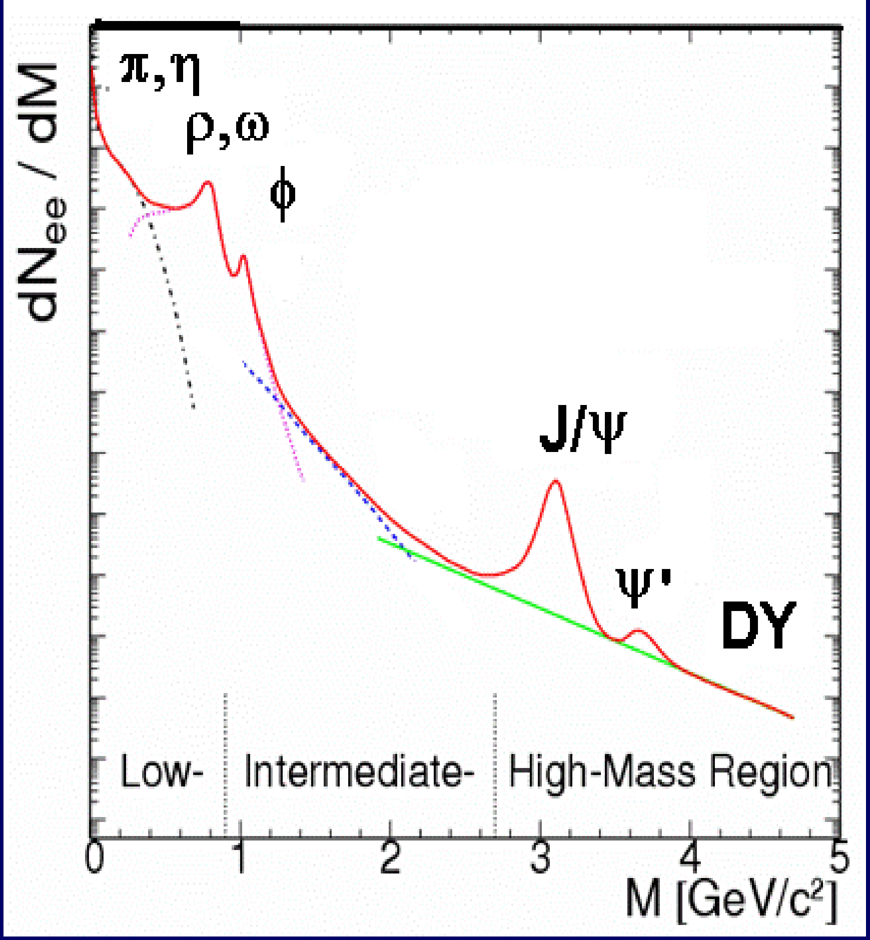
NA60 results on thermal dimuons

Sanja Damjanovic
NA60 Collaboration

Erice, 16-24 September

Thermal dileptons in high energy nuclear collisions



Production sources

LMR: M<1 GeV

hadronic: $\pi\pi \rightarrow \rho^* \rightarrow \ell\ell$

prime probe of chiral symmetry restoration

(*R. Pisarski, PLB '82*)

IMR: M>1 GeV

hadronic: ???

partonic: $qq \rightarrow \ell\ell$

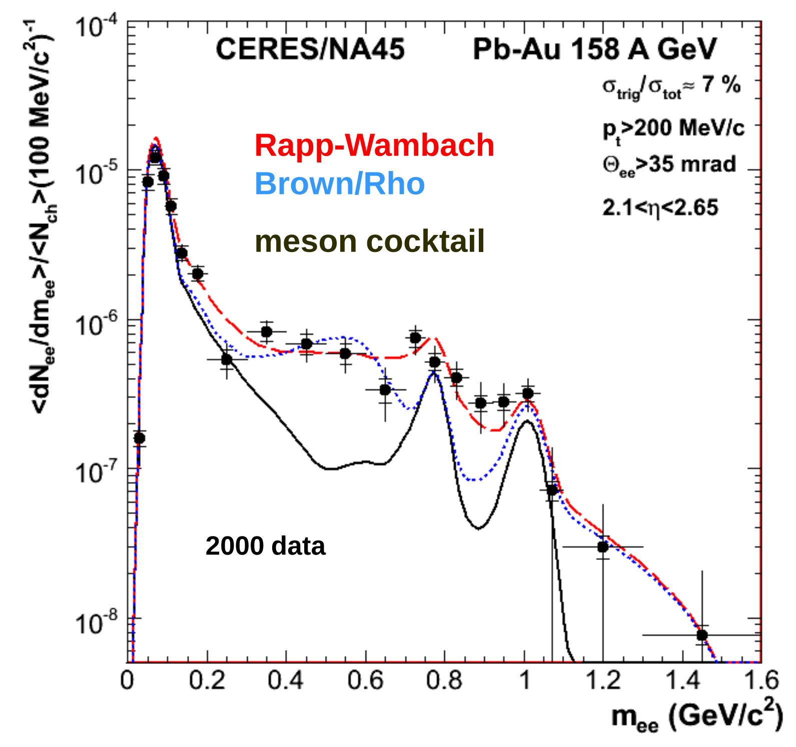
original expectation :

prime probe of deconfinement

(Kajantie, McLerran, al. '82 ff)

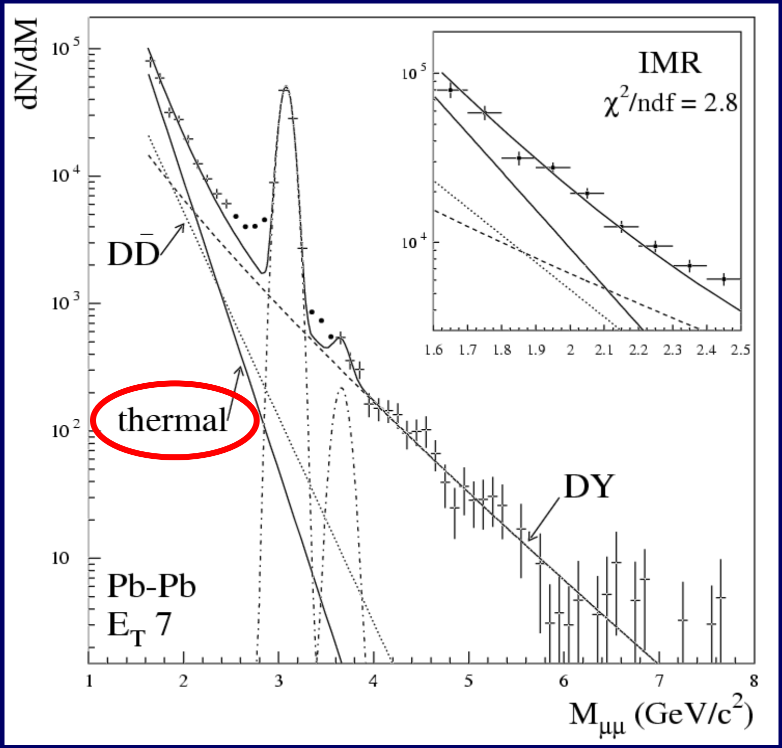
Previous SPS results on excess dileptons

LMR: mostly NA45/CERES



statistical accuracy and resolution insufficient to unambiguously determine the in-medium spectral properties of the ρ

IMR: NA34, NA38, NA50

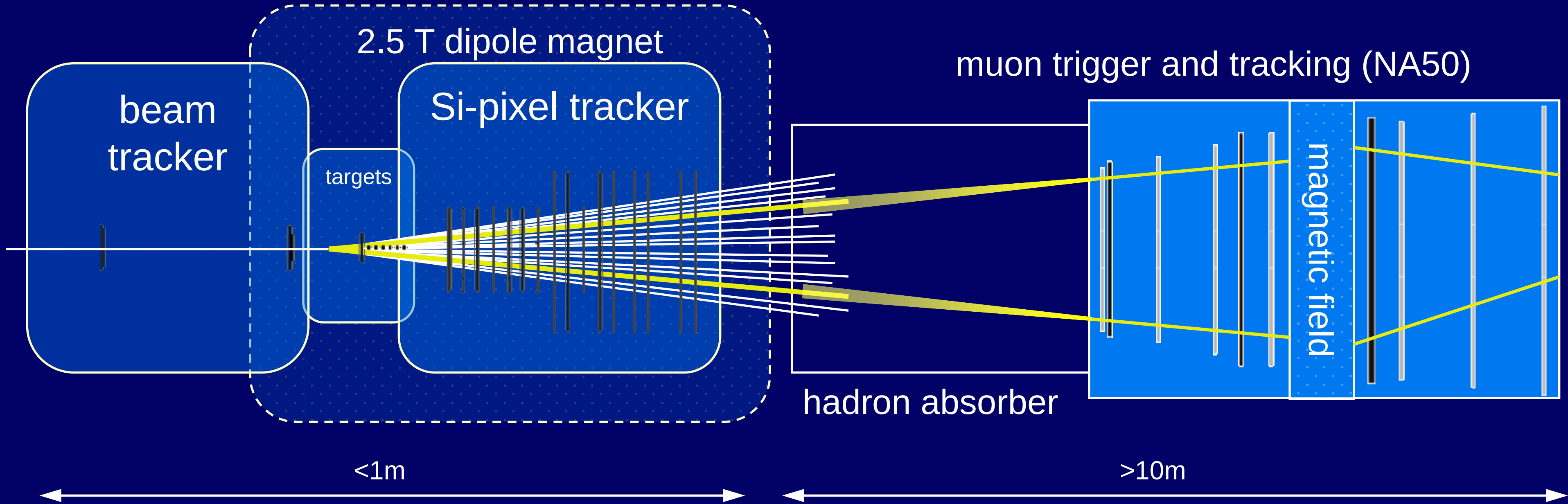


no experimental capability to distinguish a prompt thermal dileptons from decay dileptons due to open charm

A third generation experiment:

NA60

Measuring dimuons in NA60: concept



Track matching in coordinate <u>and</u> momentum space

Improved dimuon mass resolution

Distinguish prompt from decay dimuons

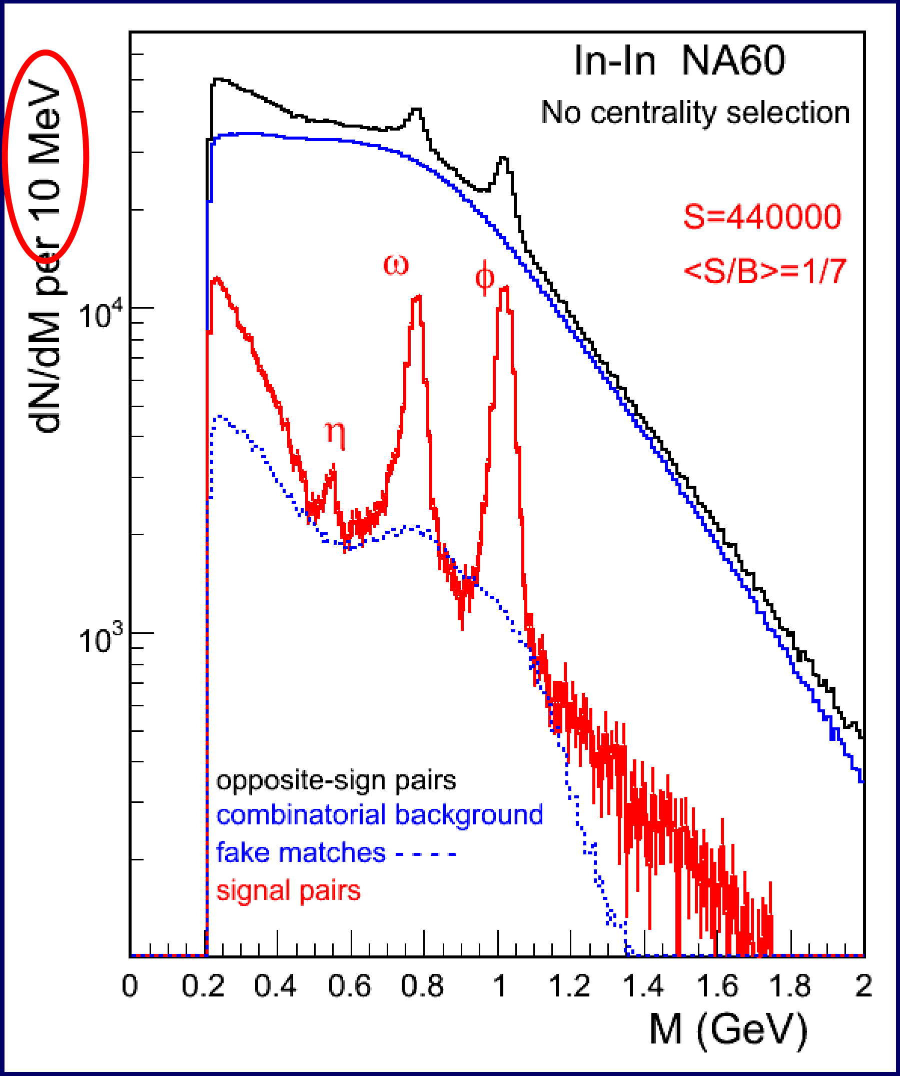
Additional bend by the dipole field

Dimuon coverage extended to low p_T

Radiation-hard silicon pixel detectors (LHC development)

