Dimuon Production In PbPb Collisions at 20-160 AGeV at the CERN SPS: Mapping the QCD Phase Diagram in the Transition Region with a New NA60-like Experiment

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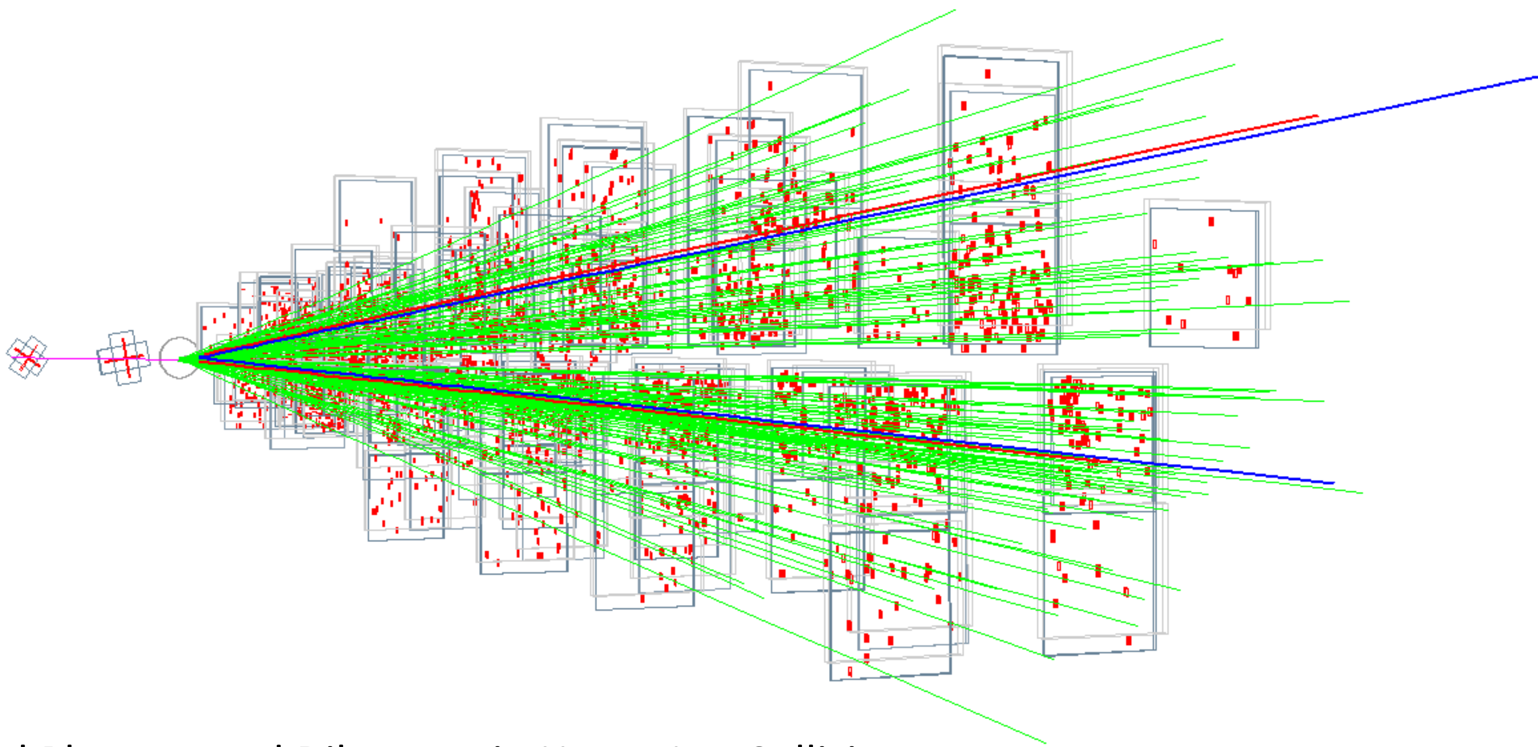
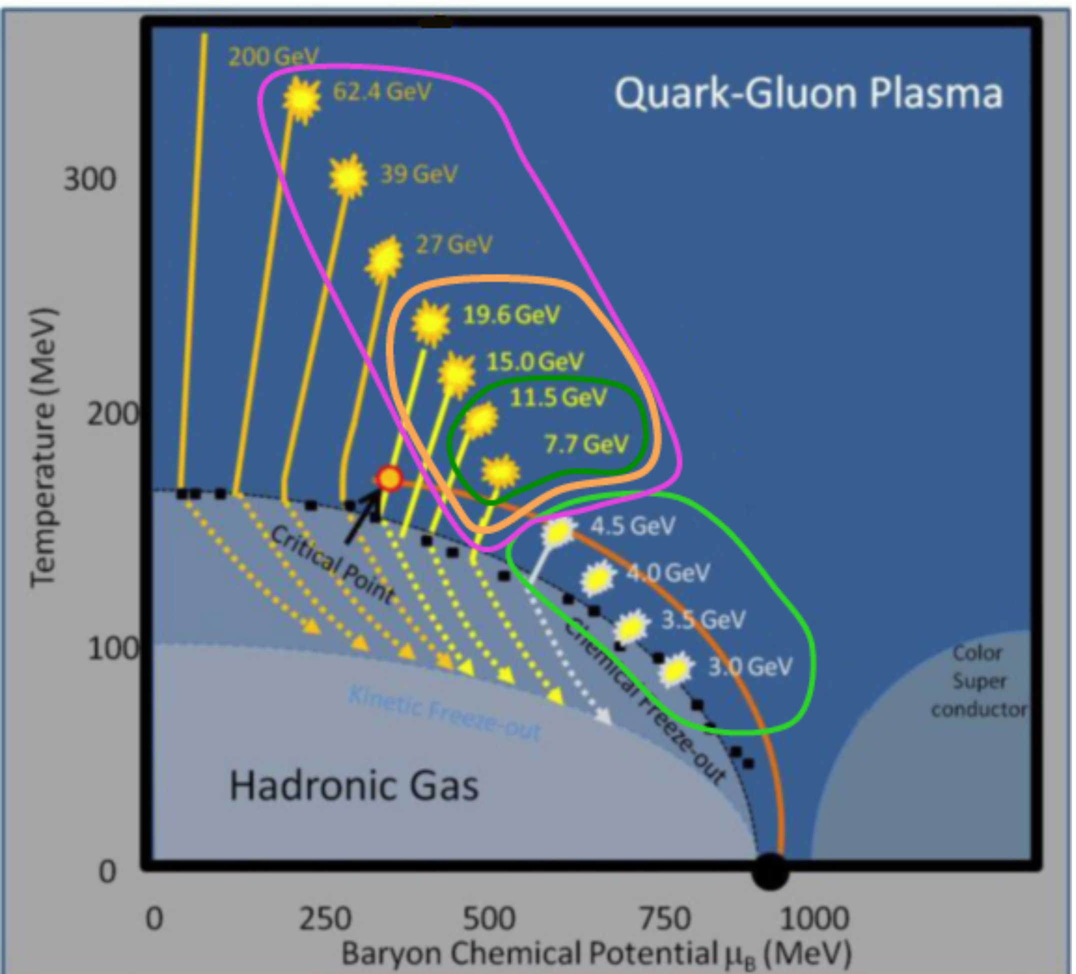


TPD 2014 - Thermal Photons and Dileptons in Heavy Ion Collisions
RIKEN BNL Research Center Workshop - 22/08/2014

NA60+: prime physics goal

➢ Systematic measurement of EM radiation over the full energy range from SIS-100/300 to top SPS: ≈20 AGeV to 160 AGeV



RHIC:
- good coverage, but much lower statistics than fixed target experiments

FAIR (CBM):
- SIS-100 (>2020) limited coverage
- SIS-300 better coverage but unclear timeline (>2025)

SPS:
- Wide coverage of phase diagram
- Existing facility
- Competitive high-intensity beams
- Other experimental program (NA61) already ongoing

Comparison of ion beams

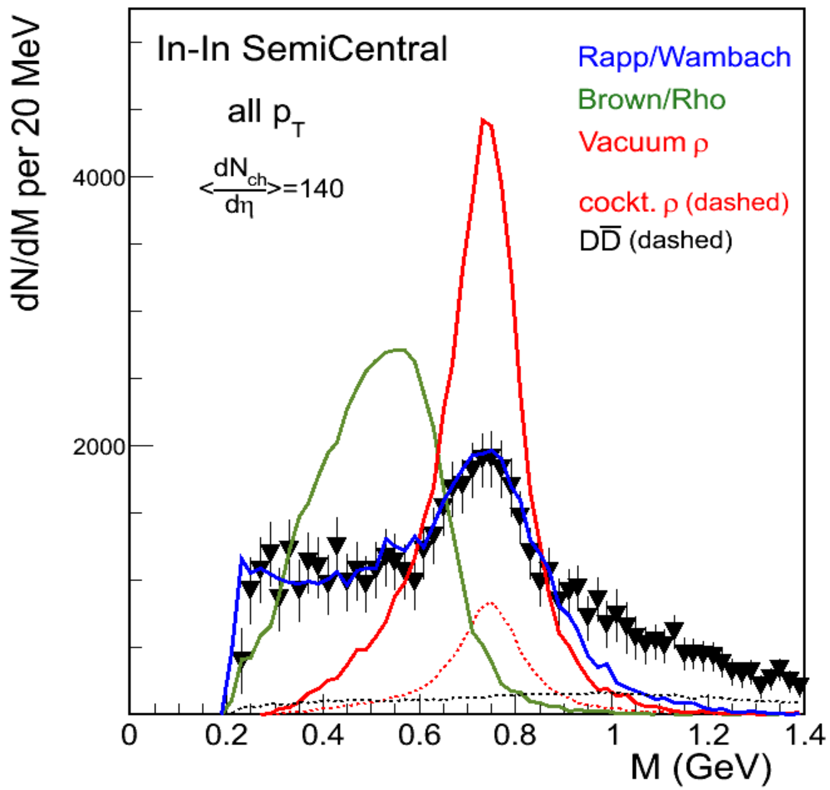
	SPS			SIS100/300
Energy range: [AGeV]	11 – 158			< 11 – 35 (45)
	beam intensity [Hz]	target thickness [λ_i]	interaction rate [Hz]	interaction rate [Hz]
NA60 (2003)	2.5×10^6	20%	5×10^5	
new injection scheme	10^8	10%	10^7	10^5 - 10^7
	10^8	1%	10^6	
LHC AA			5×10^4	

- Luminosity at the SPS comparable to that of SIS100/300
- No losses of beam quality at lower energies except for emittance growth
- RP: seems not a problem in EHN1
- Pb beams presently scheduled for the SPS in 2016-2017, 2019-2021

