An overview of recent STAR jet measurements and futurity

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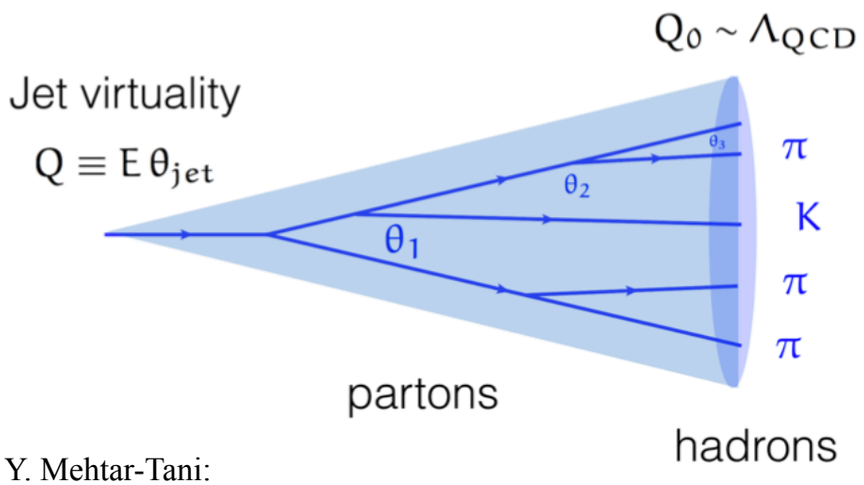
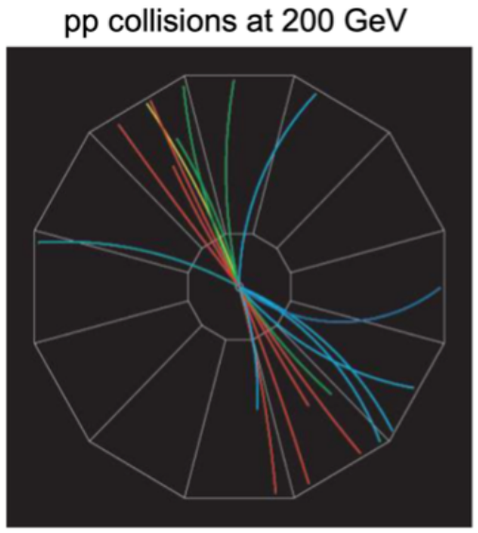
Jets in vacuum

Jet measurement in p+p collisions

Vacuum timelike parton shower



Y. Mehtar-Tani:
NPA 956 (2016) 168-175



In experiment:

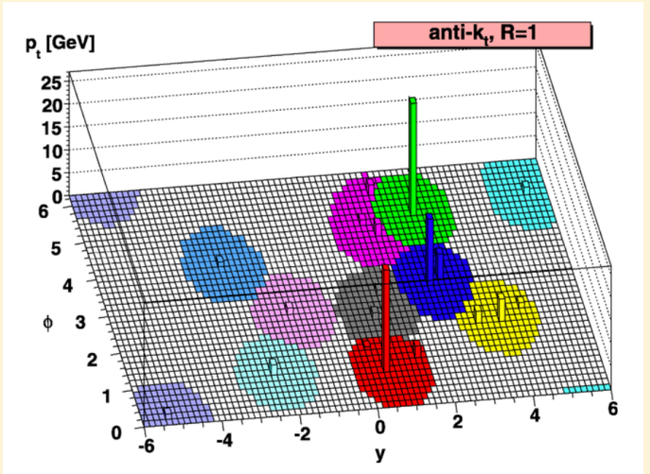
anti-k_T sequential recombination algorithm

$$d_{ij} = \min\,(p_{\mathrm{T},i}^{-2}, p_{\mathrm{T},j}^{-2})\frac{\Delta R_{ij}^2}{R^2},$$

and, $d_{i\mathrm{B}} = p_{\mathrm{T},i}^{-2}$

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

$\approx$



Salam, EPJC (2010) 67: 637–686

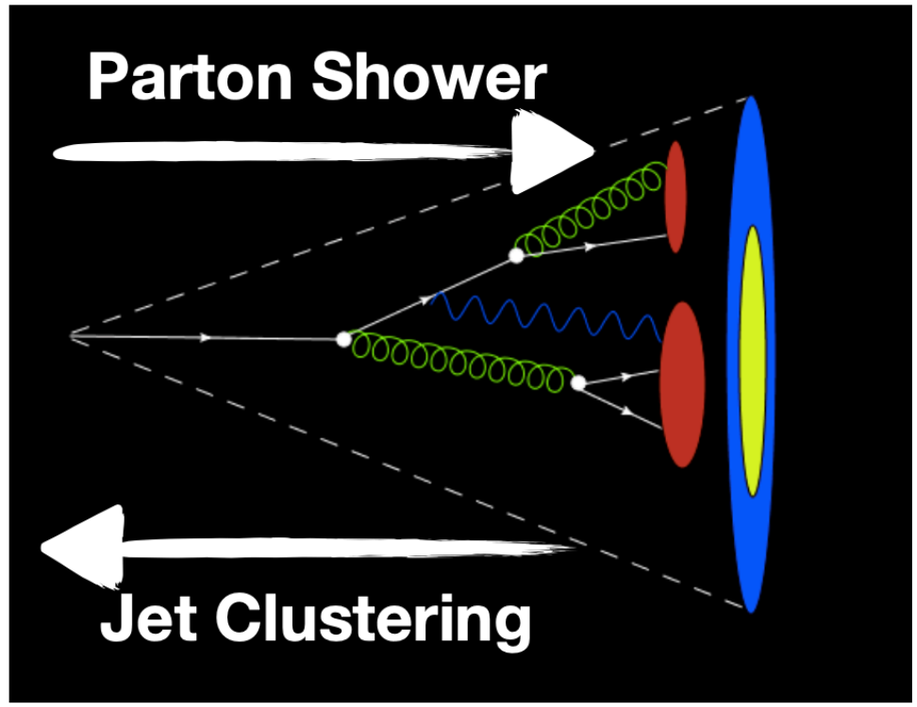
- pQCD and non-pQCD effects at RHIC
- To constrain parameters in parton shower models
- Vacuum-baseline for heavy-ion collisions (finite-temperature QCD medium)

Jet substructure measurement in p+p collisions

SoftDrop jet grooming:

IRC/Sudakov-safe

Lakoski, Marzani, and Thaler; PRD 91, 111501(R) (2015)



Courtesy: Raghav Kunnawalkam Elayavalli

Declustering jet branching history by removing soft branch until it satisfies this condition:

$$z_g = \frac{\min\,(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}} > z_{cut}(R_g/R_{jet})^{\beta}$$

$\beta = 0$;

$z_{cut} = 0.1$ → no angular dependence; soft branch at least 10% of total momentum of the pair

Kinematics of each branching:

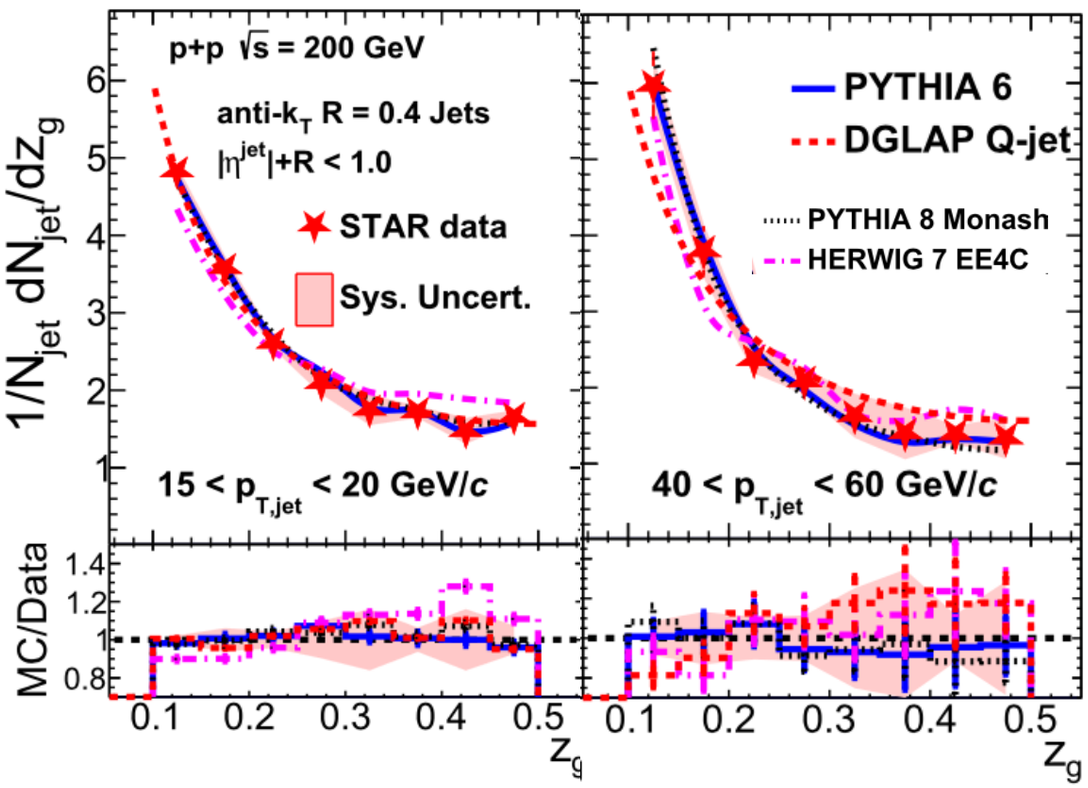
- Groomed jet radius, R_g
- Groomed momentum sharing, z_g

