A Talk About Jets Which Everyone Will Understand

Robert Líčeník

WEJČF, Bílý potok, 14. 6. 2022

A Talk About Jets Which Everyone Will Understand *(hopefully)*

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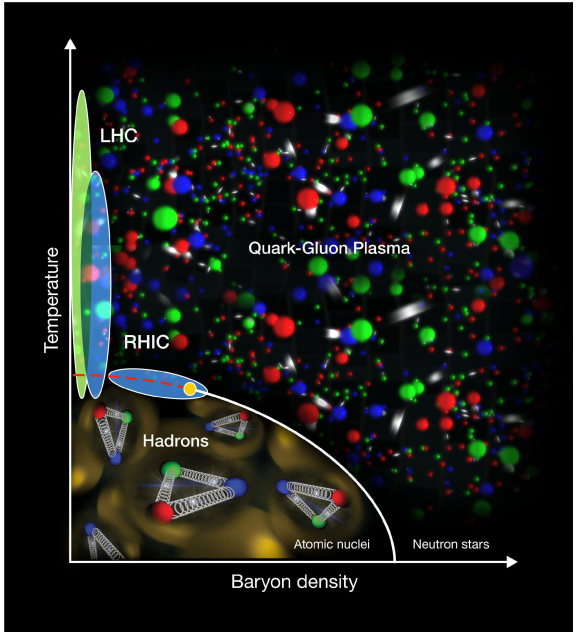
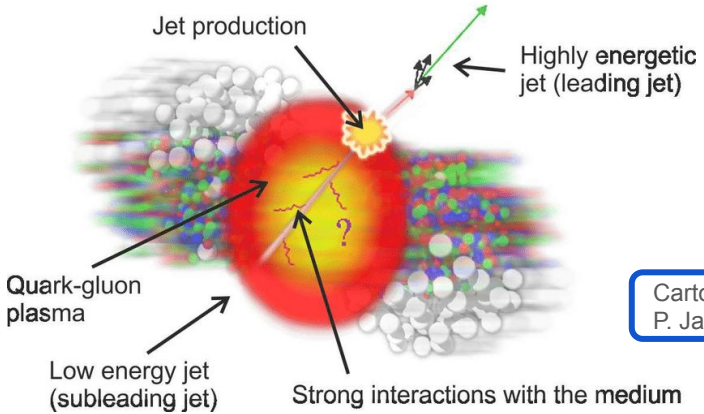
Contents

Episode 0: Why jets?

Why Jets?

- Hard QCD process (fragmentation)
- “Decay products” of interesting particles (H,t,W,Z)
- They probe the quark-gluon plasma (QGP)
- Jet quenching is key smoking-gun evidence for QGP existence
- What is QGP?



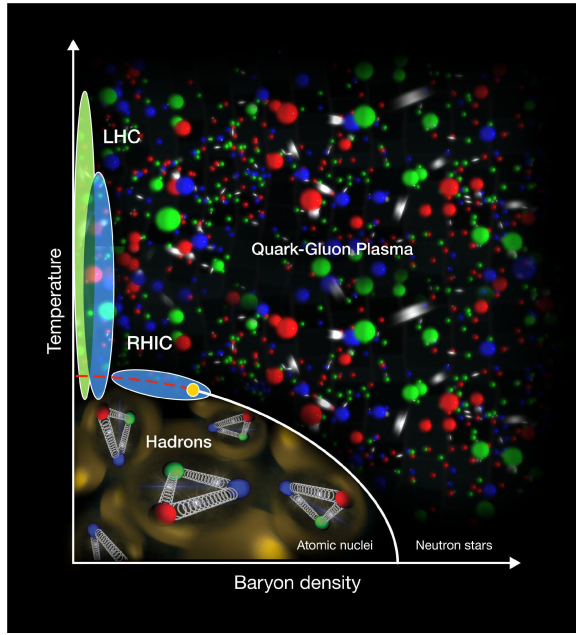


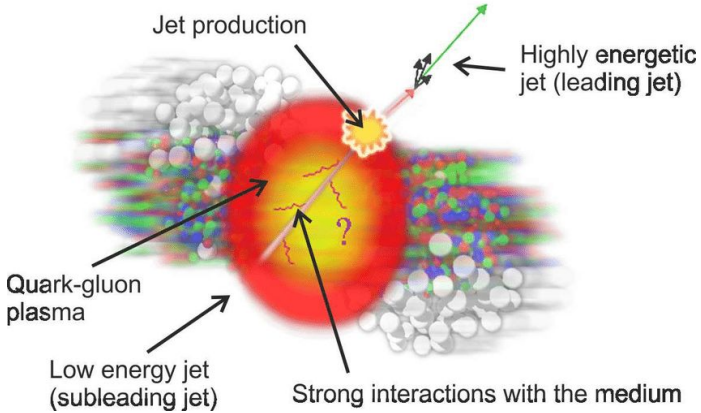
Cartoon by P. Jacobs

Why Jets?

I will not talk about this much, but it's cool!

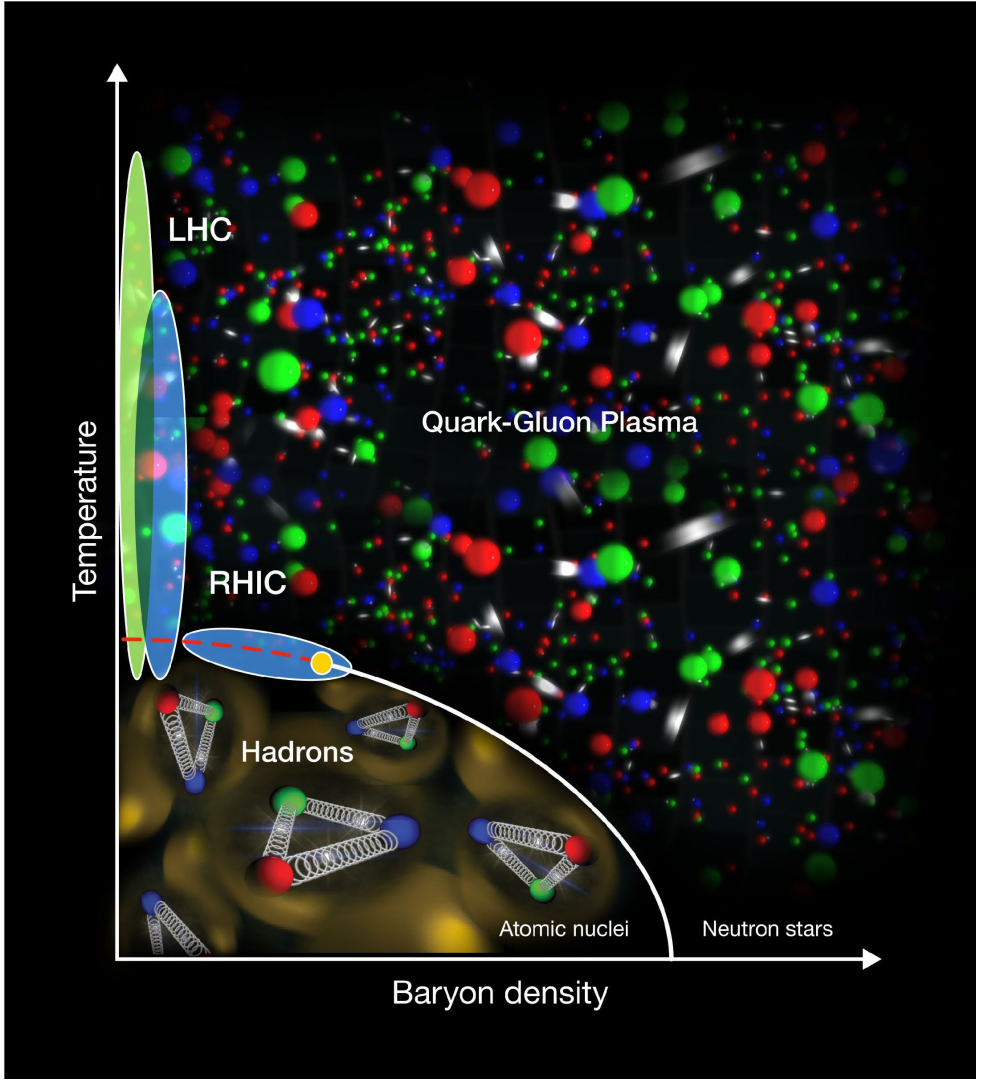
- Hard QCD process (fragmentation)
- "Decay products" of interesting particles (H,t,W,Z)
- They probe the quark-gluon plasma (QGP)
- Jet quenching is key smoking-gun evidence for QGP existence
- What is QGP?



