

## Instructions for tutors / moderators

version of 6.2.2023  
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### 1. Name of the measurement: **Looking for strange particles in ALICE**

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**3. Supported languages:** English

### 4. Short description

- Visual inspection of proton-proton collision events to identify and categorise strange particles (V0s : Ks,  $\Lambda$ , anti- $\Lambda$ ) from their decay pattern, combined with invariant mass calculation.
- Analysis of large datasets of lead-lead collision events, background subtraction and fitting of peak (find mass, width and number of events)
- Calculation of yields for Ks,  $\Lambda$ , anti- $\Lambda$  for different centrality regions
- Strangeness enhancement calculation

### 5. The analysis package

The initial analysis package was developed simplifying the ALICE event display and was based on ROOT. In 2021 a web-based version was developed. It does not require installation; the measurements are done via a browser; internet connection is needed.

In 2022 a new web-based version was developed, allowing the saving of results on a server. (The results from the visual analysis are uploaded by each student and the tutor can retrieve and merge them. The results from the large scale analysis are uploaded and entered in a spreadsheet which calculates strangeness enhancement.

2022 version-students: <https://alice-web-masterclass.app.cern.ch/home>

2022 version-tutors: <https://teacher-alice-web-masterclass.app.cern.ch/session>

2021 version (no saving of results): <https://masterclass.fizyka.pw.edu.pl>

Description of the measurement : <https://alice-masterclass.web.cern.ch>

### 6. Data

*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  $\Lambda$

- 10 datasets for centralities 0-10%, 10-20% ... 90-100% containing anti- $\Lambda$

## 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  $K_s$ ,  $\Lambda$ , anti- $\Lambda$  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 histograms; upload results on a server.

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

The tutors retrieve the results of 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 functions to the background and the signal and find the number of events in the peak. They

all together find the number of  $K_s$ ,  $\Lambda$ , anti- $\Lambda$  in a large sample of pp events and then in a large sample of lead events.

#### 5 *Find $V_0$ s in different centrality regions*

The 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  $K_s$ ,  $\Lambda$ , anti- $\Lambda$  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)

#### *Preparation (tutor)*

At URL <https://teacher-alice-web-masterclass.app.cern.ch/session> the tutor creates an “event” and for this event one or more sessions (one per room / breakout room in case of online masterclasses). Suggestion : Use event names obvious for the moderators, for example CERN-02032022 (location and date). The session password needs to be communicated to the students.

#### *Visual analysis (individually)*

Each group of 2 or 3 students is assigned a “student number” which defines the dataset to analyse; they inspect each event, find the  $V_0$ (s) with the  $V_0$  finder, try to guess the particle types from the decay pattern, calculate the invariant mass and classify the mother particle according to its value.

#### *Find $V_0$ s in different centrality regions*

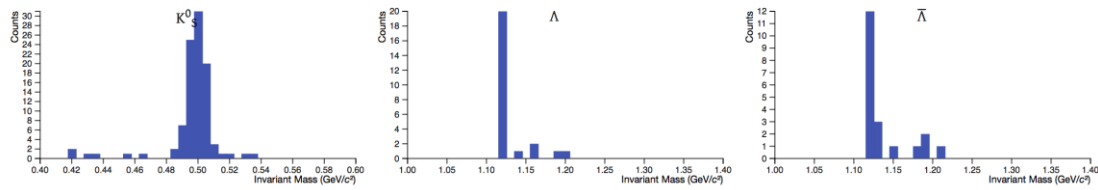
Each group of 2 or 3 students is assigned a centrality region; they have to find the number of  $K_s$ ,  $\Lambda$ , anti- $\Lambda$  in this region from the invariant mass distribution, by fitting functions to the background (2<sup>nd</sup> degree polynomial) and to the peak (Gaussian); they need to decide on the ranges to be used for the fit and inspect visually the quality of the fit. They are encouraged to analyse data from more centralities if time allows.

### 10. Presentation of results

#### *Results from visual analysis*

The students must have uploaded the results of the visual analysis on the server. The tutor chooses the session, at the URL <https://teacher-alice-web-masterclass.app.cern.ch/strangeness-visual-analysis> and ticks the box under “Results”: the measurements from all students, corresponding to the different datasets, are filled in the histograms for  $K$ ,  $\Lambda$ , anti $\Lambda$ . 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 (to be discussed in the large scale analysis section).

