Looking for strange particles in ALICE

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CERN-Fermilab Hadron Collider Physics Summer School
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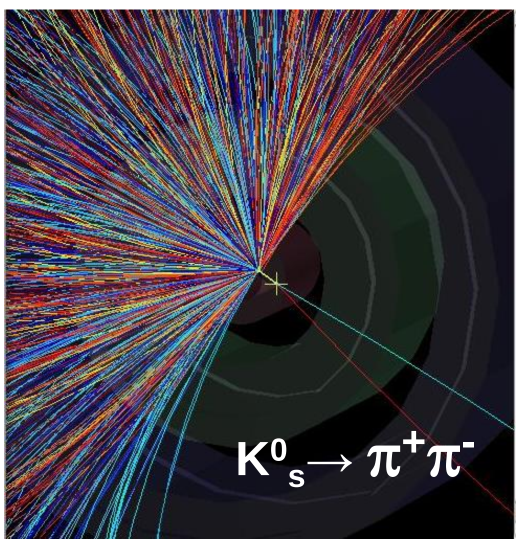
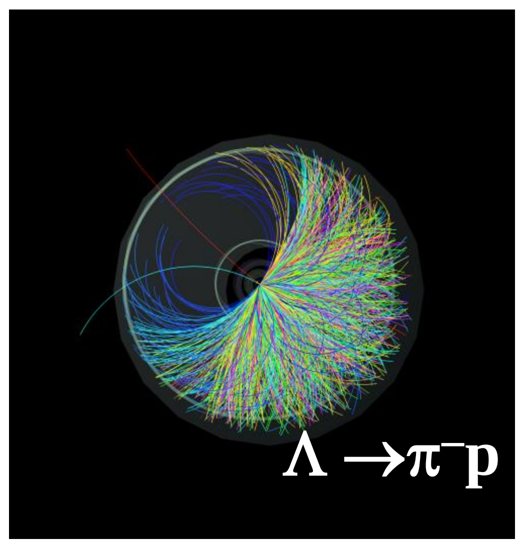
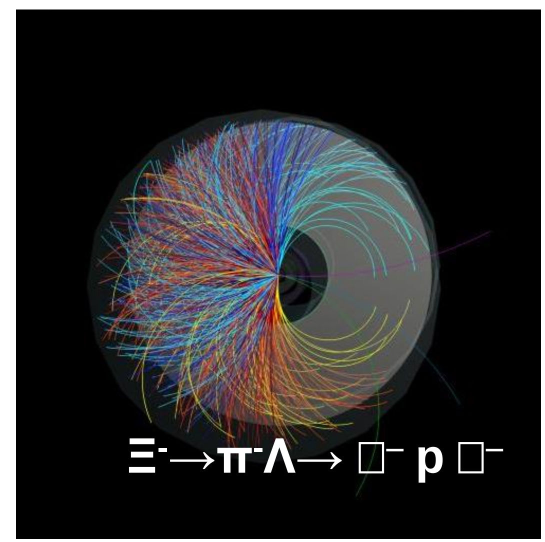
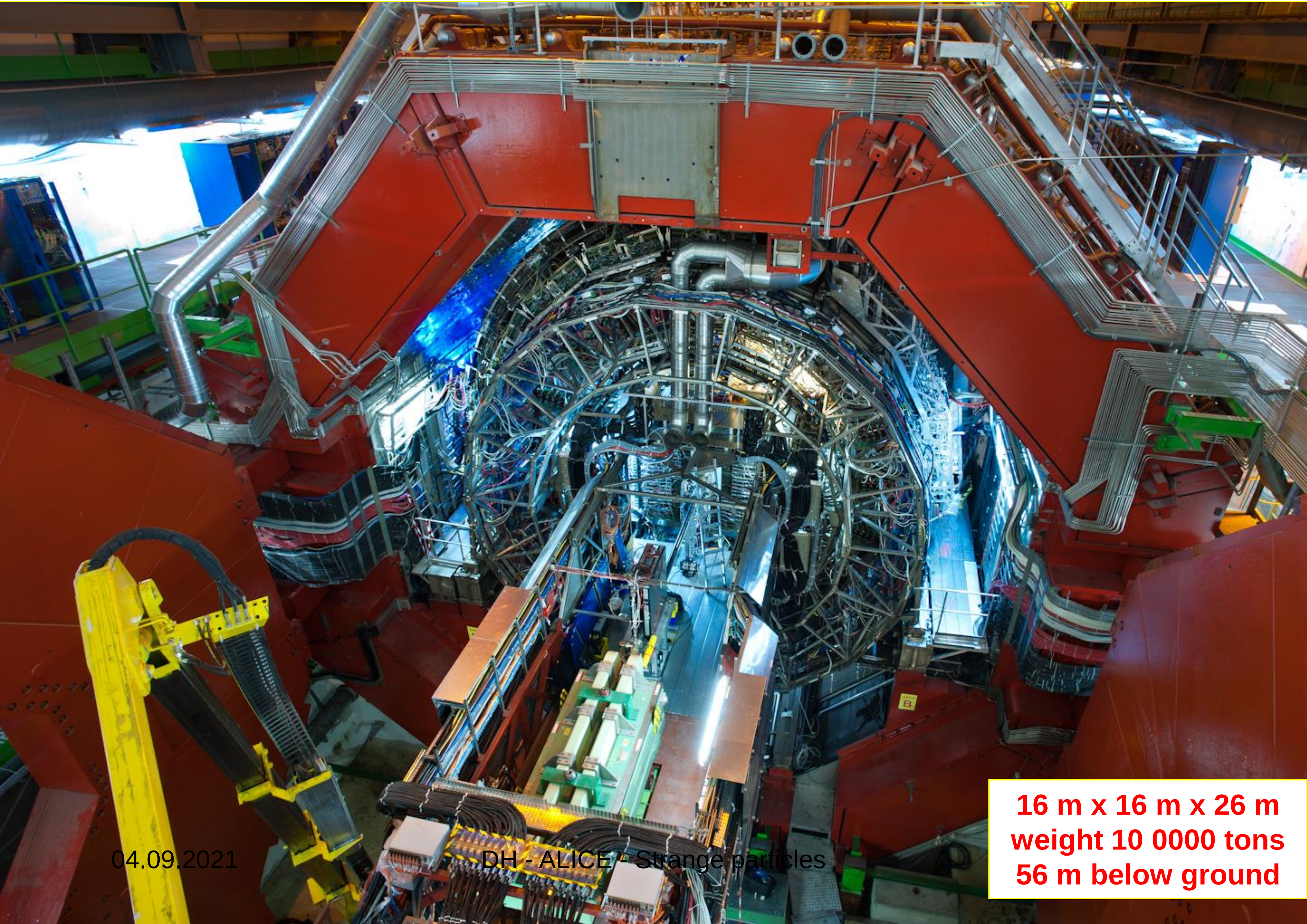






