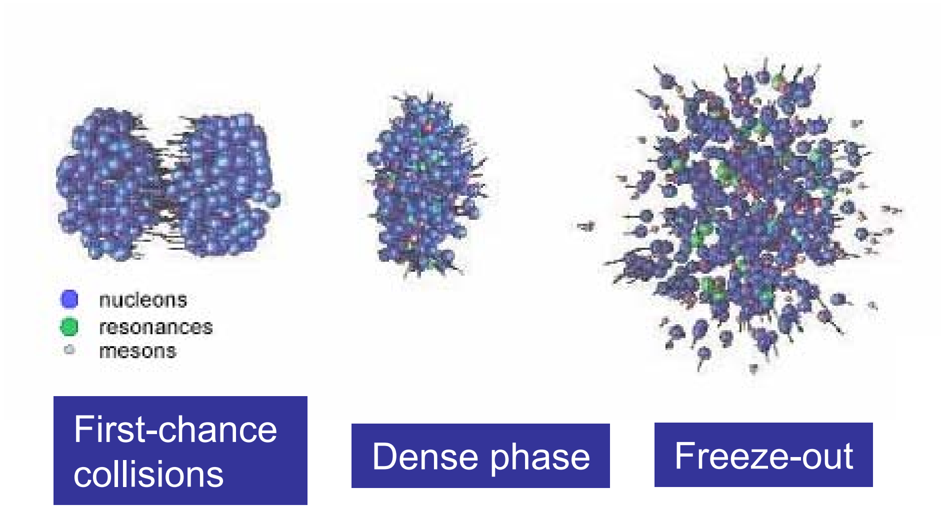
2nd HADES Summerschool 2006

# Experimental overview

Romain Holzmann, GSI

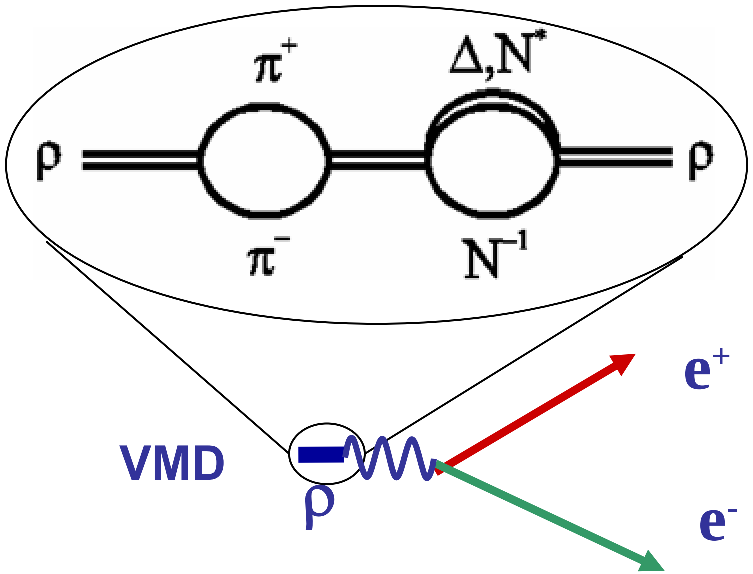
- Brief introduction
- A bit of history
- Past & present experiments
- Some conclusions & outlook

# Motivation (Hot and Dense Hadronic Matter)



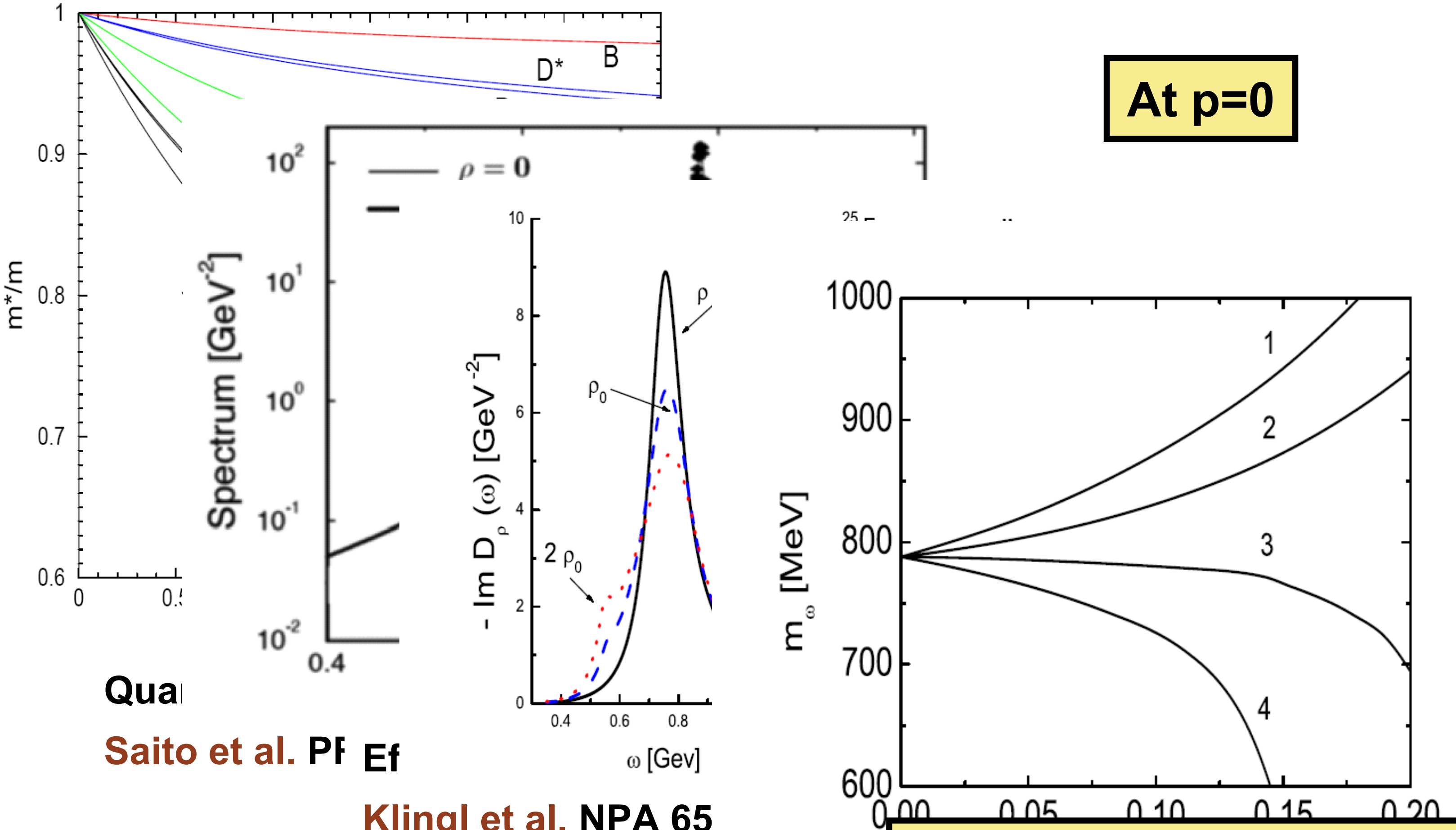

- The dilepton signal contains **contributions from throughout the collision**, ...
- ... i.e. also **direct radiation** from the **early phase.**

⇨ It probes the **electromagnetic structure of dense/hot nuclear (or partonic) matter.**




→ **in-medium spectral functions**

# Various predictions... need to be sorted out!




**At p=0**

**Qua**

**Saito et al. PI**

**Ef**

**Klingl et al. NPA 65**

**Couplec**

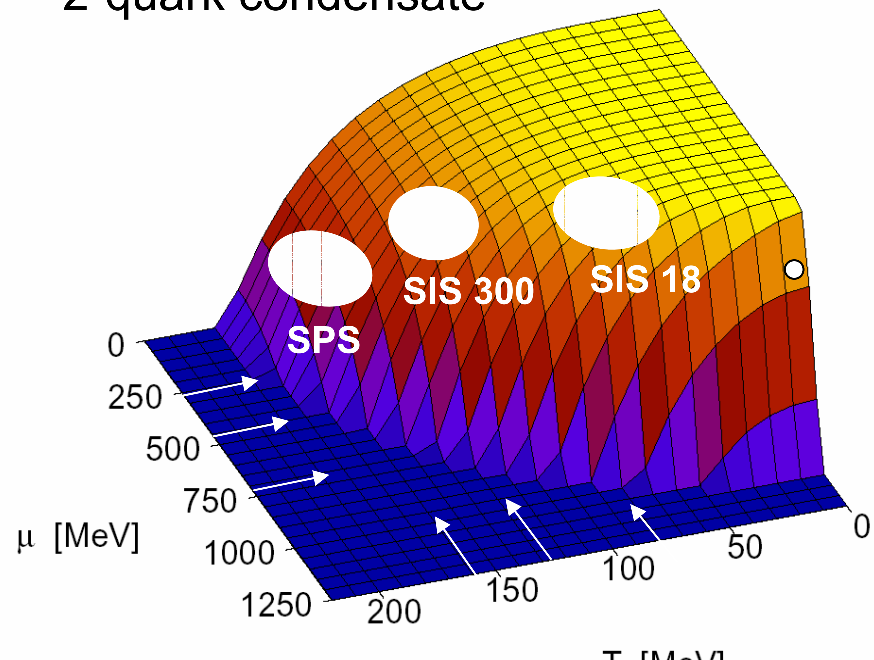
**M. Lutz**

**At p≠0**

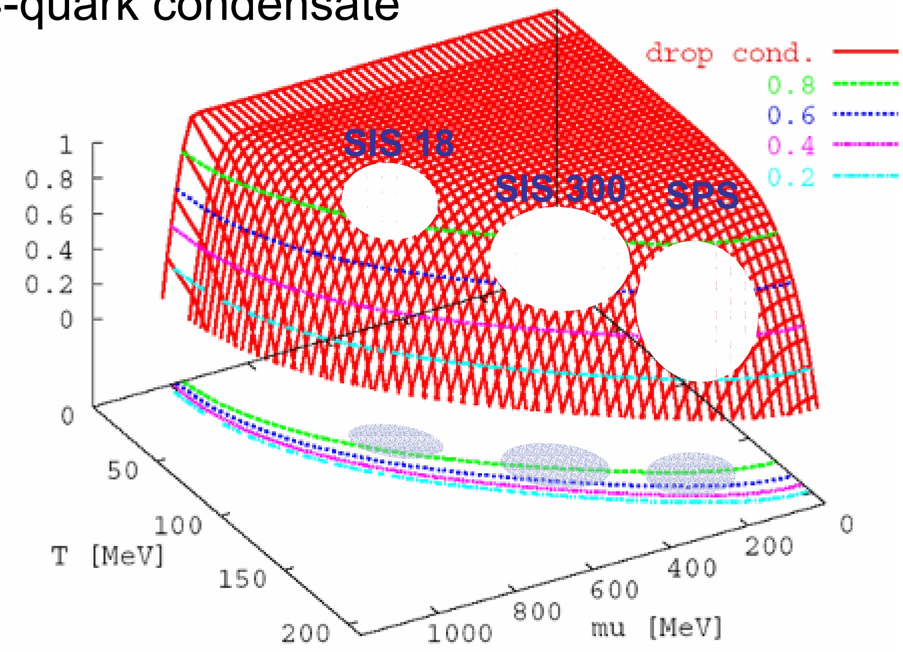
**+ collisional broadening due to inelastic reactions**

# Motivation (Chiral Symmetry Restoration)

- Substantial depletion of the condensates already in collisions at moderate beam energy.

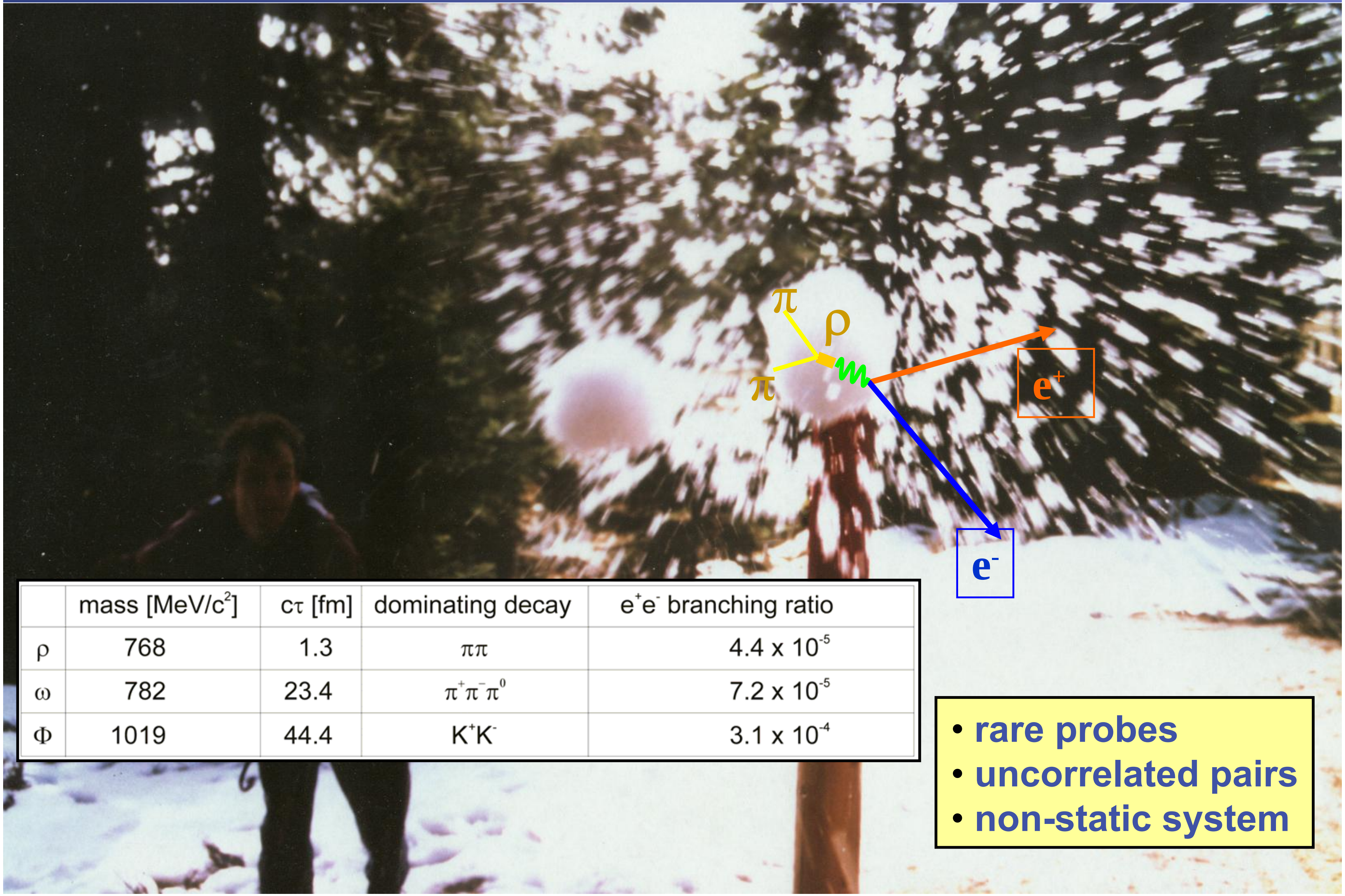



J. Wambach et al.




S. Leupold, Trento Workshop 2005

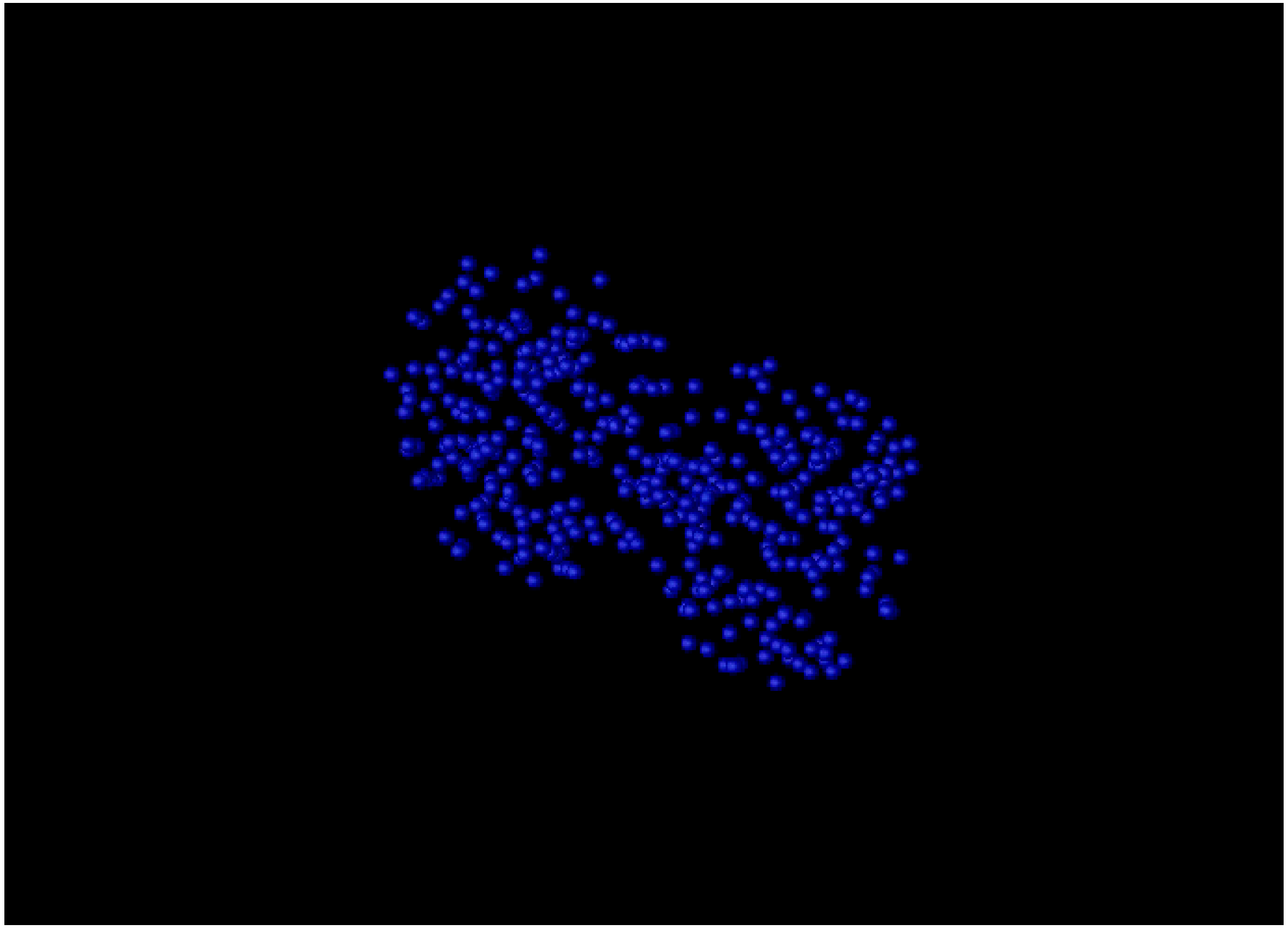
# The experimental challenge ...




| | mass [MeV/c²] | cτ [fm] | dominating decay | $e^+e^-$ branching ratio |
|---|---|---|---|---|
| ρ | 768 | 1.3 | $\pi\pi$ | $4.4 \times 10^{-5}$ |
| ω | 782 | 23.4 | $\pi^+\pi^-\pi^0$ | $7.2 \times 10^{-5}$ |
| Φ | 1019 | 44.4 | $K^+K^-$ | $3.1 \times 10^{-4}$ |

- **rare probes**
- **uncorrelated pairs**
- **non-static system**

# A+A collision in transport theory

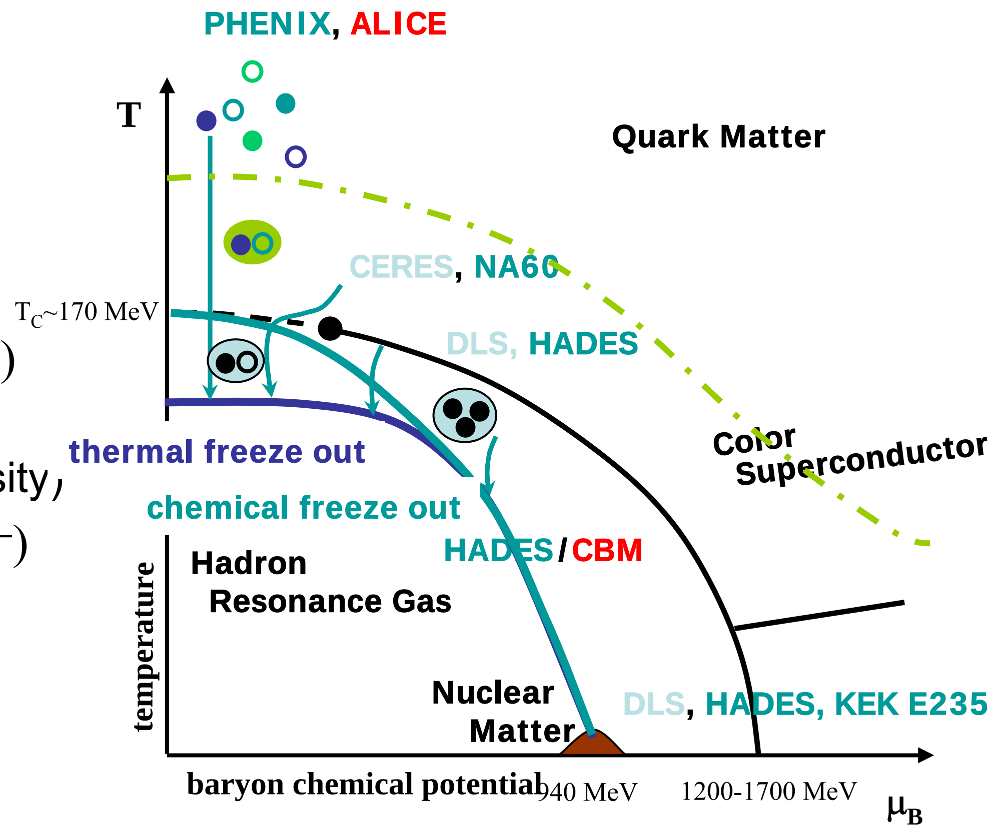


1 AGeV Au+Au
b = 3 fm

# Lepton pairs as probes of nuclear matter: Experiments past, present and future

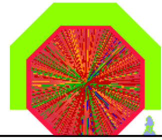
Experiments at different √s probe different regions of phase diagram

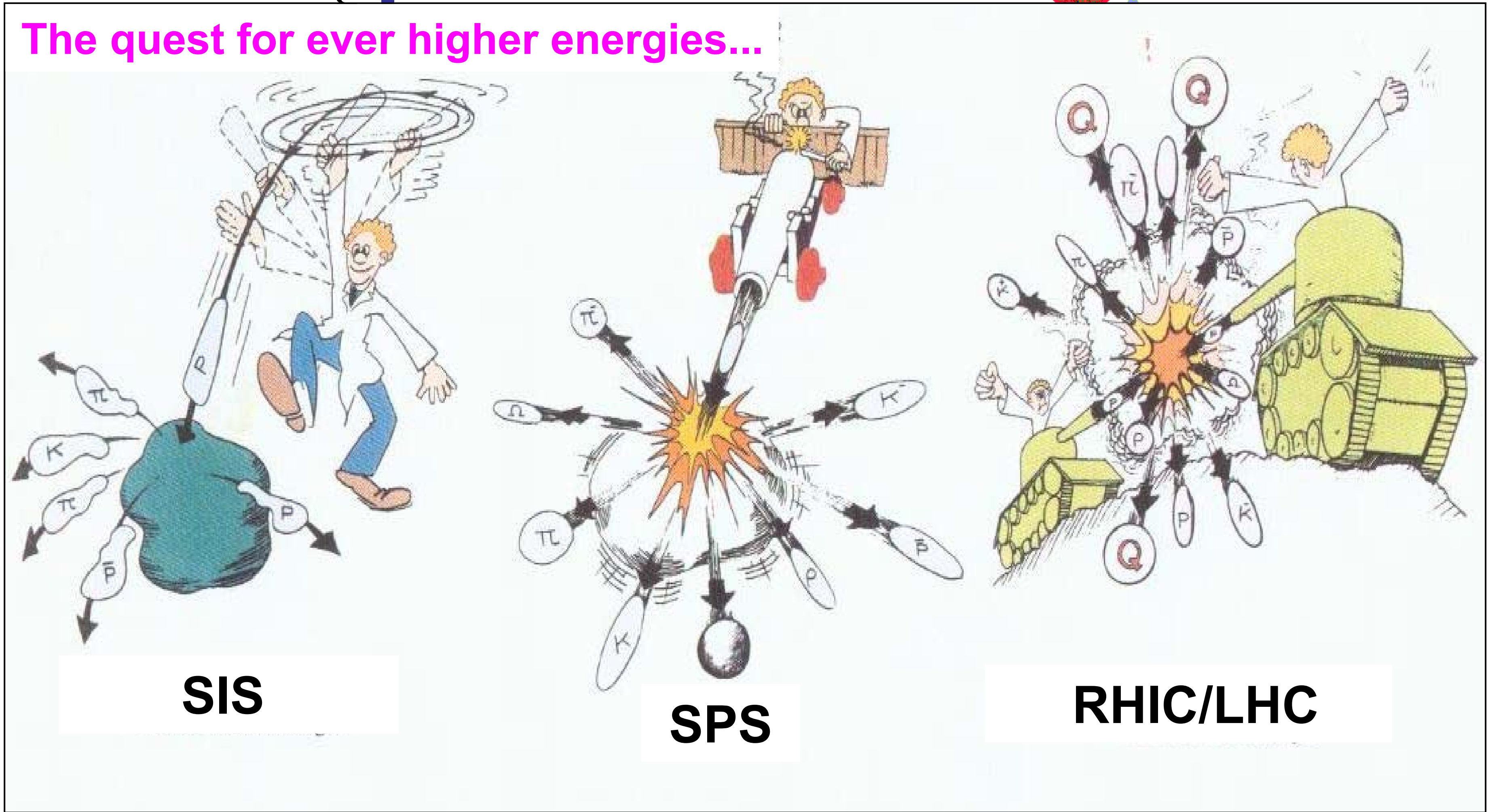
- DLS, HADES, KEK E325 ($e^+e^-$)
  - BEVALAC/SIS
  - normal nuclear matter density
  - dense hadronic matter
- CERES ($e^+e^-$), NA50, NA60 ($\mu^+\mu^-$)
  - CERN SPS
  - transition region (high T, low density)
- PHENIX ($e^+e^-$ ), ALICE ($e^+e^-$ , $\mu^+\mu^-$)
  - RHIC
  - QGP region (deconfined matter)
- CBM ($e^+e^-$ and/or $\mu^+\mu^-$)
  - FAIR (highest densities)



# Overview (of HI expts.)

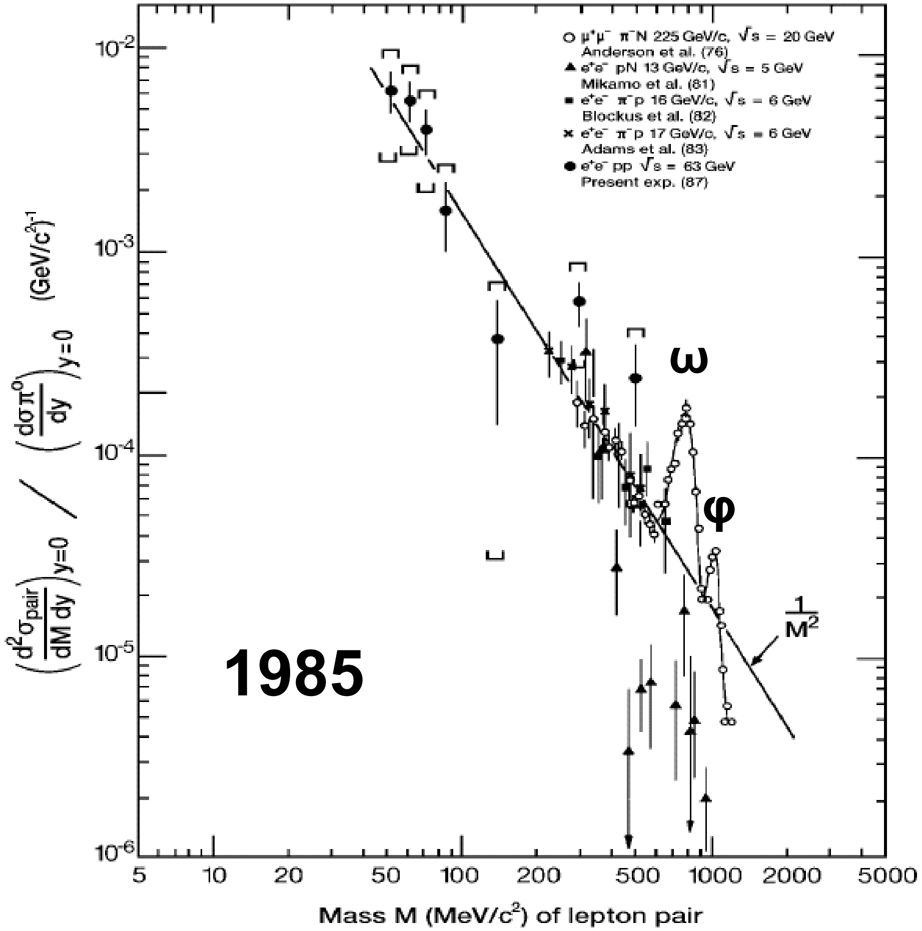
LHC





# The beginning: anomalously high yields

H.J. Specht in Lecture Notes on Physics 221/1985




Compilation of results on dilepton production

(Fermilab, SLAC, ISR, KEK. 1975-1985)

➔ **"anomalous" excess over Drell-Yan at low mass**

➔ **Main motivation for the CERN SPS dilepton expts.**

# The early HI experiments (the 1990'ies)

1. HELIOS/NA34 at the CERN SPS ($e^+e^-$, $\mu^+\mu^-$, $\gamma$)

2. CERES/NA45 at the CERN SPS ($e^+e^-$)

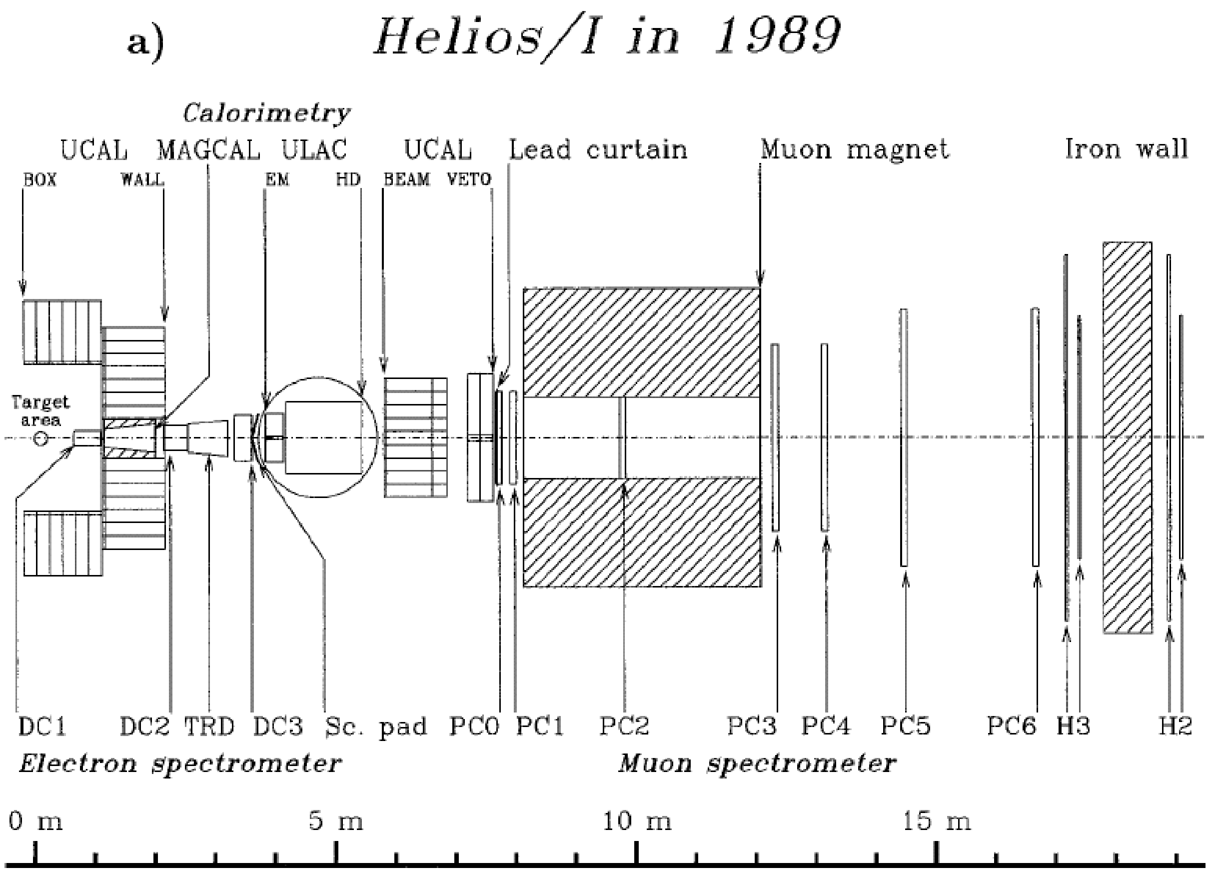
3. NA38/NA50 at the CERN SPS ($\mu^+\mu^-$)

