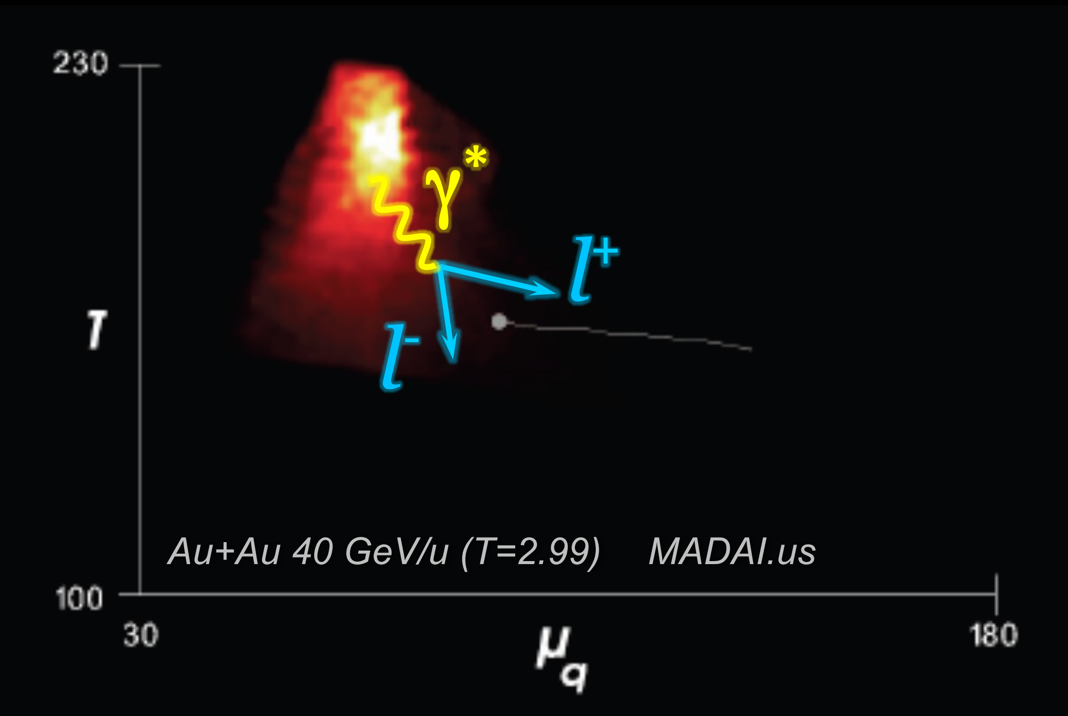
INTERNATIONAL SCHOOL OF NUCLEAR PHYSICS
34th Course: PROBING THE EXTREMES OF MATTER WITH HEAVY IONS
ERICE–SICILY: 16 – 24 SEPTEMBER 2012

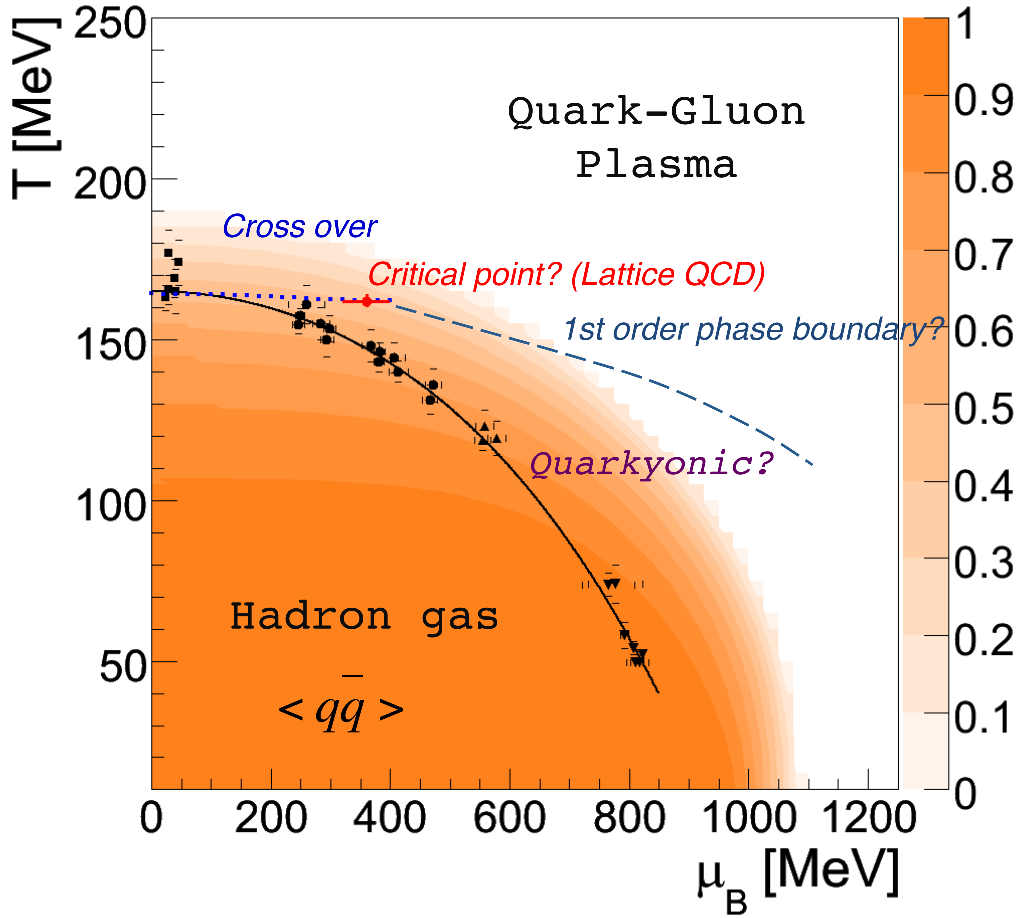


Rare probes of matter at highest densities

Tetyana Galatyuk
Technische Universität Darmstadt / GSI

for the HADES and CBM Collaborations

Searching for landmarks of the phase diagram of matter



- Chemical „freeze-out“ points from measured particle yields analyzed with Statistical Hadronization Model
  - Universal conditions for freeze-out (?)
  - Why is it working at low beam energies?

- *?* Crossover transition at small μ_B
- *?* Possible 1st order phase transition and critical point at large μ_B

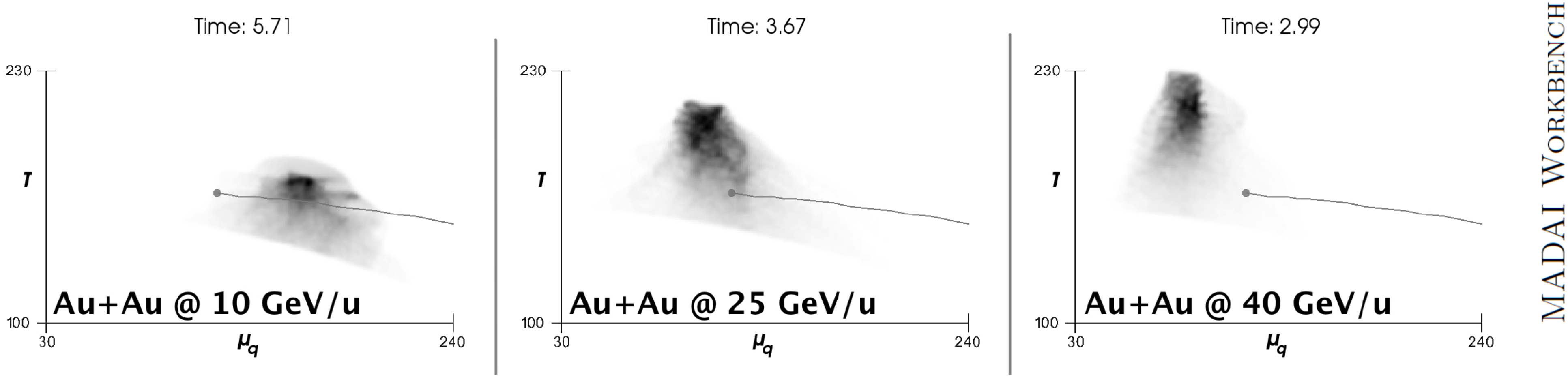
- *?* Phase structure at large μ_B
  → ***Quarkyonic Matter?***
  Confined gas of perturbative quarks (from N_c limit)

- QCD inspired effective models predict the melting of the condensate

SHM : J. Cleymans, K. Redlich, PRC 60 054908
Lattice : Z. Fodor et al., hep-lat/0402006, F. Karsch
<qqbar> : B.J. Schäfer and J. Wambach

Hot and dense matter

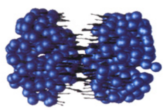
Time-evolution of the hot and dense QCD medium in T - μ space from model calculation



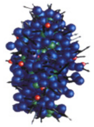
an incident beam energy of 25 GeV/u seems to provide the best opportunity for creating and probing QCD matter in the vicinity of the CEP.

H. Petersen et al. , arXiv:1202.0076v1 [nucl-th]

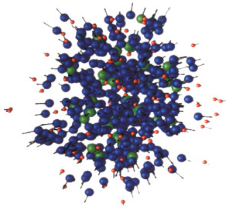
π, η, K, ϕ, Λ, Ξ, Ω, …



first-chance collisions



dense matter
τ < 10 fm



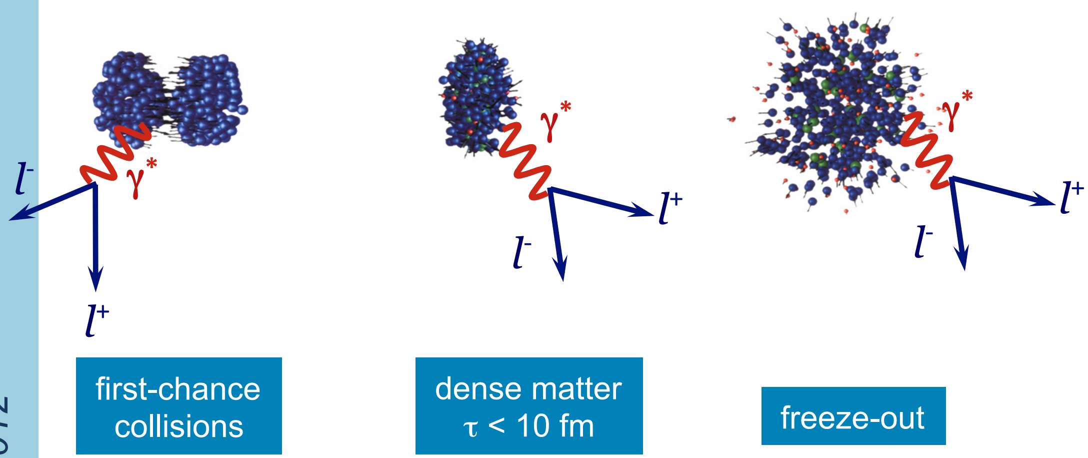
freeze-out

Bulk observables:

- Equation-of-state
- Collective expansion
- e-by-e physics
- Hadron-chemistry

Searching for landmarks of the phase diagram of matter with dileptons

π, η, K, ϕ, Λ, Ξ, Ω, …



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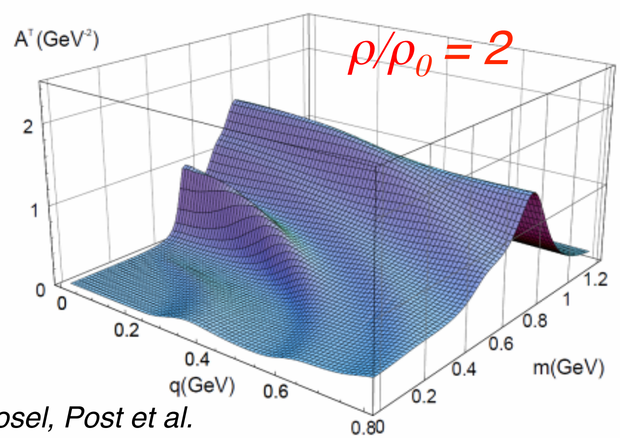


S. Leupold, U. Mosel, Post et al.
NPA 741 (2004) 81, NPA 780 (2006) 187

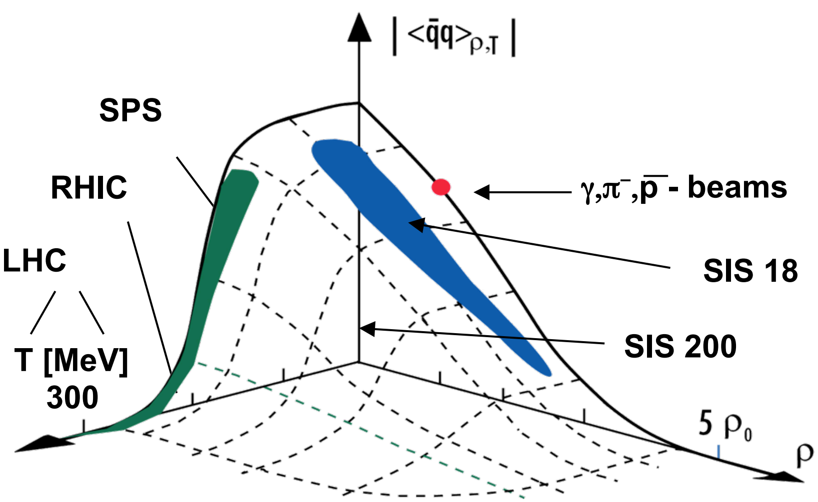
"Microscopic" probes:

- Vector current coupling to photons (and dileptons)
  - **Emissivity of hadronic matter**
  - **In-medium spectral functions**

Dileptons and the phase diagram of matter

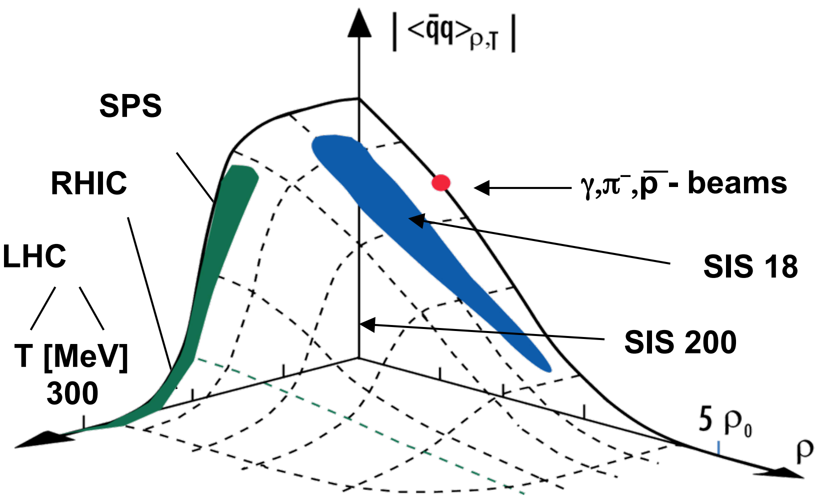
„I wonder if it finally will turn into a bluff...“

Use ρ as a probe for the restoration of χ symmetry



Robert D. Pisarski, PLB 110 (1982), …

Use ρ as a probe for the restoration of χ symmetry



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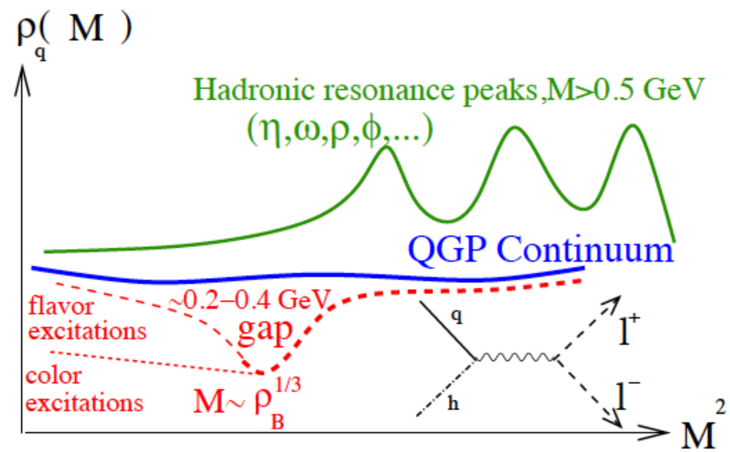
Dileptons from exotic phases…



*S. Lottini and G. Torrieri, **PRL 107**, 152301 (2011)*
S. Lottini and G. Torrieri, arXiv:1204.3272v1 [nucl-th]
…

Dileptons and the phase diagram of matter

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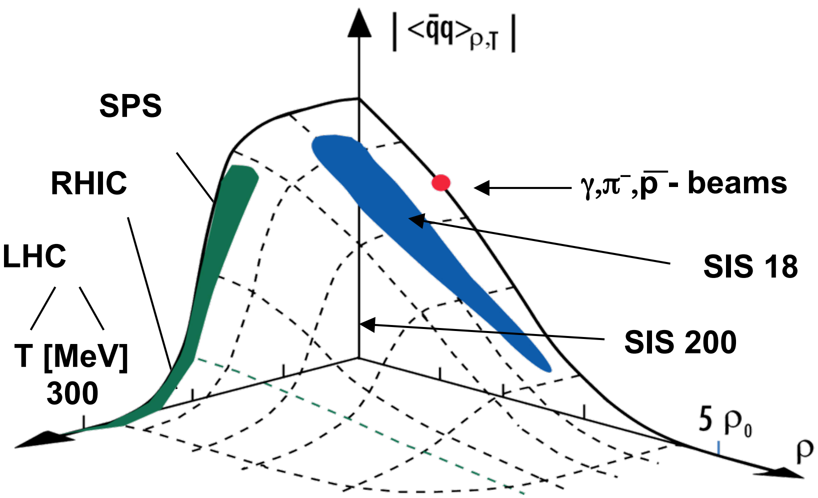

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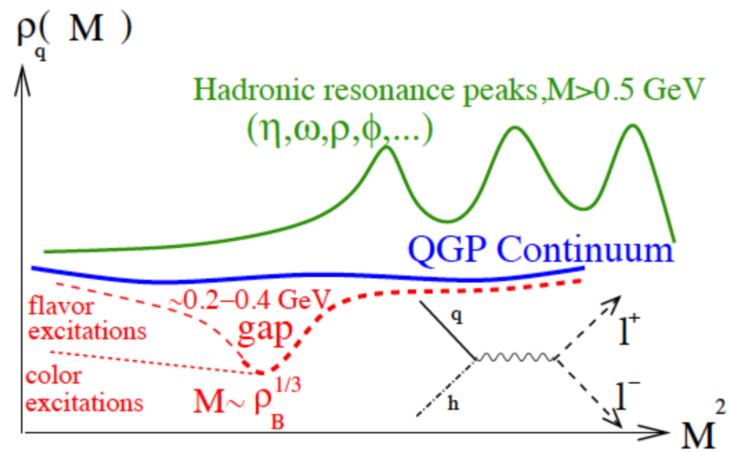

*S. Lottini and G. Torrieri, **PRL 107**, 152301 (2011)*
S. Lottini and G. Torrieri, arXiv:1204.3272v1 [nucl-th]
…

→ Experimental test

The experimental challenge…

- Lepton pairs are rare probes (branching ratio $O(10^{-4})$)
- at SIS energies sub-threshold vector meson production

The experimental challenge…

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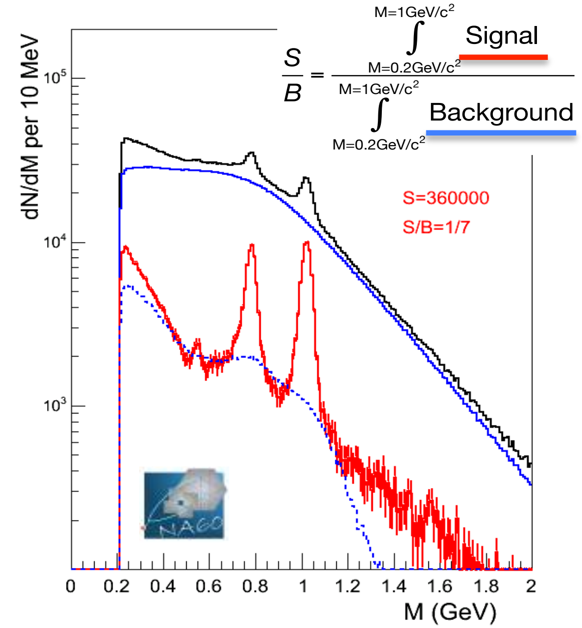
- Large combinatorial background from:
  - **In e^+e^-:** Dalitz decays (π^0) and conversion pairs
  - **In $\mu^+\mu^-$:** weak π, K decays



