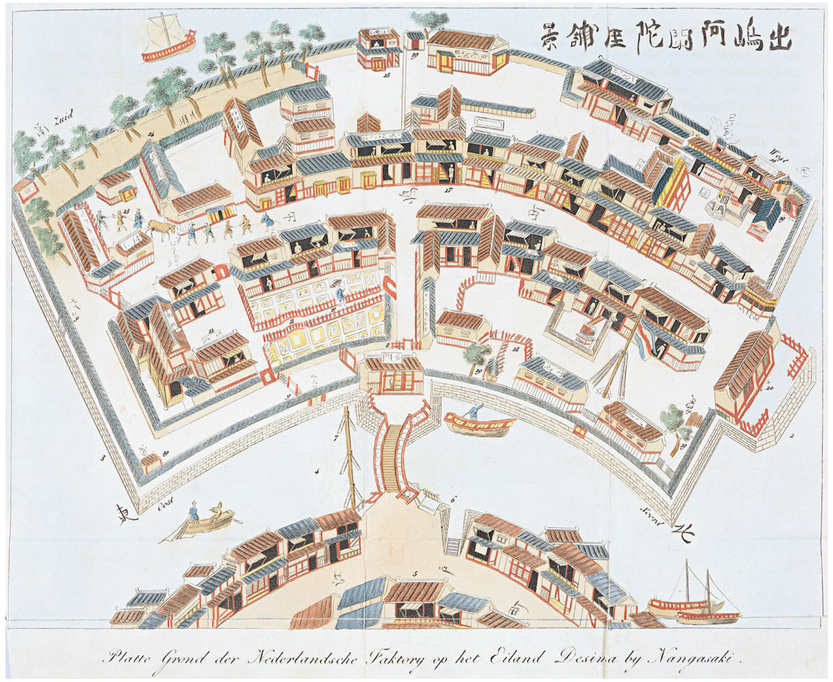
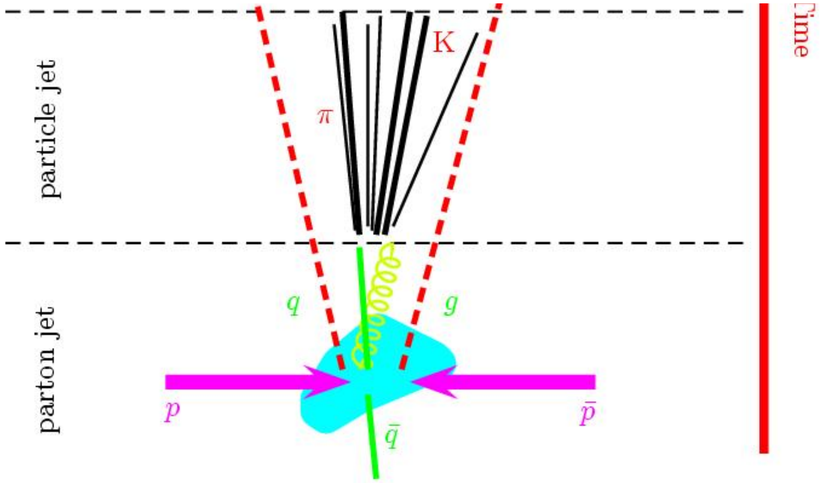
NATIONAL SCIENCE FOUNDATION
U.S. DEPARTMENT OF ENERGY | Office of Science
VANDERBILT UNIVERSITY





Jets

Substructures and Energy-Energy Correlators

Raghav (Rithya)
Kunnawalkam Elayavalli [they/them]
Vanderbilt University
raghavke.me

HP2024 NAGASAKI

14:00
Radius dependent jet quenching measurements from ATLAS — *Anne Marie Sickles*
Convention Hall 1 14:00 - 14:20

Jet substructure measurements with small and large radius jets with ATLAS — *Martin Rybar*
Convention Hall 1 14:20 - 14:40

Jet fragmentation and substructure correlations in pp and Pb--Pb at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with ALICE
Bas Hofman

15:00
Isolating perturbative QCD splittings in heavy-ion collisions — *Adam Takacs*
Convention Hall 1 15:00 - 15:20

Probing hadronization and quark-gluon plasma using collinear-drop jet observables at RHIC — *Dr Yang-Ting Chien*
Convention Hall 1 15:20 - 15:40

Leading order, next-to-leading order, and non-perturbative parton collision kernels: Effects on the jet substructures
Dr Shuzhe SHI

Identifying the onset of early-vacuum showers and medium-modified showers with the Lund jet plane in high-pT jets wi
Vangelis Vladimirov

First measurement of the jet axis decorrelation with photon-tagged jets in pp and PbPb at 5.02 TeV with CMS
17:00 *Molly Park*

Constraining the color-charge effects of energy loss with jet axis-based substructure studies in PbPb collisions at 5.02
Mr Raghunath Pradhan

Detection of jet shower width and survival bias effect with photon-tagged jet girth and groomed jet radius in pp and Pb.
Matthew Nguyen

Extraction of jet-medium interaction details through jet substructure for inclusive and gamma-tagged jets
18:00 *Yasuki Tachibana*

Effects of hadronic reinteraction on jet fragmentation from small to large systems — *Mr Hendrik Roch*
Convention Hall 1 18:10 - 18:30

09:00
Jet quenching and medium response using photon+jet events in ATLAS — *Dominik Karol Derendarz*
Room 102 09:00 - 09:20

Searching for jet-induced diffusion wakes of quark gluon plasma via jet- track correlations in heavy ion collisions with t
Yeonju Go

Visualizing How Jet Structure Shapes Jet Wakes — *Arjun Srinivasan Kudinoor*
Room 102 09:40 - 10:00

10:00
Jet transport in QGP fluid — *Tan Luo*
Room 102 10:00 - 10:20

Jet Drift in Heavy Ion Collisions — *Joseph Bahder*
12:00 *Room 102* 11:50 - 12:10

Jet entropy as a probe of jet collimation — *João Barata*
Room 102 12:10 - 12:30

09:00
Energy-energy correlators of inclusive jets from small to large collision systems with the ALICE experiment
Anjali Nambrath

Study of energy-energy correlator of jets in PbPb collisions at CMS — *Jussi Viinikainen*
Convention Hall 1 09:20 - 09:40

Energy-energy correlators of inclusive jets in heavy-ion collisions — *Dr Yayun He*
Convention Hall 1 09:40 - 10:00

10:00
Probing the Short-Distance Structure of the Quark-Gluon Plasma with Energy Correlators — *Zhong Yang*
Convention Hall 1 10:00 - 10:20

Exploiting Two- and Three-point Charge-Energy Correlators at STAR as Probes of Jet Evolution — *Andrew Tamis*
11:00 *Convention Hall 1* 10:50 - 11:10

The two-point energy correlator in the QGP: from gamma+jet to inclusive jets — *Carlota Andres*
Convention Hall 1 11:10 - 11:30

EECs in heavy ions and in the Lund plane — *Alba Soto Ontoso*
Convention Hall 1 11:30 - 11:50

First measurement of the energy-energy correlator in the back-to-back limit using archived ALEPH e+e- data at 91.2 Ge
12:00 *Yu-Chen (Janice) Chen*

Extracting the anomalous dimensions of energy-correlators in charged jets in pp collisions at 13 TeV with ALICE
Ananya Rai

J/ψ production within a jet in high-energy proton-proton and nucleus-nucleus collisions — *Dr Shan-Liang Zhang*
11:00 *Convention Hall 1* 10:50 - 11:10

Energy correlators for gluon splitting to heavy quarks — *Jasmine Therese Brewer*
Convention Hall 1 11:10 - 11:30

Probing QCD dynamics with jet substructure in LHCb kinematics — *Dr Ezra Lesser*
Convention Hall 1 11:30 - 11:50

Charm Meson Tagged Jets in Au+Au Collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV — *Mr Diptanil Roy*
12:00 *Convention Hall 1* 11:50 - 12:10

Differential measurements of in-jet fragmentation of charmed mesons and baryons in pp collisions with ALICE
Jochen Klein

Probing hadronization with the charge correlator ratio in pp and Ru+Ru/Zr+Zr collisions at $\sqrt{s_{\mathrm{NN}}}$
Youqi Song

Probing Hadronization Through Jet Substructure Analysis — *Nuno Olavo Gonçalves Mendes Madureira*
Room 107 11:30 - 11:50

Measurements of Baryon-to-Meson Ratios Inside Jets in Au+Au and p+p Collisions at $\sqrt{s_{NN}} = 200$ GeV at
00 *Gabe Dale-Gau*

Probing jet hadrochemistry and charged-particle jet radial profile modifications in pp and Pb--Pb collisions with ALICE
Sierra Lisa Weyhmiller

EFT-based factorization of jet quenching observables in heavy ion collisions — *Dr Yacine Mehtar-Tani*
Room 102 11:30 - 11:50

What I hope to do

- Why are we as a community interested in these quantities - JSS and EECs
- What have we learned so far about QCD and about QGP (quantitatively)
- What are we currently measuring and how can we push the envelope?

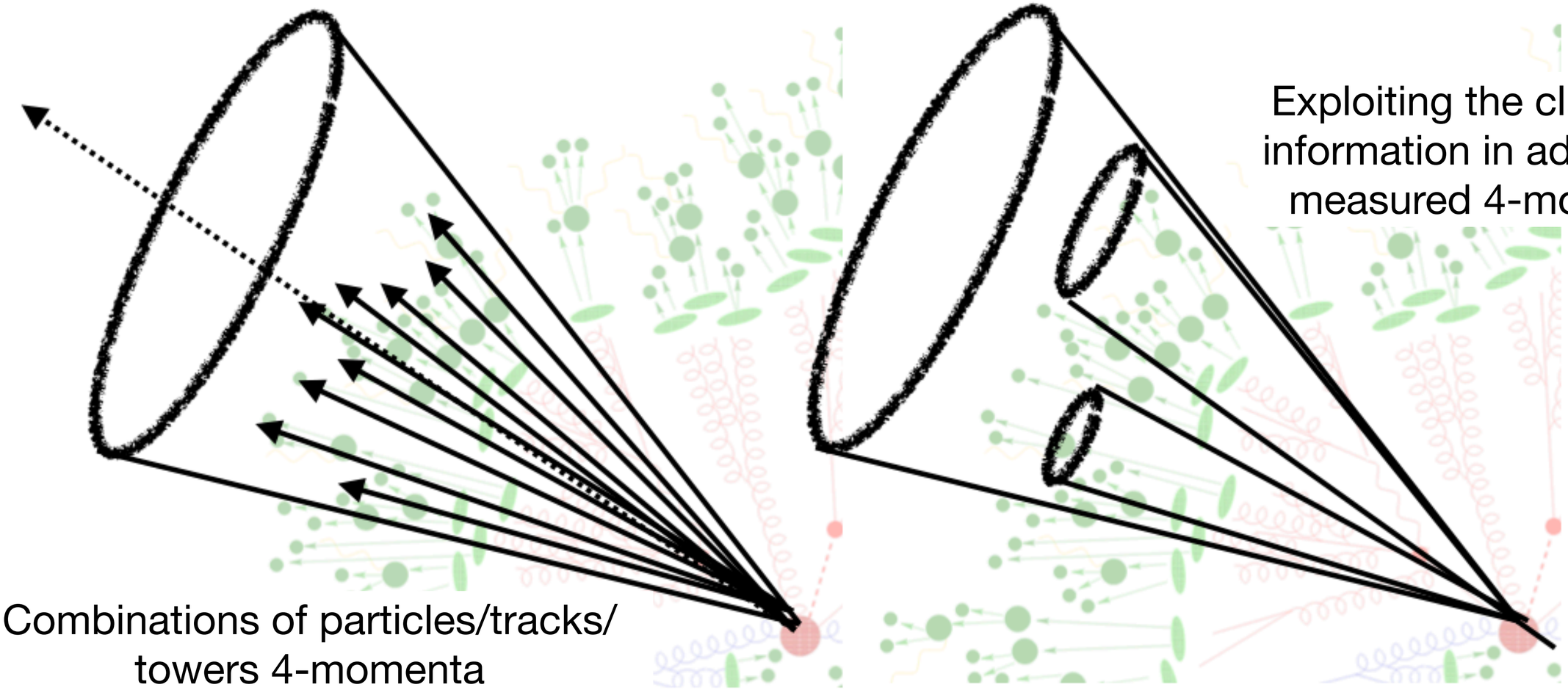
What I will not do

- Definition and details of all substructure observables
- Exhaustive summary of all measurements (new and old) on this topic (sorry)
- One specific path for the future - there are many and we need them all!

Introducing our observables

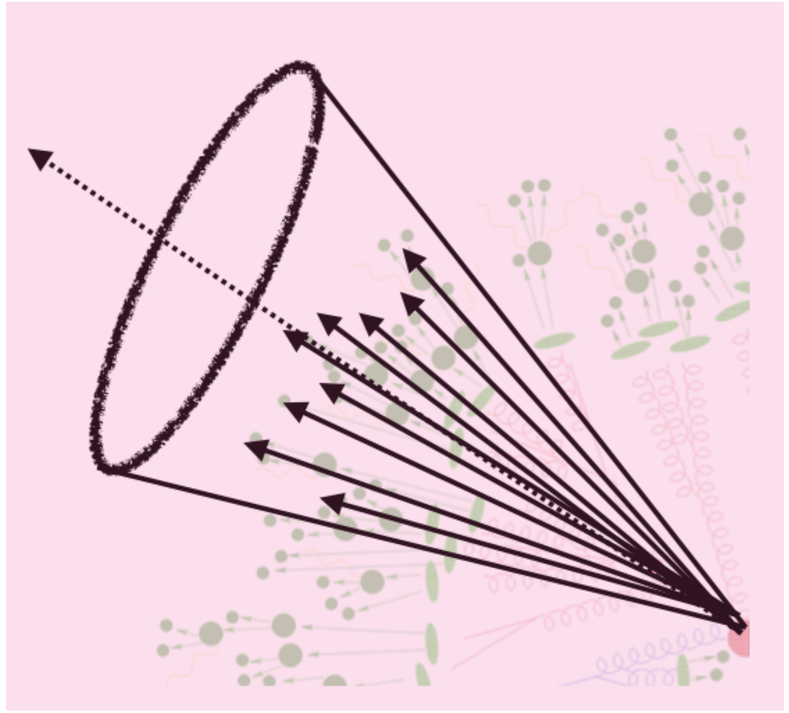
Types of jet substructure observables

A useful way to tag jet populations



Exploiting the clustering information in addition to measured 4-momenta

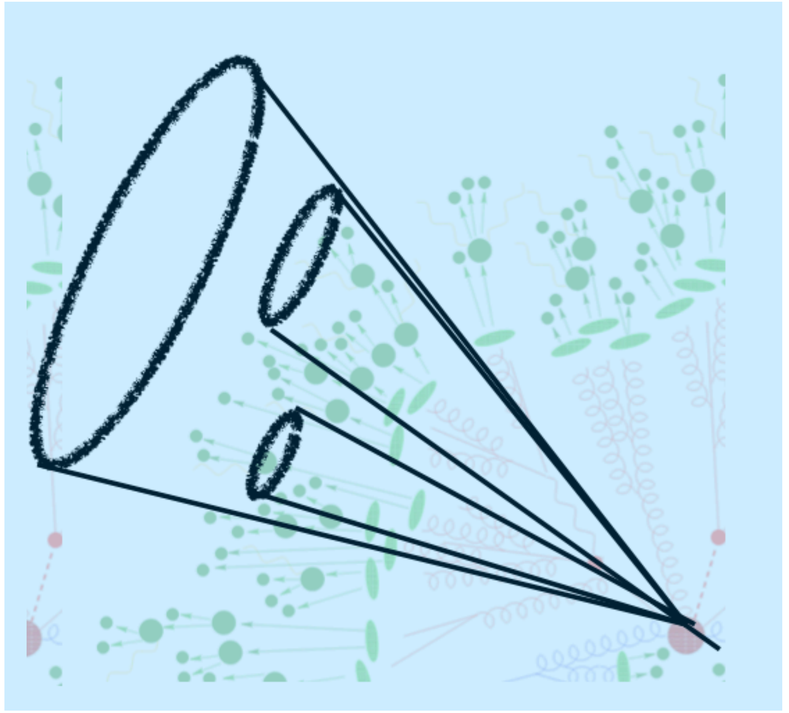
Combinations of particles/tracks/ towers 4-momenta



