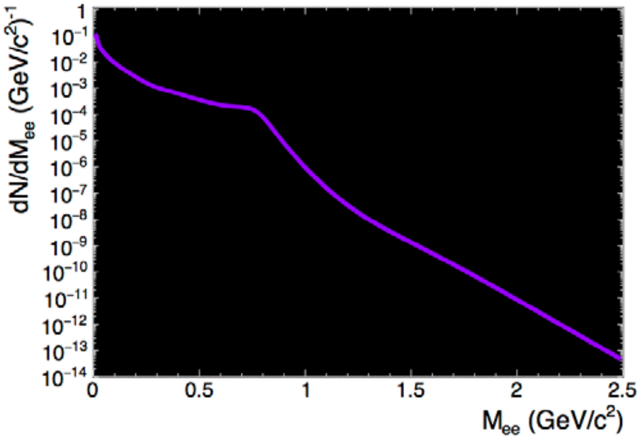
- Shines throughout the collision
- No strong FSI → leave reaction volume undisturbed
- Encodes information on matter properties (T, ρ_B, τ_{coll})

- Real γ characterized by transverse momentum
- Lepton pairs carry extra information: invariant mass

Unique direct access to in-medium spectral function

$$\frac{dN_{ll}}{d^4q d^4x} = -\frac{\alpha_{em}^2}{\pi^3}\frac{L(M^2)}{M^2} f^{BE}(q_0,T)\,\mathrm{Im}\Pi_{em}(M,q,T,\mu_B)$$

McLerran - Toimela formula, Phys. Rev. D 31 (1985) 545



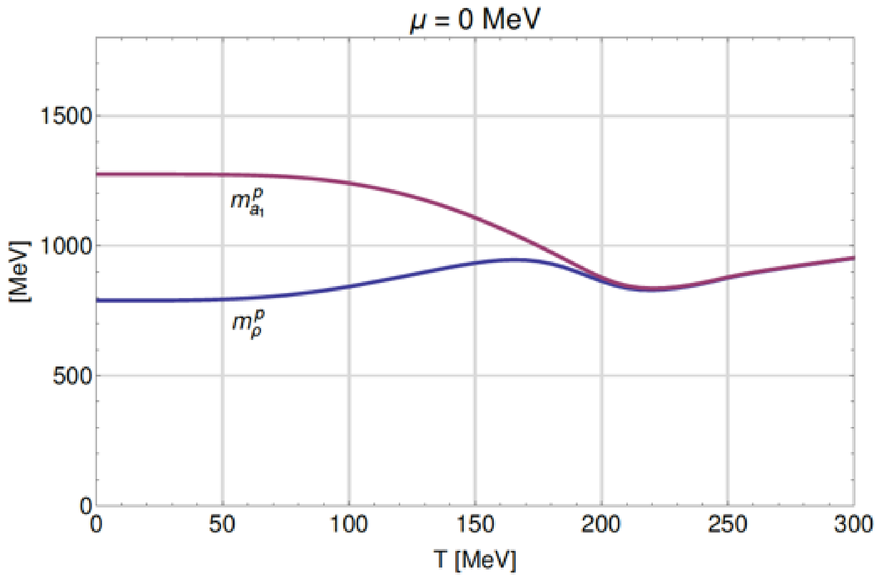
Chiral symmetry of QCD

Spontaneously broken in the vacuum

$$\langle 0 | \bar{q}q | 0 \rangle = \langle 0 | \bar{q}_L q_R + \bar{q}_R q_L | 0 \rangle \neq 0$$

Restoration at finite T and μ_B manifests itself through mixing of vector and axial-vector correlators

The vector correlator is directly accessible in HIC



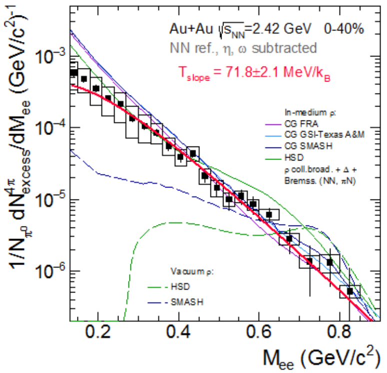
C. Jung et al., Phys. Rev. D 95, 036020 (2017)

Hohler and Rapp, Phys.Lett. B731 (2014)

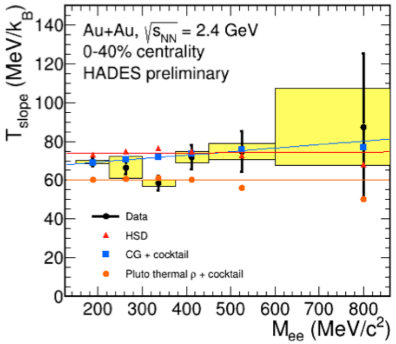
Thermal radiation from HADES

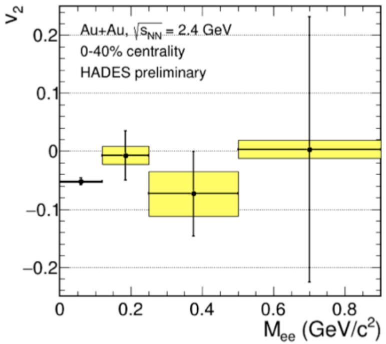
Au+Au collisions, 0–40%, 2% interaction length target, 4 weeks beam on target, 8 kHz event rate

- Spectrometer
  - M_{ll} of excess pairs
- Chronometer
  - $\int_{0.3GeV}^{0.7GeV} \frac{dN_{ll}}{dM} \sim \tau_{fireball}$
- Thermometer
  - $if \; \frac{\mathrm{Im}\,\Pi^{\mu\nu}_{EM}}{M^2} \sim const.$
- Barometer
  - T_{eff} vs. M_{ll}
  - v_2 vs. M_{ll}
- Polarimeter
  - γ^* polarization via lepton angular distribution

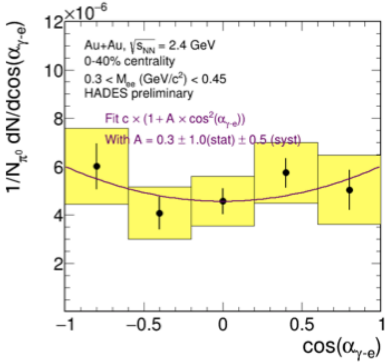


HADES submitted



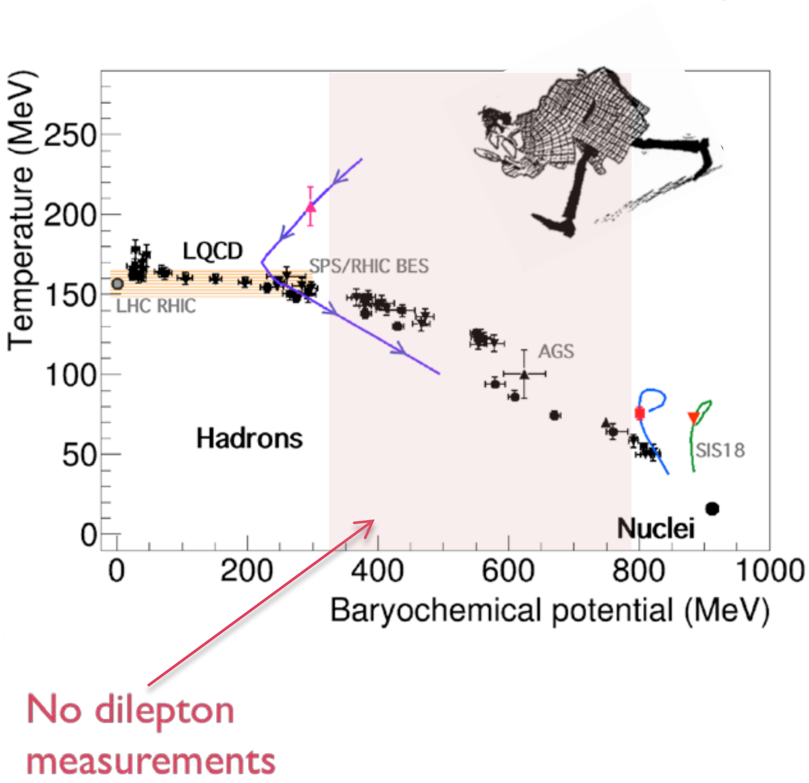


HADES preliminary, S. Harabasz QM18



NA60: PRL 96 (2009) 222301
HADES: PRC 84 (2011) 014902
E. Speranza et al., Phys.Lett. B782 (2018)

