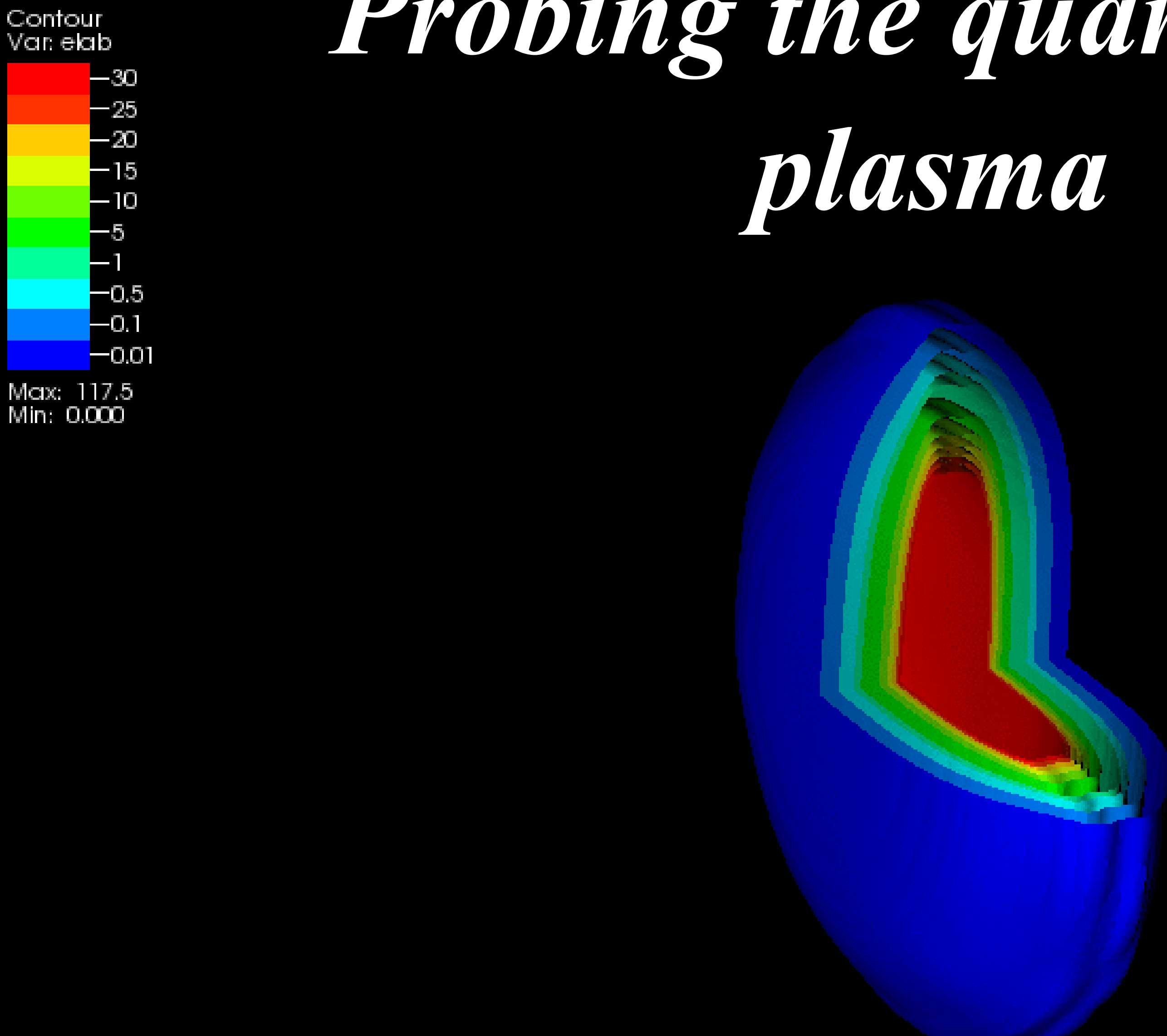
Probing the quark gluon plasma

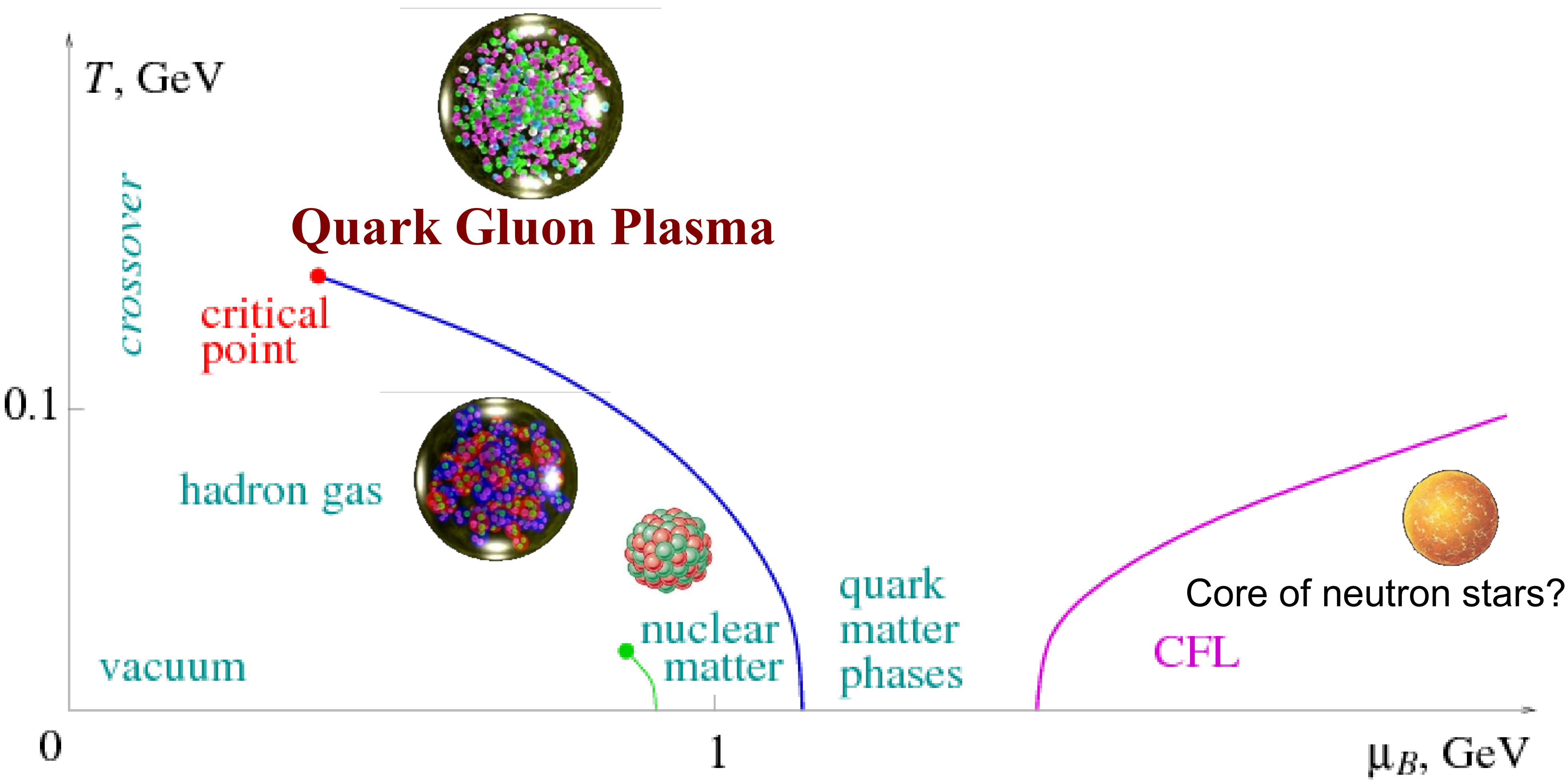


Christine Nattrass

University of Tennessee at Knoxville

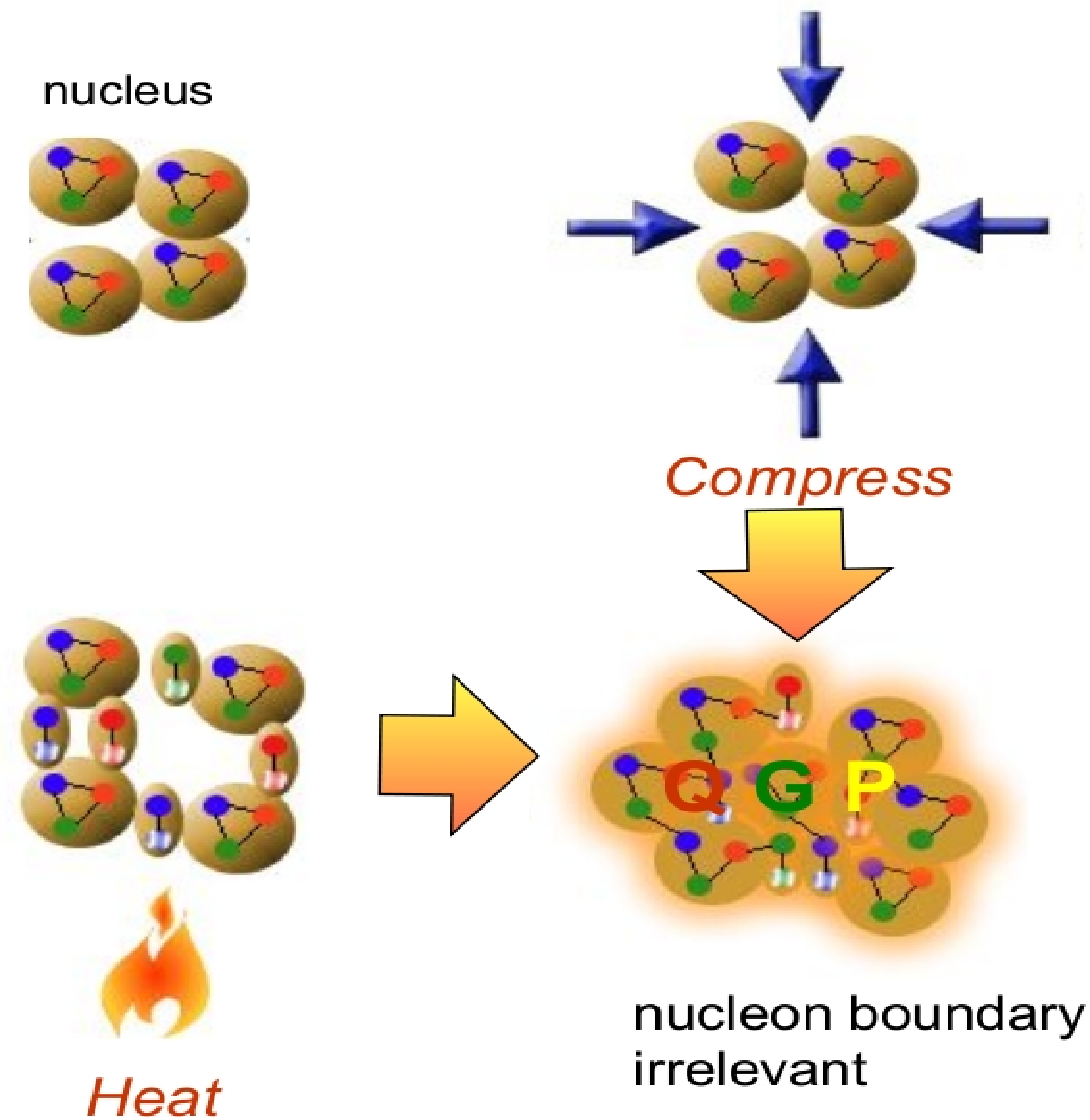
Calculations done on the Titan supercomputer by the CJet collaboration https://sites.google.com/site/cjetsite/

