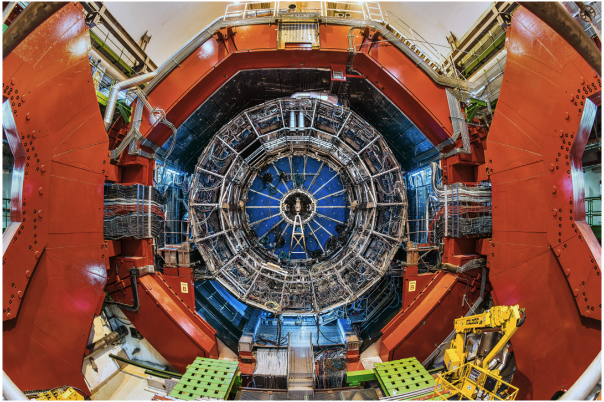


Introduction to ALICE and heavy-ion physics

Mike Sas

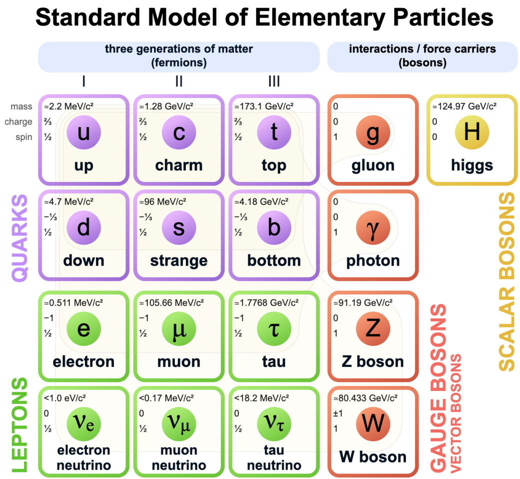
CERN

December 1, 2023

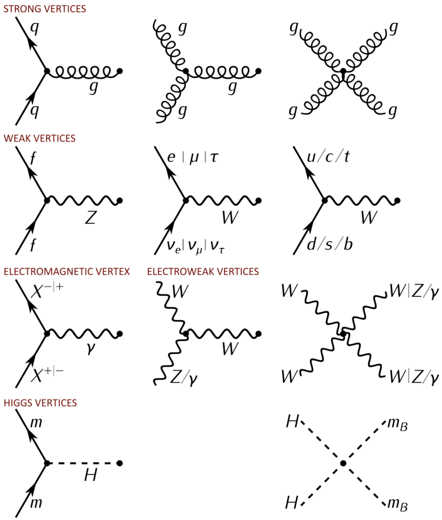
The standard model

What are...:

- fundamental particles?
- hadrons?
- mesons and baryons?
- leptons, gauge bosons?
- Higgs..
- how are forces mediated?
- why are there no single quarks?

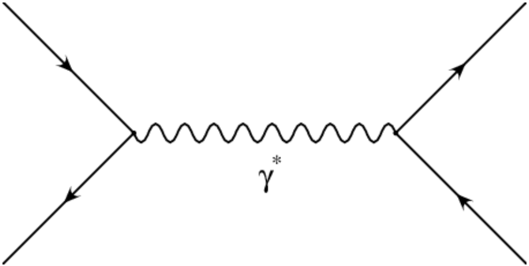


Feynman diagrams



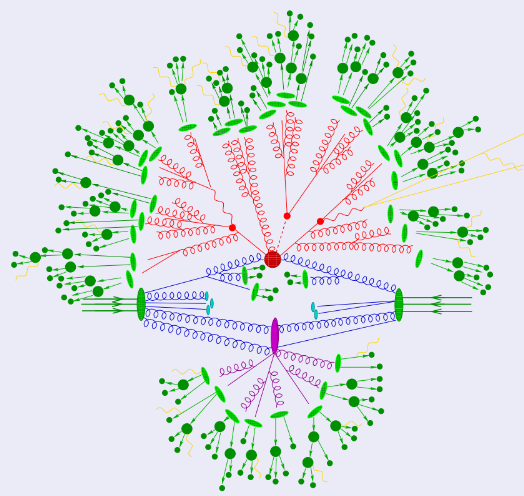
e^+e^- collision

- Simplest collision
- Colliding fundamental particles produce extremely clean events

