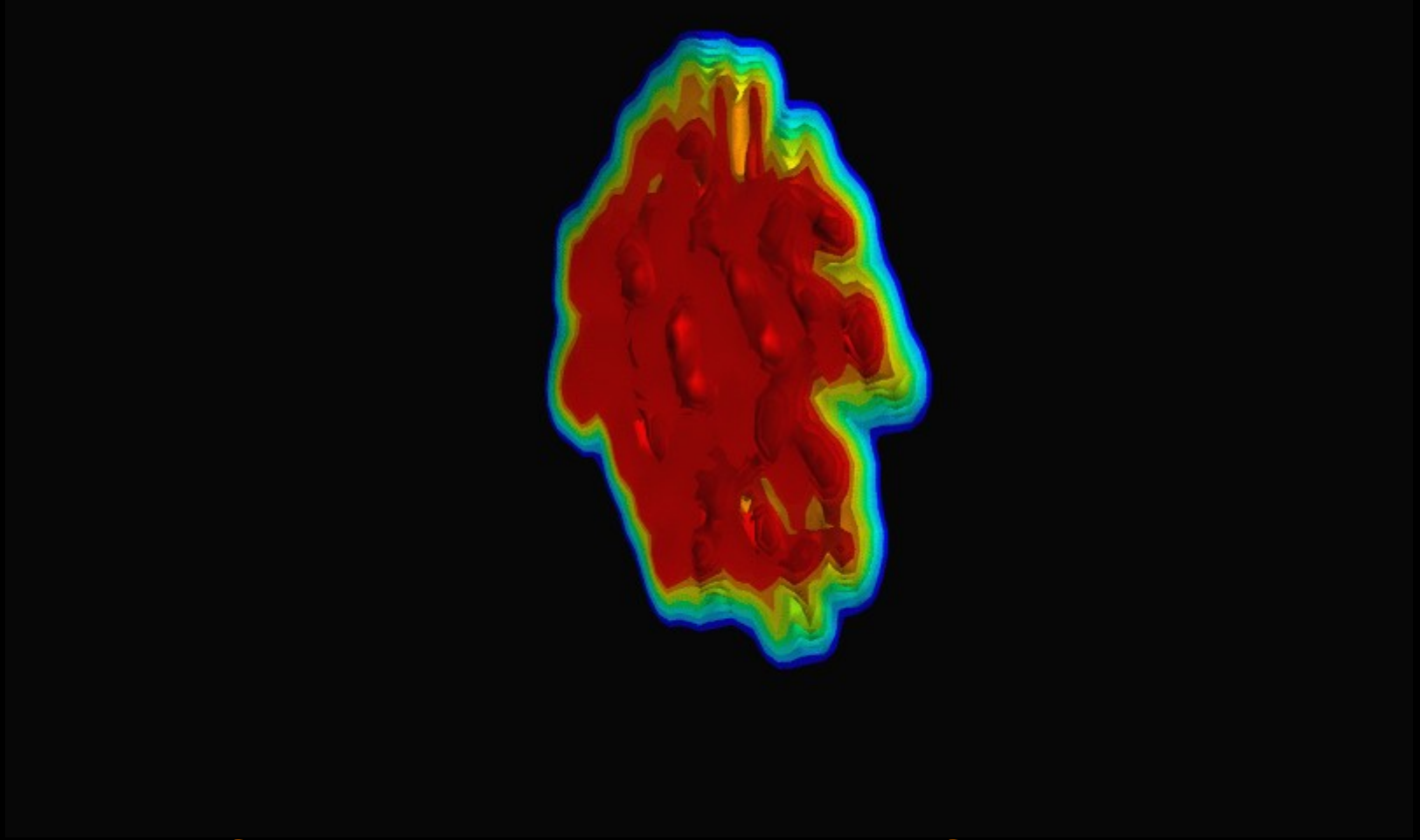
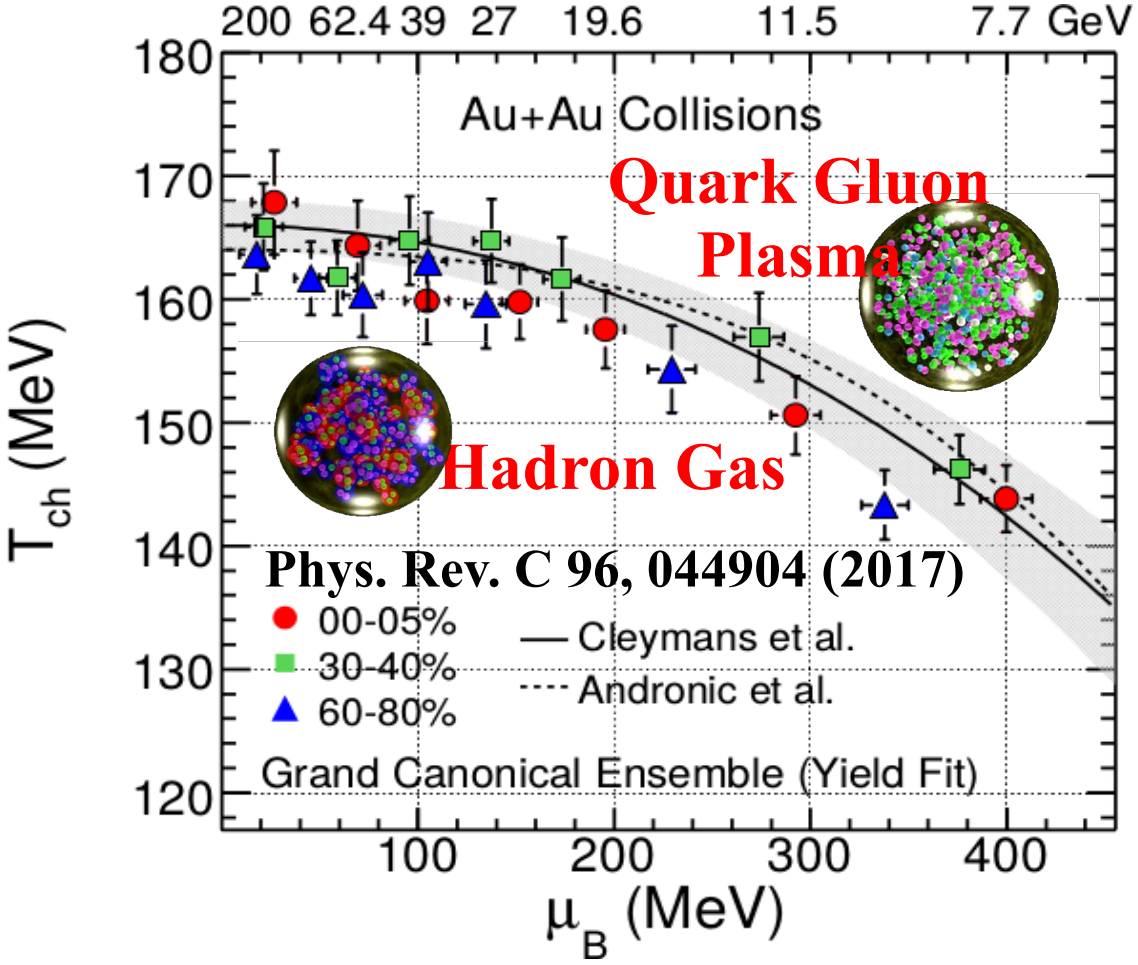
Image from arXiv:1009.3244



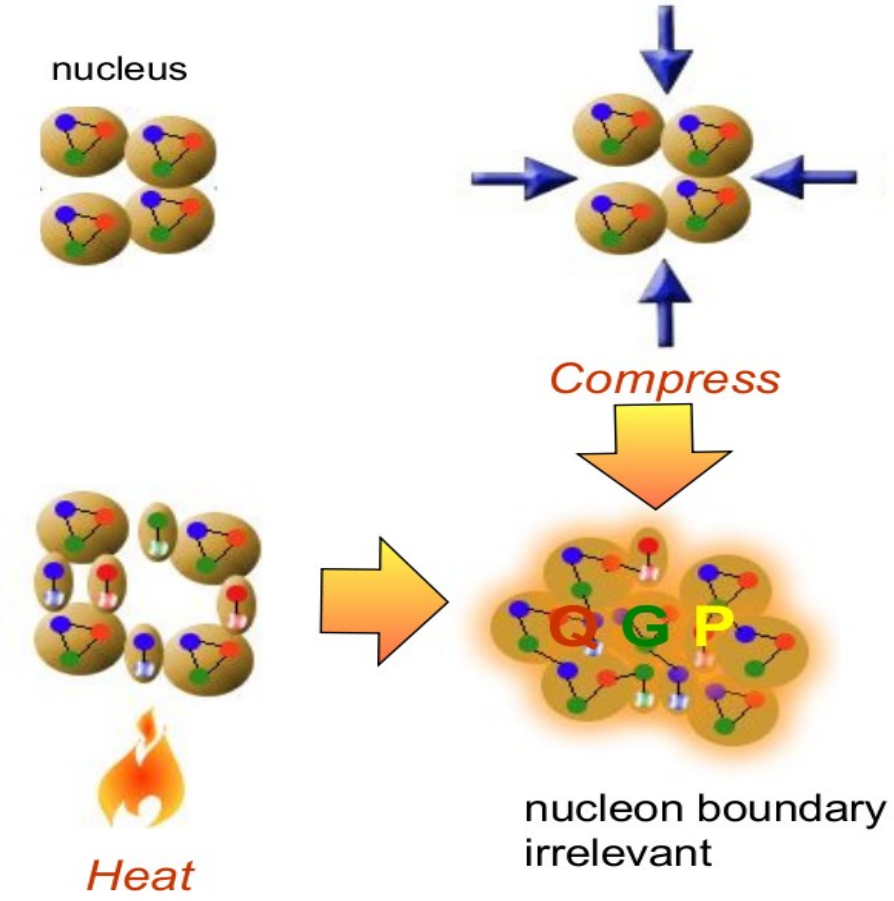
Quantifying properties of liquid nuclei

Christine Nattrass, University of Tennessee, Knoxville

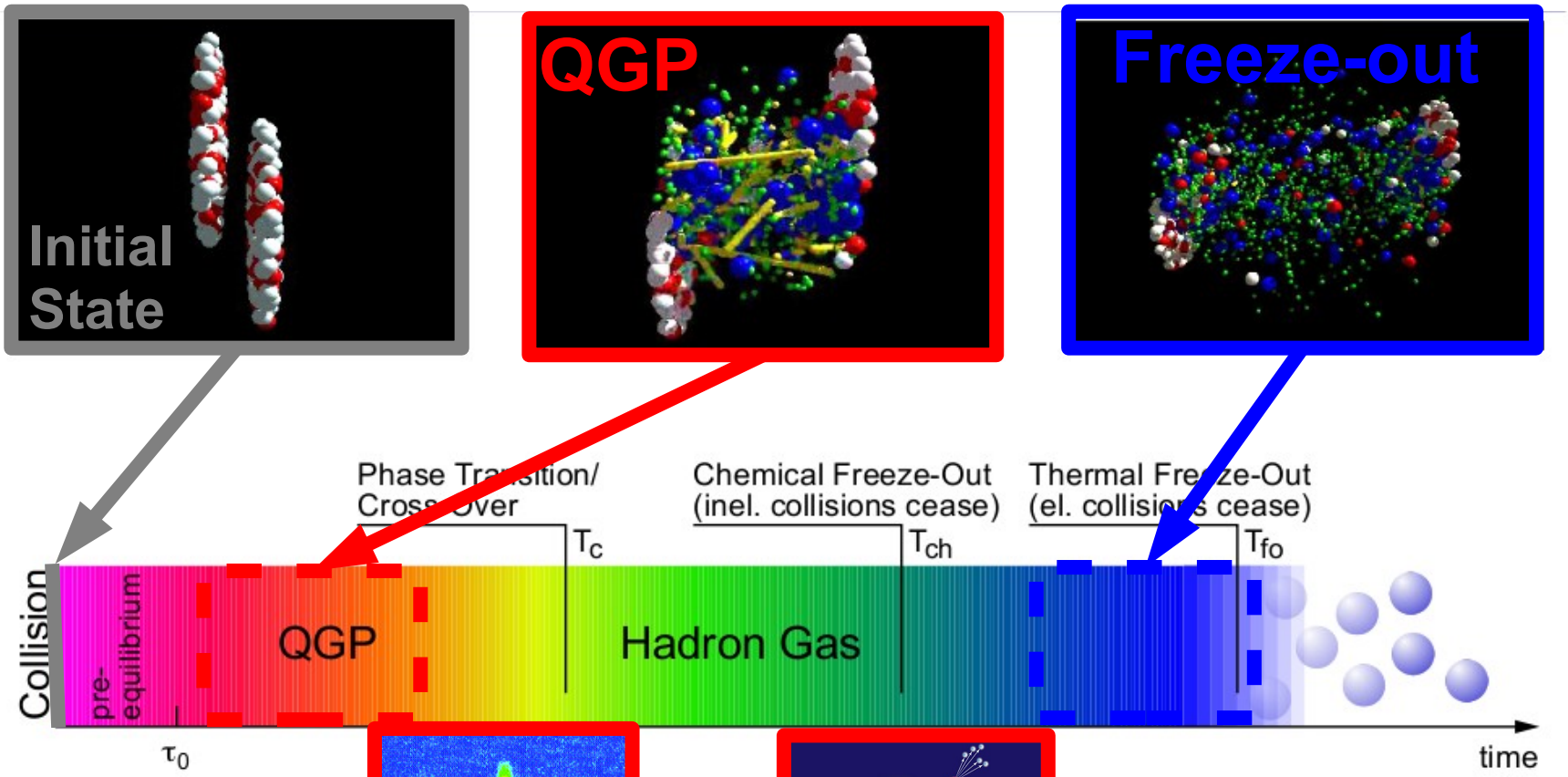
QCD Phase Diagram



How to make a Quark Gluon Plasma



The phase transition in the laboratory



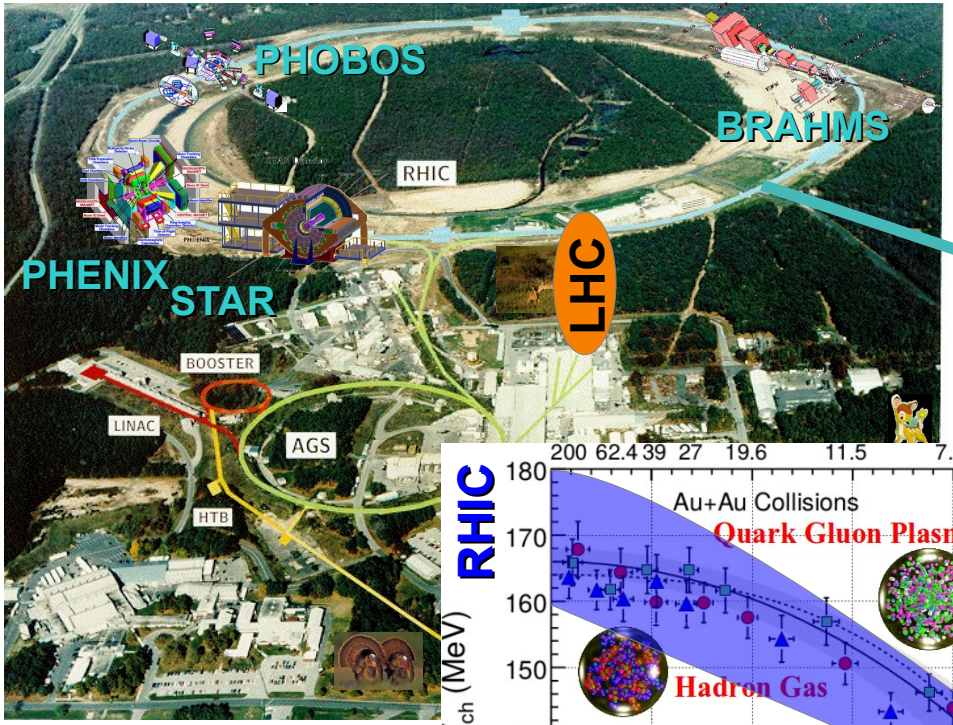
Hydrodynamical flow

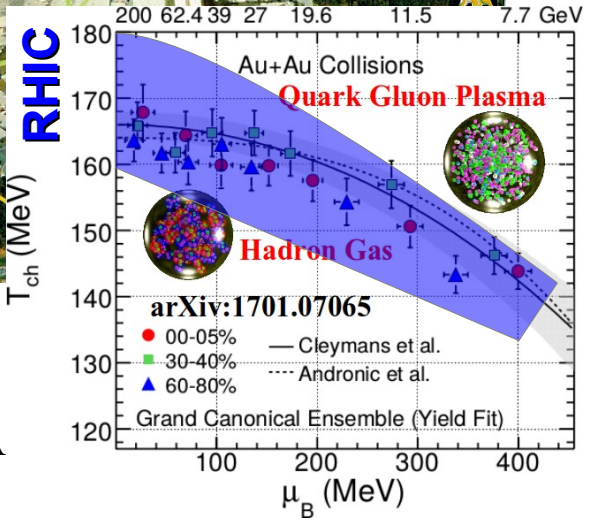
K, O'Hara, S. Hemmer, M. Gehm, S. Granade, J. Thomas
Science 298 **2179 (2002)**

