Search of QCD critical point: dilepton measurements in the range 40-158 AGeV at the SPS

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on behalf of

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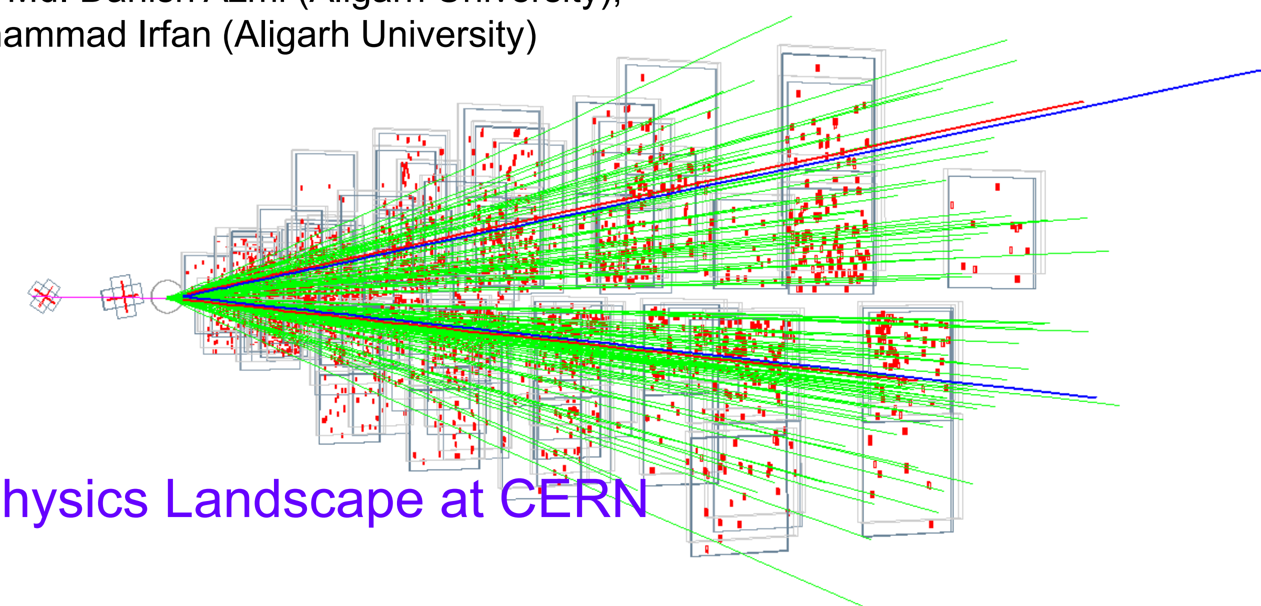


New Opportunities in the Physics Landscape at CERN

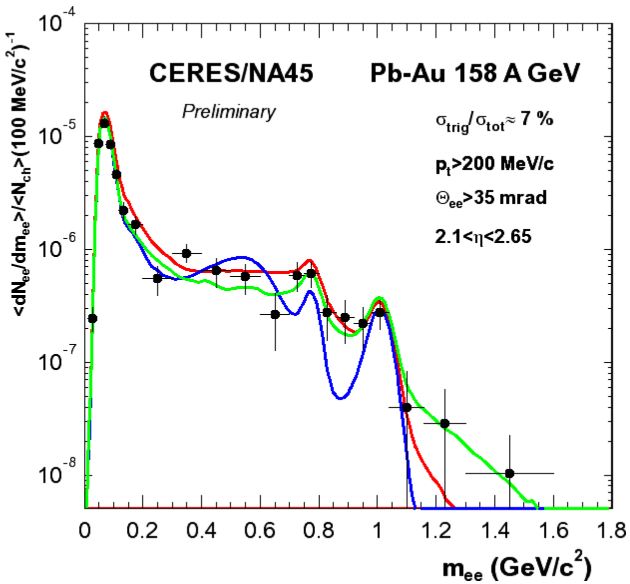
CERN - 11/05/2009

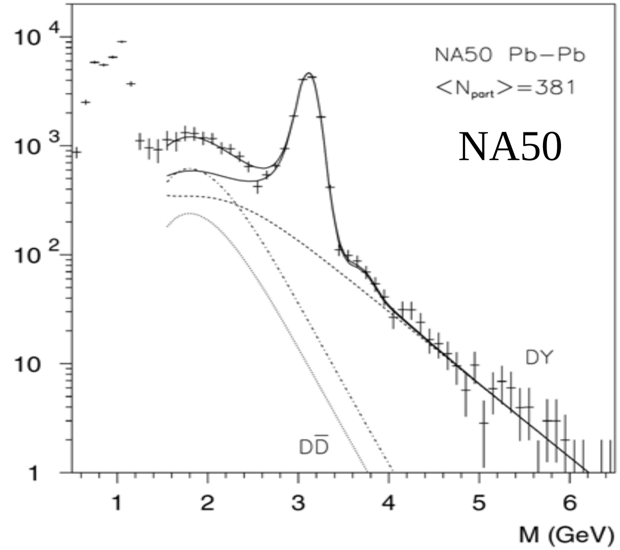
Experimental landscape in dilepton measurements in 2000

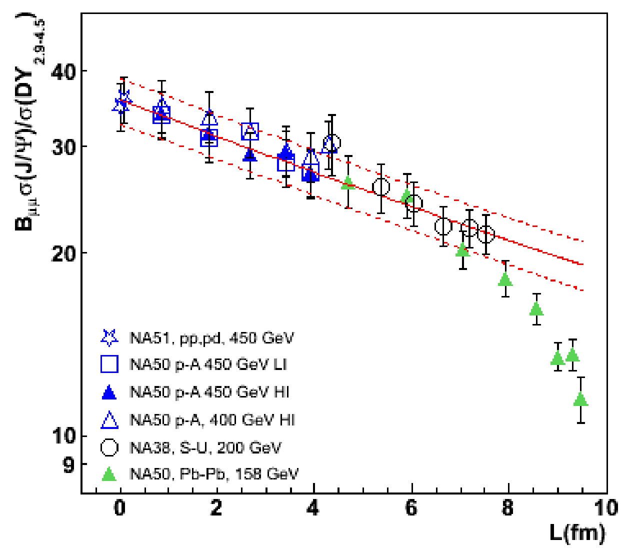
Strong excess below 1 GeV in e^+e^- mass spectrum dominated by ρ meson:
Which in-medium properties?
Connection with chiral symmetry restoration?

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

Anomalous J/ψ suppression in Pb-Pb collisions:
Connection with deconfinement?
Scaling variable for the onset of suppression?

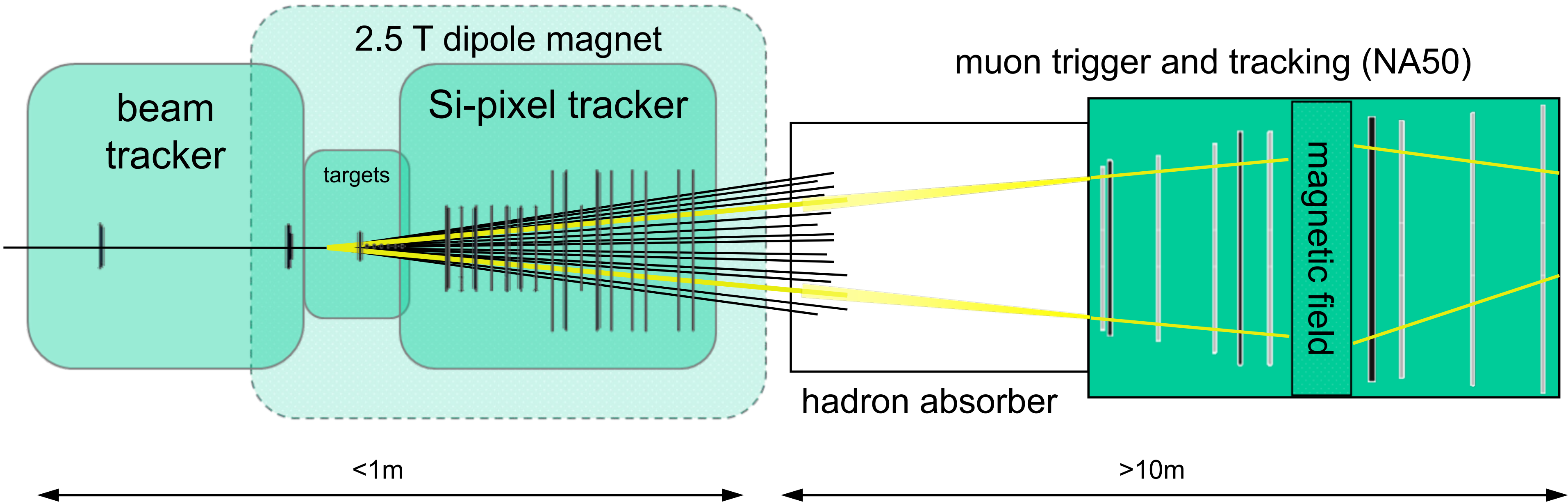






Measurements with better statistics and resolution, and with lighter projectiles, were needed !

The revolutionary 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 for ALICE and ATLAS)

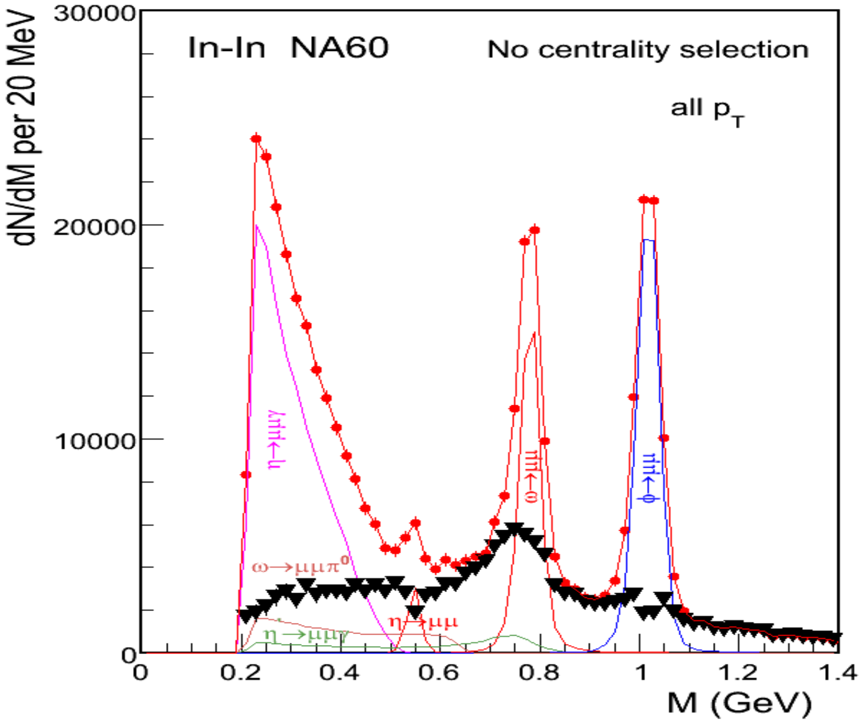
High luminosity of dimuon experiments maintained

3

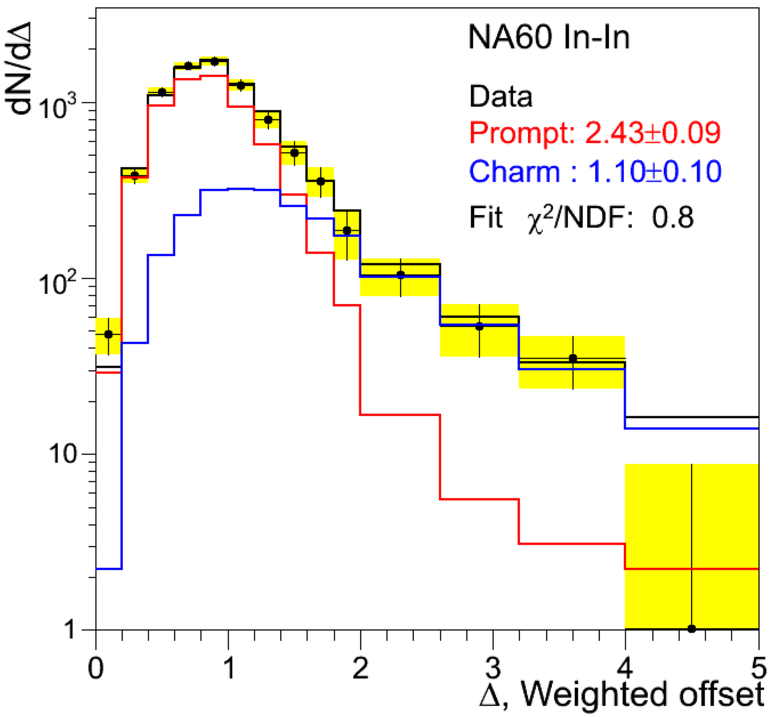
High precision measurements in In-In at 158 AGeV

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

Phys. Rev. Lett. 96 (2006) 162302



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



440000 events below 1 GeV:
Progress 1000 in statistics
2-3 in mass resolution (only 4 weeks run!)

charm not enhanced;
excess above 1 GeV prompt

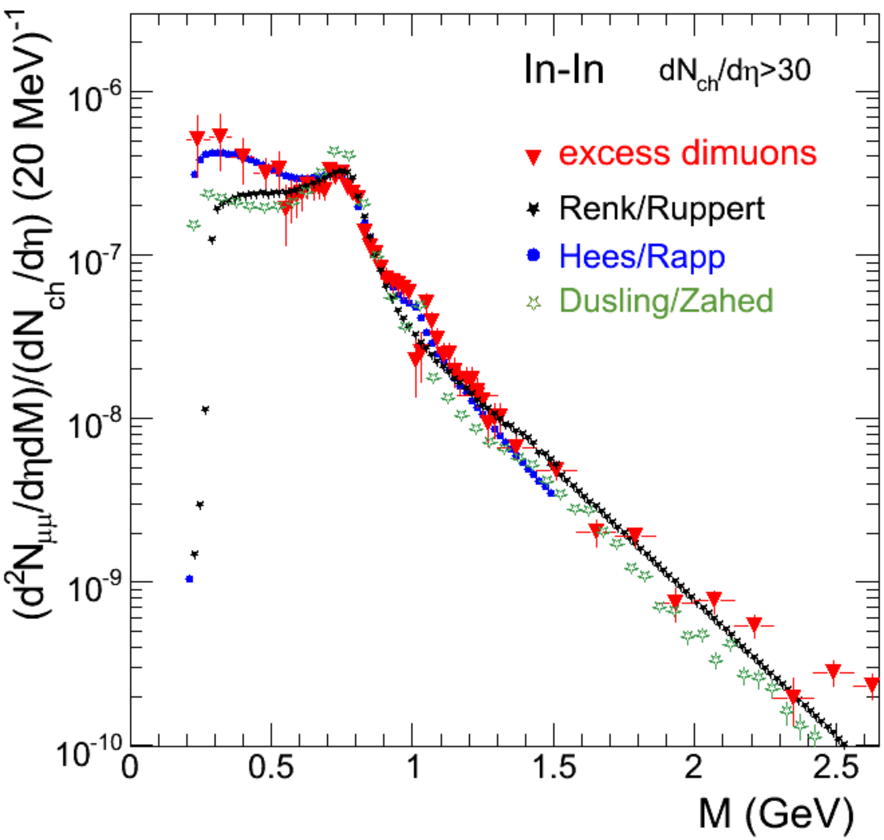
Excess mass spectrum up to 2.5 GeV

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

Acceptance corrected spectrum (p_T>0.2 GeV)

Absolute normalization → comparison to theory in absolute terms!