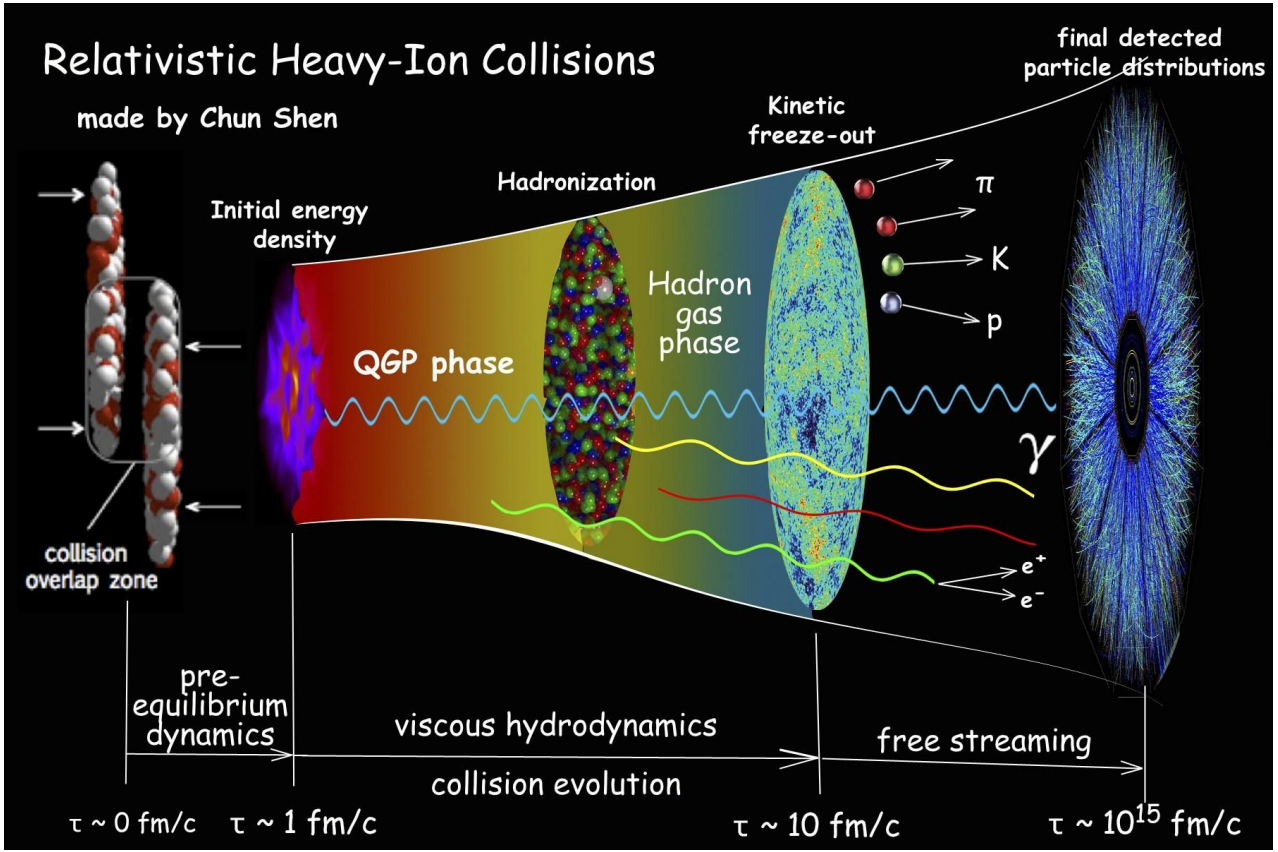


Let's Zoom In

- QGP existed shortly after Big Bang
- Extreme in all aspects
- Re-created in heavy ion collisions

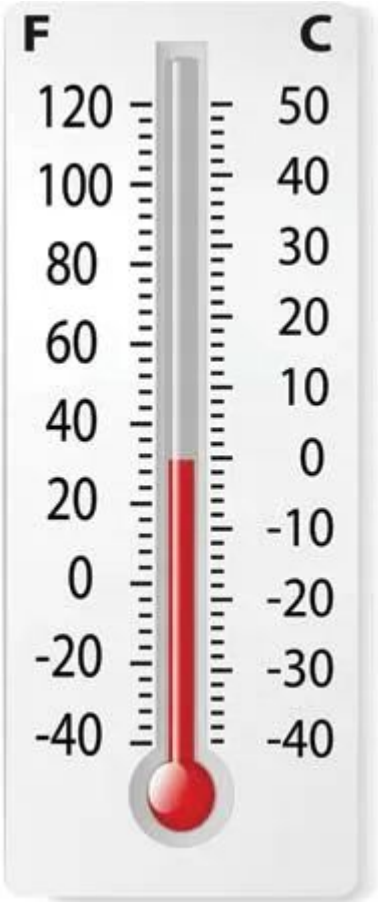


Heavy Ion Collisions - Short Intro

- 

How To Study QGP?

- Thermometer?



