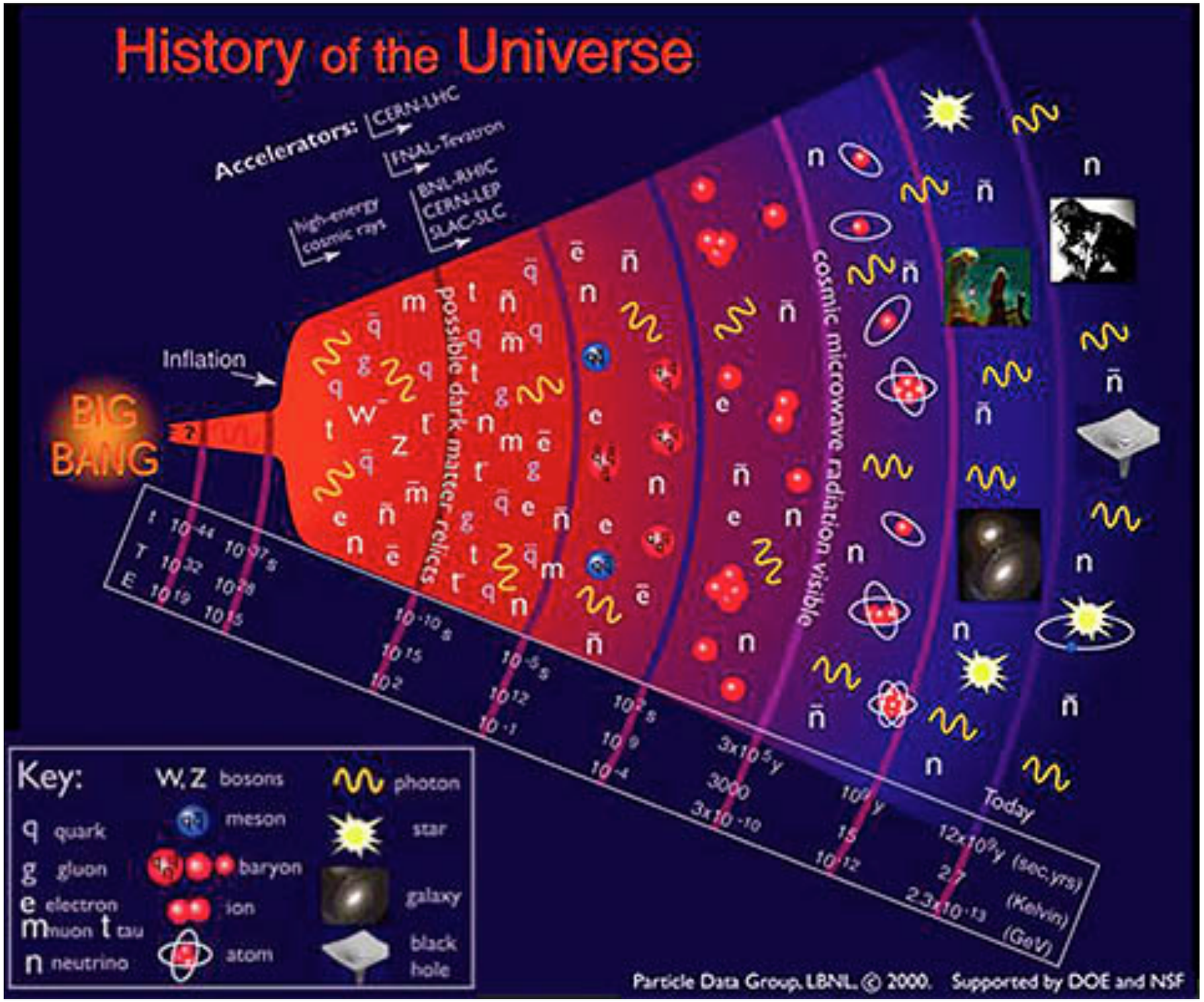
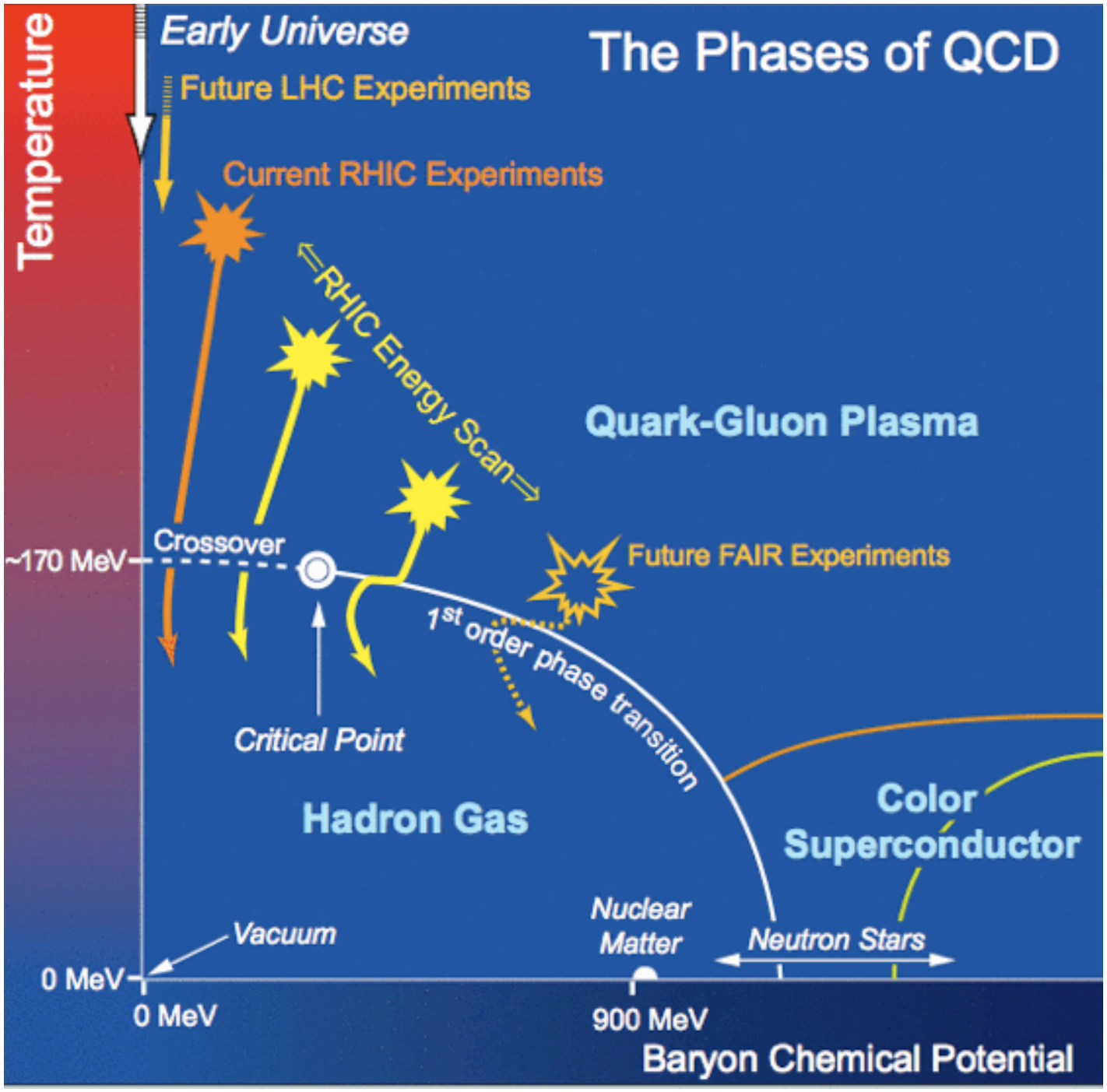
Heavy Ion Physics in 30 Minutes

Anne M. Sickles
Brookhaven

early universe



Phases of QCD



produce and study hot QCD matter!

Timeline of a Collision

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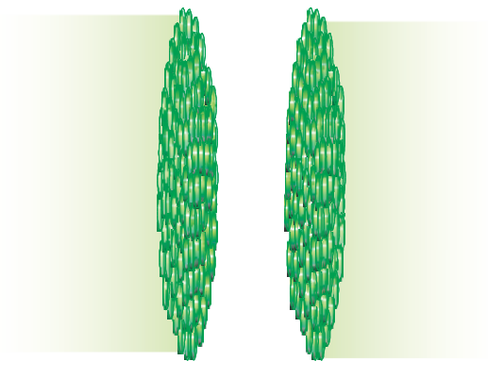

incoming
nuclei

A. M. Sickles **illustration: S. Bass**

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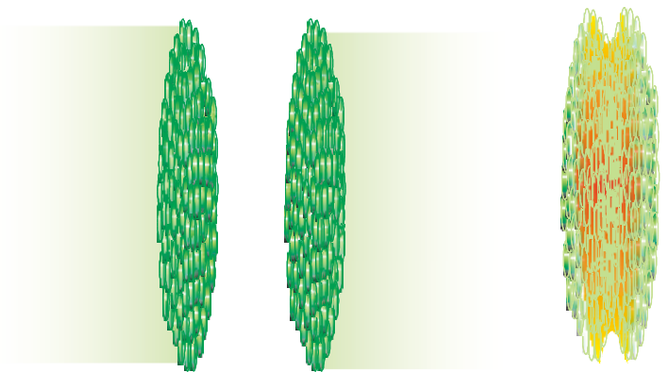

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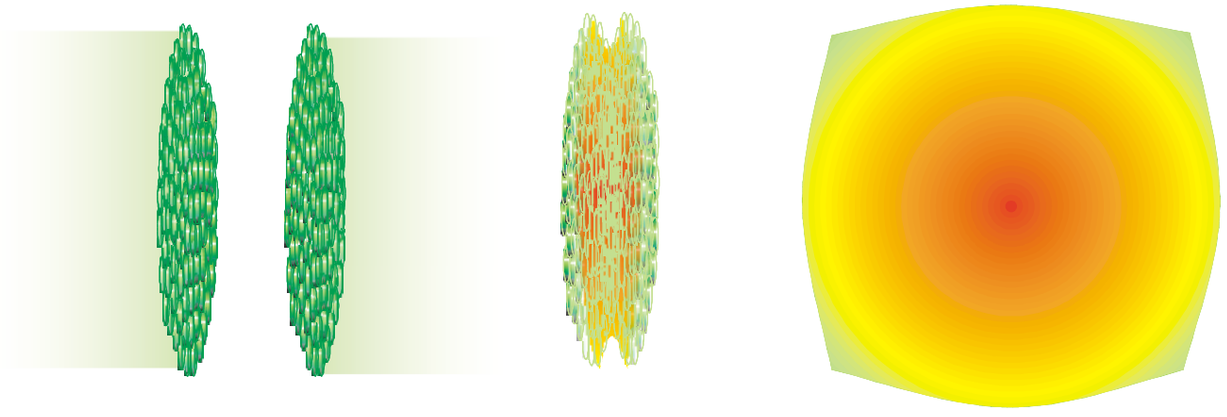

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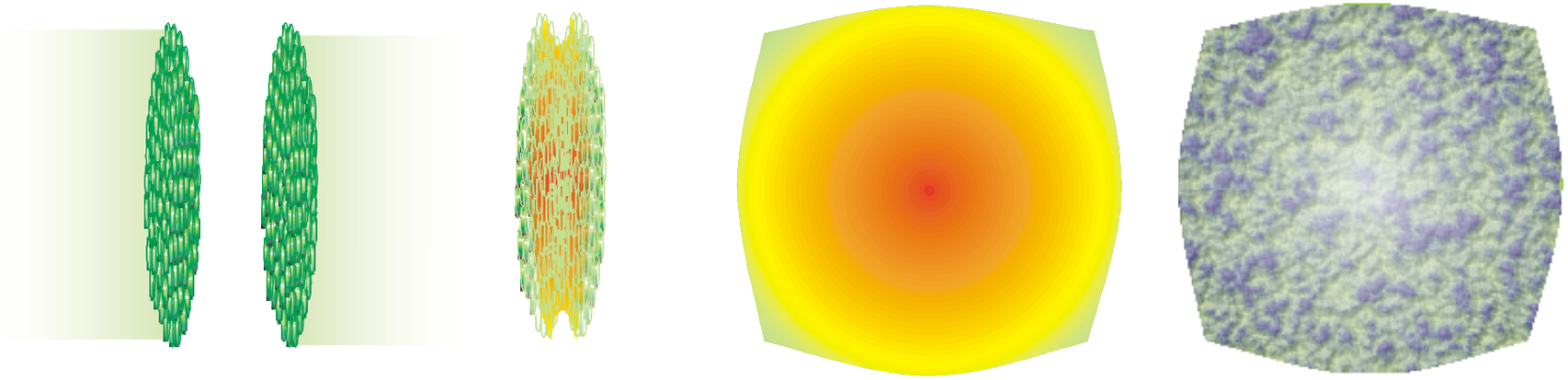

incoming nuclei

hot matter

hadronic gas

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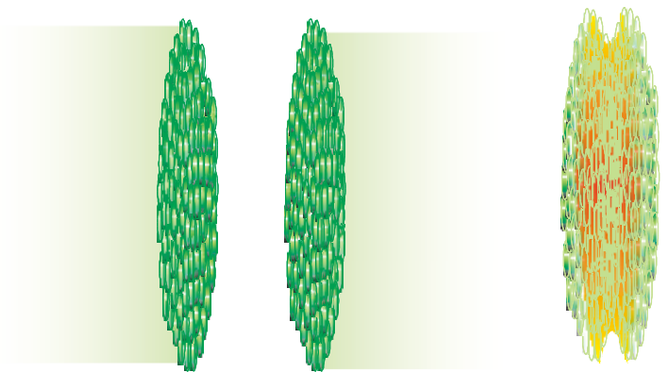
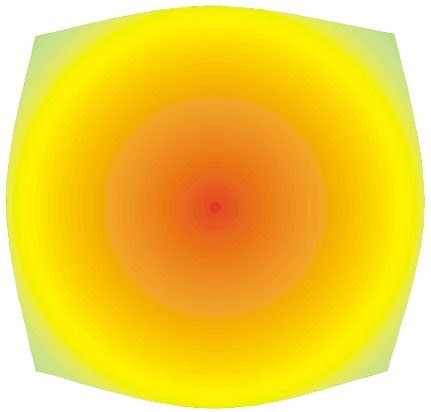
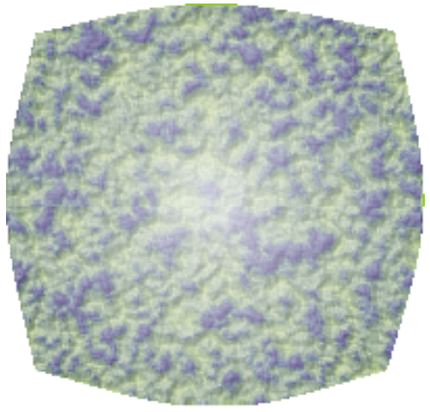


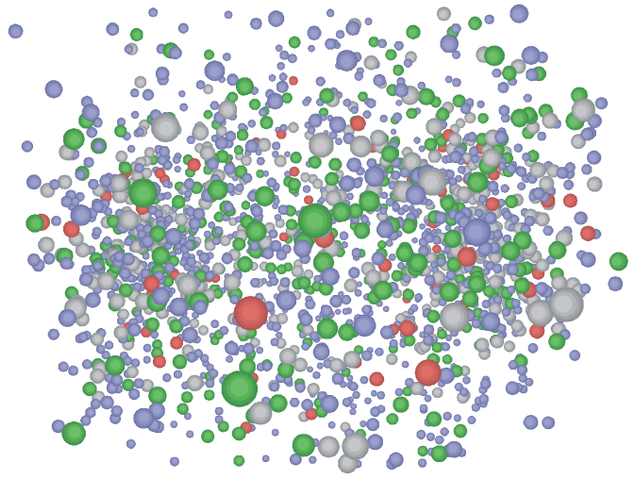
incoming nuclei



hot matter



hadronic gas



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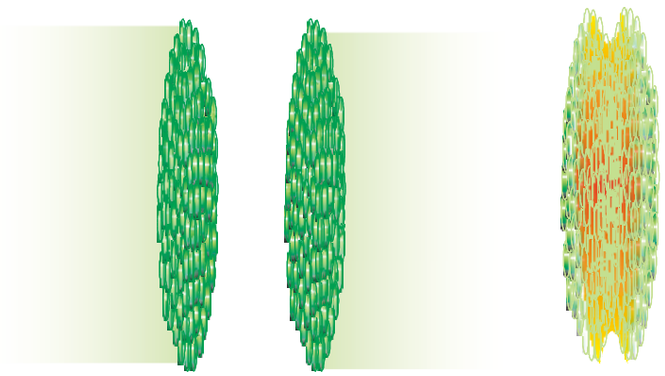

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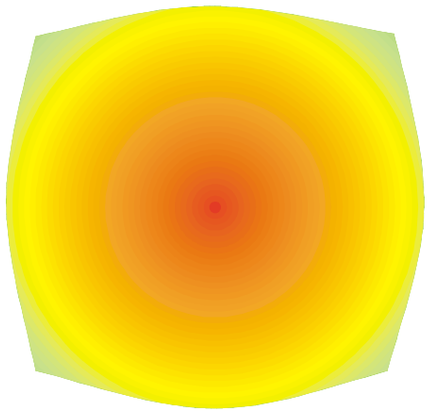
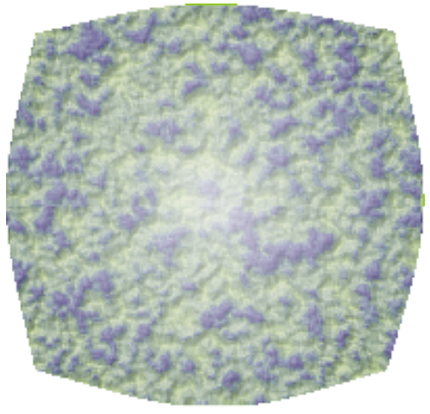
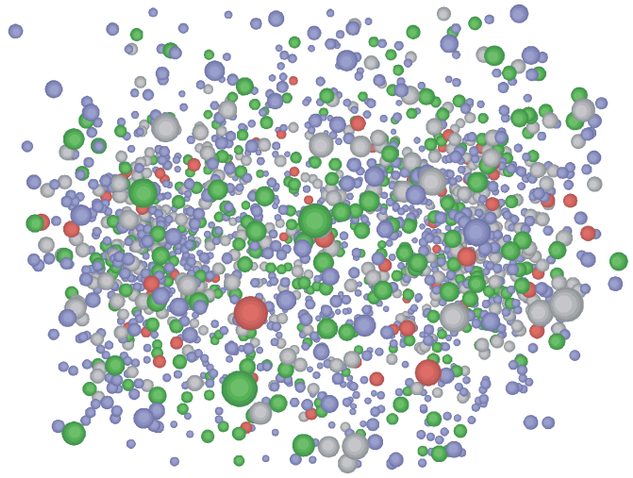


hot matter



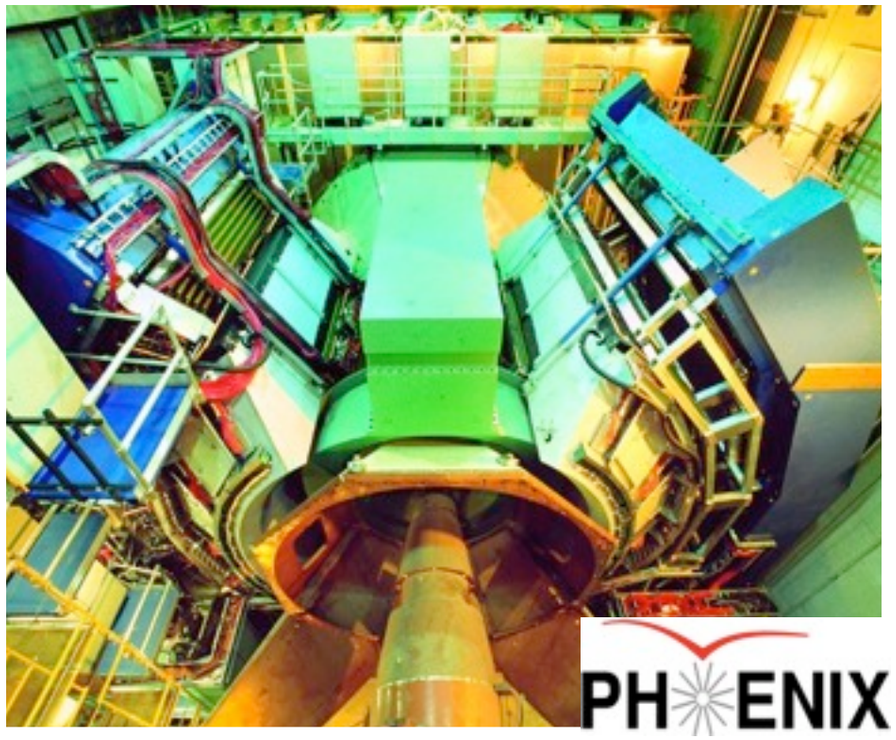
hadronic gas



- radius of Au nuclei: ~7fm = 7×10^{-15}m
- time to traverse the nucleus: $7 \times 10\text{-}15\text{m}/(3 \times 10^{8}\text{m/s}) = 20 \times 10^{-23}$s

