Di-Electron Spectroscopy with HADES

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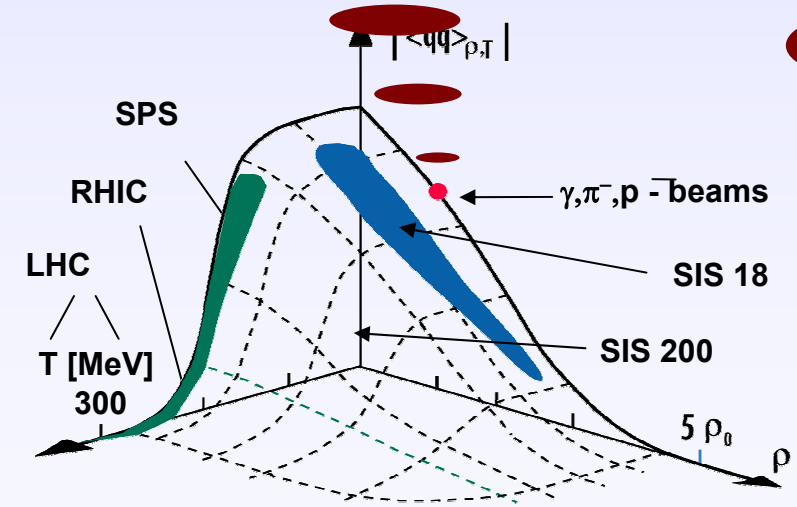
for the HADES collaboration

- Introduction
  - the case of moderate beam energies
- The HADES experiment
  - setup
  - data analysis
- First results & comparison with theory

The physics case

Study the properties of hot and dense nuclear matter with emphasis on electromagnetic probes in the time-like regime!

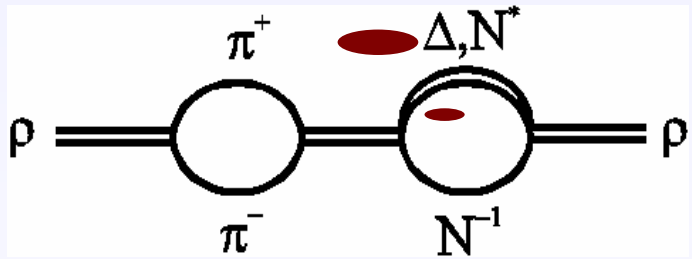
Partial restoration of chiral symmetry (vs. T,ρ)



Klingl, Lutz & Weise

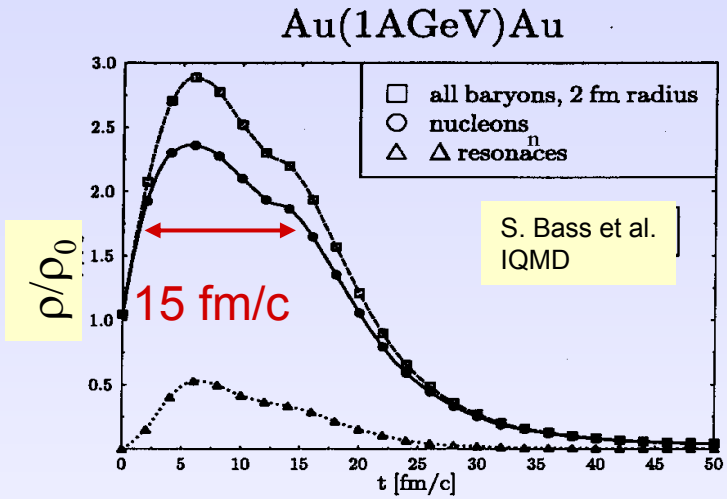
- What are the relevant observables as nuclear density and/or temperature change?
- Quark picture vs. hadronic picture?

Additional self-energy terms due to meson-baryon coupling

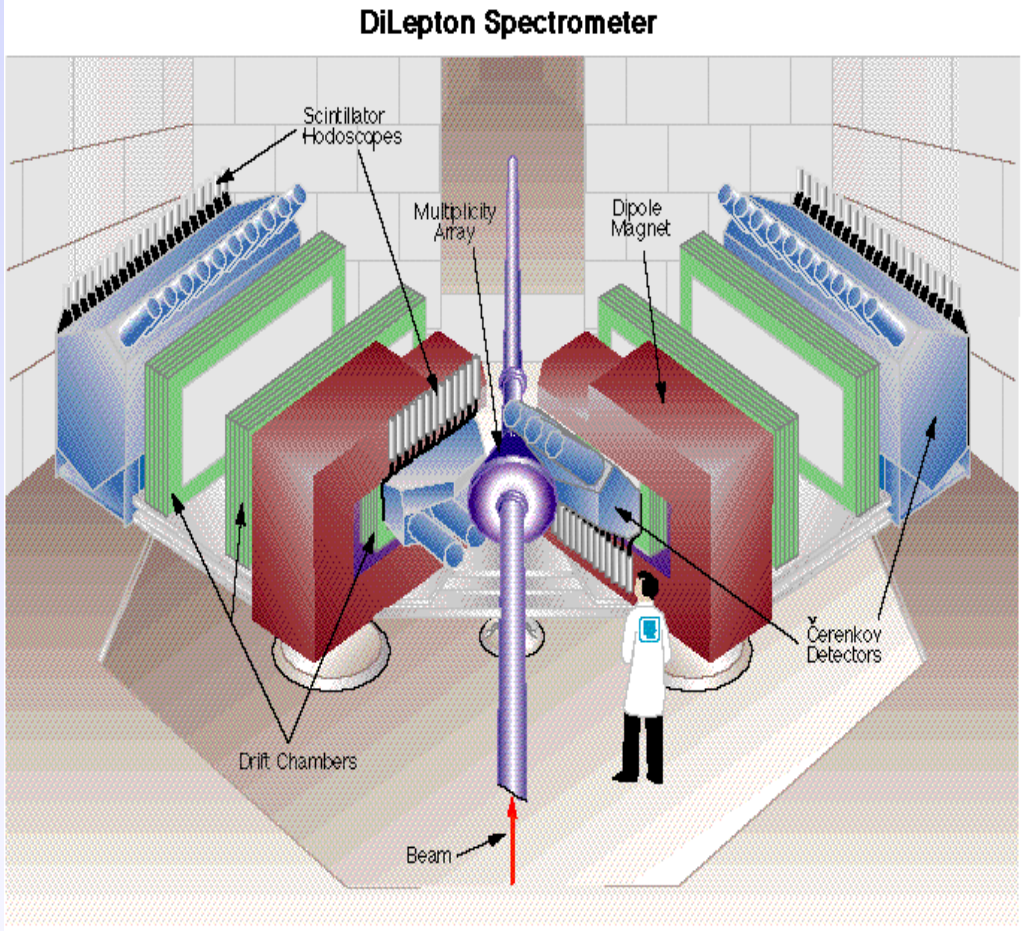


The case of moderate beam energies

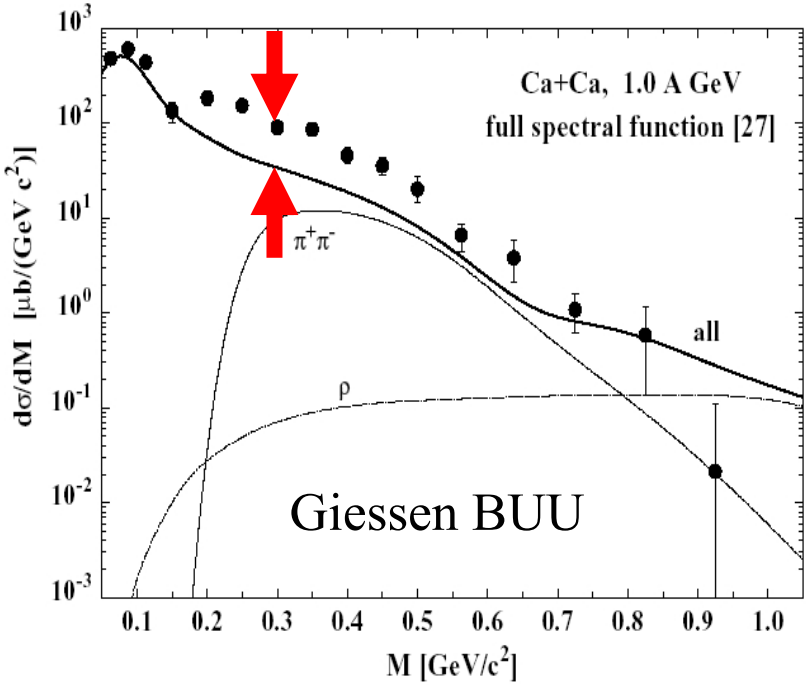
- **Final state of HI collision @ 1-2 AGeV ($\sqrt{s_{NN}}$ = 2.3-2.7 GeV)**
  - up to 200 charged particles
  - up to 10 % pions → **baryon dominated**
  - very little strangeness
- **Increase of baryon density**
  - $\Delta\tau$ (max ρ/ρ^0 =2-3) = 15 fm/c
  - fireball comparatively **long-lived** …
  - … at **moderate densities and moderate T**
- **Production of vector mesons below threshold**
  - co-operative processes (multi-step)
  - production confined to high-density phase
  - **one vector meson decaying into a lepton pair per 1-10 million reactions!!!**



A reminder: The controversial DLS result



DLS at the Bevalac (1987-1995)

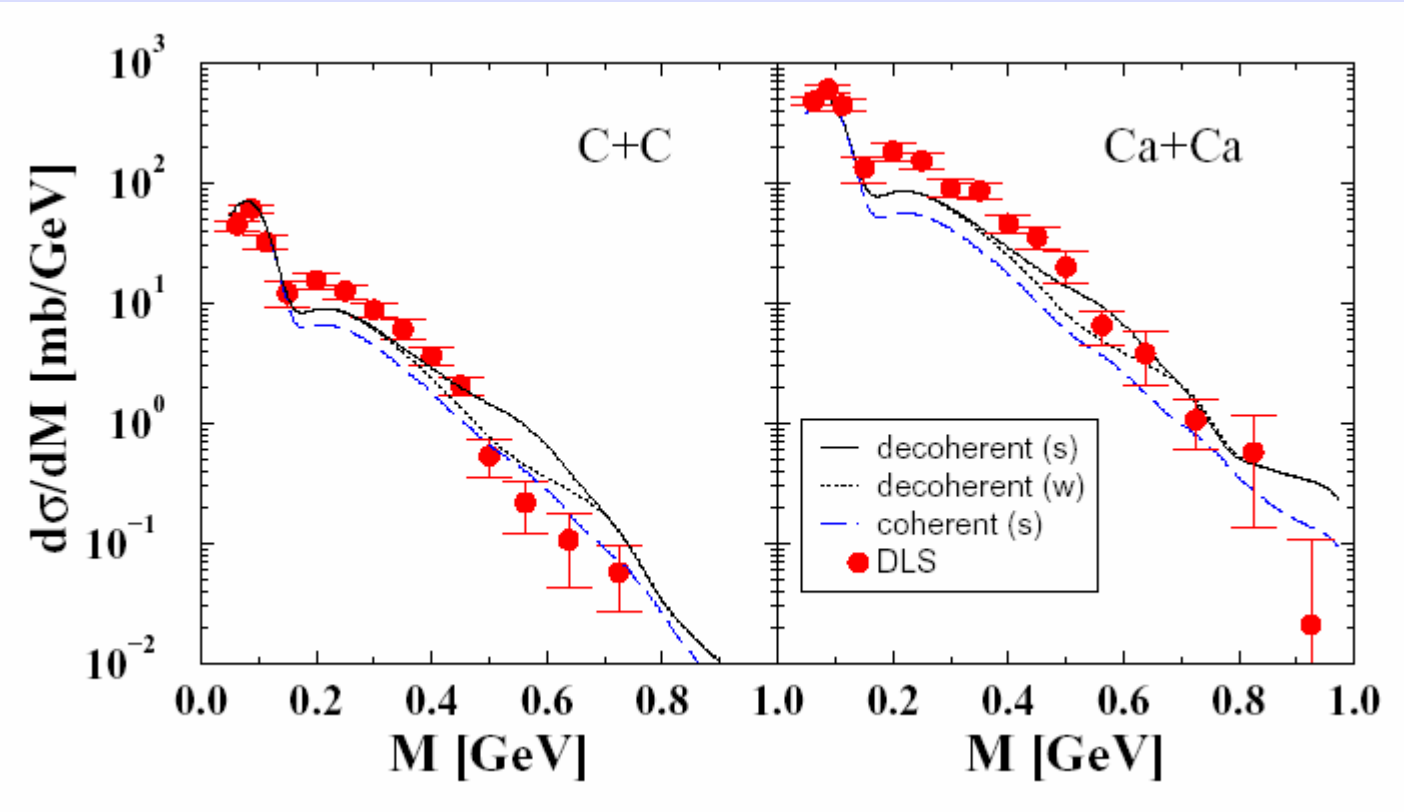


Data: **R.J. Porter et al.:** PRL 79 (1997) 1229
BUU model: **E.L. Bratkovskaya et al.:** NP A634 (1998) 168
transport + in-medium spectral functions

→ DLS puzzle!?

RQMD description of the DLS data

Calculation: K. Shekhter, C. Fuchs et al. (Tübingen)
Phys. Rev. C68 (2003) 014904



- collisional broadening of ω ($\rightarrow \Gamma(\omega) = 200$ MeV)
- extended VDM + decoherence
- BR scaling of VM

High Acceptance DiElectron Spectrometer

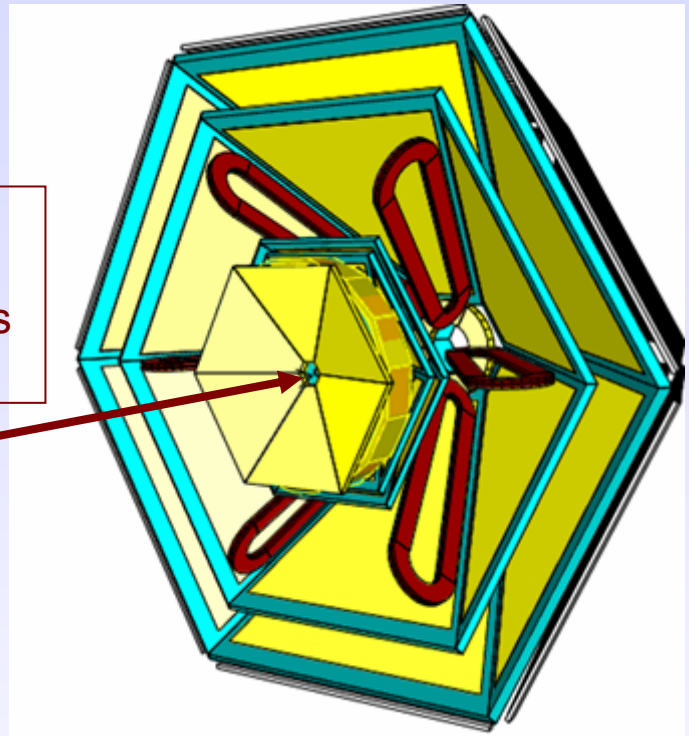
Use di-electron pairs to investigate vector meson production (ρ, ω, ϕ).

- Spectrometer with
  - high geometric acceptance
  - high invariant mass resolution
  - high rate capability
- Utilizes dedicated LVL2 trigger to select events before storing.
- Installed at the SIS18 at GSI.

Project launched in late 1994,
6 years R&D and construction.