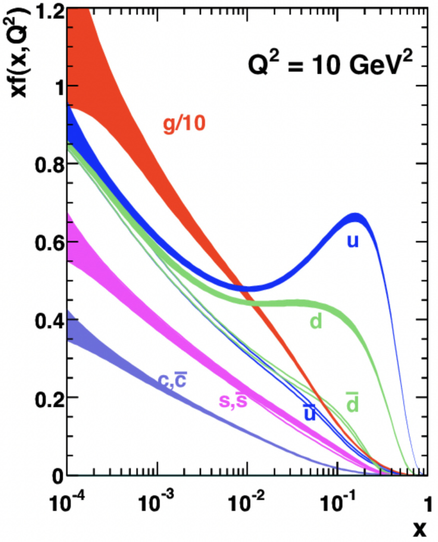


pp collision

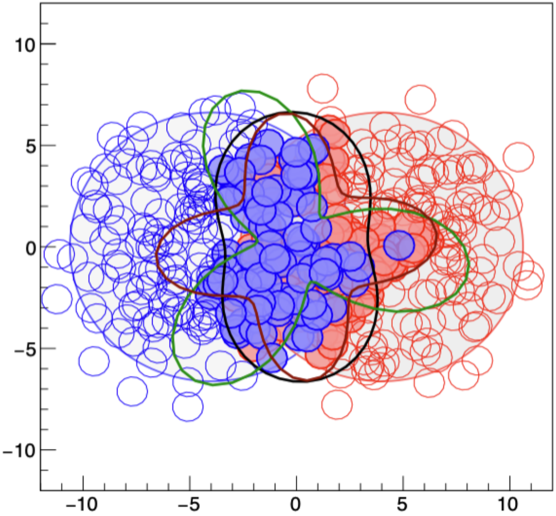
- pp collisions are something different...
- What is a proton?



pp collision

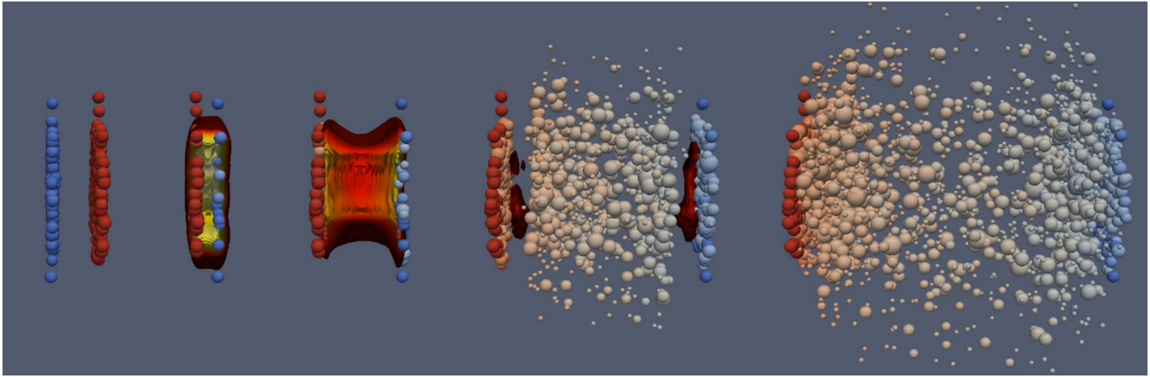


Heavy-ion collisions



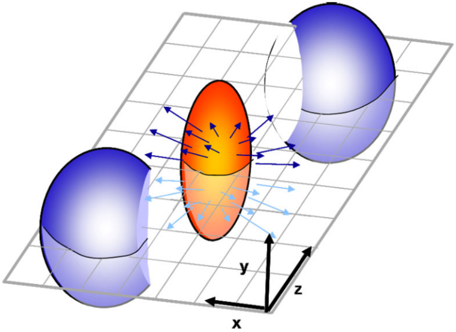
Heavy-ion collisions

Initial state → QGP → hadronization → hadron cascades



Geometry of a heavy-ion collisions

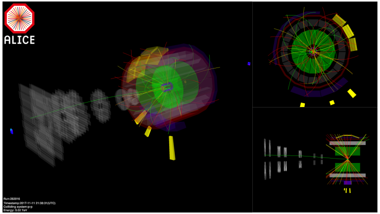
- Why do we name it heavy-ion collisions?
- Colliding in many different ways..!
- The shape of the QGP will have many implications on our measurements!



My big questions in heavy-ion physics

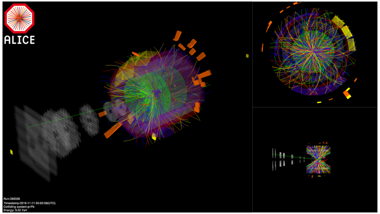
- What are the different particle production mechanisms across different system sizes?
- How does the Quark Gluon Plasma form, evolve, and transition again into hadronic matter?
- Can we find the onset of the QGP? $\rightarrow$ Is there a QGP droplet formed in small systems?

