Prospects of Dilepton Experiments

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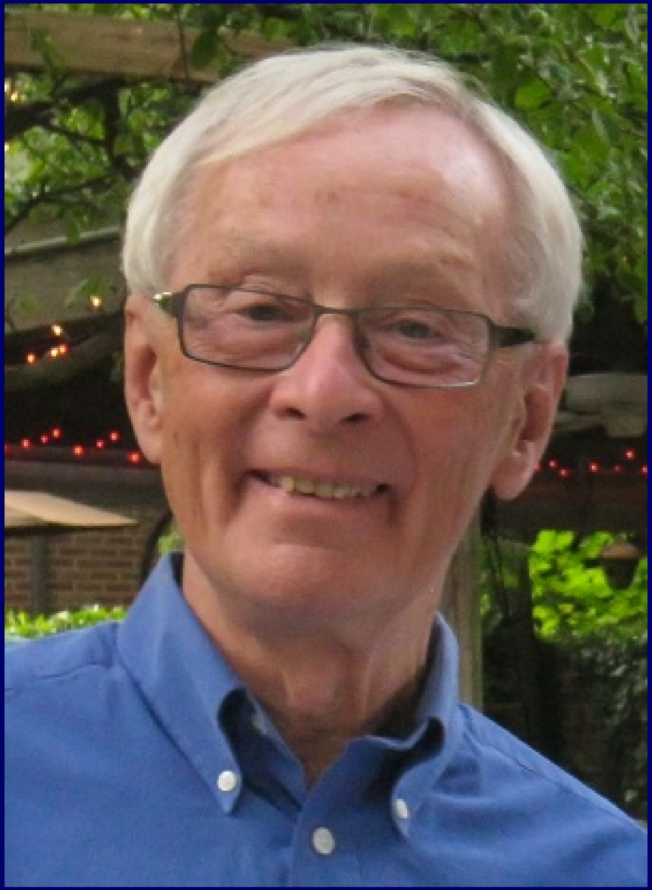
EMMI Workshop, GSI, February 15-16, 2013



William J. Willis (1932-2012)

Outline

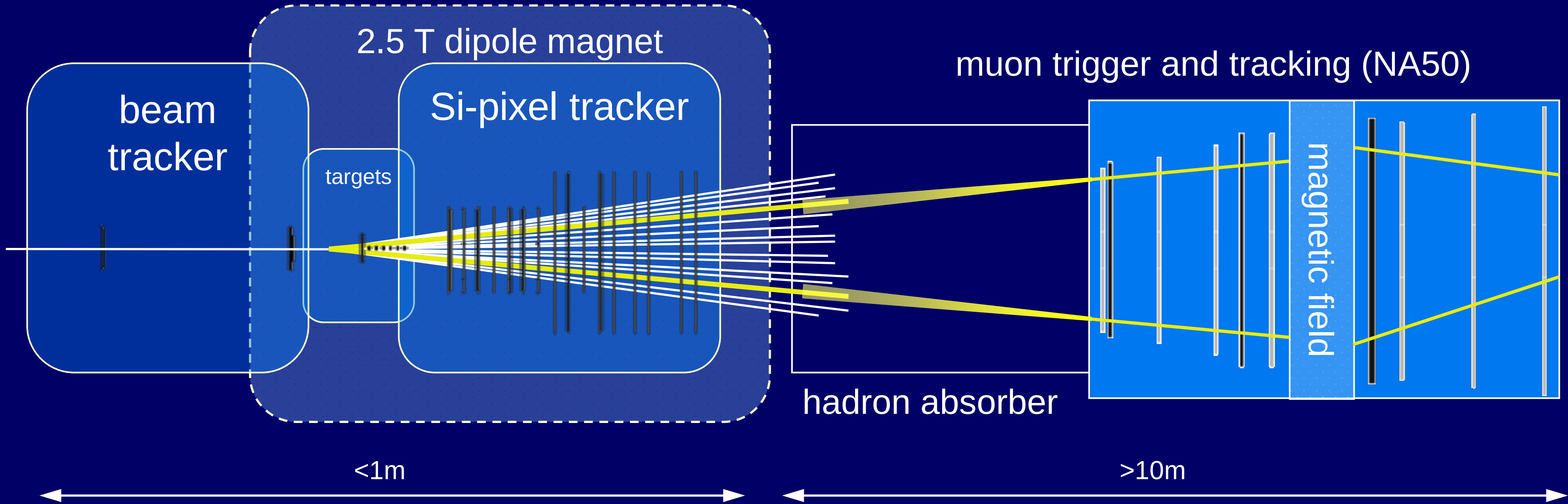
- Summary of NA60 results

- General comments on data quality

- The high-energy frontier (AA and pp)

- The low-energy frontier

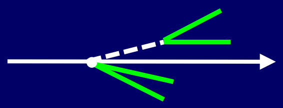
Measuring dimuons in NA60: concept



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

Improved dimuon mass resolution

Distinguish prompt from decay dimuons



Additional bend by the dipole field

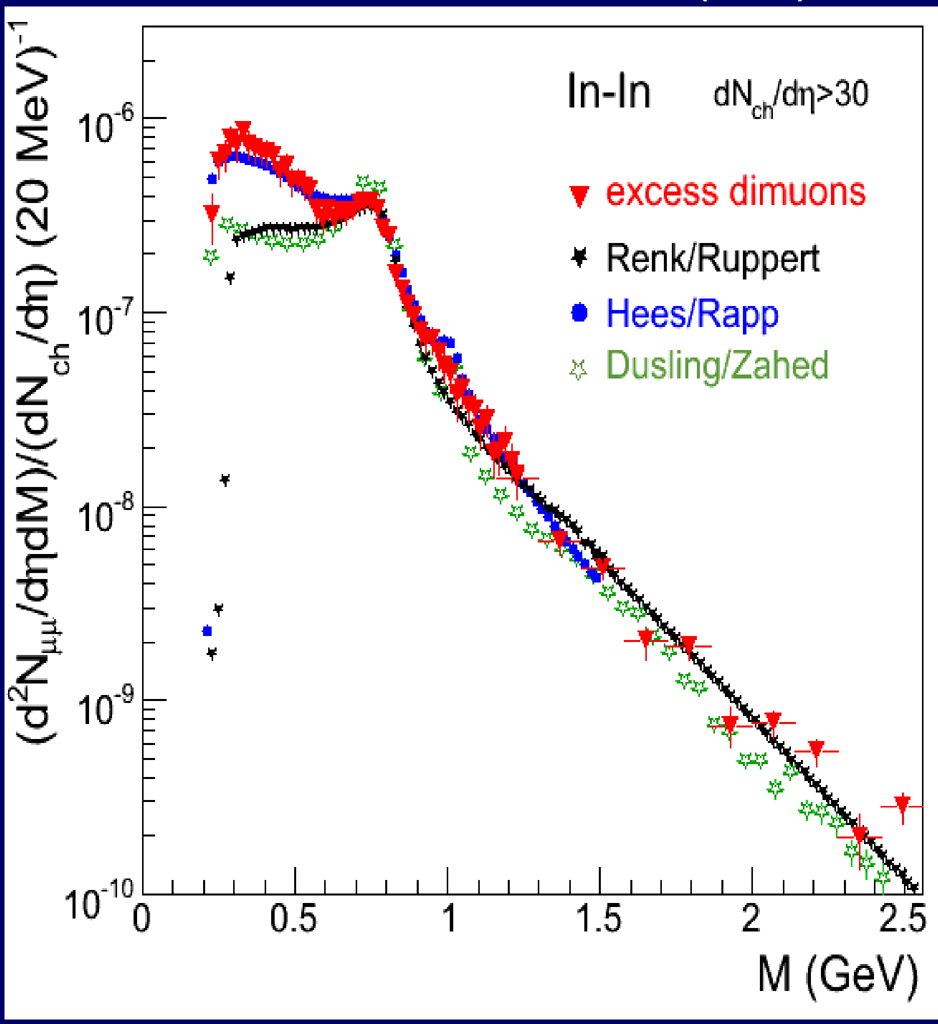
Dimuon coverage extended to low p_T

Radiation-hard silicon pixel detectors (LHC development)

High luminosity of dimuon experiments maintained

Inclusive excess mass spectrum

[Eur. Phys. J. C 59 (2009) 607-623]
CERN Courier 11/ 2009, 31-35
Chiral 2010 , AIP Conf.Proc. 1322 (2010) 1-10



all known sources subtracted

integrated over p_T

fully corrected for acceptance

absolutely normalized to $dN_{ch}/d\eta$

M<1 GeV

ρ dominates, 'melts' close to T_c

best described by H/R model

M>1 GeV

~ exponential fall-off → 'Planck-like'

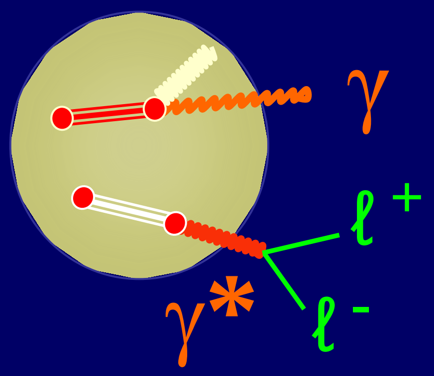
fit to $dN/dM \propto M^{3/2} \times \exp(-M/T)$

range 1.1-2.0 GeV: T=205 12 MeV
1.1-2.4 GeV: T=230 10 MeV

$T>T_c$: partons dominate

only described by R/R and D/Z models

Electromagnetic Probes: the case for lepton pairs



photons: 1 variable: p_T

lepton pairs: 2 variables: M, p_T

relevant for thermal radiation:

p_T sensitive to temperature and expansion velocity

M only sensitive to temperature (Lorentz invariant)

approximate mass spectrum (for flat spectral function, and interpreting T as the average temperature over the space-time evolution)

$$dN/dM \propto M^{3/2} \times \exp(-M/T)$$ → ‘Planck-like’

the only true (Lorentz invariant) thermometer of the field

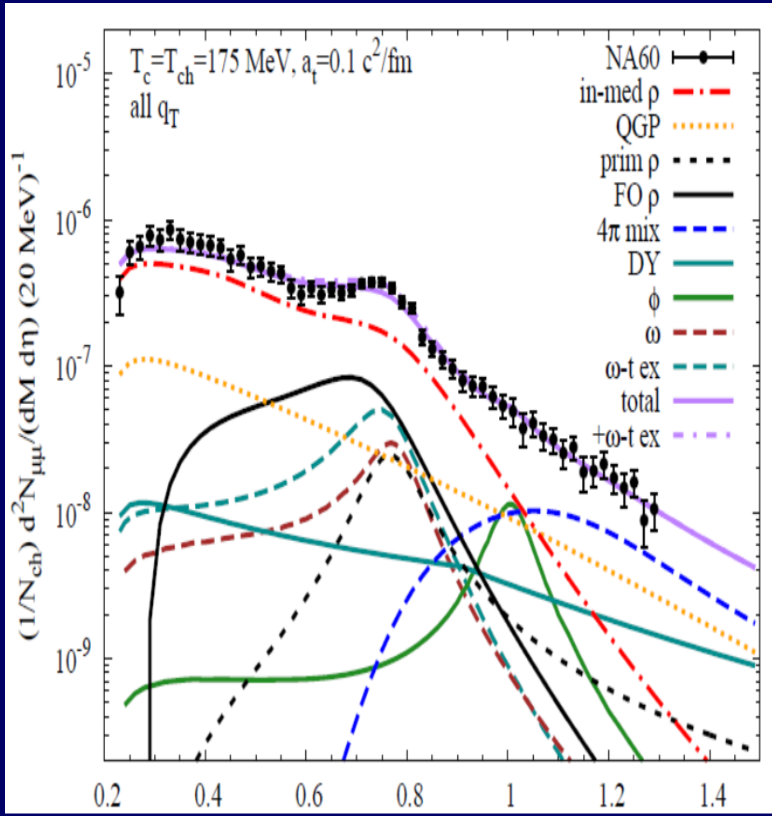
systematic uncertainties:

theory, from fits to RR and DZ: T =215 MeV; $T_{1.2\ GeV}$=205, $T_{2.5\ GeV}$ = 225

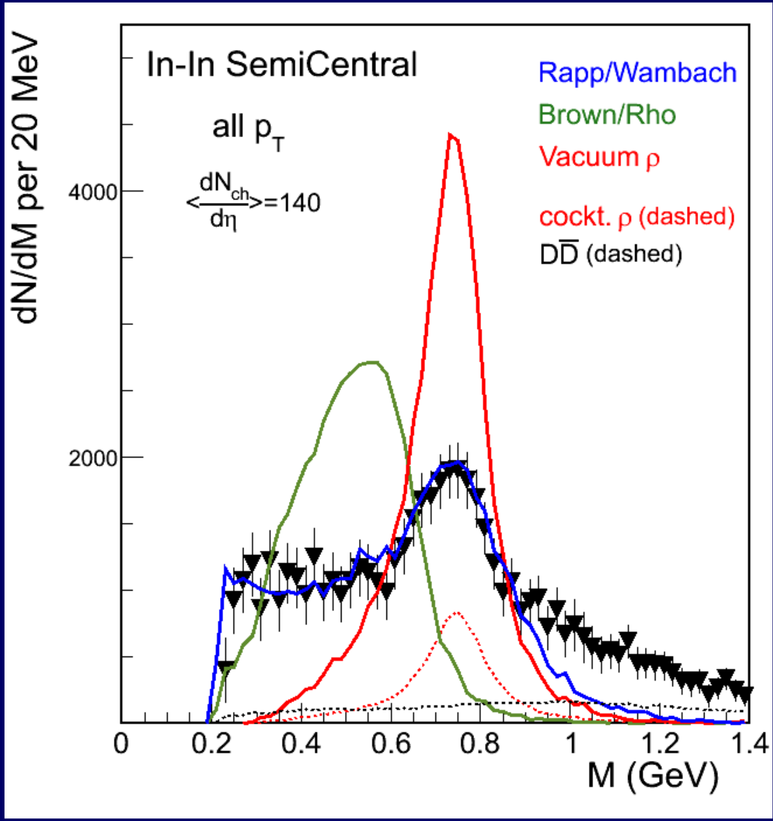
data: oversubtraction of DY by 20/30% → ΔT= -10/-20 MeV

The approach to chiral restoration

van Hees+Rapp (2008)



Phys. Rev. Lett. 96 (2006) 162302



data acceptance-corrected

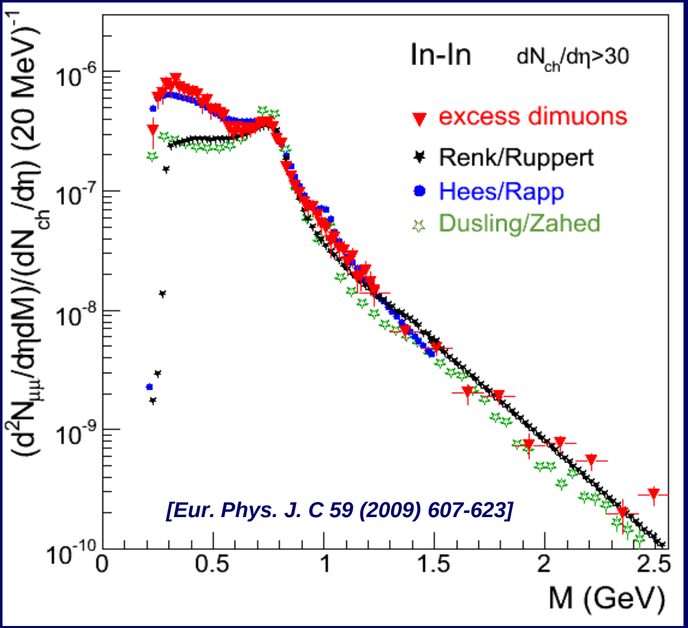
'spectrum directly reflects thermal emission rate' (Rapp)

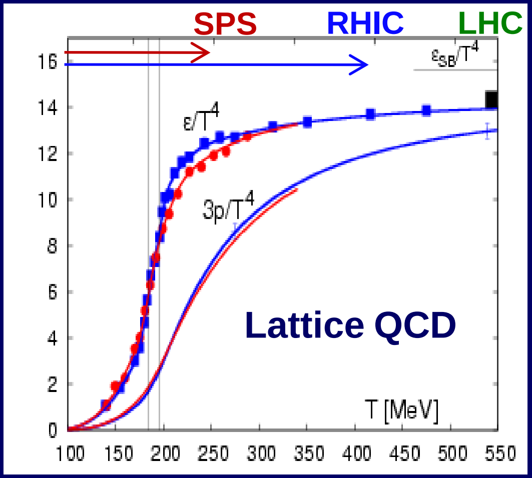
before acceptance correction:

underlying space-time averaged ρ spectral function (purely accidental)

Only broadening of ρ observed, no mass shift

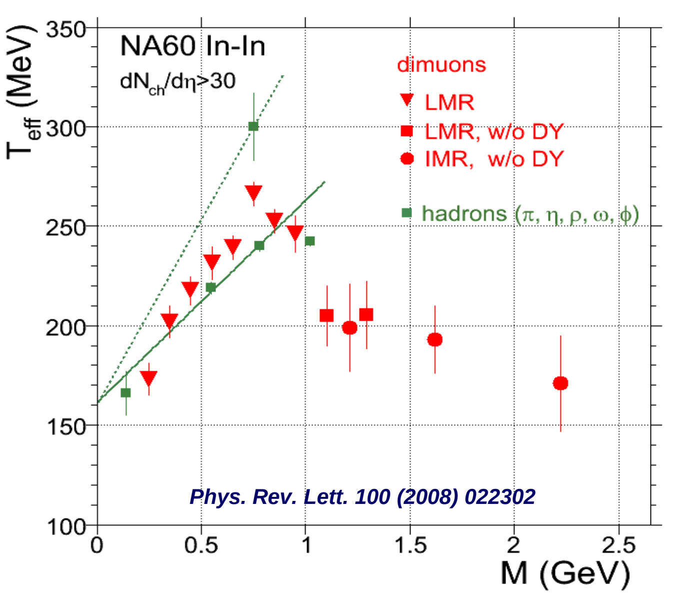
Combined conclusions from mass and p_T spectra





rapid rise of energy density ε, slow rise of pressure p (not ideal gas)

→ EoS above T_c very soft initially (c_s minimal)



M >1 GeV

- T_{eff} independent of mass within errors

mass spectrum: T = 205 12 MeV

p_T spectra: $<T_{eff}>$ = 190 12 MeV

- same values within errors

T = 205 MeV > T_c = 170 (MeV)

negligible flow → soft EoS above T_c

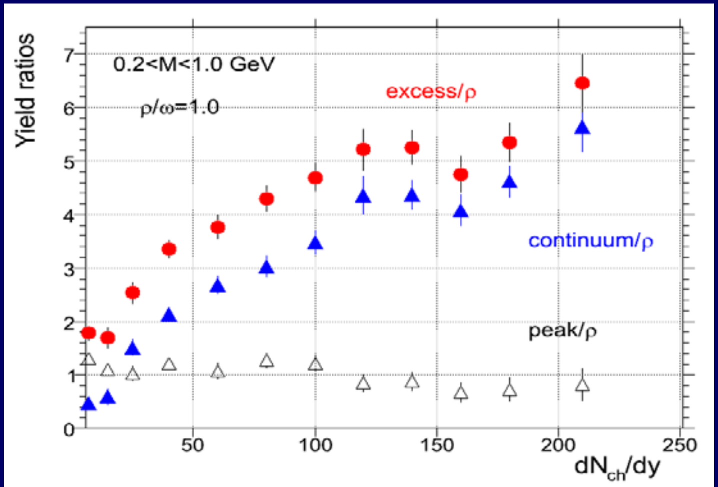
all consistent with partonic phase

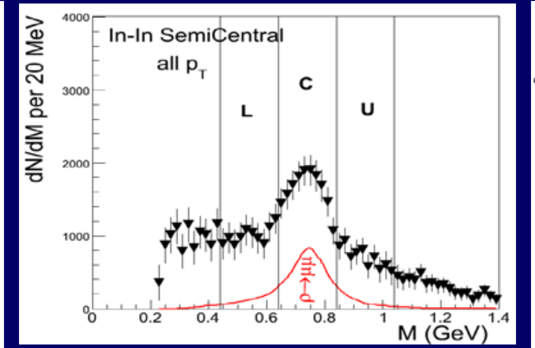
Centrality dependences

Comprehensive results on the centrality dependence of all acceptance-corrected mass and p_T/m_T spectra and their correlations

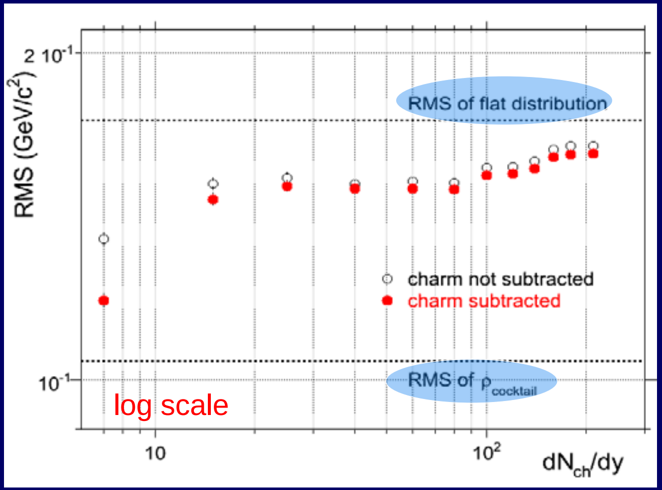
Valuable input to theoretical modeling …

Specific example: shape of the ρ spectral function (data before acc. corr.)





