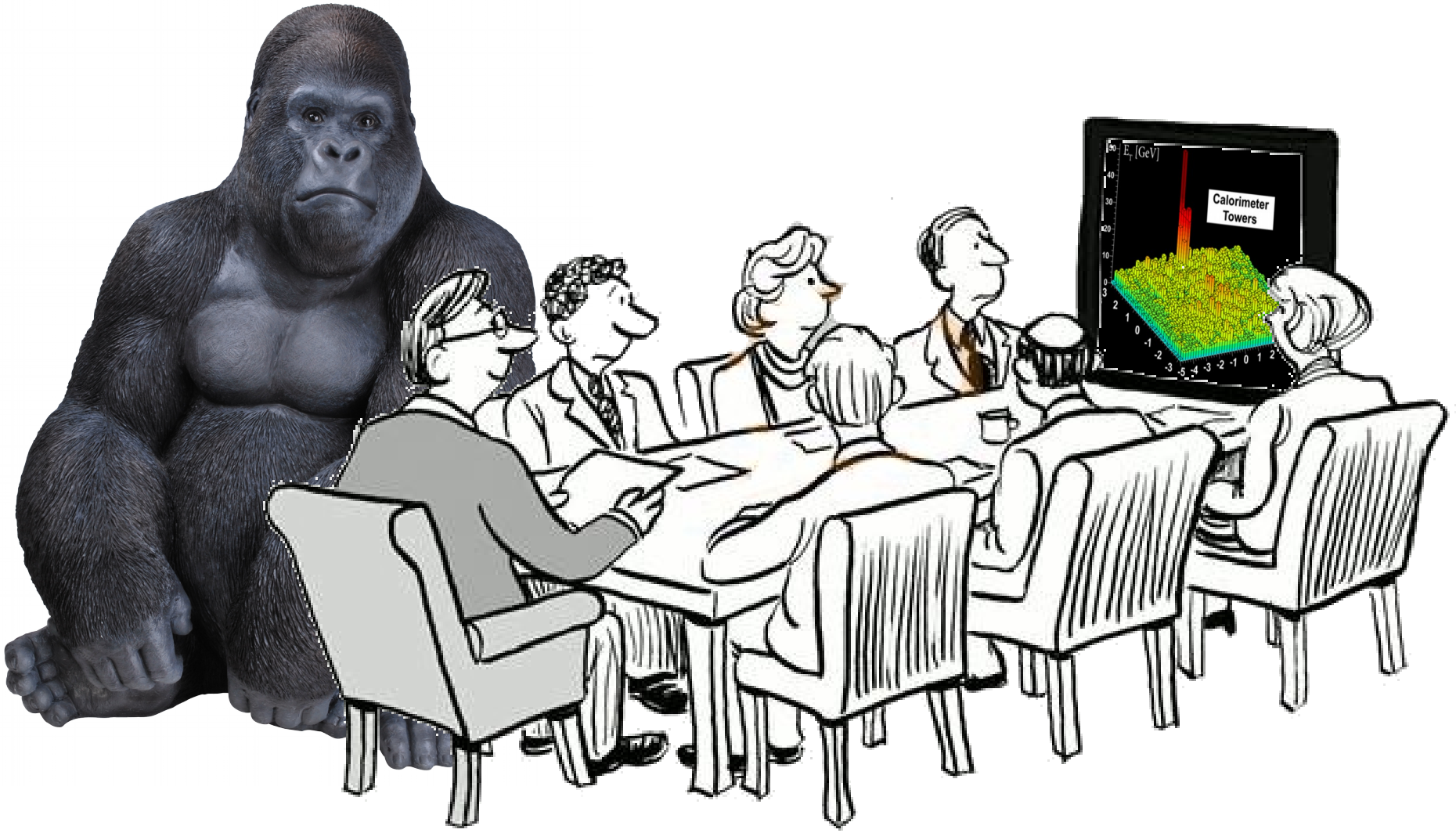
Separating signal from background

Christine Nattrass

University of Tennessee, Knoxville

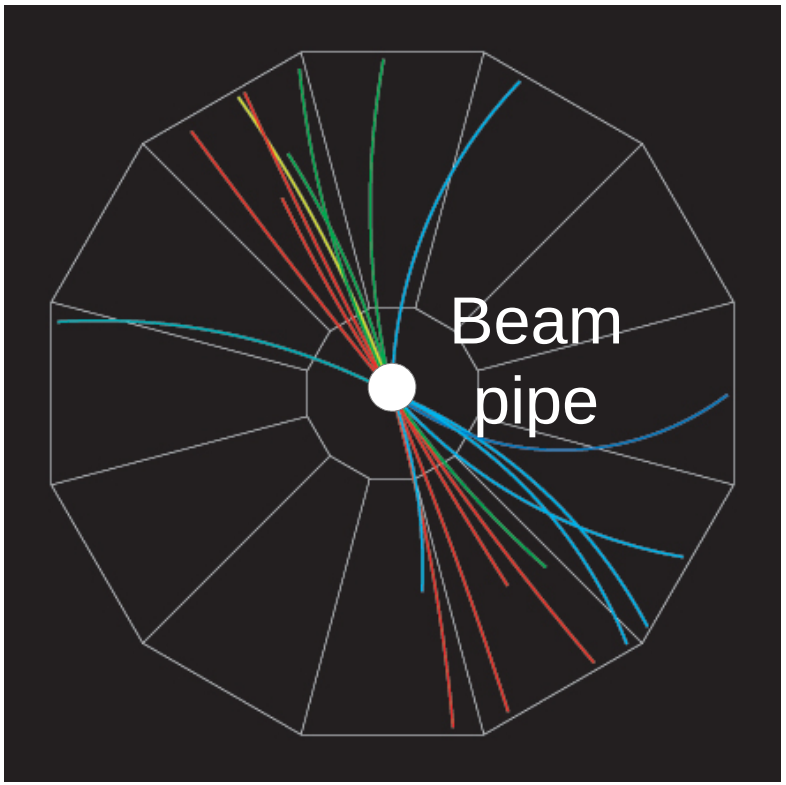
Partly based on Connors, Nattrass, Reed, & Salur arxiv:1705.01974, accepted in RMP

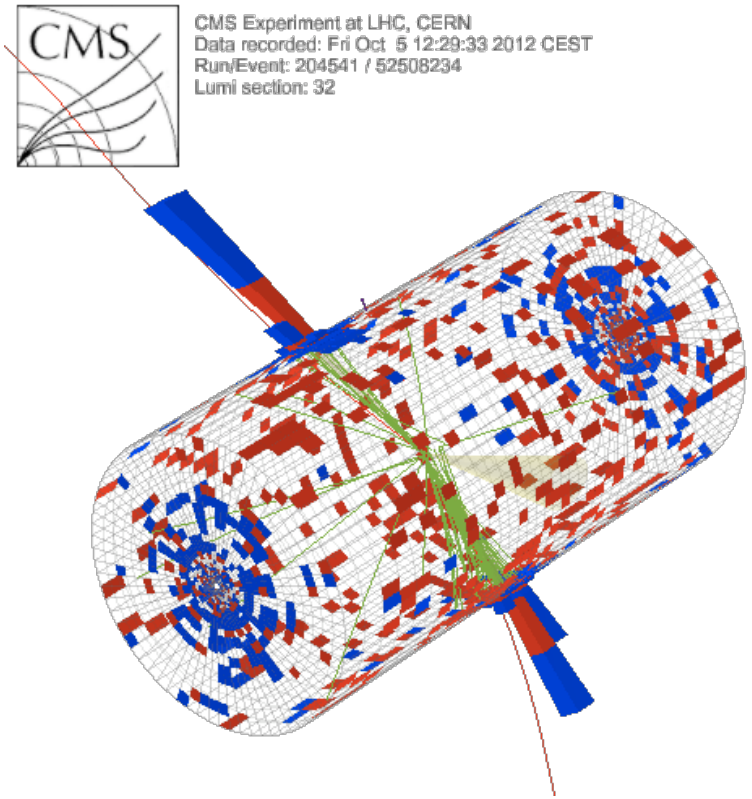

E_T [GeV]
Calorimeter Towers

What is a jet?

