4단계 BK21 2차년도 연구발표회

$\Xi_c^{0,+}$ production with ALICE and Ξ_{cc}^{++} production with ALICE 3

인하대학교 물리학과

미래형 신재생에너지 물리인재 교육연구팀

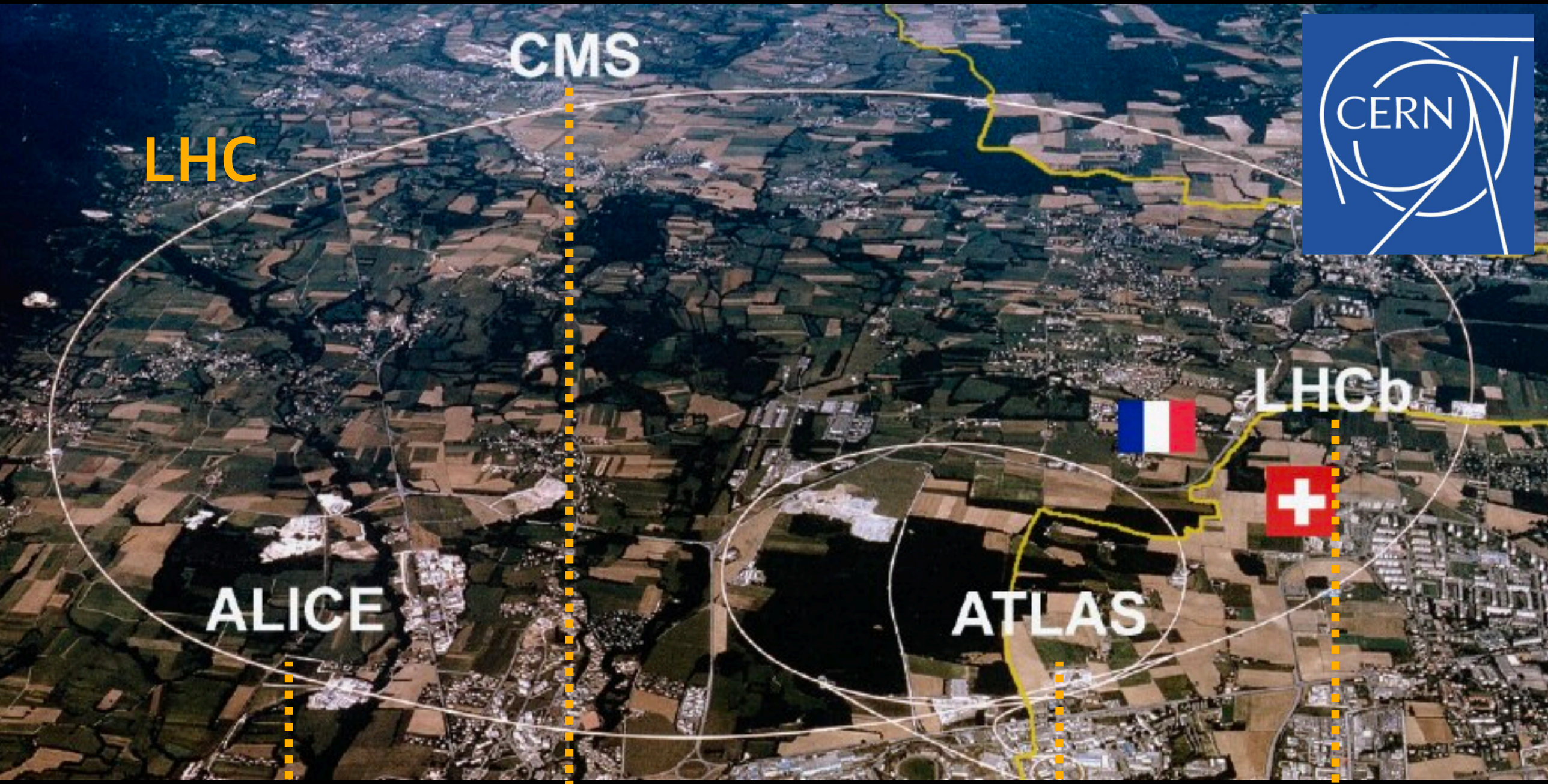
Jinjoo Seo

Inha University

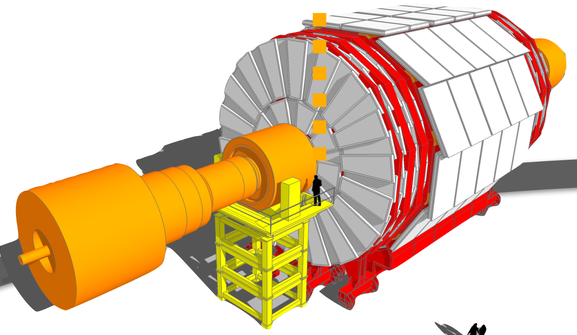
2022. 02. 08

ALICE

