VISIM Meeting, Monbachtal 2007

Low Mass Lepton Pairs – *past, present and future*

Joachim Stroth, Univ. Frankfurt/GSI

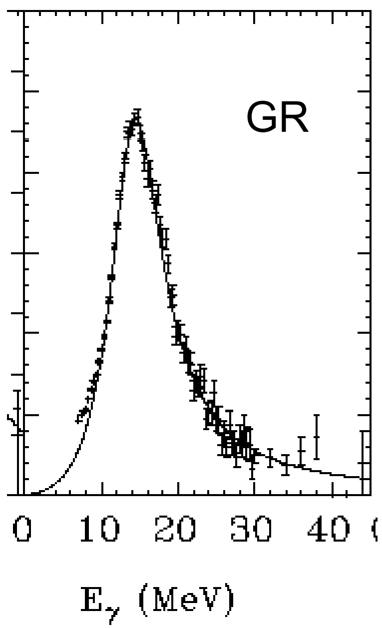
- introduction
- pair spectra
- excess yield
  - thermal radiation
  - transport
- p_T spectra
- next generation experiments

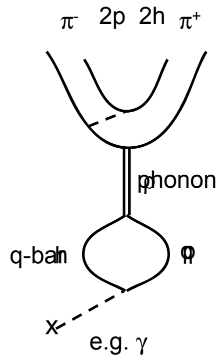
Electromagnetic structure of dense/hot matter

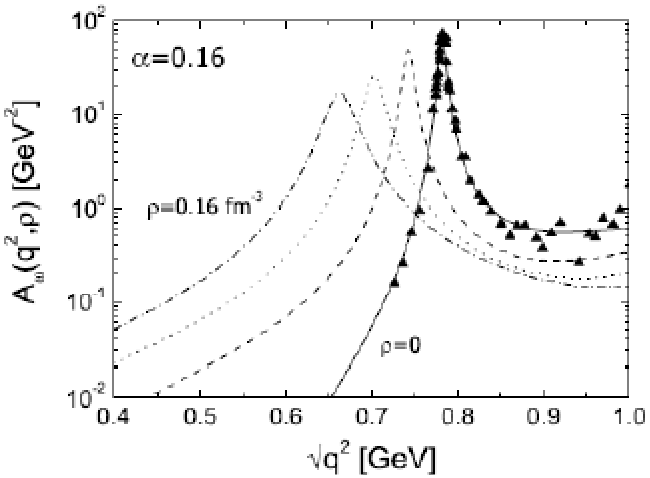
Lepton pairs, can probe the electromagnetic structure of nuclear matter under extreme conditions.

They couple through time-like photons and test the **spectral properties** of hadronic/quark-gluon matter on the femto-scale.

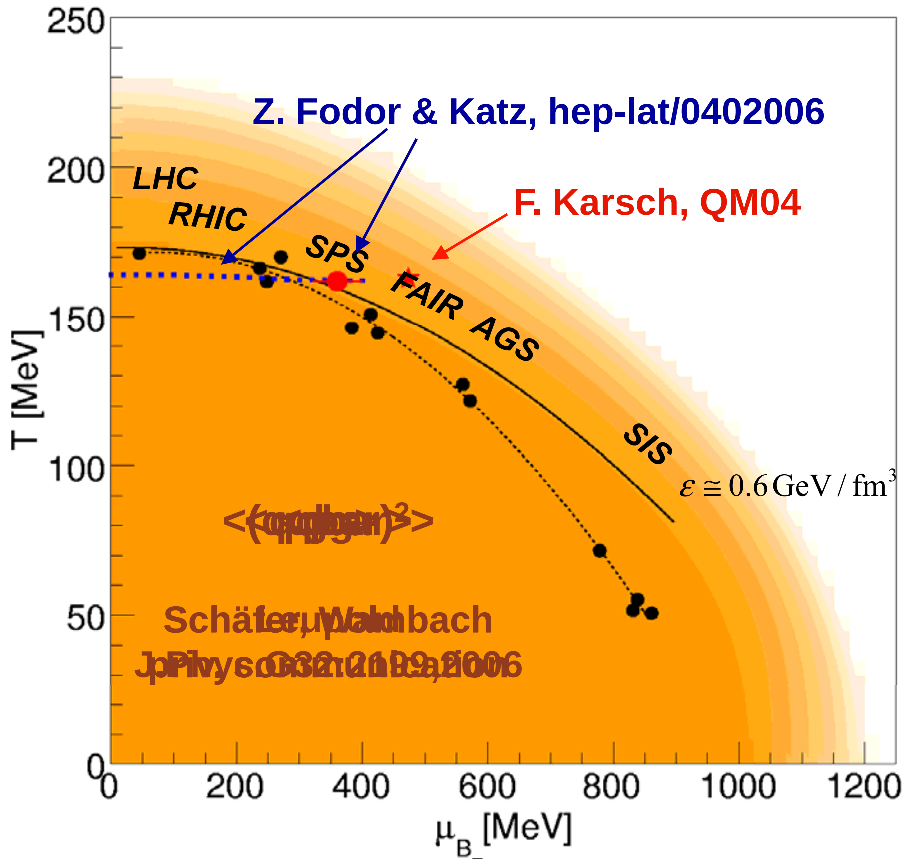
☞ time reversed processes of reactions in a e^+e^- collider.







Exploring the phase diagram of matter



Chemical freeze-out puts landmarks in the experimentally unknown regions.

- Universal conditions for freeze-out?
- Limiting temperature T_{max}?

LQCD explores unknown regions from solid grounds at μ_B=0.

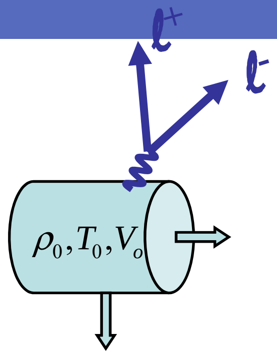
- $T_c = T_{max}$?
- T_c = 170 MeV or T_C = 190 MeV?

QCD inspired models demonstrate the melting of the condesates.

P. Braun-Munzinger, K. Redlich, J. Stachel (e.g. nucl-th/0304013)
J. Cleymans, K. Redlich (e.g. PRC 60 054908)

The Observable

introduction



Thermal emission...

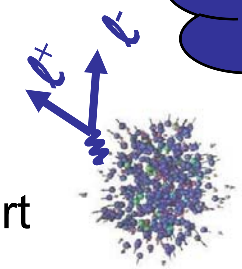
isentropic expansion

Nuclear many body theory, detailed balance, ..

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

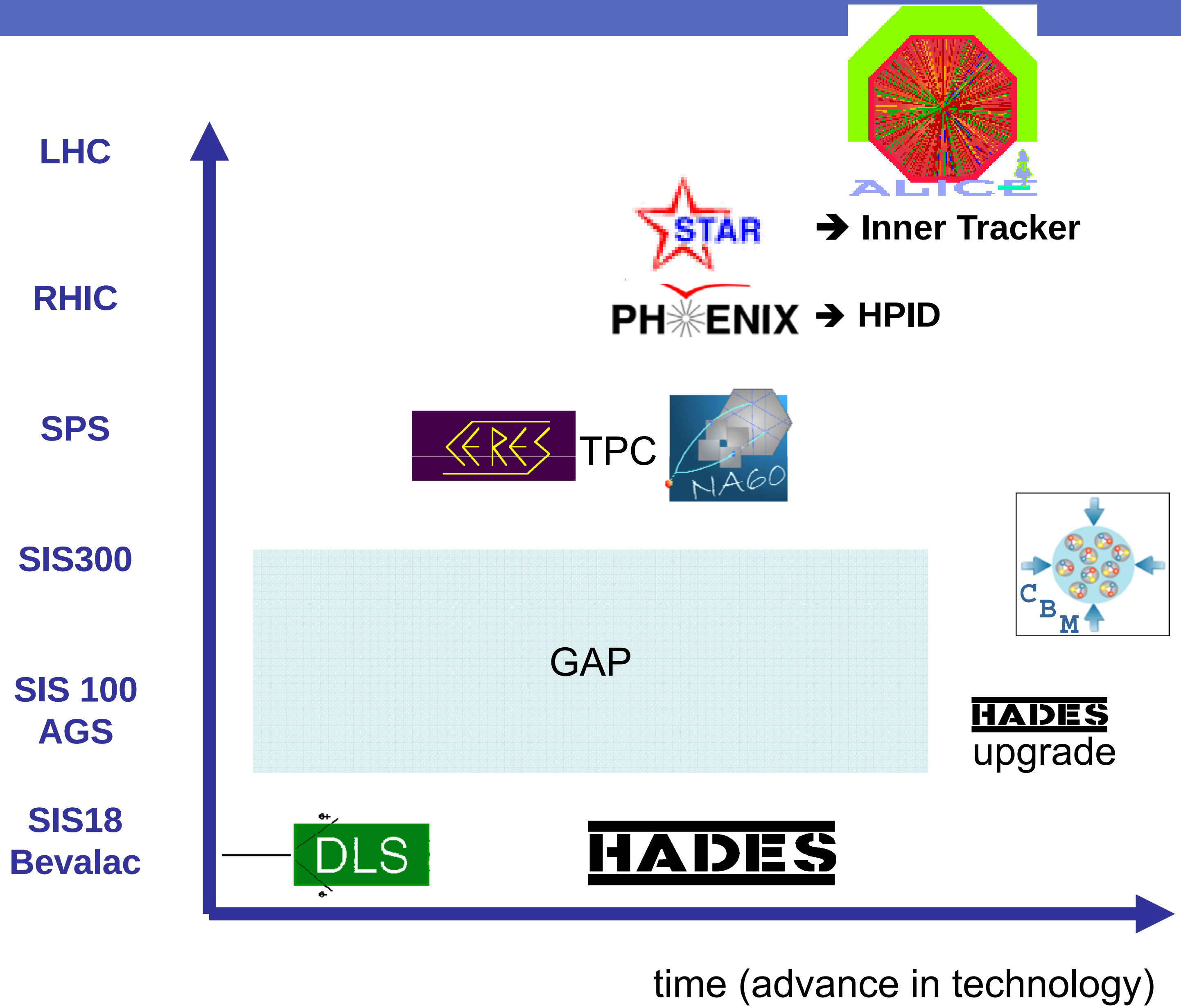
Spectrometer

Hydro, statistical expansion models, ..



... or microscopic transport

Overview on experiments (low-mass pairs)



Experimental challenges

introduction

Resolution

Helps to self–analyze the spectral shape

- ✓ Excellent (low-mass tracking)
- ✓ Good statistics

Acquire good statistics

Permits a multi-differential analysis

- ✓ Good pair acceptance ("4π" spectrometer)
- ✓ High trigger rates
- ✓ Trigger

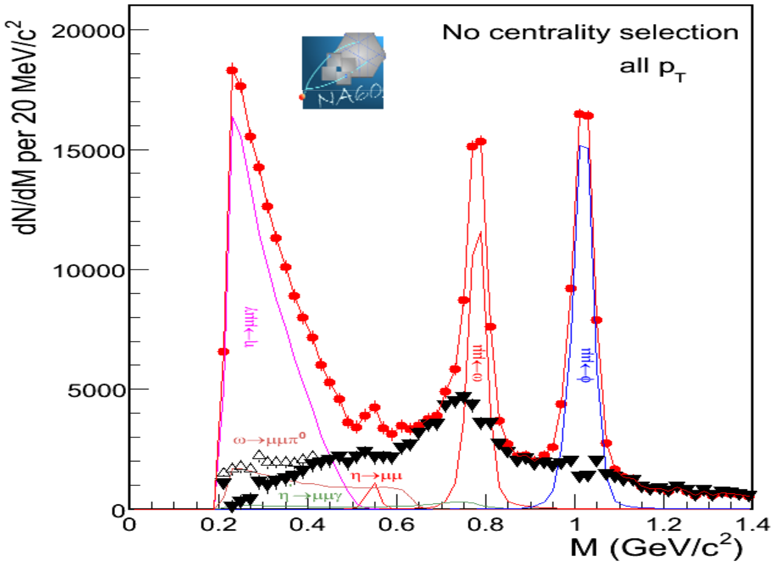
Minimize signal-to-background

Reduces the systematic and statistical error

- ✓ Physical background → rejection strategy
- ✓ Fake tracks → excellent detectors

Contributions from conventional sources

- ✓ Partially self-analyzing (see resolution)
- ✓ Need to measure neutral mesons or rely on models



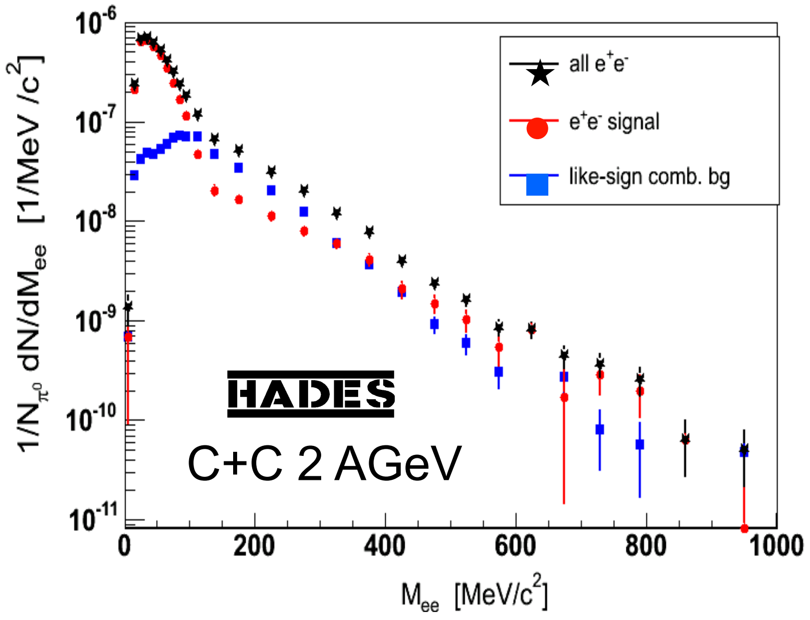
Decay	BR	
$\eta \to \mu^+\mu^-$	$5.8 \pm 0.8 \cdot 10^{-6}$	PDG
$\eta \to e^+e^-$	$< 7.7 \cdot 10^{-5}$	PDG
$\eta \to e^+e^-$	$5 \pm 1 \cdot 10^{-9}$	χPT
$\pi^0 \to e^+e^-$	$6.2 \pm 0.5 \cdot 10^{-8}$	PDG
$\pi^0 \to e^+e^-$	$7 \pm 1 \cdot 10^{-8}$	χPT

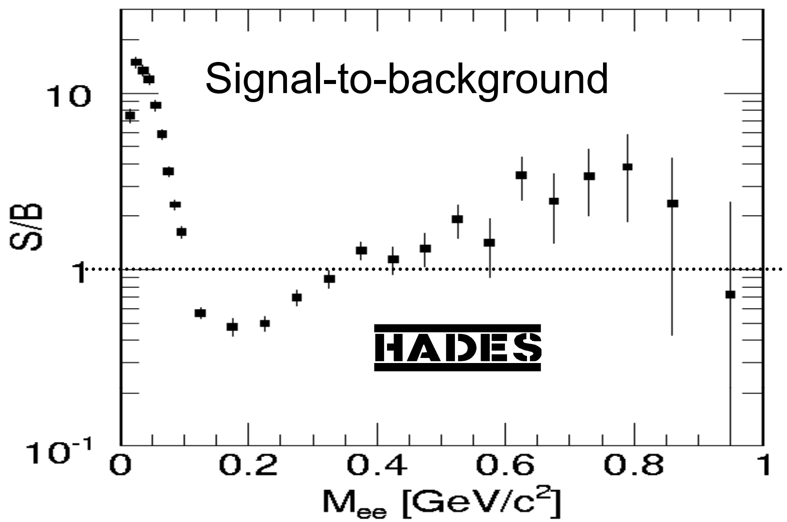
Compilation by R. Holzmann.