A. M. Sickles **illustration: S. Bass**

PHENIX & STAR



PHENIX

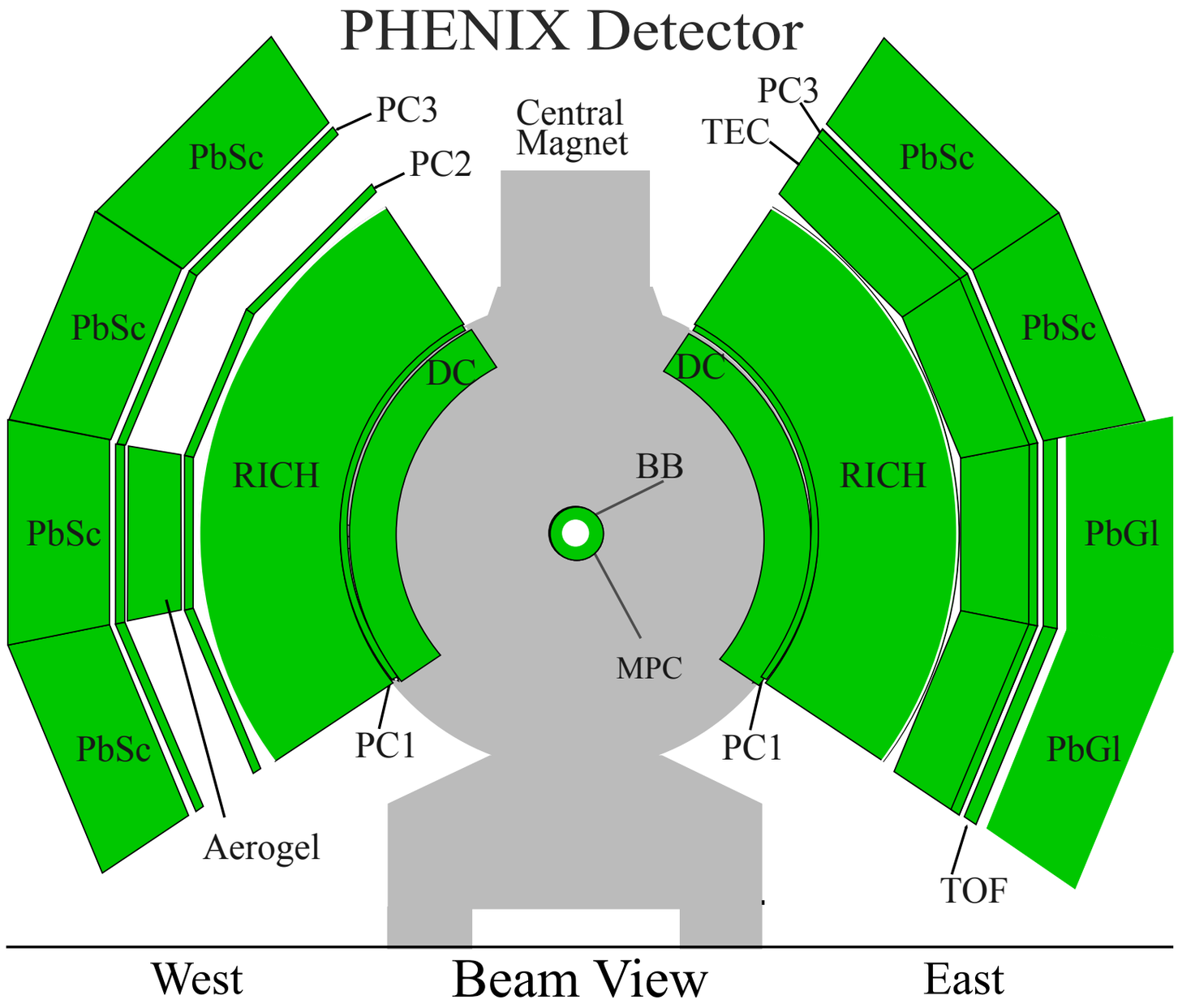
rare probes
high event rates
excellent
calorimeter

STAR

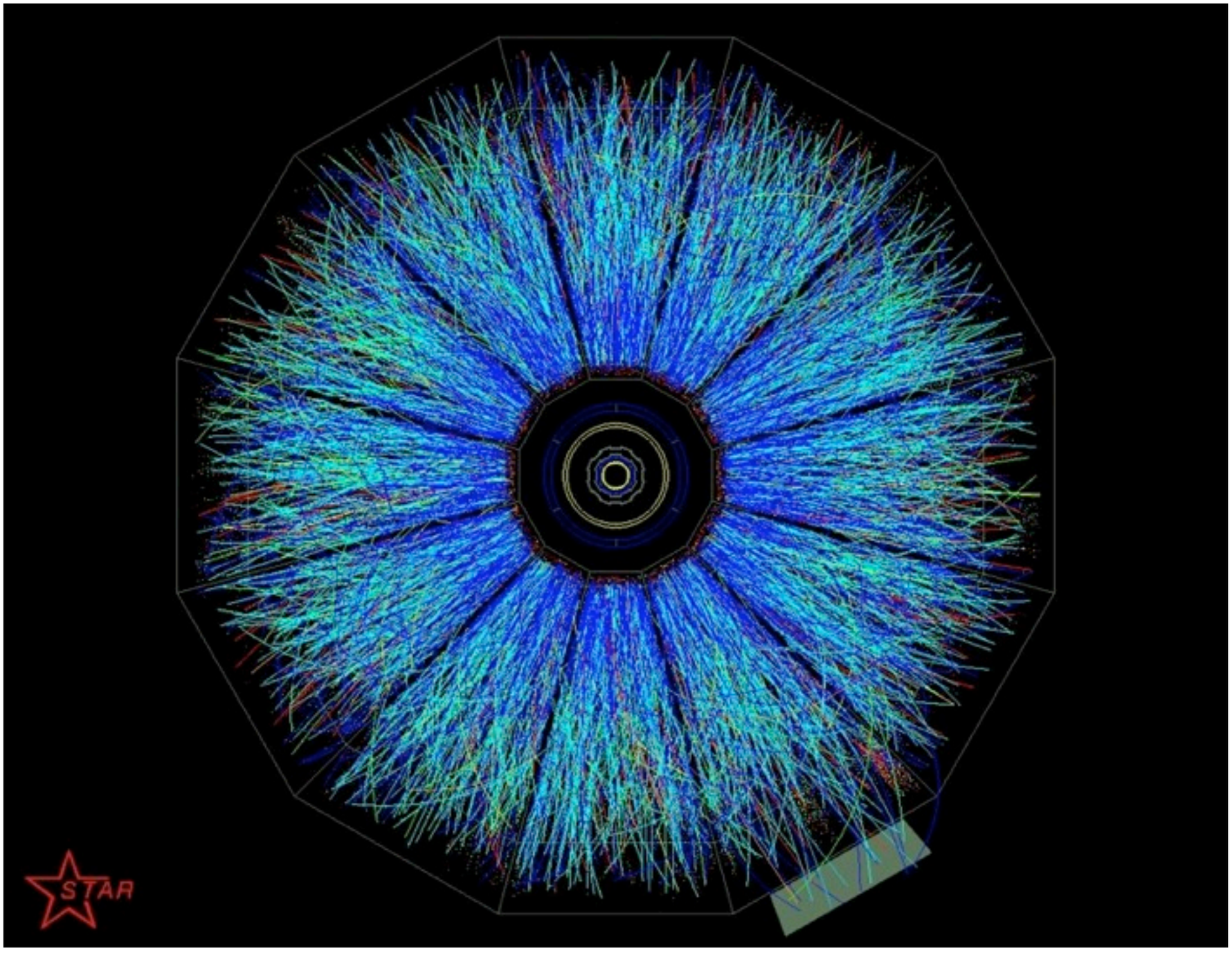
large acceptance
TPC for charged
particle tracking
and identification

detectors complementary

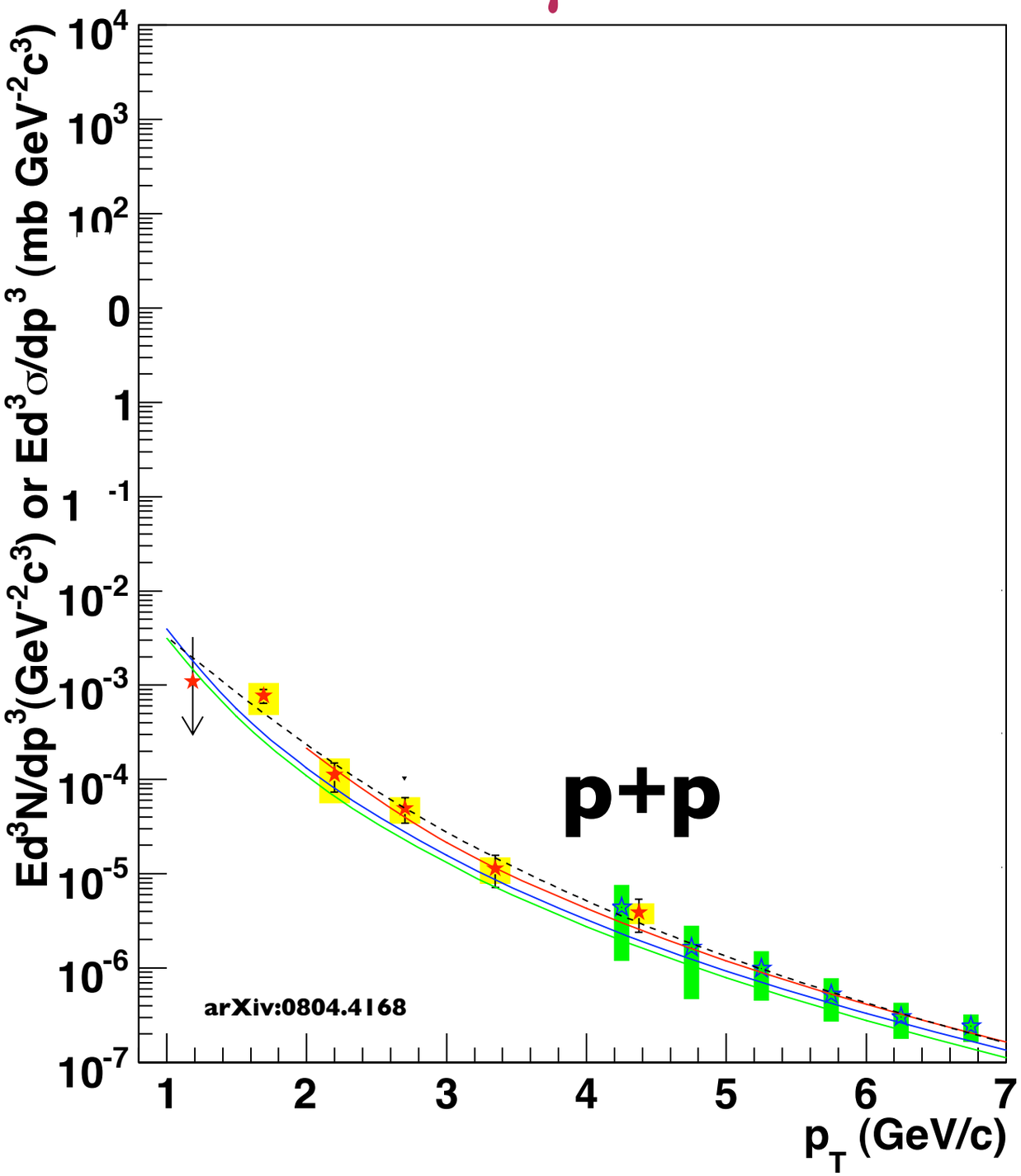
PHENIX



- electrons, muons, photons, high rate


STAR

hot QCD matter!



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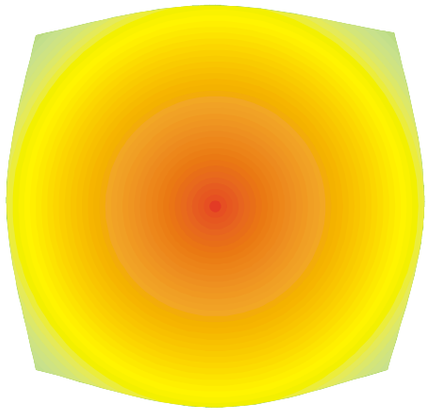

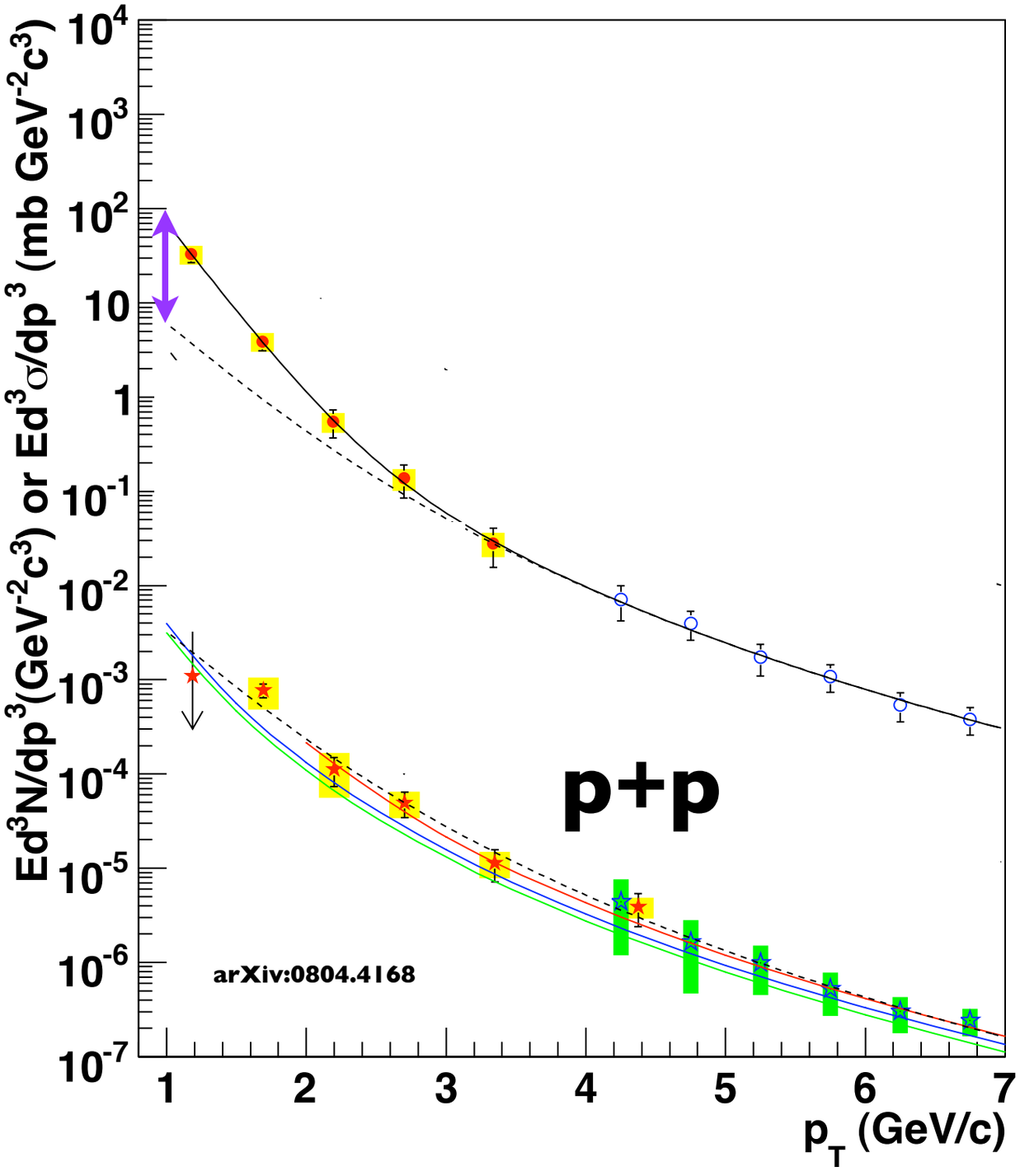

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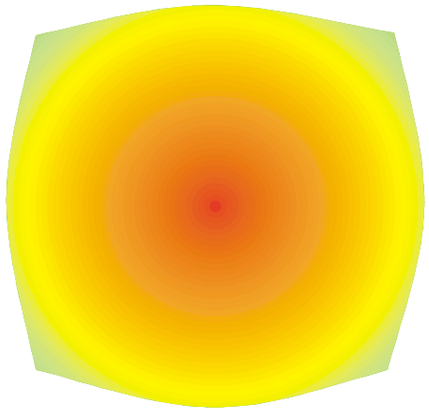

