The Plasma and The Spectrum

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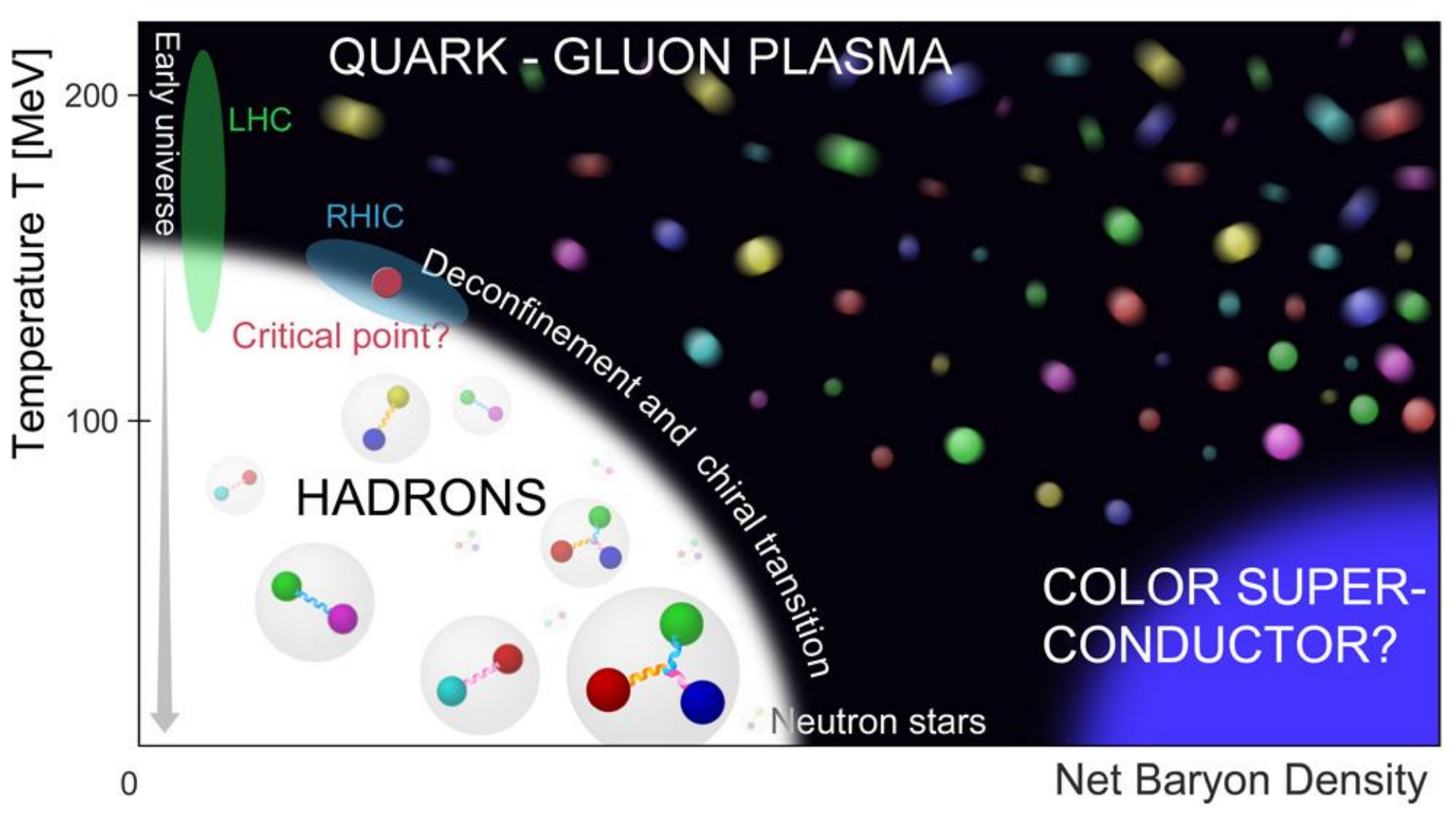
Nordic Winter School 2019


QUARK - GLUON PLASMA
Early universe
LHC
RHIC
Deconfinement and chiral transition
Critical point?
HADRONS
COLOR SUPER-
CONDUCTOR?
Neutron stars
Temperature T [MeV]
200
100
0
Net Baryon Density

Relativistic **H**eavy-**I**on **C**ollider

➔ Au+Au at $\sqrt{s_{NN}}$ = 200GeV;