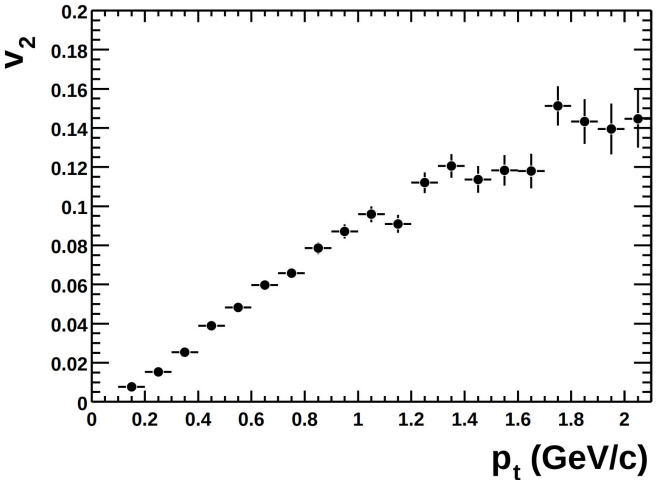
How To Study QGP?

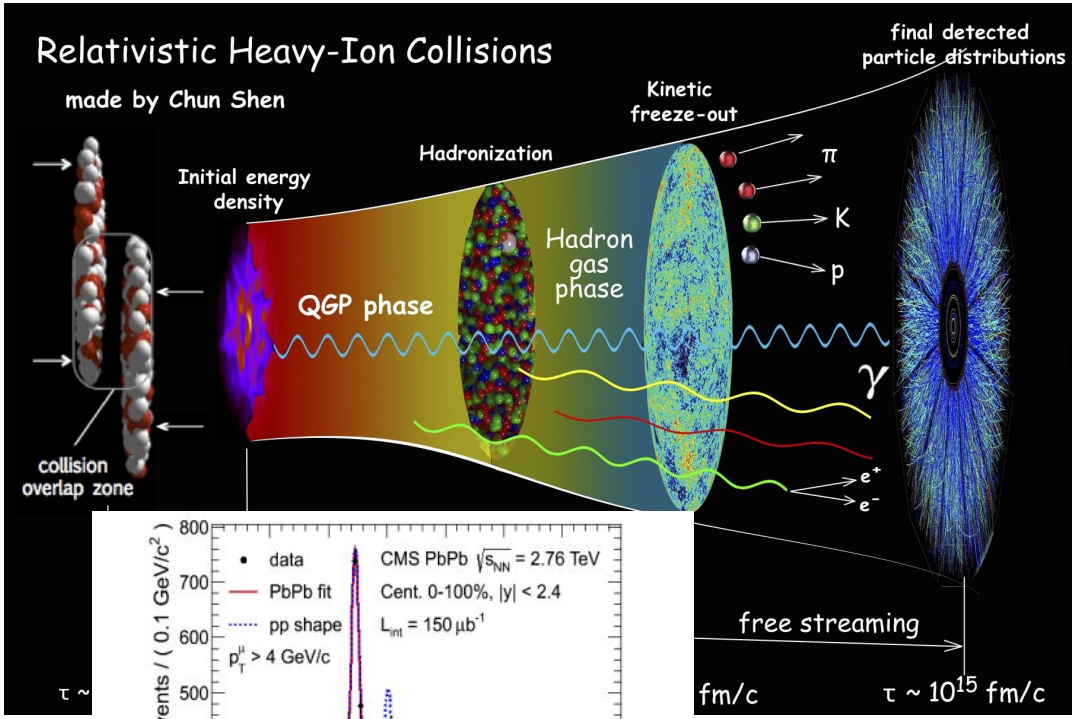
- ~~Thermometer?~~
- Probes

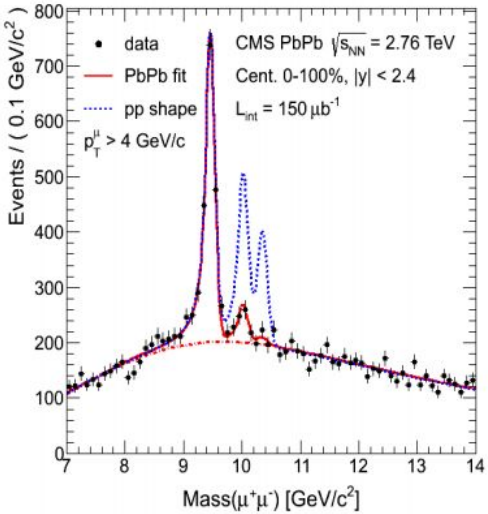
How To Study QGP?

- Soft probes
- EM probes
- Hard probes

STAR, PRL 86 (2001)



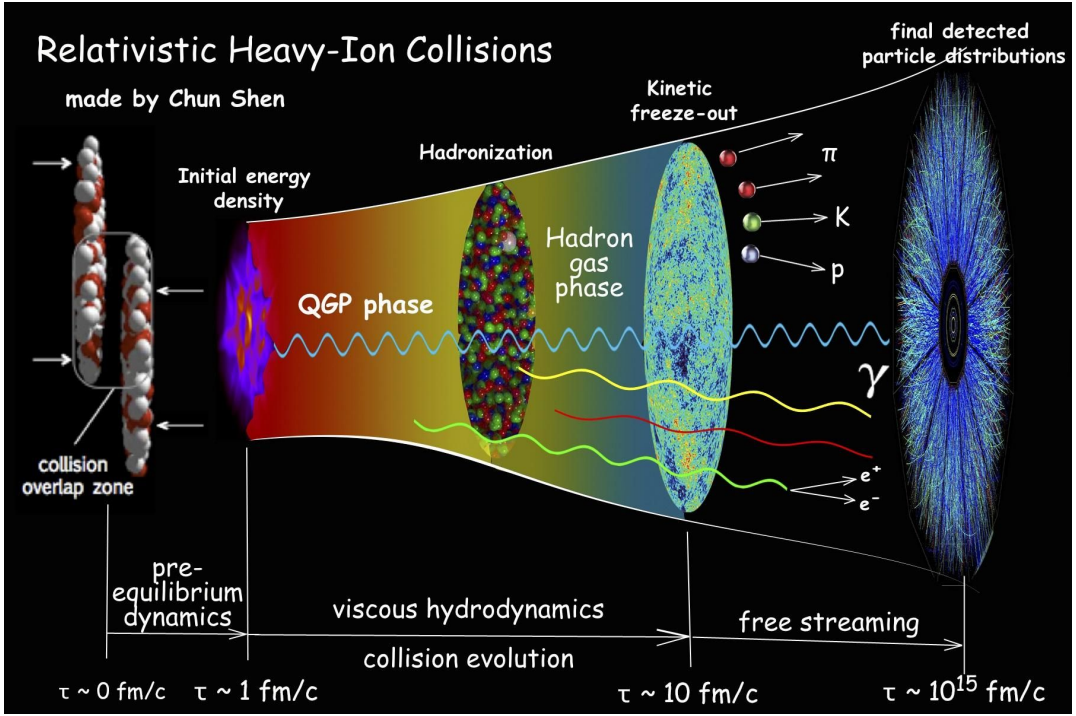




CMS, PRL 109, 222301 (2012)

How To Study QGP?

