Dilepton and strangeness production probed with HADES

Anar Rustamov for the HADES collaboration

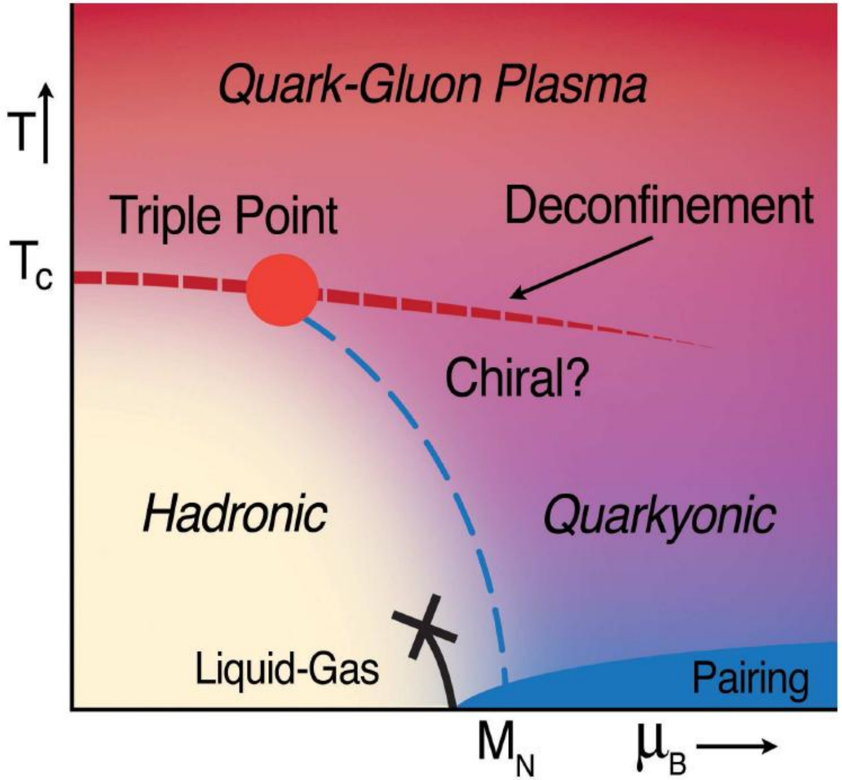
GSI Helmholtzzentrum für Schwerionenforschung

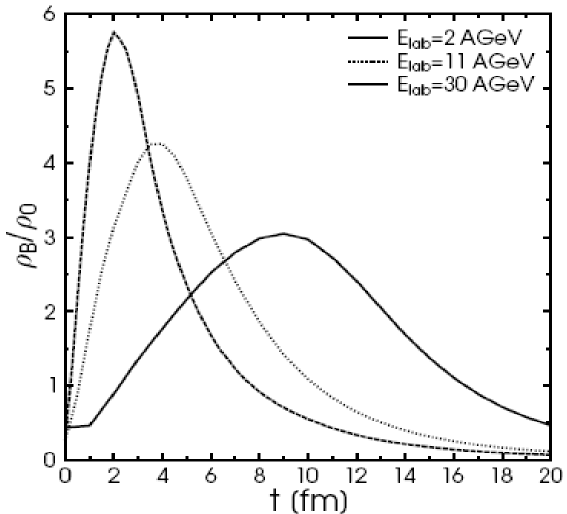
Outline

- physics motivation
- HADES spectrometer
- dilepton production
  - excess yield (systematic investigation)
  - understanding the excess
- strangeness production
  - comparison to stat. model
- summary

Physics Motivation

Andronic et al. in arXiv:0911.4806v3





- moderate densities and temperatures $\rho=(1\div3)\rho_o$, T=50÷100 MeV
- system stays in an excited state for 10-15 fm/c

Are there new forms of matter ?

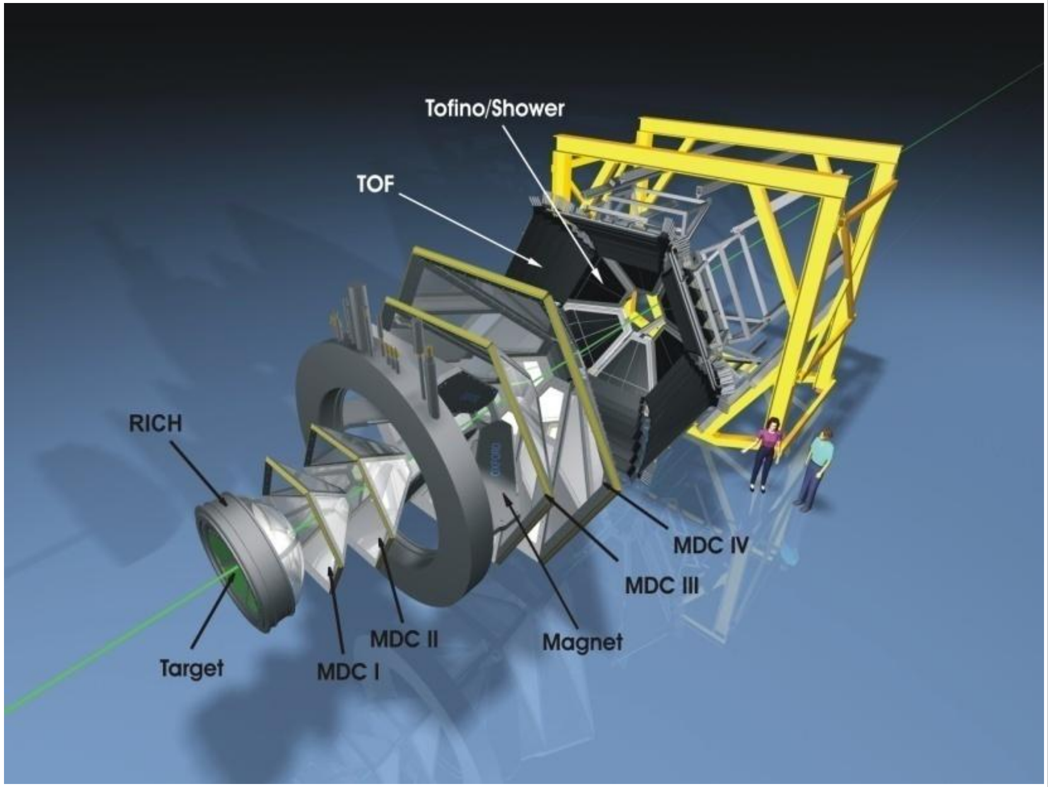
Properties of hadrons in matter
(Chiral symmetry restoration ?)

probing the medium with:

- dilepton production
- strangeness production

HADES spectrometer

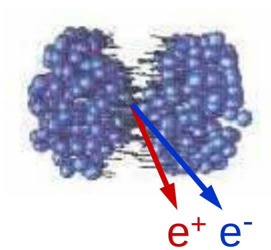
- **Acceptance**
  - $\varphi \sim 2\pi$
  - $15^o < \theta < 85^o$
  - pair ~ 30%
- **Momentum resolution**
  - Magnet: 0.1-0.34 Tm
  - MDC: 24 drift chambers
  - σ_m~ 2% at ρ/ω region
- **Particle identification**
  - RICH
  - Time of flight
  - Pre-Shower
  - MDC (for hadrons)
- **Trigger**
  - LVL1- charged particle mult.
  - LVL2- single electron trigger



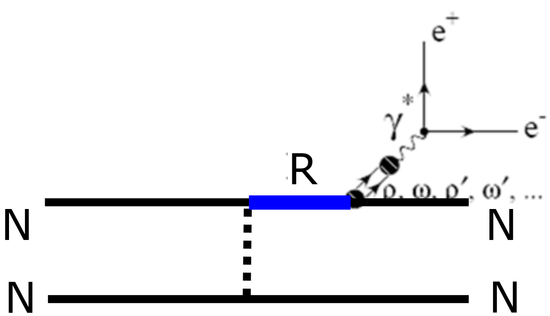
dilepton production

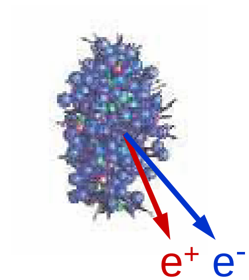
Dilepton sources

dilepton sources at SIS energy (HI beams of 1-2 A GeV)

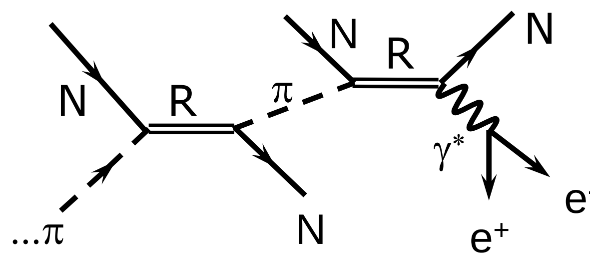


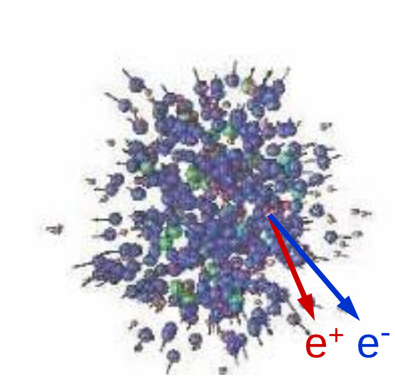
first chance collisions
elementary collision of nucleons



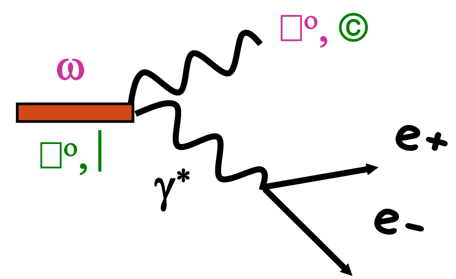


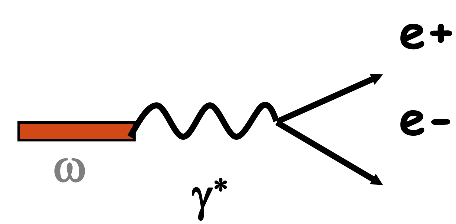
hot and dense phase
multistep production
of resonances and mesons



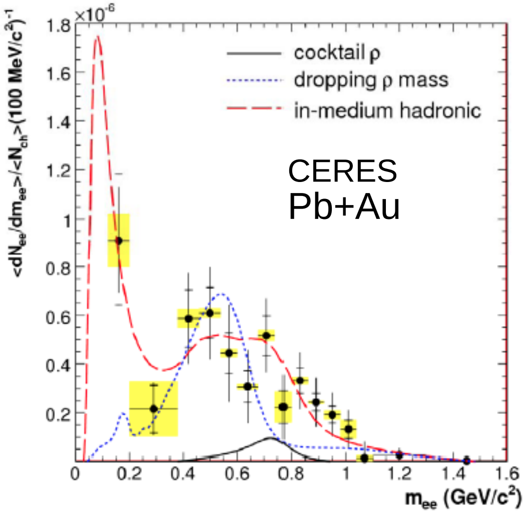


Freeze –out
decays of (long-lived)
states (π^0, η, ω)