What is a jet?

p+p → dijet





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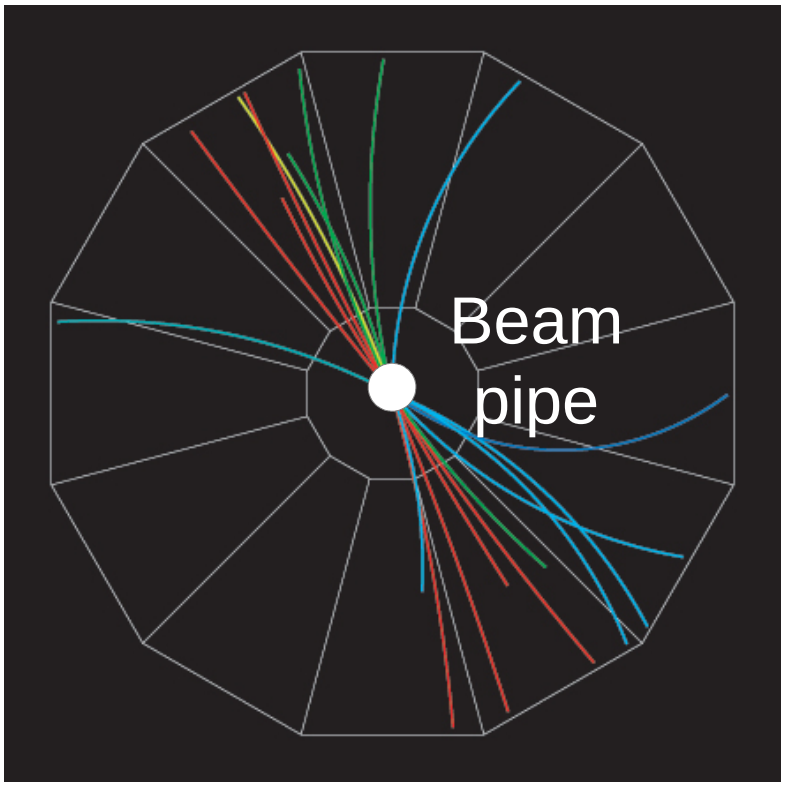
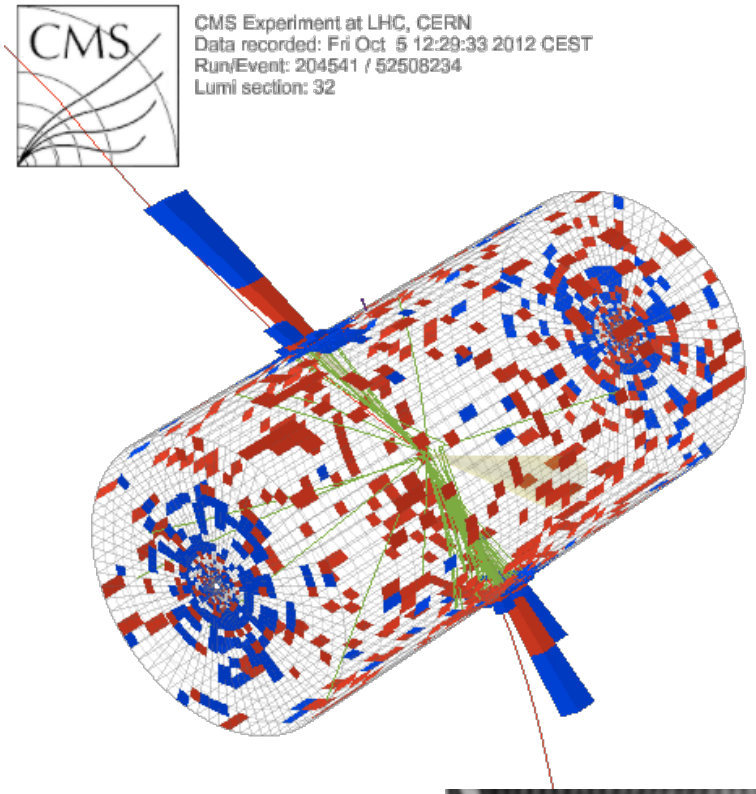
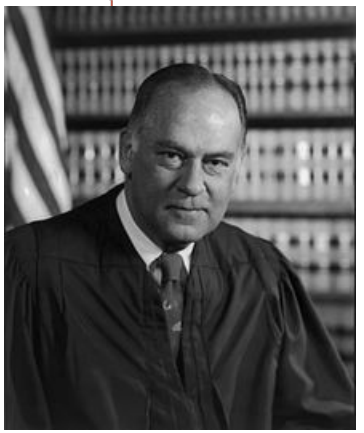




"I know it when I see it"

US Supreme Court Justice Potter Stewart,
Jacobellis v. Ohio



Jet finding in pp collisions

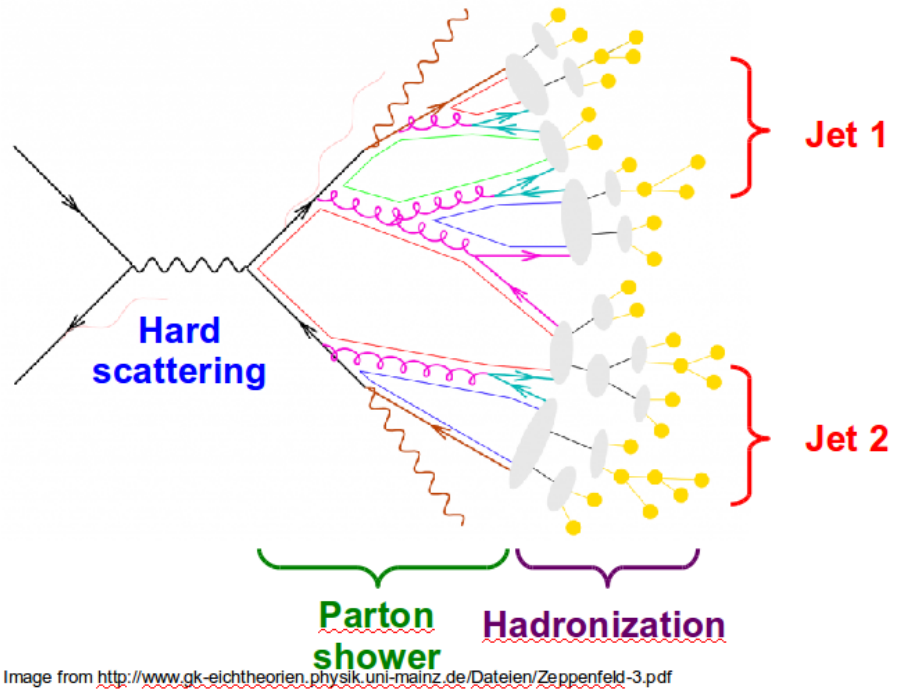


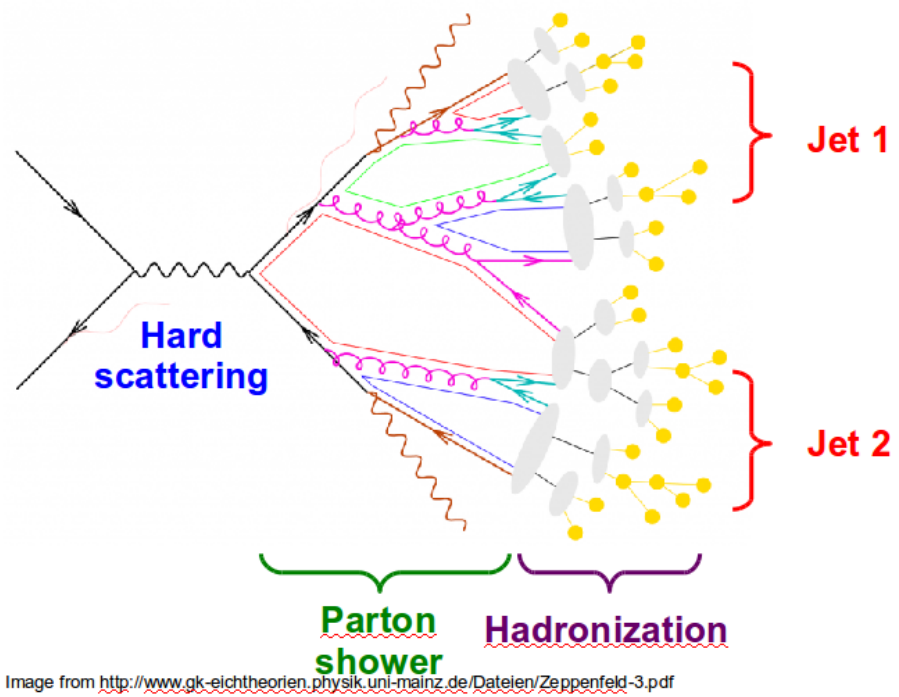
Image from http://www.gk-eichtheorien.physik.uni-mainz.de/Dateien/Zeppenfeld-3.pdf

- Jet finder: groups final state particles into jet candidates
  - Anti-k_T algorithm
    JHEP 0804 (2008) 063 [arXiv:0802.1189]
- Depends on hadronization
- Ideally
  - Infrared safe
  - Colinear safe

Snowmass Accord: Theoretical calculations and experimental measurements should use the same jet finding algorithm. Otherwise they will not be comparable.

A jet is what a jet finder finds.