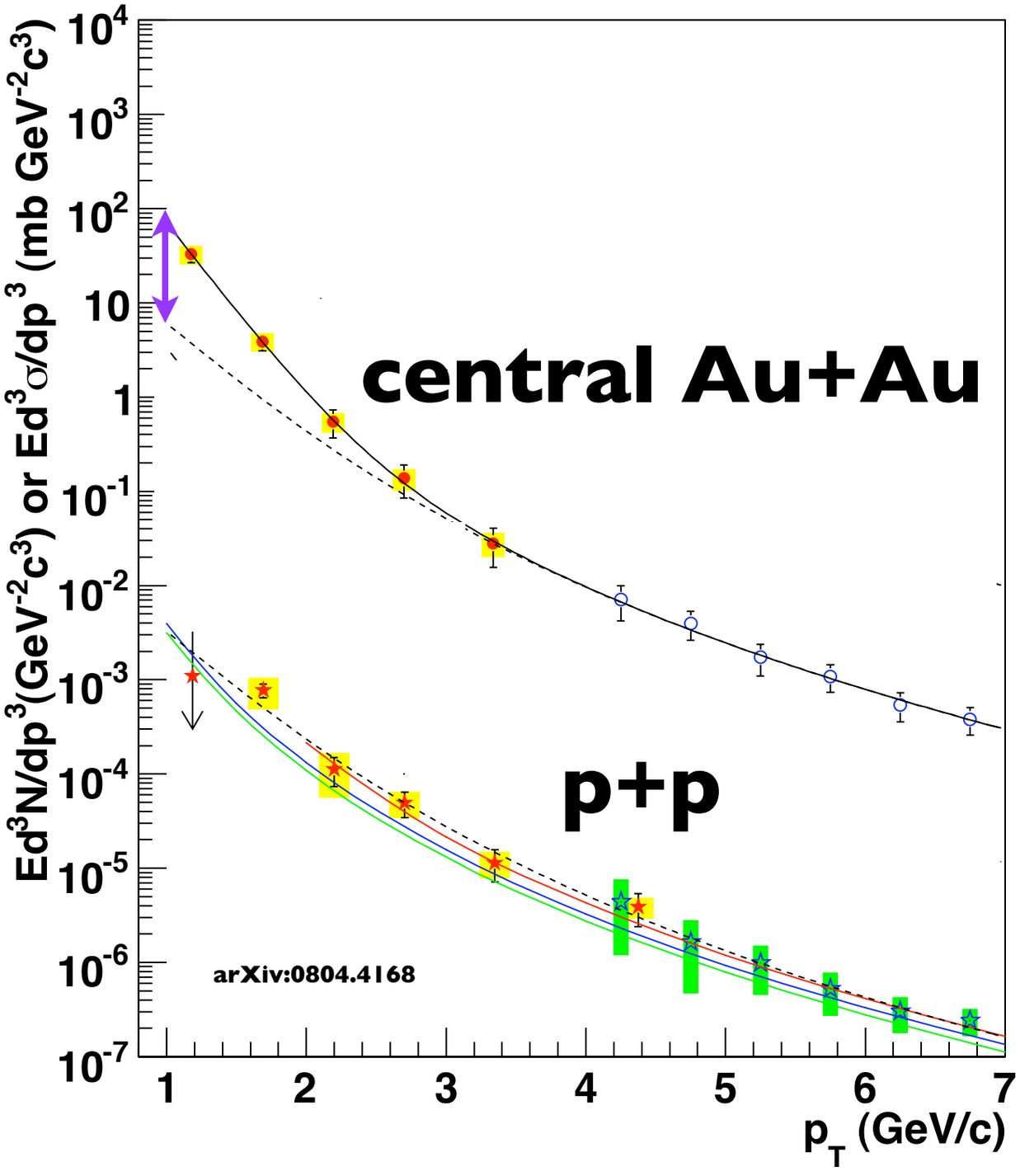

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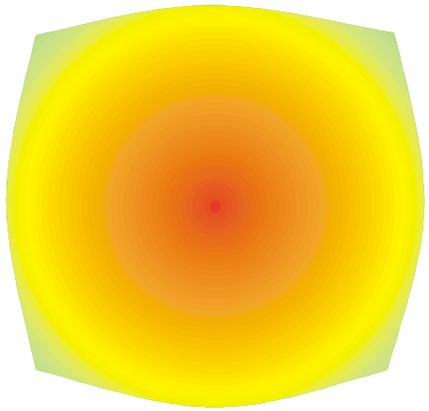
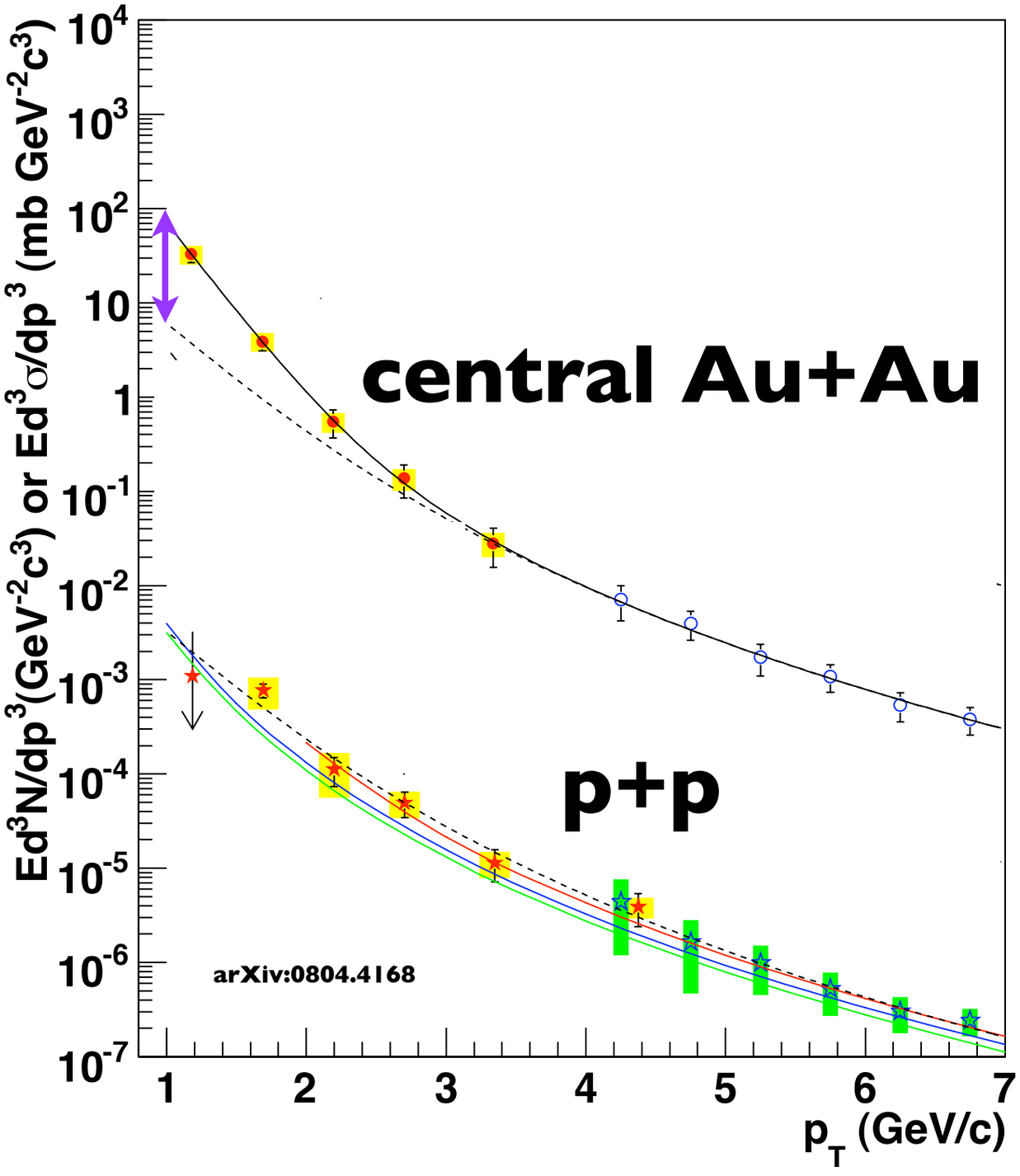


excess:
221±23±18MeV



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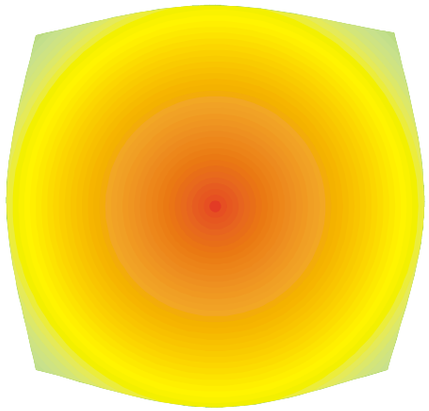

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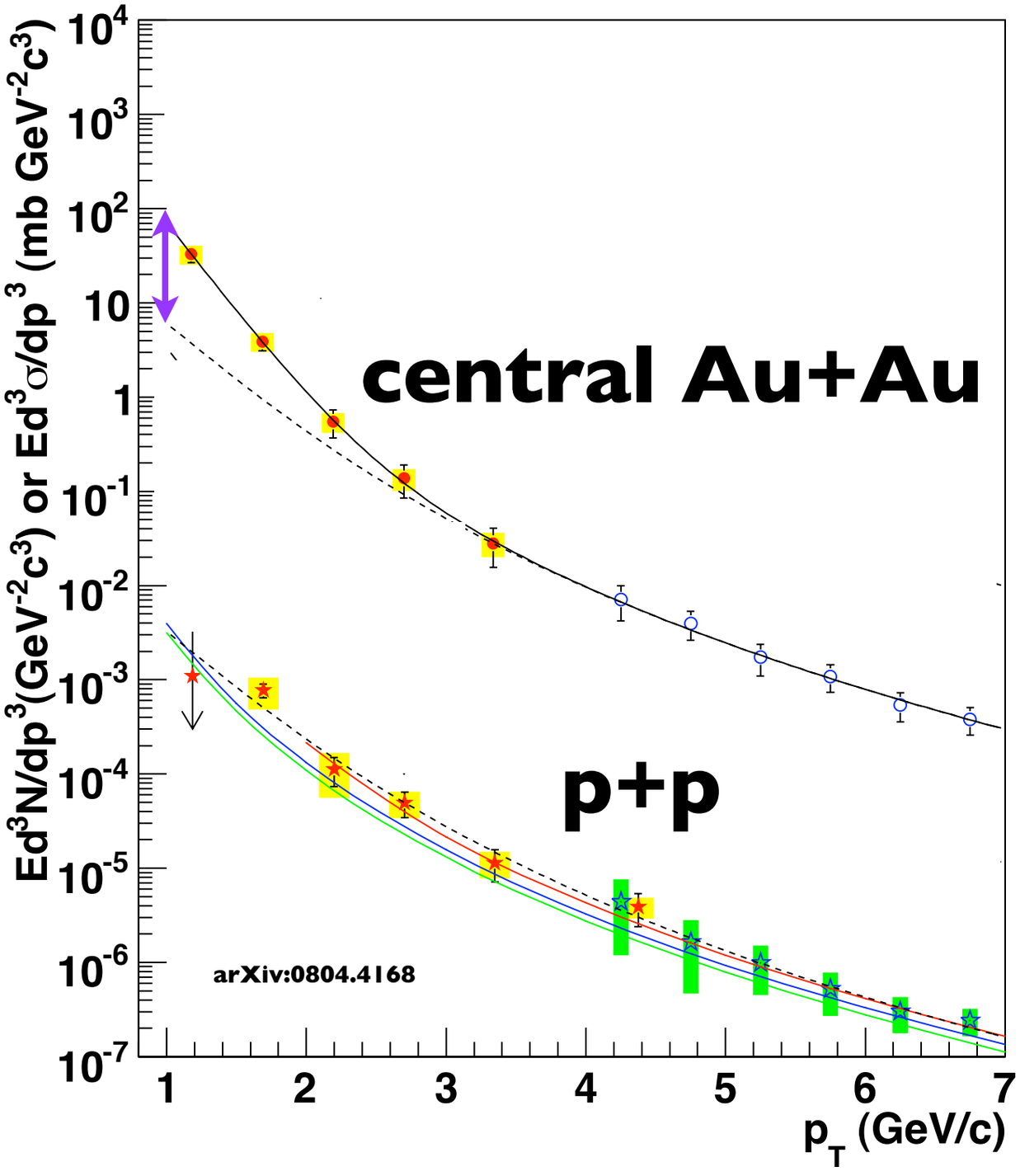
consistent with initial
T ~ 300-600MeV



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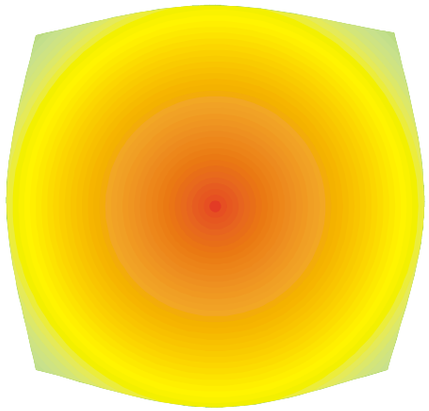

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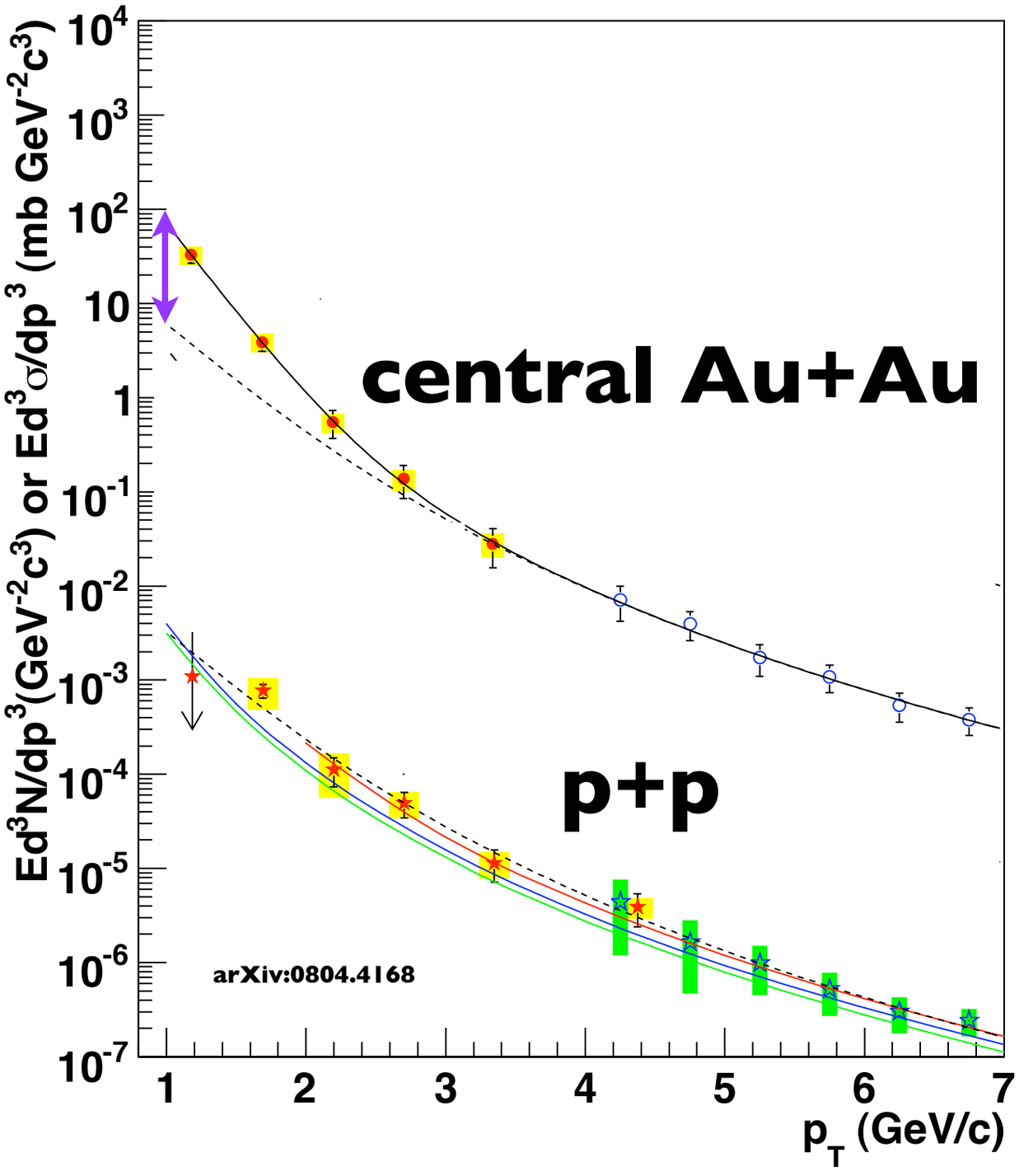
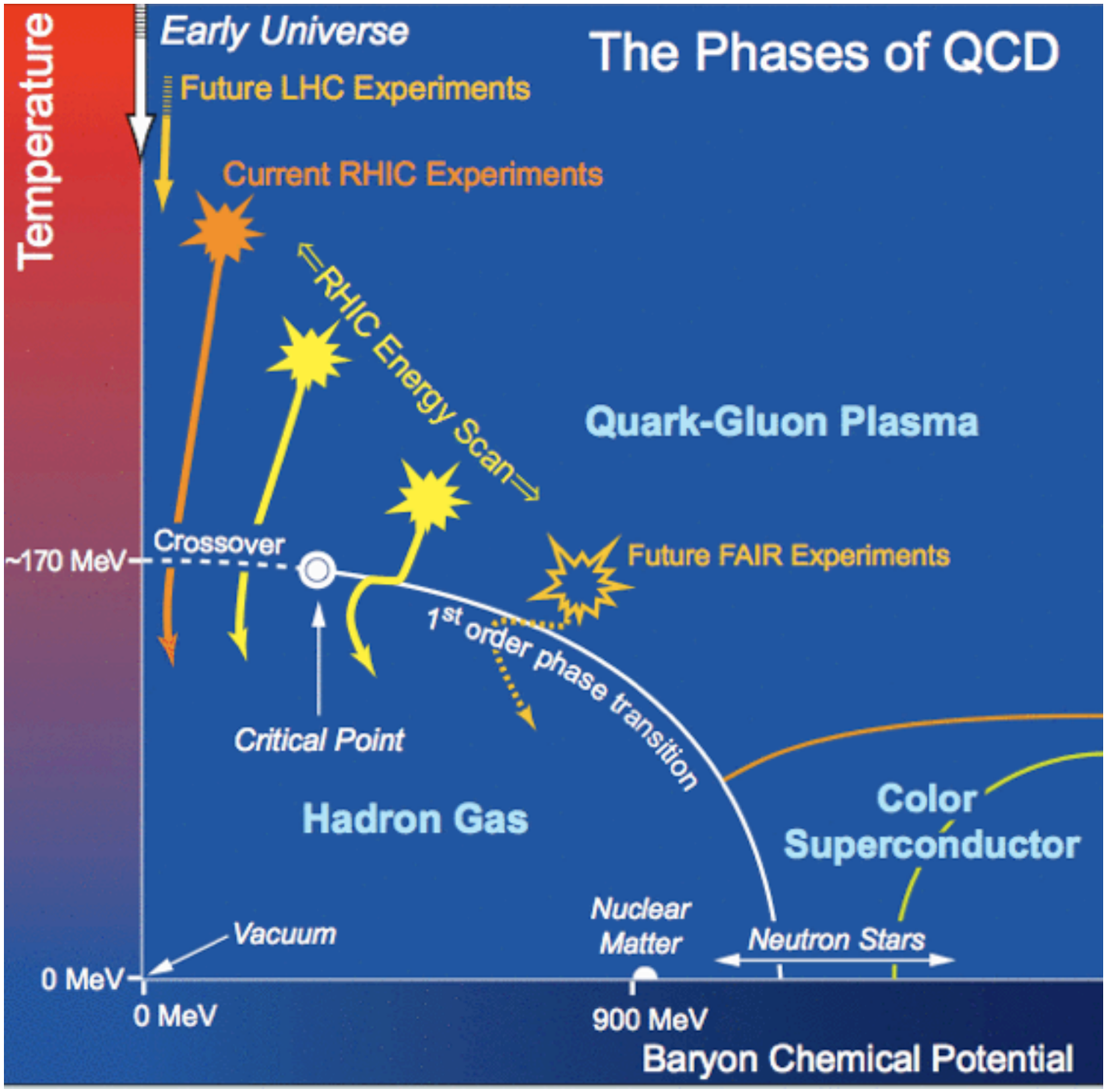
T~few trillion K

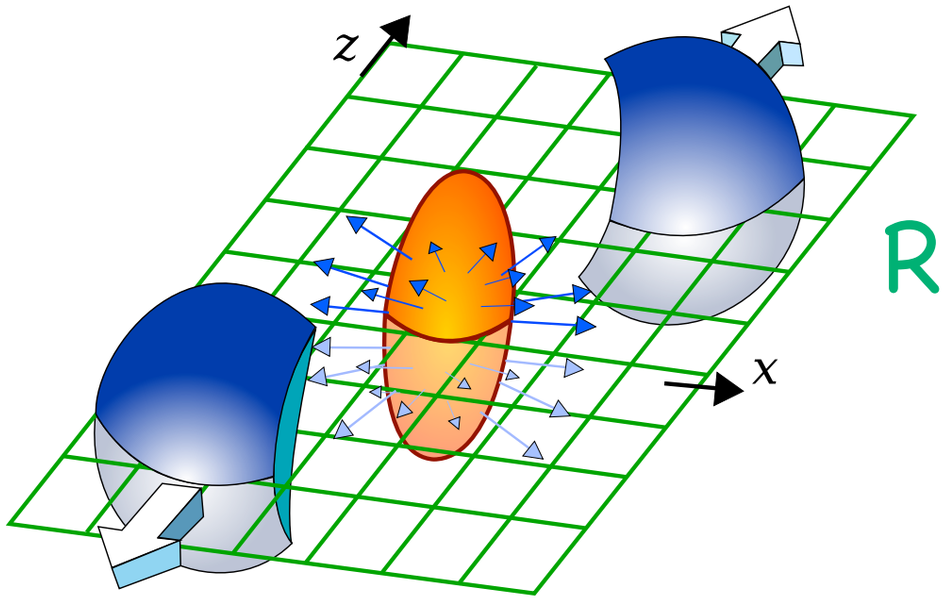


Phases of QCD



produce and study hot QCD matter!

