


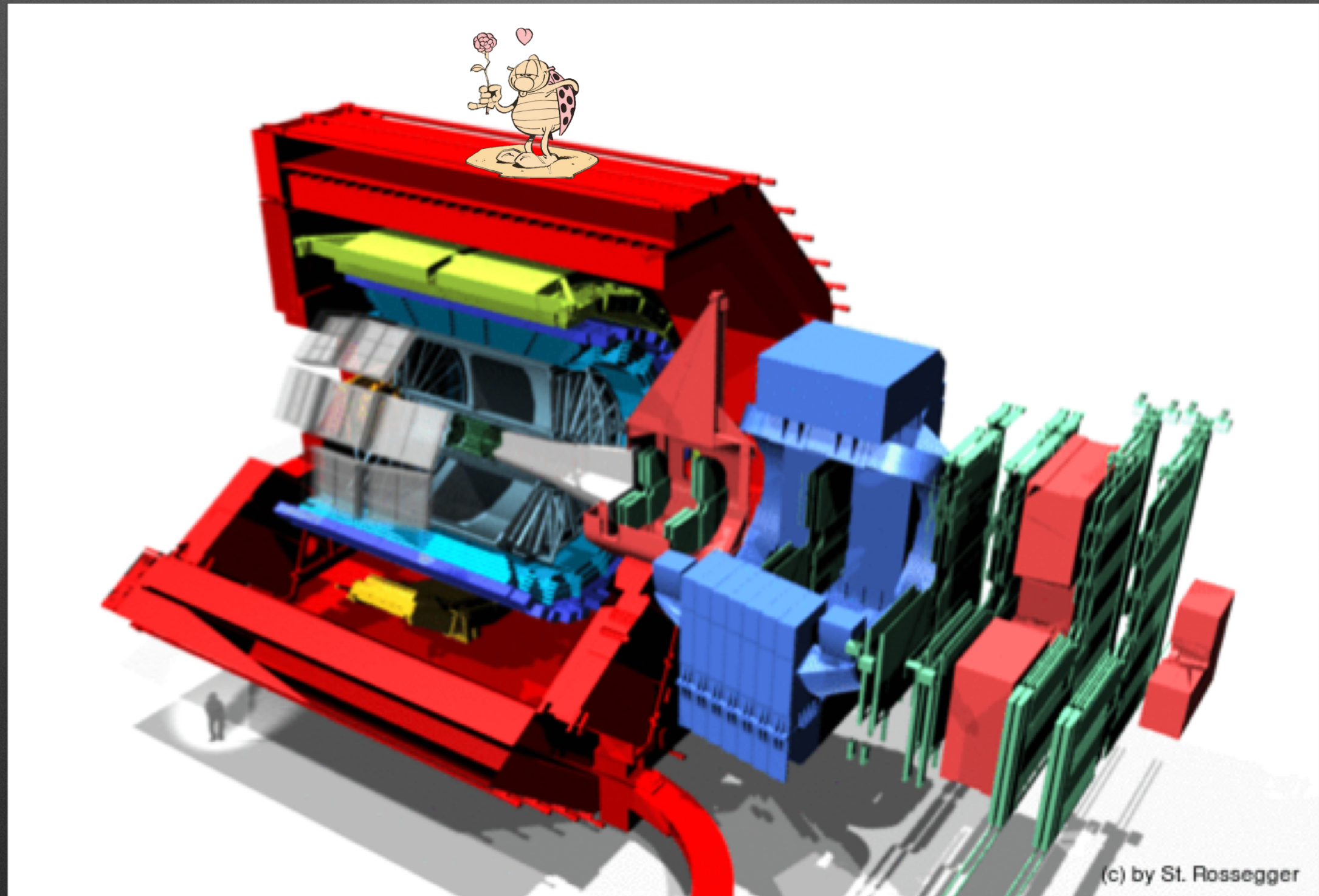
Sur la piste d'étranges particules avec ALICE

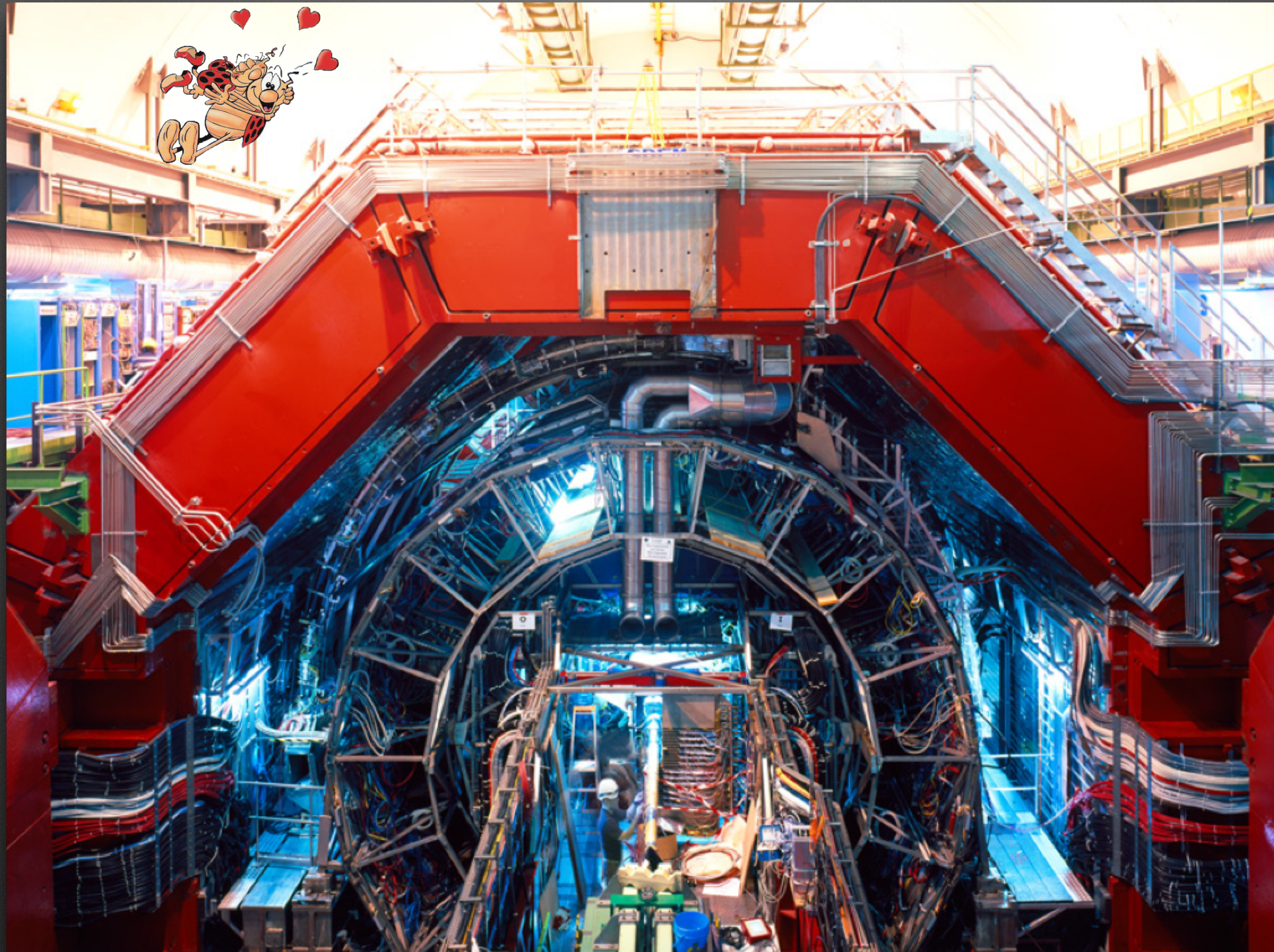


Master Class Strasbourg 2019



Vous avez dit ALICE.... ?





Le défi à relever...

- Près de 10.000 particules traversent le détecteur lors de chaque collision ... jusqu'à 90 particules par cm^2 au plus près du point d'interaction

- Mesurer chacune de ces particules :

