Correlations between hard probes and bulk dynamics in small systems

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For the JETSCAPE collaboration

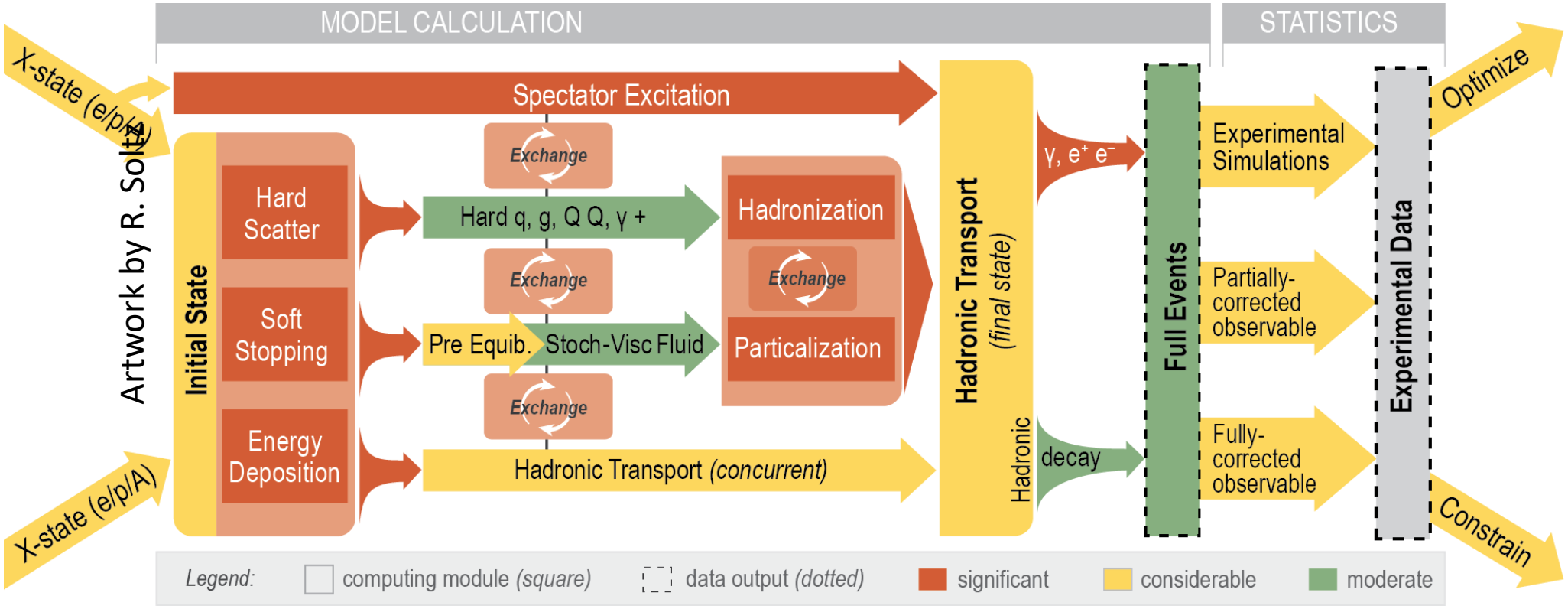
Based on e-Print: 2407.17443 [hep-ph]

Outline

- The new X-SCAPE multi-stage framework
- 3D-Glauber+MUSIC (bulk)
- I-MATTER + PYTHIA + MATTER (hard)
- A new working model for small systems in p-p and p-A
- **Exact energy momentum conservation**
- Calculations with and without Final State energy loss
- Correlations between hard probes and bulk dynamics

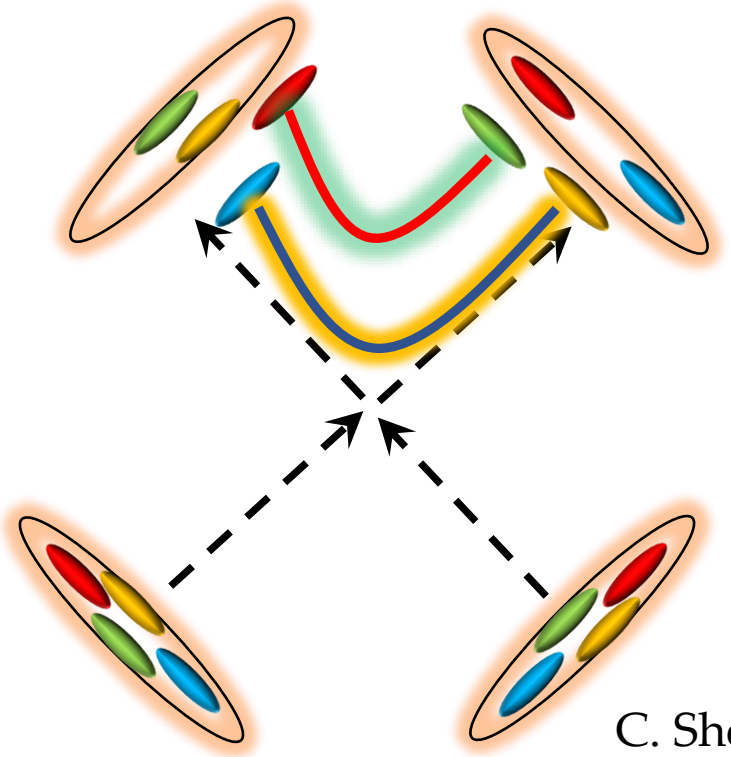
X-SCAPE framework

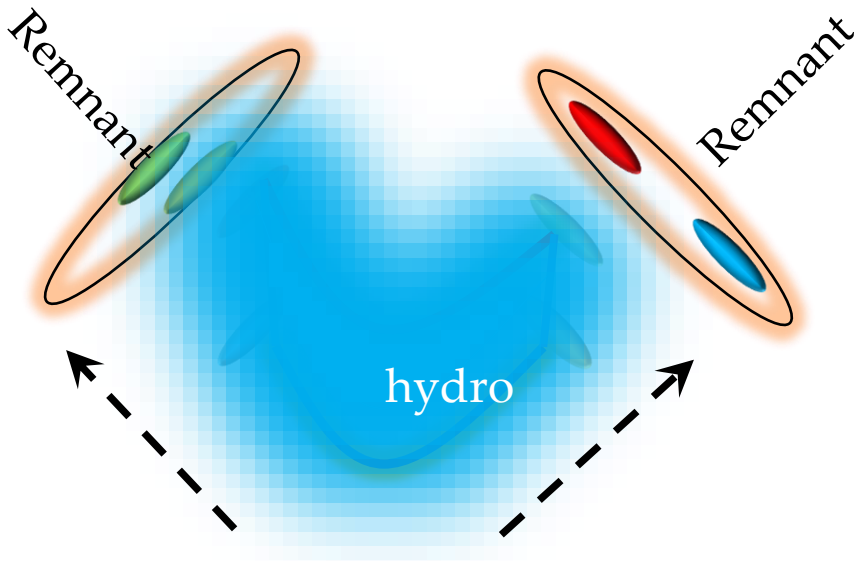
- A new framework that allows the user to determine the order of operations
- Time can go backwards and forwards !
- Backward evolution allows for natural implementation of ISR.
- Can be run with an arbitrary number of modules.



X-SCAPE module: 3D Glauber + MUSIC

- Nucleons have multiple hot spots within them.
- Strings connect pairs of hot spots
- String 4-momentum and baryon density seeds hydro simulation
- Hydro evolves producing particles
- Remnants go down beam line.

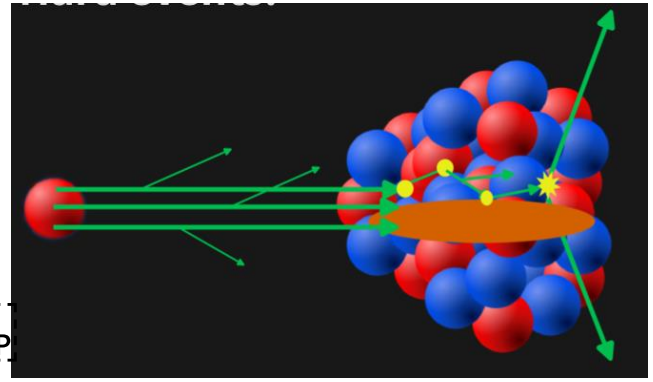




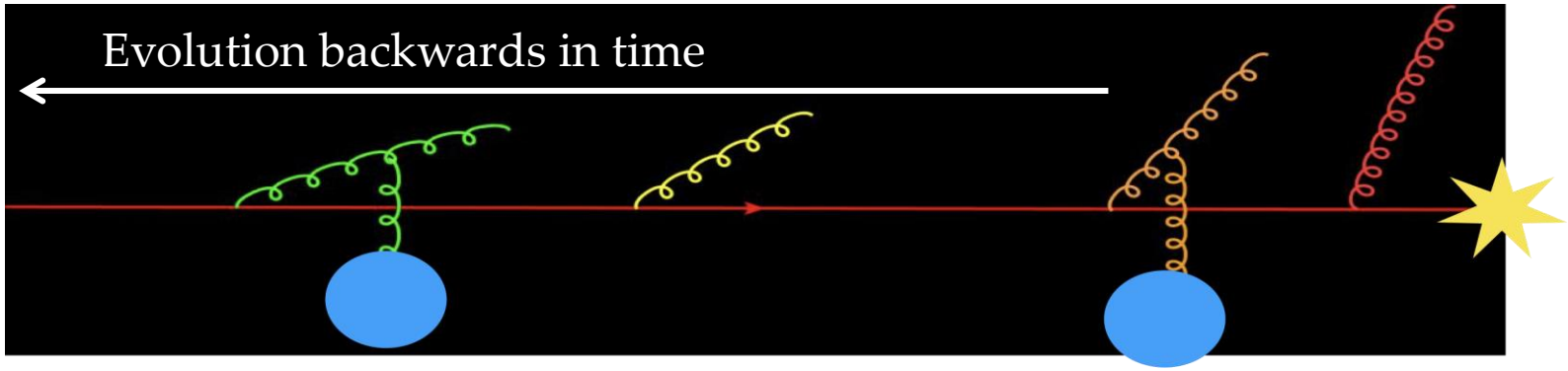
C. Shen and B. Schenke, PRC97 024907 (2018), PRC105, 064905 (2022)

X-SCAPE module: I-MATTER

- Call Pythia (ISR-FSR-OFF) to generate MPI scatterings
- Start each parton at $Q^2 = -p_T^2$ and evolve up to $Q^2 = -1$ GeV^2.
- A well-established method of generating ISR*
- Run Matter backwards in time with i-MATTER.
- Parton energy increases with splits, keep track of position
- Final parton at most negative time is the parent.