2005 Announcement:

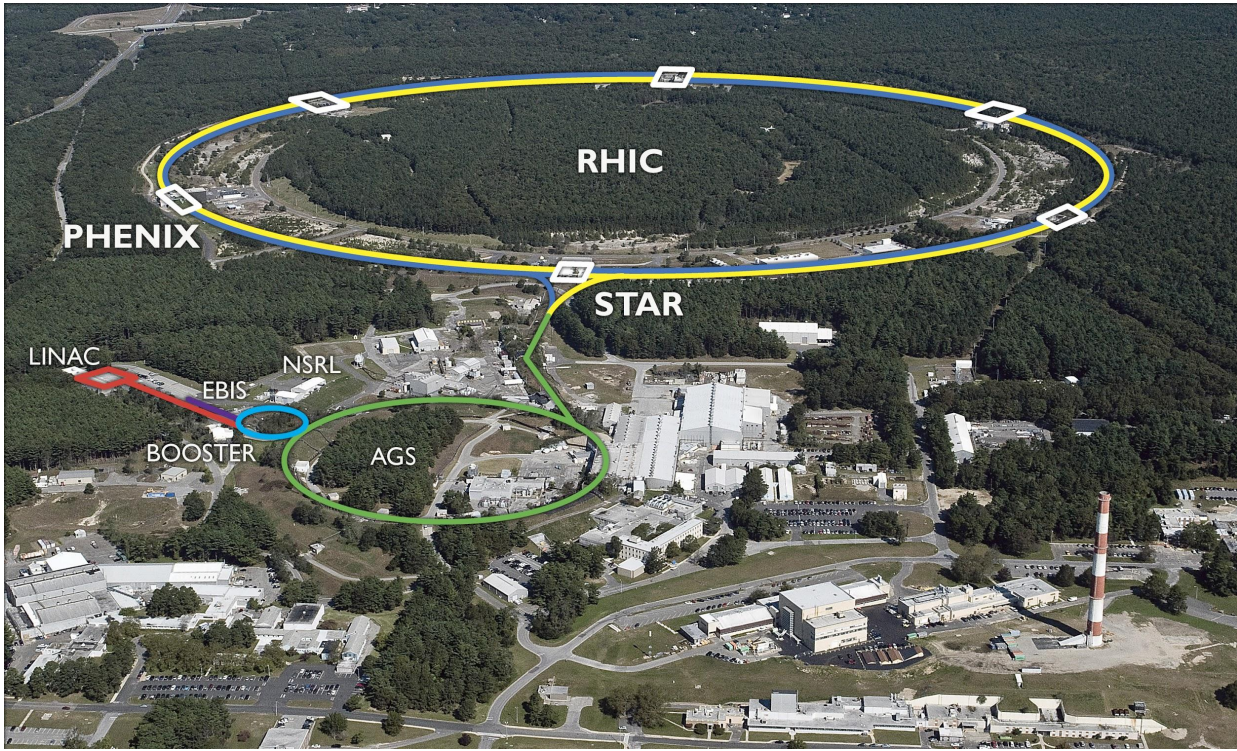
Quark **G**luon **P**lasma is created!

Evidence:

➔ Jet-quenching;
➔ Collective flow(?);

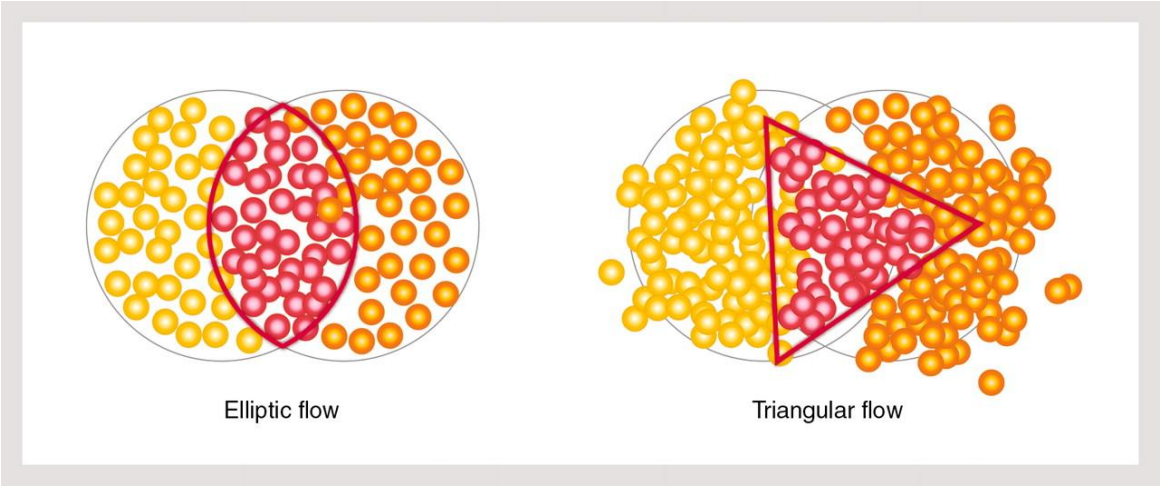
⬇

Anisotropies in emitted particles!



➔ Geometry of initial overlapping region propagates to the final state: **medium expands collectively;**

QGP as a low-viscosity fluid!