Jet Mass, angularities,
Energy-Energy Correlators

Charge correlator

Charge-Balance function



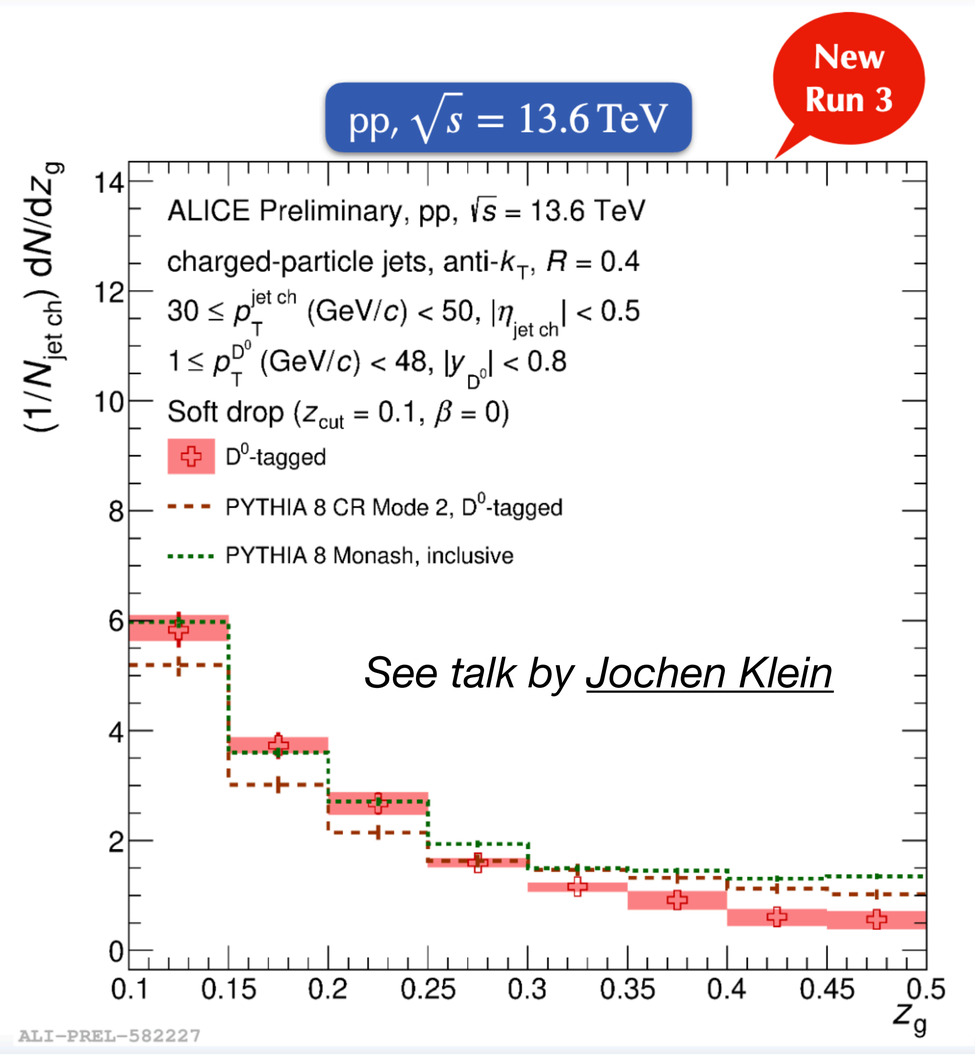
Groomed observables

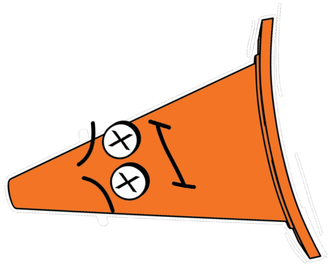
Multi-fold correlations
of splittings

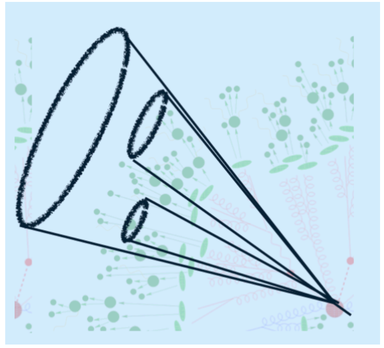
Lund Planes

Vacuum pQCD to npQCD

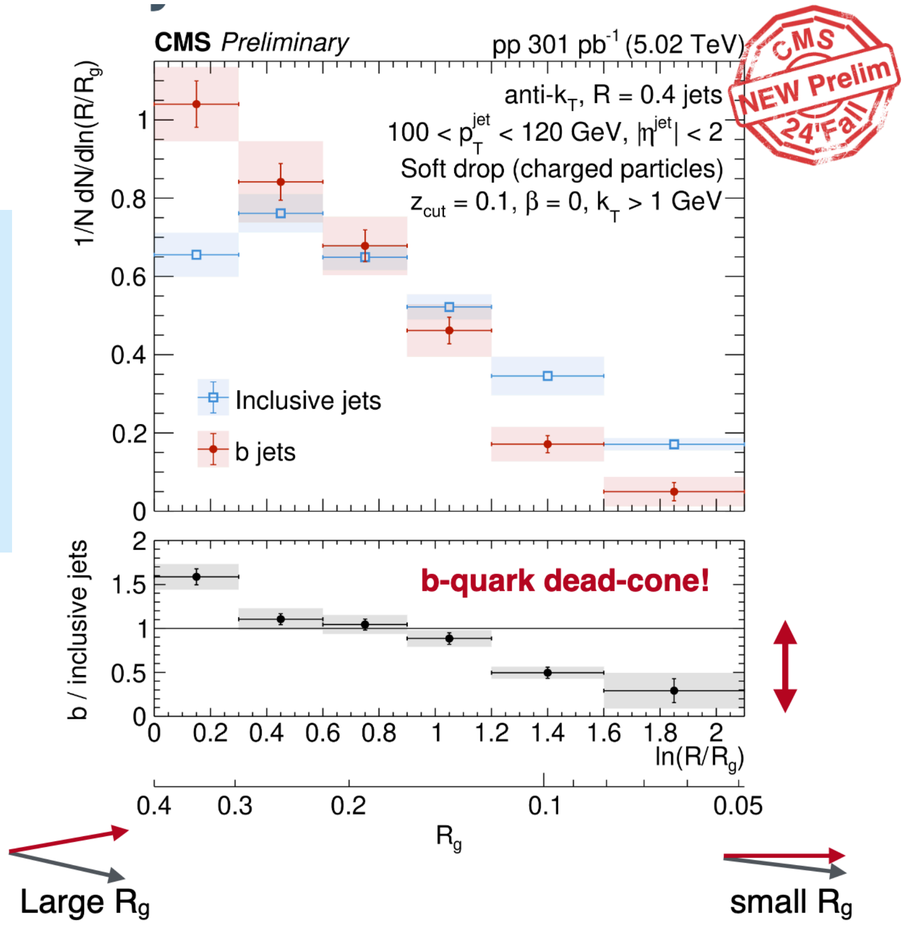
Differential studies of the Dead Cone!







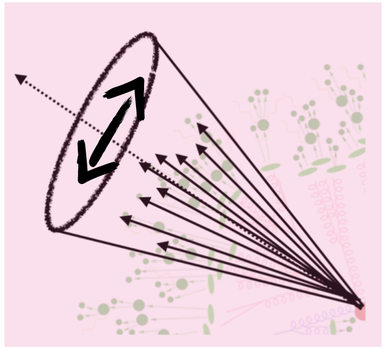
See talk by Lida Kalipoliti



- High statistics allows to study $c \rightarrow c + g$ spitting functions

- Mass dependence with b-jets tagged with b-hadrons (potential flavor dependence?)

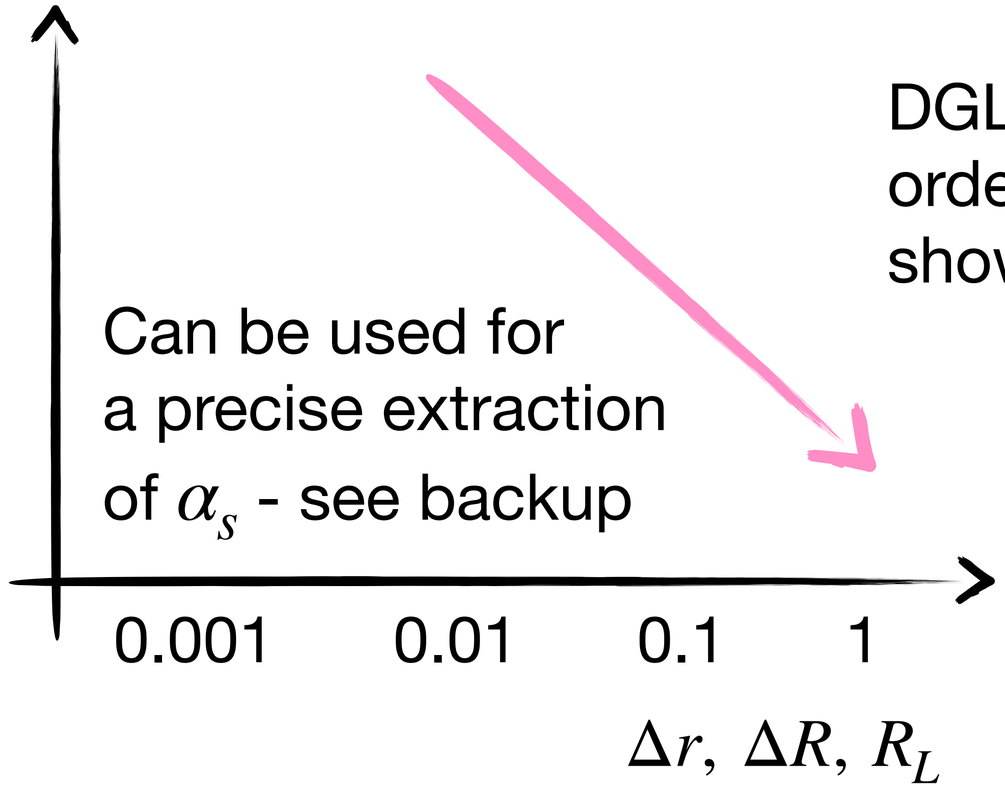
Energy-Energy Correlators



$$\text{Normalized EEC} = \frac{1}{\sum_{Jets}\sum_{i\neq j}\frac{E_i E_j}{{p_{T,Jet}}^2}} \frac{d\left(\sum_{Jets}\sum_{i\neq j}\frac{E_i E_j}{{p_{T,Jet}}^2}\right)}{d\,(\Delta R)}$$

- Energy weighted pairwise distance of particles within your jet (or the event!)

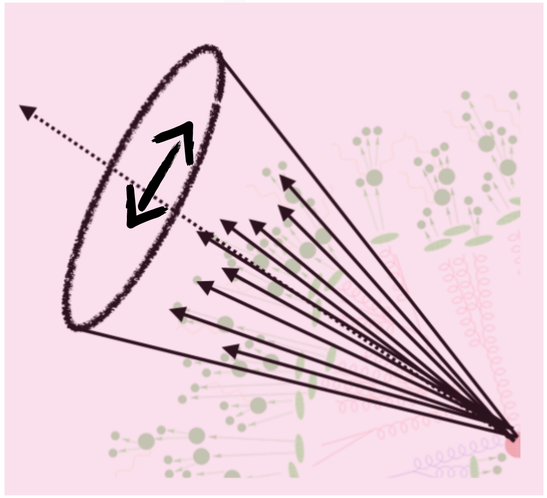
Hofman, Maldacena JHEP 0805 (2008) 012
Dixon, Moult, Zhu PRD 100, 014009 (2019)
Andres, Holguin et. al PRL. 130, 26, 262301 (2023)
Andres, Holguin et. al JHEP 09 (2023) 088



DGLAP style ordered parton shower

Energy-Energy Correlators

$$\text{Normalized EEC} = \frac{1}{\sum_{Jets}\sum_{i\neq j}\frac{E_i E_j}{{p_{T,Jet}}^2}} \frac{d\left(\sum_{Jets}\sum_{i\neq j}\frac{E_i E_j}{{p_{T,Jet}}^2}\right)}{d\,(\Delta R)}$$



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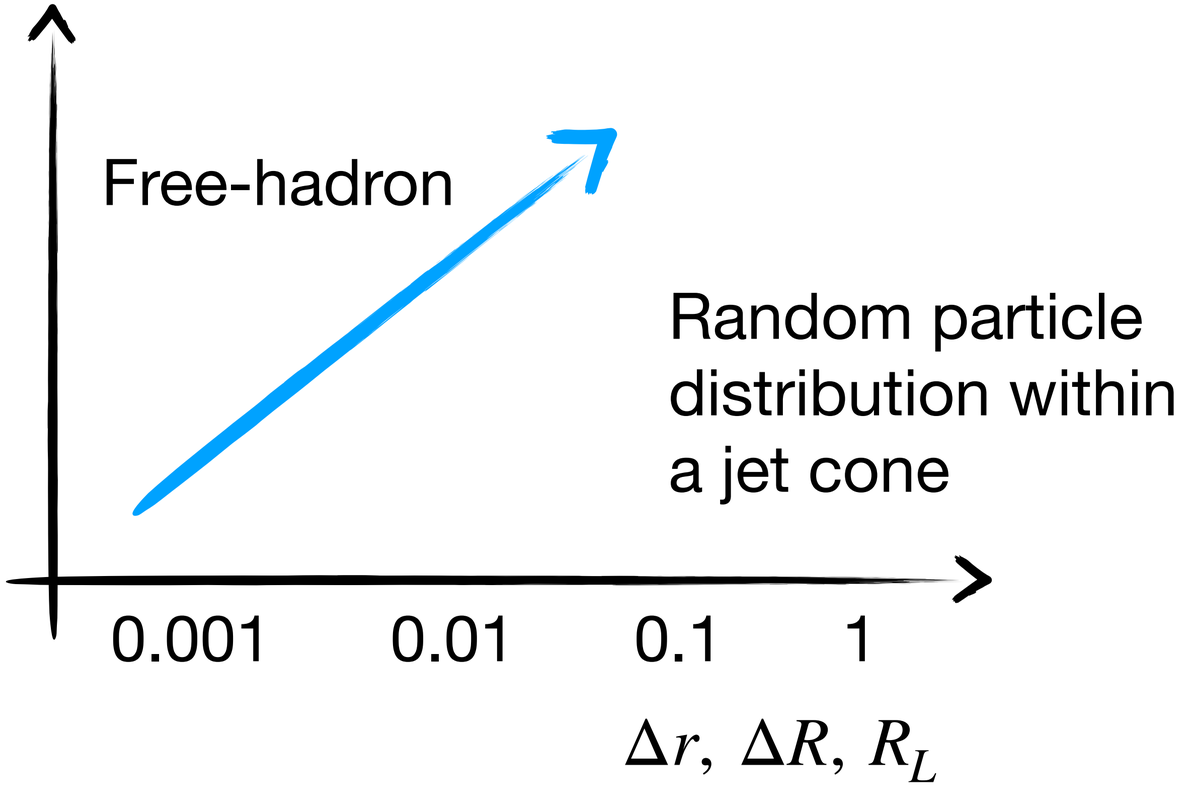
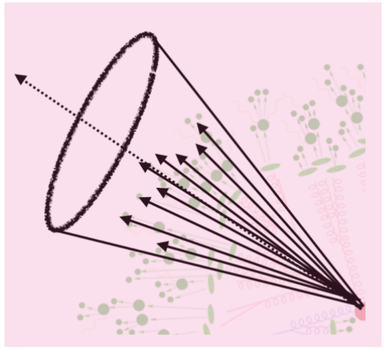


Energy-Energy Correlators



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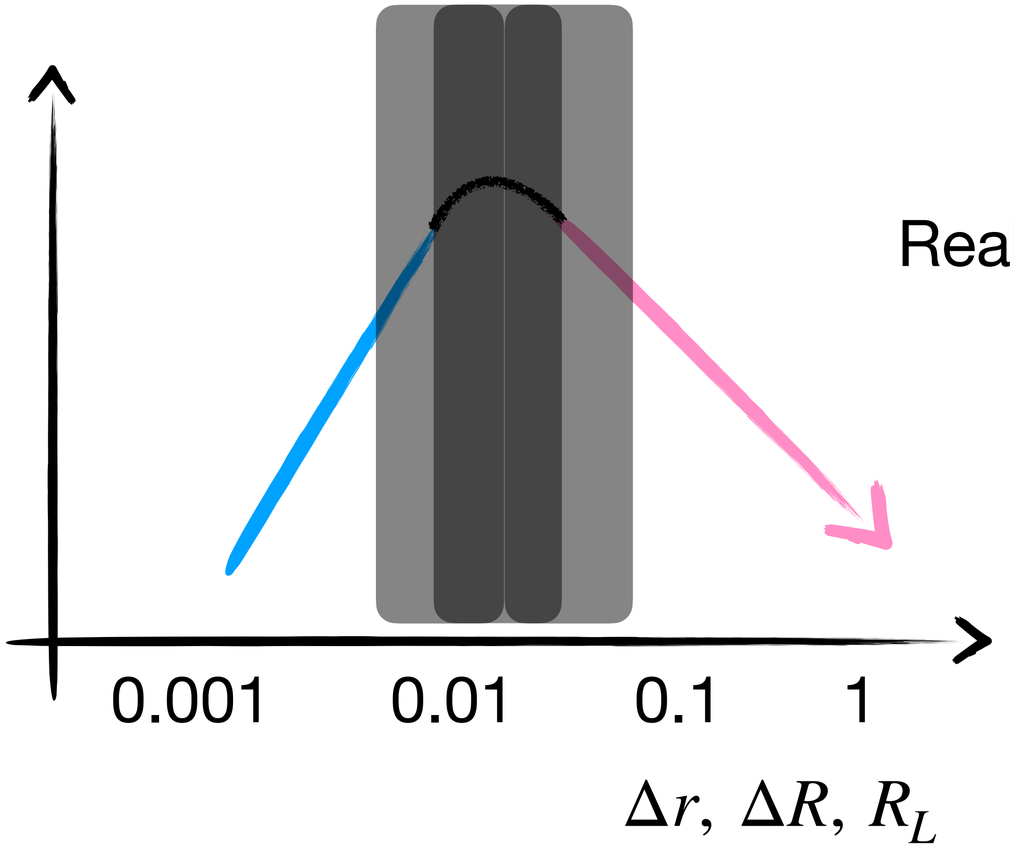
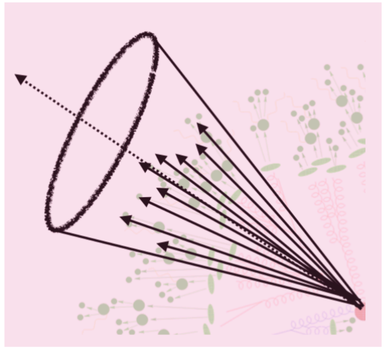
- Energy weighted pairwise distance of particles within your jet (or the event!)
- Potential separation of scales - crucial for physics of multi-scale processes!



Realistic jet!