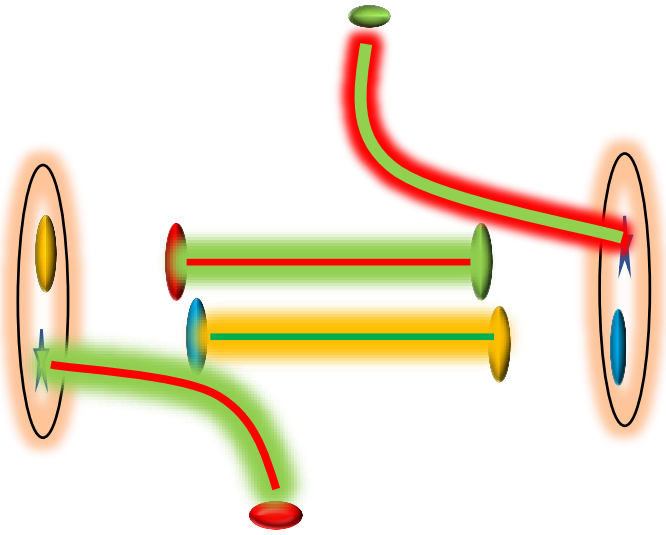
Framework can handle Initial State-E-loss, current results only include Vacuum shower

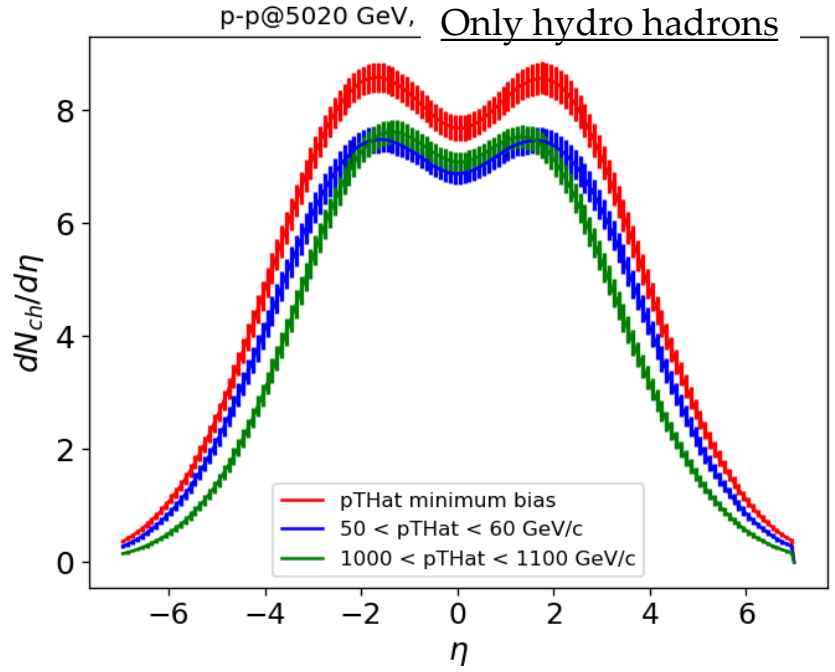


*T. Sjostrand
Phys.Lett.B 157 (1985) 321.

Physical Model

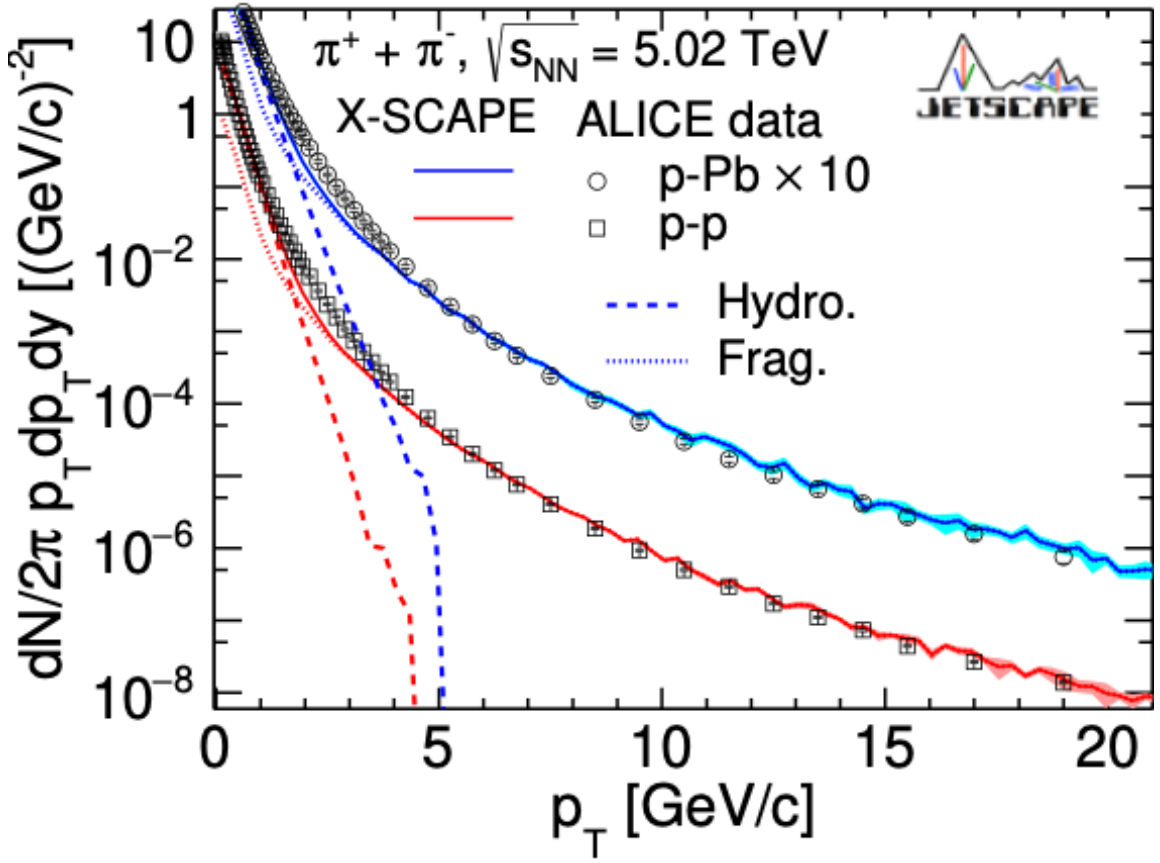
- Hard initial state partons are included in a hot spot
- Hard partons scatter with ISR and FSR.
- ***Hard energy removed from nucleons, not available for hydro evolution***
- Some strings get pulled out by hard processes, fragmented by string breaking
- Strings that don't get pulled out are liquified into a fluid, evolves and produces particles
- More jet energy → more fragmentation hadrons, less hydro (Cooper-Frye) hadrons