Les compter,

localiser leur trajectoire,

Identifier leur nature (cf le livret PDG),

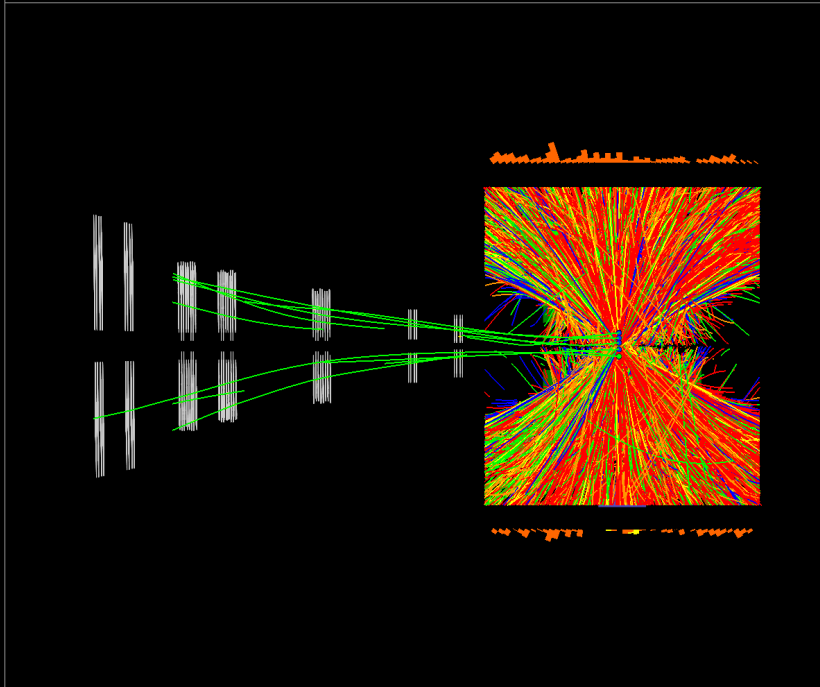
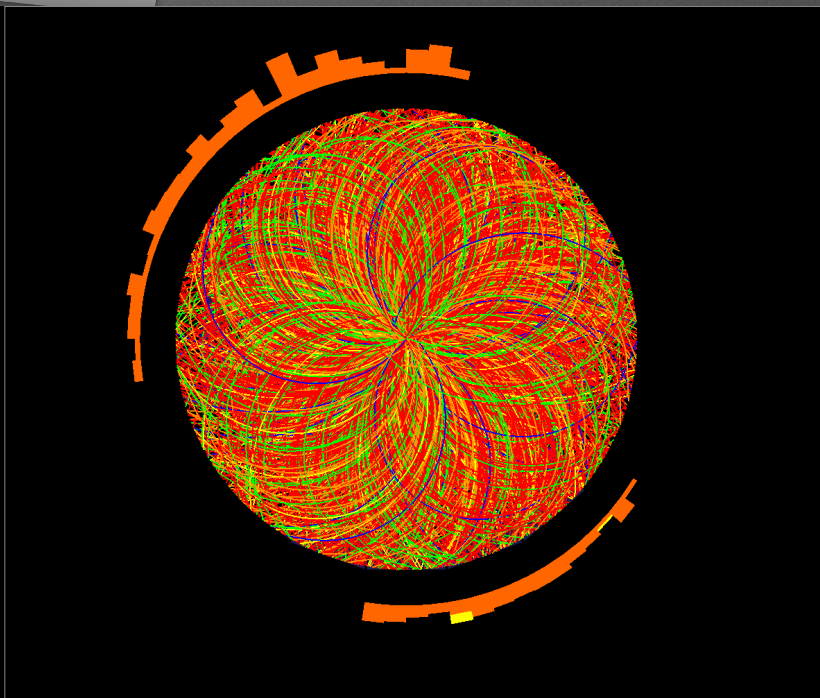
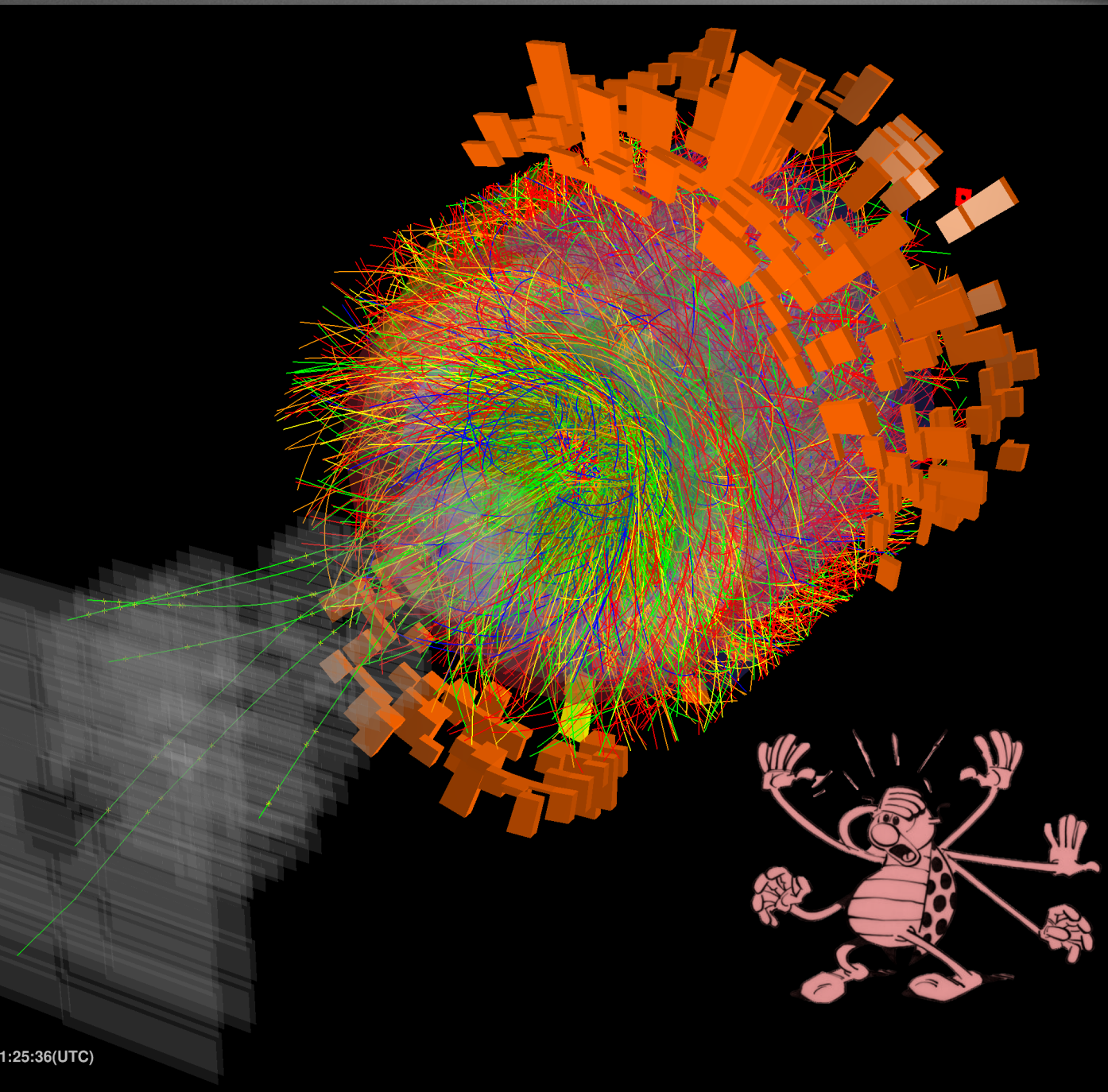
Établir leur (Energie, quantité de mouvement).

