



Can we use jets to probe QGP evolution?

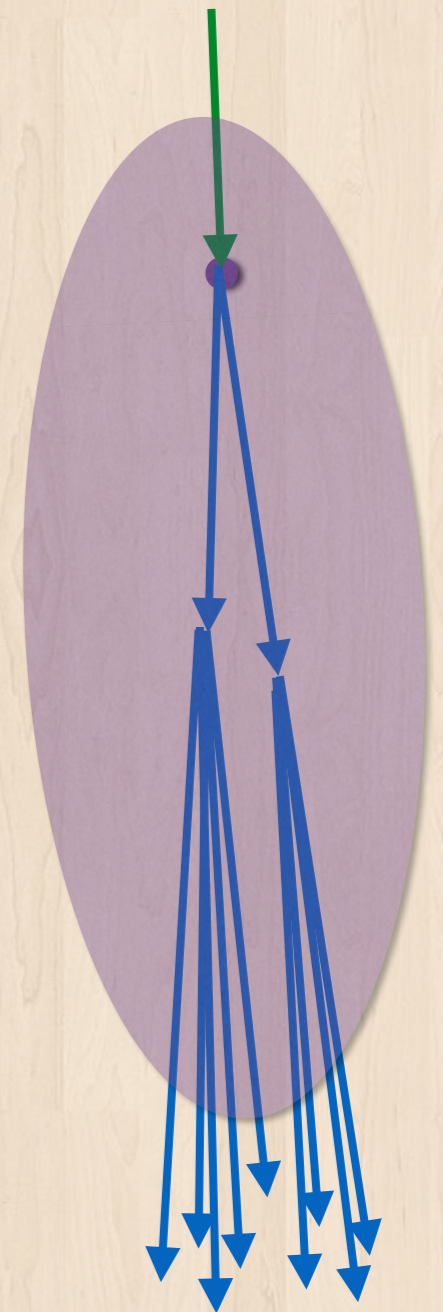
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QCD Challenges pp to AA 2024, Sep 3 2024

With a focus on challenges

Jets and QGP evolution

- What properties are we aiming to probe?
- Some potential questions
 - Can QGP **resolve** the shower?
 - How does energy **dissipate** in QGP?
 - **Wake** effect?
 - Molière scattering?
 - **Color charge** dependence?
 - **Space-time** picture of parton shower?
 - ...



Approaches

- Roughly a few (overlapping) categories
 - Use specialized observables to isolate specific QGP effects
 - Time-inspired substructure observables
 - Go through time-averaged quantities and extract information
- For today aim to provide some starting points for discussion. Many things are open-ended

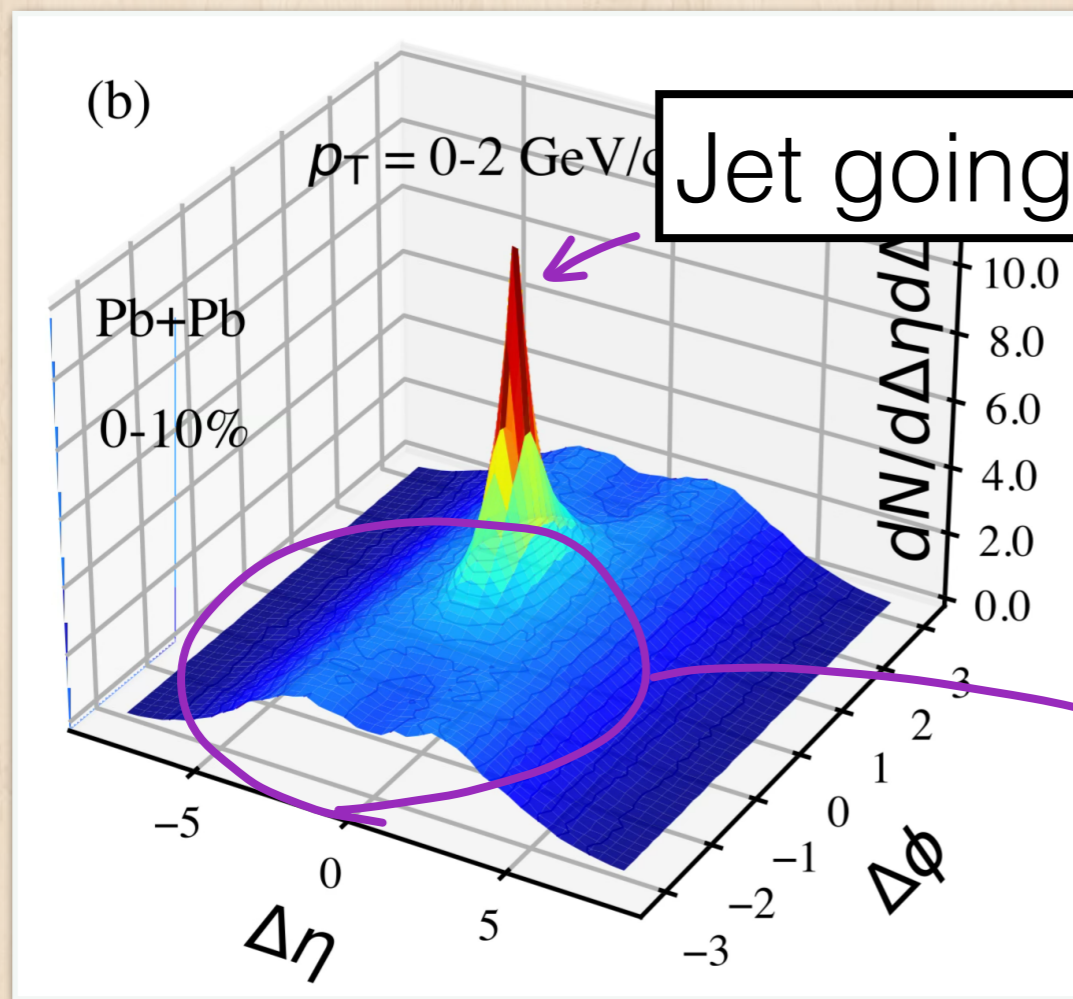
Hunting for specific
QGP effects

QGP effects people look for

- There are many things people try to search for
 - Color (de)coherence? (Groomed angle, EEC, Lund plane-inspired observables, ...)
 - Molière scattering/acoplanarity/ R_g ?
 - Things filling into the void of dead cone effect? (b/c-jet substructure)
 - Wake effect? (V-h correlation, jet-h in V events, ...)
 - ...

