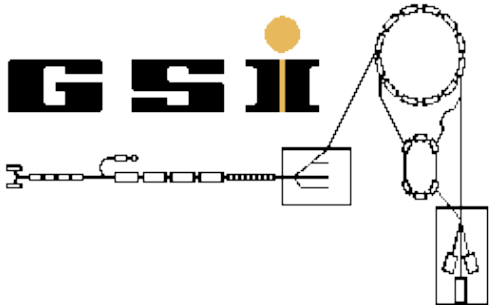
Dilepton production studied with the HADES Spectrometer

Anar Rustamov for the HADES collaboration

GSI Helmholtzzentrum für Schwerionenforschung

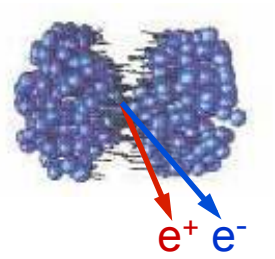


Outline

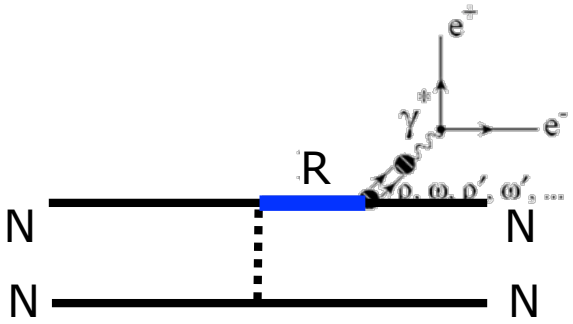
- dilepton sources
- physics motivation
- dilepton spectra
  - p+p data
  - p+A data
  - A+A data
    - excess yield
      - systematic investigation
- summary

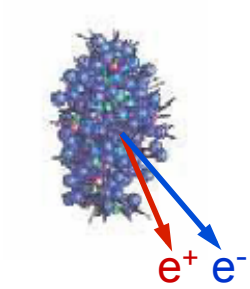
Dilepton sources

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

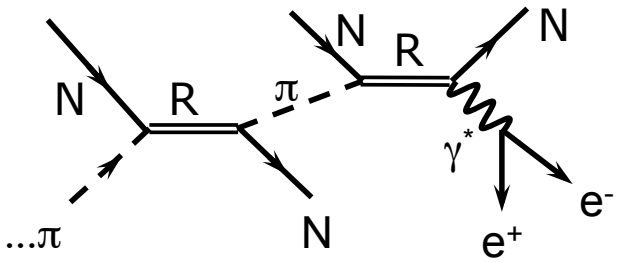


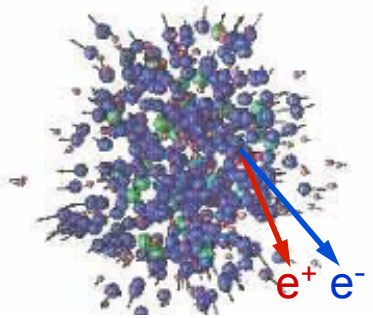
first chance collisions
elementary collision of nucleons



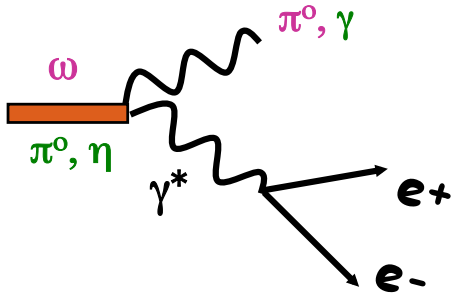


hot and dense phase
multistep production
of resonances and mesons

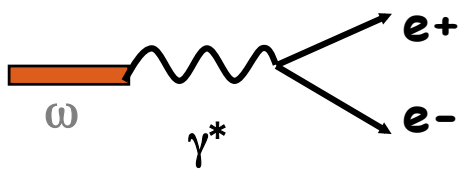




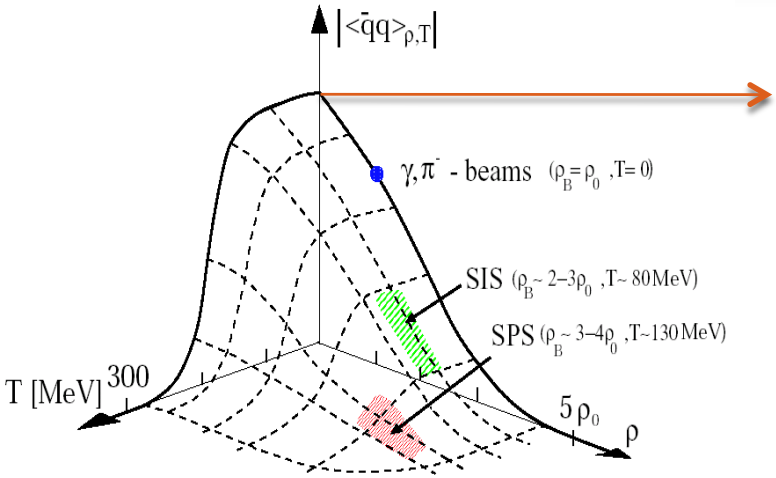
Freeze –out
decays of (long-lived)
states (π^0, η, ω)



study the hot and dense phase
are there new forms of matter ?
probing the medium with vector mesons



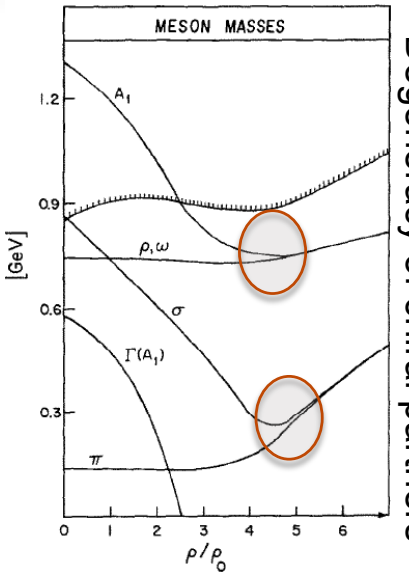
Historic motivation



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: $<|\bar{q}q|>$, … ⇒ $\frac{m^*_{\rho,\omega}}{m_{\rho,\omega}} = 1 - (0.18 \pm 0.06)\frac{\varrho}{\varrho_0}$

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

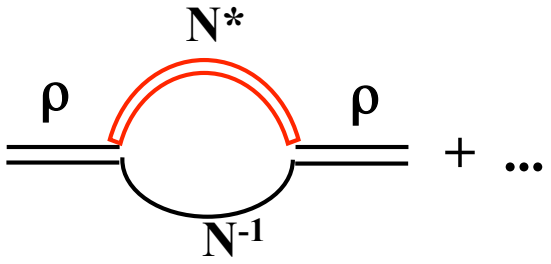
T. Hatsuda and S. Lee, PRC 46 (1992)

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

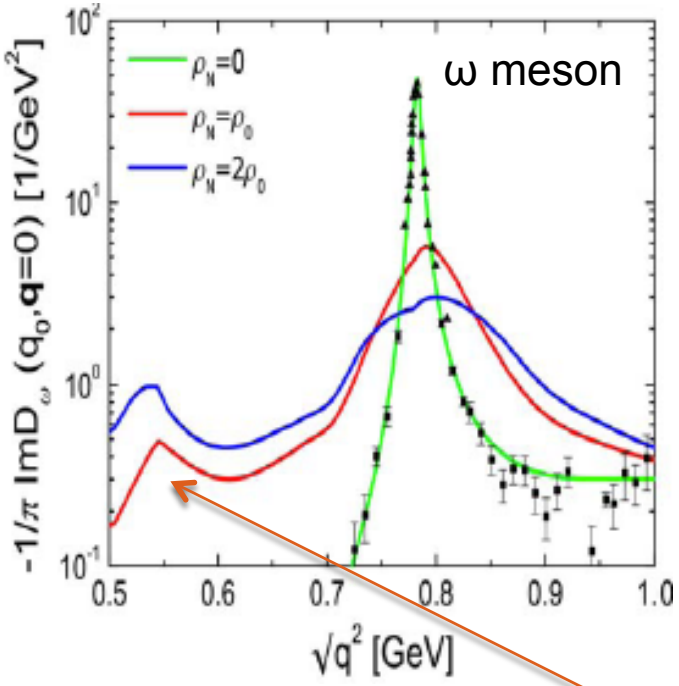
Hadronic models

Richer information

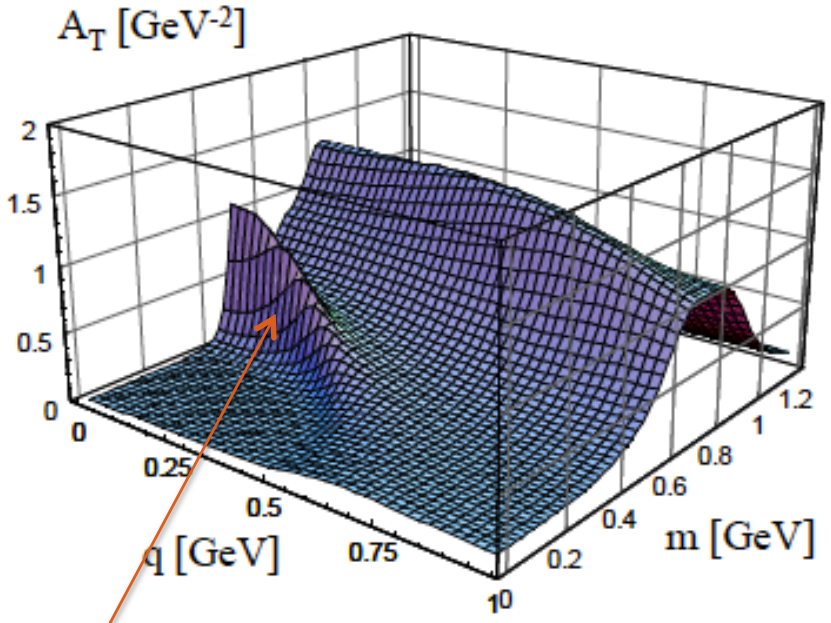
- Coupling of mesons to resonances
  - shifts
  - broadening
  - new structures



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



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



structures in spectral functions due to meson-N* to coupling

Experimental approach

Mass distributions of the hadrons inside medium:

$$m_{h\to l1(p1)l2(p2)} = \sqrt{(p_1 + p_2)^2} \qquad p_1(E_1,\vec{p}_1) \text{ and } p_2(E_2,\vec{p}_2) \text{ are four momenta}$$

- hadrons should be short lived (ρ, ω, ϕ)
- p1,p2 should be undistorted by medium (leptons)

