Jet quenching in small systems

Discussion Group 3

Reminder of issues: poster I

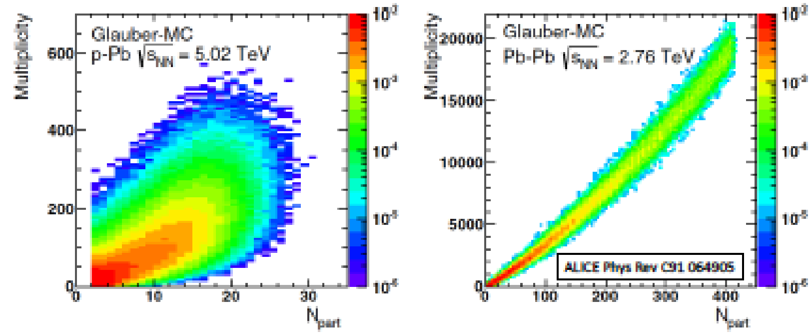
1. Jet quenching effects in small systems expected to be small; little guidance from theory
2. characterization of collision geometry in small systems is challenging: large relative fluctuations of Event Activity → large model dependence of $\langle T_{pA} \rangle$

Choice of observables: jets, hadrons

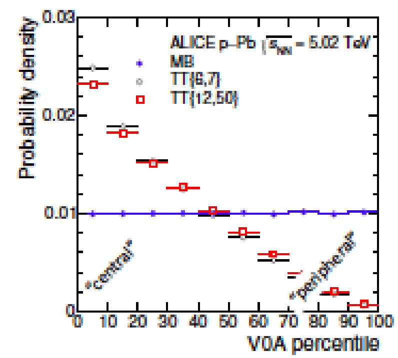
- inclusive suppression
- triggered coincidence: recoil suppression and deflection
- jet substructure

EA and "centrality"

Glauber calculations showing correlation of forward multiplicity with calculated N_{part} for p+Pb and Pb+Pb; p+Pb has much larger relative fluctuations.



EA bias due to the presence of a hard process:



V0A: forward multiplicity in Pb-going direction

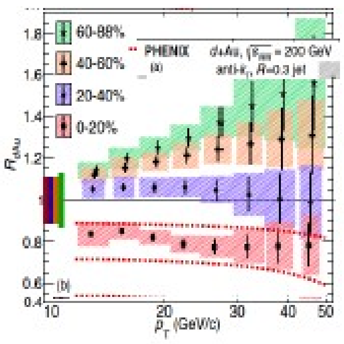
Blue: MB distribution in decile bins (uniform by construction)

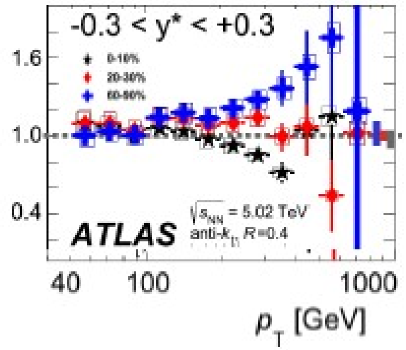
Black: biased distribution due to track in central barrel with $6<p_T<7$ GeV/c

Red: biased distribution due to track in central barrel with $12<p_T<50$ GeV/c

Reminder of issues: poster II

Inclusive R_{pA} and semi-inclusive jet measurements

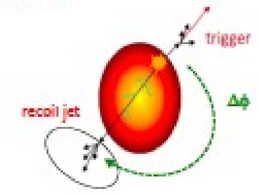




- Inclusive and coincidence measurements do not give consistent picture of quenching
- Coincidence preferred due to issues with <TpA>
- Is 400 MeV (90% CL) a significant constraint?