Pair spectra

e^+e^- yields (HADES)

pair spectra





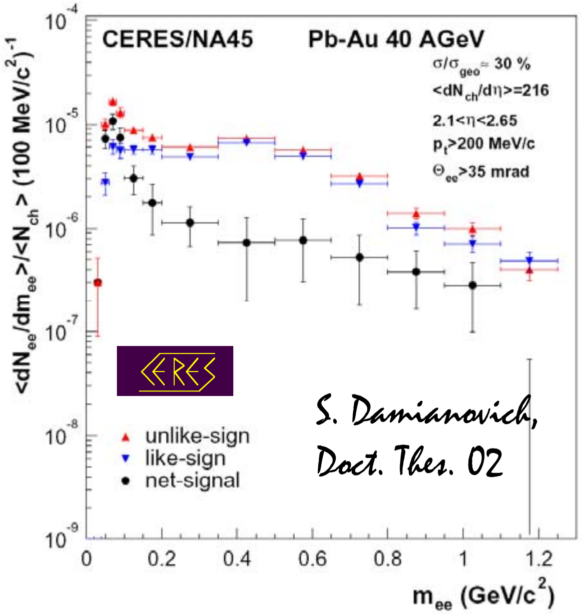
Completed runs (results)

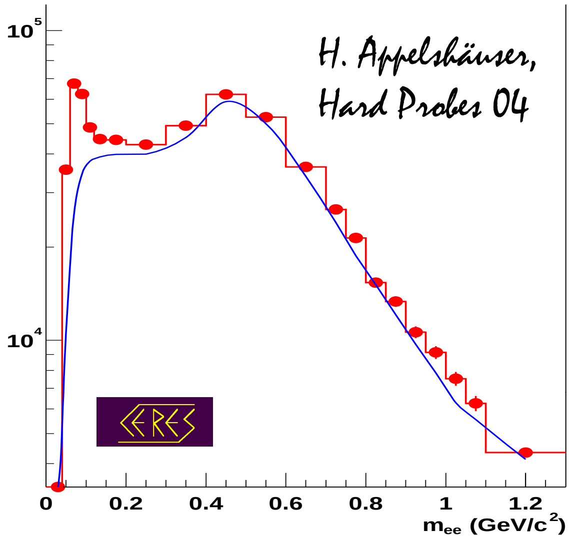
- C+C 2 AGeV (final)
  - 1 10^8 events analyzed
  - 23 10^3 signal pairs
  - 2.3 10^{-4} signal pairs/event
- C+C 1 AGeV (final)
- Ar+KCl C+C 1.75 AGeV (prelim.)

S/B (C+C)		
@ M [GeV/c²]	*0.2*	*0.6*
2 AGeV	0.5	2
1 AGeV	0.9	5

e^+e^- yields (Ceres)

pair spectra





Completed HI runs (results)

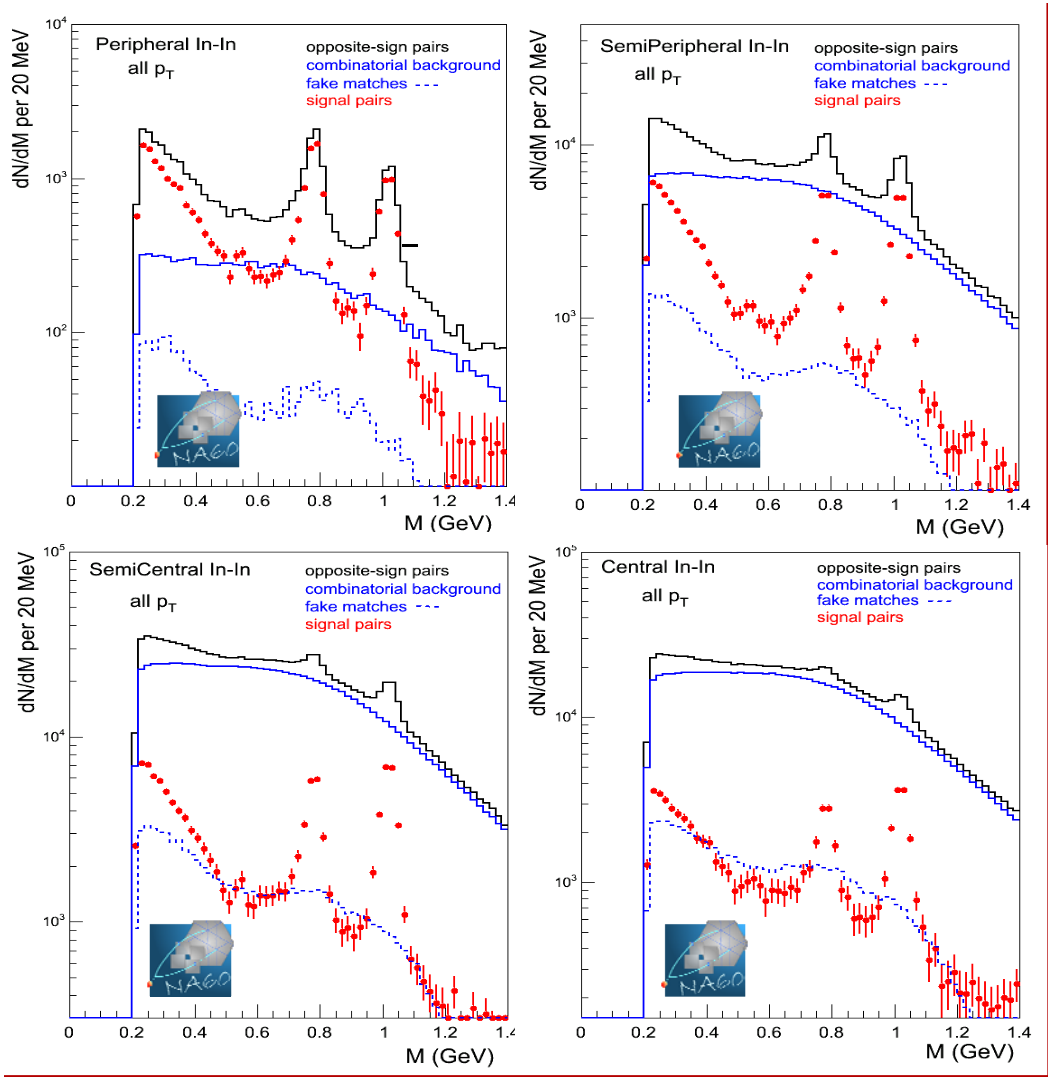
- S+Au 200 AGeV (final)
- Pb+Au 158 AGeV (final)
- Pb+Au* 40 AGeV (final)
- Pb+Au* 158 AGeV (final)
  - 1.8 10^7 events analyzed
  - 8.2 10^3 signal pairs
  - 4.6 10^{-4} signal pairs/event

* with TPC

S/B		
@ M [GeV/c²]	*0.2*	*0.6*
40 AGeV	0.25	0.13
158 AGeV	0.08	0.06

$\mu^+\mu^-$ yields (NA60)

pair spectra



J. Seixas, QM06

Completed HI runs (results)

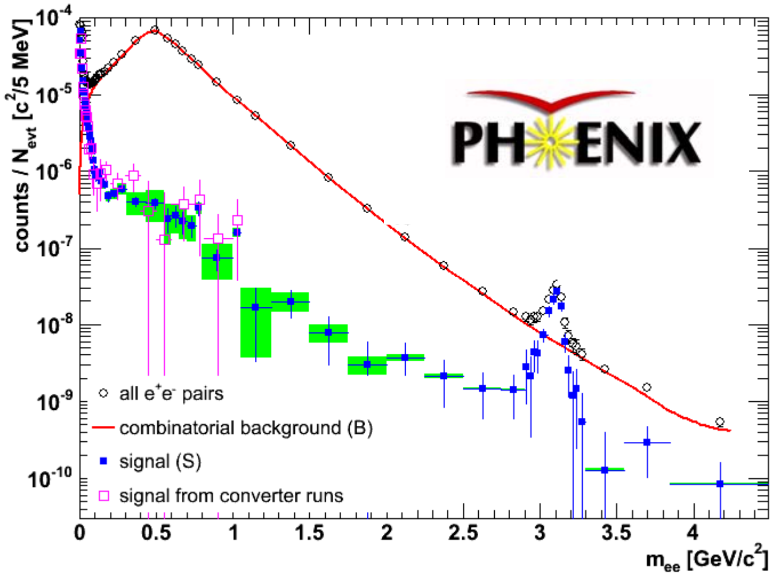
– In+In 158 *A*GeV (final))

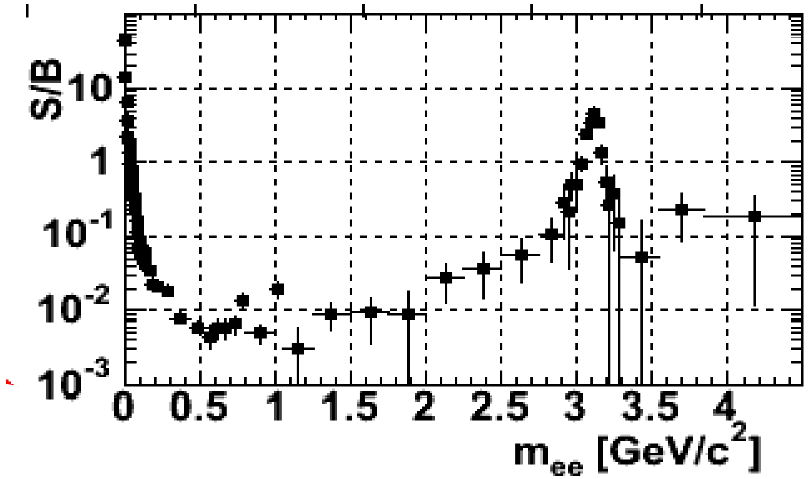
- 1.3 10^8 events (analyzed)
- 3.6 10^5 signal pairs
- 2.7 10^{-3} signal pairs/event

S/B (In+In)		
@ M [GeV/c²]	*0.2*	*0.6*
periph.	5	0.9
semi-periph.	1	0.14
semi-centr.	0.33	0.06
centr.	0.35	0.07

pair spectra

e^+e^- yields (PHENIX)





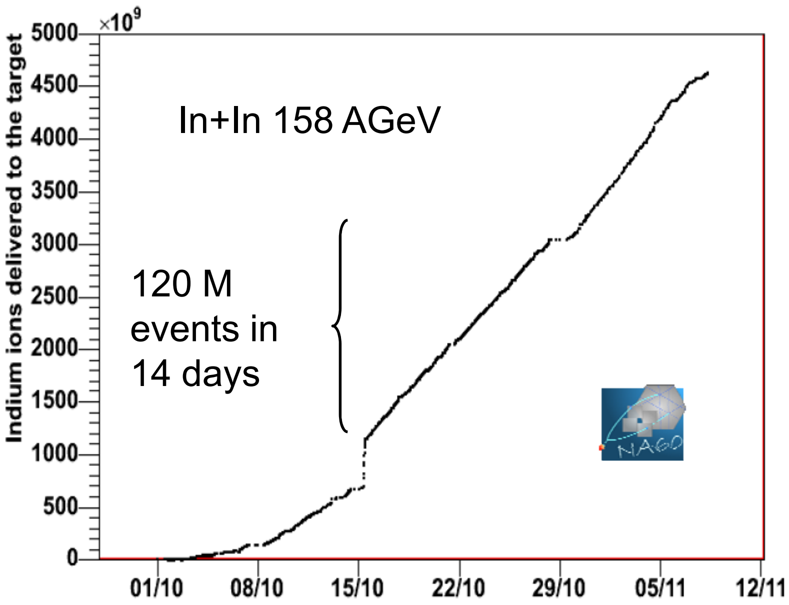
Completed runs (results)

