The ALICE Experiment

Henrik Qvigstad
henrik.qvigstad@fys.uio.no

University of Oslo

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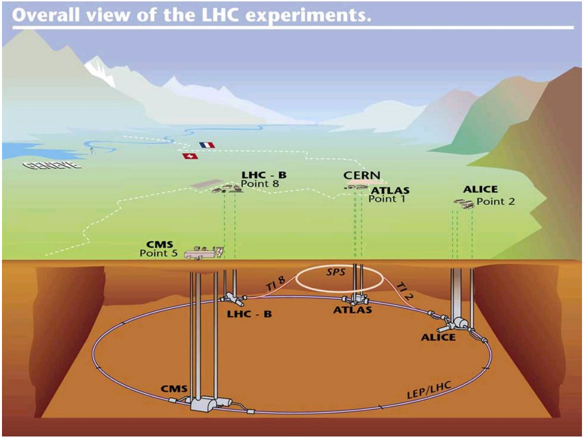
The Large Hadron Collider



Beam of (Design):

- p-p at 7 TeV, $\sqrt{s} = 14\,\text{TeV}$, and
- Pb-Pb at 2.76 TeV, $\sqrt{s} = 5.5\,\text{TeV}$

Why We Collide

particles and nuclei

For Particles, collisions inform:

- structure,
- fundamental interactions, and
- resonances (particles.)

For Nuclei, collisions inform:

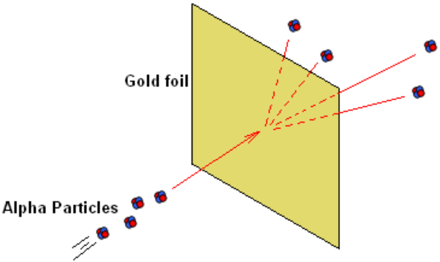
- structure,
- collective effects,
- nuclear phase diagram.

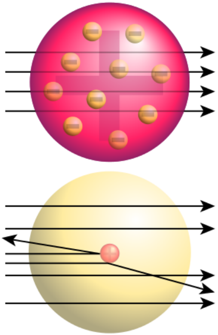
Why We Collide

Particles

Collisions provide information about structure.

- The classic Rutherford Scattering:





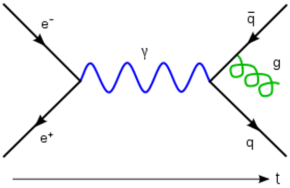
with GeigerMarsden (Gold foil) experiment disproved the plum pudding model in favor of nuclear model.

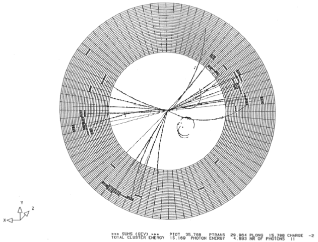
Why We Collide

Particles

Collisions provide information about fundamental interaction

- Electron-positron annihilation produce "3-Jet Topology" events:





interpreted within the standard model to be product of $q\bar{q}$ creation and radiation of gluons through QCD Bremsstrahlung.

Why We Collide

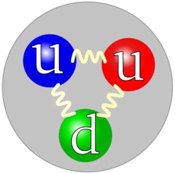
Composite Particles

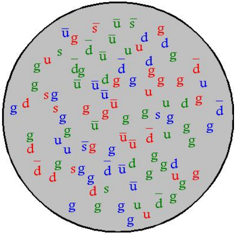
Protons

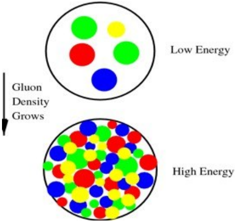
- can be accelerated at a smaller accelerator radius

, and collisions of

- provide a large range of discovery.







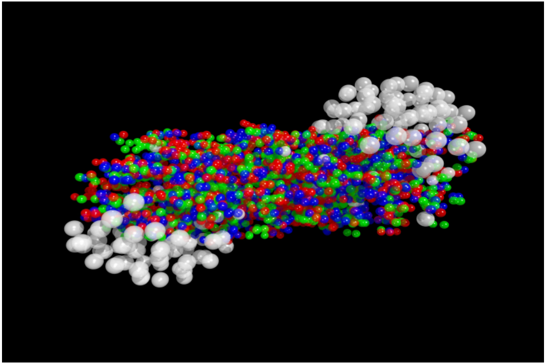
A proton-proton collision at LHC typically consists of ~ 10 hard interactions (collisions).