Phase diagram of nuclear matter

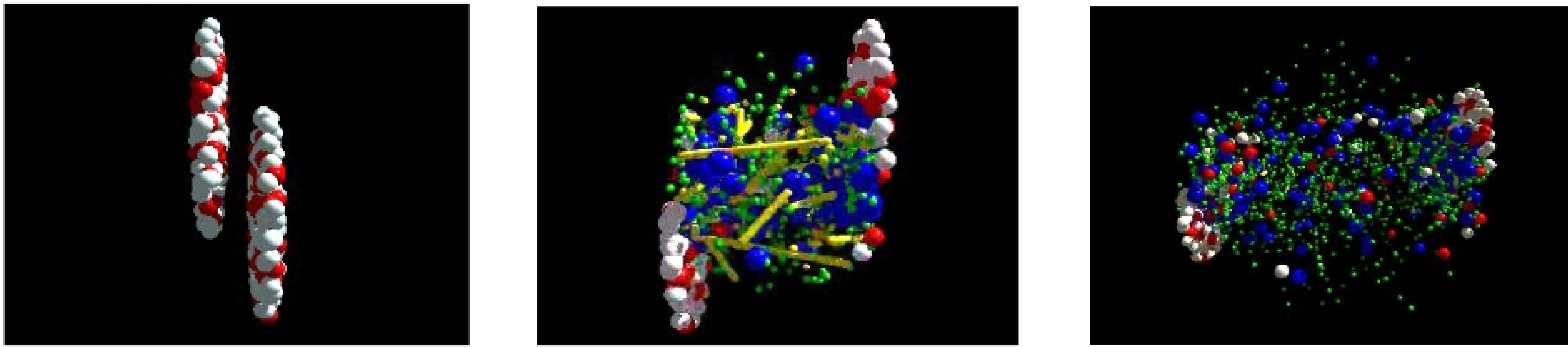


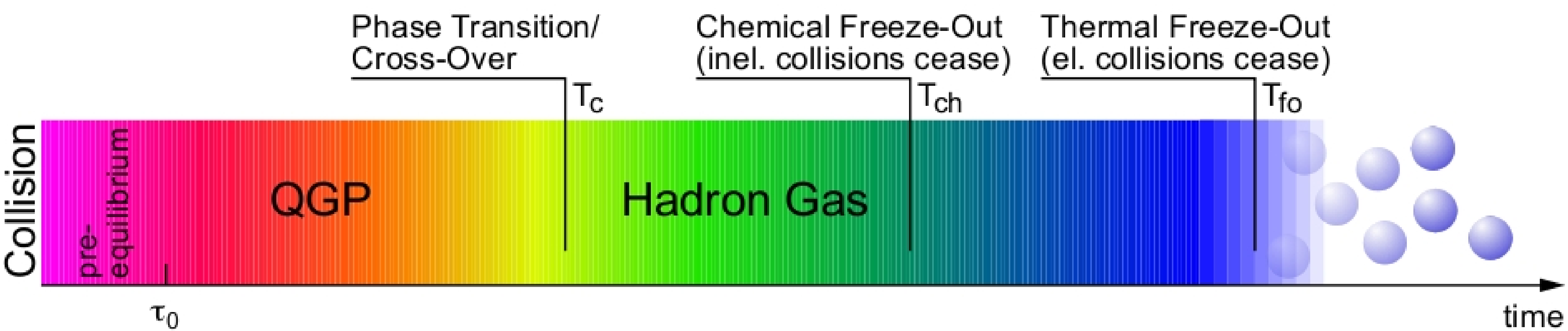
Quark Gluon Plasma – a *liquid* of quarks and gluons created at temperatures above ~170 MeV ($2\cdot10^{12}$K) – over a million times hotter than the core of the sun

How to make a Quark Gluon Plasma

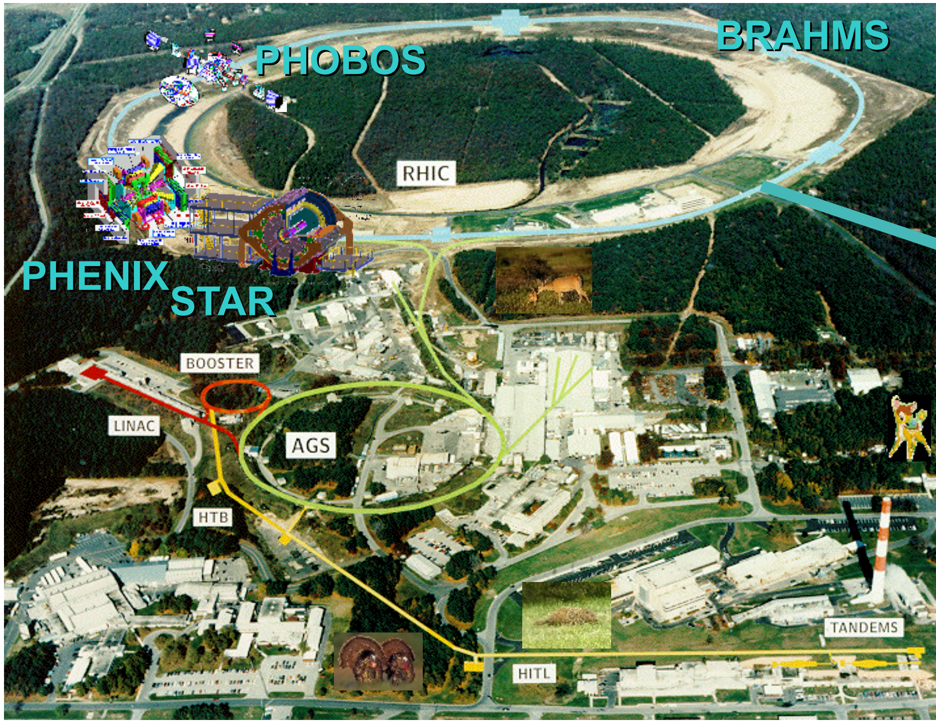


The phase transition in the laboratory



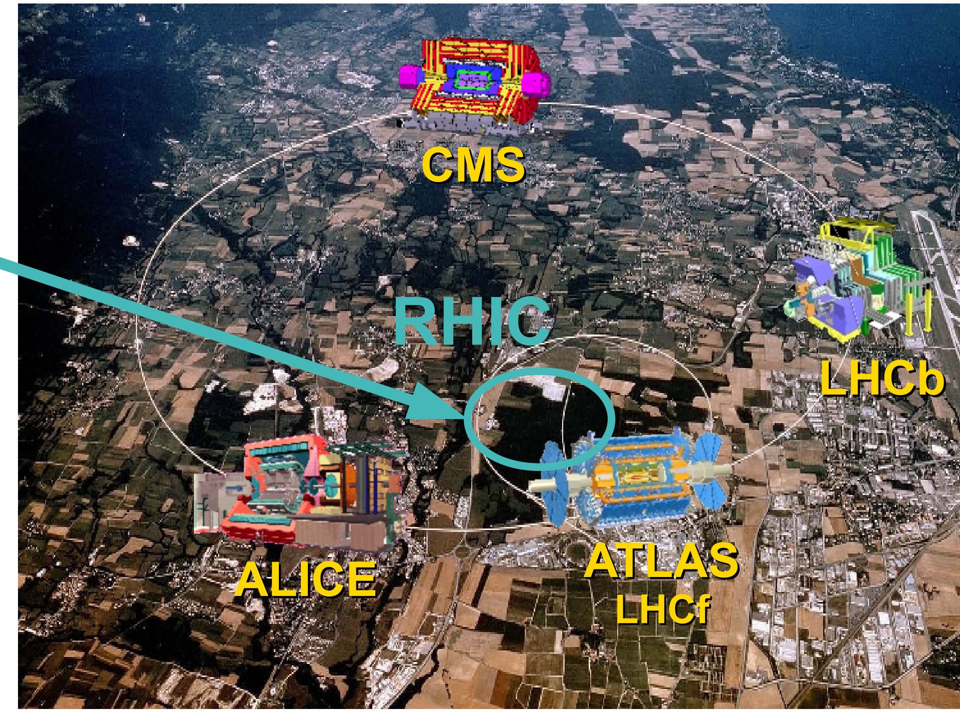


Relativistic Heavy Ion Collider

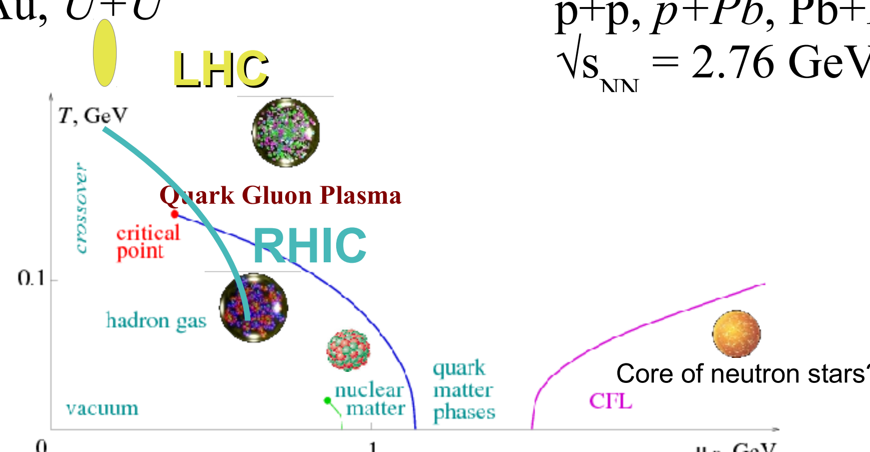


Upton, NY
1.2km diameter
p+p, d+Au, Cu+Cu, Au+Au, *U+U*
$\sqrt{s_{NN}}$ = 9 - 200 GeV

Large Hadron Collider



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



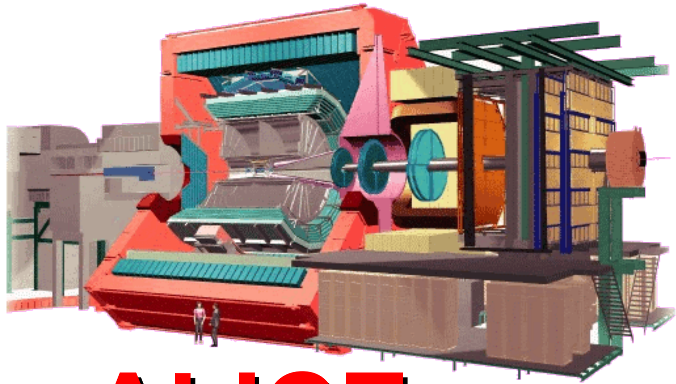
Comparison of colliders

	RHIC	**LHC**	
$\sqrt{s_{NN}}$ (GeV)	9-200	2760, 5500	*center of mass energy*
$dN_{ch}/d\eta$	~1200	~1600	*number of particles*
T/T_c	1.9	3.0-4.2	*temperature*
ε (GeV/fm^3)	5	~15	*energy density*
τ_{QGP} (fm/c)	2-4	>10	*lifetime of QGP*

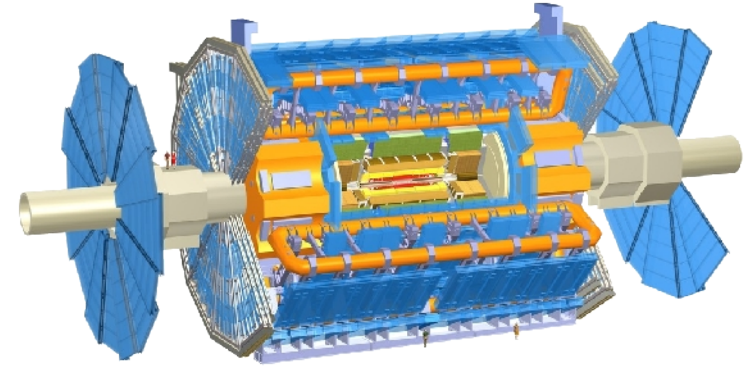
RHIC and LHC:

Cover 2 –3 decades of energy ($\sqrt{s_{NN}}$ = 9 GeV –5.5 TeV)

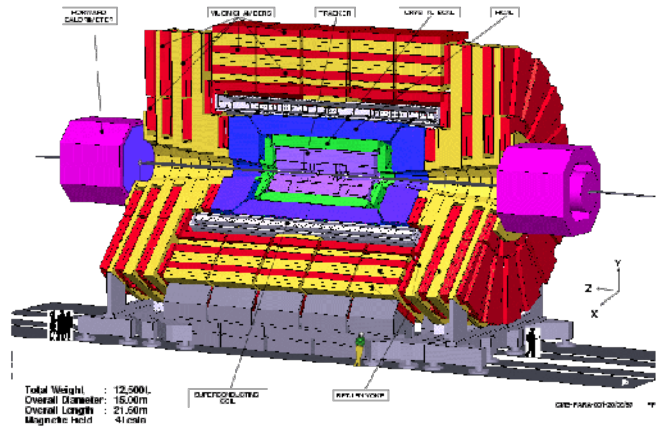
To discover the properties of hot nuclear matter at T ~ 150 –600 MeV