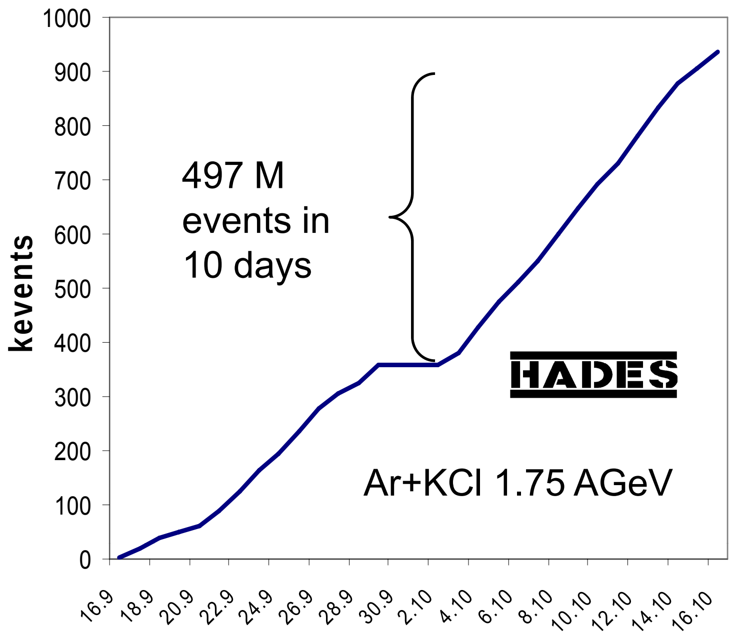
- p+p 200 GeV
- Au+Au 200 AGeV

S/B (Au+Au)		
@ M [GeV/c^2]	*0.2*	*0.6*
200 AGeV	0.03	0,006

Event collection: NA60 and HADES

	Data volume	Trigger purity	Trigger limitation
NA60 In+In (2003)	4.5 TB	2.7 10^{-3}	Works as long as $\gamma\tau(\pi)$ is large compared to the flight path before absorber At low energies muons have still to traverse the absorber
HADES Ar+KCl (2005)	9 TB	2.3 10^{-4}	Fake (ring) matches, can be improved if MDC is in the trigger. At high energies by multiplicities of electrons from π^0 (Dalitz and conversion)



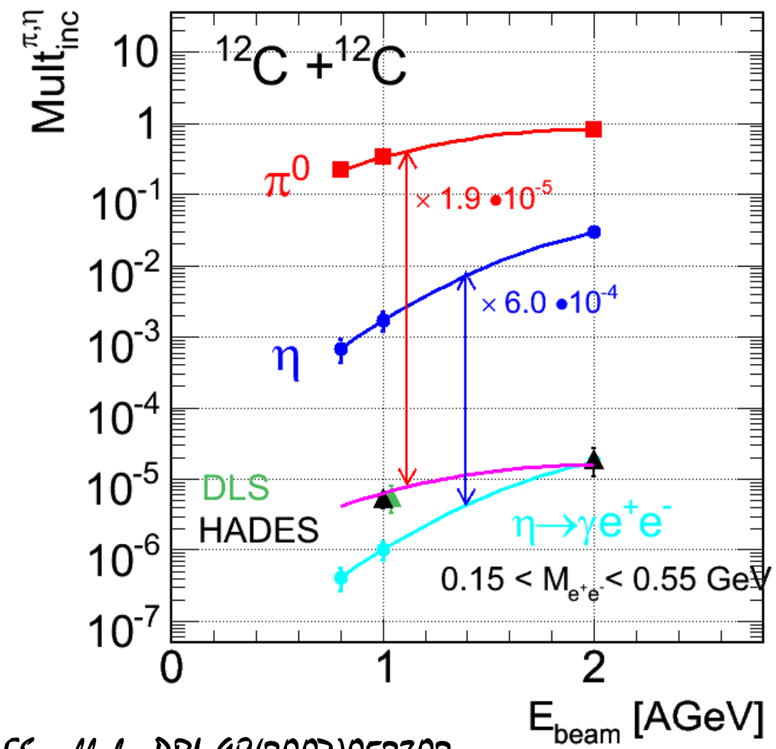


Excess yield

The DLS puzzle

excess yield

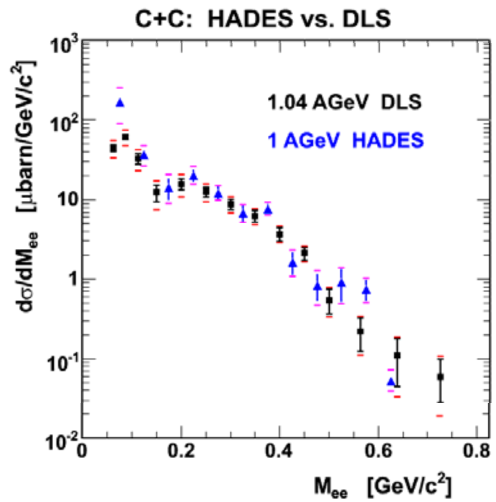
Electron pair excitation function:

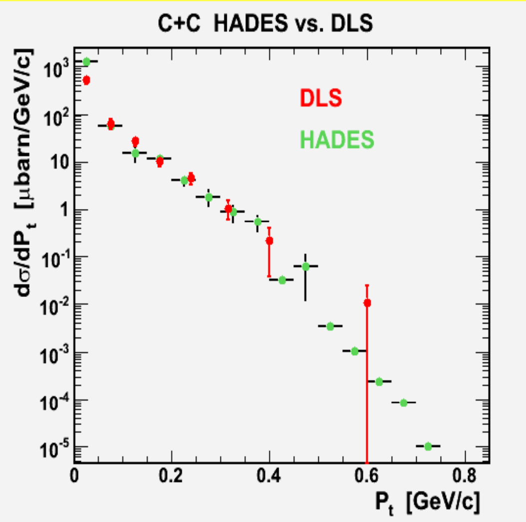


HADES collab., PRL 98(2007)052302

- **No contradiction** between DLS and HADES
- Strong evidence for extra contributions from **decays of baryonic resonances**.

DLS HADES

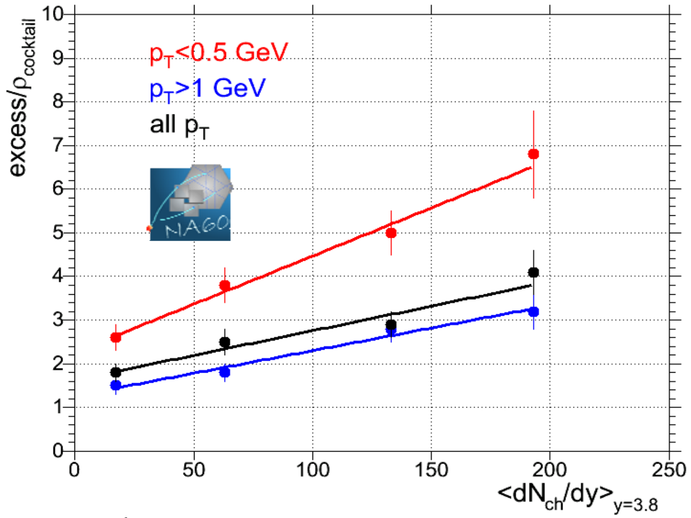




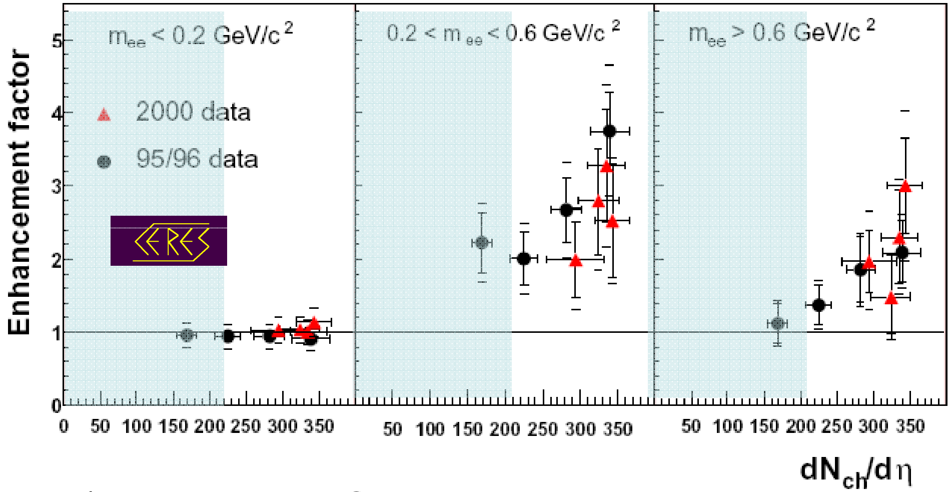
PhD Yvonne Pachmayer, Frankfurt

Centrality dependence of the excess (SPS)

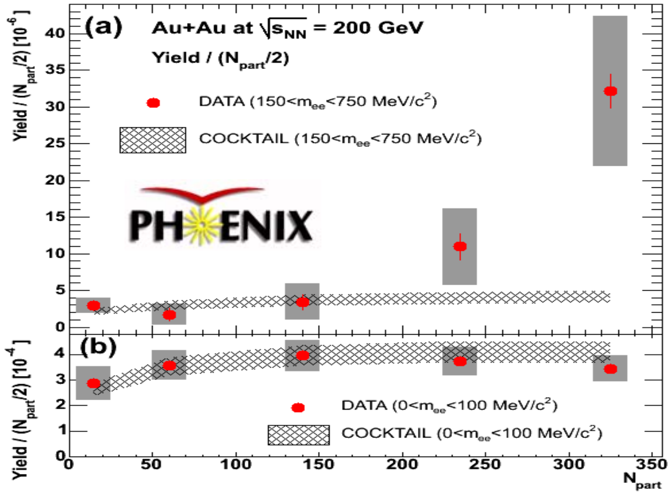
- Enhancement grows with centrality (CERES 158 AGeV)
- Pair multiplicity grows stronger than linear with centrality (PHENIX)
- Excess yield relative to cocktail ρ grows with centrality (NA60)
- Excess grows when going down in energy from 158 AGeV to 40 AGeV (not shown here).



S. Damianovic, HQ06



S. Iourevich, Doct. Thes. 05



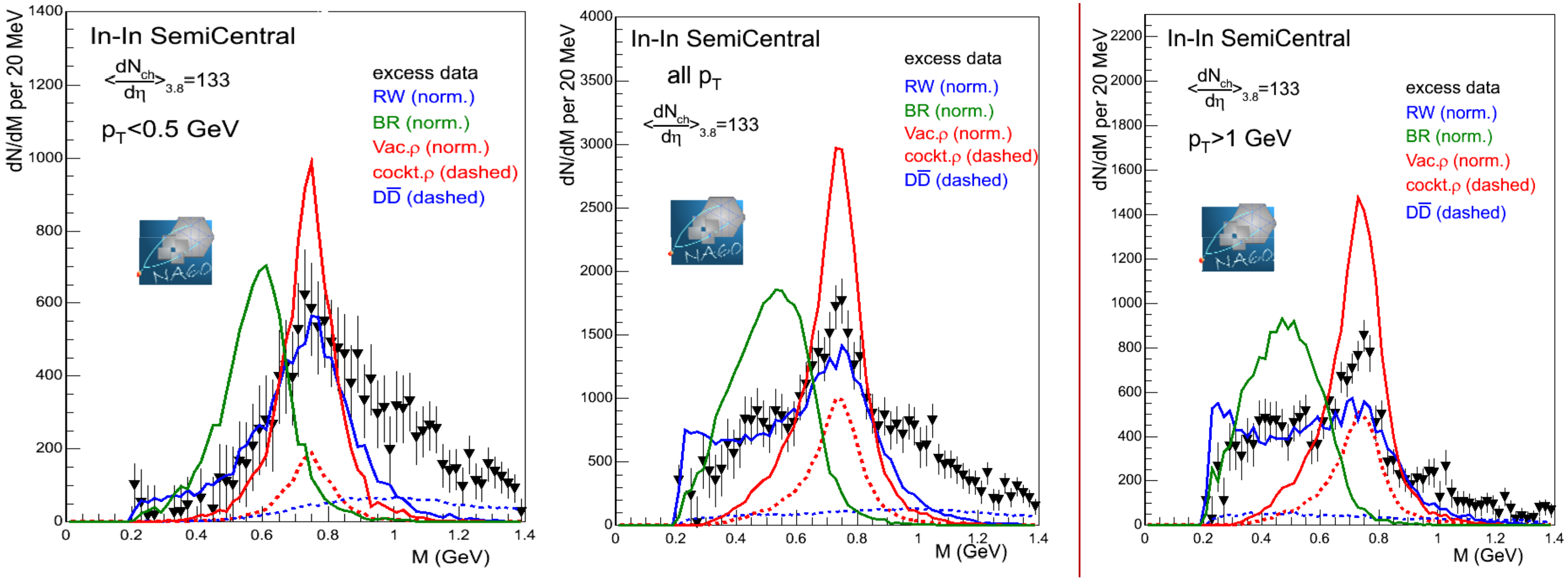
A. Toja, CPOD 2007

Excess yield and thermal radiation

Subtracted spectra (NA60)

excess yield and thermal radiation

- ππ annihilation now accepted as dominant source
- Data disproves a scenario assuming a purely shifting ρ
- Smallest contribution from cocktail ρ to the excess for pt < 0.5 GeV/c
  - Excess suppressed on the low-mass side due to acceptance!