Why We Collide

Nuclei

Nuclear collisions

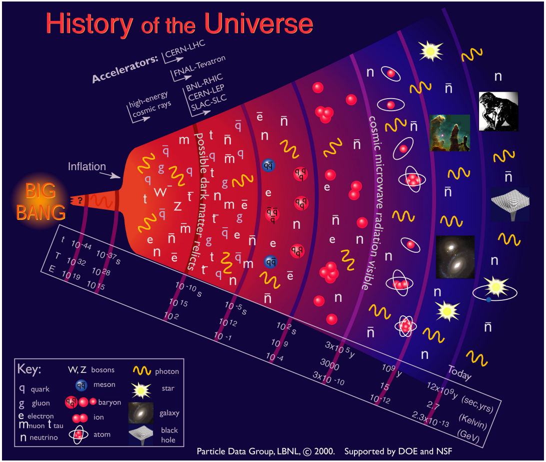
- provide an insight into the collective behavior of high density, high energy density, Nuclear Matter.



Why We Collide

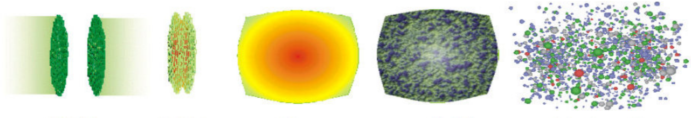
Nuclei, QGP

The beginning of the universe was also quite dense and hot.

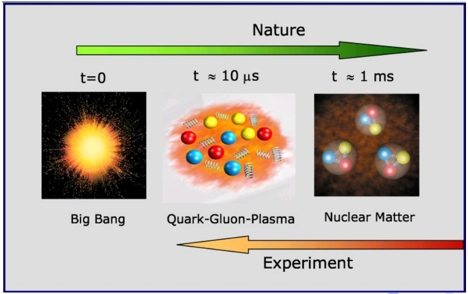


Quark Gluon Plasma

The evolution of the nuclear matter in an nuclear - nuclear collisions

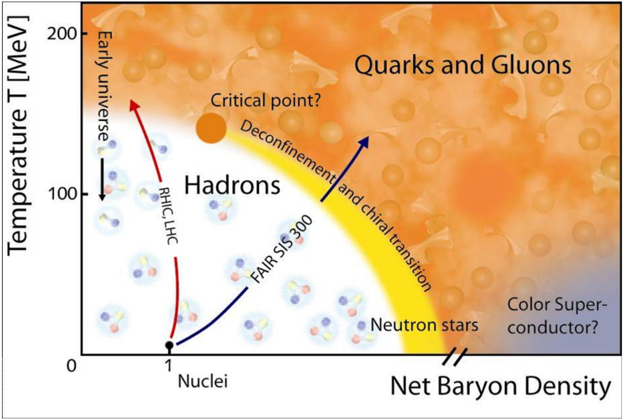


, produces a state of matter not seen since $t \simeq 10^{-6}$ after The Big Bang.



Quark Gluon Plasma

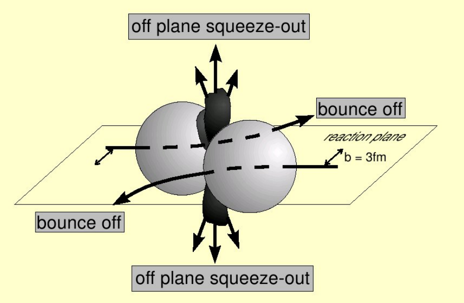
What is QGP really?
Imagine an Nuclear Phase Diagram,



with an transition/crossover to an de-confided state of quarks and gluons.

Flow

Non-central Nuclear-Nuclear collisions exhibit flow:

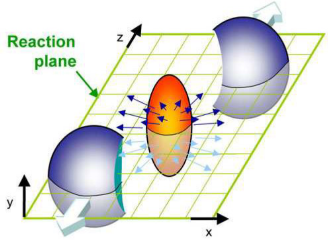


In "low" energy collisions, this is considered the product of:

- Bounce-Off, the collective "deflection" of the "spectating" region of the collision, and
- Squeeze-Out, pressure gradiants act out of plane for the "participating" region of the collision.

Flow

At "high" energy, flow is an product of the anisotropi of an non-central collision.