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



M<1 GeV thermal $\pi\pi \rightarrow \rho \rightarrow \mu\mu$

Strong ρ broadening – no mass shift

In-medium effects dominantly driven by baryons

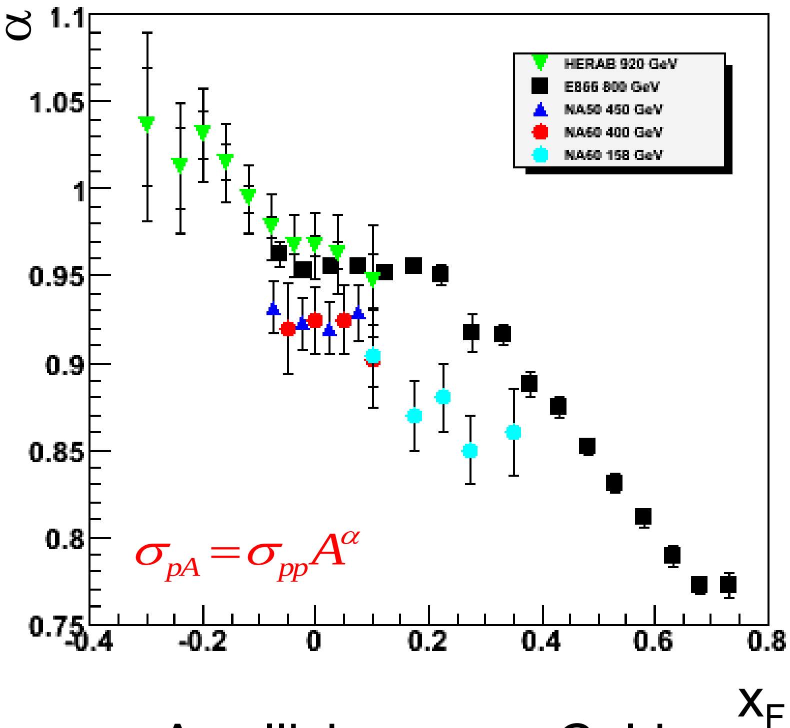
M>1 GeV thermal $qq \rightarrow \gamma \rightarrow \mu\mu$
suggested dominant by T_{eff} vs M
(supported by R/R, D/Z)

and/or multipion processes (H/R)

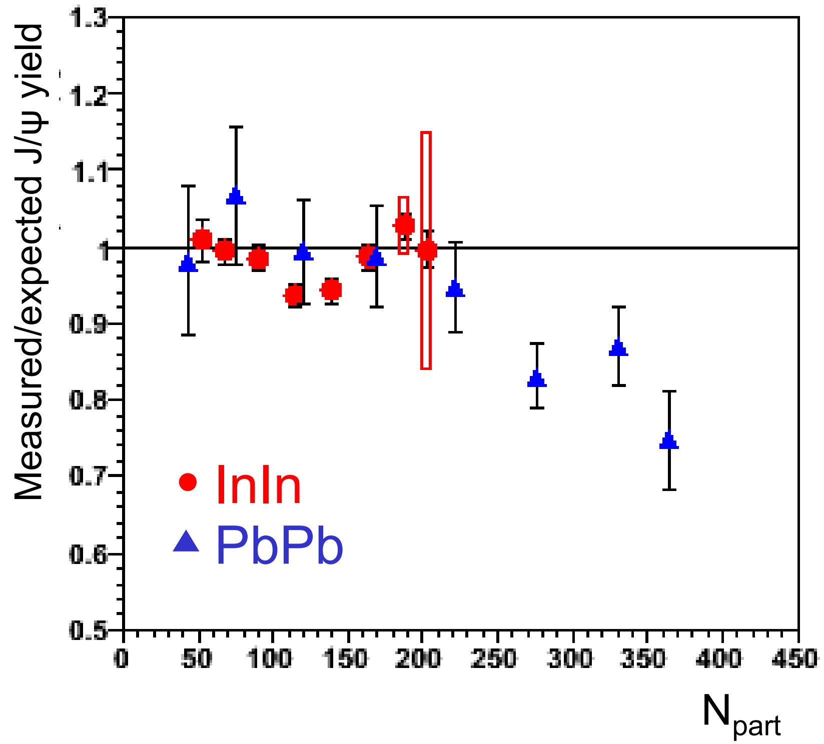
Emission dominantly from matter around or above T_c

5

J/ψ suppression in p-A and In-In collisions at 158 GeV/nucleon



pA collisions Cold nuclear matter effects strongly depend on x_F and √s



AA collisions
Anomalous suppression relevant for PbPb collisions but almost no suppression for the lighter InIn system

The NA60 accomplished program and other measurements

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

What was part of the program and could not be done:

- 2002 Lead run

New Pb-Pb at 158 GeV (completion of the former program)

→ Maximization of in-medium effects better with small surface-to-volume ratio ions

→ Combine existing results on hadronic p_T spectra, elliptic flow and dilepton spectra (M and p_T) altogether:

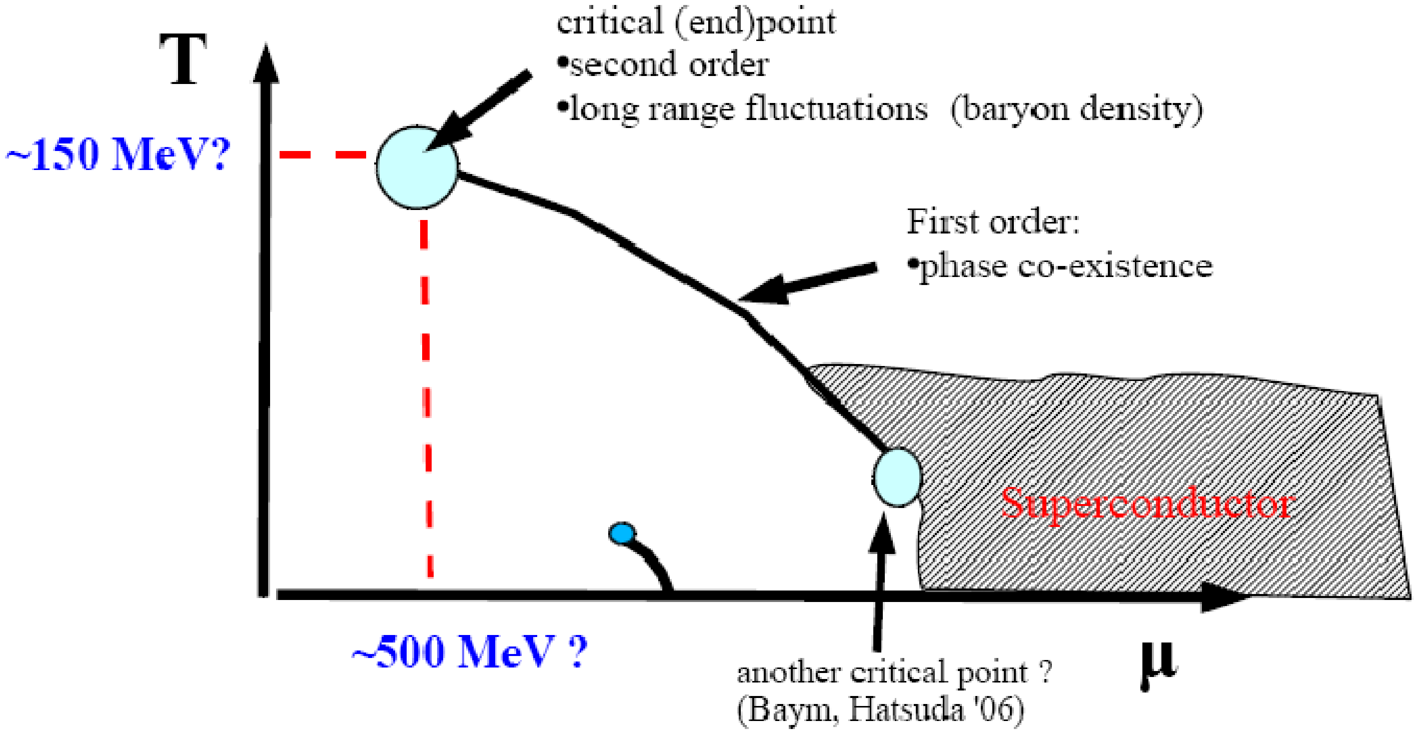
unambiguous tag for the emission region of some contribution in terms of T and v_{flow}

→ Substantial increase of statistical accuracy in assessment of J/ψ suppression with respect to NA50 avoiding to use Drell-Yan

New Pb-Pb and/or other systems at lower energy

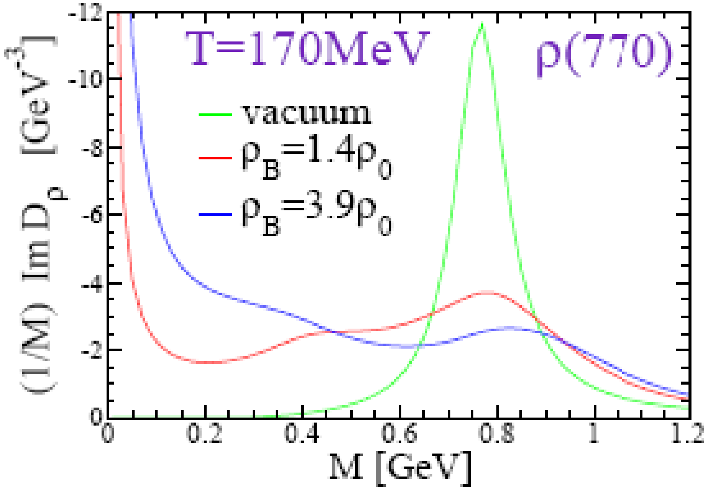
The QCD phase diagram

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

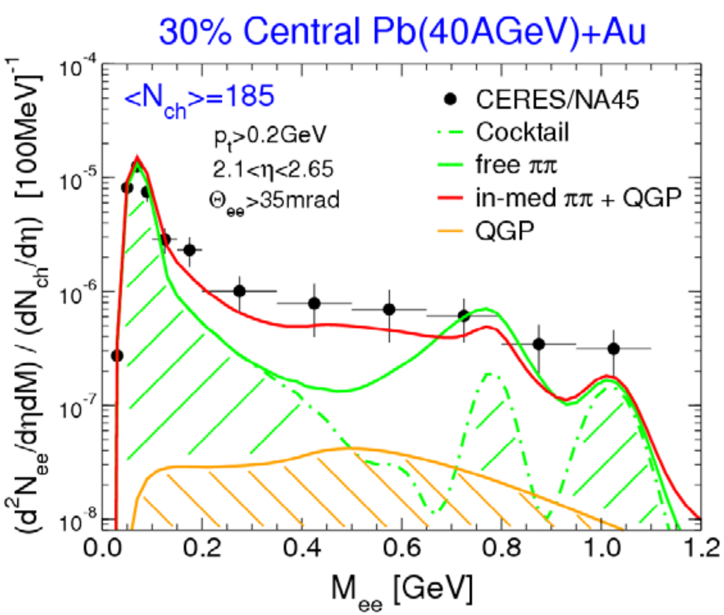


N.B.: Critical point of water: T_c=647.096 K, p_c = 22.064 MPa, ρ_c = 322 kg/m3

Low mass dileptons: top to low SPS energies



Decrease of energy 160 to 40 AGeV: predicted net ρ in-medium effects, in particular for M<0.4 GeV, increase by a factor 2 because of baryons!



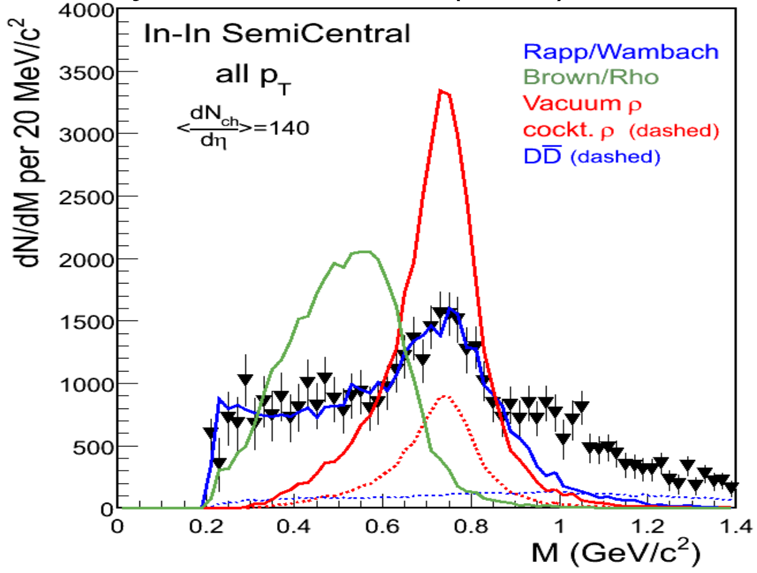
Pioneering measurement by CERES at 40 AGeV: enhancement increases! Seems to confirm importance of baryonic effects

Might not be just coincidental with expectation of emergence of CP

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

Low mass dileptons: chiral symmetry restoration

Phys. Rev. Lett. 96 (2006) 162302



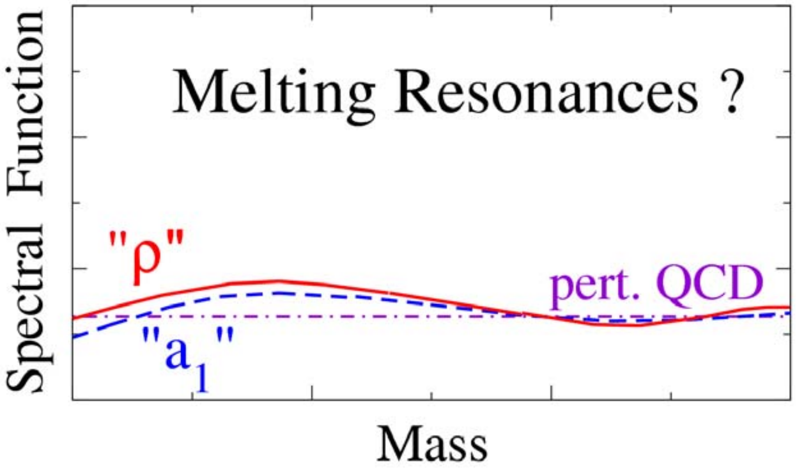
Theoretical yields normalized to data for M<0.9 GeV

Only broadening of ρ (RW) observed
Brown-Rho scaling ruled-out

→ which connection with chiral symmetry restoration?

