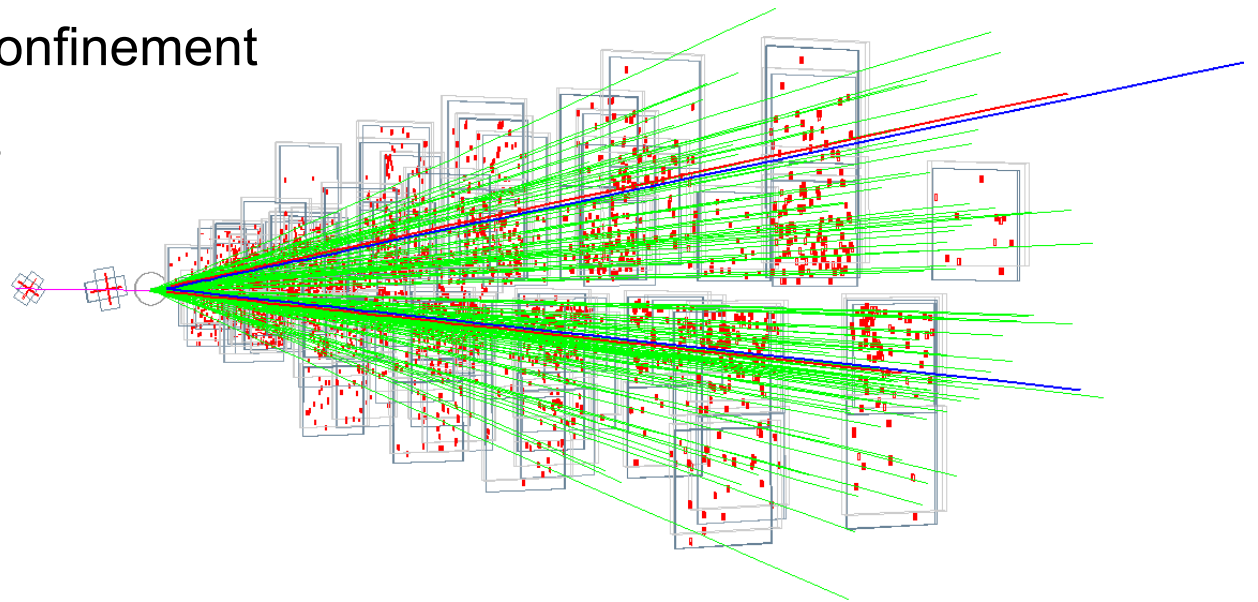
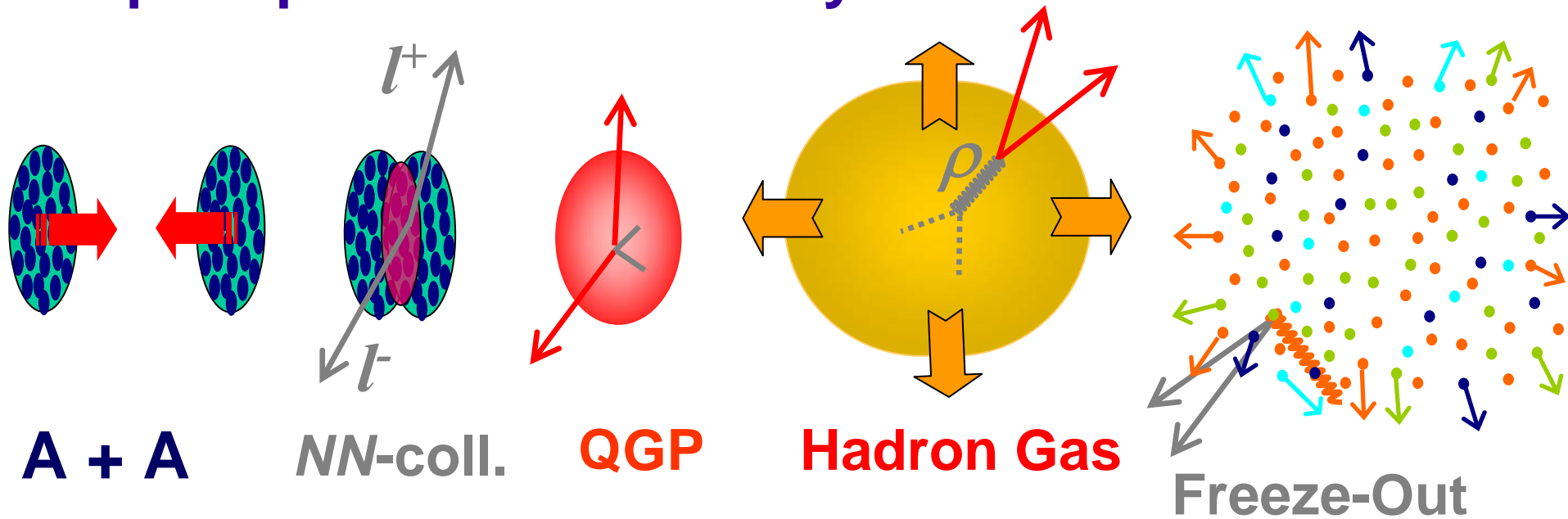


# Electromagnetic probes in nuclear collisions: low and intermediate mass dileptons at the SPS

- Motivation
- $\omega$ ,  $\eta$  Dalitz form factors
- $\rho$  spectral function and chiral restoration
- Radial flow and deconfinement
- New measurements



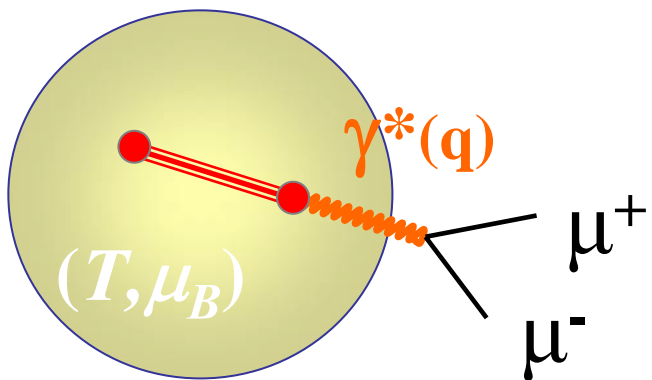
# Dilepton production in heavy ion collisions



## Sources of Dilepton Emission:

- primordial (Drell-Yan)  $qq$  annihilation:  $NN \rightarrow l^+l^- X$
- **emission from equilibrated matter (thermal radiation)**
  - **Quark-Gluon Plasma:**  $qq \rightarrow l^+l^-, \dots$
  - **Hot+Dense Hadron Gas:**  $\pi^+\pi^- \rightarrow l^+l^-, \dots$
- final-state hadron decays:  $\pi^0, \eta \rightarrow \gamma^+l^-, D, \bar{D} \rightarrow l^+l^- X, ^2, \dots$

# Dilepton Rate in a strongly interacting medium



Dileptons produced by annihilation of thermally excited particles:

- $q\bar{q}$  in QGP phase
- $\pi^+\pi^-$  in hadronic phase

Boltzmann factor

photon self-energy

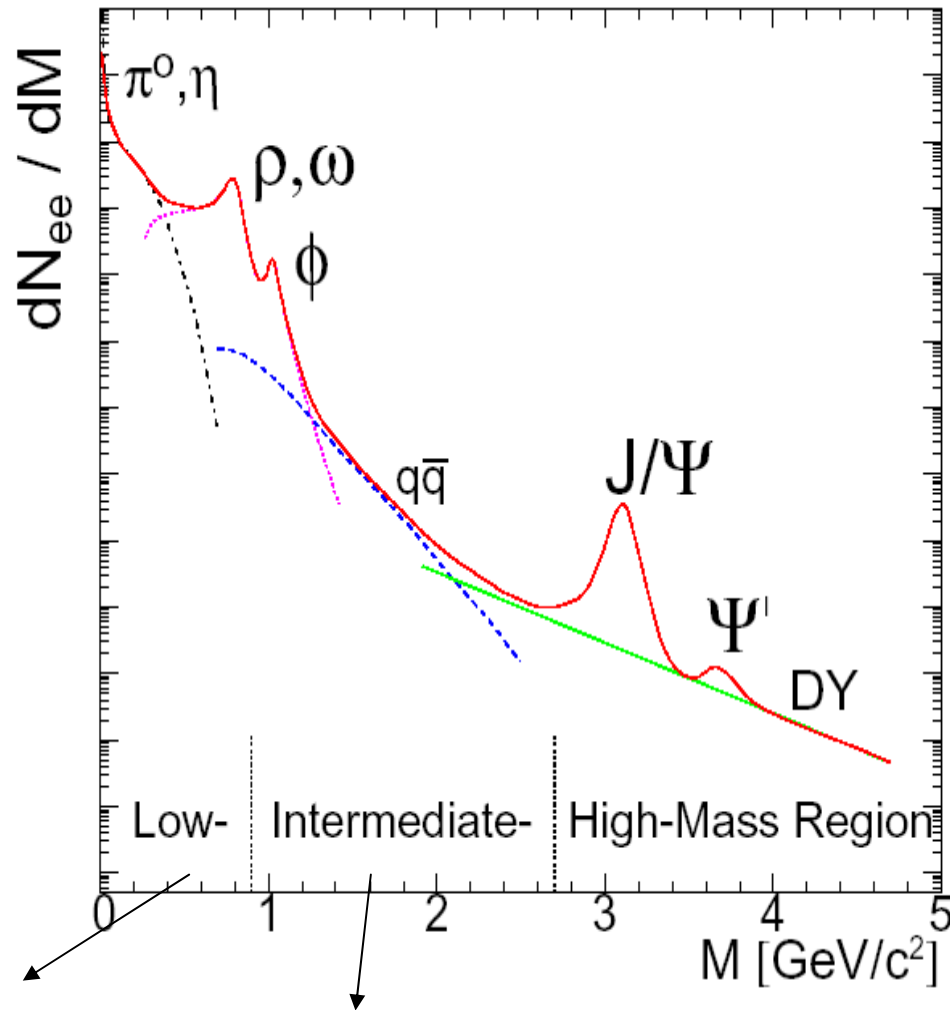
$$\frac{dR_{l+l-}}{dq^4} = -\frac{\alpha^2}{\pi^3 M^2} f^B(q_0; T) \text{Im}\Pi_{em}(q_0, \vec{q})$$

$$\text{Im}\Pi_{em}(s) = \begin{cases} \frac{-s}{12\pi} N_c \sum_{u,d,s} (e_q)^2 \left[ 1 + \frac{\alpha_S(s)}{\pi} + \dots \right] & \text{Partonic phase} \\ \sum_{\rho,\omega,\phi} \left[ \frac{m_V^2}{g_V} \right]^2 \text{Im} D_V(s) & \text{Hadronic phase: Vector-Meson Dominance} \end{cases}$$

spectral function

# Schematic dilepton spectrum in heavy ion collisions

Characteristic regimes for different mass intervals:



Hadron gas  
(dominated by  $\pi\pi$ )

QGP and/or hadron gas  
(multipion)

# $\rho$ spectral function in hot and dense hadronic matter

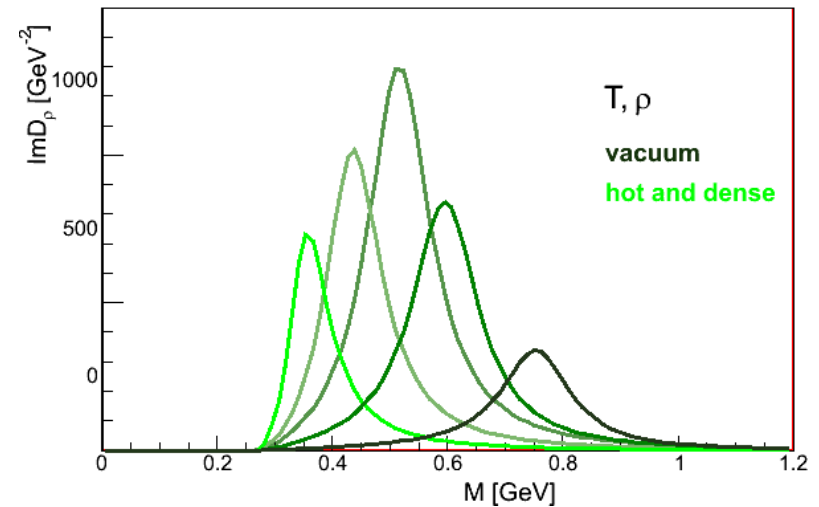
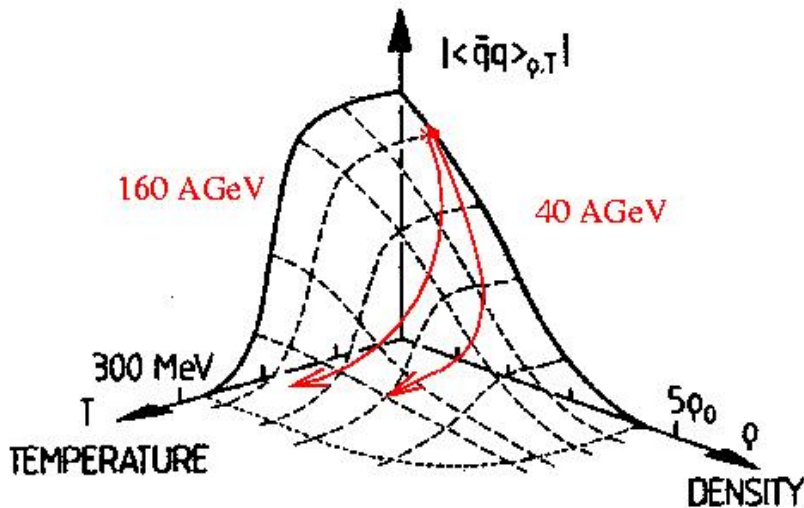
Dropping mass scenario

Brown/Rho et al., Hatsuda/Lee

explicit connection between hadron masses and chiral condensate

universal scaling law

$$m_\rho^* / m_\rho^0 = \langle \bar{q}q \rangle_{\rho,T}^{1/2} / \langle \bar{q}q \rangle_0^{1/2}$$



$$\langle \bar{q}q \rangle_{\rho,T}^{1/2} / \langle \bar{q}q \rangle_0^{1/2} = \left(1 - C \frac{\rho}{\rho_0}\right) \left(1 - (T / T_c^x)^2\right)^\alpha$$

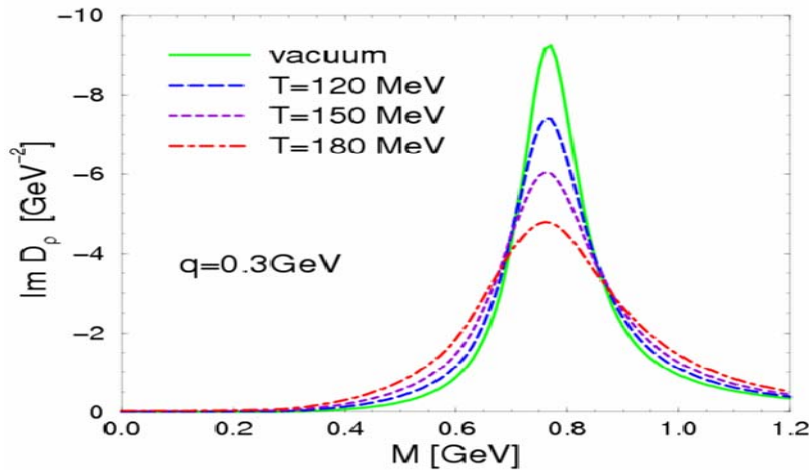
continuous evolution of pole mass with T and  $\rho$  ; broadening at fixed T, $\rho$  ignored

# $\rho$ spectral function in hot and dense hadronic matter

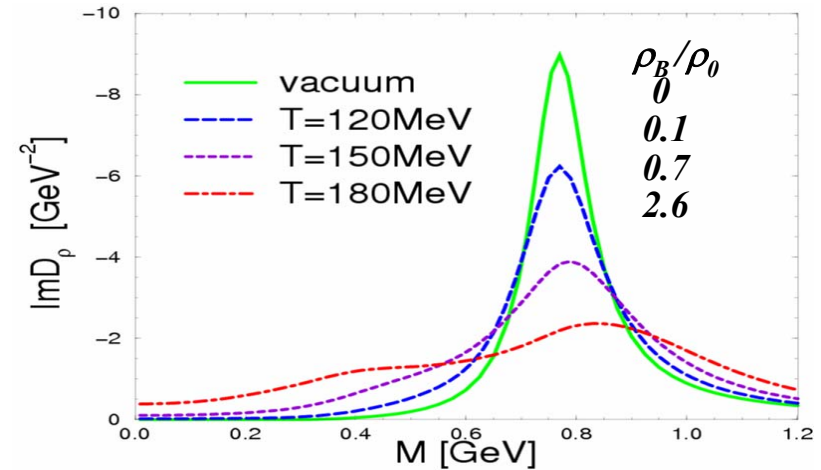
Hadronic many-body approach

Rapp/Wambach et al., Weise et al.

hot matter



hot and baryon-rich matter



$$D_\rho(q^2; \mu_B, T) = \left( q^2 - m_\rho^2 - \Pi_{\rho\pi\pi} - \Pi_{\rho B} - \Pi_{\rho M} \right)^{-1}$$

$\rho$  is dressed with:

hot pions  $\Pi_{\rho\pi\pi}$ ,

baryons  $\Pi_{\rho B}$  (N,  $\Delta$  ..)

mesons  $\Pi_{\rho M}$  (K,  $a_1$  ..)

$\rho$  “melts” in hot and dense matter

- pole position roughly unchanged

- broadening mostly through baryon interactions

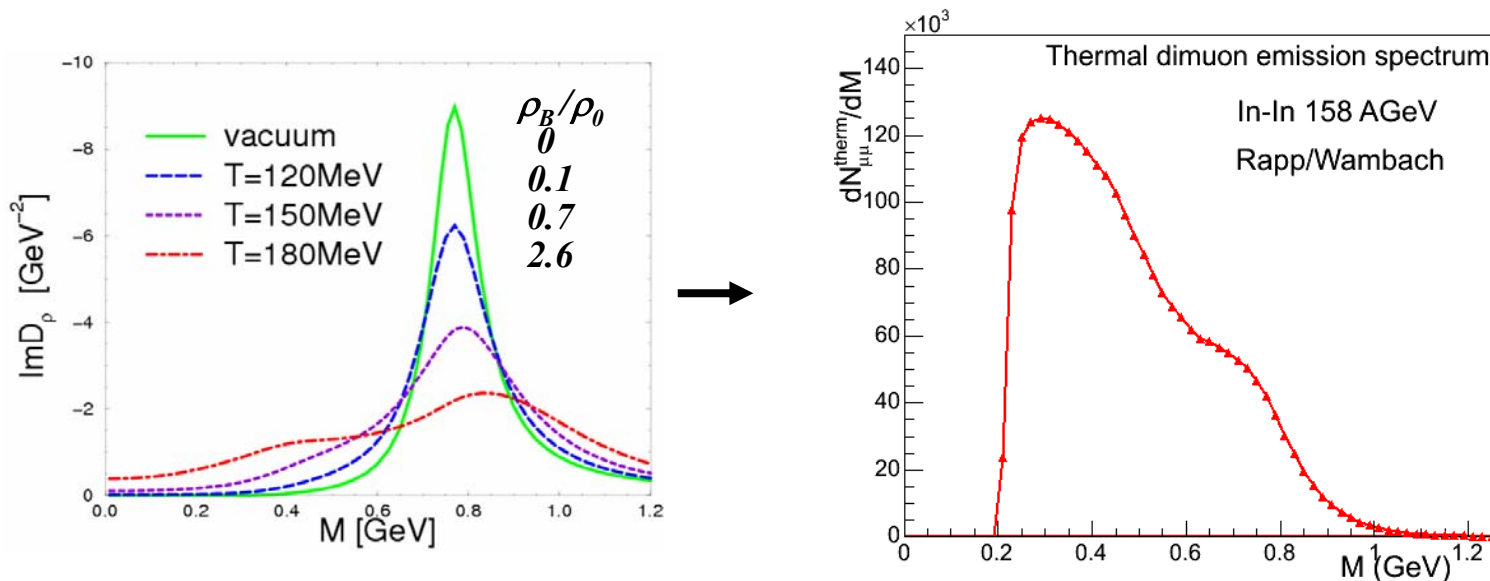
# Experimentally observable mass spectrum

continuous emission of thermal radiation during life time of expanding fireball

→ integration of rate equation over space-time and momenta required

$$\frac{dN_{\mu\mu}^{therm}}{dM} = \int_{\tau_0}^{\tau_{fo}} d\tau V_{FB}(\tau) \int \frac{Md^3q}{q_0} \frac{dN_{\mu\mu}^{therm}}{d^4x d^4q}(M, q; T, \mu_i)$$

example: broadening scenario

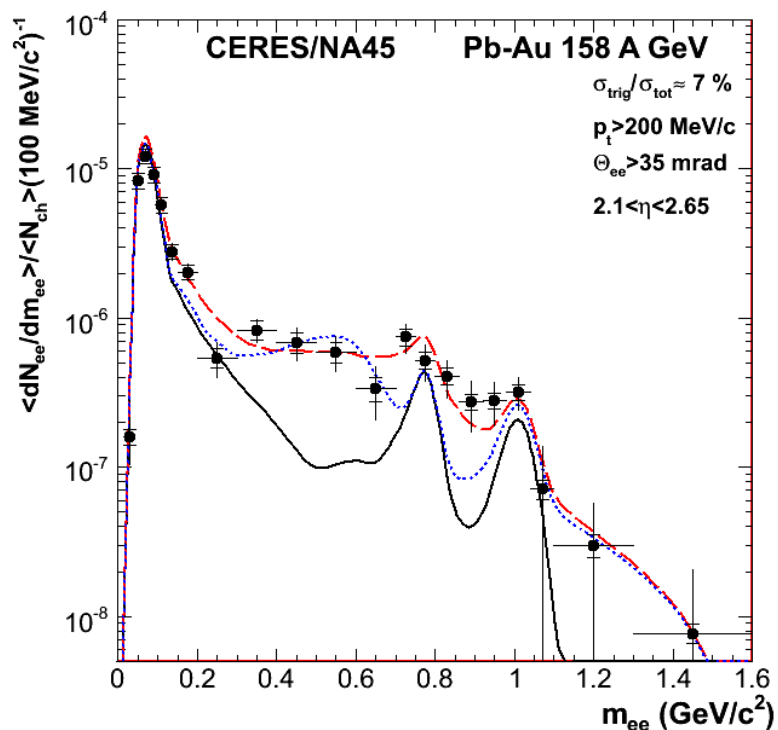


→ Spectral function accessible through rate equation, integrated over space-time and momenta

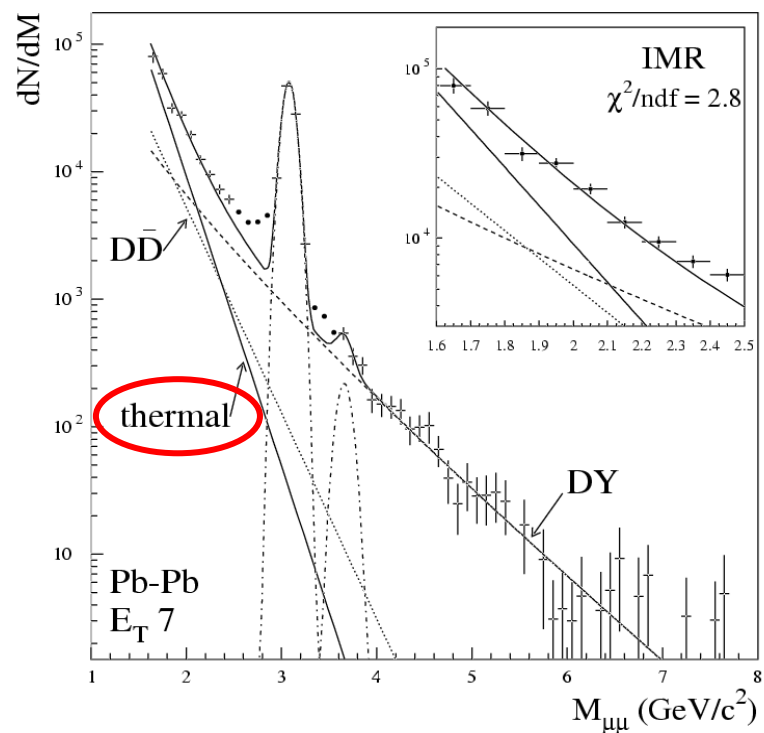
$$\frac{dN_{\mu\mu}}{dM} \approx f(M) \times \langle \exp(-M/T) \rangle \times \langle \text{spectral function} \rangle^7$$

# Experimental landscape in dilepton measurements in 2000

Strong excess below 1 GeV in  $e^+e^-$  mass spectrum dominated by  $\rho$  meson:  
Which in-medium properties?  
Connection with chiral symmetry restoration?