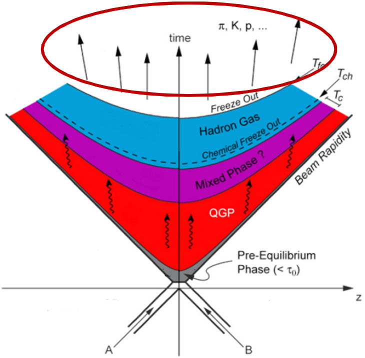
Flow can be mathematically described as

$$\frac{dN}{d\phi} \propto \frac{1}{2\pi}\left[1+\Sigma_{n=1}^{\infty} 2v_n \cos n(\phi-\Psi_n)\right] \quad (1)$$

$$\propto 1 + 2v_1 \cos\phi + 2v_2 \cos 2\phi + \ldots \quad (2)$$

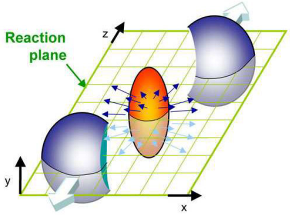
Flow

Flow is an product of all the stages of the collision



- Understanding all the phases of the collision and the their contribution to the final state is an massive undertaking.
- Flow components are essential to understanding the collision in terms of Hydrodynamic Models.

Flow



The Equation Of Stadte (EOS), the relationship between Temperature, Pressure, and Volume, is informed by the two first flow components.

- Direct Flow, v_1,
- Elliptic Flow, v_2.

The higher order flow components,

- v_3, v_4...

contain information about Viscosity.

Photons

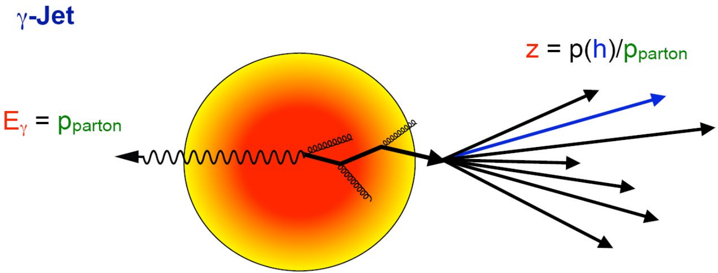
Photons are not affected by the nuclear medium of the collision, and are thus excellent candidates as an direct probe of the interaction in the medium.

Sources of Photons:

- Direct Photons
  - Prompt Photons, photons from initial hard scattering;
  - Fragmentation Photons, photons that are part of the fragmentation of an quark into a jet;
  - Thermal Photons;
  - Bremsstrahlung of high momentum quarks in the medium.
- Decay Photons,
  - decay of mesons, π^0, η, ω, ...
  - pair production, bremsstrahlung,
  - ...

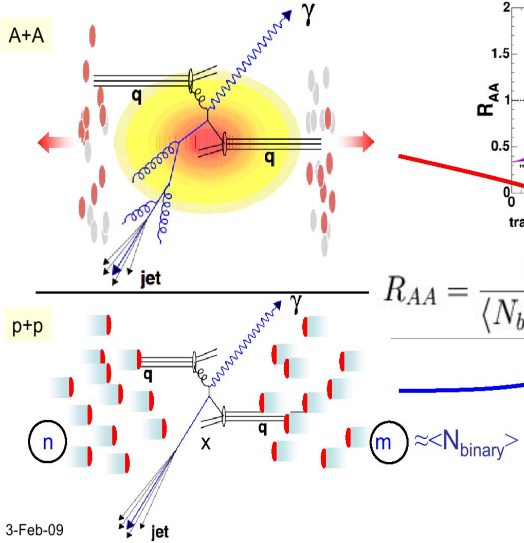
Photon-Jet

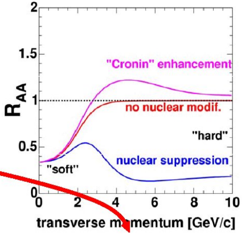
Hard scatterings of patrons give rise to photon-jet, $gq \to \gamma q$,



- The photon escapes the medium un–perturbed.
- The quark looses energy through Nuclear Bremsstrahlung as it traverses the medium.

