WG5 Summary

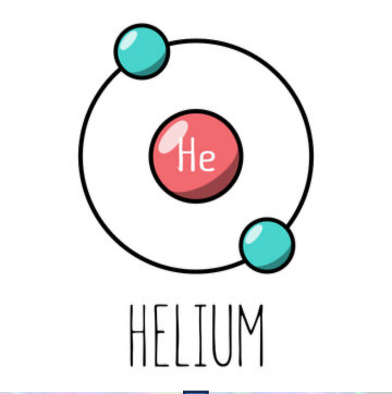
Jack Holguin and Valentina Zaccolo

MPI@LHC 2023

From small to large nuclei

We had discussions on:

- light nuclei fixed target experiments
  - Chiara Lucarelli
- Collectivity(?) in small to large systems
  - Mattia Faggin, Austin Alan Baty, Ante Bilandzic
- Event generators for heavy ion collisions
  - Guilherme Milhano , Daniel Pablos Alfonso
- Jet Quenching in heavy ion collisions
  - Carlota Andres, Ezra Lesser, Jasmine Brewer



From small to large nuclei

We had discussions on:

- light nuclei fixed target experiments
  - Chiara Lucarelli
- Collectivity(?) in small to large systems
  - Mattia Faggin, Austin Alan Baty, Ante Bilandzic
- Event generators for heavy ion collisions
  - Guilherme Milhano , Daniel Pablos Alfonso
- Jet Quenching in heavy ion collisions
  - Carlota Andres, Ezra Lesser, Jasmine Brewer

Also… my comfort talking about these topics

Less

↓

More

Disclaimer

A lot of interesting physics was discussed.

I have, maybe unfairly, reduced each talk to selected result(s).

Disclaimer

A lot of interesting physics was discussed.

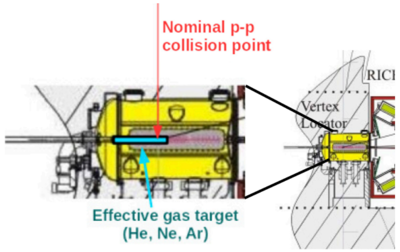
I have, maybe unfairly, reduced each talk to selected result(s).

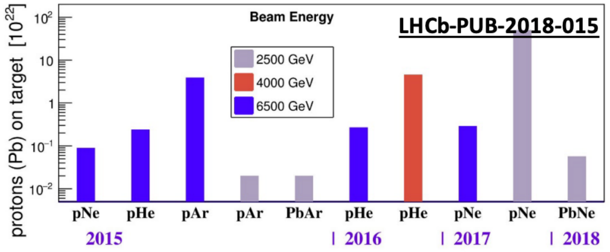
I will give some comments and observations at the end.

Helium fixed target at LHCb

LHCb fixed-target programme

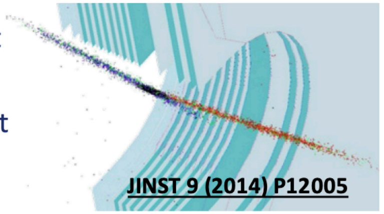
- The *System for Measuring Overlap with Gas* (**SMOG**) can inject gas in LHC beam pipe around (±20 m) the LHCb IP.
- Originally conceived for precise luminosity measurements through **Beam-Gas Imaging**.
- For machine safety, **only noble gases** with a maximum pressure of **2x10^{-7} mbar** (x100 nominal LHC vacuum) can be injected → Luminosity: $\mathcal{L} \sim \mathcal{O}(10^{29}\ cm^{-2} s^{-1})$.





Since 2015, exploited for LHCb fixed-target physics programme

→ Collected physics samples with different targets and different centre of mass energies.



Unique opportunities at the LHC:

- Collisions with **targets of mass number A intermediate** between p and Pb → **Reproduce CR interactions (*pp*, *p*He)**
- **Energy range** $\sqrt{s_{NN}} \in [30, 115]$ GeV for beam energy in $[0.45, 7]$ TeV → **Unexplored gap** between SpS and LHC/RHIC.

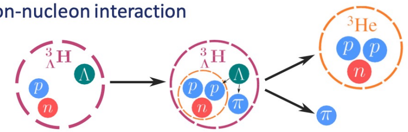
Helium fixed target at LHCb

Application: Hypertriton

- Hypertriton life-time and binding energy gives access to hyperon-nucleon interaction
  → **Constrains on maximum mass of neutron stars**

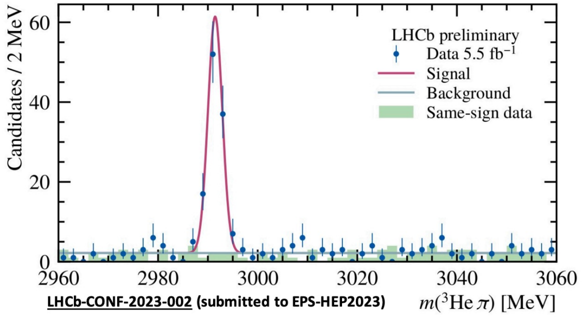
Search for 2-body decay into He:

$^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He}\,\pi^{-} + cc$



Results:
(Run2 *pp* collisions at $\sqrt{s} = 13$ TeV)
- **Yields:**
  - 61 ± 8 Hypertriton
  - 46 ± 7 anti-Hypertriton
- Statistical **mass precision**: 0.16 MeV

Under investigation:
- Systematic corrections on mass scale:
  - Charge-sign dependent energy-loss
  - Tracking corrections for Z=2
- Efficiency and acceptance corrections

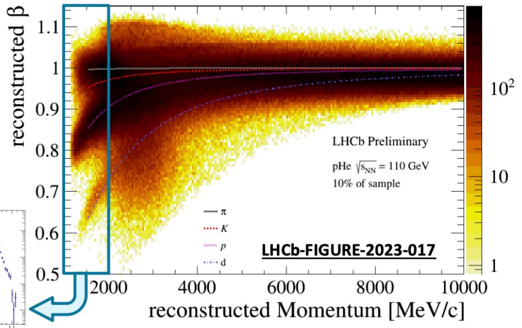


LHCb-CONF-2023-002 (submitted to EPS-HEP2023)

(Anti-)deuteron identification

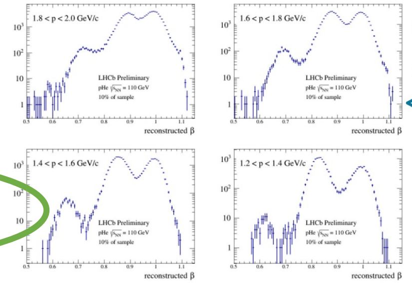
Reconstructed tracks refitted to determine β → Iterative procedure rerunning Kalman fit with different β hypotheses

1. At least 15 OT hits required on each track
2. Change β following χ^2_{fit} decrease (gradient descent) without outliers removal → $\chi^2_{\mathrm{fit}} = \chi^2_{\mathrm{track}} + [(t_{M1} - \langle M1 \rangle)/\sigma_{M1}]^2$
3. Fit around minimum to estimate β_{fit} and its uncertainty
4. If fit at minimum has outliers, removed and reiterate procedure



- **~10% of SMOG *pHe*** ($\sqrt{s_{NN}} = 110$ GeV) dataset
- **Background suppression:** $\sigma(\beta) < 0.02$, $\chi^2_{\mathrm{OThits}}/\mathrm{ndf} < 2$

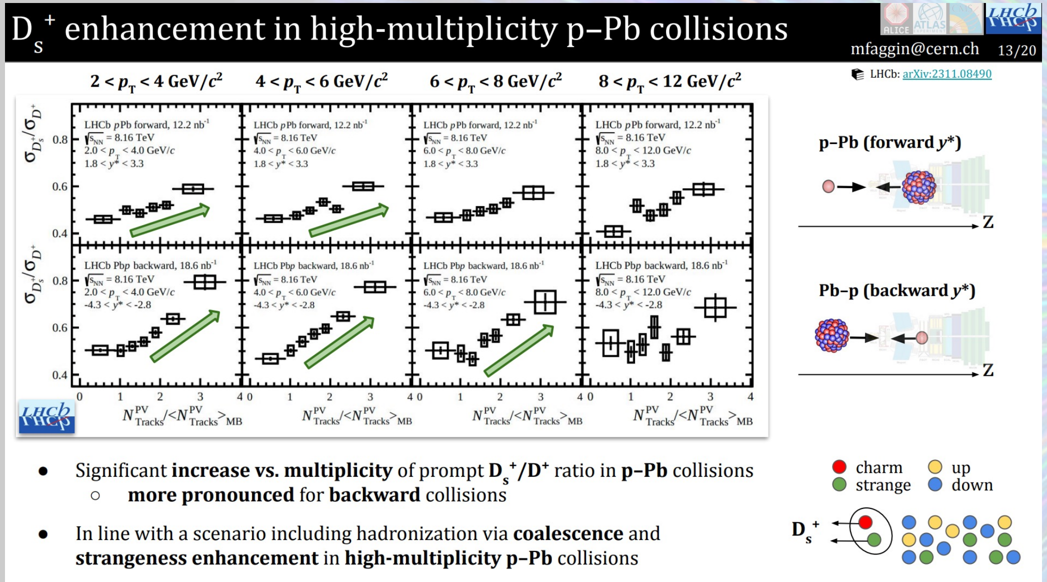
First deuteron candidates observed in *p*He data!

