



Jet quenching and energy loss: An experimentalist perspective.

Sevil Salur
Rutgers University

My Charge:

A pedagogical lecture on jet quenching and energy loss

- See Talks during 2018 Summer Workshops for latest beautiful results



<https://www.bnl.gov/pqgm2018/>



<https://www.bnl.gov/jets18/>

Opportunities and Challenges with Jets at LHC and beyond

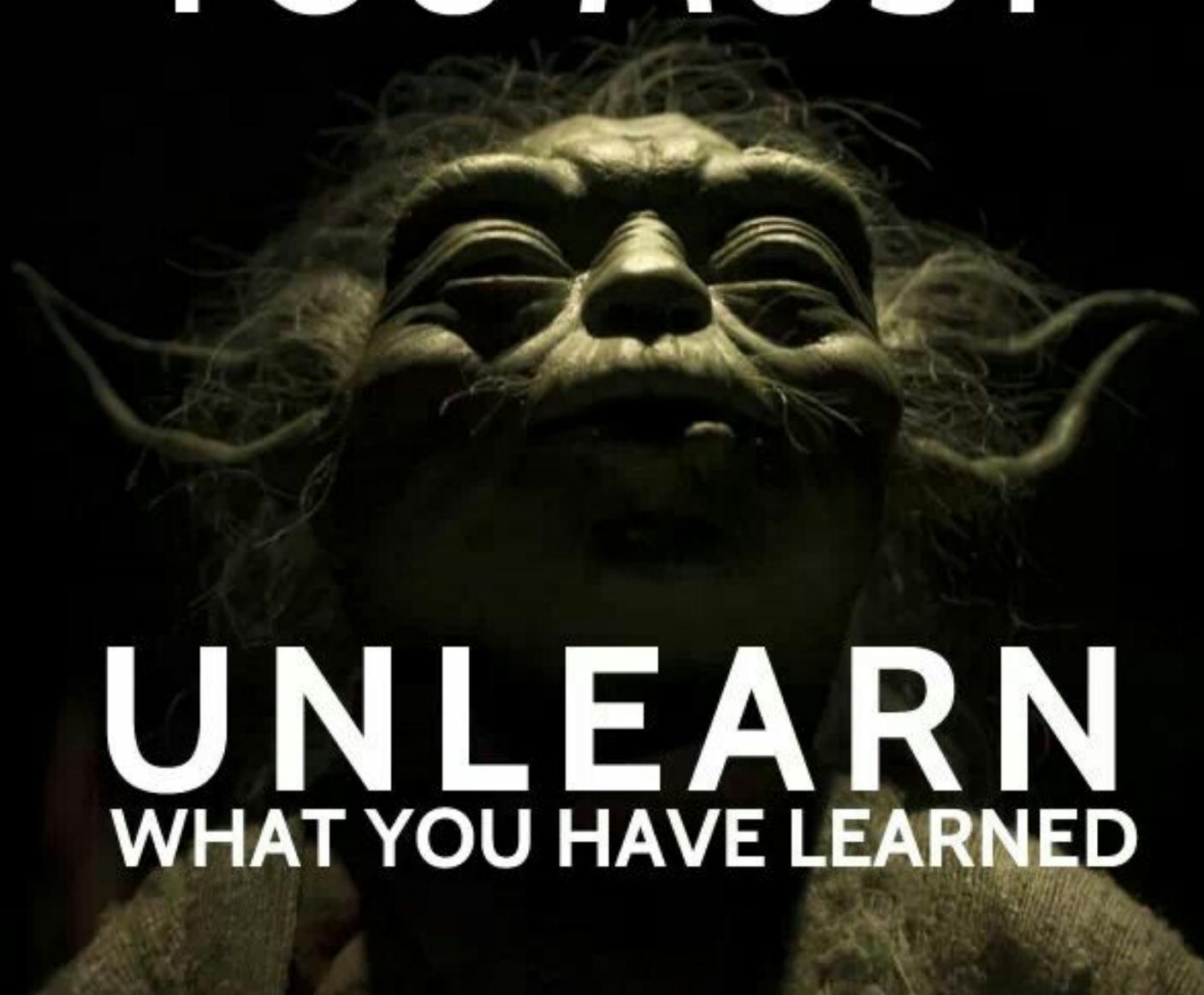
9-12 June 2018
Other Institutes
America/New_York timezone

Search...



<https://indico.cern.ch/event/716363/>

YOU MUST

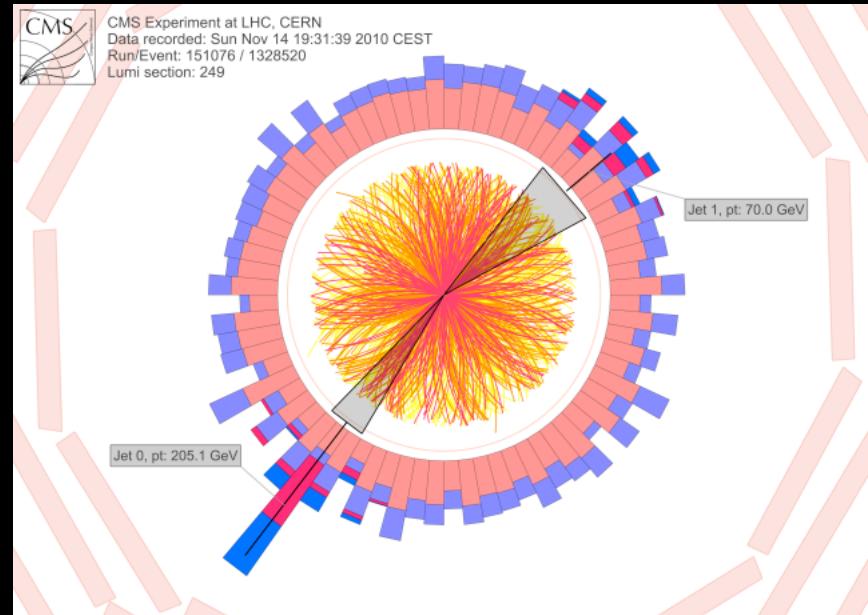


**UNLEARN
WHAT YOU HAVE LEARNED**

My Charge:

A pedagogical lecture on jet quenching and energy loss...

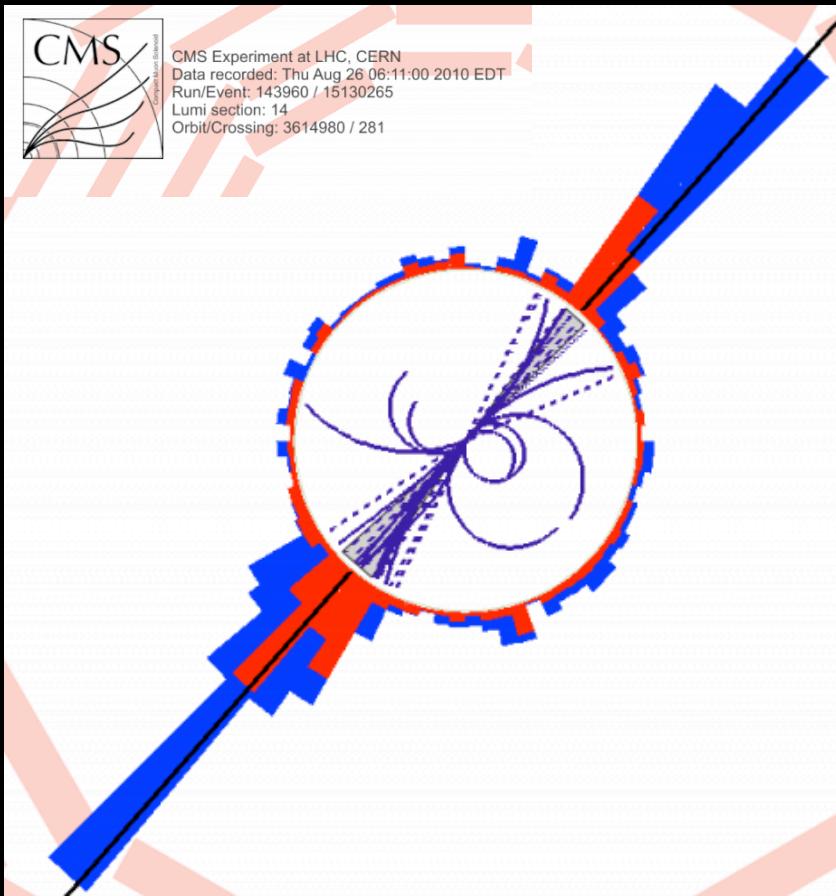
Jets in the medium



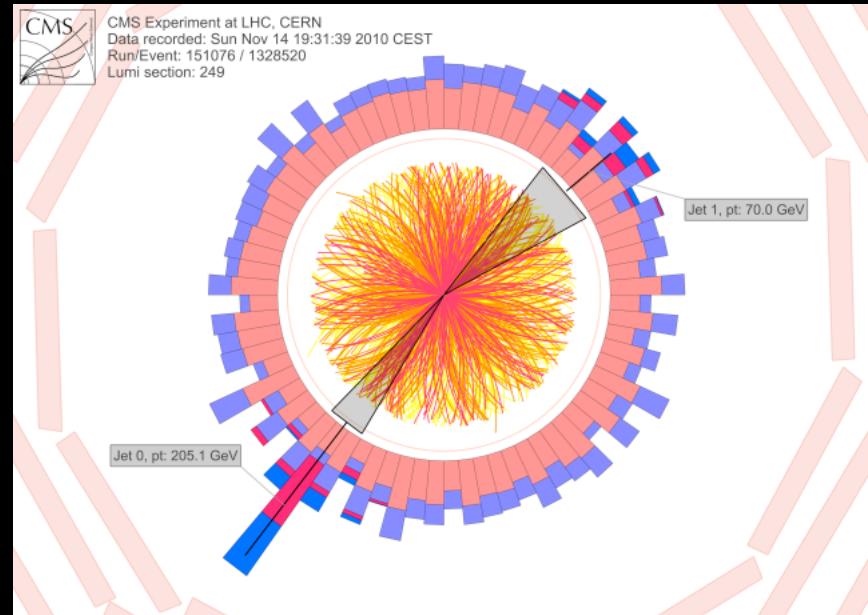
My Charge:

A pedagogical lecture on jet quenching and energy loss...

Jets in the vacuum

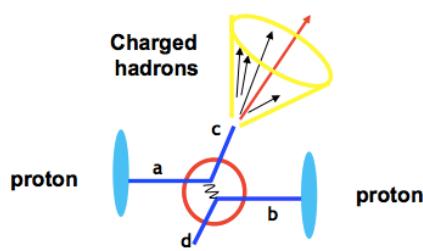


Jets in the medium

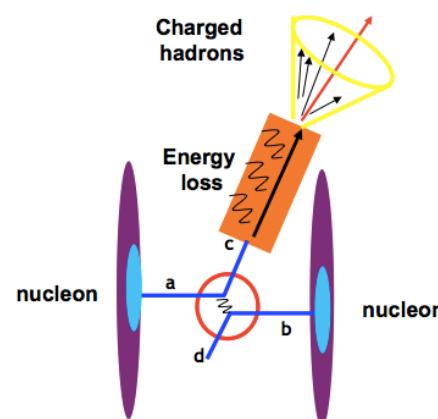


Experimental search for “interesting” phenomena

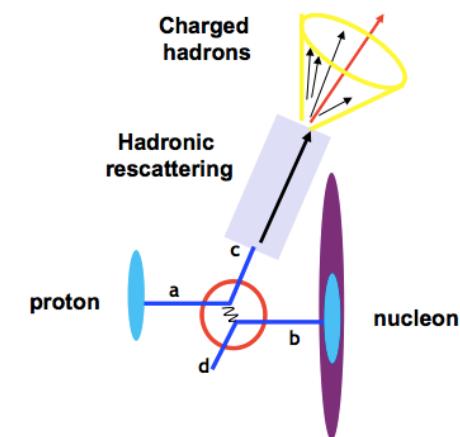
- Look at elementary p+p and p+A collisions
 - Measure an observable (e.g. Hard probes such as jet production)
- Look at Heavy Ion collisions
 - Measure the same observable as we do in p+p and p+A
- Compare them, is there something new?



Parton Distribution Function
Hard-scattering cross-section
Fragmentation function



Nuclear PDF
Hard-scattering cross-section
Energy Loss in Medium
Fragmentation function

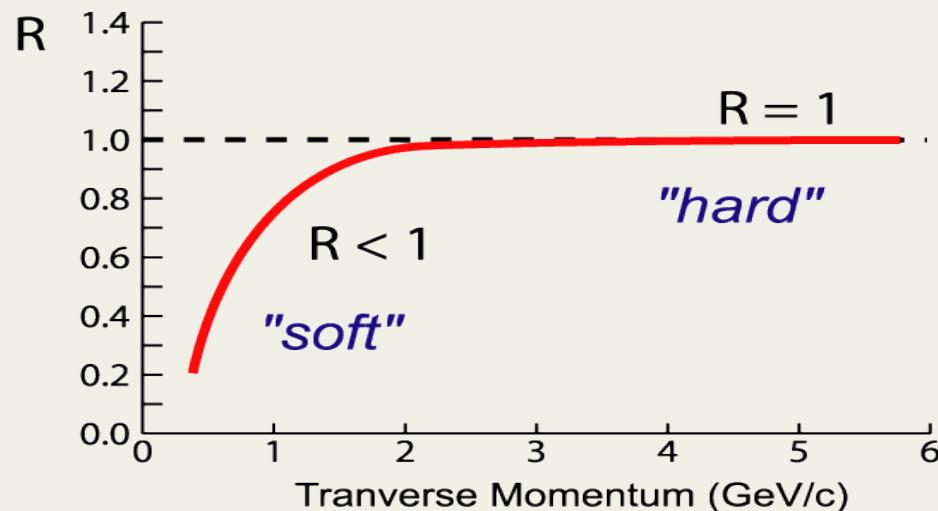


Nuclear PDF
Hard-scattering cross-section
Hadronic rescattering
Fragmentation function

A simple Physics Observable:

Nuclear
Modification
Factor:

$$R_{AA} \equiv \frac{\text{Yield in } A + A \text{ Events}}{N_{Bin}(\text{Yield in } p + p \text{ Events})}$$

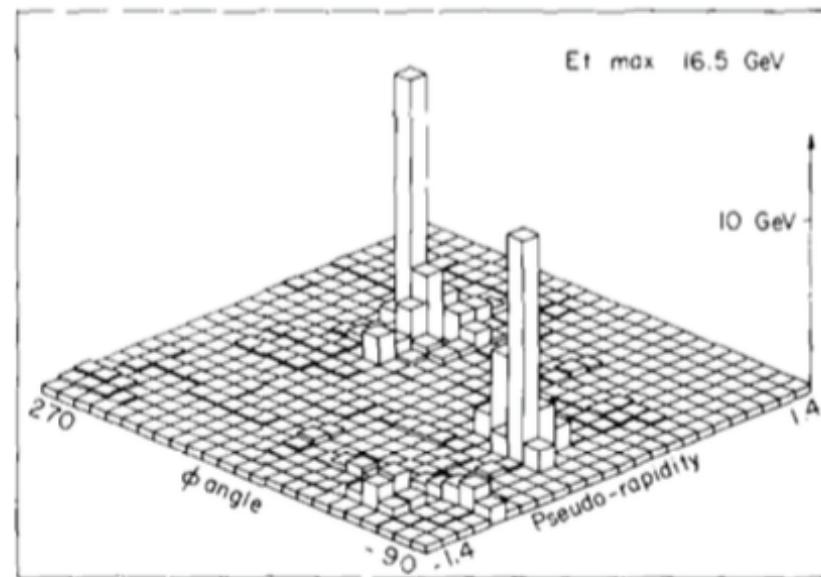
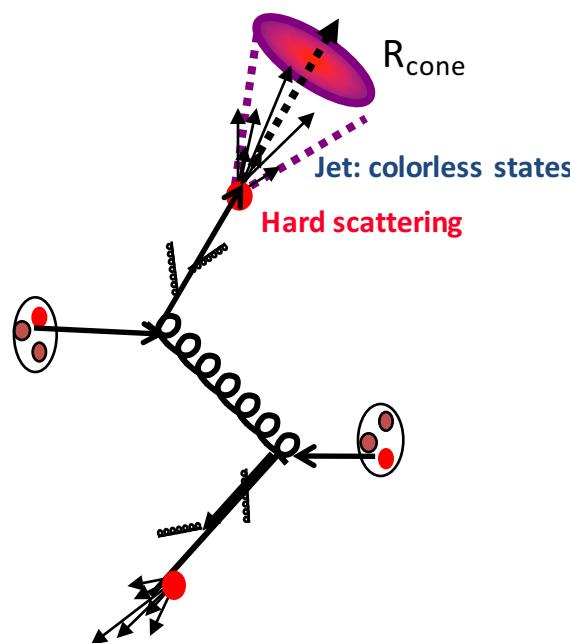


If no “effects”:
 $R < 1$ in regime of soft physics
 $R = 1$ at high- p_T where hard scattering dominates

Jets in the vacuum:

OBSERVATION OF JETS IN HIGH TRANSVERSE ENERGY EVENTS AT THE CERN PROTON ANTIPORON COLLIDER

UA1 Collaboration, CERN, Geneva, Switzerland



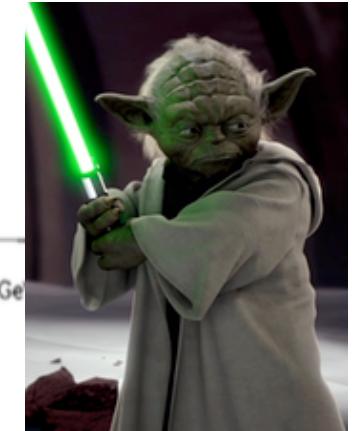
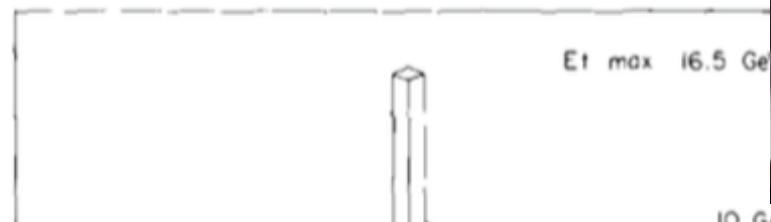
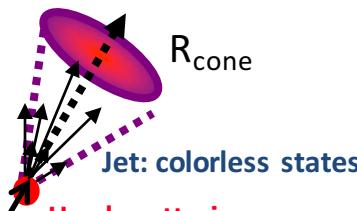
Jets are the experimental signatures of quarks and gluons.
They are expected to reflect kinematics and topology of partons.

24 March 1983

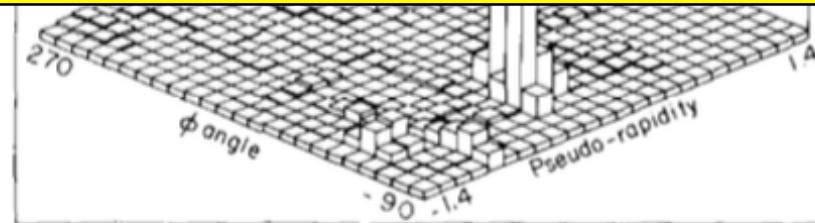
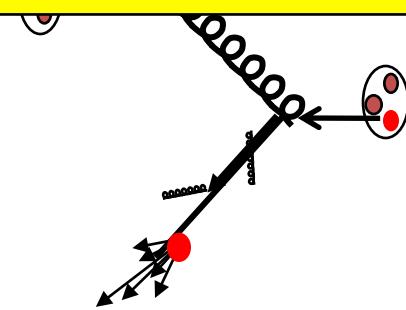
Jets in the vacuum

OBSERVATION OF JETS IN HIGH TRANSVERSE ENERGY EVENTS AT THE CERN PROTON ANTIPORON COLLIDER

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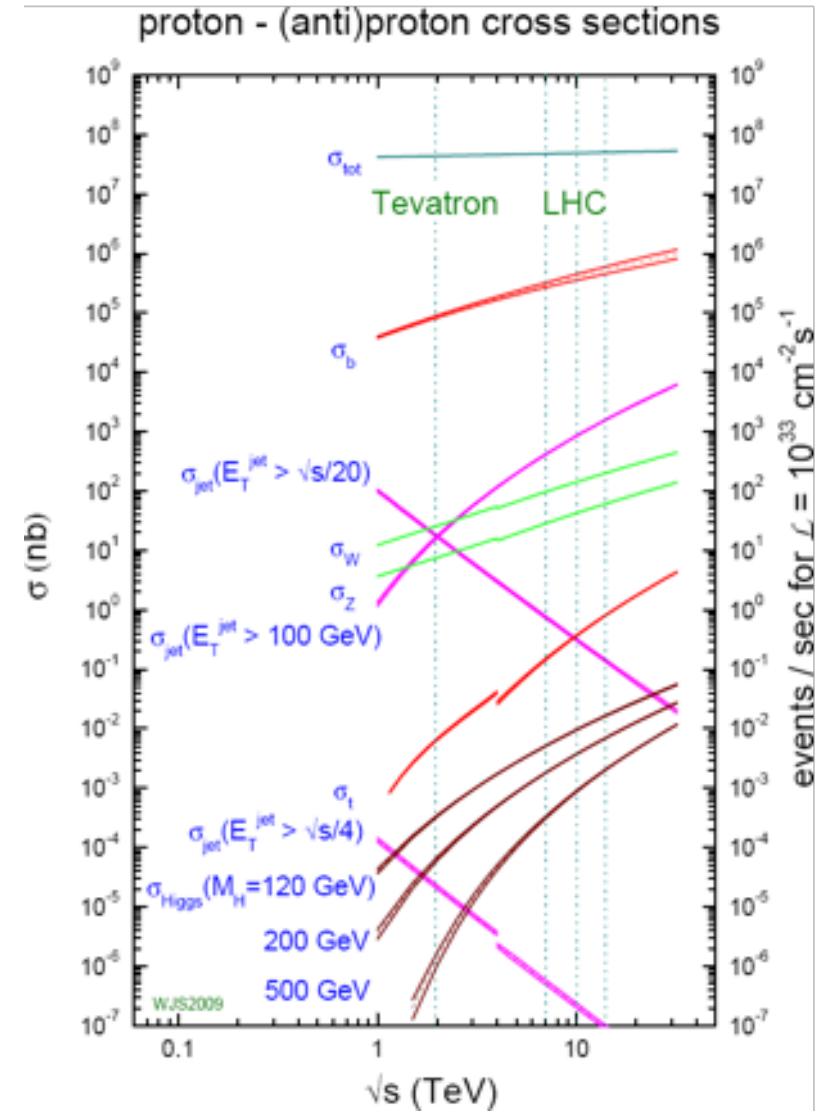
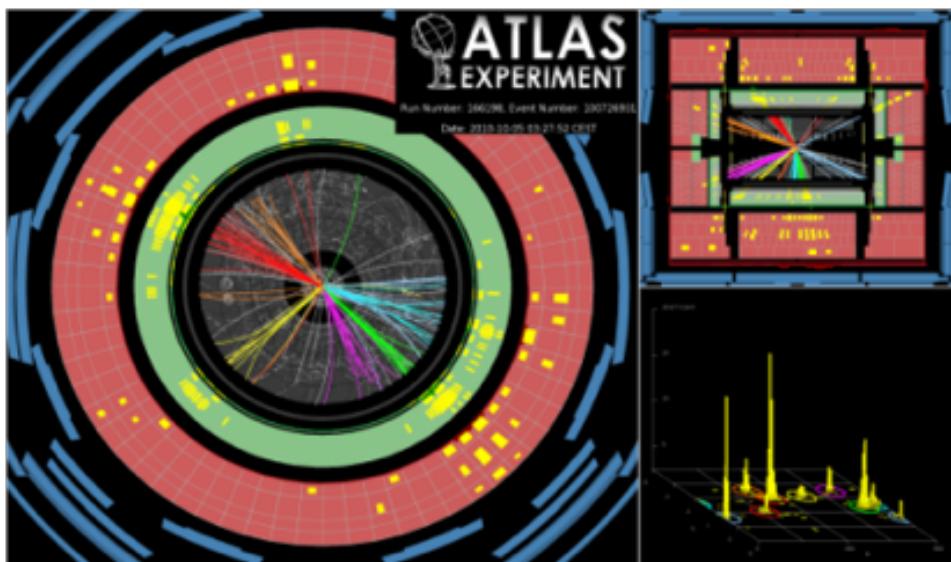
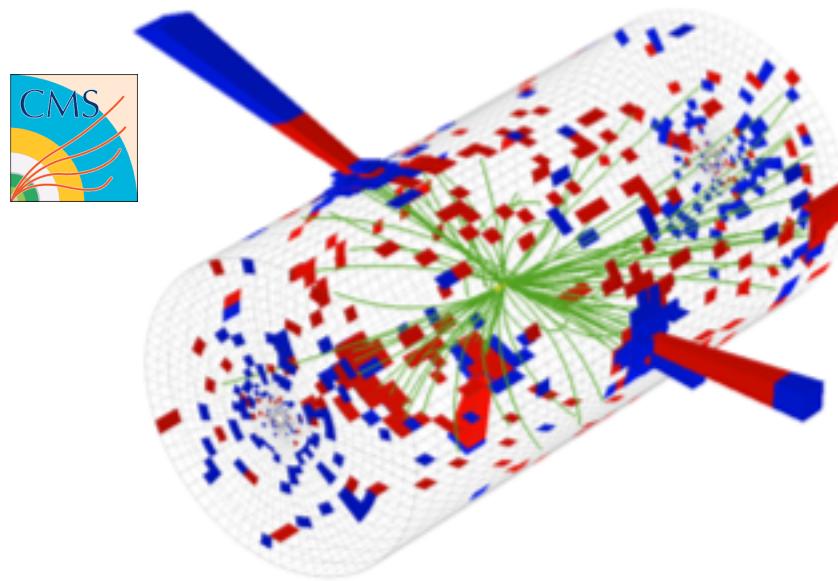


But Jets are Not Partons, Partons are Not Jets!



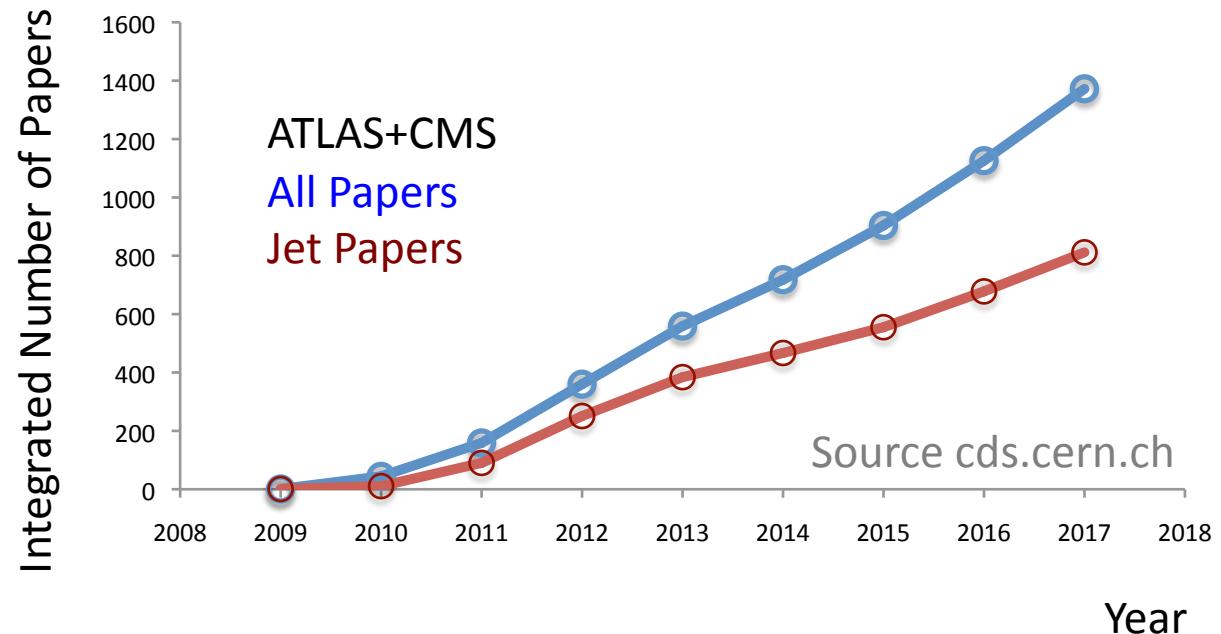
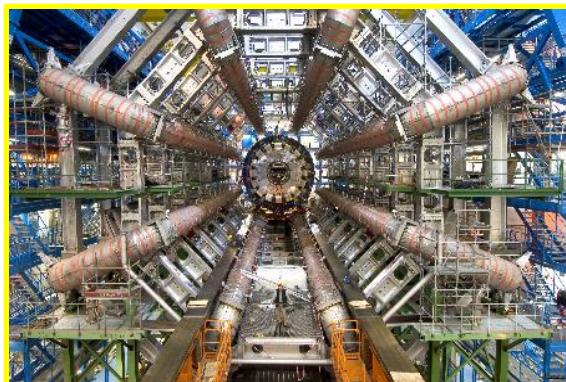
Jets are the experimental signatures of quarks and gluons.
They are expected to reflect kinematics and topology of partons.

LHC data is dominated by jets



Sevil Salur

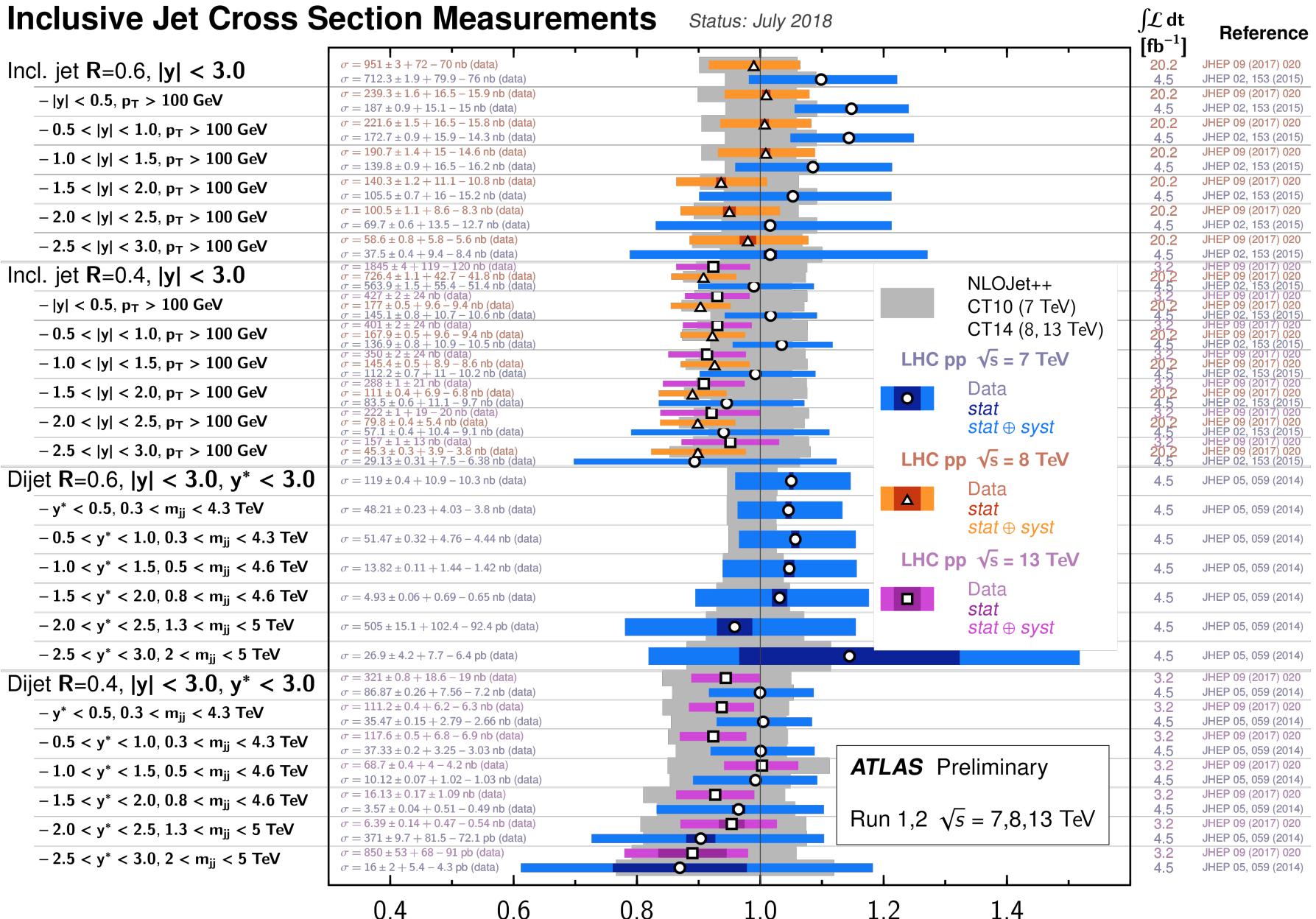
> 50% of ATLAS & CMS papers use jets



Any analysis that require, quark, gluon, i.e., parton or their absence in an event.

