Measurements of Flow in Pb-Pb and Xe-Xe – a year of analysis (+ maybe some more...)

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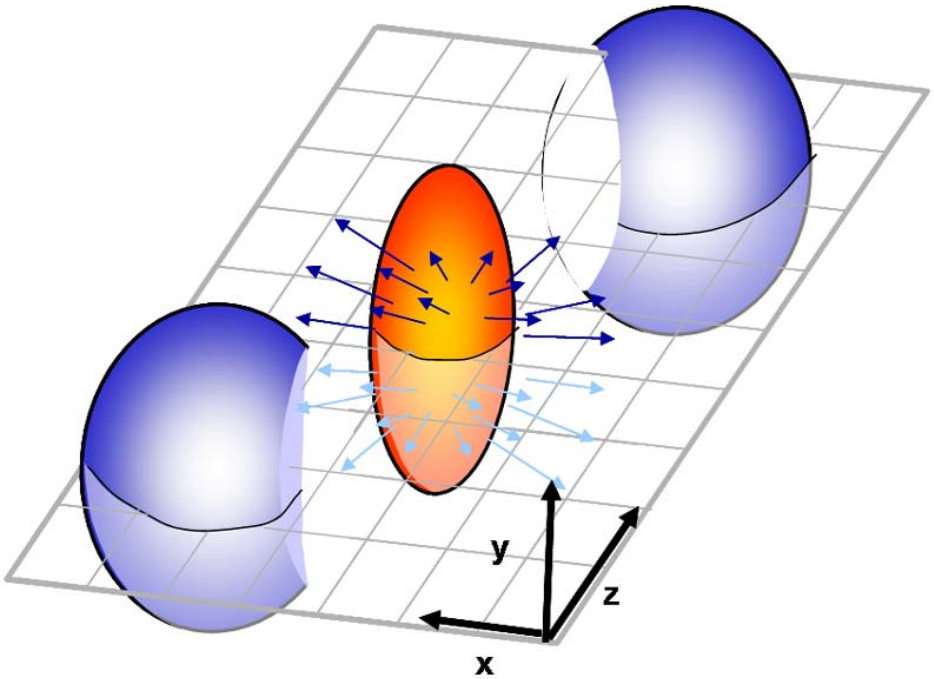
Who am I?

- Graduated from Engineering Physics in 2016
- Master thesis in nuclear theory
- Summer Student at CERN 2014
- About to complete second year of Ph.D. in ALICE

Outline of this talk

1. Analysis topic: anisotropic flow
2. Something about courses & teaching
3. Future plans

What is flow?



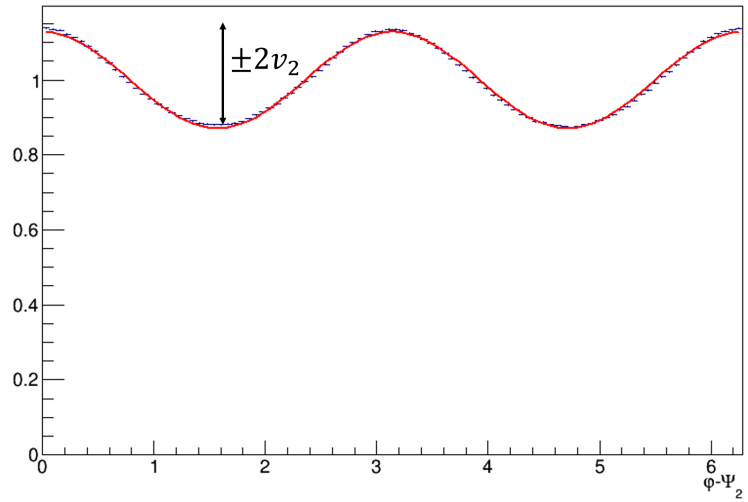
http://www.quantumdiaries.org/wp-content/uploads/2011/02/FlowPr.jpg

- System in thermal equilibrium, expanding with the pressure gradient (flow)
- Non-central collisions $\Longrightarrow$ anisotropic flow
- Studying this reveals properties of the QGP, in particular related to hydrodynamics
- Events are divided into centrality classes