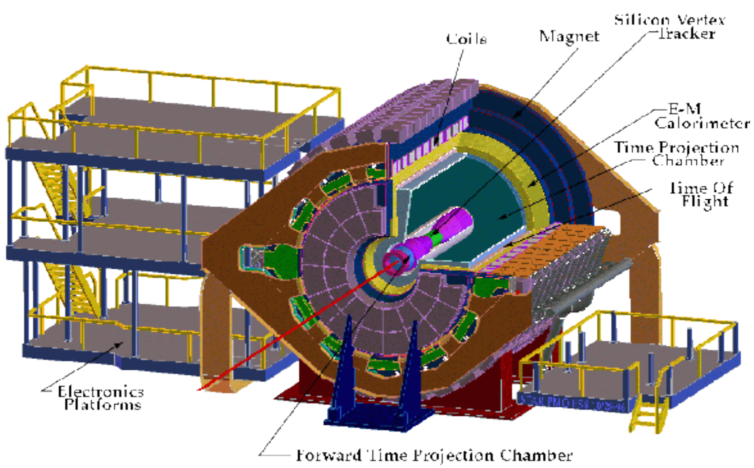
ALICE



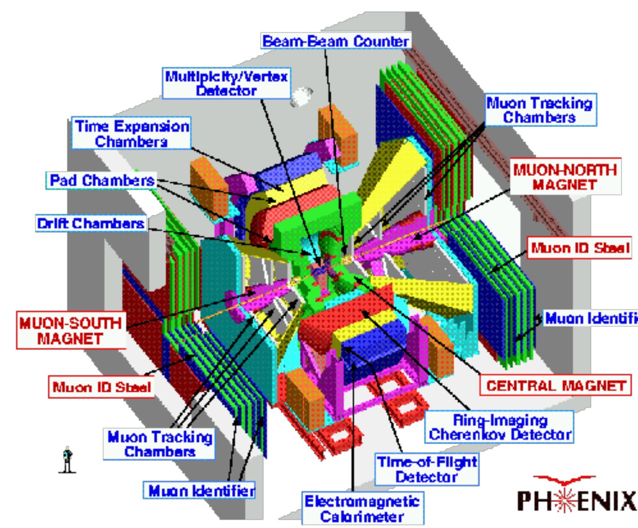
ATLAS



CMS

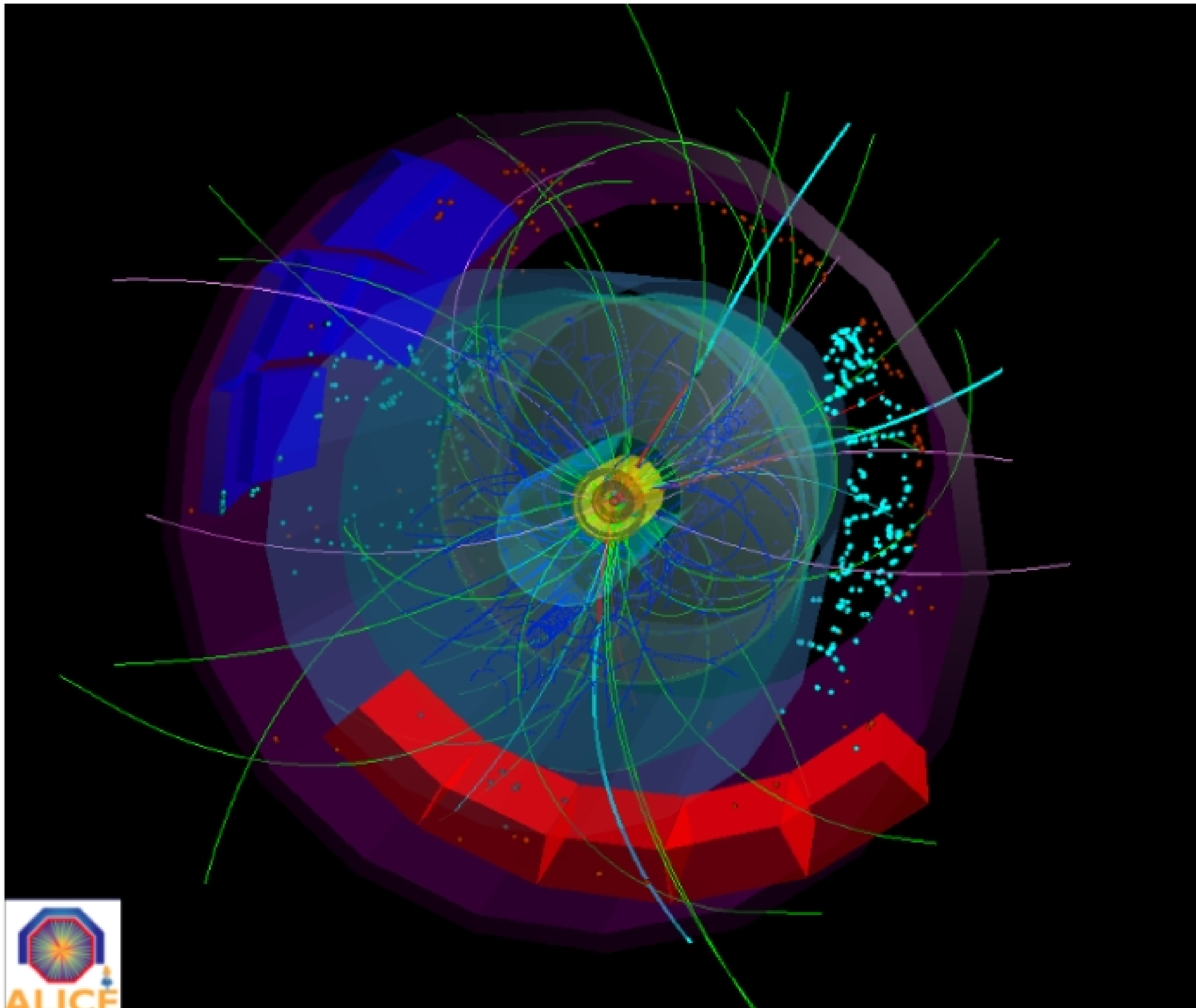


STAR



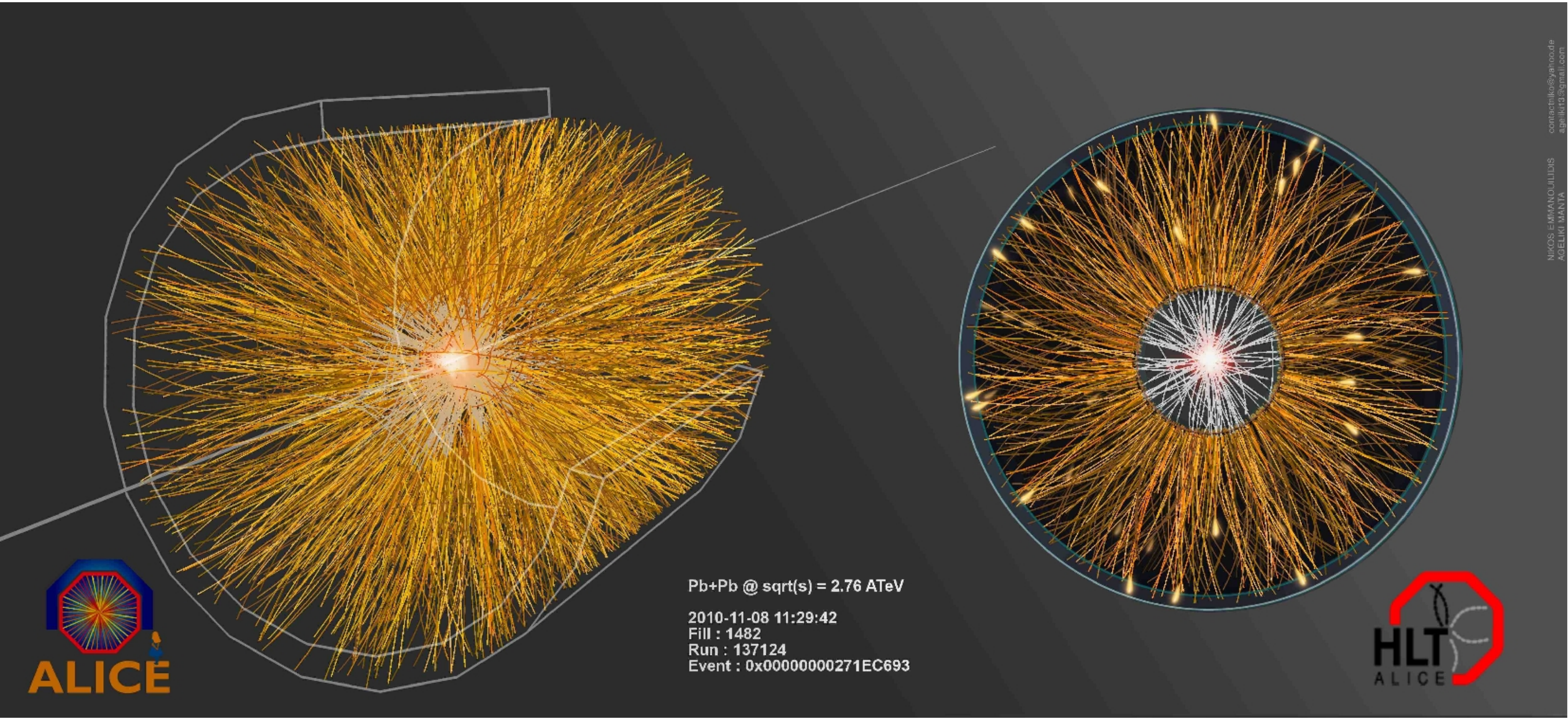
PHENIX

p+p collisions

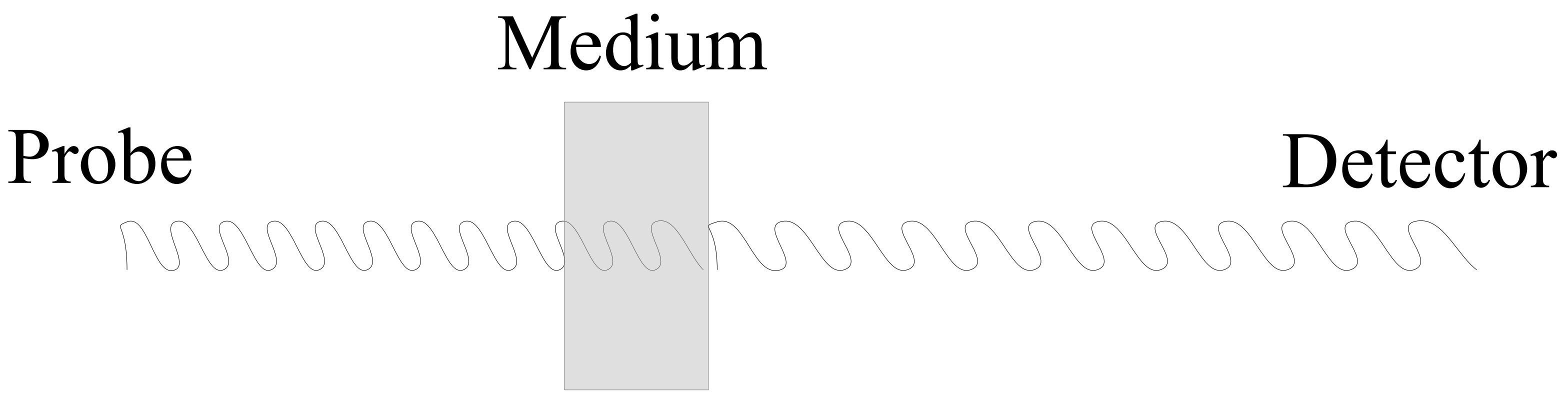


3D image of each collision

Pb+Pb collisions

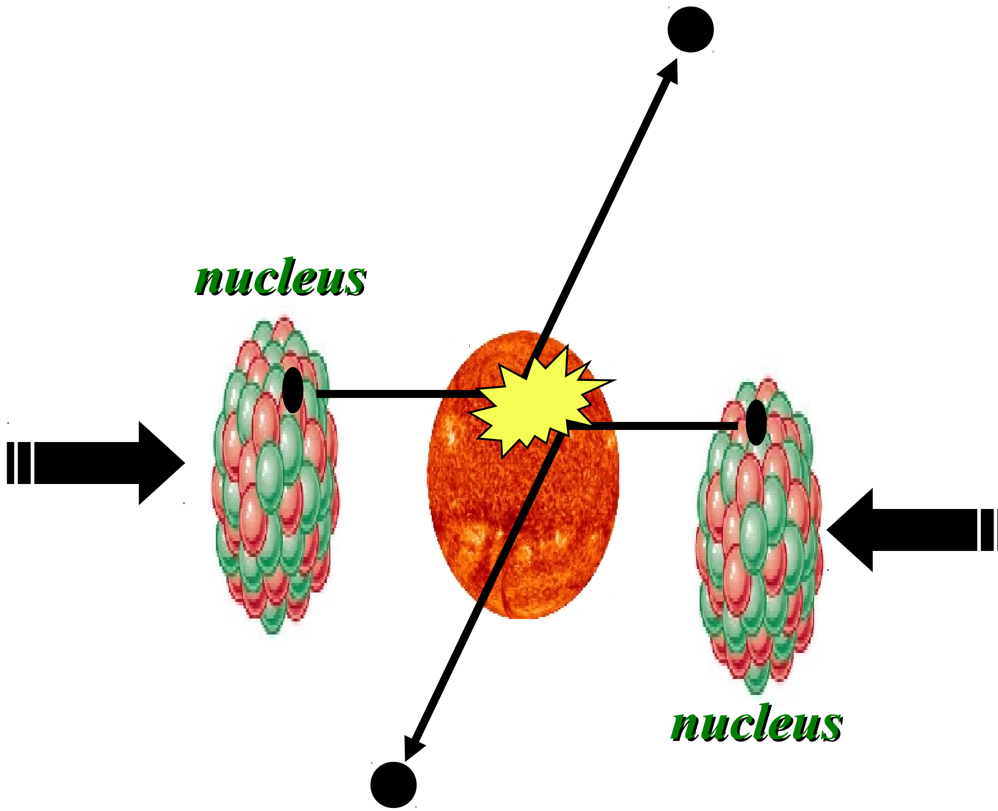


Probing the Quark Gluon Plasma



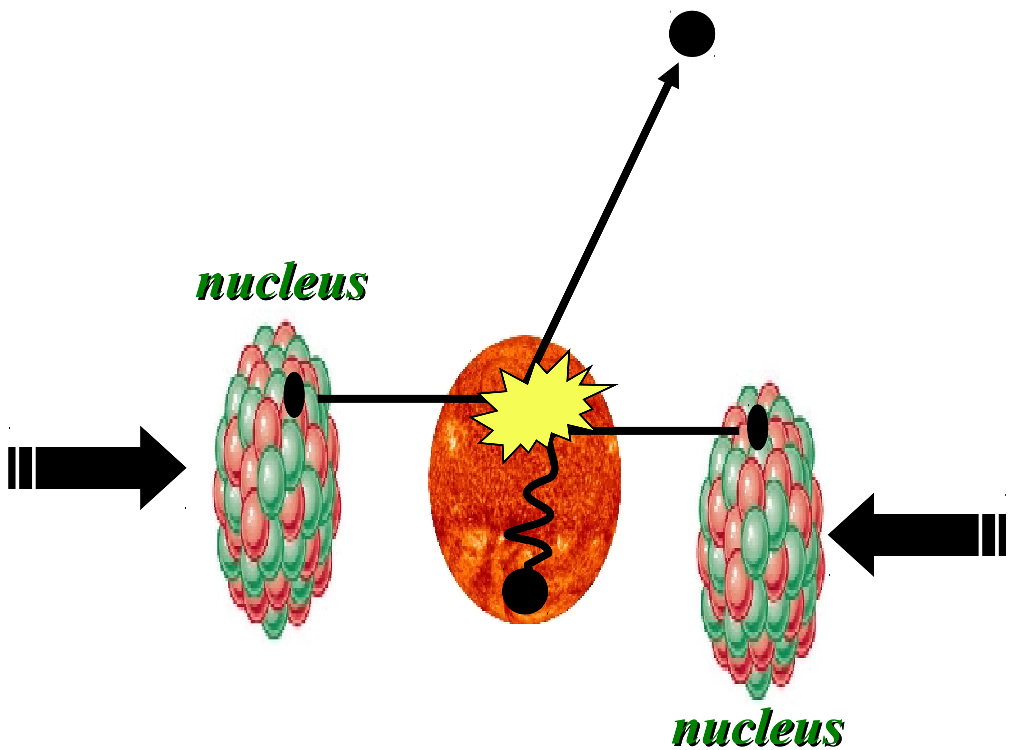
Want a probe which traveled through the collision
QGP is very short-lived (~1-10 fm/c) →
cannot use an external probe