인하대학교 INHA UNIVERSITY 1954

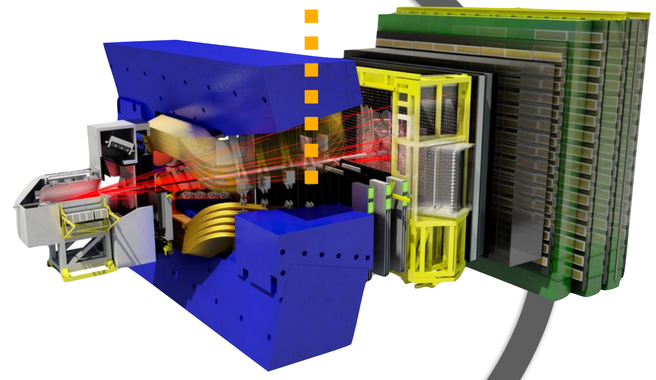

CMS
LHC
LHCb
ALICE
ATLAS
CERN

LHC

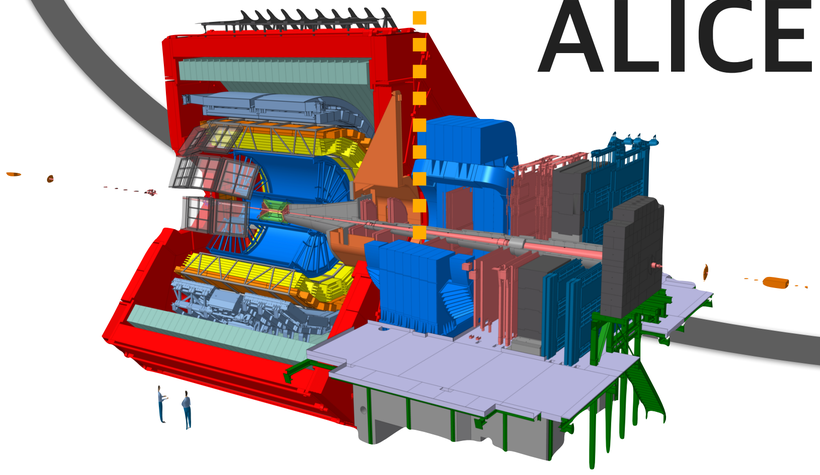


CMS

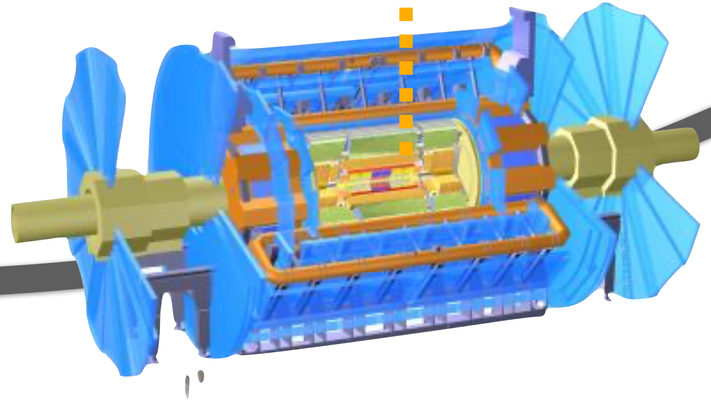
LHCb



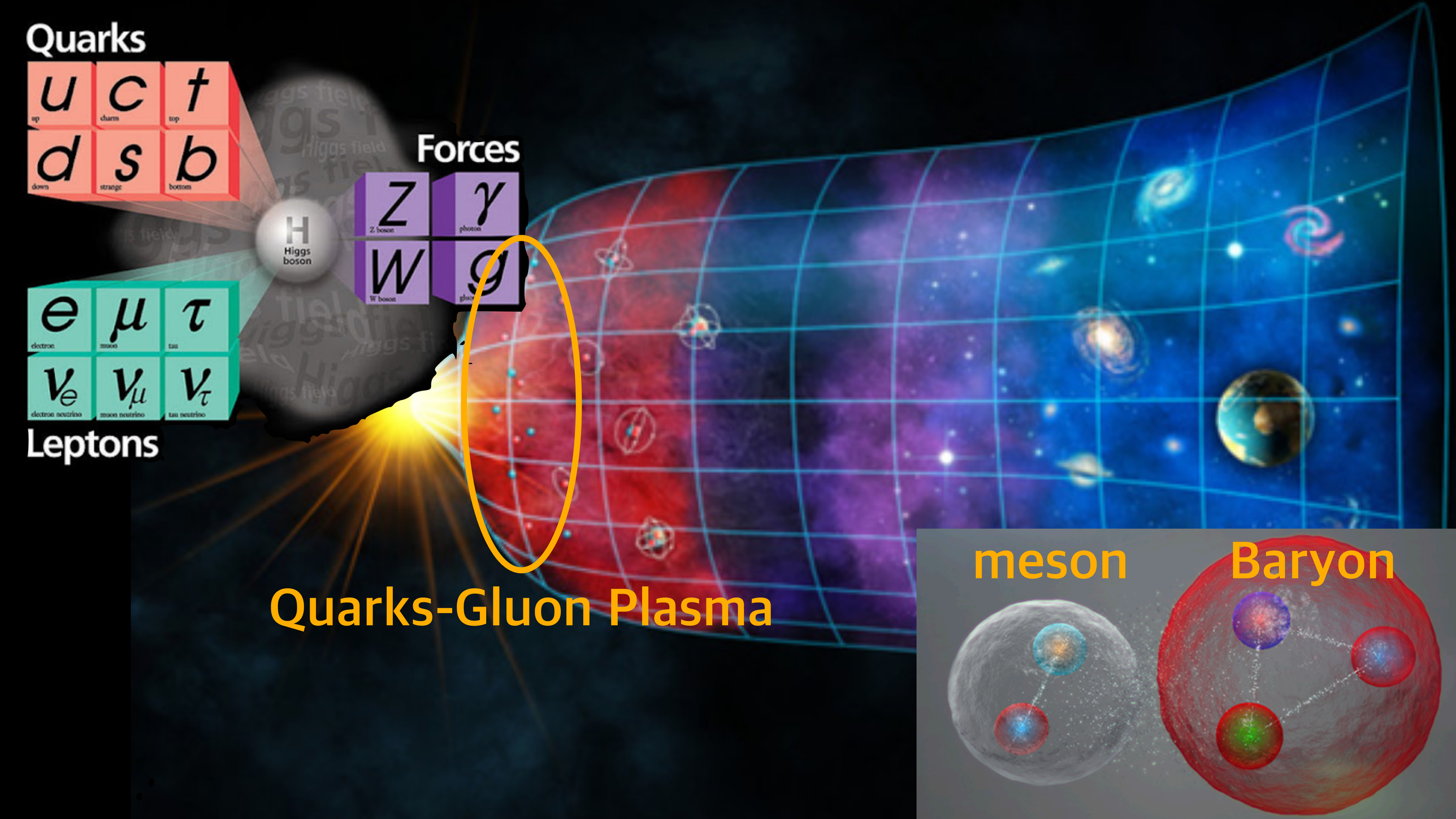
ALICE



ATLAS

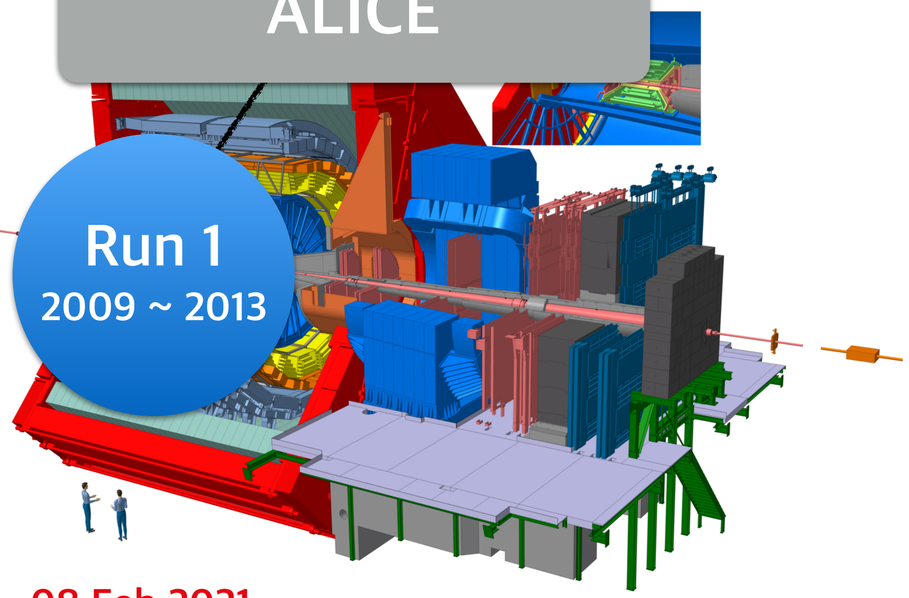


A Large Ion Collider Experiment


Quarks
u c t
up charm top
d s b
down strange bottom
Leptons
e μ τ
electron muon tau
νe νμ ντ
electron neutrino muon neutrino tau neutrino
H
Higgs boson
Forces
Z γ
Z boson photon
W g
W boson
Quarks-Gluon Plasma
meson
Baryon