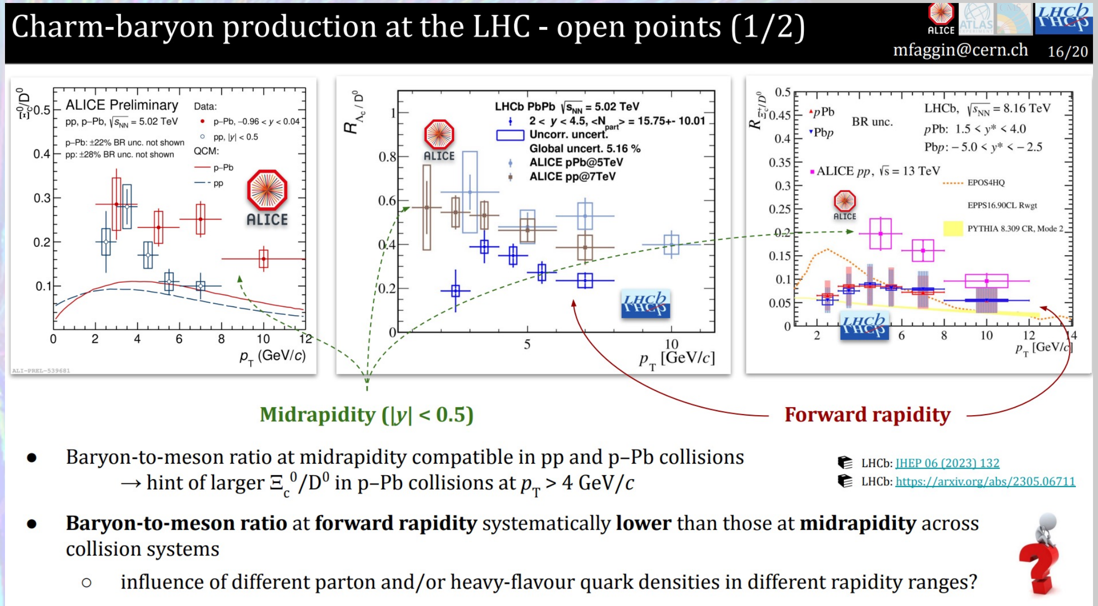


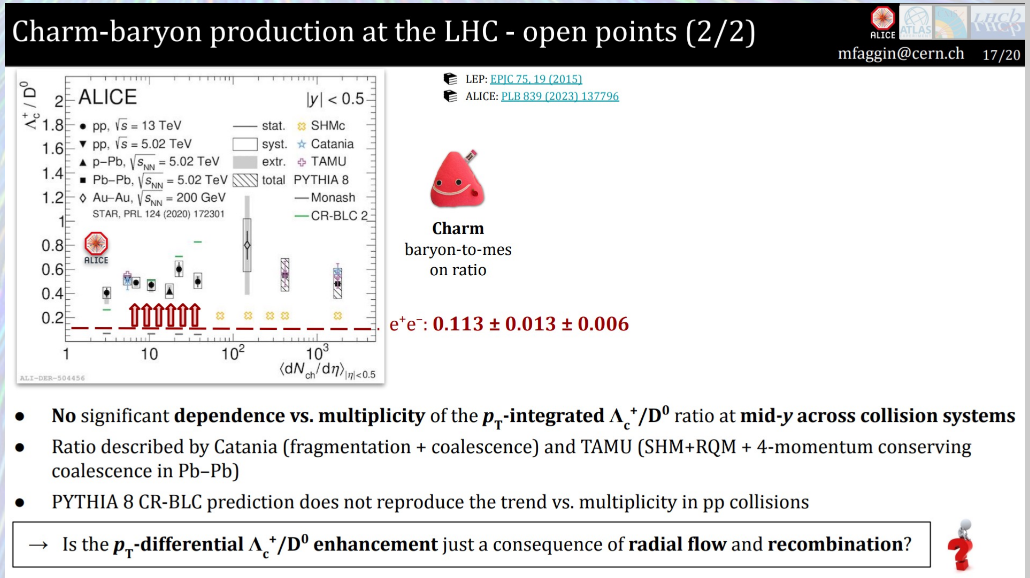
LHCb-FIGURE-2023-017

Under investigation:
- Some DATA/MC discrepancies in OT response
- Efficiencies and systematics studies
- Improve background suppression to expand momentum range where clean identification achievable

Collectivity or not in p-Pb?







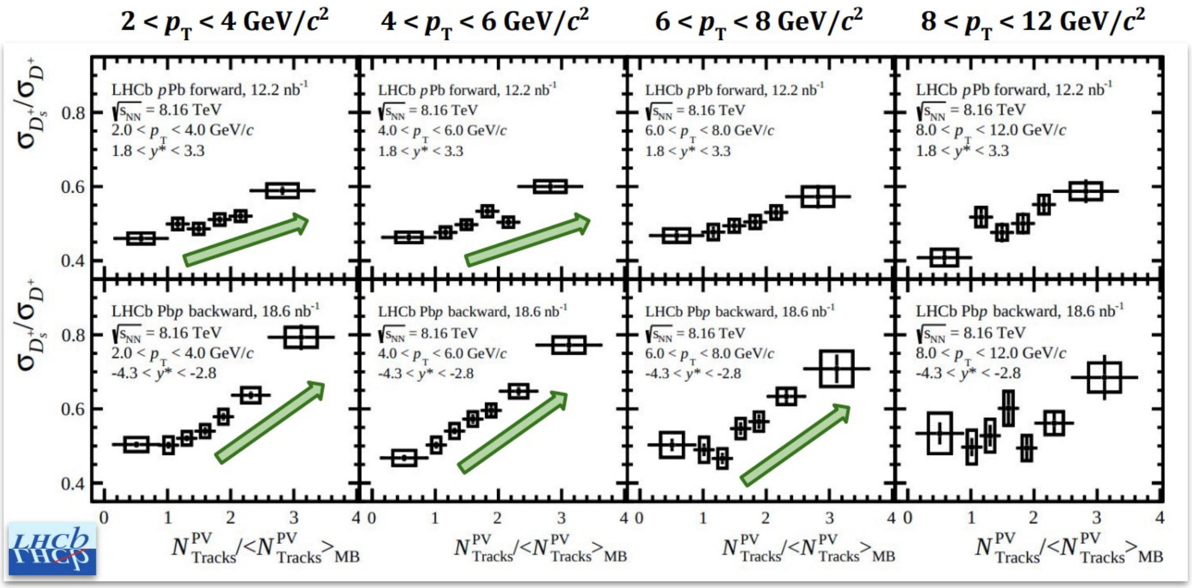
Mattia Faggin

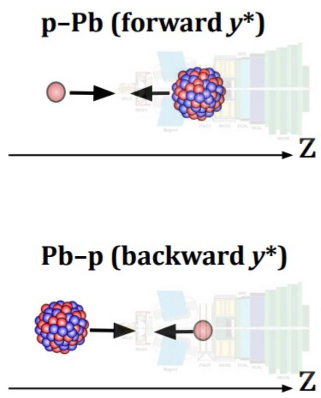
Collectivity or not in p-Pb?