(Z/jet)-hadron correlation

As an example: looking for diffusion wake

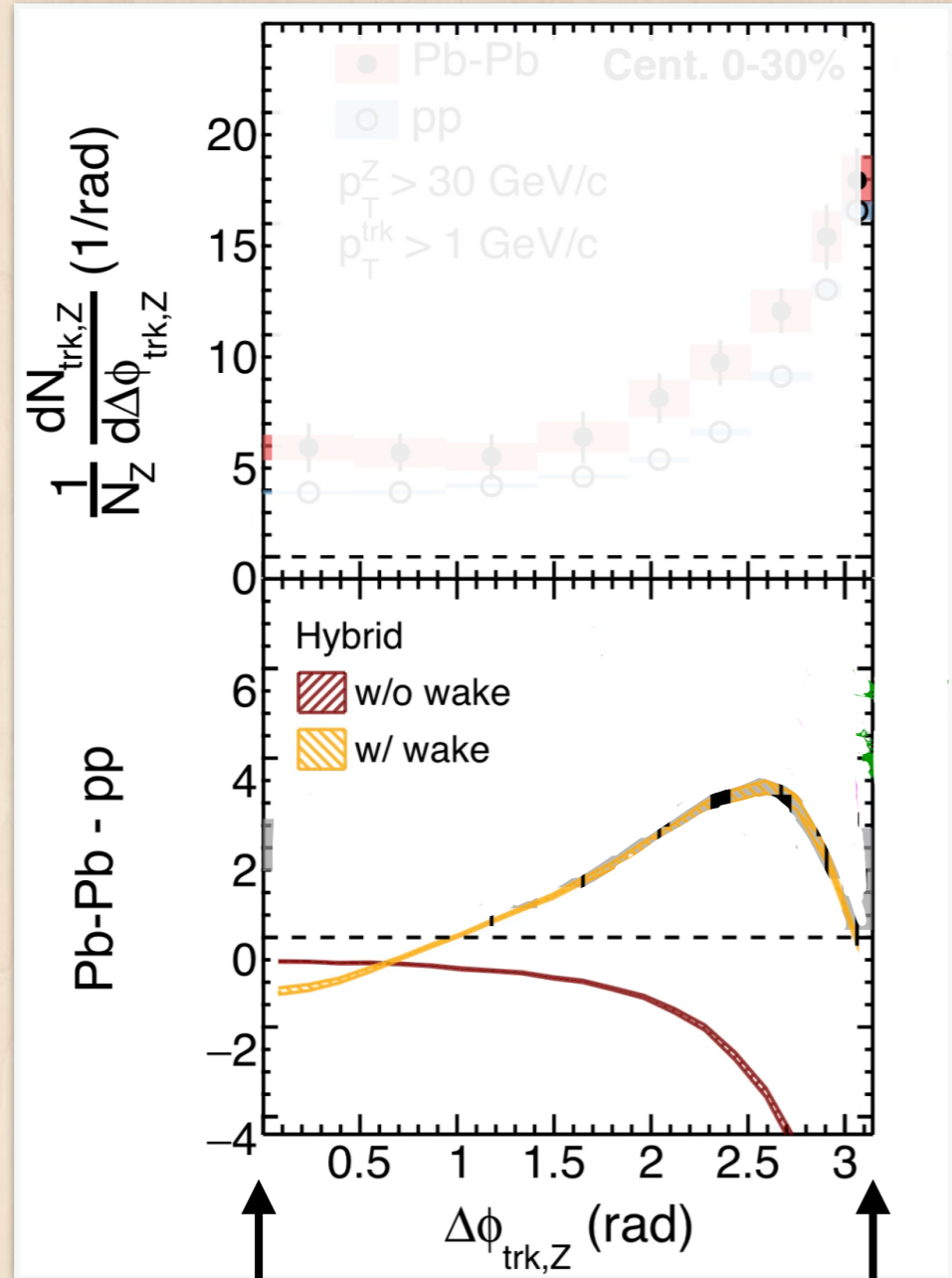


Jet going through QGP



example from CoLBT

Z-hadron correlation



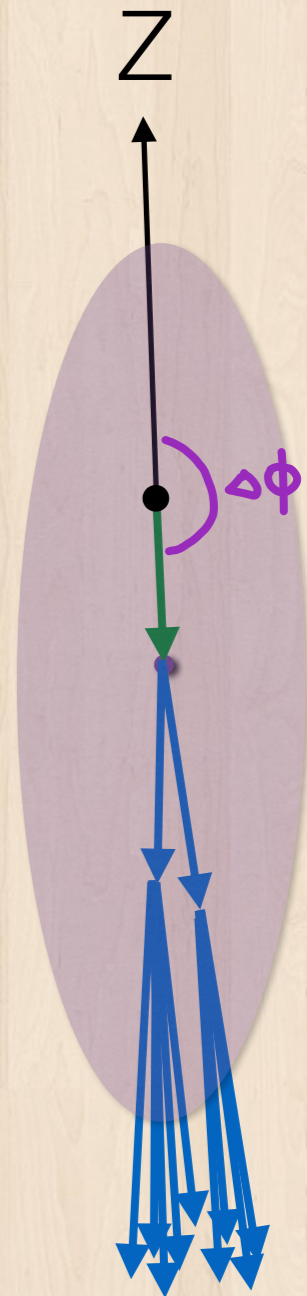
Z side

Jet side

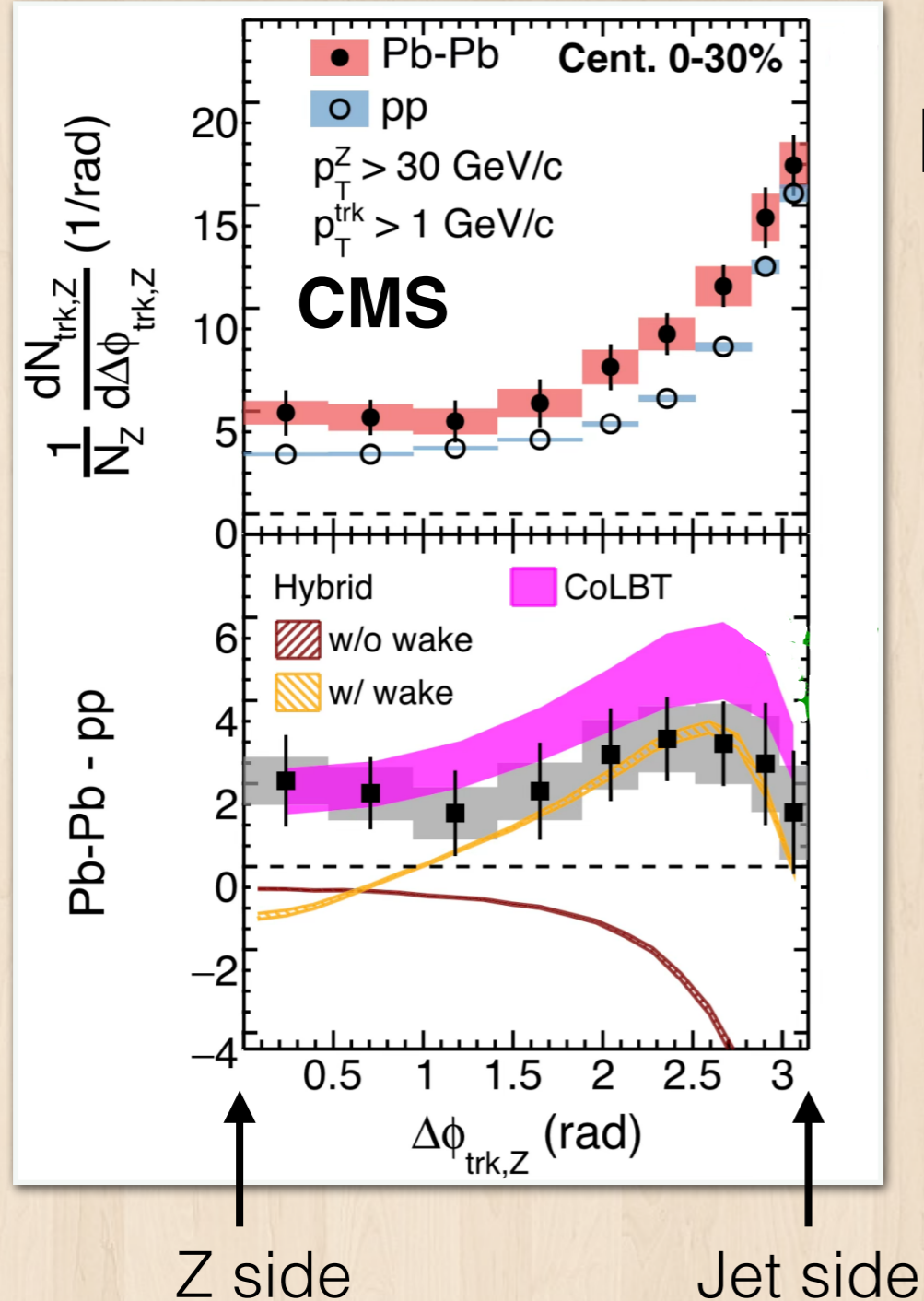
Looking at all particles associated to Z

Enhancement all over the place

Multi-parton interaction (MPI) masking potential signal



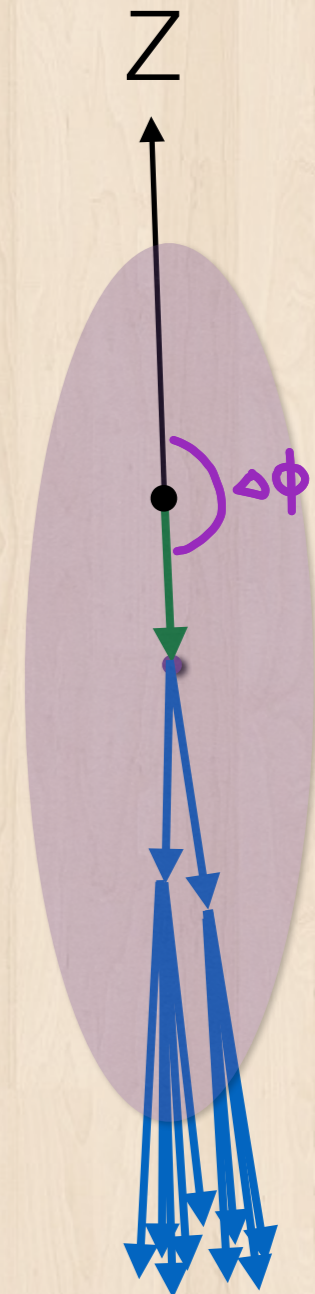
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Looking at all particles associated to Z