ALICE Overview

ALICE



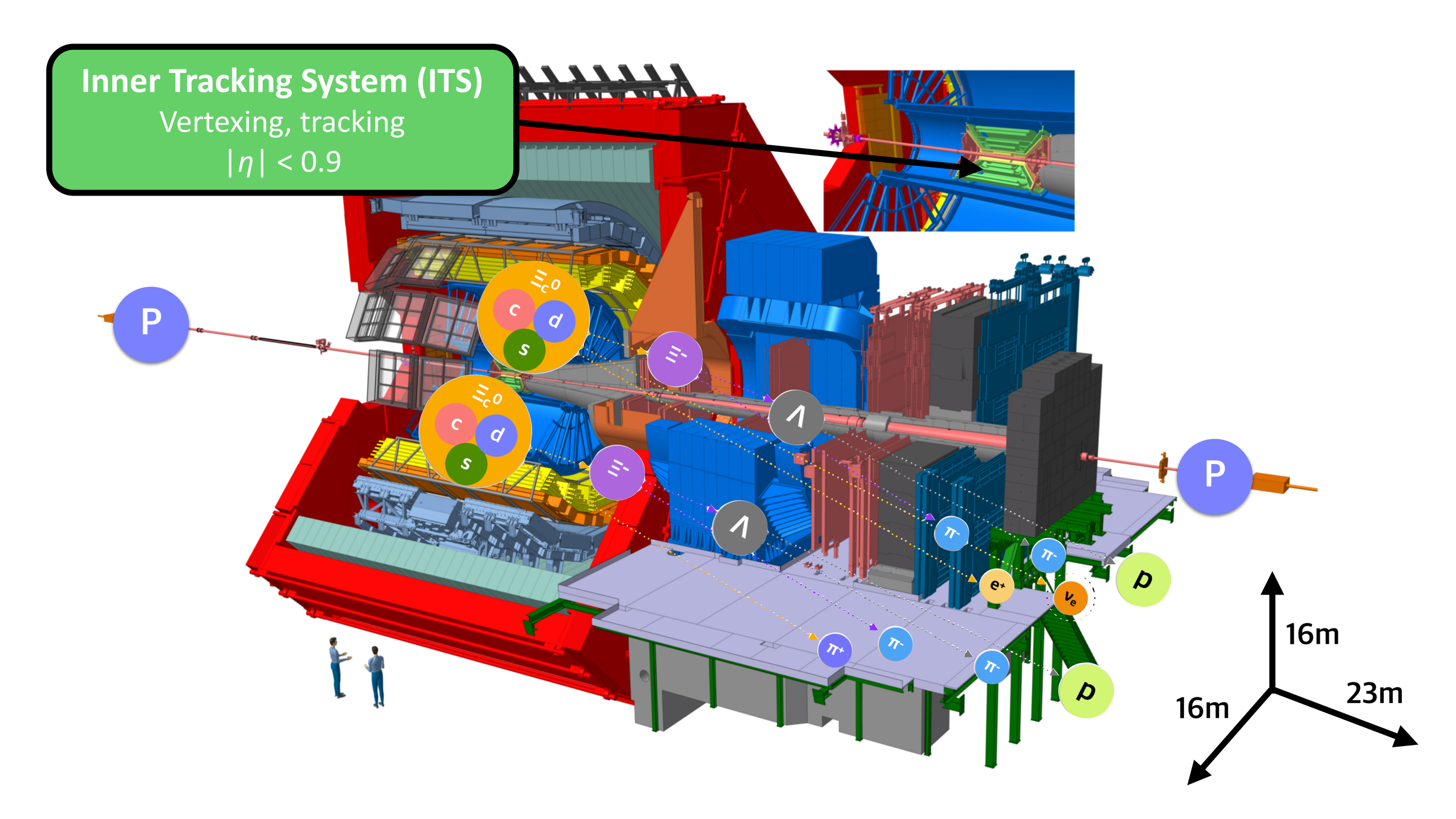
Run 1
2009 ~ 2013