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

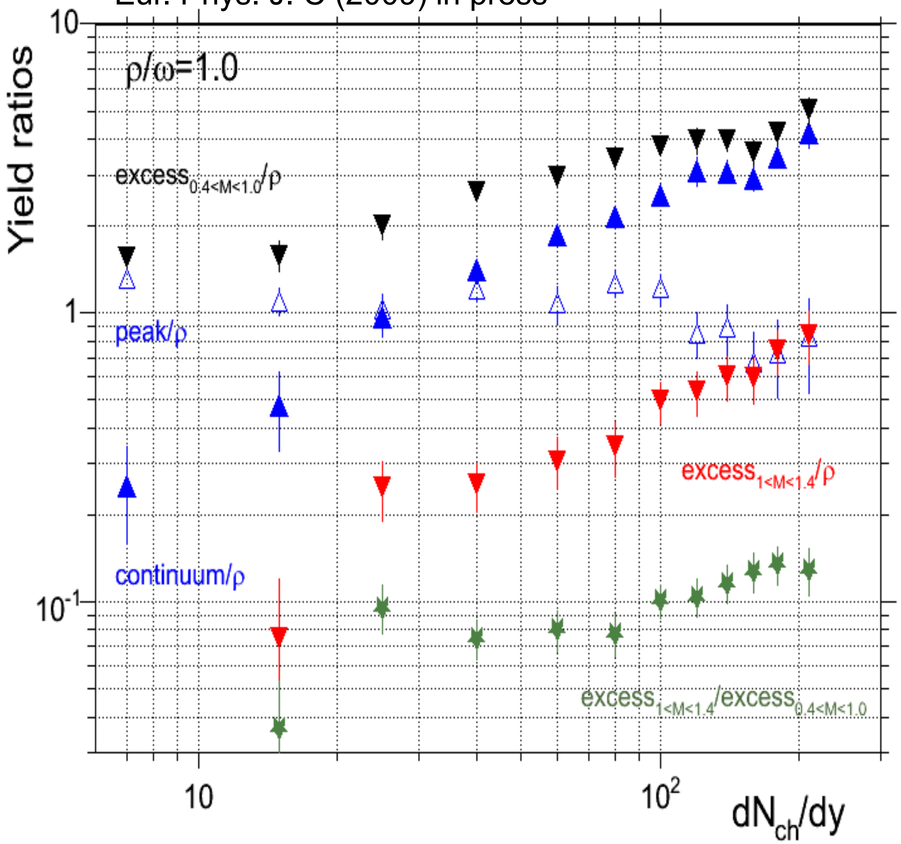
At CP extended lifetime close to T_c : higher sensitivity to chiral restoration?



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

Low mass dileptons: constraints in fireball lifetime

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



NA60 precision measurement of excess yield (ρ-clock):

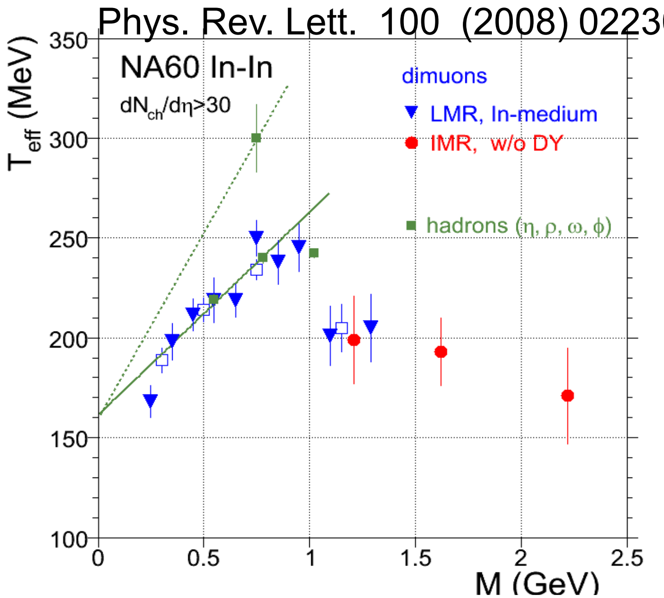
provided the most precise constraint in the fireball lifetime (6.5±0.5 fm/c) in heavy ion collisions to date!

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

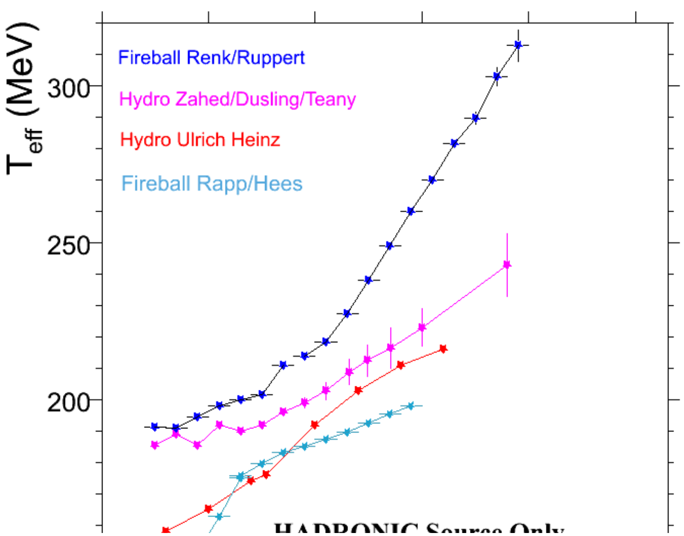
Nice example of complementary measurements with NA61

NA60 results on p_T spectra for in-medium excess



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

$qq \rightarrow \gamma \rightarrow \mu\mu$

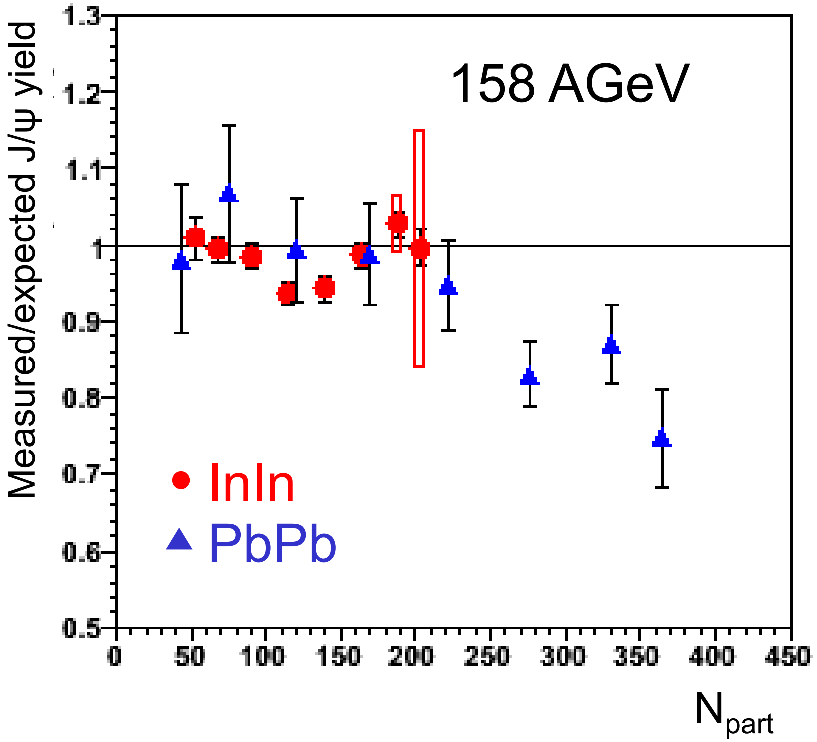


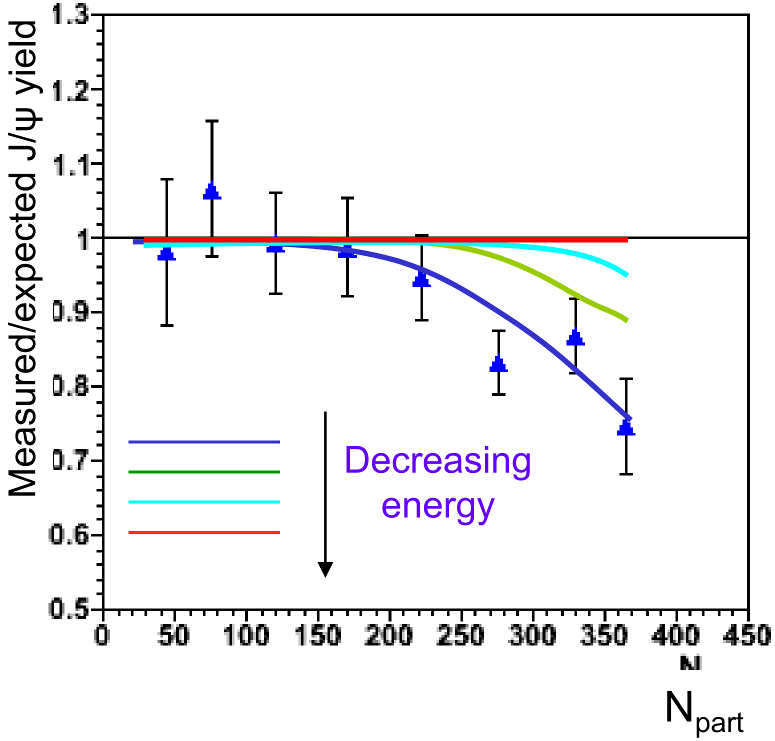
HADRONIC source alone ($2\pi+4\pi+a_1\pi$) (in HYDRO and other models of fireball expansion) → continuous rise of T_{eff} with mass, no way to get a discontinuity at M=1 GeV

Uncertainty in fraction of QGP: 50%, 60%, 80%, …. But a strong contribution of partonic source needed to get a discontinuity in T_{eff}

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

Charmonium production in AA: top to low SPS energies



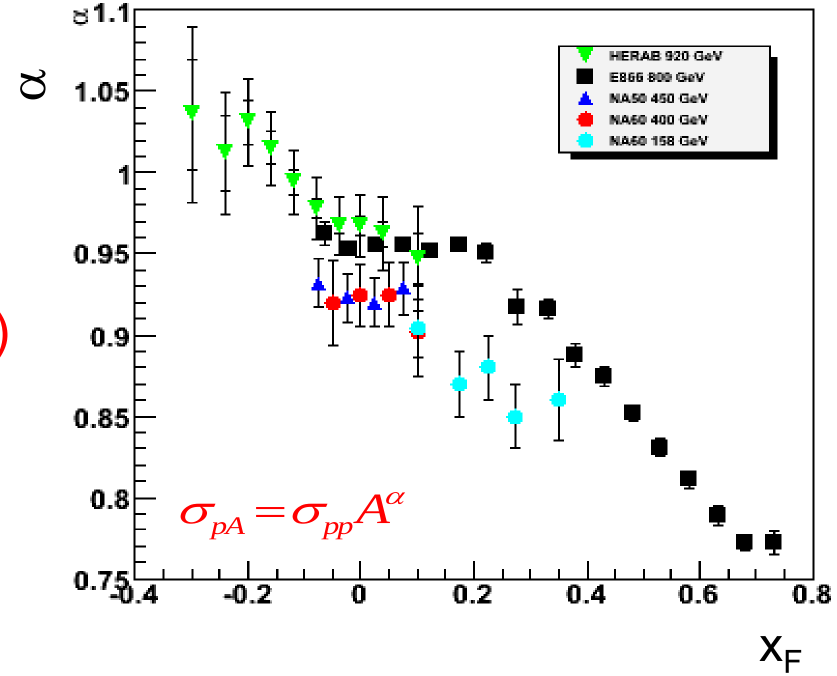


Anomalous suppression relevant for PbPb collisions but almost no suppression for the lighter InIn system at 158 AGeV

Anomalous suppression expected to decrease when decreasing √s However, effect of a qualitatively different (baryon-rich) QGP still a theoretically unexplored domain

Charmonium production in pA: top to low SPS energies

pA collisions: cold nuclear matter effects
strongly depend on x_F and $\sqrt{s}$



Energy dependence of $\chi_c/(J/\psi)$ and $\psi'/(J/\psi)$
useful to constrain/rule out different models (no dependence in CEM, energy dependence in NRQCD)

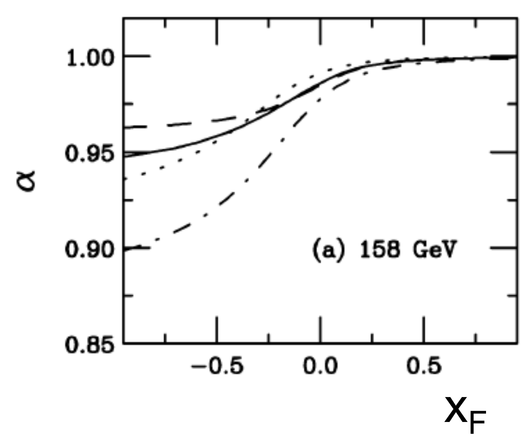
Charmonium suppression in pA:
sensitive to

1) charmonium formation time effects

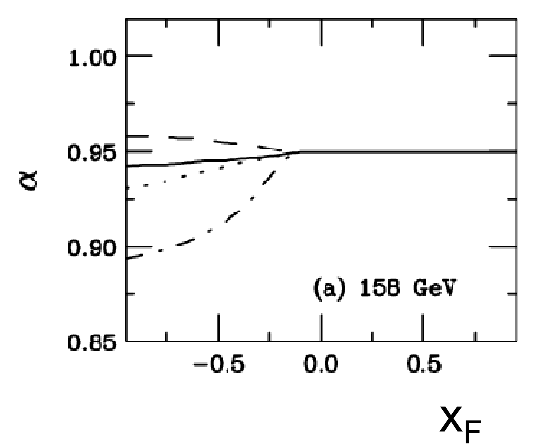
High energy → resonance formed outside the nucleus
Low energy → resonance can be formed inside nuclear matter

2) Energy dependent color octet vs color singlet fraction

color singlet

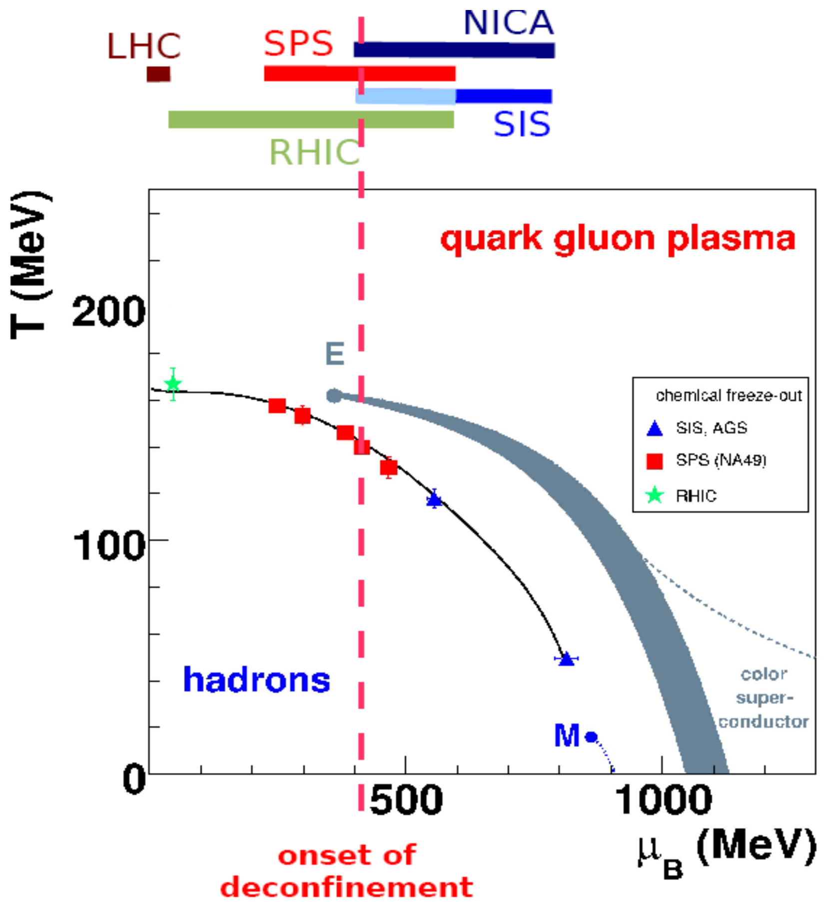


color octet



QCD critical point search – experimental landscape

partly complementary programs
planned at CERN SPS 2011
BNL RHIC 2010
DUBNA NICA 2013
GSI SIS-CBM 2016