Semi-inclusive jet quenching observables

- Trigger-normalized yield suppression BDMPS $\sim <\hat{q}L^2>$
- Azimuthal deflection $\sim <\hat{q}L>$

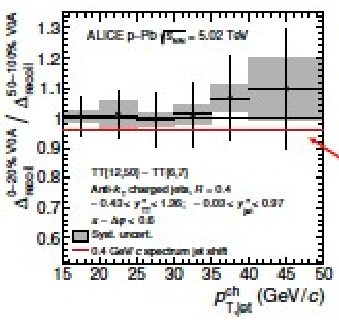


No requirement to associate Event Activity and geometry:

$$\frac{1}{N_{\rm trig}^{\rm AA}} \frac{d^2 N_{\rm jet}^{\rm AA}}{dp_{\rm T,jet}^{\rm ch} d\eta_{\rm jet}}\Bigg|_{p_{\rm T,trig}\in {\rm TT}} = \left(\frac{1}{\sigma^{\rm AA\to h+X}} \cdot \frac{d^2\sigma^{\rm AA\to h+jet+X}}{dp_{\rm T,jet}^{\rm ch} d\eta_{\rm jet}}\right)\Bigg|_{p_{\rm T,h}\in {\rm TT}}$$

In case of no nuclear effects

$$\frac{1}{N_{\rm trig}^{\rm AA}} \frac{d^2 N_{\rm jet}^{\rm AA}}{dp_{\rm T,jet}^{\rm ch} d\eta_{\rm jet}}\Bigg|_{p_{\rm T,trig}\in {\rm TT}} = \left(\frac{1}{\sigma^{\rm pp\to h+X}} \cdot \frac{d^2\sigma^{\rm pp\to h+jet+X}}{dp_{\rm T,jet}^{\rm ch} d\eta_{\rm jet}}\right)\Bigg|_{p_{\rm T,h}\in {\rm TT}} \times \frac{T_{\rm AA}}{T_{\rm AA}}$$



Compare trigger-normalized recoil jet spectra for high and low multiplicity p+Pb

Measured limit: medium-induced energy transport out of cone of radius R=0.4 is less than 400 MeV (90% CL)

Inclusive R_{pA} and semi-inclusive limit are not compatible [4]. My guess: uncorrected biases in $\langle T_{pA}\rangle$ due to QCD correlations, beyond the increase in pp UE[5].

What is a small system?

Is there a continuum pp -> pA -> AA?

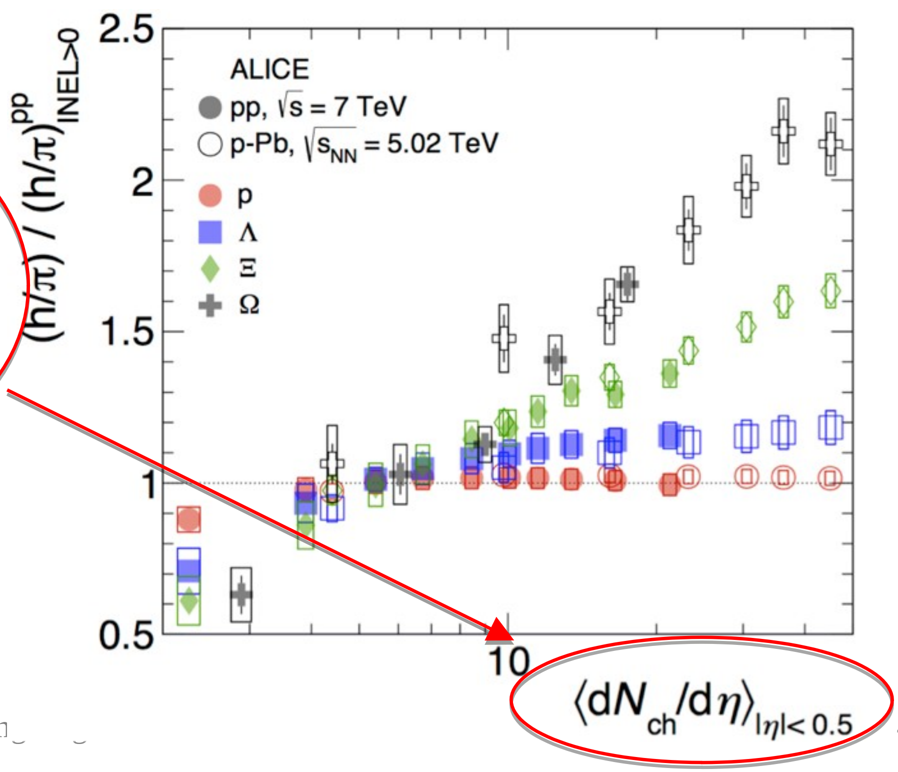
- pp -> pA : increase density but not size
- pA -> AA : increase both size and density

cannot turn effects "on and off" : physics lies in how things change

- systematic check: regions of common EA in different systems

Scaling quantities:

- Large systems: $\hat{\gamma}_L = \left(\frac{dN_{\mathrm{ch}}}{d\eta}\right)^{\frac{1}{3}}$
- Small systems $\hat{\gamma}_S = \left(R\,\langle p_{\mathrm{T}}\rangle\,\frac{dN_{\mathrm{ch}}}{d\eta}\right)^{\frac{1}{4}}$



Other observables: forward ET

What are the theoretical expectations for jet quenching in small systems?

No detailed calculations to date, only parametric projections:

- scaling by multiplicity ; assumes continuum large AA $\rightarrow$ small systems

(a) BDMPS approach:

- soft induced radiation occurs early
- Signatures: soft, large-angle radiation; softening of fragmentation at low-z
- Relative effects largest for lowest p_T^{jet}

(b) Monte Carlo approach (e.g. JEWEL):

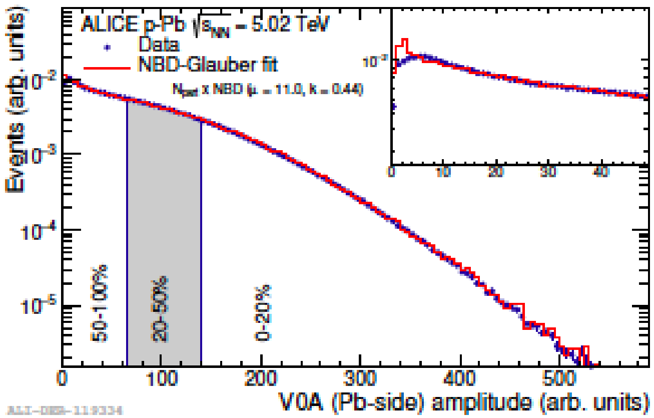
- Small systems do not present any special barrier: thin medium can be accommodated
- needs a medium: hydro, transport; both are discretized
  - Model of medium needs to be calibrated/tuned on soft observables

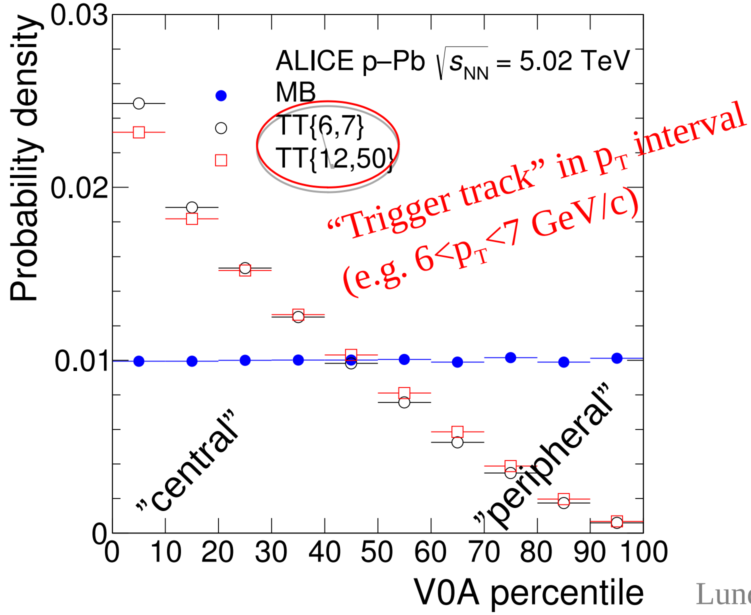
(c) Angantyr: jet-medium interaction via shoving mechanism