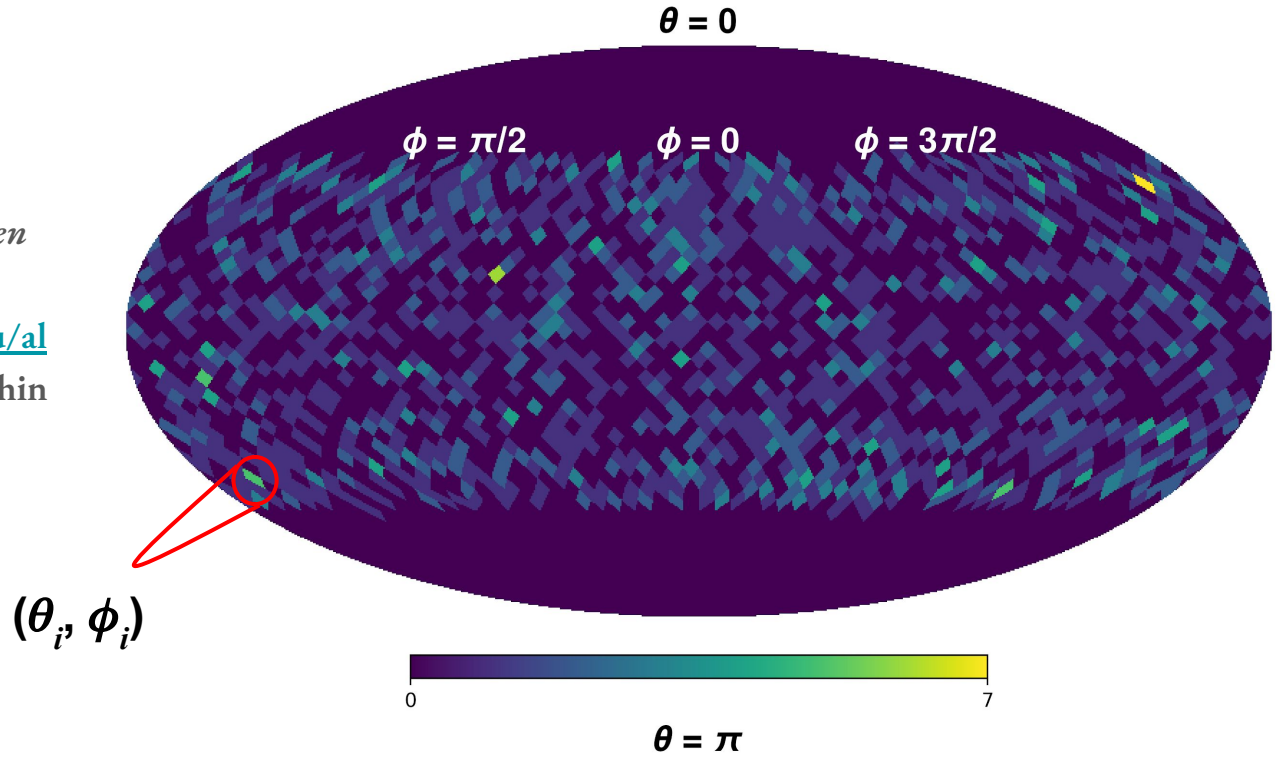


➔ Azimuthal correlations:

- Hydrodynamic nature of the medium;
- Transport coefficients;
- Fluctuations in initial state.

$$f(\phi) = \frac{1}{2\pi}\left[1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\phi - \psi_n))\right]$$

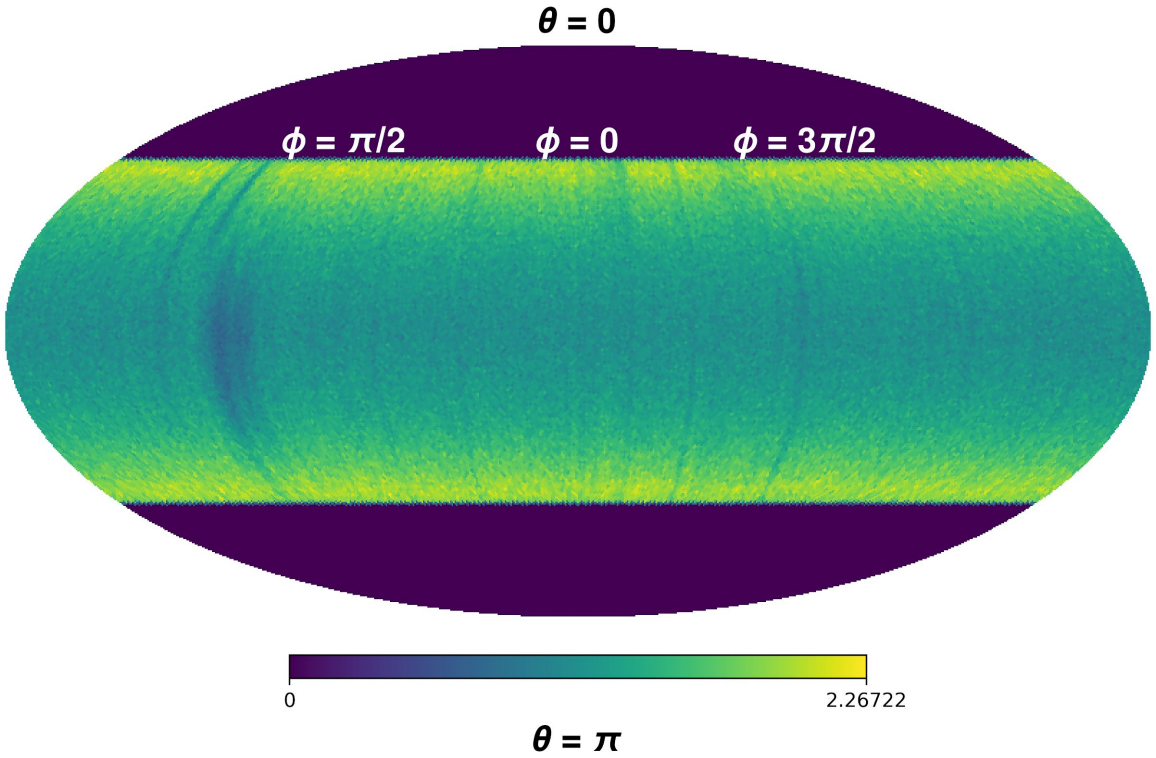
- Mapping particles: particle correlations on a sphere;
- ALICE data from *CERN Open Data portal* [extracted with https://github.com/cbourjau/alice-rs] at $\sqrt{s_{NN}} = 2.76TeV$ within $|\eta| < 0.9$;
- $\eta = -\log[\tan(\theta/2)]$;
- 10-15% centrality.



$$f(\theta,\phi) = \sum_{l=0}^{\infty} \sum_{m=-l}^{l} a_{lm} Y_{lm}(\theta,\phi)$$

First consideration:

Detector anisotropies!



