QCD物理研讨会暨基金委重大项目“量子色动力学的相结构和新颖拓扑效应研究”年度学术交流会

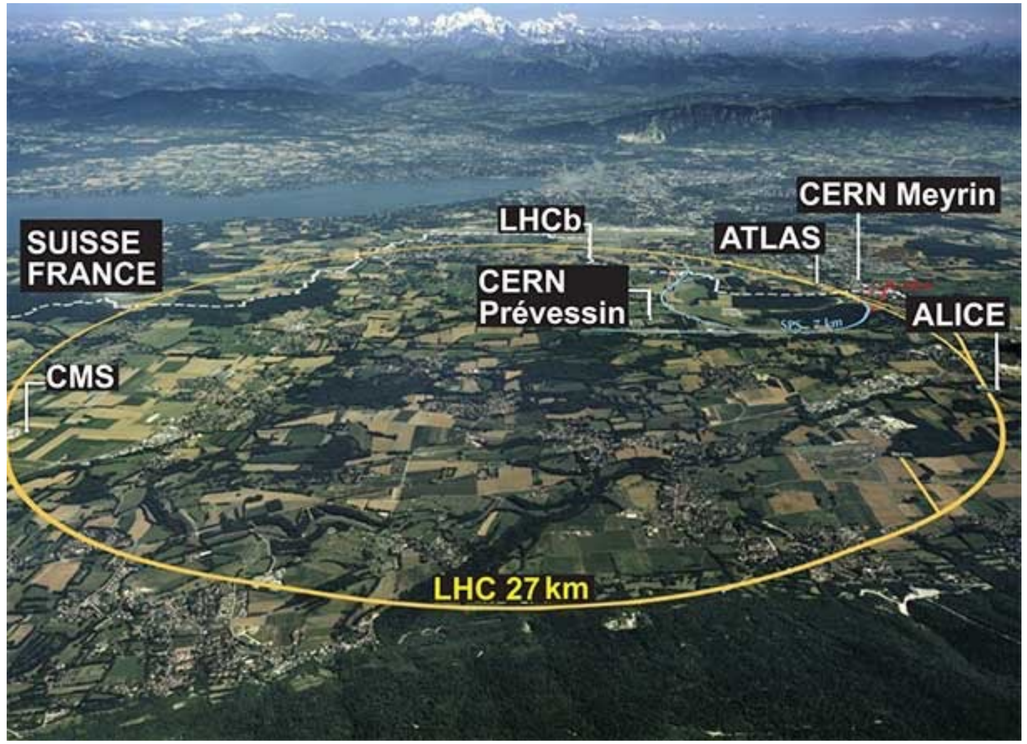
LHC-ALICE实验手征反常效应研究进展

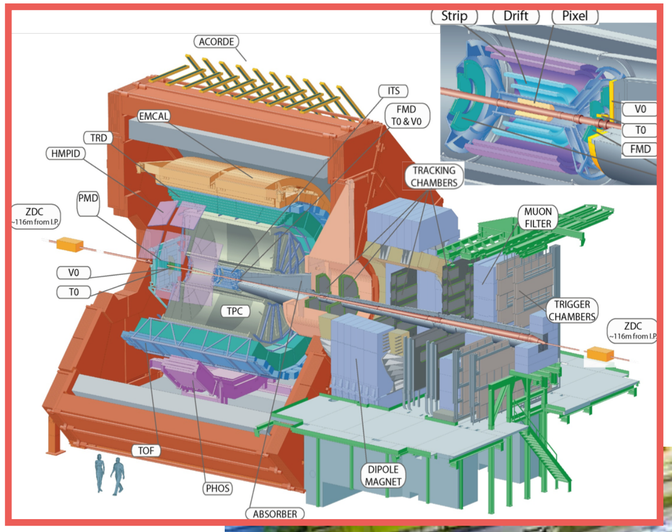
寿齐烨
复旦大学

- ALICE实验手征反常效应研究
- ALICE实验奇特物质研究

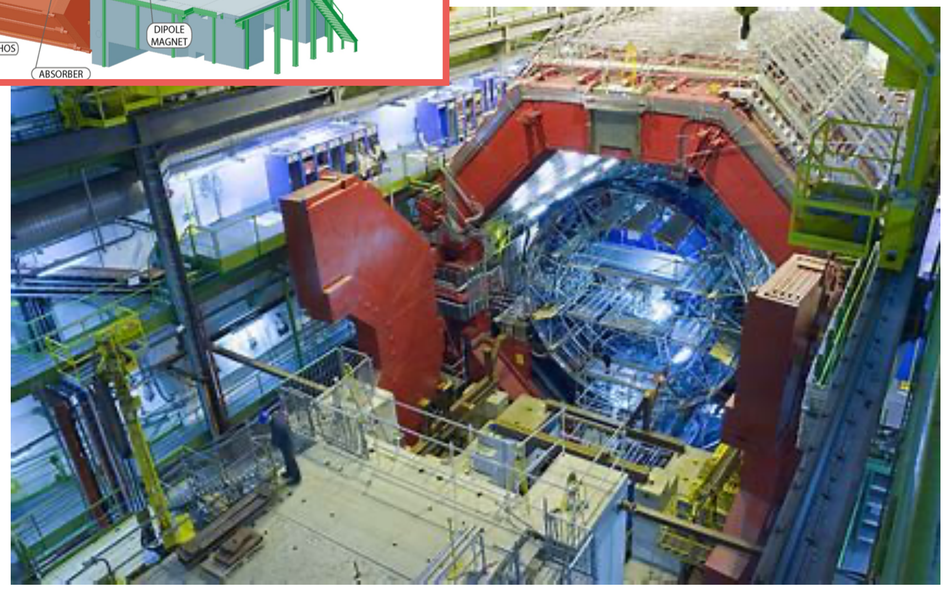
2022年7月

ALICE实验

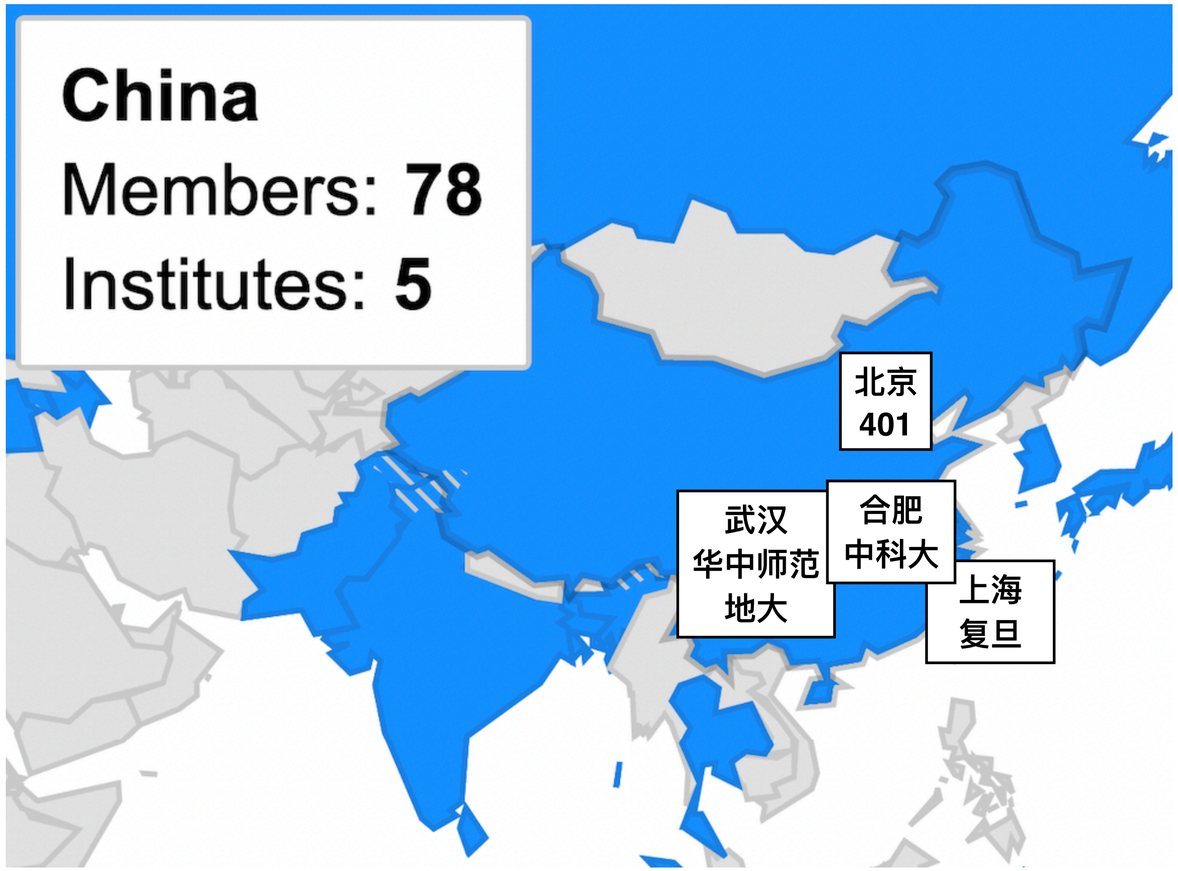




41 countries
177 institutes
1800 members



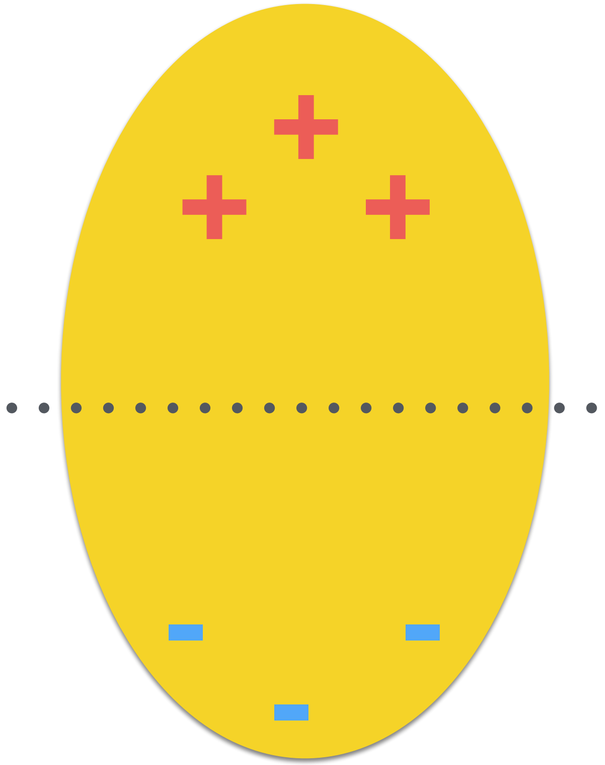
ALICE中国组



- 华中师范：喷注、重味、奇异、关联等，硅像素探测器
- 中国地质大学：重味
- 原子能院：冷核效应等
- 中科大：夸克偶素、双轻子等
- 复旦：奇特现象（手征反常）和奇特物质等

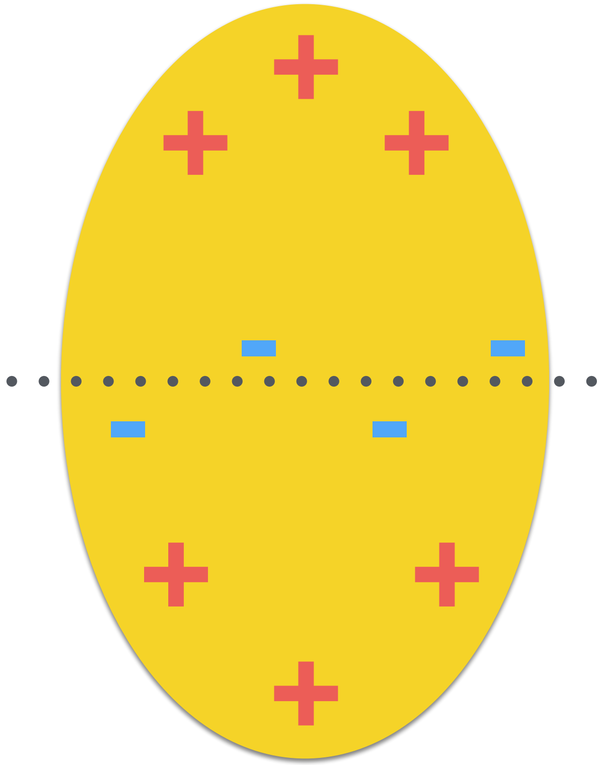
中国组以1/23的人员贡献了1/8的论文

手征反常效应



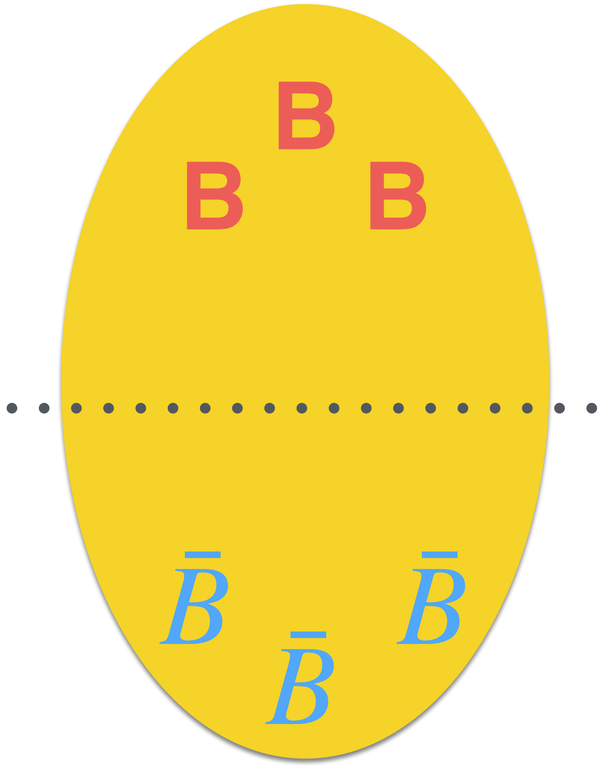