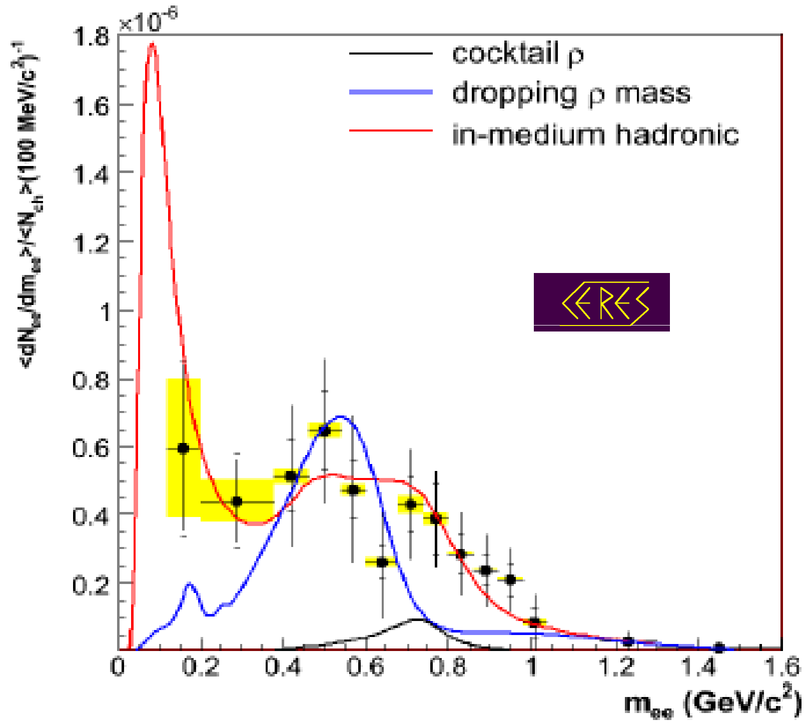


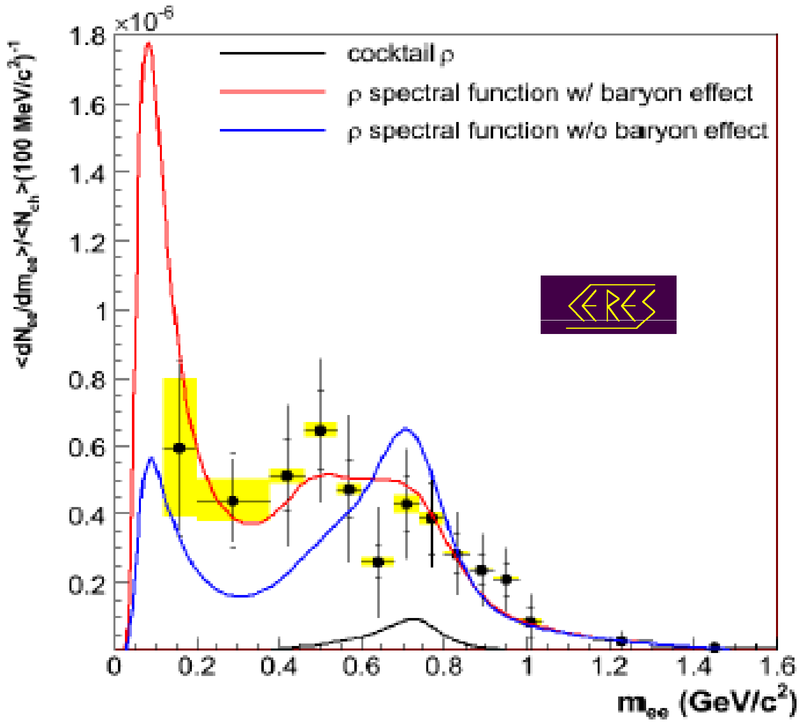
S. Damianovic, HQ06

Subtracted spectra (CERES)

excess yield and thermal radiation

- Broadening of ρ driven by baryonic effects
- Good sensitivity at lower masses
  - Connection to the photon point (Turbide et al., Alam et al.)

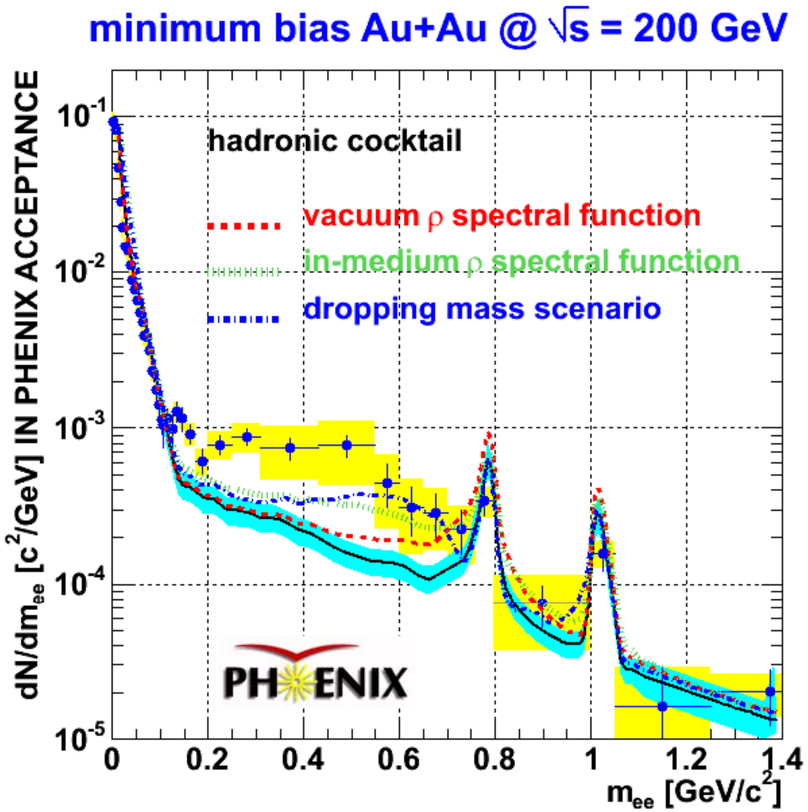




CERES coll., nucl-ex/0611022

Mass spectrum (PHENIX)

- Excess above ω pole mass?
- Huge excess around m_{ee} ~ 400 MeV/c^2



PHENIX coll., arXiv:0706.3034

Broad range enhancement:
150 < m_{ee} < 750 MeV
3.4±0.2(stat.) ±1.3(syst.)±0.7(model)

R.Rapp, Phys.Lett. B 473 (2000)
R.Rapp, Phys.Rev.C 63 (2001)
R.Rapp, nucl/th/0204003

Excess yield and transport

Enhancement and transport

excess yield and transport

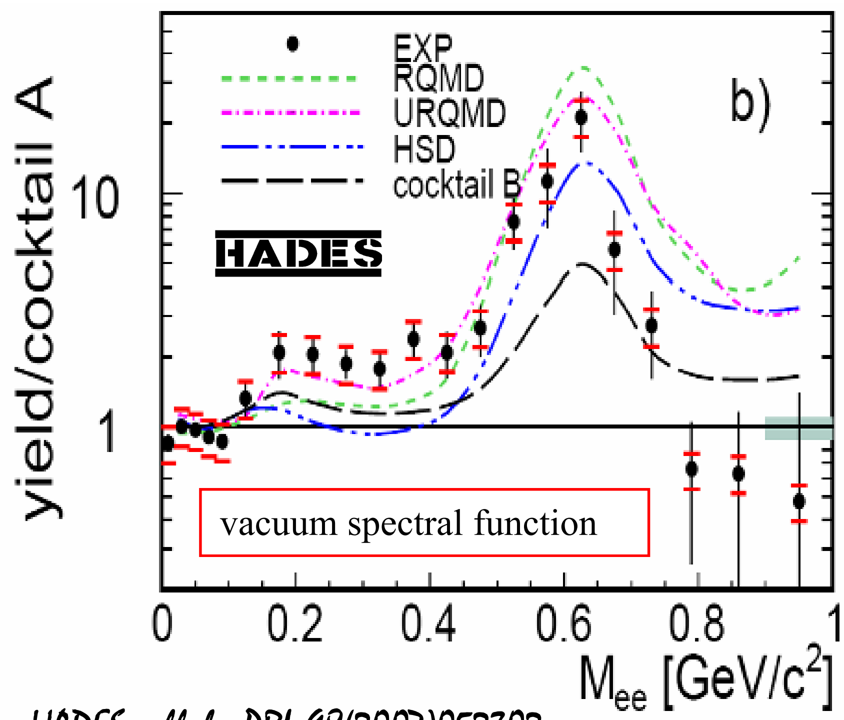
RQMD: M. D. Cozma, C. Fuchs, E. Santini, A. Faessler, Phys. Lett. B 640, 150 (2006)

UrQMD: D. Schumacher, S. Vogel, M. Bleicher, nucl-th/06080401**.**

HSD (v2.5): W. Cassing and E. L. Bratkovskaya, Phys. Rep. 308, 65 (1999).

Transport calculations
based on
vacuum spectral functions ...

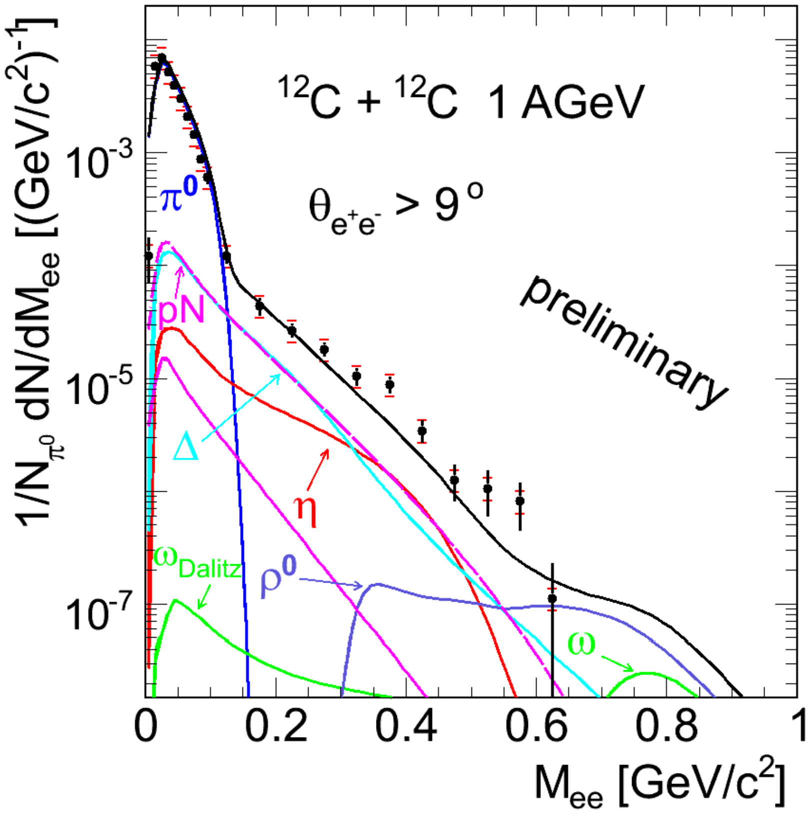
- qualitatively describe the data.
- undershoot between $200<M_{ee}<500$ MeV/c^2.
- overshoot for $M_{ee}>700$ MeV/c^2.

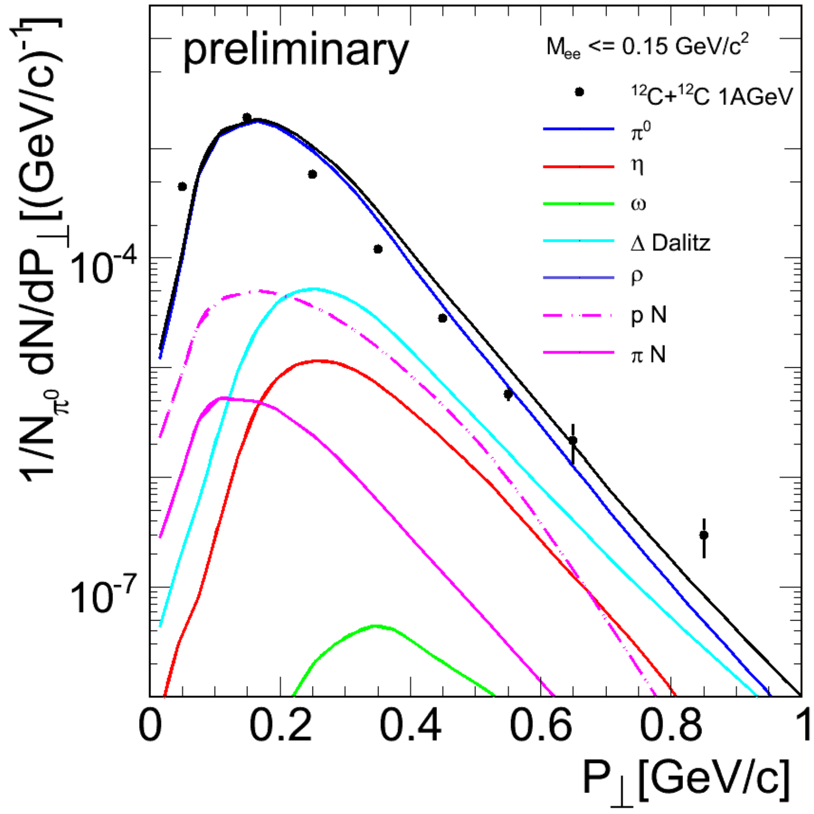


HADES collab., PRL 98(2007)052302

PhD Malgorzata Sudol, Frankfurt

HADES – HSD vacuum





Inv. mass

Good agreement

Undershoot at ~ 0.4 GeV/c^2 ?