- Localiser l'origine de chacune des particules avec une précision du micron





PbPb collisions at 5.02 TeV

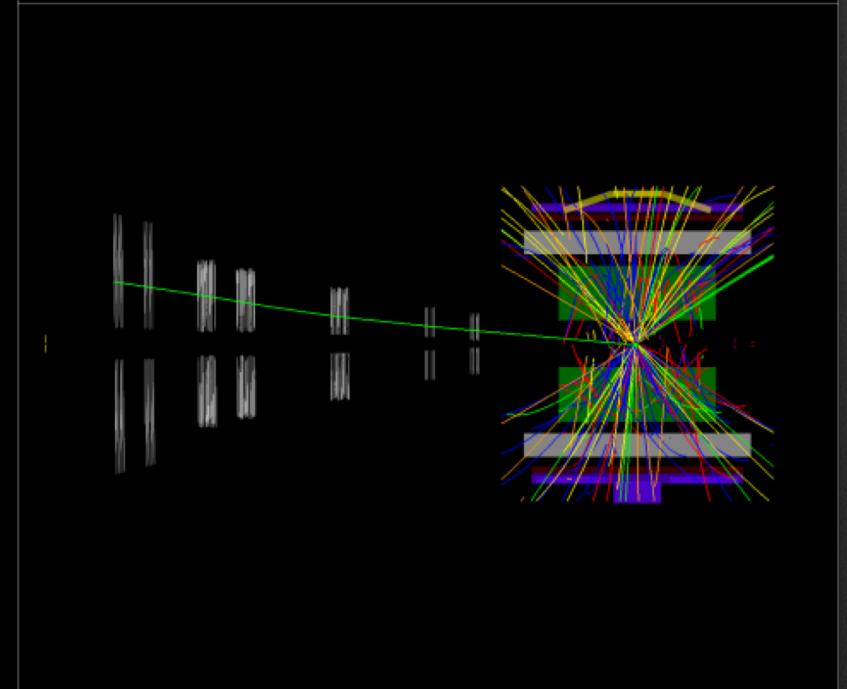
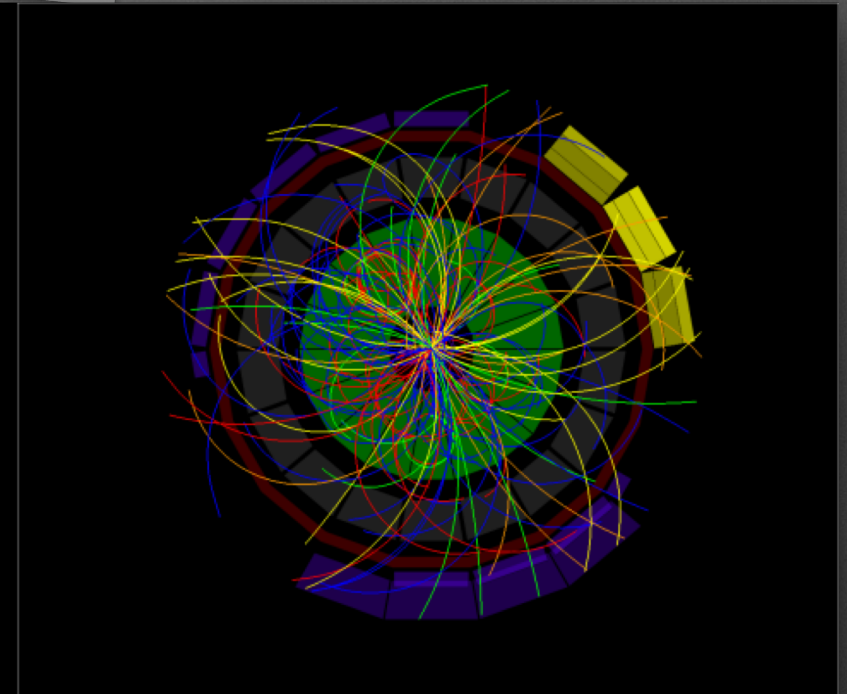
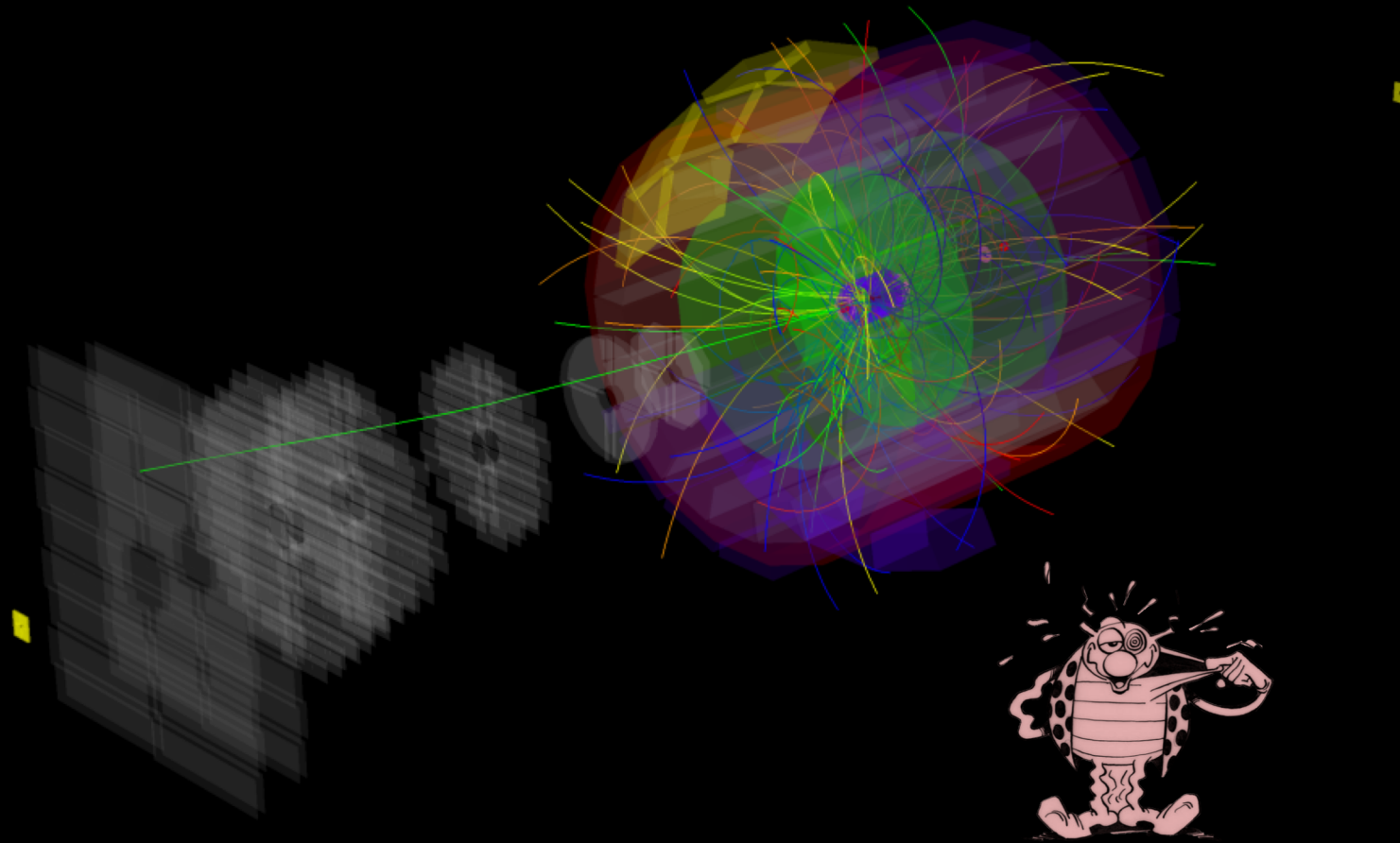


Run:244918
Timestamp:2015-11-25 11:25:36(UTC)
System: Pb-Pb
Energy: 5.02 TeV



ALICE
A JOURNEY OF DISCOVERY

pPb collisions at 5.02 TeV

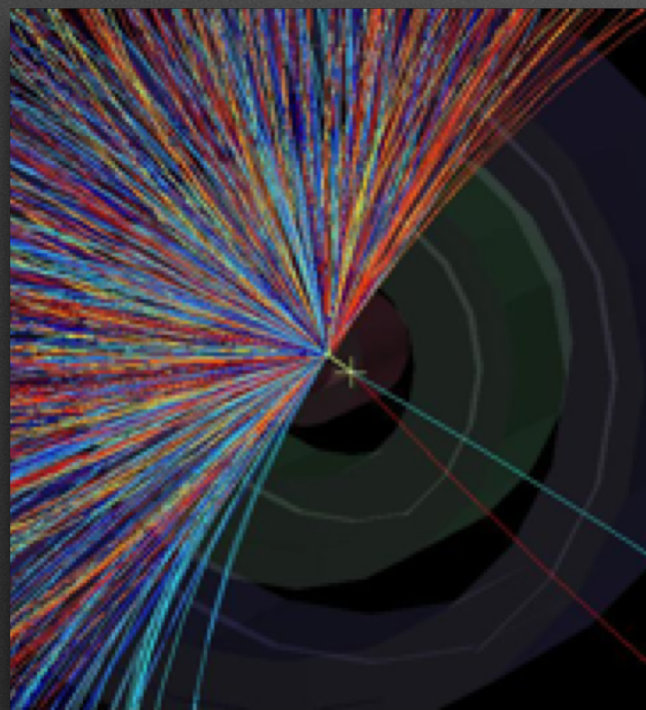


Run:265305
Timestamp:2016-11-10 14:12:26(UTC)
Colliding system:p-Pb
Energy: 5.02 TeV