Jet quenching

https://physics.aps.org/articles/v7/97

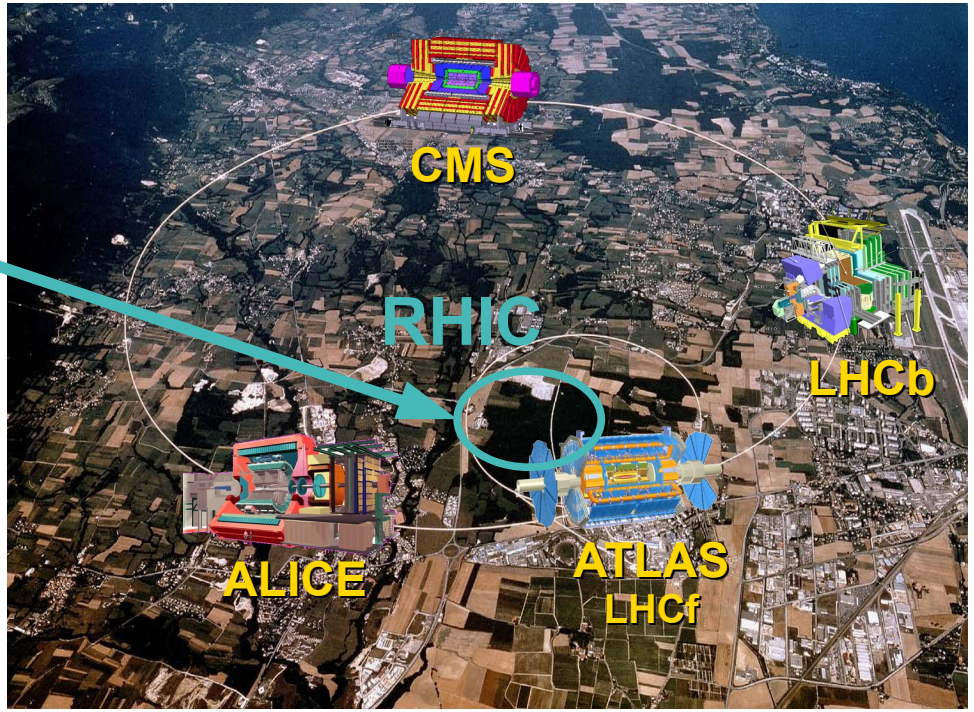
Relativistic Heavy Ion Collider



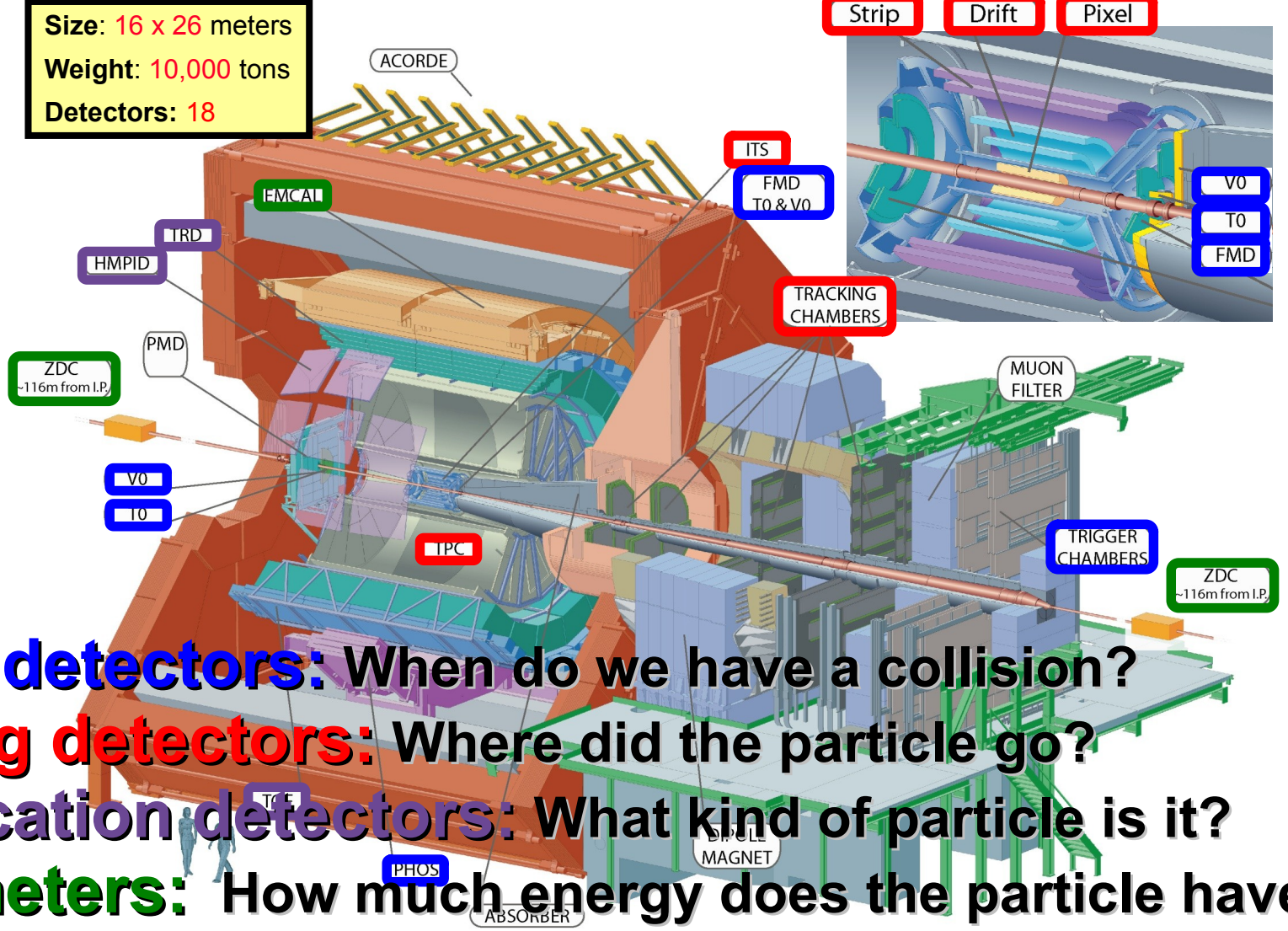


Upton, NY
1.2km diameter
p+p, d+Au, Cu+Cu, A
$\sqrt{s_{NN}}$ = 9 - 200 GeV

Large Hadron Collider



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



Trigger detectors: When do we have a collision?

Tracking detectors: Where did the particle go?

Identification detectors: What kind of particle is it?

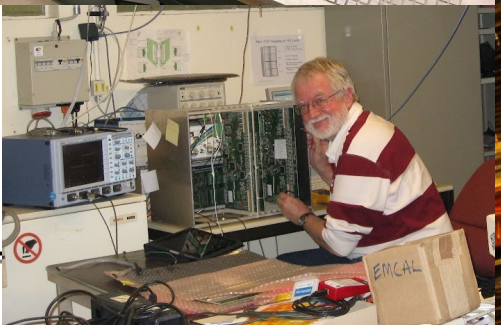
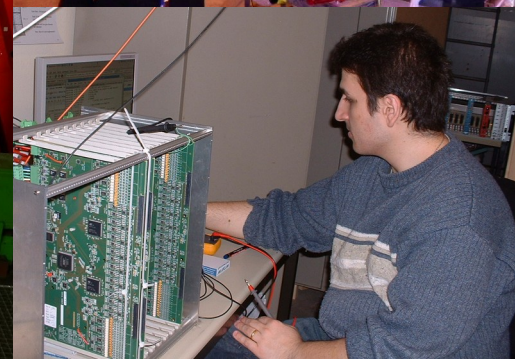
Calorimeters: How much energy does the particle have?