P_t Distributions

M_{ee} < 0.15 GeV/c² - π^0 dominated

M_{ee} > 0.15 GeV/c²:

– Bremsstrahlung important at low p_t

Medium modifications in transport (HADES)

excess yield and transport

RQMD: M. D. Cozma, C. Fuchs, E. Santini, A. Faessler, Phys. Lett. B 640, 150 (2006)
UrQMD: D. Schumacher, S. Vogel, M. Bleicher, nucl-th/06080401.
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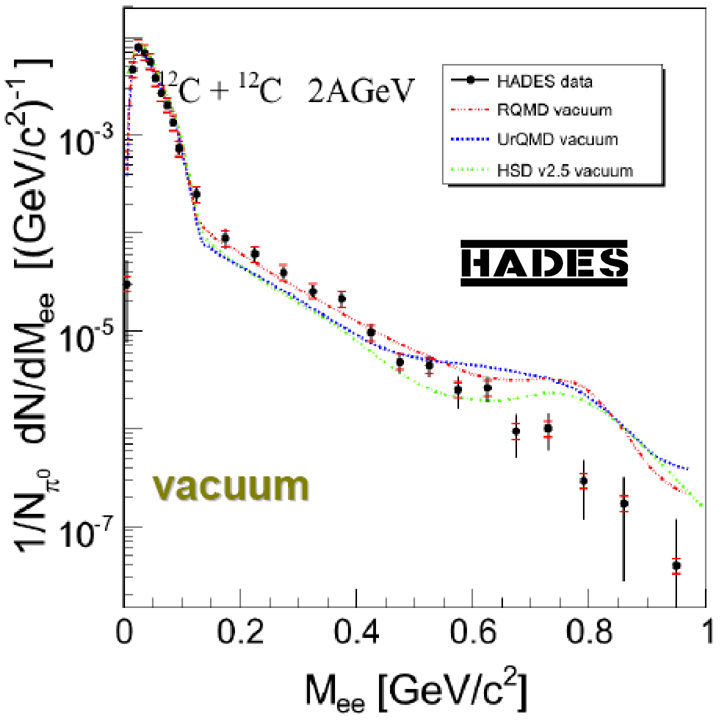
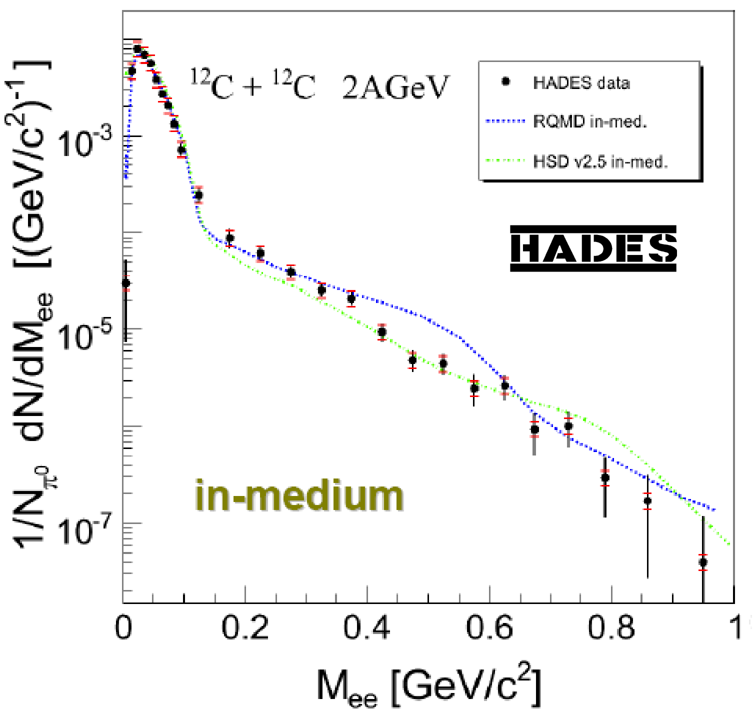


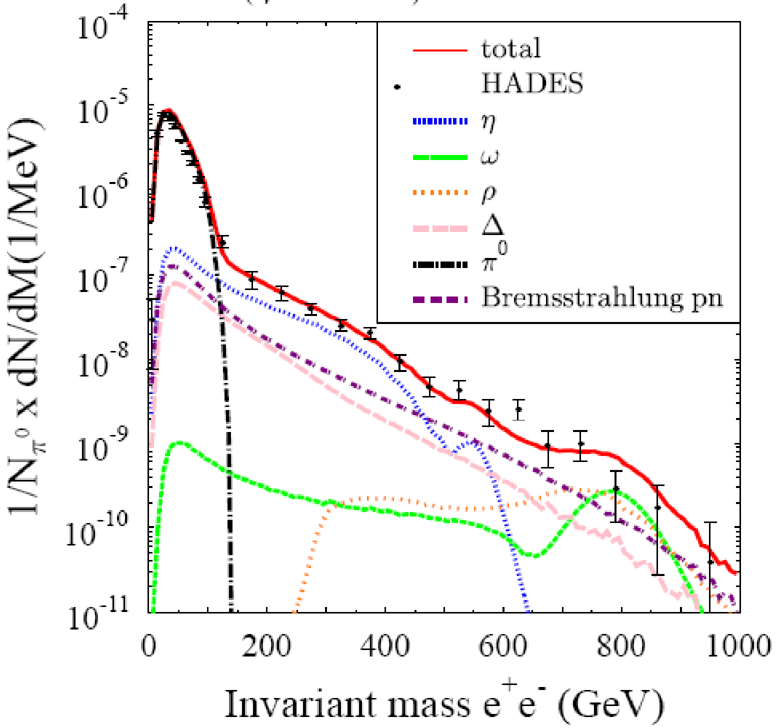


PhD Malgorzata Sudol, Frankfurt

Uncertainties in the η and ω production

excess yield and transport

$$\sigma(np \to np\omega) = \sigma(pp \to pp\omega)$$
$$\sigma(np \to np\eta) = 2\sigma(pp \to pp\eta)$$
$$(\eta \to e^+e^-) = 7.7\ 10^{-6}$$



$$\sigma(np \to np\omega) = \sigma(pp \to pp\omega)$$
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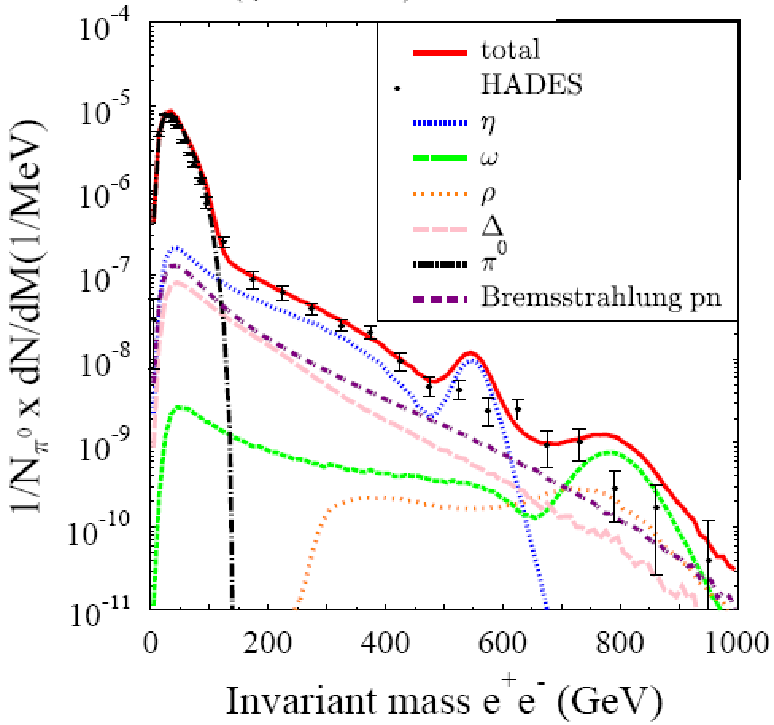
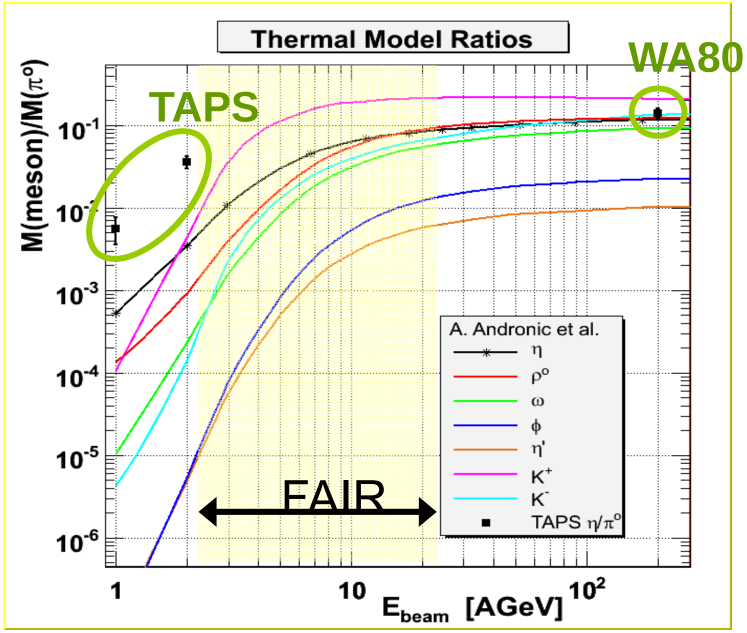
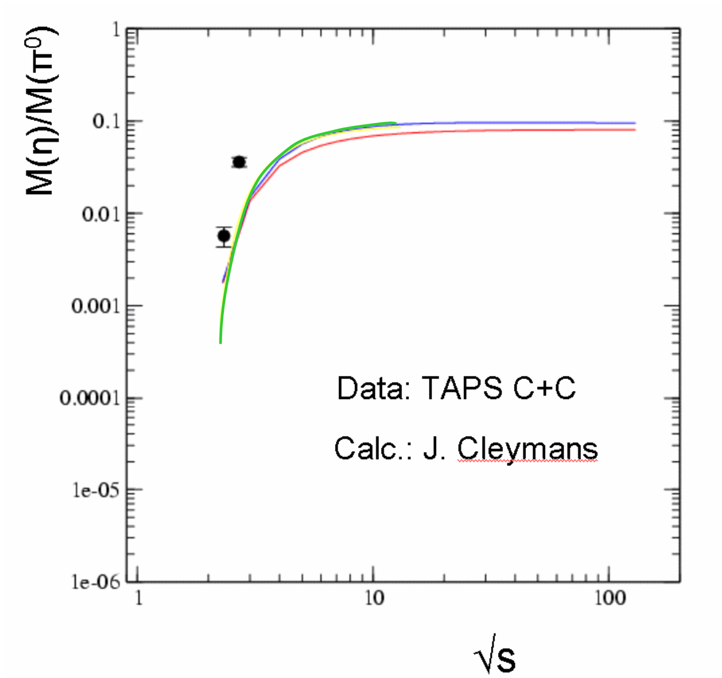


J. Aichelin et al., nucl-th/0702004

η production in the statistical model

- Iso-spin effects in η production not fully under control (see arXiv:nucl-th/0702004v1)
- Validity of statistical model at low energies and for small systems not evident



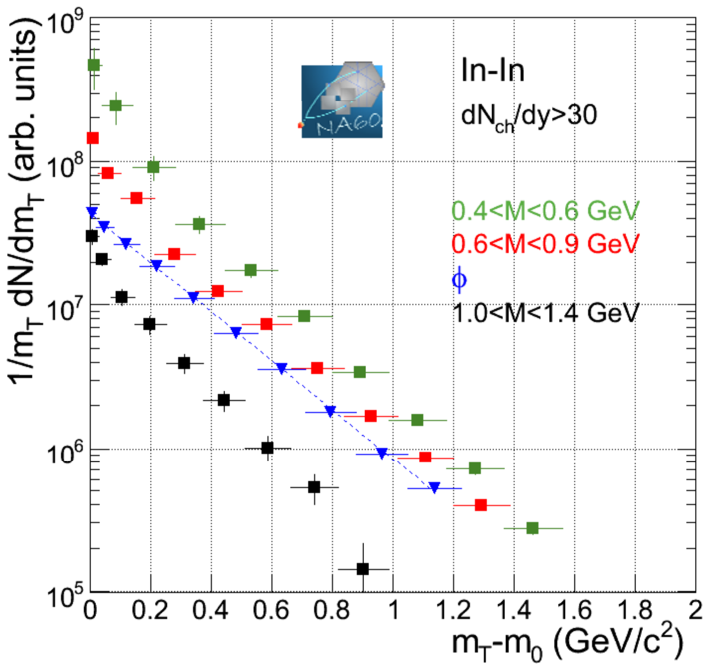


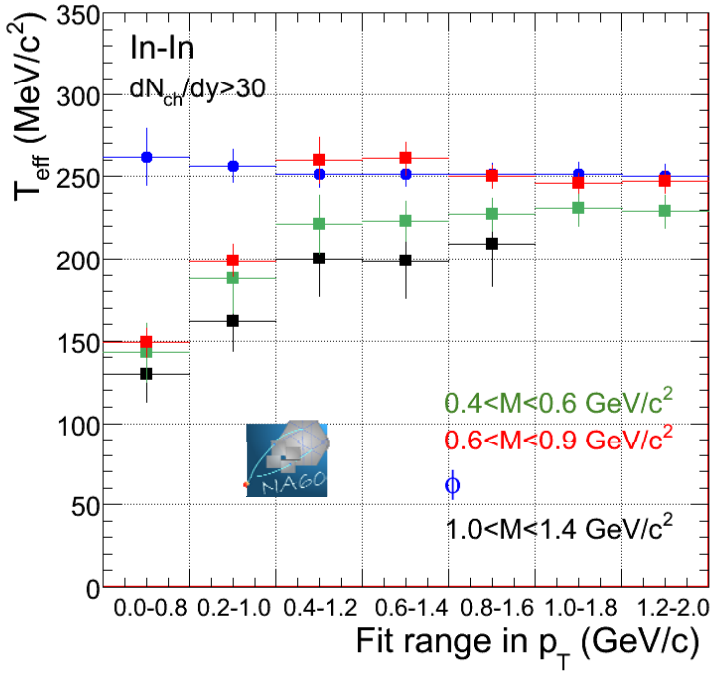
Compilation by R. Holzmann and A. Andronic, priv. comm.