NA60-like experiment:

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

Running conditions

Energy scan

tentatively 5 points: 40-60-80-120-160 AGeV

Ion beams

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

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

Complete systematics: running with intermediate A nucleus as indium

→ i.e. important for understanding scaling varible behind J/ψ suppression

Proton beams

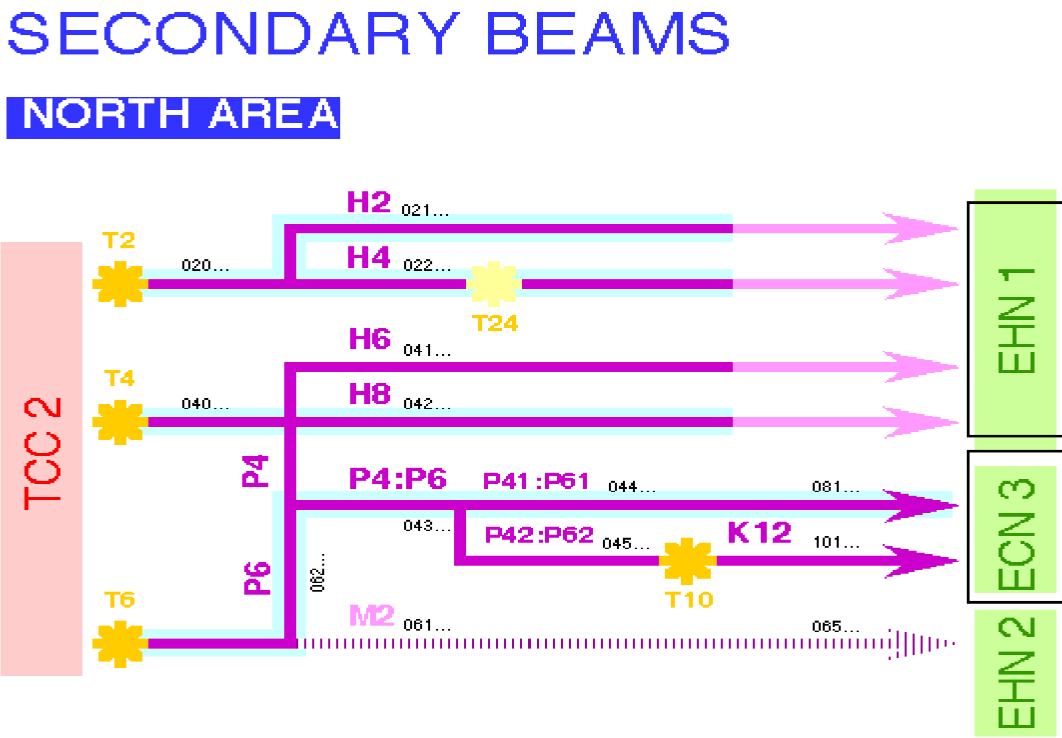
Needed for reference measurements (charmonium study for instance)

Beam intensities

Ions: 10^7-10^8/s on a 15-20% λ_I nuclear target

protons: 10^9-10^{10}/s on a 15-20% λ_I nuclear target

Ideas on possible new installation



Investigating new possible location in main hall

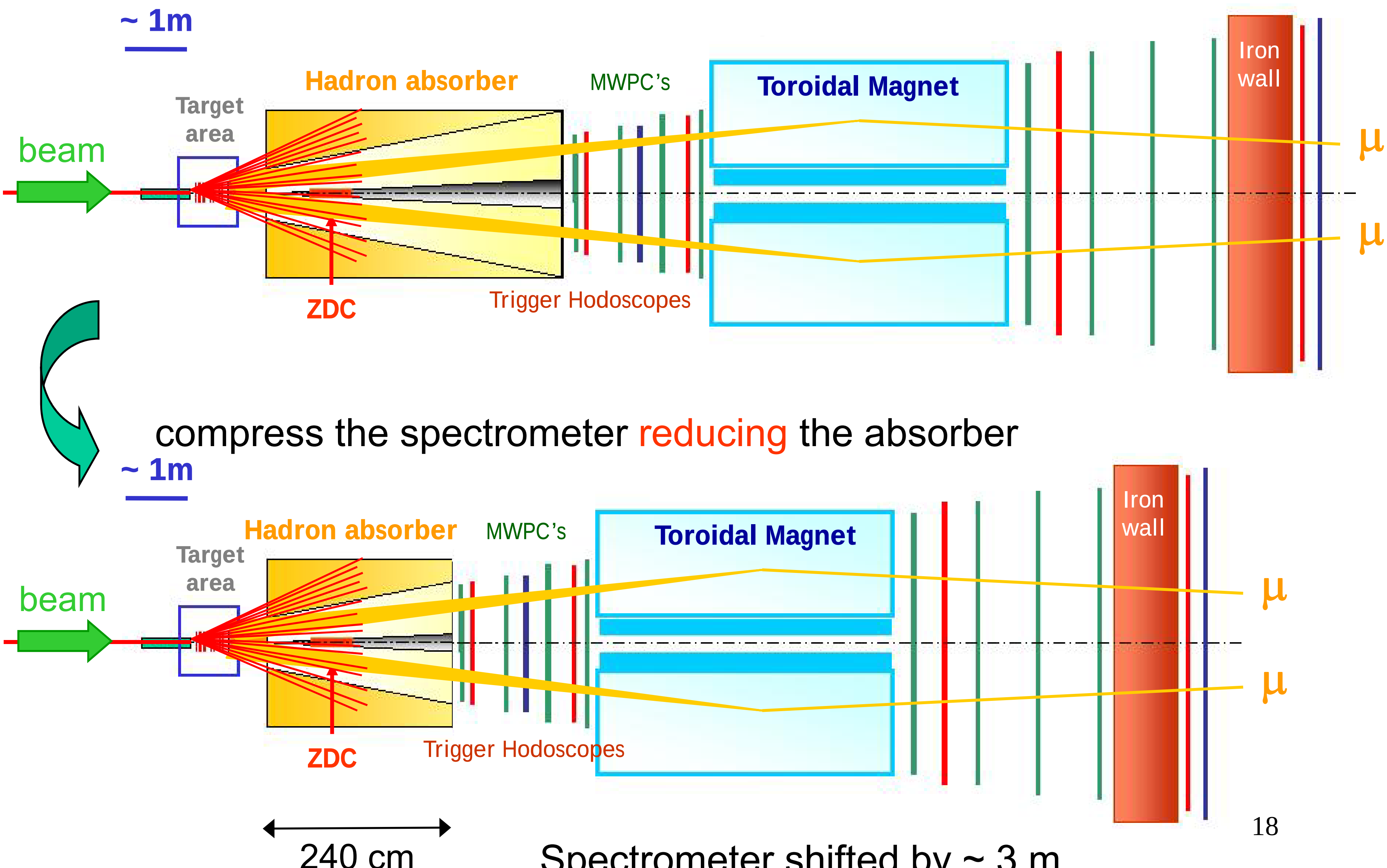
Previous NA60 location ECN3: incompatible with NA62

H8 (previously used by NA45) seems a good option

Location, radiation and safety issues under discussion with beam people (I. Efthymiopoulos)

Apparatus layout: first ideas for lower energies

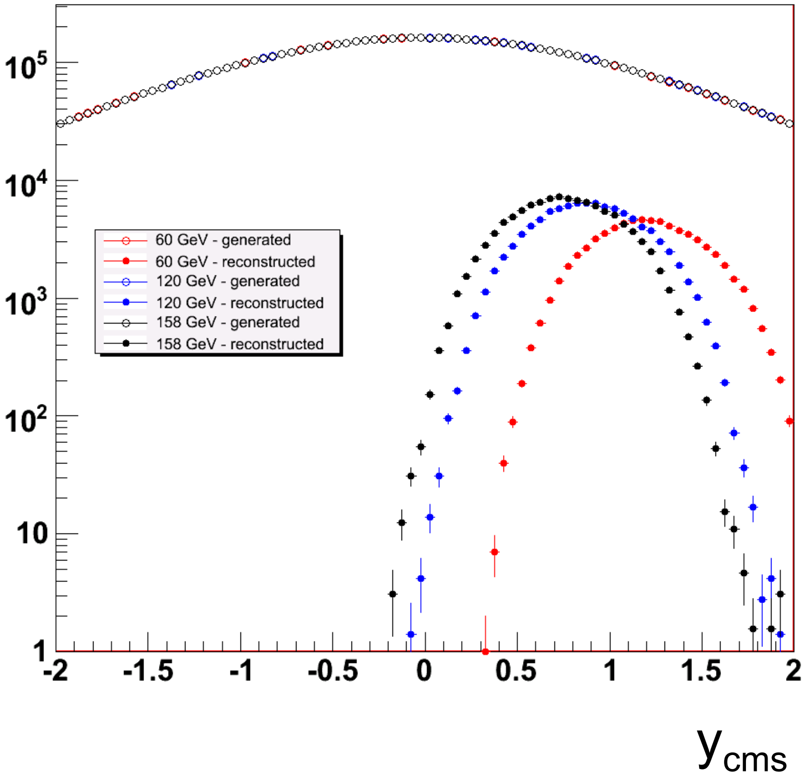
NA60 muon spectrometer covers the y range 0-1 in the cms system @ 158 GeV



Spectrometer shifted by ~ 3 m

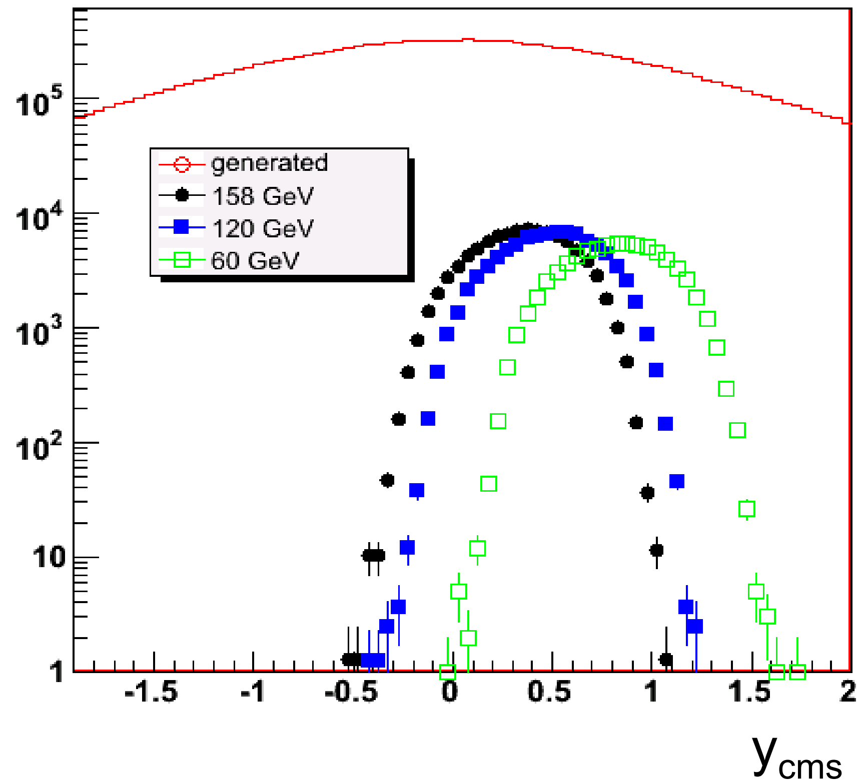
standard NA60 spectrometer

ω simulation



compressed spectrometer

ω simulation



$\langle y_{lab} \rangle_{158}$ = 2.91 Δy = 0.76

$\langle y_{lab} \rangle_{120}$ = 2.77 Δy = 0.9

$\langle y_{lab} \rangle_{60}$ = 2.43 Δy = 1.24

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

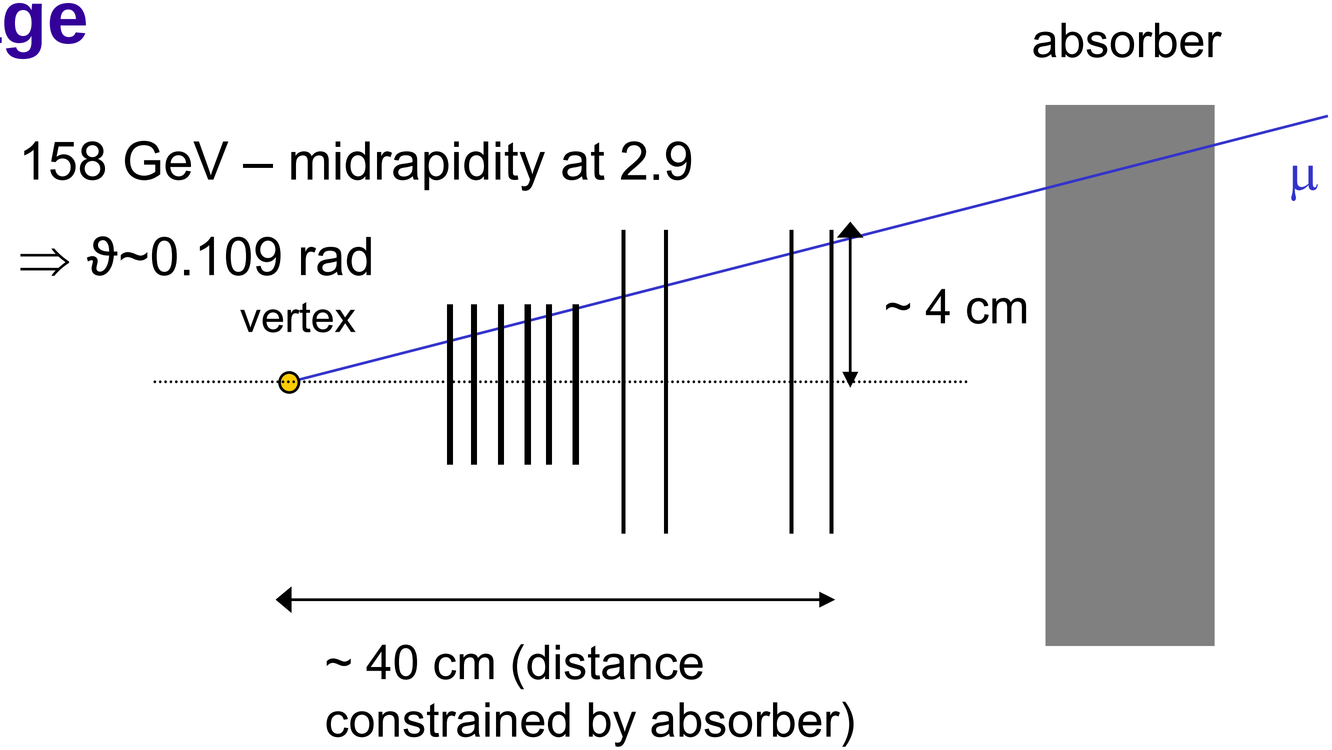
$\langle y_{lab} \rangle_{158}$ = 2.91 Δy = 0.35