Jet finding in AA collisions



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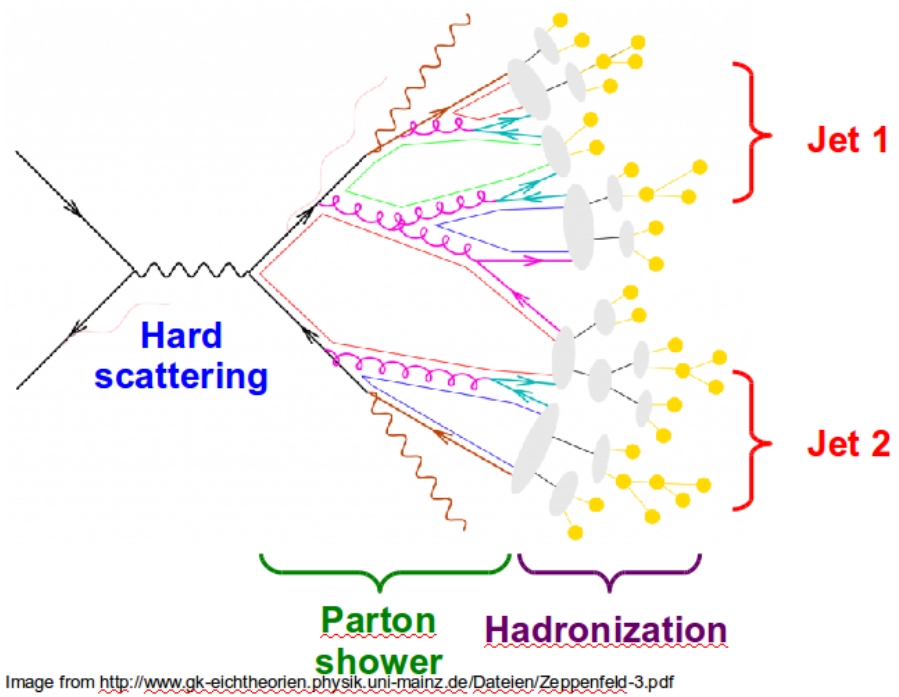
- Combinatorial jet candidates
- Energy smearing from background
- Large, fluctuating, correlated background
- Sensitive to methods to suppress combinatorial jets and correct energy
- Focus on narrow/high energy jets

Jet finding in AA collisions



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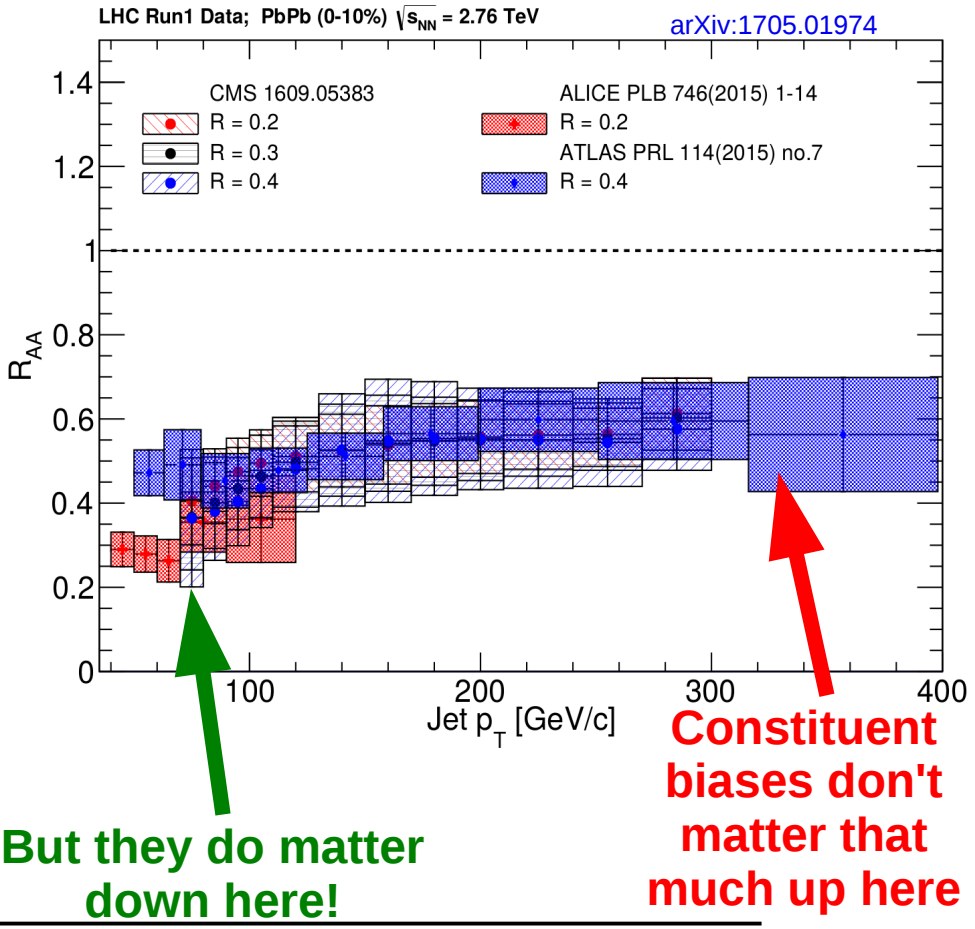
We need an accord on how to treat background

Background is a solved problem.
– Unnamed

ATLAS

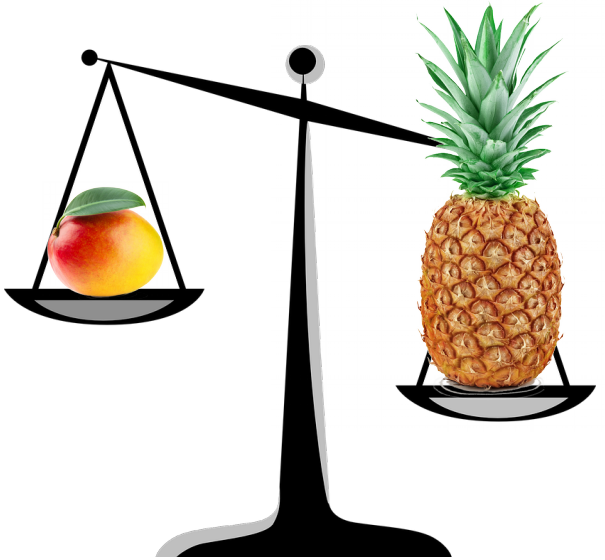
Background subtraction method:

- Iterative procedure
  - **Calorimeter jets:** Reconstruct jets with R=0.2. v_2 modulated <Bkgd> estimated by energy in calorimeters excluding jets with at least one tower with $E_{tower} > \langle E_{tower} \rangle$
    Track jets: Use tracks with p_T>4 GeV/c
  - Calorimeter jets from above with E>25 GeV and track jets with p_T>10 GeV/c used to estimate background again.
- Calorimeter tracks matching one track with p_T>7 GeV/c or containing a high energy cluster E >7 GeV are used for analysis down to E_{jet} = 20 GeV



Phys. Lett. B 719 (2013) 220-241

ATLAS



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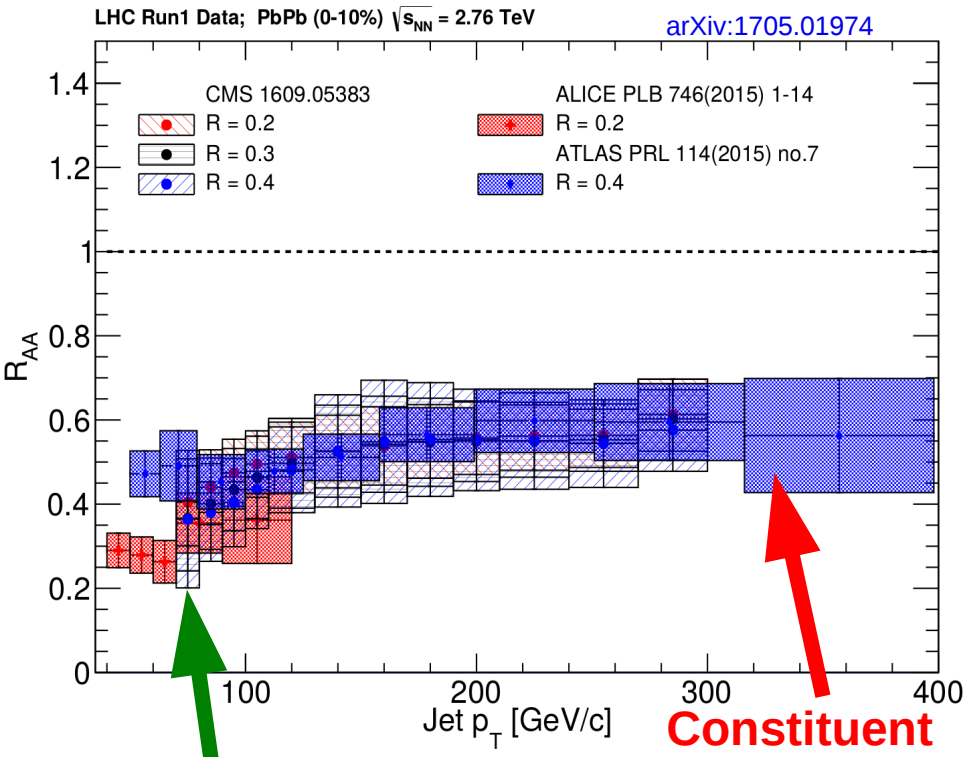