R_{AA}





$$R_{AA} = \frac{d^2N_{AA}/dp_{\mathrm{T}}dy}{\langle N_{binary}\rangle d^2N_{pp}/dp_{\mathrm{T}}dy}$$

varies with impact parameter ***b***

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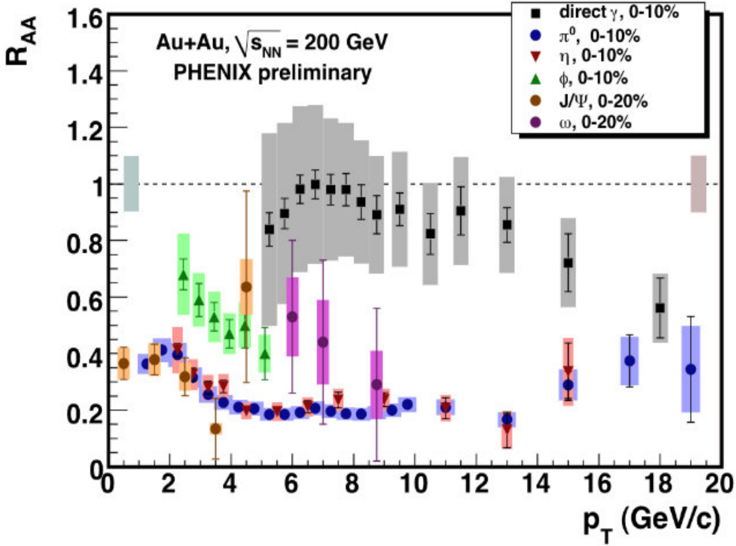
R_{AA}



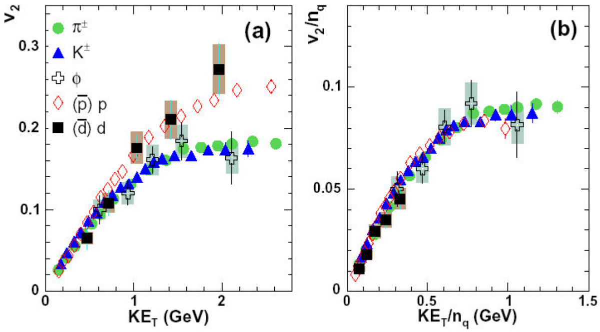


Figure: quark scaling at the PHENIX, RHIC

ALICE

(A Large Ion Collider Experiment)

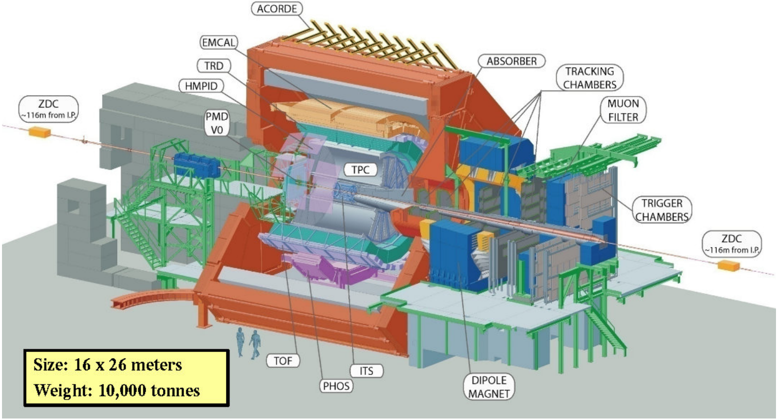


Figure: ALICE Detektor Eksperimentet

ALICE

(A Large Ion Collider Experiment)

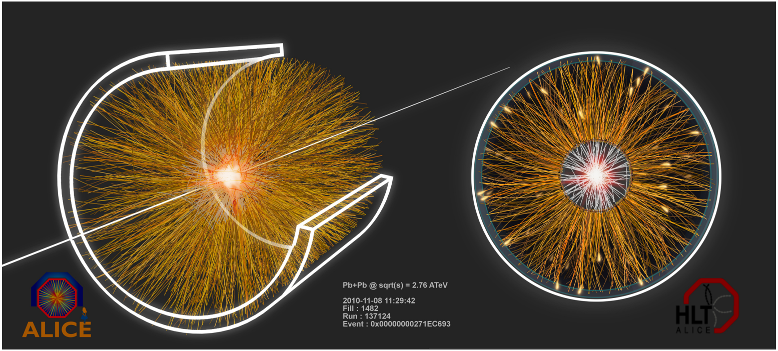
Only a small selection of particles have a lifetime large enough to reach the detectors:

- Charged Particles, e.g. $e^{-/+}$, $\mu^{-/+}$,$\pi^{-/+}$, $p/\bar{p}$, and $K^{-/+}$;
- Photons (γ);
- Neutrons ($n/\bar{n}$); and
- Neutrinos: ν_e, ν_μ, ν_τ, $\bar{\nu}_e$, $\bar{\nu}_\mu$, and $\bar{\nu}_\tau$.

