Hard probe path lengths and event-shape engineering of the quark-gluon plasma

Govert Nijs

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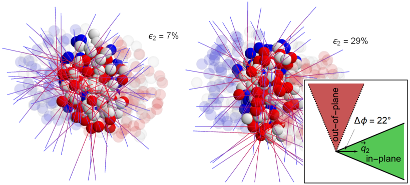
Based on:

- Beattie, GN, Sas, van der Schee, 2203.13265

Motivation

- Hard probes lose energy while traversing the QGP.
- Energy loss depends on path length.
- Can we make this cartoon a bit more quantitative?

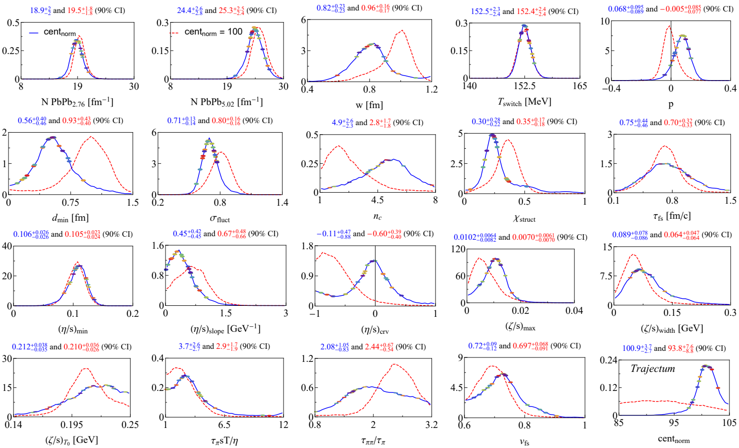


Trajectum

- New heavy ion code developed in Utrecht/MIT/CERN.
- Contains initial state, hydrodynamics and freeze-out, as well as an analysis suite.
- Easy to use, example parameter files distributed alongside the source code.
- Fast, fully parallelized.
- Publicly available at `sites.google.com/view/govertnijs/trajectum/`

[GN, van der Schee, Gürsoy, Snellings, 2010.15130; 2010.15134]

Parameters used: MAP values from Bayesian analysis



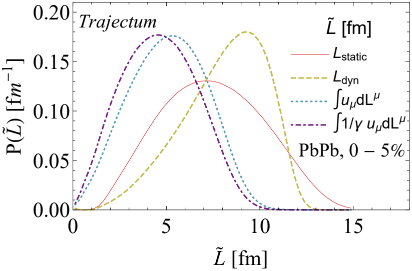
[GN, van der Schee, 2110.13153]

Different path length measures

- L_{static} is the distance from the probe origin to the freeze-out surface at $\tau = \tau_{\text{fs}}$.
- L_{dyn} is the same distance, but measured along a lightlike path.
- $\int u_\mu dL^\mu$ takes the fluid velocity into account.
- $\int T^\alpha/\gamma u_\mu dL^\mu$ also takes time dilation and hotspots into account.
- $\int T^3/\gamma u_\mu dL^\mu$ is what is expected up to $\mathcal{O}(v^2)$ assuming probes do not change direction.

Several different pathlength measures

- $L_{\rm dyn}$ has a ‘cliff’ at $\tau \sim 11$ due to the lifetime of the QGP.
- Velocity- and temperature-dependent measures are considerably smaller.



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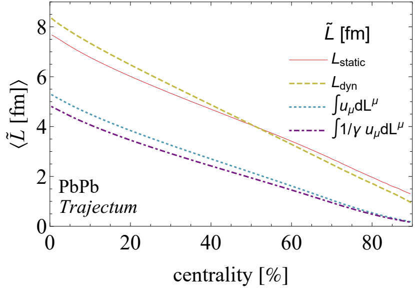
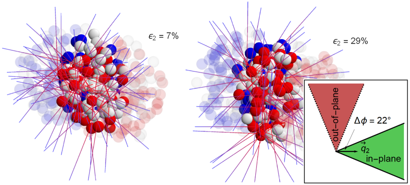


Event shape engineering

- For each event, we compute $q_2 = \left|\sum_{i=1}^{M} e^{2i\varphi}\right| / \sqrt{M}$, which measures how elliptical the particle distribution is.



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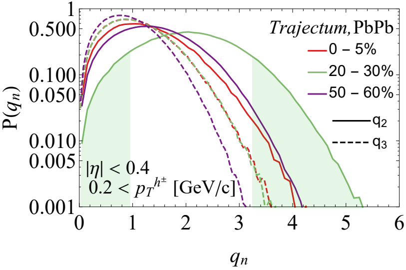
- We then select the 10% lowest or highest q_2 values in each centrality bin.



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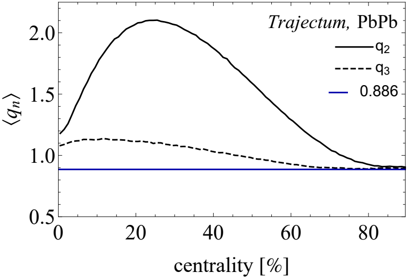
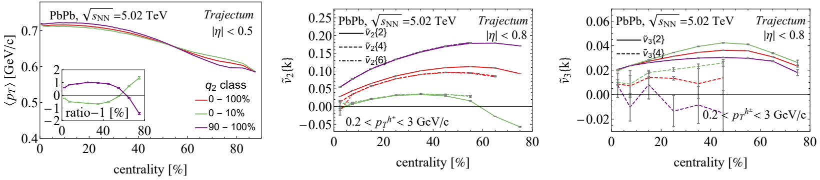
- q_2 has a mild but important dependence on centrality: must use narrow centrality bins.