$\langle y_{lab} \rangle_{120}$ = 2.77 Δy = 0.47

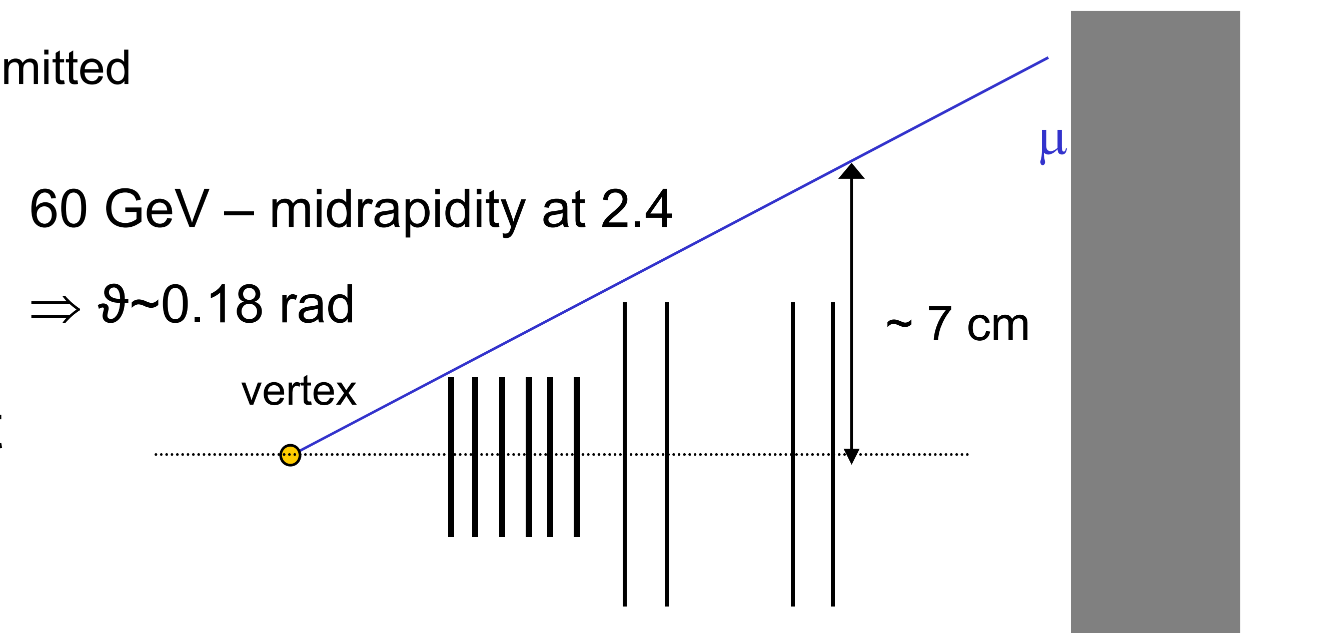
$\langle y_{lab} \rangle_{60}$ = 2.43 Δy = 0.79

Rapidity coverage at 60 GeV similar as with standard absorber at 158 GeV ...

Rapidity coverage of the pixel telescope



At 60 GeV particles are emitted in a much wider cone

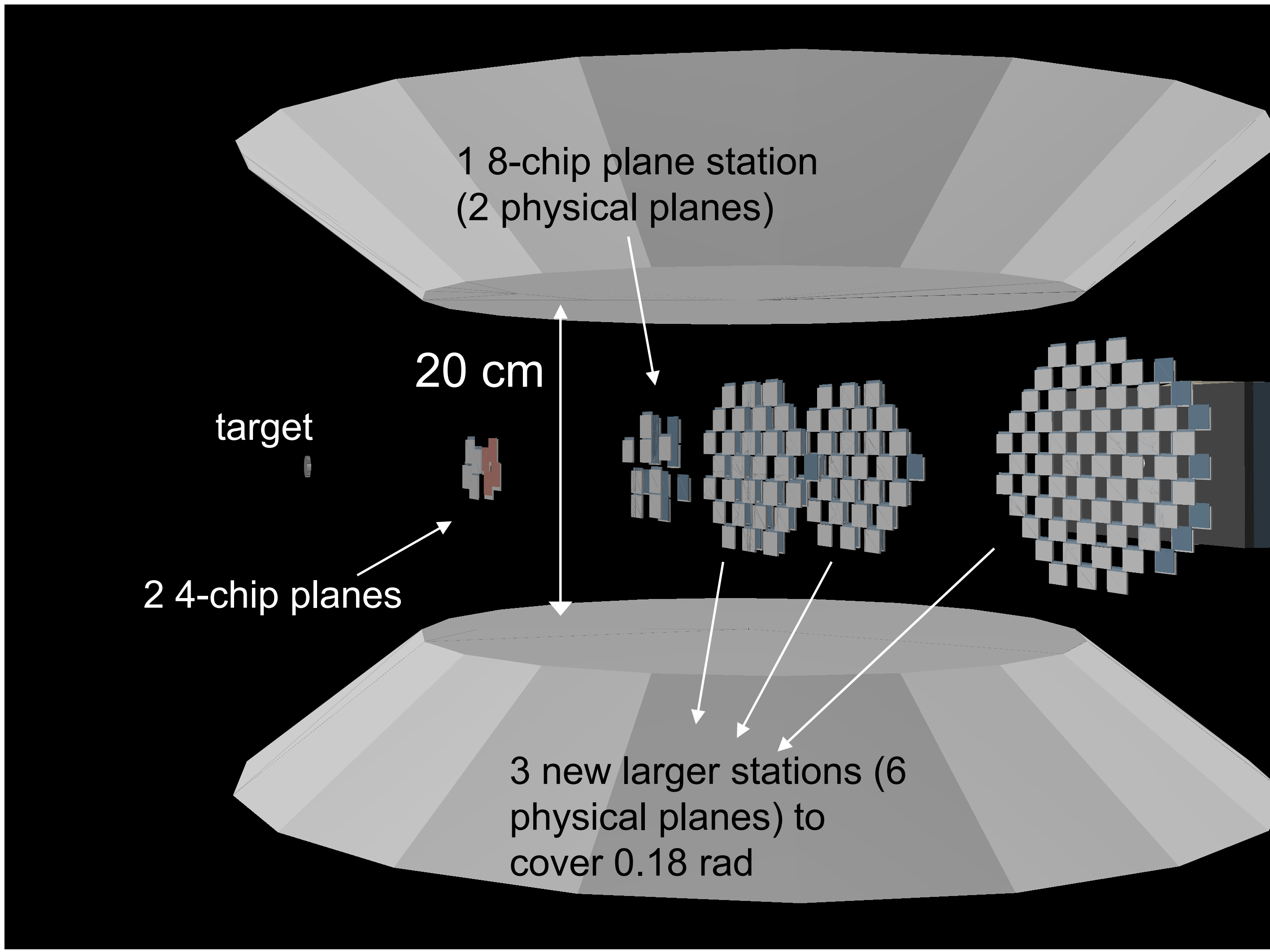


The old pixel telescope does not provide sufficient coverage

A new pixel telescope setup – first ideas

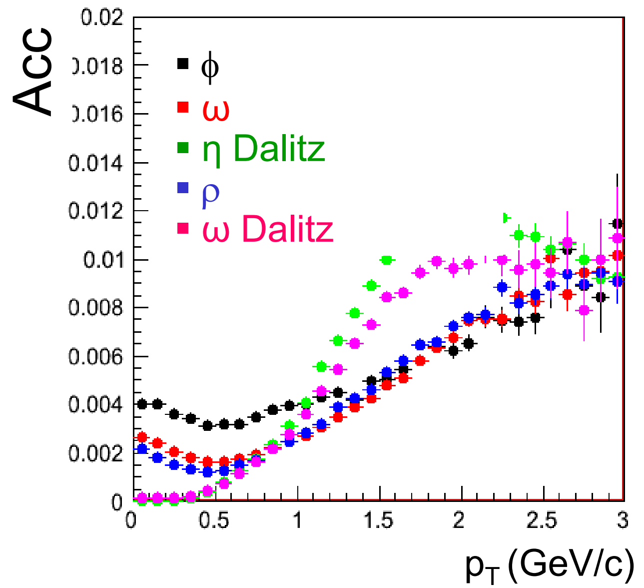
PT7-like larger dipole magnet: 2.5 T – 20 cm gap

y covering requires 240 ALICE chips (2.7 times more than previous telescope)

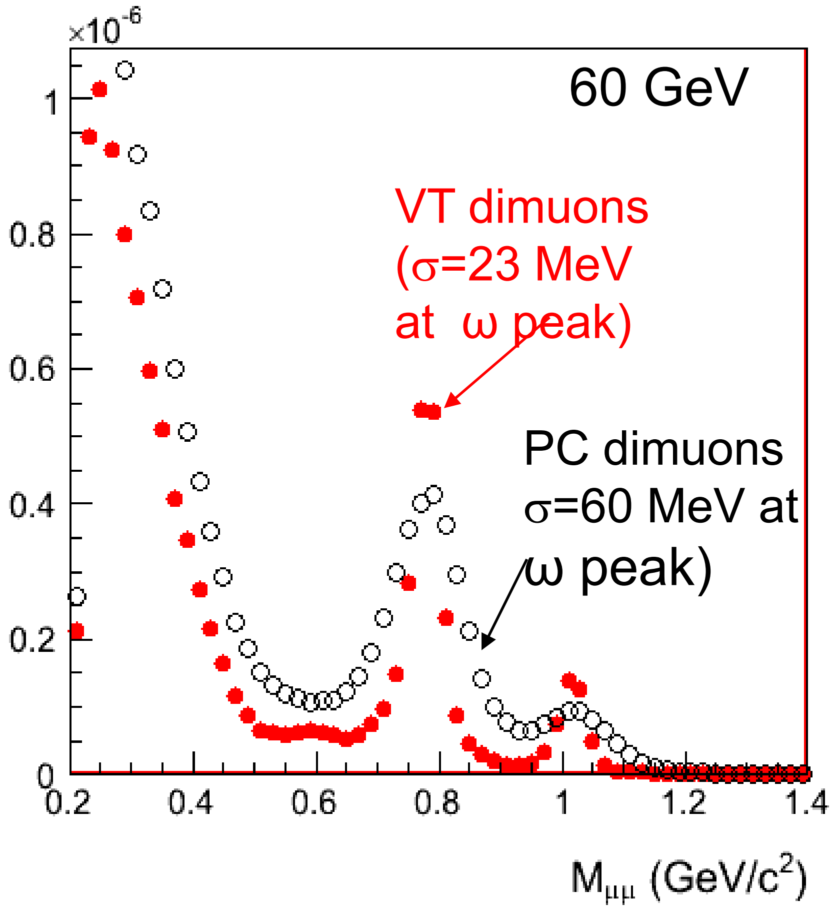


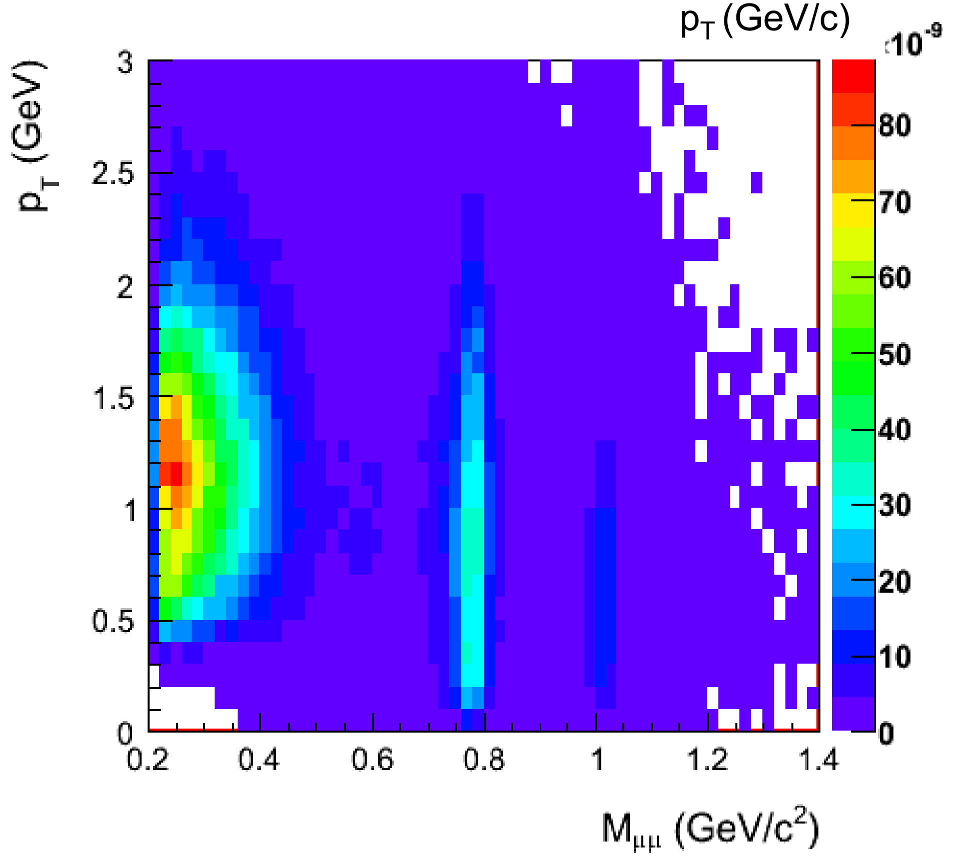
Dimuon reconstruction

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

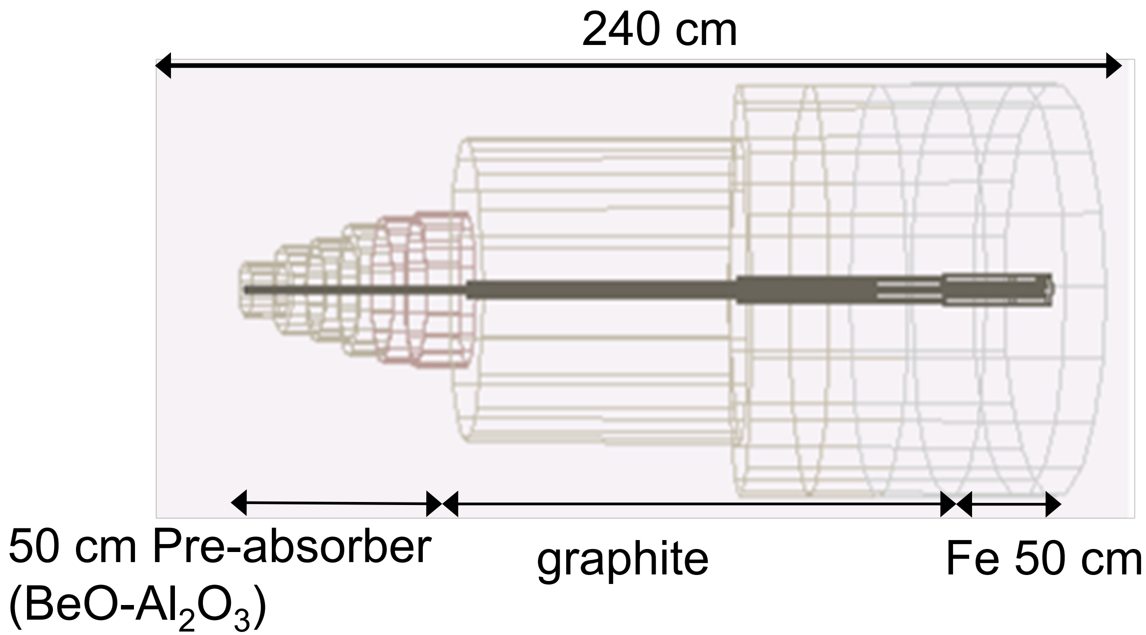


Dimuon Matching rate ~ 70 %





A closer look at the absorber



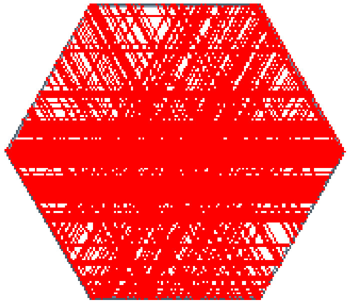
Reduced absorber

Transverse size increased by 50%

But, can it still contain the hadronic shower?