pp



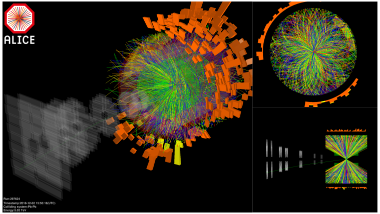
$N_{\mathrm{particles}} \sim 10^1$

p–Pb



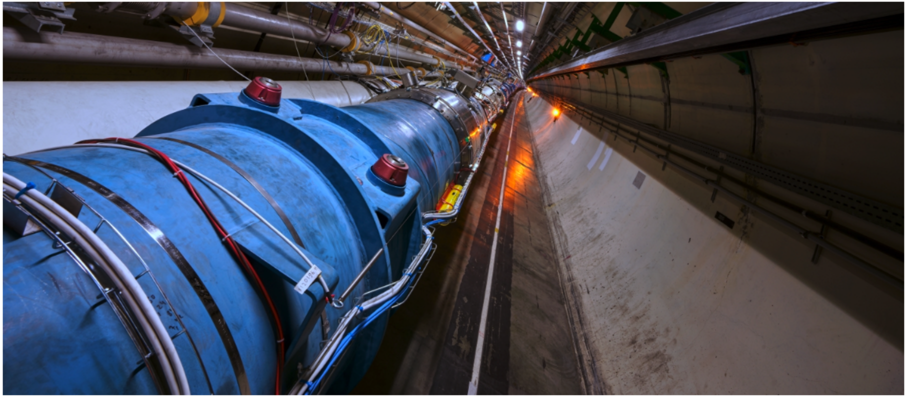
$N_{\mathrm{particles}} \sim 10^2$

Pb–Pb

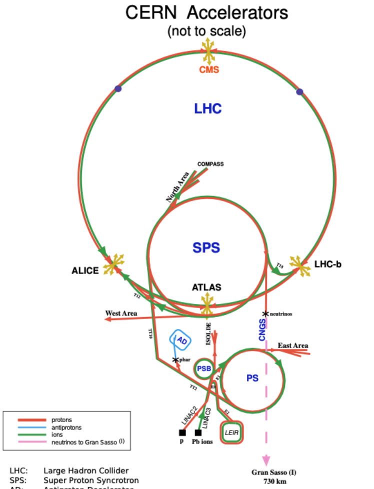


$N_{\mathrm{particles}} \sim 10^4$

LHC tunnel



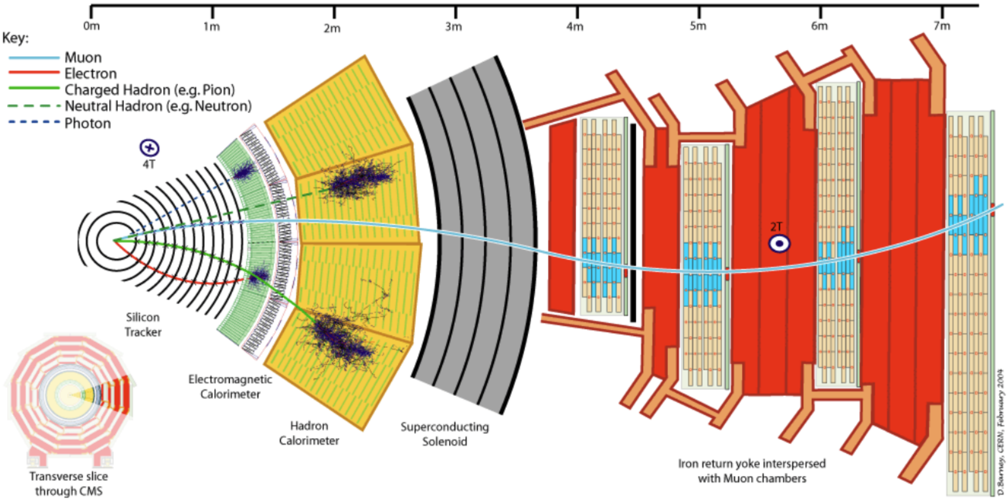
The accelerator chain



LHC:	Large Hadron Collider
SPS:	Super Proton Syncrotron
AD:	Antiproton Decelerator
ISOLDE:	Isotope Separator Online Device
PSB:	Proton Synchrotron Booster
PS:	Proton Synchrotron
LINAC:	Linear Accelerator
LEIR:	Low Energy Ion Ring
CNGS:	Cern Neutrinos to Gran Sasso

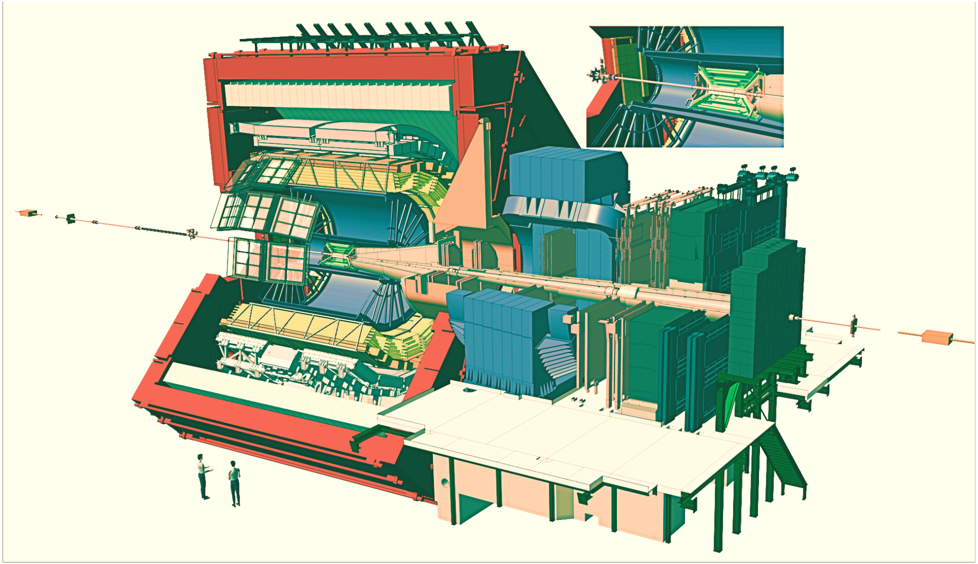
Rudolf LEY, PS Division, CERN, 02.09.96
Revised and adapted by Antonella Del Rosso, ETT Div.,
in collaboration with B. Desforges, SL Div., and
D. Manglunki, PS Div. CERN, 23.05.01