ALICE : A Large Ion Collider Experiment

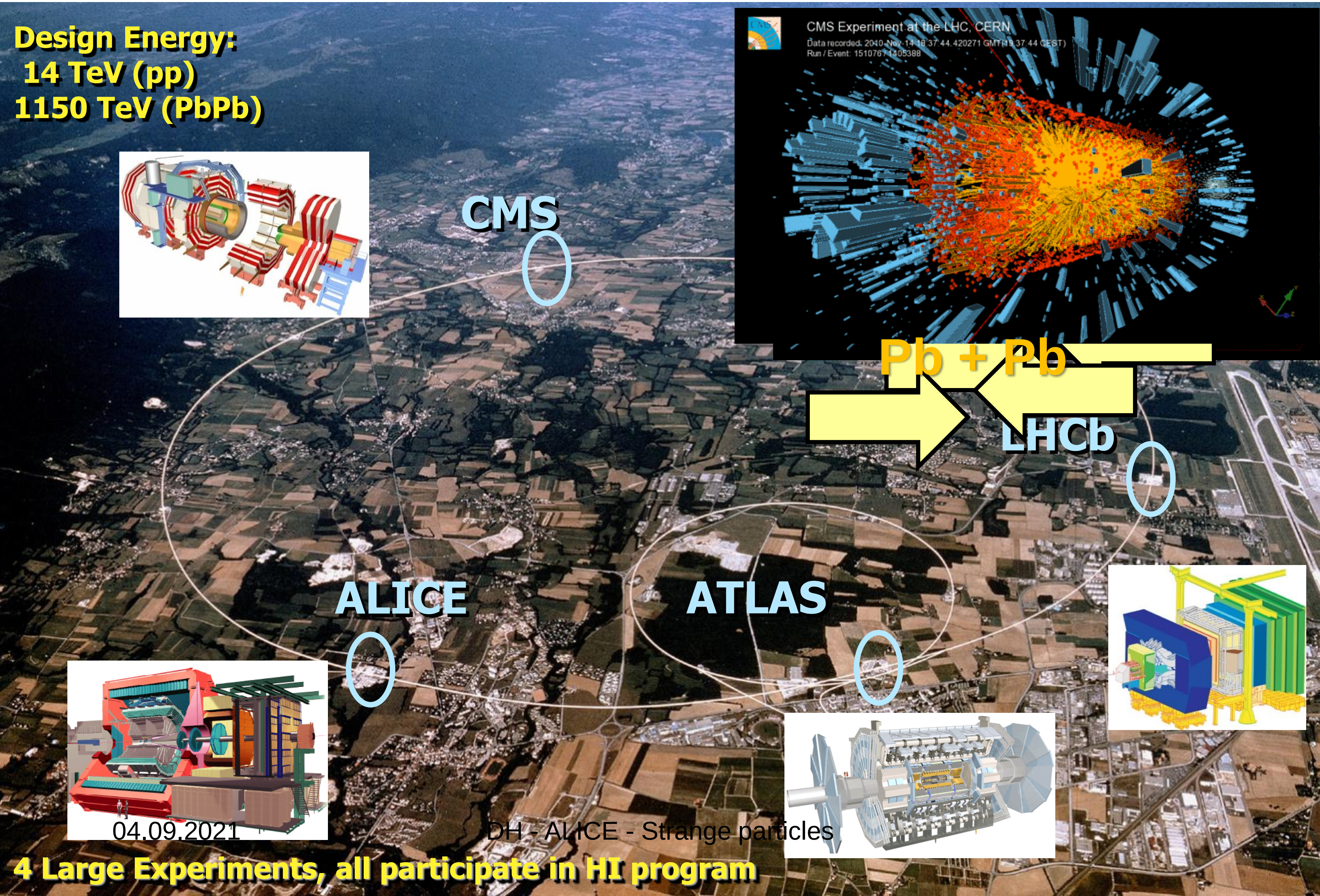


16 m x 16 m x 26 m
weight 10 0000 tons
56 m below ground

Collider of 'Large Hadrons'

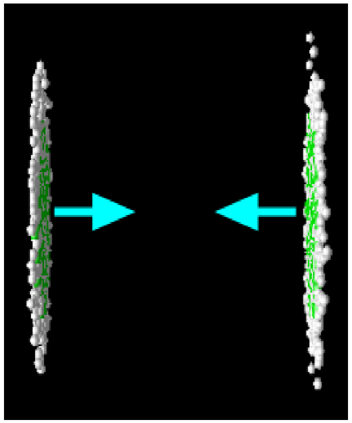
Large Hadron Collider

Design Energy:
14 TeV (pp)
1150 TeV (PbPb)

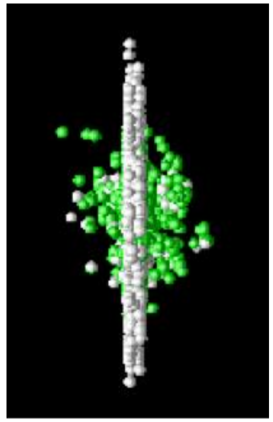


4 Large Experiments, all participate in HI program

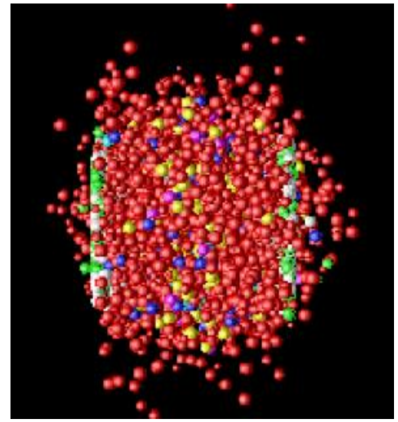
Heavy Ion Collisons at Relativistic Energies



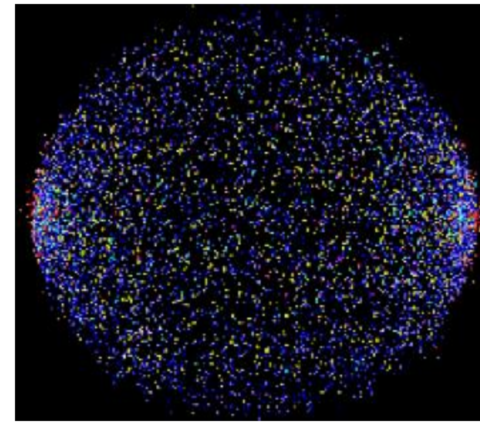
The heavy-ion beams travel at 99.9999% of the speed of light.
The two ions look flat as pancakes due to relativity (Lorentz contraction)