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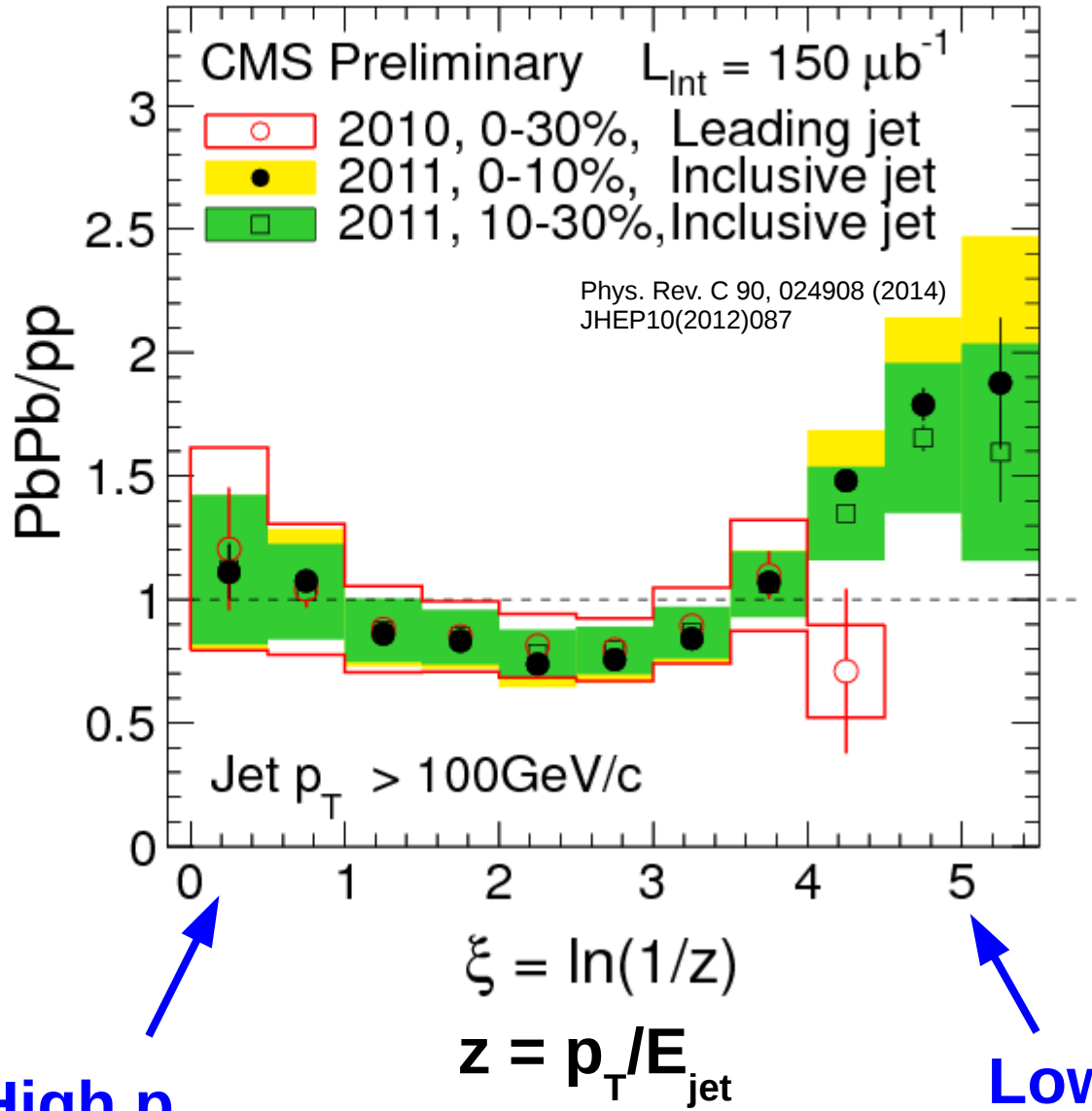
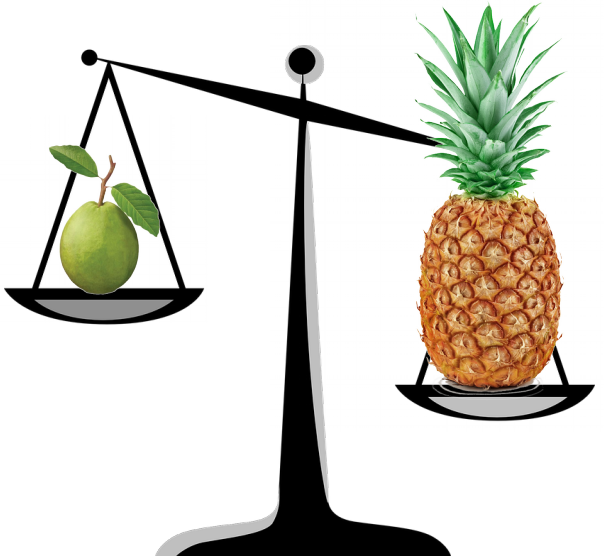
Different jets are different.

– Rosi Reed

What you see depends on where you look





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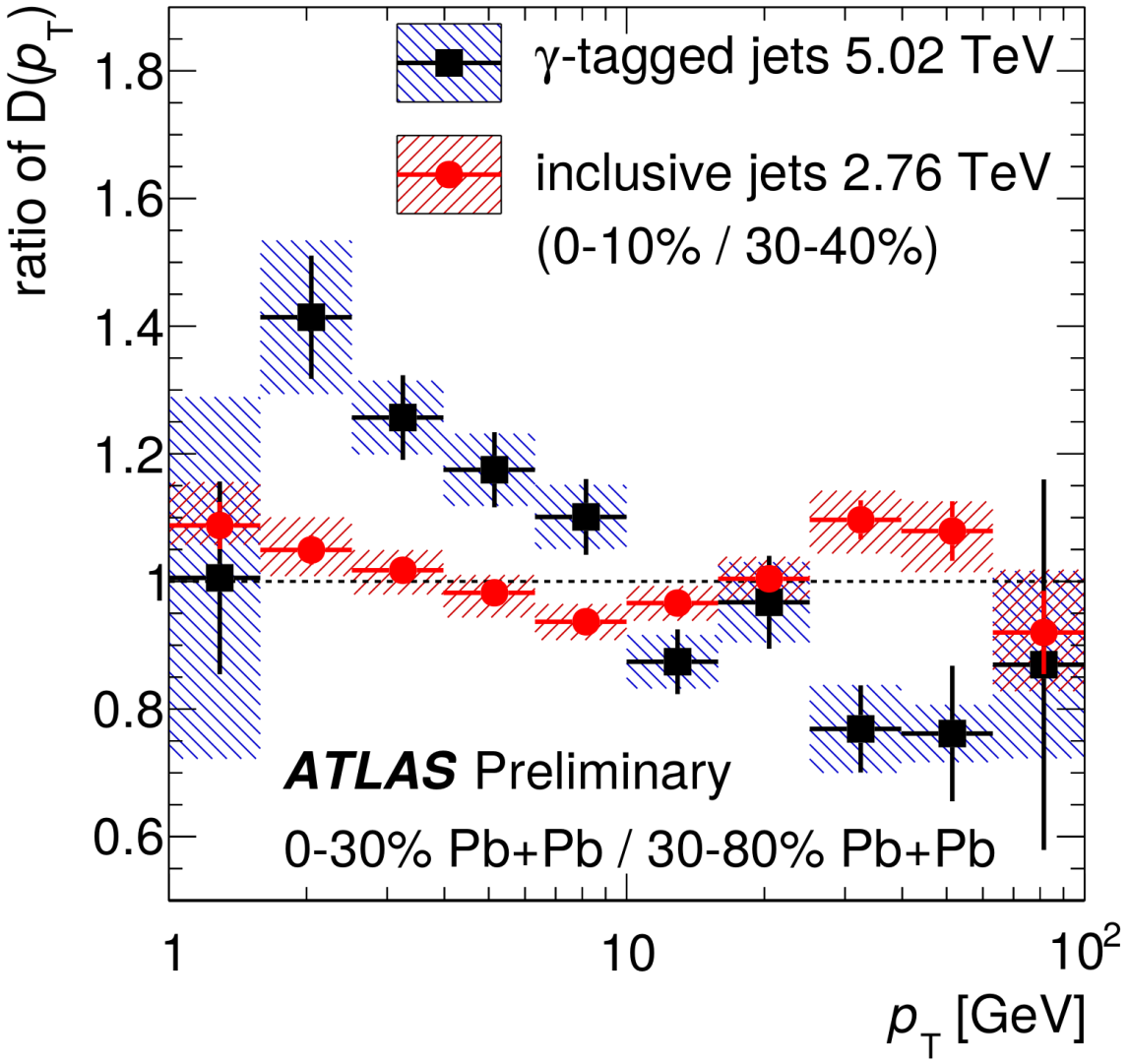

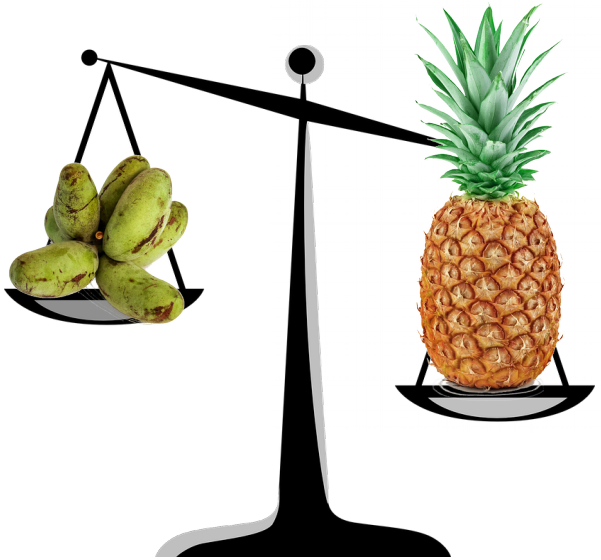

What should we measure?