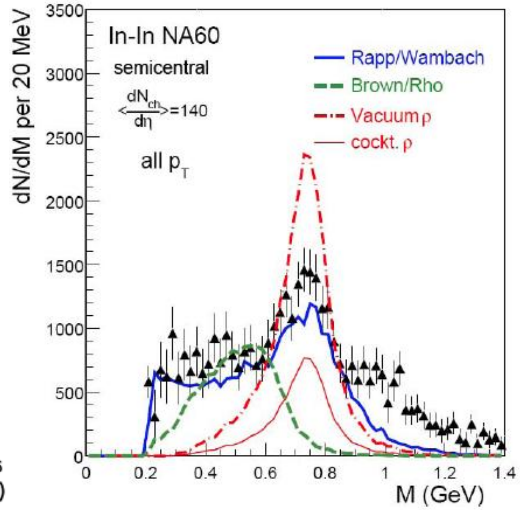




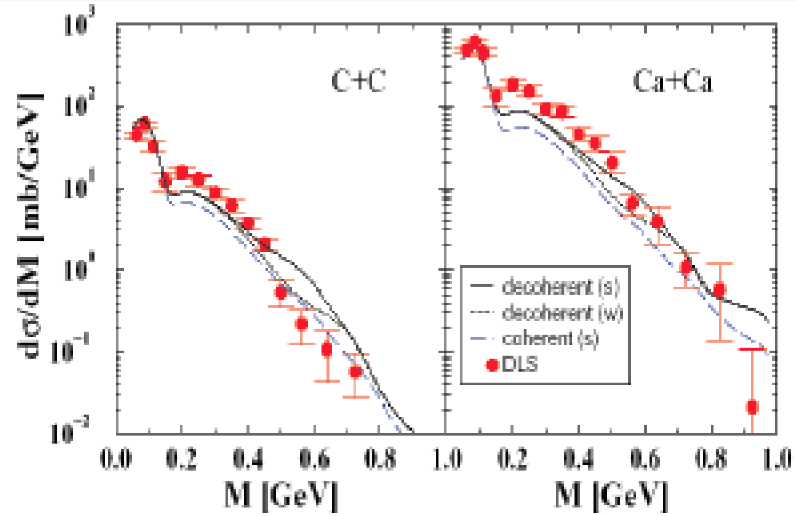
Low vs. High



D. Adamova et al. nucl-ex/0611022

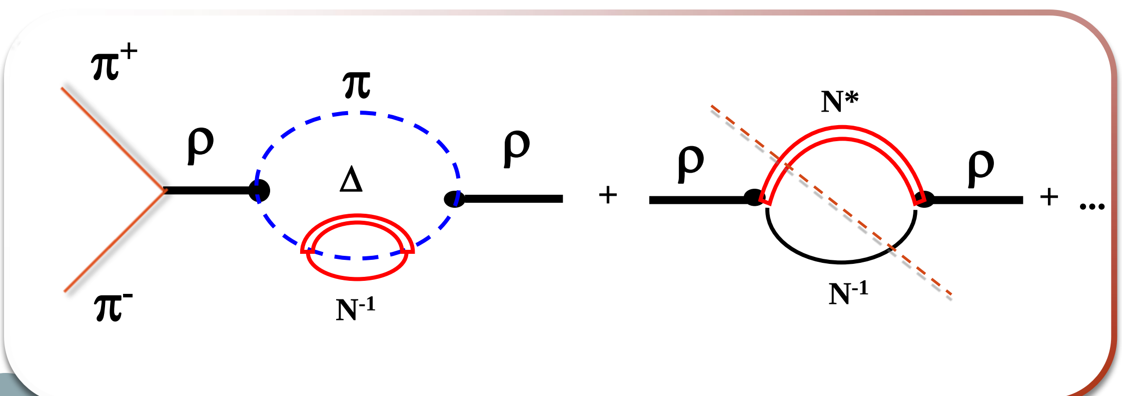


R. Arnaldi et al., PRL 96 (2006) 162302

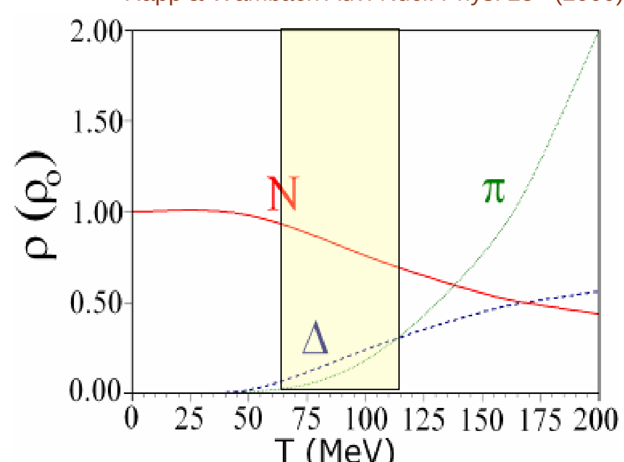


R. J. Porter et al., PRL 79 (1997)

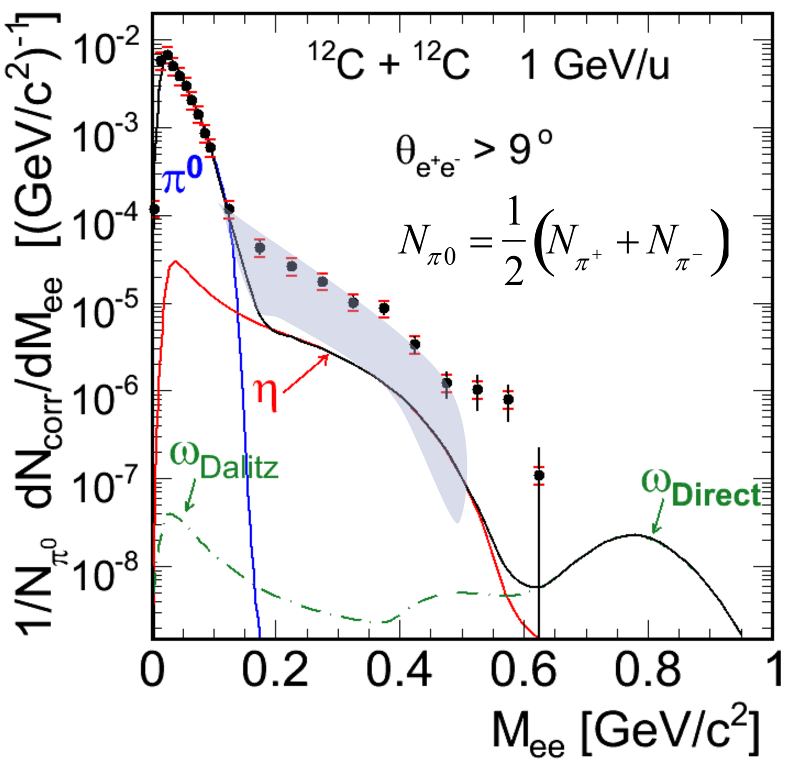
- High energy: 158 A GeV/c
  - major part is due to in medium ρ broadening
- Low energy: 1-2 A GeV: not explained

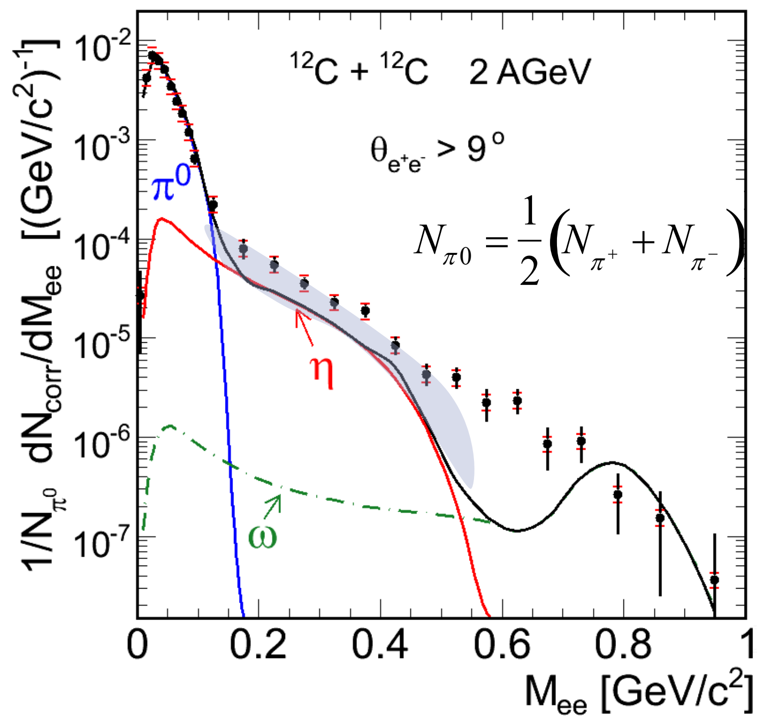


Rapp & Wambach Adv. Nucl. Phys. 25 (2000)



C+C data at 1 and 2 AGeV





multiplicities in simulation from TAPS measurements Z. Phys. A359 (1997)65

$$F(E) = \frac{Y_{exc}(E) + Y_{\eta}(E)}{Y_{\eta}(E)}$$

F(2.0) = 1.9 ± 0.2(stat) ± 0.3(sys) ± 0.3(η sys)

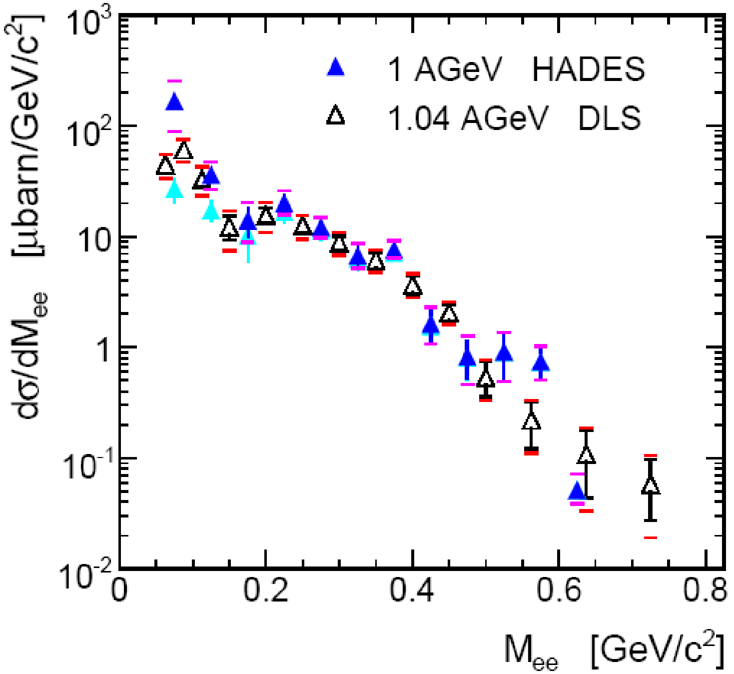
F(1.0) = 6.8 ± 0.6(stat) ± 1.3(sys) ± 2.0(η sys)

PRL 98, 052302 (2008)

