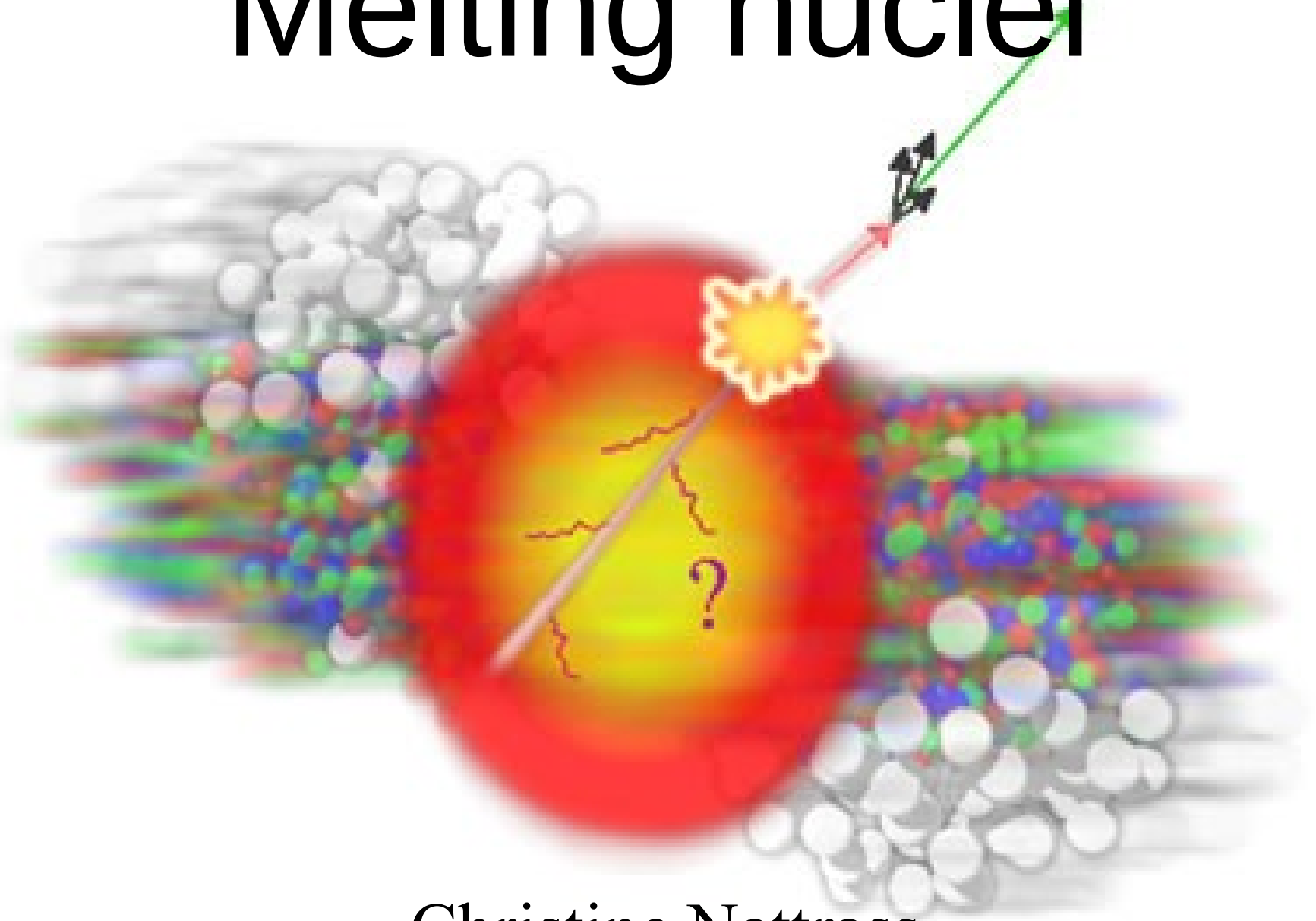
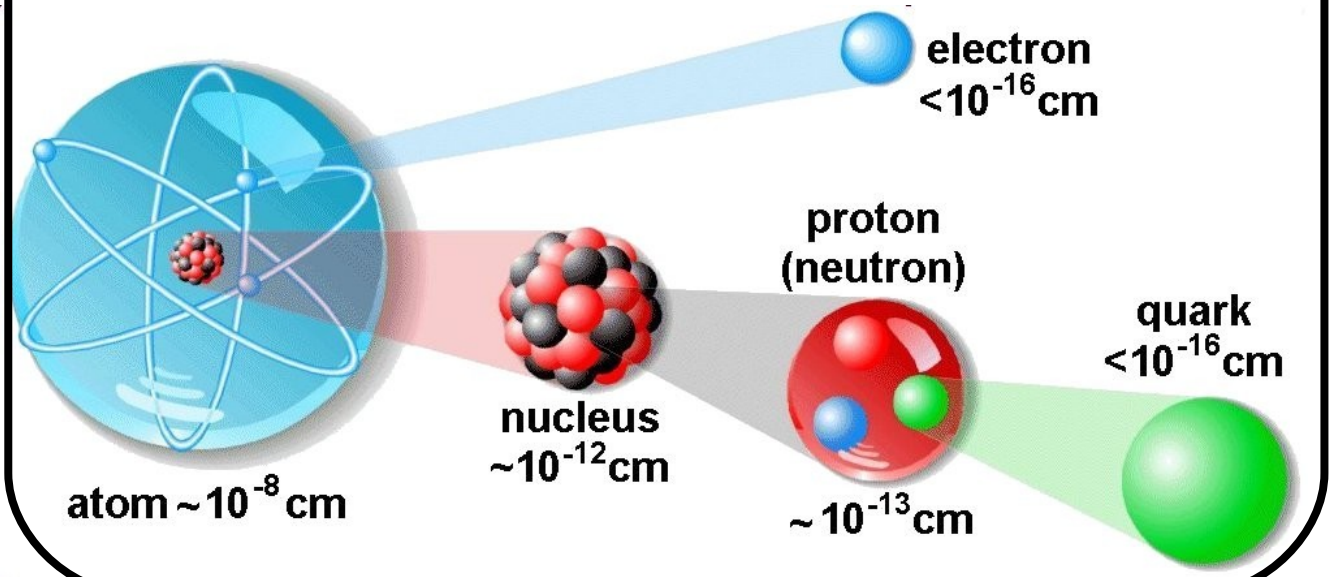
Melting nuclei