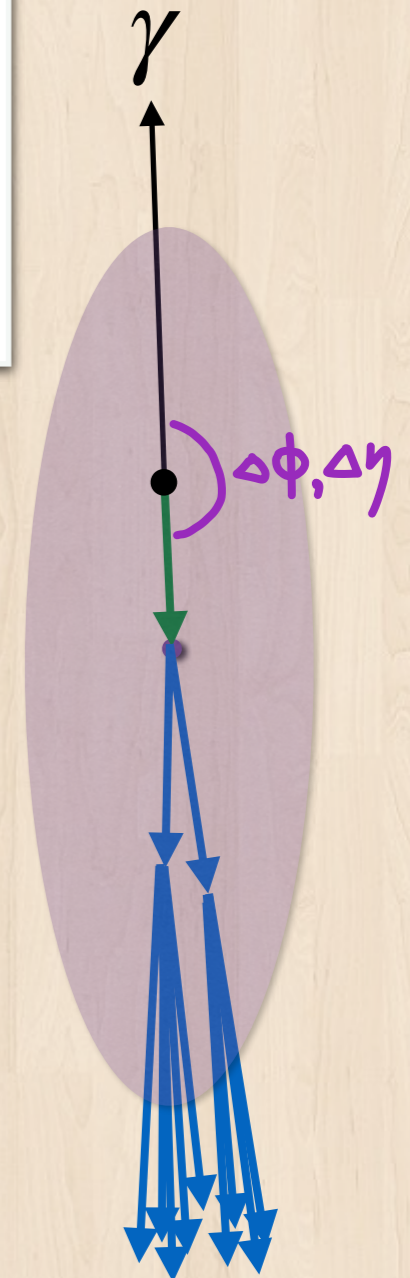
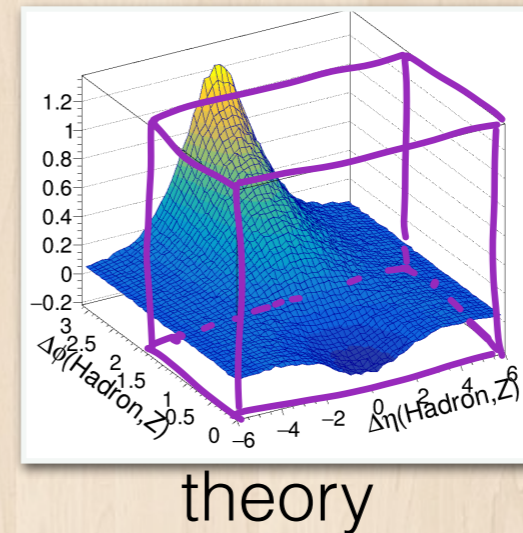
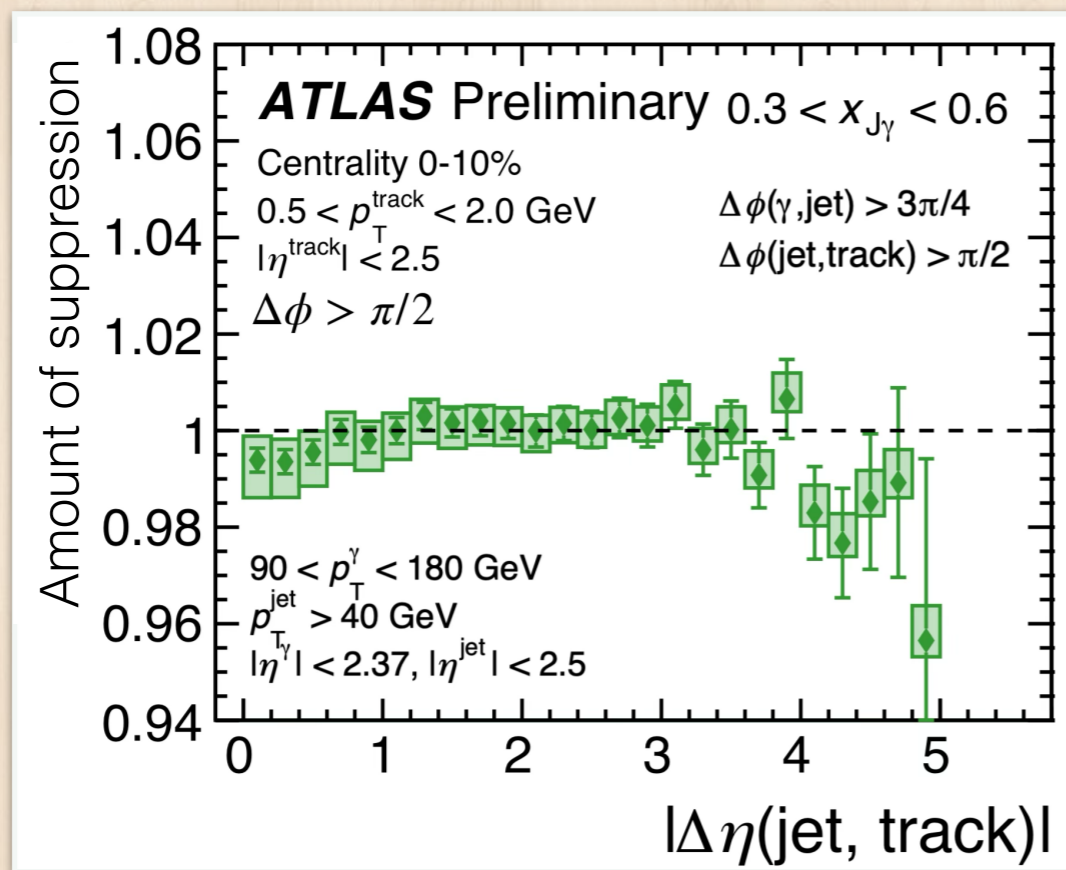
Enhancement all over the place

CoLBT: Multi-parton interaction (MPI) masking potential signal



Can we see the depletion?

Imbalanced configuration



A bit of hint? Not significant for now

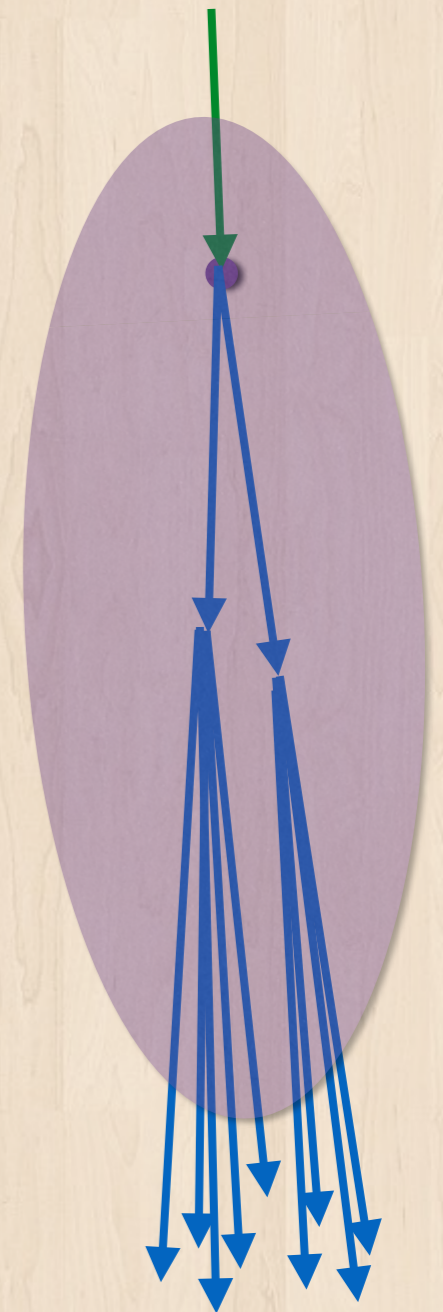
Challenges

- Things are not very significant for now
 - **More clever way to design observables?**
 - Wait for more data?
- Similarly for many other things we try to pin down
- What's the **bigger picture**? Suppose we see the wake and some of the other proposed things. How do we **connect back to a unified picture of QGP**?