How do we measure particles - example of CMS

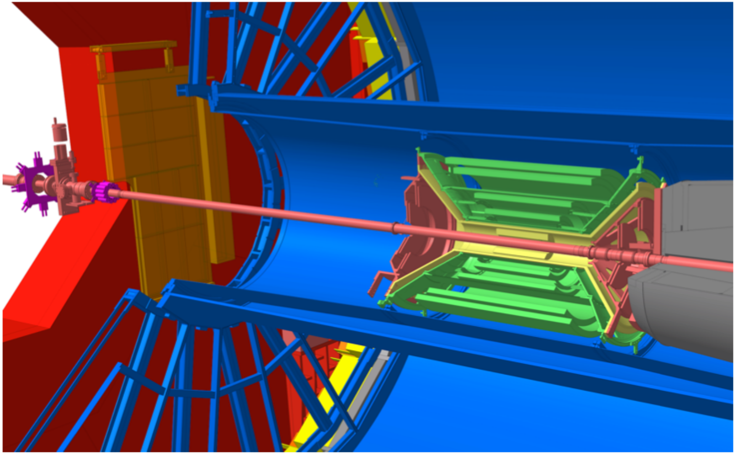


The ALICE detector

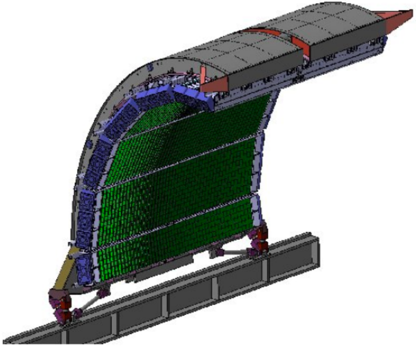
- ITS
- TPC
- EMCal
- PHOS

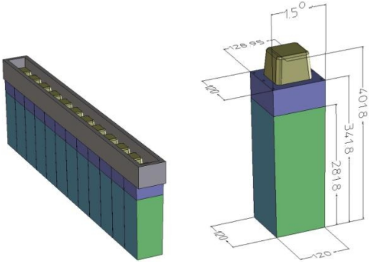


The inner barrel



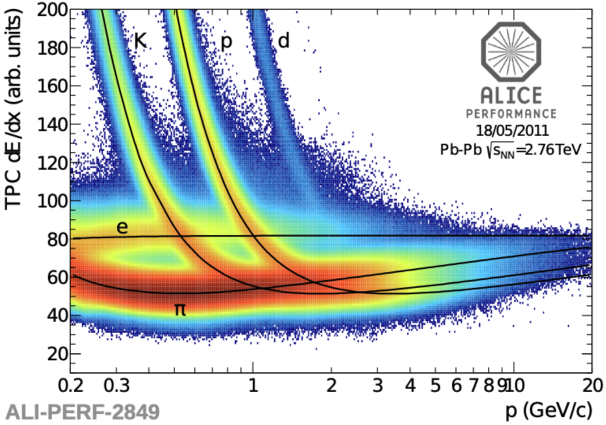
How do we measure photons?



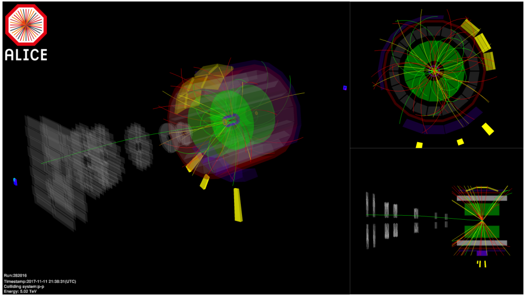


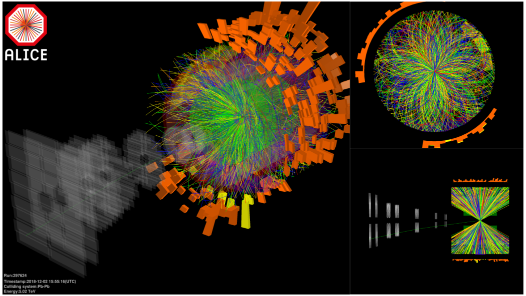
Measuring charged particles with the TPC

How do we identify particles?



