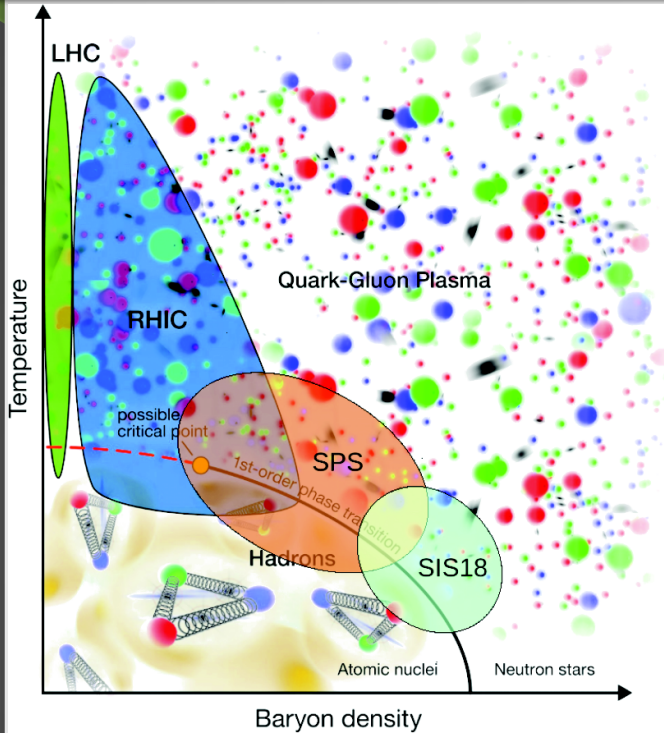


# The onsets of deconfinement and fireball of NA61/SHINE

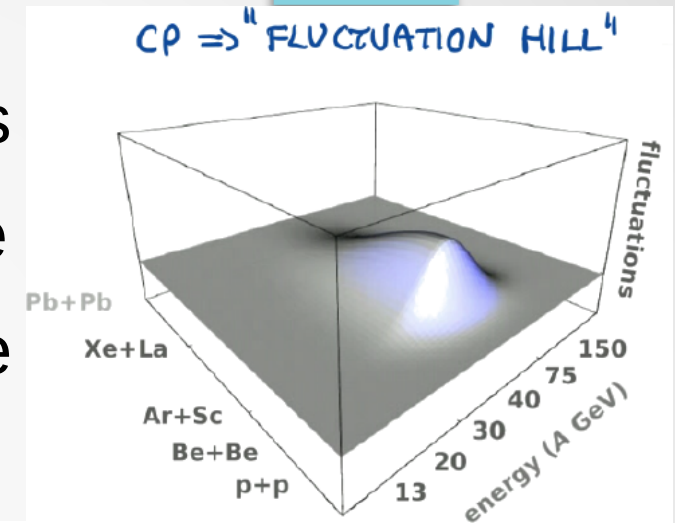
Dag Larsen

Krakow  
2018-06-07

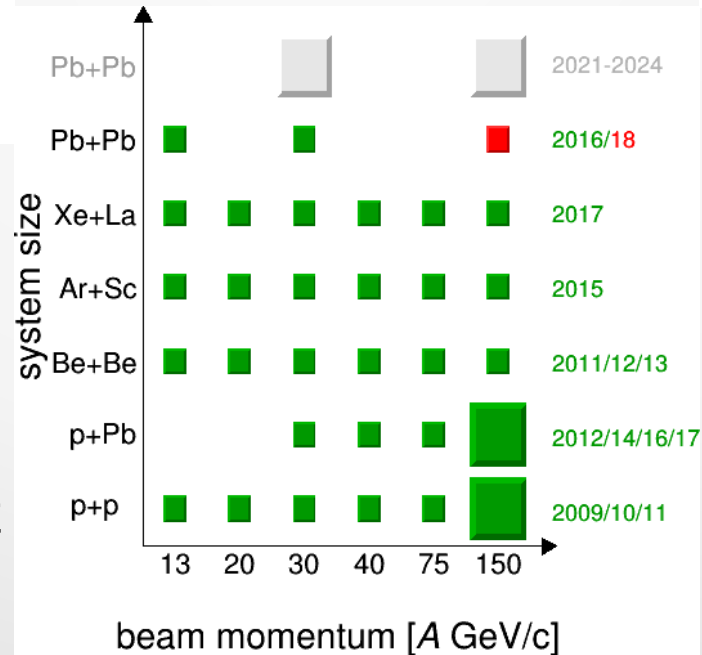
# NA61/SHINE physics programme



- Strong interactions
- Neutrino reference
- Cosmics reference

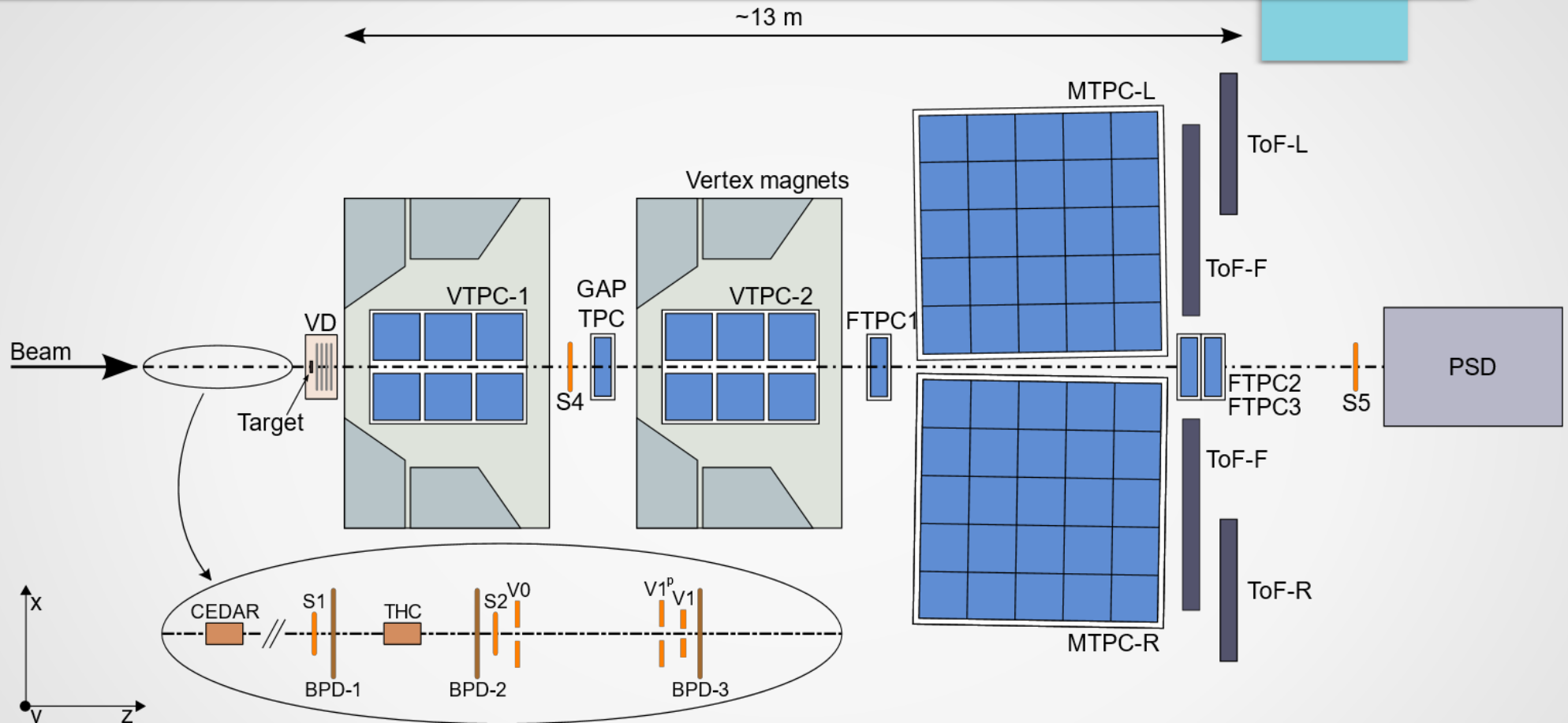


- Strong interactions:
- Search for critical point
  - Study properties of onset of deconfinement



2D energy/system size scan of p+p, p+A and A+A collisions

# The NA61/SHINE facility



- S1, S2, V1, V1: trigger system for event selection
- VD: high-precision determination of primary vertex
- VTPC: 1.5 T magnetic field, momentum measurement, resolution:  $10^{-4}$

