HIC Physics Reach: Preliminary analysis

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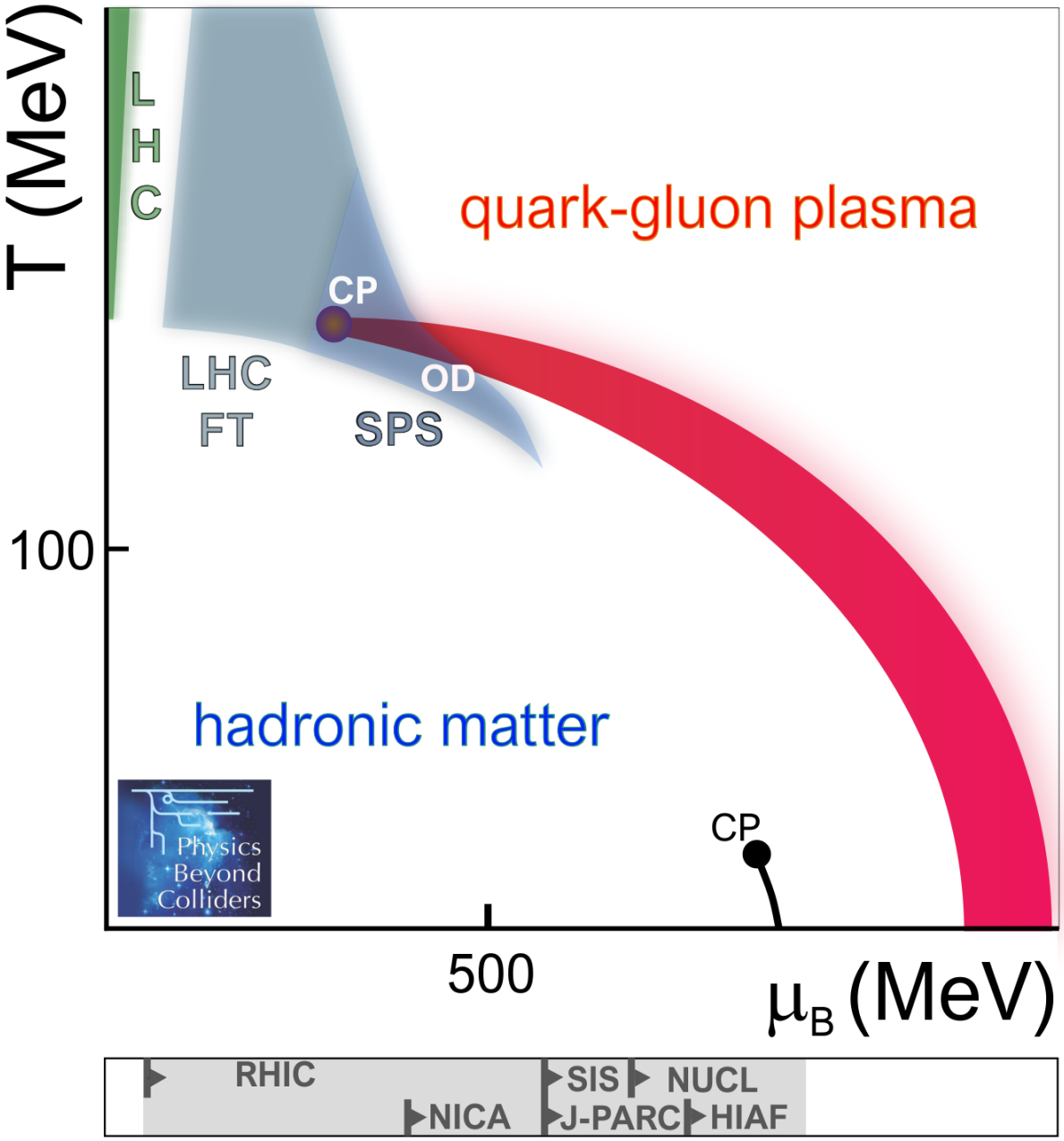
Physics Beyond Colliders Annual Workshop
CERN, 7 to 9 November 2019