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



rapid initial increase of relative yield; reflects the number of ρ's regenerated in $\pi^+\pi^- \rightarrow \rho^* \rightarrow \mu^+\mu^-$

→ 'ρ clock'

monotonic increase of the width, approaching that of a flat distribution

→ 'melting' of the ρ

Other Dilepton Experiments – Present and Future

The high energy frontier

- RHIC PHENIX, STAR
- LHC ALICE

The low energy frontier

- RHIC LE STAR
- SPS NA60-like
- SIS300 CBM
- SIS100 HADES, CBM
- NICA MPD

Relevance

M <1 GeV → chiral restoration
M >1 GeV → hadrons vs. partons (precise meas. of T)

Dream: energy dependence from

$\sqrt{s}$ = 4 − 5500 AGeV

with data quality equivalent to NA60

Principal obstacle to reach this:

colliders not competitive to fixed-target experiments in terms of interaction rate

General comments on data quality

Decisive Parameters for Data Quality

Luminosity → Effective Luminosity

Luminosity → Overall precision

Signal/Background ratio → Effective Luminosity

Signal/Background ratio → Overall precision

Interaction Rates I_R (Luminosity σ_{int})

- Fixed target (SPS, SIS100/300): 10^6-10^7/s (NA60 5 10^5)
- Colliders (LHC upgrade): 5 10^4/s

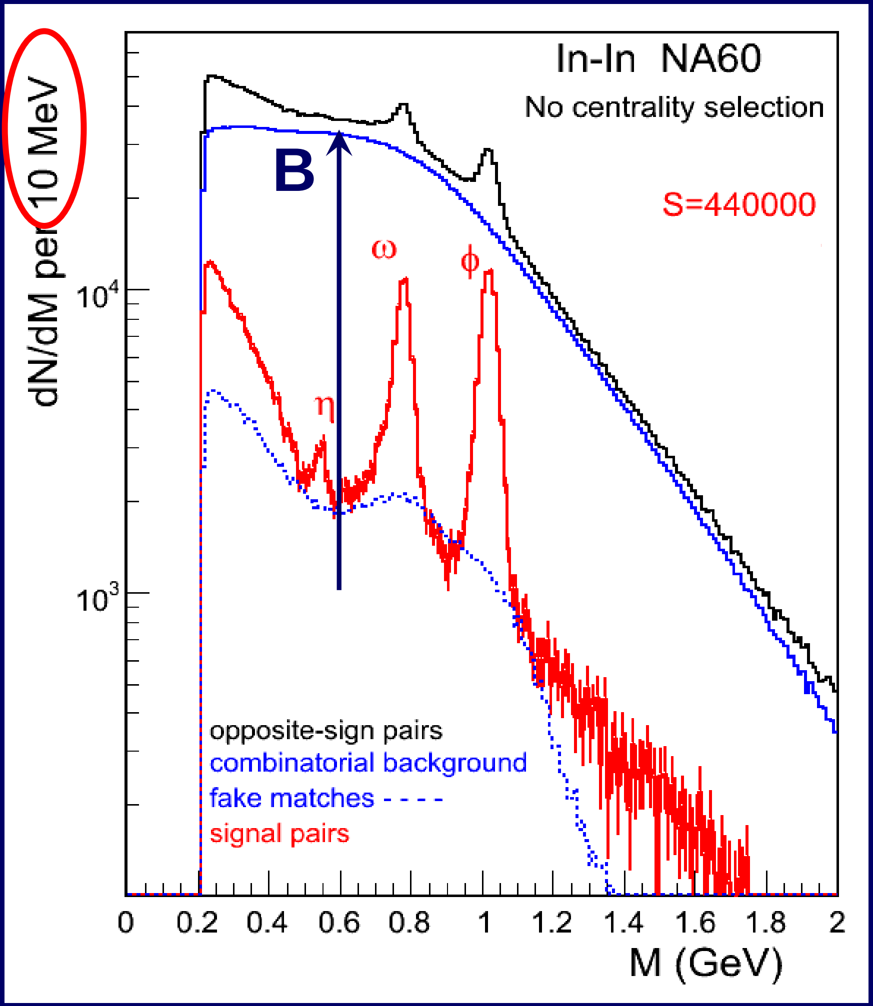
Signal/Background ratio S/B (B - combinatorial background)

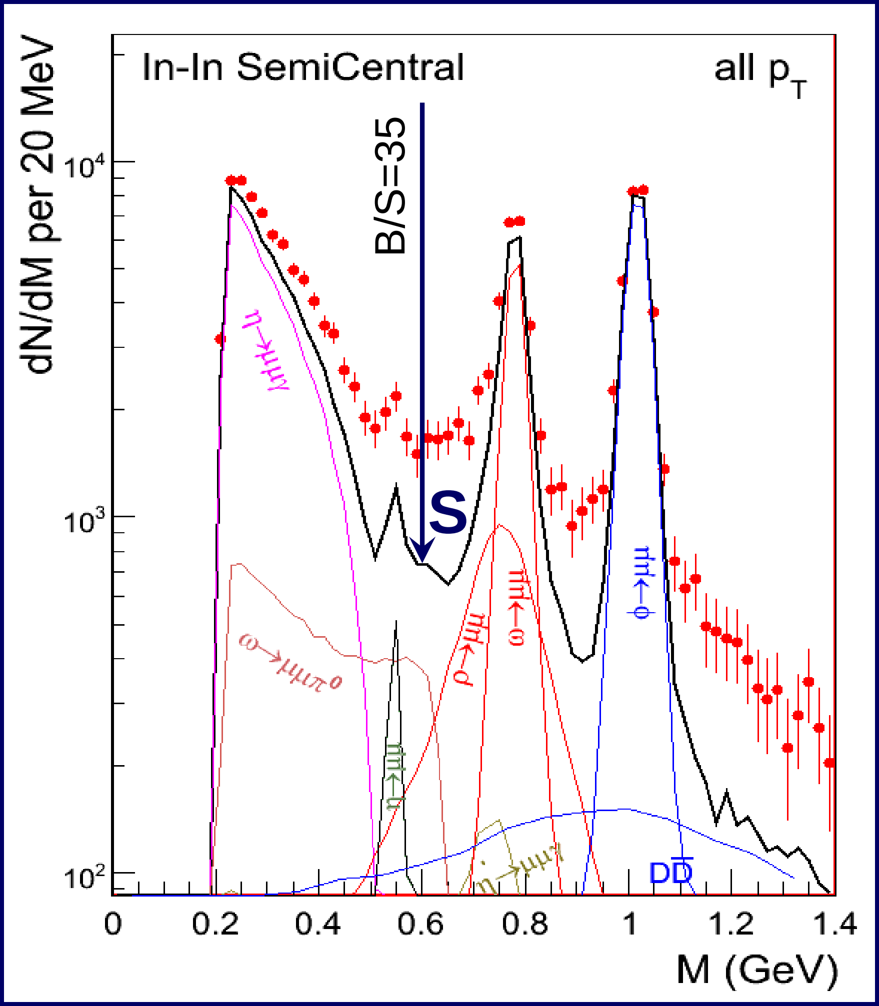
- range of B/S for different experiments: 20 - 1000 → B/S >>1
- effective signal size: $S_{eff} \sim I_R$ S/B reduction by factors of 20-1000 !

Overall precision

- systematics due to S/B: $\delta S_{eff}/S_{eff} = \delta B/B$ B/S $\delta B/B = 2\ldots5$ 10^{-3}

Assessment of B/S: choice of S





choose hadron cocktail in mass window 0.5-0.6 GeV for S

- free from prejudices on any excess; no ‘bootstrap’; most sensitive region
- unambiguous scaling between experiments; B/S $\propto$ dN_{ch}/dy

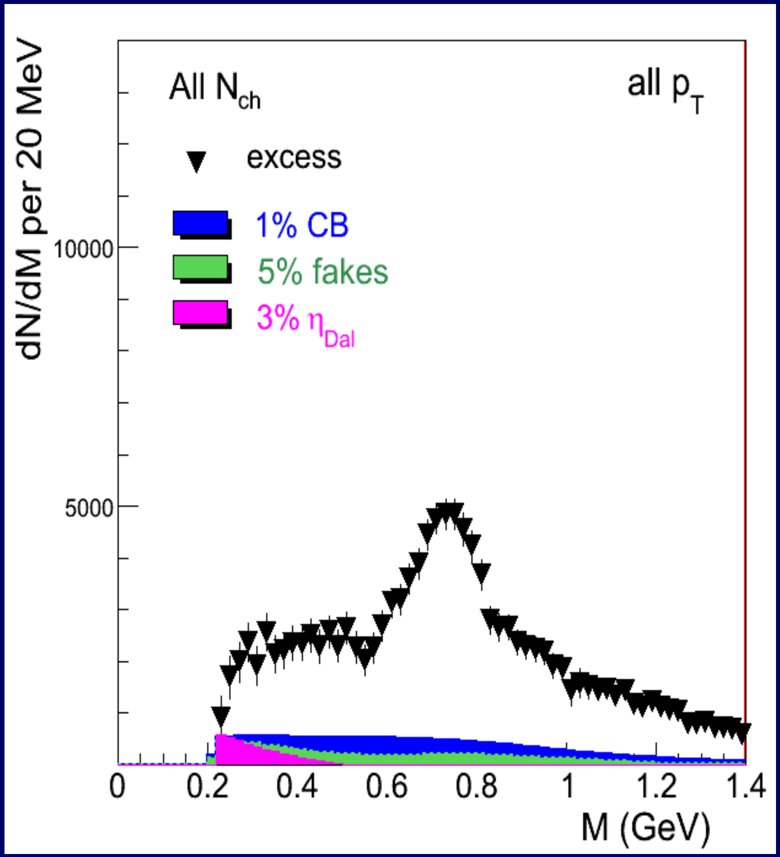
Combinatorial Background/Signal in Dilepton Experiments

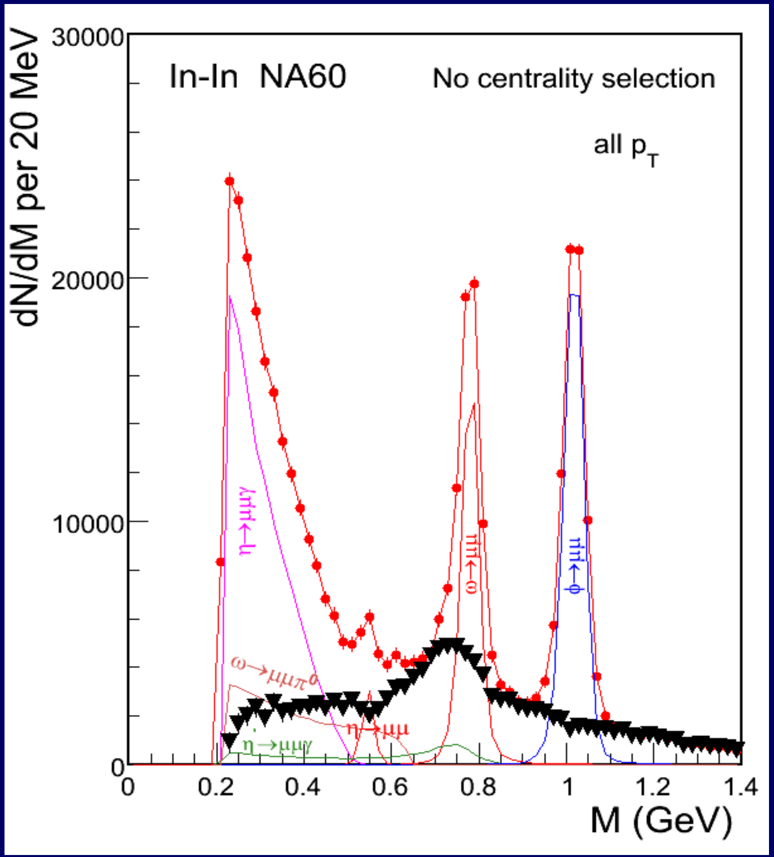
Reference: hadron cocktail at masses of 0.5-0.6 GeV

Experiment	Centrality	Lepton flavor	B/S as meas. or simul.	B/S rescaled to $dN_{ch}/dy=300$
HADES-SIS100	semicentr	e^+e^-	20	60
CERES DR	semicentr	e^+e^-	80	100
CERES SR/TPC	central	e^+e^-	110	100
PHENIX with HBD	central	e^+e^-	250	100
PHENIX w/o HBD	central	e^+e^-	1300	600
STAR	central	e^+e^-	400	200
ALICE Upg ITS	central	e^+e^-	1200	200
CBM-SIS100	central	e^+e^-	80	100
CBM-SIS300	central	e^+e^-	100	100
NA60 (InIn)	semicentr	$\mu^+\mu^-$	35	80
NA60-like (20AGeV)	central	$\mu^+\mu^-$	80	100
CBM-SIS300	central	$\mu^+\mu^-$	200	200

data / simulations PbPb

Examples for precision in NA60





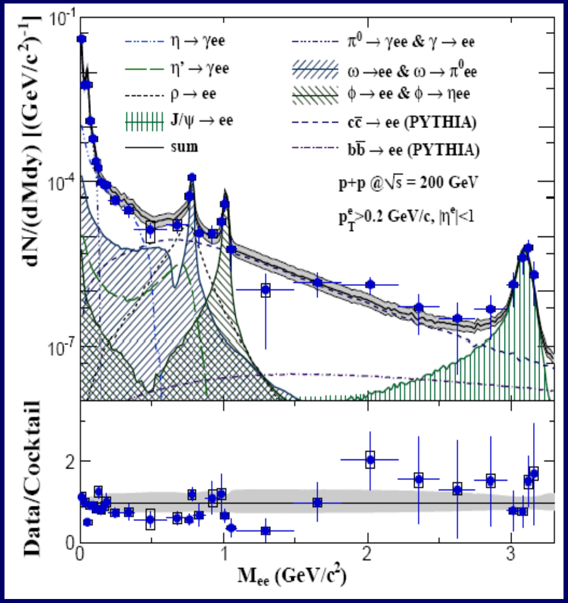
Systematic errors due to combinatorial background, fake-match tracks and the η Dalitz

Isolation of excess by subtraction of measured decay cocktail based solely on local criteria; accuracy 2-3%

Precision measurement of the η- and ω Dalitz EM Transition Form Factors (PDG 2010 ff)
(removal of the previous 40% error in that hadron cocktail region)

The high energy frontier

Di-electron results from STAR (QM2012)



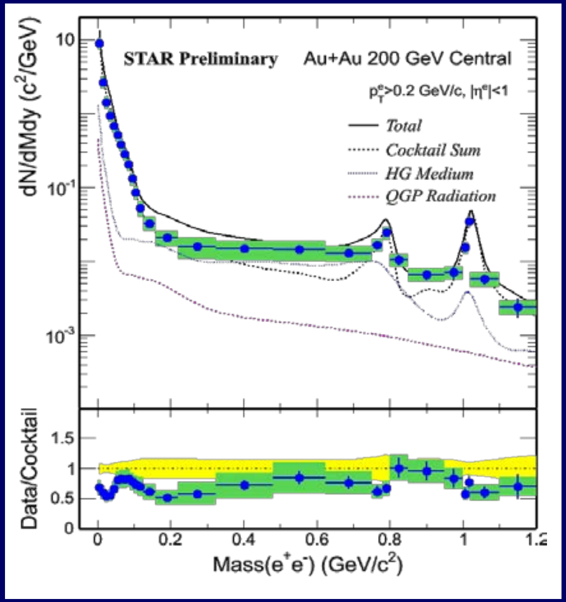
B/S=400 (central)

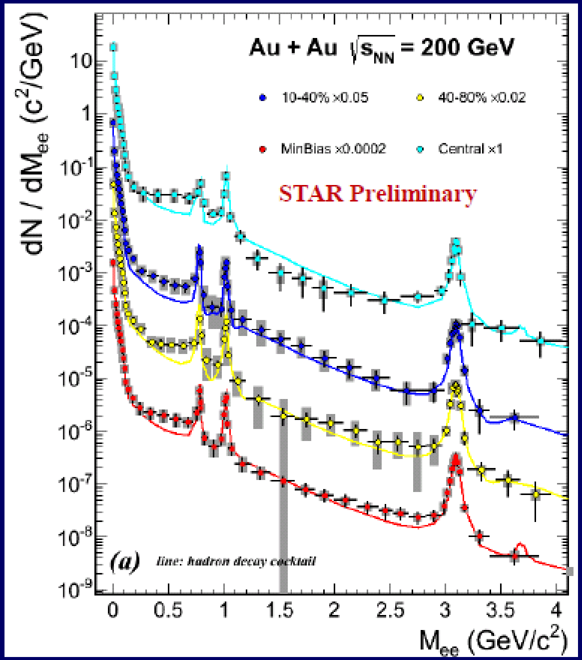
← data/cocktail <1 →

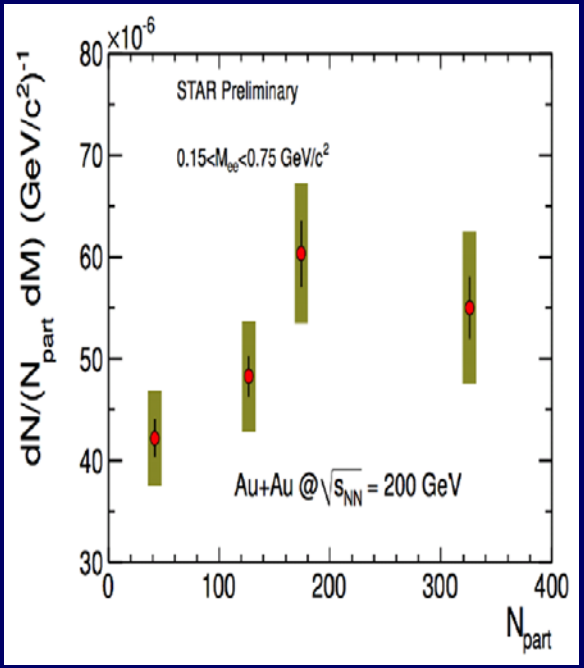
cocktail normalization?

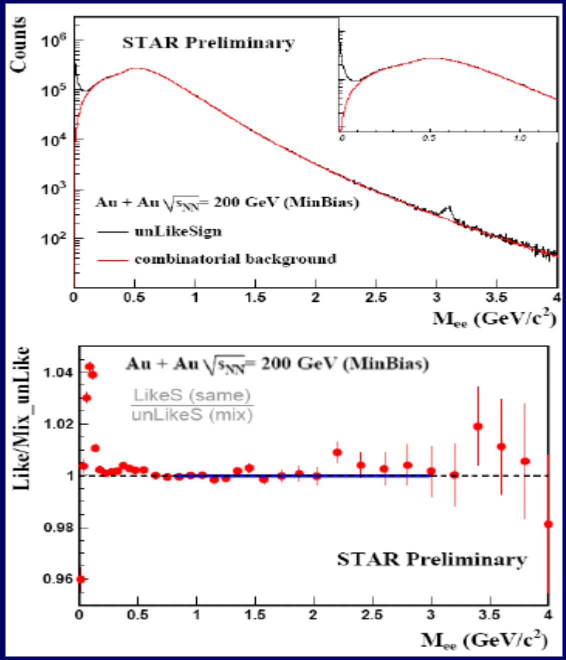
centrality dependence
of enhancement NA60-like
(within the large errors)

still: oversubtraction of
background by 0.1- 0.2%?

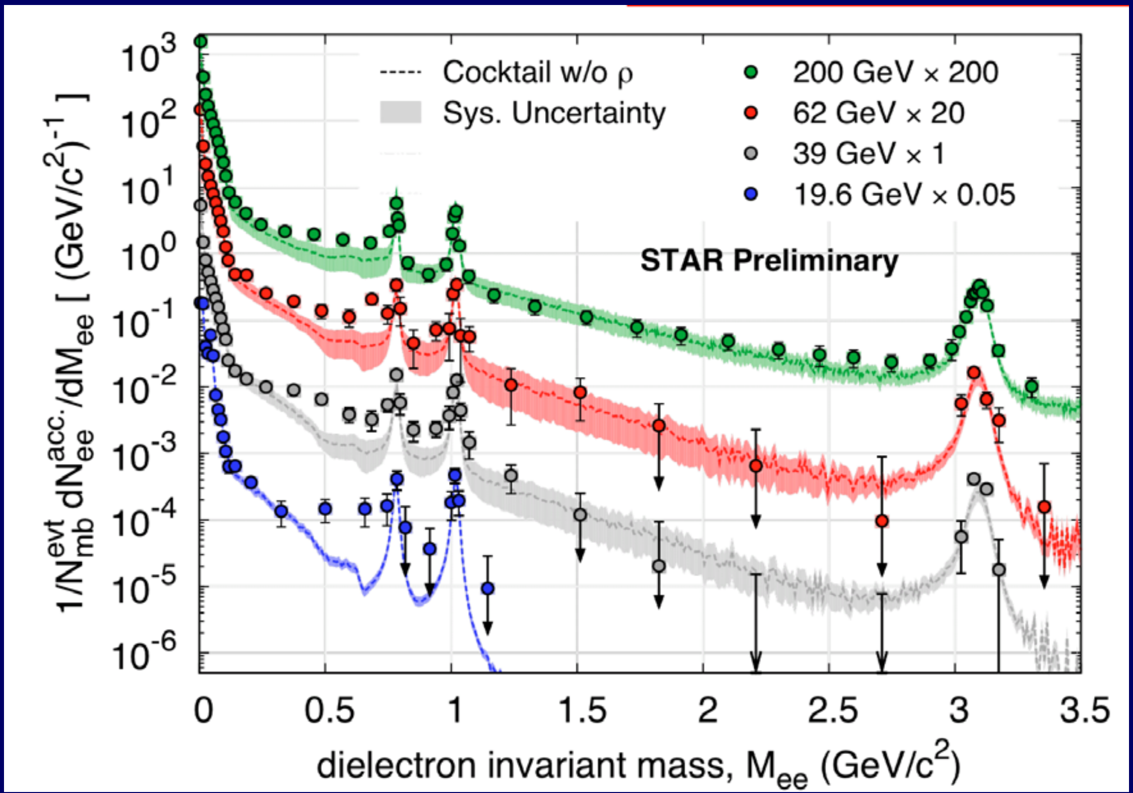








STAR data from RHIC Energy Scan



hardly any change of LMR excess with beam energy

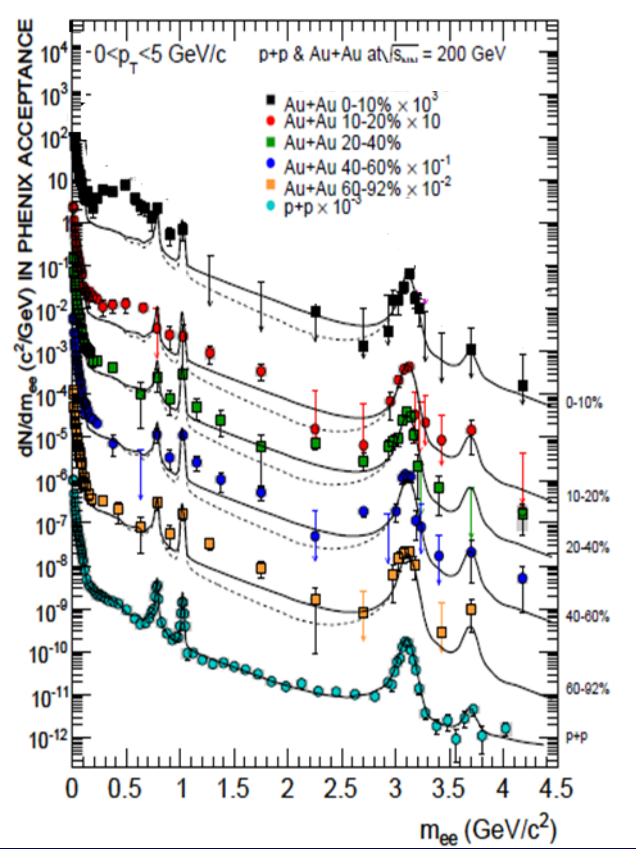
no chance for IMR at lower RHIC energies?