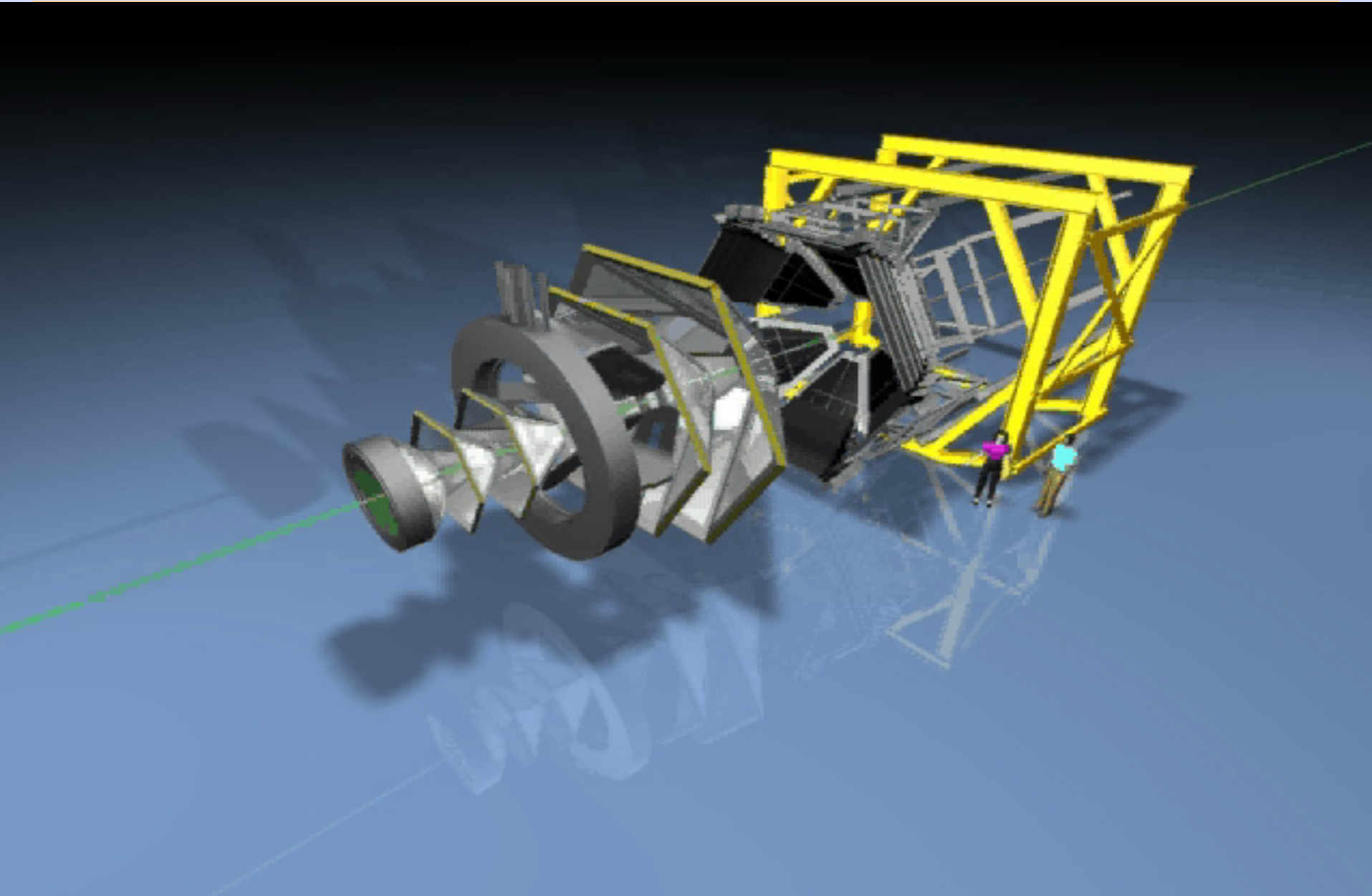
First production run in 2002

Beams of:
- Pions
- Protons
- Nuclei



Operated by a collaboration of more than 100 physicists from Cyprus, Czech Rep., France, Germany, Italy, Poland, Portugal, Russia, Slovakia, Spain

The HADES experiment @ GSI



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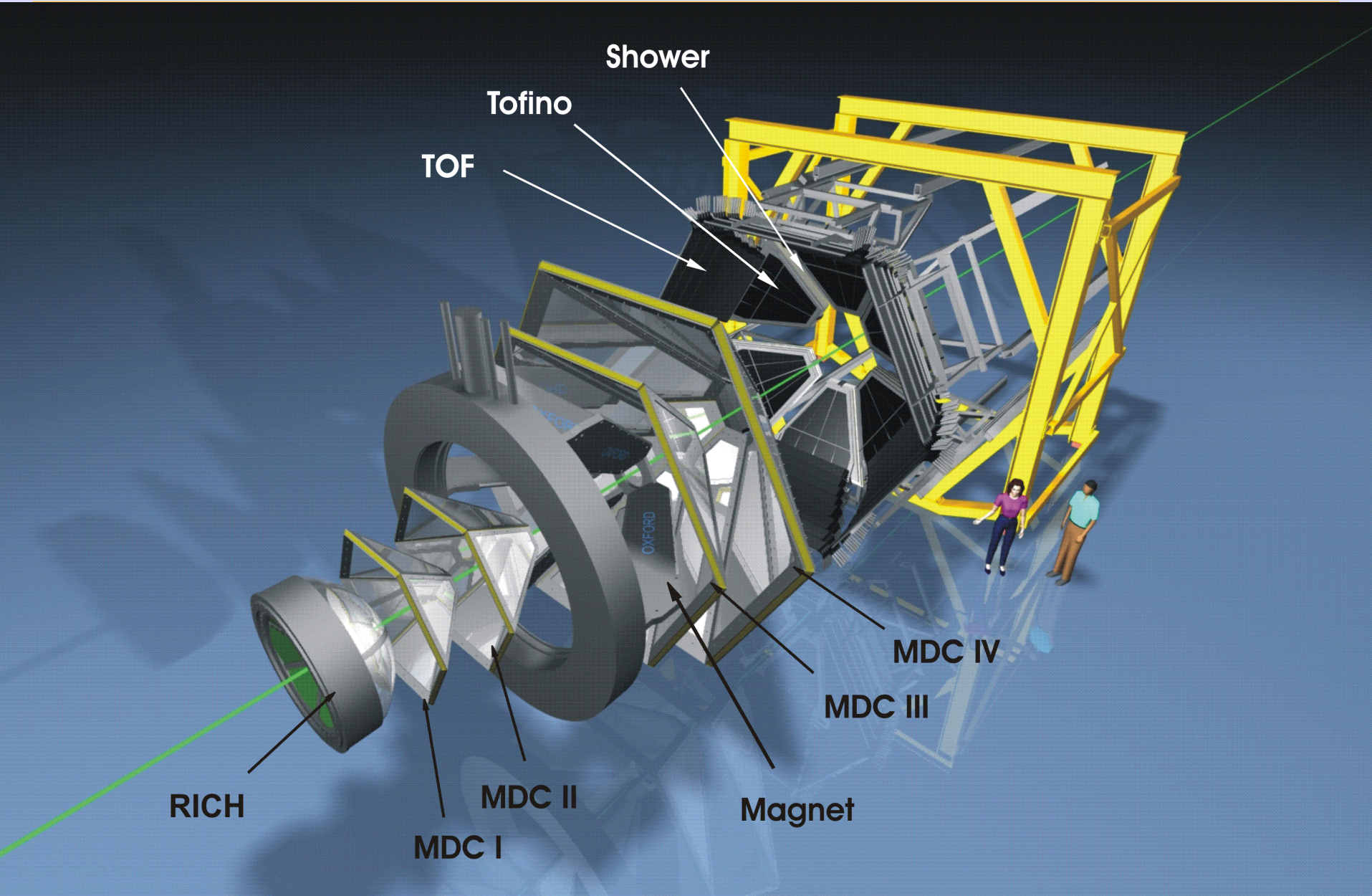


The spectrometer design

Geometry

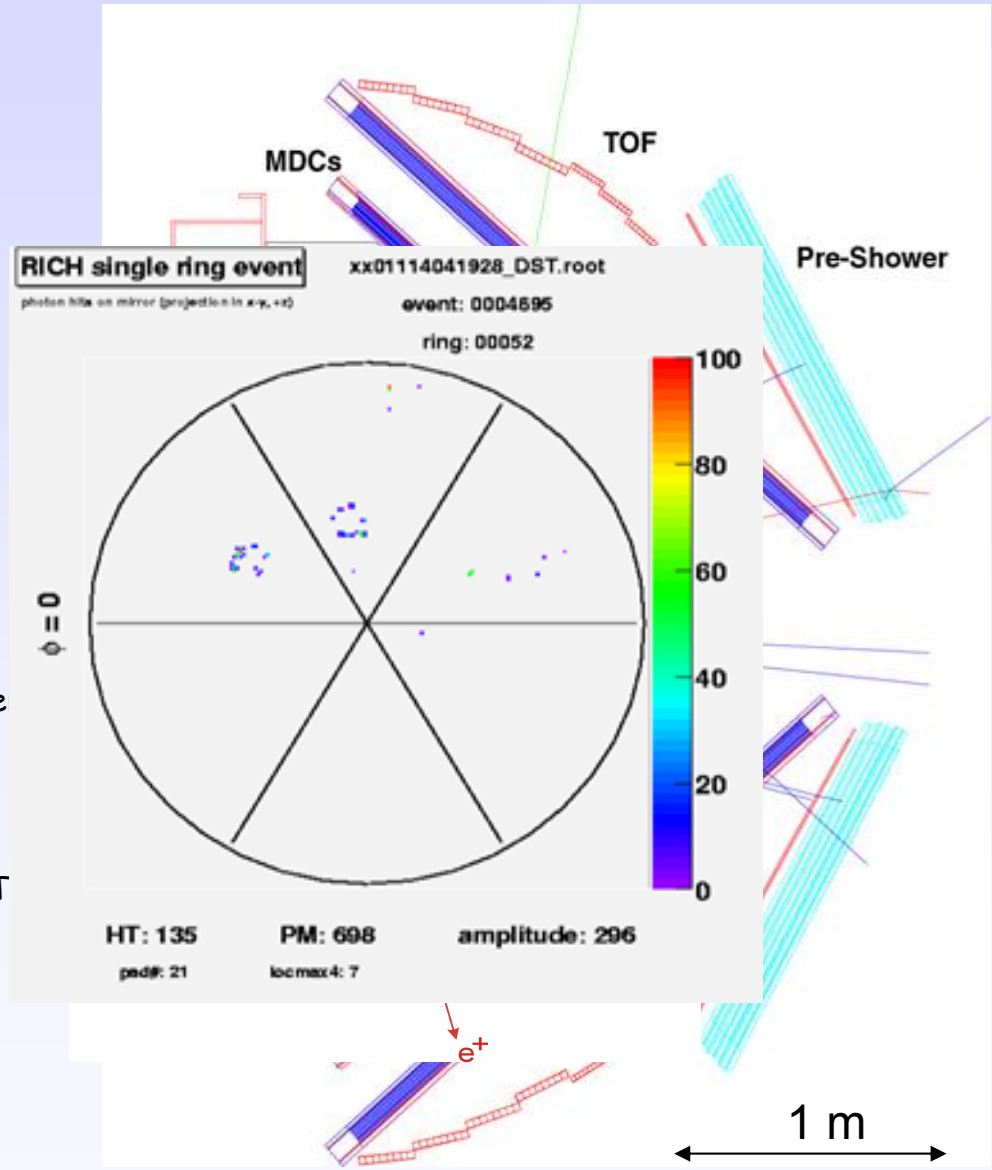
- Full azimuth, polar angles 18° - 85° (y = 0 – 2)
- Segmented solid targets or LH_2 target
- Pair acceptance ≈ 0.35

Particle identification

- **RICH:** CsI solid photo cathode, C_4F_{10} radiator, $N_0 \approx 80$, pion suppression ≈ 10^4
- **TOF:** 384 scintillator rods
- **TOFino:** 24 scintillator paddles
  → temporary solution, RPC in future
- **Pre-Shower:** 18 pad chambers & lead converte

Momentum measurement

- **ILSE:** superconducting toroid with Bρ = 0.36 T
- **MDC:** 24 multi-wire drift chambers, single-cell resolution ≈ 100 μm



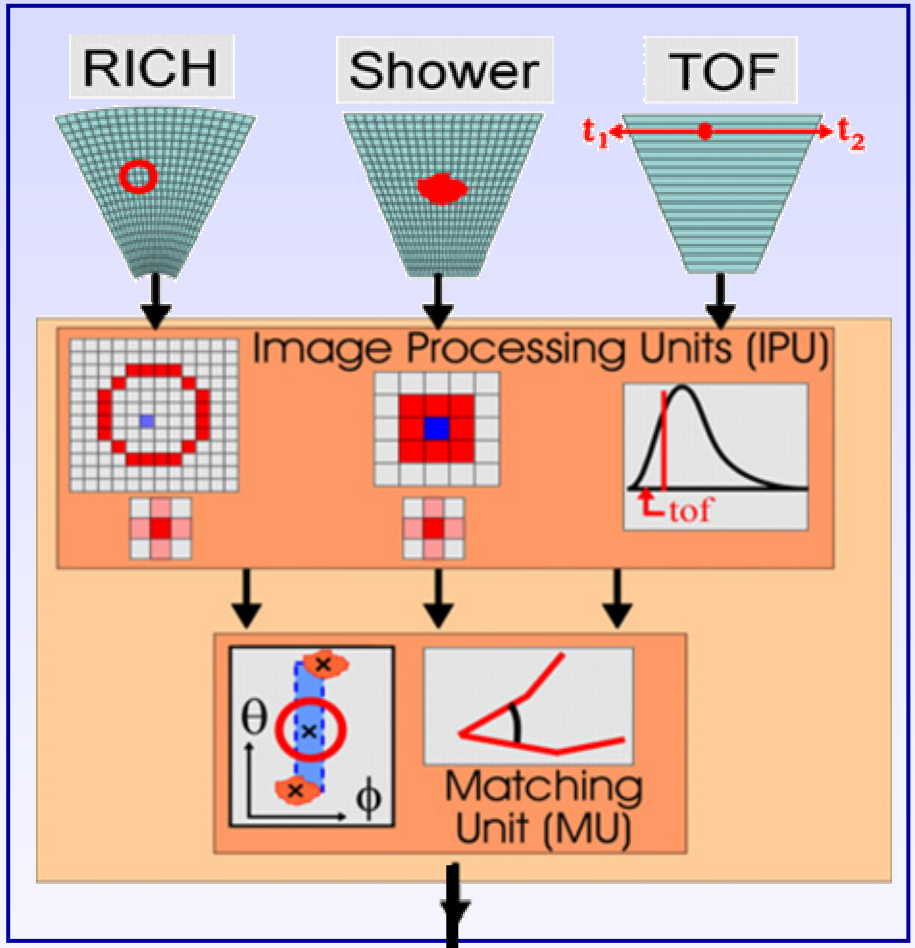
Fast 2nd level trigger

Up to 20 kHz LVL1
fast multiplicity trigger

full event information digitized

on-line selection of electron candidates

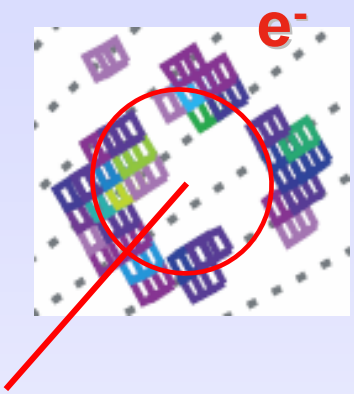
enhancement 10 - 100



LVL2 triggered events are transported to mass storage

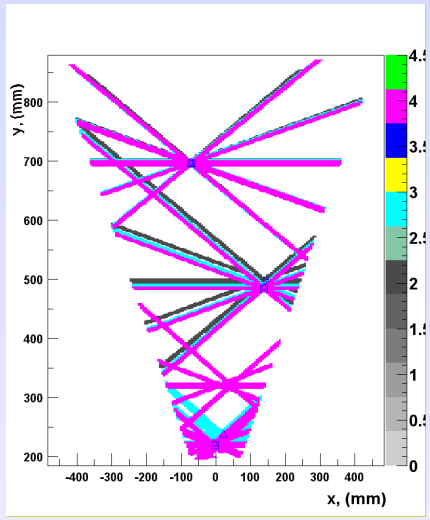
Electron identification

RICH pattern



+

Track matching



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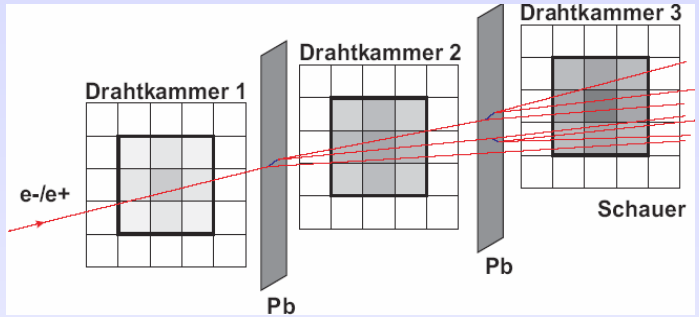
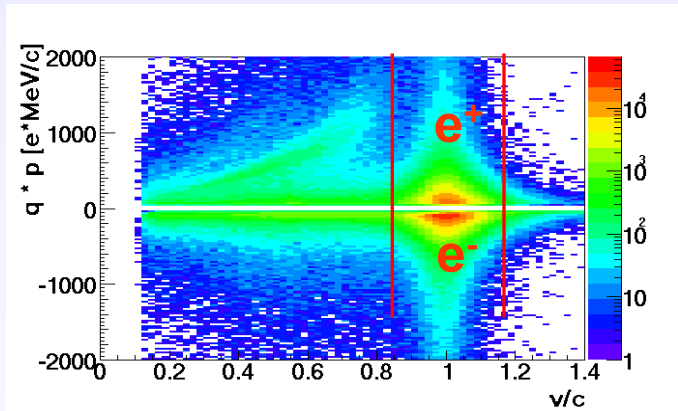
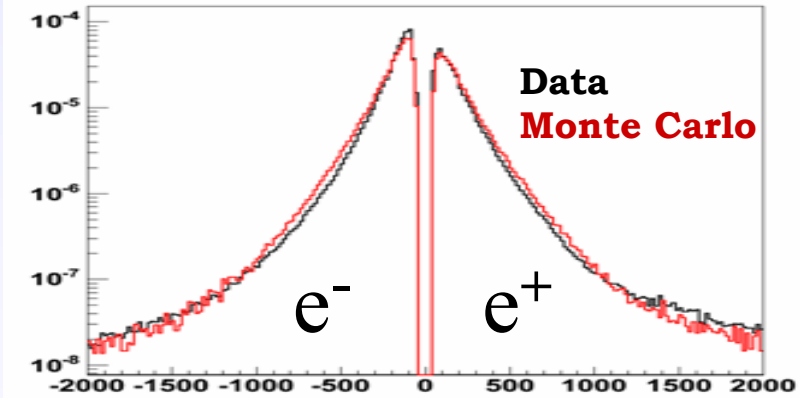
Pre-Shower condition