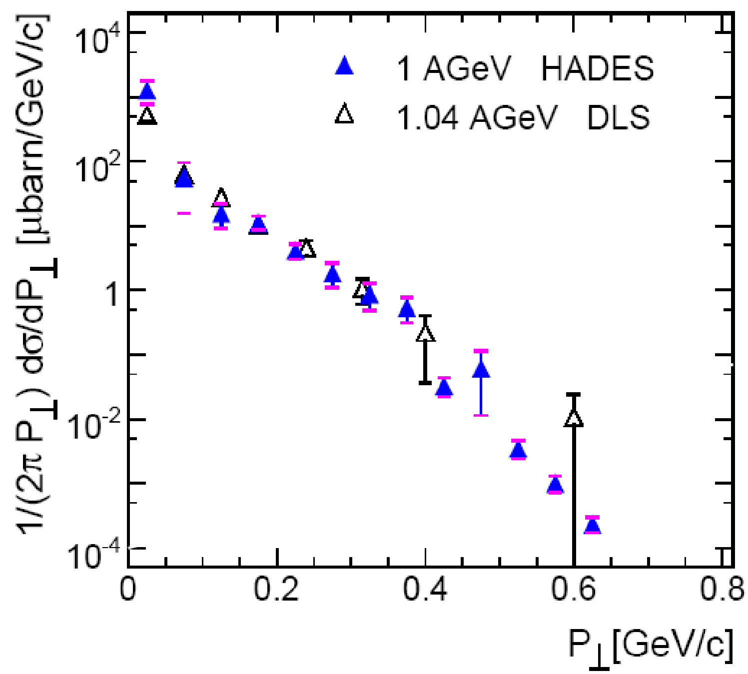
PLB 663 (2008) 43-48

Comparison to DLS data

HADES data filtered with DLS acceptance



DLS Data: R.J. Porter et al.: PRL 79 (1997) 1229

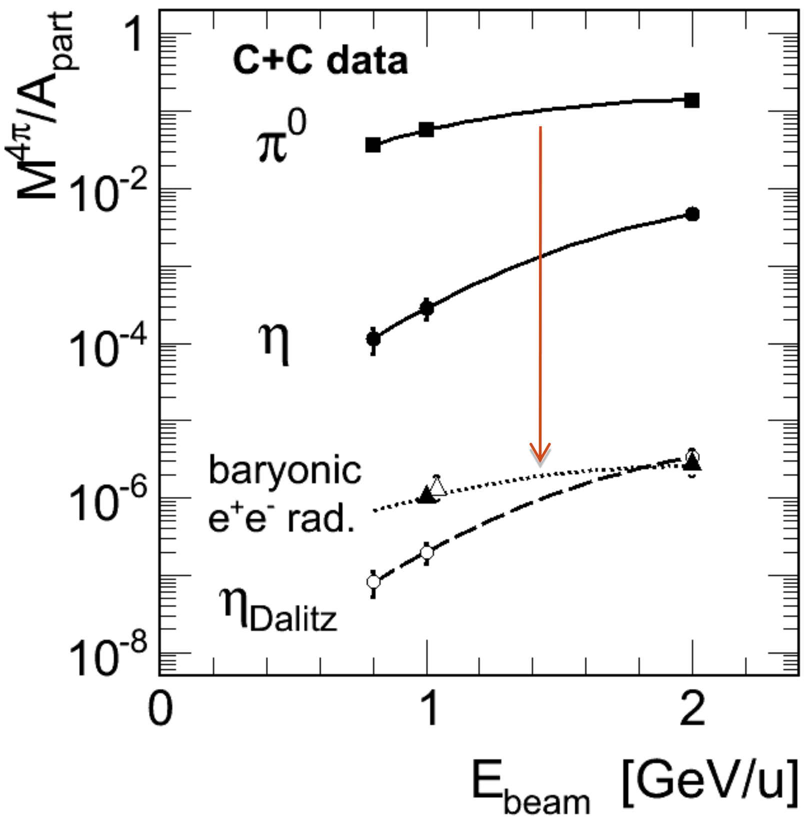


J. Carroll at

International Workshop on Soft Dilepton Production
August 20-22,1997, LBNL

HADES and DLS data agree

Energy dependence



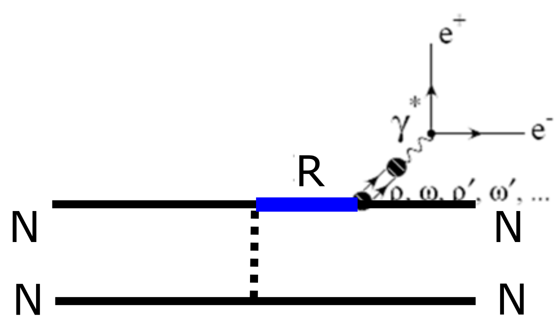
△ DLS data, C+C

▲ HADES data C+C

π^0 and η mult. from TAPS data
Z. Phys. A359 (1997)65

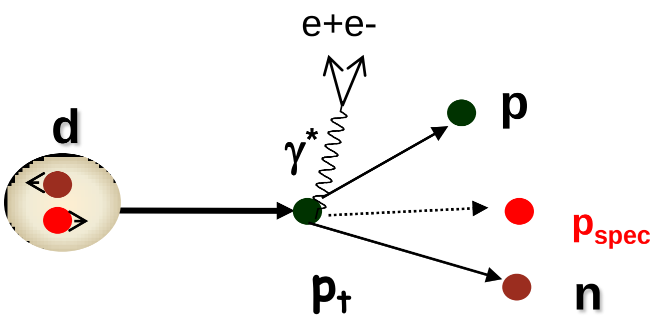
Excess scales with energy: like π production

radiation from first-chance collisions should be understood



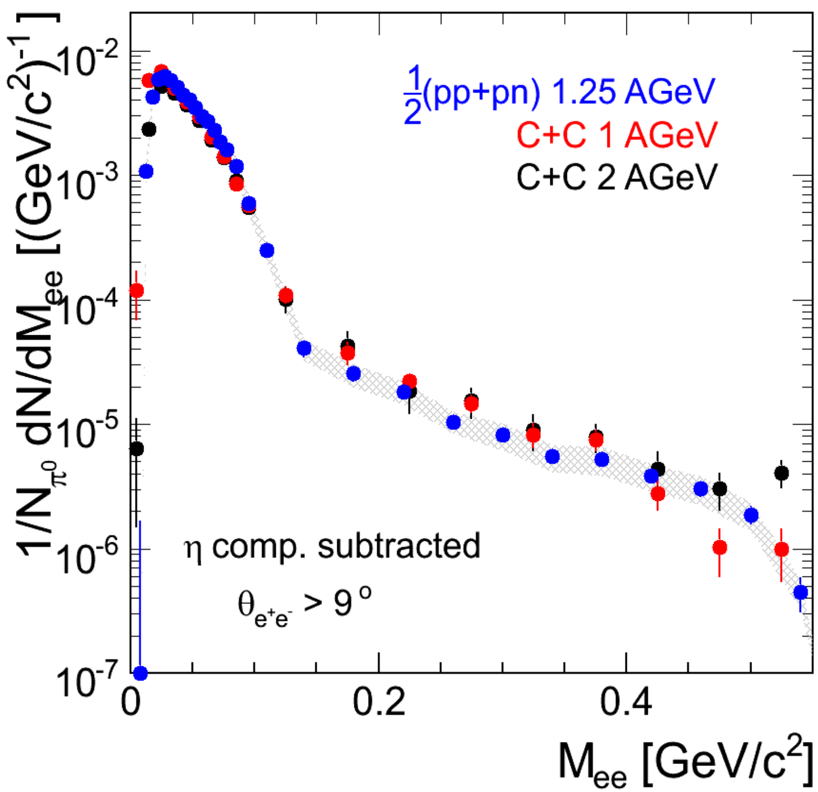
elementary reactions, understanding the first-chance collisions

Experimental check



η contribution subtracted

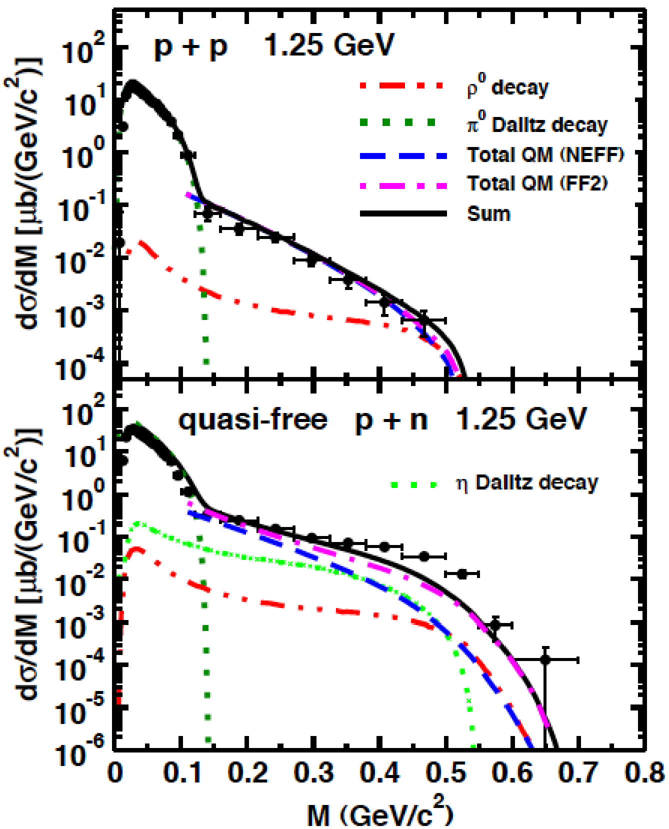
Phys.Lett.B690 (2010)118



- **C+C data is reproduced (within 20%) by superposition of NN interactions**

NN data should be understood first !