Dileptons in the LMR (M<1 GeV): ρ spectral function

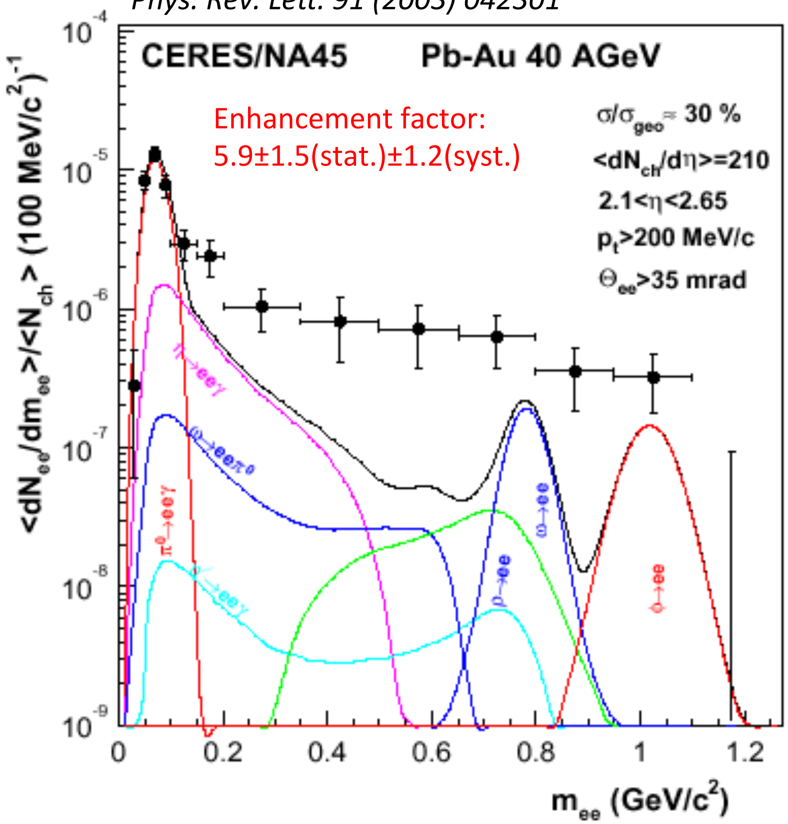
- High energy: 160 AGeV In-In

Phys. Rev. Lett. 96 (2006) 162302



- Low energy: only one low-statistics measurement in Pb-Au at 40 AGeV

Phys. Rev. Lett. 91 (2003) 042301

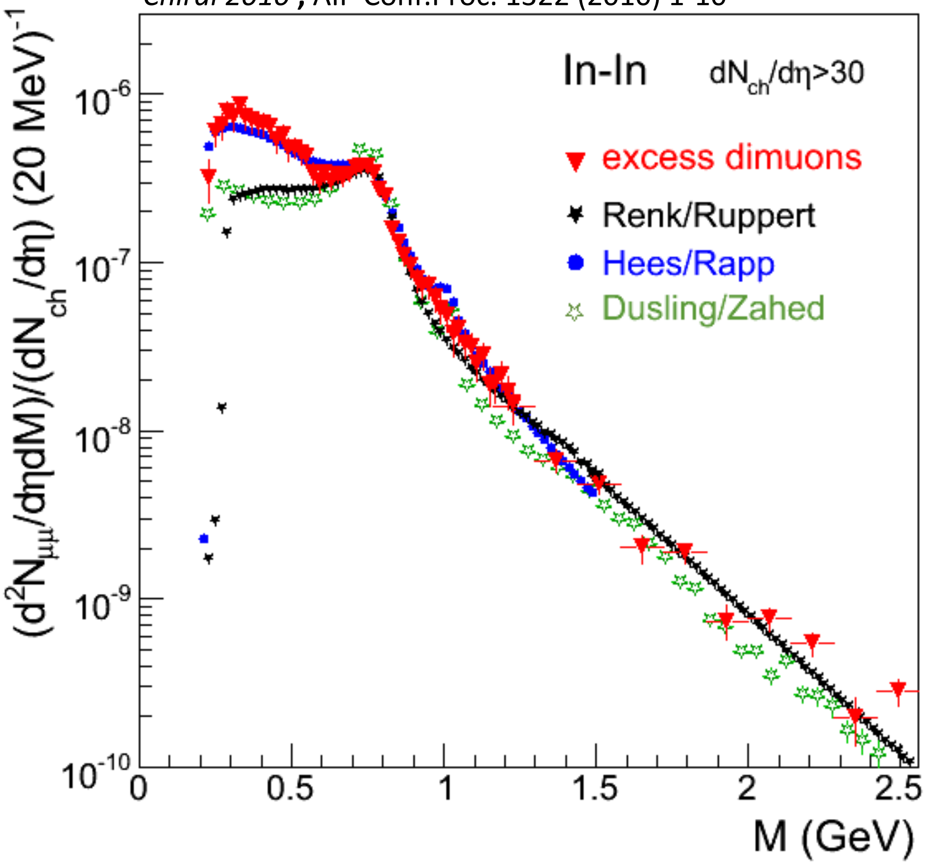


- Broadening of ρ spectral function driven by the total baryon density
  - should get maximal at low energy
  - commonly linked to chiral symmetry restoration – though in model dependent way

➔ Measurement of ρ spectral function with utmost precision
  - Possible surprises? Critical point?

Dileptons in the IMR: chiral symmetry restoration

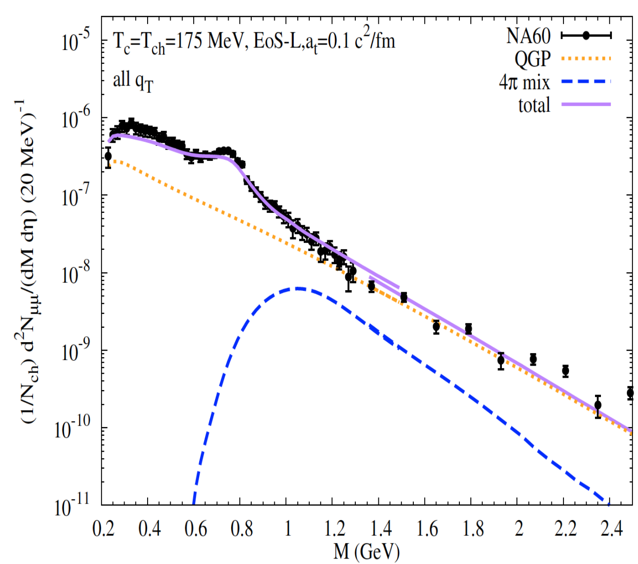
[Eur. Phys. J. C 59 (2009) 607-623]
CERN Courier 11/ 2009, 31-35
Chiral 2010, AIP Conf.Proc. 1322 (2010) 1-10



- Physics processes in IMR
  - Drell-Yan (power law ~ *Mn*)
  - Thermal radiation
    - QGP
    - Hadron gas

- Chiral symmetry restoration
  - hadronic radiation for M<1.5 GeV dominated by 4π processes via $a_1\pi \rightarrow \mu\mu$ (chiral mixing)

Hees – EM probes Trento workshop - 2013



- Lower energy: decrease of QGP, DY and open charm

→ improved sensitivity to excess from hadronic radiation

Dileptons in the IMR: source temperature

[Eur. Phys. J. C 59 (2009) 607-623]
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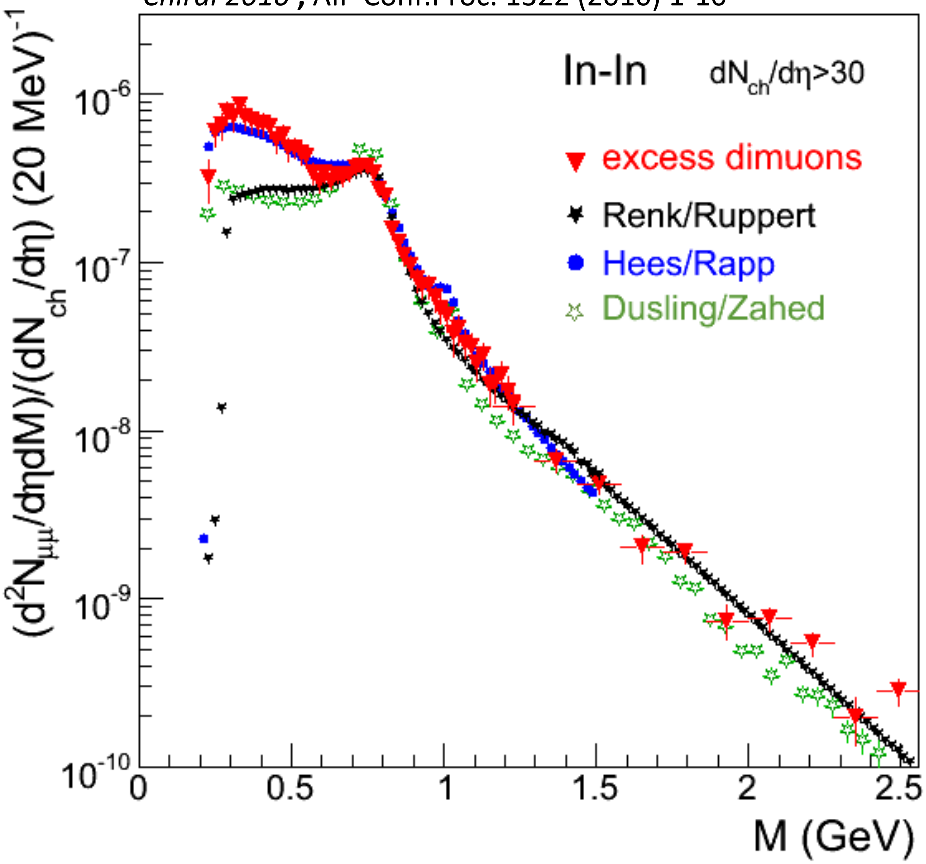


- Physics processes in IMR
  - Drell-Yan (power law ~ *Mn*)
  - Thermal radiation
    - QGP
    - Hadron gas

- Thermal spectrum for M>1.5 GeV (flat spectral function) ~ $M^{3/2}$ *exp(-M/T)*:
  ➔ fit gives average T of emitting source (M Lorentz invariant, i.e. no blueshift)

- Full SPS energy: NA60 In-In
  - Fit to range
    1.1-2.0 GeV: T=205±12 MeV
    1.1-2.4 GeV: T=230±10 MeV

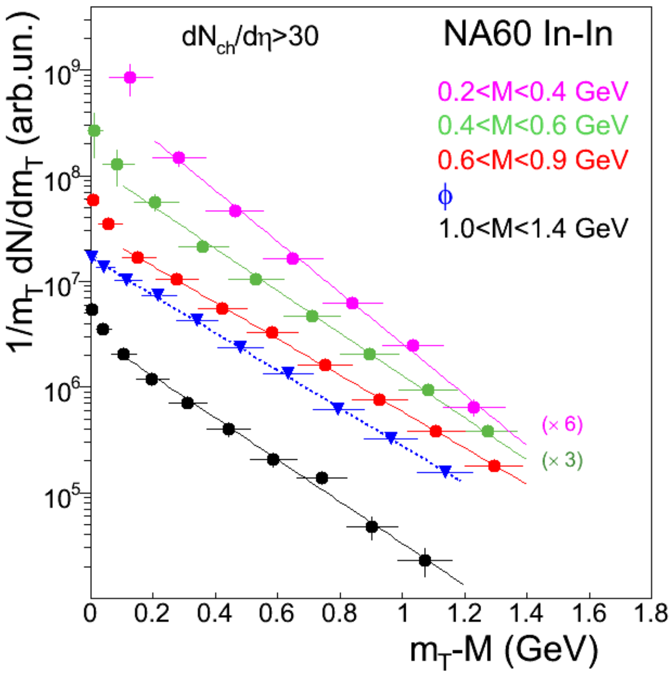
$T > T_c$ ➔ deconfinement at full SPS energy

- Decrease of T for decreasing energy expected - plateau around onset of deconfinement?

