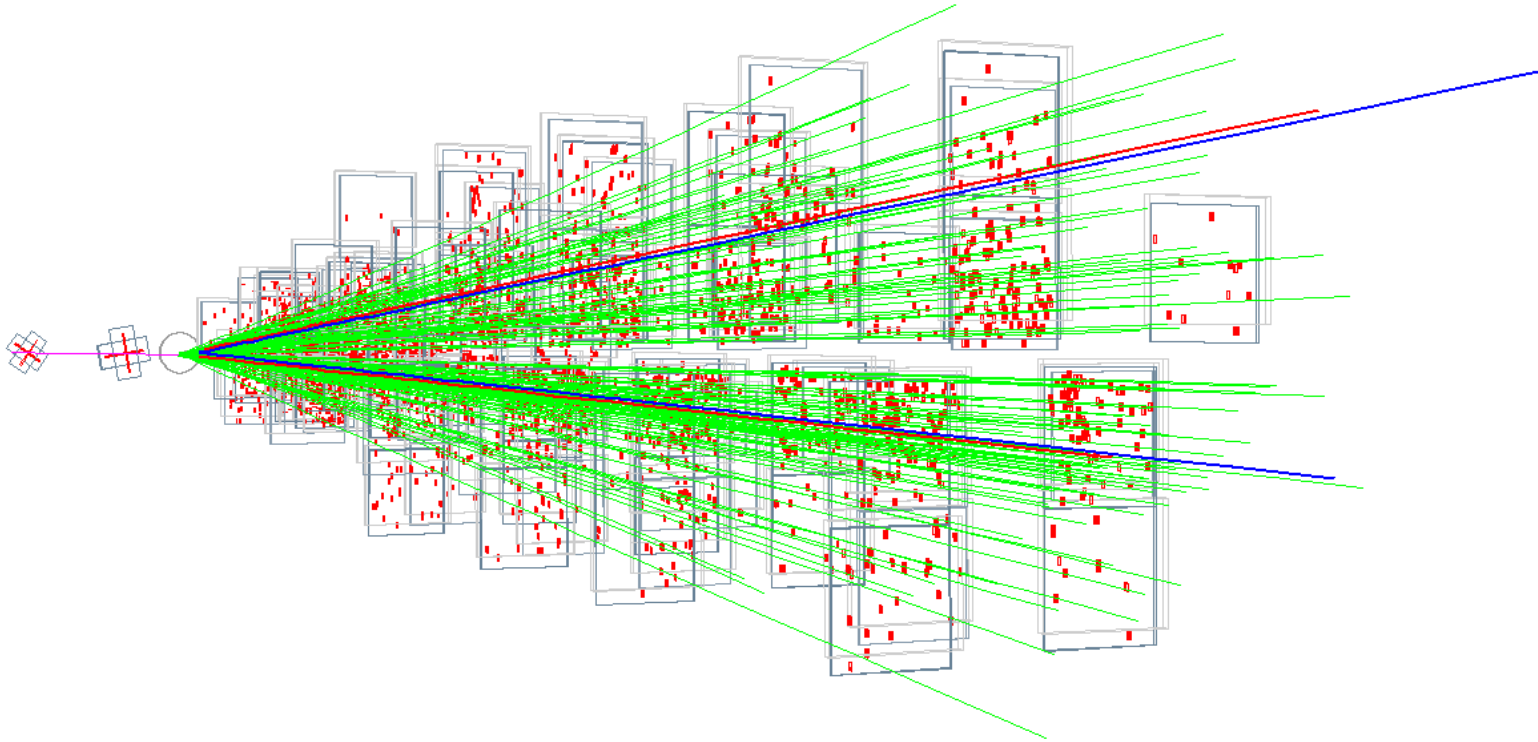
# Dimuon Production In PbPb Collisions at 20-160 AGeV at the CERN SPS: Mapping the QCD Phase Diagram in the Transition Region

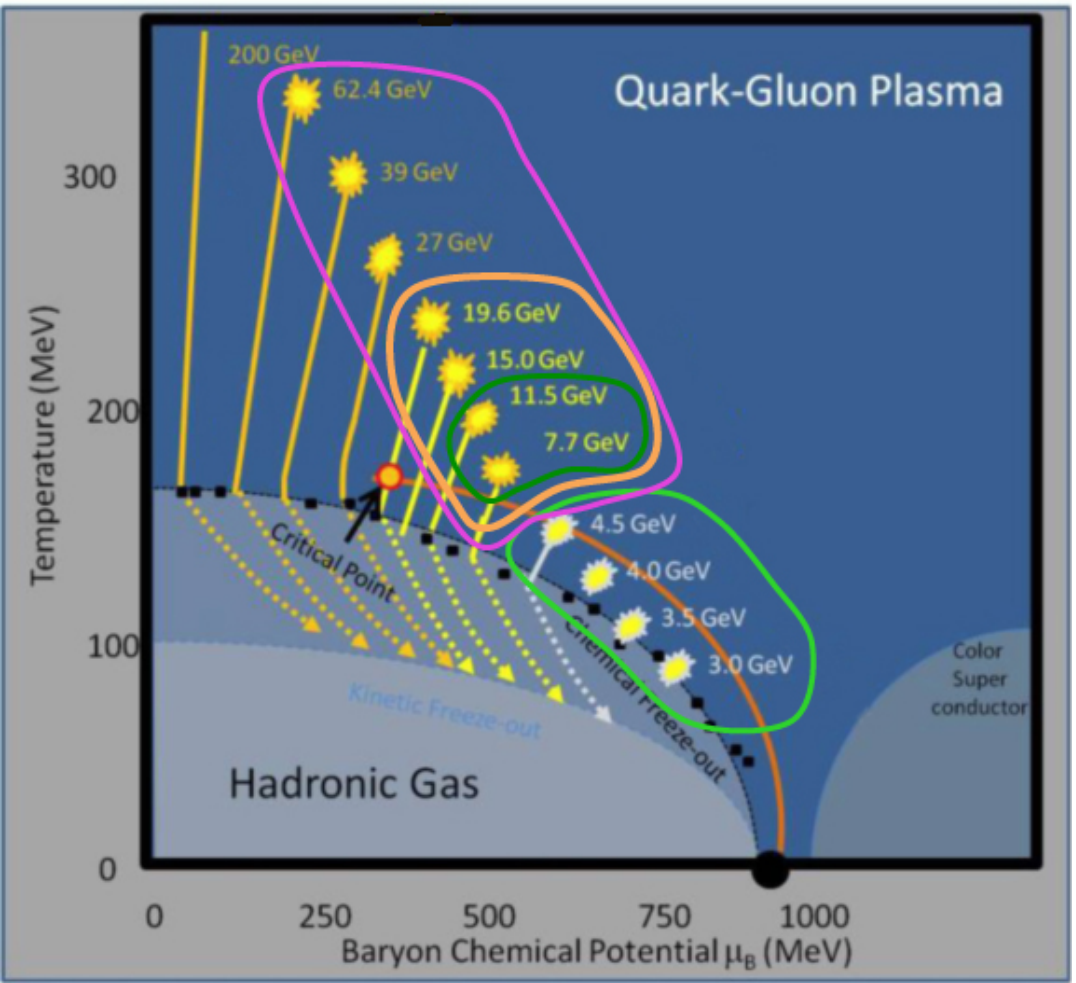
Gianluca Usai – University of Cagliari and INFN



ICNFP 2014
Kolymbari - Crete 29/07/2014

# 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

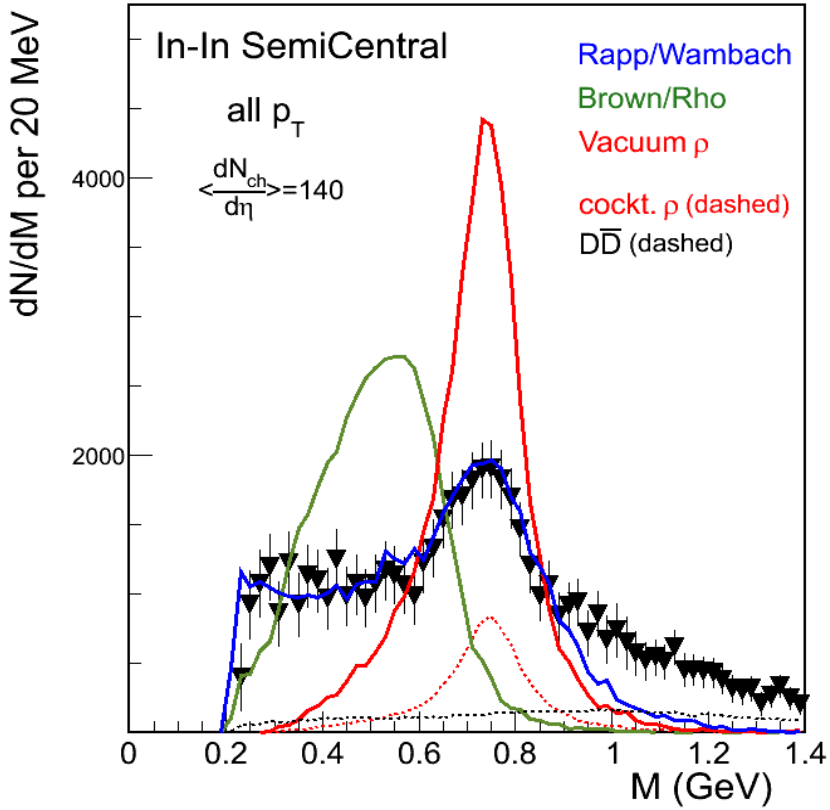
**FAIR (CBM)**:
- SIS-100 (>2020) limited coverage
- SIS-300 better coverage but unclear timeline (>2025)