Energy-Energy Correlators



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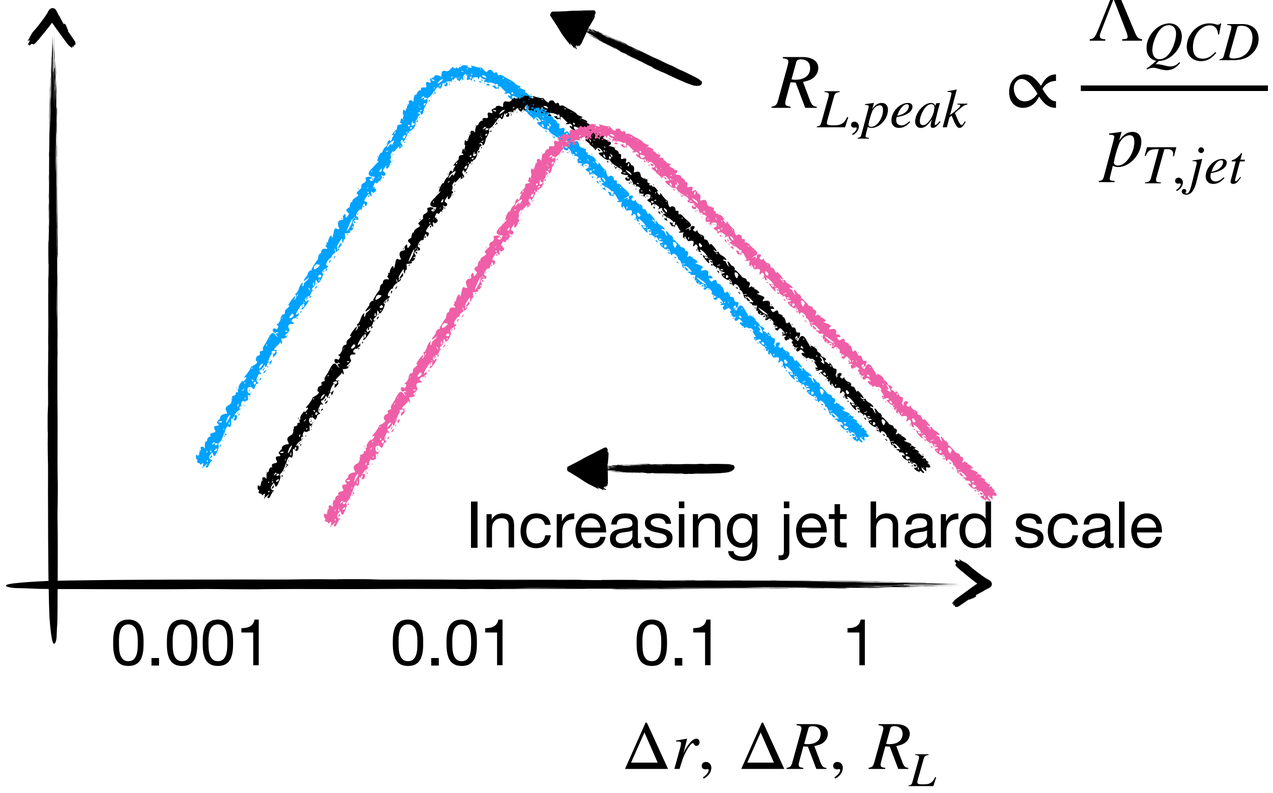
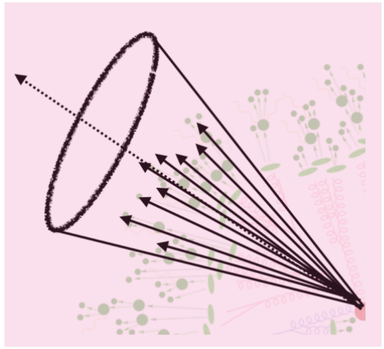
- Energy weighted pairwise distance of particles within your jet (or the event!)
- Indication of the initial hard scattering scale!



Energy-Energy Correlators



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- Energy weighted pairwise distance of particles within your jet (or the event!)
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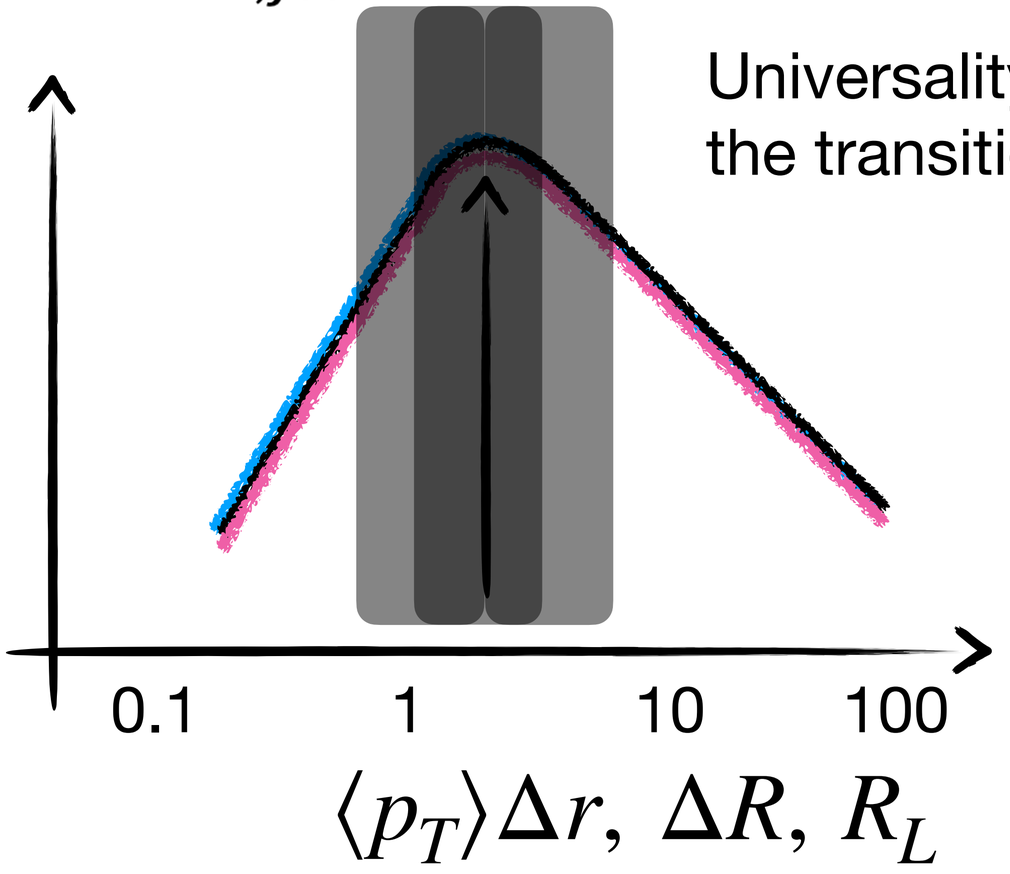
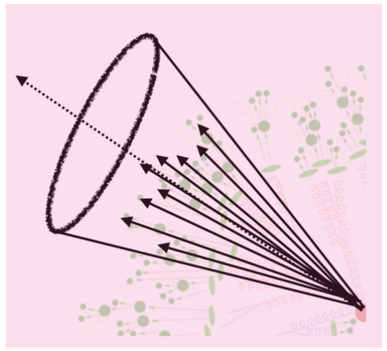
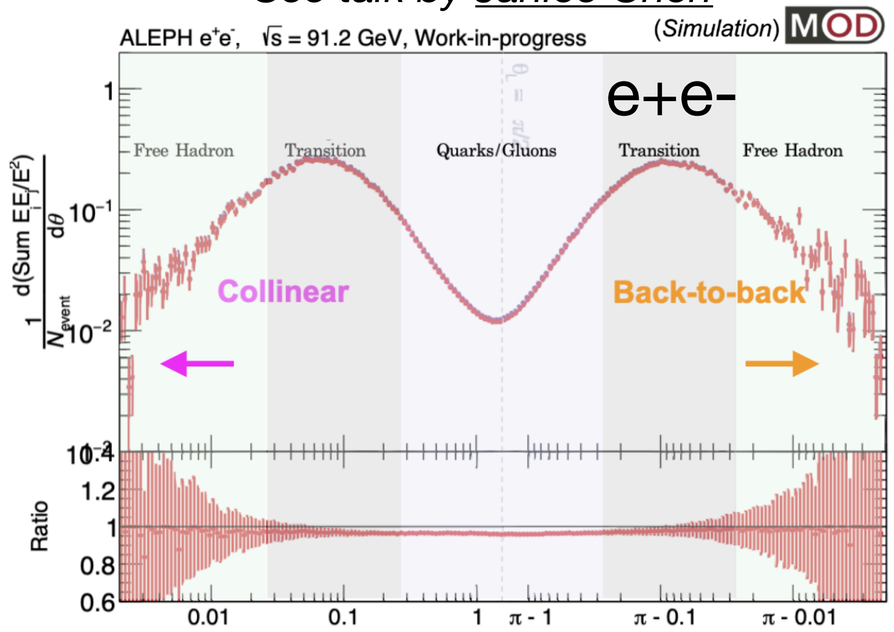


Universality of the transition region!

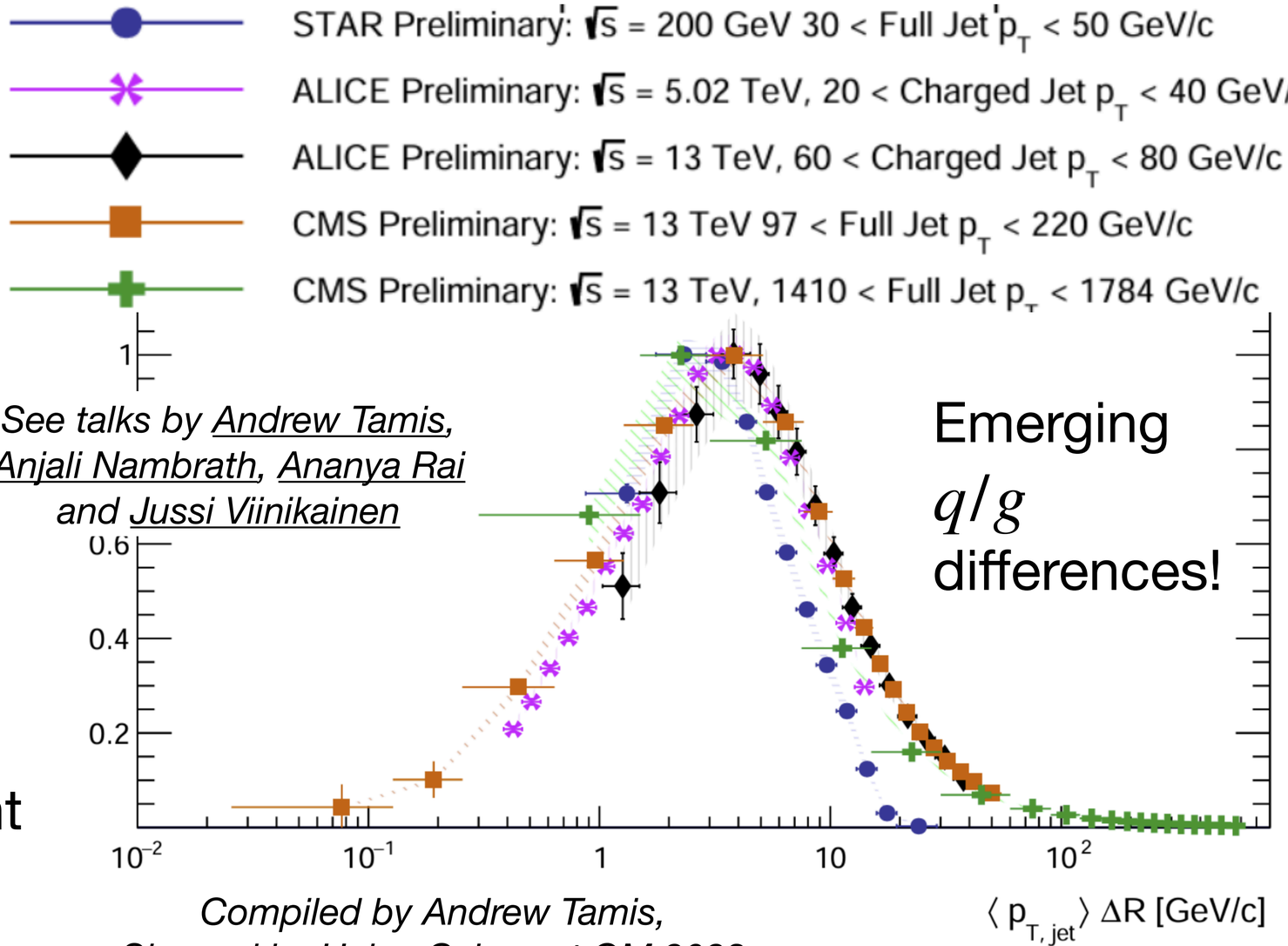


General structure of 2-point correlators within jets!

See talk by Janice Chen



ALEPH, ALICE, STAR, CMS, 2-point correlators: O(10) - O(1000) GeV



See talks by Andrew Tamis, Anjali Nambrath, Ananya Rai and Jussi Viinikainen

Emerging q/g differences!

Compiled by Andrew Tamis, Showed by Helen Caines at QM 2023

QGP properties and q/g $(\vec{x}, t)$ evolution

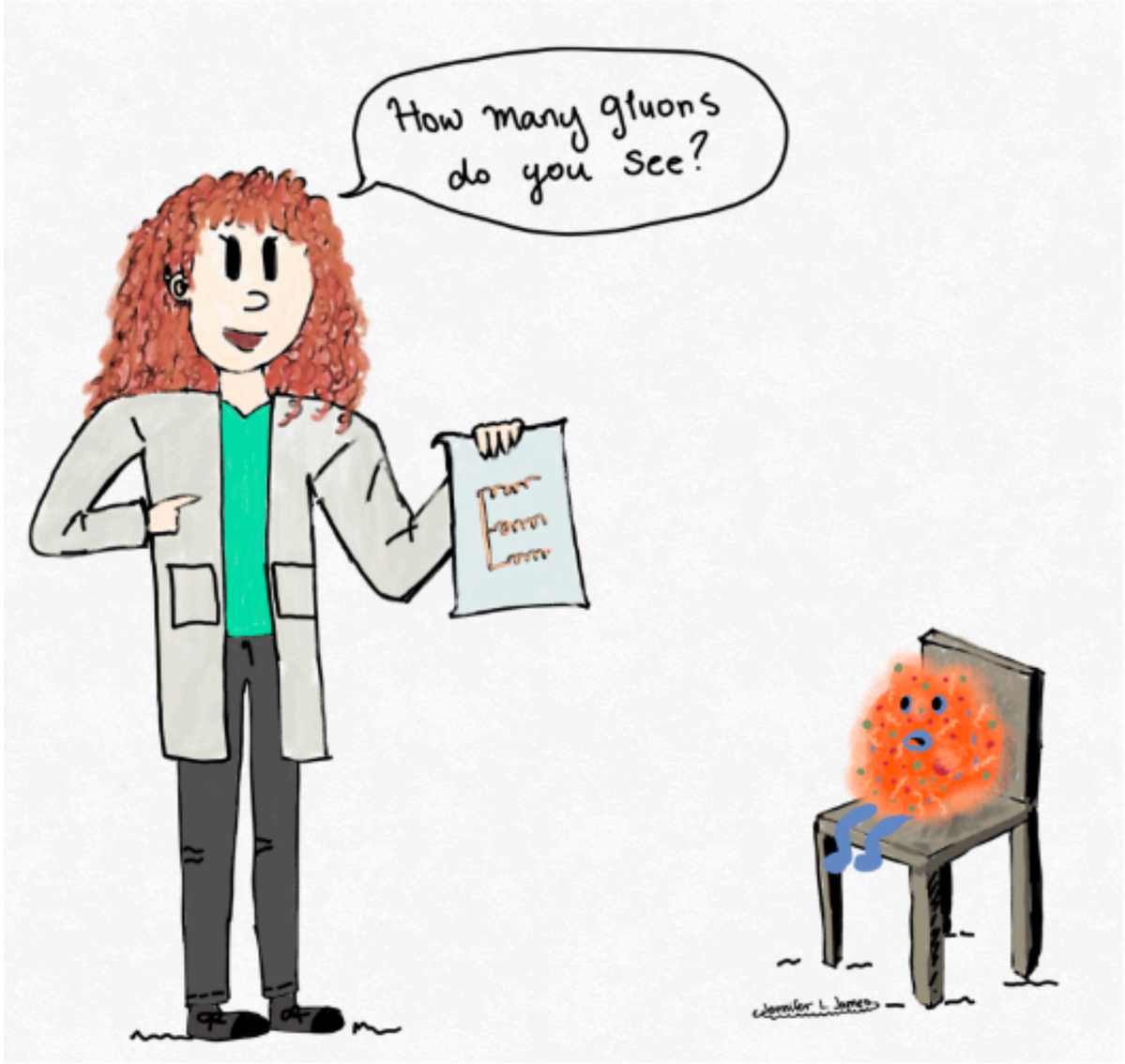
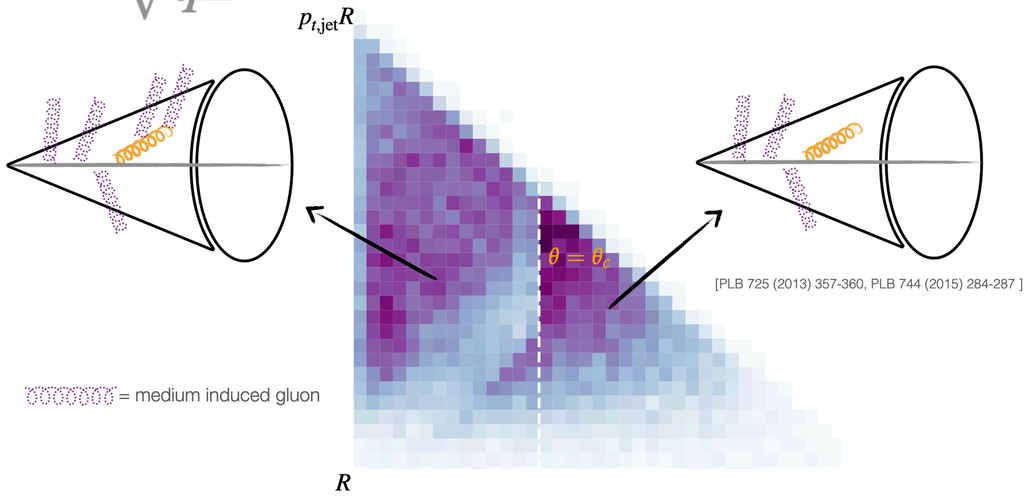