手征磁效应

Chiral magnetic effect



手征磁波

Chiral magnetic wave



手征涡旋效应

Chiral vortical effect

手征反常效应

在LHC能区开展手征反常效应实验研究，更适合厘清背景机制

观测量：方位角关联量γ和δ

2.76 TeV和5.02 TeV Pb-Pb碰撞测量结果均已发表

5.44 TeV Xe-Xe碰撞结果也已完成

已提取出信号的可能强度和上限

观测量：电荷不对称（A_{ch}）依赖的椭圆流

2.76 TeV测量已发表，但是

背景机制？

如何分离信号和背景？

信号强度？

观测量：重子间的γ和δ关联

暂无结果

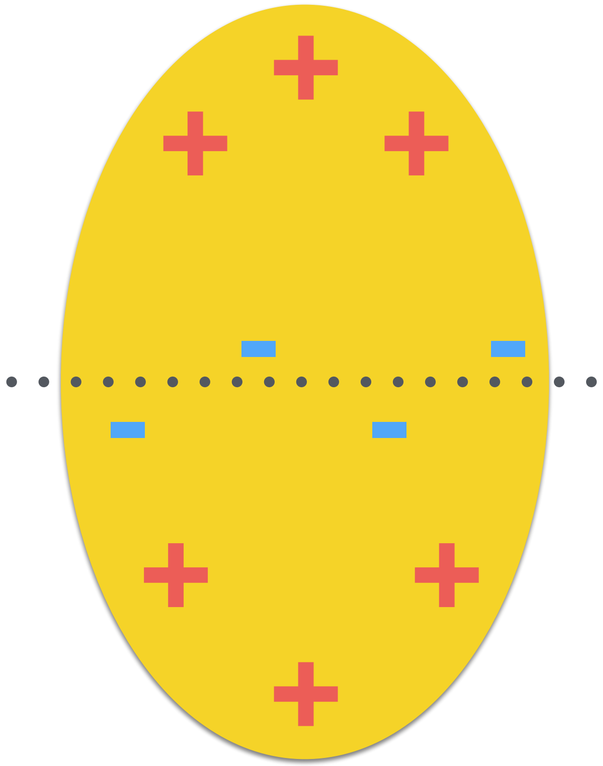
手征磁效应
Chiral magnetic effect

手征磁波 重点
Chiral magnetic wave

手征涡旋效应 重点
Chiral vortical effect

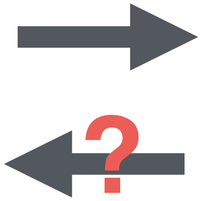
手征磁波实验测量

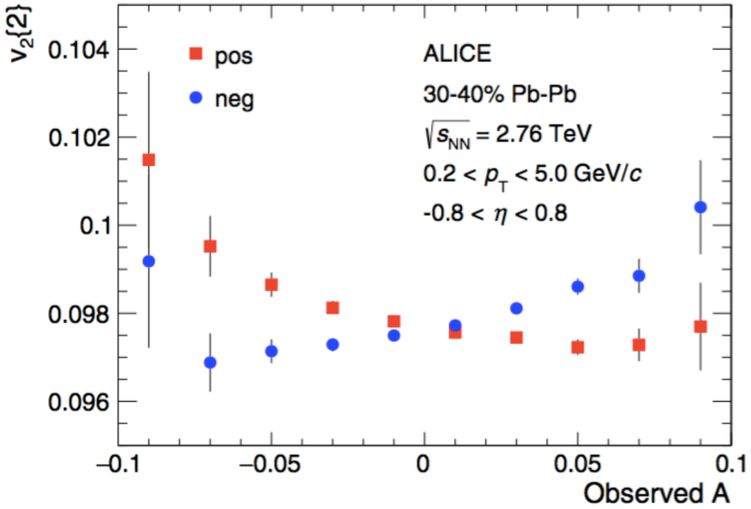
PRL 114 (2015) 252302
PRC 93 (2016) 044903