heavy ions at CERN



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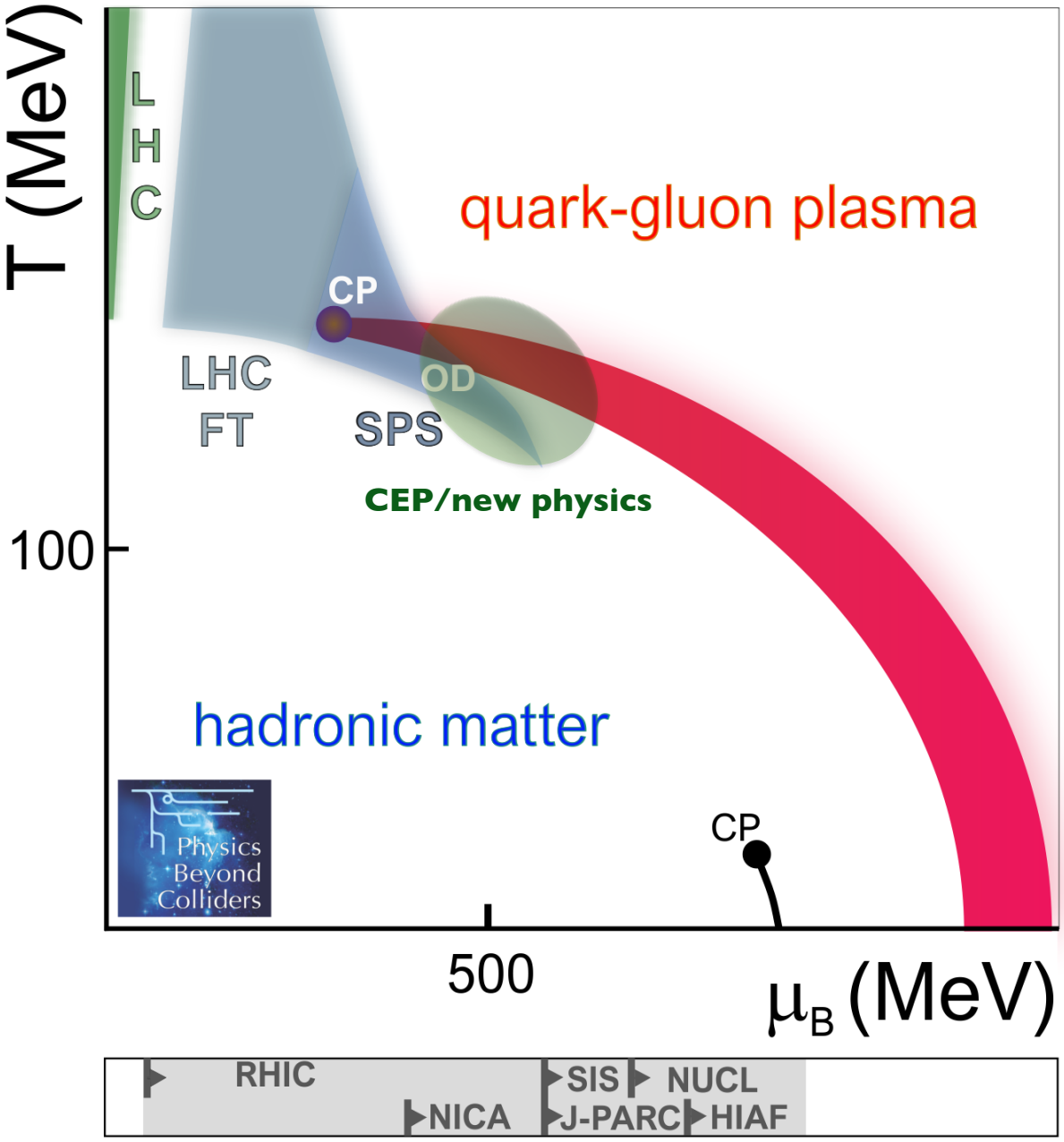
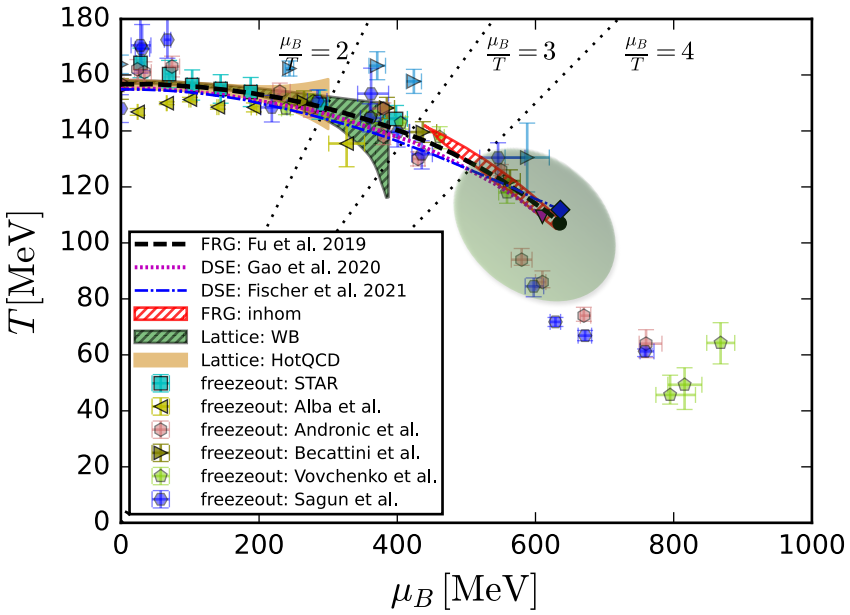
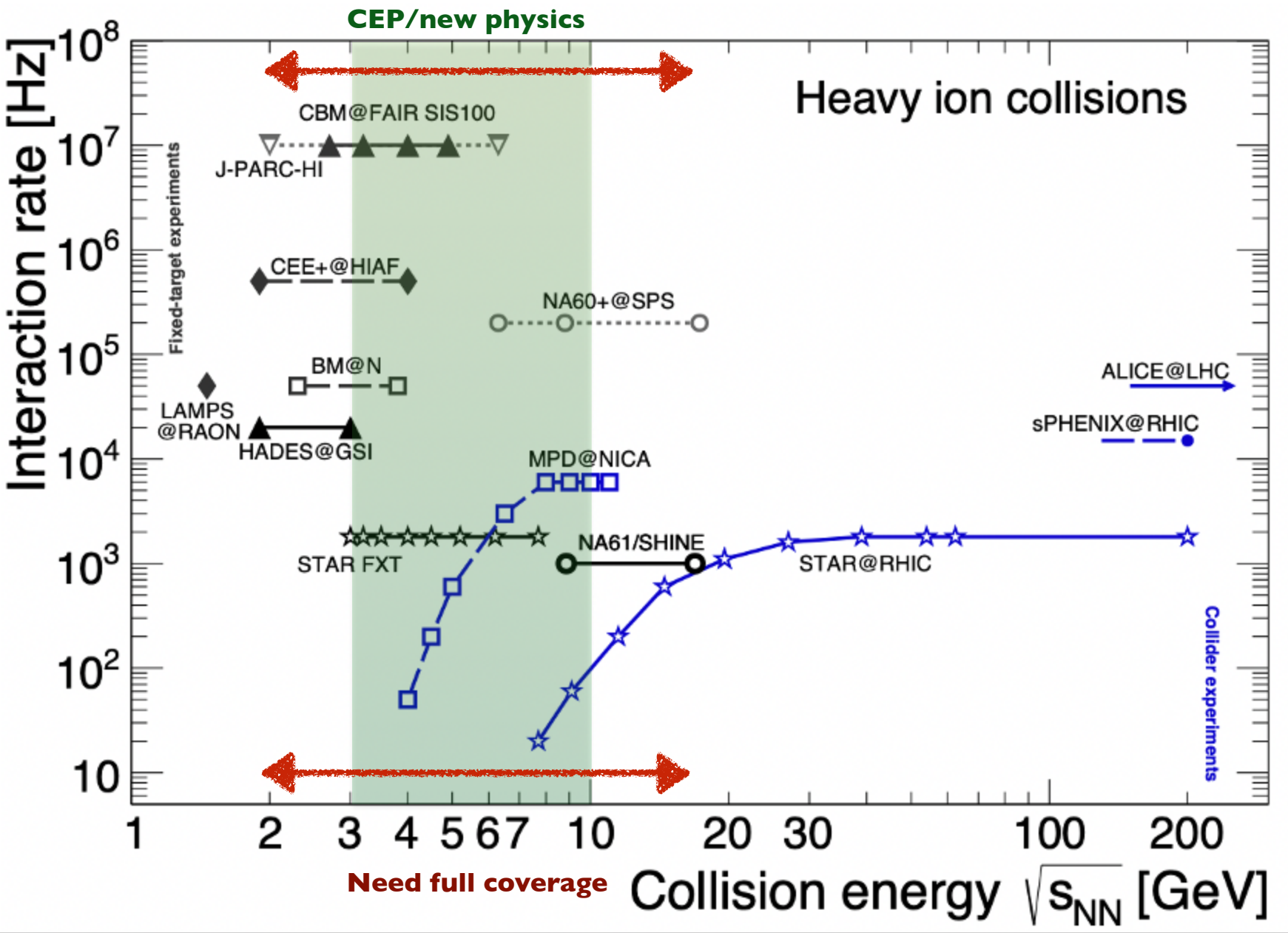