➔ Superpose all event maps from 10-15%: $F^{all}(\theta, \phi)$;

➔ $f(\theta, \phi) \rightarrow \bar{f}(\theta, \phi) = f(\theta, \phi)/F^{all}(\theta, \phi)$;

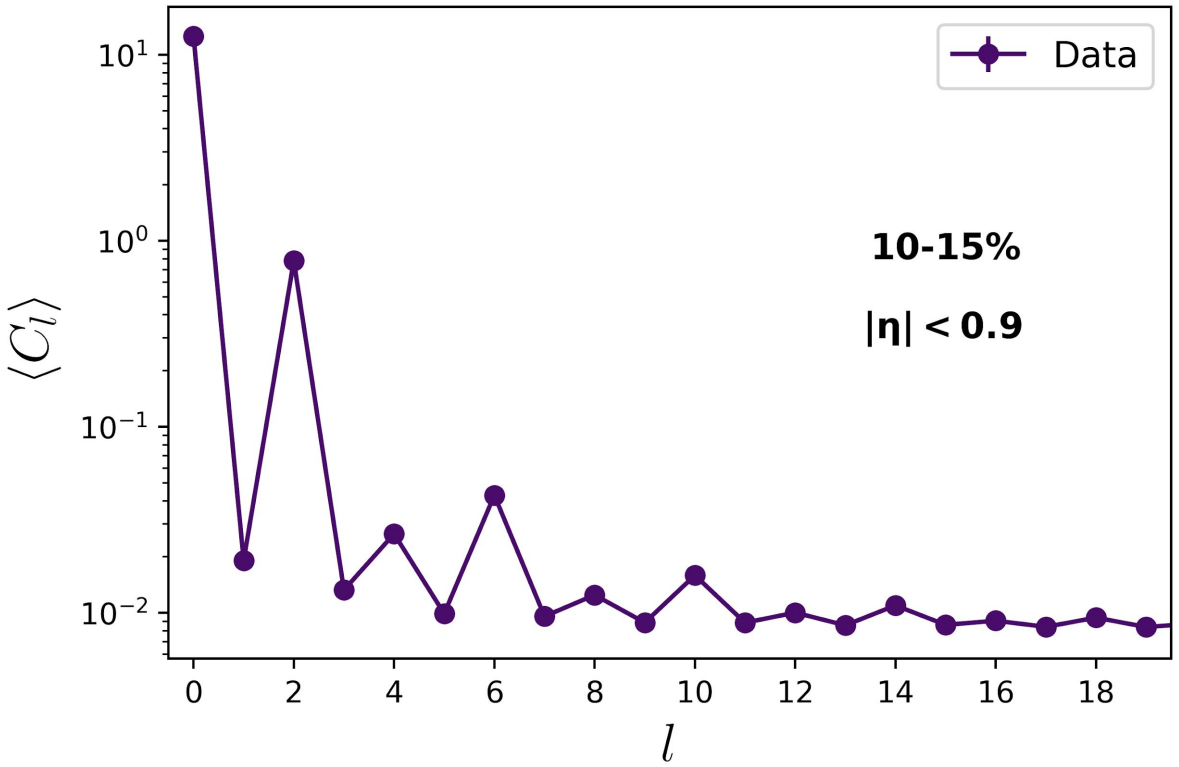
$$\bar{f}(\theta,\phi) = \sum_{l=0}^{\infty} \sum_{m=-l}^{l} \bar{a}_{lm} Y_{lm}(\theta,\phi) \quad \Rightarrow \quad C_l = \frac{1}{2l+1} \sum_{m=-l}^{m=l} |\bar{a}_{lm}|^2$$

➔ Calculate C_l for each event and take the average over them all;

Seemingly special features:

➔ Enhanced even modes relative to odd ones;
- ♦ Symmetry.

➔ Suppressed $l = 4n$, for $n > 0$;