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

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

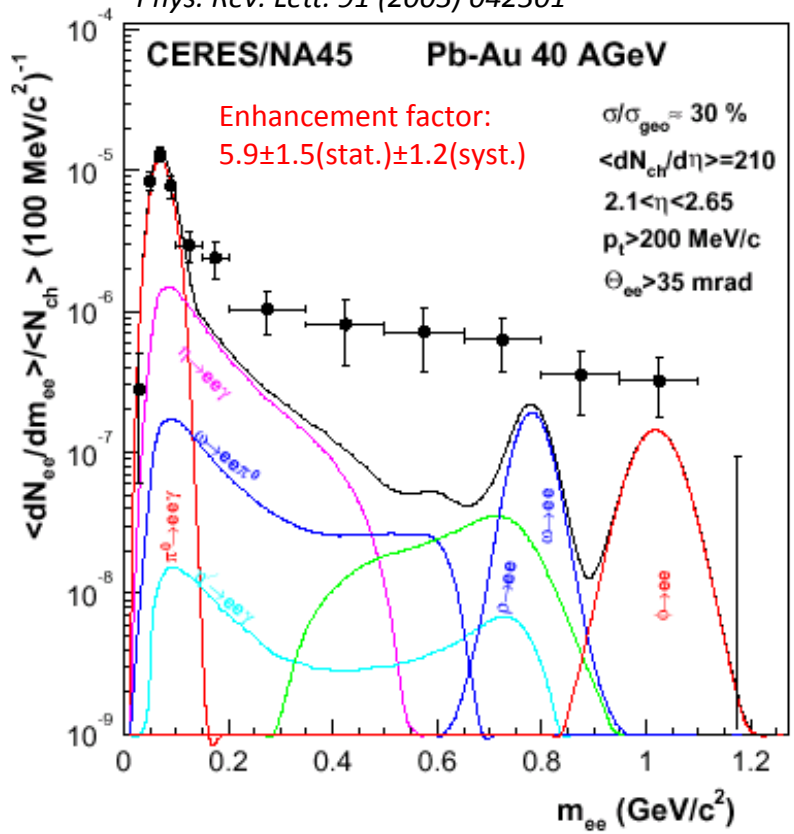
- High energy: 160 AGeV In-In

*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*

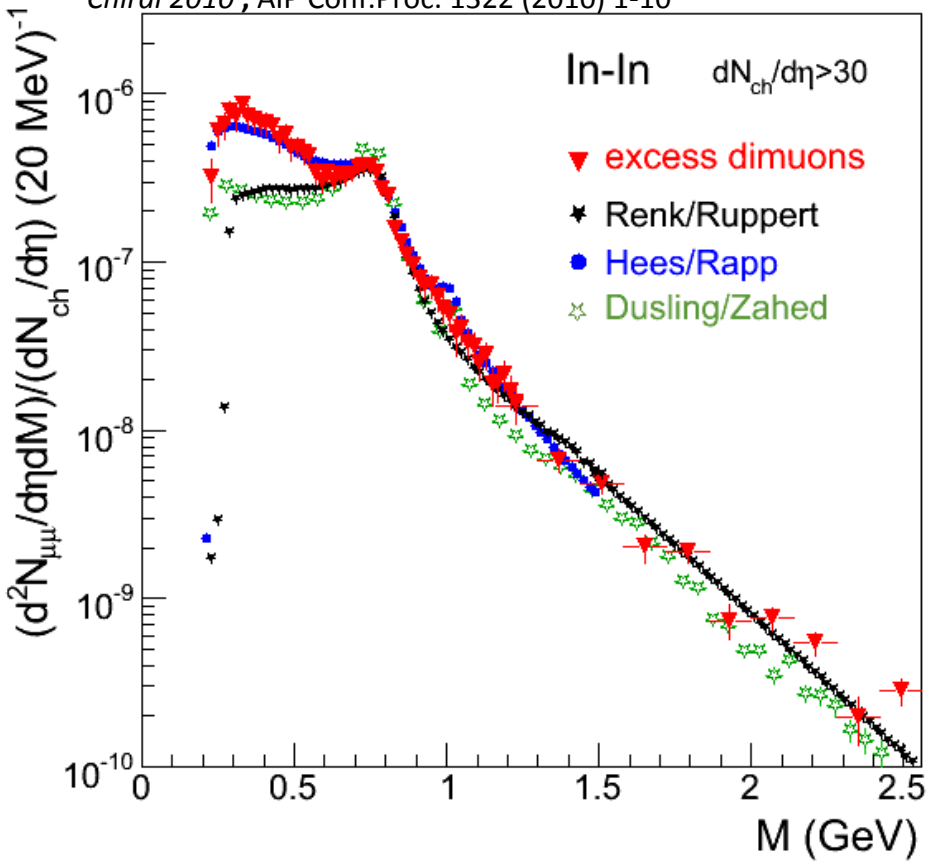



- Broadening of ρ spectral function driven by the total baryon density
  - should get maximal at low energy

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

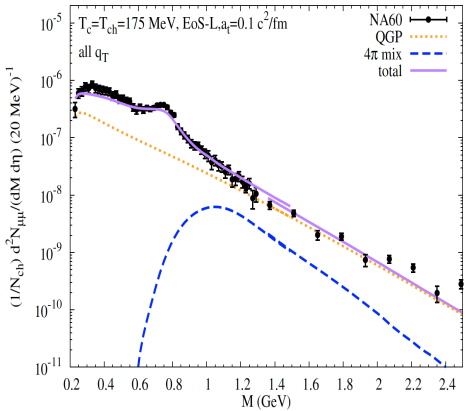
# Dileptons in the IMR: source temperature and chiral symmetry restoration

*[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 ~ $M^n$)
  - 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
- Chiral symmetry restoration: hadronic radiation for M<1.5 GeV dominated by $4\pi$ processes via $a_1\pi \rightarrow \mu\mu$ (chiral mixing)

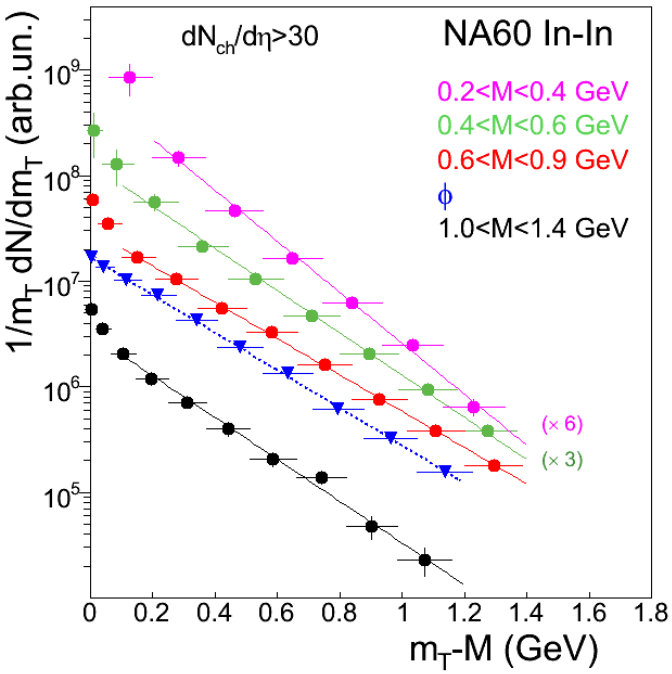
*Hees – EM probes Trento workshop - 2013*




- Lower energy: decrease of QGP, DY and open charm
  ➔ improved sensitivity to excess from hadronic radiation

# Partonic radiation and onset of deconfinement

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

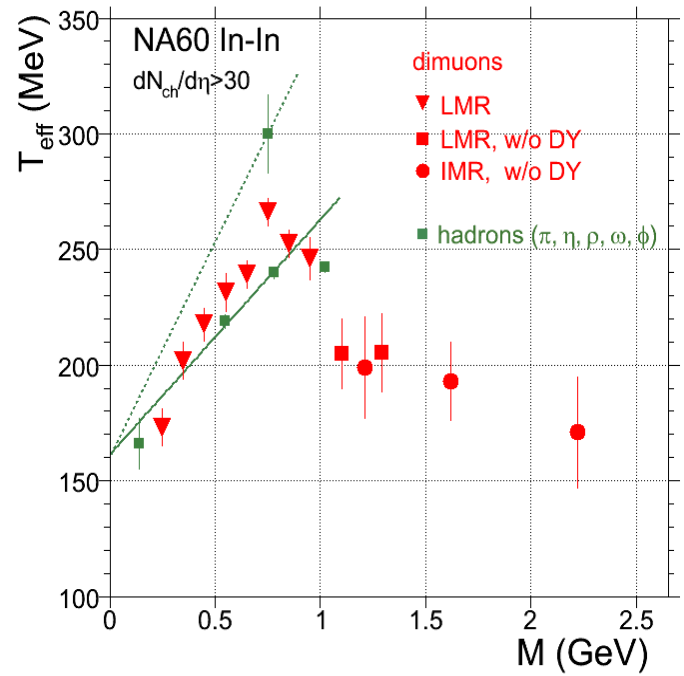



$m_T$ spectra (left): fit with

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

Collective motion (radial flow)

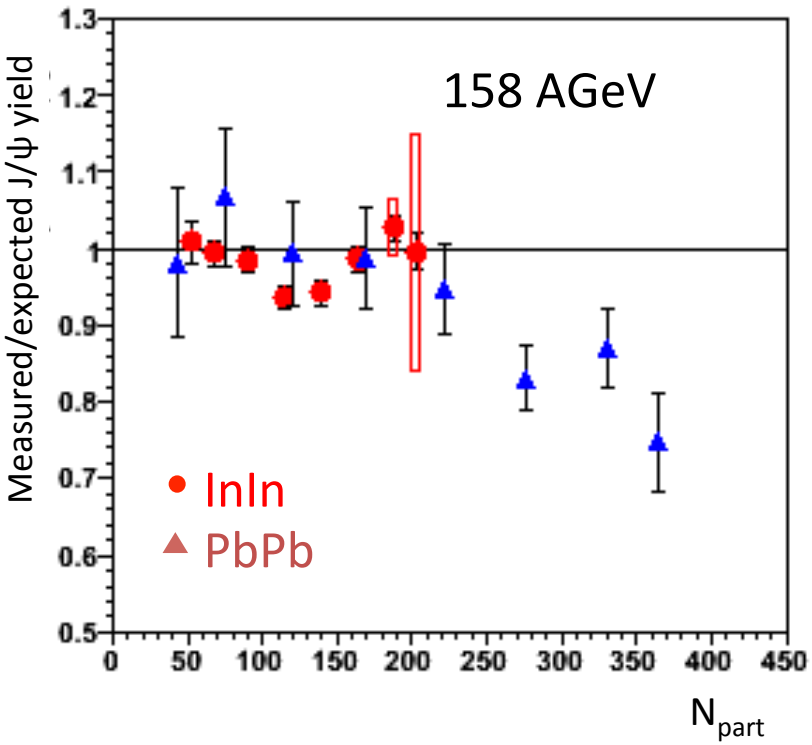
$$T_{eff} \approx T + M\left\langle v_R^2 \right\rangle$$