The experimental challenge…

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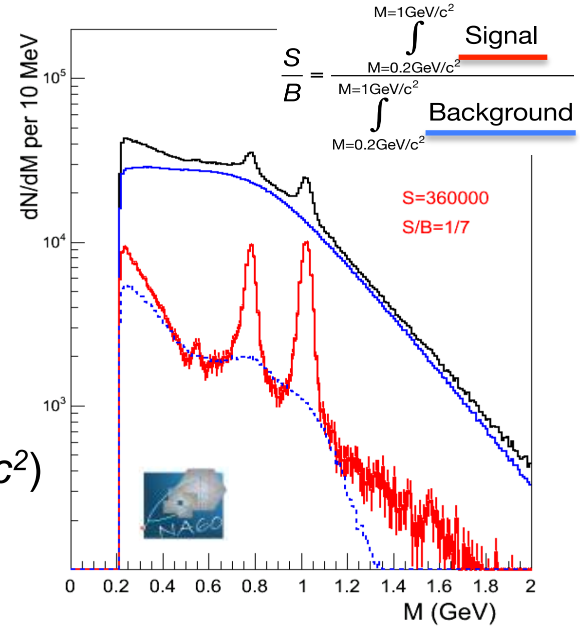
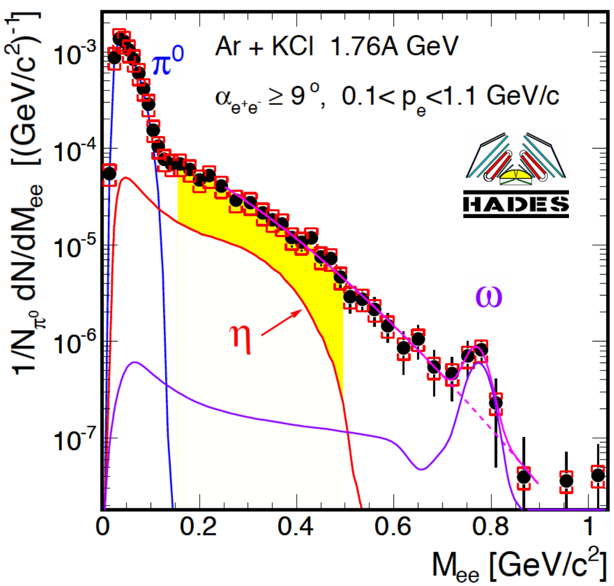
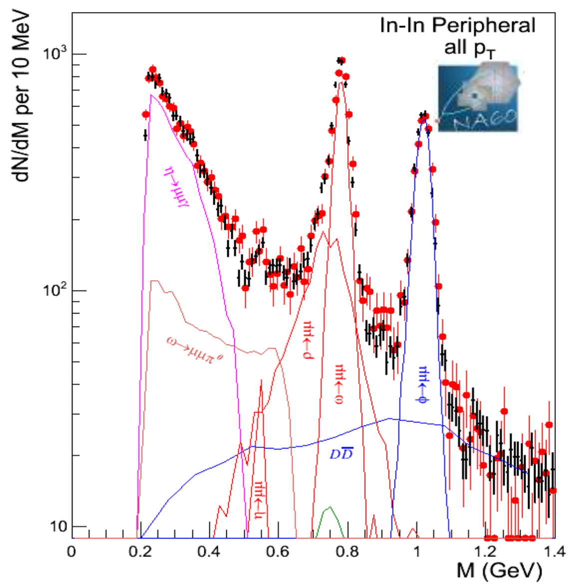


- Large combinatorial background from:
  - **In e^+e^-:** Dalitz decays (π^0) and conversion pairs
  - **In $\mu^+\mu^-$:** weak π, K decays

- Isolate the contribution to the spectrum from the dense stage (***X Factor*** = *excess yield above hadronic cocktail in $0.2<M_{ll}<0.6$ GeV/c^2*)

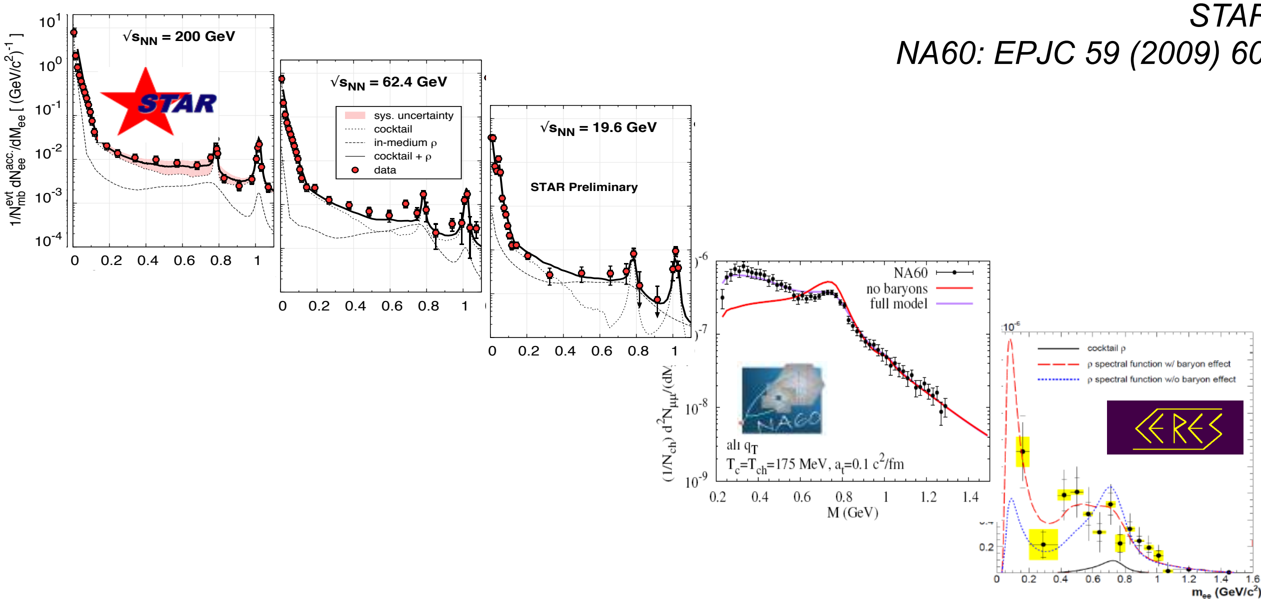




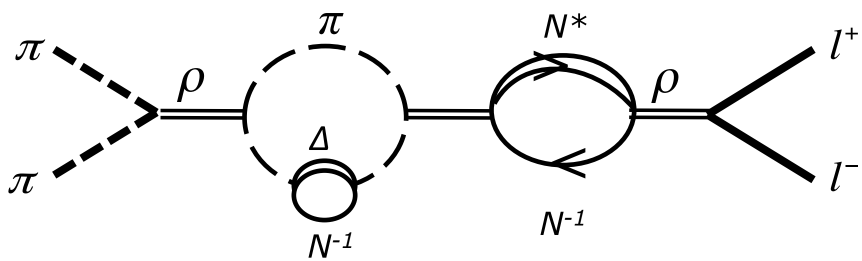
Virtual photon radiation from hot and/or dense QCD matter

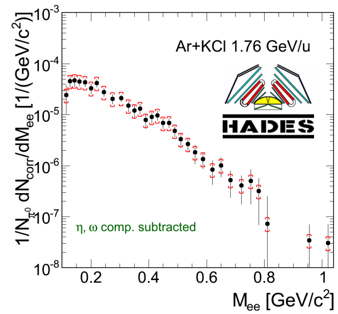
T

Model: Ralf Rapp
STAR: QM2012, CERES: Phys. Lett. B 666 (2006) 425,
NA60: EPJC 59 (2009) 607, HADES: HADES: Phys.Rev.C84 (2011) 014902



- Isolation of excess by a comparison with a **measured** decay cocktail
- Contributions from the **dense phase** are quite **featureless**
  → strong broadening of in-medium states.



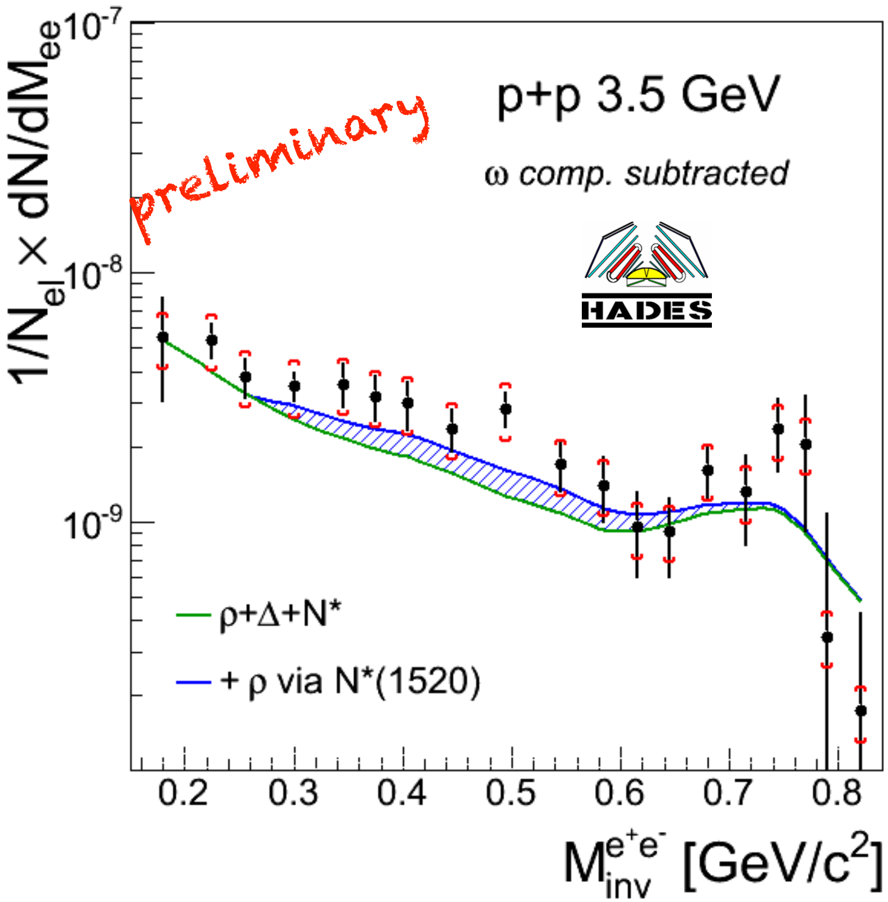


The ρ (dominant source) is broad because **it couples to baryons**

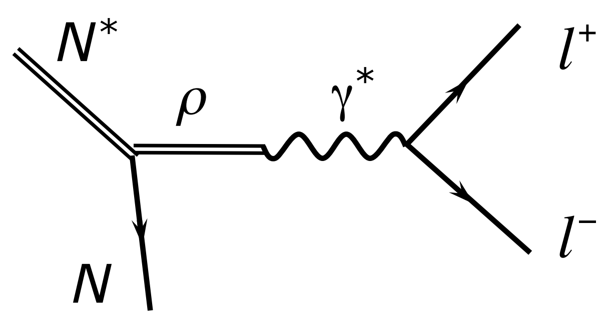
μ_B

Dileptons: from SIS to SPS...