Christine Nattrass
University of Tennessee, Knoxville

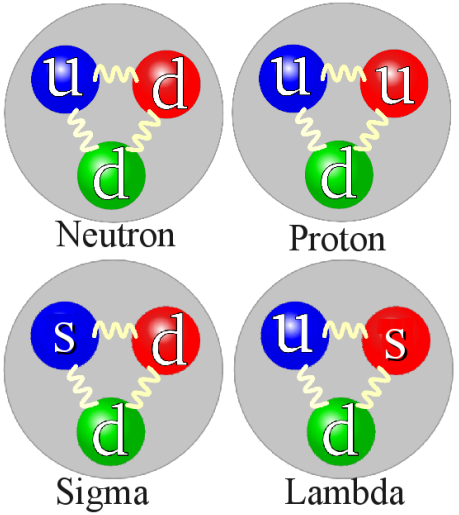
Structure of matter



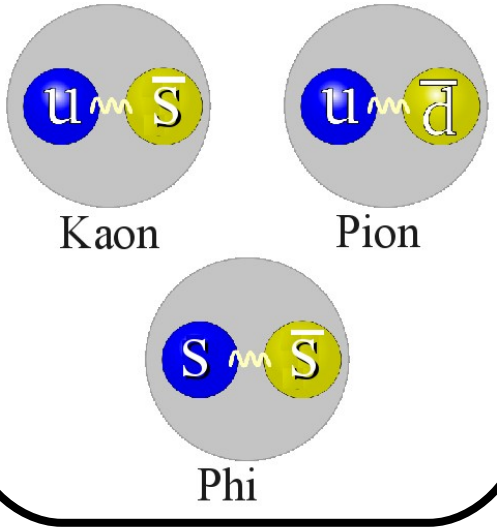
Standard model

Hadrons

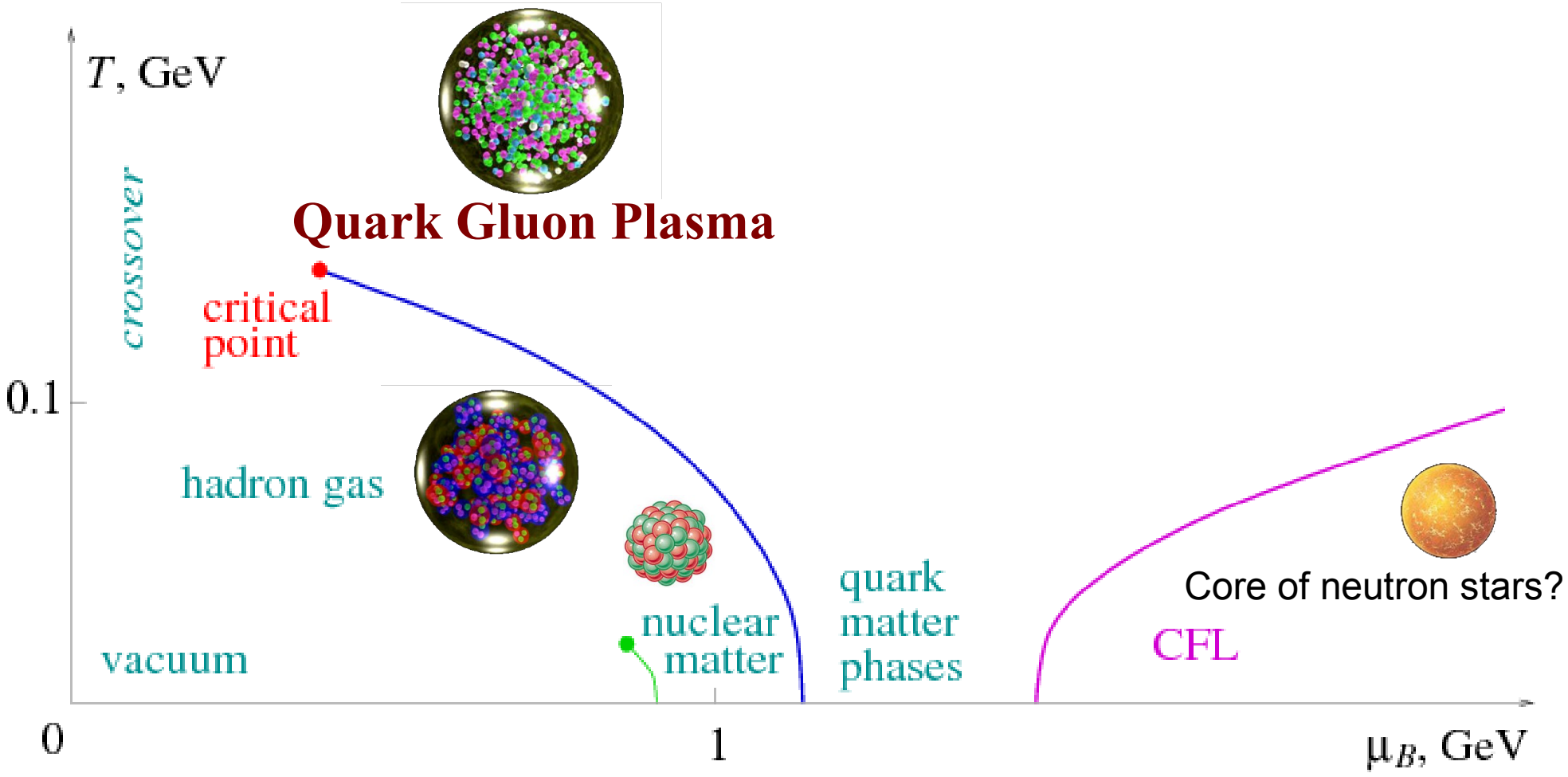
Baryons



Mesons

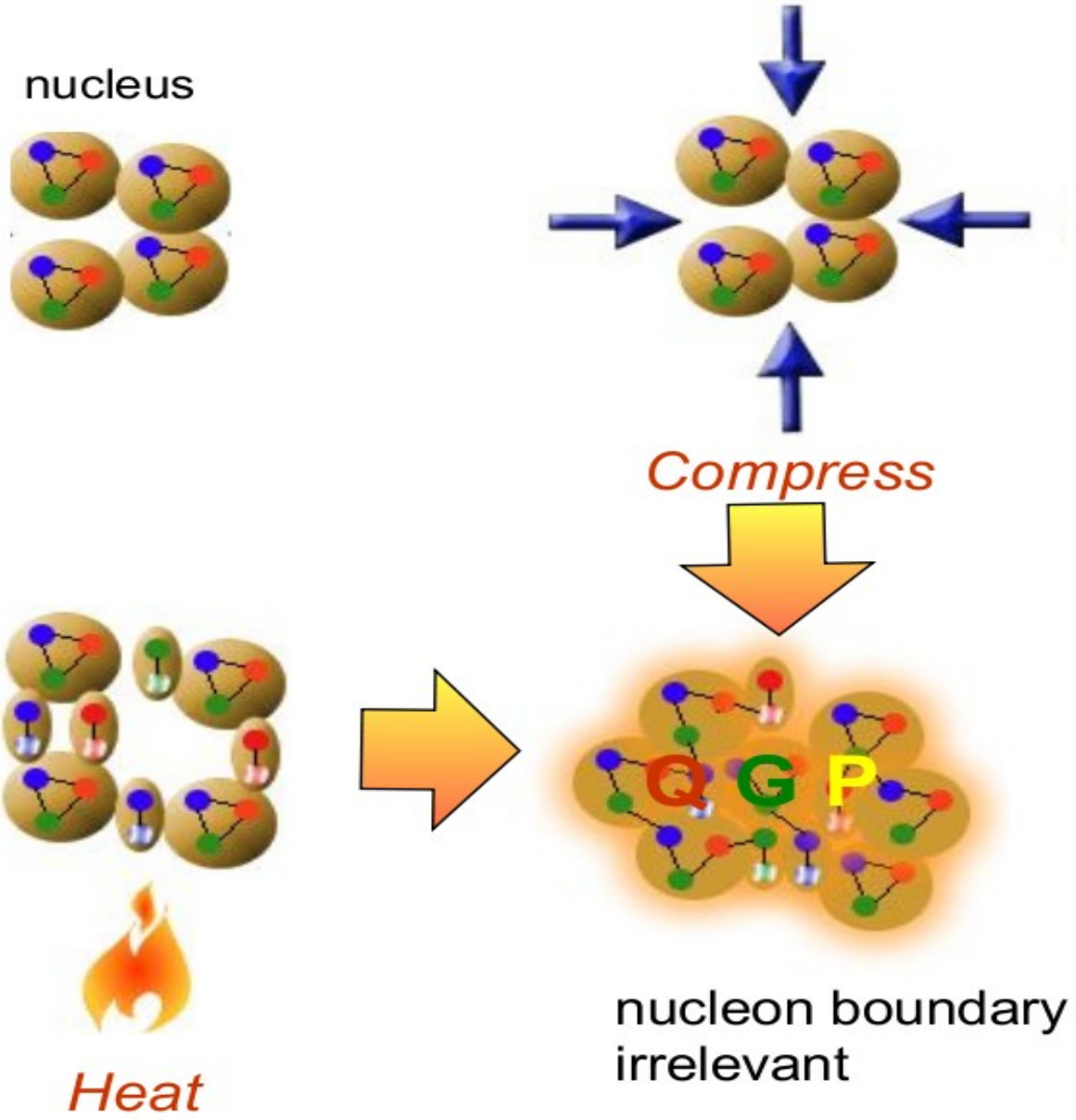


Phase diagram of nuclear matter

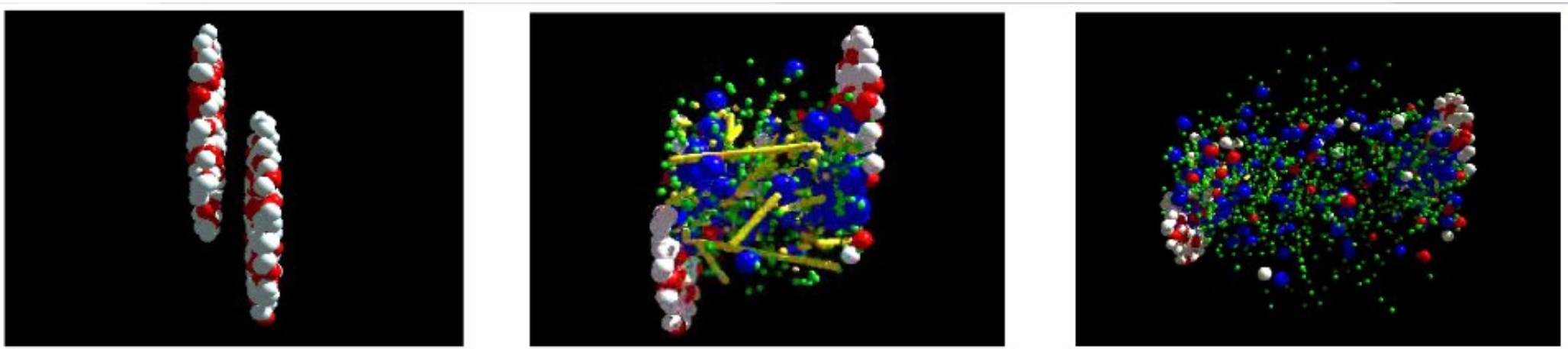


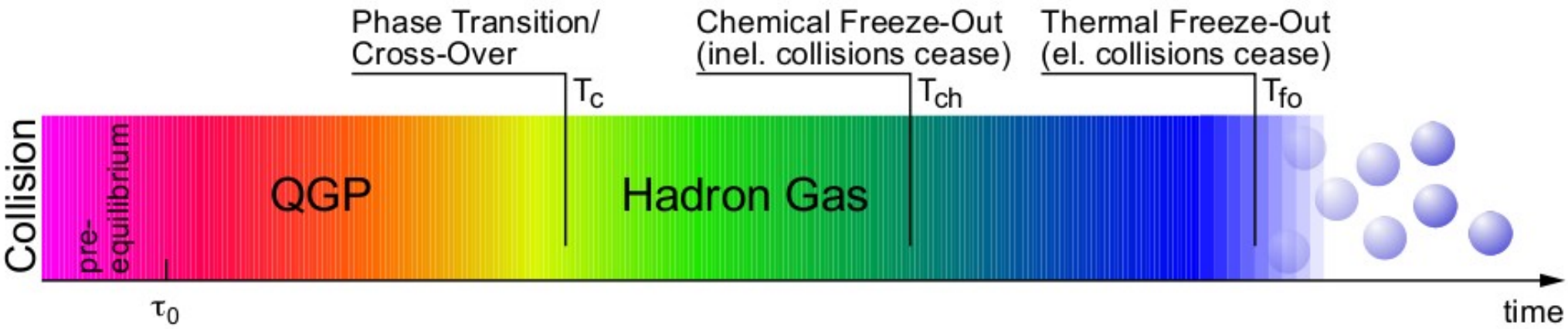
Quark Gluon Plasma – a *liquid* of quarks and gluons created at temperatures above ~170 MeV ($2 \cdot 10^{12}$K) – over a million times hotter than the core of the sun

How to make a Quark Gluon Plasma

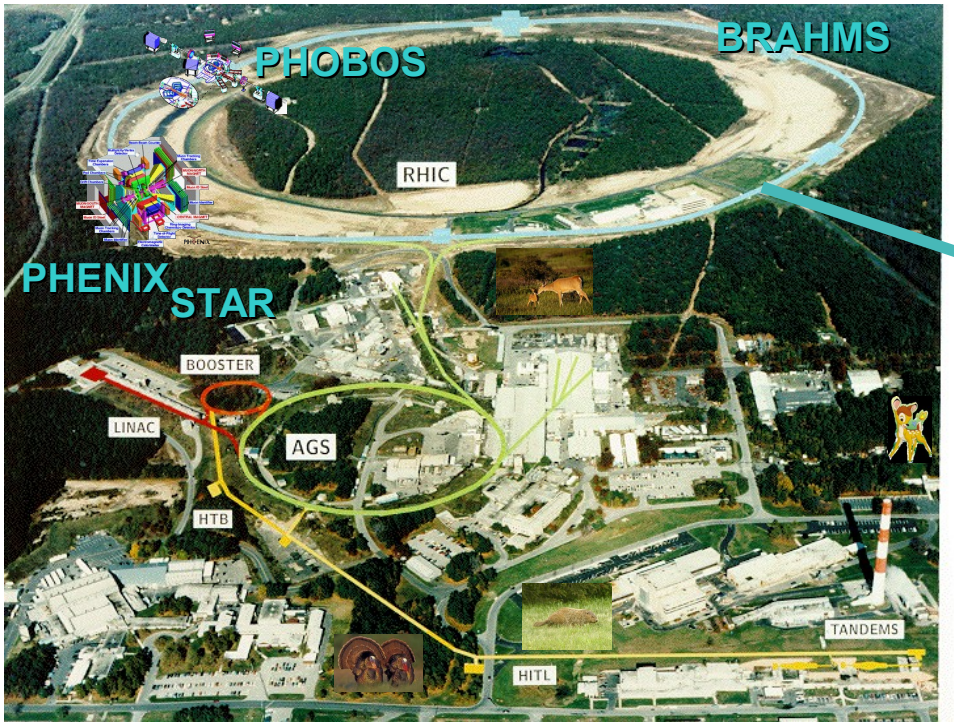


The phase transition in the laboratory



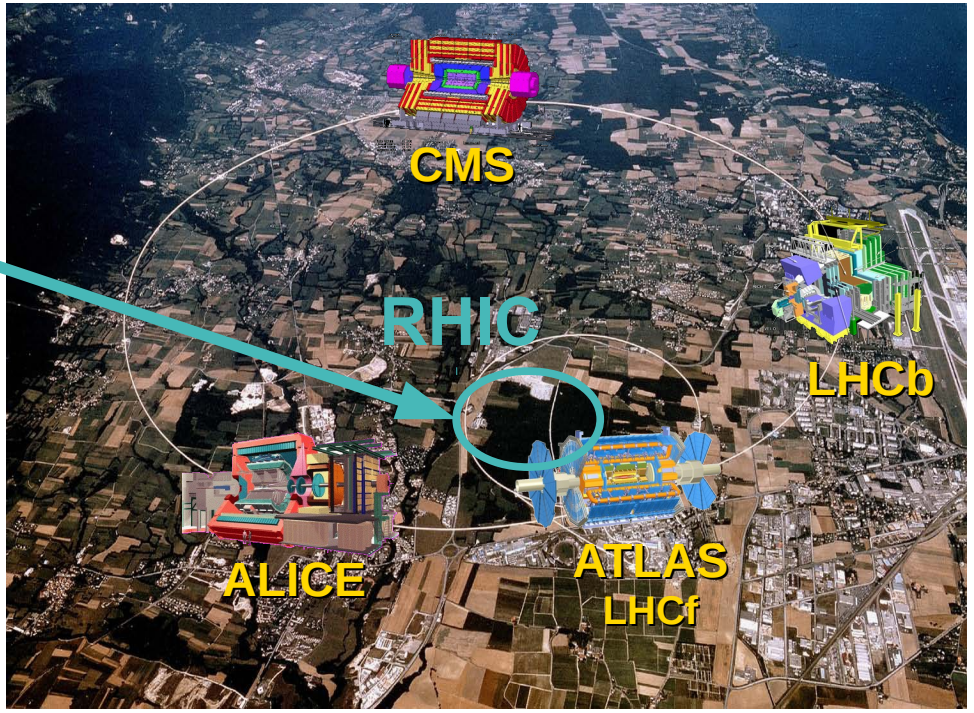


Relativistic Heavy Ion Collider

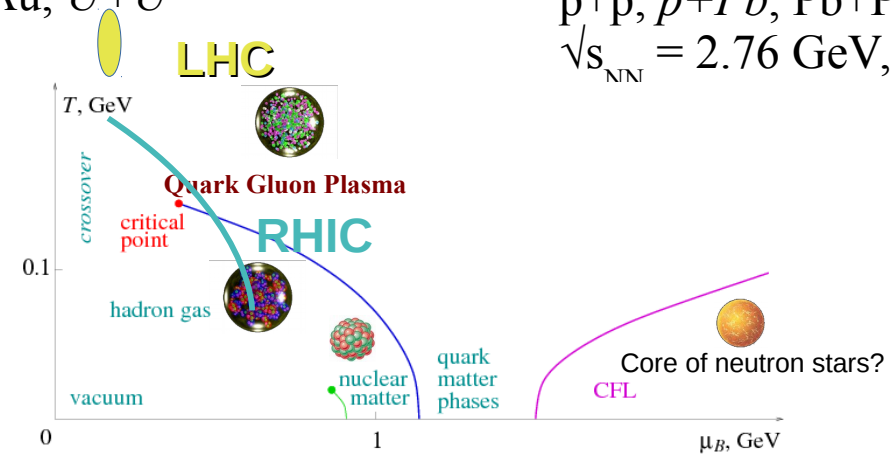


Upton, NY
1.2km diameter
p+p, d+Au, Cu+Cu, Au+Au, *U+U*
$\sqrt{s_{NN}}$ = 9 - 200 GeV

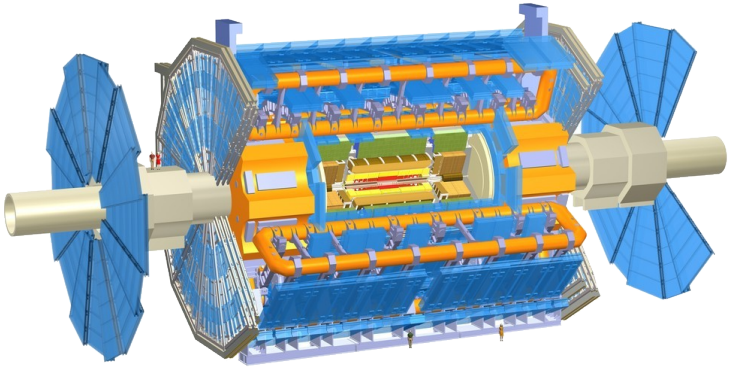
Large Hadron Collider



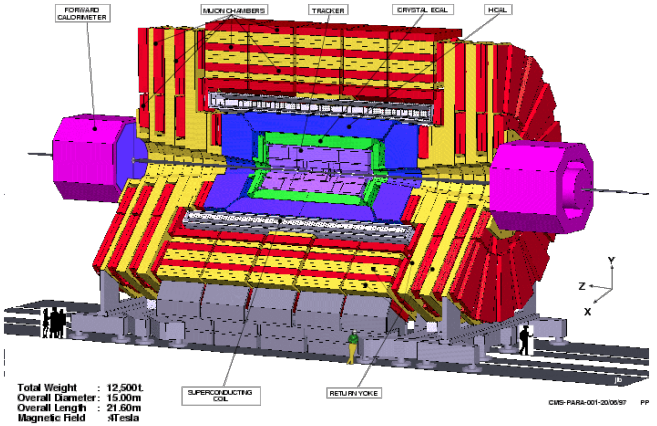
Geneva, Switzerland
8.6km diameter
p+p, *p+Pb*, Pb+Pb
$\sqrt{s_{NN}}$ = 2.76 GeV, *5.5 TeV*