Precision studies of the QCD phase diagram with dileptons

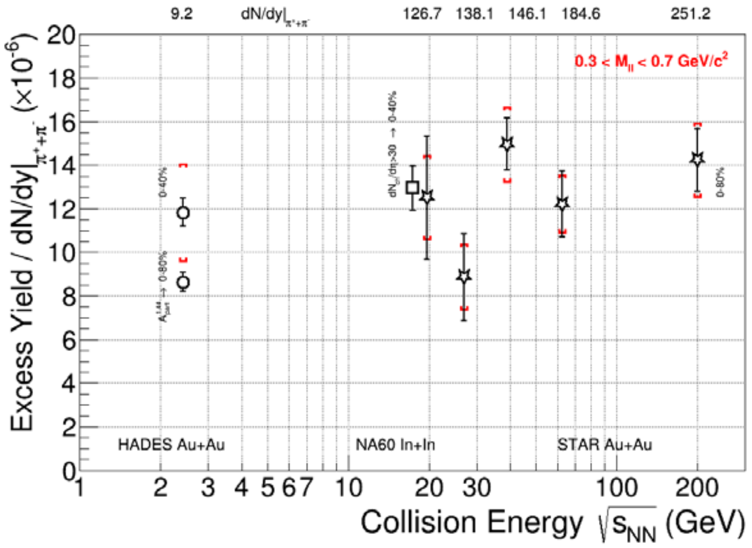


- Phase transition (and QCD critical point)
  - Excitation functions
    - Low-mass excess yield
    - Emitting source temperature
- Chiral symmetry restoration
  - Isolation of dilepton spectrum from ρ-a_1 chiral mixing

Hohler and Rapp, Phys.Lett. B731 (2014)
Jung, Tripolt, et al., Phys.Rev. D95, 036020 (2017)

Thermal dileptons excitation functions

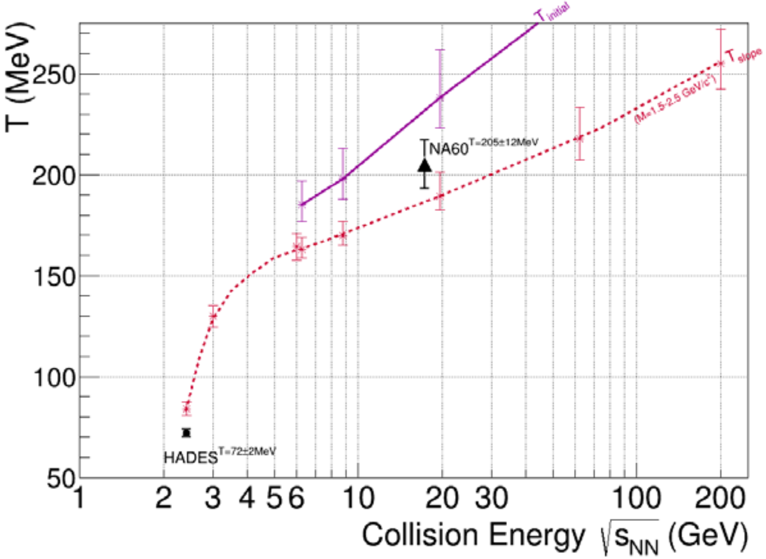
Low-mass excess yield per pion



$$\int_{0.3GeV}^{0.7GeV} \frac{dN_{ll}}{dM} \sim \tau_{fireball}$$

U.W. Heinz and K. S. Lee, PLB 259, 162 (1991)
H.W. Barz, B. L. Friman, J. Knoll and H. Schulz, PLB 254, 315 (1991)
R. Rapp, H. van Hees, PLB 753 (2016) 586

Emitting source T

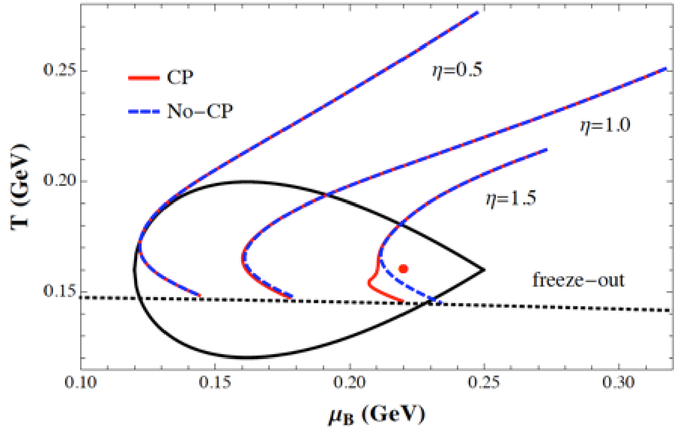


$$if \frac{\mathrm{Im}\,\Pi^{\mu\nu}_{EM}}{M^2} \sim const. \Rightarrow \frac{dN_{ll}}{d^4q d^4x} \sim f^{BE}(q_0,T)$$

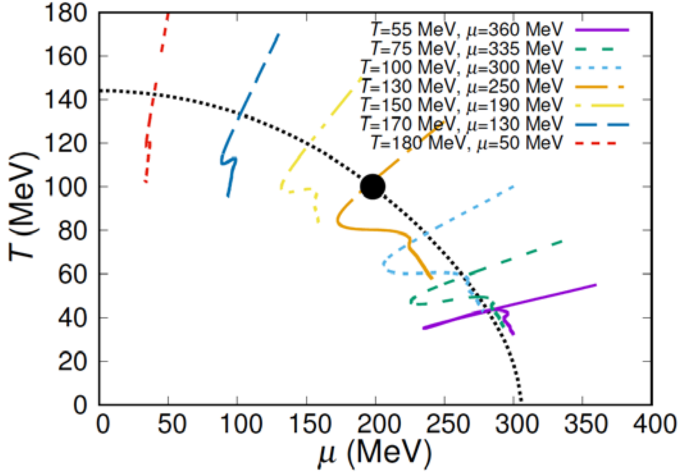
NA60 Collab., Chiral 2010, AIP Conf.Proc. (2010) 1322
R. Rapp, H. van Hees, PLB 753 (2016) 586

Mapping the QCD phase diagram with dileptons

Hydrodynamic evolution trajectories near the critical point



A. Monnai, S. Mukherjee, Y. Yin, Phys.Rev. C95 (2017) no.3, 034902

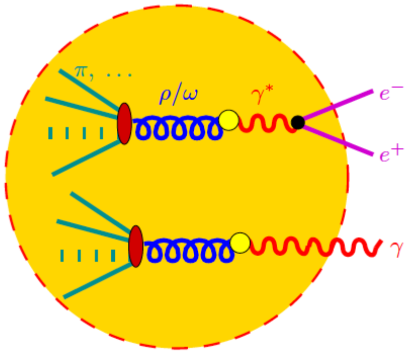


C. Herold, CPOD 2018

What are the possible signatures in dilepton radiation?

→ "Extra radiation" around phase transition (& critical point?)
→ QCD caloric curve (plateau around onset of deconfinement?)

Why high interaction rates to study dileptons?