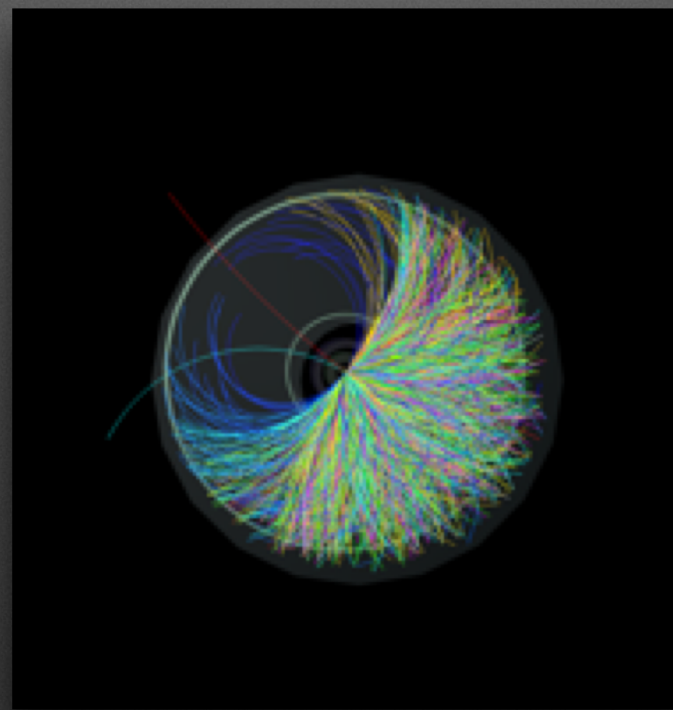


Les particules étranges

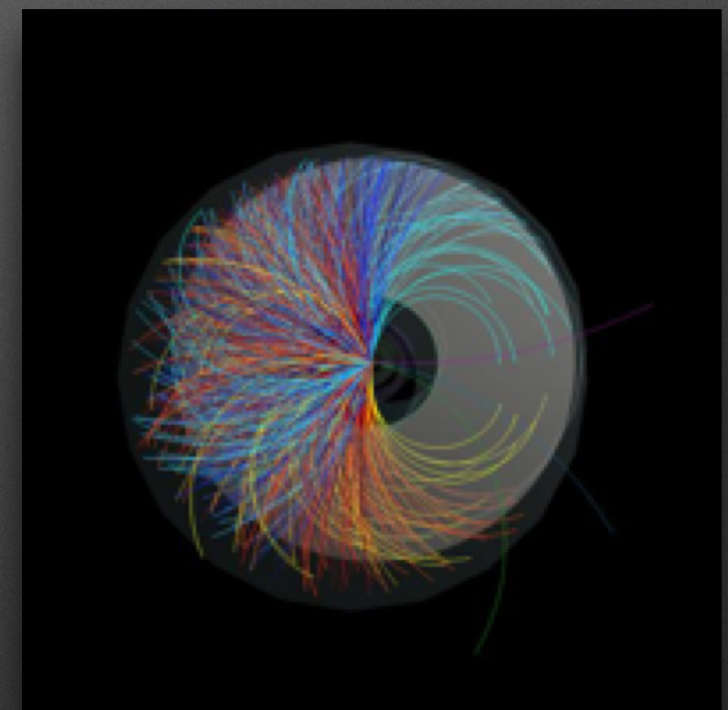
$$K_S^0 = d\bar{s}$$



$$\Lambda^0 = uds$$



$$\Xi^0 = uss$$



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

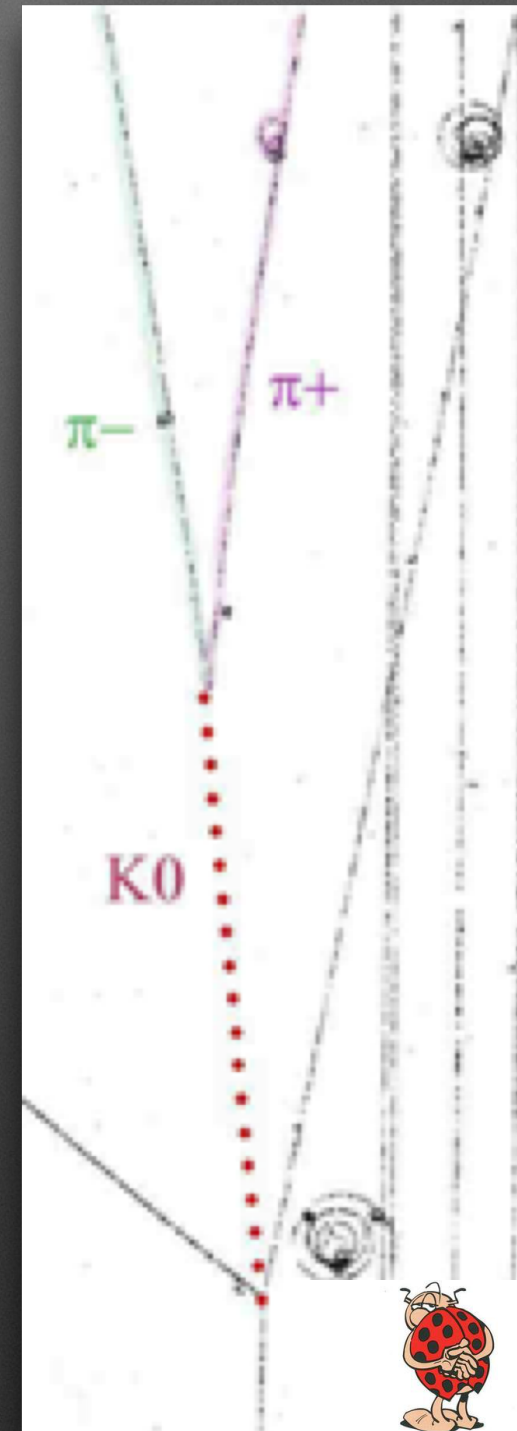
$$\Lambda^0 \rightarrow \pi^- p$$

$$\Xi^0 \rightarrow \pi^- \Lambda \rightarrow \pi^- p$$



Etranges particules étranges

- Hadrons (baryons ou mésons) contenant au moins un **quark étrange**
- Nous nous intéressons aux particules étranges **neutres** qui parcourent une certaine distance (**mm ou cm**) avant de se désintégrer





<http://pdg.lbl.gov>

K_S^0

$$I(J^P) = \frac{1}{2}(0^-)$$

Mean life $\tau = (0.8954 \pm 0.0004) \times 10^{-10}$ s (S = 1.1) Assuming *CPT*

Mean life $\tau = (0.89564 \pm 0.00033) \times 10^{-10}$ s Not assuming *CPT*

$c\tau = 2.6844$ cm Assuming *CPT*

CP-violation parameters [ff]

$$\text{Im}(\eta_{+-0}) = -0.002 \pm 0.009$$

$$\text{Im}(\eta_{000}) = -0.001 \pm 0.016$$

$$|\eta_{000}| = |A(K_S^0 \rightarrow 3\pi^0)/A(K_L^0 \rightarrow 3\pi^0)| < 0.0088, \text{ CL} = 90\%$$

CP asymmetry A in $\pi^+ \pi^- e^+ e^- = (-0.4 \pm 0.8)\%$

K_S^0 DECAY MODES

	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes			
$\pi^0 \pi^0$	$(30.69 \pm 0.05) \%$		209
$\pi^+ \pi^-$	$(69.20 \pm 0.05) \%$		206
$\pi^+ \pi^- \pi^0$	$(3.5 \begin{smallmatrix} +1.1 \\ -0.9 \end{smallmatrix}) \times 10^{-7}$		133


<http://pdg.lbl.gov>


$$I(J^P) = 0(\frac{1}{2}^+)$$

Mass $m = 1115.683 \pm 0.006$ MeV

$$(m_\Lambda - m_{\bar{\Lambda}}) / m_\Lambda = (-0.1 \pm 1.1) \times 10^{-5} \quad (S = 1.6)$$

$$\text{Mean life } \tau = (2.632 \pm 0.020) \times 10^{-10} \text{ s} \quad (S = 1.6)$$

$$(\tau_\Lambda - \tau_{\bar{\Lambda}}) / \tau_\Lambda = -0.001 \pm 0.009$$

$$c\tau = 7.89 \text{ cm}$$

Magnetic moment $\mu = -0.613 \pm 0.004 \mu_N$

Electric dipole moment $d < 1.5 \times 10^{-16} \text{ e cm}$, CL = 95%

Decay parameters

$$p\pi^- \quad \alpha_- = 0.642 \pm 0.013$$

$$\bar{p}\pi^+ \quad \alpha_+ = -0.71 \pm 0.08$$

$$p\pi^- \quad \phi_- = (-6.5 \pm 3.5)^\circ$$

$$" \quad \gamma_- = 0.76 [n]$$

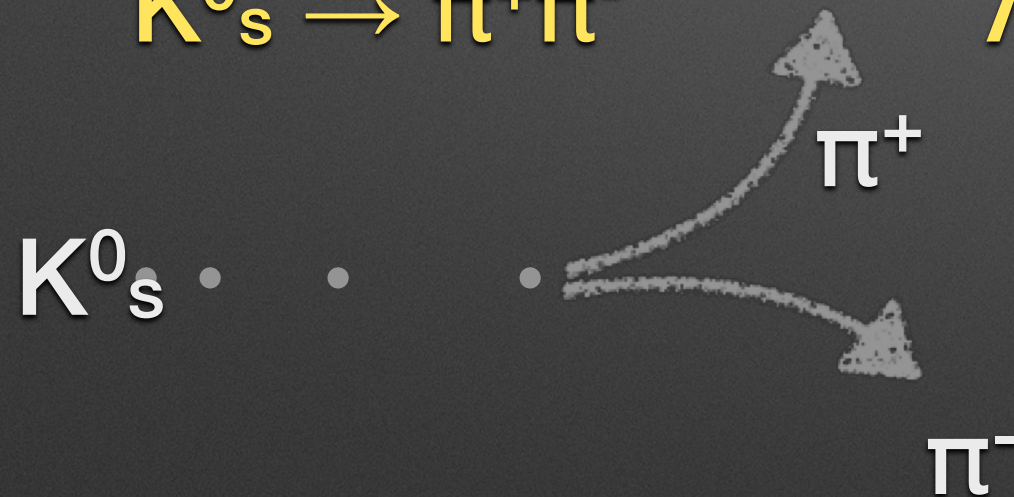
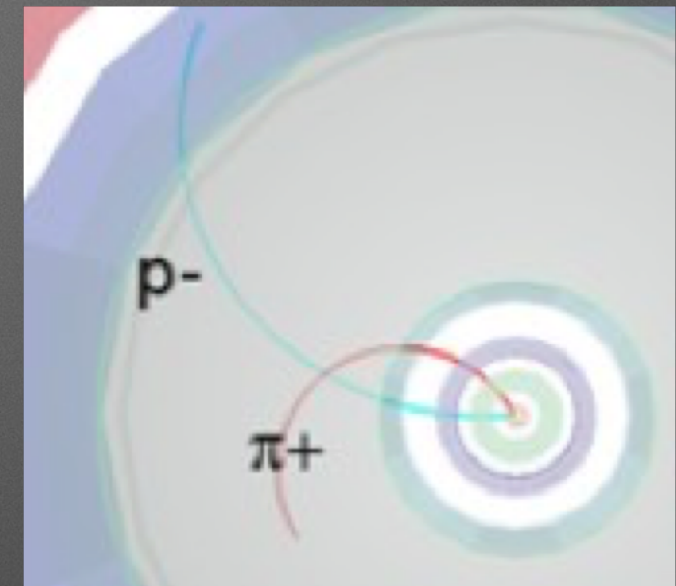
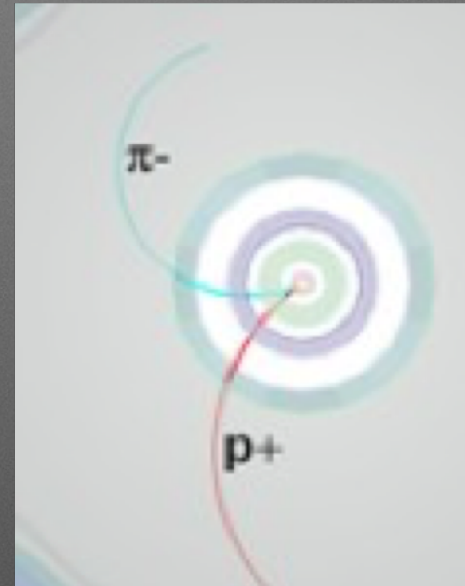
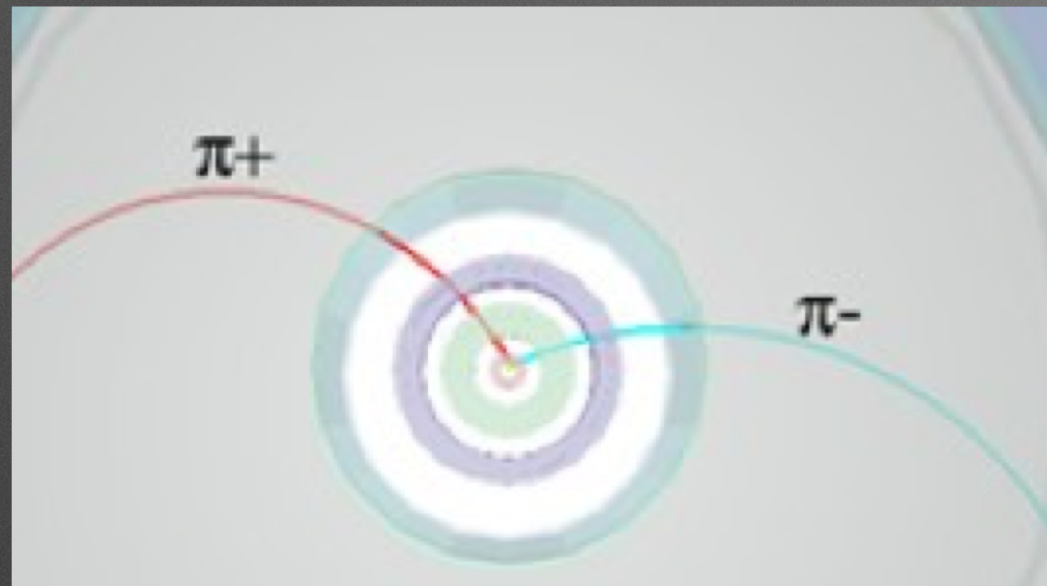
$$" \quad \Delta_- = (8 \pm 4)^\circ [n]$$