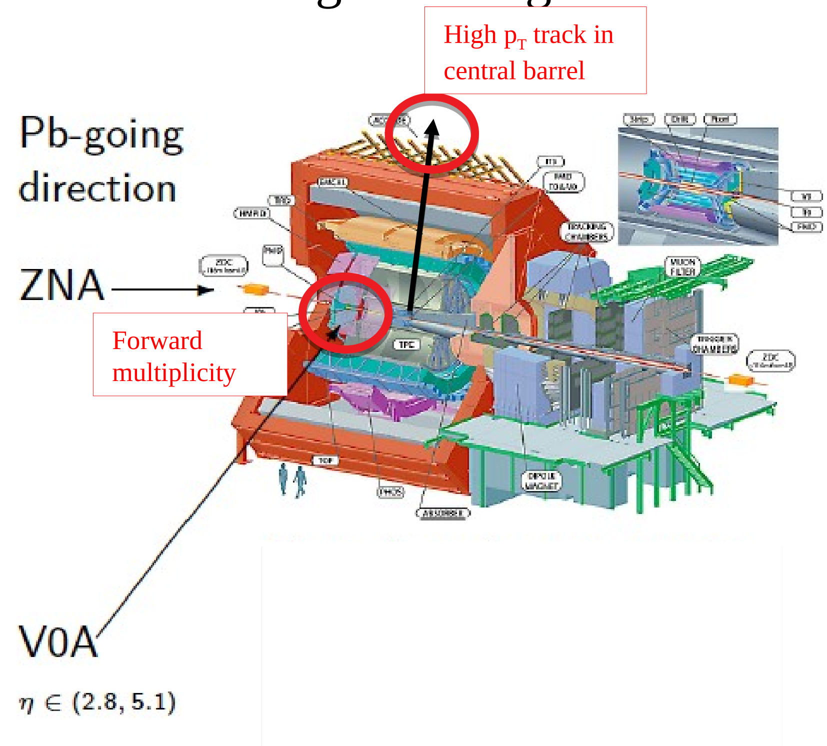
- No external model of medium
- Deep connection to flow: same physical mechanism

What generates high multiplicity in small systems? How can data check models?

EA bias in p+Pb: how does high-Q^2 process in central region change the distribution?