Inclusive Jet Cross Section Measurements

Status: July 2018

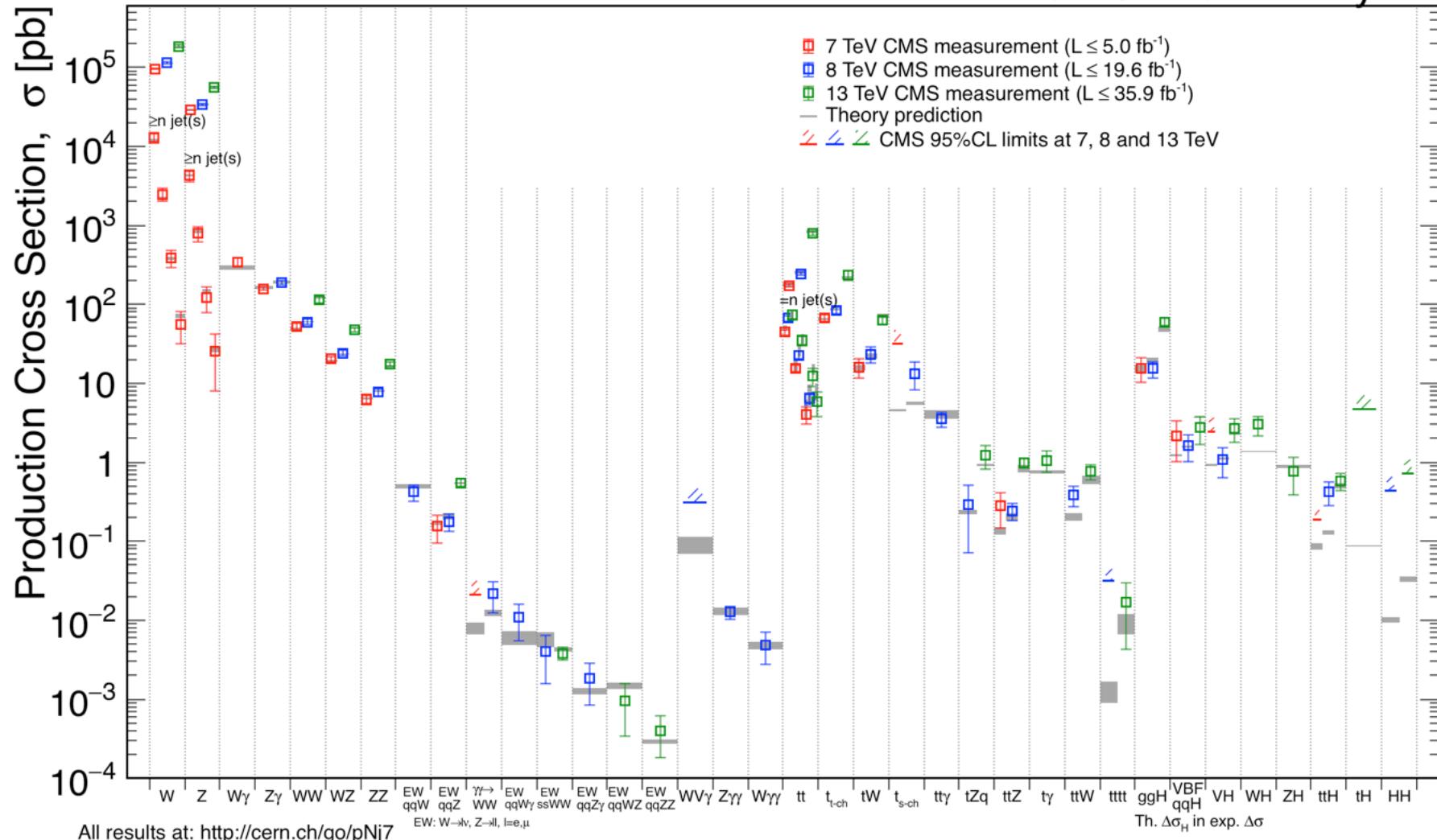


Jet spectra with various R parameters from pp collisions are well understood. Consistent with calculations.

Summary of the cross section measurements of Standard Model processes.

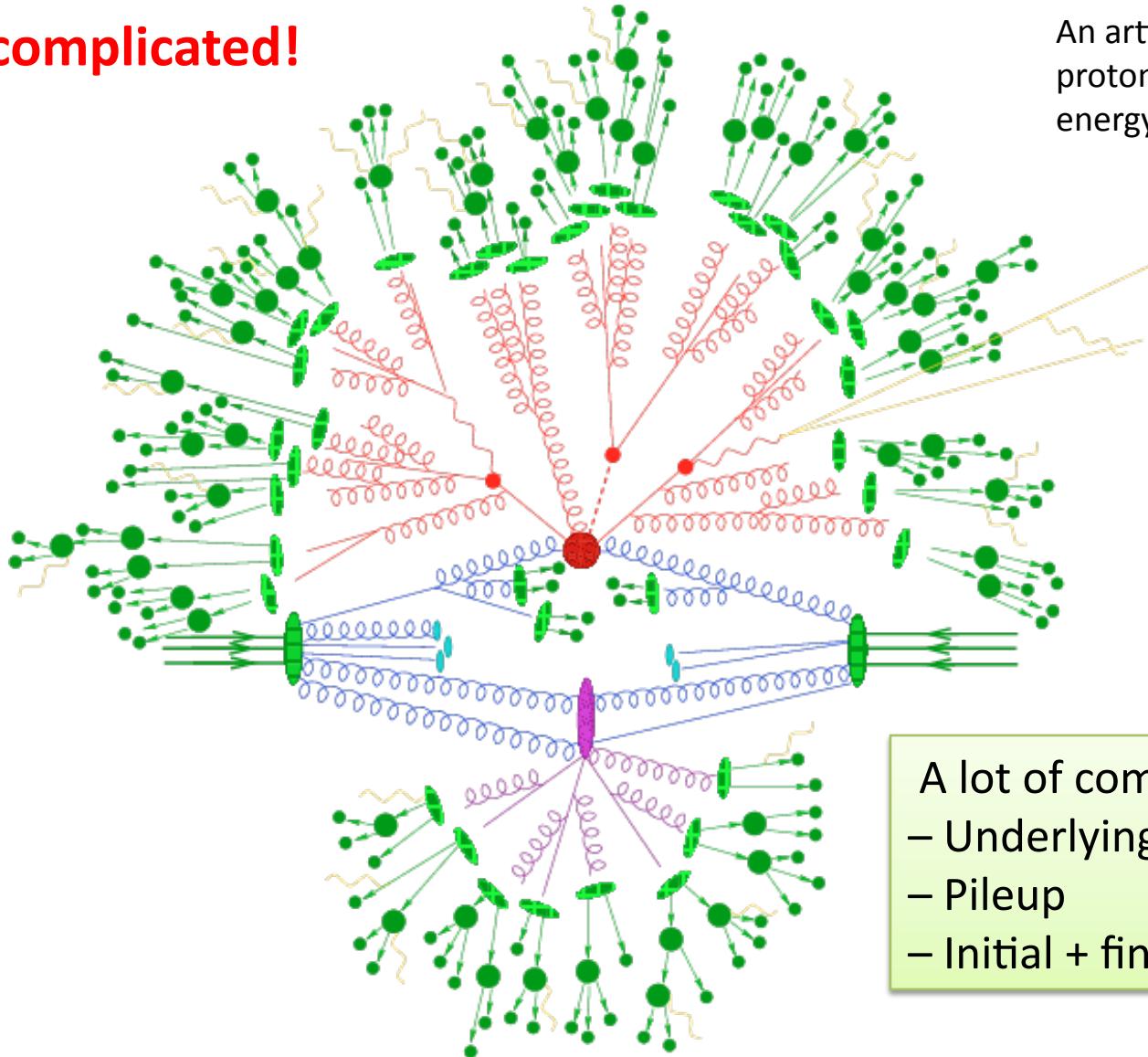
July 2018

CMS Preliminary



Measuring known processes at LHC energies using Jets
Triumph for SM and Theory Calculations

Jets are complicated!

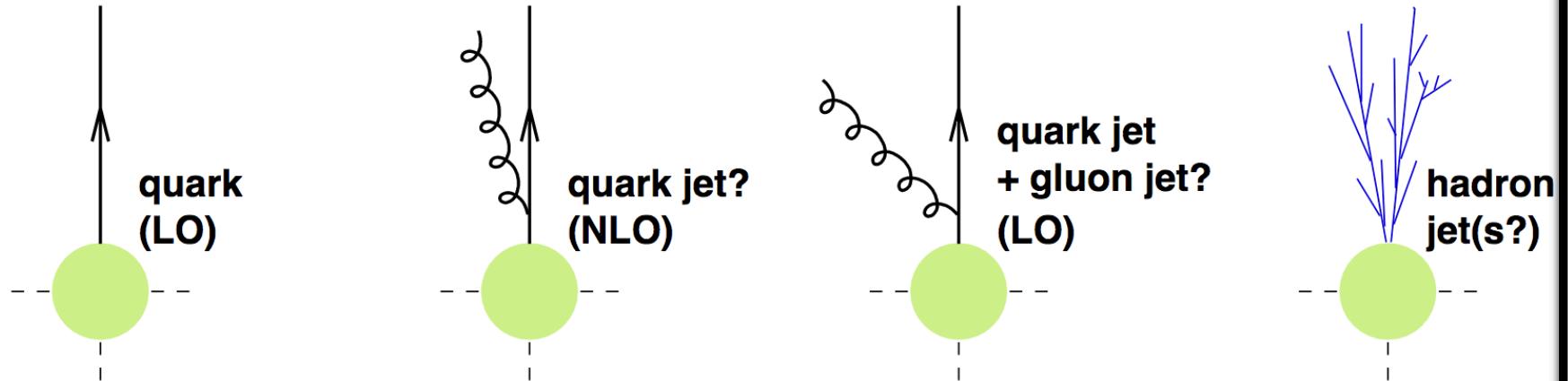


An artistic view of a proton-proton scattering event at high energy (courtesy of F. Krauss)

A lot of complications!
– Underlying event
– Pileup
– Initial + final state radiation

The whole event is color connected and at higher orders radiation can even be emitted.

Partons (quarks, gluons) are not trouble-free concepts...



- ▶ Partons split into further partons
- ▶ Jets are a way of thinking of the 'original parton'
- ▶ A 'jet' is a fundamentally ambiguous concept (e.g. requires a resolution)

Jets are only meaningful once you've got a **jet definition**



Fermi National Accelerator Laboratory

FERMILAB-Conf-90/249-E
[E 741/CDF]

A resolution: SnowMass Accord

Toward a Standardization of Jet Definitions *

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Eugene, Oregon 97403*

~10 years to realize the need! →

December 1990

* To be published in the proceedings of the 1990 Summer Study on High Energy Physics, *Research Directions for the Decade*, Snowmass, Colorado, June 25 - July 13, 1990.



Operated by Universities Research Association Inc. under contract with the United States Department of Energy

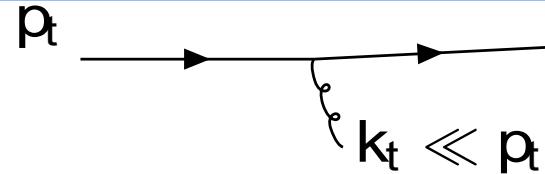
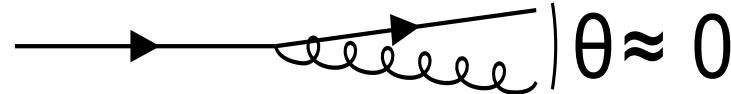
ABSTRACT

In order to reduce uncertainties in the comparison of jet cross section measurements, we are proposing a standard jet definition to be adopted for QCD measurements involving light quarks and gluons. This definition involves the use of a cone in the $\eta - \phi$ metric with a radius of 0.7 units.

Several important properties that should be met by a jet definition are [3]:

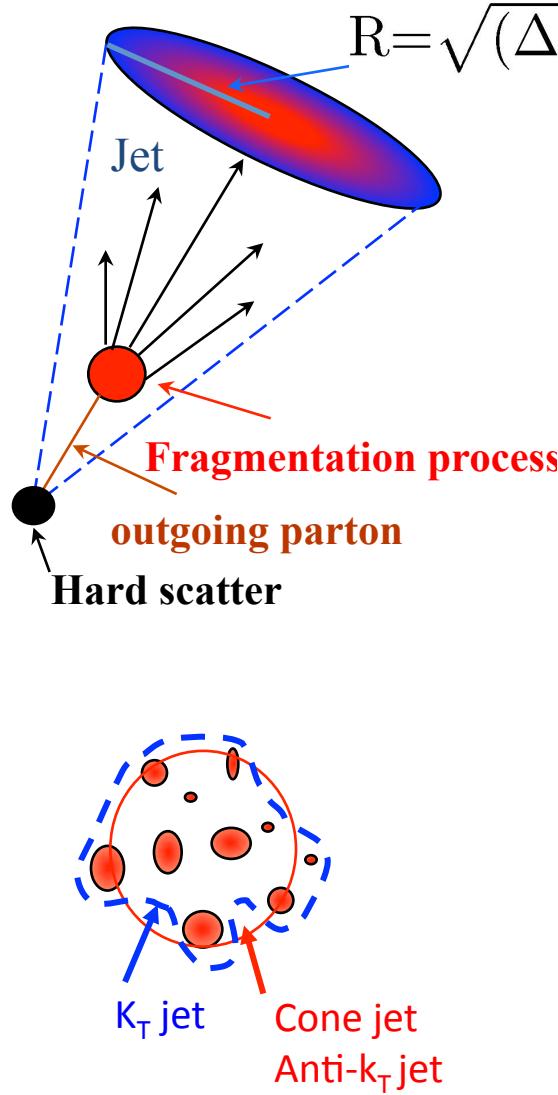
1. Simple to implement in an experimental analysis;
2. Simple to implement in the theoretical calculation;
3. Defined at any order of perturbation theory;
4. Yields finite cross section at any order of perturbation theory;
5. Yields a cross section that is relatively insensitive to hadronization.

Must be stable for collinear splitting and soft gluon emission.



Experimental and theoretical definitions of jets must match!

A Variety Jet Reconstruction Algorithms

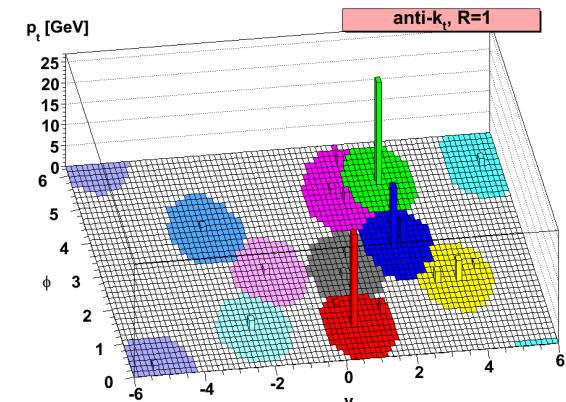
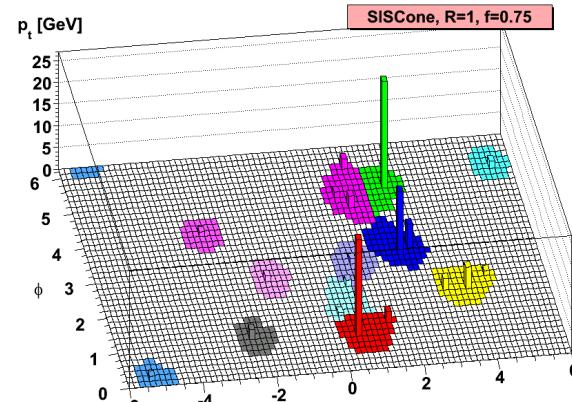
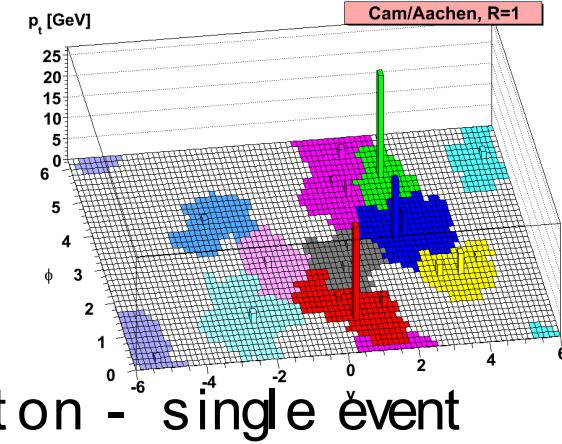
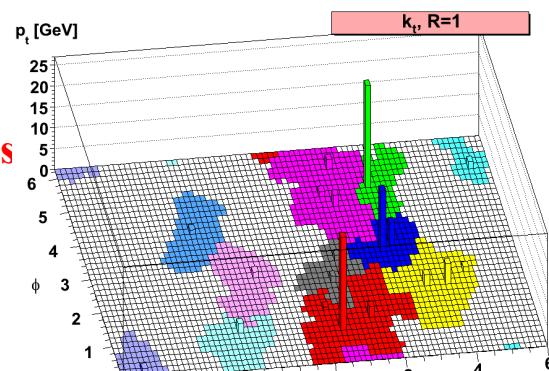


$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

Cone Algorithm: Top-down approach

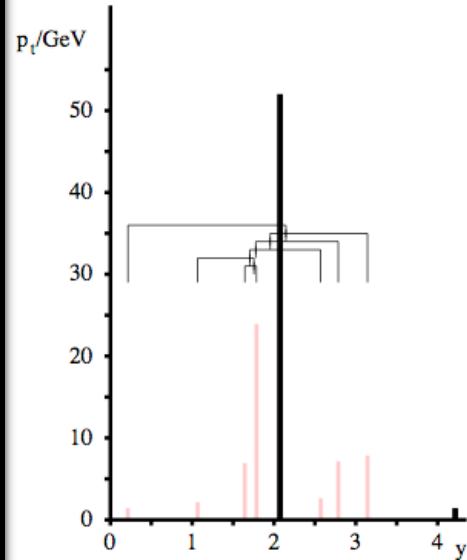
Sequential recombination: Bottom-up approach

Cluster pairs of objects close in relative p_T



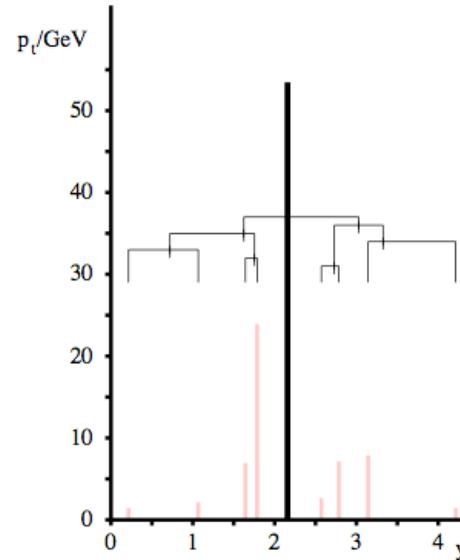
Hierarchical substructure

anti- k_t algorithm



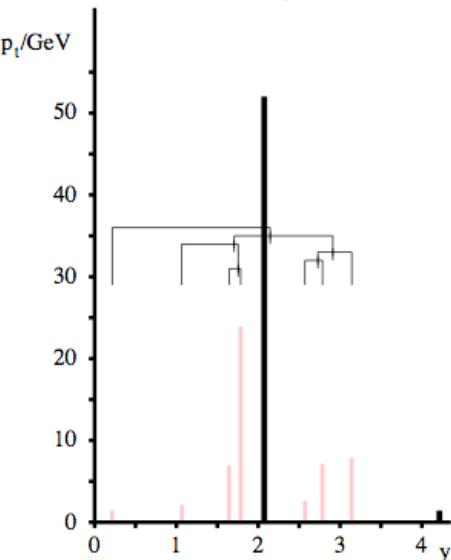
merge to hardest

k_t algorithm



merge to softest

Cambridge/Aachen



merge to closest

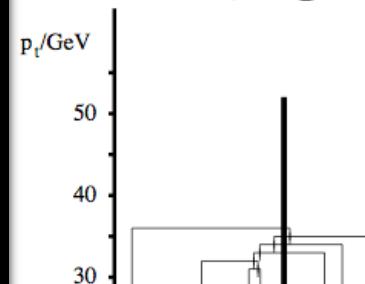
courtesy of Matteo Cacciari

There is no an unambiguous definition of a jet

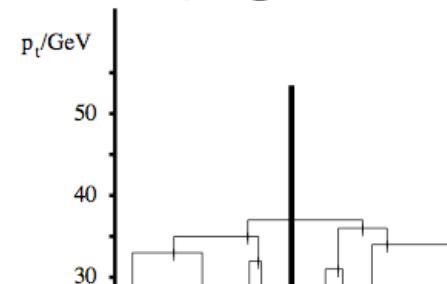
Slide by
Gavin Salam

Hierarchical substructure

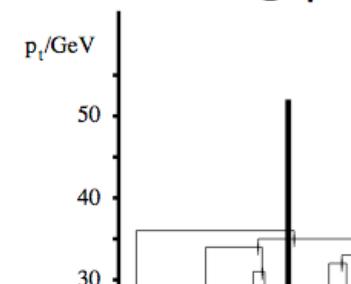
anti- k_t algorithm



k_t algorithm



Cambridge/A



A jet is what a jet finder finds.

merge to hardest

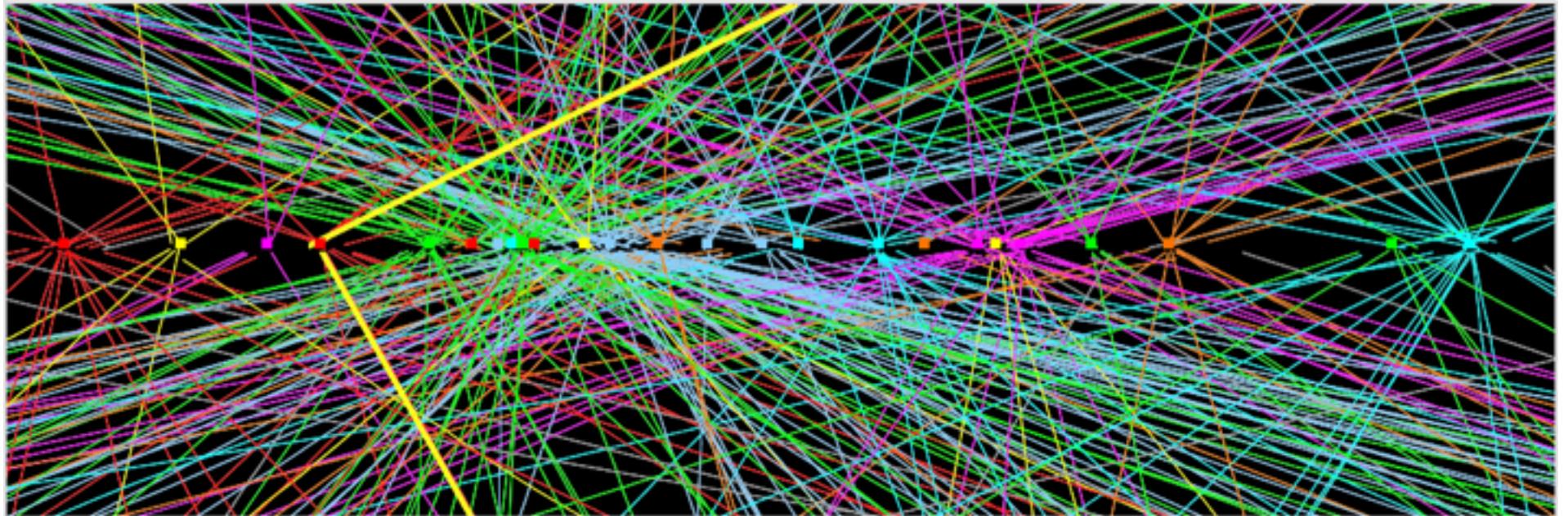
merge to softest

merge to closest

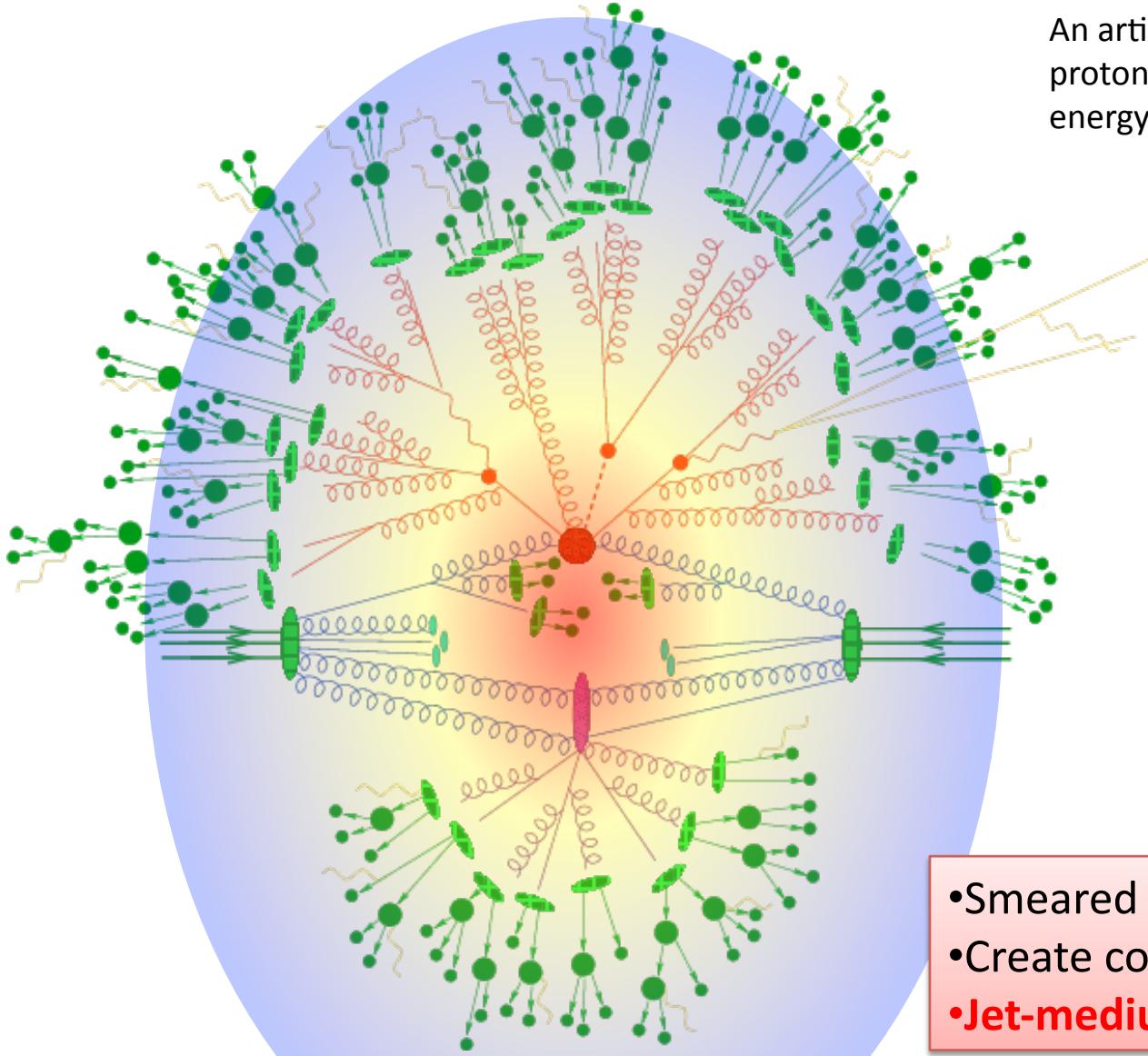
courtesy of Matteo Cacciari

There is no an unambiguous definition of a jet

A jet is what a jet finder finds – including pile-up & fake estimations



Most of the recent jet related developments involve corrections/
removal of pile-up for precise jet reconstruction. ☺



An artistic view of a proton-proton scattering event at high energy (courtesy of F. Krauss)

- Smeared kinematics
- Create combinatorial “jets”
- Jet-medium interactions**

Jets are even more complicated in heavy ion collisions!

Sevil Salur

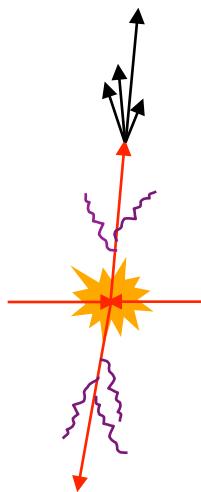
Why do we want to do this difficult study in Nuclear Collisions?

Lifetime of QGP is short ($O(fm/c)$) - not feasible to probe it with an external probe!

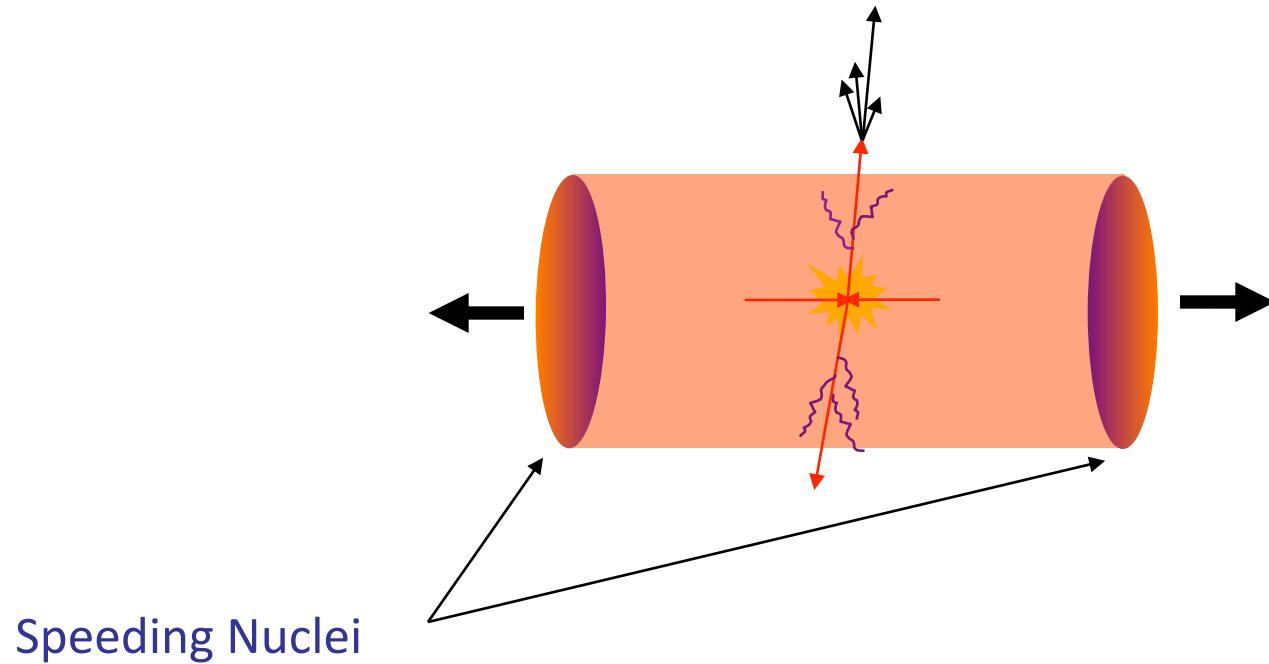


Why do we want to do this difficult study in Nuclear Collisions?