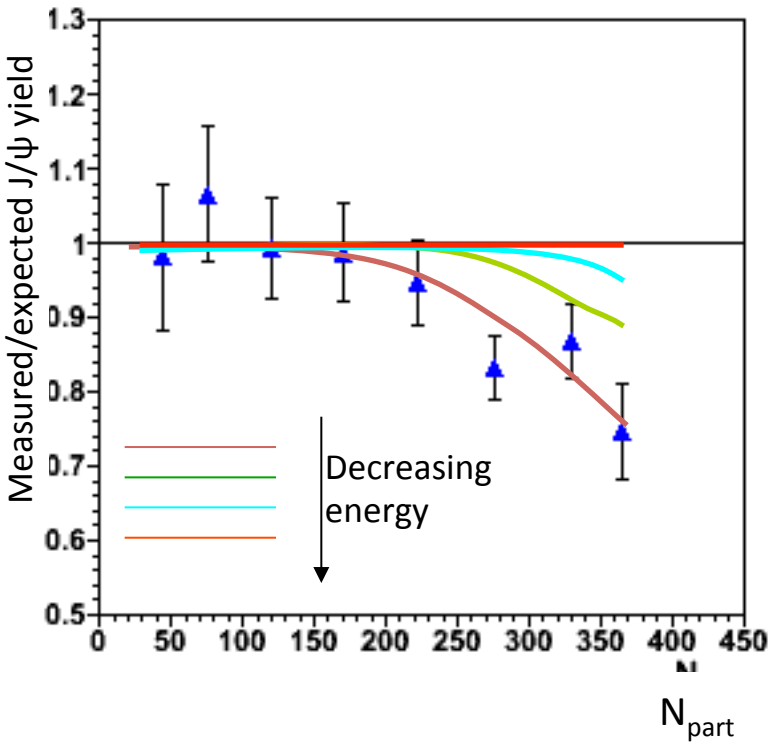



- Hadronic radiation: $T_{eff}$ rise consistent with radial flow of a hadronic source: $\pi^+\pi^- \rightarrow \rho \rightarrow \mu^+\mu^-$ in LMR; $4\pi$ in IMR (the latter negligible at 160 AGeV)
- QGP radiation: $T_{eff}$ almost flat, consistent with an early source with low flow (dominant at 160 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 $\chi_c$ by detecting the decay photon (originally part of NA60 program)

# Comparison of ion beams

| | SPS | | | SIS100/300 |
|---|---|---|---|---|
| Energy range: [AGeV] | 11 – 158 | | | < 11 – 35 (45) |
| | beam intensity [Hz] | target thickness [$\lambda_i$] | interaction rate [Hz] | interaction rate [Hz] |
| NA60 (2003) | $2.5\times10^6$ | 20% | $5\times10^5$ | |
| new injection scheme | $10^8$<br>$10^8$ | 10%<br>1% | $10^7$<br>$10^6$ | $10^5$ - $10^7$ |
| LHC AA | | | $5\times10^4$ | |

- 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

# Running conditions foreseen

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

- Objectives for total sample of reconstructed pairs
  - NA60 (2003): total sample (thermal + cocktail) ≈ $5 \cdot 10^5$
  - NA60+: 4th generation experiment

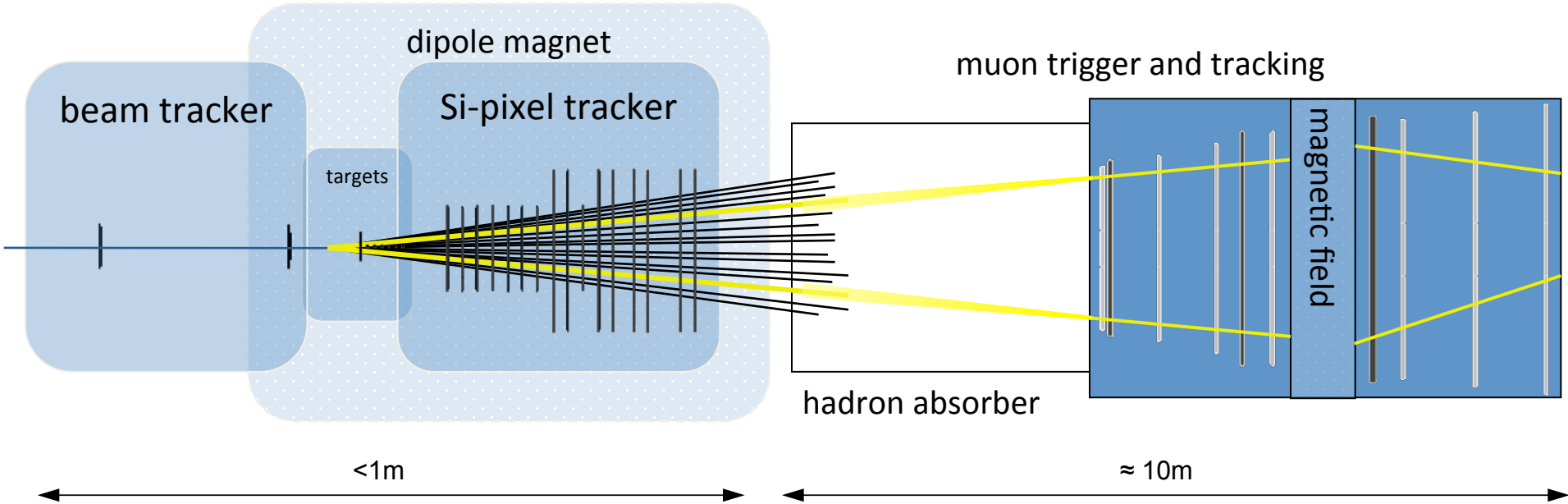
➔ Objective: > $10^7$ rec pairs from thermal radiation at each energy

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

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

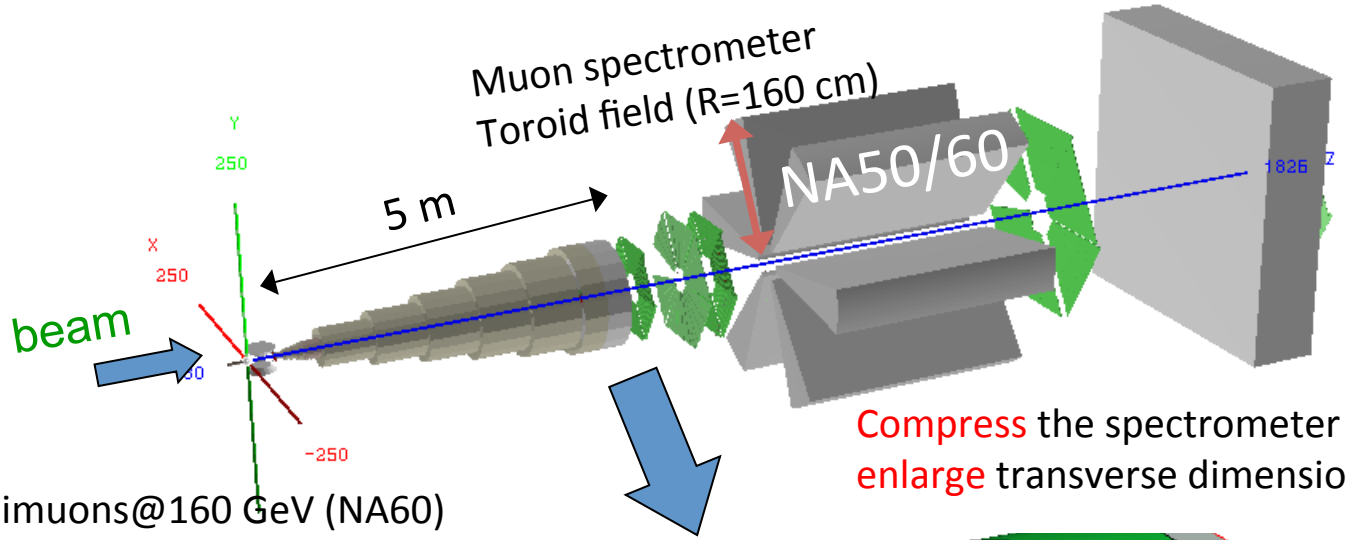
# NA60+ detector concept

Two-spectrometer concept (successfully exploited by NA60)



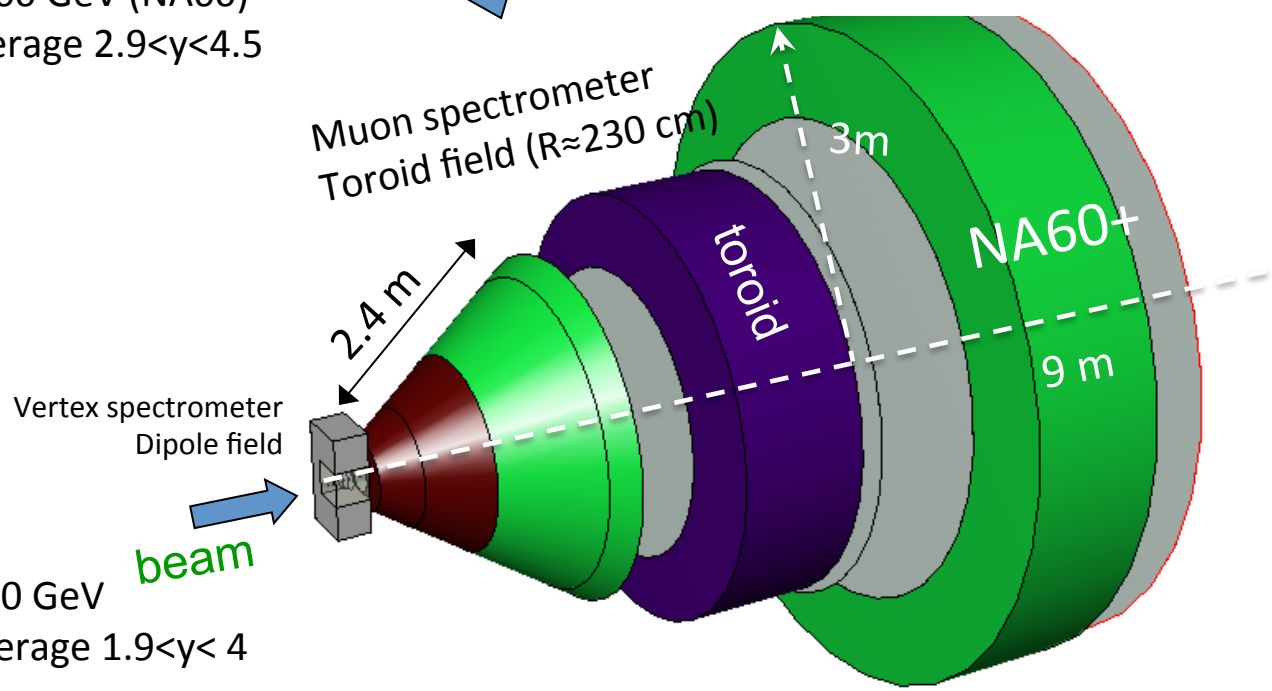

- Hybrid silicon pixel detectors (High luminosity of dimuon experiments must be maintained)
- Tracking and trigger stations: GEMs and/or MWPCs
- Track matching in coordinate and momentum space
  - improved dimuon mass resolution
  - distinguish prompt from decay dimuons