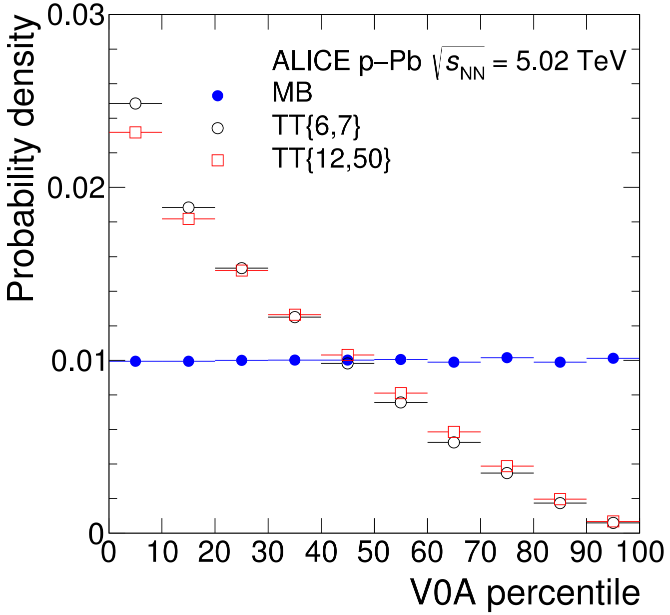


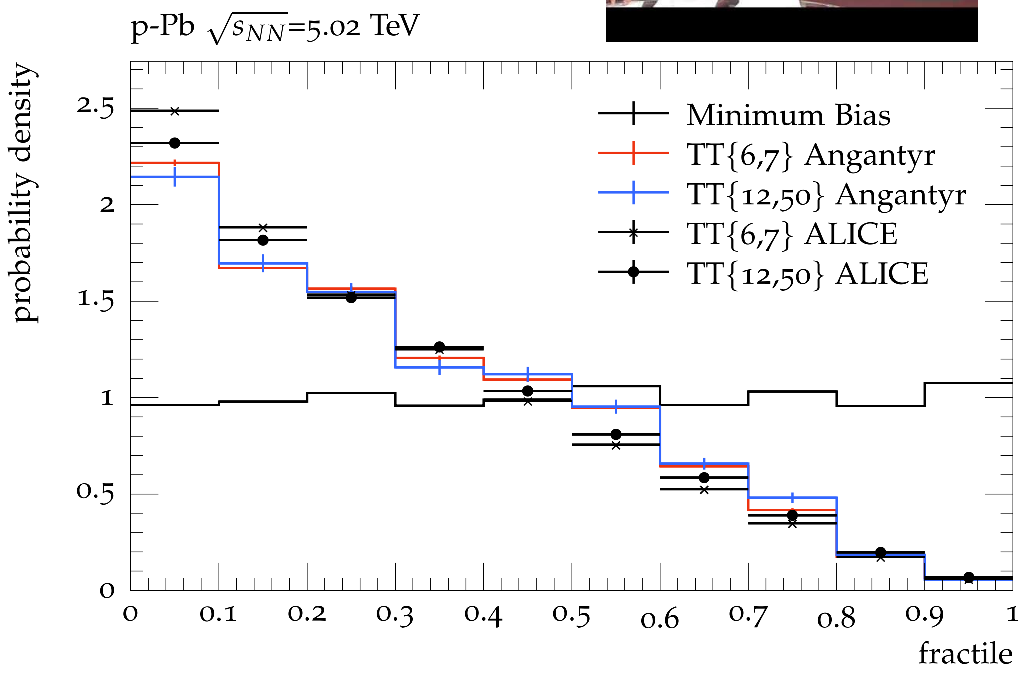
Mechanisms:

- Ncoll bias (geometry)
- QCD correlations (color flow)