Probes of the Quark Gluon Plasma



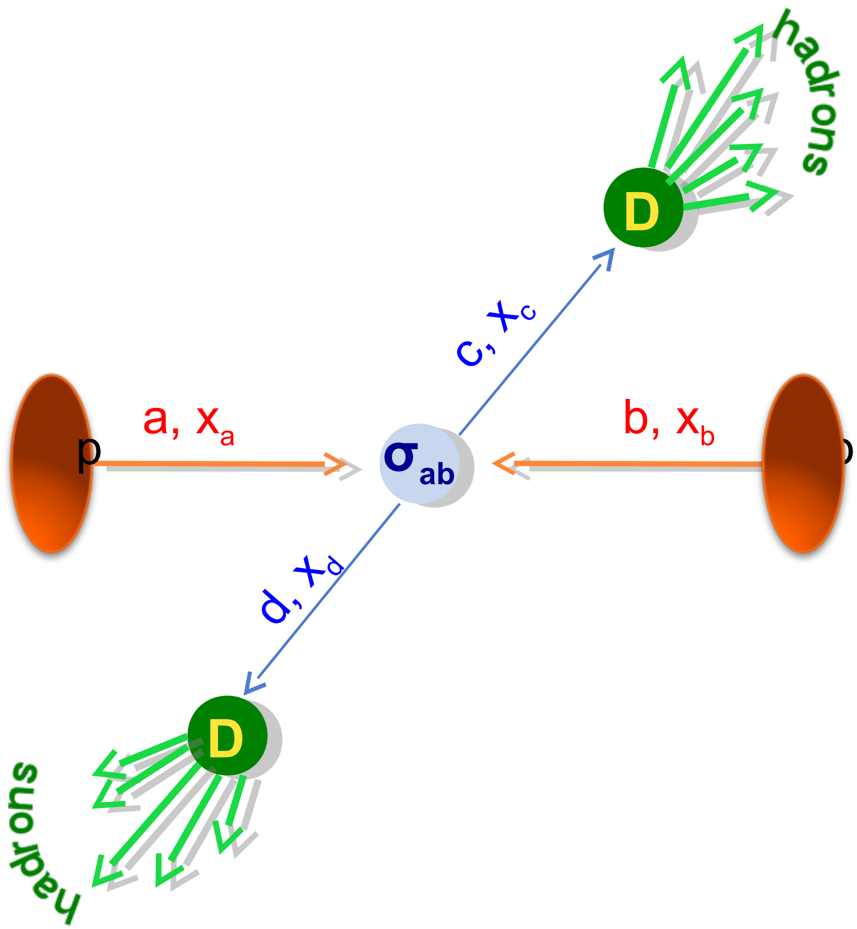
Want a probe which traveled through the medium
QGP is short lived → need a probe created in the collision

Probes of the Quark Gluon Plasma

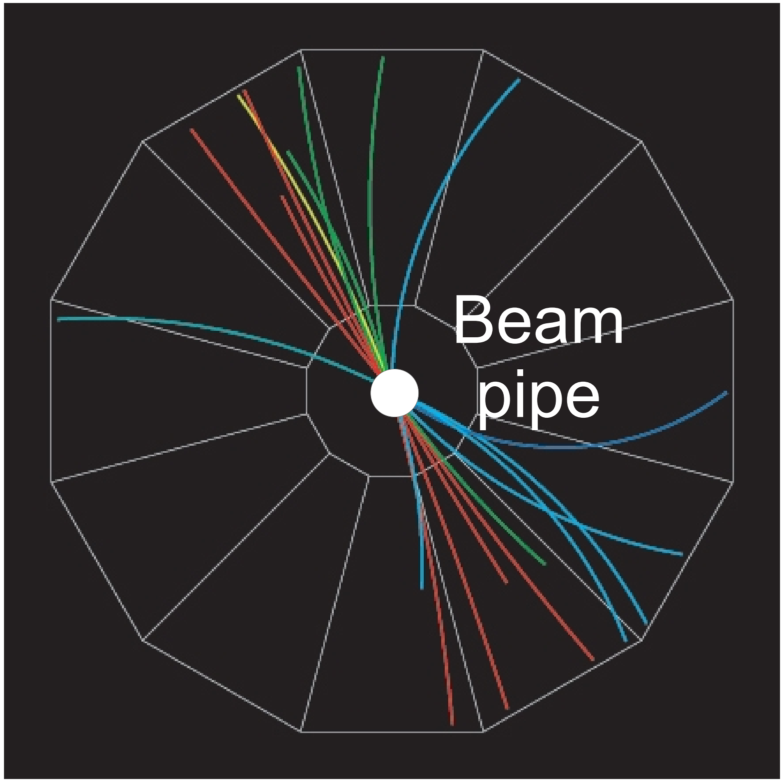


Want a probe which traveled through the medium
QGP is short lived → need a probe created in the collision
We expect the medium to be dense → absorb/modify probe