- Soft probes
- EM probes
- Hard probes

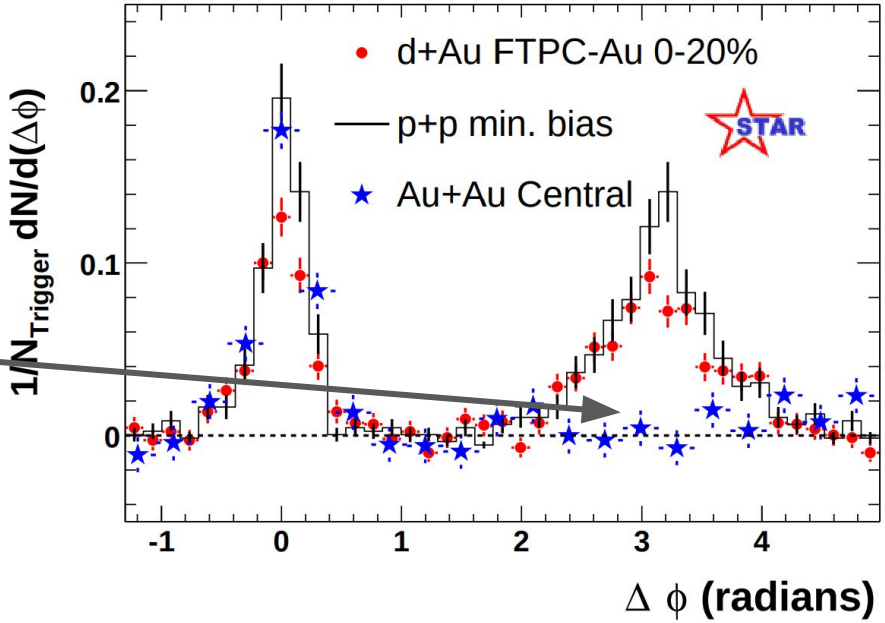


Jets are a critical probe of QCD matter

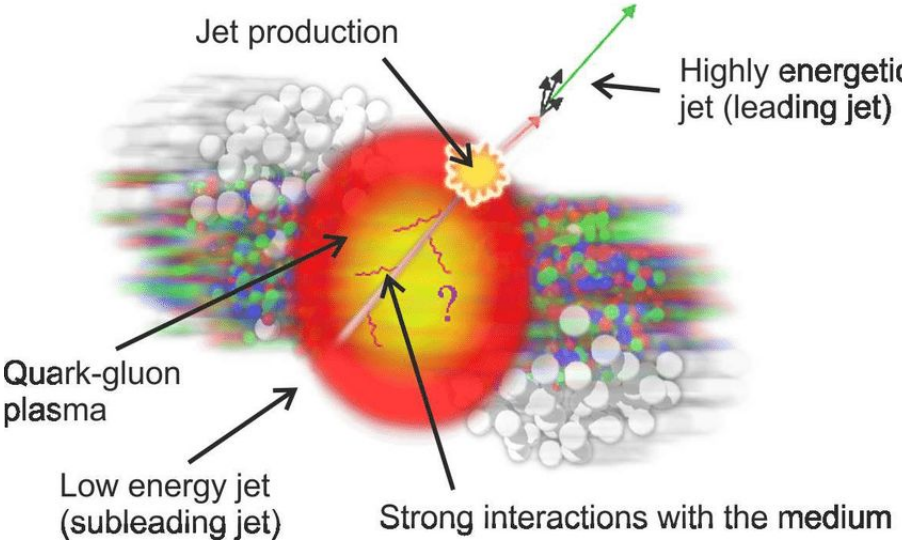
Episode 1: Pre(jet)history

First Observation of Jet Quenching

- High-p_T hadron suppression

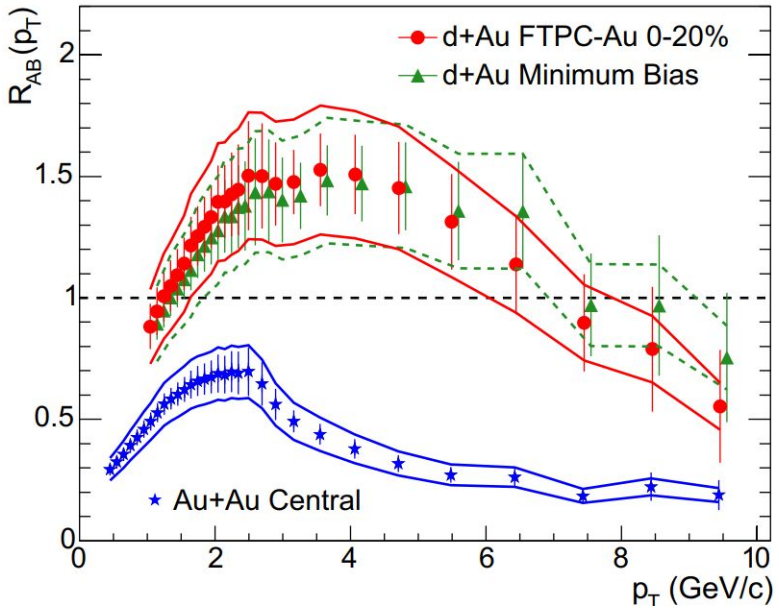


STAR, NPA. 757 (1–2): 102–183

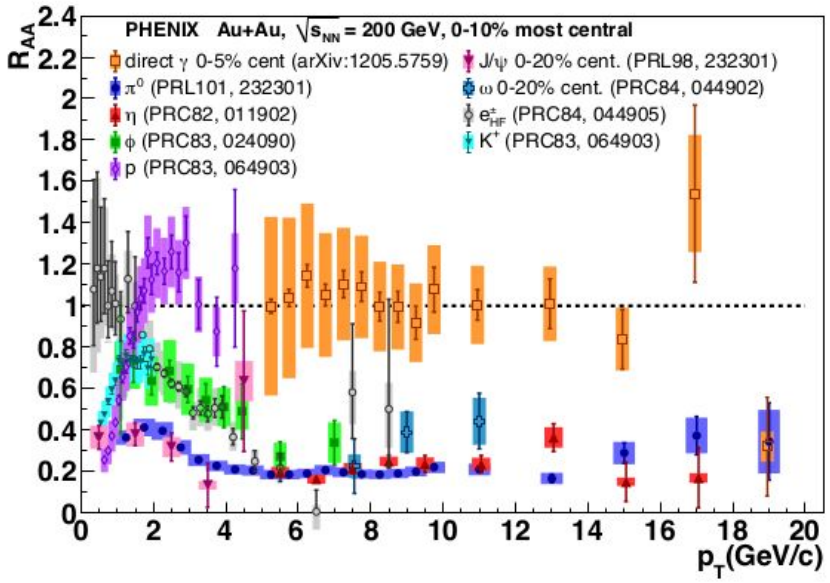


Alpha-Omega Observable

$$R_{\mathrm{AA}} = \frac{\frac{\mathrm{d}^2 N_{\mathrm{AA}}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}}{\langle N_{\mathrm{coll}} \rangle \times \frac{\mathrm{d}^2 N_{\mathrm{pp}}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}}$$