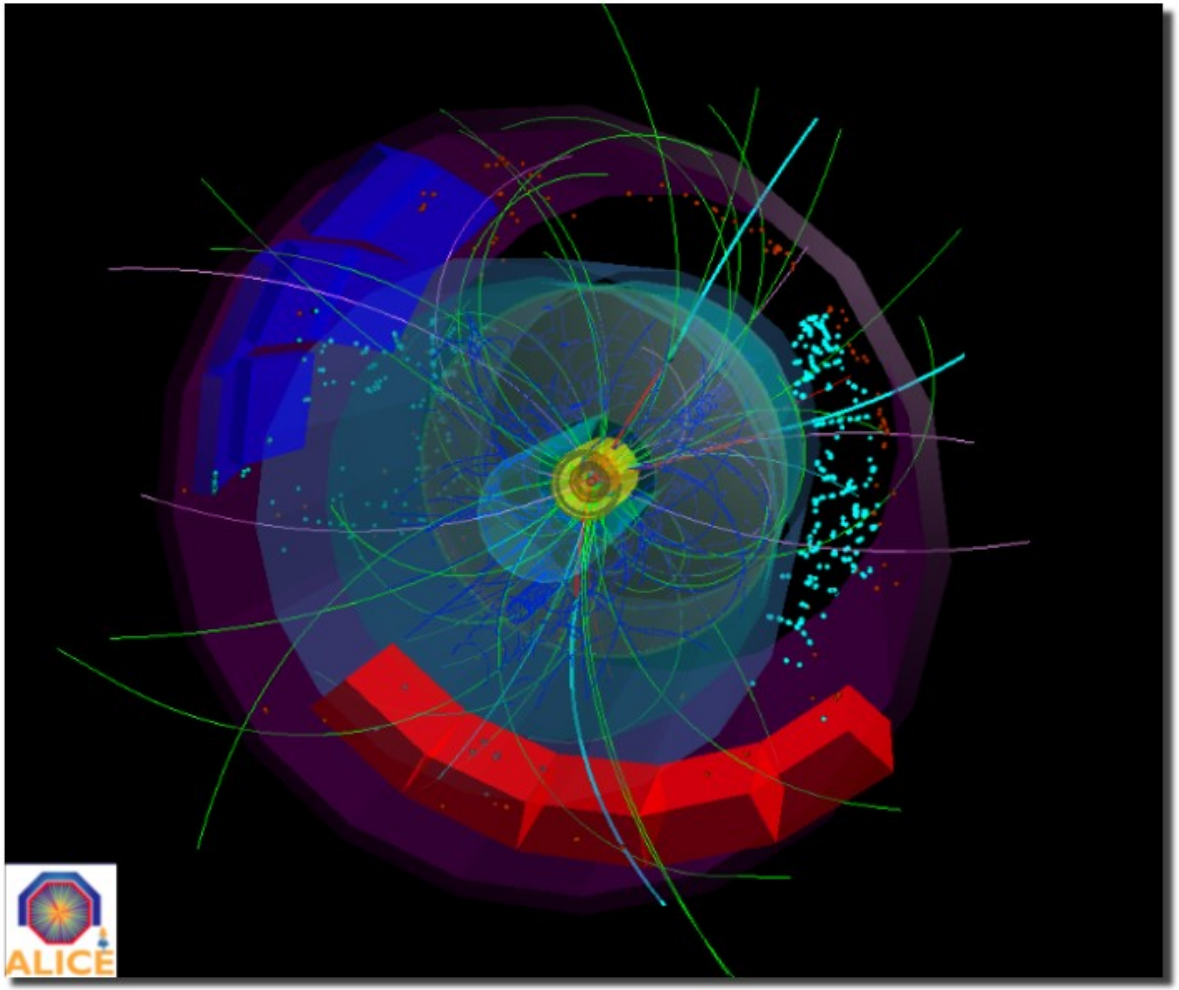




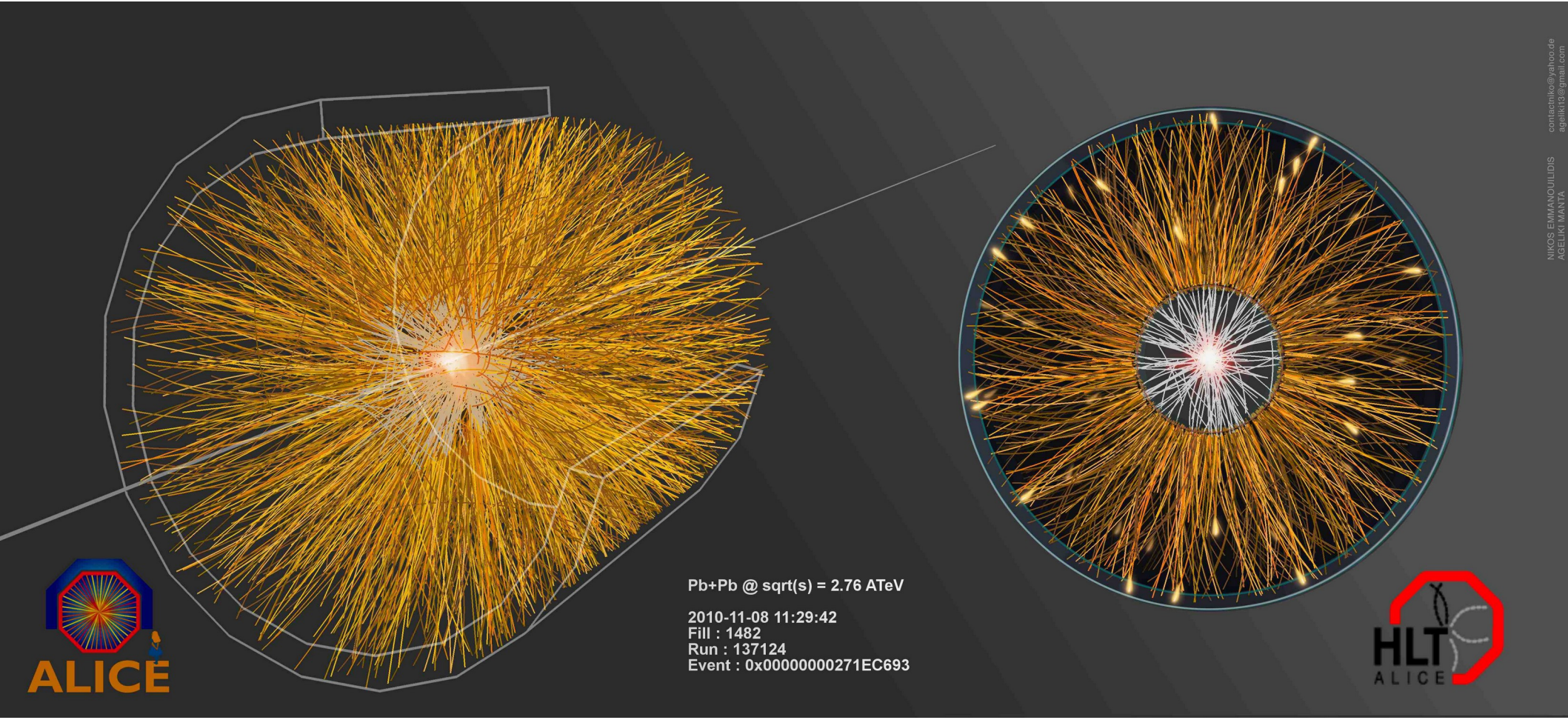



EMCAL


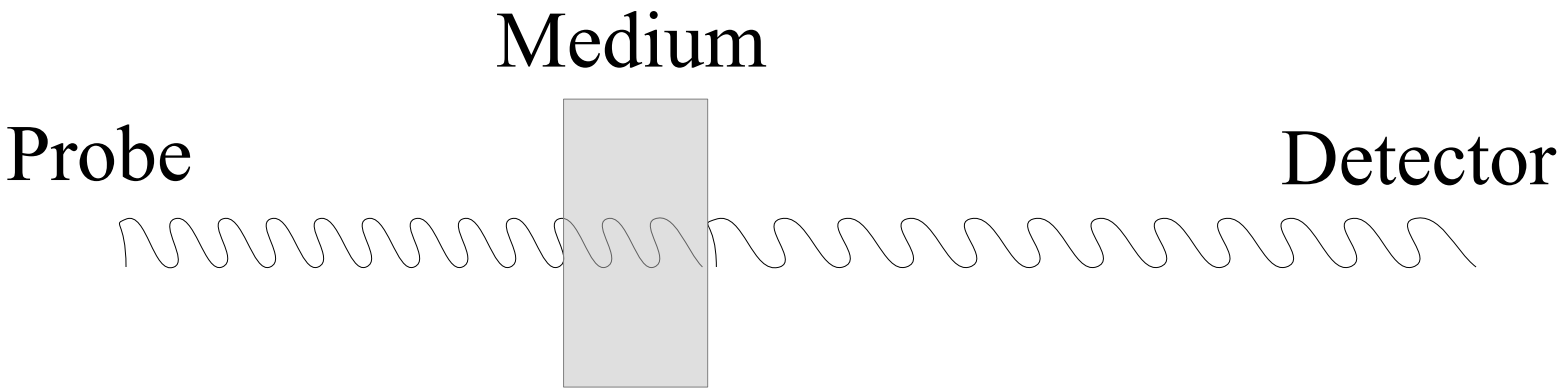
p+p collisions



Pb+Pb collisions

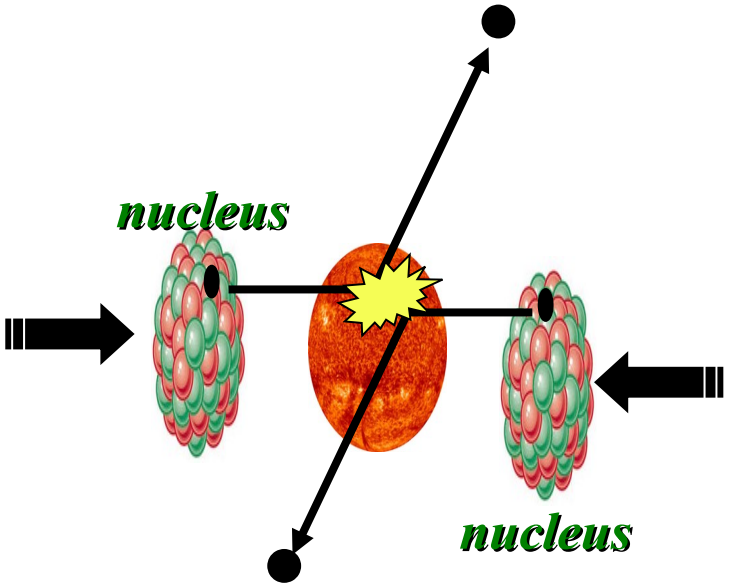


Probing the Quark Gluon Plasma



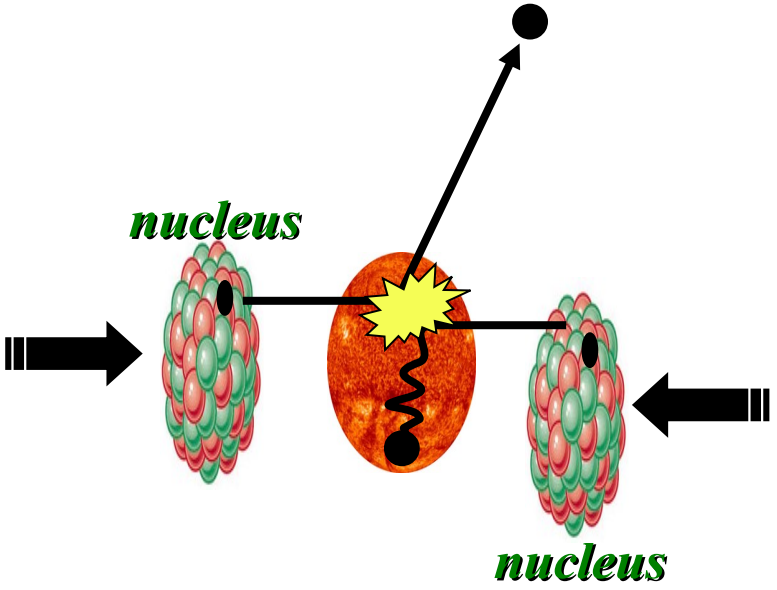
Want a probe which traveled through the collision
QGP is very short-lived (~1-10 fm/c) →
cannot use an external probe