4. DLS at the Bevalac ($e^+e^-$)

# HELIOS at the CERN SPS



## The NA34 apparatus in 1989




HELIOS did

- $e^+e^-$,
- $\mu^+ \mu^-$,
- and photons

# p + W dimuons

# HELIOS

Data from Masera et al., NPA 590 (1995) 93

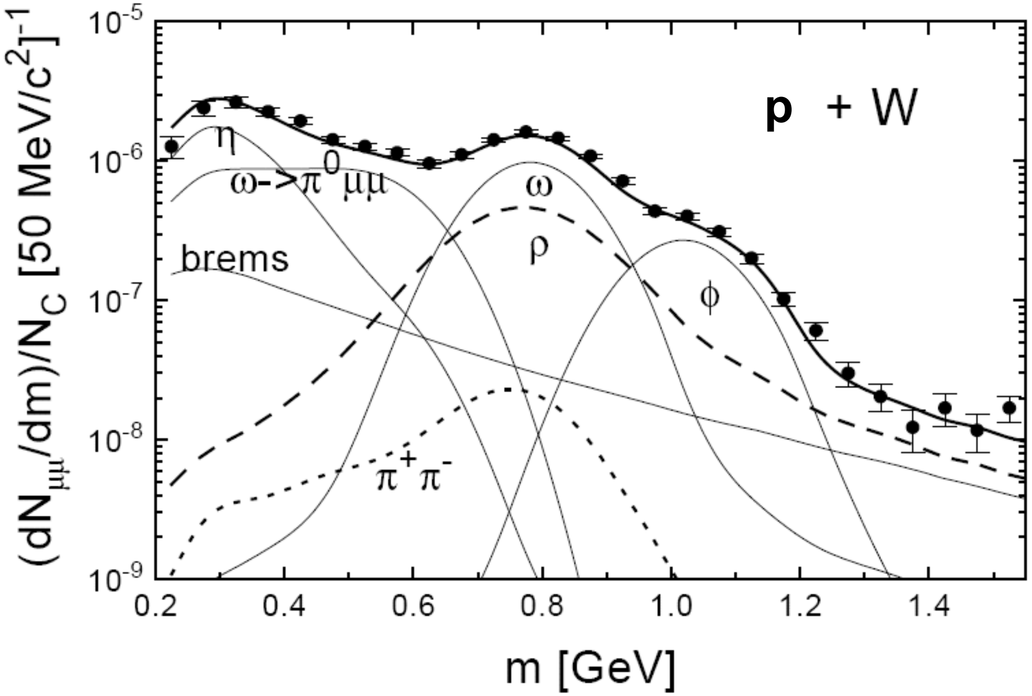



Figure 1b

Compared with BUU

Cassing et al., PLB 377 (1996) 5

➔ **Data agree with cocktail of free meson decays**

# S + W dimuons

# HELIOS

Data from Masera et al., NPA 590 (1995) 93

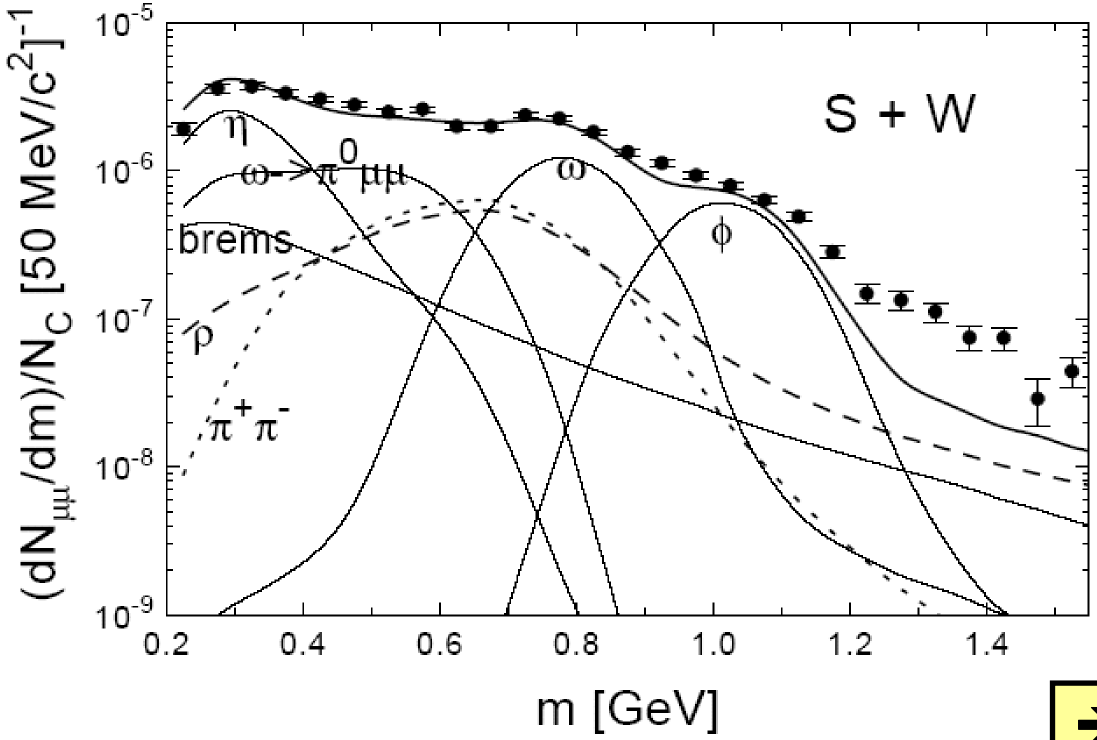



Figure 4

**Excess yield !!**

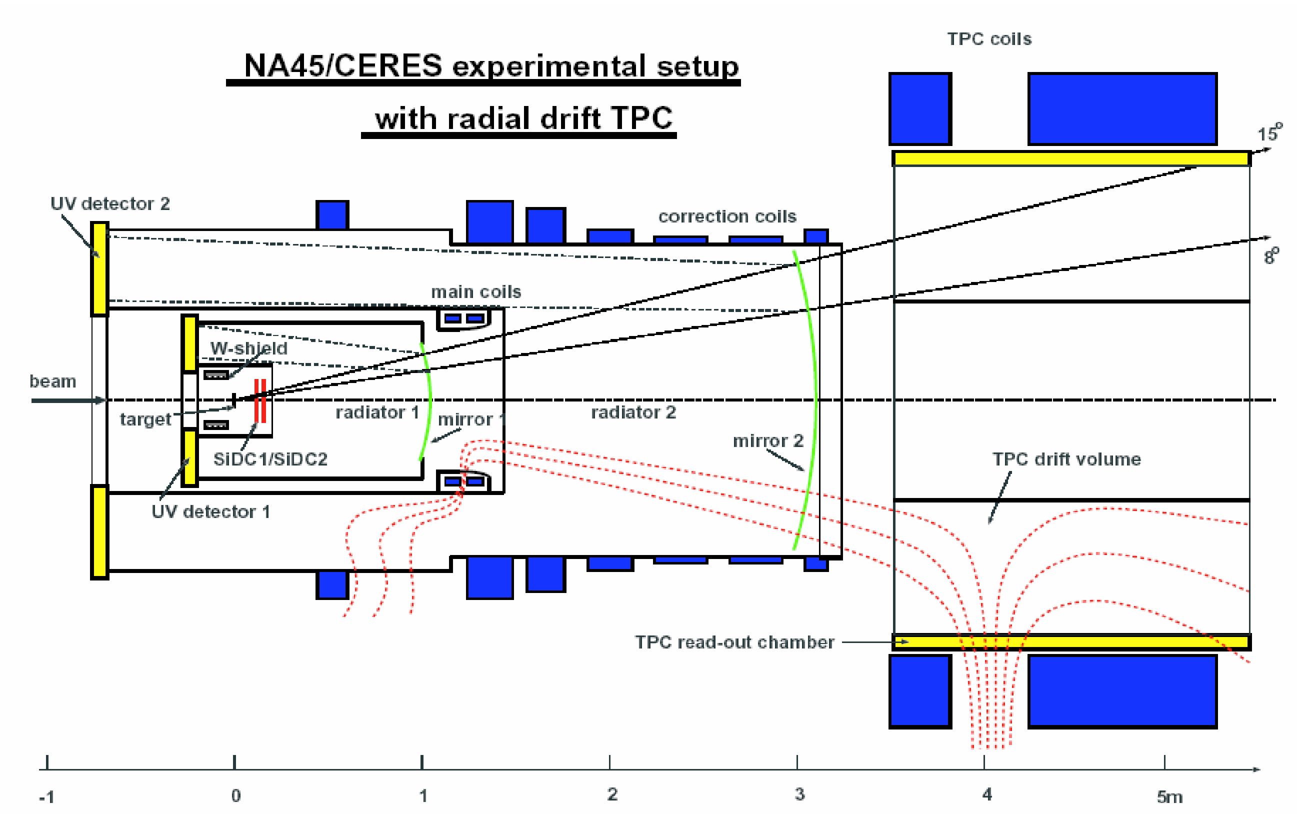
Compared with BUU

Cassing et al., PLB 377 (1996) 5

**➔ Model needs in-medium ρ to agree with data**

# CERES at the CERN SPS

**< year 2000** **> year 2000**




- $\phi$ symmetry
- dE/dx in silicon drift for background rejection
- 3.8 % mass resolution (TPC upgrade)

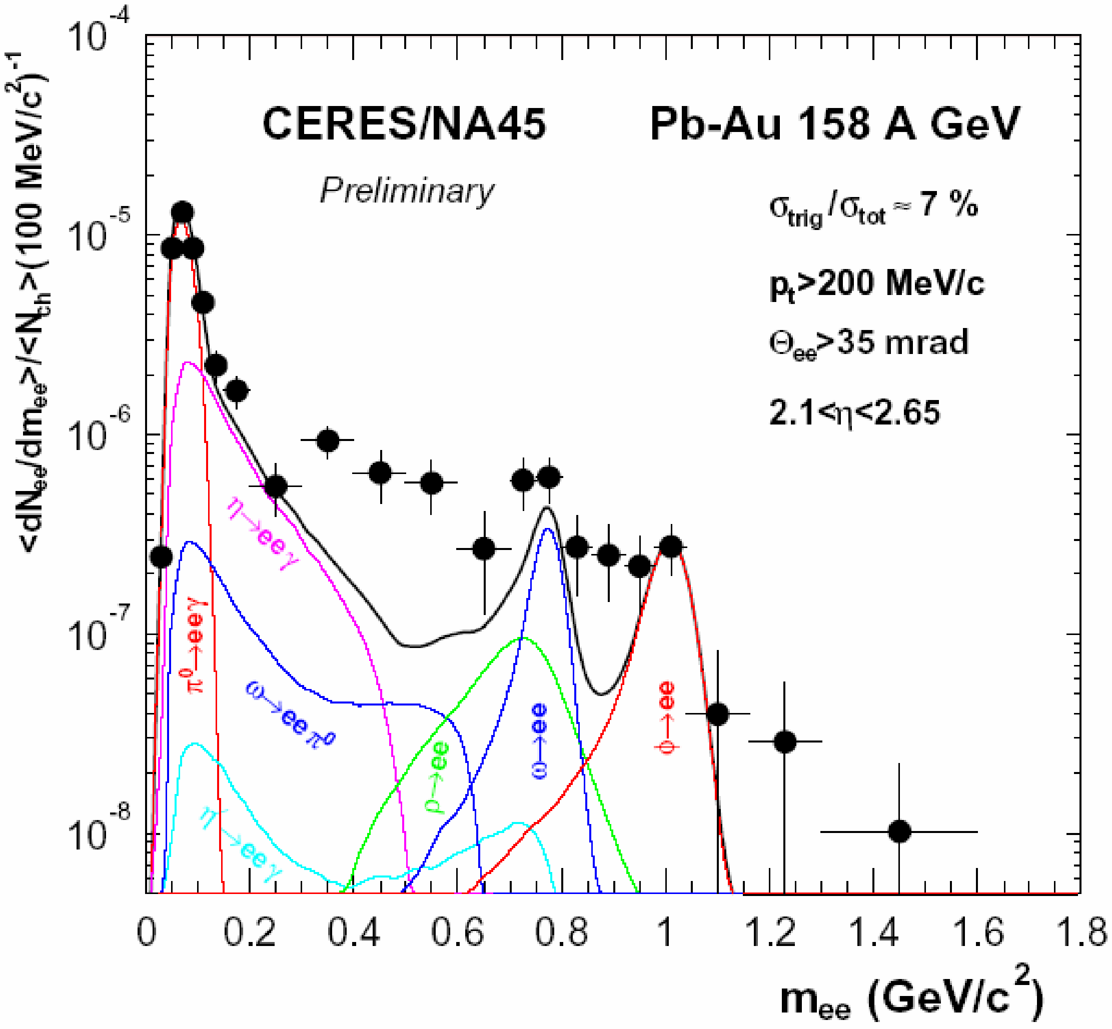
# CERES data (Pb+Au 158 AGeV)

CERES

**High-resolution analysis**

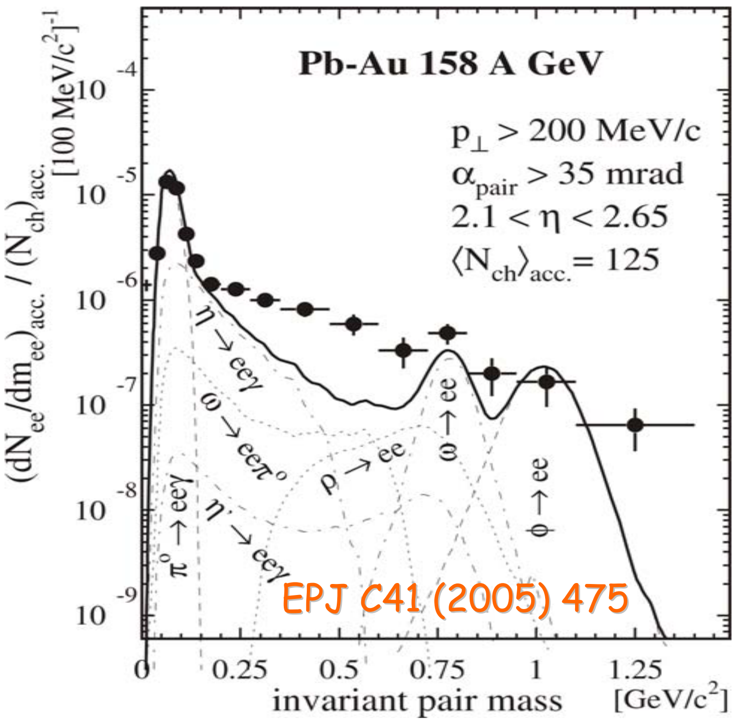
**Large excess yield:**

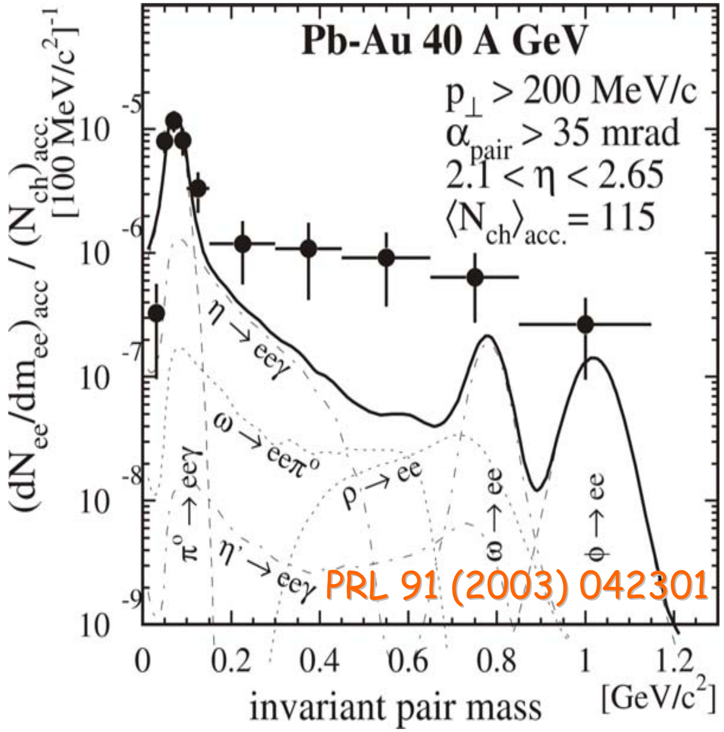
- **at low masses**
- **also between ω and ϕ**




J. Stachel, ISHIP 2006 and NPA 774 (2006) 43c

# CERES: Low-mass dilepton enhancement

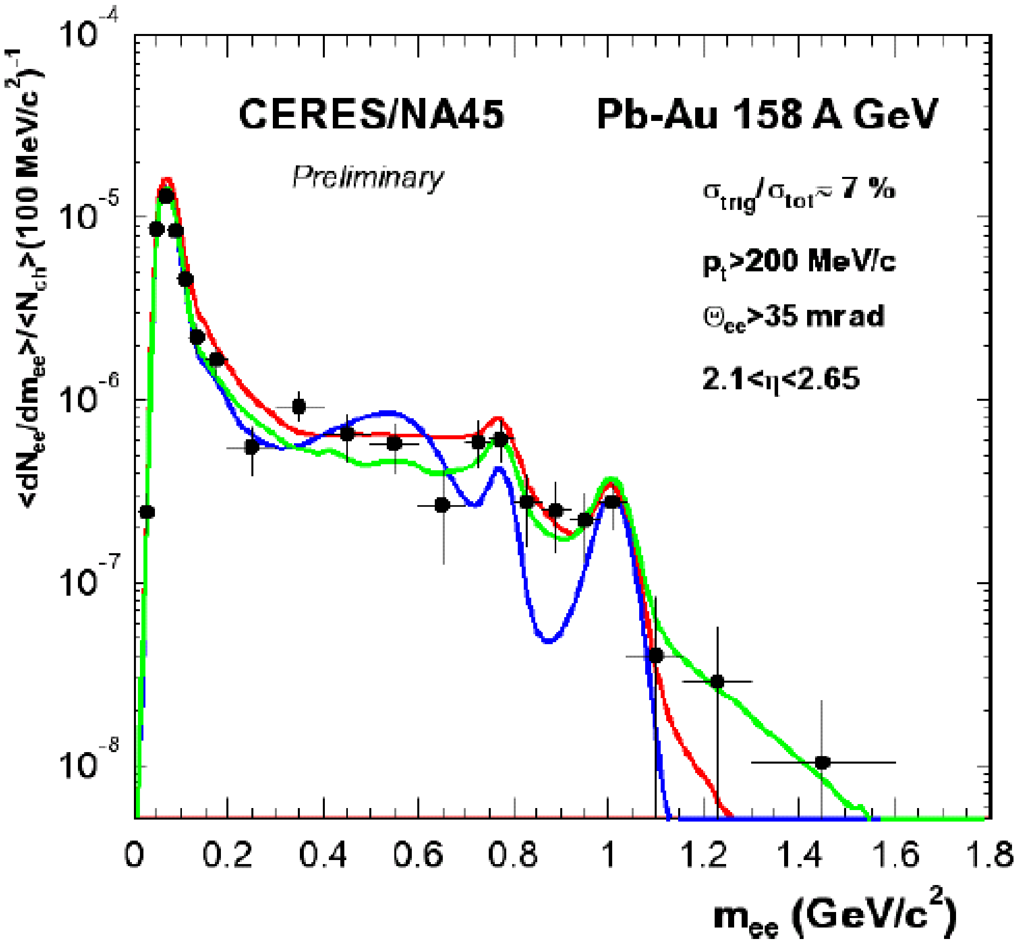



- Central A-A collisions exhibit a strong enhancement of low-mass dilepton production as compared
- to p-A reactions (CERES, HELIOS)

- Vacuum properties of vector mesons do not suffice to describe data, needed are:
  - pion annihilation (accounts for part only)
  - in-medium modifications of vector meson properties
  - broadening and/or mass shift of the rho meson

# CERES vs. Theory




calculation by R.Rapp using Rapp/Wambach medium modification of rho spectral function

calculation by R.Rapp using Brown-Rho scaling

B. Kämpfer, thermal emission

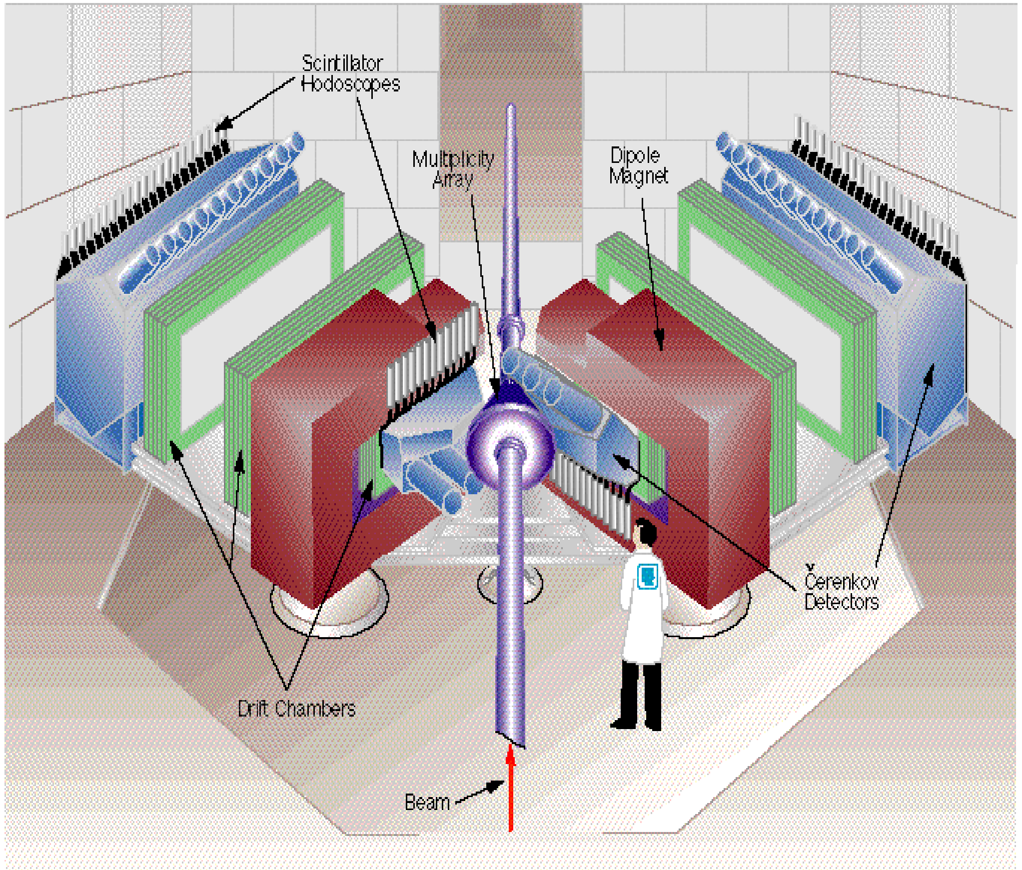
...added to the cocktail.

in the 0.8 < m < 0.98 GeV region:
Brown-Rho curve: $\chi^2/n = 2.4$
the other two curves: $\chi^2/n \sim 0.3$

