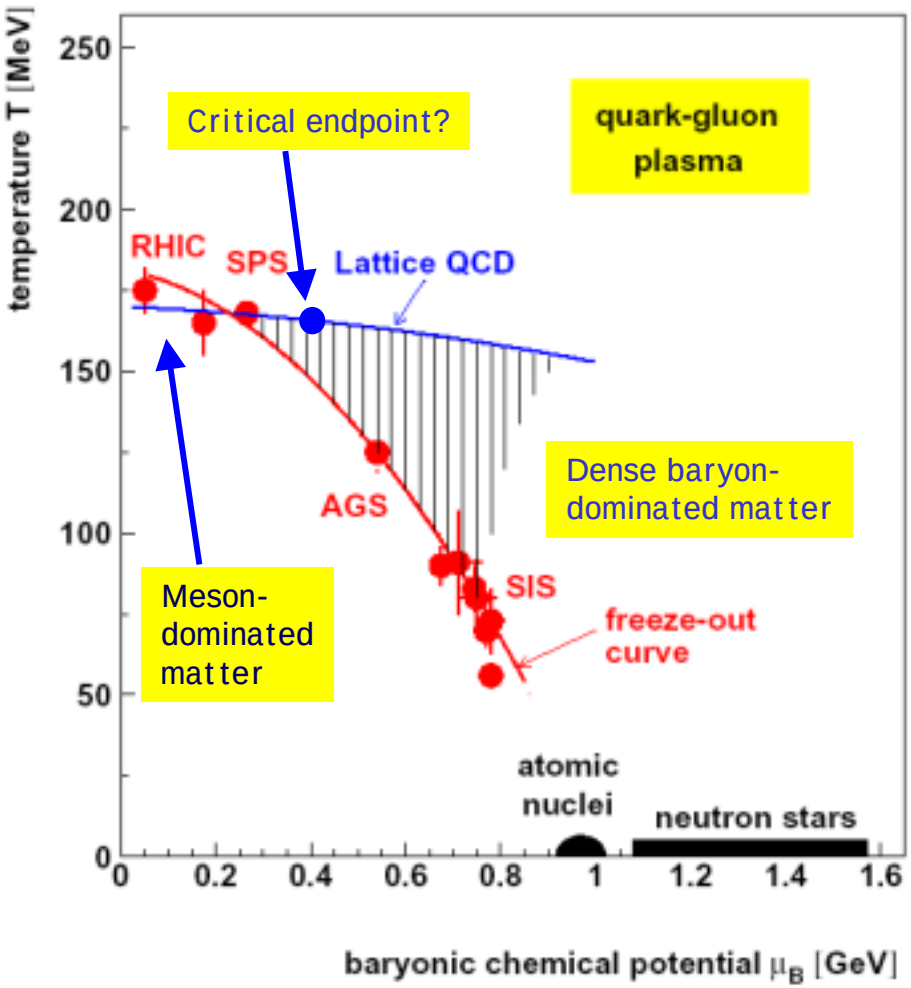
Physics opportunities at FAIR@GSI

B. Friman, GSI

- Probing the QCD phase diagram
- The critical end point
- Properties of mesons at high baryon densities
- Strangeness production

The QCD phase diagram



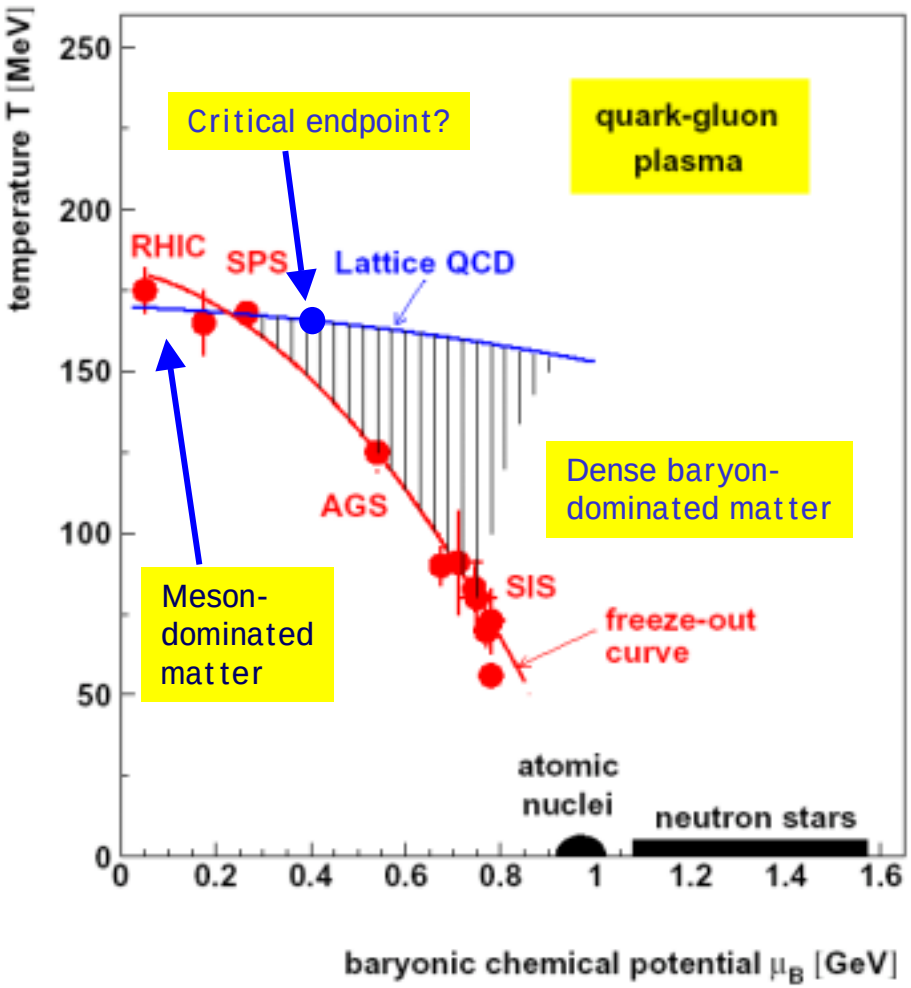
To map out the QCD phase diagram need:

High, intermediate and low energies

At E = 10 – 45 AGeV:

- Probe matter at high baryon densities
- Open charm near threshold
- Strangeness maximum
- Dileptons: ρ, ω, ϕ, J/Ψ in matter
- Collective flow
- Chiral restoration
- Deconfinement
- Critical end point?

The QCD phase diagram



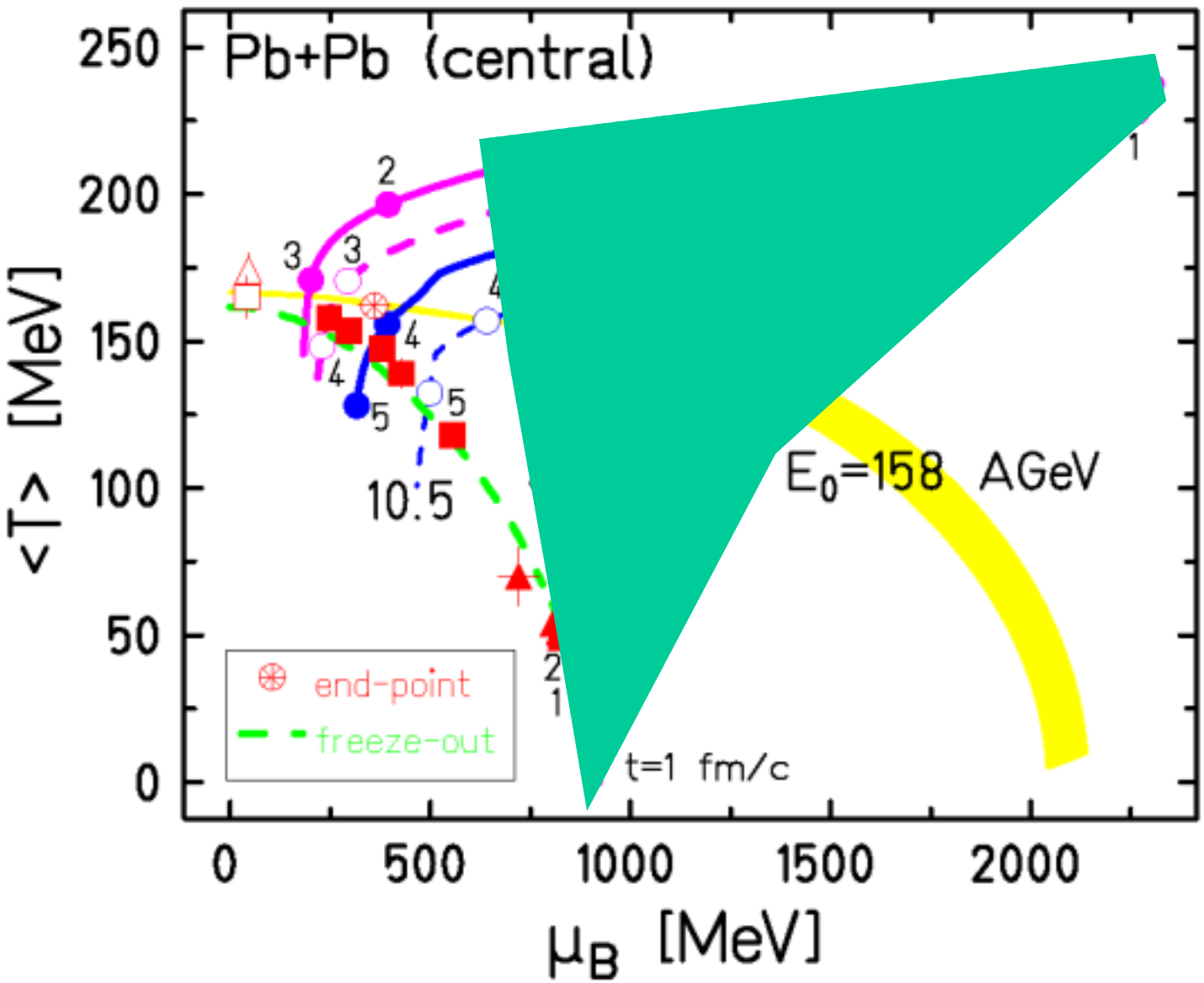
To map out the QCD phase diagram need:

High, intermediate and low energies

At E = 10 – 45 AGeV:

- Probe matter at high baryon densities
- Open charm near threshold
- Strangeness maximum
- Dileptons: ρ, ω, ϕ, J/Ψ in matter
- Collective flow
- Chiral restoration
- Deconfinement
- Critical end point?

“Trajectories” (3 fluid hydro)

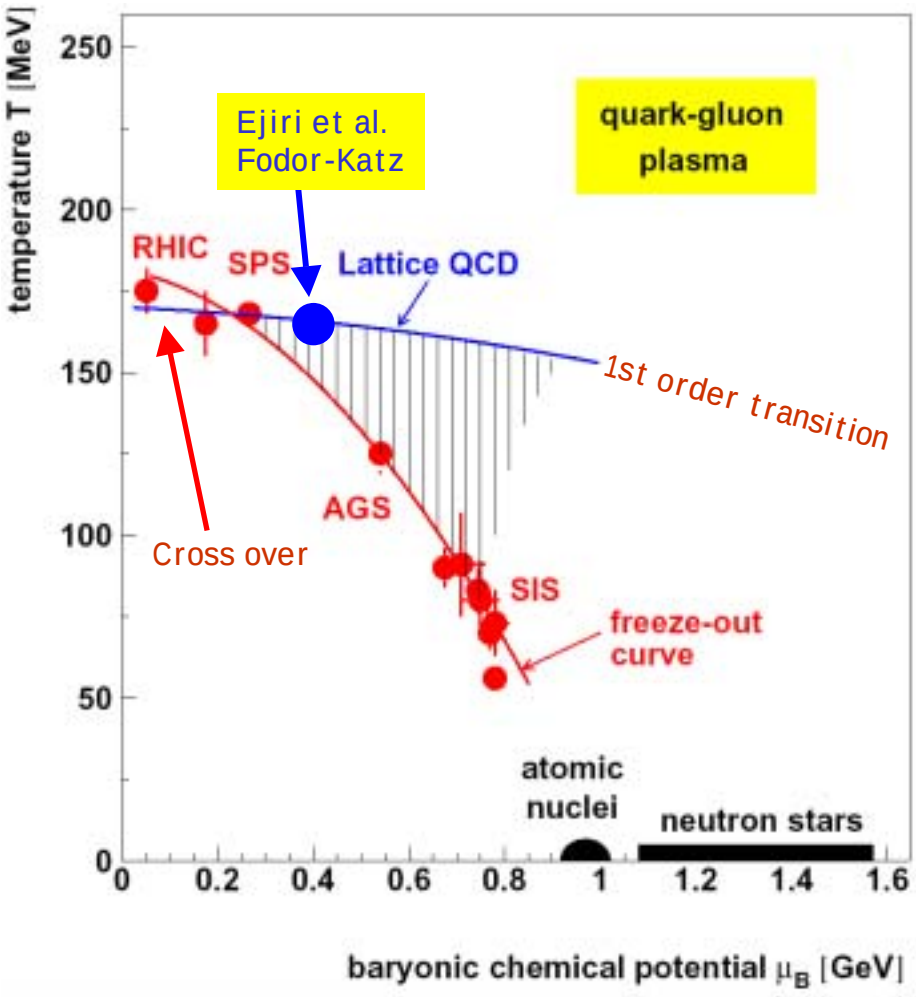


Ivanov & Toneev

Hadron gas EOS

System not in general in equilibrium!

The critical end point



Ejiri et al. (Bielefeld-Swansea):
$T^c \approx 160$ MeV, $\mu_B{}^c \approx 420$ MeV

Fodor & Katz: $\mu_B{}^c \approx 360$ MeV

E =30 - 40 AGeV

Position of CEP still uncertain!

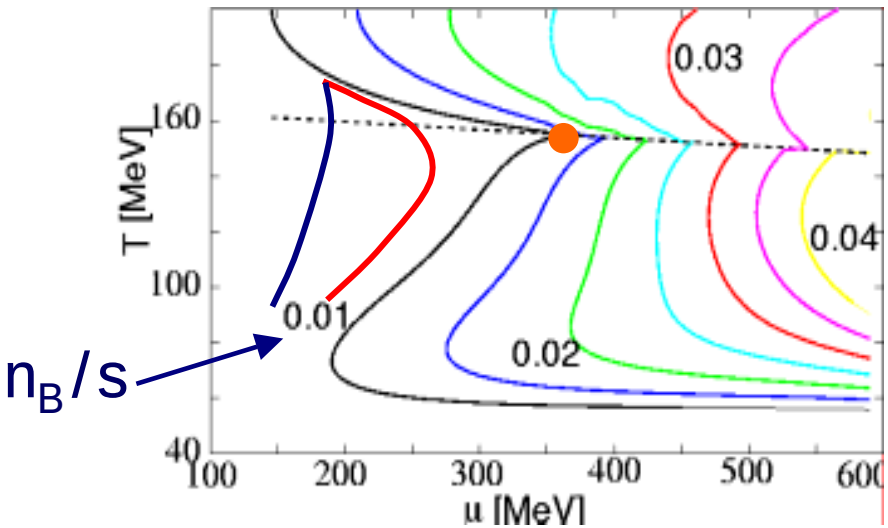
μ_B of critical point depends critically on the quark mass m_q

Continuum extrapolation missing

Adiabatic paths near the critical end point

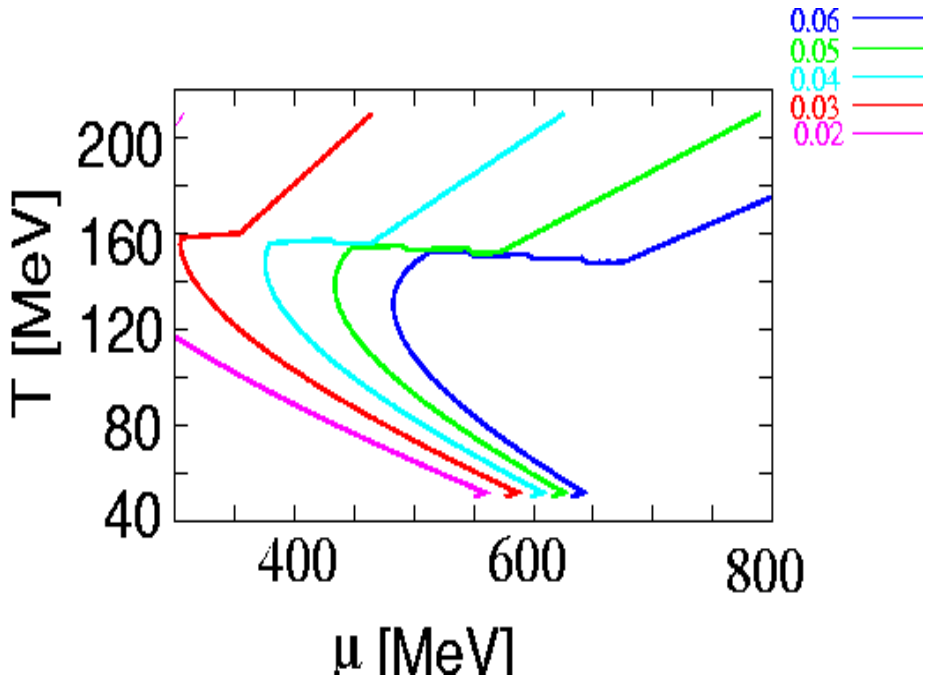
M. Asakawa & C. Nonaka

With end point



Focusing due to soft modes

1st order transition



Critical slowing down:
dynamical path? entropy production?