P_t distributions

Acceptance corrected p_t spectra (NA60)

- Excess yield dominantly at low p_t
- p_t slopes show weak centrality dependence (not shown below)
- Systematic uncertainties (not shown below):
  - grow with centrality and towards lower p_t

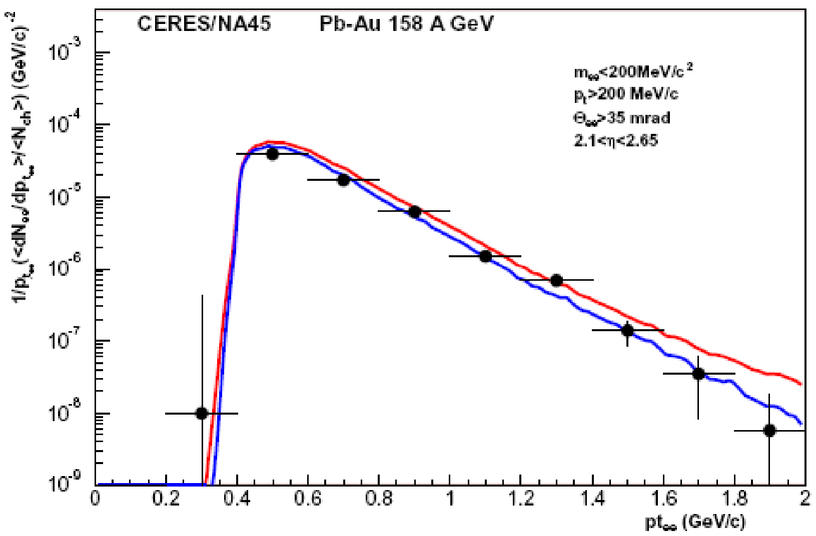


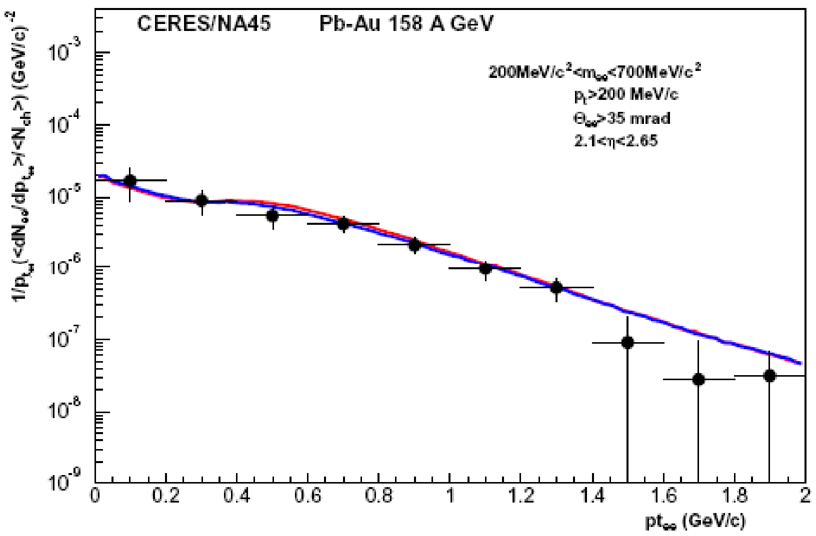


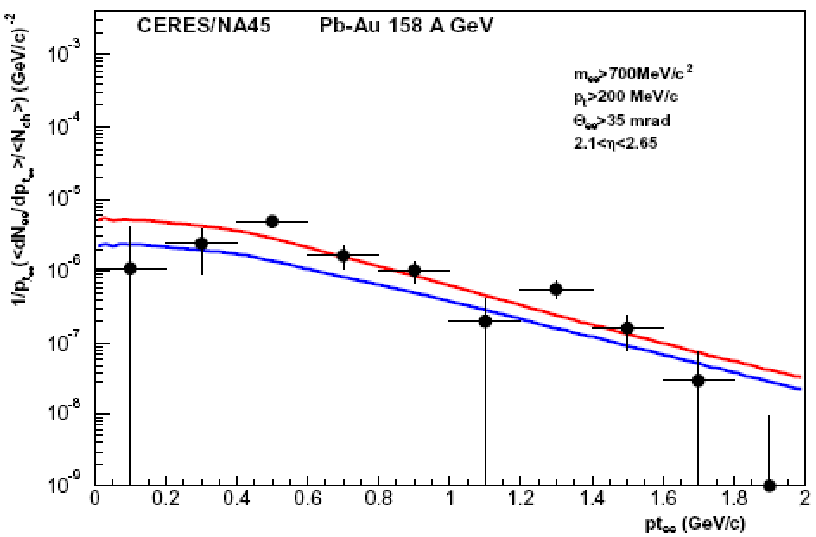
J. Seixas, QM06

p_t: spectra (CERES)

p_T distributions







p_t weakly sensitive on type of spectral function in a $\pi\pi$ annihilation scenario.

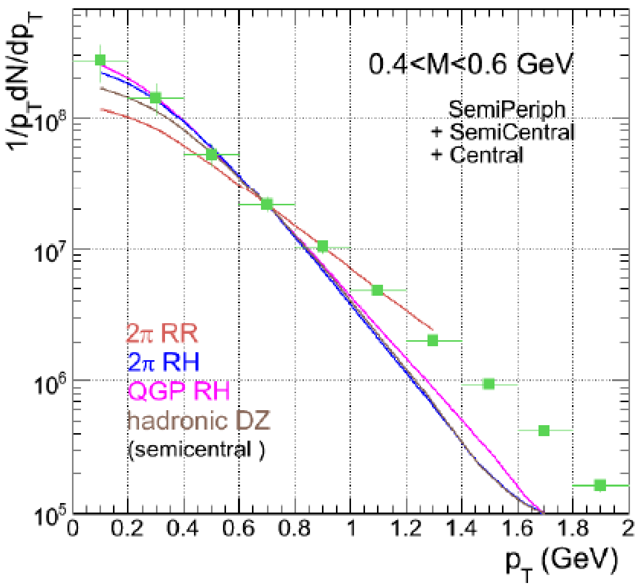
S. Iourevich, Doct. Thes. 05

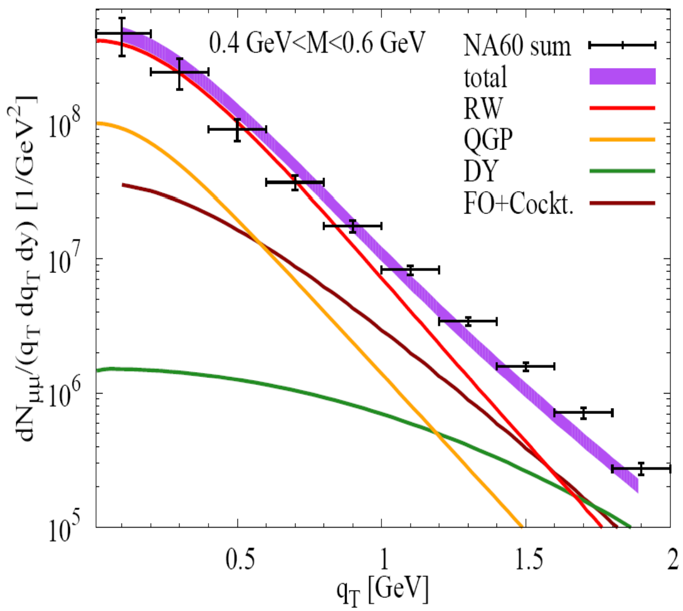
$p_{t:}$: closer look (NA60)

p_T distributions

Improved expansion model (H: van Hees, R. Rapp ..):

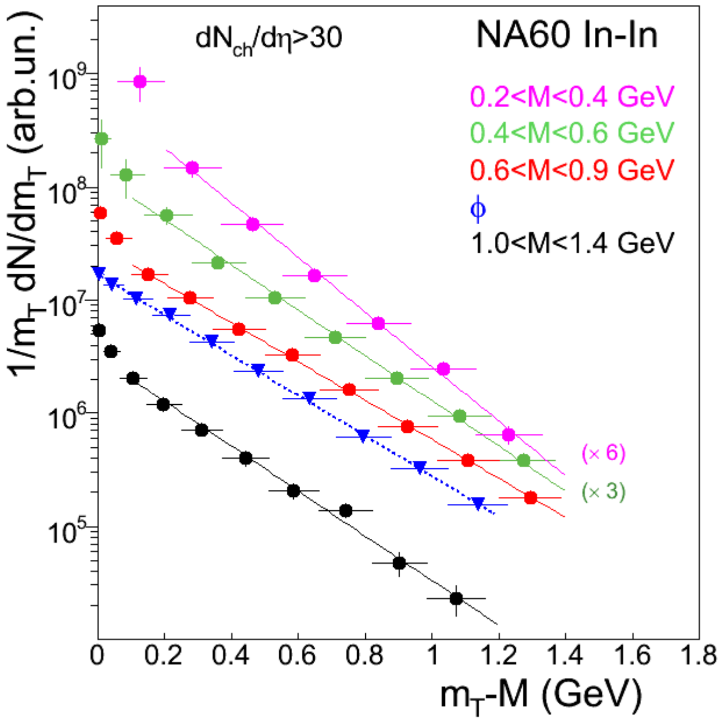
1. initial hard processes ↔ Drell Yan
2. “core” ↔ emission from thermal source
3. “corona” ↔ emission from “cocktail” mesons
4. after thermal freeze-out ↔ emission from “freeze-out” mesons

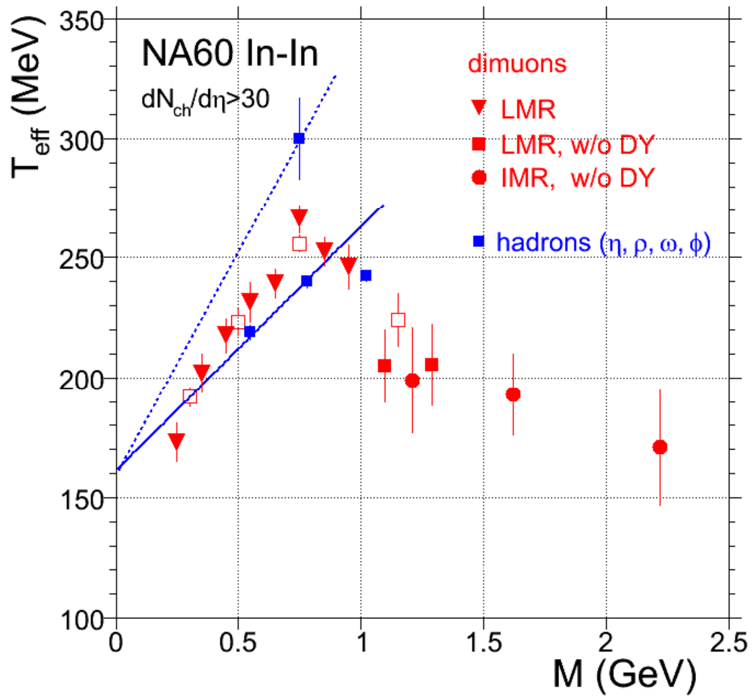




p_t: efficiency/acceptance corrected (NA60)

- non-trivial behavior of slope parameter beyond M = 1 GeV/c^2.
- continuum pairs show flow
- Hot ρ?

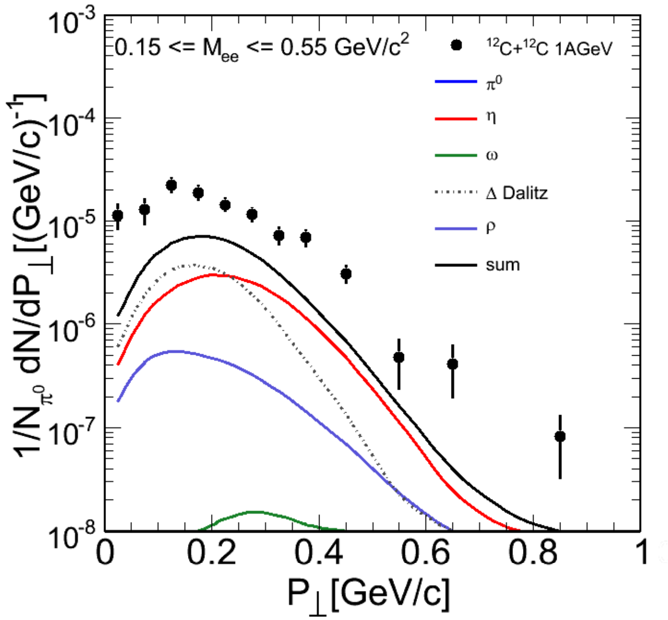


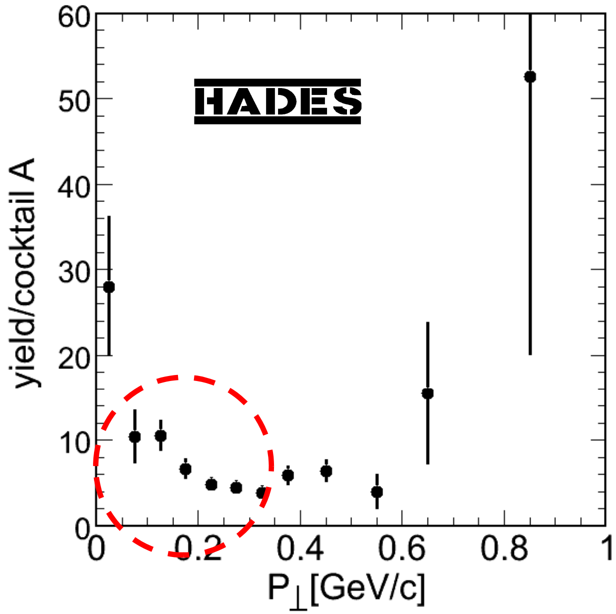


H. Specht + NA60, INPC07

P_t Spectra 1 AGeV C+C

p_T distributions





Good agreement in π^0 region

Underestimation for M_{ee}> 0.15 GeV/c^2

Excess over Cocktail A ($\pi^0 + \eta + \omega$)