High luminosity of dimuon experiments maintained

Low-mass data sample for 158 AGeV In-In



subtraction of

- combinatorial background
- fake matches between the two spectrometers

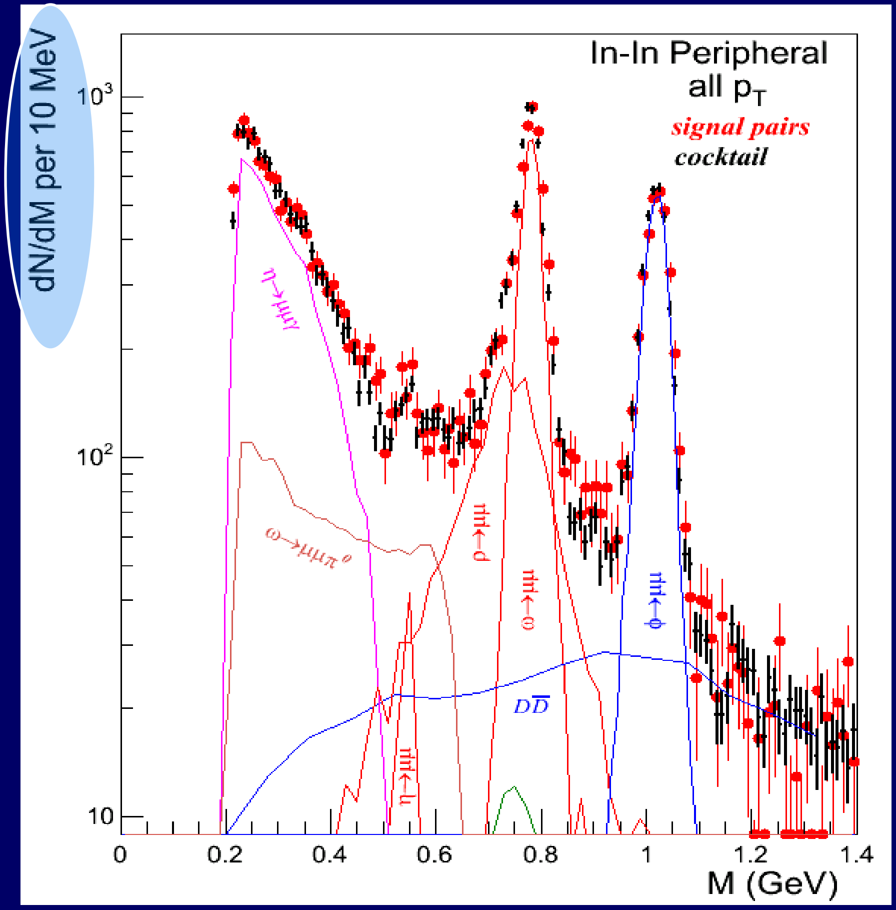
↓

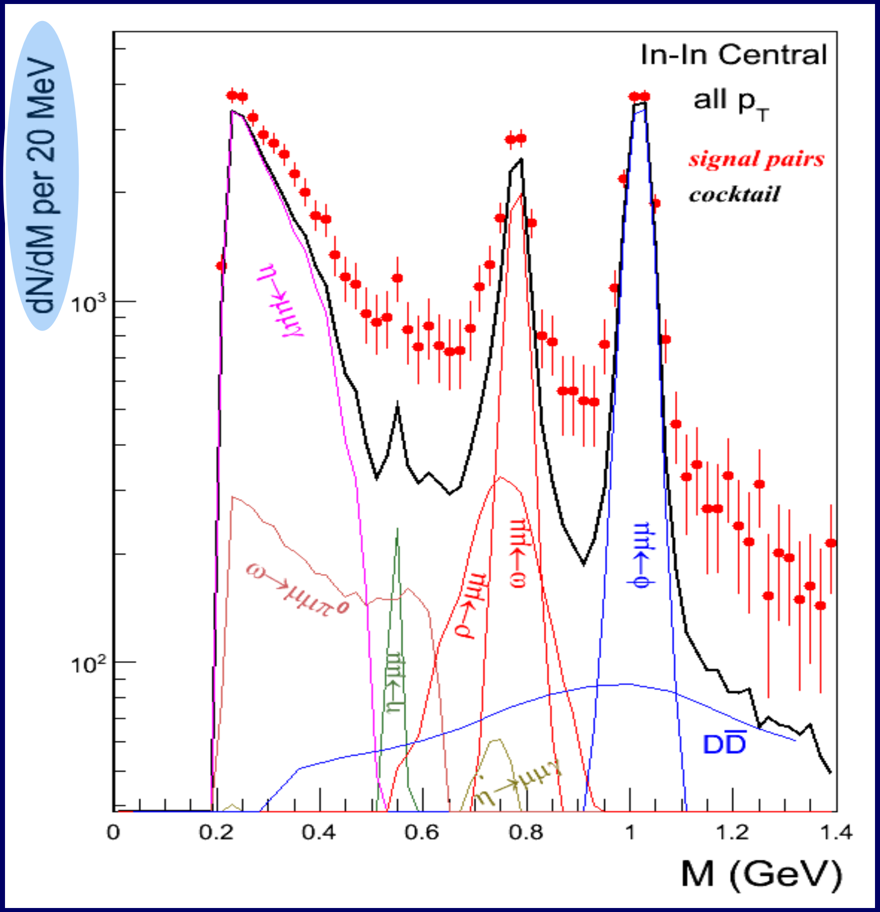
net sample:
440 000 events

for the first time, η, ω, ϕ clearly visible in dilepton channel in AA

mass resolution:
20 MeV at the ω position

Comparison of known hadron decays to the data



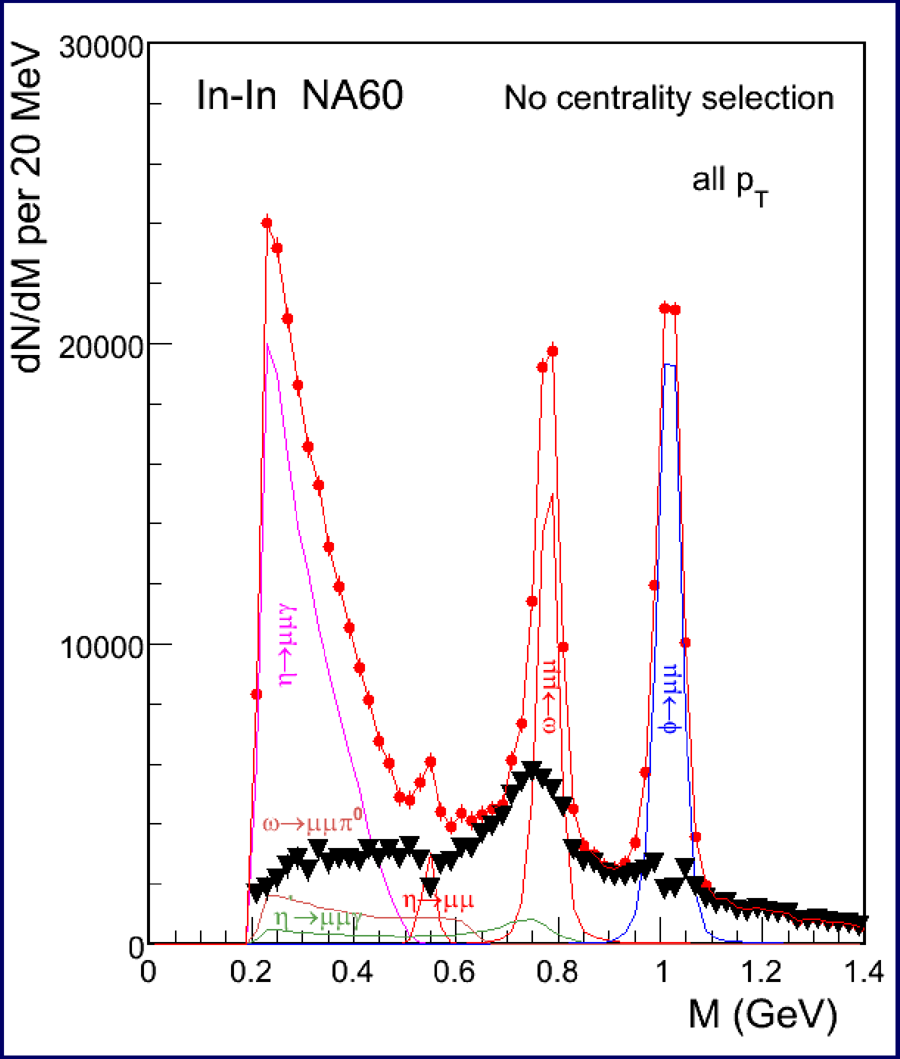


<u>Peripheral data</u>
well described by meson decay 'cocktail' (η, η', ρ, ω, ϕ) and DD

<u>More central data</u>
Clear excess of data above decay 'cocktail'. But, what is the spectral shape of the excess?

Excess dimuons

Phys. Rev. Lett. 96 (2006) 162302



isolation of excess by subtraction of measured decay cocktail (without ρ), based solely on local criteria for the major sources η, ω and φ