Simulation of shower by URQMD 1.3 (mbias events) + GEANT3 with Fluka:

Reduced absorber:
Average occupancy in first chambers (mbias events): 20-40 hits/event

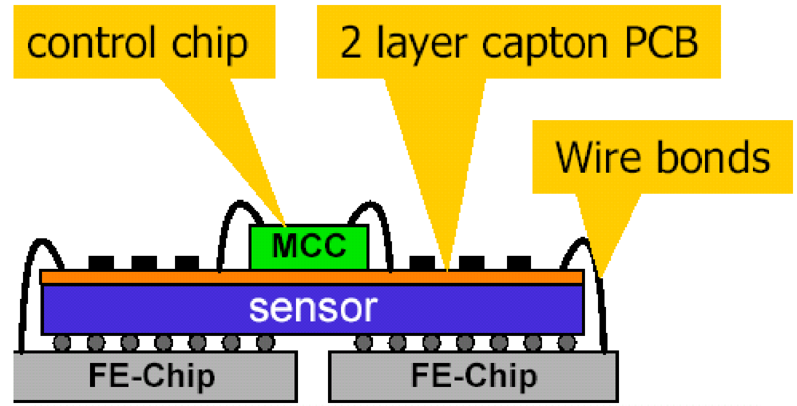


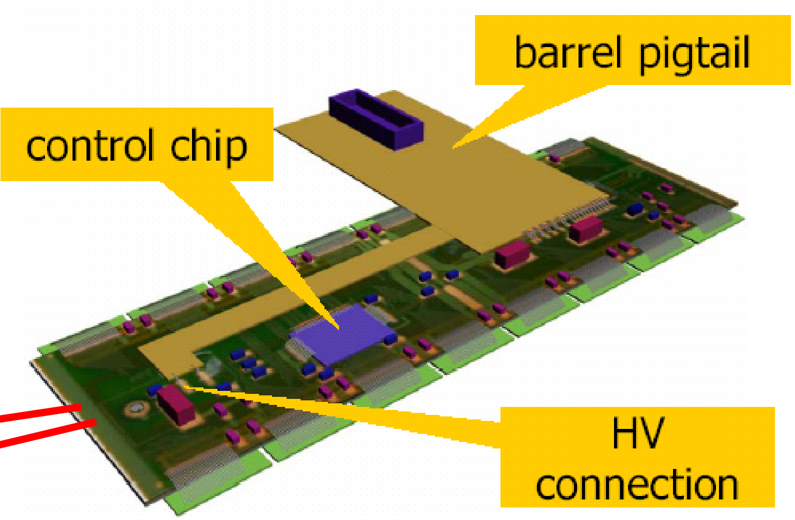
Conservatively double this → a factor ~ 10 larger than maximum possible

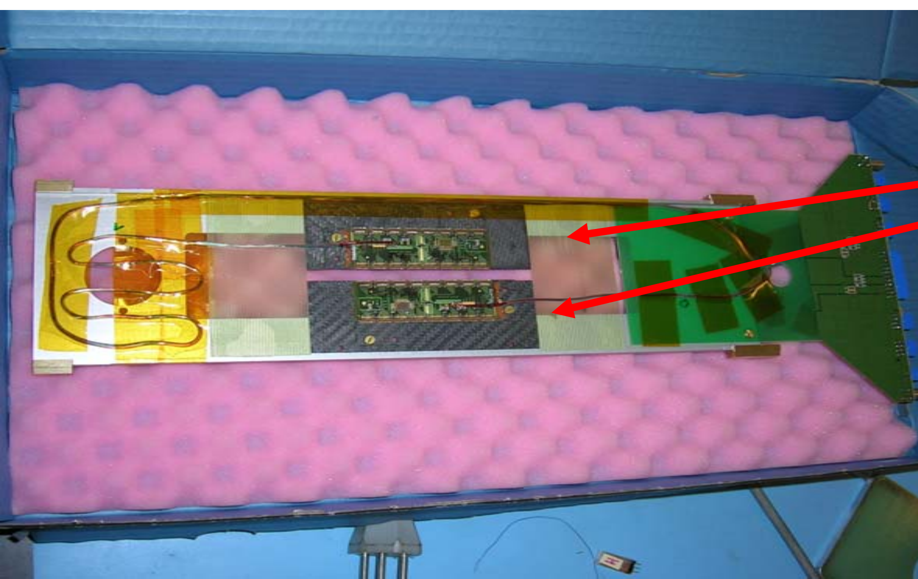
Occupancy in chambers beyond ACM magnet looks OK

Options for a new pixel telescope: ATLAS pixels

- One single sensor with active area = 16.4 × 60.8 mm^2
- 16 Chips with ~ 50000 pixels of 50 × 400 mm^2 total
- thinned assemblies (300 μm)
- no thick hybrid pcb
- 40 MHz readout





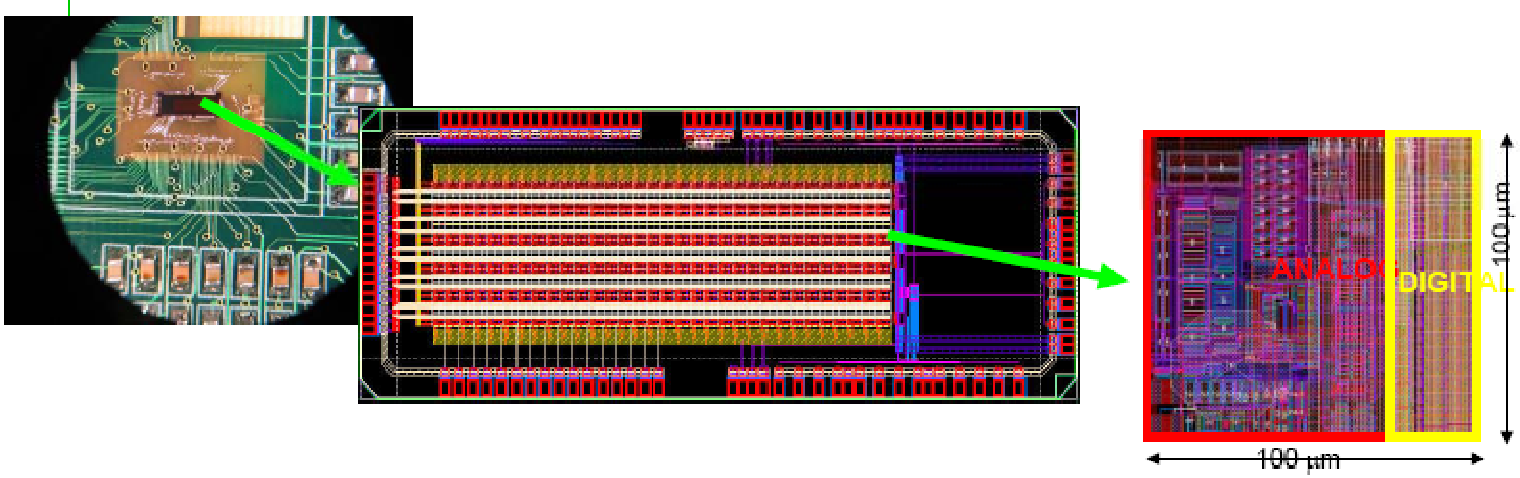


2 Planes with different geometry using ATLAS pixel modules built and operated in NA60 2004 proton run

Options for a new pixel telescope: new pixel technology for FAIR (PANDA) Experiments

- Designed to cope with an interaction rate of 10^7/s
- Pixel cell 100x100 μm^2
- Readout chip (130 nm CMOS):
  -100x100 cells covering 1 cm^2
  - time position with 6 ns resolution (rms)
  - triggerless readout
- Hybrid technology: single chip assemblies might be OK for our application

Second pixel readout prototype produced and tested (5x2 mm^2, 4 folded columns, 320 readout cells)



A silicon pixel readout ASIC in CMOS 0.13 um for the PANDA Micro Vertex detector - D. Calvo et al., IEEE Trans.

Options for a new pixel telescope: new pixel technology for FAIR (PANDA) Experiments

CBM vertex tracker: use of pixel planes (besides microstrips) under discussion

→ Possible common interest with CBM for development of new pixel planes with PANDA technology

→ Discussion with GSI people presently on-going

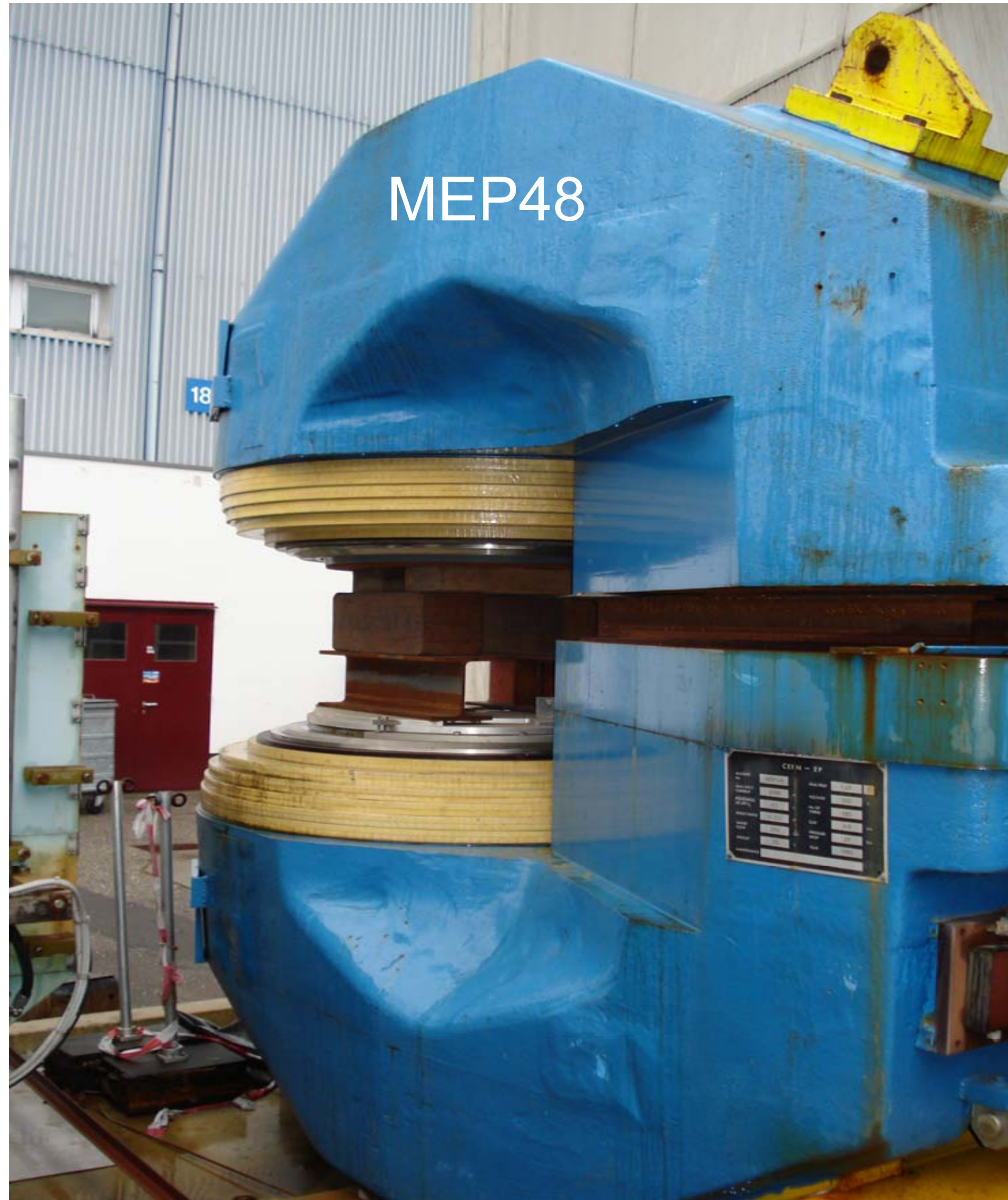
Available magnets at CERN

Pixel magnet: MEP48

Gap width 410 mm,
diameter 1000 mm
B=1.47 T @ 200 Amp, 200 V

B~2.5 T reducing the gapsize to 200 mm

(end of 2007) left standing outside!



Muon spectrometer magnet:

ACM or

Morpurgo dipole magnet?

opening 1.6 m
length 3.5 m
B=1.9 T @ 6000 Amp

Presently in H8 – used by ATLAS

Summary of first ideas for a new NA60-like experiment

Pixel telescope

- ATLAS pixels: faster, thinner (even larger DAQ rate, even better mass resolution (?))

– Possible collaboration to develop new technologies/detector with GSI people

Muon spectrometer

-Reduced absorber: reasonable rapidity coverage and muon matching tested down to 60 GeV (increase in combinatorial background not yet assessed)

- ACM magnet OK – Morpurgo magnet?