Charged Particles are measured by the tracking detectors (ITS/TPC/TRD) Photons/Hadrons are measured by calorimeters (PHOS/EMCAL). Together with special purpose detectors (HMPID/TOF/ACORDE/TRD) particle identification is achieved for a large range.

ALICE Tracking

The tracks of an heavy Ion Collisions:

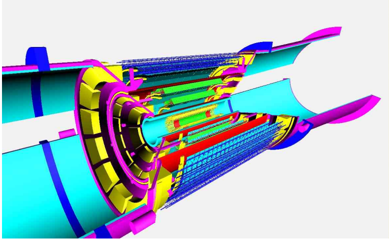


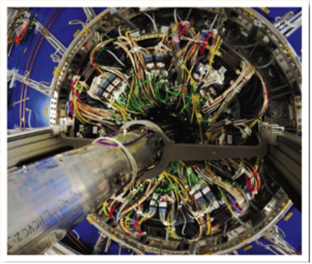
. The measurement and reconstruction of tracks is one of the main challenges in HIC.

ALICE Tracking
ITS

The Inner Tracking System (ITS) of ALICE consists of 6 Layers:

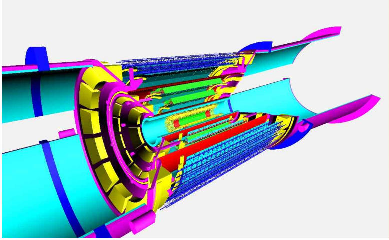
- 2 Layers of Silicon Pixel Detectors (SPD),
- 2 Layers of Silicon Drift Detectors (SDD), and
- 2 Layers of Silicon Strip Detectors (SSD).

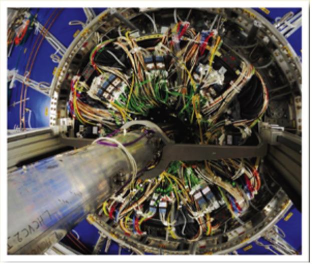




ALICE Tracking
ITS

The Inner Tracking System (ITS):

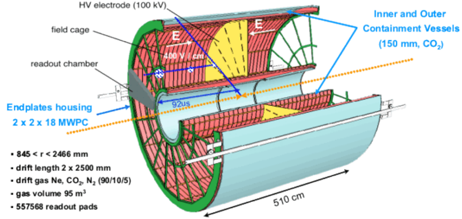




- is used for vertex determination, and in conjunction with the TPC for track parameterisation.

ALICE Tracking
TPC

The Time Projection Chamber (TPC)



- . Charged particles Ionize the contained $Ne\text{-}CO^2$ gas. The ions travel toward the central electrode, and the electrons travel towards the end planes, where they are measured.
- Position on the plane combined with the drift time, gives position in 3D-space.
- dE/dx is measured through ionization charge.

PID and tracking

The momentum of an particle traversing the TPC can be measured by finding the radios of its track:

$$R = \frac{p_T}{qB} \quad (3)$$

Identification can be achieved when this momentum is combined with energy loss:

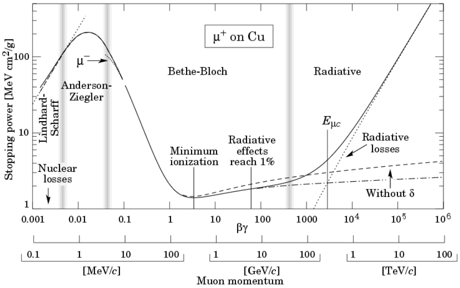


Figure: Stopping power for positive muons in copper ($\frac{dE}{dx}$)