$$n\pi^0 \quad \alpha_0 = 0.65 \pm 0.04$$

$$pe^- \bar{\nu}_e \quad g_A/g_V = -0.718 \pm 0.015 [i]$$

Λ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$p\pi^-$	(63.9 \pm 0.5) %		101
$n\pi^0$	(35.8 \pm 0.5) %		104

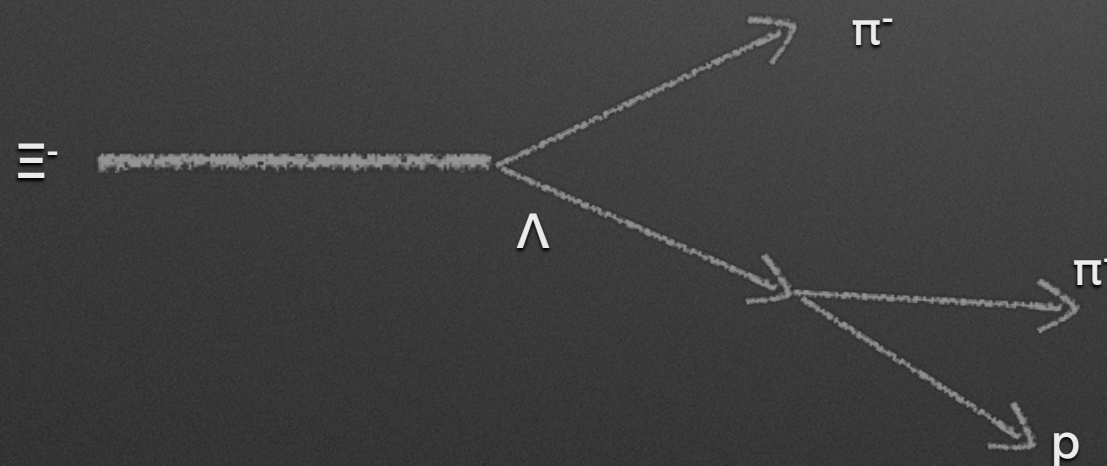
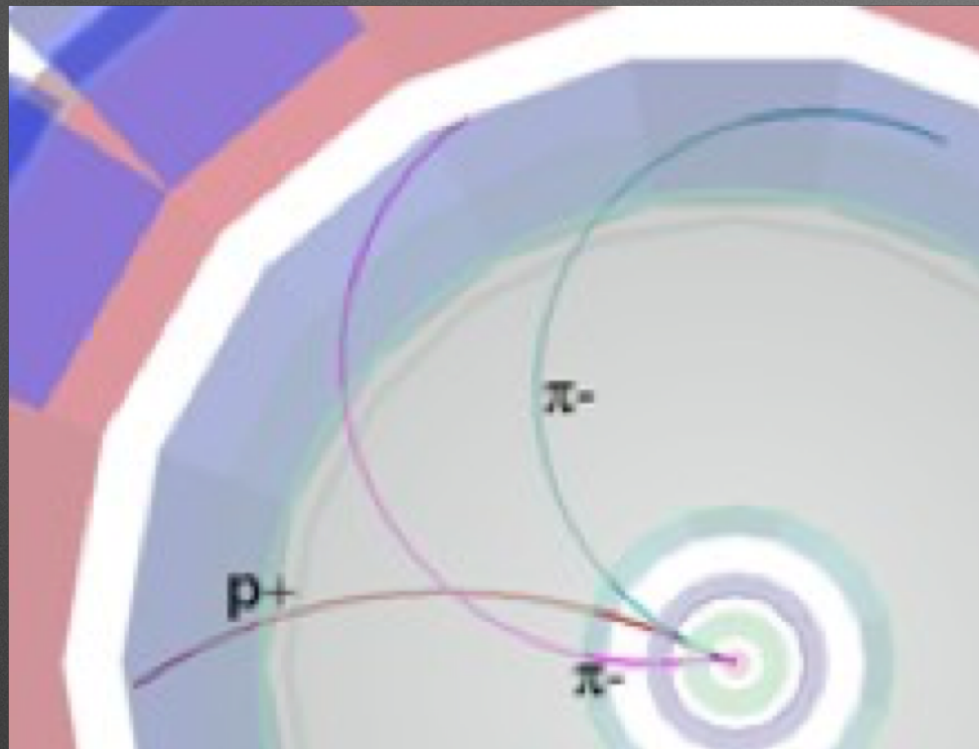
Décroissance en forme de V