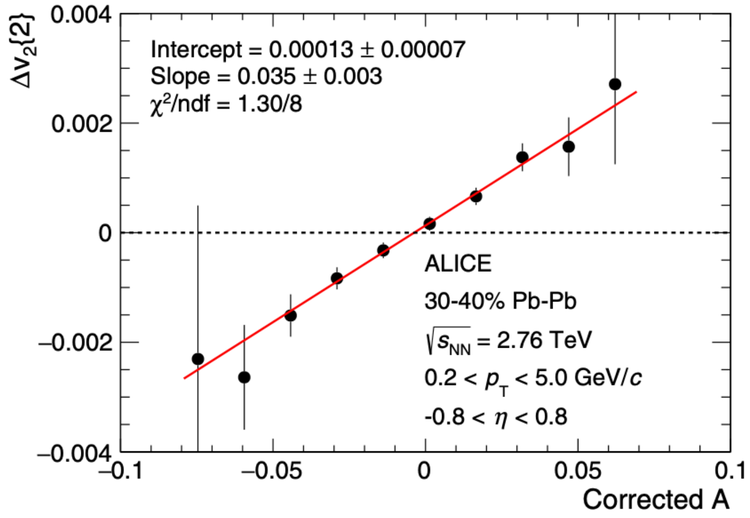


$$\Delta v_2 = v_2^- - v_2^+ = rA_{\mathrm{ch}}$$

$$A_{\mathrm{ch}} = \frac{N^+ - N^-}{N^+ + N^-}$$

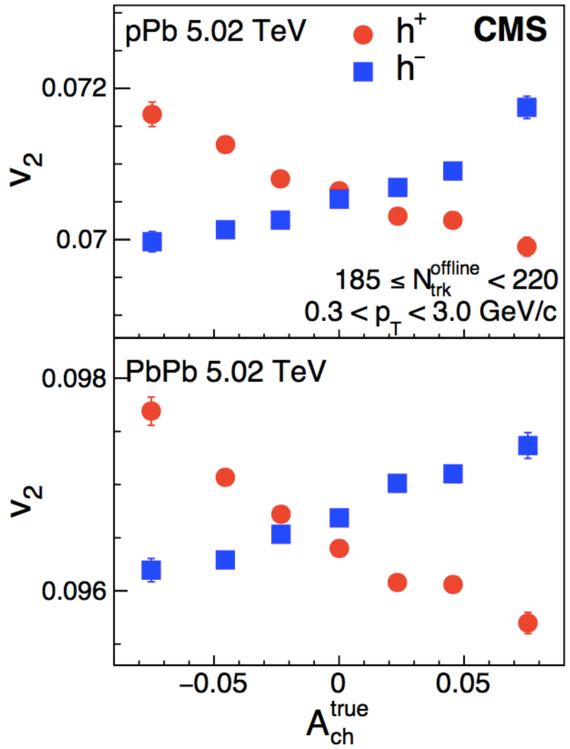


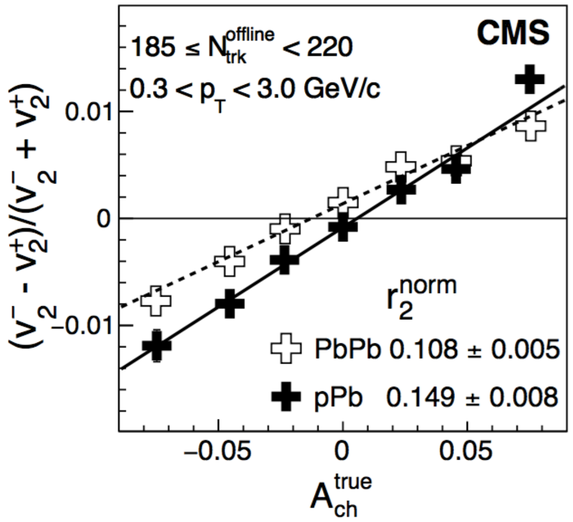


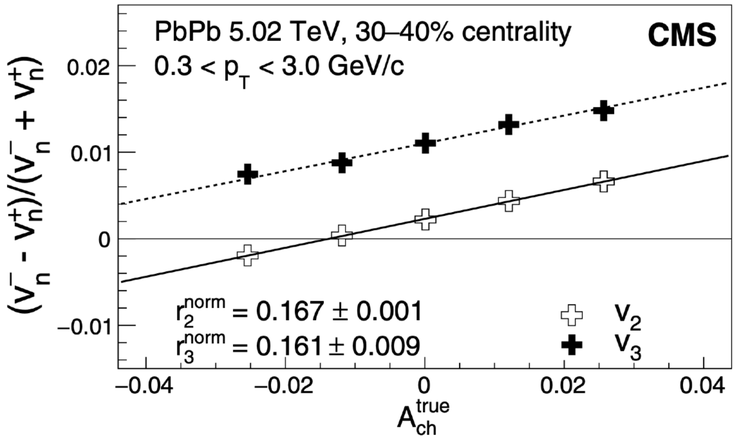


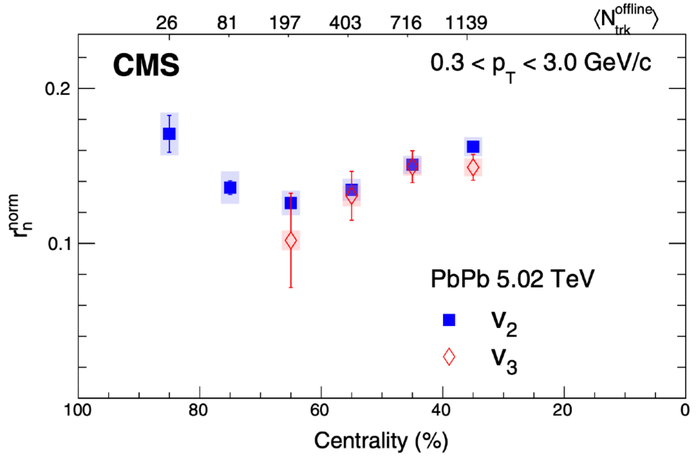
手征磁波实验测量

PRC 100 (2019) 064907





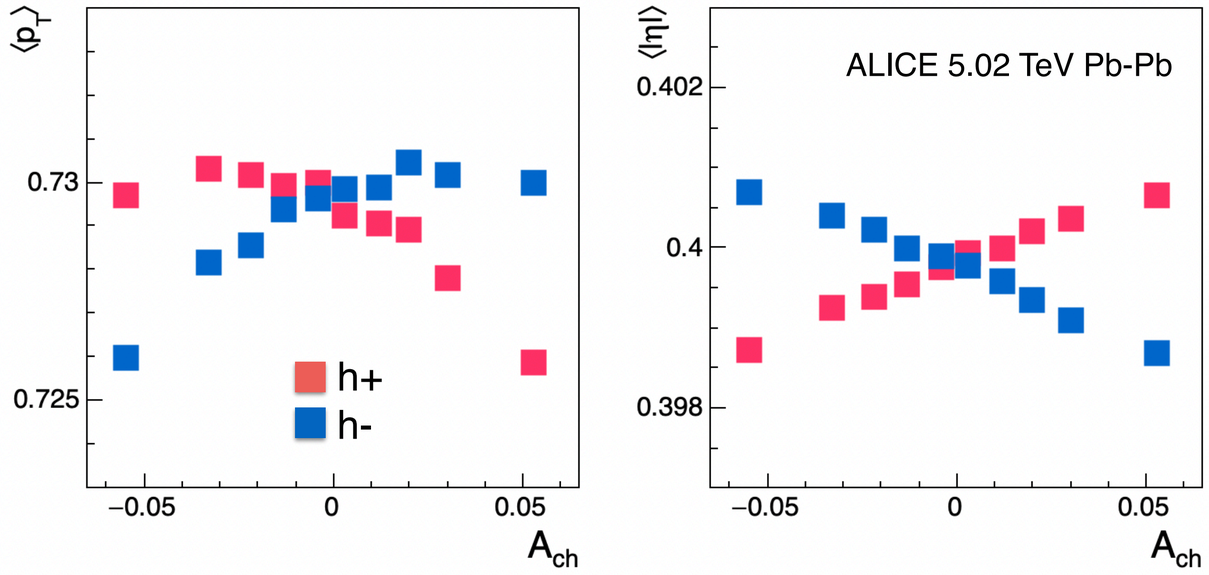


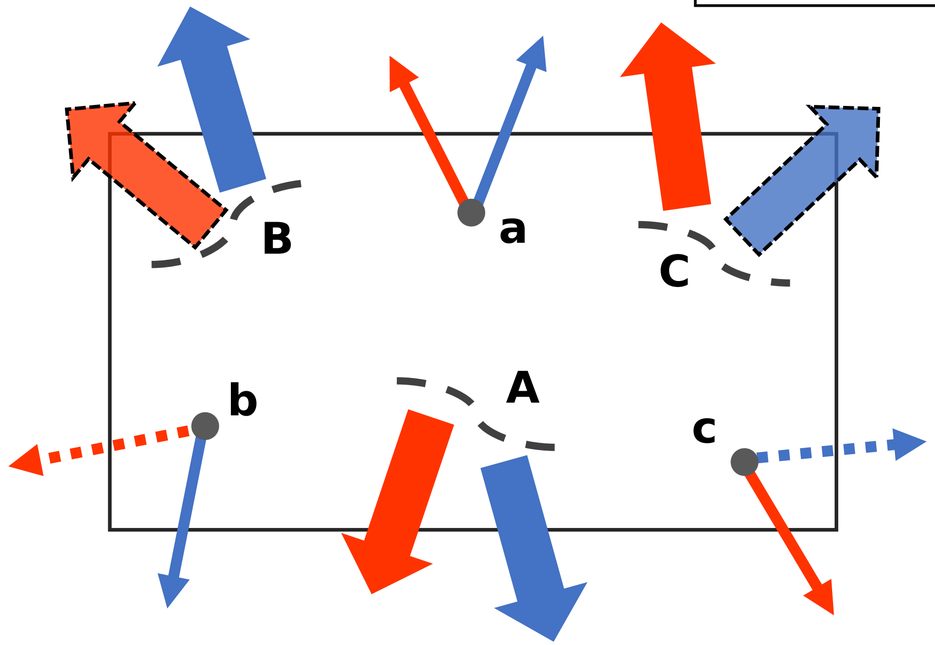


- Agreement between AA/pA results, and v_2/v_3 results
- A common underlying mechanism generates the observed slope

手征磁波测量中的背景：局域电荷守恒

PLB, 726 (2013) 239–243
PRC, 103 (2021) 034906