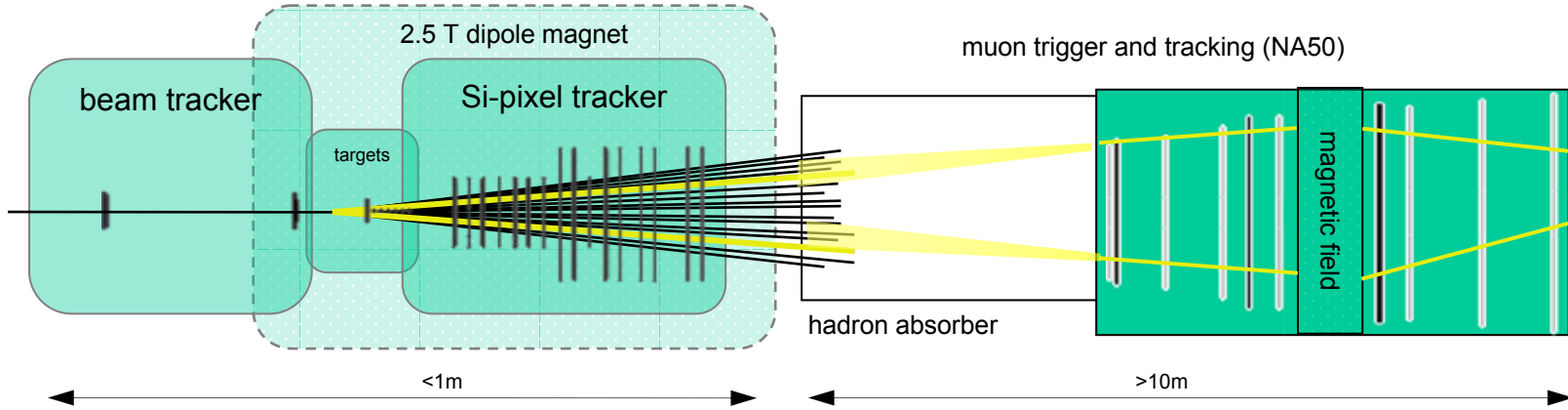
Strong excess in  $\mu^+\mu^-$  mass spectrum above 1 GeV:  
Thermal dimuons or  
enhanced open charm?



Measurements with higher statistics and resolution were needed



# The NA60 concept



Track matching in coordinate and momentum

Improved dimuon mass resolution

Distinguish prompt from decay dimuons

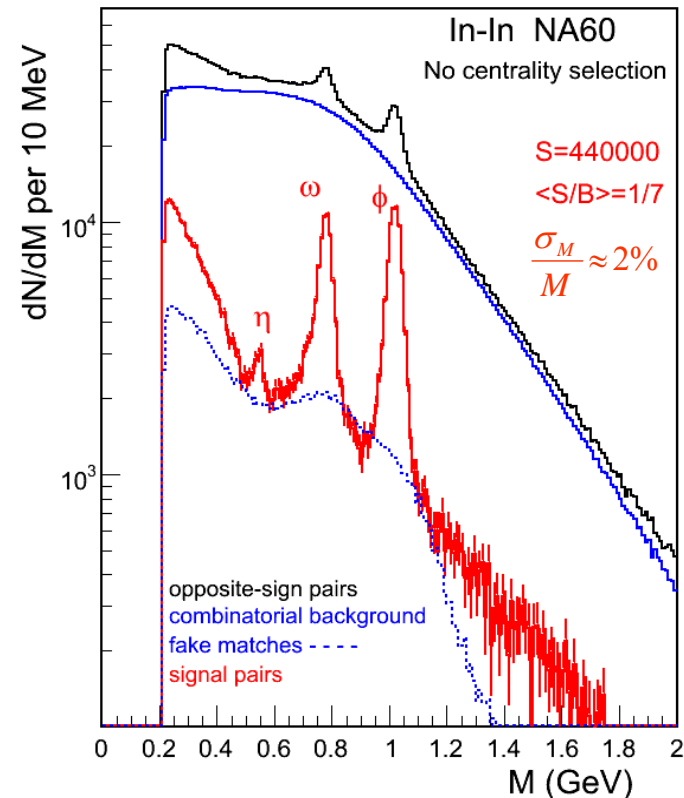
Additional bend by the dipole field

Dimuon coverage extended to low  $p_T$

Radiation-hard silicon pixel detectors (LHC development for ALICE and ATLAS)

High luminosity of dimuon experiments kept

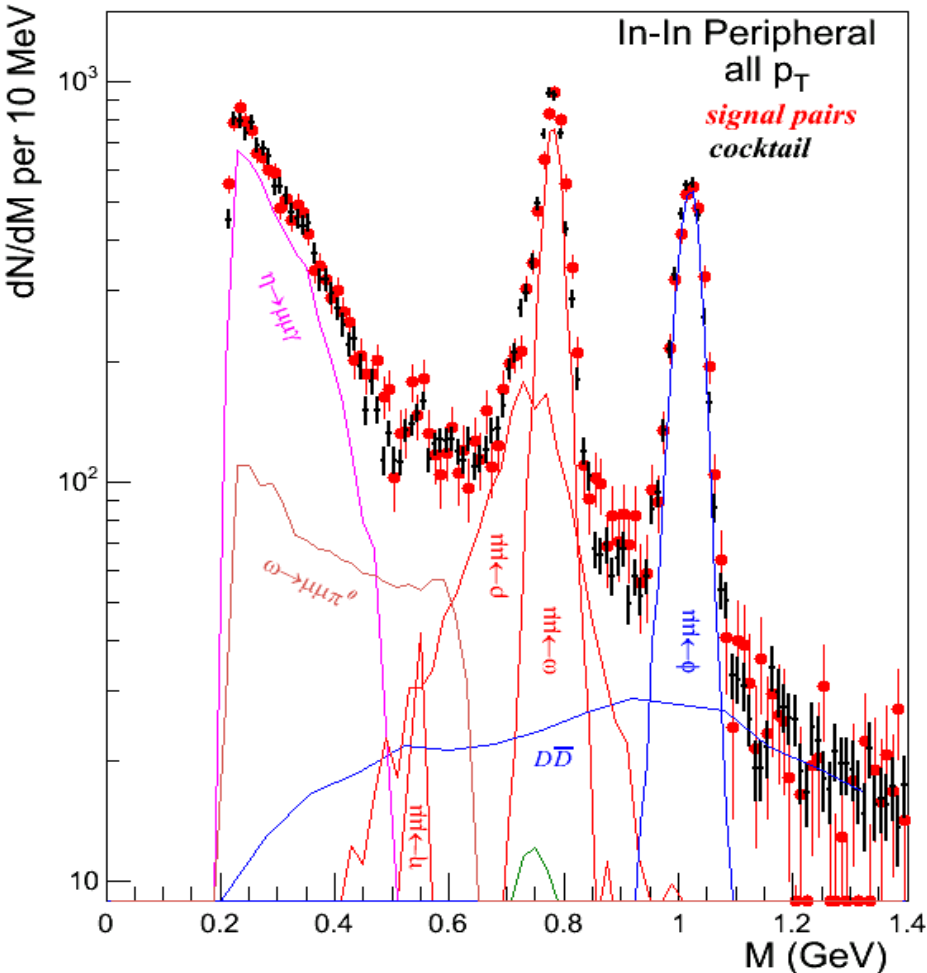
Phys.Rev.Lett. 96 (2006) 162302



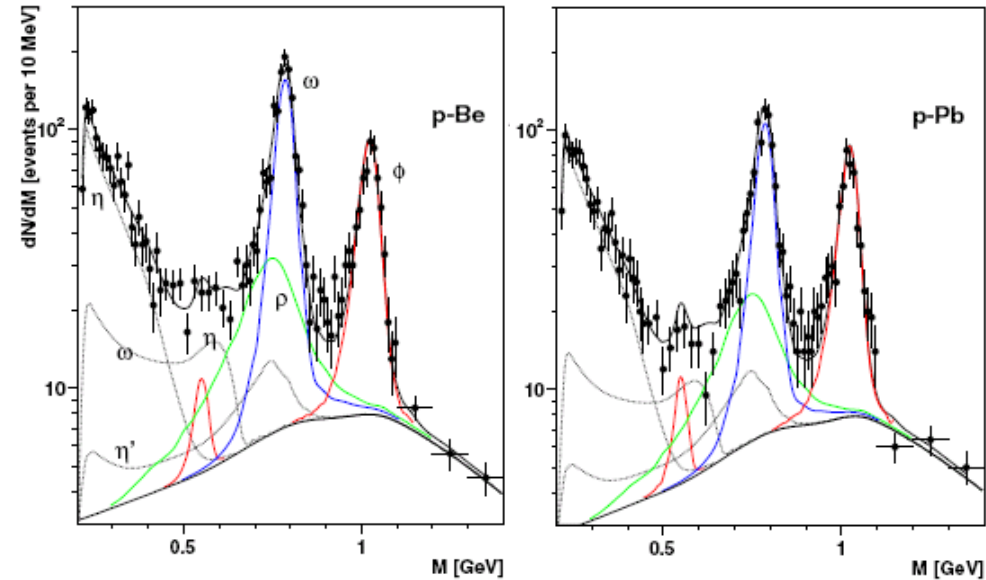
# NA60 LMR data: peripheral ( $N_{ch} < 30$ ) In-In collisions

Well described by meson decay 'cocktail':  $\eta$ ,  $\eta'$ ,  $\rho$ ,  $\omega$ ,  $f$  and  $D\bar{D} \rightarrow \mu\mu$  contributions (Genesis generator developed within CERES and adapted for dimuons by NA60).

Eur.Phys.J.C 49 (2007) 235



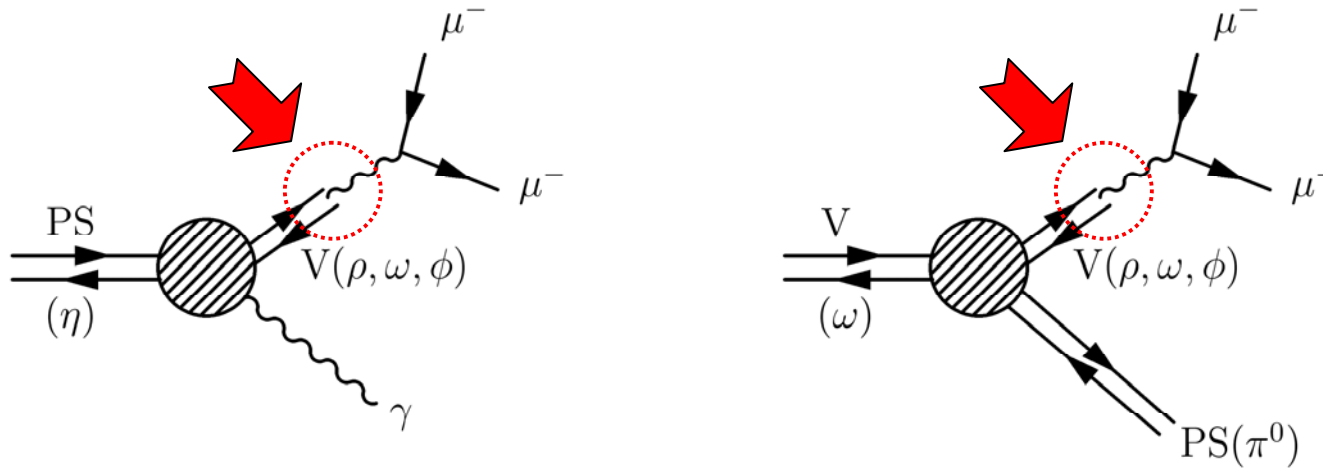
Eur.Phys.J.C 43 (2005) 407



Similar cocktail describes NA60  
p-Be, In, Pb 400 GeV data

# EM transition form factors $\eta \rightarrow \mu\mu\gamma$ - $\omega \rightarrow \mu\mu\pi$

**Vector Meson Dominance Model (VDM):** Photon-hadron interactions proceed via a transition to a vector meson



VMD model provides a description of the electromagnetic form factor

$$F(M) = \frac{\sum_{V=\rho,\omega,\phi} [g_{ABV}/2g_{V\gamma}] m_V^2 \frac{1}{m_V^2 - M^2 - i\Gamma_V m_V}}{\sum_{V=\rho,\omega,\phi} [g_{ABV}/2g_{V\gamma}]}$$

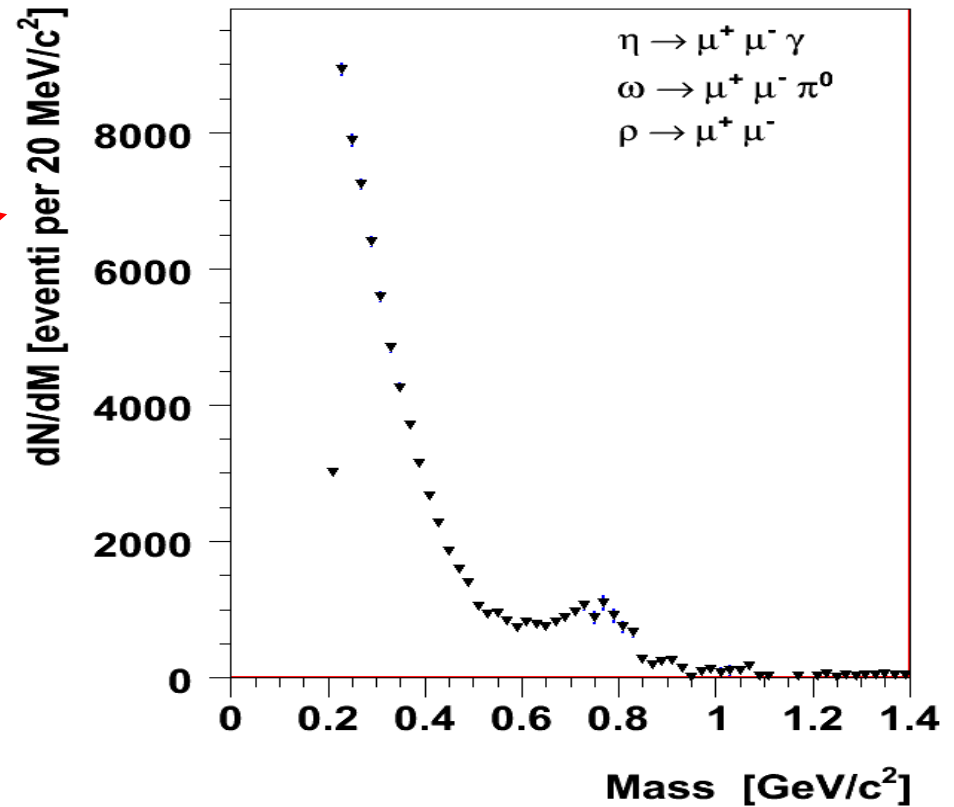
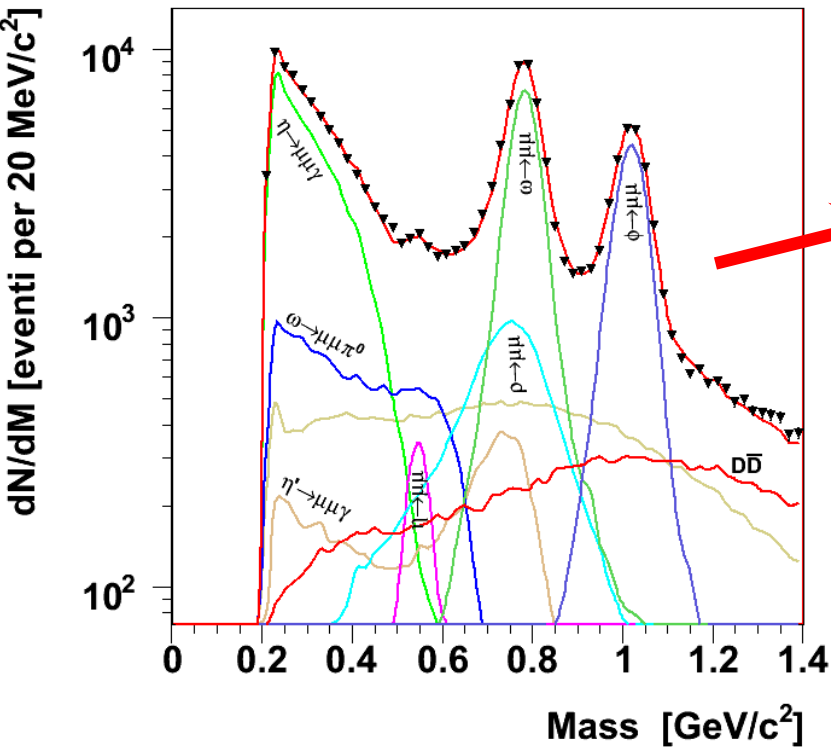
Pole approximation:  $|F(m_{\mu\mu}^2)|^2 = (1 - m_{\mu\mu}^2 / \Lambda^2)^{-2}$

# Isolation of Dalitz decays

Fit expected sources:

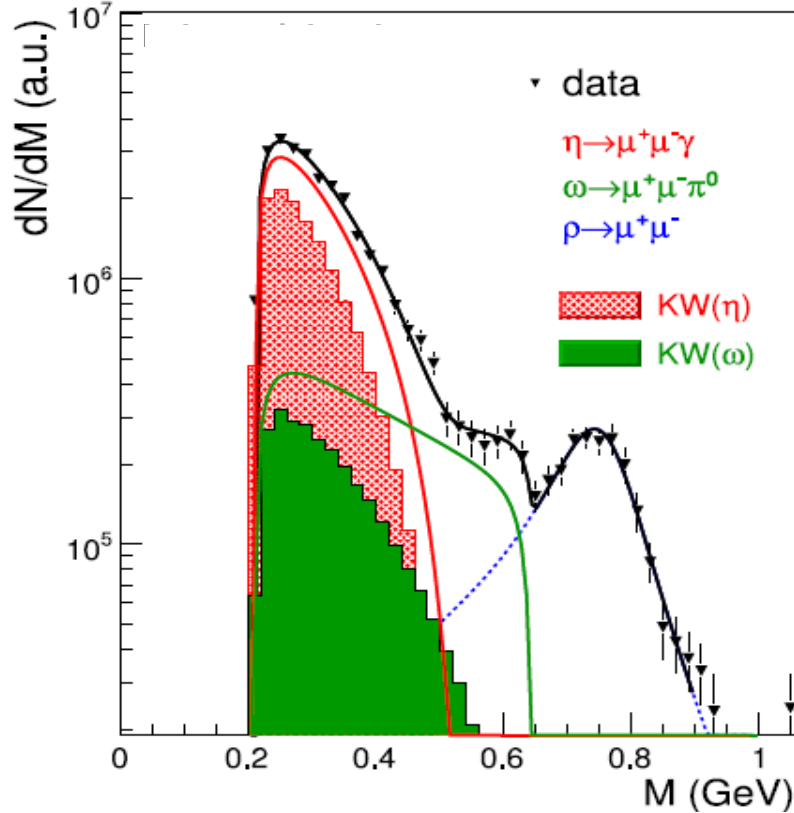
- **2-body** and **Dalitz** decay of the neutral mesons  $\eta$ ,  $\rho$ ,  $\omega$ ,  $\eta'$ ,  $\phi$
- open charm contribution