idealized picture



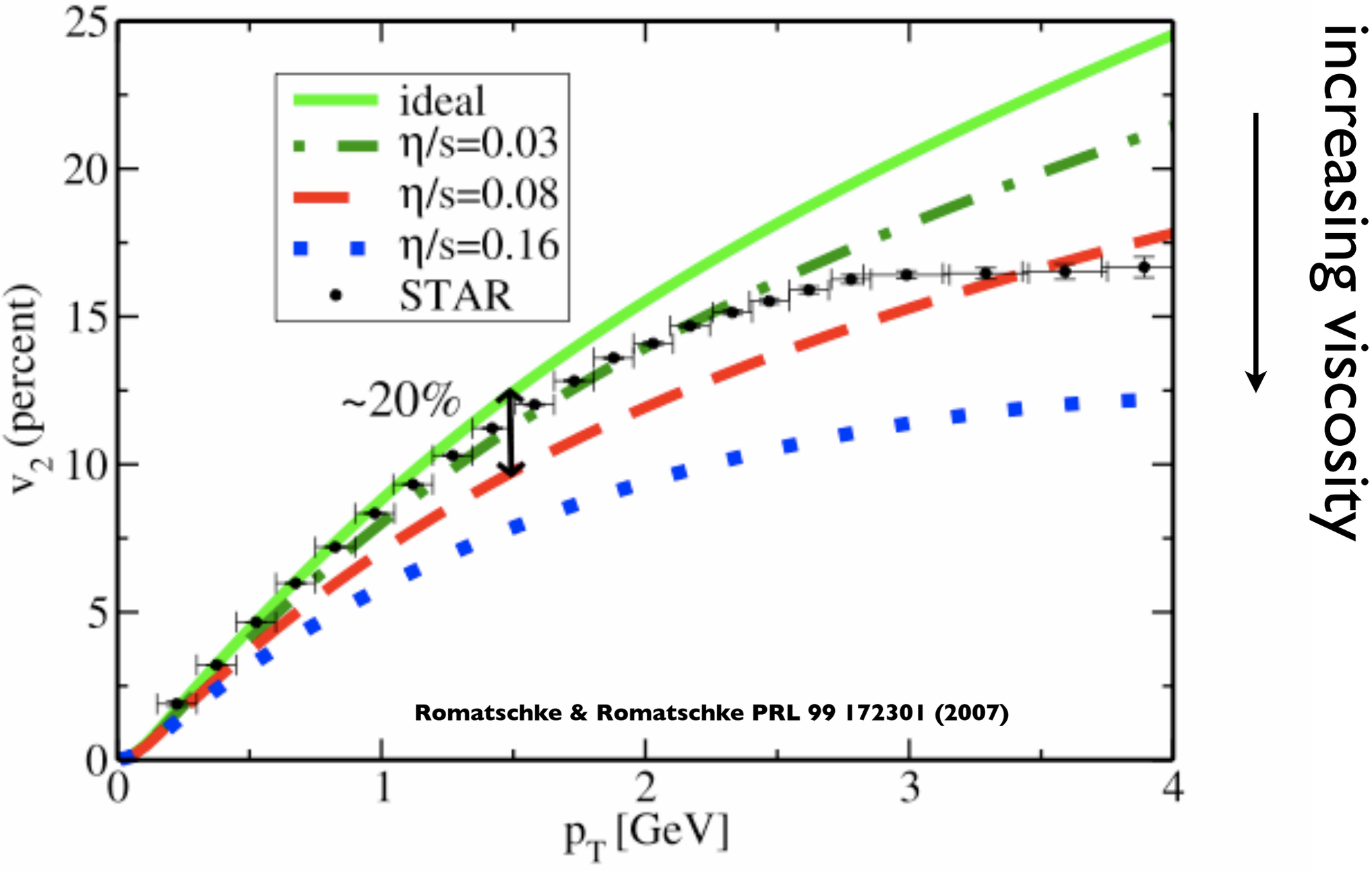
Reaction Plane

- if angle of particles w/respect to reaction plane is measured:

$$\frac{dN}{d(\Psi - \phi)} \propto 1 + 2v_2 \cos(\Psi - \phi) + \dots$$

- characterize matter in terms of v2

hydrodynamic



momentum

perfect fluid?

conjectured lower bound!

QGP!

- QGP seems to be in the vicinity of conjectured quantum lower bound for η/s
- conjecture based on calculation done on 10 dimensional black holes!
  - based on the insight from string theory of the duality between 4 dimensional strongly coupled gauge theories and higher dimensional gravity theories (Maldacena Adv. Theor. Math. Phys. 2, 231, 1998)

see Physics Today May 2005

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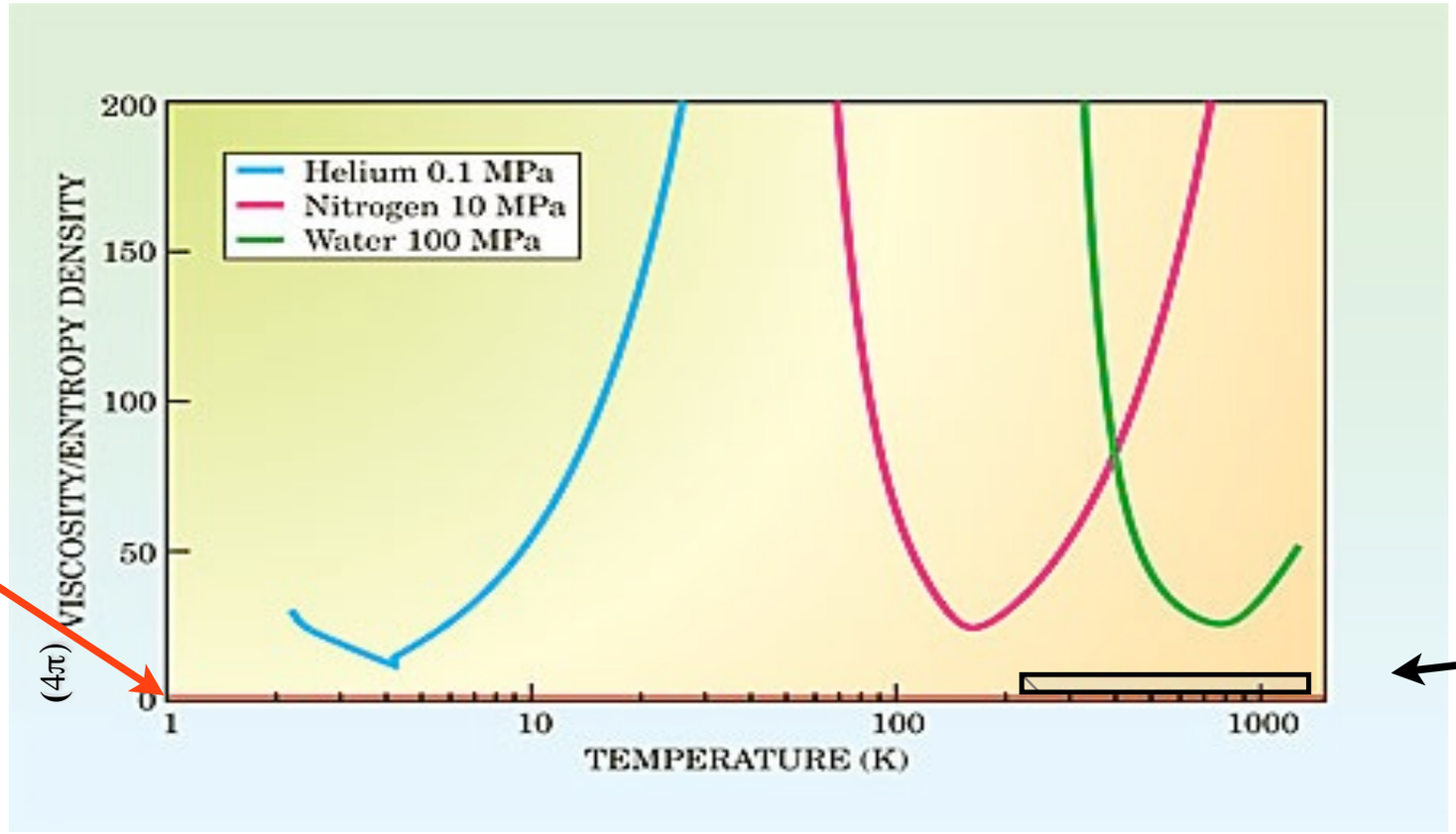

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see Physics Today May 2005

microscopic nature

parton$_i$(E)

microscopic nature

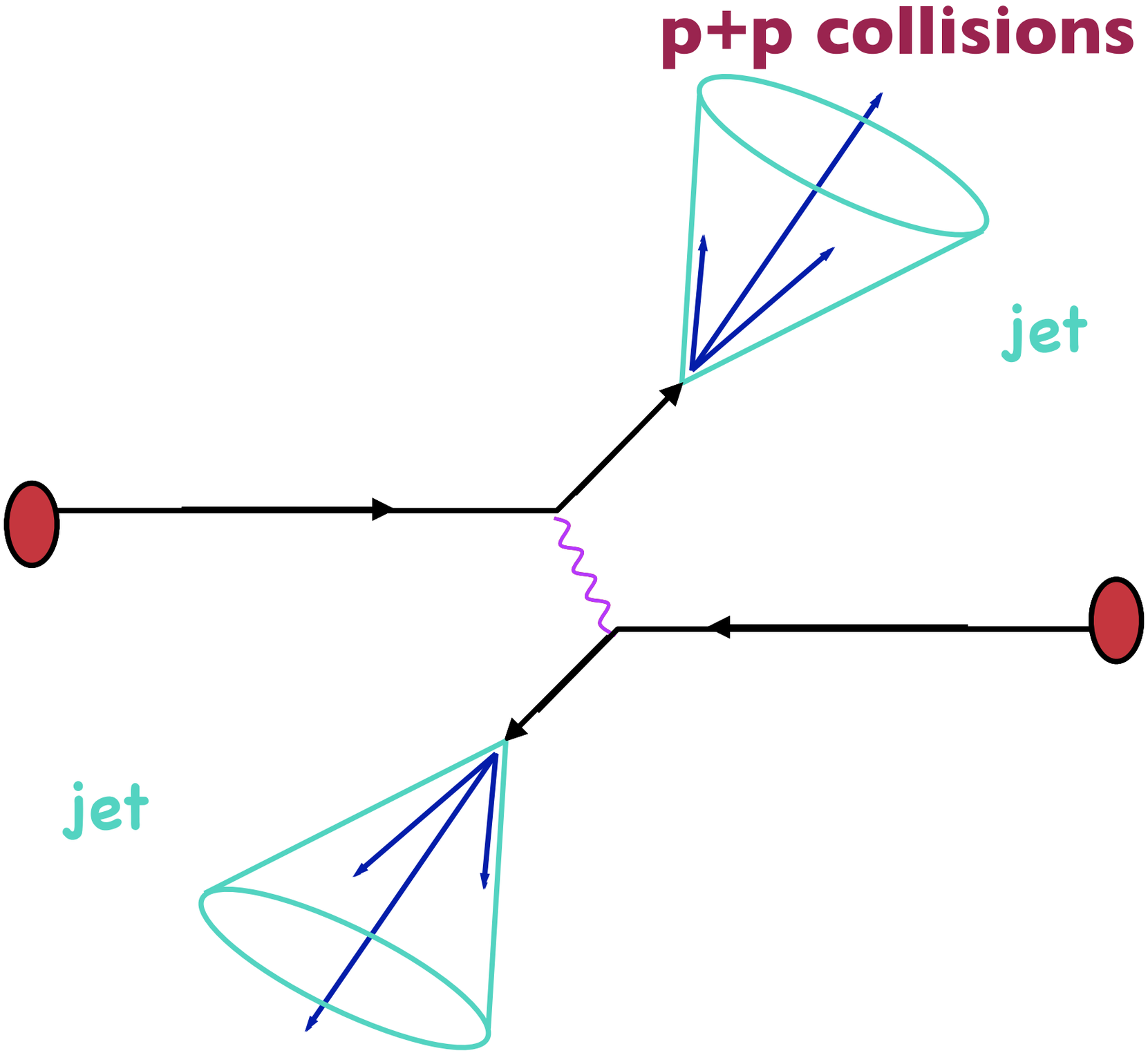
microscopic nature

microscopic nature

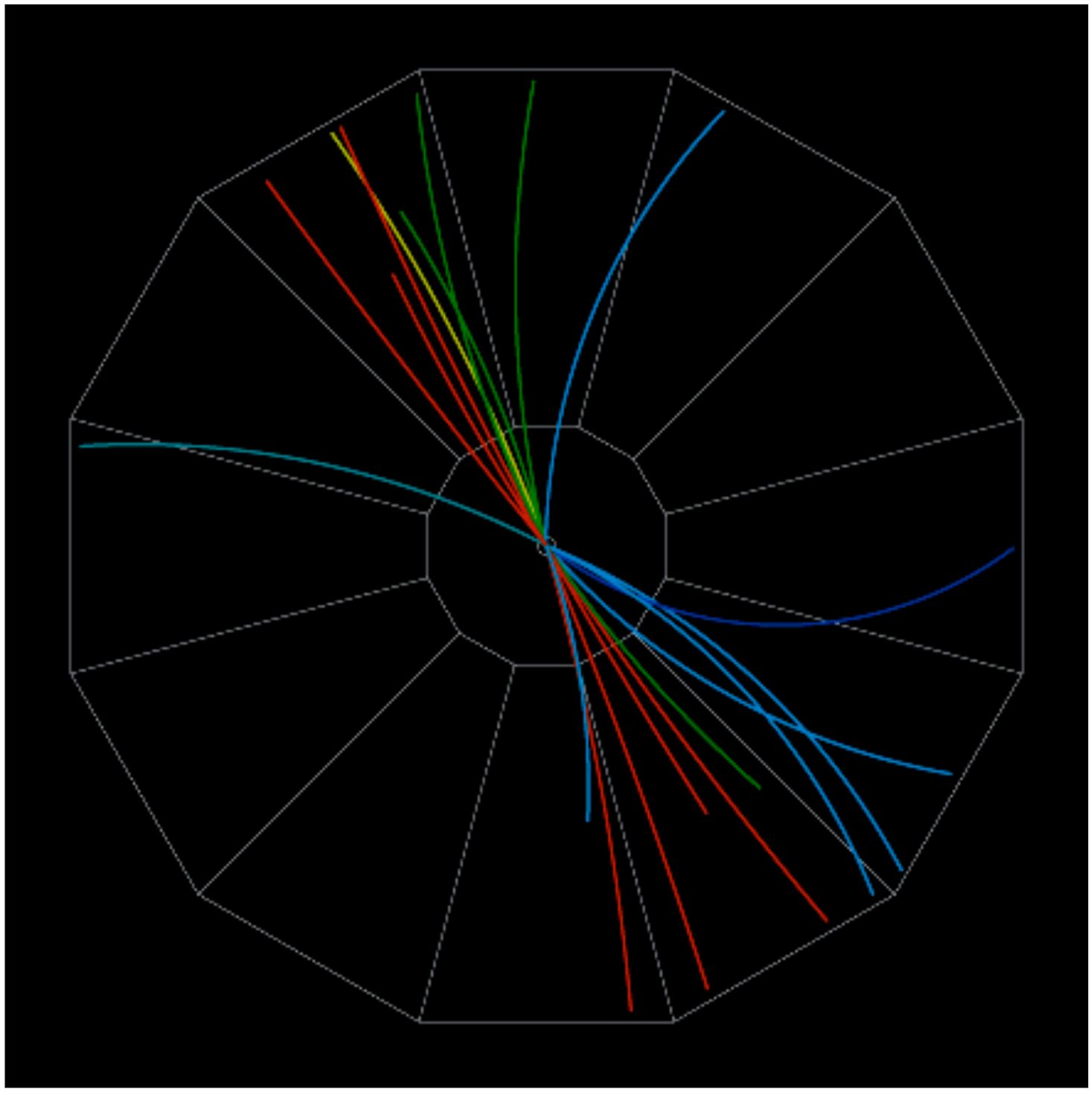
→determine the mechanism(s) of interactions

→determine the strength of the interactions

probing the QGP

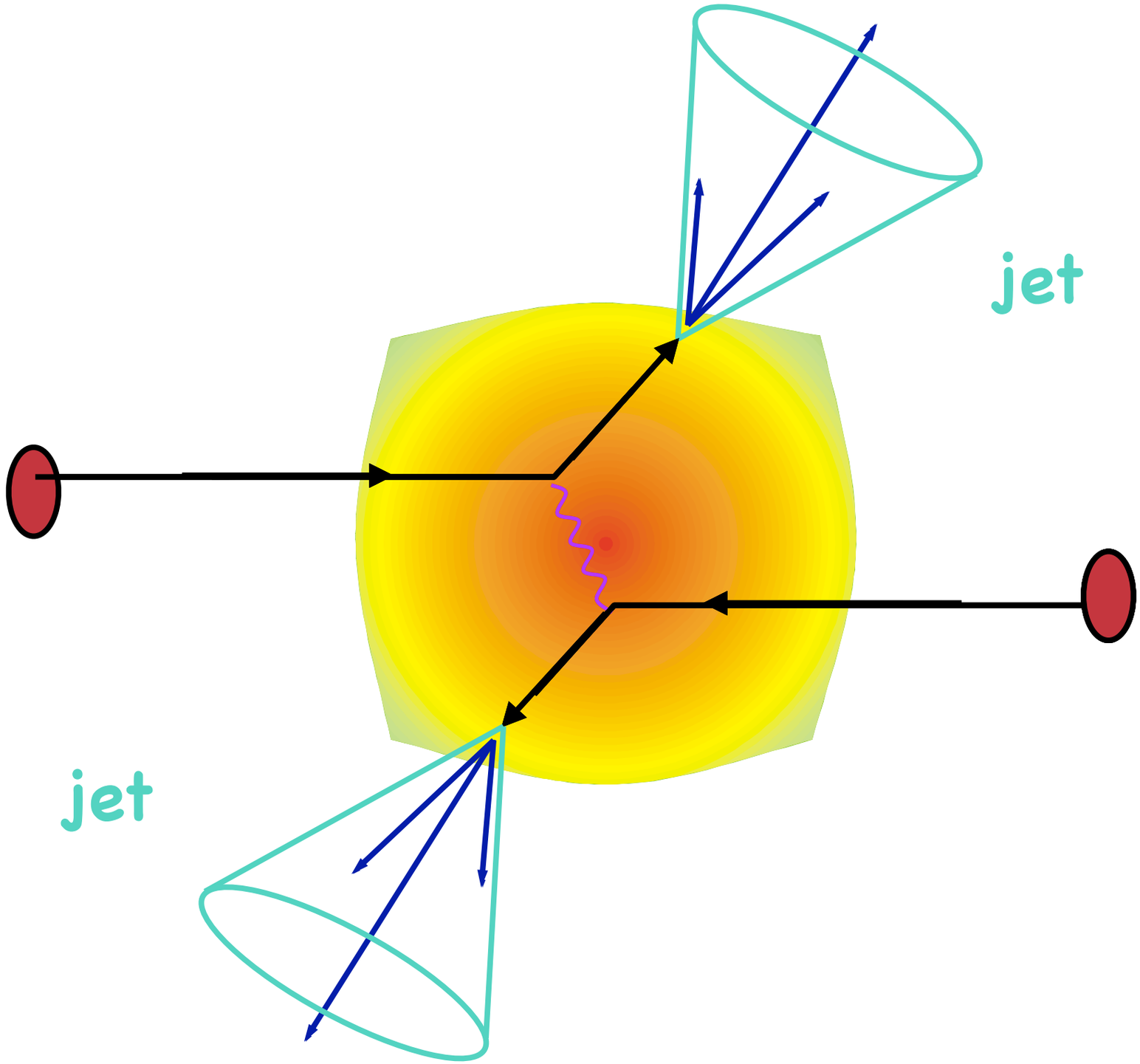


p+p jet



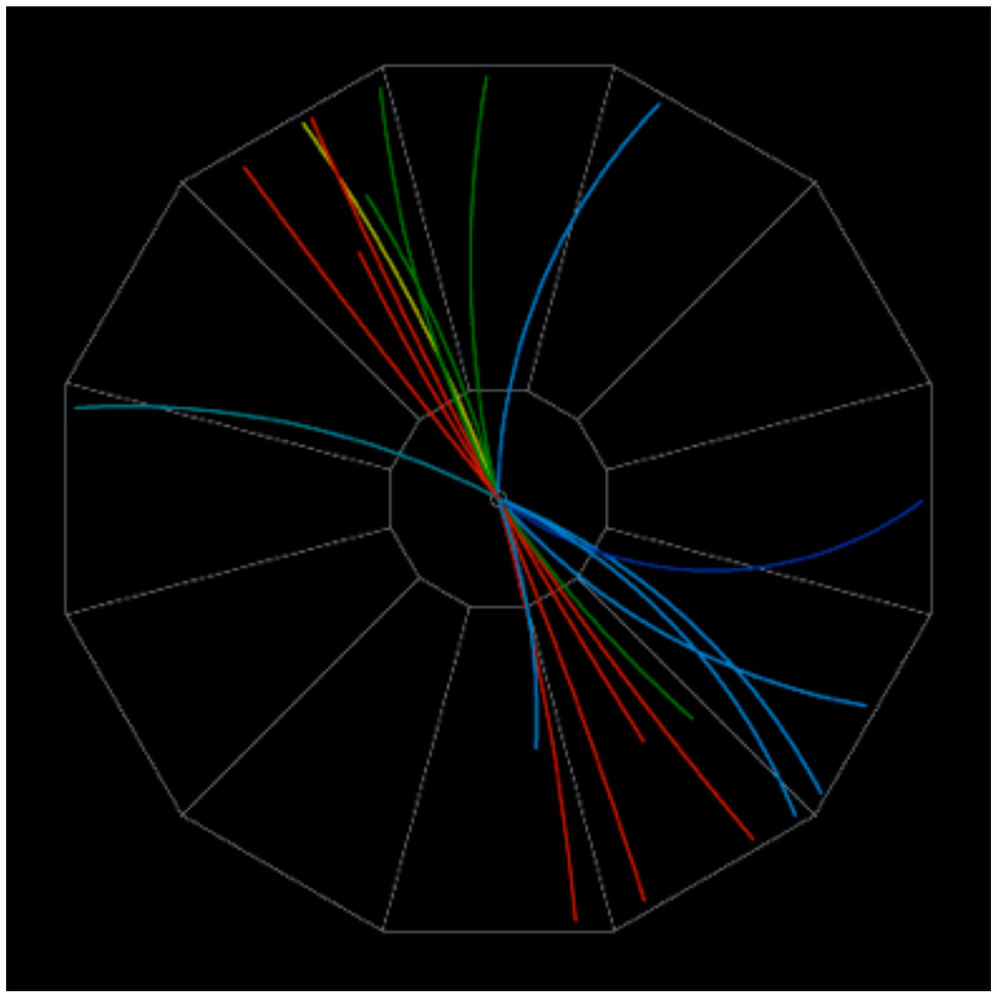
probing the QGP

Au+Au collisions



experimental challenge!

find this...