Jets

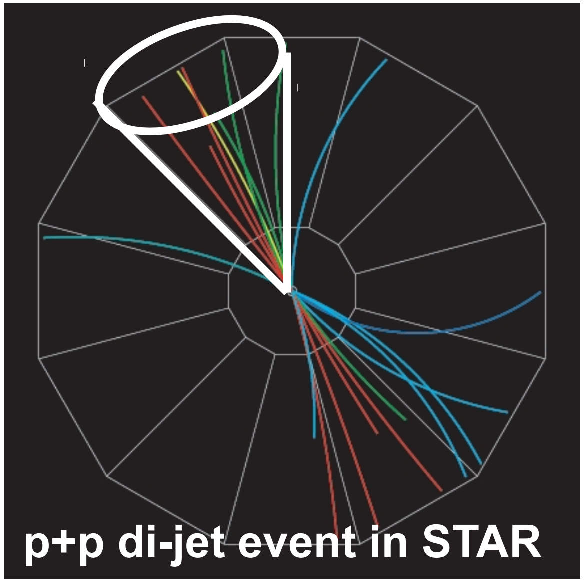


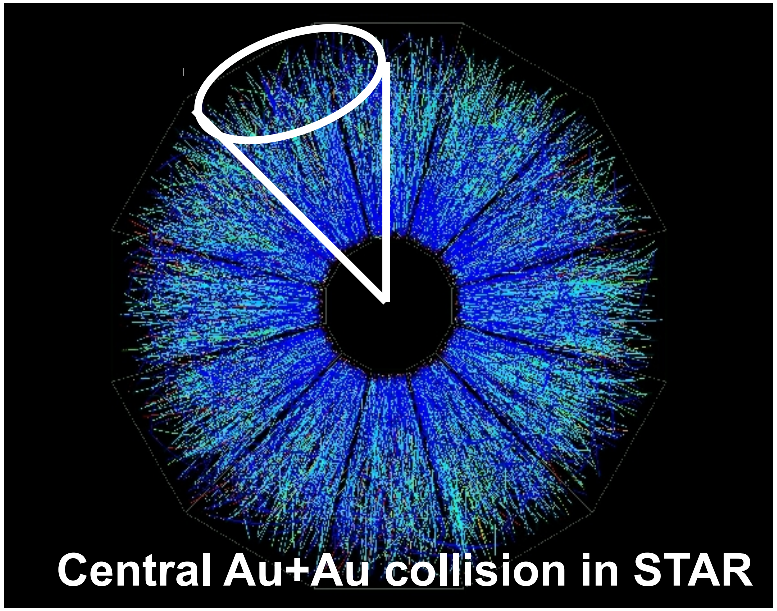
p+p → dijet



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

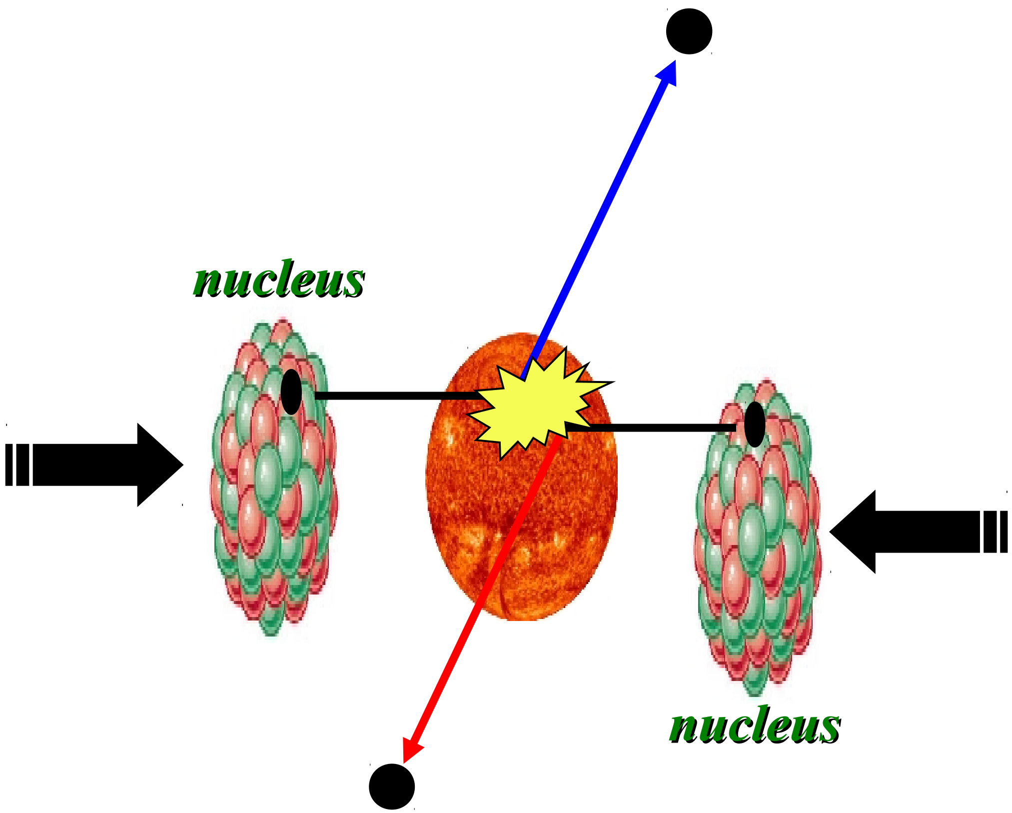
Jet reconstruction



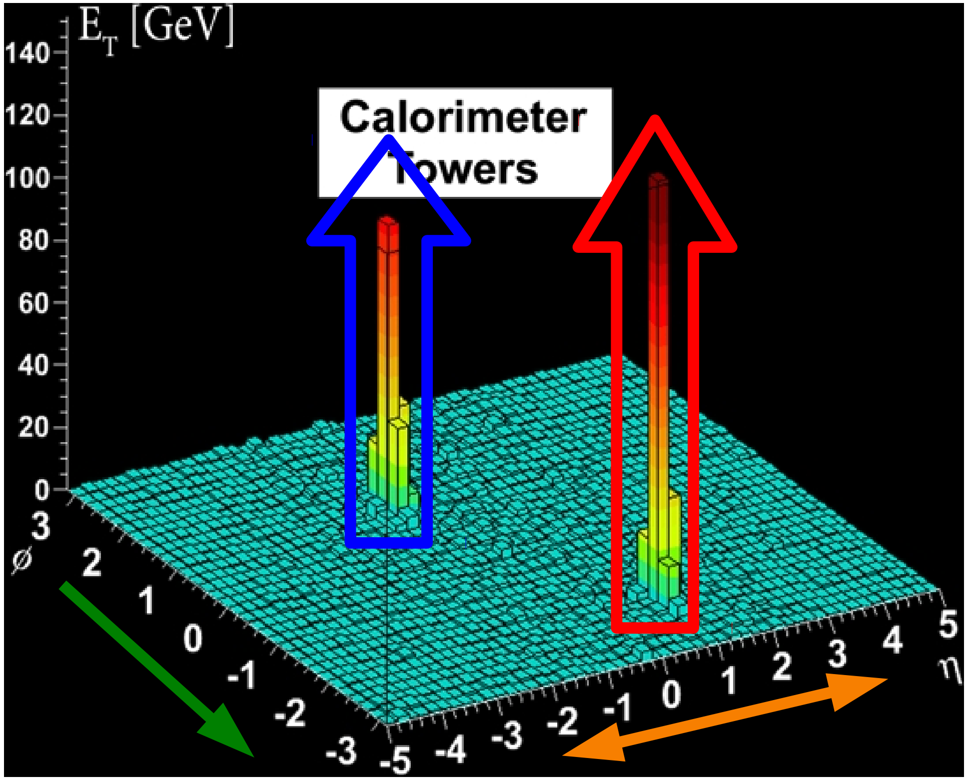


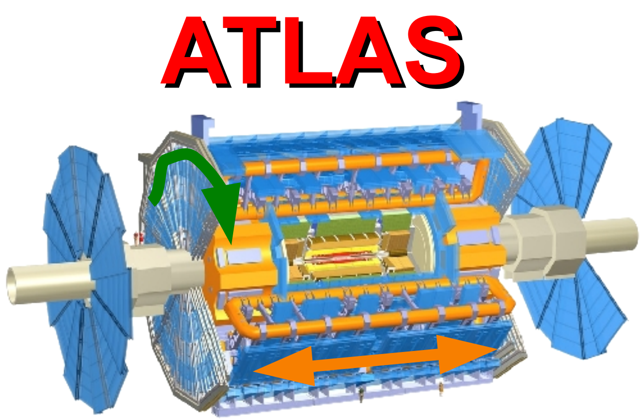
- Identify all of the particles in the jet → parton energy, momentum
- Difficult in heavy ion collisions – but possible!

Jets

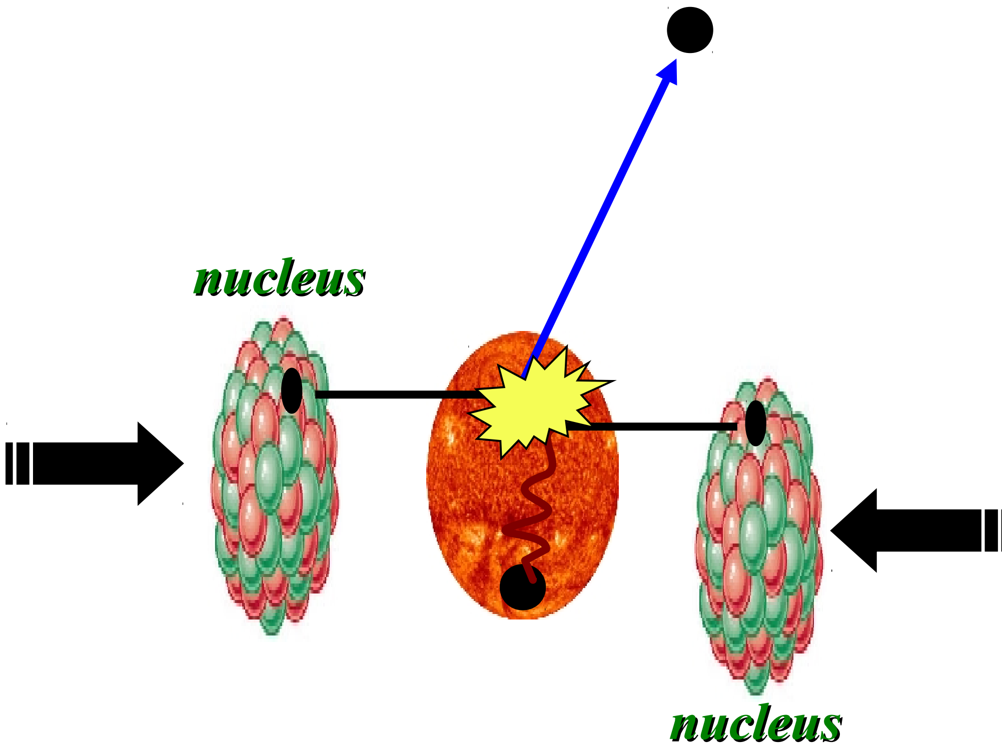


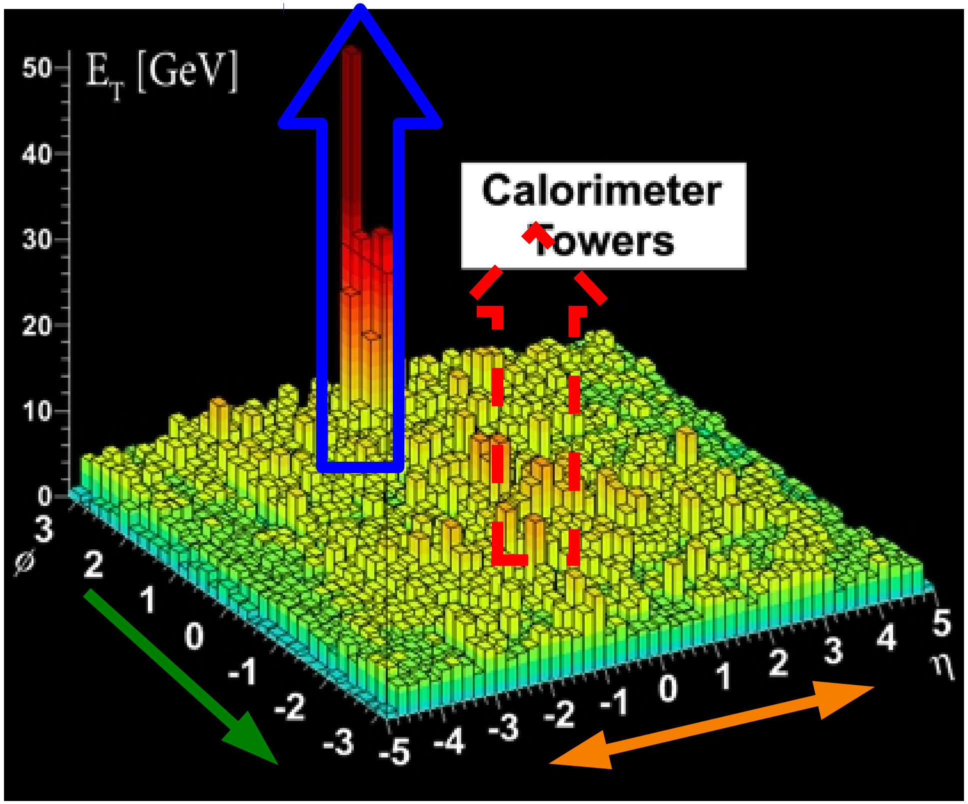
Phys.Rev.Lett. 105 (2010) 252303

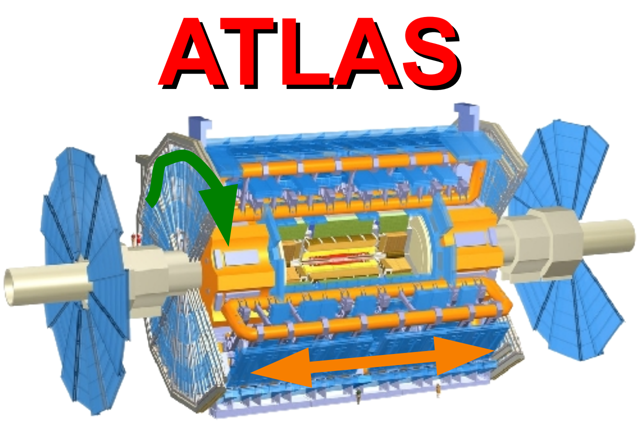




Quenched jets





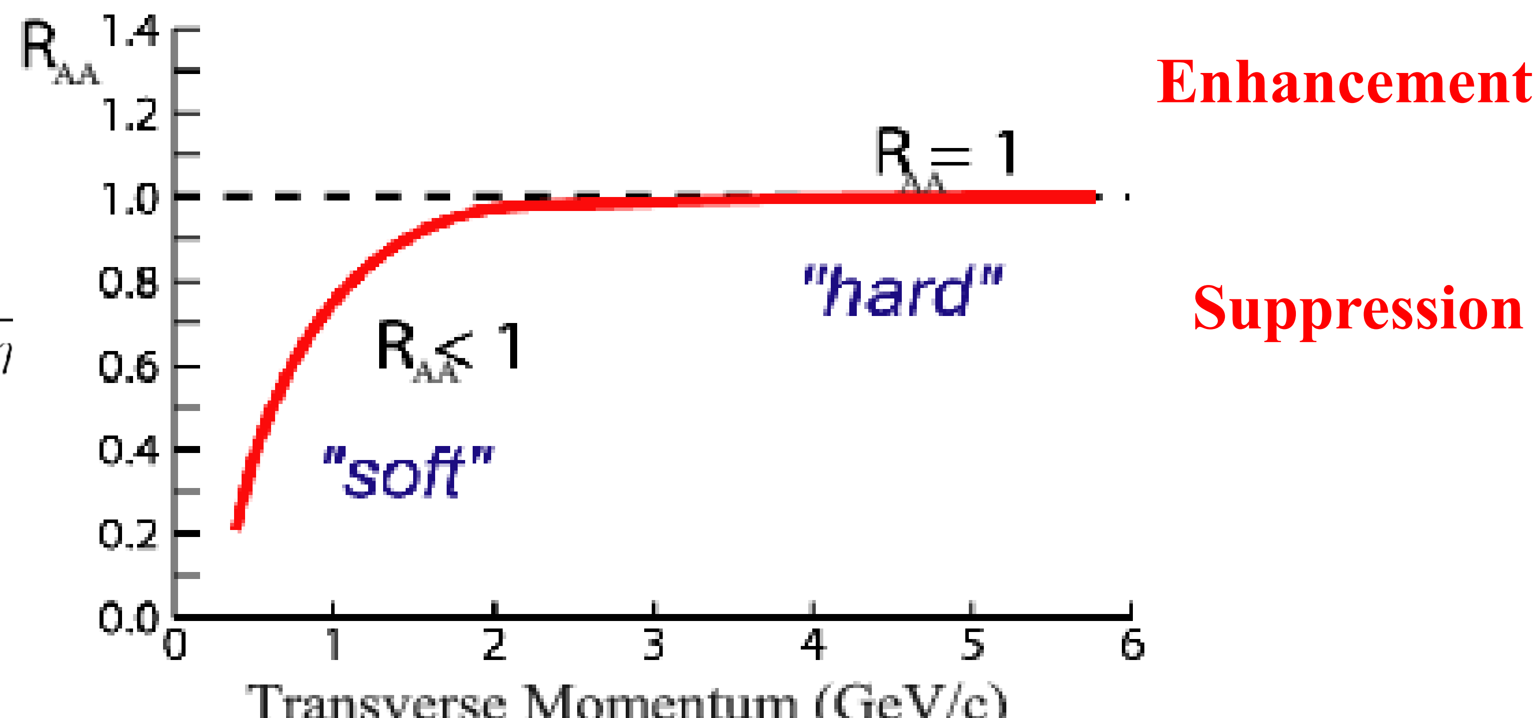


- One of the jets is absorbed by the medium
- The quark or gluon has equilibrated with the medium
- Phys. Rev. Lett. 105, 252303 (2010)