Isolation of Dalitz and  $\rho$  decays by subtraction of other sources

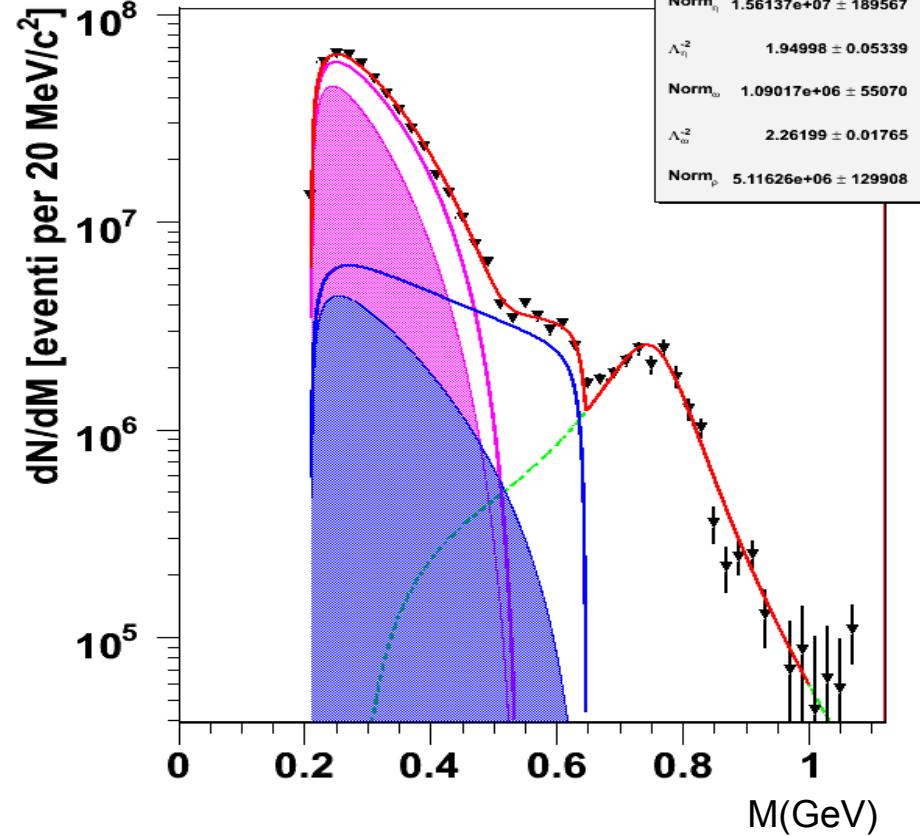


# Acceptance corrected spectra

In-In peripheral PLB 677 (2009) 260



pA 400 GeV - preliminary



**Rho 2-body decay:** line shape characteristic for hadro-production

$$\frac{dR(\rho \rightarrow \mu^+ \mu^-)}{dM} = \frac{\alpha^2 m_{\rho}^4}{3(2\pi)^4} \frac{\left(1 - \frac{4m_{\pi}^2}{M^2}\right)^{3/2} \left(1 - \frac{4m_{\mu}^2}{M^2}\right)^{1/2} \left(1 + \frac{2m_{\mu}^2}{M^2}\right)}{\left(M^2 - m_{\rho}^2\right)^2 + M^2 \Gamma^2} (2\pi M T)^{3/2} e^{-\frac{M}{T}}$$

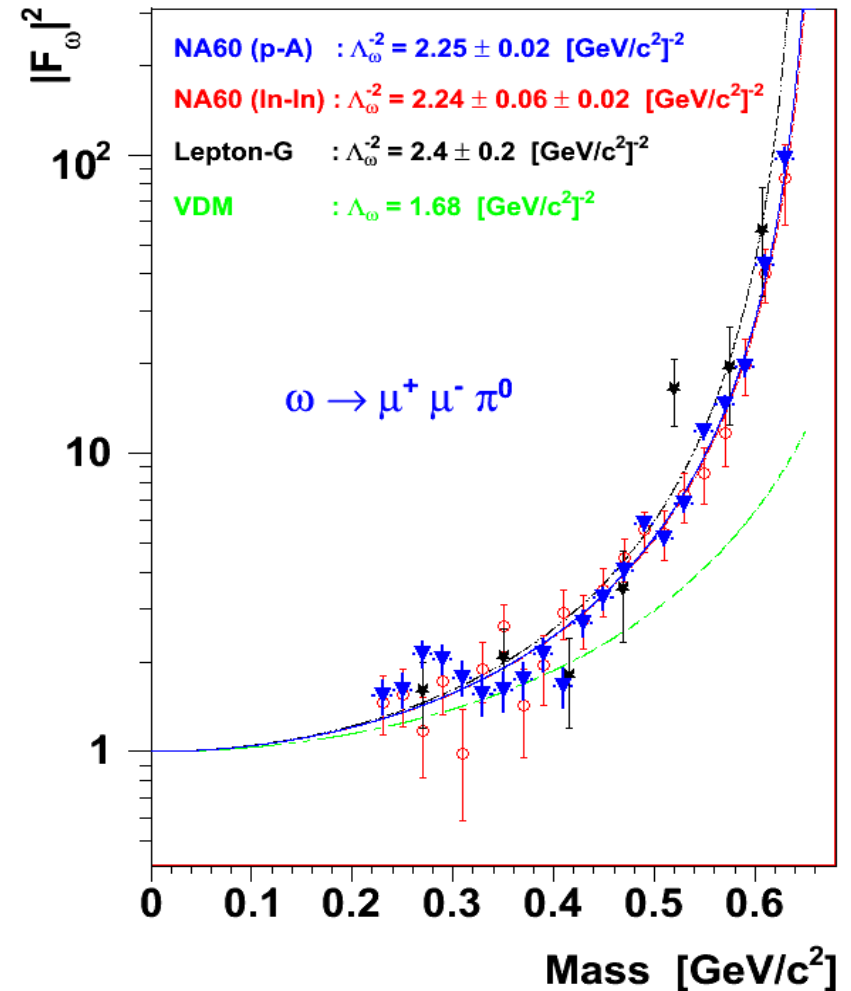
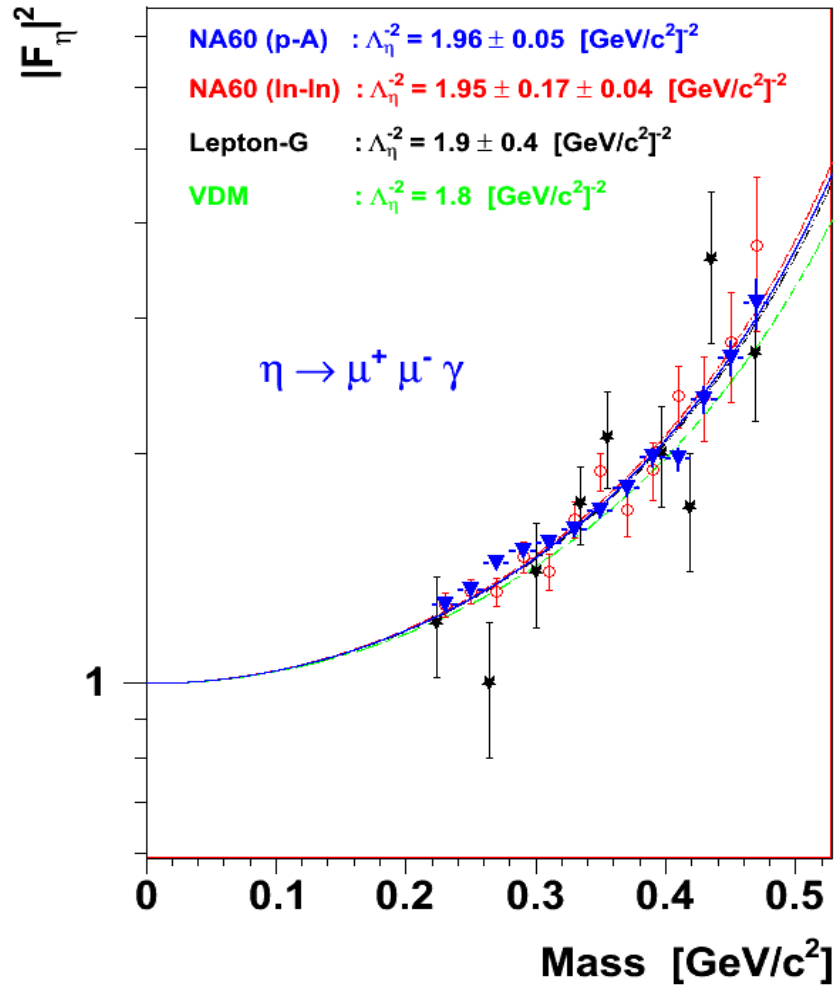
**Dalitz processes:**  
Kroll-Wada  
times form-factor

$$\frac{d\Gamma(\eta \rightarrow \mu^+ \mu^- \gamma)}{dm_{\mu\mu}^2} = \frac{2\alpha}{3\pi} \frac{\Gamma(\eta \rightarrow \gamma\gamma)}{m_{\mu\mu}^2} \left(1 - \frac{m_{\mu\mu}^2}{m_{\eta}^2}\right)^3 \left(1 + \frac{2m_{\mu}^2}{m_{\mu\mu}^2}\right) \left(1 - \frac{4m_{\mu}^2}{m_{\mu\mu}^2}\right)^{1/2} \times |F_{\eta}(m_{\mu\mu}^2)|^2$$

$$\frac{d\Gamma(\omega \rightarrow \mu^+ \mu^- \pi^0)}{dm_{\mu\mu}^2} = \frac{\alpha}{3\pi} \frac{\Gamma(\omega \rightarrow \pi^0 \gamma)}{m_{\mu\mu}^2} \left(1 + \frac{2m_{\mu}^2}{m_{\mu\mu}^2}\right) \left(1 - \frac{4m_{\mu}^2}{m_{\mu\mu}^2}\right)^{1/2} \left[ \left(1 + \frac{m_{\mu\mu}^2}{m_{\omega}^2 - m_{\pi^0}^2}\right)^2 - \frac{4m_{\omega}^2 m_{\mu\mu}^2}{m_{\omega}^2 - m_{\pi^0}^2} \right]^{3/2} \times |F_{\omega}(m_{\mu\mu}^2)|^2$$

# Form factors

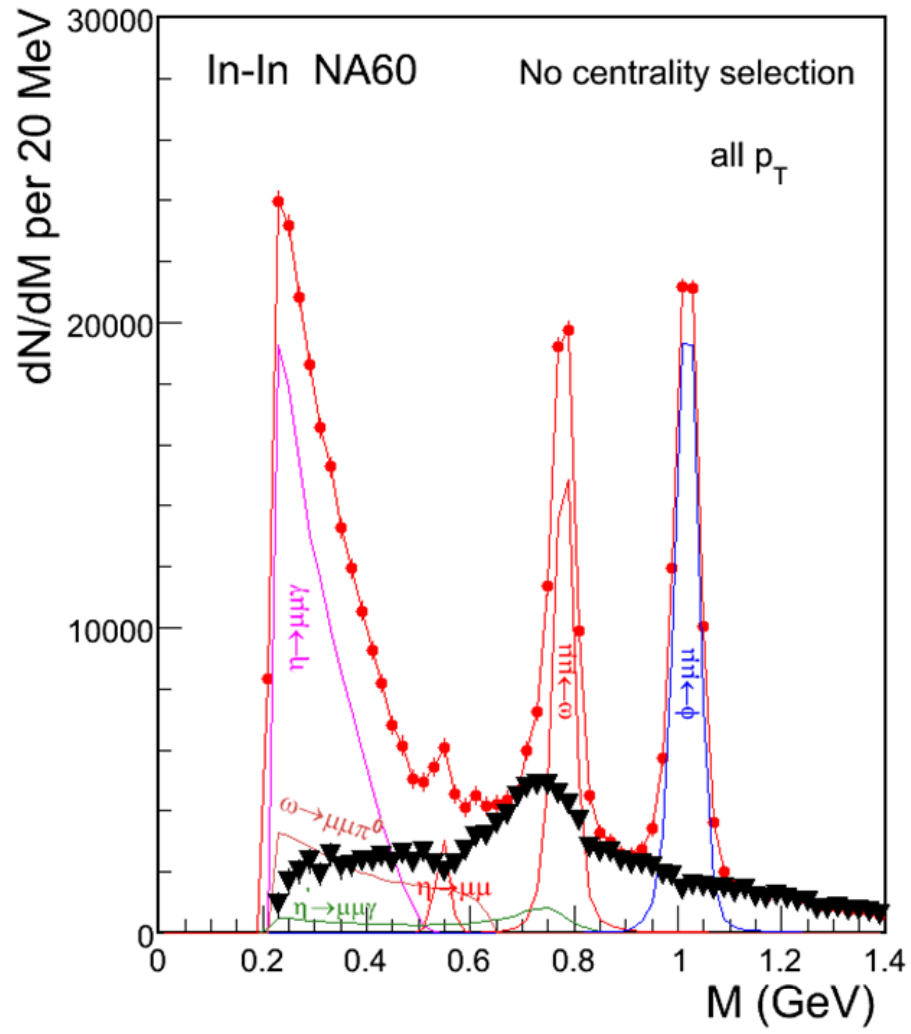
In-In peripheral PLB 677 (2009) 260  
pA 400 GeV - preliminary



- Confirmed **anomaly** of  $F_\omega$  wrt the VDM prediction
- Significantly improved errors** wrt the Lepton-G results
- Form factor ambiguity in the hadron cocktail **removed**

# Excess dimuons in In-In collisions at the SPS

*Phys. Rev. Lett. 96 (2006) 162302*



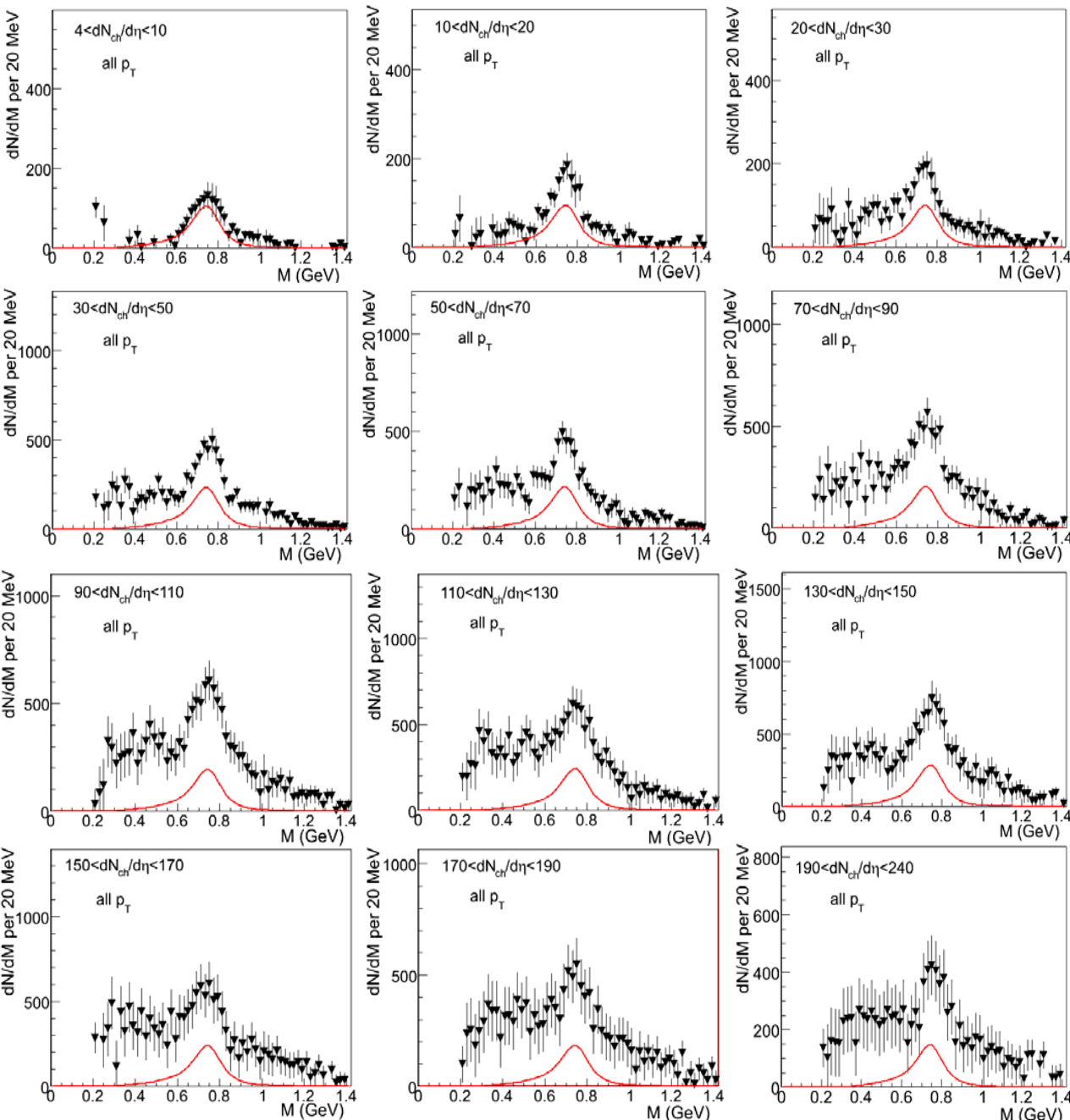
Peripheral data: well described by meson decay cocktail ( $\eta$ ,  $\eta'$ ,  $\rho$ ,  $\omega$ ,  $\phi$ ) and DD

More central data (shown):  
**existence of excess dimuons**

isolation of excess by subtraction of the **measured** decay cocktail (without  $\rho$ ), based solely on **local** criteria for the major sources  $\eta$  Dalitz,  $\omega$  and  $\phi$

# Excess vs centrality

Eur.Phys.J.C 49 (2007) 235



- Excess above the cocktail  $\rho$  (bound by  $\rho/\omega=1.0$ ), centered at nominal  $\rho$  pole
- Monotonically rises and broadens with centrality

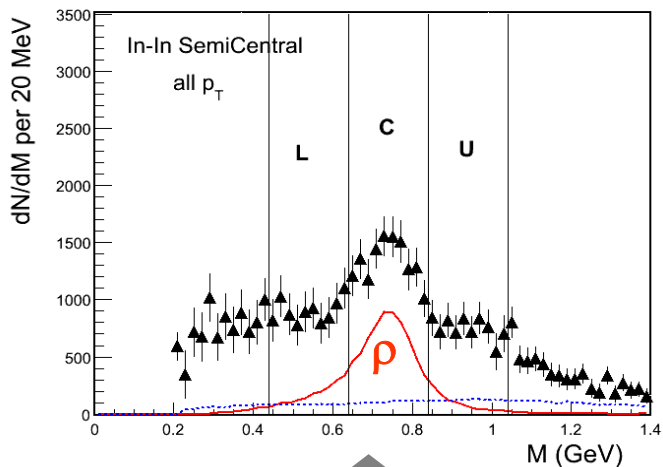
By coincidence, NA60 acceptance roughly removes the phase-space factor

⇒  $\rho$  spectral function convoluted over the fireball evolution is directly measured



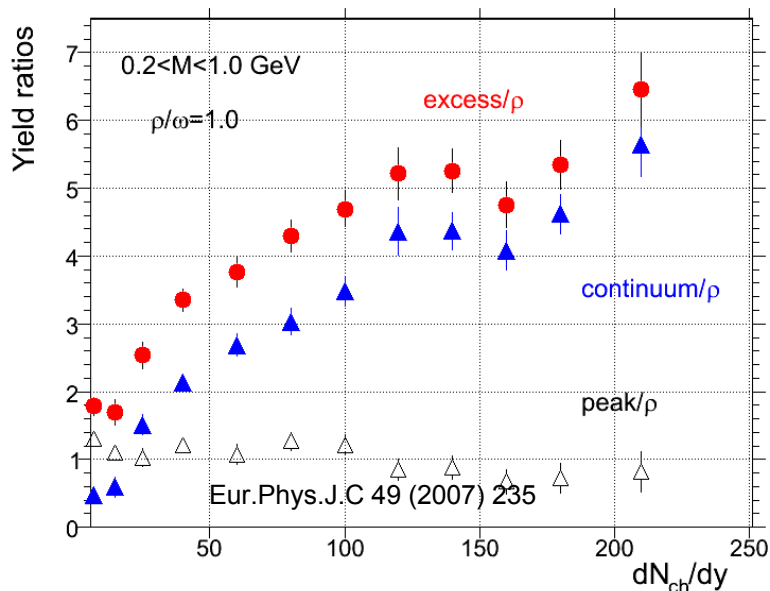
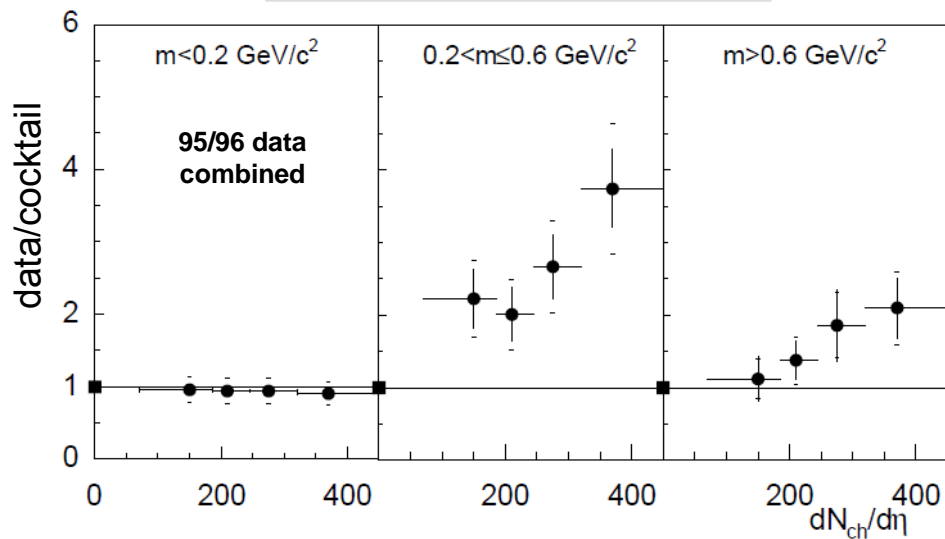
# Centrality dependence of excess yields

NA60, In-In 158A GeV



peak:  $R=C-1/2(L+U)$  continuum:  $3/2(L+U)$   
cocktail  $\rho$  is fixed by  $\rho/\omega=1.0$