Compilation of state-of-the-art lattice & functional QCD phase structure results

Heavy ion physics

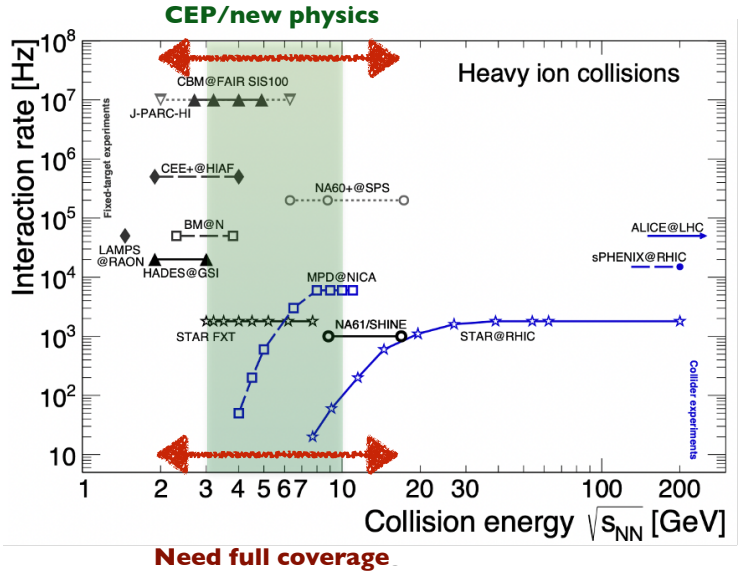


Galatyuk, A982 (2019) update 2021; CBM, EPJA 53 3 (2017) 60

Heavy ion physics

HIC @ SPS

- Complementary to running and planned experiment the **CEP/new physics** regime
- Uniqueness:
  - ★ Combined coverage of large range in temperature and density
  - ★ Interaction rate & observables



NA60++

- Search for the CEP (caloric curve)
- Deconstructing chiral symmetry breaking ($\rho - a_1$ mixing, J/ψ suppression)
- Lifetime of the fireball, transport properties

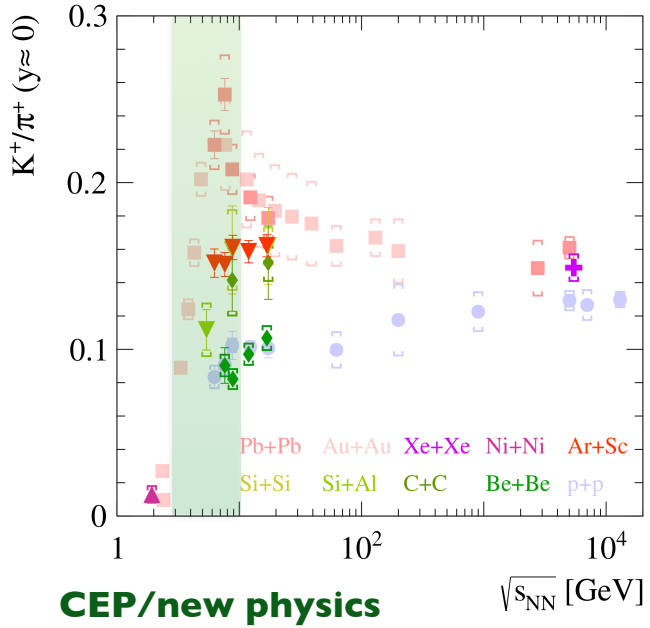
NA61/SHINE++

- Deconstructing confinement with collision data from collisions with light and medium mass ions (varying the system size)
- Testing the full time line (dynamics) of a heavy ion collision

NA61/SHINE++ in 2027+

- Energy scan with light and medium-mass ions to study the **phase diagram of strongly-interacting matter**
- Measurements of heavy-hadron resonances in large statistic p+p interactions
- Measurements with antiproton beams and reference measurements for neutrino experiments

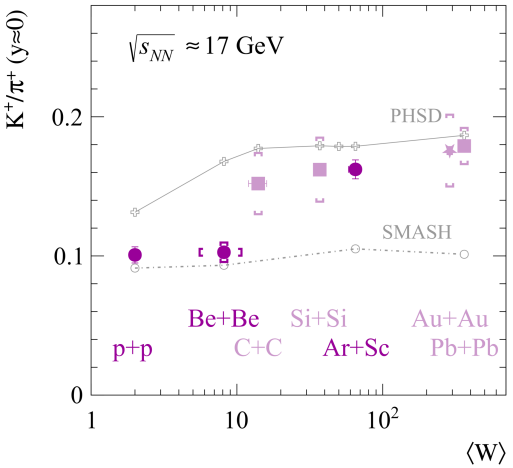
Nucleus-nucleus collisions - the single-plot data summary