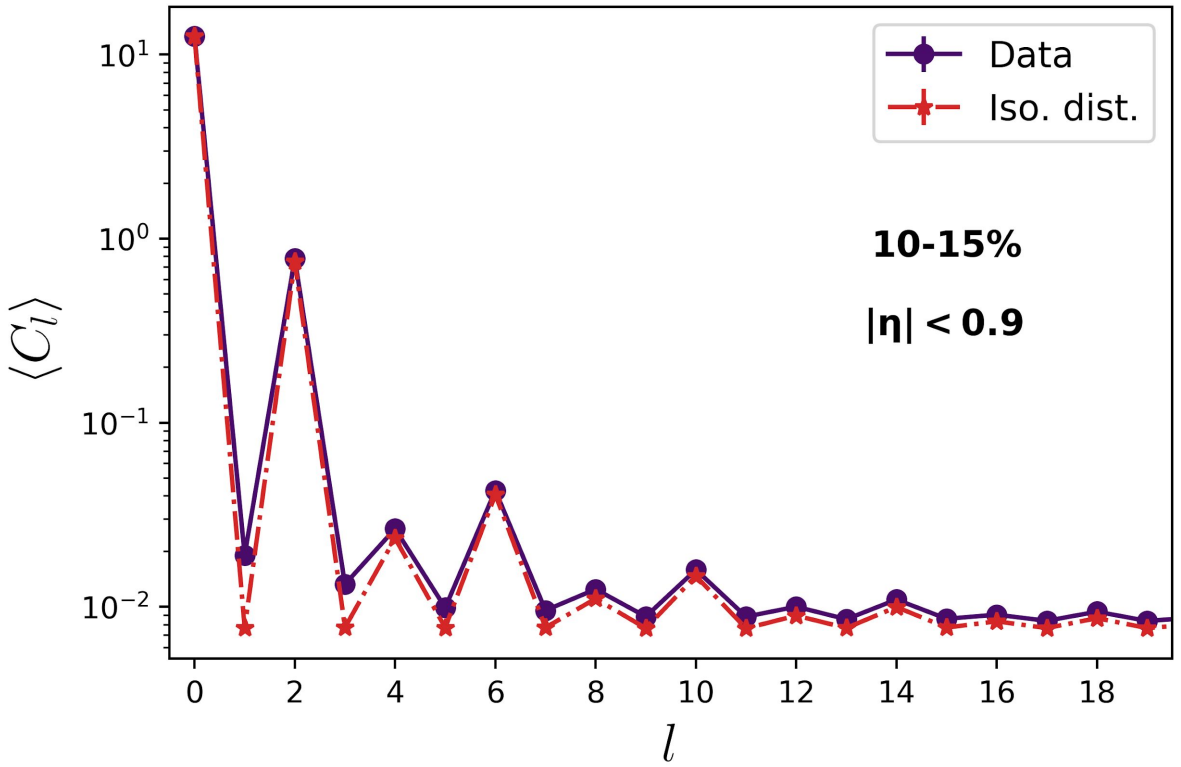


Second consideration:

Detector's limited coverage!

- ➔ Create isotropic distributions with same multiplicities as data events within $|\eta| < 0.9$;
- ➔ All a_{l0} coefficients survive!

$$C_l \overset{m \neq 0}{=} \frac{1}{2l+1}\left(\sum_{m=-l}^{m=l} |a_{lm}|^2 - |a_{l0}|^2\right)$$

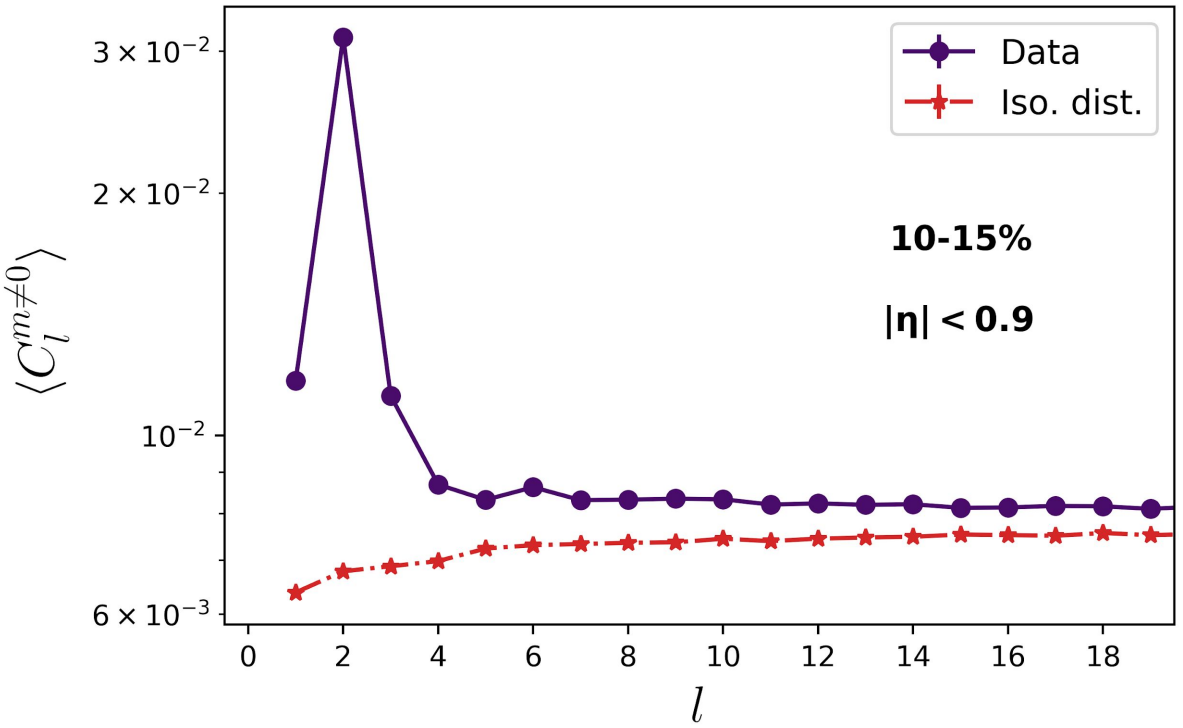


Strong C_2 signal!

- ➔ $l = 1, 3, 4, 6$;
- ➔ Could be related to collective flow;
  - ♦ QGP as fluid!