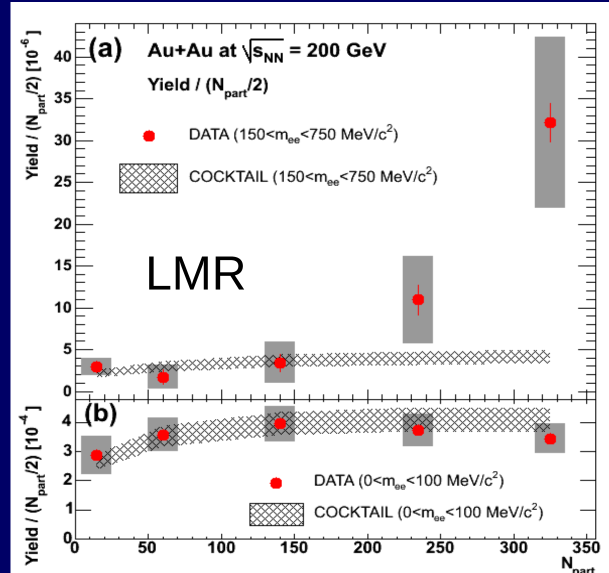
Interpretation for the LMR excess:

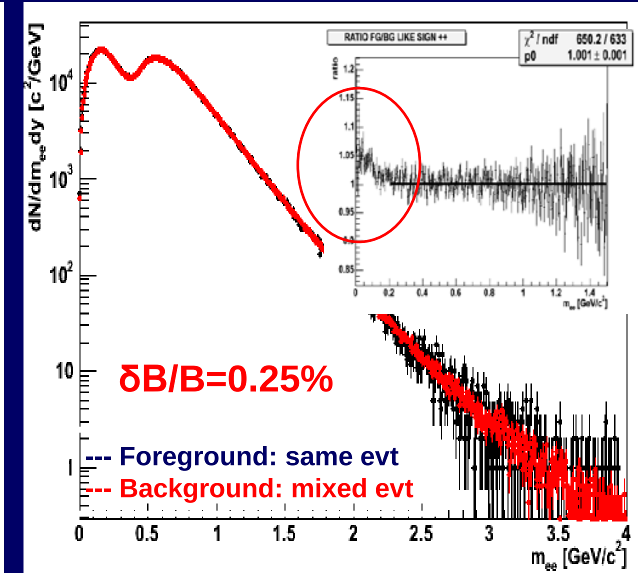
total baryon density almost the same at SPS and across the RHIC energy range (dN(p+pbar)/dy = 110 and 102 at SPS and highest RHIC, resp.)

→ baryon interactions dominate ρ broadening (see talk R.Rapp)

Di-electron results from PHENIX

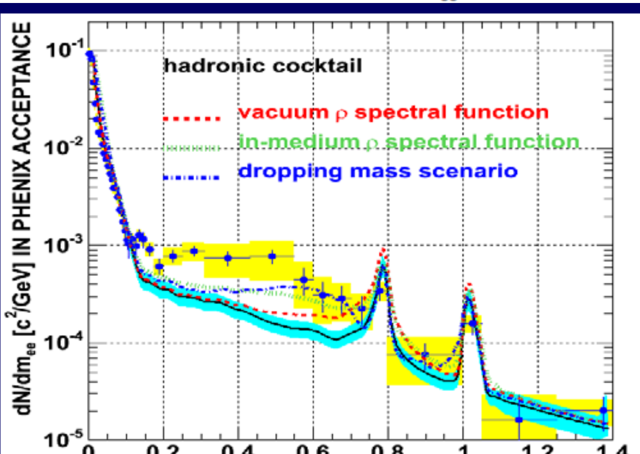


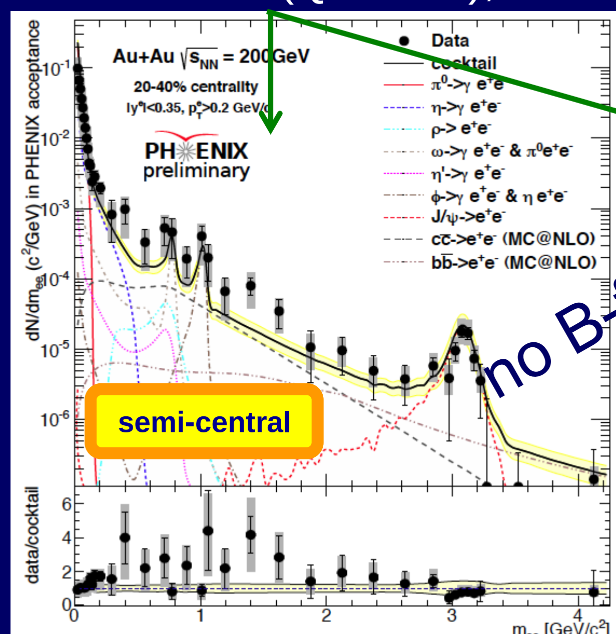


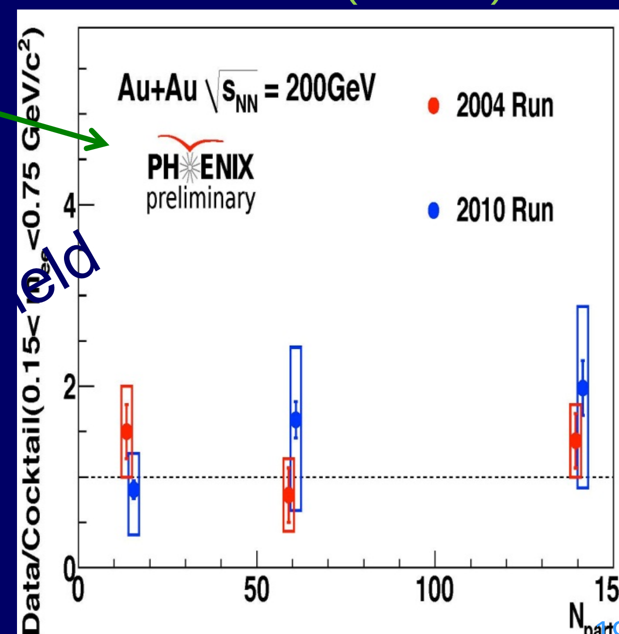


Previous results (PRC 2010); B/S=1300 (central)

HBD results (QM2012); factor of 5 → B/S=250 (→100!)

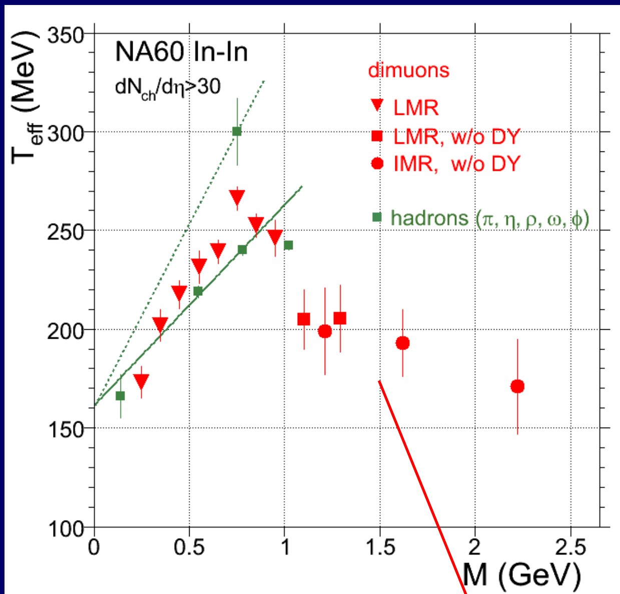






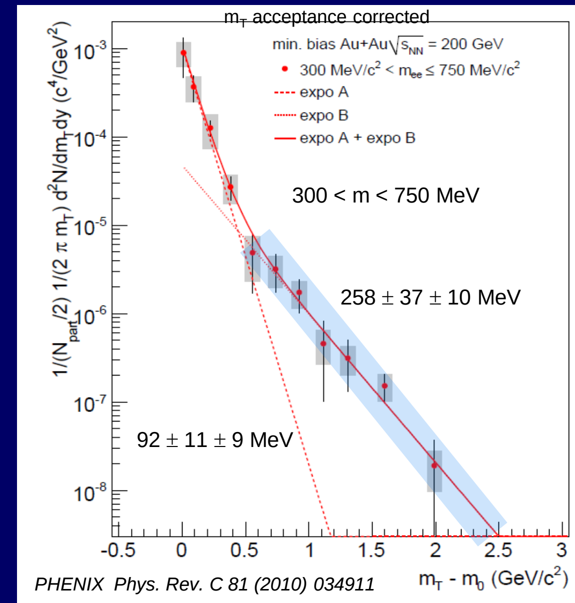
H.J.Specht, GSI 2013

Comparing p_T/m_T data at SPS and RHIC

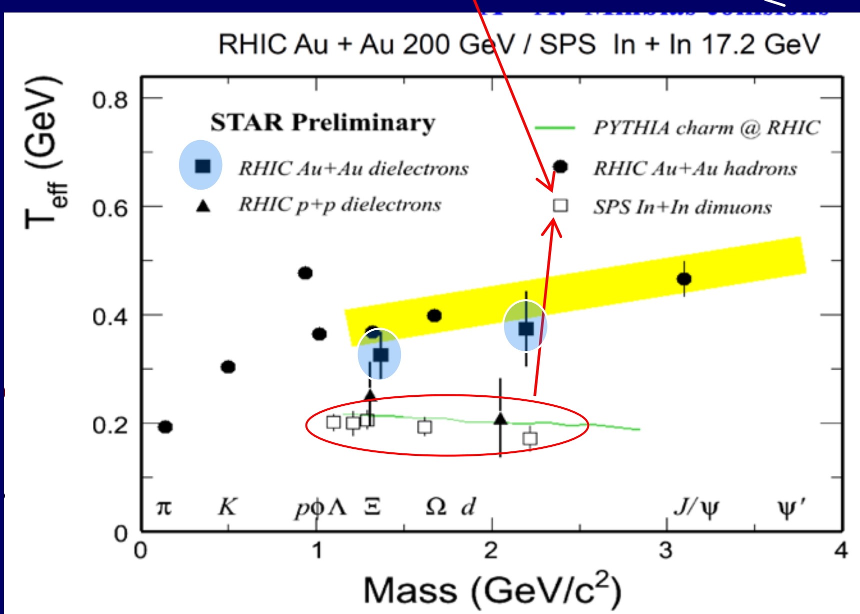


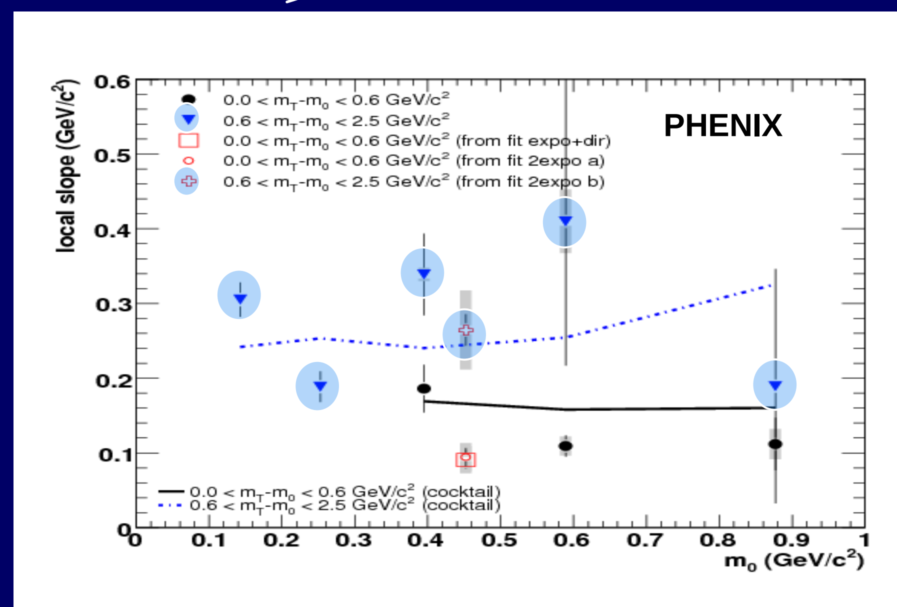
NA60: all known sources subtracted

acceptance-corrected in M-p_T-y-cosΘ space



RHIC data: incomplete and uninterpretable (mixture of all sources)





Wish list for the future at RHIC

Solve the PHENIX mystery and its relation to the STAR results

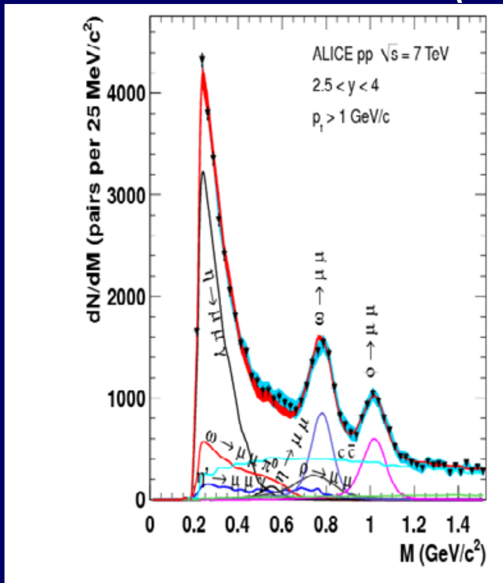
Direct measurement of the charm contribution to the IMR region
(STAR: Silicon Vertex Upgrade and e-μ correlations)

Higher overall precision in the IMR region

Appropriate analysis of the p_T/m_T data
(requires disentangling the sources both in the LMR and IMR)

Dileptons in ALICE

ALICE collab. arXiv:1112.2222 (2011)



Presence:
pp collisions

first data

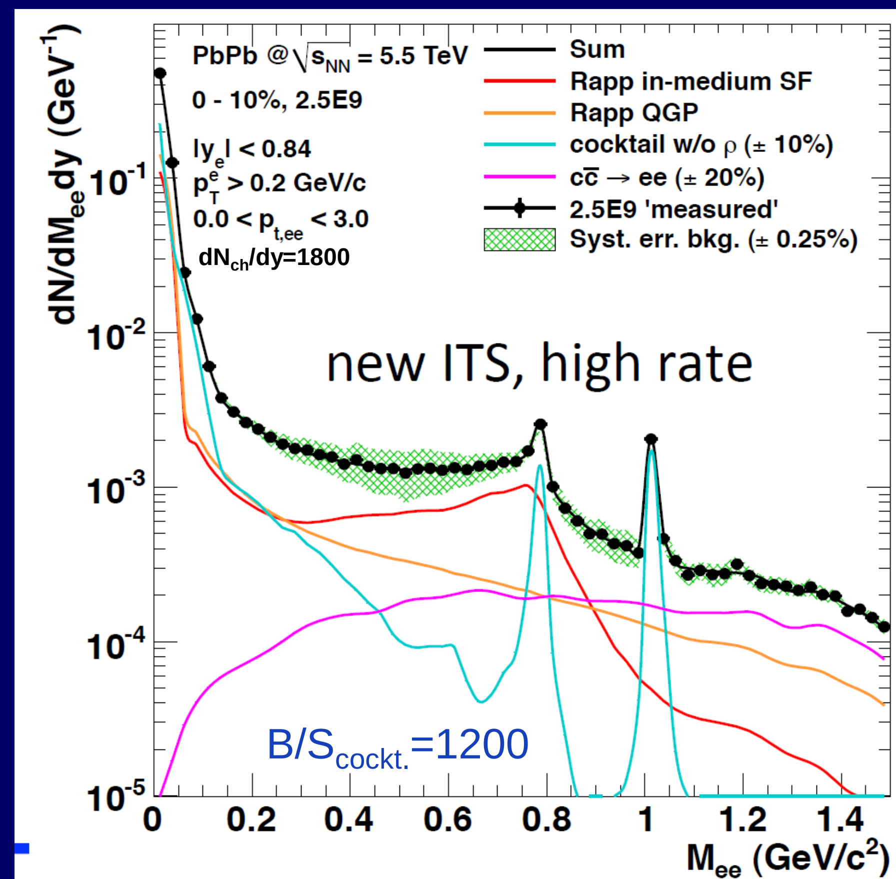
← dimuons

dielectrons
↓

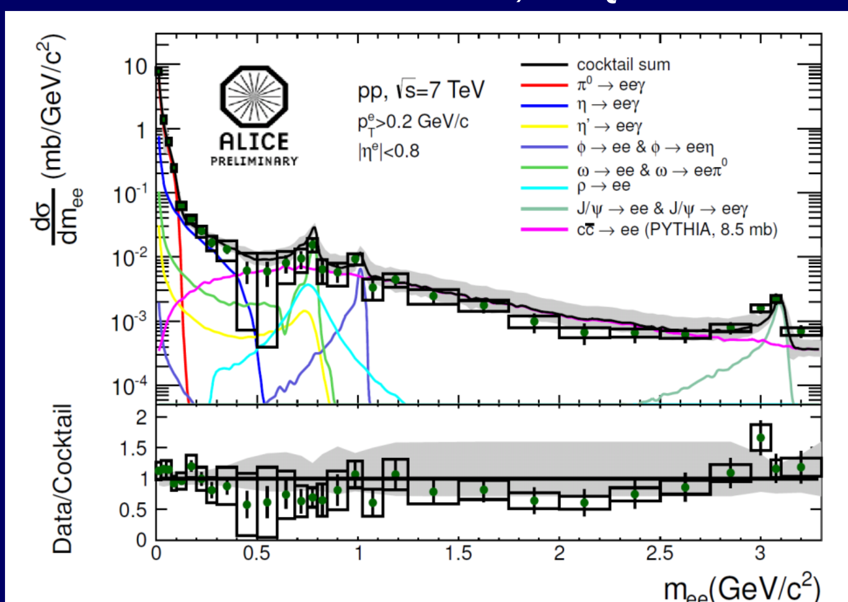
Future:
Pb-Pb collisions

chances for high precision IMR?
simulations for dielectrons in LMR

ALICE Tech. Design Rep. to LHCC, September 2012

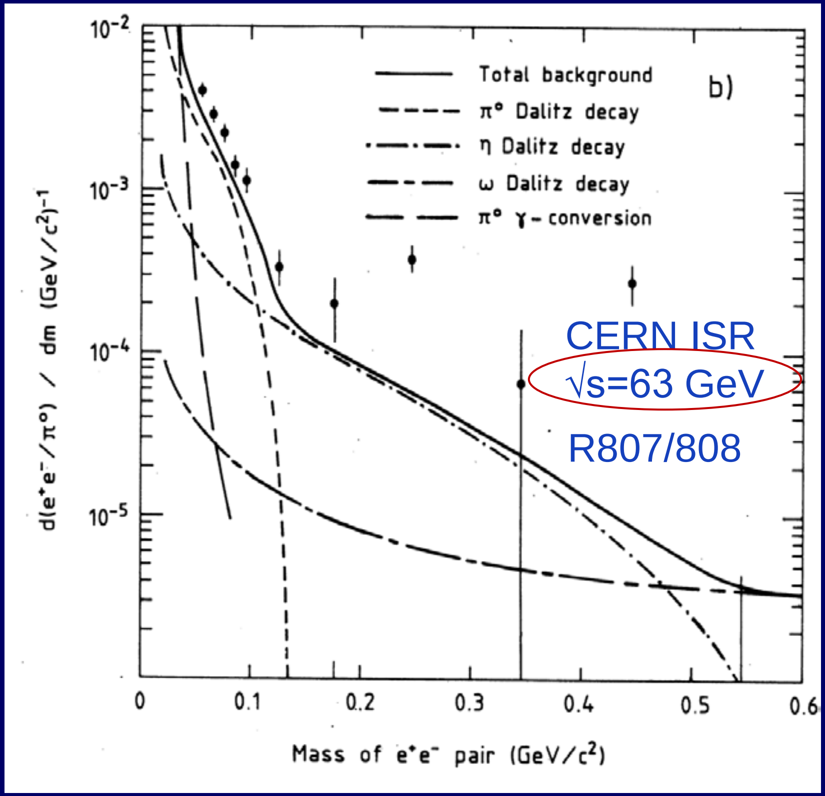


M.Koehler for the ALICE collab., Hot Quarks 2012



An almost forgotten opportunity:
pp at the highest energies and highest multiplicities

T. Akesson et al., PLB152 (1985) 411 and PLB192 (1987) 463; W. Hedberg, PhD thesis, Lund (1987)

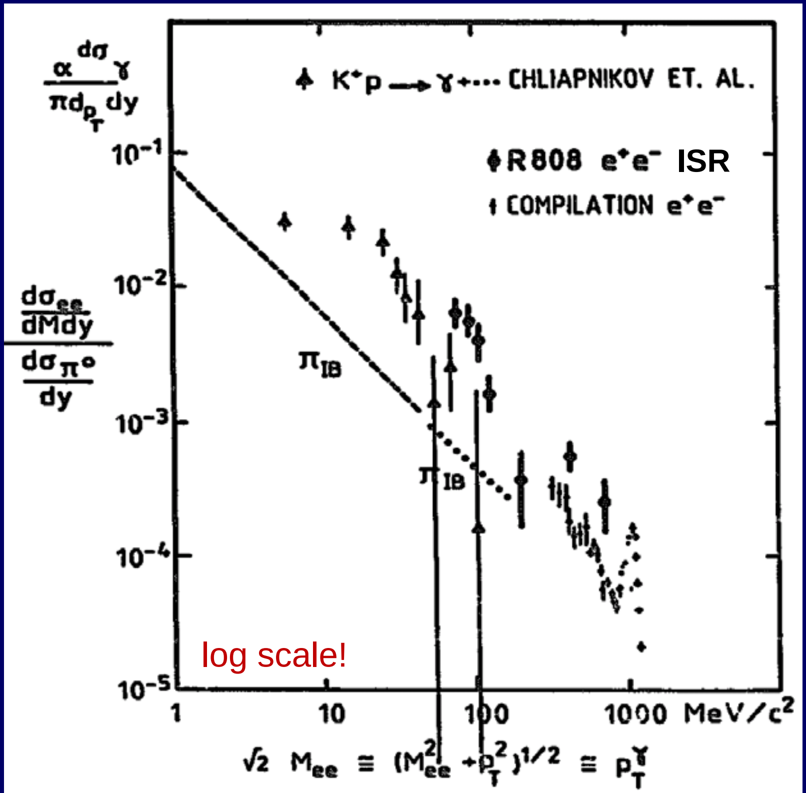


the only dilepton excess ever seen in pp

multiplicity dependence almost quadratic

Watch out both in pp and AA!