D_s^+ enhancement in high-multiplicity p–Pb collisions

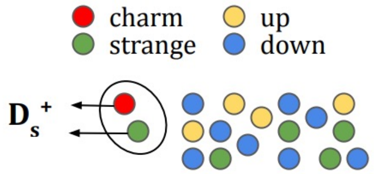
mfaggin@cern.ch

LHCb: arXiv:2311.08490





- Significant **increase vs. multiplicity** of prompt D_s^+/D^+ ratio in **p–Pb** collisions
  - **more pronounced** for **backward** collisions
- In line with a scenario including hadronization via **coalescence** and **strangeness enhancement** in **high-multiplicity p–Pb** collisions



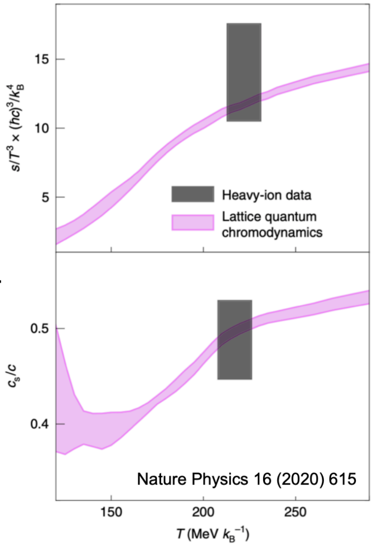
Collectivity in Pb-Pb

Previous Extractions of c_s

- Extraction of c_s using ALICE data
  - Comparison of 0-5% 2.76 and 5.02 TeV data
  - Changing energy density at fixed volume

$$c_s^2(T_{eff}) = \frac{dP}{d\epsilon} = \frac{sdT}{Tds}\bigg|_{T_{eff}} = \frac{d\ln\langle p_T\rangle}{d\ln(dN_{ch}/d\eta)} = 0.24 \pm 0.04$$

- Uncertainties limited by only having 2 energies
  - Used available published ALICE data
- Energy dependence of p_T, N_{ch} not unique to AA



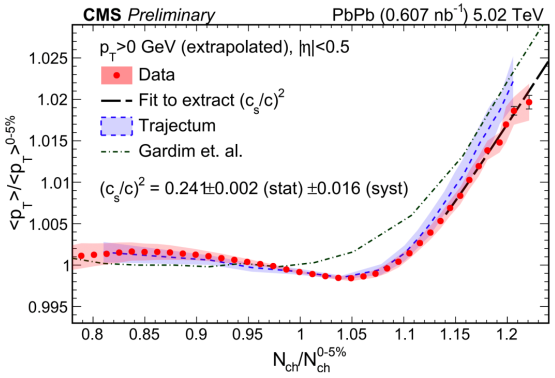
6

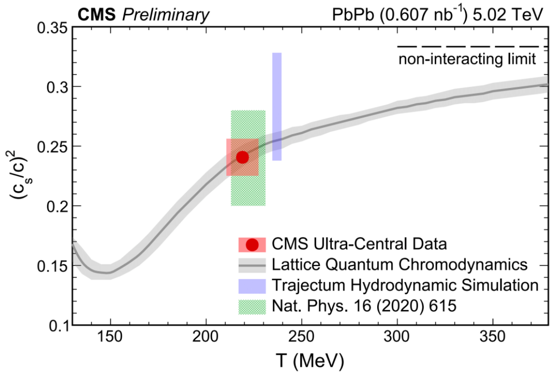
Austin Alan Baty

Summary

- First measurement of the speed of sound in QGP using UCC collisions
- Good agreement with lattice QCD (2+1 flavors)
  - Constrains equation of state - interesting to look at lower T (at RHIC?)
  - Confirms deconfined d.o.f.
- Origin of 'dip' still not understood - fluctuations?

More documentation at:
CMS PAS HIN-23-003



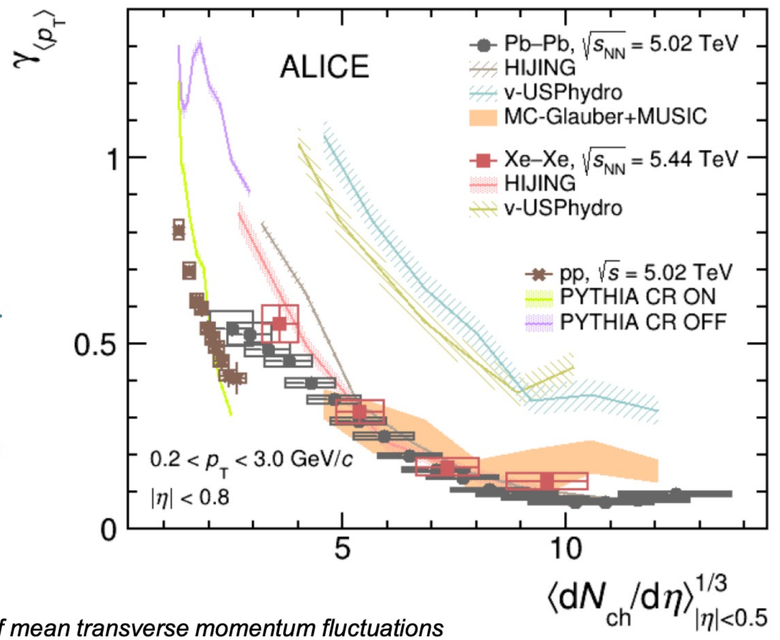


Enhancements between system sizes

ALICE

Skewness and kurtosis of $\langle p_T \rangle$ fluctuations

- Measurements performed in three different collision systems: Pb–Pb, Xe–Xe and pp.
- Common proxy for system size: $\langle \mathrm{d}N_{ch}/\mathrm{d}\eta \rangle^{1/3}_{|\eta|<0.5}$
- Main results for standardized skewness:
  - Positive standardized skewness of $\langle p_T \rangle$ fluctuations in Pb–Pb, Xe–Xe and pp collisions – an essential consequence of hydrodynamic evolution;
  - However, positive skewness of $\langle p_T \rangle$ fluctuations also for small system size – difficult to reconcile with hydro;
  - Hydro model MUSIC with Monte Carlo Glauber initial conditions qualitatively describes skewness;
  - PYTHIA captures qualitatively the same measurements in pp collisions (colour reconnection (CR) mechanism plays a pivotal role).



ALICE Collaboration, *"Skewness and kurtosis of mean transverse momentum fluctuations at the LHC energies"*, Submitted to PLB, 2308.16217

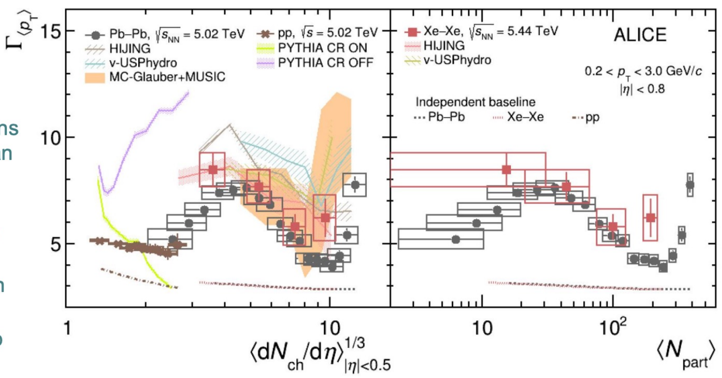
Ante Bilandzic

Enhancements between system sizes

Ante Bilandzic

Skewness and kurtosis of $\langle p_T \rangle$ fluctuations

- Intensive skewness, as a function of system size and N_{part}.
- Main results:
  - Positive intensive skewness of $\langle p_T \rangle$ fluctuations in Pb–Pb, Xe–Xe and pp collisions, larger than the independent baseline;
  - Neither version of PYTHIA (with and without color reconnection mechanism) can describe pp data;
  - Only hydro-based models capture the sudden rise in most central collisions;
  - Non-trivial system size dependence in Pb–Pb and Xe–Xe, monotonic decrease in pp.



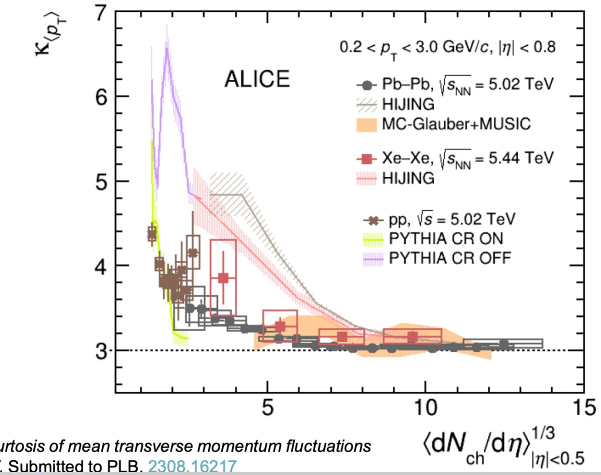
ALICE Collaboration, *"Skewness and kurtosis of mean transverse momentum fluctuations at the LHC energies"*, Submitted to PLB, 2308.16217

Accessing higher point correlators appears as a strong discriminator between models.

This is perhaps expected, they push models beyond their design.

Skewness and kurtosis of $\langle p_T \rangle$ fluctuations

- Kurtosis as a function of system size
- Main results:
  - Kurtosis of $\langle p_T \rangle$ fluctuations in Pb–Pb, Xe–Xe and pp collisions decreases as system size increases;
  - Kurtosis approaches independent Gaussian baseline only in most central collisions;
  - Only PYTHIA with color reconnection can qualitatively describe pp data;
  - MC-Glauber+MUSIC captures Pb–Pb data in most central collisions;
  - HIJING overestimates the data.