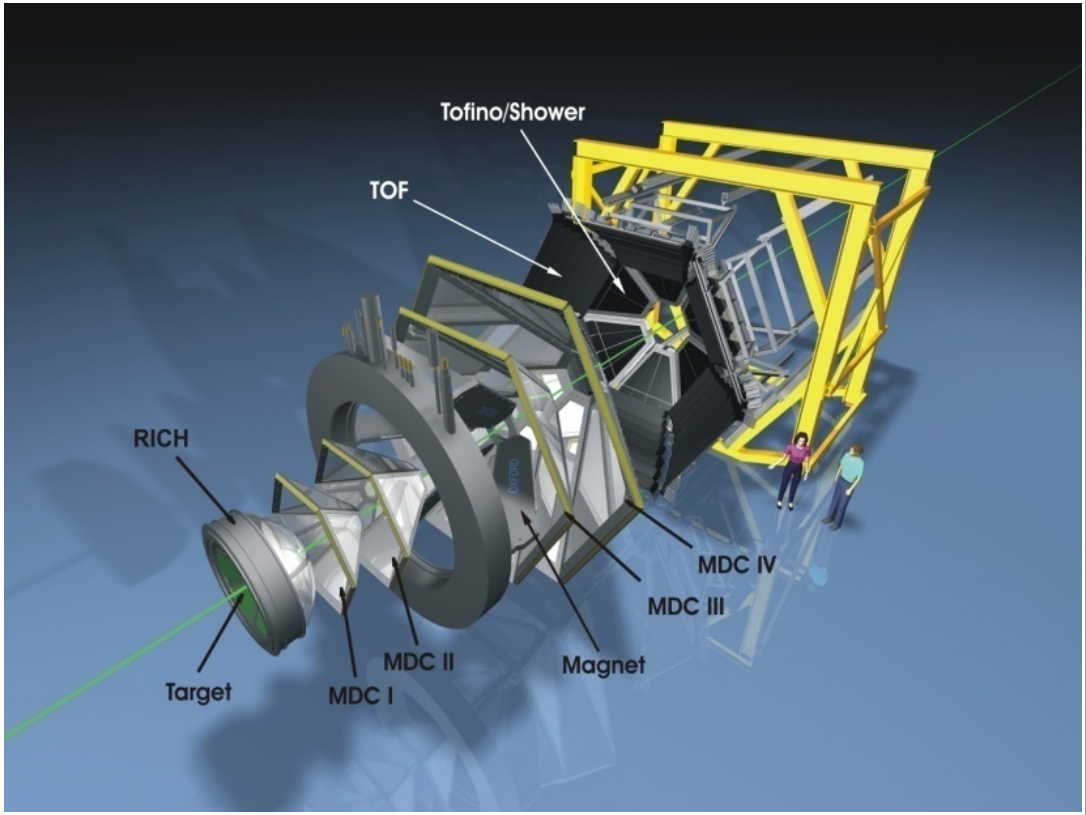
	Mass [MeV]	cτ [fm]	Γ/Γ_{tot}->ee
ρ	770	1.3	4.7×10^{-5}
ω	782	23.4	7.07×10^{-5}
Φ	1020	44.4	2.97×10^{-4}

Experimental challenge

- small branching to leptons
- high background

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

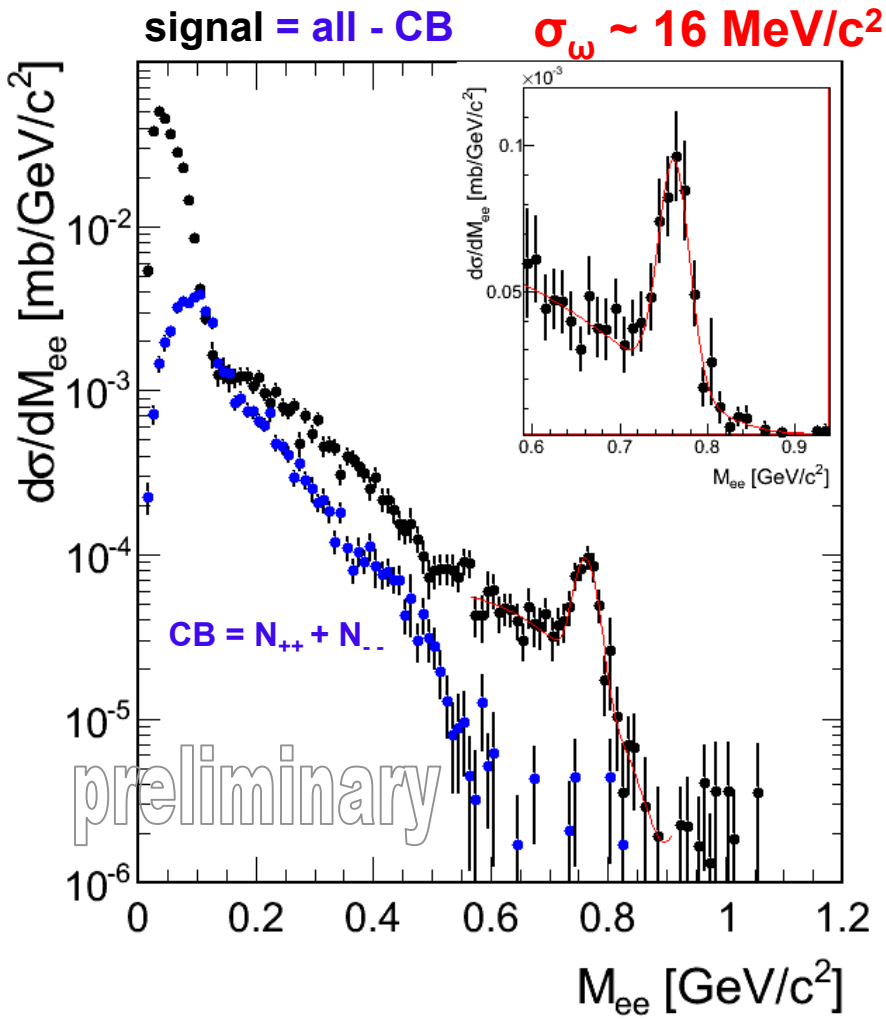


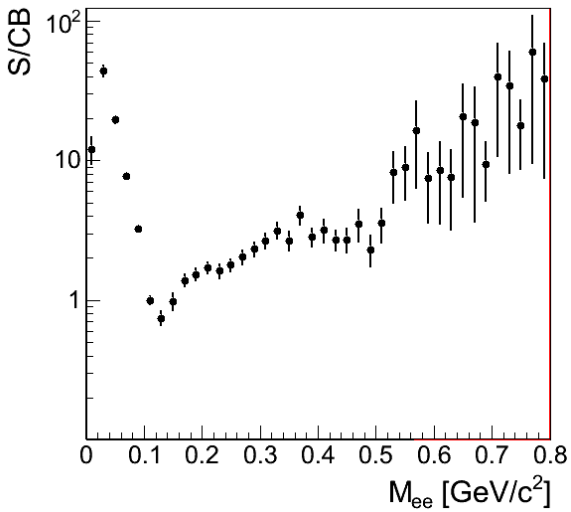
Measured reactions

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

Dilepton spectra for pp data

Normalized to pp elastic, corrected for inefficiency





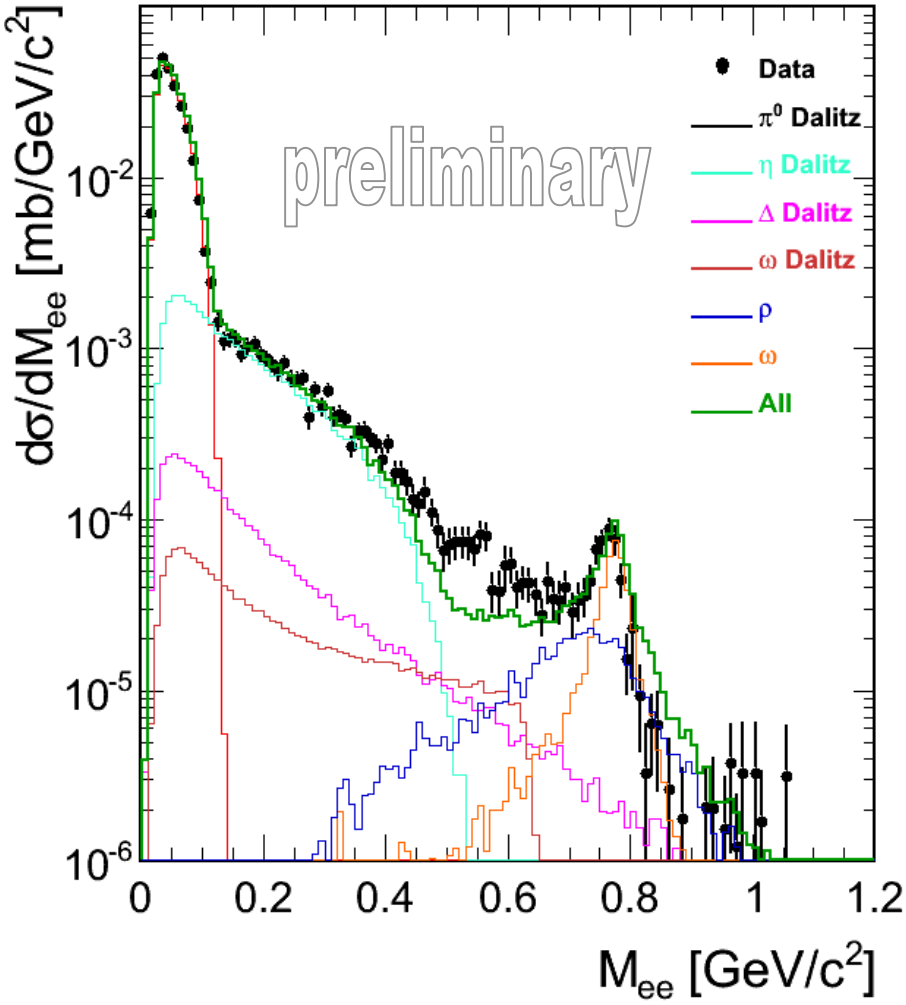
high S/CB ratio

Number of pairs:

- All : ~ $6.1*10^4$
- M <0.15 : ~ $5.5*10^4$
- 0.6 < M < 0.82 : ~ 451

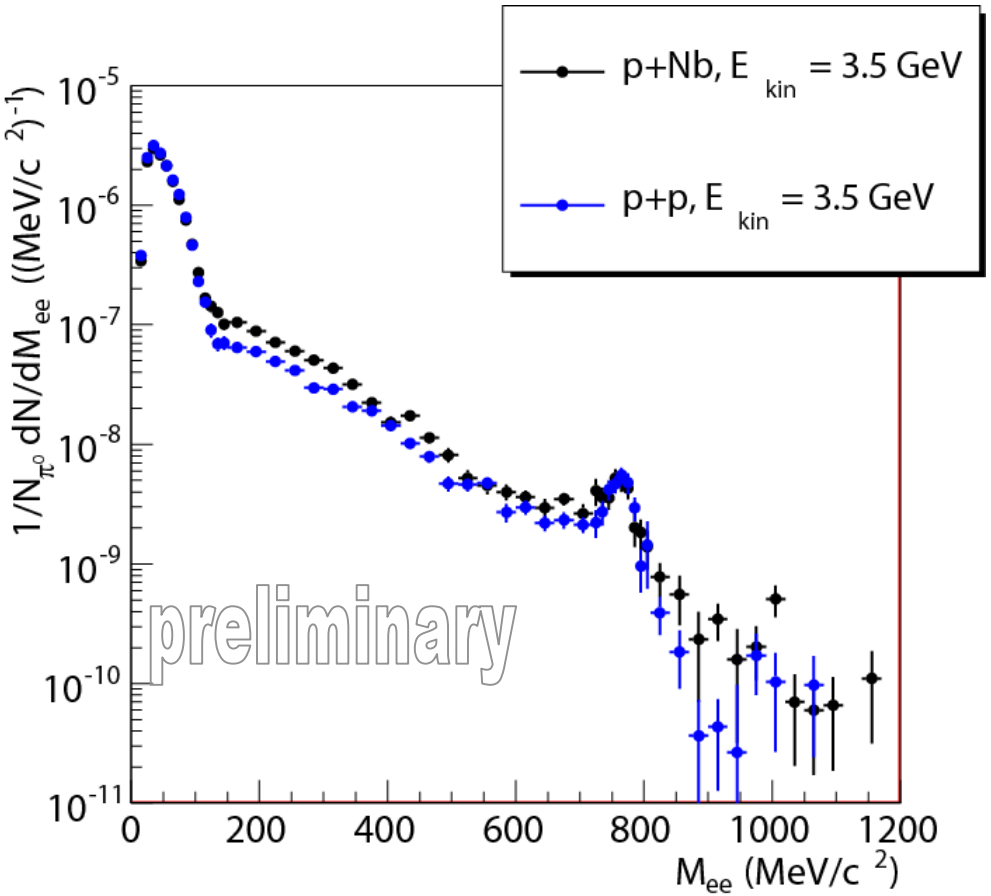
“Cocktail” simulation

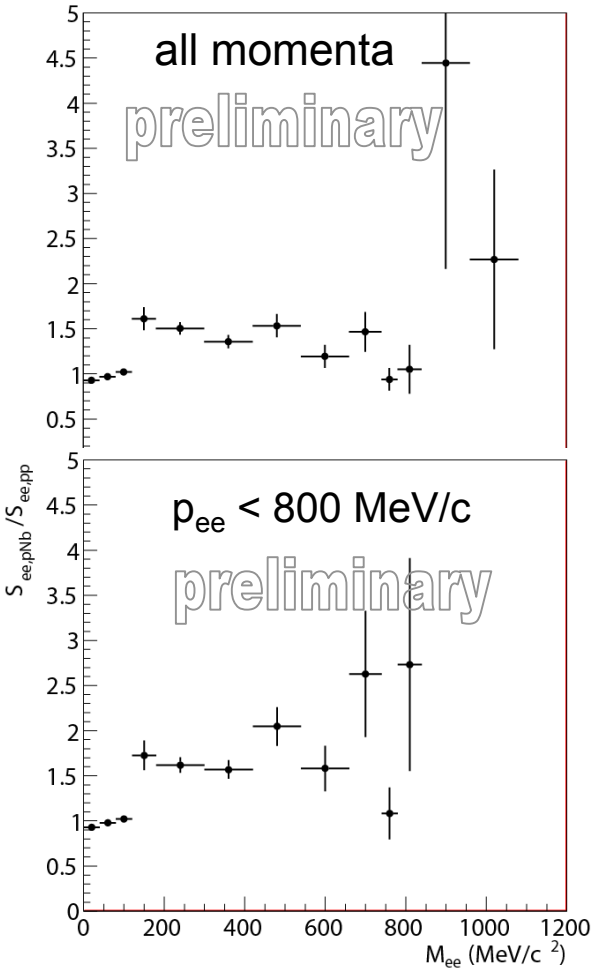
- particle production
  - η, ω, ρ via phase space
  - Δ through 1 π exchange
- particle decays
  - form-factors
  - mass dep. Width
    - *Fröhlich et al, arxiv:0708.2382*
- cross sections in 4π [mb]
  - π: 16 ± 2.6 (from data)
  - Δ: 7.5 fixed from PYTHIA
  - η: 0.93 ± 0.2 (fit to data)
  - ω: 0.25 ± 0.05 (fit to data)
  - ρ: 0.38 ± 0.07 (fit to data)



p+Nb data at 3.5 GeV

Investigation of ω meson modifications at nuclear ground state density



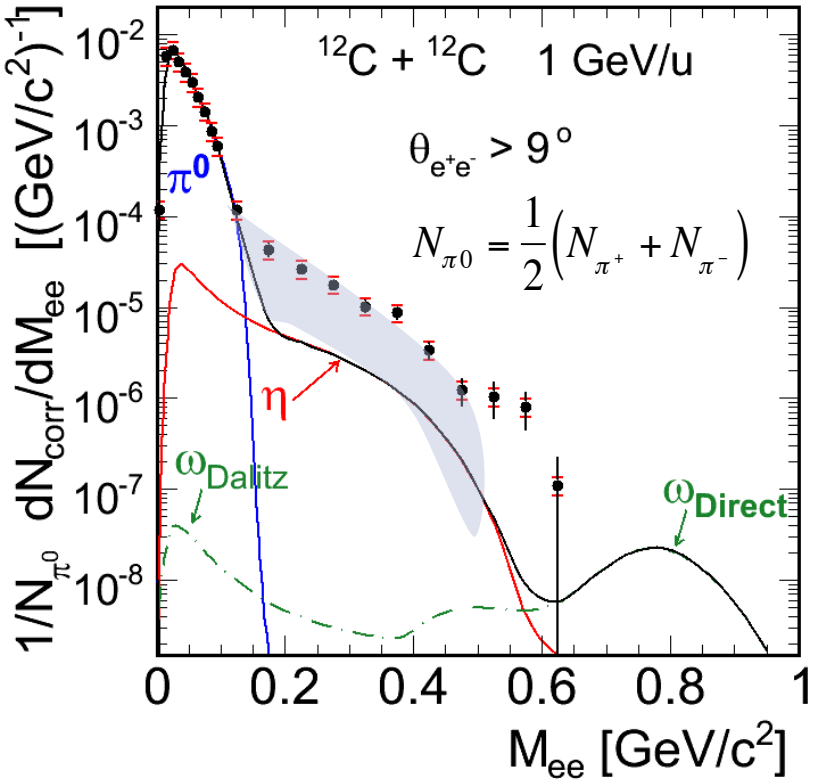


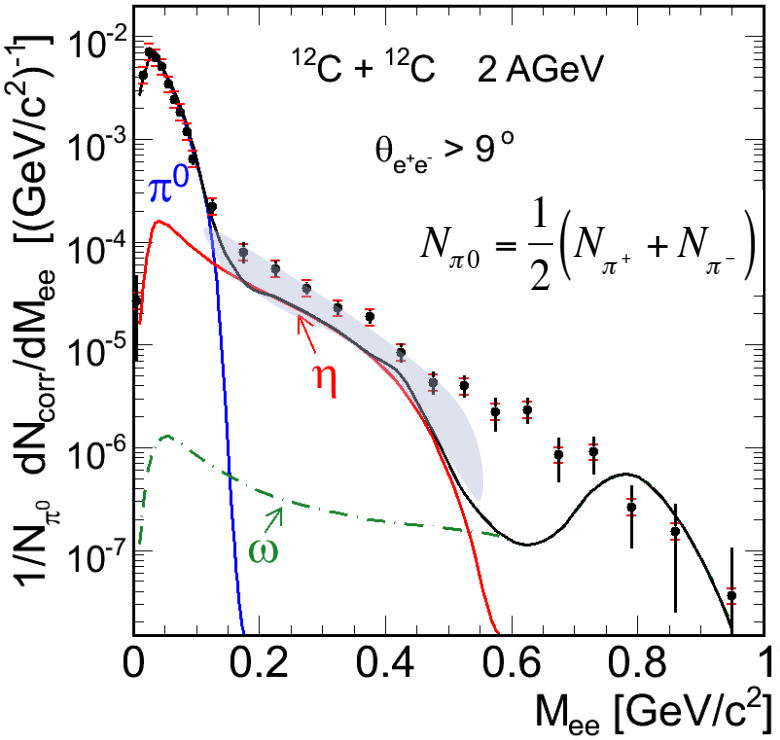
for details see: M. Weber, parallel session A4

HADES

A+A reactions

C+C data at 1 and 2 AGeV





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

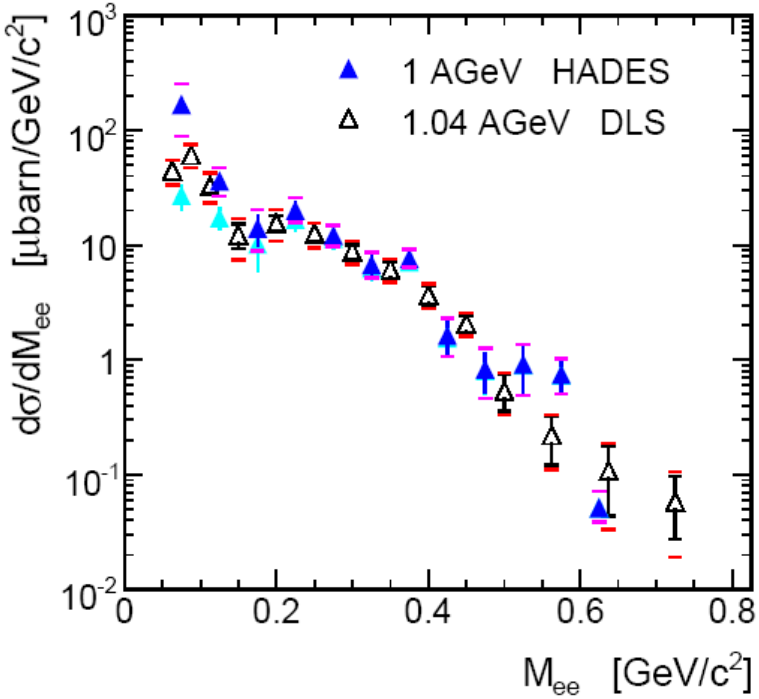
$$F(E) = \frac{Y_{exc}(E) + Y_\eta(E)}{Y_\eta(E)}$$

F(2.0) = 1.9 ± 0.2(stat) ± 0.3(sys) ± 0.3(η sys) PRL 98, 052302 (2008)

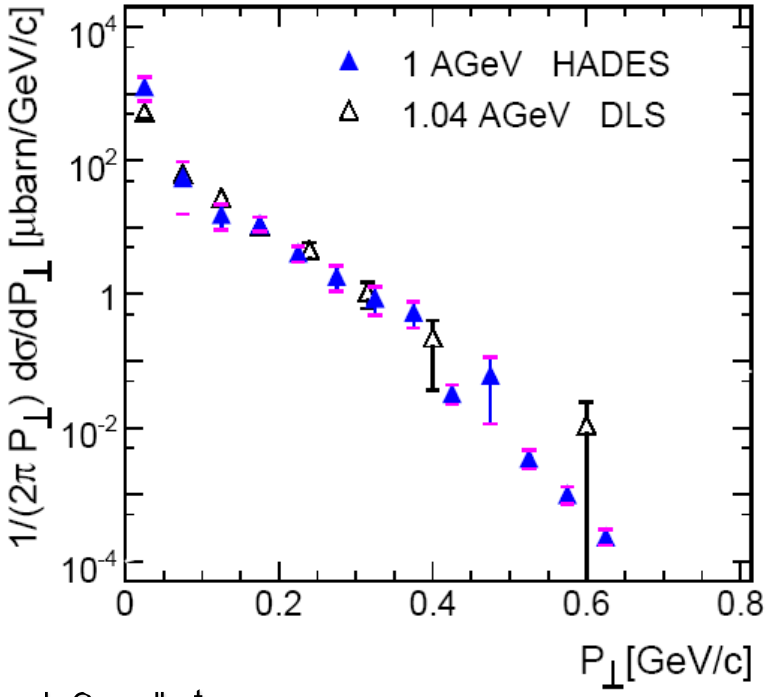
F(1.0) = 6.8 ± 0.6(stat) ± 1.3(sys) ± 2.0(η sys) PLB 663 (2008) 43-48