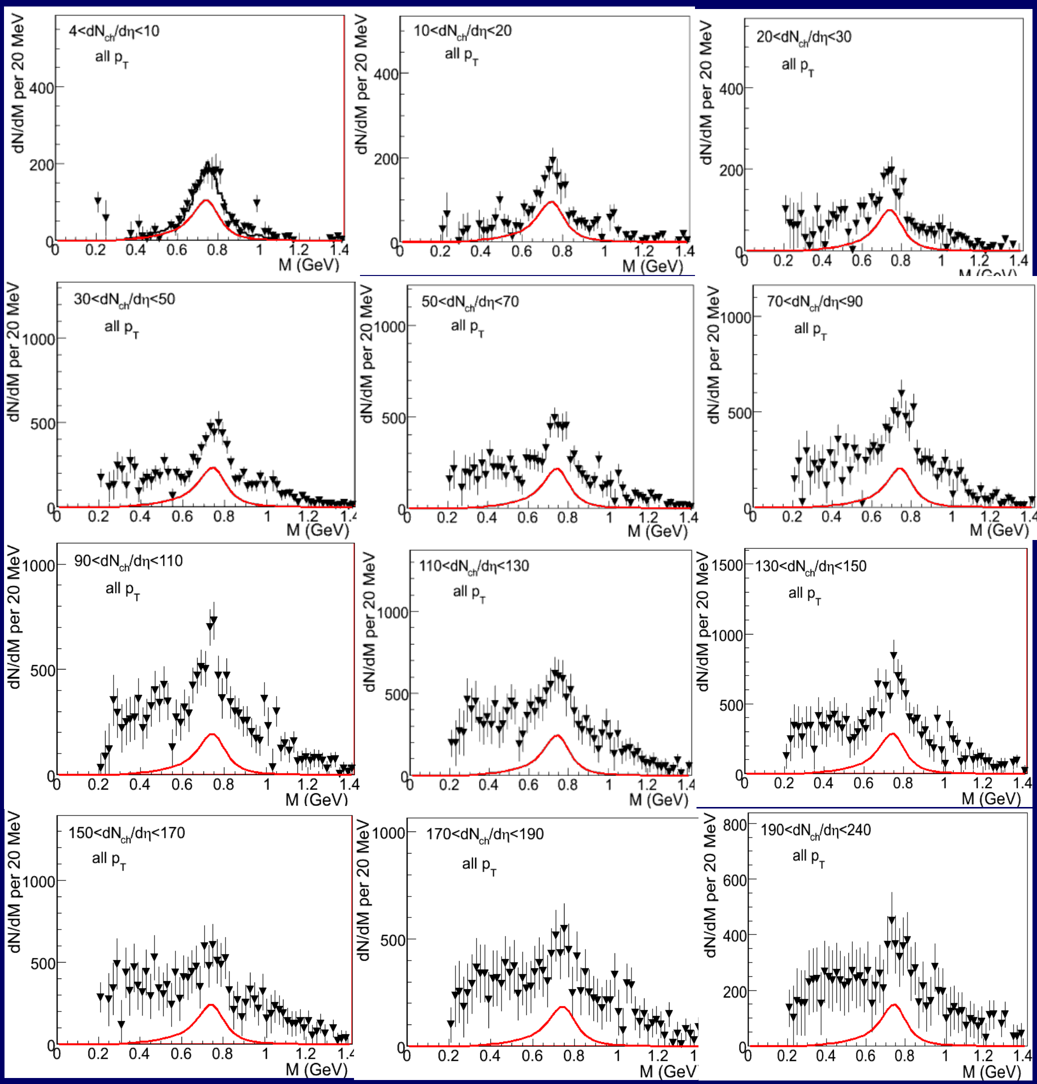
ω and φ : fix yields such as to get, after subtraction, a smooth underlying continuum

η : fix yield at p_T >1 GeV profiting from the very high sensitivity of the spectral shape of the Dalitz decay to any underlying admixture from other sources; lower limit from peripheral data

accuracy 2-3%, but results robust to mistakes even at the 10% level

Excess mass spectra in 12 centrality windows

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



all p_T

no cocktail ρ subtracted
DD subtracted

clear excess above the cocktail ρ (bound to the ω with ρ/ω=1.0)

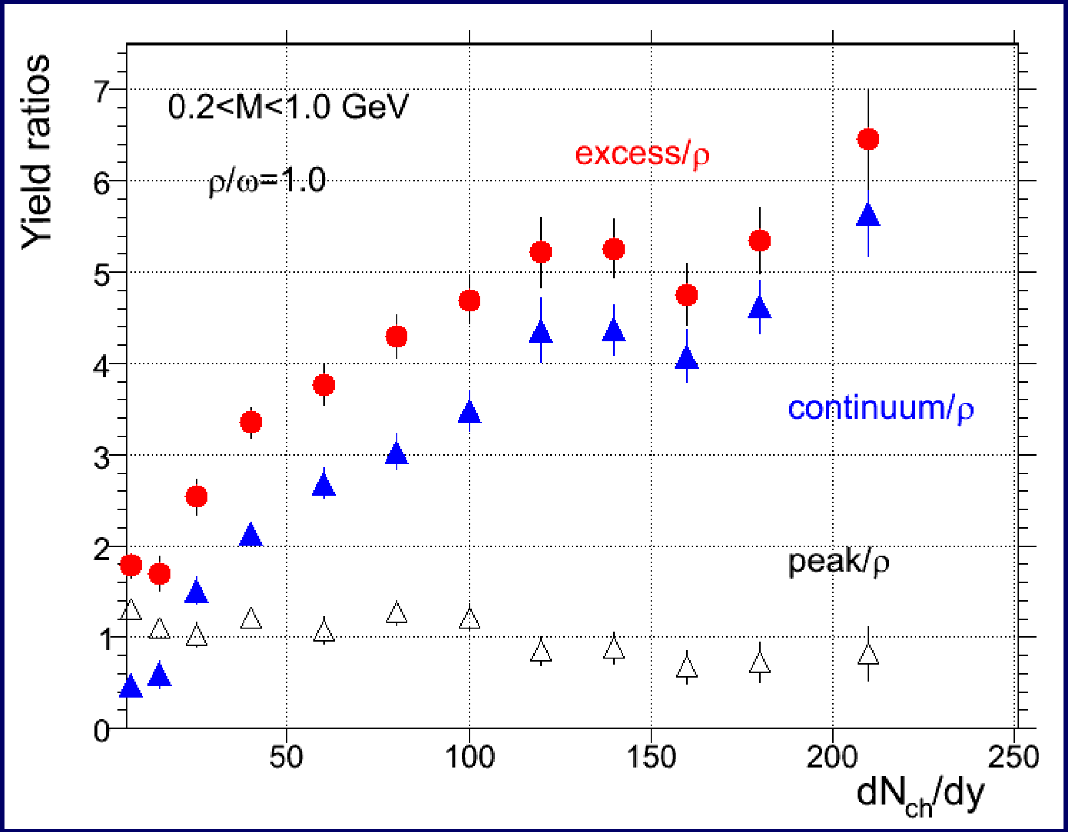
excess centered at the nominal ρ pole rising with centrality

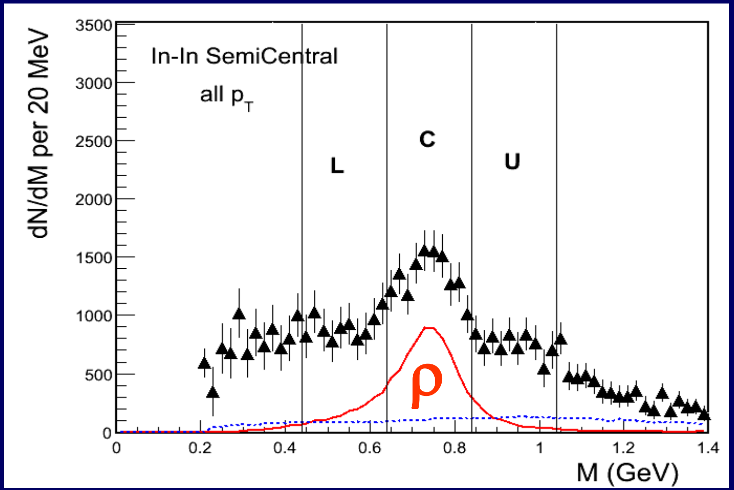
monotonic broadening with centrality

↓

"melting" of the ρ

Centrality dependence of excess yields





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

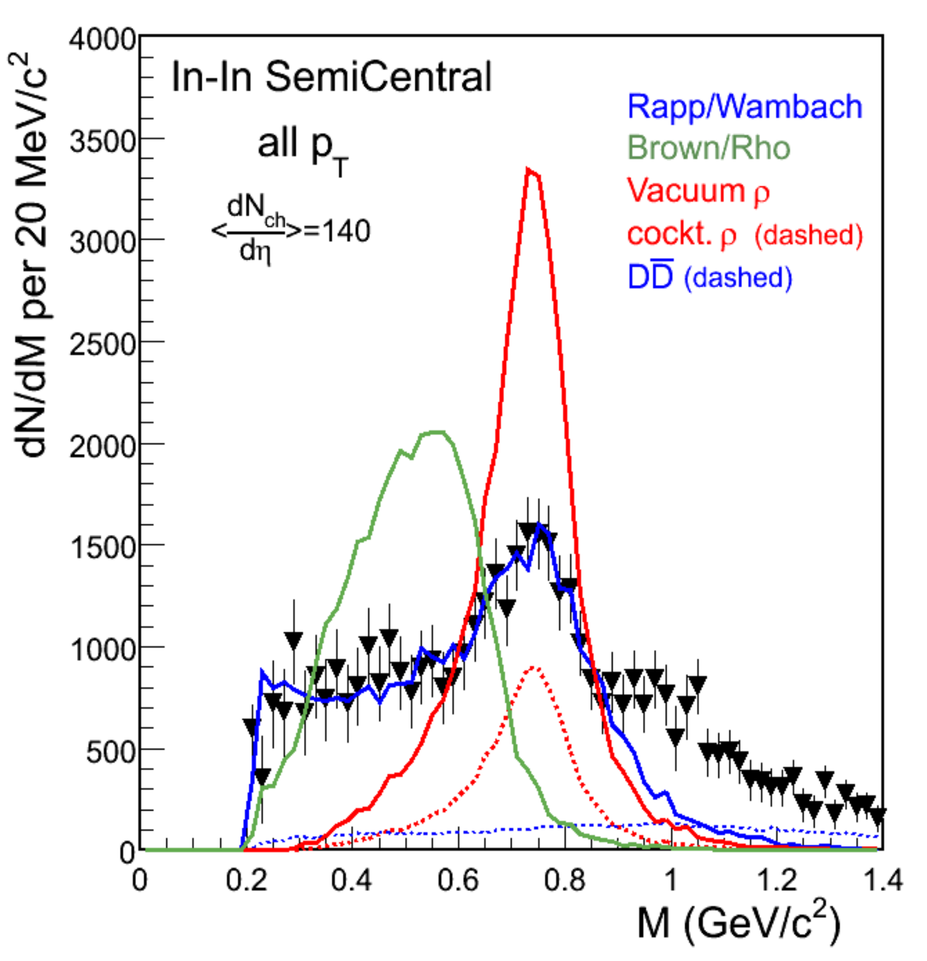
normalization to cocktail ρ, bound to ω with ρ/ω=1.0

-strong increase of continuum (by a factor of >10)
- decrease of ρ peak (nearly a factor of 2)

- total reflects the number of ρ's regenerated in $\pi\pi \rightarrow \rho^* \rightarrow \mu\mu$ ('ρ clock')

Comparison of data to RW, BR and Vacuum ρ

Phys. Rev. Lett. 96 (2006) 162302



Predictions by Rapp (2003) for all scenarios

Theoretical yields normalized to data for M<0.9 GeV

Data and predictions as shown, after acceptance filtering, roughly mirror the ρ spectral function, averaged over space-time and momenta.
(Eur.Phys.J.C 49 (2007) 235)

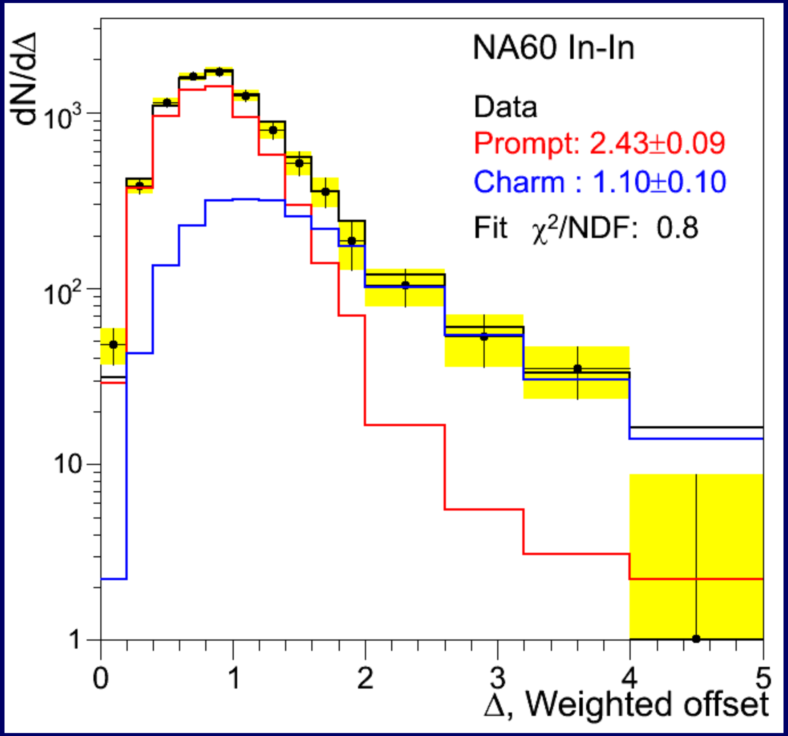
Only broadening of ρ (RW) observed, no mass shift (BR)