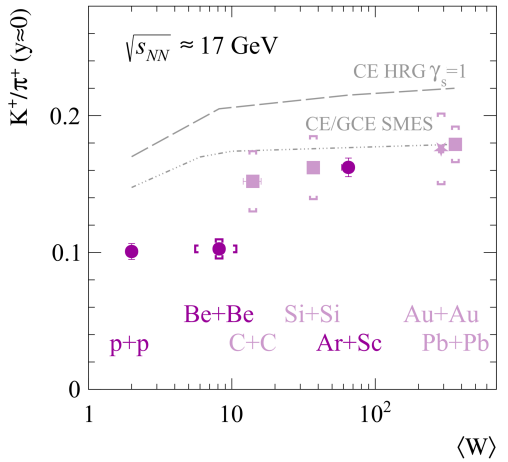
CEP/new physics

Rich data which is not described by models

string models



statistical models



NA61/SHINE++ in 2027+

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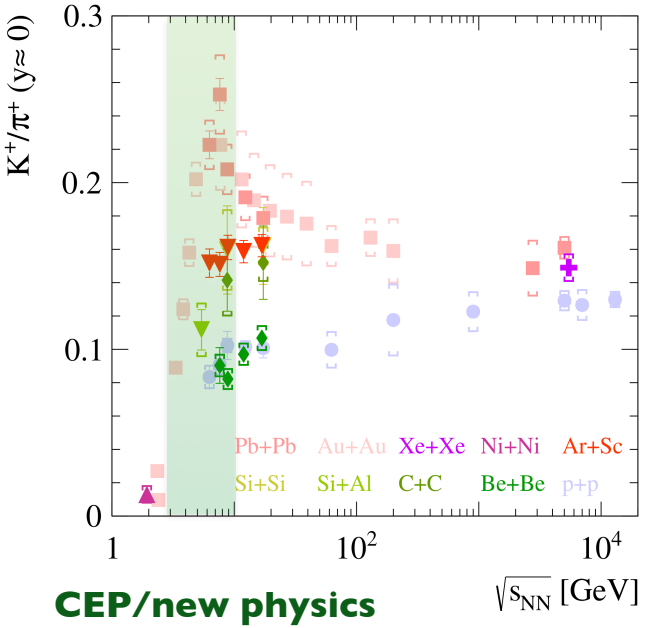

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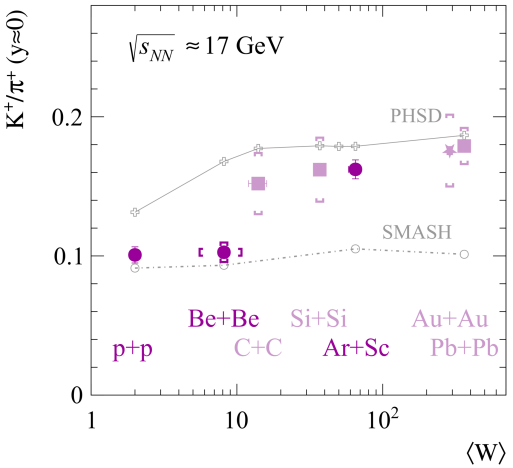

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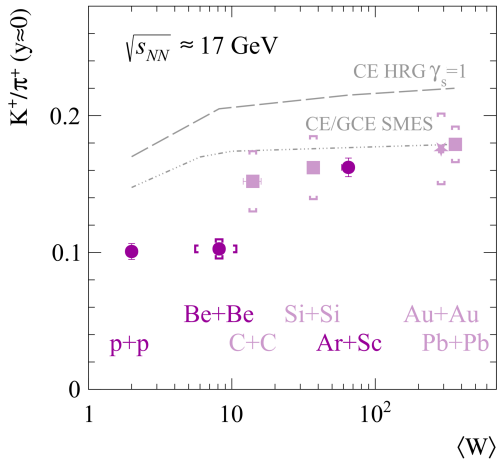
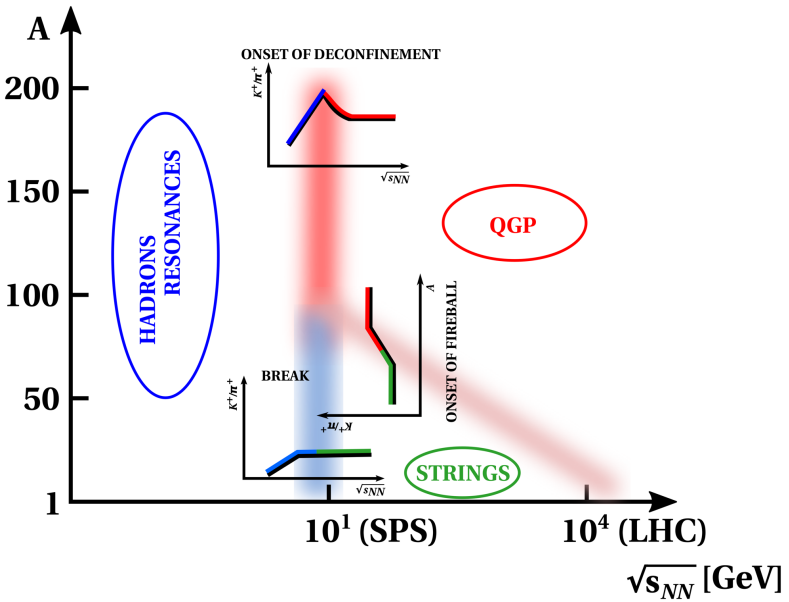


Testing the timeline/dynamics of HICs

Medium- and light-ion energy scan

Nucleus-nucleus collisions -
the single-plot interpretation summary



arXiv:2205.06726

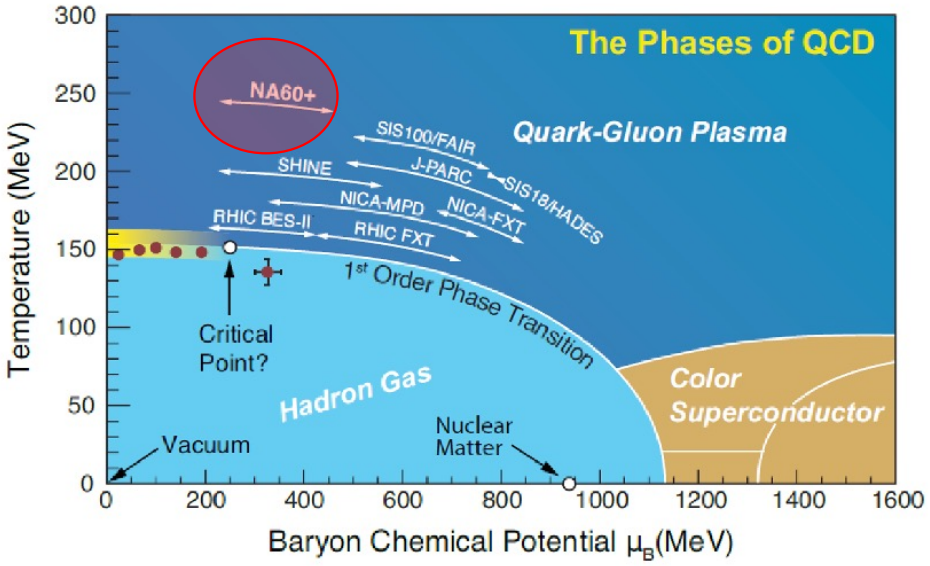
Deconstructing confinement

- Need for new data with beams A<40.
- Beams requested by NA61/SHINE:

p_{beam} (A GeV/c)	$\sqrt{s_{NN}}$ (GeV)	^{10}B # days	^{16}O # days	^{24}Mg # days	^{40}Ar # days
13	5.1	7	7	7	7
30	7.6	7	7	7	7
150	16.8	7	7	7	7

- Successful detector upgrade (LS2) allows to take up to 100M events per reaction
- NA61/SHINE experience indicates need of primary beams
- Program complementary to NA60++

Thermal dimuons in NA60+: motivation



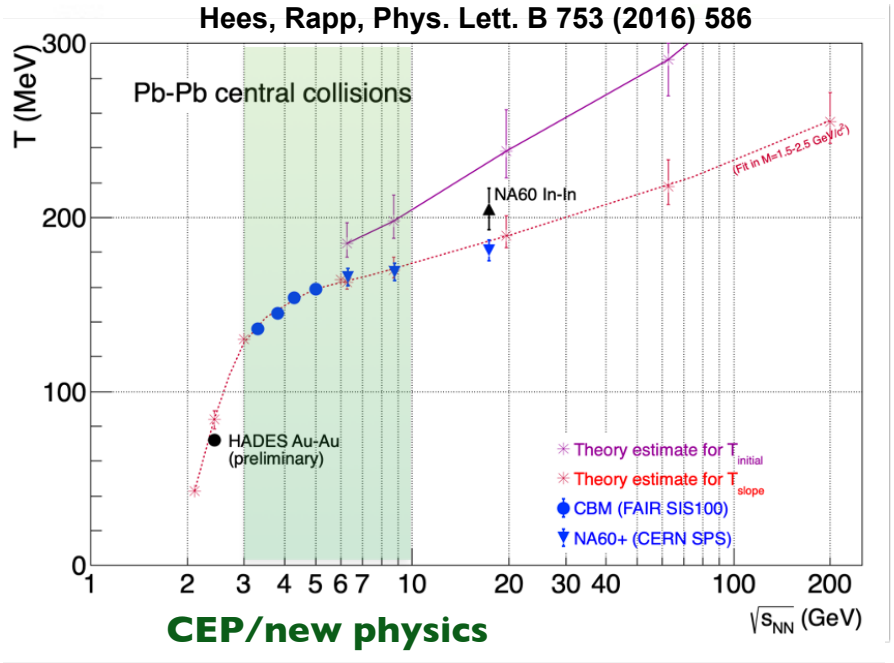
- QCD phase diagram:
  - Existence of critical point and first order phase transition put forward

Additional chiral phase transition:

- Exploration of changes in the hadron spectrum

- Aims at precision measurements of thermal dimuon mass spectra in beam energy scan at high μ_B:
  - Measurement of temperature (M>1.5 GeV) → **Caloric curve**
  - Measurement of yield (0.3<M<0.7) → **Fireball lifetime**
  - Measurement of yield (0.9<M<1.4 GeV) → **ρ-a_1 chiral mixing**
- Additional measurement of dimuon elliptic flow:
  - Measurement of elliptic flow (v_2) vs mass and p_T → **further insight into phase transition**