➔ Requires systematic measurement of T vs beam energy with precision on the MeV level to assess the slope of T decrease and the possible flattening

Partonic radiation and onset of deconfinement

- Disentangling QGP vs hadronic radiation ➔ m_T spectra in different mass bins

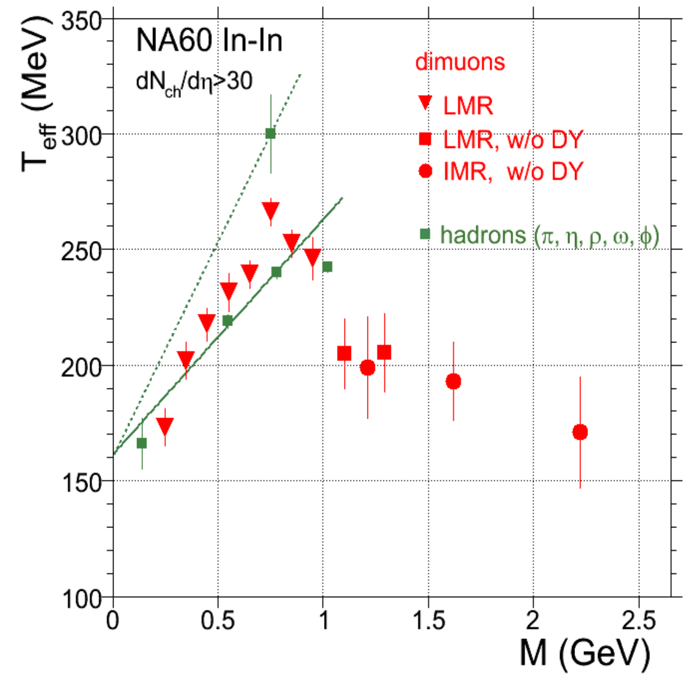


m_T spectra (left): fit with

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

Collective motion (radial flow)

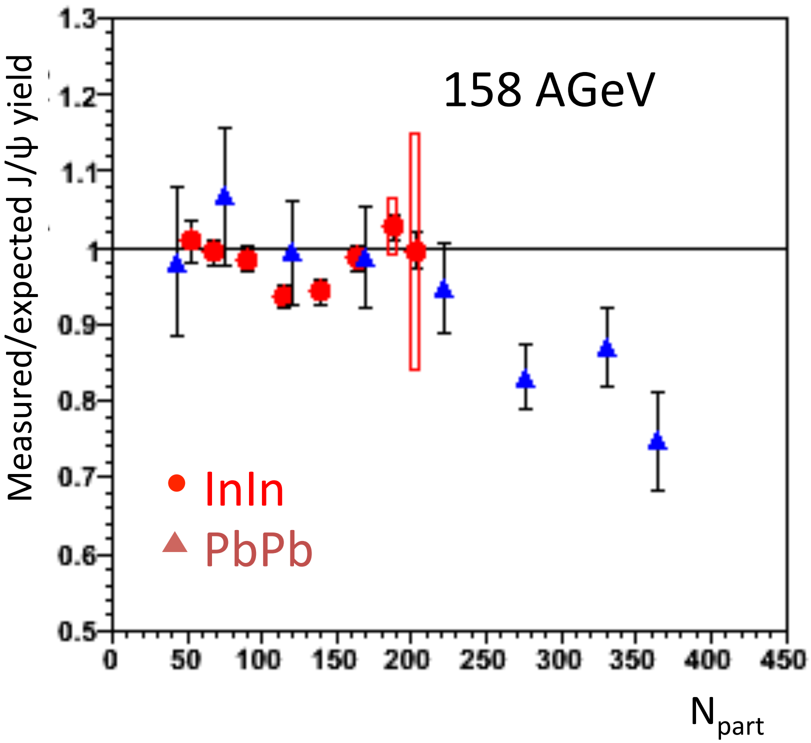
$$T_{eff} \approx T + M\left\langle v_R^2 \right\rangle$$

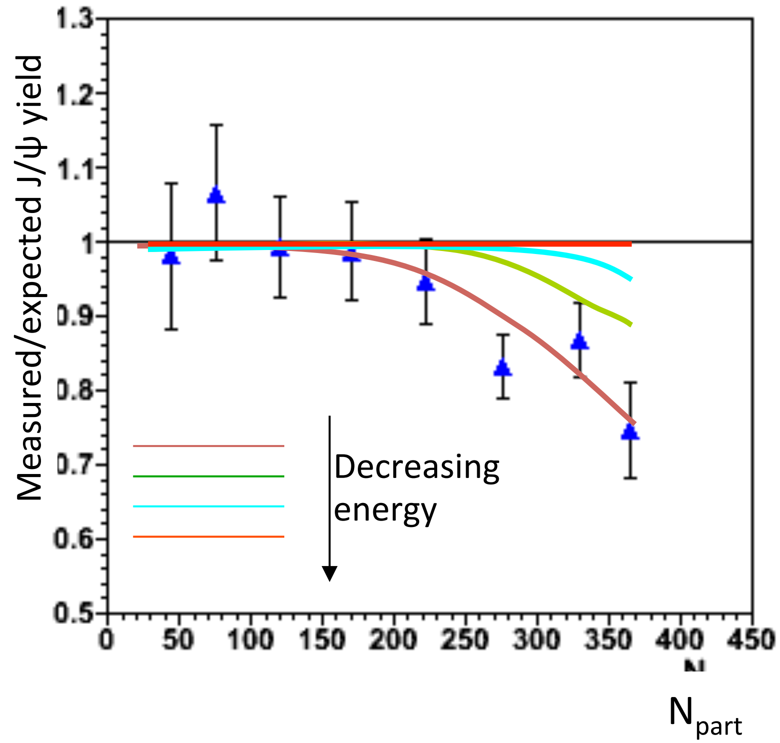


- Hadronic radiation: T_{eff} rise consistent with radial flow of a hadronic source: $\pi^+\pi^- \rightarrow \rho \rightarrow \mu^+\mu^-$ in LMR; 4π in IMR (the latter negligible at 160 AGeV)
- QGP radiation: T_{eff} almost flat, consistent with an early source with low flow (dominant at 160 AGeV)

- T_{eff} vs M sensitive to QGP vs hadronic yield - for decreasing collision energy, increase of HG radiation/decrease of QGP ➔ progressive reduction/disappearance of drop
- Systematic precision measurement from SPS energies down to SIS100 energies

Charmonium production in AA: top to low SPS energies





- Anomalous suppression relevant for PbPb collisions, but almost no suppression for the lighter InIn system at 158 AGeV

- Identify thresholds for charmonium suppression via SPS energy scan

- Topmost SPS energy: detailed study of χ_c by detecting the decay photon (originally part of NA60 program)

Running conditions foreseen

- Energy scan
  - tentatively : 20-(30)-40-(60)-80-(120)-160 AGeV

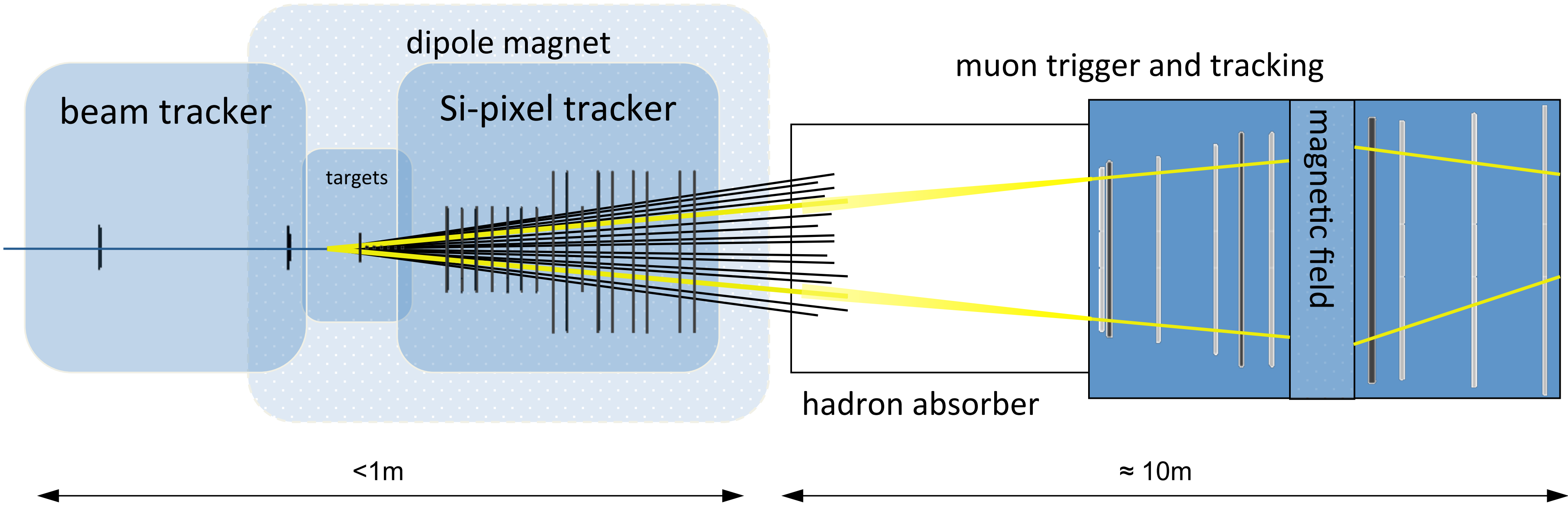
- Objectives for total sample of reconstructed pairs
  - isolation of hadronic spectrum up to M≈2 GeV
  - measurements of T and T_{eff} vs M with an accuracy on the MeV level
  - ➔ > 10^7 rec pairs from thermal radiation at each energy
  - ➔ statistics increase by a factor ≈100 over NA60 at each energy

- Ion beams
  - Consistent use of Pb ions for all energies

- Proton beams
  - Needed for reference measurements (Drell-Yan and charmonium)

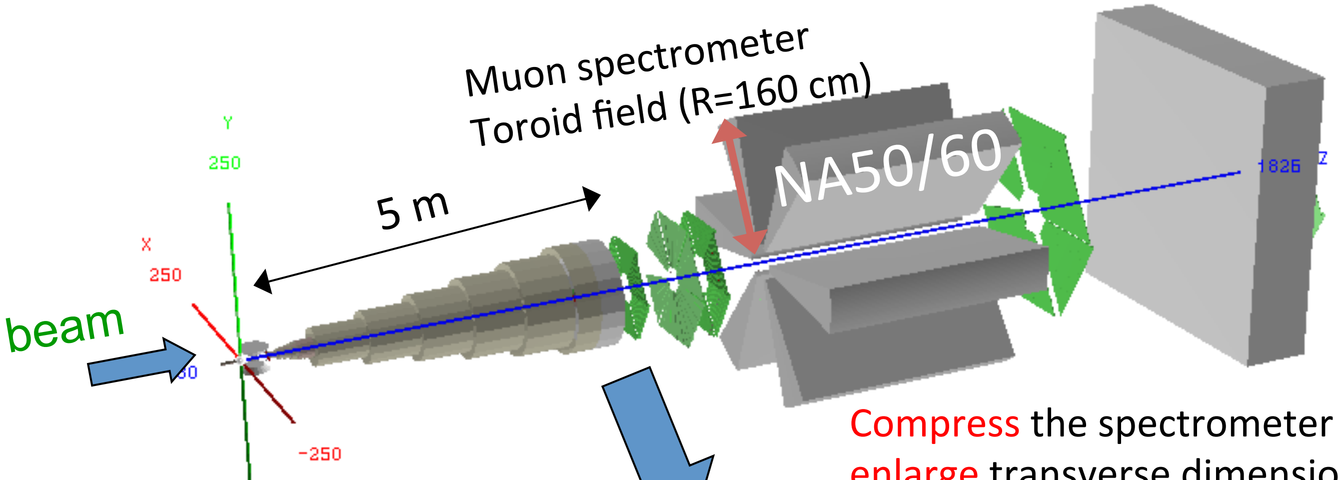
NA60+ detector concept

- Two-spectrometer concept: already proven to be very successful by NA60



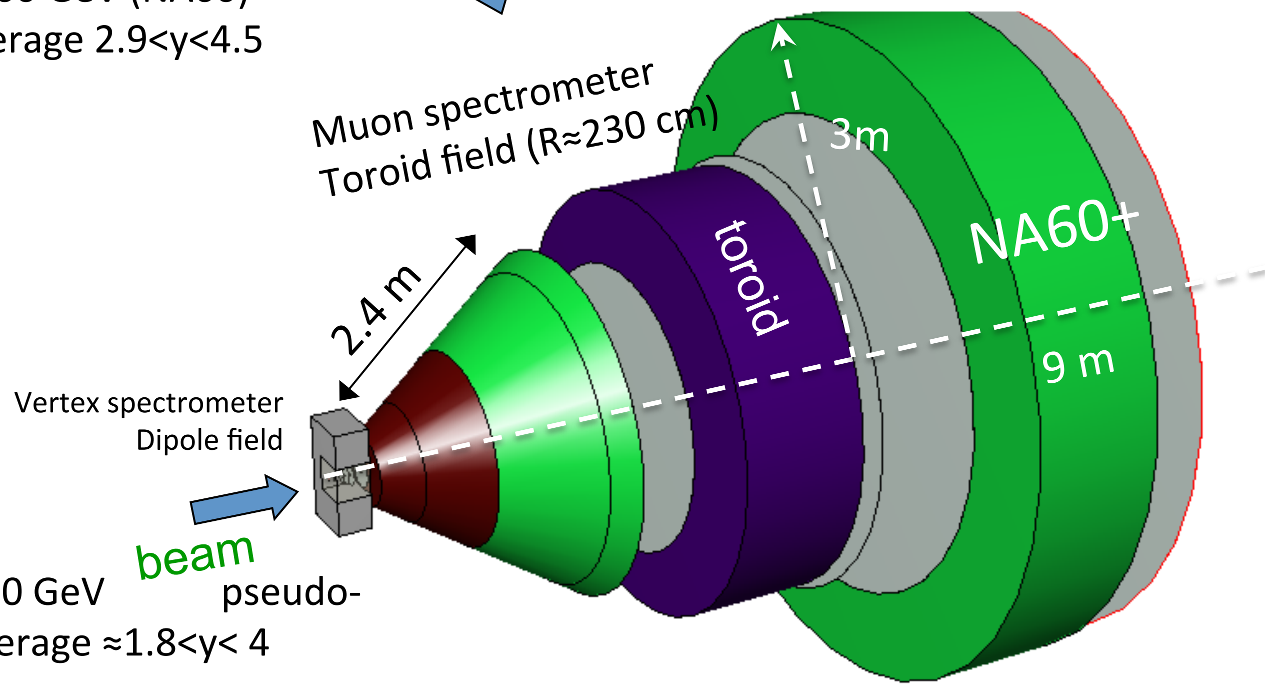
- Hybrid silicon pixel detectors (High luminosity of dimuon experiments must be maintained)
- Tracking and trigger stations: GEMs and/or MWPCs
- Track matching in coordinate and momentum space
  - improved dimuon mass resolution
  - distinguish prompt from decay dimuons

