1. Name of the measurement: Looking for strange particles in ALICE

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3. Supported languages: English, French, German, Italian, Portuguese, Czech, Greek

4. Short description
- Use of simplified ALICE event display based on ROOT to identify and categorise strange particles (V0s : Ks, Λ, anti-Λ) from their decay pattern, combined with invariant mass calculation.
- Analysis of large datasets, background subtraction and fitting of peak (find mass, width and number of events)
- Calculation of yields for Ks, Λ, anti-Λ for different centrality regions for lead collision data
- Strangeness enhancement calculation

5. Prerequisites (Software, Operating system...):
- Internet connection (to download the software for the measurement; to send results from all groups to one computer for merging)
- ROOT installation (version > 28)
- Operating system : MacOSX, Linux, Obundu

To run the package on windows, you can use the **Virtual Machine** method, which allows you to run Scientific Linux on any operating system. Install Virtual Box; to create the Virtual Machine, download the OVA image from:

https://jblomer.web.cern.ch/jblomer/ALICE%20Masterclass%20v2.1.ova

For the visual analysis
- 19 datasets with 15 events each (containing V0s) from pp data (2011)

For the large scale analysis
- 1 dataset with 21000 events from pp data (2011)
- 1 dataset with 15000 events from lead-lead (2011)

For the large scale analysis in different centrality classes (lead-lead data)
- 10 datasets for centralities 0-10%, 10-20% ... 90-100% containing Ks
- 10 datasets for centralities 0-10%, 10-20% ... 90-100% containing Λ
- 10 datasets for centralities 0-10%, 10-20% ... 90-100% containing anti-Λ

7. Proposed outline for the day
- 08:30 – 08:45 Arrival & Welcome
- 08:45 – 10:45 Lectures (for example: twice 45 minutes + time for questions & discussion)
  proposed subjects

particles and forces, standard model and open questions, CERN, LHC
methods of particle physics : accelerators and detectors
the physics of heavy ion collisions, the ALICE detector

- 10:45 – 11:45 Visit to laboratory/experimental site/installation

- 11:45 – 12:50 Lunch

- 13:00 – 13:15 Introduction to the measurement
- 13:15 - 13:30 Learning the tools ; demonstration of part I
- 13:30 – 14:00 Measurement : visual analysis
- 14:00 – 14:15 Collection of results and discussion of part I
- 14:15 – 14:20 Break
- 14:20 – 14:30 Introduction to large scale analysis – background subtraction - demonstration of part II
- 14:30 – 14:50 Measurement : find number of V0s in different centrality regions
- 14:50 – 15:10 collection of results from part II; calculation of yields; strangeness enhancement
- 15-10 – 15:30 discussion of results and preparation for the Video-conference
- 16:00 – 17:00 Video-conference

8. Students´ tasks

1 *Learn the tools (the whole class)*

The tutors show on a screen the tools of the analysis programme (menus, buttons, calculator, invariant mass calculation, histograms); explain how to use them. Tutors and students analyse together examples of K_s, Λ, anti-Λ decays and calculate the invariant mass.

2 *Visual analysis (individually)*

Students work by themselves at computers, in groups of 2 or 3; they analyse visually 15 events, find the V0s, classify them, update tables and histograms; save results on a file.

3 *Collection of results from visual analysis (the whole class)*

The tutors collect the results from each group and merge them. See next section.

4 *Introduction to large scale analysis (the whole class)*

Tutors instruct the students how to analyse a large event sample, fit curves to the background and the signal and find the number of events in the peak. They all together find the number of K_s, Λ, anti-Λ in a large sample of pp events and then in a large sample of lead events.

5 *Find V0s in different centrality regions*

Students work by themselves at computers, in groups of 2 or 3; each group is assigned a centrality region and they have to find the number of K_s, Λ, anti-Λ in this region.

6   *Collection of results from large scale analysis; calculation of yields and strangeness enhancement*

See section 10.

9. How they do it (step by step)

Visual analysis (individually)

Each group of 2 or 3 students is assigned a dataset to analyze; they inspect each event, find the V0(s) with the V0 finder, try to guess what type of particles they are from the decay pattern, calculate the invariant mass and classify them according to its value.