Elementary reactions

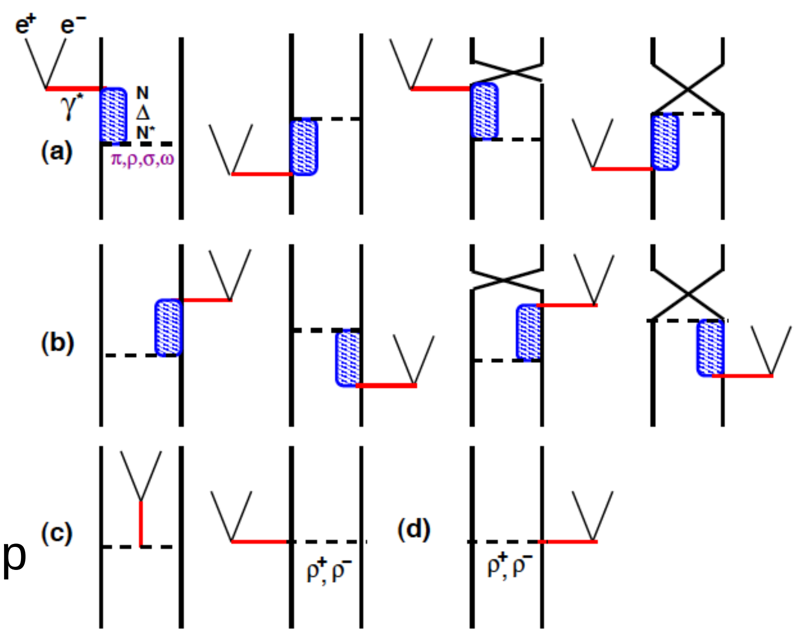


better description

Experimental observation
no trivial isospin dependence for higher masses in intermediate mass range, np data is enhanced by a factor of ~10

emission from nucleon line

emission from internal line for n+p

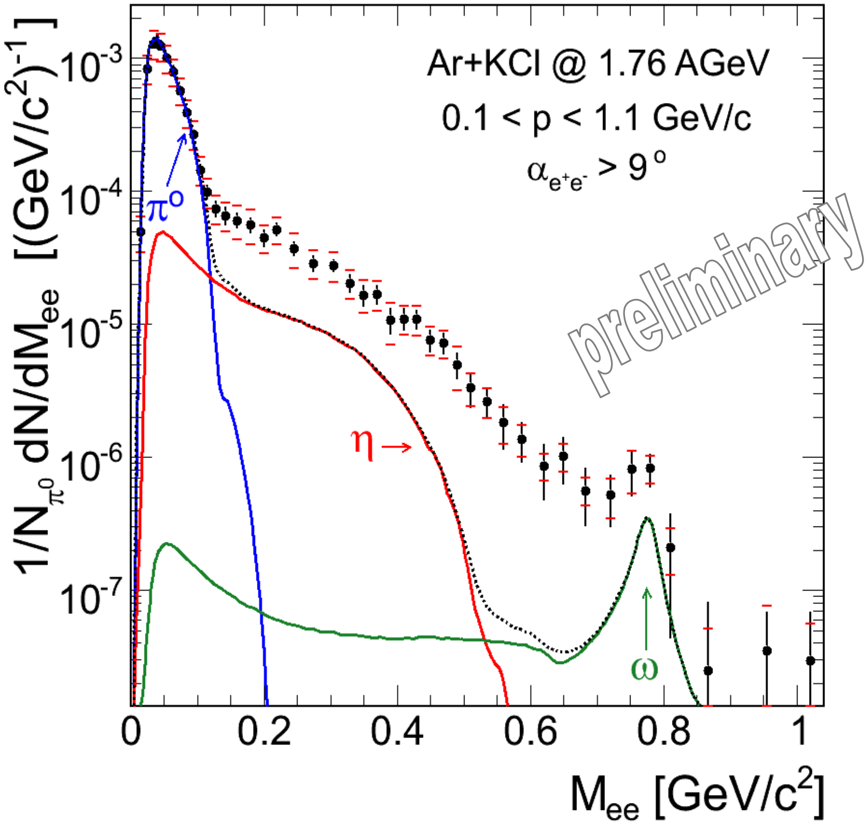


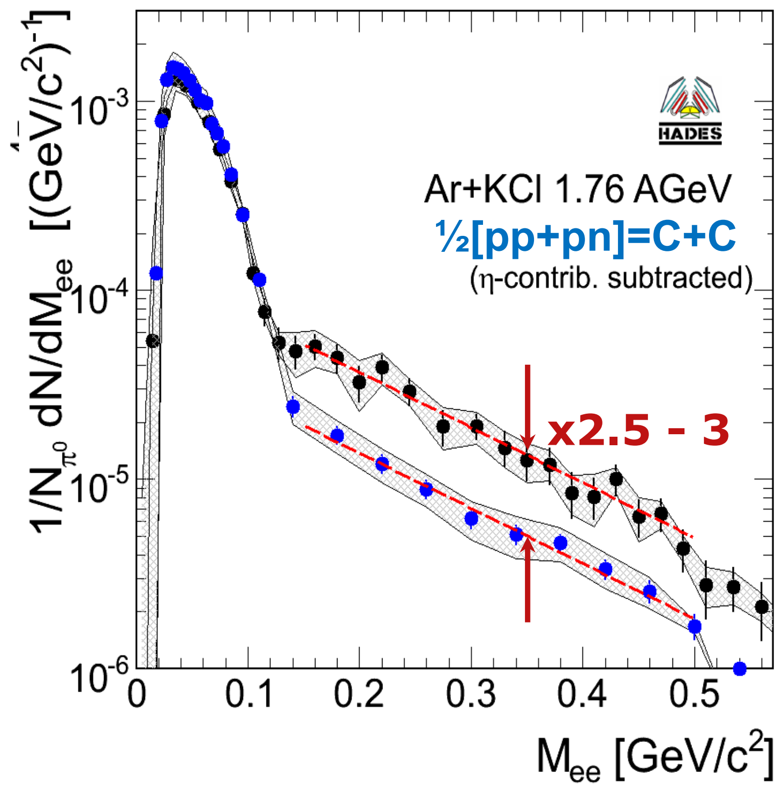
R. Shyam and U. Mosel, arXiv:1006.3873 [hep-ph]

L. Kaptary and B. Kämpfer, NPA 764 (2006), 338
R. Shyam and U. Mosel, PRC 67 (2003), 065202

going to heavier system

Ar+KCl data at 1.76 GeV



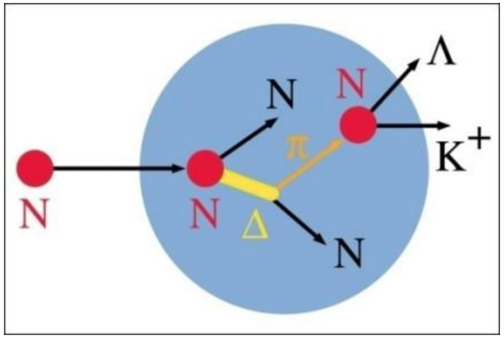


- first ω peak seen at SIS energies
- strong enhancement over hadronic cocktail !

excess scales with Apart : more than linear (≈$A^{1.4}$)

signal from dense phase ?

strangeness production



Kaon production at low energies

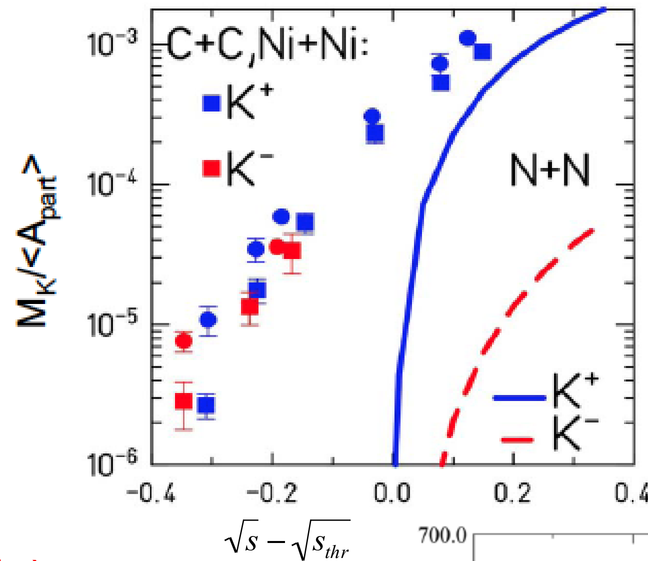
- ✓ NN collisions:
  - ✧ K^+ production
  - ✧ NN ->NK⁺Λ $E_{thr}^{kin} = 1.582\text{GeV}$
  - ✧ K^- production
  - ✧ NN->NNK+K- $E_{thr}^{kin} = 2.494\text{GeV}$
- ✓ AA collisions
  - ✧ secondary collisions
    - ❖ NN->NΔ
    - ❖ Δ->Nπ
    - ❖ NΔ->NKΛ or NΔ->NKΣ
    - ❖ πN->KΛ or πN->KΣ

      (equal centrality dependence for $K^{\pm}$!)
    - ✧ coupled Kaon productions

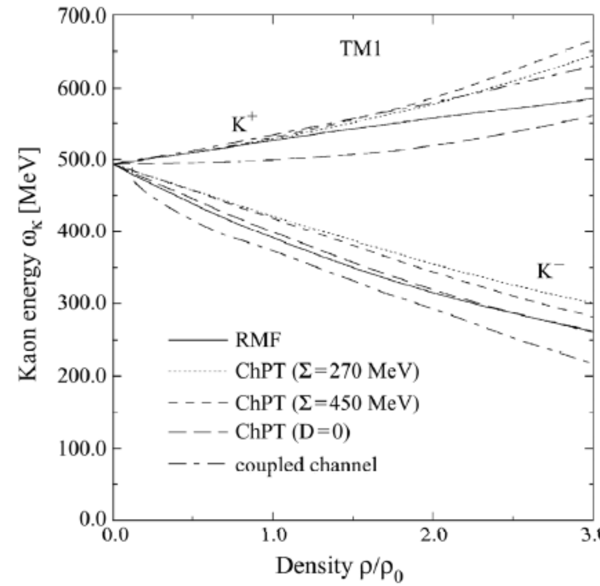
    (strangeness exchange)
    - ❖ NN-> NK⁺Λ
    - ❖ Λπ -> NK⁻
    - ✧ reduced in-medium K⁻ mass →

KaoS-collaboration

Ni + Ni → K⁺, K⁻ + X



Phys. Rev. Lett. 78 4007(1997)



PLB 175 (1986) 57

Explains the observations! (transport approach)!

Phys. Rev. Lett. 90, 10

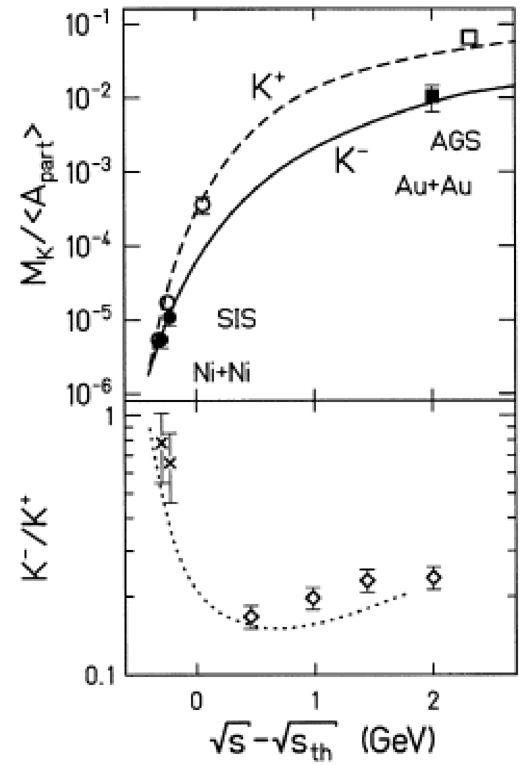
Kaon production at low energies

Statistical approach (canonical ensemble for the strangeness)

$$\frac{M_{K^+}}{A_{\text{part}}} \approx \exp(-\frac{E_{K^+}}{T})\left[g_\Lambda V \int \frac{d^3p}{(2\pi)^3} \exp\left(-\frac{(E_\Lambda - \mu_B)}{T}\right)\right]$$

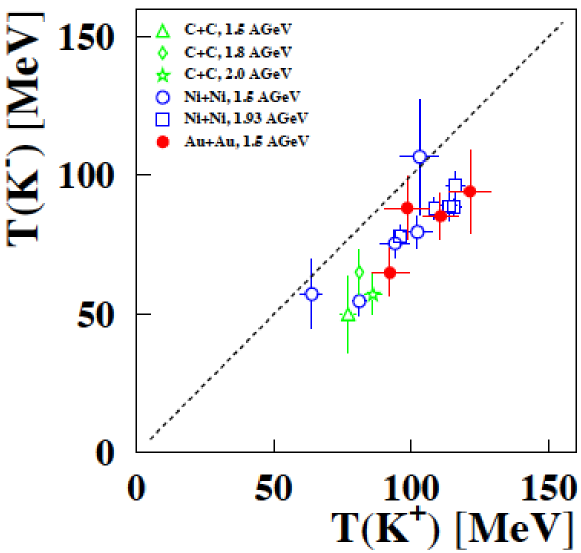
$$\frac{M_{K^-}}{A_{\text{part}}} \approx \exp(-\frac{E_{K^-}}{T})\left[g_{K^+} V \int \frac{d^3p}{(2\pi)^3} \exp\left(-\frac{E_{K^+}}{T}\right)\right]$$

common freeze-out parameters (by definition)
using free masses for kaons!
Explains the observations!