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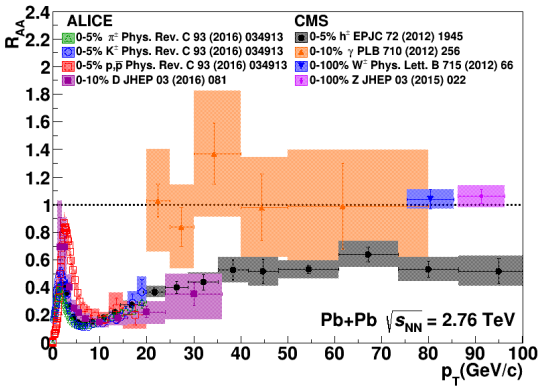

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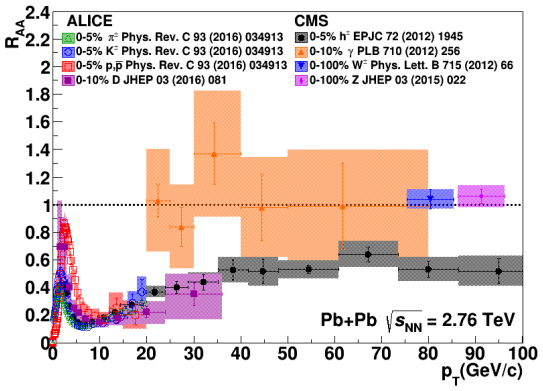

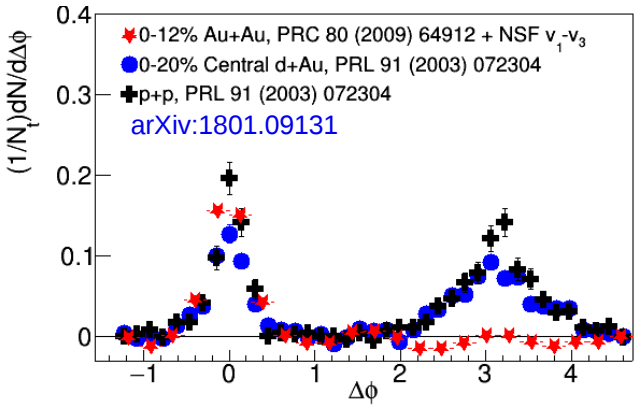

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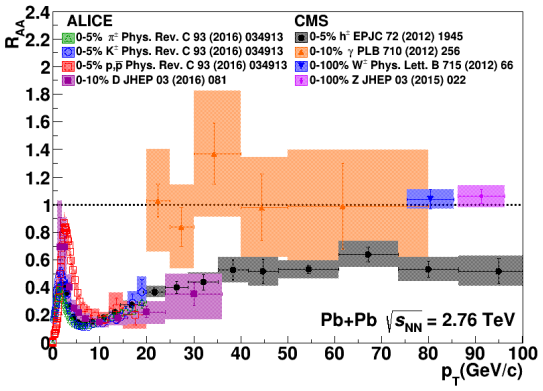

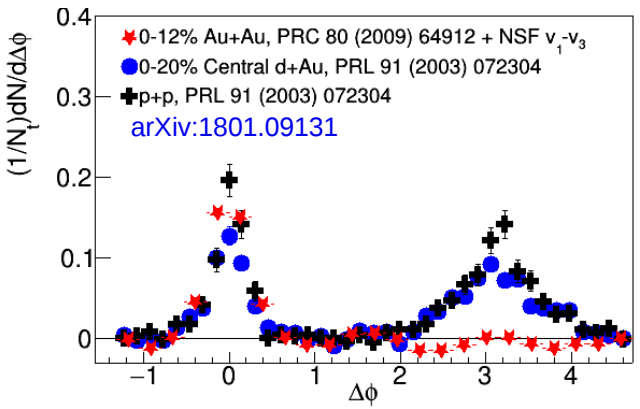

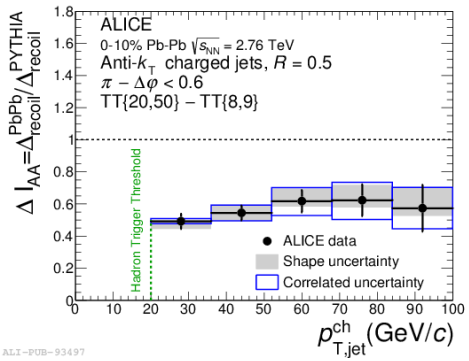

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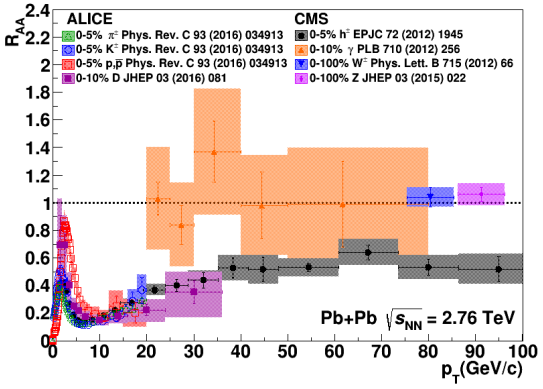