W.J. Willis, PANIC, Kyoto 1987 Nucl.Phys. A478 (1988) 151c



unification of dilepton excess with 'soft photons':

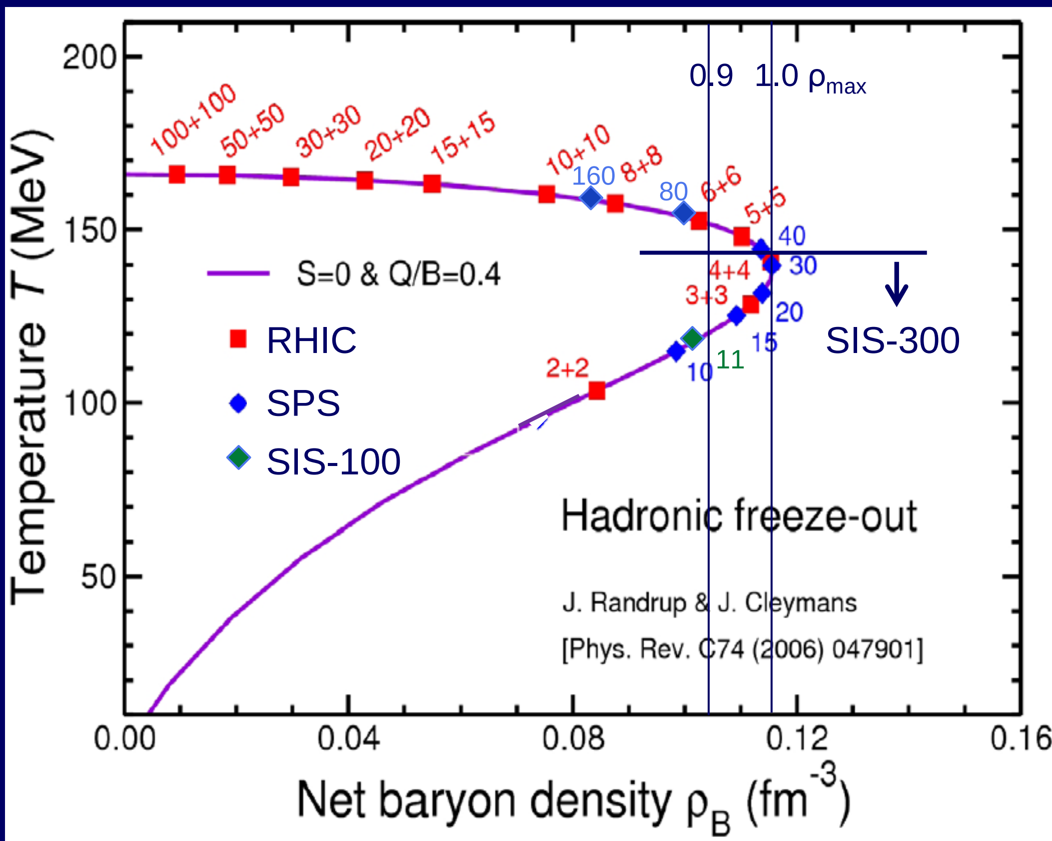
P. Chliapnikov et al. (1984), J. Antos et al. (1993), V. Perepelitsa et al., DELPHI (2004,2006, 2010)

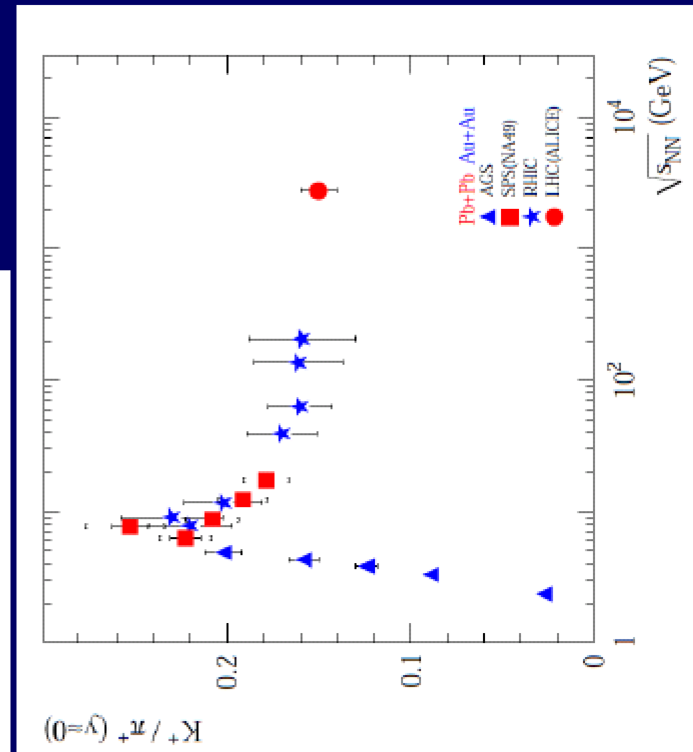
The low energy frontier

SPS Energy Range

Prime physics goal:

systematic measurement of EM radiation and charm over the full energy range from SIS-100 (11 AGeV) to top SPS (160 AGeV)





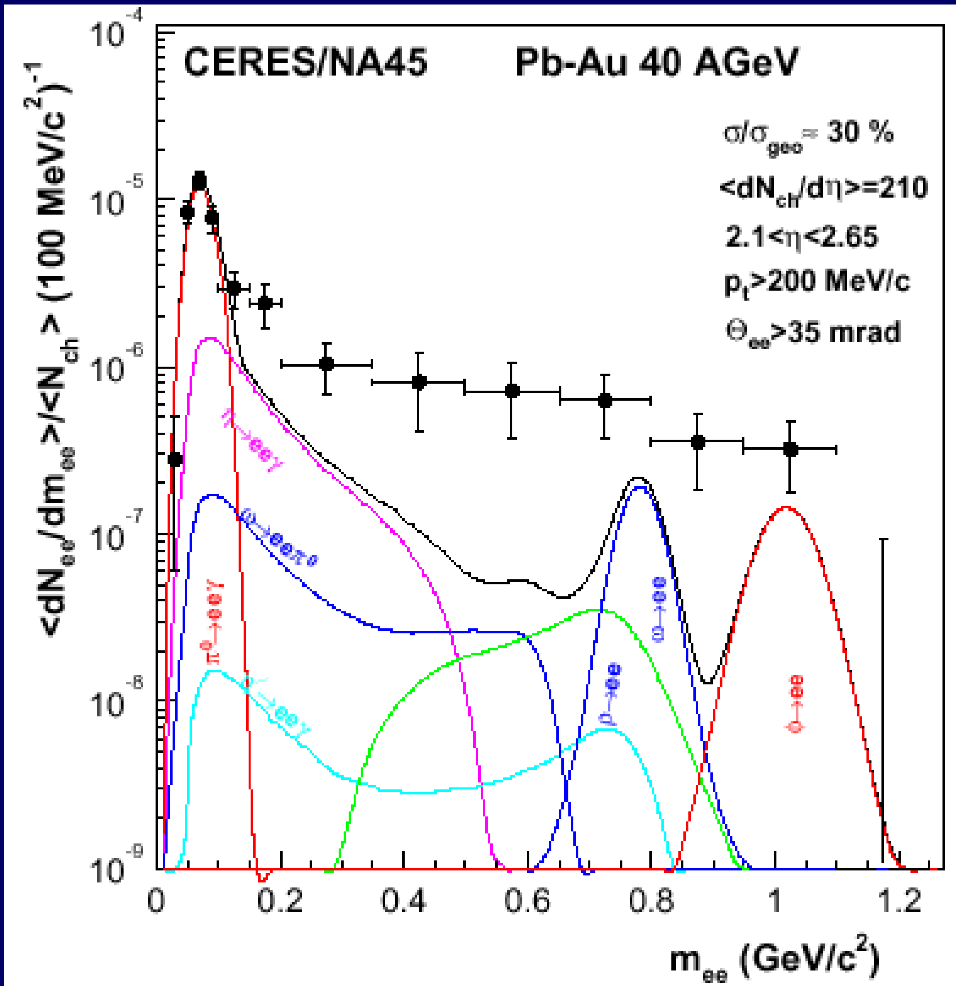
Problem of SIS-300:
max beam energy 35 AGeV

only low side of peak covered

would not see onset of deconfinement (+critical point?)

The only dilepton data at lower SPS energies so far

Phys. Rev. Lett. 91 (2003) 042301



Enhancement factor:
5.9 1.5(stat.) 1.2(syst.)

(published   1.8 (syst. cocktail) removed due to the new NA60 results on the η and ω FFs)

Higher baryon density at 40 than at 158 AGeV

↓

Larger enhancement in support of the decisive role of baryon interactions

Beam conditions: CERN vs. GSI/FAIR

	SPS			SIS100/300
Energy range: [AGeV]	10 – 158			< 11 – 35 (45)
	beam intensity [Hz]	target thickness [λ_i]	interaction rate [Hz]	interaction rate [Hz]
NA60 (2003)	2.5 10^6	20%	5 10^5	
new injection scheme	10^8 10^8	10% 1%	10^7 10^6	10^5 - 10^7
LHC AA			5 10^4	

Luminosity at the SPS comparable to that of SIS100/300

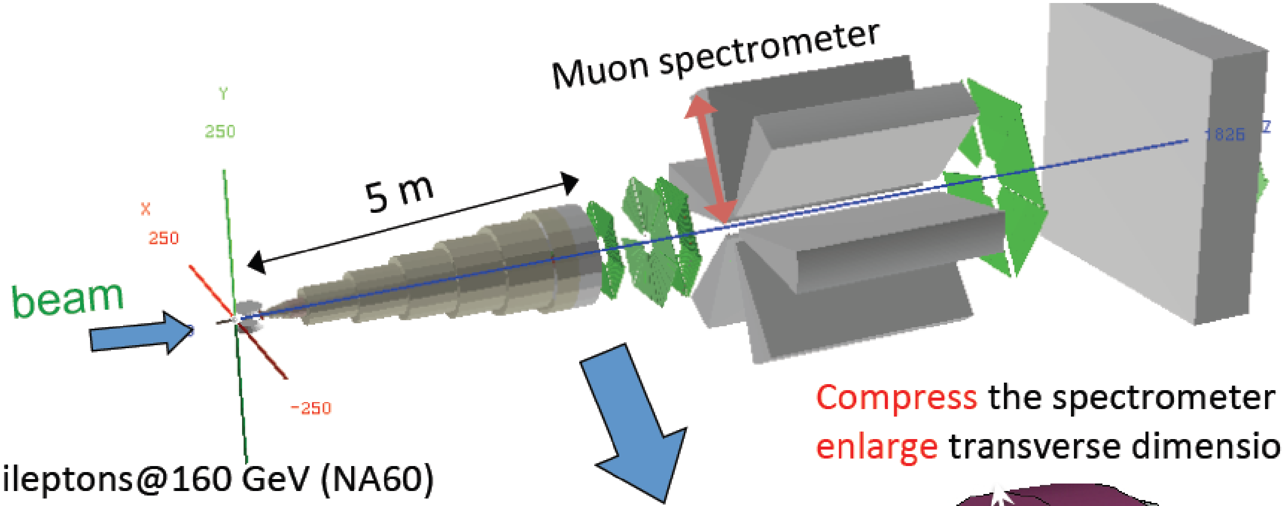
No losses of beam quality at lower energies except for emittance growth

RP limits at CERN in EHN1, not in (former) NA60 cave

Pb beams scheduled for the SPS in 2016-2017, 2019-2021

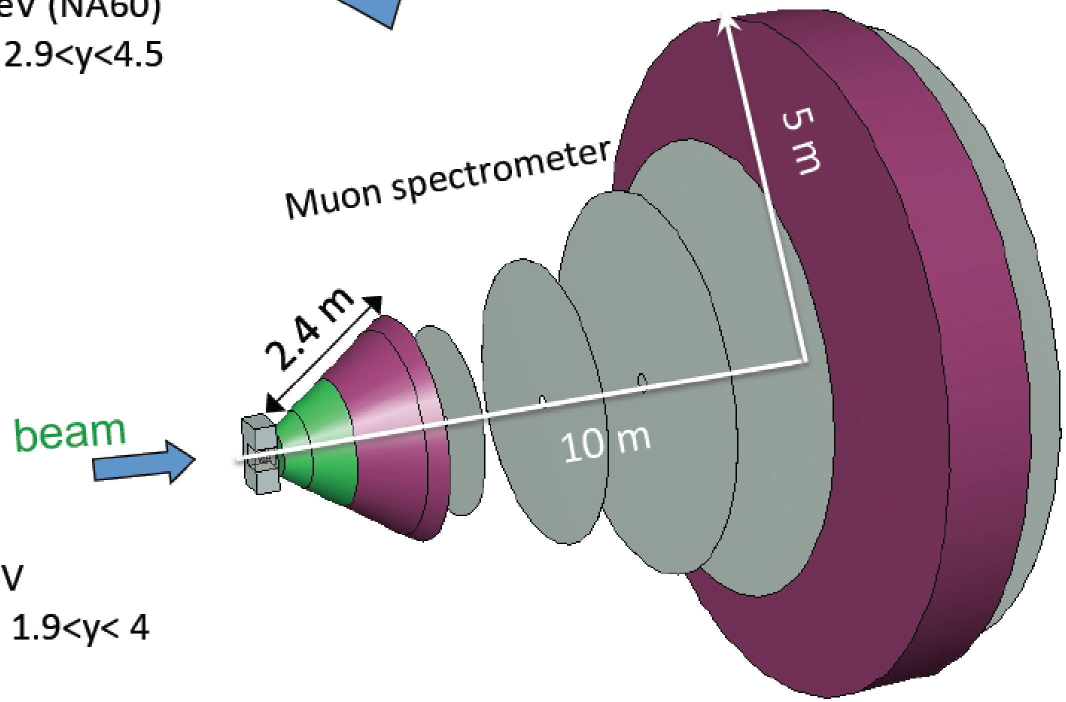
From the high to a low energy apparatus layout

G. Usai,
this meeting



dileptons@160 GeV (NA60)
rapidity coverage 2.9<y<4.5

Compress the spectrometer reducing the absorber and enlarge transverse dimensions



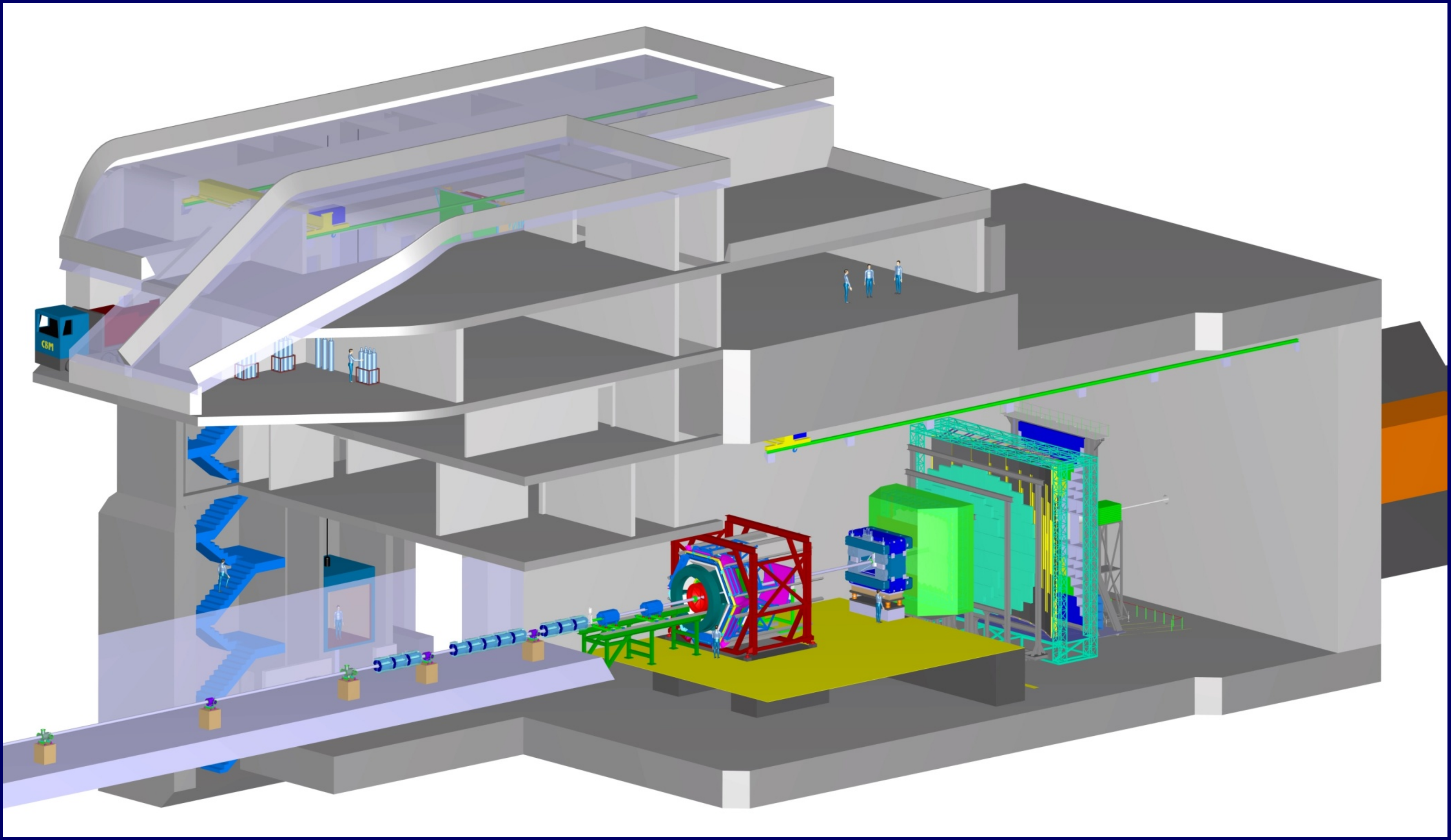
Generic geometry (Fluka)

dileptons@20 GeV
rapidity coverage 1.9<y< 4

Longitudinally scalable setup for running at different energies

3

Present concept at GSI FAIR



Operation of HADES and CBM in the same cave at SIS-100

How to optimize the physics outcome for the next 10-15 y

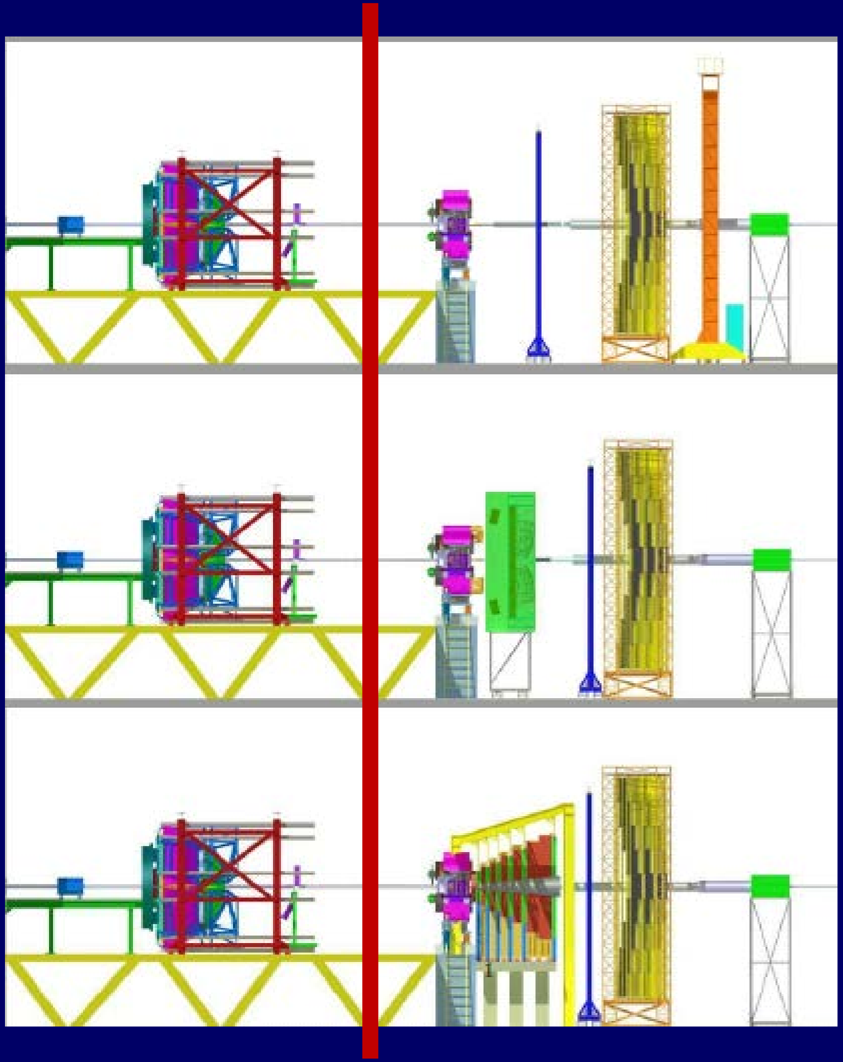
Proposal: split HADES and CBM at SIS-100

HADES at SIS-100

Upgrade HADES, optimized for e^+e^-, to also cope with Au-Au (now Ni-Ni)

Merge with part of personell of CBM

Profit from suitable R&D of CBM



CBM at SPS

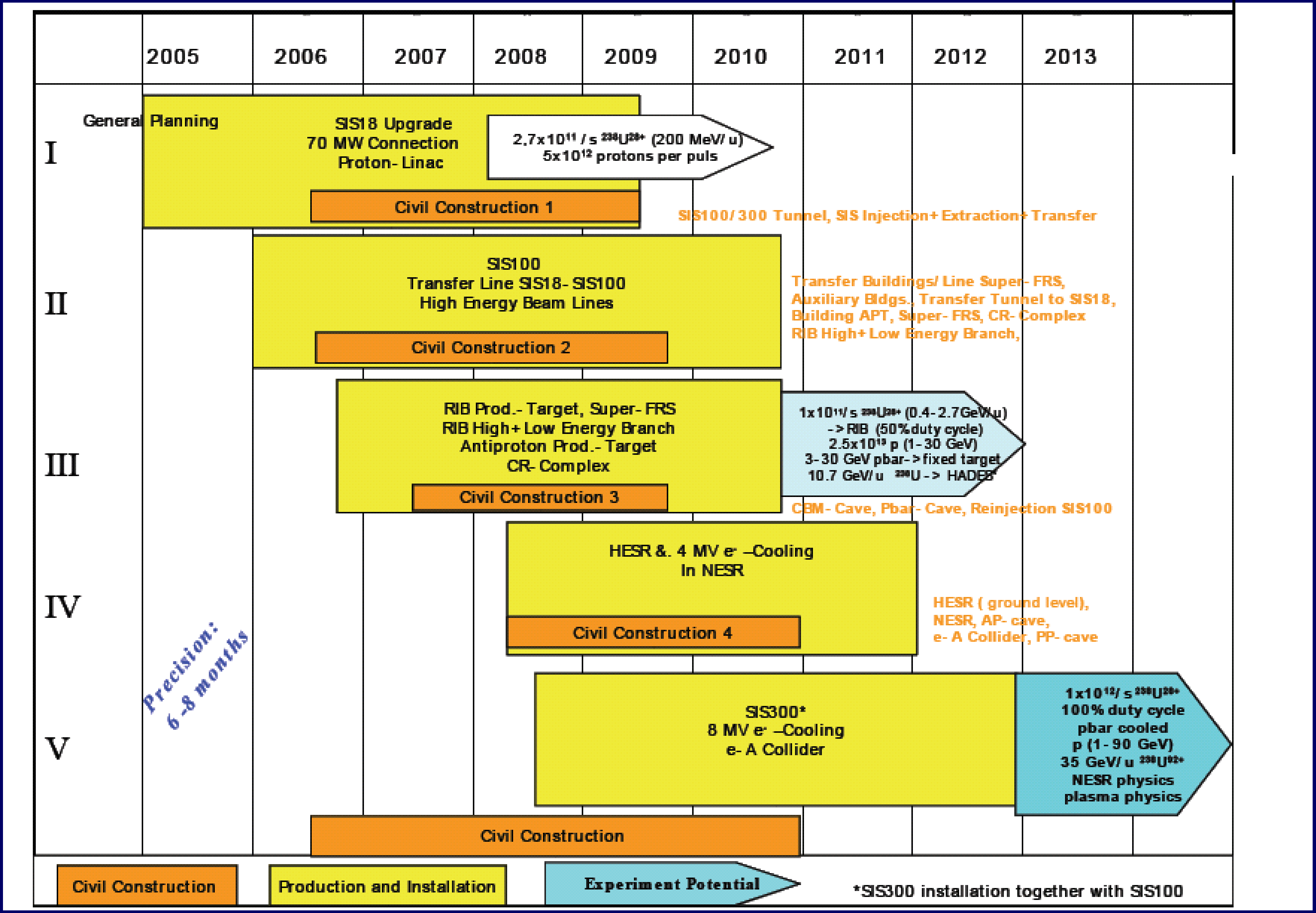
Modify CBM to be optimal (magnet) for either e^+e^- or $\mu^+\mu^-$; role of hadrons?