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




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

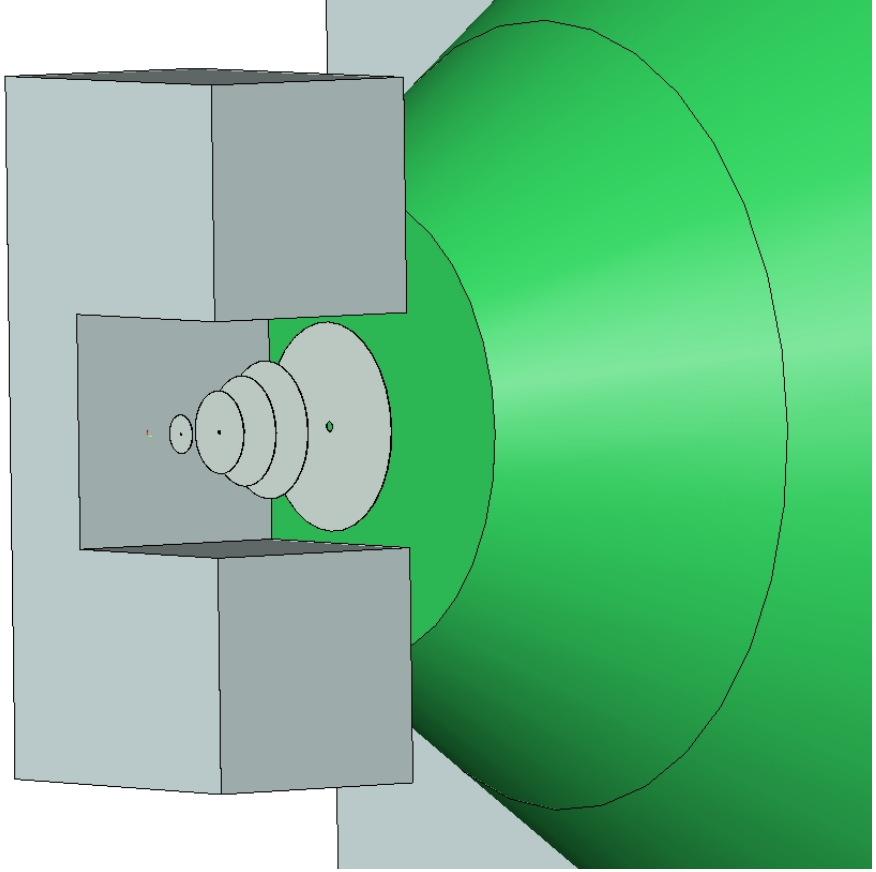
Compress the spectrometer reducing the absorber and enlarge transverse dimensions

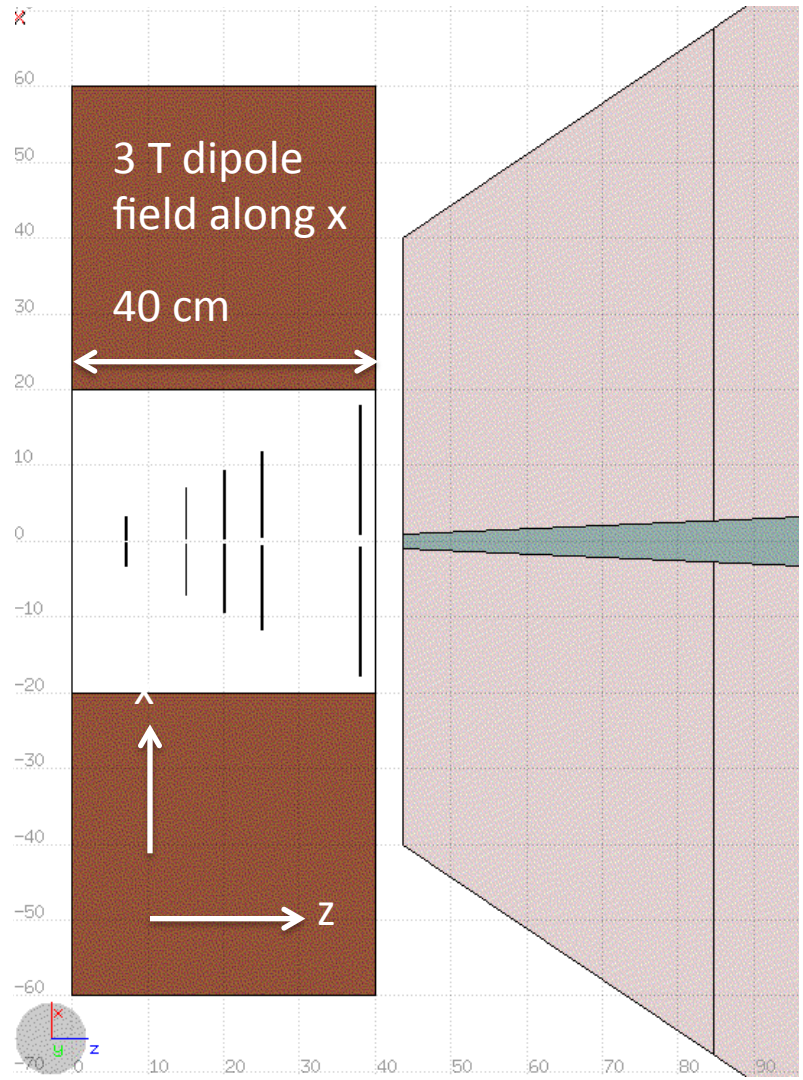



dimuons@20 GeV
rapidity coverage 1.9<y< 4

Longitudinally scalable setup for running at different energies

# The vertex spectrometer






- Required rapidity coverage @20 GeV starting from <y>=1.9 ($\vartheta$~0.3 rad)
- 5 silicon pixel planes at 7<z<38 cm
- Pixel plane:
  - 400 $\mu$m silicon + 1 mm carbon substrate
  - silicon material budget ≈0.5% $X_0$
  - 10-15 $\mu$m spatial resolution

# The muon spectrometer

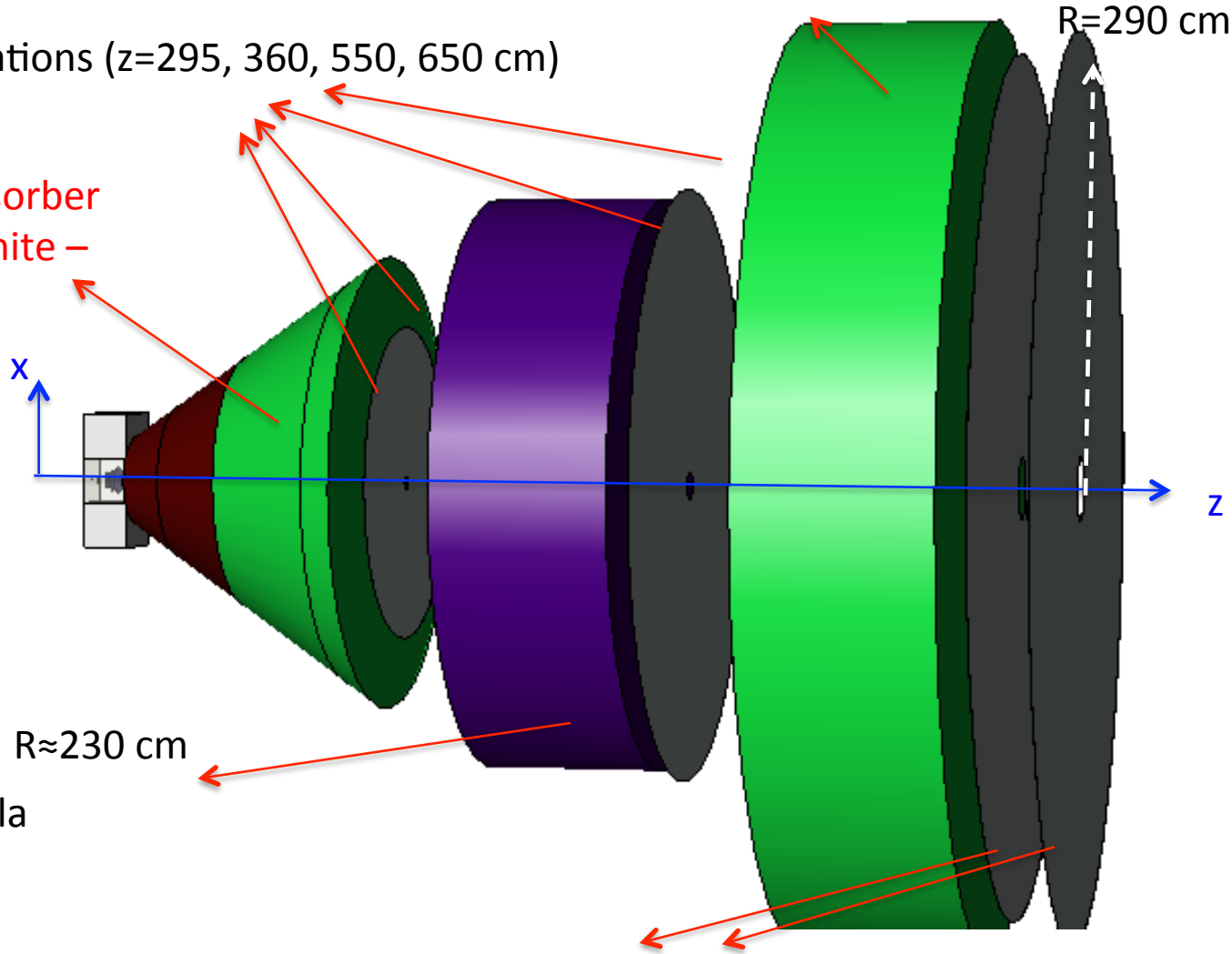
Muon Tracker

- ✓ 4 tracking stations (z=295, 360, 550, 650 cm)

Muon wall (graphite - 120 or 180 cm)

R=290 cm

Hadron absorber (BeO, graphite – 240 cm)




Toroid magnet:

- ✓ 150 cm long; R≈230 cm
- ✓ B ≈0.5/R Tesla

Trigger stations

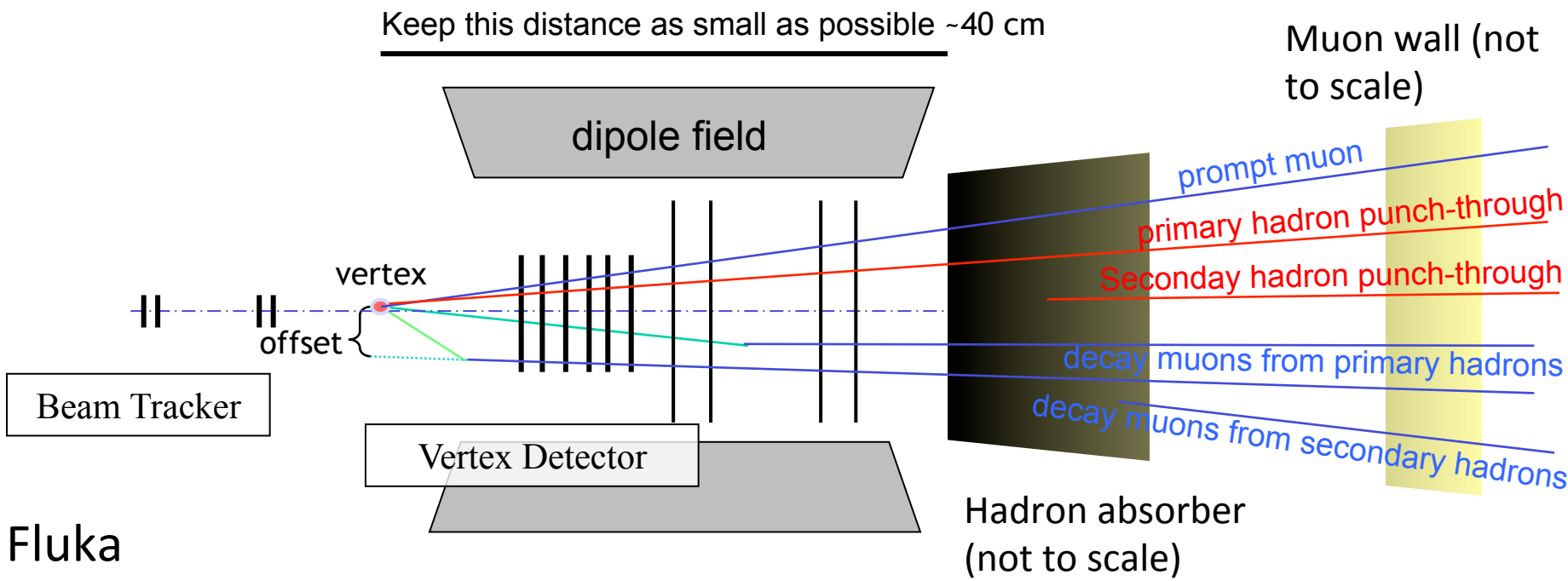
- ✓ 2 trigger stations placed after muon wall (ALICE-like) at z = 840, 890 cm
- ✓ No particular topological and $p_T$ constraints introduced contrary to NA60 hodo system (muons required in different sextants)

# 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, $\pi$)
  - Muons from secondary hadrons
- Background generation
  - Parametric $\pi$ and K event generator (built-in decayer for $\pi$ 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, $\lambda_i$=0.15 (past NA60 conditions)

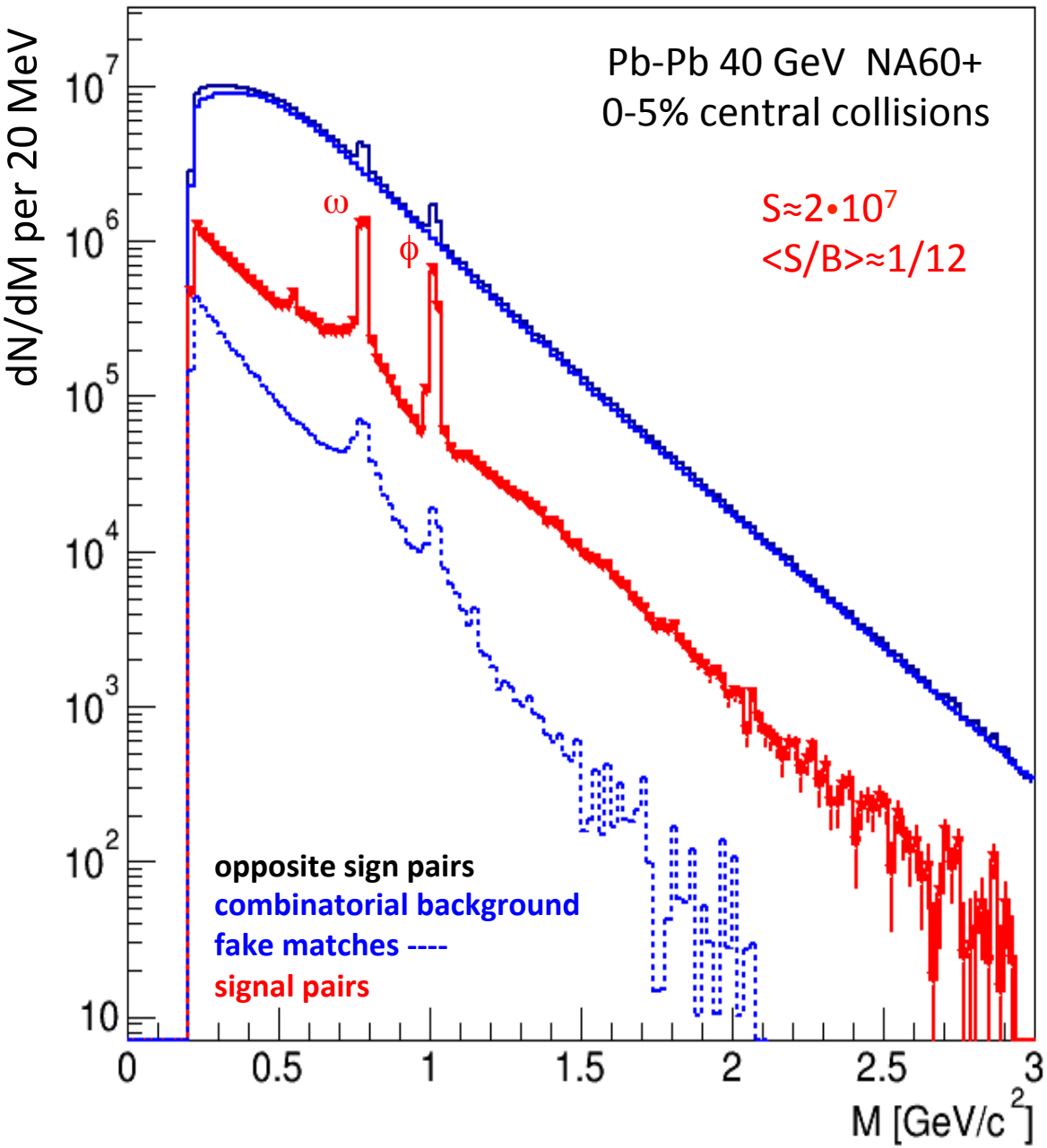
  ➔ minimum bias trigger rate (essentially bkg rate) ≈ 15-20 kHz

- 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

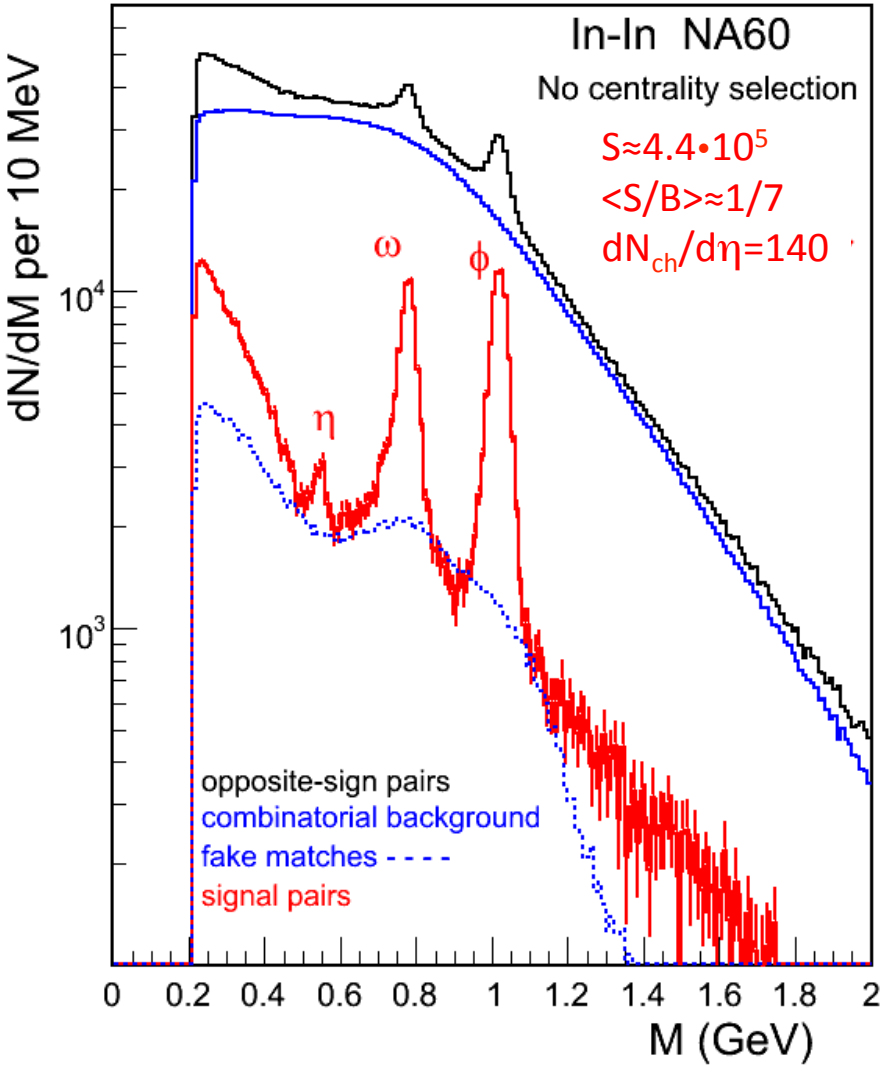
➔ ≈ $10^7$ reconstructed pairs from thermal radiation in central collisions