Find V0s in different centrality regions

Each group of 2 or 3 students is assigned a centrality region; they have to find the number of K_s, Λ, anti-Λ in this region from the invariant mass distribution, by fitting curves to the background and to the peak; they have to decide on the ranges to be used and inspect visually the quality of the fit.

10. Presentation of results

Collection of results from visual analysis

The students must have saved the results of the visual analysis on a file. If there is connection/communication between computers, they must all send these files to the tutor's computer; a USB memory stick can also be used. Choosing "Teacher's mode", the tutor gets all results files, corresponding to the different datasets, one after the other, thus merging all results. The merged histograms of mass distributions (as in the following plot) can be used for comments on the mass value of each particle, width of the distribution, background events (to be discussed in the large scale analysis section).
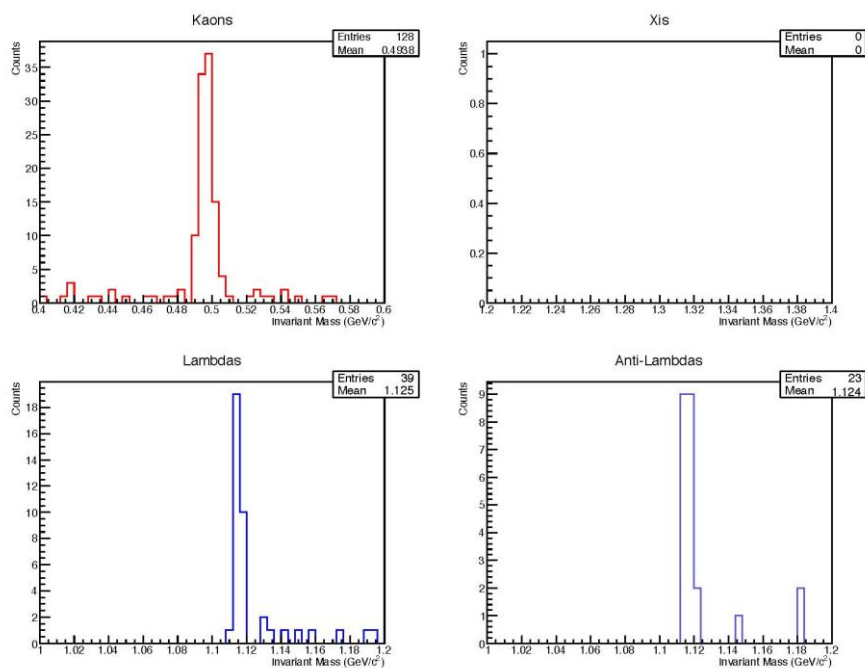
If it is too difficult to merge the files with the results, a simple table can be made, to include the numbers of K_s, Λ, anti-Λ of each dataset and add them up. The long scale analysis results will be used for the videoconference.

Collection of results from long scale analysis; calculation of yields and strangeness enhancement

Each group reports the number of K_s, Λ, anti-Λ they found in the centrality class that they have analysed. The results are entered in a spreadsheet as in the picture. The number of events in the corresponding centrality region is already in the spreadsheet. (This will be provided as an excel file or as a spreadsheet on googledocs).

These measurements will be used to calculate the strangeness enhancement factor in lead collisions. At this point some new concepts need to be introduced.

The centrality of a collision : related to the impact parameter, distance between the colliding lead nuclei perpendicular to the beam axis; not measurable; instead we use, e.g. cuts on the VZERO signal and thus define the centrality classes (see section 13 of description of the measurement on the web site). Quantitative estimate of the collision centrality is given by the number of participating nucleons N_{part} which is given in the table for each centrality class.

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

Yield (for a certain particle type) : the number of particles (of this type) produced per interaction= Nparticles(produced)/Nevents

The number of particles measured is less than the number of particles produced; to find the latter we need to know the efficiency; we have estimated efficiency values, for K_s, Λ and anti-Λ, as shown in the table.