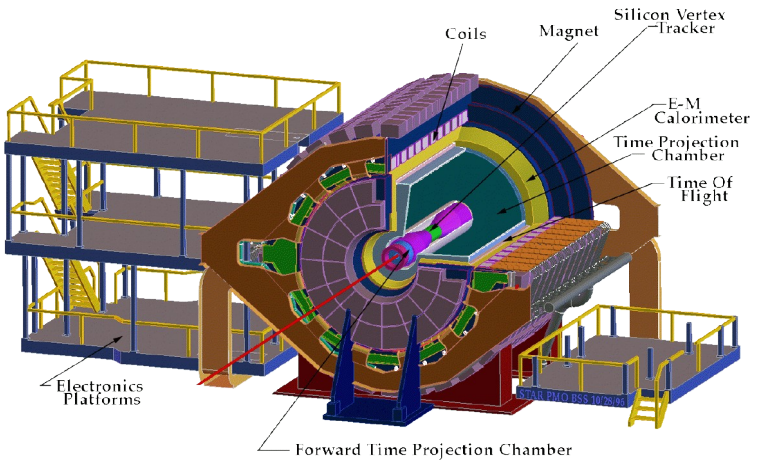
ALICE



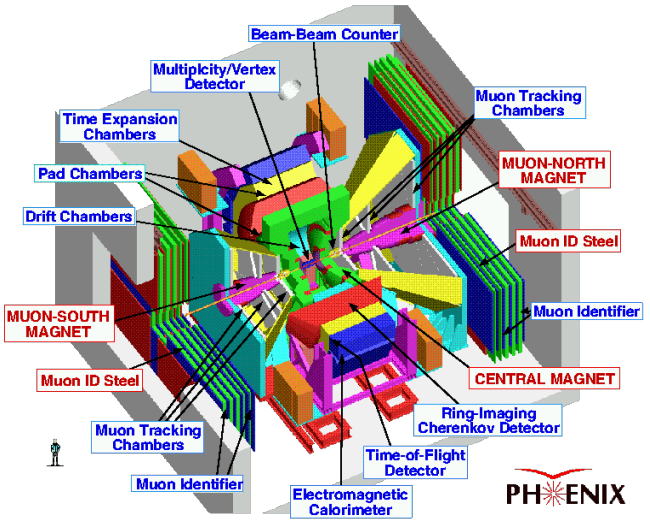
ATLAS



CMS

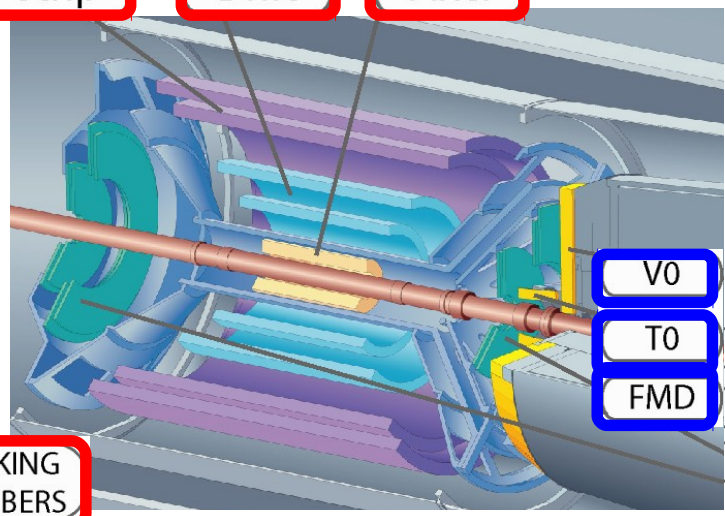


STAR



PHENIX

Size: 16 x 26 meters
Weight: 10,000 tons
Detectors: 18

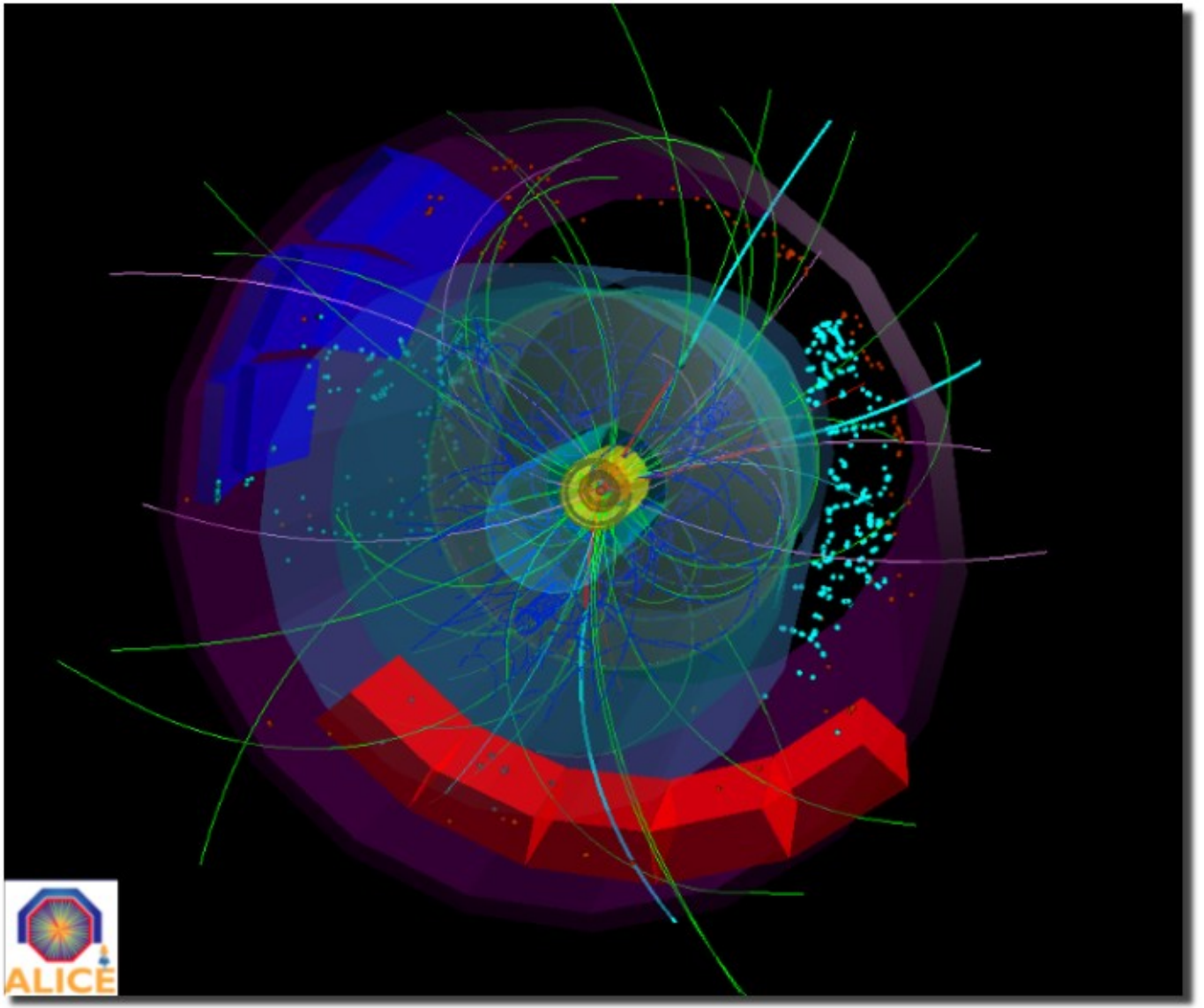


ACORDE
ITS
FMD
T0 & V0
EMCAL
TRD
HMPID
TRACKING
CHAMBERS
PMD
ZDC
~116m from I.P.
MUON
FILTER
V0
T0
TPC
TRIGGER
CHAMBERS
ZDC
~116m from I.P.

Trigger detectors: When do we have a collision?
Tracking detectors: Where did the particle go?
Identification detectors: What kind of particle is it?
Calorimeters: How much energy does the particle have?