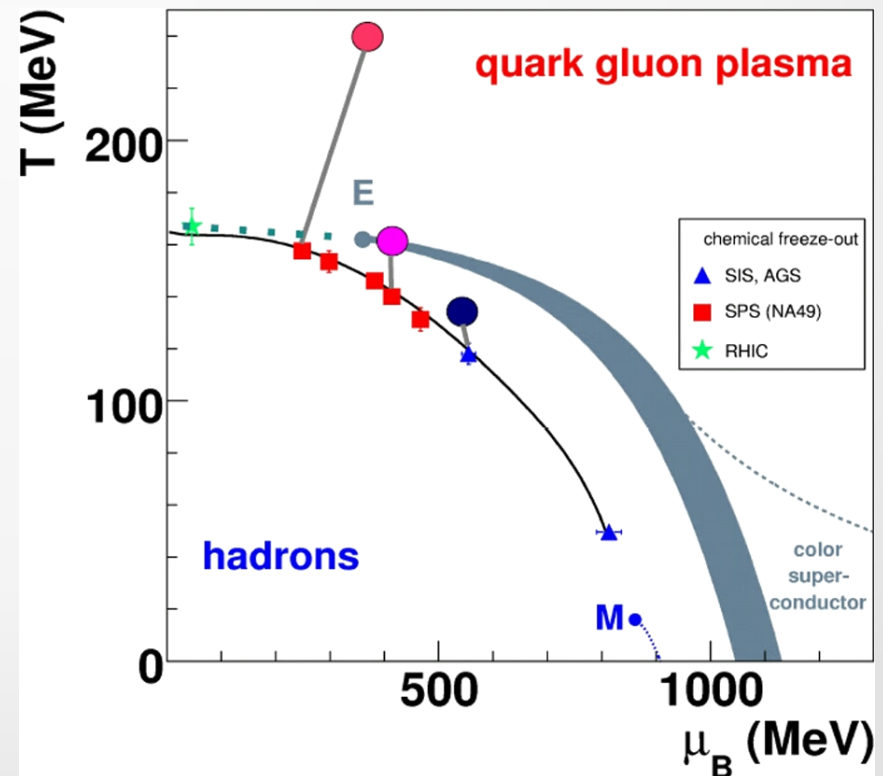
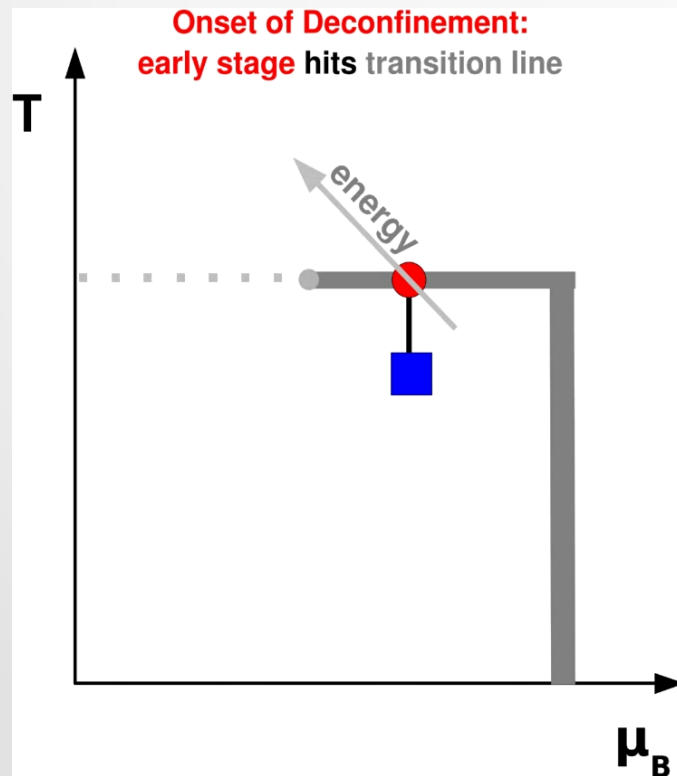
- MTPC:  $dE/dx$  measurement, specific energy loss
- ToF: Time-of-flight measurements, improves particle identification
- PSD: zero-degree calorimeter, determine forward energy

# Data taking capabilities

- Ion beams:
  - Primary: Ar, Xe, Pb 13A – 150/160A GeV/c
  - Secondary: Be from Pb fragmentation, 13A – 150/160A GeV/c
- Hadron beams:
  - Primary: proton 400 GeV/c
  - Secondary: hadron beams: pion, kaon, proton 13 – 400 GeV/c
- Targets:
  - Solid state from ~1 mm to ~1 m
  - Liquid hydrogen target 20 cm
- Data taking rate: 1 M events/day (currently)