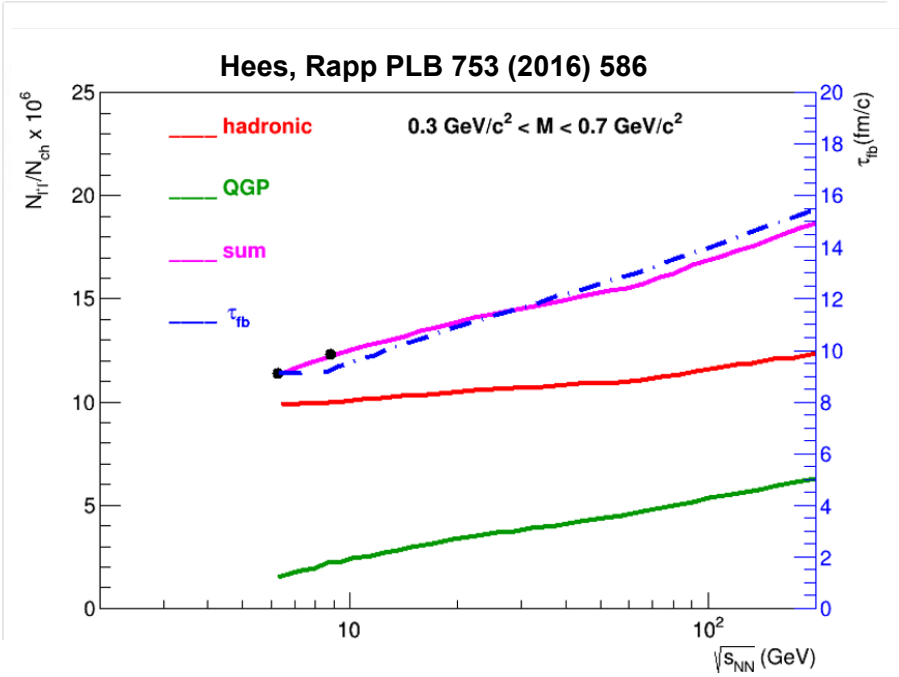
Caloric curve and fireball lifetime



CEP/new physics

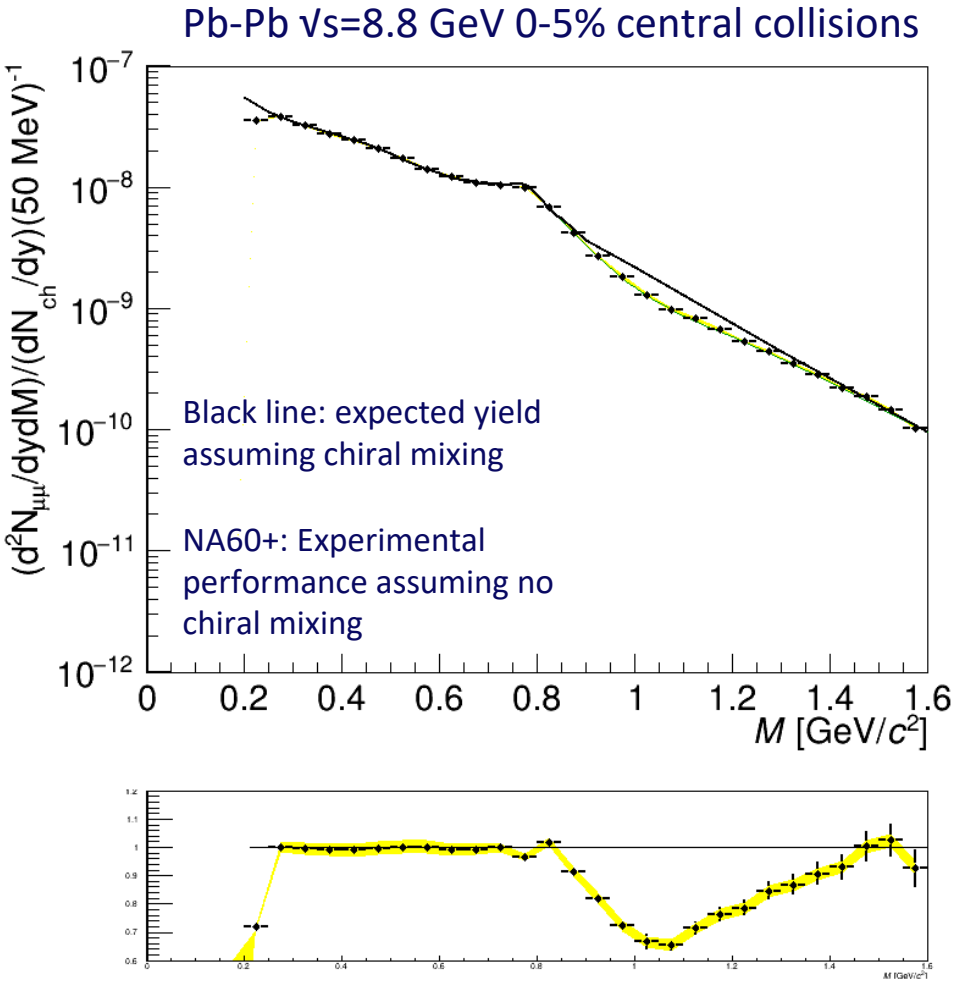
~3% uncertainty on the T_{slope} measurement:
- Allows an **accurate mapping** of the √s-dependence of T_{slope} around T_c

Precise measurement of thermal yield in 0.3<M<0.7 GeV **sensitive** to the fireball lifetime



Testing the timeline/dynamics of HICs

ρ-a_1 chiral mixing

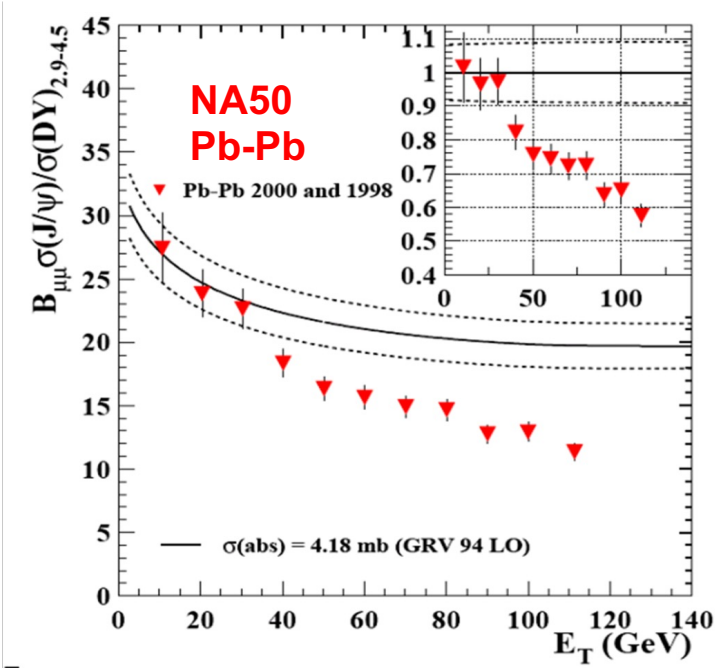


ρ-a_1 chiral mixing:
yield enhancement in 1<M<1.5 GeV

Measurement challenging, but **sensitivity to enhancement!**

Deconstructing chiral symmetry breaking

Charmonium measurement in NA60+: motivation



- Accurate studies were performed at √s=17.3 GeV (NA50, NA60)
- QGP-induced suppression evaluated with respect to a cold nuclear matter reference obtained with systematic p-A studies
- **~30-40% anomalous suppression effect** possibly due to disappearance of feed-down from χ_c and ψ(2S)

Deconstructing confinement

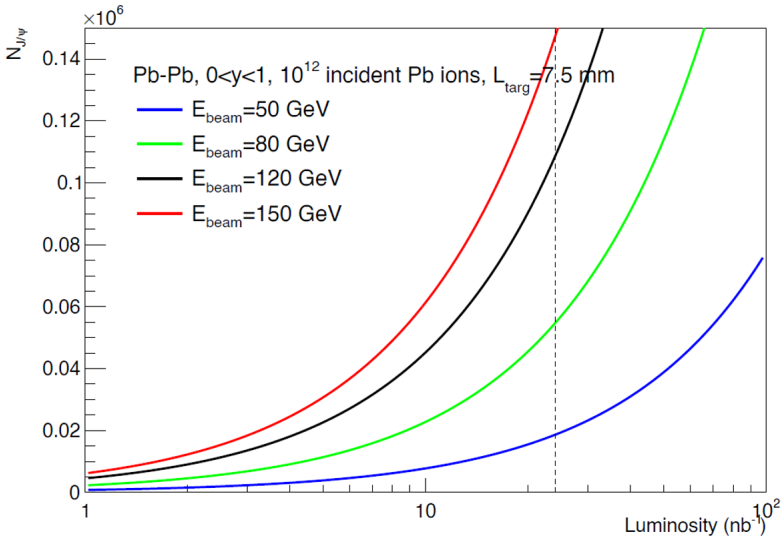
J/ψ production not studied below top SPS energies!