Comparison to DLS data

HADES data filtered with DLS acceptance



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

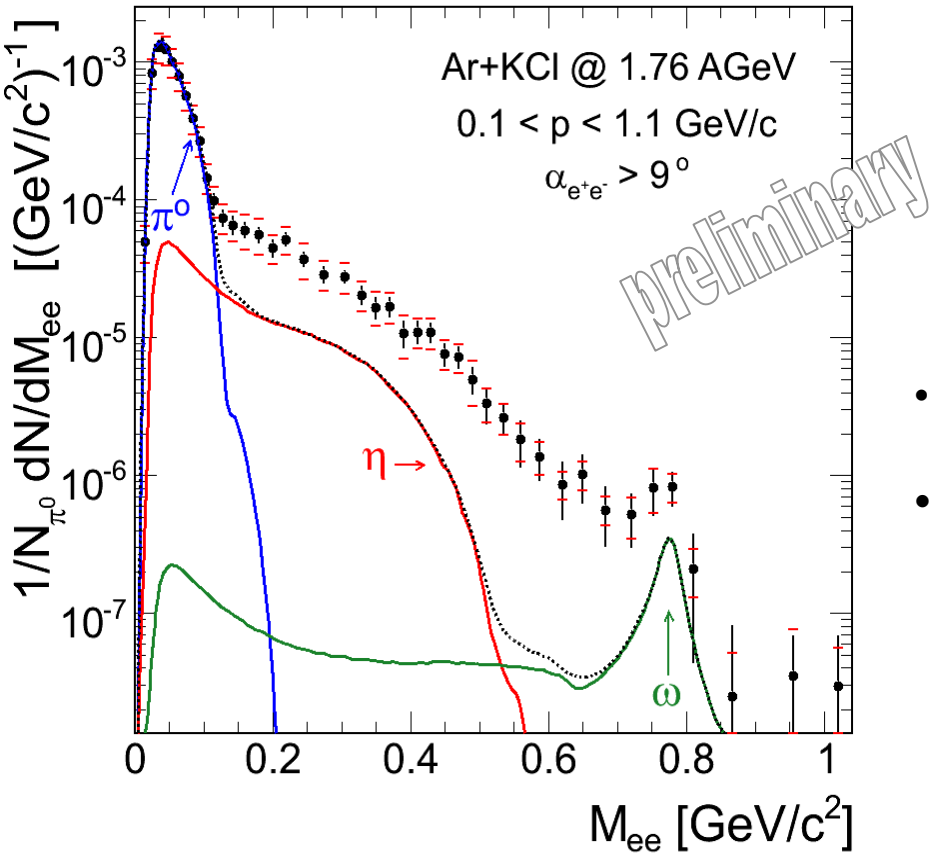


J. Carroll at

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

HADES and DLS data agree

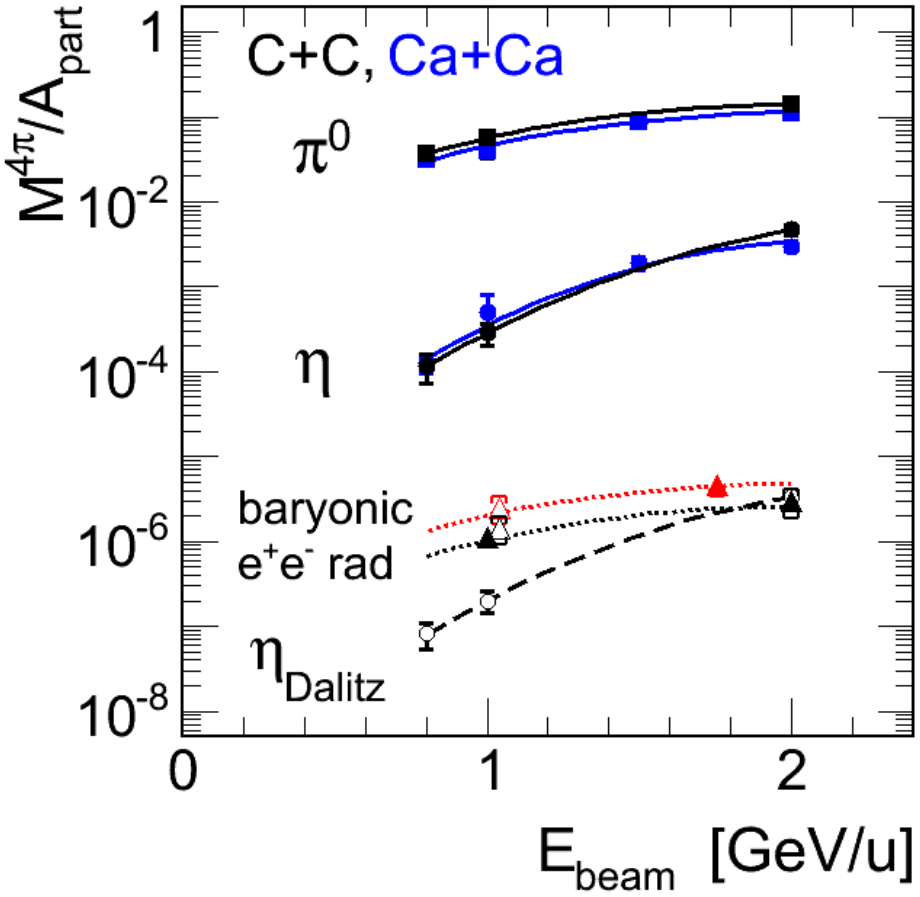
Ar+KCl data at 1.76 GeV



Efficiency-corrected di-electron spectrum normalized to the number of neutral pions

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

Excess yield

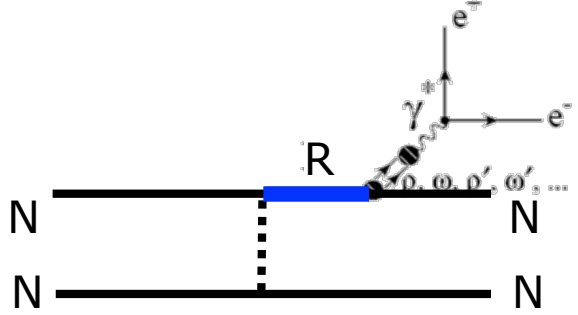


- DLS data, C+C
- DLS data, Ca+Ca
- HADES data C+C
- HADES data Ar+KCl

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

Excess scales with:

- **Energy: like π production**

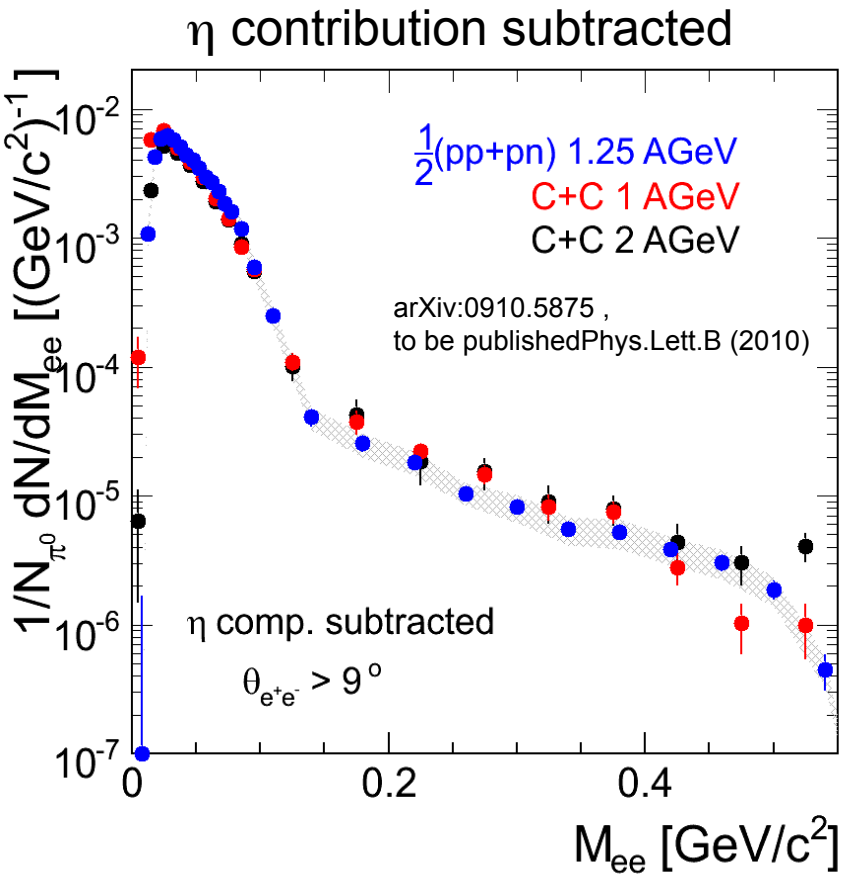


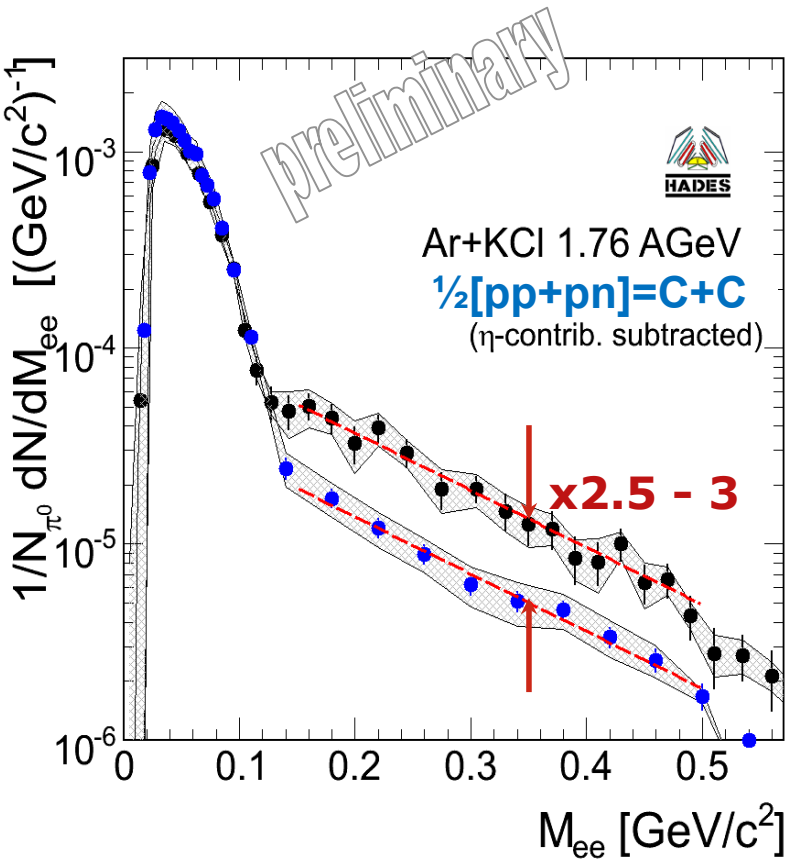
- **Apart : more than linear**

HADES

understanding the excess

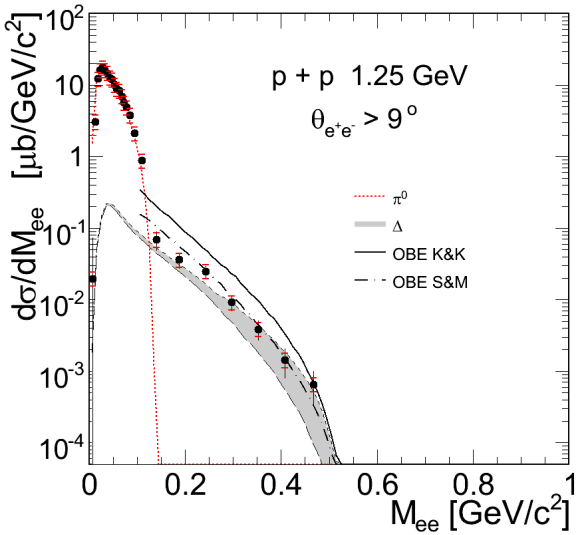
Experimental check

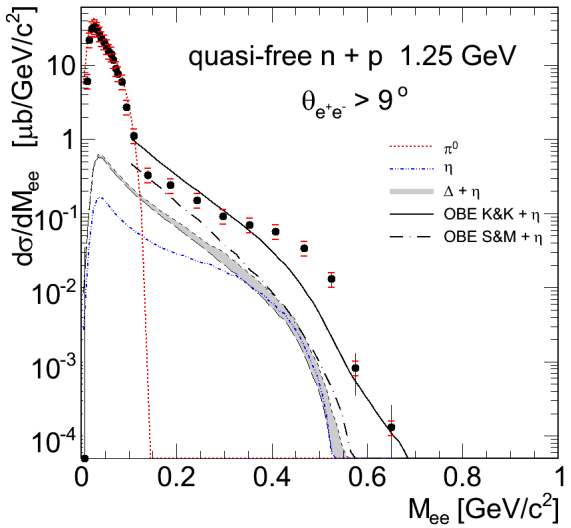




- **C+C data reproduced (within 20%) by superposition of NN interactions**
- **Ar+KCl data overshoots the NN data by a factor of ~2.5;**