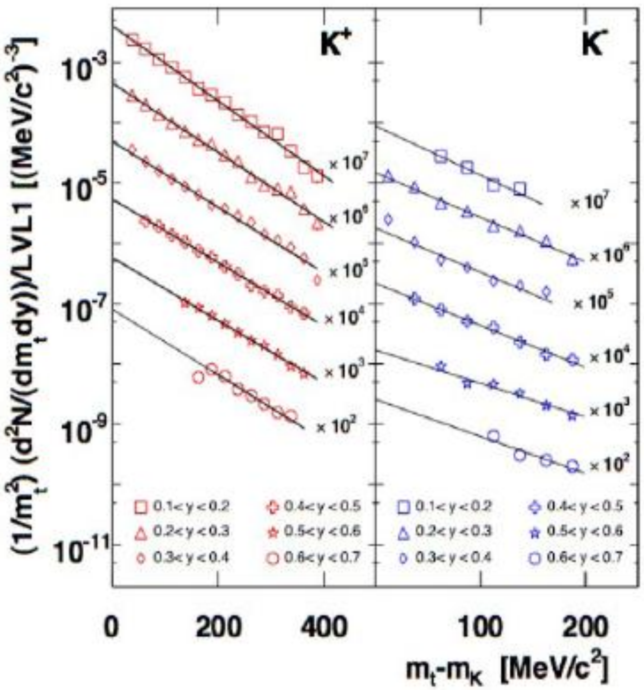
J. Cleymans et al., Phys. Lett. B 485(2000) 27

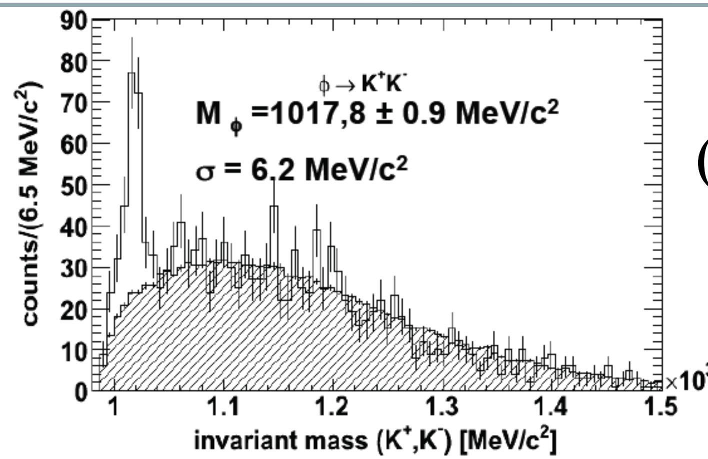
contradicts with these results



$K^{\pm}$ and ϕ reconstruction

PRC 80, 025209 (2009)





$$\left(\sqrt{s}-\sqrt{s_{thr}}\right)_{pp} = -284\,\mathrm{MeV}$$

$$N^{\phi} = 0.18 N^{K^-}, \quad N^{K^-}_{thermal} = 0.82 N^{K^-}$$

$$T_{eff}^{K^+} = 89 \pm 1 \pm 2\,\mathrm{MeV}$$

$$T_{eff}^{K^-} = 69 \pm 2 \pm 4\,\mathrm{MeV}$$

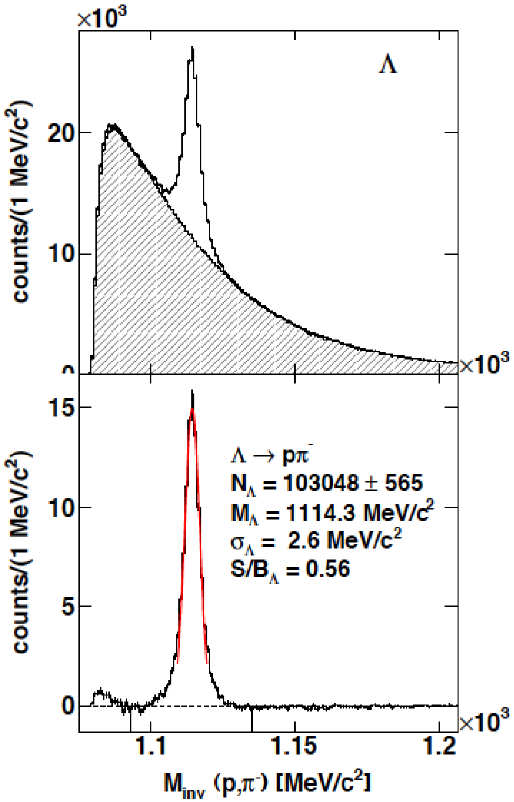
$$T_{eff}^{\phi} = 84 \pm 8\,\mathrm{MeV}$$

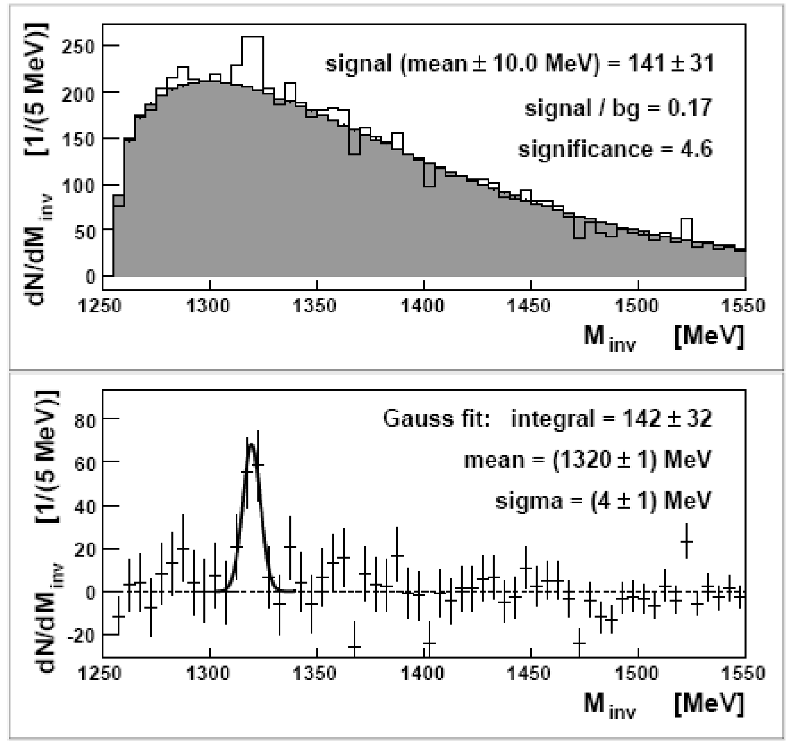
different inverse slopes for K^-
Is due do its emission from ϕ meson!
(confirmed by simulations)

support for stat. model

Λ and Ξ⁻ reconstruction

$$\Xi^- \to \Lambda \pi^-$$
$$\downarrow$$
$$p\pi^-$$





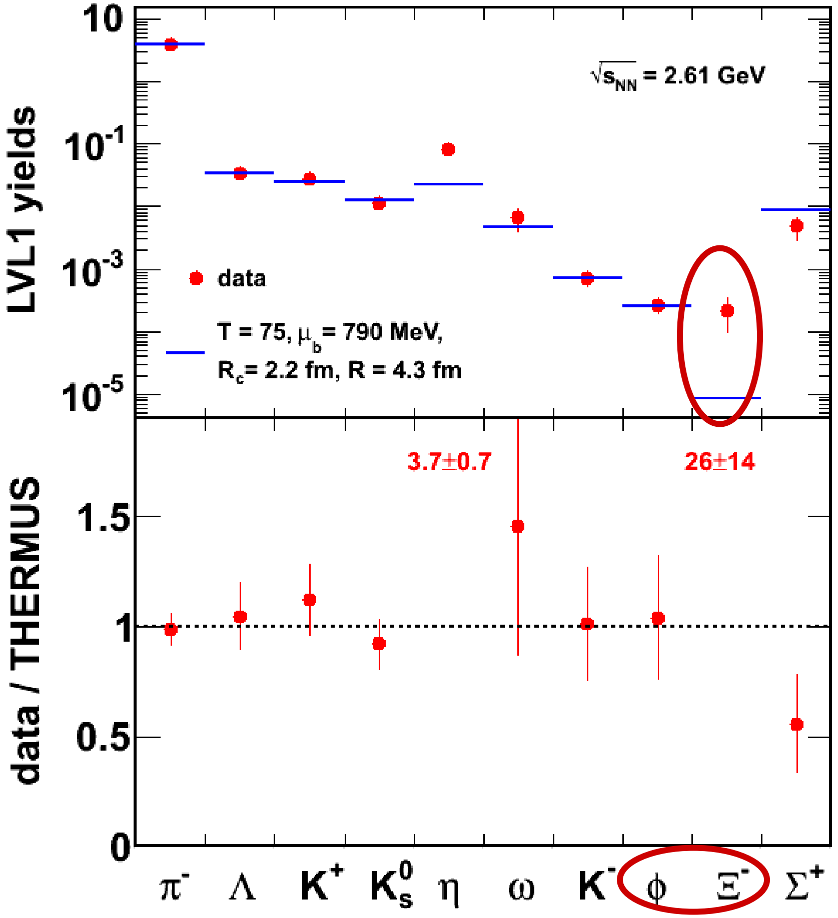
PRL 103, 132301 (2009)

$$\left(\sqrt{s} - \sqrt{s_{thr}}\right)_{pp} \approx -635\,\text{MeV}$$

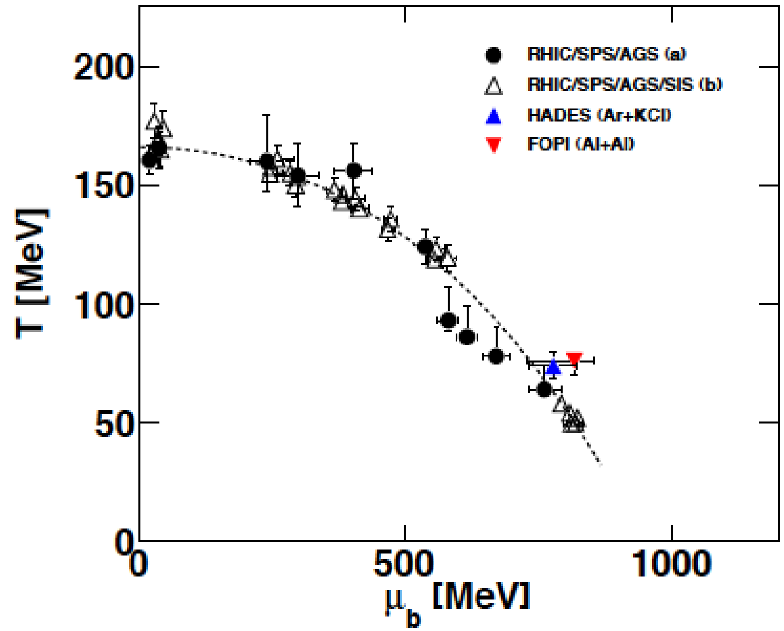
$N_{\Xi^-} \approx N_\phi$ large Ξ⁻ production!