ALICE Collaboration, *"Skewness and kurtosis of mean transverse momentum fluctuations at the LHC energies"*, Submitted to PLB, 2308.16217

Event generators for A-A

Guilherme Milhano's 5 lessons

lesson #1

vacuum like jet fragmentation very important driver of how much and how a jet ends up modified

learning about jet quenching from MC requires careful analysis

lesson #2

QGP sees and interacts with constituents of evolving shower

substructure modifications are a powerful tool to understand shower/QGP interaction

learning about jet quenching from MC requires careful analysis

lesson #3

QGP response to traversal by partons is an important component of jets in HI collisions

contribution extremely important for jet substructure

MC essential to identify the physical mechanisms involved in jet quenching

lesson #4

not all observed modifications of HI wrt pp

can be attributed to jet quenching

MC essential to decide what is quenching and what is not

Event generators for A-A

Guilherme Milhano's 5 lessons

lesson #1

vacuur

learni

lesson #2

sis #

QGP res

MC e

lesson #5

MC essential to learn about the QGP with jets

 # learning from scrutiny, not from MC/data agreement #

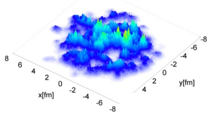
Event generators for A-A

Daniel Pablos Alfonso

Concurrent Mini-jet+Hydro Evolution

Elements of the framework:

Schenke, Tribedy & Venugopalan - PRL '12

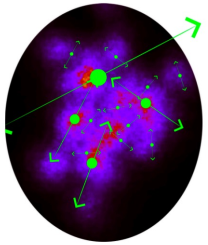


$\tau = 0$

- Initial state from IP-Glasma.
- Finite mini-jet production probability at each binary collision.

$\tau = 0.4\,\mathrm{fm}/c$

- Hydro. energy-momentum from IP-Glasma.
- Mini-jets lose energy to the QGP (Hybrid Model) above T_c :
  - → Gaussian source into hydro. e.o.m.

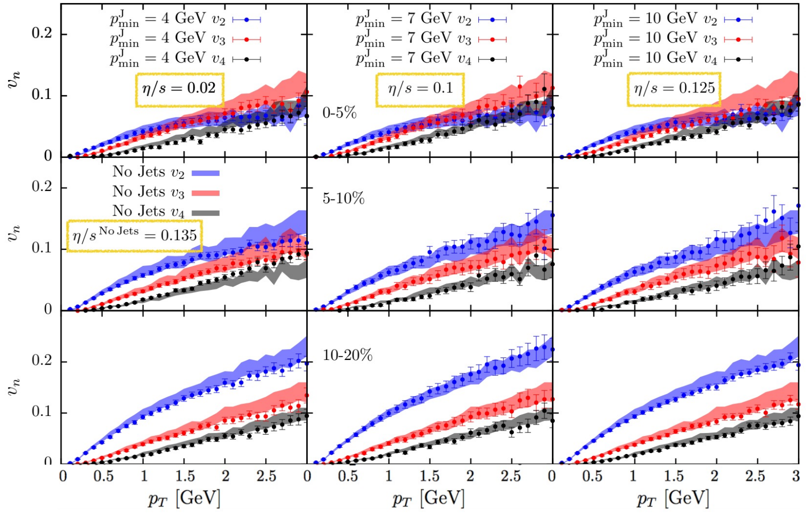


$\tau_{\text{freeze-out}}$

- Cooper-Frye bulk.
- Hadronize non-stopped partons through Lund string model:
  - → If parton close to hypersurface, sample thermal partons to build colourless string.
  - → If not, construct single colourless string with all such "corona" partons.
- Everything evolves with UrQMD.

DP, Singh, Gale, Jeon - 2202.03414

Impact on η/s extraction



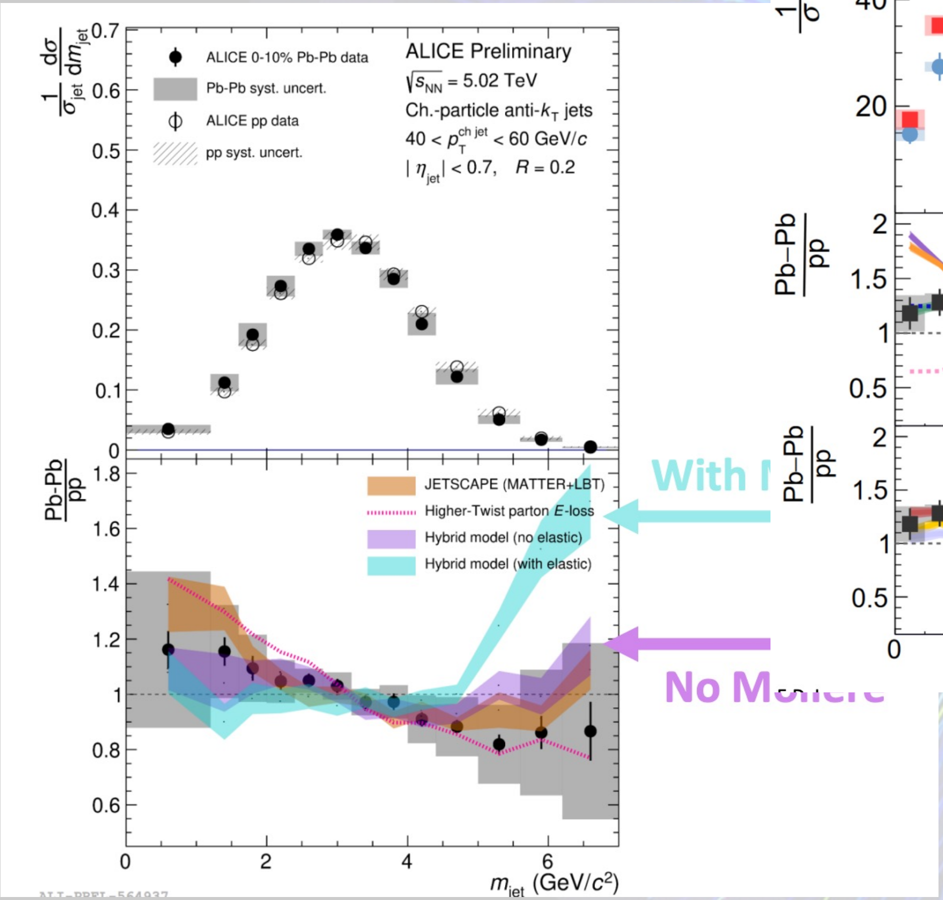
- Quite different viscosities needed to get the same flow strength depending on mini-jets abundance.
- Single rescaling of viscosity absorbs differences in differential v_2, v_3 and v_4.

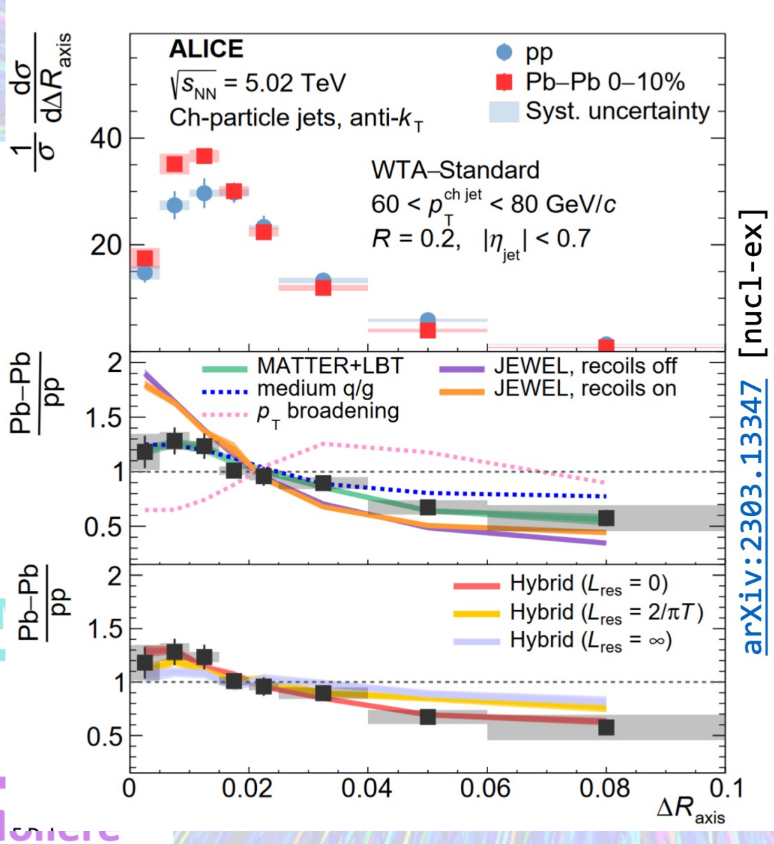
DP, Singh, Gale, Jeon - 2202.03414

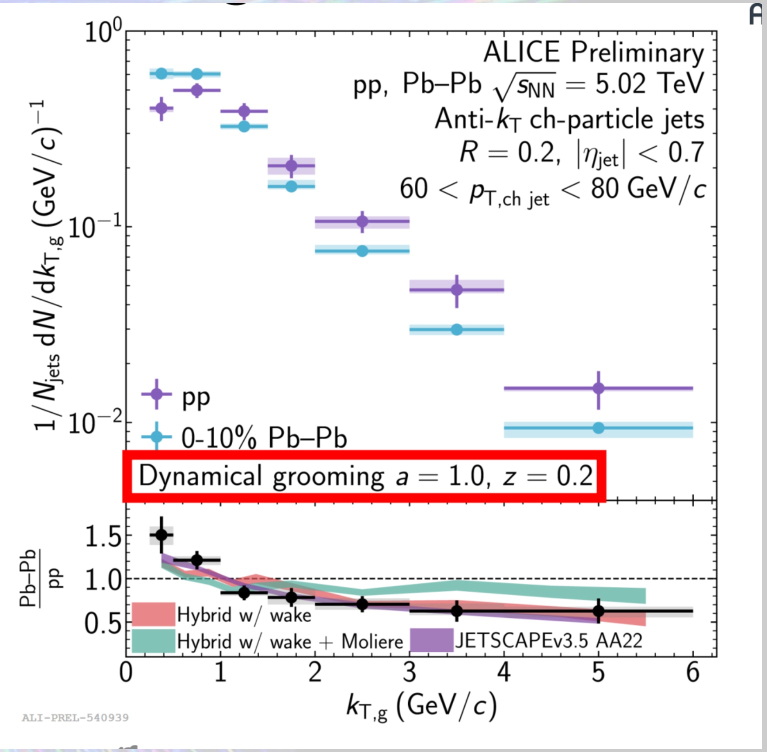
An example of complicating phenomena in the shower models, mini-jets…

