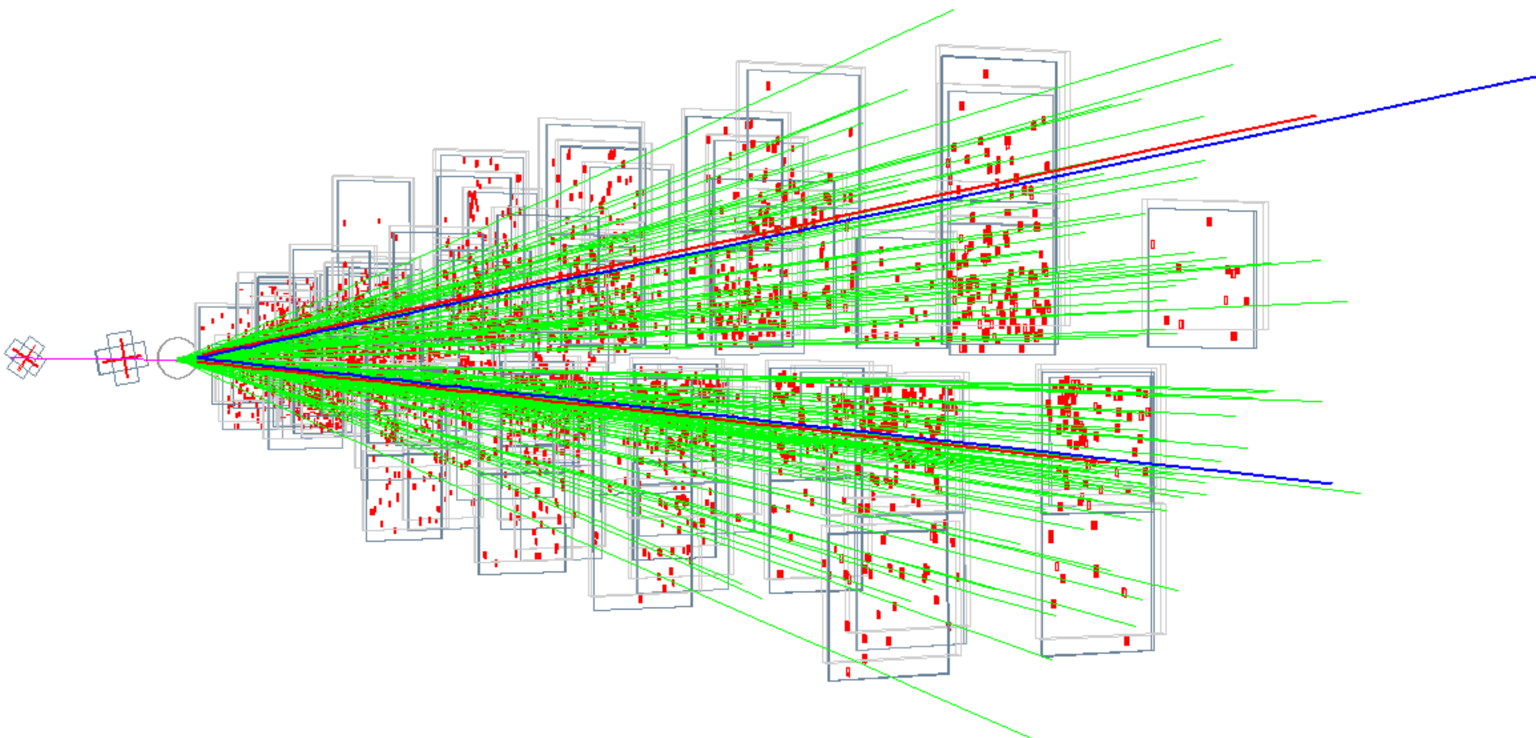
The QCD phase diagram and search of critical point: dilepton measurements in the range 20-158 AGeV at the CERN-SPS

Gianluca Usai –University of Cagliari and INFN



GSI Emmi workshop
16/02/2013

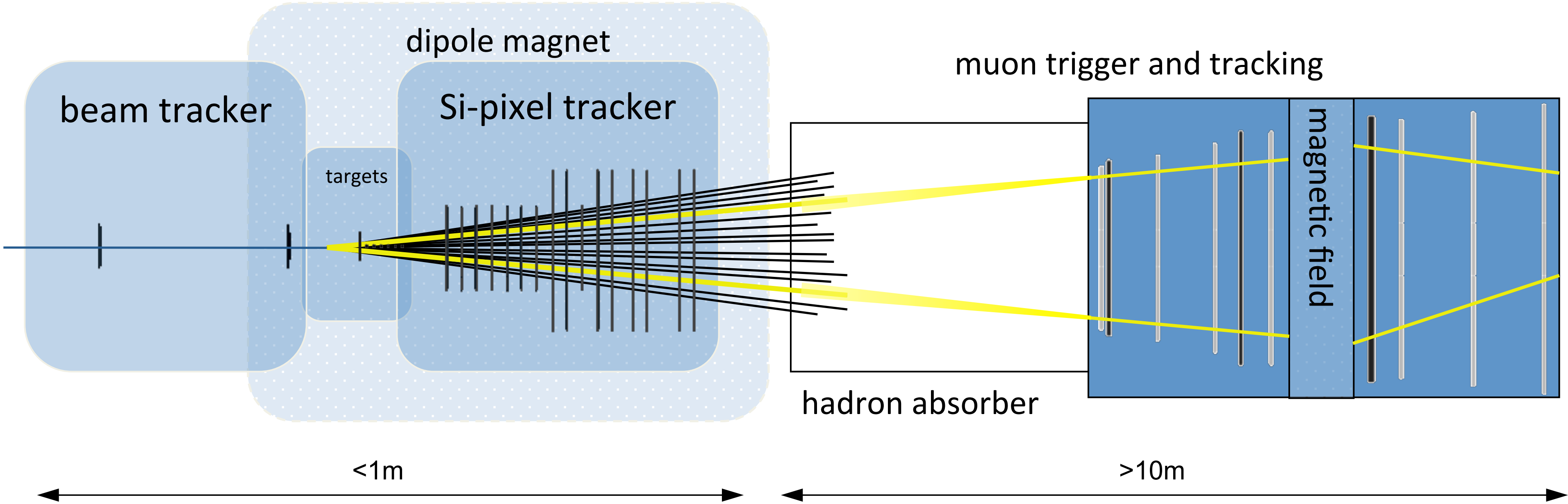
Outline

- NA60: past precision di-muon measurements in HI at top-most SPS energy (158 AGeV)

- Search of the QCD critical point and onset of deconfinement: di-muon measurements from top-most SPS energy to 20 AGeV

- First results for a new spectrometer for low energy dilepton (and quarkonia) measurements at the CERN SPS

High precision muon measurements in HI collisions



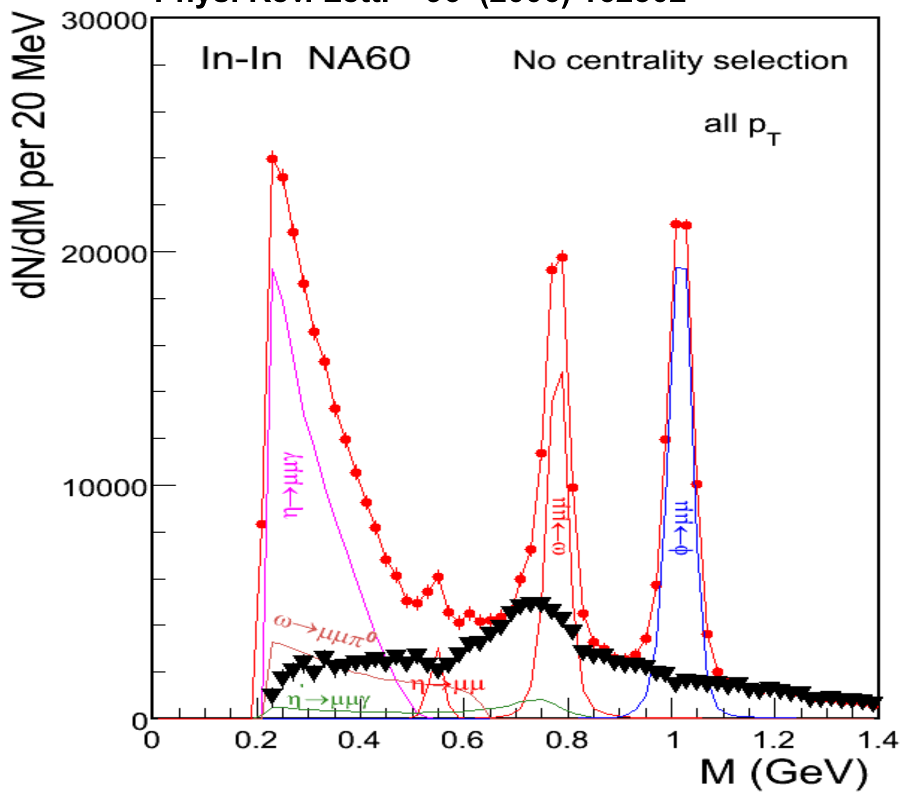
- ✓ Track matching in coordinate <u>and</u> momentum space
  - Improved dimuon mass resolution
  - Distinguish prompt from decay dimuons
- ✓ Radiation-hard silicon pixel detectors (LHC developments)
  - High luminosity of dimuon experiments maintained
- ✓ Concept working at high energy (NA60)

Does it work also at low energy (20-30 GeV)?

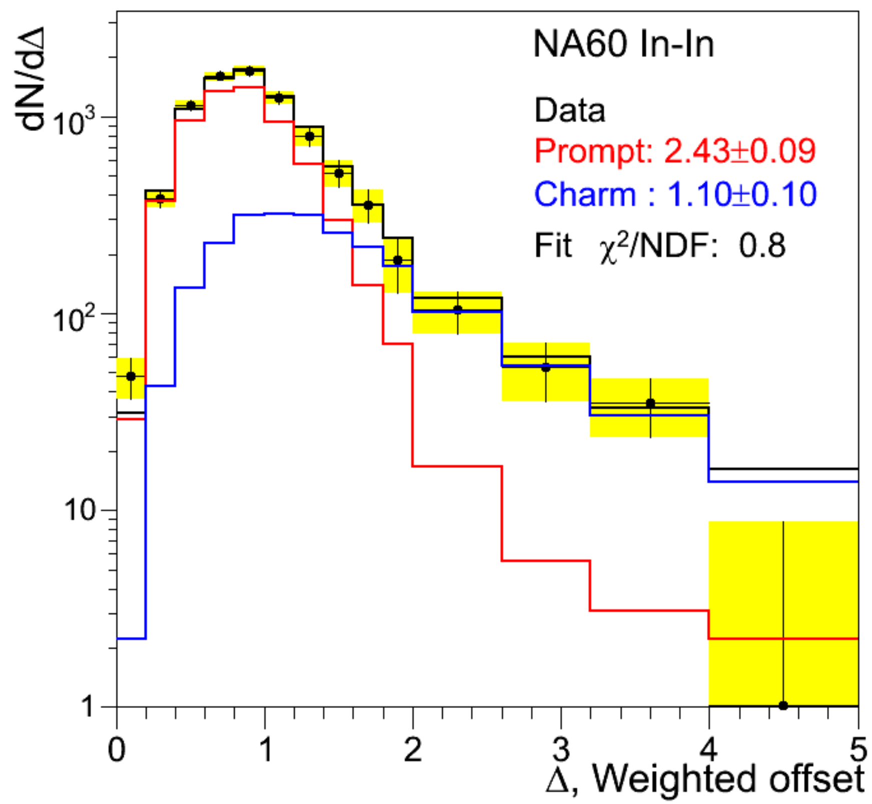
NA60: In-In at 158 AGeV

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



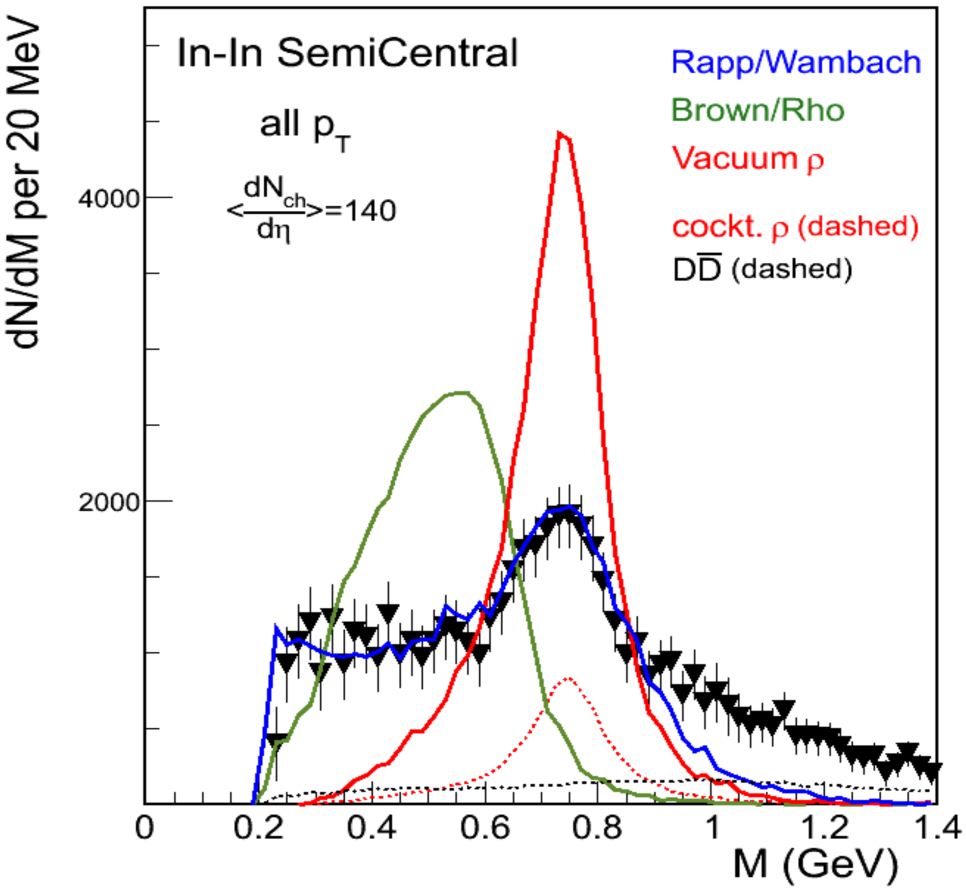
- 440000 events below 1 GeV (3 weeks run)
- 23 MeV mass resolution at the ω