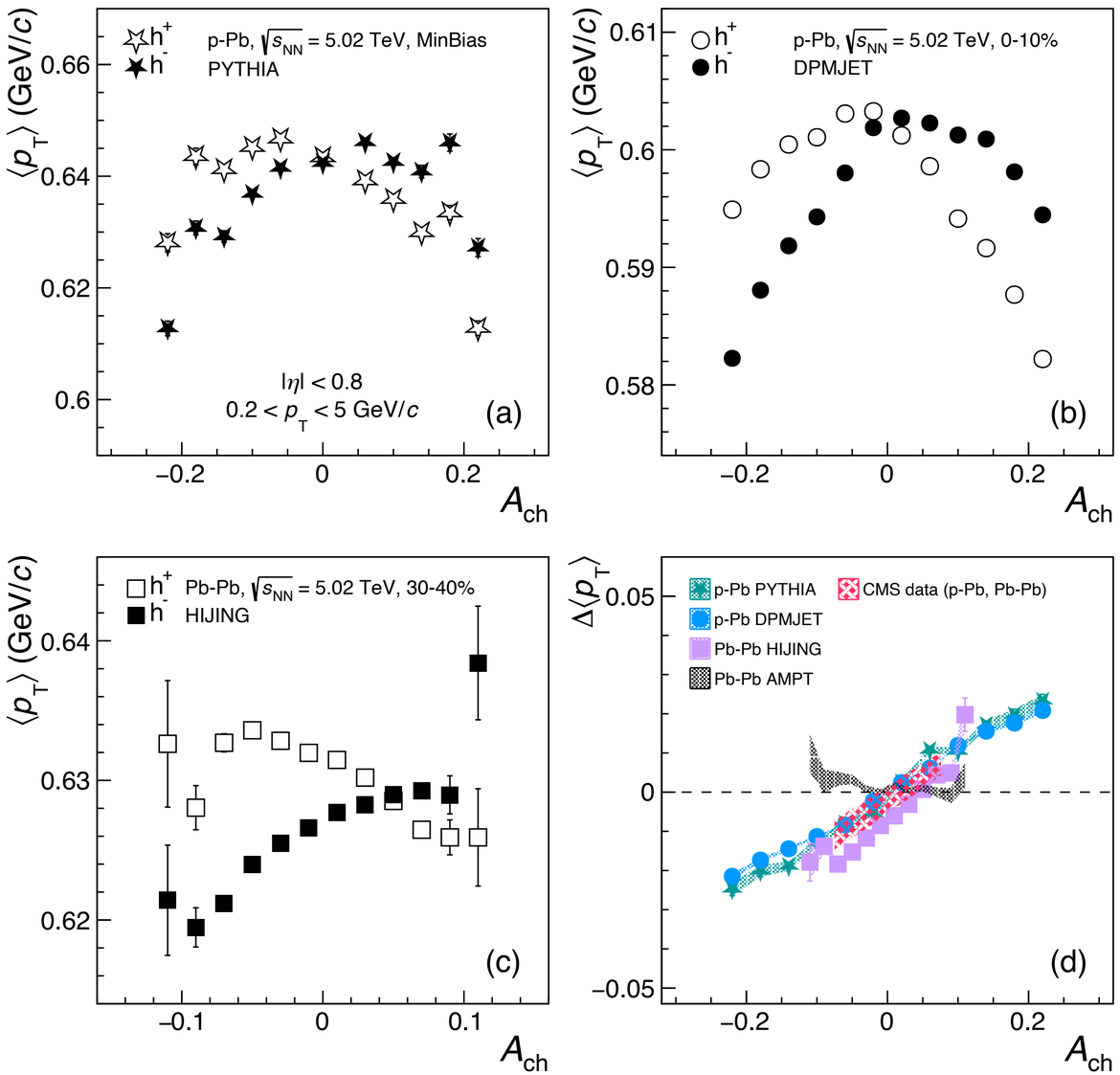




$$\Delta\langle p_{\mathrm{T}}\rangle = \frac{p_{\mathrm{T}}^{a}m^{a} + p_{\mathrm{T}}^{b}m^{b}}{m^{a}+m^{b}} - \frac{p_{\mathrm{T}}^{a}m^{a} + p_{\mathrm{T}}^{c}m^{c}}{m^{a}+m^{c}}$$

$$= \frac{m^{a}\left(m^{c}-m^{b}\right)\left(p_{\mathrm{T}}^{a}-p_{\mathrm{T}}^{b}\right)}{(m^{a}+m^{b})(m^{a}+m^{c})},$$

手征磁波测量中的背景：局域电荷守恒



PLB, 726 (2013) 239–243
PRC, 103 (2021) 034906

$$A_{\mathrm{ch}} = \frac{N^{+} - N^{-}}{N^{+} + N^{-}}$$

A_{ch} is a ***tricky*** observable!

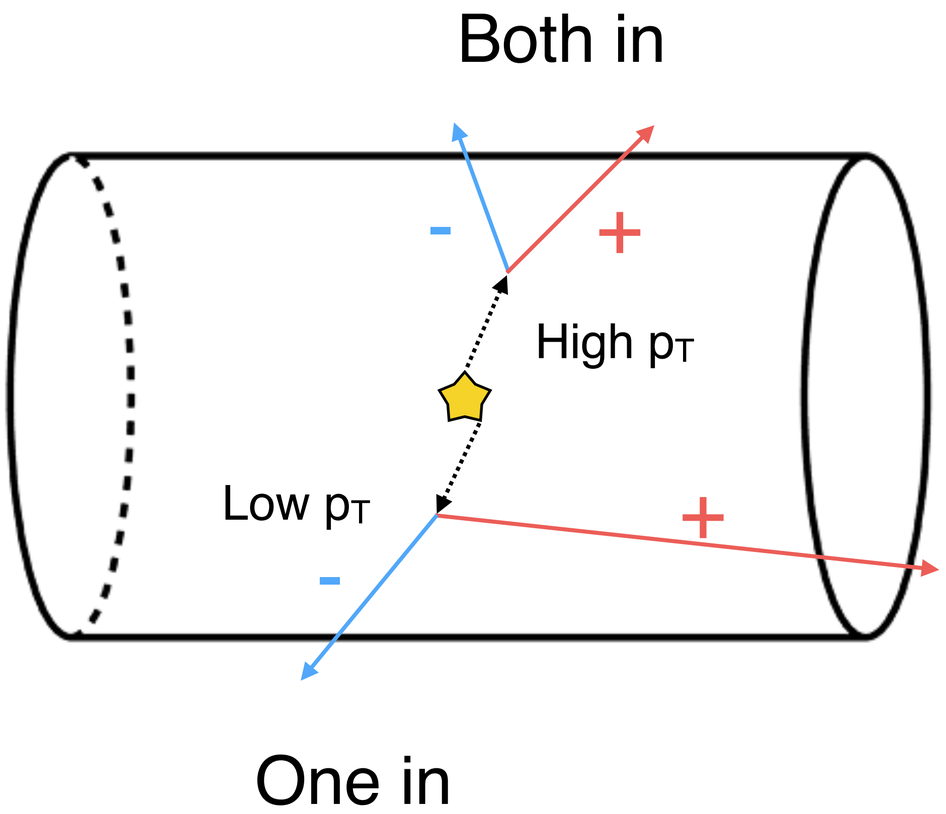
It doesn't just cut on the number of particles as it appears to be.