Vacuum splitting in p+p collisions at $\sqrt{s} = 200$ GeV

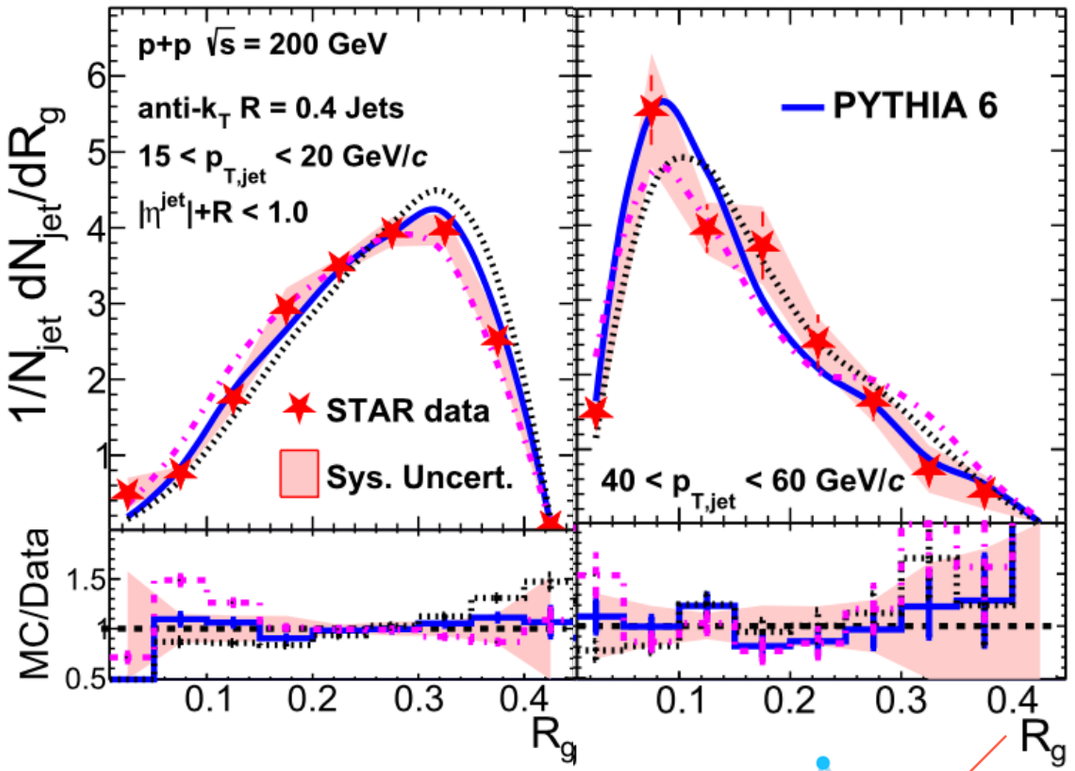
STAR: PLB 811 (2020) 135846

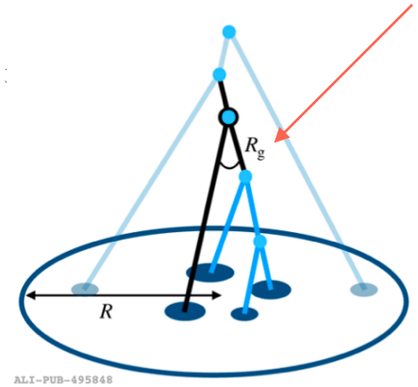
Groomed jet substructure observables

Groomed momentum sharing (z_g)



Groomed jet radius (R_g)





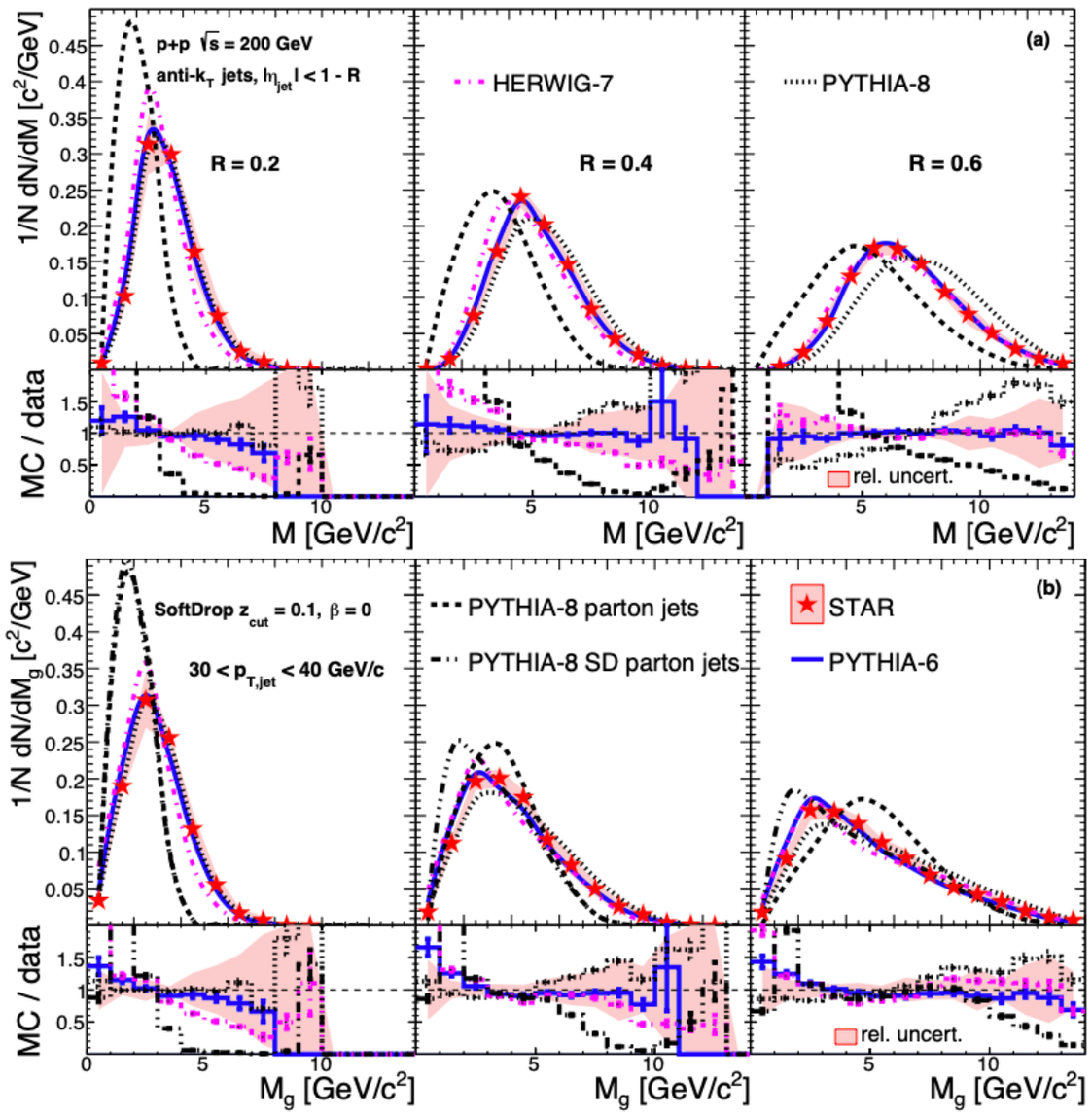
- z_g follows DGLAP splitting kernel
- Unlike z_g, R_g shows a dependence on $p_{T,jet}$ above 25 GeV/c
- At higher $p_{T,jet}$ → narrower substructure with asymmetric splitting in a jet
- STAR-tuned PYTHIA-6 Perugia 2012 describes the jet substructure observables at RHIC

Monika Robotková's talk: Today, 17.30

Jet mass in vacuum

p+p collisions $\sqrt{s} = 200$ GeV

STAR, arXiv: 2103.13286 (Accepted by PRD)



- Ungroomed Jet mass: $M = |\sum_{i \in \text{jet}} p_i|$
- Groomed jet mass: $M_{\text{g}} = |\sum_{i \in \text{jet}} p_{\text{g}}|$

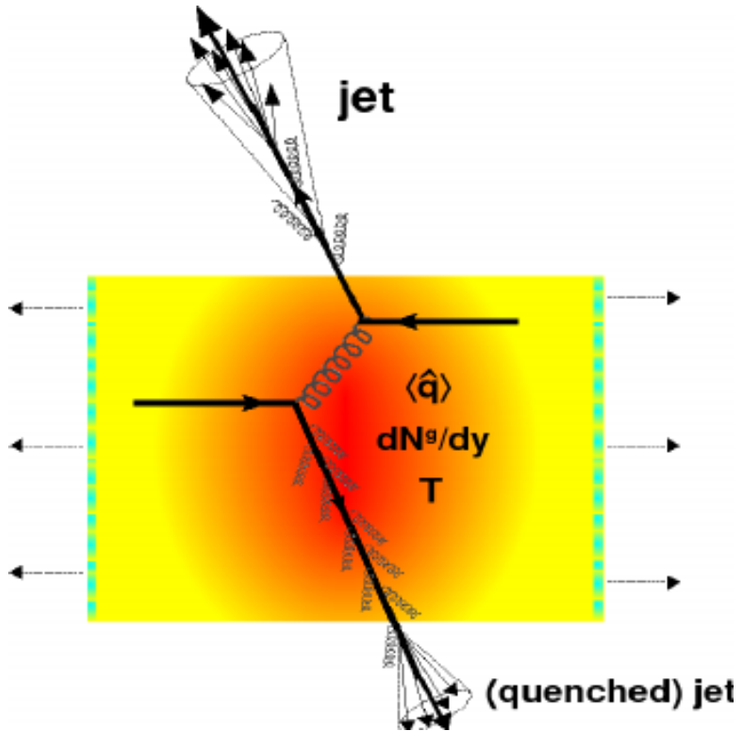
$p_{\text{g}} \rightarrow$ momentum of the constituent in a groomed jet