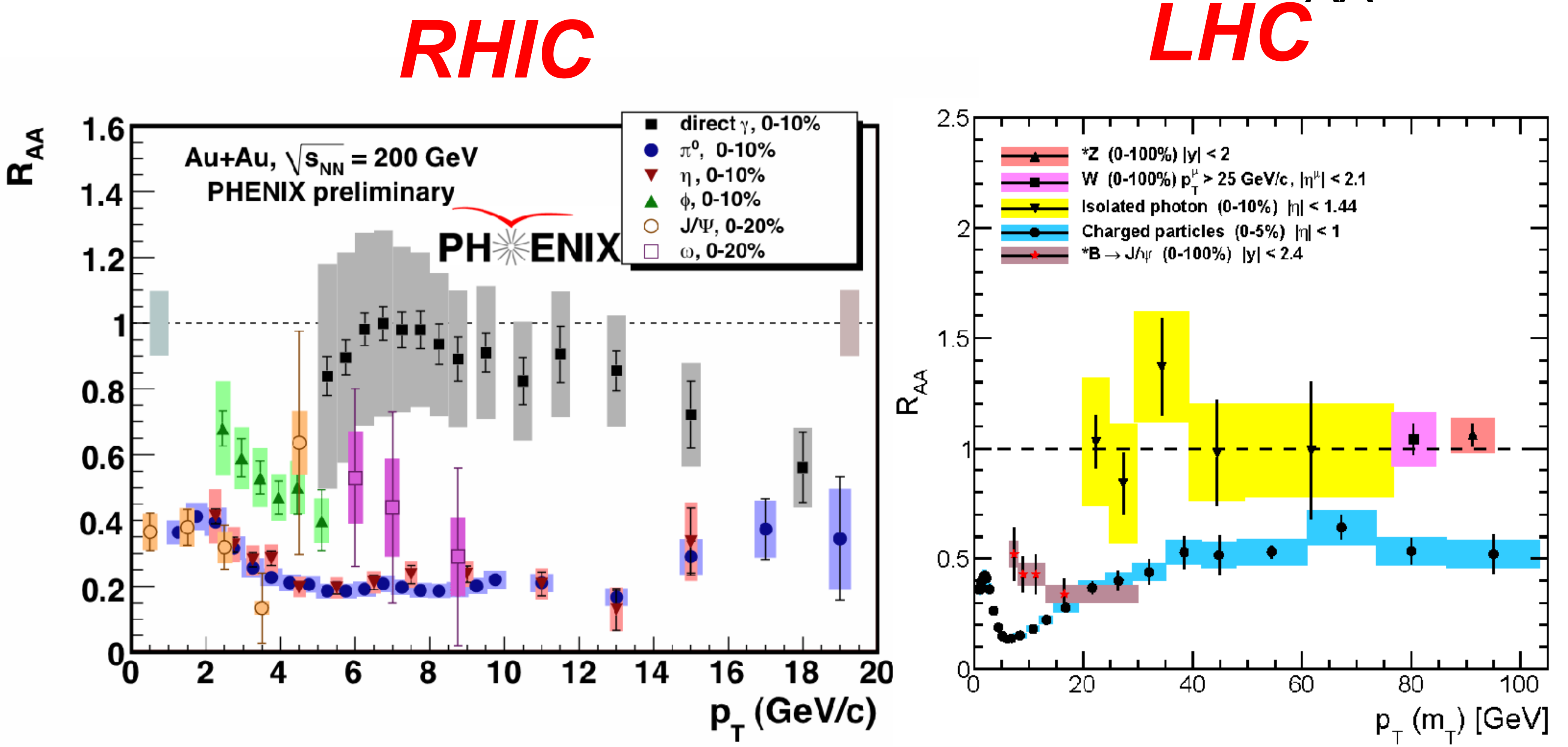
Nuclear modification factor

- 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

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



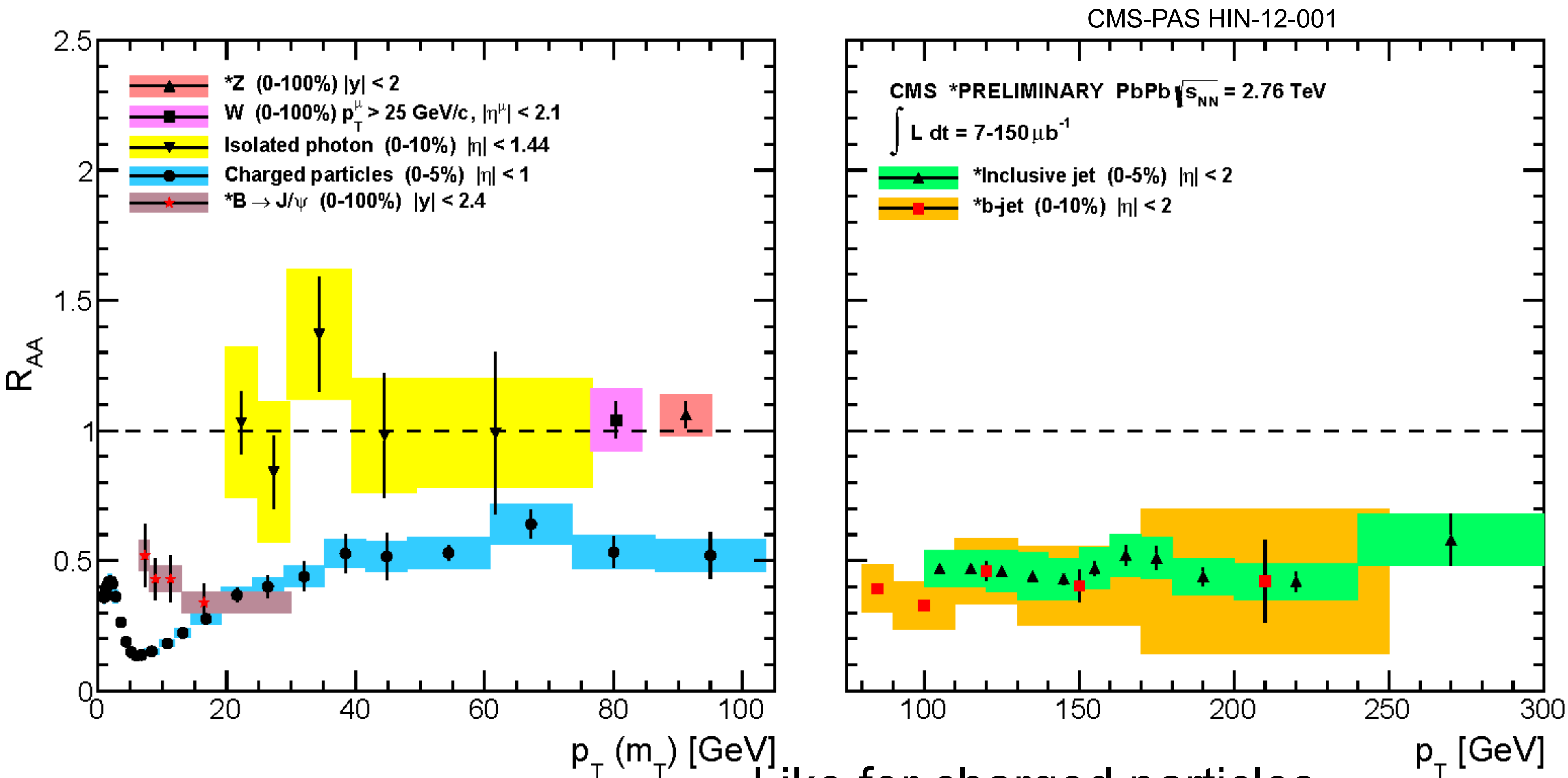
Nuclear modification factor R_{AA}



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

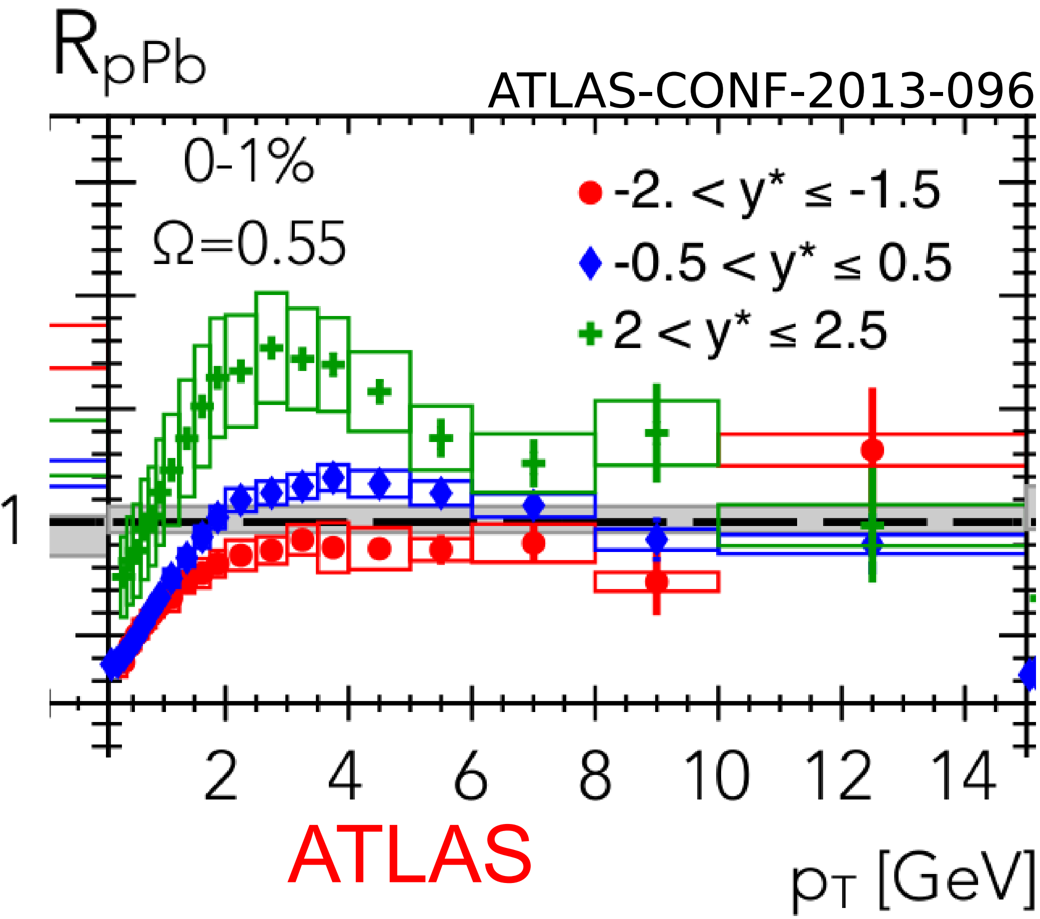
Nuclear modification factor R_{AA} at LHC

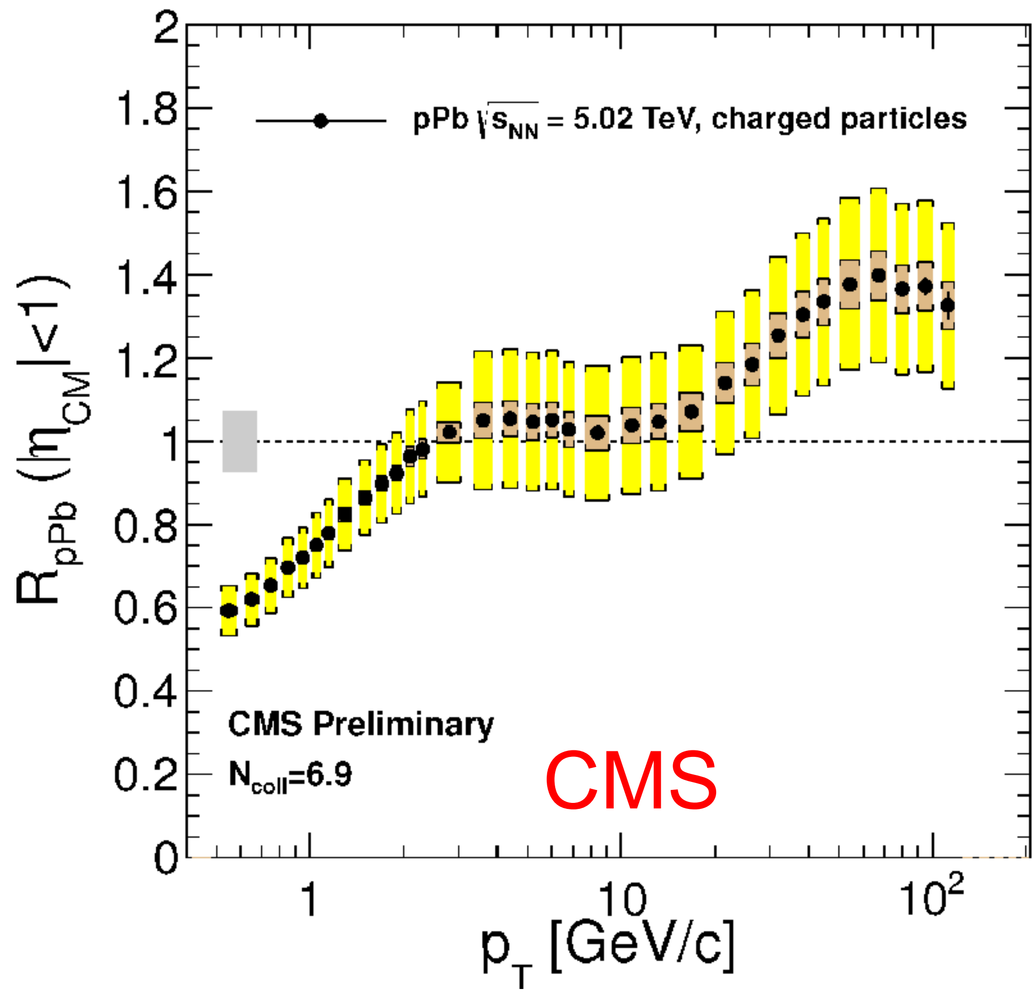
Fully unfolded inclusive jet R_{AA}
pp 2.76 TeV reference