Elliptic flow, v_2

- Fourier decomposition: $\frac{dN}{d\phi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos\left(n\left(\phi - \Psi_R\right)\right)$
- v_1 = directed flow (uninteresting for us)
- v_2 = elliptic flow (dominant)
- v_3 = triangular flow (fluctuation dependent)
- Problem: $\left(v_n^{meas}\right)^2 = \left(v_n^{coll}\right)^2 + \sigma^2 + \delta$, δ = non-flow

Track distribution vs. $\phi - \Psi_2$:



Methods

$$\frac{dN}{d\phi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos\left(n\left(\phi - \Psi_R\right)\right)$$

- Three methods are used:
  1. Event plane method
  2. Q cumulant method
  3. Scalar product method

Methods

$$\frac{dN}{d\phi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos\left(n\left(\phi - \Psi_R\right)\right)$$

Event plane method

- Ψ_R is estimated event-by-event using

$$\Psi_n \approx \frac{1}{2} \arctan\left(\frac{\langle \sin(n\phi) \rangle}{\langle \cos(n\phi) \rangle}\right)$$

  (can be shown as an exercise)
- Problem: $(\phi - \Psi_R)$ is computed track-by-track. Including or excluding this track from the estimate of Ψ_R introduces different biases of v_n

Methods

$$\frac{dN}{d\phi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos\left(n\left(\phi - \Psi_R\right)\right)$$

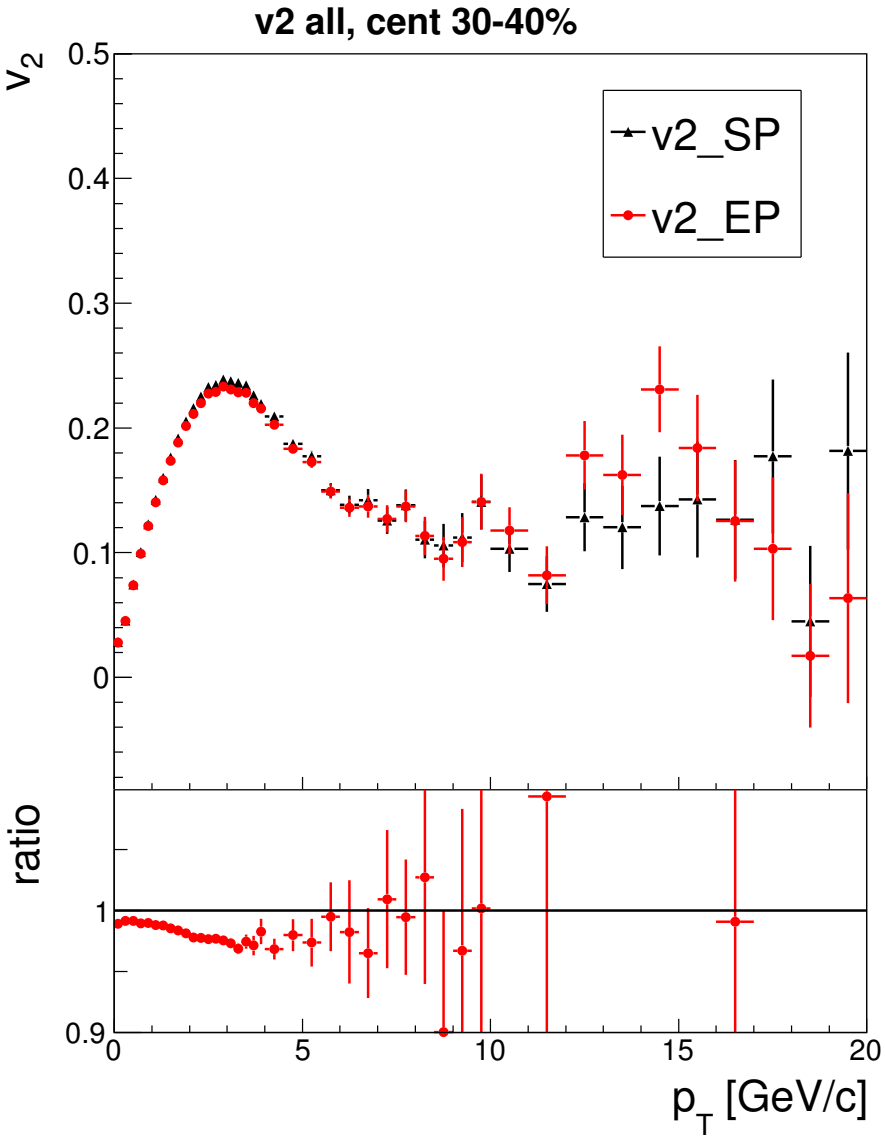
Q-cumulants and scalar product

- Correlations between particles are used to eliminate Ψ_R
- Assuming no direct correlations between particles (non-flow), one can show:

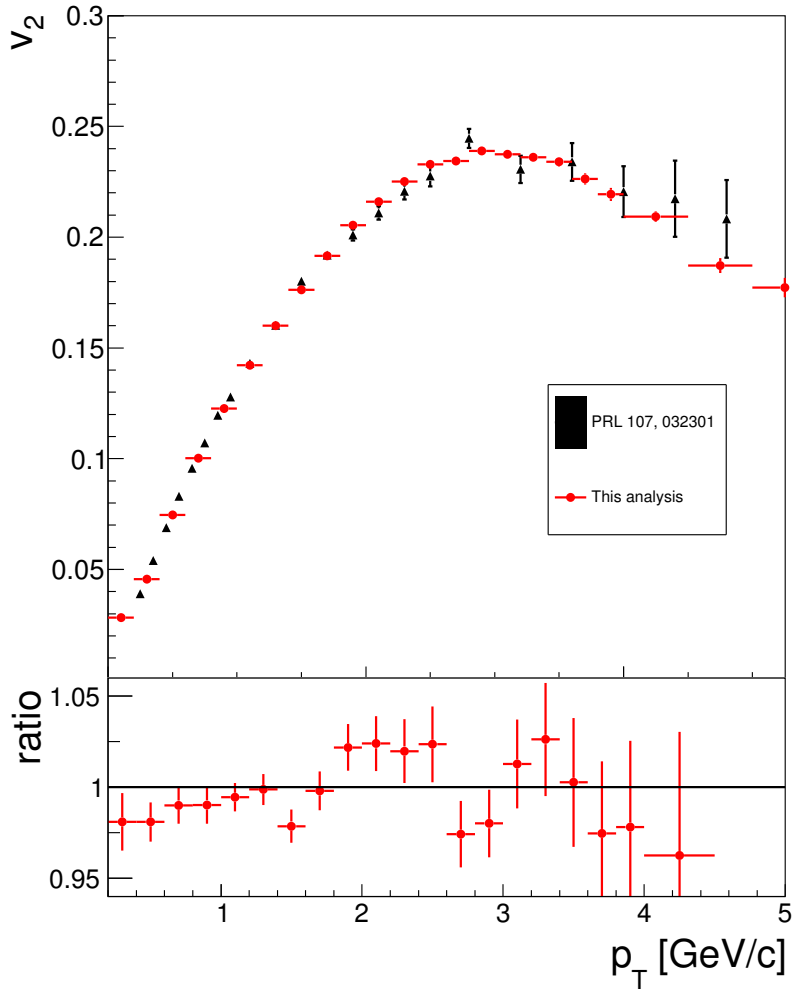
$$v_n^2 \approx \langle \cos(n(\phi_1 - \phi_2)) \rangle = \frac{1}{M(M-1)} \sum_{i=1}^{M} \sum_{j \neq i}^{M} \cos(n(\phi_i - \phi_j))$$

- Can be generalised to correlations between multiple particles to suppress non-flow
- Scalar product uses particles from different sub-events separated by a gap in detector acceptance (also suppresses non-flow)

First results (using Pb-Pb data from 2013, 2.76 TeV)



Comparison to published results (scalar product):