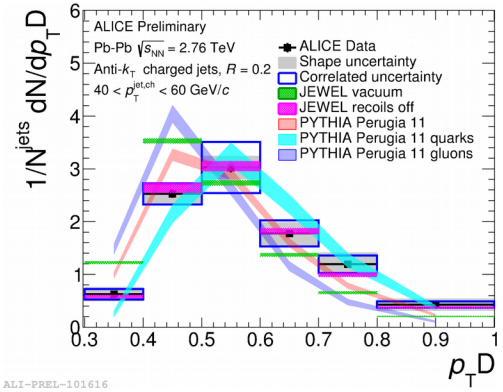

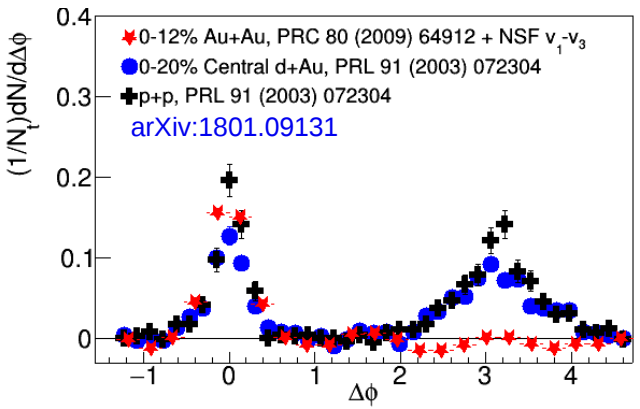

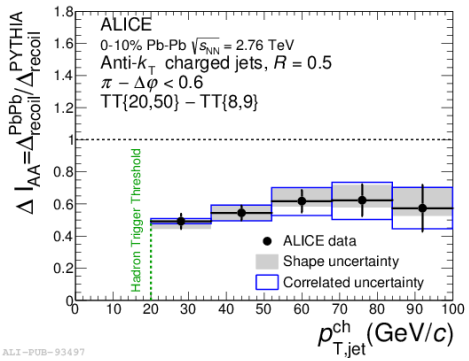

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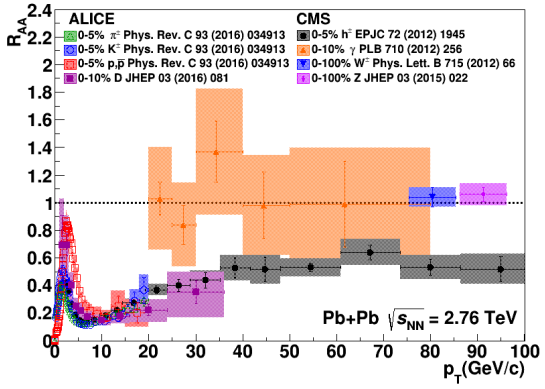
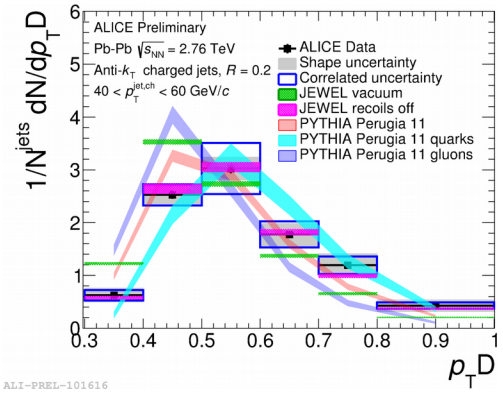
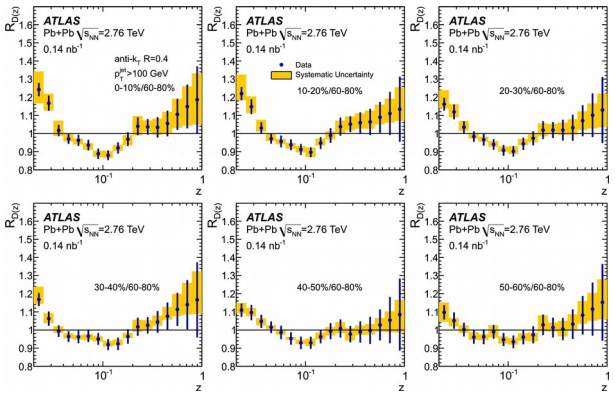
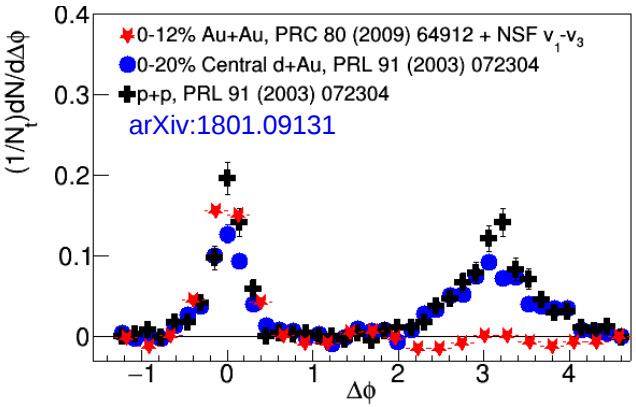
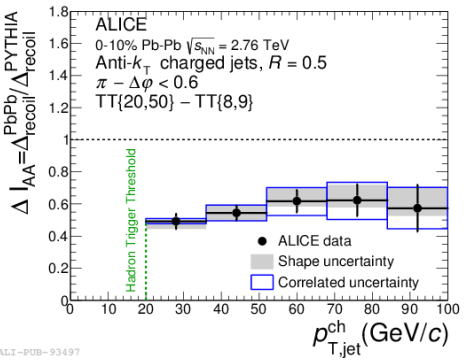










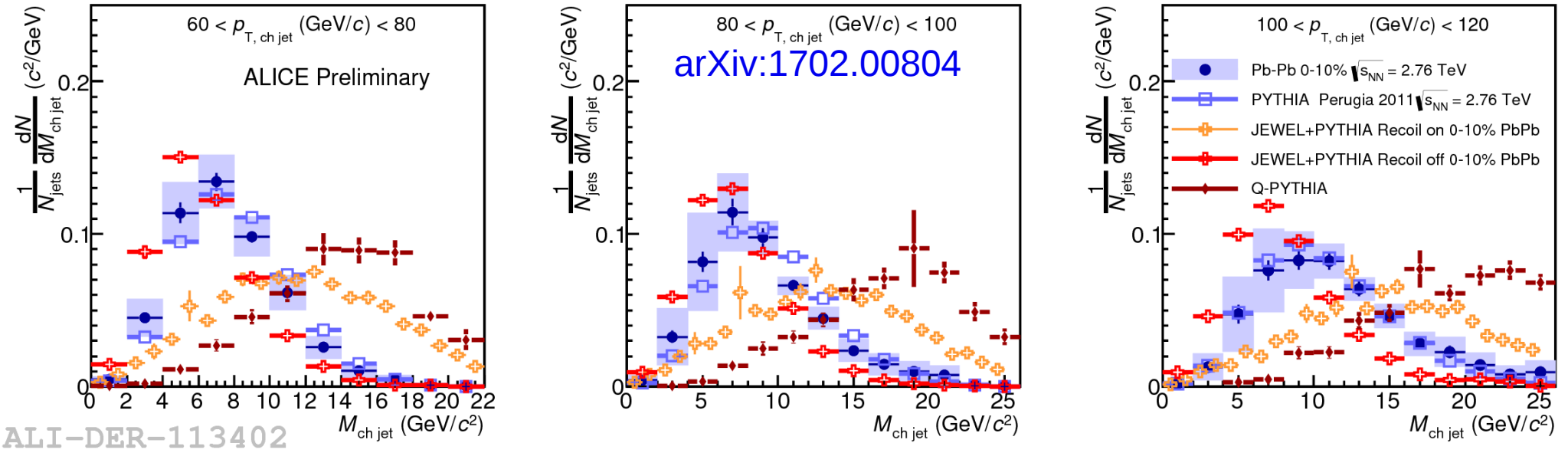
Bias & background

- **Experimental background subtraction methods:** **complex, make assumptions, apply biases**
- **Survivor bias:** **Modified jets probably look more like the medium**
- **Quark/Gluon bias:**
  - **Quark jets are narrower, have fewer tracks, fragment harder [Z Phys C 68, 179-201 (1995), Z Phys C 70, 179-196 (1996),]**
  - **Gluon jets reconstructed with k_T algorithm have more particles than jets reconstructed with anti-k_T algorithm [Phys. Rev. D 45, 1448 (1992)]**
  - **Gluon jets fragment into more baryons [EPJC 8, 241-254, 1998]**
- **Fragmentation bias:** **Experimental measurements explicitly select jets with hard fragments**