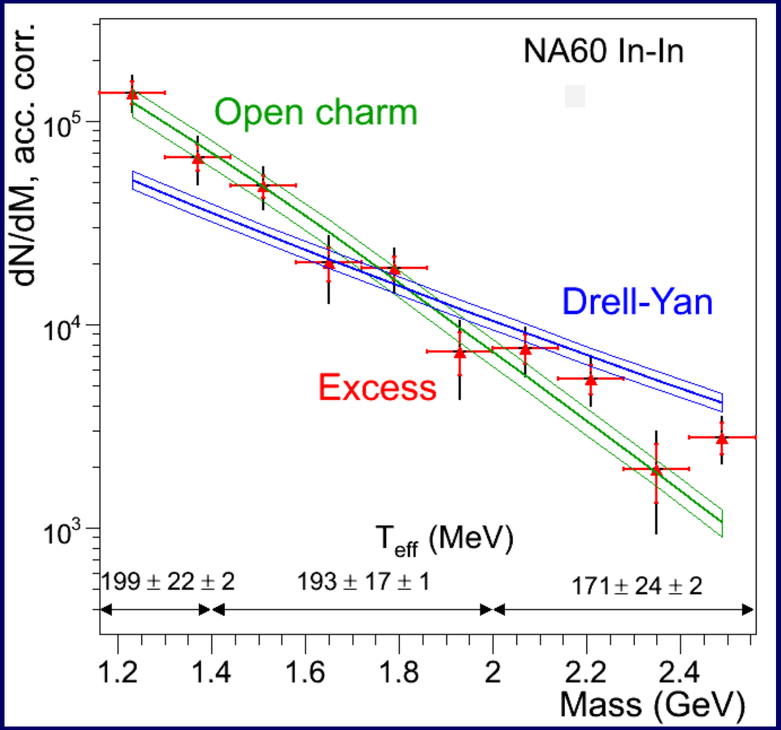
Extension to intermediate mass region

subm. to Eur.Phys.J. C (2008)

measurement of muon offsets $\Delta\mu$: distance between interaction vertex and track impact point

isolation of excess by subtraction of measured open charm and Drell-Yan



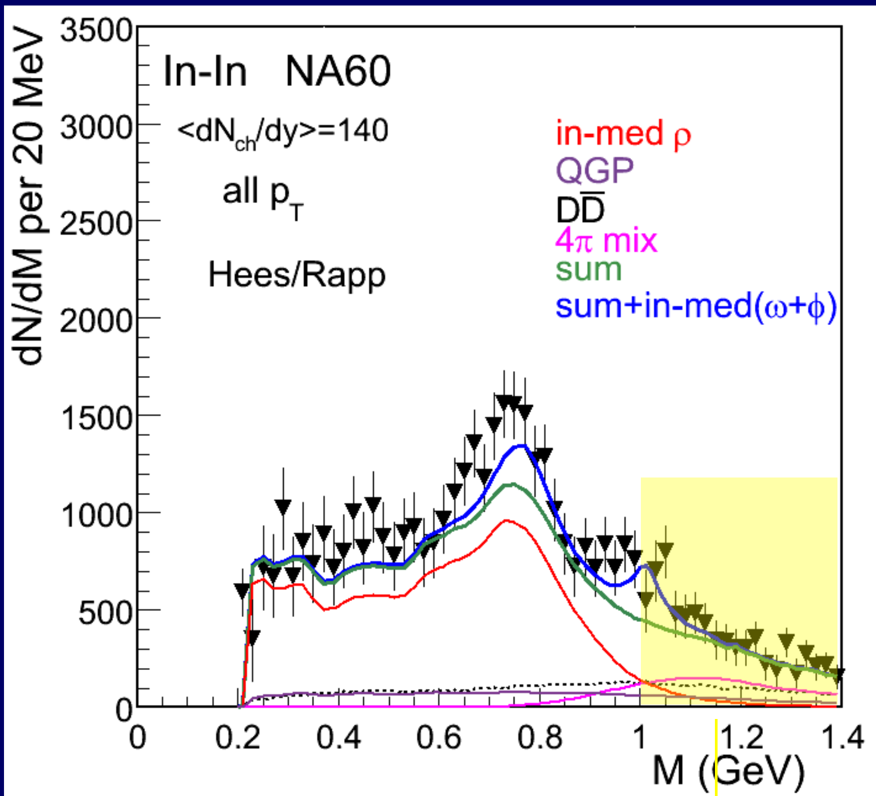


charm not enhanced;
excess prompt; 2.4 × DY

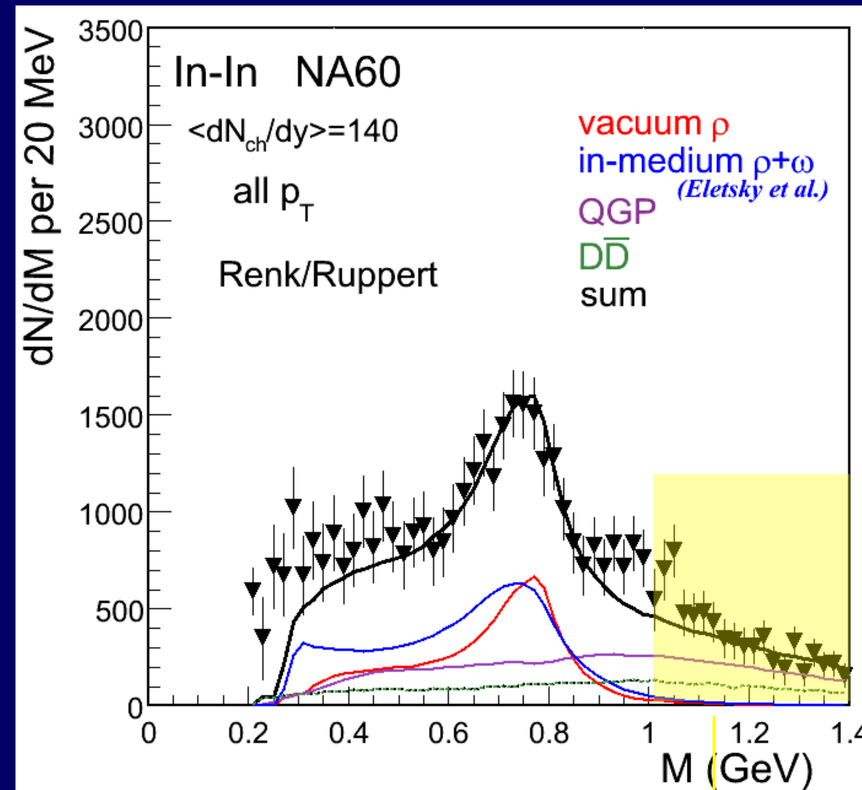
excess similar to open charm
steeper than Drell-Yan

Hadron-Parton 'Duality' for M >1 GeV

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



Renk/Ruppert, Phys.Rev.Lett.(2008)



Mass region above 1 GeV described in terms of hadronic processes, 4π …

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

How to distinguish?

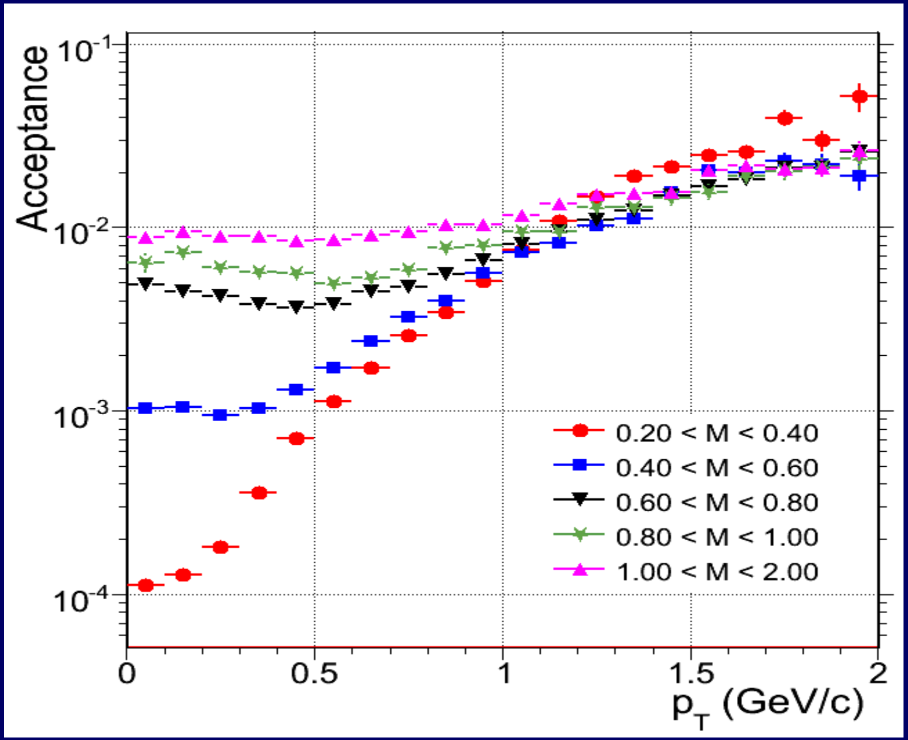
Transverse momentum spectra

Strategy of acceptance correction

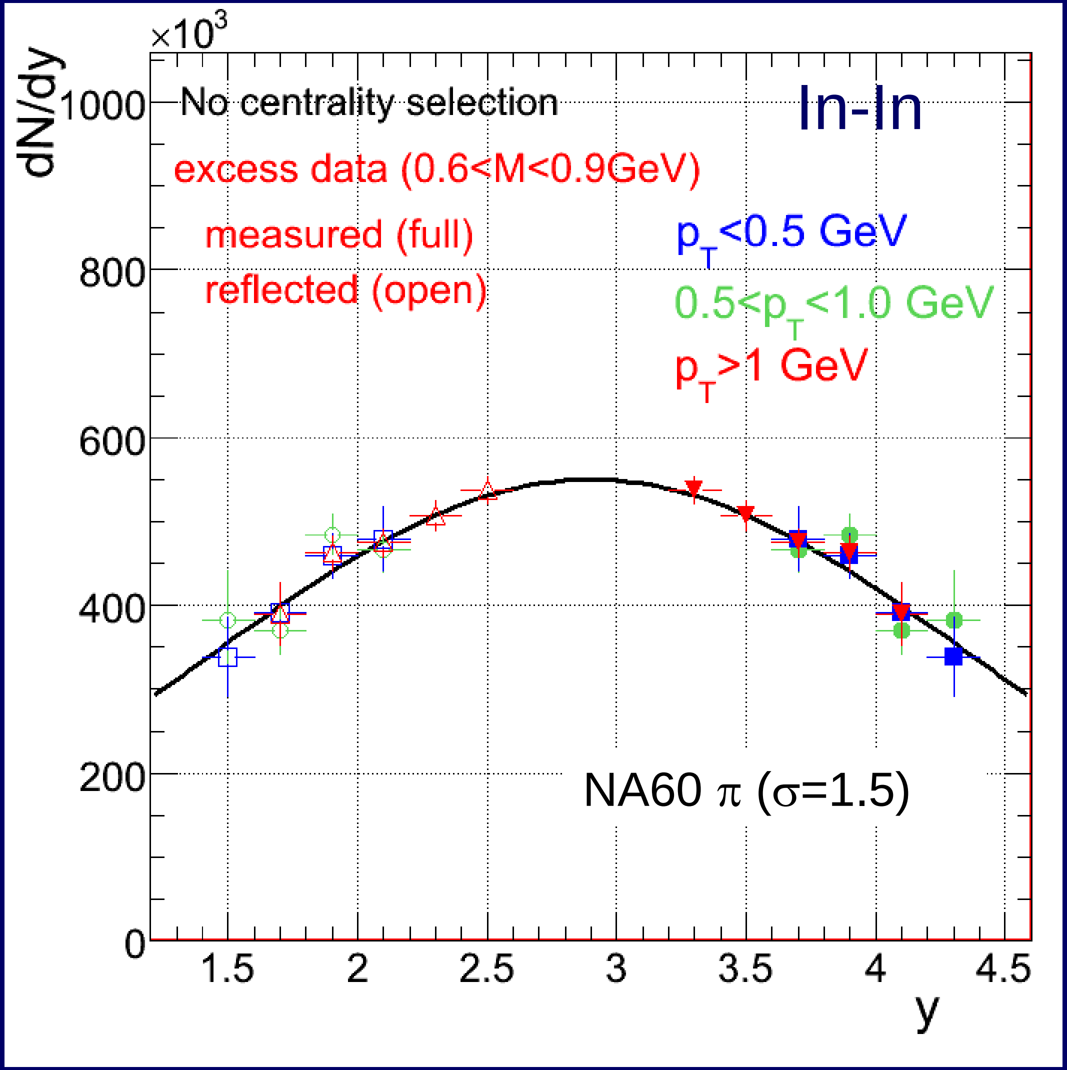
- reduce 4-dimensional acceptance correction in M-p_T-y-cosΘ_{CS} to 2-dimensional correction in M-p_T, using measured y distributions and measured cosΘ_{CS} distributions as an input