Signatures of the critical end point?

Critical point: fluctuations of the order parameter are soft

Look for rise and fall of E-by-E fluctuations! (Stephanov, Rajagopal, Shuryak)

- transverse momentum
- pion multiplicity
- proton number (Hatta, Stephanov)

. . . . .

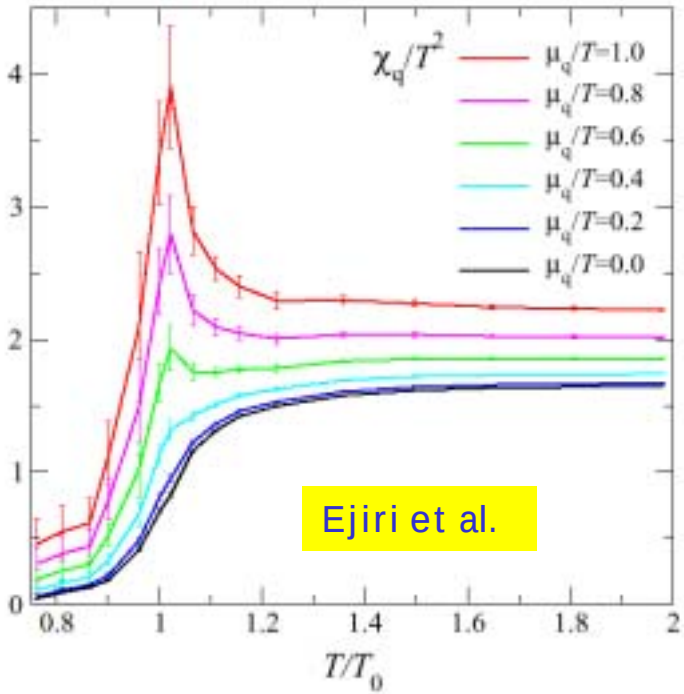
Finite time and finite size effects (Berdnikov, Rajagopal)

Slowing out of equilibrium

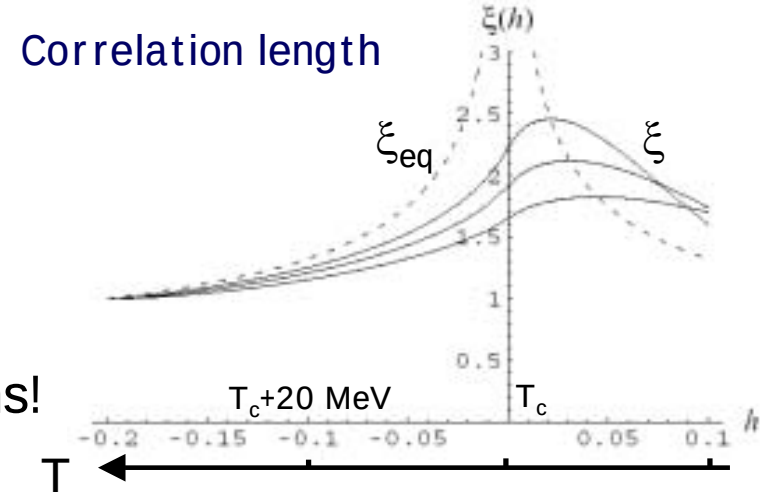
Depend on dynamical path

Exciting prospects, but still many unknowns!