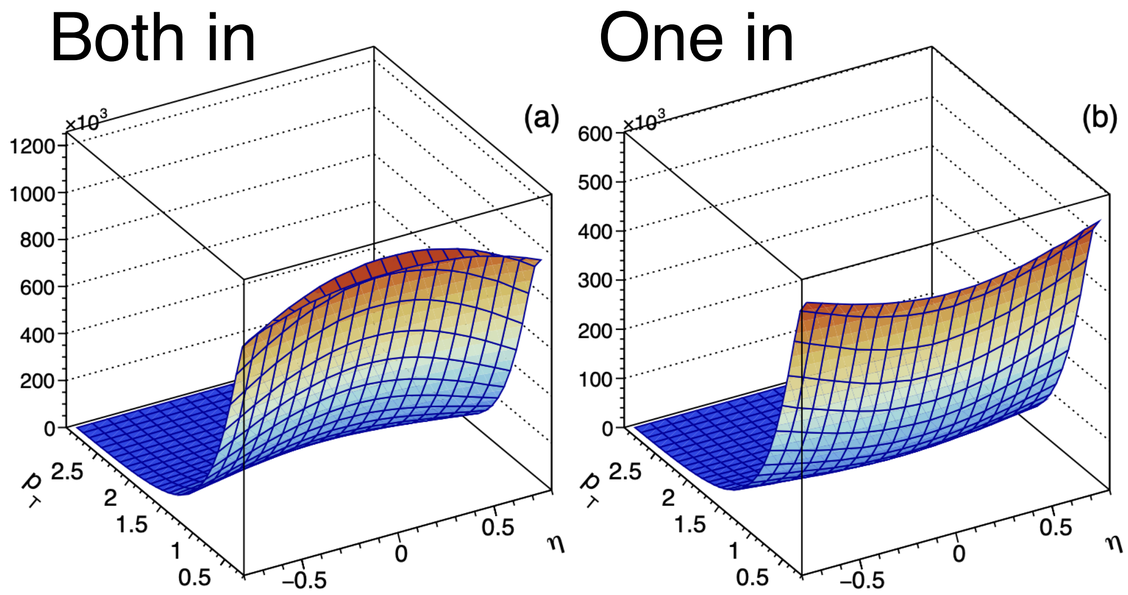
When selecting events with a specific A_{ch}, in practice, one preferentially applies nonuniform p_{T} and η cuts on the charged particles