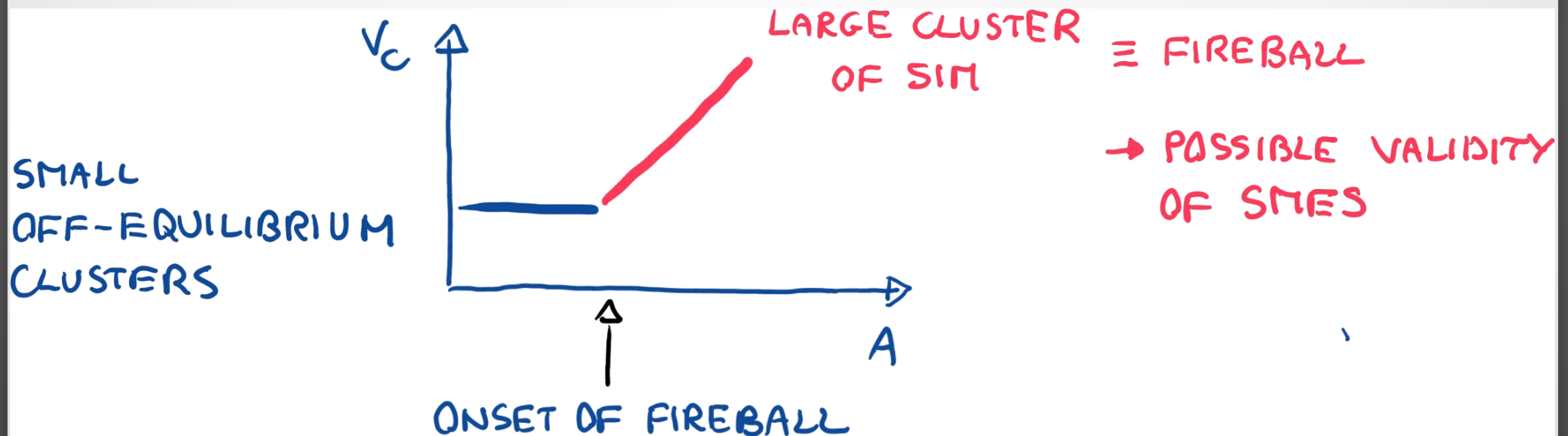
# Onset of deconfinement

- Beginning of creation of quark-gluon plasma (QGP) in nucleus-nucleus (A+A) collisions with increasing collision energy  $\sqrt{s_{NN}}$

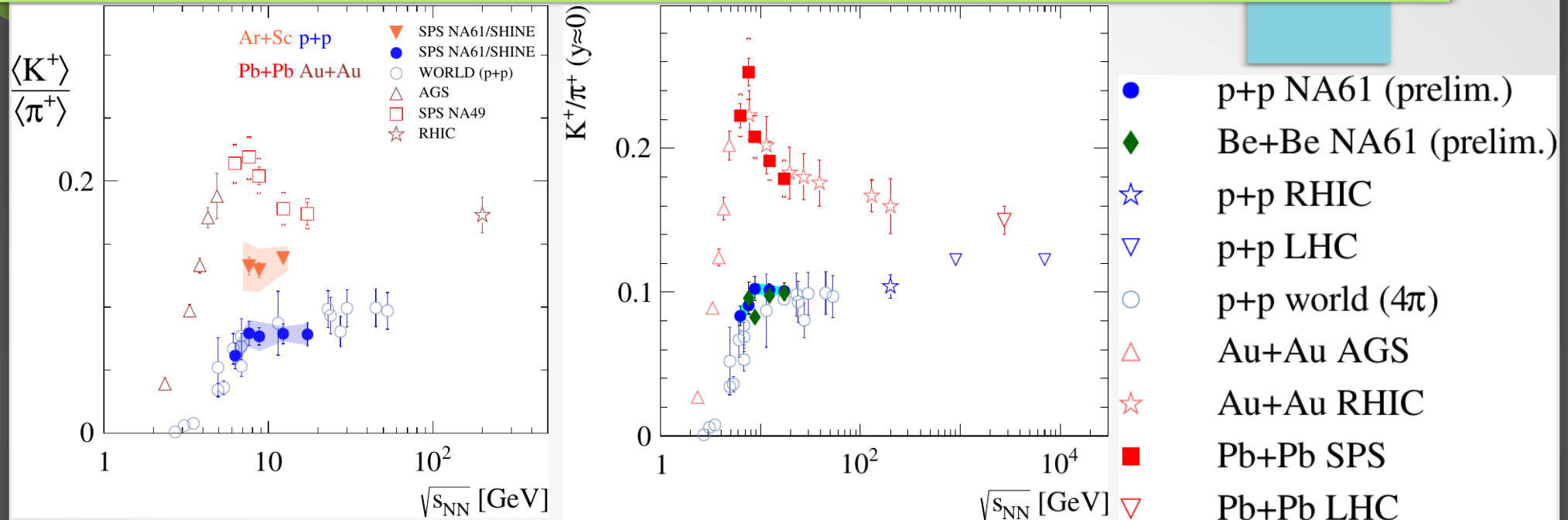


# Onset of fireball

- Beginning of creation of large clusters of strongly interacting matter (SIM) in nucleus-nucleus collisions with increasing mass number (A)