Quark number susceptibility



Correlation length



Effects of baryon density

Mass splittings because charge conjugation symmetry broken at $n_B \neq 0$

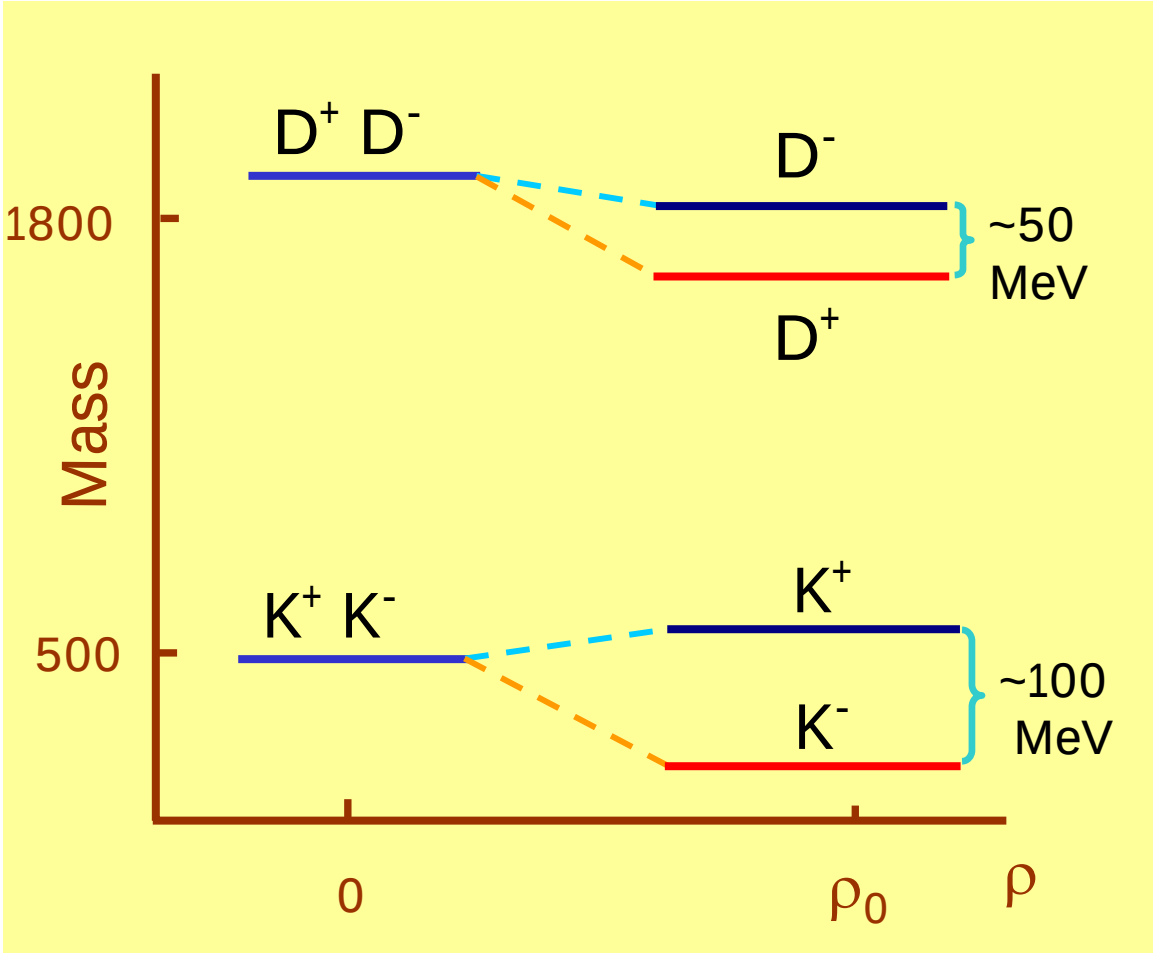
$|D^-\rangle = |d\bar{c}\rangle$

$|D^+\rangle = |c\bar{d}\rangle$

$|K^+\rangle = |u\bar{s}\rangle$

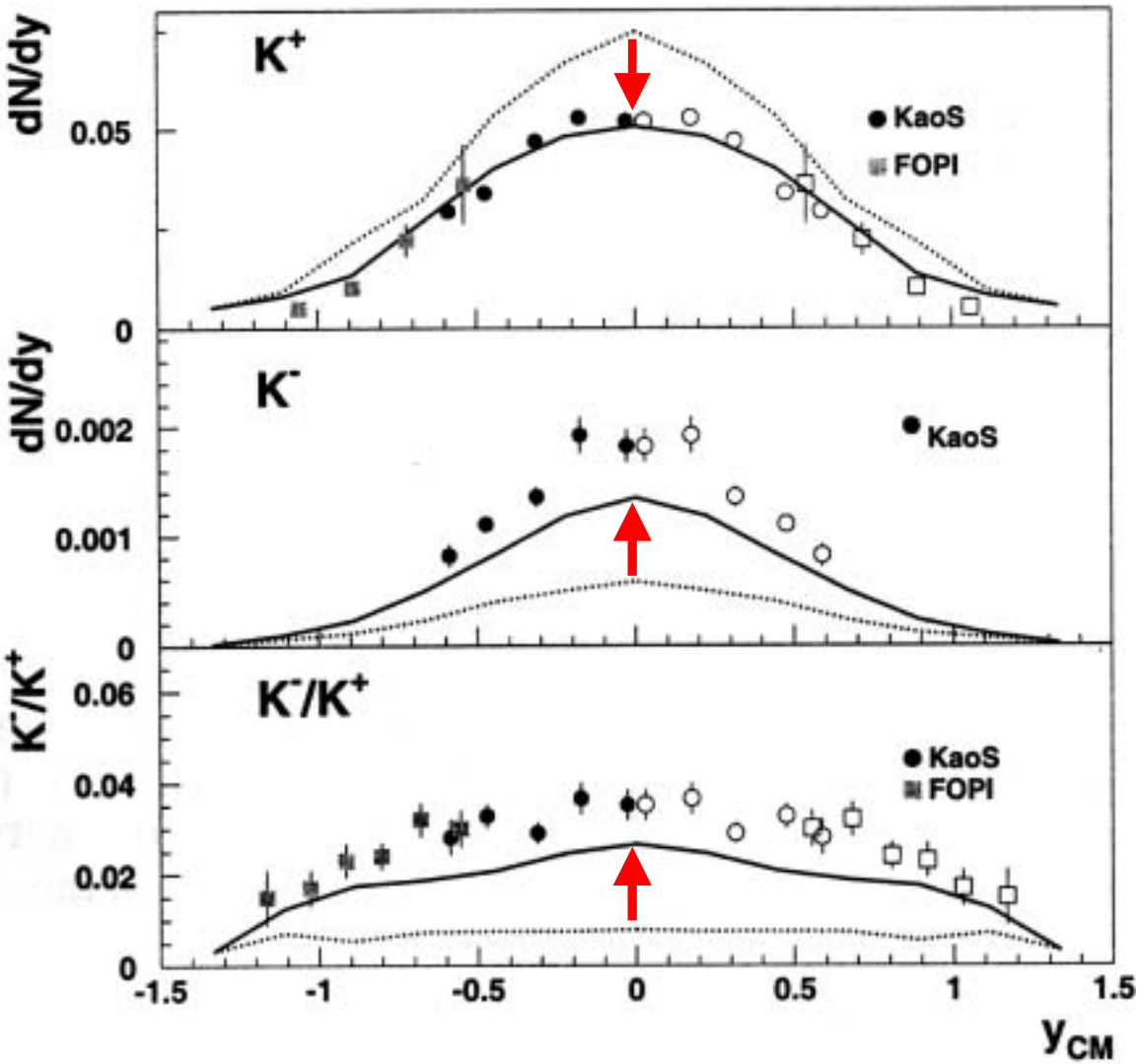
$|K^-\rangle = |s\bar{u}\rangle$

Easier to produce K^-, D^+ in dense matter, characteristic flow



Kaon production near threshold

Ni+Ni (1.93 GeV) KaoS & FOPI @ GSI Calculation: Li & Brown



Repulsive potential

Suppression of K^+

Attractive potential

Enhancement of K^-

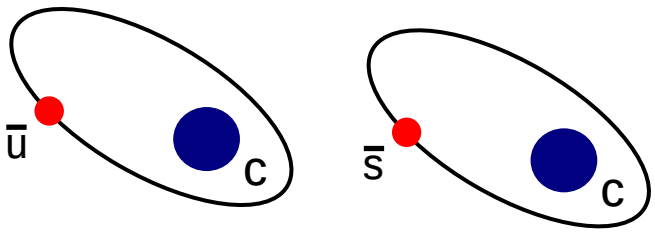
Flow and spectra consistent with in-medium potentials

Explore D-meson properties in dense matter at energies around charm-threshold

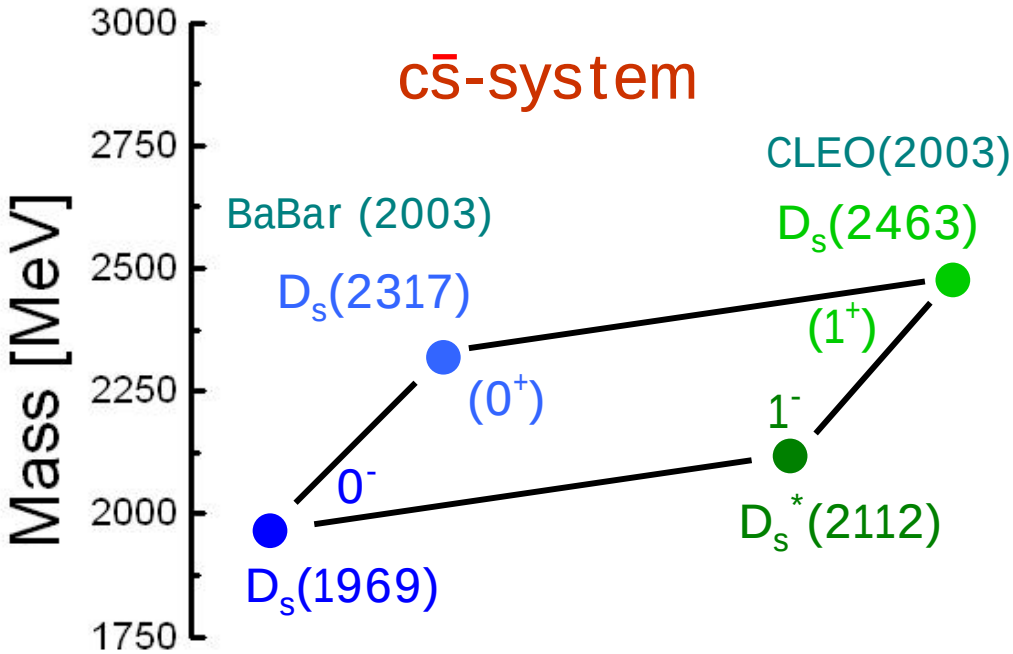
$E \approx 10\text{-}20$ AGeV

Chiral partners of D-mesons?

D-mesons:
- heavy-light system
- hydrogen atom of QCD



Light-quark-cloud
probes chiral symmetry



Chiral mass shifts ≈ 350 MeV

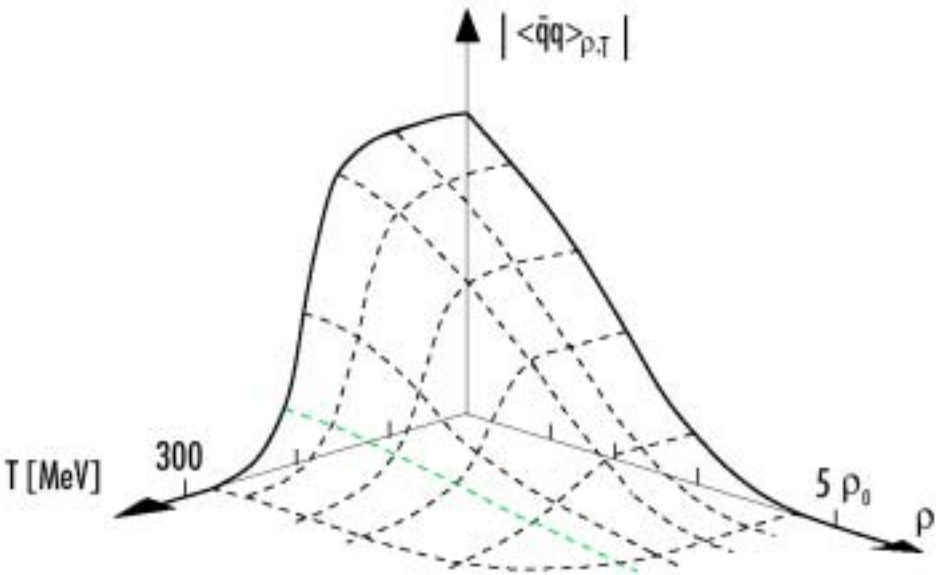
Heavy-quark-symmetry
+ chiral symmetry:
chiral doubling of D-mesons
(Nowak-Rho-Zahed and Bardeen-Hill, 92-93)