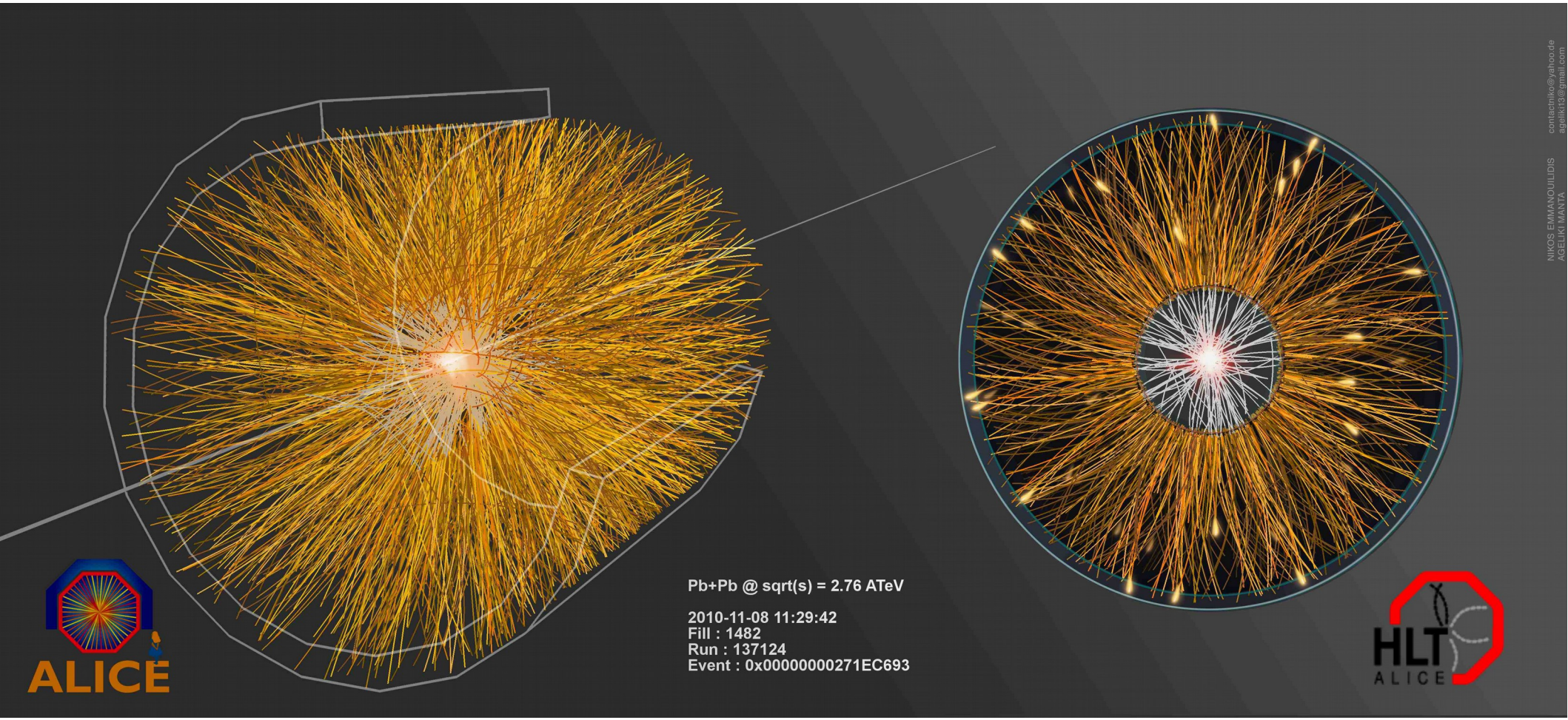
TOF
PHOS
DIPOLE
MAGNET
ABSORBER

p+p collisions



3D image of each collision

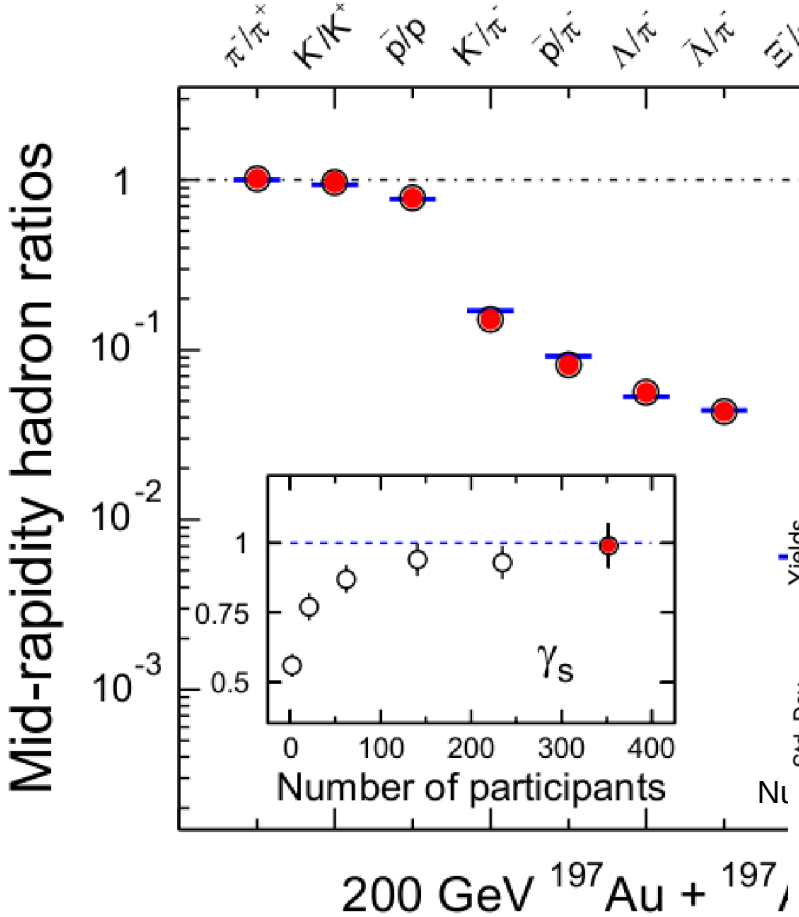
Pb+Pb collisions

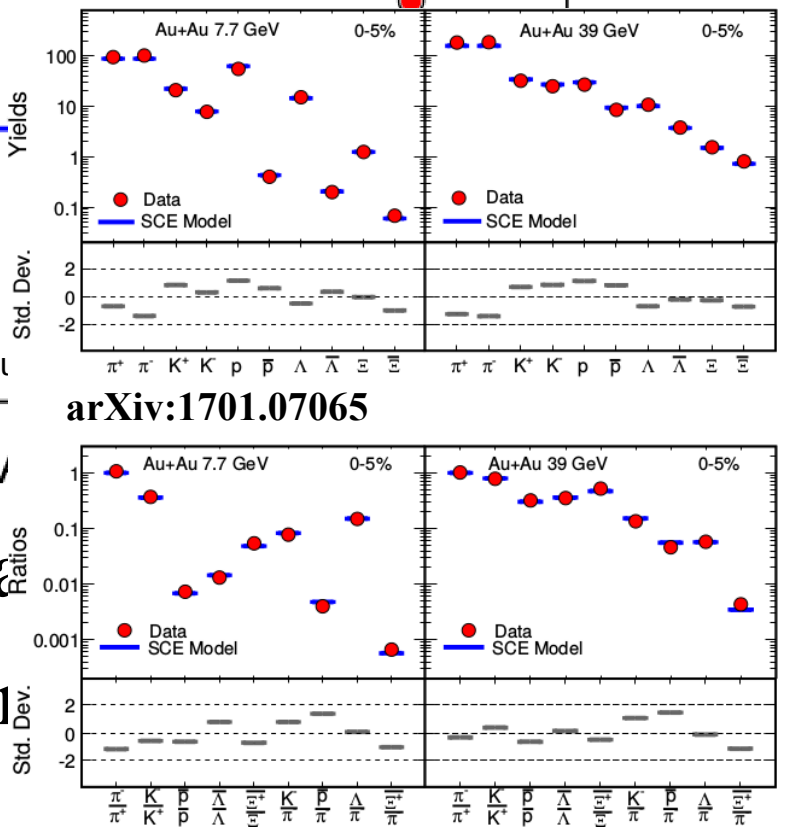


QGP Chemistry

Chemistry - equilibrium

T~170 MeV

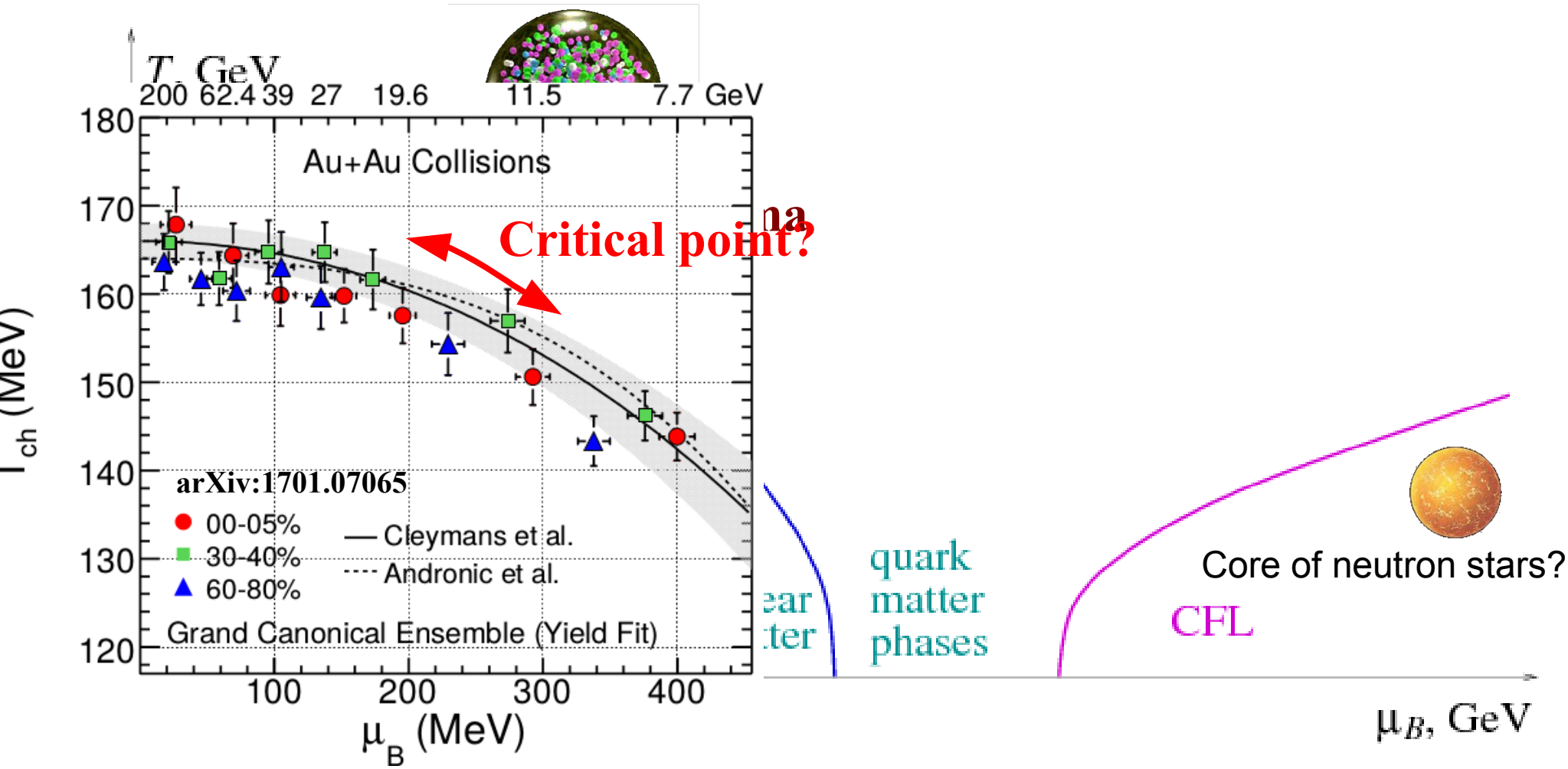




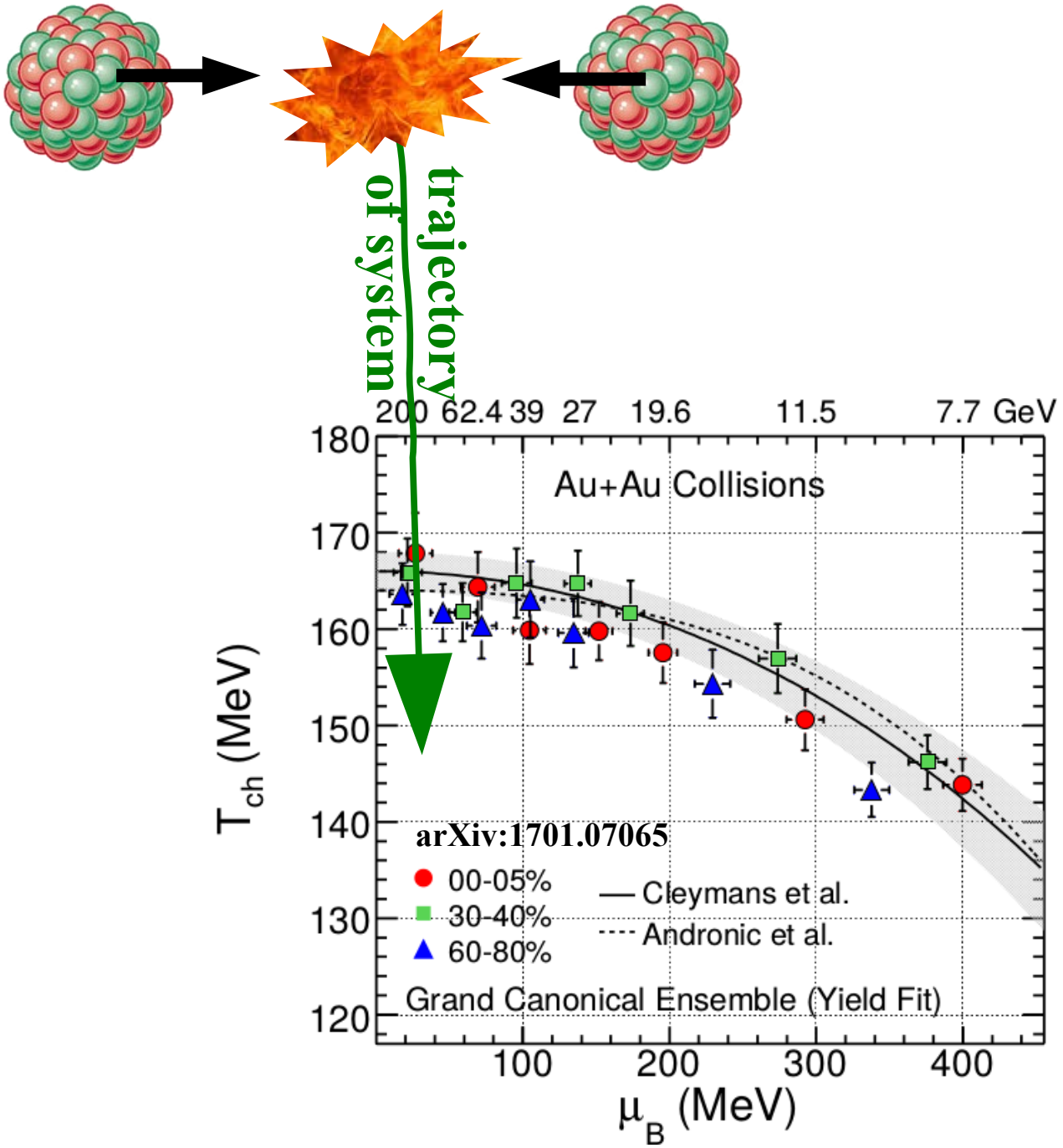
arXiv:1701.07065

- Ratios of particles expected from a
- Even strange quarks are at equilibr

Phase diagram of nuclear matter

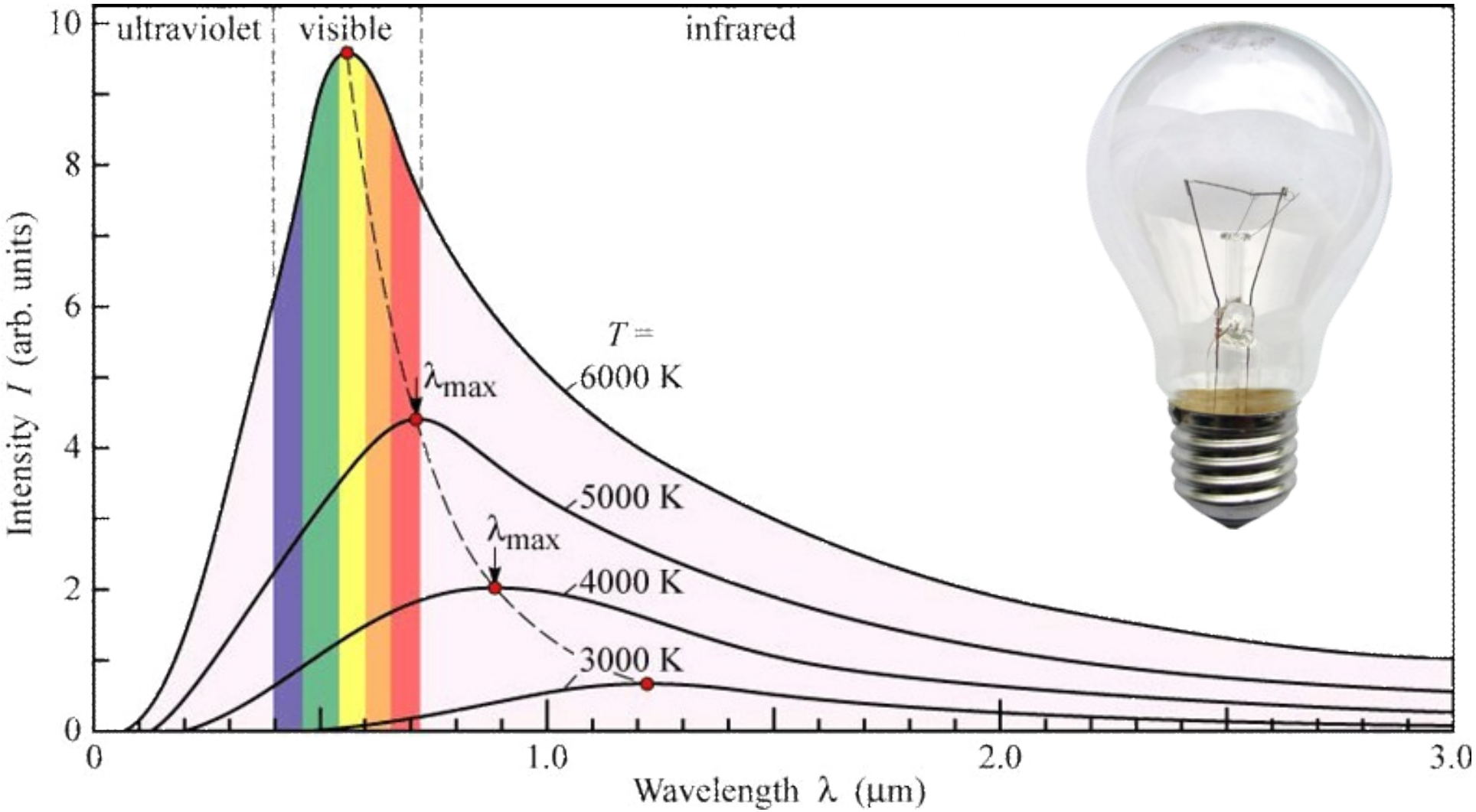


Quark Gluon Plasma – a *liquid* of quarks and gluons created at temperatures above ~170 MeV ($2 \cdot 10^{12}$K) – over a million times hotter than the core of the sun


trajectory of system
200 62.4 39 27 19.6 11.5 7.7 GeV
Au+Au Collisions
T_{ch} (MeV)
μ_B (MeV)
arXiv:1701.07065
00-05%
30-40%
60-80%
Cleymans et al.
Andronic et al.
Grand Canonical Ensemble (Yield Fit)