- Charm not enhanced
- Excess above 1 GeV prompt

Chiral symmetry restoration: Brown-Rho scaling vs broadening of ρ meson

Rapp-Wambach: hadronic model predicting strong broadening/no mass shift

Brown/Rho scaling: dropping mass due to dropping of chiral condensate



Predictions for In-In by Rapp et al (2003) for $dN_{ch}/d\eta$ = 140, covering all scenarios

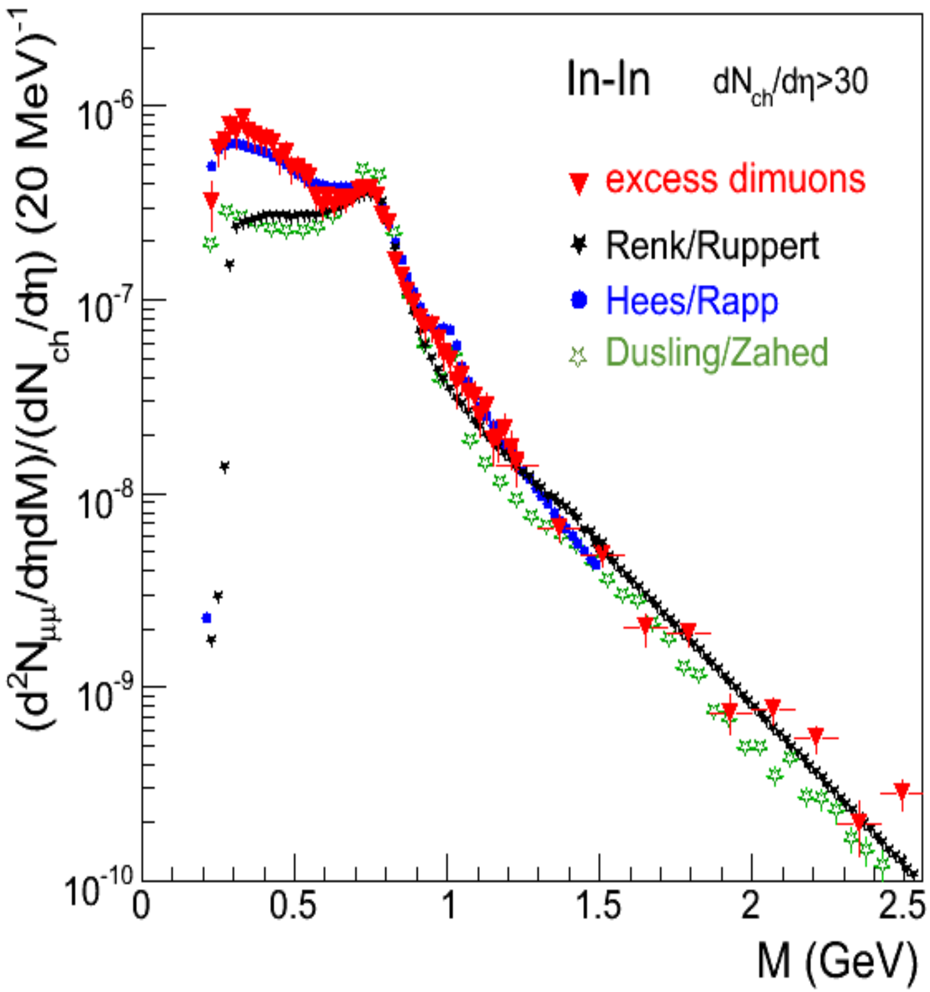
Theoretical yields normalized to data in mass interval < 0.9 GeV

After acceptance filtering, data and predictions display spectral functions, averaged over space-time and momenta

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

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

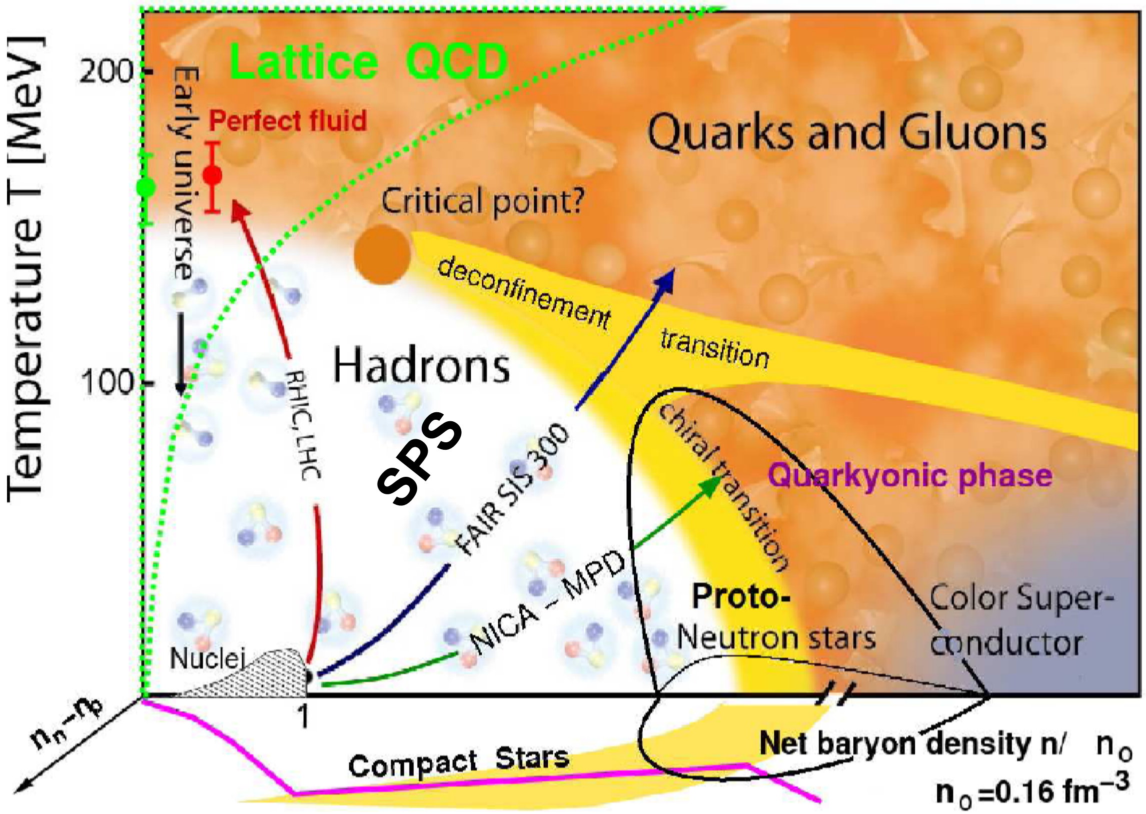
only described by R/R and D/Z models

Dilepton measurements in the range 20-158 AGeV at the CERN-SPS

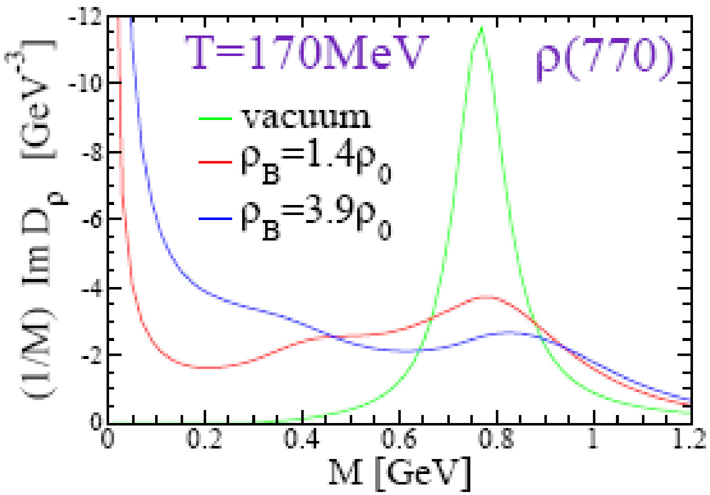
The QCD phase diagram

QCD phase diagram poorly known in the region of highest baryon densities and moderate temperatures

Fundamental question of strong interaction theory: is there a critical point?

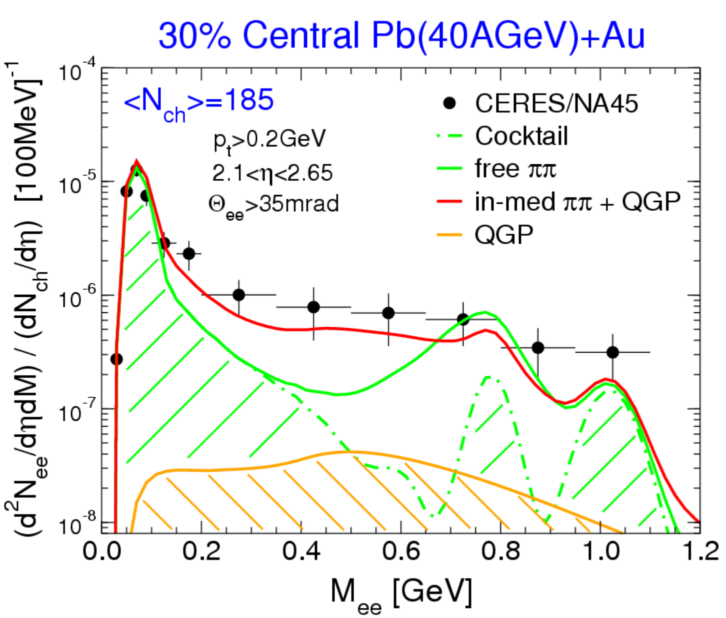


Why measuring low mass dileptons from top to low SPS energies?



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

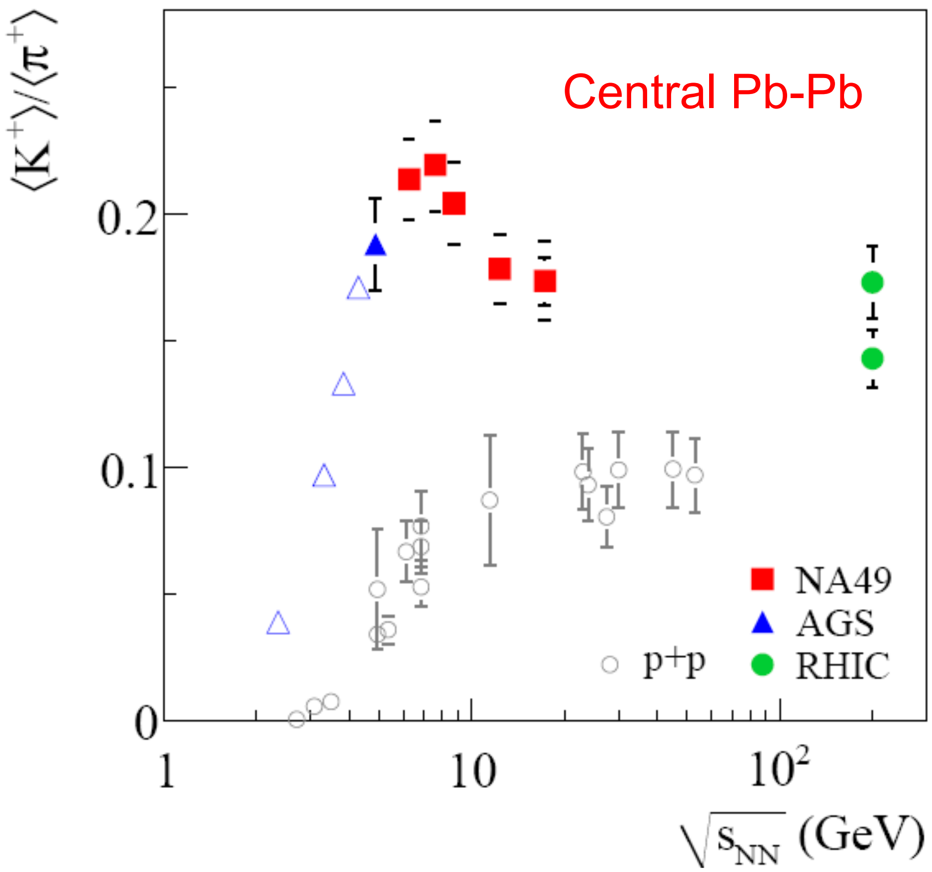


Might not be just coincidental with expectation of emergence of CP: dilepton production sensitive to baryon density fluctuations

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

Low mass dileptons measurements: which energy interval to explore?