Jet Quenching

Ezra Lesser





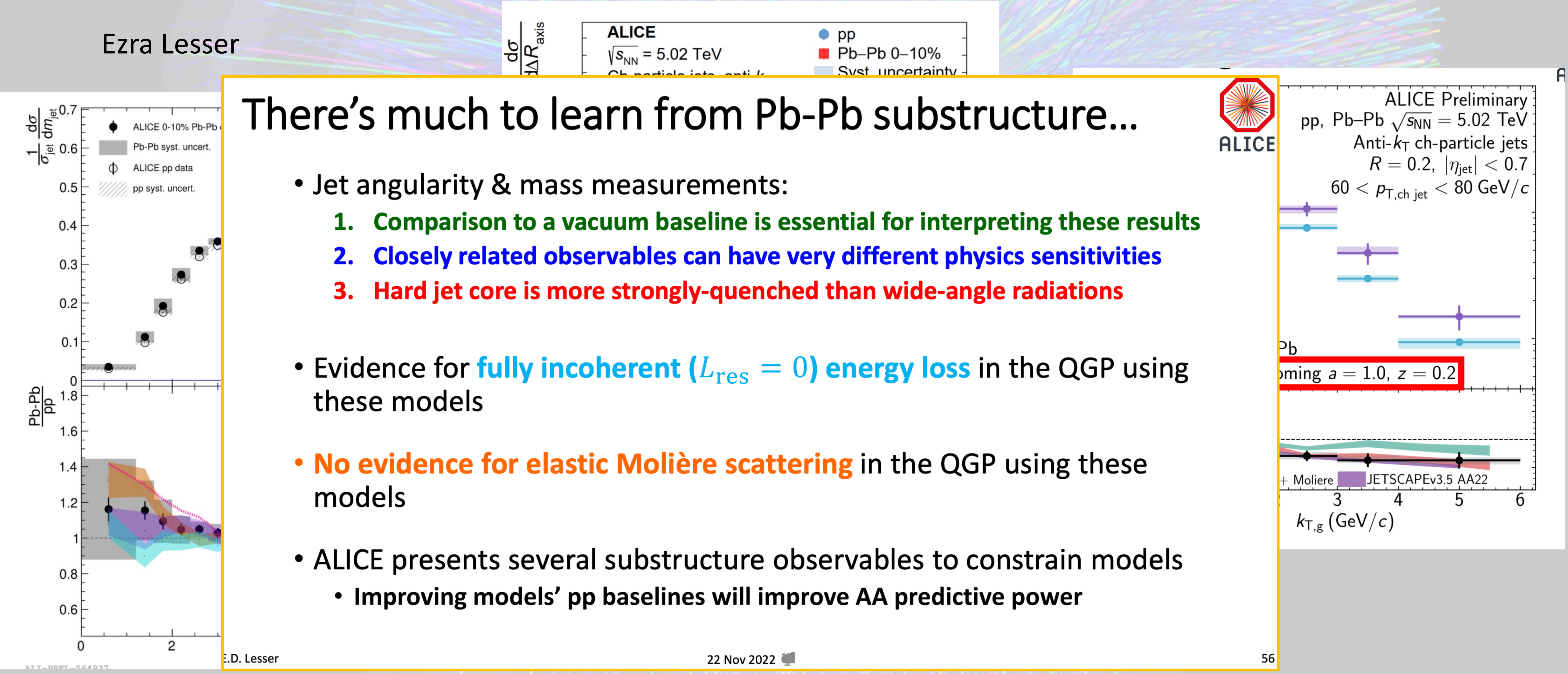


With Moliere

No Moliere

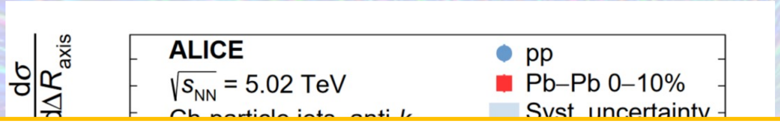
Jet Quenching

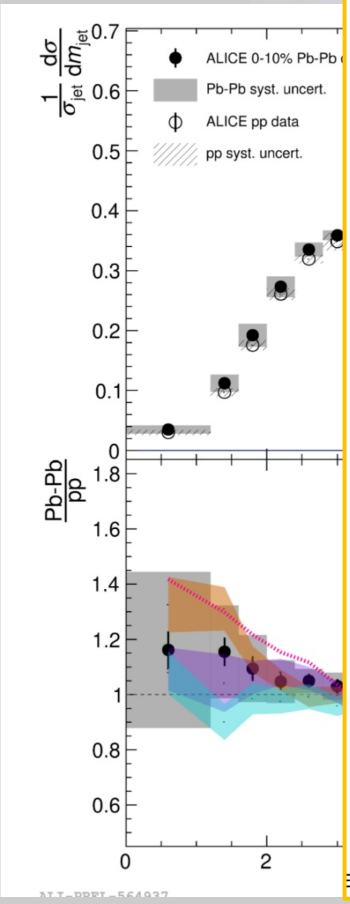
Ezra Lesser

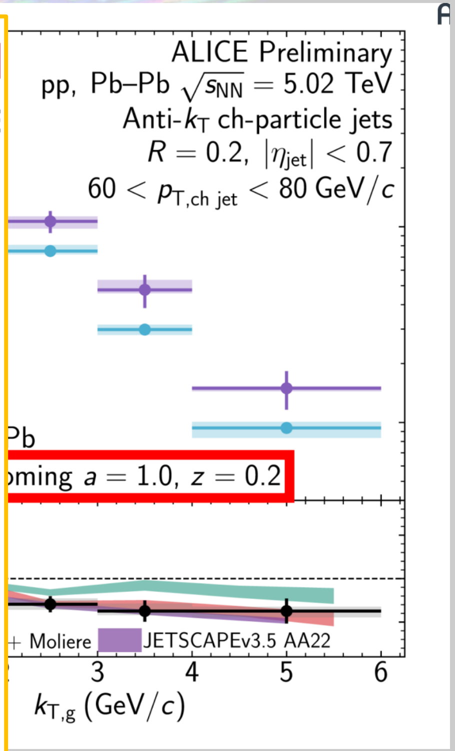


Jet Quenching

Ezra Lesser



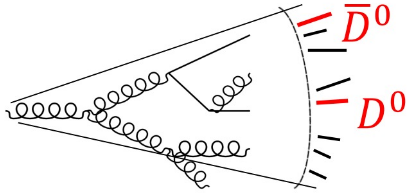




There's much to learn from Pb-Pb substructure…

- Jet angularity & mass measurements:
  1. **Comparison to a vacuum baseline is essential for interpreting these results**
  2. **Closely related observables can have very different physics sensitivities**
  3. **Hard jet core is more strongly-quenched than wide-angle radiations**
- Evidence for **fully incoherent ($L_{res} = 0$) energy loss** in the QGP using these models?
- **No evidence for elastic Molière scattering** in the QGP using these models?
- ALICE presents several substructure observables to constrain models
  - **Improving models' pp baselines will improve AA predictive power**