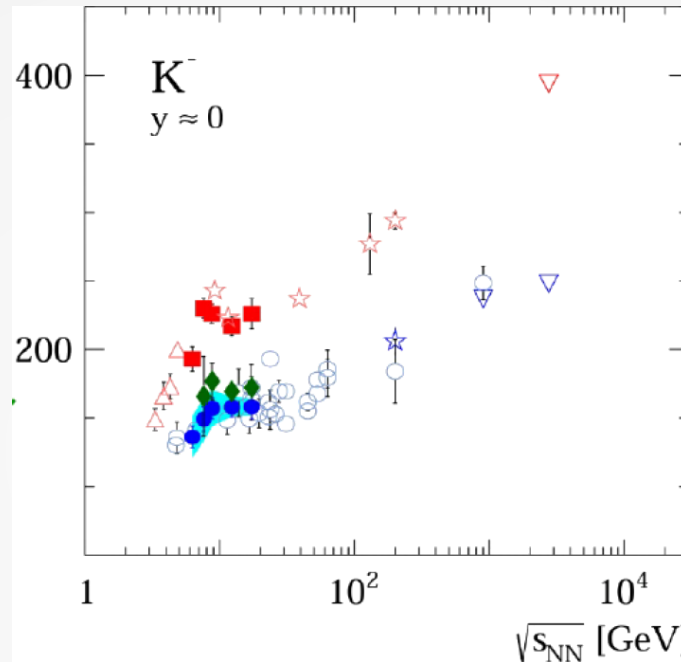
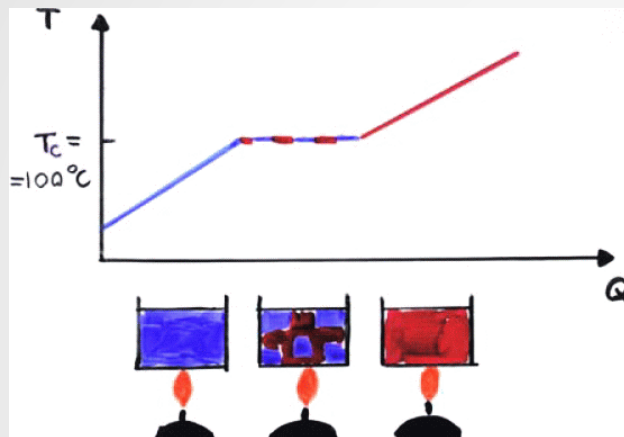


# Particle ratios



- Rapid changes in  $K^+/\pi^+$  (horn) observed for Pb+Pb collisions; predicted by SMES as signature of deconfinement
- Step seen for p+p
- Be+Be close to p+p
- However: Ar+Sc  $\langle K^+ \rangle / \langle \pi^+ \rangle$  is between p+p/Be+Be and Pb+Pb

# Inverse slope (step)



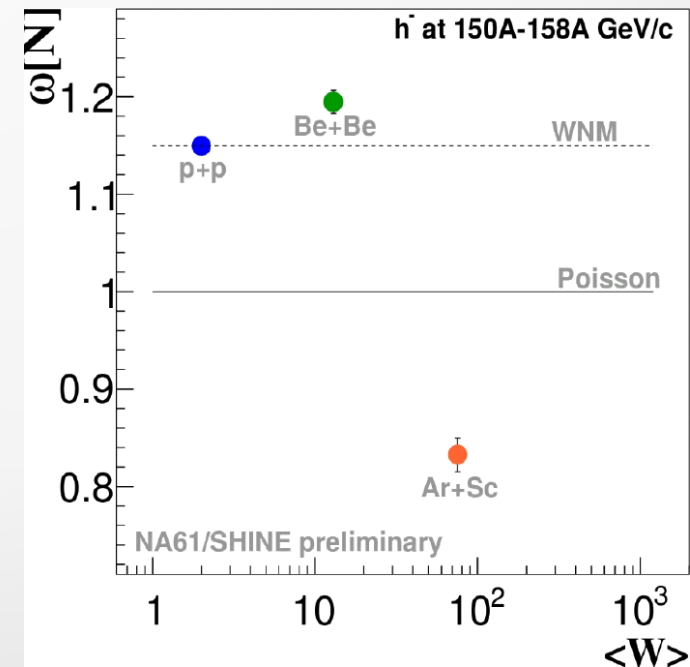
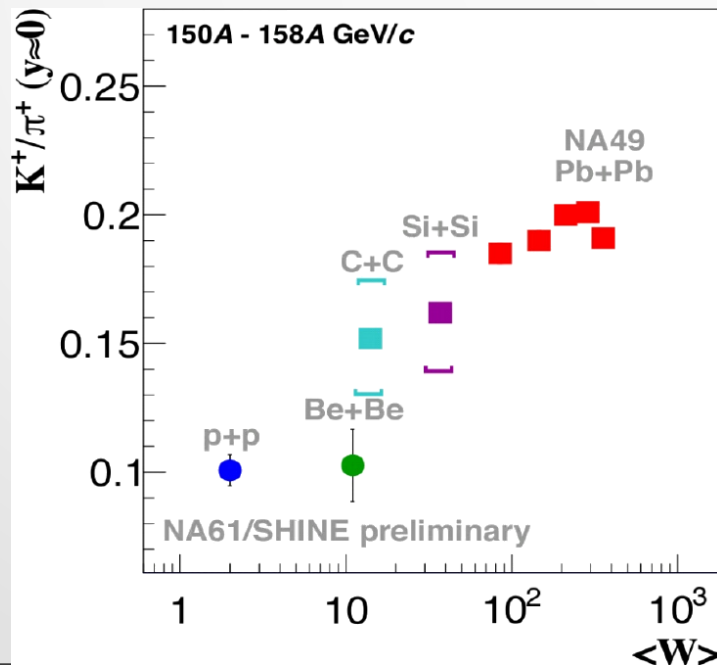
- p+p NA61 (prelim.)
- ◆ Be+Be NA61 (prelim.)
- ☆ p+p RHIC
- ▽ p+p LHC
- p+p world (4π)
- △ Au+Au AGS
- ☆ Au+Au RHIC
- Pb+Pb SPS
- ▽ Pb+Pb LHC