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

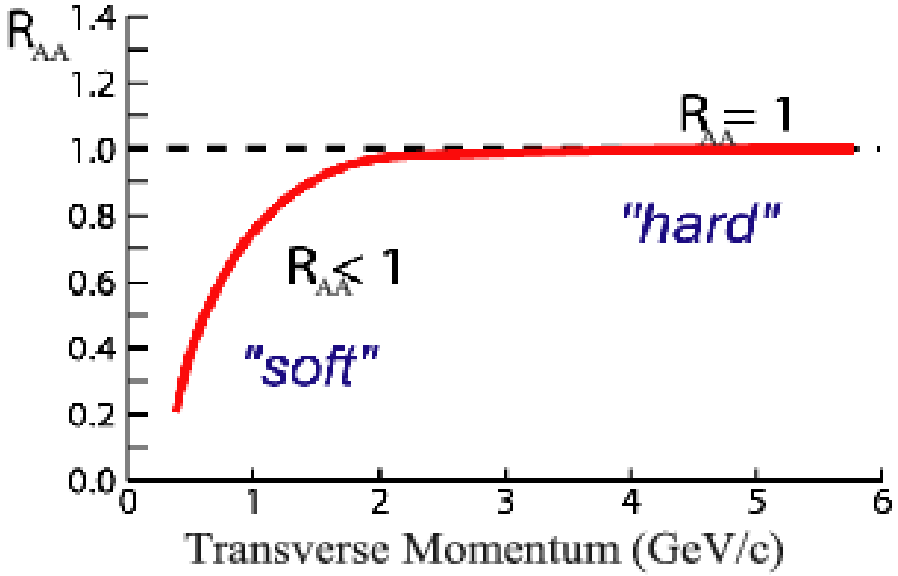
Probes of the Quark Gluon Plasma



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

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

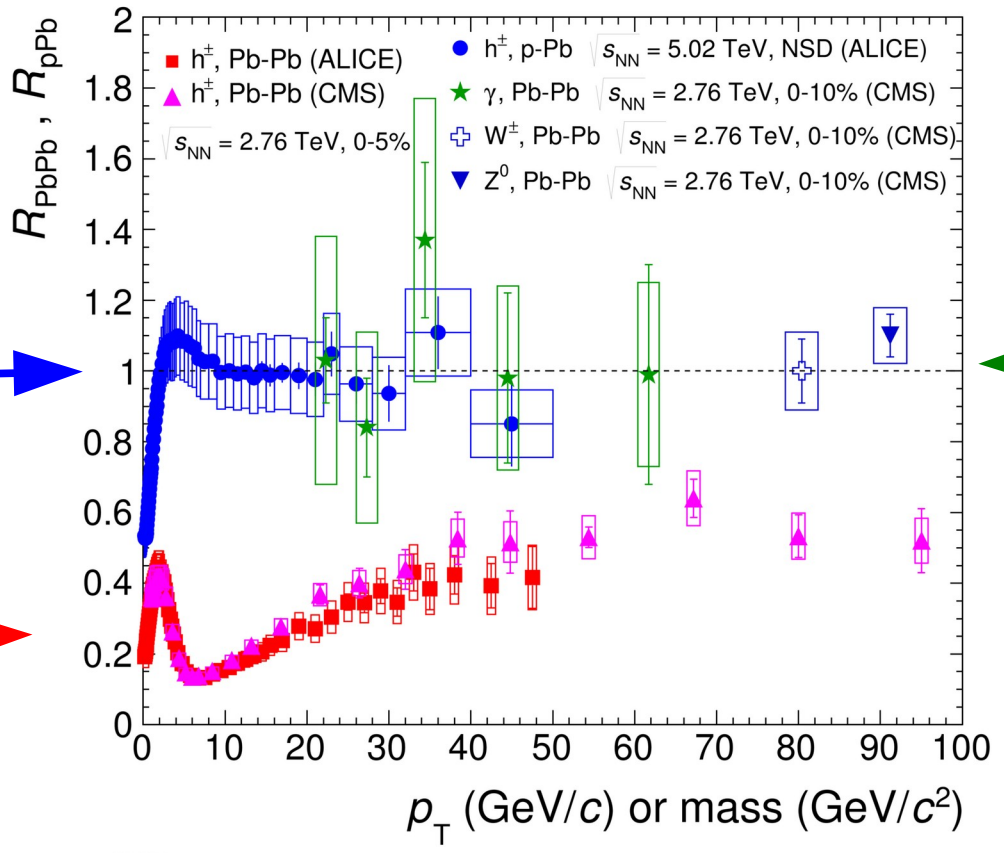


Enhancement

Suppression

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

Nuclear modification factor

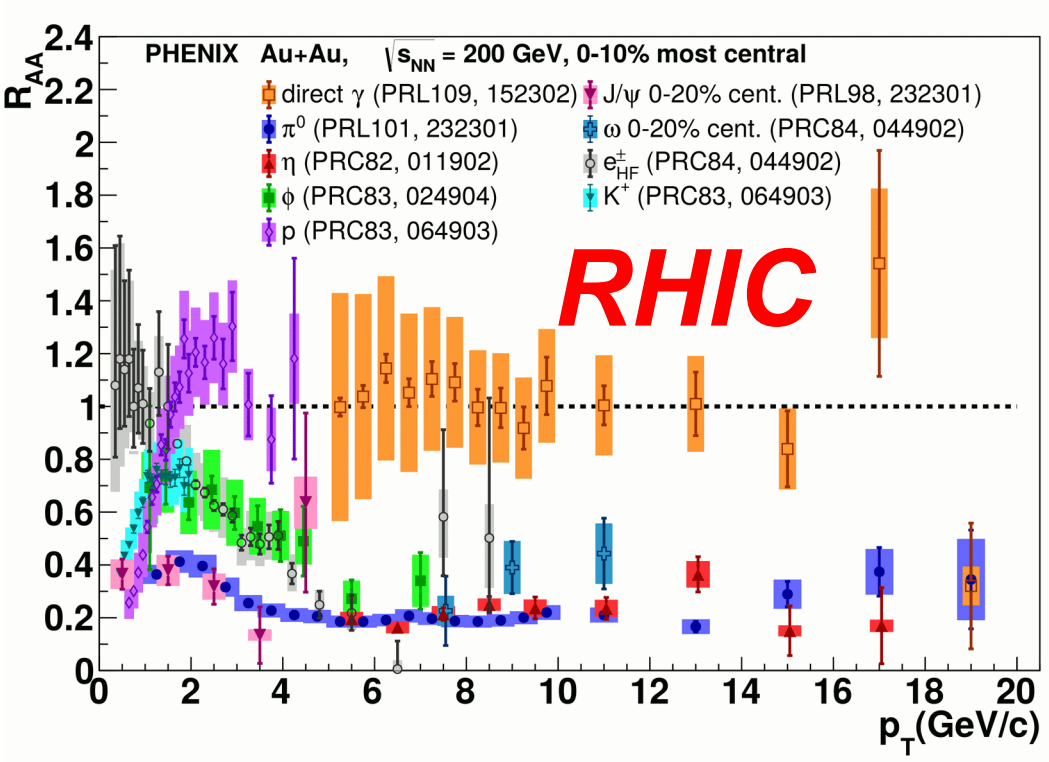


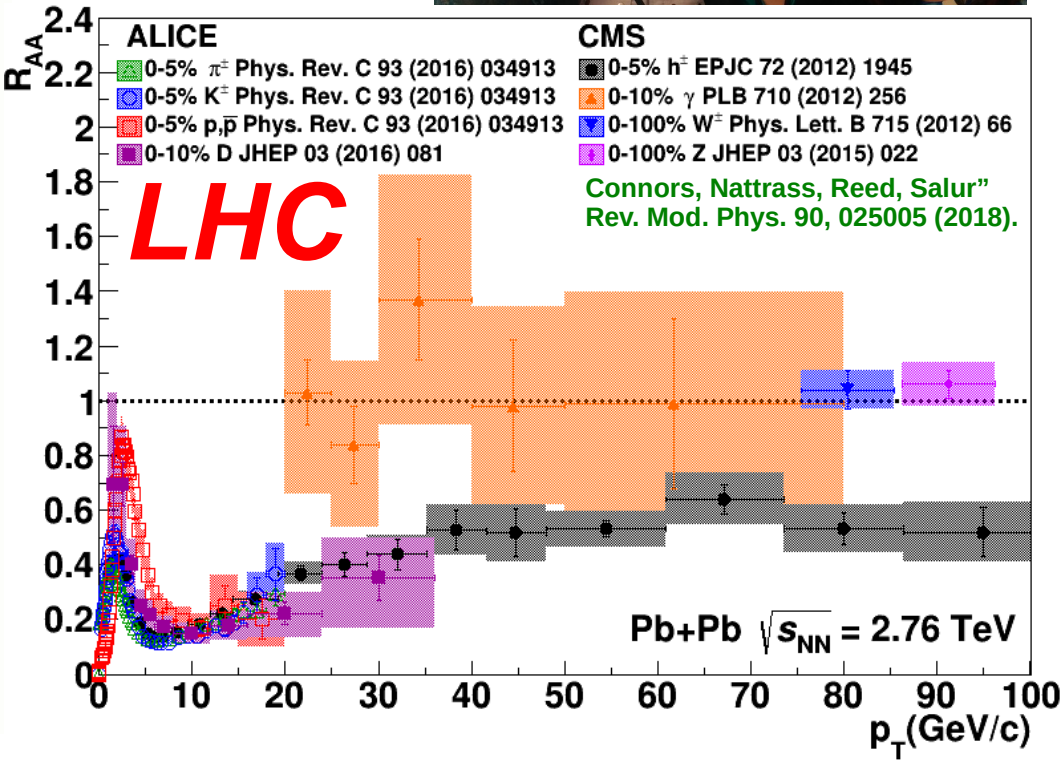
Control →

Probe →

← **Control**

Nuclear modification factor R_{AA}

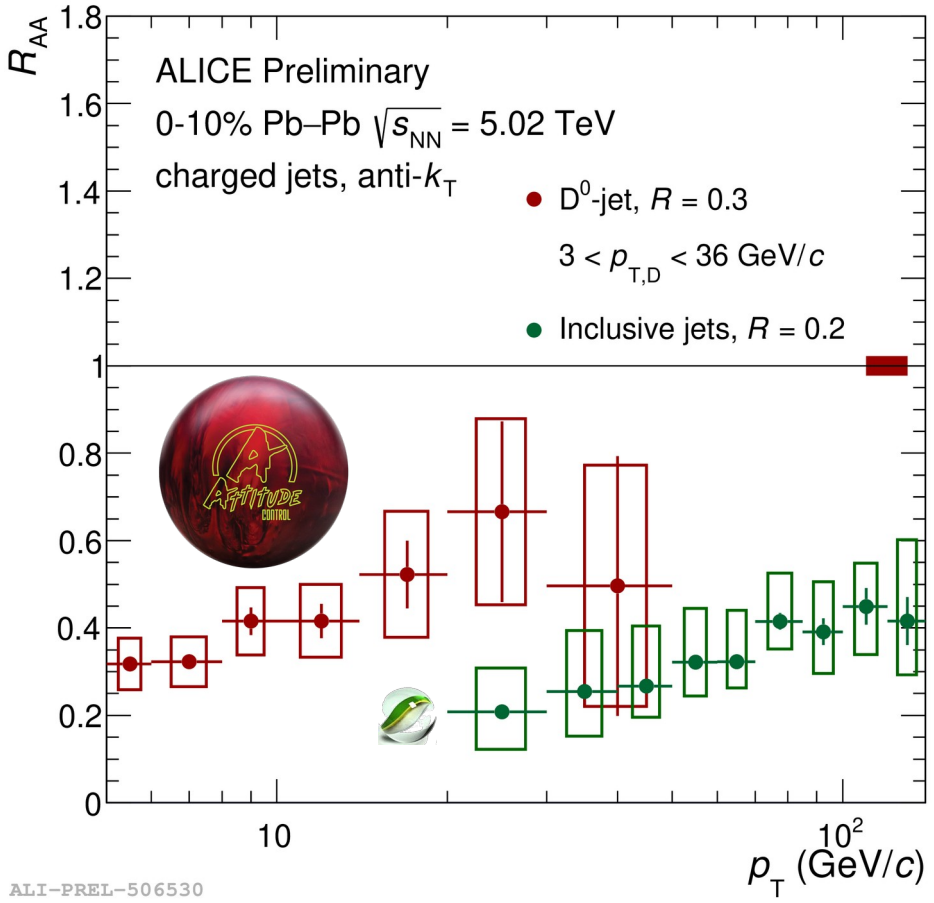


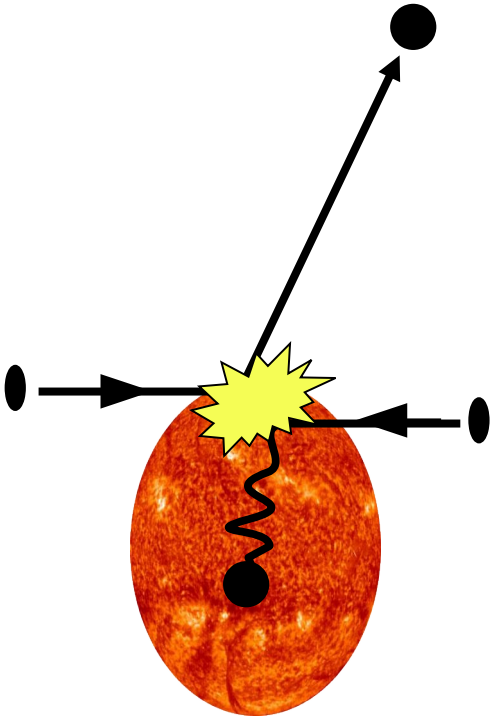


Electromagnetic probes **– consistent with no modification – medium is transparent to them**
Strong probes **– significant suppression – medium is opaque to them - even heavy quarks!**

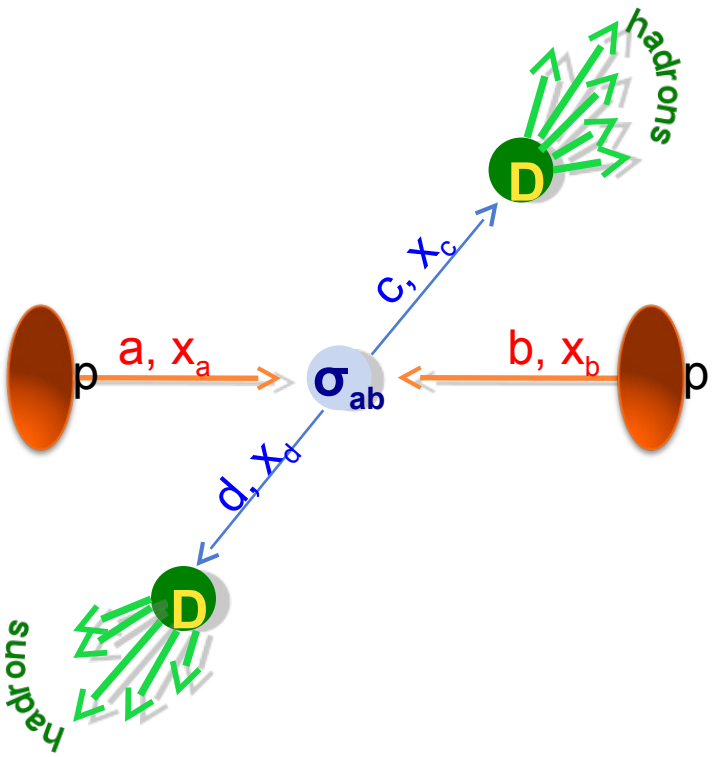
D^0-tagged jets

Antonio Da Silva

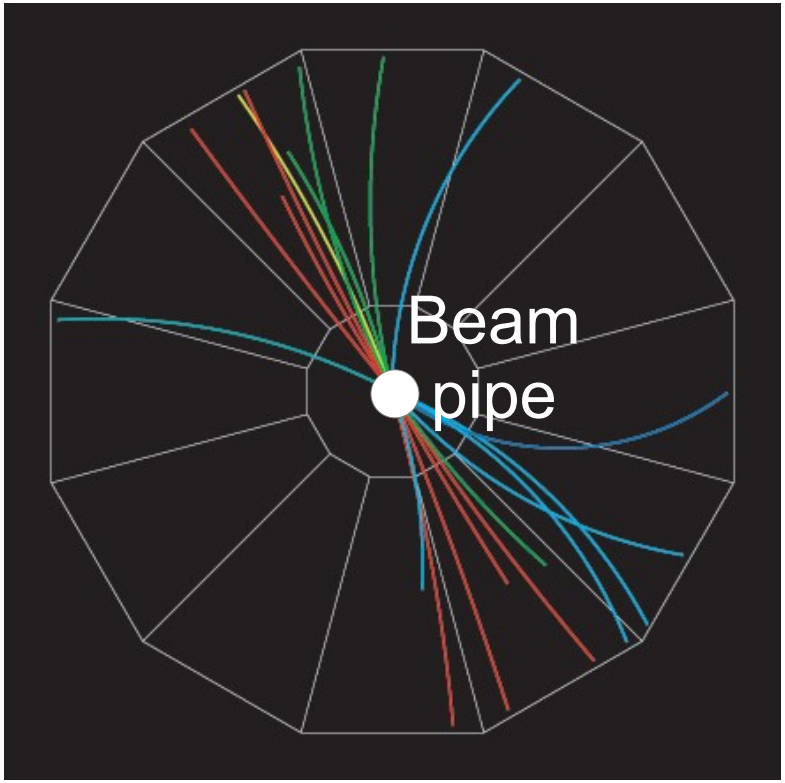




Jets

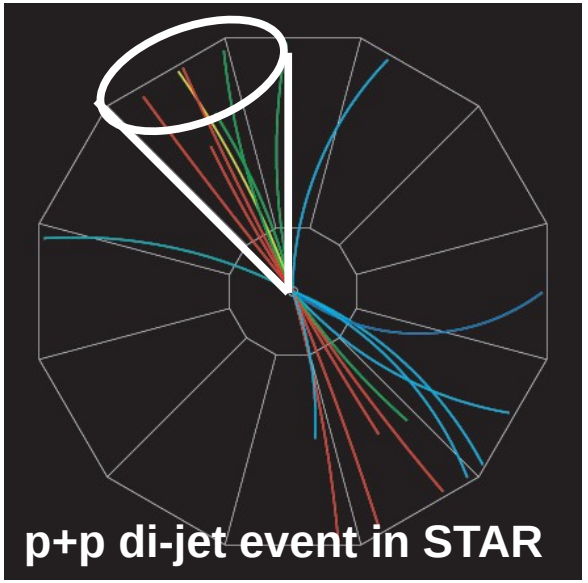


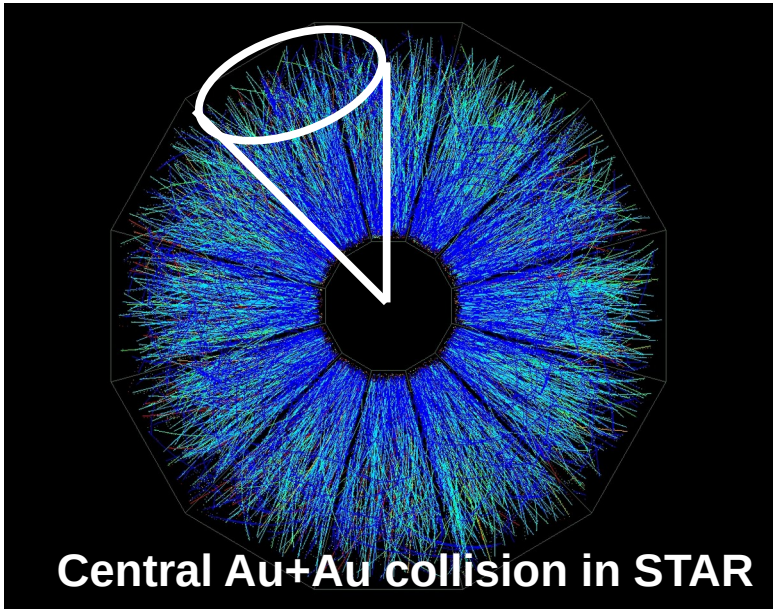
p+p → dijet



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

Jet reconstruction

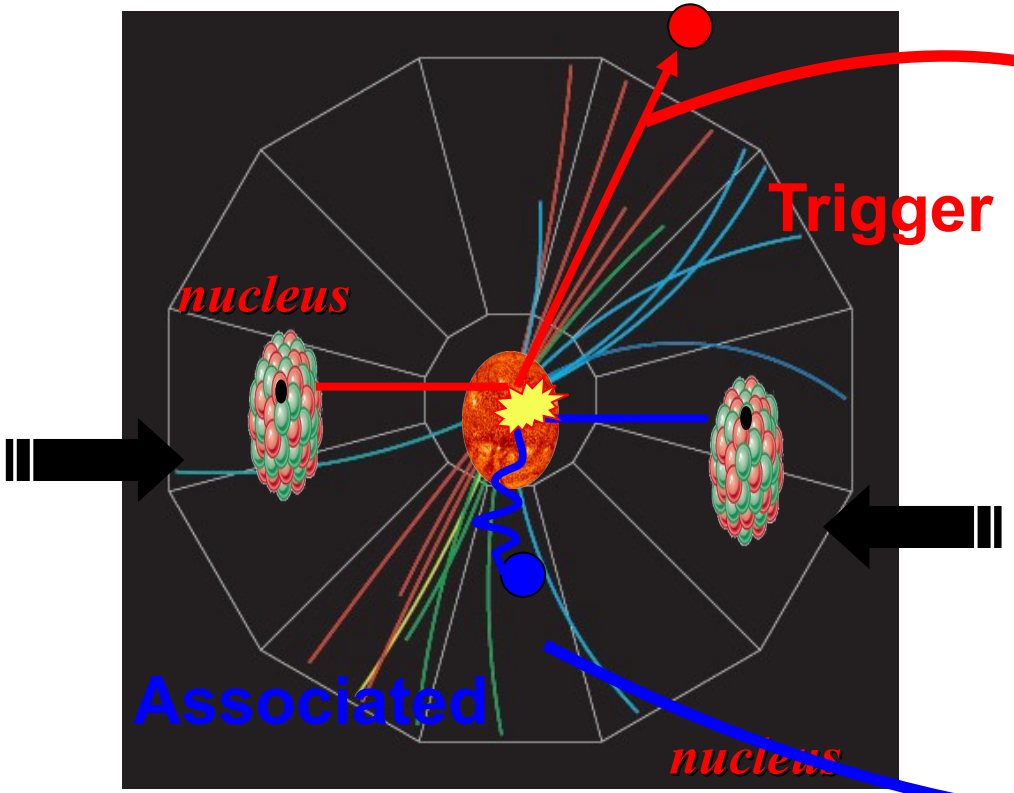


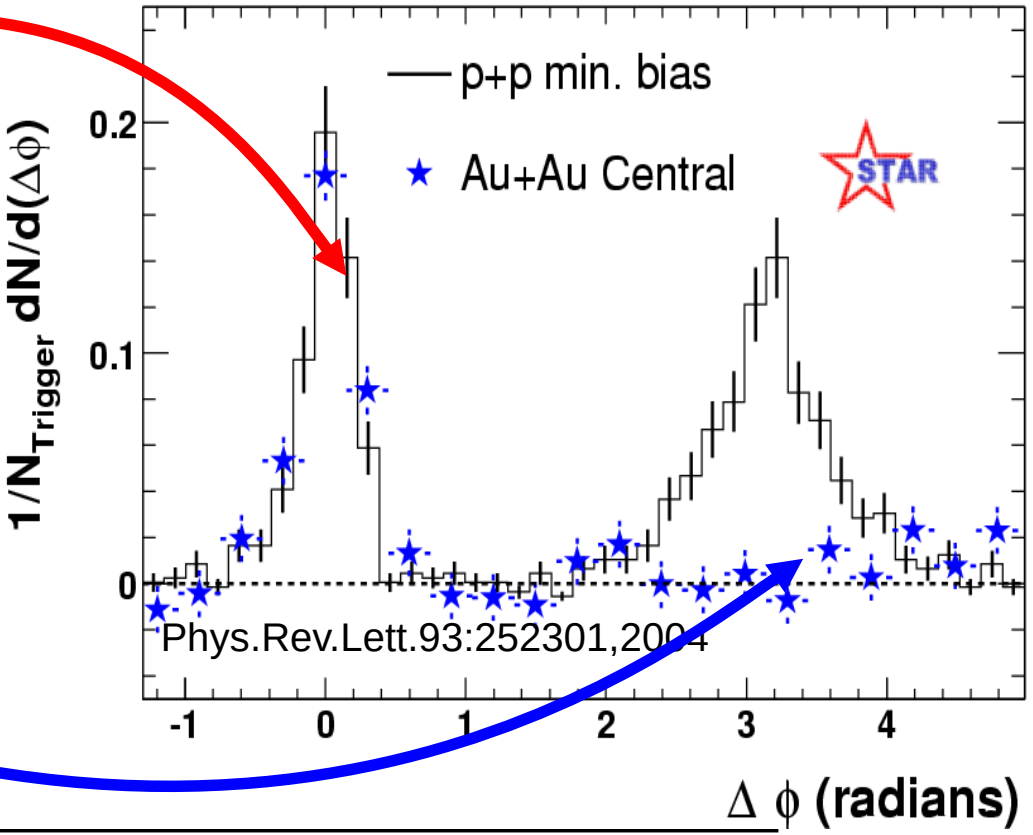


- Identify all of the particles in the jet → parton energy, momentum
- Difficult in heavy ion collisions – but possible!