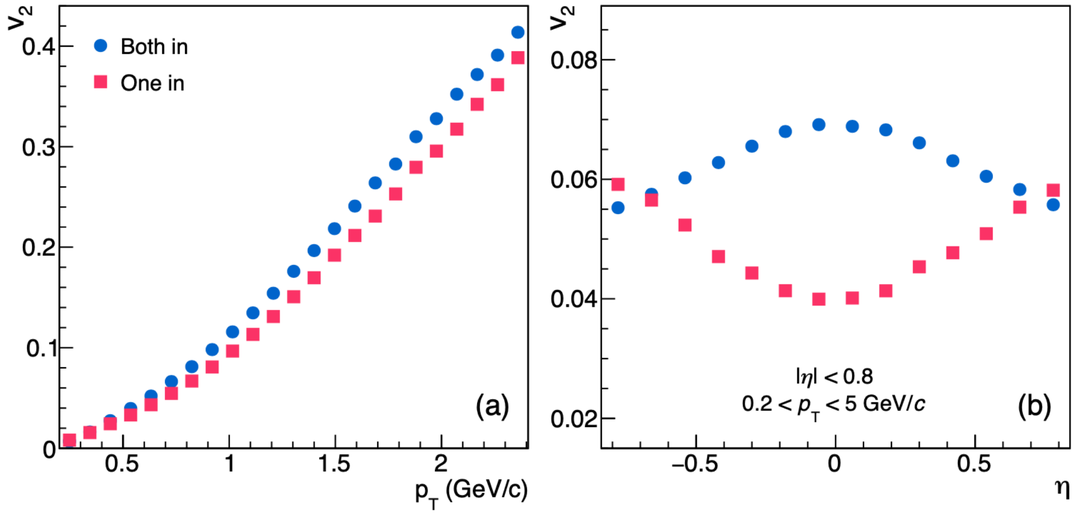
手征磁波测量中的背景：局域电荷守恒 + v_2

PRC, 103 (2021) 034906
PLB, 820 (2021) 136580

BW+LCC Model

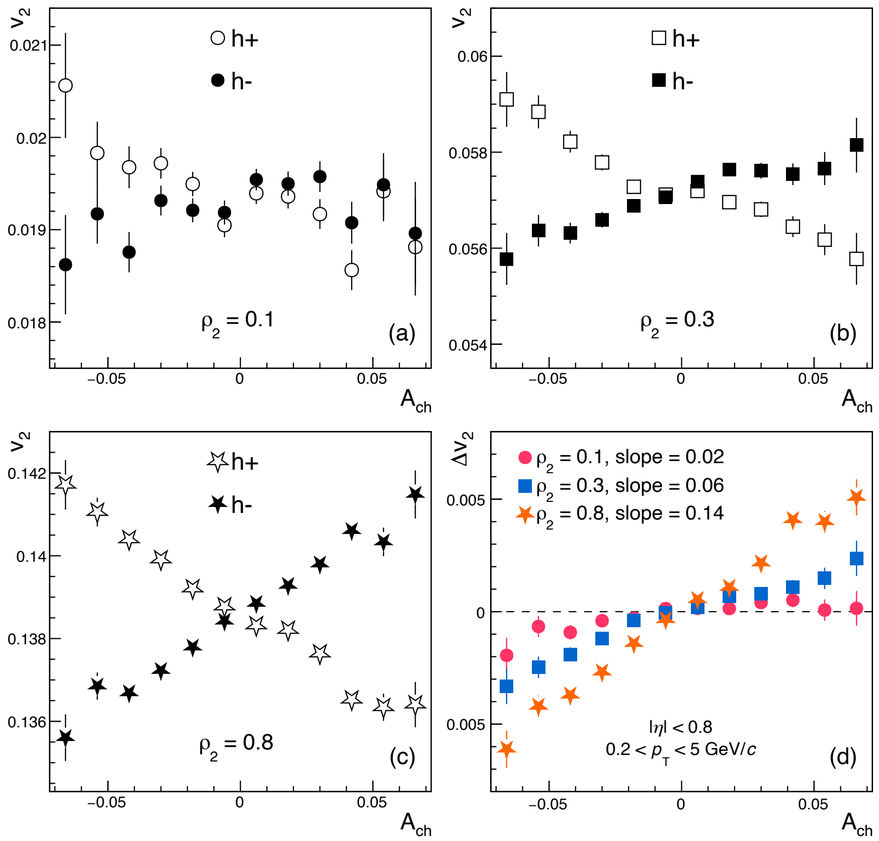




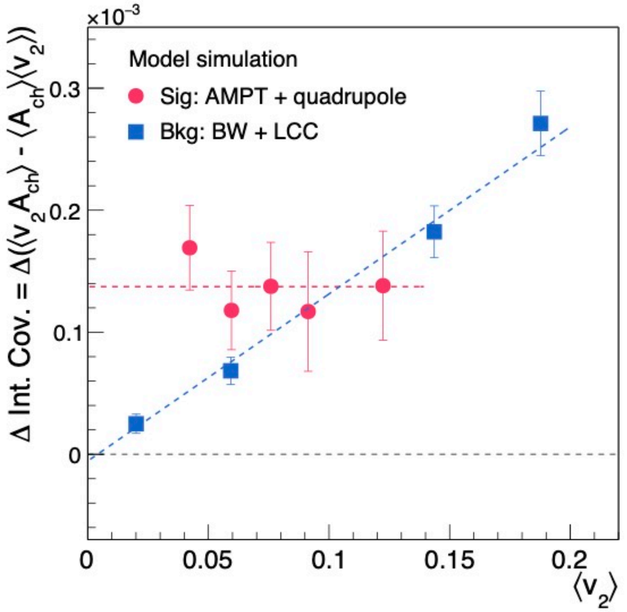


手征磁波测量中的背景：局域电荷守恒 + v_2

BW+LCC Model

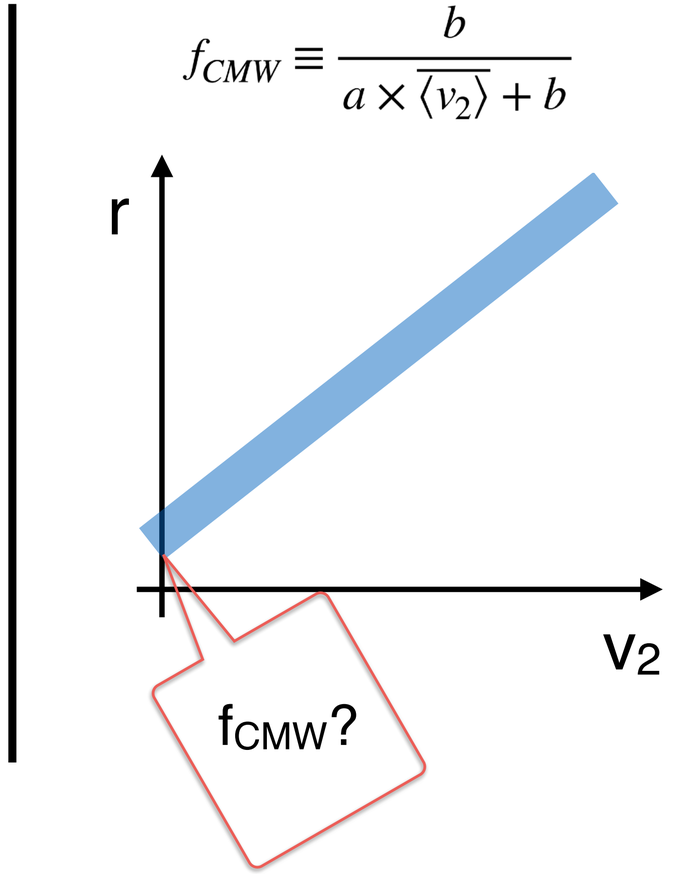


PLB, 820 (2021) 136580



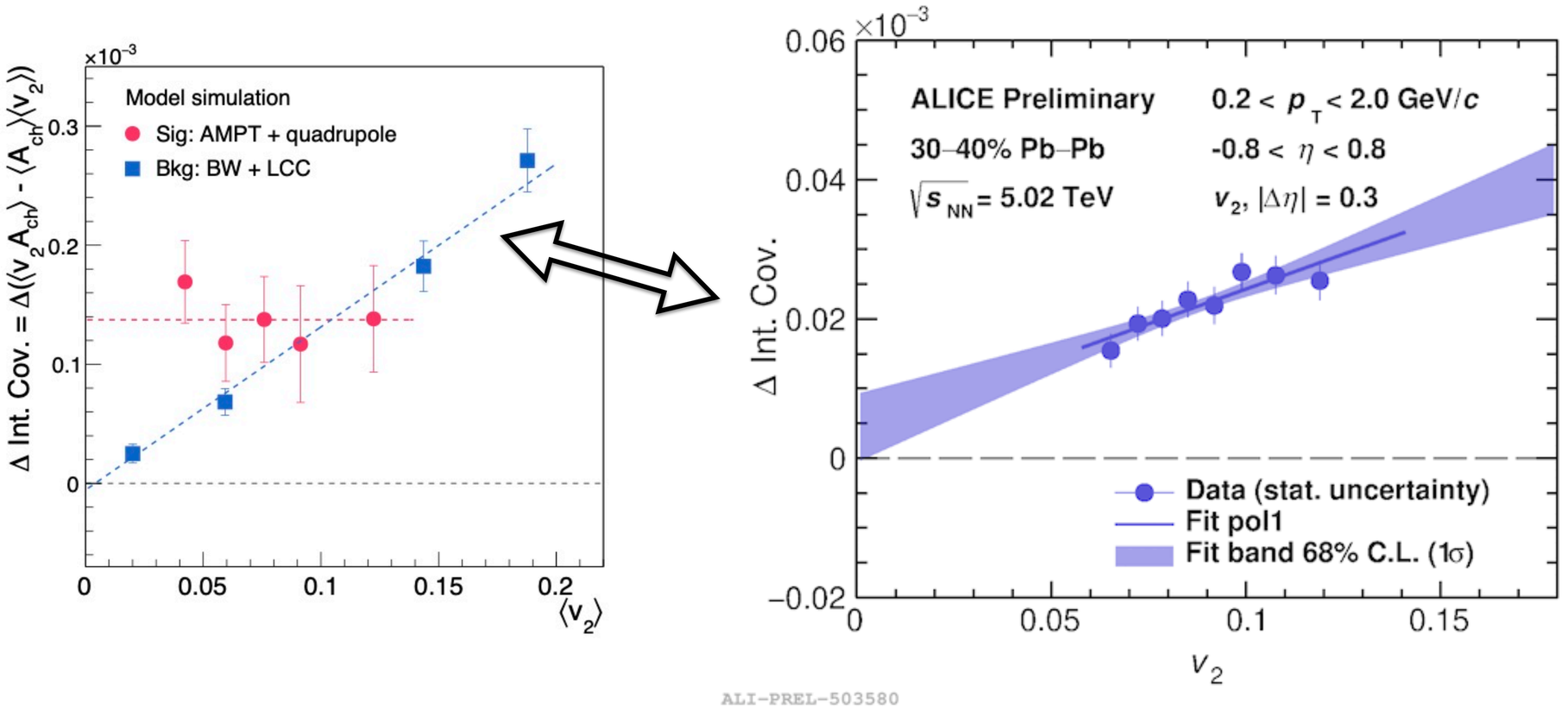
Exp. data

$$f_{CMW} \equiv \frac{b}{a \times \overline{\langle v_2 \rangle} + b}$$



ESE is a powerful tool to constrain the LCC background

手征磁波实验测量：分离信号和背景



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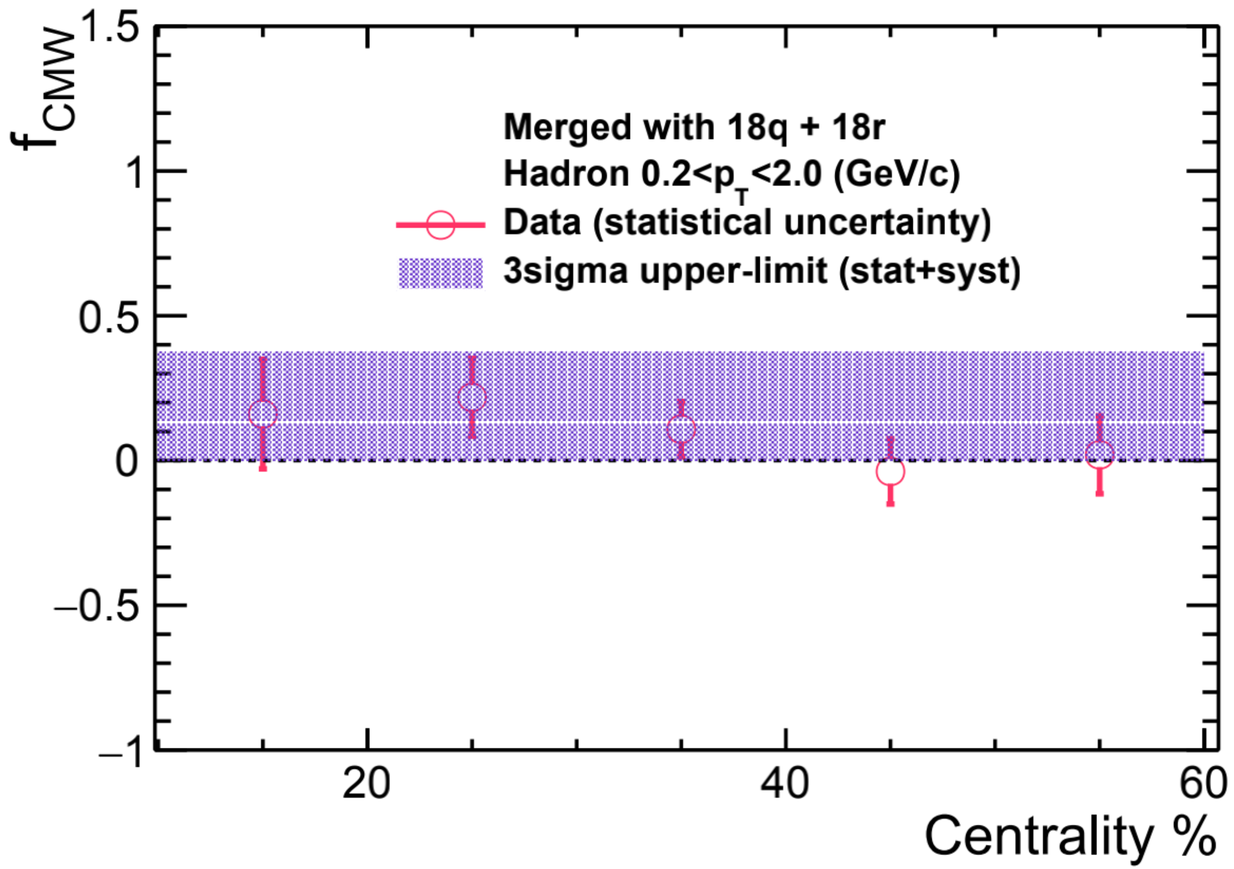
手征磁波实验测量：分离信号和背景