## Mass Histograms



*Results from large scale analysis; calculation of yields, strangeness enhancement*

Each group uploads the results (number of Ks,  $\Lambda$ , anti- $\Lambda$  they found and the corresponding centrality class). The results are entered in a table as in the picture (in italics : average value if more than one measurements entered)

Centrality	No. participants	No. events	No. K	Efficiency K	Yield K	Enhancement K	No. L	Efficiency L	Yield L	Enhancement L	No. AL	Efficiency AL	Yield AL	Enhancement AL
0 - 10%	360	213	4,738.7	0.260	85.567	<b>1.901</b>	1,114.0	0.200	26.150	<b>2.355</b>	1,051.6	0.200	24.685	<b>2.223</b>
10 - 20%	260	290	4,339.7	0.260	57.555	<b>1.771</b>	1,187.1	0.210	19.493	<b>2.430</b>	1,090.6	0.210	17.908	<b>2.233</b>
20 - 30%	186	302	3,506.3	0.290	40.035	<b>1.722</b>	1,222.8	0.220	18.404	<b>3.207</b>	896.3	0.220	13.490	<b>2.351</b>
30 - 40%	129	310	2,741.3	0.290	30.493	<b>1.891</b>	668.5	0.220	9.802	<b>2.463</b>	571.4	0.220	8.378	<b>2.105</b>
40 - 50%	85	302	1,476.0	0.290	16.853	<b>1.586</b>	401.0	0.220	6.036	<b>2.302</b>	351.5	0.220	5.290	<b>2.018</b>
50 - 60%	52	300	742.5	0.290	8.534	<b>1.313</b>	149.8	0.200	2.496	<b>1.556</b>	168.7	0.200	2.811	<b>1.752</b>
60 - 70%	30	315	418.3	0.350	3.794	<b>1.012</b>	88.0	0.200	1.397	<b>1.509</b>	89.3	0.200	1.418	<b>1.532</b>
70 - 80%	16	350	148.6	0.260	1.633	<b>0.816</b>	45.0	0.200	0.643	<b>1.302</b>	45.0	0.200	0.643	<b>1.302</b>

These measurements are used to calculate the strangeness enhancement factor in lead collisions. At this point some new concepts need to be introduced. (They may have been explained during the introduction)

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 =  $N_{particles(produced)}/N_{events}$

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 Ks,  $\Lambda$  and anti- $\Lambda$ , as shown in the table.

For the proton-proton collisions we assume:

$Ks\text{-Yield}(pp) = 0.25 / \text{interaction}$

$\Lambda\text{-Yield}(pp) = 0.0615 / \text{interaction}$  ; the same for anti- $\Lambda$

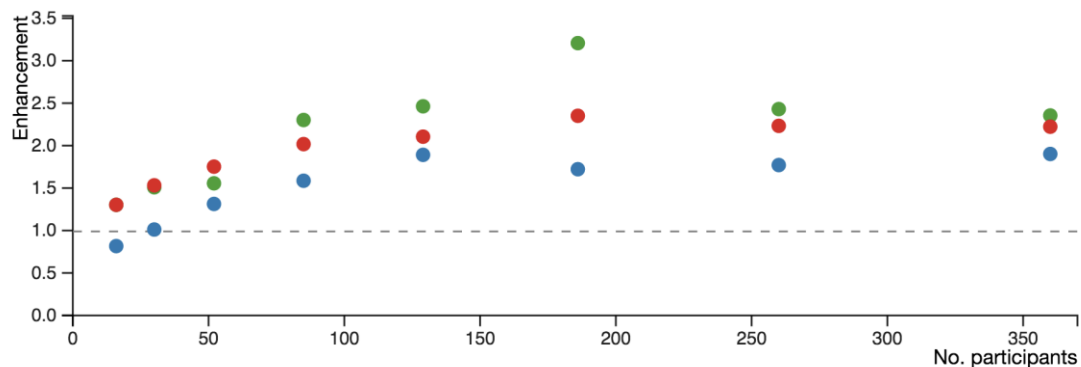
$\langle N_{part} \rangle = 2$

NOTE : these yields for  $K_s$  and  $\Lambda$  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  $\Lambda$  yields at 900 GeV and 7 TeV [internal ALICE notes].

With all this information the yields and enhancement factors (in bold) are calculated for each centrality class (formulas embedded in the spreadsheet).