ALICE Tracking
PID

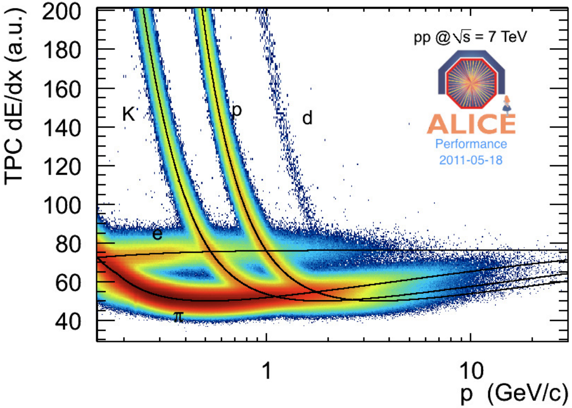
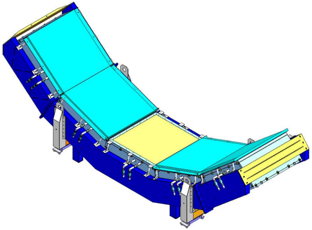


Figure: TPC $\frac{dE}{dx}$ momentum performance.

ALICE Calorimeters



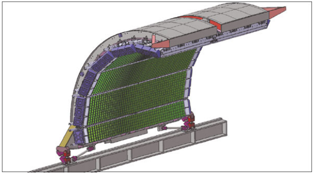
The Photon Spectrometer (PHOS), is

- high energy resolution,
- high granularity (position),
- small acceptance,

electromagnetic calorimeter.

The ALICE ElectroMagnetic Calorimeter (EMCAL)

- is of lower resolution,
- but has higher acceptance.



PHOS

The ALICE PHOton Spectrometer

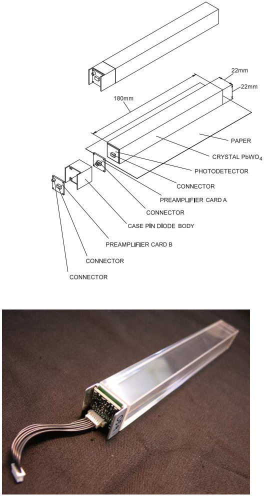


Figure: A diagram and image of the assembly of a single PHOS cell.

Figure: A PHOS Module

- At design, PHOS consists of 5 modules, each containing 64×56 cells positioned in a array.
- Each cell consists of a $PbWO_2$ scintillation crystal and a Avalanche Photo–Diode (APD).
- The crystals are 18 cm long, or

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PHOS

The ALICE PHOton Spectrometer

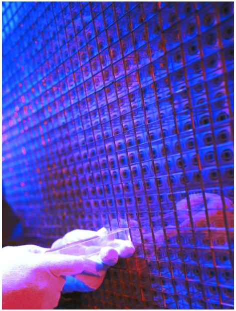


Figure: Close–up of the front of a crystal array.

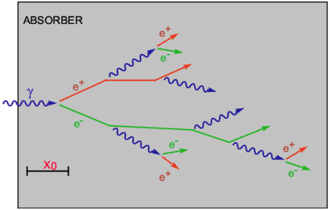
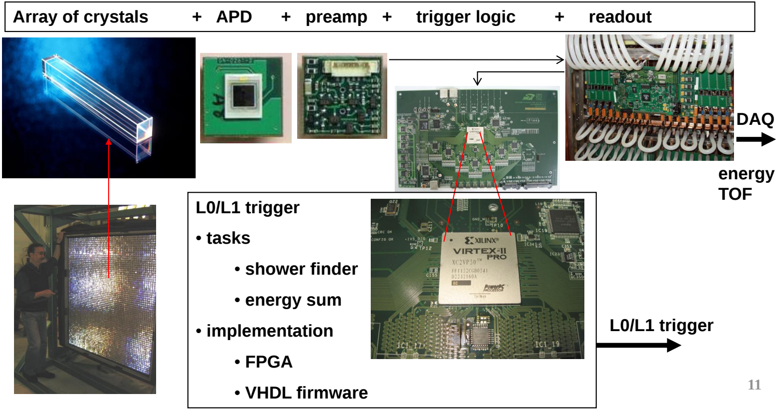


Figure: Illustration of an Electron Magnetic Shower. X_0 is an "Radiation Length".

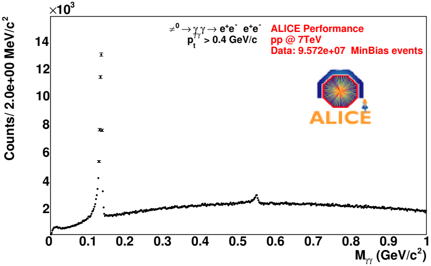
- A high energy photon (or electron) entering PHOS deposits its energy in the form of a electromagnetic shower.
- The cell APDs measure this energy in the form of scintillation light.