Elementary reactions

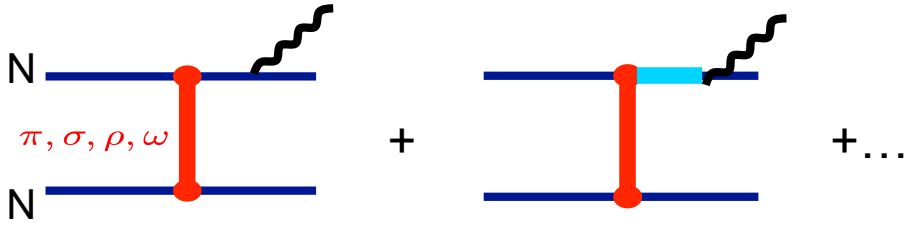




Experimental observation

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

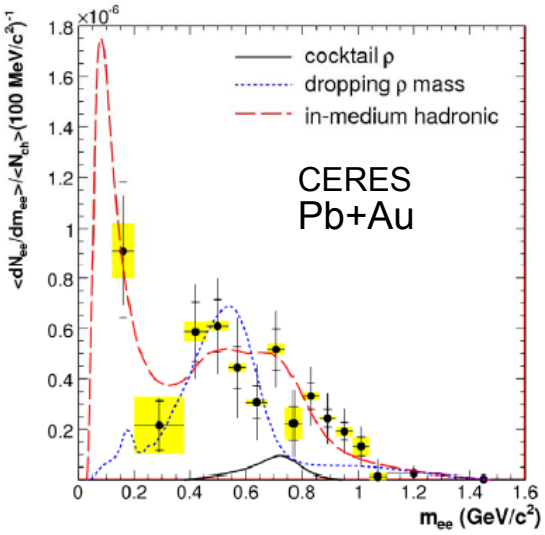
OBE calculations



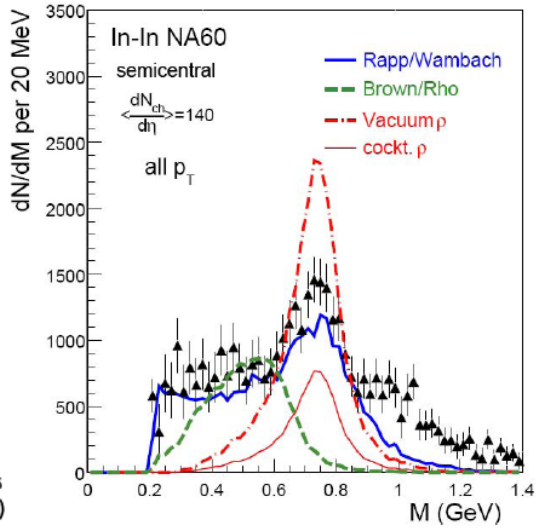
- p+p data
  - described (K&K in shape)
- n+p data
  - not described yet (different shape)

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

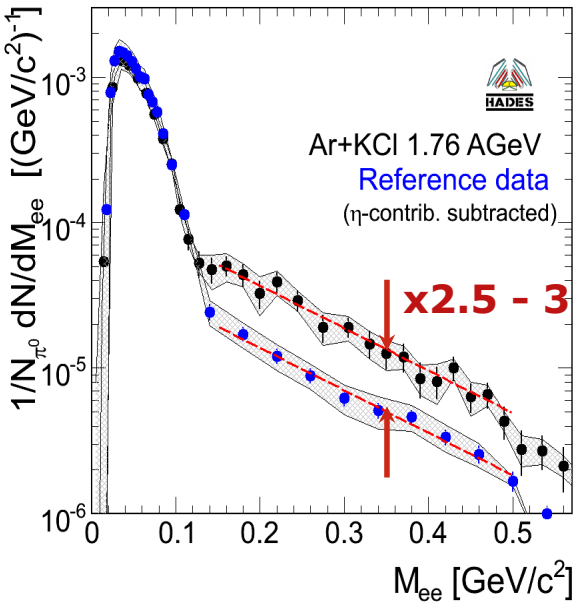
Low vs. High

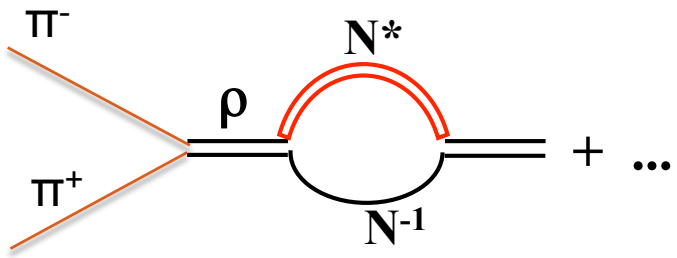


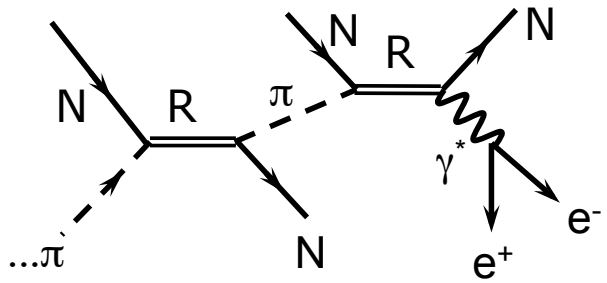
D. Adamova et al. nucl-ex/0611022



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







- High energy: 158 A GeV/c
  - explained by theory (hadronic models)

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

Summary

- Meson production in pp reactions at T_{kin} = 3.5 GeV is investigated
- For the first time inclusive cross sections for the π^0, η, ω and ρ mesons are reconstructed
- Reference spectra for the p+Nb run at the same beam kinetic energy is obtained
    - no changes in line shape of ω is observed

- Excess observed in DLS is confirmed by HADS 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

The HADES collaboration

Cyprus:
Department of Physics, University of Cyprus

Czech Republic:
Nuclear Physics Institute, Academy of Sciences of Czech Republic

France:
IPN (UMR 8608), Université Paris Sud

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

Italy:
Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud
Istituto Nazionale di Fisica Nucleare, Sezione di Milano

Poland:
Smoluchowski Institute of Physics, Jagiellonian University of Cracow

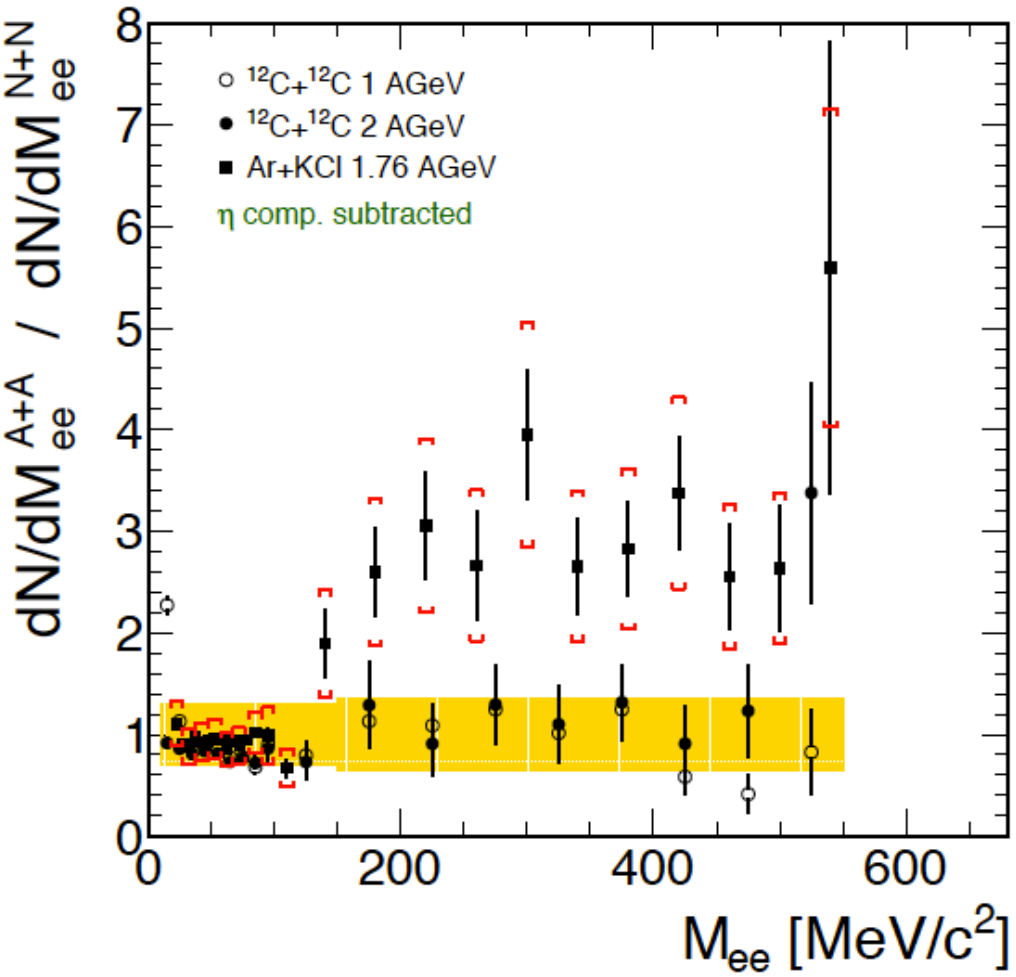
Portugal:
LIP-Laboratório de Instrumentação e Física Experimental de Partículas