CERES, Pb-Au 158A GeV



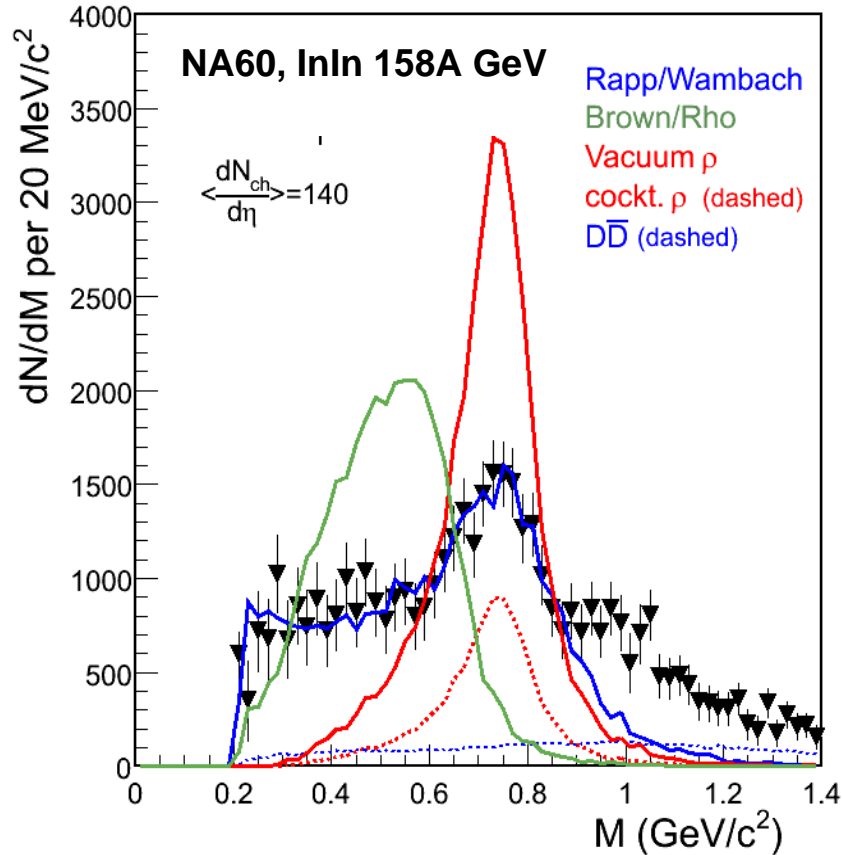
rapid initial increase of total - already 3 at  $dN_{ch}/dh=N_{part}=50$

Total excess wrt "cocktail"  $r$ : indicative of the number of  $r$  generations: ( $\rho$  - clock)

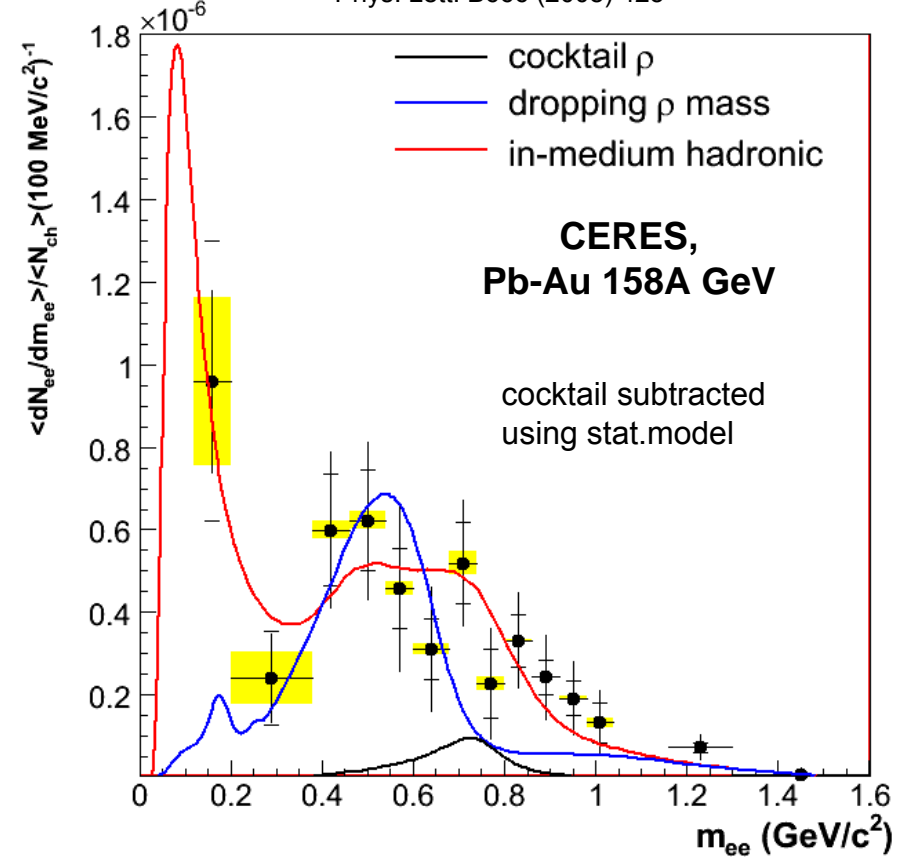
strong increase of continuum (by a factor of >10)

# Comparison of data to RW, BR and Vacuum $\rho$

Phys. Rev. Lett. 96 (2006) 162302



Phys. Lett. B666 (2008) 425



Predictions by Rapp (2003) for all scenarios

Theoretical yields normalized to data for  $M < 0.9$  GeV

Only broadening of  $\rho$  (RW) observed, no mass shift (BR)

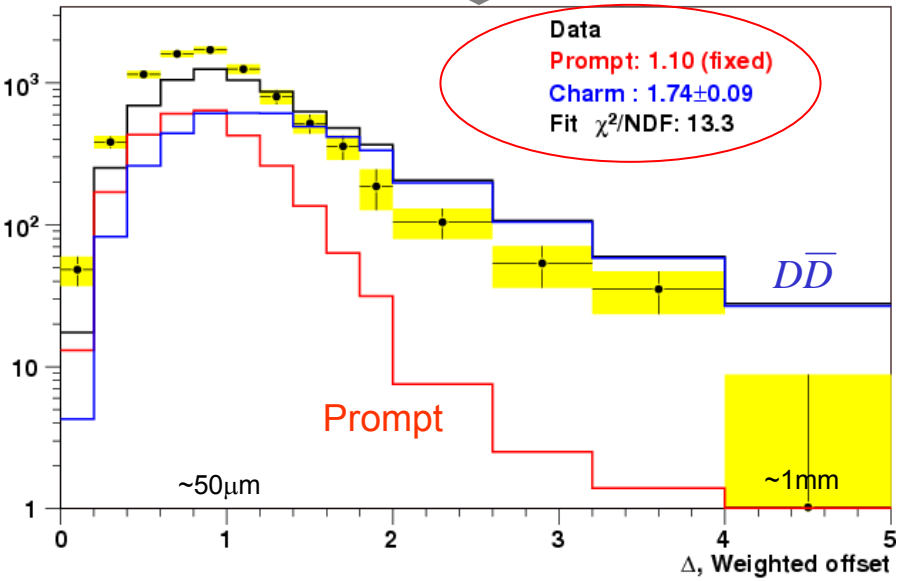
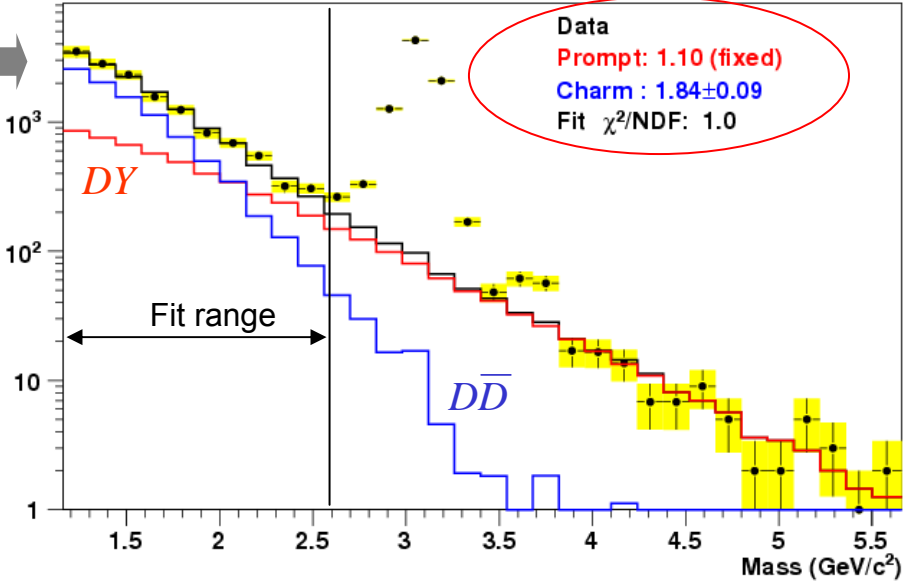
# Extension to intermediate mass region

Eur.Phys.J. C59 (2009) 607

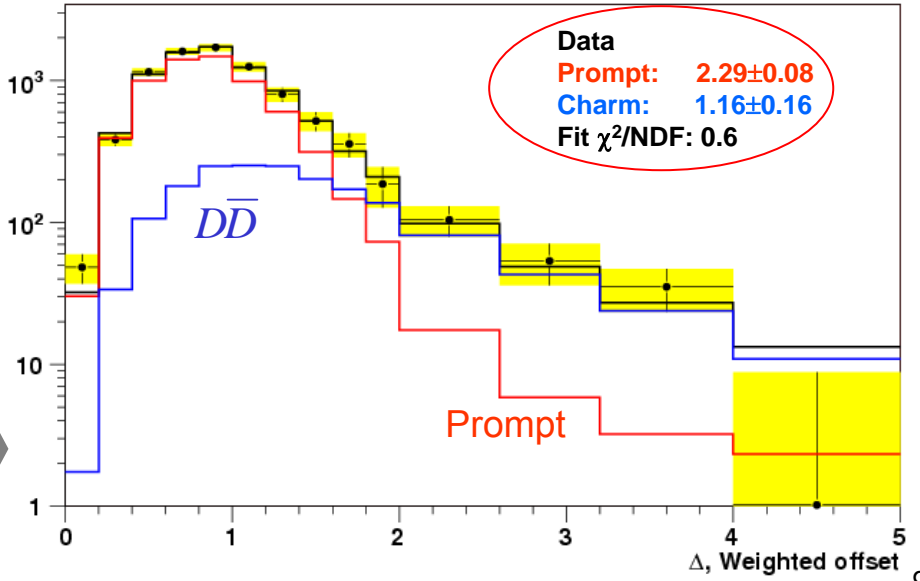
Mass spectrum is similar to NA50:  
 Good description by Drell-Yan + ~2xOpen Charm  
 (extrapolated from pA data)

Such explanation is rejected by the spectra of dimuon **offsets** wrt the interaction vertex!

$$\Delta_{\mu} = \sqrt{(\Delta x^2 V_{xx}^{-1} + \Delta y^2 V_{yy}^{-1} + 2\Delta x \Delta y V_{xy}^{-1})} / 2 \quad \Delta_{\mu\mu} = \sqrt{(\Delta^2_{\mu 1} + \Delta^2_{\mu 2})} / 2$$



Offset fit shows that the enhancement is not due to Open Charm ⇒ **the excess is prompt**



# NA60 IMR excess ( $1.16 < M < 2.56 \text{ GeV}/c^2$ )

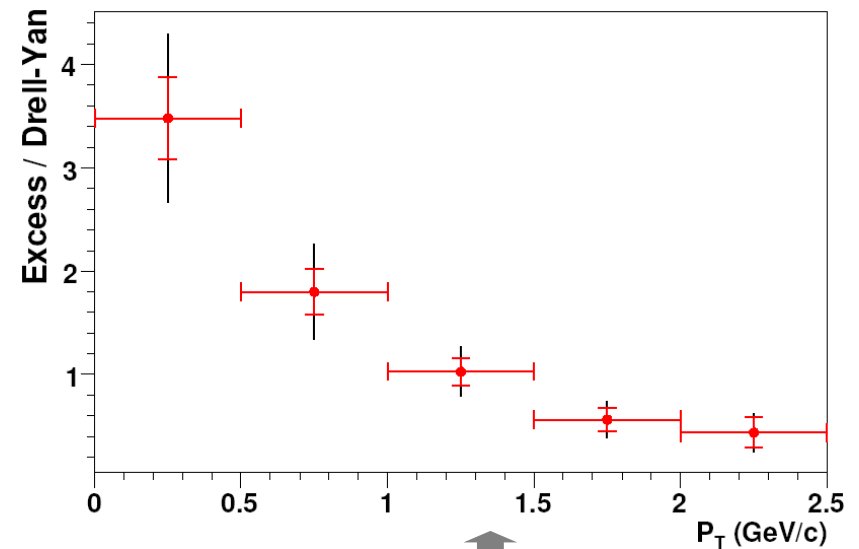
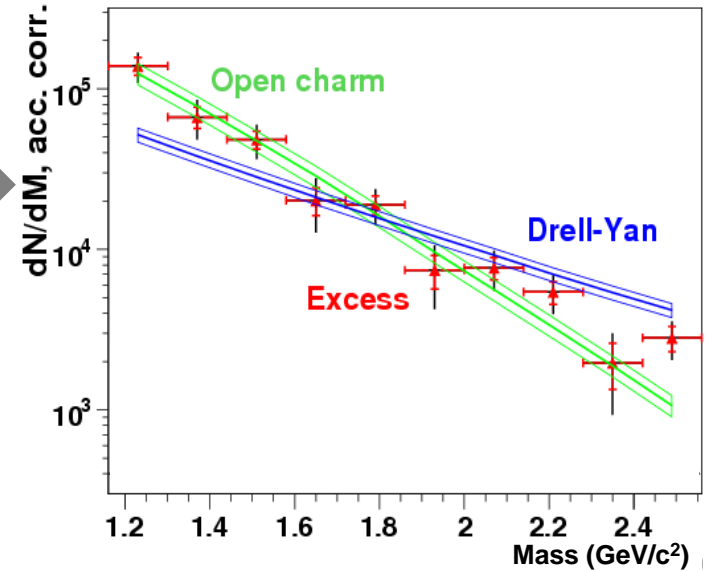
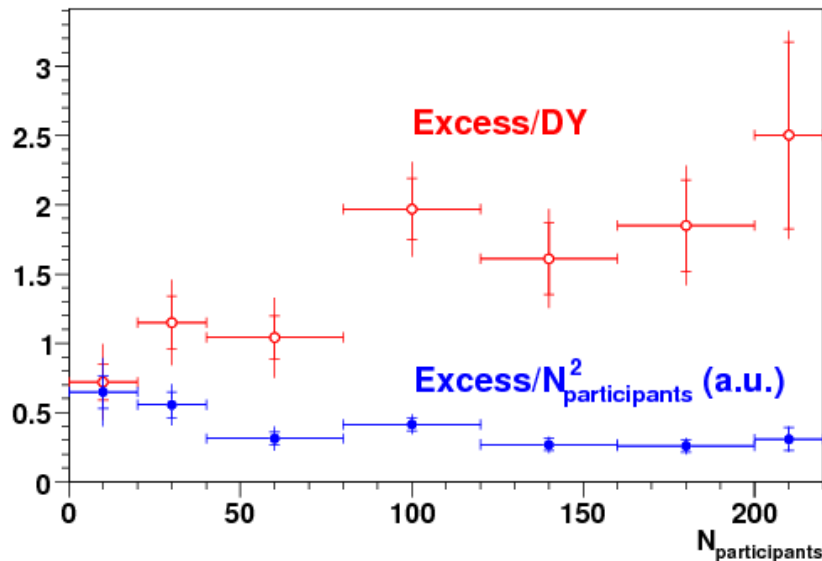
Mass shape and yield close to Open Charm

$D\bar{D}$  contribution measured agrees within  $\sim 20\%$  with NA50 pA data (same kinematical domain  $|\cos\theta_{CS}| < 0.5$ )

$\Rightarrow$  no strong  $D\bar{D}$  modifications.

Scales with centrality faster than Drell-Yan ( $\sim N_{\text{bin.coll}}$ ), but less faster than  $N_{\text{participants}}^2$

Eur.Phys.J. C59 (2009) 607



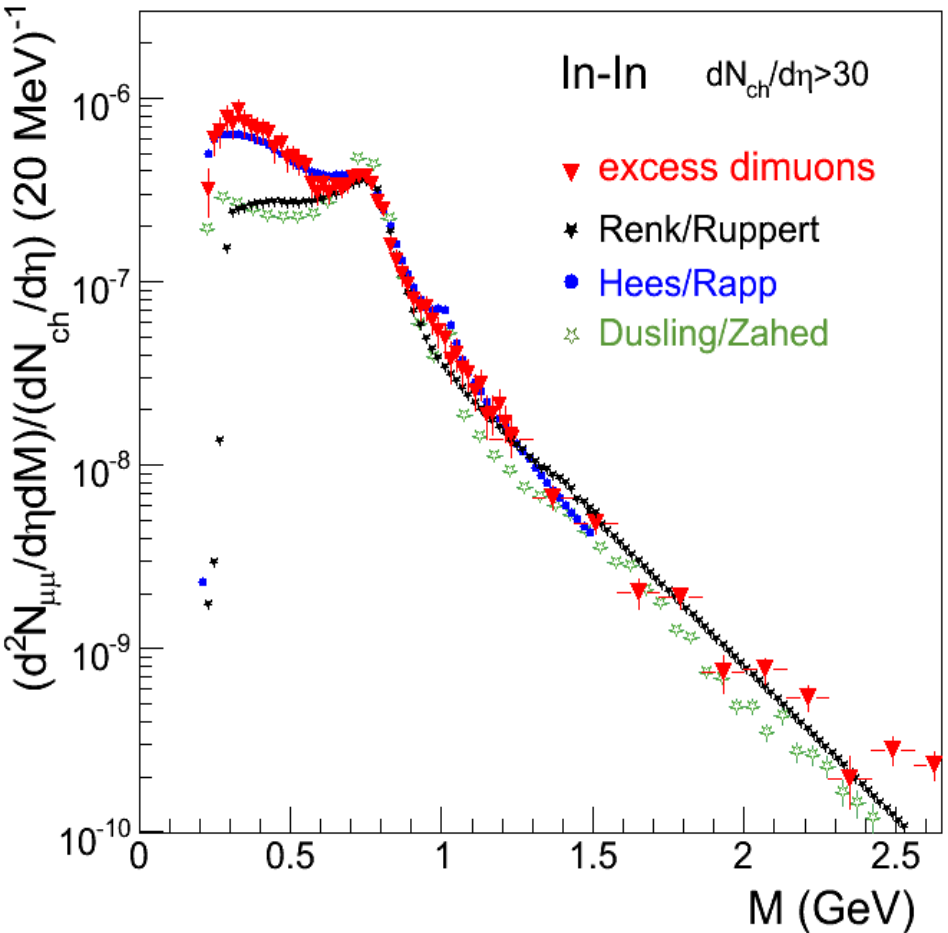
Much softer in  $p_T$  than Drell-Yan: rules out higher-twist DY? [Qiu, Zhang, Phys. Lett. B 525, (2002) 265]20

# Excess mass spectrum up to 2.5 GeV

All known sources (hadro-cocktail, open charm, DY) subtracted

Acceptance corrected spectrum ( $p_T > 0.2$  GeV)

Absolute normalization  $\rightarrow$  comparison to theory in absolute terms!



**thermal**  $\pi\pi \rightarrow \gamma \rightarrow \mu\mu$  ( $M < 1$  GeV)

&&

**thermal**  $qq \rightarrow \gamma \rightarrow \mu\mu$  ( $M > 1$  GeV)

suggested dominant by  $T_{\text{eff}}$  vs  $M$   
(supported by R/R, D/Z)

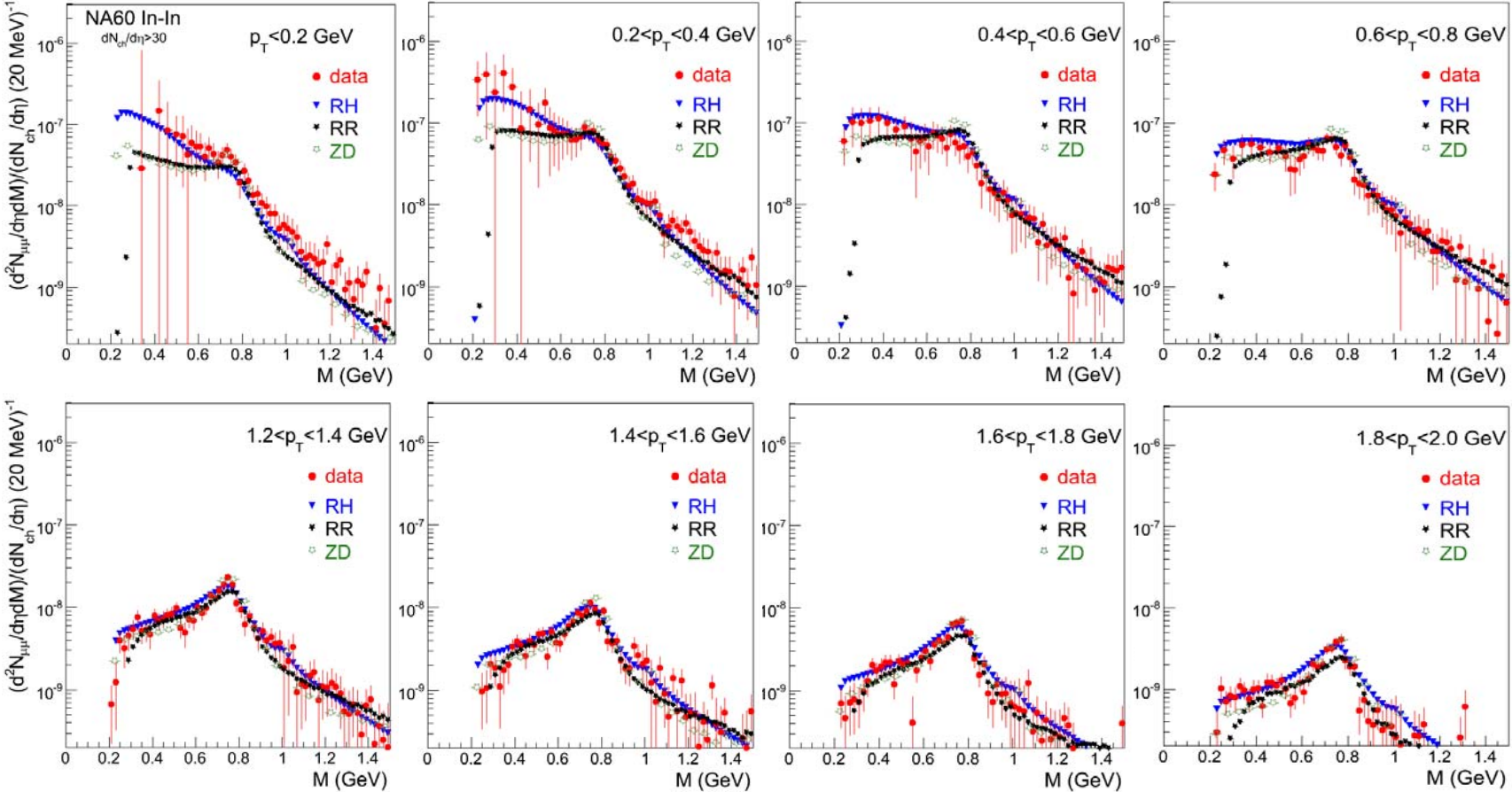
also multipion processes (H/R)