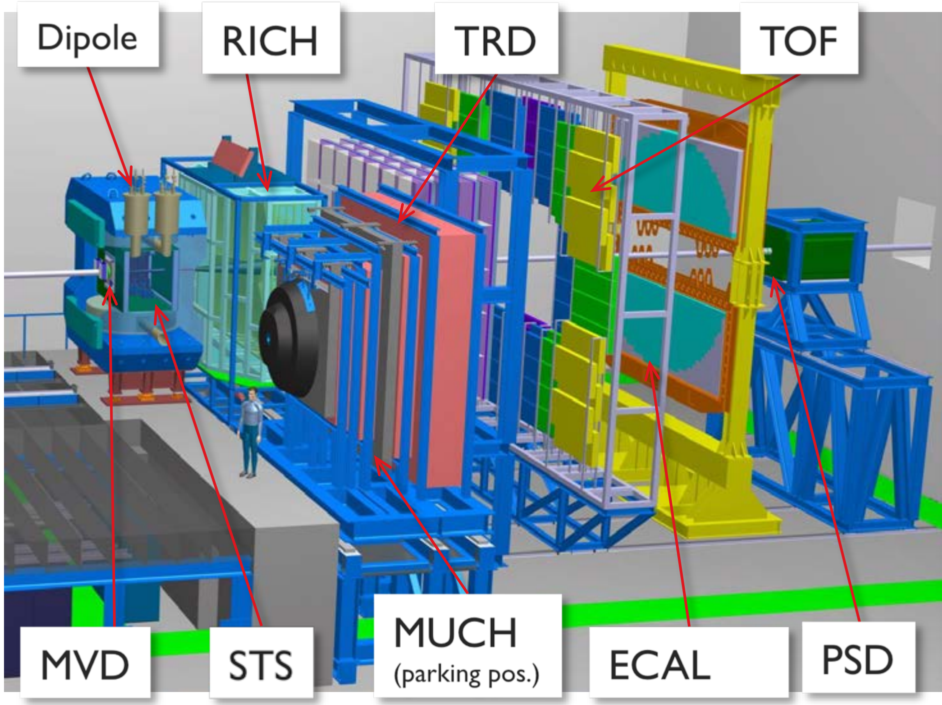
- Lowest order rate ~α^2_{em}
- Dilepton production – rare processes

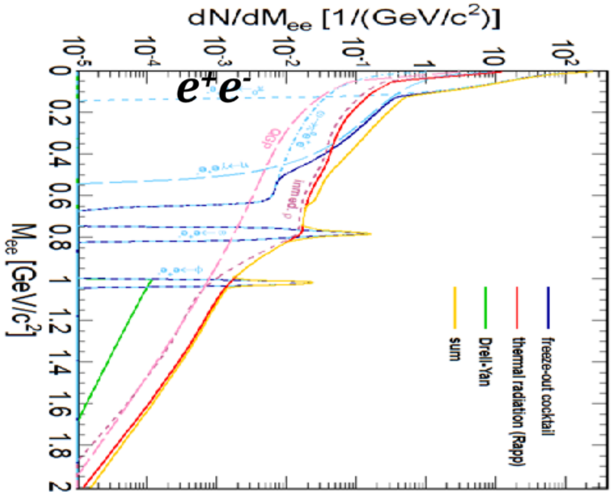
- Interaction rate:
  - Fixed-target O(R_{int} = 10^6 – 10^7/s)
  - Colliders O(R_{int} = 5×10^4/s)

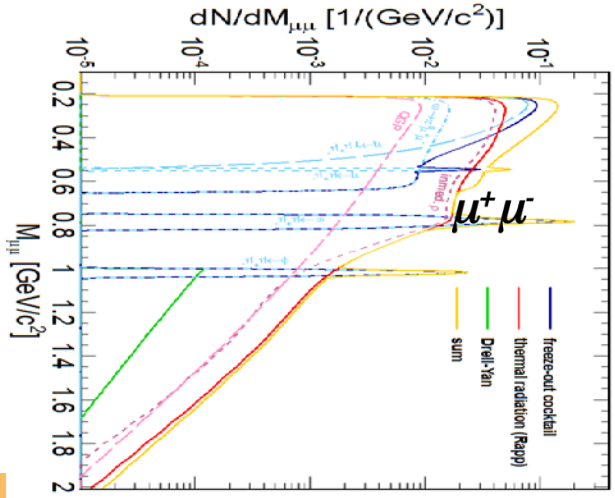
- Signal-to-Combinatorial Background ratio (S/B):
  - For different experiments S/B << 1 → B/S (10 - 100)
  - Effective signal size: S_{eff}~R_{int} × S/B → reduction by factor of 10 to 100

The CBM Experiment

- Designed for (mid-rapidity) $\sqrt{s_{NN}}$ ~7.7 GeV
- Tracking, momentum determination, vertex reconstruction: radiation hard silicon pixel/ strip detectors in a magnetic dipole field
- Hadron identification: TOF
- Photons, π^0, η: ECAL
- Electron identification: RICH, TRD, ToF
- Muon identification: instrumental absorber







Objectives

- Isolation of excess pairs up to M=2 GeV/c^2
- Mid-rapidity coverage is important
- Systematic measurements of
  - → Excess yield and shape
  - → $T_{\text{emitting source}}$
  - → T_{eff} vs. mass
  - → v_2 vs mass
  - → Polarization

with precision of %

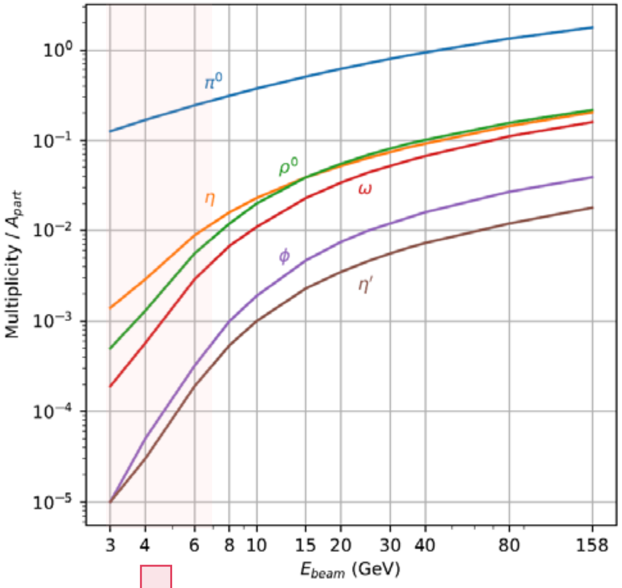
Performance studies

- Hadronic "cocktail" generator Pluto (ω, ϕ)
- Thermal radiation – coarse-grained transport approach

R. Rapp and J. Wambach, EPJA 6 (1999) 415
TG *et al.*, EPJA 52 (2016) 131

- Hadron and photon BG – transport model calculations, Au+Au collisions, 0-10% and min-bias
- Simulations with realistic detector geometries, material budget, and response

Fixing important components of the "hadronic cocktail"



No η, ω, ϕ measurements!

Low-Mass Region:

- ω, ϕ subtract peaks such to get a smooth M_{ll} continuum
  - ϕ cross check / compare with ϕ→ K^+K^-
- π^0 and η important component of the cocktail
  - η → $\mu^+\mu^-$ decays peak is visible
  - η → γγ – calorimetery
  - Photon conversion method
  - π^0 - cross-check with the high-statistics π sample → $\pi^0 \approx ½(\pi^+ + \pi^-)$

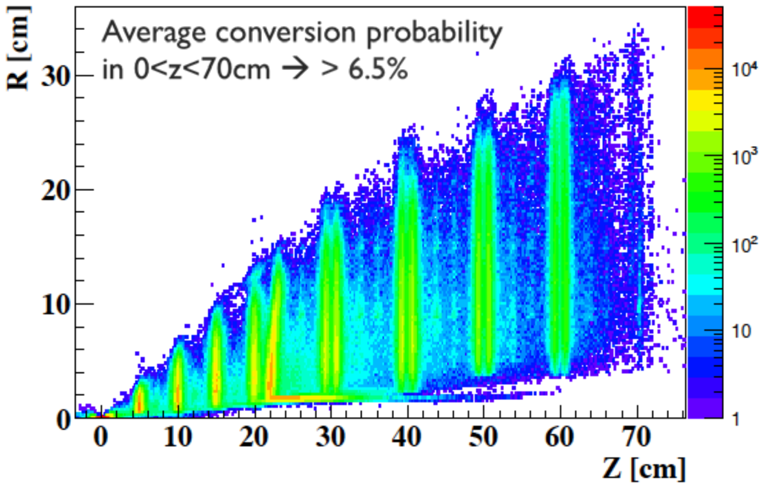
Intermediate-Mass Region:

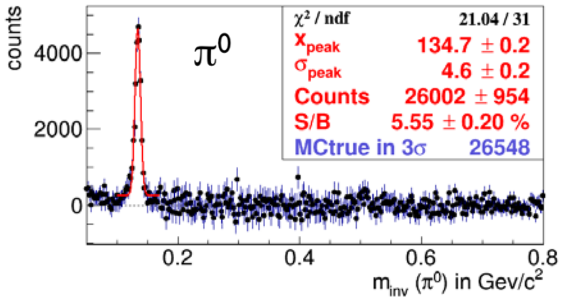
- Negligible correlated charm contribution
- Significant reduction of Drell-Yan (pA measurements!)
- Decrease of QGP

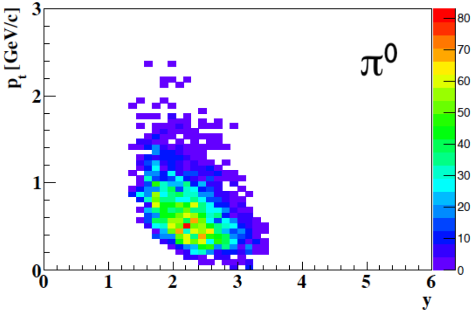
Reconstruction of π^0/η Au+Au 8*A* GeV

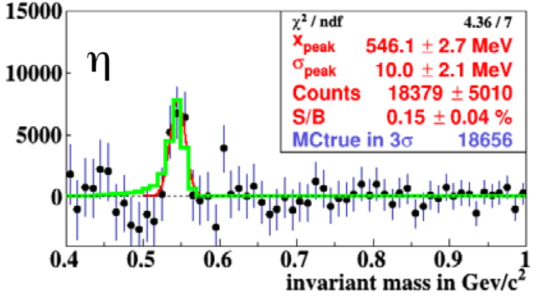
- Measure $\pi^0/\eta \rightarrow \gamma\gamma$ via conversion of γ in detector material
- Event-mixing for background estimation
- Detection capability ~10^{-4} (reconstruction, PID RICH+ToF, conversion probability)

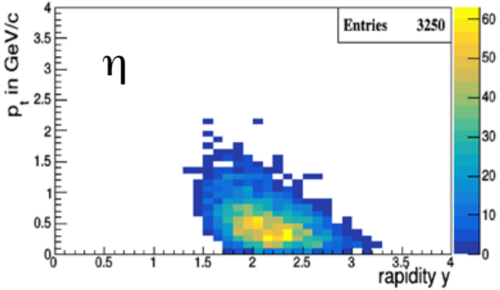
CBM tomography: z vertex of $e^{+/-}$ from γ conversion



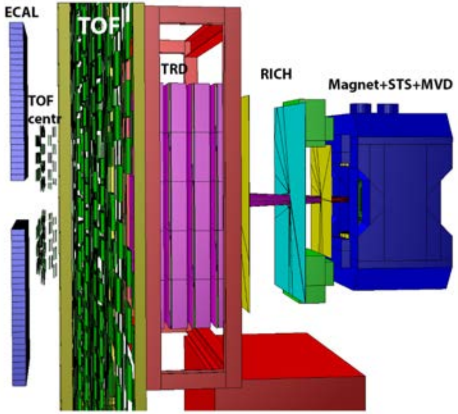






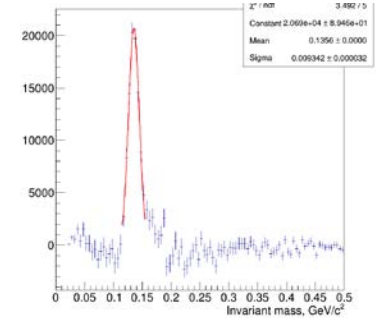


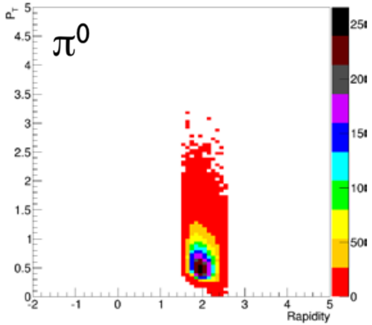
Neutral meson reconstruction with ECAL



- Study π^0, η performance in terms of efficiency and S/B ratio
  - Distance to the target
  - Distance between calorimeter halves
  - Amount of material in front of ECAL (full setup with ToF and TRD)

π^0



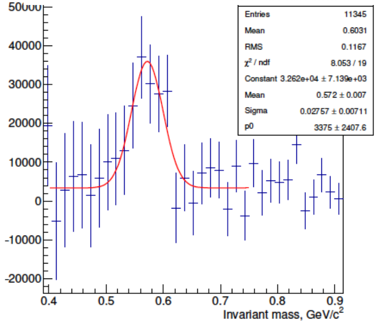


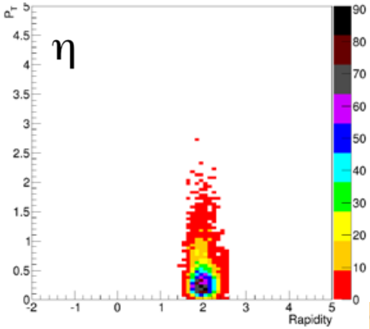
1.5 million events

Efficiency = 3.5%

S/B =1.4%

η



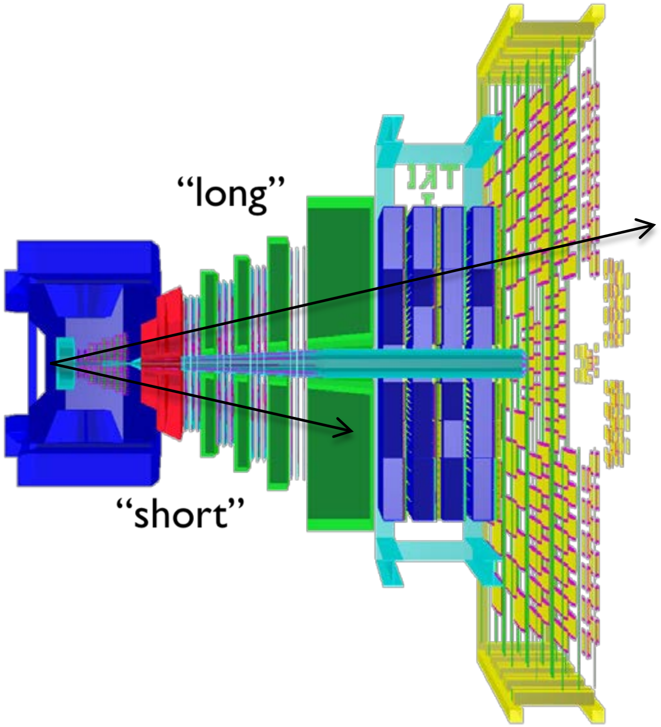


5 million events

Efficiency = 2.4%

S/B = 2×10^{-4}

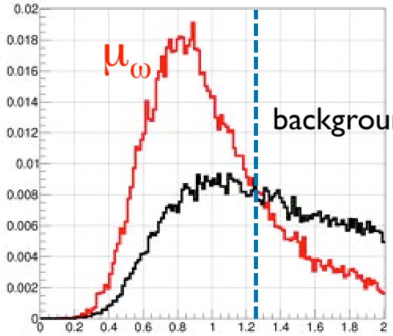
CBM μ setup



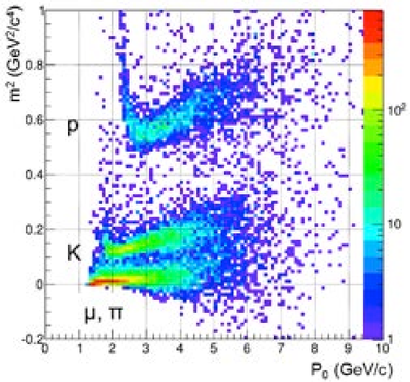
4 absorbers: 60 cm C + (20+20+30) cm Fe
4 triple GEM stations