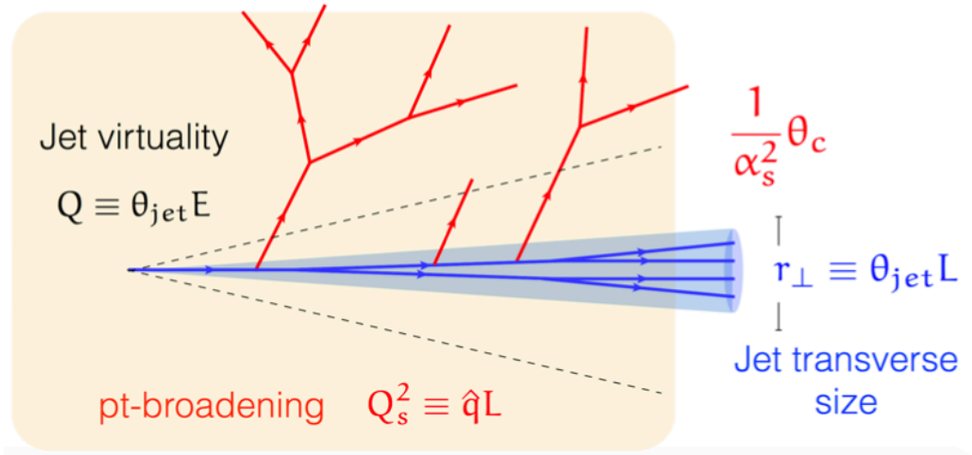
- Mean and width increase:
  - With jet R $\rightarrow$ inclusion of wide-angle radiation
  - With jet $p_{\text{T}} \rightarrow$ increasing radiation phase-space
- M_{g} is smaller than M

  Reduction of soft radiations
- STAR tuned PYTHIA-6 Perugia 2012 well-describes the measurements

Jets in heavy-ion collisions at RHIC: Jet quenching

Jet quenching and its consequences





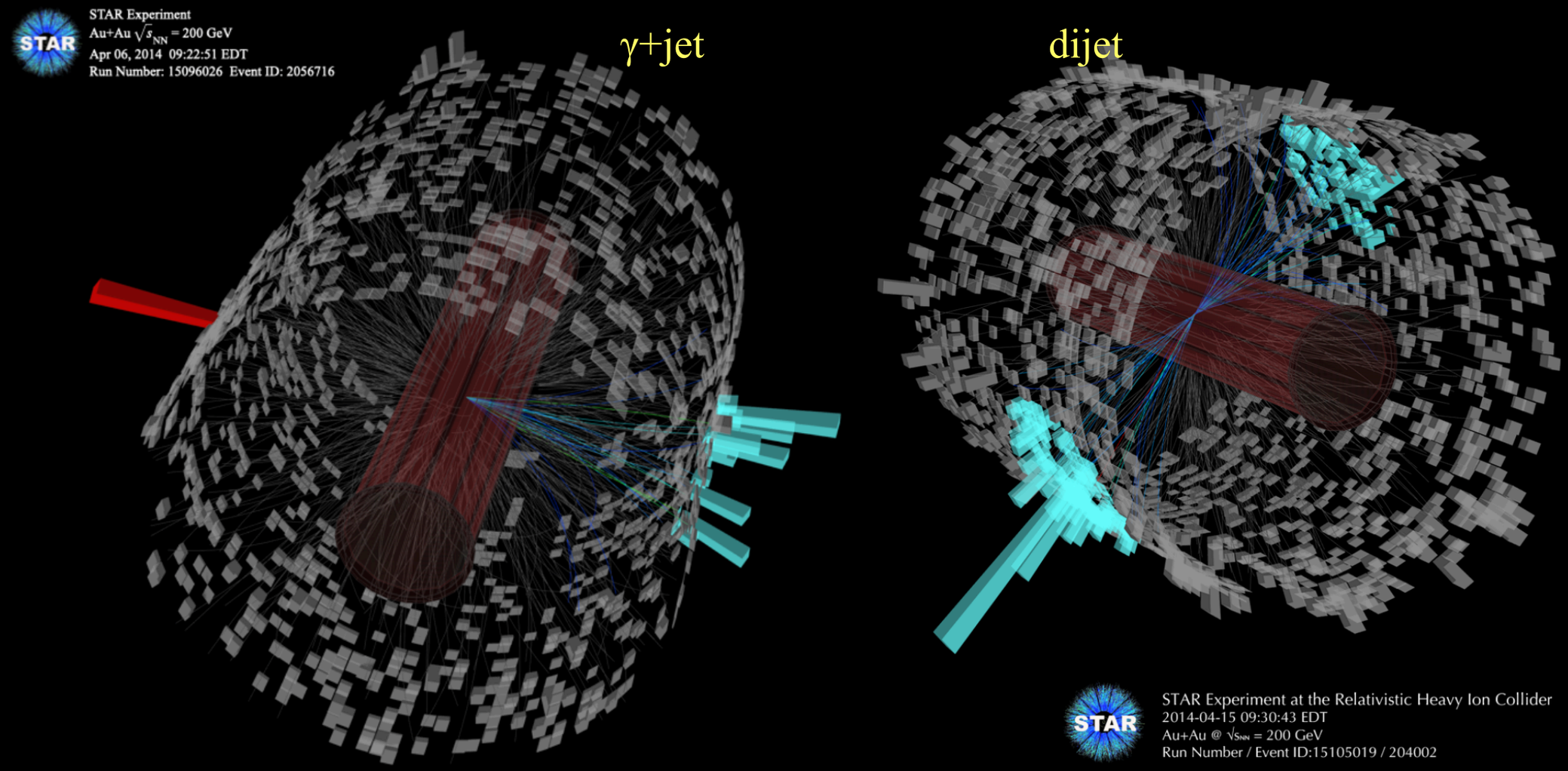
Y. Mehtar-Tani: NPA 956 (2016) 168-175

Simultaneous effect of vacuum shower and medium-induced gluon radiation

Consequences:

- Parton energy loss (high-p_T hadron/ jet suppression)
- Large angle radiation (jet radius dependence)
- Modification of parton shower (jet shape and substructure)
- Jet deflection (azimuthal decorrelations)

Jet program at STAR



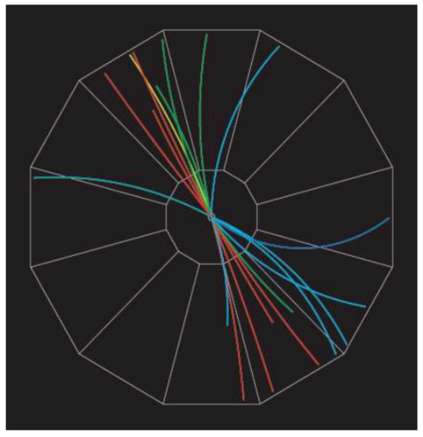
Recent heavy-ion jet measurements:

(This talk mainly focuses on)

- Inclusive jet
- Semi-inclusive γ+jet and hadron+jet

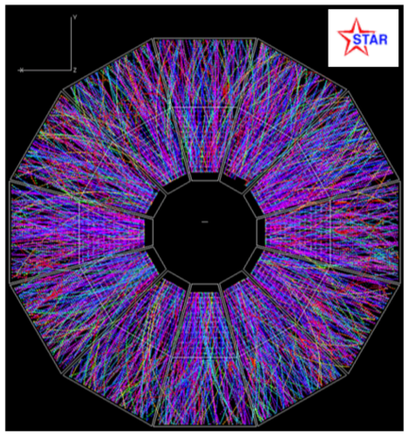
Experimental techniques to measure jets in heavy-ion collisions

pp collisions at 200 GeV



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

AuAu collisions at 200 GeV



$\text{Au} + \text{Au} \rightarrow \text{X}$

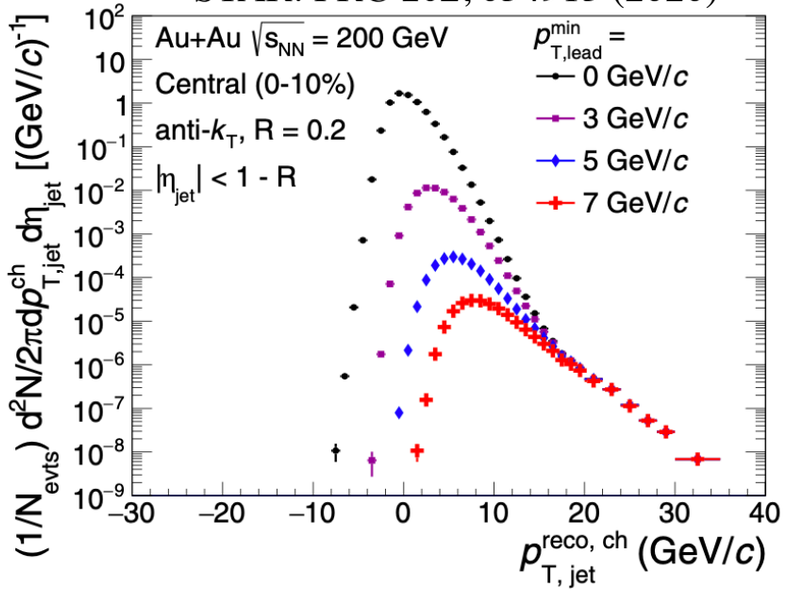
- In heavy-ion collisions: large uncorrelated soft background