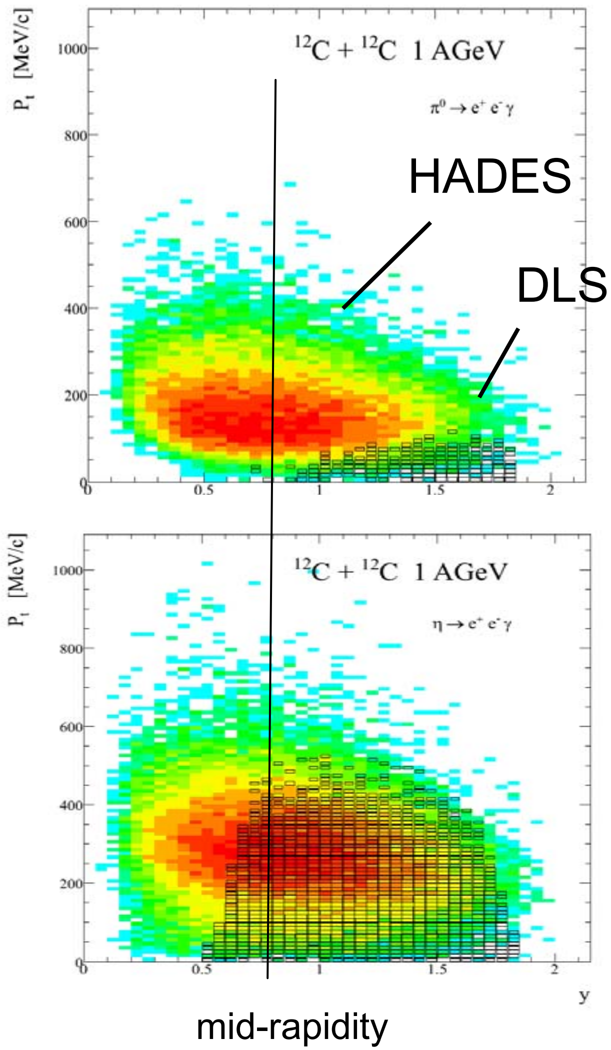
D. Miskoviec, Quark Matter 2005

## Electron pairs in the 1-2 AGeV regime

DiLepton Spectrometer

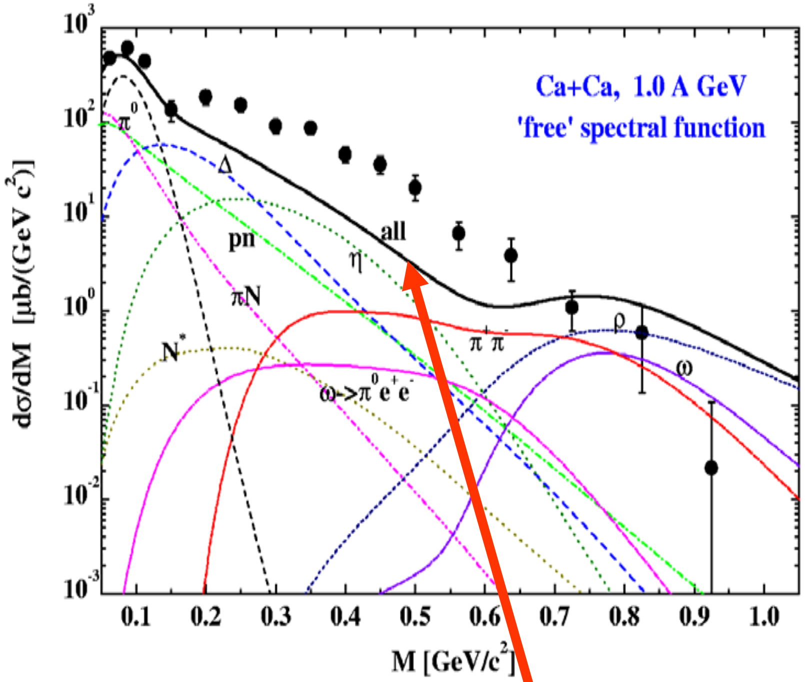



## DLS acceptance

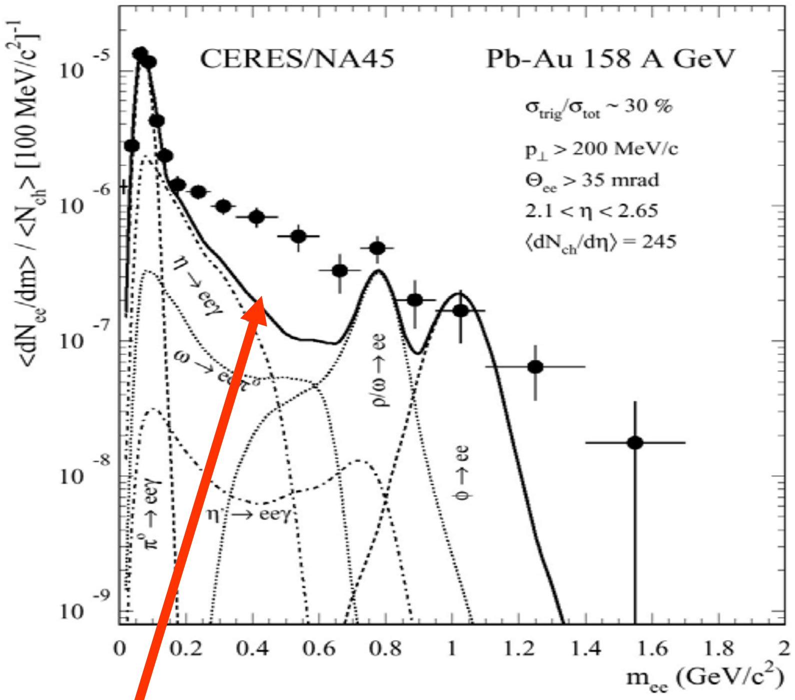


# DLS: enhanced dilepton yields in A+A

**DLS** at Bevalac @ 2 AGeV




**CERES** at SPS @158 AGeV



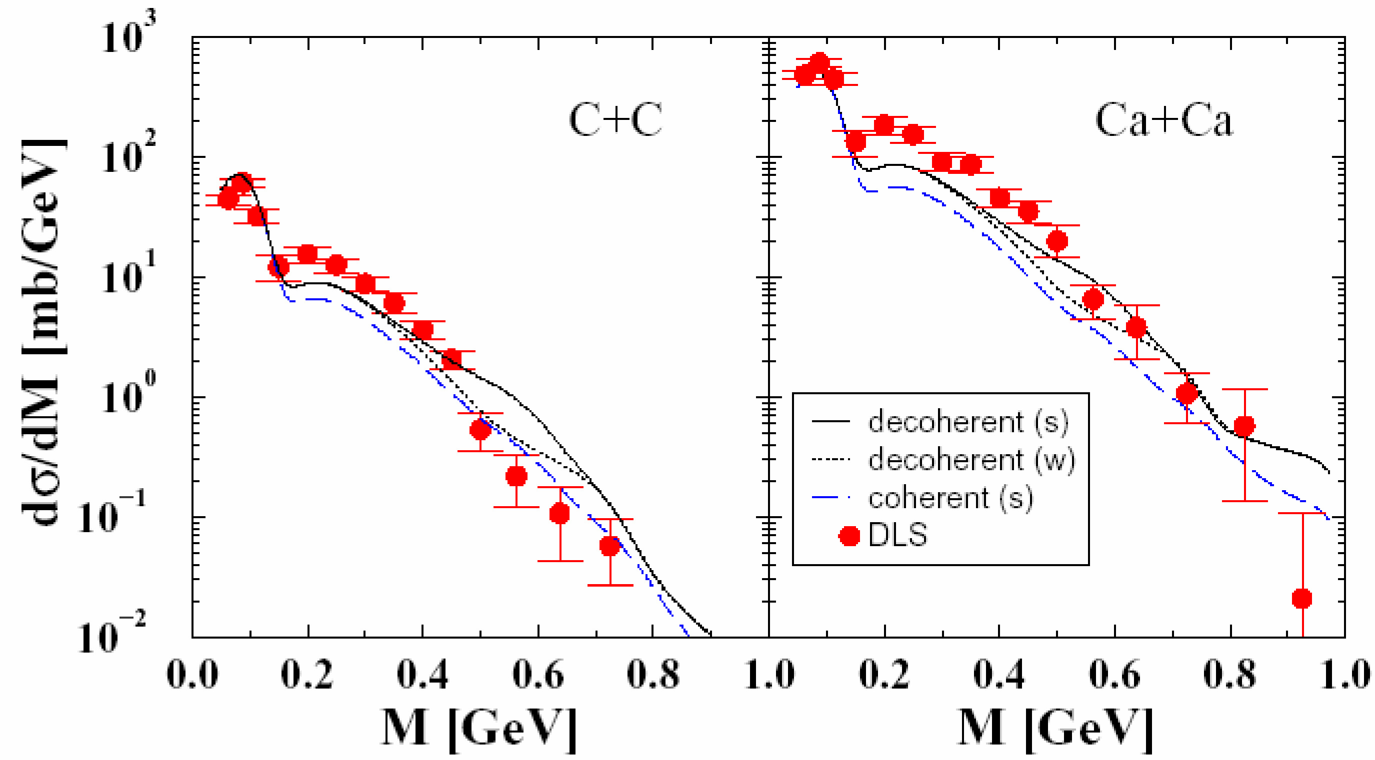

**Data:** **R.J. Porter et al.:** PRL 79(97)1229

**Model:** **E.L. Bratkovskaya et al.:** NP A634(98)168, BUU, vacuum spectral function

**Strong dilepton enhancement over hadronic cocktails**

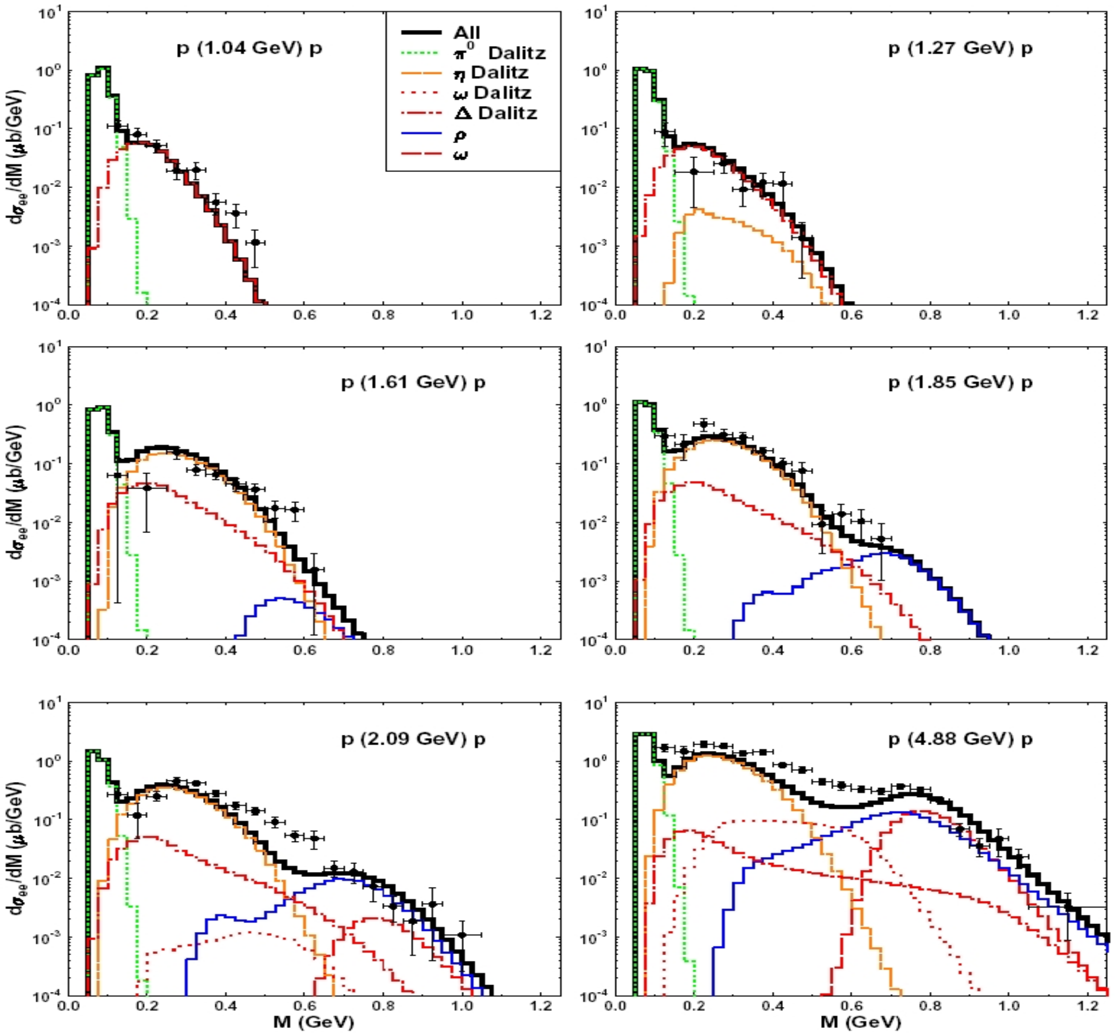
# RQMD description of the DLS data

**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

# A reminder: the DLS pp data

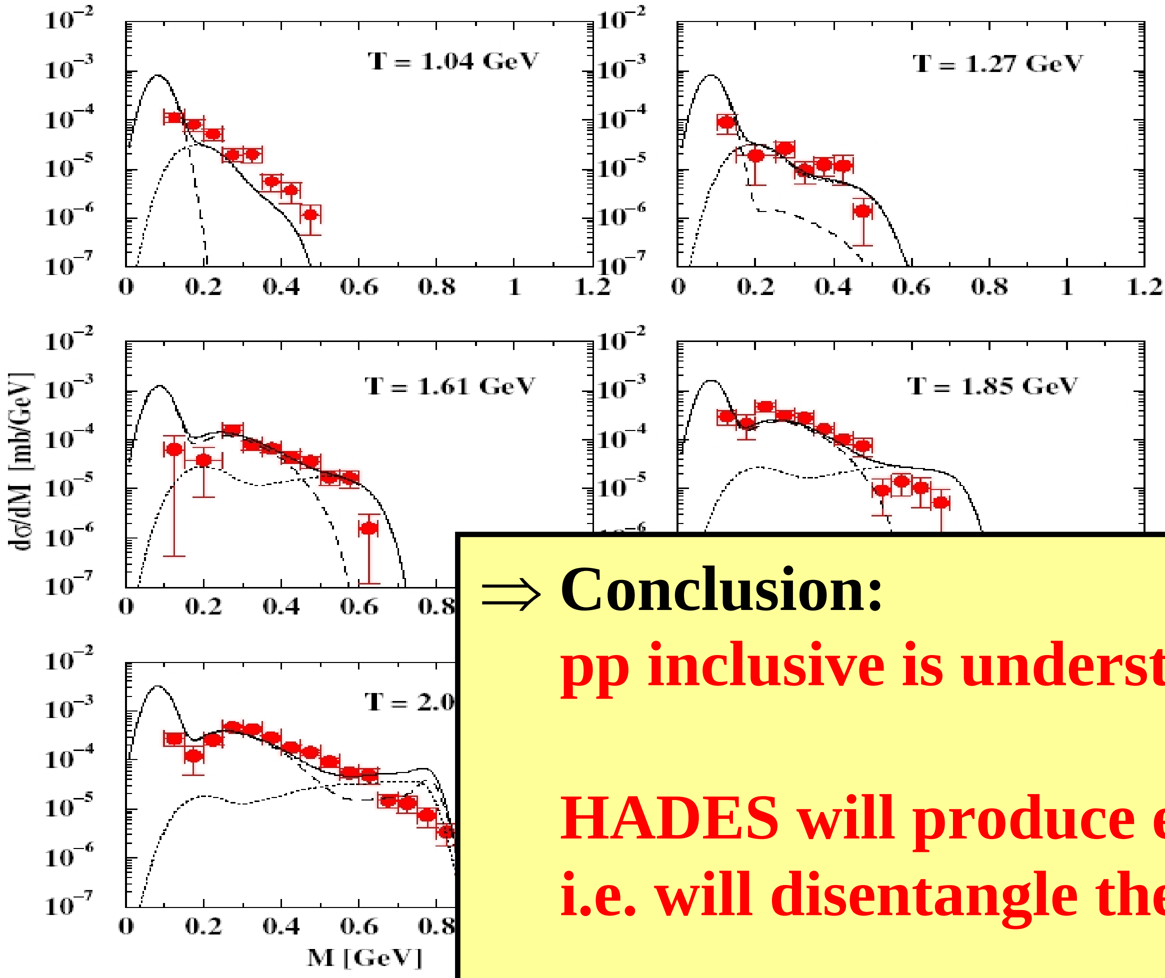



**Data:** Wilson et al.
PRC 57 (1997) 1865

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

$\Rightarrow$ **Fair agreement of total yields**

# pp: more and better theories...



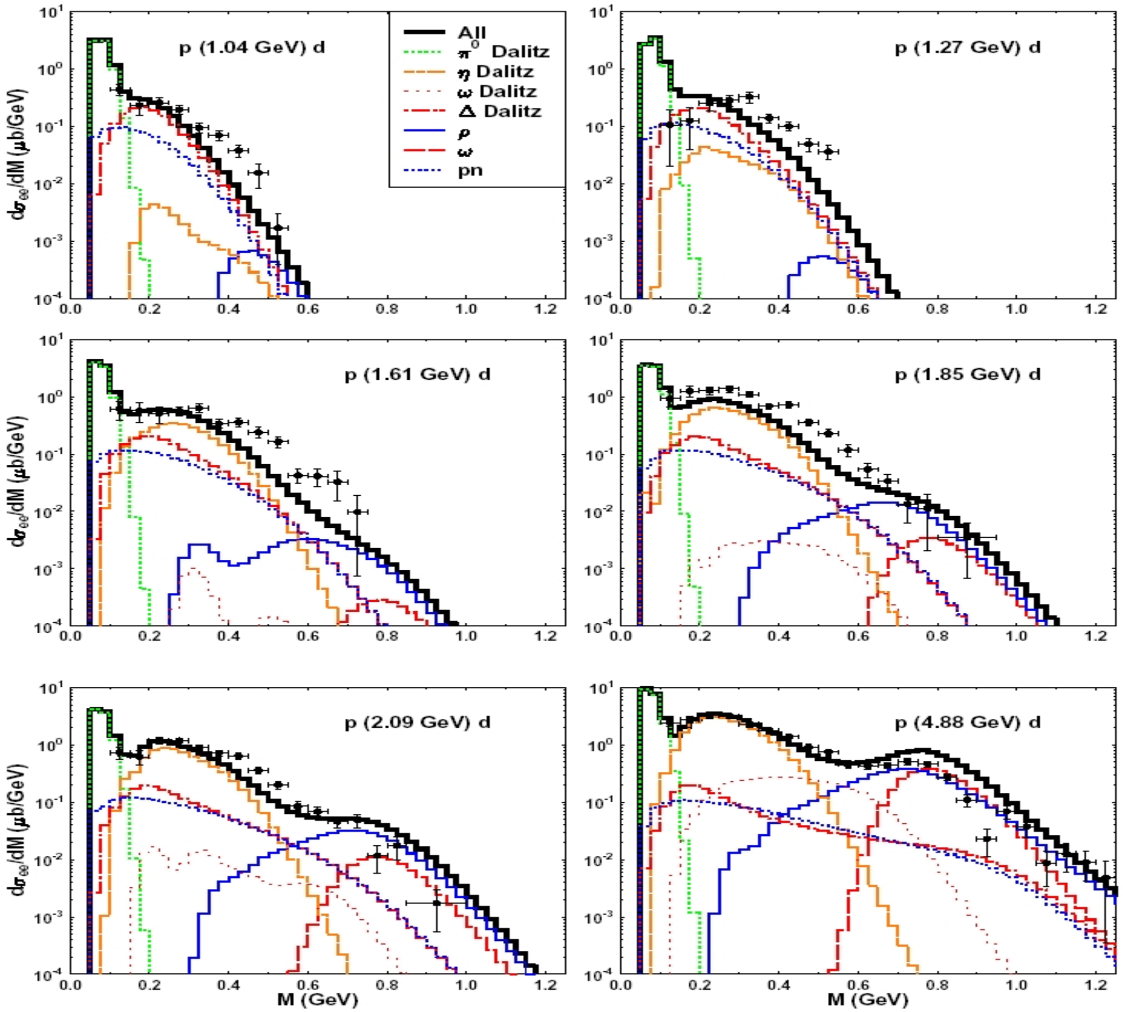

Resonances + decays

Faessler, Fuchs et al.
J. Phys. G29 (2003) 603

⇒ **Conclusion:**
**pp inclusive is understood!**

**HADES will produce exclusive data,**
**i.e. will disentangle the $e^+e^-$ cocktail!**

# Real trouble starts with pd data!



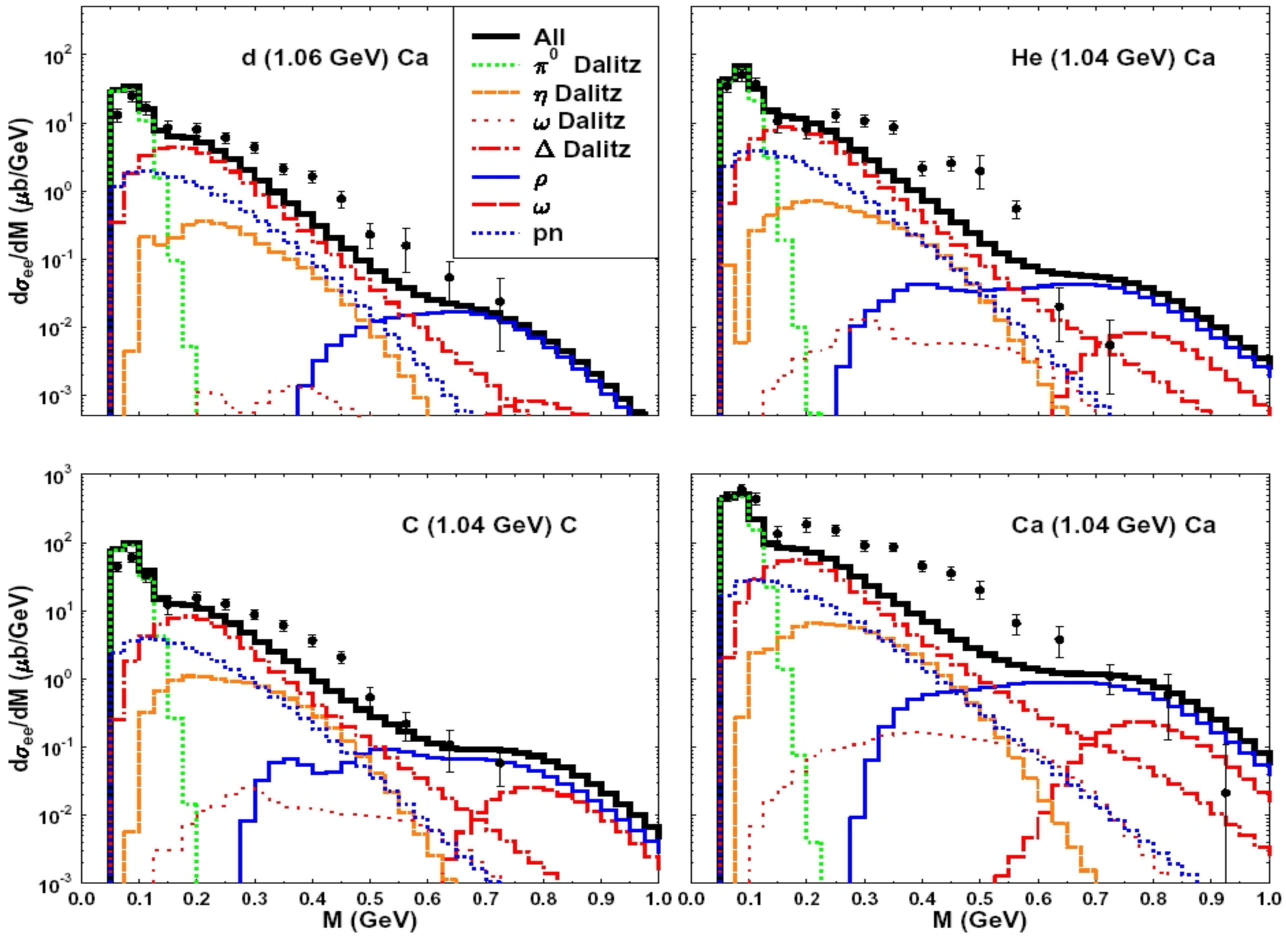

**Data:** DLS

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

**What's different?**

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

# 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!

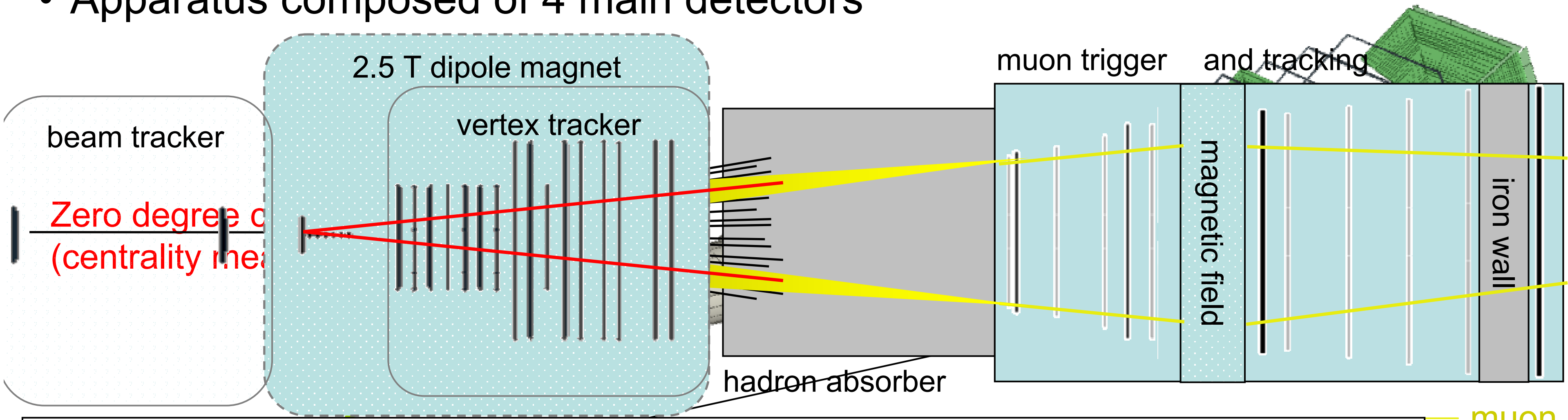
➔ **To be compared to HADES results soon!**

# In-medium Vector Meson spectroscopy

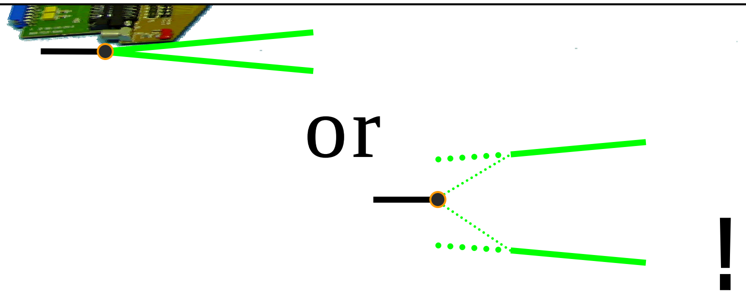
1. NA60 at the CERN SPS   (In+In $\rightarrow \mu^+\mu^-$)
2. E325 at the KEK PS   (p+Cu $\rightarrow e^+e^-$)
3. CB/TAPS at ELSA   ($\gamma$+A $\rightarrow \omega \rightarrow \pi^0\gamma$)
4. HADES at GSI   (p+A $\rightarrow e^+e^-$)
5. CLAS at JLAB   ($\gamma$+A $\rightarrow e^+e^-$)

# The NA60 experiment at CERN

- Fixed target dimuon experiment at the CERN SPS
- Apparatus composed of 4 main detectors




Concept of NA60: place a *silicon tracking telescope* in the vertex region to measure the muons *before* they suffer multiple scattering in the absorber and *match* them (in both angles and momentum) to muon measured in the spectrometer

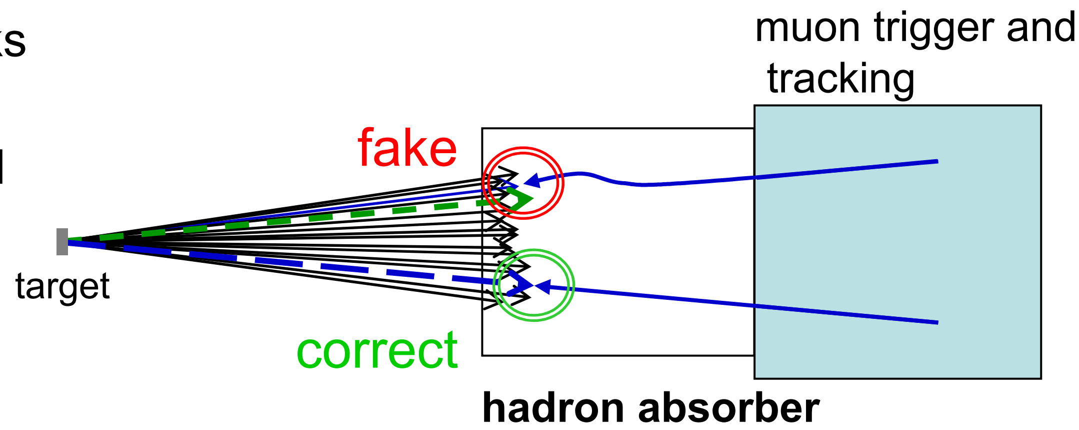



- Origin of muons can be accurately determined
- Improved dimuon mass resolution

(~20 MeV/$c^2$ at $\omega$ instead of 80 MeV/$c^2$)

# Fake matches

- "Fake Matches" are those tracks where a muon track from the Muon Spectrometer is matched to the wrong track from the Vertex Tracker

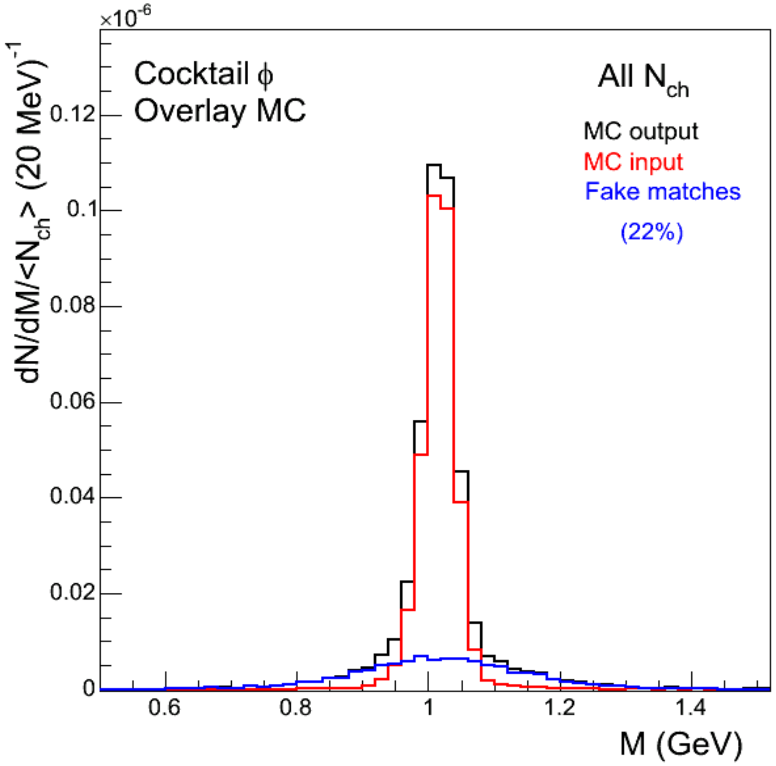


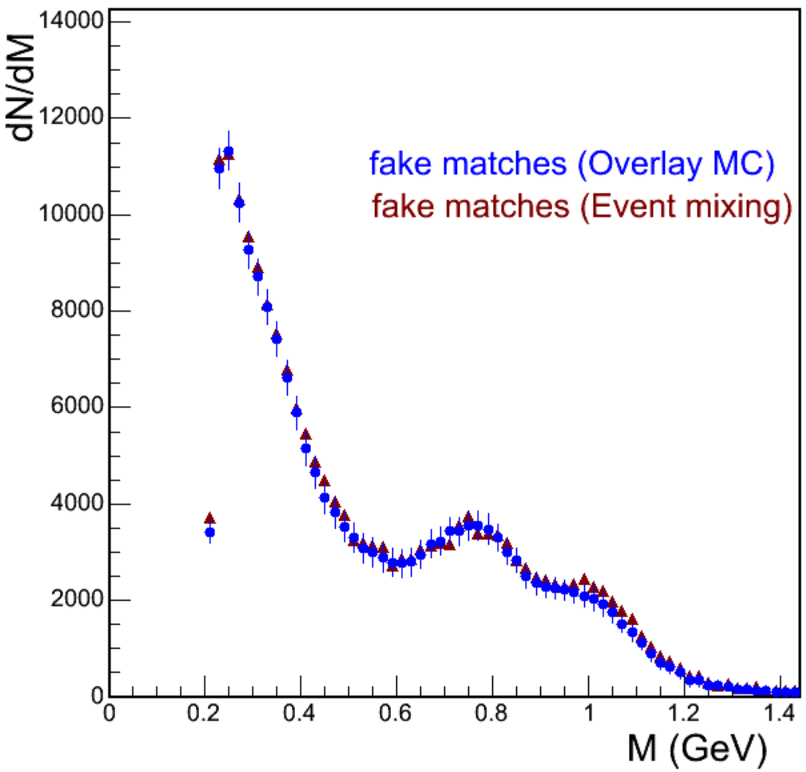

- Fake matches of the signal pairs (<10% of CB) can be obtained in two different ways:
  - Overlay MC

    Superimpose MC signal dimuons onto real events. Reconstruct and flag fake matches. Choose MC input such as to reproduce the data. Start with hadron decay cocktail + continuum; improve by iteration.
  - Event mixing

    More rigorous, but more complicated.

# Example of overlay MC: the $\phi$



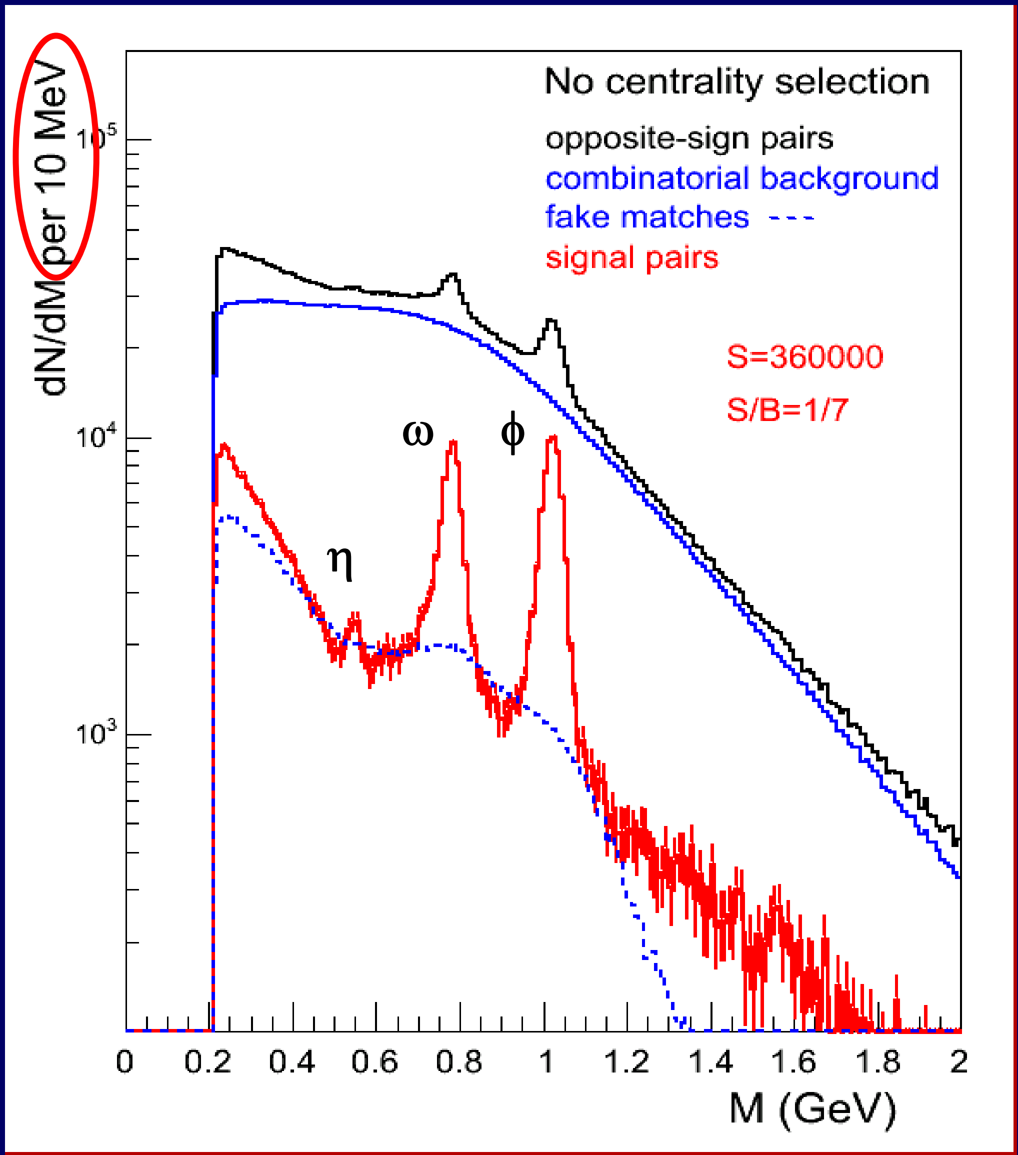




$\sigma_\phi$ = 23 MeV

$\sigma_{fake}$ = 110 MeV

Fakes calculation with Overlay MC and Mixing method agree in absolute level and shape within 5%!

# Subtraction of CB and fakes




Net data sample:
360 000 events

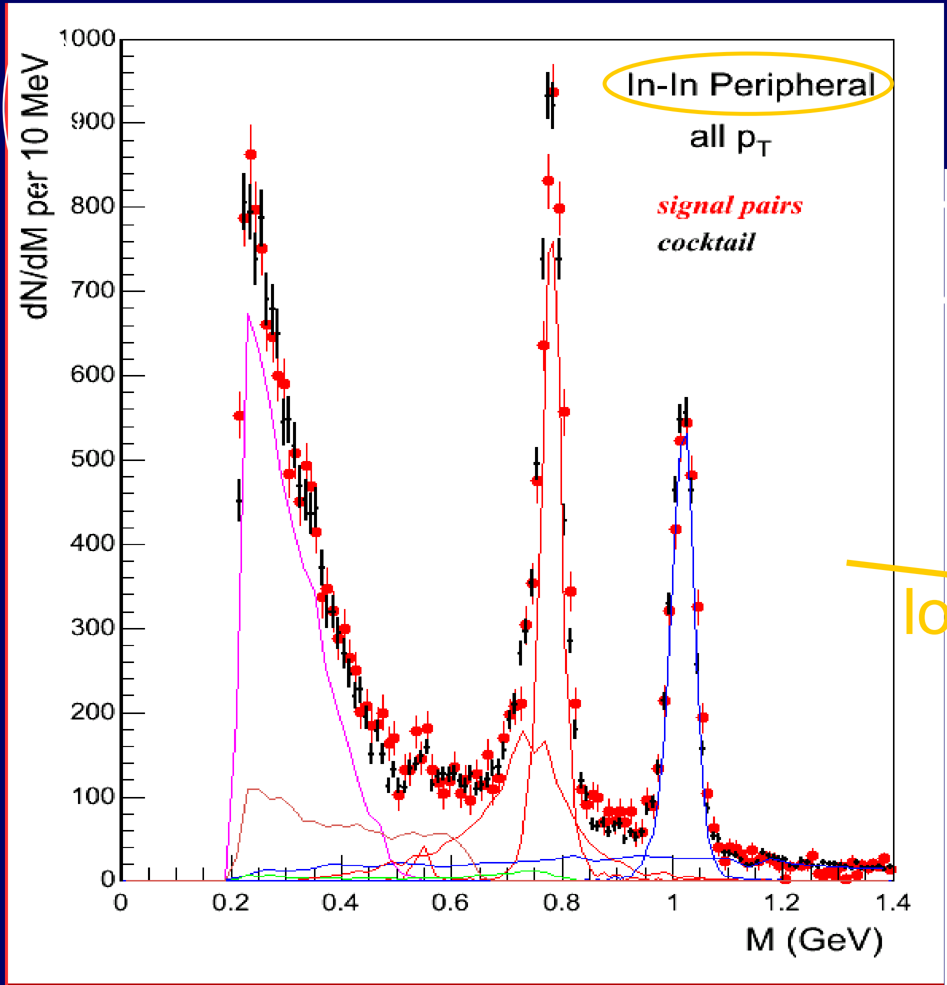
Fakes / CB < 10 %

For the first time, ω and φ peaks clearly visible in dilepton channel ; even η→μμ seen

Mass resolution:
23 MeV at the φ position

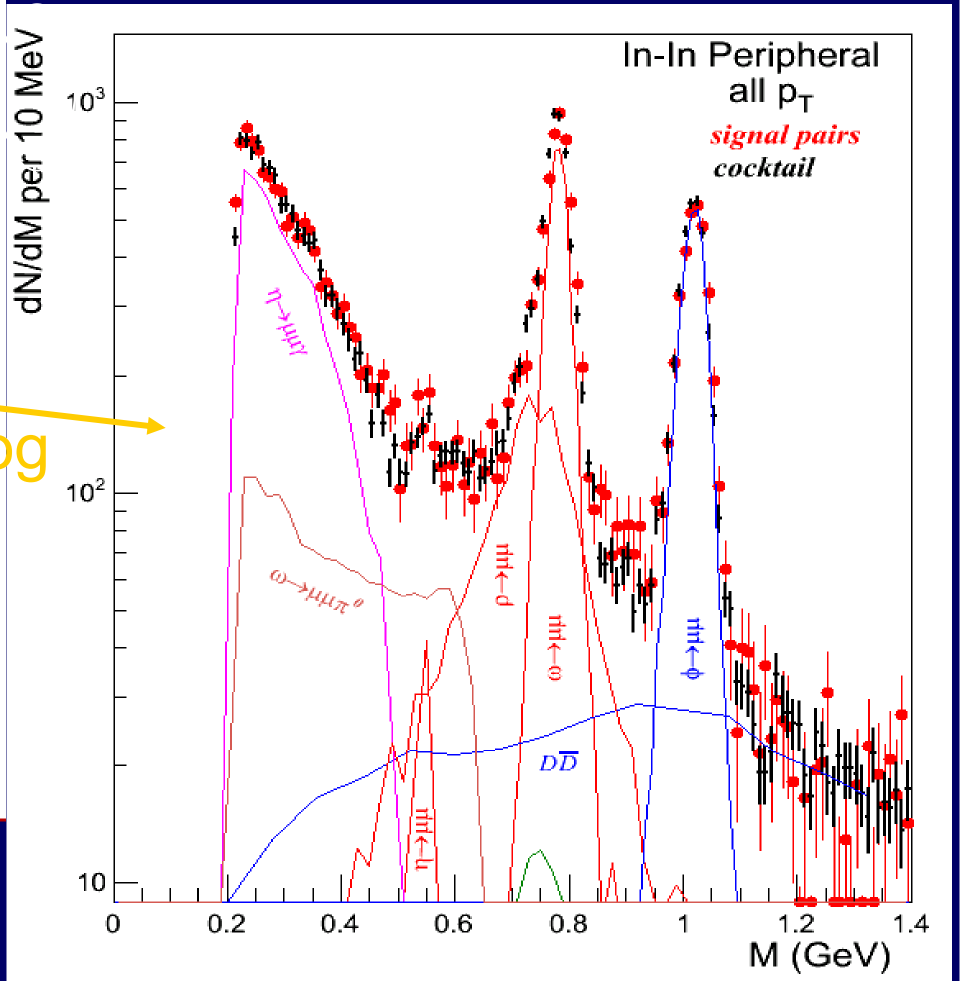
Progress over CERES:
statistics: factor >1000
resolution: factor 2-3