Merge with ‘CERN’ effort towards a NA60 successor experiment

Profit from suitable R&D of CBM, in particular for Si

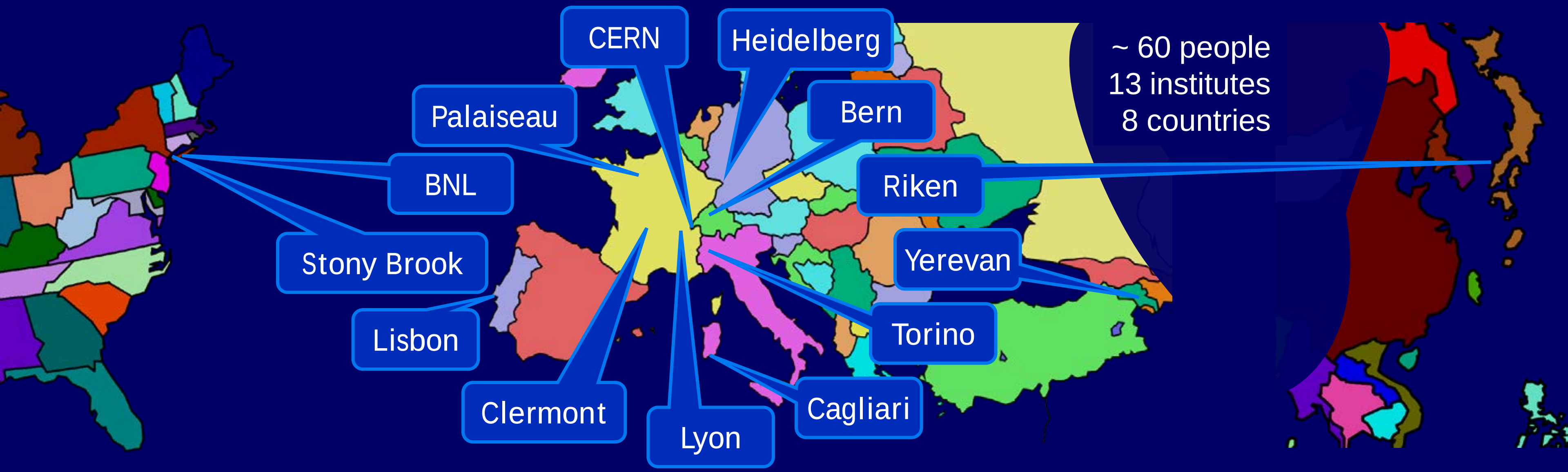
If SIS-300 would be approved in >2020, one could continue CBM there in >2027

GSI Planning as of 2004



The NA60 experiment

http://cern.ch/na60



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

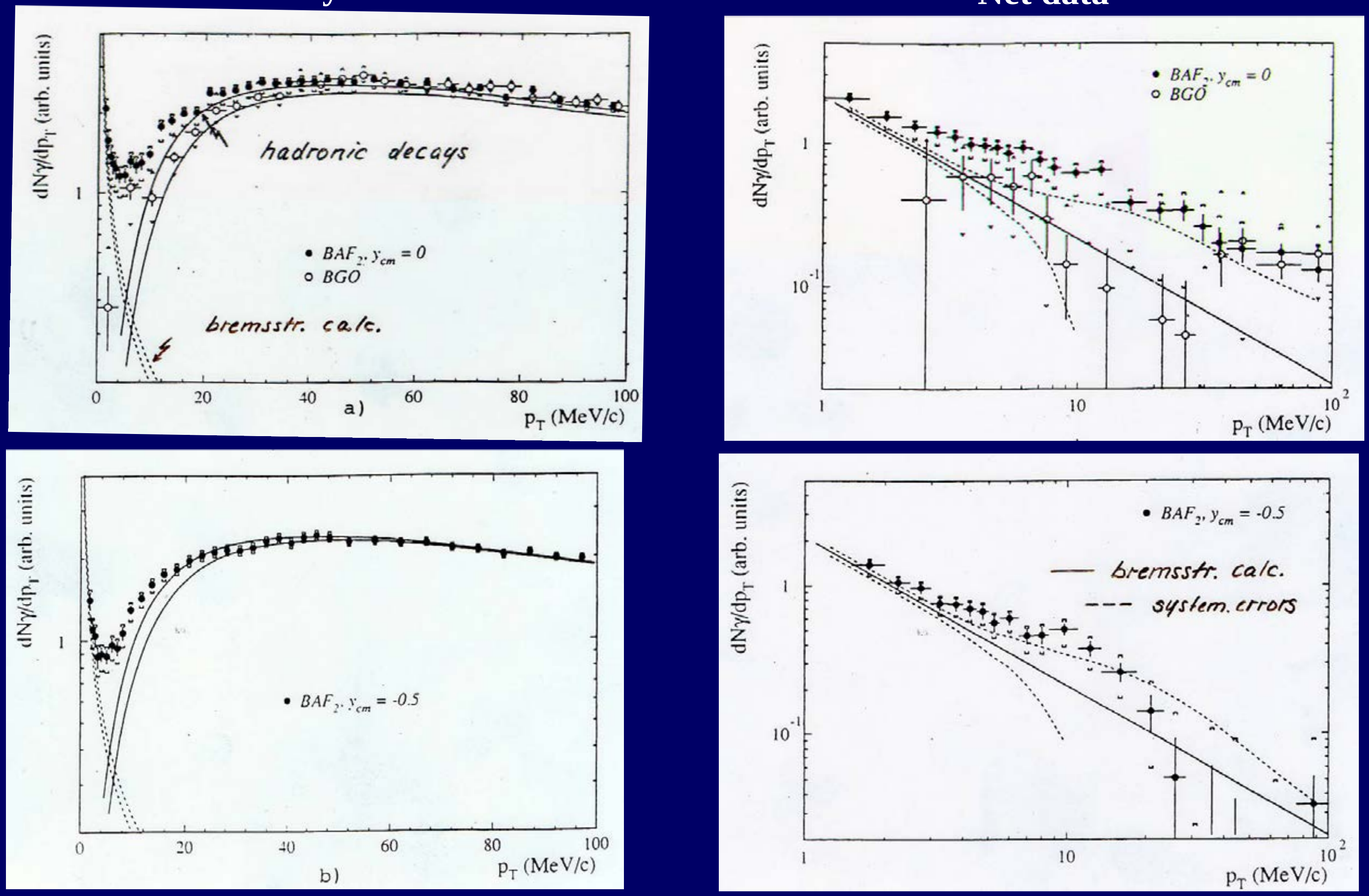
BKP

Soft Photon Bremsstrahlung

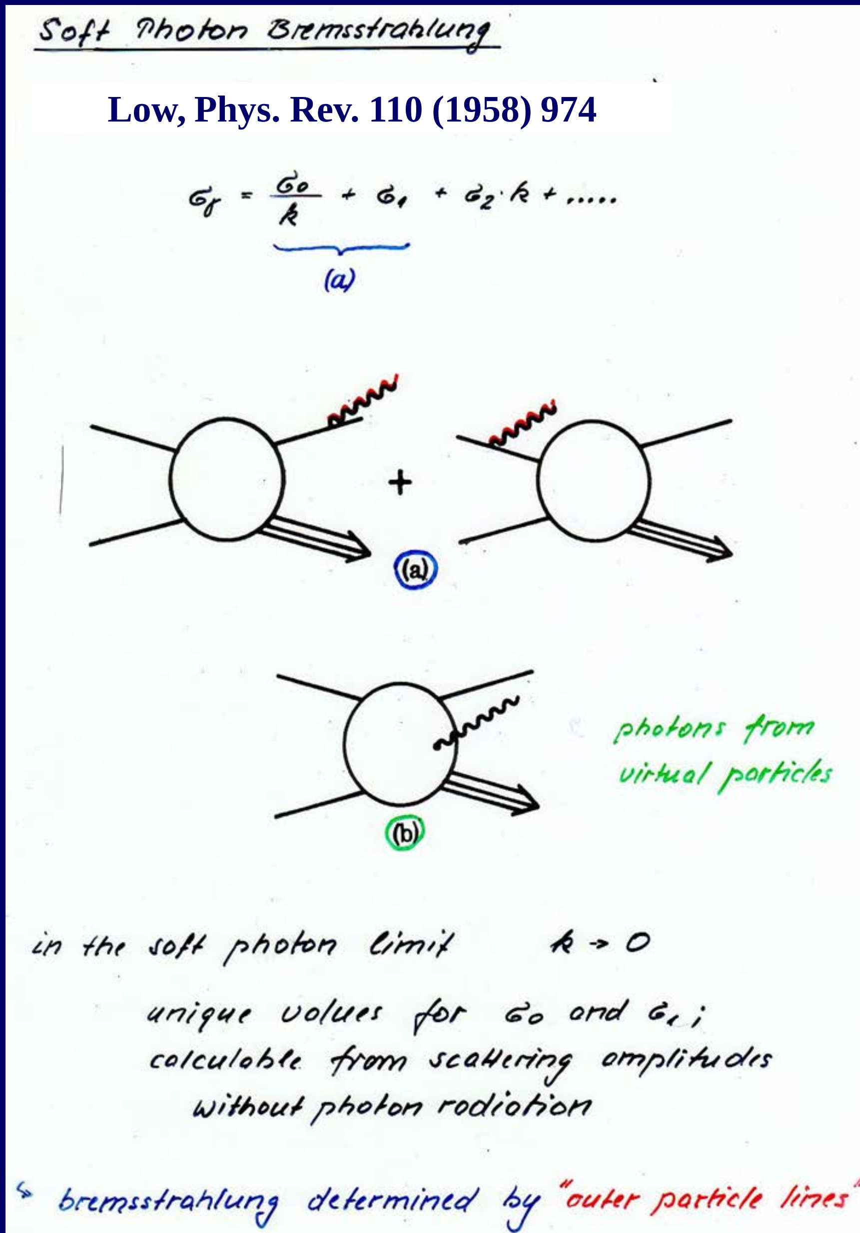
pBe at 450 GeV/c   SOPHY/BACY within HELIOS/NA34

Anthos et al., Z.Phys. C59 (1993) 547

Raw data + Decay Simulations   **Net data**



Soft Photon Bremsstrahlung



pp, pA

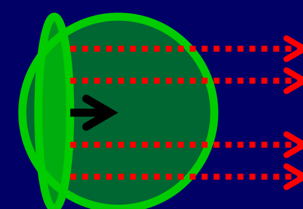
incoherent Bremsstrahlung:

hadrons radiate independently

"coherence":

hadrons radiate, not partons inside

AA



coherent Bremsstrahlung:

nuclei radiate, not hadrons inside

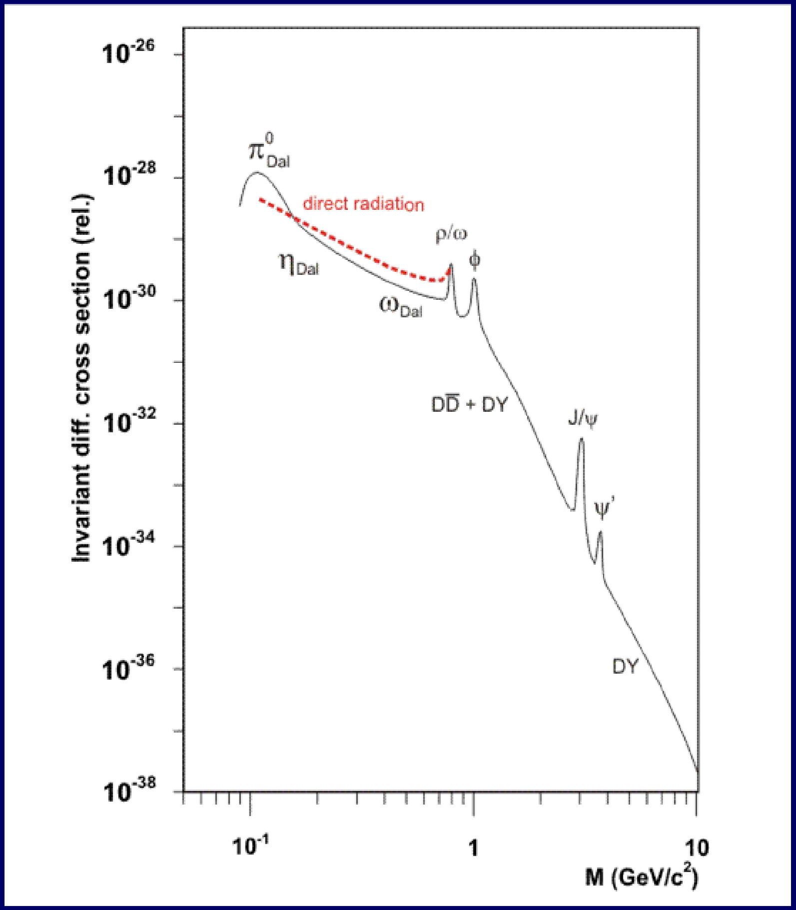
→ $\sigma \sim Z^2$! ⟶ collision dynamics

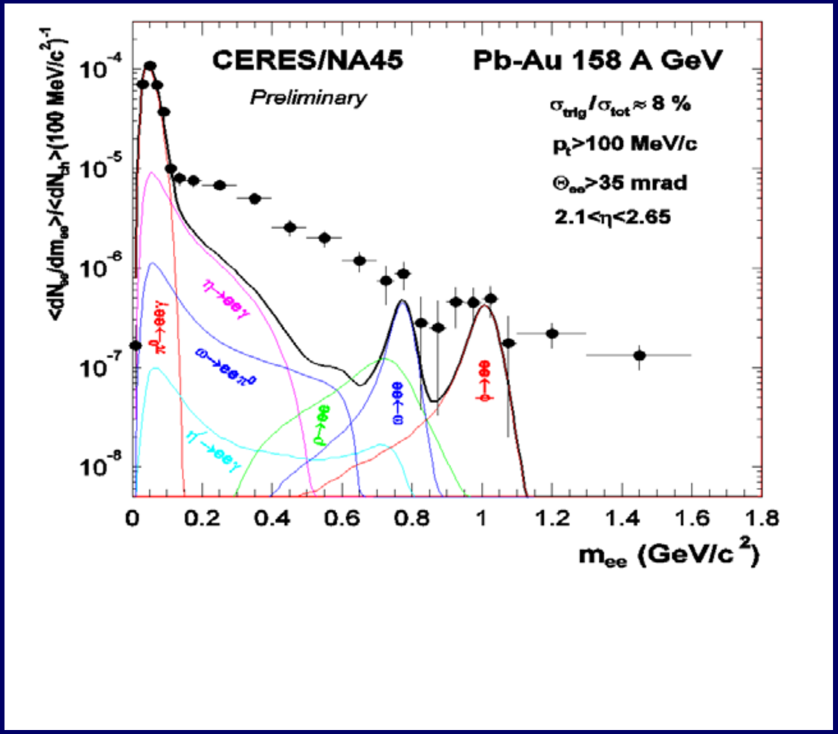
other sources of soft photons

"(first) window to chiral symmetry?"

C.Gale, HP2004

Soft Electron Pairs





cuts p_T<50, m_T<100

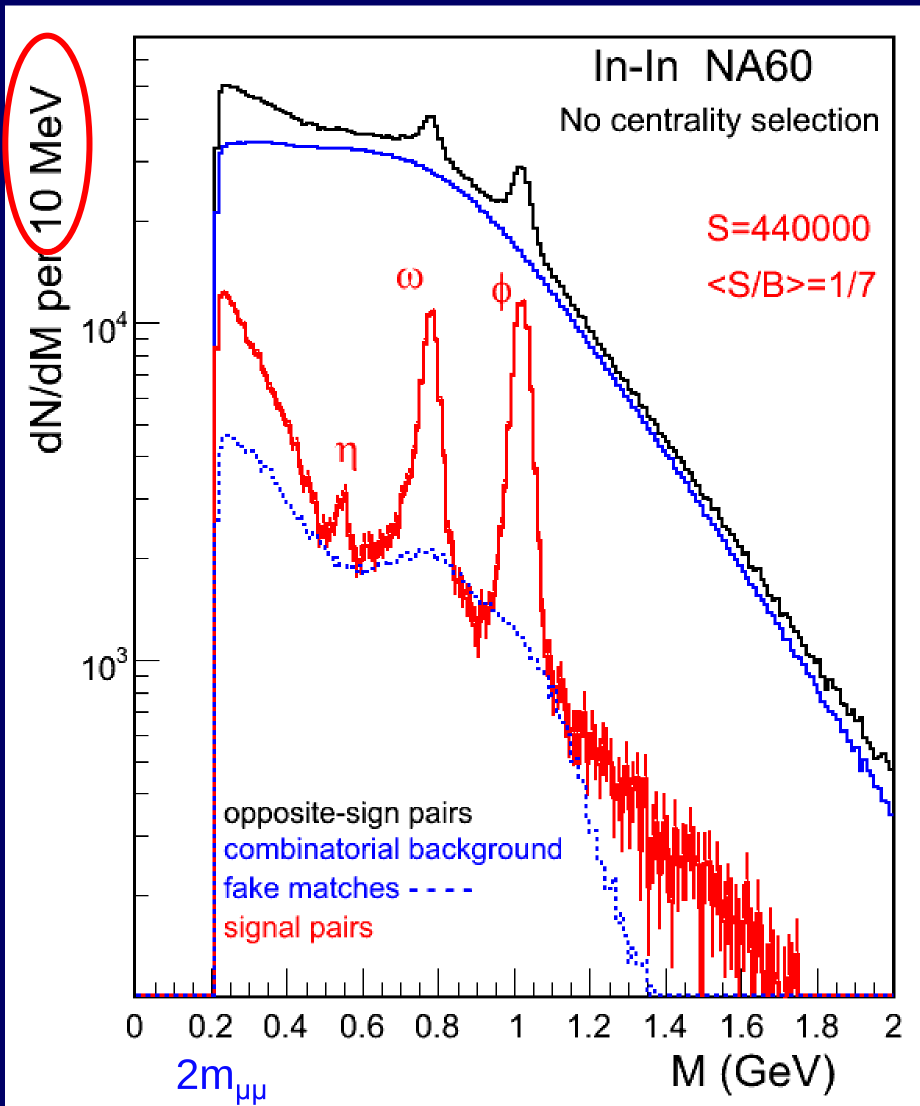
→ explore π^0 Dalitz region

(absolute normalization required)

S/B ratio may stay >1.2

Soft electron pairs have analogous information to soft photons

Data sample for 158A GeV In-In



subtraction of

- combinatorial background
- fake matches between the two spectrometers

S/B highest of all experiments, past and present (see below)

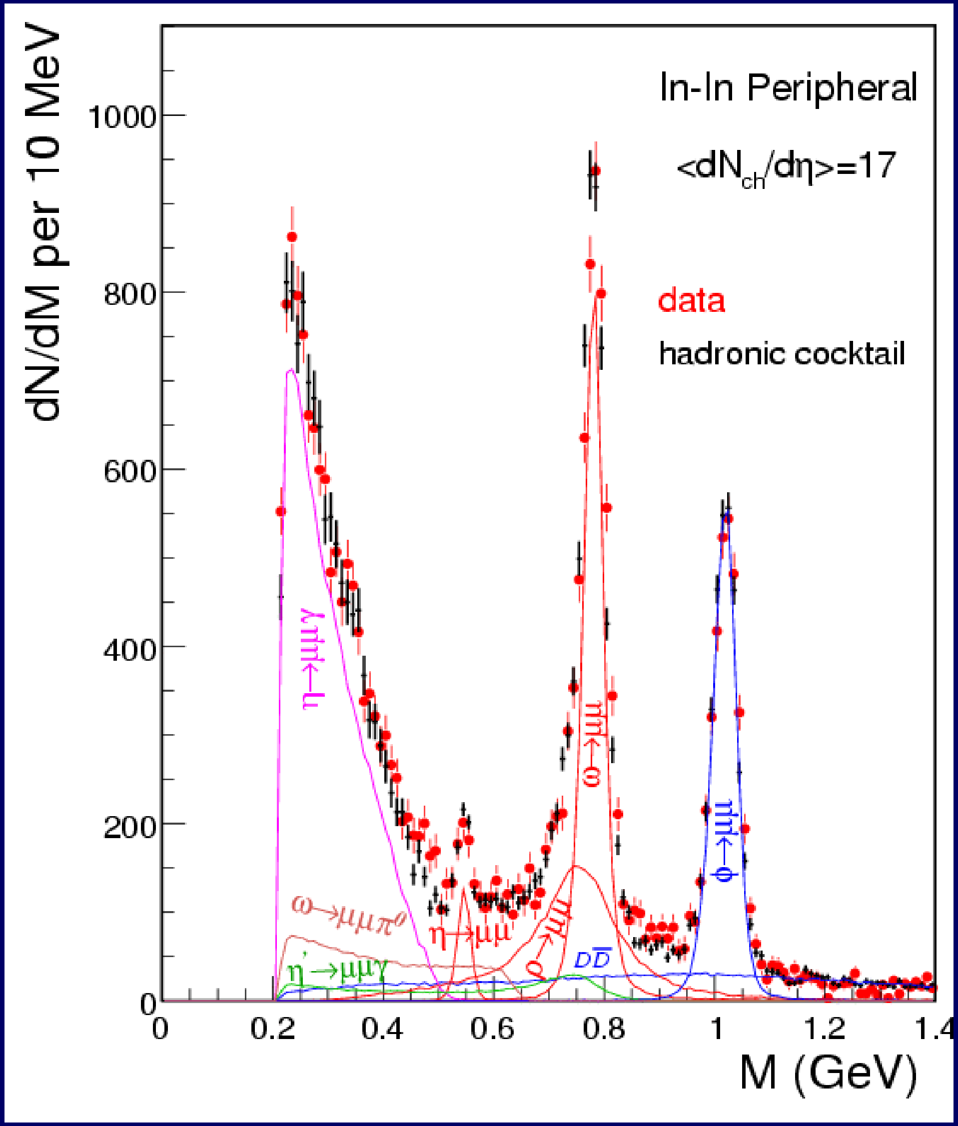
net sample:
440 000 events

effective statistics also highest of all experiments

mass resolution:
20 MeV at the ω position

η, ω, φ completely resolved

Understanding the peripheral data



Monte Carlo simulation of the expected dilepton sources:

electromagnetic decays:

2-body: $\eta, \rho, \omega, \phi \rightarrow \mu^+\mu^-$

Dalitz : $\eta, \eta' \rightarrow \mu^+\mu^- \gamma$

$\omega \rightarrow \mu^+\mu^-\pi^0$

EM transition form factors of the η and ω Dalitz decays remeasured here

semileptonic decays:

uncorr. $\mu^+\mu^-$ from $D\overline{D}$

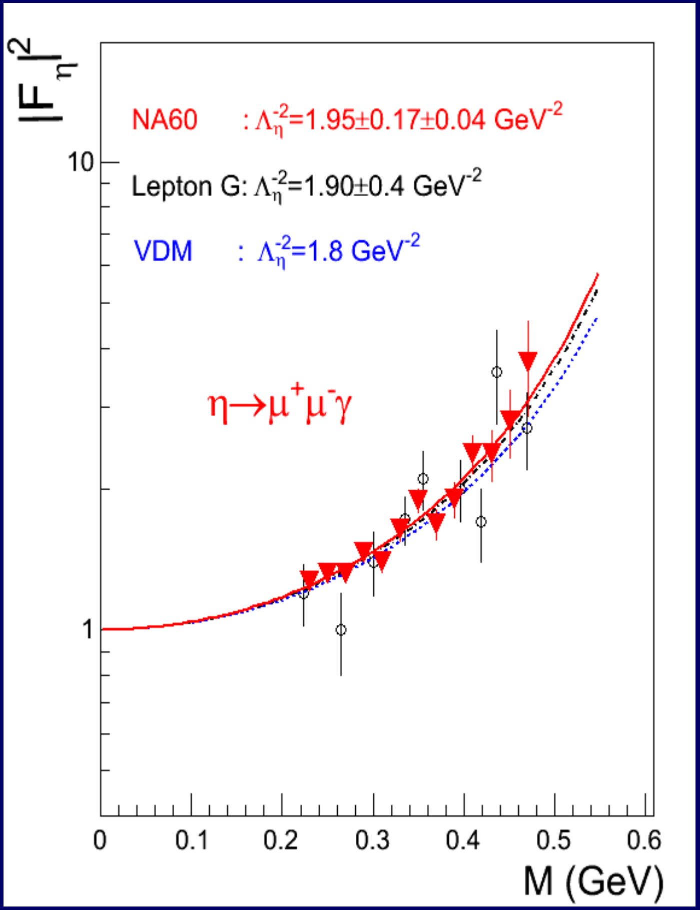
fit with free parameters:

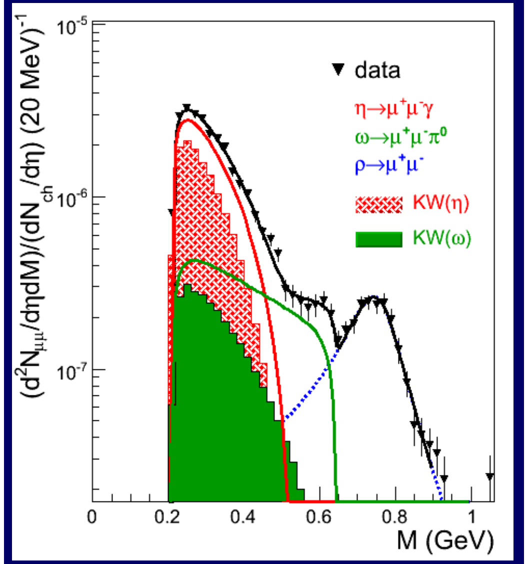
η/ω, ρ/ω, ϕ/ω, $D\overline{D}$

'perfect' description of the data

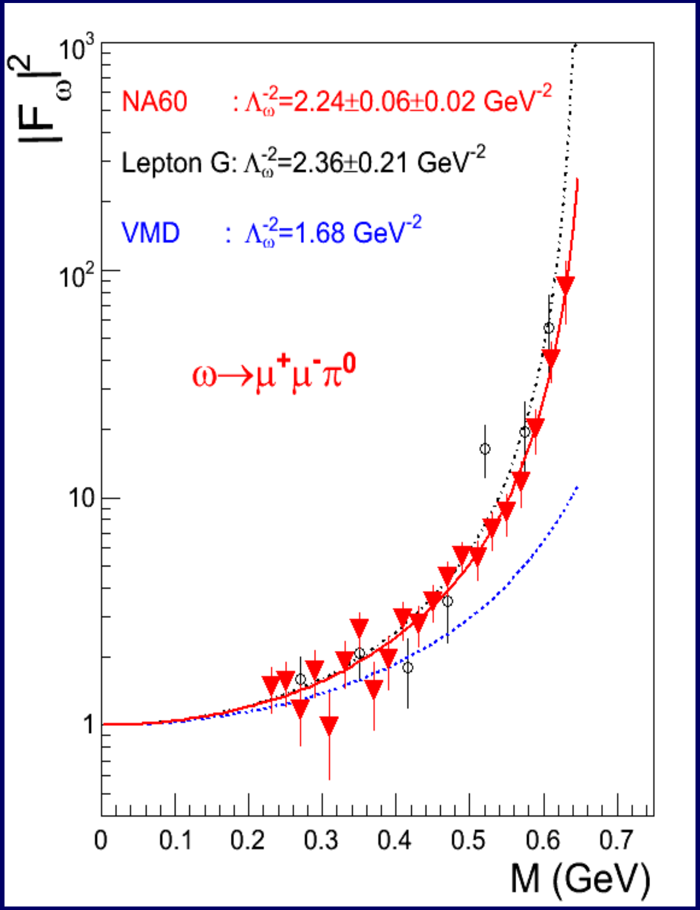
Results on Electromagnetic Transition Form Factors

Phys. Lett. B 677 (2009) 260





data corrected for acceptance



Perfect agreement of NA60 and Lepton G, confirming ω anomaly

Large improvement in accuracy; for ω, deviation from VMD 3 → 10 σ

NA60 p-A data: complete agreement, still higher accuracy (to be published)

NA60 results in the new edition of the PDG

LIGHT UNFLAVORED MESONS
$(S = C = B = 0)$

For $I = 1$ (π, b, ρ, a): $u\bar{d}$, $(u\bar{u} - d\bar{d})/\sqrt{2}$, $d\bar{u}$;
for $I = 0$ $(\eta, \eta', h, h', \omega, \phi, f, f')$: $c_1(u\bar{u} + d\bar{d}) + c_2(s\bar{s})$

$\omega(782)$ $\qquad I^G(J^{PC}) = 0^-(1^{--})$

$\omega(782)$ BRANCHING RATIOS

PDG 2008

$\Gamma(\pi^0\mu^+\mu^-)/\Gamma_{total}$ $\qquad$ **Γ_7/Γ**

VALUE (units 10^{-4})	*DOCUMENT ID*	*TECN*	*COMMENT*
0.96±0.23 OUR FIT			
0.96±0.23	DZHELYADIN 81B	CNTR	25–33 $\pi^- p \to \omega n$

PDG 2010

$\Gamma(\pi^0\mu^+\mu^-)/\Gamma_{total}$ $\qquad$ **Γ_7/Γ**

VALUE (units 10^{-4})	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
1.3 ±0.4 OUR NEW AVERAGE		Error includes scale factor of 2.1. [(0.96 ± 0.23) × 10^{-4} OUR 2009 AVERAGE]		
1.72±0.25±0.14	3k	ARNALDI 09	NA60	158*A* In–In collisions
0.96±0.23		DZHELYADIN 81B	CNTR	25–33 $\pi^- p \to \omega n$

PARAMETER Λ IN $\omega \to \pi^0\mu^+\mu^-$ DECAY

In the pole approximation the electromagnetic transition form factor for a resonance of mass *M* is given by the expression:

$$|F|^2 = (1 - M^2/\Lambda^2)^{-2},$$

where for the parameter Λ vector dominance predicts $\Lambda = M_\rho \approx 0.770$ GeV. The ARNALDI 09 measurement is in obvious conflict with this expectation. Note that for $\eta \to \mu^+\mu^-\gamma$ decay ARNALDI 09 and DZHELYADIN 80 obtain the value of Λ consistent with vector dominance.

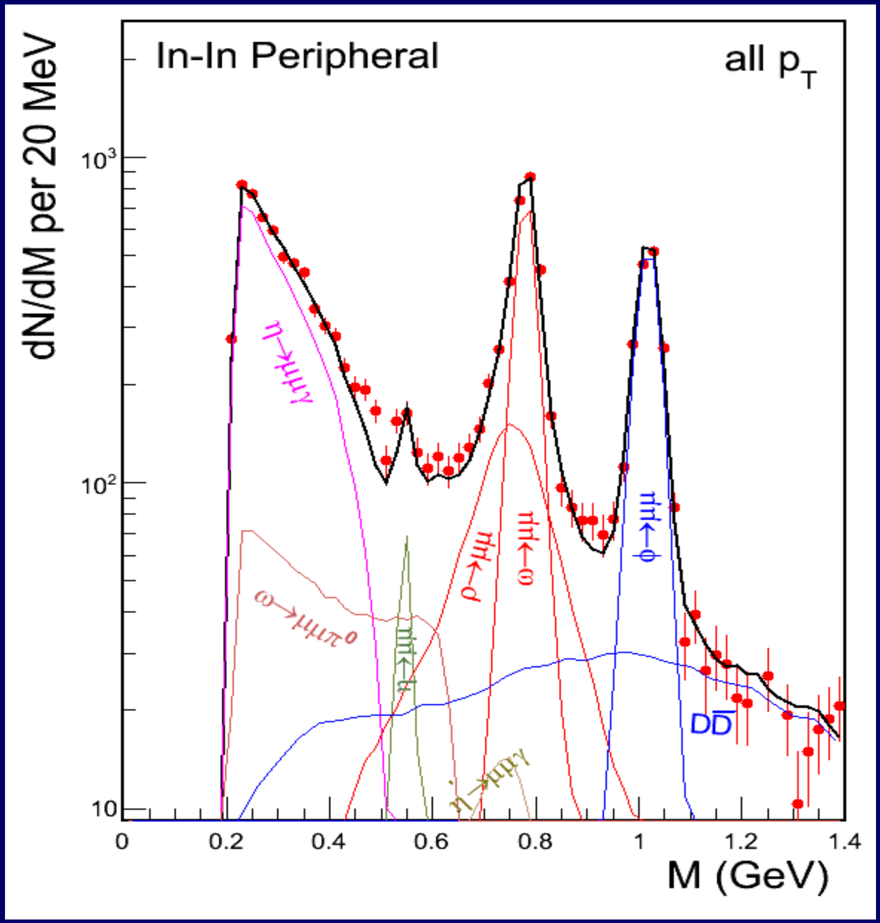
VALUE (GeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
0.668±0.009±0.003	3k	ARNALDI 09	NA60	158*A* In–In collisions
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.65 ±0.03		DZHELYADIN 81B	CNTR	25–33 $\pi^- p \to \omega n$

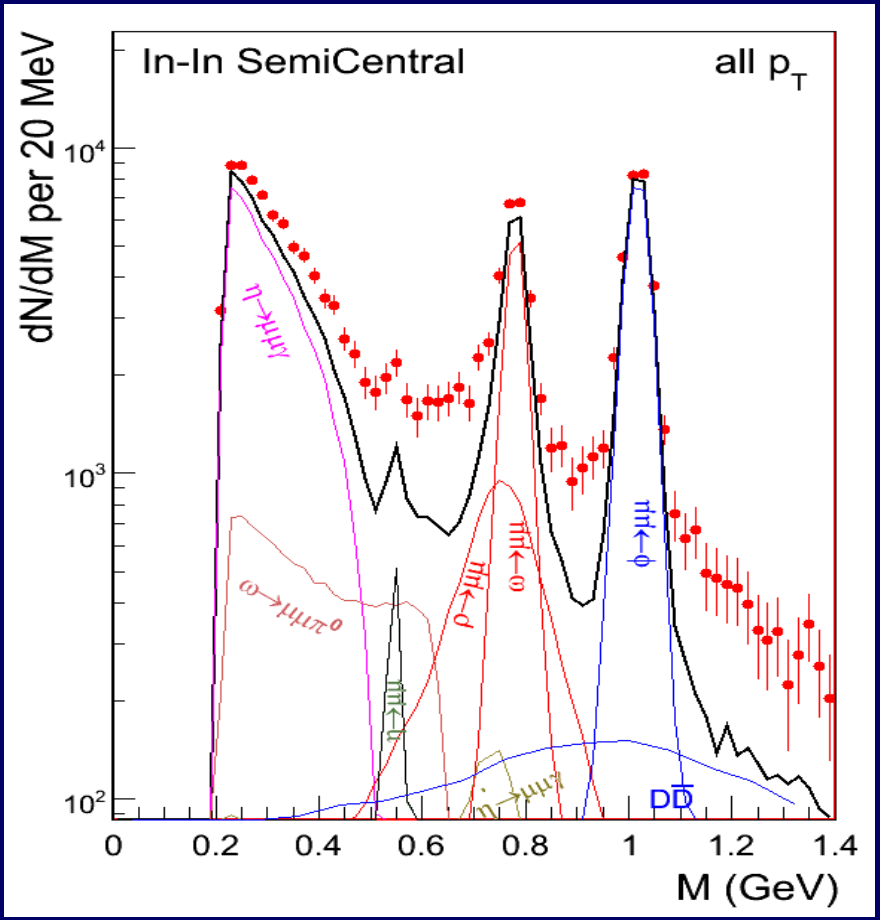
$\omega(782)$ REFERENCES

ARNALDI 09 PL B677 260 R. Arnaldi *et al.* (NA60 Collab.)
DZHELYADIN 81B PL 102B 296 R.I. Dzhelyadin *et al.* (SERP)
DZHELYADIN 80 PL 94B 548 R.I. Dzhelyadin *et al.* (SERP)

First result from a heavy-ion experiment in the PDG ever

Moving to higher centralities



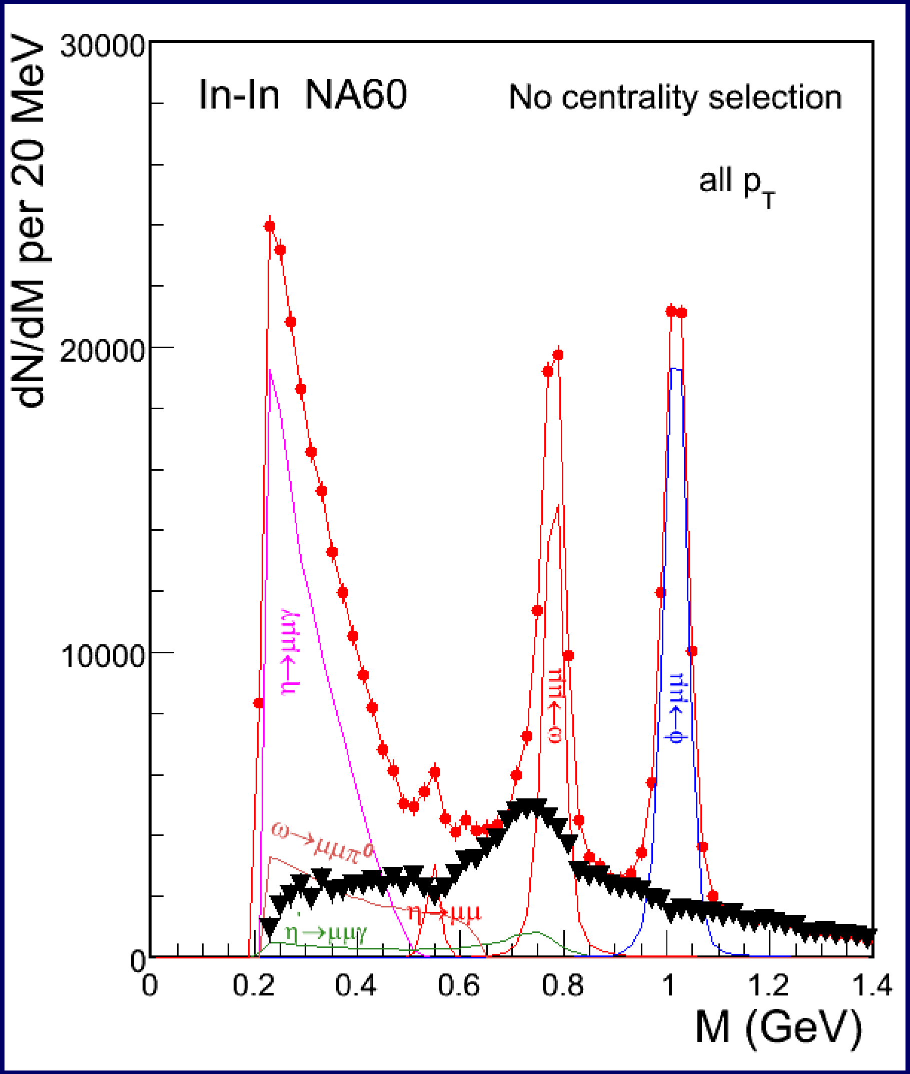


<u>Peripheral data</u>
well described by meson decay cocktail (η, η', ρ, ω, ϕ) and $D\overline{D}$

<u>More central data</u>
clear excess of data above decay cocktail; spectral shape ???

LMR (M<1 GeV) - isolation of 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, based on the very high sensitivity to the spectral shape of the Dalitz decay

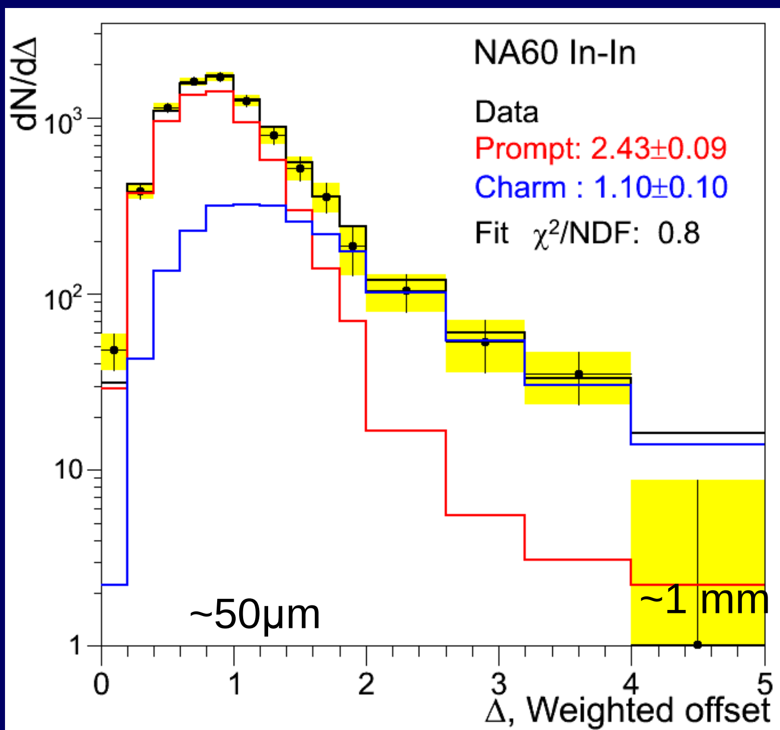
accuracy 2-3%, but results robust to mistakes even at the 10% level

keep information on subtracted hadrons and process separately

IMR (M>1GeV) – isolation of excess dimuons

Eur.Phys.J. C 59 (2009) 607

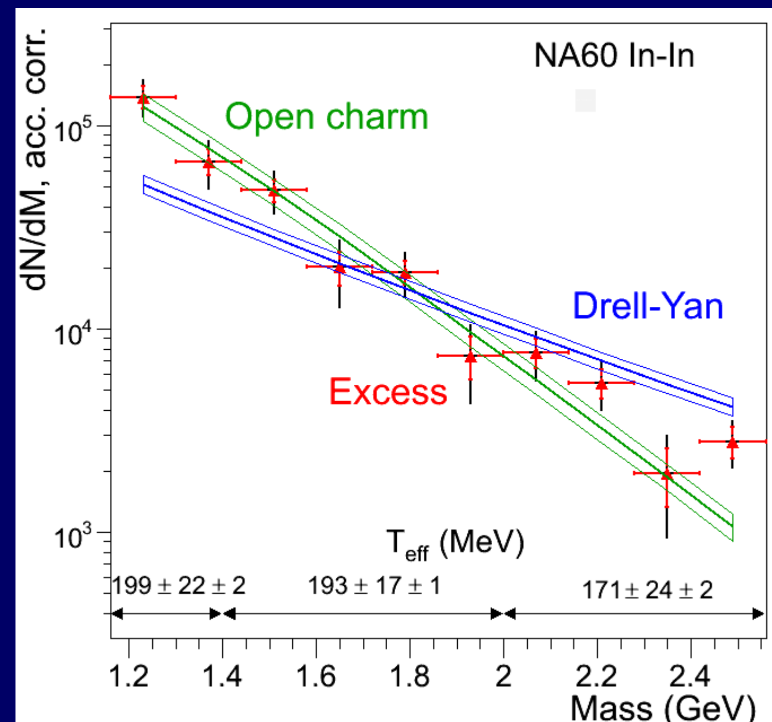
measurement of muon offsets Δμ: distance between interaction vertex and track impact point



charm not enhanced

excess prompt; 2.4   DY

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



excess similar to open charm

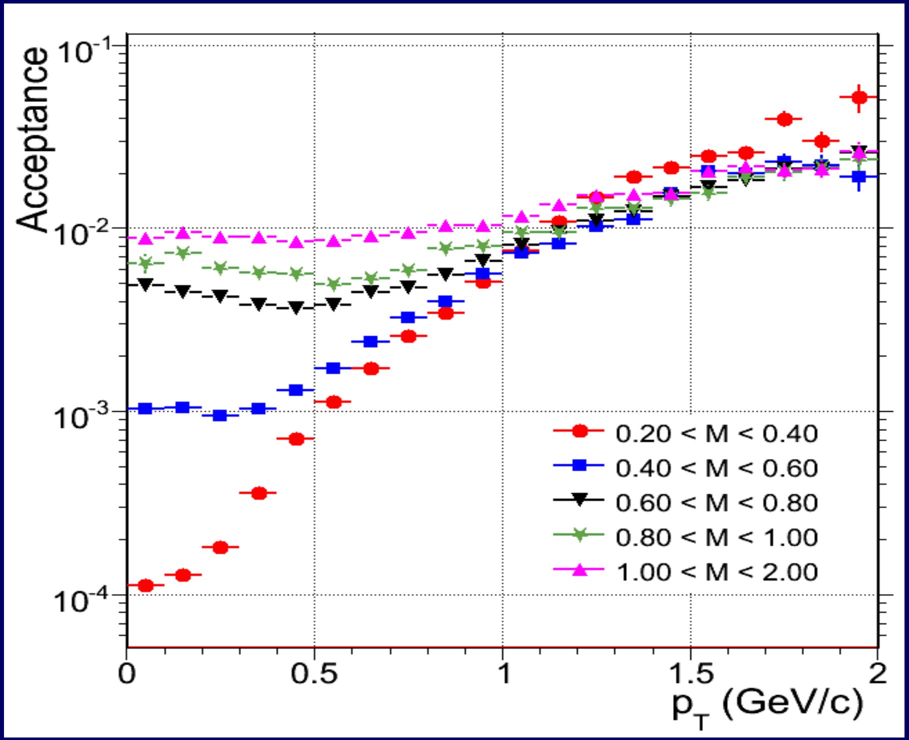
steeper than Drell-Yan

Acceptance correction

reduce 4-dimensional acceptance correction in M-p_T -y-cosΘ_{CS} to (mostly) 2-dimensional corrections in pairs of variables. Example M-p_T, using measured y distributions and measured cosΘ_{CS} distributions as an input; same for other pairs (iteration)