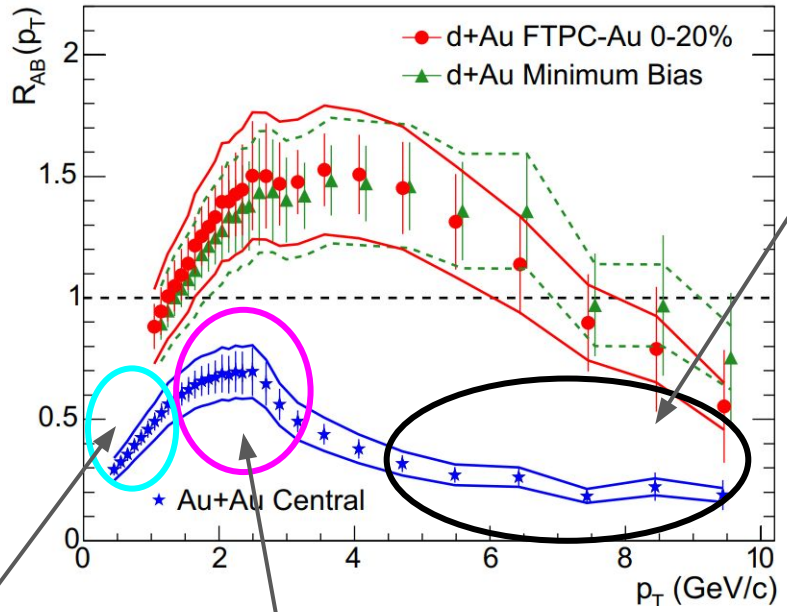
STAR, PRL 91.072304 (2003)

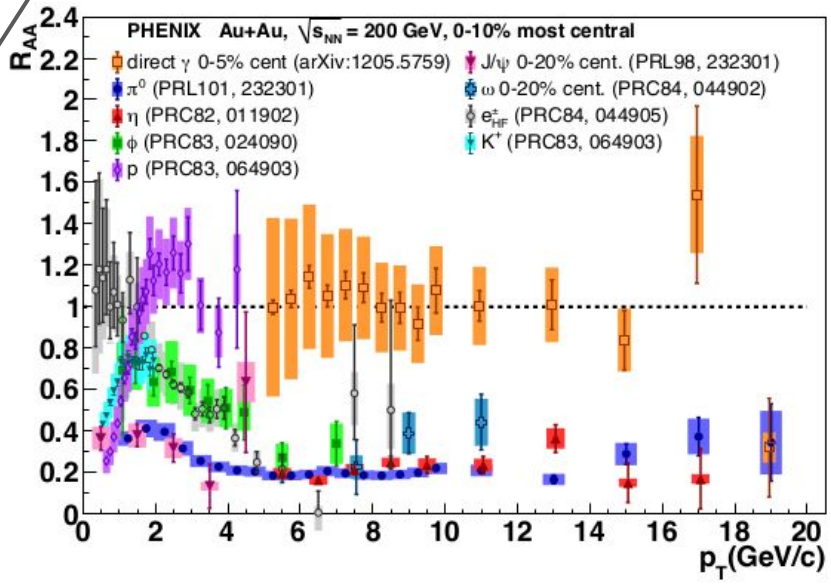


J. Phys.: Conf. Ser. 589 (2015)

Alpha-Omega Observable

$$R_{AA} = \frac{\frac{d^2 N_{AA}}{dp_T dy}}{\langle N_{coll} \rangle \times \frac{d^2 N_{pp}}{dp_T dy}}$$





Soft QCD, don't care

Cronin effect

STAR, PRL 91.072304 (2003)

J. Phys.: Conf. Ser. 589 (2015)

So We Have Everything?

- Broader exploration of jet quenching mechanisms
- Different jet measurements: inclusive, coincidence, heavy flavor, substructure,...

Turns out we really can and should reconstruct jets

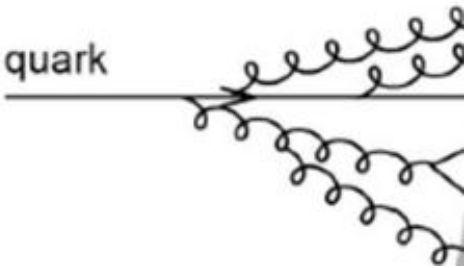
Episode 2: What jets?

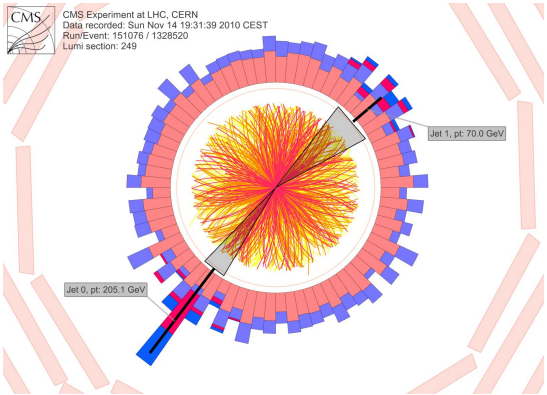
What Are Jets?

*only for illustrative purposes

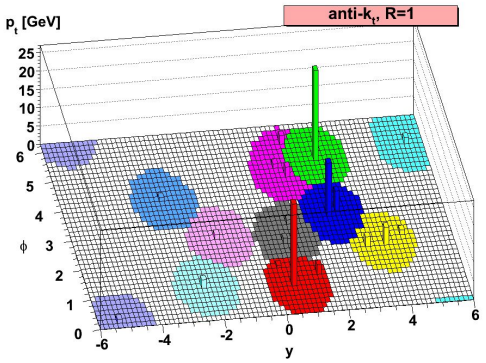
What Are Jets?

- Depends on definition
- Quantum chromodynamics: product of hard parton (q/g) fragmentation
- Detector: bunch of particles in one region (“collimated spray of hadrons”)
- Experimentalist (like me): whatever a jet-finding algorithm says





JHEP (2008) 0804:063

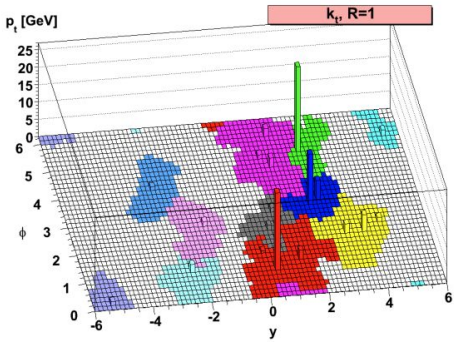


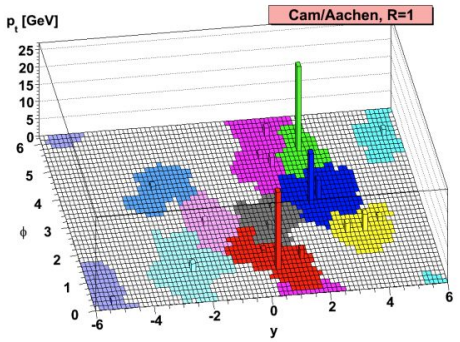
Jet Clustering Algorithms (Actually Used)