- requires separate treatment of the excess and the other sources, due to differences in the y and the cosΘ_{CS} distributions

acceptance vs. M, p_T, y, and cosΘ understood to within <10%, based on a detailed study of the peripheral data



Experimental results on the y distribution of the excess



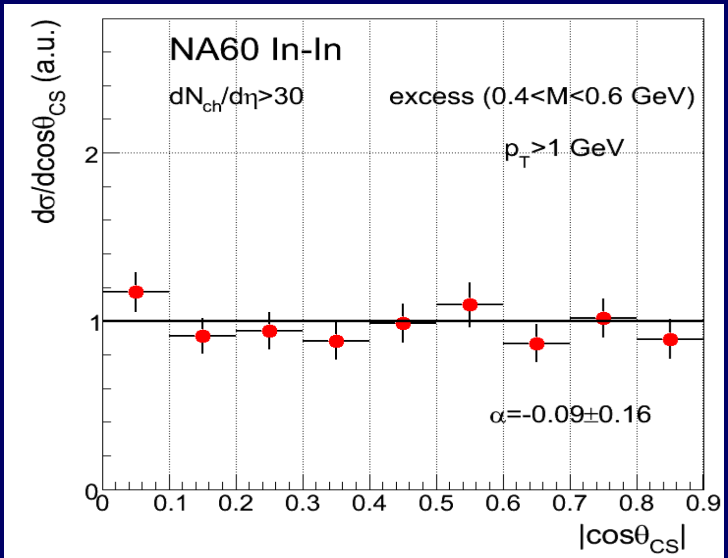
use measured mass and p_T spectrum as input to the acceptance correction in y (iteration procedure)

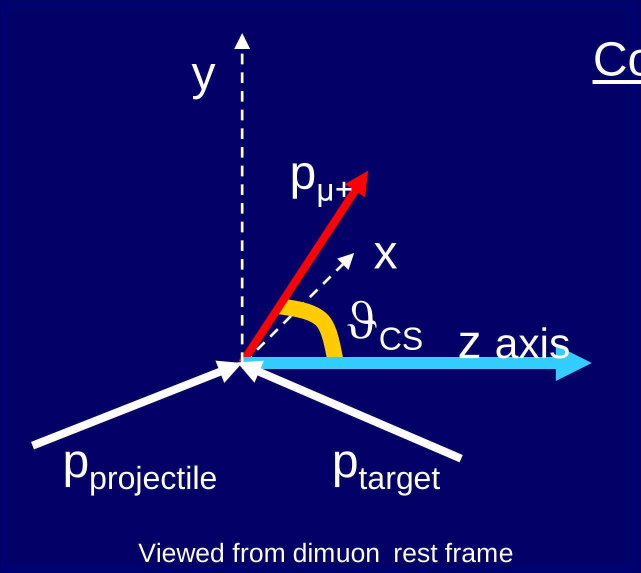
results close to rapidity distribution of pions, independent of p_T

↓

average rapidity density in NA60 acceptance smaller by only ~15% than at mid-rapidity

Experimental results on $\cos\Theta_{CS}$ distributions: excess

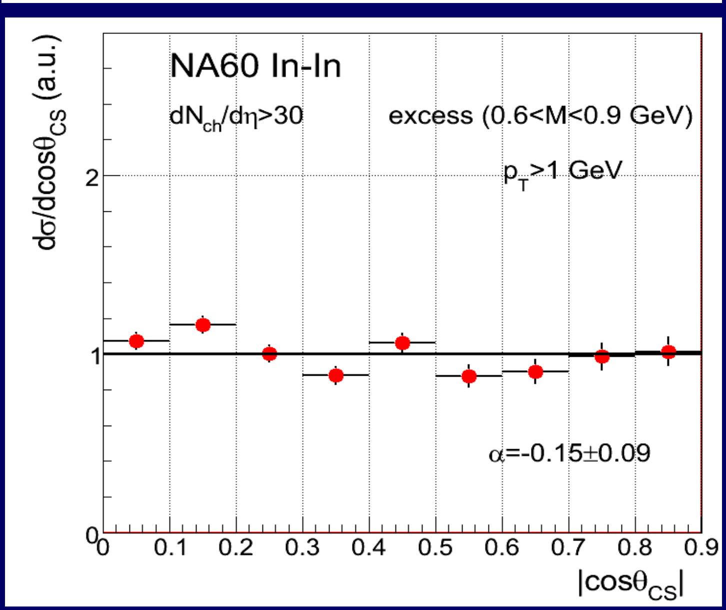




<u>Collins Soper frame</u>

integration over azimuth angle

$$\frac{d\sigma}{d\cos\theta} = 1 + \alpha\cos^2\theta$$



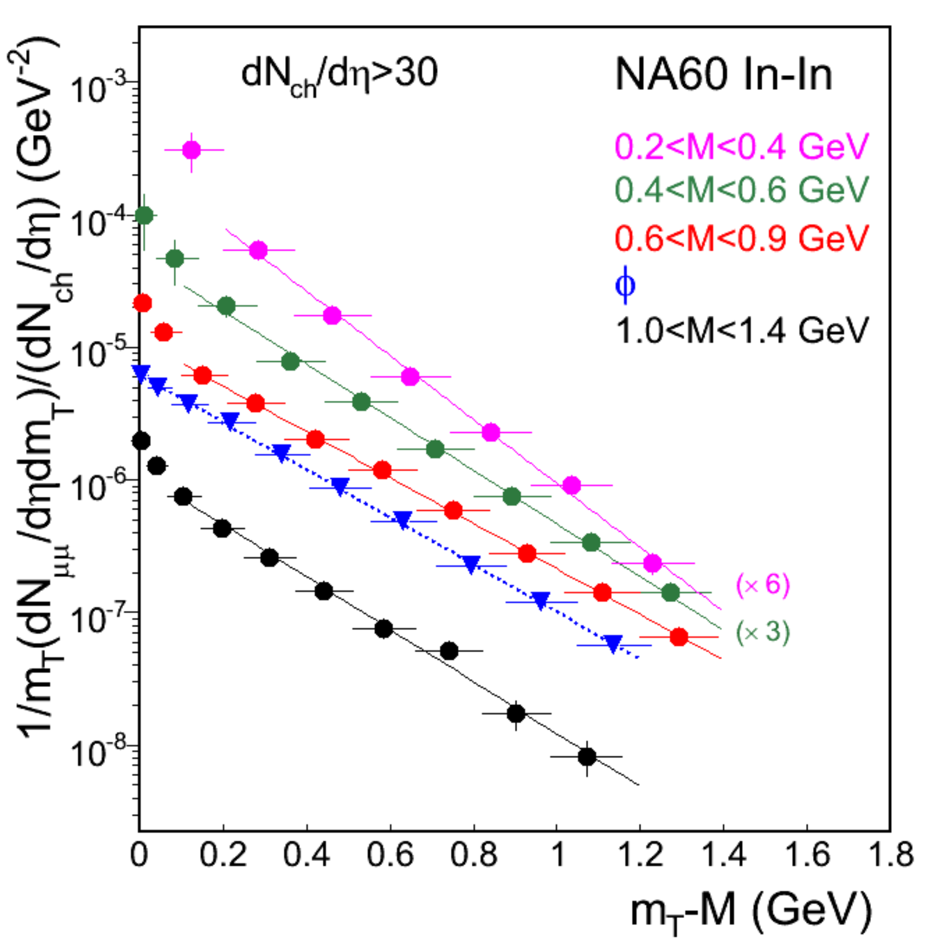
For the first time, the polarization of thermal radiation is measured and found to be zero (different from DY), as anticipated since decades.

Polarization also found to be zero for the ω and ϕ

errors purely statistical

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 ϕ)

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?

What can we learn from p_T spectra?

Radial Flow

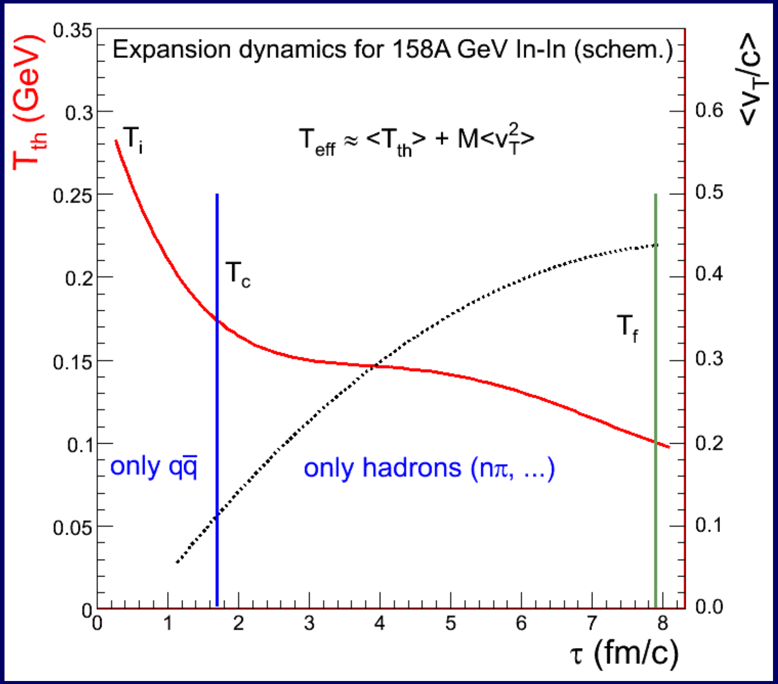
Origin of dileptons

Dilepton transverse momentum spectra

three contributions to p_T spectra

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)

note: final-state lepton pairs themselves only weakly coupled



hadron p_T spectra:
determined at T_f (restricted information)