  Different techniques used to mitigate and correct

Using minimum leading constituent p_T cut-off

Inclusive jet measurement

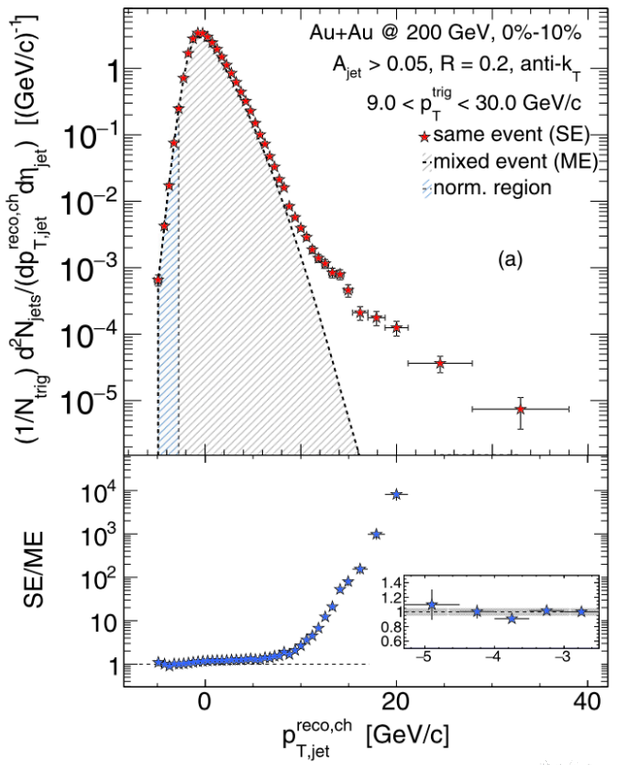
STAR: PRC **102**, 054913 (2020)



Using mixed event

Semi-inclusive jet measurement

STAR: PRC 96, 024905 (2017)



- Unfolding procedure to correct jet p_T spectra

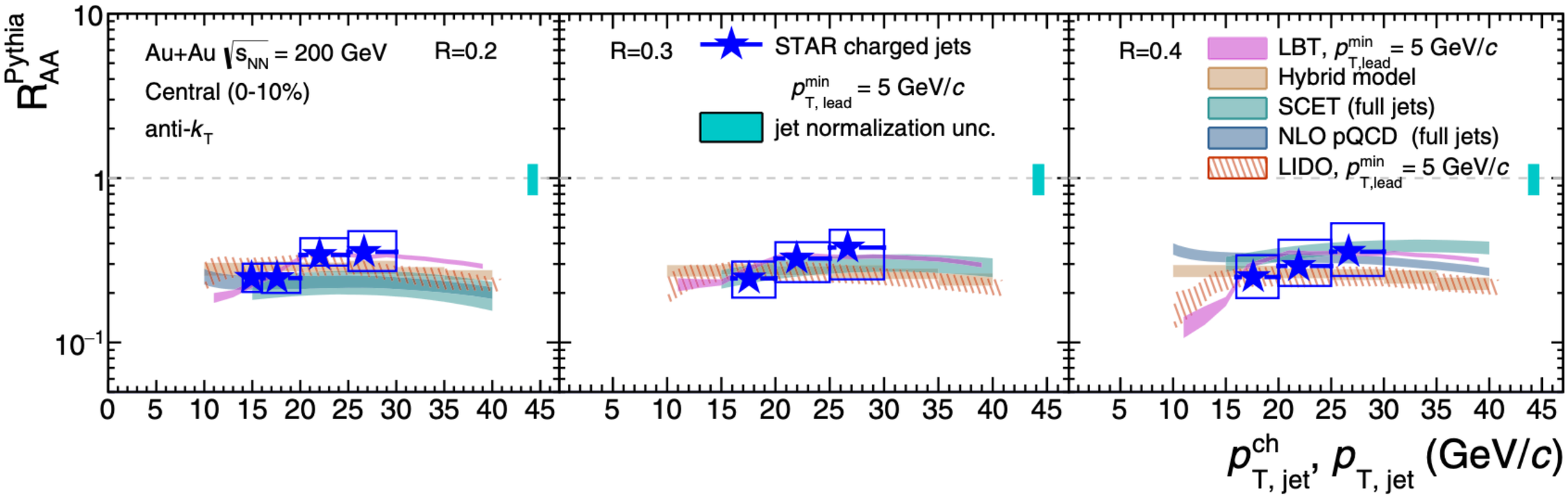
  By factorizing heavy-ion background and detector effects

Inclusive charged-jet suppression at RHIC

$$R_{\mathrm{AA}}^{\mathrm{Pythia}}(p_{\mathrm{T,jet}}) = \frac{1}{< T_{\mathrm{AA}} >} \frac{Y(p_{\mathrm{T,jet}})^{\mathrm{AA}}}{Y(p_{\mathrm{T,jet}})^{\mathrm{pp-Pythia}}}$$

$< T_{\mathrm{AA}} > \rightarrow$ Nuclear thickness factor

STAR: PRC **102**, 054913 (2020)



- Strong suppression of inclusive charged-jet yield in central collisions
- R_{AA} shows no jet R dependence
- Different theory predictions consistent with the data (within uncertainties)

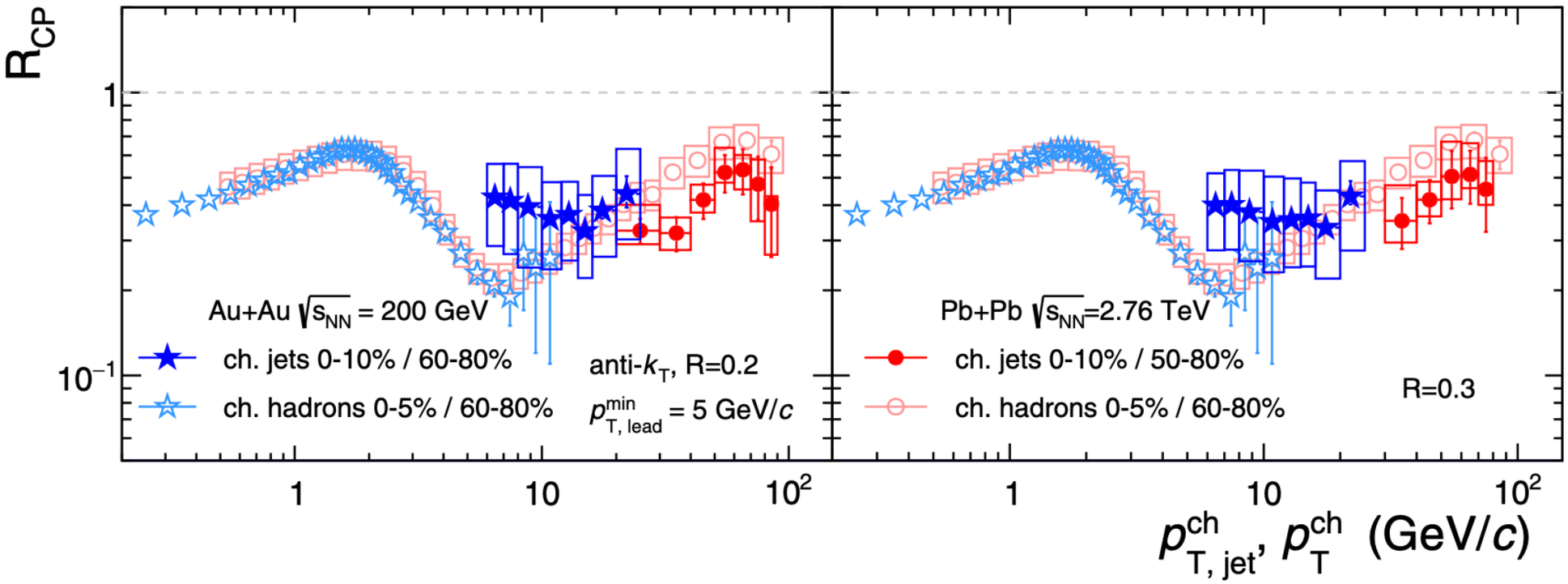
Full jet R_{AA} measurement afoot in STAR…

Inclusive charged-jet suppression (RHIC vs. LHC)

$$R_{\mathrm{CP}}\,(p_{\mathrm{T,jet}}) = \frac{1}{< T_{\mathrm{AA}} >} \frac{Y(p_{\mathrm{T,jet}})^{\mathrm{central}}}{Y(p_{\mathrm{T,jet}})^{\mathrm{peripheral}}}$$

$< \mathrm{T_{AA}} > \rightarrow$ Nuclear thickness factor

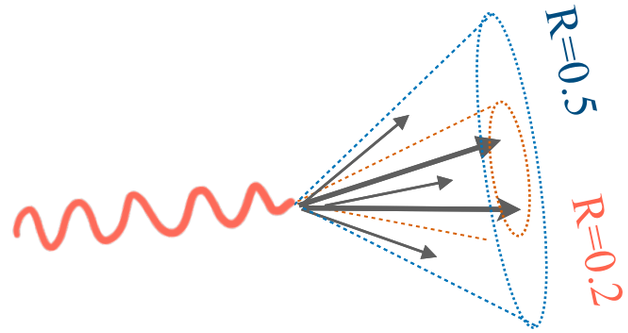
STAR: PRC **102**, 054913 (2020)