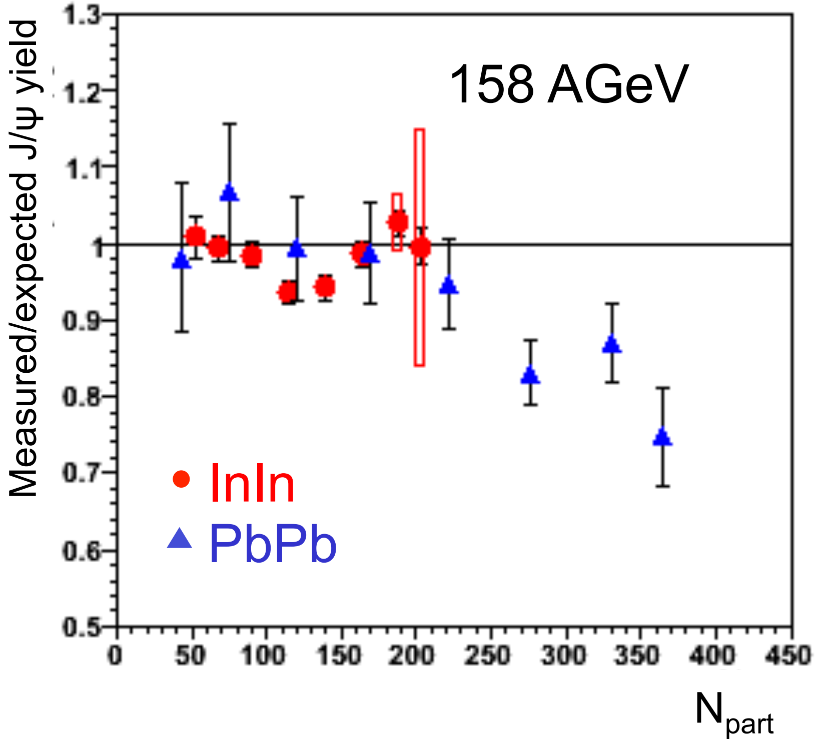
Steepening of the increase of the pion yield with collision energy and sharp maximum in the energy dependence of the strangeness to pion ratio. Onset of deconfinement?

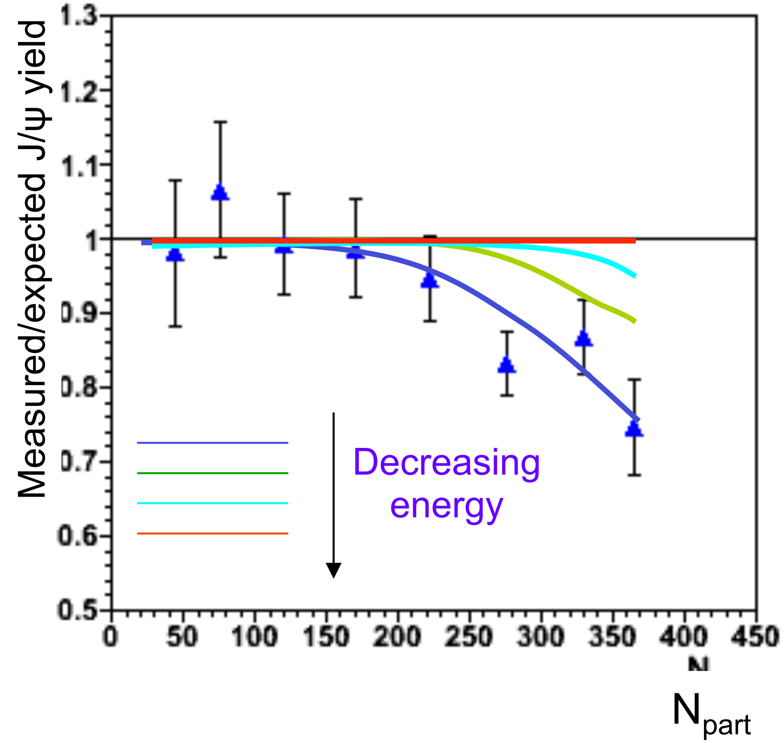


Experimental search of critical point at SPS:

Energy scan from ~ 20-30 GeV towards topmost SPS energy

Charmonium production in AA: top to low SPS energies



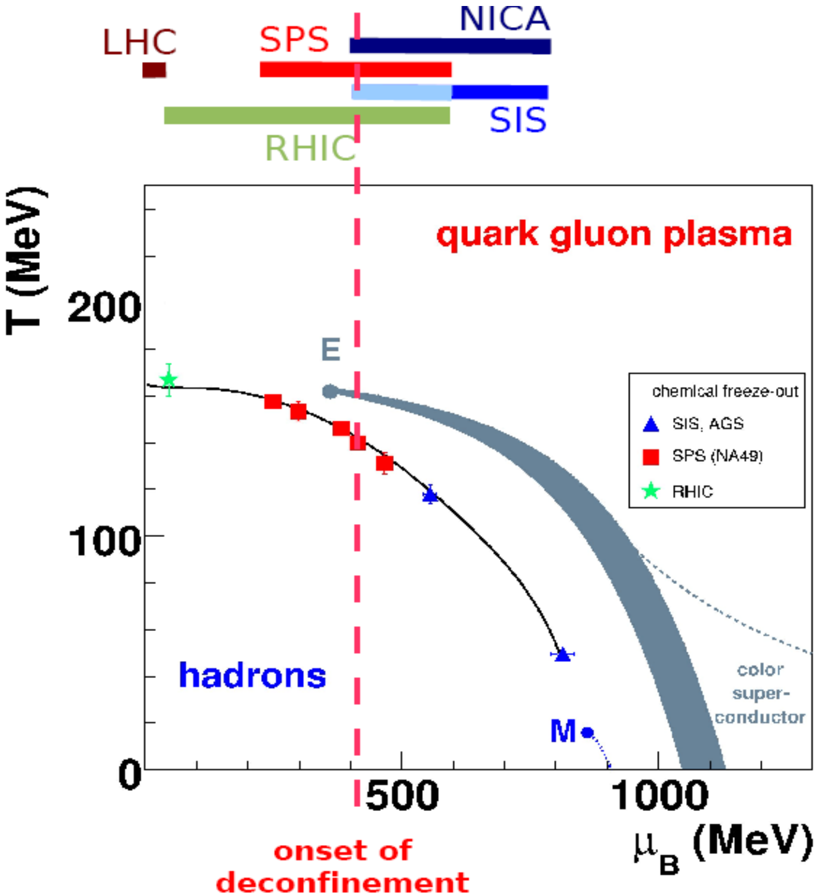


Anomalous suppression relevant for PbPb collisions but almost no suppression for the lighter InIn system at 158 AGeV

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

Competitiveness

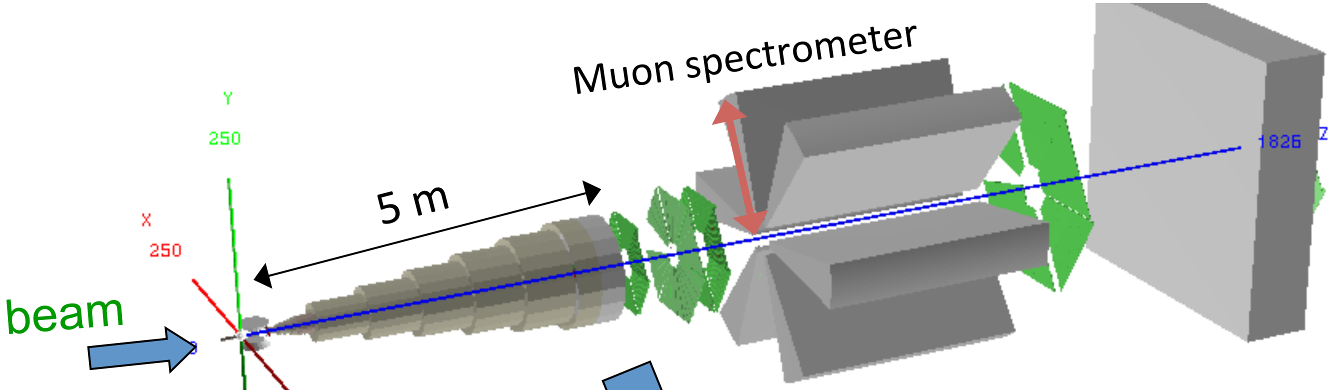
partly complementary programs planned at CERN SPS
BNL RHIC
DUBNA NICA
GSI SIS-CBM



NA60' experiment at CERN

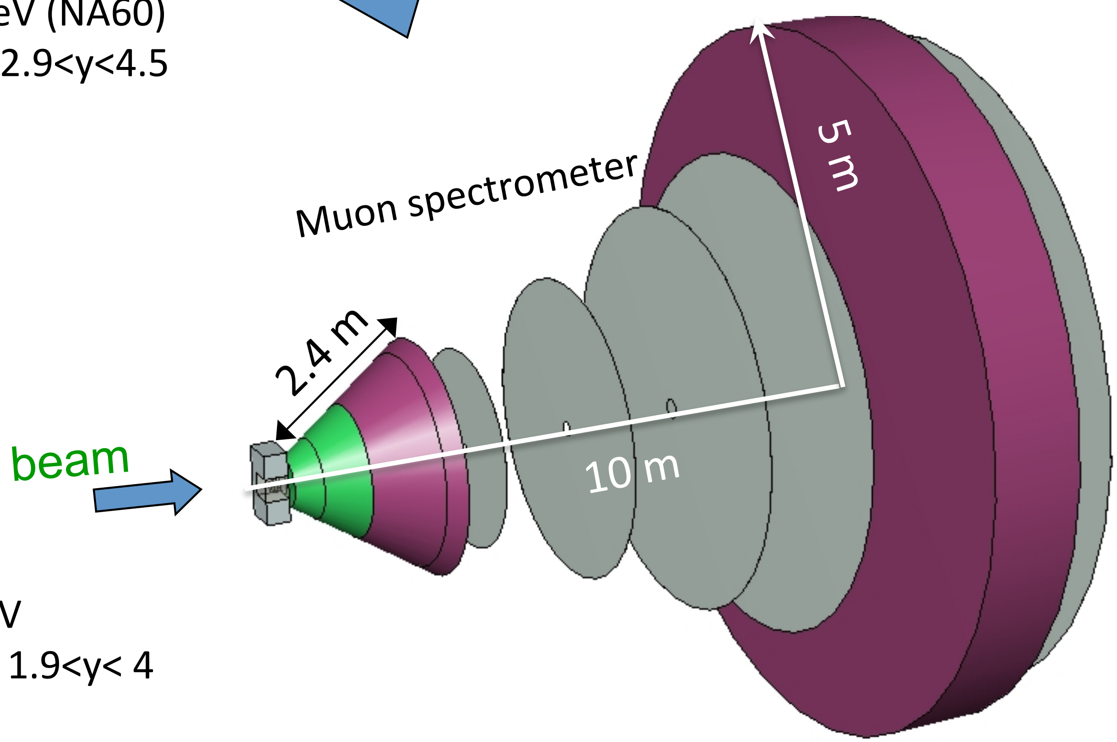
- Availability of ion beams at CERN: dilepton experiment covering a large energy interval - crucial for QCD phase diagram
- Energy interval not covered by any other experiment: unique experiment
- Experiment focused on dileptons: highly optimized for precision measurements
- Complementary to NA61

From the high to a low energy apparatus layout



Compress the spectrometer reducing the absorber and enlarge transverse dimensions