# Comparison of hadron decay cocktail to data



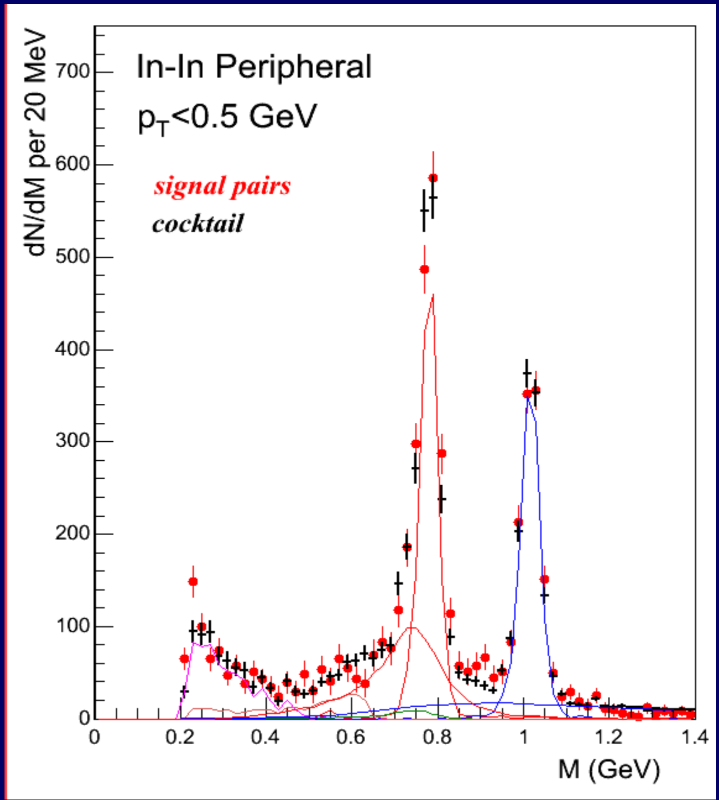

log

all $p_T$

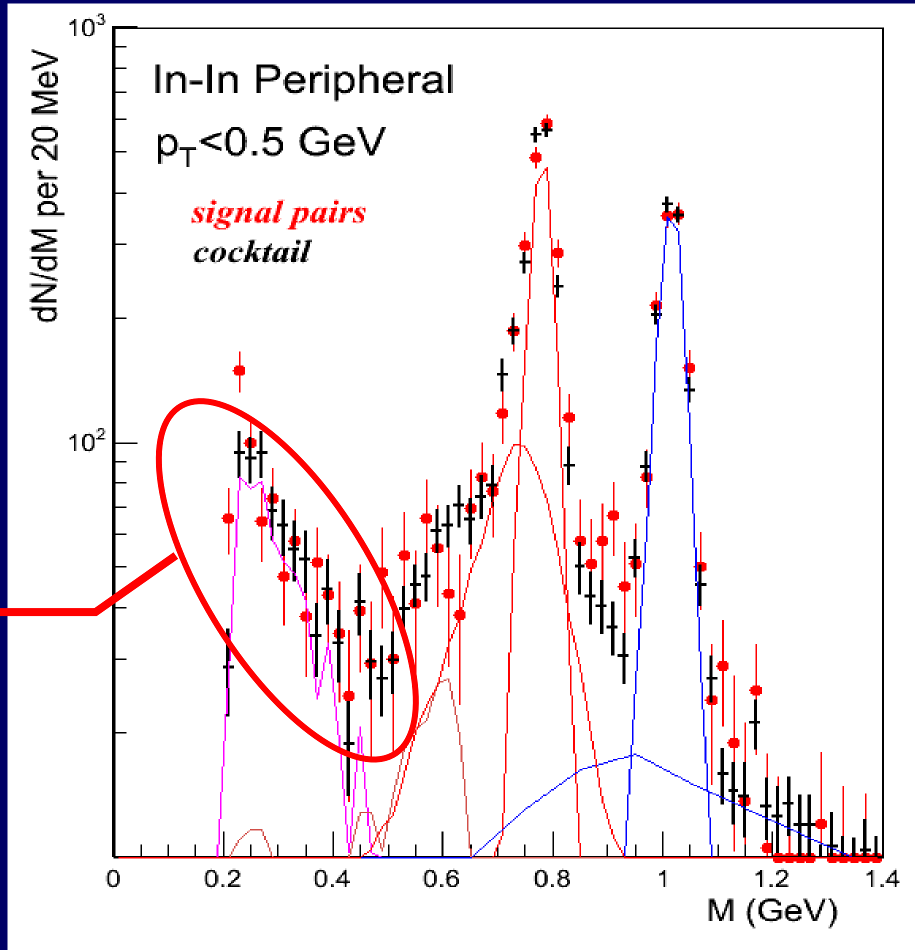



Very good fit quality

# Comparison of hadron decay cocktail to data



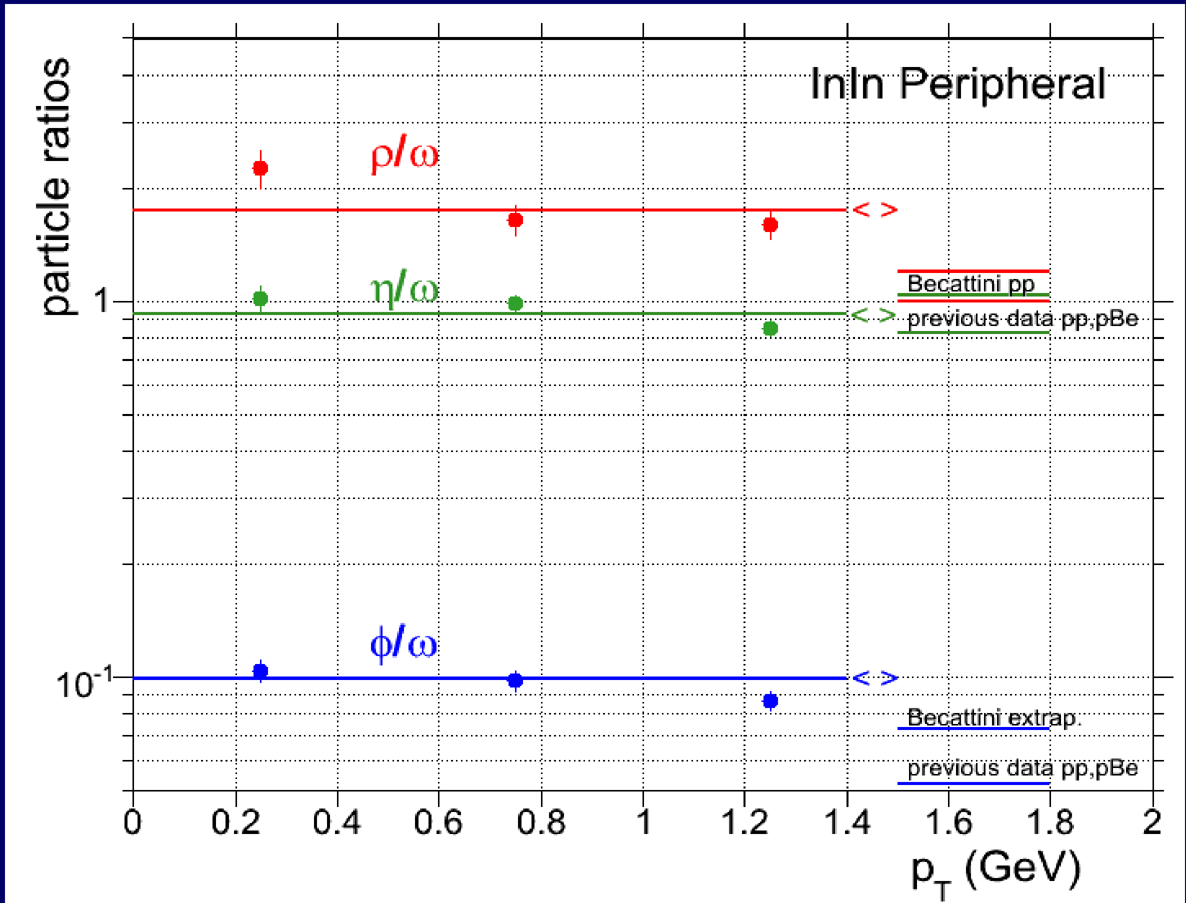

$p_T$ < 0.5 GeV




The η region (small M, small $p_T$)
is remarkably well described

→ the (lower) acceptance of NA60
in this region is well under control

# Particle ratios from the cocktail fits




η/ω and φ/ω nearly independent of $p_T$; 10% variation due to the ω

enhanced ρ/ω, mostly at low $p_T$ (due to $\pi\pi$ annihilation, see later)

General conclusion:

- peripheral bin very well described in terms of known sources
- low M and low $p_T$ acceptance of NA60 under control

# Understanding the cocktail for the more **central** data

Need to fix the contributions from the hadron decay cocktail

Cocktail parameters from peripheral data?

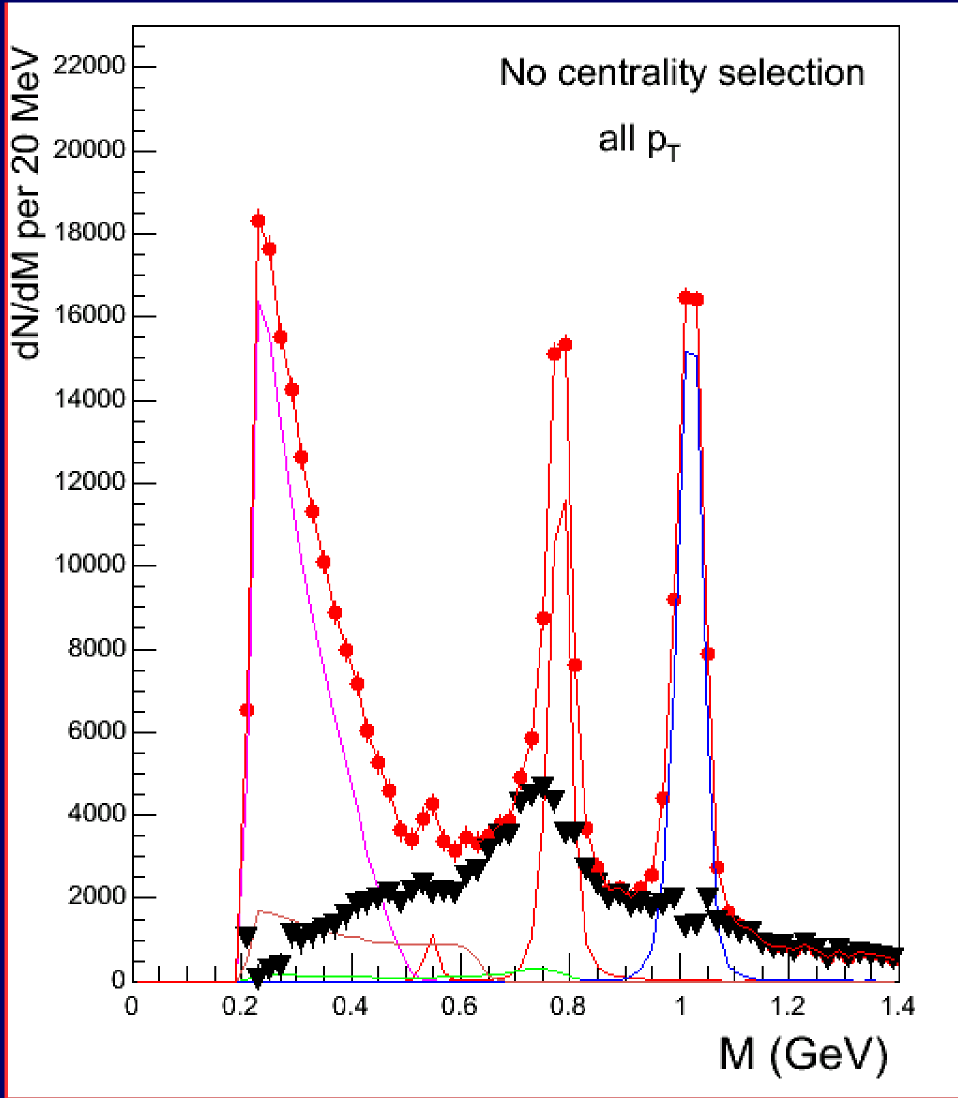
How to fit in the presence of an unknown source?

$\rightarrow$ Nearly understood from high $p_T$ data, but not yet used

Goal of the present analysis:

Find **excess above cocktail** (if it exists) without fits

# Isolate possible excess by subtracting cocktail (without $\rho$) from the data



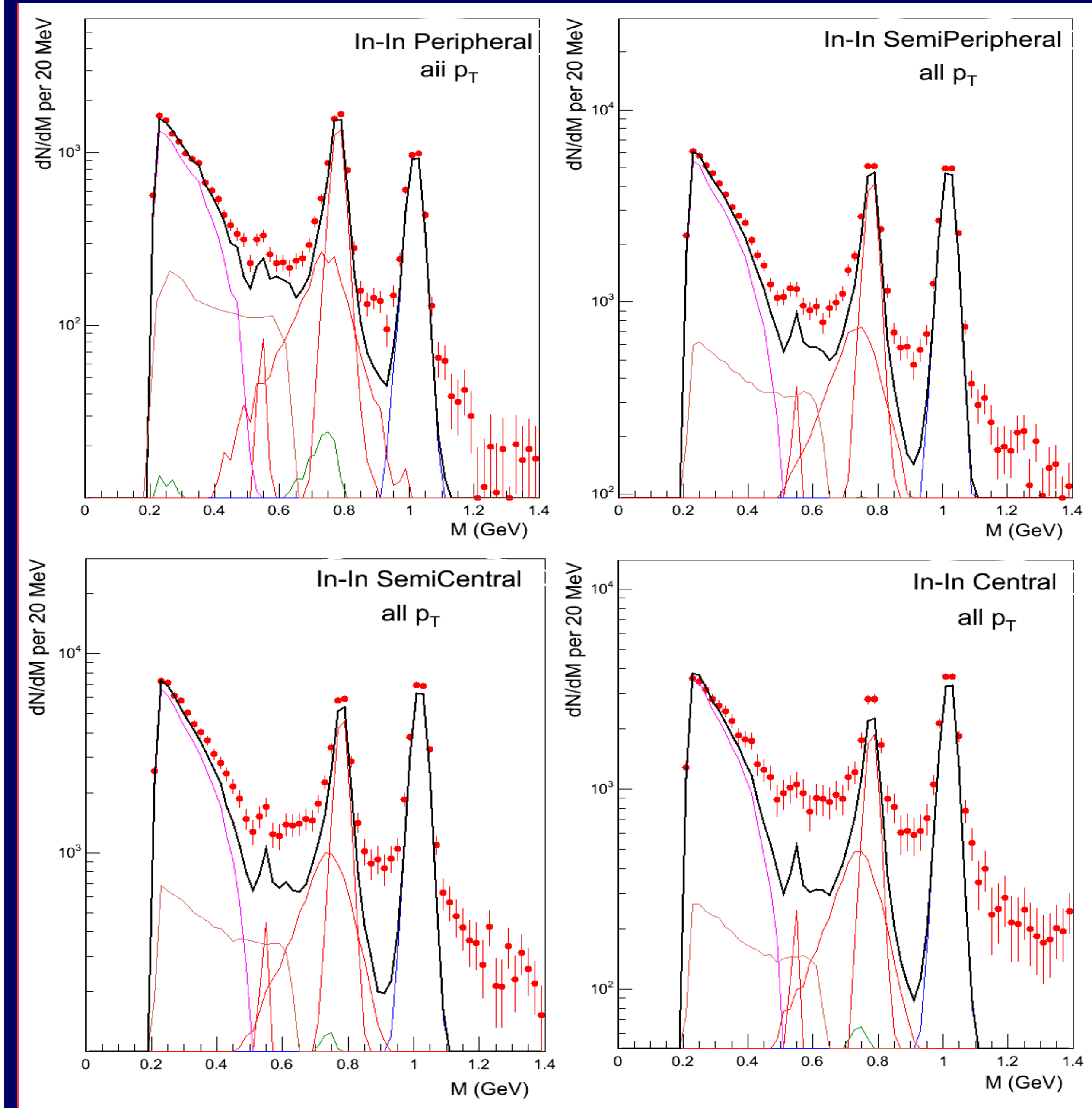

$\eta$ : set upper limit, defined by "saturating" the measured yield in the mass region close to 0.2 GeV

$\rightarrow$ leads to a lower limit for the excess at very low mass

$\omega$ and $\phi$ : fix yields such as to get, after subtraction, a smooth underlying continuum

*difference spectrum* robust to mistakes even on the 10% level, since the consequences of such mistakes are highly localized.

# Comparison of data to "conservative" cocktail




all $p_T$

Cocktail definition: see previous slide

$\rho/\omega$ fixed to 1.2

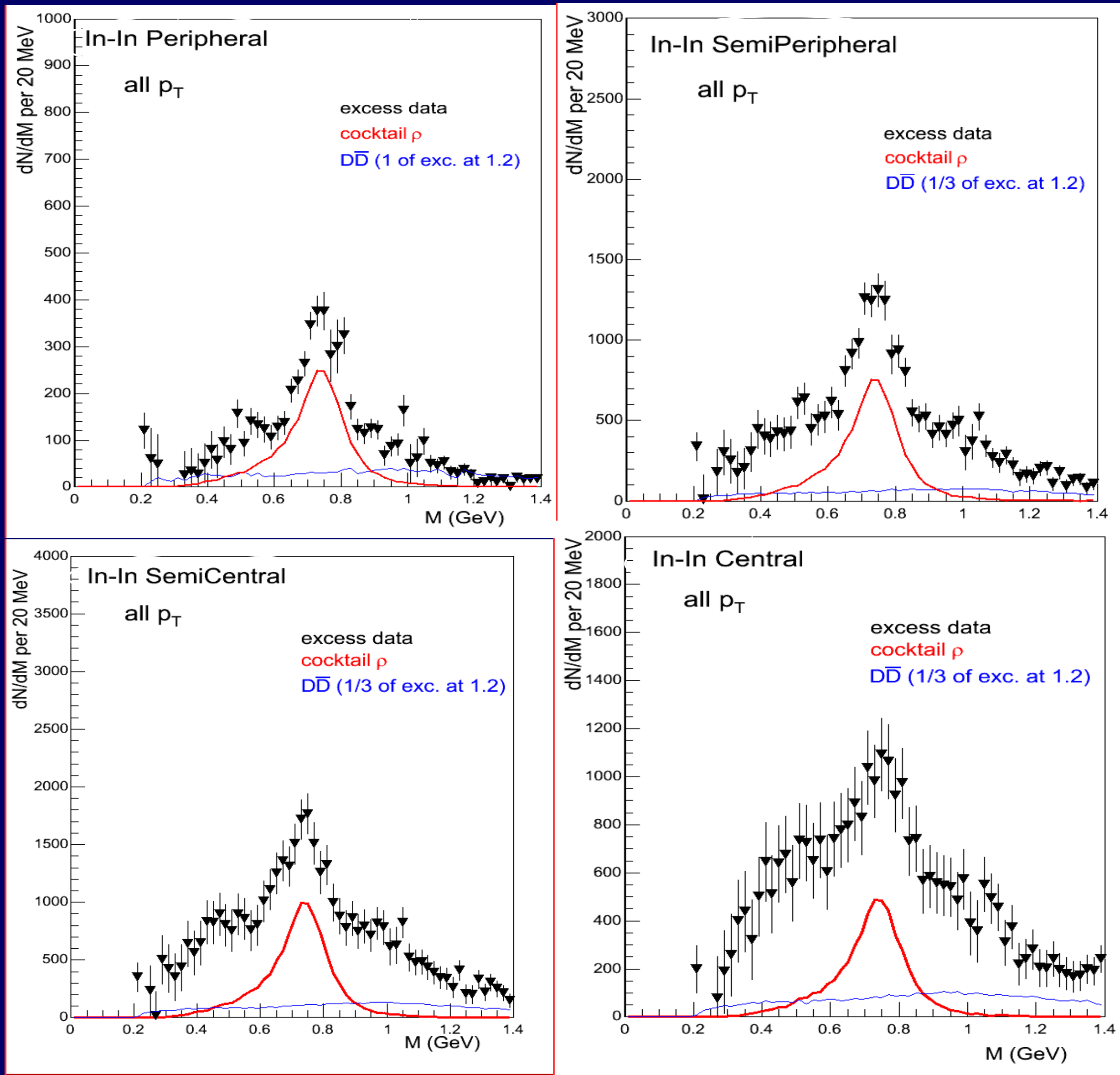
● data

-- sum of cocktail sources including the $\rho$

Clear excess of data above cocktail, rising with centrality

But: how to recognize **the spectral shape of the excess**?

# Excess spectra from difference: data - cocktail




all $p_T$

No cocktail ρ and no $D\bar{D}$ subtracted

Clear excess above the cocktail ρ, centered at the nominal ρ pole and rising with centrality

Similar behaviour in the other $p_T$ bins

# Systematics

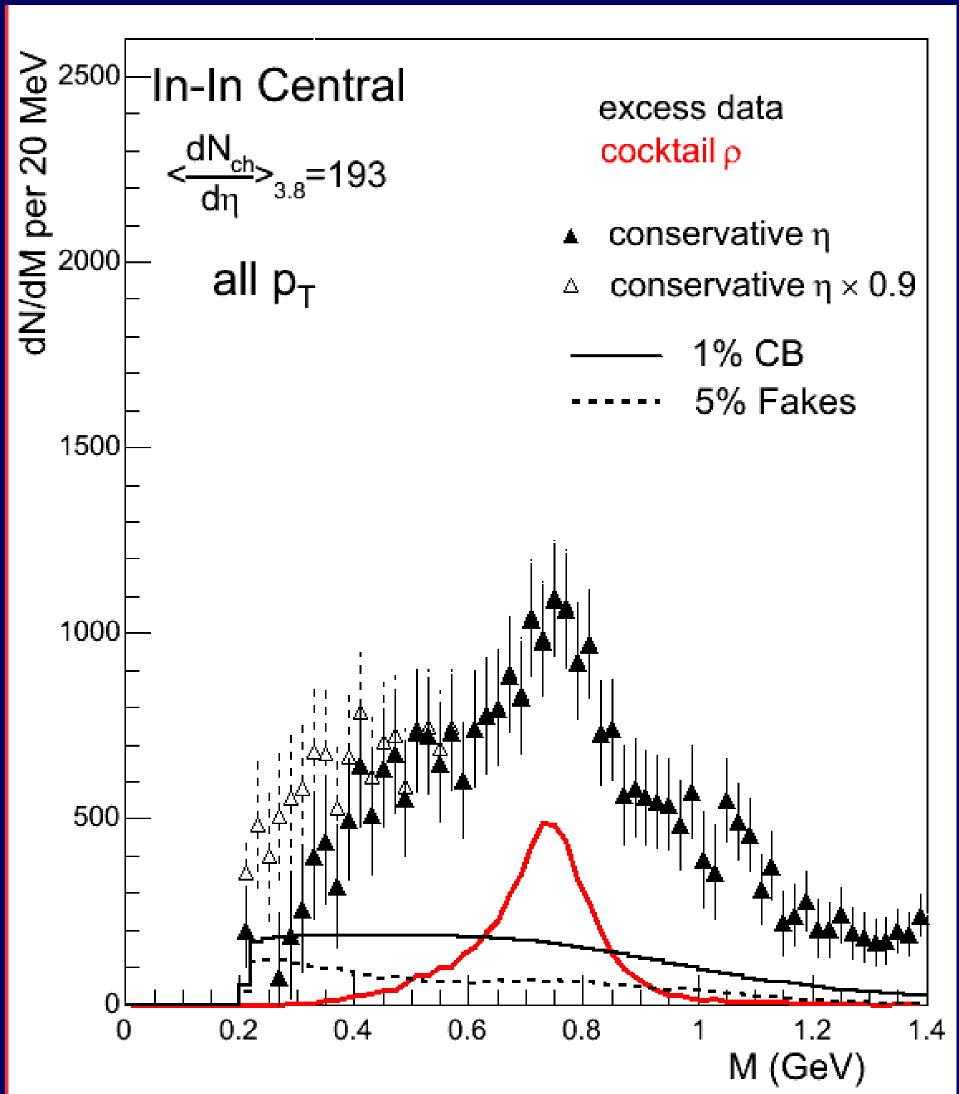



Illustration of sensitivity

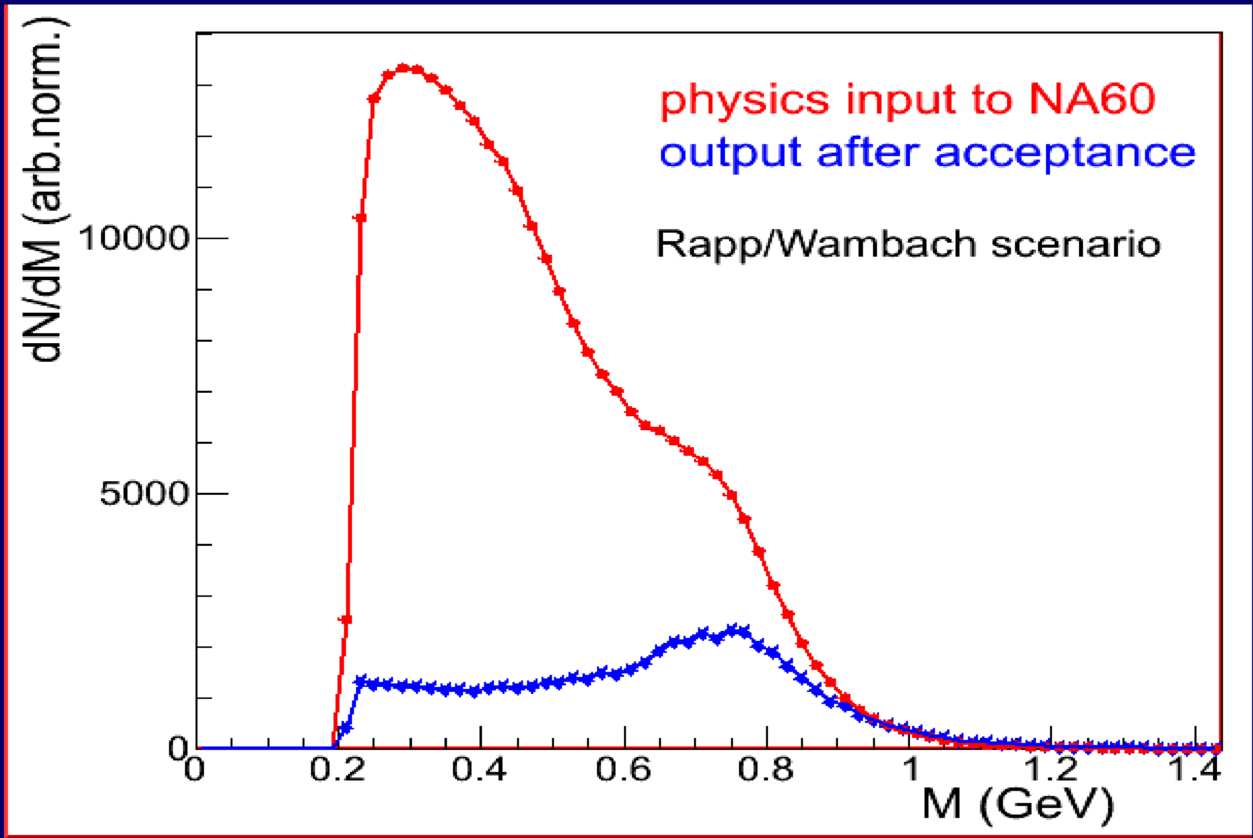
- to correct subtraction of combinatorial background and fake matches;
- to variation of the η yield

Systematic errors of continuum 0.4<M<0.6 and 0.8<M<1GeV   25%

Structure in ρ region completely robust

# Acceptance filtering of theoretical prediction

$$dN_{\mu\mu}/dM \approx f(M) \times \langle \exp(-M/T) \rangle \times \langle spectral\ \ function \rangle$$




all $p_T$

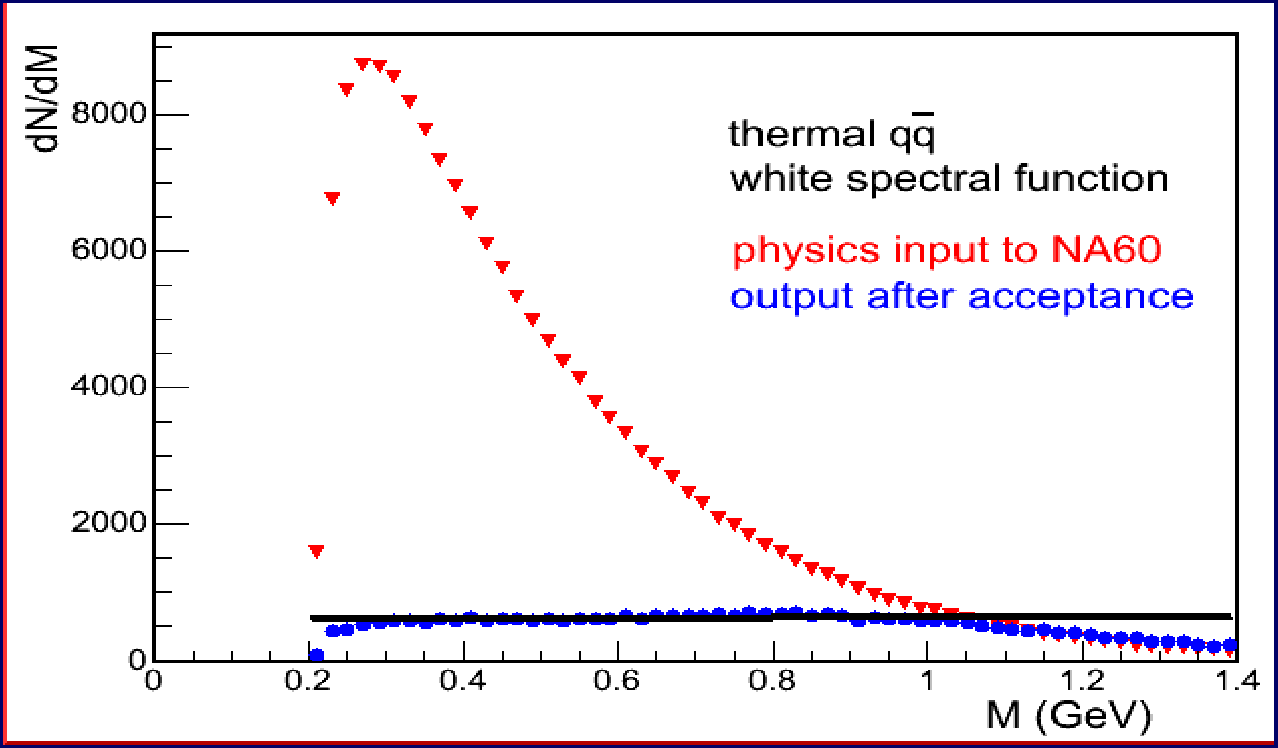
Input (example):

thermal radiation based on RW spectral function

Output: spectral shape much distorted relative to input, but somehow reminiscent of the spectral function underlying the input; by chance?