- Strong suppression of inclusive charged-jet yield in central with respect to peripheral collisions
- R_{CP} shows no jet R dependence
- Similar level of suppression between inclusive charged hadron and jet yield (within the same p_{T} interval)
- Same level of suppression at RHIC and the LHC (although different p_{T} interval)

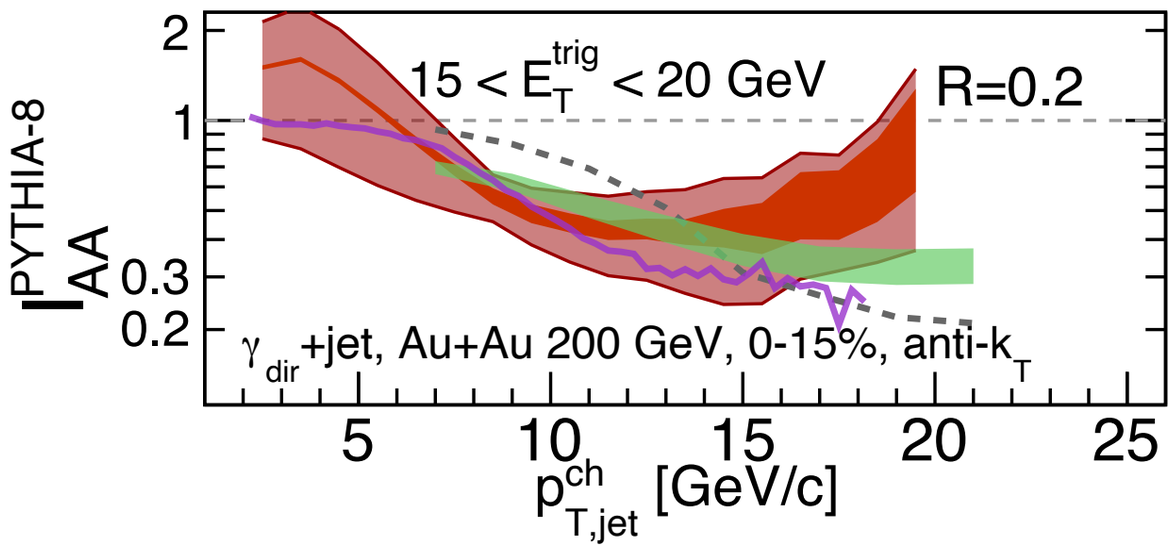
Full jet R_{CP} measurement will access higher jet p_{T} at RHIC.

Semi-inclusive γ+jet measurement

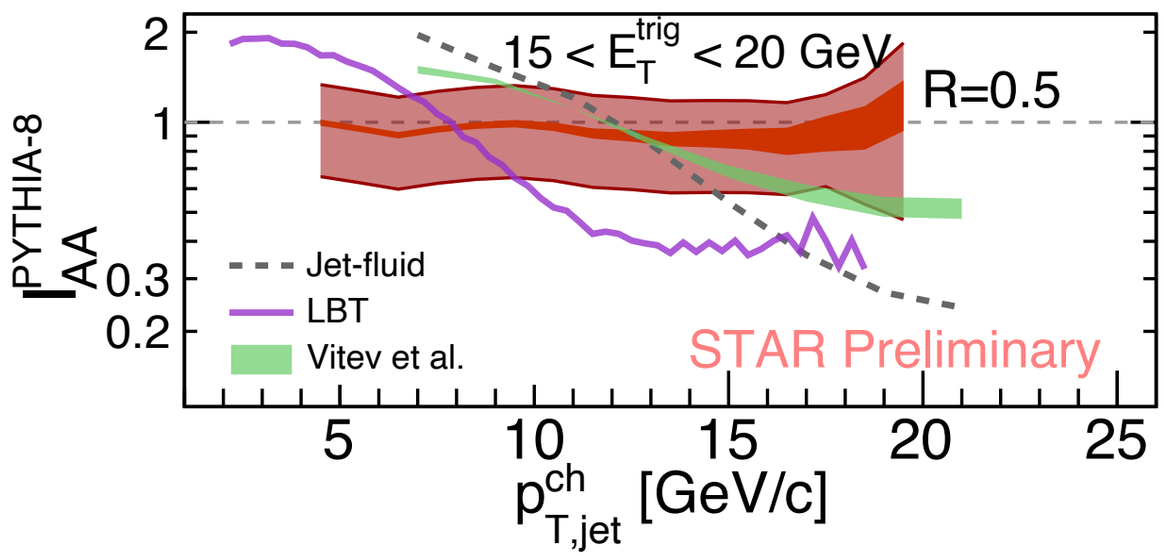


p+p reference: PYTHIA-8

***R*=0.2**



***R*=0.5**



- p_T-dependence of suppression is different between theory predictions and data
- A hint of jet *R* dependence of suppression

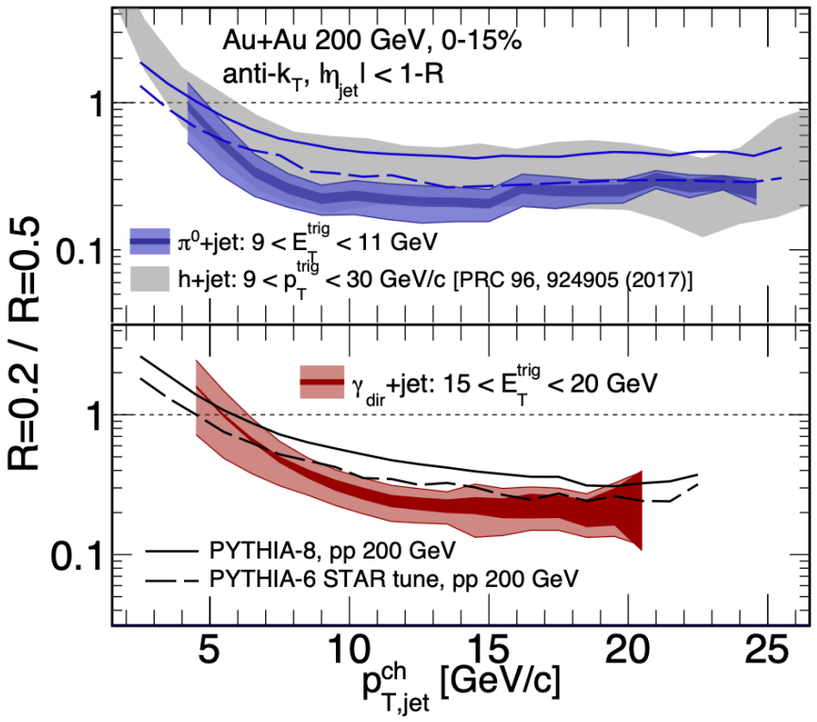
  Expect improvement in precision with data-taking in Run23-25

Jet-fluid: jet shower + medium response [Chang, et al., PRC 94 (2016), 024902]
LBT: coupled LBT+hydro [Chen, et al., PLB 777 (2018) 707]
Vitev: Soft Collinear Effective Theory [Sievert, et al., PLB 795 (2019) 502]

Intra-jet broadening in heavy-ion collisions

Yield ratio for R=0.2 to 0.5 and comparison between A+A and p+p

Semi-inclusive γ+jet, π^0+jet, and h+jet

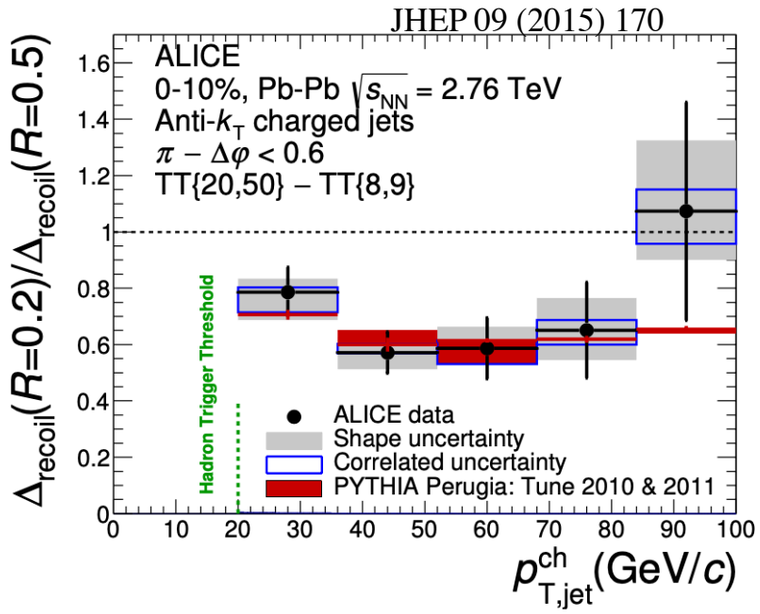


Need to resolve discrepancies between two PYTHIA versions

No hints of intra-jet broadening in central heavy-ion collisions at RHIC and the LHC