$D_s(0^+) \not\to D(0^-) + K$

$D_s(0^+) \to D_s(0^-) + \pi$

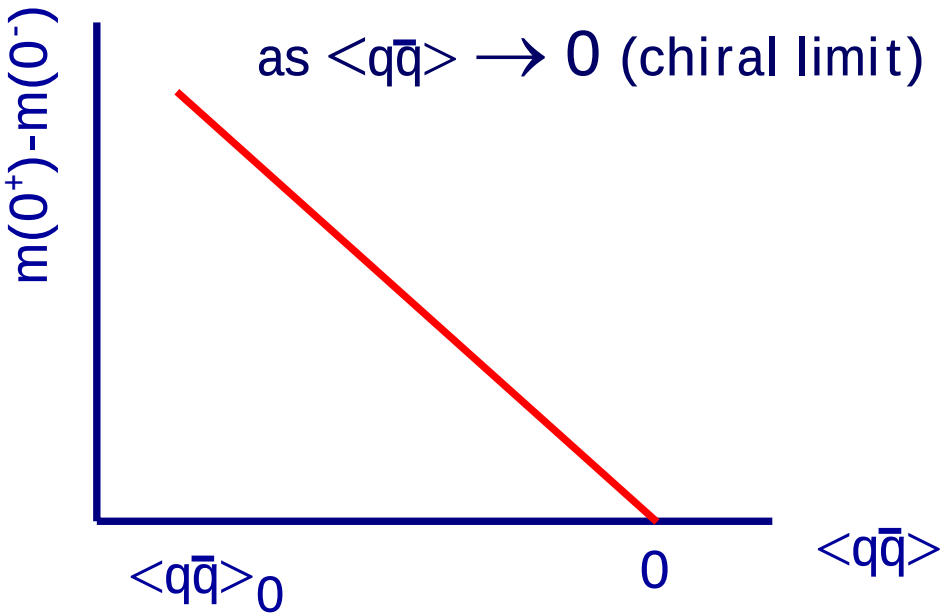
D mesons in matter

If chiral doubling scenario for D mesons correct



then $m(0^+)-m(0^-) \rightarrow 0$ etc.

as $\langle q\bar{q}\rangle \rightarrow 0$ (chiral limit)



Harada, Rho, Sasaki (2003)

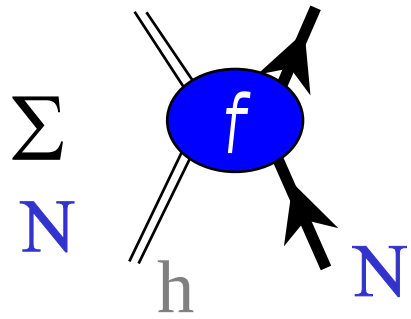
D-meson production in nuclear collisions offer a unique opportunity to explore chiral dynamics in dense matter

Beyond mean-field approximation

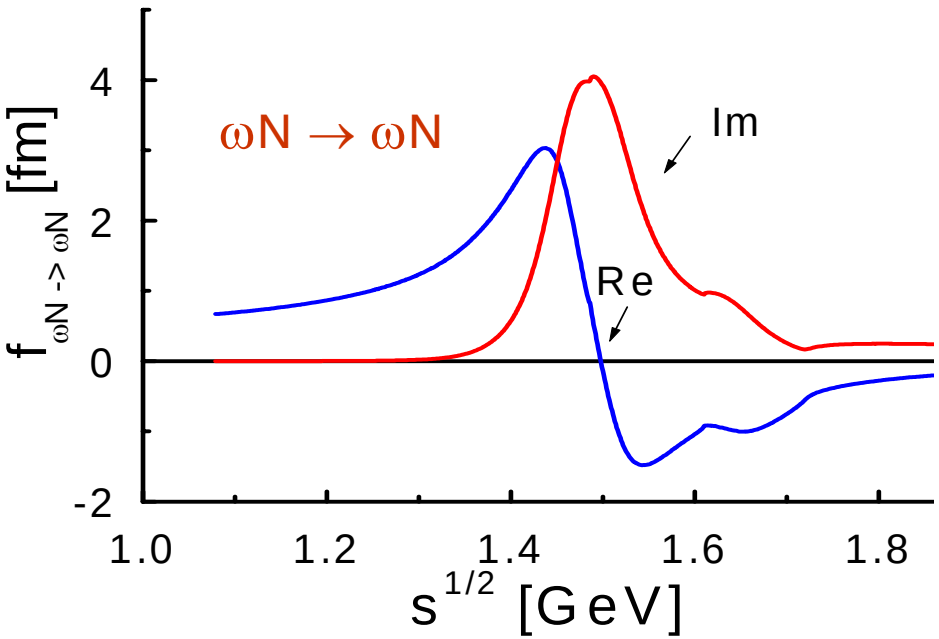
Spectral functions change due to scattering

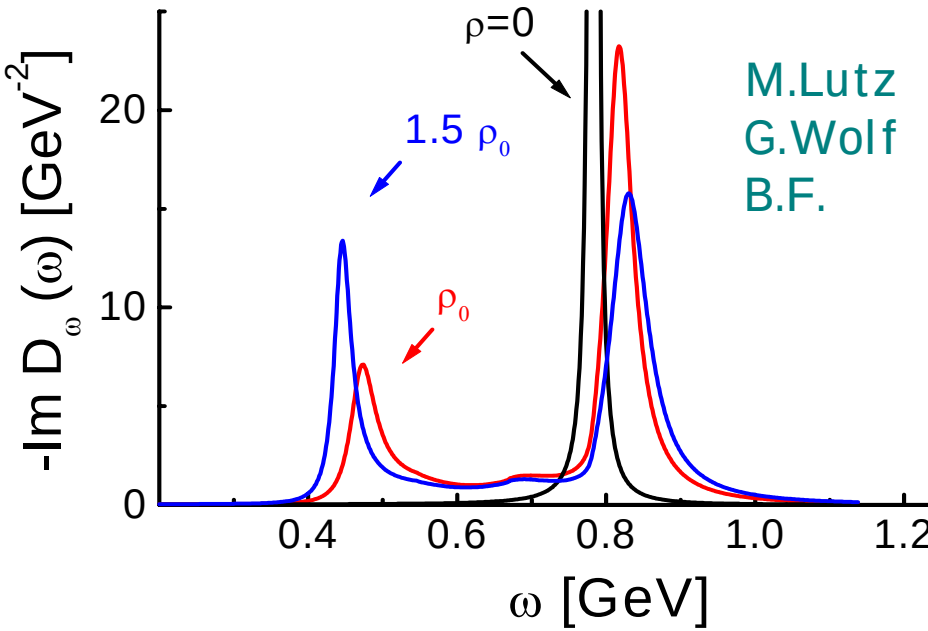
Low-density expansion:

$$\Sigma_h(\rho_N) = -4\pi\left(1+\frac{m_h}{m_N}\right)\bar{f}_{hN}\,\rho_N + \ldots$$



Resonances in scattering amplitude
⇒ peaks in spectral function





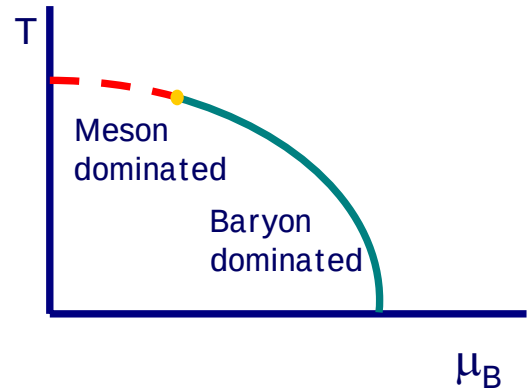
Baryon density vs. temperature

Baryon dominated matter:
meson spectral functions
determined by baryon resonances

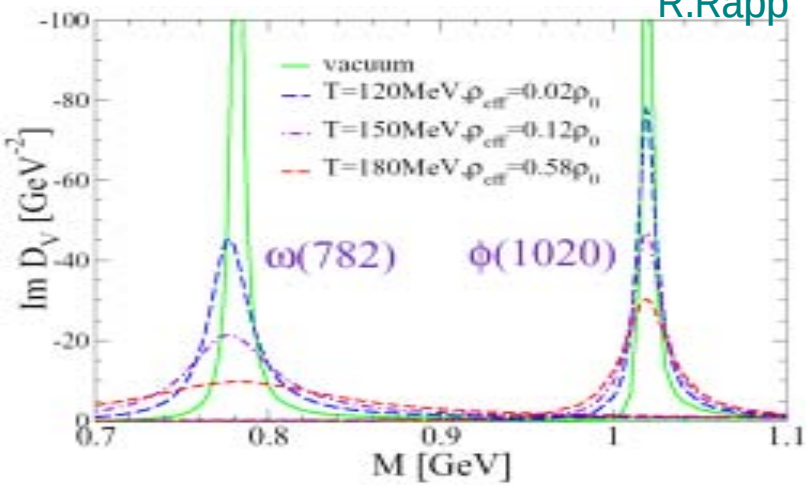
Meson dominated matter:
meson spectral functions
determined by
meson resonances