Image credit: Jennifer James (Vanderbilt)

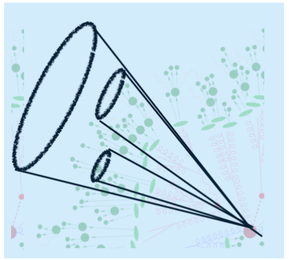
$$\theta_c = \frac{2}{\sqrt{\hat{q}L^3}}$$

Compilation by Alba Soto

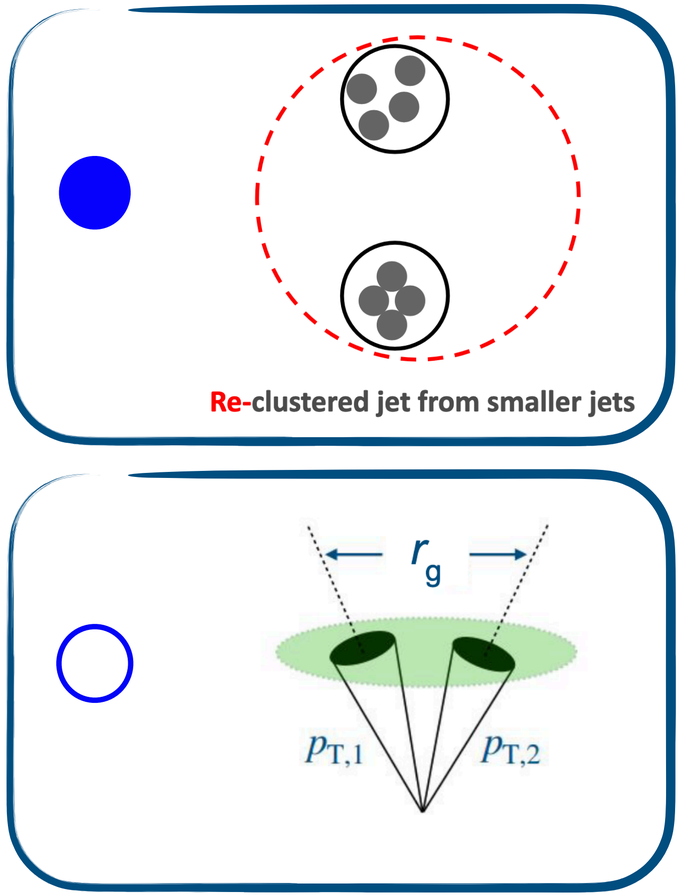


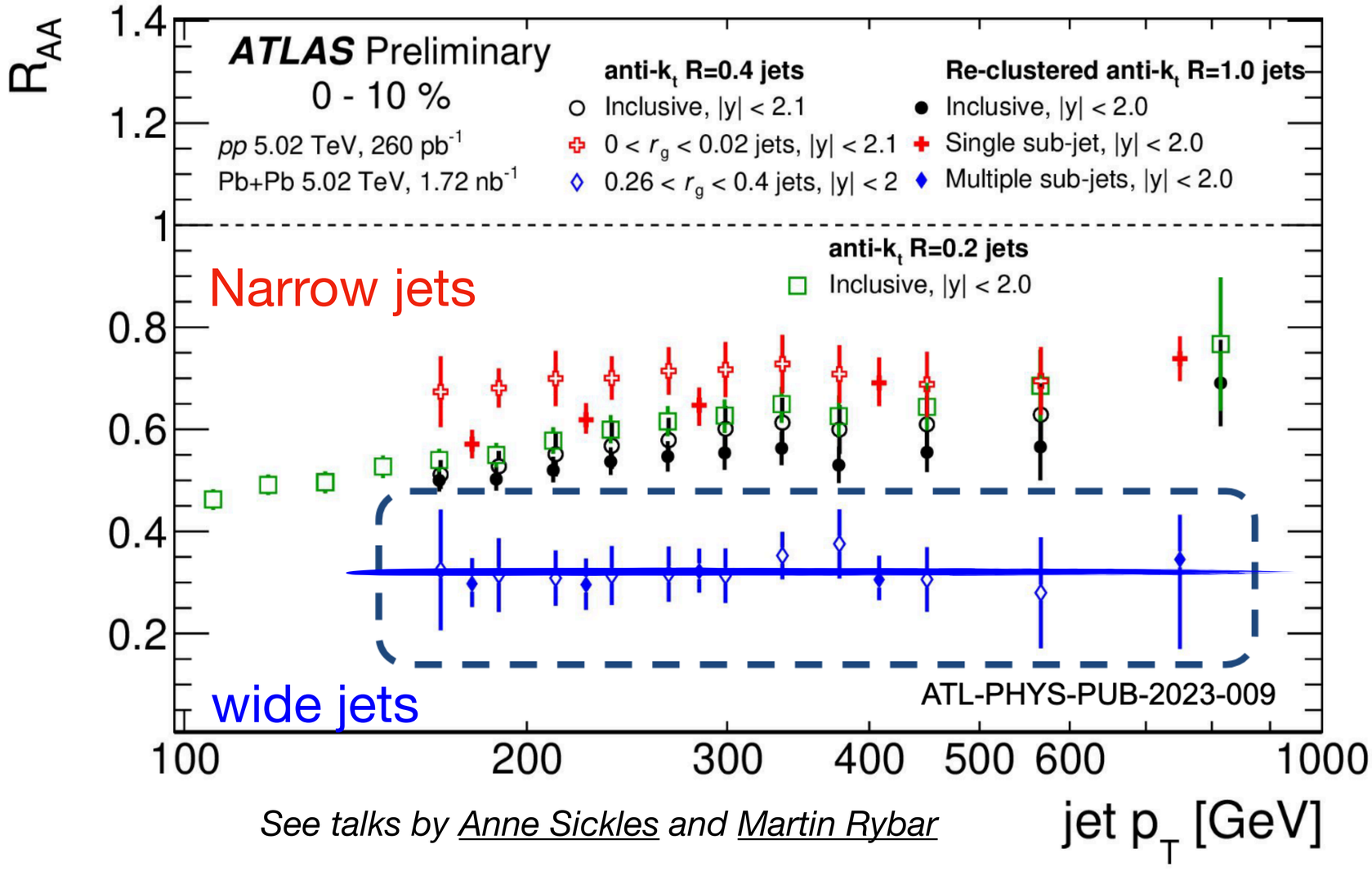
[PLB 725 (2013) 357-360, PLB 744 (2015) 284-287]

- Can we use jet substructure observables to study *how* jets lose energy?
- How can we experimentally ask this question?

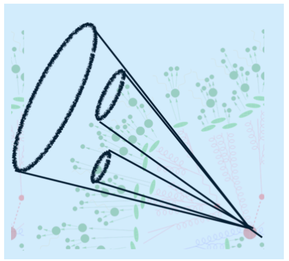


Does energy loss depend on angle/scale?

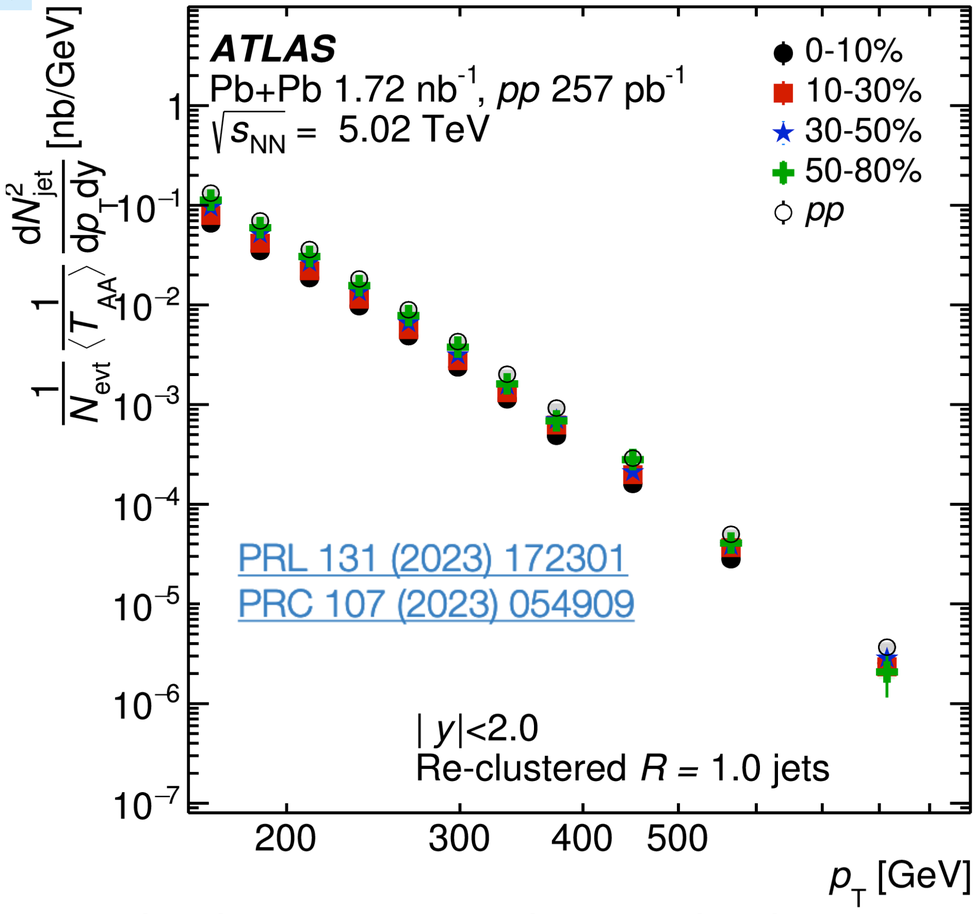


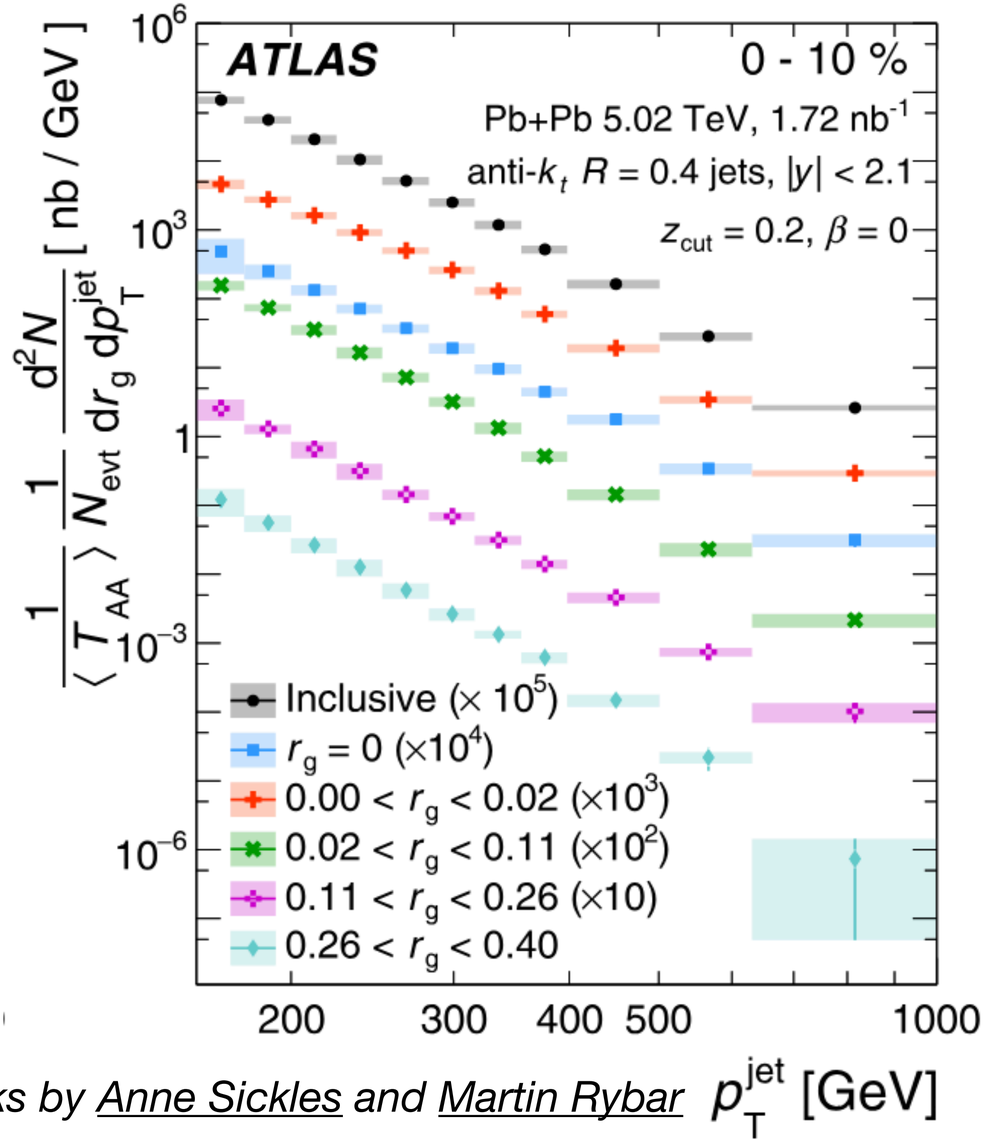


See talks by Anne Sickles and Martin Rybar



Does energy loss depend on angle/scale?



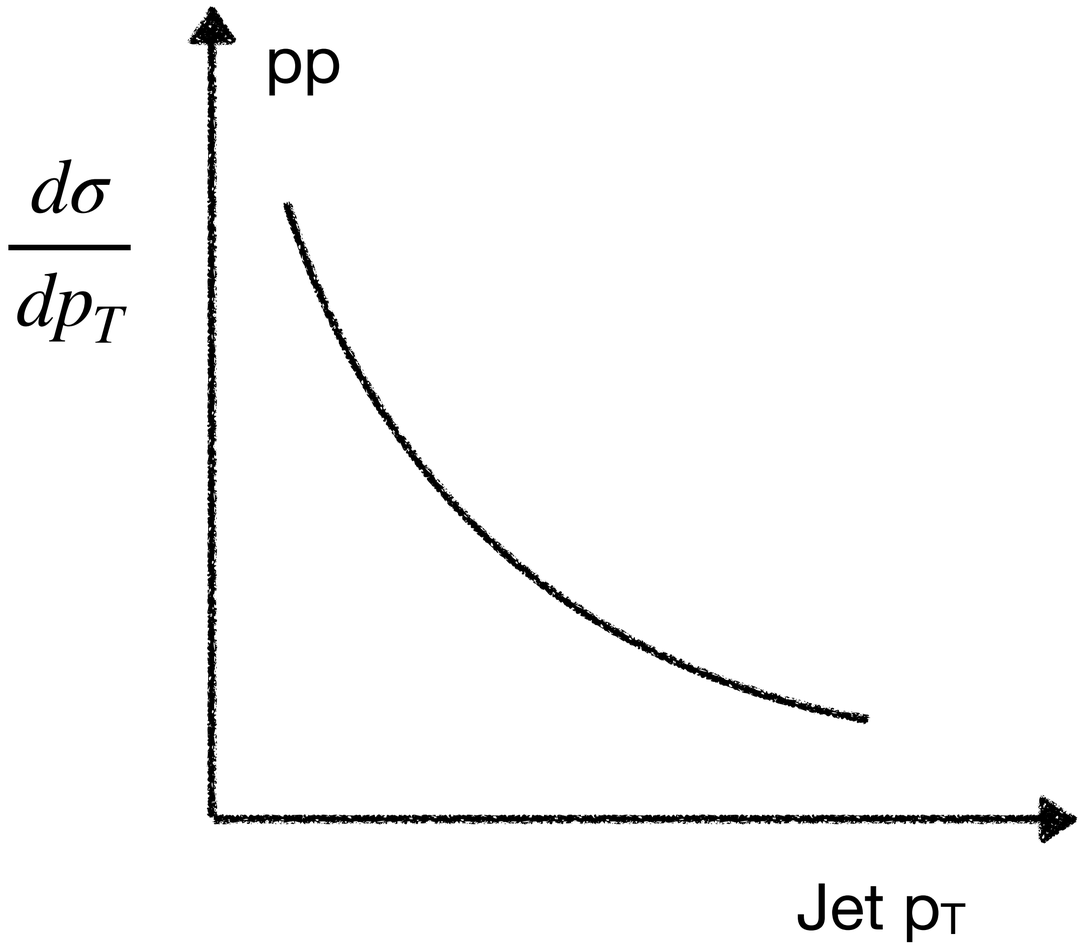


Lets compare both vacuum and quenched spectral shape to quantify similarity in energy loss

See talks by Anne Sickles and Martin Rybar

What is the selection bias?