Measuring dimuons at $20<E_{lab}<160$ GeV



Compress the spectrometer reducing the absorber and enlarge transverse dimensions

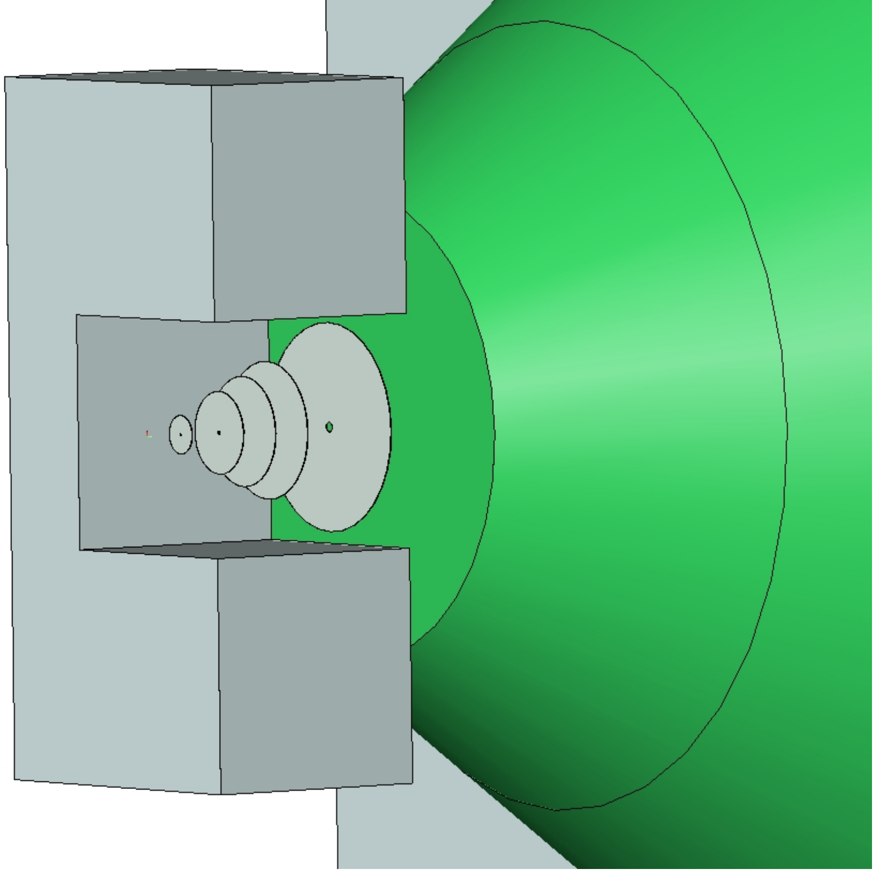
dimuons@160 GeV (NA60)
rapidity coverage 2.9<y<4.5

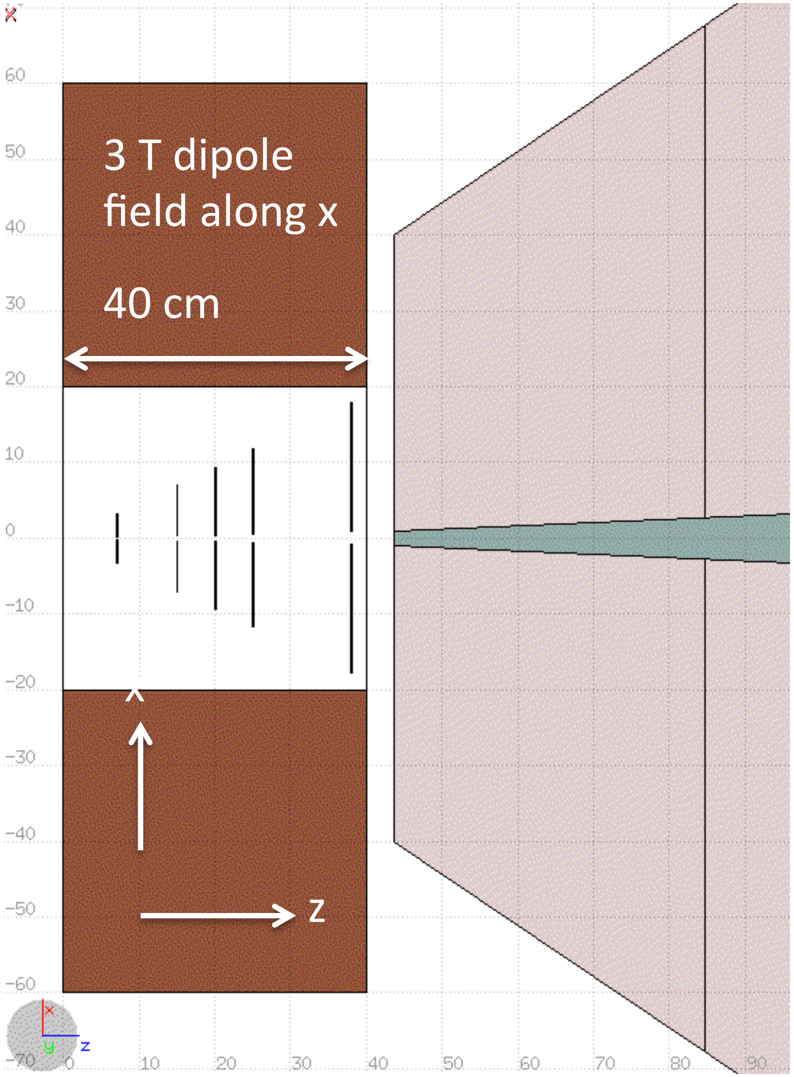


dimuons@20 GeV pseudo-
rapidity coverage ≈1.8<y< 4

Longitudinally scalable setup for running at different energies

The vertex spectrometer





- angular coverage down to η≈1.8 at 20 AGeV (ϑ~0.3 rad)
- 5 silicon pixel stations at 7<z<40 cm
- Pixel plane:
  - 400 μm silicon + 1 mm carbon substrate
  - silicon material budget ≈ 1% X_0
  - 10-15 μm spatial resolution

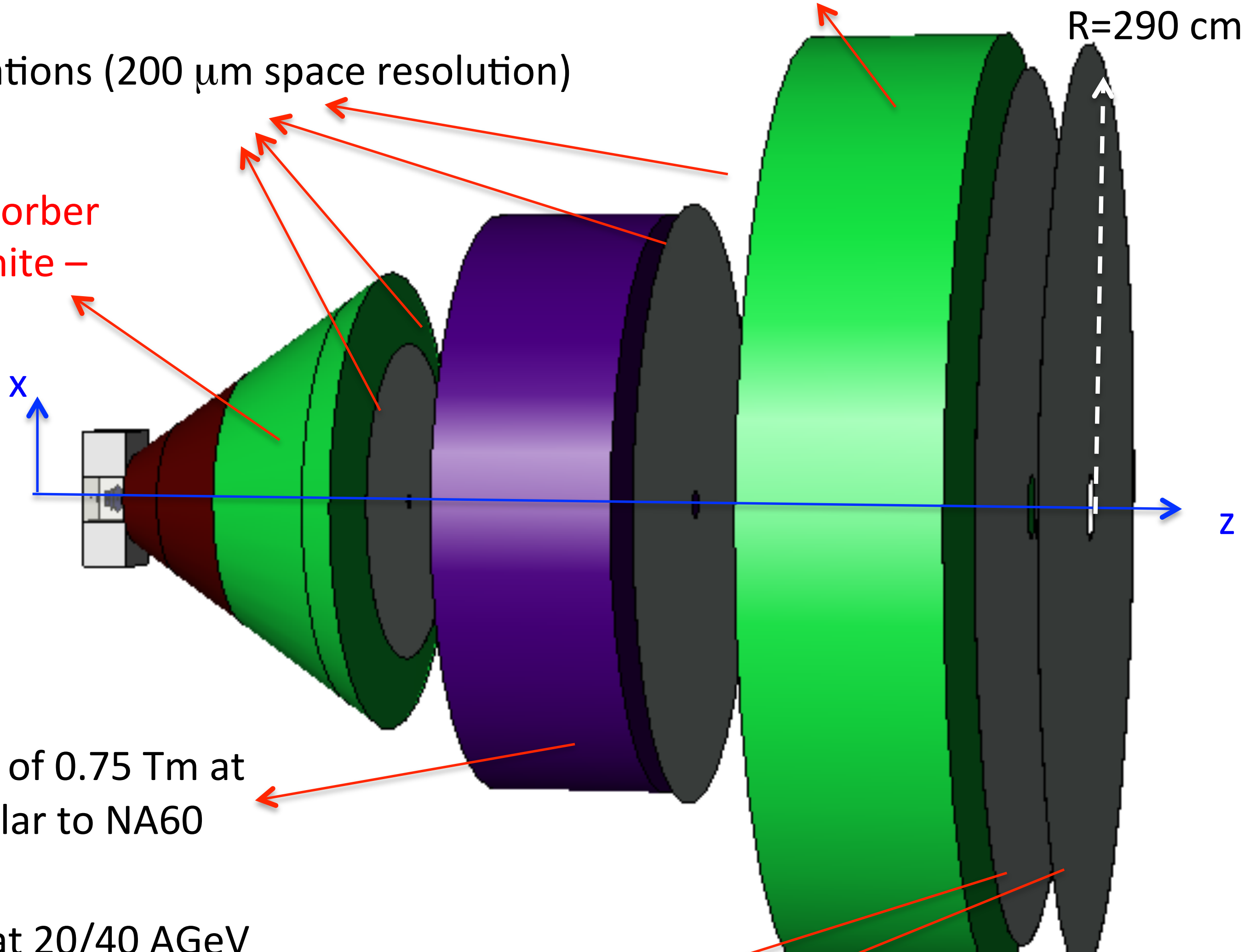
The muon spectrometer

Muon Tracker

✓ 4 tracking stations (200 μm space resolution)

Muon wall (graphite - 120 or 180 cm)

Hadron absorber (BeO, graphite – 240 cm)



Toroid magnet:

✓ field integral of 0.75 Tm at R = 1 m (similar to NA60 ACM field)

✓ simulations at 20/40 AGeV performed also with a reduced field integral of 0.3 Tm at R = 1 m

Trigger stations

✓ 2 trigger stations placed after muon wall (ALICE-like)