Meson mixing at $\mu_B \neq 0$

Complication:
Resonances smeared by
collision broadening



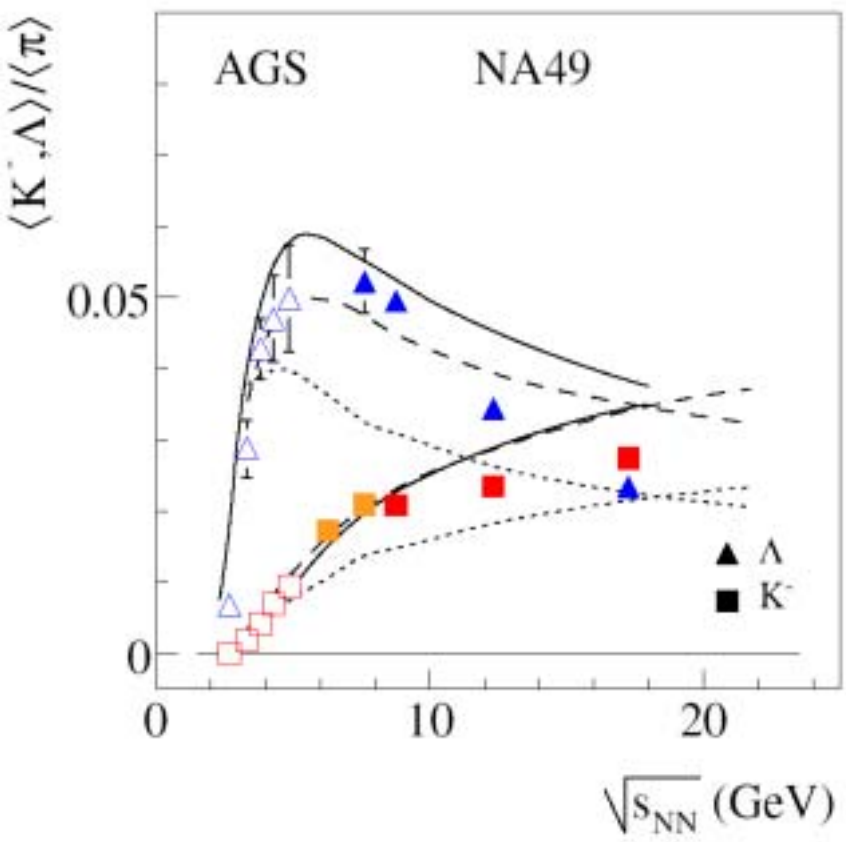
R.Rapp

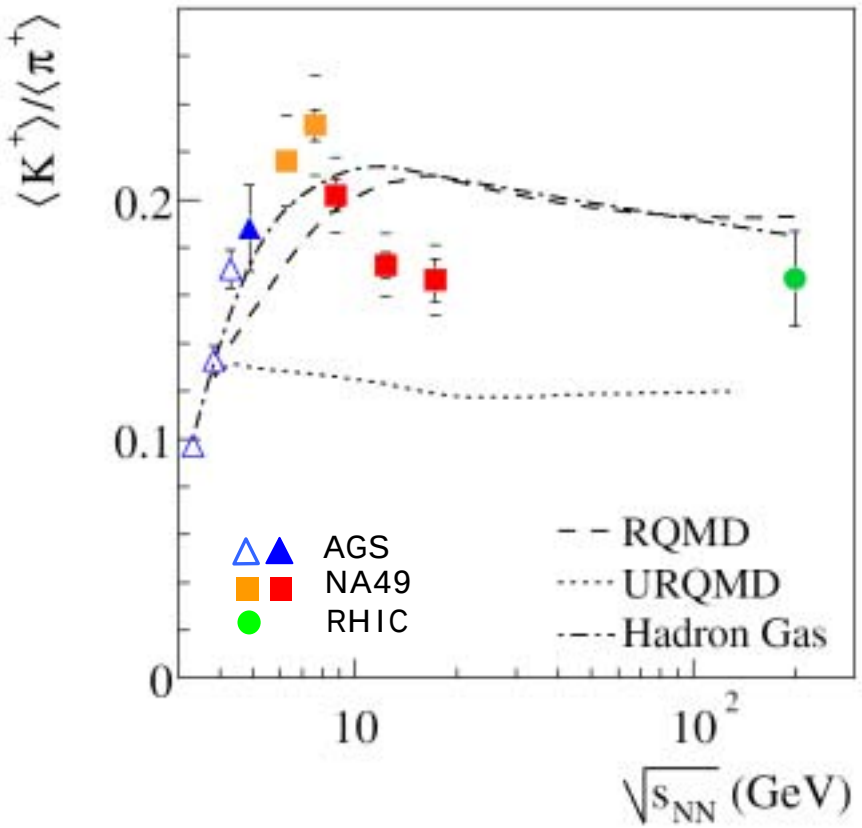


Such effects must be understood before one can draw conclusions on chiral symmetry and masses

Need high resolution, high statistics dilepton data over a wide range of energies (T vs. μ_B)

Strangeness maximum





Peak in Λ/π at 10-30 AGeV

Rise: threshold dynamics

Decrease: $\mu_B \rightarrow 0$

$\mu_\Lambda = 2\,\mu_B/3 + \mu_S$

$\mu_K = \mu_B/3 - \mu_S$

Sharp maximum in K^+/π^+ at ~30AGeV

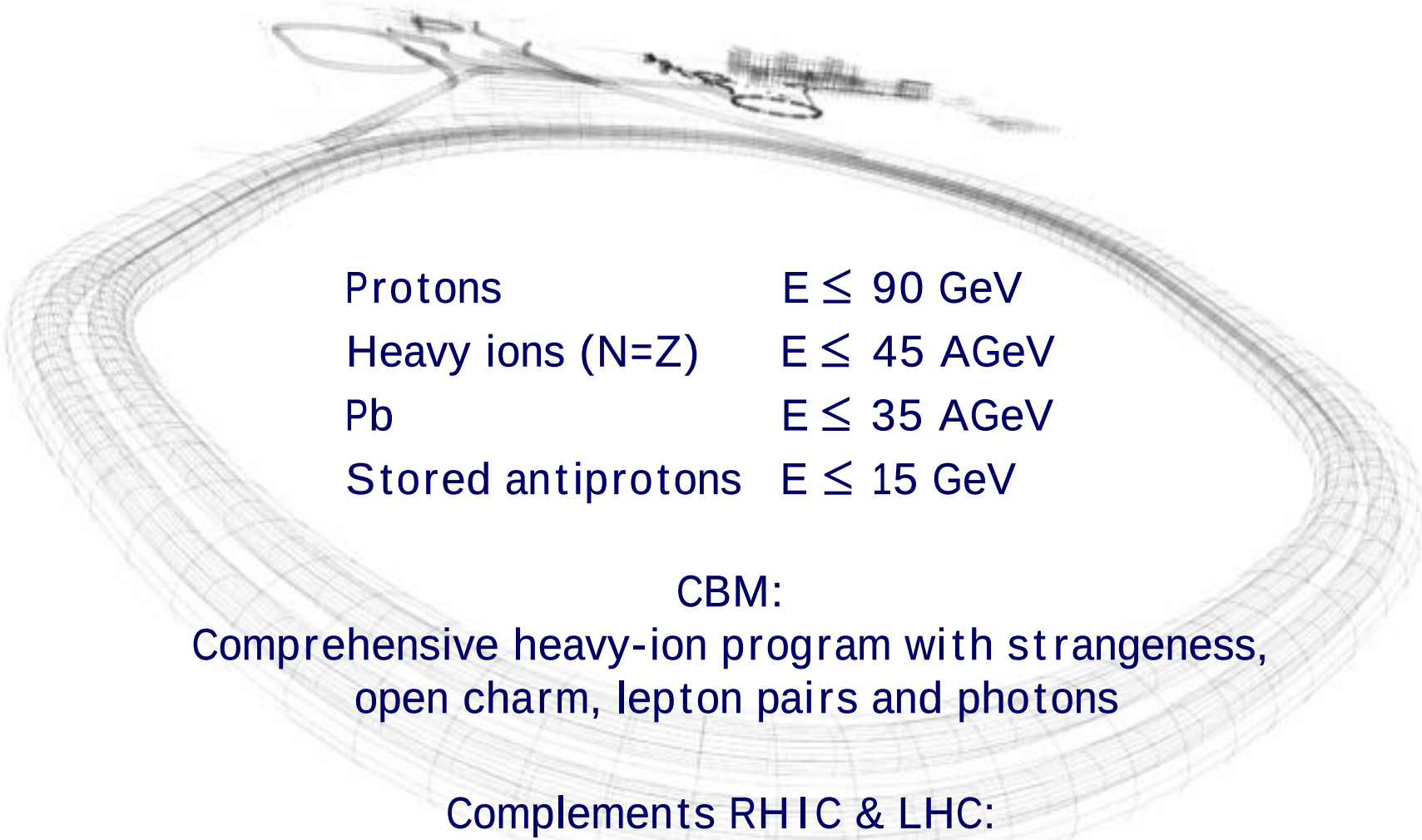
Not reproduced by thermal models with smooth parameters!