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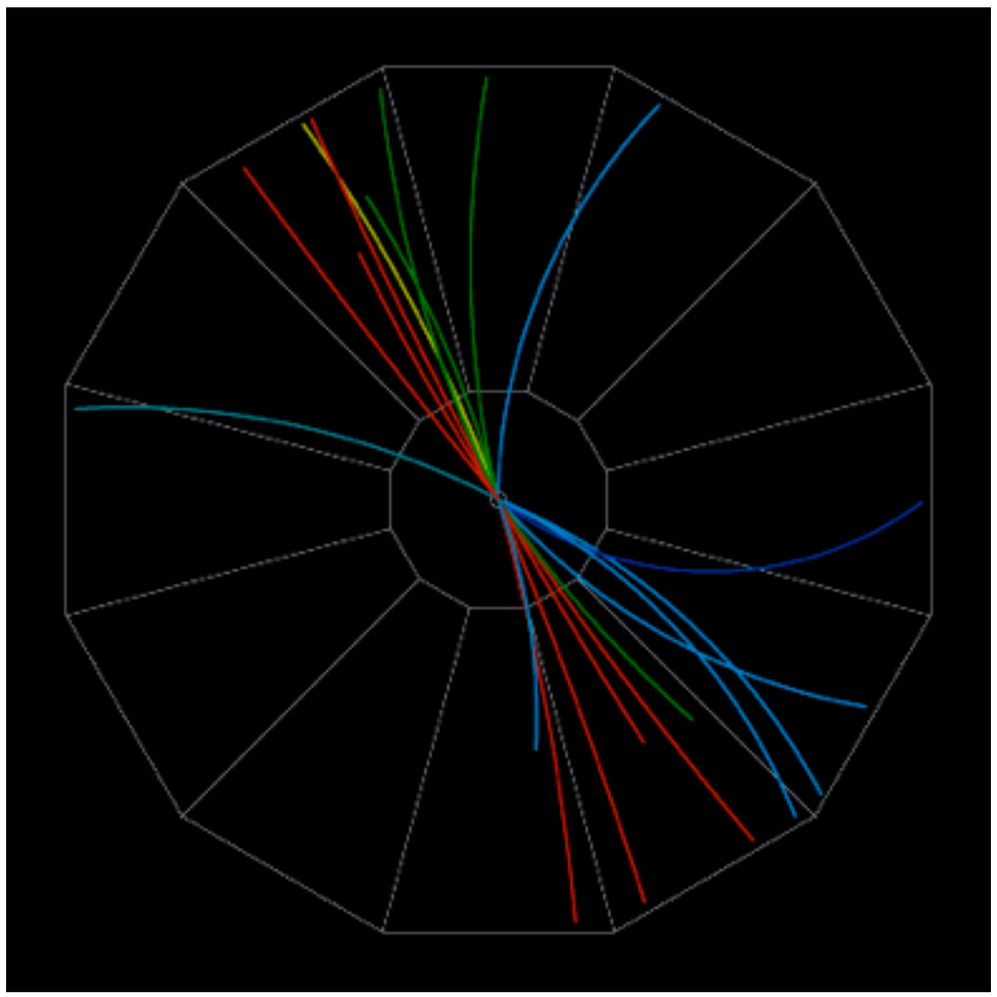
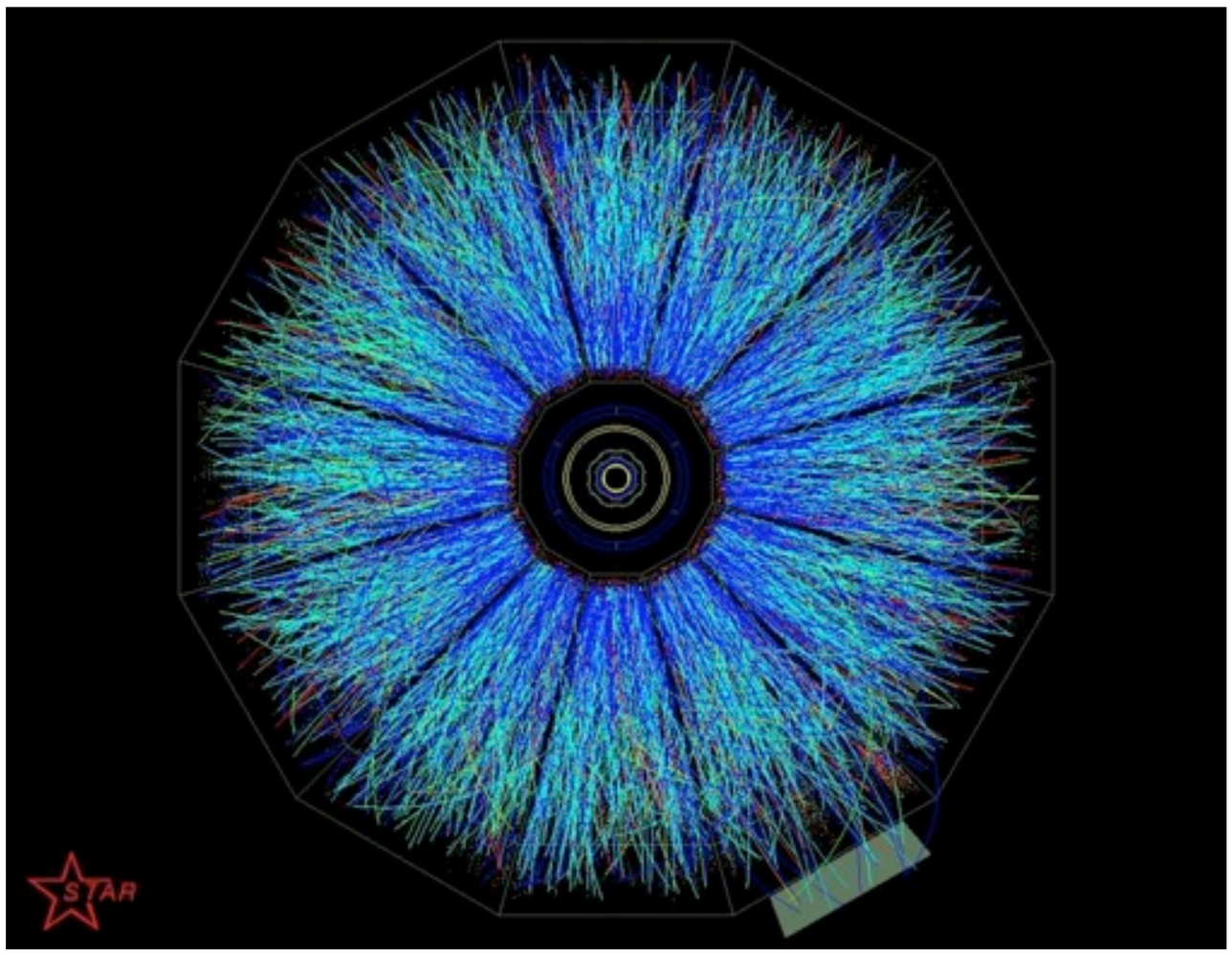
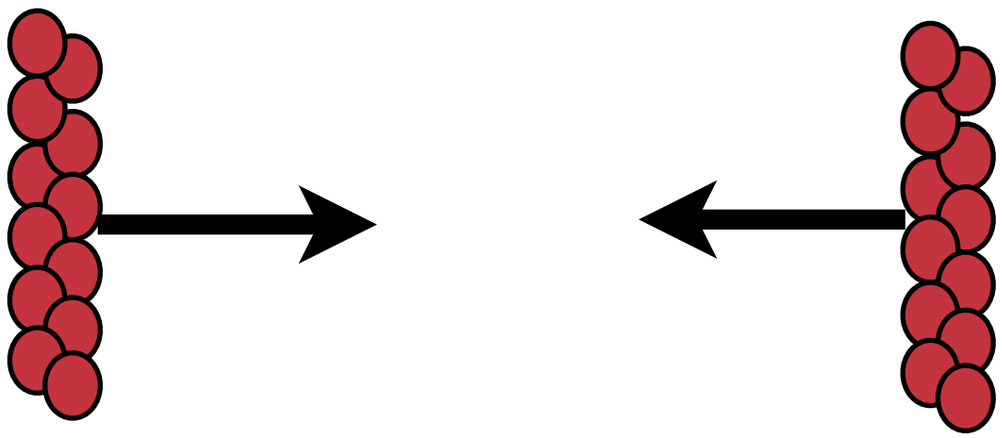


in here!