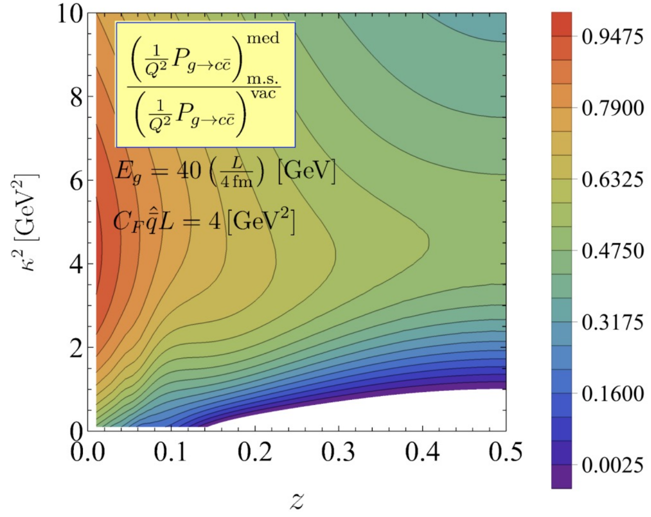
Jet Quenching – new observables

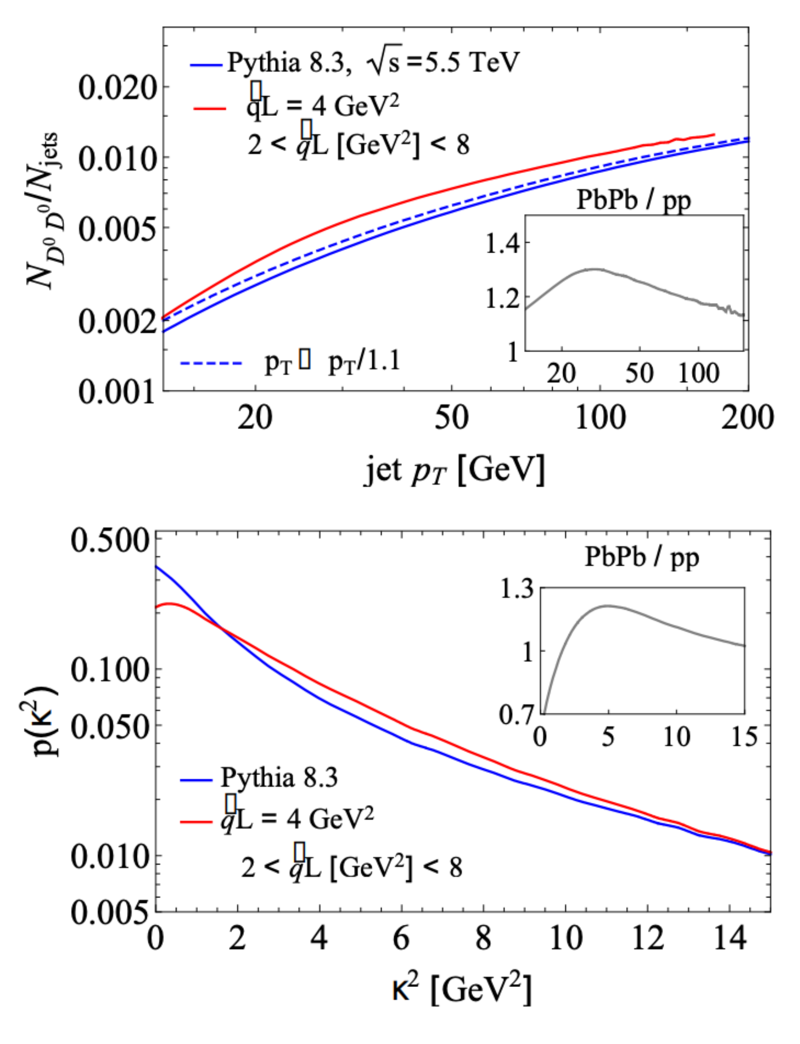


Get kinematics of g → $c\bar{c}$

Reweight each splitting by

$$w^{med}_{g\to c\bar{c}}(E_g, k_c^2, z) = 1 + \frac{\left(\frac{1}{Q^2}P_{g\to c\bar{c}}\right)^{\text{med}}(E_g, k_c^2, z)}{\left(\frac{1}{Q^2}P_{g\to c\bar{c}}\right)^{\text{vac}}(k_c^2, z)}$$



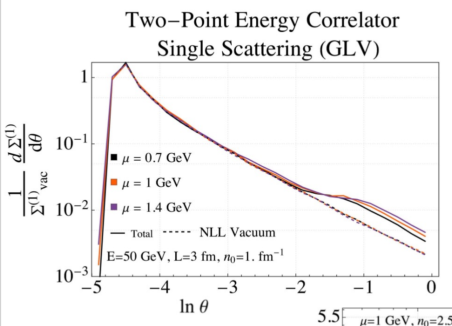


Jasmine Brewer

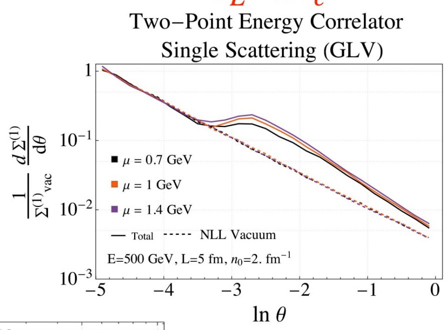
Jet Quenching – new observables

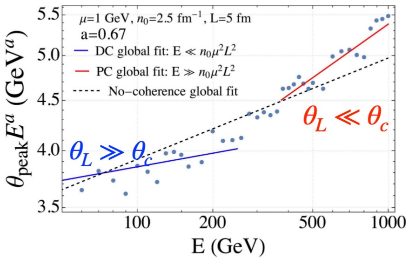
Results GLV

$\theta_L \gg \theta_c$



$\theta_L \ll \theta_c$



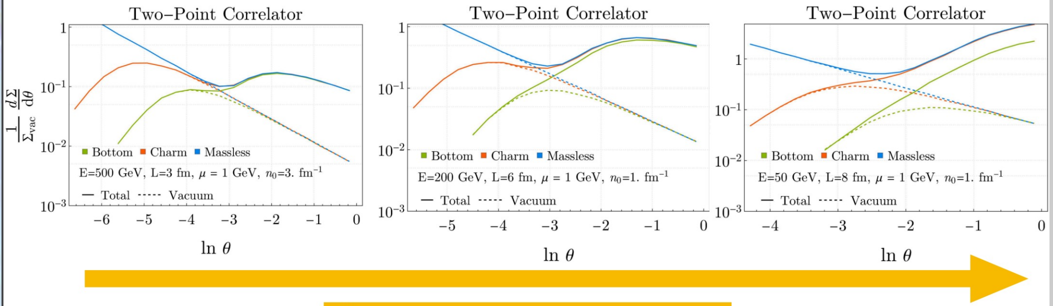


GLV calculation from: Ovanesyan, Vitev, 1109.5619

Coherence transition not as clearly observed **as** in the **multiple scattering** case

Carlota Andres

HF jets: filling the dead-cone



$\frac{\theta_L}{\Theta_0} \to 1$: Filling the dead-cone

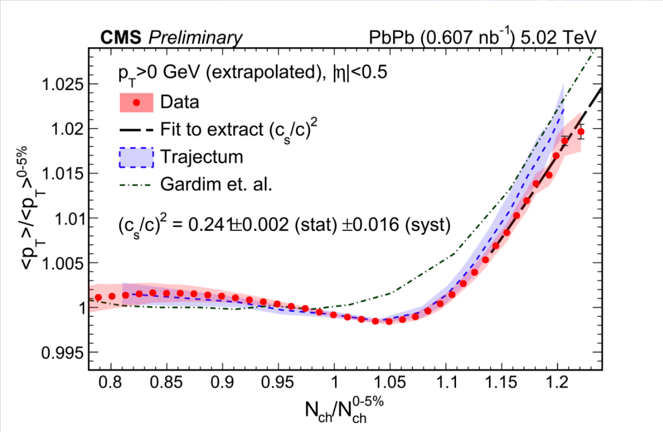
Armesto, Salgado, Wiedemann, arXiv: hep-ph/0312106

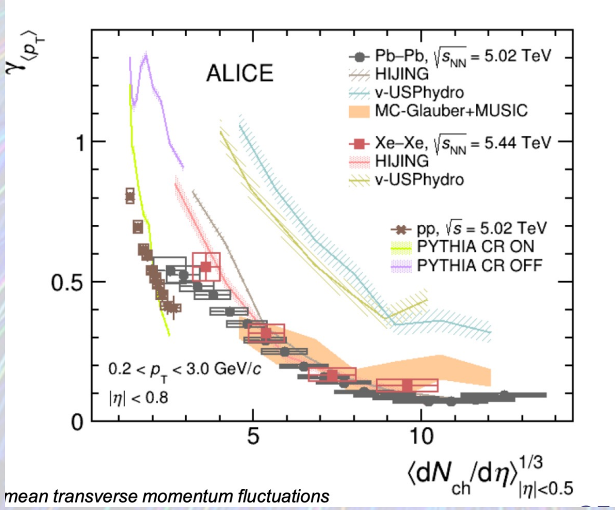
EEC sensitive to the **dead-cone and its medium modifications**

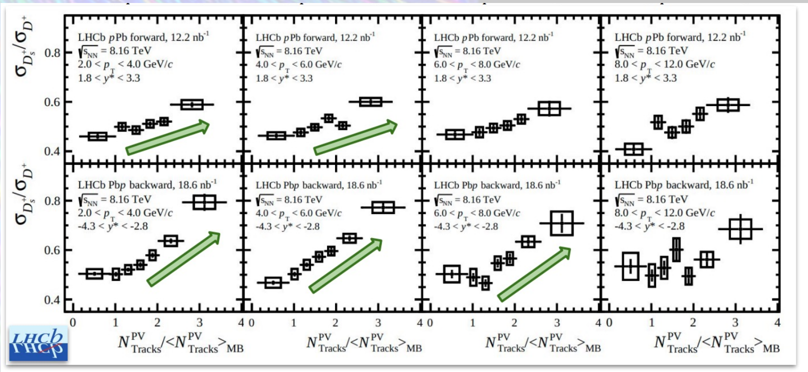
CA, Dominguez, Holguin, Marquet, I. Moult, 2307.15110

Overall observations

- We now have extensive lists of measured observables in nucleon collisions. Some give insight, some are overwhelmingly inclusive…
  - Successful observables are typically simple in at least either analysis or theoretical motivation.
  - Successful observables often give trivial ‘null’ results in pp.
  - For these simple observables, careful ratios are our friends.