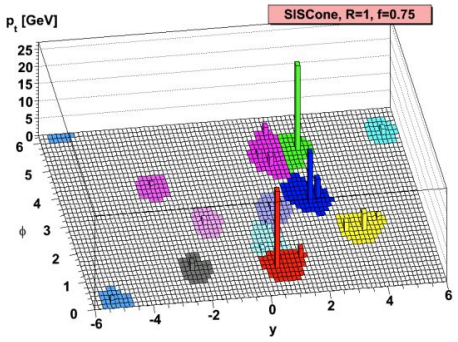
$$d_{ij} = \min(k_{ti}^{2p}, k_{tj}^{2p}) \frac{\Delta_{ij}^2}{R^2}$$

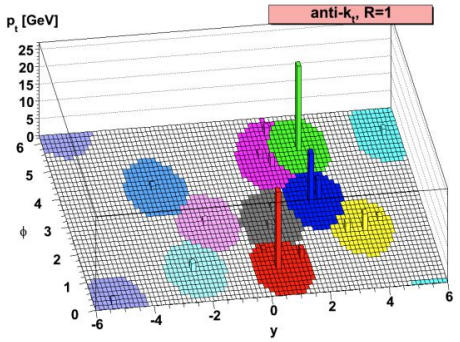
$$\Delta_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

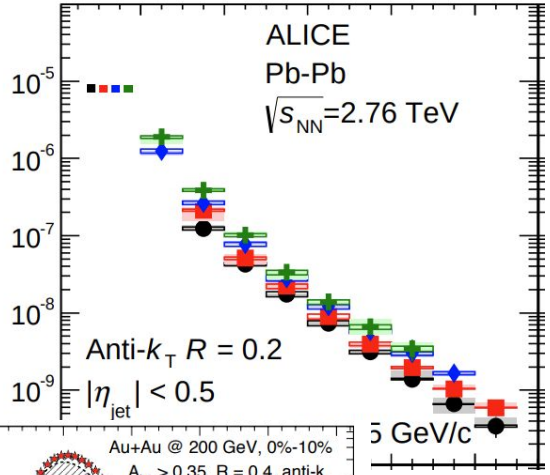
- Minimize distance between particles
- Results are *R*-dependent
- Results are algorithm-dependent
- $p = 1$ -> k_T (soft first, background)
- $p = 0$ -> Cambridge/Aachen (only angular dependence, substructure)
- $p = -1$ -> anti-k_T (hard first, real jets)
- Infrared and Collinear safety

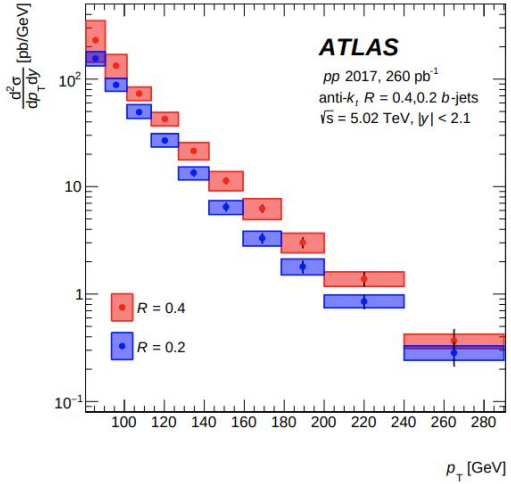


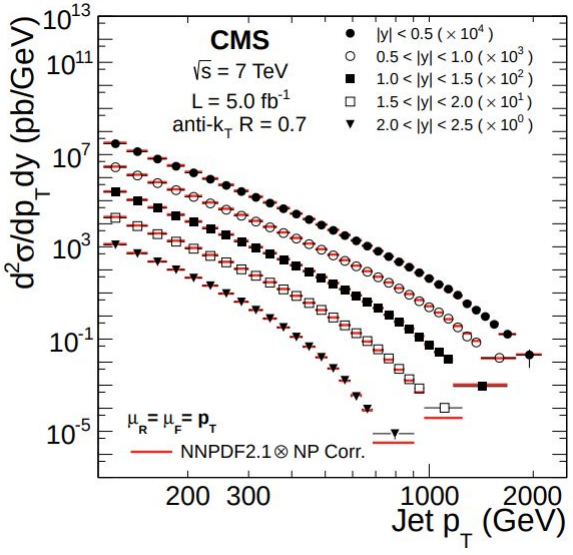


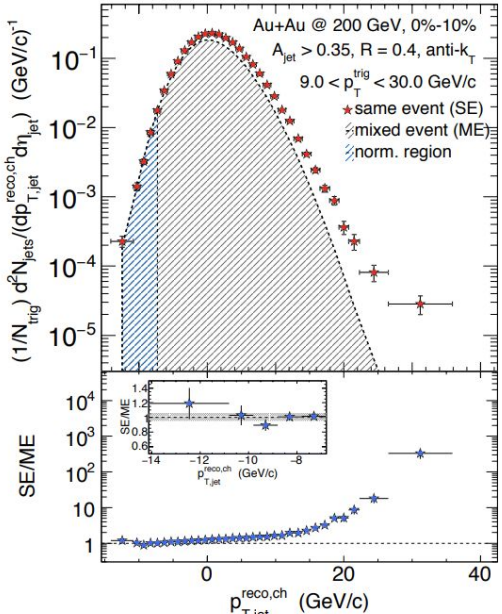





ALICE
Pb-Pb
$\sqrt{s_{NN}}$=2.76 TeV
Anti-k_T R = 0.2
$|\eta_{jet}| < 0.5$
5 GeV/c


ATLAS
pp 2017, 260 pb^{-1}
anti-k_t R = 0.4,0.2 b-jets
$\sqrt{s}$ = 5.02 TeV, $|y| < 2.1$
R = 0.4
R = 0.2
p_T [GeV]


CMS
$\sqrt{s}$ = 7 TeV
L = 5.0 fb^{-1}
anti-k_T R = 0.7
$|y| < 0.5$ ($\times 10^4$)
$0.5 < |y| < 1.0$ ($\times 10^3$)
$1.0 < |y| < 1.5$ ($\times 10^2$)
$1.5 < |y| < 2.0$ ($\times 10^1$)
$2.0 < |y| < 2.5$ ($\times 10^0$)
$\mu_R = \mu_F = p_T$
NNPDF2.1 ⊗ NP Corr.
Jet p_T (GeV)


Au+Au @ 200 GeV, 0%-10%
A_{jet} > 0.35, R = 0.4, anti-k_T
$9.0 < p_T^{trig} < 30.0$ GeV/c
same event (SE)
mixed event (ME)
norm. region
SE/ME
$p_{T,jet}^{reco,ch}$ (GeV/c)


Anti-kT, anti-kT everywhere
imgflip.com

Jets are objects that need to be treated carefully

Episode 3: How jets?