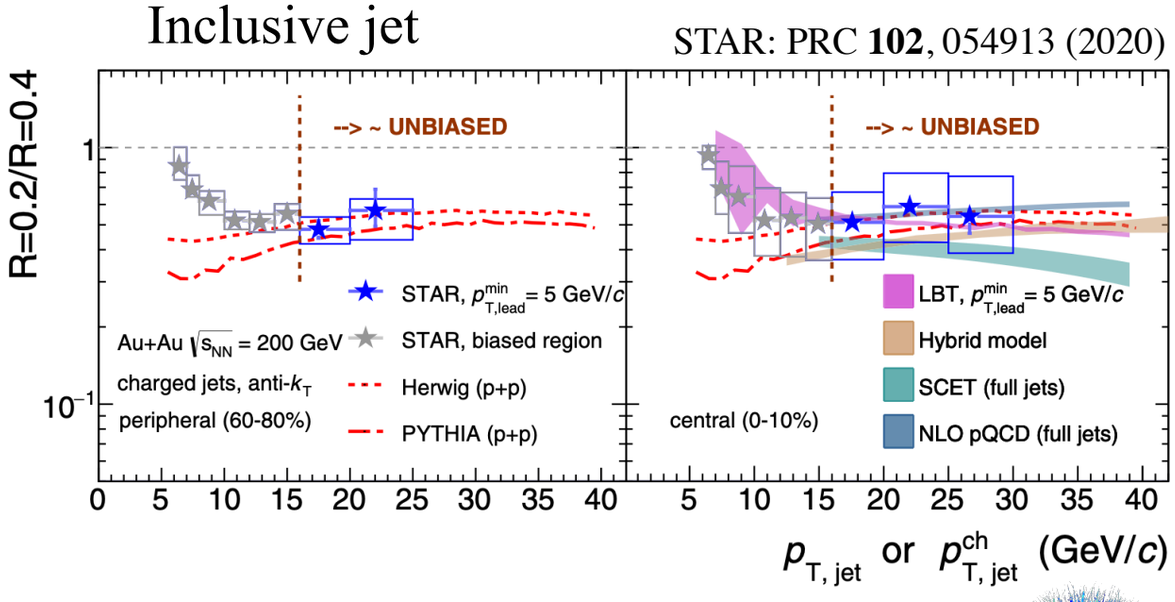
LHC/ALICE measurement Pb+Pb 2.76 TeV

JHEP 09 (2015) 170



Inclusive jet

STAR: PRC **102**, 054913 (2020)

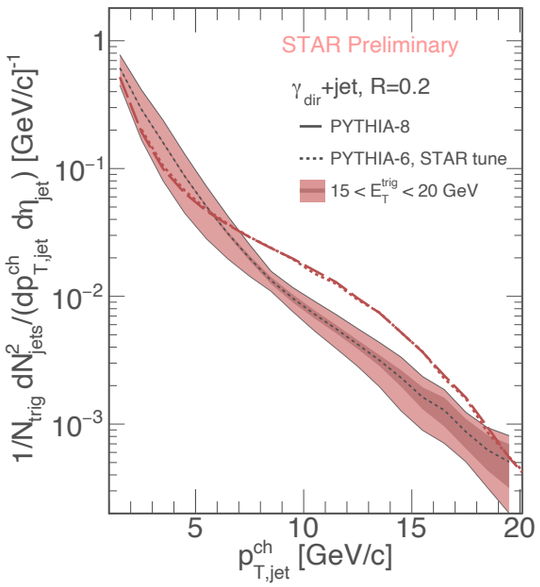


Parton energy loss: RHIC vs LHC jet measurements

Let us investigate recent measurements of jet yield suppression at RHIC and LHC.