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

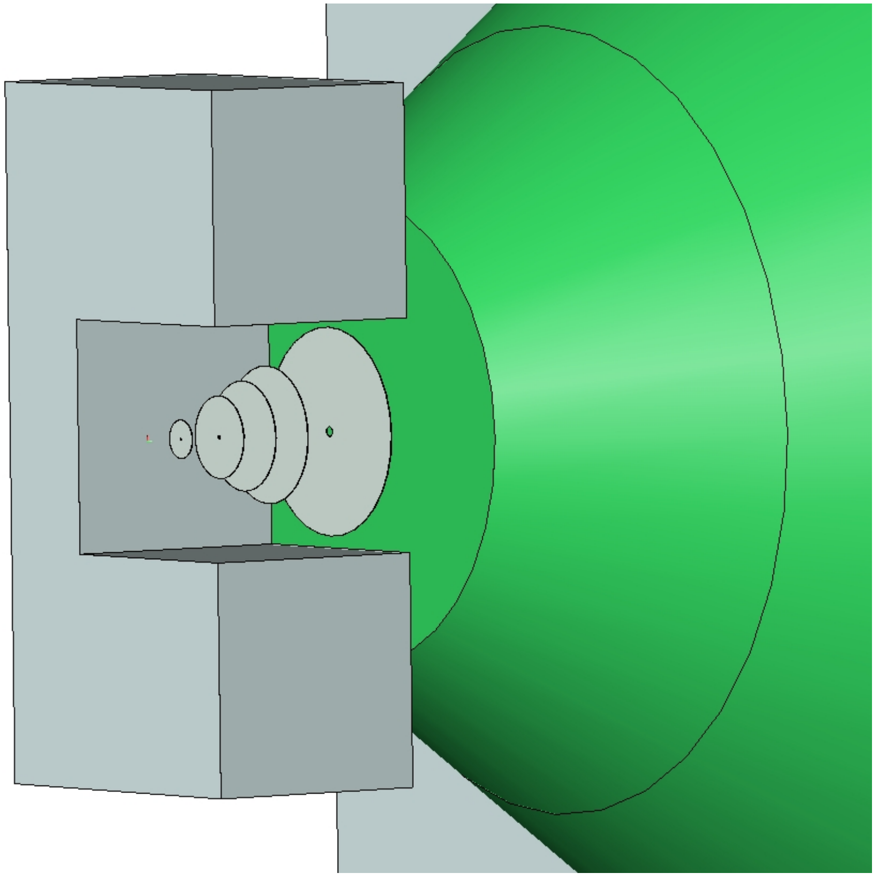


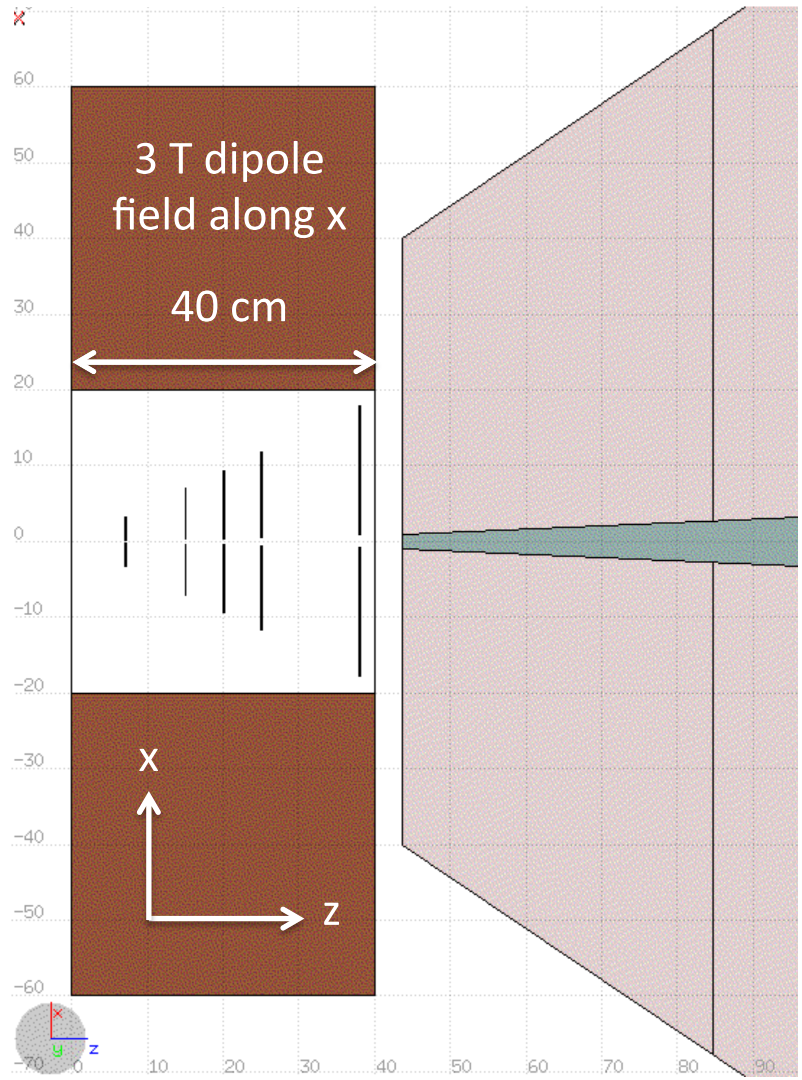
Generic geometry (Fluka)

dileptons@20 GeV
rapidity coverage 1.9<y< 4

Longitudinally scalable setup for running at different energies

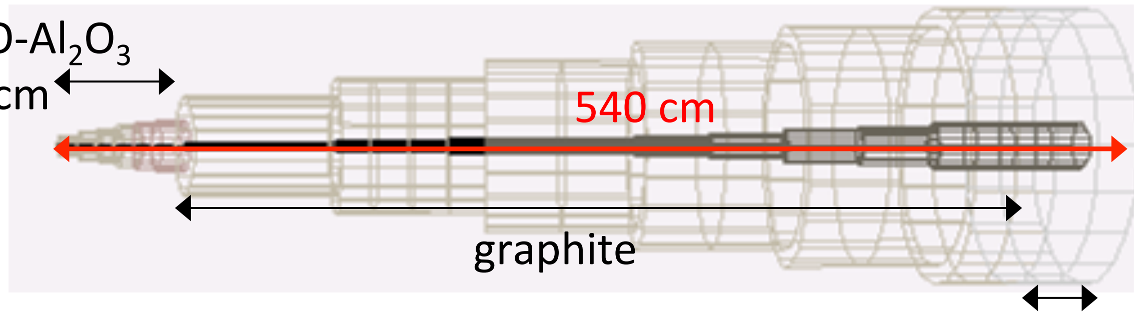
The vertex spectrometer





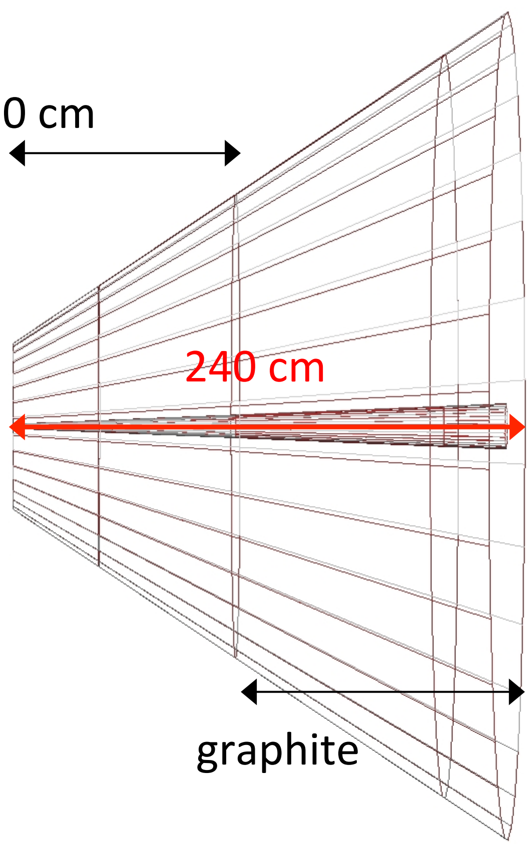
- ✓ Required rapidity coverage @20 GeV starting from <y>=1.9 (ϑ~0.26 rad)
- ✓ 5 silicon pixel planes at 7<z<38 cm
- ✓ Pixel plane:
  - 400 μm silicon + 1 mm carbon substrate
  - material budget ≈0.5% X_0

The hadron absorber and muon wall



High energy setup absorber

- ✓ 14 λ_I , 50 X_0: contains fully hadronic showers
- ✓ High energy muon wall: 120 cm Fe



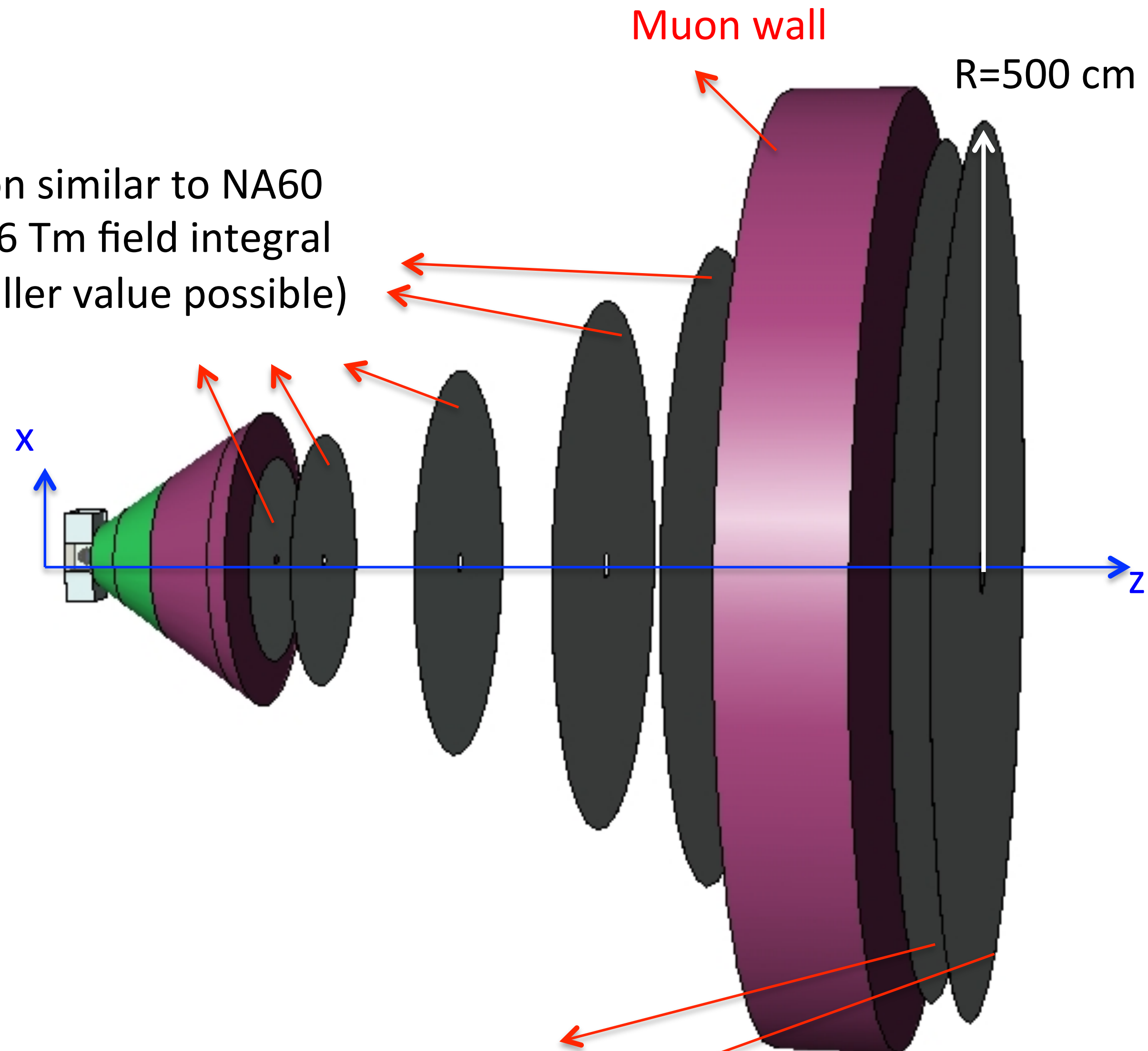
Low energy setup absorber

- ✓ E loss: main factor together with detector transverse size which determines p_T-y differential acceptance
- ✓ Compromise with signal muon energy loss: ≈ 1 GeV at most to get muons into the spectrometer with yLab~2 and $p_T \geq 0.5$ GeV
- ✓ 7.3 λ_I , 14.7 X_0: potentially not containing fully the hadronic shower
- ✓ Low energy muon wall: 160 cm graphite

The muon spectrometer

Muon Tracker

- ✓ 5 tracking stations
- ✓ Momentum resolution similar to NA60 high energy setup (0.6 Tm field integral considered – but smaller value possible)



Trigger system

- ✓ 2 trigger stations placed after muon wall (ALICE-like)
- ✓ No particular topological constraints introduced contrary to NA60 hodo system (muons required in different sextants)

Simulation tools

Fast simulation (signal)

- ✓ Hadron cocktail generator derived from NA60GenGenesis
- ✓ Apparatus defined in setup file describing layer properties:
  - geometric dimensions of active and passive layers
  - material properties
- ✓ Multiple scattering generated in gaussian approximation (Geant code)
- ✓ Energy loss imposed and corrected for deterministically according to Bethe-Bloch

Fluka (background)

- ✓ 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

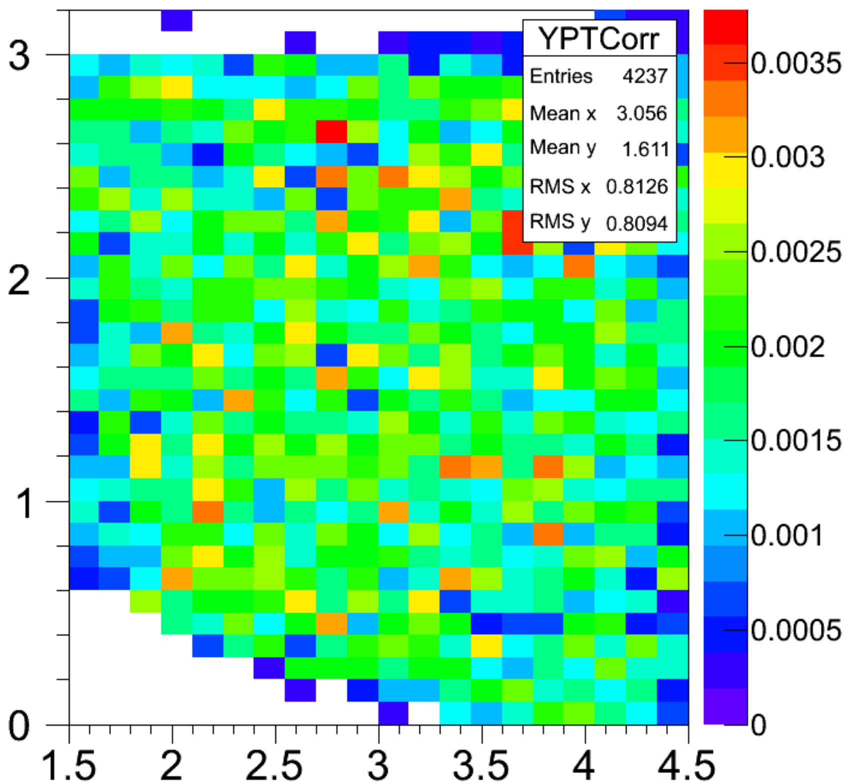
Track reconstruction

- ✓ Setup parameters:
  - x, y resolutions of active layers
  - detector efficiencies: 90% for pixel, 90% muon stations
- ✓ Background hits sampled from multiplicity distributions (π and K) to populate vertex detector (signal embedded in background)
- ✓ Track reconstruction started from hits in trigger stations
- ✓ Kalman fit adding hits in muon stations and vertex detector
- ✓ Correct match: only correct hits associated to track
- ✓ Fake match: one or more wrong hits associated to track