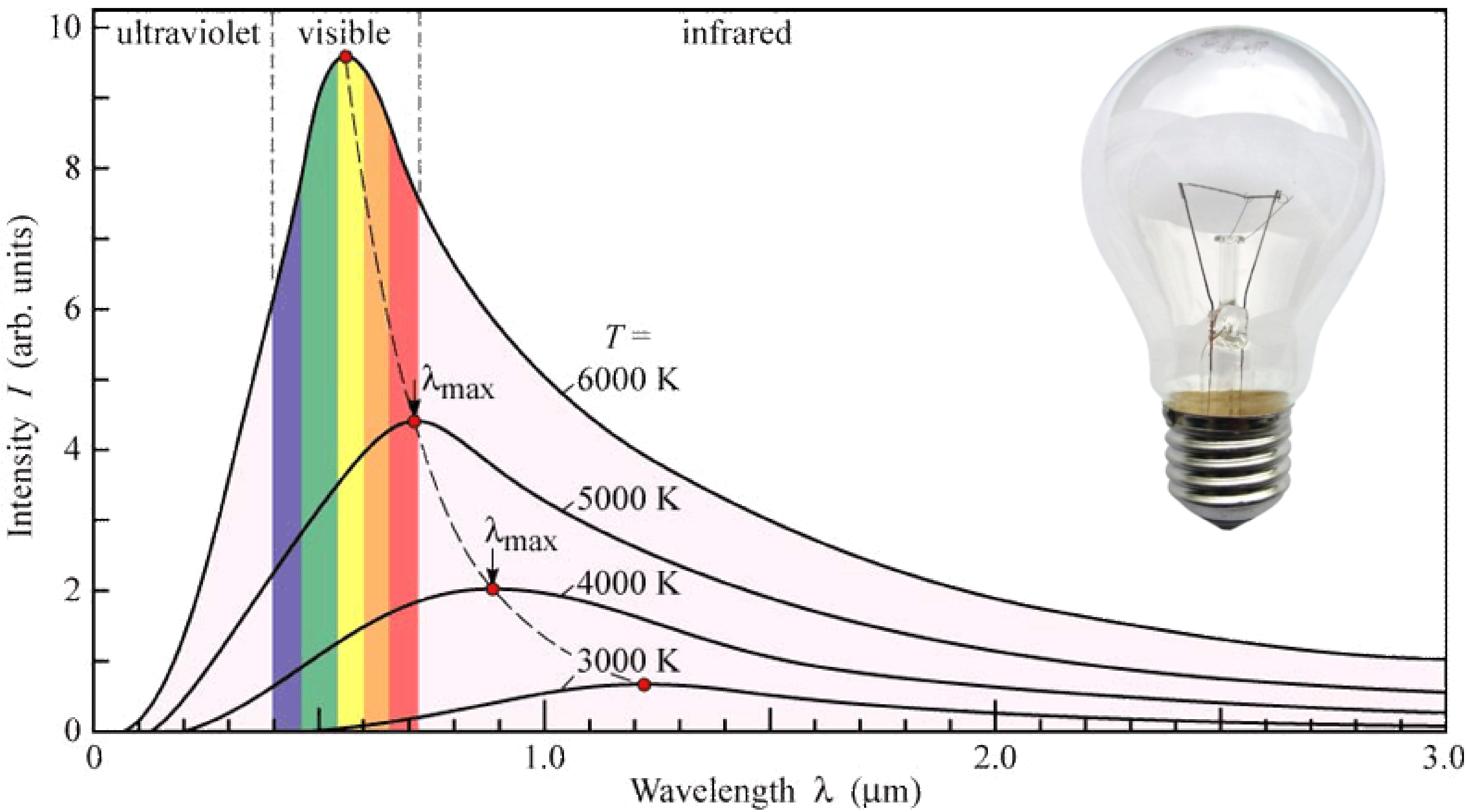
Like for charged particles,
high-p_T jet R_{AA} flat at ≈ 0.5

p+Pb as a control

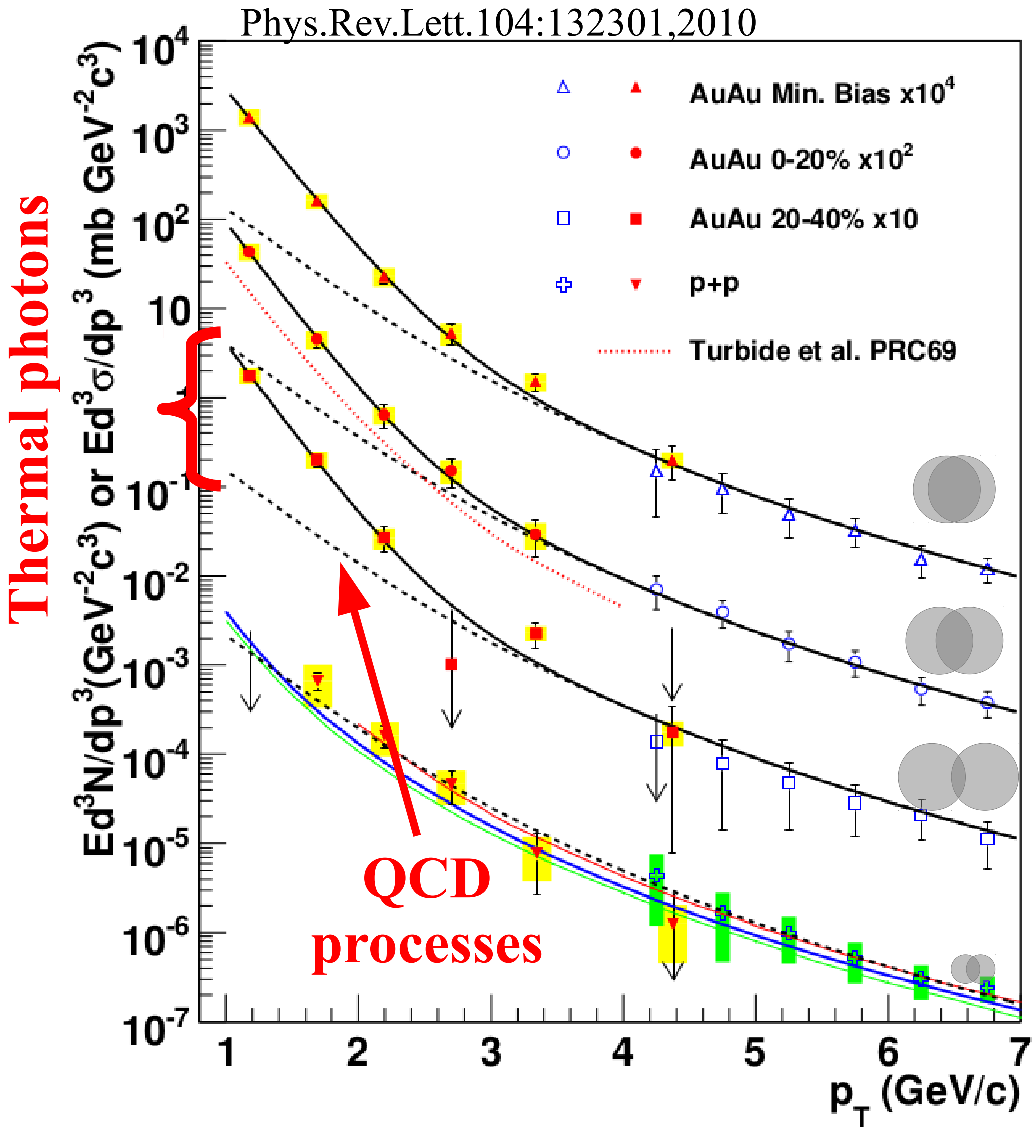


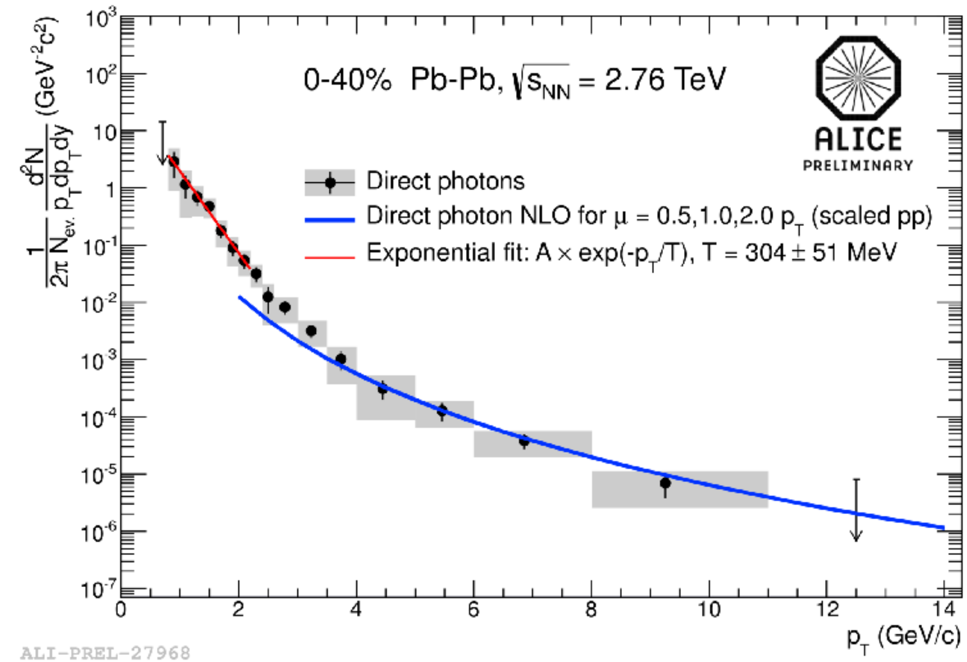


Measuring temperature



Thermal photons



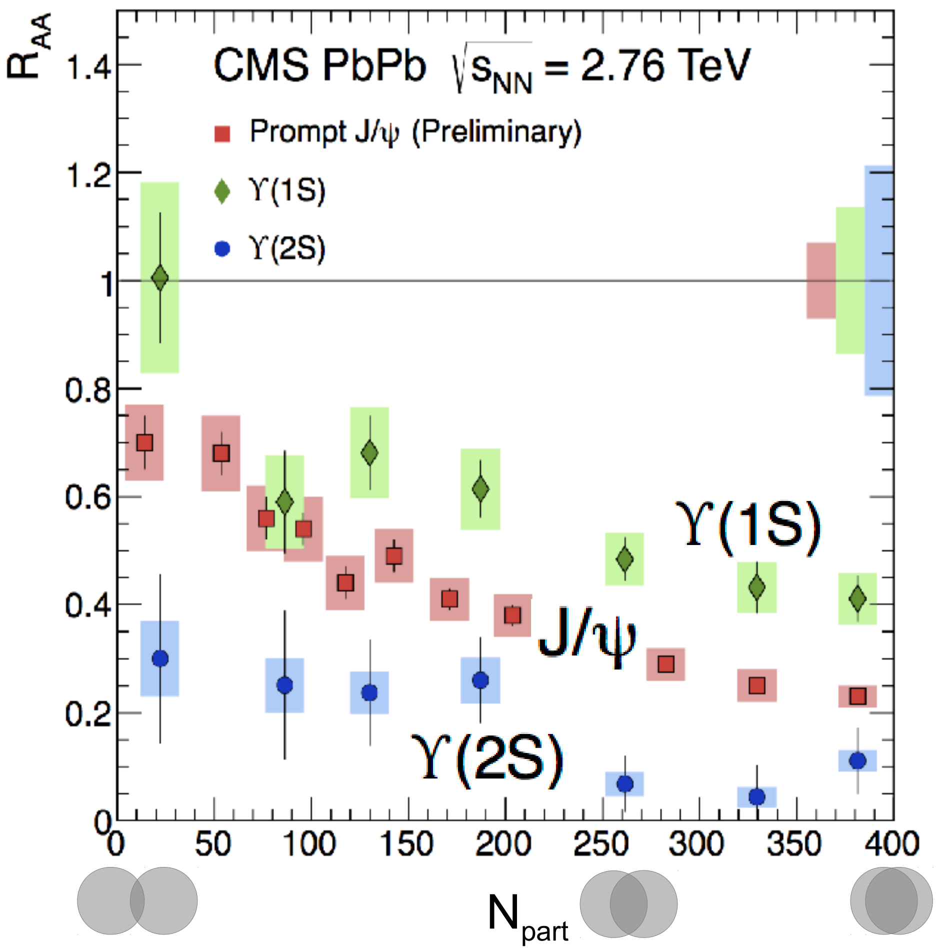


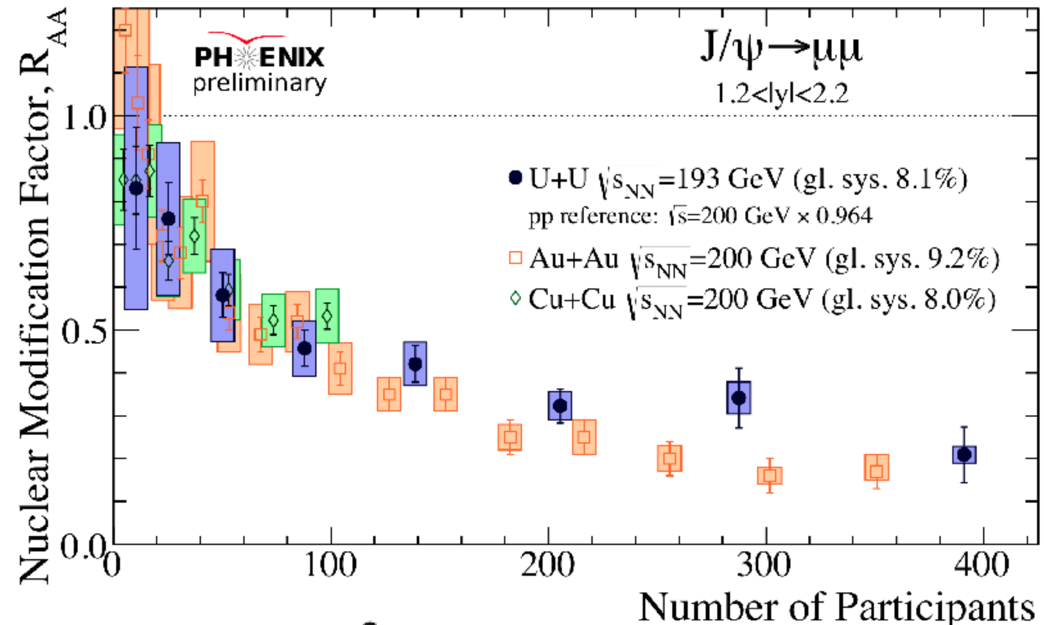
ALICE collaboration:
Pb+Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV
Inverse slope: T = 304 +/-51