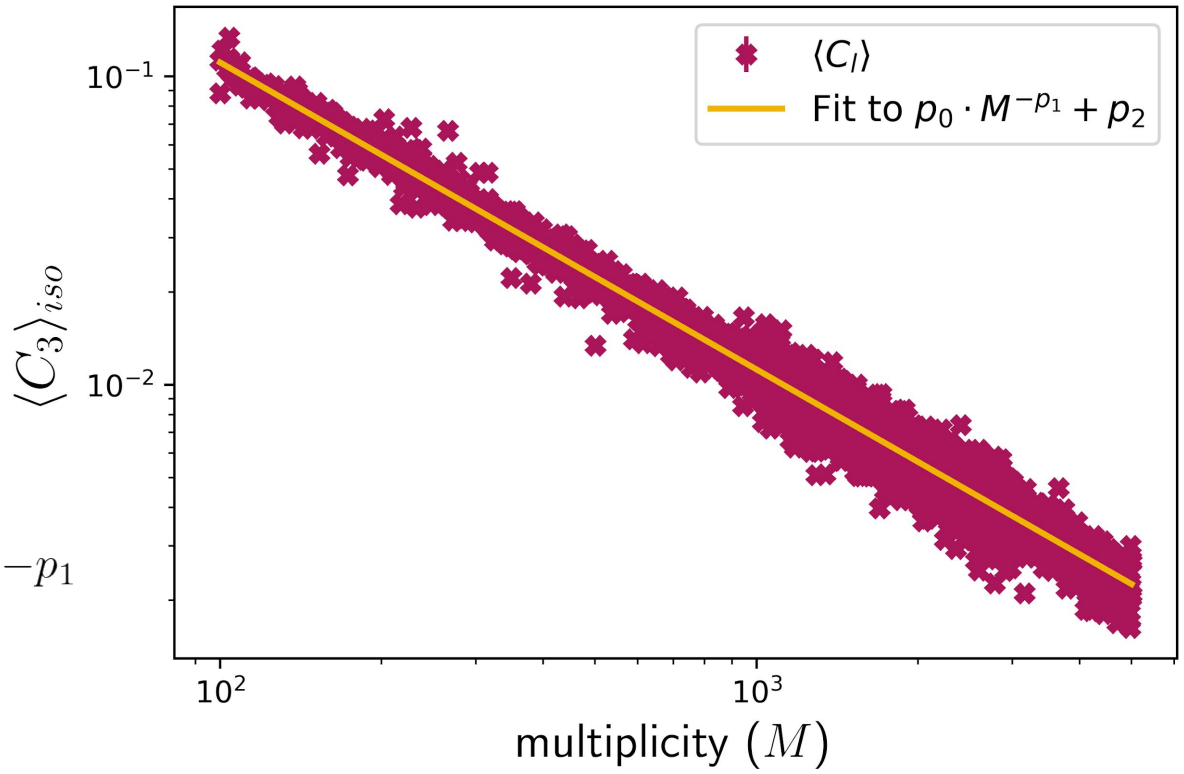
Third consideration:

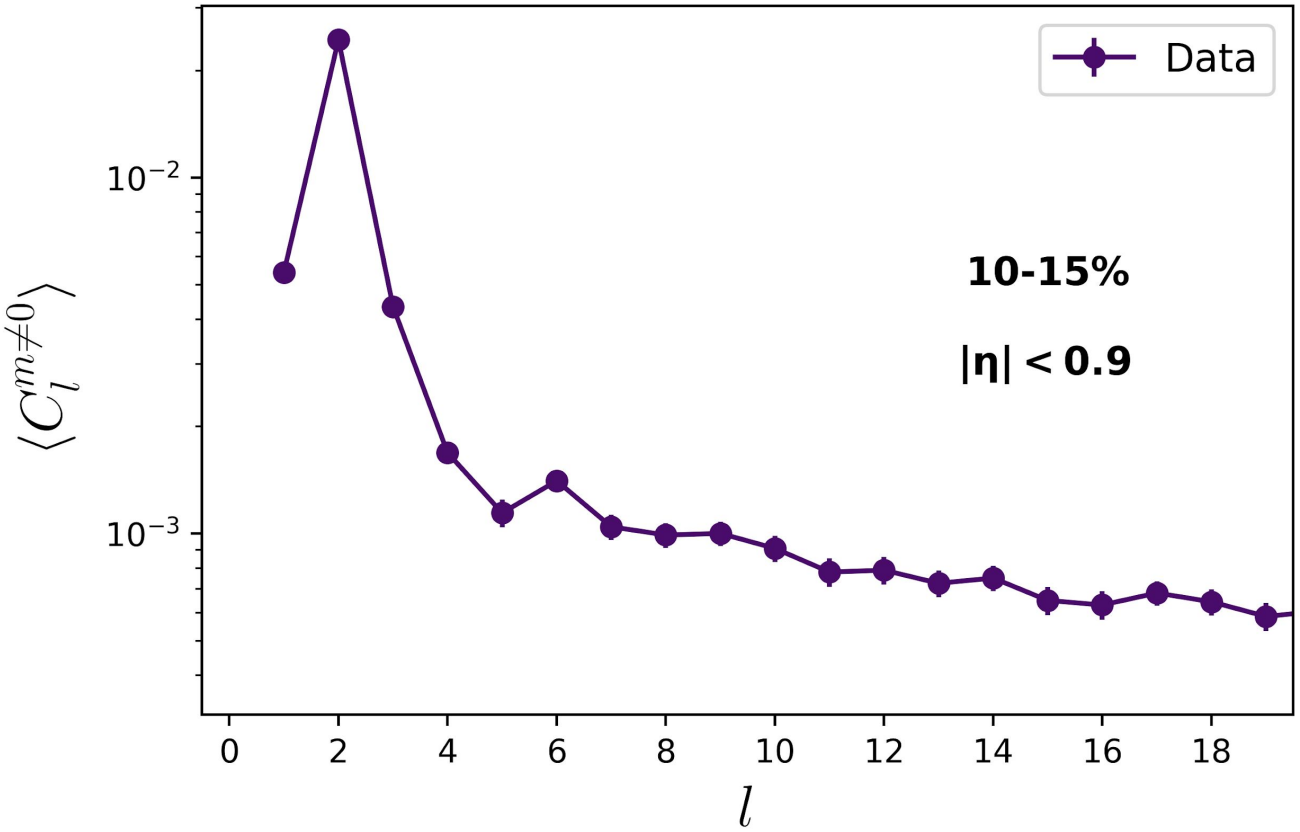
Sparsity and pixelation!