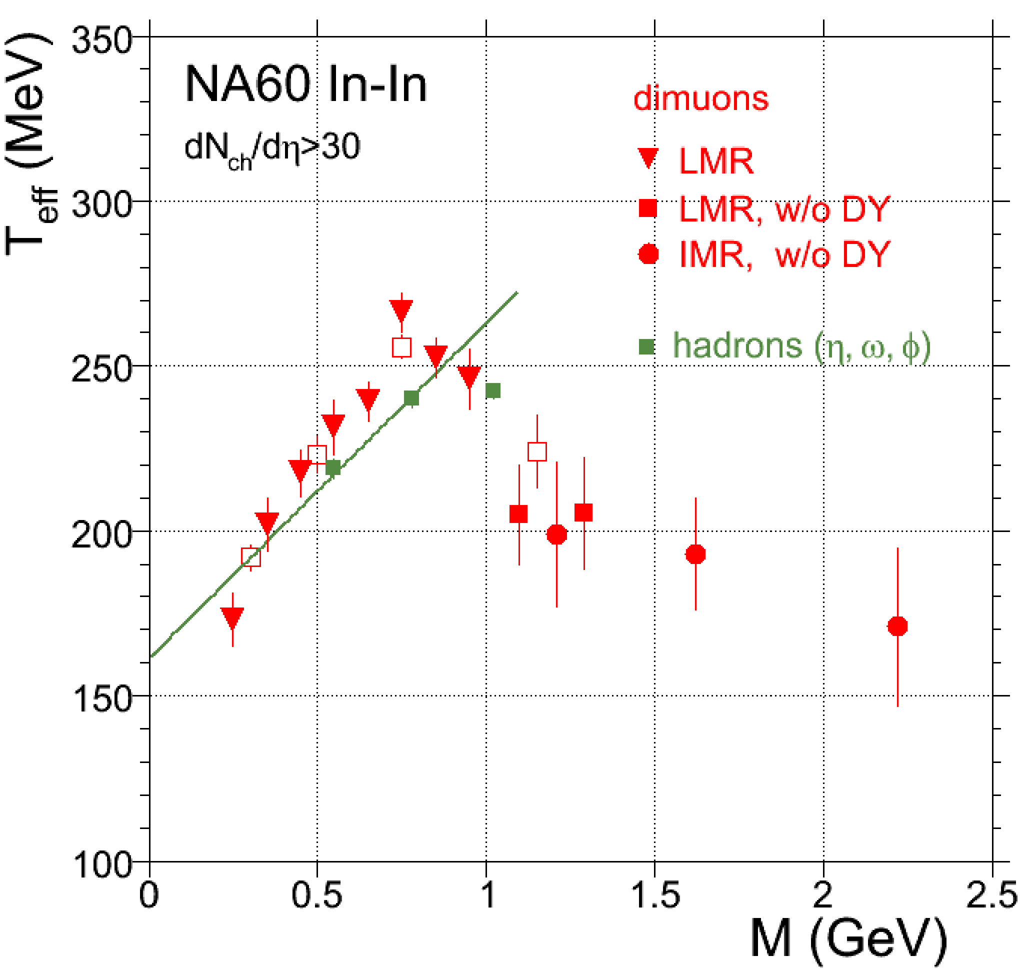
dilepton p_T spectra:
superposition from all fireball stages

early emission: high T, low v_T
late emission: low T, high v_T

final spectra from space-time folding
over T-v_T history from $T_i \rightarrow T_f$
(including low-flow partonic phase)

→ handle on emission region, i.e. nature of emitting source

Evolution of inverse slope parameter T_{eff} with mass



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

Rise reminiscent of radial flow of a hadronic source

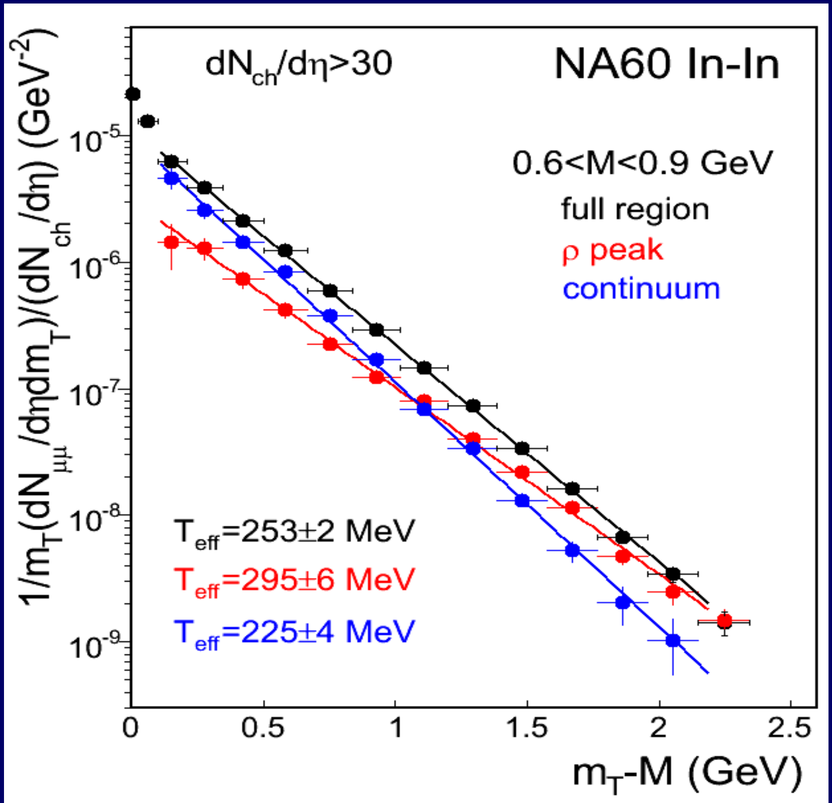
But:
thermal dimuons emitted continuously during fireball expansion (reduced flow), while hadrons are emitted at final freeze-out (maximal flow); how can T_{eff} be similar?

Systematic errors studied in great detailed (CB, cocktail subtraction, acceptance, y and $\cos\vartheta_{CS}$ distributions, subtraction of DY and open charm → on level <= statistical errors.

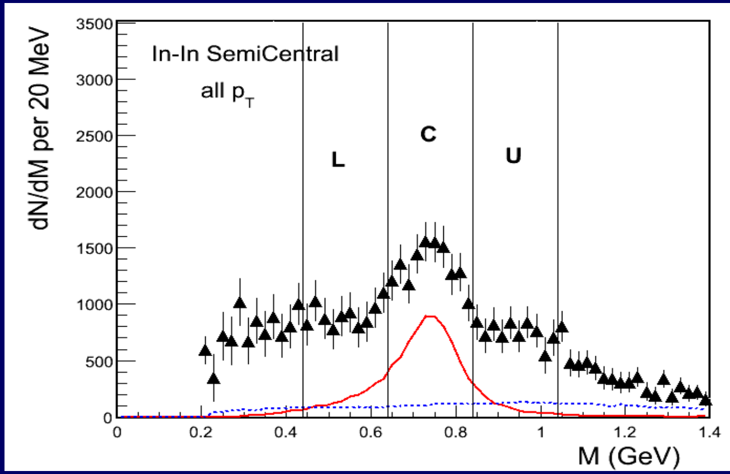
Disentangling the m_T spectra of the ρ peak and the continuum

Shape analysis and p_T spectra

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



use side-window subtraction method



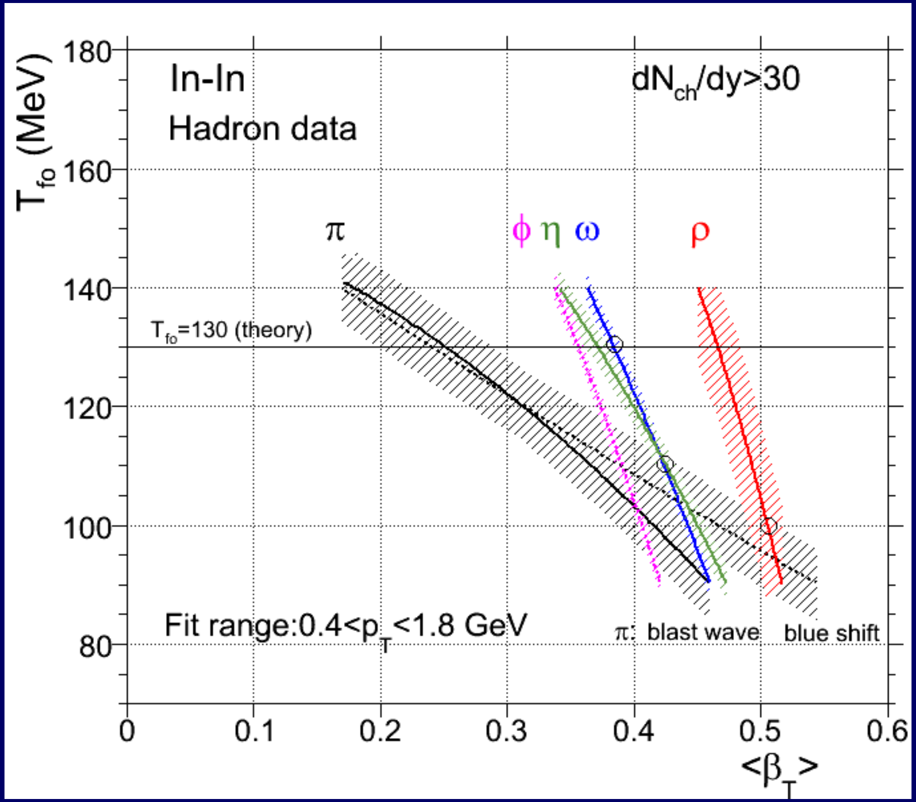
peak: C-1/2(L+U)
continuum: 3/2(L+U)

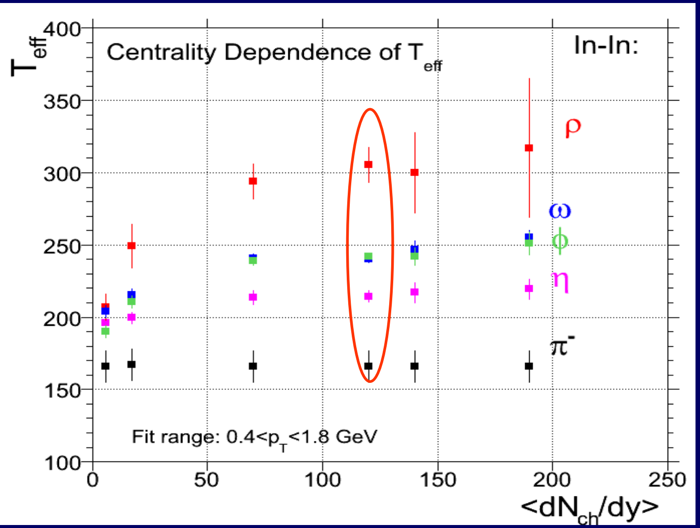
m_T spectra very different for the ρ peak and continuum:

T_{eff} of peak higher by 70+-7 MeV than that of the continuum !

all spectra pure exponential, no evidence for hard contributions

Hierarchy in hadron freeze-out





large difference between ρ and ω (same mass)

← use of Blast wave code

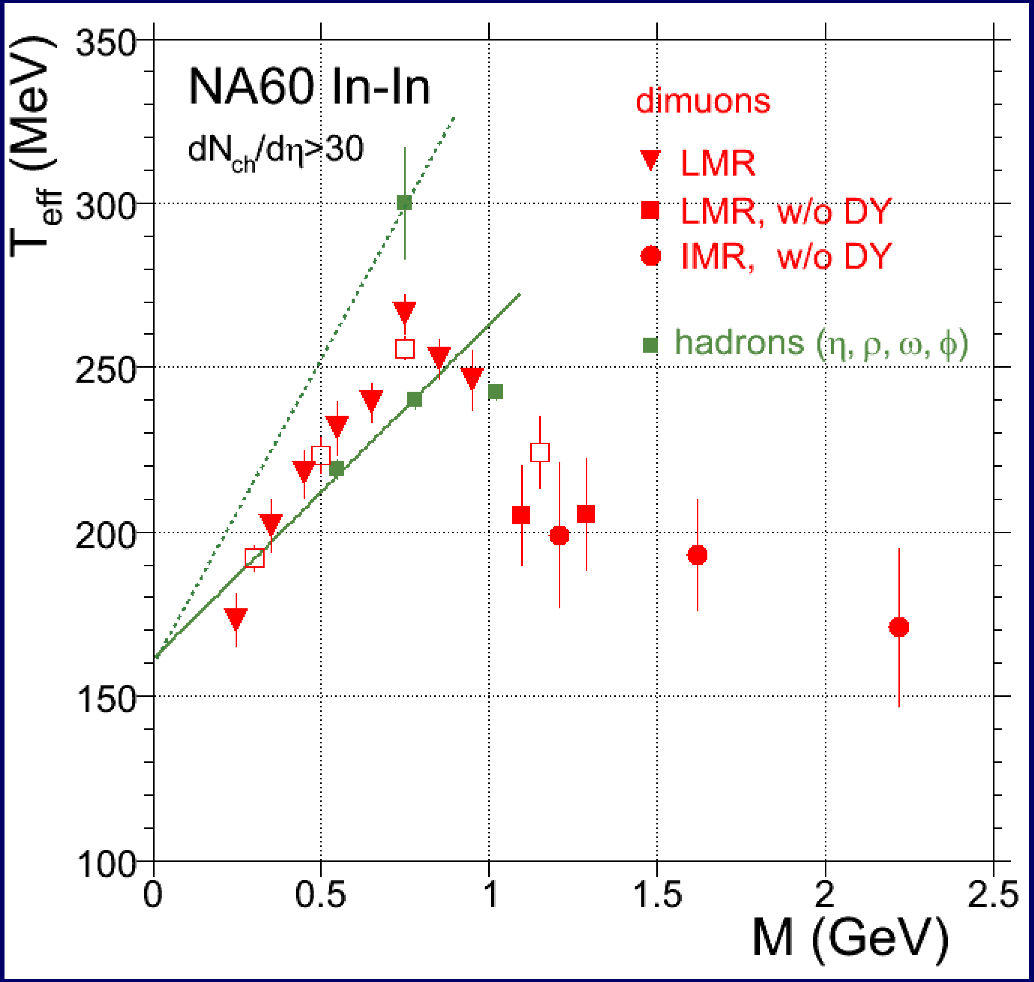
for a given hadron M, the measured T_{eff} defines a line in the T_{fo}-v_T plane