velocity vs. momentum



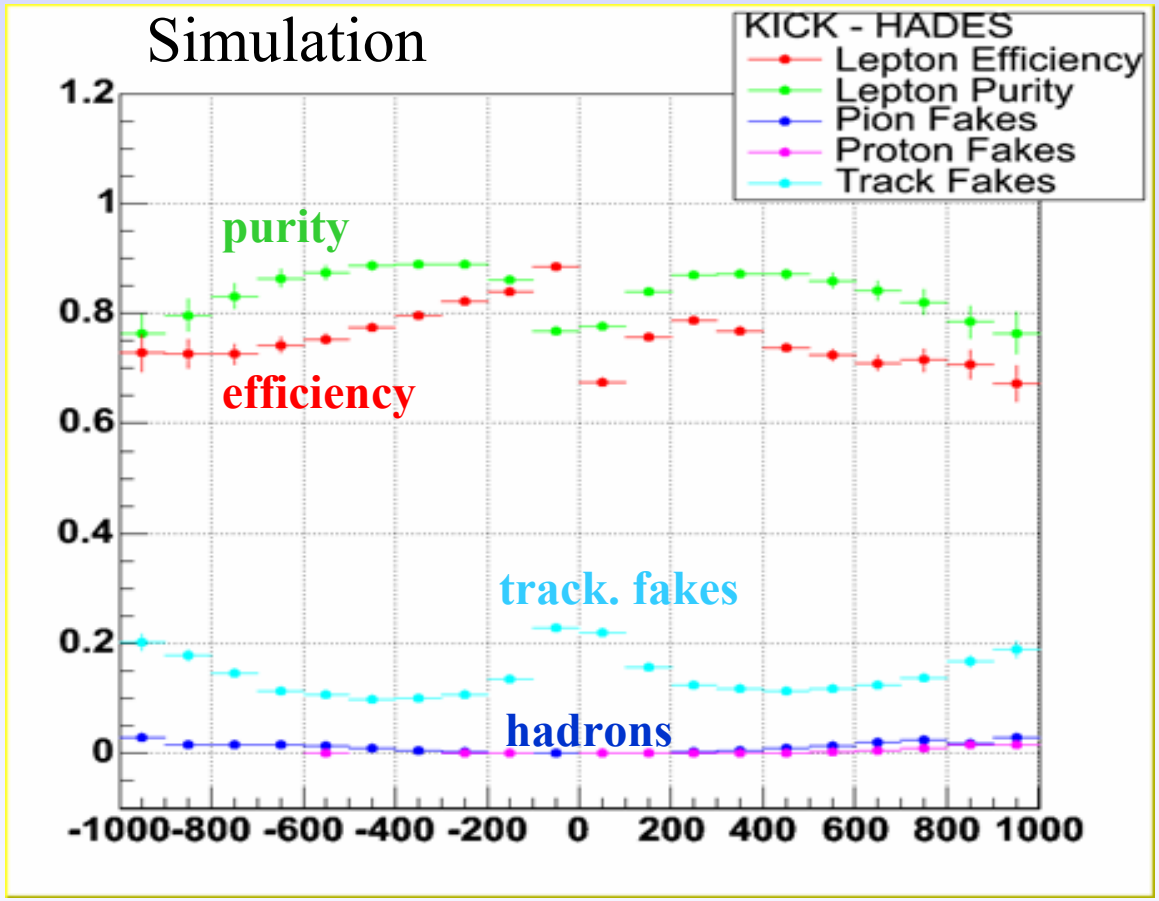


Momentum * charge [MeV/C]

HADES experimental runs

- November 2002: **C+C 2 AGeV commissioning and physics runs** LVL1
  - target= 2 x 2.5%, 56% d.s. LVL1 trigger + 44% LVL2 trigger **1200 Mevents**
  - 6 sectors with low-resolution tracking, 2 with high-resolution
- October 2003: **p+p commissioning run (1 GeV, 2 GeV)**
  - full coverage with outer MDC III (4 MDC IV, $\Delta p/p \approx 3.5$ % at 0.7 GeV/c)
- February 2004: **p+p 2.2 GeV production run**
  - target 5 cm LH_2 **500 Mevents**
- August 2004: **C+C 1AGeV production run**
  - 3x1.5 % target, 50% d.s. LVL1 trigger + 50% LVL2 trigger **1650 Mevents**
- September 2005: **Ar+KCl 2AGeV production run**
  - 4x1.0 % target, 50% d.s. LVL1 trigger + 50% LVL2 trigger **2200 Mevents**

Singles efficiencies and purities after PID and matching



Low-resolution tracking mode used ($\sigma_M/M \approx 10\%$)

Efficiency: ≈80%

Purity: ≈85%

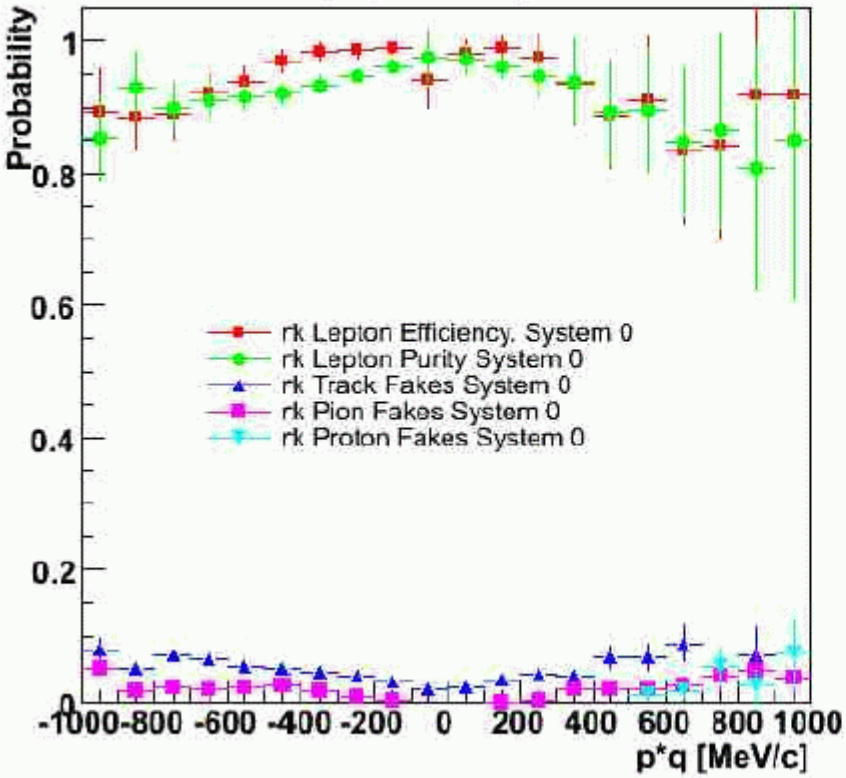
Contamination:

- lepton fakes ≈15% (mostly closed pairs)
- hadrons <3%

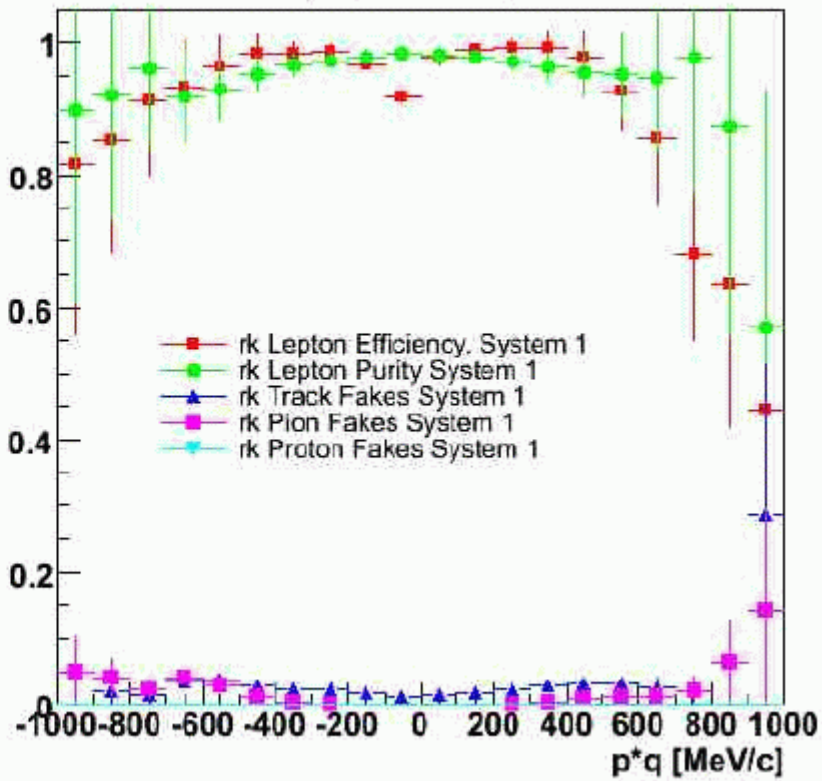
High-resolution analysis

(2 sectors only)

$\theta < 45^o$



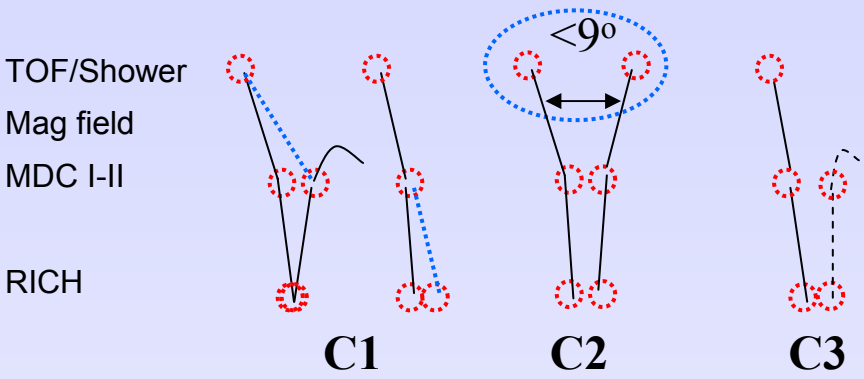
$\theta > 45^o$



Efficiency: >90%

Purity: >95%

Pair clean-up strategies



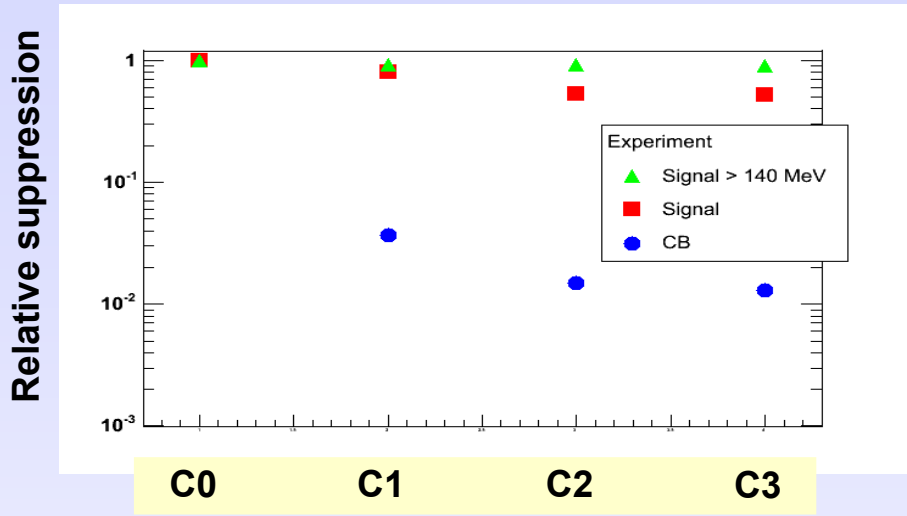
Pair rejection cuts:

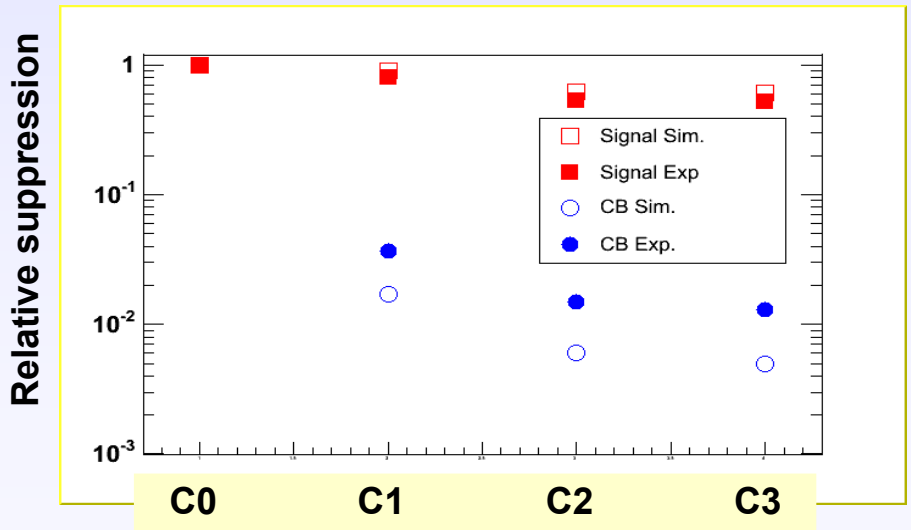
- **C0 = pairing**
- **C1 = C0 + double hit rejection**

  Remove tracks with ambiguous detector hit(s)
- **C2 = C1 + opening angle <9°**

  Remove both tracks from sample
- **C3 = C2 + close pair cand. rejection**

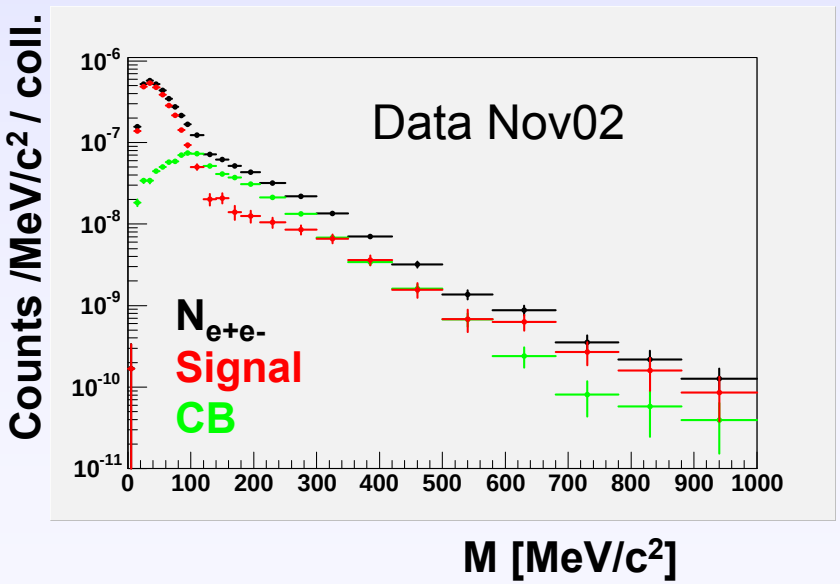
  Remove track if a non-fitted track candidate is within 10°

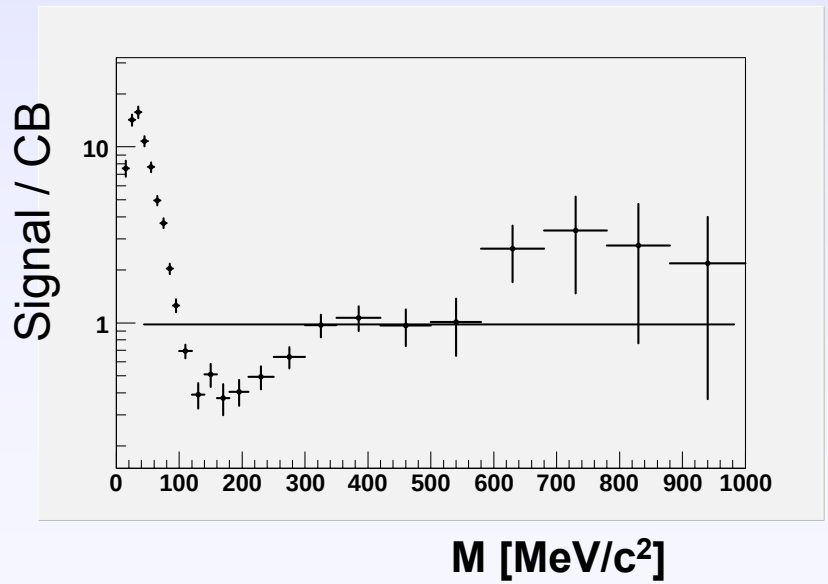




Combinatorial background subtraction

- **Combinatorial background (CB):**
  - from like-sign pairs
  - $CB_{+-} = N_{e+e+} + N_{e-e-}$ or $CB = 2 \bullet \sqrt{N_{e+e+} N_{e-e-}}$
- **Signal:**
  - $S_{+-} = N_{e+e-} - CB_{+-}$

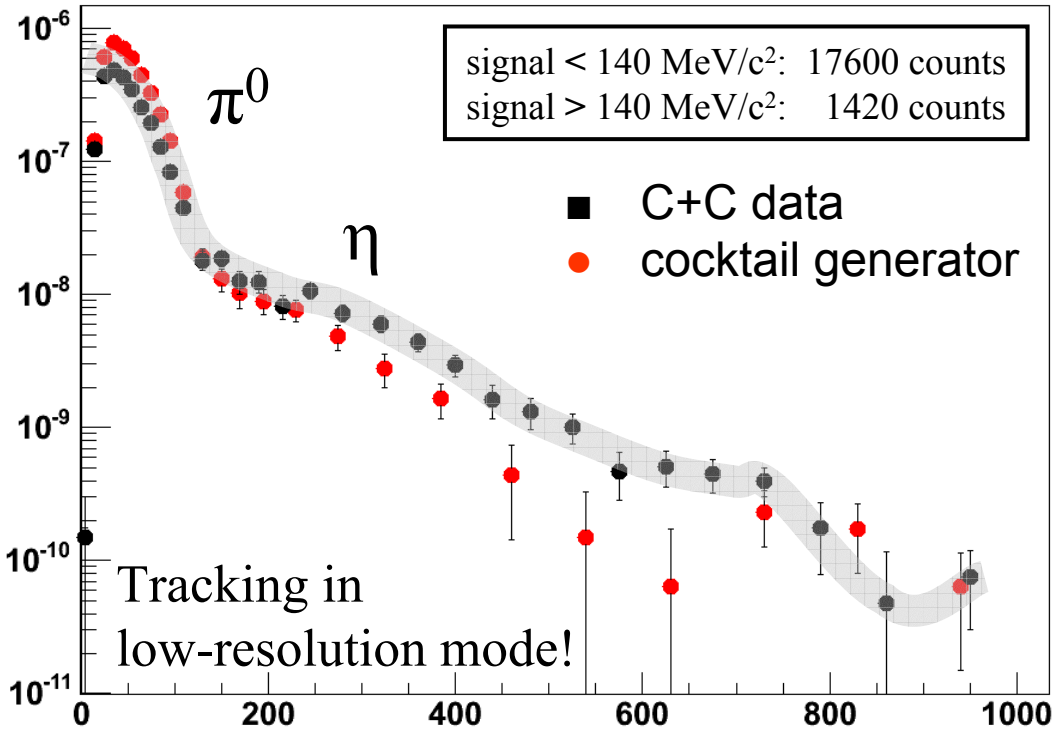




Raw 2 AGeV C+C e^+e^- mass spectrum

No efficiency / acceptance correction!
Normalized to the pion multiplicity.