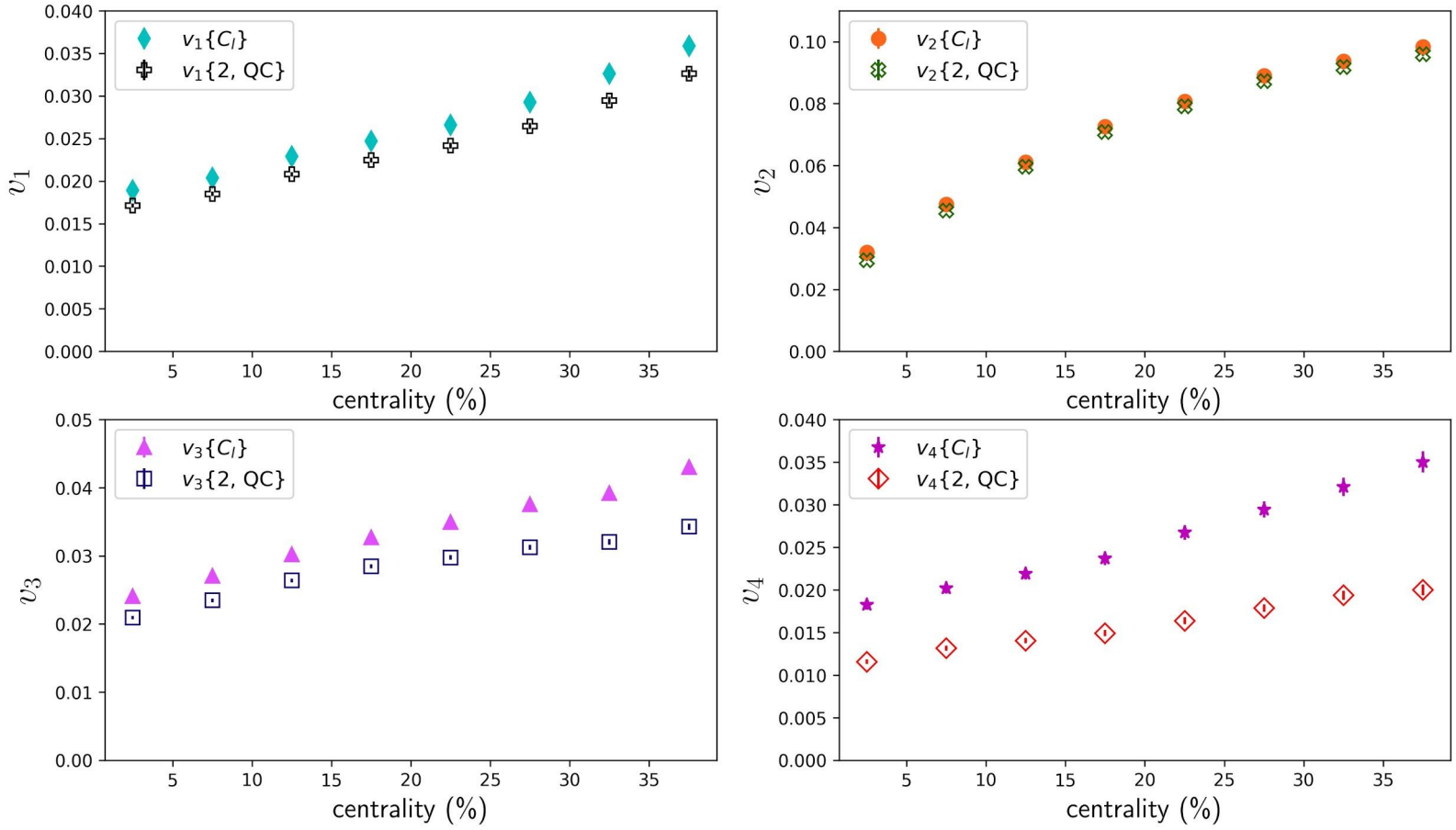
- ➔ Particle sparsity leads to fluctuations of order of C_l;
- ➔ Check how $\langle C_l \rangle$ changes with typical event multiplicity;
  - ♦ Fit to $p_0 \cdot M^{-p1} + p_2$;