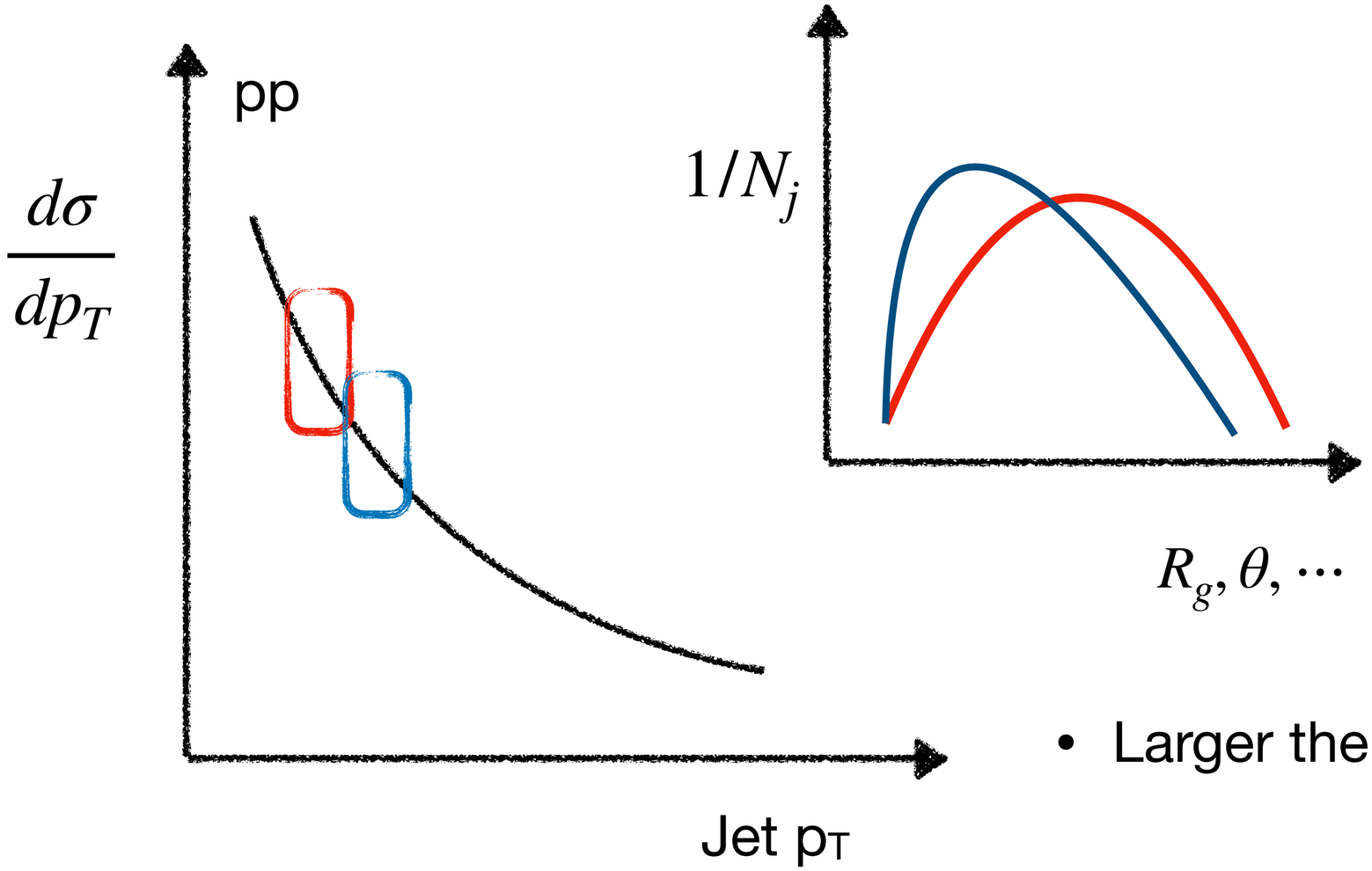
For inclusive jets…



- Lets say we start with some jet spectra -

What is the selection bias?

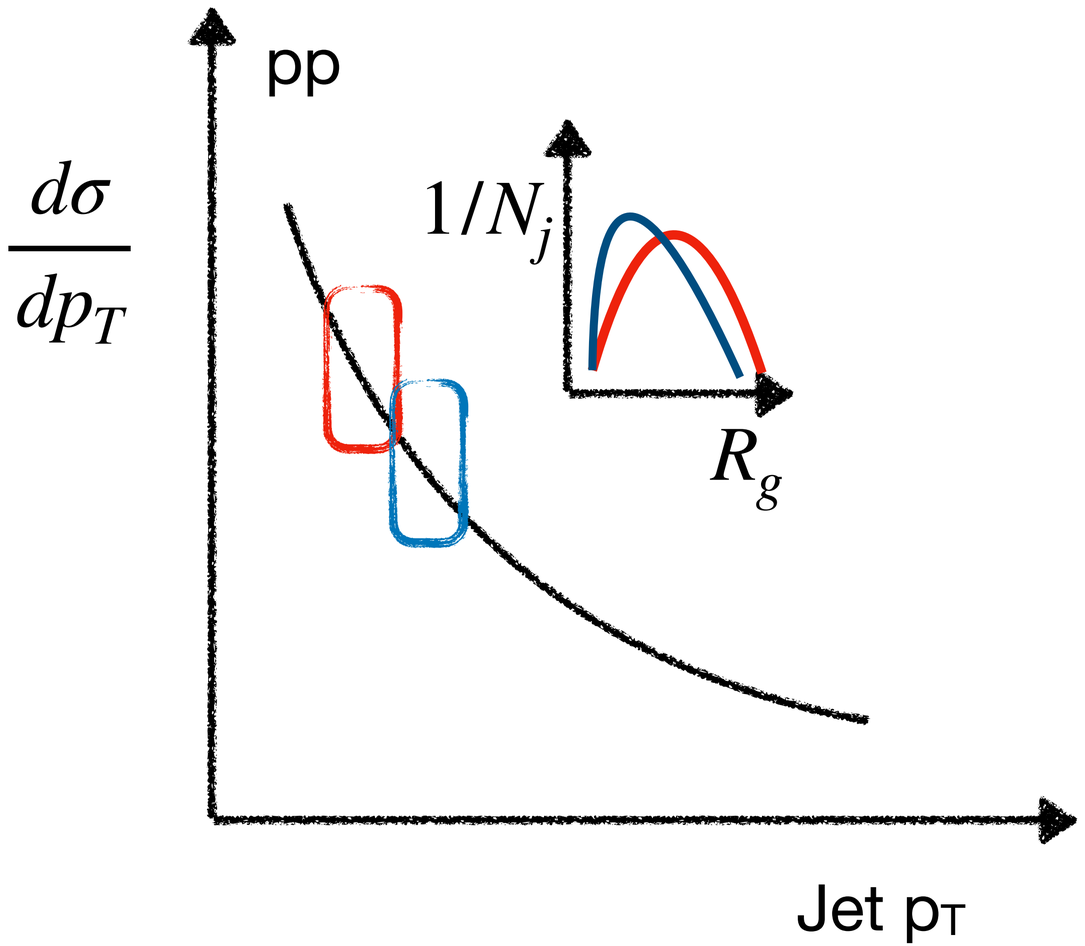
For inclusive jets…

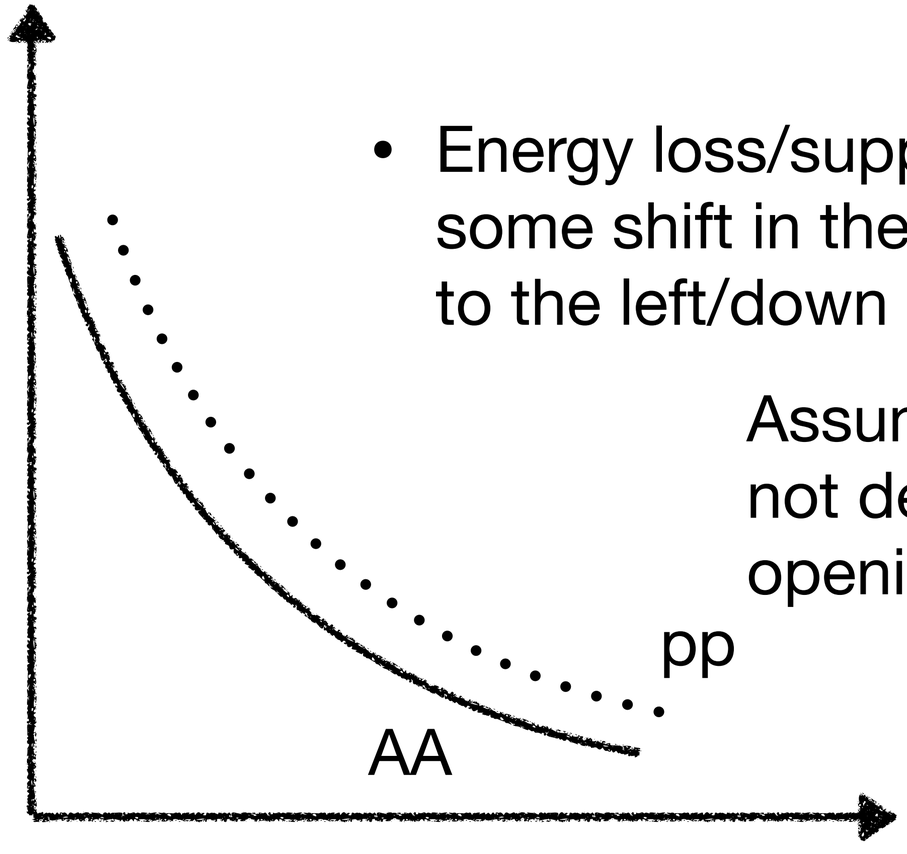


- Larger the boost (jet p_T) - smaller the angle!

What is the selection bias?

For inclusive jets…



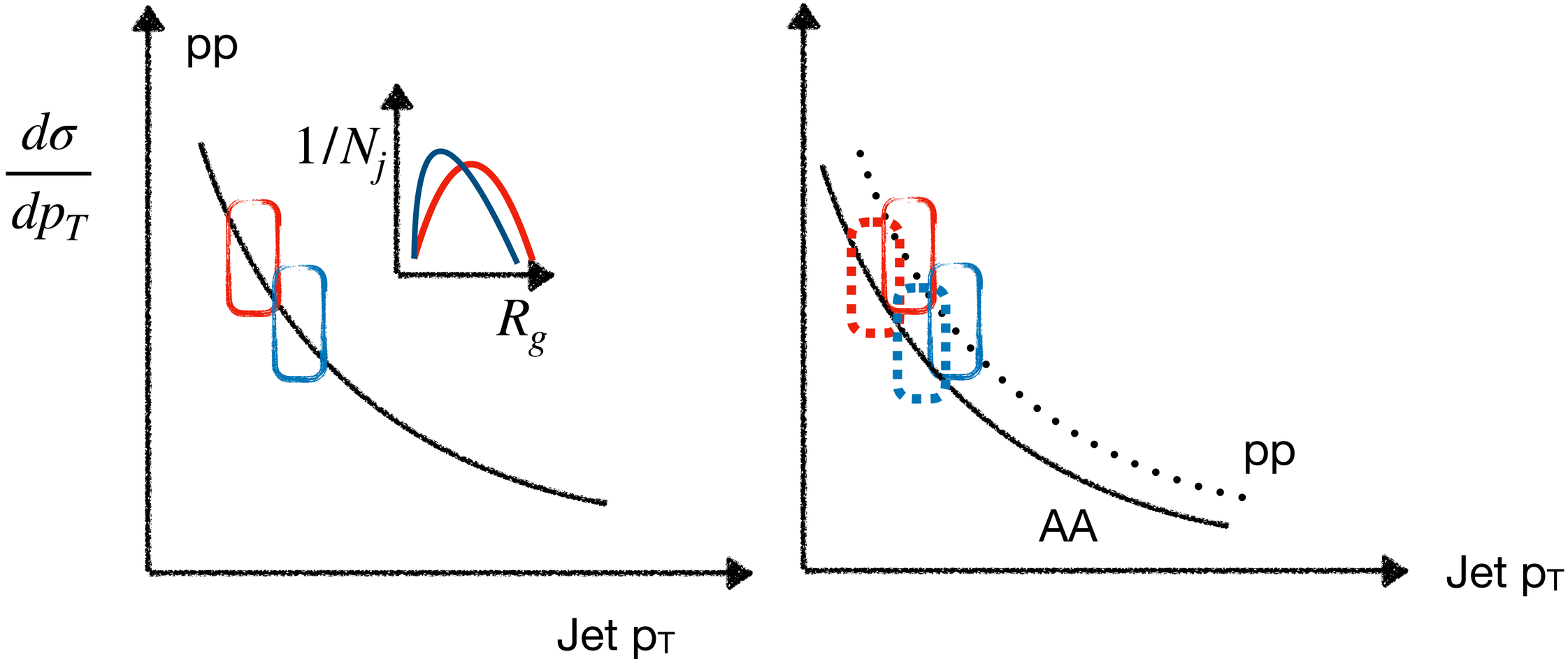


- Energy loss/suppression is some shift in the spectra to the left/down

Assume energy loss not dependent on opening angle!

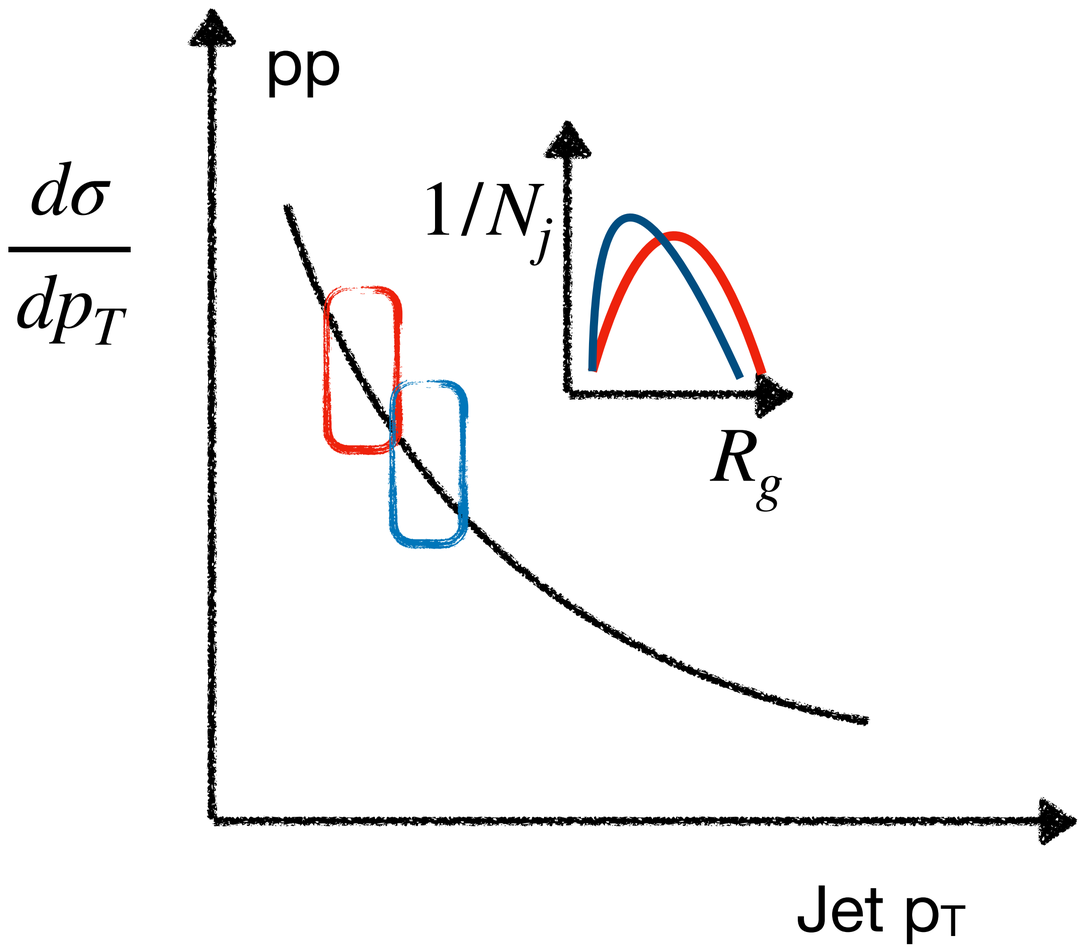
What is the selection bias?