# Understanding the spectral shape at the output

$$dN_{\mu\mu}/dM \approx f(M) \times \langle \exp(-M/T) \rangle \times \langle spectral\ \ function \rangle$$




all $p_T$

Input:

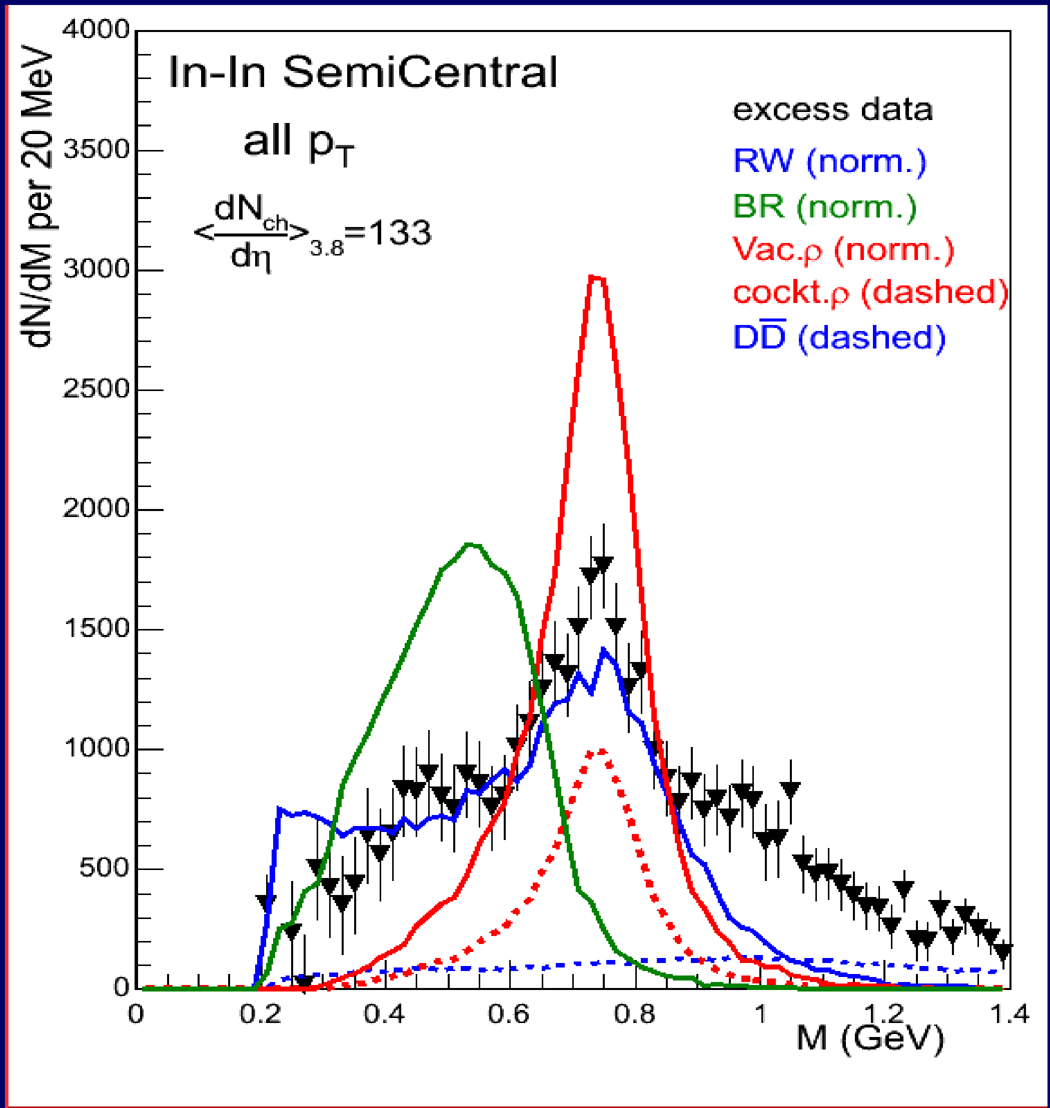
thermal radiation based on white spectral function

Output:

white spectrum !

By pure chance,
for all $p_T$ and the slope of the $p_T$ spectra of the direct radiation,
the NA60 acceptance roughly compensates for the phase-space factors and directly “measures” the <spectral function>

# Comparison of data to RW, BR and Vacuum ρ




Predictions for In-In by Rapp et al (2003) for $\langle dN_{ch}/d\eta \rangle = 140$, covering all scenarios

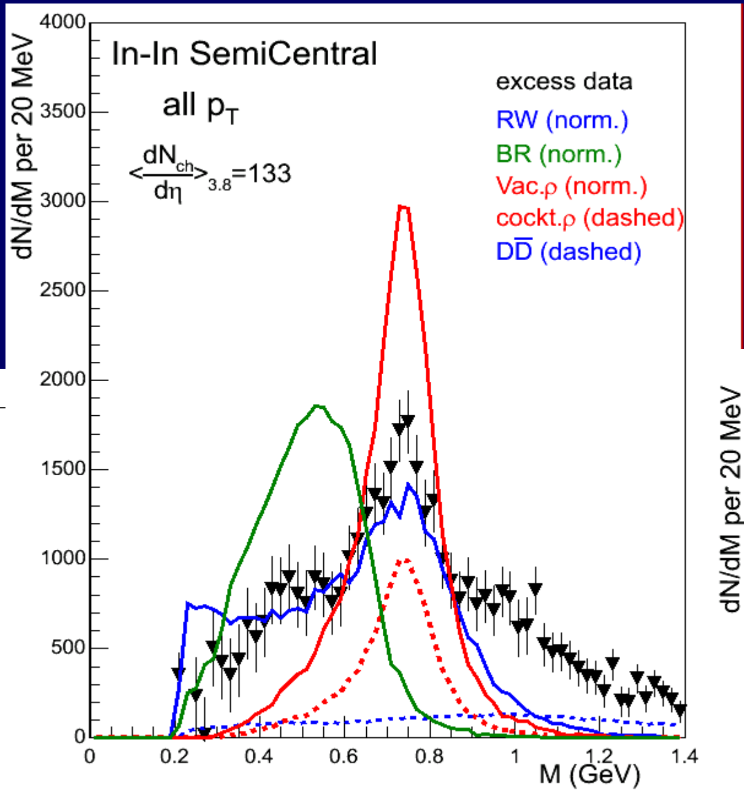
Theoretical yields, folded with acceptance of NA60 and normalized to data in mass interval < 0.9 GeV

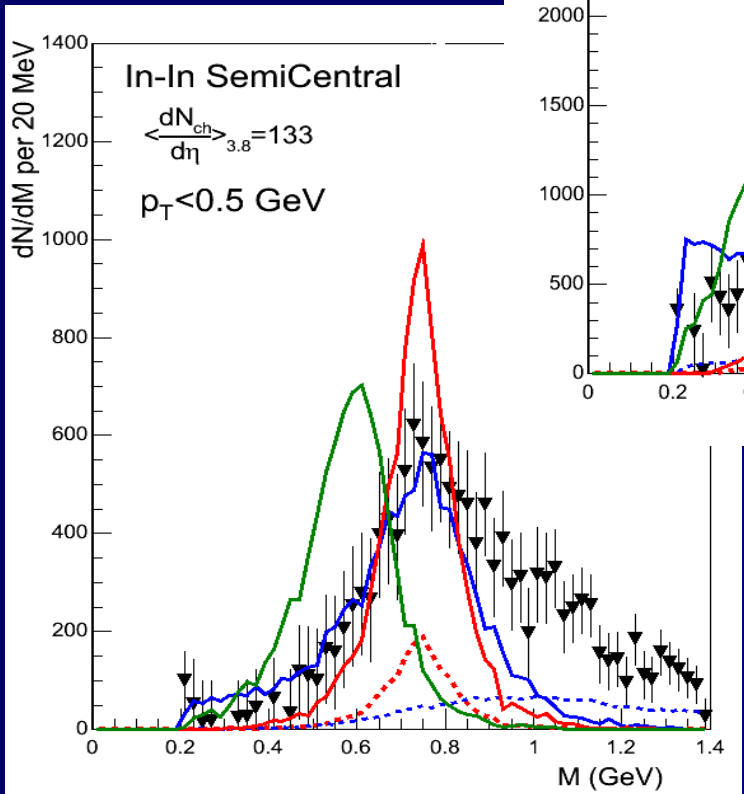
Only broadening of ρ (RW) observed, no mass shift (BR)

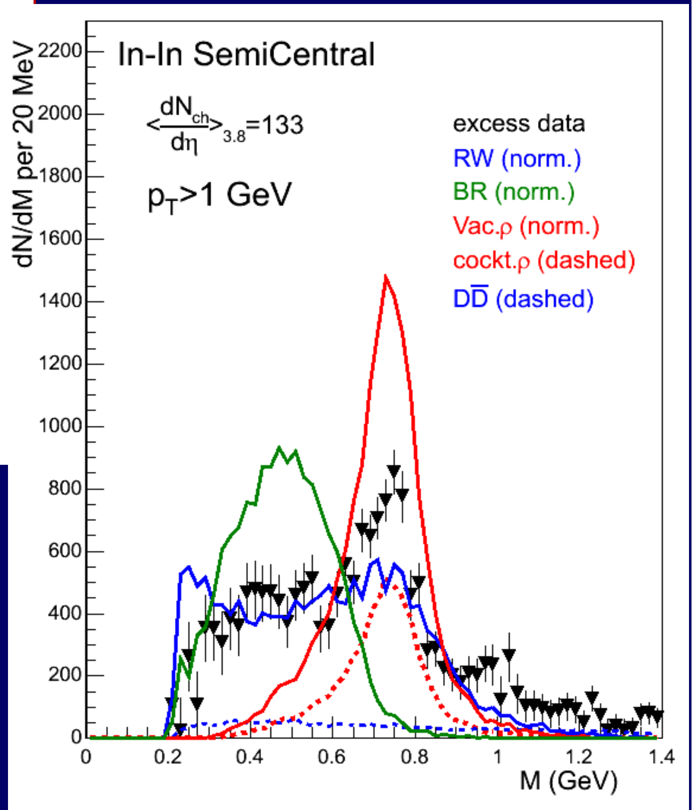
# Comparison of data to RW, BR and Vacuum ρ

$p_T$ dependence

same conclusions



# New theoretical developments since QM05

Brown and Rho, comments on BR scaling, nucl-th/0509001
Brown and Rho, formal aspects of BR scaling, nucl-th/0509002

Rapp and van Hees, parameter variations for $2\pi$, unpublished
Rapp and van Hees, $4\pi$, $6\pi$… processes , hep-ph/0603084
Rapp and van Hees, $4\pi$, $6\pi$… processes , hep-ph/0604269

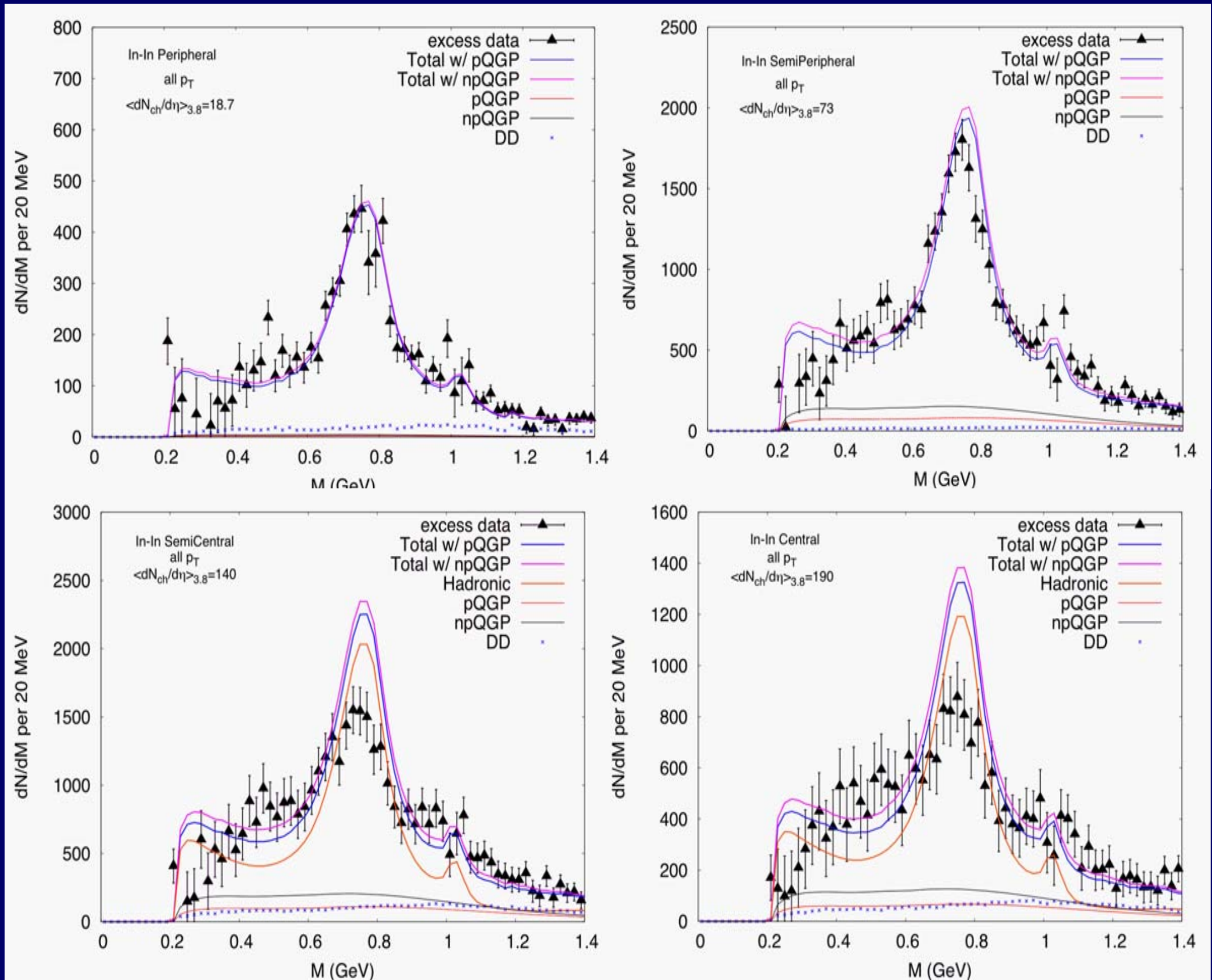
Renk and Ruppert, finite T broadening, Phys. Rev. C71 (2005)
Renk and Ruppert, finite T broadening and NA60, hep-ph/0603110
Renk, Ruppert, Müller, BR scaling and QCD Sum Rules, hep-ph/0509134
Renk, Ruppert, Müller, theoretical thoughts on NA60, unpublished

Skokov and Toneev, BR scaling and NA60, Phys. Rev. C73 (2006)

Dusling and Zahed, Chiral virial approach and NA60, nucl-th/0604071

Bratkovskaya and Cassing, HSD and NA60, in progress

# Chiral Virial Approach Dusling/Zahed

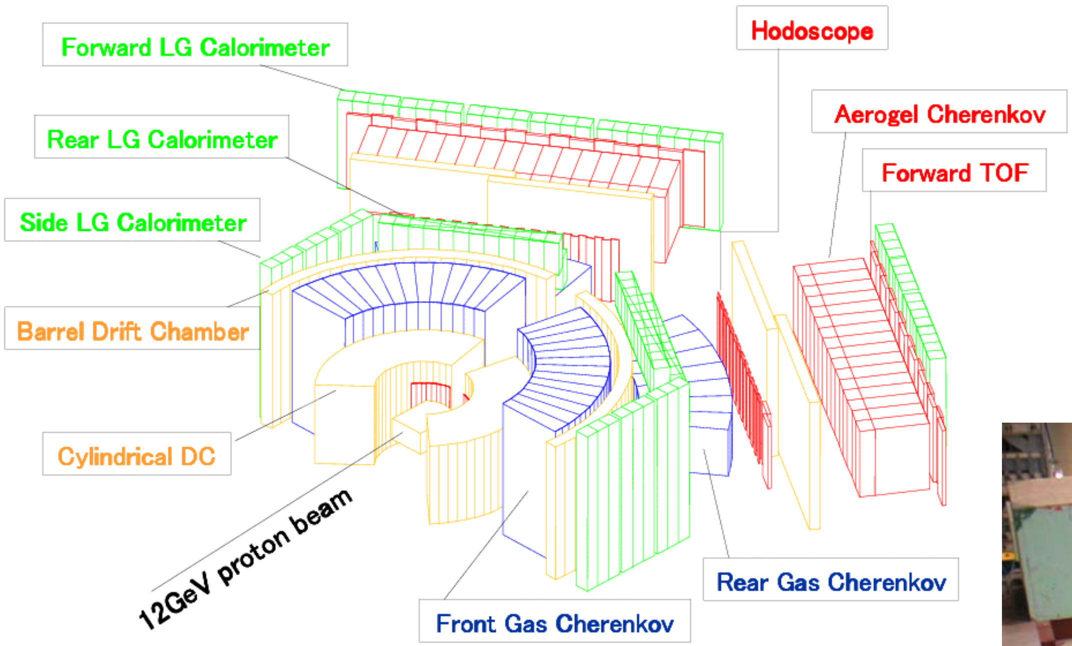


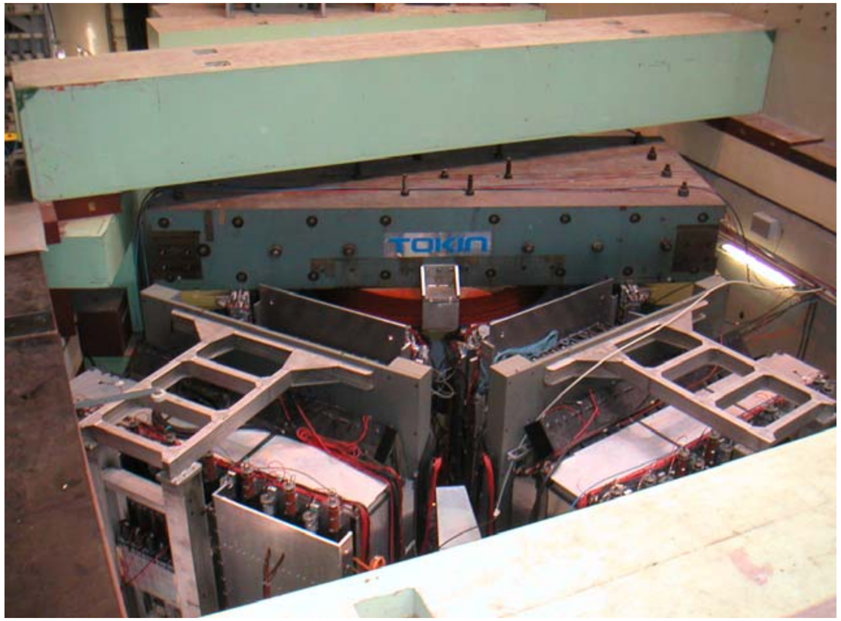

First attempt to describe the centrality dependence of the excess data.

Reasonable description, but increasing overestimate of central ρ peak

# E325 experiment at KEK

E325



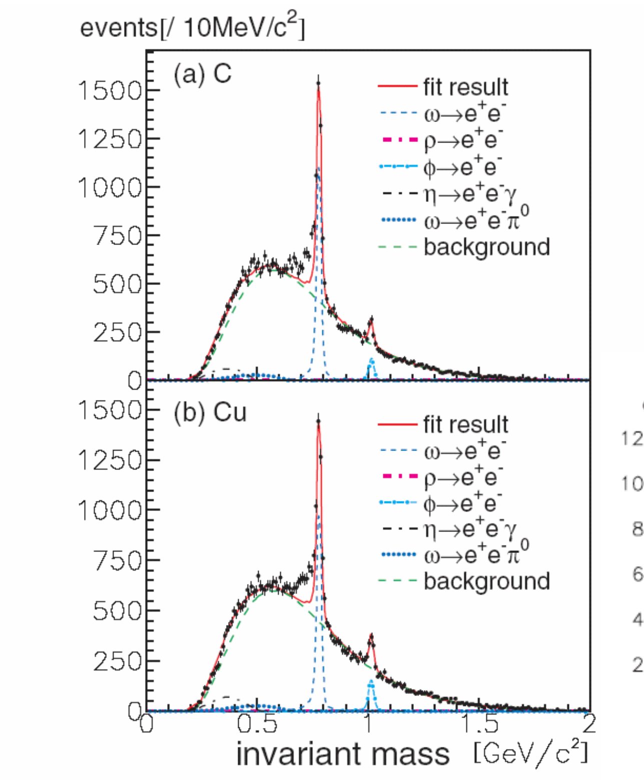




**12 GeV p + C, Cu → ρ, ω → $e^+e^-$**

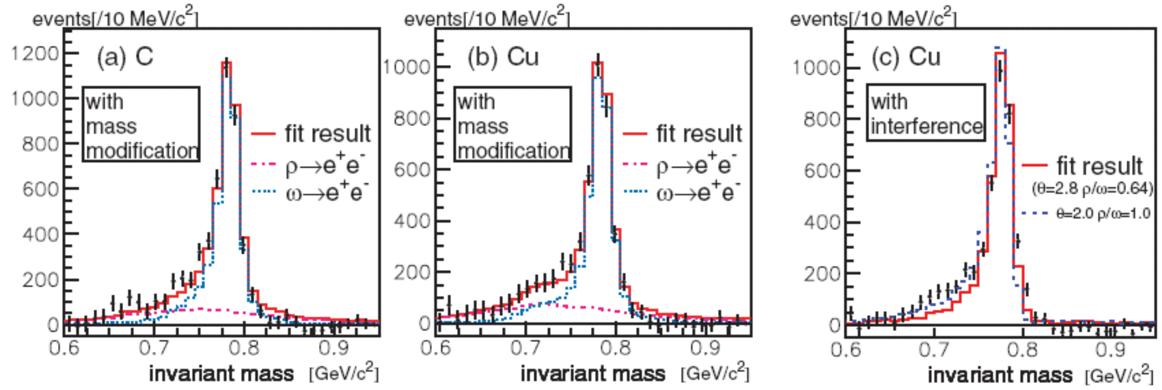
# VM spectral shapes from p+A

**E325**

Naruki et al., PRL 96 (2006) 092301




Cocktail fitted to data, with known BR.




➔ **Simulations a with mass-shifted ρ (-9%) describe data.**

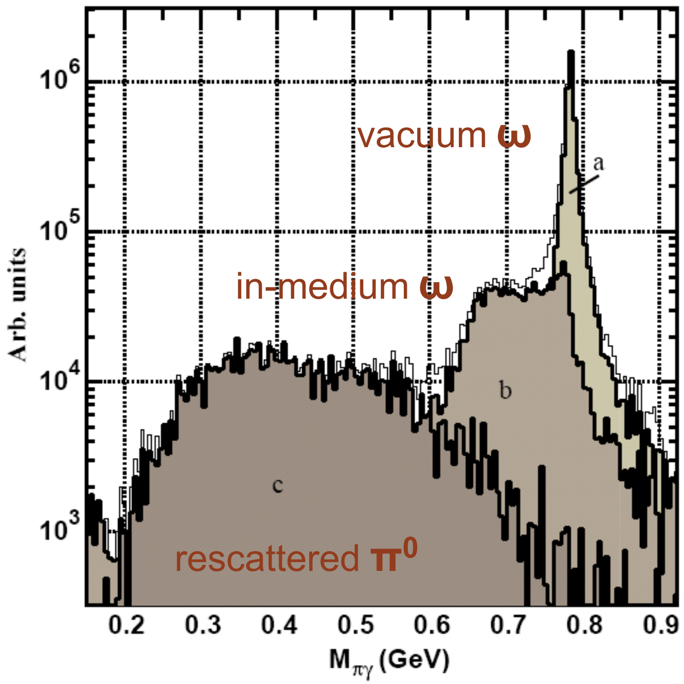
HADES pA proposal submitted to GSI PAC!

# CB/TAPS at ELSA $\gamma + A \rightarrow \omega \rightarrow \pi^0 \gamma$

**Advantage:** **large BR** **into 3-photon channel (8.5%)**

**Problem:** **rescattering of $\pi^0$**

**But simulation says that this can be managed...**




Messchendorp et al., EJP A11 (2001) 95

Conclusion also supported by BUU transport.

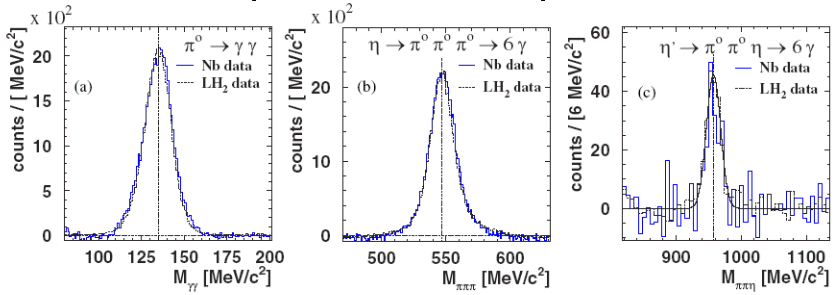
Mosel et al., EJP A20 (2004) 499

# CB/TAPS at ELSA

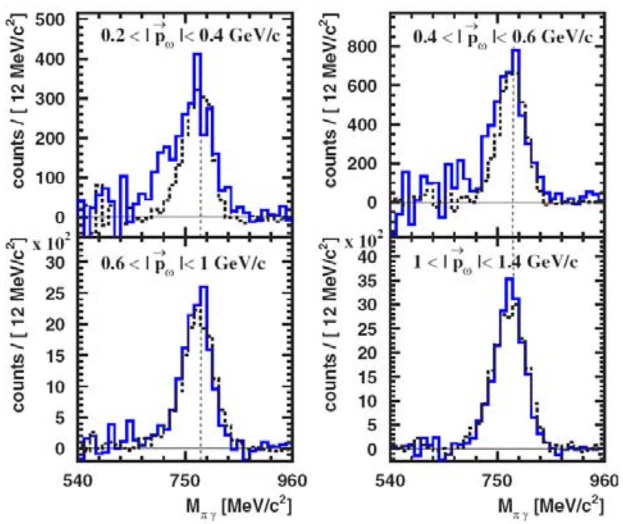
Measurement done at ELSA tagged photon beam with combined Crystal Barrel/TAPS setup:

Targets: $LH_2$, C, Nb
Energy: 0.64 – 2.53 GeV

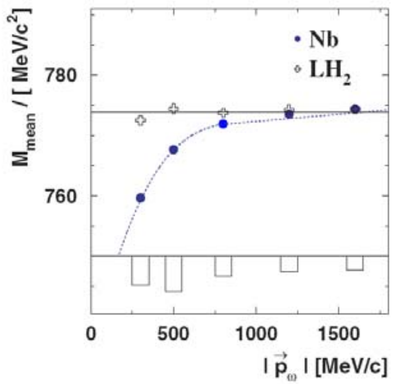
Multi-photon line shapes




Reconstructed ω



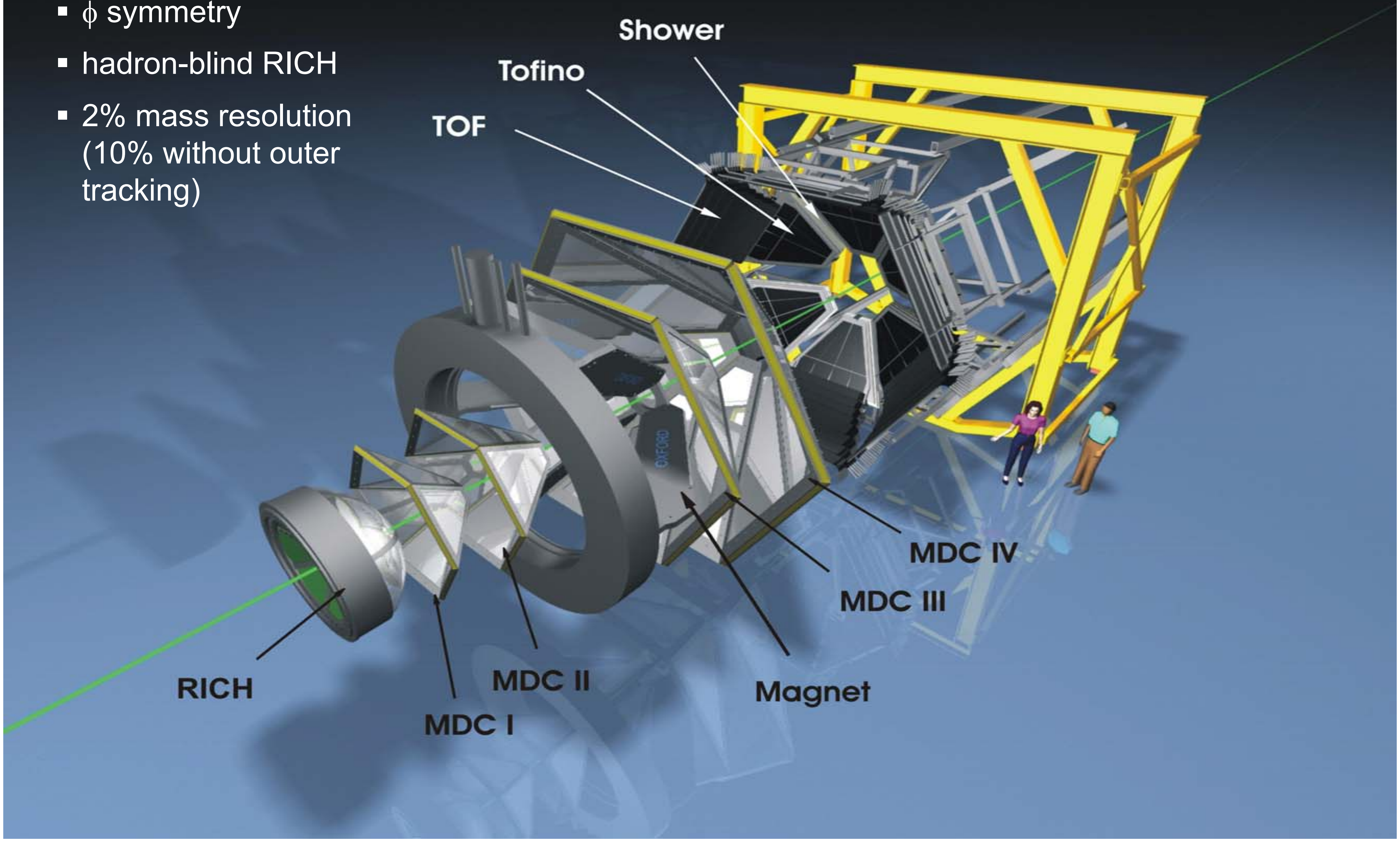

Momentum dependence




**→ shift of ω or f.s.i. of $\pi^0$ ?**

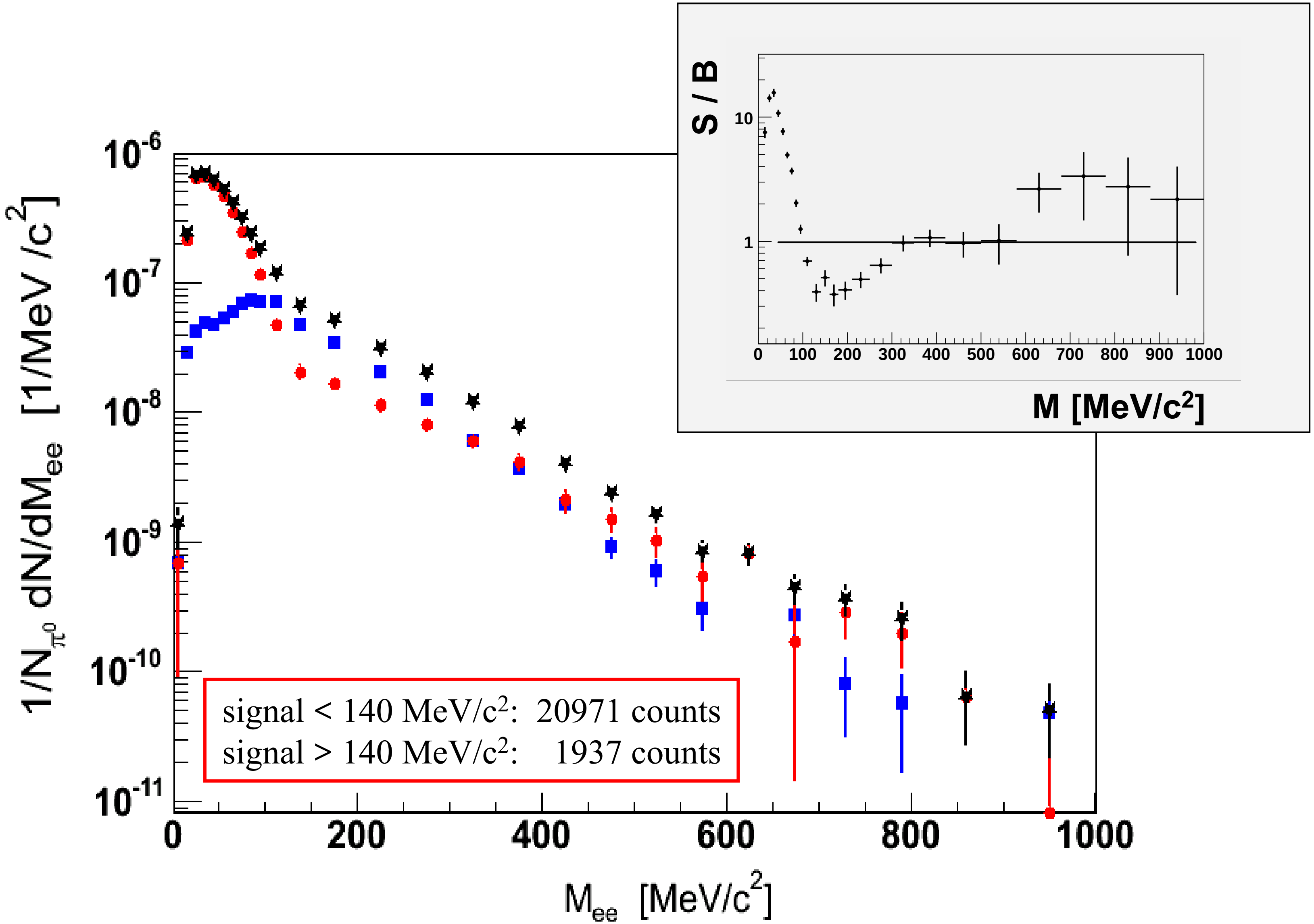
# The HADES experiment at GSI

- $\phi$ symmetry
- hadron-blind RICH
- 2% mass resolution (10% without outer tracking)