Description with Stat. Model

THERMUS:Comput.Phys.Commun.180:84-106,2009



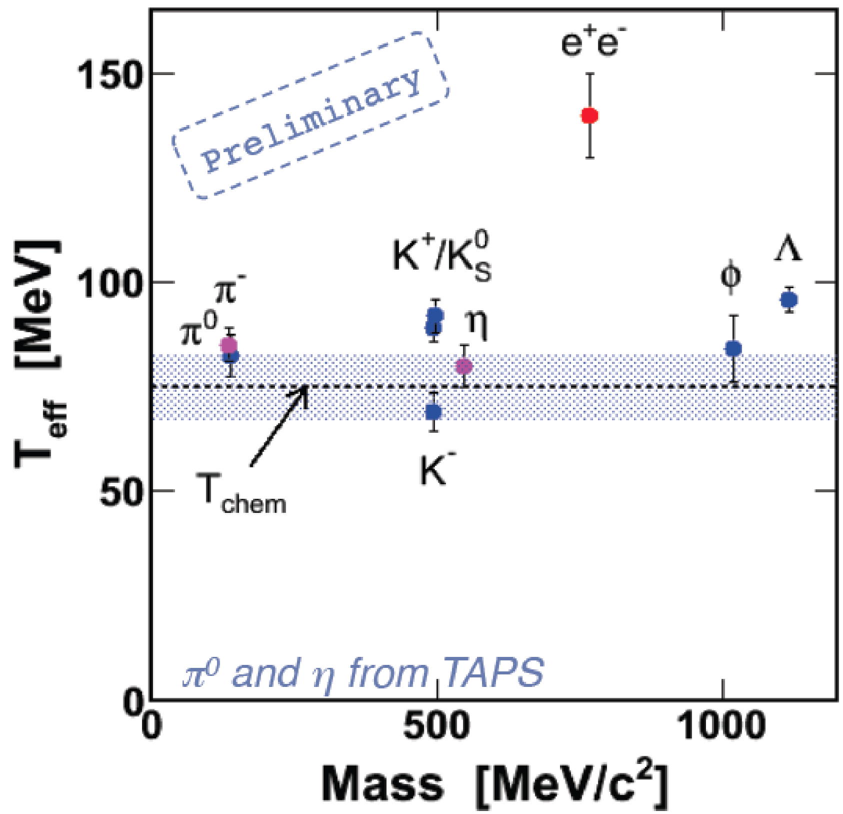
η from TAPS measurements
Σ from strangeness conservation



Mixed canonical ensemble

- ✓fails to describe Ξ⁻ and η
- ✓ϕ is described without strangeness suppression (strangeness neutral)

Everything put together



$T_{chem} \approx T_{eff}$

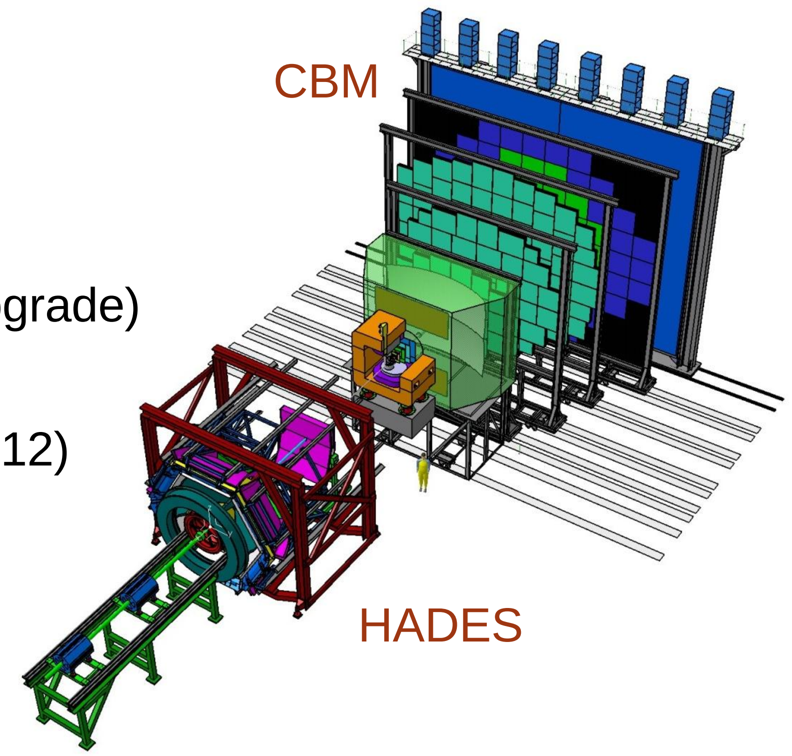
no mass dependence of T_{eff}

(small flow effects?)

large T_{eff} for ρ/ω (absorption effect?)

HADES future experiments

- Upgraded HADES
    - new RPC detectors (50-80ps time res.)
    - new MDCI detectors
    - forward wall
    - ~20 kHz event rates for Au+Au (DAQ upgrade)
        - Au+Au at 1.25 AGeV
        - Ag+Ag at 1.65 AGeV } (2011-2012)
        - pion induced reactions (2012)
- HADES moves to FAIR/SIS100 (after 2016)
  (see talk by K. Lapidus)



Summary

- Dilepton part
  - Excess observed in DLS is confirmed by HADES experimentally
  - The observed excess scales with energy like pion production and more than linear with Apart
  - The excess in light system (C+C) is reproduced by superposition of NN interactions
  - The observed enhancement in DLS data already exists in elementary reactions
  - True excess observed in Ar+KCl reactions, probably connected to baryonic resonance propagation in matter
- Strangeness part
  - Reconstruction of the ϕ meson and double strange state is shown
  - Different inverse slopes of kaons can be explained by taking into account K^- emission from the ϕ
  - Statistical model fails to describe Ξ^- and η states
  - No strong mass dependence of T_{eff} was observed

The HADES collaboration

<u>Cyprus:</u>
Department of Physics, University of Cyprus

<u>Czech Republic:</u>
Nuclear Physics Institute, Academy of Sciences of Czech Republic

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IPN (UMR 8608), Université Paris Sud

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FZ Dresden-Rossendorf
IKF, Goethe-Universität Frankfurt
II.PI, Justus Liebig Universität Giessen
PD E12, Technische Universität München

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Istituto Nazionale di Fisica Nucleare, Sezione di Milano

<u>Poland:</u>
Smoluchowski Institute of Physics, Jagiellonian University of Cracow

<u>Portugal:</u>
LIP-Laboratório de Instrumentação e Física Experimental de Partículas

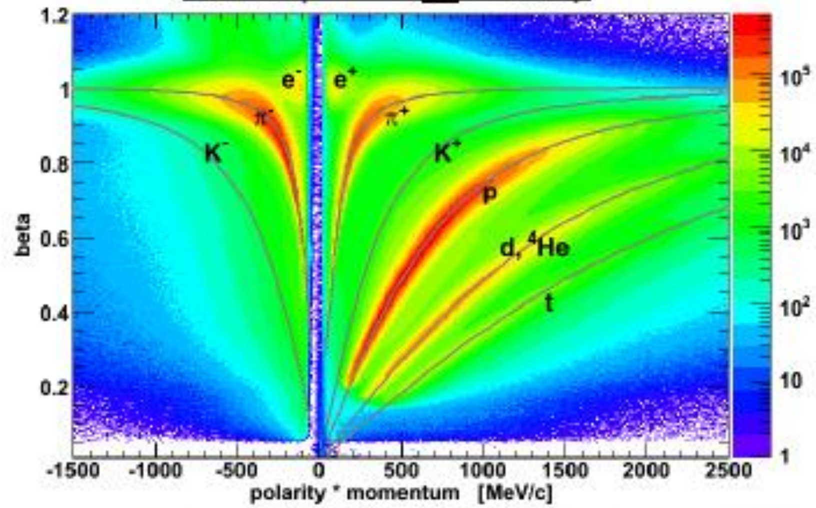
<u>Russia:</u>
INR, Russian Academy of Science
Joint Institute of Nuclear Research
ITEP

<u>Spain:</u>
Departamento de Física de Partículas, University of Santiago de Compostela
Instituto de Física Corpuscular, Universidad de Valencia-CSIC

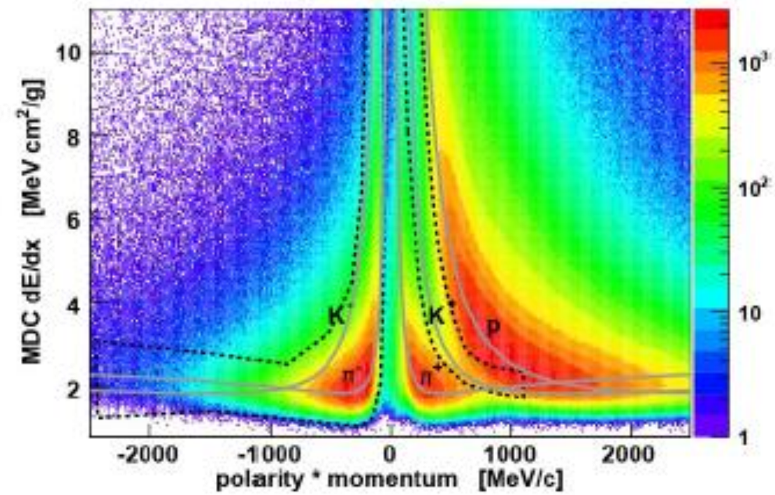
17 institutions
120+ members

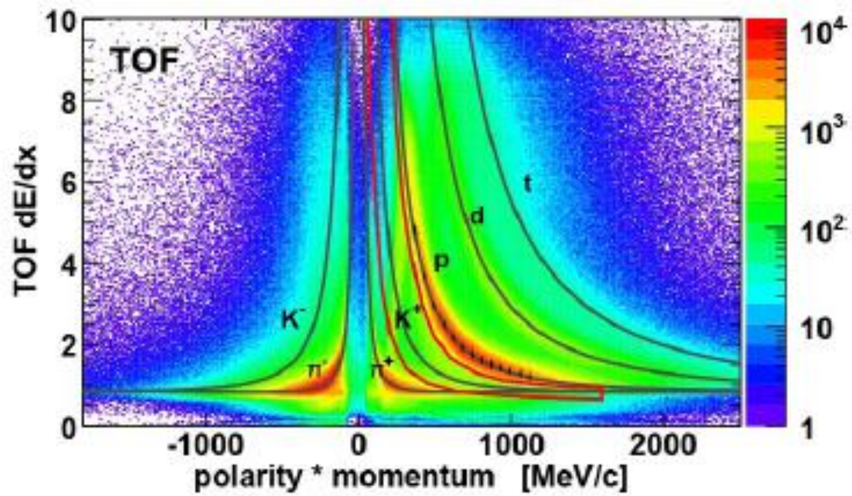
Particle identification

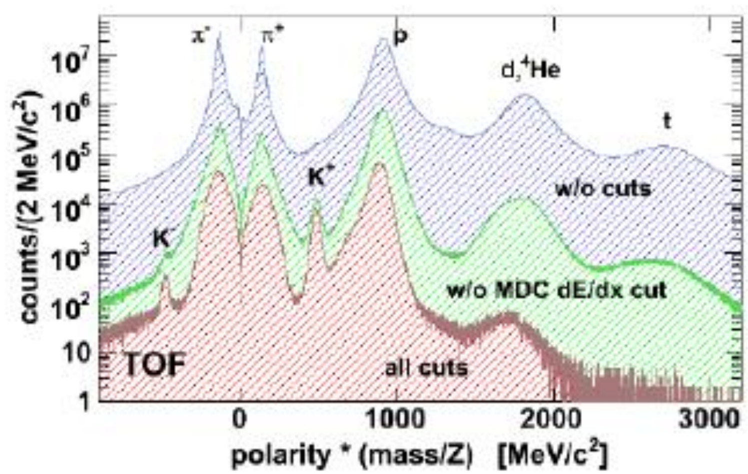
TOF (44° < Θ < 88°)