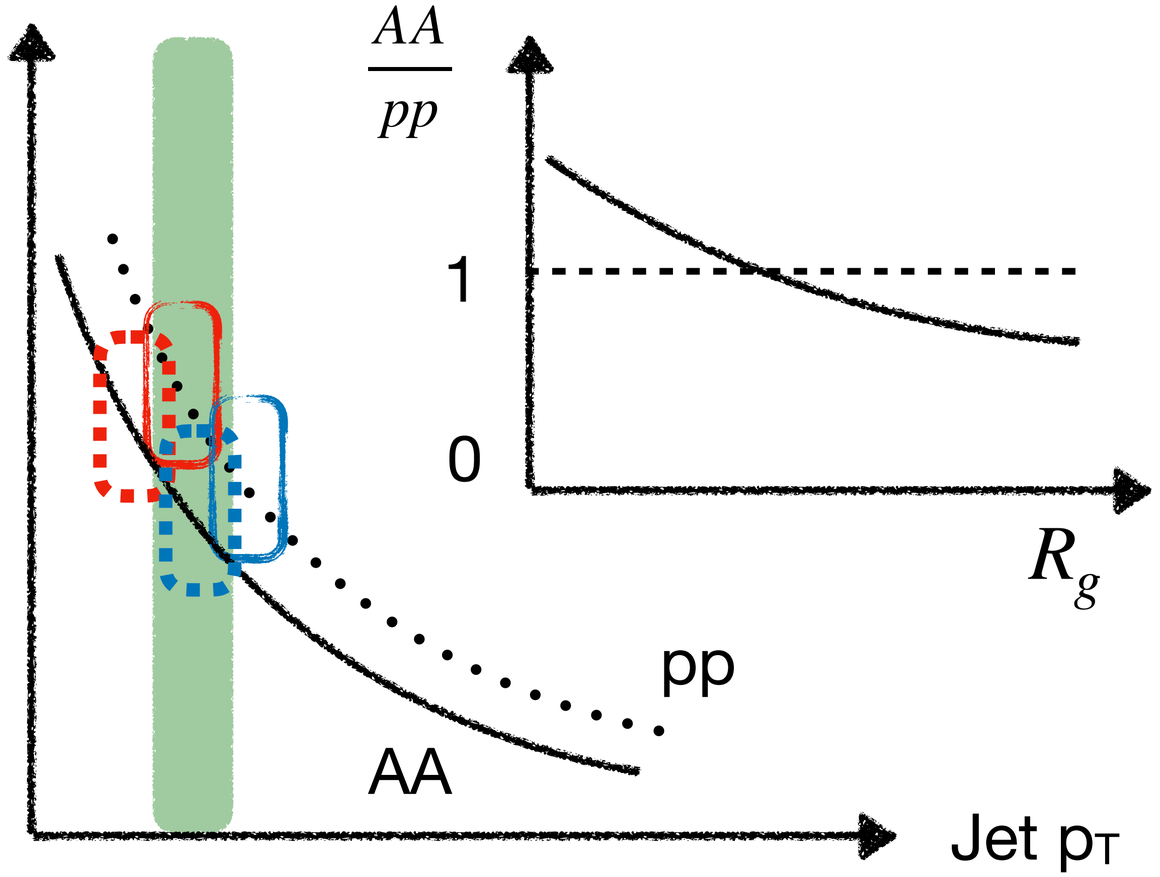
For inclusive jets…



What is the selection bias?

For inclusive jets…

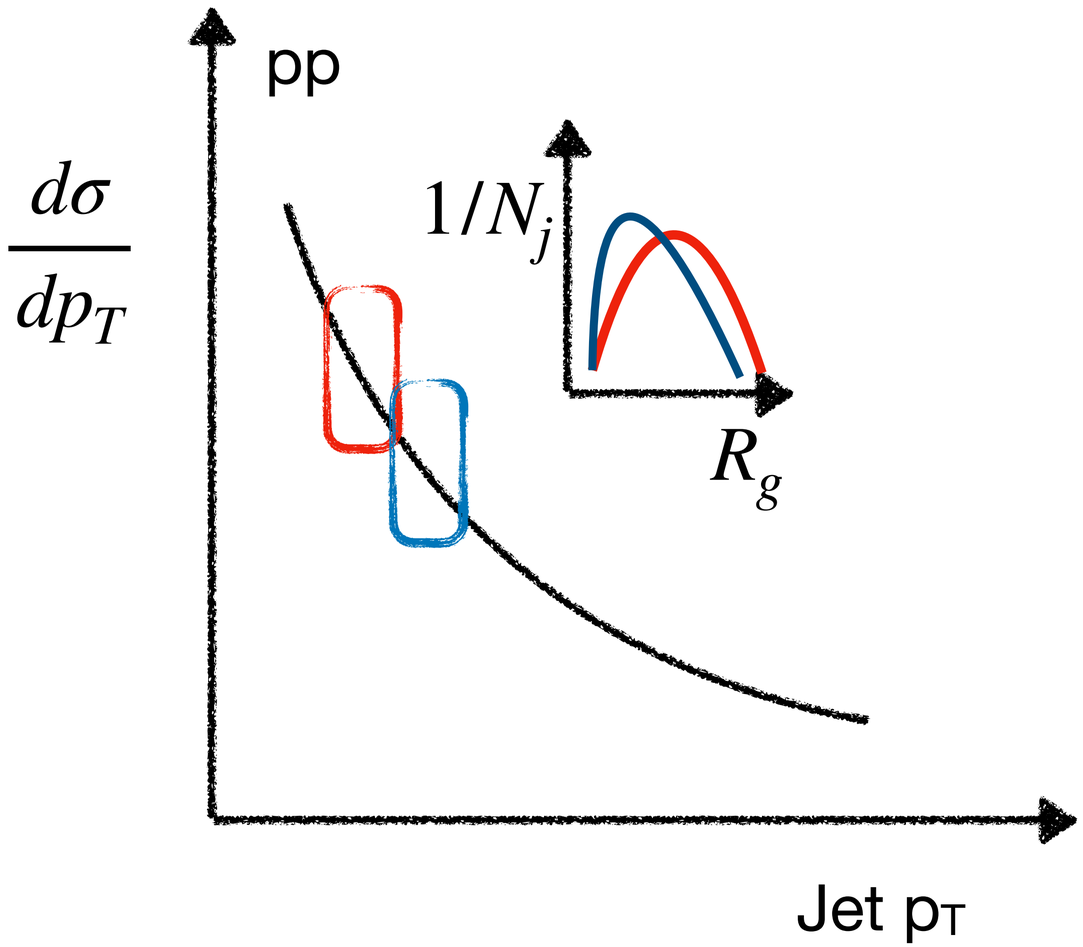


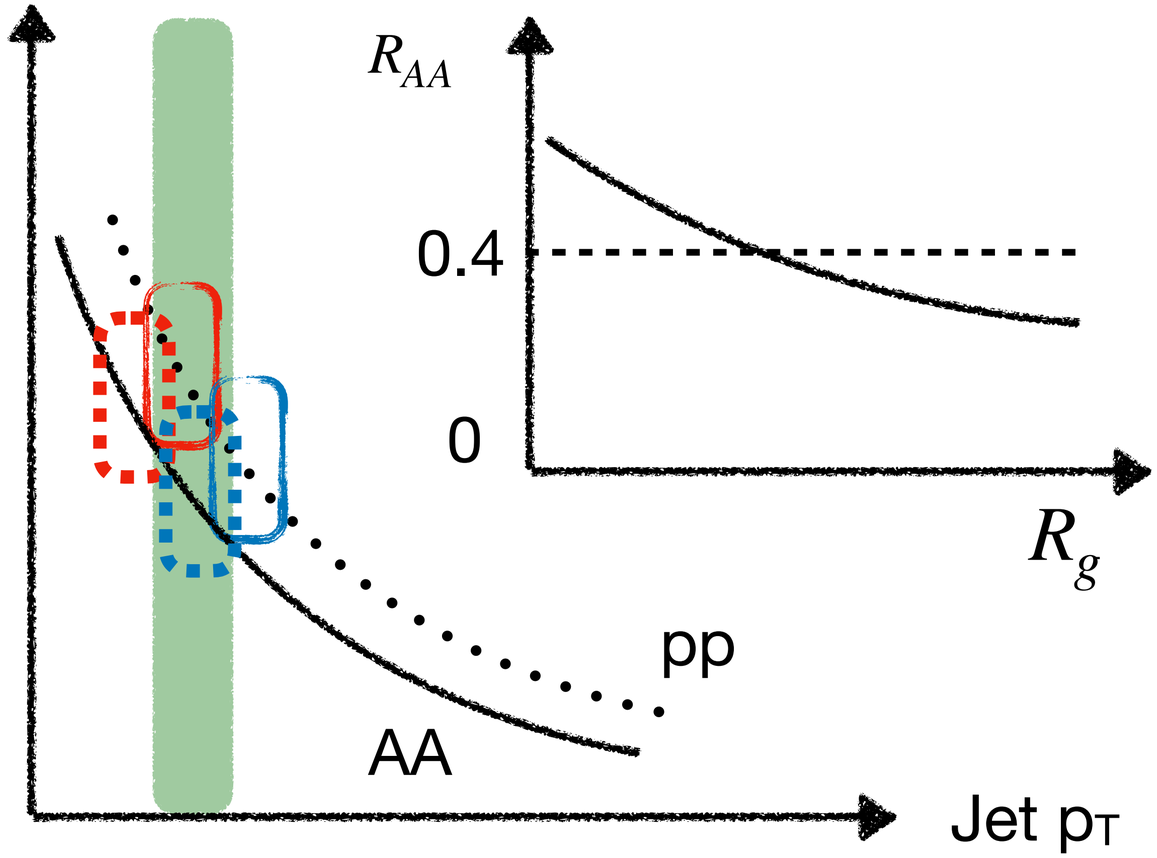


Choosing a fixed jet p_T results in your substructure obvs showing modification

What is the selection bias?

For inclusive jets…

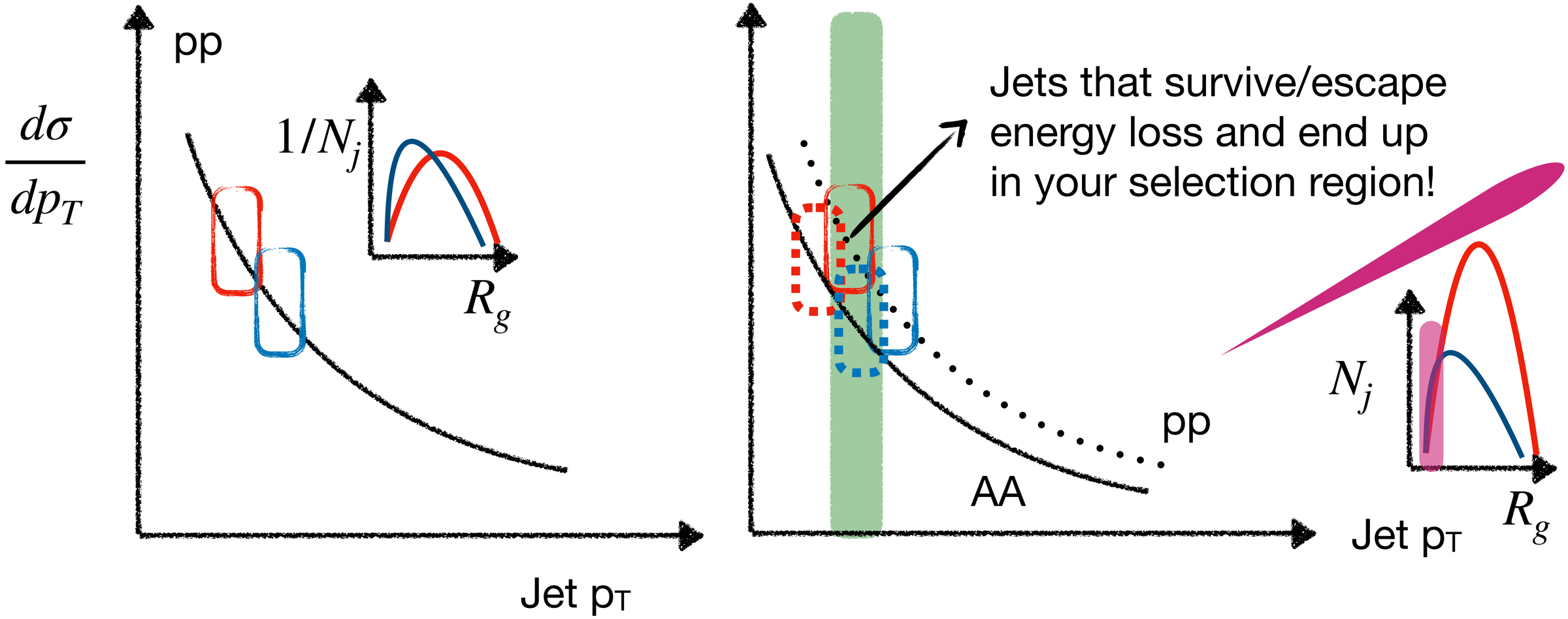




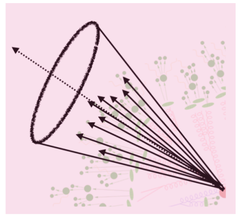
Choosing a fixed jet p_T results in your substructure obvs showing modification

One additional bias

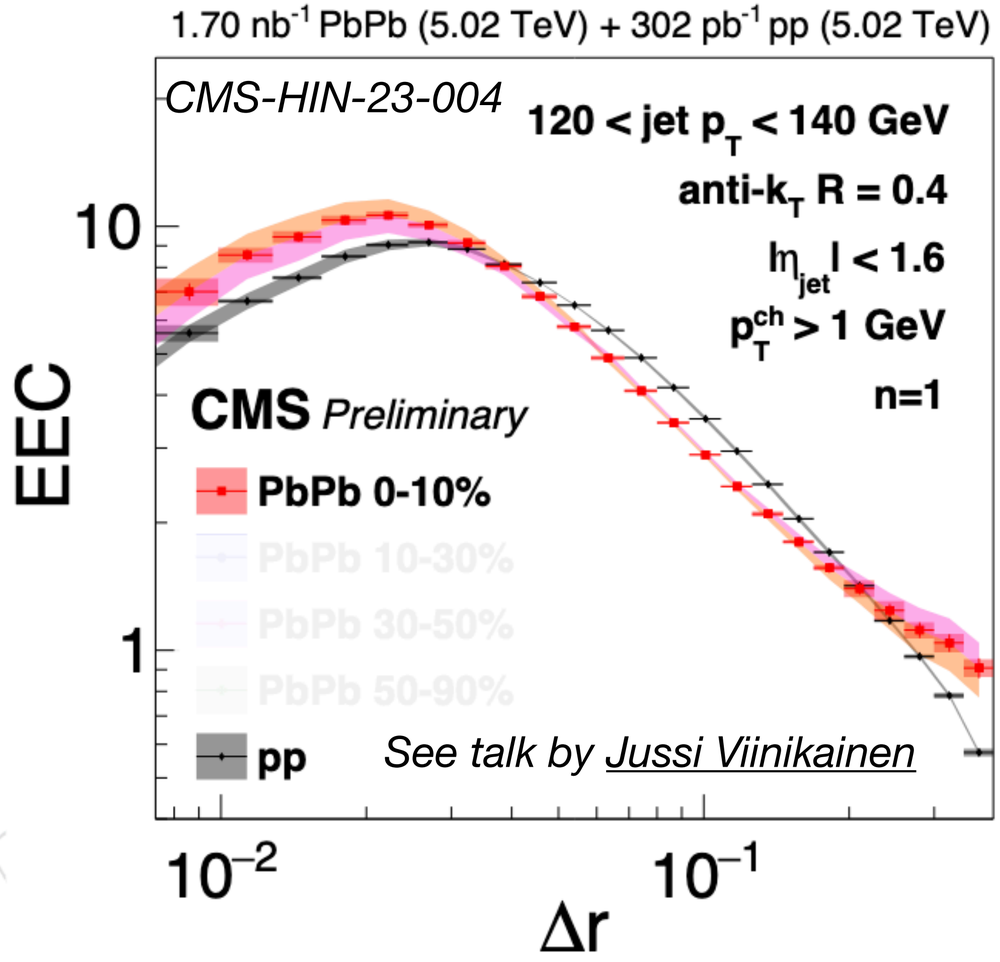
For inclusive jets…

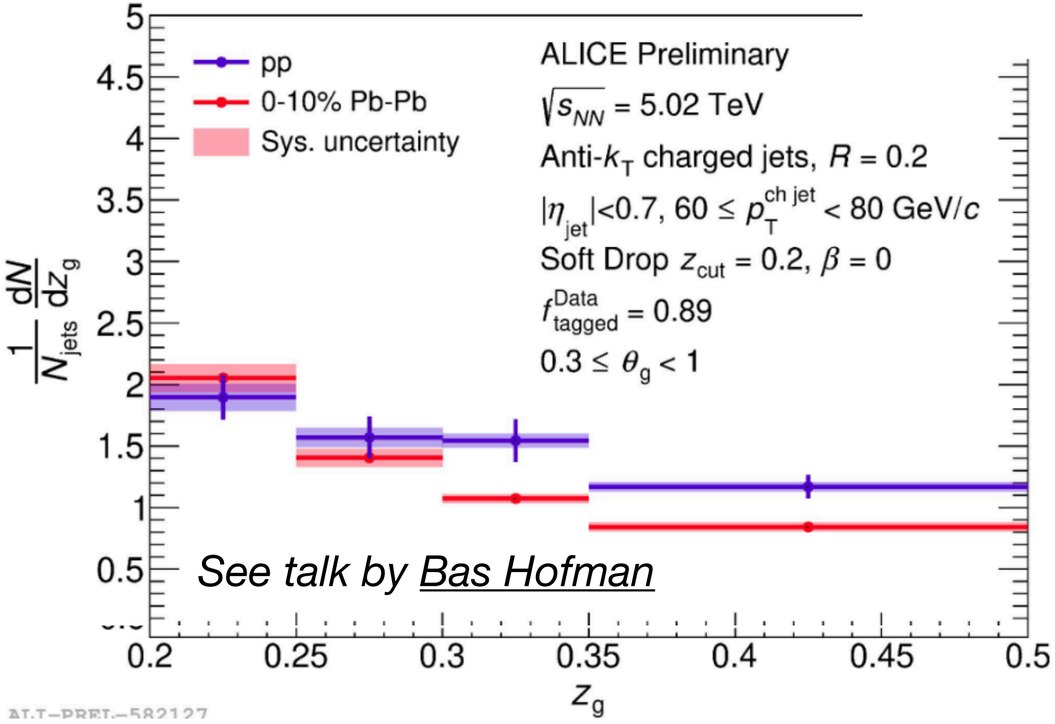


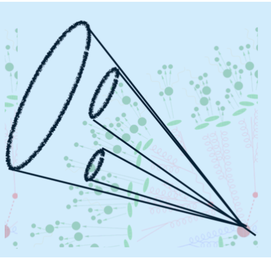
Beware the survivors!



Energy loss and narrowing



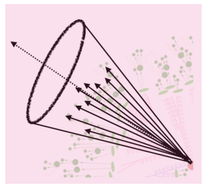




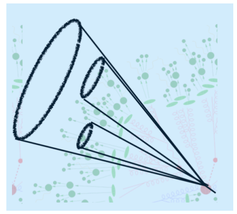
- We now have evidence of PbPb jets starting at higher virtuality
- Exploring systematic methods to reduce such biases with differential measurements!