Performance studies: Pb-Pb 0-5% central collisions

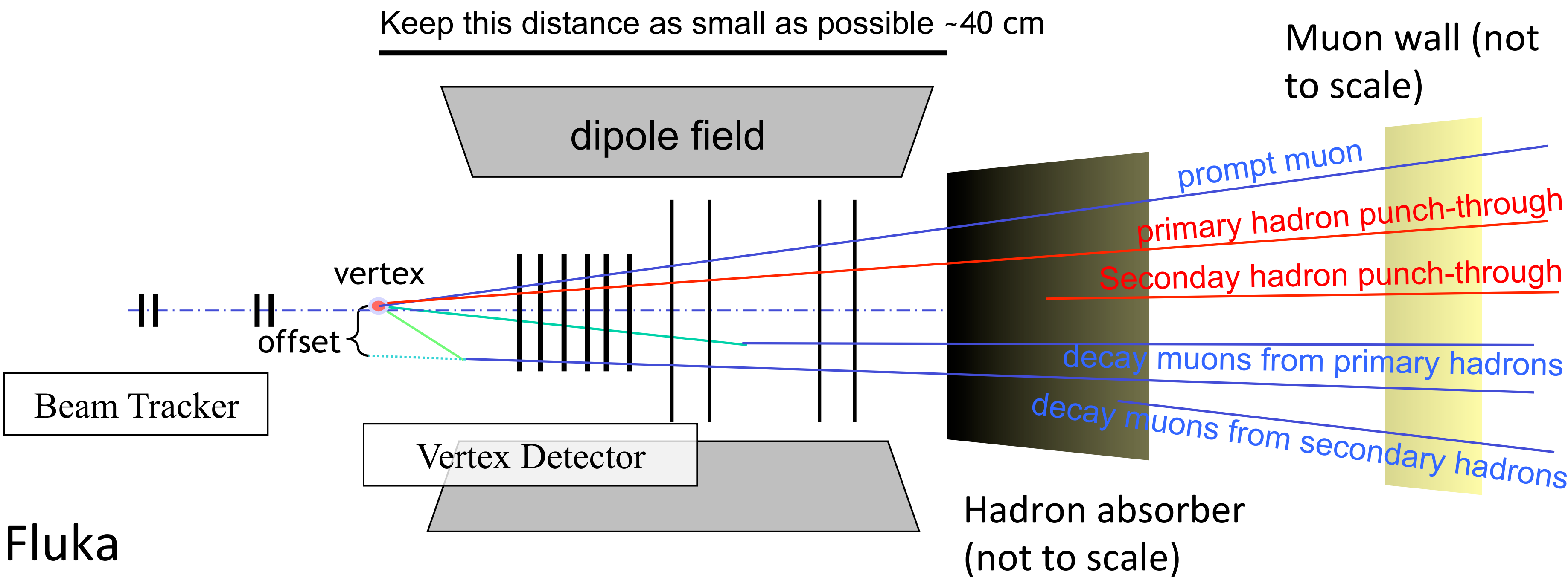
➢ Signal

- Hadron cocktail generator derived from NA60 Genesis using statistical model (Becattini et al.); $dN_{ch}/d\eta=270$
- Thermal radiation generator based on theoretical calculation in PbPb at 40 GeV (R. Rapp)
- Drell-Yan and open charm estimated with Pythia

➢ Fast simulation tool and reconstruction tool

- Apparatus defined in terms of geometry and material for each layer
- Multiple scattering generated in gaussian approximation (Geant code)
- Energy loss simulated with Bethe-Bloch neglecting energy fluctuations
- Reconstruction based on Kalman filter with embedding on full event in pixel detector
- Fake match: one or more wrong hits associated to track

Combinatorial background



- **Fluka**
  - Full hadronic shower development in absorber
  - Punch-through of primary and secondary hadrons (p, K, π)
  - Muons from secondary hadrons

- **Background generation**
  - Parametric π and K event generator (built-in decayer for π and K)
  - Apparatus geometry defined in consistent way with fast simulation tool
  - Hits in detector planes recorded in external file for reconstruction

Triggering on dimuons and expected sample size

- Triggering scheme under investigation:
  - tracklet reconstruction in trigger stations after muon wall + fast track reconstruction in muon stations

- Beam intensity: $L \approx 2.5 \cdot 10^6$/s, λ_i=0.15 (past NA60 conditions)

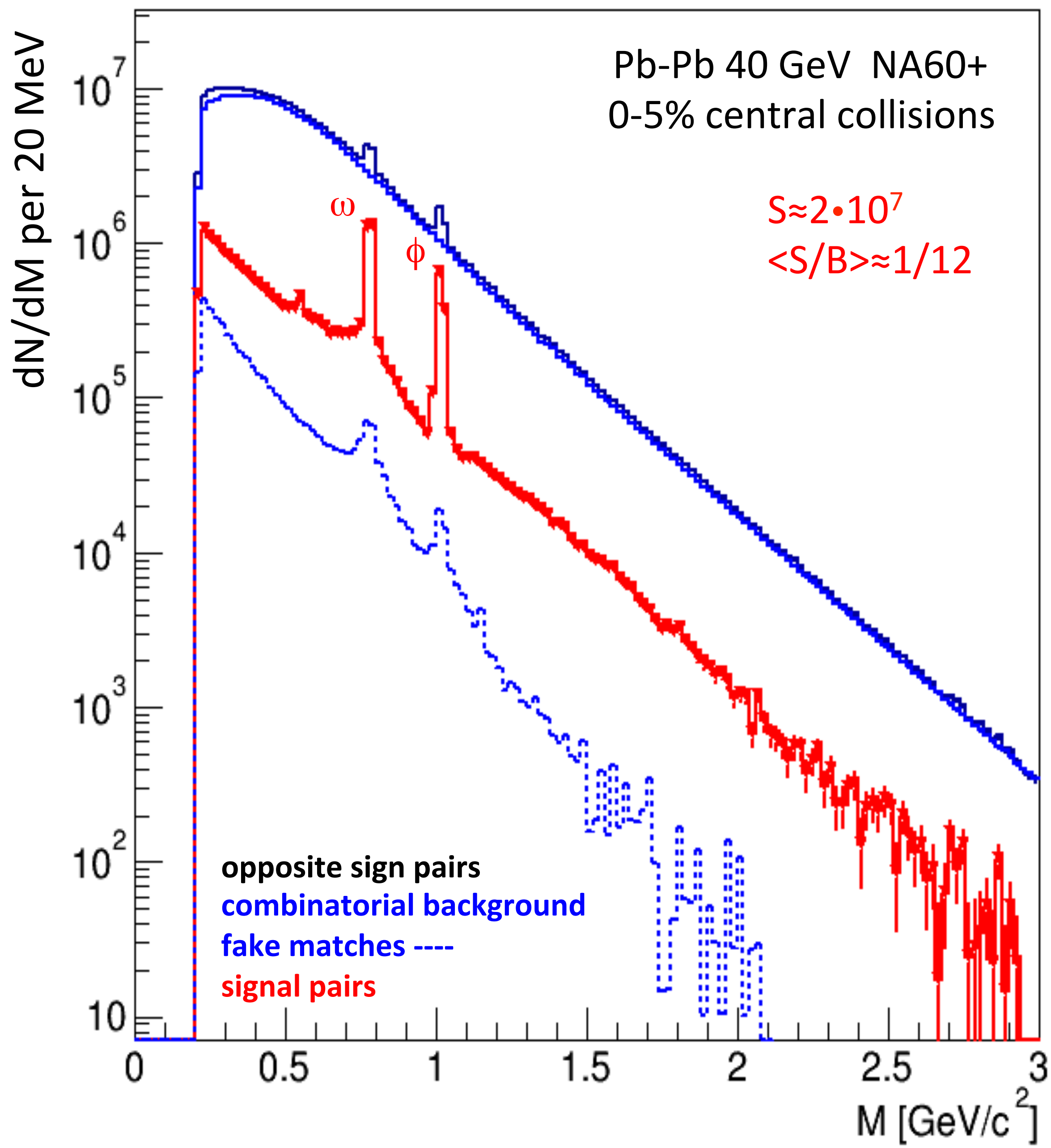
  ➔ minimum bias trigger rate (essentially bkg rate) ≈ 15-20 kHz

- NA60+ improvements over NA60:
  - Higher trigger rate capability (limited to < ≈ 4 kHz in NA60)
  - Significantly larger acceptance, in particular for M<0.5 GeV: > 10
  - Pb-Pb vs In-In

- 15-20 days of beam time in Pb-Pb at 40 GeV

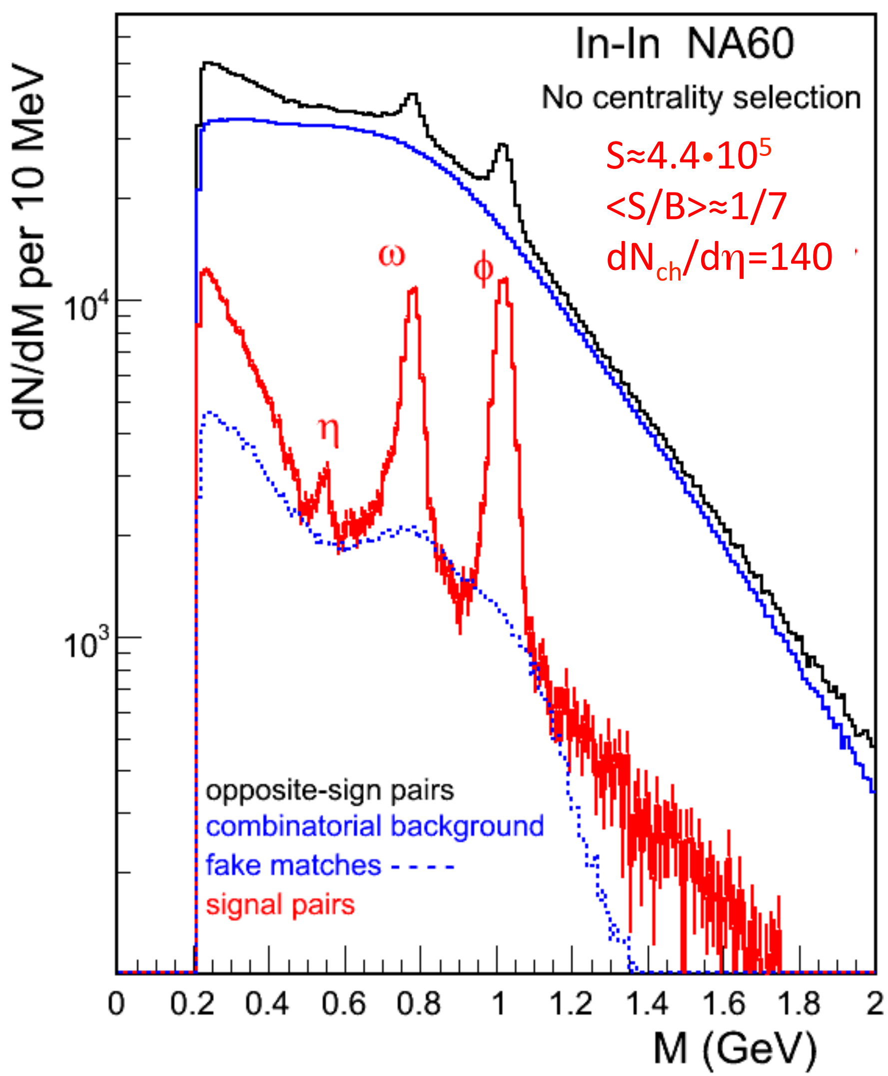
➔ ≈ 10^7 reconstructed pairs from thermal radiation in central collisions