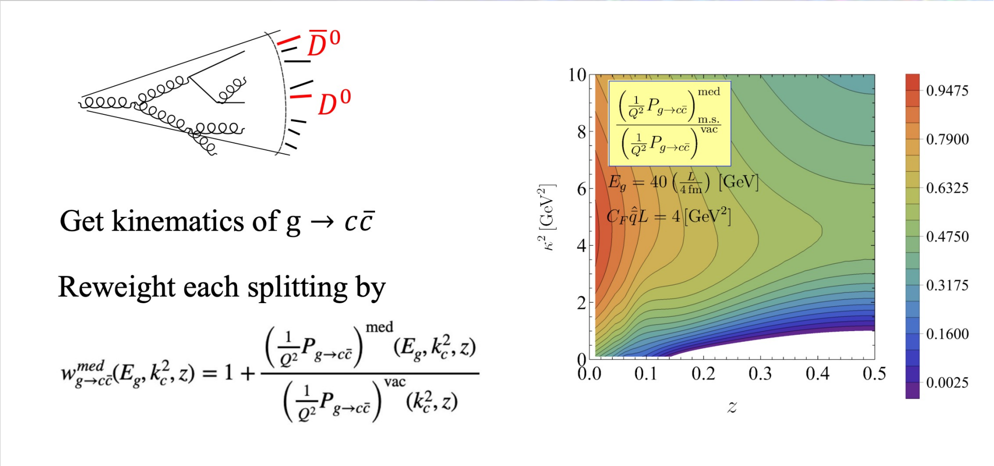


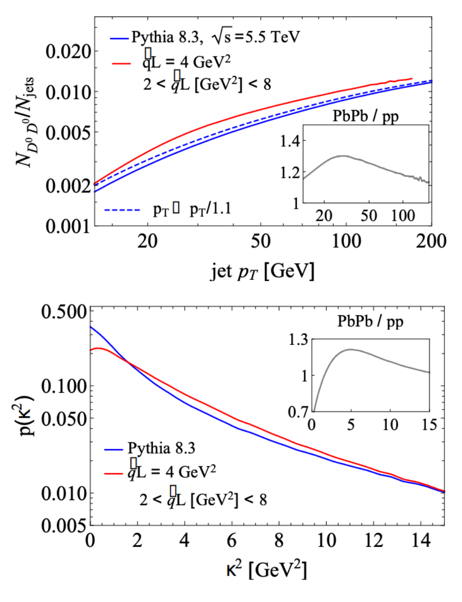


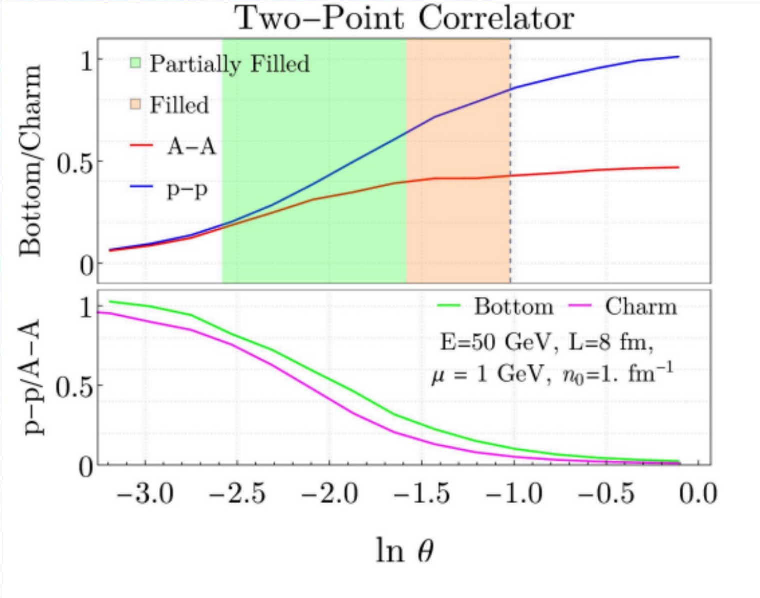


Overall observations

- We now have extensive lists of measured observables in nucleon collisions. Some give insight, some are overwhelmingly inclusive…
  - Successful observables are typically simple in at least either analysis or theoretical motivation.
  - Successful observables often give trivial ‘null’ results in pp.
  - For these simple observables, careful ratios are our friends.

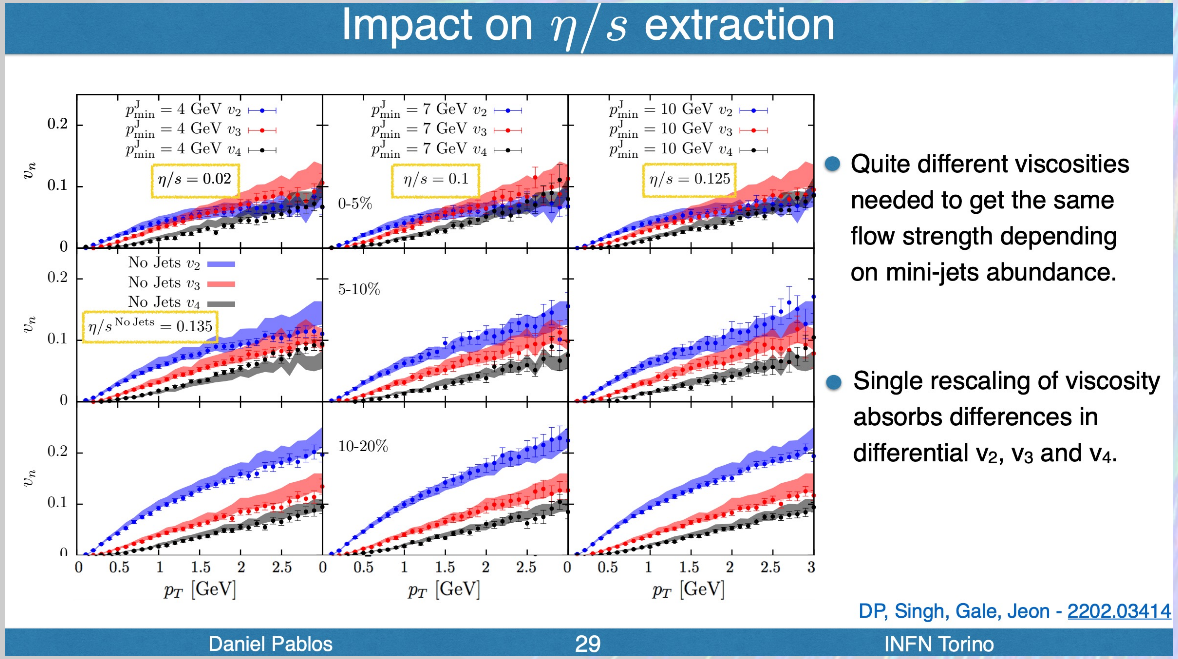






Overall observations

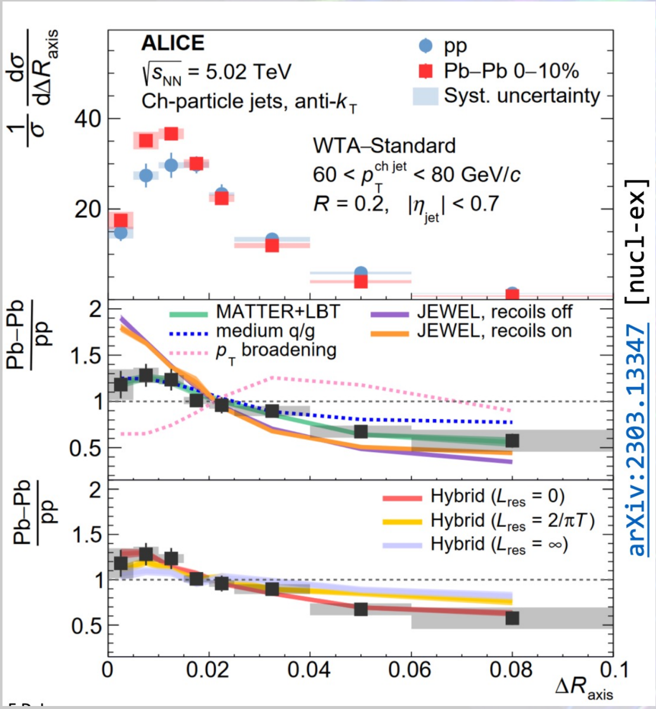
- We should be very careful to understand the physics models before drawing conclusions.
  - Remember Guilherme's lessons



Very different physical processes can easily have overlapping signals in our benchmark observables.