NOTE : the numbers of events of each dataset are given; also the number of participants corresponding to each centrality region; the estimated efficiency values for each particle type are also given.

Based on these calculations the plot showing the enhancement factors for  $K_s$ ,  $\Lambda$  and anti- $\Lambda$  versus the number of participants is filled:



## 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

For the creation of the “event” and sessions within the event, the tutors need to log in with a CERN account. For those who do not have such an account, the service account **alicemc** can be used. Contact [despina.hatzifotiadou@cern.ch](mailto:despina.hatzifotiadou@cern.ch) for the password.

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.

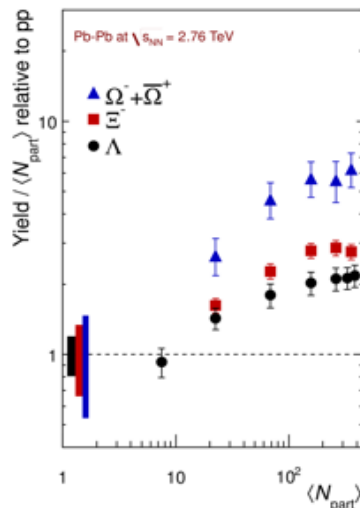
### For moderators

The moderators need to go to the URL below and log in.

<https://teacher-alice-web-masterclass.app.cern.ch/session>

They choose “Large Scale Analysis” on the left-hand menu and select the “event” (the event name should be a combination of the city/institute and date). This displays the results, both the table and the plot of strangeness enhancement versus number of participants.

They can comment the results, compare with the published ALICE results, see below, and ask questions to the students of each institute.



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#### 14. Supporting material (talks, films, animations, documentations...)

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>

Four videos explaining the measurements and the use of the software

<https://twiki.cern.ch/Edutech/AliceMasterClasses>

The above tutorials use the root-based version of the exercise. The details (and looks) are different, but the basic idea is the same.

Drone video “Flying over ALICE”

<https://www.youtube.com/watch?v=yWBWzIUCNpw>

## APPENDIX

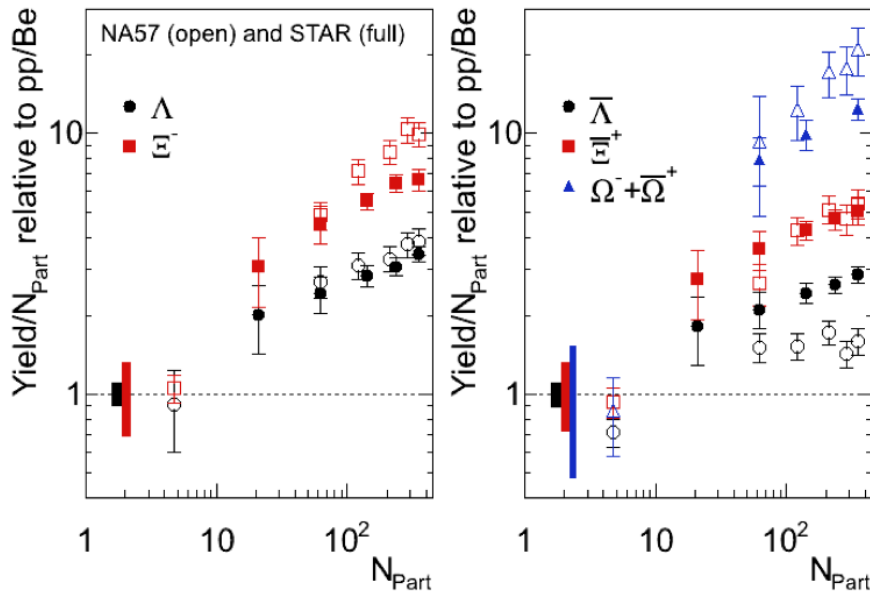
### Strangeness enhancement

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).