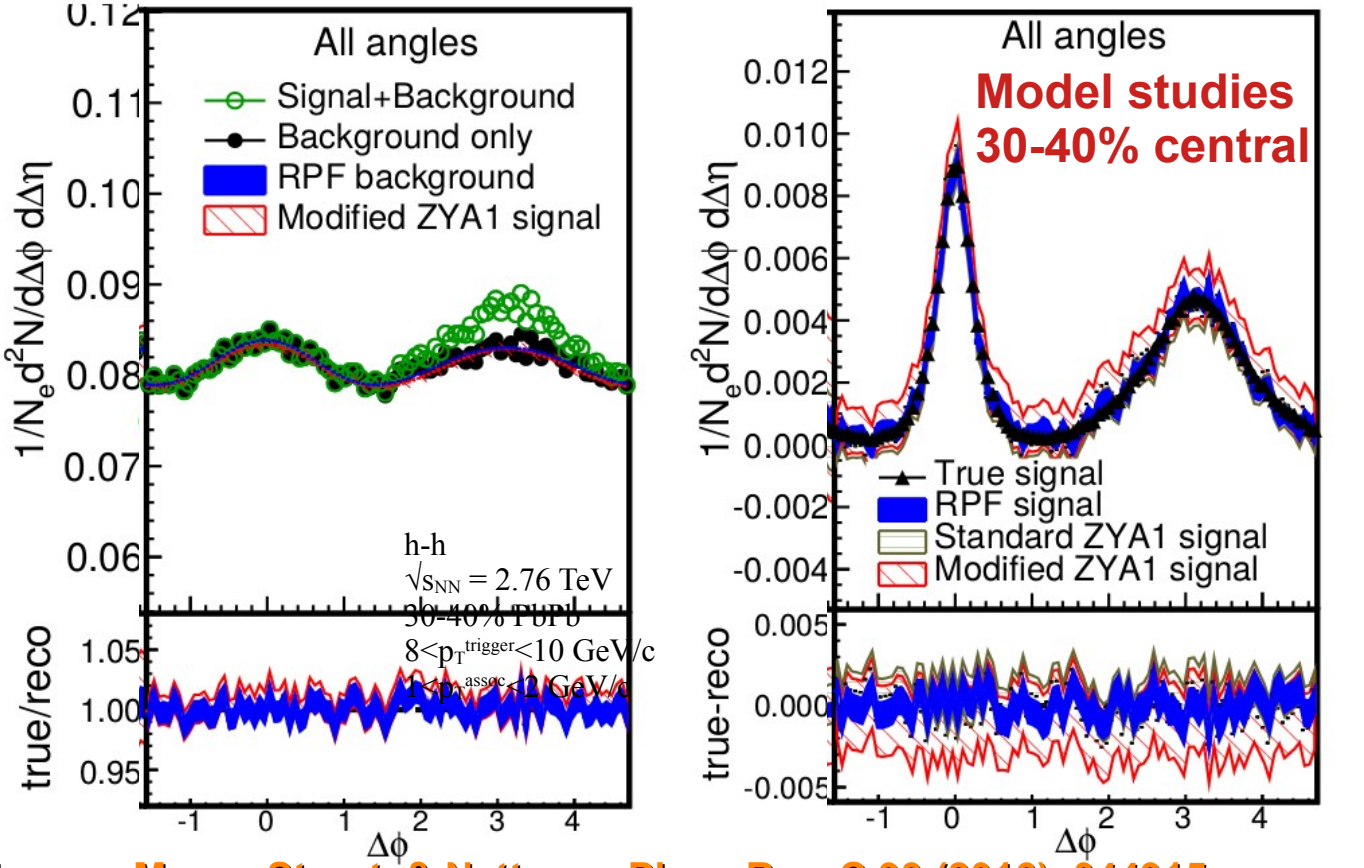
Di-hadron correlations

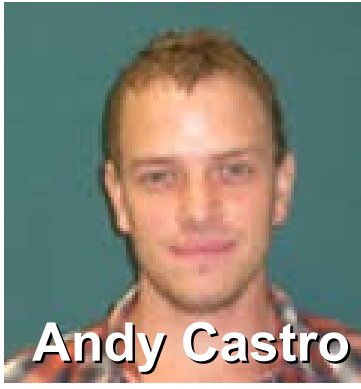
p+p → dijet





Method development



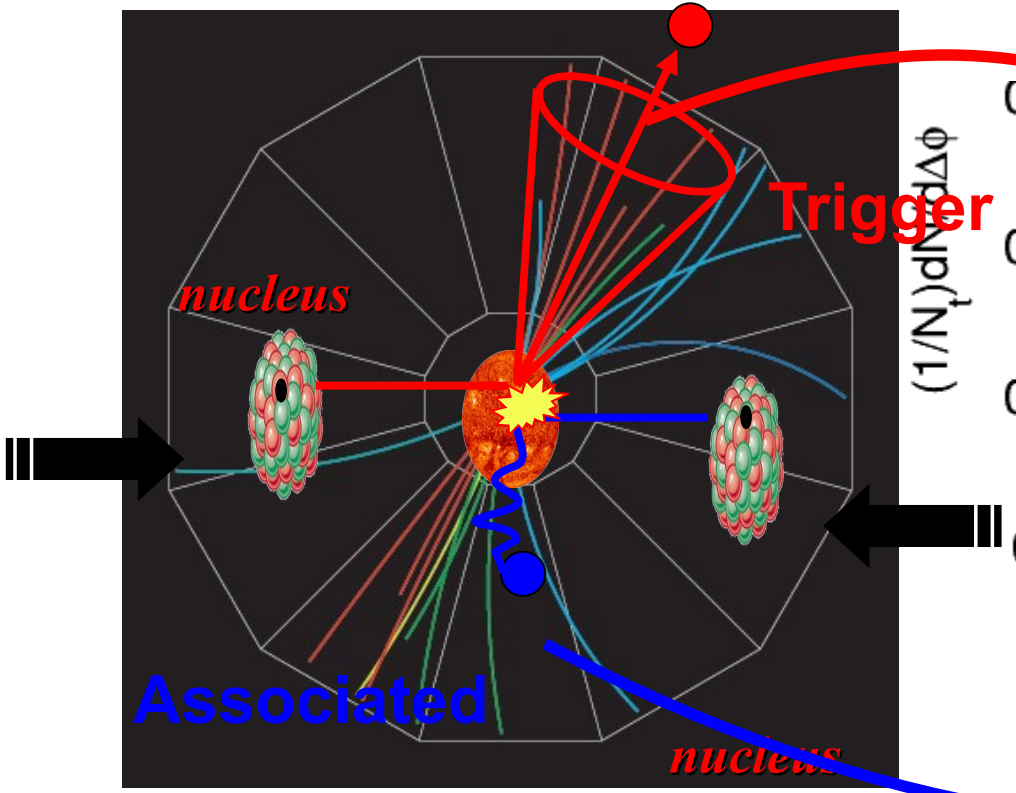


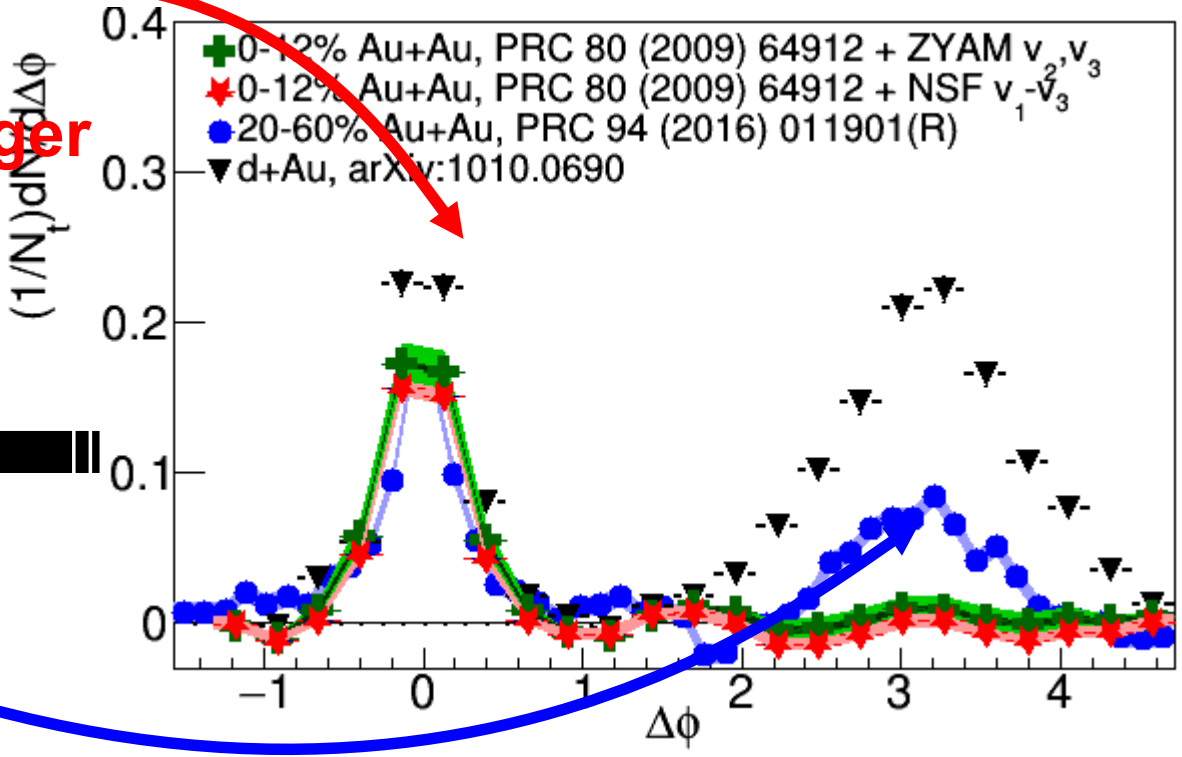
Sharma, Mazer, Stuart, & Nattrass, Phys. Rev. C 93 (2016), 044915
Nattrass & Todoroki, Phys. Rev. C 97 (2018), 054911
Sharma, Perez, Castro, Kumar, & Nattrass, Phys. Rev. C 98 (2018), 014914

Di-hadron correlations

p+p → dijet

Nattrass, Sharma, Mazer, Stuart, Bejnood
Phys. Rev. C 94, 011901(R) 2016
Nattrass, Phys. Rev. C 97, 034916 (2018).

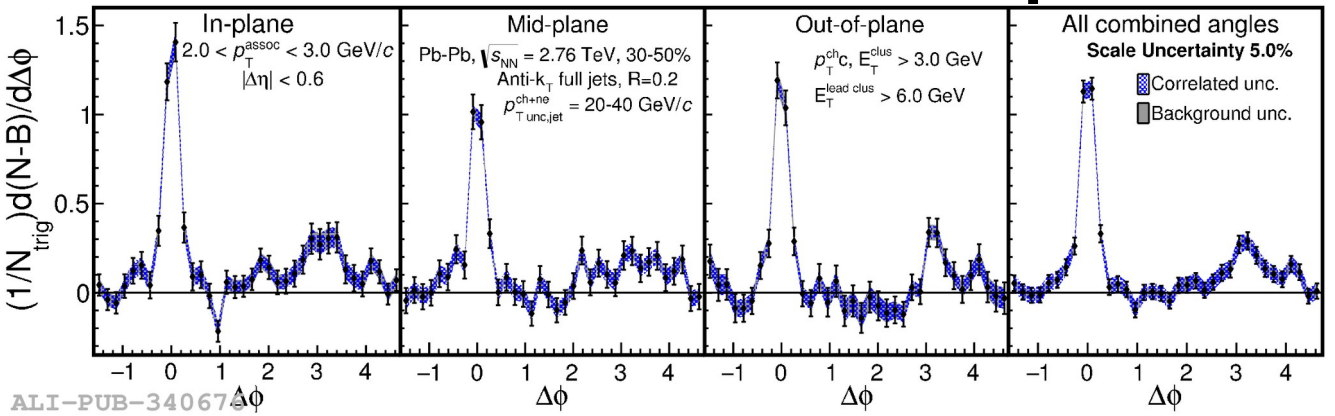




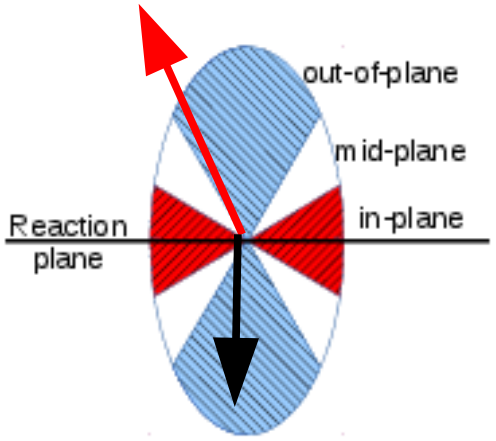
Jet-hadron correlations vs reaction plane

Full jets
1) signal+bkgd
2) bkgd dominated
3) bkgd RPF fit

Phys. Rev. C 101, 064901 (2020)