- Goal:
  - Clean dilepton signal for low- and intermediate mass pairs
  - "Trigger" on high-mass pairs (J/ψ)
- Challenge:
  - μ at low energies
  - Efficient weak decay rejection
- Strategy:
  - μ ID after hadron absorber with intermediate tracking layers
  - Triple GEM detectors with pad read-out

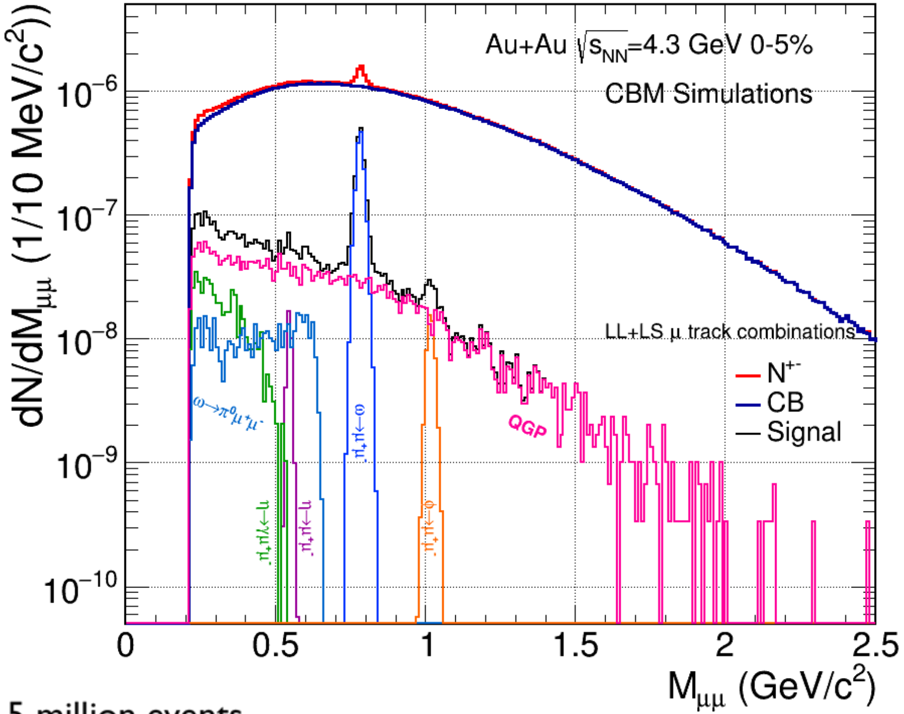
Quality of the muon track candidates (χ^2_{MuCh})



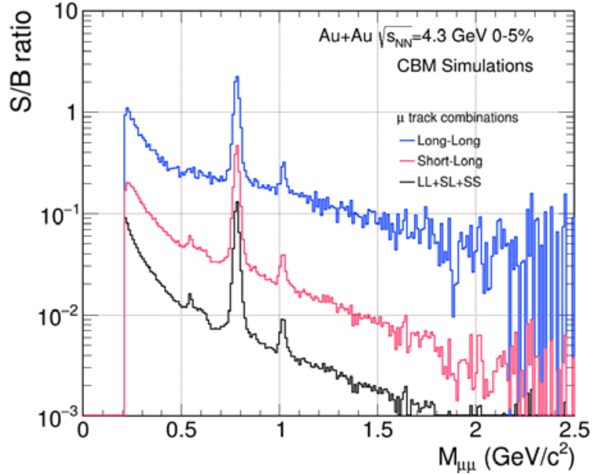
Punched through hadrons in ToF



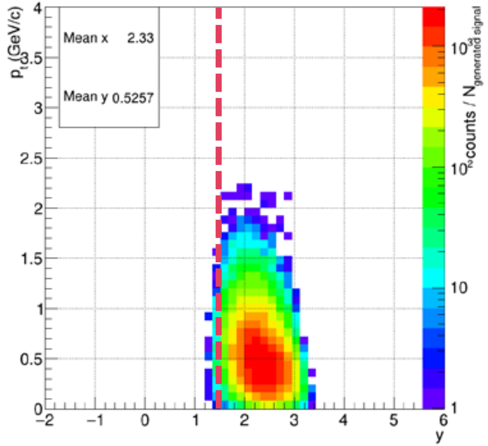
Dimuon results Au+Au 8*A* GeV



Signal to background ratio

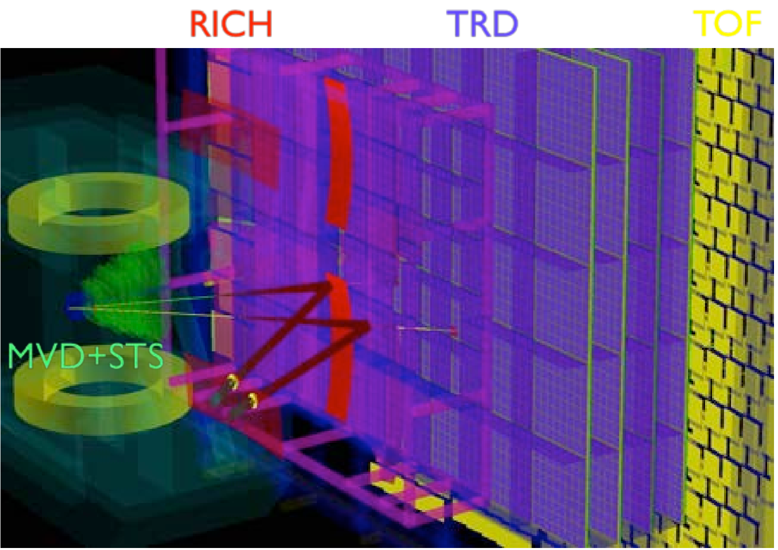


Phase space coverage



5 million events
Signal detection capability ~1%
ω mass resolution 15.6 MeV

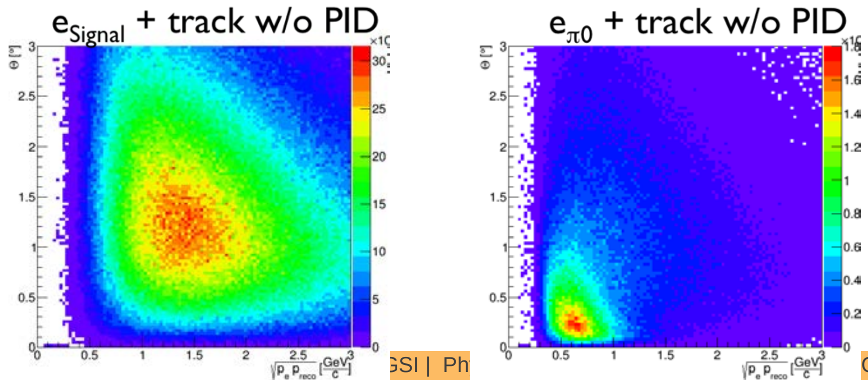
CBM electron setup



- Goal:
  - Clean dilepton signal for low- and intermediate mass pairs
  - "Trigger" on high-mass pairs (J/ψ)
- Challenge:
  - No electron identification before tracking
  - Background due to material budget of the tracking system
- Strategy:
  - Sufficient π discrimination
  - Reduction of background by reconstructing pairs from γ-conversion and π^0 Dalitz decay

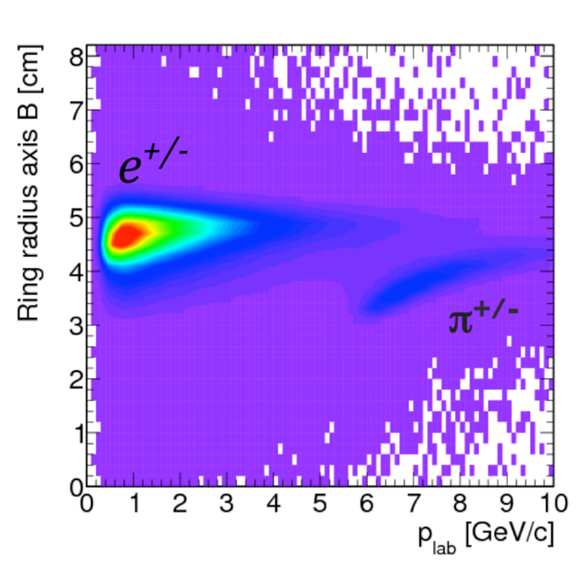
CBM-PHYS-note-2006-001
TG PhD, Frankfurt University (2009)