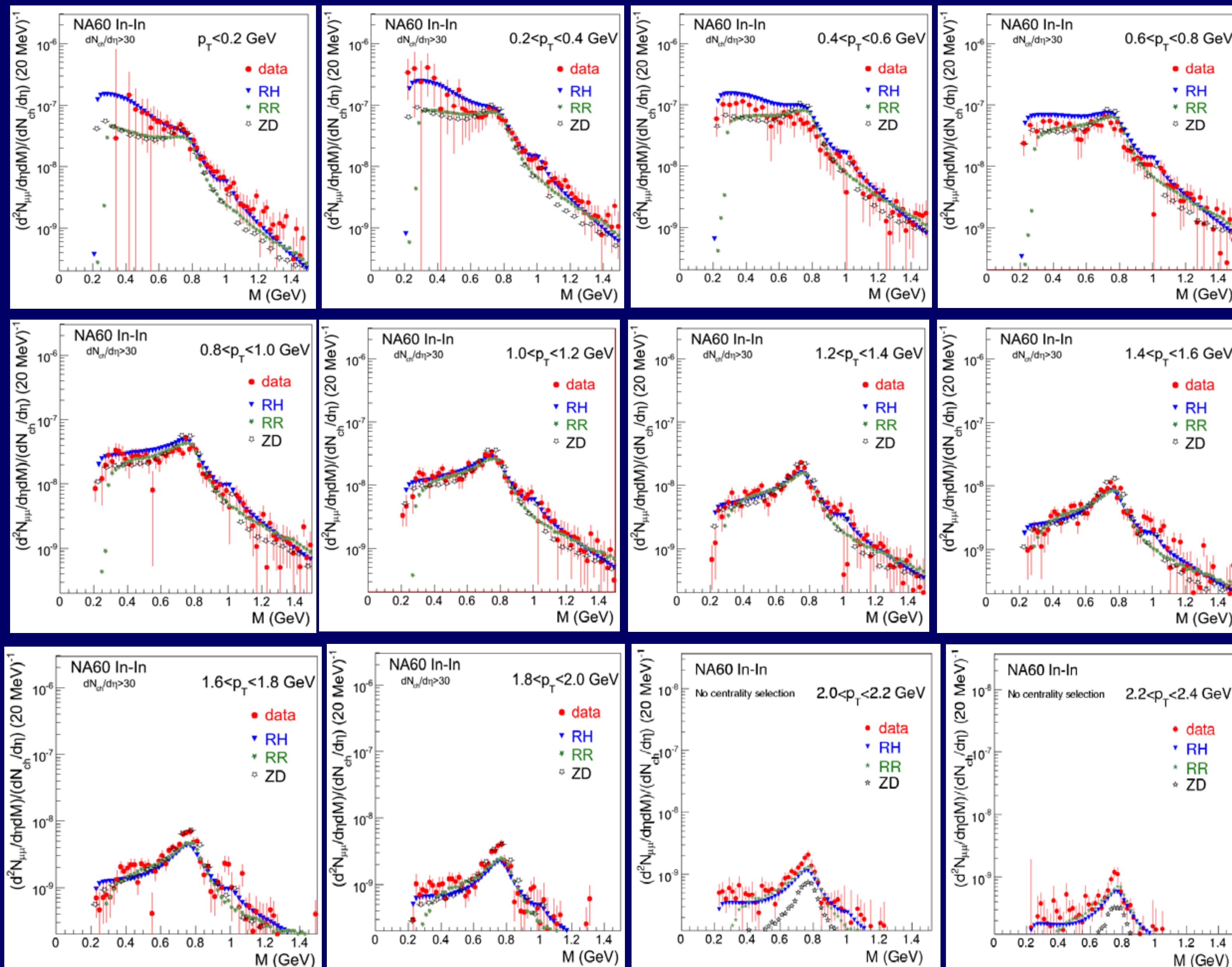
requires separate treatment of the excess and the other sources, due to differences in the y and the cosΘ_{CS} distributions

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



Thermal Radiation

Acceptance-corrected M-p_T matrix of excess



Rho Spectral Function

Unfolding the convoluted mass spectrum?

- Pure spectral function completely masked by the required convolution steps towards observable thermal radiation

- Strict unfolding impossible

- Realistic way: project out space-time averaged ρ-spectral function by use of a suitable correction function

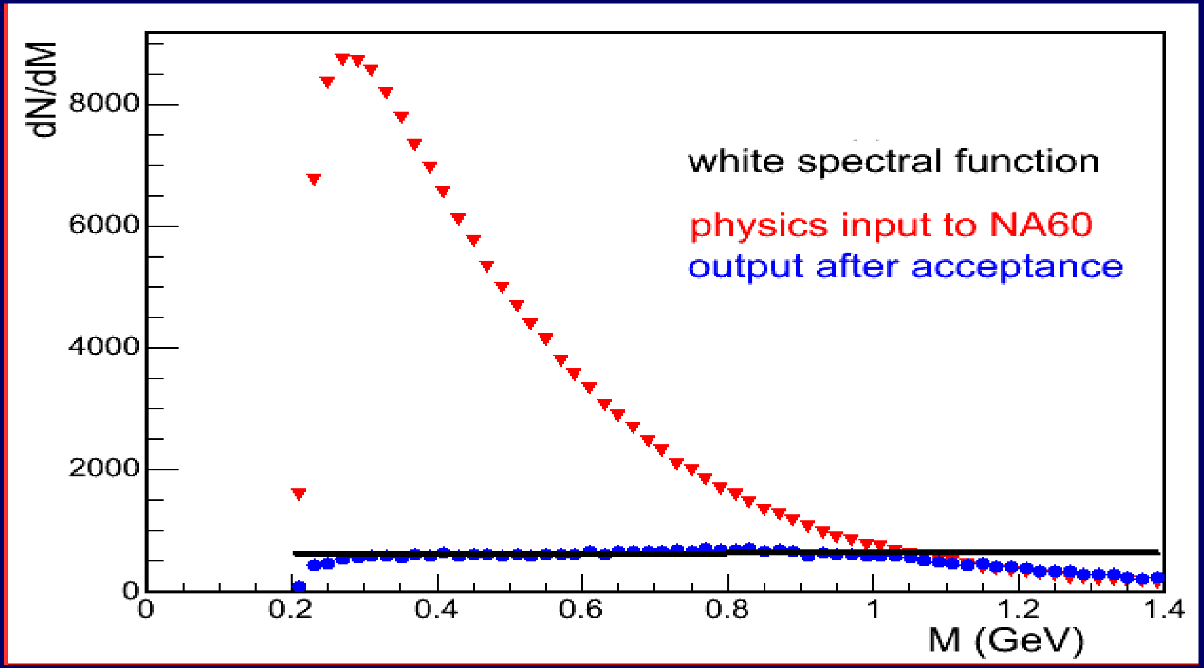
By pure chance

↓

Acceptance filtering by the NA60 set-up

$$dN_{\mu\mu}/dM \approx M^{3/2} \times \langle \exp(-M/T) \rangle \times \langle spectral\ \ function(M) \rangle$$

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



all p_T

input:

thermal radiation based on a white spectral function

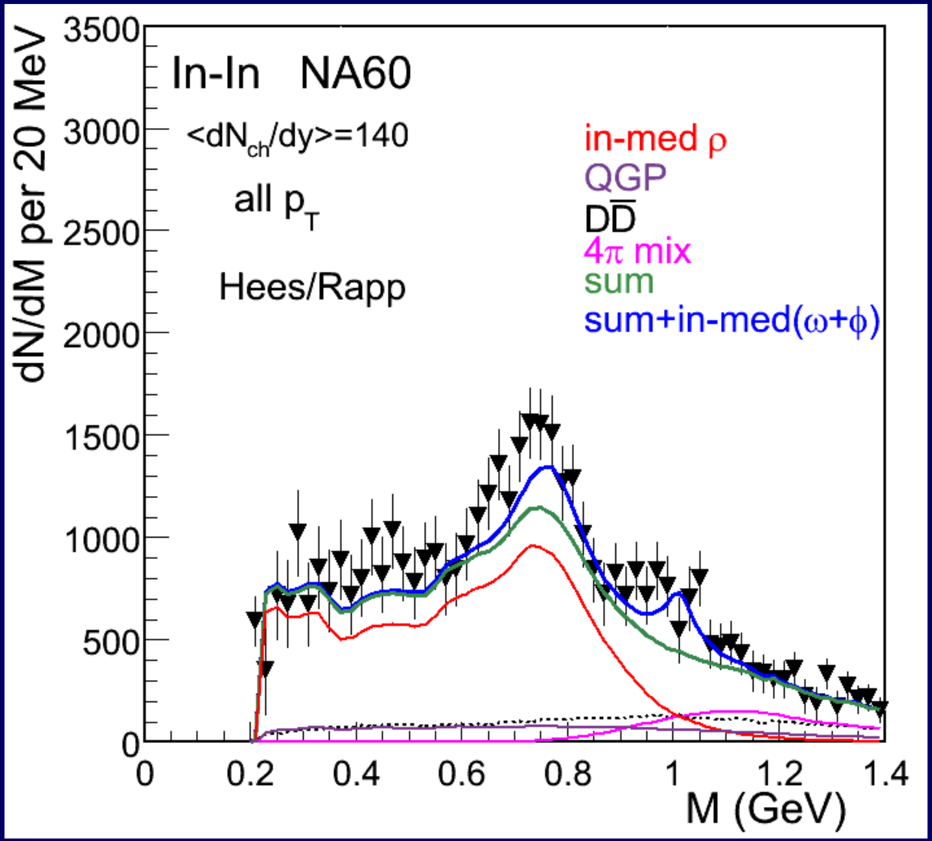
output:

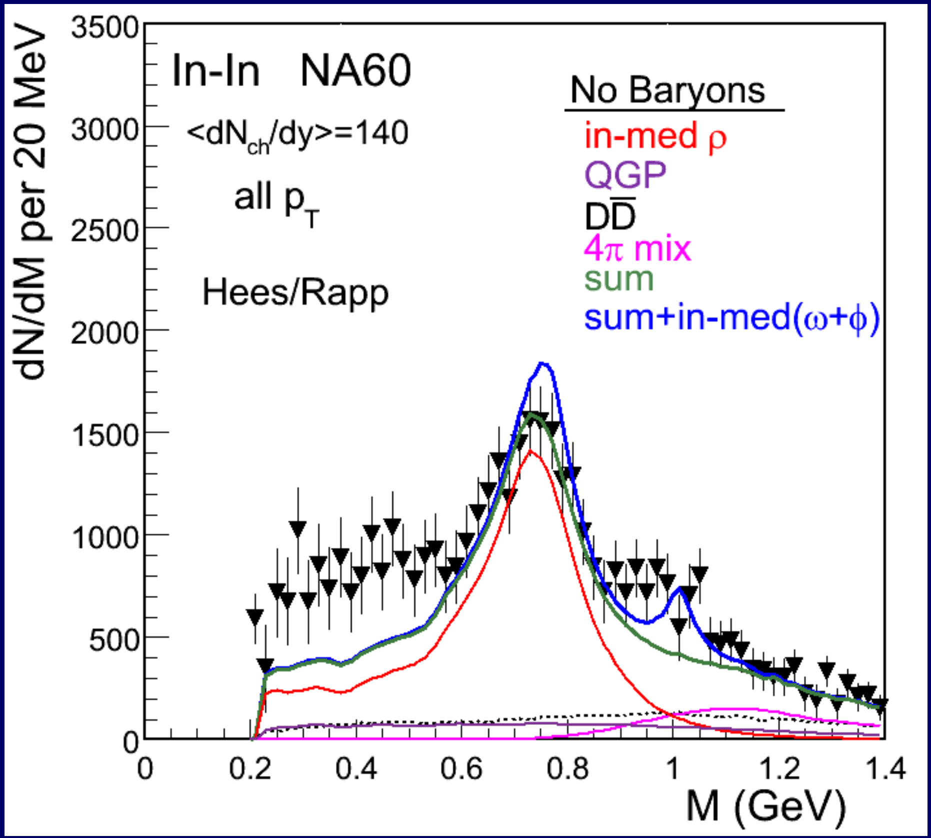
white spectrum !

By pure chance,
for the M-p_T characteristics of thermal radiation, without p_T selection,
the NA60 acceptance roughly compensates for the phase-space factors and directly ‘measures’ the <spectral function>

Role of baryons in broadening the ρ

van Hees and Rapp, Phys.Rev.Lett. 97 (2006) 102301





Whole spectrum reasonably well described, even in absolute terms

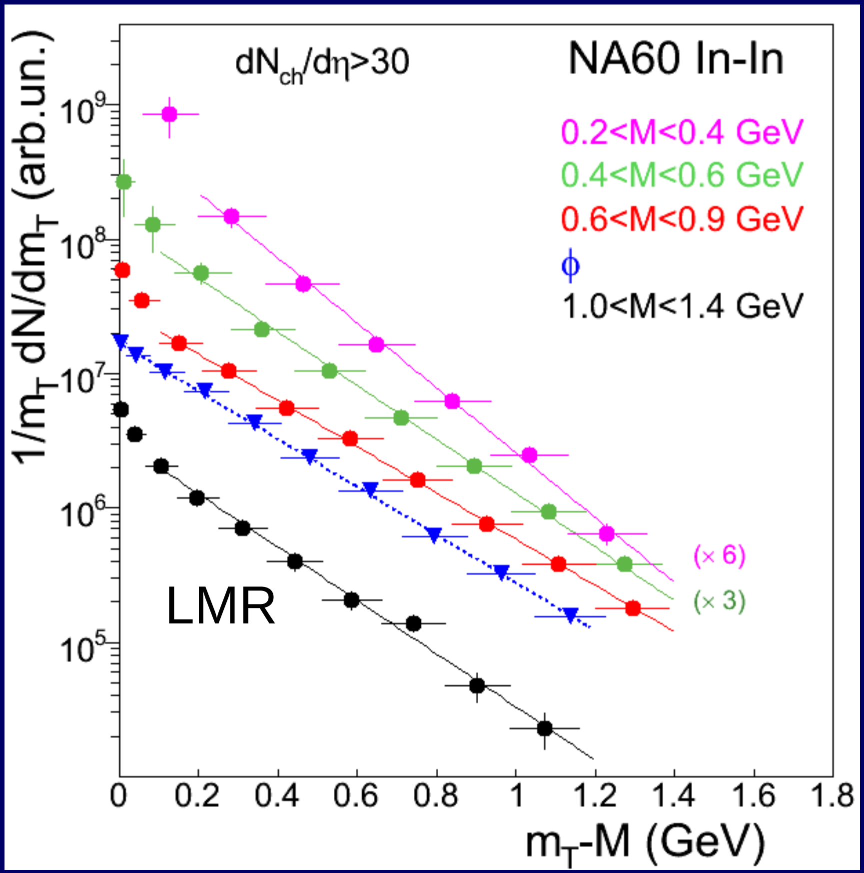
In this model, low-mass tail requires baryon interactions

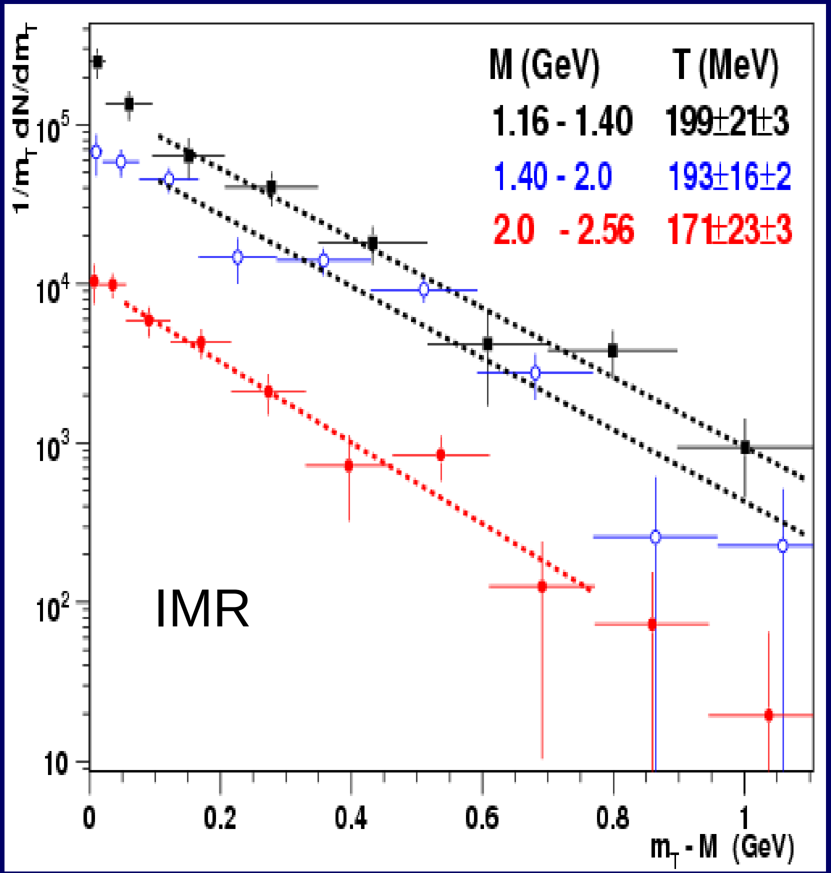
Radial expansion and the EoS close to T_c

Transverse mass distributions of excess dimuons

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

Phys. Rev. Lett. 100 (2008) 022302 *Eur. Phys. J. C 59 (2009) 607*



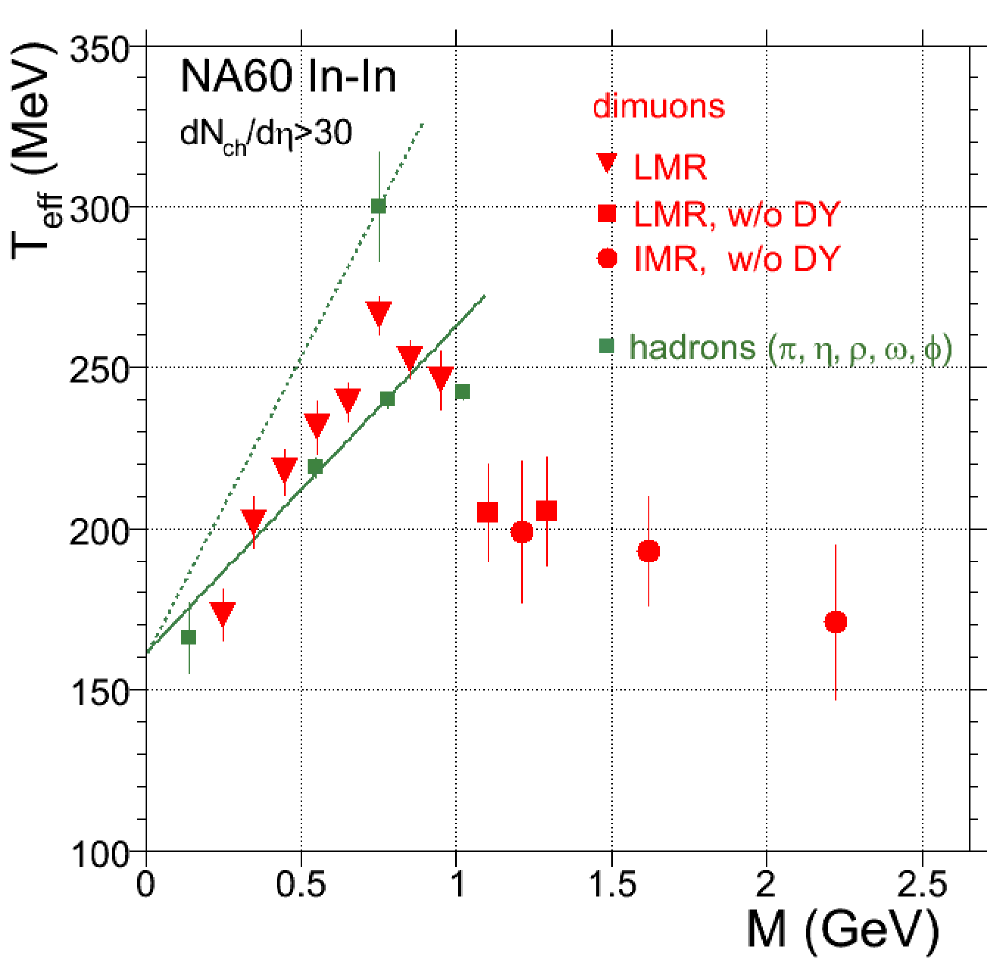


all m_T spectra exponential for m_T-M > 0.1 GeV; <0.1 GeV ??

fit with $1/m_T\ dN/m_T \sim \exp(-m_T/T_{eff})$; T_{eff} – 'effective temperature'

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 $\pi^+\pi^-\to\rho\to\mu^+\mu^-$), taking the freeze-out ρ as the reference (from a separate analysis of the ρ peak and the continuum)

Drop signals sudden transition to a low-flow, i.e. an early source → partonic origin (here $q\bar{q}\to\mu^+\mu^-$)

Dominance of partons for M>1 GeV also from p_T spectra

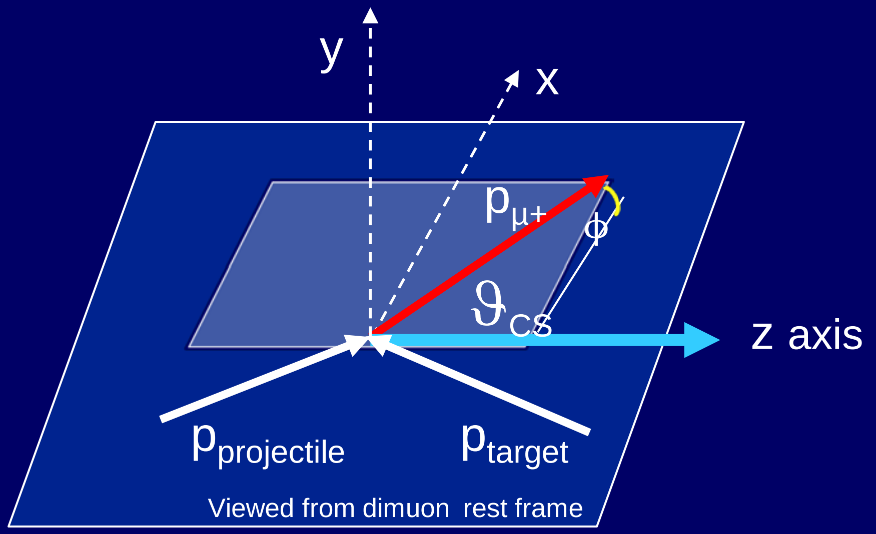
Angular distributions

Angular distributions

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

λ, μ, ν : structure functions related to helicity structure functions and the spin density matrix elements of the virtual photon

Choice of reference frame: Collins-Soper (CS)



In rest frame of virtual photon:

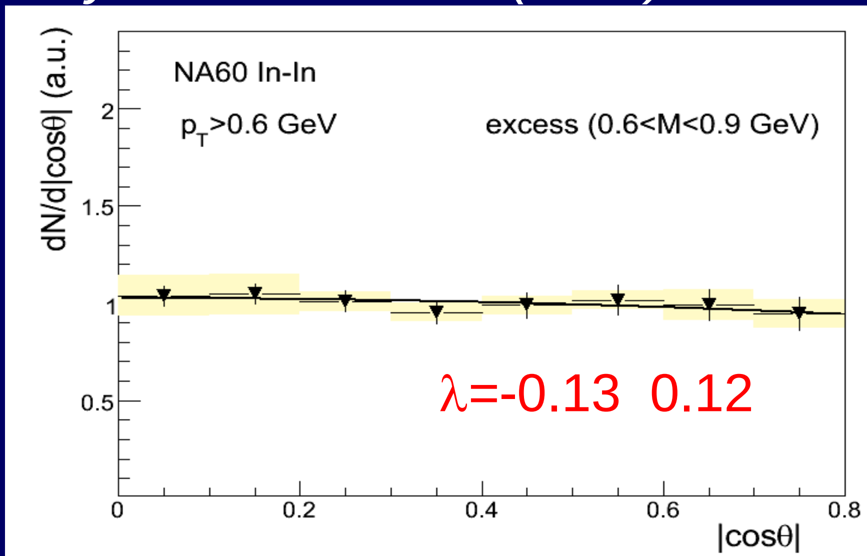
θ : angle between the positive muon $\mathbf{p}_{\mu+}$ and the z-axis.