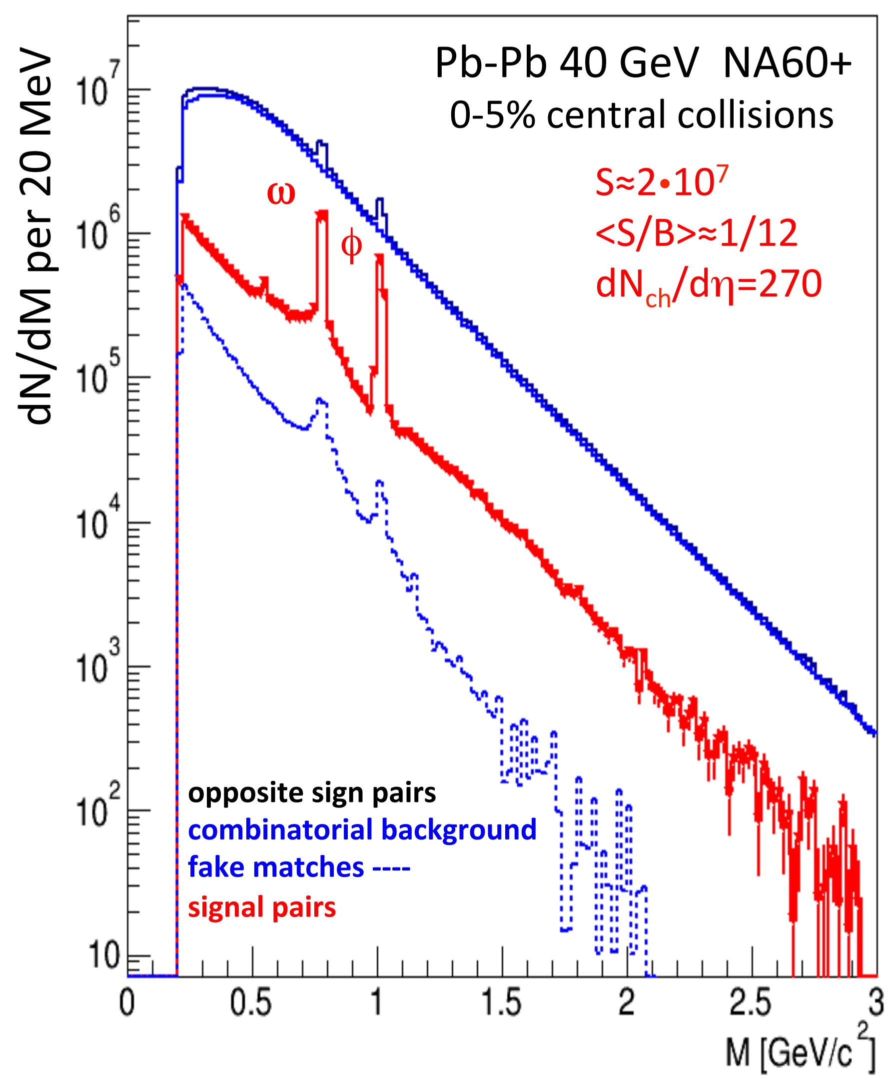
Pb-Pb 0-5% central collisions: data sample



- Subtraction of:
  - Combinatorial background
  - Fake matches
- Precision of combinatorial background subtraction: 0.5%
- $2 \cdot 10^7$ reconstructed signal pairs
- Mass resolution: 10-15 MeV at the ω position
- lower field toroid: increase of S/B by just 30-40% ➔ measurement still very precise

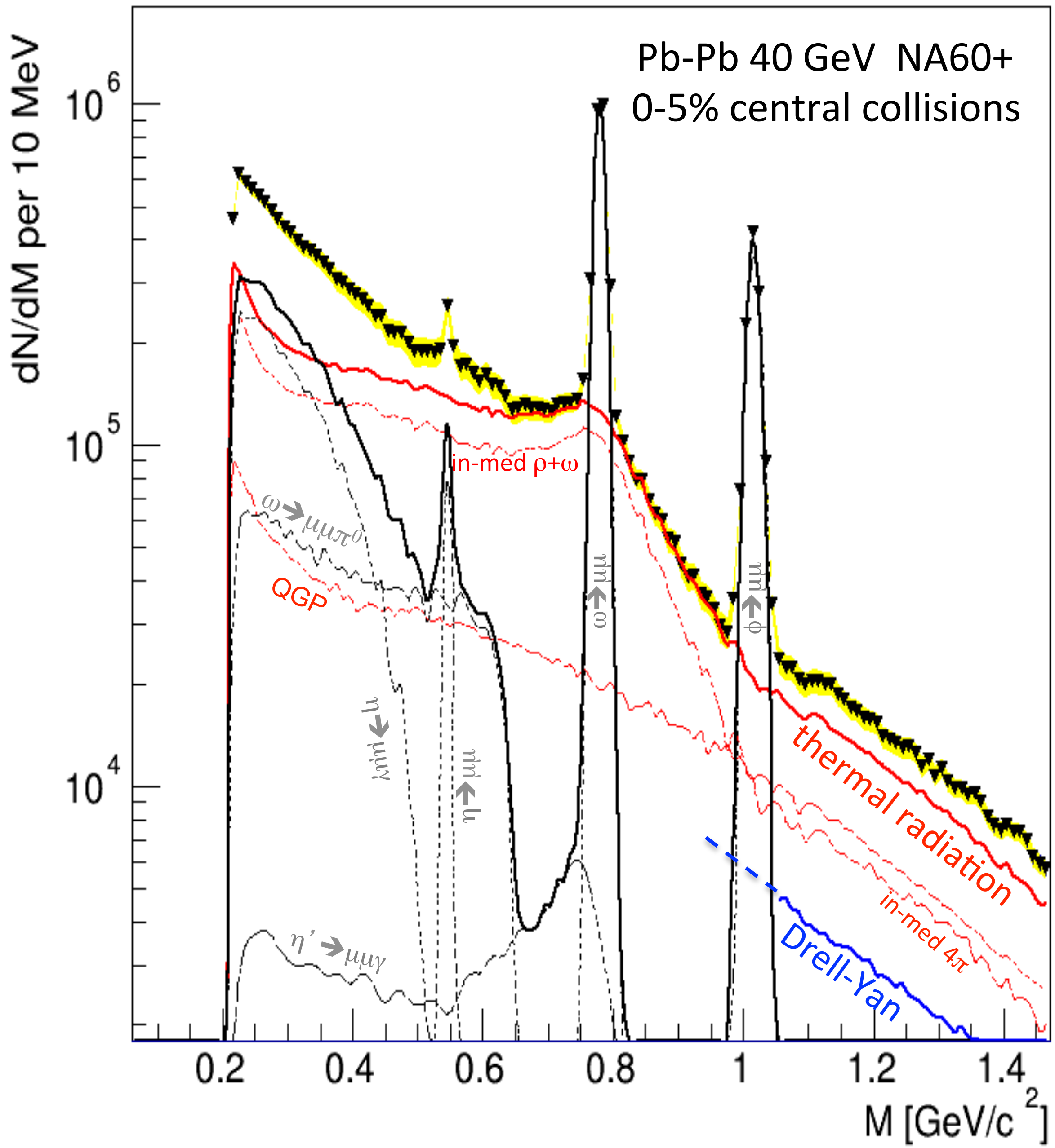
NA60 vs NA60+





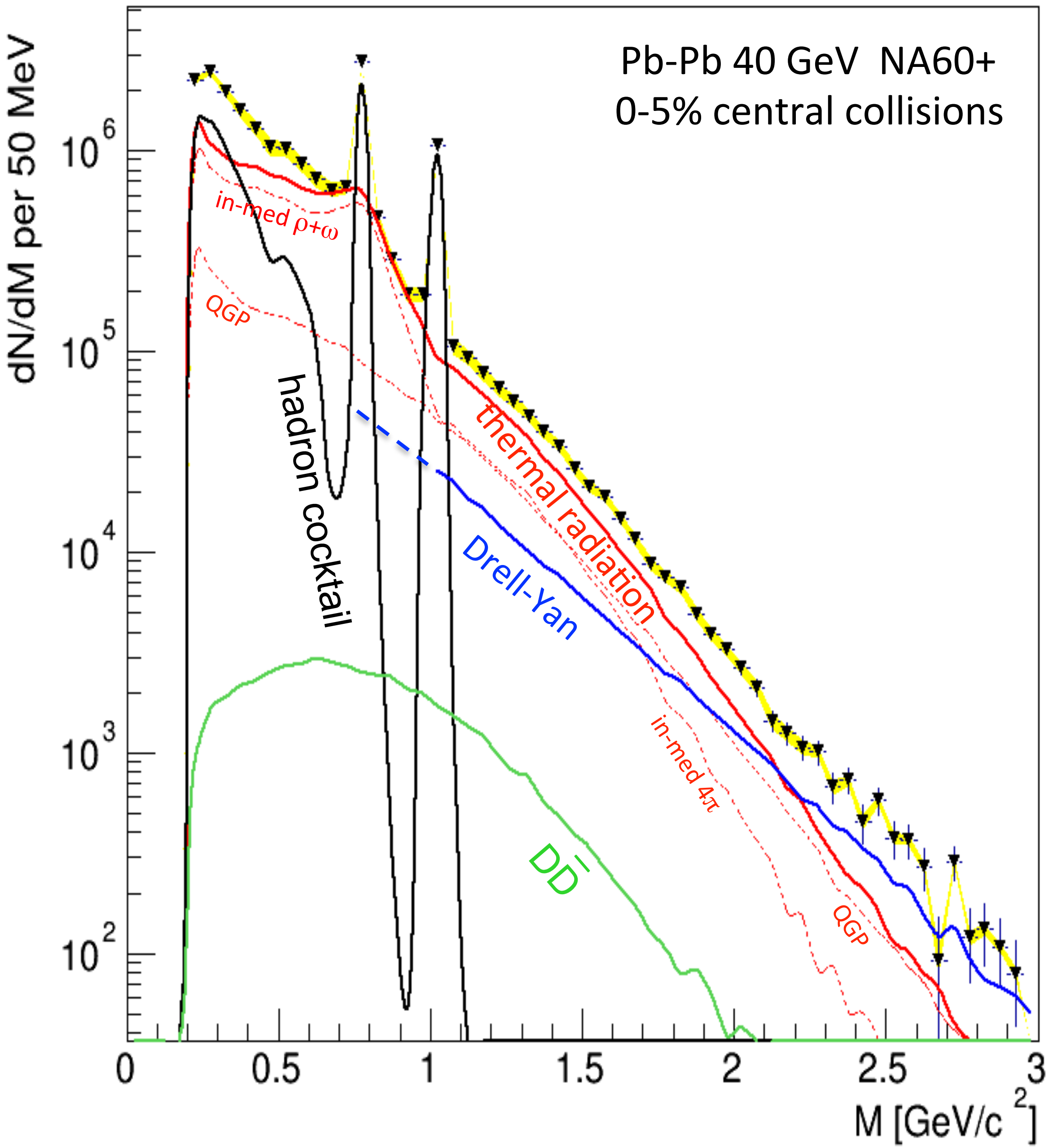
➢ Minimum bias collisions: progress in statistics over NA60 by a factor ≈ 100

Pb-Pb 0-5% central collisions: LMR (M<1 GeV)



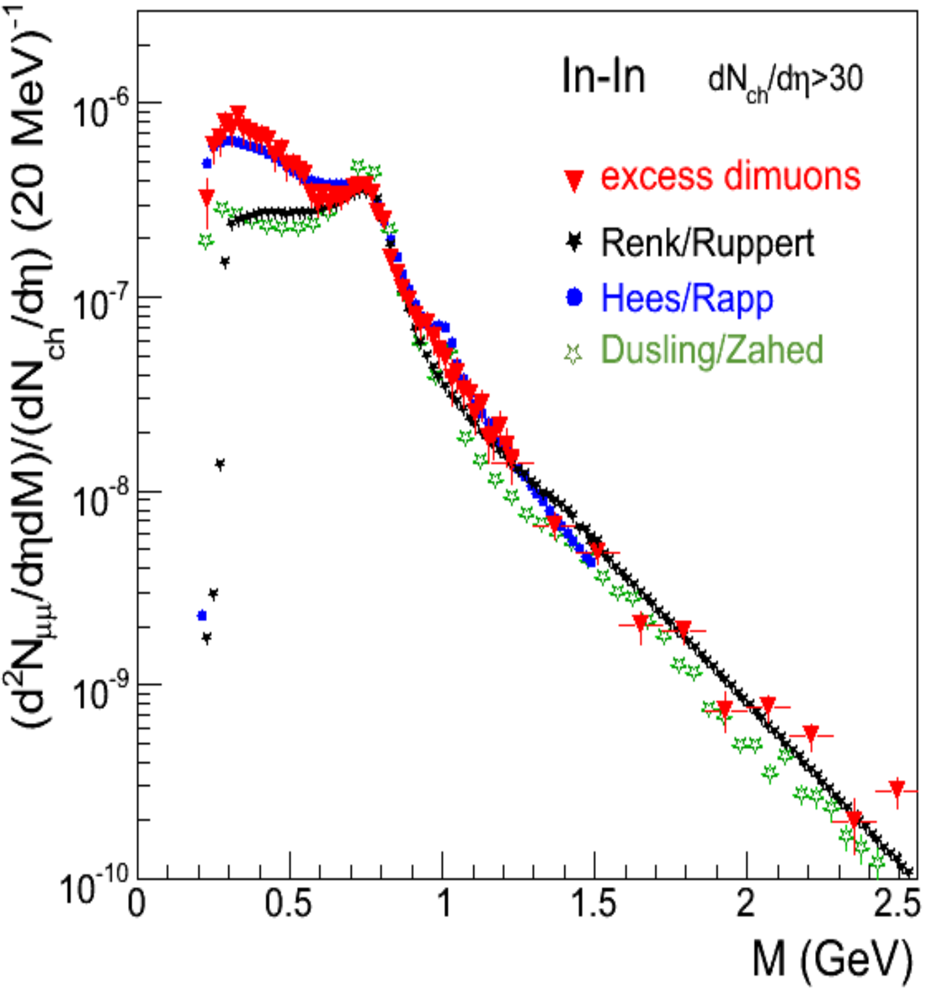
- Thermal radiation yield dominated by in-medium ρ+ω
- Precise isolation of excess *à la* NA60