PHOS

Electronics



PHOS



arXiv: 1103.2217

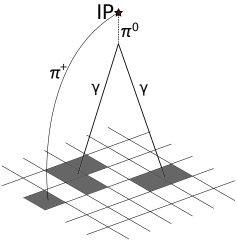
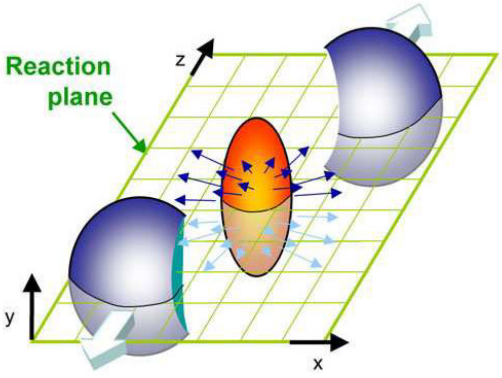


Figure: Invariant mass distribution of all photon pairs with $p_T > 0.4\,\mathrm{GeV/c}$

Physics Part II: The Results

Elliptic Flow



Remember, flow that happens in-plane*, Elliptic Flow, has a positive v_2,

$$\frac{dN}{d\phi} = 2v_2 \cos 2\phi.$$

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Elliptic Flow

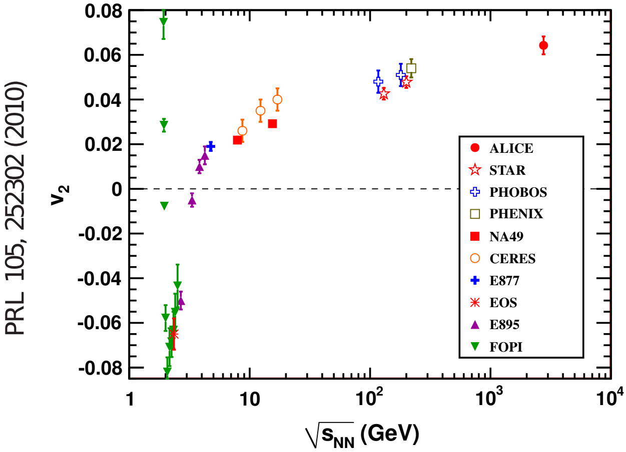


Figure: Integrated elliptic flow at 2.76 TeV in Pb-Pb 20%-30% centrality class compared with results from lower energies taken at similar centralities.

Elliptic Flow

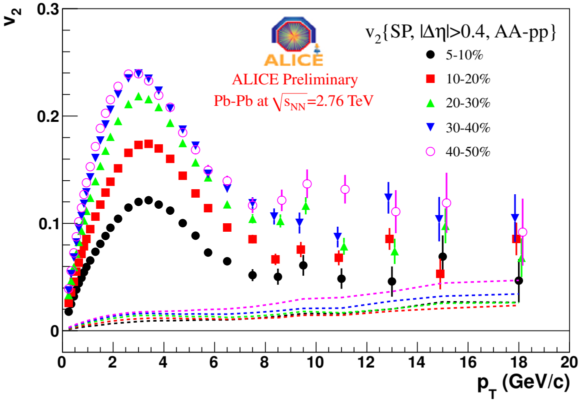


Figure: Integrated elliptic flow at 2.76 TeV in Pb-Pb

Elliptic Flow

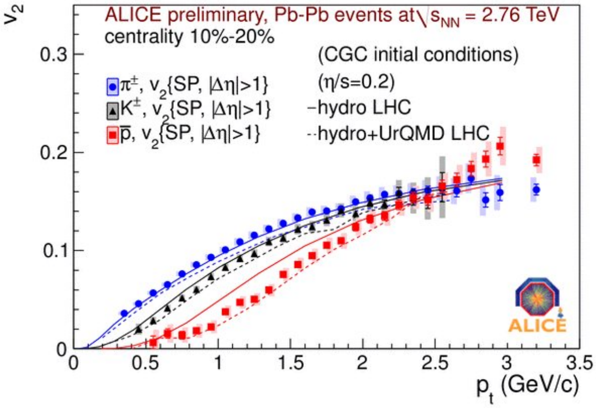
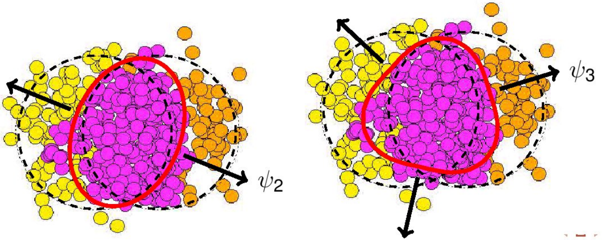