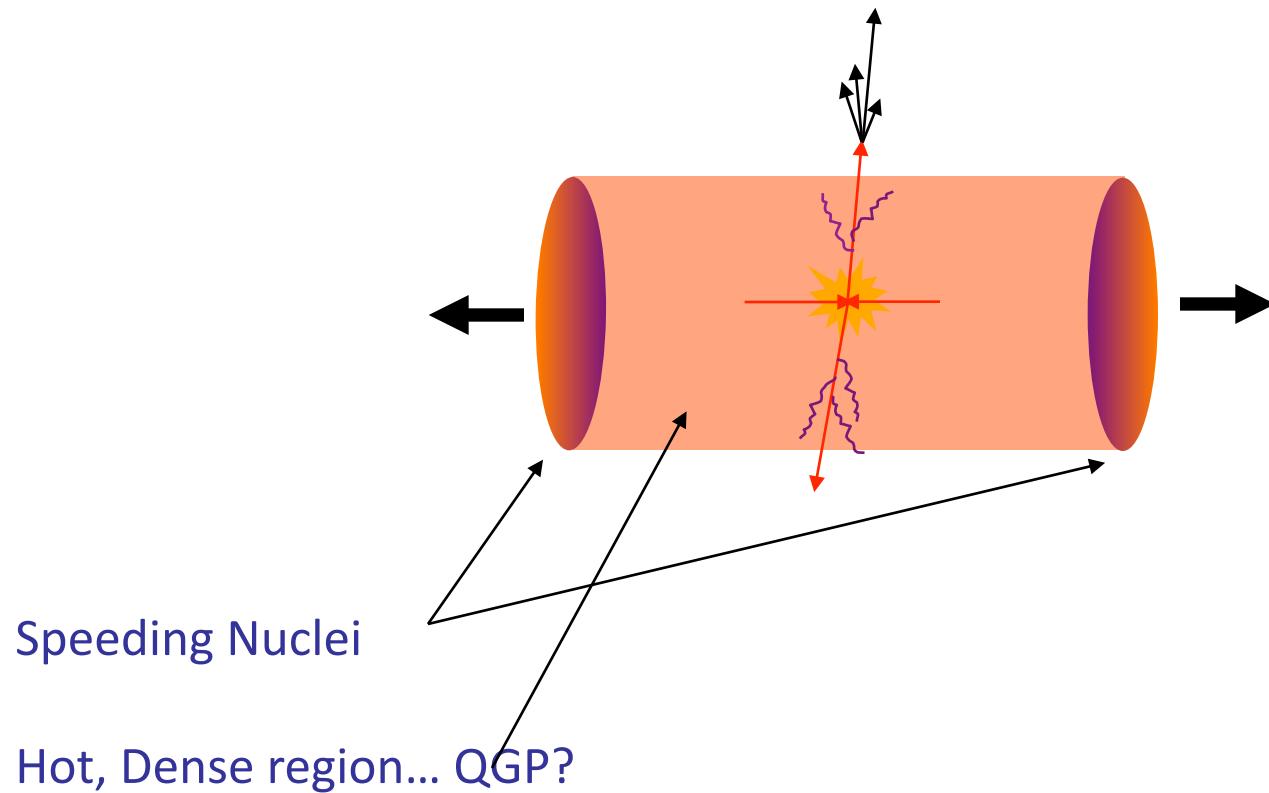
So start with an internal probe!



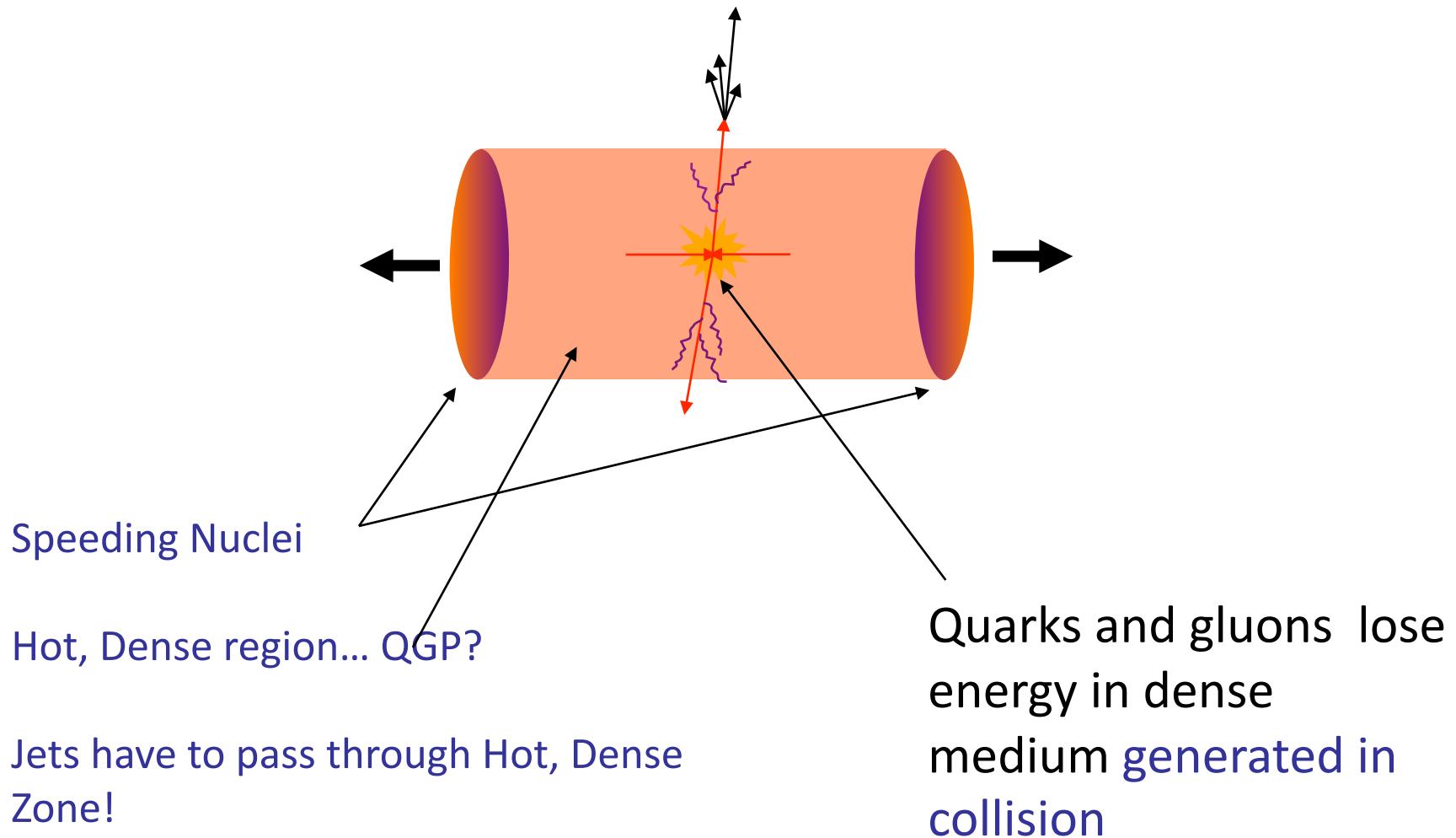
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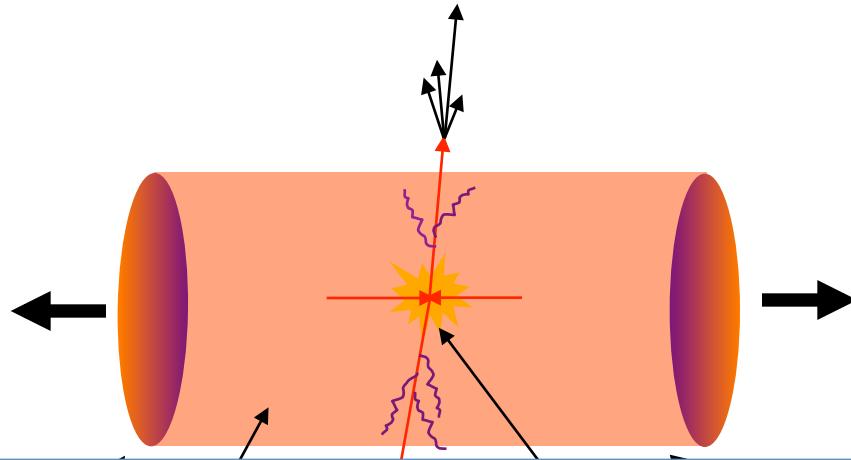
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Why do we want to do this difficult study in Nuclear Collisions?



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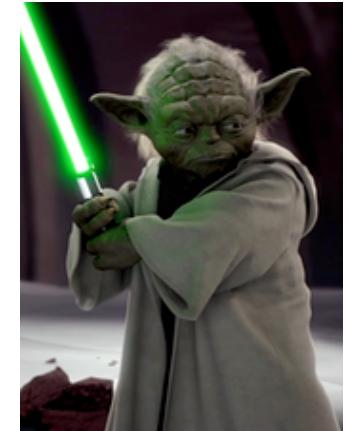
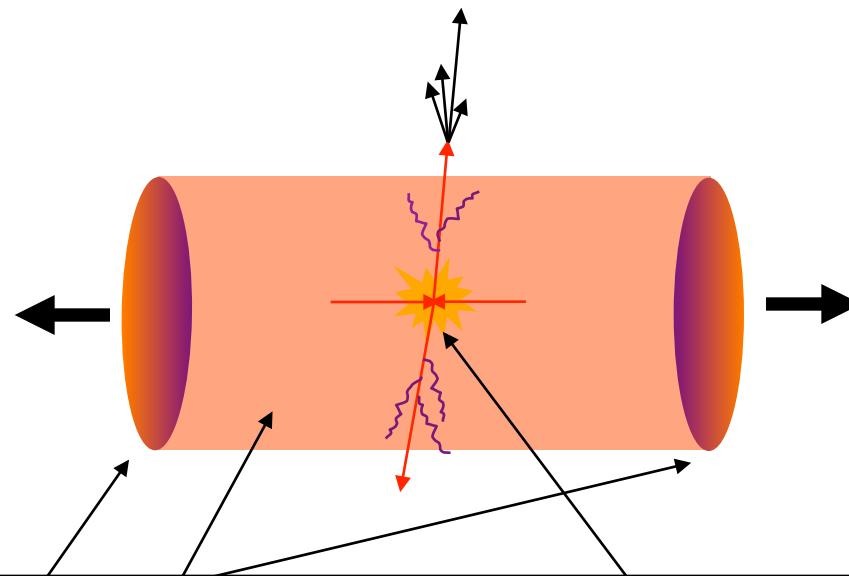


Diagnosing QCD medium: (simplified idea) pass a QCD-sensitive internal probe through it, then look for any modifications due to the medium.

Goal with jets: Extract QGP transport coefficients

- q : transverse momentum diffusion (radiative energy loss)
- e : longitudinal drag (collisional energy loss)

Why do we want to do this difficult study in Nuclear Collisions?

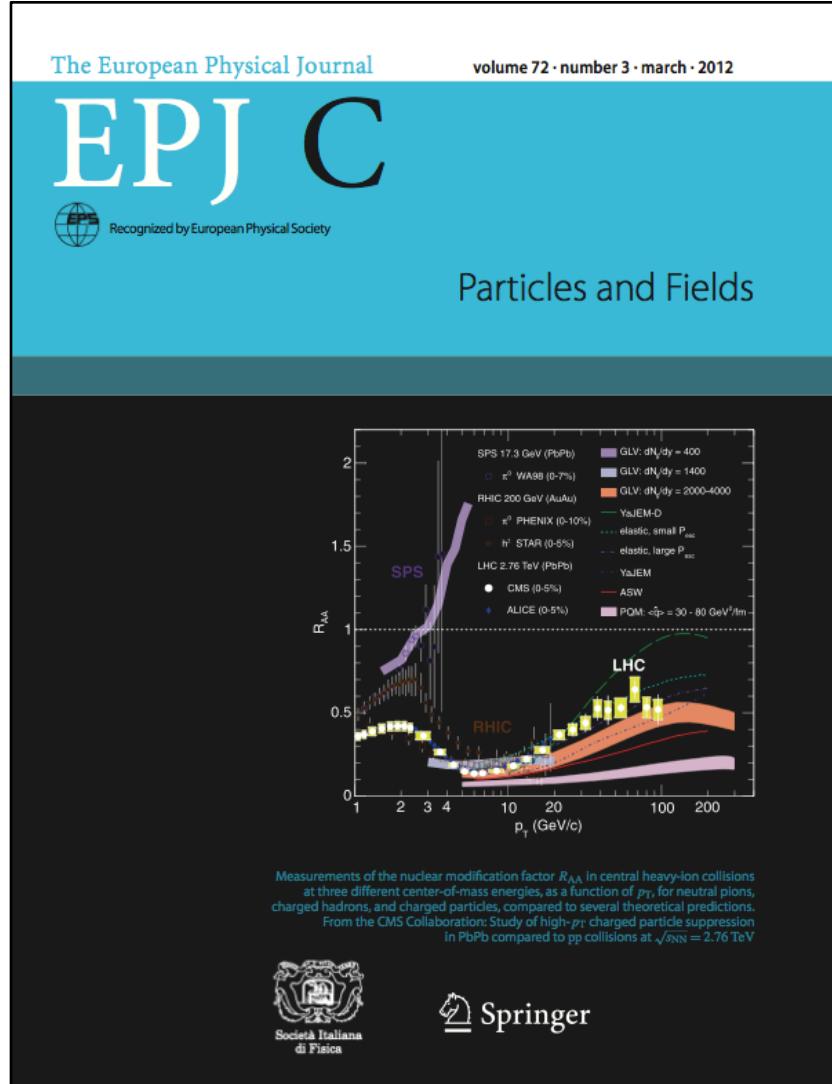
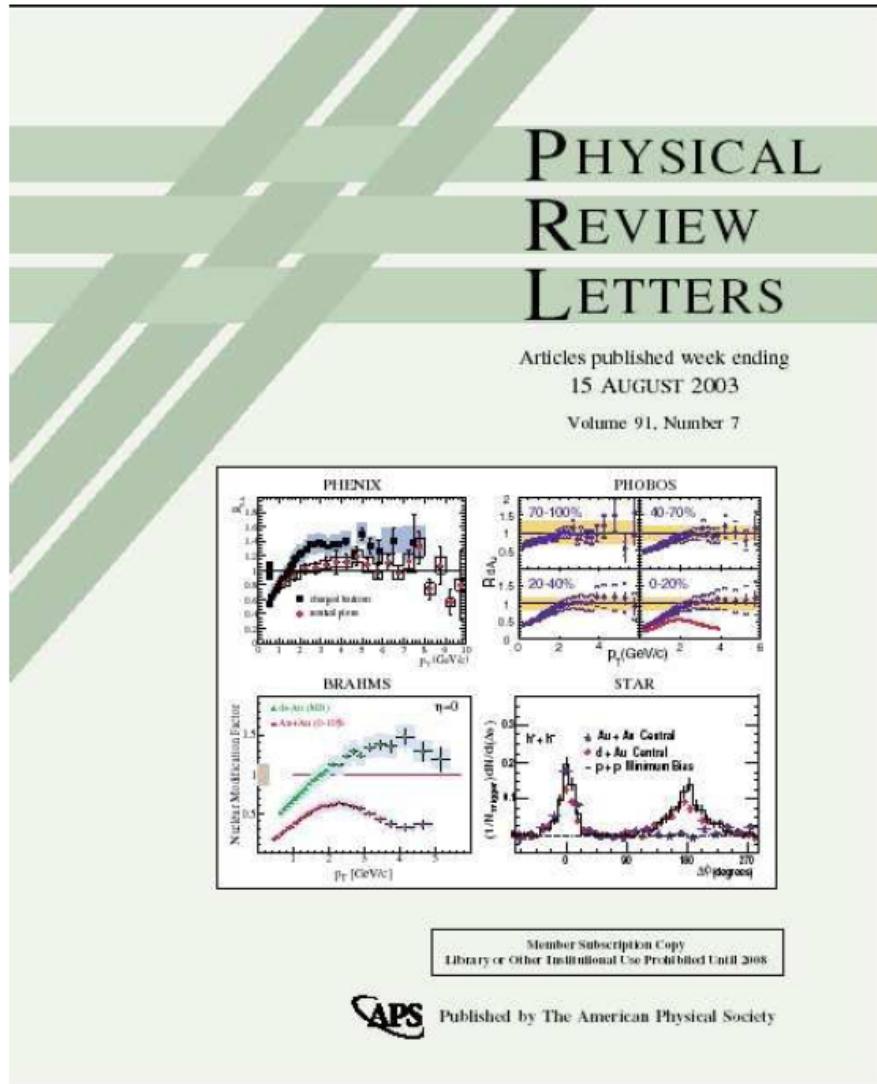


Our Goal is to study the fundamental physics processes of jet quenching in order to learn the properties of QGP.

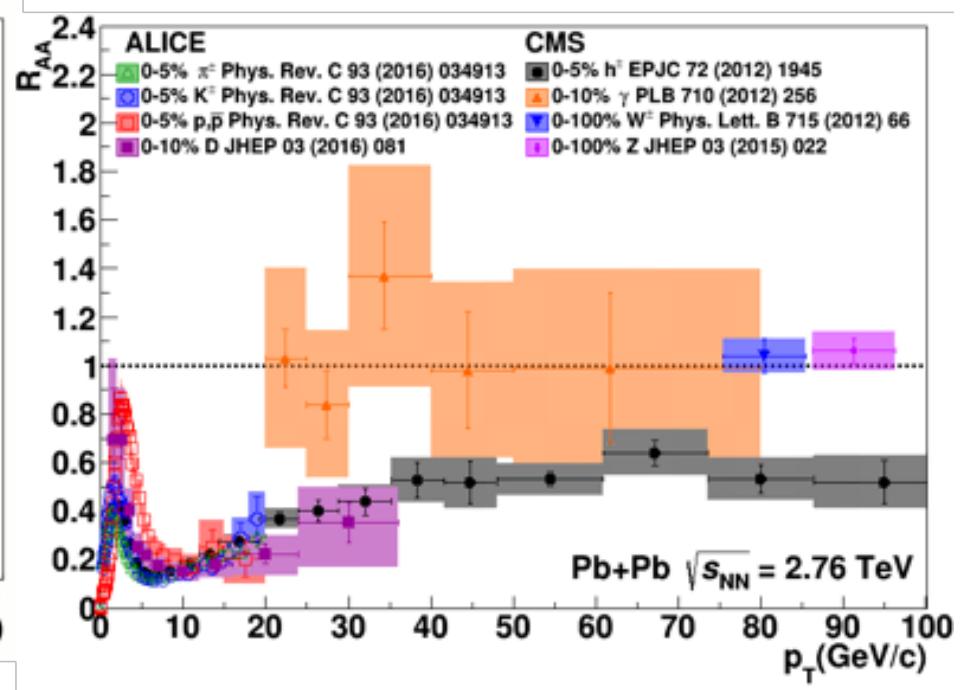
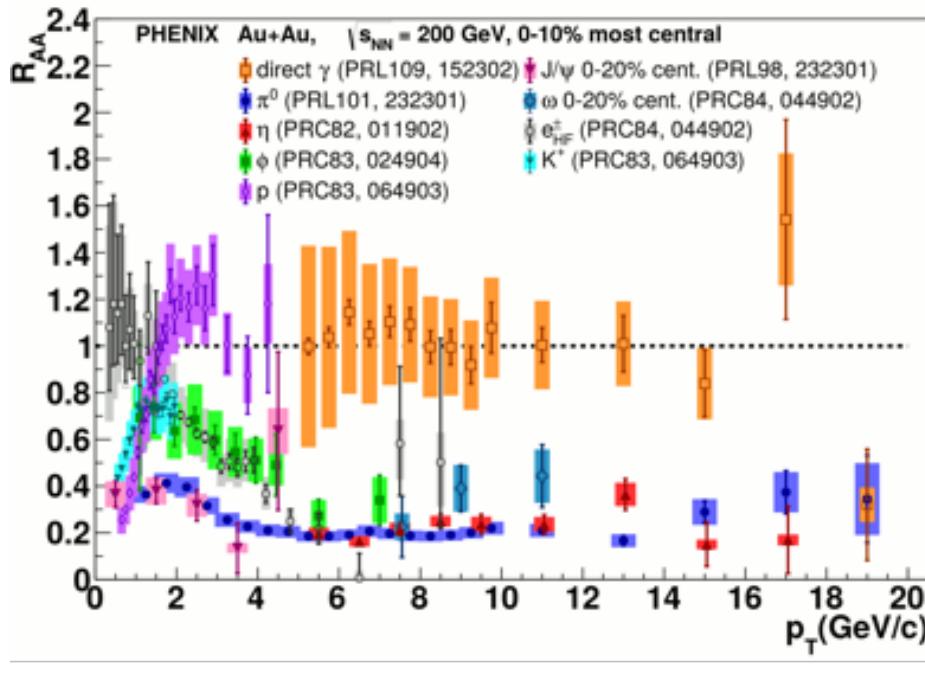
Jets have to pass through Hot, Dense Zone!

energy in dense medium generated in collision

Heavy Ion Jets: First steps w/o jet reco

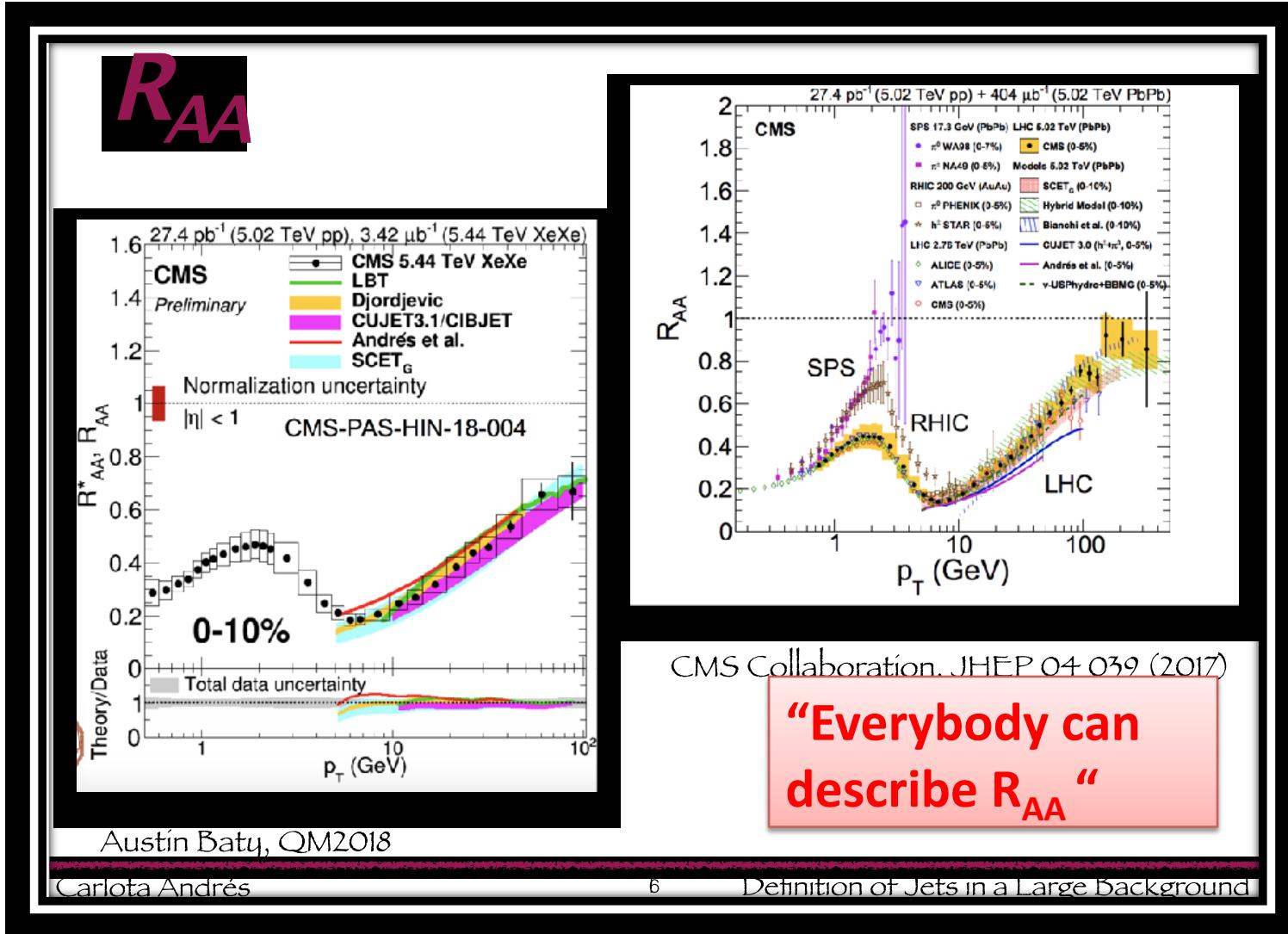


Nuclear modification factors



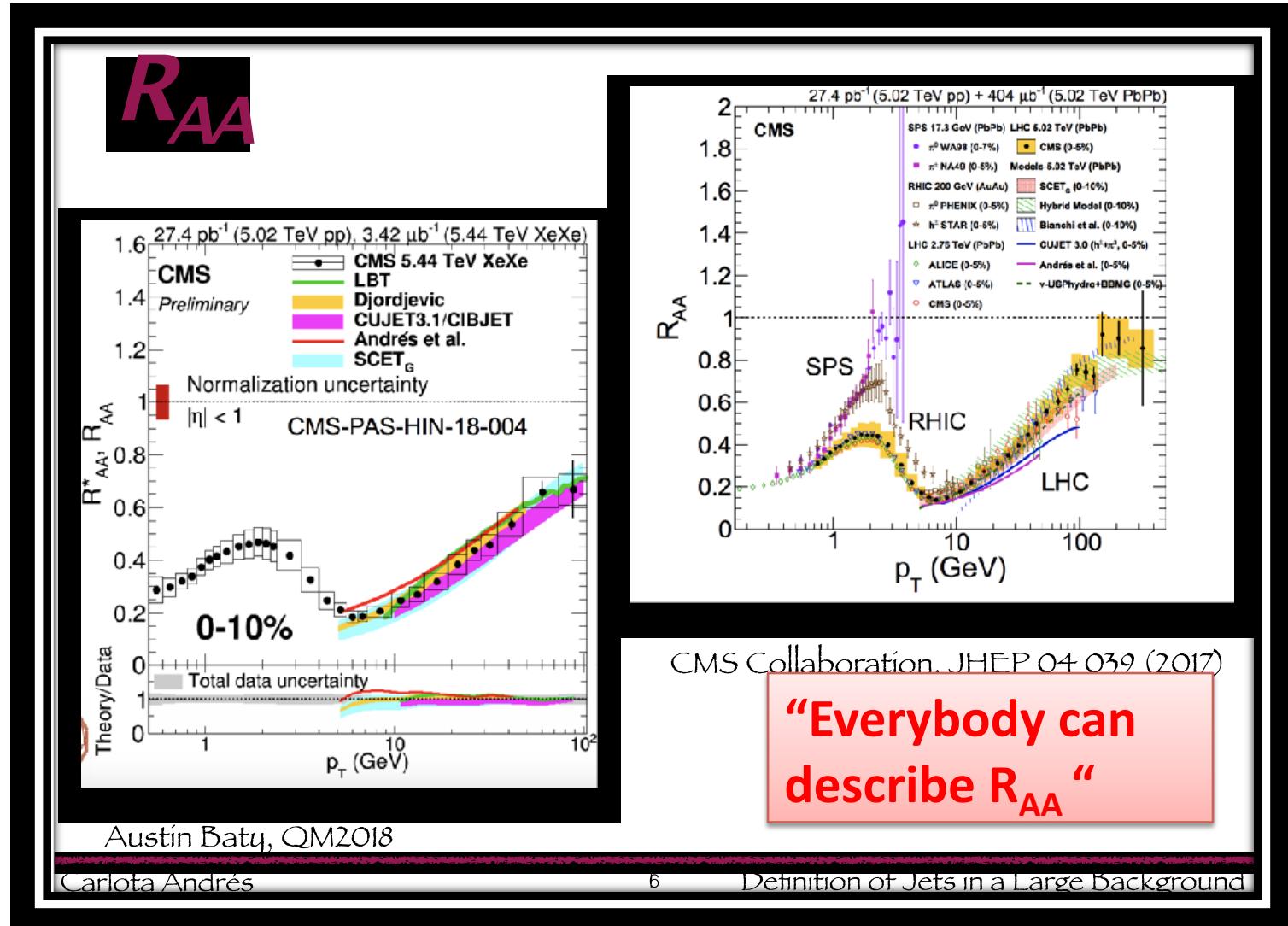
Electromagnetic probes – consistent with no modification – medium is transparent to them
Strong probes – significant suppression – medium is opaque to them - even heavy quarks!

Controls in ppb, dAu not suppressed.
Recent measurements extend to ~ 1 TeV!



- Leading hadron measurements do not capture the entire process
Hadron R_{AA} is not too discriminative between models

Courtesy of Carlota Andres

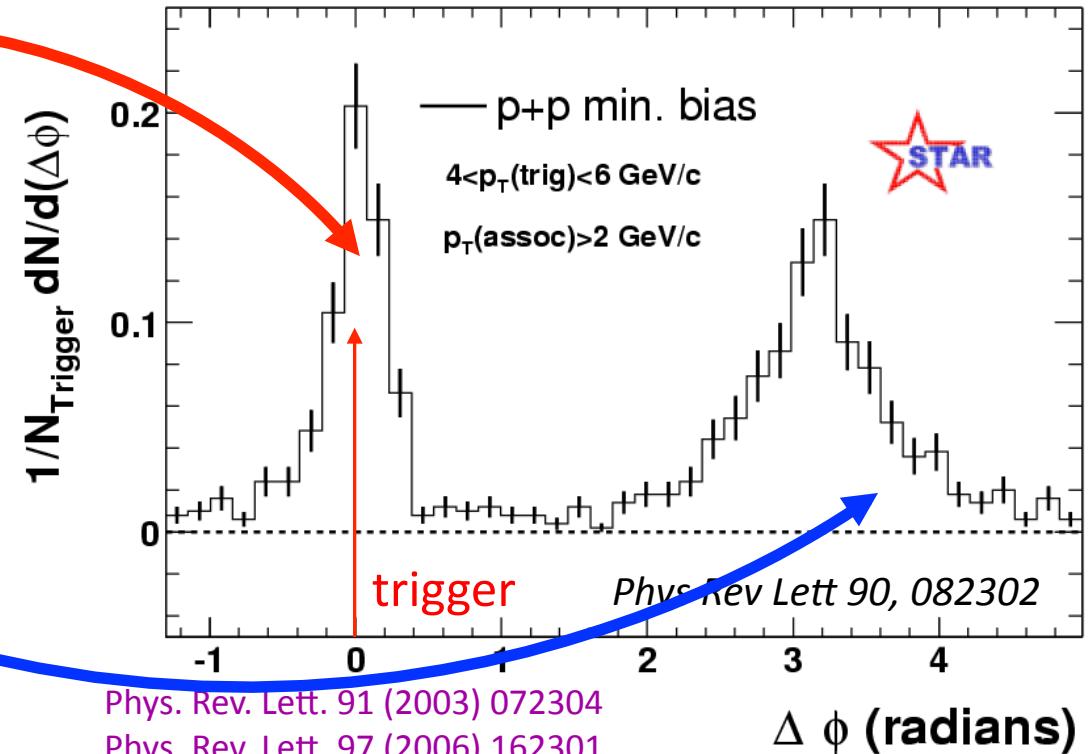
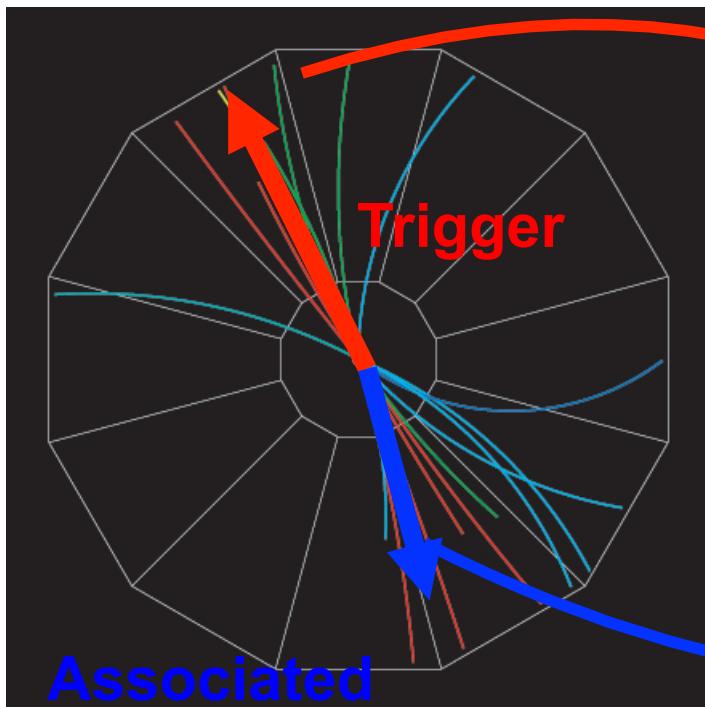


- Leading hadron measurements do not capture the entire process
Hadron R_{AA} is not too discriminative between models

Courtesy of Carlota Andres

Heavy Ion Jets: First Steps w/o jet reco

$p+p \rightarrow \text{dijet}$

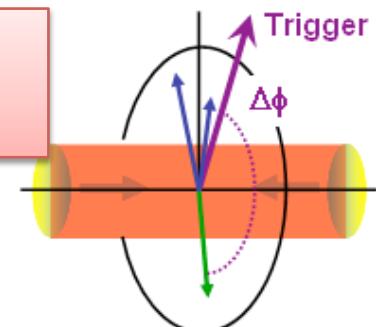


Jet Measurements are difficult!