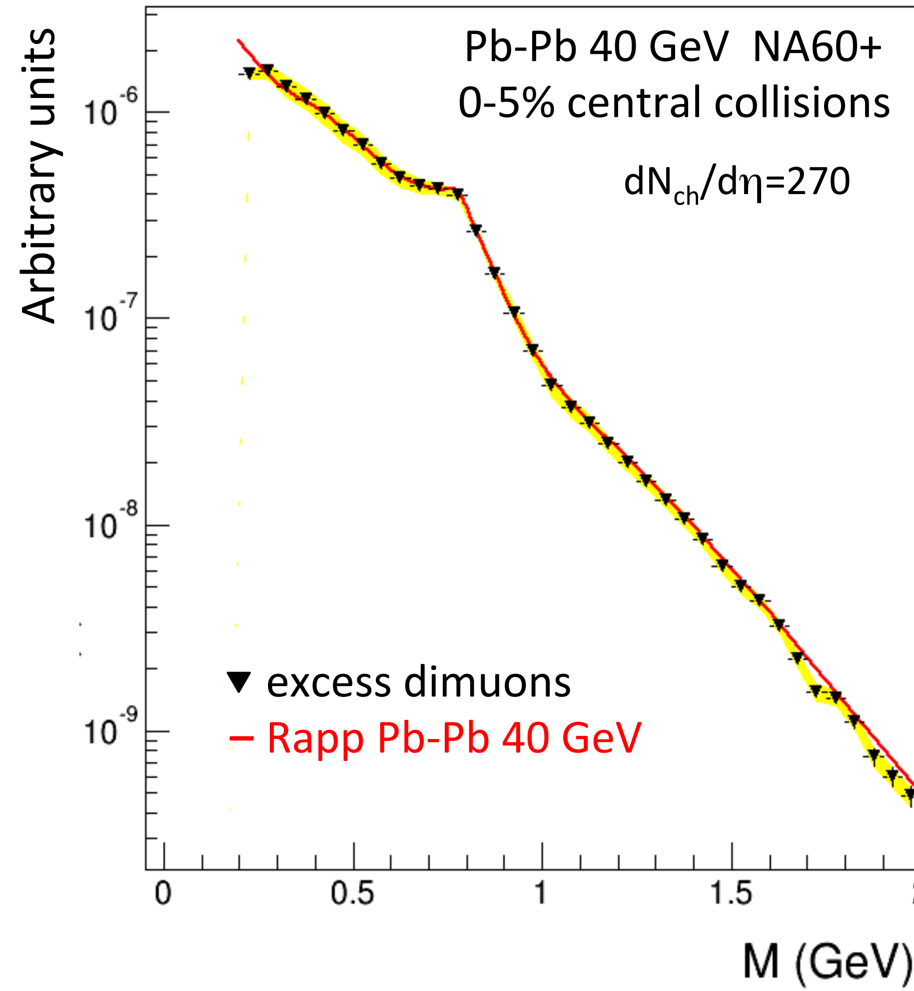
Pb-Pb 0-5% central collisions: full mass spectrum



- Thermal radiation yield up to 2.5-3 GeV
- QGP yield still significant at 40 GeV
- Drell-Yan gets stronger than QGP above 2.5 GeV
- Open charm yield negligible

Inclusive excess mass spectrum: NA60+ (40 AGeV PbPb) vs NA60 (160 AGeV InIn)

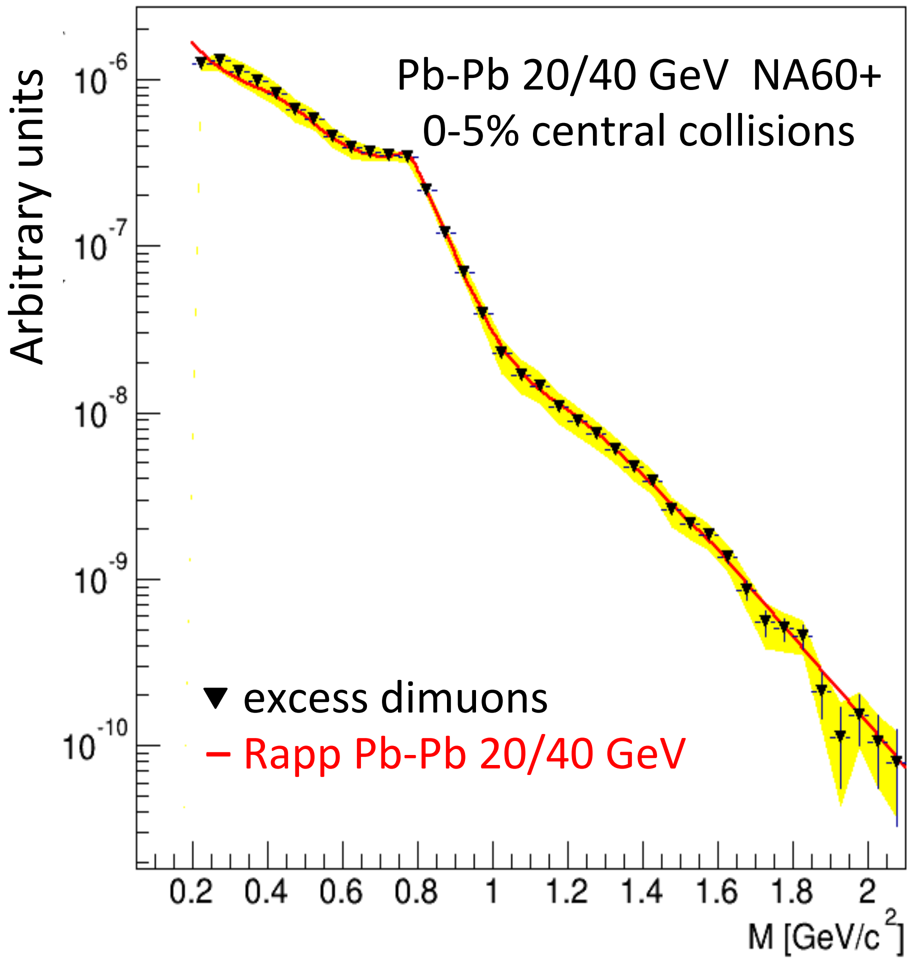




- All known sources subtracted; mass spectra integrated over p_T
- Mass spectra fully corrected for acceptance

Inclusive excess mass spectrum: hadronic radiation

- Mass Spectrum fully corrected for acceptance

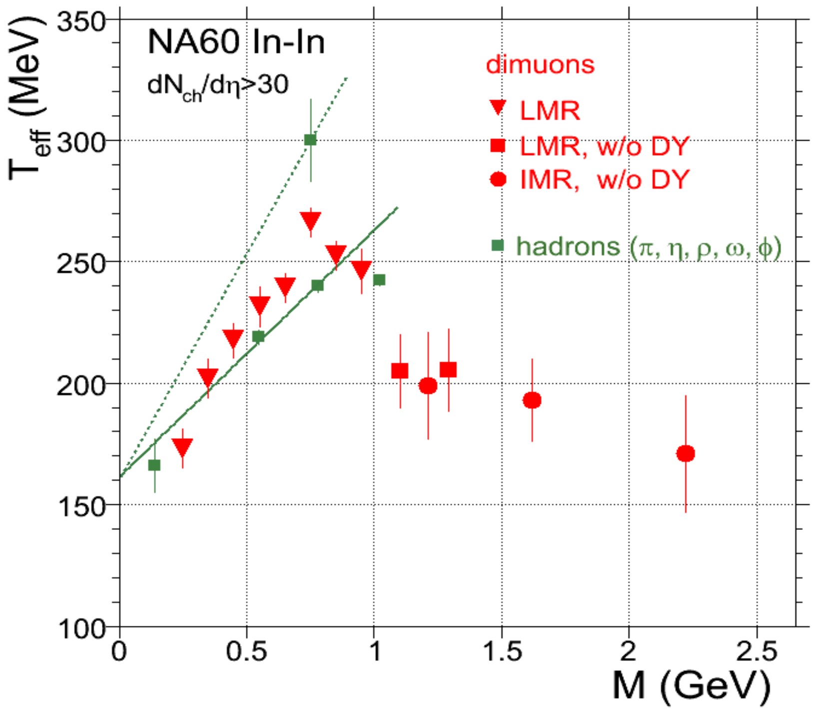


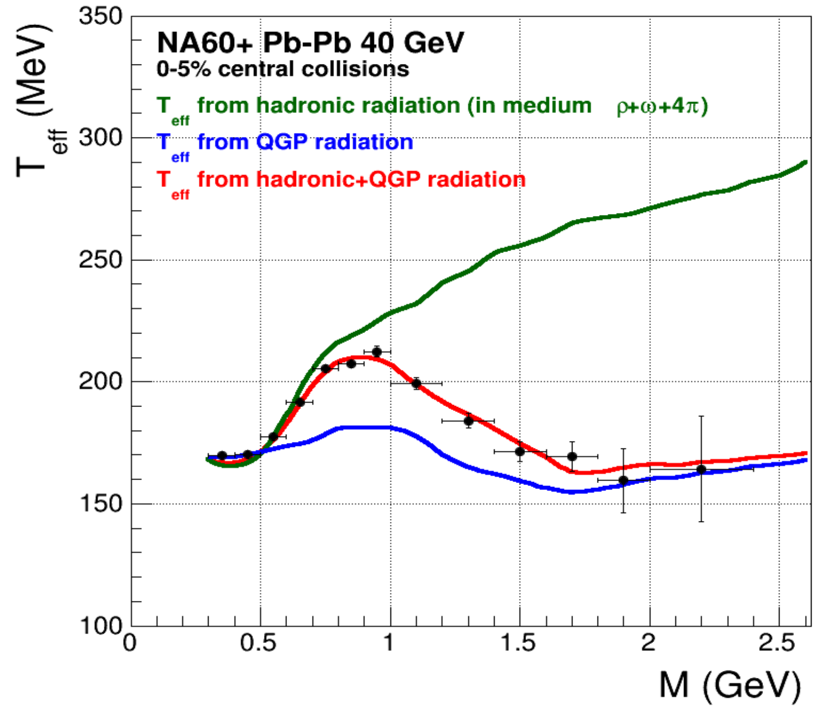
- Performance for study of hadronic radiation in IMR. Scenario with
  - Negligible QGP radiation
  - Hadronic radiation for Pb-Pb central collisions at 20/40 GeV
  - Same background level as Pb-Pb 40 GeV

- Stand-alone study of excess up to M ≈ 2 GeV

→ Best sensitivity to ρ-a_1 chiral mixing

Pb-Pb 0-5% central collisions: performance of T_{eff} measurement from m_T spectra