Soft observables



- High q_2 leads to high $v_2\{2\}$ as expected.
- ESE selected $v_2\{4\}$ and $v_2\{2\}$ are close together, indicating a narrow range of underlying v_2.
- ESE selected $\langle p_T \rangle$ is in agreement with $\rho(v_2\{2\}^2, \langle p_T \rangle)$.
- ESE selected $v_3\{2\}$ shows a negative correlation between v_2 and v_3, in agreement with $SC(3,2) < 0$.

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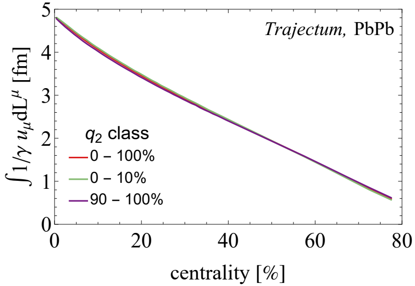
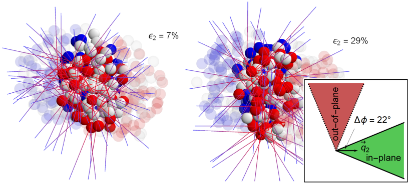
ESE selected path length

- Path length does not change when selecting on q_2 alone.
- Something else is needed.



In-plane vs. out-of-plane probes

- q_2 can also be given a direction.
- We define probes with azimuthal angle difference $\Delta\varphi < 22^\circ$ as being in-plane.
- Out-of-plane probes are defined analogously.
- We expect the average path length to be shorter in-plane than out-of-plane.



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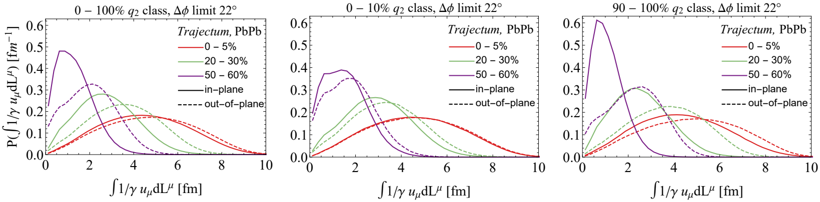
Path length distributions



- Indeed path length is on average shorter in-plane than out-of-plane.
- ESE can enlarge these differences when selecting the largest q_2 values.
- For central collisions, the smallest q_2 remove differences almost completely.

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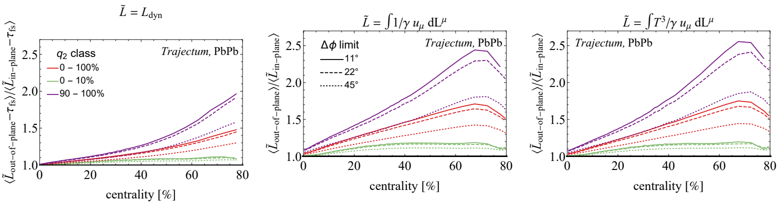
Out-of-plane to in-plane average path length ratio



- ESE can increase the path length differences by a factor 2.
- Choosing the $\Delta\varphi$ limit to be 22° instead of 45° gains another factor 2, but decreasing to 11° yields little gain.
- Larger path length differences for $\int T^\alpha/\gamma u_\mu dL^\mu$ than for $L_{\rm dyn}$.
- See also QM talk by Caitlin Beattie `https://indico.cern.ch/event/895086/contributions/4715857/`.

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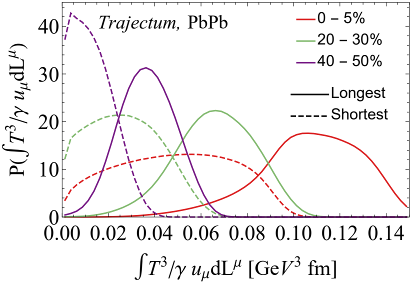
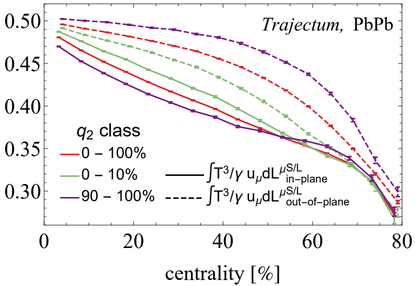
Back-to-back probes

- We can also produce probes back-to-back.
- We then show the longest and shortest path of each pair separately.



Adding ESE and in-/out-of-plane selection

- We show the average path length ratio of shortest over longest.
- Selecting in-plane pairs can decrease the ratio.
- Selecting elliptical events further decreases the ratio.



Conclusions and outlook

Conclusions:

- In-plane probes have a smaller average path length than out-of-plane probes.
- Choosing a $\Delta\varphi$ limit of 22° gives a larger path length difference compared to 45°, by a factor of 2.
- Selecting high q_2 events enhances this difference by a further factor of 2.
- In back-to-back probes event plane selections and event shape engineering can decrease the path length ratio between the pair.

Outlook:

- Implementing a full parton shower in *Trajectum*.

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