neutre (**invisible**) donne naissance à 2 traces de courbures



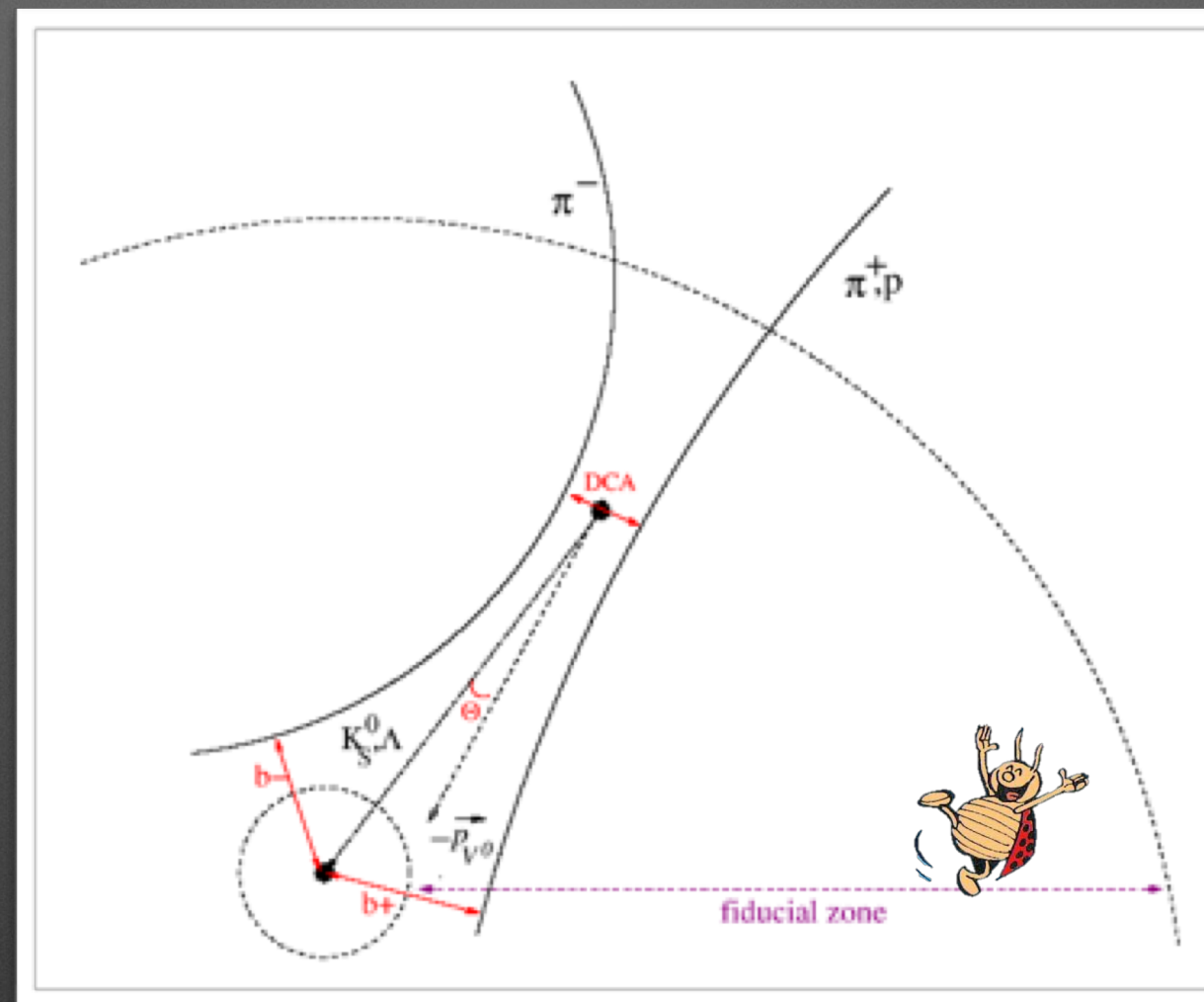
Décroissance en cascade



Une particule chargée suivie d'une décroissance en V



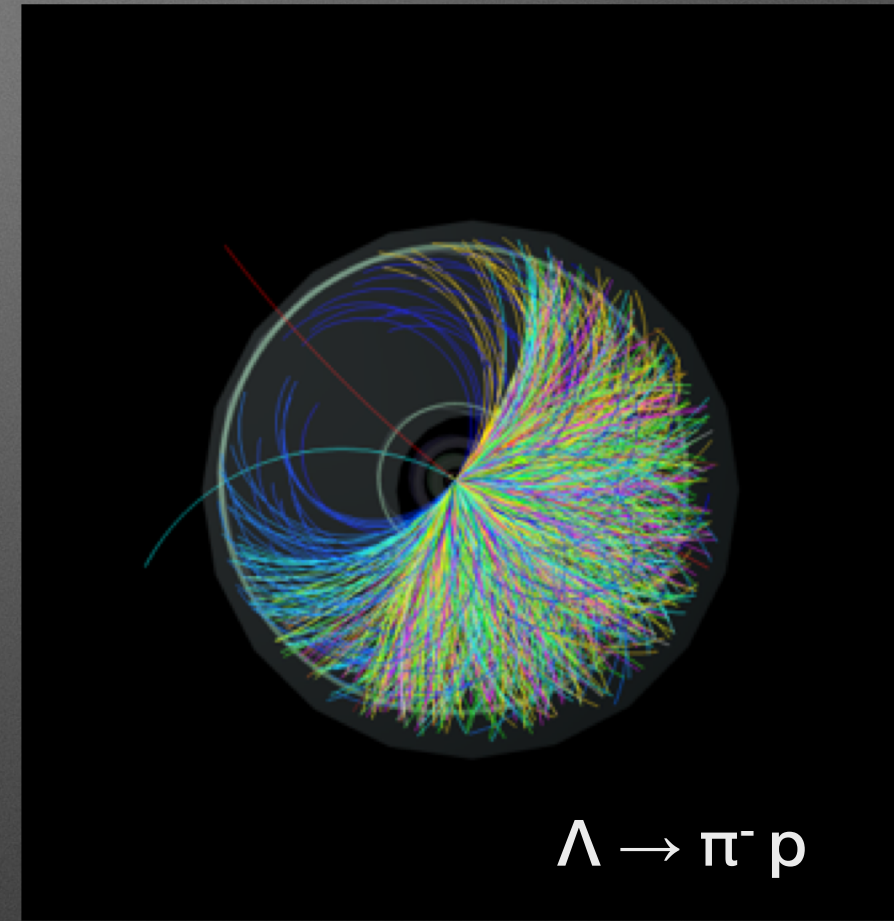
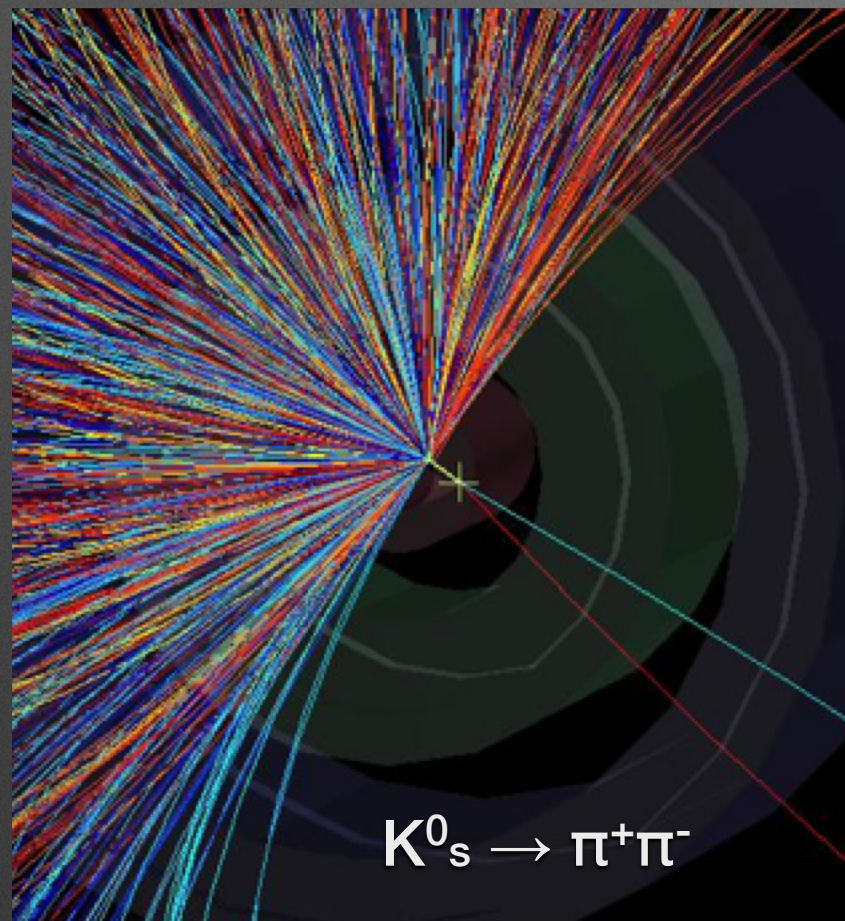
Trouver les Vs ?



Rechercher 2 traces de courbures **opposées** issues du **même** vertex, qui n'est pas le vertex de l'interaction



Trouver les Vs ?



Rechercher 2 traces de courbures **opposées** issues du **même** vertex, qui n'est pas le vertex de l'interaction



Identifier les Vs ?

- Calculer la masse invariante

- Conservation de l'énergie :

$$E = E_1 + E_2$$

- Conservation de la quantité de mouvement :

$$\vec{p} = \vec{p}_1 + \vec{p}_2 \quad \left(\vec{p} = m\vec{v} \right)$$

- Energie totale :

$$E^2 = p^2 c^2 + m^2 c^4$$

Identifier les Vs ?

- Calculer la masse invariante

- Conservation de l'énergie :

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→ → →

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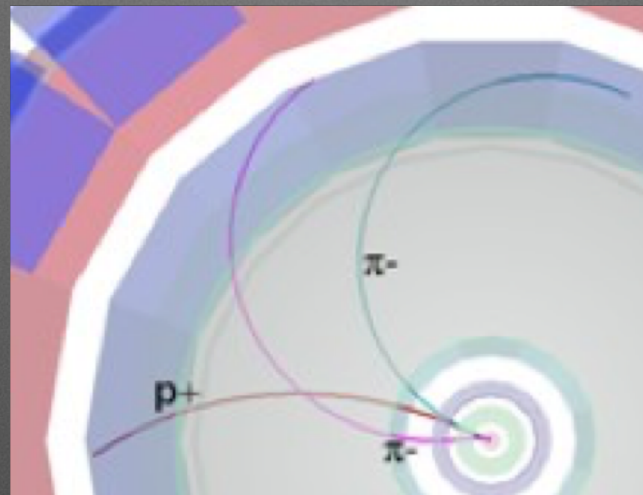
$$E^2 = p^2 c^2 + m^2 c^4$$

Calculer la **masse** de la particule initiale à partir des masses, énergie et quantités de mouvement des particules finales

$$m^2 = m_1^2 + m_2^2 + 2 \left(E_1 E_2 - \vec{p}_1 \cdot \vec{p}_2 \right)$$

Identifier les Vs ?

$$m^2 = m_1^2 + m_2^2 + 2 \left(E_1 E_2 - \vec{p}_1 \cdot \vec{p}_2 \right)$$



- Identification réalisée par des détecteurs spécialisés
- Rayon de courbure de la trajectoire des particules dans un champ magnétique :