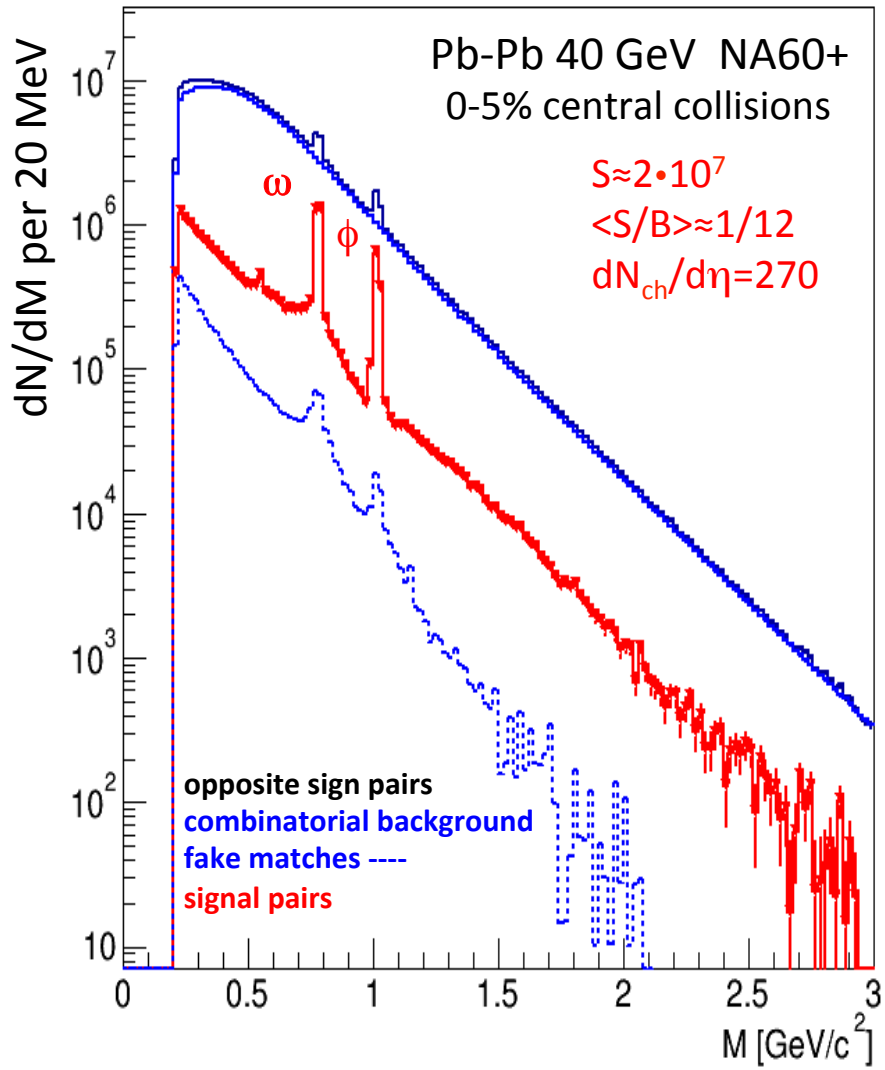
# Pb-Pb 0-5% central collisions: data sample