Phase transition?

Summary

- Critical endpoint: look for fluctuations
- Light-heavy mesons: mass splitting at finite baryon density
- New D mesons in matter (chiral partners?)
- Dilepton data at different energies (different μ_B/T)
  Useful for unraveling meson/baryon resonances, meson mixing etc.
- Strangeness maximum, K^+/π^+ horn
- J/Ψ, flow …

These problems can be explored at FAIR@GSI

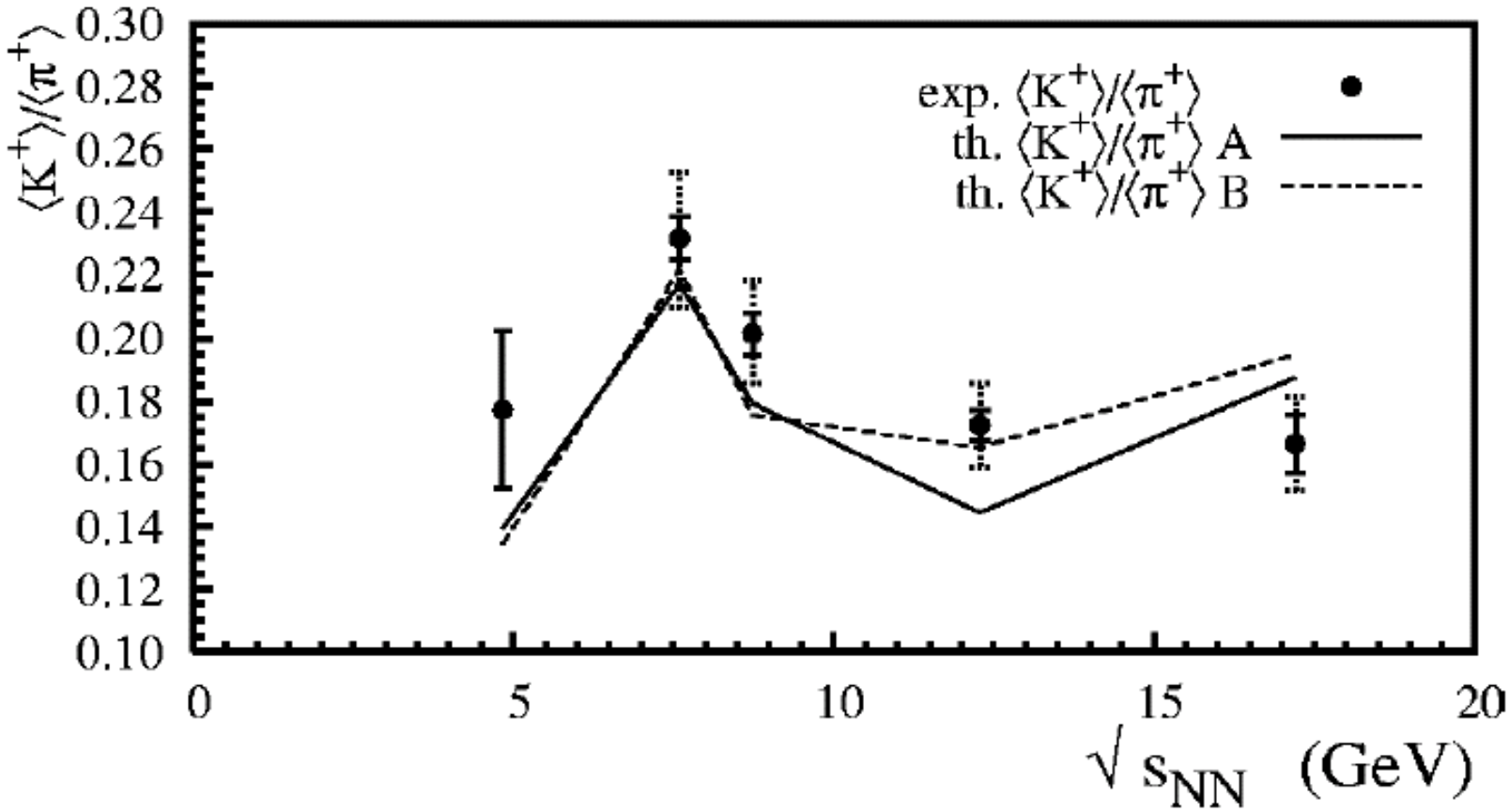


Protons	$E \leq 90$ GeV
Heavy ions (N=Z)	$E \leq 45$ AGeV
Pb	$E \leq 35$ AGeV
Stored antiprotons	$E \leq 15$ GeV

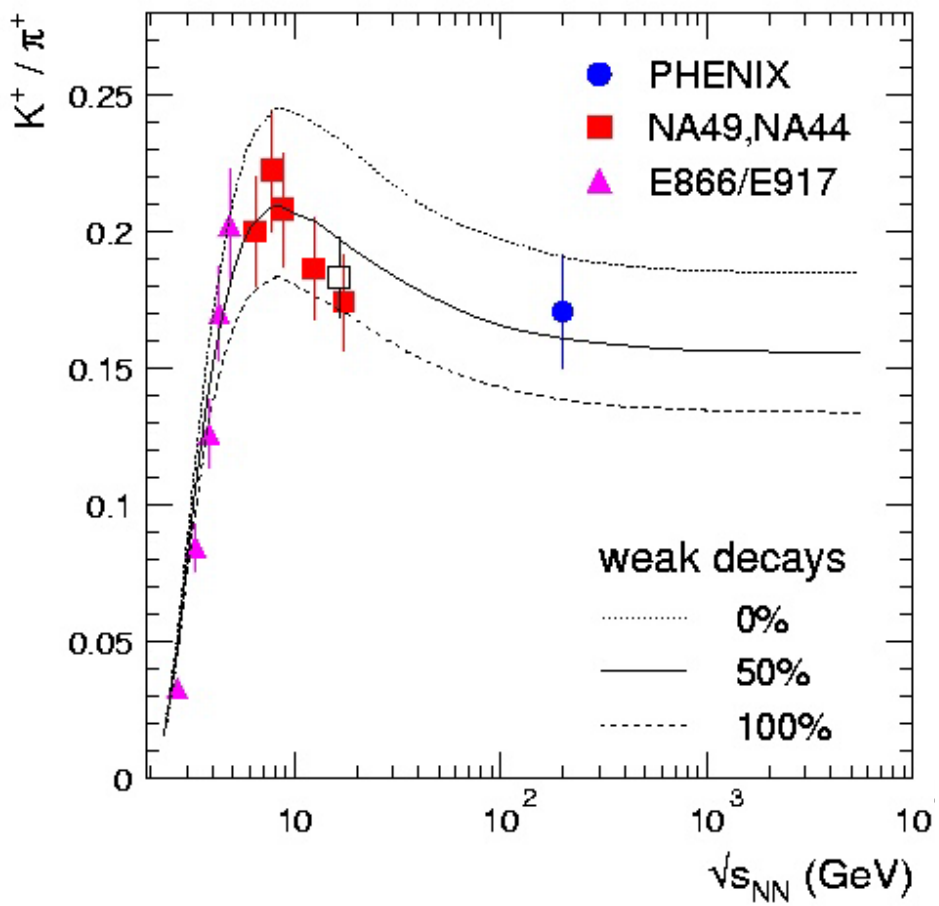
CBM:
Comprehensive heavy-ion program with strangeness, open charm, lepton pairs and photons