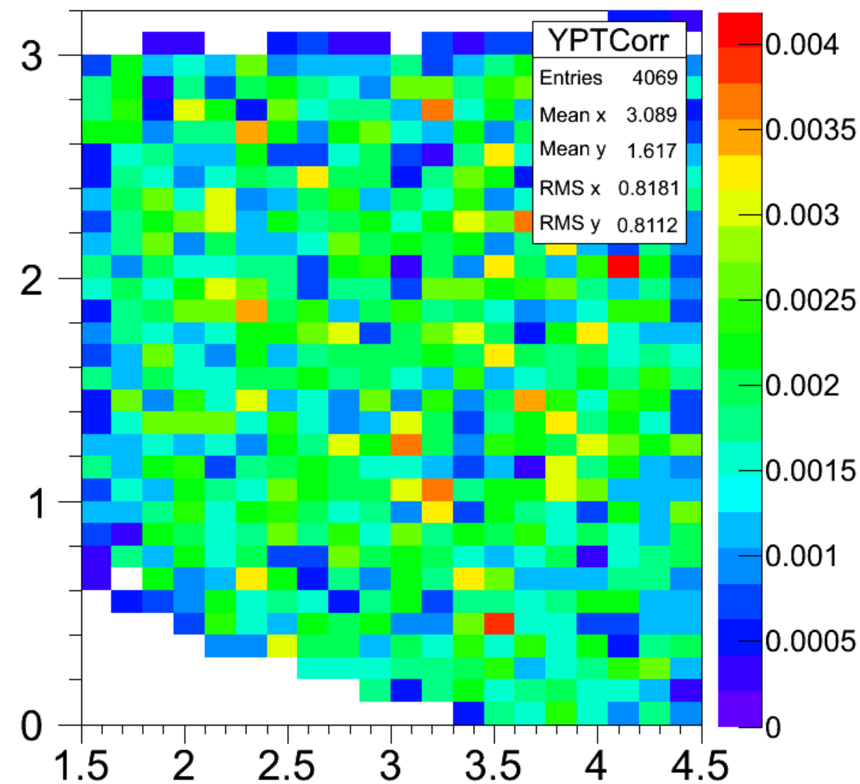
Single muon acceptances

$5x10^3\ \mu^+$ generated with uniform $1.5<y<4.5$ and $0<p_T<3$ and tracked through spectrometer

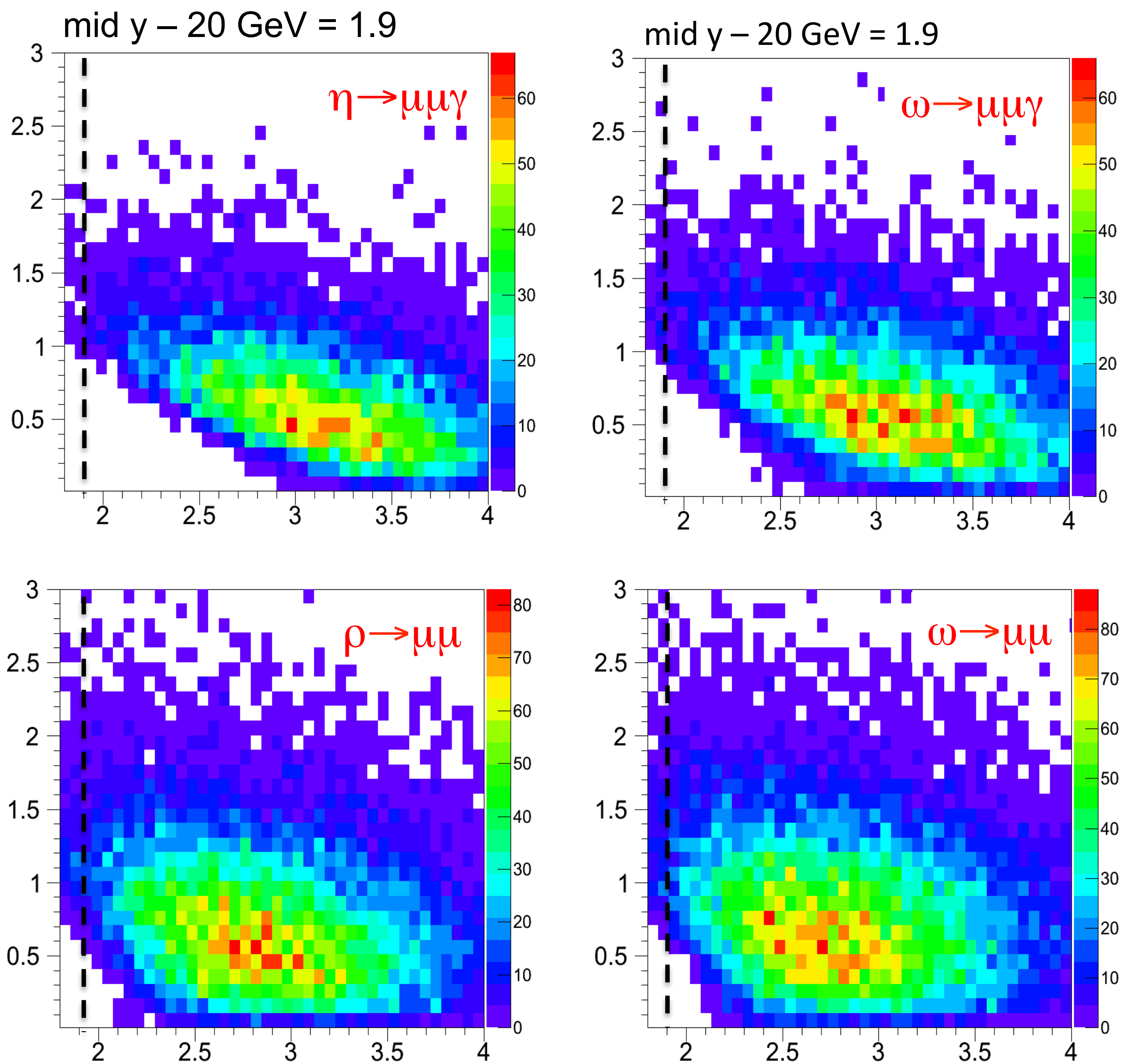
fast sim + rec (correct match)
85% global eff