From pp to Pb–Pb collisions...





Measuring photons with the ALICE detector

Photon Conversion Method (PCM)

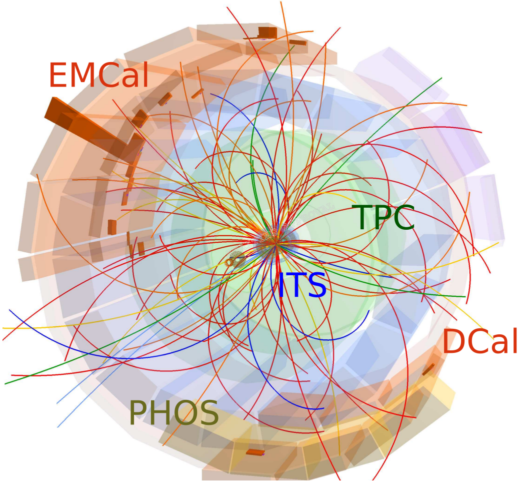
- ITS and TPC, conversion probability $\sim$ 8%
- $E_{\gamma} > 100$ MeV, $E_{\pi^0} > 300$ MeV

PHOS calorimeter

- $PbWO_4$ crystals (cell size 2.2 cm x 2.2 cm)
- $E_{\gamma} > 200$ MeV, $E_{\pi^0} > 400$ MeV

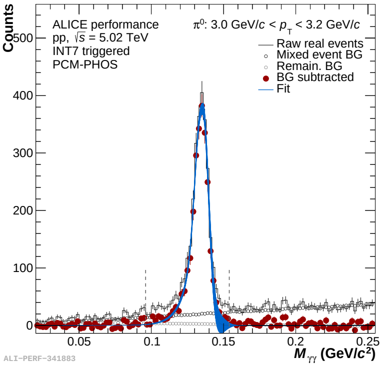
EMCal calorimeter

- Pb-scintillator towers (cell size 6 cm x 6 cm)
- $E_{\gamma} > 700$ MeV, $E_{\pi^0} > 1.4$ GeV



Particle reconstruction

$$\pi^0 \to \gamma\gamma$$

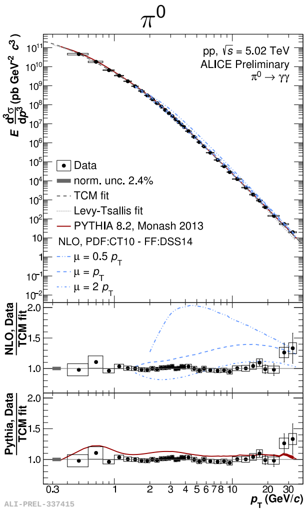


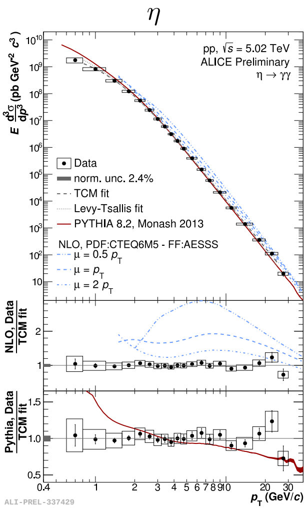
So.. how does it actually work:

$$M_{\gamma\gamma} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1-\cos(\Theta))}$$

- For every collision look at all pairs of photons
- Calculate the invariant mass and fill the histogram
- Calculate the integral of the peak, subtracting the background!