 For the proton-proton collisions we assume:

Ks-Yield(pp) = 0.25 /interaction
Λ-Yield(pp) = 0.0615 /interaction ; the same for anti-Λ
 $<N_{part}>$ = 2

NOTE : these yields for Ks and Λ refer to proton-proton collisions at 2.76 TeV (same energy as for Pb-Pb collisions, 2.76 TeV per nucleon pair); they have been calculated by interpolation, between measured K_s and Λ yields at 900 GeV and 7 TeV [internal ALICE notes].

With all this information the enhancement factors can be calculated for all centrality classes, as in the table.

centrality	<Npart>	Nevents	NKs	efficiency Ks	yield Ks	Ks enhancem	Nlambda	efficiency L	Yield Lambda	Lambda enh	Nantilambda	effic antiL	yield antiLam	antiL enha
0-10	360	213	4816	0.26	86.963	1.933	1066	0.2	25.023	2.253	980	0.2	23.005	2.071
10–20	260	290	4638	0.26	61.512	1.893	1185	0.21	19.458	2.426	1142	0.21	18.752	2.338
20-30	186	302	3750	0.29	42.818	1.842	917	0.22	13.802	2.405	875	0.22	13.170	2.295
30-40	129	310	2610	0.29	29.032	1.800	621	0.22	9.106	2.288	550	0.22	8.065	2.026
40-50	85	302	1493	0.29	17.047	1.604	363	0.22	5.464	2.084	332	0.22	4.997	1.906
50-60	52	300	777	0.29	8.931	1.374	182	0.2	3.033	1.891	169	0.2	2.817	1.756
60-70	30	315	409	0.35	3.710	0.989	89	0.2	1.413	1.526	88	0.2	1.397	1.509
70-80	16	350	149	0.26	1.637	0.819	71	0.2	1.014	2.055	34	0.2	0.486	0.984

NOTE : the numbers of events of each dataset are given; also the numbers of participants corresponding to each centrality region; you have to fill in the numbers of K_s, Λ and anti-Λ; the estimated efficiency values are given; yields and enhancement factors are calculated (formulas embedded in the spreadsheet).

This table can be filled in already prepared spreadsheets, see section 12.

Embedded in the spreadsheets are also scatter plots showing the enhancement factors for K_s, Λ and anti-Λ versus the number of participants.
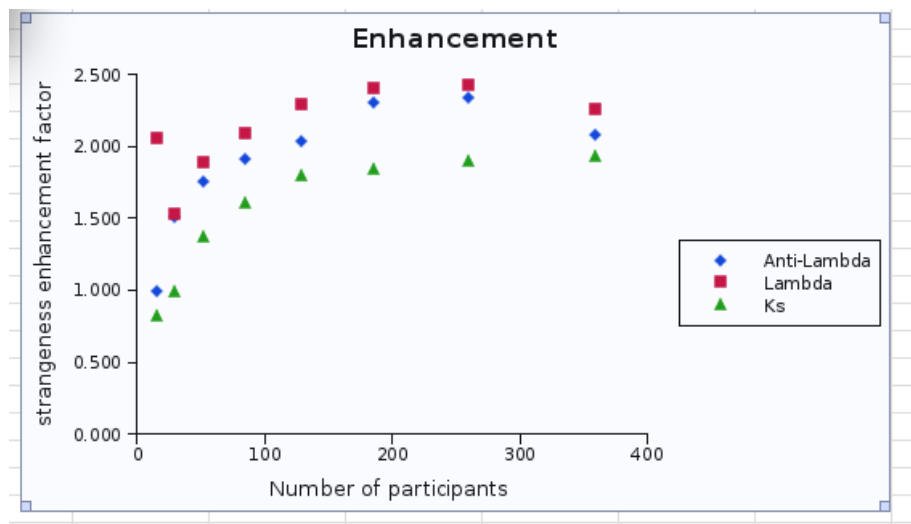
11. What can be discussed

Strangeness enhancement : one of the first signals for quark gluon plasma, see appendix.
Temperature calculation, see appendix.
A number of proposed questions and their answers have also been included in the appendix.

12. For tutors and moderators: Details on combination and discussion

For tutors
It is important that the results are already discussed before the videoconference. The video-conference will be very brief when it comes to physics discussion, and the students should already have come to a conclusion with their measurements.