nucleons in nuclei

nucleons in nuclei



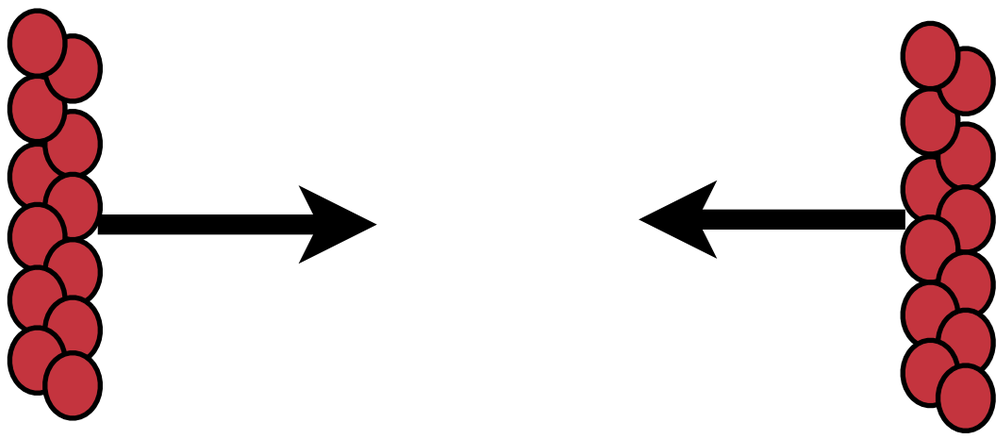
central collision

b small

N_{part} ~ 2*A

N_{coll} large

nucleons in nuclei



central collision

b small

N_{part} ~ 2*A

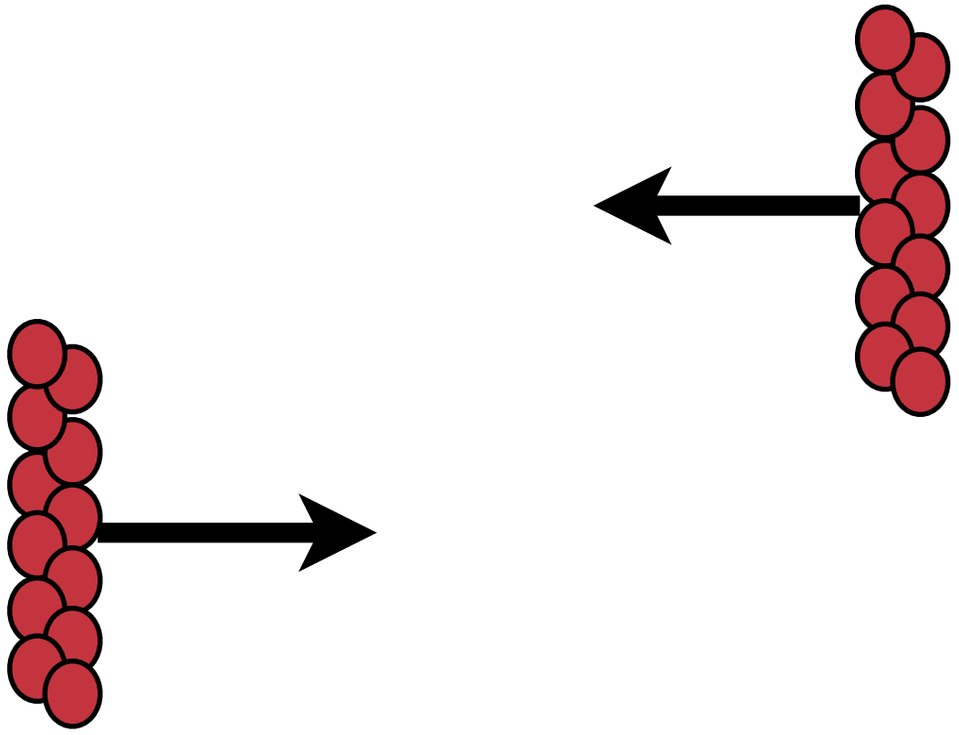
N_{coll} large

peripheral collision

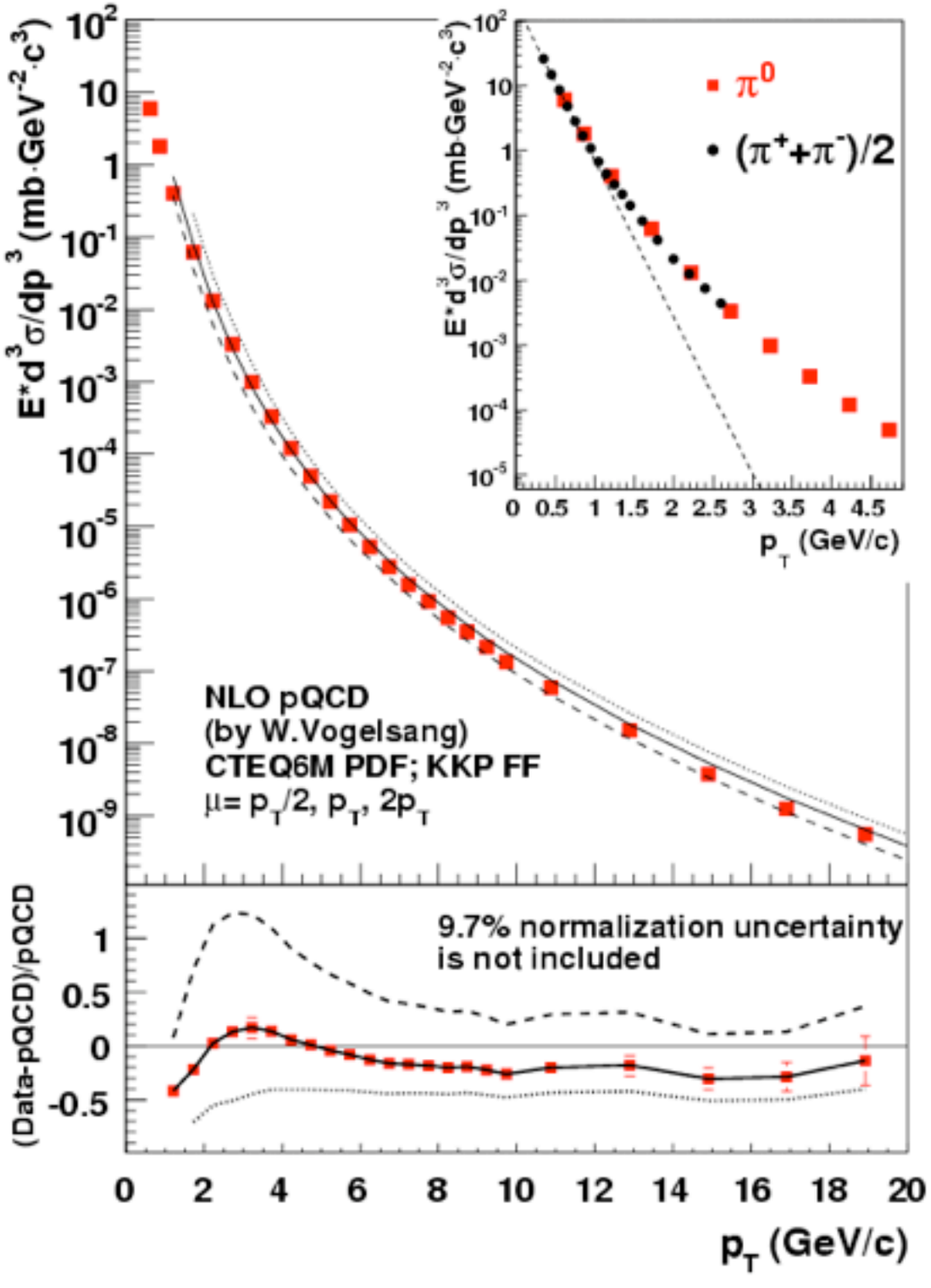
b large

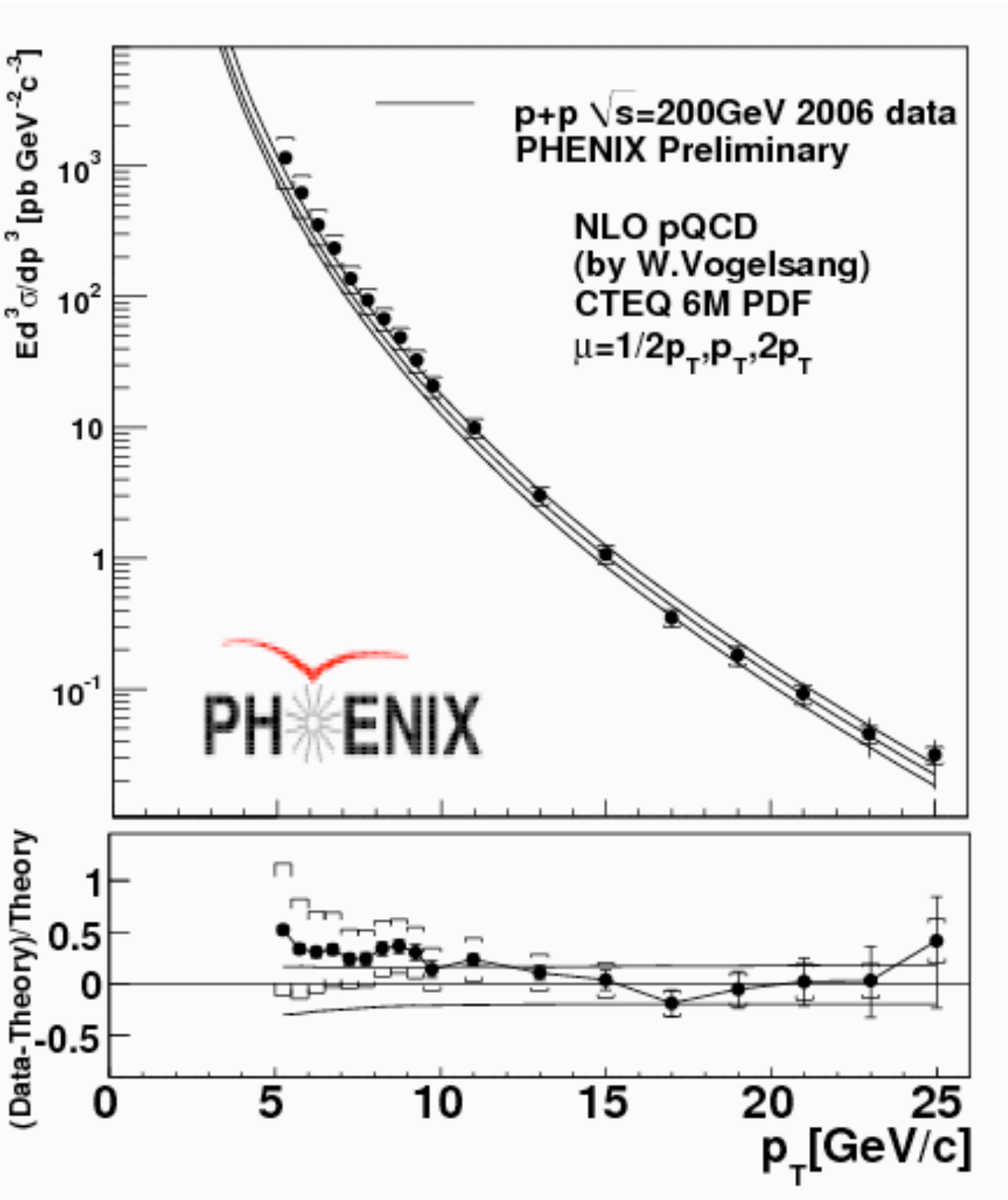
N_{part} small

N_{coll} small



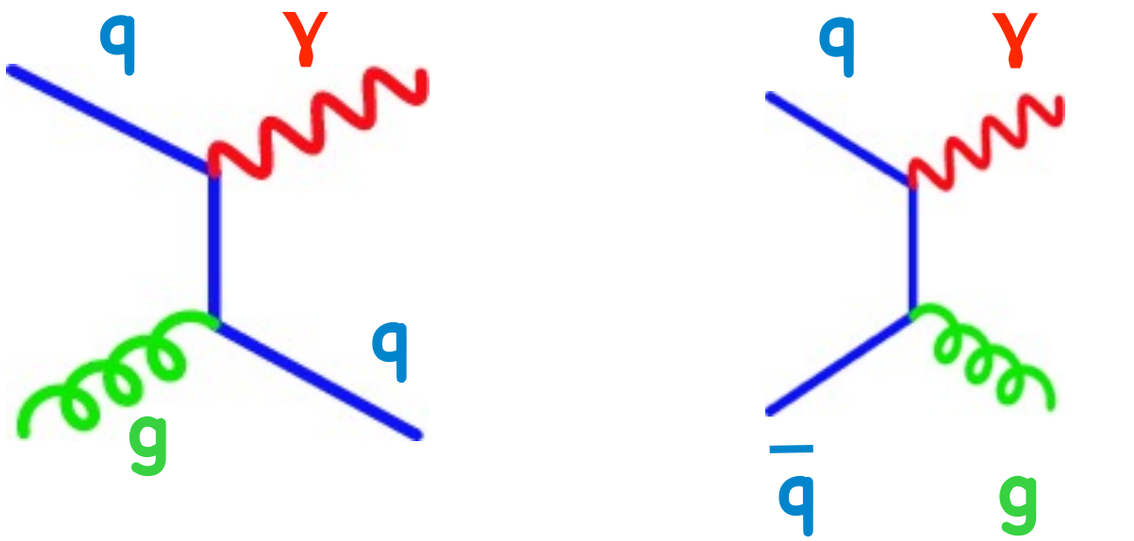
calculable & measurable!





Testing Expectations

- QCD processes can produce photons:



Compton Scattering

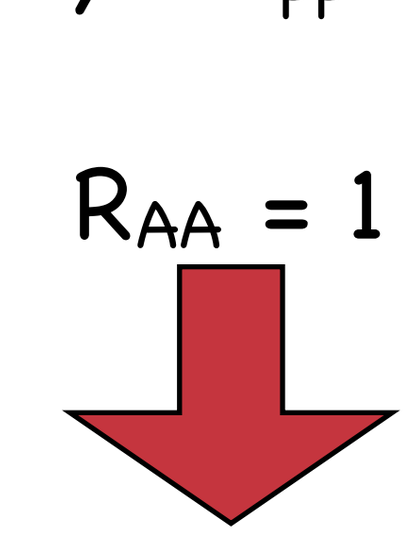
Annihilation

- Photons escape the colored final state without interacting
- If the initial state in heavy ion collisions is like a collection of p+p collisions, photon spectra should scale from p+p

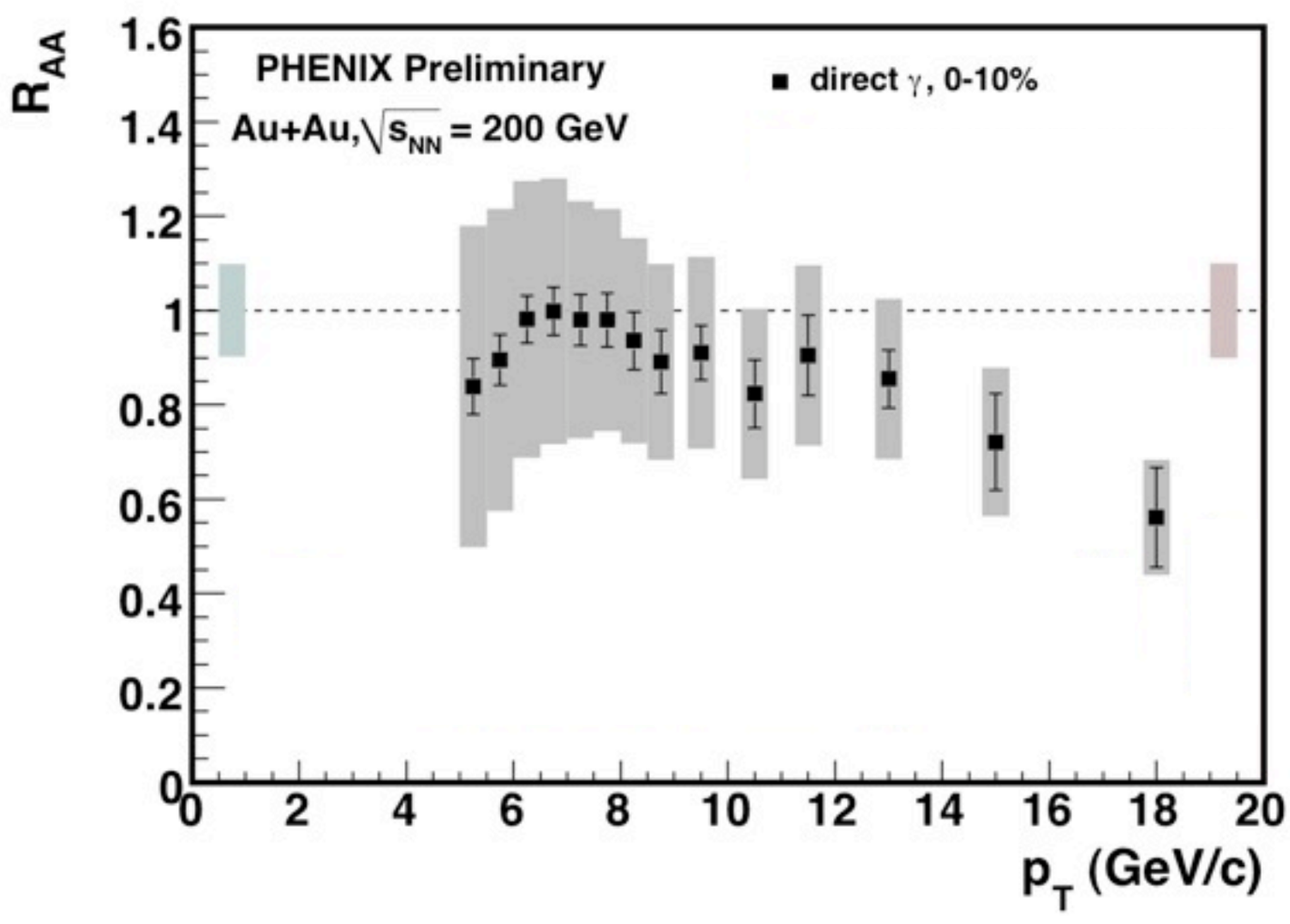
γ: control measurement

$$R_{AA} = \frac{\text{yield}_{AA}}{\text{yield}_{pp} * N_{coll}}$$

$R_{AA} = 1$



no nuclear effects



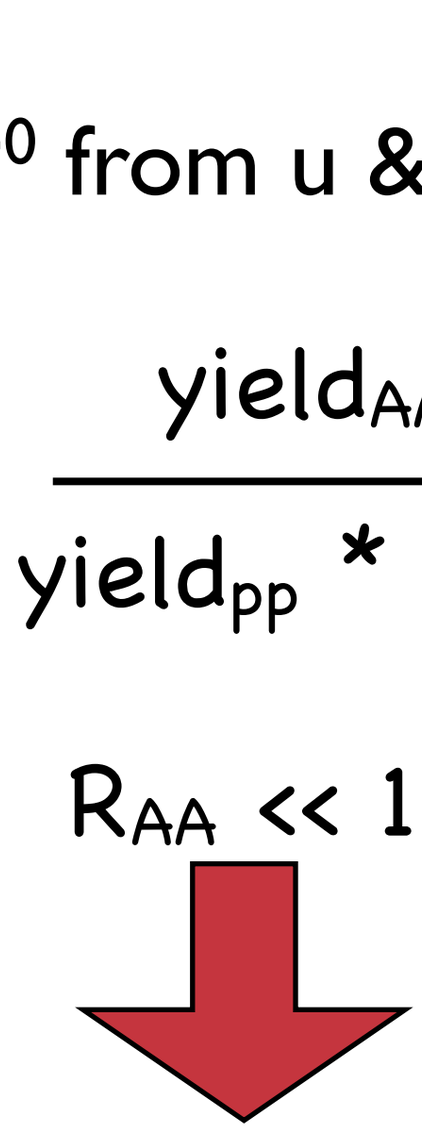
γ: no color charge → insensitive to produced matter
$R_{AA}(p_T<14\text{GeV/c})$ consistent with unity

π^0: light meson

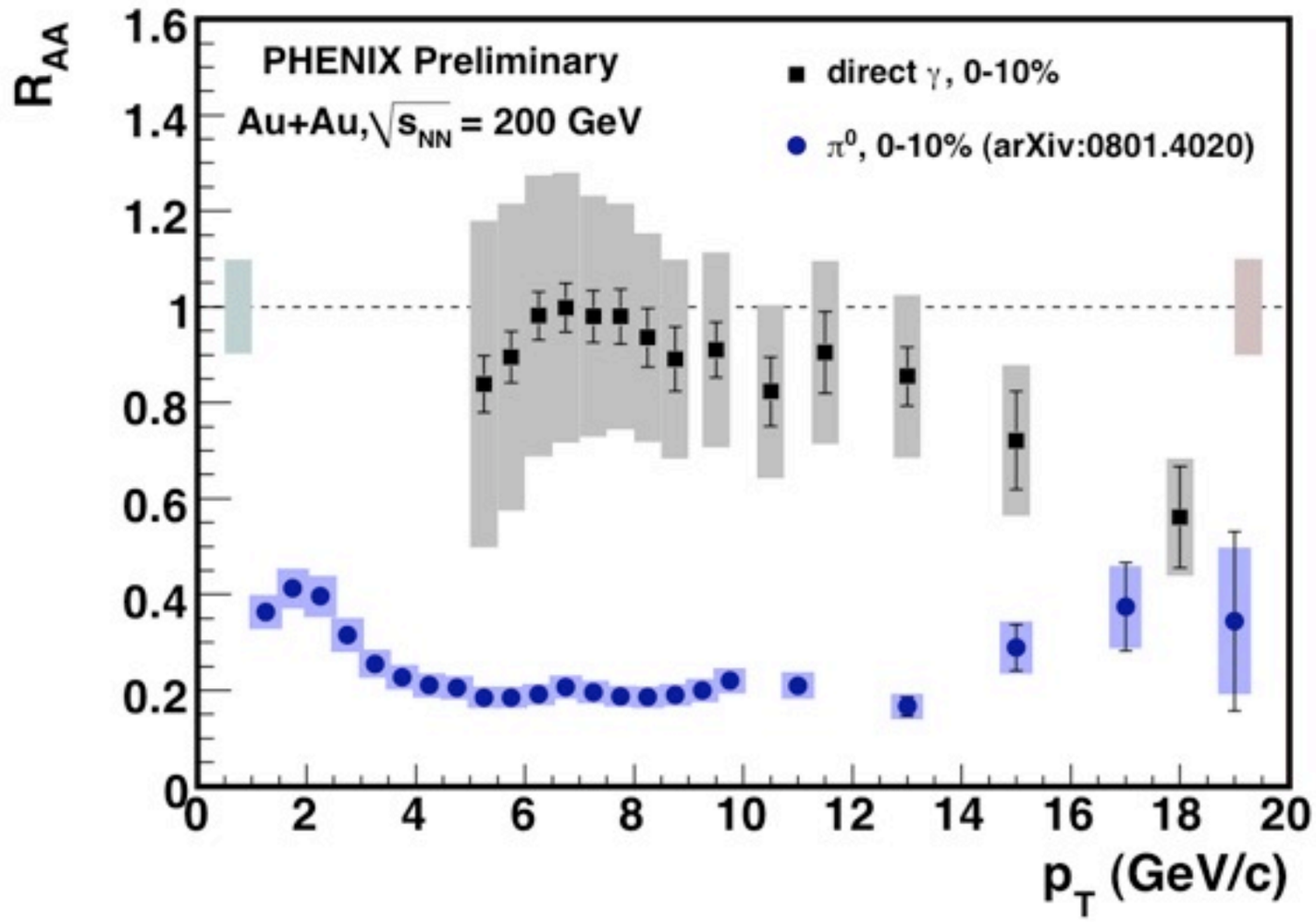
π^0 from u & d quarks and gluons traversing matter

$$R_{AA} = \frac{\text{yield}_{AA}}{\text{yield}_{pp} * N_{coll}}$$

$R_{AA} \ll 1$



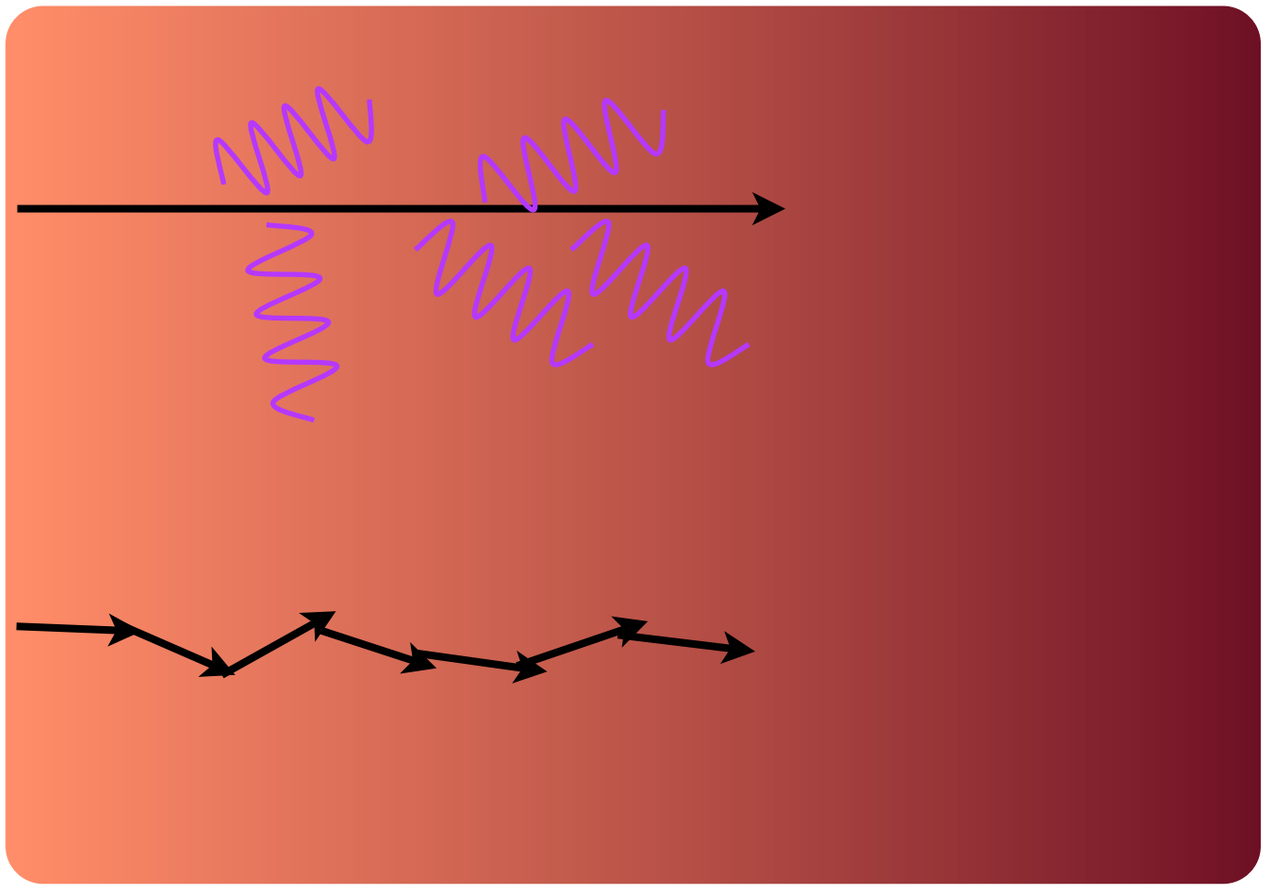
effects of QGP



what happens to the energy?

gluon radiation

collisional broadening

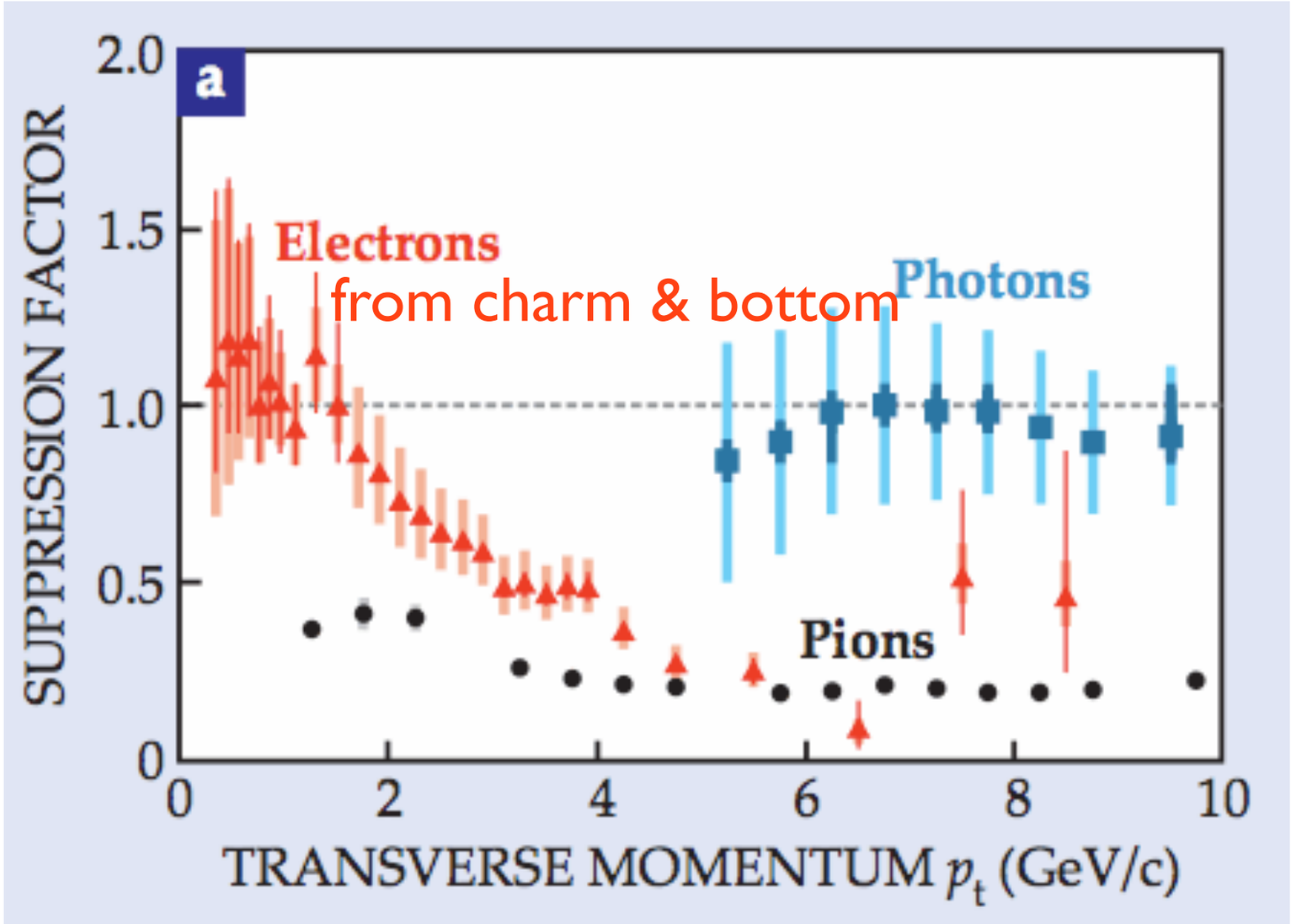


- is the energy thermalized in the end?