Neutral mesons in pp collisions

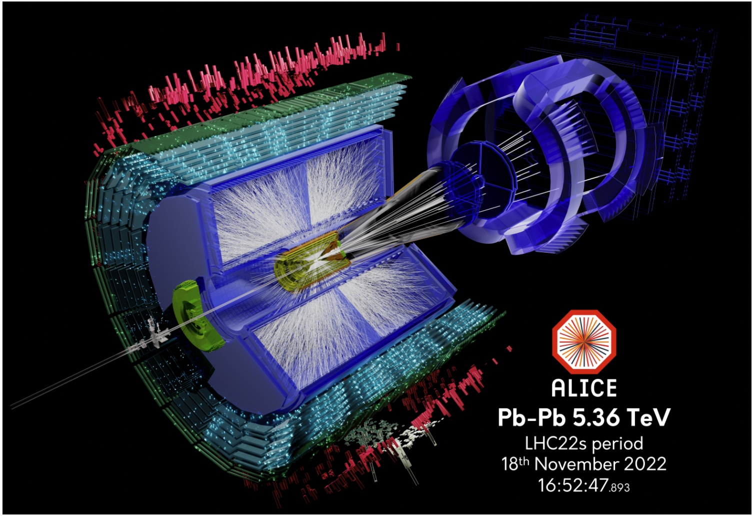




Summary

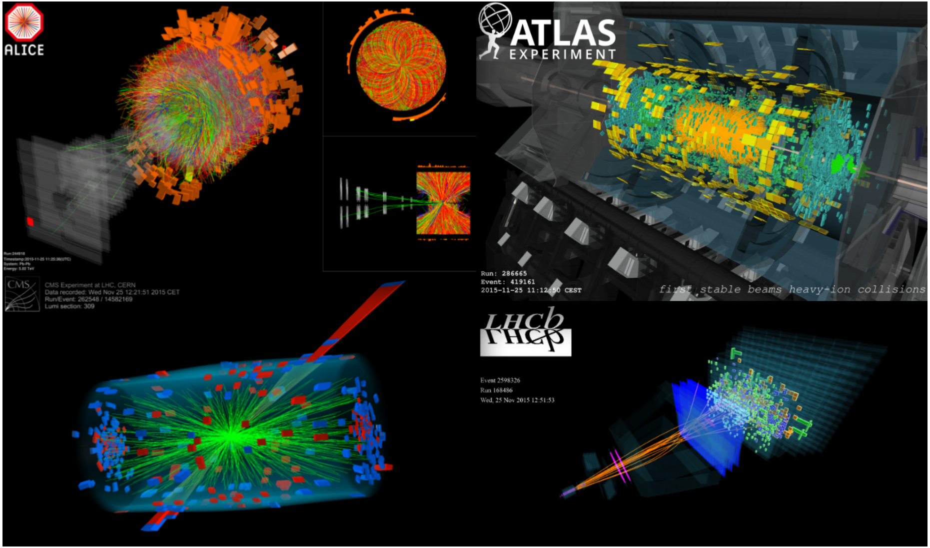
In this presentation:

- Brief introduction to particle physics and the QGP
- Showed what we are interested in at CERN and ALICE
- Questions?!

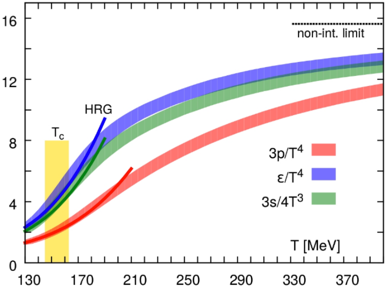


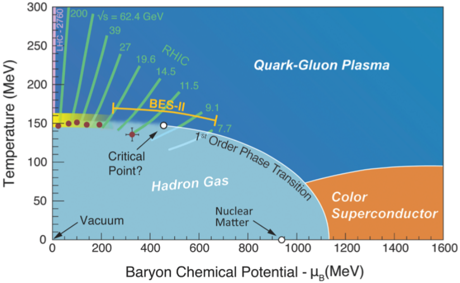
Backup

Backup – all event displays



The phase transition





- Analogous to the phase diagram of water: solid/liquid/gas/, we have one for the state of QCD matter
- Which phases do we know of? What makes this so different?
- Deconfinement!

Signatures of the QGP

- **Modified particle production**
  Particles are produced via

$$\sigma_{h_1 h_2 \to x} = f_i^{h_1}(x_1, Q^2) f_j^{h_2}(x_2, Q^2) \otimes \sigma^{ij \to k}(x_1 p_1, x_2 p_2, Q^2) \otimes D_{k \to x}(z, Q^2)$$

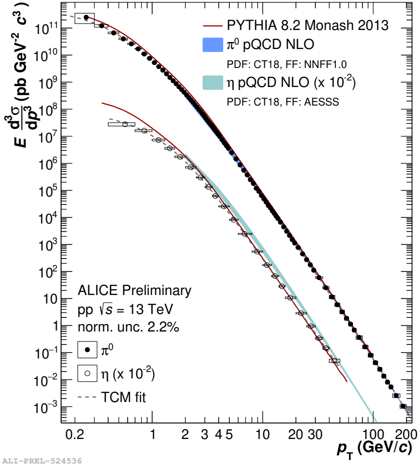
- **Energy loss**
  Particles lose energy by traversing the medium

$$R_{\mathrm{AA}} = \frac{dN^{\mathrm{AA}}/dp_{\mathrm{T}}}{< T_{\mathrm{AA}} > d\sigma^{\mathrm{pp}}/dp_{\mathrm{T}}}$$

- **Anisotropic flow**
  Spatial anisotropy of the produced system leads to a momentum anisotropy

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1 + \sum_{n=1}^{\infty} 2v_n cos(n(\varphi - \Psi_R))\right)$$

π^0 and η production



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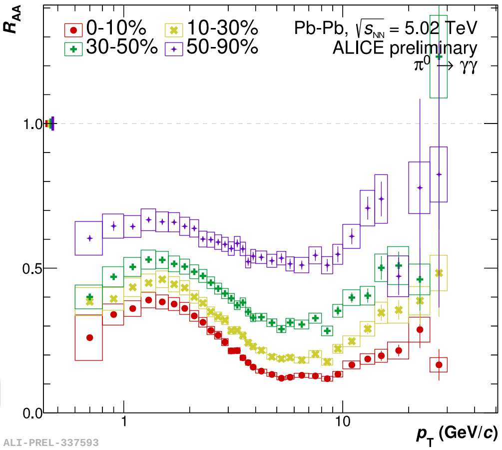
π^0 energy loss in Pb–Pb collisions