Time-inspired jet substructure

Jet substructure

- Many substructure observables proposed
- Look at particle distribution and attempt to reconstruct the parton shower history
- Shower history is arbitrary in vacuum
 - We pick an ordering variable and connect lines with that



Challenge: spacetime picture

- In HI, popular (often implicit) choice: angular ordering
- Then we can build arguments from there. Examples...
 - Formation time of shower splits
 - “Large angle splits happen early on”
- But — spacetime picture now matters: QGP is hotter early on. Different shower history = different quenching effect
- **Can we establish the splitting sequence experimentally?**

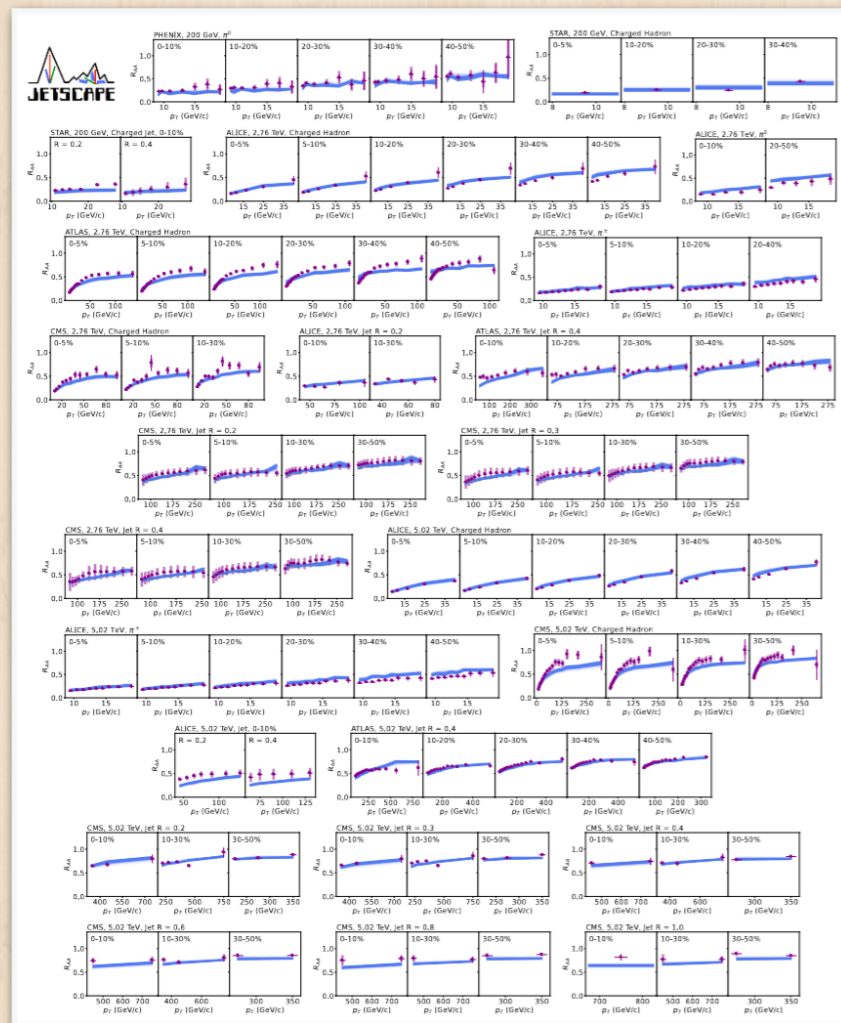
Parameter extraction

(Time-)averaged quantities

- I mean the majority of existing measurements: RAA, fragmentation function, etc.
- Here the way to go would be performing data-theory/
model comparisons and dig out information from there
- Example: global analysis (but not limited to)

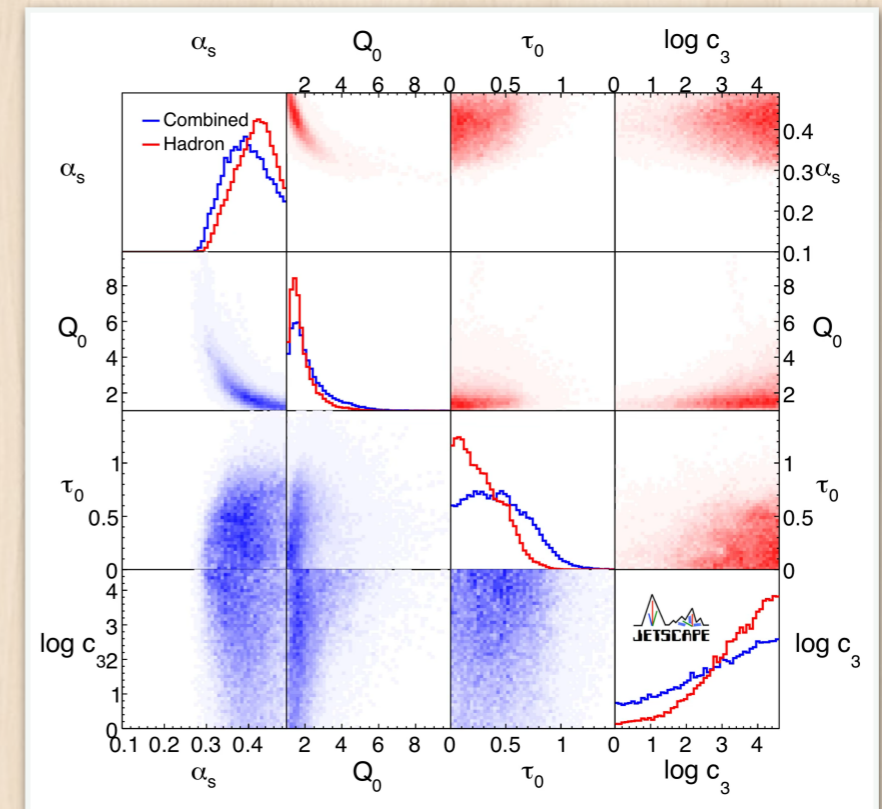


One example: hadron/jet R_{AA}



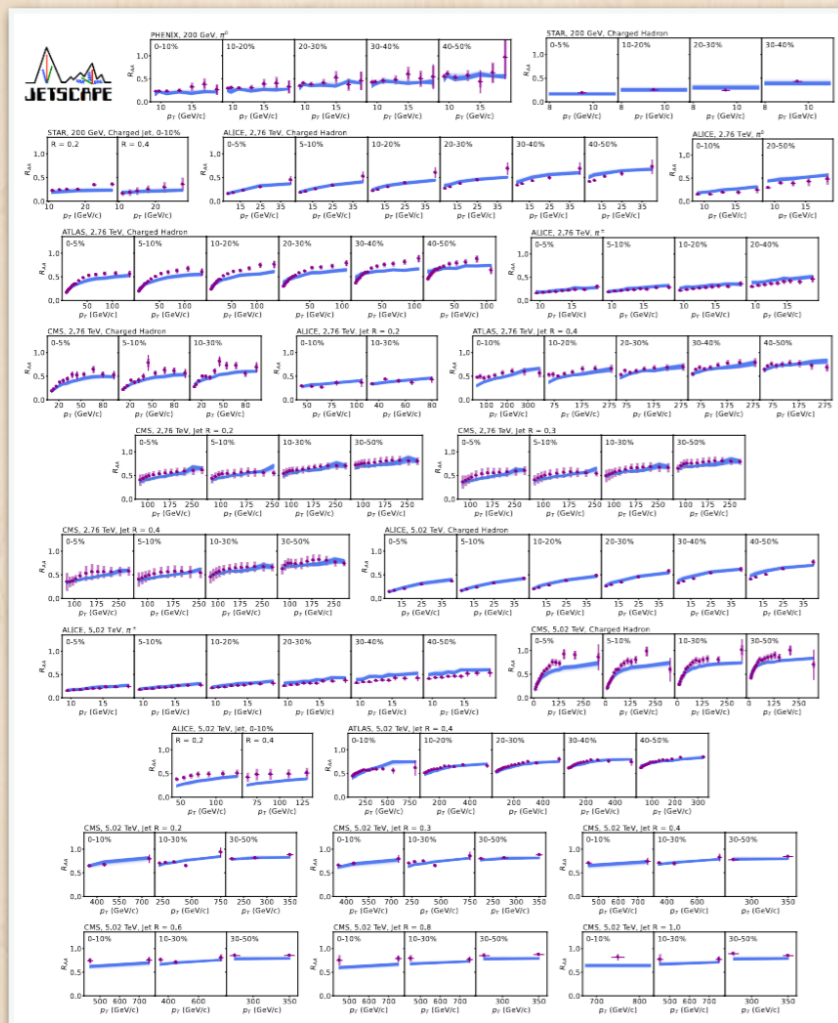
Each point = one QGP evolution profile

Analysis



Compare model parameter space with different QGP properties and see which one fits the best