- First tracking stations after the absorber cannot be of old MWPC type

Possible new location

- Main hall EHN1 H8 beam line

- Problems of radiation safety and shielding under discussion

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L. Gatignon, D. Calvo, J. Heuser

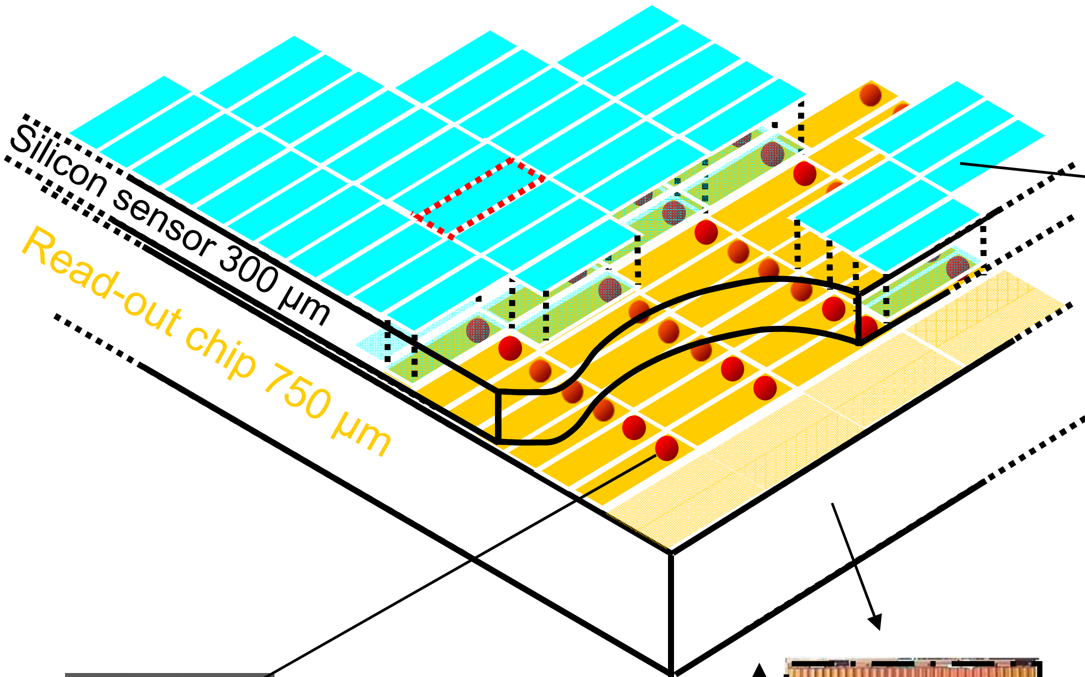
BACKUP

Radiation tolerant pixels

- Radiation tolerant silicon pixel detectors became available only recently
- NA60 uses sensor + readout chips developed for the ALICE collaboration

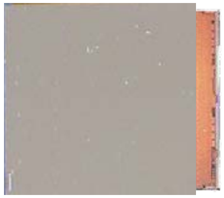
Pixel sensor

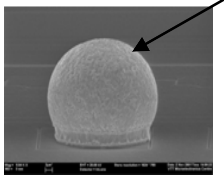
- 12.8 x 13.6 mm^2 active area
- 32 x 256 cell matrix
- 50 x 425 μm^2 cell size



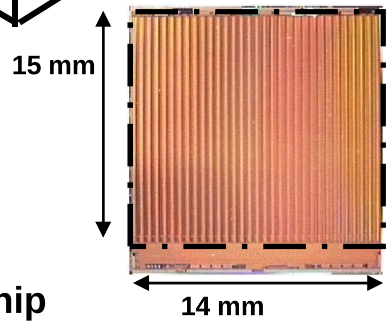
sensor

Assembly
(sensor + R/O chip)





25 µm solder bump

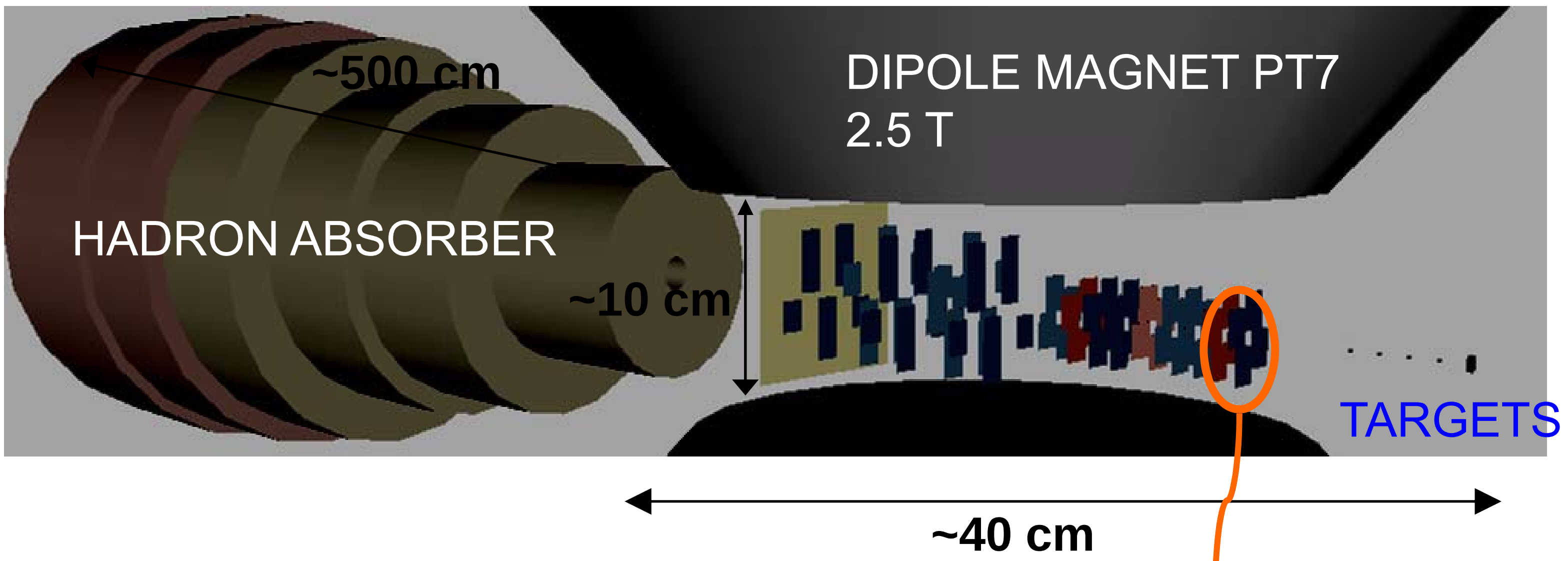


Read-out chip

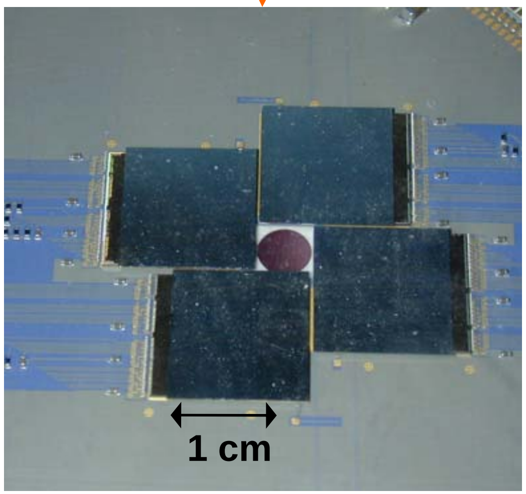
ALICE1LHCb read-out chip

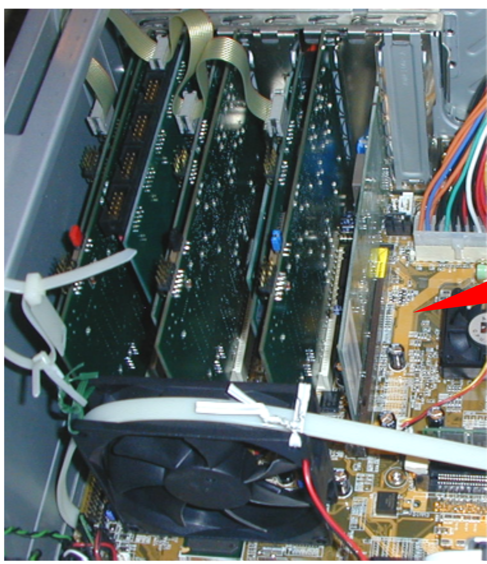
- Operated at 10 MHz clock
- Radiation tolerant up to ~ 30 Mrad
- 32 columns parallel read-out

The NA60 pixel vertex detector

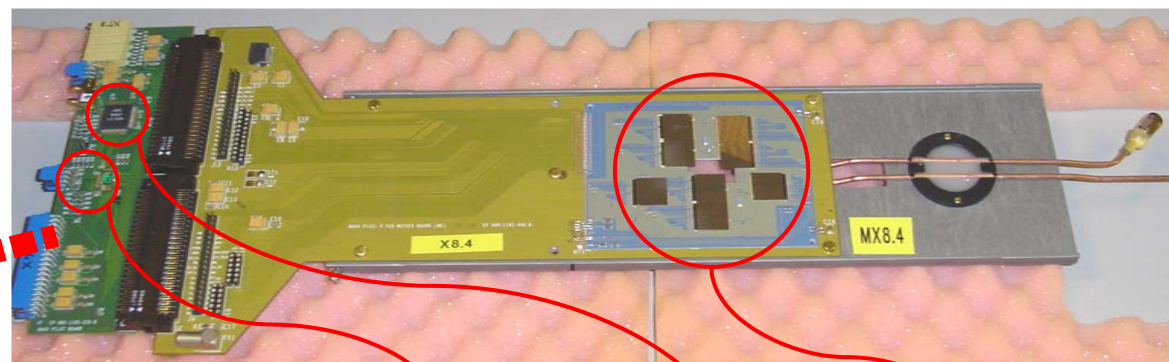


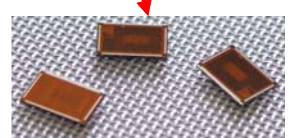
- 12 tracking points with good acceptance
  - 8 "small" 4-chip planes, plus
  - 8 "big" 8-chip planes (4 tracking stations)
- ~ 3% X_0 per plane
  - 750 μm Si read-out chip
  - 300 μm Si sensor
  - ceramic hybrid
- 800'000 R/O channels - 96 pixel assemblies





DAQ PCs with CFD card
and Pilot Mezzanine
(around 140 MB/burst)

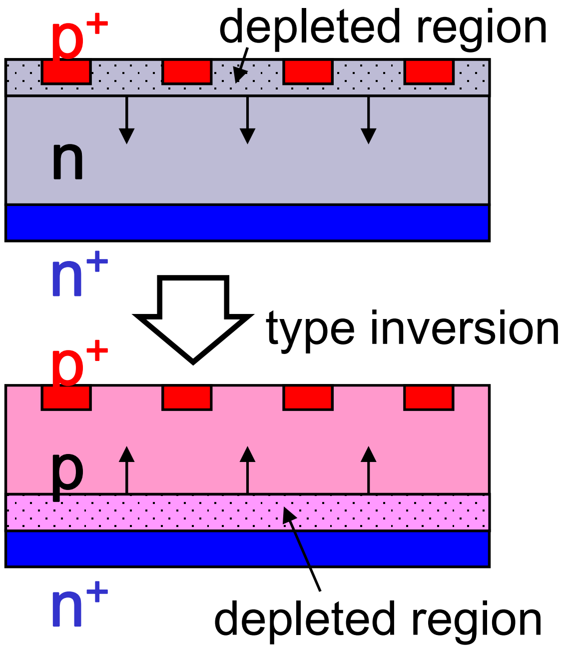




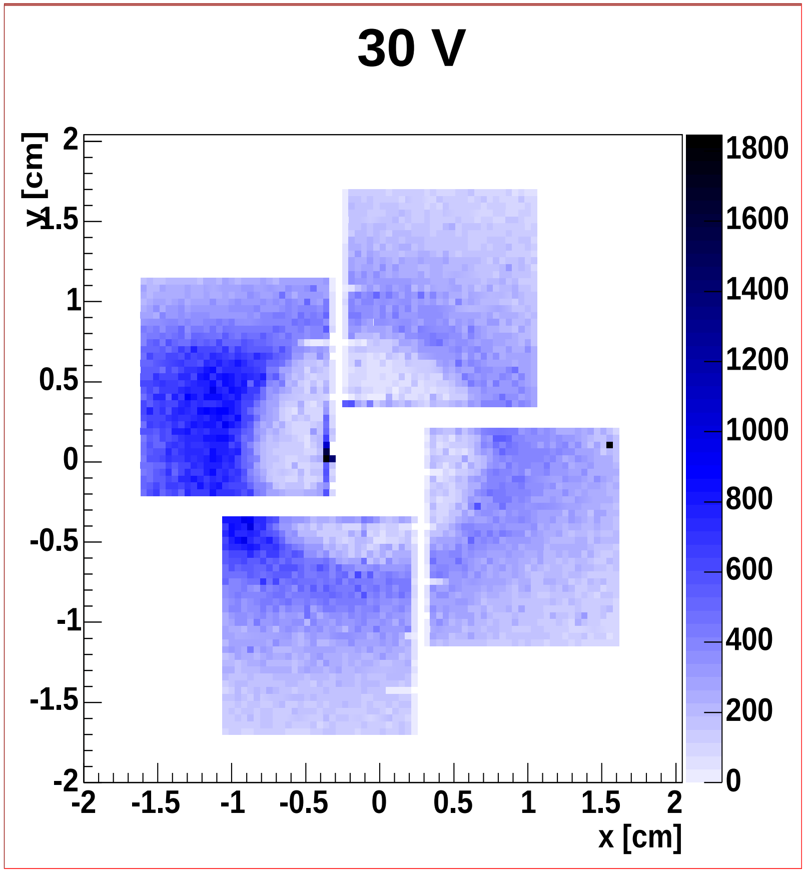
GOL chip

hybrid with
assemblies

Pixel telescope *killed*



Hit maps taken during a bias voltage scan after 4 weeks



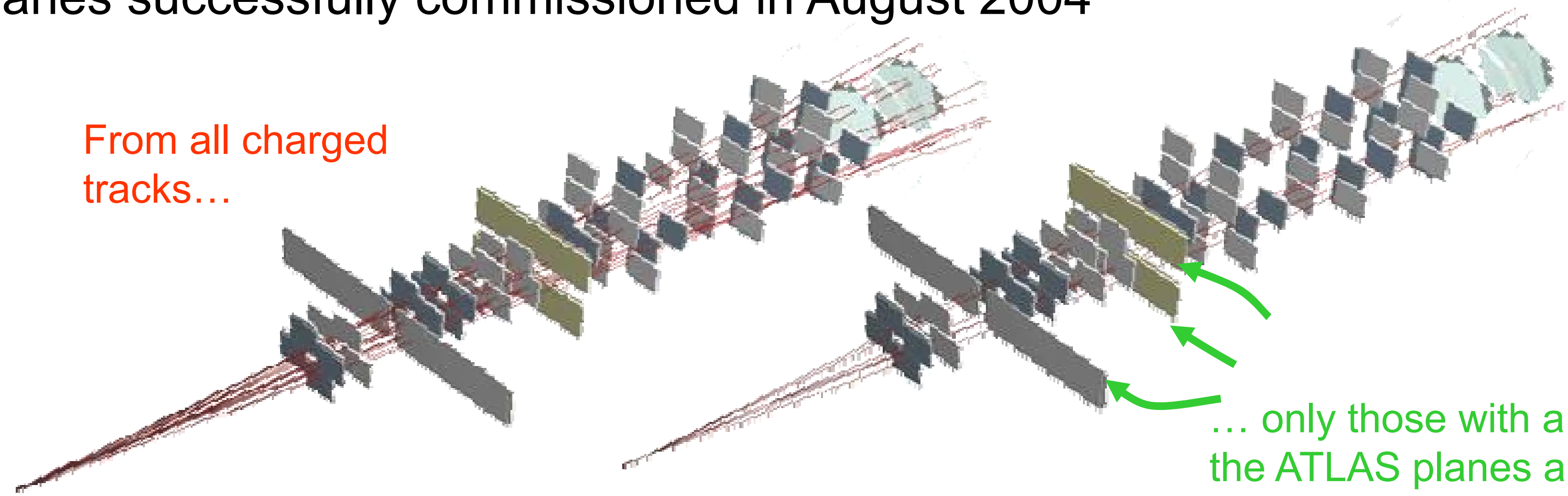
- Radiation induces changes in the effective doping.
- After a certain fluence the sensor undergoes type inversion: it needs to be fully depleted to operate correctly.
- After type inversion the doping concentration is constantly growing, so that also the depletion voltage increases