Track topology CB rejection cut

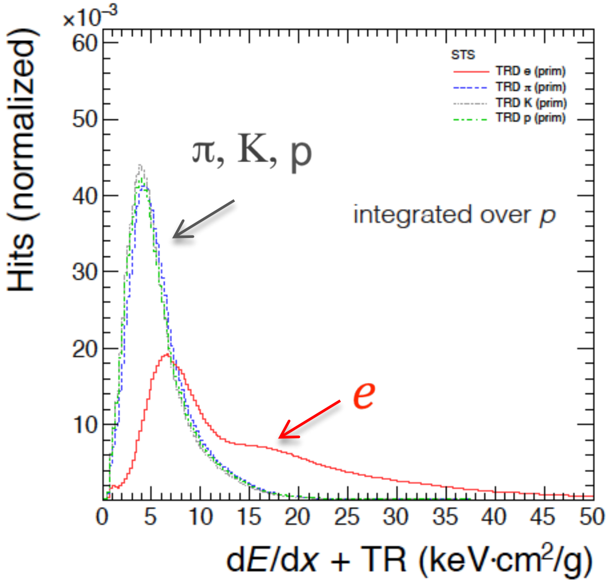


Electron identification: Discriminating input variables

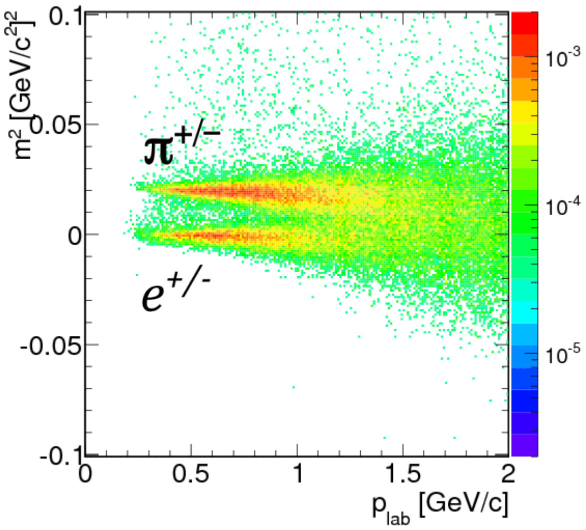
RICH ring radius vs. momentum



TRD signal for single hits with TR production

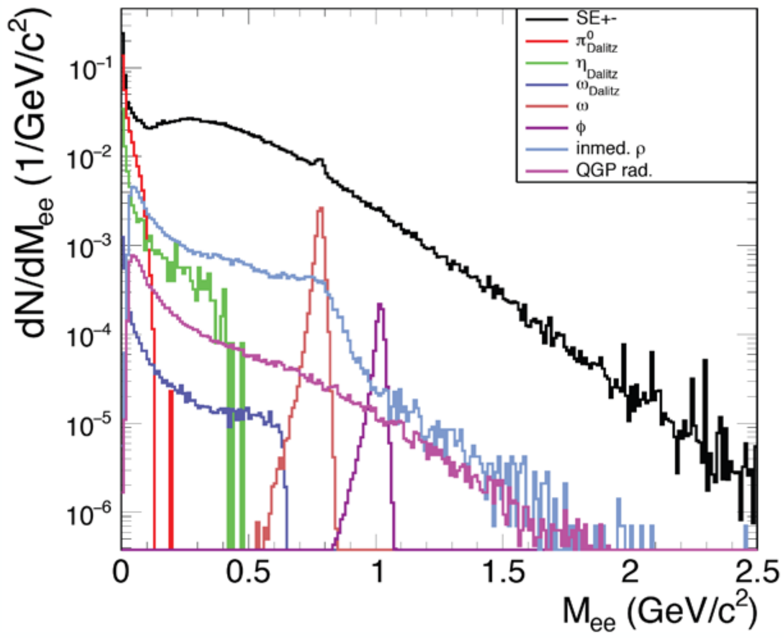


RICH identified electrons in TOF



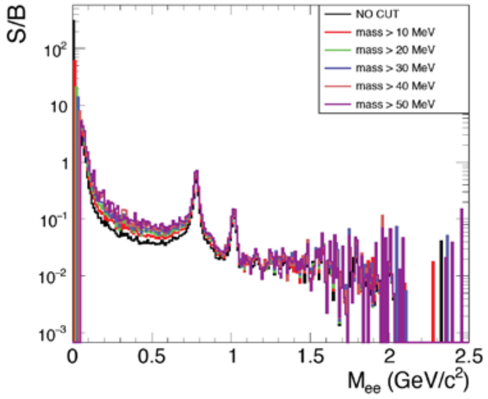
Nonlinear Analysis: Artificial Neural Networks are used to identify leptons

Dielectron results Au+Au 8*A* GeV

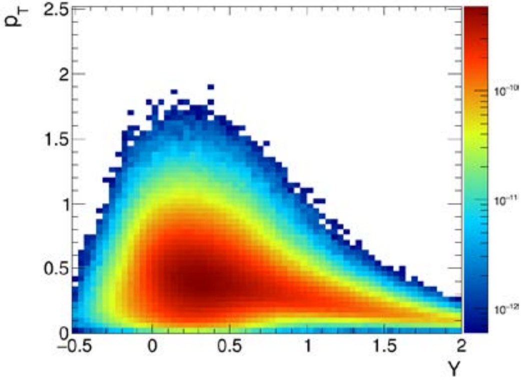


5 million events
0-10%
70% of max field
detection capability ~3-4%
ω mass resolution 17 MeV

Signal to background ratio



Phase space coverage



- Two independent analysis (CbmAnaDielectronTask.cxx, PaPa framework)
- Comparable results w.r.t. Signal-to-Background ratio, signal detection efficiency

Possible running scenario

90 days beam time per year for CBM

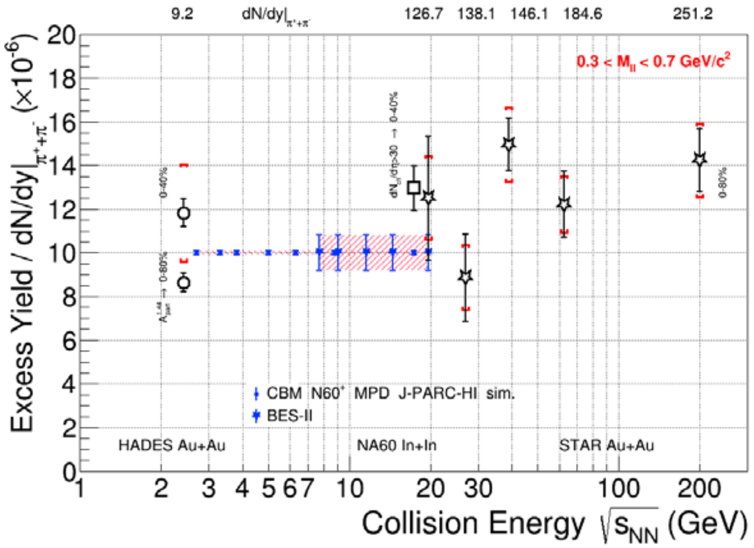
- Ag+Ag 4.5A GeV (10 days)
- p+(C)Au 29 GeV (20 days)
- Energy scan: Au+Au 4.5 – 7 – 11A GeV
- 100 kHz interaction rate
- 20 days / energy

Expected integral yields after 20 days of running at 100 kHz, selecting 10% most central Au+Au collisions 8*A* GeV, assuming 50% duty cycle