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

different hadrons have different coupling to pions (ρ 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 ρ as the reference

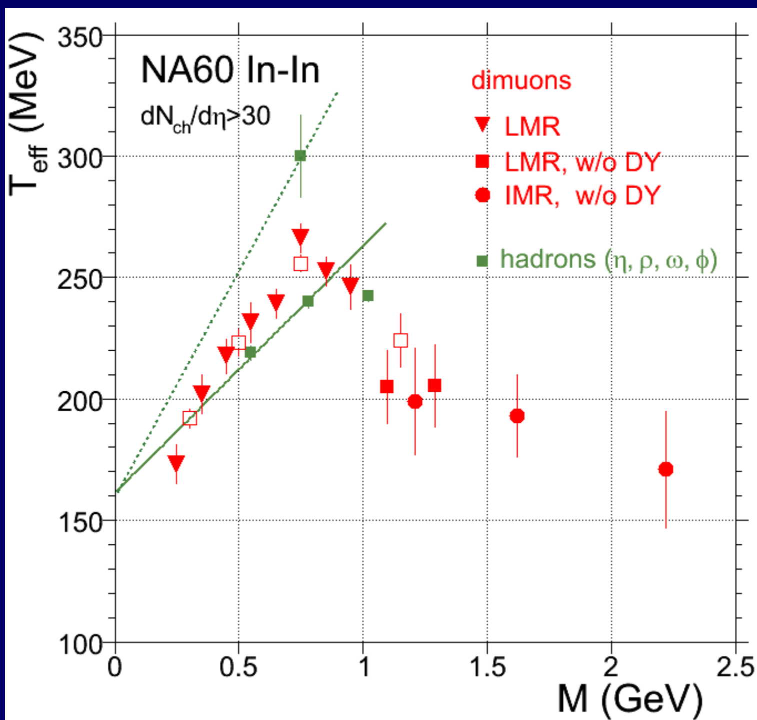
Drop signals sudden transition to low-flow source, i.e. source of partonic origin (here $qq\rightarrow\mu\mu$)

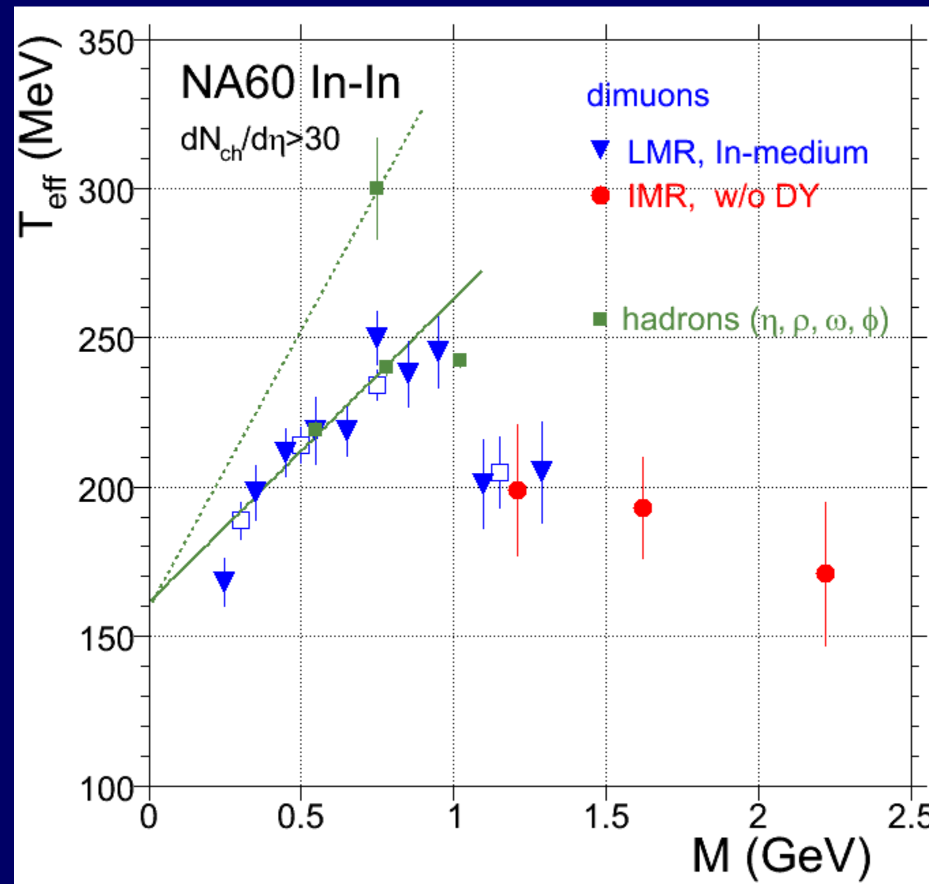
Combining M and p_T of dileptons seems to overcome hadron-parton duality