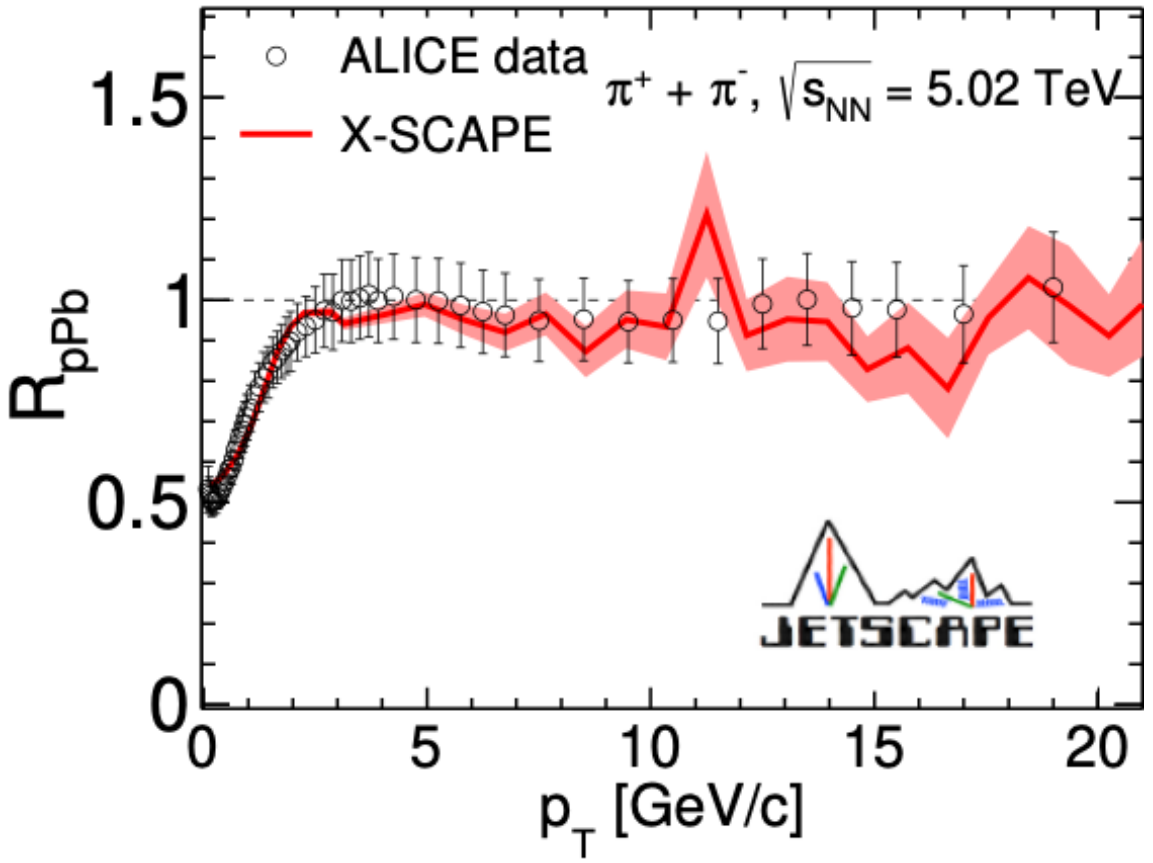




Hadrons with no final state energy loss

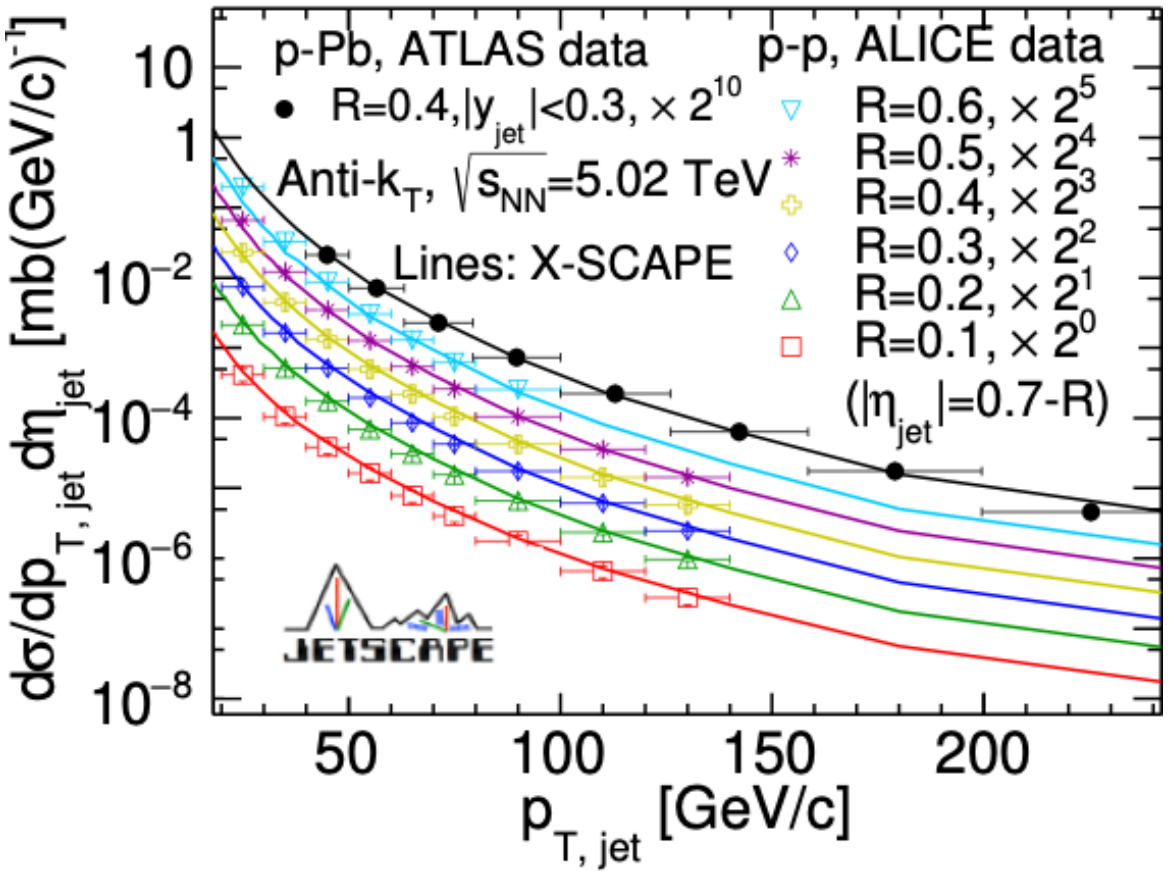
Set min $\hat{p}_{T,min}$ in Pythia ~ 8 GeV, softer phenomena modelled by hydro.
Hadron spectra in p-p and p-A.

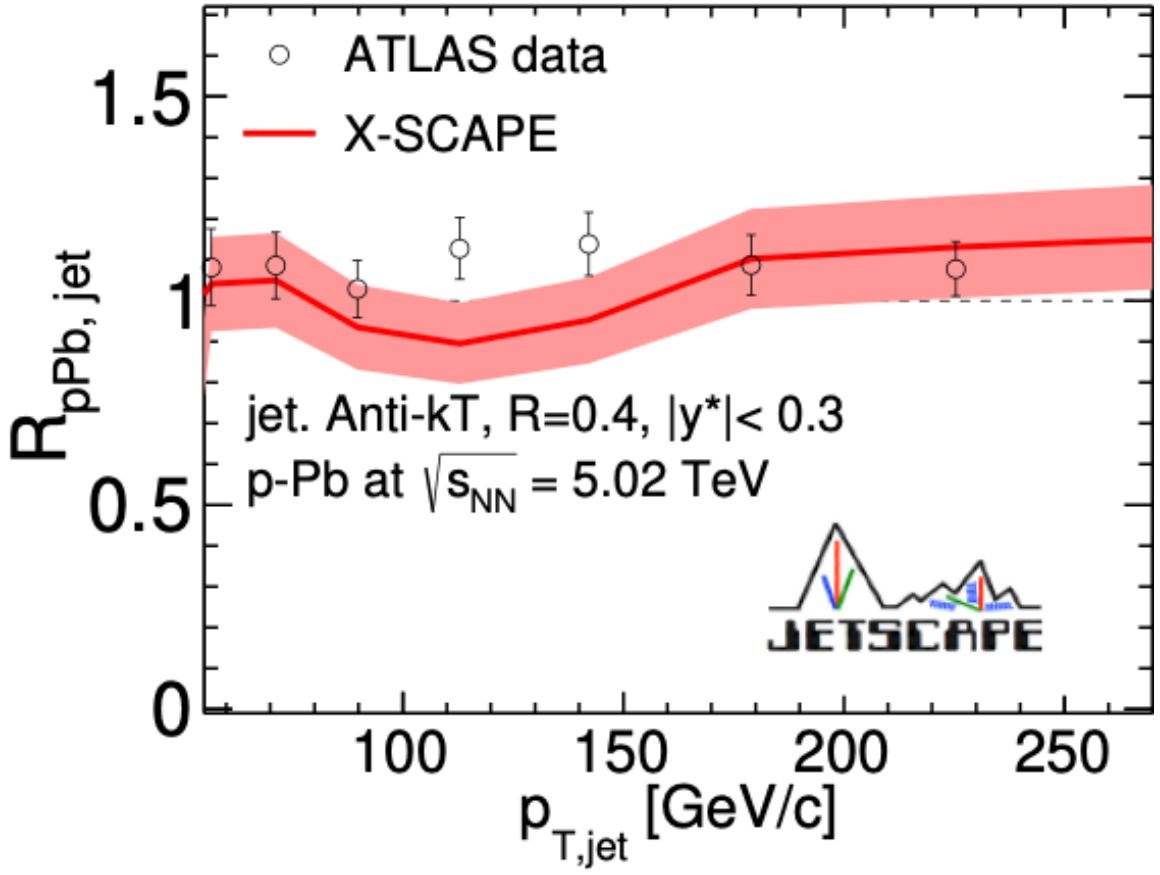




Jets with no final state energy loss

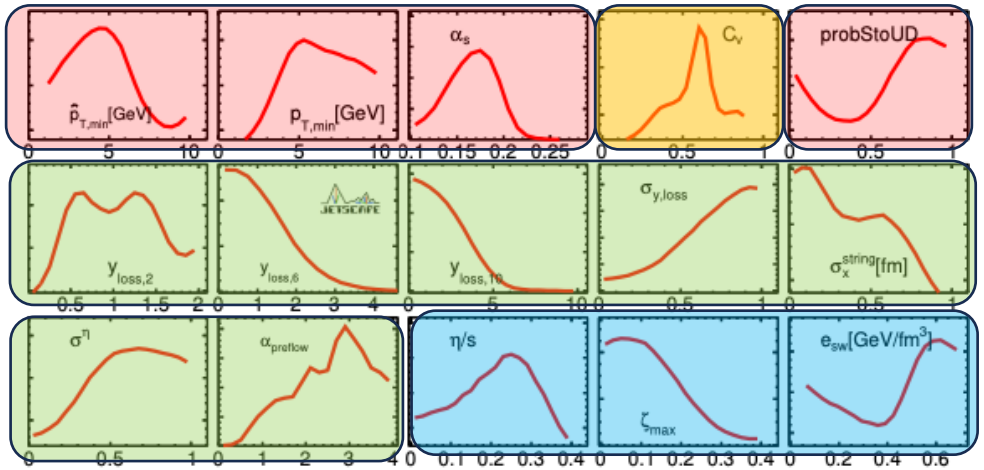
- Jets in p-p and p-A
- Simple background subtraction: only use fragmentation hadrons in jet clustering





Identified hadrons and Bayesian calibration

- Fits improved by *minimal* Bayesian calibration (15 parameters)
- The low p_T hadron yields improved by soft particle production from hydro