$$\frac{1}{M_{\pi^0} N_{evt.}^{LVL1}} \frac{dN}{dM_{e^+e^-}} \left[\mathrm{MeV/c^2}\right]^{-1}$$



$M_{e^+e^-}\left[\mathrm{MeV/c^2}\right]$

Systematic errors:

- PID cuts
- pair clean-up
- normalization

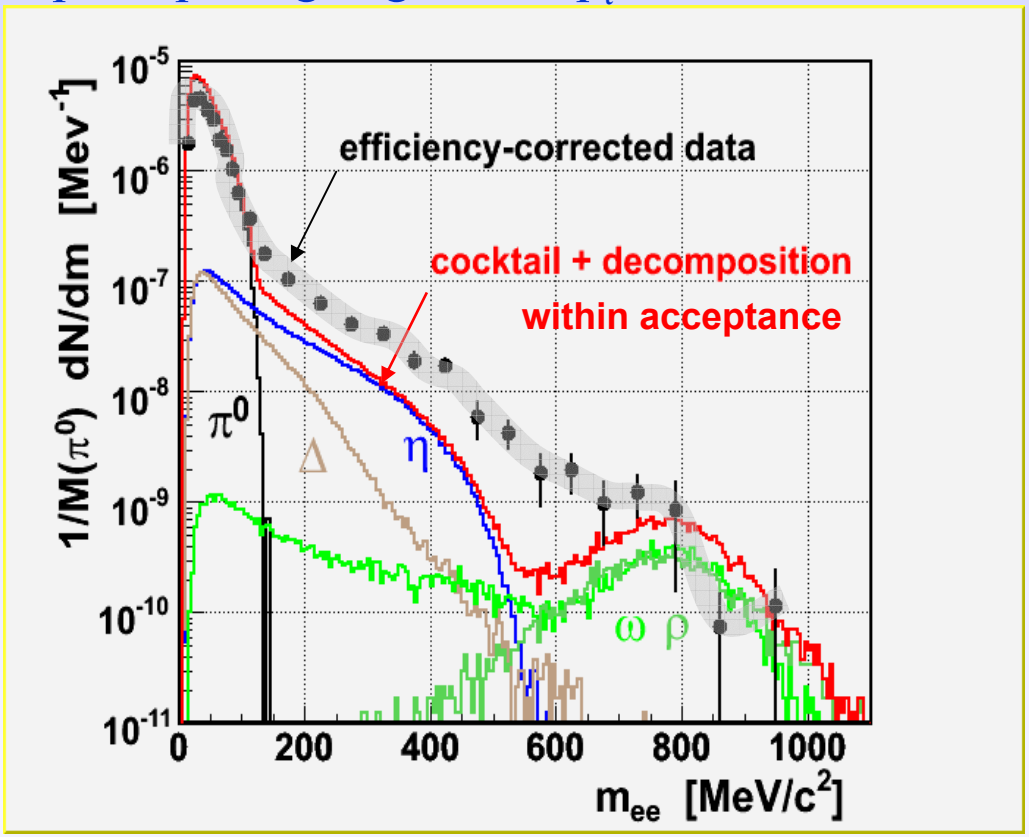
$\Rightarrow$ **+40%/-30%**

Efficiency-corrected mass spectrum

pair opening angle >9°, p_t > 100 MeV/c

Efficiency correction applied to pair data (e^- and e^+ legs):

→ accounts for
- detector inefficiencies
- reconstruction inefficiencies



Compared with a cocktail based on known or m_t-scaled meson multiplicities and their vacuum decay properties within HADES geometric acceptance and mass resolution ($\sigma_m(\omega)$ = 10%).

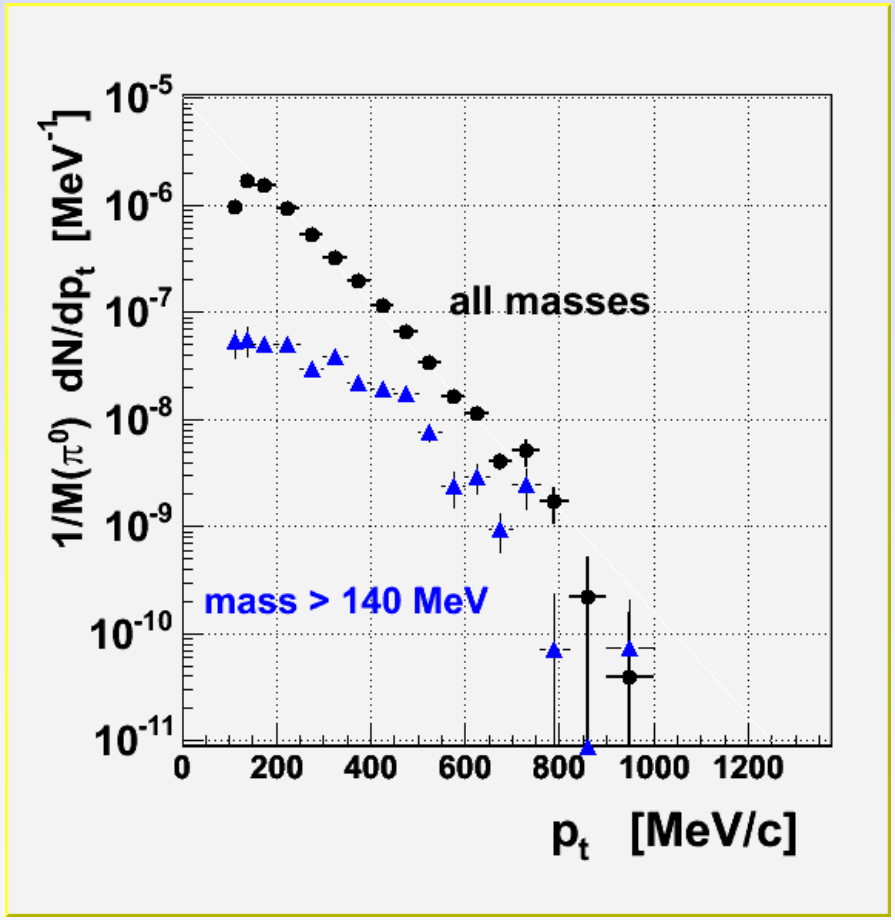
systematic errors: +50%/-40%

p_t spectra with mass cuts

pair opening angle >9°, p_t > 100 MeV/c

efficiency-corrected data

only statistical errors are shown



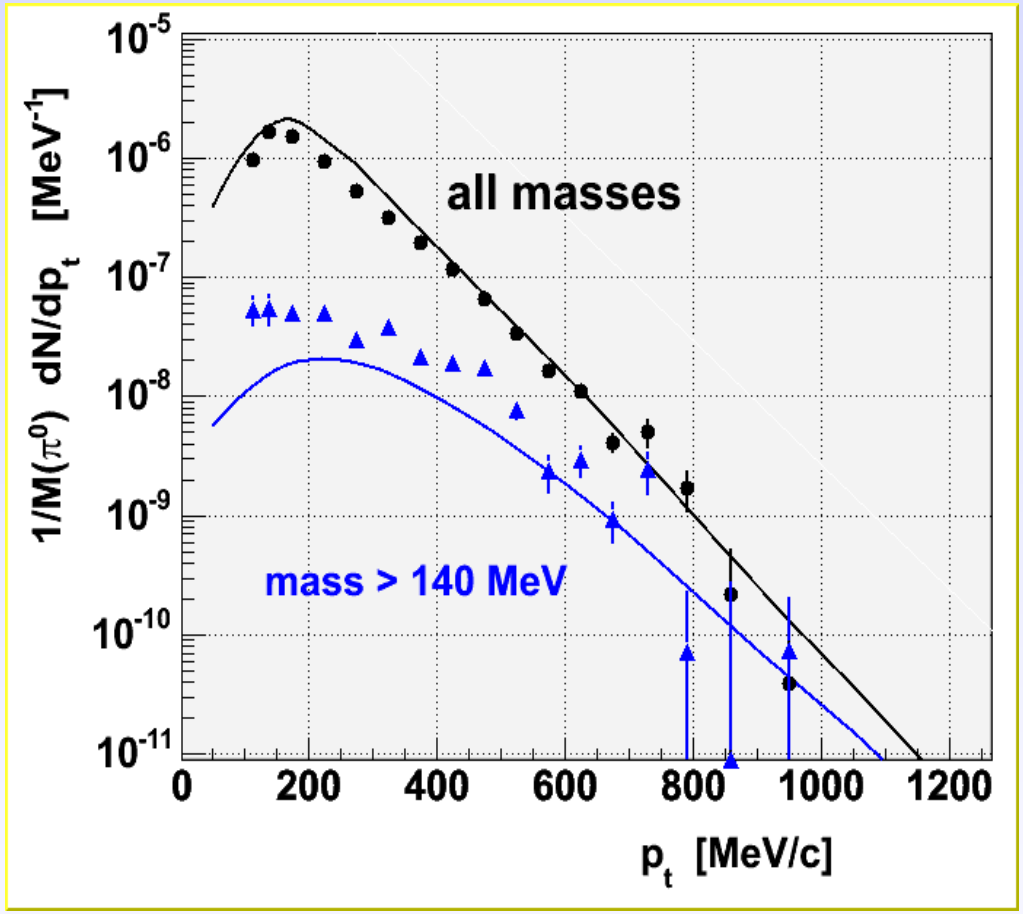
Comparison with transport theory (I)

HSD v2.5 of May ´05, E. Bratkovskaya et al.

- Giessen HSD
- Tübingen RQMD
- Rossendorf
- Frankfurt UrQMD
- etc.

Comparison of efficiency-corrected data with theory folded with HADES filter:

- geometrical acceptance
- momentum resolution

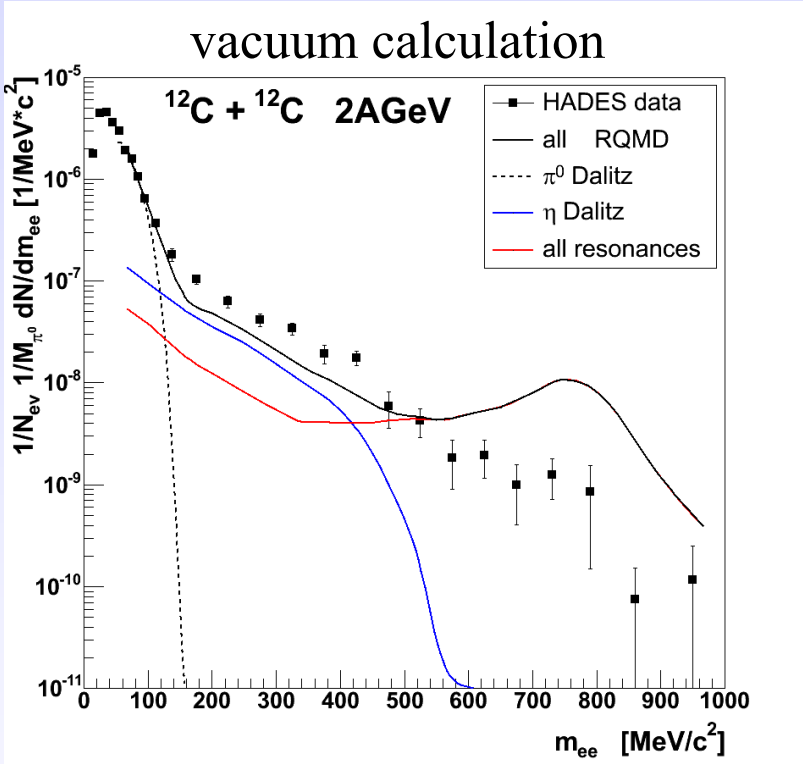


pair opening angle >9°, P_t > 100 MeV/c

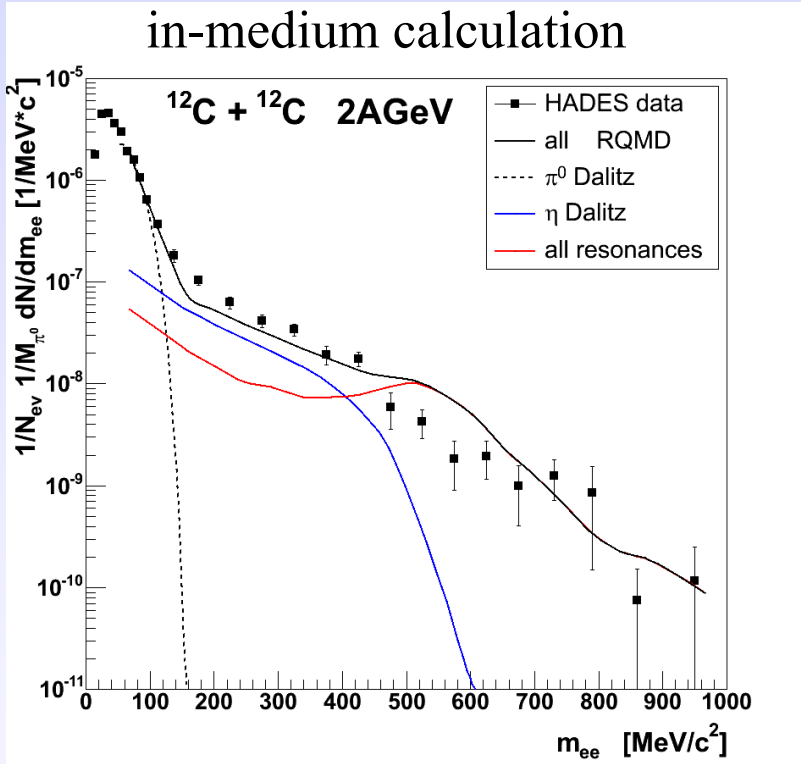
Comparison with transport theory (II)

RQMD calculation done by D. Cozma and C. Fuchs

vacuum calculation



in-medium calculation

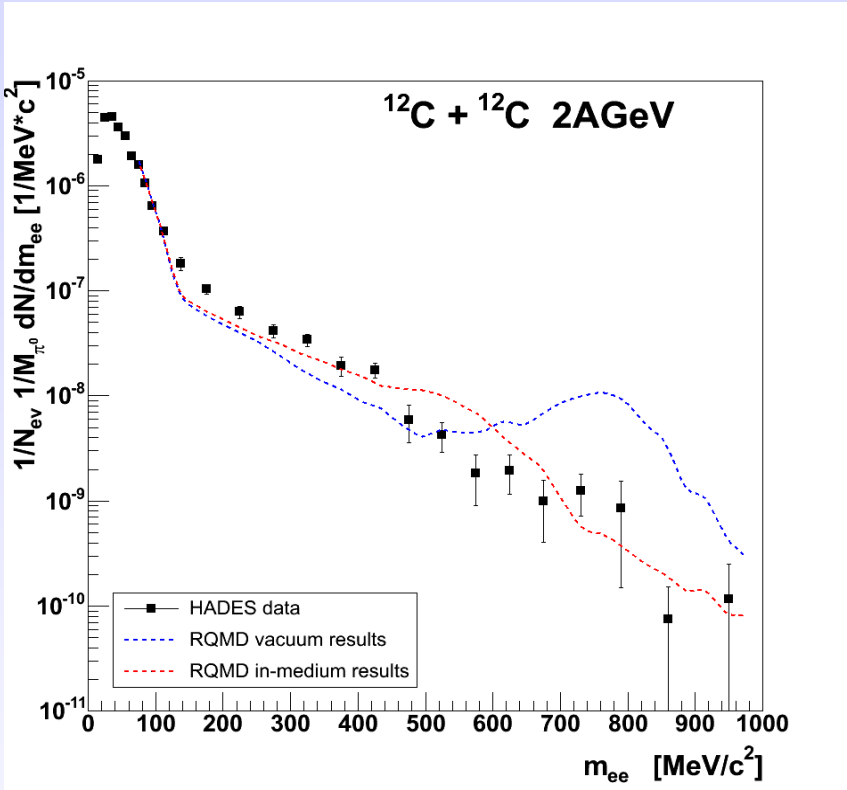


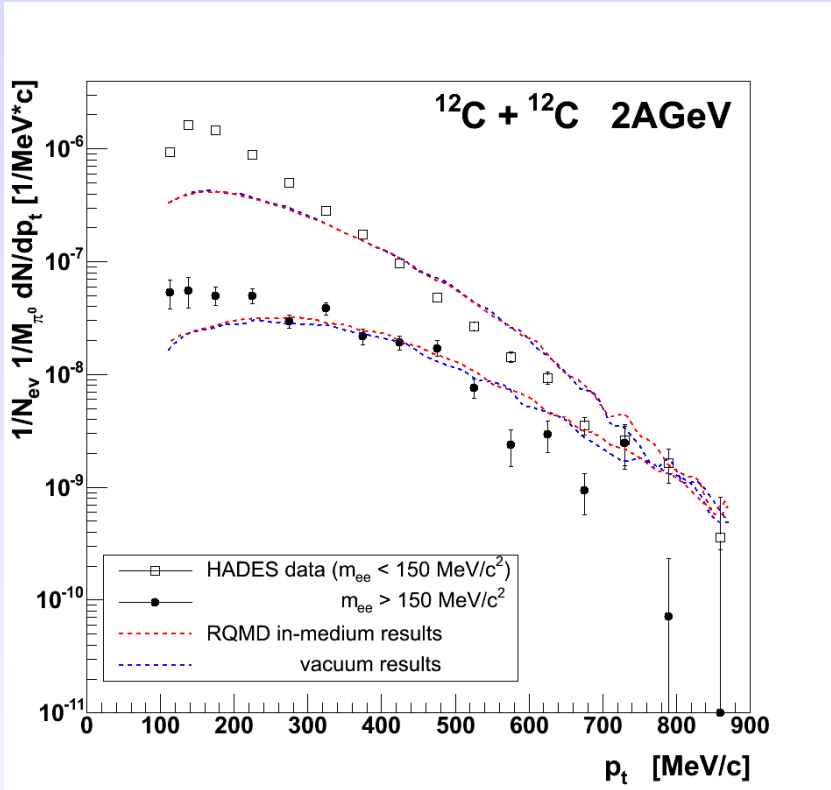
pair opening angle >9°
P_t > 100 MeV/c
resolution smeared

- collisional broadening
- extended VDM + decoherence
- Brown-Rho scaling of VMs

See Phys. Rev. C68 (2003) 014904 for details.