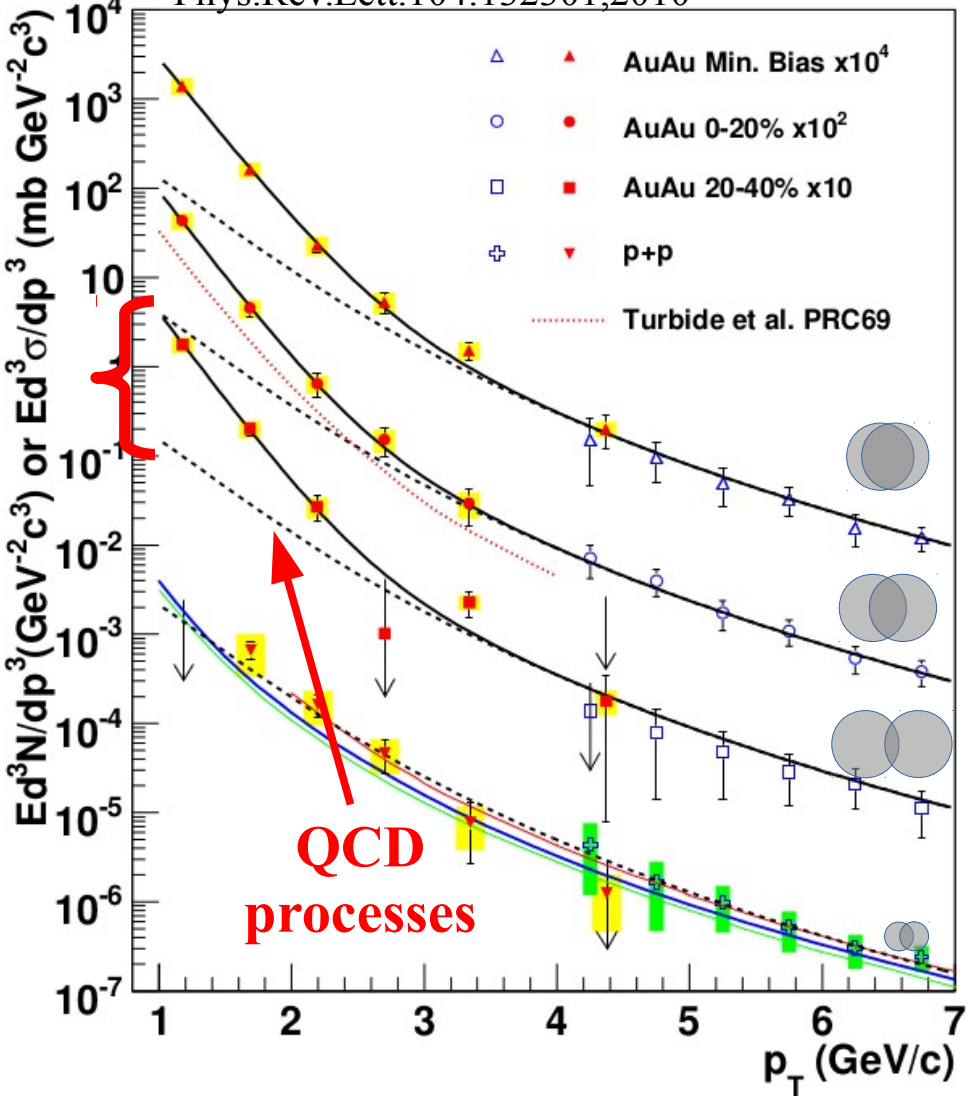
QGP Thermometers

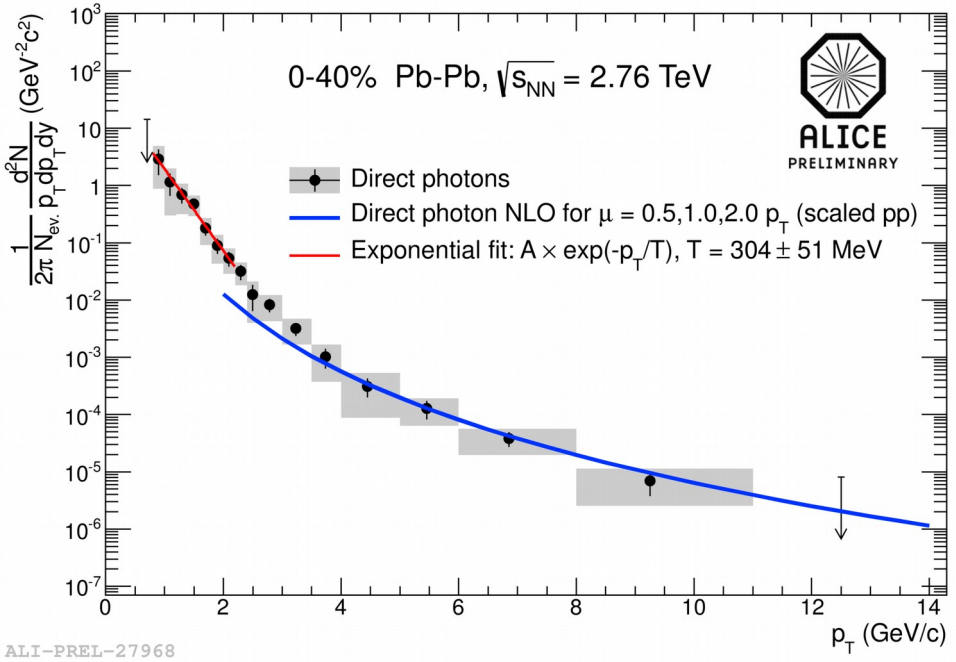
Measuring temperature



Thermal photons

Phys.Rev.Lett.104:132301,2010





ALICE collaboration:
Pb+Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV

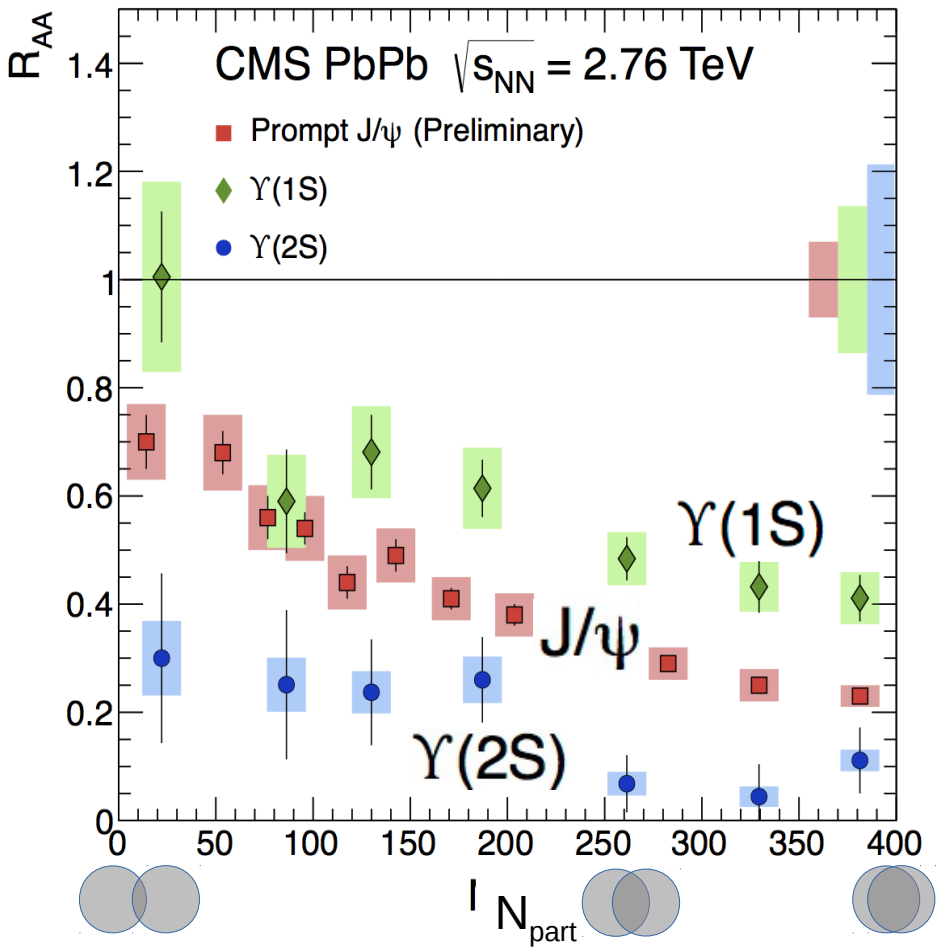
Inverse slope: T = 304 +/-51

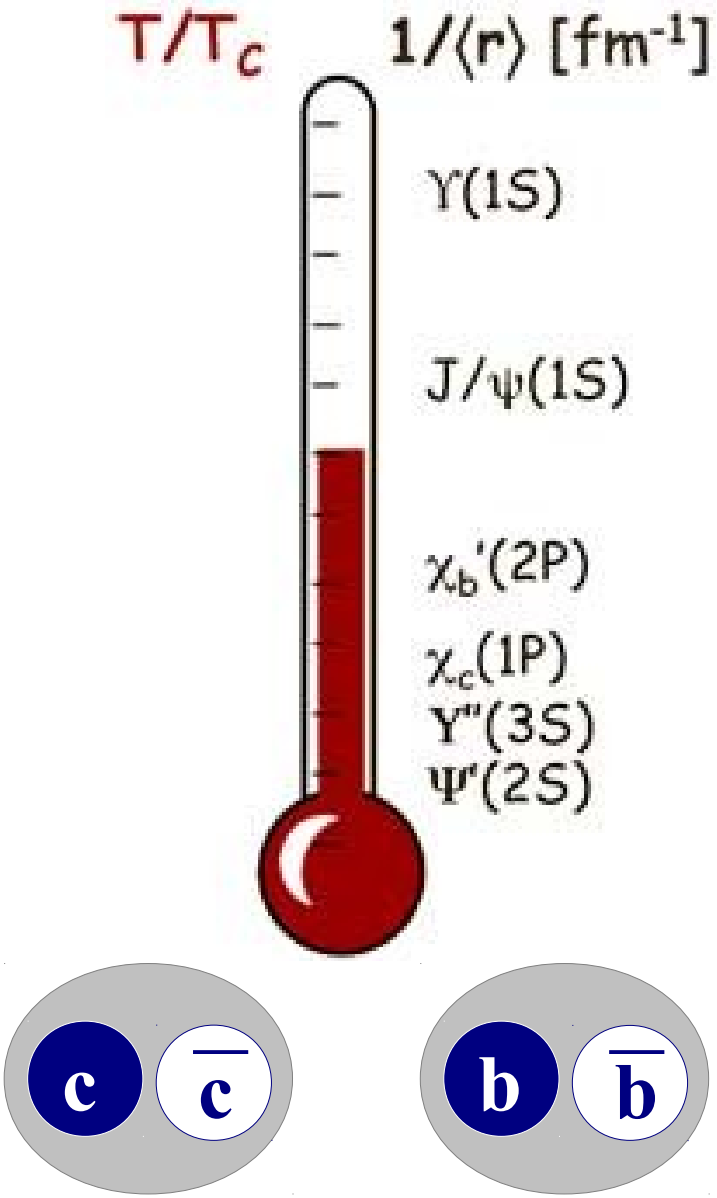
PHENIX collaboration: Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV

Inverse slope: T = 221 +/- 19 (stat) +/- 19 (syst) MeV

Building a quarkonium-thermometer

CMS-PAS HIN-11-011

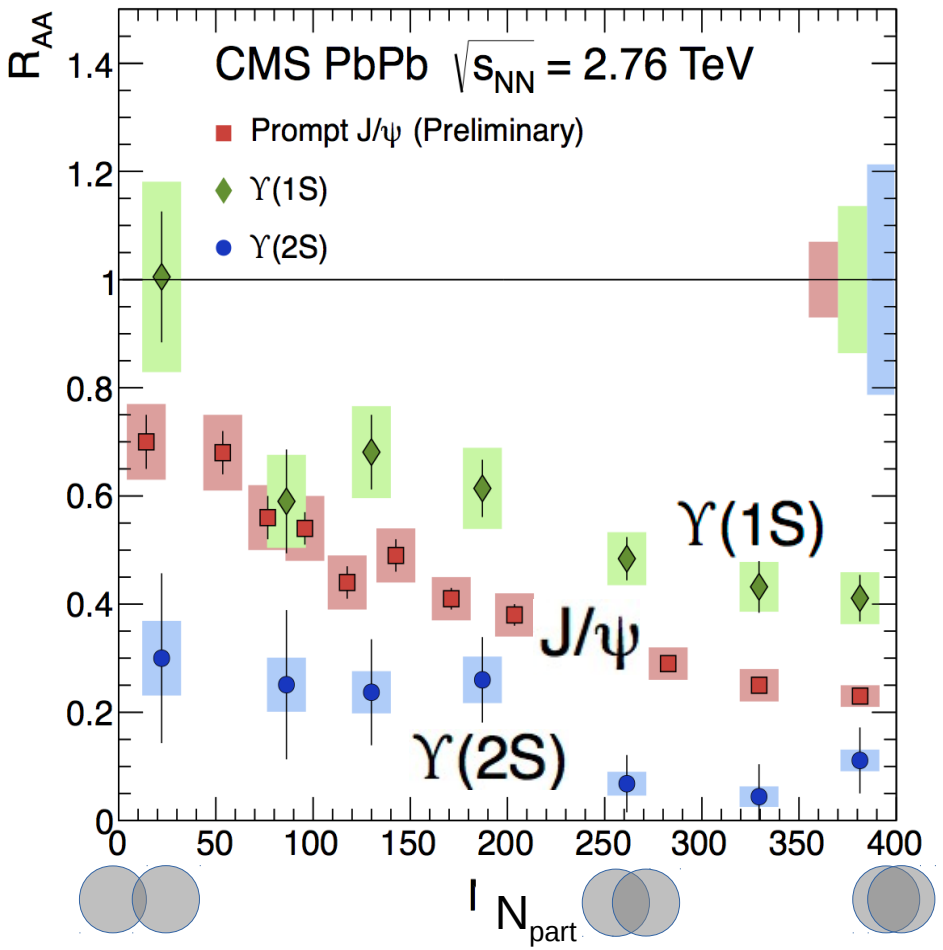




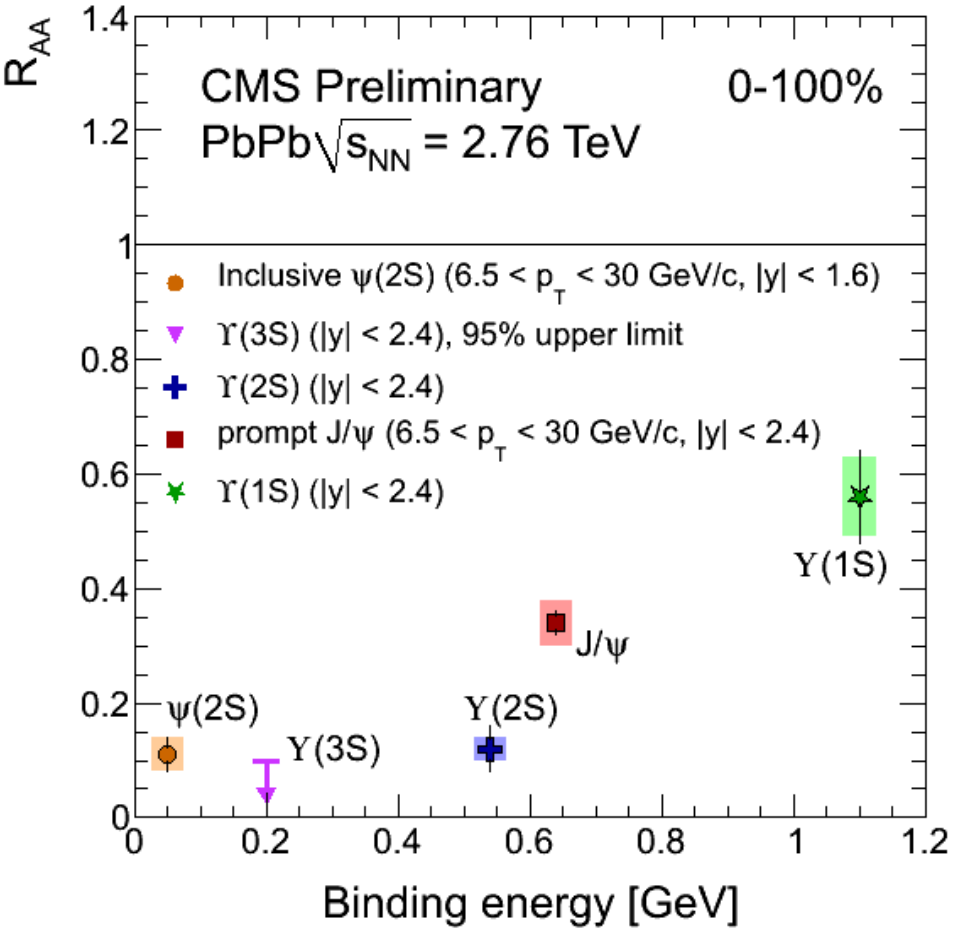
Clear hierarchy in R_{AA} of different quarkonium states

Building a quarkonium-thermometer

CMS-PAS HIN-11-011



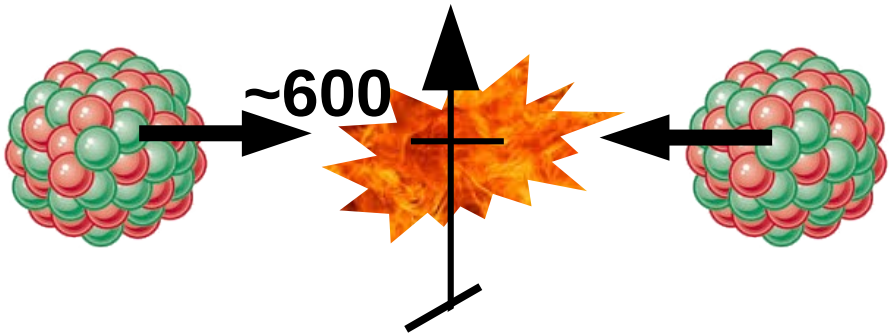
Note: $6.5<p_T<30$ GeV for J/ψ and ψ(2s)



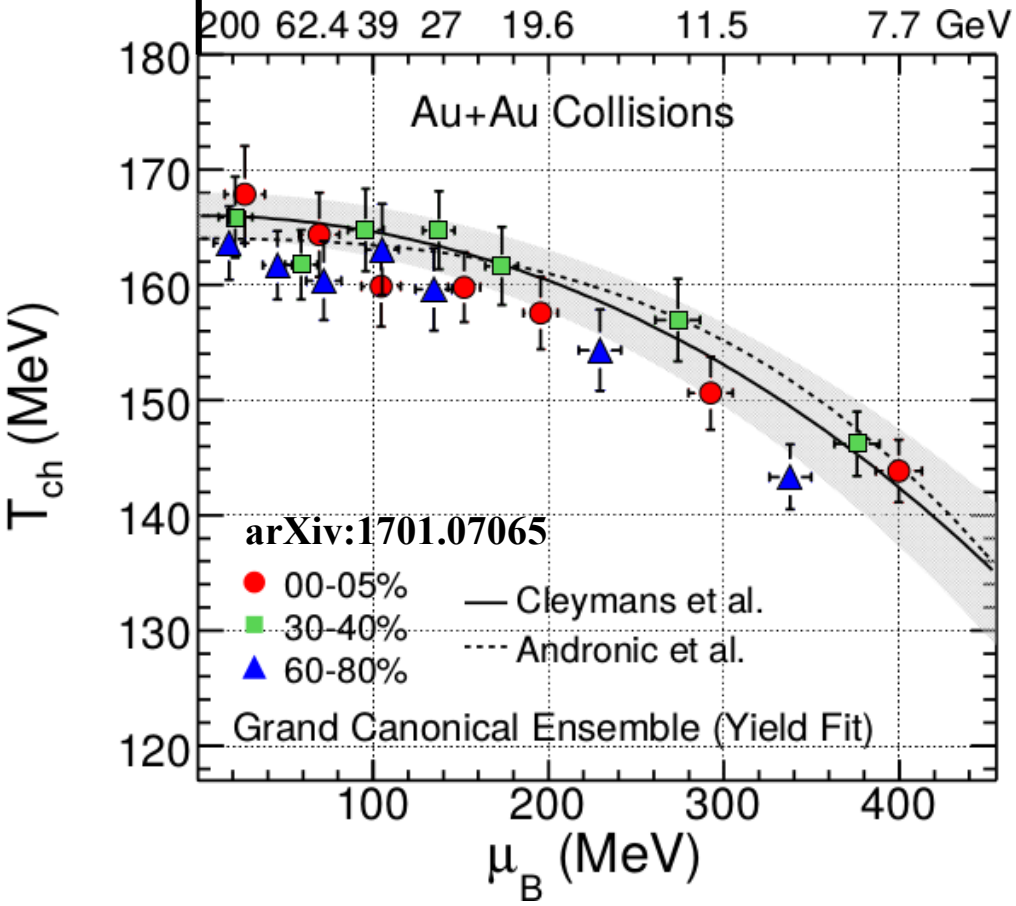
Clear hierarchy in R_{AA} of different quarkonium states

Expected in terms of binding energy

CMS-PAS HIN-12-014, HIN-12-007



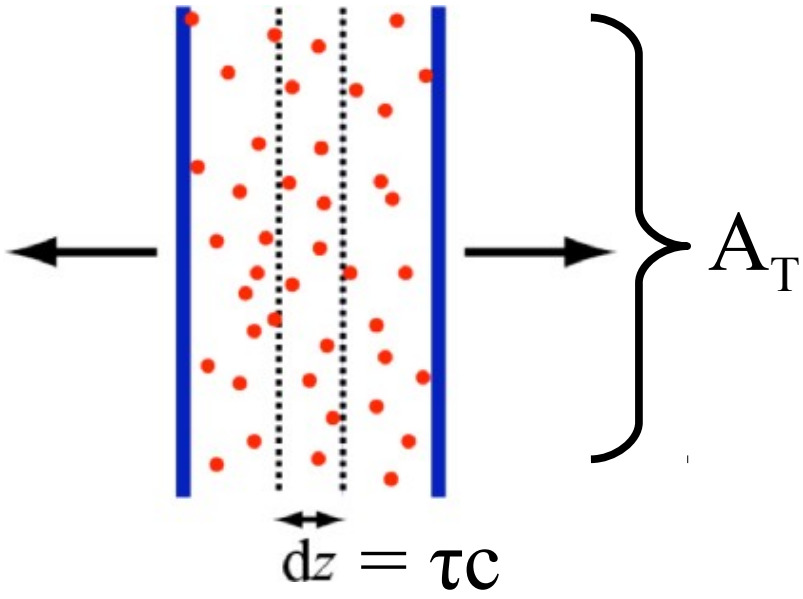
trajectory of system



QGP Energy Density

How can we estimate the energy density?