Russia:
INR, Russian Academy of Science
Joint Institute of Nuclear Research
ITEP

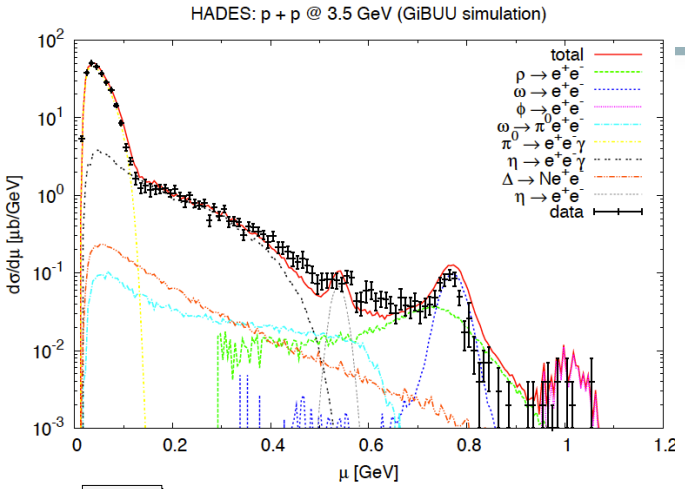
Spain:
Departamento de Física de Partículas, University of Santiago de Compostela
Instituto de Física Corpuscular, Universidad de Valencia-CSIC