Ideal Jet Analysis

1. Measure all particles in the event
2. Feed them into jet finder
3. Magic happens
4. We have jets
5. Subtract background
6. Correct for instrumental effects
7. Estimate systematic uncertainties
8. Publish and profit

Ideal Jet Analysis

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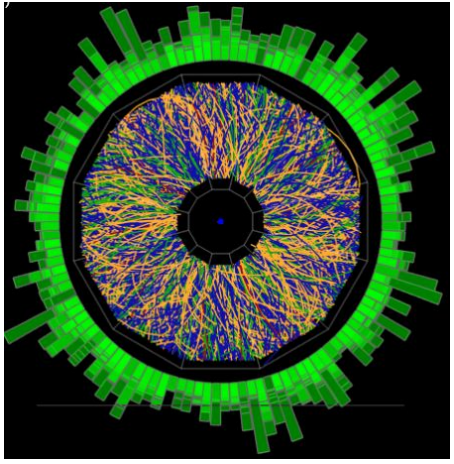
*at least at STAR



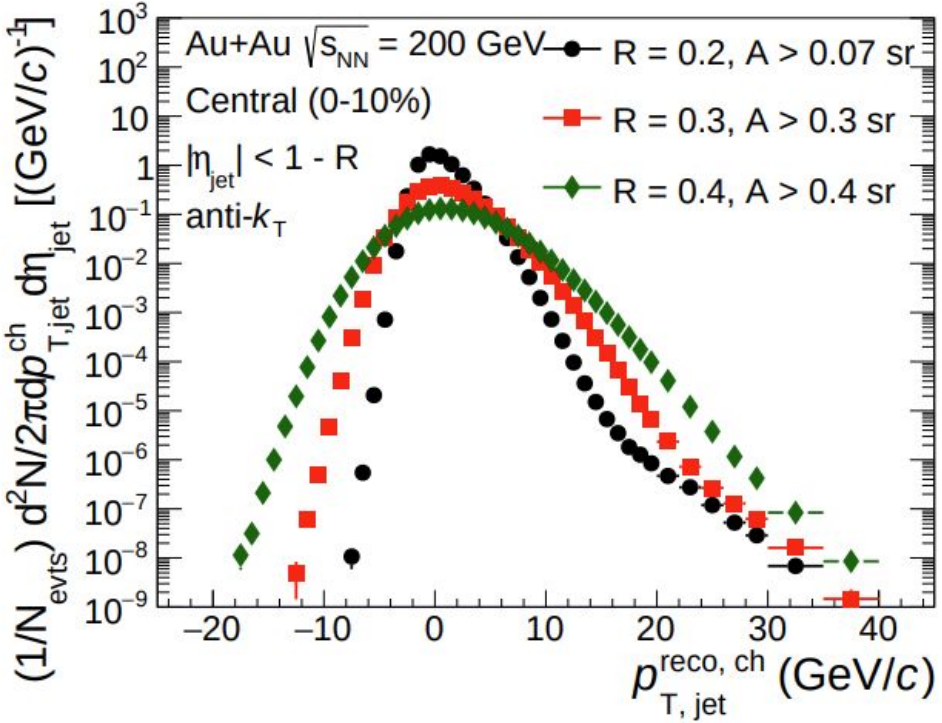
Approximation - Charged Jets

1. Only charged particles
2. Feed them into jet finder
3. Magic happens
4. We have jets
5. Subtract background

$$p_{\mathrm{T,jet}}^{\mathrm{reco,i}} = p_{\mathrm{T,jet}}^{\mathrm{raw,i}} - \rho \cdot A_{\mathrm{jet}}^{\mathrm{i}}, \text{ where } \rho = \mathrm{median}\left\{ \frac{p_{\mathrm{T,jet}}^{\mathrm{raw,i}}}{A_{\mathrm{jet}}^{\mathrm{i}}} \right\}$$

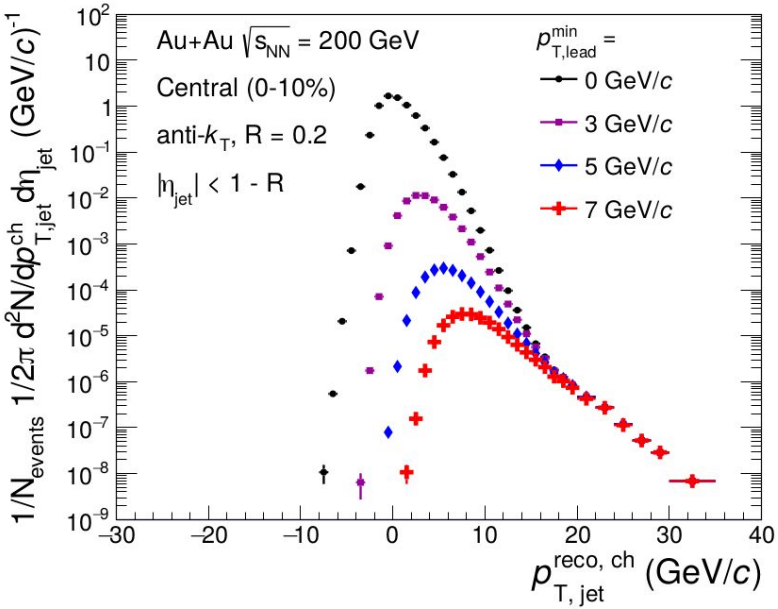
We don't really know what is background

STAR, PRC 102 (2020) 5, 054913



5. Reducing Background

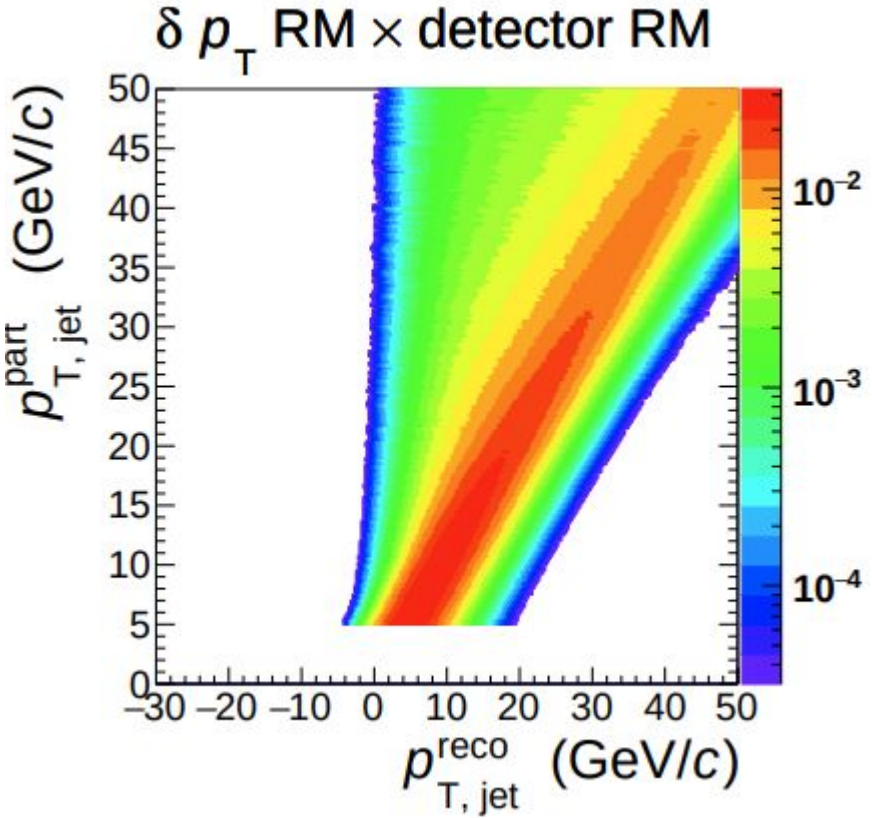
- Combinatorial jets suppressed by imposing cut on leading hadron transverse momentum ($p_{T,lead}$)
- Imposes bias on jet fragmentation and breaks collinear safety