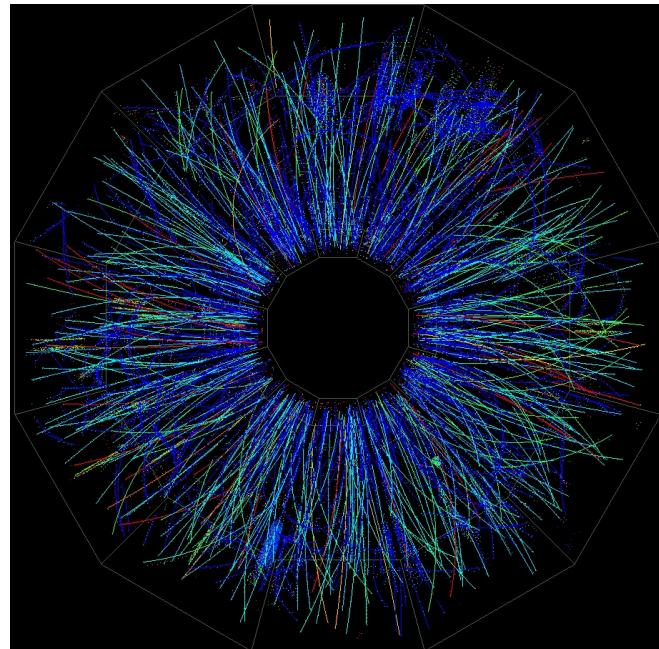
Simplify the problem by looking only at the leading hadron.

Select high momentum particles
→ biased towards jets

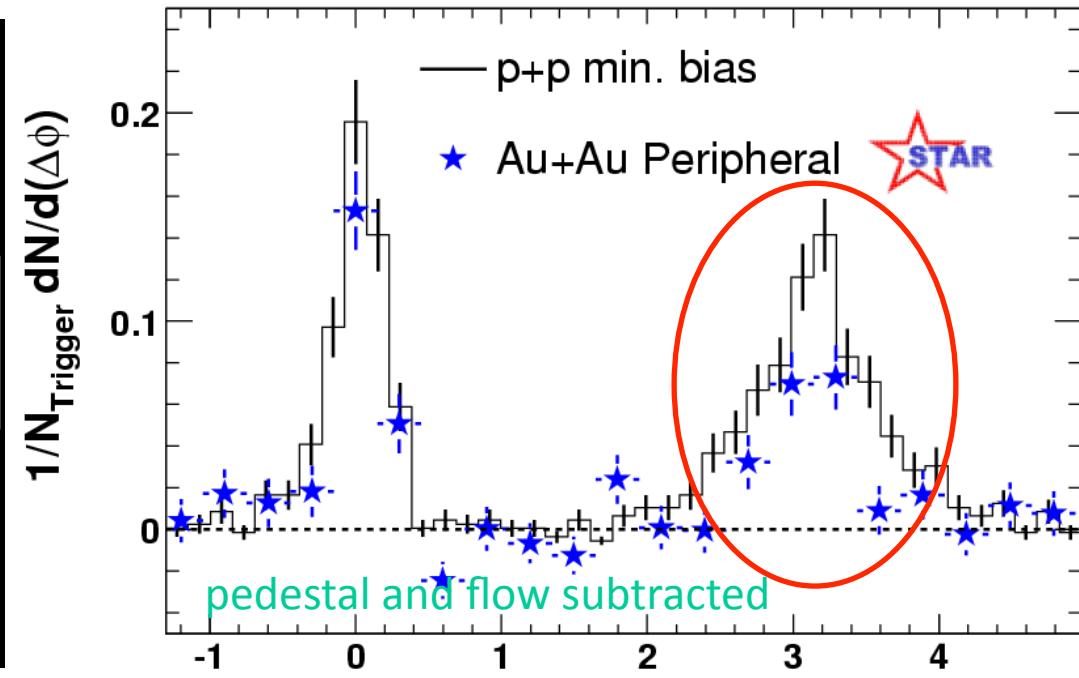
Sevil Salur



Heavy Ion Jets: First Steps w/o jet reco



peripheral Au+Au collisions

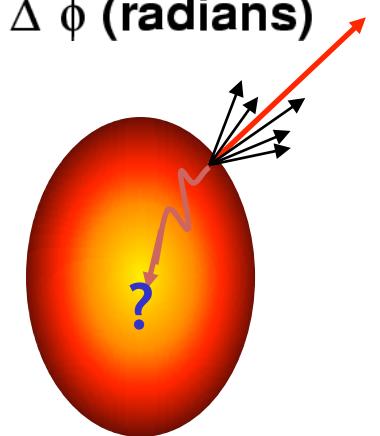


Phys. Rev. Lett. 91 (2003) 072304

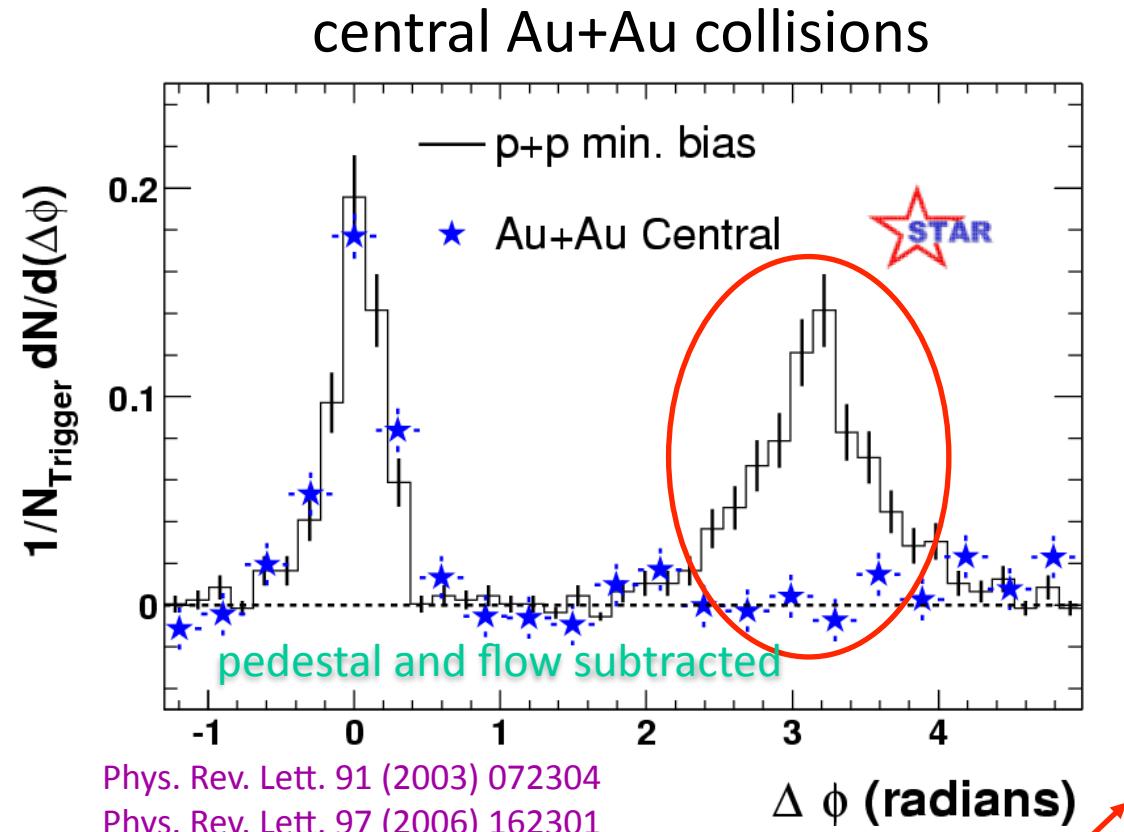
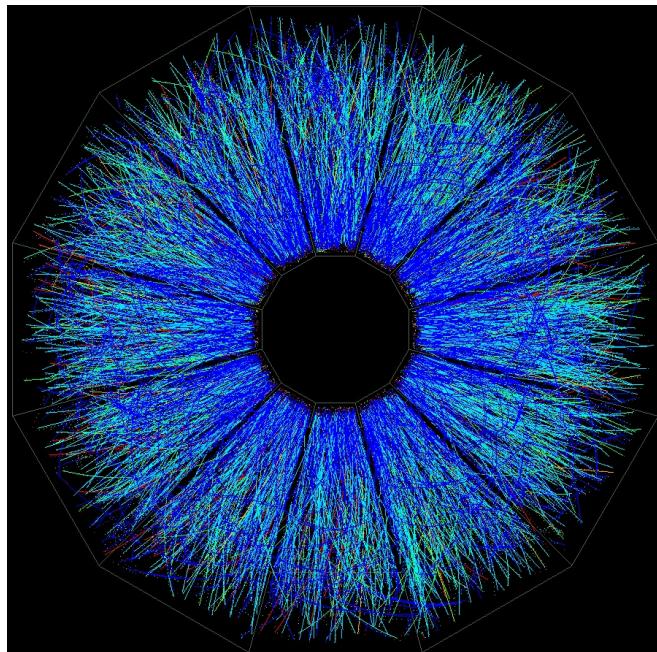
Phys. Rev. Lett. 97 (2006) 162301

Near side $\Delta\phi \approx 0$: $p+p$, Au+Au similar

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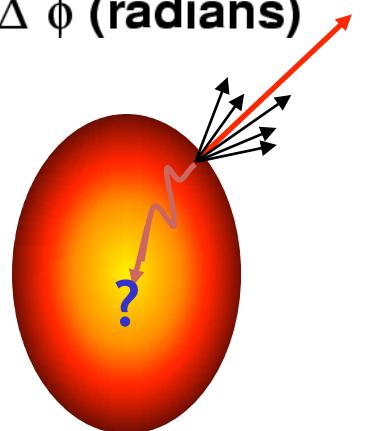


Heavy Ion Jets: First Steps w/o jet reco



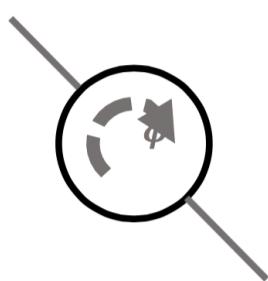
$\Delta\phi \approx 0$: peripheral and central Au+Au similar to p+p
 $\Delta\phi \approx \pi$: strong suppression of back-to-back correlations in central Au+Au

Sevil Salur

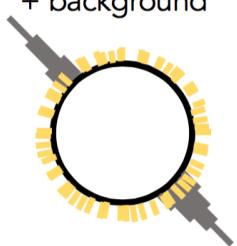


Correlations: What to subtract?

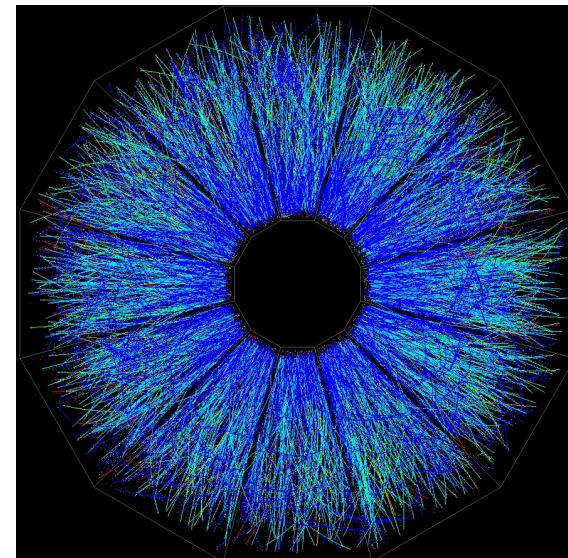
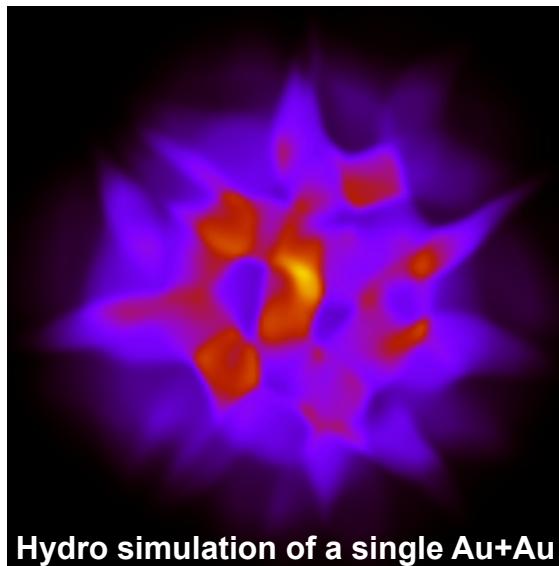
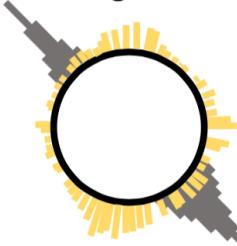
in pp
jet partonic level



in pp
jet hadronic level
+ background



in Pb-Pb
jet hadronic level
+ background



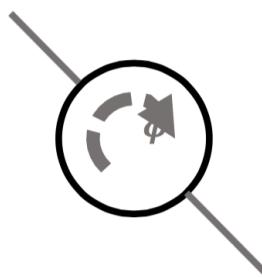
Shown is the energy density in the transverse plane.
For more information on the simulation refer
to [arXiv:1009.3244](https://arxiv.org/abs/1009.3244).

Jets → background for flow

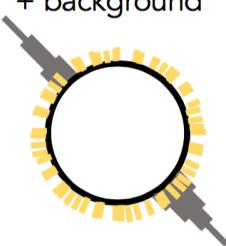
Flow → background for jets

Correlations: What to subtract?

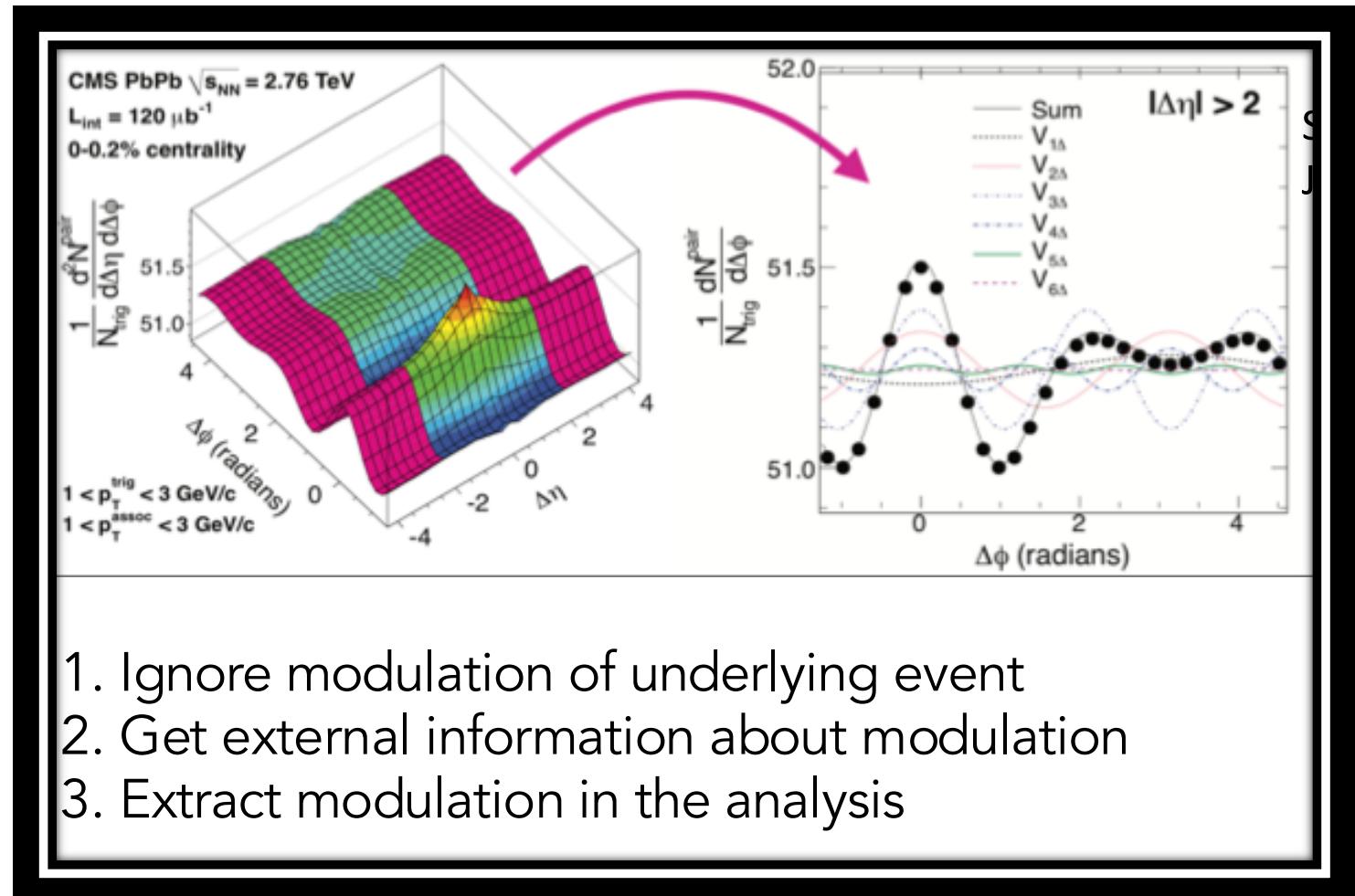
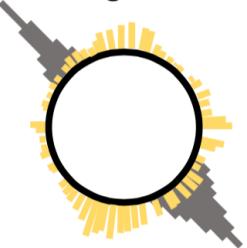
in pp
jet partonic level



in pp
jet hadronic level
+ background



in Pb-Pb
jet hadronic level
+ background

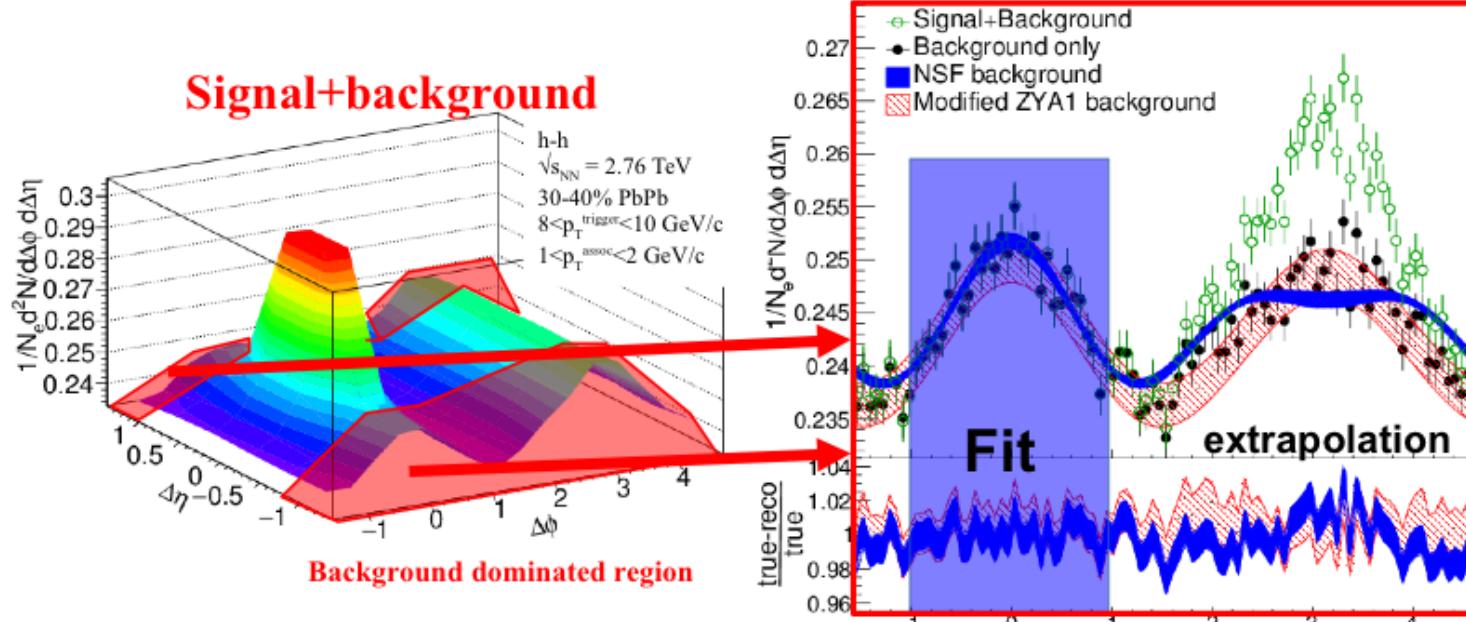


1. Ignore modulation of underlying event
2. Get external information about modulation
3. Extract modulation in the analysis

Courtesy of Eliane Epple

Near-Side Fit (NSF) method

No reaction plane dependence
(NOT used by this analysis)

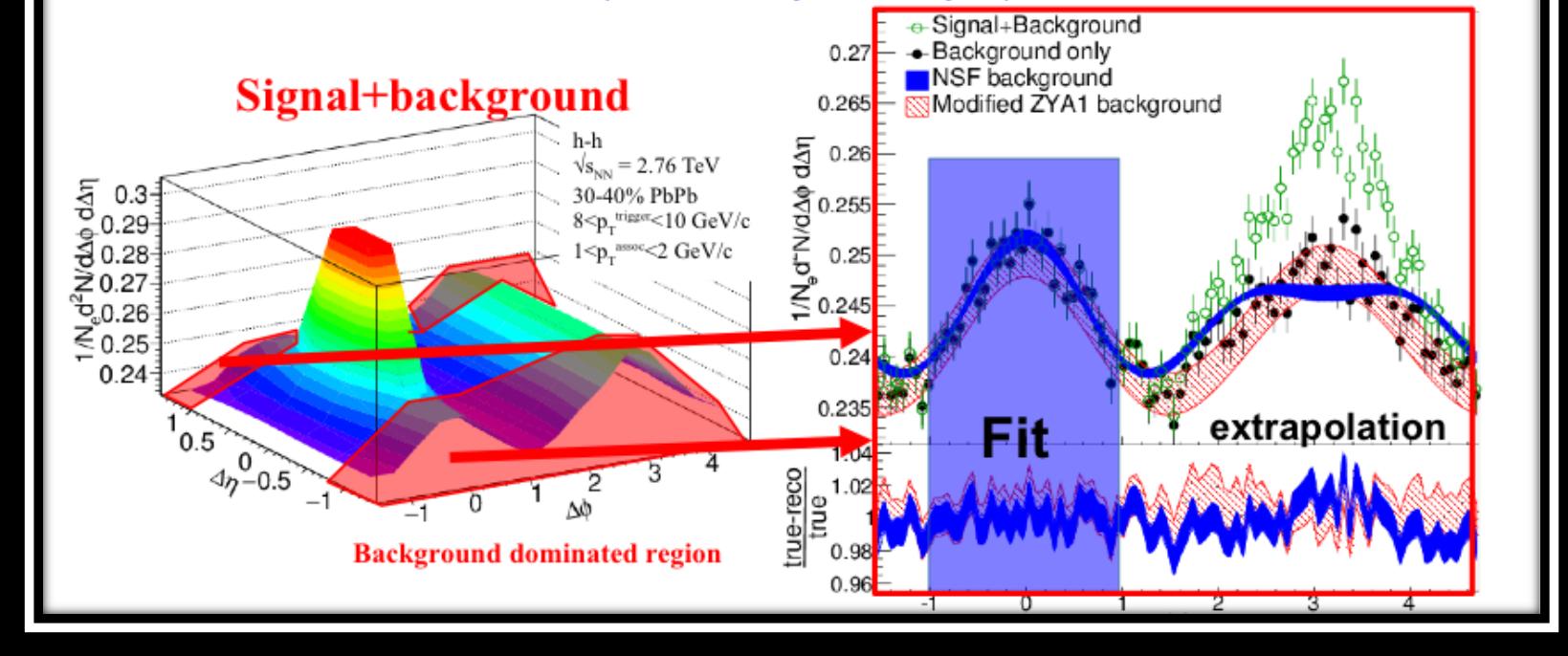


Courtesy of Joel Mazer

- Robust, uses information from each event plane orientation
- Doesn't require independent measurements of v_n , extracted from fits
- Reconstructs signal with fewer assumptions and less bias while giving smaller errors than ZYAM

Near-Side Fit (NSF) method

No reaction plane dependence
(NOT used by this analysis)



Courtesy of Joel Mazer



Background removal of correlations is not as simple as first believed.

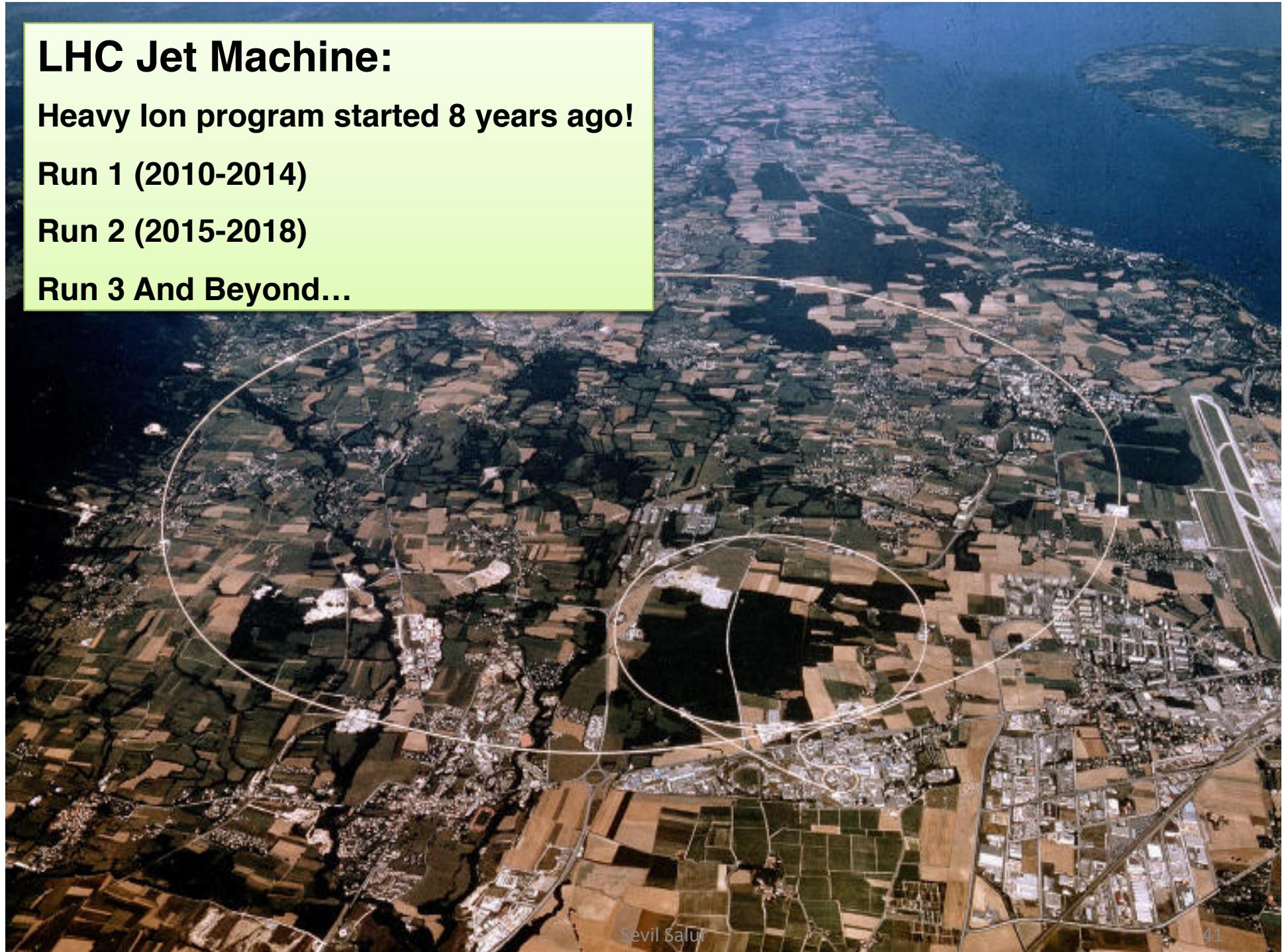
LHC Jet Machine:

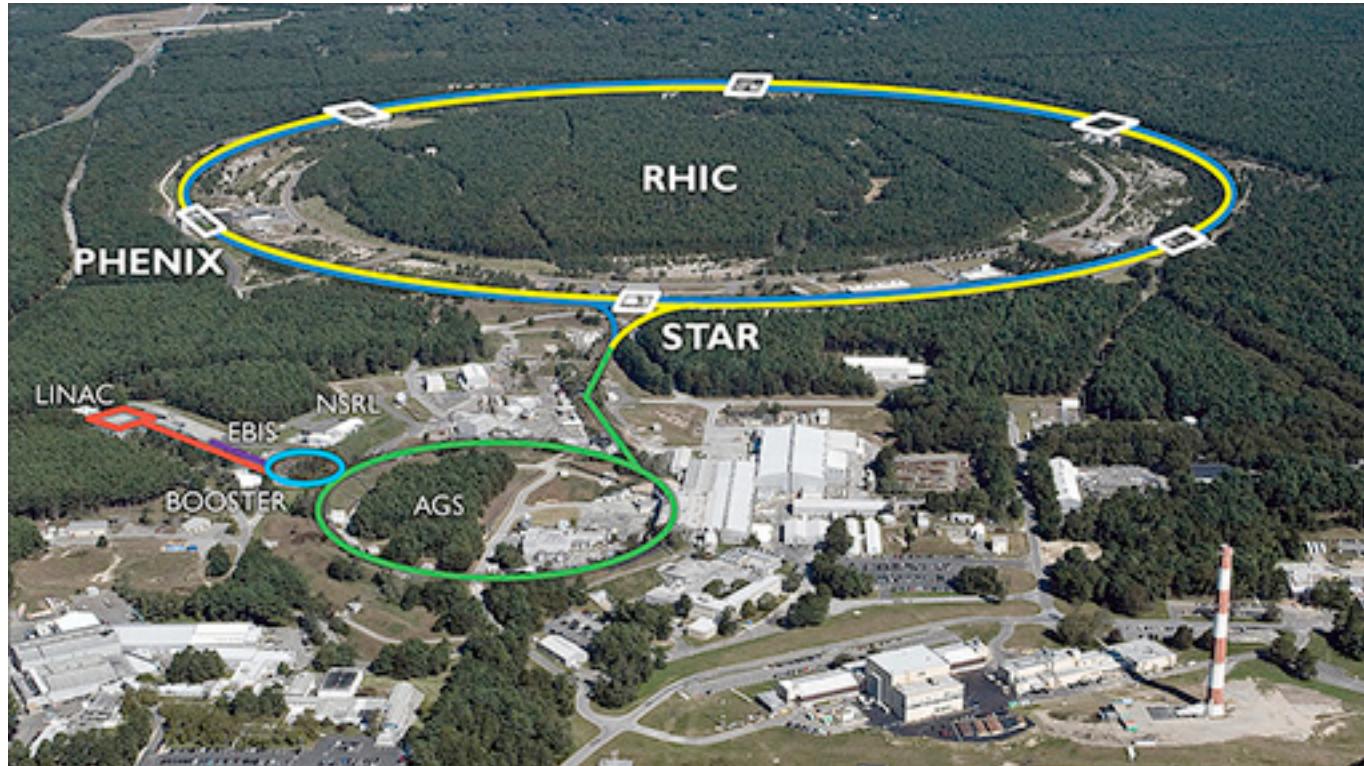
Heavy Ion program started 8 years ago!