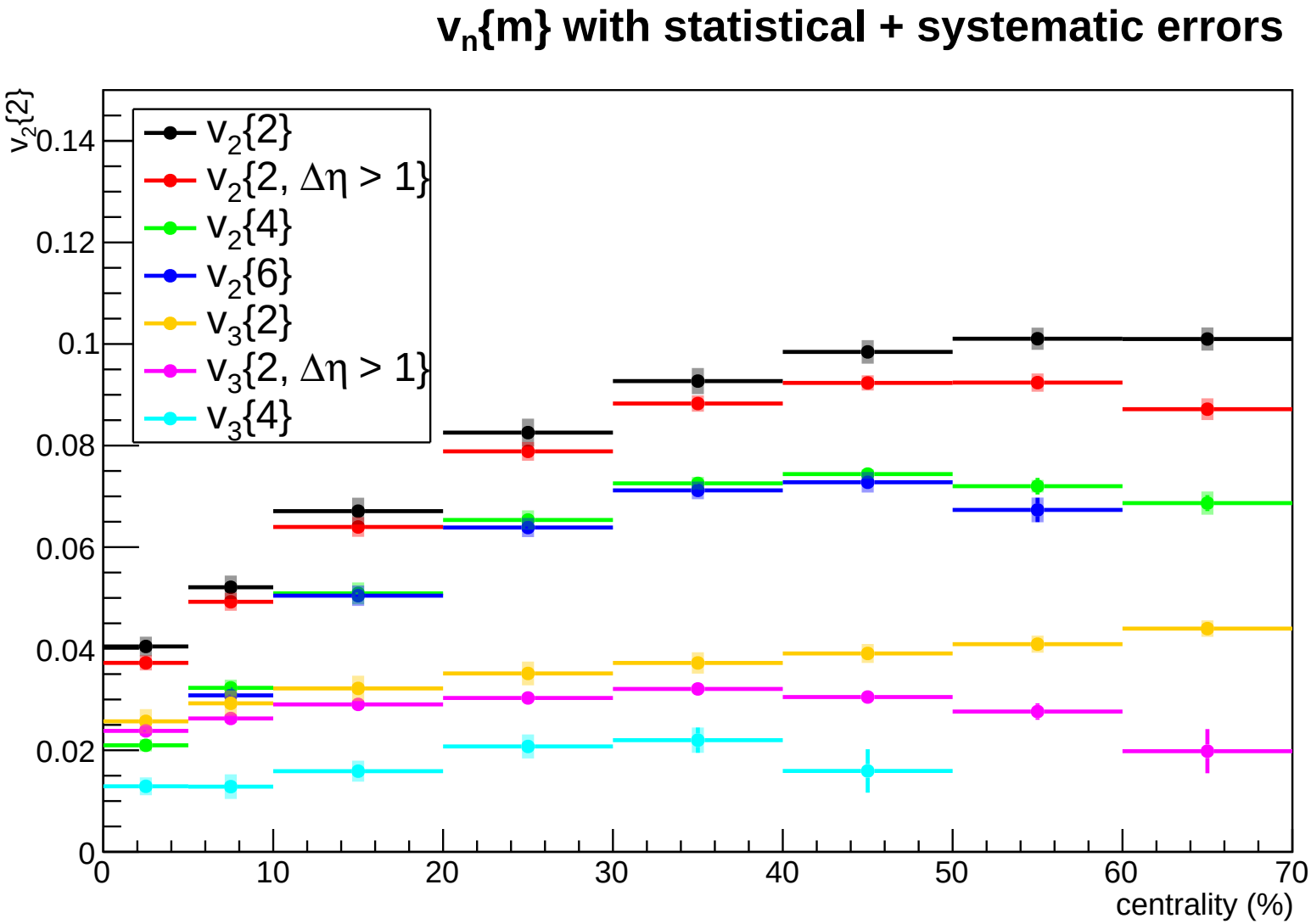


New collision system: Xe-Xe

- $^{129}\mathrm{Xe}$ ions were collided during one day in October 2017
- Excellent opportunity to search for new physics results
- Smaller system: can be used together with Pb-Pb results to constrain theoretical models
- About one million events were analysed
- I carried out similar measurements as in Pb-Pb
- Worked with a paper in a group of four people