p+p also interesting: TBD

p+Pb hard process bias: Angantyr vs. ALICE data



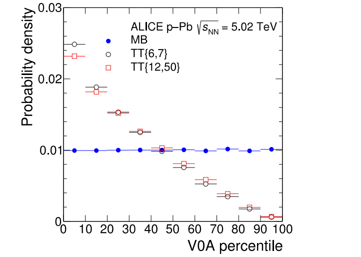


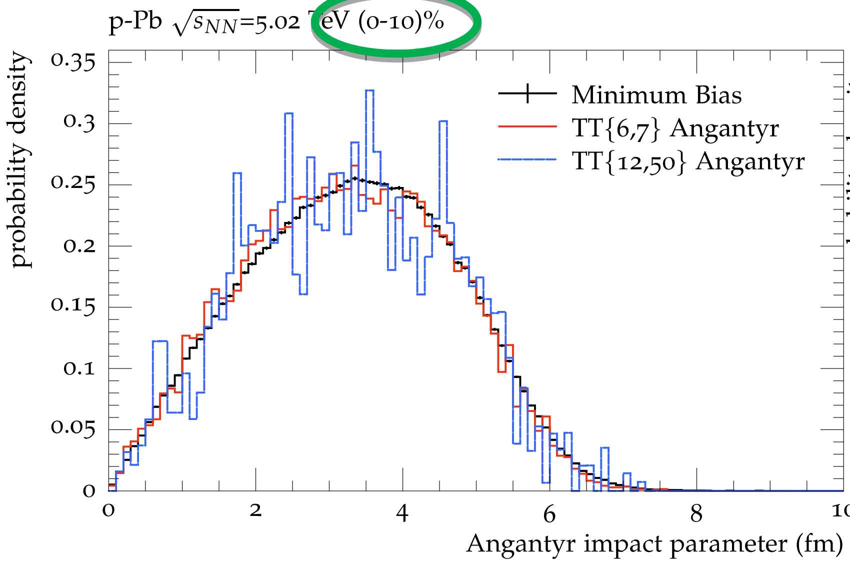
Excellent agreement of model with data

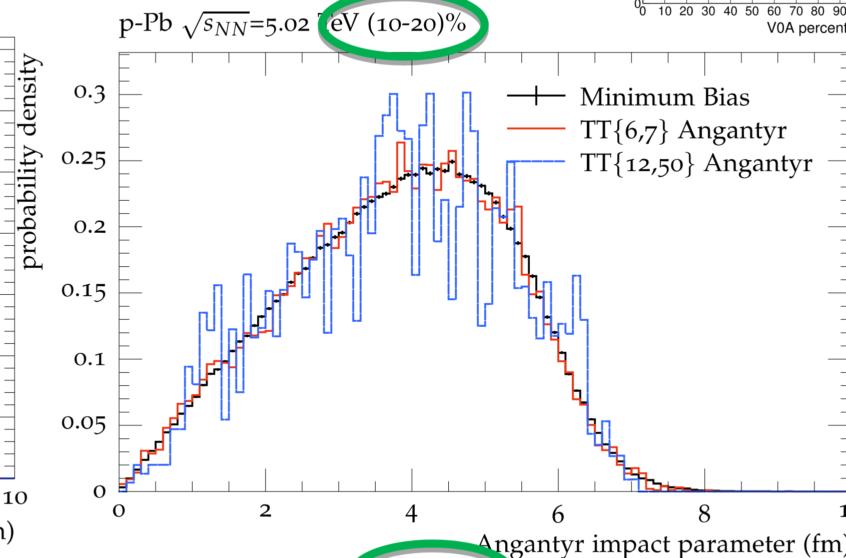
Use model to explore the nature of the bias. Possible contributions:

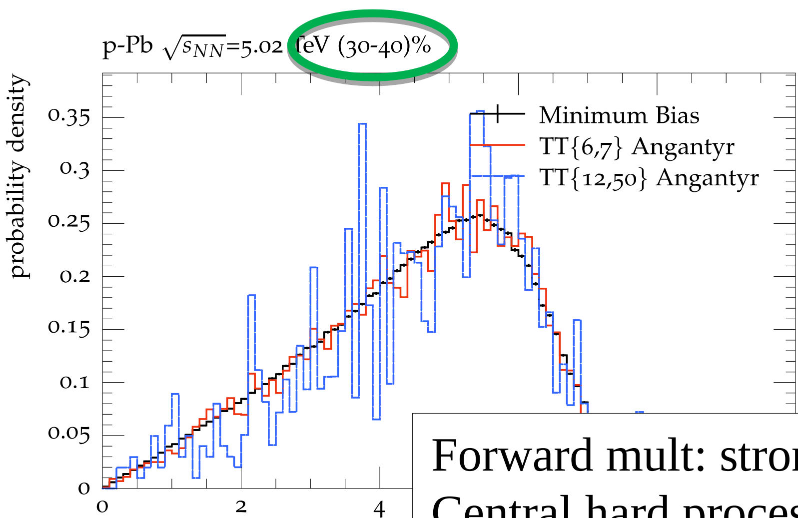
- Ncoll weighting (geometric bias)
- Color correlations (strings connect central and forward)
- Energy-momentum convservation (unlikely at LHC but let's see…)

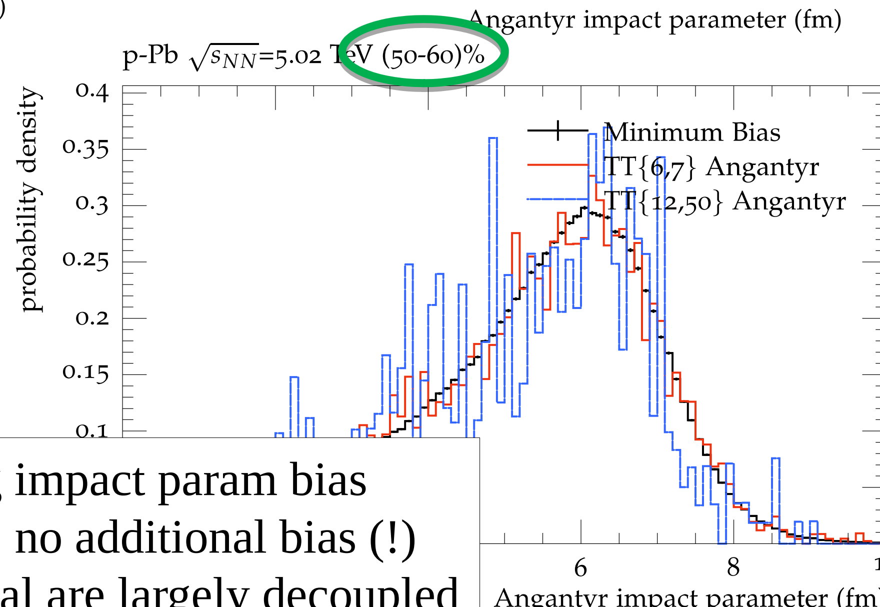
Angantyr: bias in impact parameter distribution due to central hard process