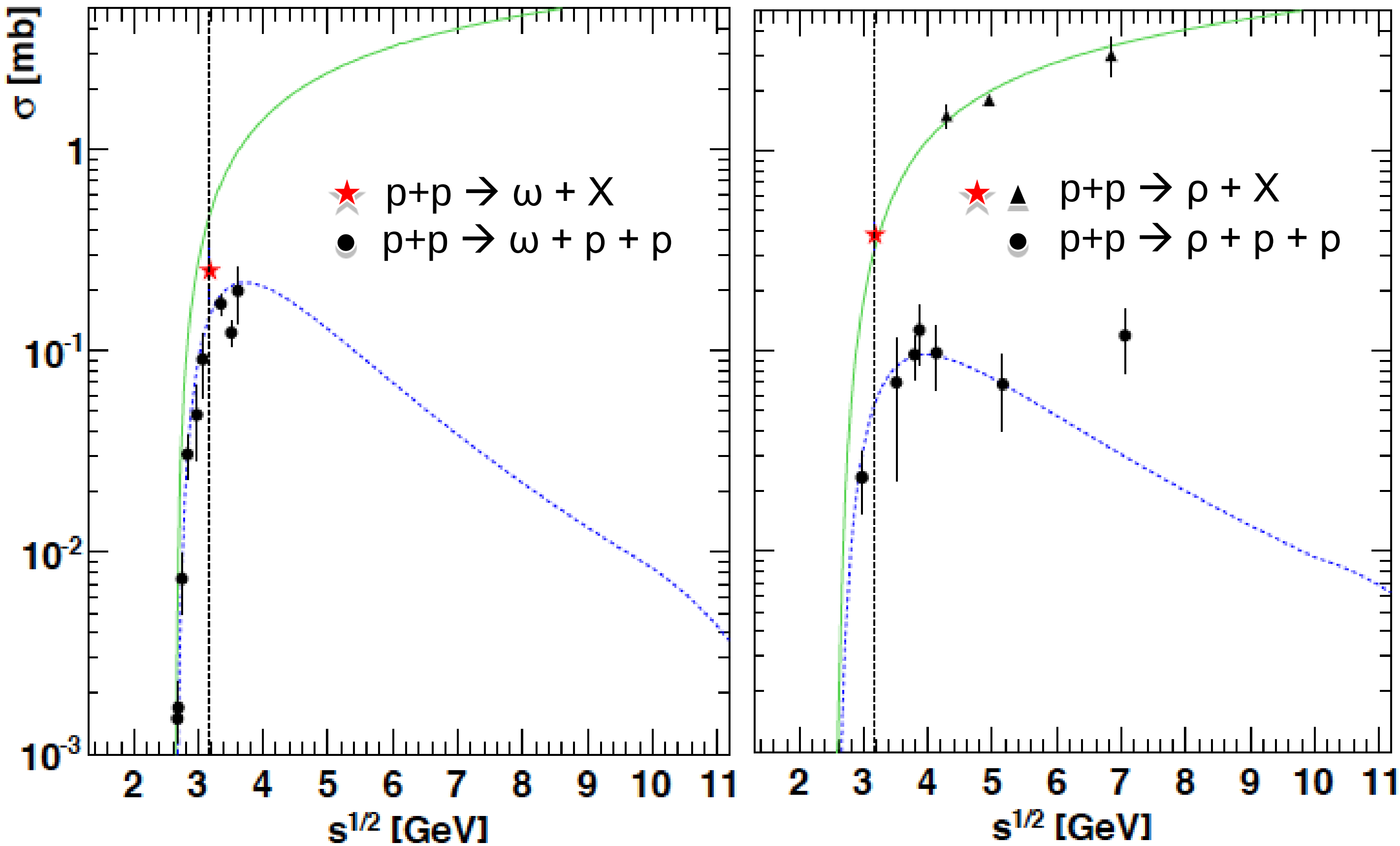
MDC







ρ/ω cross sections



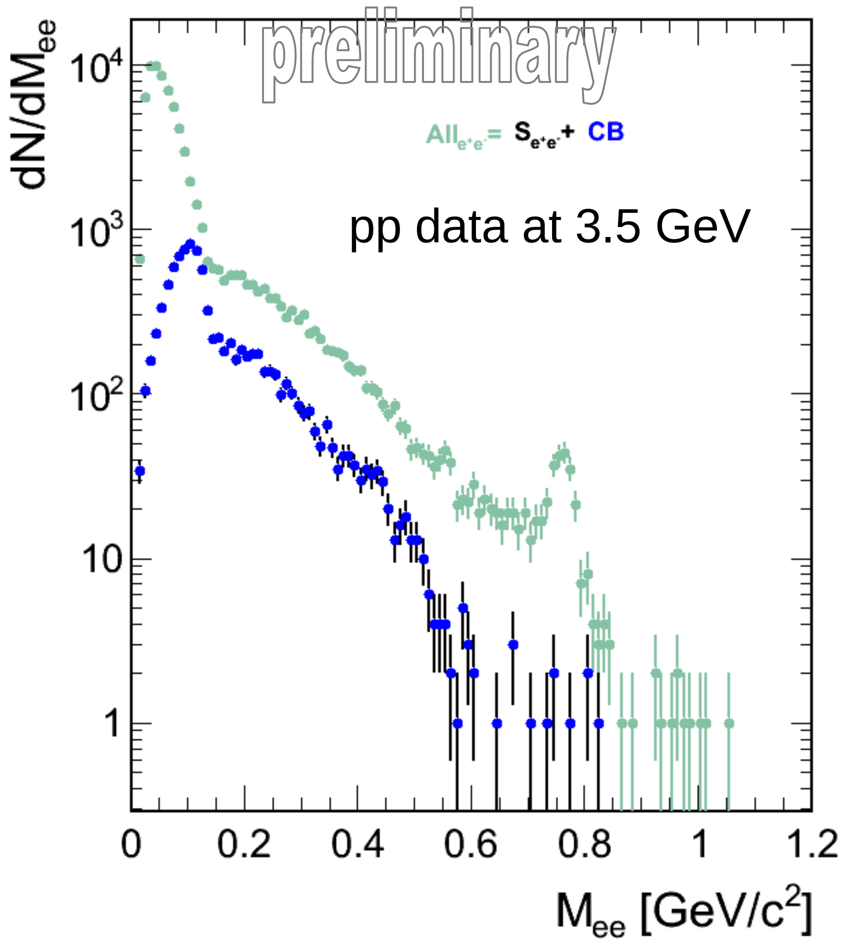
Acceptance correction to large extent is model independent !

Cross sections were obtained from simulated cocktail by changing the ρ/ω ratio until simulation fits the data

W. Cassing, E. Bratkovskaya, Physics Reports 308 (1999) 65 -233

Dilepton spectra for pp data

Not efficiency corrected.   Inside HADES acceptance

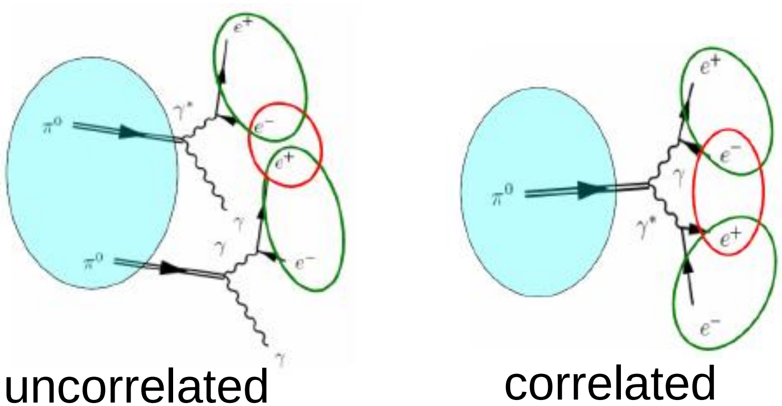


Particle identification:

- RICH-MDC matching
- Time of flight cuts
- Shower cuts

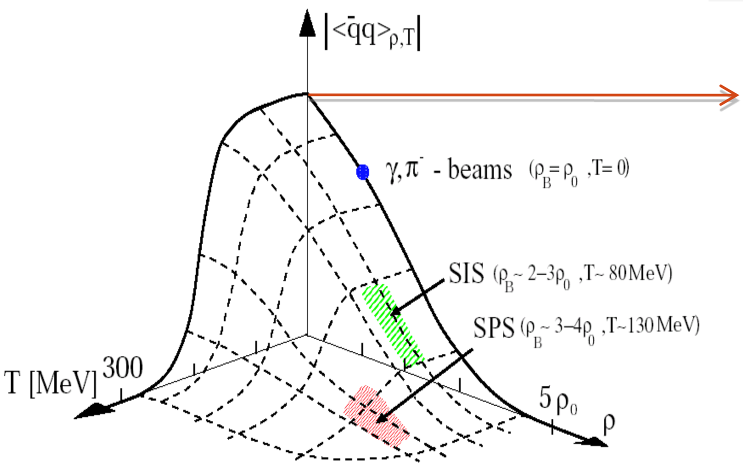
Combinatorial Background (CB) reduction

- Close partner cut
- Momentum cut   80 < P [MeV/c] < 2000
- Track fitting quality cut