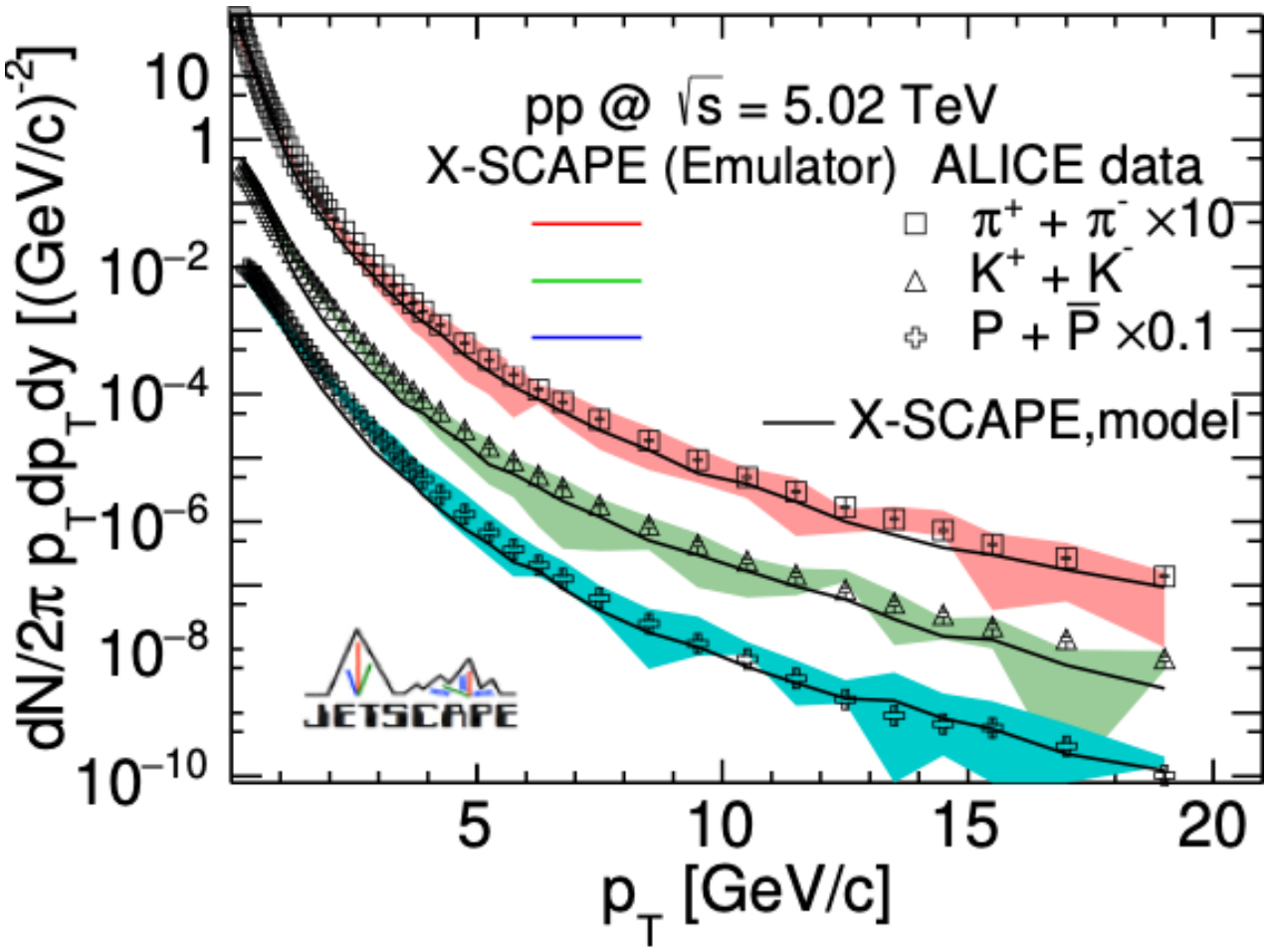


PYTHIA parameters

I-MATTER parameter

3D Glauber parameters

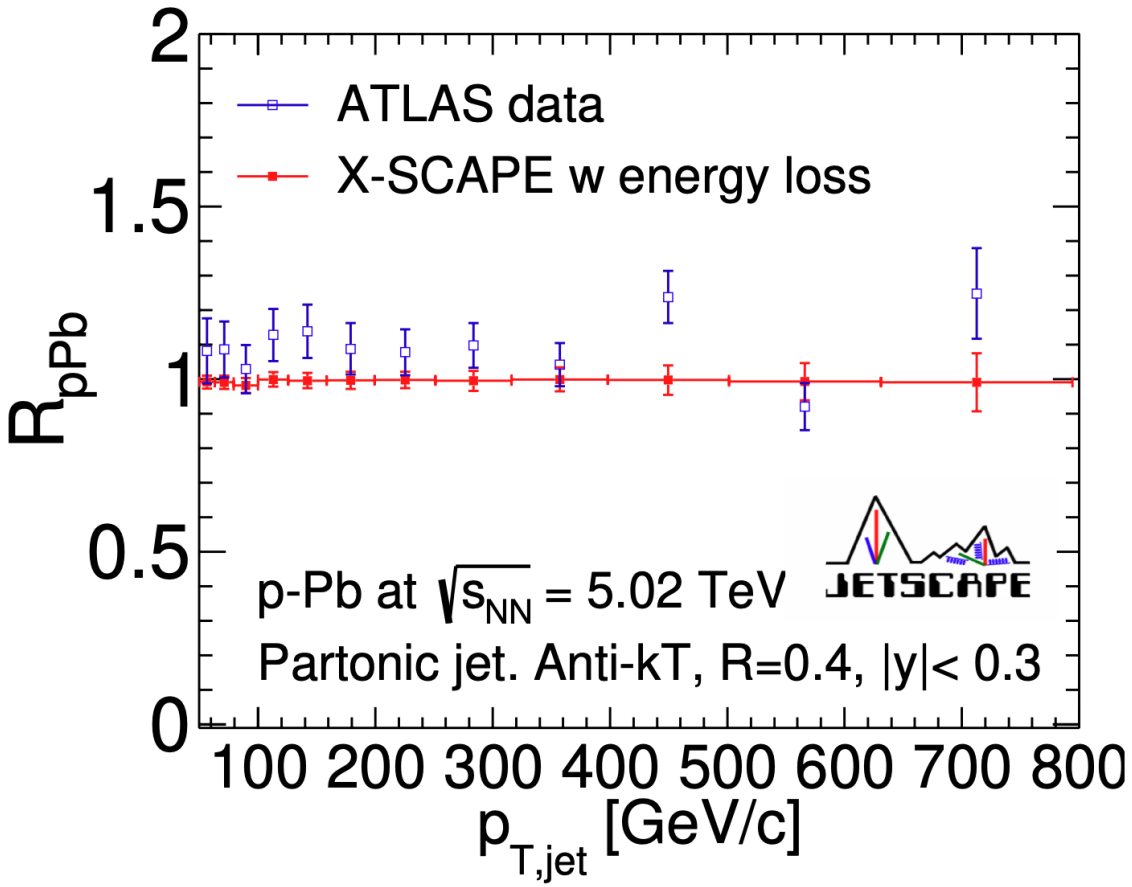
Hydro parameters

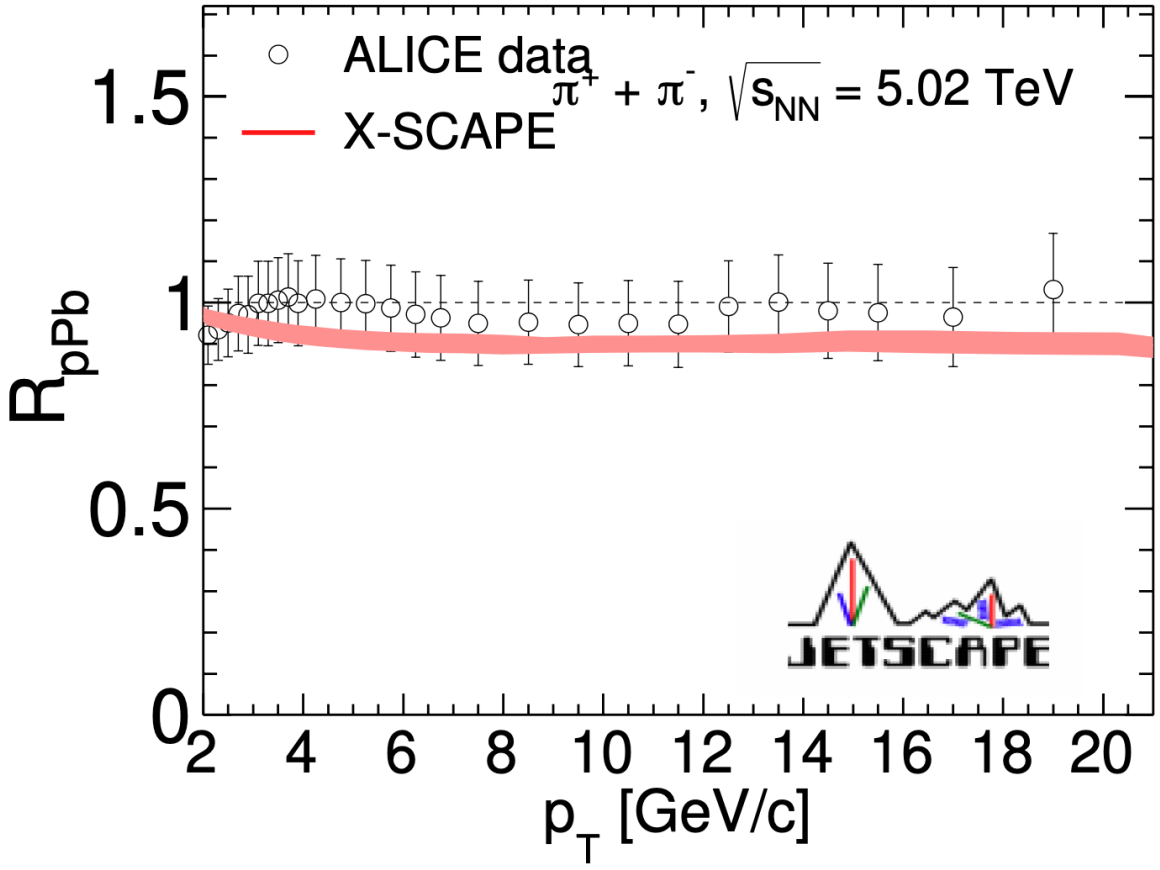


Need a large-scale Bayesian analysis (Note each event has a 3 D hydro)!

Does the hydro medium induce final state E-loss?