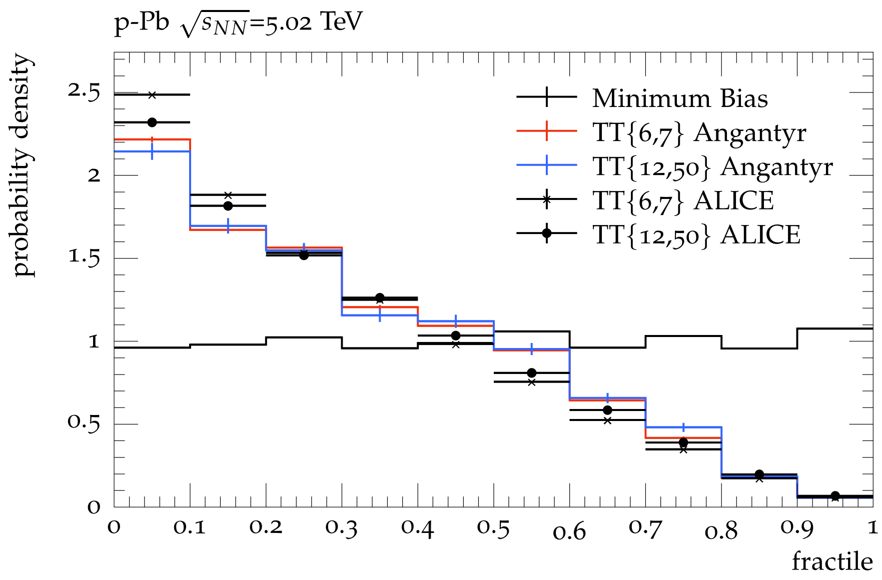


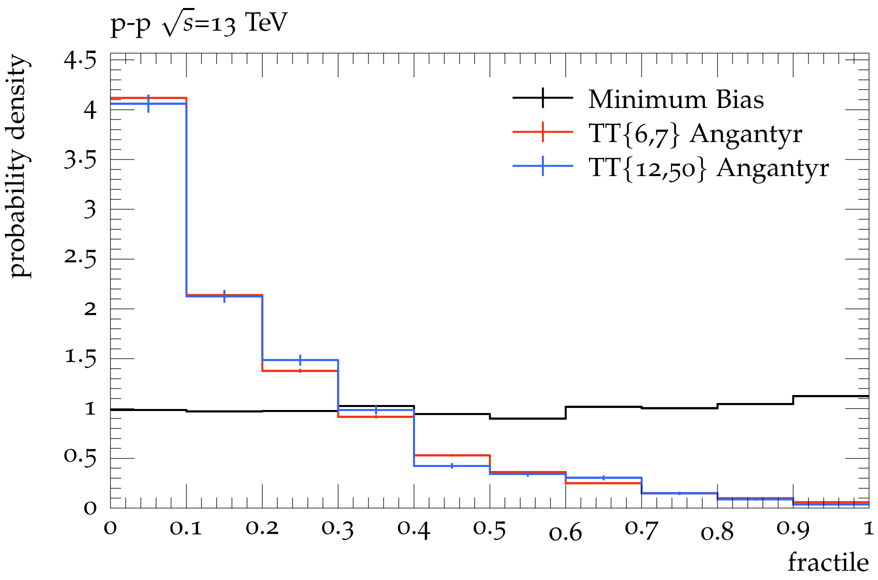
Forward mult: strong impact param bias
Central hard process: no additional bias (!)
→ forward/central are largely decoupled

New prediction: forward mult bias in pp

p+Pb: model and data agree

p+p: not yet measured!