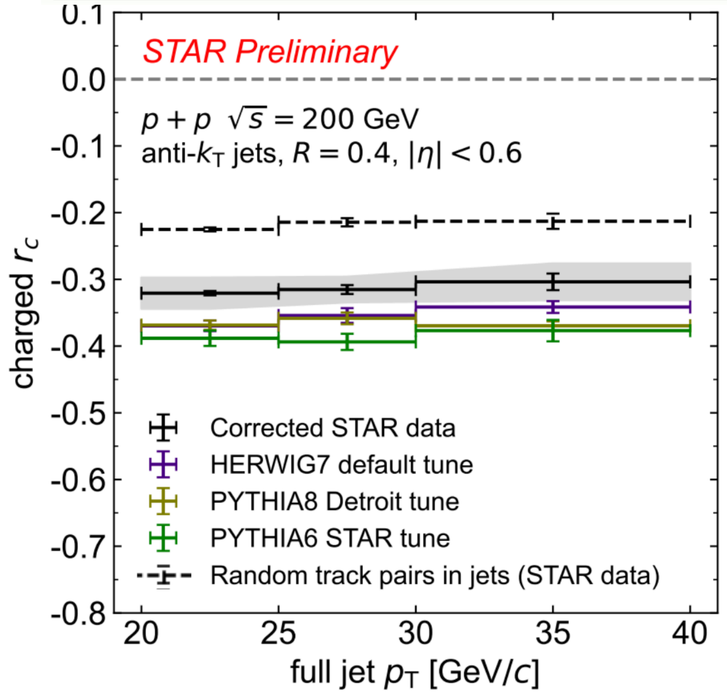
Looking ahead/ whats next?

Exploiting substructure to probe hadronization



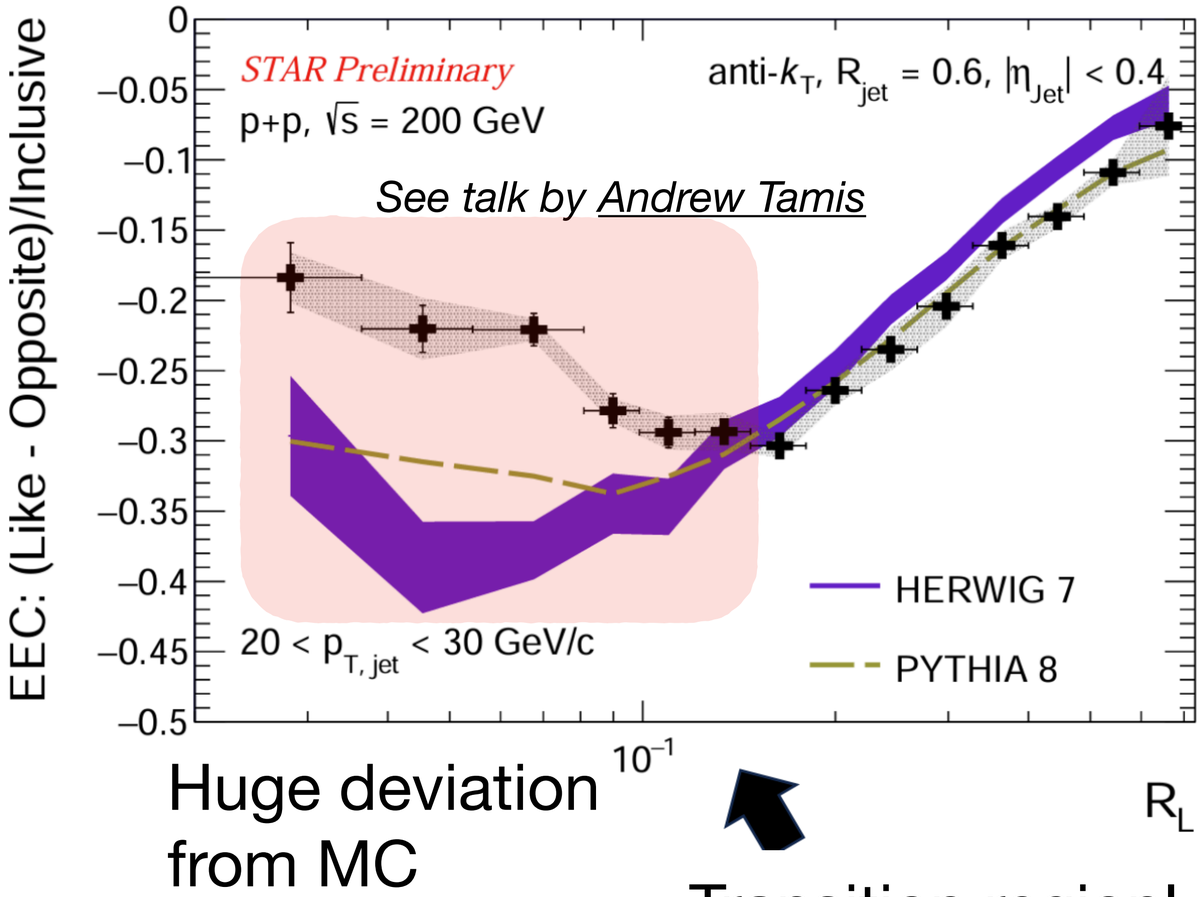
$$r_c = \frac{\text{same} - \text{opposite}}{\text{same} + \text{opposite}}$$





See talk by Yougi Song

See talk by Nuno Olavo

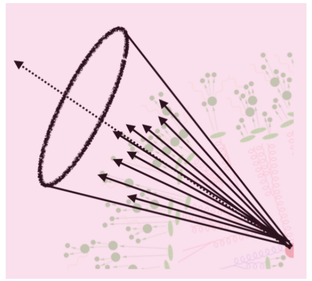


See talk by Andrew Tamis

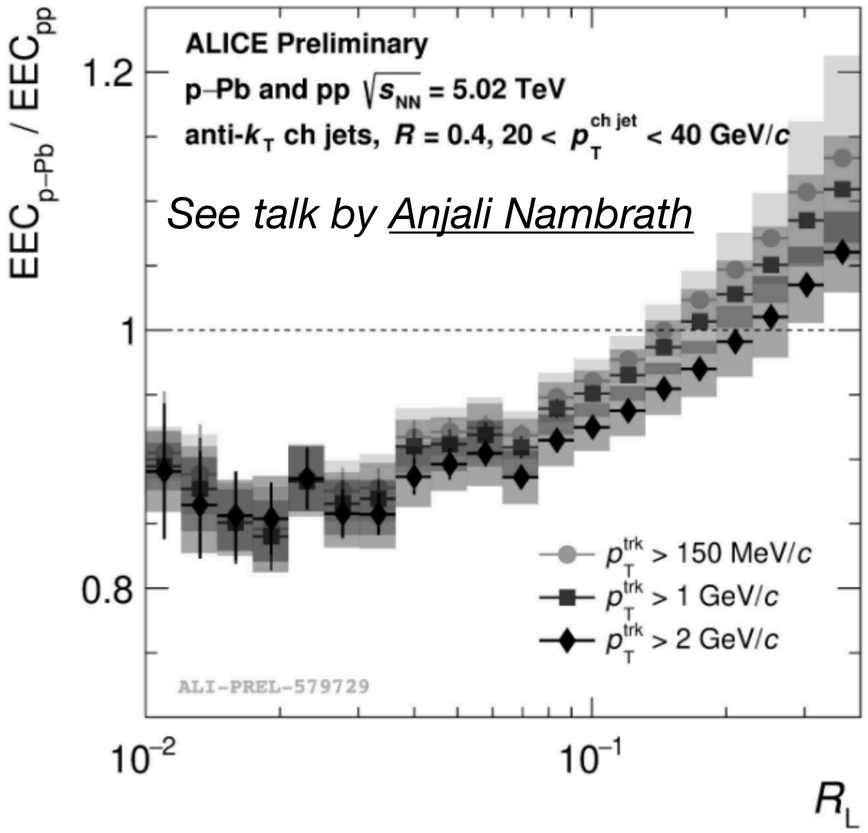
Huge deviation from MC

Transition region!

- Substructure observables show clear sensitivity to charge separation and string breaking within vacuum jets!



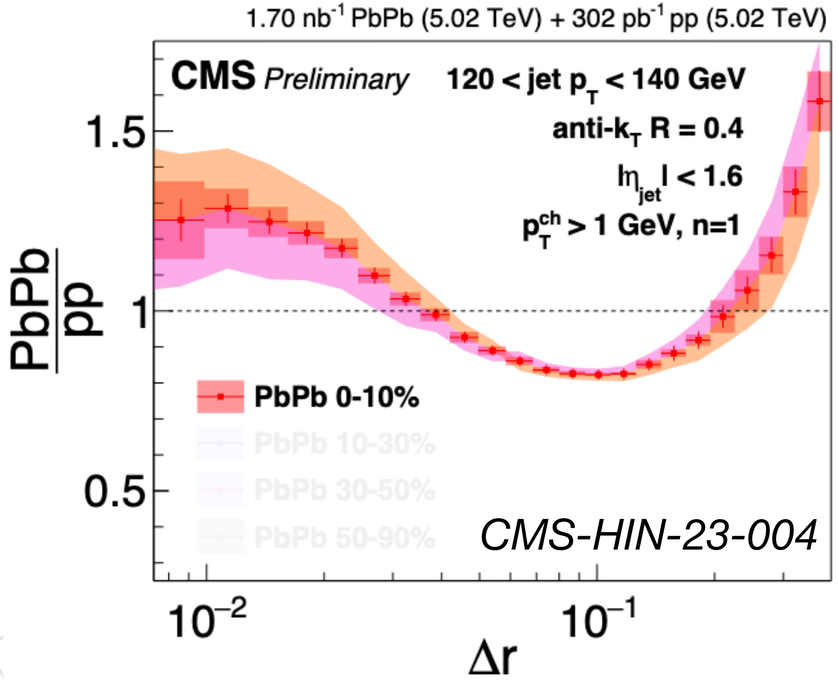
Modifications of EECs

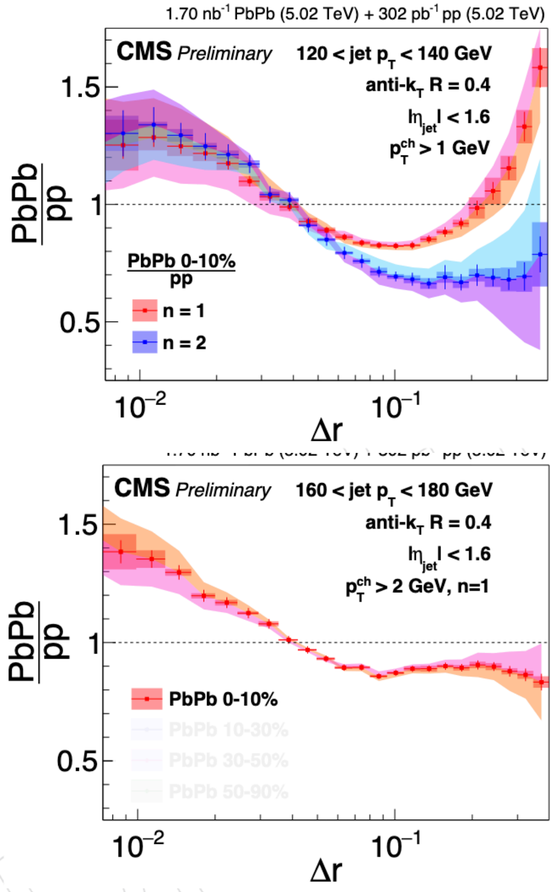


See talk by Anjali Nambrath

- No energy loss with modification at large R_L

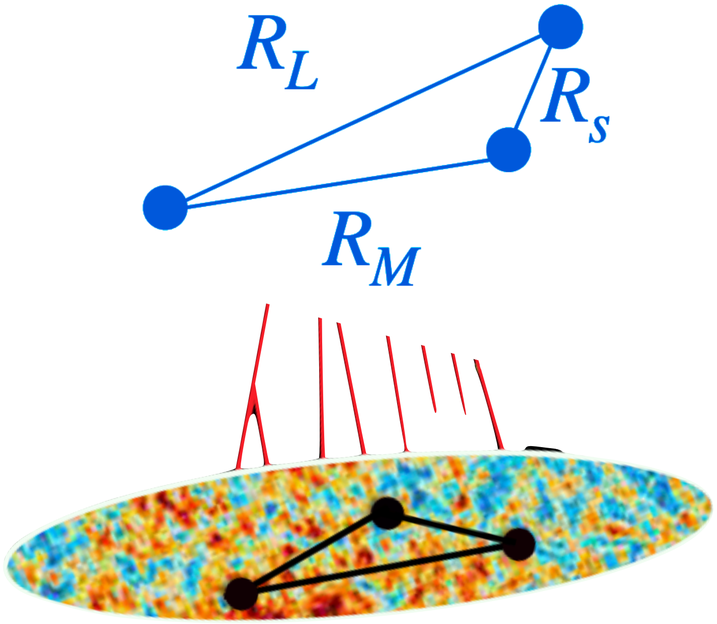
See talk by Jussi Viinikainen





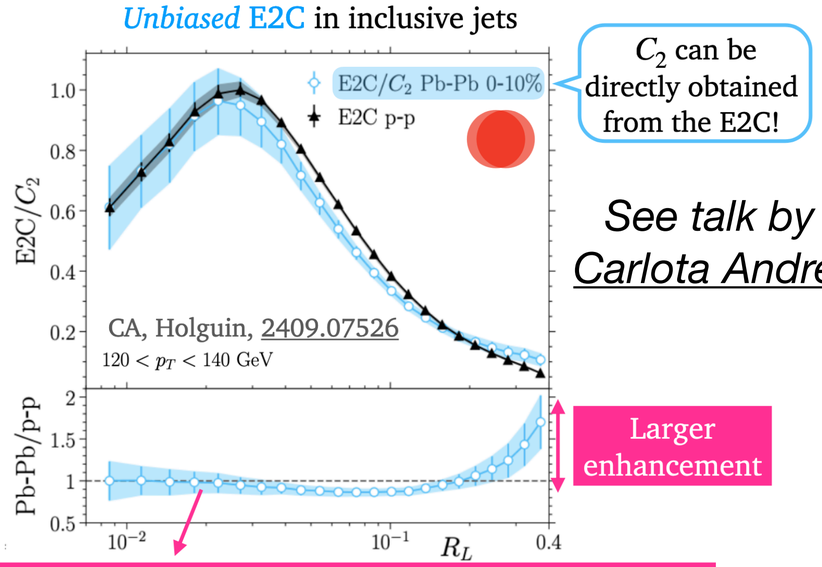
- Enhancement in PbPb goes away with track $p_T > 2$ GeV or E^2E^2 potential disentangling of **medium response/recoils, wake, elastic 2-2 scatterings and coherence-decoherence transition**

3-point EEE-Corr



Bossi et. al. 2407.13818

Making use of inclusive jets!



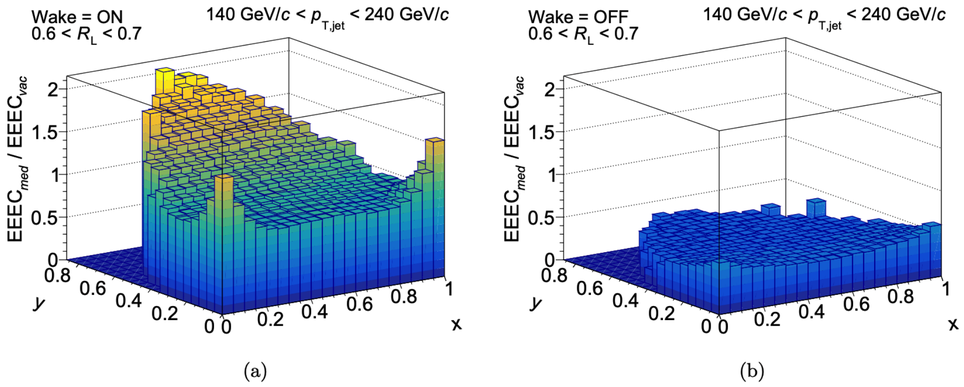
C_2 can be directly obtained from the E2C!