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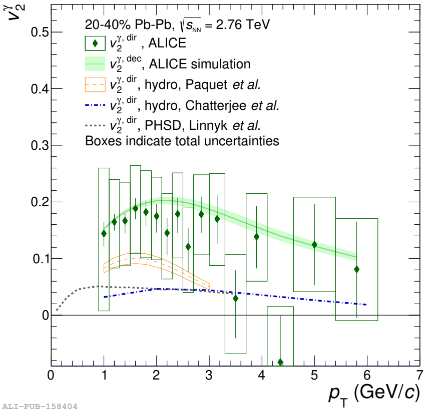
Direct photon flow in Pb–Pb collisions

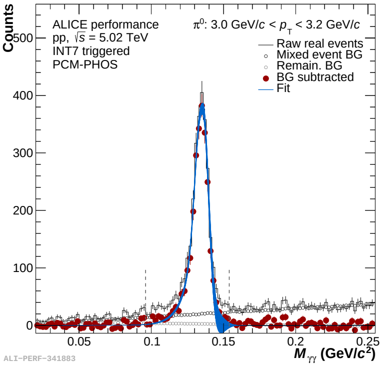


Neutral meson reconstruction in ALICE

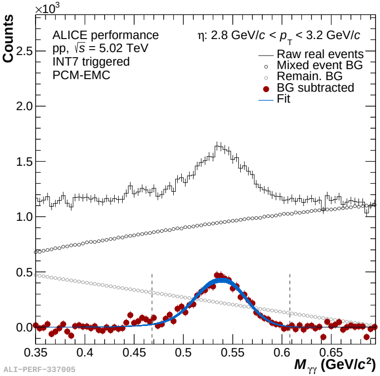
Analysis strategy:

1. Reconstruct the photons
2. Obtain the meson raw yield: integrate $M_{\rm inv}$ distributions
3. Correct raw yield for efficiency, acceptance, feed-down from secondaries
4. Combine the different reconstruction methods

π^0



η



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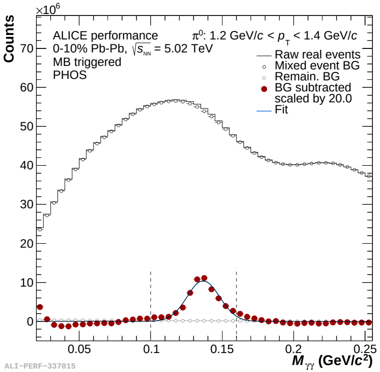
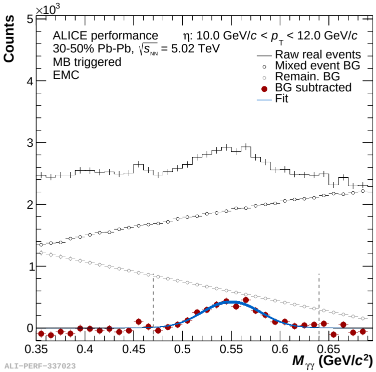


η



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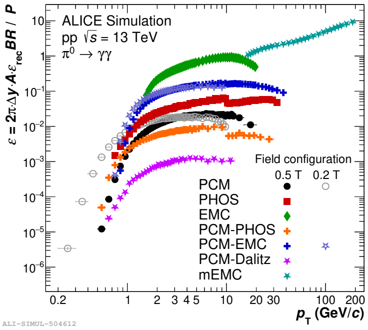

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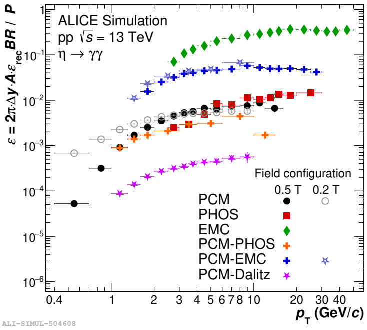

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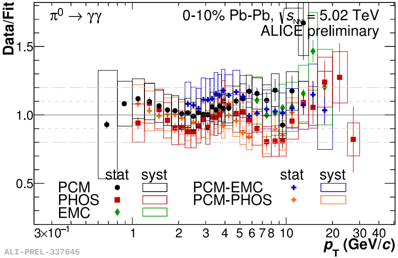
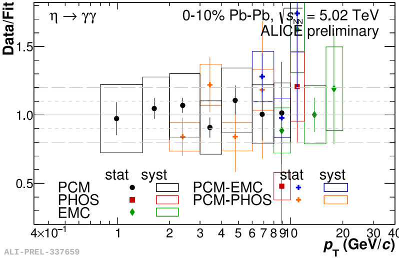