**Planck-like** mass spectrum;  
falling exponentially

**Agreement** with theoretical  
models up to 2.5 GeV!

# NA60 excess vs $p_T$ : comparison to theory

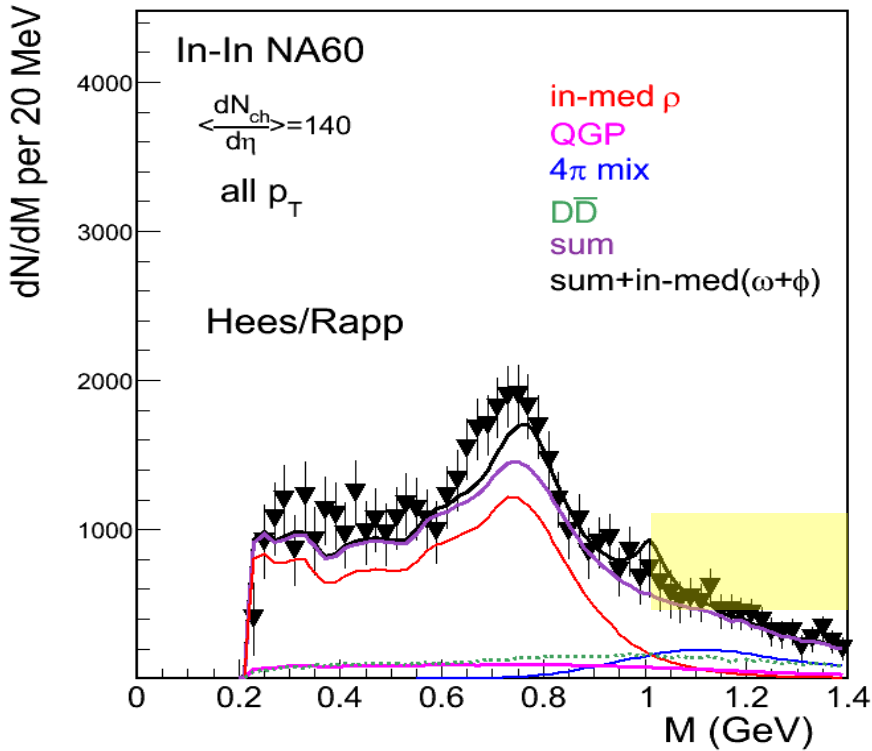
*Eur. Phys. J. C 61 (2009) 711*



Absolute normalization both for theory and data  
 Differences at low masses reflect differences in the tail of  $\rho$  spectral function  
 Differences at high masses,  $p_T$  reflect differences in flow strength

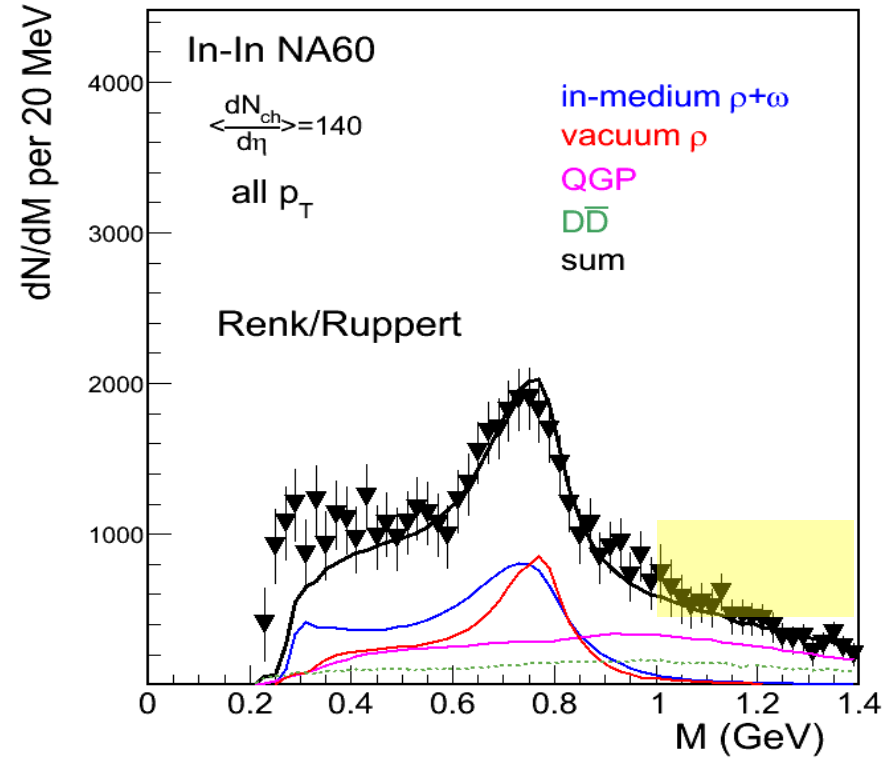
# Hadron-Parton Duality for $M > 1$ GeV

Hees/Rapp Phys.Rev.Lett. (2006)



Mass region above 1 GeV described in terms of **hadronic processes**,  $4\pi$  ...

Renk/Ruppert, hep-ph/0702012



Mass region above 1 GeV described in terms of **partonic processes**,  $q\bar{q}$ ...

How to distinguish?

# Radial flow and $p_T$ spectra

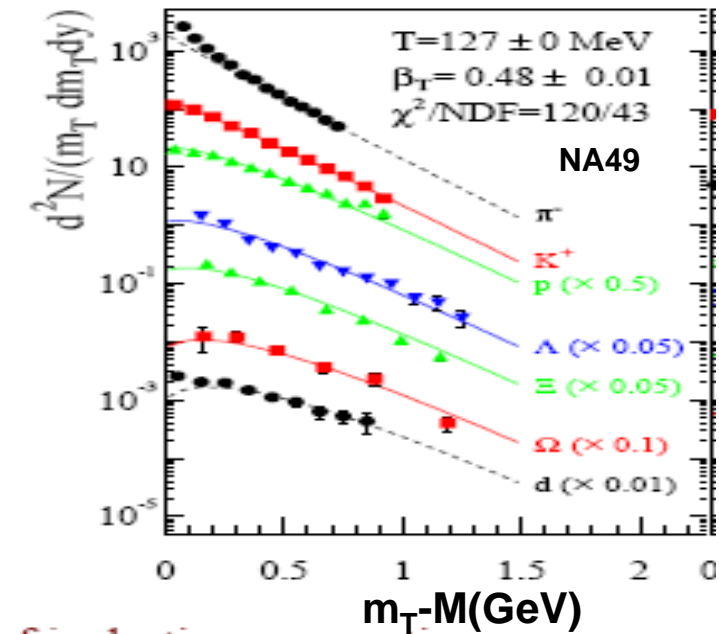
thermalization due to interactions

collective (flow) velocity  $v_T$  same for all particles

two components in  $p_T$  spectra: thermal and flow

$$p_T = p_T^{\text{th}} + M v_T$$

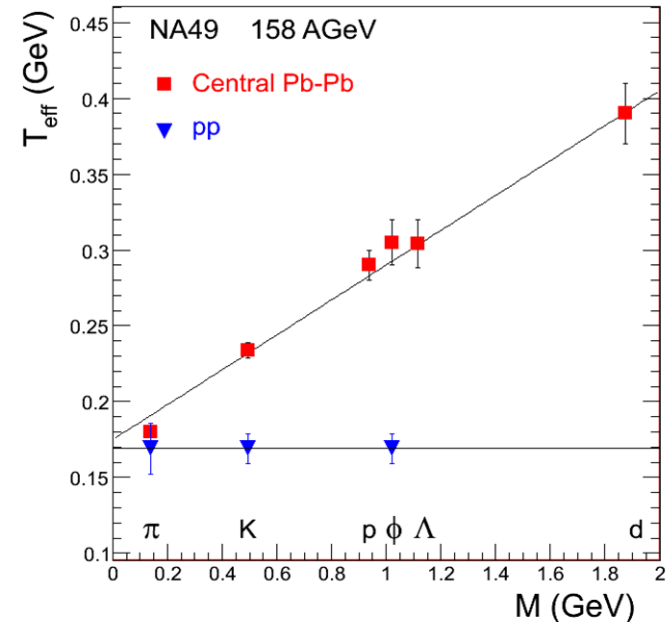
hadron  $p_T$  spectra: determined at freeze-out  $\rightarrow$  mass ordering



2-parameter fits  $\rightarrow T_f, v_T$

$$\frac{dN}{m_T dm_T} \propto e^{-m_T/T_{\text{eff}}}$$

$$T_{\text{eff}} \approx T_f + m \langle v_T \rangle^2$$

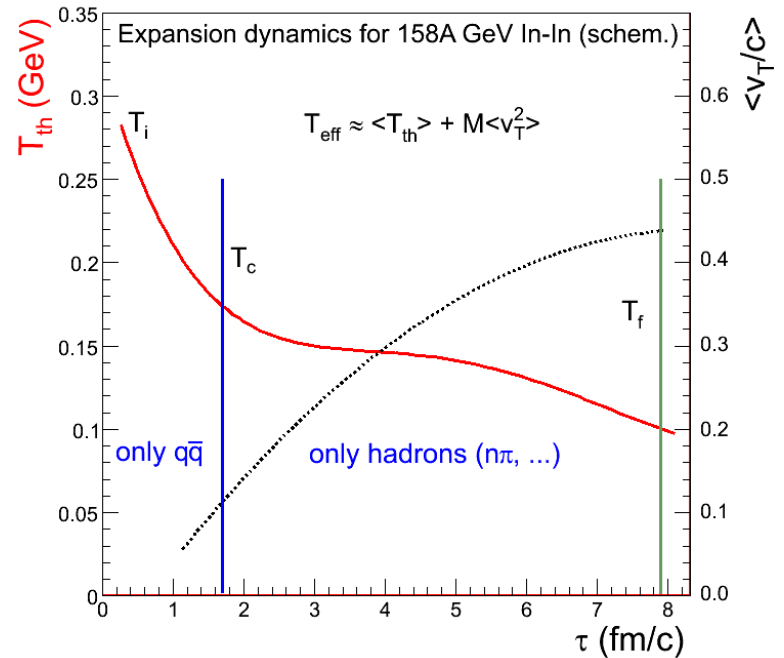
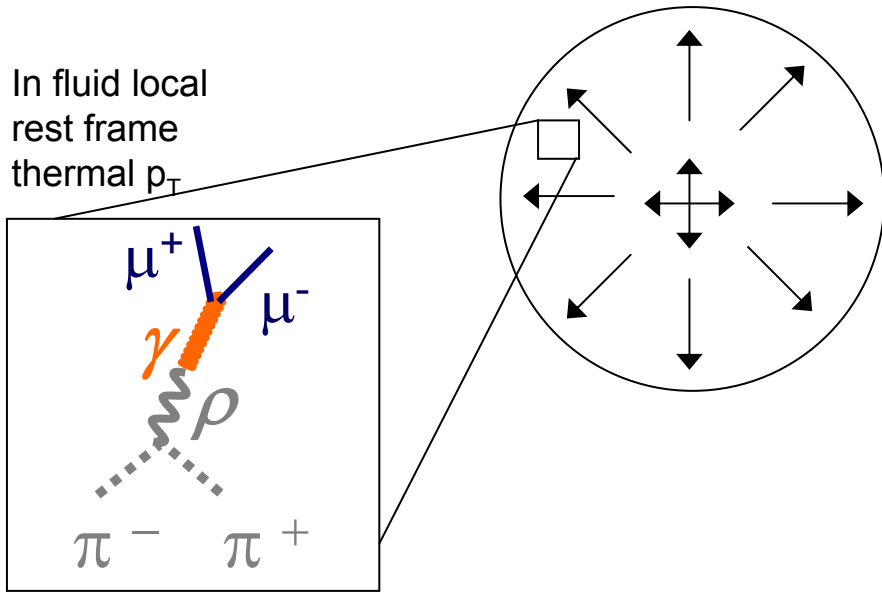


1-parameter fits  $\rightarrow T_{\text{eff}}$



# Lepton pair emission and radial flow

Muon pairs coming from  $\rho$  decay or other in-medium processes: continuum emission during the **full fireball lifetime** (4-dim volume)



$T$  - dependence of **thermal distribution** of “mother” hadrons/partons

$M$  - dependent **radial flow** ( $v_T$ ) of “mother” hadrons/partons

$p_T$  - dependence of **spectral function**, weak (dispersion relation)

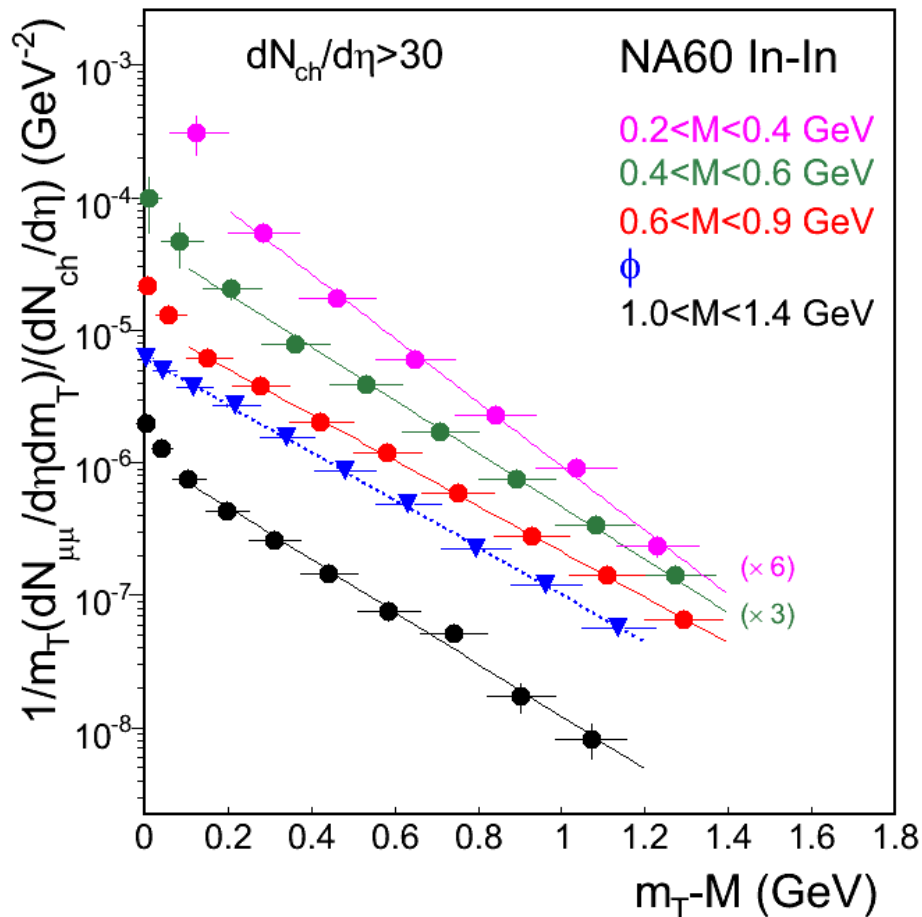
$\Rightarrow$  emission of lepton pairs senses:

- large  $T$  and small  $v_T$  at early times
- small  $T$  and large  $v_T$  at later time

**handle to distinguish between emitting source**

# Centrality-integrated excess $m_T$ spectra

Phys. Rev. Lett. 100 (2008) 022302



transverse mass:  $m_T = (p_T^2 + M^2)^{1/2}$

absolute normalization

steepening at low  $m_T$ ; not observed for hadrons (like  $\phi$ )

monotonic flattening of spectra with mass up to  $M=1$  GeV, followed by a steepening above

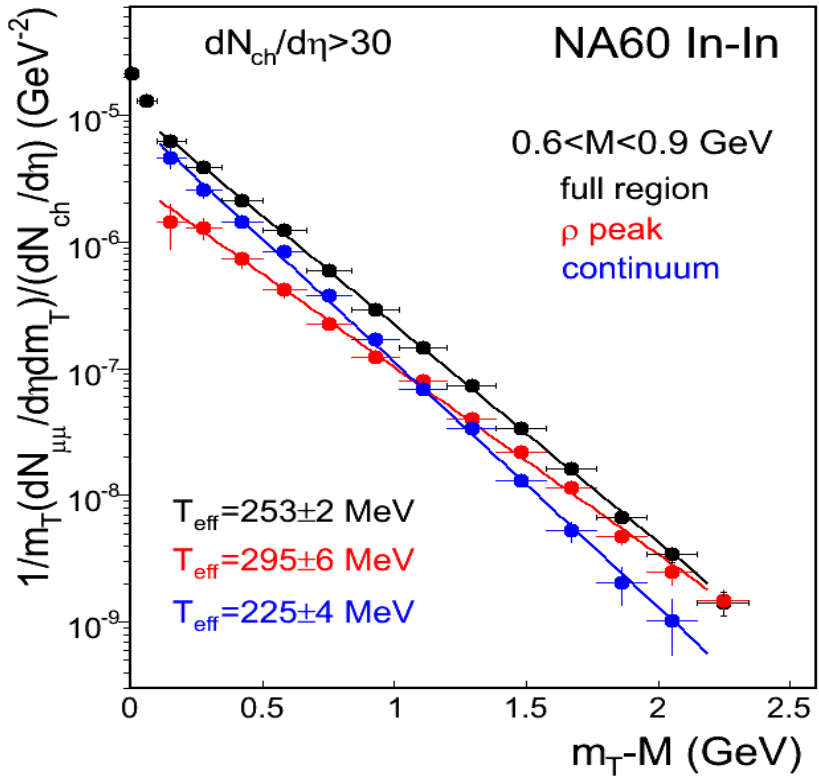
fit  $m_T$  spectra for  $p_T > 0.4$  GeV with

$$\frac{1}{m_T} \frac{dN}{dm_T} \sim \exp\left(-m_T/T_{eff}\right)$$

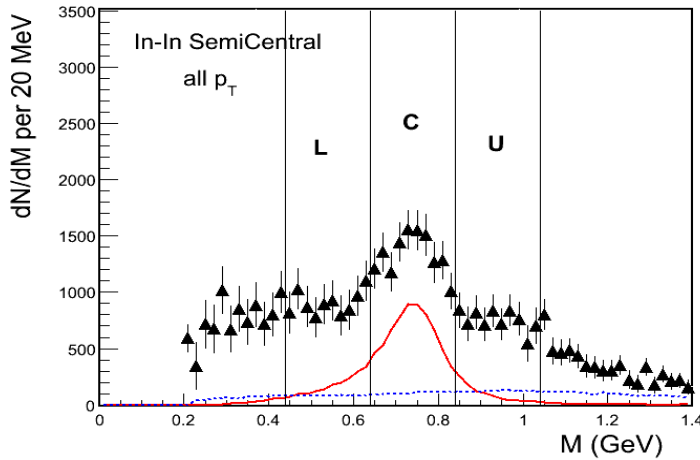
signs for mass-dependent radial flow?

# Shape analysis and $p_T$ spectra

identify the  $\rho$  peak with the freeze-out  $\rho$  in the dilute final stage, when it does not experience further in-medium influences.