- 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

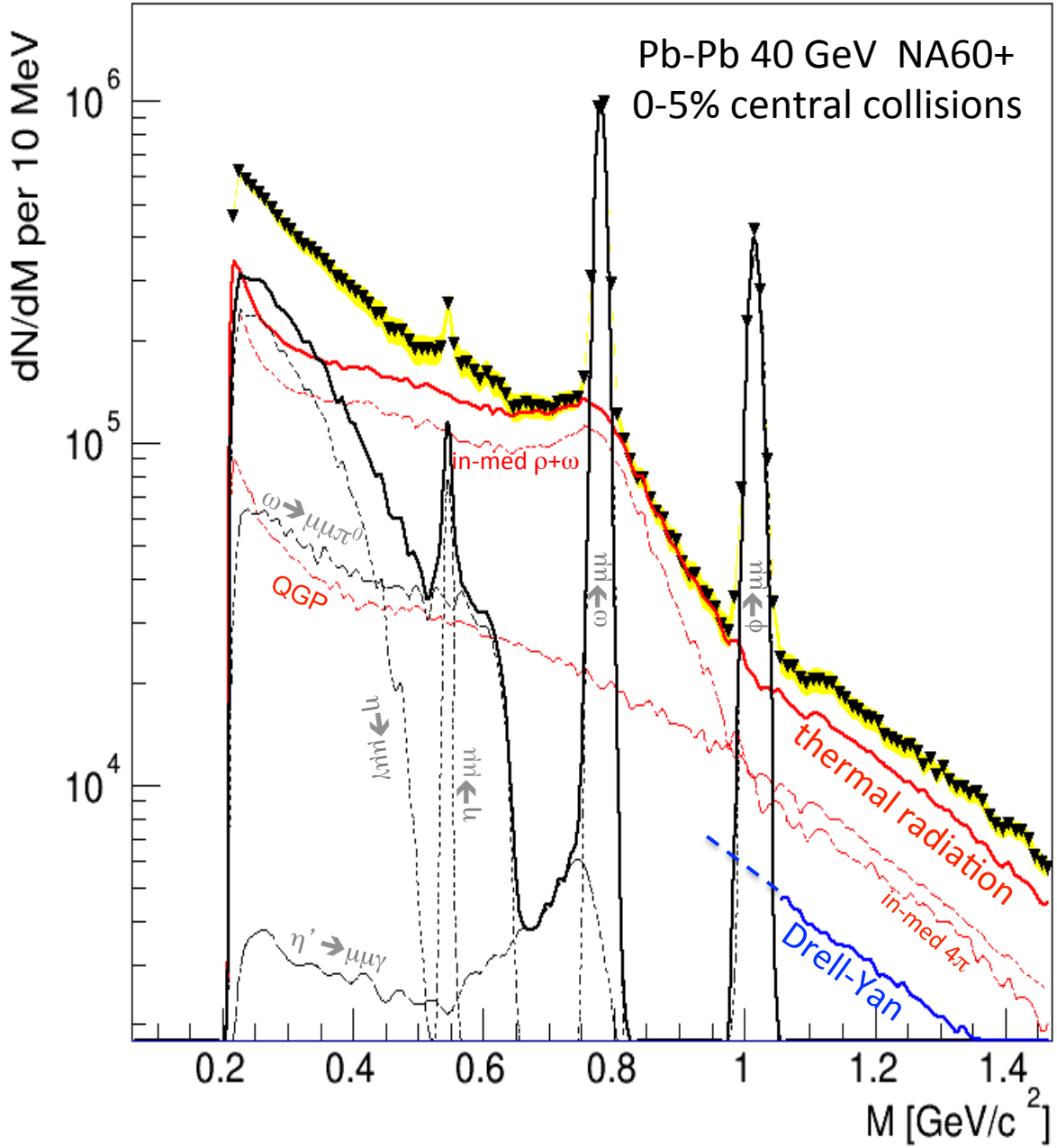
# NA60 vs NA60+



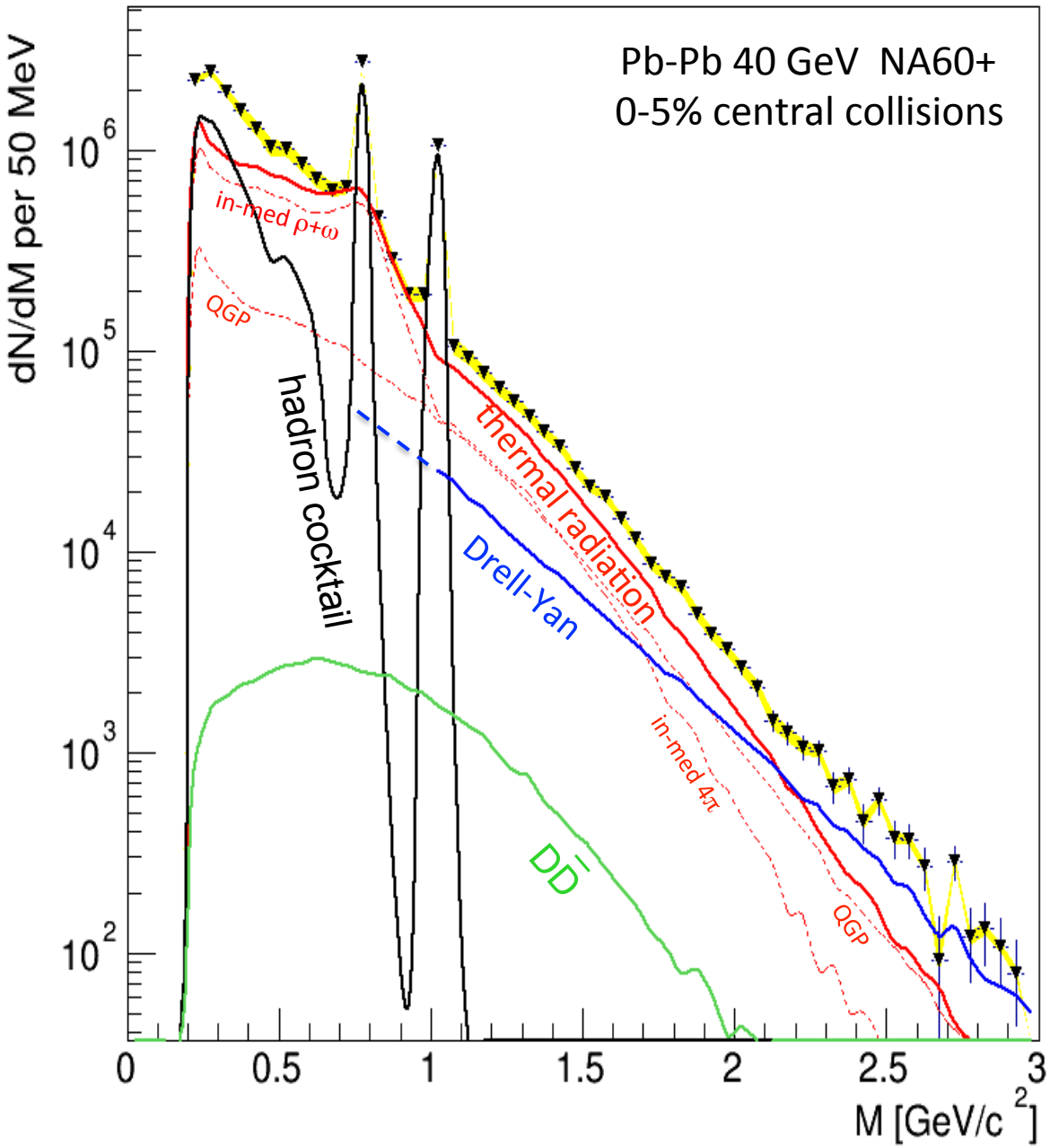

- Minimum bias collisions: progress in statistics over NA60 by a factor ≈ 100

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



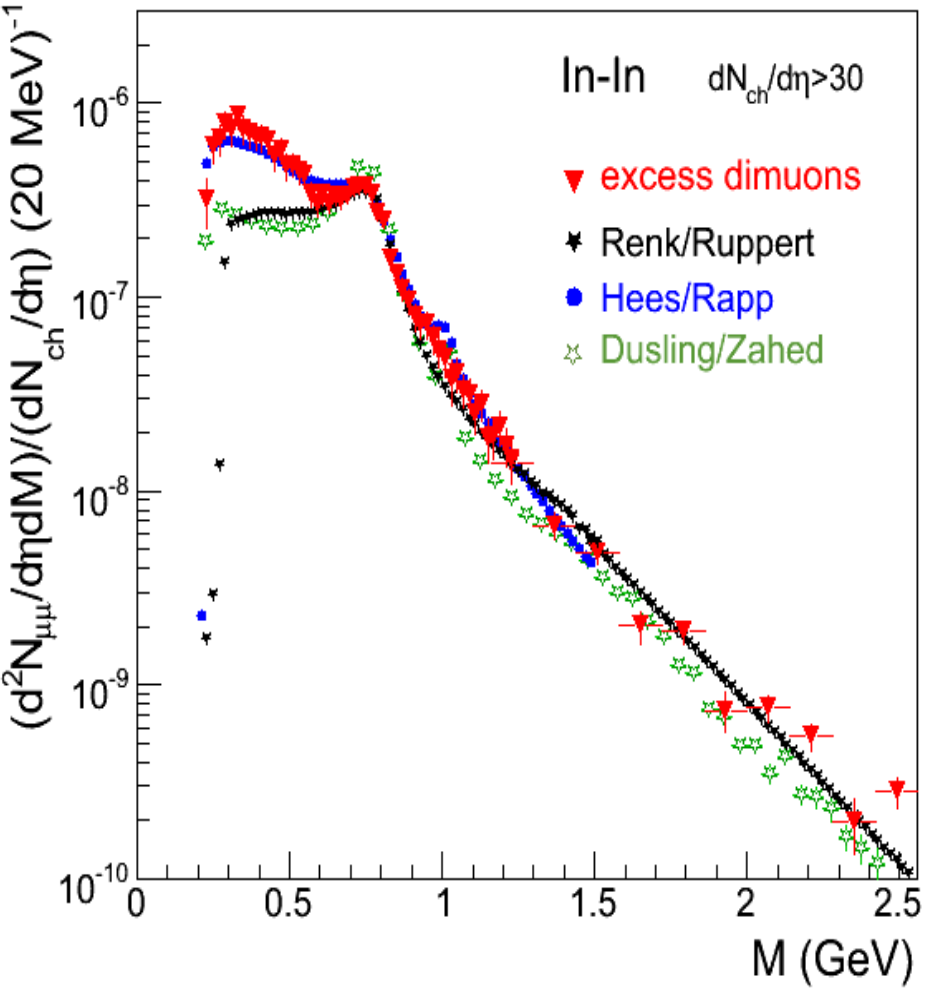

- Thermal radiation yield dominated by in-medium ρ+ω
- Precise isolation of excess *à la* NA60

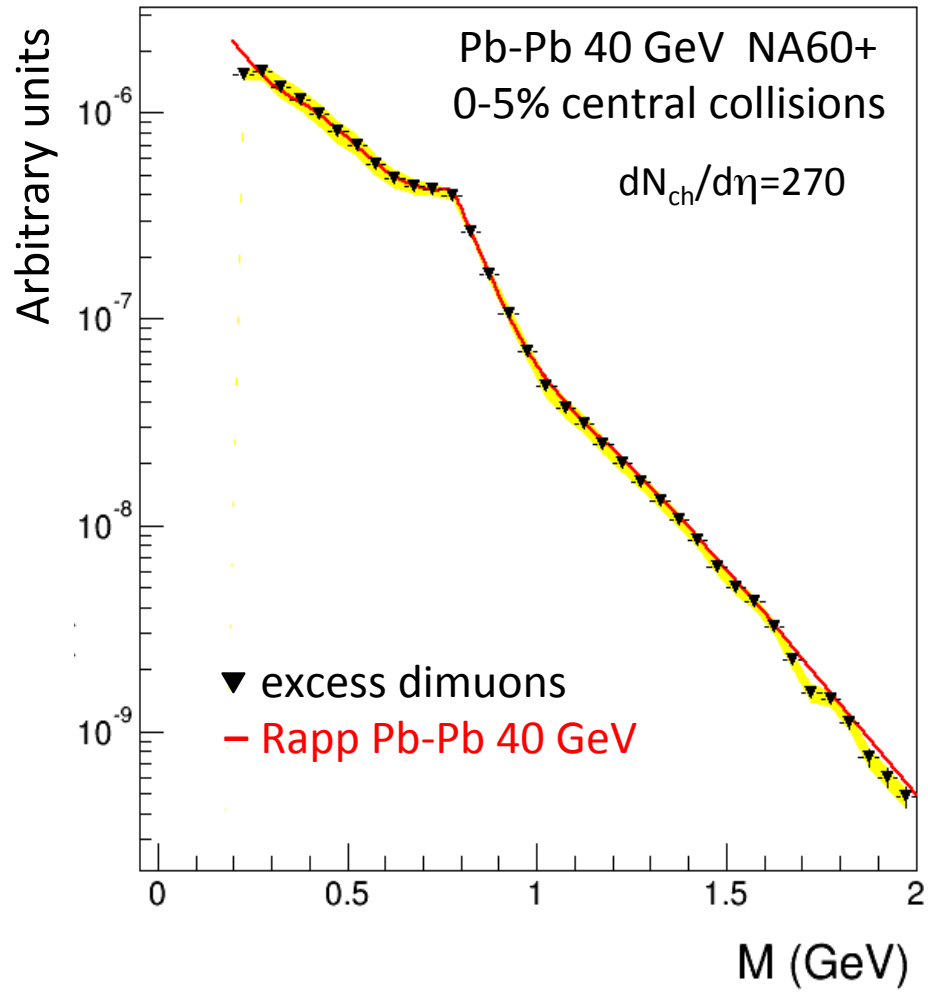
# Pb-Pb 0-5% central collisions: full mass spectrum




- 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)

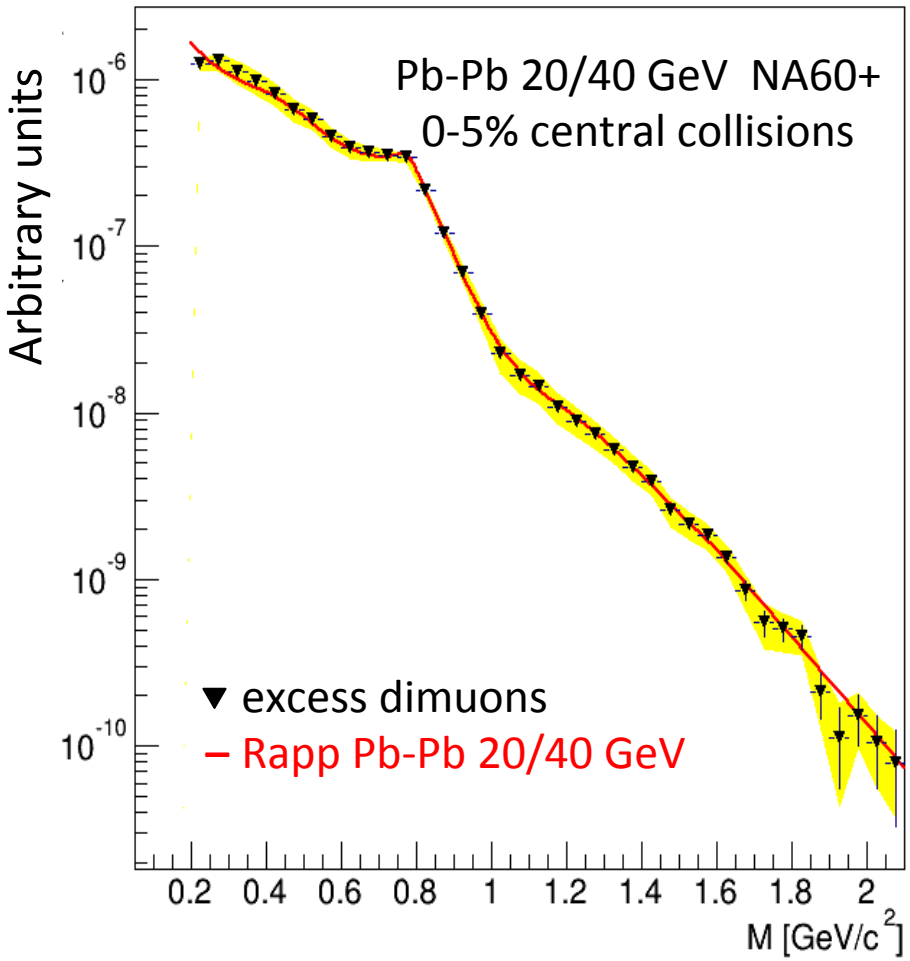



- All known sources subtracted; mass spectra integrated over $p_T$
- Mass spectra fully corrected for acceptance