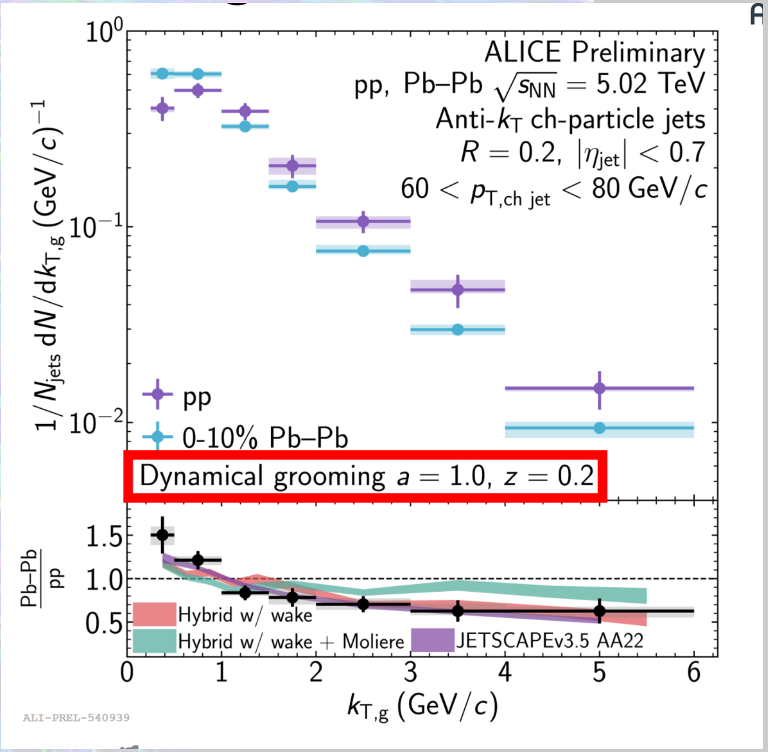
Overall observations

- We should be very careful to understand the physics models before drawing conclusions.
  - Remember Guilherme's lessons



- Evidence for **fully incoherent ($L_{res} = 0$) energy loss** in the QGP using these models
- **No evidence for elastic Molière scattering** in the QGP using these models

These statements on JETSCAPE or physics?

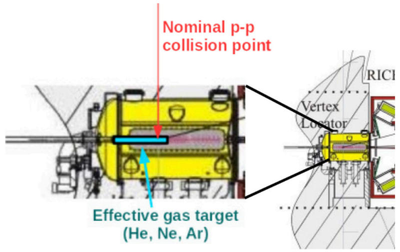


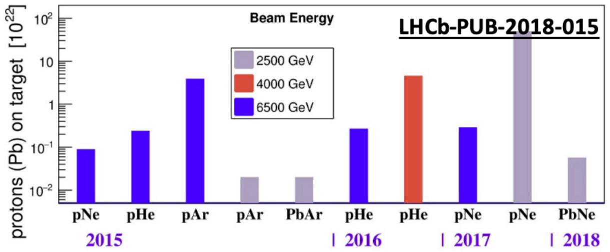
Overall observations

- I think links to 'core' physics and physics outside of collider applications are great.

LHCb fixed-target programme

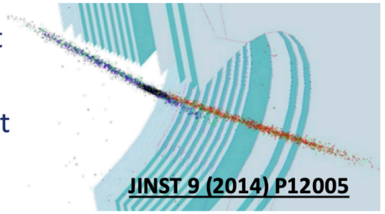
- The *System for Measuring Overlap with Gas* (SMOG) can inject gas in LHC beam pipe around (±20 m) the LHCb IP.
- Originally conceived for precise luminosity measurements through **Beam-Gas Imaging**.
- For machine safety, **only noble gases** with a maximum pressure of **2×10^{-7} mbar** (x100 nominal LHC vacuum) can be injected → Luminosity: $\mathcal{L}\sim\mathcal{O}(10^{29}\ cm^{-2}s^{-1})$.





Since 2015, exploited for LHCb fixed-target physics programme

→ Collected physics samples with different targets and different centre of mass energies.



Unique opportunities at the LHC:

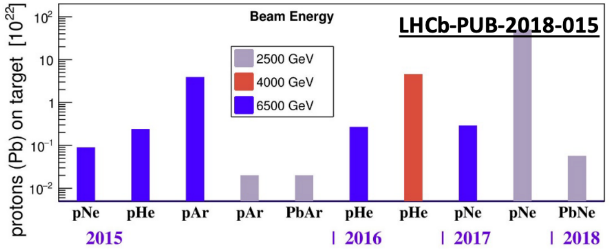
- Collisions with **targets of mass number A intermediate** between p and Pb → **Reproduce CR interactions (*pp*, *p*He)**
- **Energy range** $\sqrt{s_{NN}} \in [30, 115]$ GeV for beam energy in $[0.45, 7]$ TeV → **Unexplored gap** between SpS and LHC/RHIC.

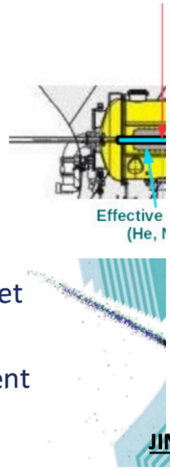
Overall observations

- I think links to ‘core’ physics and physics outside of collider applications are great.

LHCb fixed-target programme

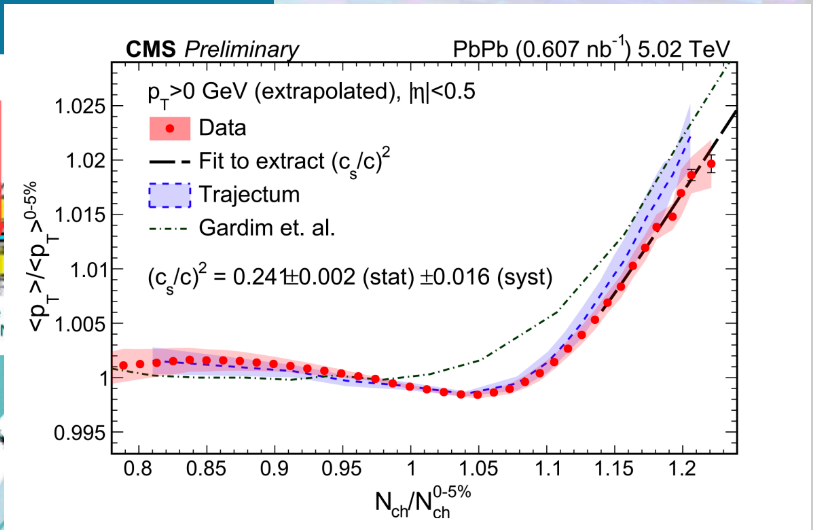
- The *System for Measuring Overlap with Gas* (**SMOG**) can inject gas in LHC beam pipe around (±20 m) the LHCb IP.
- Originally conceived for precise luminosity measurements through **Beam-Gas Imaging**.
- For machine safety, **only noble gases** with a maximum pressure of **2×10^{-7} mbar** (x100 nominal LHC vacuum) can be injected → Luminosity: $\mathcal{L} \sim \mathcal{O}(10^{29}\ cm^{-2} s^{-1})$.





Since 2015, exploited for LHCb fixed-target physics programme

→ Collected physics samples with different targets and different centre of mass energies.



Unique opportunities at the LHC:

- Collisions with **targets of mass number A intermediate** between p and Pb → **Reproduce CR interactions (*pp*, *pHe*)**
- **Energy range** $\sqrt{s_{NN}} \in [30, 115]$ GeV for beam energy in $[0.45, 7]$ TeV → **Unexplored gap** between SpS and LHC/RHIC.

(Hard) Questions for the future

- What core physics can we access in nuclei collisions?

- What do we need to do to meaningfully attribute observations to fundamental physics, rather than models?

(Answer… sometimes maybe more than is currently possible?)

- Can we identify more observables in pp which could provide ideal baselines for pA or AA collisions?

Final Questions and Discussion

Thank you for coming to Manchester for MPI@LHC