Predict much larger bias in pp than p+Pb

- what is underlying mechanism?

This prediction is a great outcome of this workshop

Forward neutron tagging in d+Au @ RHIC

Additional test of control over geometry in p/d+A

- Use neutron in ZDC and Hulthen wavefn of the deuteron to tag "peripheral" p+Au events
- Unfortunately not achievable at LHC due to injection system

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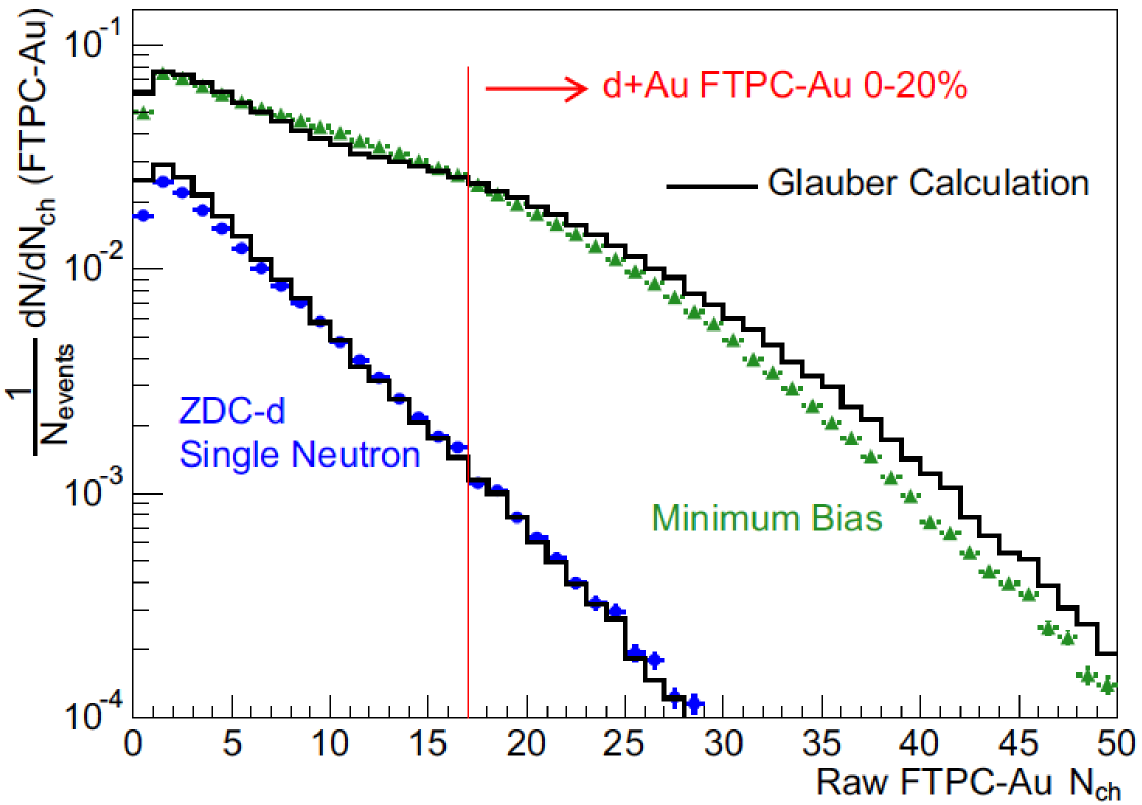

Summary: jet quenching in small systems

Effects expected to be small

- Correlation of EA and geometry is challenging: inclusive suppression (RAA) will always have limited systematic precision
- Most precise measurements utilize coincidences (and potentially substructure)
- Are current limits significant? Need calculations

Status of calculations:

- String approach: First results from Angantyr
- MC: JEWEL in progress, needs models of medium; no known show-stoppers

What do we talk about when we talk about high multiplicity in small systems?

- Are there correlations forward mult $\Longleftrightarrow$ central hard? Angantyr: No!
- This is an extremely important (and new) result: justifies usage for forward mult as independent characterization of events
- predictions for pp…

We now have a clear path forward to explore jet quenching in small systems in both experiment and theory, and know how to compare them