- Step-like structure in  $T$  observed for Pb+Pb collisions; predicted by SMES as signature of deconfinement
- Step also seen in p+p
- Be+Be close to p+p

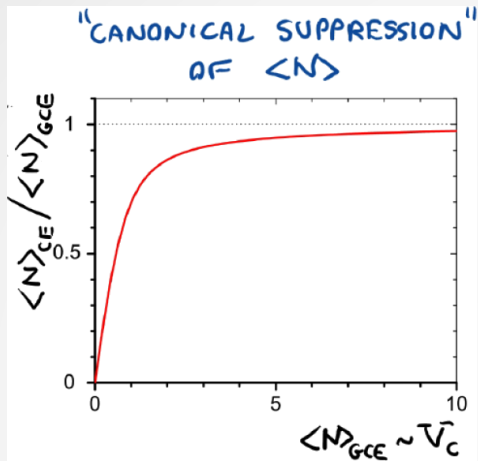


# Particle ratios/fluctuations

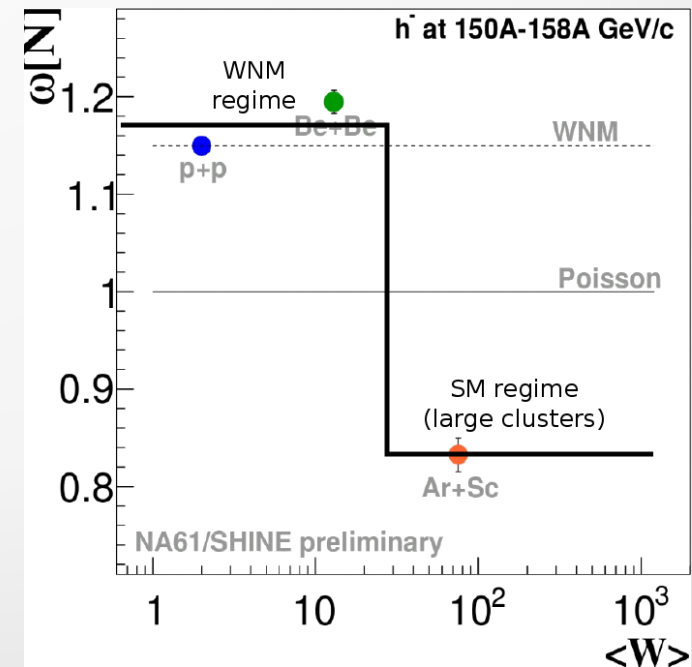
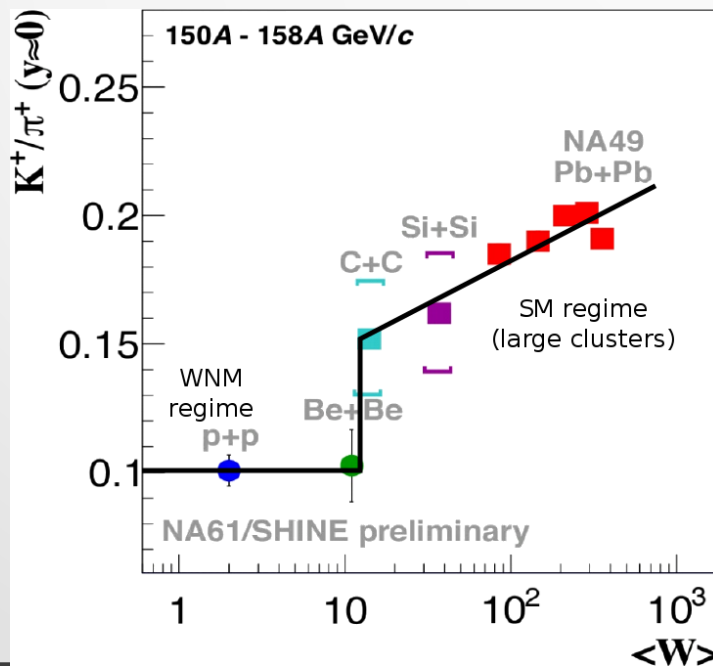
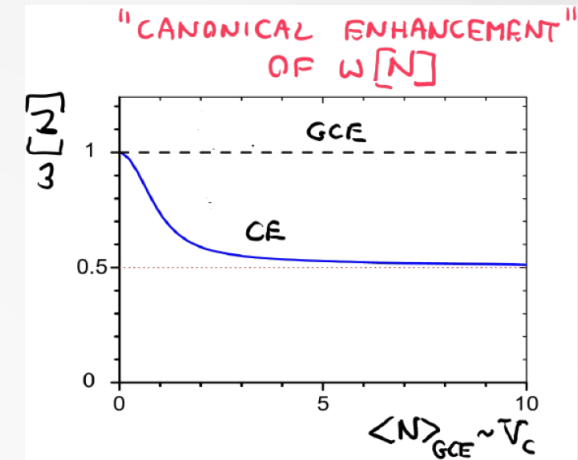
- $K^+/\pi^+$  and multiplicity fluctuations change rapidly when moving from light (p+p/Be+Be) to intermediate/heavy systems
- Heavy systems close to statistical model predictions for large volumes
  - Beginning of creation of large clusters of strongly interacting matter (onset of fireball)?