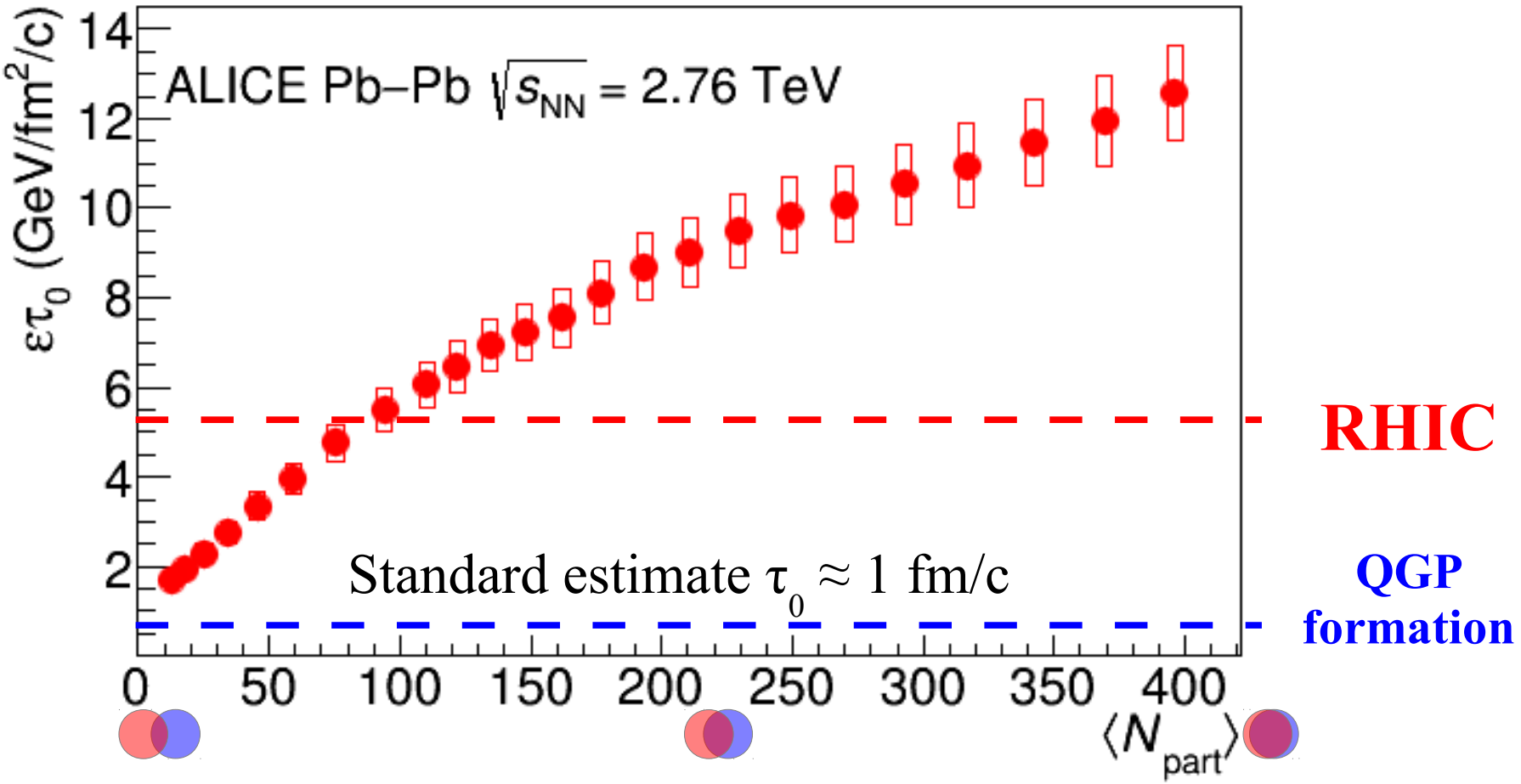
- Transverse energy (E_T)
  - sum of particle energies in transverse direction
- Volume $V = A_T \tau c$
- τ = formation time
- Energy density ε



$$\epsilon = \frac{1}{V}\frac{dE_T}{dy} = \frac{J}{A_T \tau c}\frac{dE_T}{d\eta}$$

- QGP formation for $\varepsilon > 0.5$ GeV/fm^3

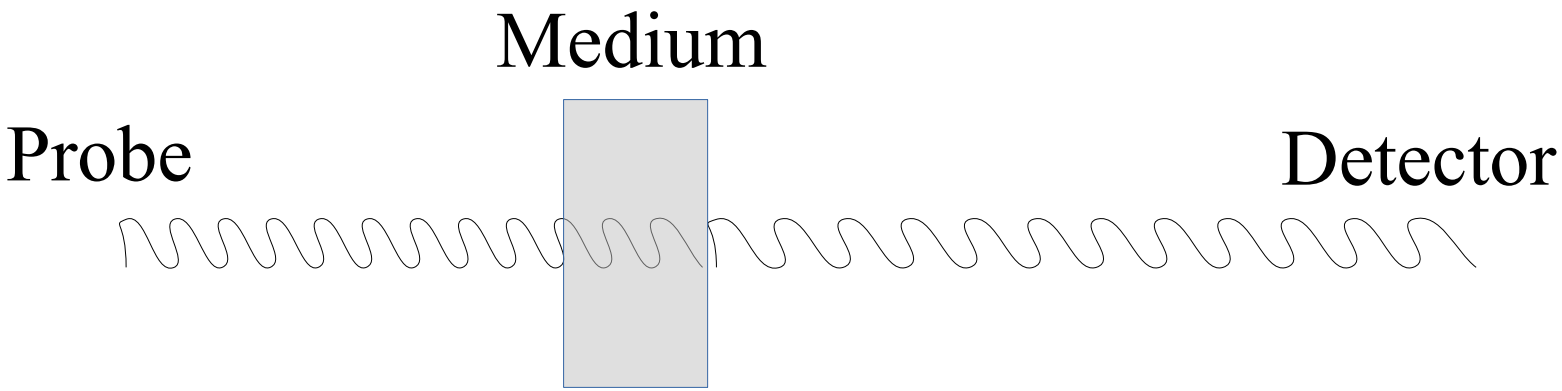
Energy density



$$\epsilon = \frac{1}{A\, c\, \tau_0} \frac{dE_T}{dy}$$

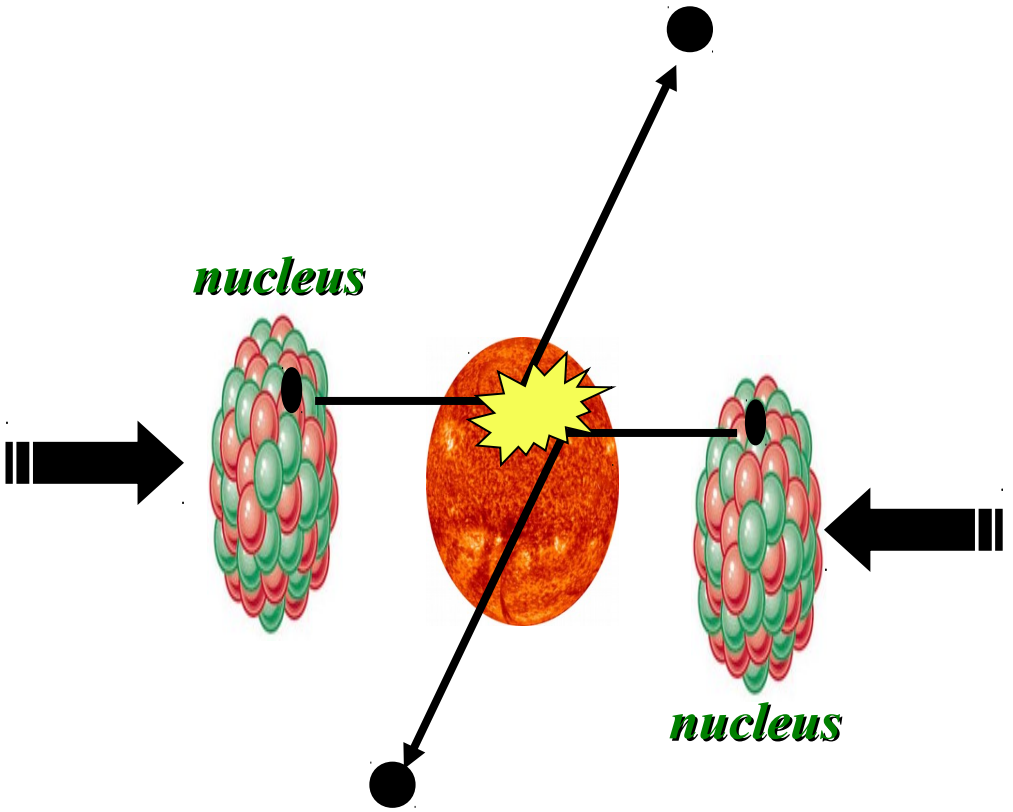
QGP Spectroscopy

Probing the Quark Gluon Plasma



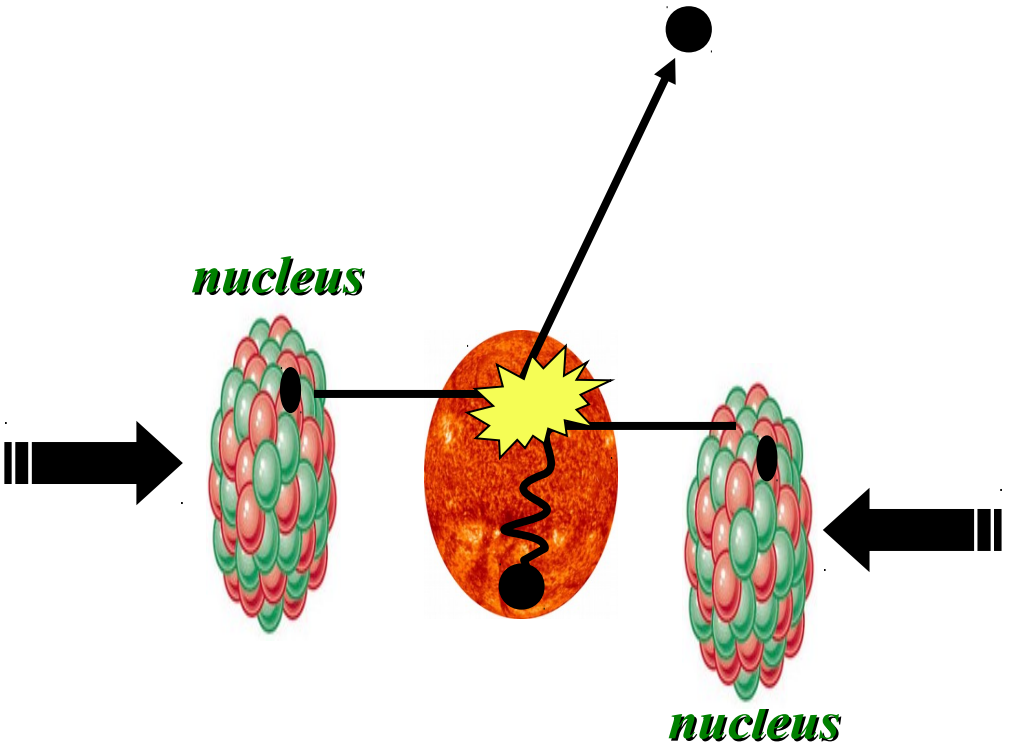
Want a probe which traveled through the collision
QGP is very short-lived (~1-10 fm/c) →
cannot use an external probe

Probes of the Quark Gluon Plasma



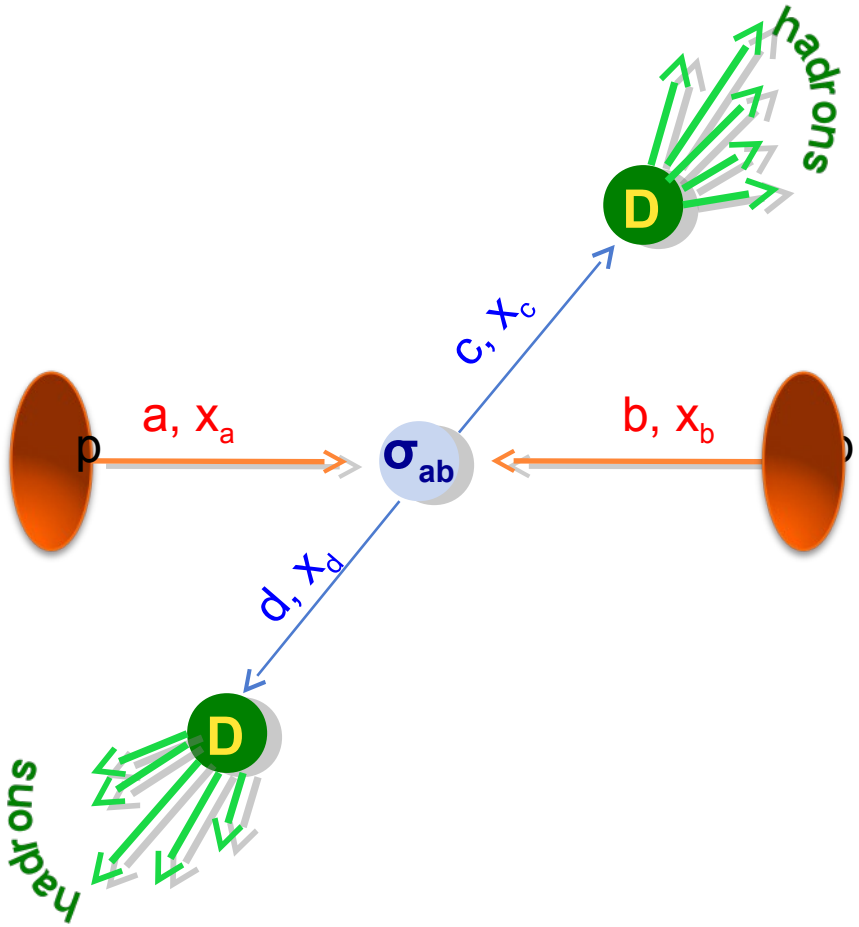
Want a probe which traveled through the medium
QGP is short lived → need a probe created in the collision

Probes of the Quark Gluon Plasma

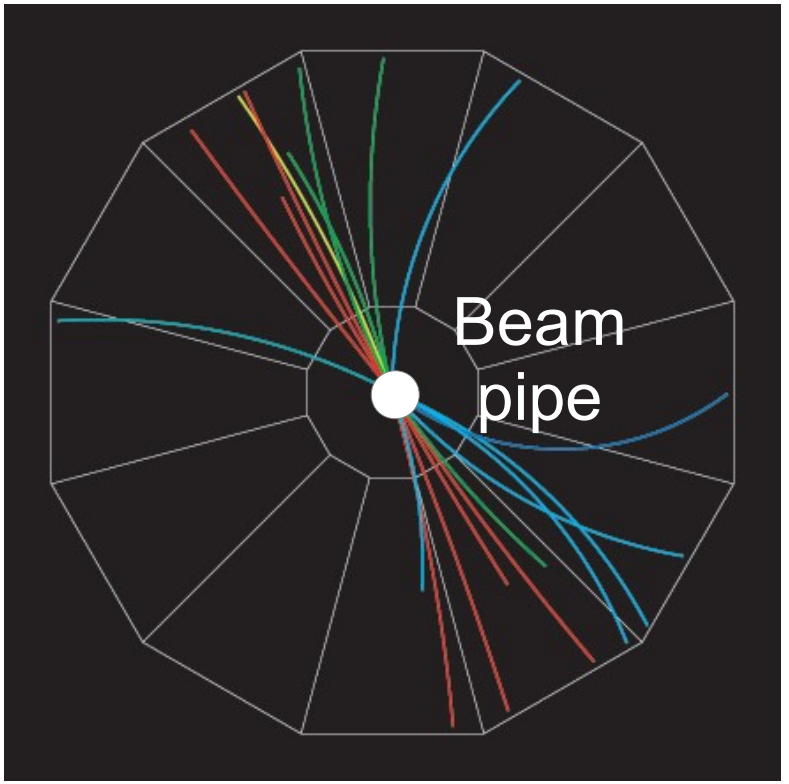


Want a probe which traveled through the medium
QGP is short lived → need a probe created in the collision
We expect the medium to be dense → absorb/modify probe