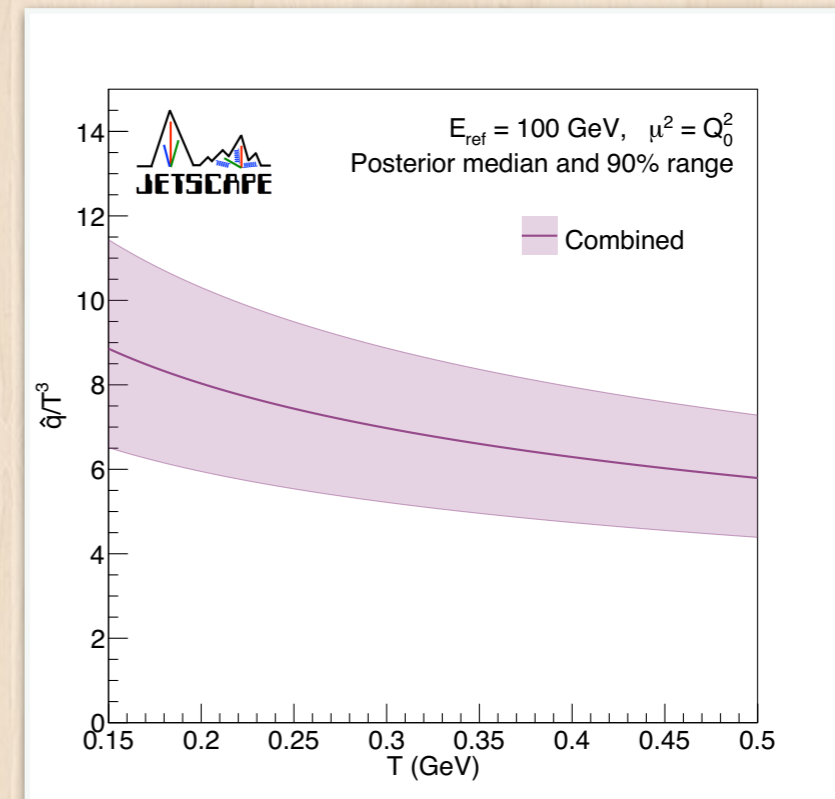
One example: hadron/jet R_{AA}



Analysis

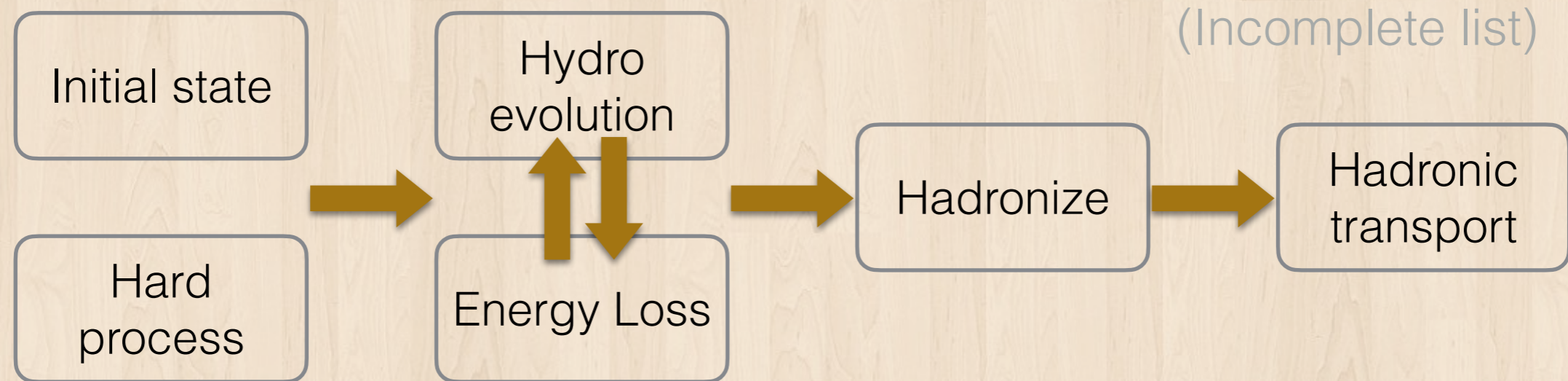


T-dependence
mostly from model



Compare model parameter space with different QGP properties and see which one fits the best

Challenges



- It's difficult to model the whole heavy-ion collision well, there are a lot of assumptions and parameters
- Within and at the interface between blocks
- Computational challenge: ~5M CPU-hour for the analysis in previous page

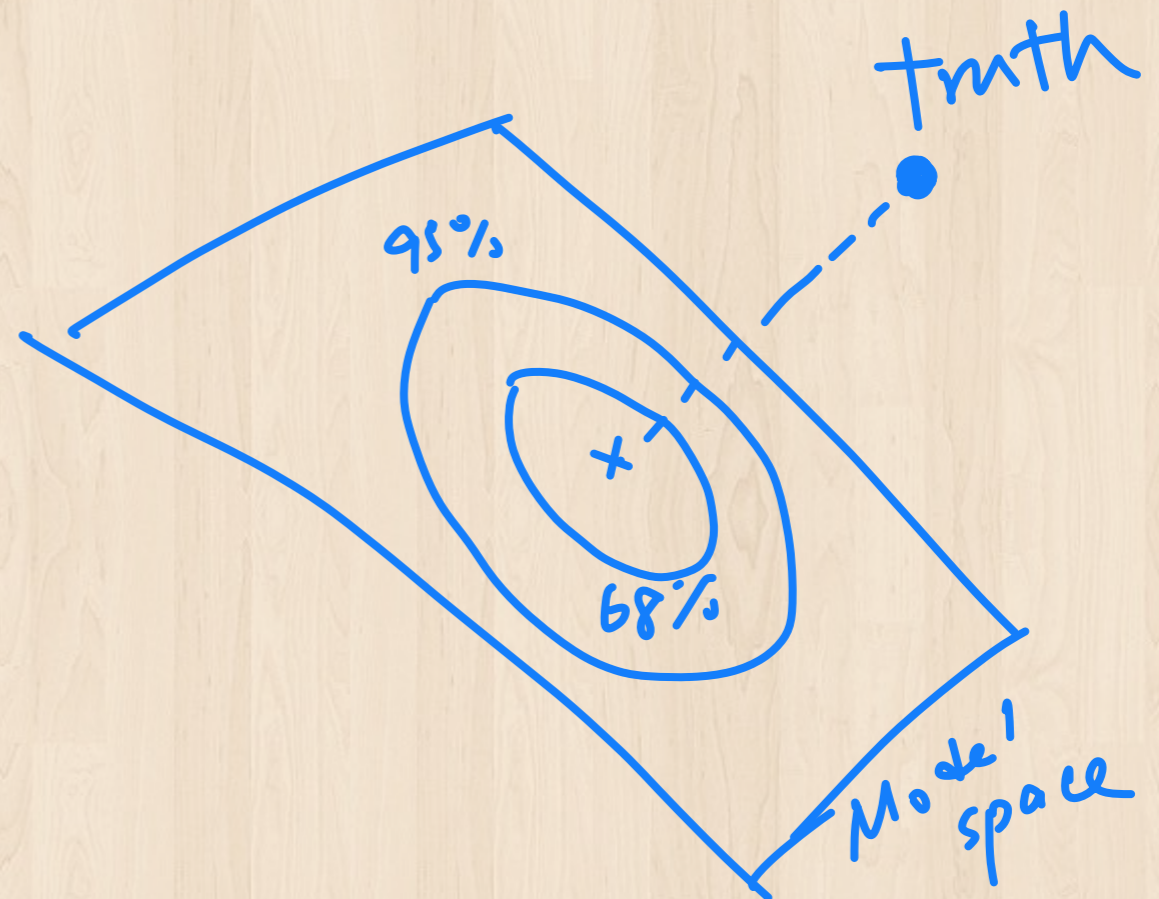
Challenges

We measure the shadow of the truth

Hard to say conclusively how far we are (c.f. LO/NLO/...)