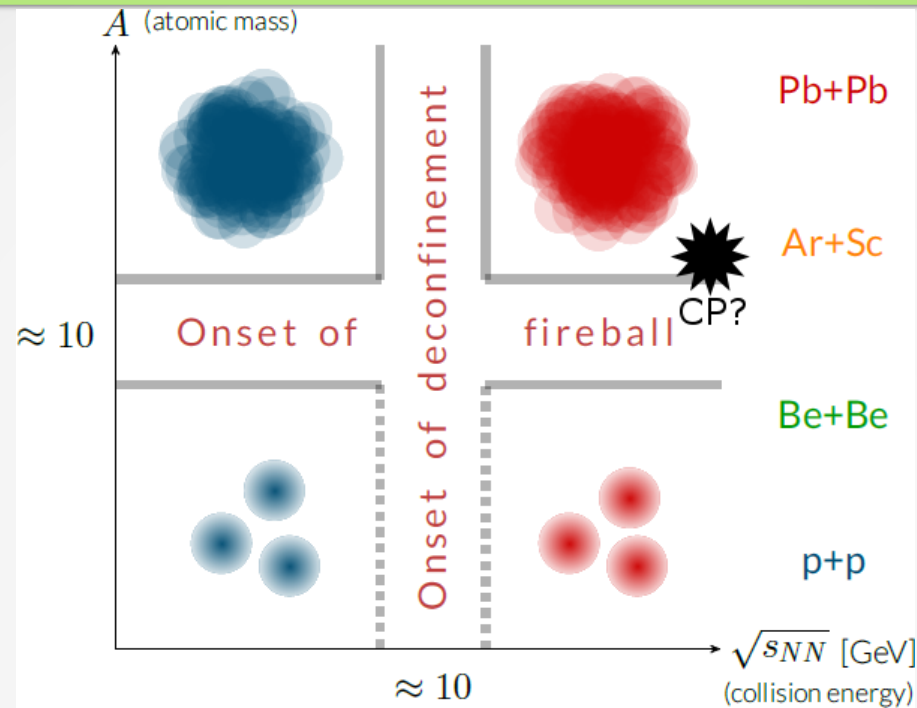
# Particle ratios and fluctuations (cont.)



- SM (IB-GCE) VS. SM (IB-CE)
- IB = Ideal Boltzmann Gas



# Onset of deconfinement vs. onset of fireball



- Two-dimensional scan conducted by varying collision energy and system size
- Indicates four domains of hadron production
- Separated by two thresholds:
  - Onset of deconfinement
  - Onset of fireball
- Onset of deconfinement well established for central Pb+Pb/Au+Au
  - Questionable for low mass nuclei/p+p