RQMD mass and p_t spectra

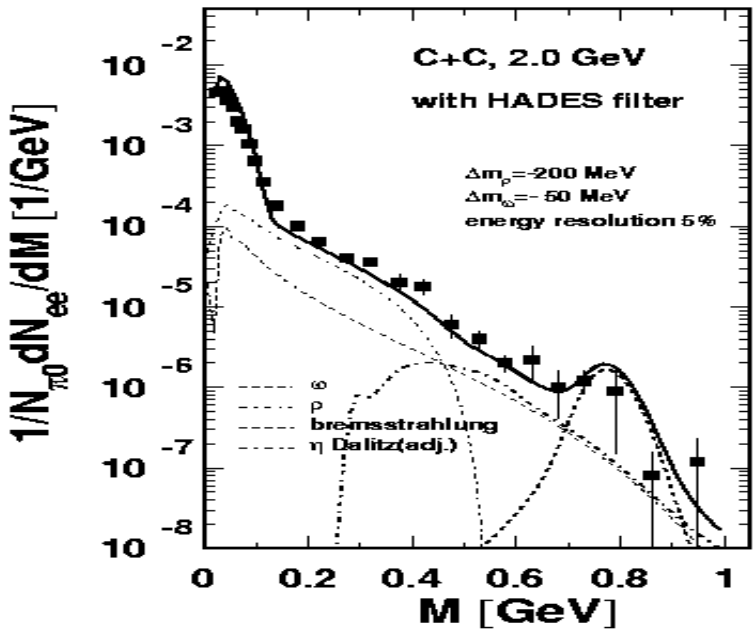




Comparison with transport theory (III)

Calculation done by B. Kämpfer et al.

(preliminary!)



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  - 6 outer drift chambers (MDC) in 4 sectors

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- September 2005: Ar+KCl 2AGeV production run
  - 4x1.0 % target, 50% d.s. LVL1 trigger + 50% LVL2 trigger — 2200 Mevents

Proton beam @ E_{kin}=2.2 GeV

$p + p \rightarrow p + p + X$

total Cross Section : 47mb	
2 charged particles : 43mb	
4 charged particles : 4mb	
$pp^{elastic}$	18.00 mb
$pn\pi^+$	13.80 mb
$pn\pi^+\pi^0$	4.00 mb
$pp\pi^0$	2.85 mb
$pp\pi^0\pi^0$	1.00 mb
$pp\pi^0\pi^0\pi^0$	0.13 mb
$p\Delta^+$	3.20 mb
$p\Delta^{++}\pi^-$	2.00 mb
$pp\pi^+\pi^-$	1.00 mb
$pp\pi^+\pi^-\pi^0$	0.40 mb
$pn\pi^+\pi^+\pi^-$	0.40 mb
$pn\pi^+\pi^0\pi^0$	0.40 mb
$pN(1535)\rightarrow p\eta$	0.15 mb

(from literature)

2-prong events:

- pp elastics scattering → test detector performance
- pp inelastic channels → inclusive π^0 and η prod.
- e^+e^- pairs → inclusive dilepton production

4-prong events:

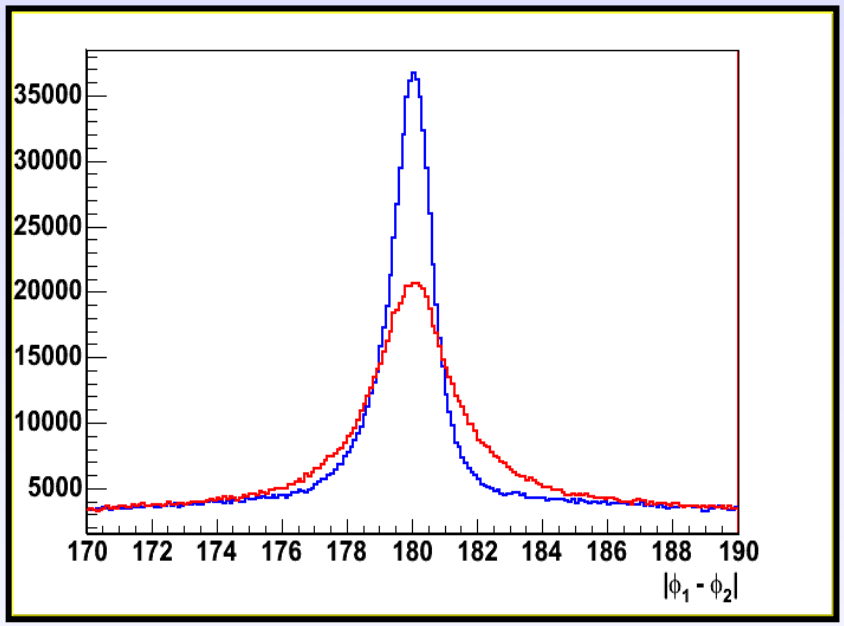
- hadronic channel $p\ p \rightarrow p\ p\ \pi^+\ \pi^-$
  → exclusive η production → **coupling to N^***
- leptonic channel $p\ p \rightarrow p\ p\ e^+\ e^-$
  → exclusive π^0 and η production → **η form factor**

Data taken in high-resolution mode!

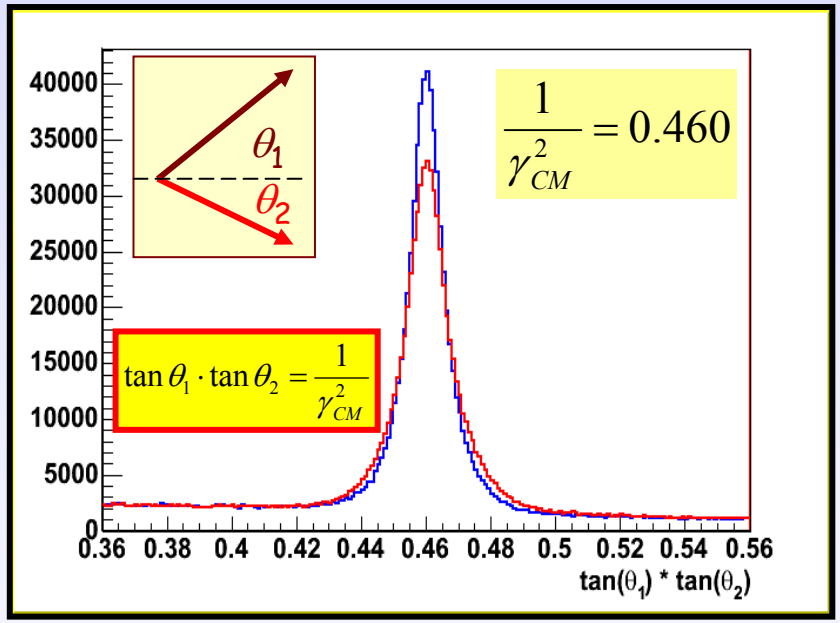
pp elastics scattering at 2.2 GeV

Coplanar reaction geometry!

Azimuthal angles



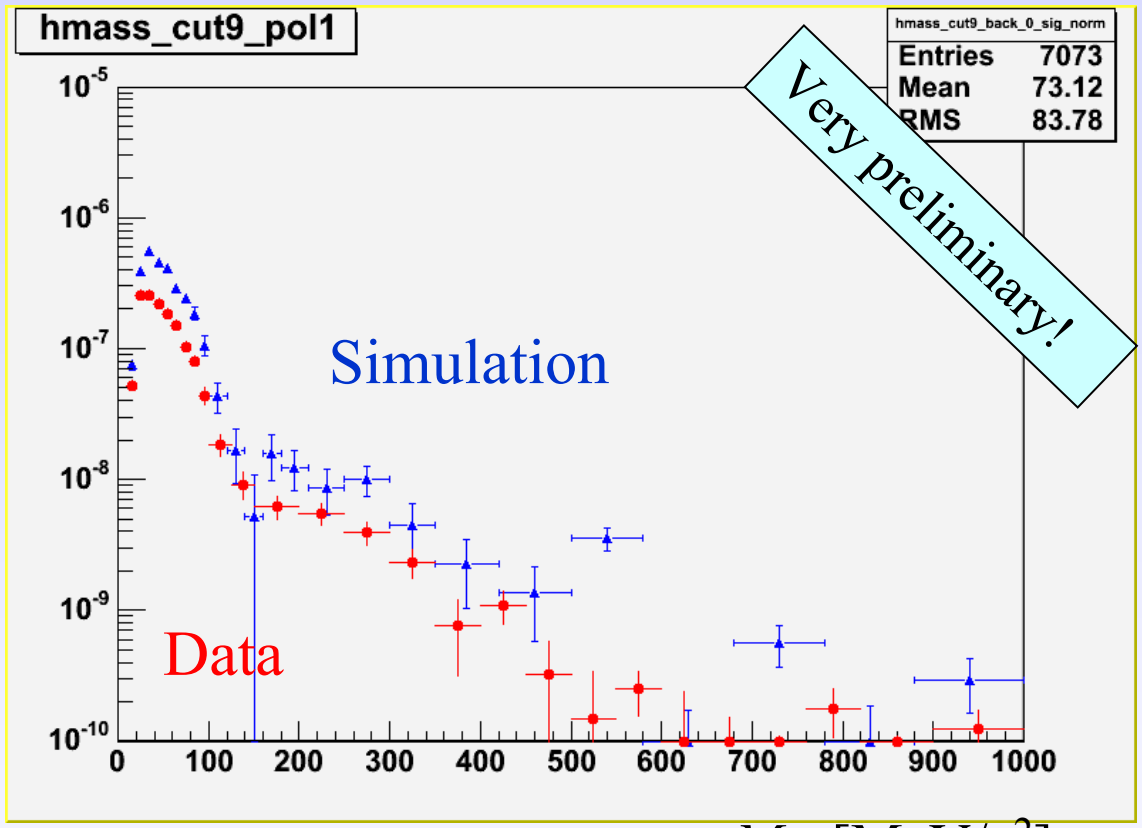
Polar angles



Spline: $\Delta\varphi = 180.0 \pm 1.4^{o}$
RK: $\Delta\varphi = 180.0 \pm 0.7^{o}$

Tests detector alignment and momentum resolution: σ_p/p = 4-5%

Inclusive e^+e^- production at 2.2 GeV



To be compared with A+A!

Exclusive η from 4-prong events

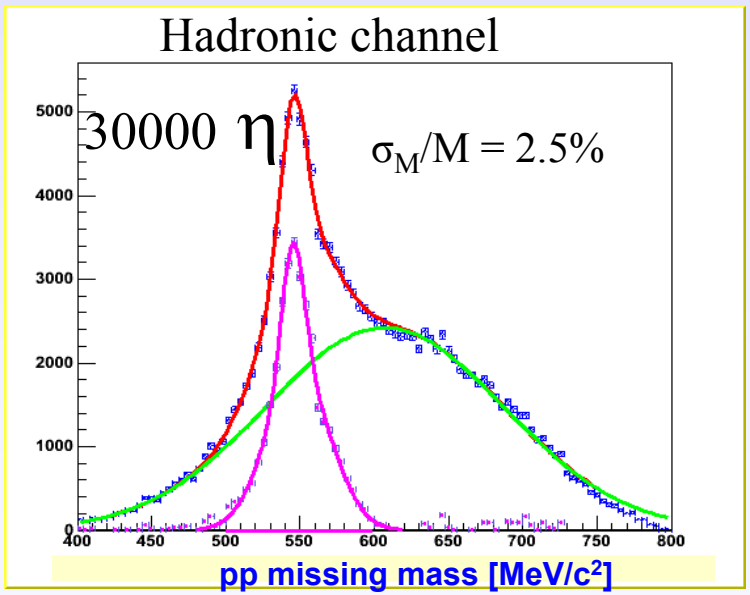
$pp \rightarrow pp\eta$ BR=22.6% $\rightarrow \pi^+\pi^-\pi^0$

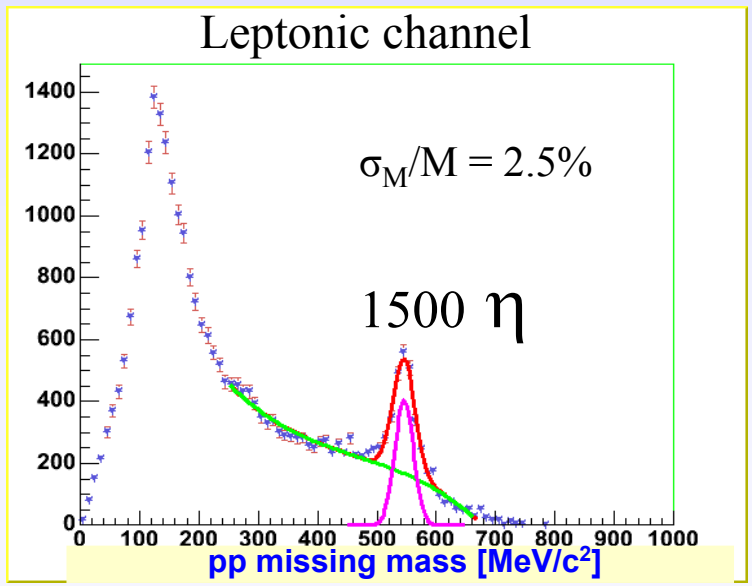
Constraint: $miss.\ mass\ of\ (pp\pi^+\pi^-) = M(\pi^0)$

$pp \rightarrow pp\eta$ BR=0.6% $\rightarrow e^+e^-\gamma$

Constraint: $miss.\ mass\ of\ (ppe^+e^-) = M(\gamma) = 0$

Result of kinematic refits:





Ph.D. A. Rustamov

→ η form factor

Conclusions & outlook

- HADES is up and running!
- First physics results obtained on C+C and p+p! (to be published soon!!!)
- Ongoing analysis of pp data
- Ongoing analysis of more 1 AGeV C+C and 2 AGeV Ar+KCl data
- Scheduled physics runs:
  - proton, deuteron and pion beams (2006)
- Completion of outer tracking system (end 2005) → full hi-res tracking
- Upgrade of TOF subsystem with RPC (2007) → Ni+Ni & Au+Au runs
- Feasibility studies for HADES operation at FAIR → 2-8 AGeV runs