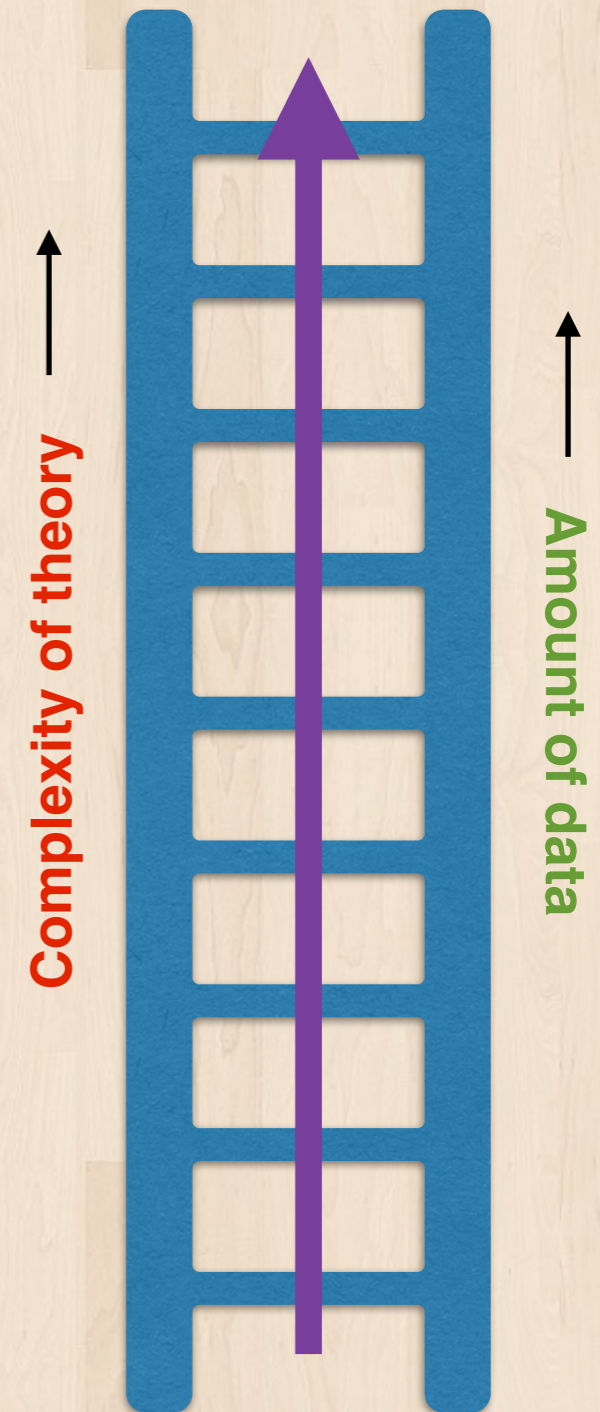
Improvement to model/theory crucial

Additional challenge: **experimental uncertainties**

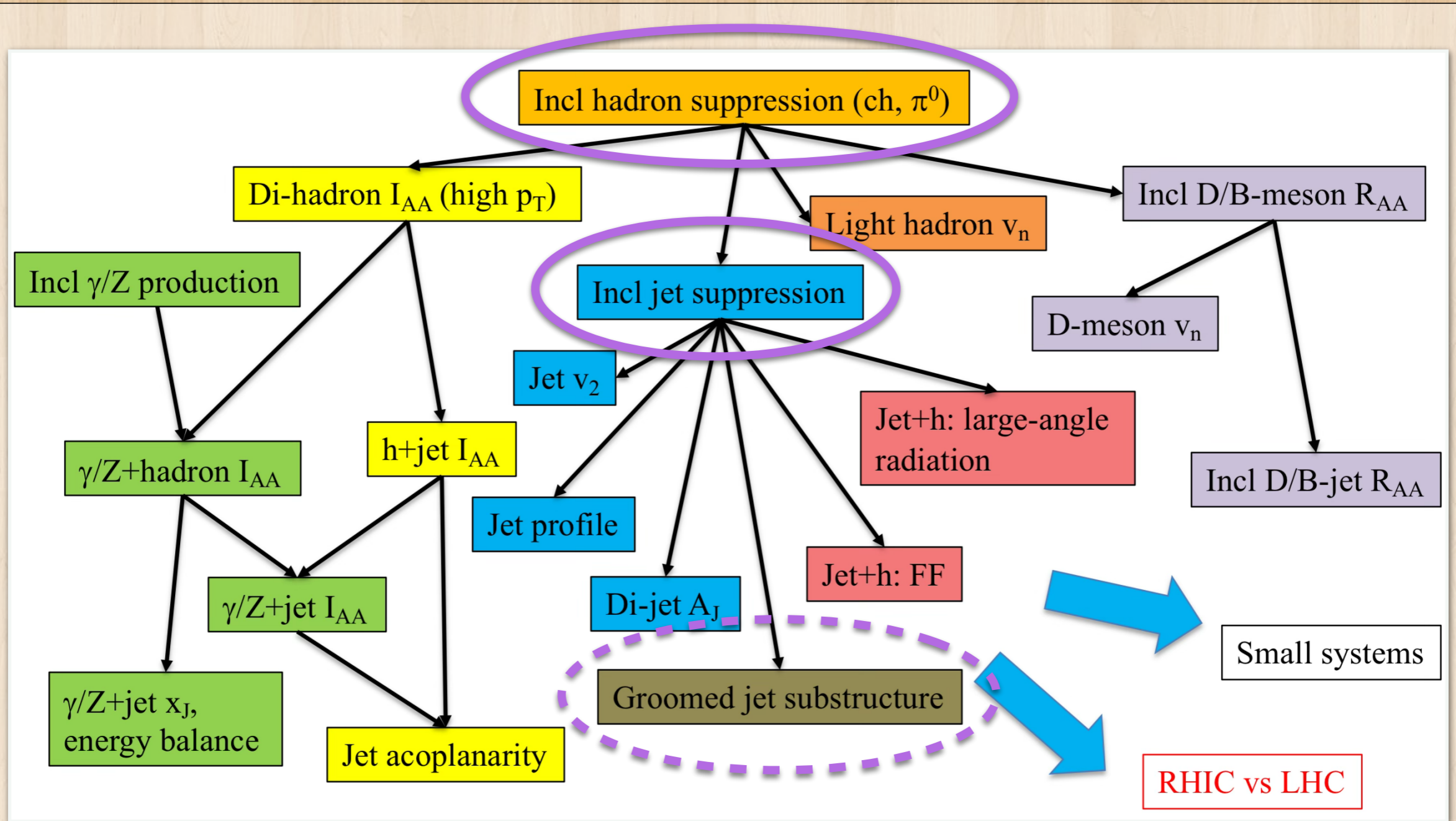


Where do we go from here?

- Even though a lot of available measurements used, this is a small subset
- Systematically **include more types of data**
- Together with **improvements on the theory/model side** as well
- Lots of interesting things to explore