Exclusive analysis: pp → ppe⁺e⁻

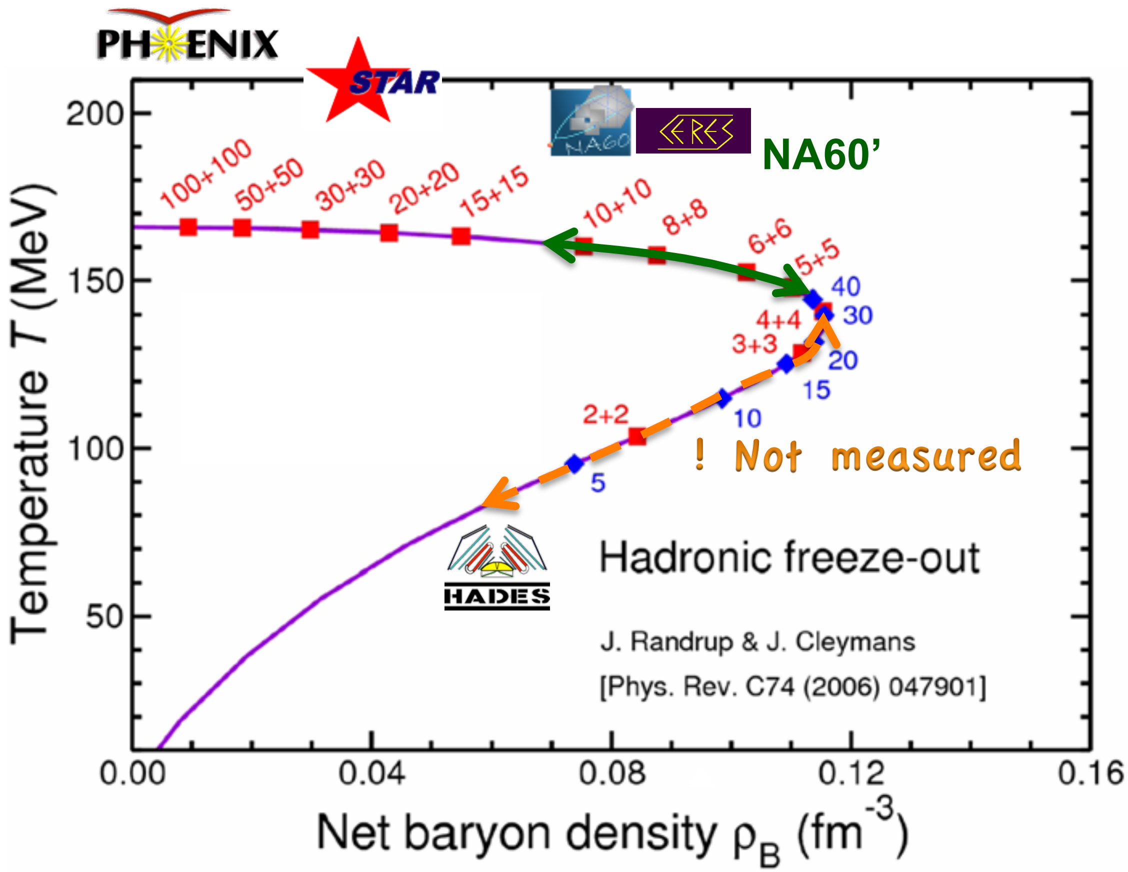


- Relative contribution is fixed through exclusive pion production
- ω contribution subtracted, η contribution suppressed by kinematics
- Dalitz decays of baryonic resonances - dominant source at low beam energies.

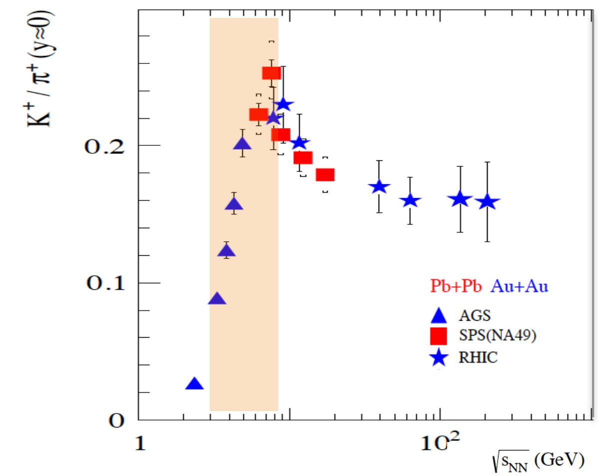


Data: in preparation, A. Dybczak
Model: M. Zetenyi and Gy. Wolf
Phys. Rev. C 67, 044002 (2003).

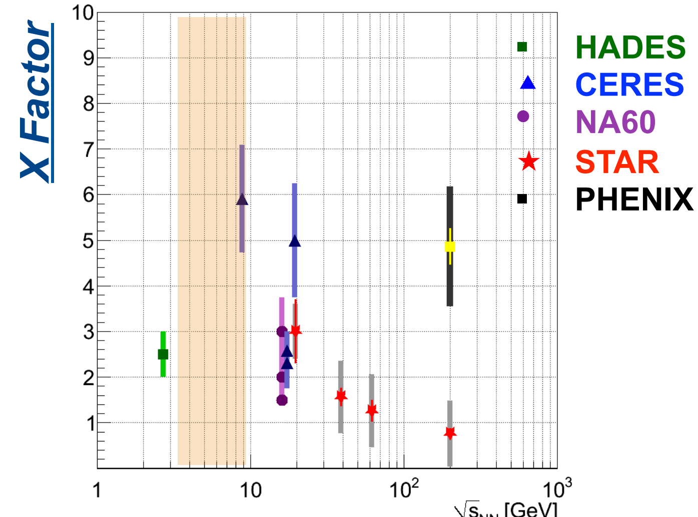
Quest: explore the regime of maximal baryon density



Evidence for onset of deconfinement at lower SPS energies (30 GeV/u)



Published low-mass enhancement factors: from SIS18 to RHIC

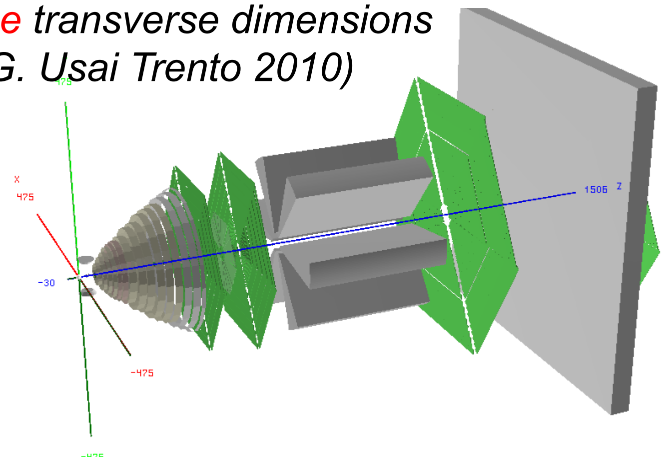


Highly interesting results from RHIC to SIS
→ importance of baryons!

No measurement for beam energies of 2-40 GeV/u

Di-muons at 30 GeV/u and below? → Tough…

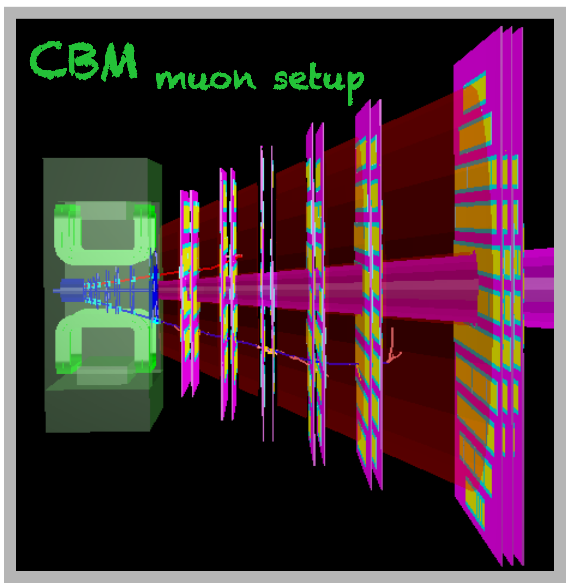
NA60' *vs. NA60 : compress the spectrometer* ***reducing*** *the absorber* ***enlarge*** *transverse dimensions (Talk G. Usai Trento 2010)*



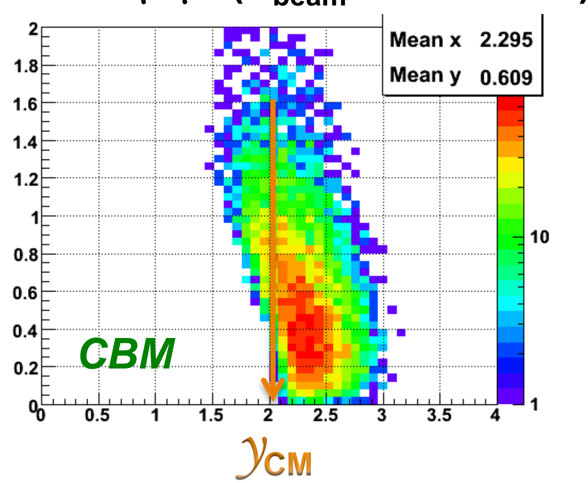
- **Challenge:**
  - **μ at low energies!**
  - High probability for weak decays of π and K before the absorber

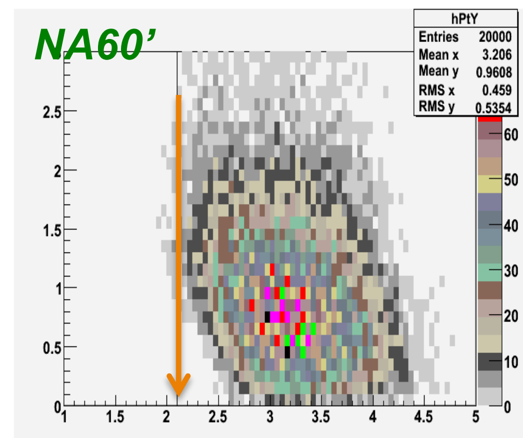
→ Substantial multiple scattering in the hadron absorber dominates the resolution for low momentum muons
→ Matching issue!
→ Phase space limitation