The two ions collide and smash through each other. Energy is transforme d into mass => new quarks and gluons



Protons and neutrons “melt” under high temperature and density; quarks and gluons exist in a deconfined state (Quark Gluon Plasma) for 10^{-23} s

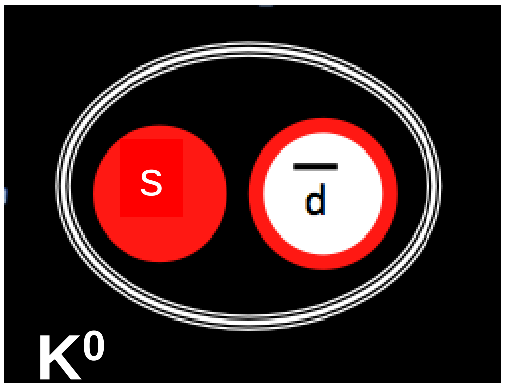


As the fireball cools down and becomes less dense quarks and gluons hadronize

Quark Gluon Plasma
Matter in the Universe up to microseconds after the Big Bang

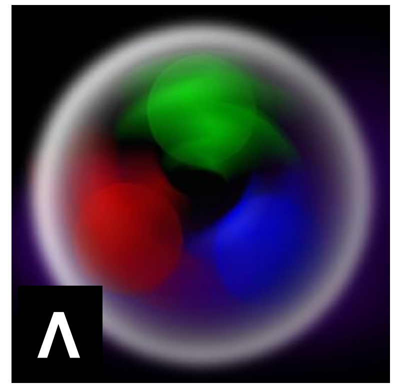
What are strange particles ?

meson

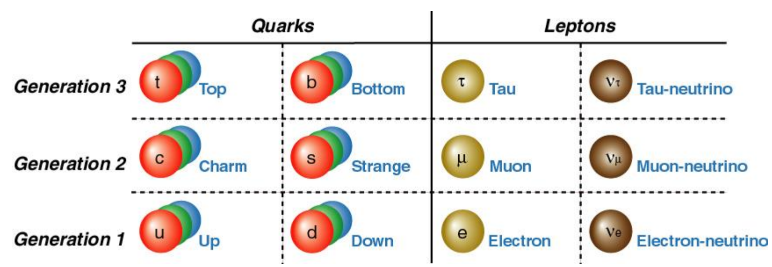


$d\bar{s}$, $\bar{d}s$

baryon



uds

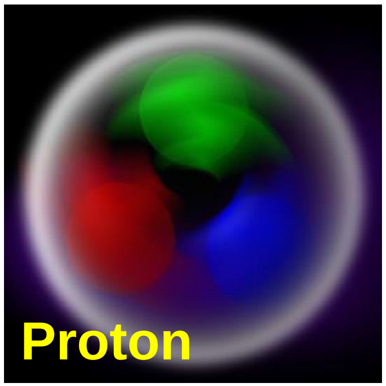


hadrons (baryons / mesons) which contain at least one strange (s) quark

Quark Confinement

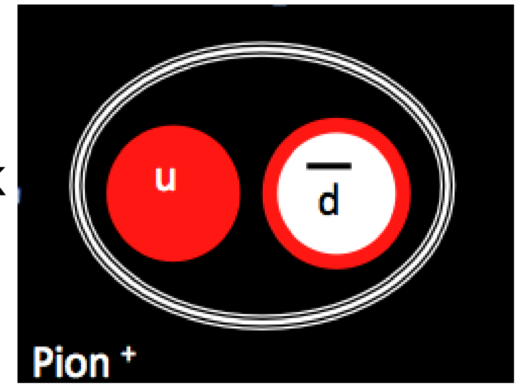
Quarks can not exist free in nature

They can only exist bound inside hadrons



baryons consisting of 3 quarks

mesons consisting of a quark and an anti-quark



Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.

These are a few of the many types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	**uud**	1	0.938	1/2
$\bar{\mathbf{p}}$	antiproton	$\bar{\mathbf{u}}\bar{\mathbf{u}}\bar{\mathbf{d}}$	–1	0.938	1/2
n	neutron	**udd**	0	0.940	1/2
Λ	lambda	**uds**	0	1.116	1/2
Ω^-	omega	**sss**	–1	1.672	3/2

Mesons $q\bar{q}$

Mesons are bosonic hadrons

These are a few of the many types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$\mathbf{u}\bar{\mathbf{d}}$	+1	0.140	0
$\mathbf{K}^-$	kaon	$\mathbf{s}\bar{\mathbf{u}}$	–1	0.494	0
ρ^+	rho	$\mathbf{u}\bar{\mathbf{d}}$	+1	0.776	1
B^0	B-zero	$\mathbf{d}\bar{\mathbf{b}}$	0	5.279	0
η_c	eta-c	$\mathbf{c}\bar{\mathbf{c}}$	0	2.980	0

We will be looking for neutral strange particles, which travel some distance (mm or cm) from the point of production (collision point) before they decay into two oppositely charged particles

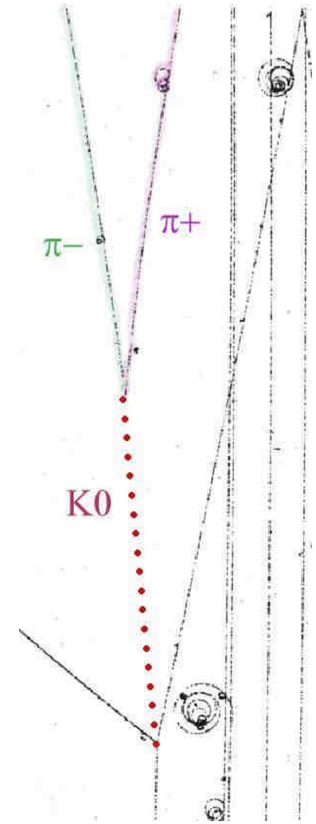
$K^0_s \rightarrow \pi^+\pi^-$

$\tau = 0.89 \times 10^{-10}$ s
$c\tau = 3 \times 10^{10}$ cm s^{-1} $\times 8.9 \times 10^{-11}$ s
2.67 cm from the point of interaction