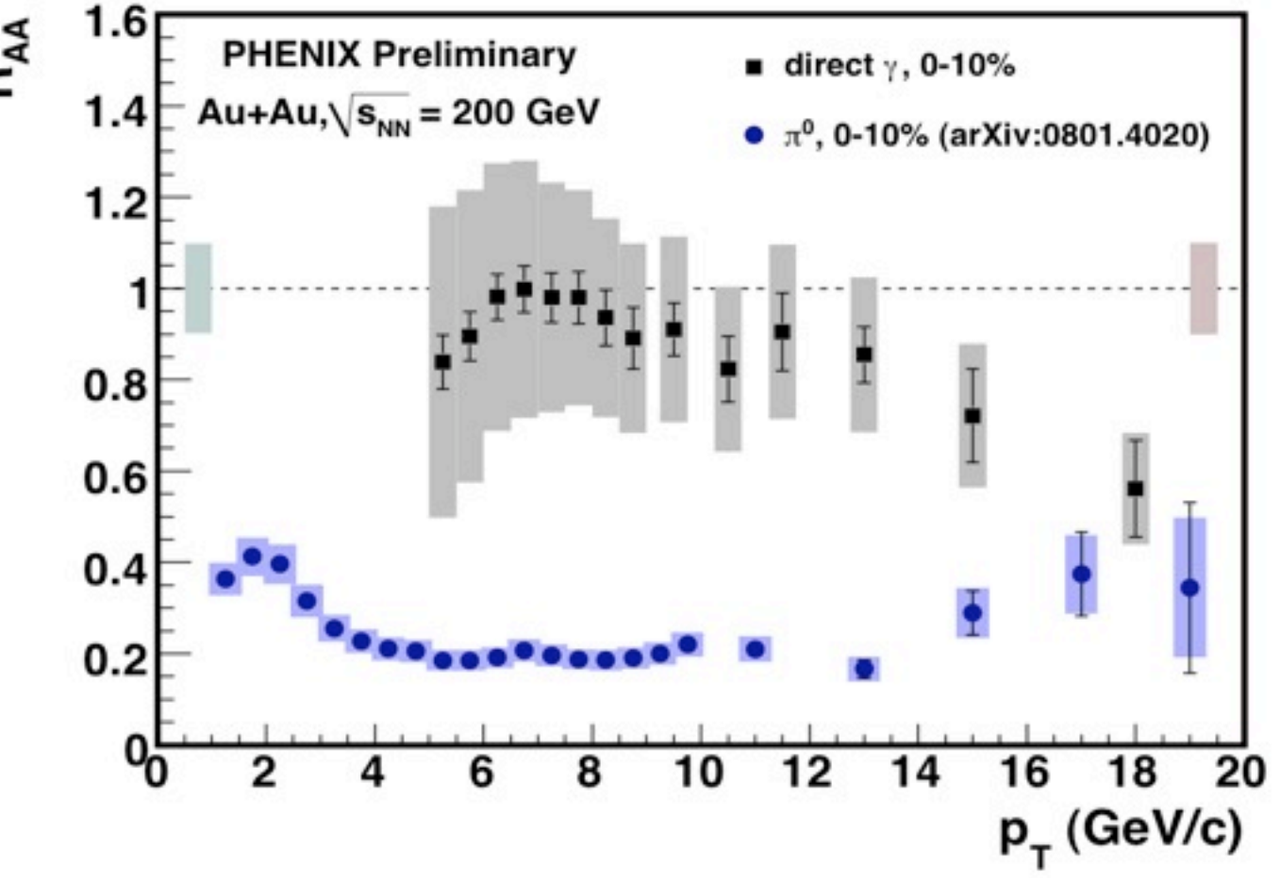
what about heavy quarks?

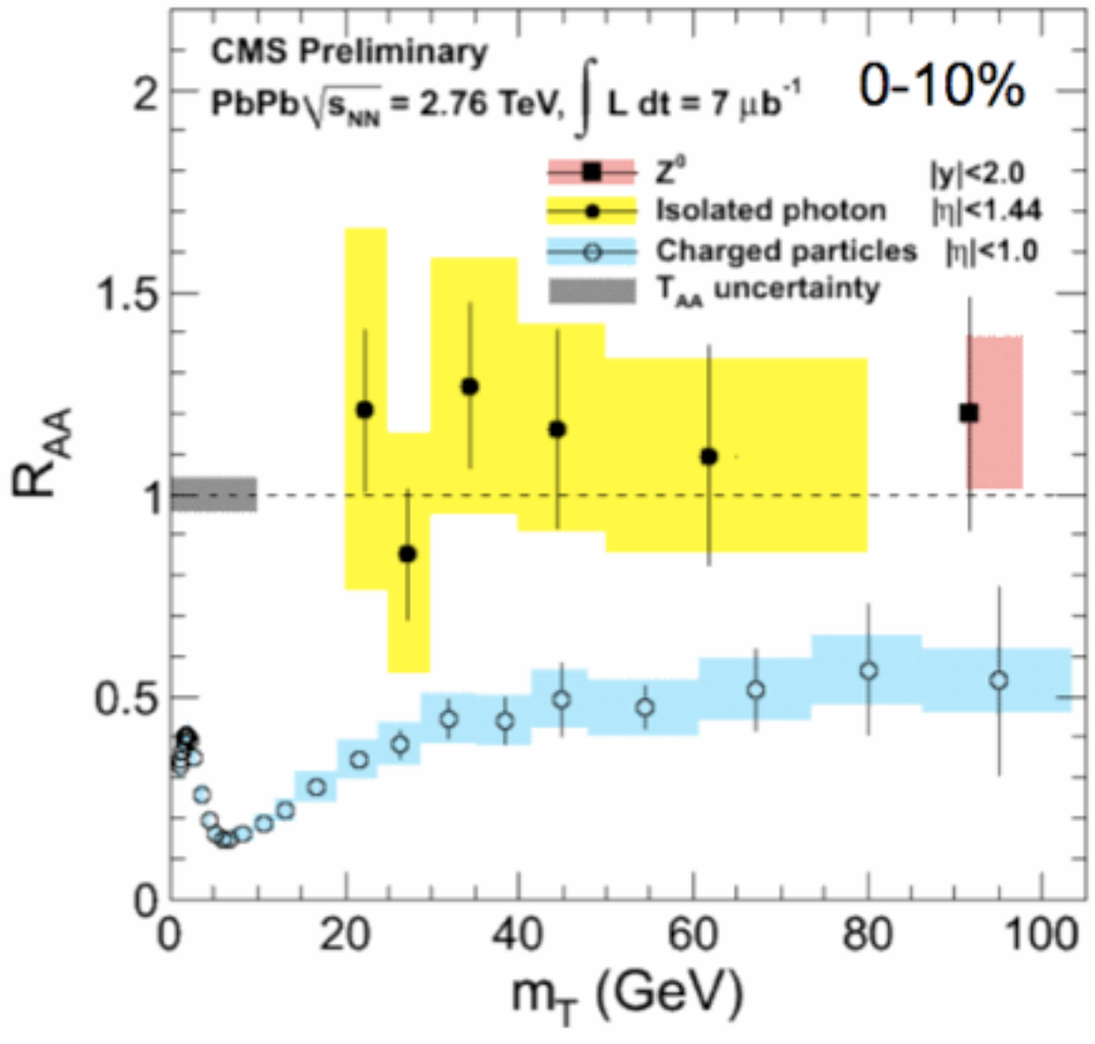
- massive quarks expected to have suppressed gluon radiation

	Charge	Mass
down	-1/3	0.006
up	+2/3	0.003
strange	-1/3	0.1
charm	+2/3	1.2
bottom	-1/3	4
top	+2/3	171

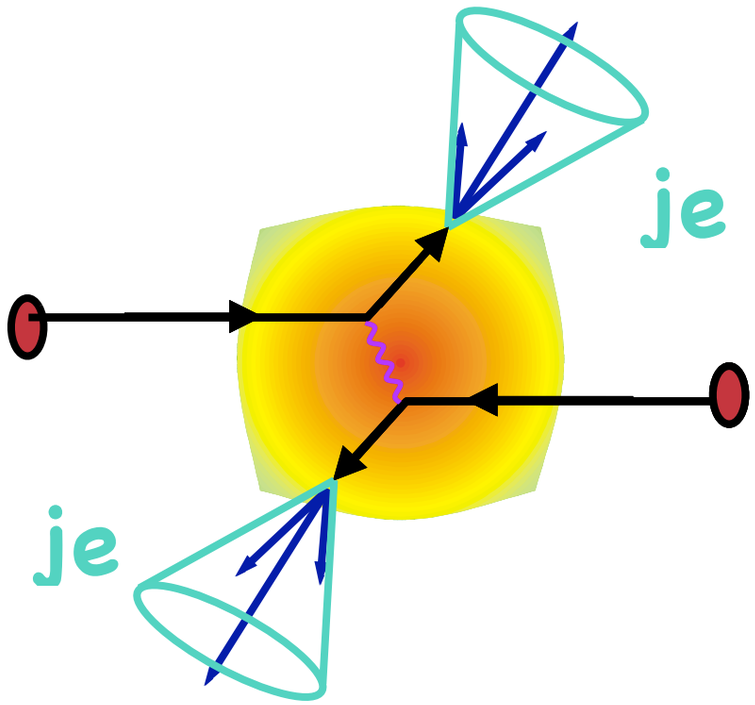


LHC!


PHENIX Preliminary
Au+Au, $\sqrt{s_{NN}}$ = 200 GeV
direct γ, 0-10%
π^0, 0-10% (arXiv:0801.4020)
R_{AA}
p_T (GeV/c)

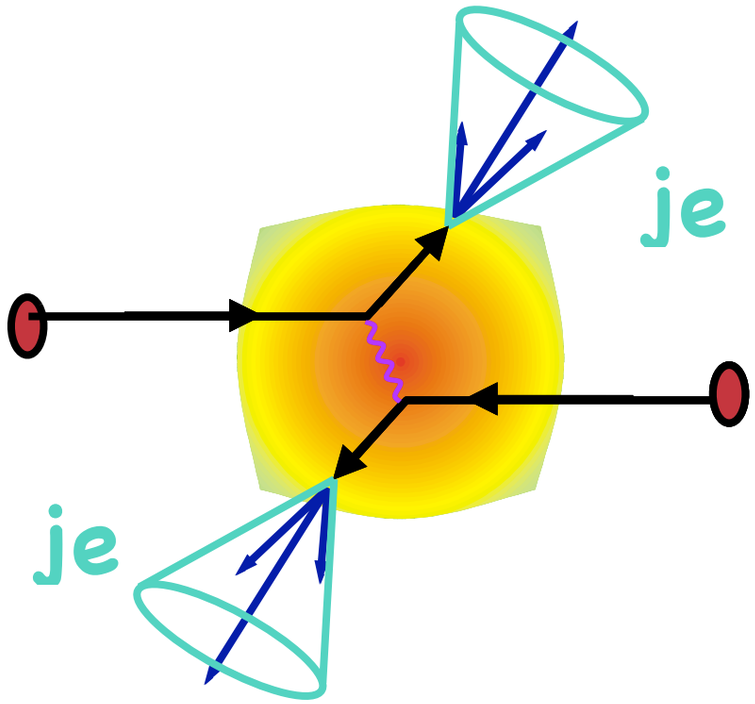

CMS Preliminary
PbPb$\sqrt{s_{NN}}$ = 2.76 TeV, $\int$ L dt = 7 μb^{-1}
0-10%
Z^0 |y|<2.0
Isolated photon |η|<1.44
Charged particles |η|<1.0
T_{AA} uncertainty
R_{AA}
m_T (GeV)

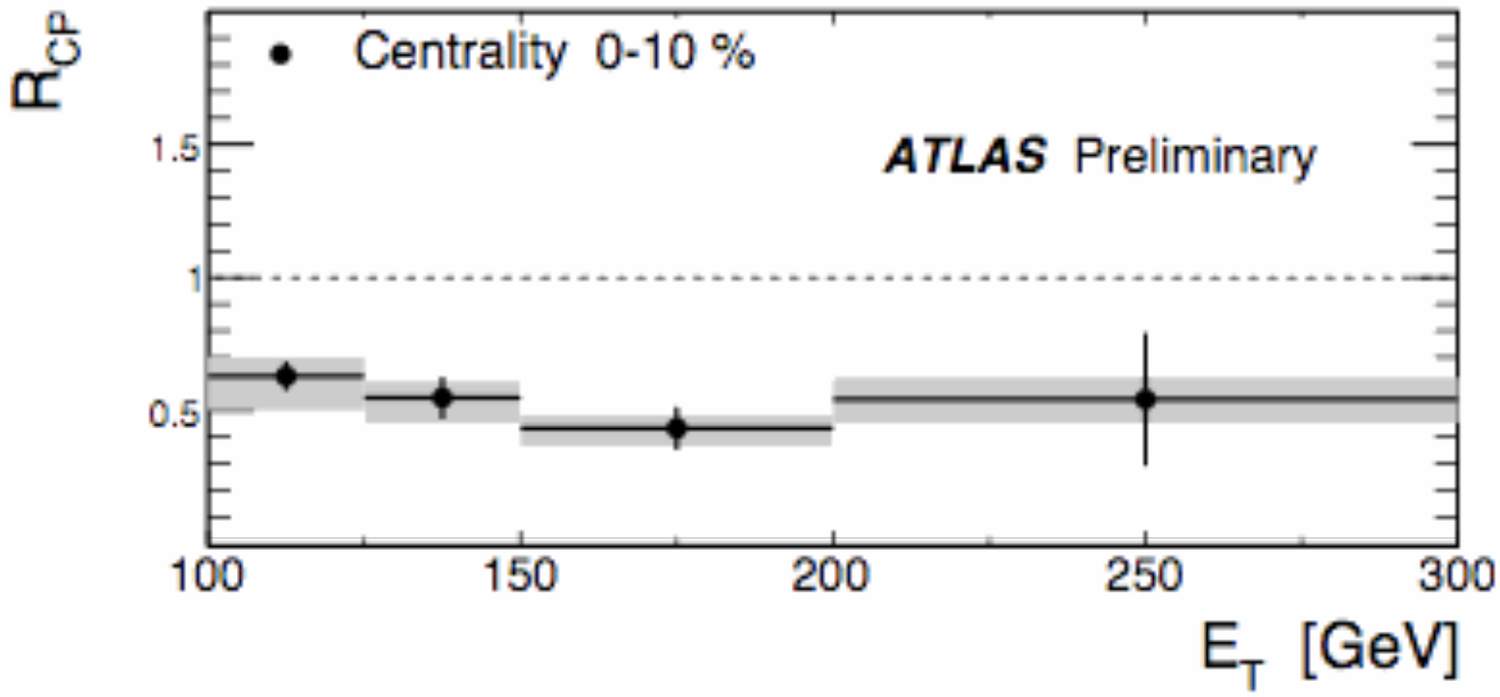
jets: collecting more energy



- even when as much energy as possible within a cone is associated with a jet, jets are still missing!
- energy must end up far from the jet or thermalized