Fill in a spreadsheet with the analysis results as described in section 10.
You will find such spreadsheets at the URL
https://drive.google.com/folderview?id=0B9FfU3MPTgvGZk8wcmFaOE9yX2s& usp=sharing

Inside this folder, there is an example spreadsheet, results-example.xls as well as spreadsheets for all institutes participating in International Masterclasses. Each institute fills in a spreadsheet with the name results-inst_name-xxxxxx.xls (inst_name is the name of the institute, e.g. CERN, Nantes, Heidelberg... xxxxxx is the date, e.g. 05032016).

If there is a problem with accessing google docs, the institutes can use excel spreadsheets with embedded scatter plots on their local computer. They can then show them by screen sharing during the videoconference.

Starting from 2017 the students do not report the results during the videoconference. This new concept was introduced because reports from up to five institutes were very repetitive.

For moderators
The moderators bring up the results, show them and comment.
This should be in the form of the spreadsheet (including the plot showing strangeness enhancement). They ask questions to the students of each institute.

13. Supporting material for students
They could be given a sheet with instructions.

14. Supporting material in general (talks, films, animations, documentations…)

Some support material can be found at
http://aliceinfo.cern.ch/public/MasterCL/MasterClassWebpage.html

also

Tutorial for the visual analysis (ALICE Masterclass looking for strange particles)
https://www.youtube.com/watch?v=vzj9LRzs7VA

Tutorial for the large scale analysis (ALICE Masterclass looking for strange particles)
https://www.youtube.com/watch?v=eoBpAyOd2wM

Drone video "Flying over ALICE"
https://www.youtube.com/watch?v=yWBWzIUCNpw

Four videos explaining the measurements and the use of the software
https://twiki.cern.ch/Edutech/AliceMasterClasses

APPENDIX

Strangeness enhancement

One of the signatures for the creation of QGP is the enhancement of strangeness. It was proposed in 1980, more than thirty years ago, as the first observable for quark gluon plasma. Twenty-five years ago, strangeness enhancement was observed in the fixed target ion experiments at the CERN Super Proton Synchrotron. Later on, strangeness enhancement was observed by experiments at the Relativistic Heavy Ion Collider at Brookhaven, near New York.

To talk of enhancement we need to compare a measured quantity with the same quantity measured under different conditions (enhancement means an increase with respect to something else). This quantity can be, for example, the number of particles of a certain species produced per interaction (yield).