Run 1 (2010-2014)

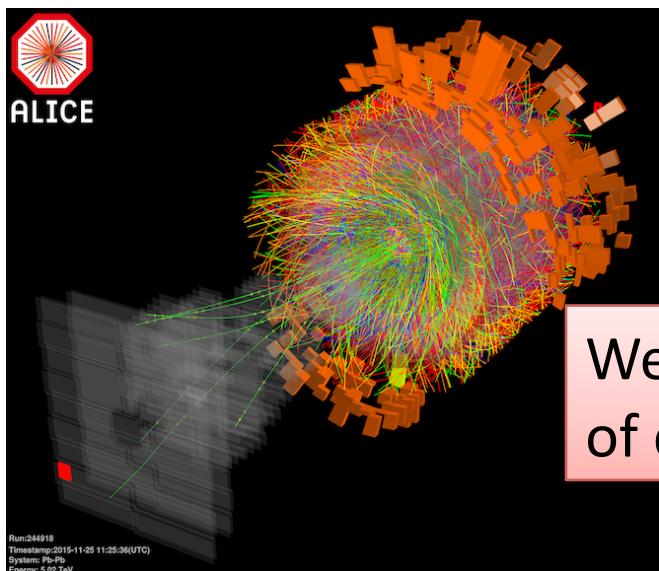
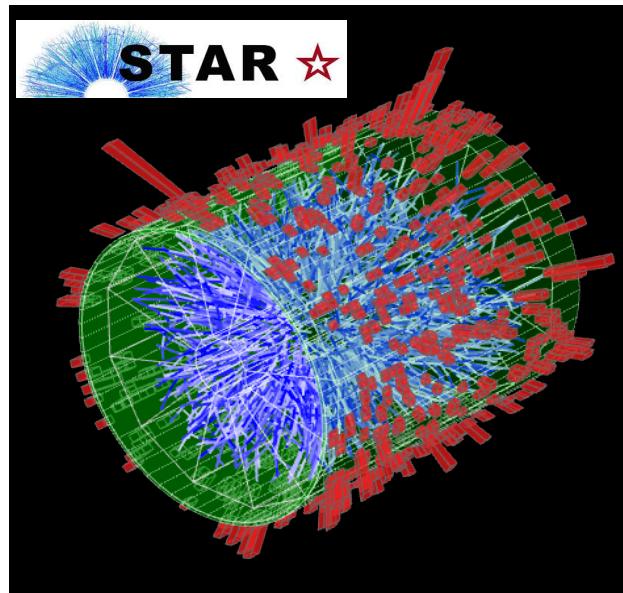
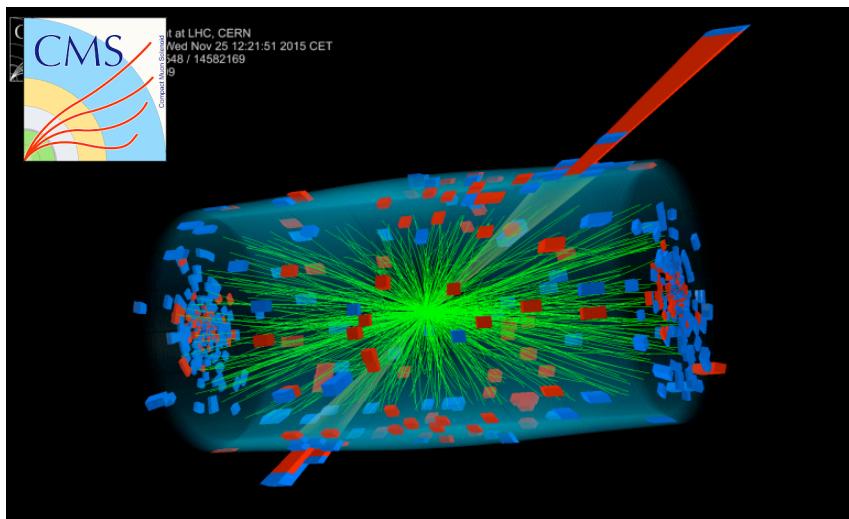
Run 2 (2015-2018)

Run 3 And Beyond...





RHIC continues to take billions of collisions.
With STAR and sPhenix, RHIC will continue to serve as the necessary QCD leverage arm!

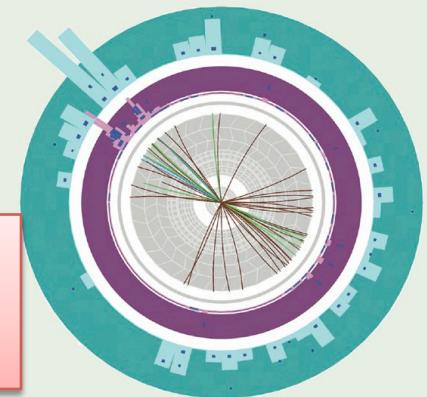


We are building upon 25 years
of cold QCD jet experience!



PHYSICAL
REVIEW
LETTERS

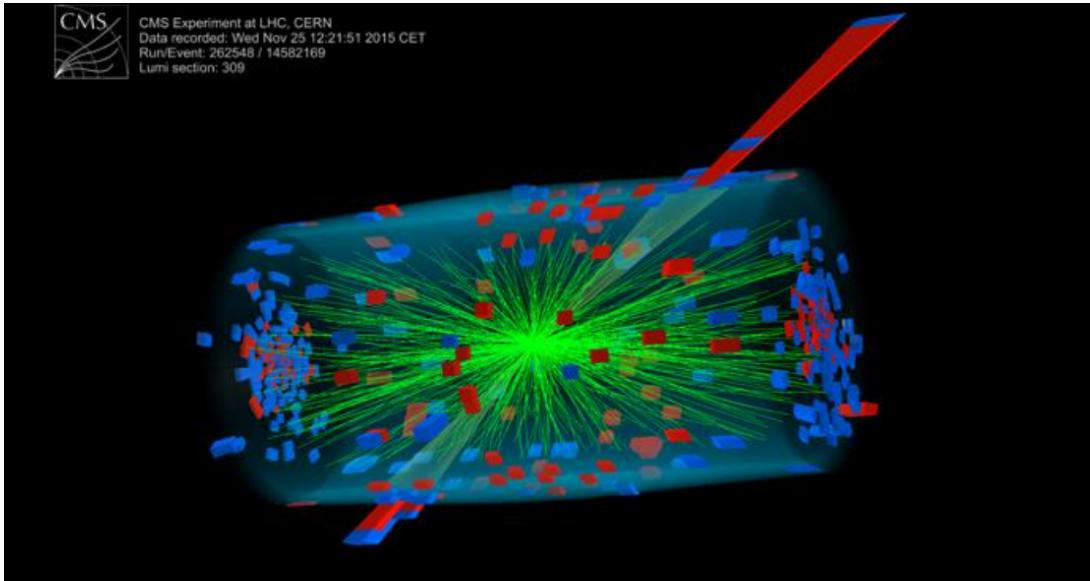
Articles published week ending 17 DECEMBER 2010



Volume 105, Number 25

Many new techniques/variable are developed and we “hot QCD
physicists ☺”, could utilize these new methods.

A jet is also never alone in HI collisions



Large Fluctuating
Underlying Event

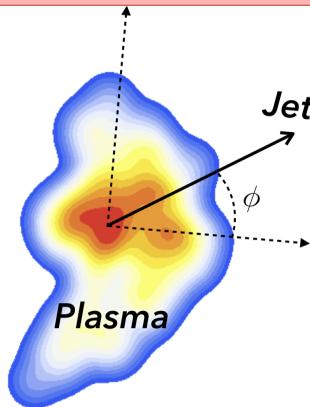
ATLAS & CMS: iterative event-by-event rejection
ALICE & STAR: event by event averaged rejection

Experimental and theoretical definitions of jets must match!
Underlying event is the hardest to match.

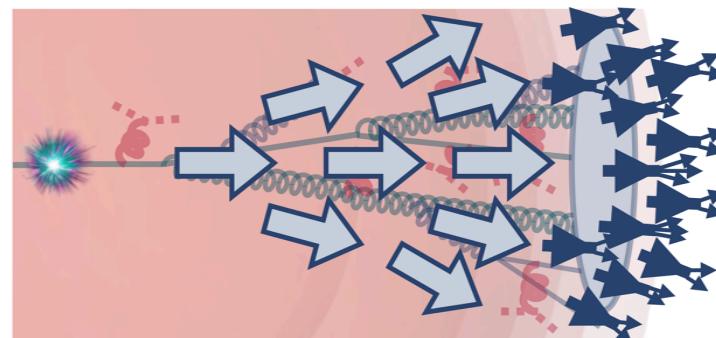
Why do we do bkg subtraction?

- “**Experimental and theoretical definitions of jets must match!**”
- Poor understanding of the non-perturbative physics
- Essential for HI physics to access low pt kinematics
- Soft sector Phenomenological modeling lacks accuracy.

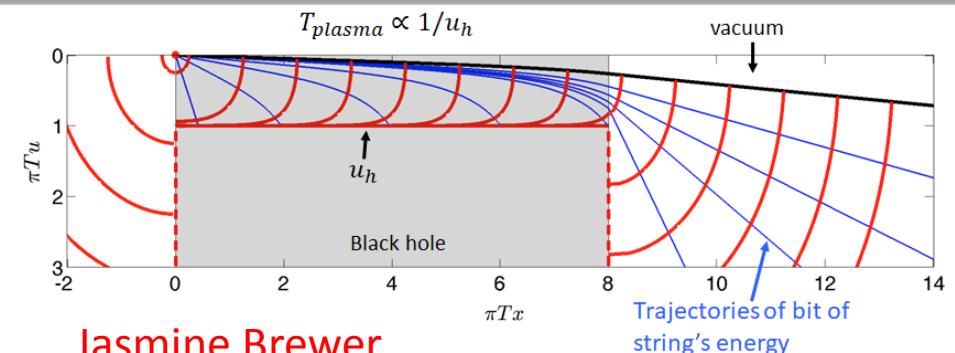
Allows comparisons using event generators, parton/string models, NLO and holographic calculations...



Shuzhe Shi



Yasuki Tachibana



Jasmine Brewer

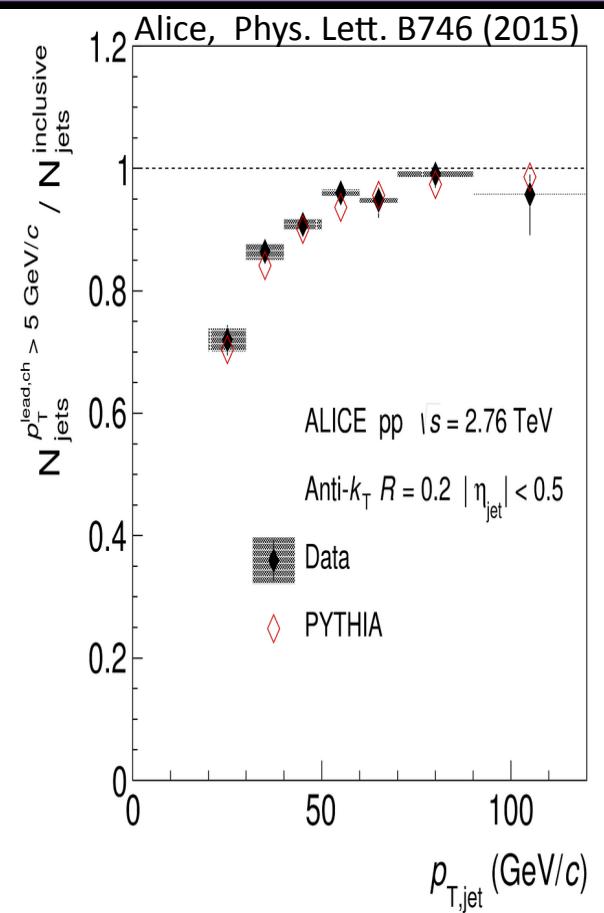
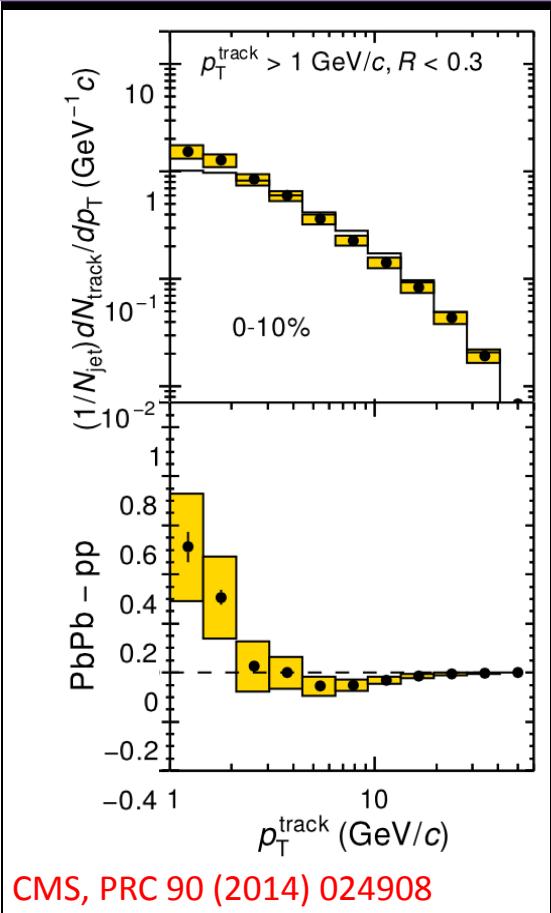


Our theory colleagues are on board!

Sevil Salur



Experimental Challenges: “Removal of Fake Jets”

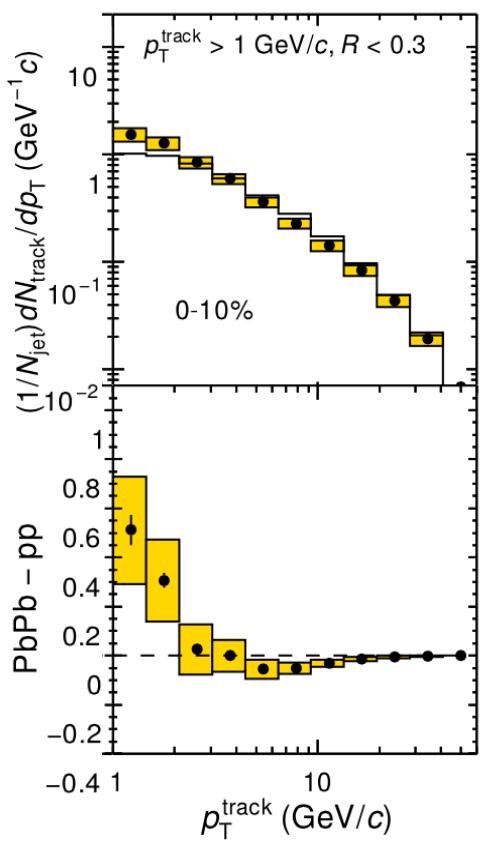


All corrections including
fake jets treatment
(p_T constituent $> 5-8 \text{ GeV}/c$)
done with Pythia
fragmentation!

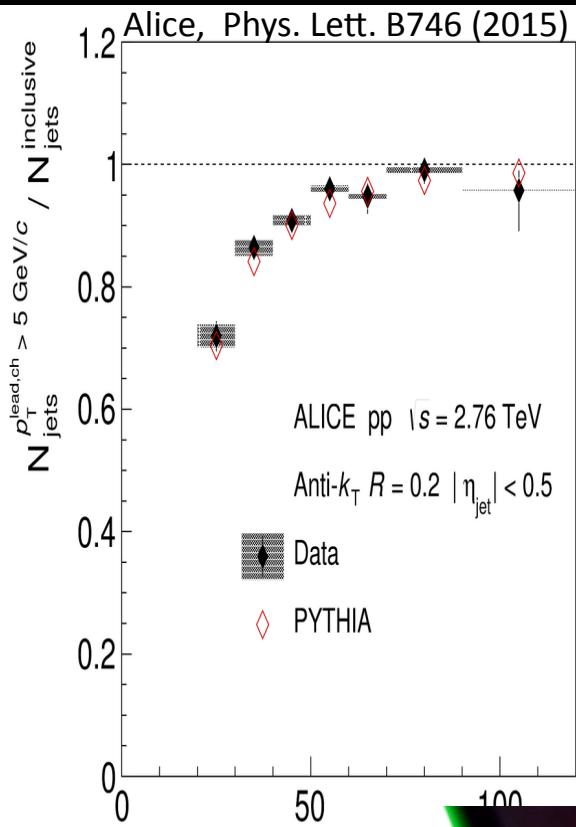




Experimental Challenges: “Removal of Fake Jets”



CMS, PRC 90 (2014) 024908



All corrections including
fake jets treatment
(p_{T} constituent $> 5-8 \text{ GeV}/c$)
done with Pythia
fragmentation!



- Are we throwing away the physics that we are interested in?
- Introducing biases?
- How to make the most of it?

What are the necessary components of a background subtraction algorithm?

- Can be used to achieve our physics goal
- Can be used in experimental measurements
- Can be used in theoretical calculations

Minimal assumption on the factorization of “soft” physics and “hard” physics.

Classification should be theoretically sound and reproducible in calculations.



What are the necessary components of a background subtraction algorithm?

- Can be used to achieve our physics goal
- Can be used in experimental measurements
- Can be used in theoretical calculations

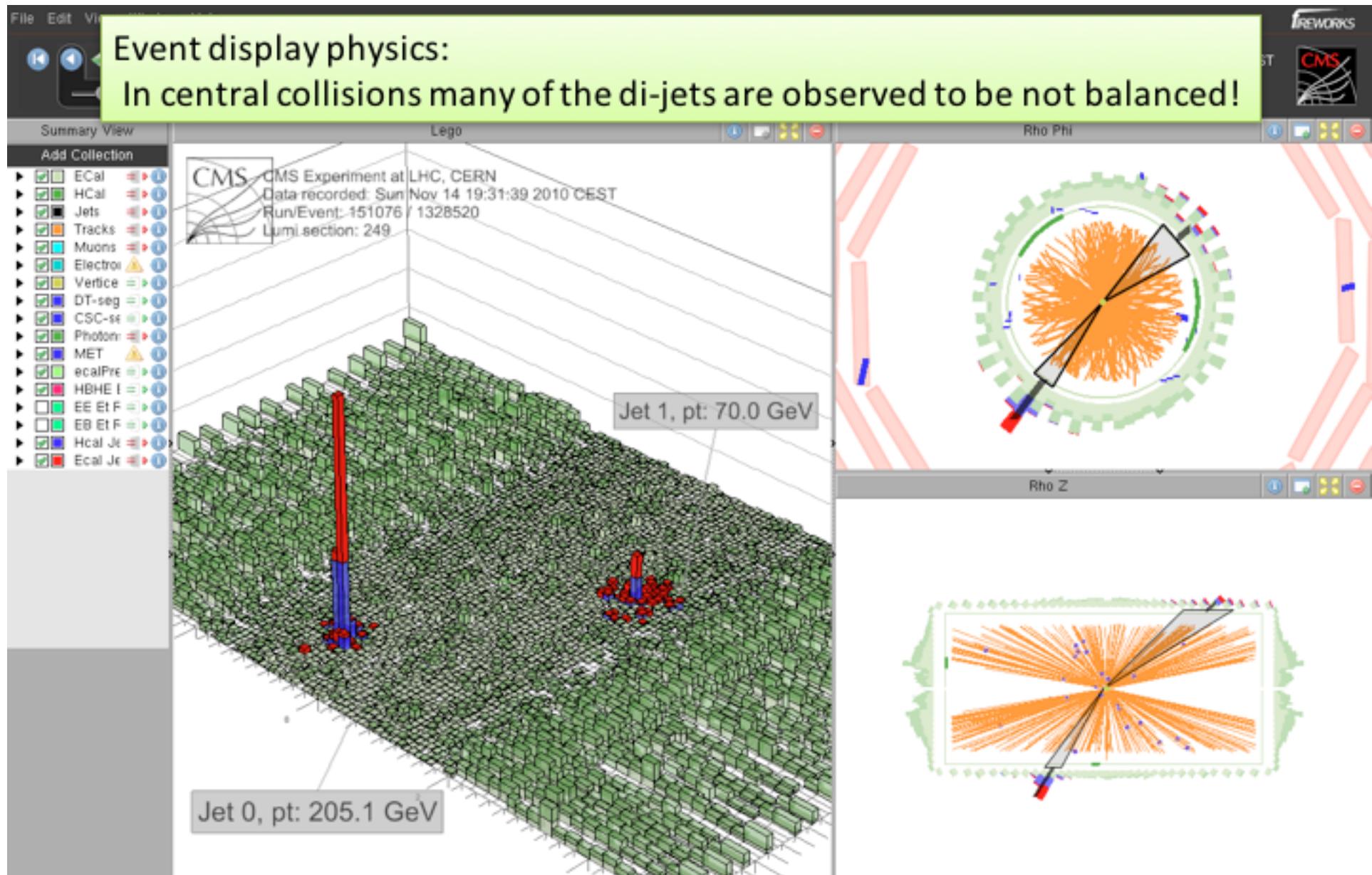
Minimal assumption on the factorization of “soft” ph
“hard” physics.

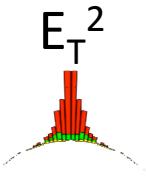
Classification should be theoretically sound and rep
in calculations.



Don't do background subtraction if it is not necessary –
provide raw measurements along with corrected results &
corrections.

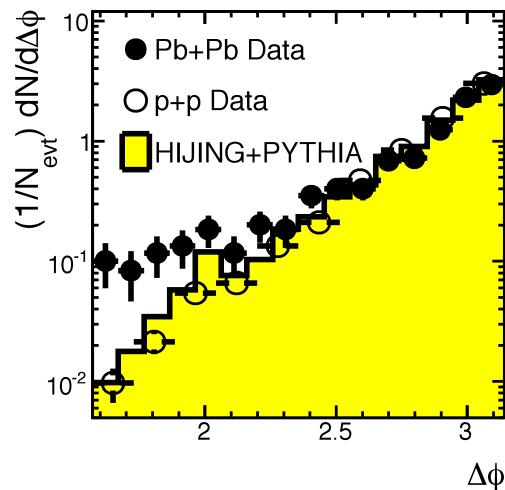
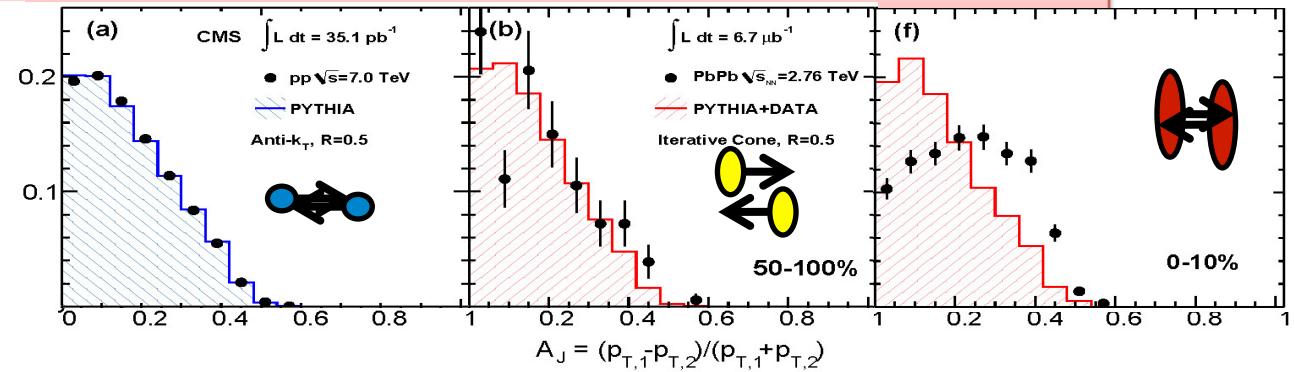
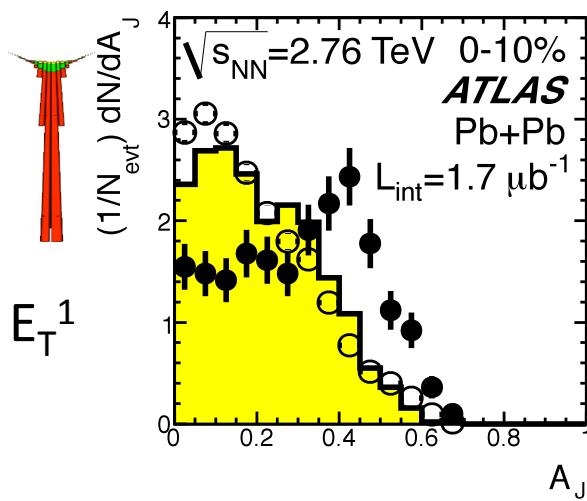
Some Lessons





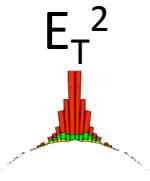
Studying Back-to-back jets

Angular correlations of jets is unmodified by the medium
Energy imbalance increases with centrality!



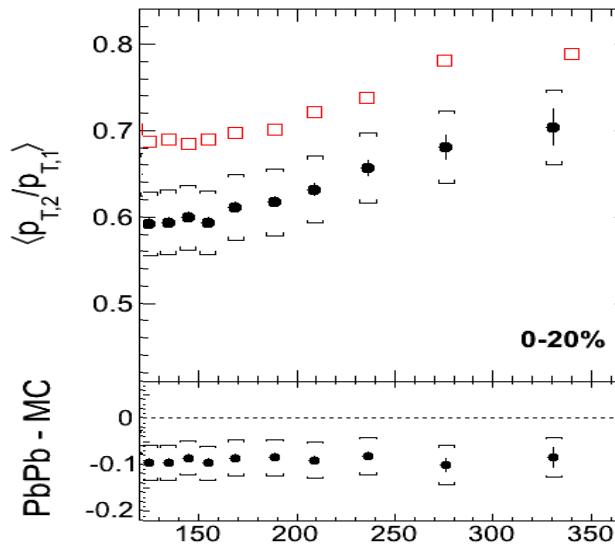
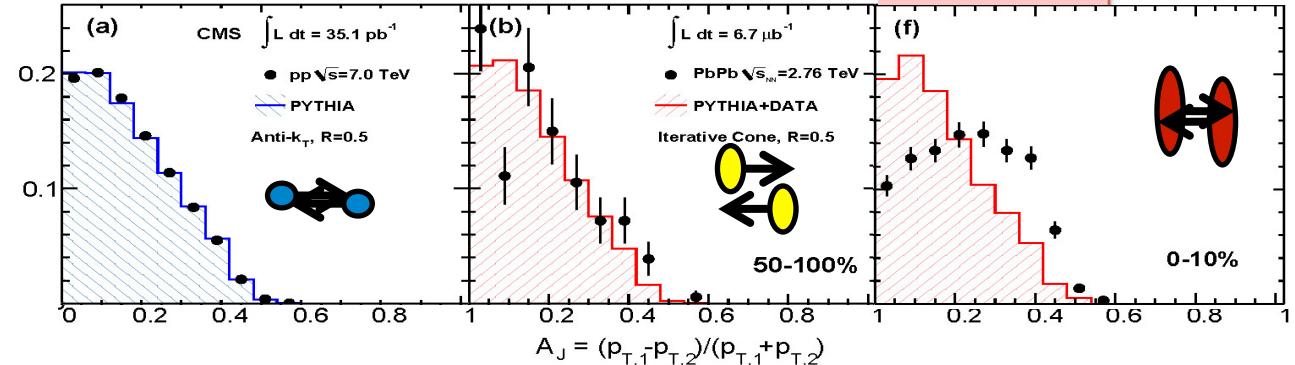
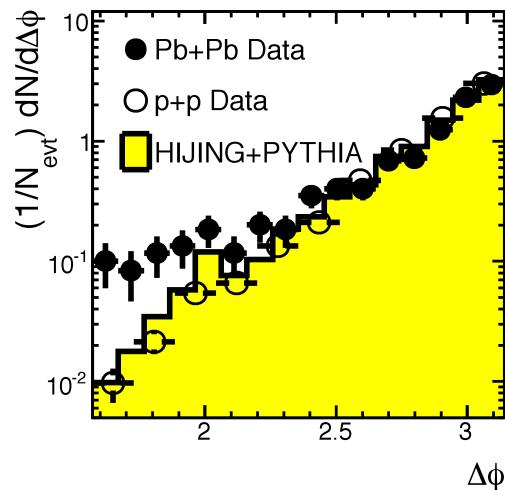
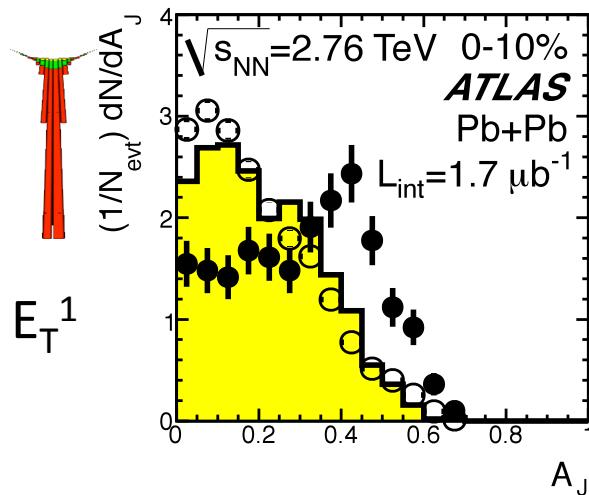
Use Asymmetry ratio :

$$A_j = \frac{E_T^{j1} - E_T^{j2}}{E_T^{j1} + E_T^{j2}}$$



Studying Back-to-back jets

Angular correlations of jets is unmodified by the medium
Energy imbalance increases with centrality!