Jets

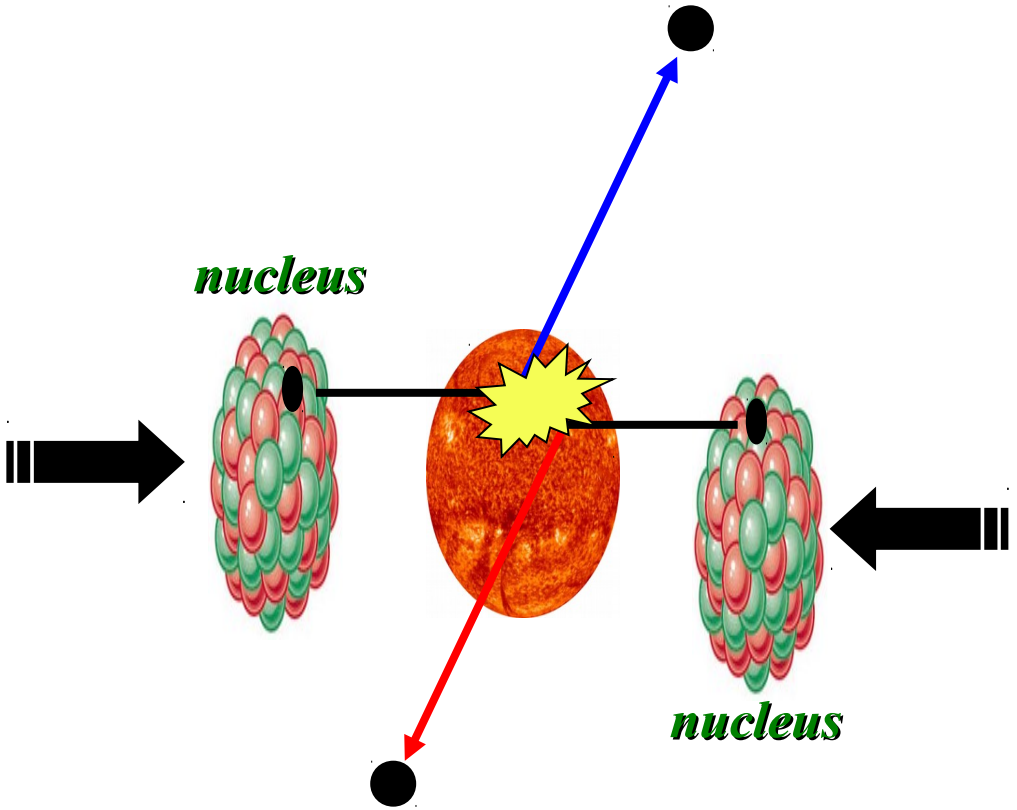


p+p → dijet

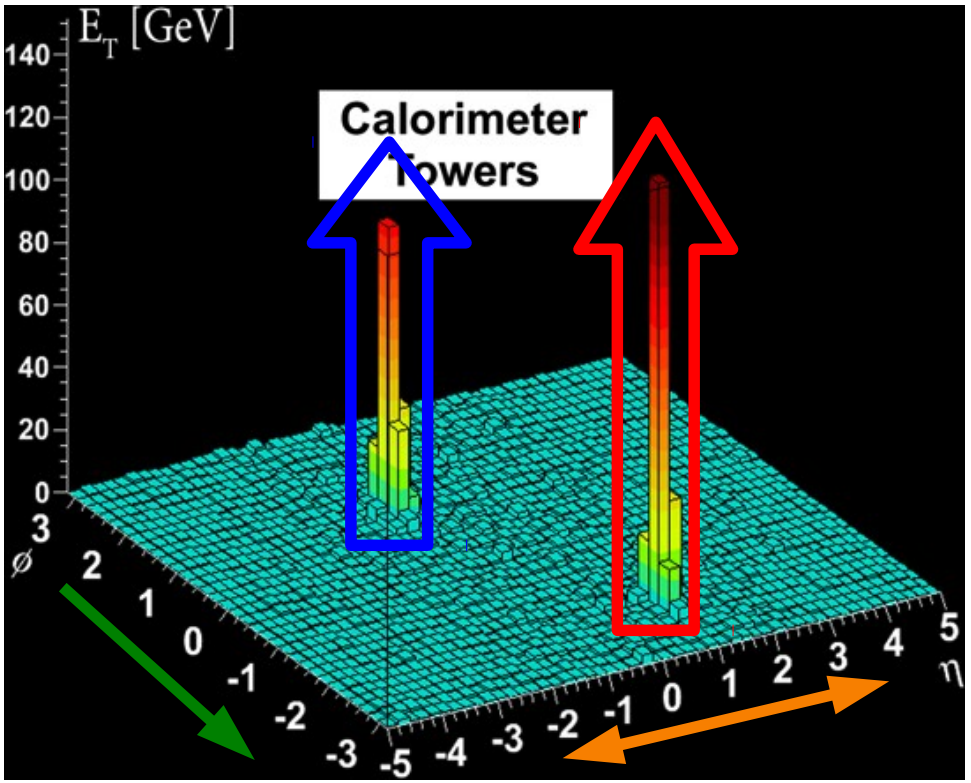


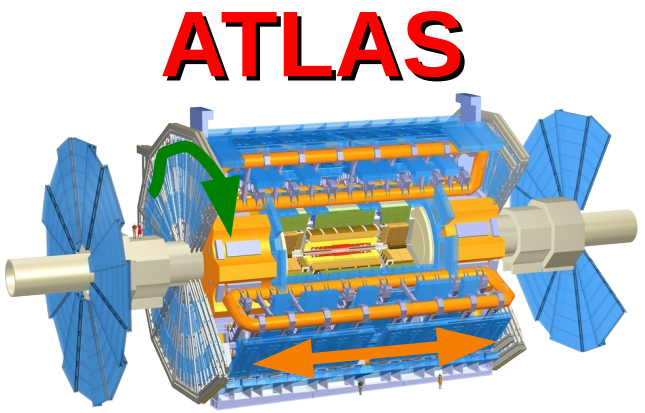
Jets – hard parton scattering leads to back-to-back quarks or gluons, which then fragment as a columnated spray of particles

Jets

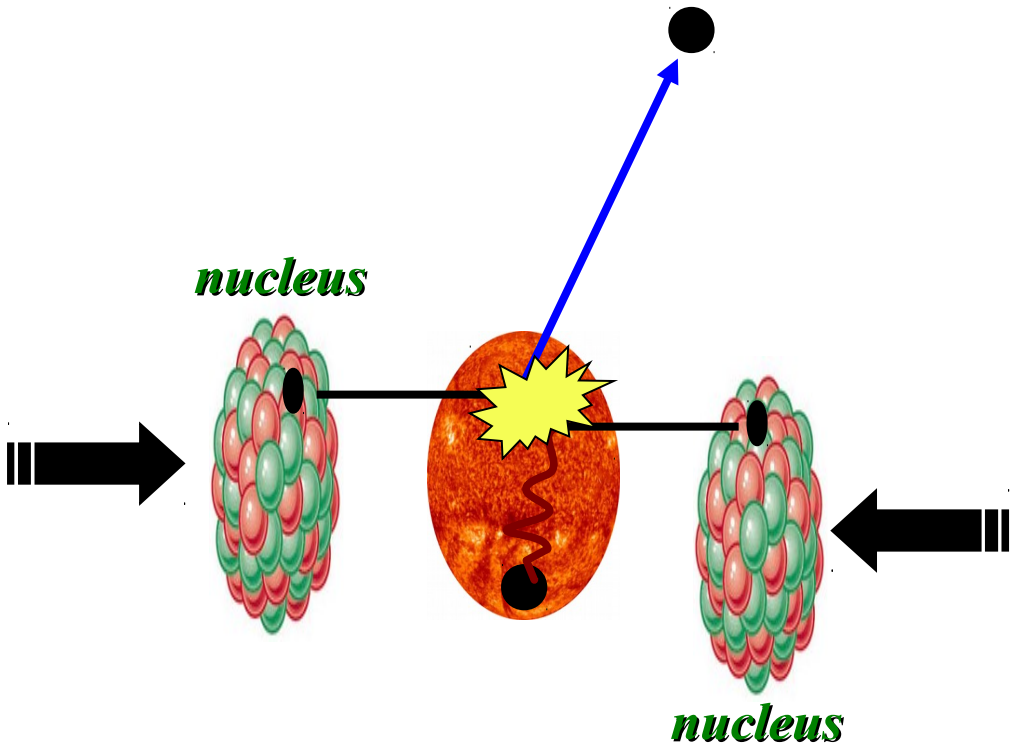


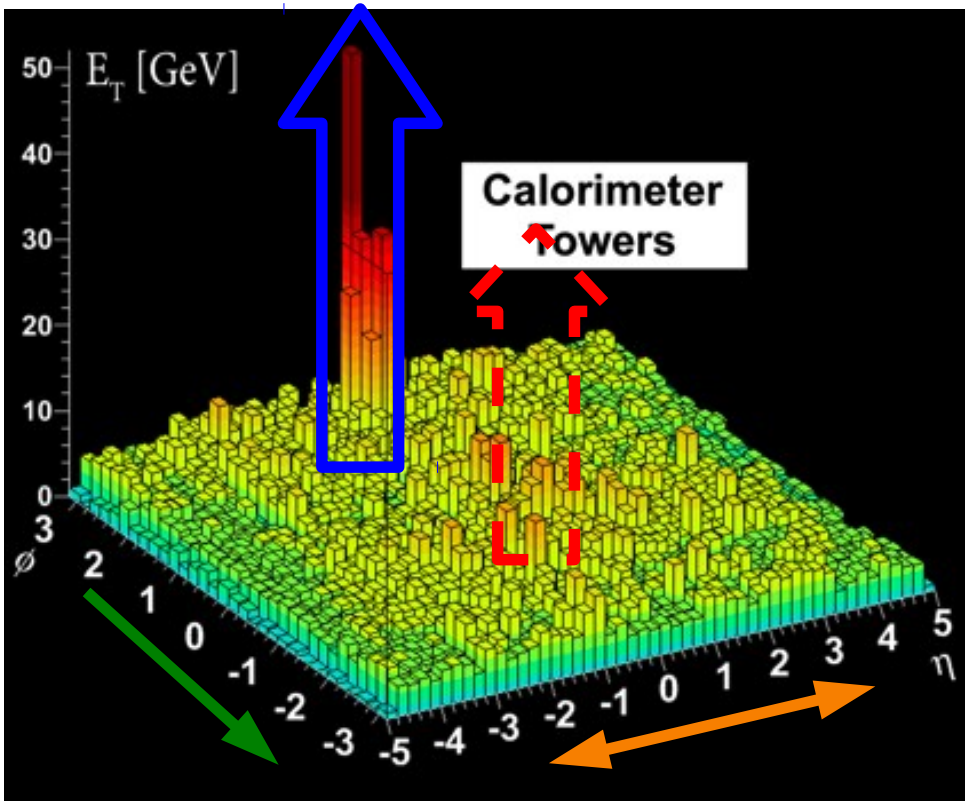
Phys.Rev.Lett. 105 (2010) 252303



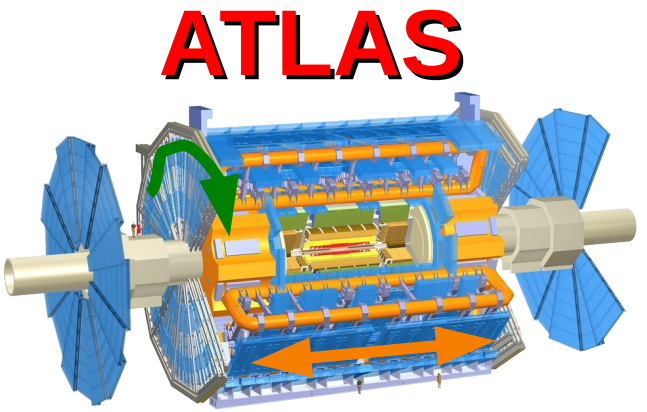


Quenched jets



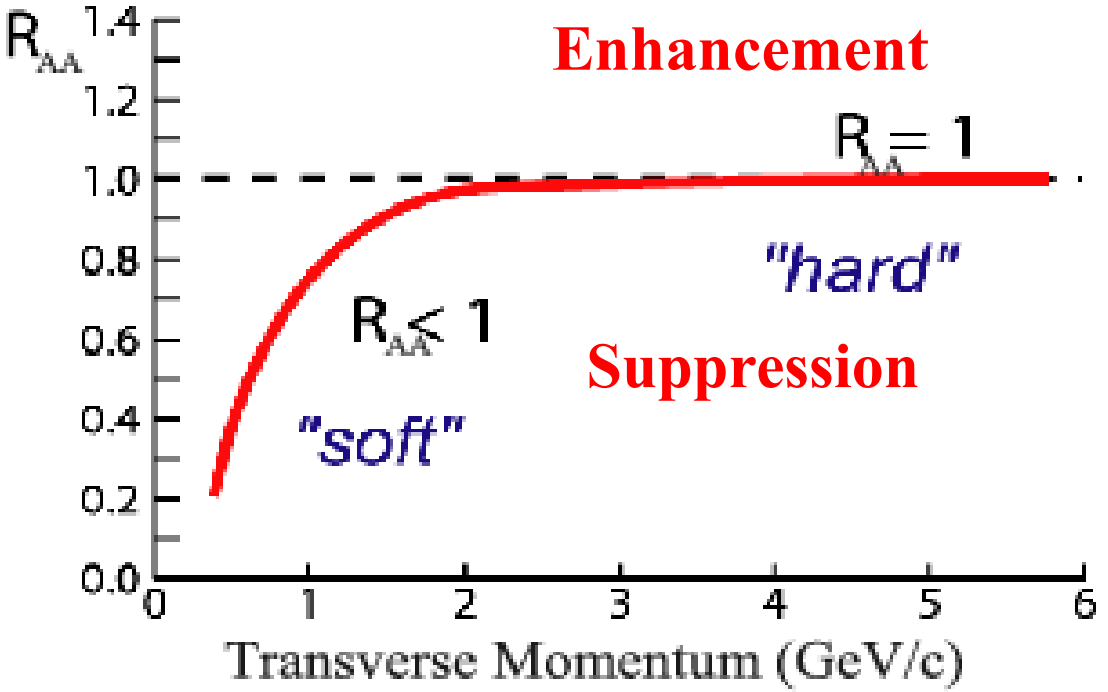


- One of the jets is absorbed by the medium
- The quark or gluon has equilibrated with the medium
- Phys. Rev. Lett. 105, 252303 (2010)



Nuclear modification factor

- Measure spectra of probe (jets) and compare to those in p+p collisions or peripheral A+A collisions
- If high-p_T probes (jets) are suppressed, this is evidence of jet quenching



$$R_{AA} = \frac{d^2N_{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{pp}/dp_T d\eta}$$