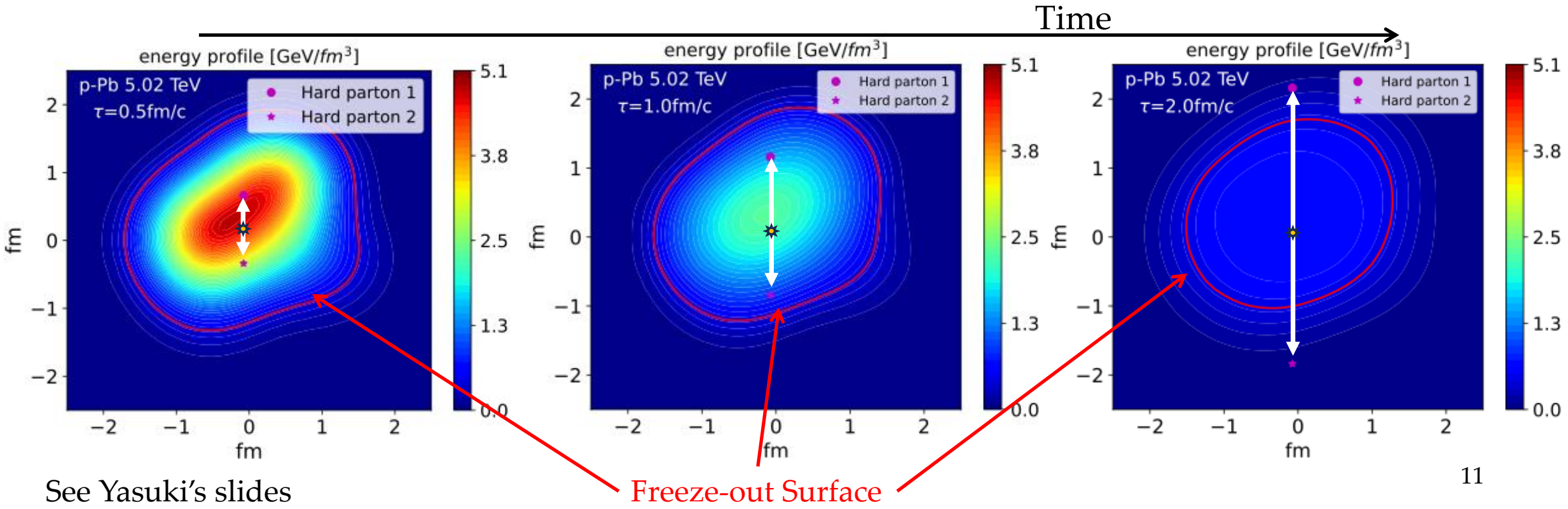
- Simulations with energy loss in MATTER turned-on
- No significant suppression in jets and leading hadrons





Does the hydro medium induce final state E-loss?

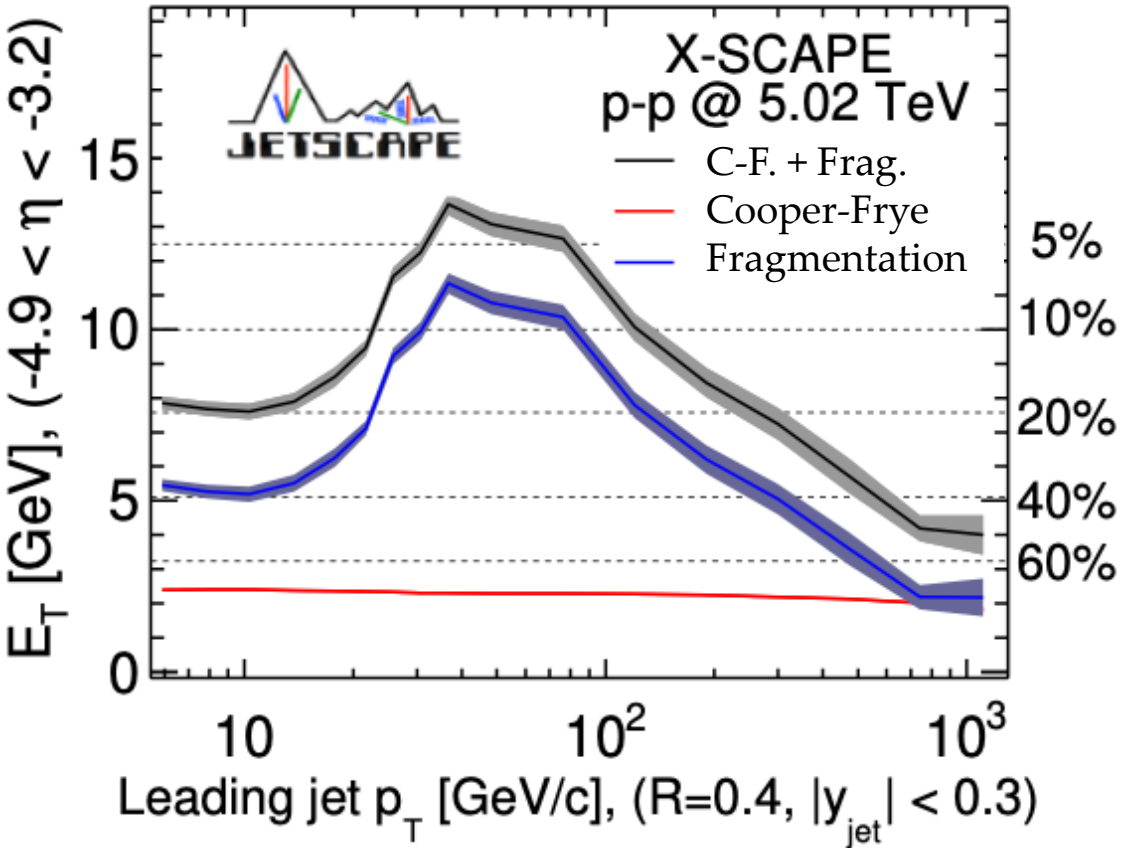
- Explanation: the medium is too small and too short lived to induce significant modification of jets and hadrons.
- Many events with partons traveling away from QGP,
- Choose event with partons close to and going through QGP (below)
- partons have escaped by 1.5 fm/c

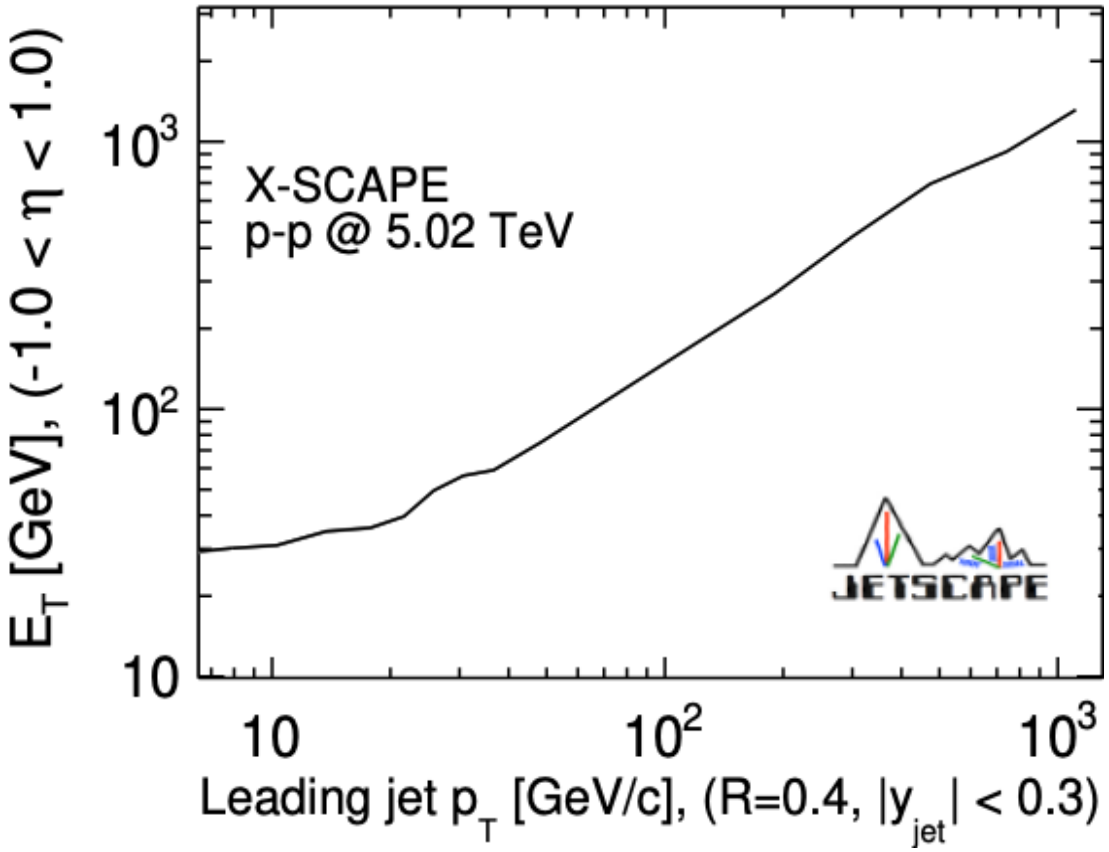


See Yasuki's slides

p-p event activity as a function of jet p_T

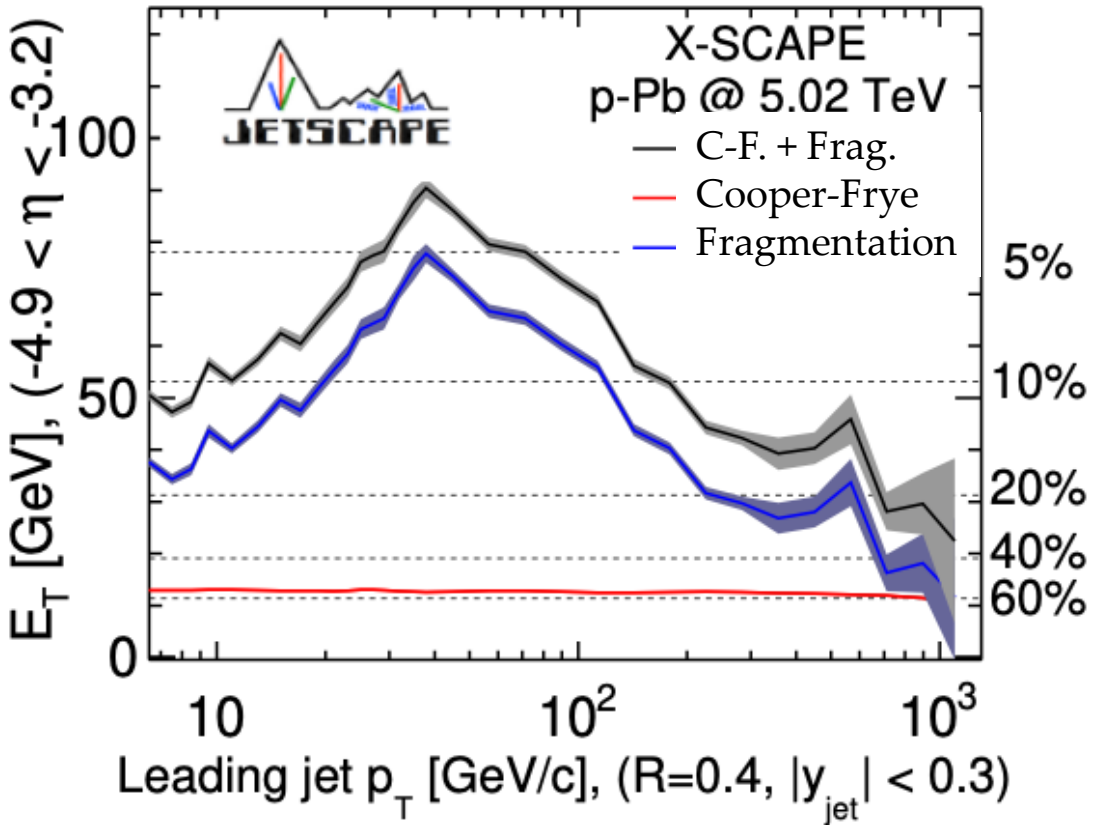
- Event activity modification in p-p with jet momentum
- We calculate the E_T from both **Cooper-Frye** hadrons and **fragmentation** hadrons
- Forward Event Activity increases with p_T , reaches a peak and then decreases.
- Mid rapidity Event Activity increases monotonically with jet p_T