See talk by Carlota Andres

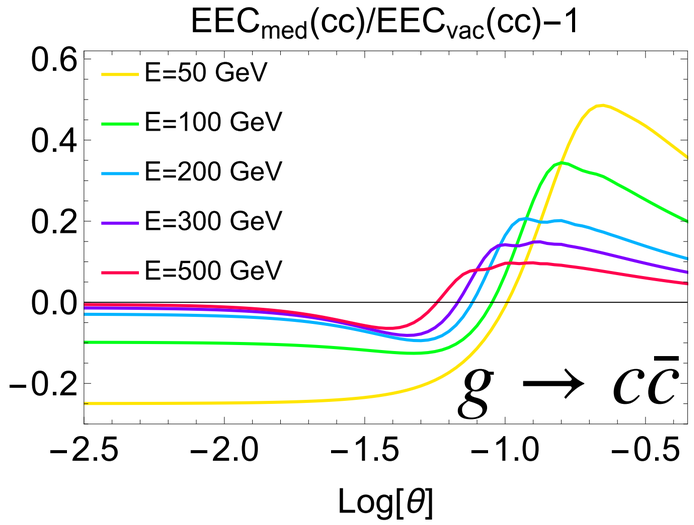
Larger enhancement

Within current uncertainties: the free hadron region is flat

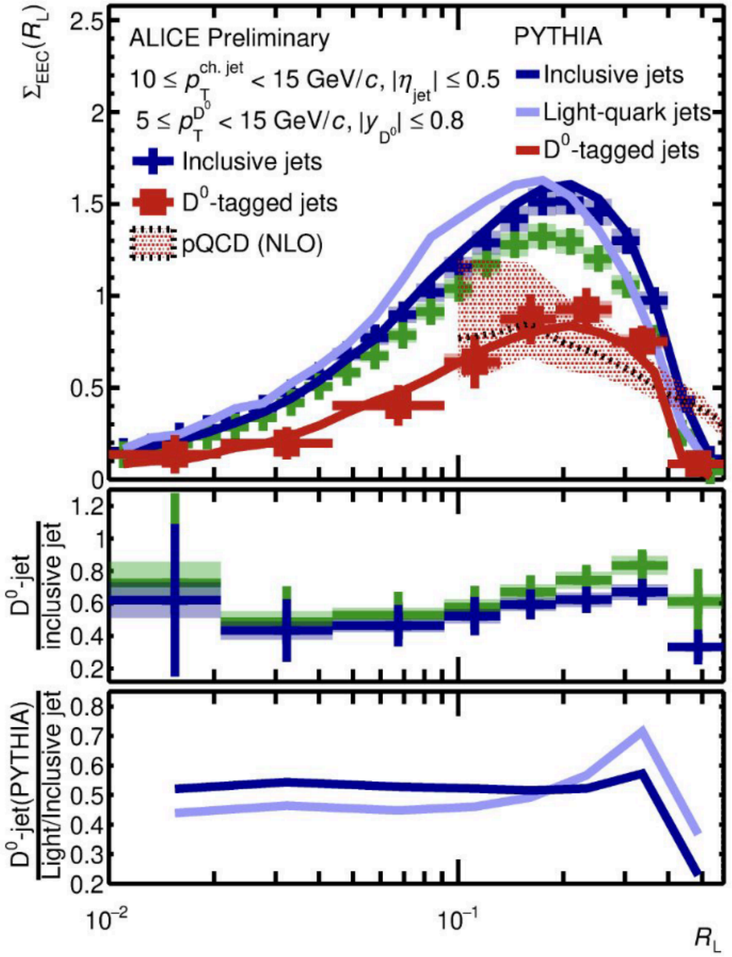
See talk by Jasmine Brewer



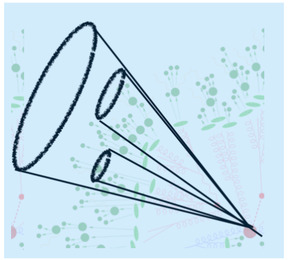
Identify signature of the wake in jets

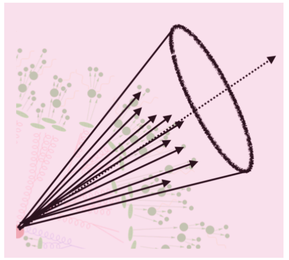


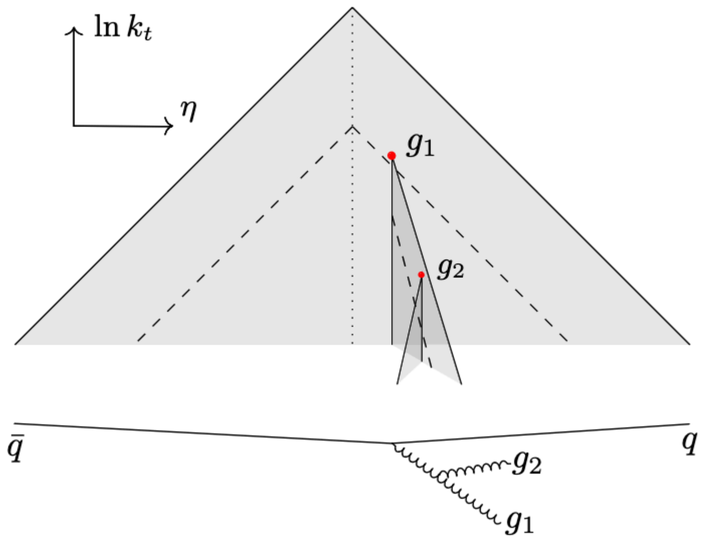
Studying the impact of flavor within the EECs



See talk by Anjali Nambrath

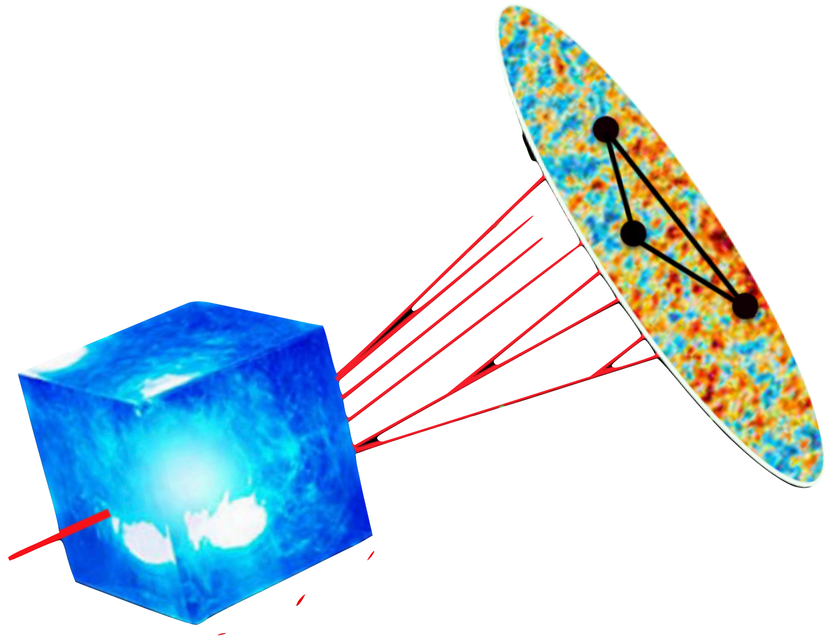




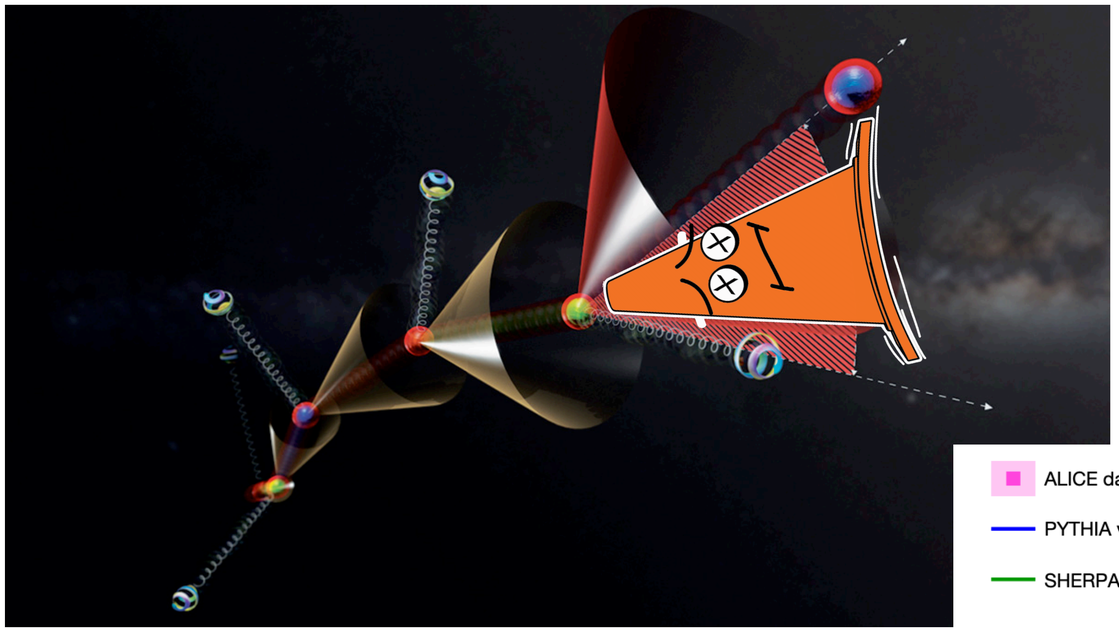


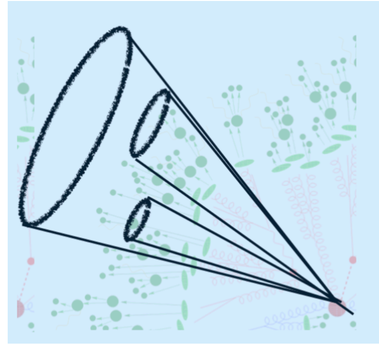
- The era of precision jet substructure is on its way
- Tools available that allow us to separate scale dependent physics for example - pQCD vs npQCD
- Experimental tomography is here!

- Interactions with the QGP are imprinted at varying scales and they are measurable now!
- Calculating EECs are a hard but necessary task for understanding QGP properties



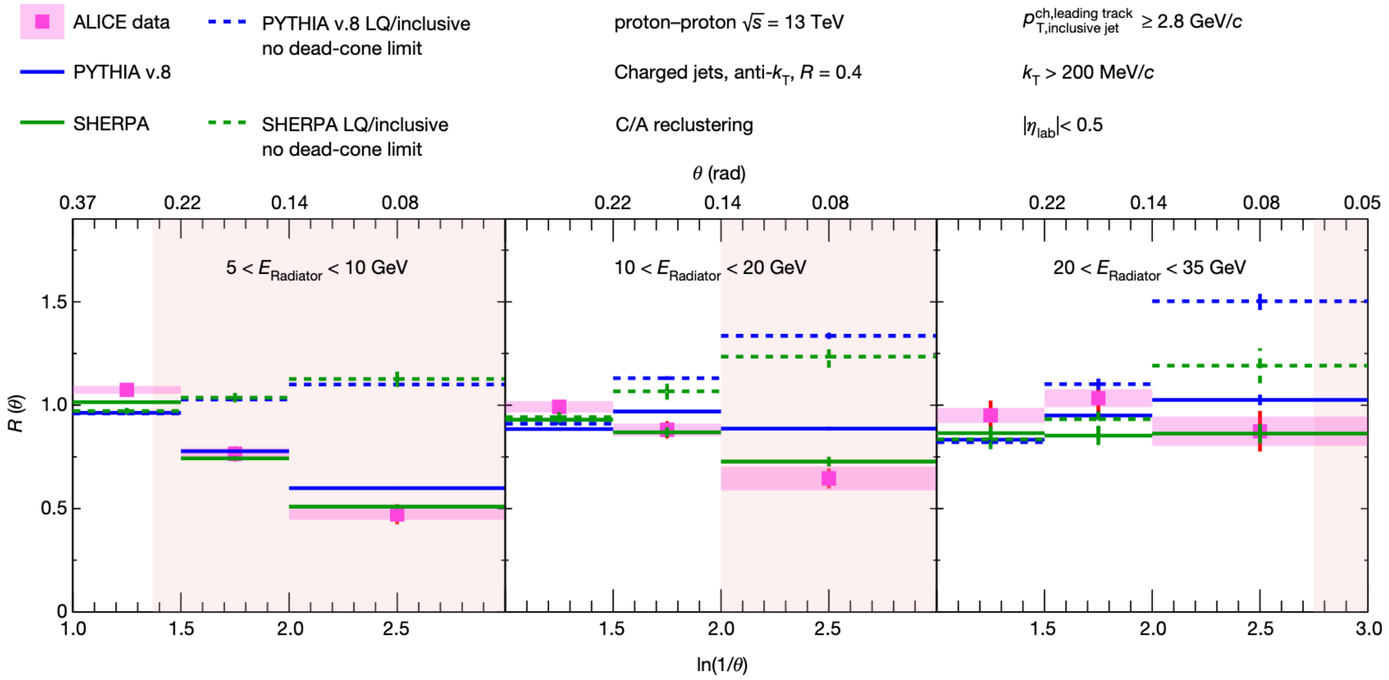
What did we learn in vacuum?





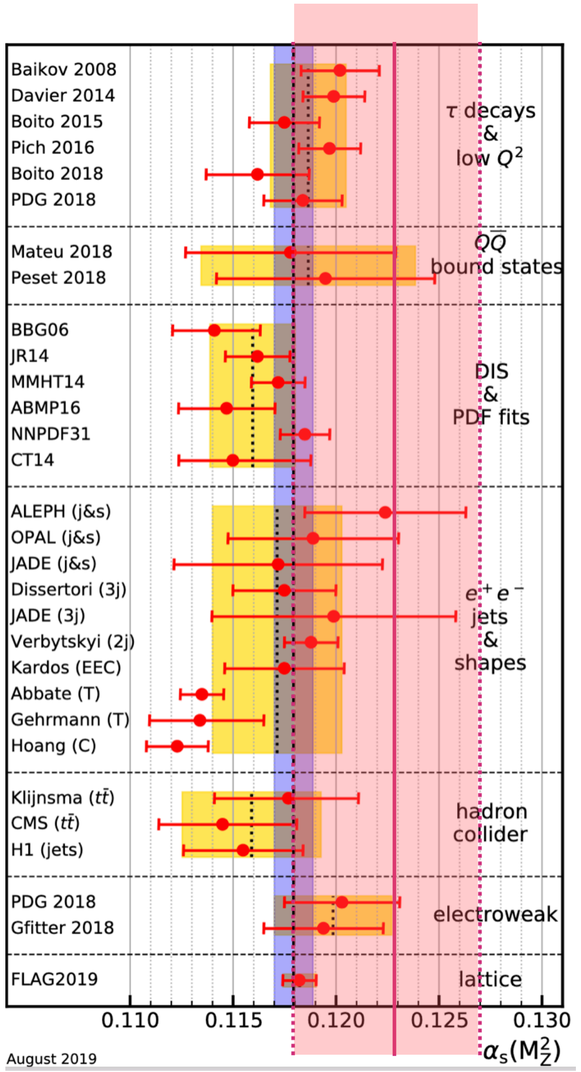
- Splittings tagged within a jet including an identified heavy flavor hadron!

ALICE, Nature 605 (2022)

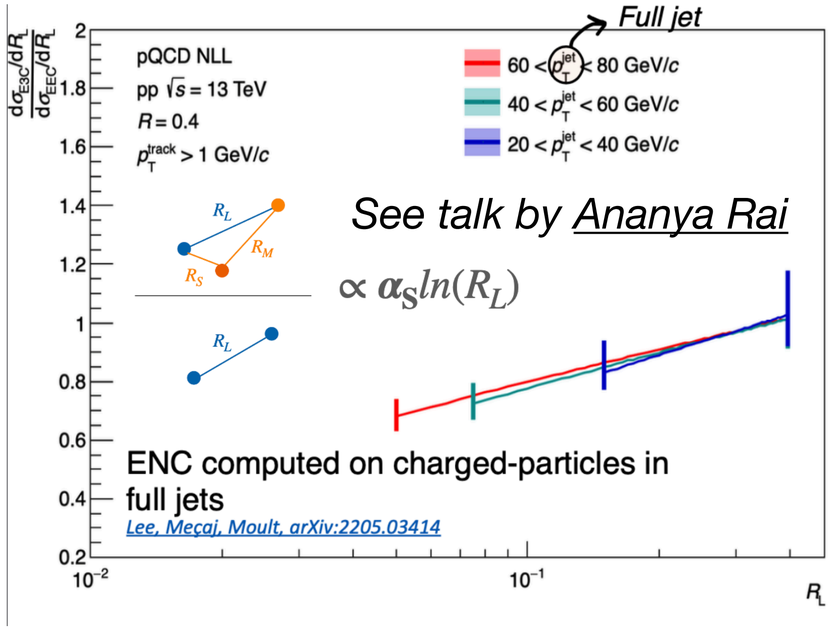


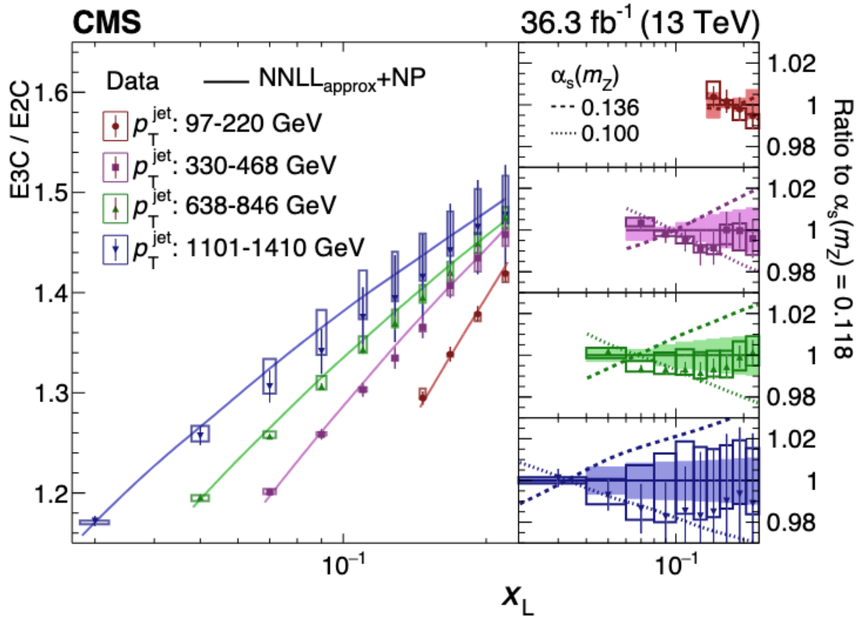
- We directly ‘saw’ the suppression of radiation contained within an angle
  - Dead cone effect!

Precise extraction of α_s



Ratio of 3-point to 2-point correlators





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$$\alpha_s(m_Z) = 0.1229^{+0.0040}_{-0.0050}$$

$$= 0.1229^{+0.0014(stat.)+0.0030(theo.)+0.0023(exp.)}_{-0.0012(stat.)-0.0033(theo.)-0.0036(exp.)}$$

α_s also shown to be running in the Lund plane!