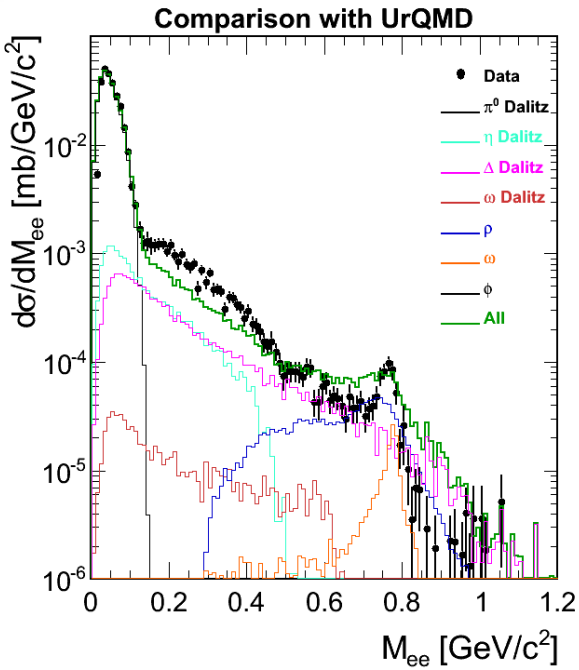
17 institutions
120+ members

Backup slides

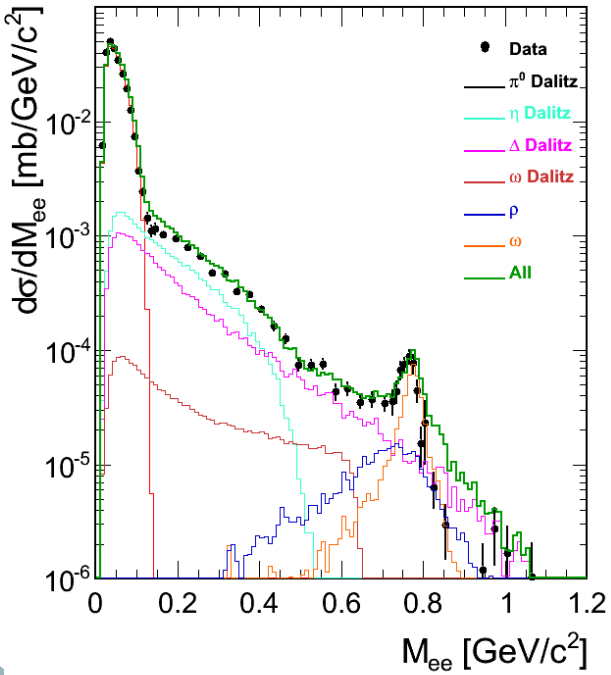


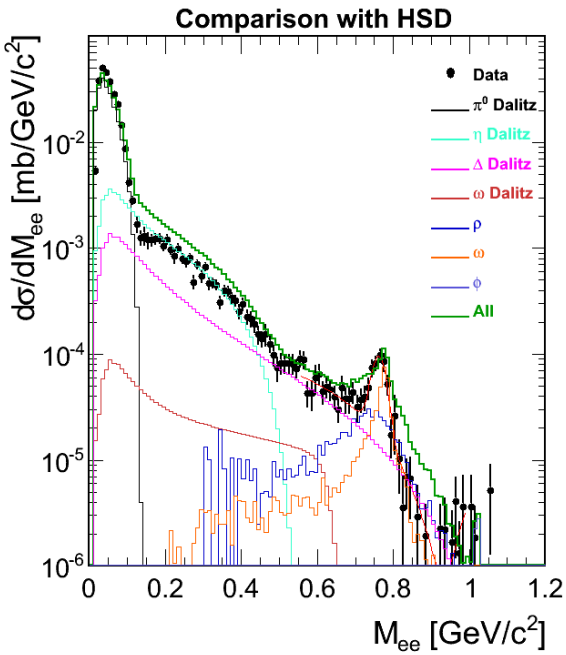
SPECTRA OF SPECTRUM



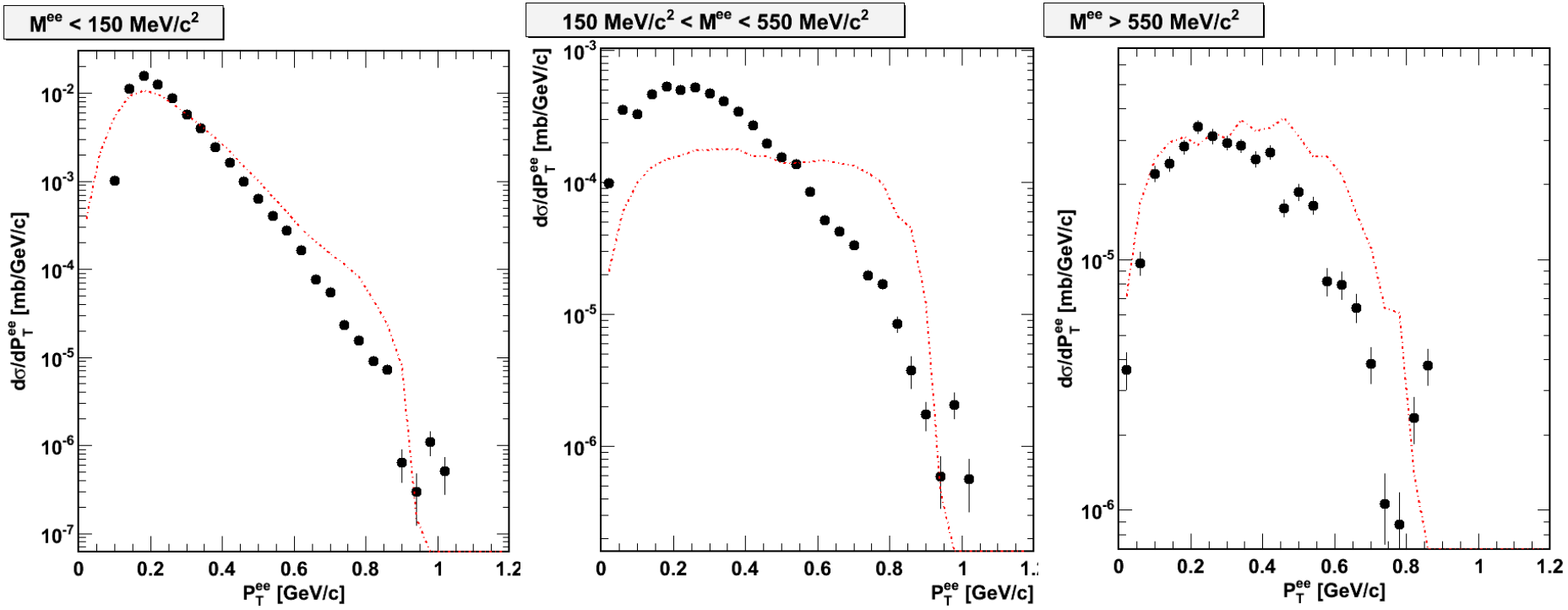


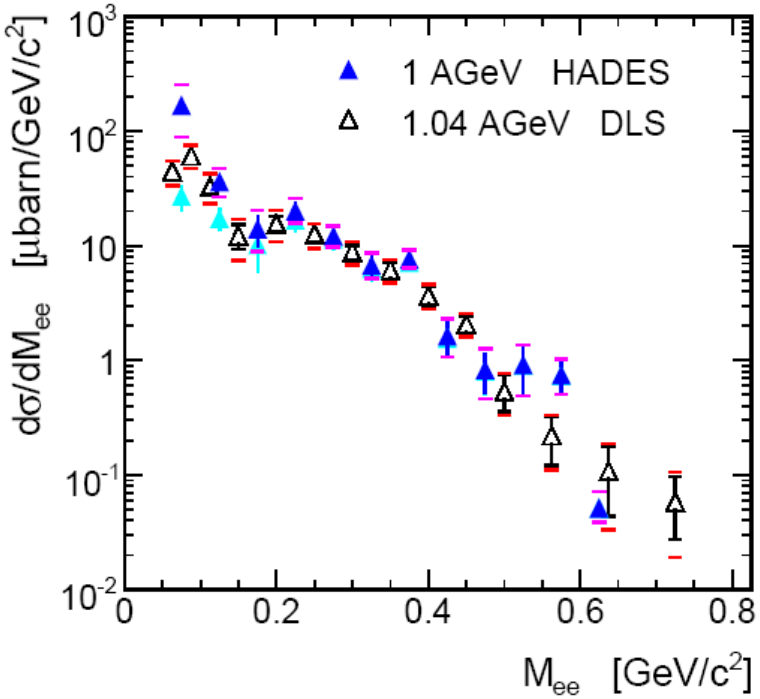
histo

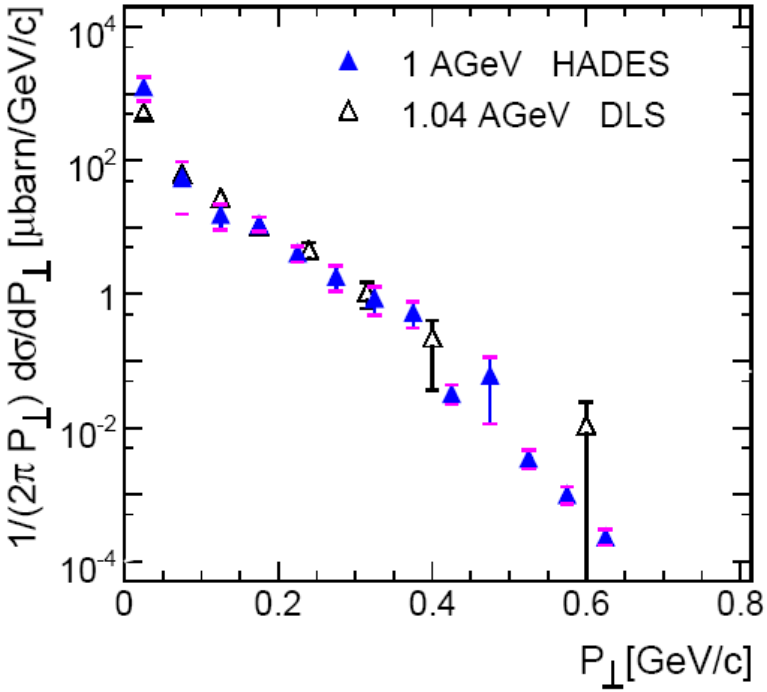




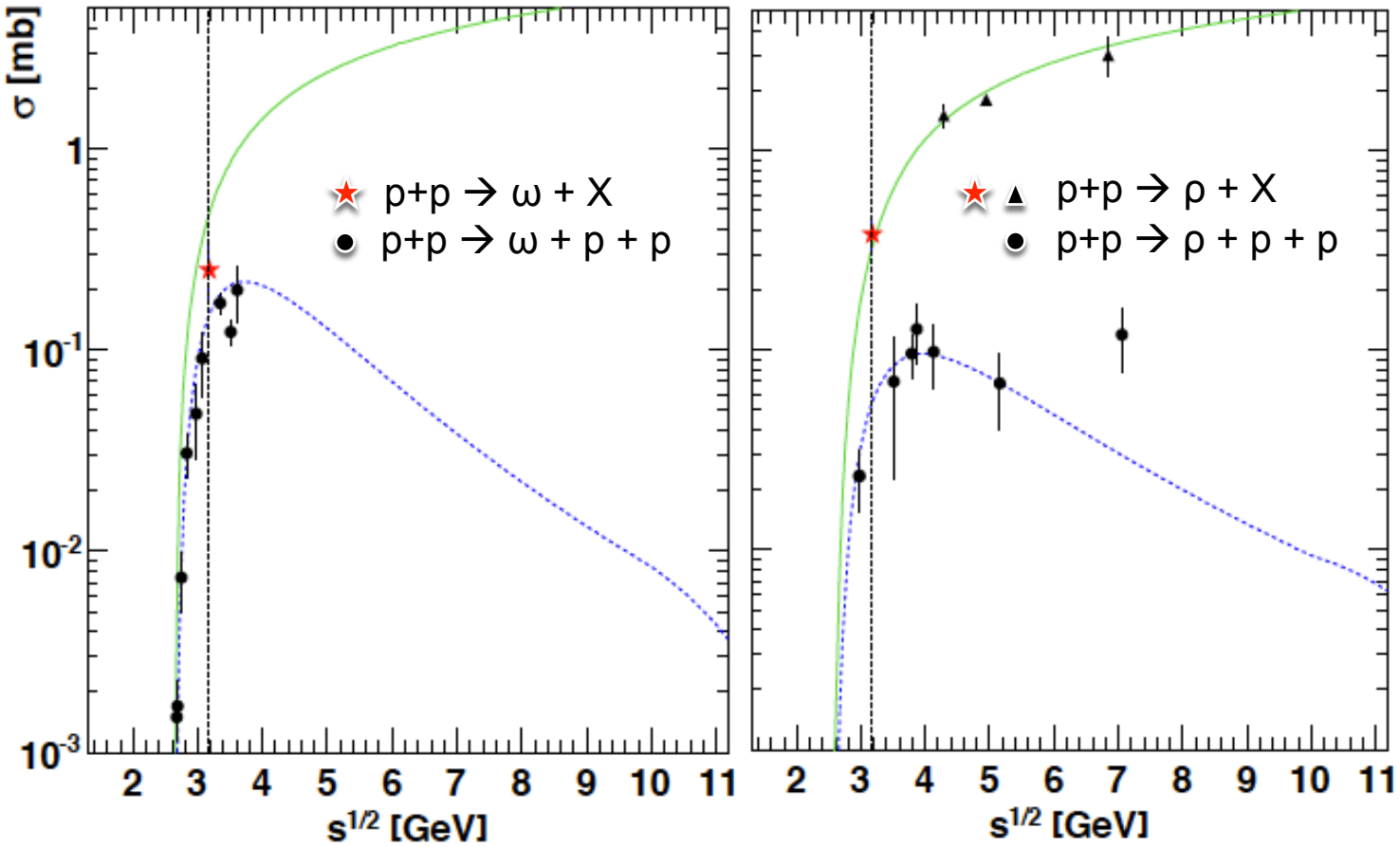
Pt distributions




1 AGeV HADES
1.04 AGeV DLS
dσ/dM$_{ee}$ [μbarn/GeV/c^2]
M$_{ee}$ [GeV/c^2]


1 AGeV HADES
1.04 AGeV DLS
1/(2π P$_\perp$) dσ/dP$_\perp$ [μbarn/GeV/c]
P$_\perp$[GeV/c]

ρ/ω cross sections



Acceptance correction to large extent is model independent !

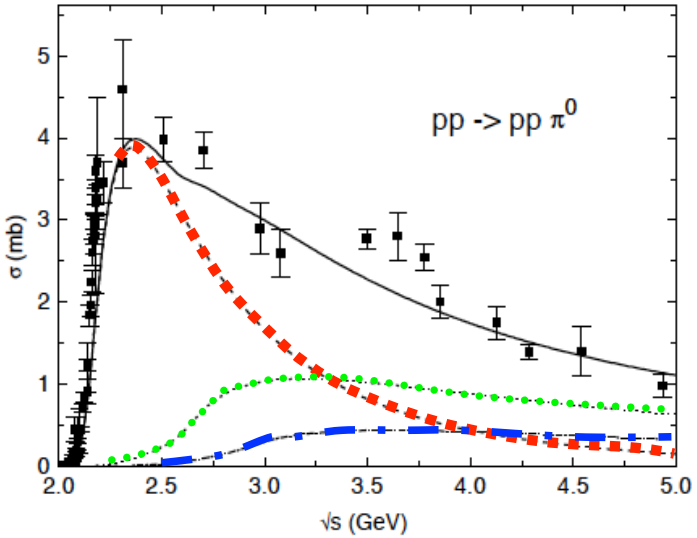
Cross sections were obtained from simulated cocktail by changing the ρ/ω ratio until simulation fits the data

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

Resonance model

$$\frac{d\sigma_{pp\to pR\to pp\pi}}{dm} = N\cdot\sigma_{pp\to pR}(m)\frac{m^2\Gamma_{R\to p\pi}}{\left(m^2-M_R^2\right)^2+m^2\Gamma_{tot}^2}$$

$$\sigma_{pp\to pp\pi^0} = \sum\frac{2}{3}\sigma_{3/2} + \sum\frac{1}{3}\sigma_{1/2}$$

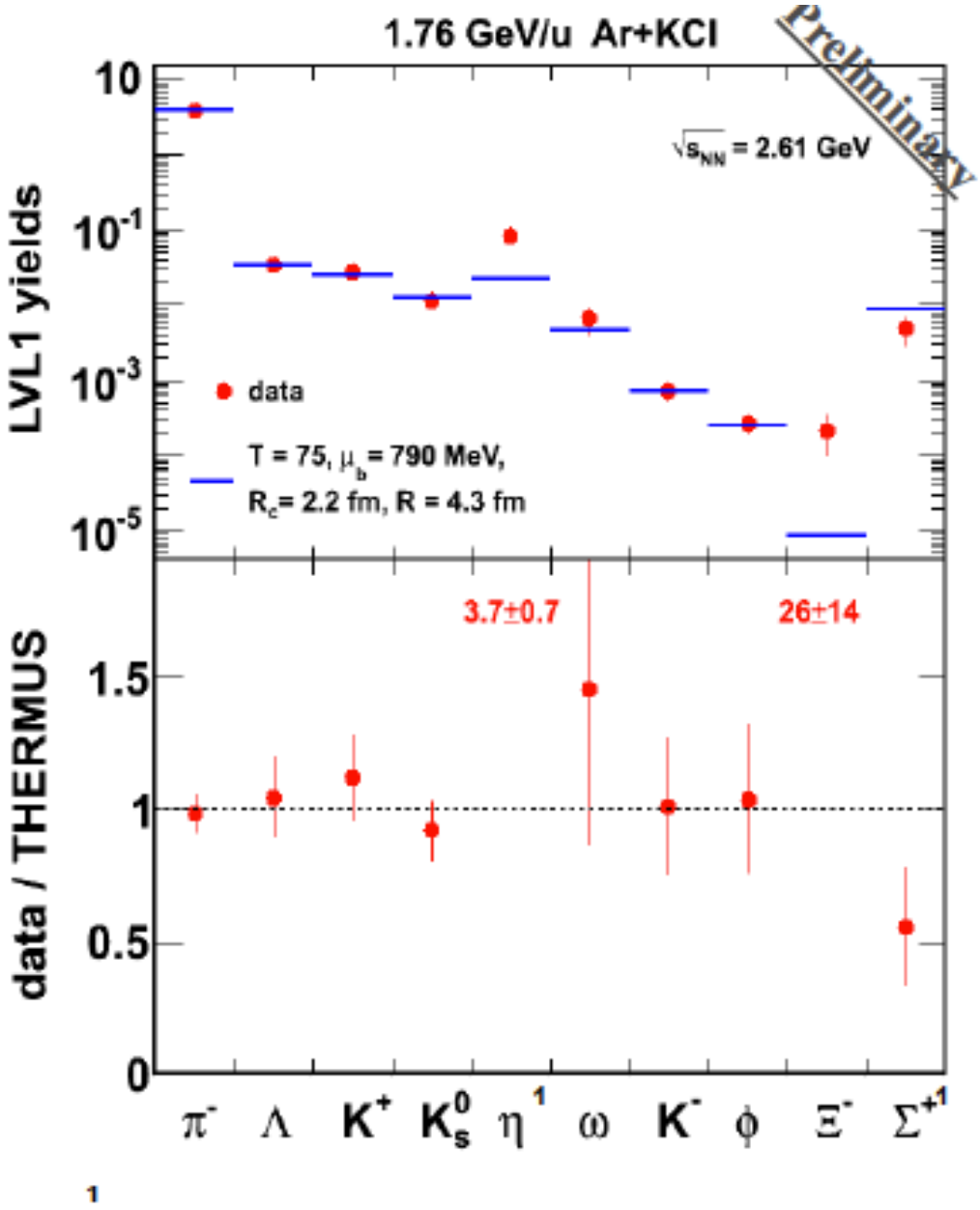


$pp\pi^0$ (2.75)
$pp\pi^0\pi^0$ (0.9*2)
$pn\pi^+\pi^0$ (5.3)
$pp\pi^0\pi^0\pi^0$ (0.4*3)
$pp\pi^+\pi^-\pi^0$ (1.6)

~ 13 mb

consistent within error bars with inclusive measurements of 16 mb !