jets: collecting more energy





- even when as much energy as possible within a cone is associated with a jet, jets are still missing!
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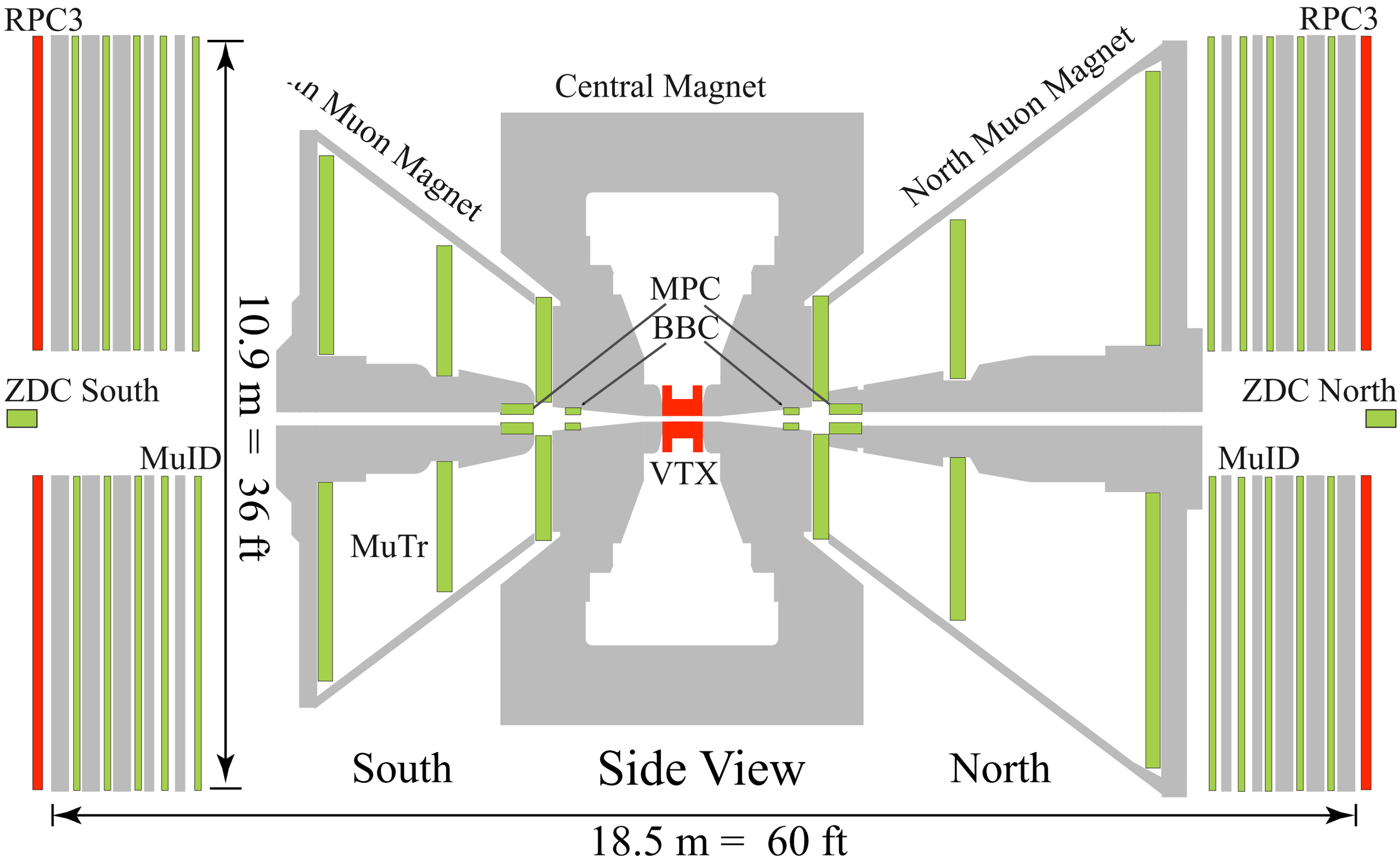
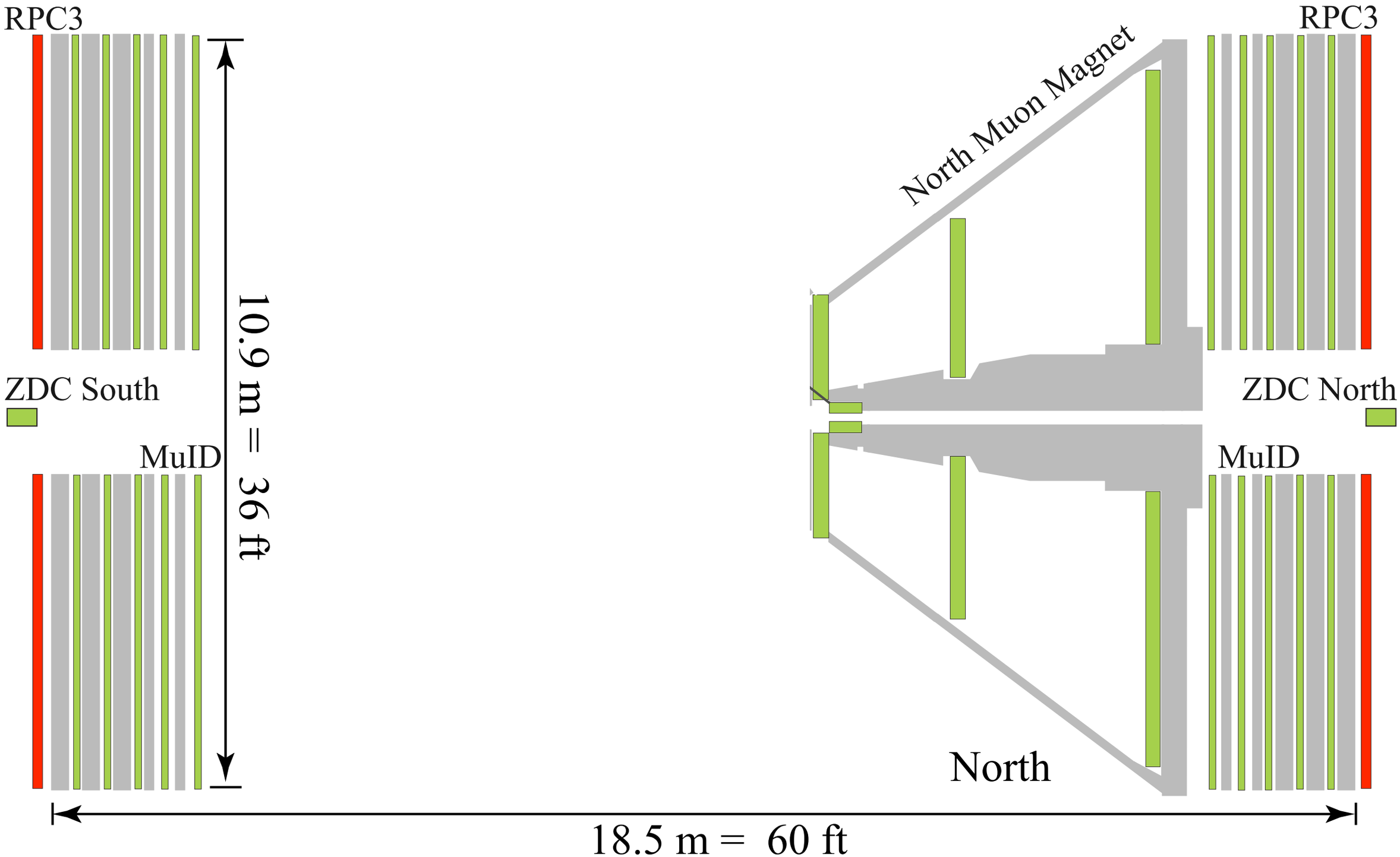
frontiers

- complicated questions → precision measurements
  - we know we made it, now study of the matter
    - near perfect fluid nature was a surprise, now pinning down η/s of fundamental interest
    - parton matter interactions remain a mystery
    - screening lengths → J/ψ, Υ states
    - are there quasiparticles?
    - ....
- complicated questions → creative minds

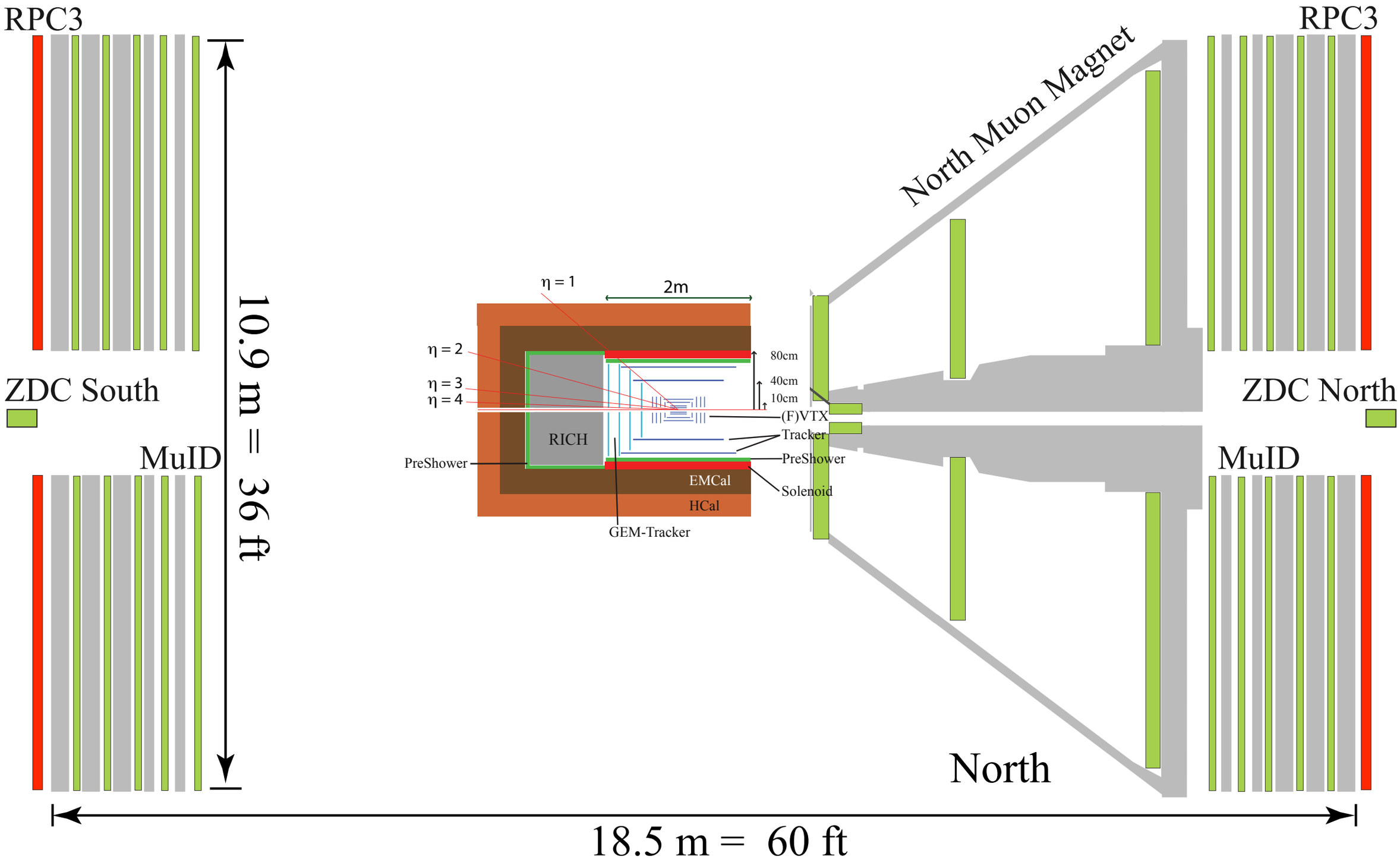
PHENIX → sPHENIX



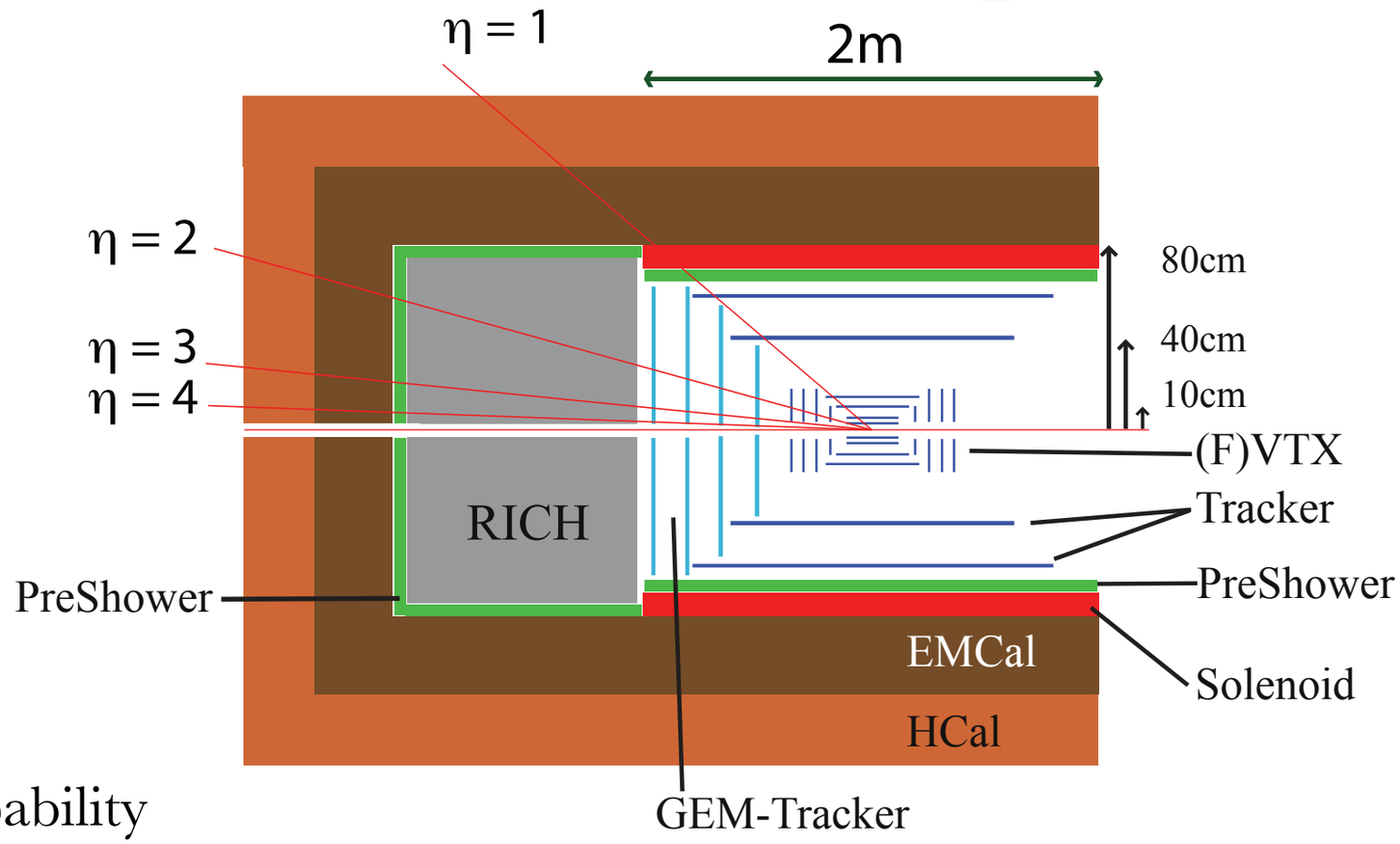
PHENIX → sPHENIX



PHENIX → sPHENIX

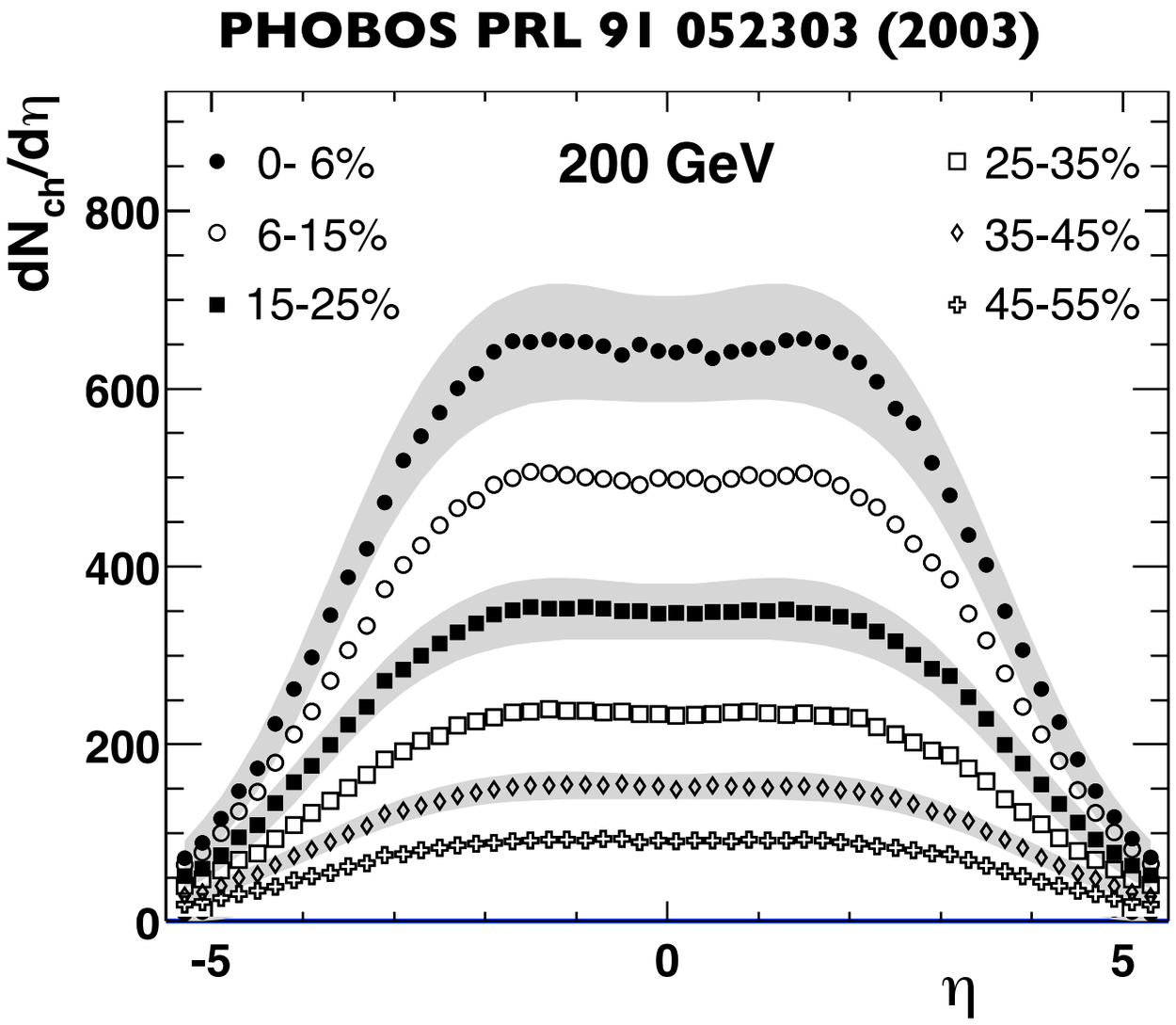


sPHENIX plan



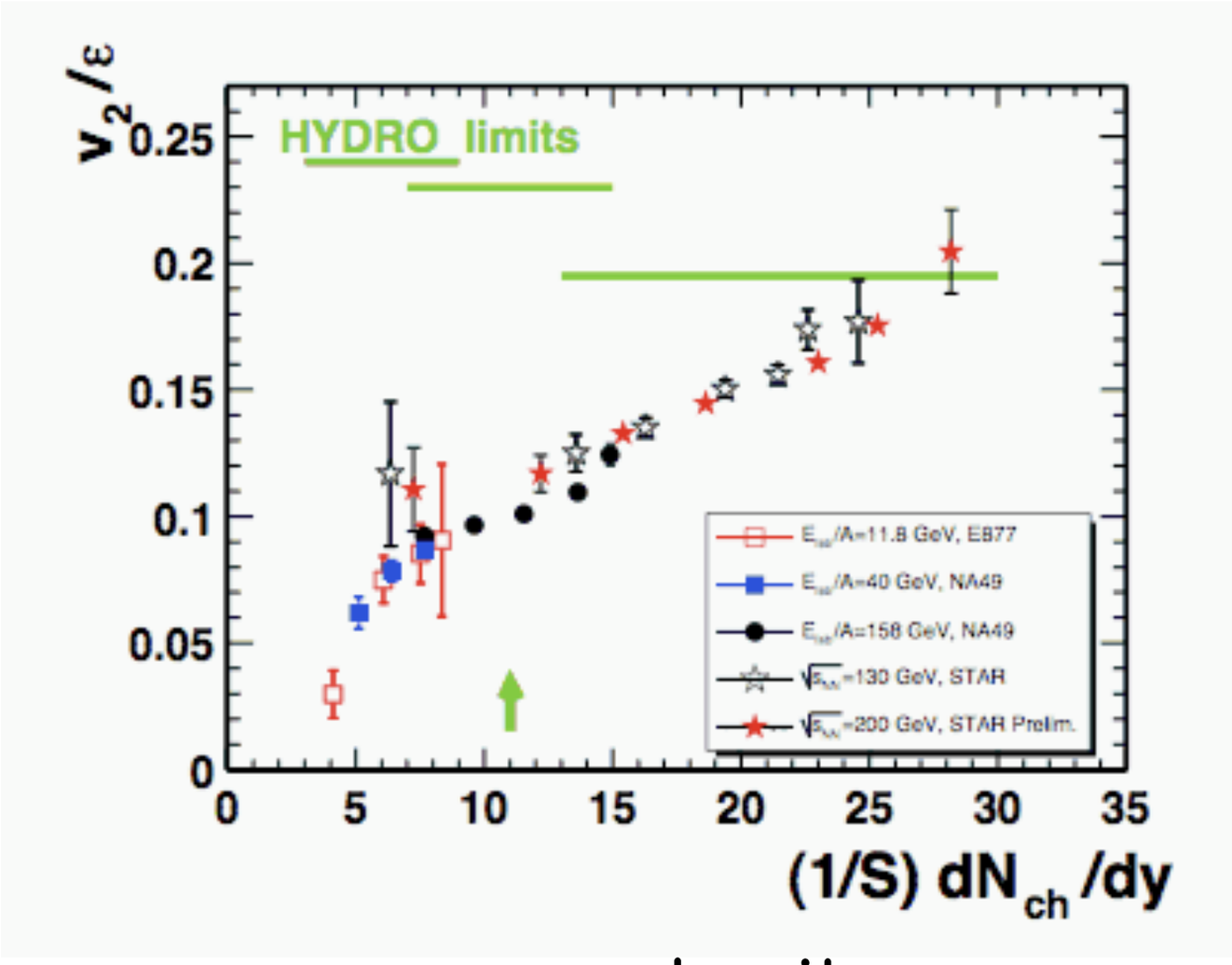
- maintain PHENIX high rate capability
  - record lots of heavy ion data without rare triggers
- retain current (future) silicon vertex detectors (VTX, FVTX)
- large uniform acceptance
- hadronic calorimetry at midrapidity
  - first at RHIC
  - provides the jet resolution & efficiency to extend to high p_T
- forward detectors for useful for spin, asymmetric collisions & e-p/e-A, A-A

Counting Particles



increasing system size
more produced particles

up to ~5000 charged particles
produced in collisions



energy density

U. Heinz