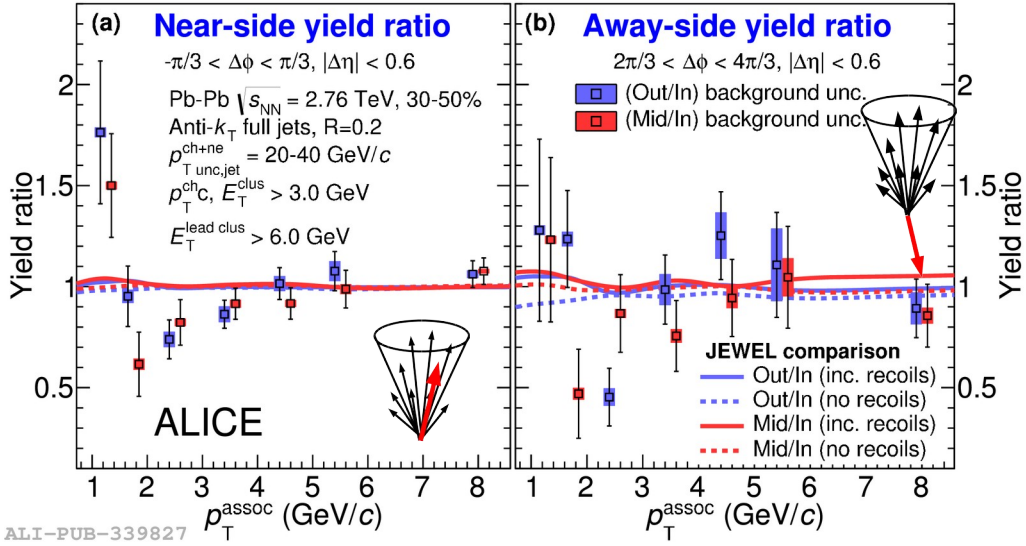


Trigger



Associated

Joel Mazer



Jet-hadron correlations vs reaction plane

Full jets
1) signal+bkgd
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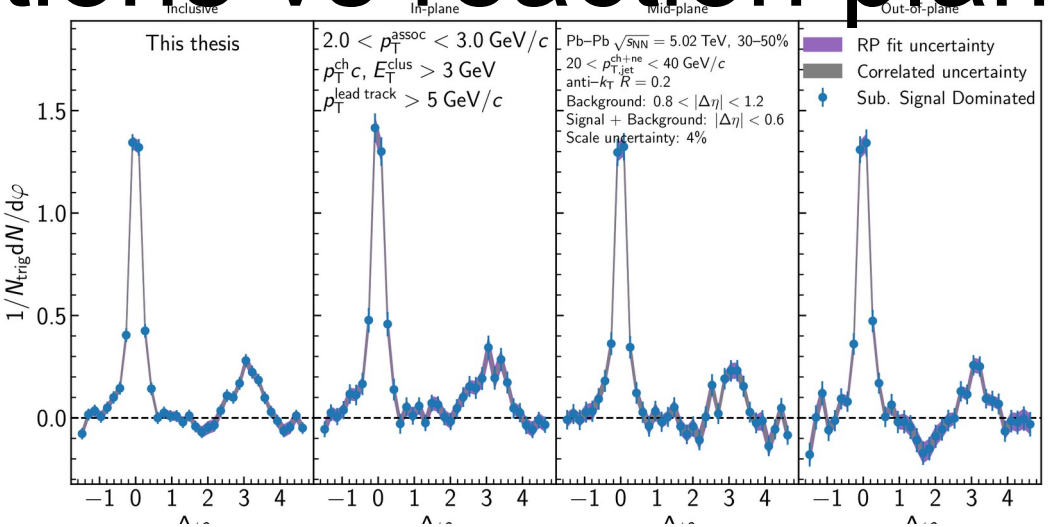
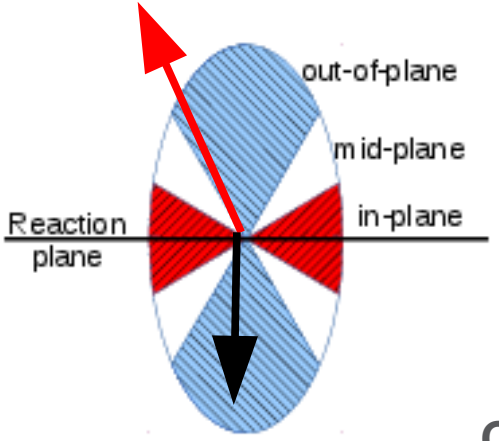
3) bkgd RPF fit

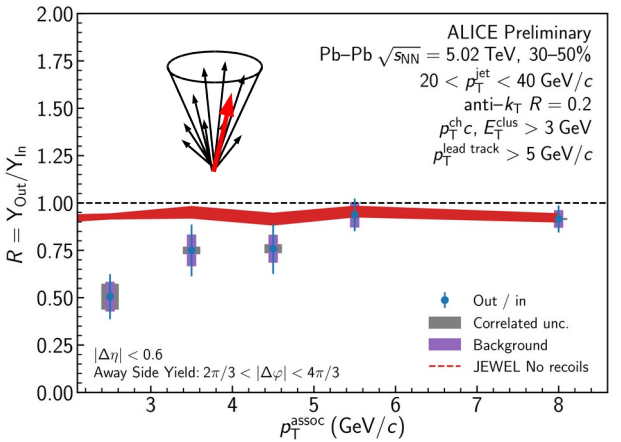


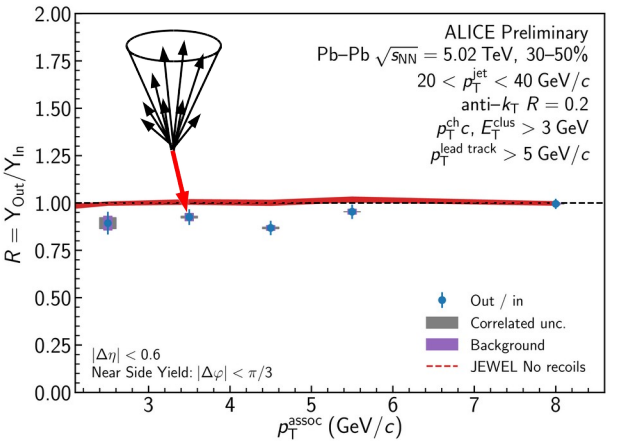
Trigger



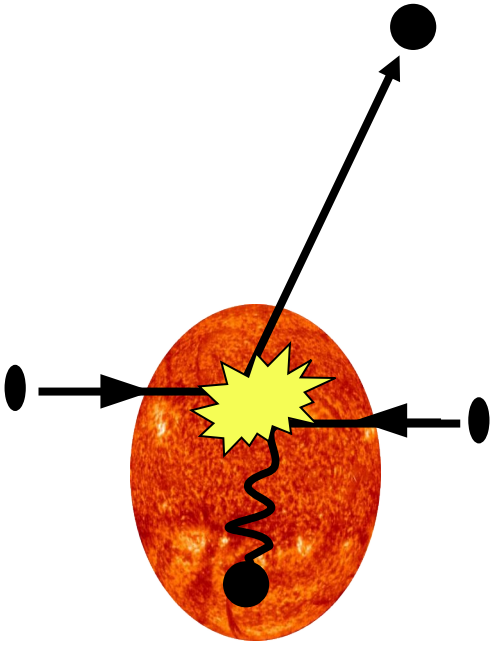
Associated

Charles Hughes

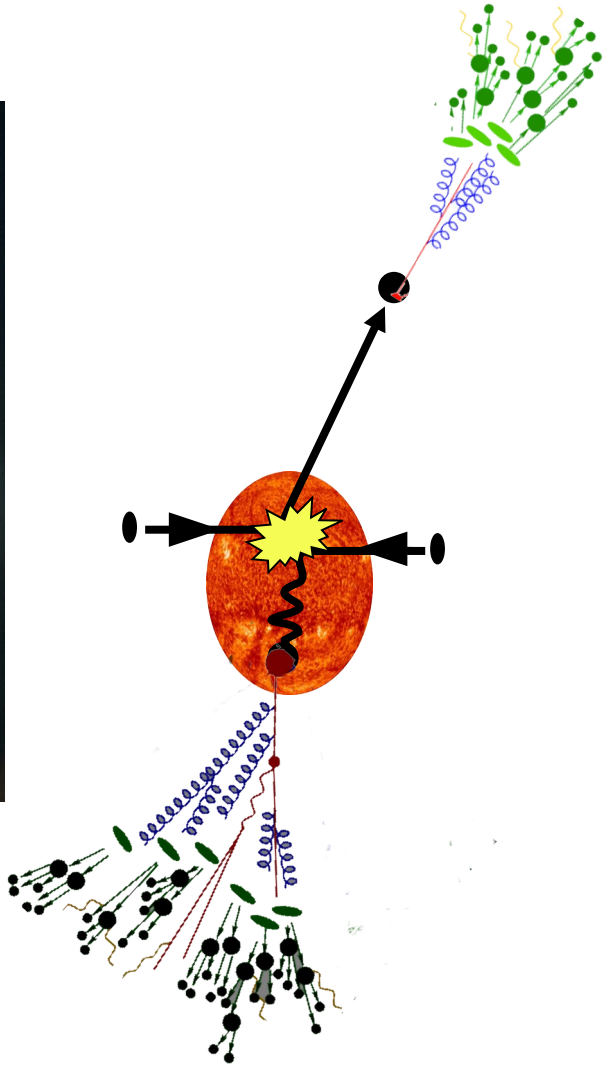




Towards quantitative understanding



There is no partionic energy loss.



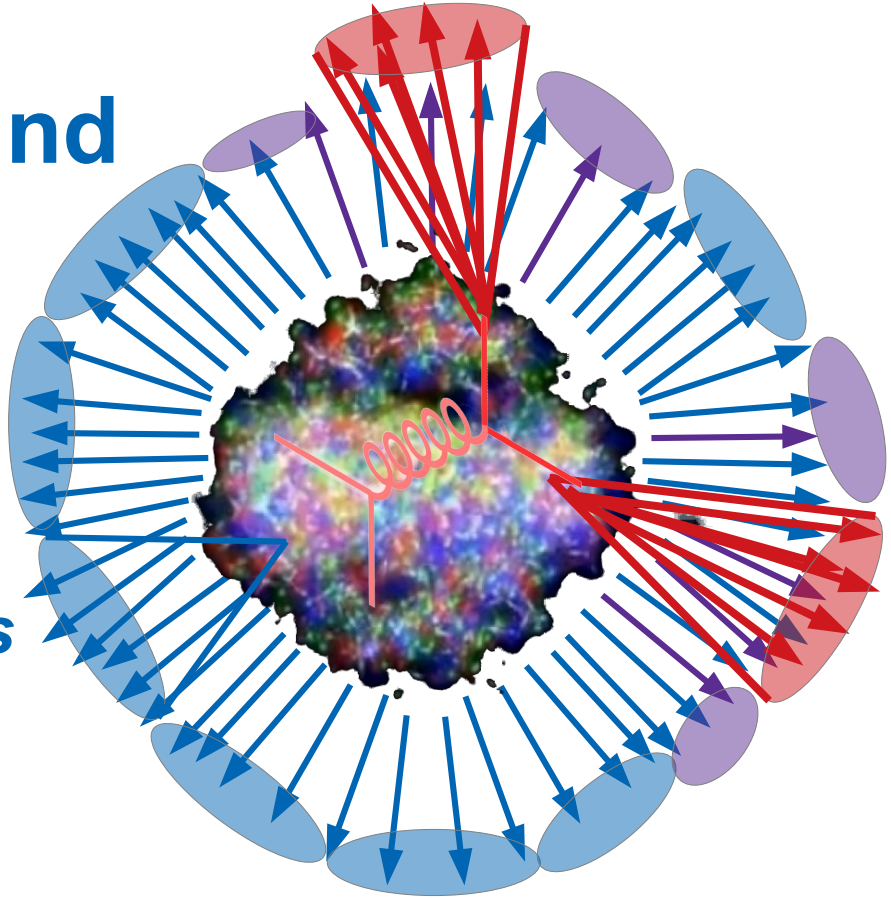
There is only partionic energy redistribution.

Signal vs Background:

The standard paradigm

More method improvements:
Hughes, Da Silva, & Nattrass
arXiv:2005.02320, accepted in PRC
More work in progress

Background



Combinatorial jets

Signal

***Some gray areas**

PYTHIA AMPT ANGANTYR HIJING JETSCAPE

Monte Carlo Model

JEWEL EPOS smash

Adopted by all major experiments (PHENIX)

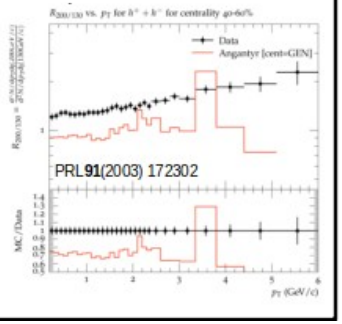
HepMC

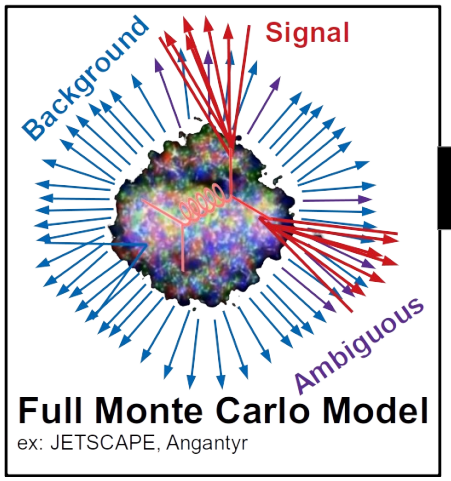
Now standard! See HEPMC in HI Workshop

HEPData → Rivet

1-week workshop workshop for implementing analyses in Rivet

Comparison to data





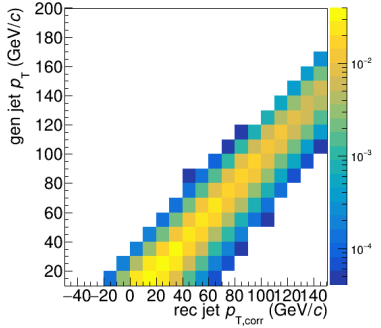
Full Monte Carlo Model

ex: JETSCAPE, Angantyr

HepMC

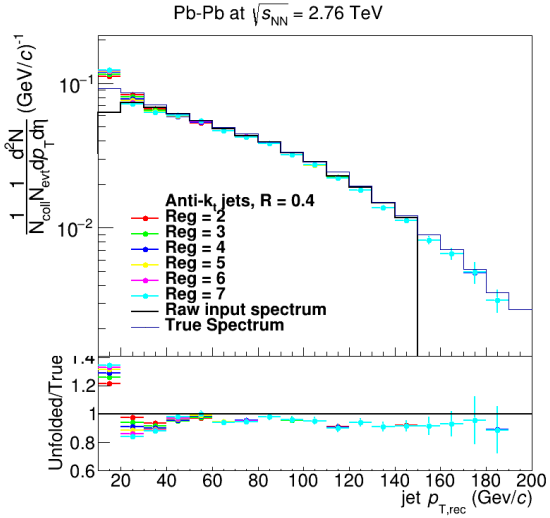
Rivet

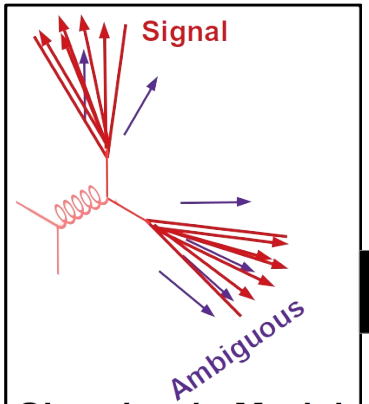
HEPData



Unfold to correct for fluctuations

Comparison to data





Signal-only Model

ex: JEWEL

HepMC

Rivet

Undergraduates!*

5 semesters	All Rivet students
20 students	35 students
10 women	14 women
5 minorities	10 minorities
3 non-traditional	5 non-traditional

Phys 494 – Course-based Undergraduate Research Experience in Relativistic Heavy Ion Physics

Instructor:
Dr. Christine Nattrass
Office: SERF 609
Phone: 974-6211
Email: christine.nattrass@utk.edu
Office hours: TBA