$\Lambda \rightarrow \pi^- p$

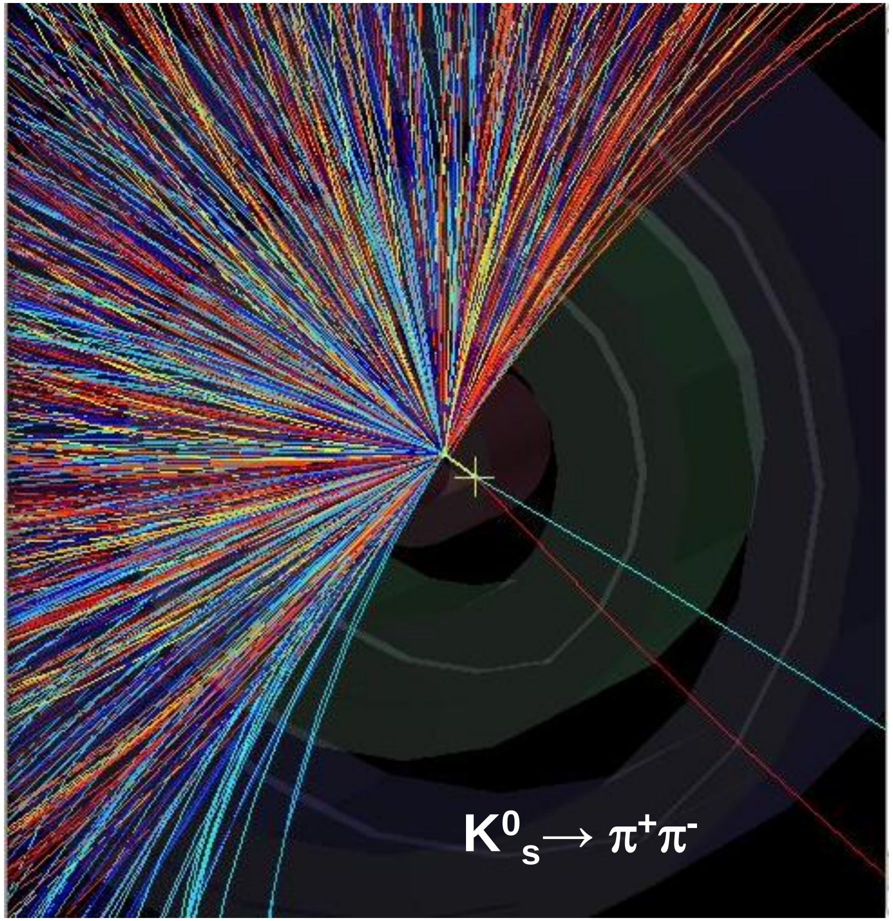
$\bar{\Lambda} \rightarrow \pi^+ \bar{p}$

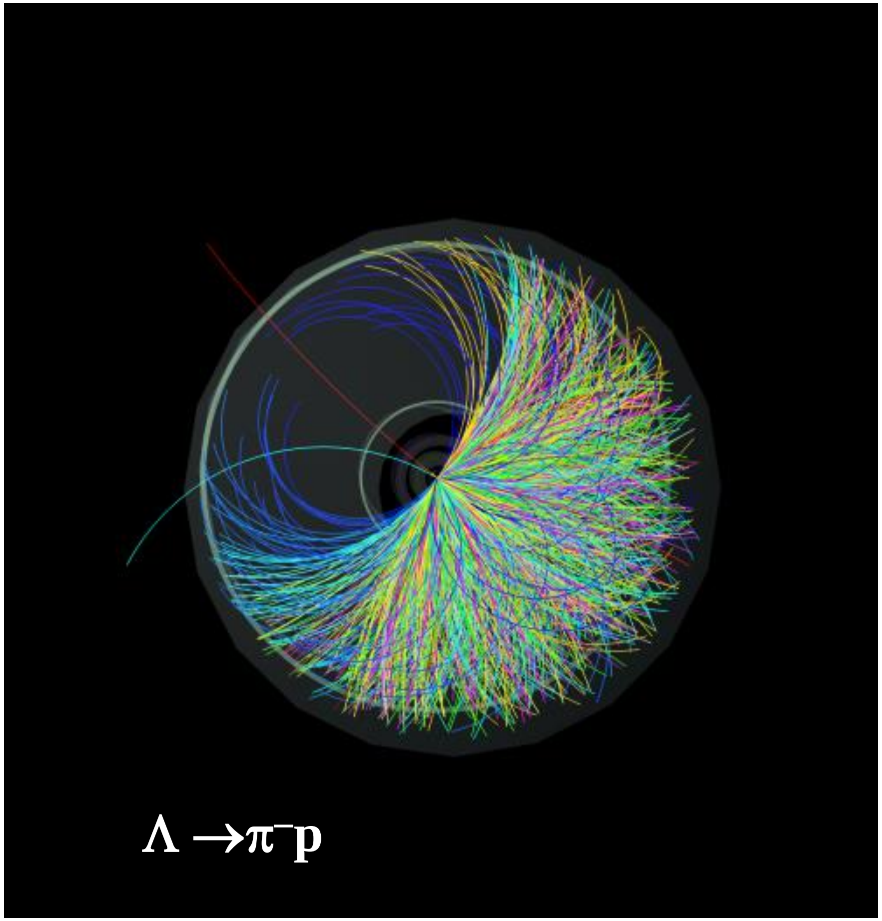
$\tau = 2.6 \times 10^{-10}$ s
$c\tau = 3 \times 10^{10}$ cm s^{-1} $\times 2.6 \times 10^{-10}$ s
7.2 cm distance from the point of interaction



Weak decays : strangeness is not conserved

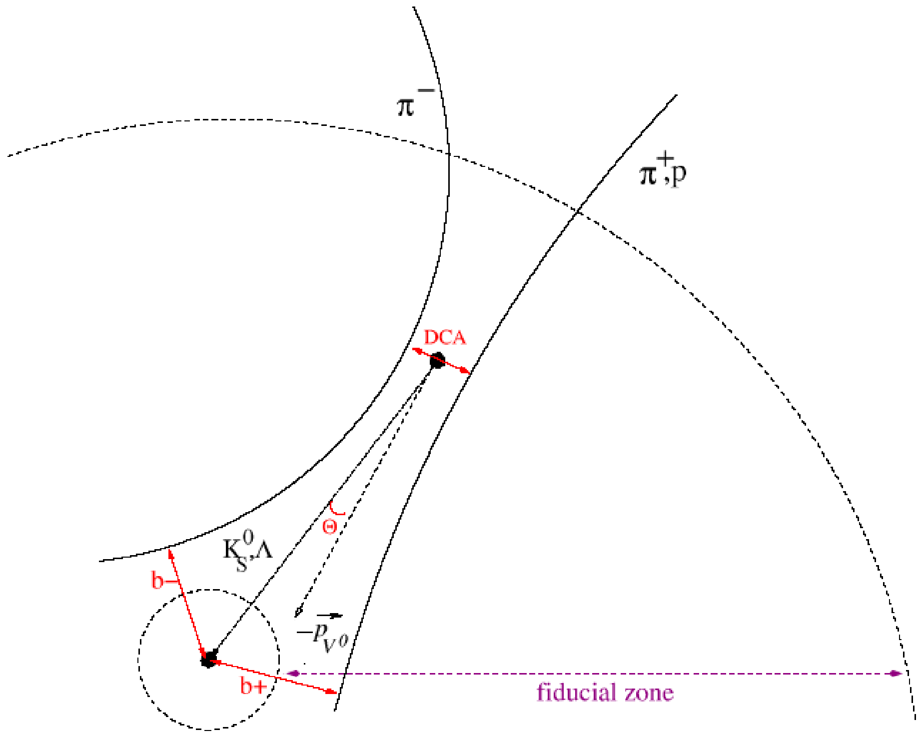
How do we find V0s ?