Many extensions

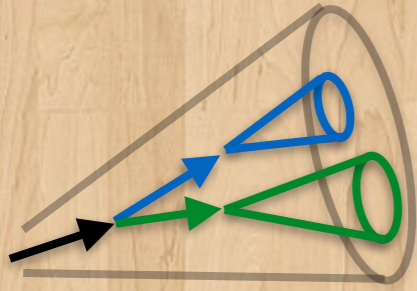


Explored so far in global analyses

Side note: understanding
the reference

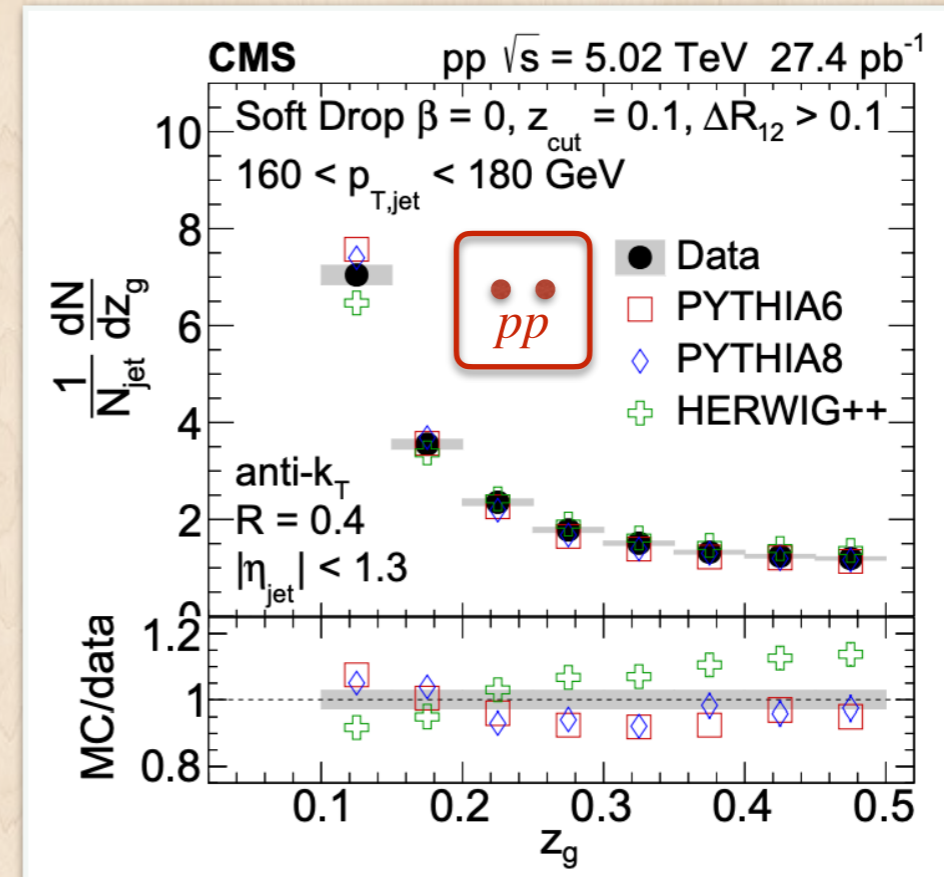
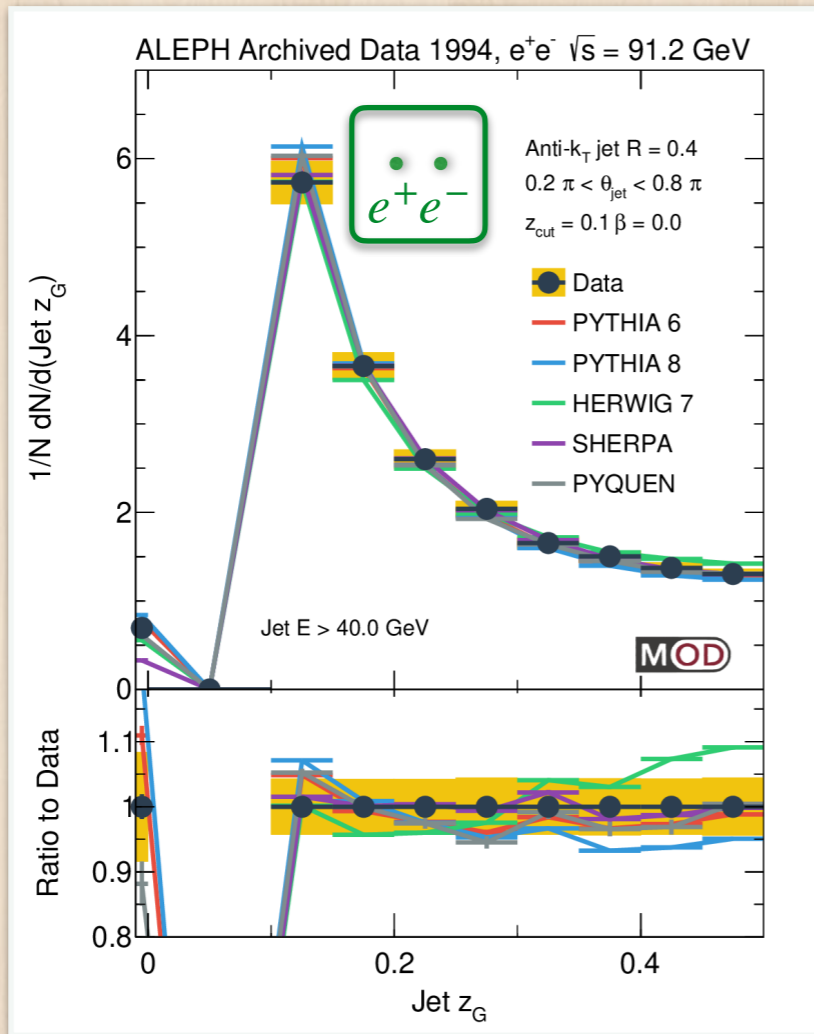
Understanding the reference

- Typically **pp** reference is used in HI measurements
- **pp** itself comes with complications with hadronic initial state
- The better we can understand vacuum evolution the better we can probe QGP
- Going to different systems and make sure we understand things, e.g. e^+e^-



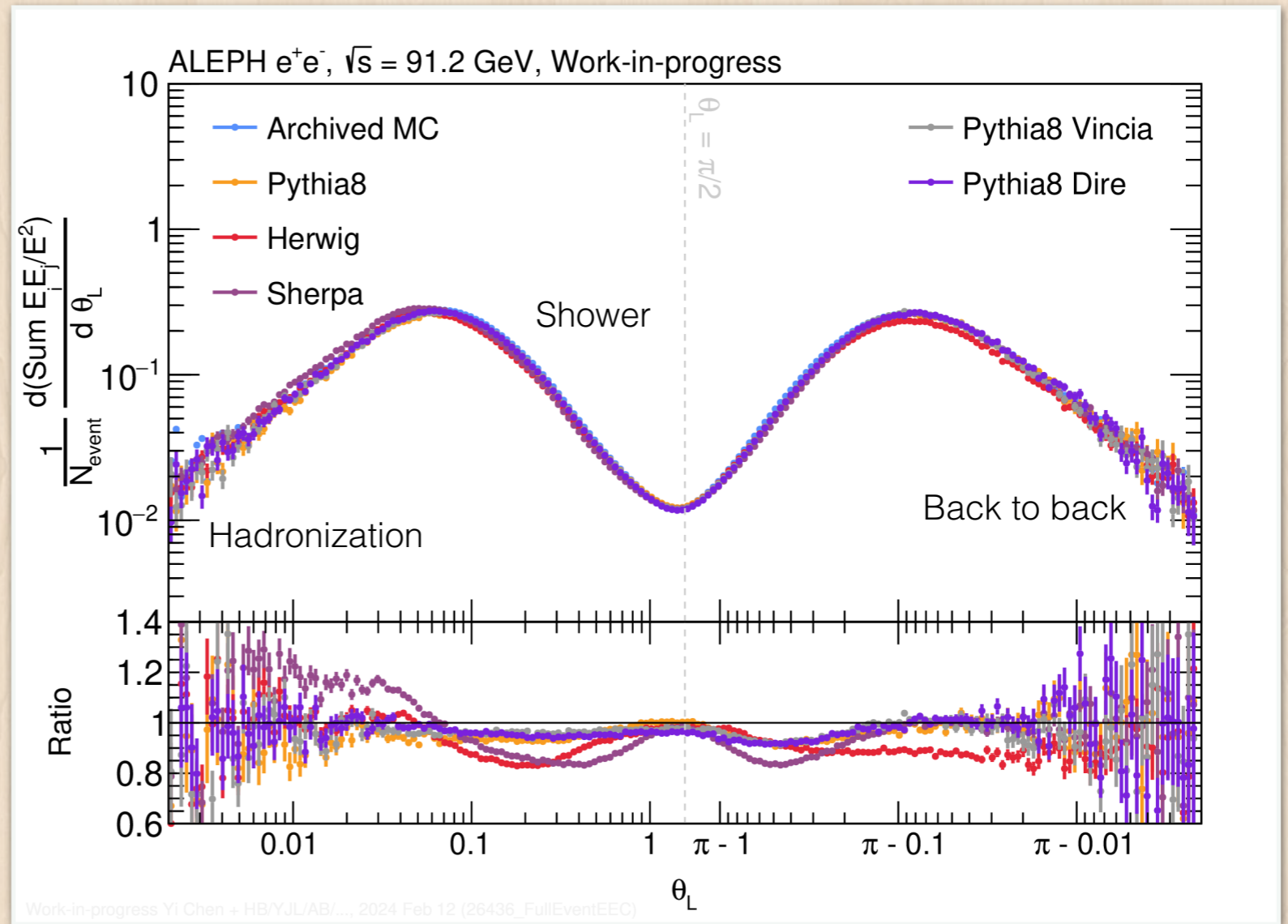
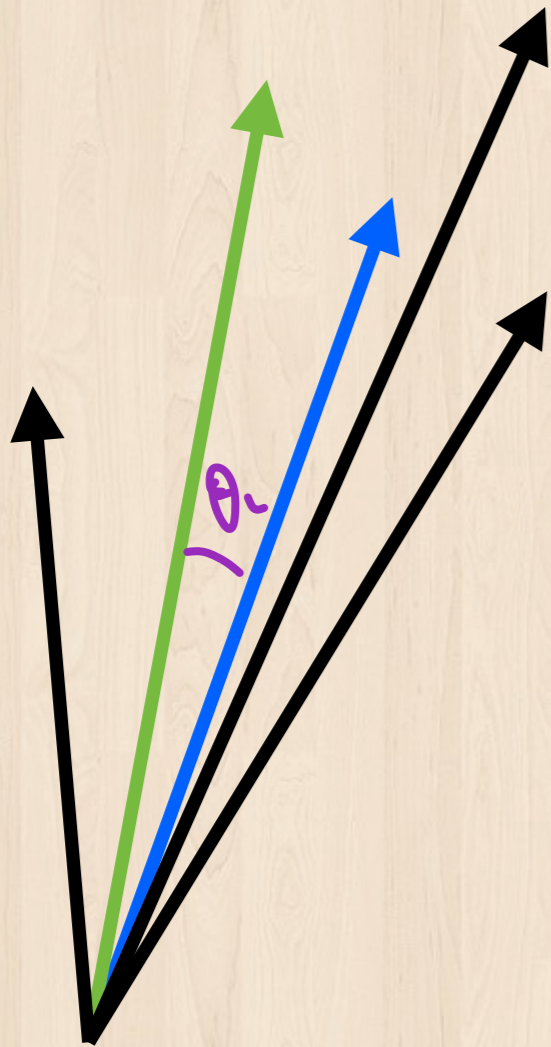
Groomed z_G