# Inclusive excess mass spectrum: hadronic radiation

- Mass Spectrum fully corrected for acceptance

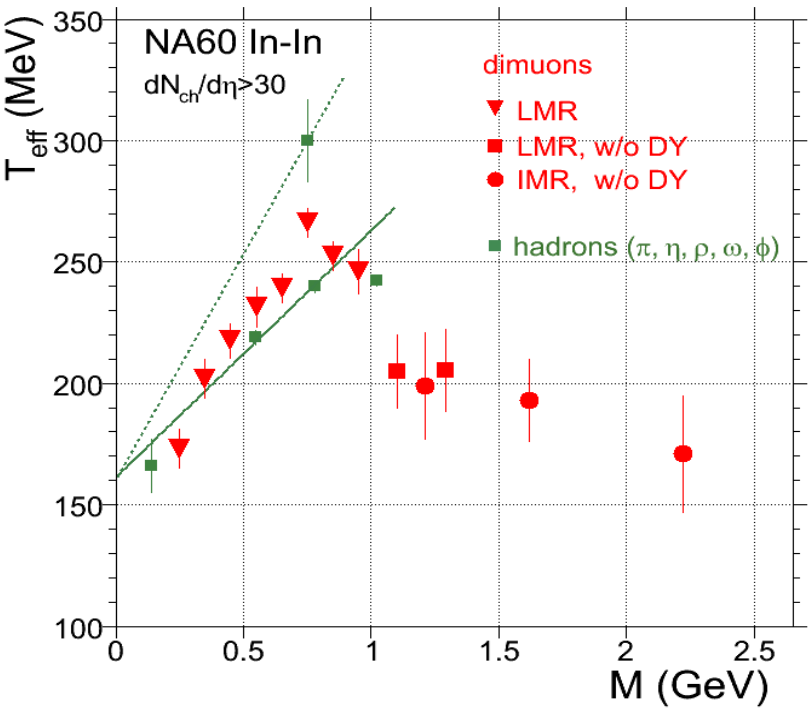


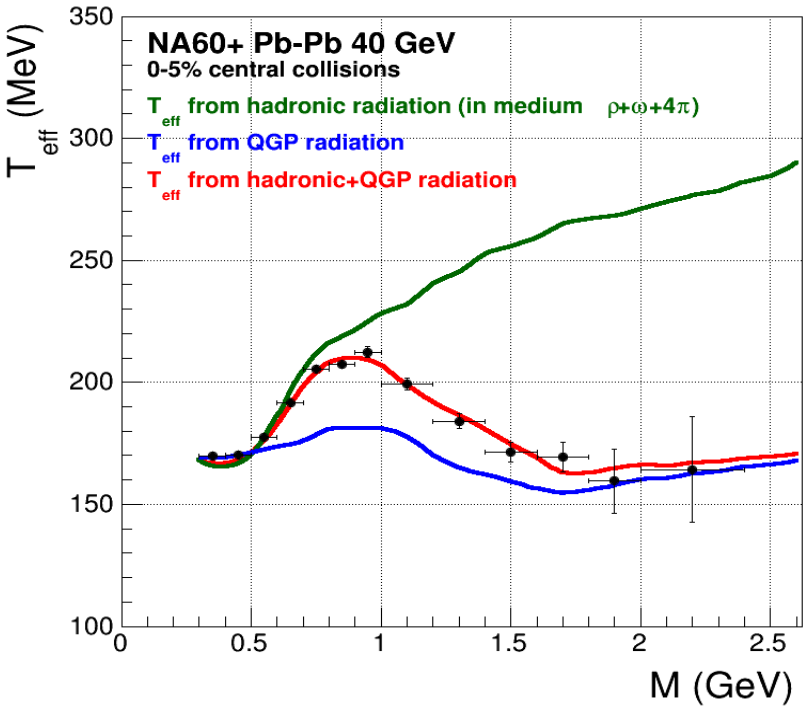

- Performance for study of hadronic radiation in IMR. Scenario with
  - Negligible QGP radiation
  - Hadronic radiation for Pb-Pb central collisions at 20/40 GeV
  - Same background level as Pb-Pb 40 GeV

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

➔ Best sensitivity to $\rho$-$a_1$ chiral mixing

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

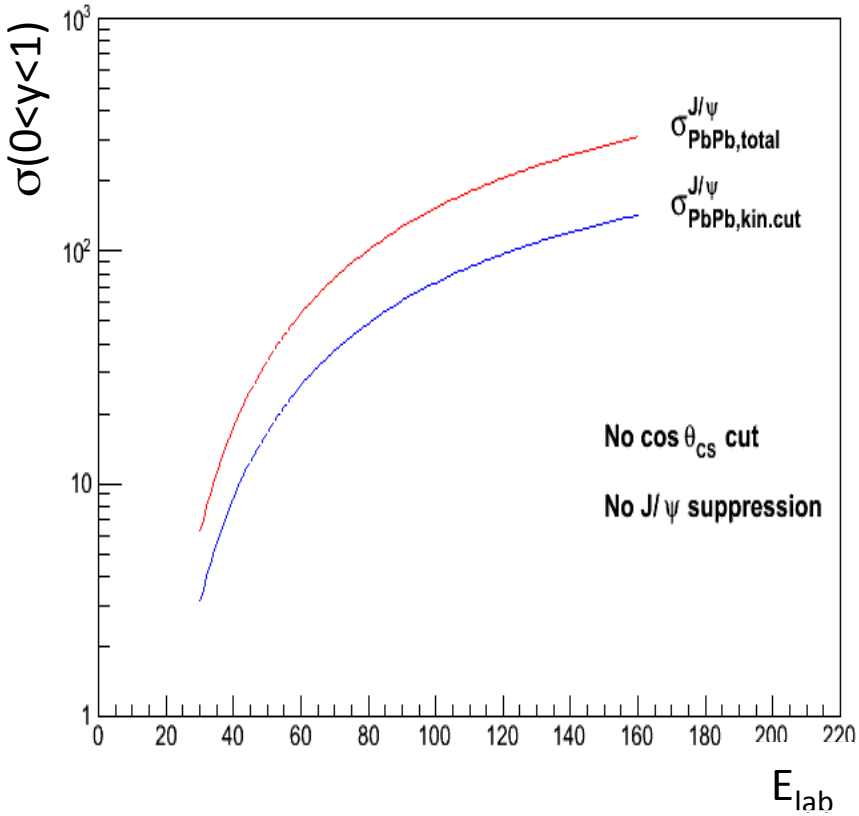


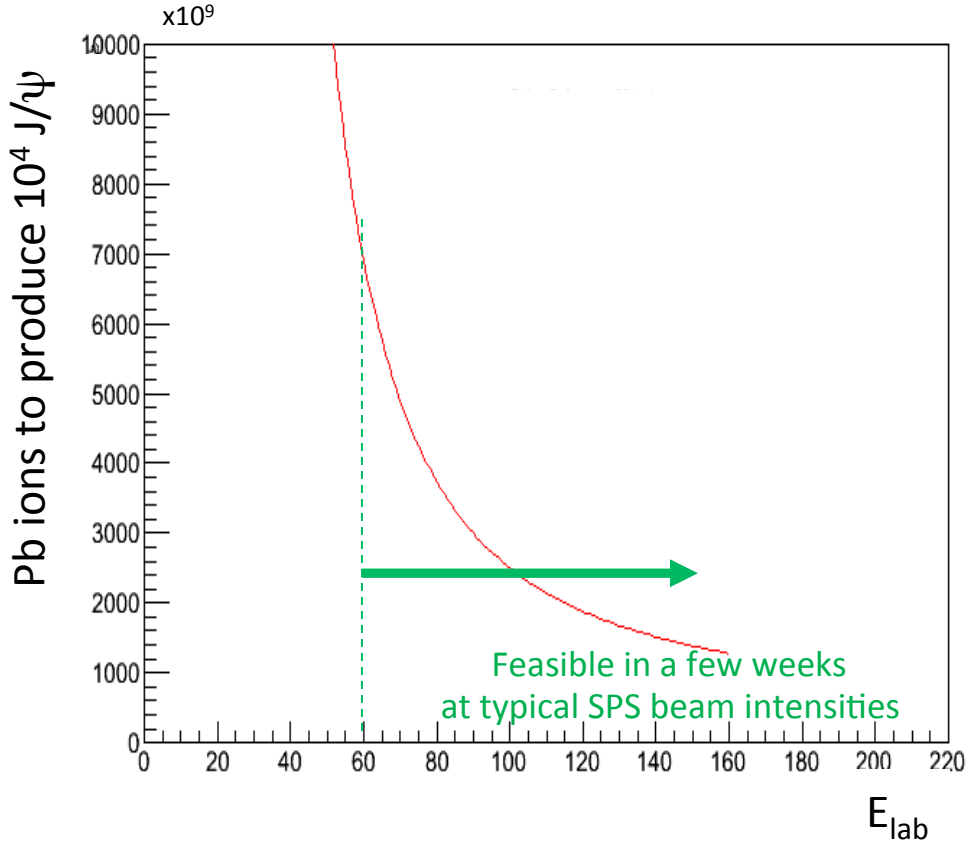




- Thermal radiation in Pb-Pb at 40 GeV (Rapp)
  - hadronic radiation: $T_{eff}$ increases monotonically from LMR to IMR up to highest masses
  - QGP radiation: $T_{eff}$ variation almost negligible

- 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
  - Ongoing discussion with CERN experts
  - Proposal for an "hexagonal cone" shape with the required angular acceptance
  - The estimated cost should not exceed ≈1.5-2 MEuro

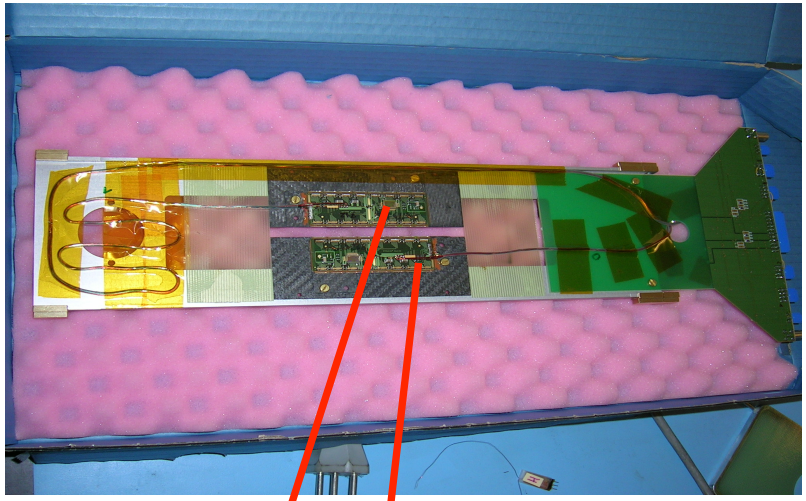
- Muon tracking stations and absorbers
  - Option of complete construction with GEMs considered (≈ 140 $m^2$)
  - Absorbers
  - Estimated cost ≈ 7-10 MEuro

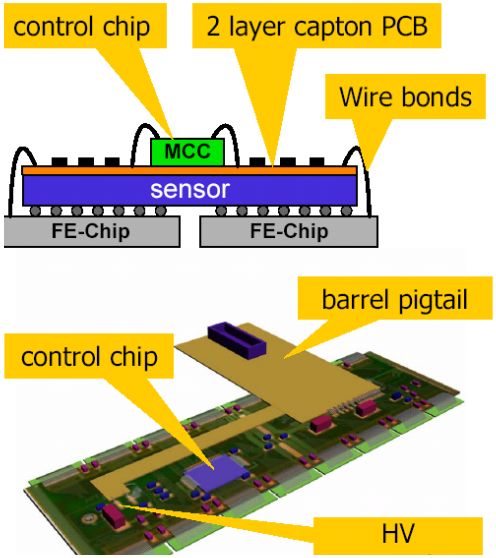
# Options for the pixel telescope

- Baseline option investigated: detector based on hybrid pixels
  - pitch 30-50 μm
  - silicon material budget ≈ 0.5% $X_0$

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

- Estimated cost: 2-3 MEuro (was 0.5 MCHF in NA60)






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 SIS-100/300 to top SPS: ≈ 20 AGeV to 160 AGeV

- Charmonium also part of the program from ≈ 60 AGeV to 160 AGeV

- Physics performance studies for LMR and IMR dileptons very encouraging
  - 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: 10-15 Meuro
  - Collaboration would require 50-100 people

- Preparation of a document to serve as a basis for a letter of intent under way