? Less absorber → more hadrons punched through

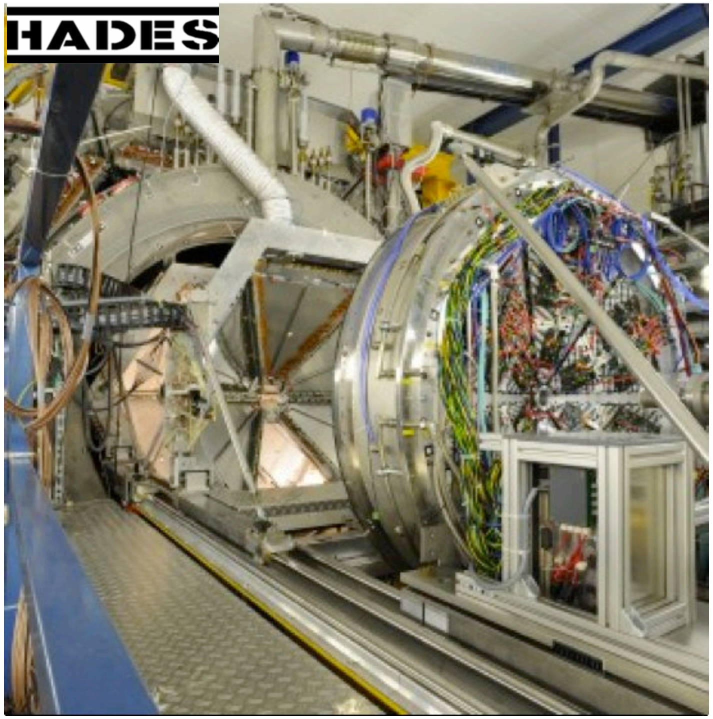


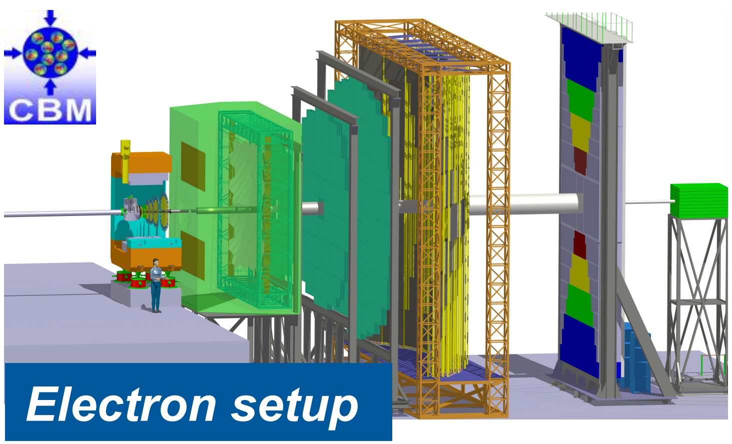
$\omega \rightarrow \mu^+\mu^-$ (E_{beam} = 30 GeV/u)





2016: HADES goes underground





SIS100:

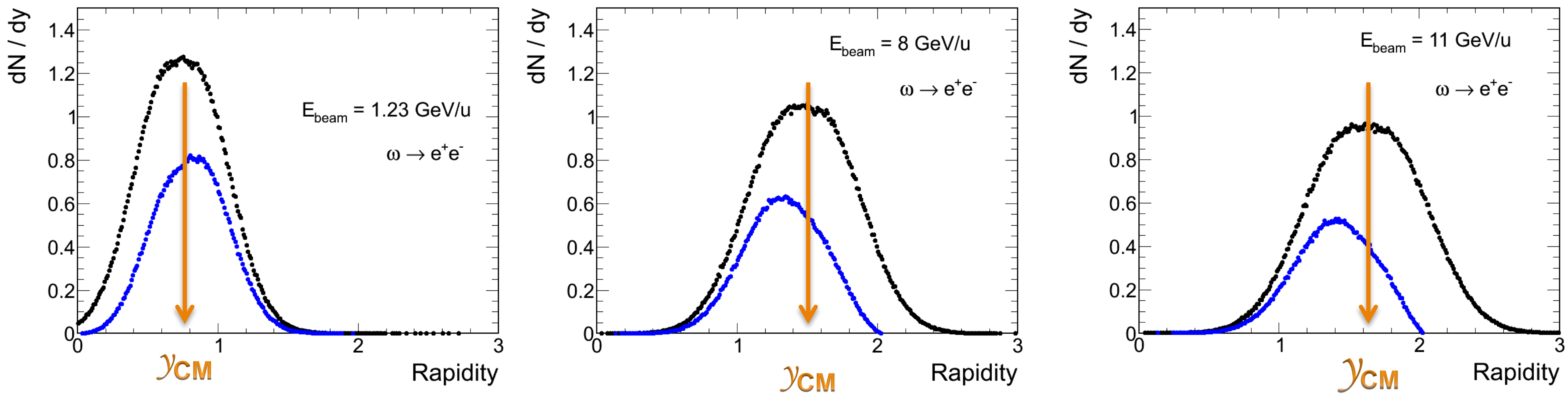
- HADES and CBM:
  - Emissivity of hot/dense nuclear matter
    - In-medium spectral functions of ρ in dense (**baryon dominated**) hadronic matter
  - Multi-strange particle excitation functions
  - Charm production in proton induced reactions
  - Bulk observables

SIS300 :

- CBM:
  - Full exploitation of rare probes a highest μ_B; fluctuations, flow

HADES at SIS100: phase space coverage for e^+e^-

The "sweet spot" is at mid-rapidity and low p_t!



E_{beam} = 1 GeV/u

- overall acceptance for di-electron pairs Acc ≈ 35%
- with nice mid-rapidity coverage

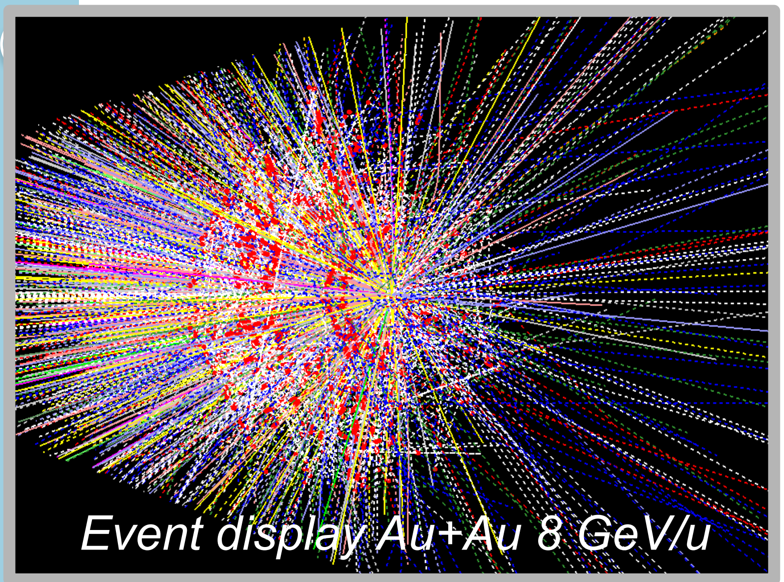
E_{beam} = 8 GeV/u

- Acc ≈ 20%
- (natural) shift towards backward rapidity

E_{beam} = 11 GeV/u

- … still High Acceptance DiElectron Spectrometer → Acc ≈ 20%
- **but…**

HADES at SIS100: problems, challenges, opportunities

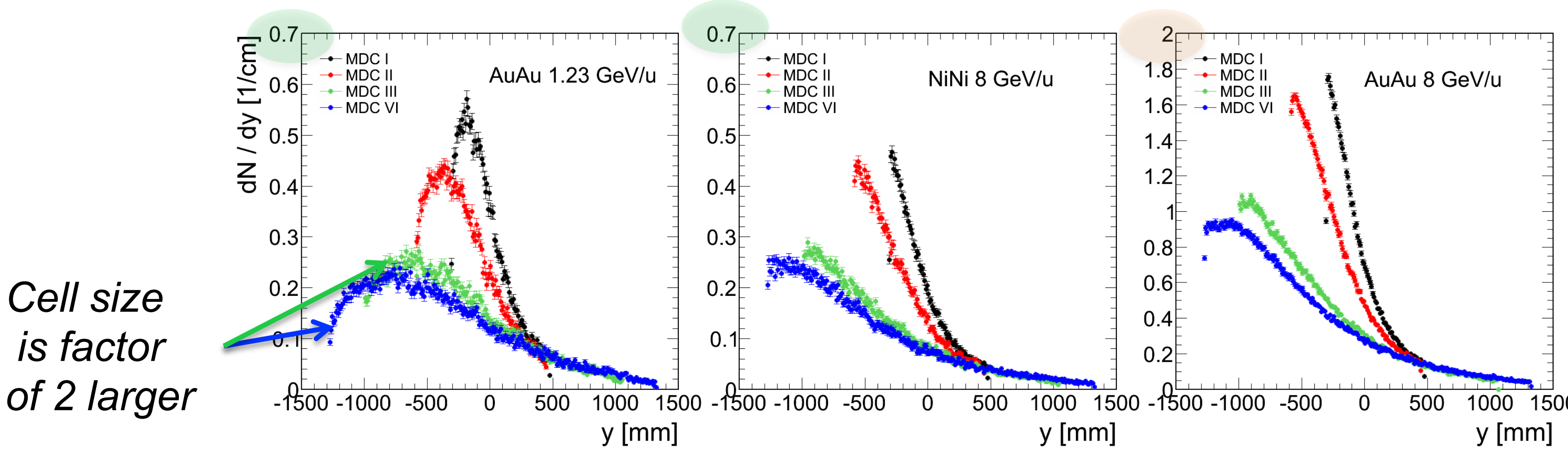


- **Challenge:** tracking issue →
  - wires introduce long range correlations between particle tracks

- Au+Au 1.23 GeV/u successfully measured in May 2012
- Ni+Ni 8 GeV/u ≈ Au+Au at 1.23 GeV/u
- Au+Au 8 GeV/u occupancy increases by factor of 4-5!