Fluka sim + rec (correct match)
81% global eff

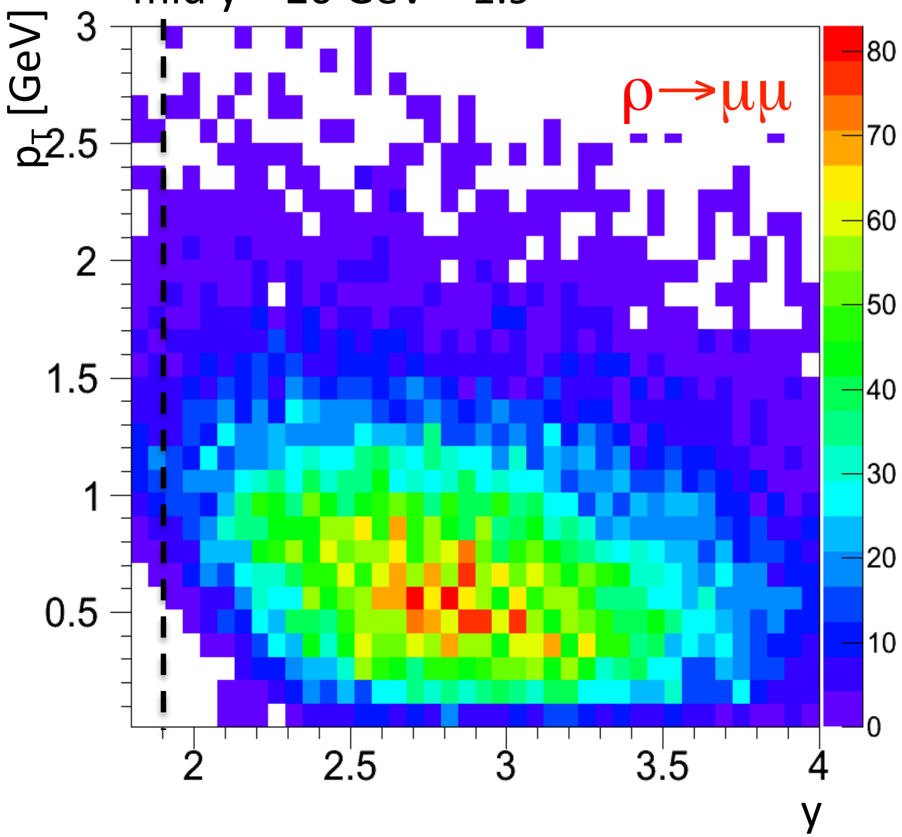


20 GeV hadron cocktail: p_T vs y coverage

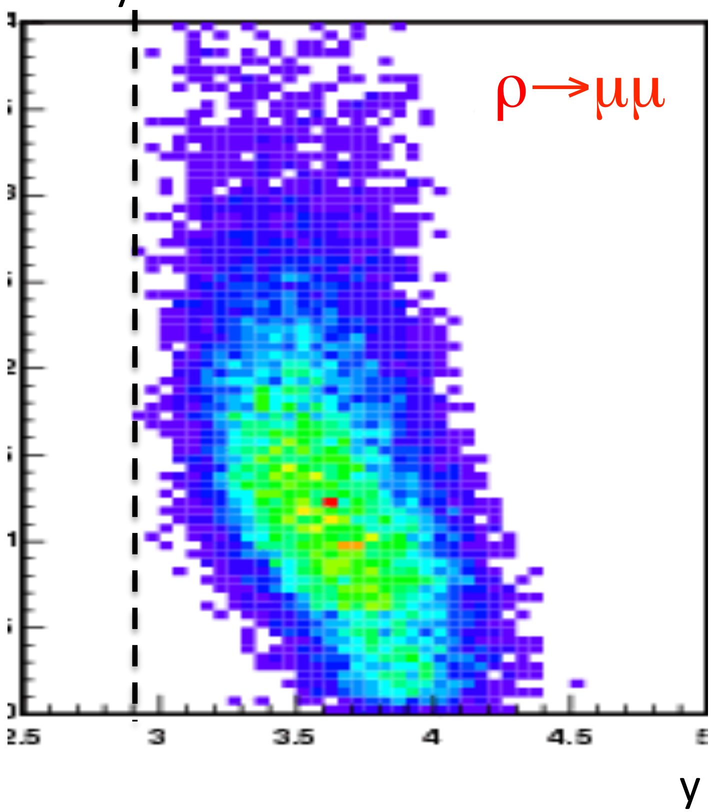


y vs p_T ρ: comparison with NA60 @ 158 GeV

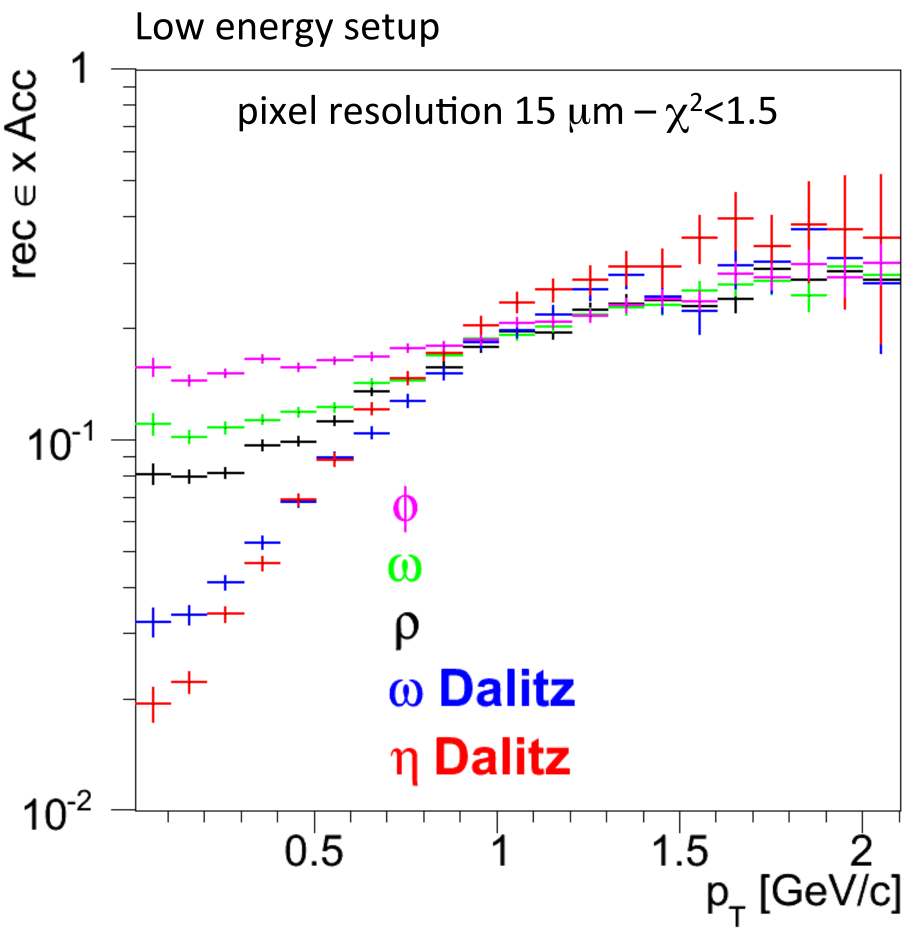
Low energy setup
mid y – 20 GeV = 1.9

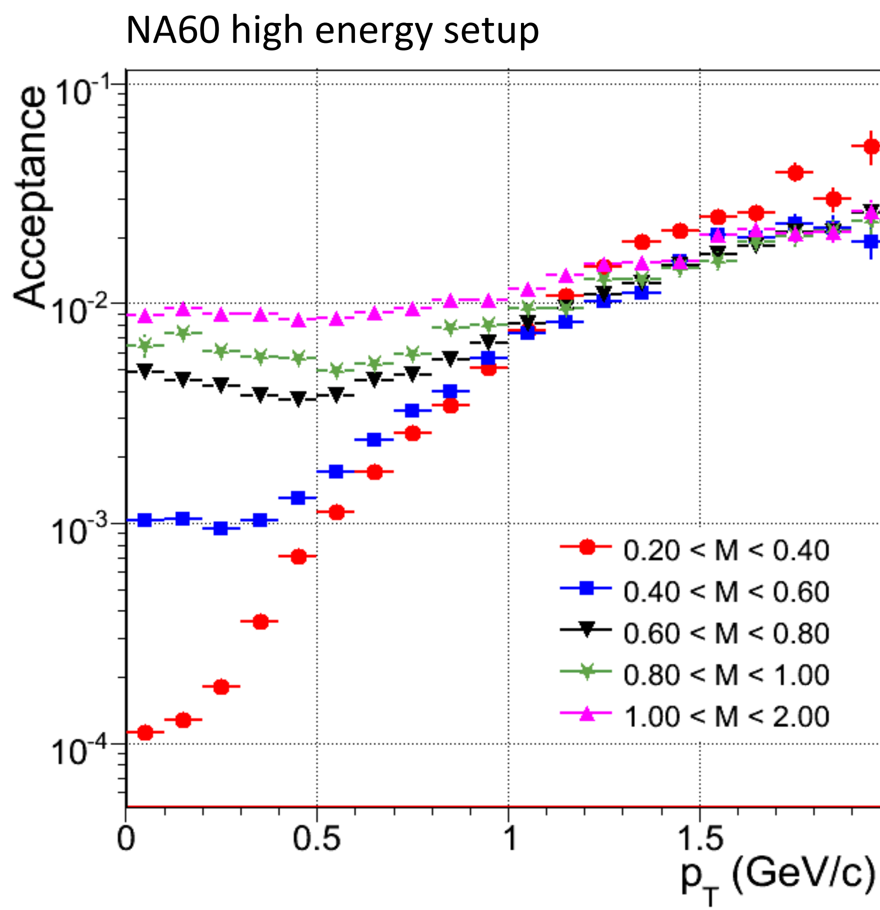


NA60 high energy setup
mid y – 158 GeV = 2.9



Signal reconstruction efficiency vs transverse momentum



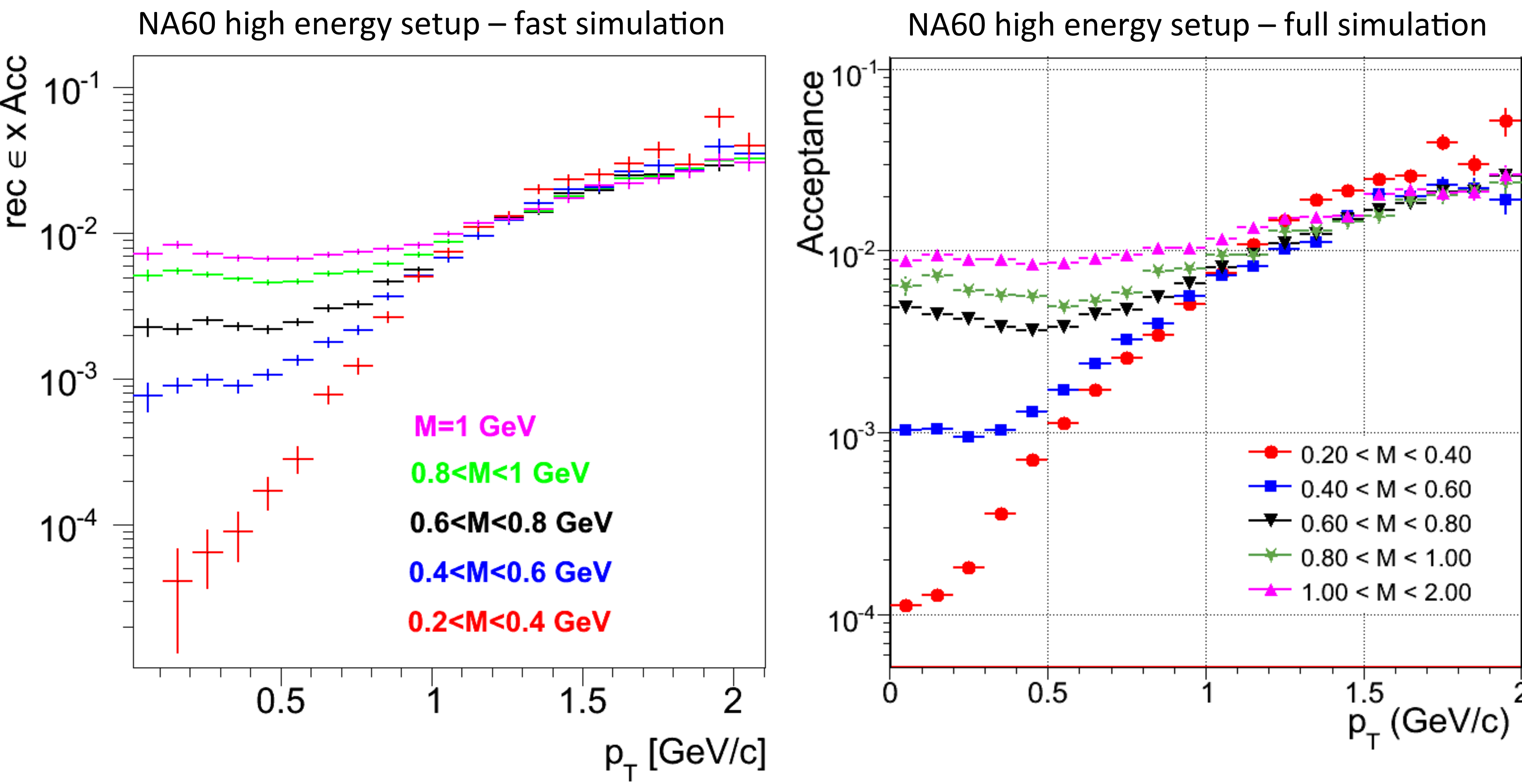


- ✓ Light absorber: broader y-p_T coverage
- ✓ No topological constraints imposed by trigger
- ✓ No dead zones introduced by dipole magnet

- ✓ Thick absober: narrower y-p_T coverage
- ✓ Trigger: muons required in different hodo sextants
- ✓ Dead zones in toroid magnet

➔ Low energy setup: rec eff x Acc better by more than one order of magnitude

Cross check: high energy setup rec ε x Acc vs p_T

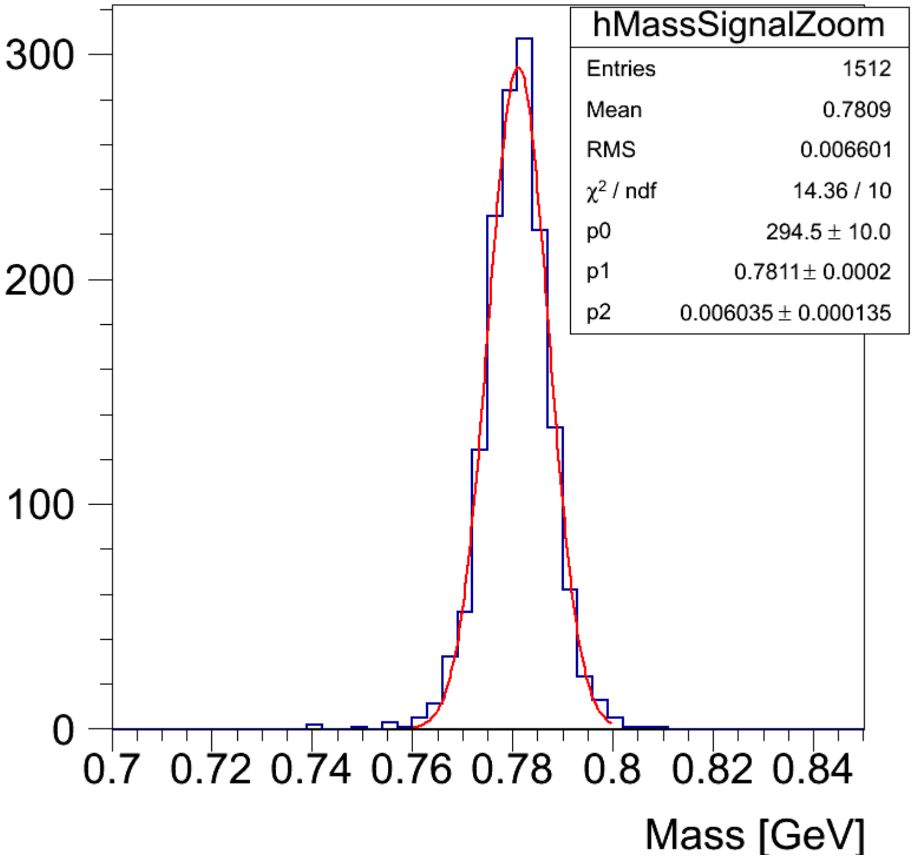


- ✓ Rec eff in different mass bins: average of rec eff for single cocktail processes (simple average in fast simulation)
- ✓ Hodo trigger condition and dead zones taken into account in fast simulation
- ✓ Very good agreement between fast and full simulation

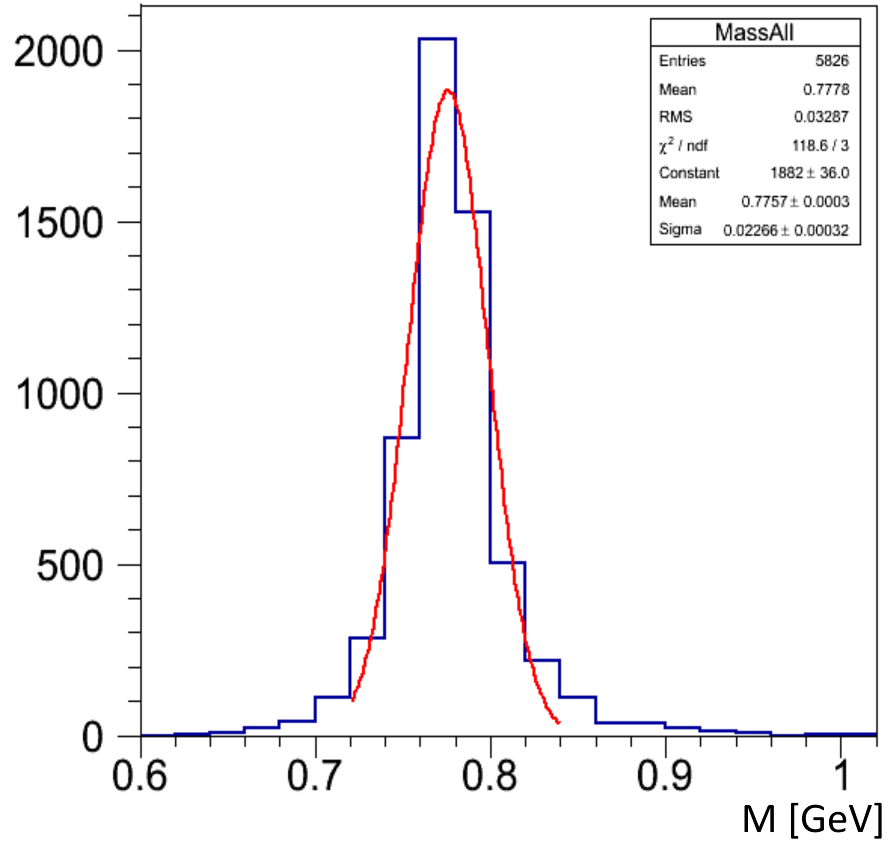
Mass resolution

Low energy energy setup

pixel resolution 15 μm - χ^2<1.5



NA60 high energy setup

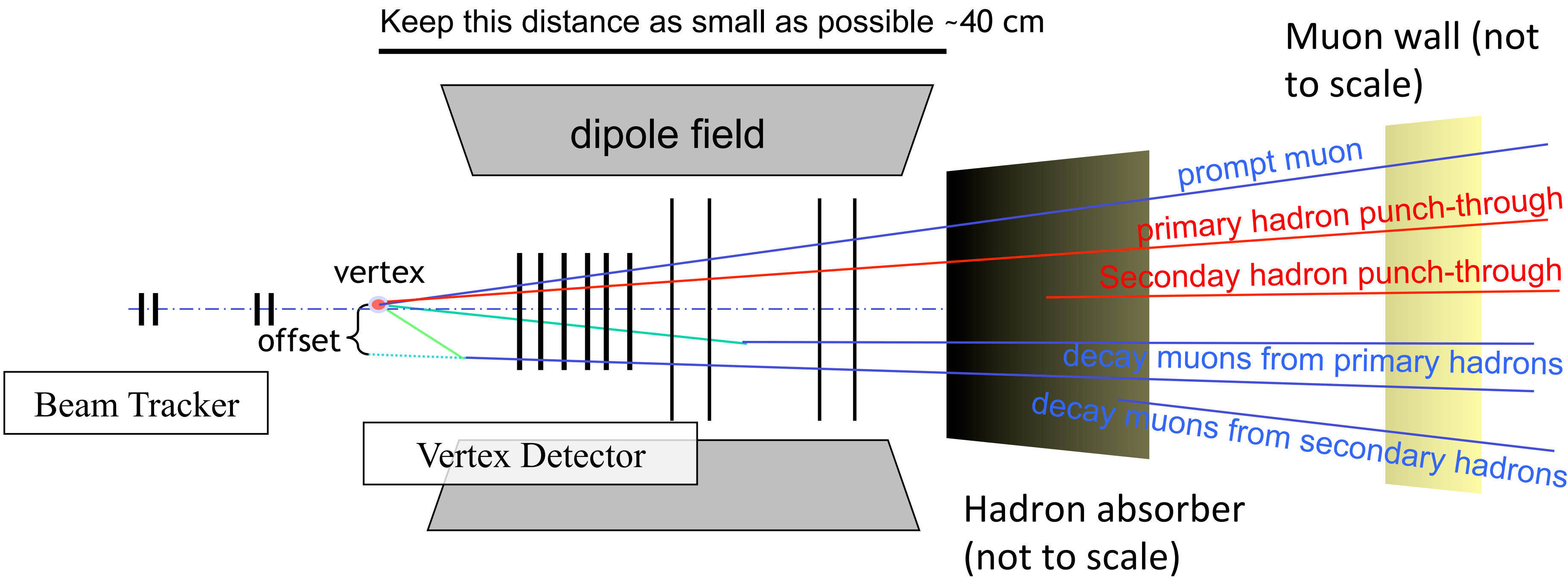


NA60 lowenergy setup:
mass resolution 6 MeV

NA60 high energy setup:
Mass resolution 23 MeV

➔ New setup: mass resolution can be improved at least by a factor 2-3 with respect to the old high energy setup