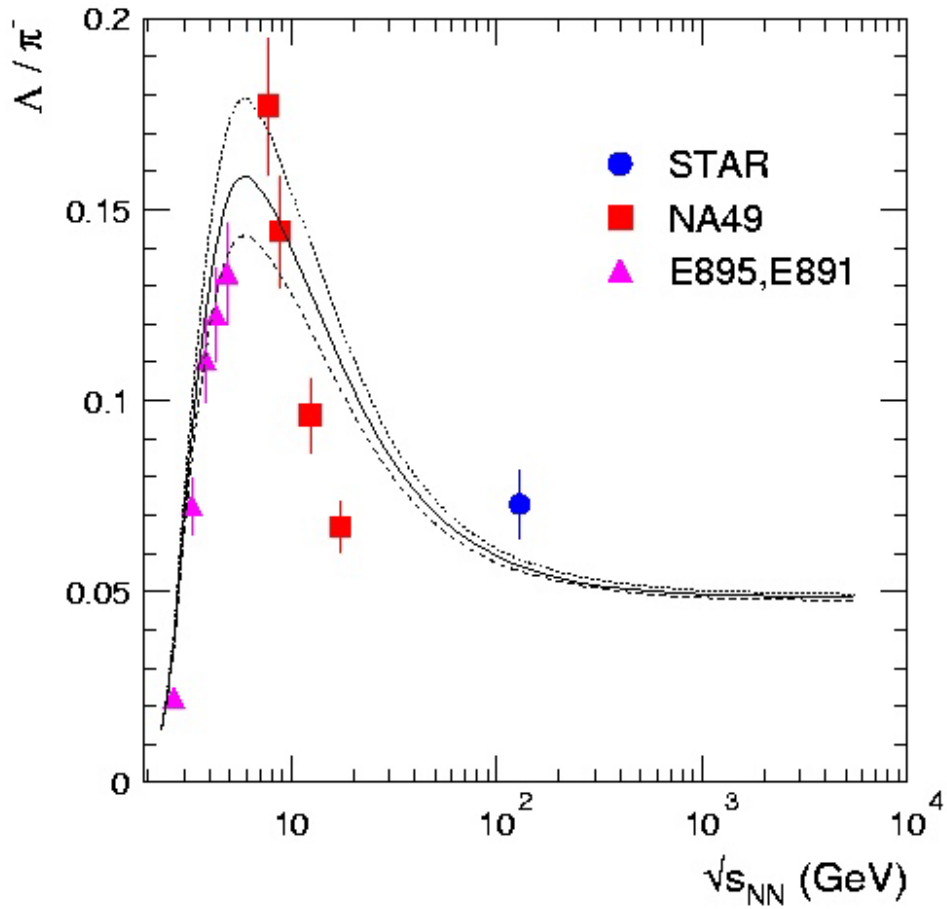
Complements RHIC & LHC:
addresses issues specific to high baryon densities

Becattini, Gazdzicki, Keränen, Manninen & Stock



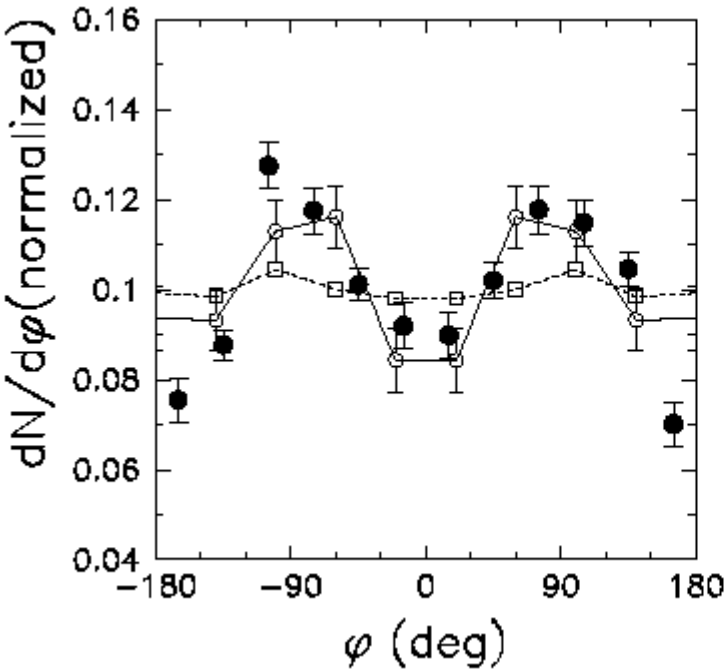
Andronic & Braun-Munzinger

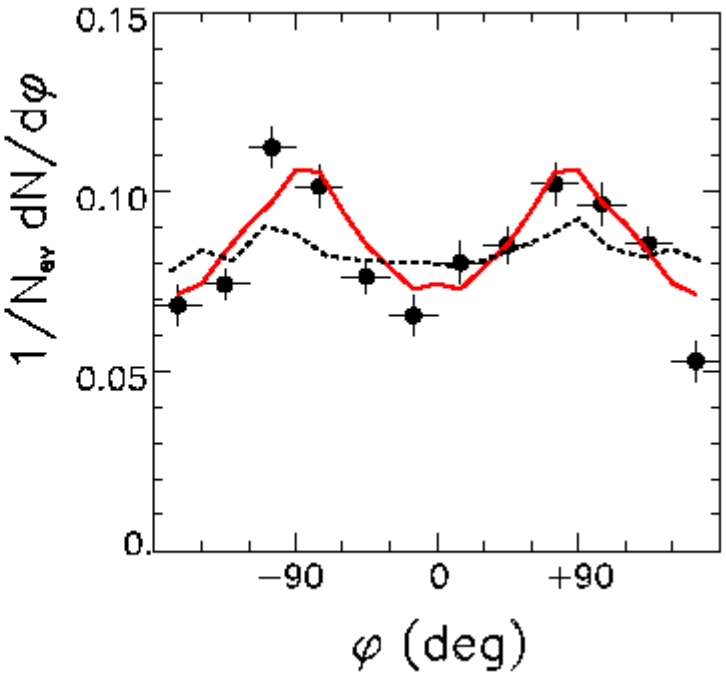




Kaos Collaboration: K^+ azimuthal distribution

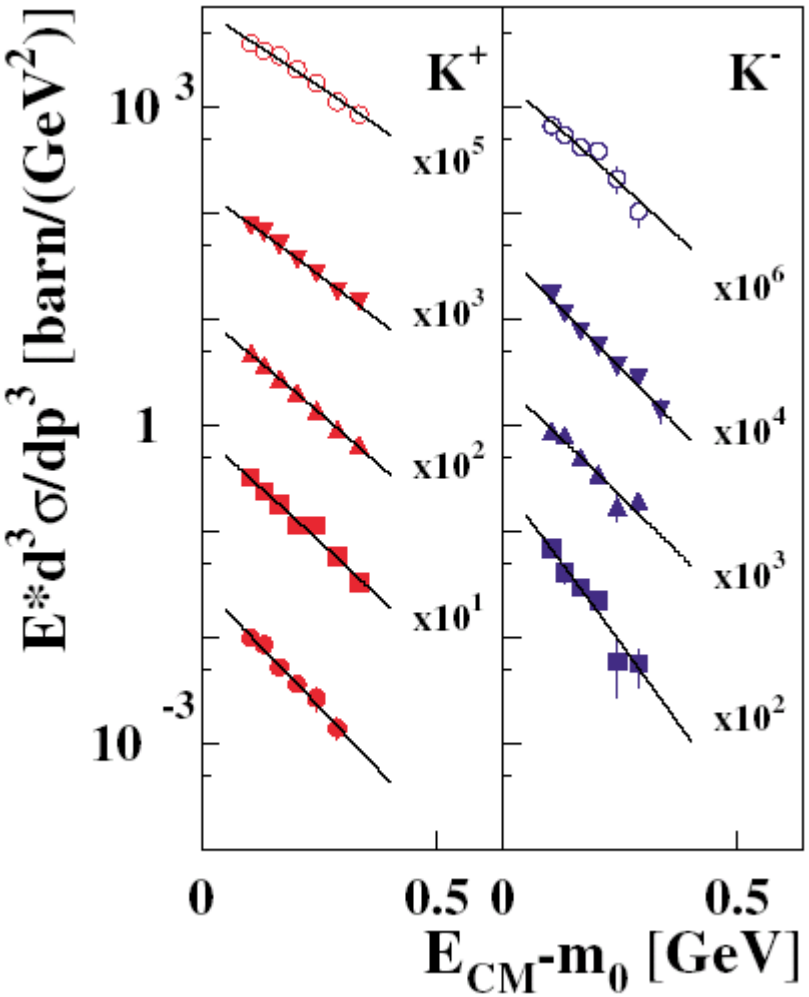
Wang *et al.*: QMD





Full lines: with potential
Dashed lines: no potetial

Kaos Collaboration: K^-,K^+ spectra



Li & Brown: BUU