$$f_{\mathrm{CMW}} \approx 0.08 \pm 0.06$$

Upper-limit ~ 37% from 0 at 99.7% CL

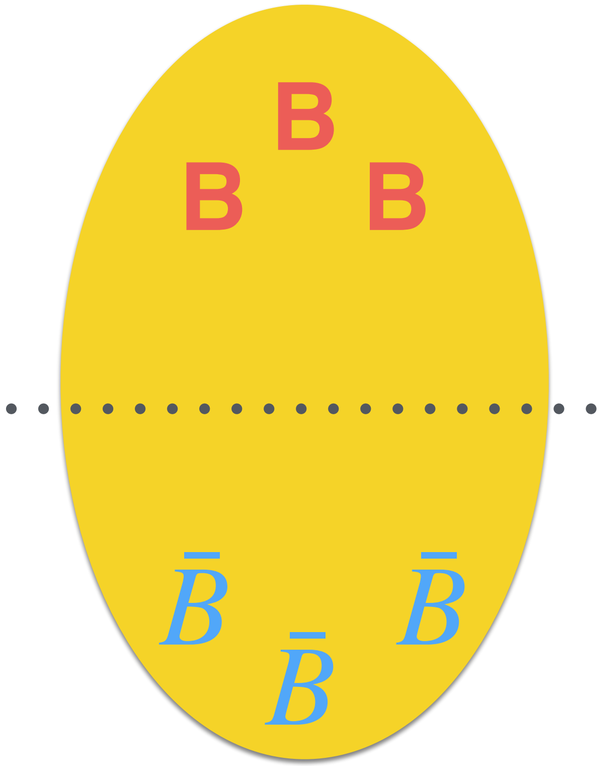
手征磁波实验测量：总结

- 手征磁波（CMW）是理论预言的一种重要的手征反常效应，与QCD真空拓扑结构和强相互作用中P/CP局域破缺等物理紧密相关，然而寻找和测量该效应时，会带入大量背景

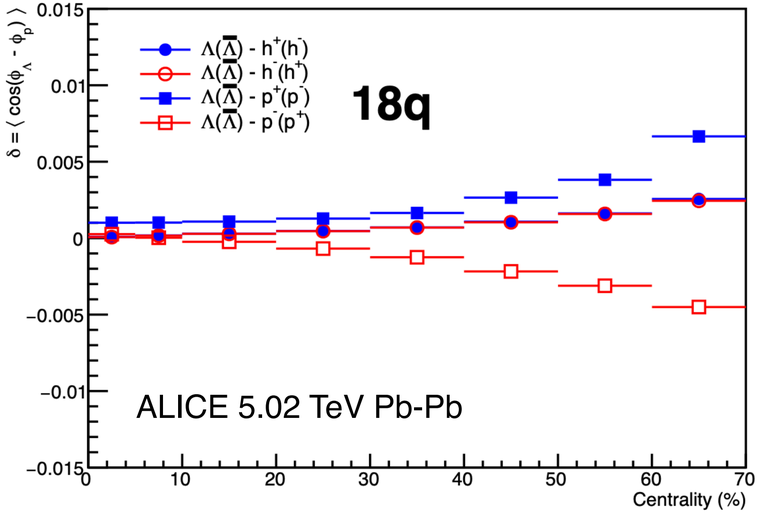
- 借助多种理论模型，对可能的背景进行了全面研究，厘清了背景来源；重点分析了背景和信号的区别，提出采用事件形状选择（ESE）方法分离CMW测量中的局域电荷守恒（LCC）背景；成功在实验中完成了测量，首次提取出了CMW信号强度。实验结果在国际学术会议QM22、SQM22上公布。

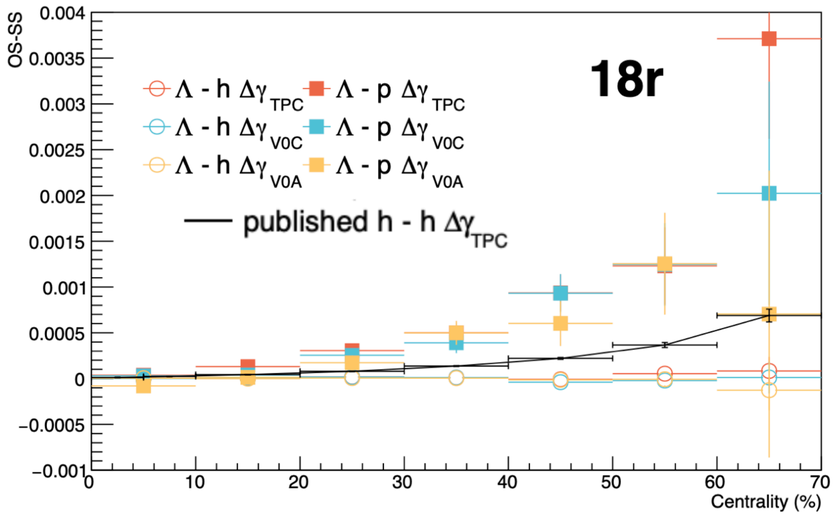
- 发表理论研究论文2篇，完成实验组分析报告、Preliminary Approval 和Paper Proposal，目前在准备正式论文的发表

手征涡旋效应实验测量



ALICE work in progress，仅供本项目内部交流





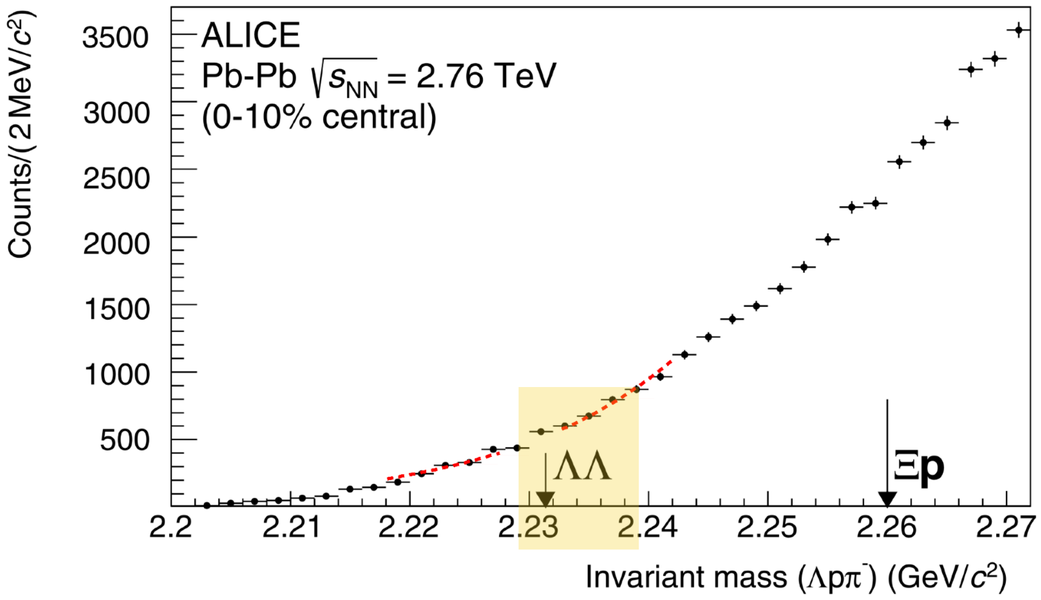
- 基于ALICE实验15和18年采集到的Pb-Pb碰撞数据，仔细重构了各种事件平面，分析Λ重子和质子沿反应平面的分离状况，观测到了明显的非平凡行为，正在结合理论工作，深入理解其中可能包含的物理机制