→ enhancement at low P_t

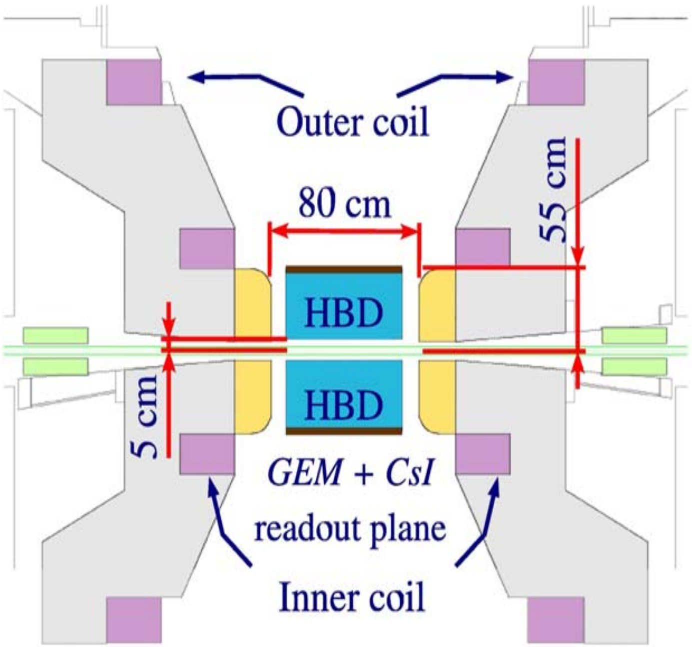
PhD Yvonne Pachmayer, Frankfurt

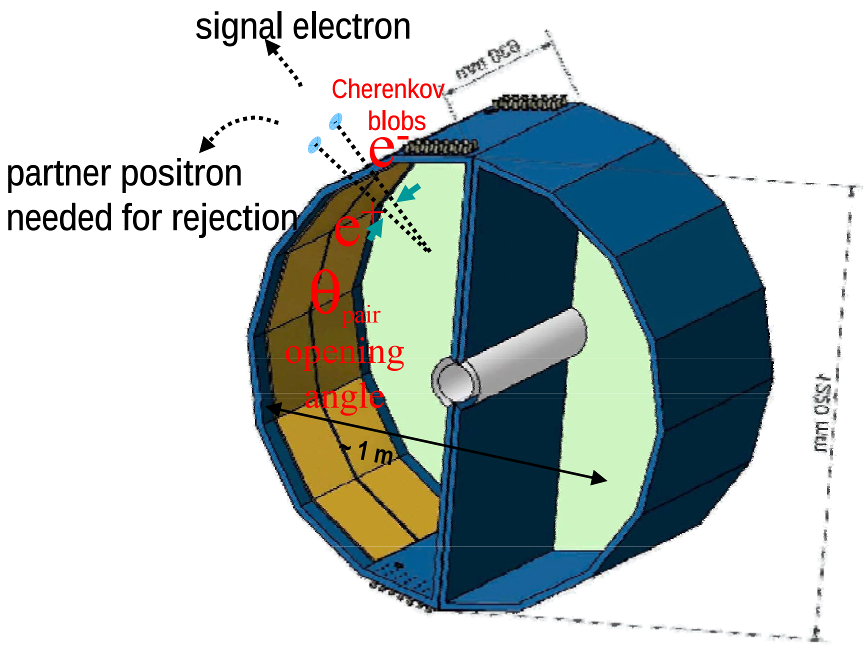
next generation experiments

PHENIX with Hadron Blind Detector

HBD concept:

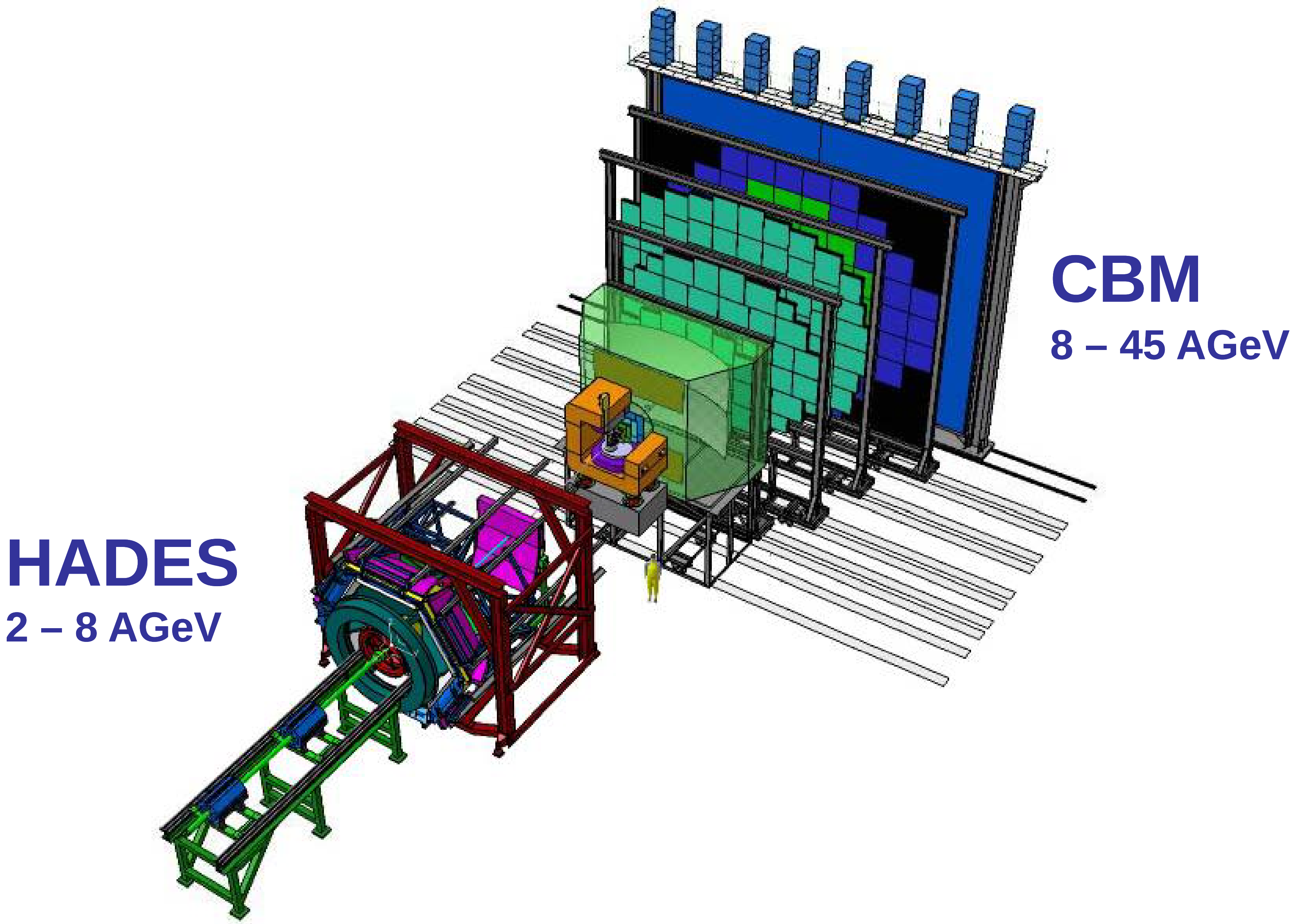
- windowless CF4 Cherenkov detector
- 50 cm radiator length
- CsI reflective photocathode
- Triple GEM with pad readout
- Reverse bias (to get rid of ionization electrons in the radiator gas)





From HADES to CBM @ FAIR

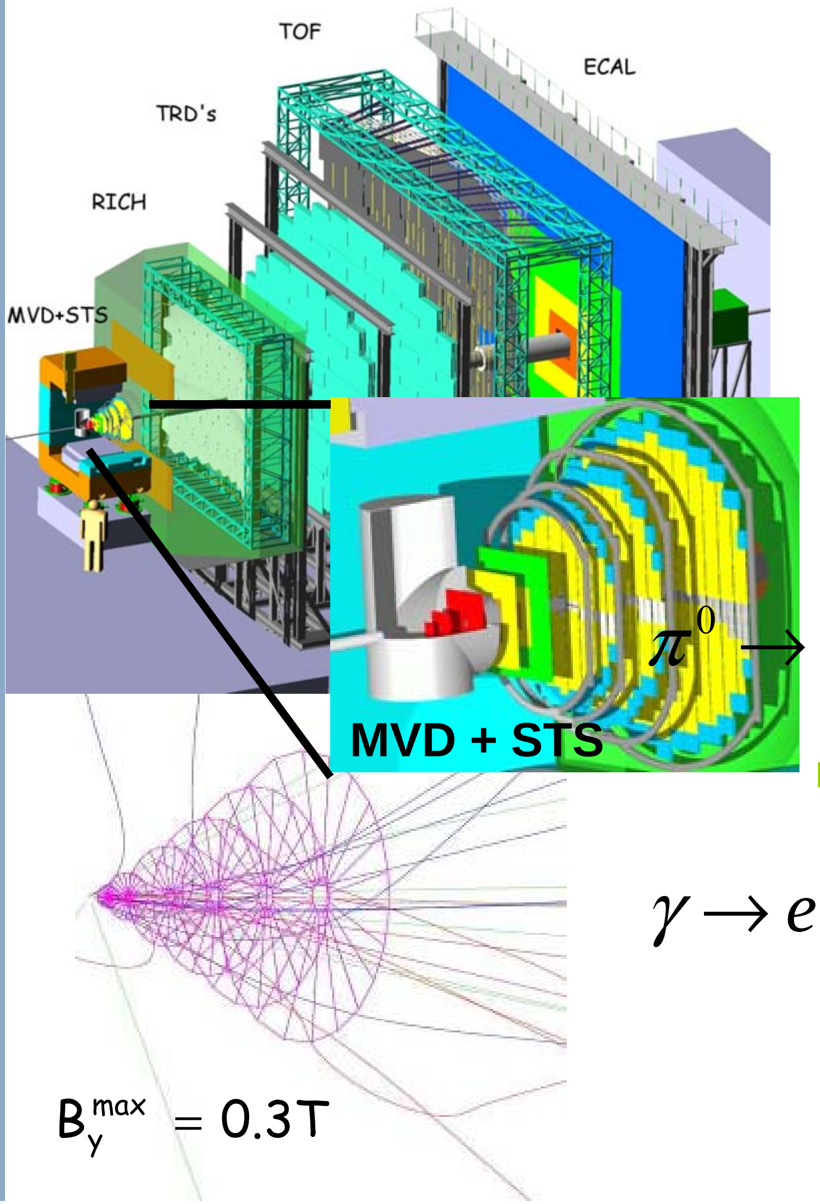
next generation experiments

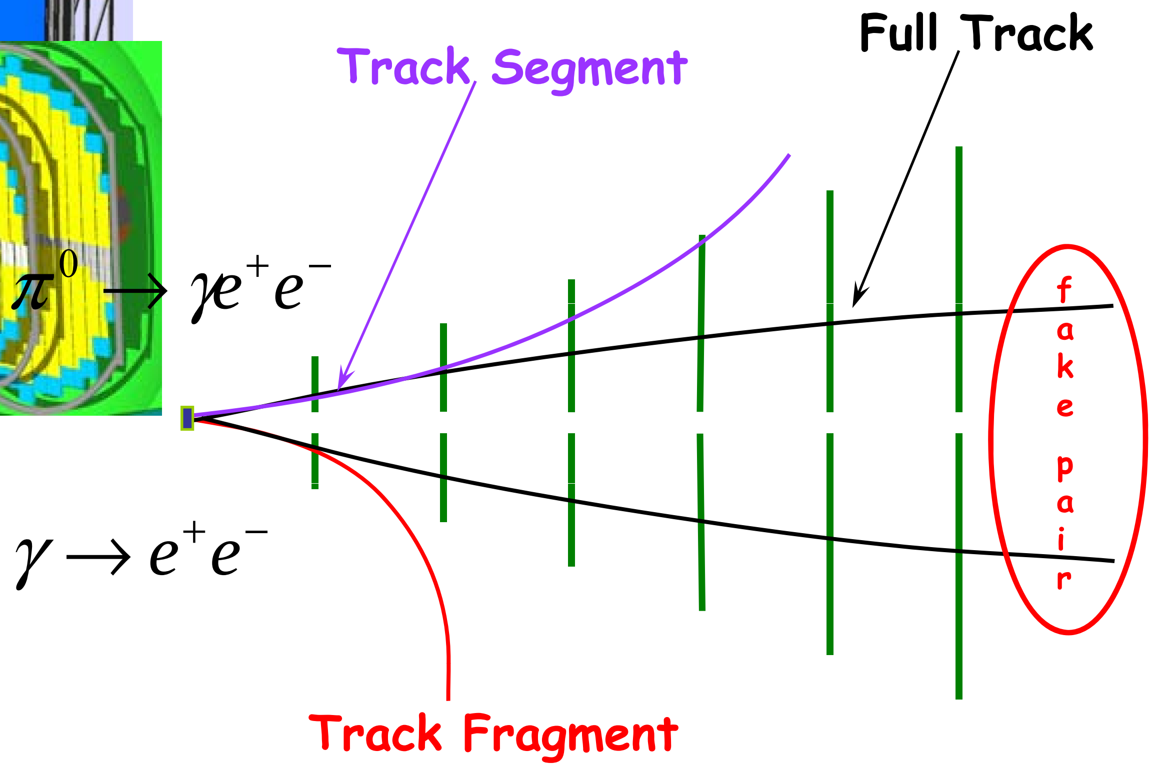


Dielectron reconstruction in CBM

Fast, high-precision tracking using silicon sensors.