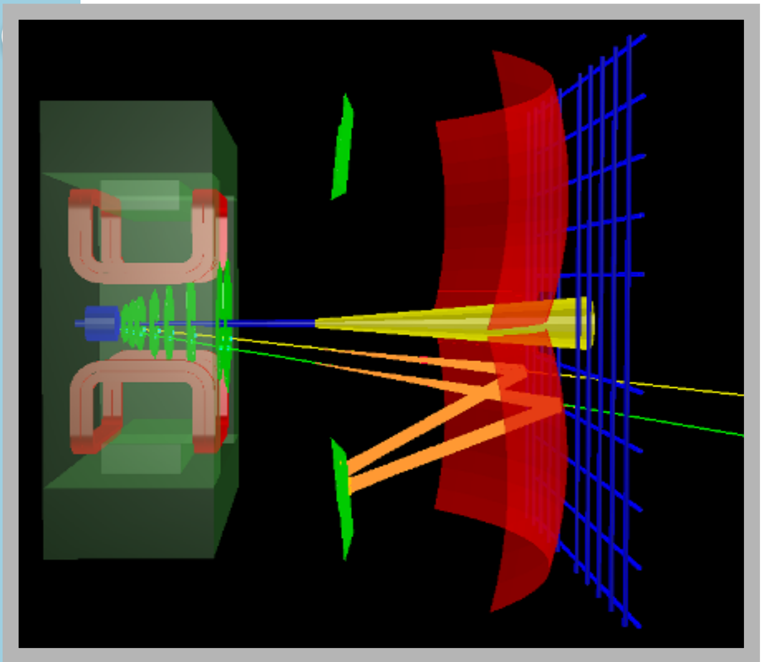
→ CBM kicks in

Occupancy in tracking chambers (b_{max} = 1 fm)

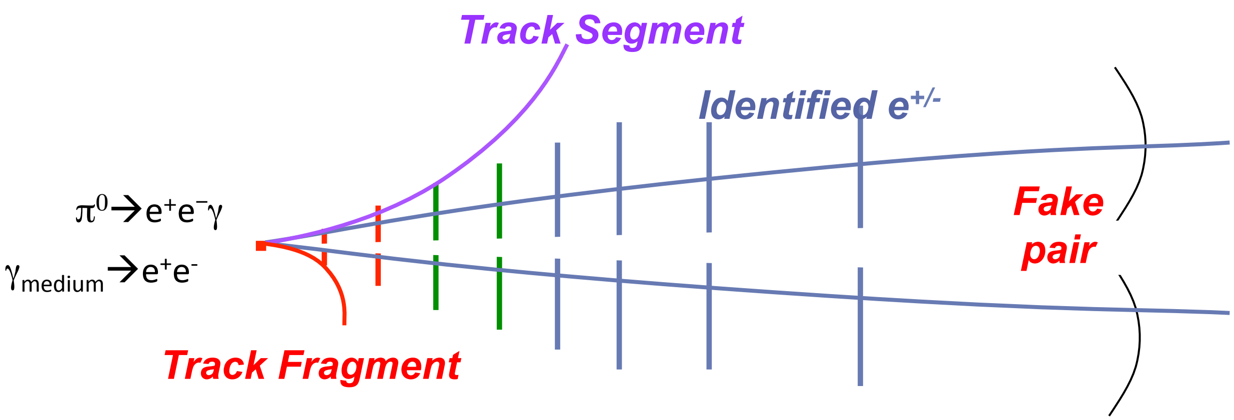


y – radial coordinate in drift chamber

Di-electron reconstruction in CBM

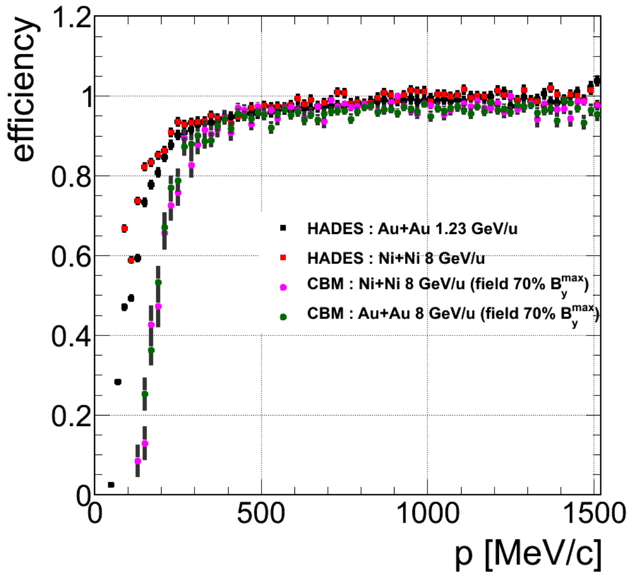


- **Challenge:**
  - No electron identification before tracking
  - Background due to material budget of the STS
  - Sufficient π discrimination (600 $\pi^{+/-}$/event, misidentification 10^{-4})
- **Strategy:**
  - Reduction of background by reconstructing pairs from γ-conversion (~3 γ) and π^0 Dalitz decay (8 π^0/event)
  - Excellent double-hit resolution in MAPS (<100μm) provides substantial close pair rejection capability



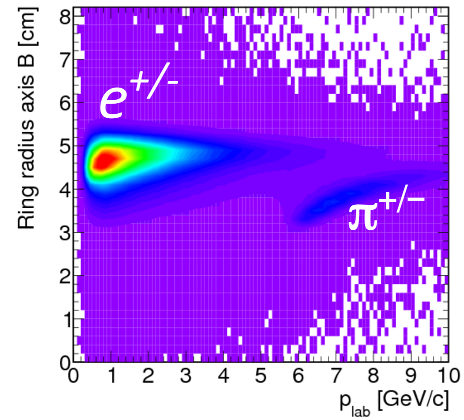
Electron identification

Track reconstruction efficiency

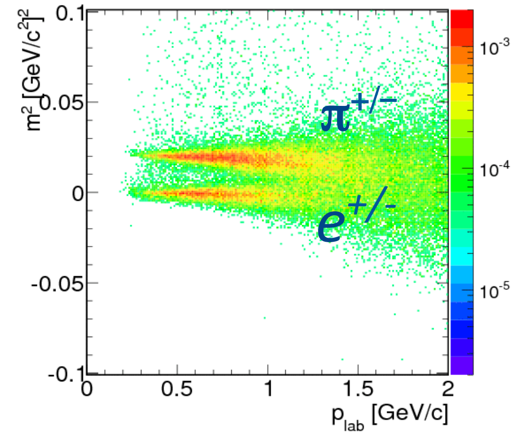


- Momentum distribution of conversion pairs are very soft
- High reconstruction efficiency is required for rejection of conversion pairs

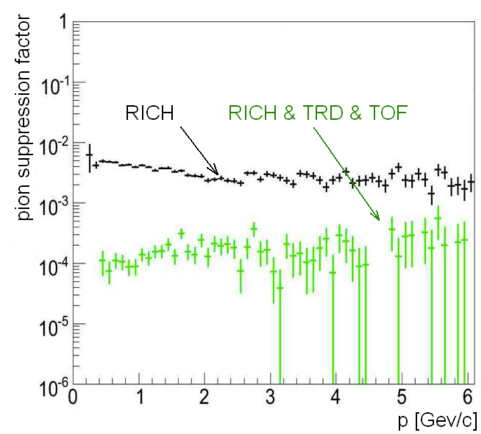
Ring radius vs. momentum



RICH identified $e^{+/-}$ in TOF



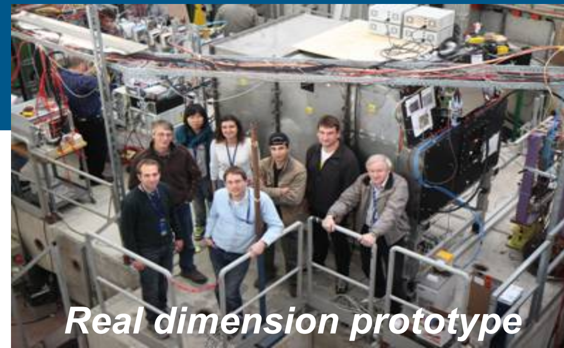
π suppression factor of 10^4 (for p < 1 GeV/c) is in reach with RICH and ToF

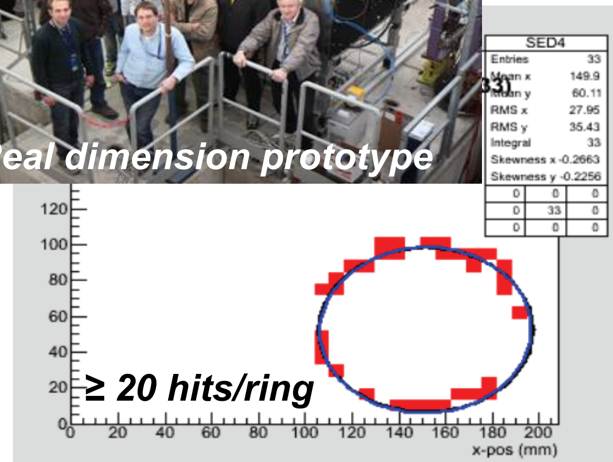


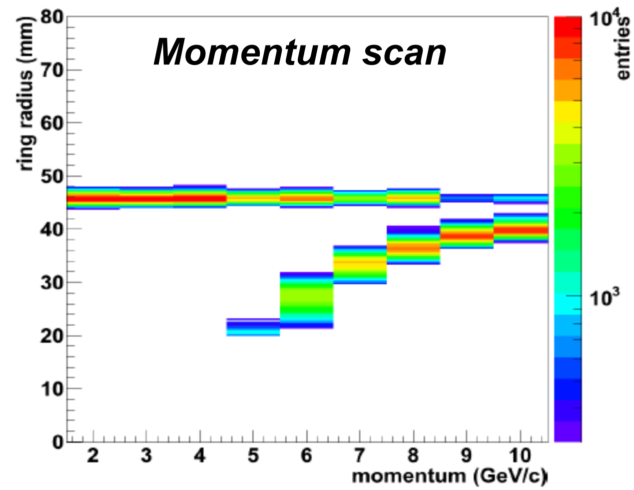
Detector R&D

RICH

- Conventional design based on commercial products (Germany, Russia, Korea)
  - Float glass mirror (carbon as backup)
  - Multi-anode PMT photo detector