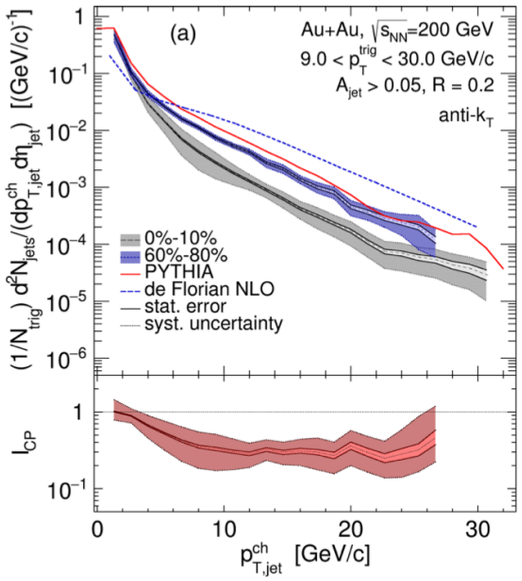
STAR/RHIC

Semi-inclusive γ+jet

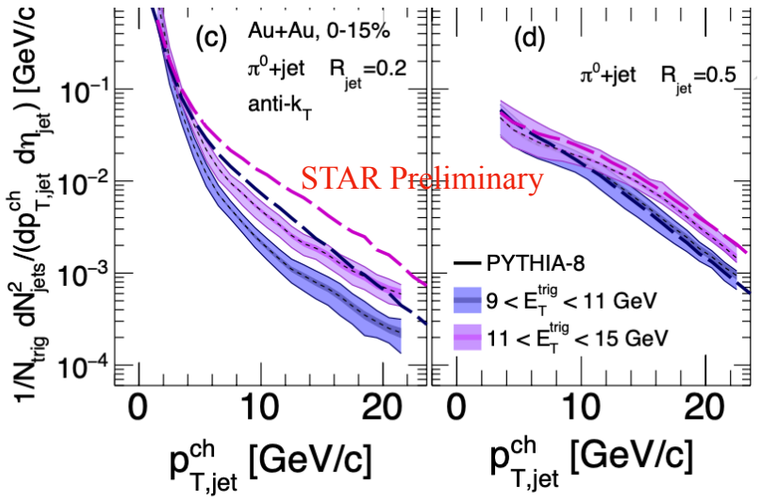


Semi-inclusive h+jet

STAR: PRC 96 (2017) 024905

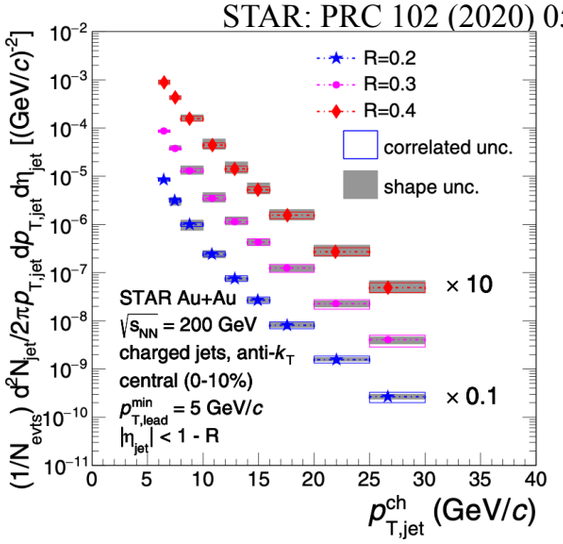


Semi-inclusive π⁰+jet



Inclusive jet

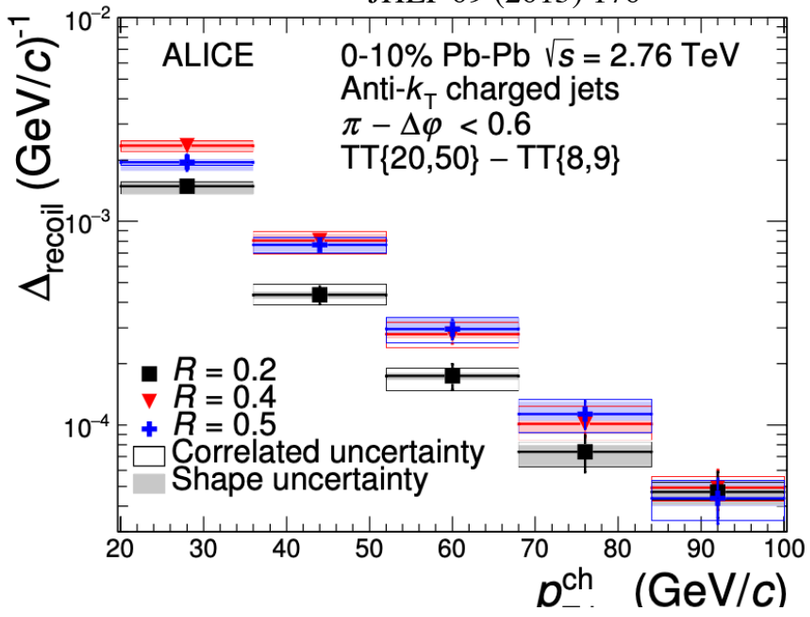
STAR: PRC 102 (2020) 054913



ALICE/LHC

Semi-inclusive h+jet

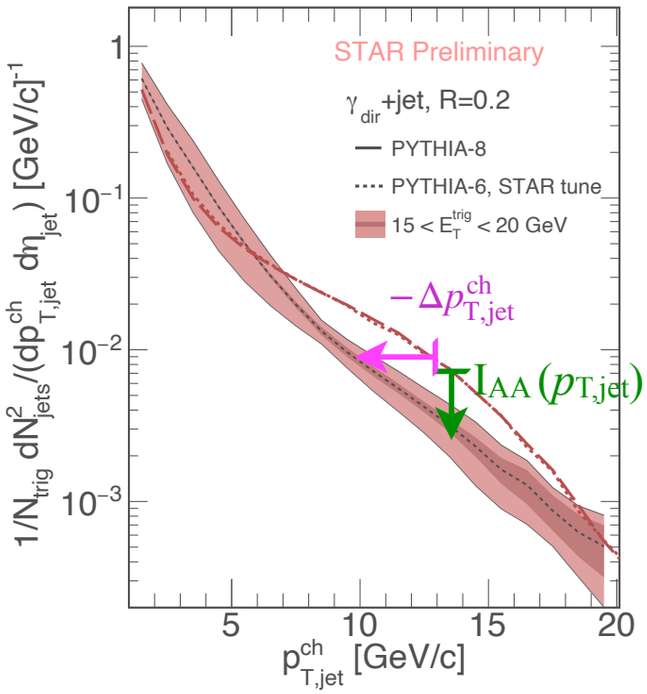
JHEP 09 (2015) 170

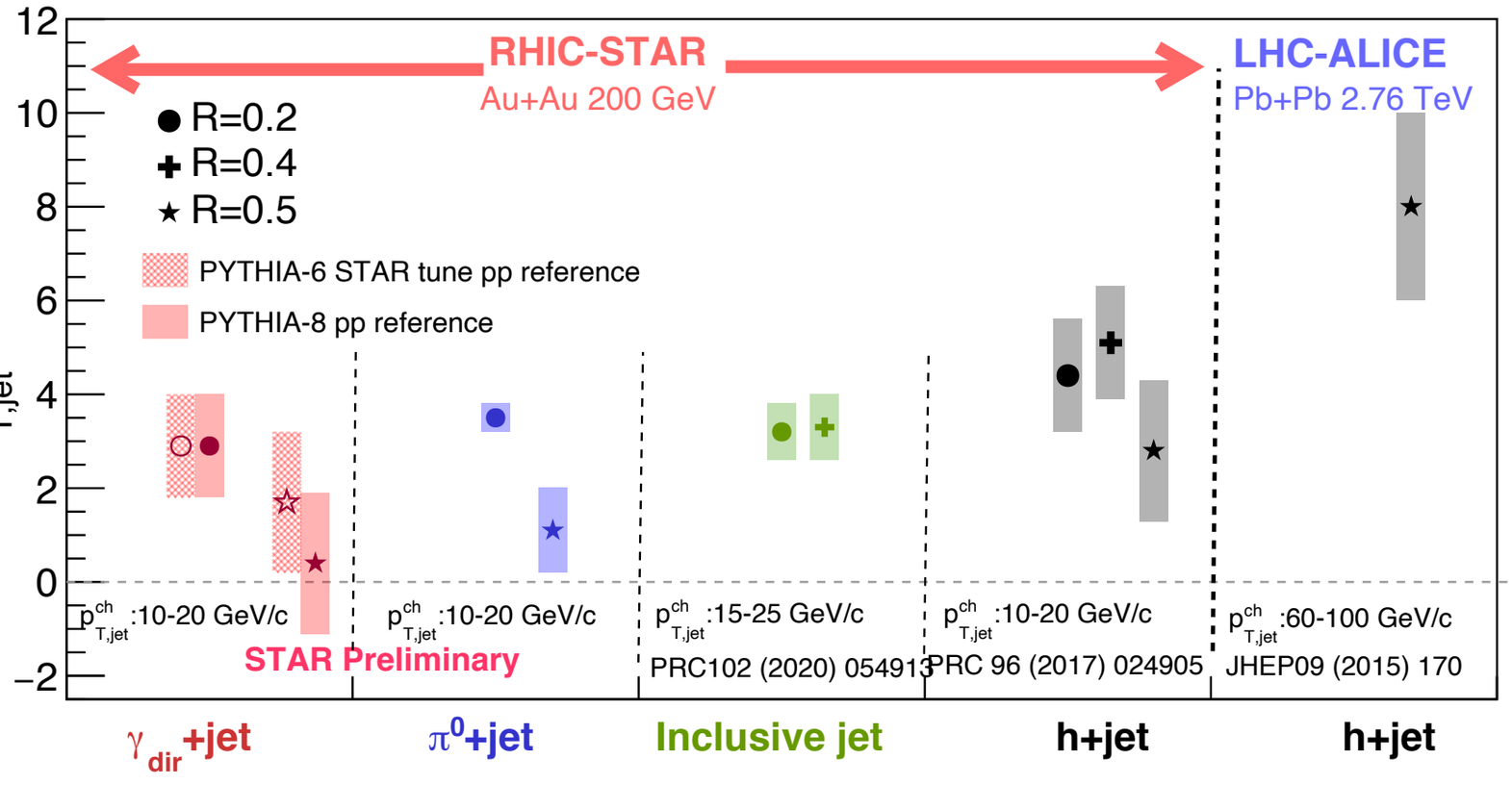


Calculate horizontal jet p_T shift from all these measurements

Charged jet p_T-spectrum shift : RHIC vs. LHC

Characterization of average out-of-cone parton energy loss





Another way to quantify jet-quenching:

Jet p_T shift ($\Delta p^{ch}_{T,jet}$)

Initial parton energy loss can also be characterized by jet p_T shift.

Note:

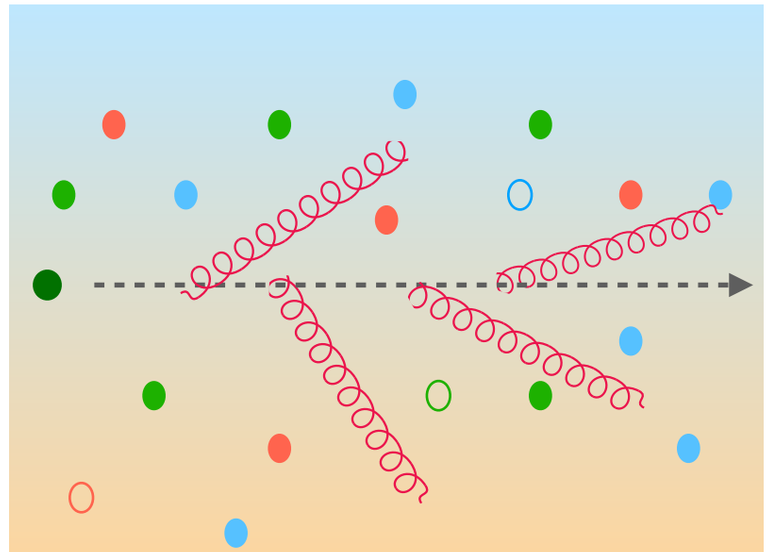
- $p_{T,jet}$ ranges at RHIC and the LHC are different in the plot
- Only charged-jets are compared here

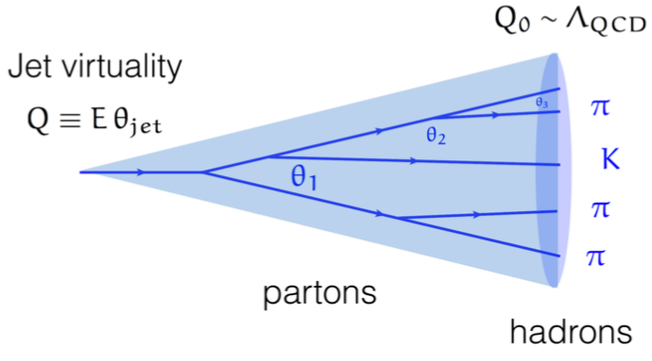
Indication of smaller in-medium energy loss at RHIC than the LHC

Ongoing jet measurements in STAR

- Hot-dense QCD medium in Au+Au collisions:
  - Full jet reconstruction
  - Jet fragmentation function
  - Jet shape
  - Heavy-flavor jet
  - Large angle deflection
- QCD medium effect in small systems
  - In Ru+Ru, Zr+Zr, and O+O collisions
- Cold QCD medium effect in p+Au
- Vacuum QCD in p+p collisions:
  - Jet substructure
  - Semi-inclusive h+jet and γ+jet
  - h+jet and γ+jet azimuthal decorrelation

Inner workings of QGP





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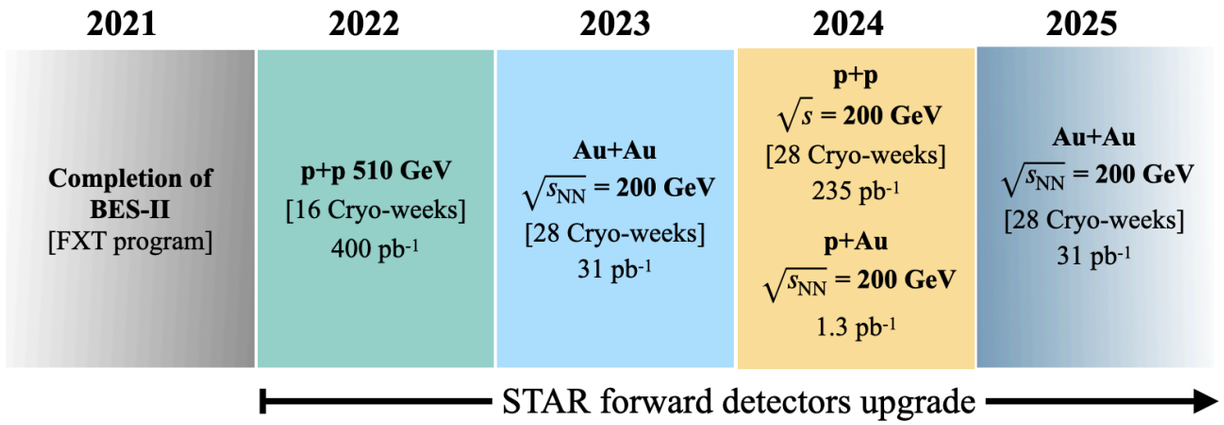
Upcoming STAR data taking and jet measurements