After a fluence ~ 5×10^{12}, many pixels are dead

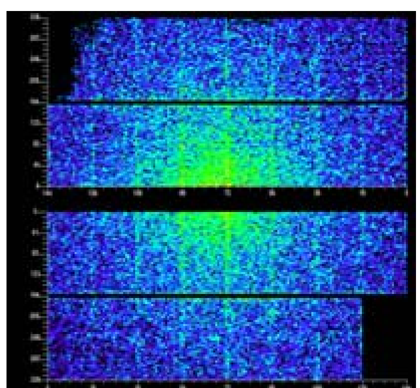
2004 pixel setup: running with ATLAS pixel planes to reject pile-up at high rate

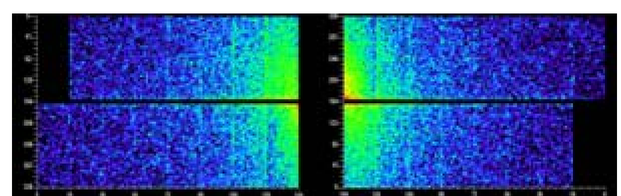
- PCI Readout and control system adapted for ATLAS pixel protocol
- Readout software implemented
- Planes successfully commissioned in August 2004

From all charged tracks…



… only those with a hit in the ATLAS planes are kept

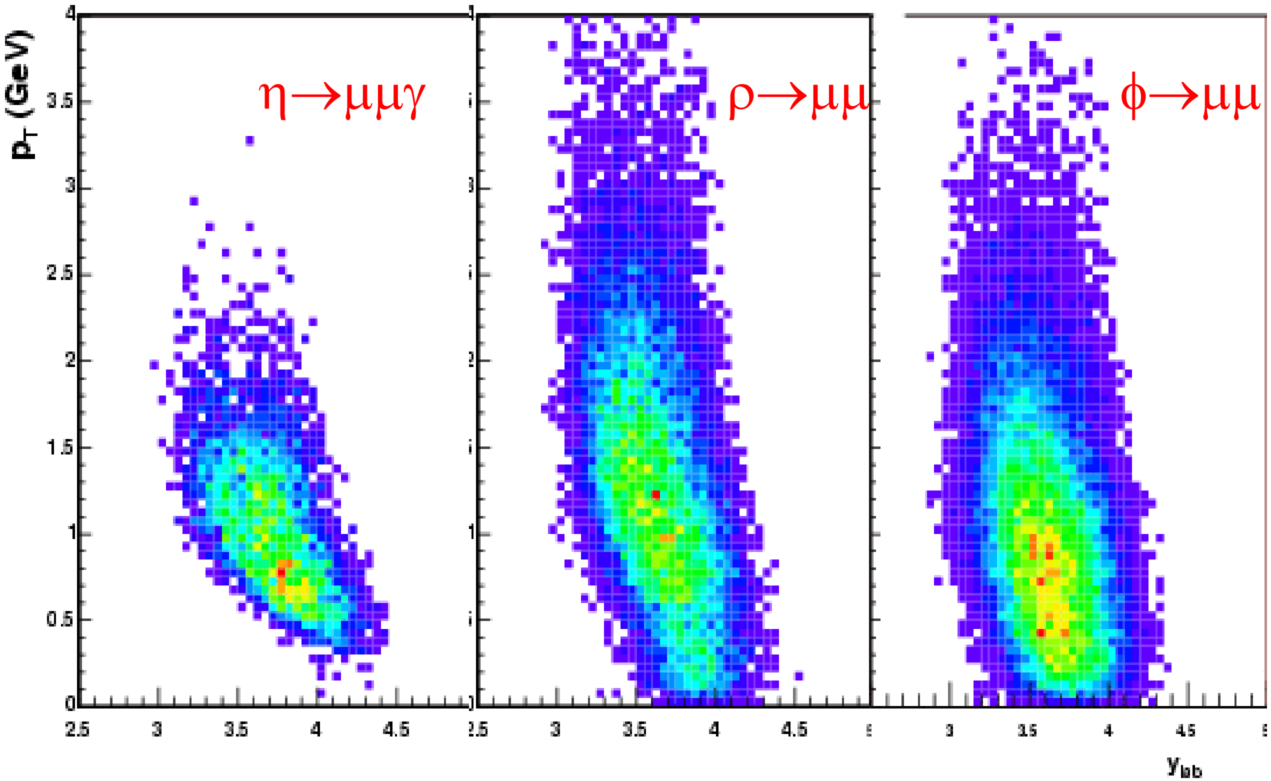




Phase space coverage (y-p_T)

NA60 was optimized to cover the range 3-4 in the lab system (the target rapidity is zero, the beam rapidity is 5.84 @ 158 GeV) corresponding to ~ 0-1 in the CMS system

phase space coverage for low mass processes (Monte Carlo)

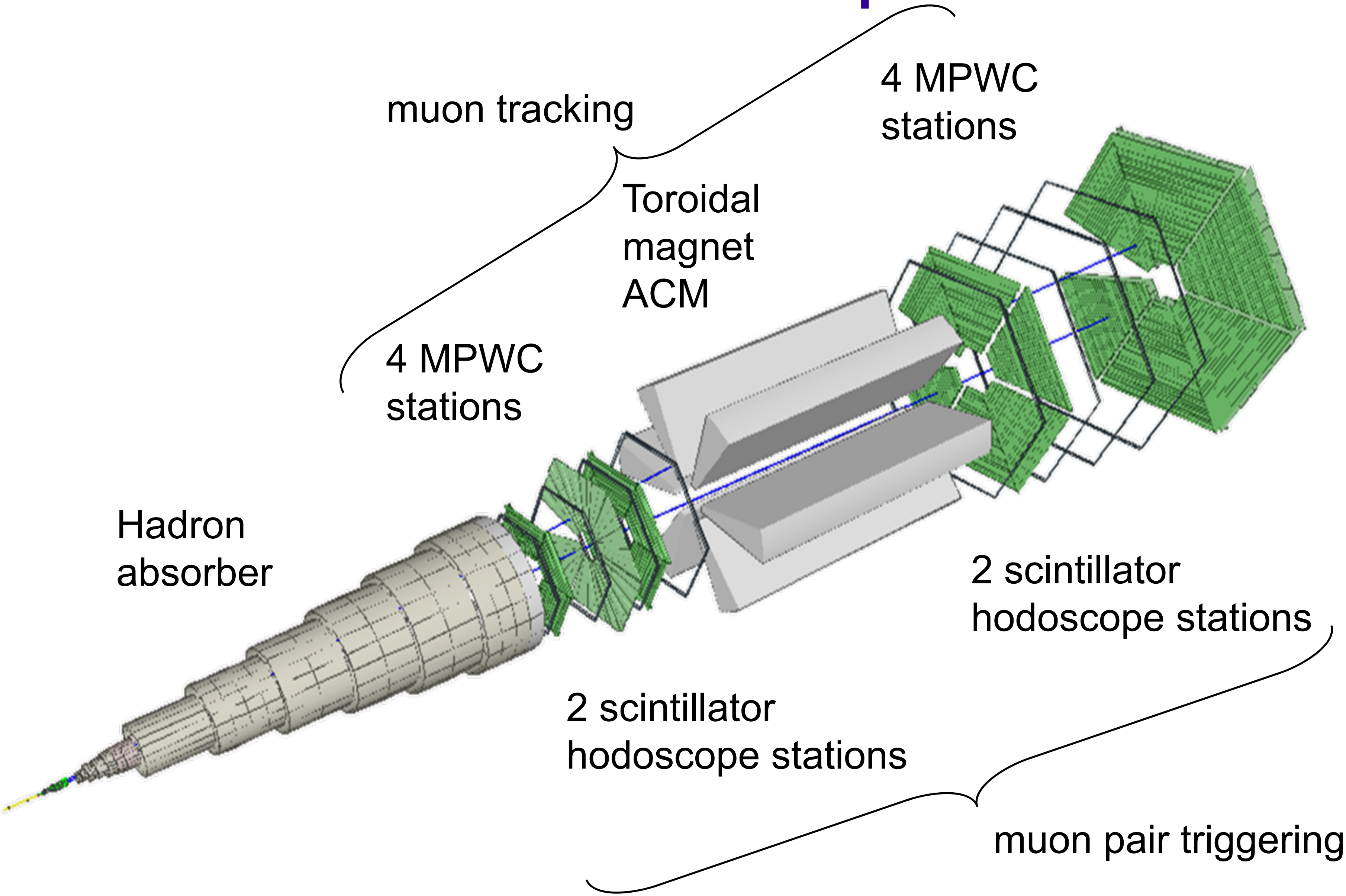


Dimuon rapidity coverage in the lab frame:

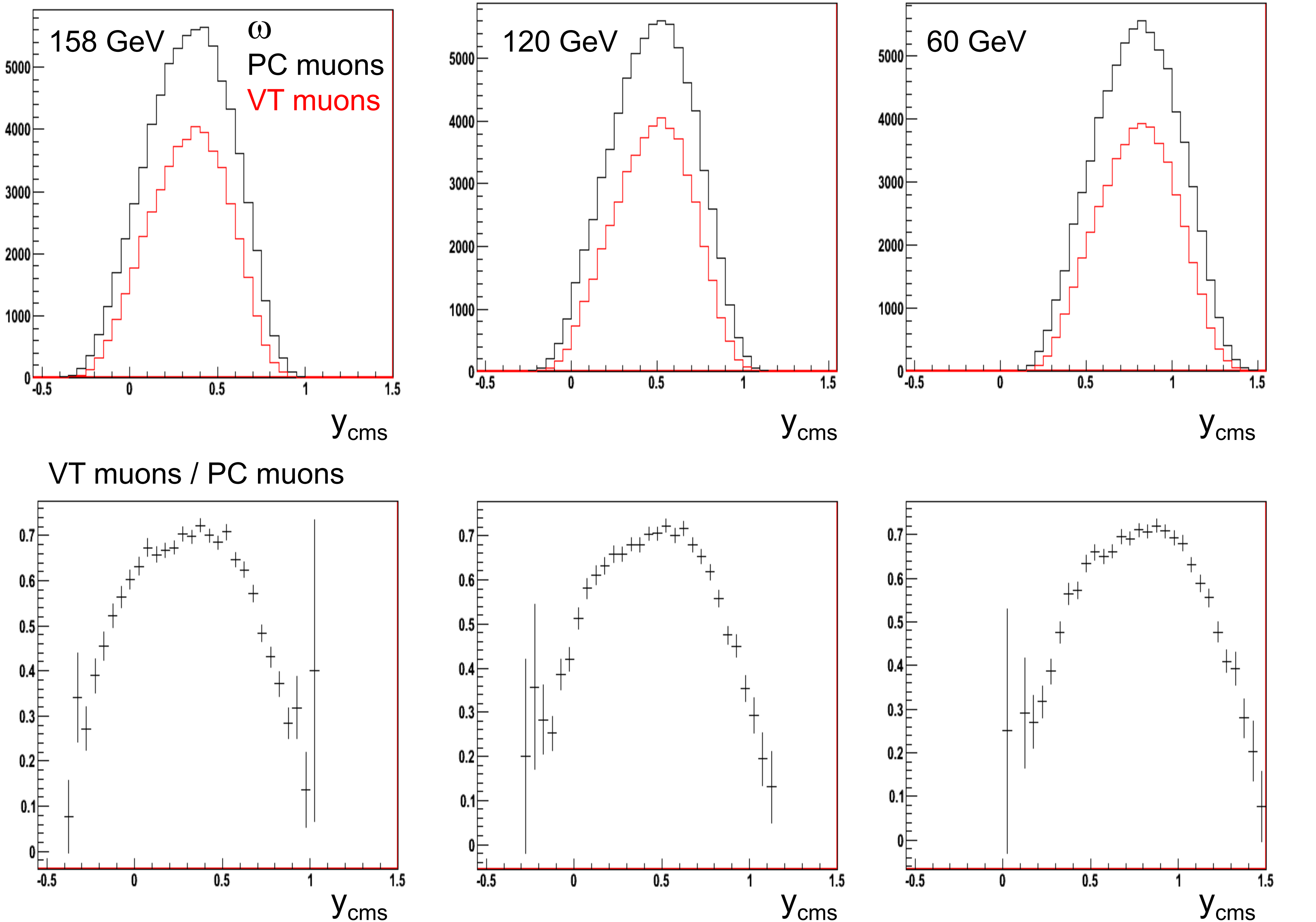
- roughly between 3.3 and 4.3 for low masses
- between 3 and 4 for the J/ψ dimuons

(mid rapidity is at 2.91)

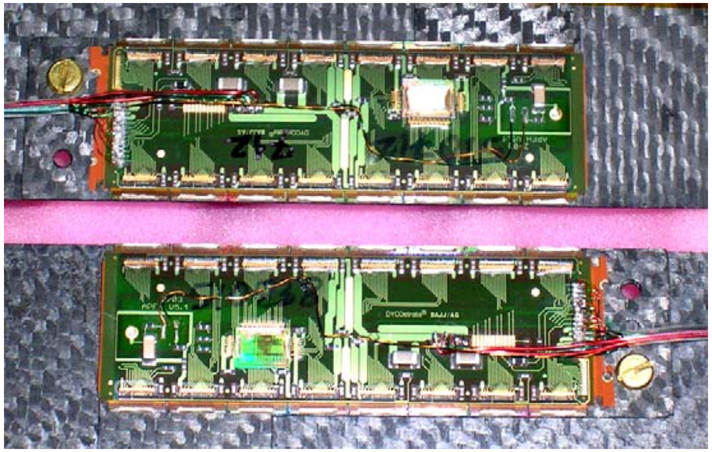
A closer look at the NA60 muon spectrometer

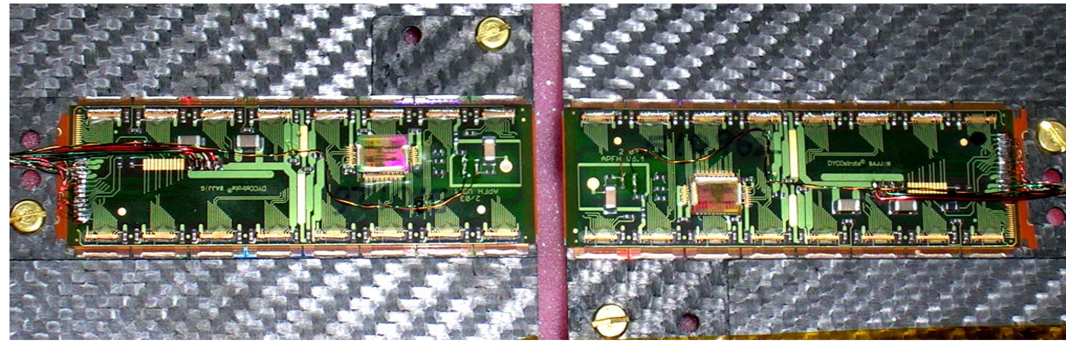


Dimuon matching rate in rapidity



The previous NA60 experience with ATLAS pixels





- 2 Planes with different geometries using ATLAS pixel modules built and operated in Spring 2004

- Further nice features:
  - thinned assemblies (300 μm)
  - no thick hybrid pcb
  - 40 MHz readout
  - intrinsically more rad-hard than ALICE sensor