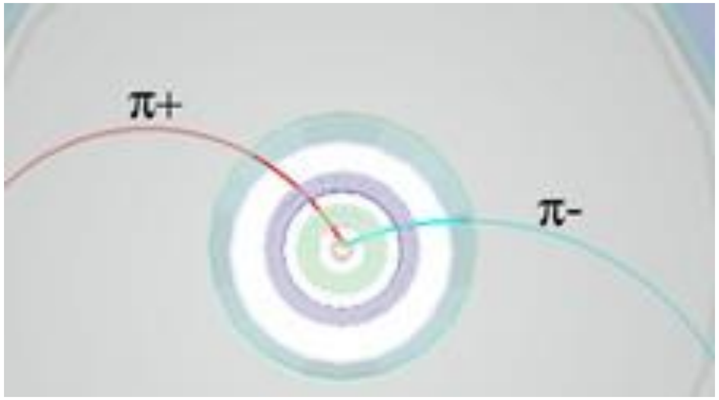
We look for two opposite tracks, having the same origin, which is not the interaction (collision) point

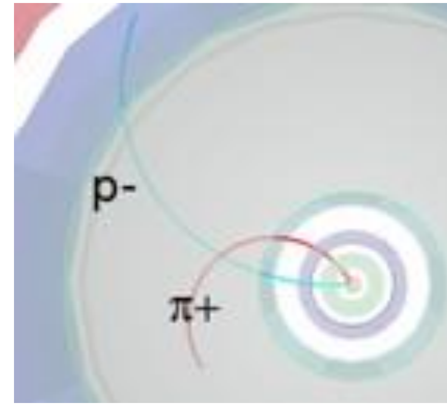
How do we find V0s ?



We look for two opposite tracks, having the same origin, which is not the interaction (collision) point

How do we identify each V0?



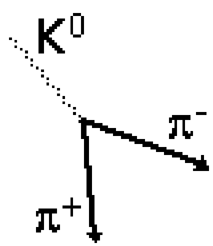


$K^0_s \to \pi^+\pi^-$

$\Lambda \to \pi^- p^+$

anti $\Lambda \to p^{-}\square^{+}$

$K^0 \to \pi^+ + \pi^-$



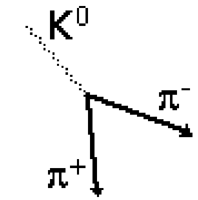
V0 decay :
a neutral particle (no track) gives suddenly two tracks

Identify V0s from the decay topology

$P = Q \cdot B \cdot R$
P momentum
Q electric charge
B magnetic field
R radius of curvature

How do we identify each V0?

$K^0 \rightarrow \pi^+ + \pi^-$



Calculate the (invariant) mass

Energy conservation $\quad E = E_1+E_2$

Momentum conservation $\quad \mathbf{p} = \mathbf{p}_1+\mathbf{p}_2$

Total energy $\quad E^2 = p^2c^2 + m^2c^4$

c=1 $\quad E^2 = p^2 + m^2$

$E = E_1+E_2 \quad E_1^2 = p_1^2 + m_1^2 \quad E_2^2 = p_2^2 + m_2^2$

$E^2 = p^2 + m^2 \quad m^2 = E^2 - p^2 =(E_1+E_2)^2 -(p_1+p_2)^2 = m_1^2 + m_2^2 +2E_1E_2 - 2\,\mathbf{p}_1 . \mathbf{p}_2$

Calculate the mass of the initial particle from the values of the mass and the momentum of the final particles

Particle Identification (done by a number of PID detectors) $\Rightarrow$ $m_1\ m_2$

Radius of curvature of the particle tracks due to magnetic field $\Rightarrow$ $p_1\ p_2$

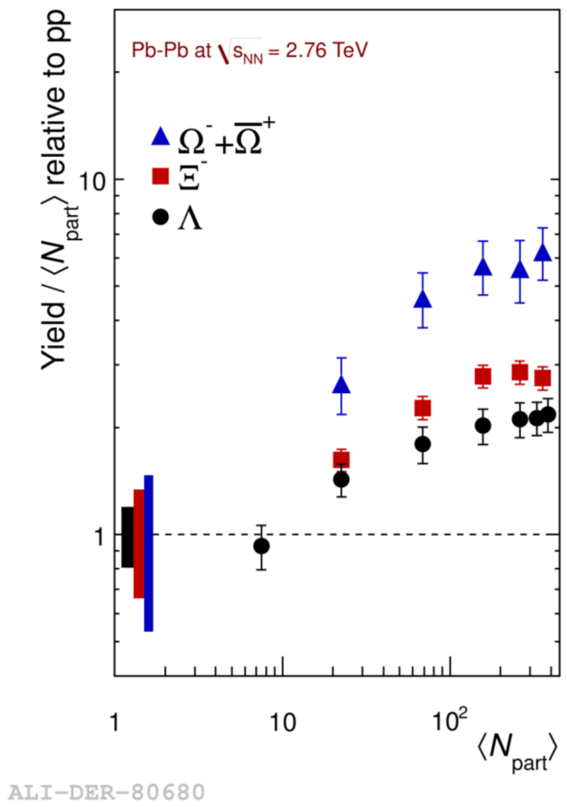
P=Q·B·R (P momentum, Q electric charge, R radius of curvature, B magnetic field)

1^{st} part of the measurement

Visual analysis of a small sample of 15 events from proton-proton collisions:
find V0s, identify and classify them (K_s, Λ, antiΛ) from the decay pattern and calculation of the invariant mass

Strangeness enhancement : one of the first signals of QGP

Enhancement increases with number of strange quarks in the hadron
Ω : 3 strange quarks
Ξ : 2 strange quarks
Λ : 1 strange quark