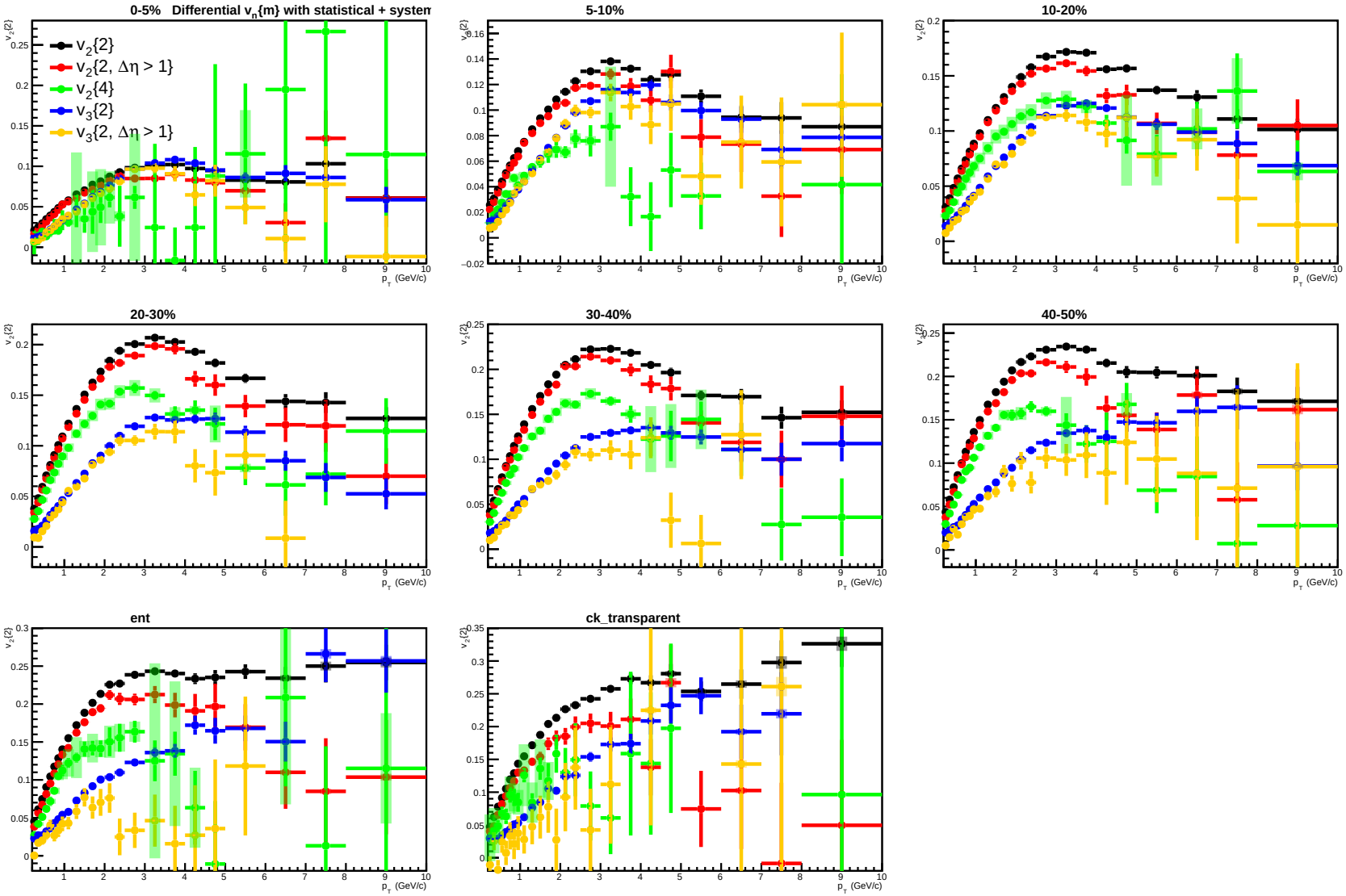
Results

Integrated measurements:



Results, cont'd

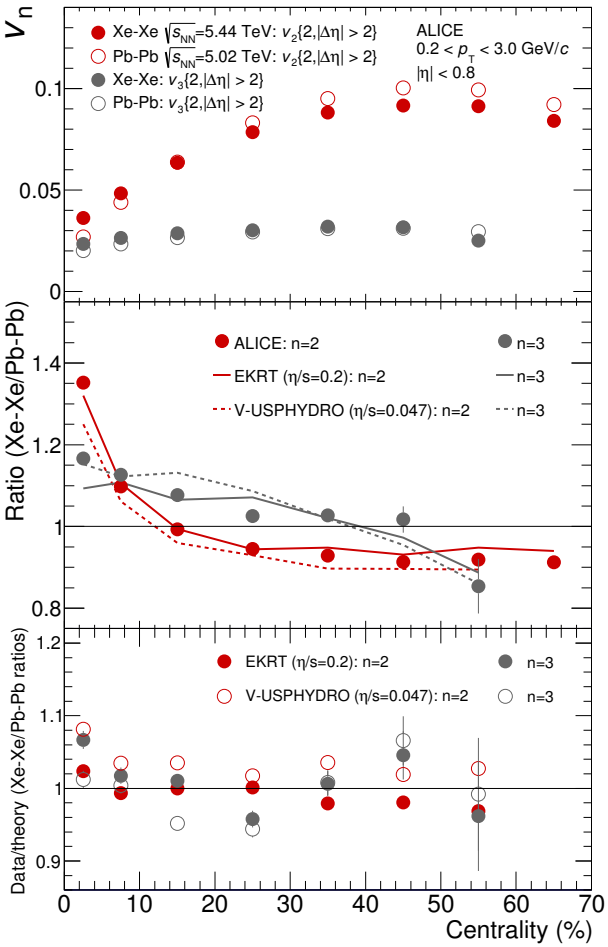
Differential measurements:

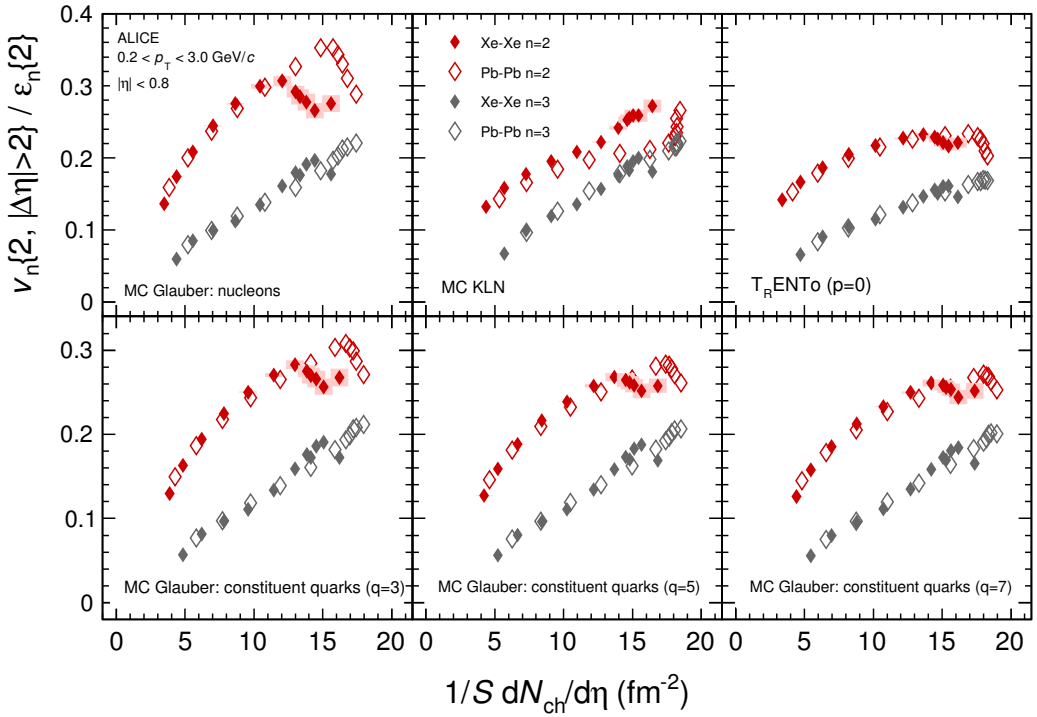


Conclusions

- My results were consistent with the ones from You Zhou for the differential measurements, but there is about a 2% difference in the inclusive ones
- Computing systematic errors is a pain
- We have a paper on arXiv, and it is submitted to PLB! arXiv:1805.01832

Physics results/conclusions (arXiv:1805.01832)



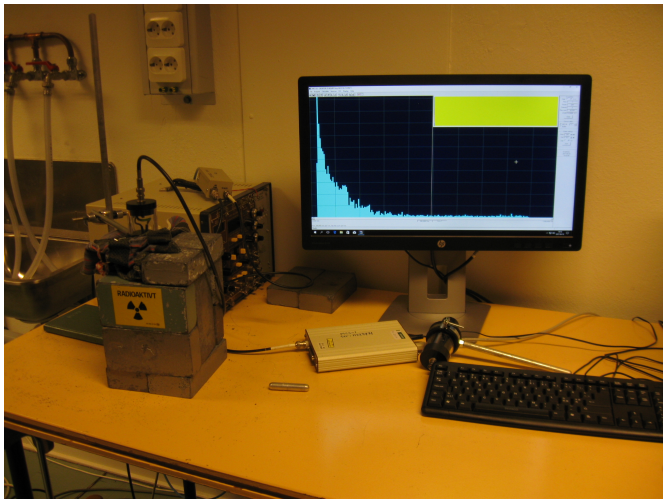


- v_n is higher in Xe-Xe in central collisions due to deformed nucleus
- Difference well described by EKRT model (a hydrodynamic model)
- E.g. MC Glauber + 5 constituent quarks (IS model) gives good scaling between the two systems