Teaching assistant: N/A

Class time & Location: TR 12:40-1:55 SERF 210

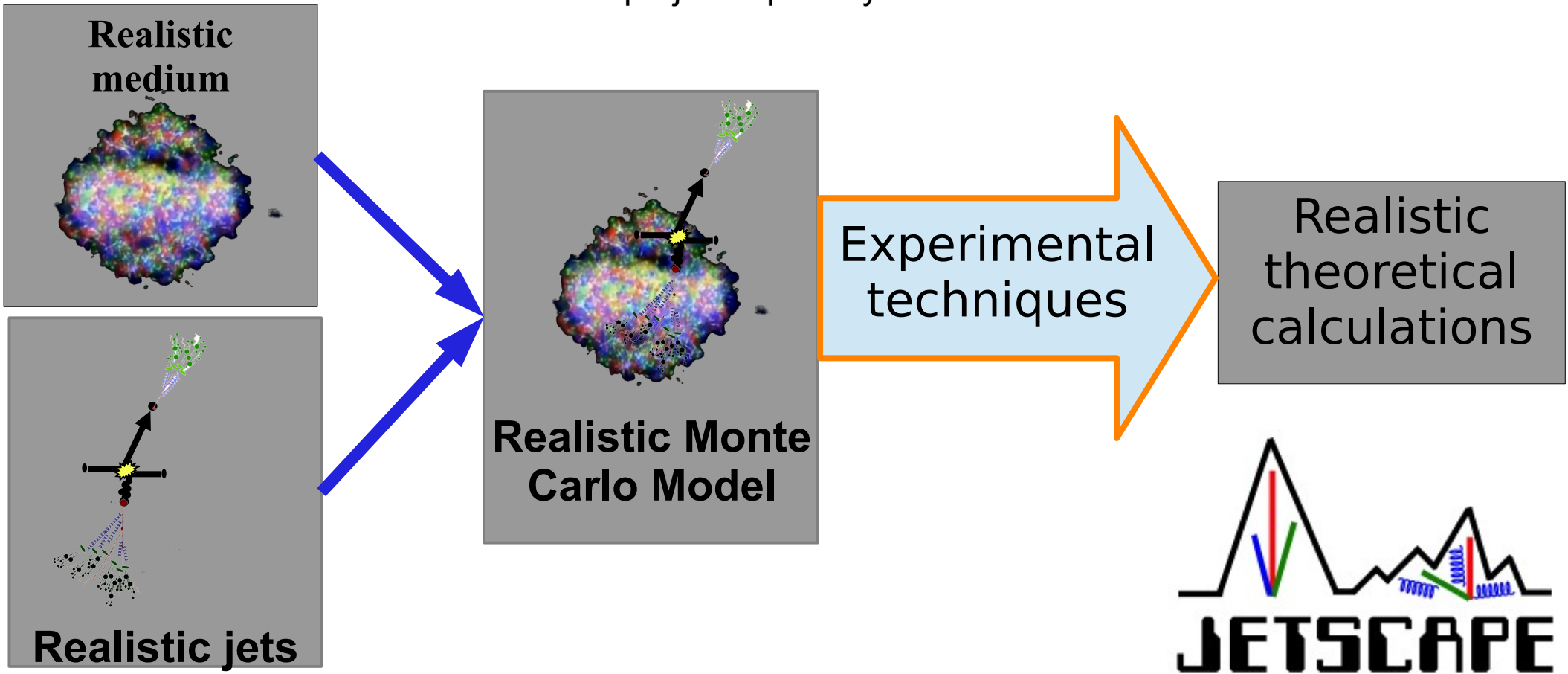
Course Description:
This course will incorporate undergraduates into a research project in high energy nuclear physics in a course setting. Each student will be responsible for implementing a heavy ion analysis in the program RIVET so that it can be used by the JETSCAPE collaboration to make comparisons between Monte Carlo models and data. Each student's project will be incorporated into a public software repository so that it is available to the field and, if possible, it will be validated by the relevant experiment and incorporated into the official RIVET software.

Left to right: Ricardo Santos (Berea), James Neuhaus, Jerrica Wilson, Mariah McCreary, Christine Nattrass, Austin Schmier (UTK)
*And one beginning graduate student

JETSCAPE Event generator

Jet **E**nergy-loss **T**omography with a **S**tatistically and **C**omputationally **A**dvanced **P**rogram **E**nvelope

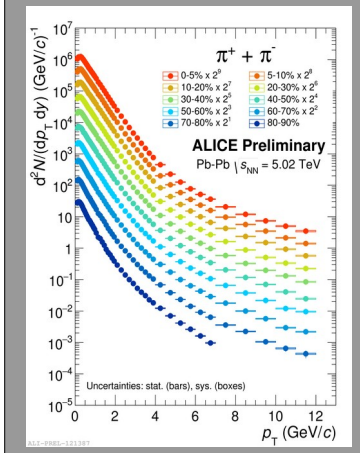
http://jetscape.wayne.edu/

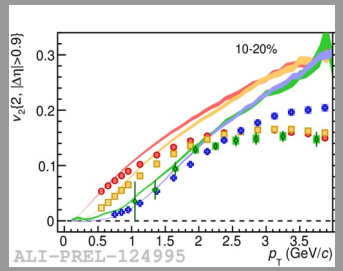


Bayesian Statistical Analysis

Models and Data Analysis Initiative

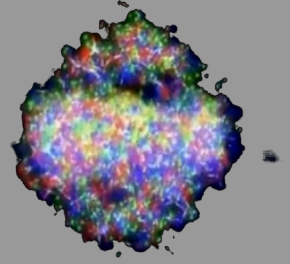
http://madai.us





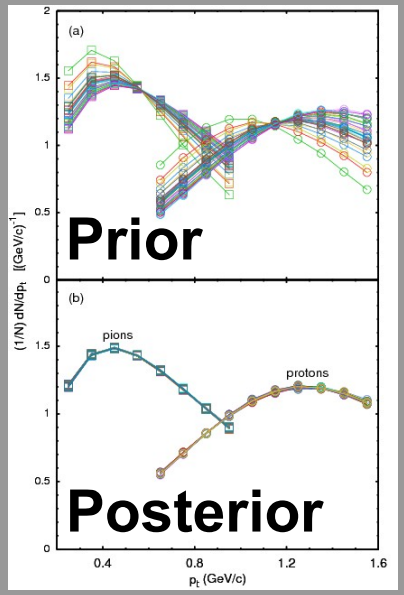
Data

Monte Carlo models

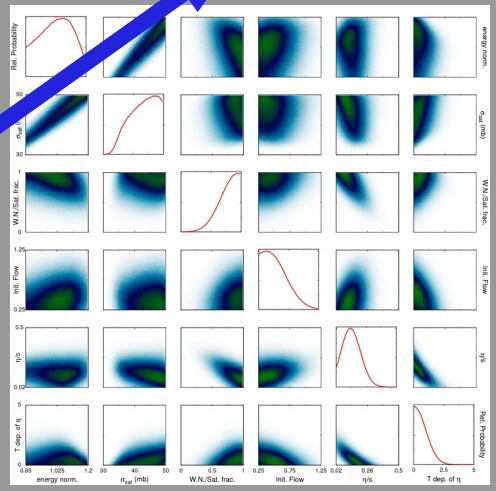


Model emulation

1) Run full model ~1000 times
2) MCMC parameter search uses emulator (interpolator) in lieu of full model