$$m_1, m_2$$

$$\vec{p}_1, \vec{p}_2$$

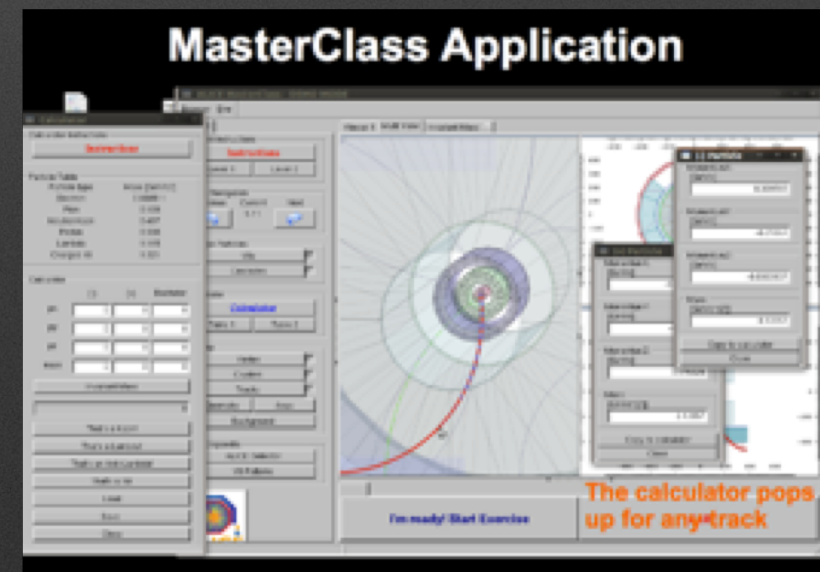
$$p = Q \cdot B \cdot \rho$$

$$p = Q \cdot B \cdot \rho$$



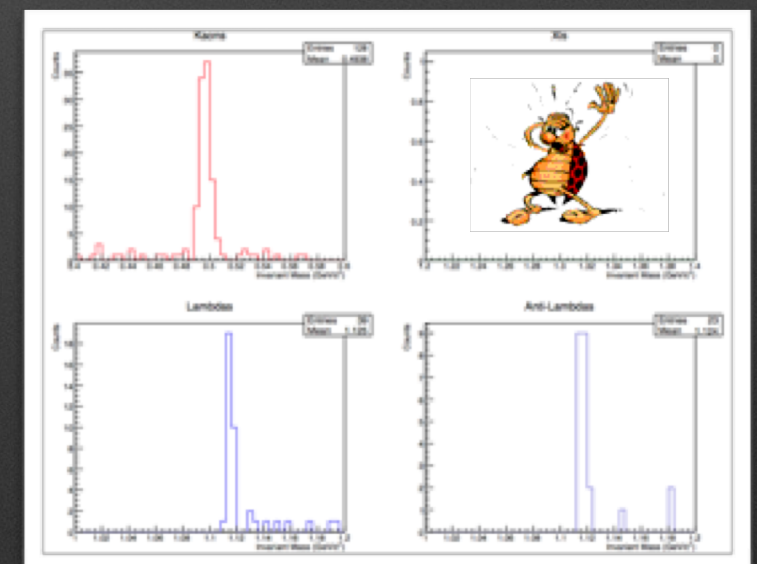
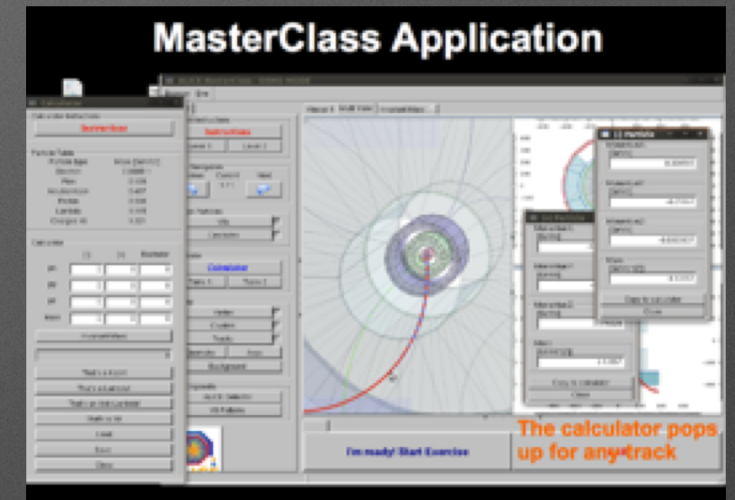
Exercice Partie 1: analyse visuelle

- Trouver V_s (K_S^0 , Λ , $\bar{\Lambda}$) à partir de la topologie de décroissance (**2 traces de charges opposées issues du même vertex**)
- Calculer la masse invariante
- Classer les particules trouvées selon leur masse
- Remplir histogrammes et tables



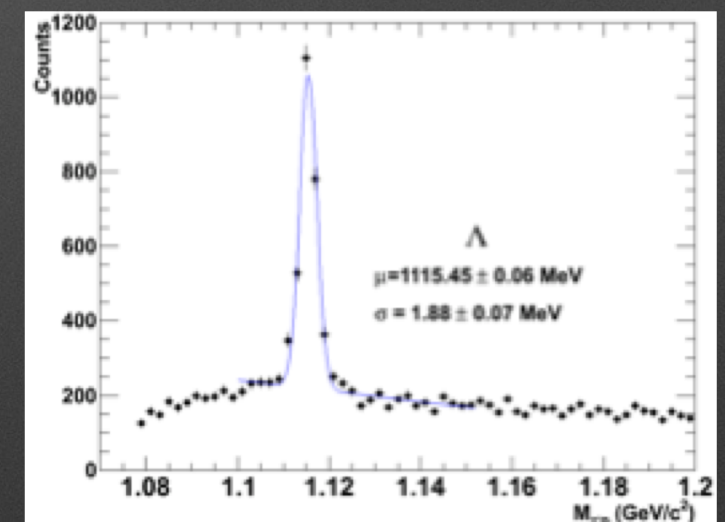
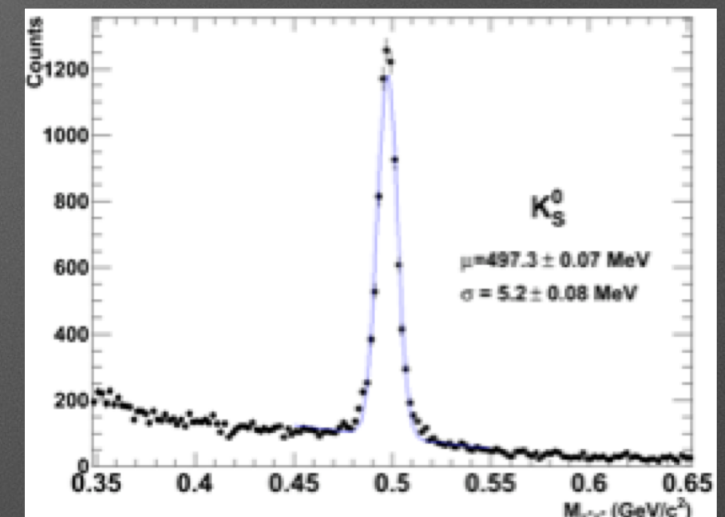
Exercice Partie 1: analyse visuelle

- Trouver V_s ($K_S^0, \Lambda, \bar{\Lambda}$) à partir de la topologie de décroissance (**2 traces de charges opposées issues du même vertex**)
- Calculer la masse invariante
- Classer les particules trouvées selon leur masse
- Remplir histogrammes et tables
- Discuter :
 - La valeur du pic de masse
 - Sa largeur
 - Le bruit de fond



Exercice Partie 2 : analyse statistique

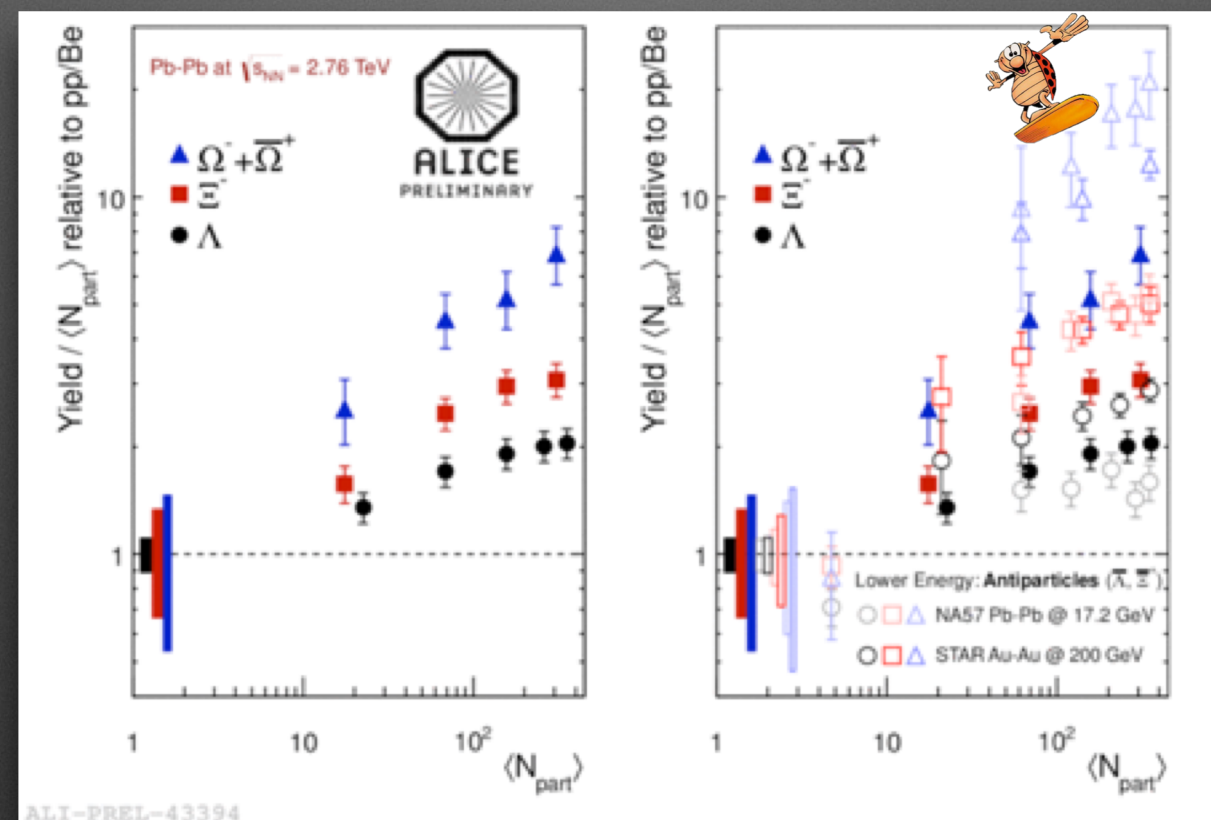
- Ajuster les histogrammes à un bruit de fond (eq. polynôme d'ordre 2) plus le signal (eq. gaussienne)
- Trouver le nombre de K_S^0 , Λ , et $\bar{\Lambda}$