Courses

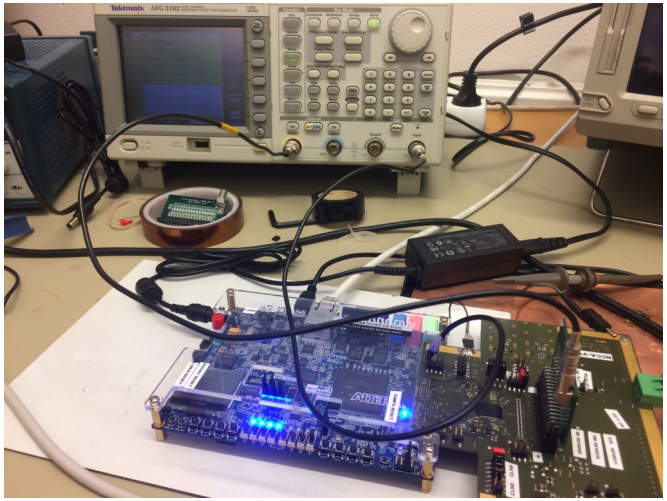
- Dark Matter: Distribution, Detection, Origin and Production, 3 ECTS - *Special course offered at our division in 2016*
- Introductory Course for Ph.D. Students, 0.5 ECTS - *Mandatory course at Science faculty*
- Introduction to Quantum Field Theory, 7.5 ECTS - *Course for Master students given at Theoretical Physics during LP3; good theoretical background*
- Computational Tools and Recipes, 7.5 ECTS - *Given by COMPUTE once every few years. Lots of exercises. I need to take care of this...*
- CERN School of Computing, 6 ECTS - *Computing-related summer school, given at a different place each year.* ***Strongly recommended!***
- Teaching and Learning in Higher Education, 4.5 ECTS. *Pedagogical course given at the Science Faculty. Consider taking this if teaching*
- Particle Physics Phenomenology, 7.5 ECTS. *Good background for physics at hadron colliders*

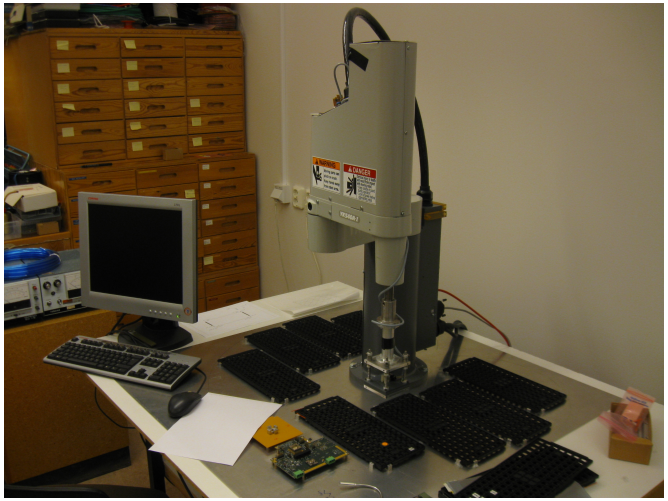
Teaching



- Lab supervision in 1st year physics together with Martin
- K3 lab: Neutron activation and half-life determination (in Swedish)
- Going for the muon lab next year

Future plans





- Starting with automatic chip testing later this month
- Analysis of flow of identified particles this summer
- Possible presentation at Hot Quarks conference in September
- Moving on to studying flow of Ξ and Ω in p-Pb to investigate origin of strangeness enhancement in heavy ion collisions, from autumn 2018 on
- Courses: GEANT4 course (September), Detector school (Copenhagen/Helsinki, October-November)

Summary

- Flow is an important observable for systems in thermal equilibrium
- I have analysed and compared results from Pb-Pb and Xe-Xe to constrain models
- Recommended summer school: CERN School of Computing
- Robotic chip testing and flow of identified particles in the near future

Thank you for your attention!