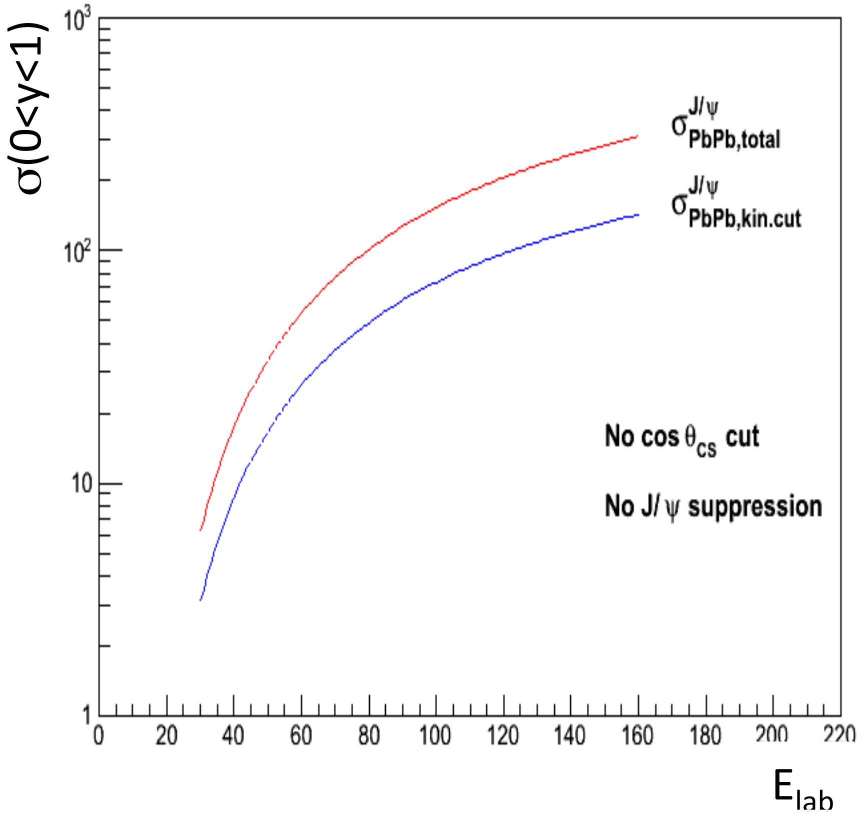


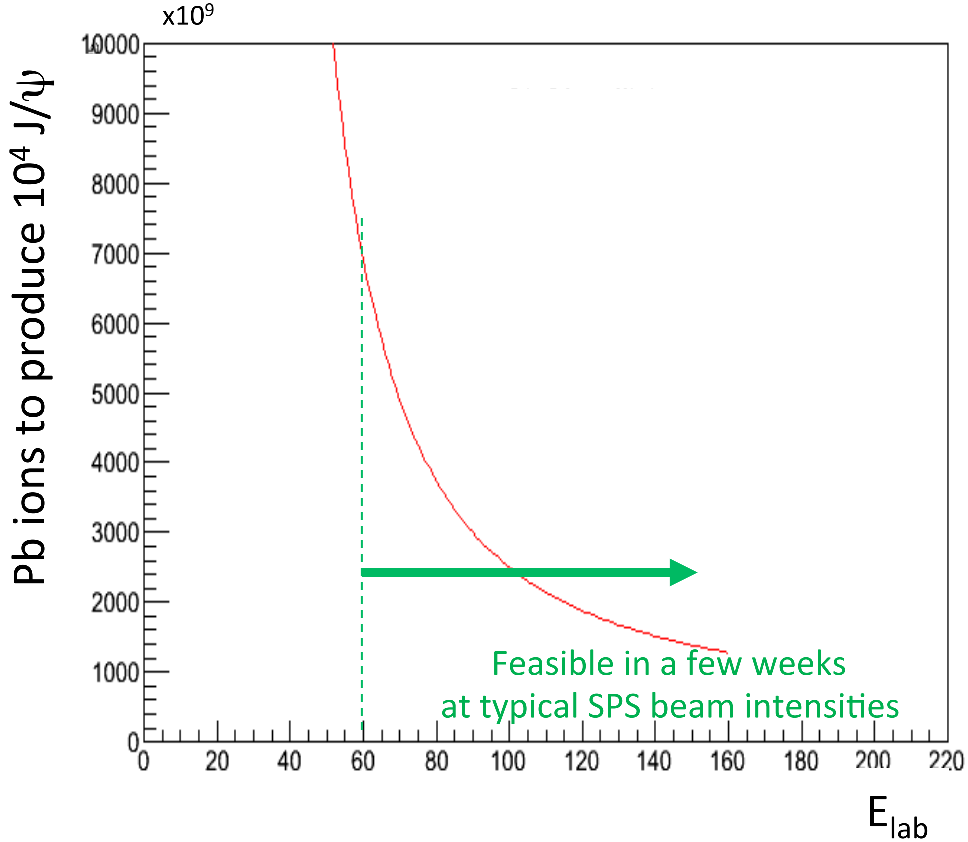


- Thermal radiation in Pb-Pb at 40 GeV (Rapp)
  - hadronic radiation: T_{eff} increases monotonically from LMR to IMR up to highest masses
  - QGP radiation: T_{eff} variation almost negligible

- Experimental measurement
  - T_{eff} can be extracted in several mass intervals up to ≈ 2.5 GeV
  - Strong sensitivity to distinguish even a small contribution of QGP down to the onset

NA60+: charmonium measurements in Pb-Pb at low energy





- Kinematic cuts and reconstruction efficiency:
  - $0<y<1$; $\cos\theta_{CS}<0.5$; $\varepsilon_{rec} \approx 10\%$

- J/ψ suppression: assume a factor 3 as at 160 AGeV (pessimistic ansatz)

- Energy scan down to $E_{lab} \approx 60$ AGeV

➔ Measurement with comparable statistics as at topmost SPS energy ($N_{J/\psi} \approx 10^4$) possible within the proposed frame

Magnets and muon system

- Dipoles: investigating re-use of PT7 or MEP48
- MEP48
  - Gap width 410 mm, diameter 1000 mm
  - B=1.47 T @ 200 Amp, 200 V
  - B~2.5 T reducing the gap size to 200 mm

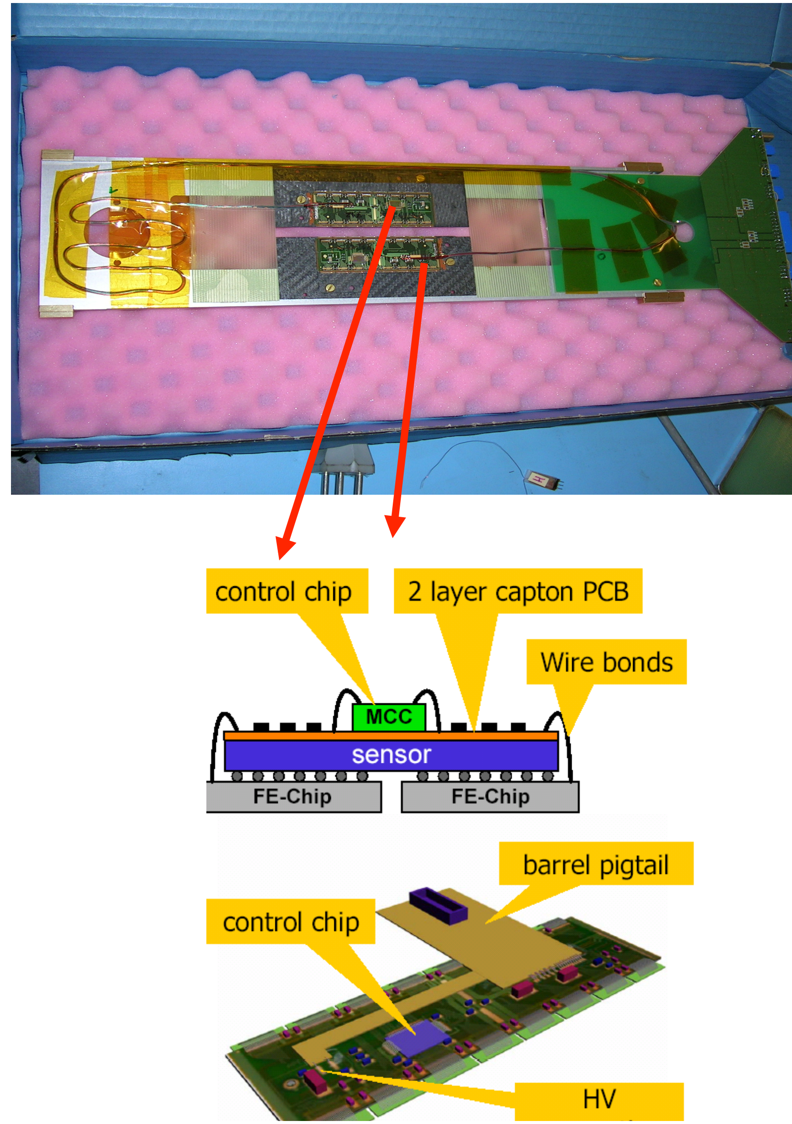
- Toroid magnet options
  - new magnet with field integral similar to ACM to cover all energies
  - re-use of ACM down to 60 AGeV and new low-field magnet at 20-40 AGeV
  - ongoing discussion with CERN experts
- Muon tracking stations
  - Option of complete construction with GEMs considered (≈ 140 m^2)

Options for the pixel telescope

- Baseline option investigated: detector based on hybrid pixels
    - Pitch 40-50 μm
    - pixel station material budget ≈ 1% X_0

- Exploration of existing technologies or new developments for LHC upgrades (past example in NA60: ATLAS pixels)

- Monolithic pixels?



2 Planes with different geometry using ATLAS pixel modules built and operated in NA60 2004 proton run

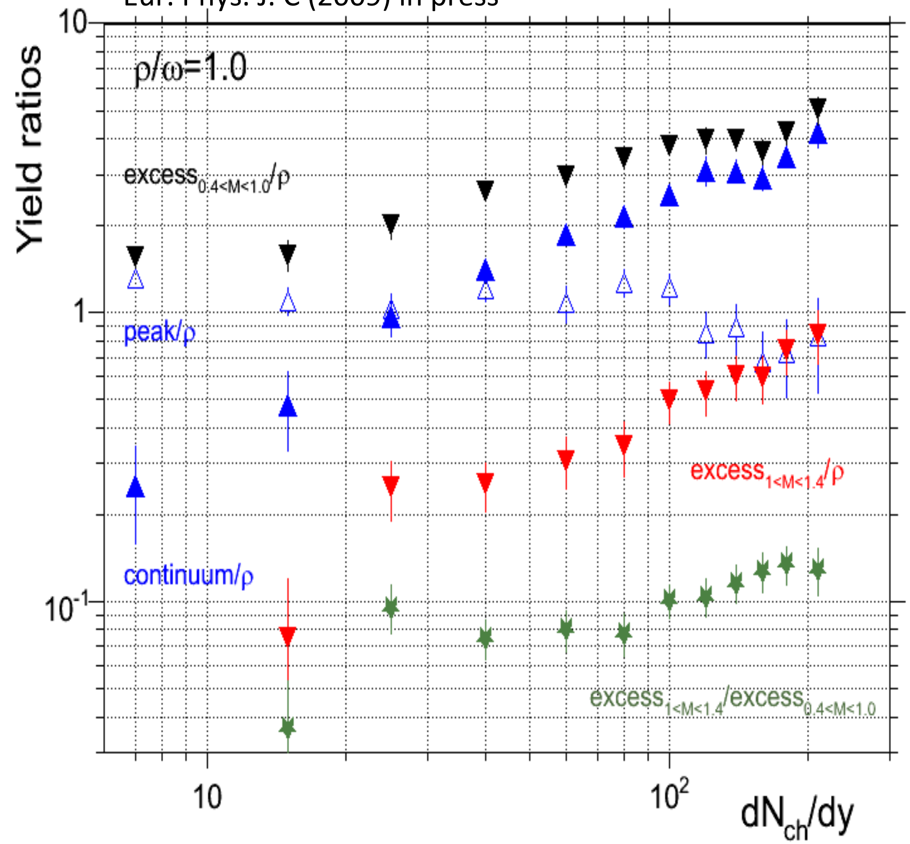
Summary

- Systematic measurement of EM radiation over the full energy range from ≈ 20 AGeV to 160 AGeV
- Charmonium also part of the program from ≈ 60 AGeV to 160 AGeV
- NA60+ at the CERN SPS: unique opportunity for dilepton measurements of utmost precision over the widest possible energy range
  - Progress in statistics of a factor ≈ 100 over NA60 within reach
  - New horizon for quantitative understanding of dilepton production (chiral symmetry restoration, onset of deconfinement)
- NA60+: two-spectrometer detector concept as NA60
  - Relatively low cost experiment at a running machine: 10-15 Meuro
  - Collaboration would require 50-100 people
- Ongoing work:
  - Submission of an expression of interest to SPSC
  - Preparation of document to serve as a basis for a letter of intent

Dileptons in LMR: measurement in fireball lifetime

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

Eur. Phys. J. C (2009) in press



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

Nice example of complementary measurements with NA61