Perform an energy scan in

E_{lab} = 20 – 158 GeV

- Decreasing √s:
  - **Onset of charmonium melting** to be correlated to T measurement via thermal dimuons
  - **Stronger CNM effects** to be accounted for with pA data taking at the same √s

Charmonium measurement in NA60+: performance



With 10^{12} incident Pb ions on a 7.5 mm Pb target → **L_{int} ~24 nb^{-1}**

NA60+ can aim at

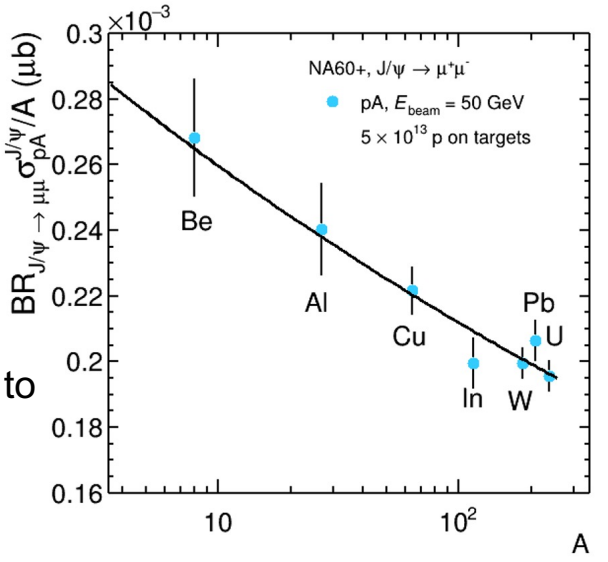
~O(10^4) J/ψ at 50 GeV

~O(10^5) J/ψ at 158 GeV

pA

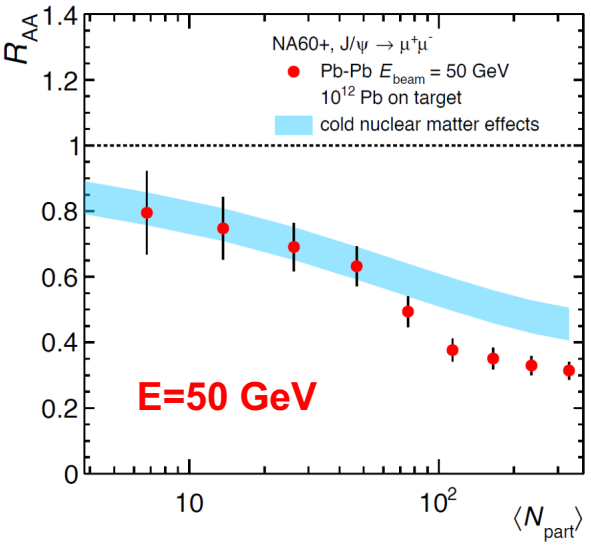
Use a system of various nuclear targets and extrapolate cross sections to pp

→ reference for R_{AA} measurement



Pb-Pb

Assume only CNM effects, extrapolated from p-A, for N_{part}<50 and 20% "anomalous" suppression for N_{part}>50

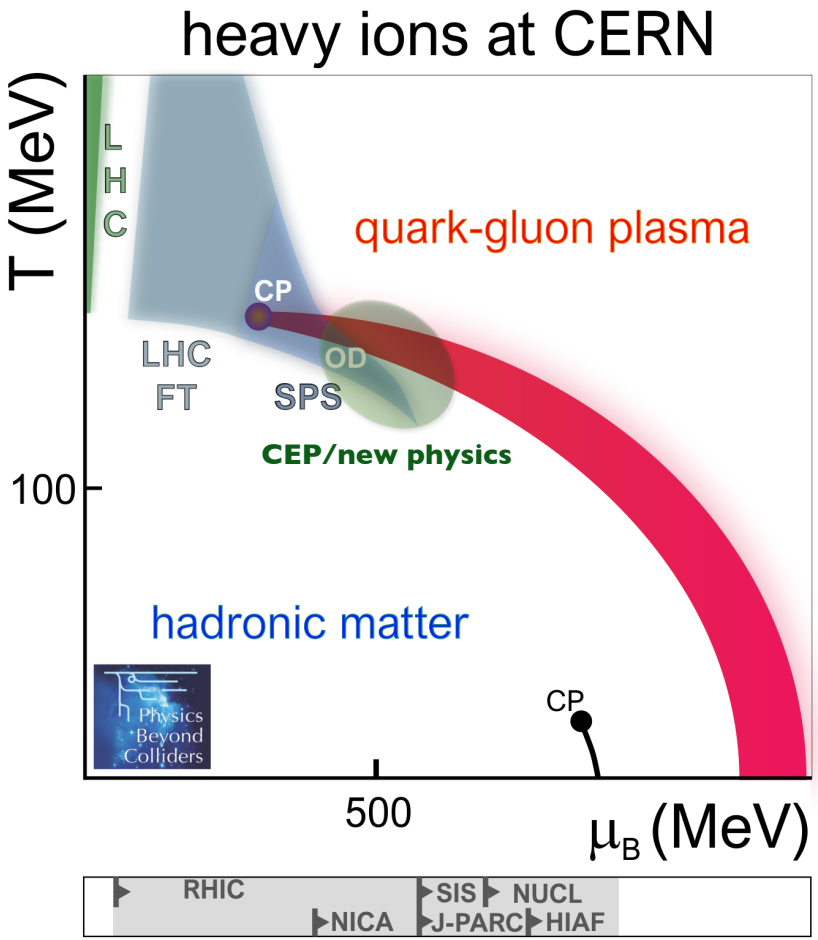


Heavy ion physics

- LHC-FT & SPS experiments offer a unique coverage of a primarily interesting part of the QCD phase structure including the potential CEP (CP) & mixed phases

- Complementary to running and planned experiments

- Uniqueness:
  - ★ Combined coverage of large range in temperature and density
  - ★ Interaction rate & observables
  - ★ Timing