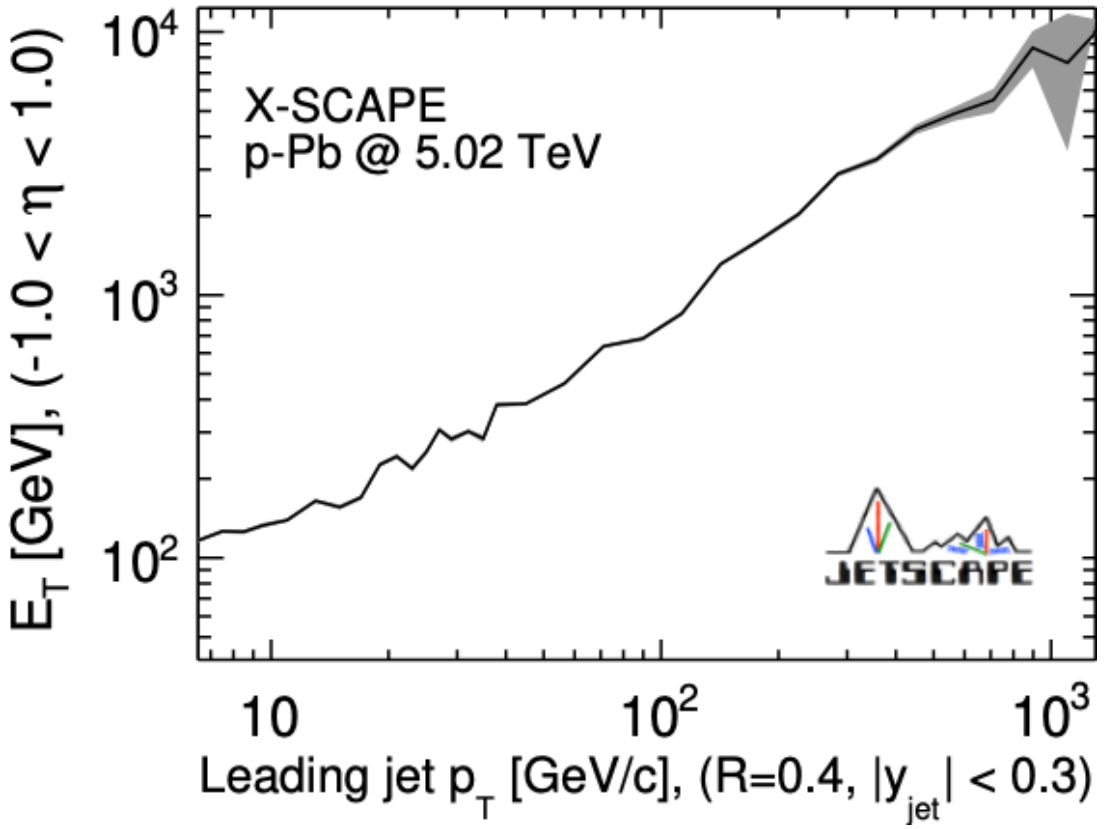




Similar hard soft correlation in p-A

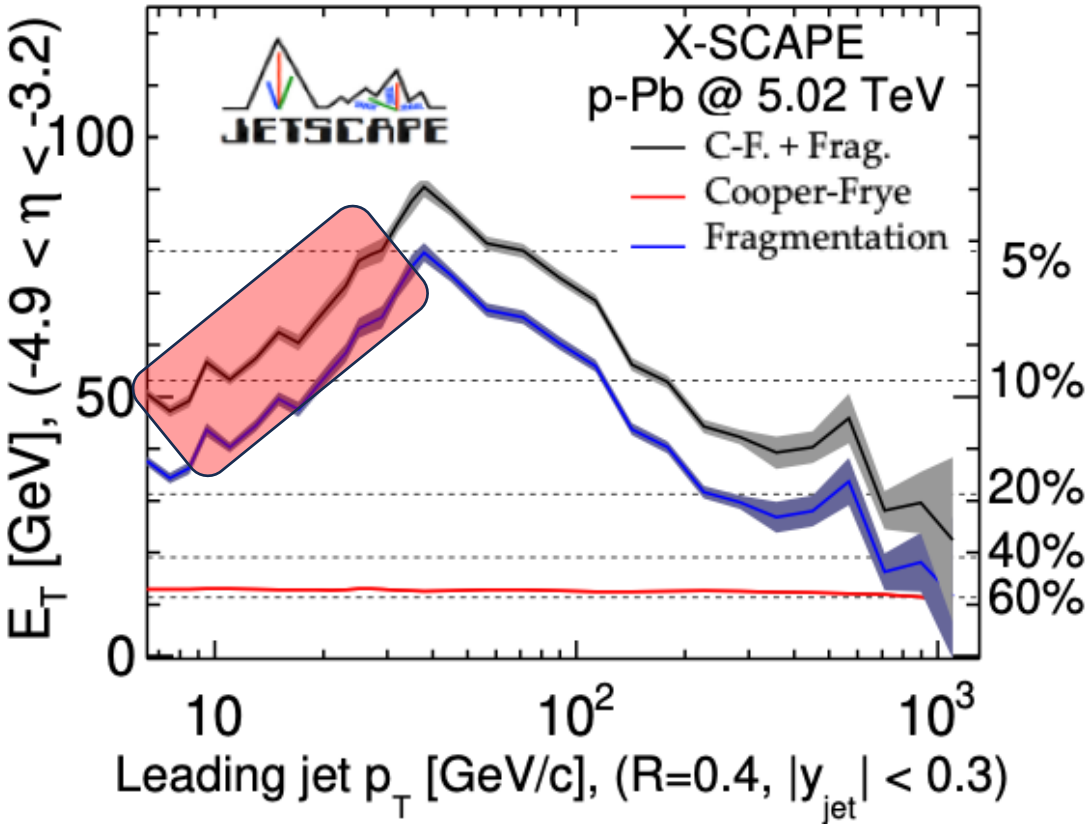
- No shadowing used yet, will modify results slightly
- Similar rise and fall in event activity with jet p_T.