$CB = N_{++} + N_{--}$

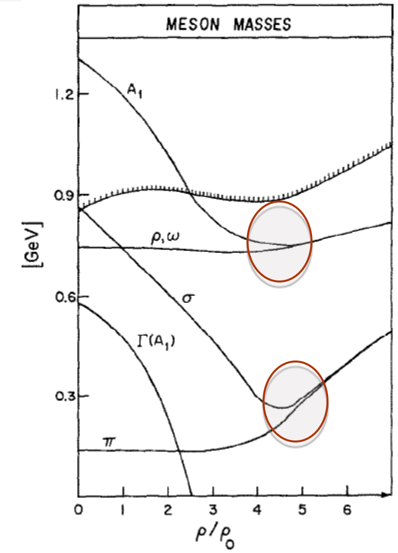
Historic motivation



Weise et al., NPA 553(1993)59

spontaneous breaking of the chiral symmetry

- appearance of Goldstone bosons
- absence of degenerate states



Degeneracy of chiral partners

V. Bernard and U. Meissner NPA 489(1988)647

Particles are excitations (quantization) of the vacuum state

change of vacuum structure ➔ change of particle properties

$\int \rho(s)ds$ — QCD sum rules / dispersion relation — QCD part: $<|\bar{q}q|>, \quad \ldots$ ⇒ $\frac{m^*_{\rho,\omega}}{m_{\rho,\omega}} = 1 - (0.18 \pm 0.06)\frac{\varrho}{\varrho_0}$

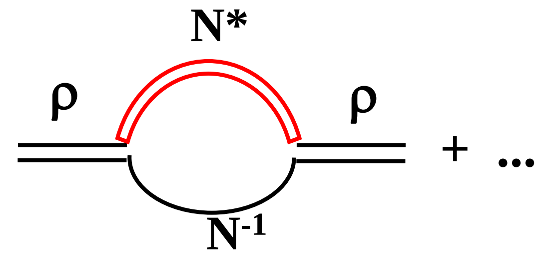
scale invariance of QCD: ⇒ Brown-Rho Scaling ⇒ $\frac{f^*_\pi}{f_\pi} = \frac{m^*_\sigma}{m_\sigma} = \frac{m^*_N}{m_N} = \frac{m^*_\rho}{m_\rho} = \frac{m^*_\omega}{m_\omega} = 0.82(\varrho = \varrho_0)$

T. Hatsuda and S. Lee, PRC 46 (1992)

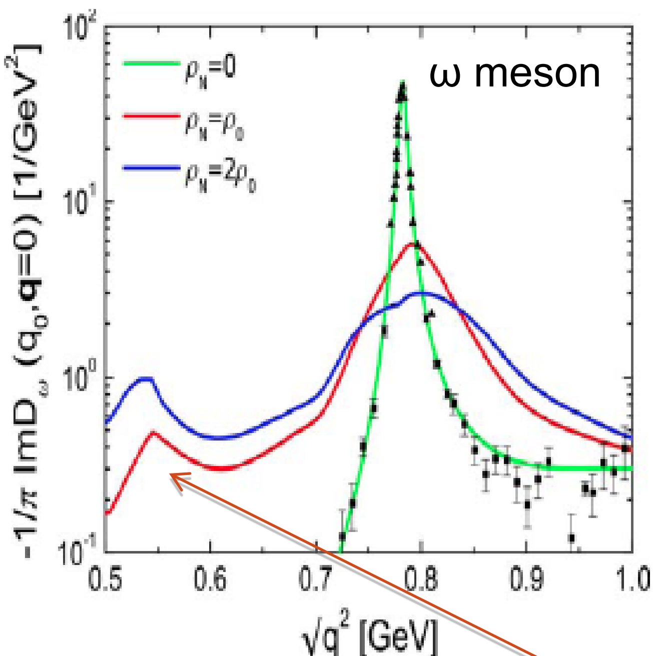
G. Brown and M. Rho, PRL 66 (1991) 2720

Hadronic models

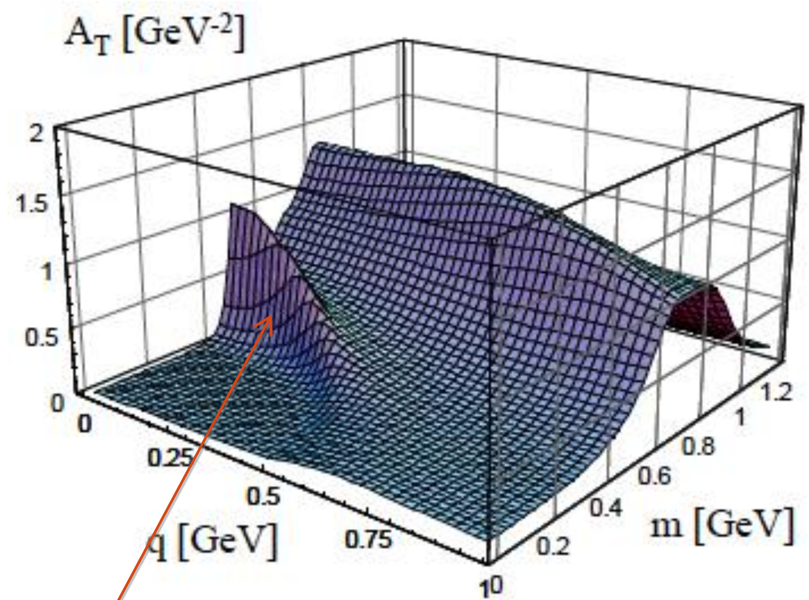
Richer information
- Coupling of mesons to resonances
- shifts
- broadening
- new structures



P. Muenlich. et.al., NPA 780 (2006) 187



M. Post et.al., NPA 741 (2004) 81

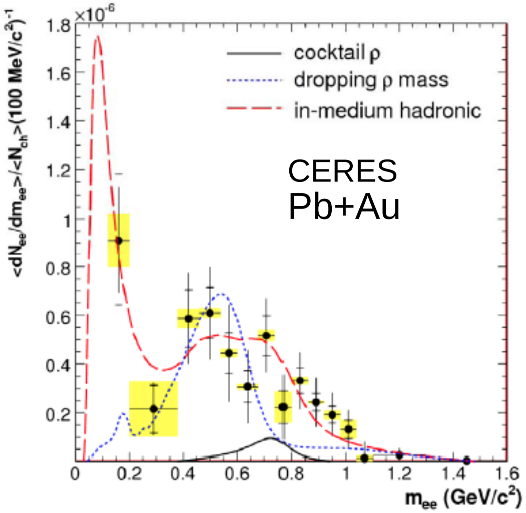


structures in spectral functions due to meson-N* coupling

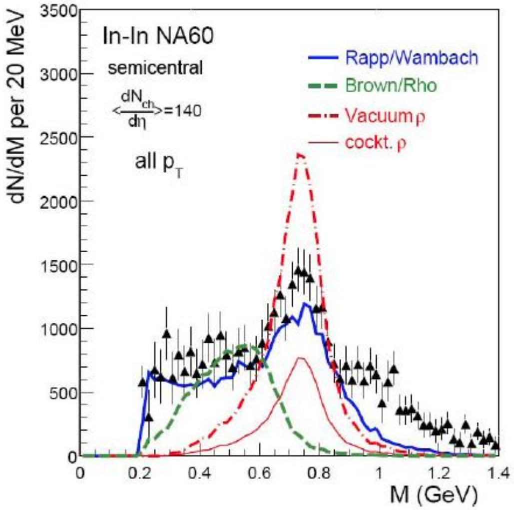
Measured reactions

reaction (E_{kin})	year	physics goal
$^{12}C+^{12}C$ (2 A GeV) $^{12}C+^{12}C$ (1 A GeV) $^{40}Ar+^{nat}KCl$ (1.76 A GeV)	2002 2004 2005	verification of the DLS data, systematic investigation of excess yield, strangeness analysis
p+p (2.2 GeV)	2004	investigation of η meson production, transition form-factors, helicity angles. Investigation of the detector performance by elastic scattering.
p+p (1.25 GeV) d+p (1.25 GeV)	2006 2007	Investigation of NN bremstrahlung and Delta Dalitz decays
p+p (3.5 GeV)	2007	Investigation of vector meson production mechanisms. Study the experimental line shape of the omega meson
p+^{93}Nb (3.5 GeV)	2008	Investigation of in medium modification of the vector mesons

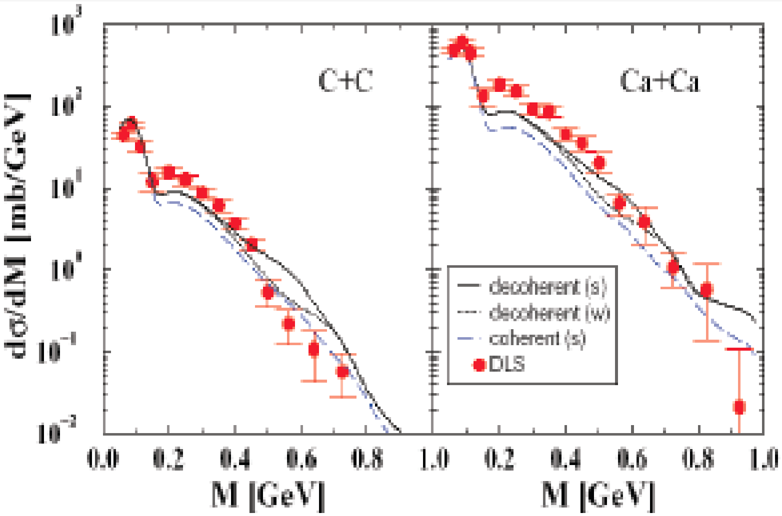
Low vs. High



D. Adamova et al. nucl-ex/0611022



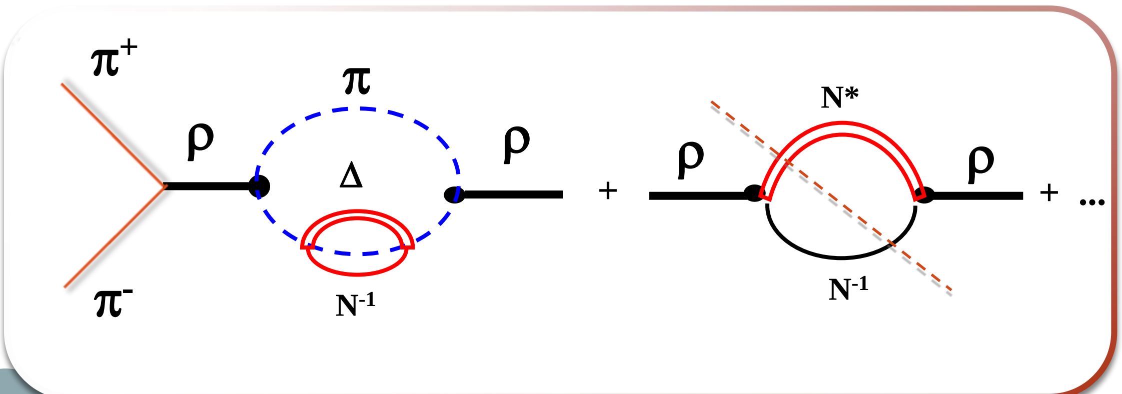
R. Arnaldi et al., PRL 96 (2006) 162302



R. J. Porter et al., PRL 79 (1997)

- High energy: 158 A GeV/c
  - major part is due to in medium ρ broadening

- Low energy: 1-2 A GeV: not explained



Rapp & Wambach Adv. Nucl. Phys. 25 (2000)