η



pp collision

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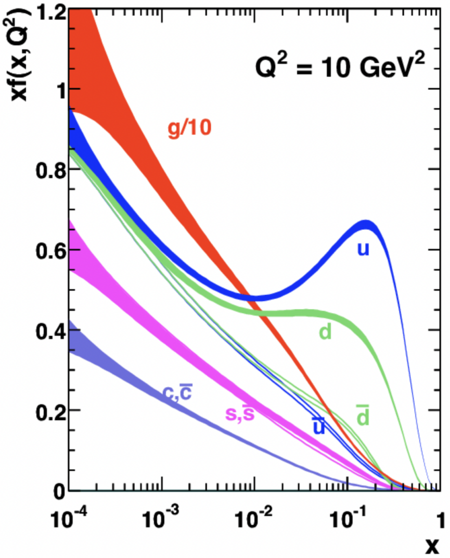
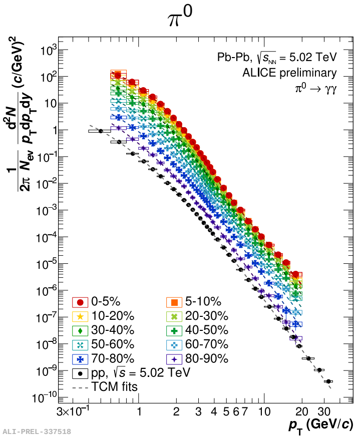
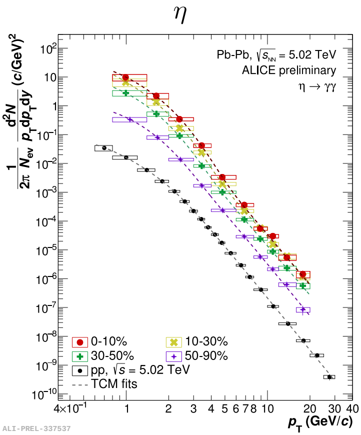
- What is a proton?



Neutral mesons in Pb–Pb collisions

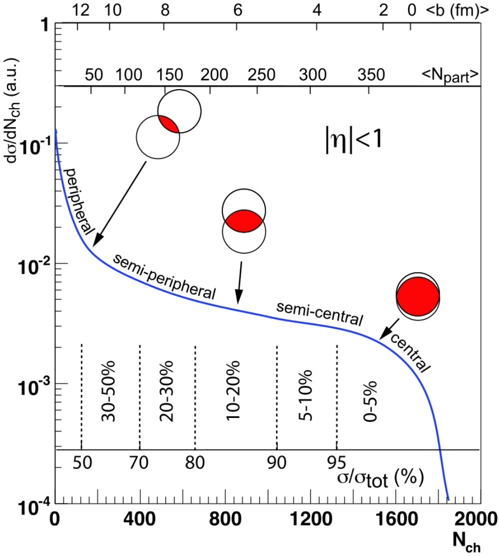




Multiplicity dependent production

- Precise spectra over large momentum range
- Allows to test model calculations, and to go towards more difficult analyses.. like trying to measuring the temperature of the QGP!

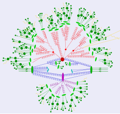
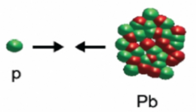
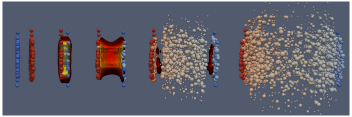
Backup – centrality



Why measure neutral mesons?

$\pi^0 \rightarrow \gamma\gamma, \quad \eta \rightarrow \gamma\gamma, \quad \omega \rightarrow \pi^0\gamma, \quad \ldots$

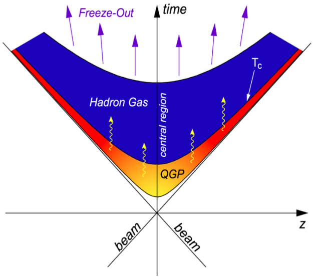
- Straightforward identification (M_{inv}) $\rightarrow$ study the particle production mechanisms
- Main background for γ_{direct} $\rightarrow$ precise neutral meson measurements lead to precise γ_{direct} measurements

pp	**p–Pb**	**Pb–Pb**
		
• Jet production • Underlying event studies	• Cold nuclear matter effects • Multiplicity dependence	• QGP effects • Centrality dependence

Direct photon production sources

Definitions:

- **Inclusive photons:** photons from any source
- **Direct photons:** photons *not* from hadronic decays
- **Decay photons:** photons from hadronic decays
- $\gamma_{incl} = \gamma_{direct} + \gamma_{decay}$



Sources of direct photons

In all collision systems:

- **prompt photons**
  - dominant at high p_{T}
  - calculable within NLO pQCD

Additional sources in AA collisions:

- **Thermal photons**
  - Scattering of thermalized particles
- **Pre-equilibrium photons**
  - Production from the glasma phase
- **Jet-Medium interactions**
  - Hard partons scattering on QGP constituents