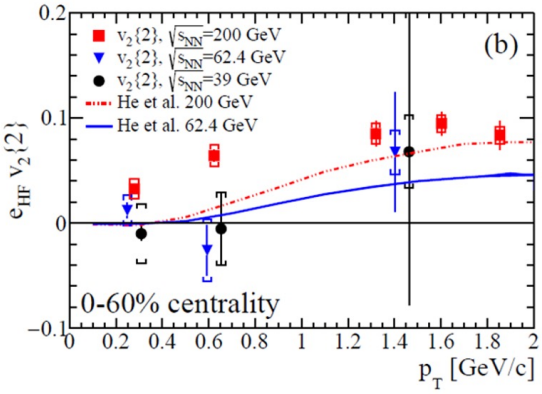


Backup slides

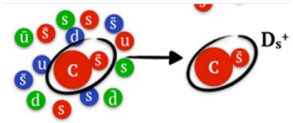
Open charm measurement in NA60+: motivation

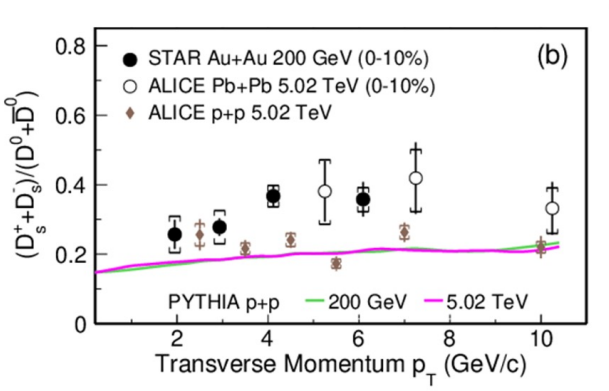
- No results at SPS energies (only indirect measurements at top SPS energy, NA60 and NA49)
- Aims at precision measurements of nuclear modification factor and elliptic flow for BOTH meson (D^0,D^+,D_s) and baryon (Λ_c) states
  - Insight into **QGP transport properties**
  - Study of **charm thermalization at low $\sqrt{s}$**
  - Insight into **hadronization mechanism** (via ratios D_s/D^0 and Λ_c/D^0)
  - Use **total charm cross section** as a reference for charmonium studies

Complements results at collider energies! Different "weight" of QGP and hadronic phase



D-meson elliptic flow and charm thermalization vanishes at low energy?

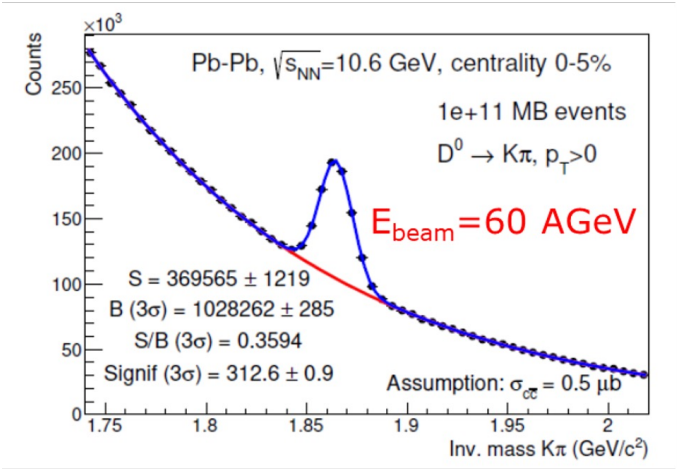




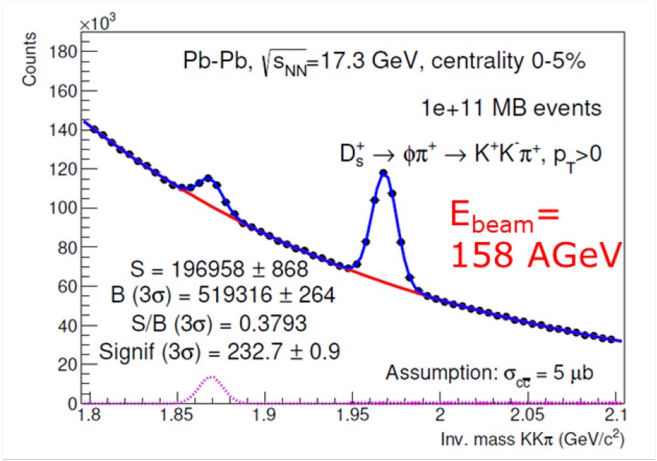
D_s enhancement due to quark recombination

Open charm measurement in NA60+: performance

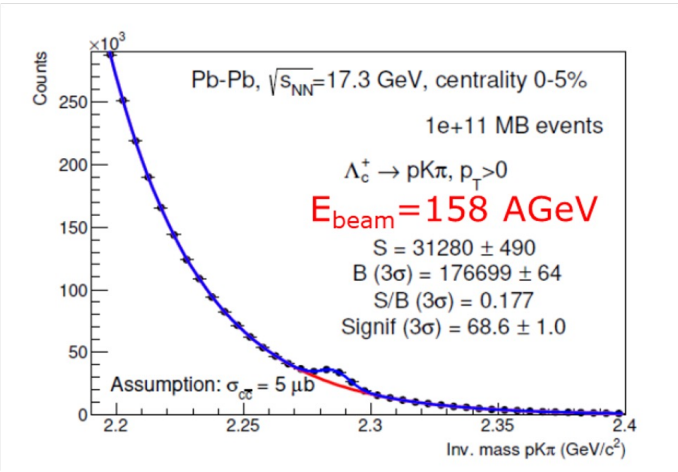
- With **~10^{11} minimum bias Pb-Pb collisions** (1 month of data taking)
  - More than $3 \cdot 10^6$ reconstructed D^0 in central Pb-Pb collisions at $\sqrt{s_{NN}}$=17.3 GeV
  - Allows for differential studies of yield and v_2 vs. p_T, y and centrality
  - D^0 accessible also at lower collision energies with statistical precision at the percent level
  - Measurement of D_s yield feasible with statistical precision of few percent
  - Λ_c baryon also accessible



$D^0 \rightarrow K\pi$



$D_s^+ \rightarrow \Phi\pi \rightarrow KK\pi$



$\Lambda_c^+ \rightarrow pK\pi$