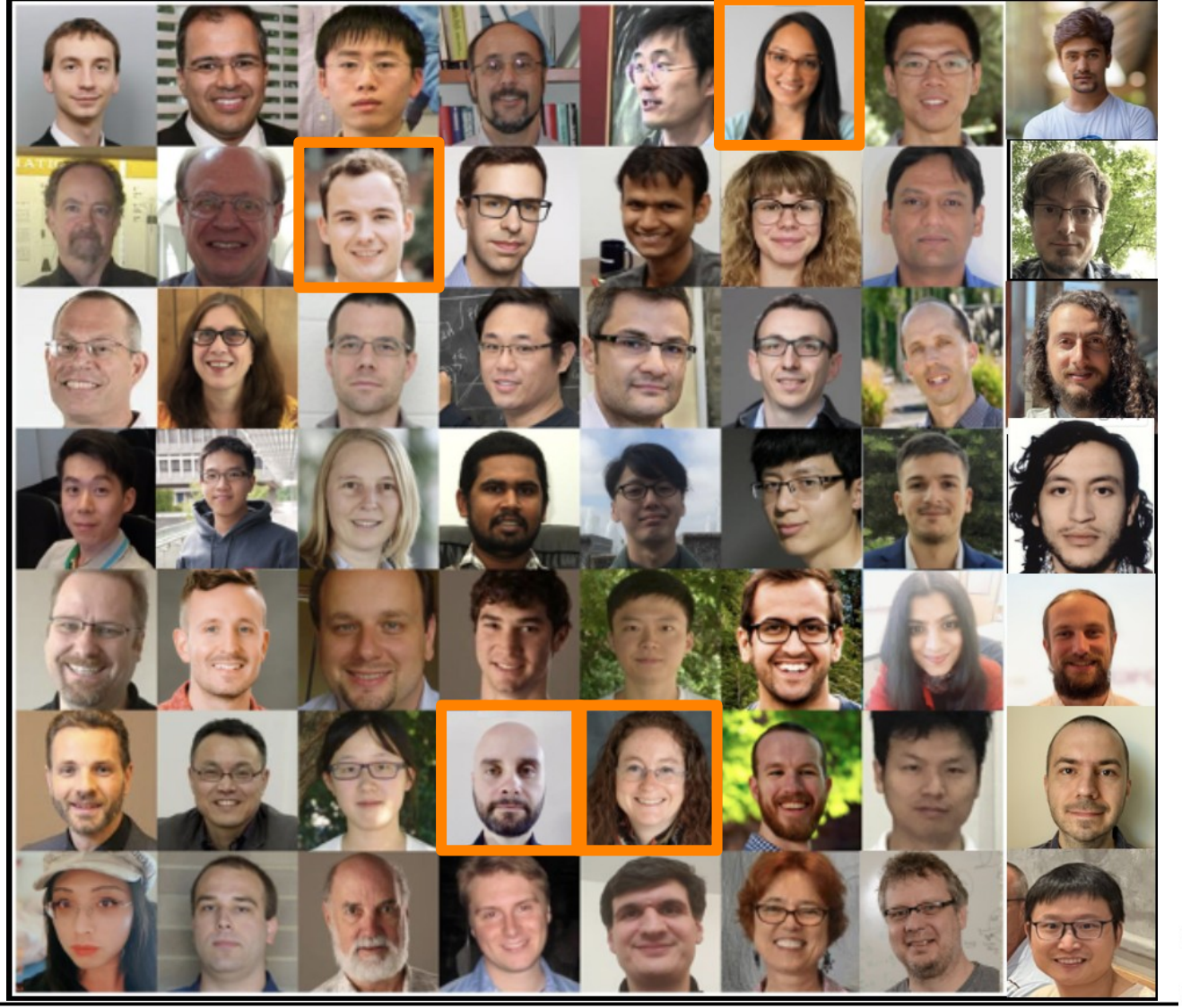


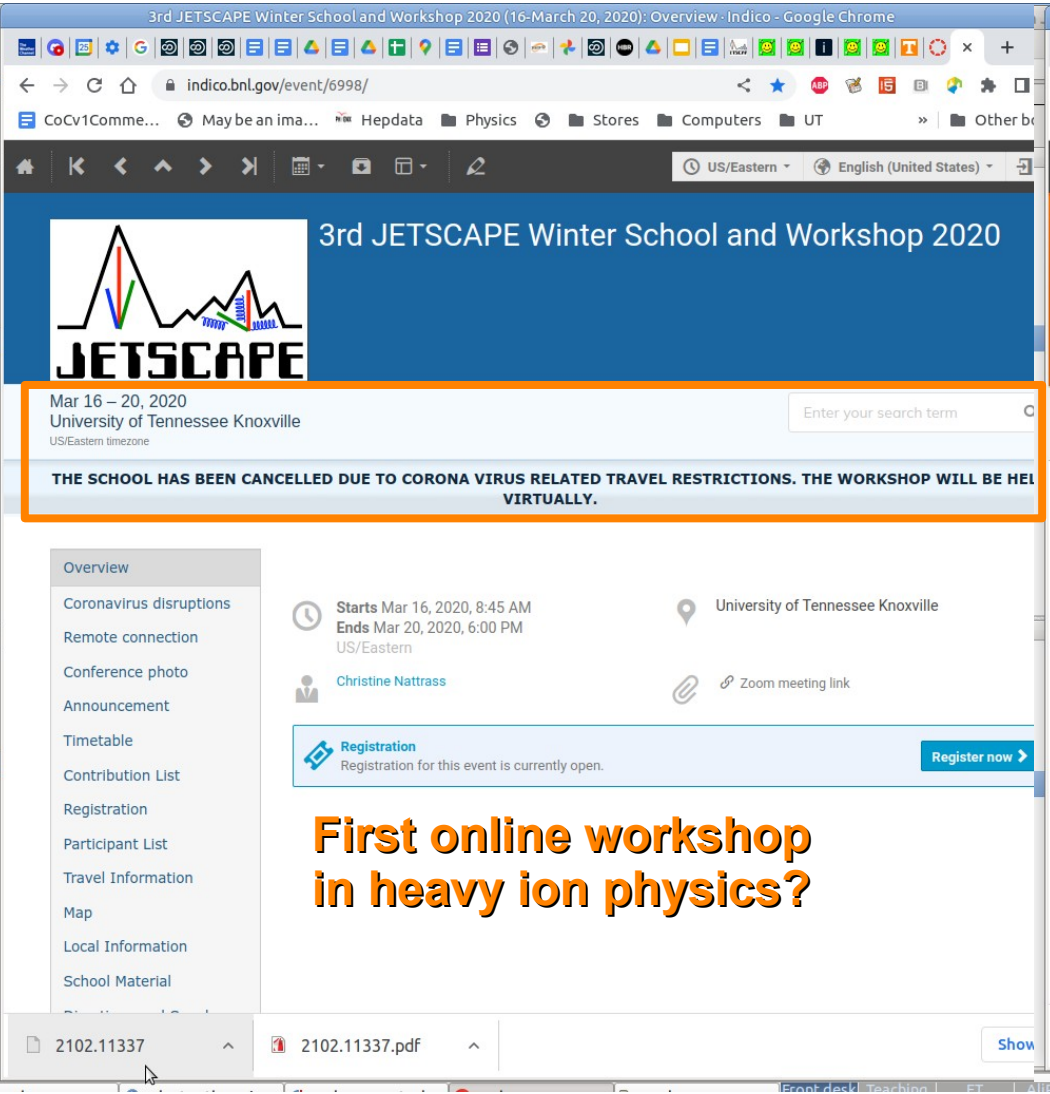
Optimization

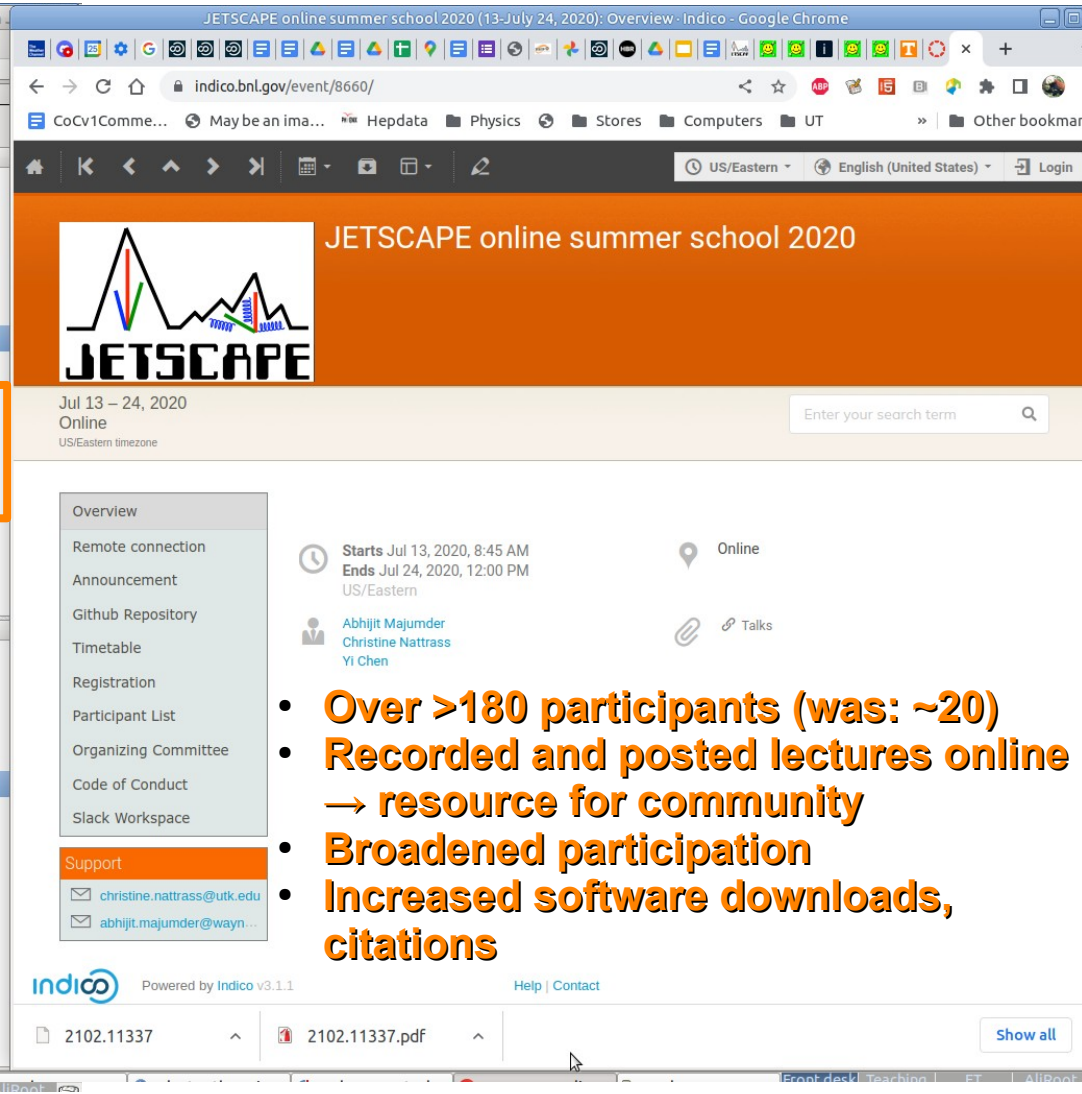


Constraint of QGP properties

Novak et al, Phys.Rev. C89 (2014) no.3, 034917




3rd JETSCAPE Winter School and Workshop 2020 (16-March 20, 2020): Overview - Indico - Google Chrome
indico.bnl.gov/event/6998/
3rd JETSCAPE Winter School and Workshop 2020
Mar 16 – 20, 2020
University of Tennessee Knoxville
US/Eastern timezone
THE SCHOOL HAS BEEN CANCELLED DUE TO CORONA VIRUS RELATED TRAVEL RESTRICTIONS. THE WORKSHOP WILL BE HEL
VIRTUALLY.
Overview
Coronavirus disruptions
Remote connection
Conference photo
Announcement
Timetable
Contribution List
Registration
Participant List
Travel Information
Map
Local Information
School Material
Starts Mar 16, 2020, 8:45 AM
Ends Mar 20, 2020, 6:00 PM
US/Eastern
University of Tennessee Knoxville
Christine Nattrass
Zoom meeting link
Registration
Registration for this event is currently open.
Register now
First online workshop
in heavy ion physics?
2102.11337
2102.11337.pdf


JETSCAPE online summer school 2020 (13-July 24, 2020): Overview - Indico - Google Chrome
indico.bnl.gov/event/8660/
JETSCAPE online summer school 2020
Jul 13 – 24, 2020
Online
US/Eastern timezone
Overview
Remote connection
Announcement
Github Repository
Timetable
Registration
Participant List
Organizing Committee
Code of Conduct
Slack Workspace
Support
christine.nattrass@utk.edu
Starts Jul 13, 2020, 8:45 AM
Ends Jul 24, 2020, 12:00 PM
US/Eastern
Online
Abhijit Majumder
Christine Nattrass
Yi Chen
Talks
Over >180 participants (was: ~20)
Recorded and posted lectures online → resource for community
Broadened participation
Increased software downloads, citations
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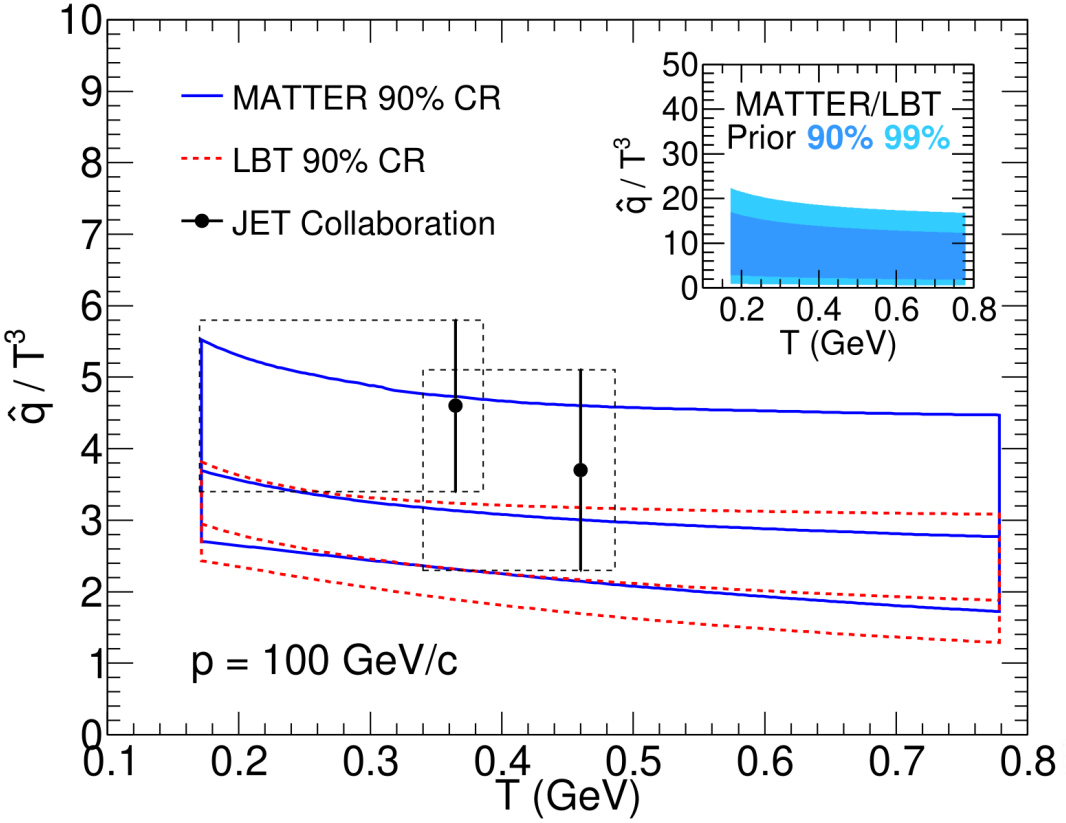
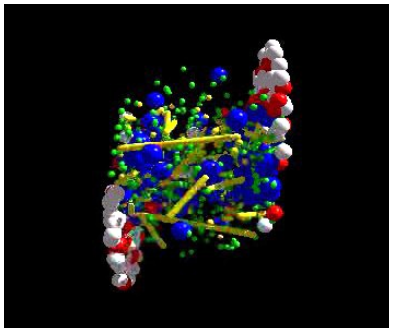
Bayesian Parameter Estimation - $\hat{q}$

Phys. Rev. C 104, 024905 (2021)

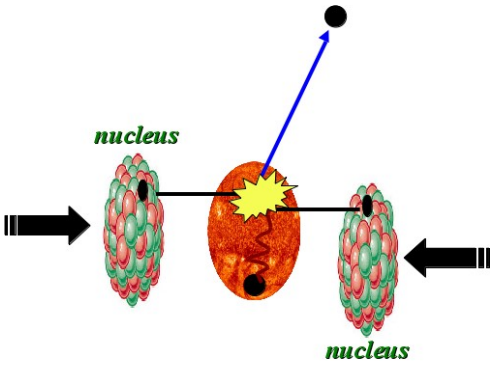
Still only includes single hadrons!

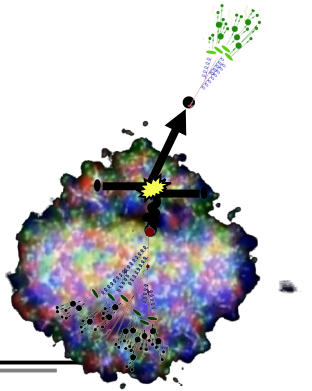


Take home messages

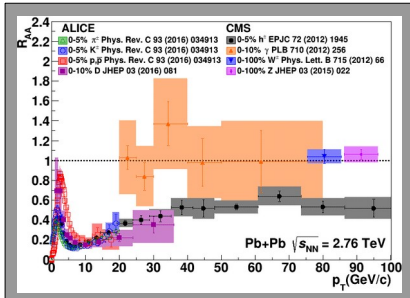


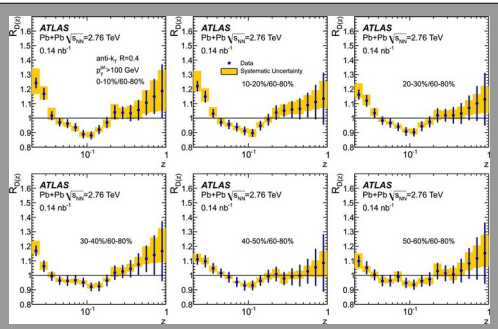
- If we get nuclear matter dense enough, we make a new phase of matter, which we produce in high energy heavy ion collisions.
- This medium is opaque to colored probes and translucent to electromagnetic probes.
- We can quantify its properties with realistic models.

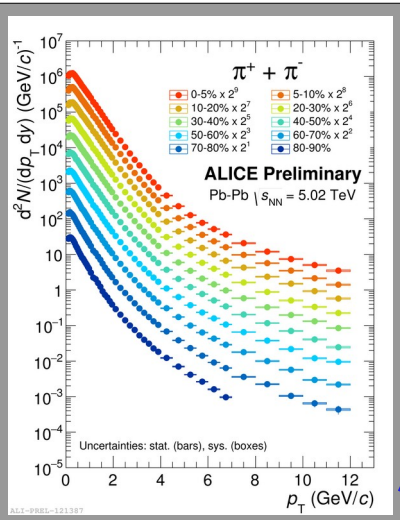


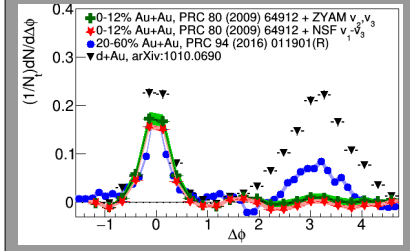


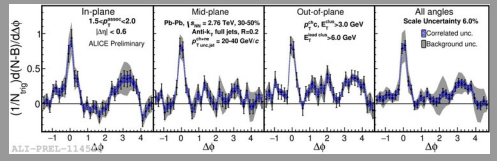
Event Generator + Bayesian Statistical analysis



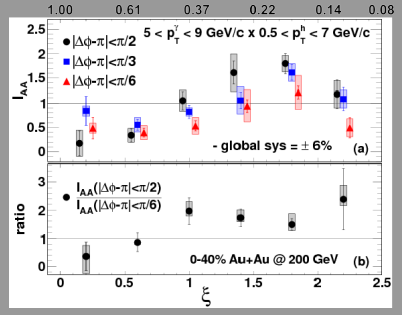


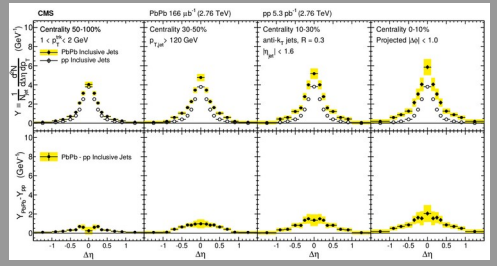


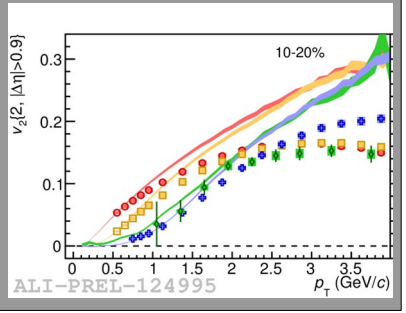


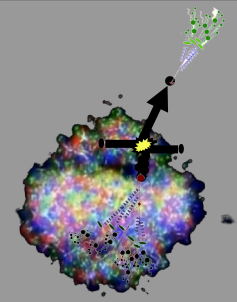


Data









Realistic theoretical calculations

Bayesian Statistical Analysis

Constraint of QGP properties

Course-based undergraduate research experience

Ask me if you want more info!

CBE—Life Sciences Education, Vol. 15, No. 2 | Articles

Early Engagement in Course-Based Research Increases Graduation Rates and Completion of Science, Engineering, and Mathematics Degrees

Stacia E. Rodenbusch, Paul R. Hernandez, Sarah L. Simmons, and Erin L. Dolan

Jennifer Knight, Monitoring Editor:

Published Online: 13 Oct 2017 | https://doi.org/10.1187/cbe.16-03-0117

Abstract

National efforts to transform undergraduate biology education call for research experiences to be an integral component learning for all students. Course-based undergraduate research experiences, or CUREs, have been championed for engagi students in research at a scale that is not possible through apprenticeships in faculty research laboratories. Yet there are f if any studies that examine the long-term effects of participating in CUREs on desired student outcomes, such as graduatir from college and completing a science, technology, engineering, and mathematics (STEM) major. One CURE program, the Freshman Research Initiative (FRI), has engaged thousands of first-year undergraduates over the past decade. Using propensity score–matching to control for student-level differences, we tested the effect of participating in FRI on students' probability of graduating with a STEM degree, probability of graduating within 6 yr, and grade point average (GPA) at graduation. Students who completed all three semesters of FRI were significantly more likely than their non-FRI peers to earn a STEM degree and graduate within 6 yr. FRI had no significant effect on students' GPAs at graduation. The effects were similar for diverse students. These results provide the most robust and best-controlled evidence to date to support calls for early involvement of undergraduates in research.

Phys 494 – Course-based Undergraduate Research Experience in Relativistic Heavy Ion Physics

Instructor:
Dr. Christine Nattrass
Office: SERF 609
Phone: 974-6211
Email: christine.nattrass@utk.edu
Office hours: TBA

Teaching assistant: N/A

Class time & Location: TR 12:40-1:55 SERF 210

Course Description:
This course will incorporate undergraduates into a research project in high energy nuclear physics in a course setting. Each student will be responsible for implementing a heavy ion analysis in the program RIVET so that it can be used by the JETSCAPE collaboration to make comparisons between Monte Carlo models and data. Each student's project will be incorporated into a public software repository so that it is available to the field and, if possible, it will be validated by the relevant experiment and incorporated into the official RIVET software.

3 semesters
15 students
8 women
3 minorities
3 non-traditional

All Rivet students
22 students
11 women
7 minorities
4 non-traditional