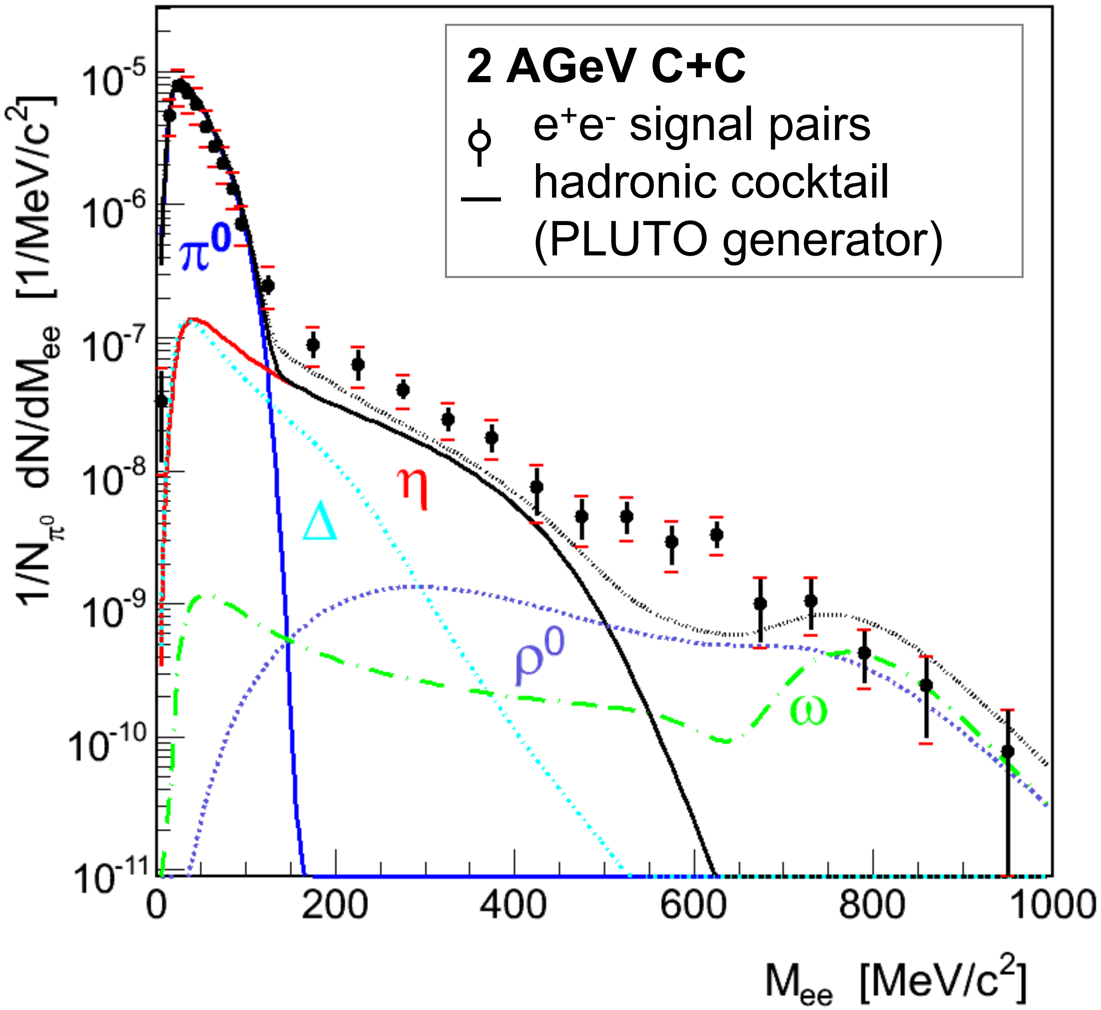


# C+C 2 AGeV: $e^+e^-$ mass spectrum

HADES



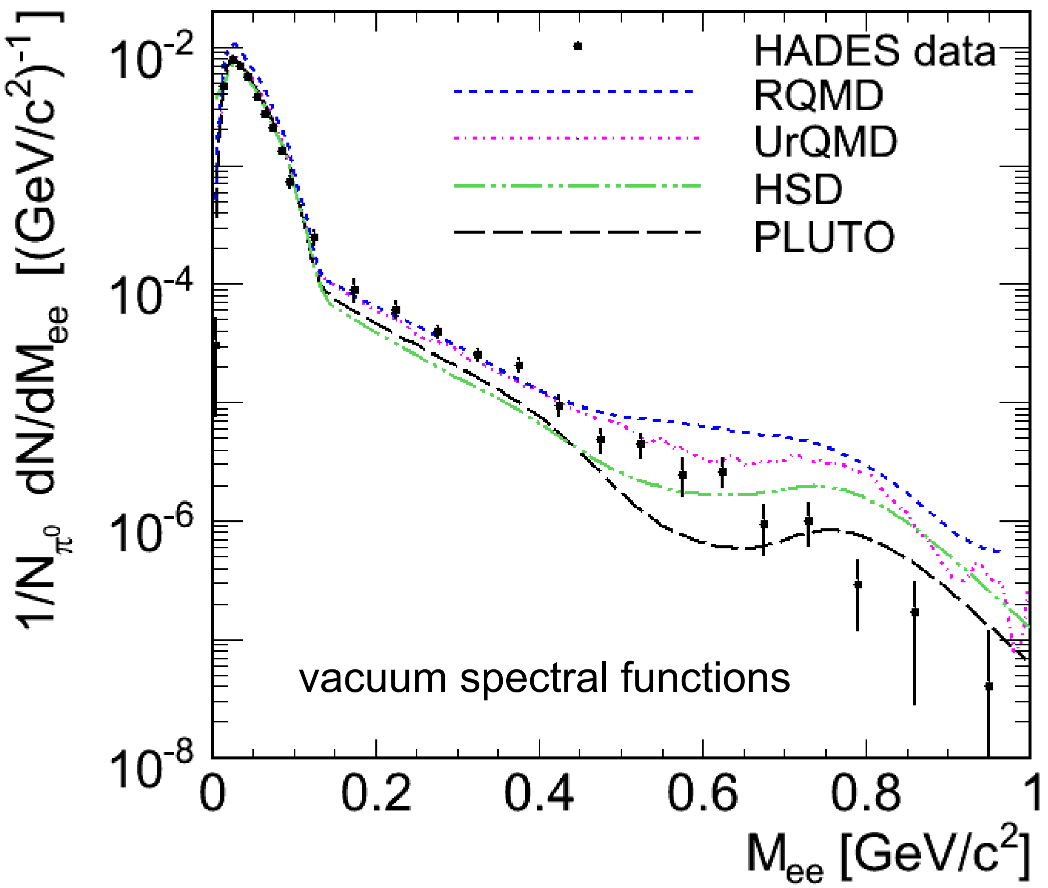
# HADES data vs. cocktail




- Electron pair yield observed in acceptance
- Corrected for reconstruction efficiency
- Cocktail yields from TAPS measurement and using $m_t$ scaling

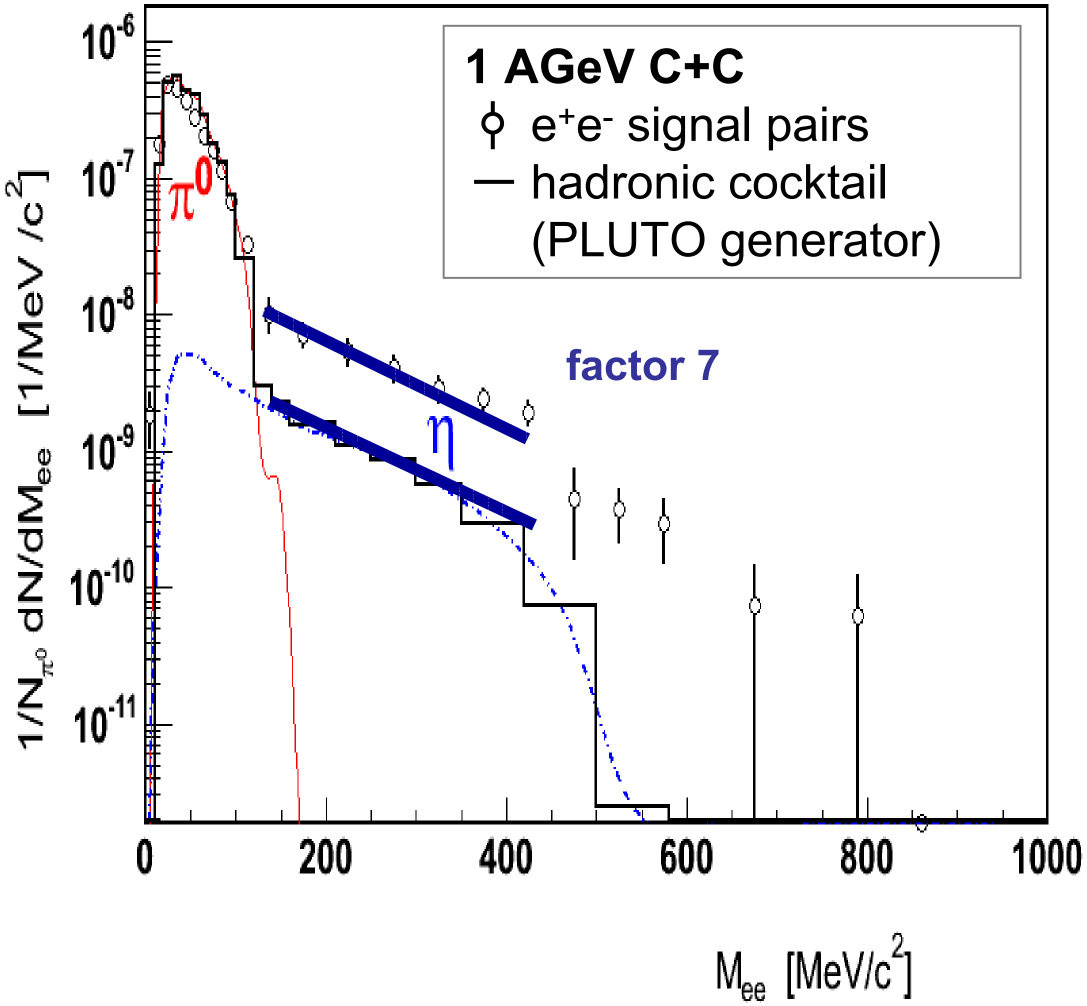
# C+C 2 AGeV: Comparison to transport

**Fig. 3b of HADES PRL**




**sys. error = 20%-30%**

# C+C 1 AGeV: HADES data (preliminary)



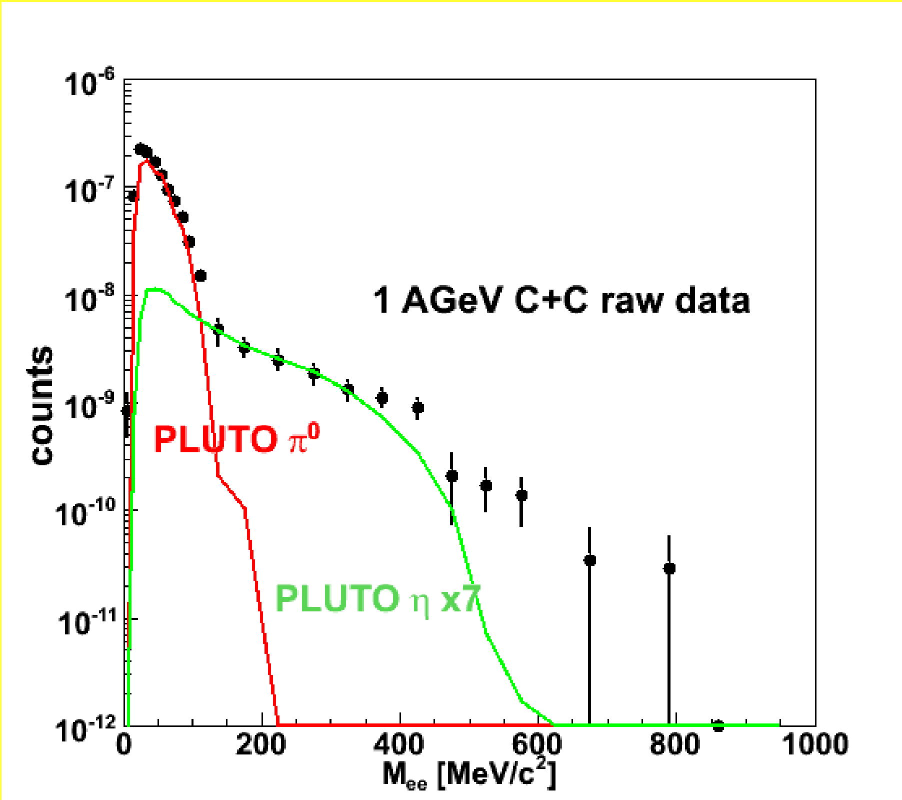

- Electron pair yield observed in acceptance
- Corrected for reconstruction efficiency
- Substantial yield above the $\eta$ contribution

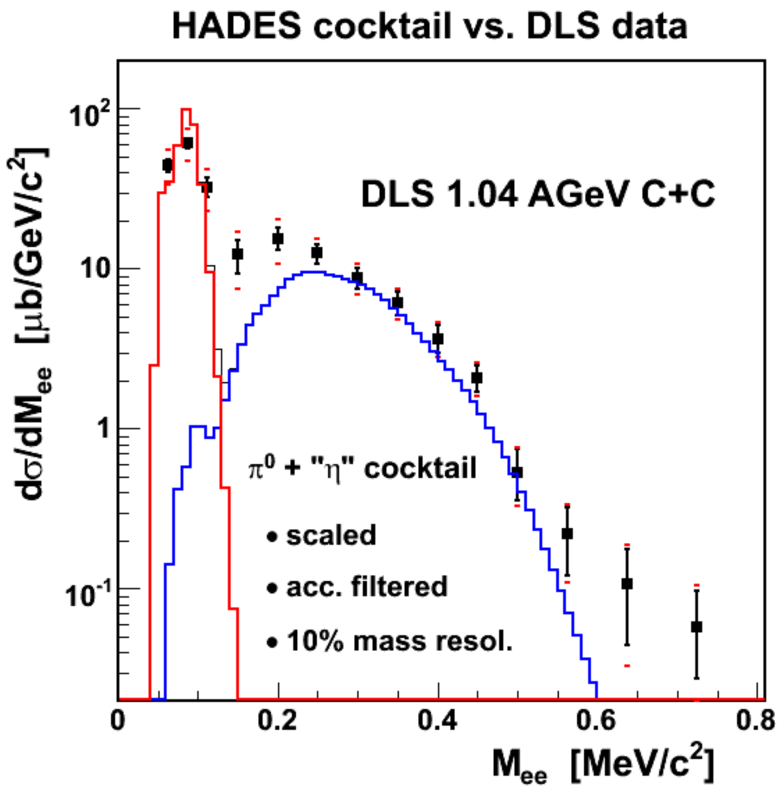
preliminary

# Comparison with the DLS results

Generated events processed by the full HADES analysis including:

- detector (in)efficiency
- reconstruction (in)efficiency




Systematic errors

- data (bg subtraction)
- simplified event generator
    - (only $\pi$,$\eta$)
    - angular distributions

# Summary of observed medium effects

| | |
|---|---|
| • NA60 | ρ broadening |
| • KEK E325 | ρ shift (-9%) |
| • CB/TAPS | ω shift (-15%) |
| • CLAS | ρ broadening  (t.b.c.) |

➔ **HADES pA proposal submitted to GSI PAC**

# The future

1. PHENIX at RHIC

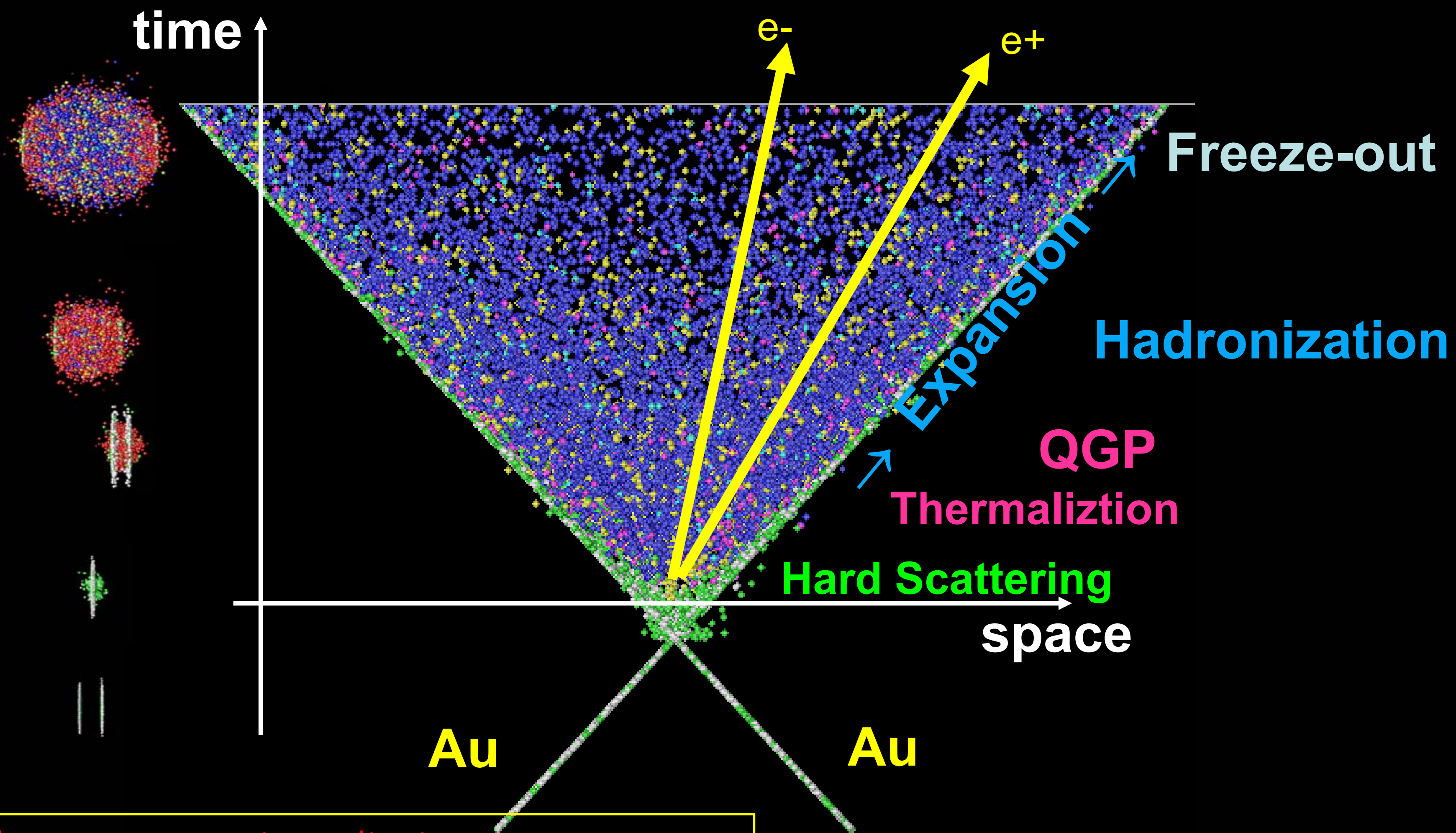
2. ALICE at the LHC

1. HADES at SIS and SIS100

2. CBM at SIS300

3. ???

# EM radiation from the fireball



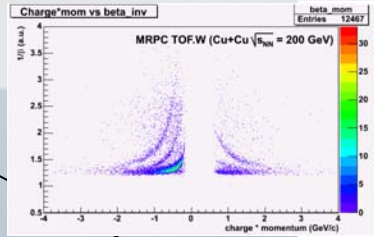

Electro-magnetic radiation: $\gamma$, e+e-, $\mu$+$\mu$-

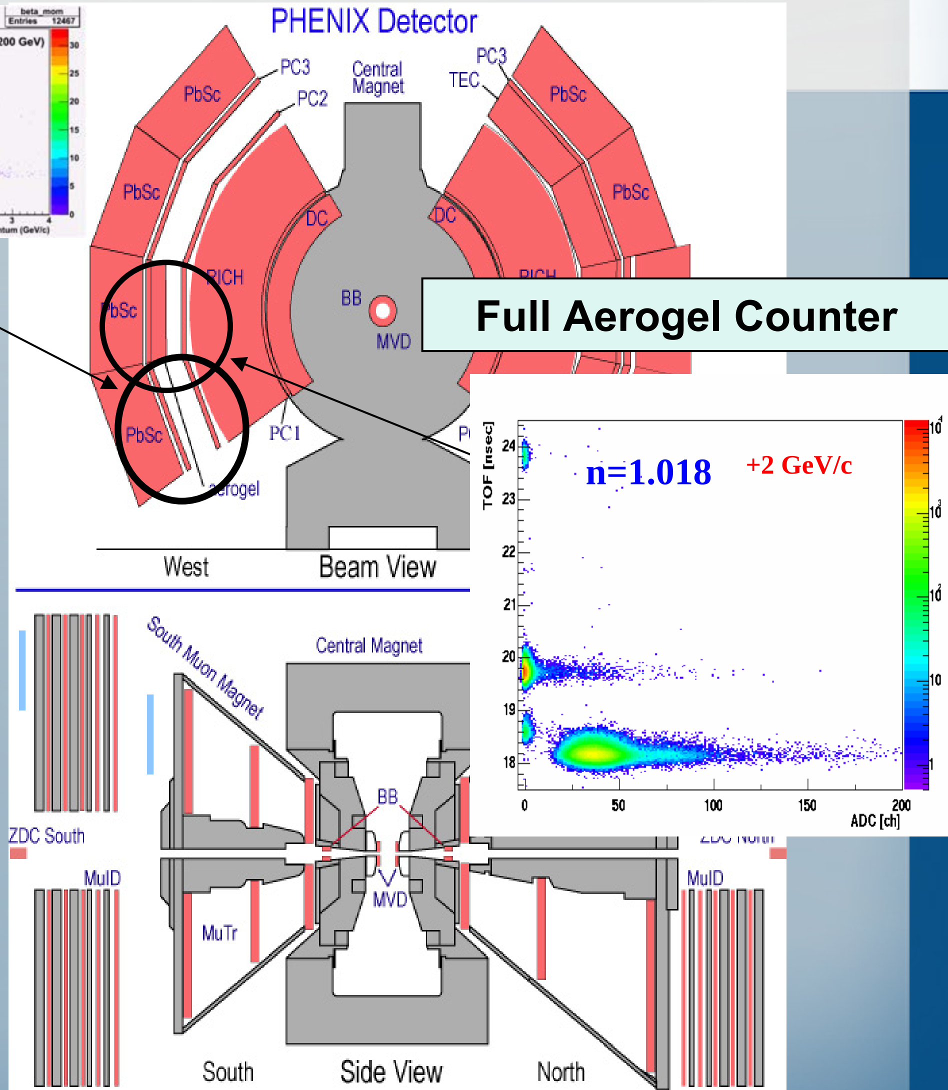
rare, emitted “any time”; reach detector unperturbed by strong final-state interactions

A. Toia QM2005

# PHENIX Configuration in Run-5

**TOF-West RPC prototype installed and tested in CuCu running.**





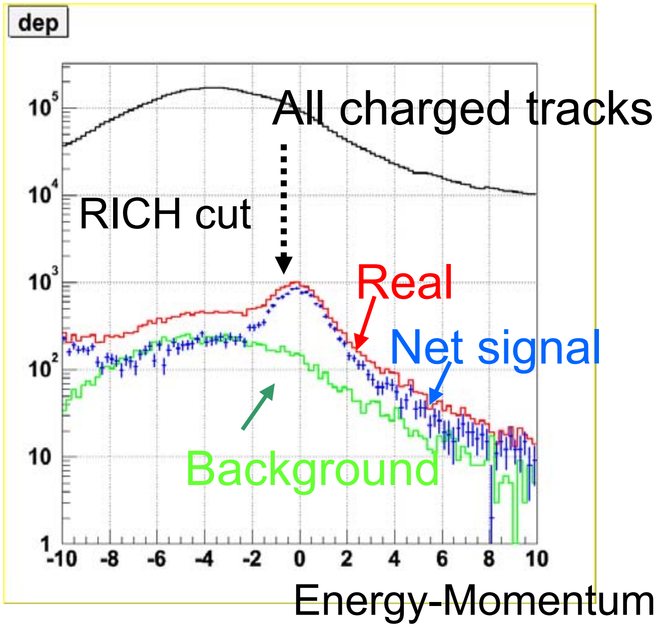

**Full Aerogel Counter**

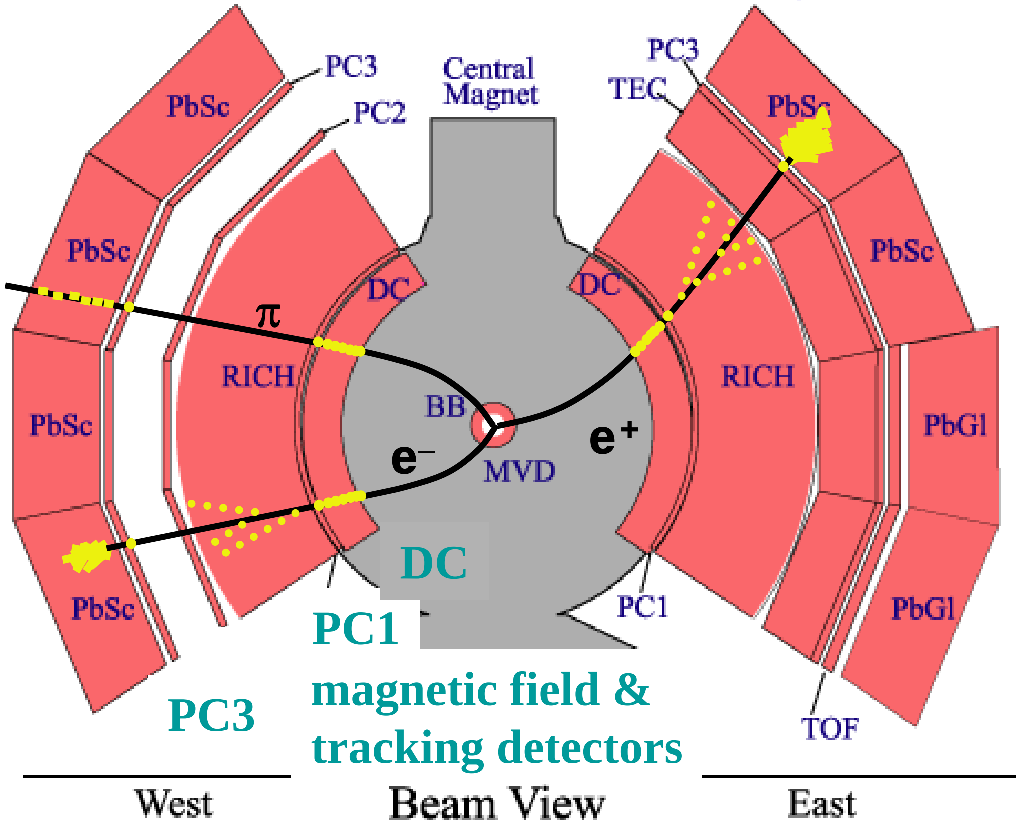
***ALSO*:**
New LVL1 Triggers (MuID and ERT)
Improved DAQ (>5kHz)
Multi-Event Buffering (95% live)
OnCal calibrations
LVL2 Filtering rare events

# Electron identification in PHENIX

PHENIX optimized for Electron ID
- track +
- Cherenkov light in **RICH** +
- shower in **EMCAL**

Charged particle tracking:
**DC, PC1, PC2, PC3** and **TEC**
Excellent mass resolution (1%)




Pair cuts
(to remove hit sharing)

# Combinatorial background reconstruction

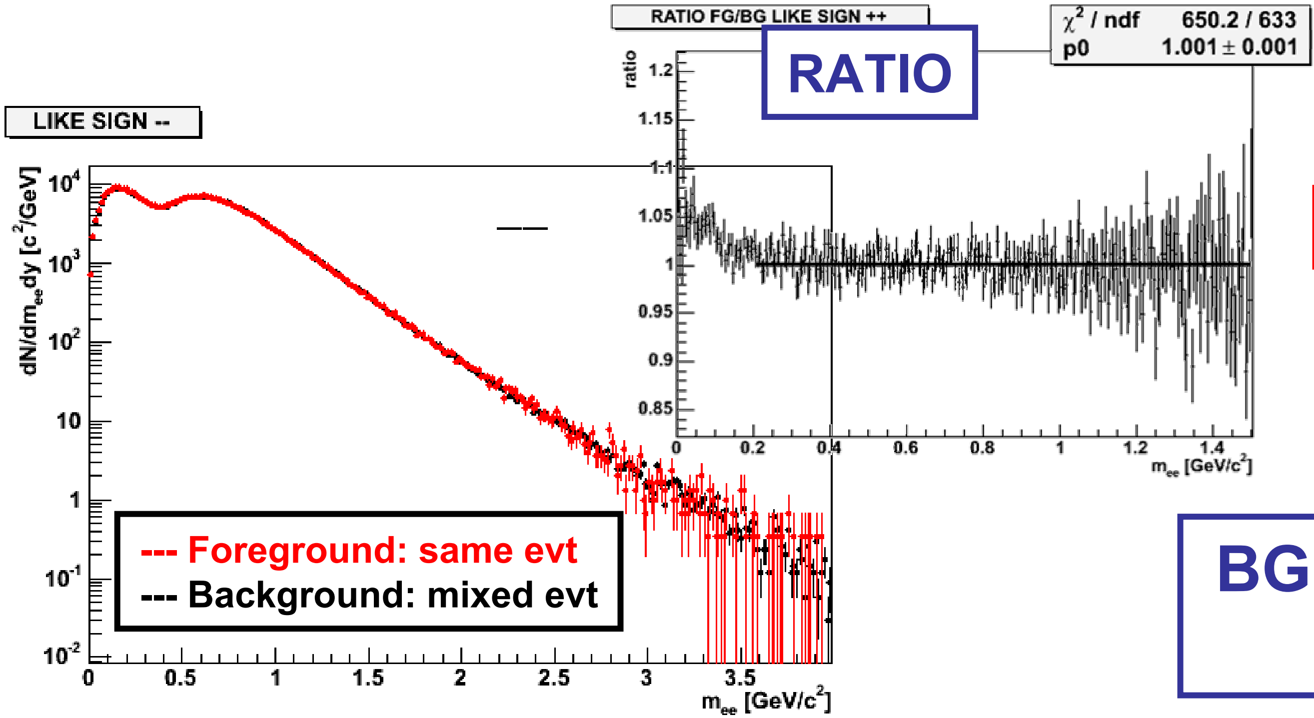
**Which belongs to which?** Combinatorial background

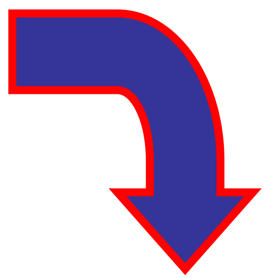
| | | | |
|---|---|---|---|
| $\gamma \rightarrow e+\ e-$ | $\gamma \rightarrow e+\ e-$ | $\gamma \rightarrow e+\ e-$ | $\gamma \rightarrow e+\ e-$ |
| $\pi^0 \rightarrow \gamma\ e+\ e-$ | $\pi^0 \rightarrow \gamma\ e+\ e-$ | $\pi^0 \rightarrow \gamma\ e+\ e-$ | $\pi^0 \rightarrow \gamma\ e+\ e-$ |

**PHENIX 2 arm spectrometer acceptance:**

$dN_{like}/dm \neq dN_{unlike}/dm$ → different shape → need event mixing

like/unlike differences preserved in event mixing → Same normalization for like and unlike sign pairs