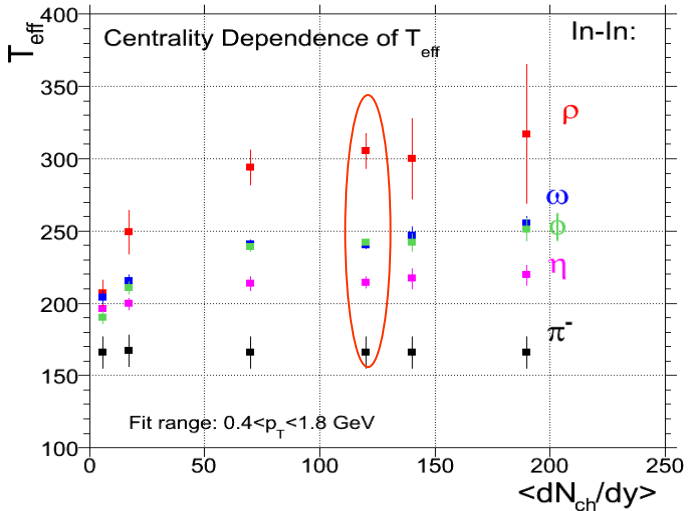
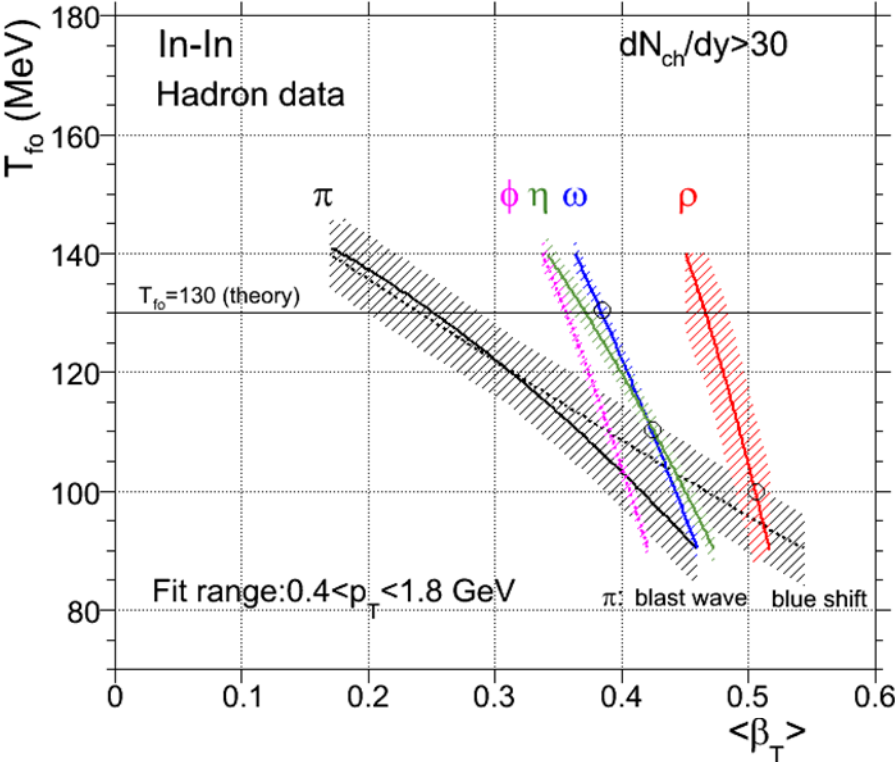
use side-window subtraction method



peak:  $C - 1/2(L + U)$   
 continuum:  $3/2(L + U)$

$m_T$  spectra very different for the  $\rho$  peak and continuum:  
 $T_{eff}$  of peak higher by  $70 \pm 7$  MeV than that of the continuum!  
 all spectra pure exponential, no evidence for hard contributions

# NA60 hadron measurements: hierarchy in hadron freeze-out



large difference between  $\rho$  and  $\omega$  (same mass)

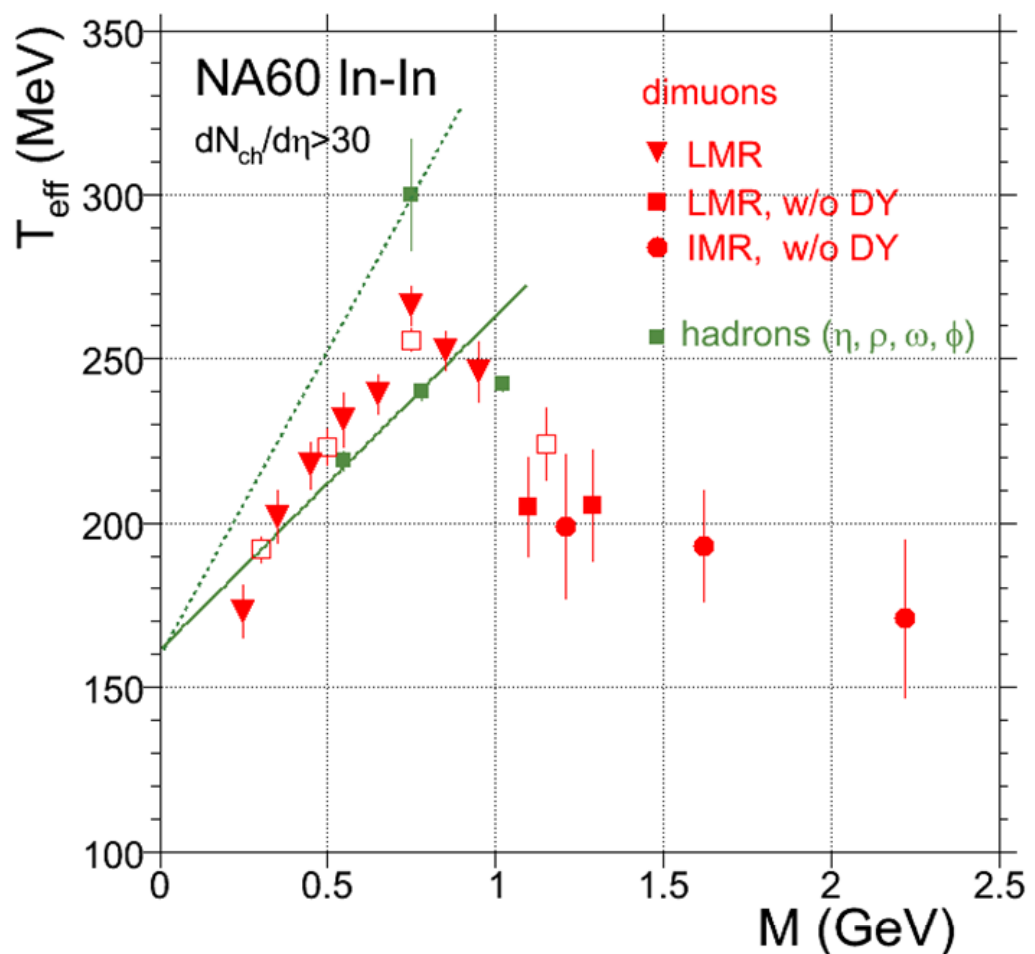
← use of Blast wave code  
 for a given hadron  $M$ , the measured  $T_{eff}$  defines a line in the  $T_{fo}-v_T$  plane

crossing of hadrons with  $\pi$  defines  $T_f$ ,  $v_T$  max reached at respective hadron freeze-out

different hadrons have different coupling to pions ( $\rho$  maximal)  
 → clear hierarchy of freeze-out (also for light-flavored hadrons)

# The rise and fall of radial flow of thermal dimuons

Phys. Rev. Lett. 100 (2008) 022302



Strong rise of  $T_{eff}$  with dimuon mass, followed by a sudden drop for  $M > 1$  GeV

Rise consistent with radial flow of a hadronic source (here  $\pi\pi \rightarrow \rho \rightarrow \mu\mu$ ), taking the freeze-out  $\rho$  as the reference

Drop signals sudden transition to low-flow source, i.e. source of partonic origin (here  $qq \rightarrow \mu\mu$ )

Combining M and  $p_T$  of dileptons seems to overcome hadron-parton duality

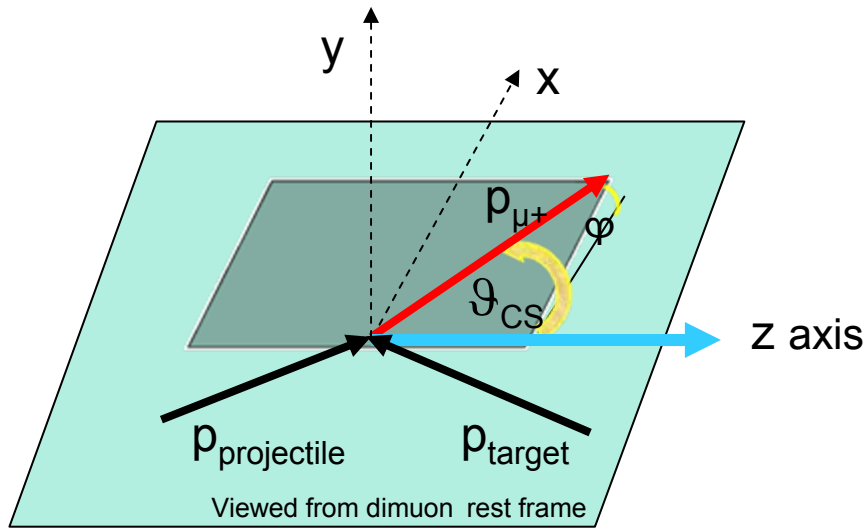
# Angular distributions

General formalism for the description of an angular distribution

$$\frac{1}{\sigma} \frac{d\sigma}{d\cos\theta d\phi} = \left( 1 + \lambda \cos^2 \theta + \mu \sin 2\theta \cos \phi + \frac{\nu}{2} \sin^2 \theta \cos 2\phi \right)$$

$d\sigma/d\cos\theta d\phi$  is the differential decay angular distribution in the rest frame of the virtual photon  $\gamma^*$  with respect to a suitably chosen axis

$\lambda, \mu, \nu$  are structure functions related to helicity structure functions and the spin density matrix elements of the virtual photon



## Collins Soper (CS) frame

$\theta$  is the angle between the positive muon  $\mathbf{p}_{\mu^+}$  and the z-axis.

The z axis is the bisector between  $\mathbf{p}_{proj}$  and  $-\mathbf{p}_{target}$

# What can we learn from angular distributions?

Analysis in the mass region  $M < 1$  GeV:

⇒ excess dileptons produced from annihilation of pions

However, pions are spinless:

⇒ Don't we expect to find a trivial result for  $\lambda$ ,  $\mu$  and  $\nu$ ?

The answer is no!

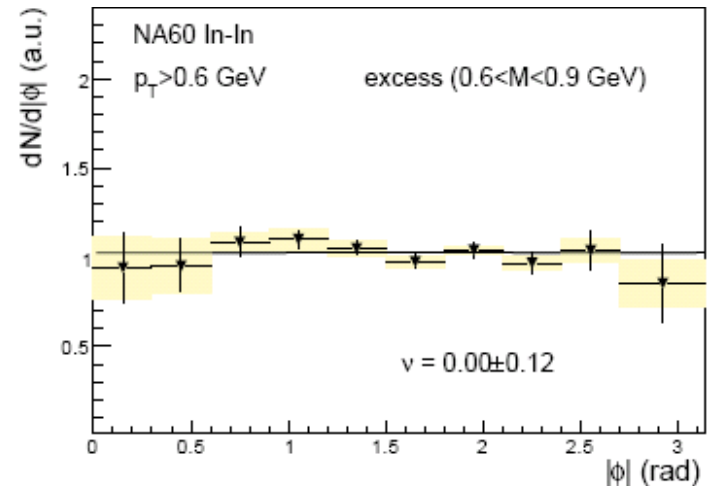
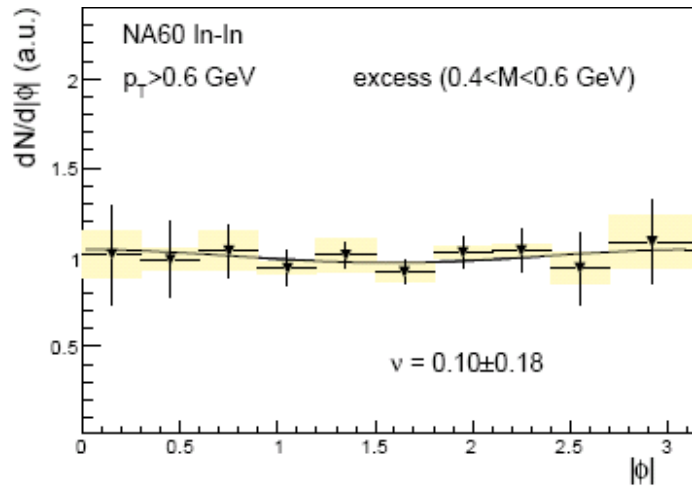
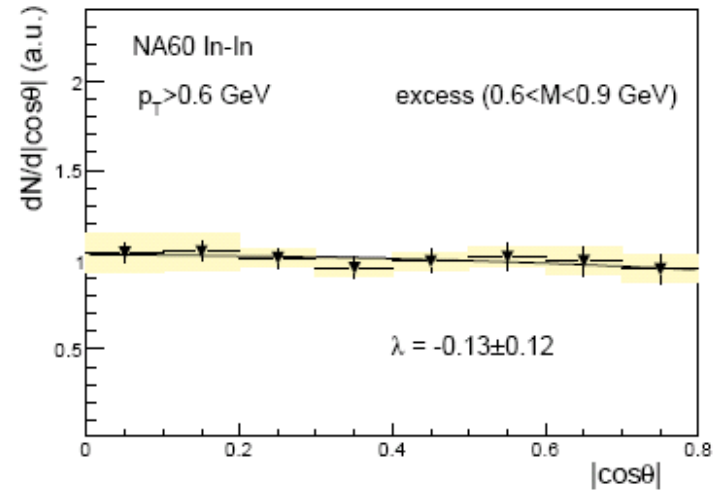
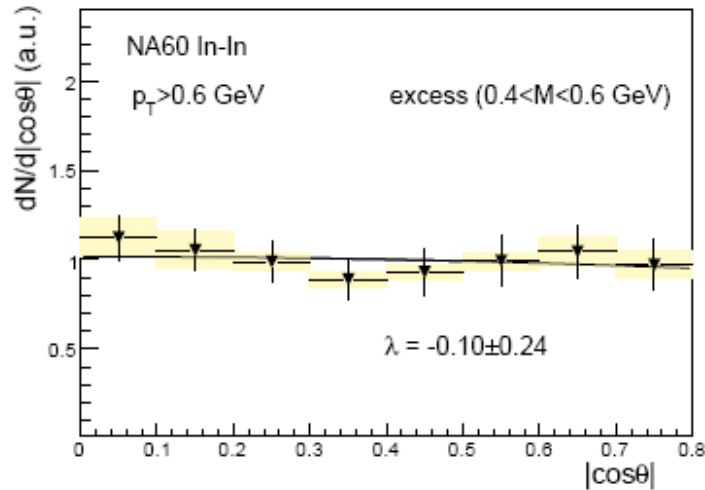
Even for annihilation of spinless particles, like  $\pi\pi$  annihilation, the structure function parameters can have any value  $\lambda, \mu, \nu \neq 0$

⇒ for collinear pions along z axis  $\lambda = -1$  → longitudinal polarization of the virtual photon

However, a completely random orientation of annihilating pions in 3 dimensions would lead to  $\lambda, \mu, \nu = 0$

# Polarization of excess dileptons

PRL 102 (2009) 222301



Lack of any polarization in excess (and in hadrons) supports emission from a **thermalized source**



# What we have learned from SPS data

Ample evidence of thermal radiation:

- $M < 1$  GeV:  $\pi\pi \rightarrow \rho \rightarrow \mu\mu$
- $M > 1$  GeV: partonic radiation and/or multipion processes

Quantitative characterization:

- Planck-like exponential shape of mass spectra (for flat spectral function)
- $m_T$  scaling of transverse momentum spectra
- Absence of any polarization in angular distributions
- Agreement between data and thermal models in yields and spectral shapes

# New measurements at lower energies and further investigation of open points

Past NA60 runs:

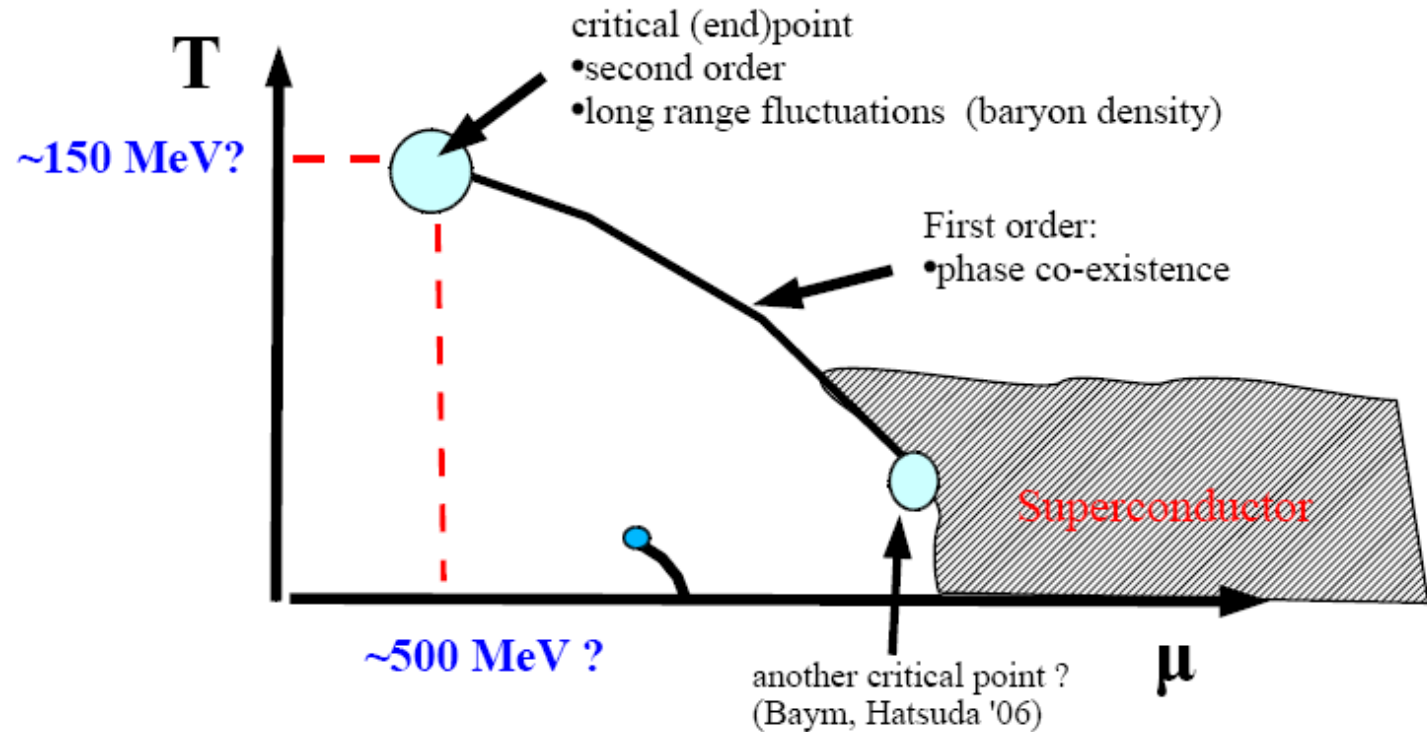
- 2003 Indium run (230 million triggers) – fully reconstructed and analysed
- 2004 proton run (100 million triggers) – analysis in progress

Original **part of the program** but **not** done:

- **2002 Lead run**

# The QCD phase diagram

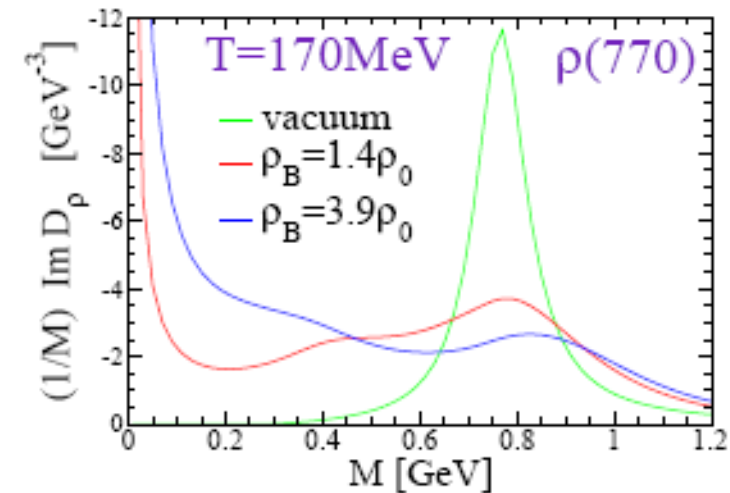
QCD phase diagram poorly known in the region of highest baryon densities and moderate temperatures – is there a critical point?



N.B.: Critical point of water:  $T_c = 647.096$  K,  $p_c = 22.064$  MPa,  $\rho_c = 322$  kg/m<sup>3</sup>

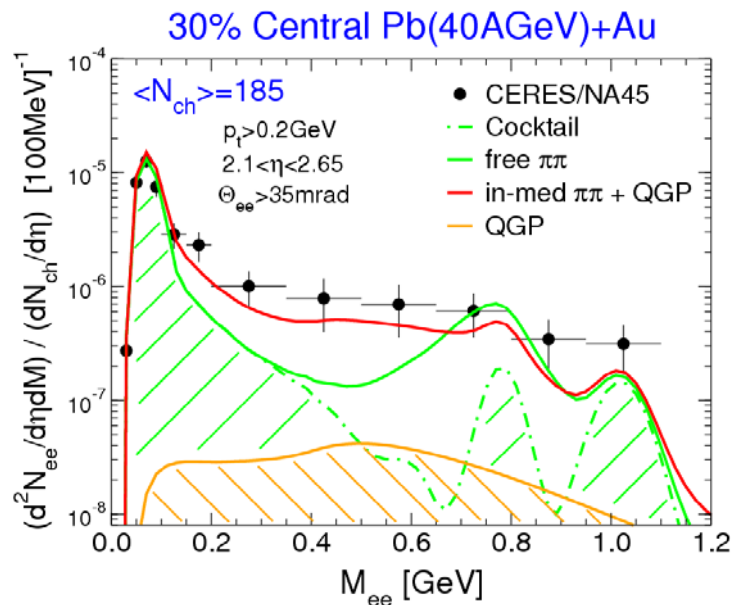
Dilepton measurements?

# Low mass dileptons: top to lower energies at SPS



Decrease of energy 160 to 40 AGeV: predicted net  $\rho$  in-medium effects, in particular for  $M < 0.4 \text{ GeV}$ , increase by a **factor 2 because of baryons!**

Pioneering measurement by CERES at 40 AGeV: **enhancement increases!** Seems to confirm importance of baryonic effects

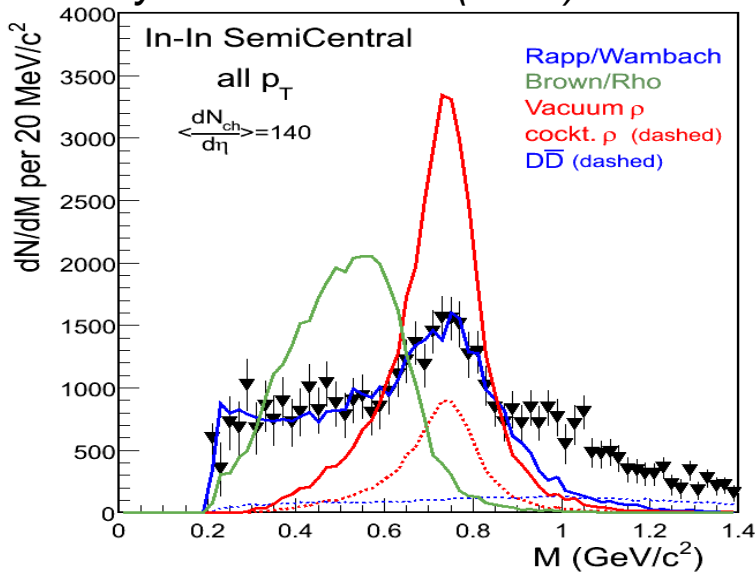


**Might not be just coincidental with expectation of emergence of CP**

**Compelling to continue research into the regime of maximal baryon density experimentally accessible**

# Low mass dileptons: chiral symmetry restoration

Phys. Rev. Lett. 96 (2006) 162302



Theoretical yields normalized to data for  $M < 0.9$  GeV

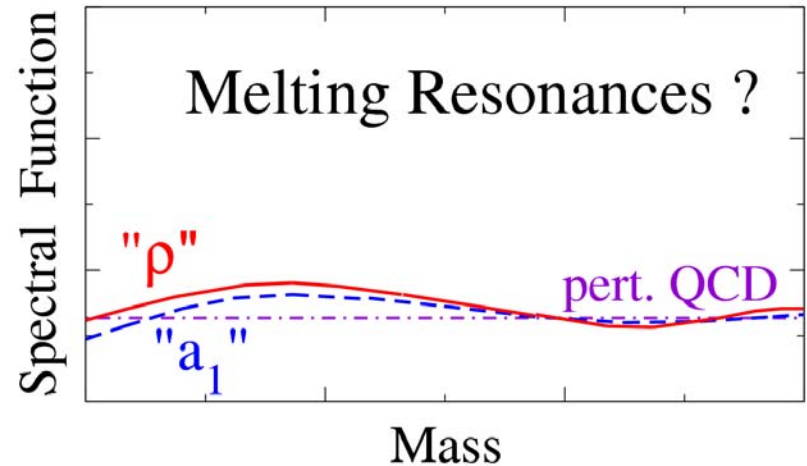
Only broadening of  $\rho$  (RW) observed  
Brown-Rho scaling ruled-out

→ which connection with chiral symmetry restoration?