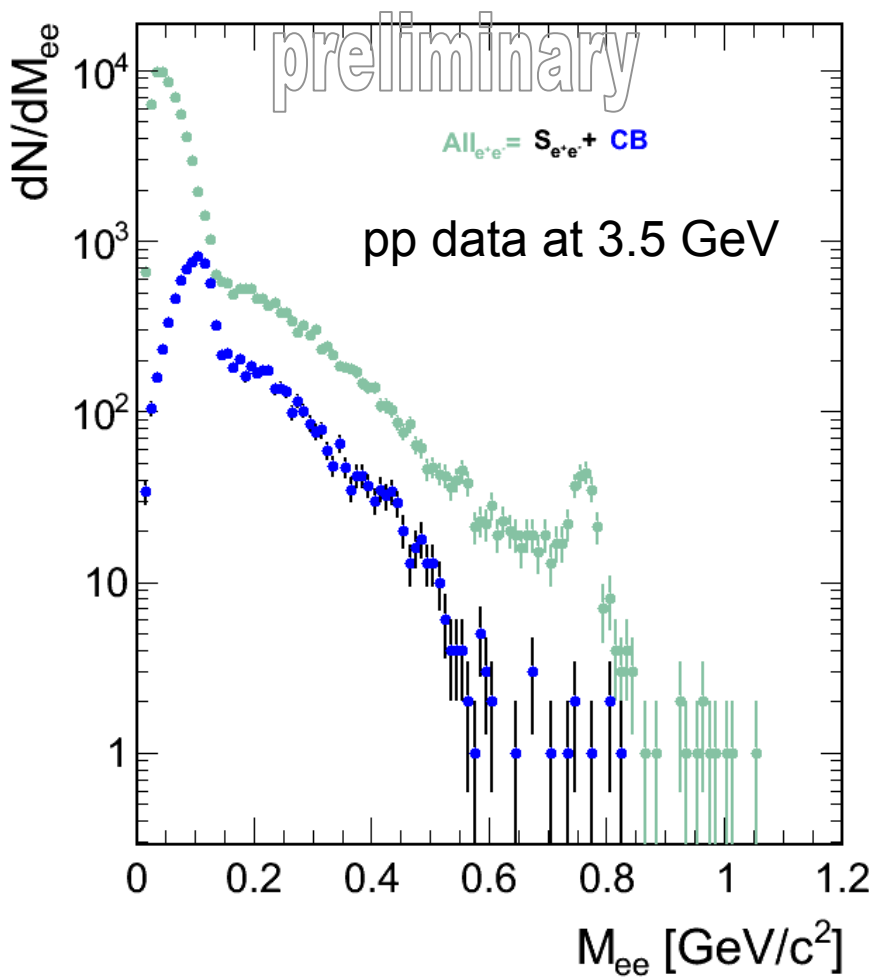
S. Teis et al. Z. Phys. A 356, 421-435 (1997)



S. Wheaton, J. Cleymans Comput.Phys.Commun.180:84-106,2009

Dilepton spectra for pp data

Not efficiency corrected. Inside HADES acceptance

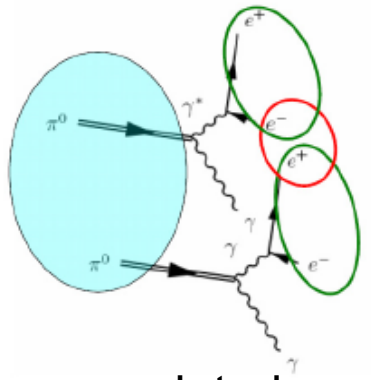


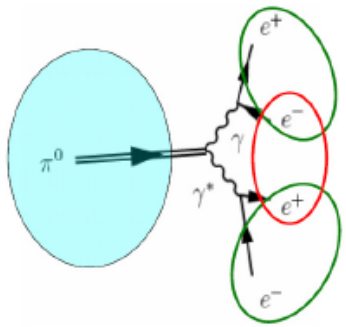
Particle identification:

- 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





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

Resonance model

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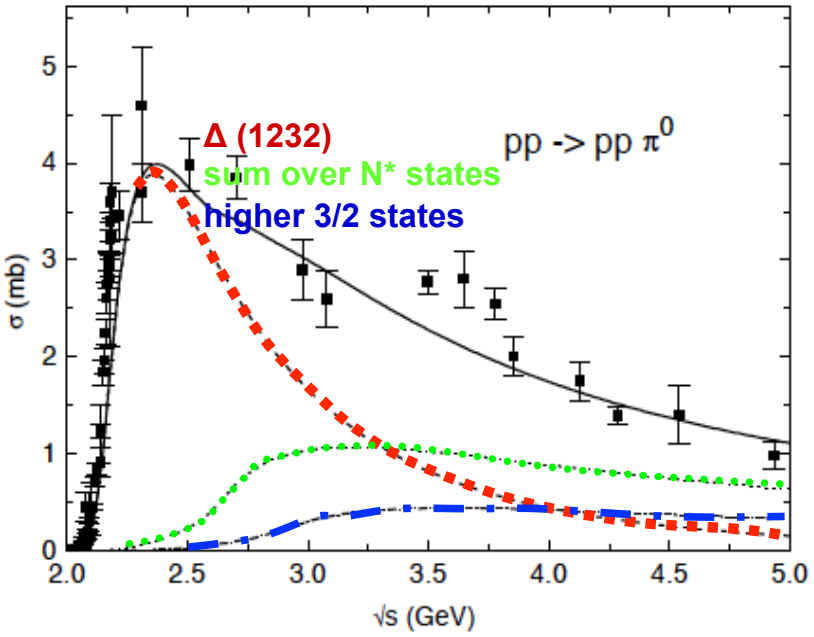

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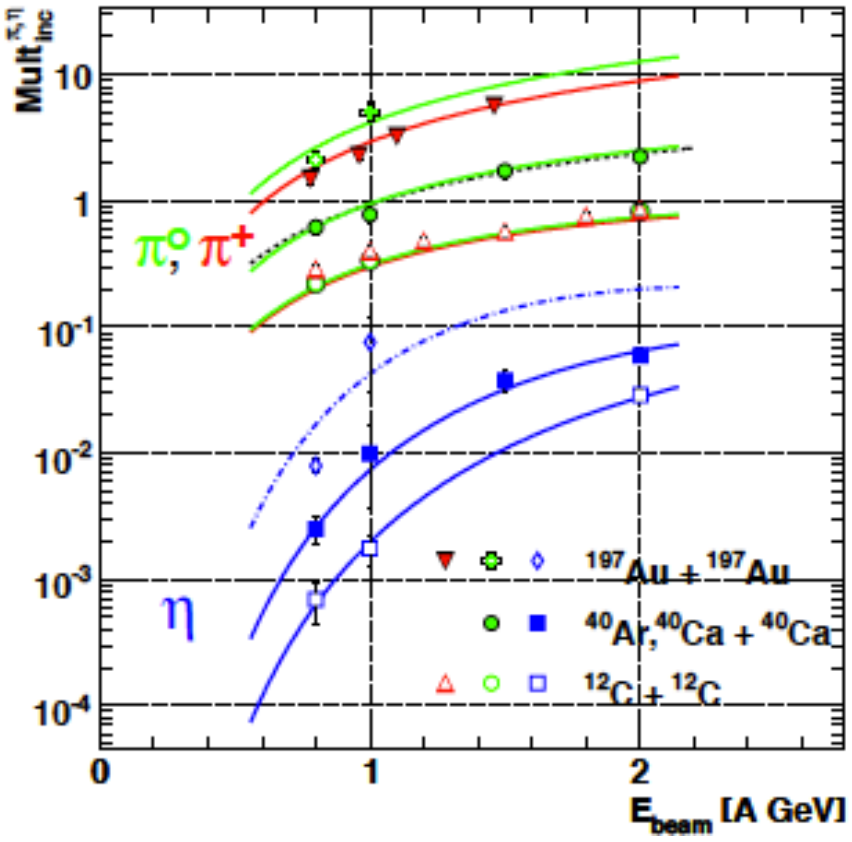
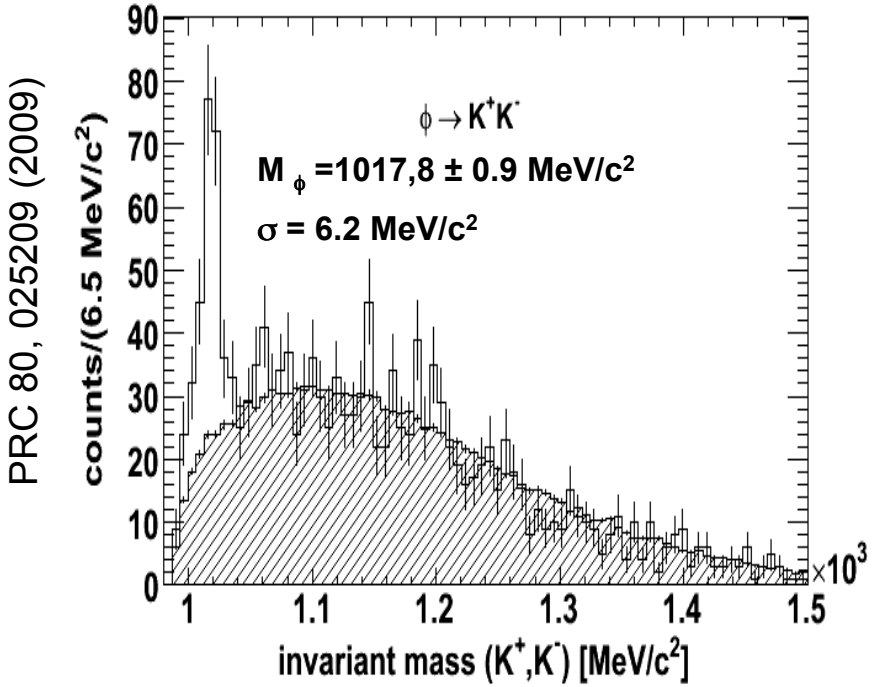

Mult$^{\pi,\eta}_{inc}$
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
1
2
E_{beam} [A GeV]
π^0, π^+
η
$^{197}Au + ^{197}Au$
$^{40}Ar, ^{40}Ca + ^{40}Ca$
$^{12}C + ^{12}C$

Strangeness production in Ar+KCl data

sub-threshold phi production

$$\sqrt{s} - \sqrt{s_{thr}} = -287\,MeV$$



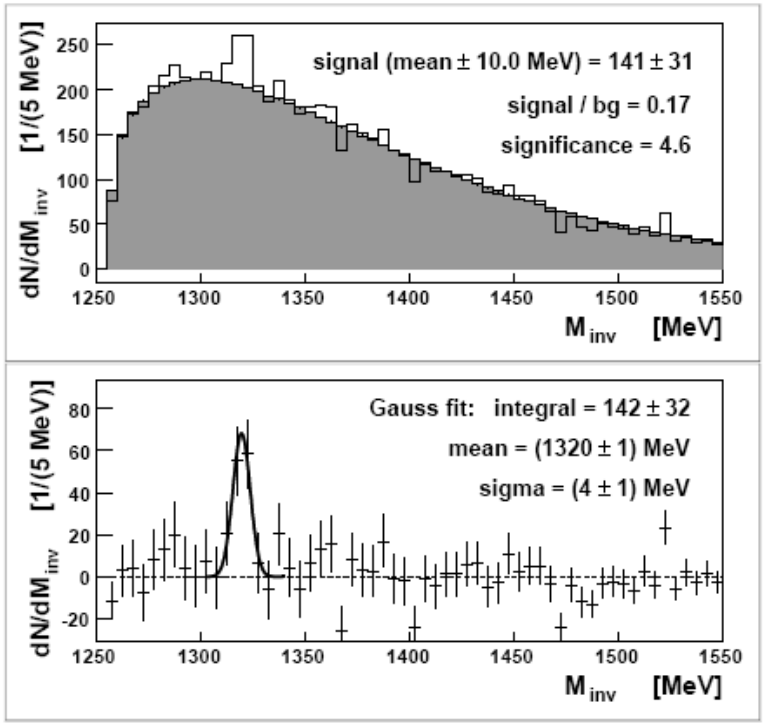
PRC 80, 025209 (2009)

$$\phi / K^- \approx 0.37 \pm 0.13$$

~ 18% of K^- are produced via ϕ mesons!

deep sub-threshold Ξ production

$$\sqrt{s} - \sqrt{s_{thr}} = -630\,MeV$$



PRL 103, 132301 (2009)

- $\Lambda \rightarrow p + \pi^-$
- $\Xi^- \rightarrow \Lambda$ + another π^-

$$\frac{\Xi^-}{\Lambda + \Sigma^o} = (5.6 \pm 1.2^{+1.8}_{-1.7})10^{-3}$$