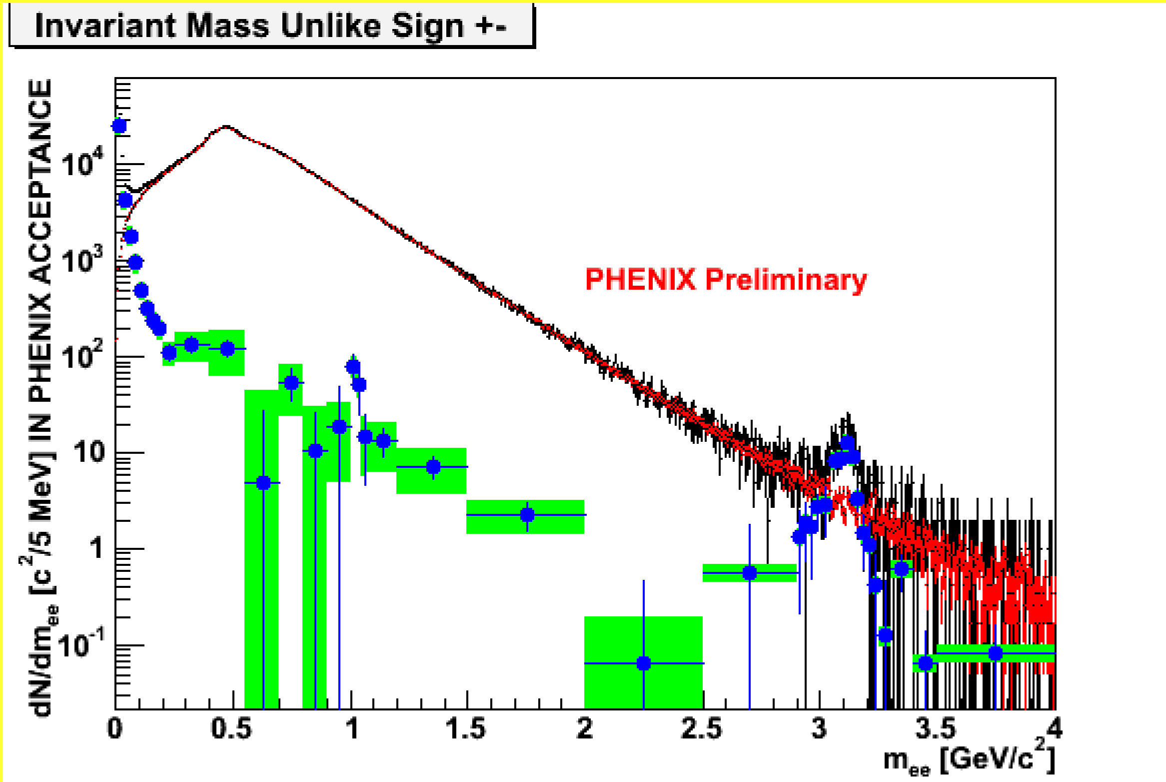
**BG fits to FG 0.1%**

# Subtracted spectrum

BG normalized to
Measured like sign yield

Integral:180,000
above $\pi^0$:15,000

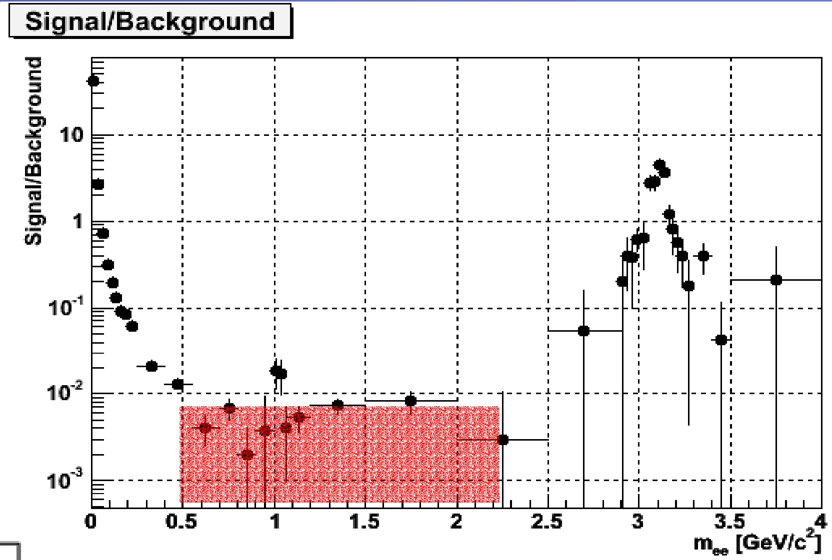
**All the pairs**
**Combinatorics**
**Signal**

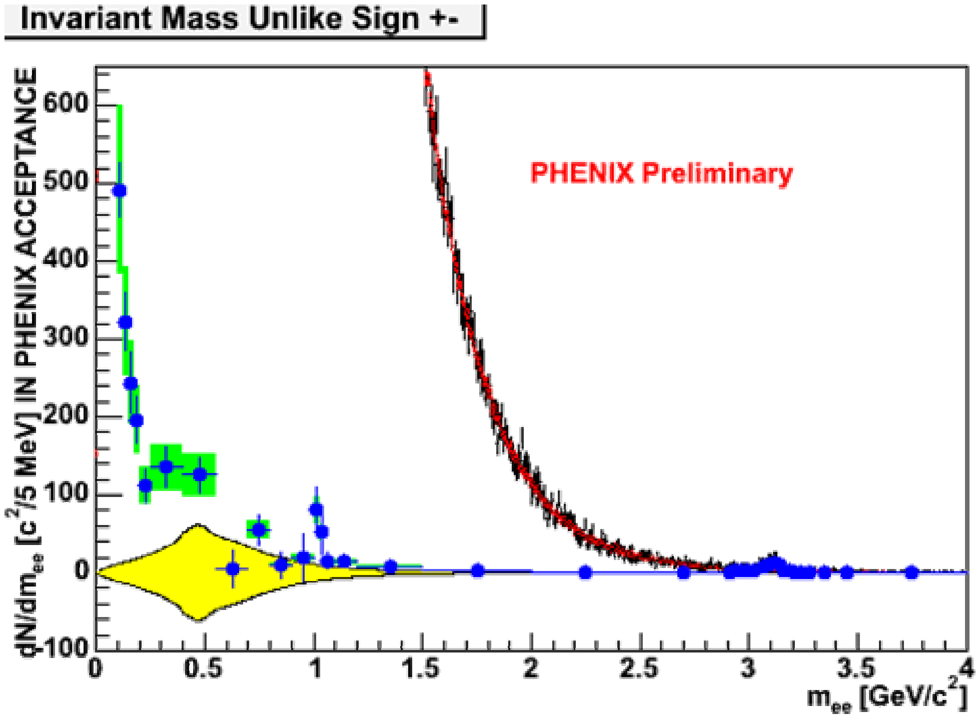



Green band: systematic uncertainty
- Acceptance
- Efficiency
- Run-by-run

# Signal-to-background ratio

- Very low signal-to-background ratio in the interesting region
  → main systematic uncertainty



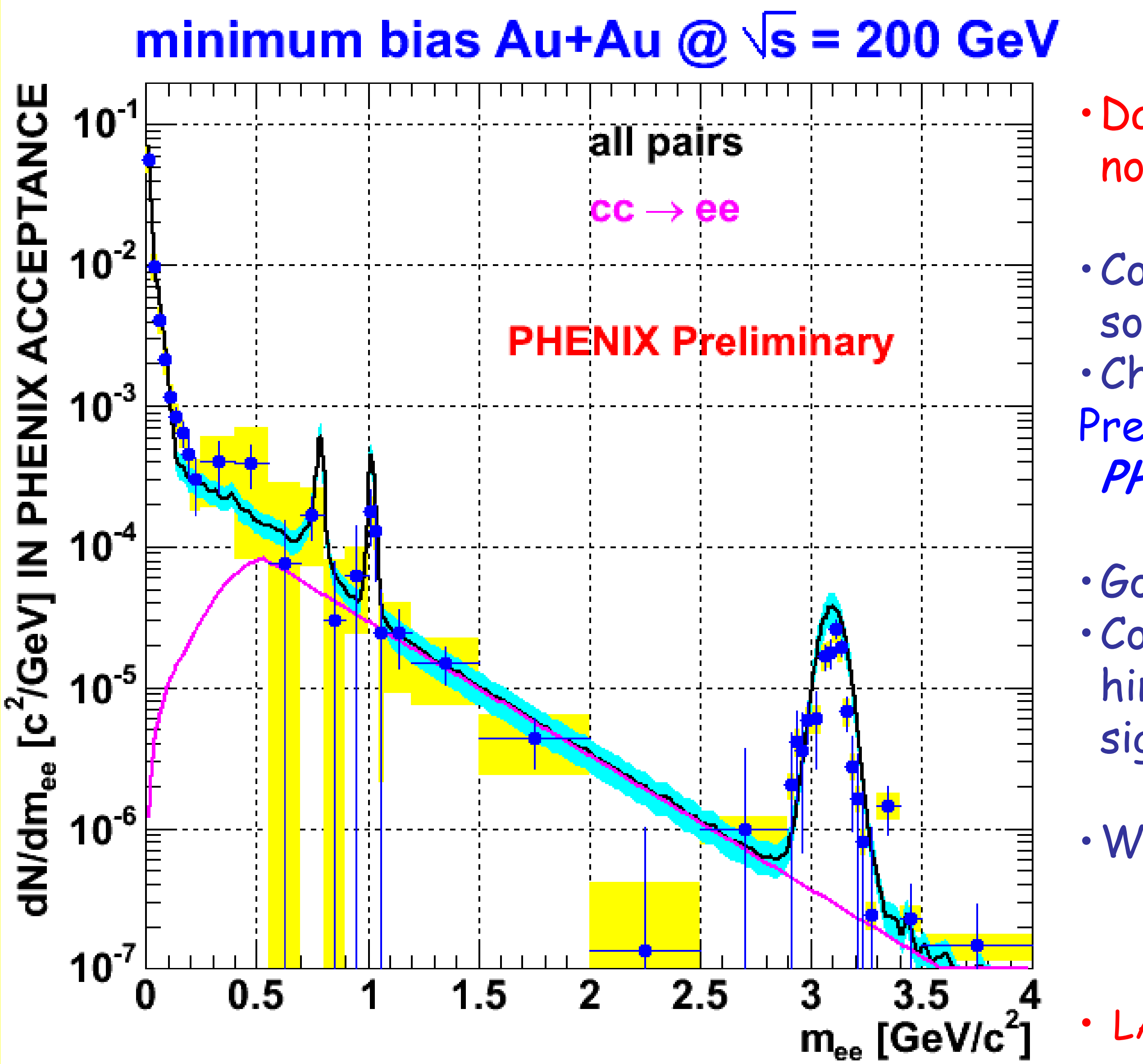

$\sigma_{signal}/signal = \sigma_{BG}/BG * BG/signal$

0.25% large!!!

Yellow band: error on combinatorial background normalization

Green band: other systematics

# Comparison with cocktail




- Data and cocktail absolutely normalized

- Cocktail from hadronic sources
- Charm from PYTHIA

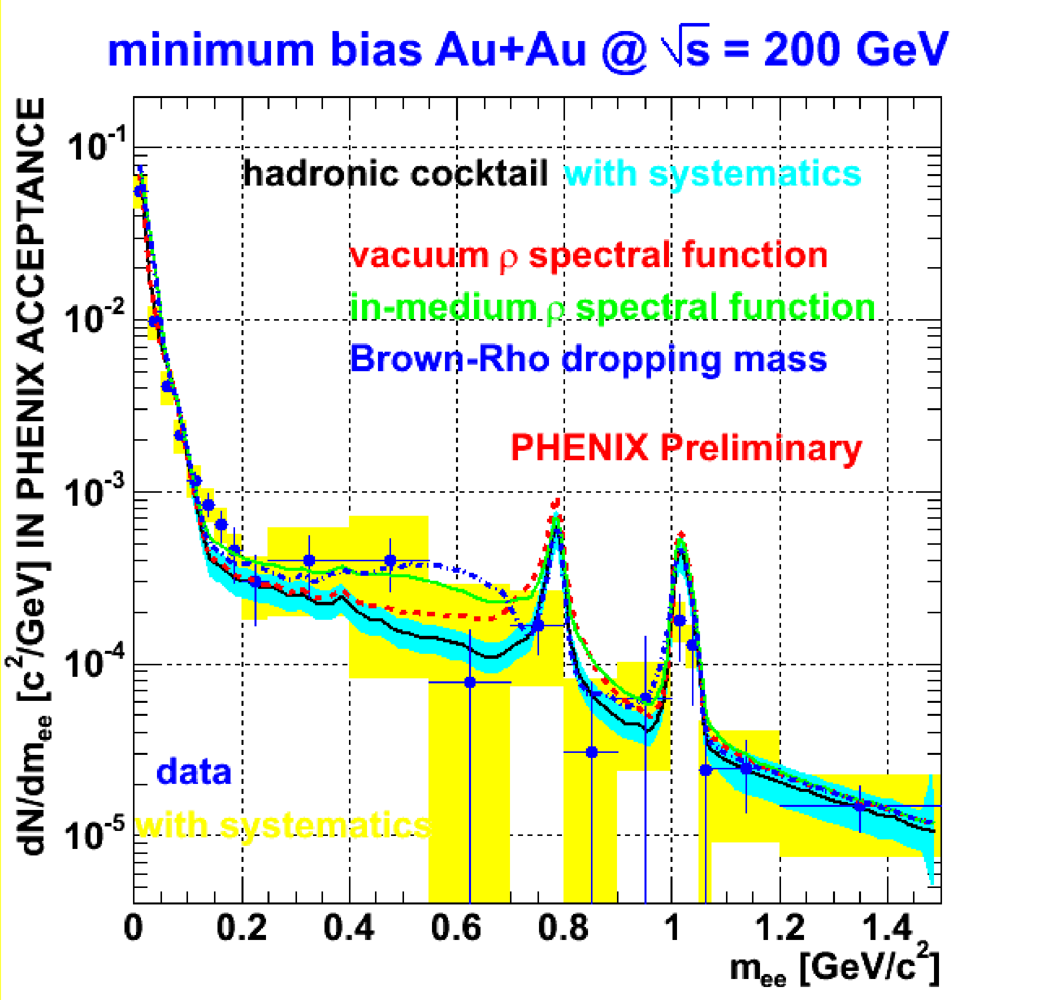
Predictions are filtered in ***PHENIX acceptance***

- Good agreement in $\pi^0$ Dalitz
- Continuum: hint for enhancement not significant within systematics

- What happens to charm?
  - Single e → pt suppression
  - angular correlation???

- LARGE SYSTEMATIC ERROR!

# Comparison with theory



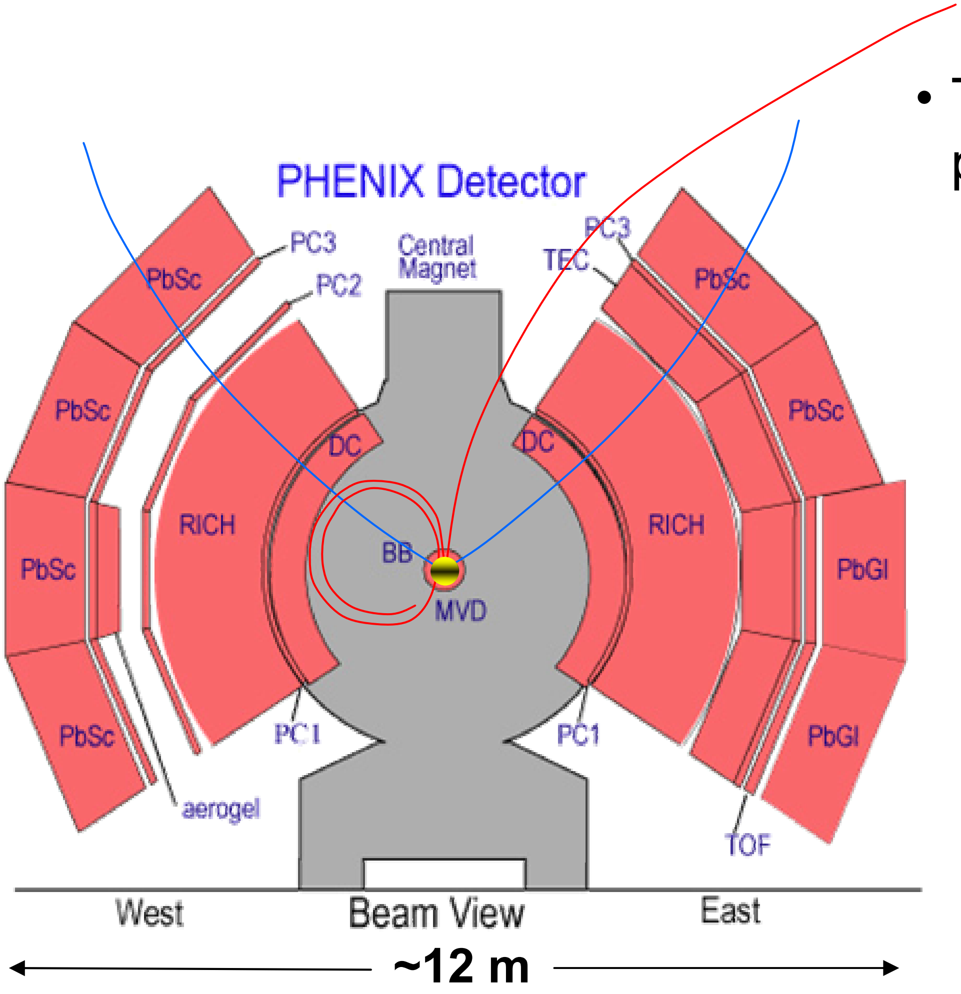

- calculations for min bias
- QGP thermal radiation included

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

- Systematic error too large to distinguish predictions
- Mainly due to S/B
- Need to improve 10x - 100x

→ HBD

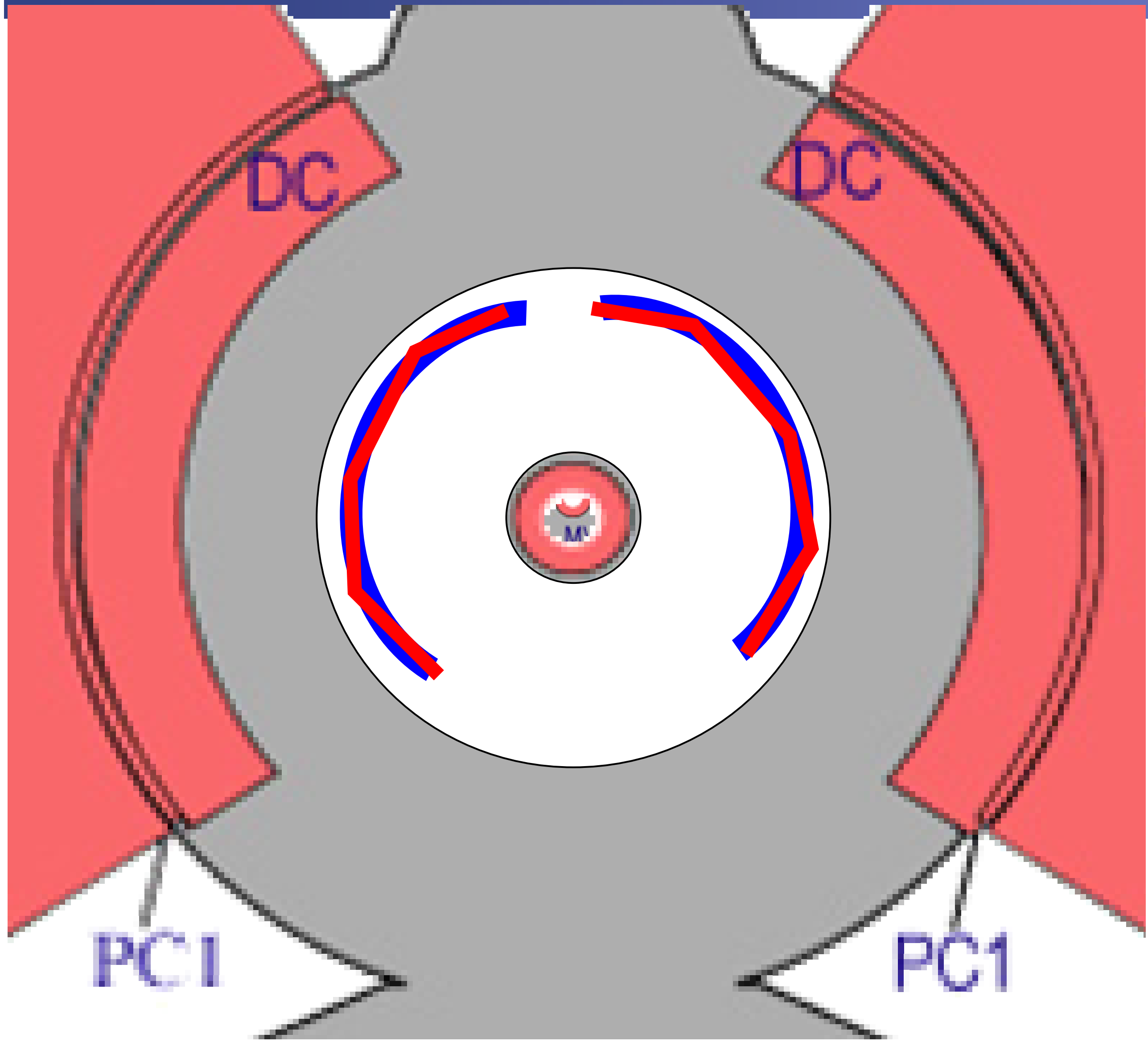
# Why so much background?




- Typically only 1 electron from the pair falls in the acceptance.
  - The magnetic field bends the pair in opposite directions.
  - Some curl up in the magnetic field and never come out.

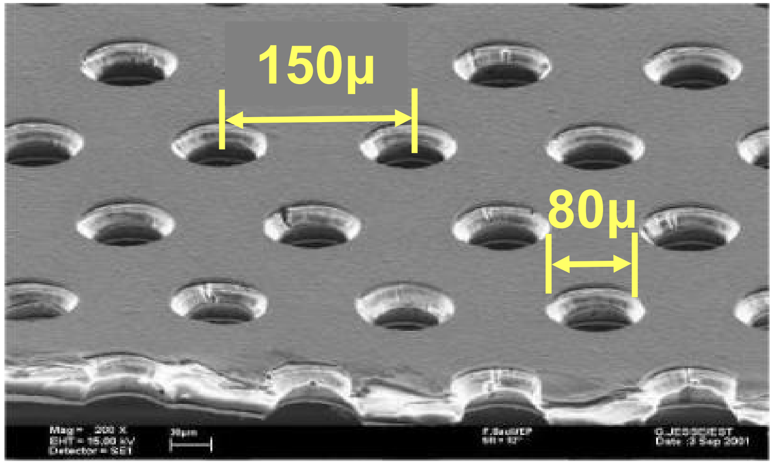
- The new detector needs:
  - >90% electron ID
  - sit near the collision
  - sit in zero B-field
    - catch $e^{+/-}$ before they get lost

# Looking closer…



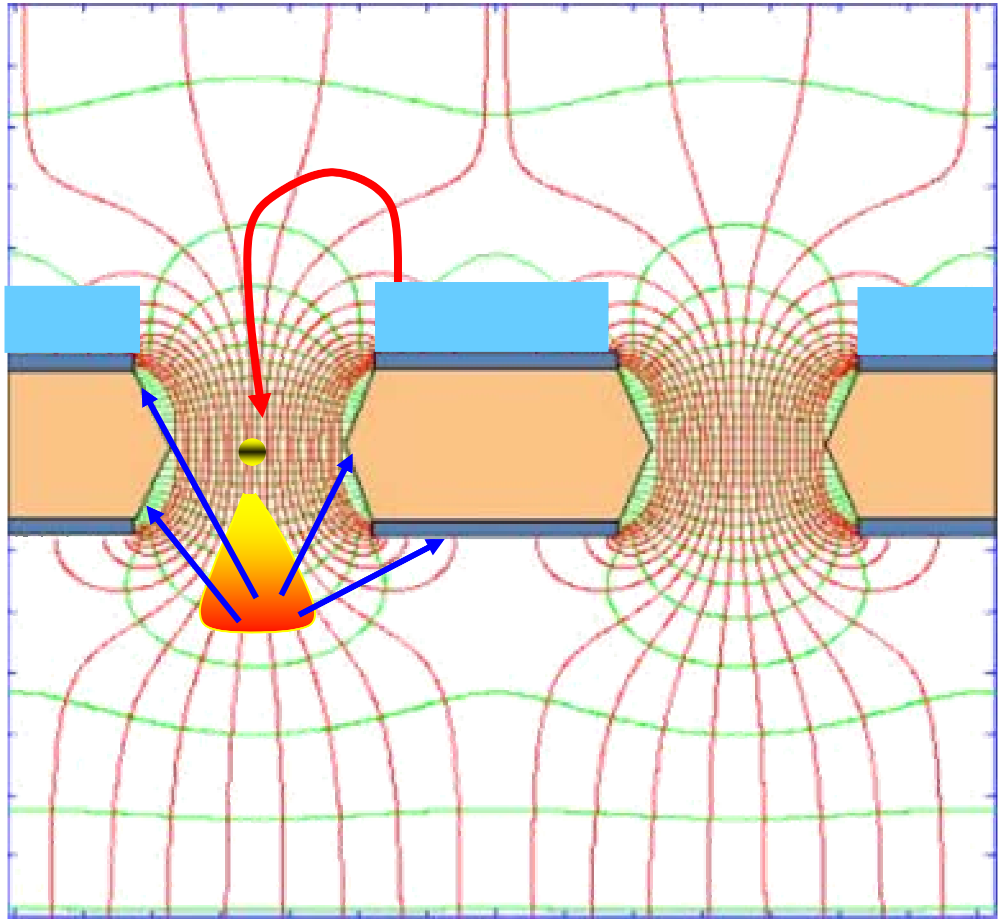

- Inner coil can cancel B-field at r < 60 cm
- Not enough room for traditional optics… mirrors won't work.
- Just put the detector right in the middle of things!
- Has potential, but…
  - must be thin
  - must detect a single UV photon and still be blind to all ionizing particles passing through it!!!

# Gas Electron Multiplier (GEM)




• The original idea by F.Sauli (mid 90s) US Patent 6,011,265

• Traditionally CHARGED PARTICLE detectors (not photons)



• Two copper layers separated by insulating film with regular pitch of holes

• HV creates very strong field such that the avalanche develops inside the holes

• Just add the photocathode

• By the way: no photon feedback onto photocathode

# The PHENIX Hadron-Blind Detector (HBD)

PHENIX

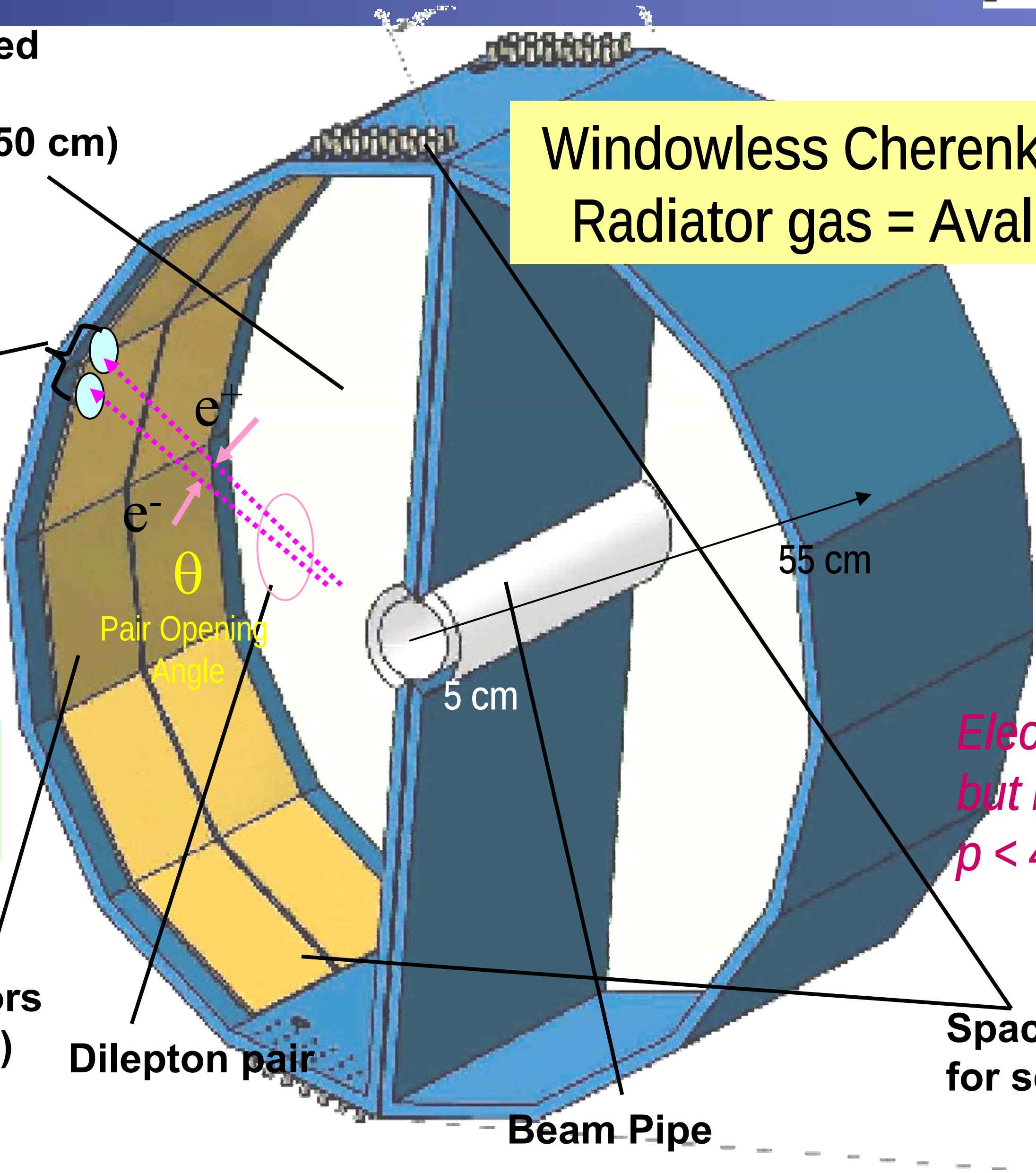
**HBD Gas Volume: Filled with $CF_4$ Radiator ($n_{CF4}$=1.000620, $L_{RAD}$=50 cm)**

Windowless Cherenkov Detector
Radiator gas = Avalanche Gas

**Cherenkov light forms "blobs" on an image plane ($r_{BLOB}$~3.36cm)**

**Pcb pad readout (~ 2x2 cm²)**

CsI photocathode covering GEMs




*Electrons radiate, but hadrons with p < 4 GeV/c do not*

**Triple GEM detectors (12 panels per side)**

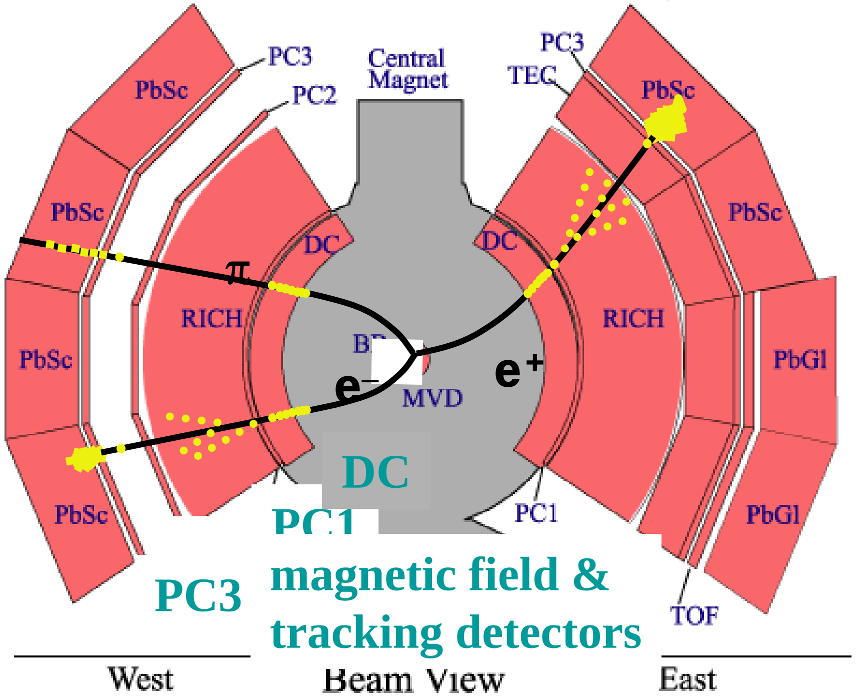
**Dilepton pair**

**Beam Pipe**

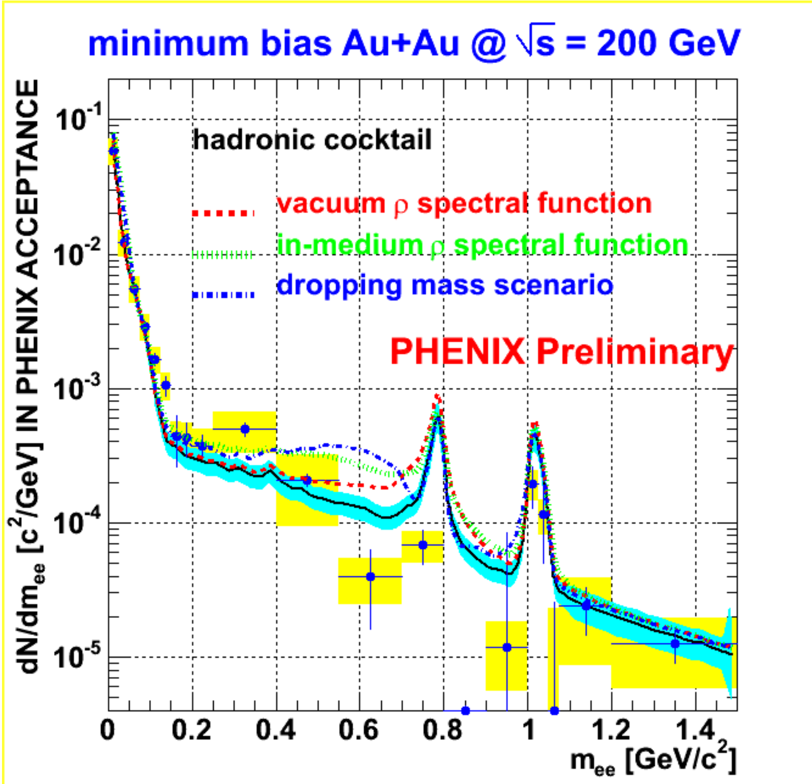
**Space allocated for services**

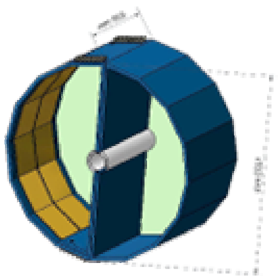
# Low-mass lepton pairs in PHENIX @ RHIC