Chiral restoration at  $T_c$ : vector and axial vector spectral functions expected to become degenerate

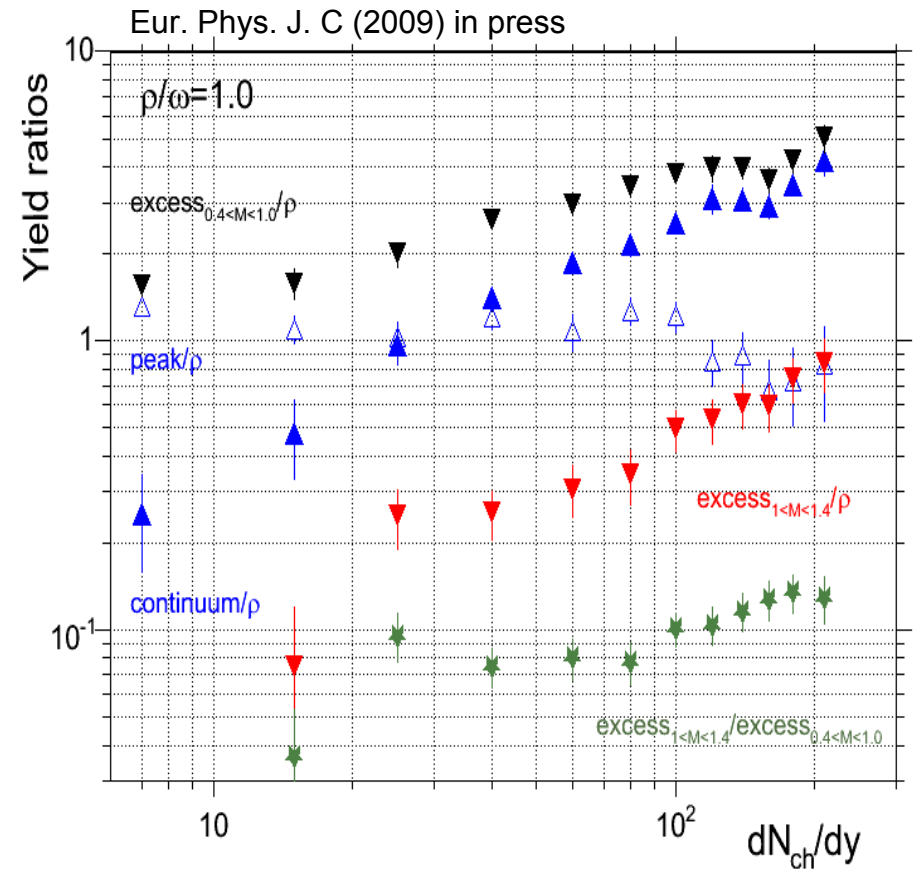
At CP extended lifetime close to  $T_c$ : higher sensitivity to chiral restoration?

Requires **independent** measurement of axial-vector spectral function ( $a_1 \rightarrow \pi\gamma$ ) or detailed theoretical modelling of axial spectral function and mixing



# Low mass dileptons: constraints in fireball lifetime

NA60 precision measurement of excess yield ( $\rho$ -clock):  
provided the **most precise constraint** in the fireball lifetime ( $6.5 \pm 0.5$  fm/c) in heavy ion collisions to date!

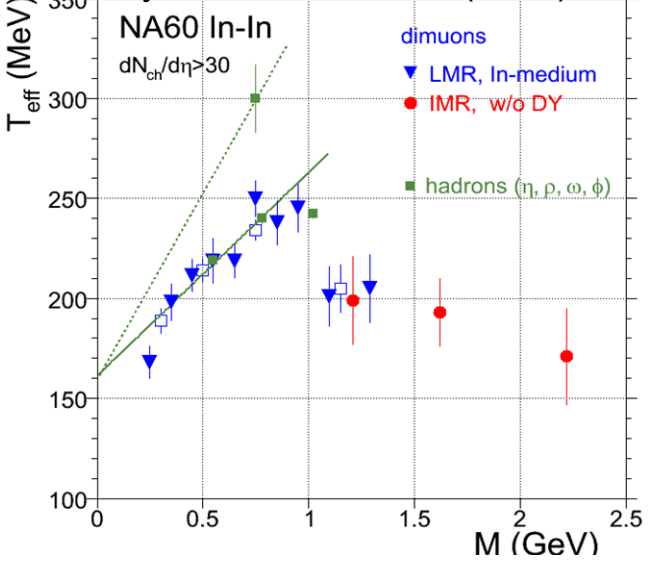


Crucial in corroborating **extended lifetime** due to soft mixed phase around CP:  
if increased  $\tau_{FB}$  observed with identical final state hadron spectra (in terms of flow)  $\rightarrow$  **lifetime extension in a soft phase**

**Nice example of complementary measurements with NA61** 38

# NA60 results on $p_T$ spectra for in-medium excess

Phys. Rev. Lett. 100 (2008) 022302

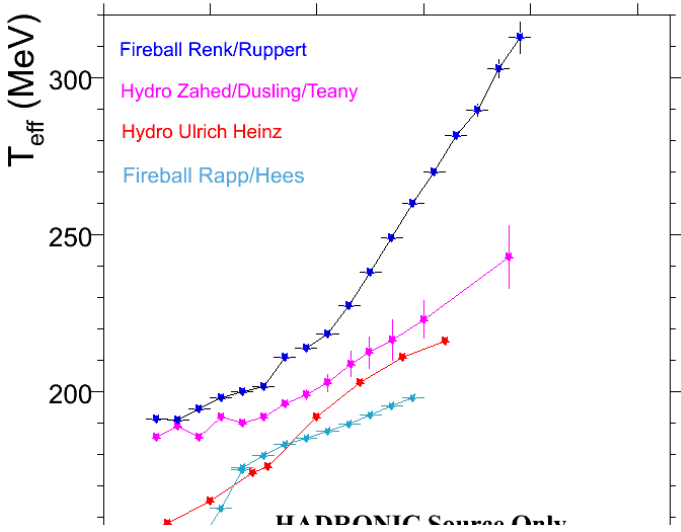


**M > 1 GeV:**  
 sudden fall of radial flow of thermal dimuons naturally explained as a transition to a qualitatively different source, i.e. mostly **partonic** radiation,  
 $qq \rightarrow \gamma \rightarrow \mu\mu$

**HADRONIC** source alone ( $2\pi+4\pi+a_1\pi$ ) (in HYDRO and other models of fireball expansion) → continuous rise of T<sub>eff</sub> with mass, no way to get a discontinuity at M=1 GeV



Uncertainty in fraction of QGP: 50%, 60%, 80%, .... but a sizeable contribution of partonic source needed to get a discontinuity in T<sub>eff</sub>



**Lower energies: will the drop disappear or reduced if partonic radiation really important at 158 AGeV? Pb-Pb at 158 GeV?**

# QCD critical point search – experimental landscape

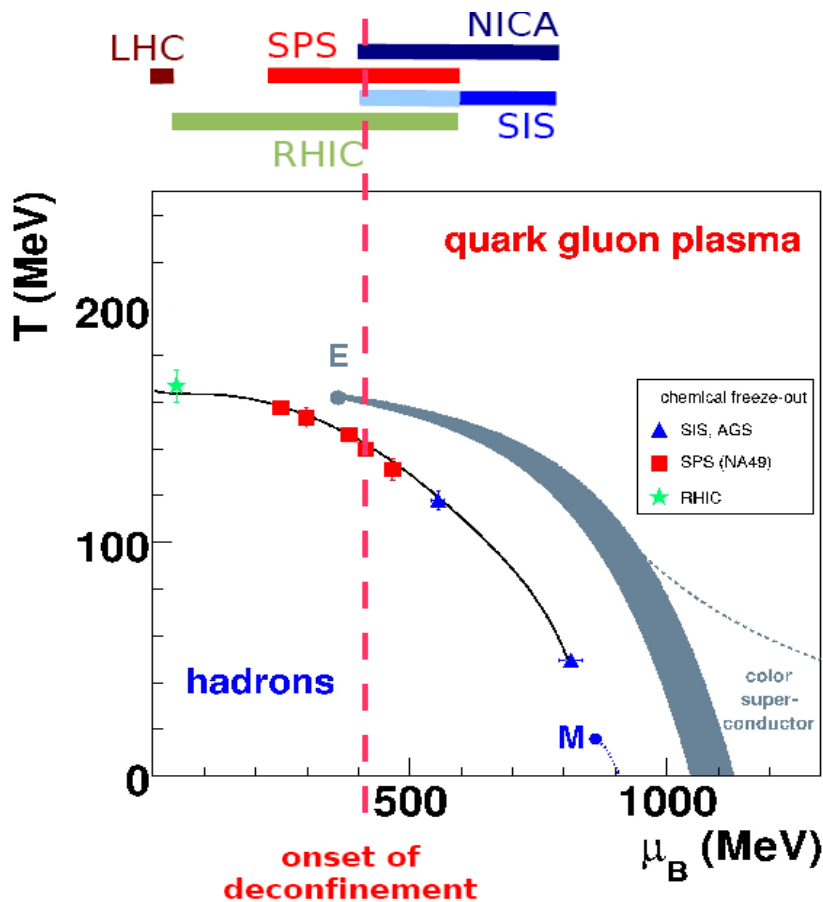
partly complementary programs

BNL RHIC 2010

DUBNA NICA 2013

GSI SIS-CBM 2016

Heavy ion beams planned at  
CERN SPS 2011



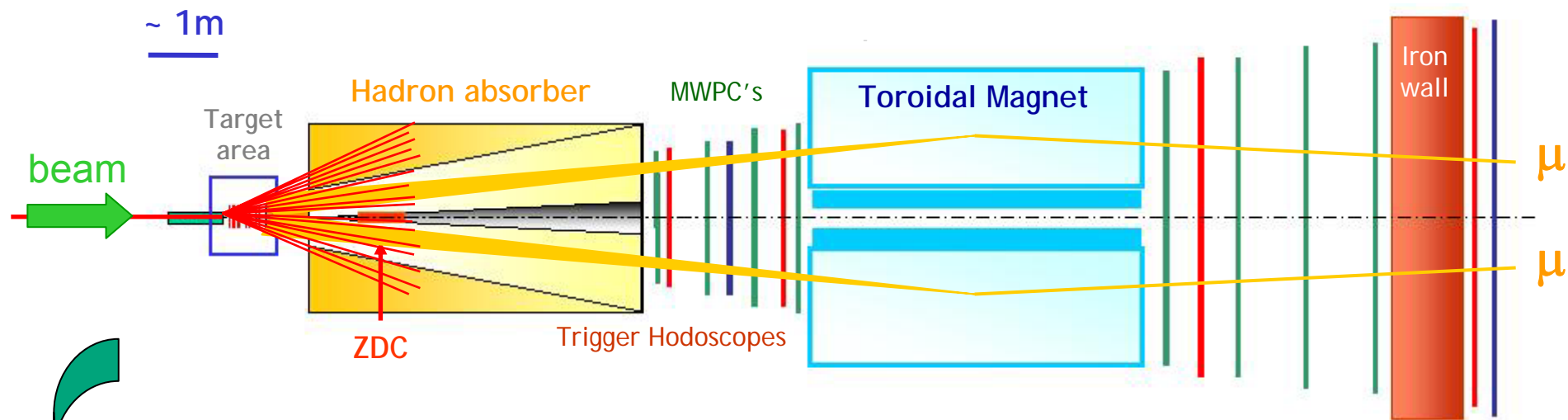
NA60-like experiment:

- Dilepton measurements in region not covered by other experiments
- High precision muon pair measurements:
  - high luminosity  $\rightarrow$  statistics
  - very good mass resolution
  - acceptance down to low  $p_T$
  - background subtraction much easier than in  $e^+e^-$
- Flexibility to change energy (and  $A$ )
- Complementary to NA61

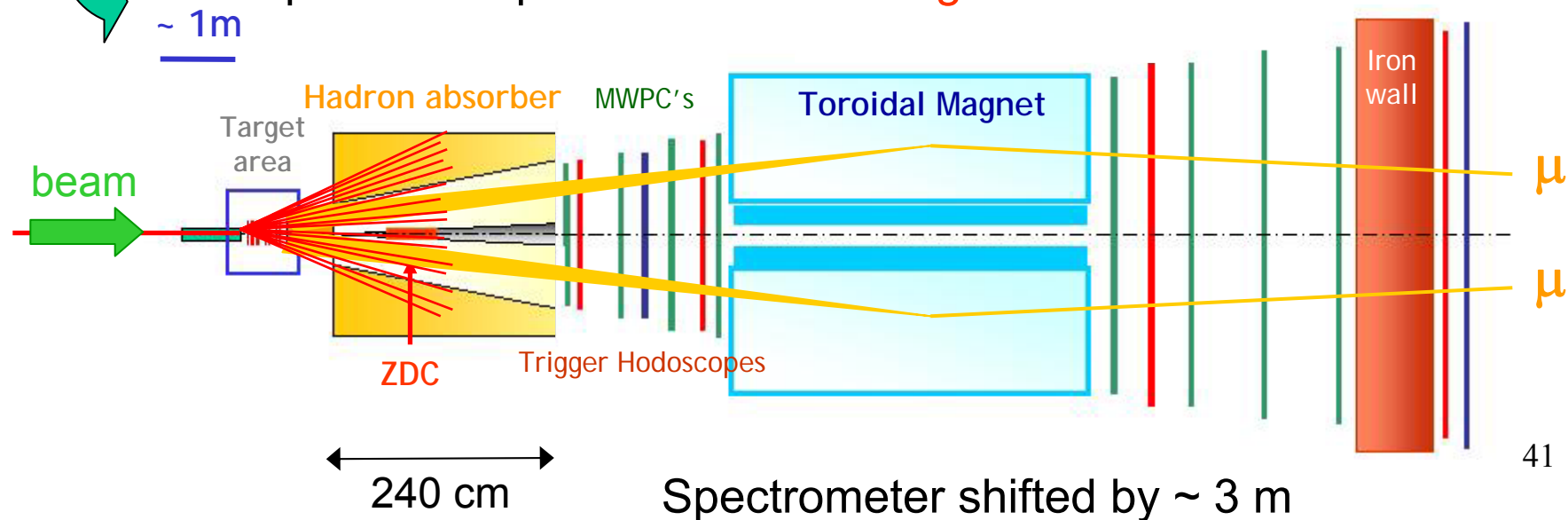


# Apparatus layout: first ideas for lower energies

NA60 muon spectrometer covers the  $y$  range 0-1 in the cms system @ 158 GeV

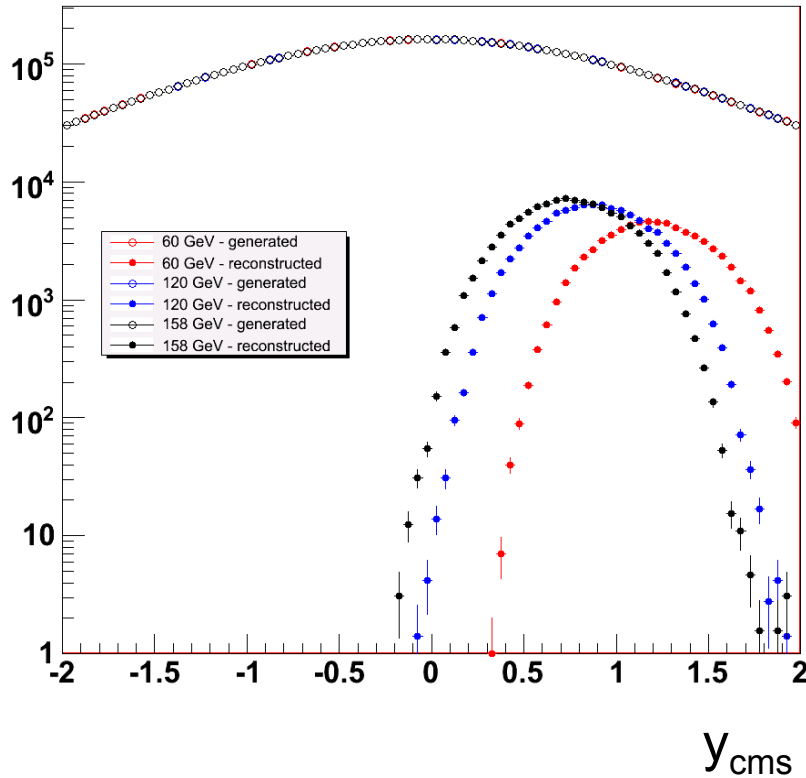


compress the spectrometer **reducing** the absorber



## standard NA60 spectrometer

$\omega$  simulation

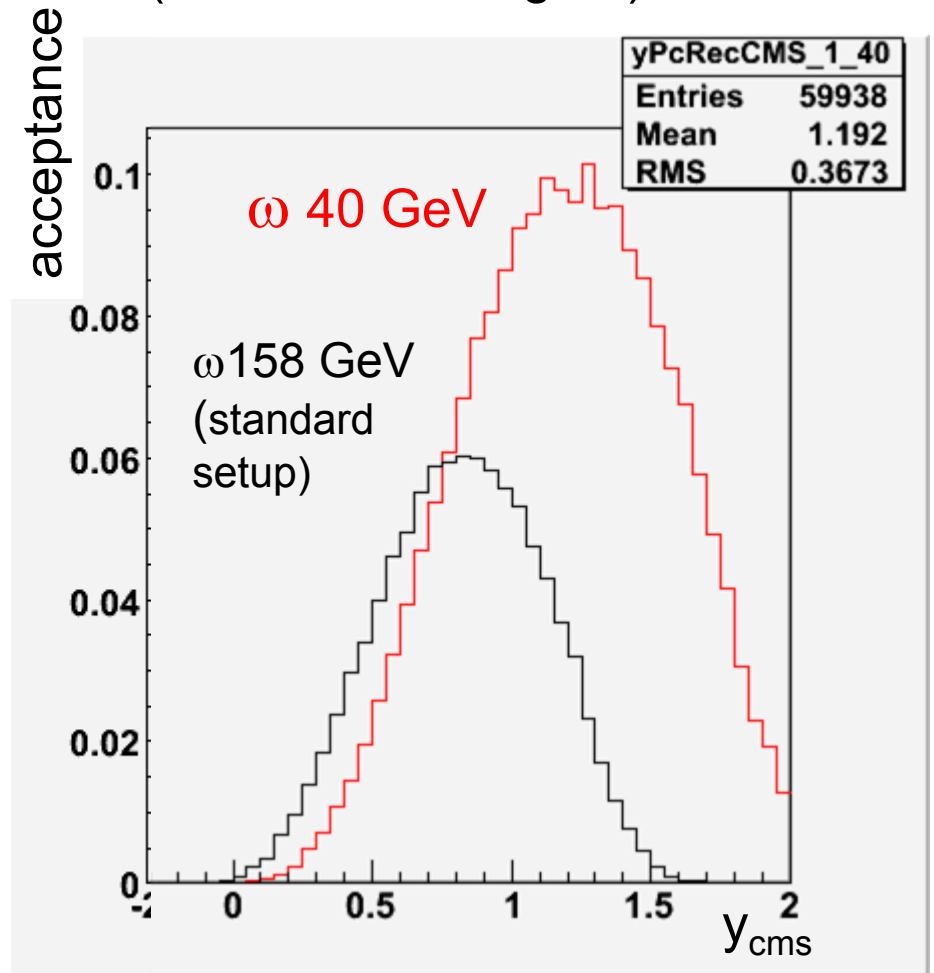


$\langle y_{lab} \rangle_{158} = 2.91 \quad \Delta y = 0.76$   
 $\langle y_{lab} \rangle_{120} = 2.77 \quad \Delta y = 0.9$   
 $\langle y_{lab} \rangle_{60} = 2.43 \quad \Delta y = 1.24$

Lowering the energy, the apparatus covers more and more **forward** rapidity

## compressed spectrometer

(and shorter magnet)

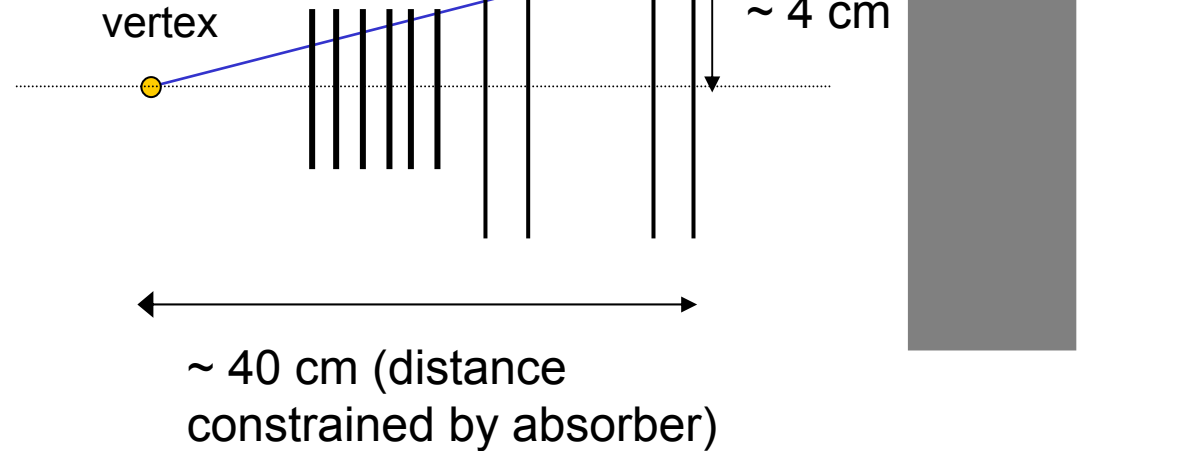


Rapidity coverage down to mid-rapidity at 40 GeV similar as with standard setup at 158 GeV ...