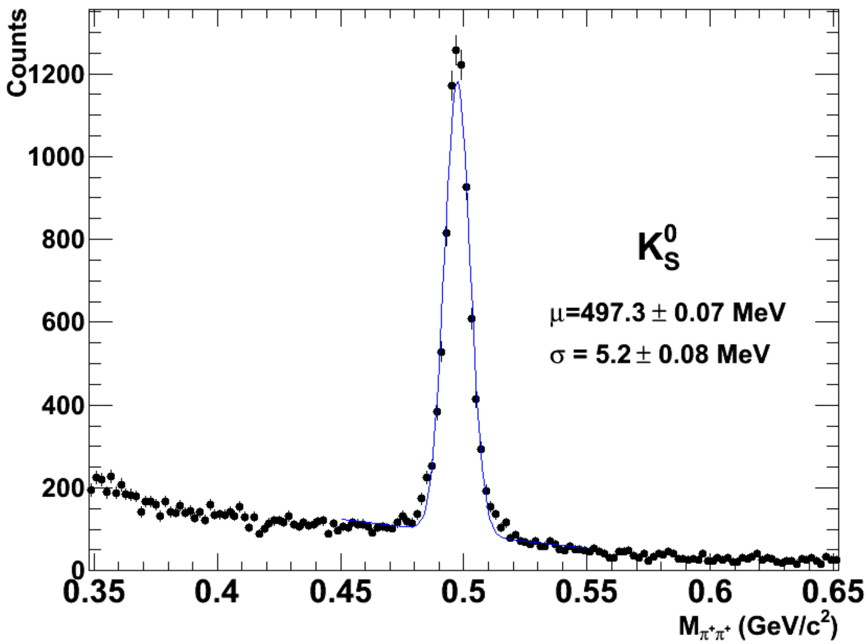


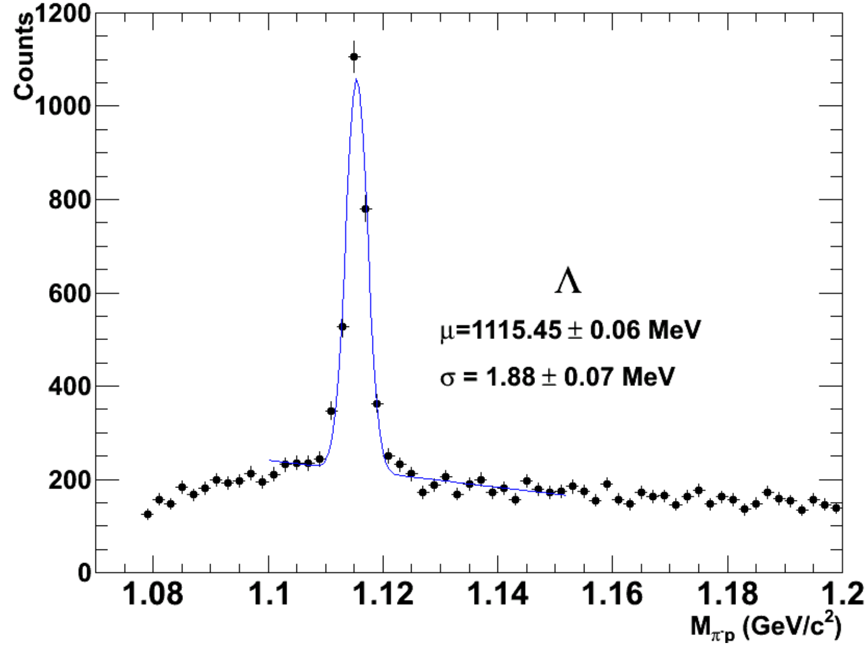
$$\frac{\text{Number of particles of a certain type per PbPb interaction}/\langle N_{part}\rangle}{\text{Number of particles of the same type per pp interaction}/2}$$

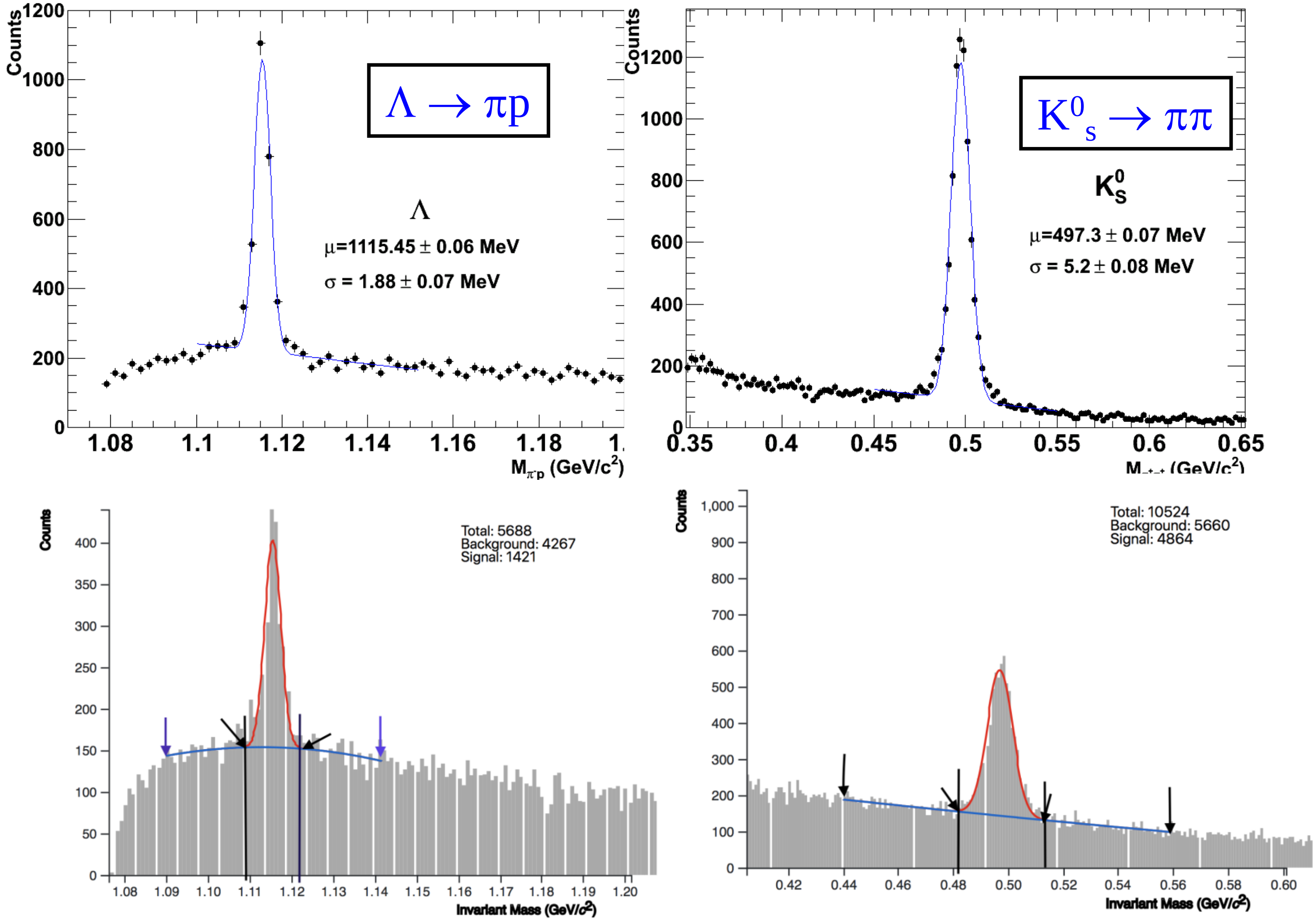
2^{nd} part of the measurement

Strangeness enhancement in lead-lead collisions

- Analysis of large event samples from lead-lead collisions in different centrality regions
- Find number of K_s, Λ, anti-Λ
- Calculate particle yields (number of particles/interaction)
- Calculate strangeness enhancement taking into account particle yields in proton-proton collisions