π^0	8,0E+06
η	3,2E+04
ω Dalitz	8,3E+04
ω	4,7E+04
ϕ	3,8E+04
in-med (at M =1.2 GeV)	8,6E+03
QGP (at M = 1.2 GeV)	8,6E+03

Thermal dileptons excitation functions

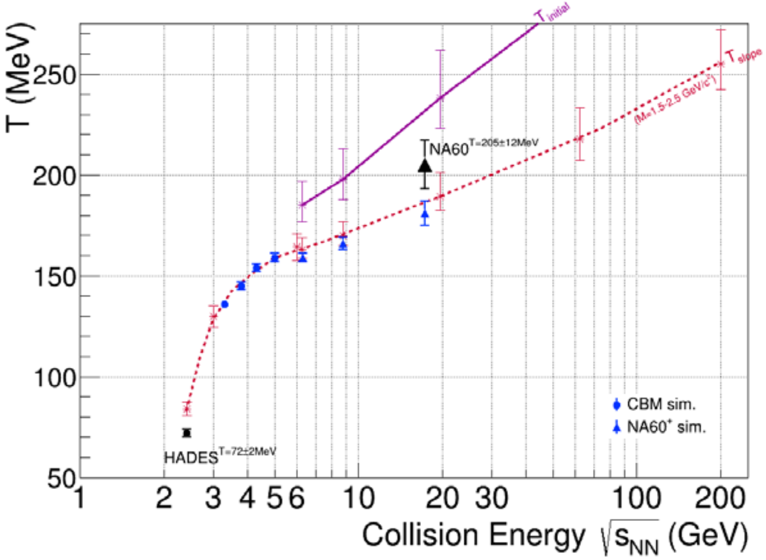
Low-mass excess yield per pion



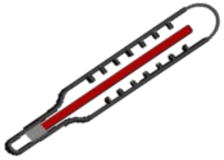
$$\int_{0.3GeV}^{0.7GeV} \frac{dN_{ll}}{dM} \sim \tau_{fireball}$$

U.W. Heinz and K. S. Lee, PLB 259, 162 (1991)
H.W. Barz, B. L. Friman, J. Knoll and H. Schulz, PLB 254, 315 (1991)
R. Rapp, H. van Hees, PLB 753 (2016) 586

Emitting source T



$$if \frac{\mathrm{Im}\,\Pi^{\mu\nu}_{EM}}{M^2} \sim const. \quad \Rightarrow \frac{dN_{ll}}{d^4q d^4x} \sim f^{BE}(q_0, T)$$

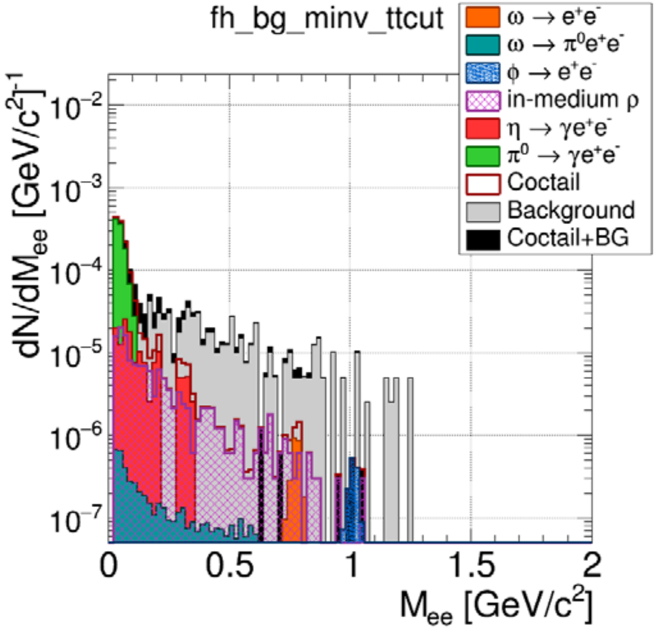


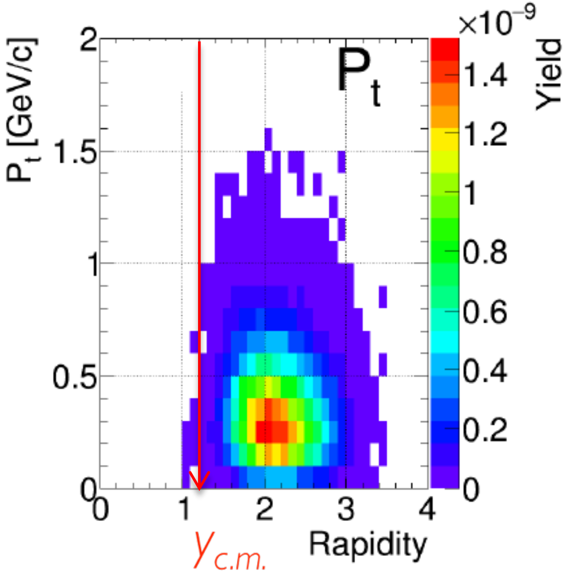
NA60 Collab., Chiral 2010, AIP Conf.Proc. (2010) 1322
R. Rapp, H. van Hees, PLB 753 (2016) 586

CBM performance: Ag+Ag 4.5*A* GeV

- Ag+Ag collisions at 4.5*A* GeV 0-43%
- Full analysis chain (60% max field)
- Statistics 10 × 10^6 events

	$\omega \to e^+e^-$	$\phi \to e^+e^-$
S/BG 40% centr.	0.08	0.25
Efficiency (%) (4π)	1.6	2.3
Mass resolution [MeV]	16.9	19.4



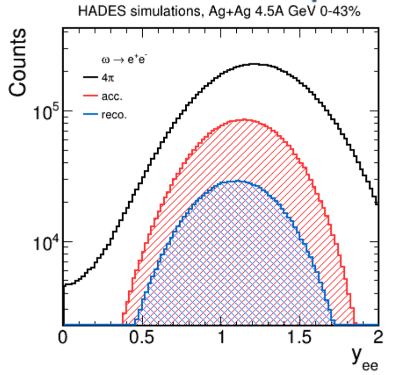


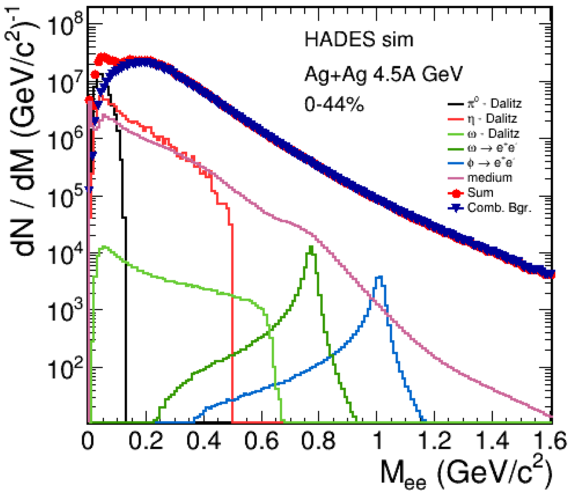
- Phase space coverage very much forward peaked
- Further optimization: magnetic field?
- High statistics simulations