$$\langle C_l^{corr} \rangle = \langle C_l^{obs} \rangle - p_0 \cdot M^{-p_1}$$





➔ **Probably reliable for *l = 10* at most...**

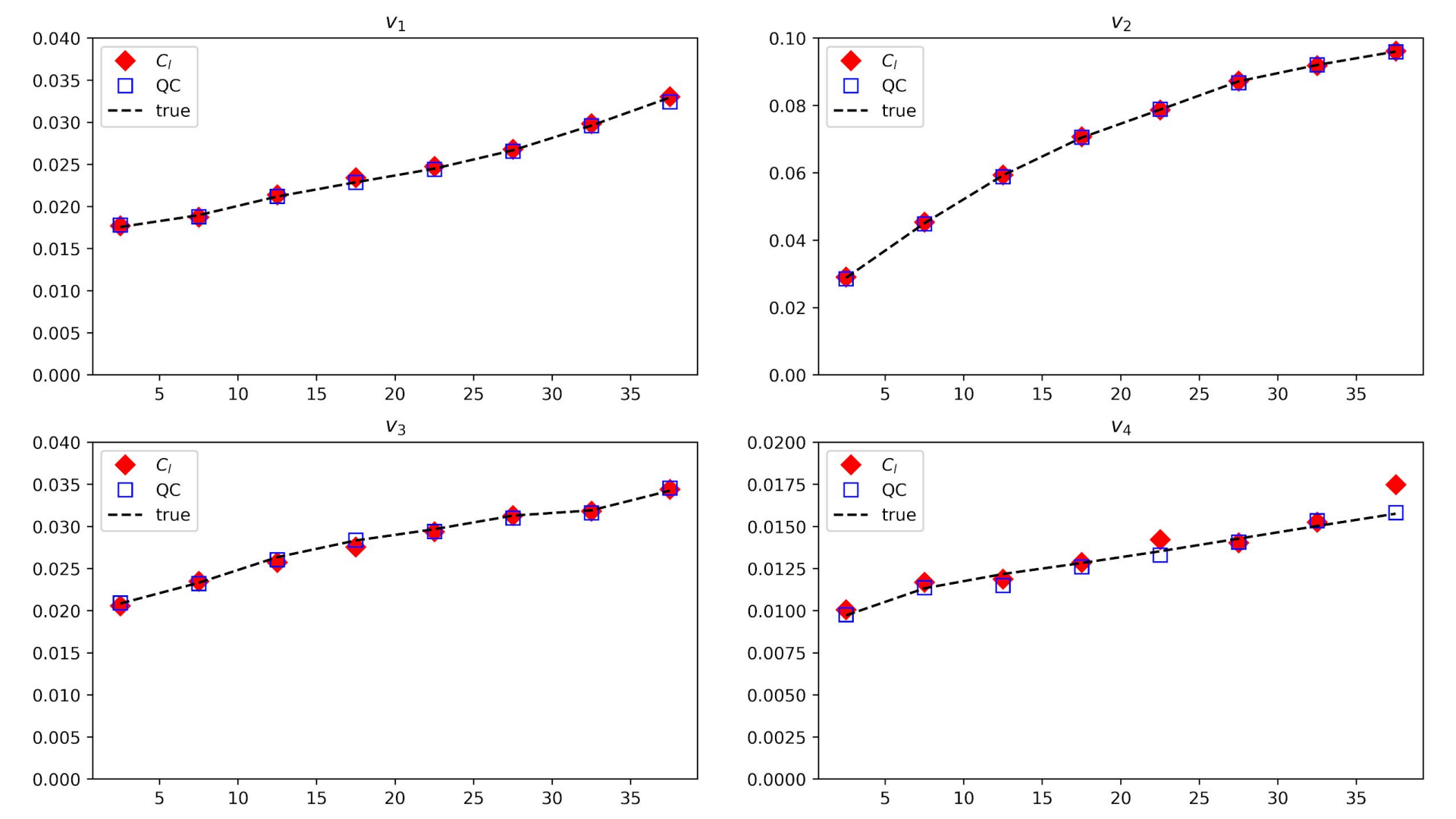


➔ **Comparison with 2nd order cumulant [arXiv:1010.0233v2]**

Conclusions

- Angular power spectrum “sees” final state anisotropies;
  - Each mode seems to be related to collective flow coefficients;
  - QGP fluidity;
- After clean-up we have a nice peak at $l = 2$ and a dumping tail;
- From corrected spectrum we can get flow coefficients and results diverge from cumulants method;
  - Even though it worked for Monte Carlo! (you can ask for proof...);
- It would be a funnier analysis at higher energies for a wider η range!


Thank you!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C_l
QC
true
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
5
10
15
20
25
30
35
v_2
C_l
QC
true
0.10
0.08
0.06
0.04
0.02
0.00
5
10
15
20
25
30
35
v_3
C_l
QC
true
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
5
10
15
20
25
30
35
v_4
C_l
QC
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0.0175
0.0150
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000
5
10
15
20
25
30
35

References

- Background: https://physicsworld.com/a/did-dark-matter-have-a-chilling-effect-on-the-early-universe/;
- QCD phase diagram: http://www.jicfus.jp/en/promotion/pr/mj/guido-cossu/;
- RHIC: https://www.bnl.gov/newsroom/news.php?a=26204;
- Initial anisotropy: http://science.sciencemag.org/content/337/6092/310.full?rss=1;
- Data: http://opendata.cern.ch/search?page=1&size=20&experiment=ALICE;