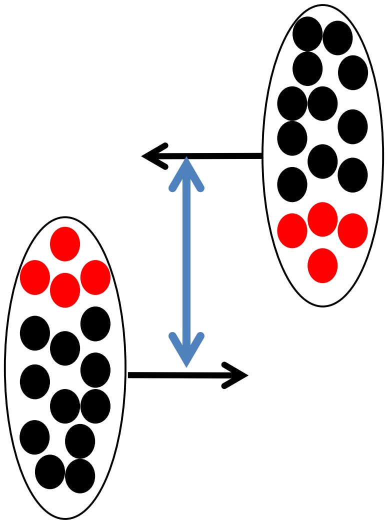

Counts
K^0_S
μ=497.3 ± 0.07 MeV
σ = 5.2 ± 0.08 MeV
$M_{\pi^+\pi^+}$ (GeV/c^2)


Counts
Λ
μ=1115.45 ± 0.06 MeV
σ = 1.88 ± 0.07 MeV
$M_{\pi^- p}$ (GeV/c^2)

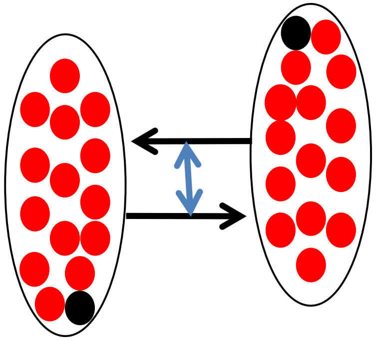


- Continuum : irreducible background due to random combinations of $\pi^+\pi^-$ or $\pi^- p$
- Fit curves to background (2[nd] degree polynomial) and peak (gaussian)
- Find number of K_s, Λ, anti-Λ after background subtraction

Geometry of a Pb-Pb collision



- Peripheral collision
  - Large distance between the centres of the nuclei
  - Small number of participants
  - Few charged particles produced (low multiplicity)

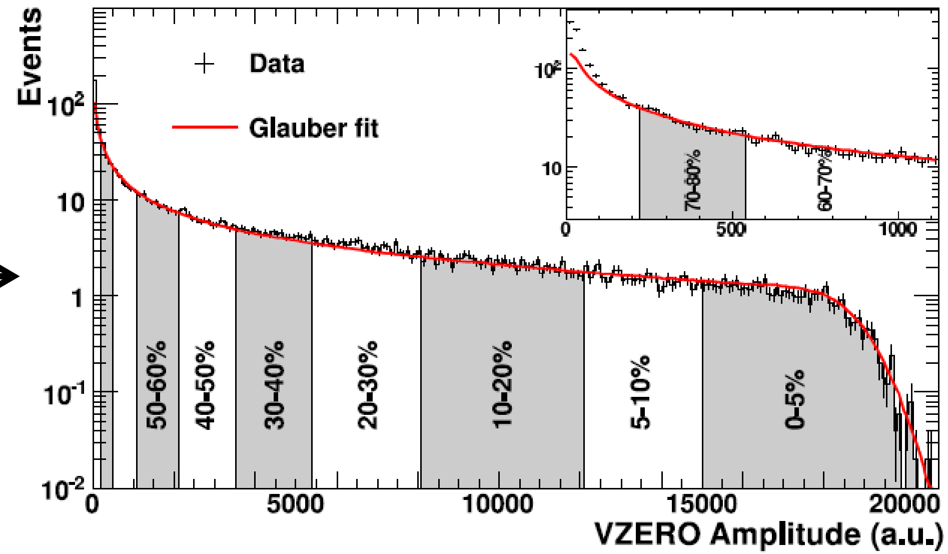


- Central collision
  - Small distance between the centres of the nuclei
  - Large number of participants
  - Many charged particles produced (high multiplicity)

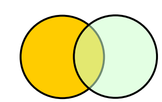
Centrality of Pb-Pb collisions

Distribution of the signal amplitude of V0 (plastic scintillators)

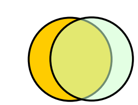
red line : described by model (Glauber)



Centrality	$dN_{ch}/d\eta$	$\langle N_{part}\rangle$	$(dN_{ch}/d\eta)/(\langle N_{part}\rangle/2)$
0%–5%	1601 ± 60	382.8 ± 3.1	8.4 ± 0.3
5%–10%	1294 ± 49	329.7 ± 4.6	7.9 ± 0.3
10%–20%	966 ± 37	260.5 ± 4.4	7.4 ± 0.3
20%–30%	649 ± 23	186.4 ± 3.9	7.0 ± 0.3
30%–40%	426 ± 15	128.9 ± 3.3	6.6 ± 0.3
40%–50%	261 ± 9	85.0 ± 2.6	6.1 ± 0.3
50%–60%	149 ± 6	52.8 ± 2.0	5.7 ± 0.3
60%–70%	76 ± 4	30.0 ± 1.3	5.1 ± 0.3
70%–80%	35 ± 2	15.8 ± 0.6	4.4 ± 0.4



peripheral collisions



central collisions

Strangeness enhancement calculation

Yield : number of particles produced per interaction = Nparticles(produced)/Nevents

Efficiency = **Nparticles(measured**)/Nparticles(produced)*

Yield = Nparticles(measured)/(efficiency x Nevents)

K_s-Yield (pp) = 0.25 /interaction ; Λ-Yield(pp) = 0.0617 /interaction ; <N_{part}> = 2 for pp

Strangeness enhancement: the particle yield normalised by the number of participating nucleons in the collision, and divided by the yield in proton-proton collisions**

*assumption on efficiency values : to match yields in Analysis Note
Measurement of Ks and Λ spectra and yields in Pb–Pb collisions at √sNN=2.76 TeV with the ALICE experiment