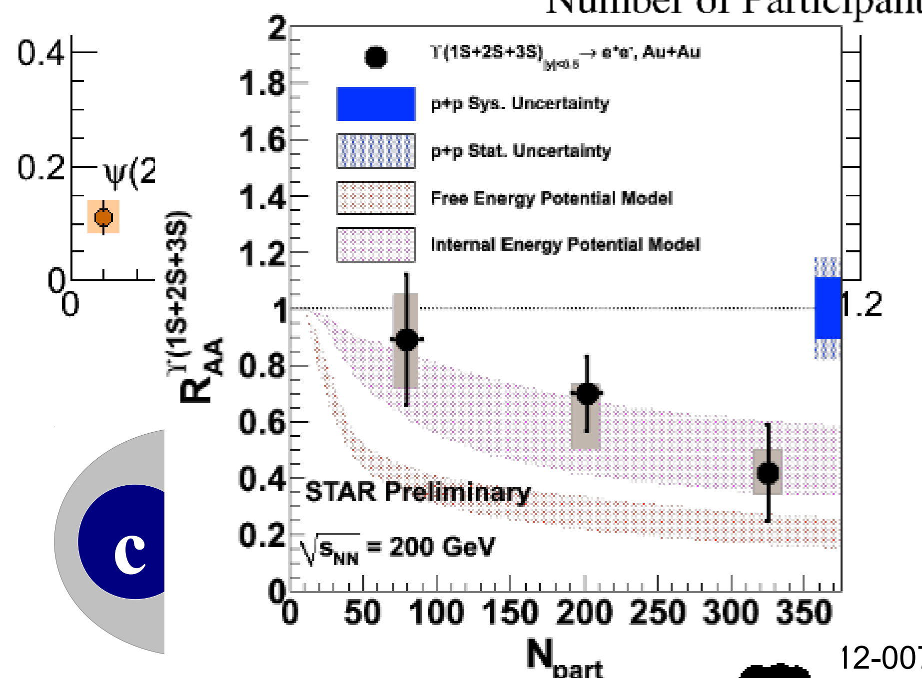
PHENIX collaboration: Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV
Inverse slope: T = 221 +/- 19 (stat) +/- 19 (syst) MeV

Building a quarkonium-thermometer

CMS-PAS HIN-11-011

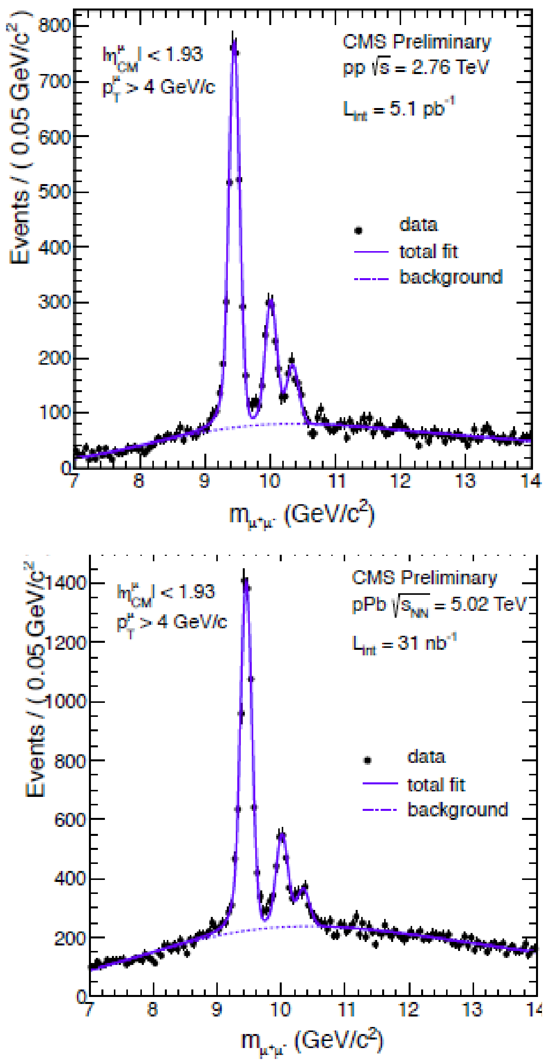


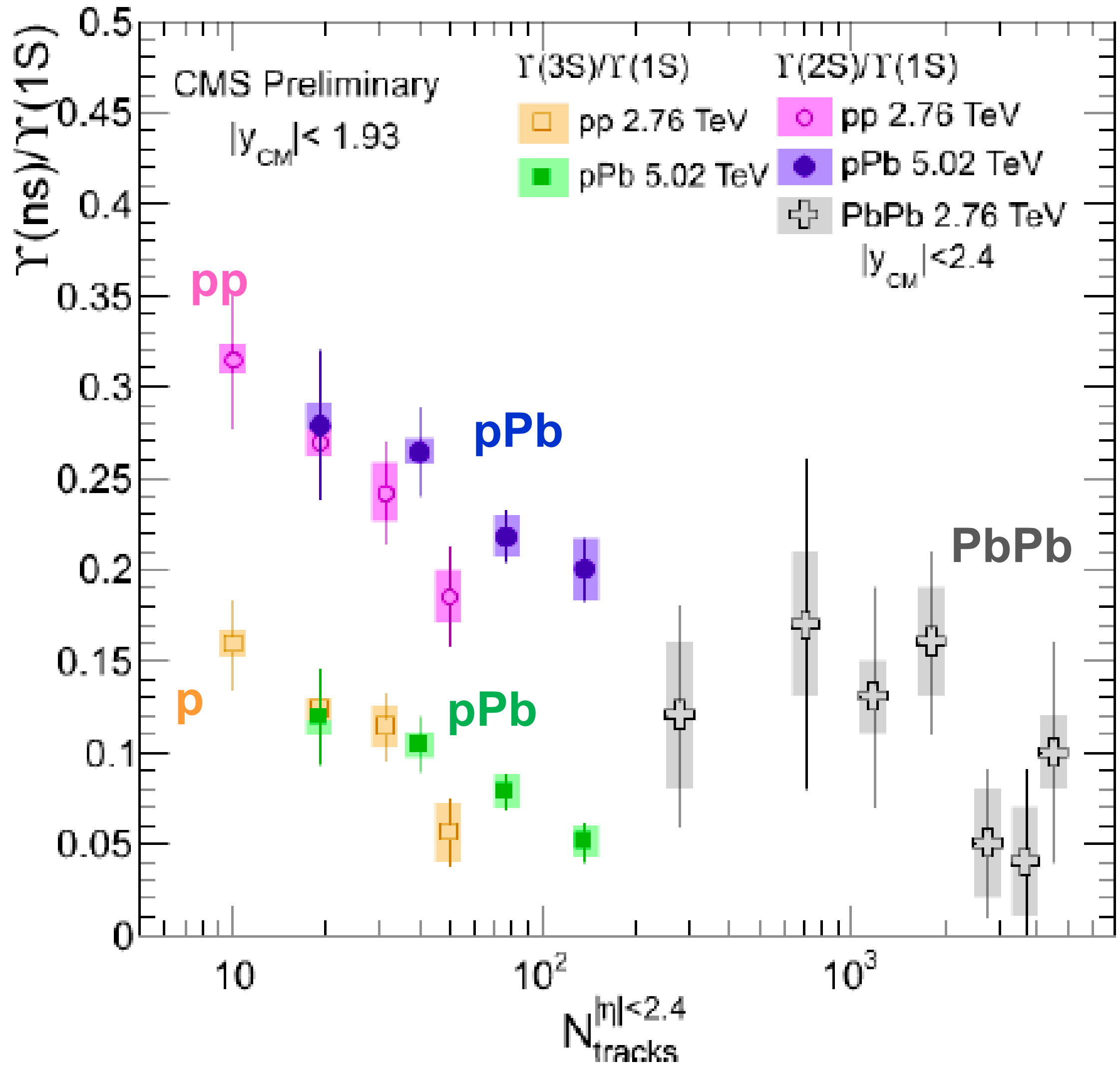




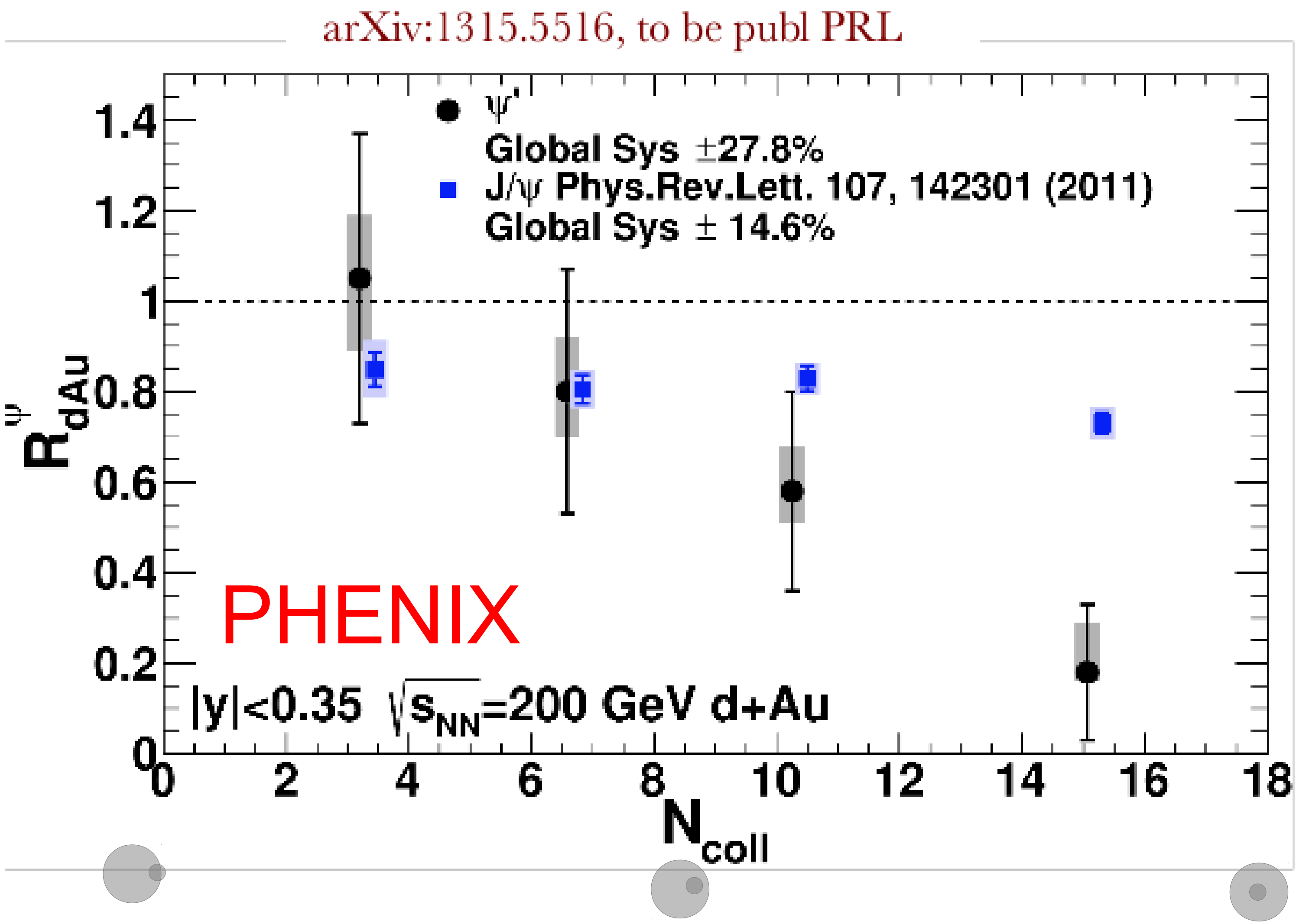
Clear hierarchy in R_{AA} of different quarkonium states

Suppression of quarkonia in p+Pb

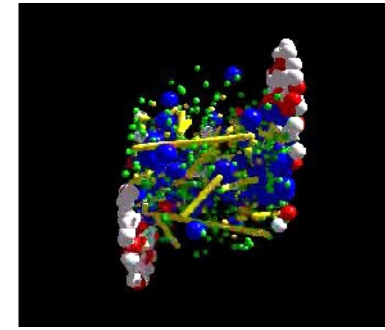




Suppression of quarkonia in d+Au



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 transparent to colored probes and translucent to electromagnetic probes...
- ...And extremely hot and dense.