The people behind it

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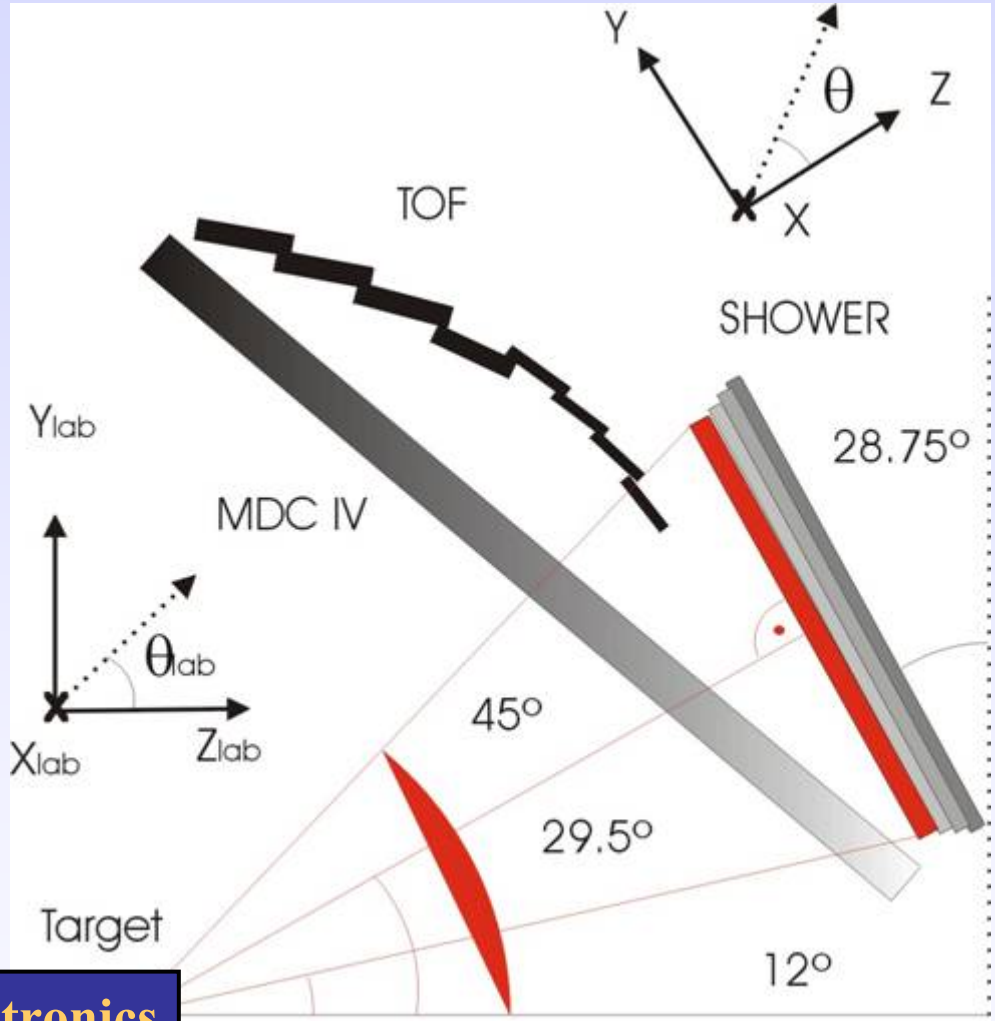
Upgrade: TOFINO replacement by RPC

- **TOFINO:**
- **time-of-flight between 18°-45°**
  - 4 paddles per sector only
  - limited resolution (350 ps)
  - insufficient granularity for HI

→ **Replace by RPCs**

Aim for:

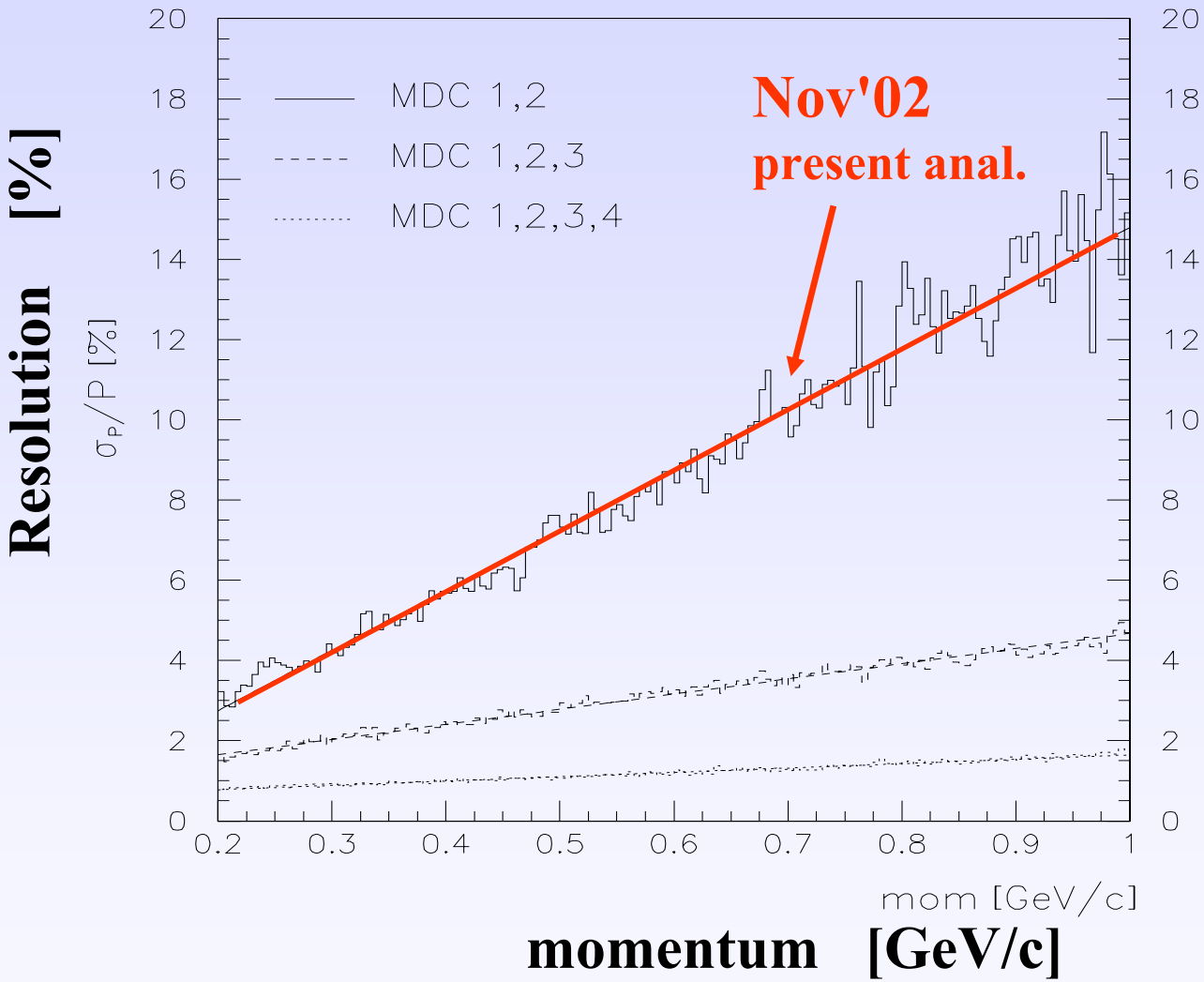
- better particle ID
- higher granularity
  → Au+Au system!



Sector array + readout electronics in beam test right now!!!

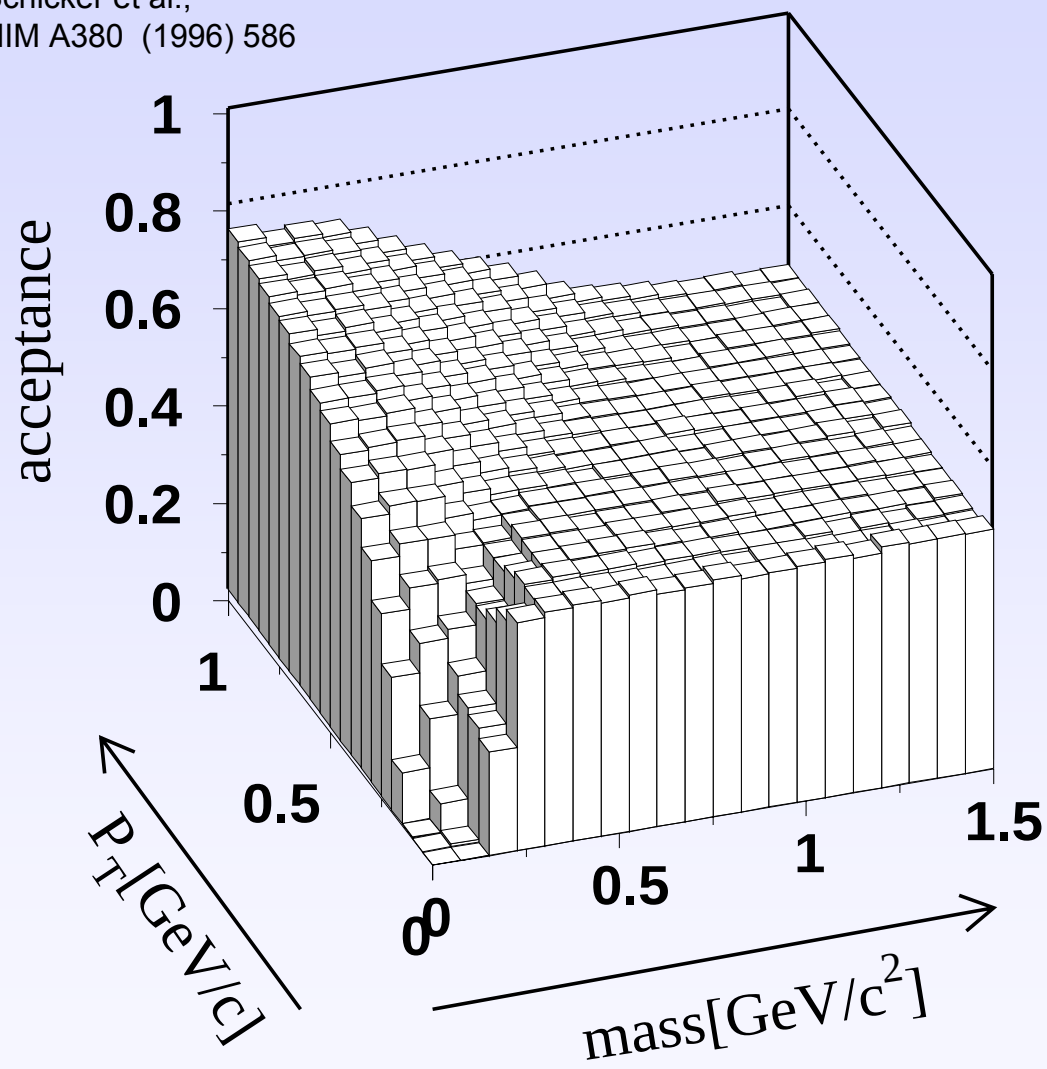
Cavalry to the rescue!

Momentum resolution: 2,3,4 MDC planes



HADES geometrical acceptance

Schicker et al.,
NIM A380 (1996) 586



Rapidity: y = 0.2 – 1.7

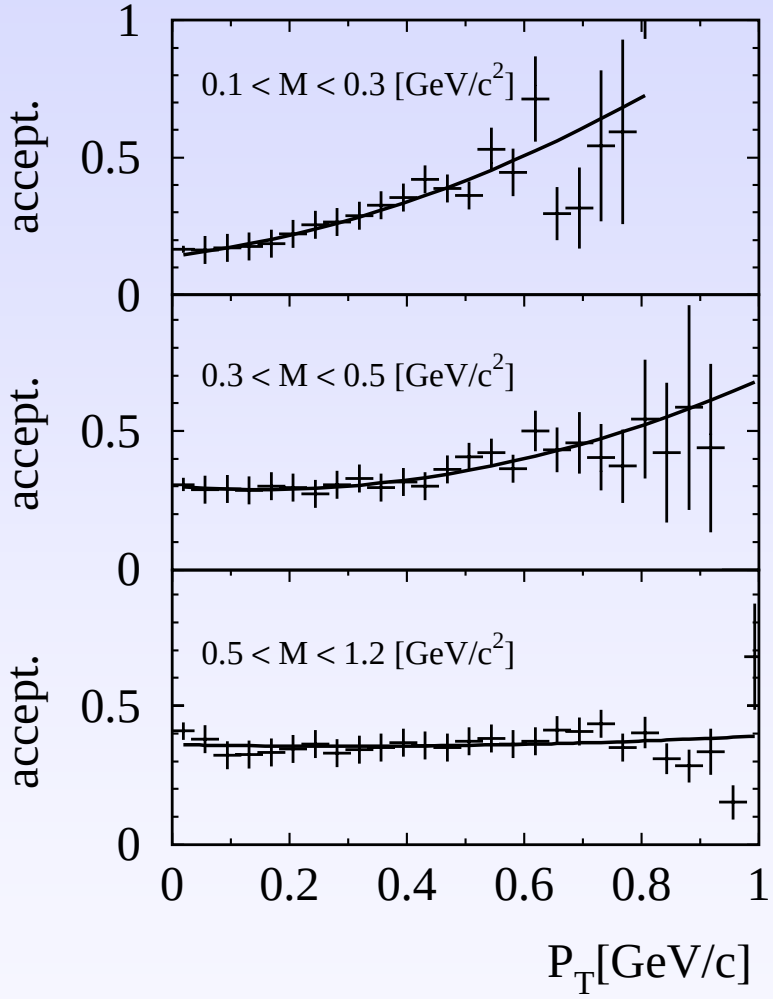
(DLS had 0.7 – 1.6)

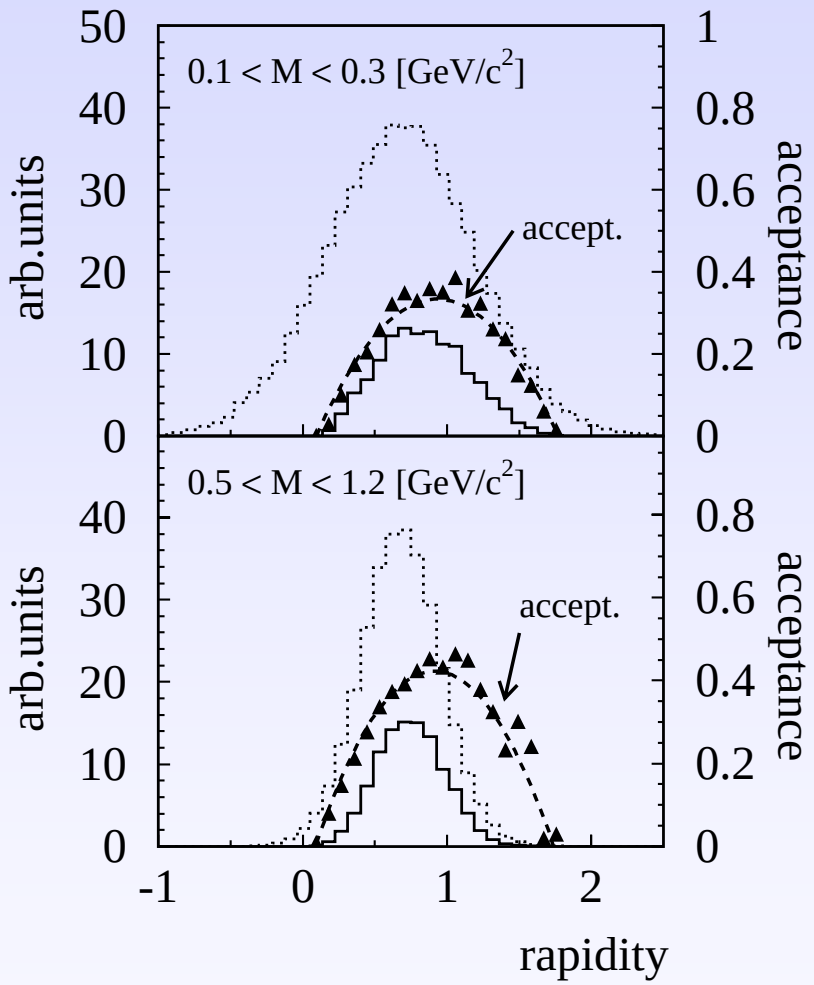
For comparison:

$y_{1/2}$ = 0.68 @ 1 AGeV

$y_{1/2}$ = 0.91 @ 2 AGeV

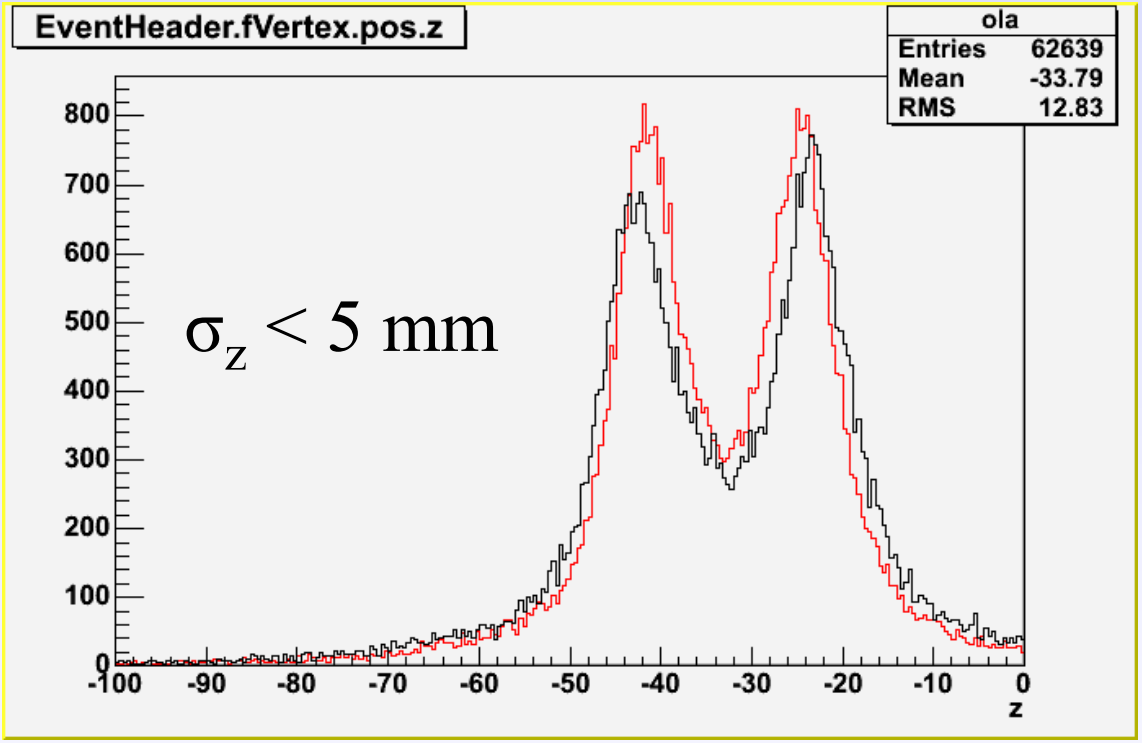
p_T & y acceptances



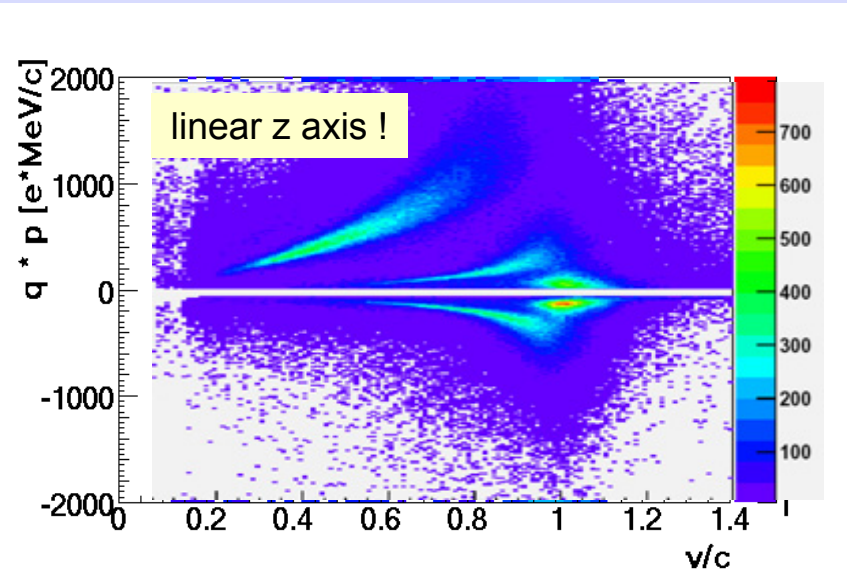


Event vertex resolution

Segmented C target: 2 x 2.5%, 2 cm apart



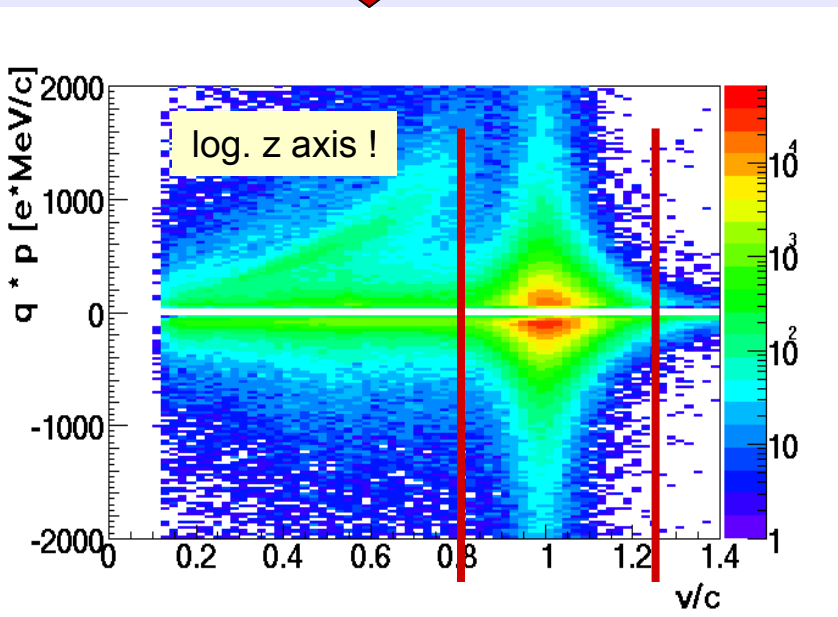
Electron/positron identification

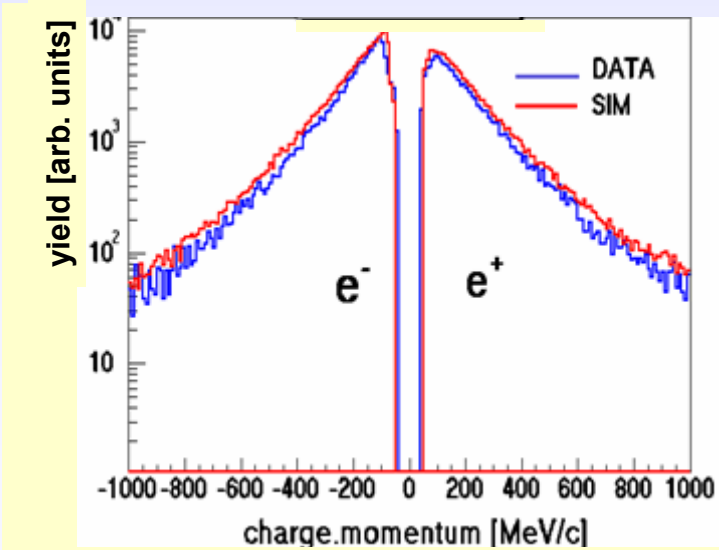


Events with lepton multiplicity ≥1 in LVL1 triggered events: only 1.2 % !

Matched RICH and META signals (LVL2)

+ matching with fully reconstructed tracks



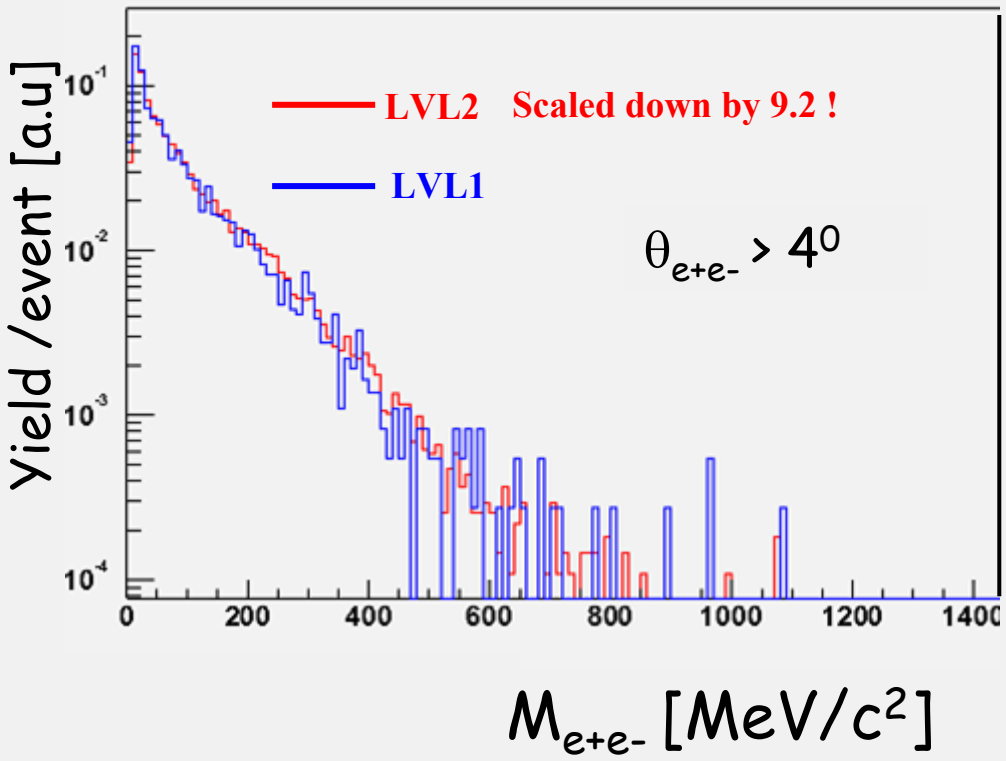


cut on β

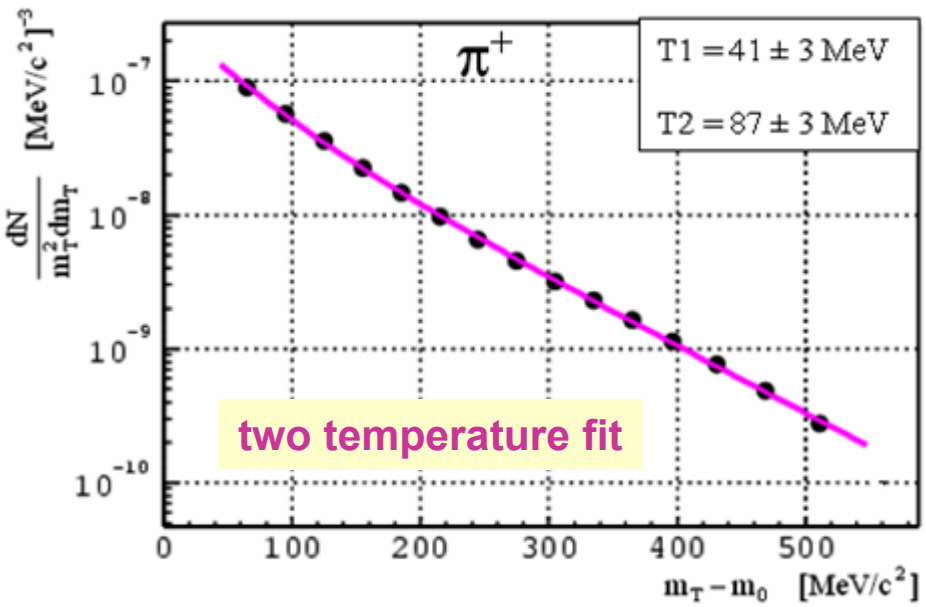
On-line/off-line comparison

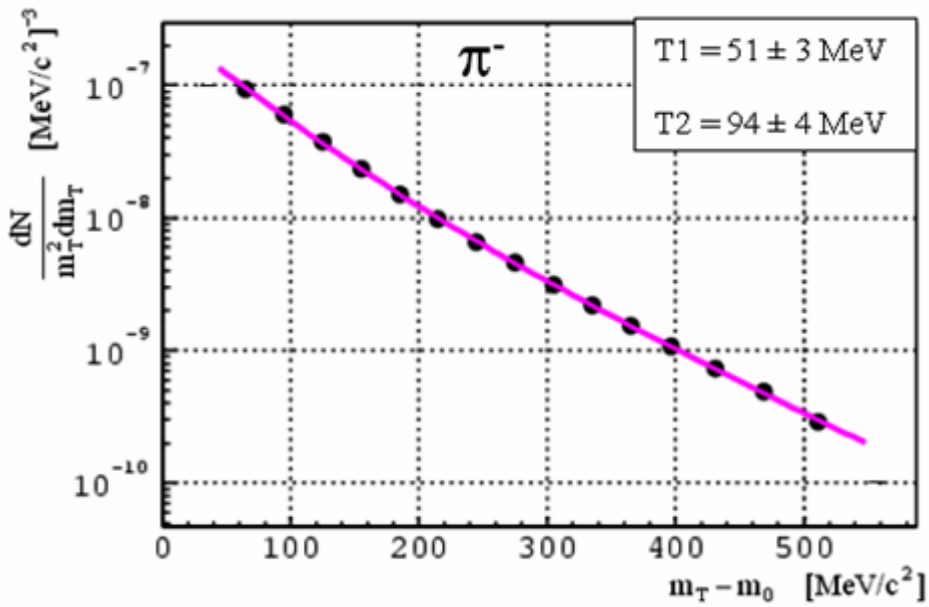
- **Trigger condition used in November 2002 run:**
  - At least one good electron candidate
  - Ring matched with META hit
- **Data rate reduced by 92 %**
- **Pair enhancement by factor of ≈ 9**
- **Single lepton efficiency of IPUs + matching ≈ 62% (pairs 82%)**

No bias on data !



Charged pions (C+C @ 2 AGeV)

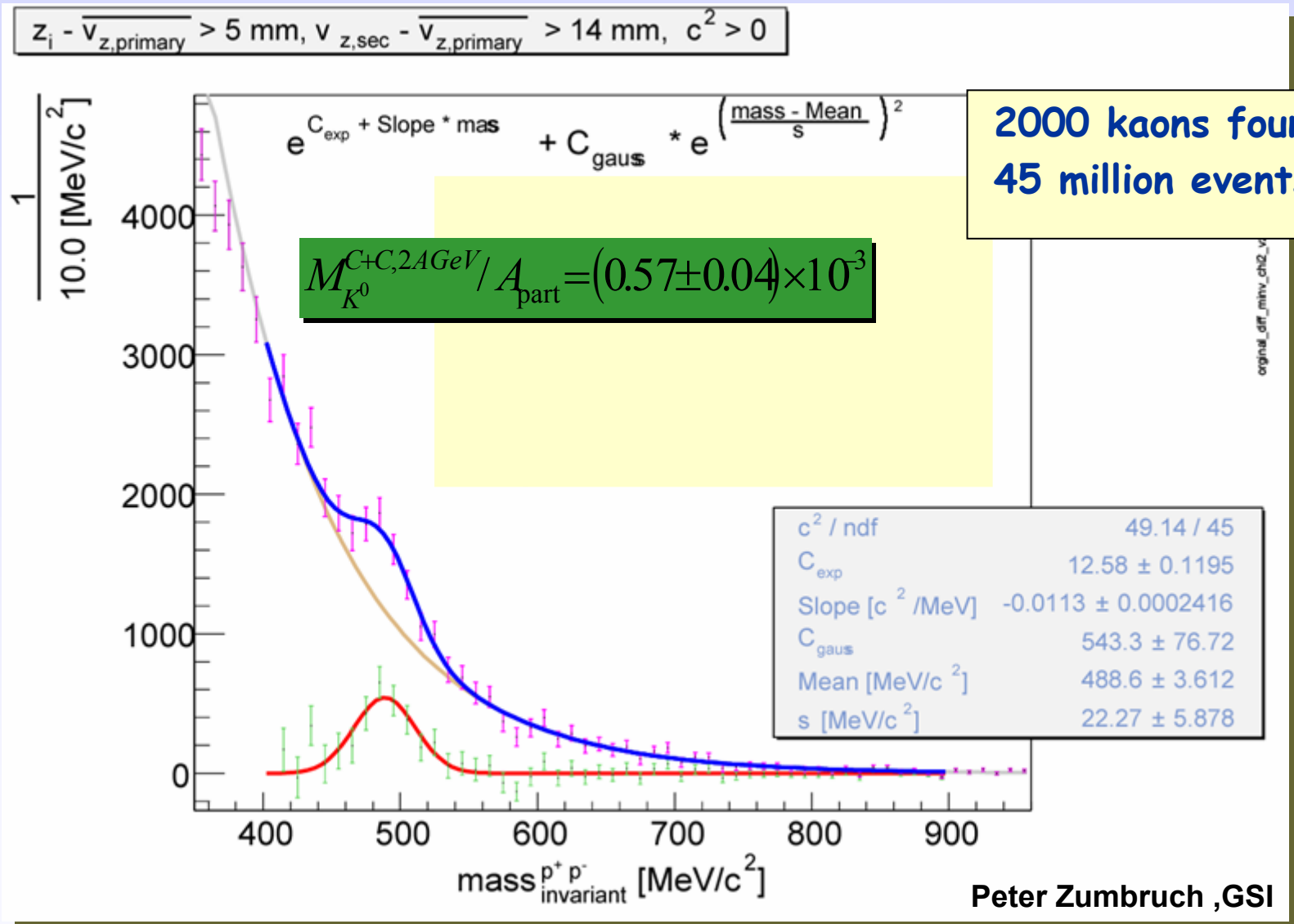




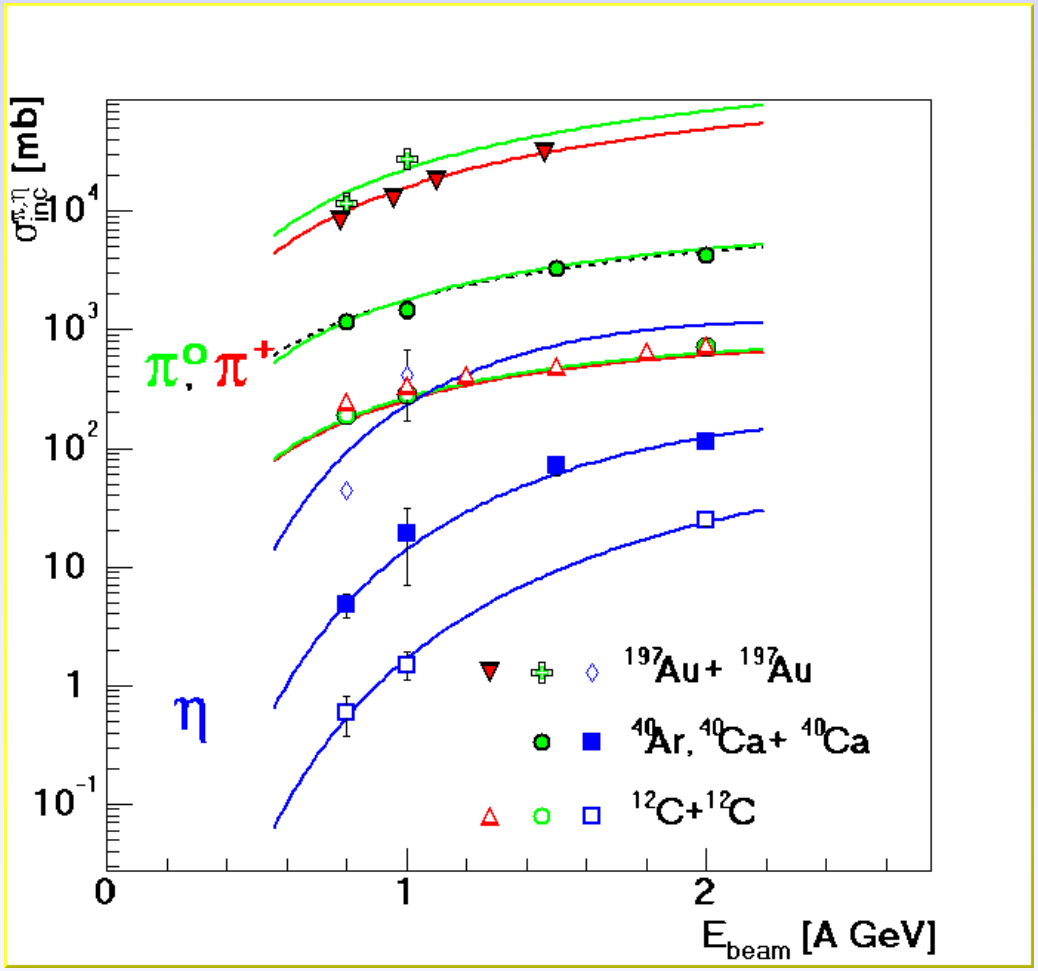
	Multiplicity	"Temperature"
HADES	$N_{\langle\pi^+\pi^-\rangle}/A_{\text{part}} = 0.148 \pm 0.018$	$T_{\pi^+} = 41 \pm 3;\ 87 \pm 3$ $T_{\pi^-} = 51 \pm 3;\ 91 \pm 4$
TAPS	$N_{\pi^0}/A_{\text{part}} = 0.138 \pm 0.014$	
KaoS	$N_{\pi^+}/A_{\text{part}} = 0.126 \pm 0.010$	$T_{\pi^+} = 40 \pm 3;\ 86 \pm 3$

Data in good agreement with TAPS/KaoS results!