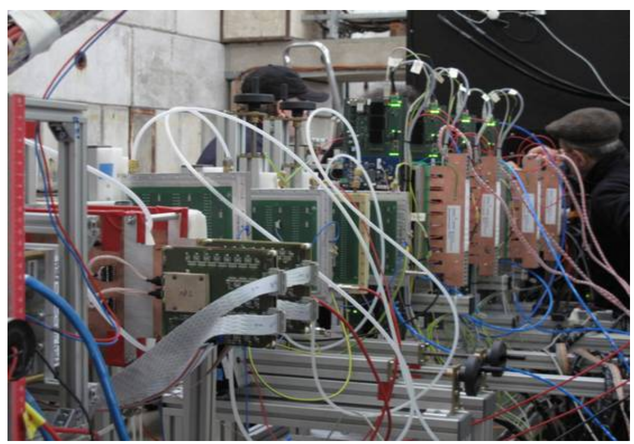


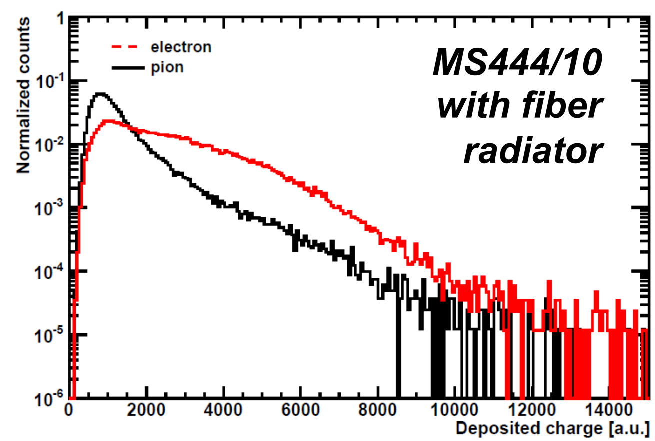


- **Test Beam at CERN T9, October 2011**
- **Mixed electron / pion beam of 2 – 10 GeV/c**

TRD

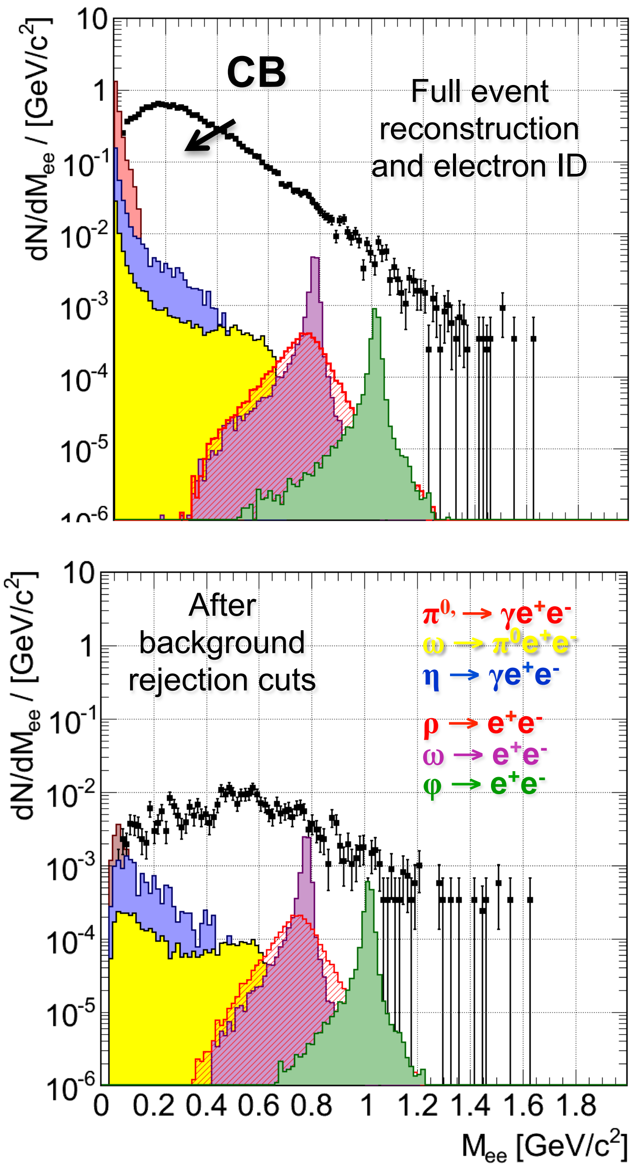
- Thin gap design based on ALICE TRD (Germany, Russia, Romania)



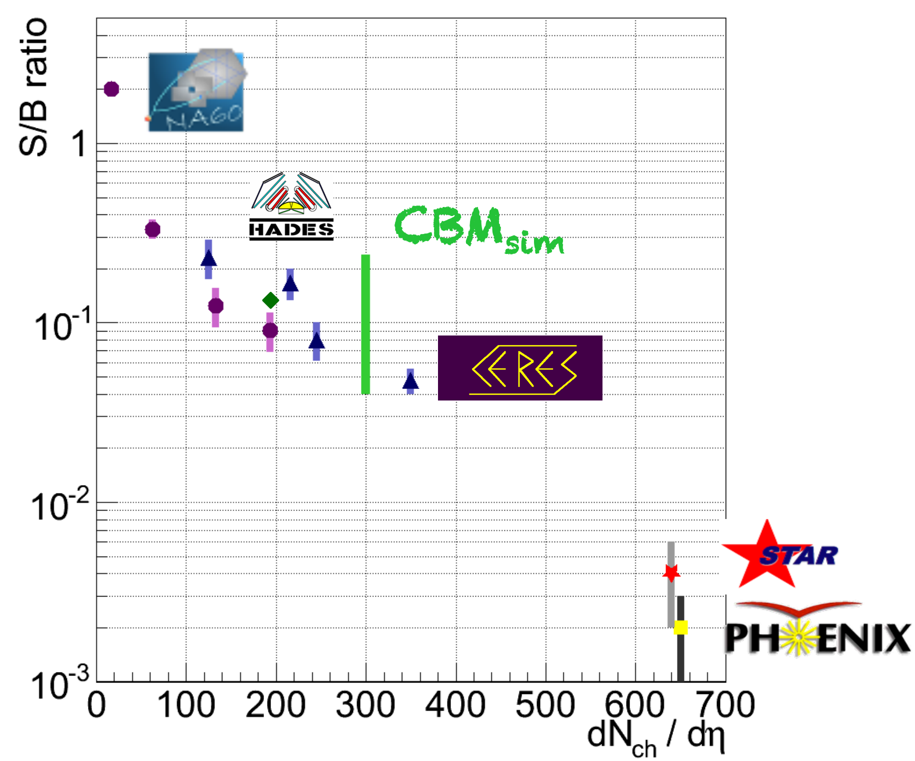


Low mass electron pairs reconstruction

Au+Au 25 GeV/u, b = 0 fm!



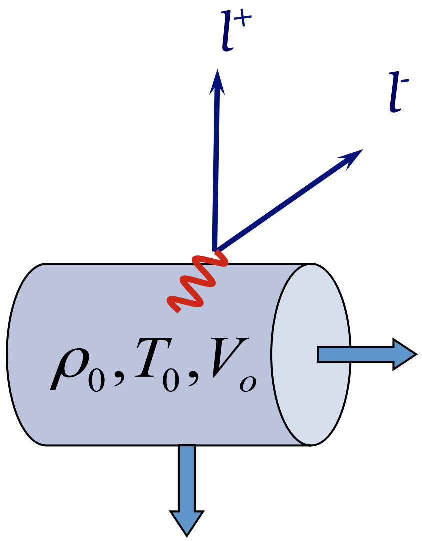
Expected signal-to-background ratio for CBM (di-electrons) compared to the existing experiments



- CBM_{sim} : Au+Au 25 GeV/u, **zero impact parameter**
- free cocktail only (without medium contribution)

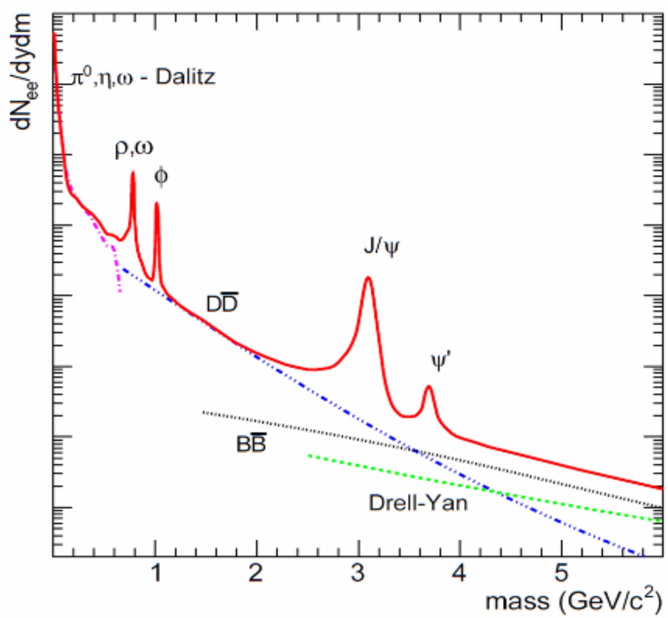
Dilepton emission rates in theory

Thermal emission...

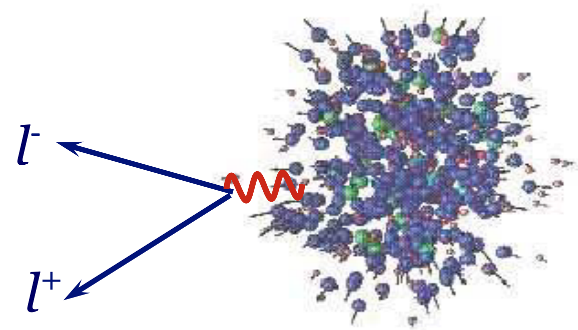


$$\frac{d^3N}{dMdydp_t} \equiv \int_{t=0}^{\infty} \frac{d^4\varepsilon}{d\mathbf{p}} \left[T(\mathbf{x}), \mu_B(\mathbf{x}), \vec{v}_{coll}(\mathbf{x}), ..\right] d\mathbf{x}$$