This plot shows strangeness enhancement observed by NA57 (fixed target heavy ion experiment at the CERN SPS) and STAR (Au-Au collisions at RHIC, the Relativistic Heavy Ion Collider in Brookhaven).
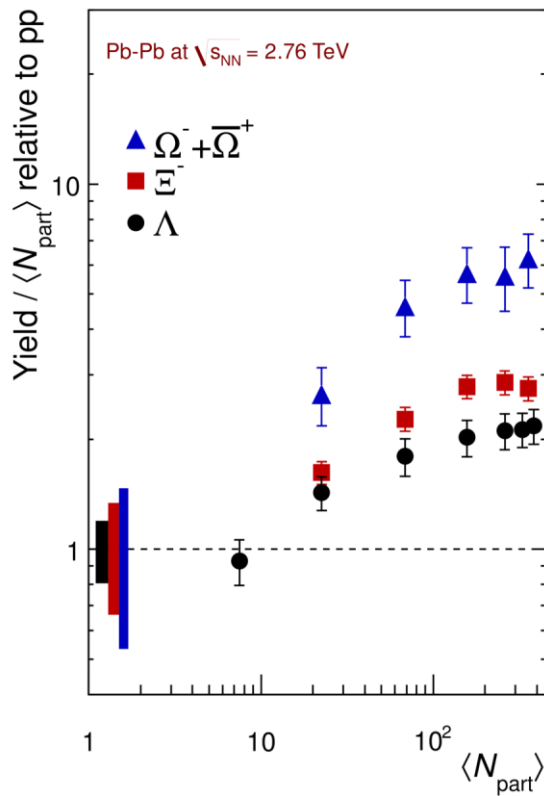The vertical axis is the particle yield normalized by the number of participating nucleons in the collision, and divided by the observed yield in proton-beryllium (or proton-proton) collisions. We observe that the strangeness enhancement increases with number of strange quarks in the hadron (Ω has 3, Ξ has 2, Λ has 1).
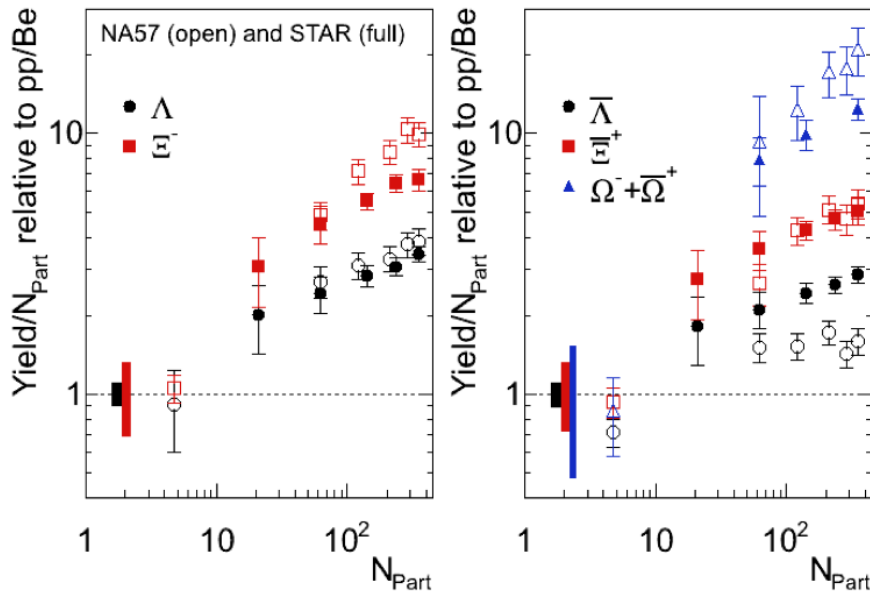
The horizontal axis in these plots is the number of participants in the collision: how many out of the 208 protons and neutrons of each of the colliding lead nuclei take part in the collision: We often use the term centrality – in central collisions most of the total of 416 nucleons participate, whereas in peripheral and ultra peripheral collisions N_{part} is small).
For the case of proton-proton collisions $N_{part} = 2$.
The following plot shows results from ALICE .

Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV

$\Omega^- + \overline{\Omega}^+$
Ξ^-
Λ

Yield / $\langle N_{part} \rangle$ relative to pp

$\langle N_{part} \rangle$

ALI-DER-80680

Temperature calculation

Our observation of the number of produced Lambdas and Kaons can serve as a *thermometer* of the matter which is produced in the collision.

If you had measured Lambdas + Anti_Lambdas and K0s per event in the 0-5% centrality Pb-Pb events and then corrected for detection efficiency (pt-integrated), you would have obtained the following values (preliminary ALICE analysis results, not yet published):