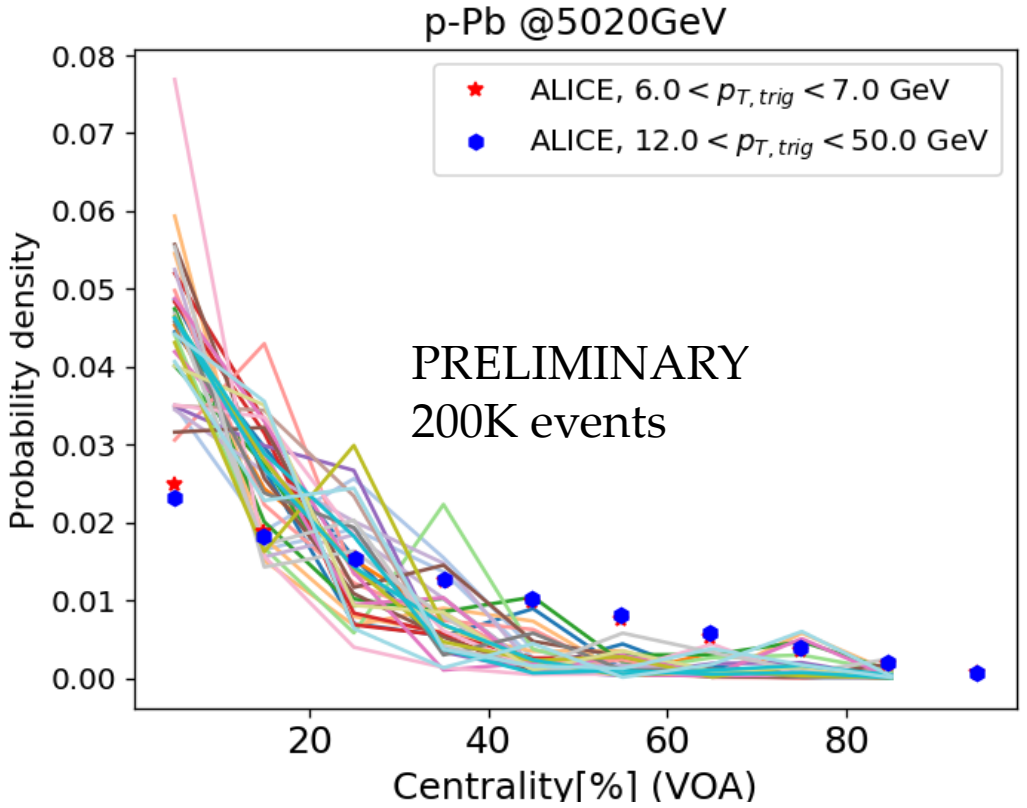




Preliminary comparison with Experiment

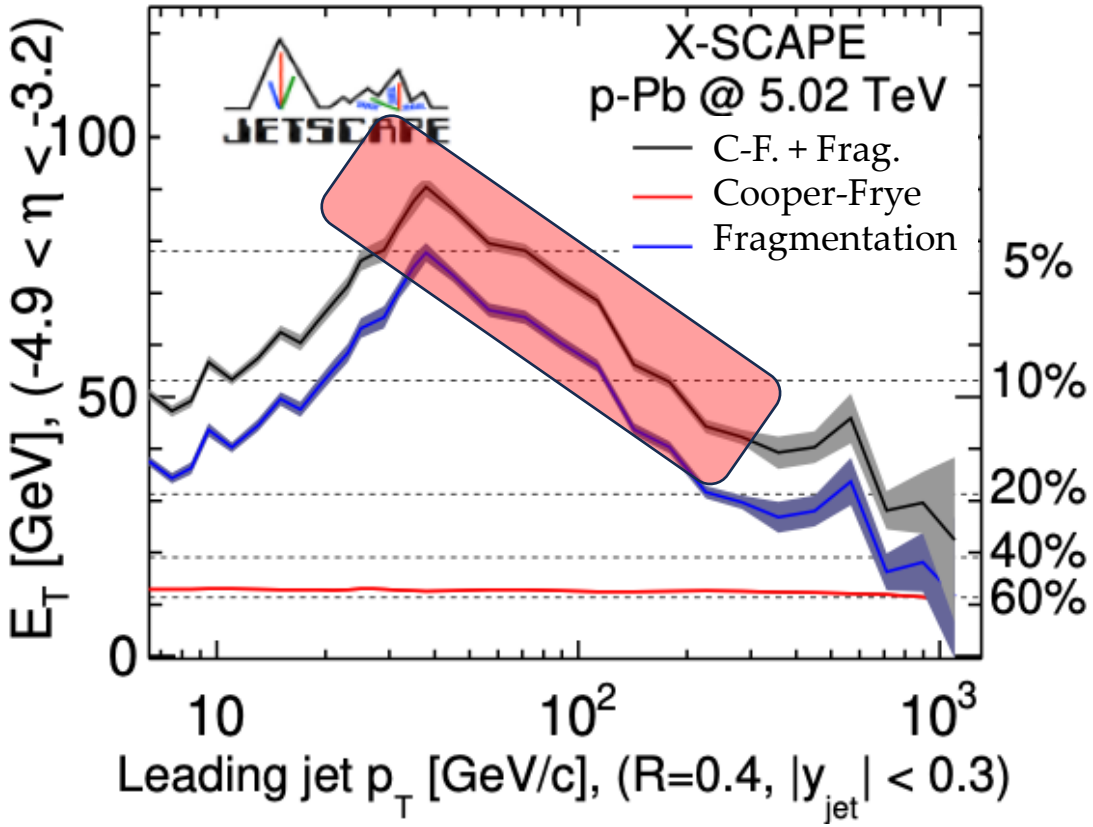
- Low p_T rise and comparison with ALICE data.
- Note: model partially calibrated on hadronic spectra only.

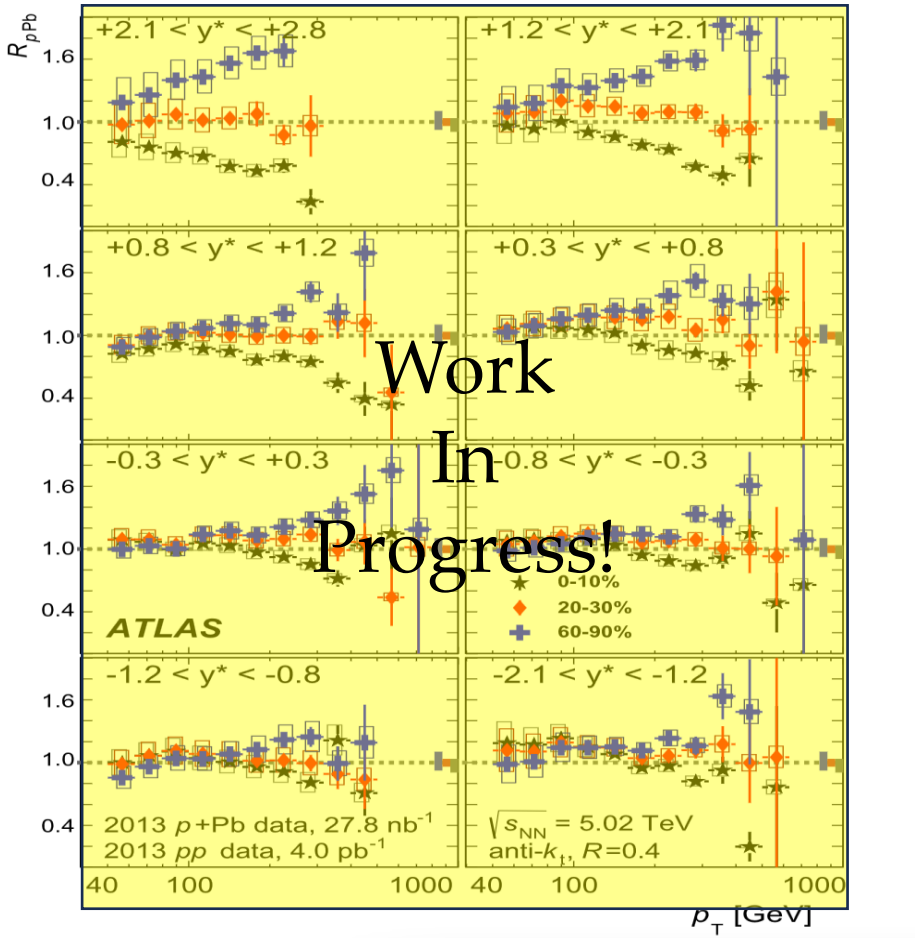




Preliminary comparison with Experiment

- High p_T turn over and decrease of event activity
- Work in progress.



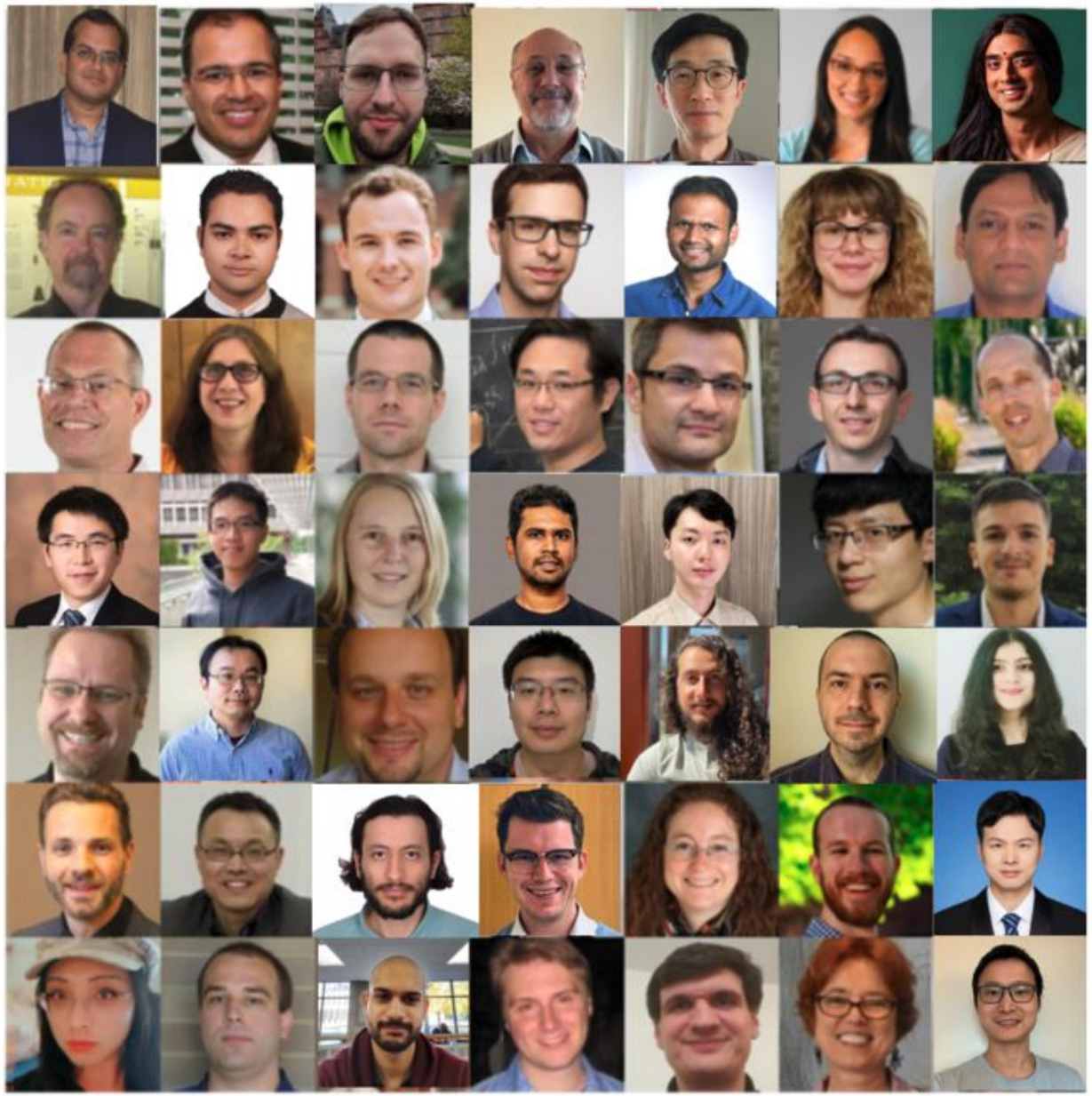


Work In Progress!