The invisible gorilla

http://www.theinvisiblegorilla.com/

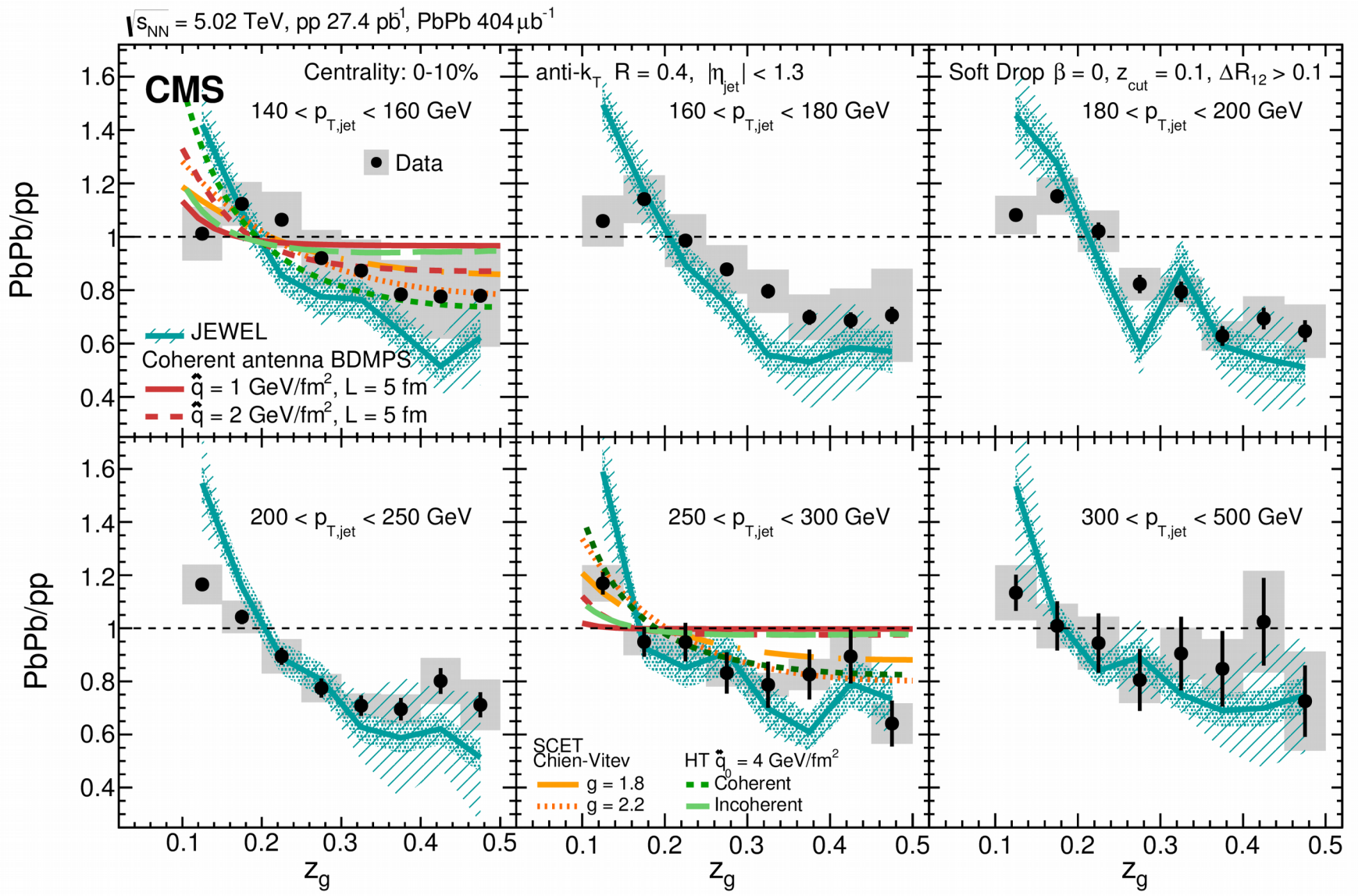
Jet mass



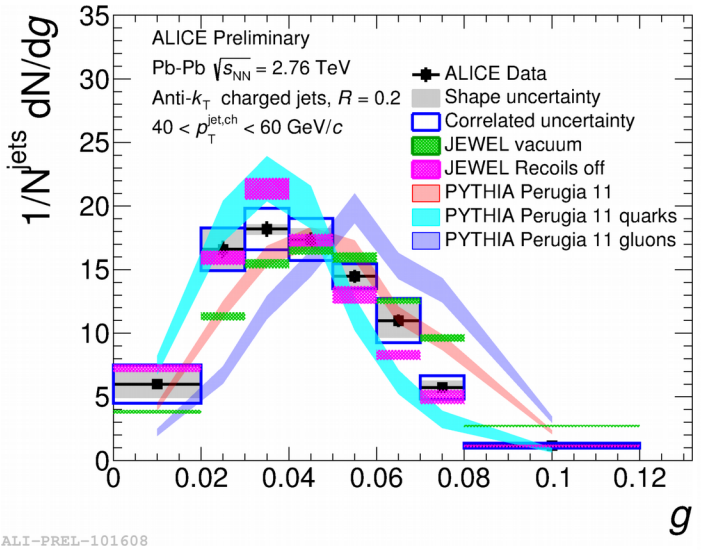
$$M = \sqrt{p^2 - p_T^2 - p_z^2} \qquad p = \sum_{i=1}^{n} p_{T_i} \cosh \eta_i \qquad p_z = \sum_{i=1}^{n} p_{T_i} \sinh \eta_i$$

- Quenching models (JEWEL, Q-PYTHIA) show a larger mass than pp-like PYTHIA jets
- Pb-Pb measurement can discriminate among these predictions

Splitting function

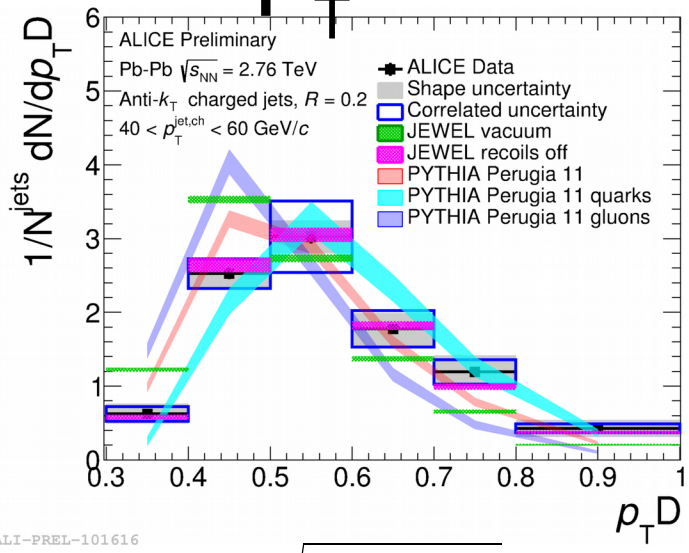


Girth g



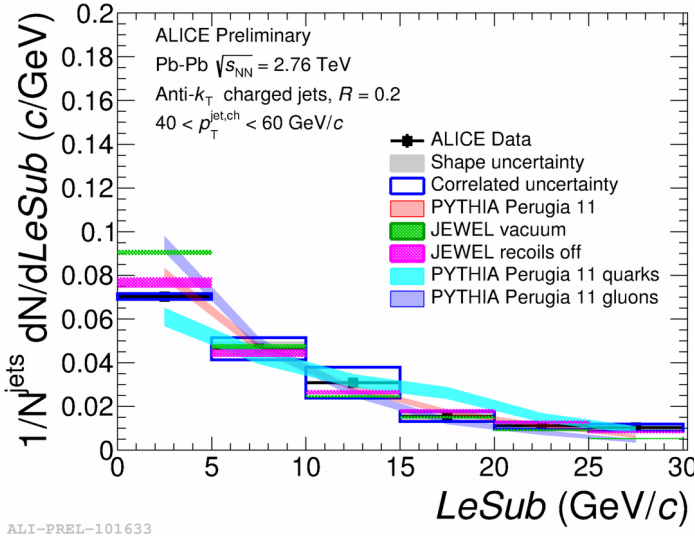
$$g = \sum_{i \in jet} \frac{p_T^i}{p_T^{jet}} r_i$$

Dispersion $p_T D$



$$p_T D = \frac{\sqrt{\sum_{i \in jet} \left(p_T^i\right)^2}}{\sum_{i \in jet} p_T^i}$$

LeSub



$$LeSub = p_T^{leading} - p_T^{subleading}$$

Jets are slightly more collimated than in pp

Agrees with PYTHIA

Jet measurement madlibs!

[Adjective] [noun] [observable] in [collision system]

Groomed	Top quark	Correlations	Proton-lead
Unfolded	B-jet	Di-jet asymmetries	Ultra-central collisions
Event-engineered	Z-boson	v_1, v_2, v_3, v_4...	
	D meson		

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Jet measurement madlibs!

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Groomed Unfolded Event-engineered	Top quark B-jet Z-boson D meson	Correlations Di-jet asymmetries v_1, v_2, v_3, v_4...	Proton-lead Ultra-central collisions

Groomed top quark di-jet asymmetries in ultracentral collisions

Unfolded Z-boson correlations in proton-lead

Groomed top jet v_4 in ultra-central collisions

Event-engineered groomed b-jet top quark di-jet asymmetries in ultra-central collisions

What should we measure?

Jupiter and the Monkey

Jupiter promised a royal reward to the one whose offspring should be deemed the handsomest.

The monkey came with the rest, and presented a flat-nosed, hairless, ill-featured young monkey.

A general laugh saluted her on the presentation of her son.

She resolutely said; "He is at least in the eyes of me, his mother, the dearest, handsomest, and most beautiful of all."

http://aesopsfables.org/F9_Jupiter-and-the-Monkey.html
Abbreviated

I do not care about jets.

Paraphrased from Sevil Salur

I want to learn about the QGP.

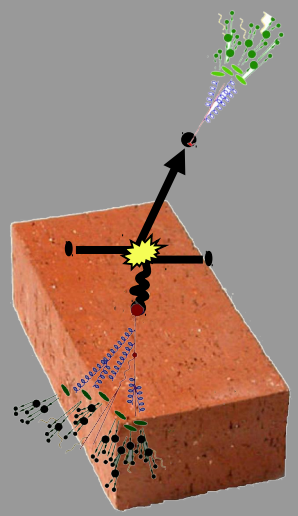
Paraphrased from Sevil Salur

What have we learned?

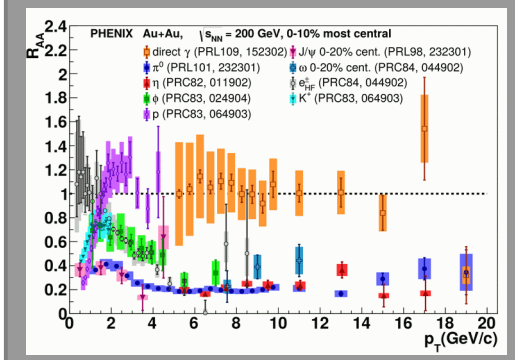
/Funny/2011/9/20/Funny_Animals_Pictures_mhsqs.jpg

JET collaboration

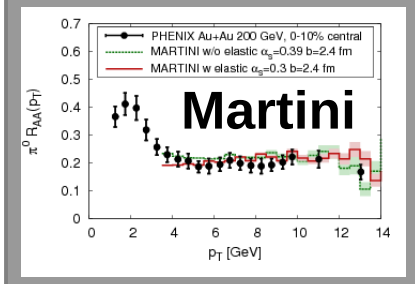
Phys. Rev. C 90, 014909 (2014)