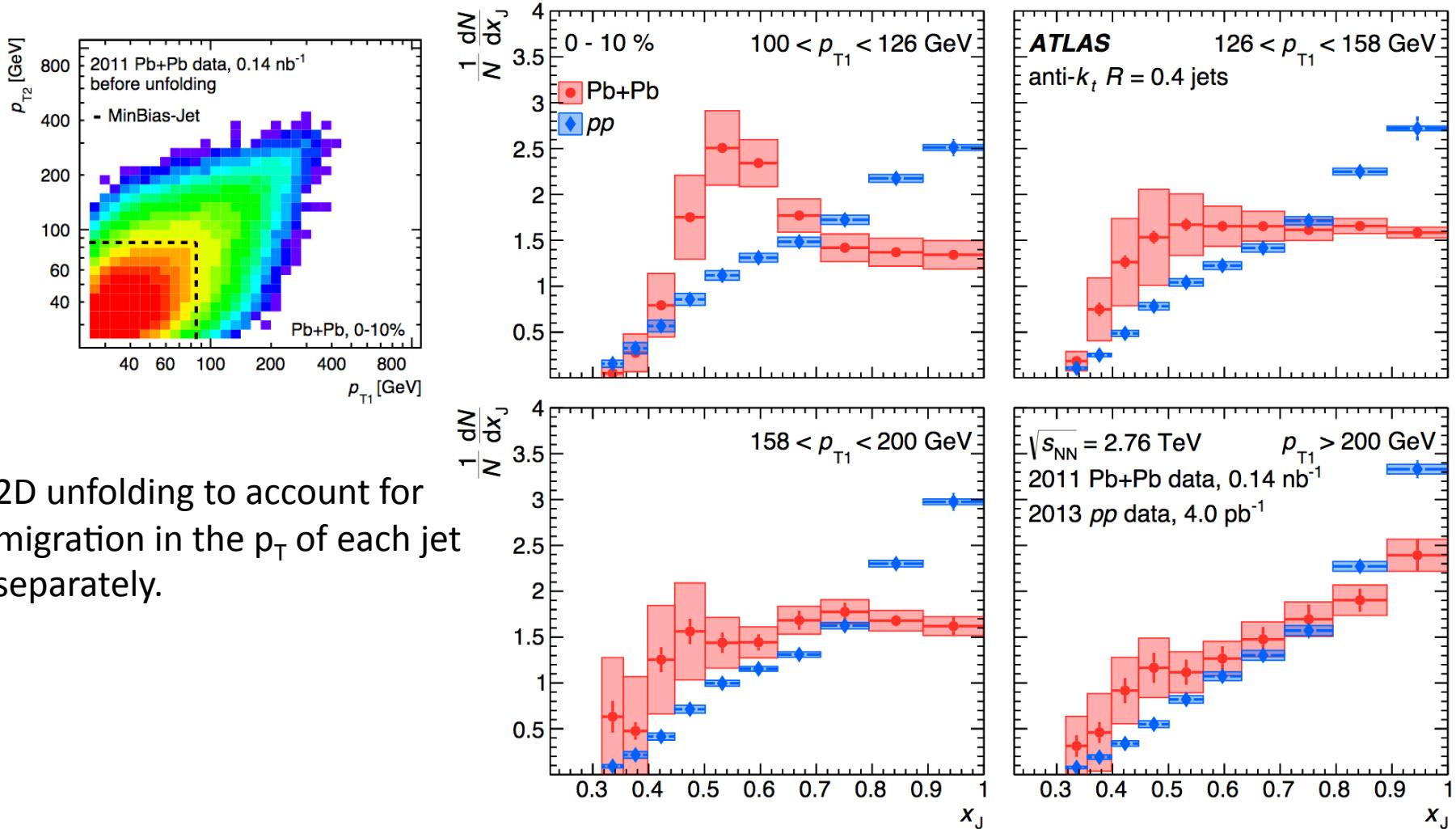


Use Asymmetry ratio :

$$A_j = \frac{E_T^{j1} - E_T^{j2}}{E_T^{j1} + E_T^{j2}}$$

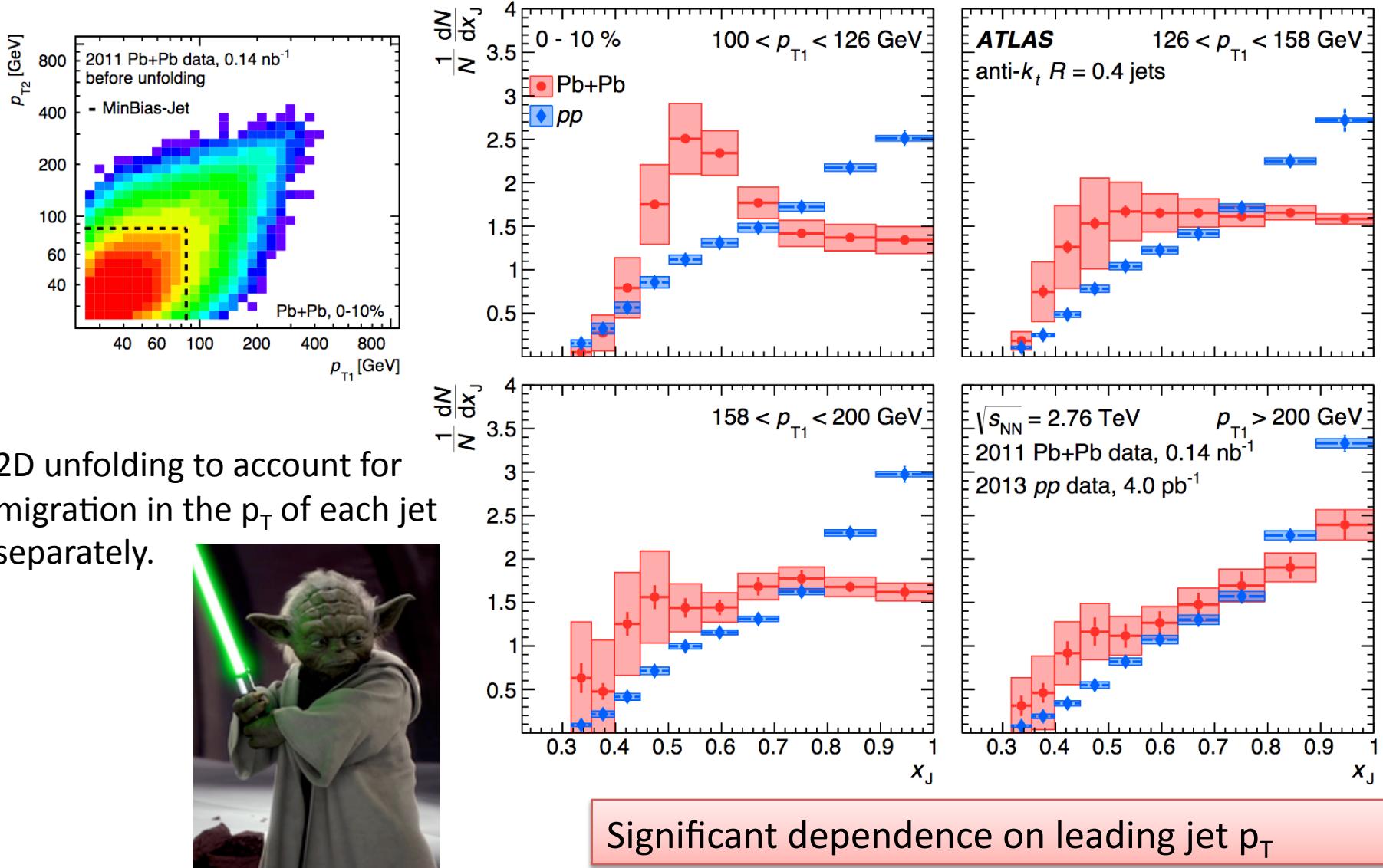
No significant dependence on leading jet p_T

Studying back-to-back results: Unfolded results



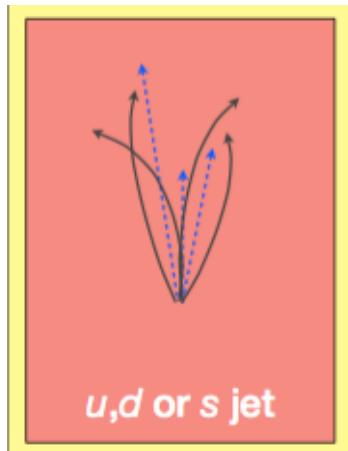
Significant dependence on leading jet p_T

Studying back-to-back results: Unfolded results

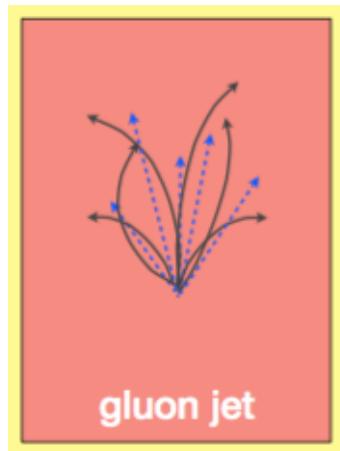


Interpretation depends on assumptions for corrections!

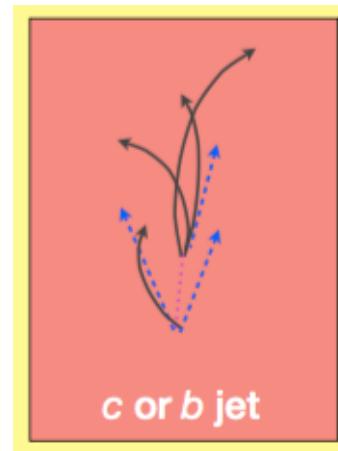
“More Sensitive” Jet Substructure Observables?



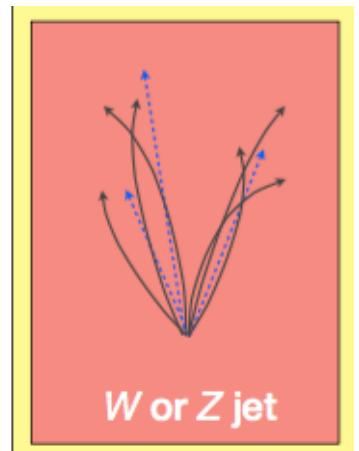
u,d or s jet



gluon jet



c or b jet



W or Z jet

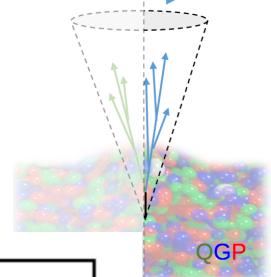
To what extent can the identities of underlying partons be deduced from properties of the jets they produce?

Jet Shapes and Fragmentation Functions are expected to be sensitive to the possible medium response to hard probes and induced radiation.

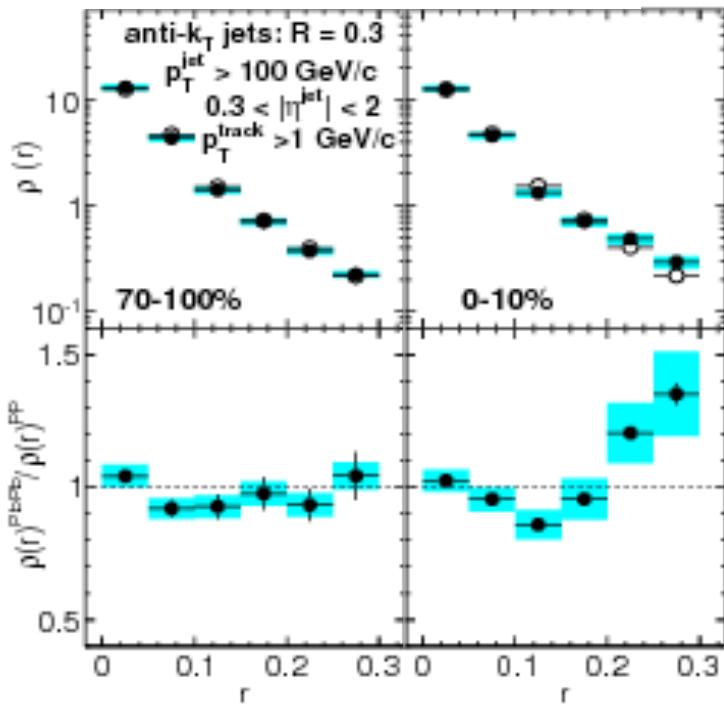


Jet Shapes:

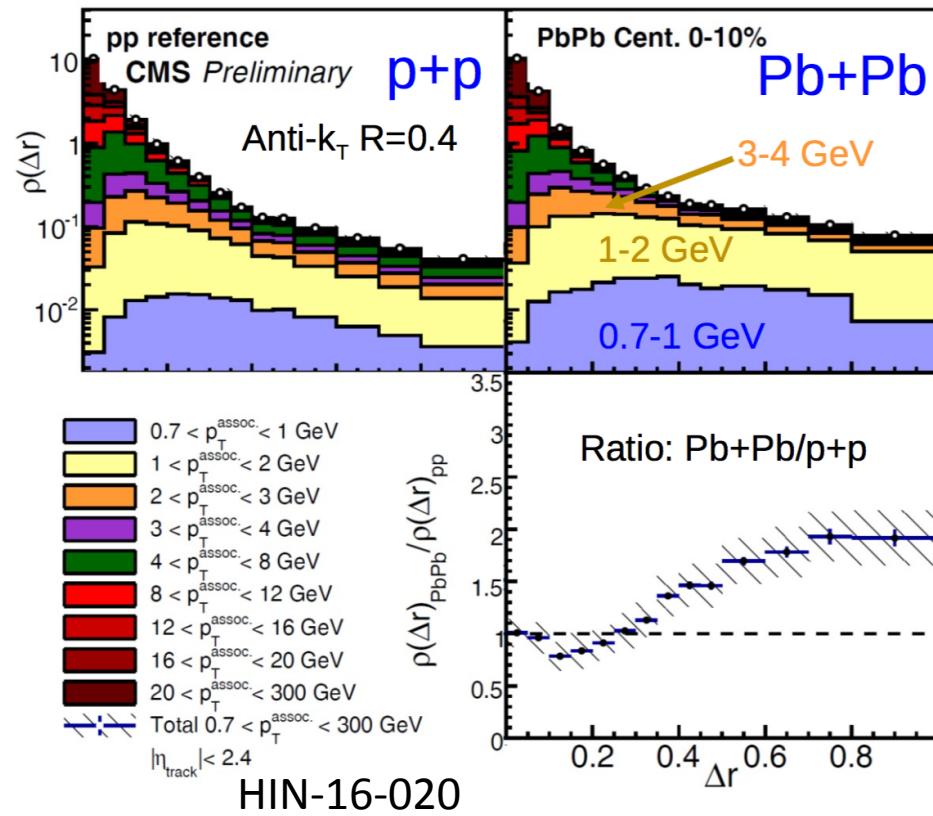
Jet axis



$$\rho(r) = \frac{1}{\delta r} \frac{1}{N_{\text{jet}} \text{ jets}} \sum \frac{\sum_{\text{tracks } \in [r_a, r_b]} p_T^{\text{track}}}{p_T^{\text{jet}}}$$

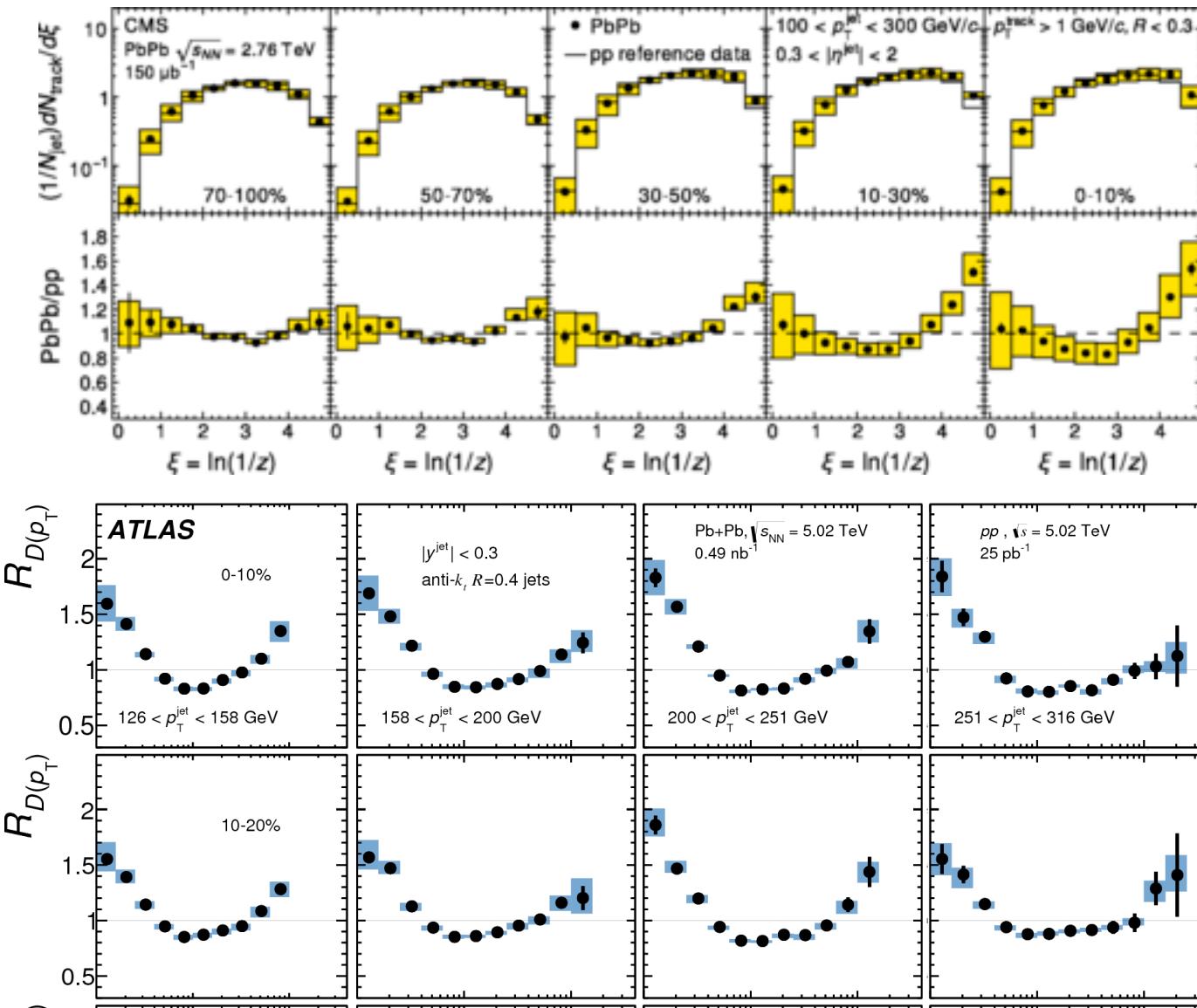


Phys. Lett. B 730 (2014) 243



Broadened jet shape due to the possible medium response to hard probes and induced radiation!

Fragmentation Functions



Enhancement of particles with a small fraction and a large fraction p_T

Measurement of jet fragmentation into charged particles in pp and PbPb collisions at

$$\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}$$

JHEP10(2012)087

The CMS collaboration

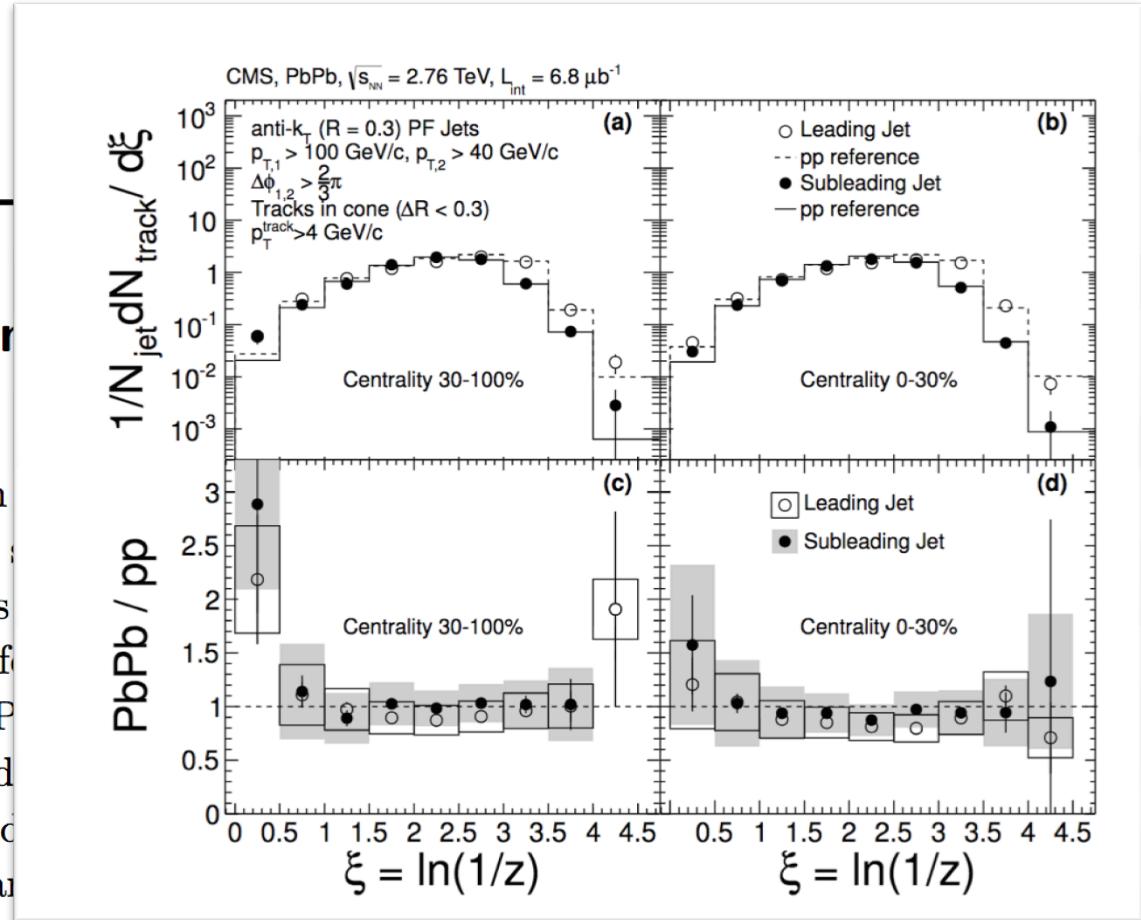
ABSTRACT: Jet fragmentation in pp and PbPb collisions at a centre-of-mass energy of 2.76 TeV per nucleon pair was studied using data collected with the CMS detector at the LHC. Fragmentation functions are constructed using charged-particle tracks with transverse momenta $p_T > 4 \text{ GeV}/c$ for dijet events with a leading jet of $p_T > 100 \text{ GeV}/c$. The fragmentation functions in PbPb events are compared to those in pp data as a function of collision centrality, as well as dijet- p_T imbalance. Special emphasis is placed on the most central PbPb events including dijets with unbalanced momentum, indicative of energy loss of the hard scattered parent partons. The fragmentation patterns for both the leading and subleading jets in PbPb collisions agree with those seen in pp data at 2.76 TeV. The results provide evidence that, despite the large parton energy loss observed in PbPb collisions, the partition of the remaining momentum within the jet cone into high- p_T particles is not strongly modified in comparison to that observed for jets in vacuum.

Measurement of jet fragmentation into charged particles in pp and PbPb collisions at $\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}$

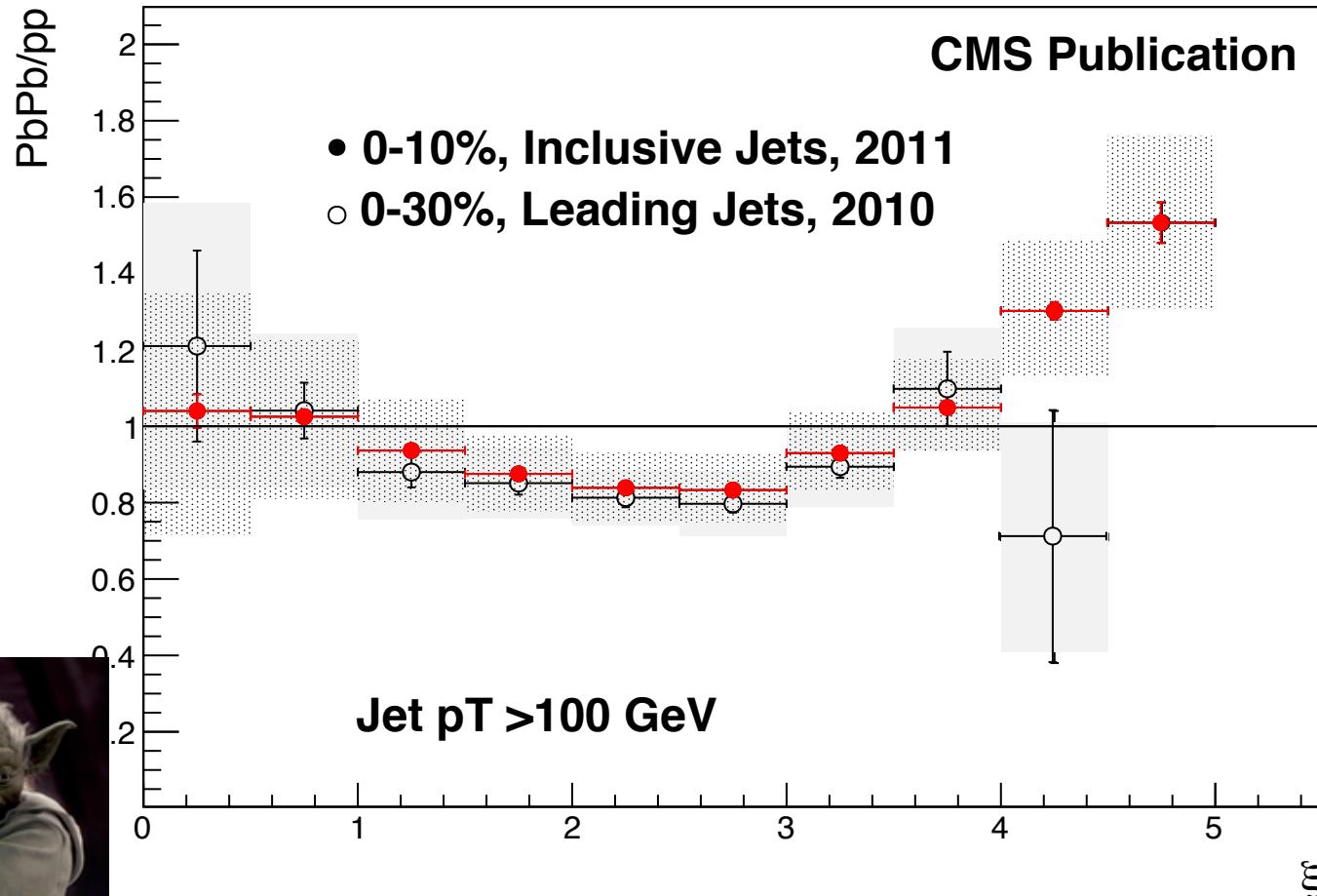
JHEP10(2012)087

The CMS collaboration

ABSTRACT: Jet fragmentation at $\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}$ per nucleon pair was measured in pp and PbPb collisions at the LHC. Fragmentation functions were measured for transverse momenta $p_T > 4 \text{ GeV}/c$ for jets with $R = 0.3$. The fragmentation functions in PbPb collisions were measured as a function of collision centrality, as well as d $\Gamma/\text{d}\xi$ in central PbPb events including contributions from both jets of the hard scattered parent pair. The fragmentation functions for the leading and subleading jets in PbPb collisions agree with those seen in pp data at 2.76 TeV. The results provide evidence that, despite the large parton energy loss observed in PbPb collisions, the partition of the remaining momentum within the jet cone into high- p_T particles is not strongly modified in comparison to that observed for jets in vacuum.

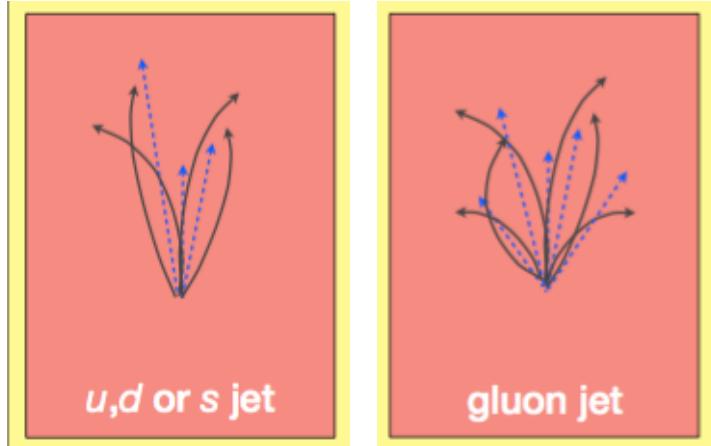


Jet Fragmentation Functions



Interpretation depends on where you look!

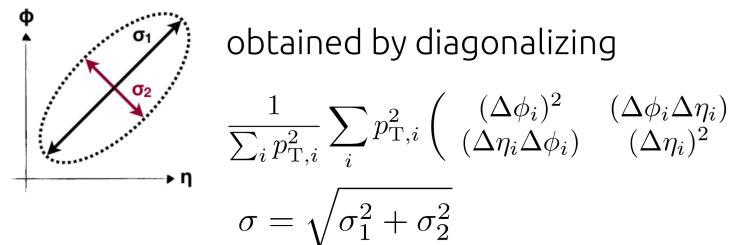
A template type analysis: Quark-gluon discrimination



Compared to gluon jets, quark jets in vacuum have:

1. Fewer constituents
2. Narrower shape
3. Harder fragmentation function and less symmetric energy sharing among constituents

1. Multiplicity: Total, Charged, Neutral → Particle-Flow in CMS
2. Width Variables



3. Energy Sharing Variables: Pull, R, $p_T D$, Girth

$$|\vec{t}| = \left| \frac{\sum_i p_{T,i}^2 |r_i| \vec{r}_i}{\sum_i p_{T,i}^2} \right| \quad \vec{r}_i = (\Delta\eta_i, \Delta\phi_i)$$

$$R = \frac{\max(p_{T,i})}{\sum_i p_{T,i}} \quad p_T D = \frac{\sqrt{\sum_i p_{T,i}^2}}{\sum_i p_{T,i}}$$

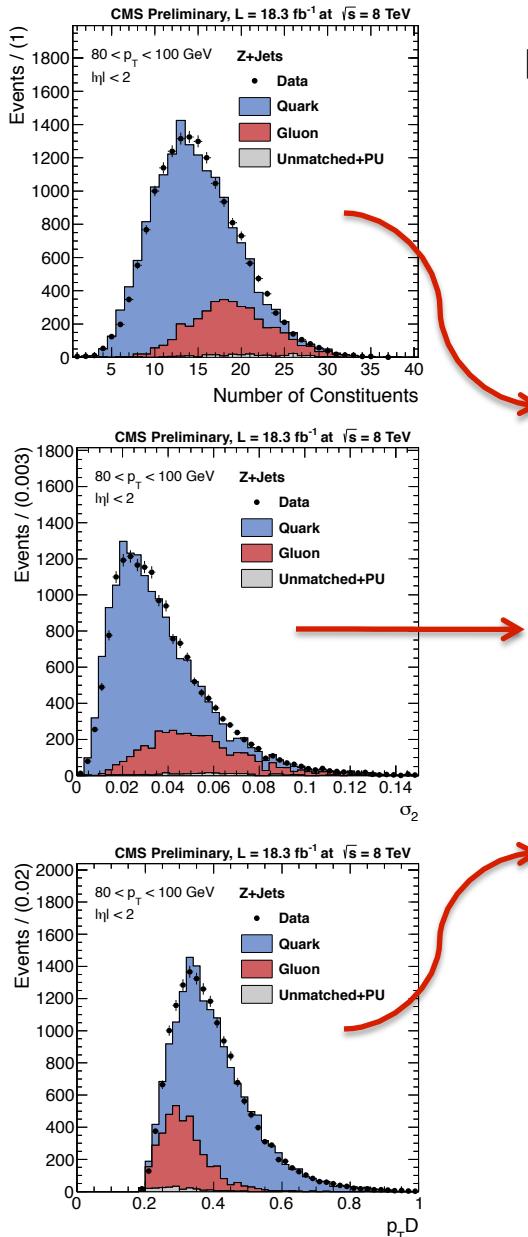
$$g = \sum_i \frac{p_T^i}{p_T^{jet}} |r_i|$$

$p_T D=1$ single jet constituent
 $p_T D=0 \propto$ number of jet constituents.

<http://cds.cern.ch/record/1599732/files/JME-13-002-pas.pdf>

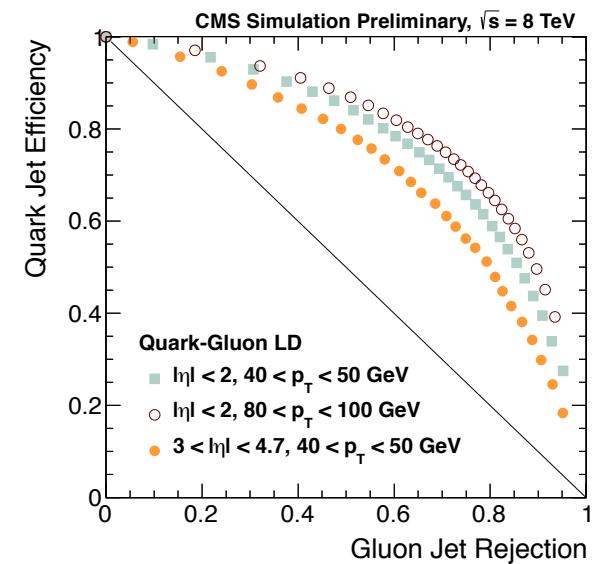
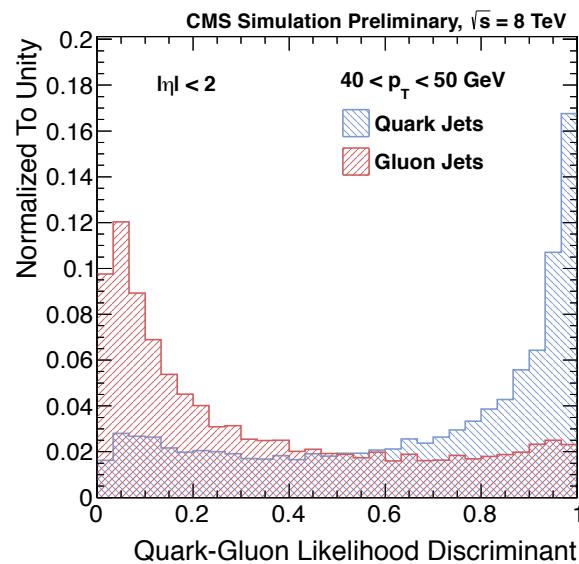
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsJME1300>

A template type analysis: Quark-gluon discrimination in pp



Likelihood based discriminator obtained by combining 3 variables:

- Total multiplicity
- Minor axis
- $p_T D$



Good background rejection and signal efficiency

Stability vs pile-up is under investigation

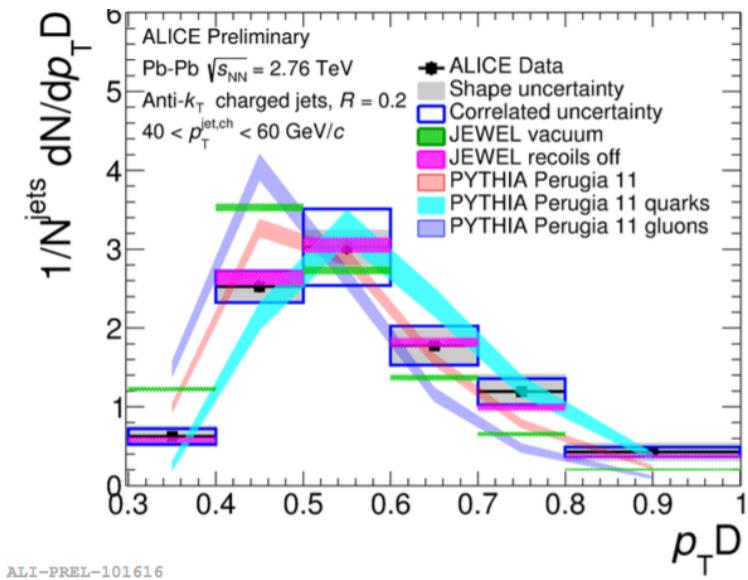
Is not directly applicable yet to AA but combine it with other taggers.