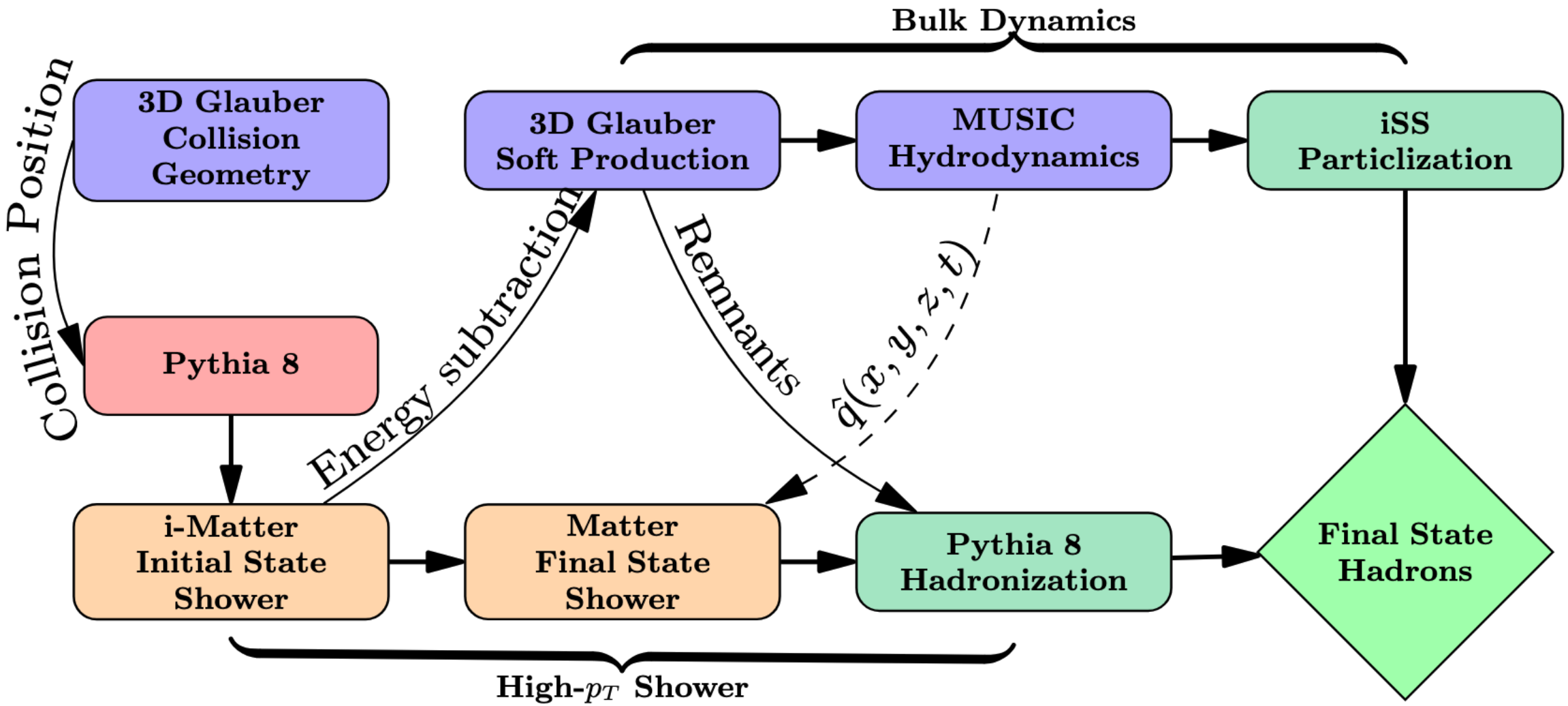
Summary and upcoming results

- New multi-stage hard-soft event generator for p-p and p-A.
- For any multiplicity!
- 3 D Glauber generates multiple hot spots in a nucleon
- MPI interactions in PYTHIA generates hard scatterings
- ISR done with i-MATTER, FSR done with MATTER
- Energy of incoming parent partons subtracted from hot spots
- Hadrons from depleted hydro and from string fragmentation
- Very good description of data on particle and jet spectra.
- Positive correlation between EA and low p_T jets (ALICE data).
- Negative energy correlation at $E > 100$ GeV (Future work, ATLAS data).

Thanks to all my collaborators @

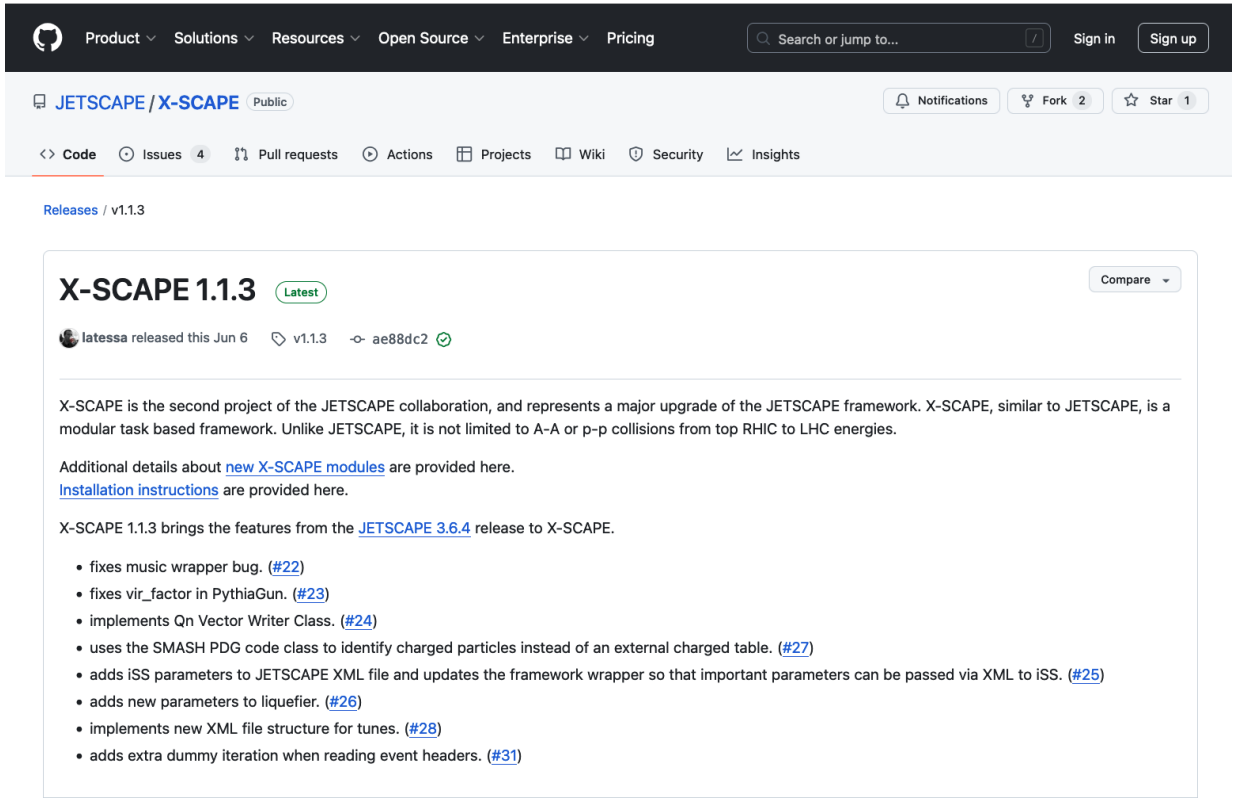


Workflow in X-SCAPE



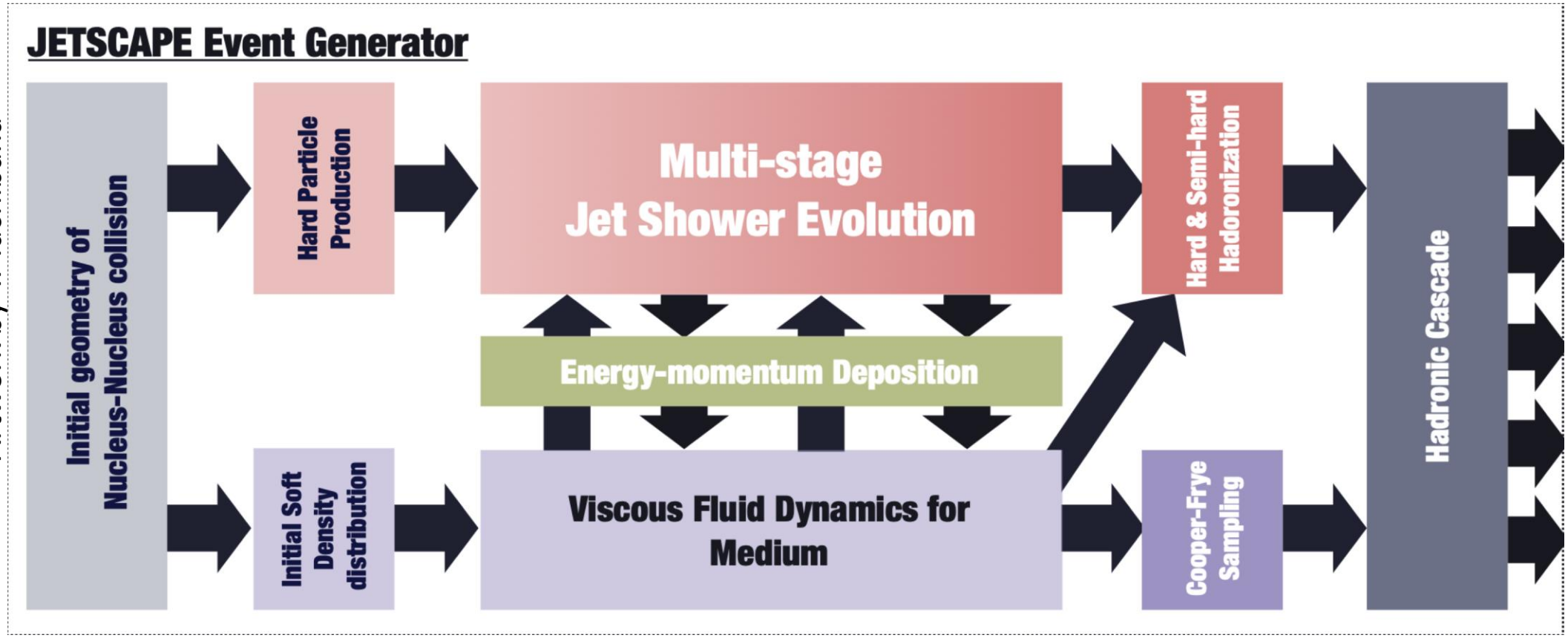
X-ion collisions with a Statistically and Computationally Advanced Program Envelop (X-SCAPE)

- Small systems in p-p, p-A etc.
  - Asymmetric systems such as d-A, A-A.
  - Require strong correlation between hard and soft sector
  - In both initial and final state.
- Lower energy A-A, for Beam Energy Scan
  - Require concurrent hydro + cascade
- Extension to e-A, for EIC.



JETSCAPE: a p-p and A-A generator

- Framework controls order of modules and information flow
- Modules are user defined, replaceable, divisible
- Can be run in pure bulk, pure hard, or interactive modes



Artwork by Y. Tachibana

JETSCAPE results (only hard sector)

- Big picture or base model (141 different data sets) vs. Fine structure