L'analyse se fera pour des collisions Pb-Pb de différentes centralités

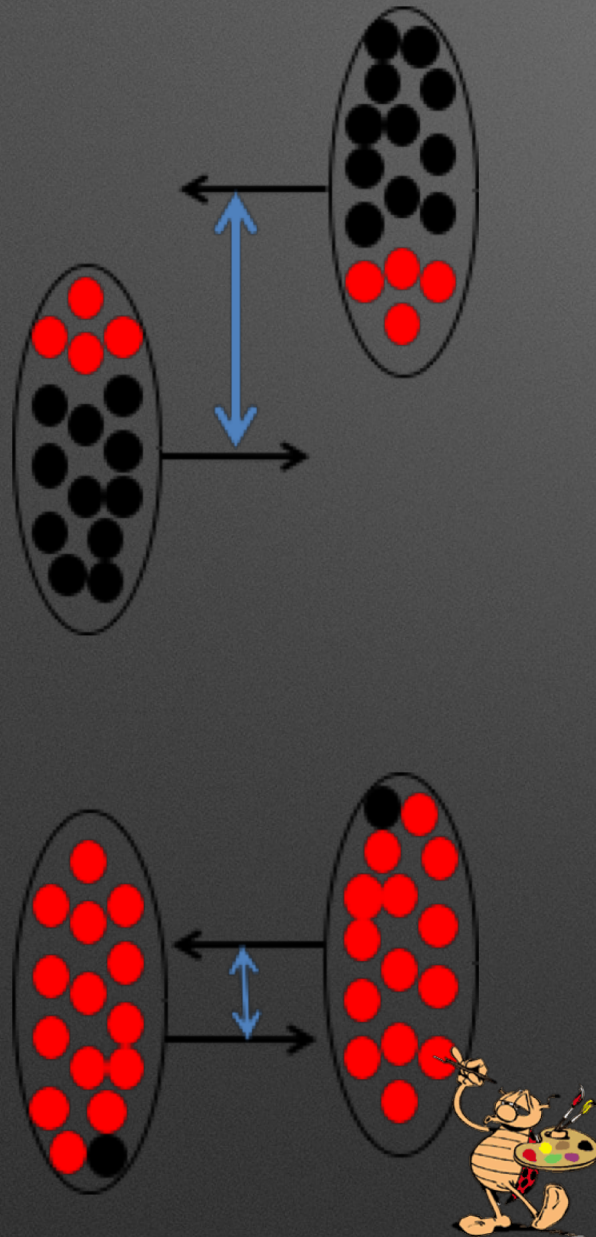
Pourquoi l'étrangeté ?

- L'augmentation de la production d'étrangeté est interprétée comme une signature de la formation du QGP



- Augmentation d'autant plus importante que le nombre de quarks étrangers est élevé

Géométrie d'une collision Pb-Pb

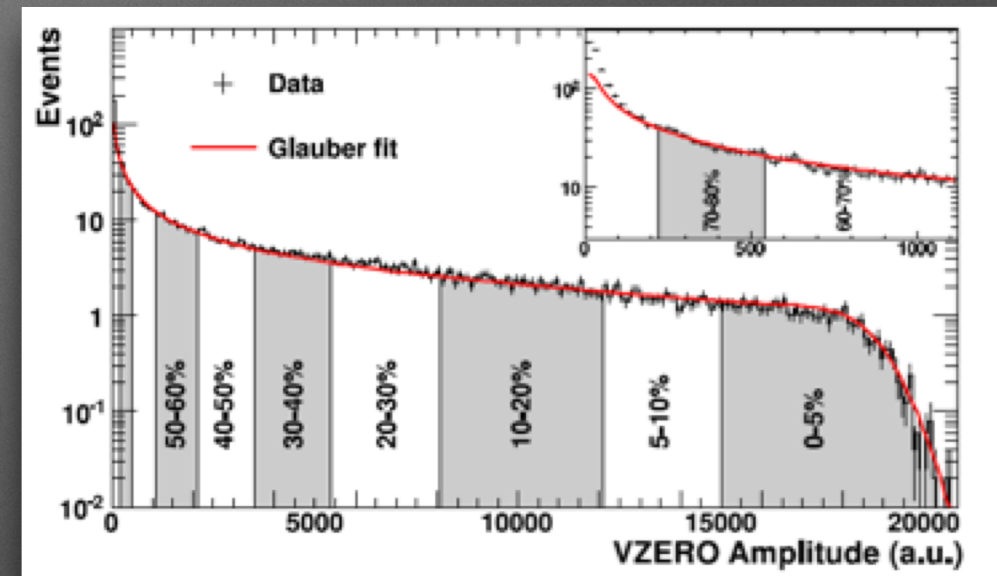


- Collision périphérique
 - Grande distance entre les centres des noyaux
 - Petit nombre de participants
 - Peu de particules produites (faible multiplicité)
- Collision centrale
 - Petite distance entre les centres des noyaux
 - Grand nombre de participants
 - Beaucoup de particules produites (multiplicité élevée)

Géométrie d'une collision Pb-Pb

- Distribution de l'amplitude du signal mesuré dans des scintillateurs plastiques

Calculs à l'aide d'un modèle (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



Périphérique



Central



Résultats

- Augmentation de l'étrangeté : le **nombre** de particules produites dans les collisions Pb-Pb normalisé au nombre de nucléons participants et au nombre de particules produites dans les collisions proton-proton

$$N_{\text{particules produites}} = \frac{N_{\text{particules}}}{N_{\text{collisions}} \times \text{efficacite}}$$

$$\text{efficacite} = \frac{N_{\text{mesure}}}{N_{\text{produit}}}$$



Results

$$\text{Augmentation} = \text{production} / (\text{Npart} \times \text{Npp} / 2)$$

- $N_{pp}(K^0_s) = 0.27$
- $N_{pp}(\Lambda) = 0.0617$

centrality	<Npart>	Nevents	NKs	efficiency Ks	yield Ks	Ks enhancement	Nlambda	efficiency L	Yield Lambda	Lambda enhancement	Nantilambda	effic antiL	yield antiLam	antiL enhancement
0-10	360	213		0.26	0	0		0.2	0	0		0.2	0	0
10-20	260	290		0.26	0	0		0.21	0	0		0.21	0	0
20-30	186	302		0.29	0	0		0.22	0	0		0.22	0	0
30-40	129	310		0.29	0	0		0.22	0	0		0.22	0	0
40-50	85	302		0.29	0	0		0.22	0	0		0.22	0	0
50-60	52	300		0.29	0	0		0.2	0	0		0.2	0	0
60-70	30	315		0.35	0	0		0.2	0	0		0.2	0	0
70-80	16	350		0.26	0	0		0.2	0	0		0.2	0	0

$$\text{Production} = \text{Nb} / (\text{Ncollisions} \times \text{efficacit })$$



Pour en savoir (encore) plus



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Looking for strange particles in ALICE

1. Overview

The exercise proposed here consists of a search for strange particles, produced from collisions at LHC and recorded by the ALICE experiment. It is based on the recognition of their V0-decays, such as $K_S^0 \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p + \pi^-$ and cascades, such as $\Xi^- \rightarrow \Lambda + \pi^-$ ($\Lambda \rightarrow p + \pi^-$). The identification of the strange particles is based on the topology of their decay combined with the identification of the decay products; the information from the tracks is used to calculate the invariant mass of the decaying particle, as an additional confirmation of the particle species.

In what follows the ALICE experiment and its physics goals are first presented briefly, then the physics motivation for this analysis. The method used for the identification of strange particles as well as the tools are described in detail; then all the steps of the exercise are explained followed by the presentation of the results; then all the steps of the exercise are explained followed by the presentation of the results as well as the method of collecting and merging all results. In the end the large scale analysis is presented.

2. Introduction.

ALICE (A Large Ion Collider Experiment), one of the four large experiments at the CERN Large Hadron Collider, has been designed to study heavy ion collisions. It also studies proton proton collisions, which primarily provide reference data for the heavy ion collisions. In addition, the proton collision data allow for a number of genuine proton proton physics studies. The ALICE detector has been designed to cope with the highest particle multiplicities anticipated for collisions of lead nuclei at the extreme energies of the LHC.

3. The ALICE Physics

Quarks are bound together into protons and neutrons by a force known as the strong interaction, mediated by the exchange of force carrier particles called gluons. The strong interaction is also responsible for binding together the protons and neutrons inside atomic nuclei.

Even though we know that quarks are elementary particles that build up all known hadrons, no quark has ever been observed in isolation: the quarks, as well as the gluons, seem to be bound permanently together and confined inside composite particles, such as protons and neutrons. This is known as confinement. The exact mechanism that causes it remains unknown.

Although much of the physics of strong interaction is, today, well understood, two very basic issues remain unresolved: the origin of confinement and the mechanism of the generation of mass. Both are thought to arise from the way the properties of the vacuum are modified by strong interaction.

The current theory of the strong interaction (called Quantum Chromo-Dynamics) predicts that at very high temperatures and very high densities, quarks and gluons should no longer be confined inside composite particles. Instead they should exist freely in a new state of matter known as quark-gluon plasma.

<http://aliceinfo.cern.ch/public/MasterCL/MasterClassWebpage.html>