- CVE目前暂无任何公开实验结果，对测量中的背景效应也知之甚少。基于本项目，有望取得重要进展

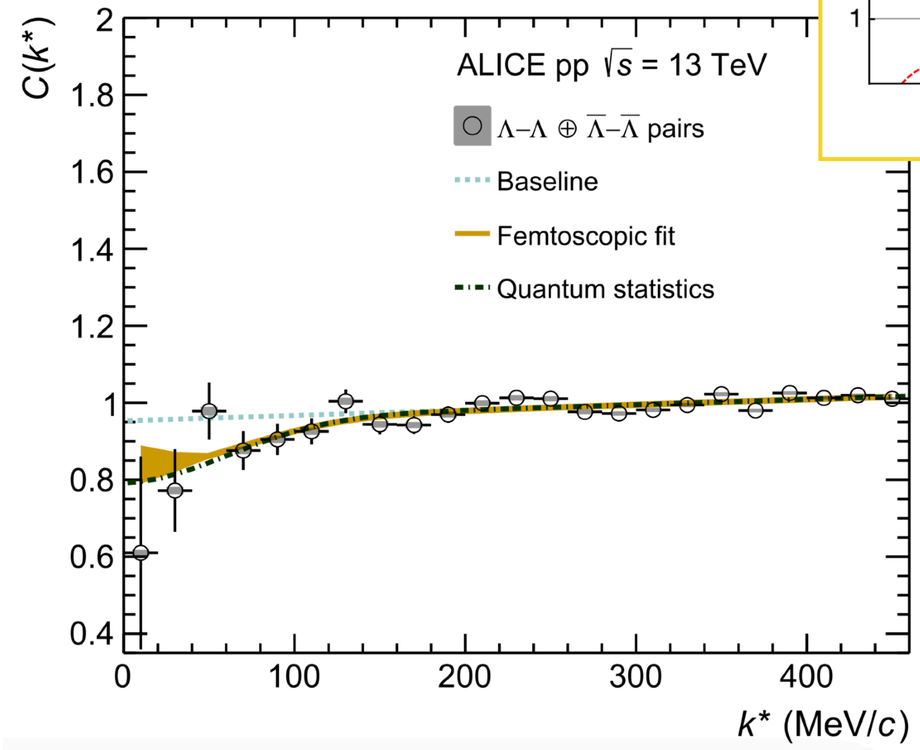
奇特物质（粒子态）研究

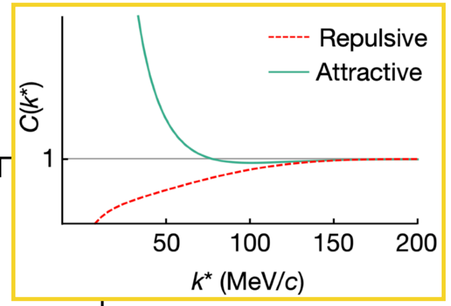
两种方法：Invariant mass reconstruction and momentum correlation

$$k^* = |\mathbf{p}_2^* - \mathbf{p}_1^*|/2 \text{ in the pair rest frame}$$



No signal or even a hint





The measured CF excludes strongly attractive interactions

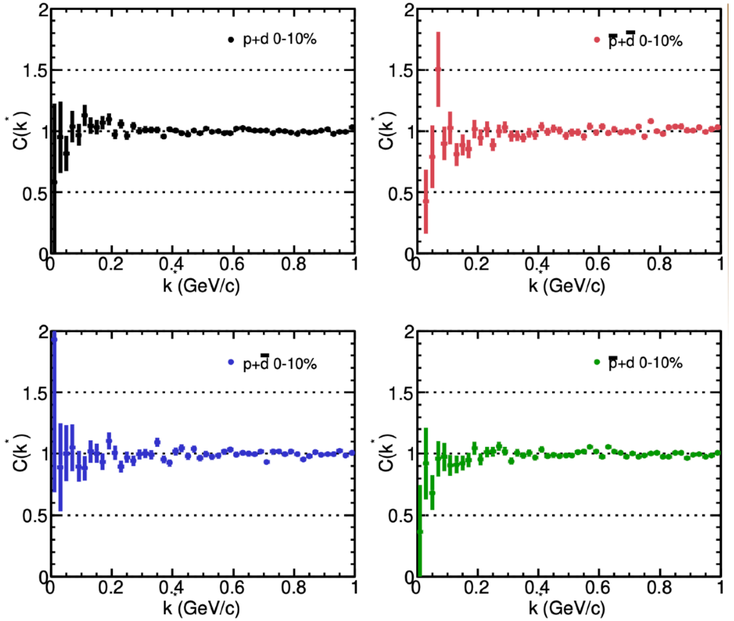
轻核间动量关联研究

- Momentum correlation is a powerful tool to investigate interactions between particles, including searching for bound states

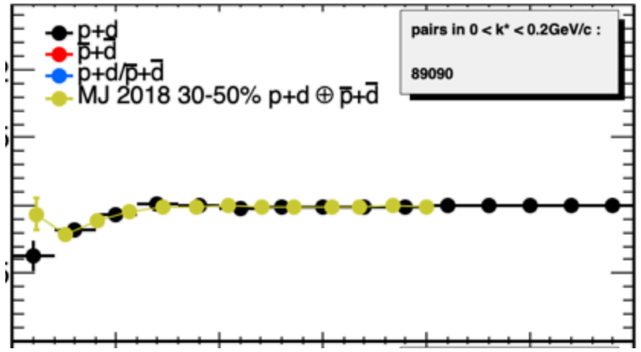
- Working on **p-d, p-t, p-He3** momentum correlation
  $^4He \rightarrow p + t?$ $^4Li \rightarrow p +^3 He?$

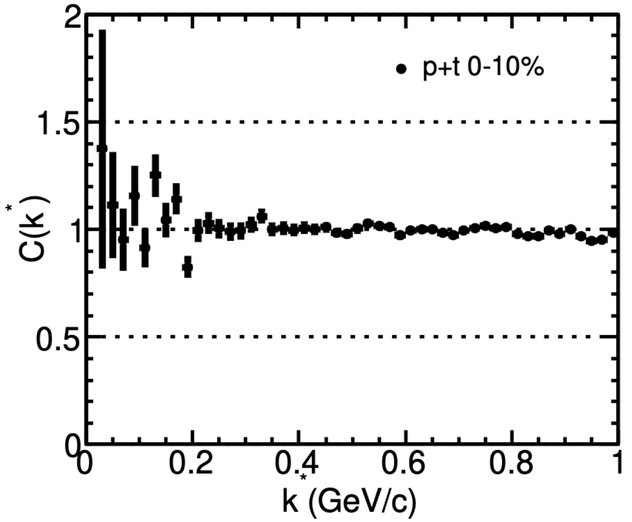
- Sensitive to the production of light nuclei

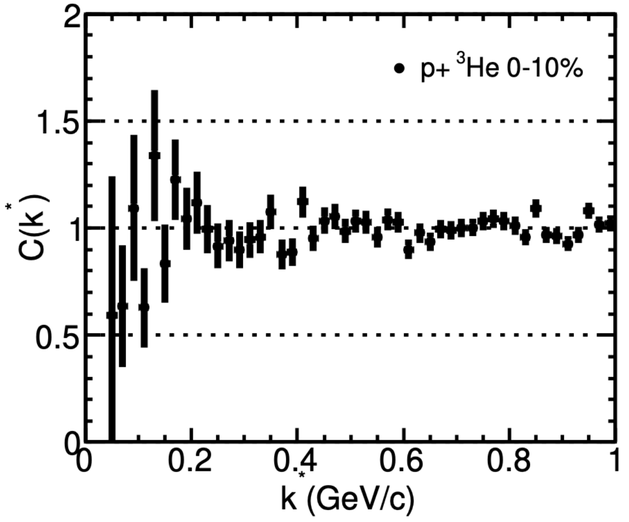
轻核间动量关联研究



ALICE work in progress，仅供本项目内部交流







- 通过动量关联方法，研究强相互作用性质，寻找奇特粒子态
- 基于ALICE实验，首次测量了质子-轻核间的动量关联，在低k*区间观测到了非平凡结构
- 进行中：深入检查各种系统不确定度、如何理解测量结果

总结

- 厘清了CMW测量中的背景机制，首次分离了信号和背景，得到了信号强度和上限
- 开展了CVE和PID CME的测量，下一步的重点目标!
- 开展了轻核间动量关联测量，下一步的重点目标!
- 正在开发基于Run 3新数据的软件分析框架，通过不变质量方法寻找奇特粒子态

今年开始的ALICE Run 3取数（新探测器+统计x100），对奇特现象和物质研究至关重要