<http://cds.cern.ch/record/1599732/files/JME-13-002-pas.pdf>

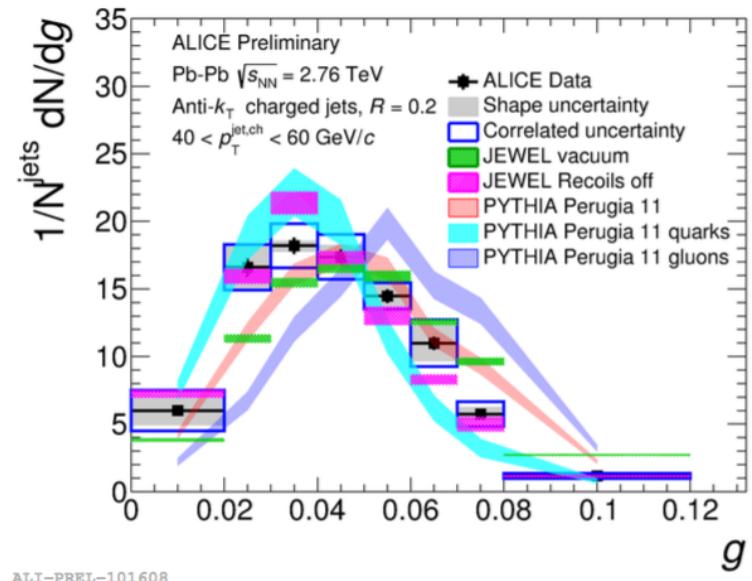
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsJME13002>

Jet Shape Variables in PbPb: Dispersion & Girth

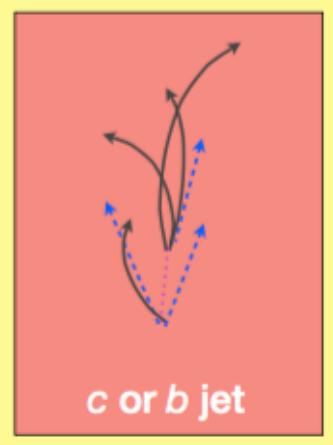
$$p_T D = \frac{\sqrt{\sum_i p_{T,i}^2}}{\sum_i p_{T,i}}$$



$p_T D$ distribution shifted to larger values
 A selection bias towards quark jets &
 harder fragmenting jets?

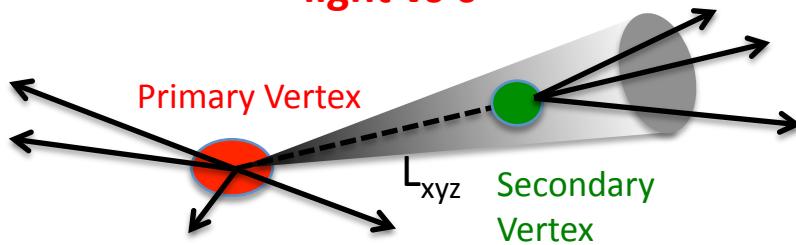


Jet girth (the p_T weighted jet) width is narrower!
 Possible bias towards quark jets?

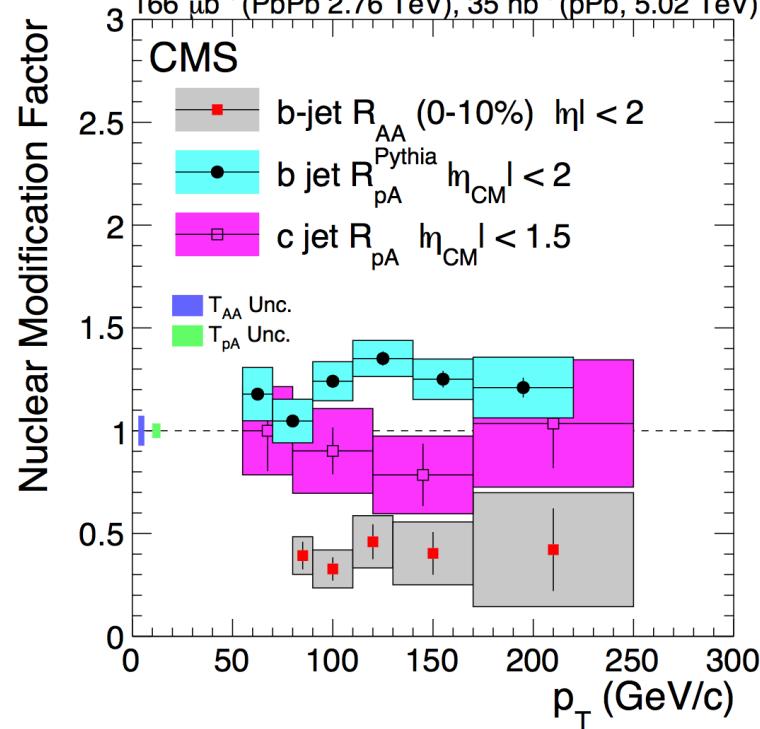
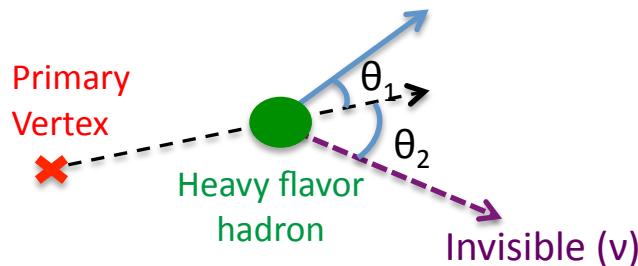


Heavy Flavour Parton Dependence

3+ Body Secondary Vertex Tagging: light vs c



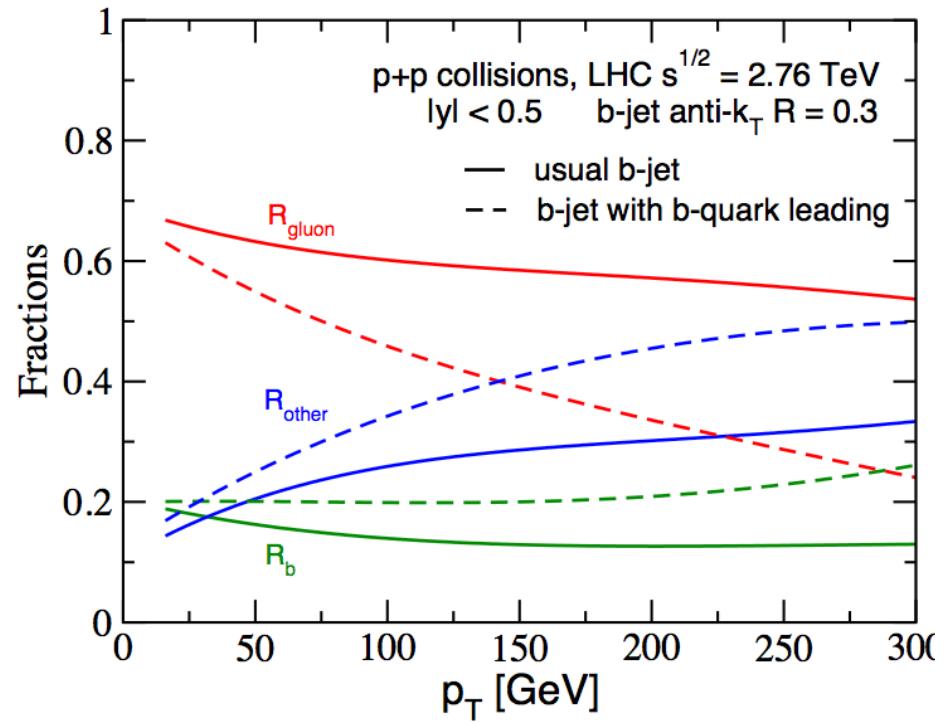
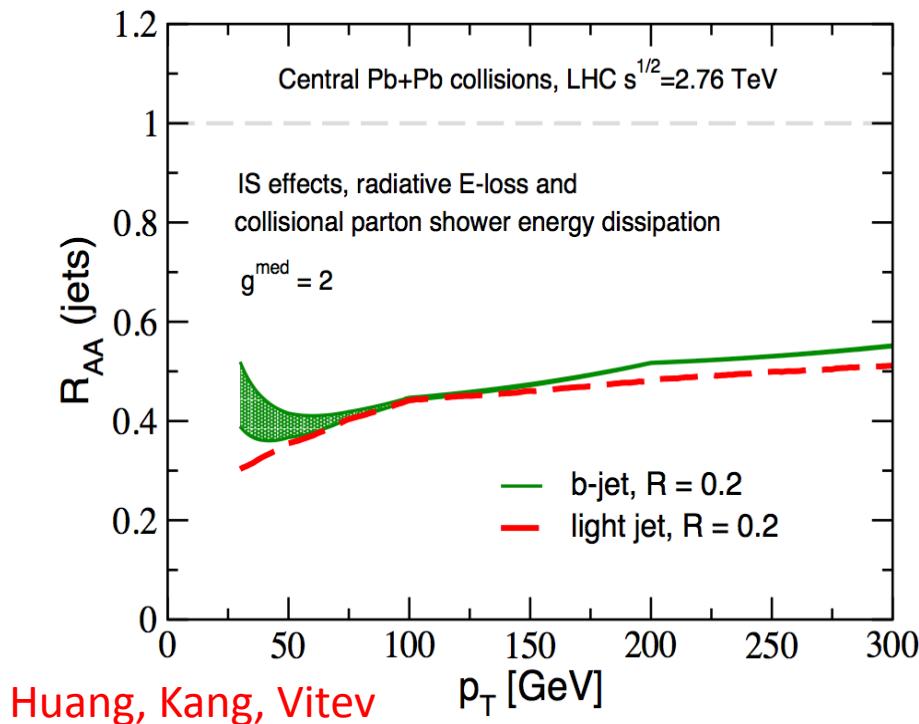
Corrected Secondary Vertex Mass: c vs b



suppression of b quarks in PbPb,
while no suppression in pPb
collisions

CMS, Phys. Rev. Lett. 113, no. 13, 132301 (2014)
CMS, Phys. Lett. B 754, 59 (2016)
CMS, arXiv:1612.08972 (2016)

Caveat: b/c jet might not be original!

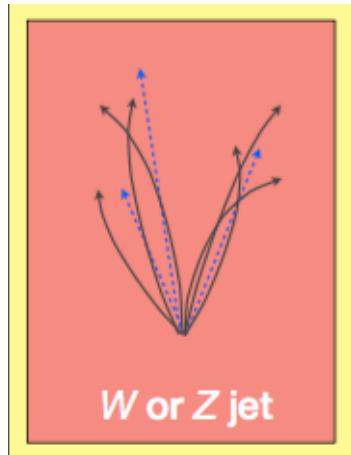


At high p_T region, mass effect can be neglected

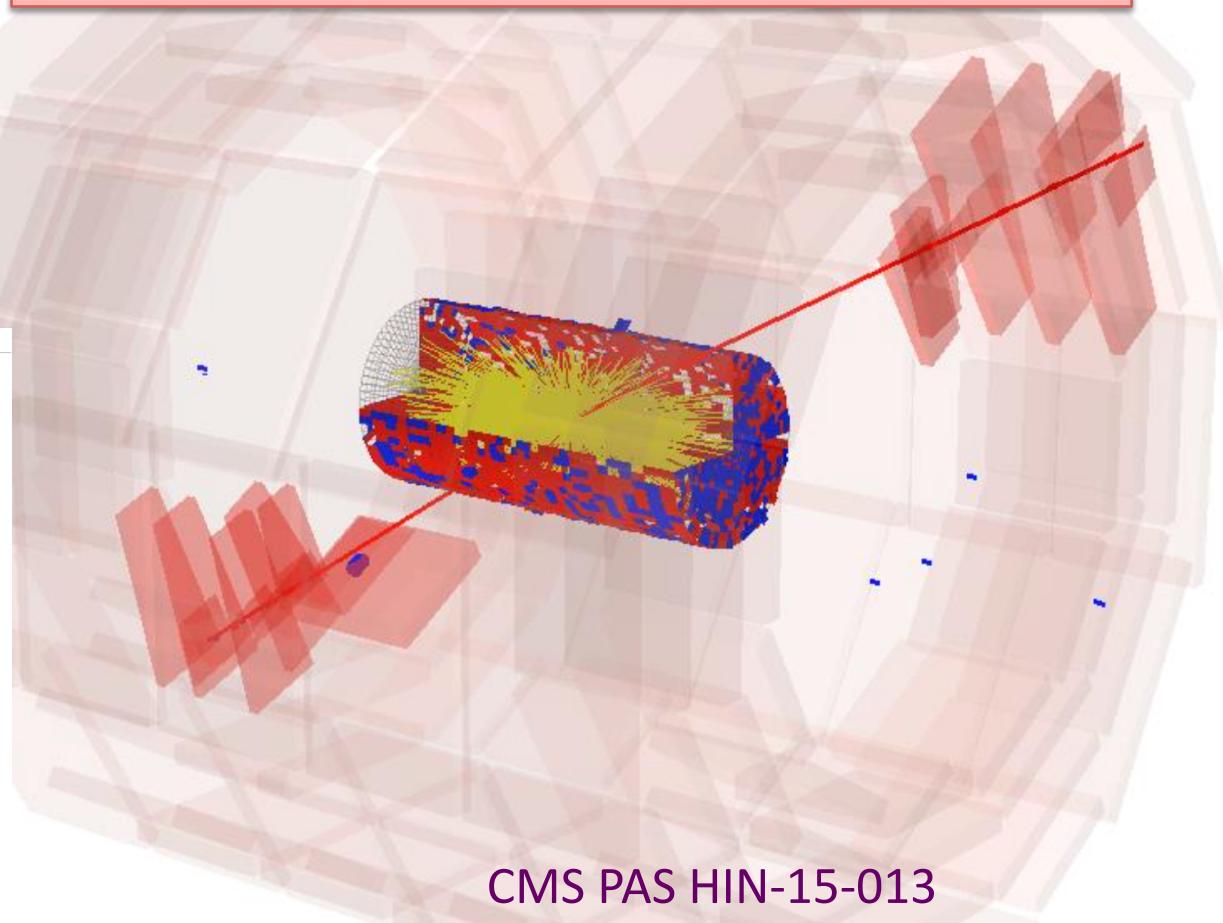
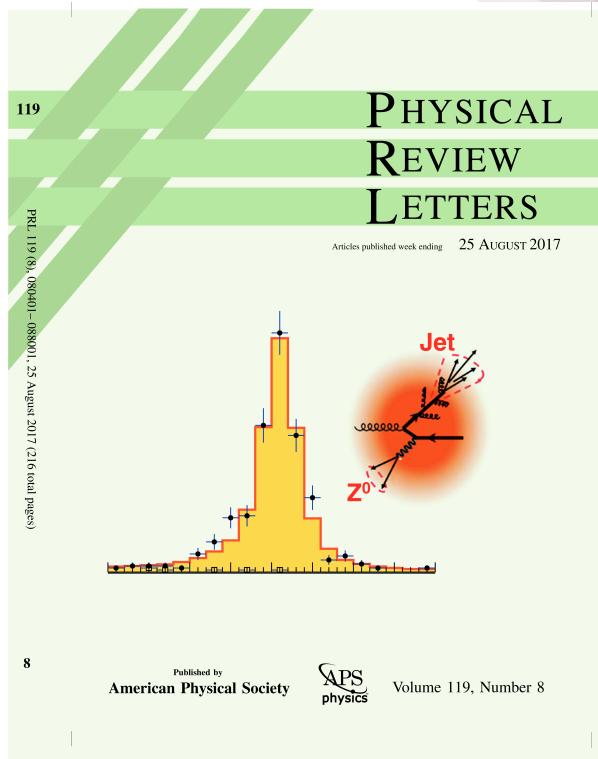
R_{gluon} :fraction of $g \rightarrow b$
 R_b :fraction of $b \rightarrow b$
 R_{other} :fraction of $q \rightarrow b$

Explore multi tags such as c/b jet with D/B and γ . Many new results released!

Z/Y+jets at 5 TeV PbPb

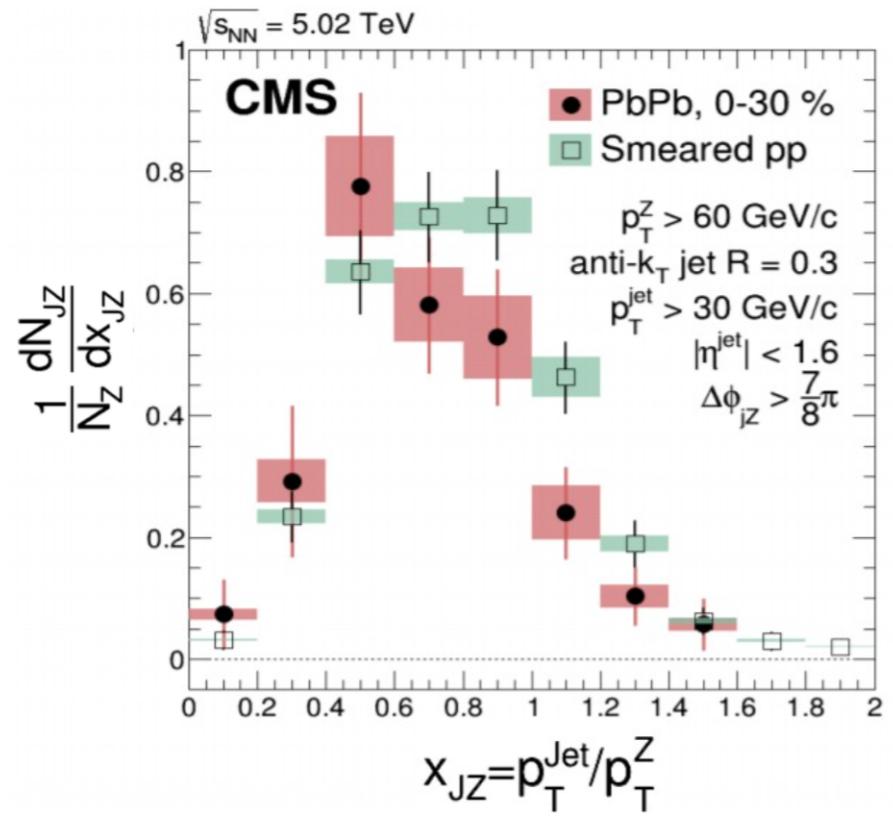
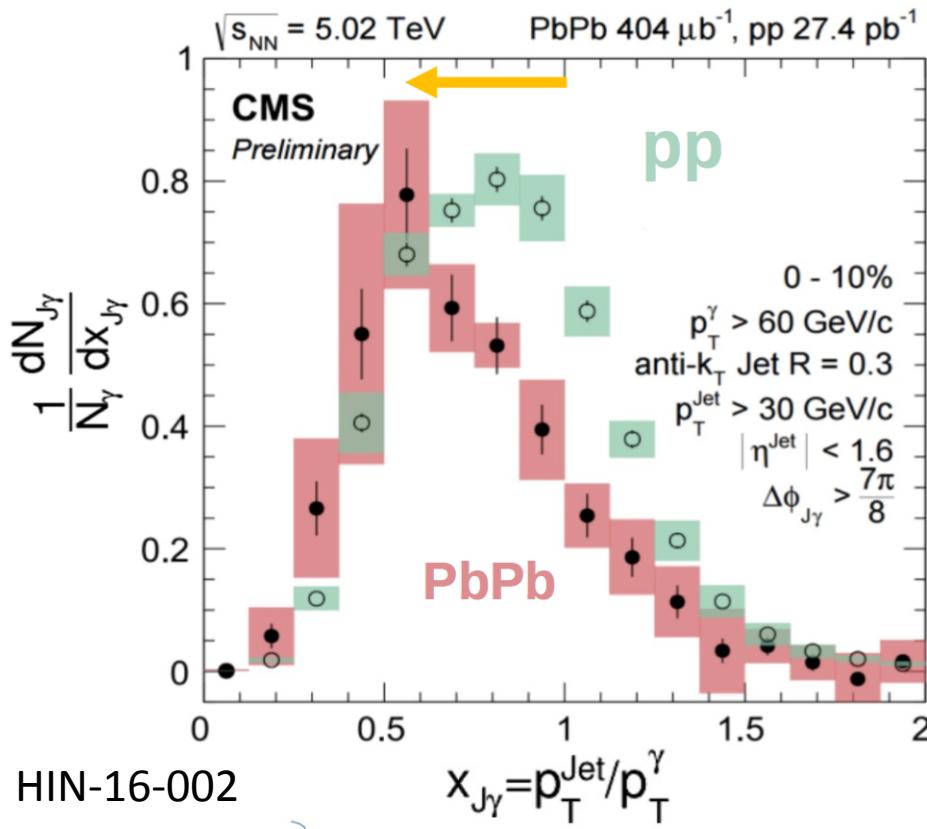


Z bosons and photons aren't affected by medium
Energy of the jet before energy loss is known.



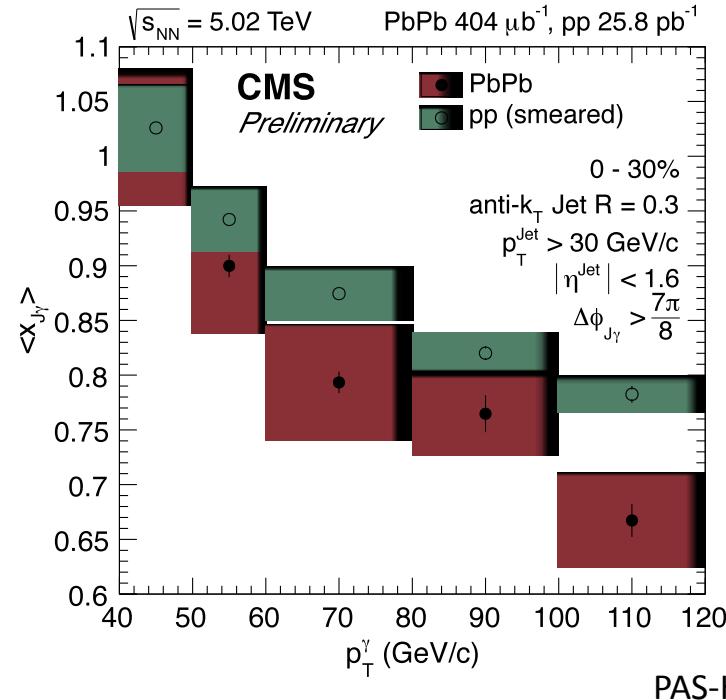
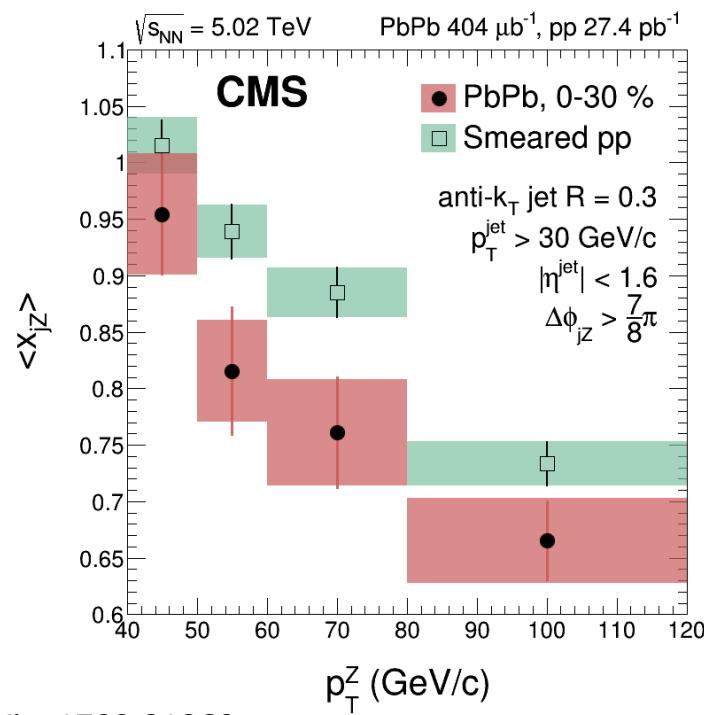
CMS PAS HIN-15-013
[Phys. Rev. Lett. 119 \(2017\) 082301](#)

Z/ γ +jets at 5 TeV PbPb



[Phys. Rev. Lett. 119 \(2017\) 082301](#)

Z/ γ +jets at 5 TeV PbPb



$$x_{J\gamma} = \frac{p_T^{\text{jet}}}{p_T^\gamma}$$

pp
PbPb

PAS-HIN-16-002

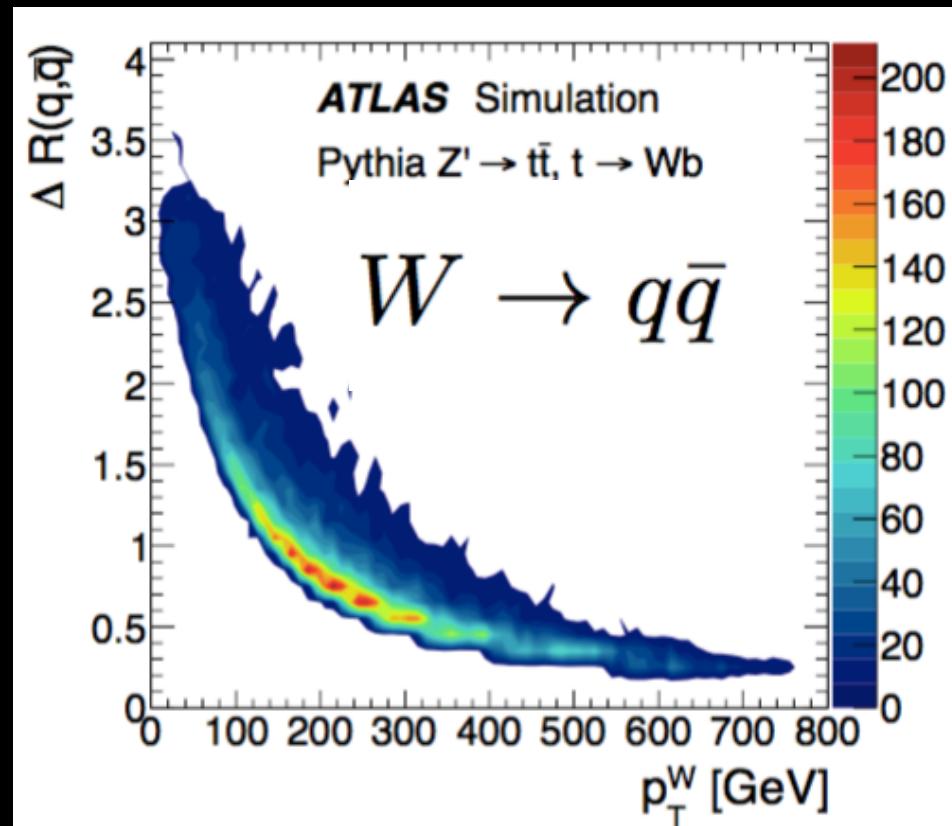
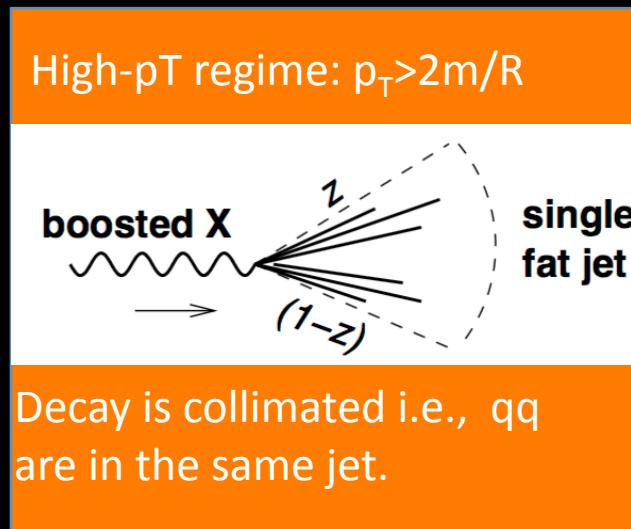
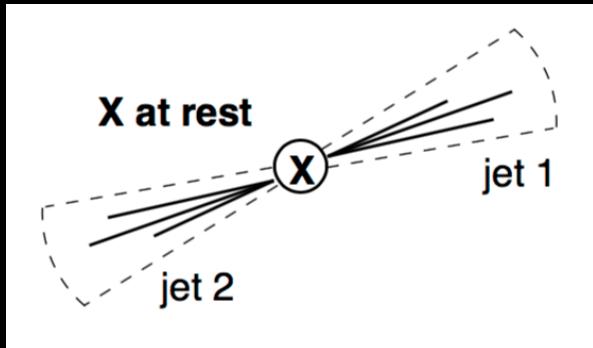
arXiv: 1702.01060

PRL 119 (2017) 082301

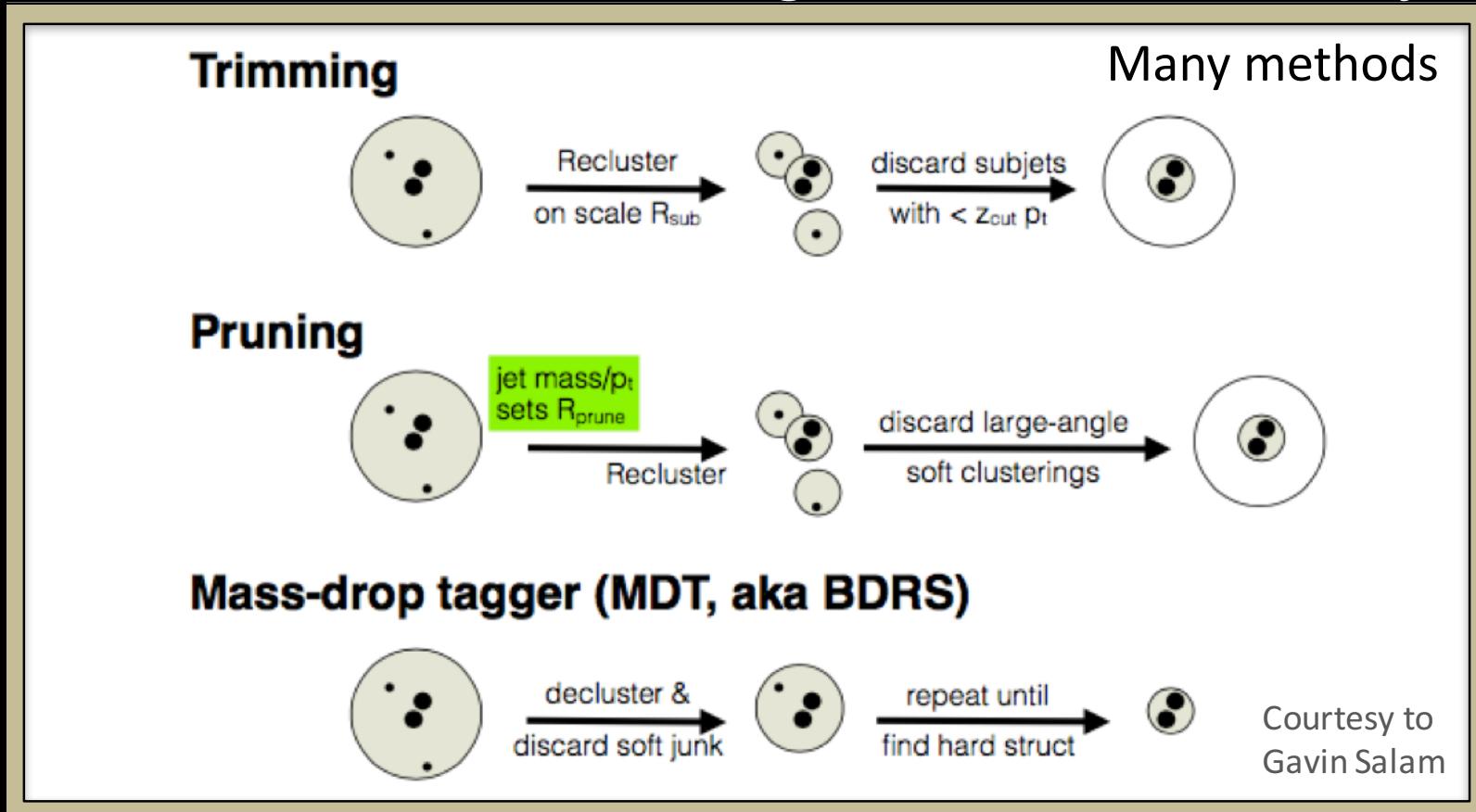
Jets loose ~15% energy due to medium interaction
Higher statistics Future LHC data is needed!