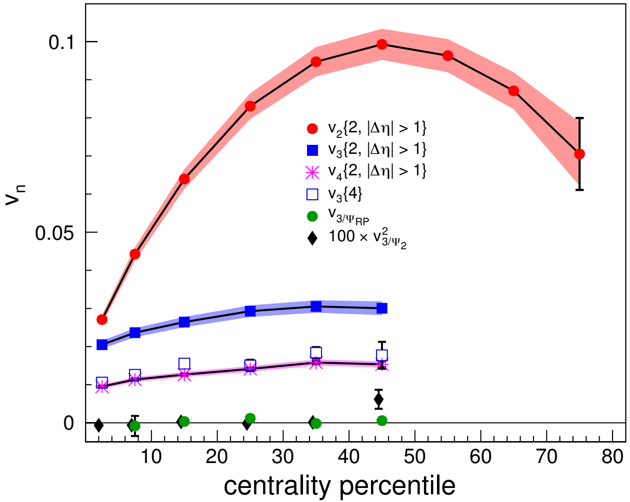
Figure: Preliminary elliptic flow of Identified particles in ALICE. Take note of mass splitting.

Flow, Higher harmonics

Higher harmonics of flow has gotten allot of attention as of late:



Flow



PRL 107, 032301 (2011)
arXiv: 1105.3865

Figure: measurement of higher harmonics of flow at ALICE. The Low contribution of higher order flow components indicates high viscosity.

R_{AA}

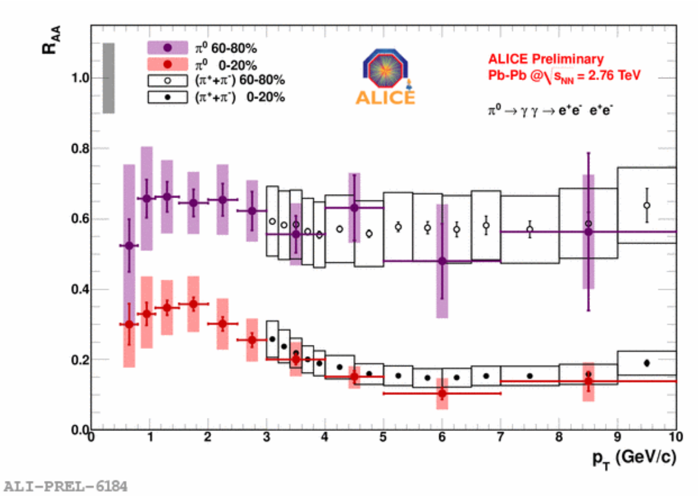


Figure: pion RAA in central (0-20) and peripheral (60-80)

My Work

- I started studying for a bachelor at UiB Fall 2004
- continued with a master in Nuclear Physics with the Bergen Nuclear/ALICE group Fall 2007, where I
  - did testing of electronics for PHOS, and
  - wrote a thesis based on a study of the π^0 based calibration algorithm of PHOS.
- I started as an PhD Student at UiO Spring 2010, where I am involved
  - with the analysis of data from the Trigger System of PHOS,
  - contribute to the maintenance/development of PHOS and its control system,
  - am studying the possibility of an production cross section measurement of the η' meson,
  - and am currently functioning as the Run Coordination Representative for PHOS, which entails 100% presence at CERN for the period.

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H. Qvigstad

Fin

Contacts for the ALICE group in Oslo:

- Trine S. Tveter (group leader): trine@lynx.uio.no
- Matthias Richter (postdoc): matthias.richter@fys.uio.no
- Henrik Qvigstad (Phd): henrik.qvigstad@fys.uio.no

ALICE Norway is also present in Bergen (UiB, HiB).
Also, take note of the opportunity to come to CERN as an summer students.