Nuclear modification factor

- Measure spectra of probe (jets) and compare to those in p+p collisions or peripheral A+A collisions
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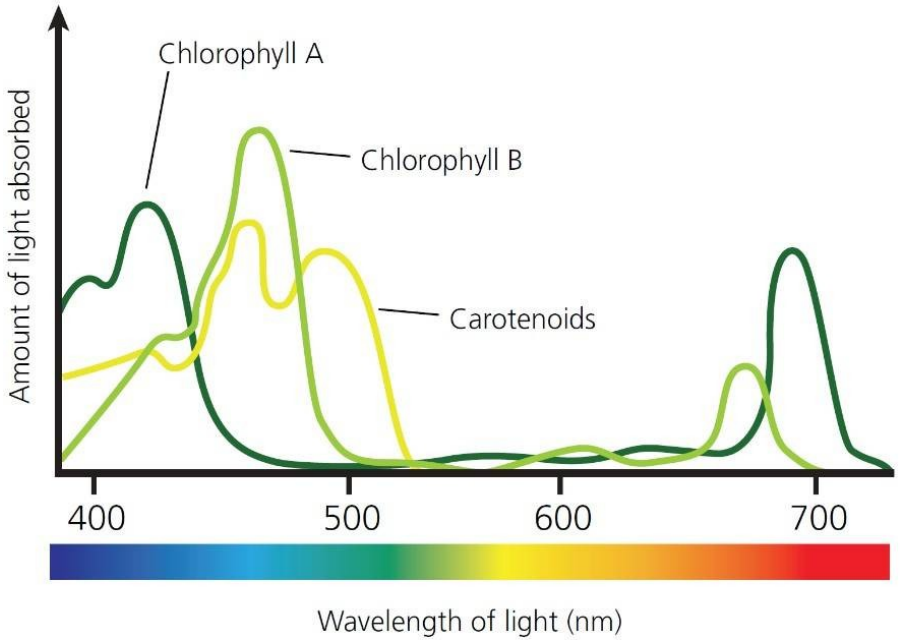
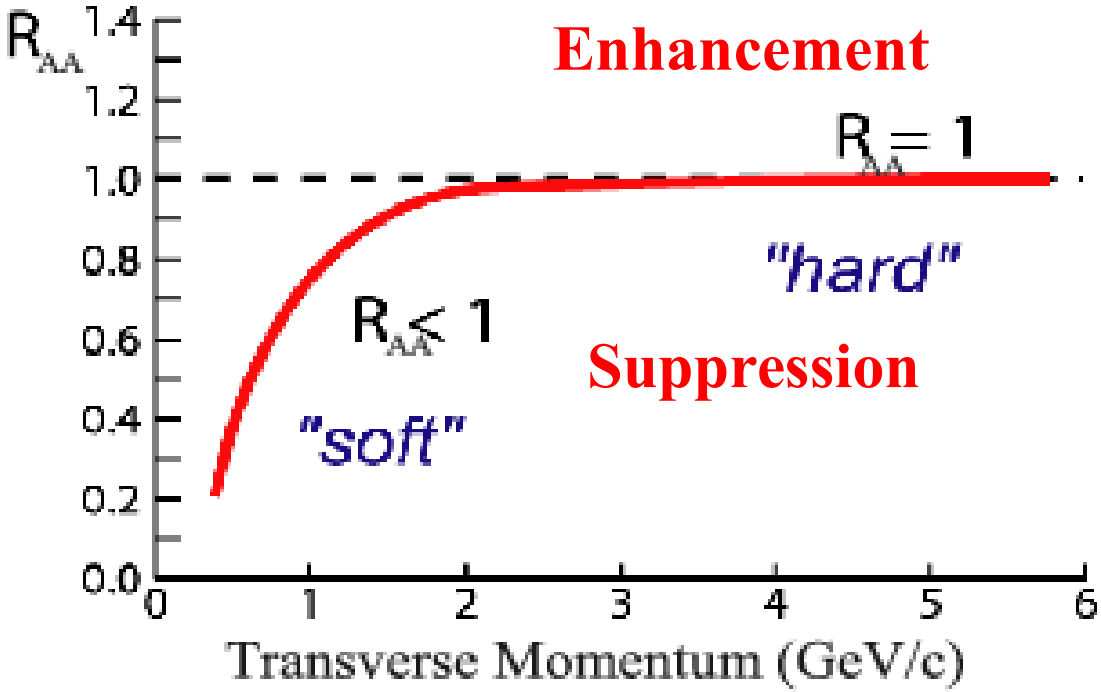
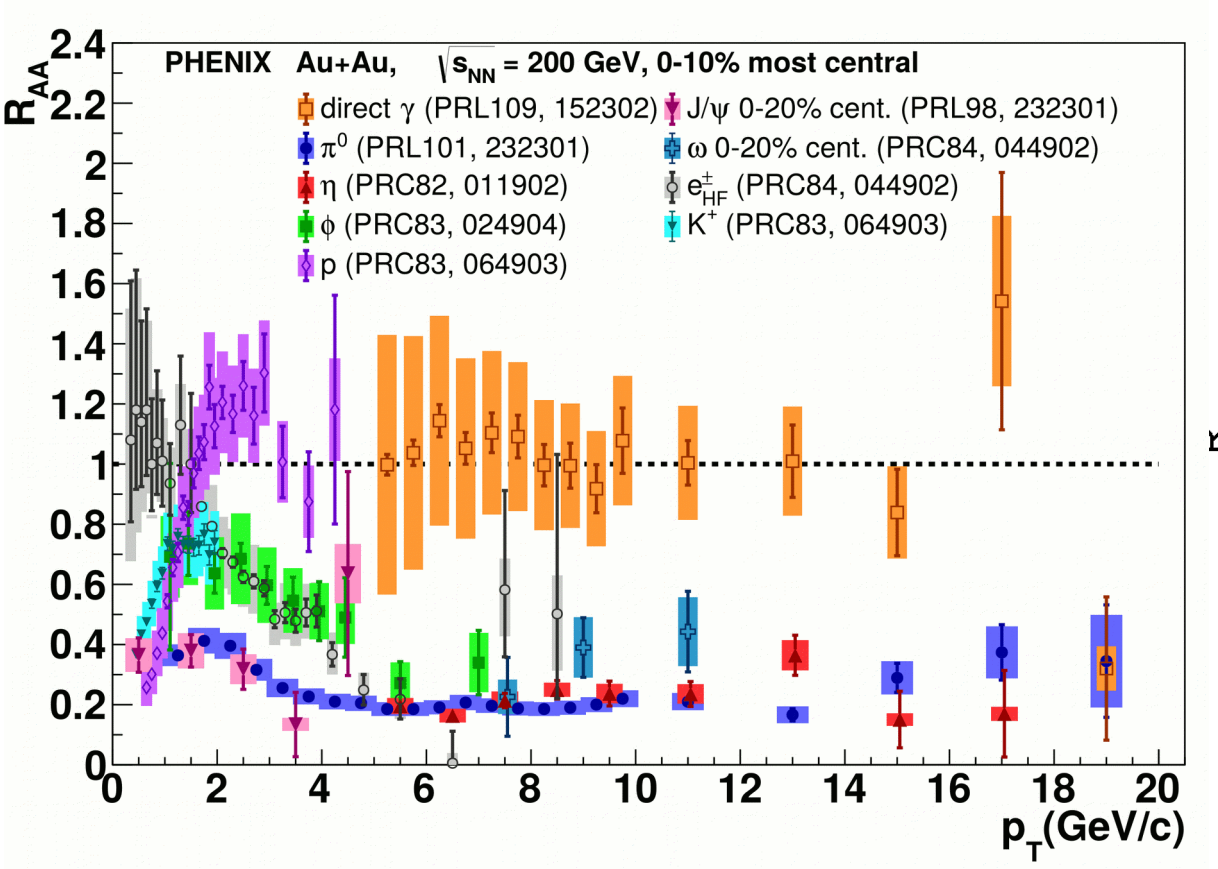




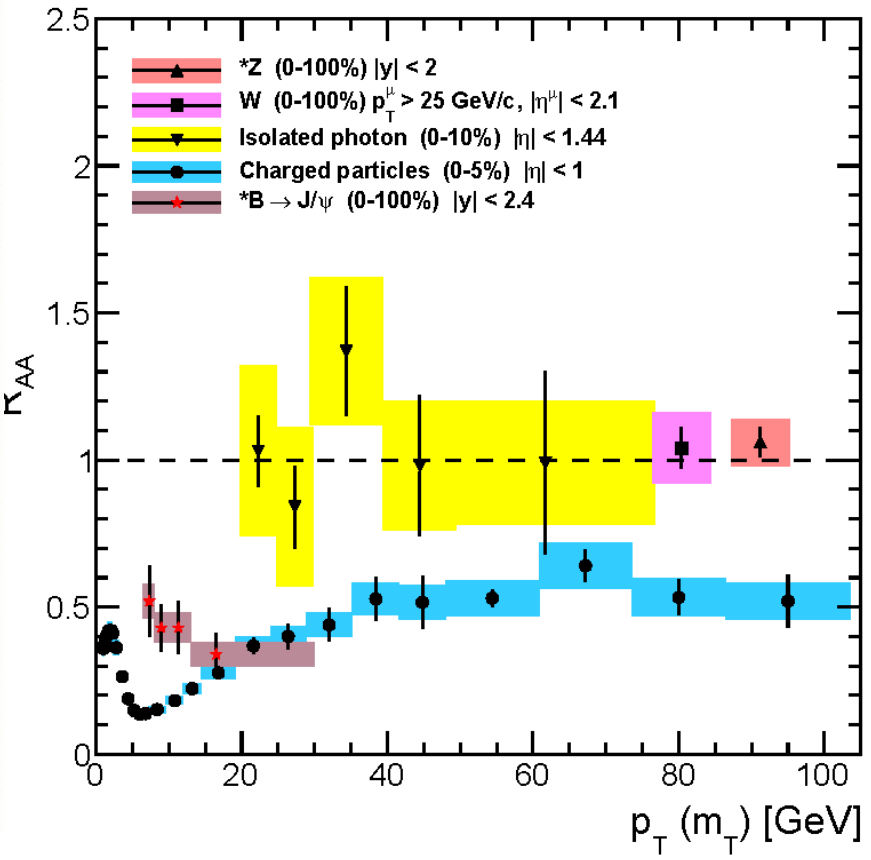
$$R_{AA} = \frac{d^2N_{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{pp}/dp_T d\eta}$$

Nuclear modification factor R_{AA}

RHIC



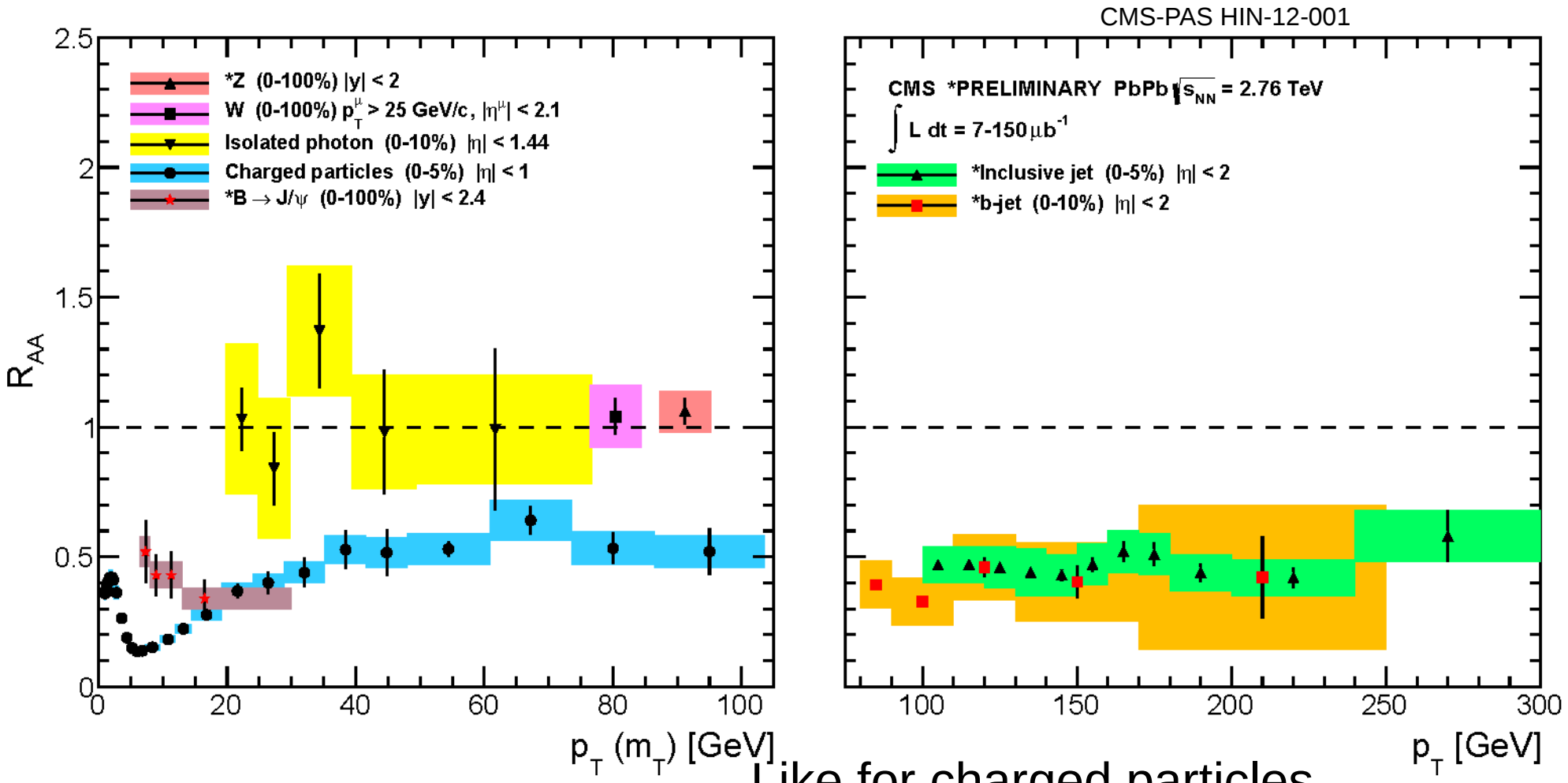
LHC



- *Electromagnetic probes* – consistent with no modification – medium is transparent to them
- *Strong probes* – significant suppression – medium is opaque to them

Nuclear modification factor R_{AA} at LHC

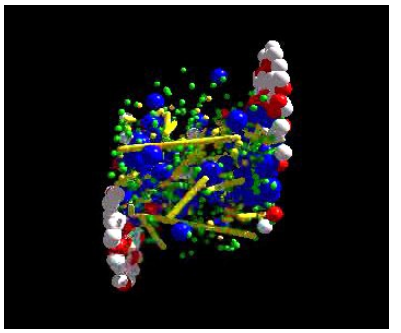
Fully unfolded inclusive jet R_{AA}
pp 2.76 TeV reference

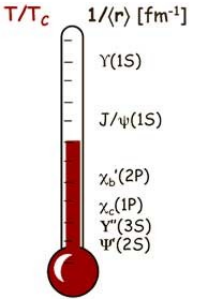


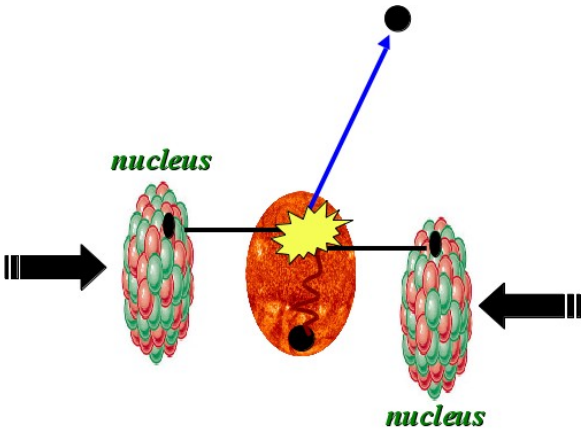
Like for charged particles, high-p_T jet R_{AA} flat at ≈ 0.5

Take home messages

- If we get nuclear matter dense enough, we make a new phase of matter, which we produce in high energy heavy ion collisions.
- This medium is extremely hot and dense...
- ...and opaque to colored probes and translucent to electromagnetic probes.







About me

- BS, Colorado State University, 2003
- PhD, Yale University, 2009
- Postdoc, University of Tennessee, Knoxville, 2009-2012
- Assistant prof, University of Tennessee, Knoxville 2012 –

- Active on issues related to women in physics
- Working on being a more effective ally for people of color
- Parent
- Brew beer & wine, keep bees, avid cook, cyclist
- Talk to me about: strategies for dealing with harassment, careers outside of physics, choosing a mentor, having kids and a career