Utilize tools developed for pp ☺ - Jet Grooming:
the systematic removal of a subset of the jet constituents
→ remove soft and wide-angle radiation from the jet



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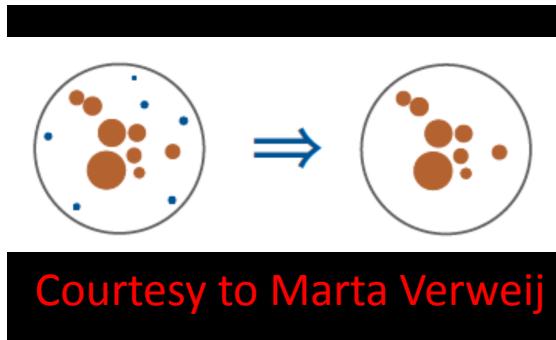
Butterworth,Davison,Rubin,Salam:Phys.Rev.Lett.100:242001,2008

Kaplan,Reherman,Schwartz,Tweedie:Phys.Rev.Lett101:142001,2008, arXiv:0806.0848

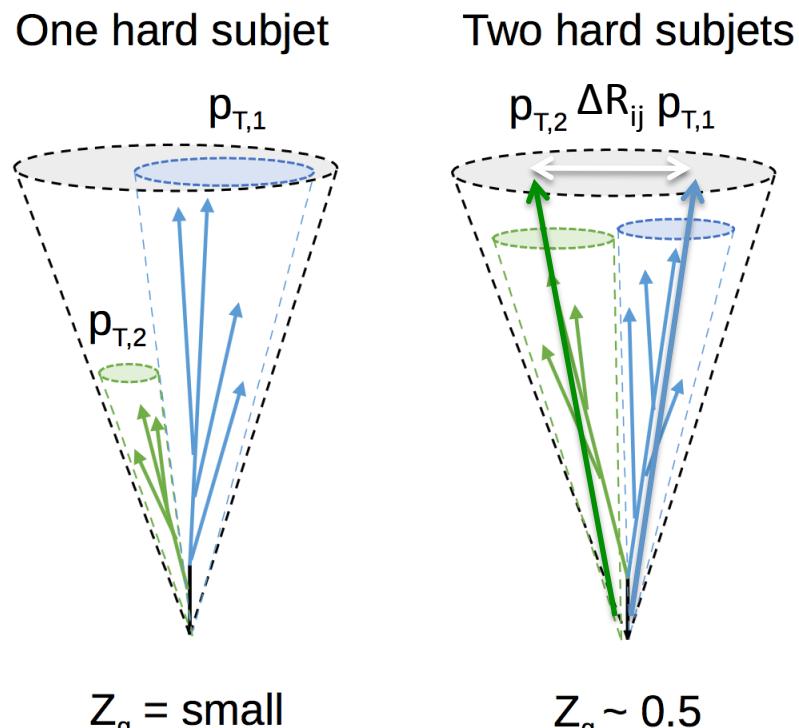
Ellis,Vermilion,Walsh:Phys.Rev.D80(2009)051501,arXiv: 0903.5081

Gallicchio and Schwartz,Phys.Rev.Lett.105:022001,2010,arXiv: 1001.5027v3 and others

Utilize tools developed for pp ☺ - Jet Grooming:
the systematic removal of a subset of the jet constituents
→remove soft and wide-angle radiation from the jet



large-angle soft radiation and
bkg removed by grooming!



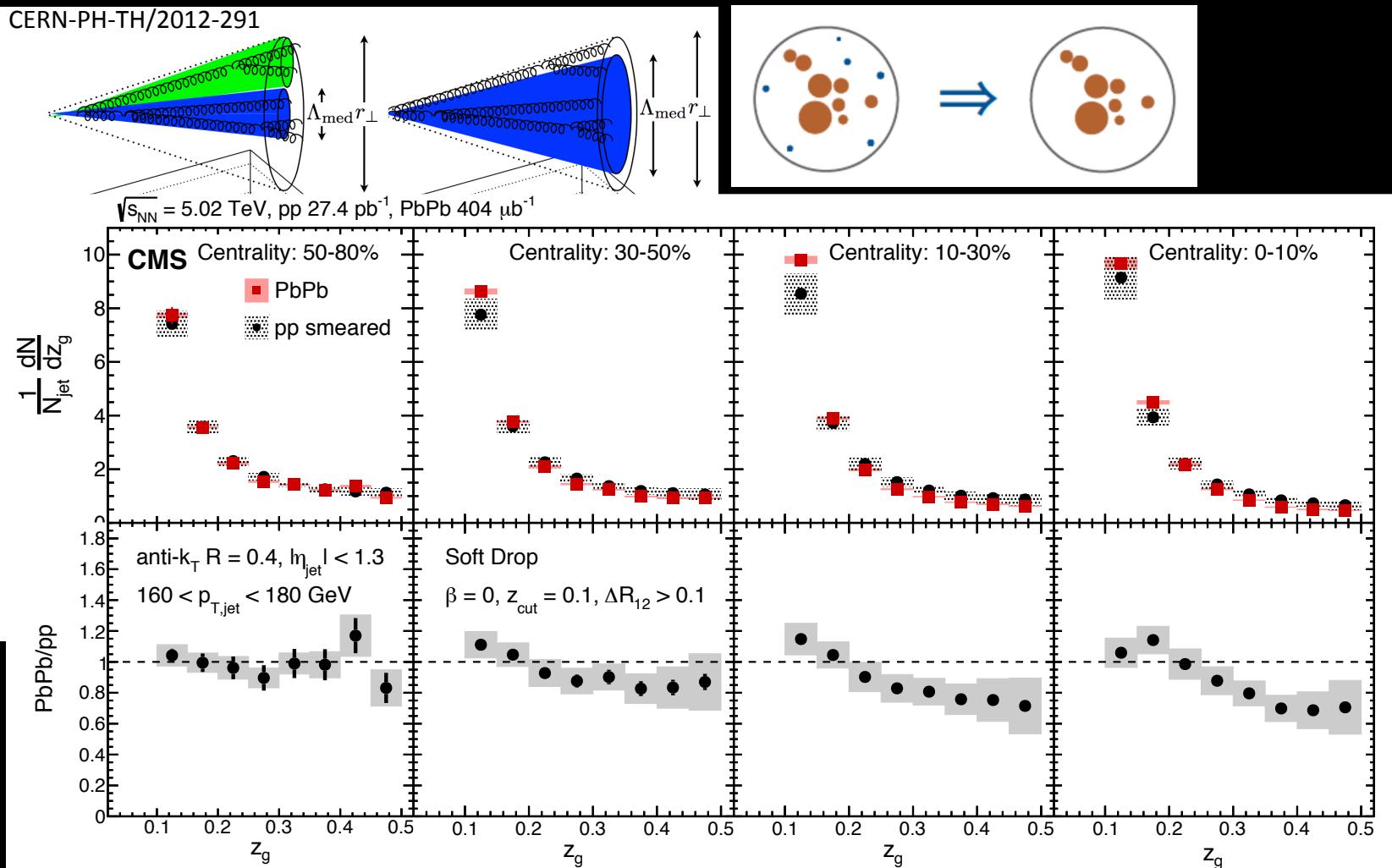
$$z_g = \frac{\min(p_{T,i}, p_{T,j})}{p_{T,i} + p_{T,j}} > z_{\text{cut}} \left(\frac{\Delta R_{ij}}{R_0} \right)^\beta,$$

Check out HP 2018 Raghav Kunnawalkam Elayavalli's talk on Thursday



Utilizing Jet Grooming

CERN-PH-TH/2012-291

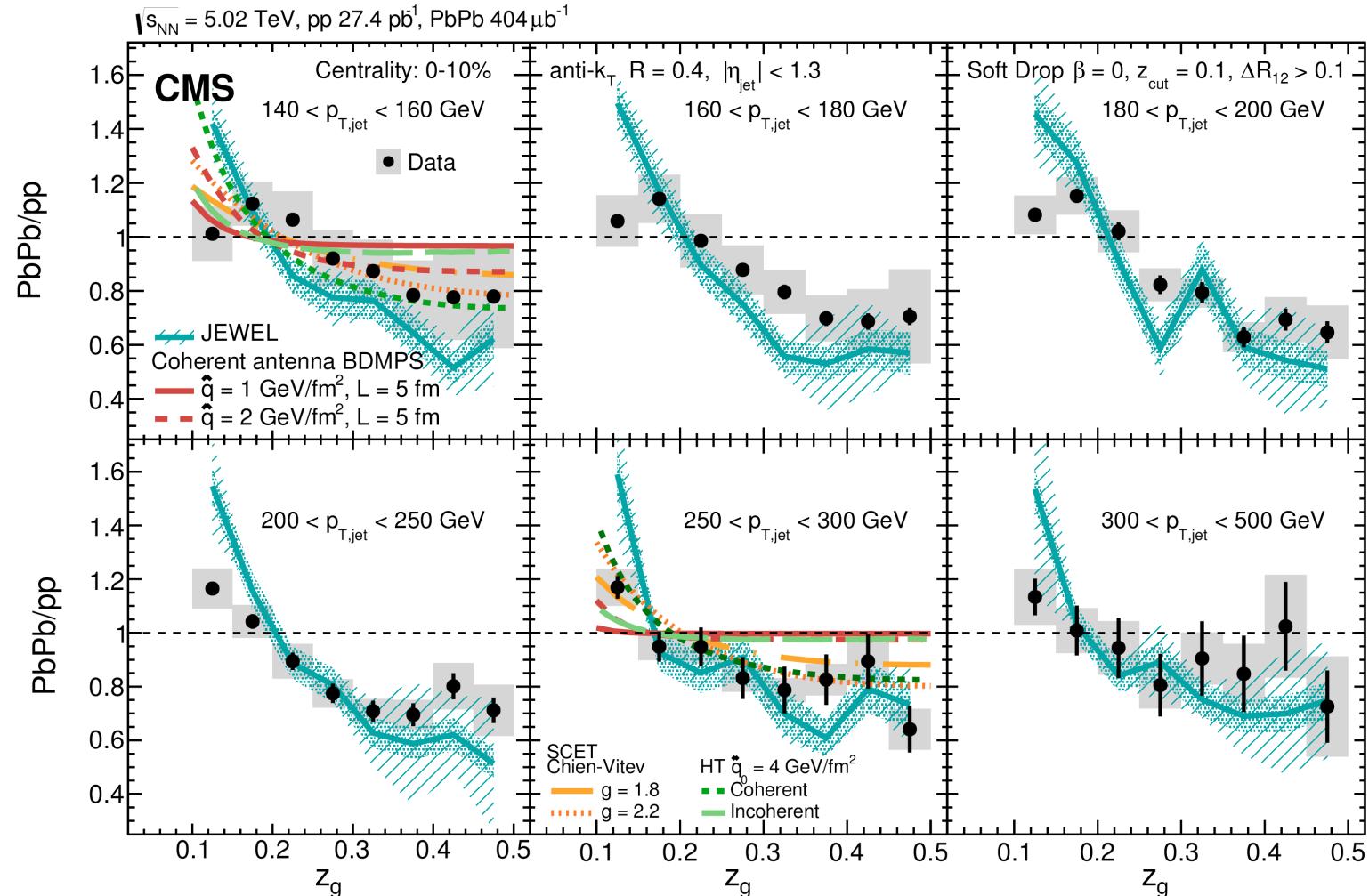


Momentum sharing between two leading subjets

$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$$

Modification of branch splitting of inclusive jet measurements !

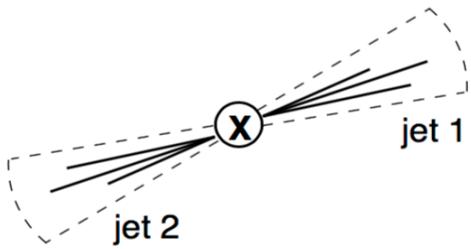
Utilizing Jet Grooming



No clear message from model comparisons
 → Need more precise and differential data

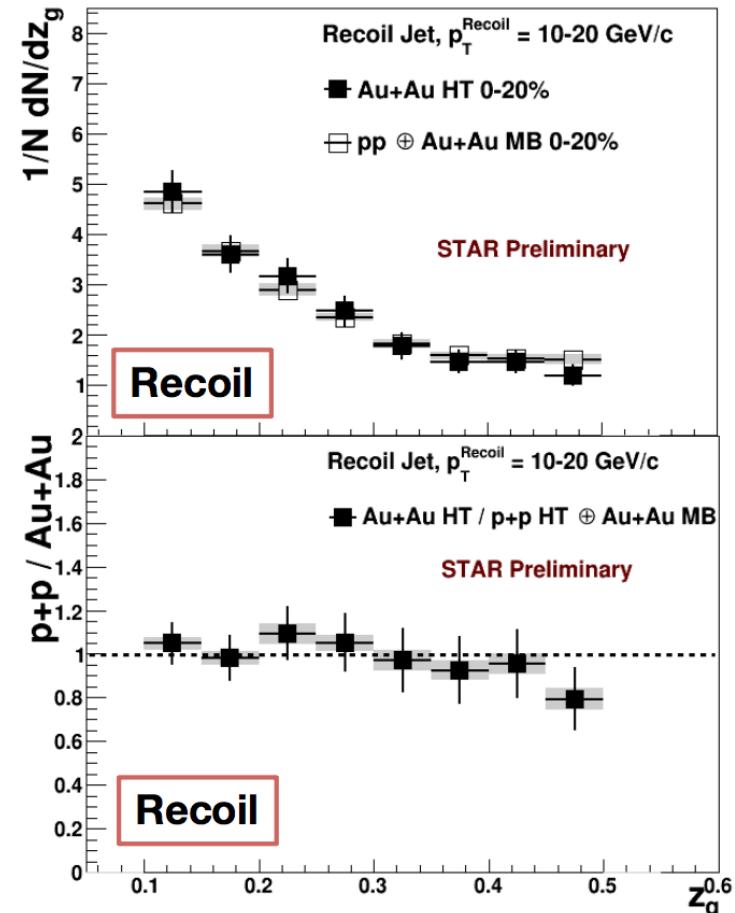
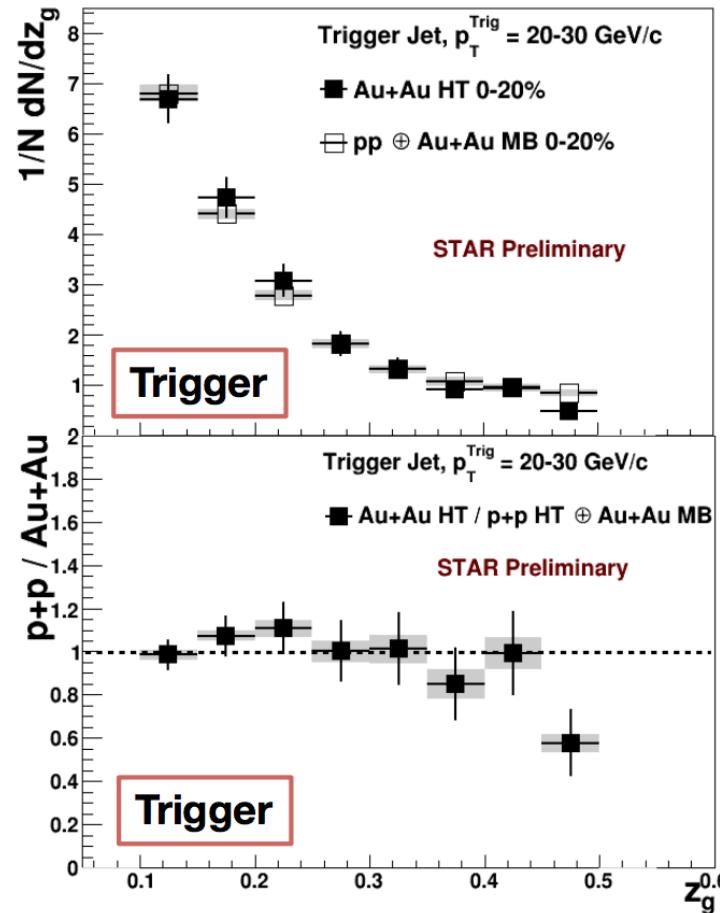
Courtesy to Marta Verweij

Sevil Salur



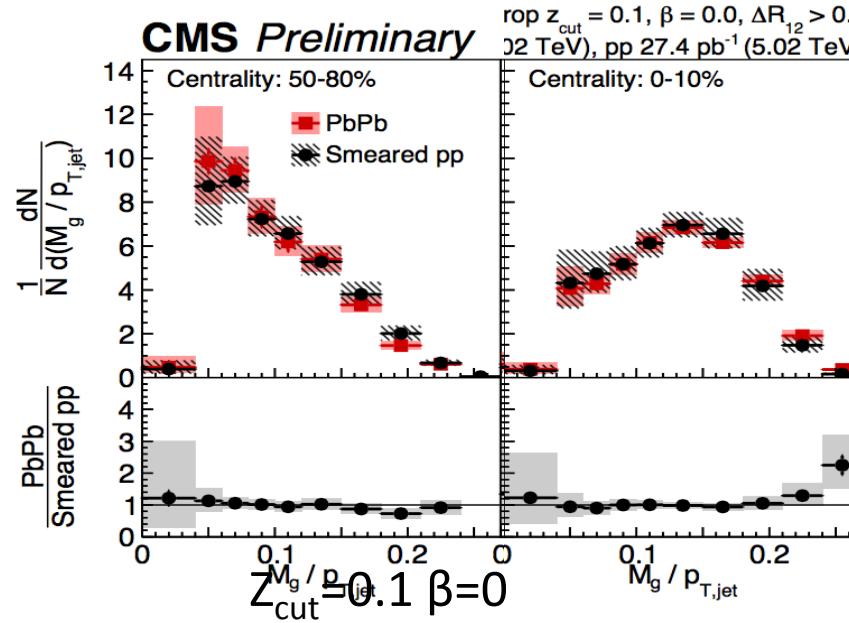
Utilizing Jet Grooming at RHIC with di-jets

Hard Core –Dijet Selection



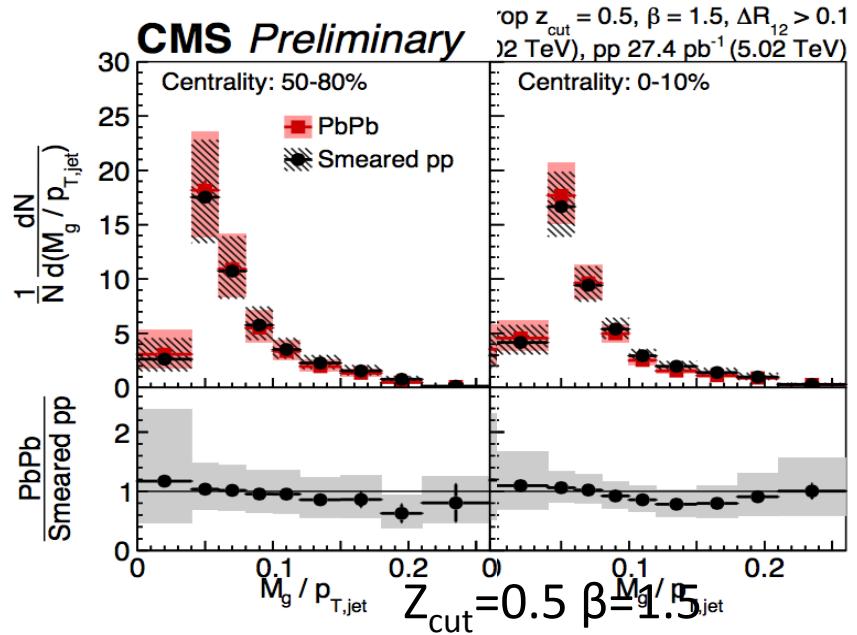
No observable difference in AuAu in comparison to pp

Groomed Jet Mass



Grooming Independent of angular separation

Core of the jet stays the same.



Grooming for larger angular separation

The periphery of the jet is sensitive to interactions of partons with the medium during the parton shower evolution.

Jet Mass w/o grooming

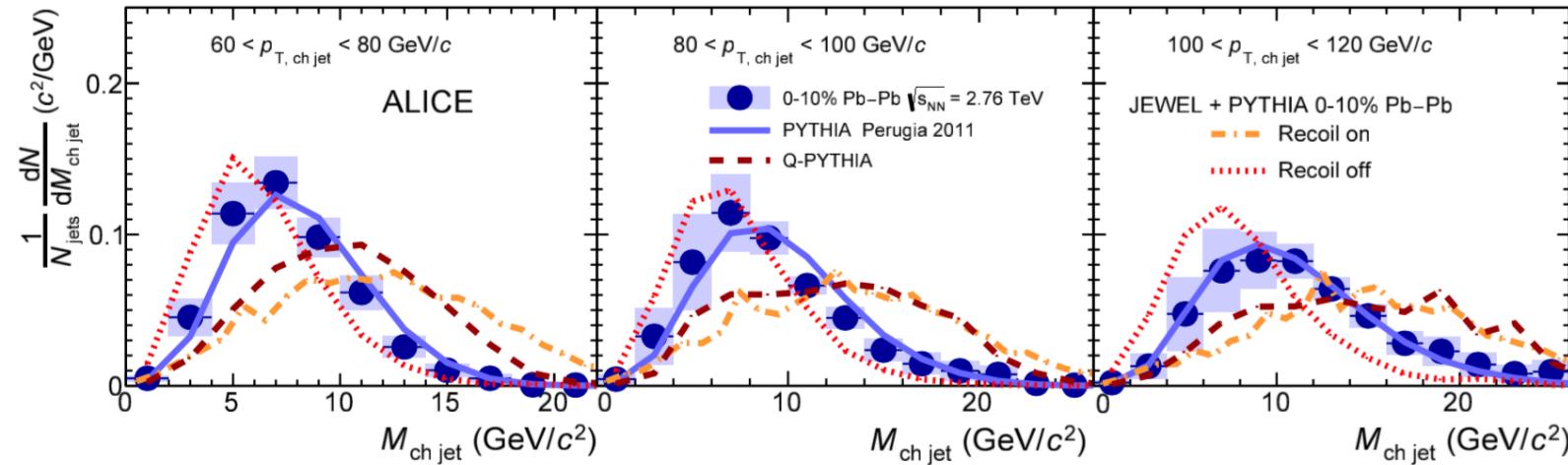


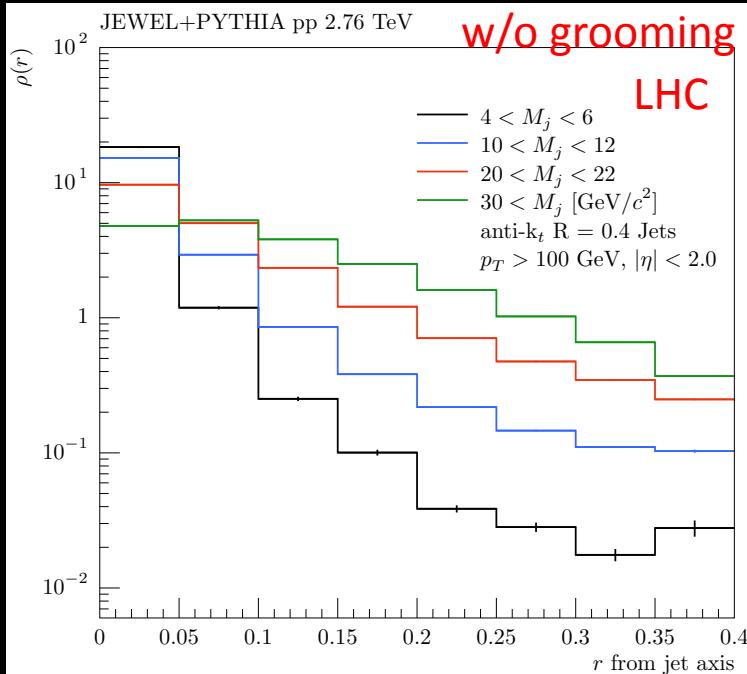
Fig. 10: Fully-corrected jet mass distribution for anti- k_T jets with $R = 0.4$ in the 10% most central Pb–Pb collisions compared to PYTHIA with tune Perugia 2011 and predictions from the jet quenching event generators (JEWEL and Q-PYTHIA). Statistical uncertainties are not shown for the model calculations.

No apparent change in jet mass.

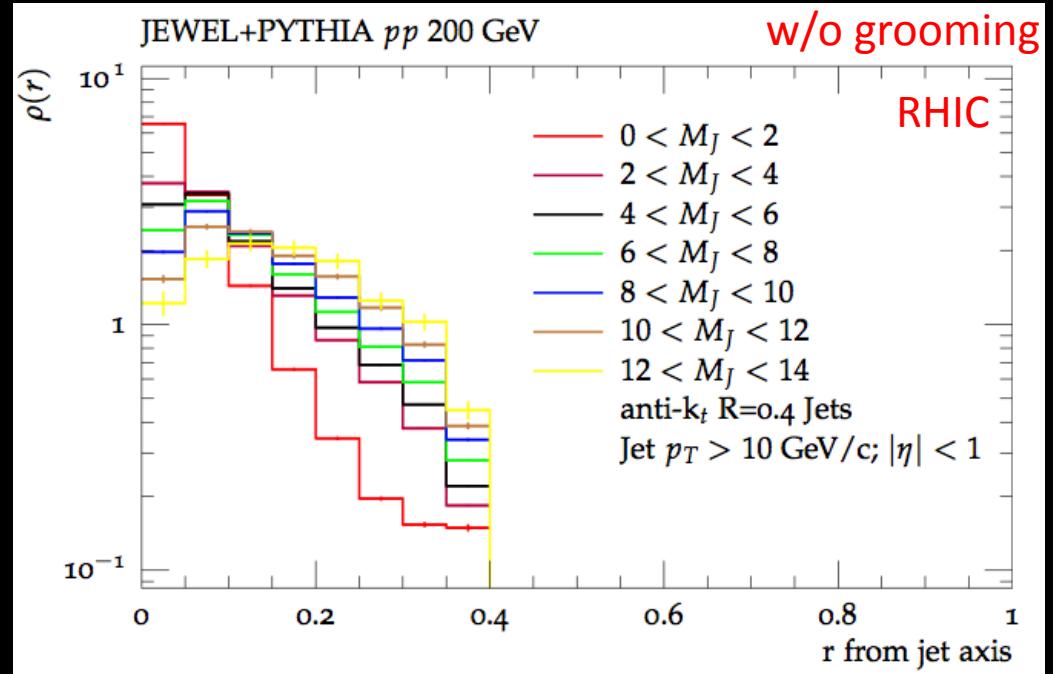
ALICE: arXiv:1702.00804 [nucl-ex]



Jet Mass dependence on Jet Shape



Raghav Kunnawalkam Elayavalli

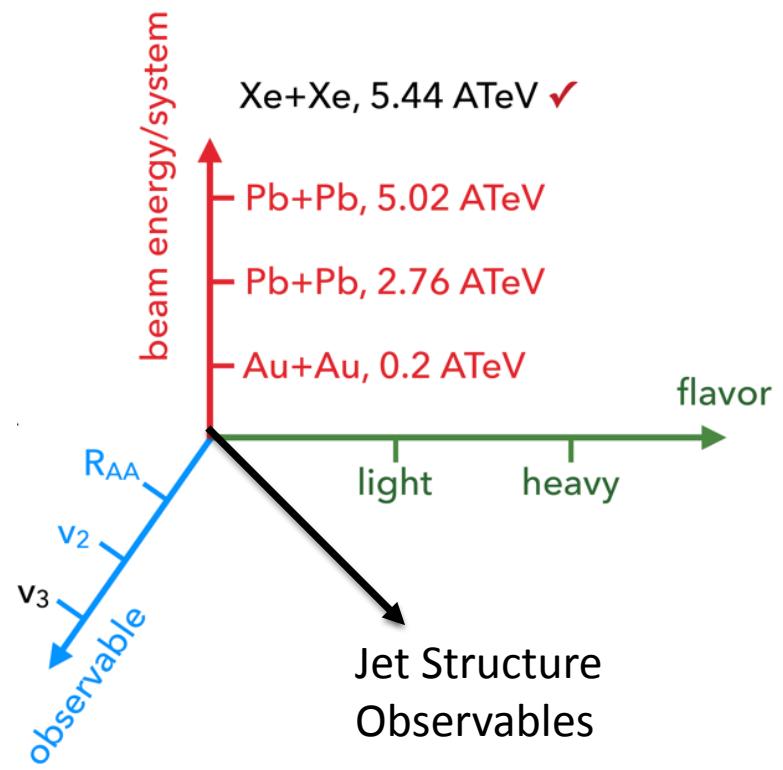


Esha Rao (CEU-DNP16-EA96 Poster Session)

Jet Shape Flattens with larger jet masses.
Mass and Shape are convoluted variables!

Precision Studies: Power of global data analysis

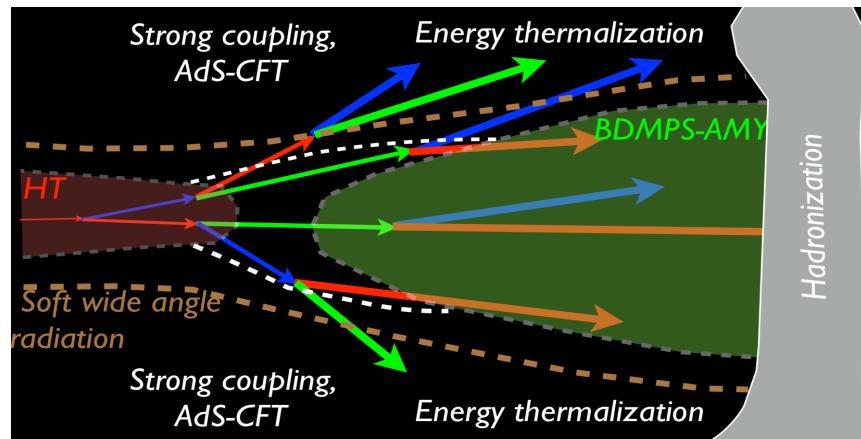
- Global fitting leverage information and differential power from individual data/observable to extract optimal amount of information
- Require large efforts in simultaneously describing background and jetty probes
 - “Standard model(s)” of HI
 - forward folding in experiments
 - quantifying contribution from individual measurement
- Cautious models’ validity and systematic bias on interpretation used in global fit



Courtesy of Shuzhe Shi

Why is JETSCAPE a potential solution ...

A. Majumder, Hard Probes '15



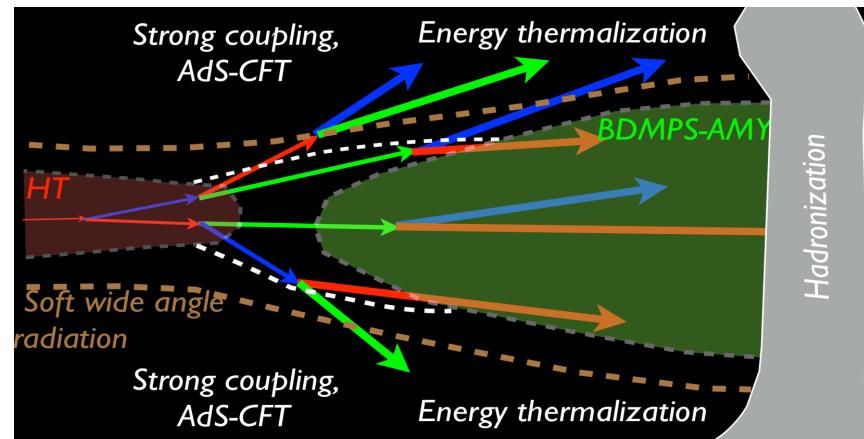
JETSCAPE:
Theoretical and
experimental physicists,
computer scientists,
statisticians



- ❖ Multi-Stage Energy Loss
- ❖ ... no one group can do it all
- ❖ Mission Statement: **Extensive, extensible event generator**
 - ❖ General. Modular. Self-contained. State-of-the-art.
- ❖ Note: Framework is agnostic to “multi-stage”, “energy loss”

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The Energy Loss
group can do it all

Use MC to study detector performance/
sensitivity to quenching observables.

Jets are useful probes to study QGP.

We have learned a lot about QGP w/o & w reconstructing jets.

Reconstructed jets with its structure evolution allow us to do global data analysis.

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Courtesy to Christine Nattrass