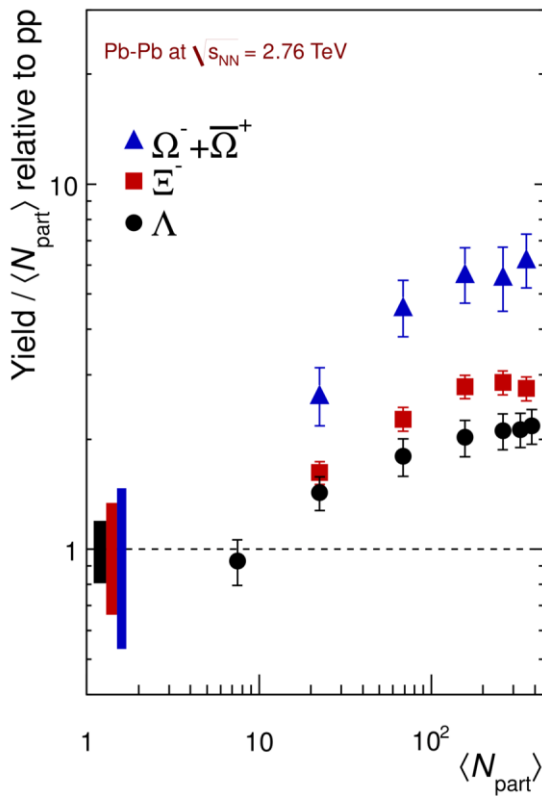
The vertical axis is the particle yield normalized by the number of participating nucleons in the collision, and divided by the observed yield in proton-beryllium (or proton-proton) collisions. We observe that the strangeness enhancement increases with number of strange quarks in the hadron ( $\Omega$  has 3,  $\Xi$  has 2,  $\Lambda$  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 .



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## 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):

$$N_{K0s} = 123.9 \pm 7 \text{ (which is the } dN/dy \text{ per event)}$$

$$N_{\Lambda} = 28.8 \pm 3$$

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

$$N_{\pi^+} = 792.1 \pm 44.1$$

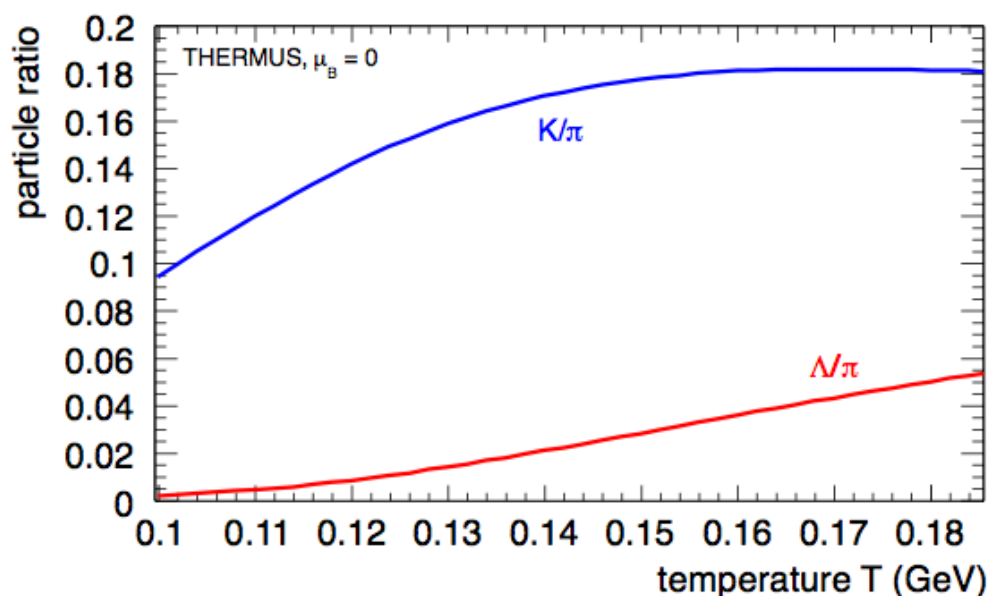
We form the ratio and obtain

$$N_{K0s} / N_{\pi^+} = 0.156 \pm 0.012$$

$$N_{\Lambda} / N_{\pi^+} = 0.036 \pm 0.004$$



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  $1.74 \times 10^{12}$  K (compared to 5.778 K on the surface of the sun -- factor 1 billion). Within  $2\sigma$  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  $\Lambda$  decays?

Because its momentum is bigger.

3. Why is that?

Imagine something heavy (the  $\Lambda$ ) spitting out something light (a  $\pi$ ); 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  $\Lambda$  or the  $K^0$  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 observed 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  $\Lambda$  not decay to two pions, like the  $K^0$ ?

Because the  $\Lambda$  is a baryon (consists of 3 quarks) whereas the  $K^0$  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.