We need to be careful with interpretations of the results

6. Correcting For Detector Effects

- Simulated response matrix
- Truth -> Measured “easy”
- Measured -> Truth hard
- Unfolding = fake-inverting the matrix



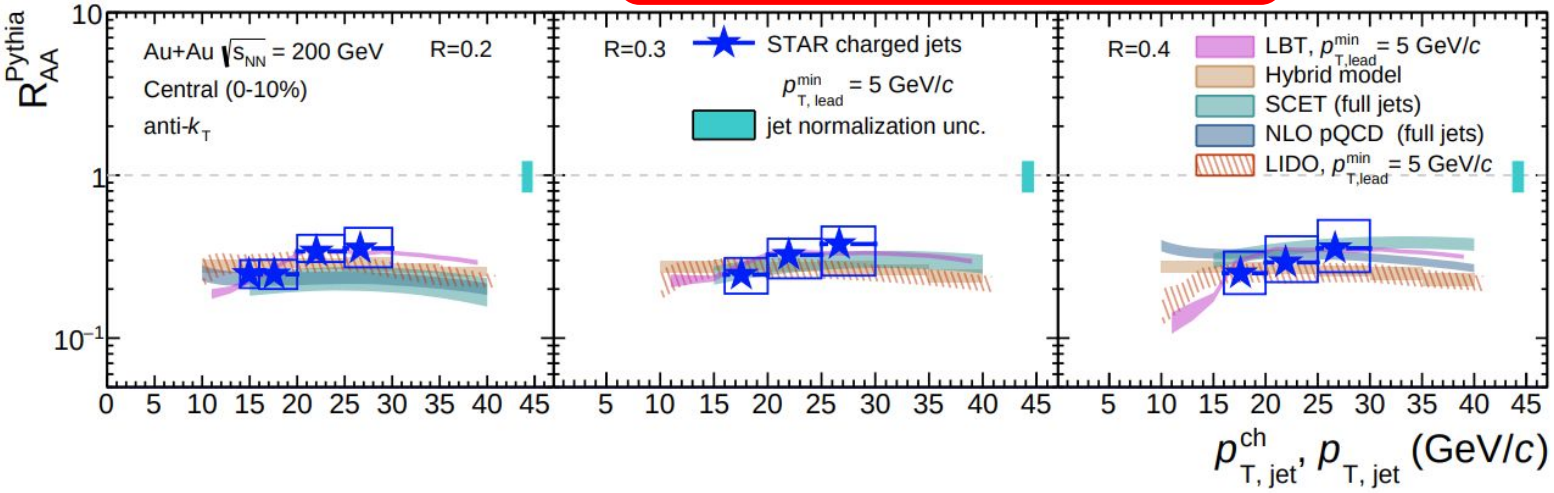
7. Systematic Uncertainties

Nature doesn't care about your cuts!

- Repeating the analysis with different conditions and getting the ~same result
- Partially inherent

8. Publish and Profit

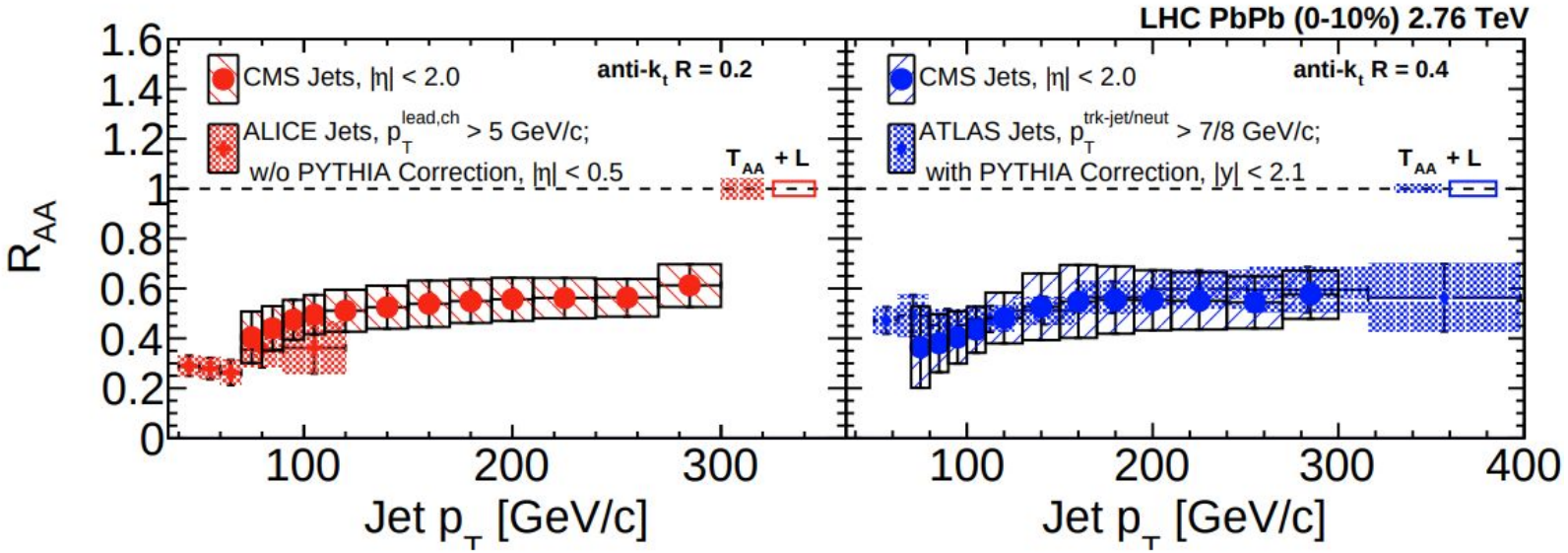
Won "Result of the Year" at STAR



Episode 4: How really jets?

Have a Real Calorimeter

CMS, PRC 96 (2017) 015202



What If You Don’t Have One

- Take what’s available
- Make lots of studies
- Make it work

Слава Україні!
Путин - хуйло!

BACKUP