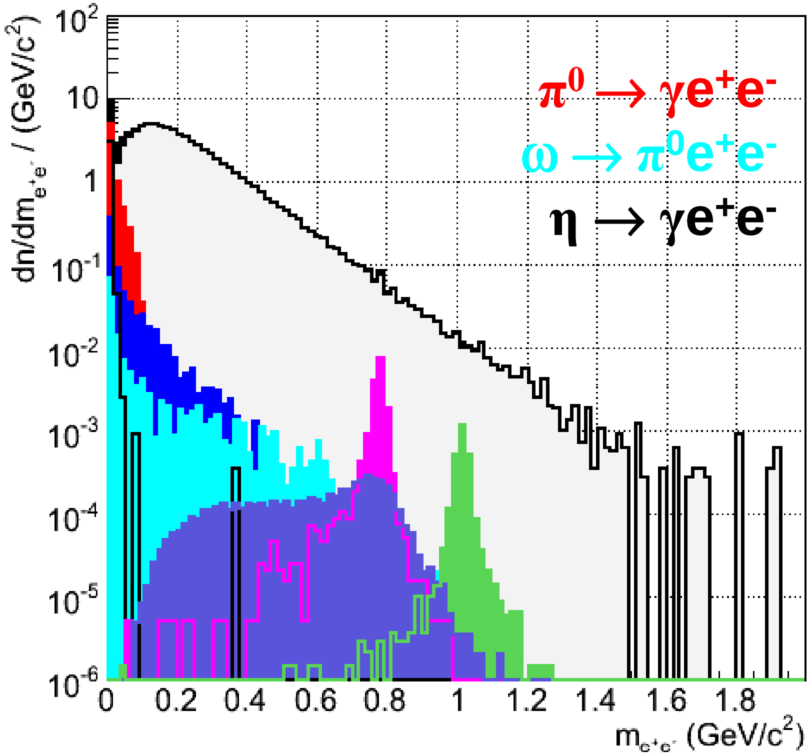
No electron identification before tracking



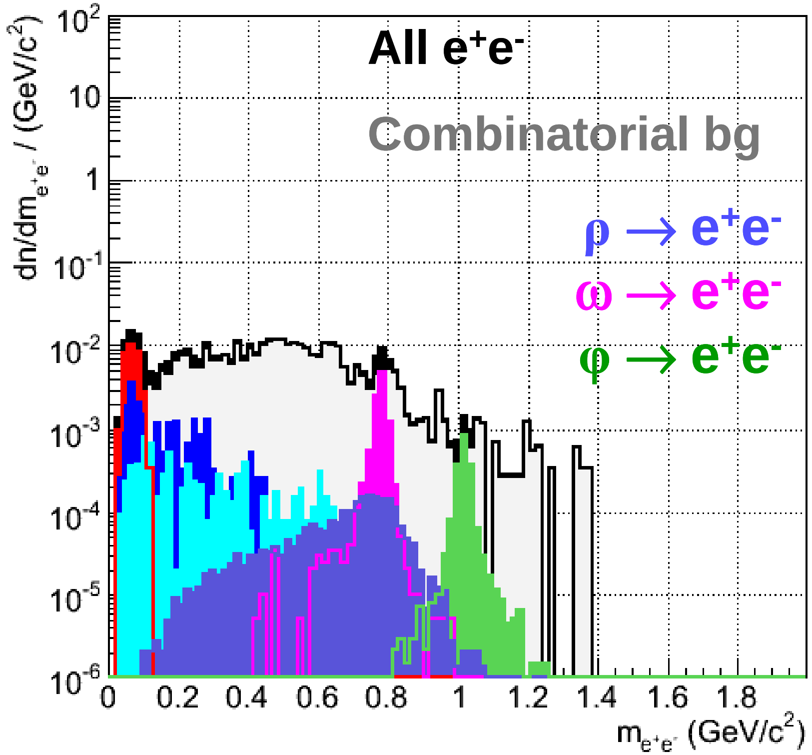


Invariant mass spectra Au+Au 25 AGeV

Identified e^+e^-



After all cuts applied



- No optimization of cuts
- Free cocktail only (without medium contribution)
- Simulated statistics is 100k events

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The muon option in CBM

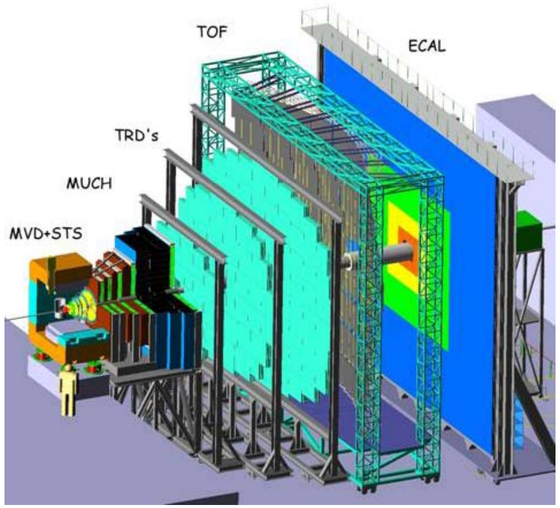
next generation experiments

Simulations Au+Au 25 *AGeV*:

- Different analysis strategies for low-mass and high-mass pairs
- Low efficiency for small invariant masses and/or low p_t (enhancement region).

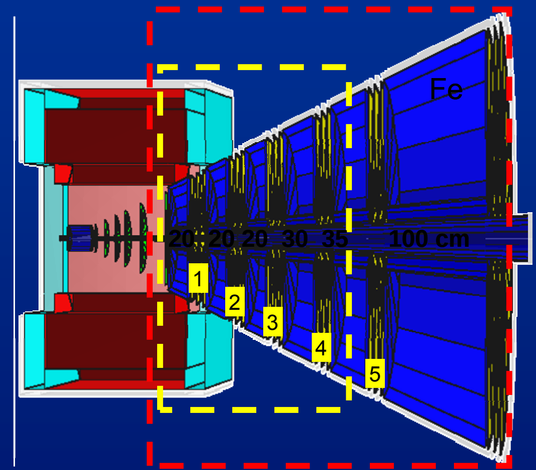
Challenging muon detector (high particle densities)

- Micro-pattern gas detectors with pad readout.



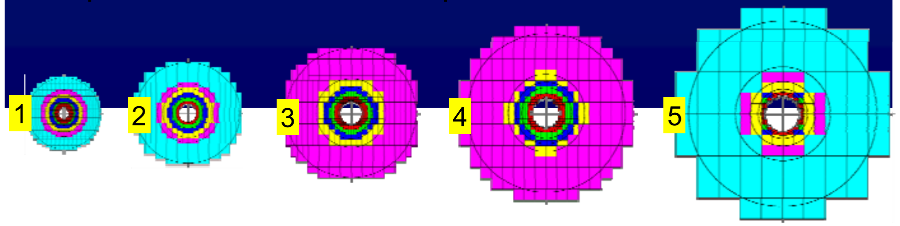
Muon Chamber System

MuCh
for measurements of:
low mass vector mesons
charmonium

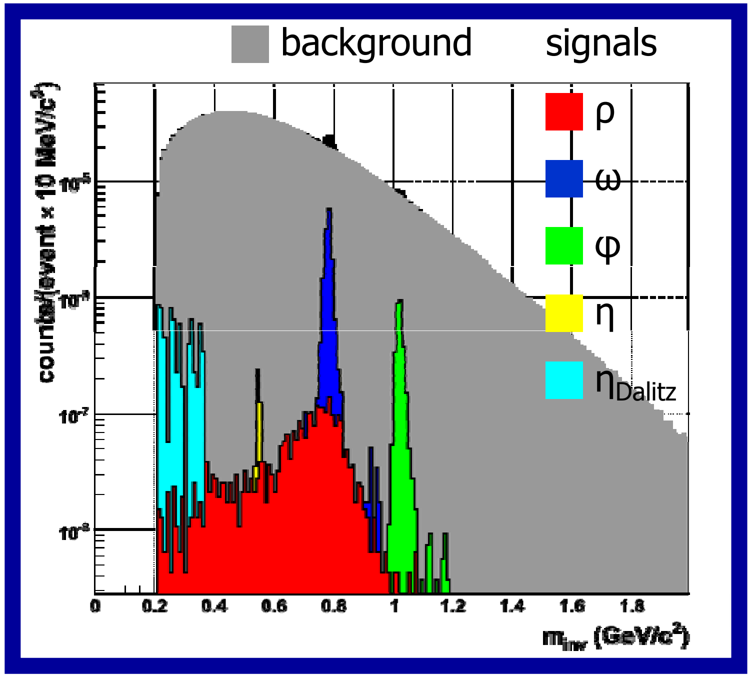


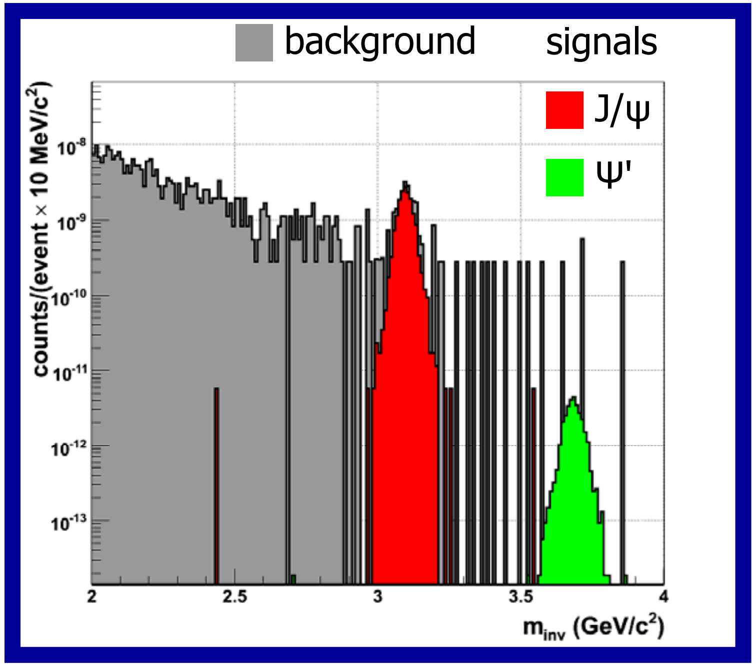
Detector requirements

- high rate capability (up to 1 MHz/cm²)
- high granularity (up to 1 hit/cm² per central Au+Au collision)
- position resolution < 300 μm



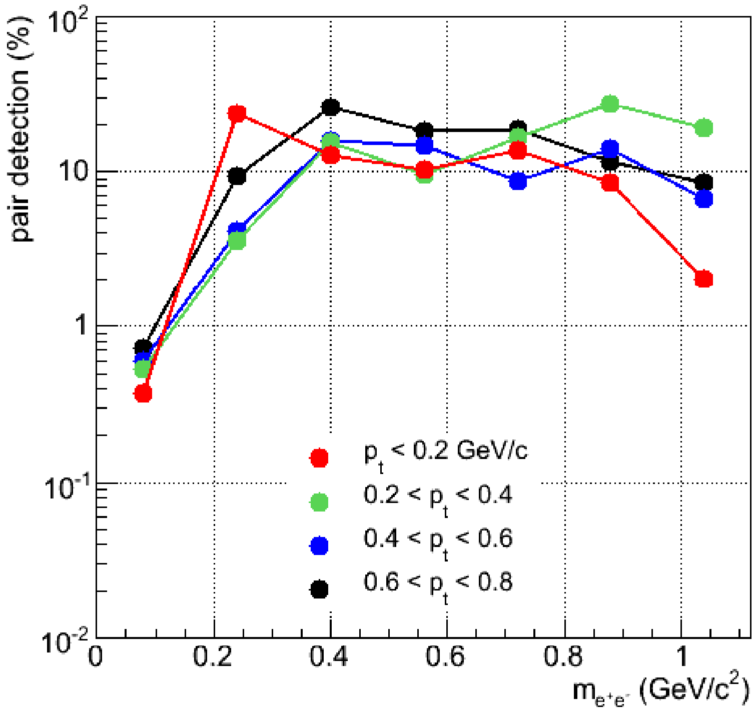
Muon pairs (CBM)



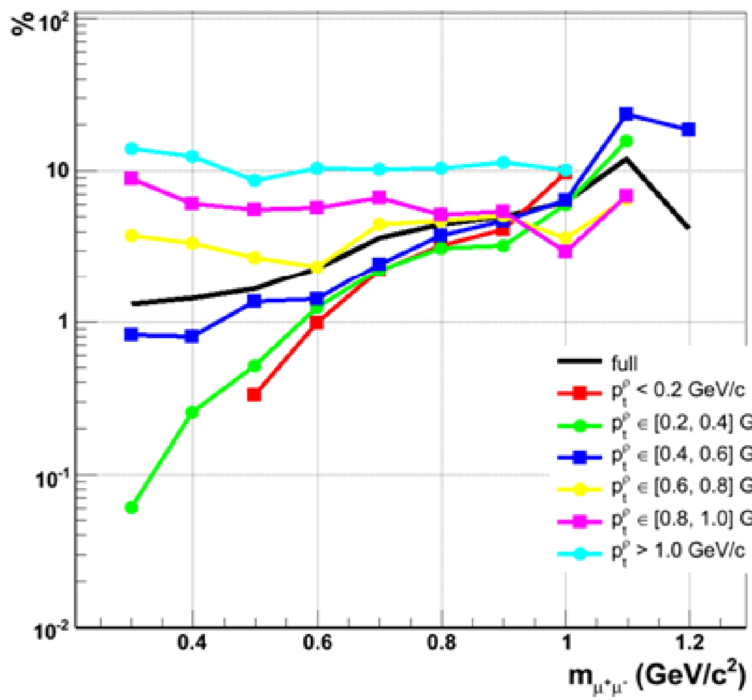


Acceptance in pt and m_{inv} plane

electrons



muons



(My) conclusions

- The quality of data will finally be determined by systematical errors.
- High statistics needed toa llow multi-differential analyses.
- Understanding the cocktail requires the measurement of neutral mesons (η, ω).
- Systematic measurements are needed to fully exploit the capabilities of low-mass lepton pair spectroscopy:
  - Compare low / high beam energies to study effects of the fireball expansion.
  - Use elementary reactions to constrain spectral functions.
- Trigger (at FAIR energies):
  - e^+e^-: most likely not possible
  - $\mu^+\mu^-$: difficult without introducing huge bias
- Excitation function of the enhancement can possibly signal a critical slowing-down of the expansion.