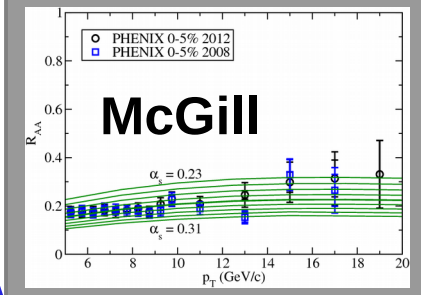


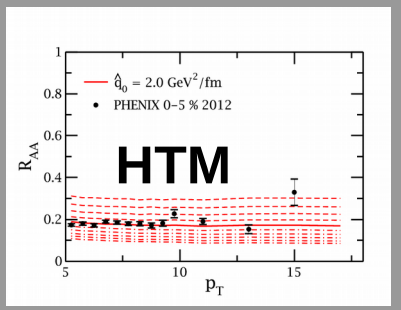
QGP brick + jet

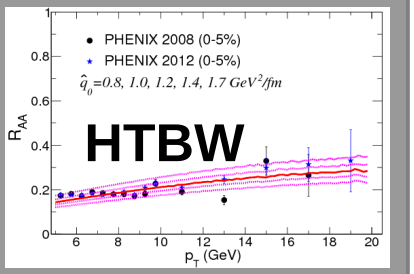


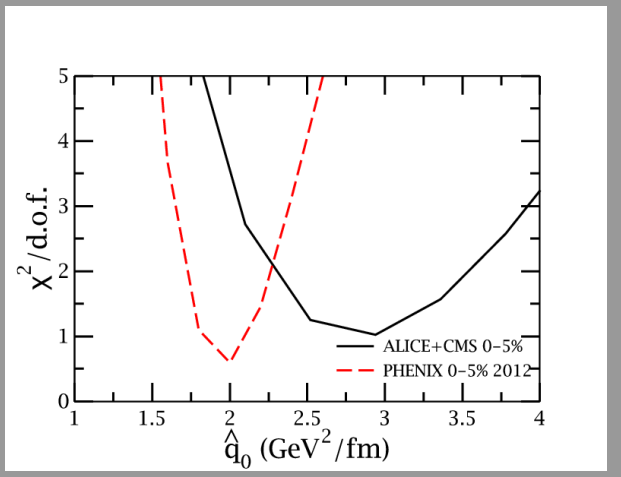
Data



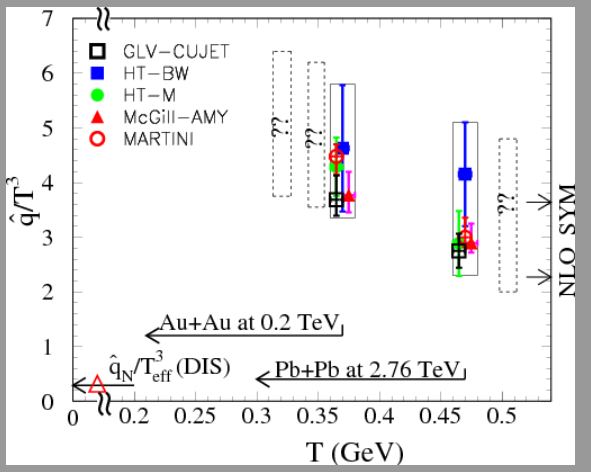








χ^2 minimization



$\hat{q} = 1.2 \pm 0.3 \ \ GeV^2$ 200 GeV Au+Au

$\hat{q} = 1.9 \pm 0.7 \ \ GeV^2$ 2.76 TeV Pb+Pb

It is 2018. What have we learned?

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- Qualitative confirmation of our model for partonic energy loss

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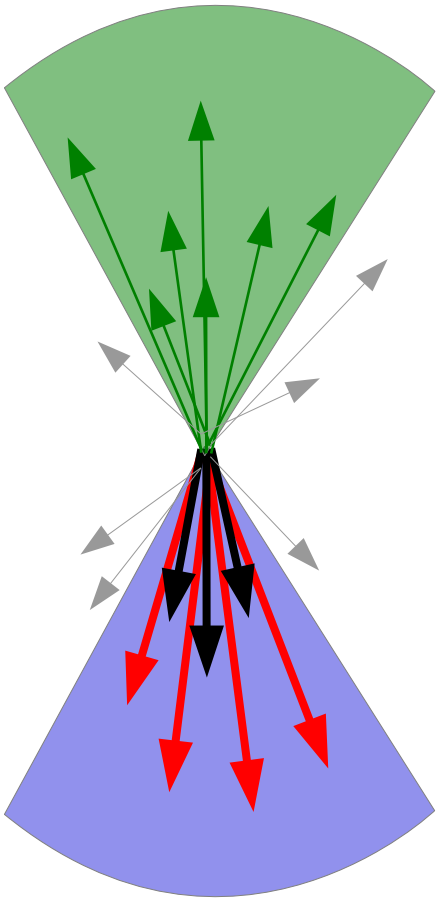
- Theoretical calculations sensitive to things we might not have under control.



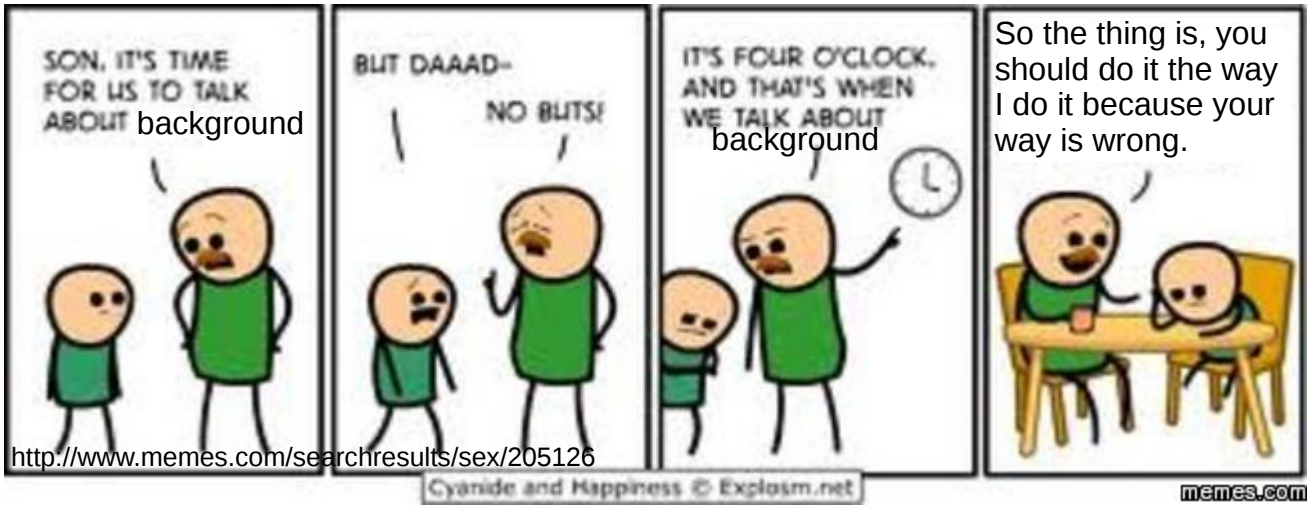
RBRC Workshop on the Definition of Jets in a Large Background

June 25-27 at BNL

Megan Connors, Guilherme Milhano, Christine Nattrass, Rosi Reed, Sevil Salur

Conclusions

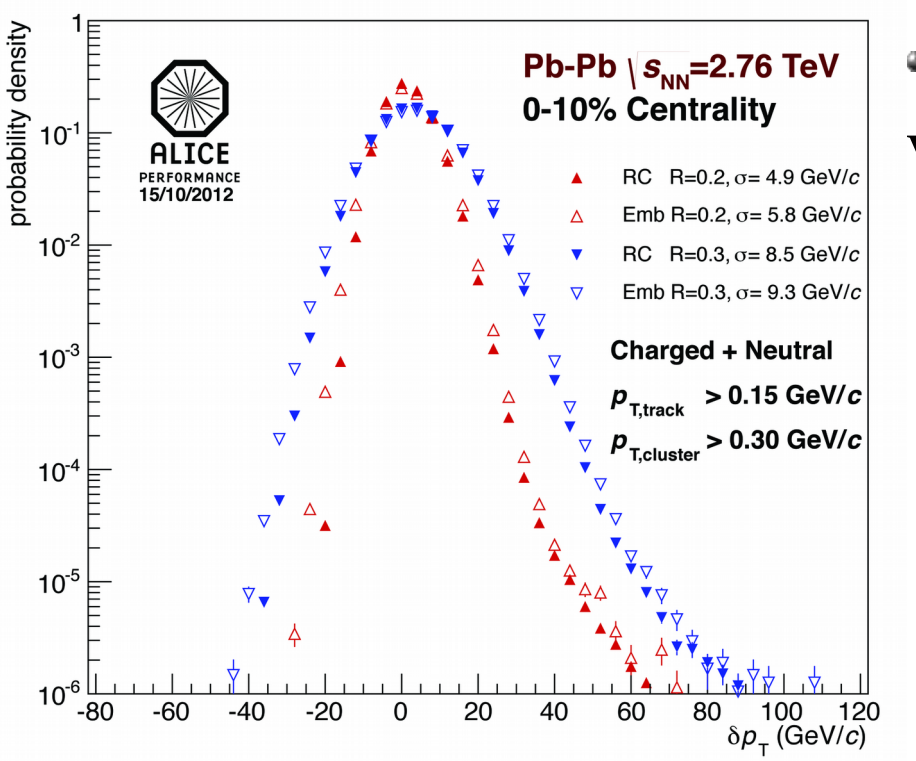
- We need to talk about background
- We should try to measure the same things
- We should report correlations between uncertainties
- We should ask whether we're learning something
- We should think about what we're *not* seeing




Connors, Nattrass, Reed, & Salur
arxiv:1705.01974, , accepted in RMP
Thank you!

Background Fluctuations

Full Jets $\sqrt{s_{NN}}$ = 2.76 TeV in PbPb



- Fluctuations in the background determined via δp_T
  - Random cones (RC)
  - Depends on
    - Constituent cut R
    - Centrality
    - Event plane
    - Detector

$$\delta p_T = p_T^{rec} - \rho \pi R^2$$

δp_T is not corrected for detector effects – Experiment specific

δp_T is used to construct unfolding response matrix