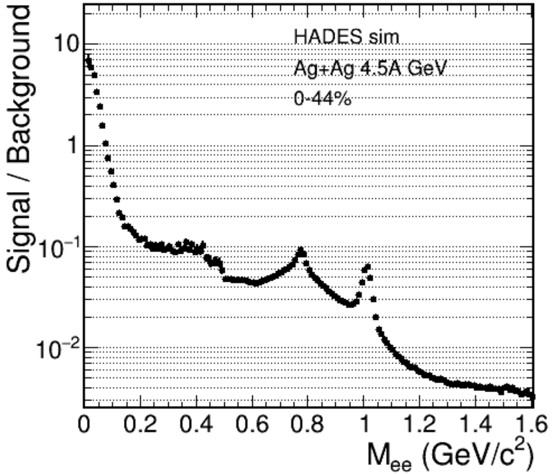
HADES performance: Ag+Ag 4.5*A* GeV

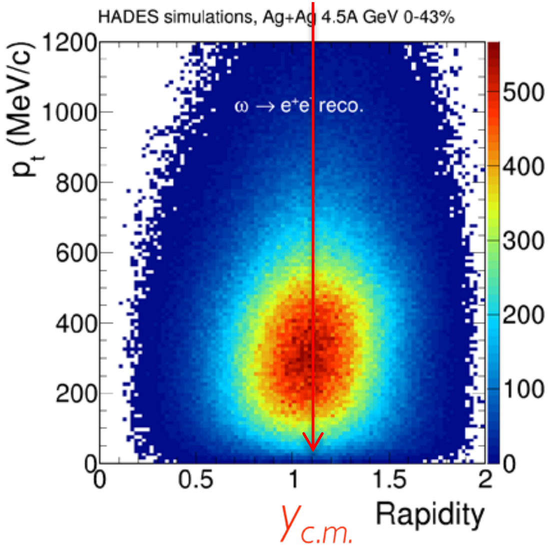
- Ag+Ag collisions at 4.5*A* GeV 0-43%
- Full analysis chain (event reconstruction, PID with RICH-ToF- ECAL is a matter of further optimizations)
- Statistics 4.5 × 10^9 events → 4 weeks beam on (2%) target, (conservative) 10 kHz accepted first level trigger rate

35% detection capability!









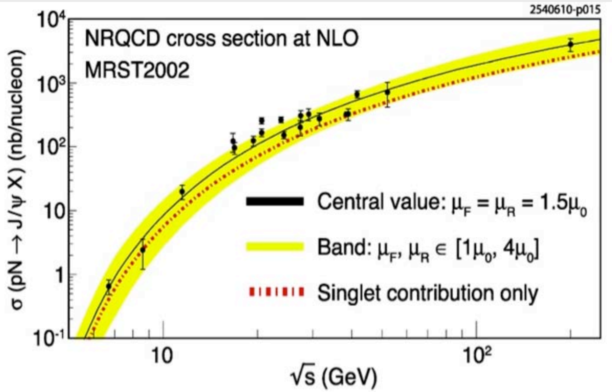
“I have a dream… “

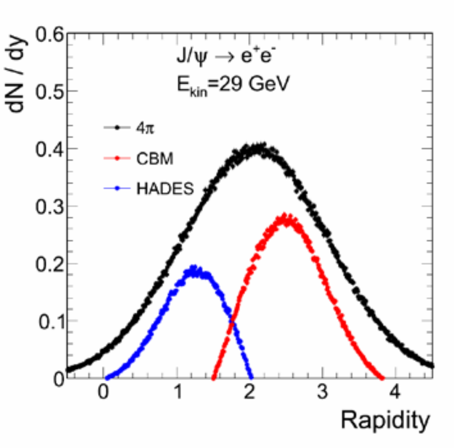
- Establish a full excitation function of dilepton radiation
  - Extract excess yields, temperatures, flow
  - Search for non-monotonic behavior of these observables
  - Study in detail the spectral distribution around 1.2 GeV/c^2 to learn about the chiral symmetry restoration
  - Understand microscopic properties of QCD matter at high μ_B region

- Large discovery potential for HADES and CBM
  - Overlap and independent confirmation of results
  - Complementary w.r.t. phase space coverage
  - Strong synergy in FAIR-Phase0

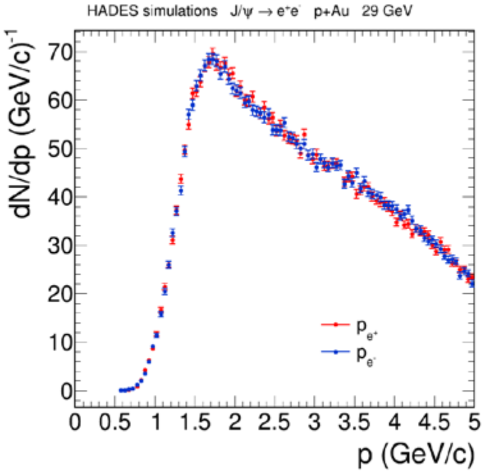
Thank you for your attention!

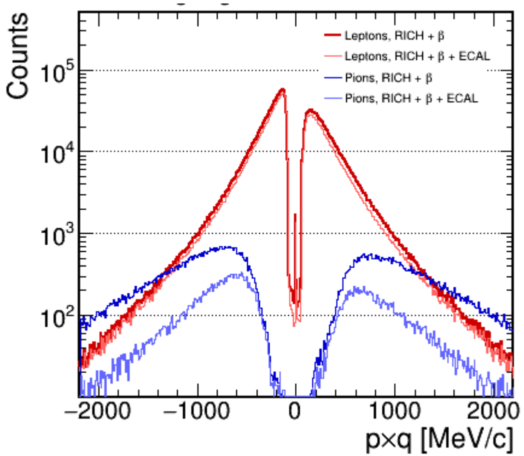
J/ψ → e^+e^- with HADES?





- Higher sensitivity to cold matter effects if charmonium is produced close to target rapidity.
- Could be studied in p+A collisions (E_{beam} = 29 GeV)

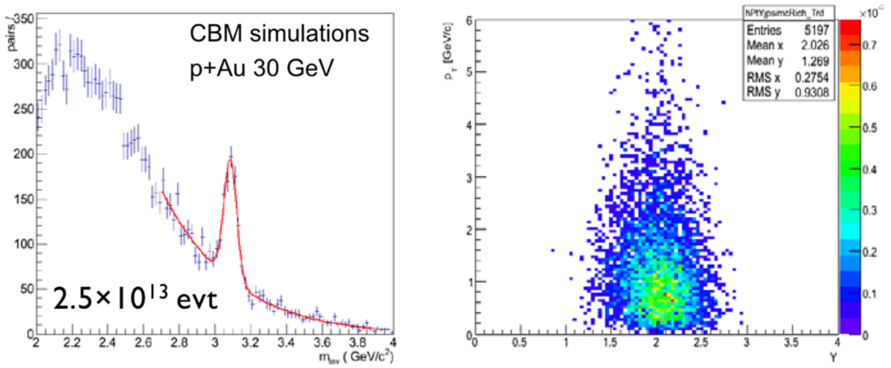




- Ongoing analysis:
  - → Event generator
  - → e/π separation at 1.5 GeV/c particle momentum using EM calorimeter seems to be sufficient

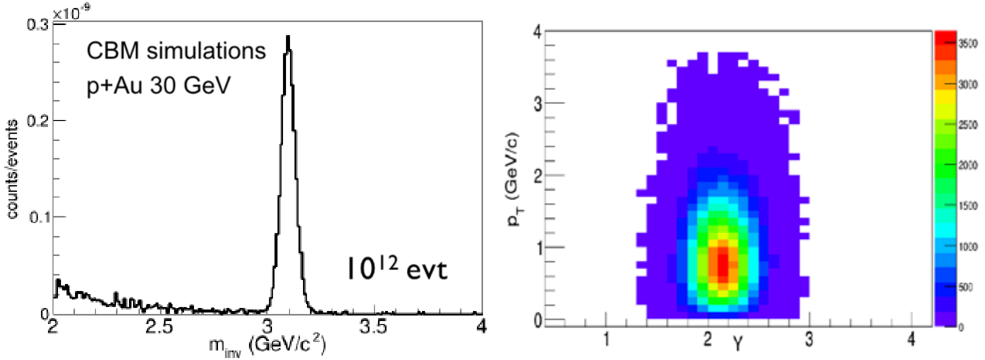
Performance of the J/ψ detection in pAu at 30 GeV

$J/\psi \rightarrow e^+e^-$



- Efficiency ~ 23.1%
- Signal-to-Background 1.25

$J/\psi \rightarrow \mu^+\mu^-$



- Efficiency ~ 4%
- Signal-to-Background 1.25

- Assuming 10^7 Hz interaction rate
- $\varepsilon \times M \times BR = 4e^{-2} \times 1e^{-8} \times 6e^{-2} = 2.4e^{-11}$
- $N_{evt} = 10 \times 24 \times 3600 \times 10^7 = 8.6e^{12}$

- 206 → in 10 days