$K^0 \rightarrow \pi^+\pi^-$ reconstruction (C+C @ 2 AGeV)



Meson multiplicity systematics

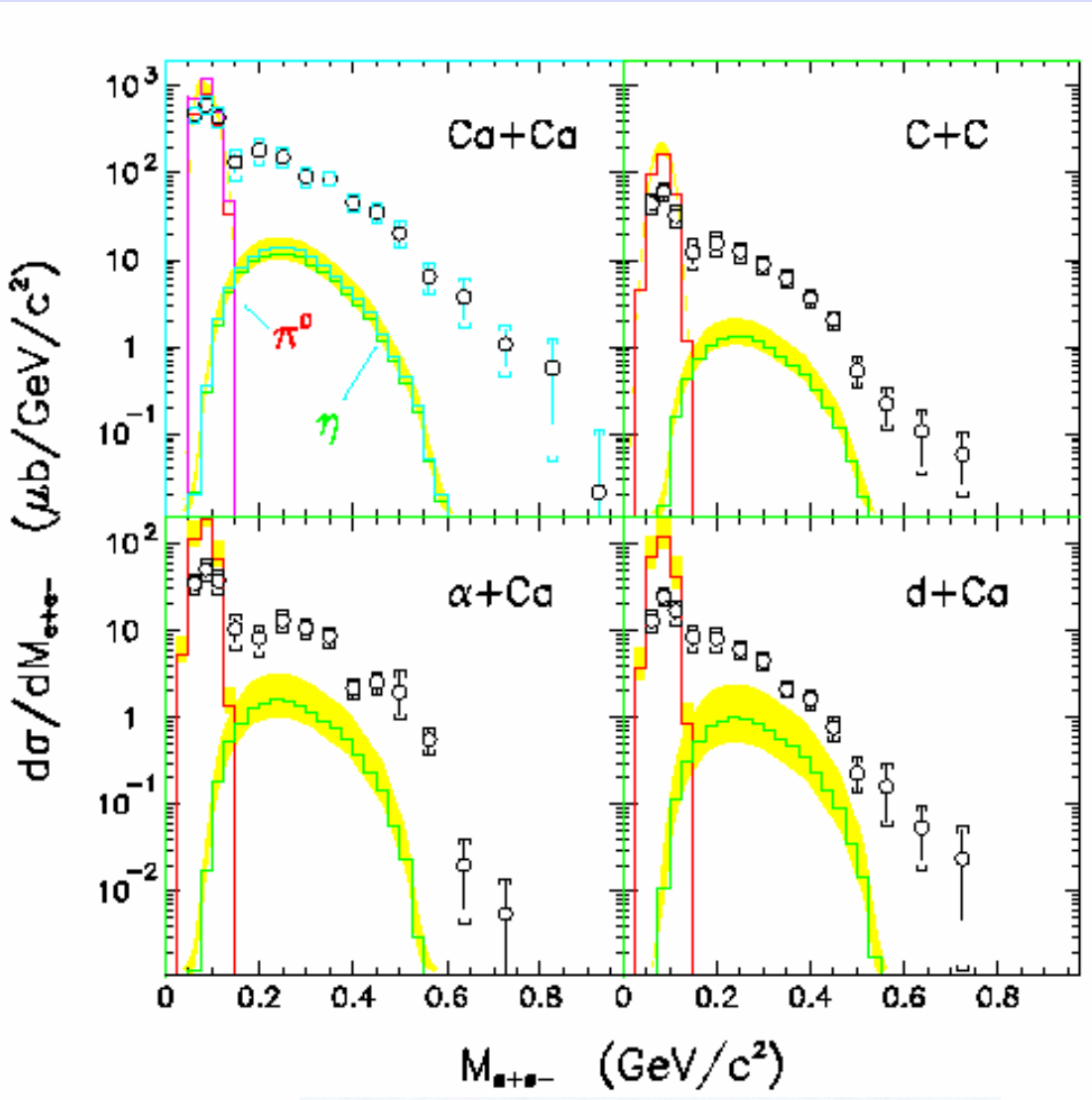


Data taken from:

- TAPS
- KaoS
- Bevalac exp.

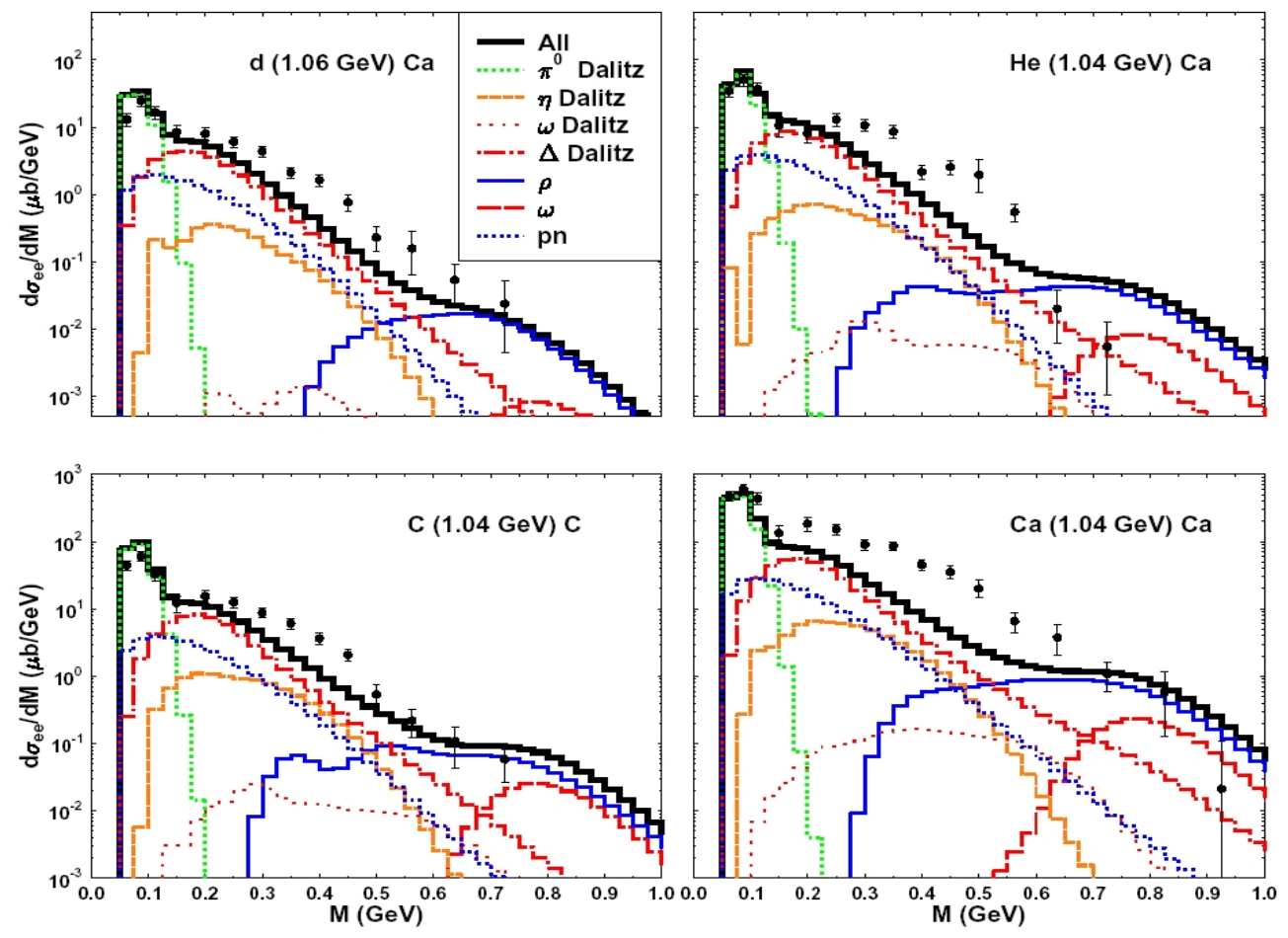
DLS excess yields

- DLS experiment observed large excess of di-electrons when compared to known sources
  - pion, eta Dalitz decays
- Effect much stronger than at SPS energies
- Visible also in light-ion induced reactions
- No conclusive theoretical explanation (yet)
  - Experimental problem or new physics ??



R.J. Porter et al., Phys. Rev. Lett. 79 (1997) 1229

General dilepton excess in DLS data!

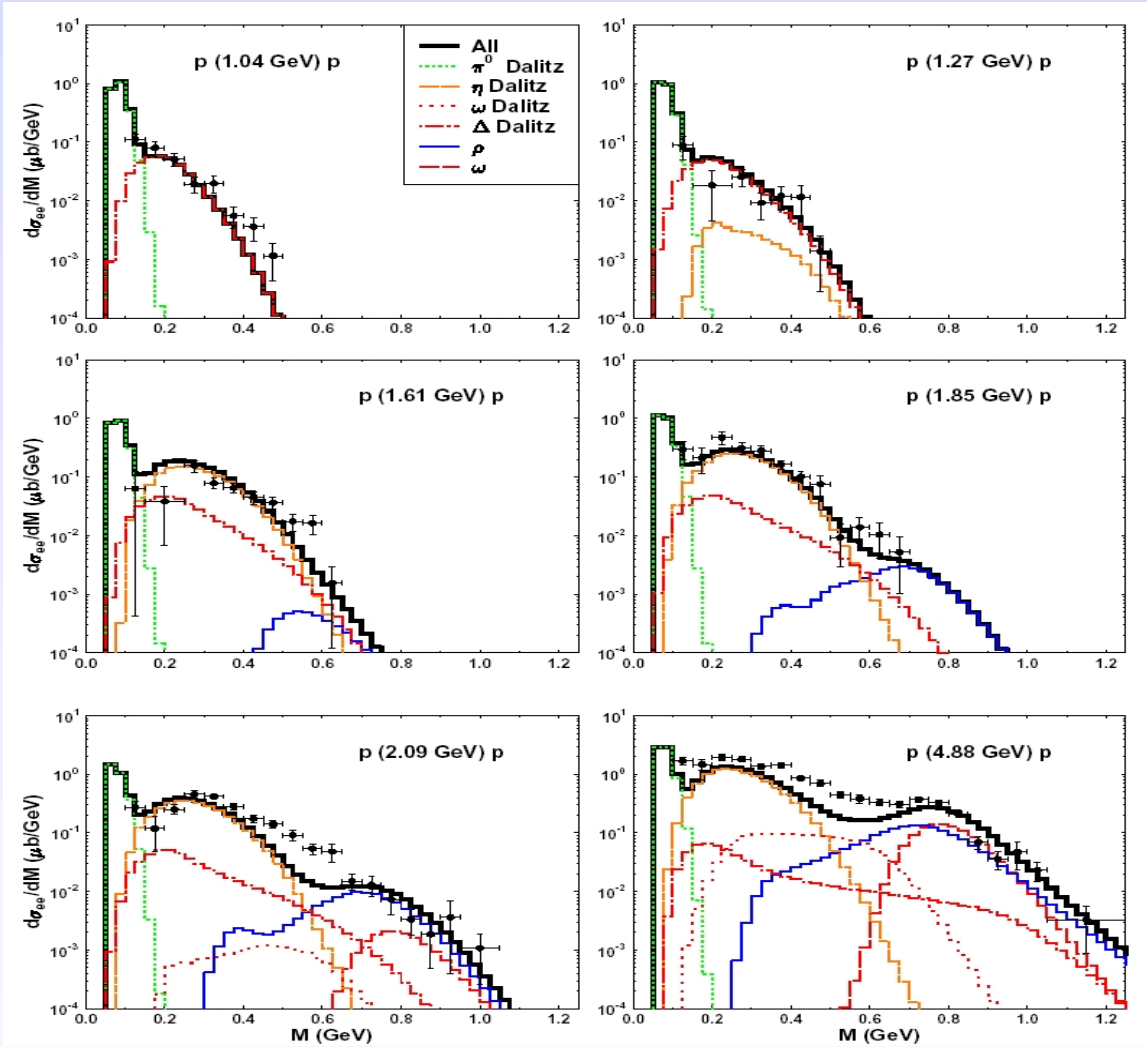


Theory:
Frankfurt UrQMD

Ernst et al. PRC 58

Overall
yield excess
in 0.2-0.6 MeV
mass region!

A reminder: the DLS pp data

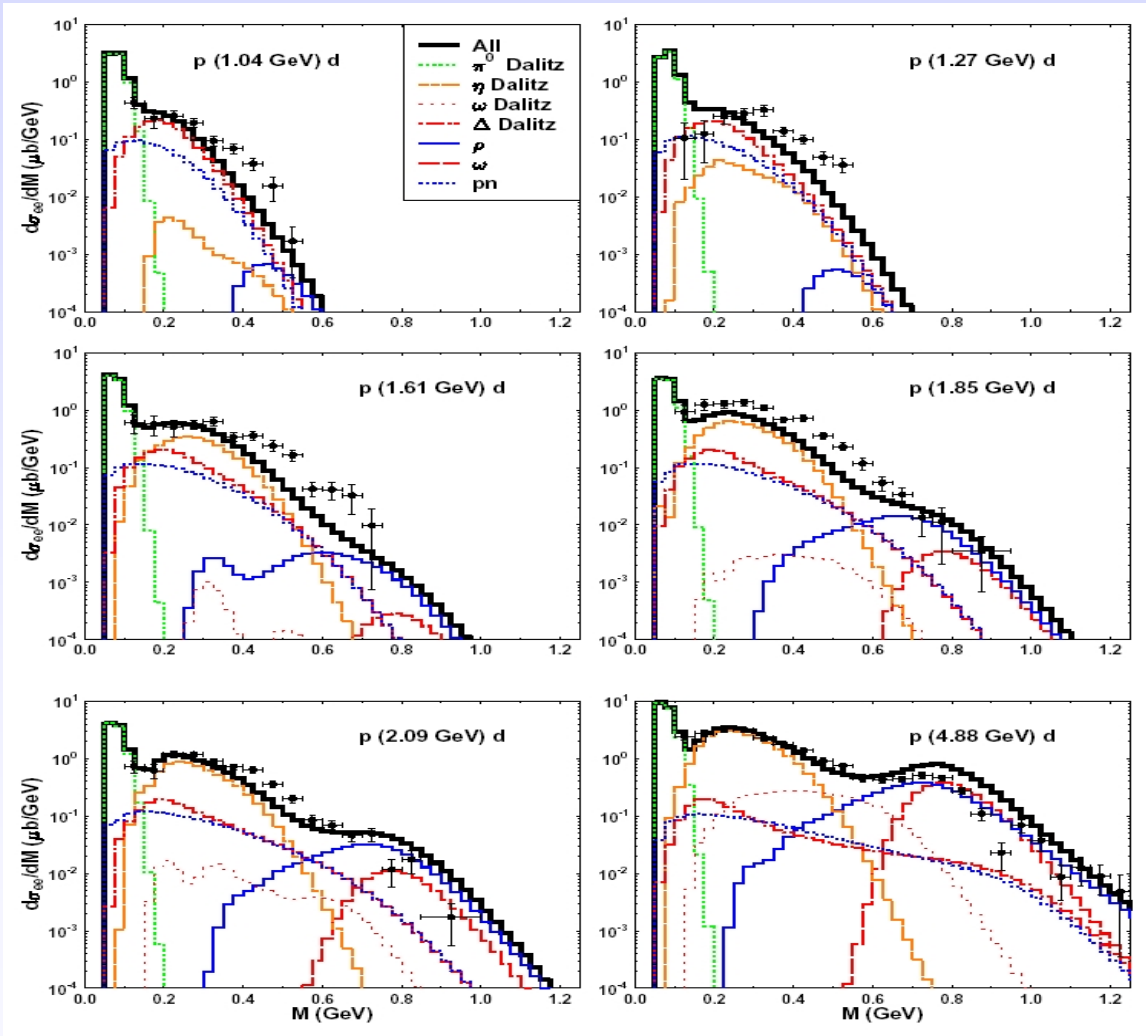


Data: Wilson et al.
PRC 57 (1997) 1865

Theory (folded with the DLS response):
C. Ernst et al.
PRC 58 (1998) 447

⇒ **Fair agreement of total yields**

Real trouble starts with pd data!



Data: DLS

Theory: Ernst et al.
PRC 58 (1998) 447

What's different?

- Fermi momentum
- correlations
- **pn** collisions

HADES in pictures