PHENIX Detector - Second Year Physics Run




S/B between $10^{-2}$ – $10^{-3}$

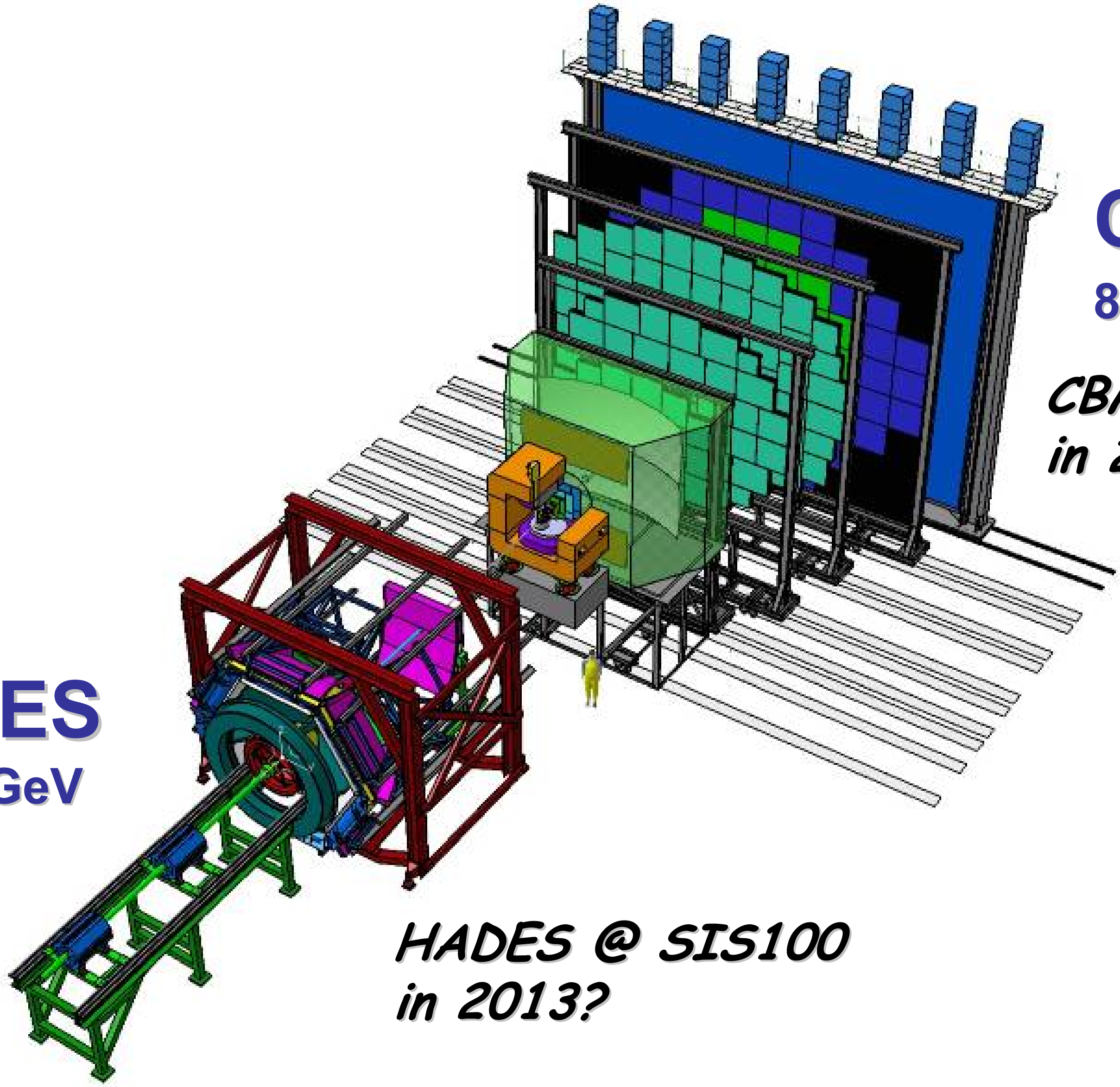


S/B will get much better once the HBD is operational

A. Toia, Hot Quarks 2006

# HADES and CBM at FAIR



**CBM**

**8 – 45 AGeV**

***CBM @ SIS300 in 2015?***

**HADES**

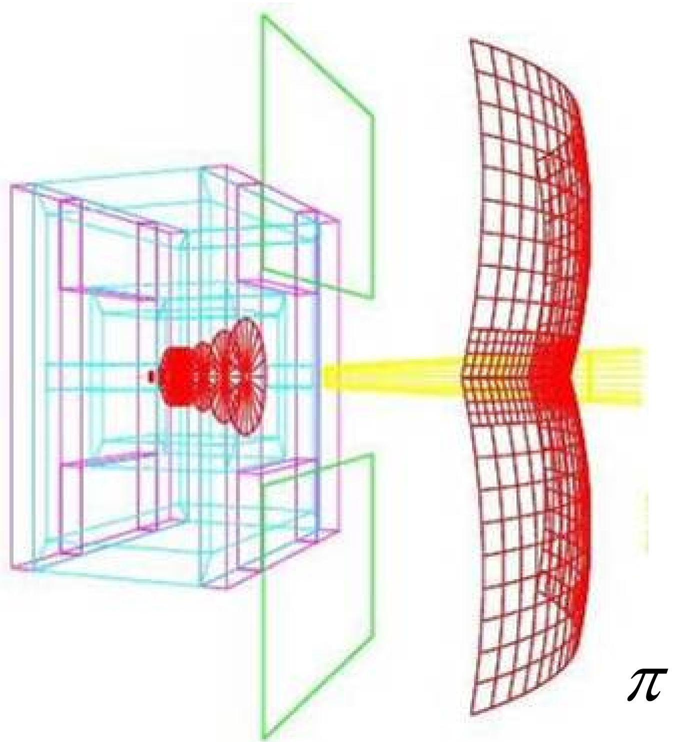
**2 – 8 AGeV**

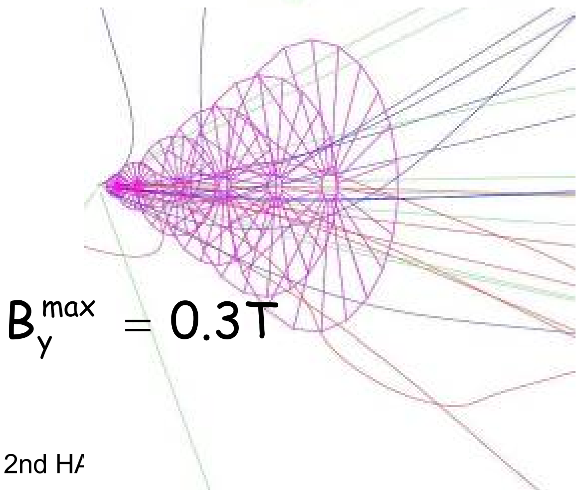
***HADES @ SIS100 in 2013?***

# Challenges for next generation experiments

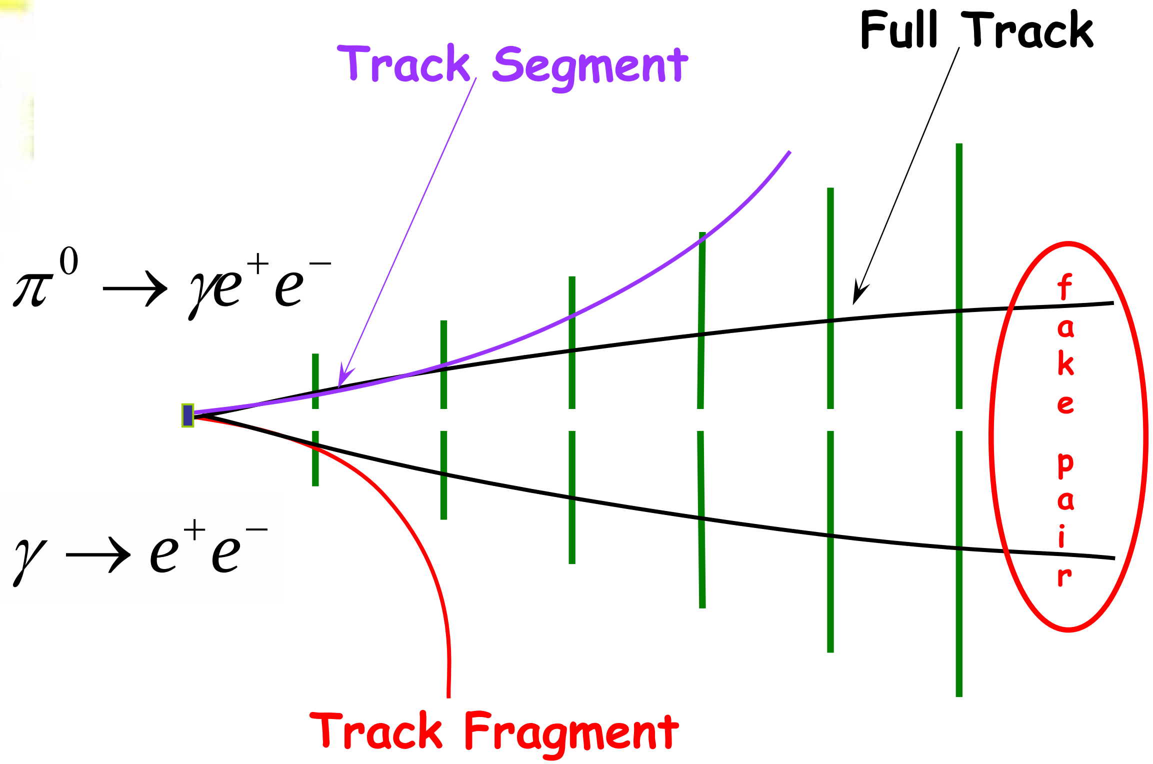
- **Improve characterization**
  - Double differential (e.g. inv. mass, $p_t$)
  - Centrality dependence
- **Reduce uncertainties**
  - Statistical errors
    - Fast detectors and DAQ
    - Develop a trigger (not always easy, excellent detectors needed)
  - Systematic errors
    - Control combinatorial background (good background rejection)
    - Control (trivial?) dilepton cocktail
    - Fully understand efficiencies of detectors, track reconstruction, rejection cuts
- **Open questions**
  - What precision is really needed to distinguish between scenarios?
  - Can one control uncertainties due to missing information about the fireball evolution?

# Dielectron reconstruction in CBM





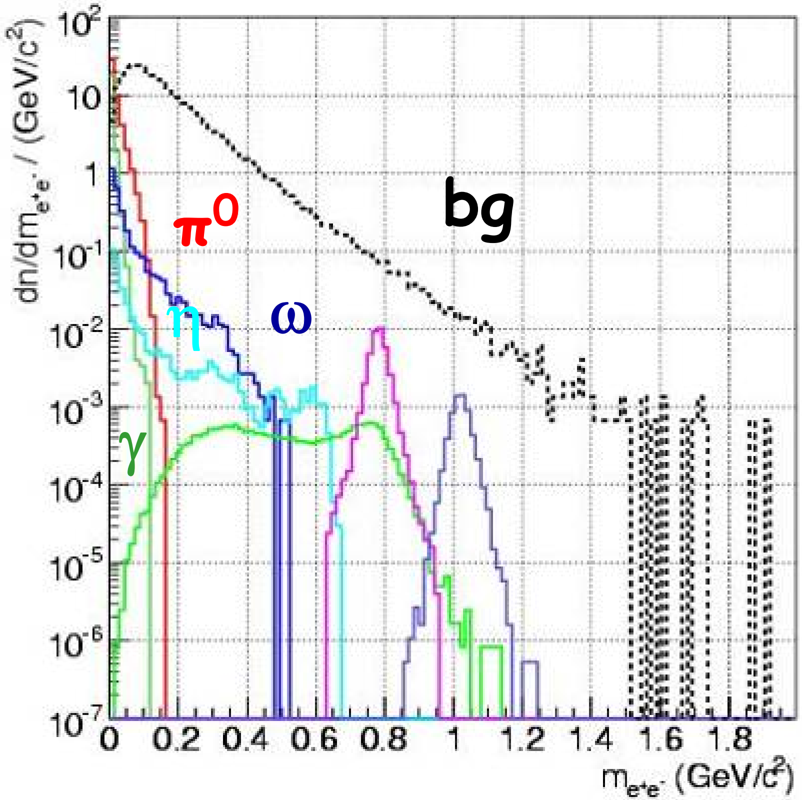

- Fast, high-precision tracking using silicon sensors
- No electron identification before tracking



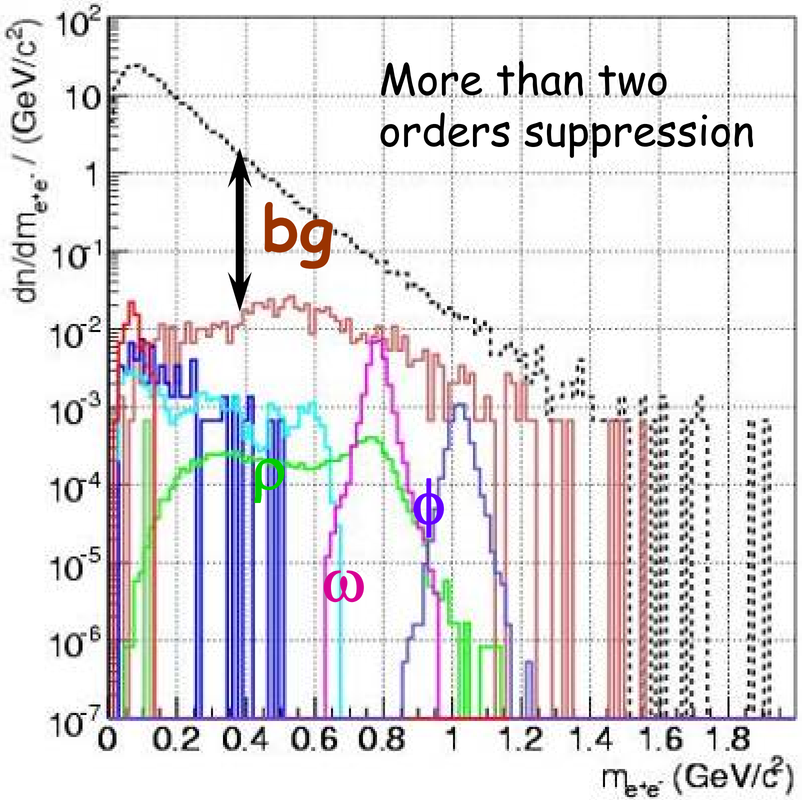
# Background rejection performance

- Au+Au 25 AGeV, central collisions
- Signal mixed into UrQMD events

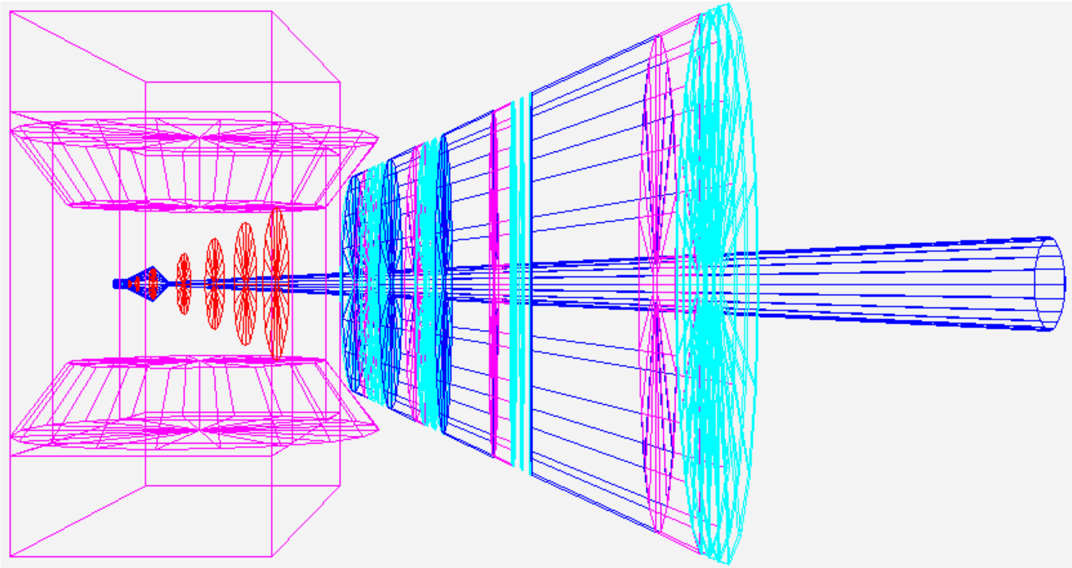
accepted

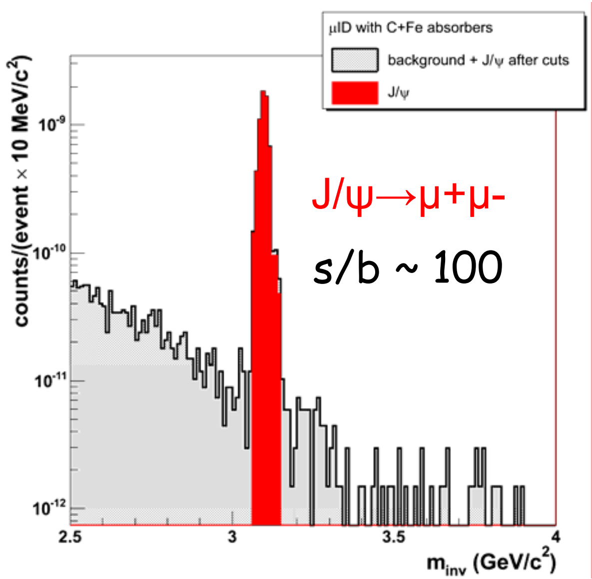


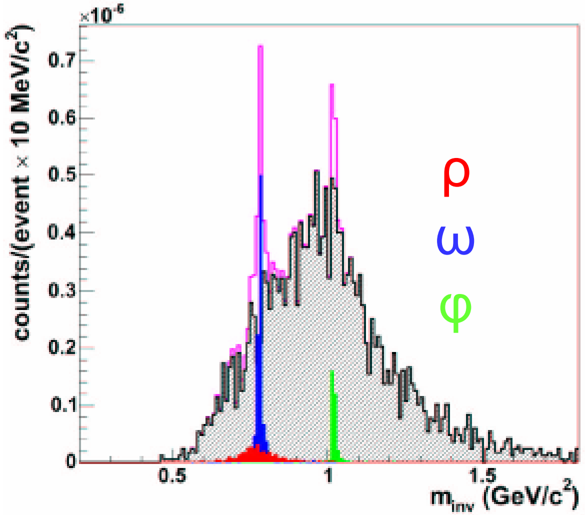

after cuts applied



# The muon option in CBM






Simulations Au+Au 25 *AGeV*:

- ☺ Excellent signal to background ratio in high mass region
- ☹ Low efficiency for small invariant masses and/or low $p_t$ (enhancement region)

Challenging muon detector (high particle densities)

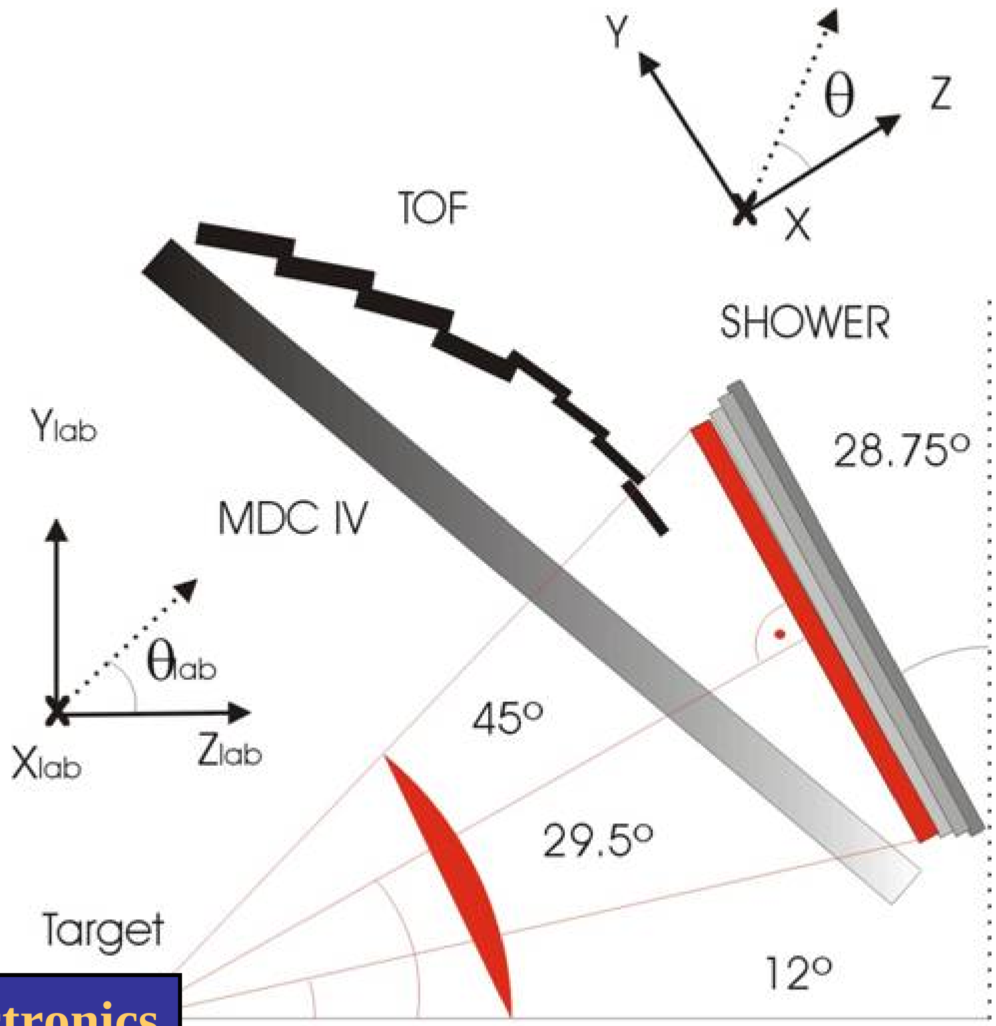
# HADES upgrade:  TOFINO replacement by RPC

- 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!



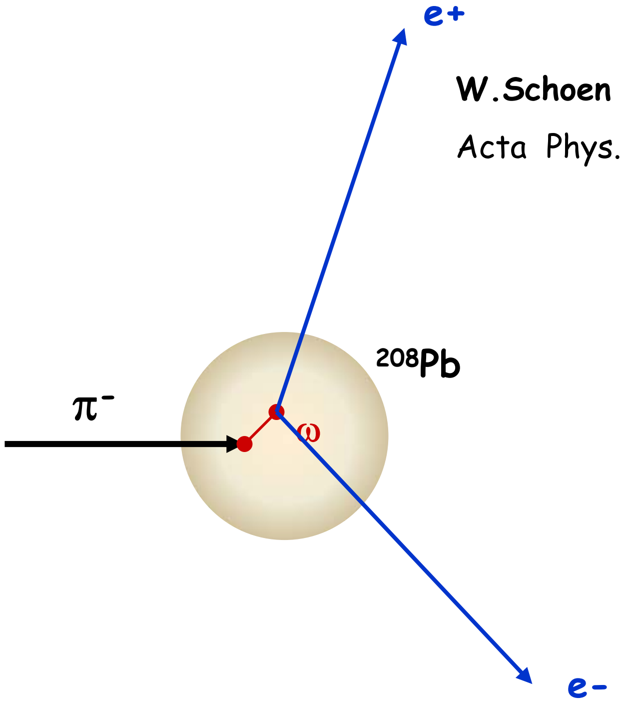

**Sector array + readout electronics tested successfully in beam !!!**

# Recoil-less omega production in $\pi A$

$\pi^- p_{bound} \rightarrow \omega n \rightarrow e^+ e^- n$

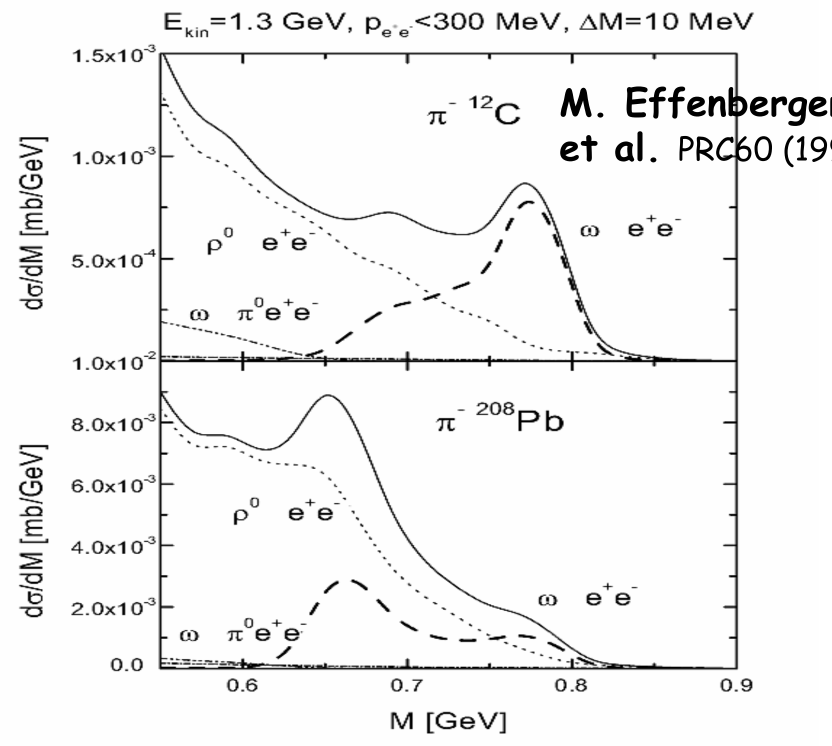
$\omega$ „at rest": $p_{e+e-} < 300$ MeV/c

✓ mass modifications in $\rho_0$




**W.Schoen et al.**

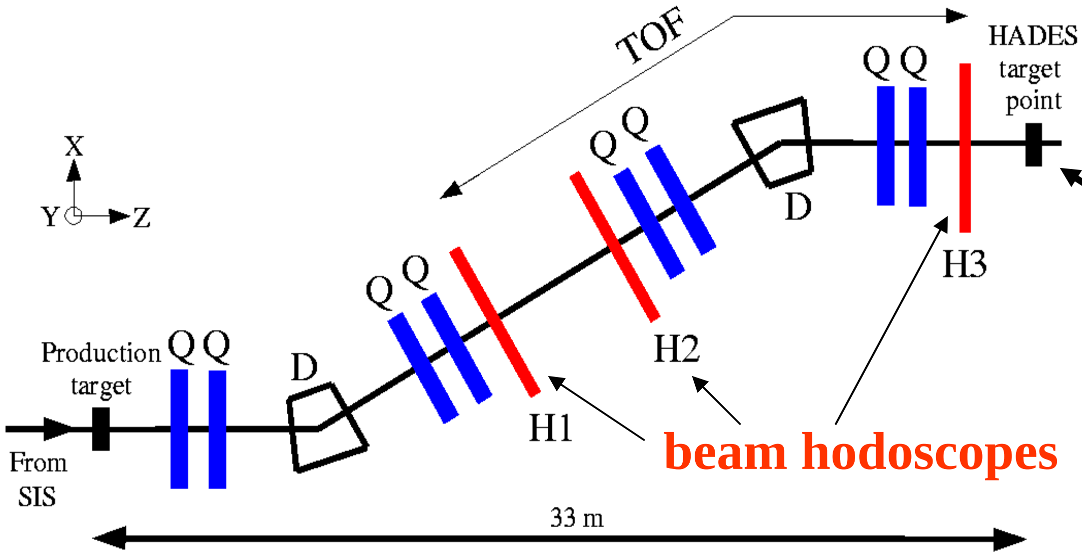
Acta Phys. Pol. B27 (1996) 2959



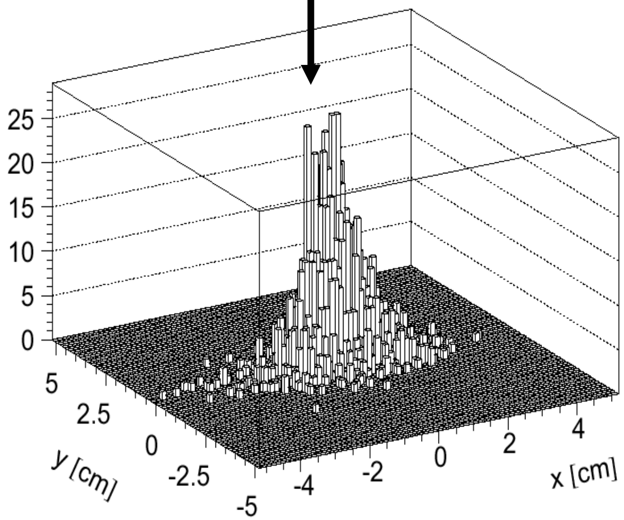

**M. Effenberger et al.** PRC60 (1999)

- uncertainties in calculations: interferences, form factors, reson. $N^*$, $\Delta$
- needs data from $\pi N \rightarrow e^+ e^- X$ !

# The GSI secondary pion beam line

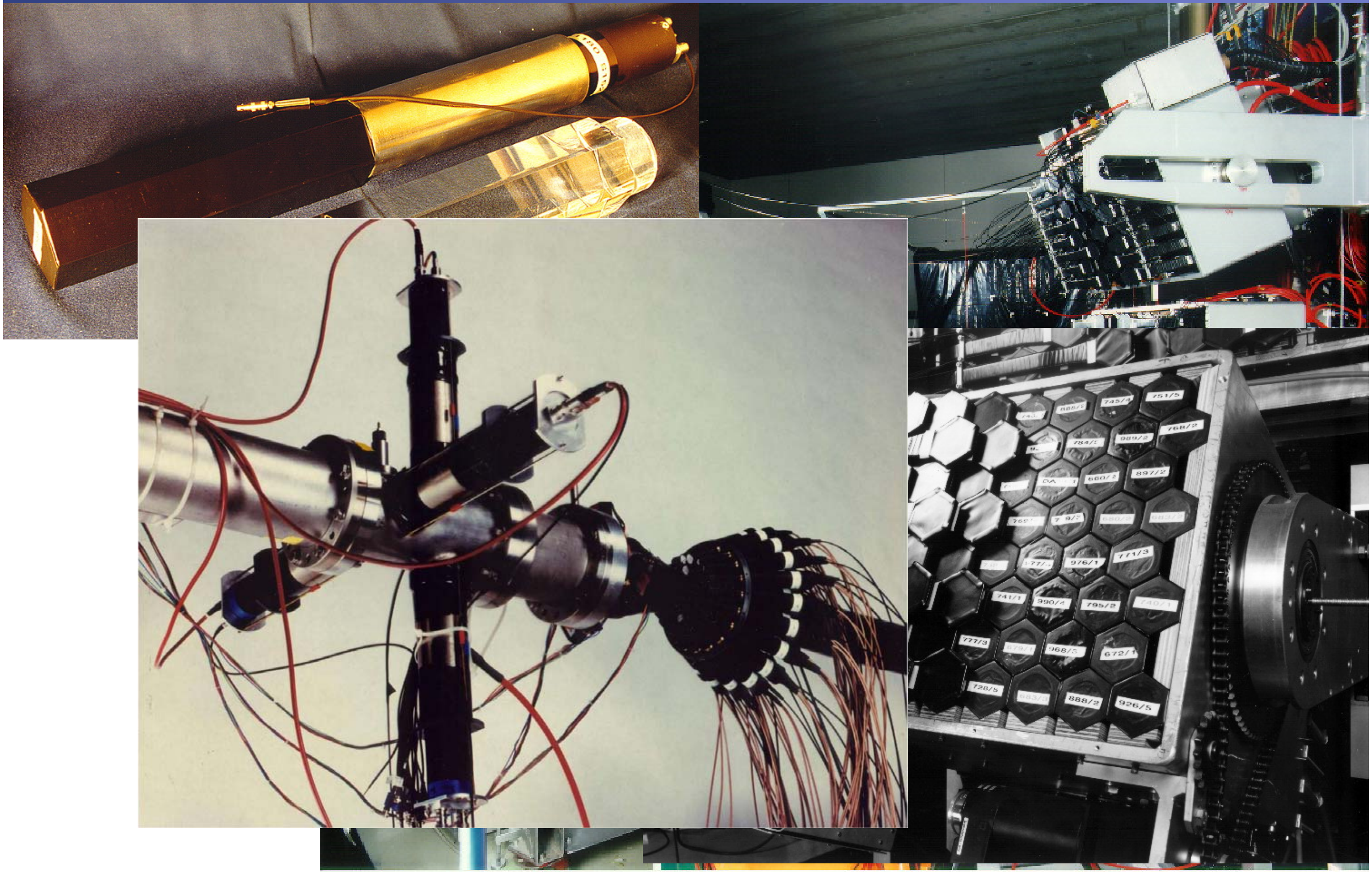



**π focus** at HADES target point




- Q doublet defines acceptance of $\Delta\Omega = 2.3$ msr
- Momenta up to 2.8 GeV/c with $\Delta p/p = 8\%$
- H1, H2 & H3 for tracking & tof ($\sigma$ =150 ps)

# Two Arm Photon Spectrometer TAPS



# Pulse-shape analysis in $BaF_2$