The rise and fall of radial flow of thermal dimuons

Correction of T_{eff} for the contribution from the freeze-out ρ

Phys. Rev. Lett. 100 (2008) 022302

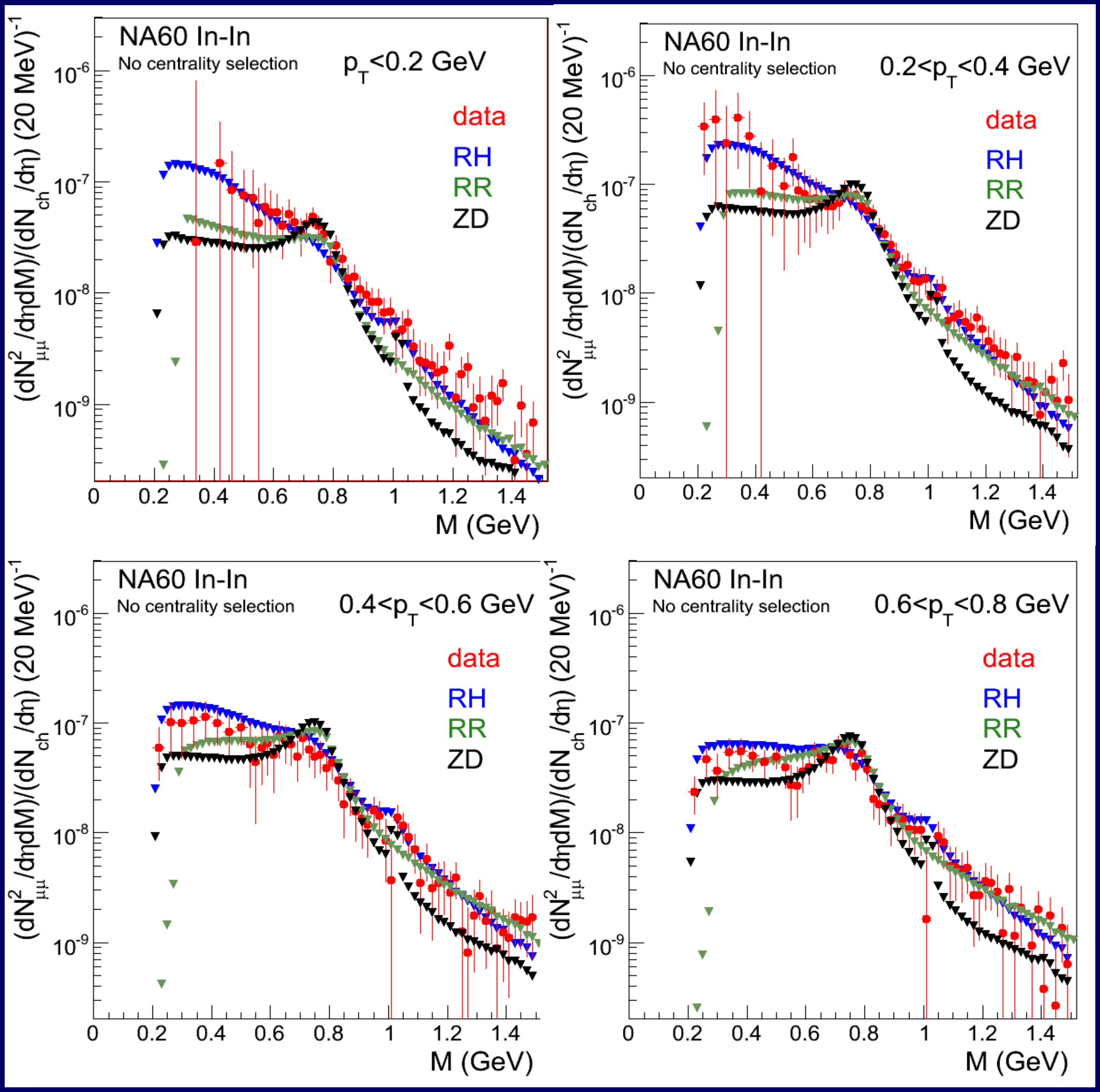




Sudden decline in T_{eff} solely due to the in-medium radiation

Acceptance-corrected mass spectra

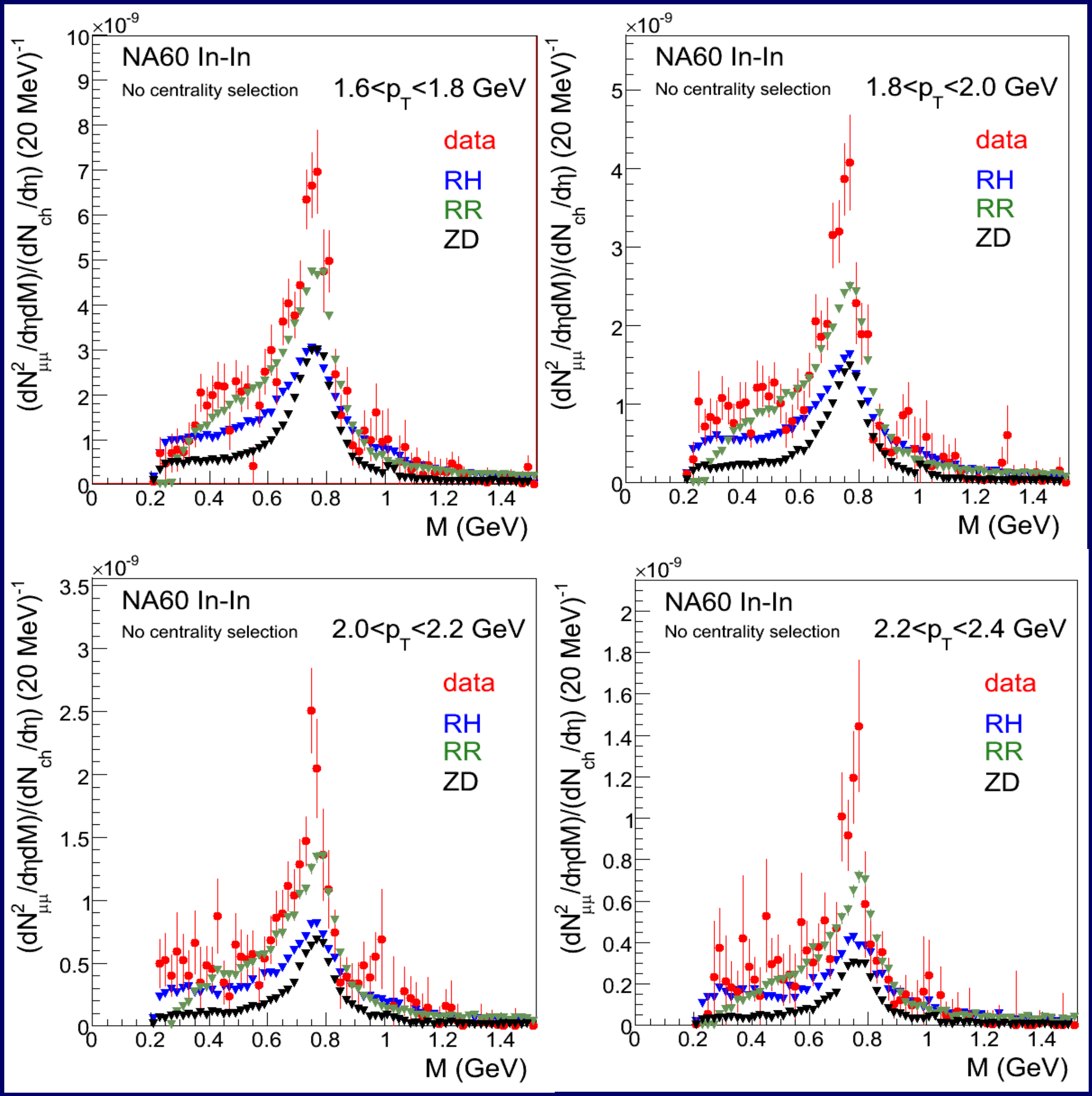
Data in comparison to theory : $0<p_T<0.8$ GeV



Absolute normalization, independent of rapidity

Differences at low mass mostly reflect differences in the low-mass tail of the spectral functions

Data in comparison to theory : $1.6<p_T<2.4$ GeV

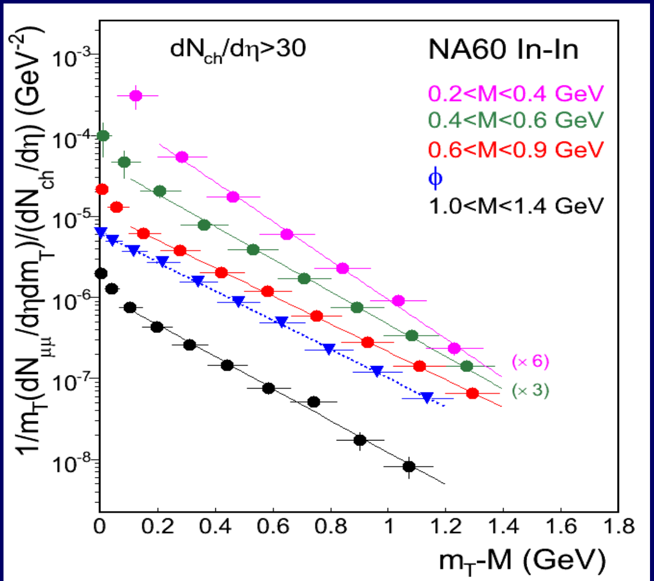


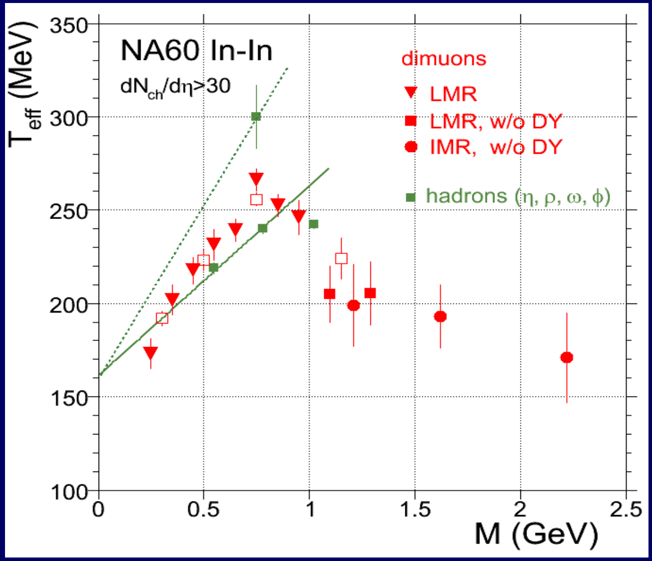
Absolute normalization, independent of rapidity

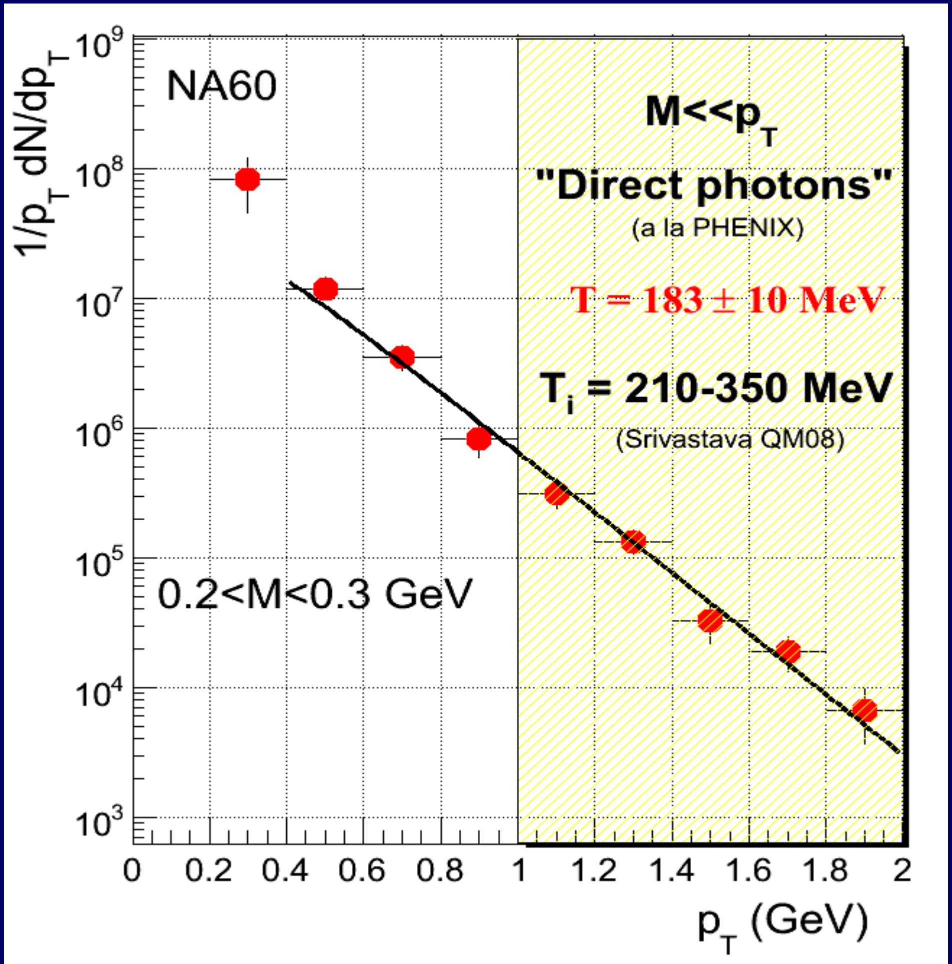
Differences at higher masses and higher p_T mostly reflect differences in the flow

Addendum

Low-mass dileptons as internal conversions of ‘direct photons’







Continuous evolution of dilepton physics

No way to single out internal conversions from other sources (pipi, a1-Dalitz, qqbar,….)

Conclusions

- Pion annihilation major contribution to the lepton pair excess in heavy-ion collisions at SPS energies in the region $M<1$ GeV

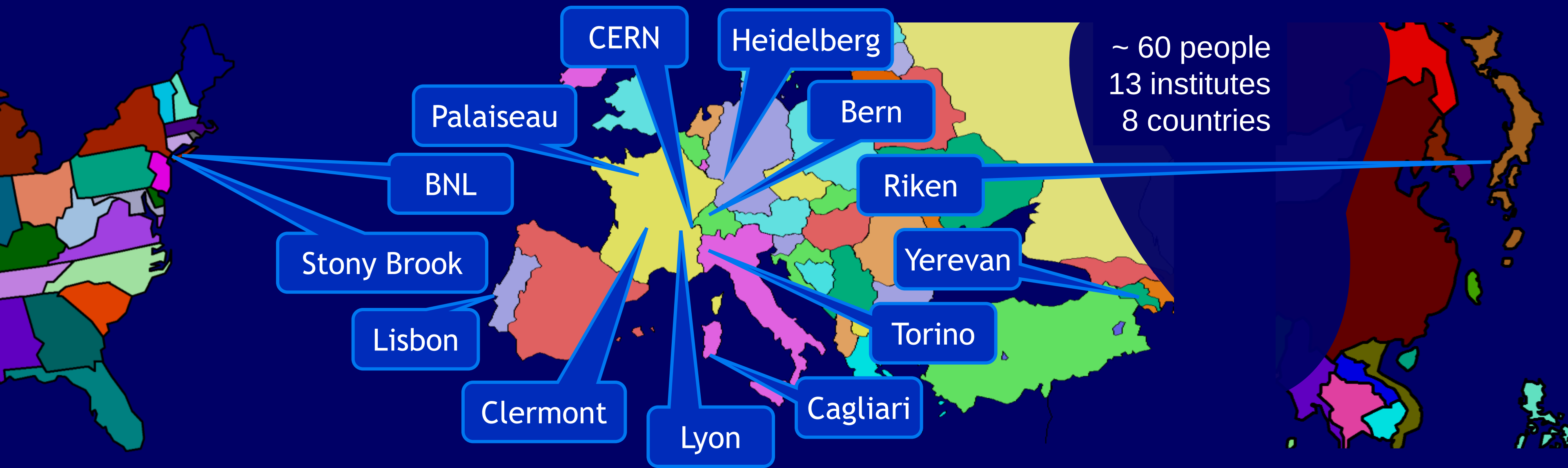
- In-medium ρ spectral function identified; no significant mass shift of the intermediate ρ, only broadening; connection to chiral restoration?

- First observation of radial flow of thermal dileptons; mass dependence tool to identify the nature of the emitting source; mostly partonic radiation for $M>1$ GeV?

- Planck-like rise of mass spectra at low p_T as well as zero polarization characteristic for thermal radiation

The NA60 experiment

http://cern.ch/na60



~ 60 people
13 institutes
8 countries

R. Arnaldi, K. Banicz, K. Borer, J. Buytaert, J. Castor, B. Chaurand, W. Chen,B. Cheynis, C. Cicalò, A. Colla, P. Cortese, S. Damjanovic, A. David, A. de Falco, N. de Marco, A. Devaux, A. Drees, L. Ducroux, H. En'yo, A. Ferretti, M. Floris, A. Förster, P. Force, A. Grigorian, J.Y. Grossiord, N. Guettet, A. Guichard, H. Gulkanian, J. Heuser, M. Keil, L. Kluberg, Z. Li, C. Lourenço, J. Lozano, F. Manso, P. Martins, A. Masoni, A. Neves, H. Ohnishi, C. Oppedisano, P. Parracho, P. Pillot, G. Puddu, E. Radermacher, P. Ramalhete, P. Rosinsky, E. Scomparin, J. Seixas, S. Serci, R. Shahoyan, P. Sonderegger, H.J. Specht, R. Tieulent, E. Tveiten, G. Usai, H. Vardanyan, R. Veenhof and H. Wöhri