# Interpretation of onset of fireball: percolation approach

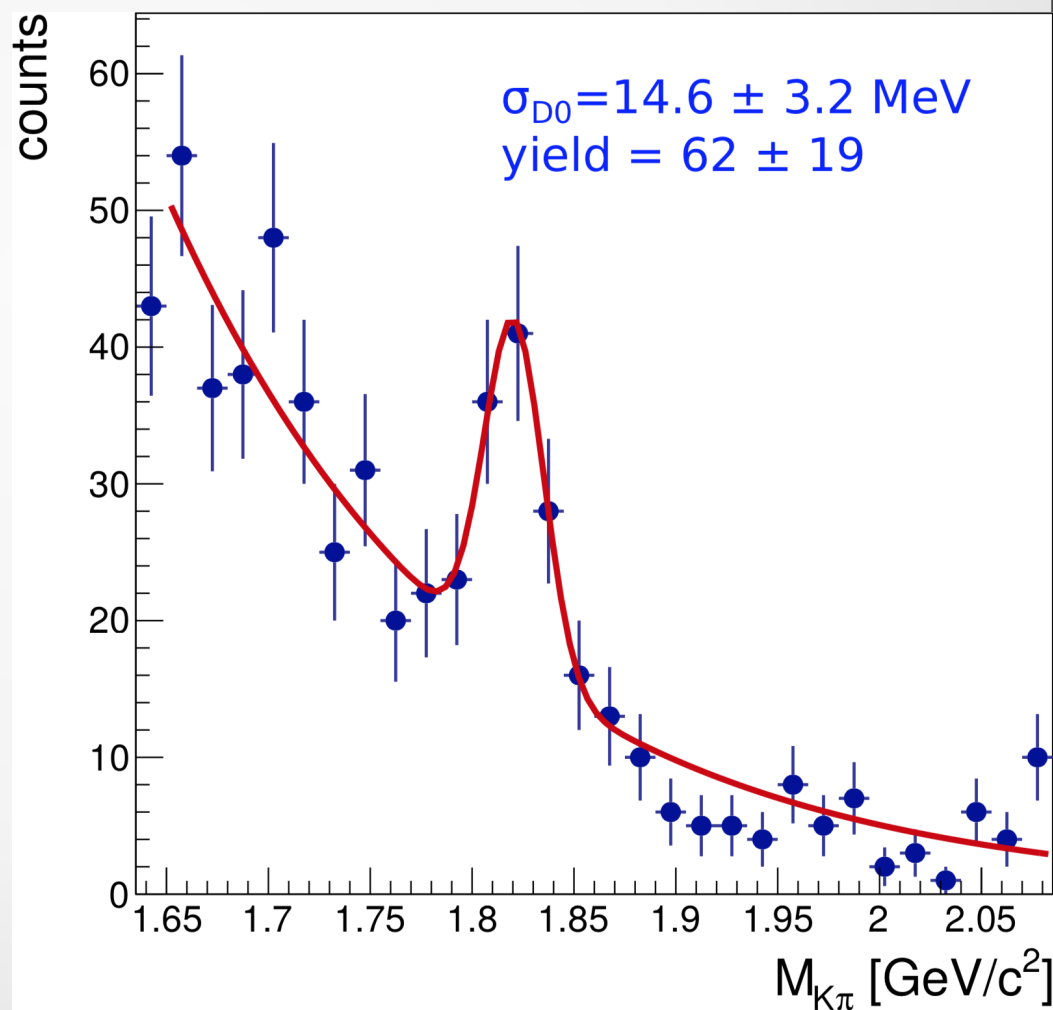
- With increasing  $A$  density of clusters (strings, partons, ...) increases. Thus probability to overlap many elementary clusters may rapidly increase with  $A \rightarrow$  percolation models
- This approach does not explain equilibrium models of large clusters
  - Baym, Physica 196 (79) 131
  - Celik, Karsch, Satz PL897 (80) 128
  - Braun, Pajares, NP B330 (33) 542
  - Armesto, Braun, Ferreiro, Pajares, PRL 77 (34) 3736
  - Cunqueiro, Ferreiro, Morag, Pajares (05) 924307

# Interpretation of onset of fireball: Ads/CFT correspondence

- Ads (gravity): Formation of a black hole horizon (information trapping surface) takes place when critical values of model parameters are reached
- CFT (QCD): Only starting from a sufficiently large nuclear mass number the formation of trapping surface in A+A collisions is possible → onset of fireball
  - Maldacena, Inf. Theor. Phys. 38 (1999) 1113
  - Shuryak, Prog. Part. Nucl. Phys. 62 (2009) 48
  - Lin, Shuryak PR D75 (2009) 124015

# D<sup>0</sup> as signal of deconfinement

- NA61/SHINE is undertaking open charm measurement programme with new Vertex Detector
  - Charm yields expected to be different in confined and deconfined matter
- Pilot data taking so far
  - Observation of D<sup>0</sup> peak
  - Higher statistics later this year
  - Upgraded Vertex Detector expected to be introduced 2021
- See poster by A. Merzlaya



# Summary & outlook

- “Horn” and “step” in particle ratio and inverse slope predicted as signature of onset of deconfinement
  - Now also appearing in lighter systems as p+p/Be+Be
- Surprisingly, Be+Be behaves similarly to p+p, while Ar+Sc is between p+p/Be+Be and Pb+Pb
  - May indicate “second” onset: onset of fireball
- Ar+Sc/Xe+La still being analysed; will provide further information



Thank you for your attention!