*pp yields at 2.76 TeV from interpolation between 900 GeV and 7 TeV
Analysis Note "Ks, Λ and antiΛ production in pp collisions at 7 TeV"

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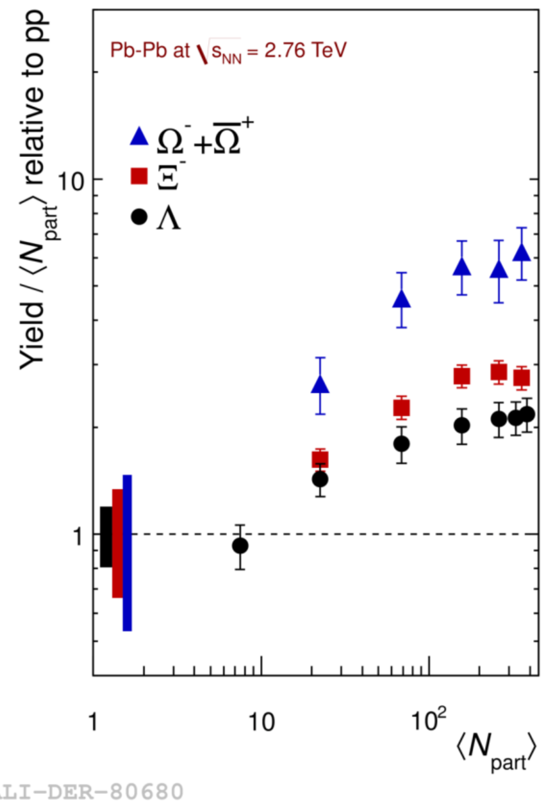
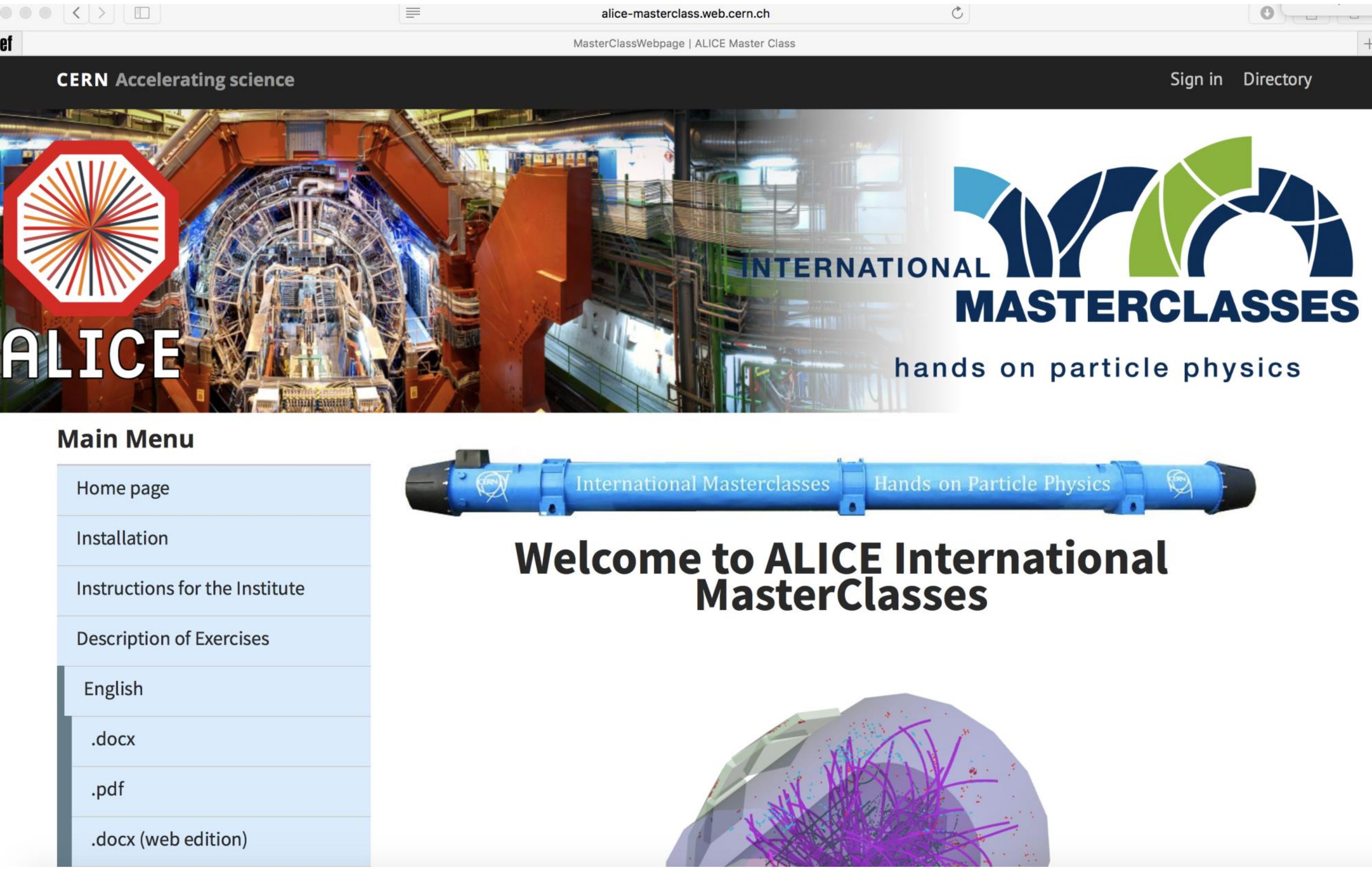


$$\frac{\text{Number of particles of a certain type per PbPb interaction}/\langle N_{part} \rangle}{\text{Number of particles of the same type per pp interaction}/2}$$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Useful links

ALICE Masterclasses (strange particles) web site https://alice-masterclass.web.cern.ch

Web version (CERN server) https://alice-web-masterclass.web.cern.ch

Web version (Warsaw server) https://masterclass.fizyka.pw.edu.pl

Web version (Trieste server) https://alice-masterclass.ts.infn.it

Results
https://docs.google.com/spreadsheets/d/1tpf86WOKb4xyQeEK90nCgmaleme5E0ZdqqgiK8yNmxk/edit#gid=1200756561

ALICE public web site https://alice.cern

ALICE collaboration web site https://alice-collaboration.web.cern.ch

Flying over ALICE (drone video) https://www.youtube.com/watch?v=yWBWzIUCNpw

To visit ALICE (virtually) : alice-outreach-virtual-visits@cern.ch

..and if you want to organise an ALICE masterclass we will be happy to assist

In-person

Remotely (zoom)

Organise a training session

Offer a virtual visit to ALICE (the cavern, if accesible, the Contol Room, Q&A)

Thanks for your attention!