Sources of combinatorial background



✓ Fluka:

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

Input parameters for background simulation: pions, kaons and protons

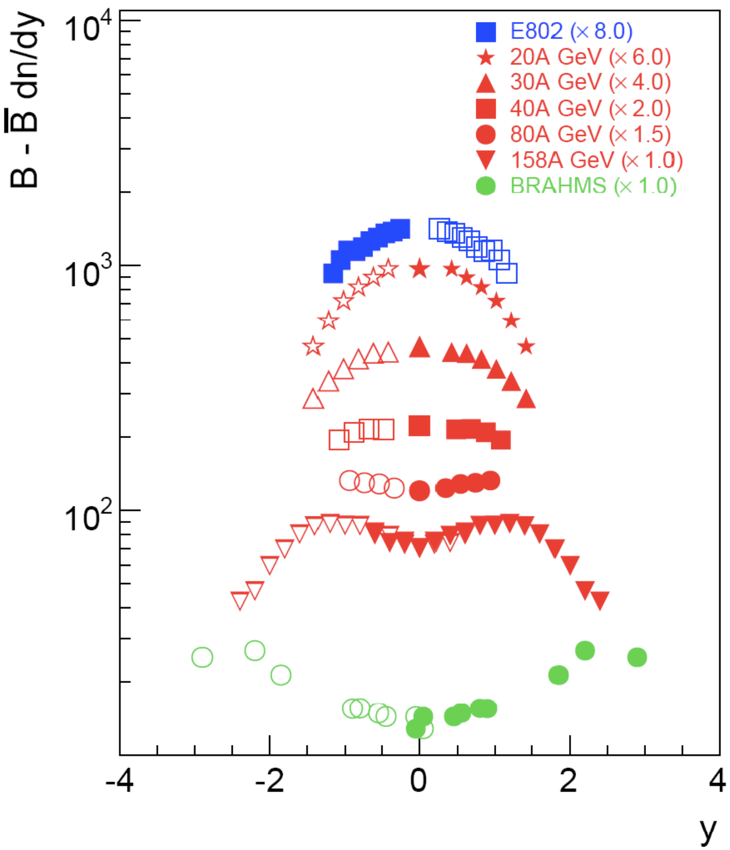
✓ Pions, kaon and protons generated based NA49 measurements for 0-5% Pb-Pb central collisions at 20, 30 GeV

✓ Pion, kaons:

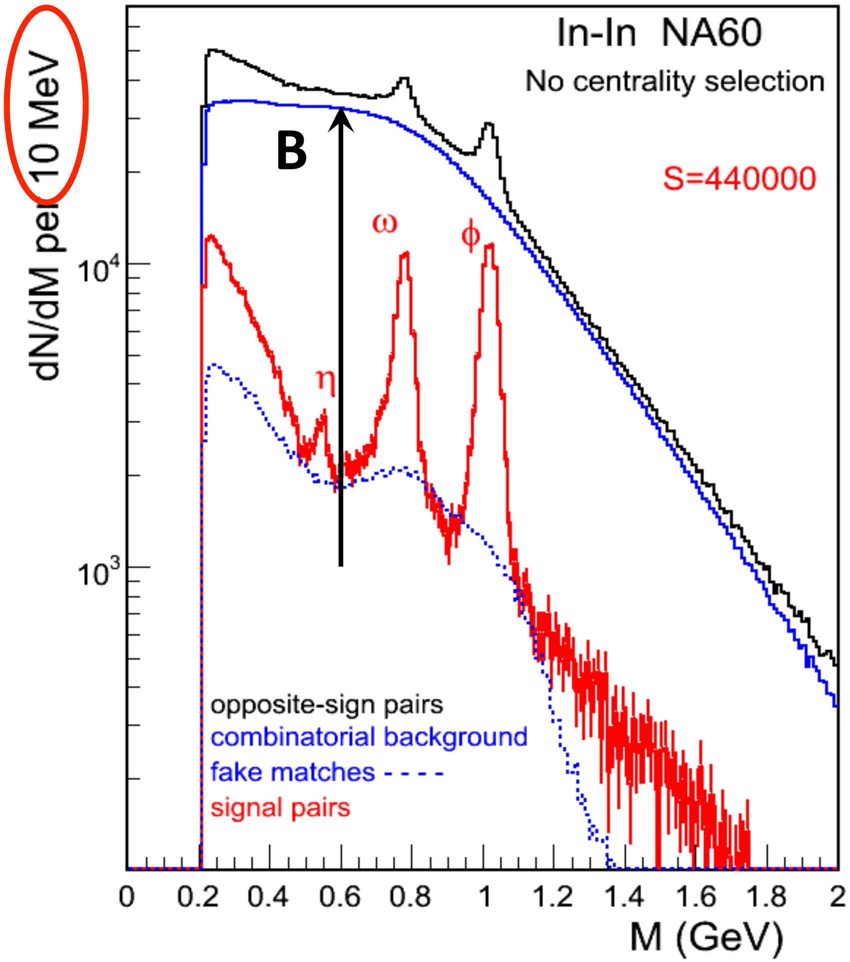
- 20 GeV: $dN_{\pi+K}/dy(NA49) \approx 180$
- 30 GeV: $dN_{\pi+K}/dy(NA49) \approx 210$

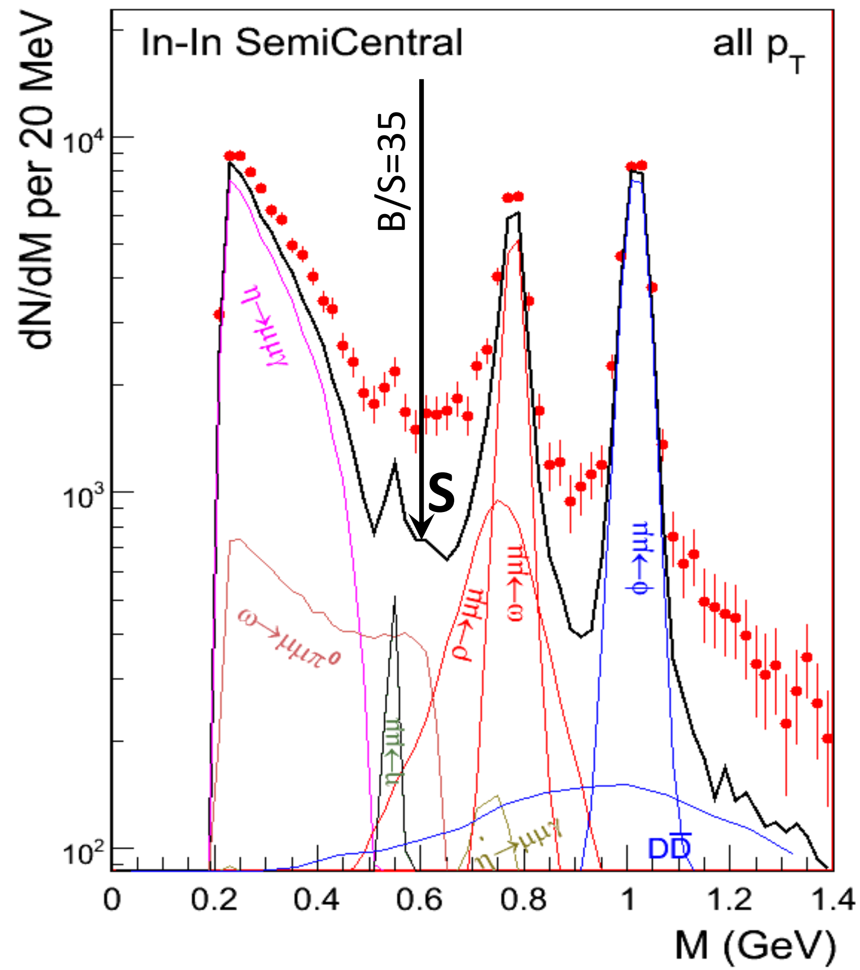
✓ Protons:

- 20 GeV: $dN_p/dy(NA49) \approx 80$
- 30 GeV: $dN_p/dy(NA49) \approx 60$



Assessment of B/S: choice of S

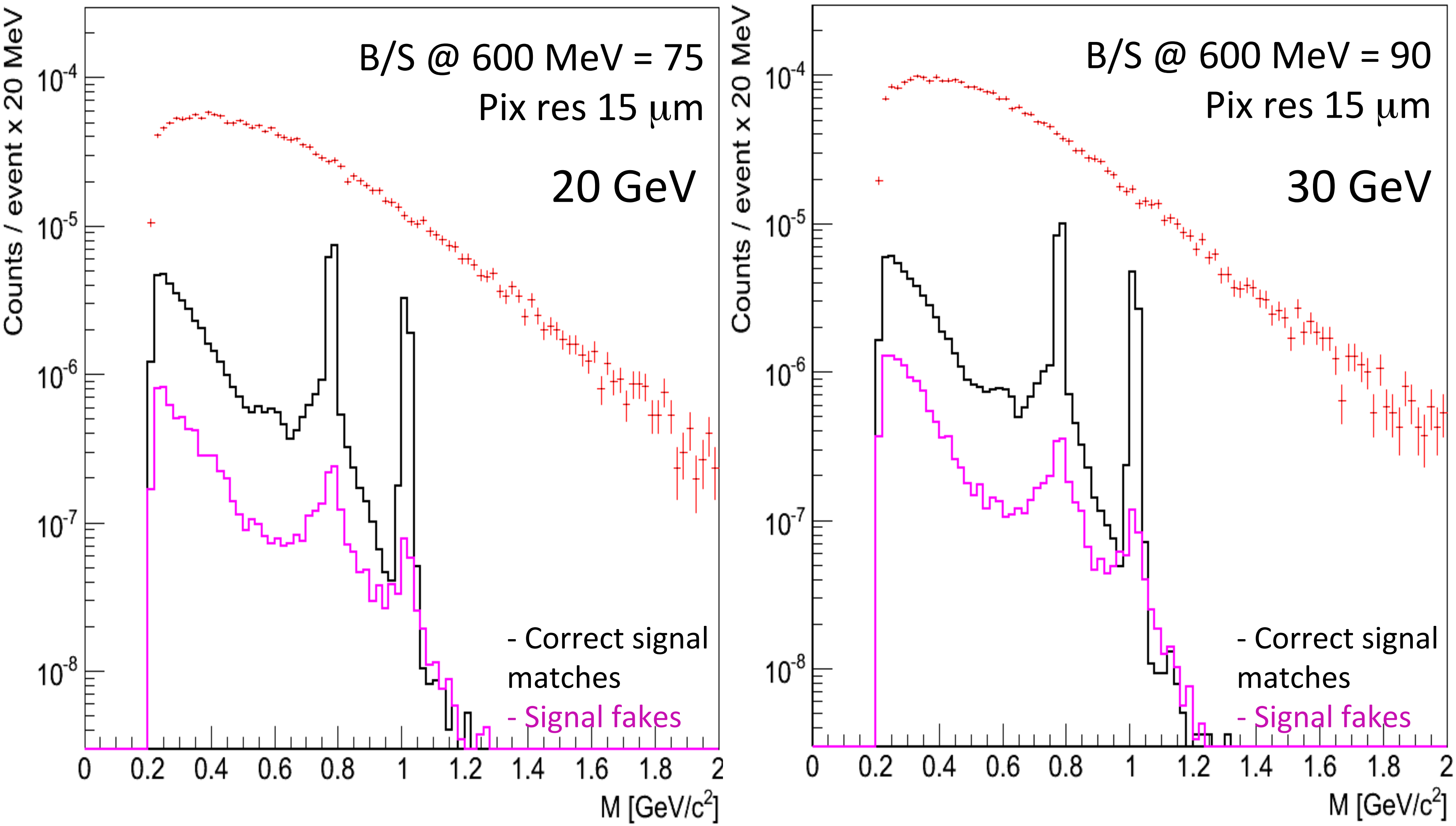




choose hadron cocktail in mass window 0.5-0.6 GeV for S

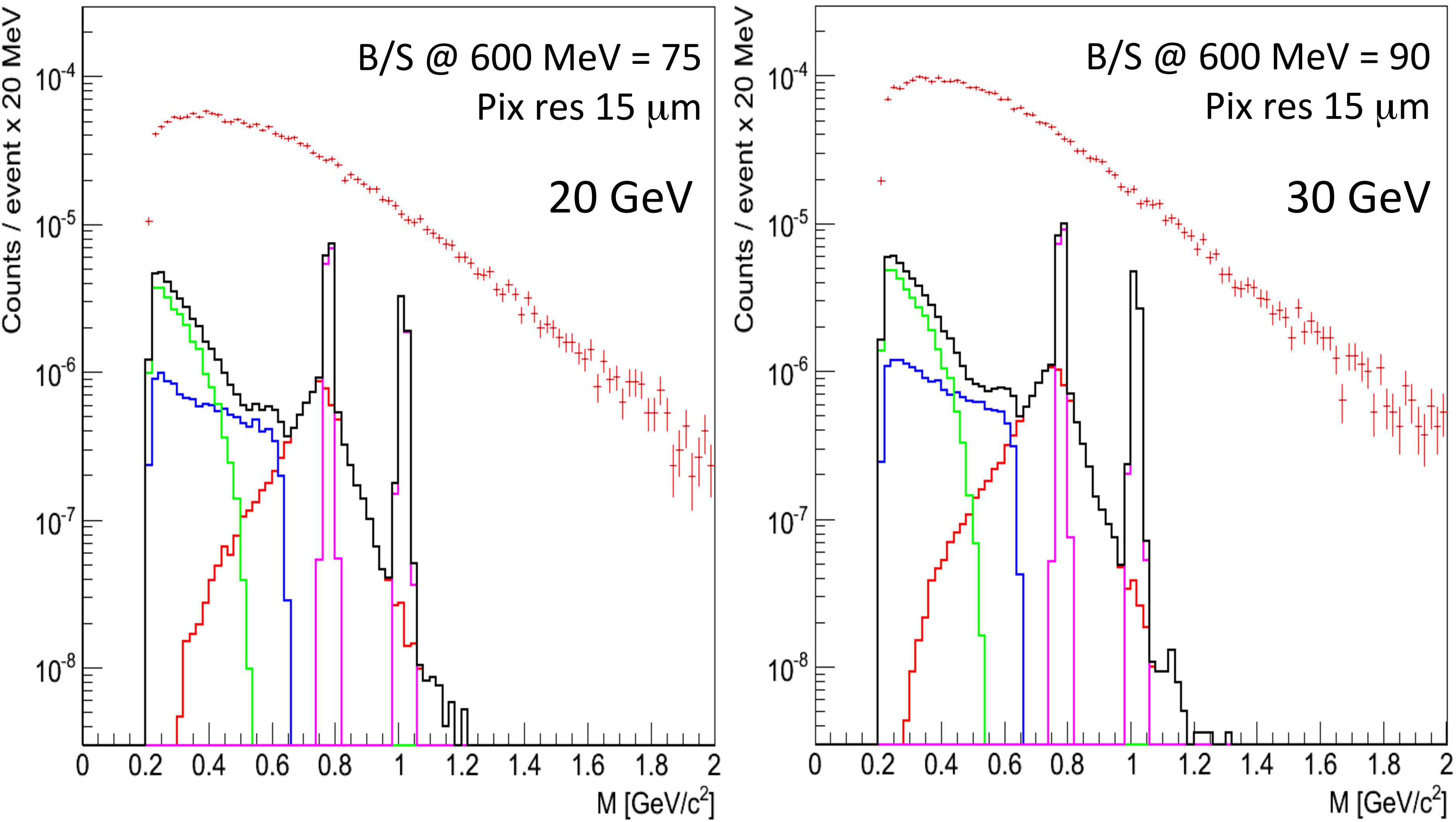
- free from prejudices on any excess; no ‘bootstrap’; most sensitive region
- unambiguous scaling between experiments; B/S dN_{ch}/dy

Hadronic cocktail and bkg in central Pb-Pb collisions at 20 and 30 GeV



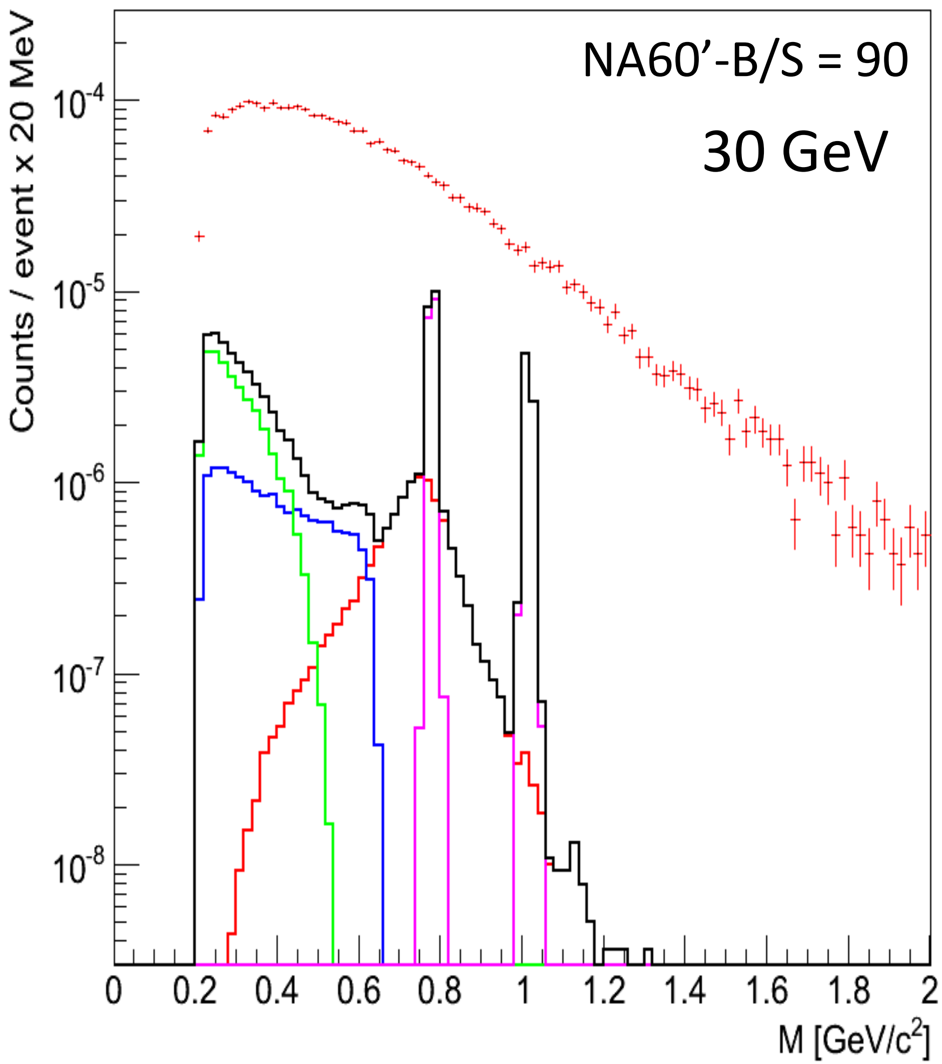
- ✓ proton contribution not yet included in mass distributions (work in progress)
- ✓ bkg including protons 10-20% higher

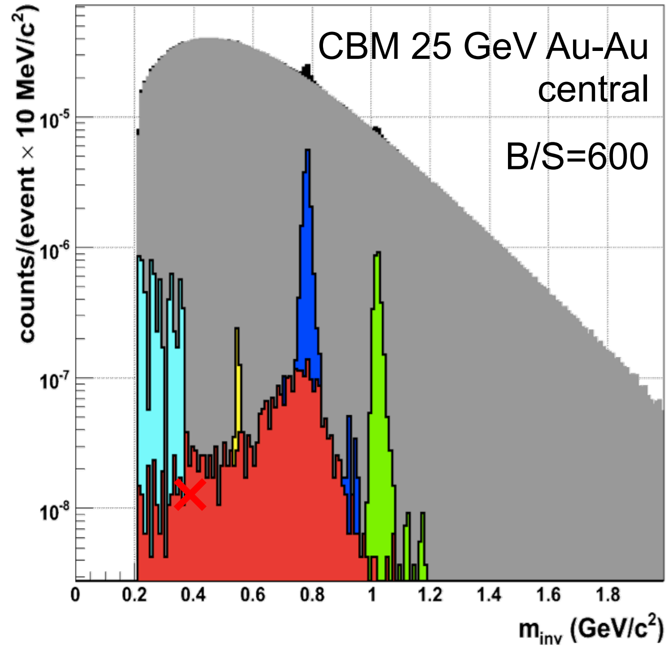
Cocktail processes and bkg in central Pb-Pb collisions at 20 and 30 GeV



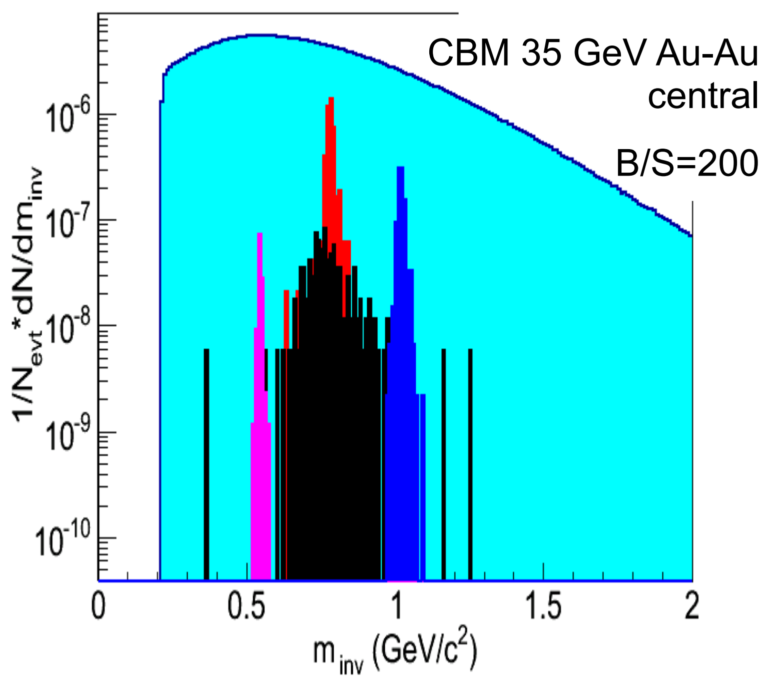
- ✓ proton contribution not yet included in mass distributions (work in progress)
- ✓ bkg including protons 10-20% higher

Comparison to CBM





New Much setup and selection cuts



✓ bkg including protons 10-20% higher

Experimental aspects

- High precision:
  - very good B/S (<100 in central collisions)
  - p_T acceptance (a factor >10 better than high energy setup)
  - 6 MeV mass resolution (a factor 2-3 better than high energy setup)

- Silicon detector: use of existing hybrid technologies possible
  - 50 μm cell, ≈0.5% material budget/plane

- Muon tracking chambers: large area but conventional detectors

- Muon spectrometer magnet:
  - large toroid magnet (R≈3 m) required but with relatively low field strength

- Further work for optimizing the setup required

Summary

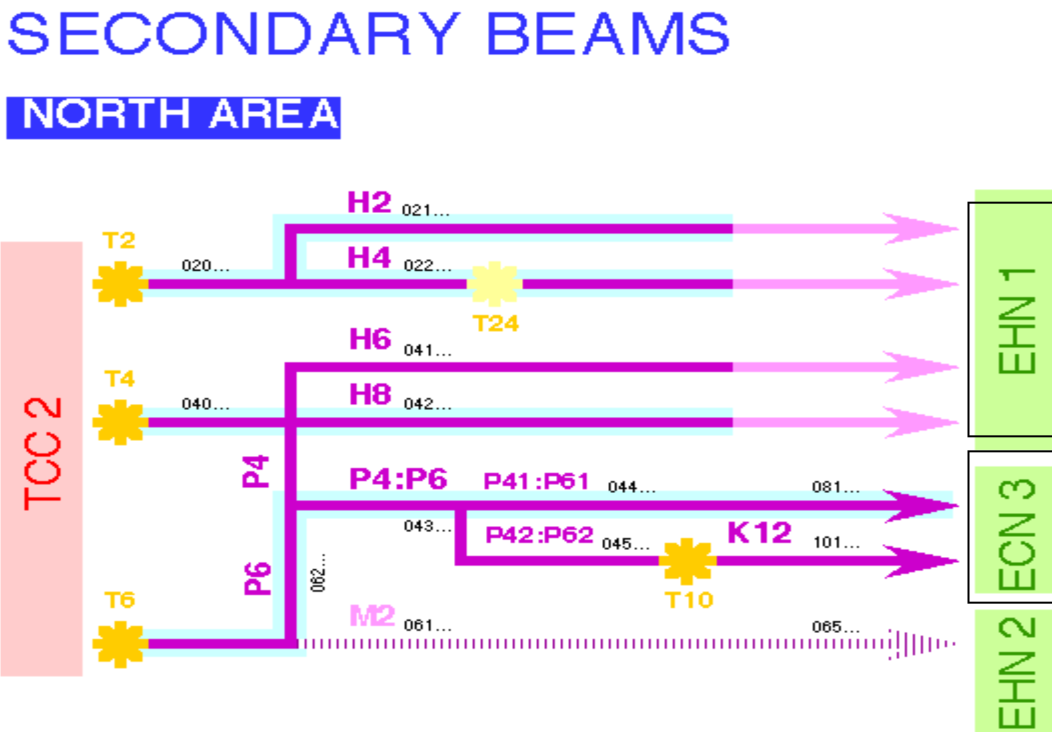
- Study of QCD phase diagram and critical point search: fundamental physics aspects addressed

- Ion beams exists and will be available for experiments at the SPS in the incoming years (presently scehduled up to 2021)

- A Dilepton experiment at CERN can provide crucial information on the QCD phase diagram:
  - Covering a large energy interval crucial for QCD phase diagram
  - Energy interval together with high luminosity not covered by any other experiment : unique experiment
  - High precision: very good B/S, p_T acceptance, mass resolution

BACKUP

Ion beams and possible installation



Investigation of new possible location in main hall

Previous NA60 location ECN3: incompatible with NA62

Location, radiation and safety issues: should be studied with beam experts but not first principle obstacle apparently present

Running conditions

- **Energy scan**
  tentatively 8 points: 20-30-40-50-60-80-120-160 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 in-medium effects

  Complete systematics: running with intermediate A nucleus as indium
  → i.e. important for understanding scaling variable behind J/ψ suppression

- **Proton beams**
  Useful for reference measurements (charmonium study for instance)

Beam intensities and yields

- **Ions**: 10^7-10^8/s on a 10-15% λ_I nuclear target
- **protons**: 10^9-10^{10}/s on a 10-15% λ_I nuclear target

Conservative based on current exisisting technologies (ATLAS) to have negligible pile-up

➡ Trigger rate: ~2 kHz (~10^4 trigger/burst)

➡ > 10^6 signal pairs / 2 weeks running at 160 AGeV

➡ Significant margins of improvement possible

- Triggering scheme