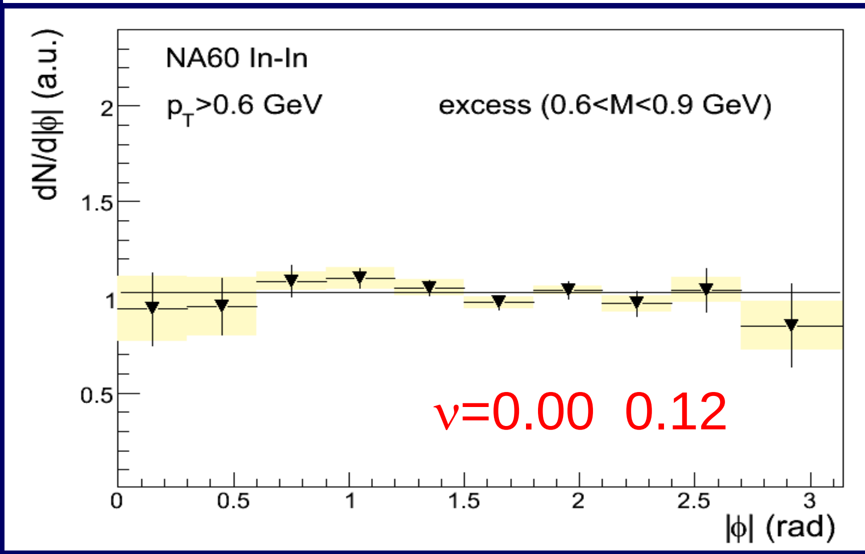
z axis : bisector between $\mathbf{p}_{proj}$ and $-\mathbf{p}_{target}$

Expectation: completely random orientation of annihilating particles (pions or quarks) in 3 dimensions would lead to λ, μ, ν = 0

Results on structure coefficients λ, μ, ν

Phys. Rev. Lett. 102 (2009) 222301





example:
excess 0.6<M<0.9 GeV

μ =   0.05   0.03 (~0 as expected)
set μ = 0 and fit projections

fit function for polar angle

$$\frac{dN}{d|\cos\theta|} \propto \left(1 + \lambda \cos^2 \theta\right)$$

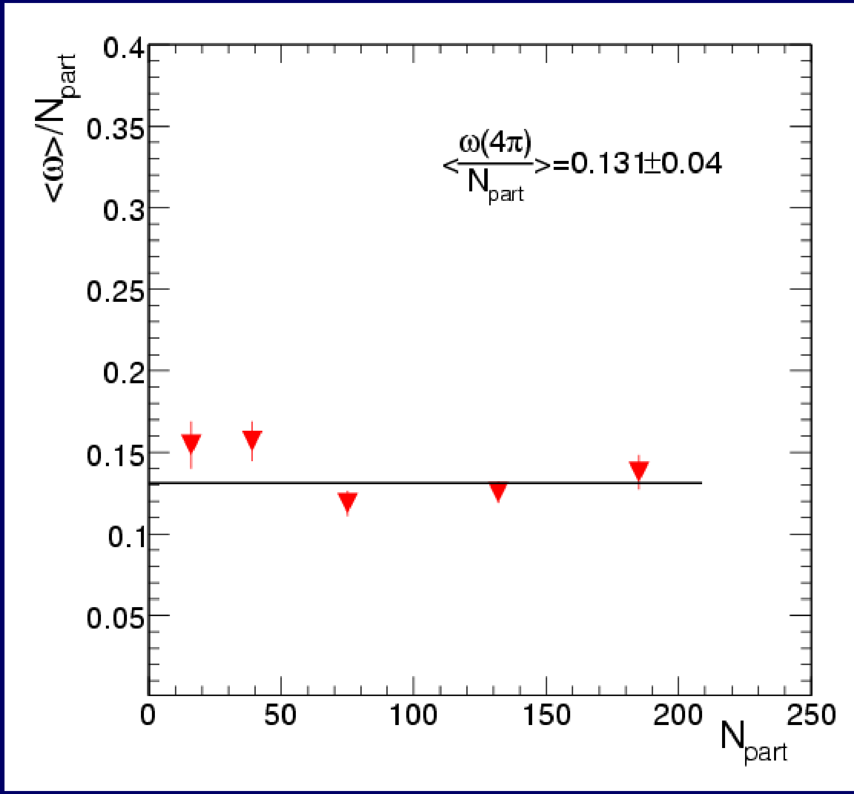
fit function for azimuth angle

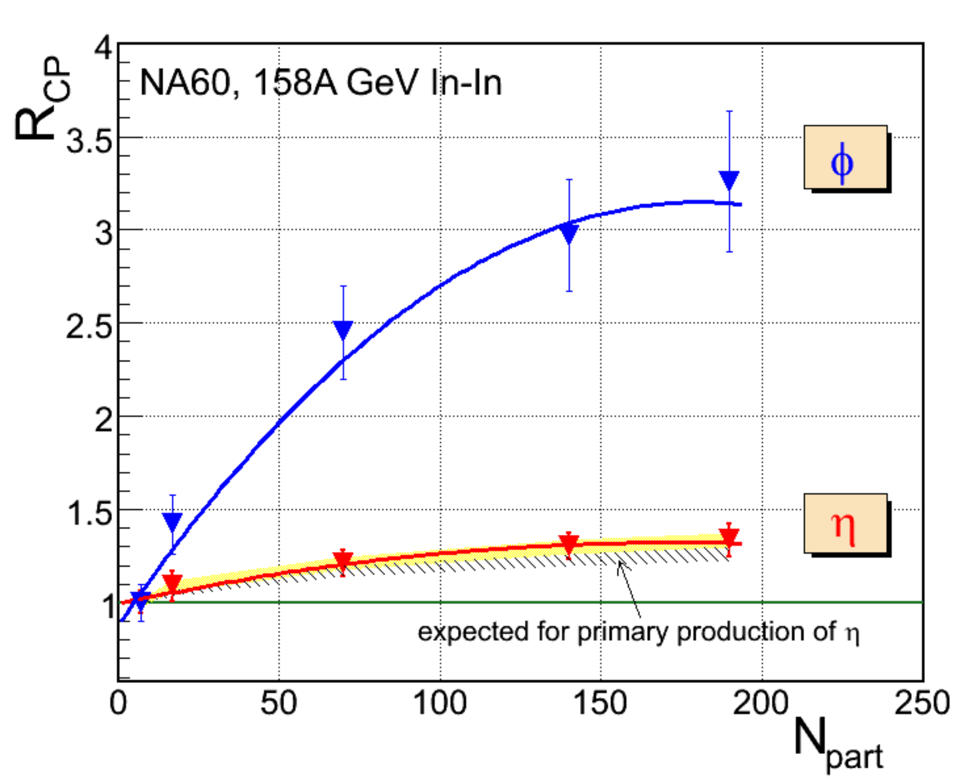
$$\frac{dN}{d|\phi|} \propto \left(1 + \frac{1}{3}\lambda + \frac{\nu}{3}\cos 2\phi\right)$$

Zero polarization within errors

Hadron results

Centrality dependence of hadron yields





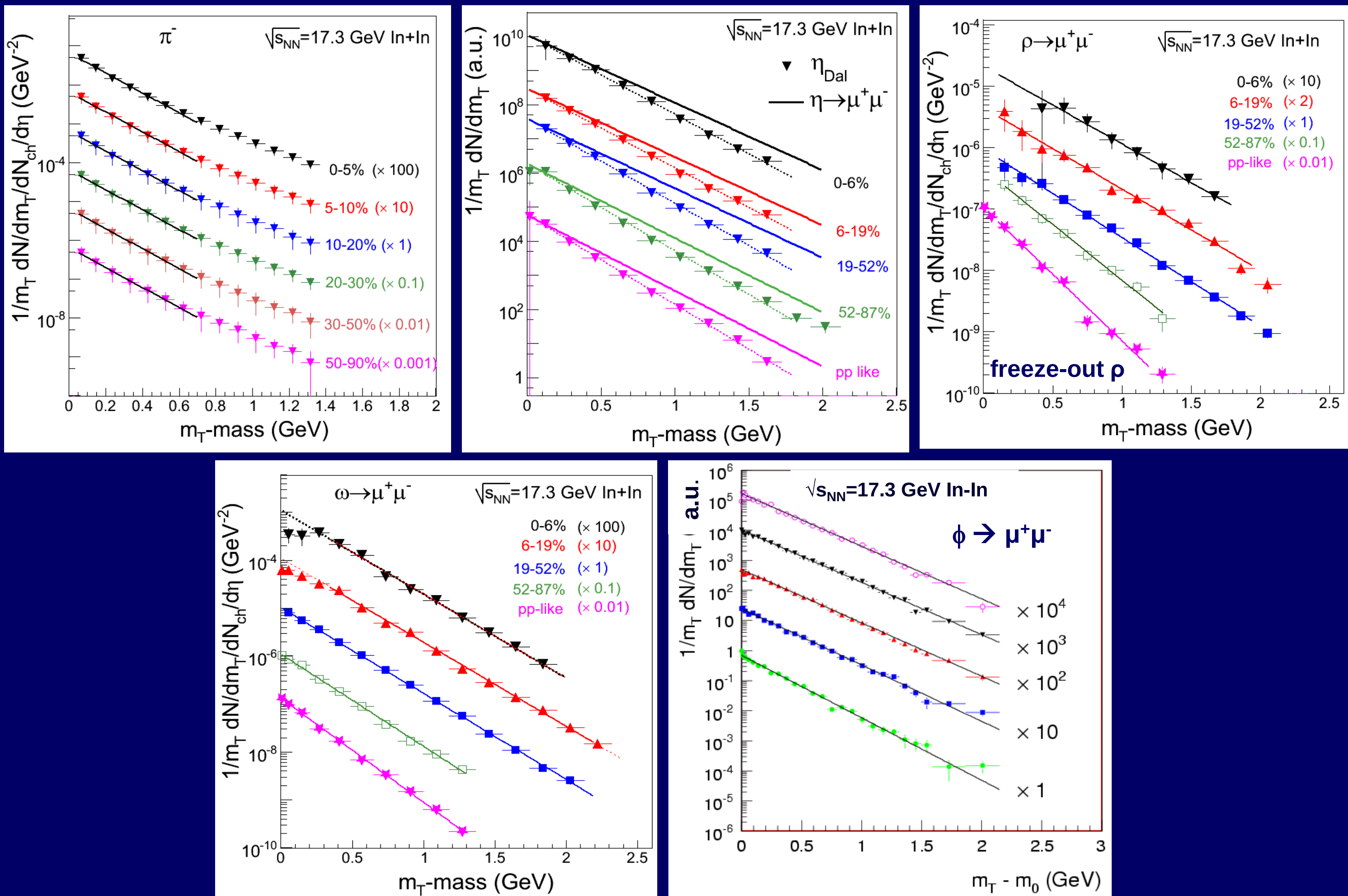
ω yield scales with N_{part}

no nuclear enhancement

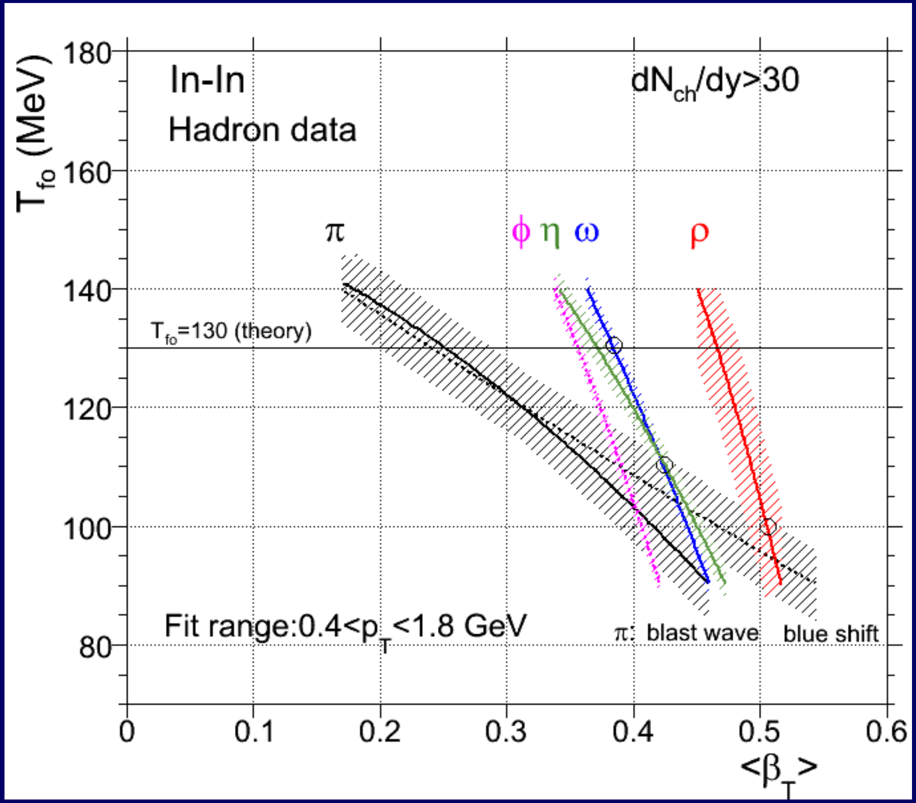
yields of hadrons with strangeness (η, ϕ) increase with N_{part}

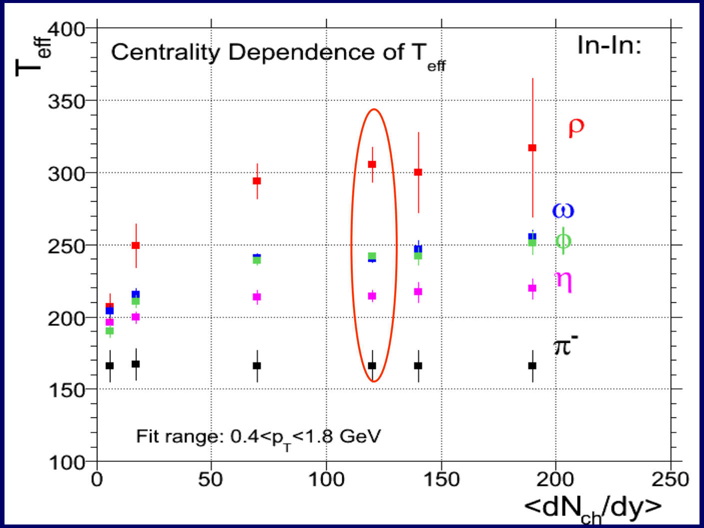
difference between η and ϕ consistent with wave function content of ssbar

Light-flavoured hadrons in NA60



Hierarchy in hadron freeze-out





large difference between ρ and ω (same mass)

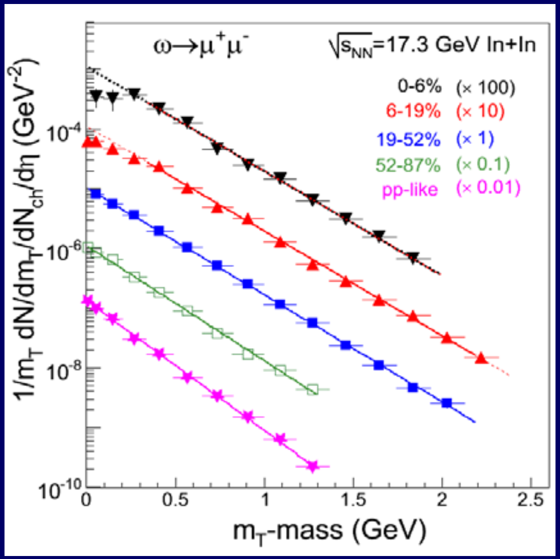
← use of Blast wave code

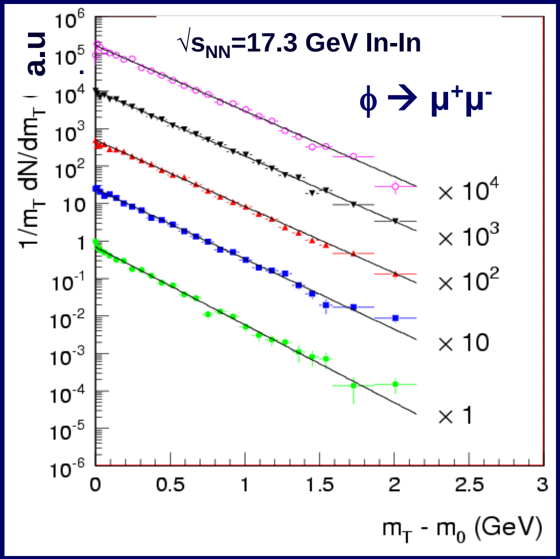
for a given hadron M, the measured T_{eff} defines a line in the T_{fo}-v_T plane

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)

Light-flavoured hadrons in NA60

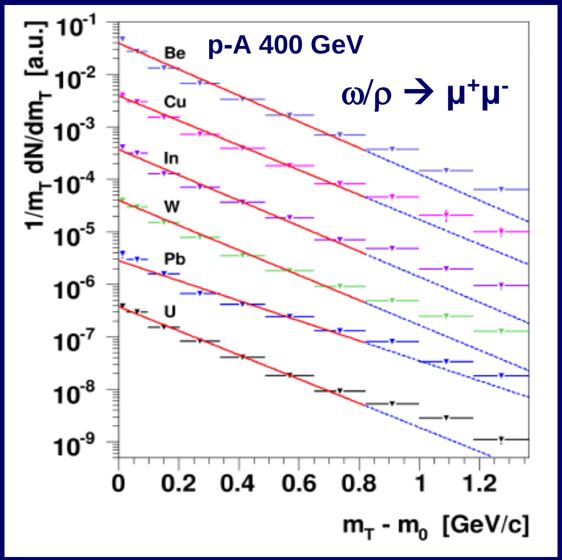


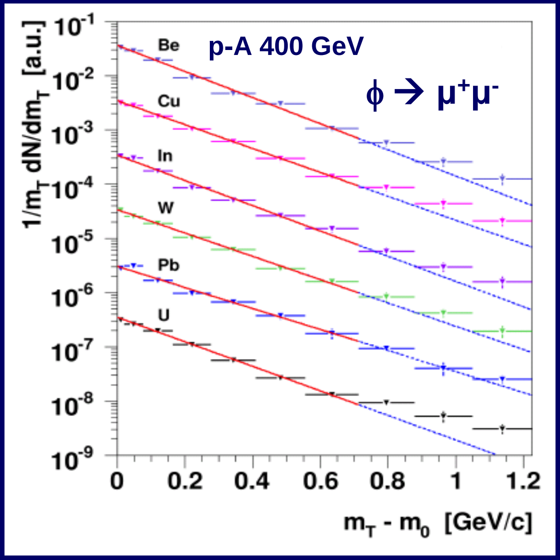


In-In at 158A GeV

low mass sample size 440 000 (peripheral alone < 10%)

pure exponential m_T spectra





p-A at 400 GeV

low mass sample size 180 000 (NA27: insufficient statistics for ρ/ω and ϕ → no p_T spectra)

upward bend of m_T spectra

→ hard scattering components

no hard scattering components at 158A GeV

Conclusions

Planck-like exponential mass spectra, exponential m_T spectra, zero polarization and general agreement with thermal models consistent with interpretation of excess dimuons as thermal radiation

Emission sources of thermal dileptons mostly hadronic ($\pi^+\pi^-$ annihilation) for M<1 GeV, and mostly partonic ($q\bar{q}$ annihilation) for M>1 GeV; associated temperatures quantified; hints at soft EoS close to T_c; direct connection to deconfinement at the SPS

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