R. Rapp, J. Wambach and H. Hees : arXiv:0901.3289

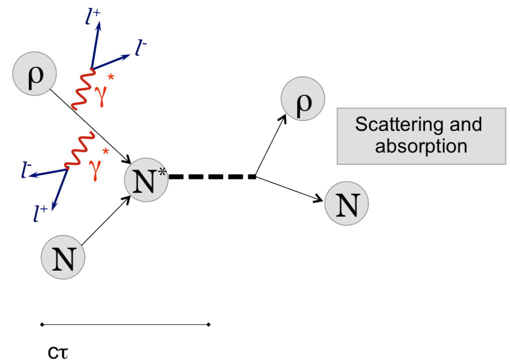


...or from transport

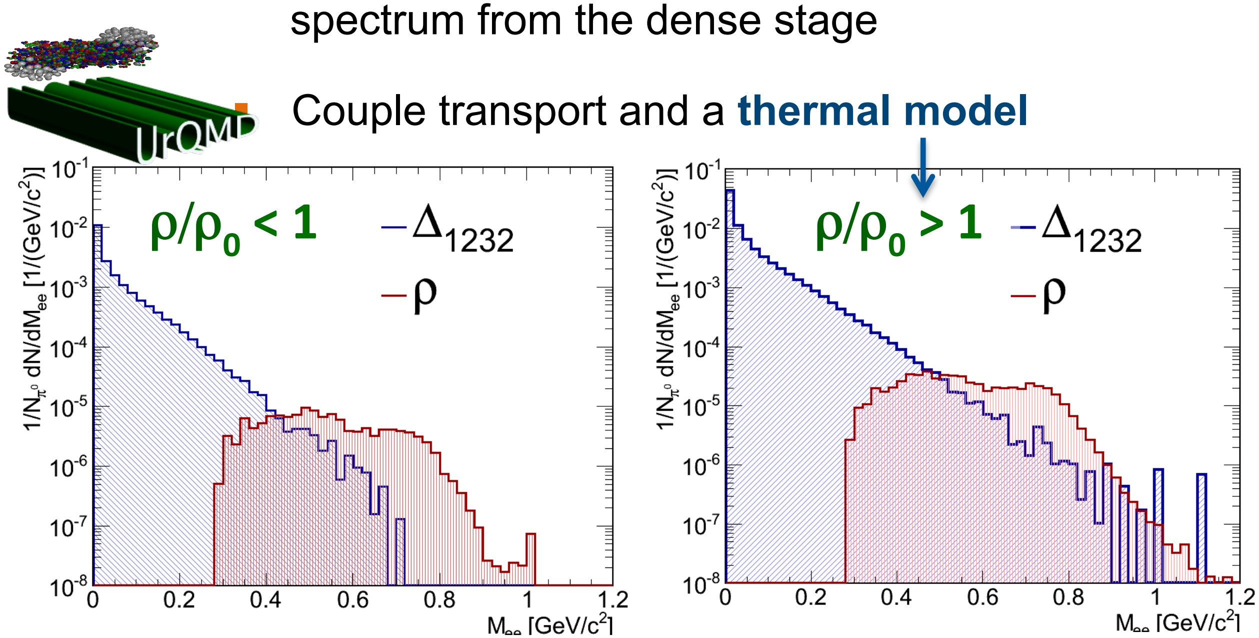


Radiation from dense matter

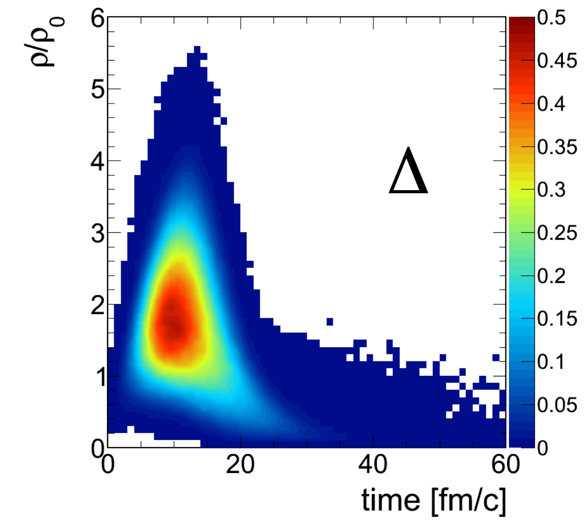
- Schematic illustration of ρ meson propagation within "shining" approach.
- Resonance can continuously emit dileptons over its whole lifetime.

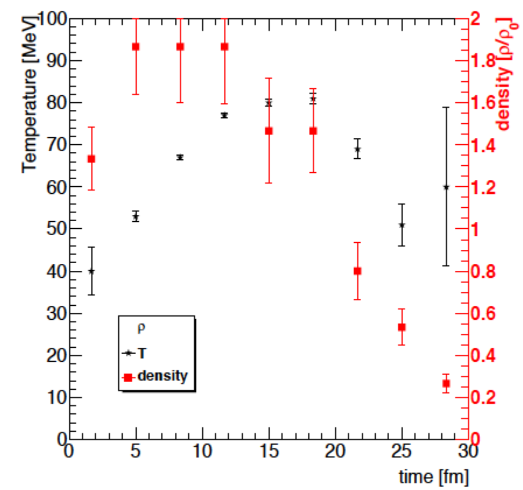


- Isolate the contribution to the spectrum from the dense stage
- Couple transport and a **thermal model**



Emission density evolution





C. Behnke

- First (points) and second (errors) moment of the density profile at a given τ.
- T – Boltzmann fit to the particle m_T spectra

Summary

Encouraging prospects for studying QCD matter in the region of compressed baryonic matter (finite μ_B)

- Explore unknown territory of the nuclear matter phase diagram with HADES and CBM:
  - Unique possibility of characterizing properties of baryon dominated matter with rare probes
  - Establish a complete excitation function of dilepton production up to energies of 40 GeV/u:
    - baryon dominated to meson dominated fireballs!
    - from "transport" to "thermal expansion" models!
    - from "no QGP" to "QGP"?

HADES at SIS100:

- Running experiment with well understood performance, accept up tp 20kHz trigger rate!
- No change of geometry, slight shift towards backward rapidities
- Medium size systems (i.e. Ni+Ni) at top SIS100 energies doable

CBM at SIS100/300:

- Electron option of CBM give access to low-mass vector mesons (and charmonium)
- **Sufficient background rejection based on track topology in tracking system**
- Feasibility studies are based on full event reconstruction and electron identification. They are still subject to further optimization!
- Electron measurements rely on established detector technology

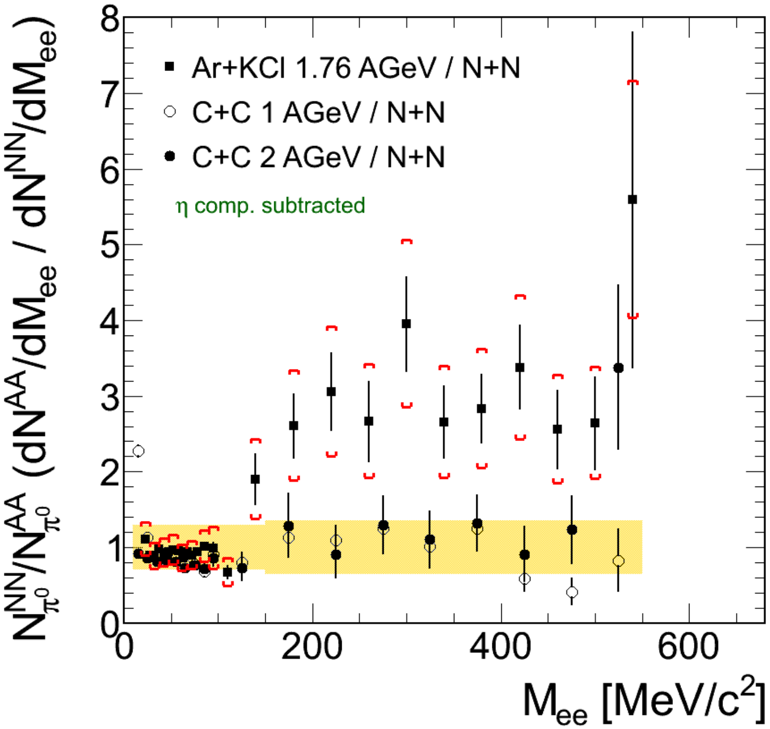
Thank you!

and all my HADES and CBM colleagues!

Bonus slides

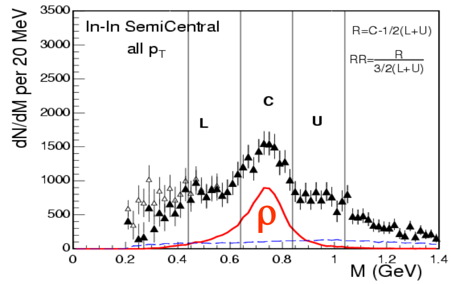
Centrality dependence of spectral shape

HADES "Δ clock"

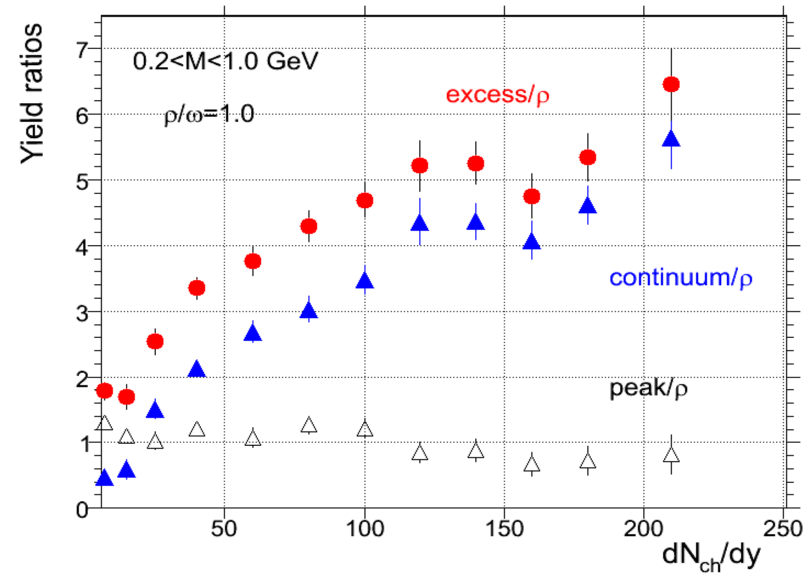


HADES: Phys.Rev.C84:014902,2011

- 34% most central collisions (A_{part}=38)
- Δ regeneration



NA60's "ρ clock"



- Rapid increase of relative yield reflects the number of ρ's regenerated in fireball

Na60 data: EPJC 61 (2009) 711

Overview of existing dilepton experiments (summary)

Experiment	System	$\sqrt{s}$	$dN_{ch}/d\eta$	E	S/B	Sys error (%)
CERES	Pb+Au	8.86	216	**5.9**	1/6	20
CERES (σ/σ_{tot} = 28%)	Pb+Au	17.2	245	**2.31**	1/13	24
CERES (σ/σ_{tot} = 7%)	Pb+Au	17.2	350	**2.58**	1/21	16
NA60(central)	In+In	17.2	193	**3**	1/11	25
NA60(semi-central)	In+In	17.2	133	**2**	1/8	25
NA60(semi-peripheral)	In+In	17.2	63	**2**	1/3	12
NA60(peripheral)	In+In	17.2	17	**1.5**	2	3
CERES	S+Au	19.5	125	**5**	1/4.3	25
PHENIX(0-10% centrality)	Au+Au	200	650		1/500	?= 50
STAR	Au+Au	200	650	**2**	1/250	
SIMULATION						
CBM (real) (b=0fm)	Au+Au	8	?	**?**	1/41*	-