$$\frac{\min(\text{blue cone}, \text{green cone})}{\text{blue cone} + \text{green cone}}$$



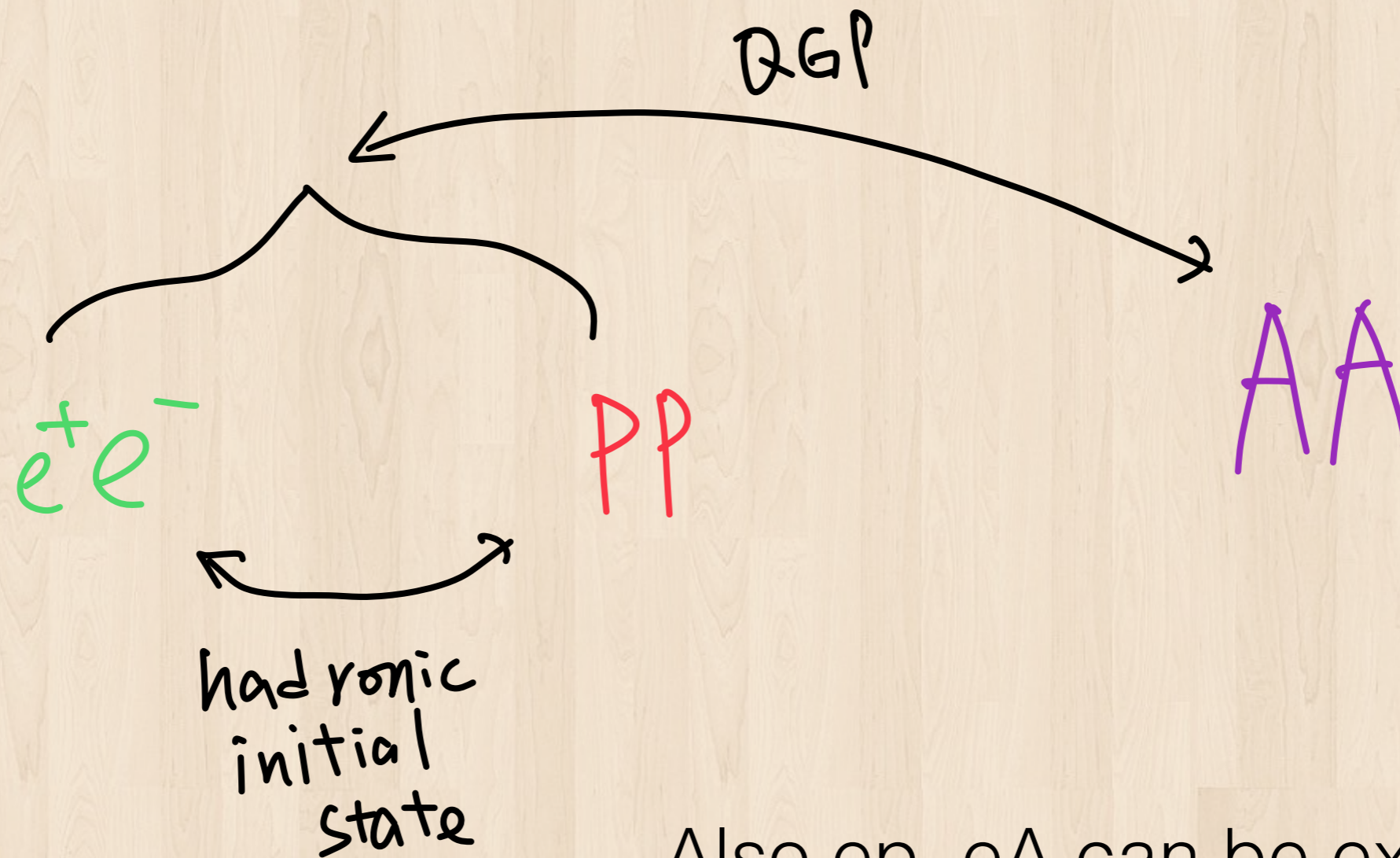
Similar behavior in e^+e^- and pp

EEC in $e^+e^- (\rightarrow Z \rightarrow jj)$



Room for improvement for models in e^+e^-

Separating effects



Also ep, eA can be explored
(e.g. HERA)

Notes

- Old data not easy to dig out. It took a full year to reach baseline understanding of event selection for ALEPH data
 - For e^+e^- , we have ALEPH but not others (yet?)
- Amount of statistics not that great — hard to go very differential
- Limited kinematic range

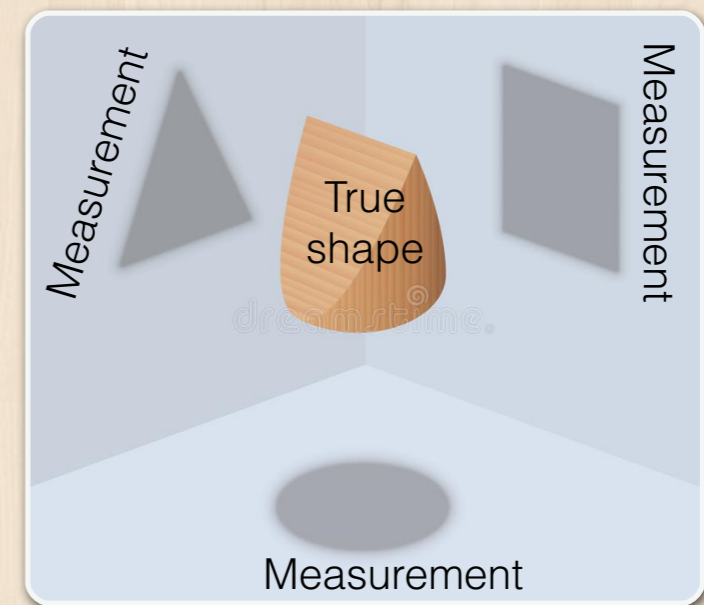
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Additional challenges not mentioned

- Pushing into the realm of medium response
 - This includes many things — for example push to lower and lower momentum + larger radii
 - Looser jet grooming settings
- Will we need to include background scheme into jet definition? When?
 - At the moment clustering algorithm is part of definition but background scheme is not
 - UE (e.g. from MPI) is part of pp jet typically. Is it part of HI jet?
- **For this workshop I assume the first item will be solved by experiment colleagues**

Jets for QGP evolution?

- Yes. The question is *how well* we can probe things
- Different challenges for different approaches
 - Modeling of the full QGP evolution
 - Jet spacetime picture
 - Observable design
 - ...
- There is a lot to do!



Backup Slides Ahead