STAR 2023-2025 run plan and physics program

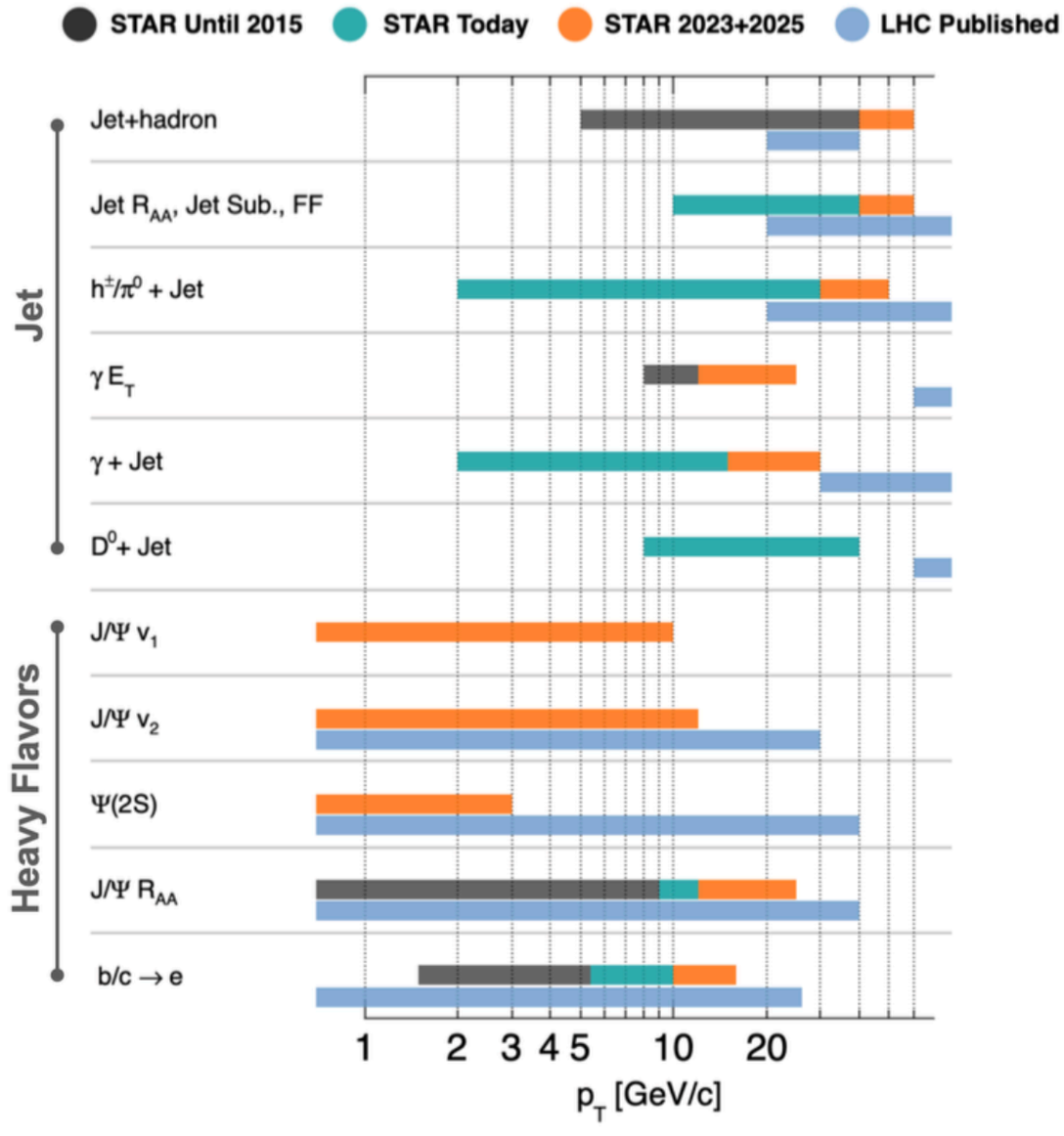
Run plan



It includes Hot-QCD and Cold-QCD STAR programs.

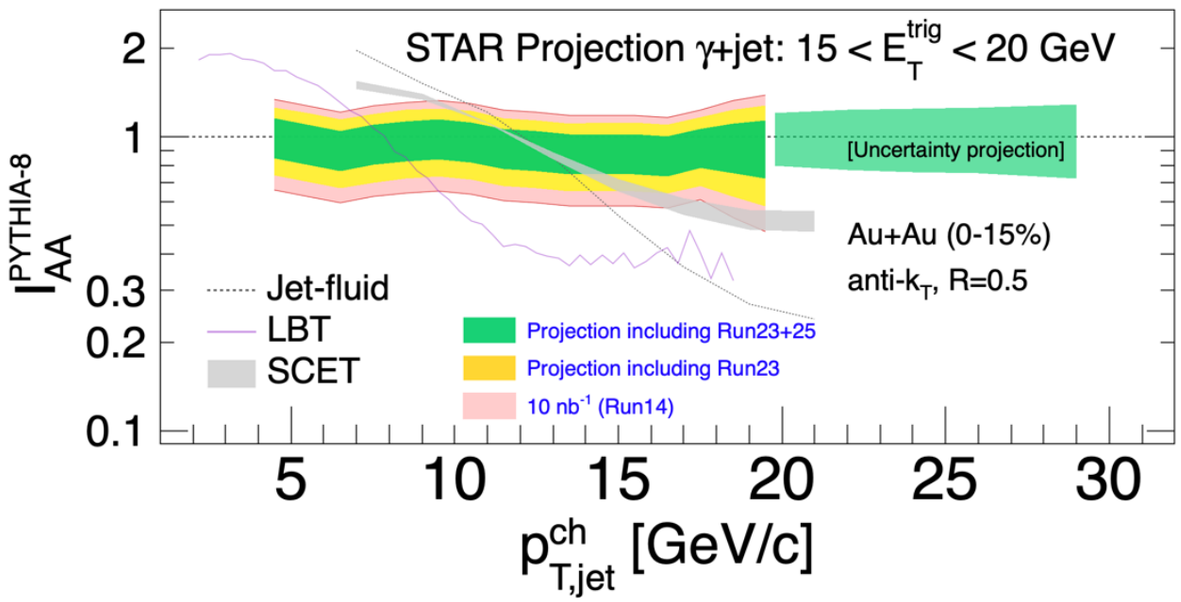
- Hot-QCD program: Study the microstructure of the QGP
  Precision jet and heavy-flavor measurements

Kinematic coverage

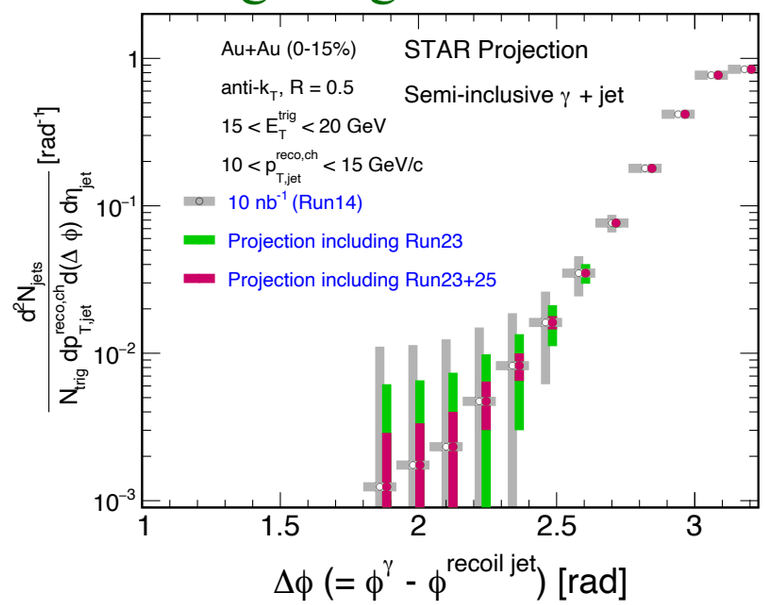


Future projection for Run23+25 HI and Run24 p+p

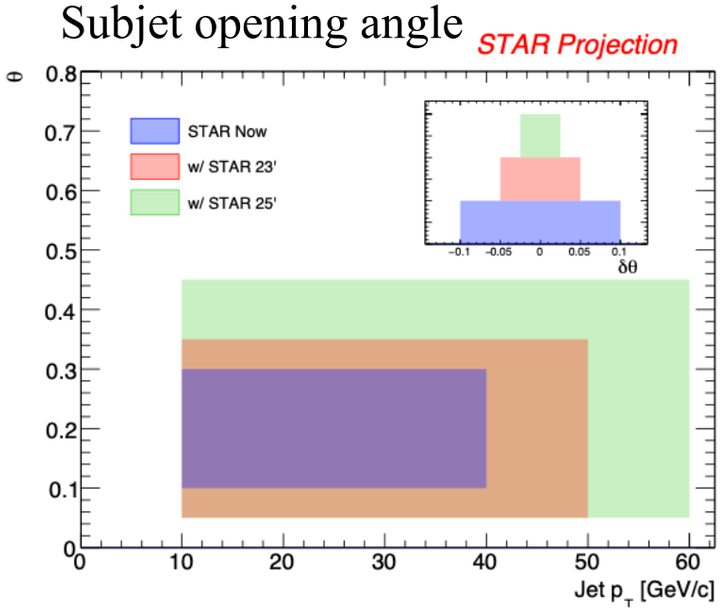
γ+jet precision measurement



Large-angle deflection



Subjet opening angle



To study medium property ($\hat{q}$) and quasi-particle in liquid QGP

Summary and outlook

STAR experiment recent measurements:

- p+p jet substructure observables to study vacuum shower and baseline for heavy-ion measurements
  - STAR tuned PYTHIA-6 Perugia 2012 well-describes the data
  - Help to constrain other Monte Carlo models at RHIC energies

- Jet quenching in heavy-ion collisions
  - Strong suppression of inclusive jet and semi-inclusive γ+jet and h+jet
  - A hint of *R* dependence of suppression in case of γ+jet and h+jet (PYTHIA-8 reference) measurements, but not in inclusive jet (PYTHIA-6 reference)

Upcoming year 2023-2025 data taking

- To study inner working of QGP with precision and large kinematic coverage
- p+p data: baseline for heavy-ion jet measurement

Thank you!