N_{K0s} = 123.9 ± 7 (which is the dN/dy per event)
N_{Λ} = 28.8 ± 3

We then put the N_{K0s} in relation with the number of produced pions per event. The following value has been measured for the 0-5% centrality Pb-Pb event
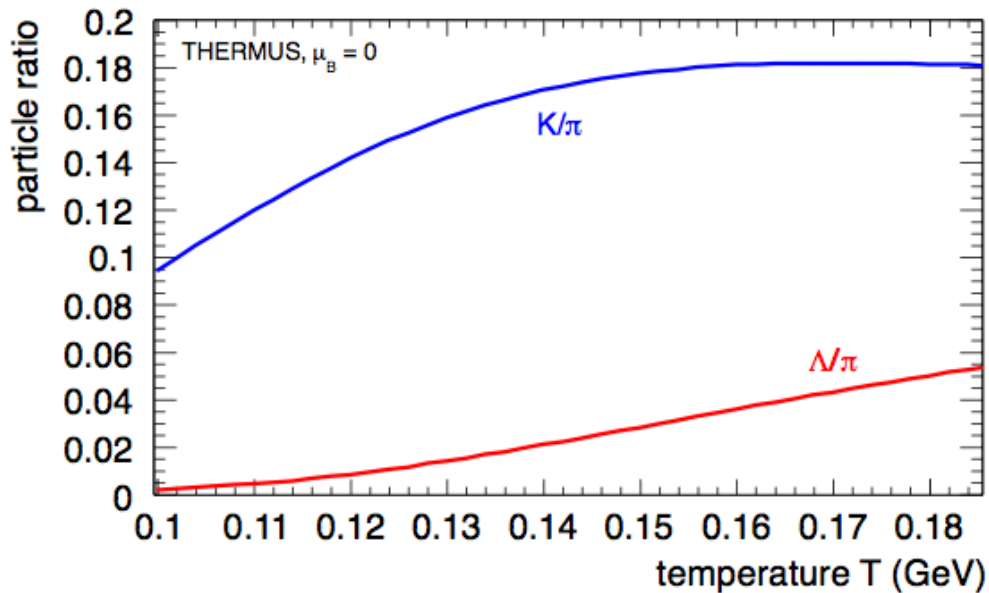
$N_{\pi+}$ = 792.1 ± 44.1

We form the ratio and obtain

N_{K0s} / $N_{\pi+}$ = 0.156 ± 0.012
N_{Λ} / $N_{\pi+}$ = 0.036 ± 0.004

From the plot below we can then roughly judge at which temperatures the particles were produced:

The curves are produced with a so-called thermal model. It relates the relative abundance of particles with the temperatures in the fireball. Very roughly speaking, it shows that the production of particle of mass m_i is proportional to $\sim \exp(-m_i/T)$. We can see this also in the plot showing that the heavier lambdas are produced less often than the lighter kaons. Thus, our observation of the number of produced Lambdas and Kaons can serve as a *thermometer* of the matter which is produced in the collision. Our results show that the temperature of the fireball is somewhere between 120 MeV and 180 MeV corresponding to roughly 1.74×10^{12} K (compared to 5.778 K on the surface of the sun -- factor 1 billion). Within 2σ the two ratios are even in agreement with a single temperature.

Proposed questions to ask (and their answers)

1. Why are the two tracks of each V0 curved in opposite directions ?

They are curved because of the magnetic field; They go in opposite directions because they have opposite charges (the initial particle is neutral – decay products positive and negative - charge conservation).

2. Why is the radius of curvature of the proton bigger than that of the pion in Λ decays?

Because its momentum is bigger.

3. Why is that?

Imagine something heavy (the Λ) spitting out something light (a π); The momentum of what remains (the proton) is not changed much -> it takes most of

the initial momentum, much more than the pion. (Think of a moving car; the passengers throw a ball out of the window; The remaining system «car without the ball» has almost all the initial momentum, the ball even if it moves with the same velocity as the car has much lower momentum since the mass of ball is much less than that of the car (momentum = mv).

4. Why don't you see the Λ or the K0 before their decay?

Because they have no charge, therefore they are not seen in the detectors. **All** particle detectors detect particles from the ionisation of some medium that it passes through. Thus neutral particles are not observed and can only be obeserved from interacting with matter or by decaying into charged particles. The tracks that we 'see' come from reconstructing the hits in the detectors; these hits come from the charged particles producing ionisation inside the material of the detector (Si for ITS; Gas for TPC) which will then produce an electrical signal.

5. Why does the Λ not decay to two pions, like the K0?

Because the Λ is a baryon (consists of 3 quarks) whereas the K0 and the pions are mesons (quark-antiquark pairs). In all decays (and all interactions) the baryon number is conserved; so there has to be a baryon in the final state (proton).

6. Why does the invariant mass have a width and is not a delta-function?

Because it is calculated from the measured momenta of the decay products and all measurements have a limited accuracy; This is correlated with the characteristics of the detector (how it works, how it is made), the electronics associated with it, the precision of reconstruction of the tracks etc. Even if we could have a detector with infinitely good resolution and tracking, the mass distribution will have a width – the intrinsic width of the resonance, which is governed by Heisenberg's uncertainty principle.