# Rapidity coverage of the pixel telescope

158 GeV – midrapidity at 2.9

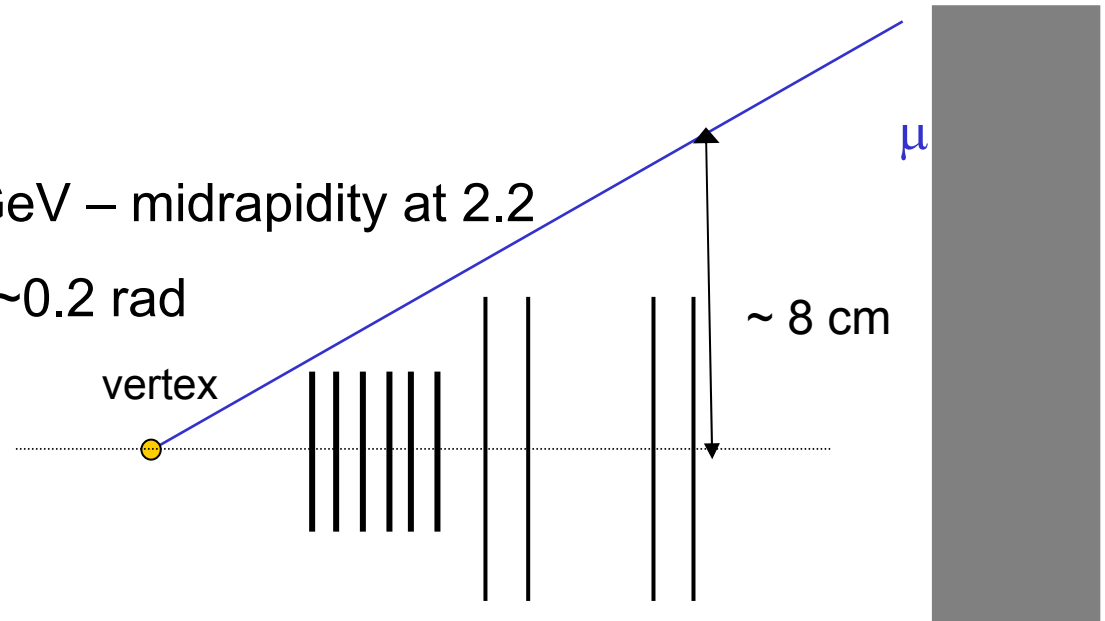
$\Rightarrow \vartheta \sim 0.109$  rad



At 40 GeV particles are emitted in a much wider cone

40 GeV – midrapidity at 2.2

$\Rightarrow \vartheta \sim 0.2$  rad

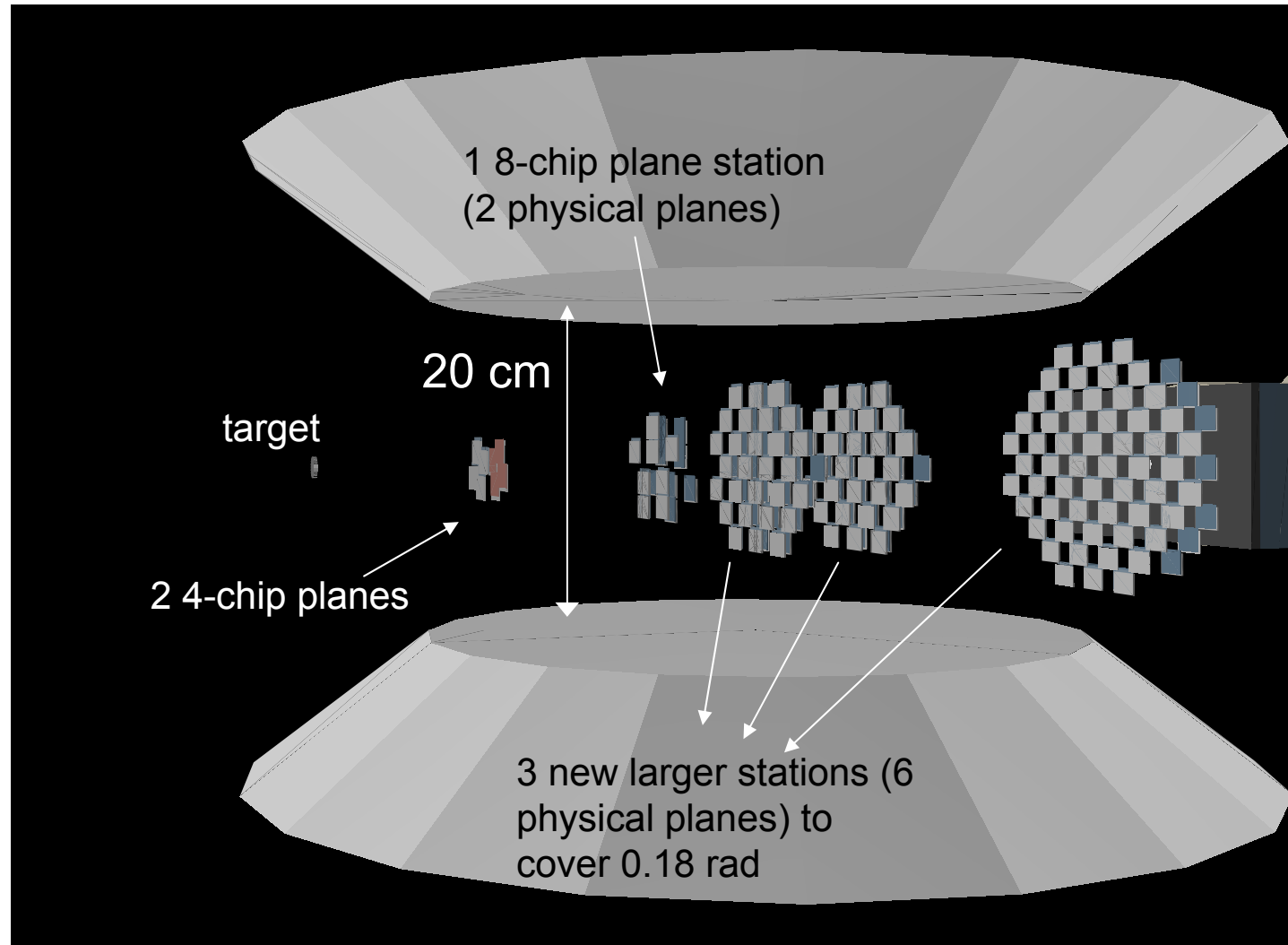


The old pixel telescope does not provide sufficient coverage

# A new pixel telescope setup – first ideas

PT7-like larger dipole magnet: 2.5 T – ~20 cm gap

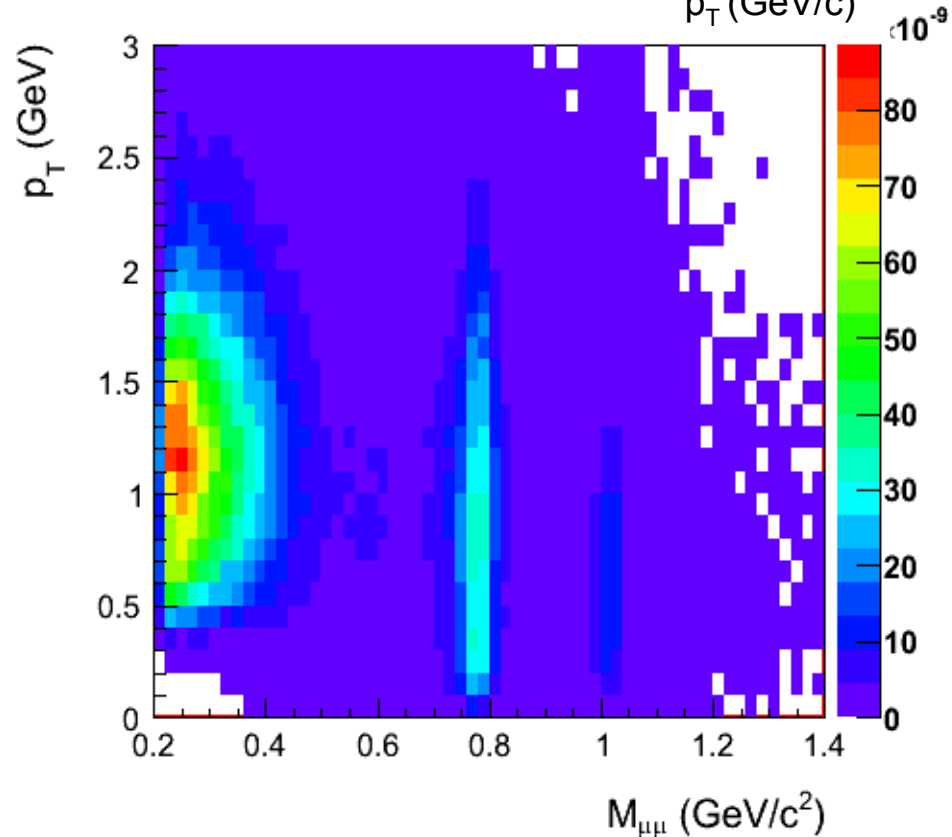
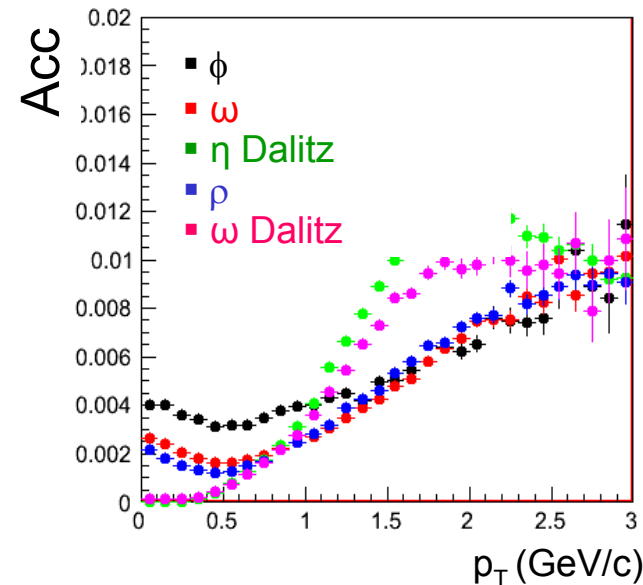
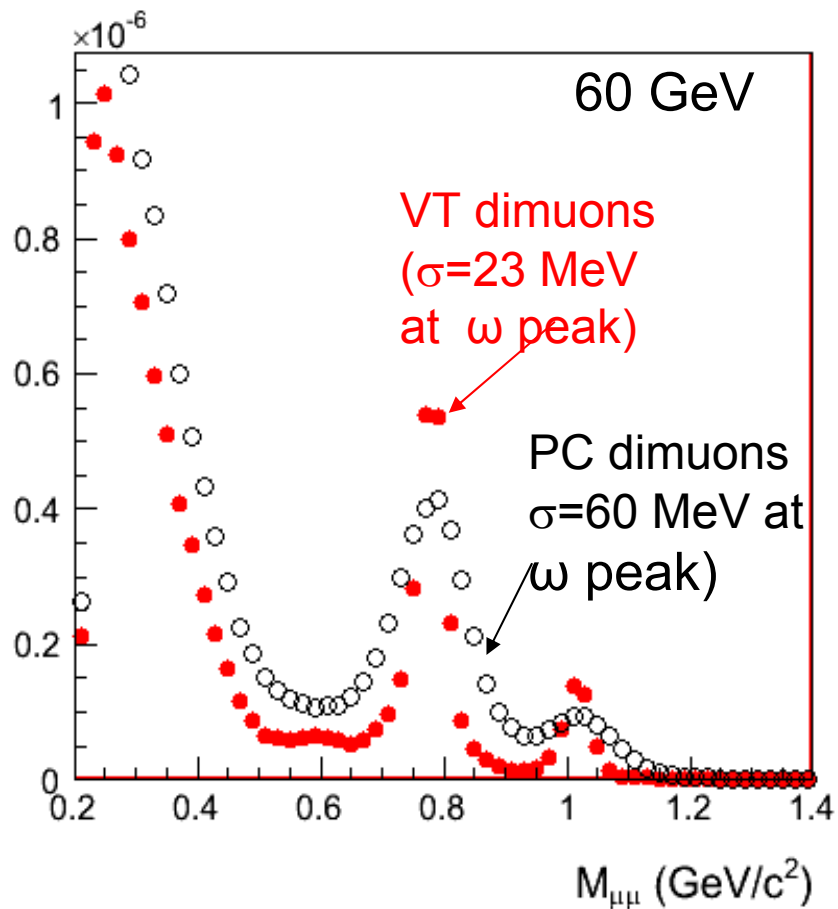
y covering requires 240 ALICE chips (~ 3 times more than previous telescope)



# Dimuon reconstruction

Hadron cocktail generated and propagated through new muon spectrometer and new pixel telescope

Dimuon Matching rate  $\sim 70\%$



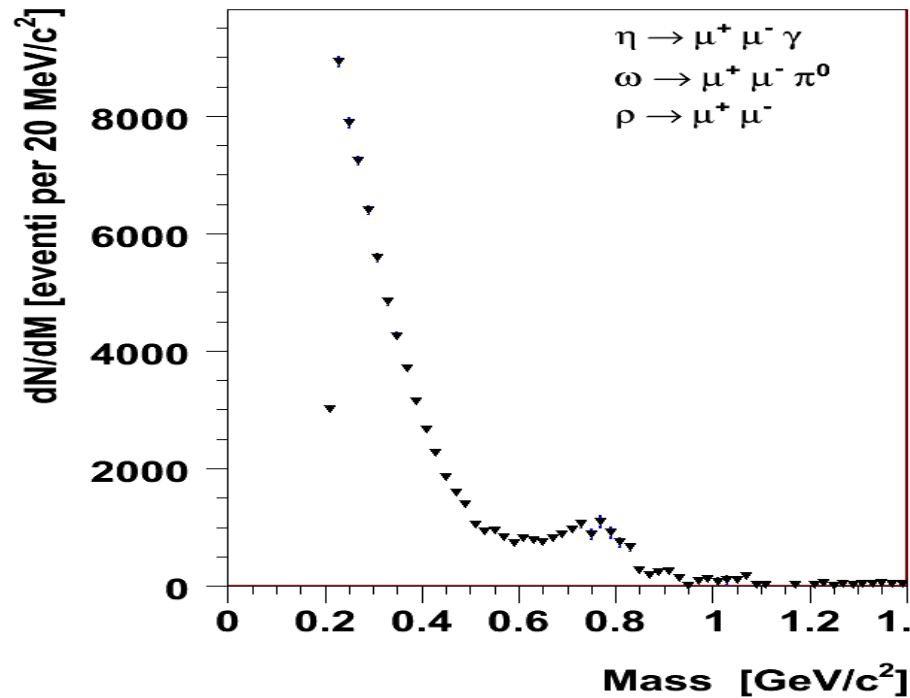
# Future plans

- Heavy ion beams should be available at the SPS again from 2011
- **Feasibility of new measurements** being studied
  - See G. Usai, presentation at “New Opportunities in the Physics Landscape at CERN” workshop, May 2009
- Discussions with accelerator people on experiment location have started
- Contacts with theorists for the preparation of a **letter of intent**

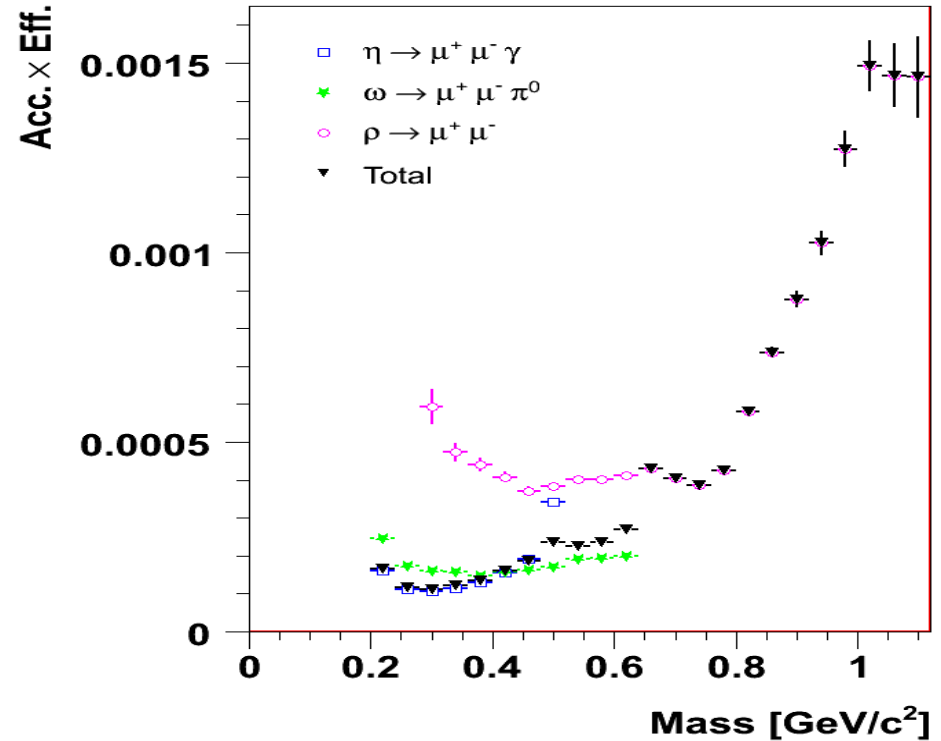
# Backup

# Isolation of Dalitz decays: acceptance correction

Isolation of Dalitz and  $\rho$  decays



Acceptance correction





# Running conditions

## Energy scan

tentatively: ~ 40-60-80-120-160 AGeV

## Ion beams

Maximization in-medium effects better with small surface-to-volume ratio ions, i.e. Pb or Au

→ suppression of freeze-out  $\rho$  (also lower energy helpful to reduce open charm, Drell-Yan and freeze-out  $\rho$ ) maximizes possible J/  $\psi$  suppression

Complete systematics: running with intermediate A nucleus as indium

→ i.e. important for understanding scaling variable behind J/ $\psi$  suppression

## Proton beams

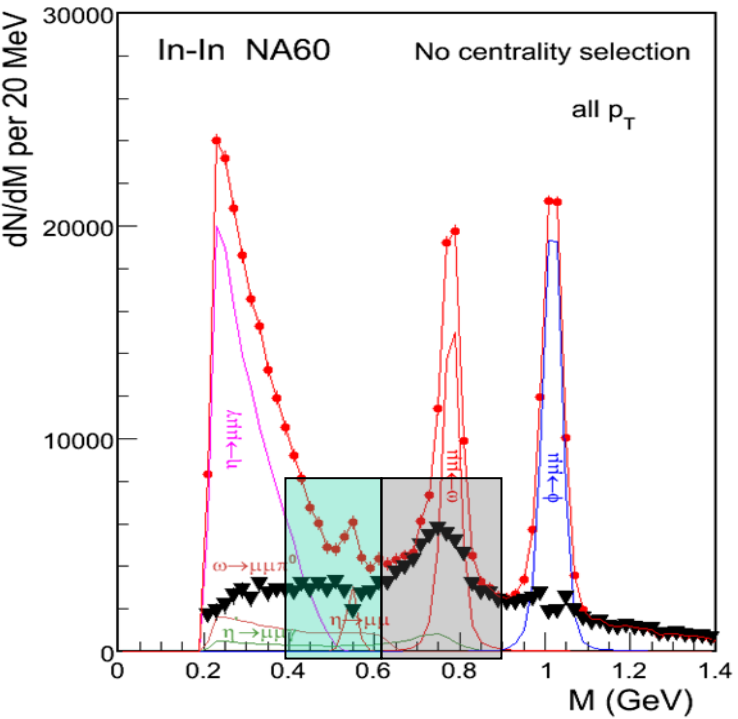
Needed for reference measurements (charm study for instance)

## Beam intensities

**ions:**  $10^7$ - $10^8$ /s on a 15-20%  $\lambda_1$  nuclear target

**protons:**  $10^9$ - $10^{10}$ /s on a 15-20%  $\lambda_1$  nuclear target

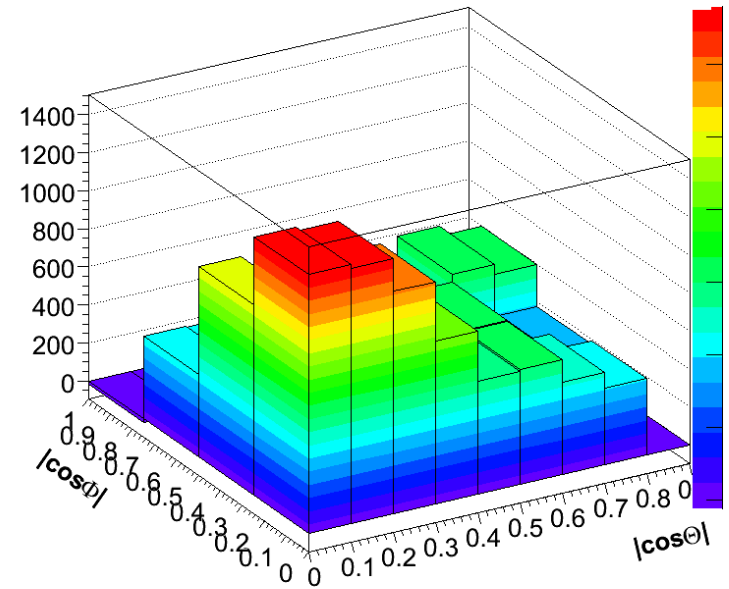
# Angular distributions in the low mass region



Results on centrality integrated data with  $p_T > 0.6$  GeV for:

- Excess dileptons in 2 mass windows:
  - 0.4 < M < 0.6 GeV (~17600  $\mu\mu$  pairs)
  - 0.6 < M < 0.9 GeV (~36000  $\mu\mu$  pairs)
- Vector mesons  $\omega$  and  $\phi$  (~73000  $\mu\mu$  pairs)

raw data 0.4 < M < 0.6 GeV



Analysis done in  $\cos\theta - \phi$  space with different binnings in  $[dN/d\cos\theta d\phi]_{m \times n}$  to study the systematics

- Steps followed for each of the  $[m \times n]$  bins:
- 1) Combinatorial background subtraction
  - 2) Assessment of fake matches
  - 3) Isolation of excess by subtraction of the known sources
  - 4) Acceptance correction in 2-dim  $\cos\theta - \phi$  space or in 1-dim