Run 2
2015 ~ 2018

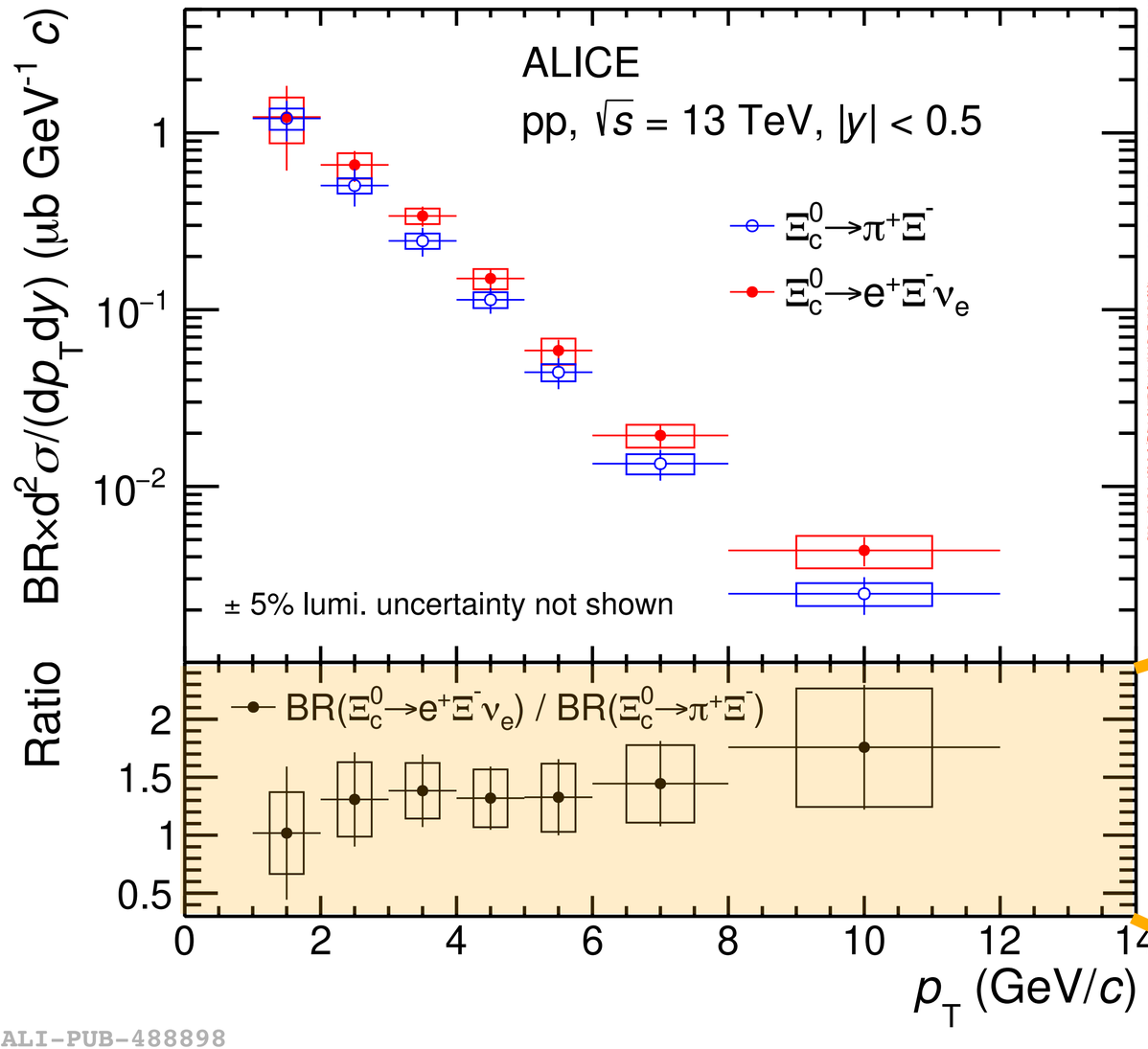
Run 3
2022 ~ 2024

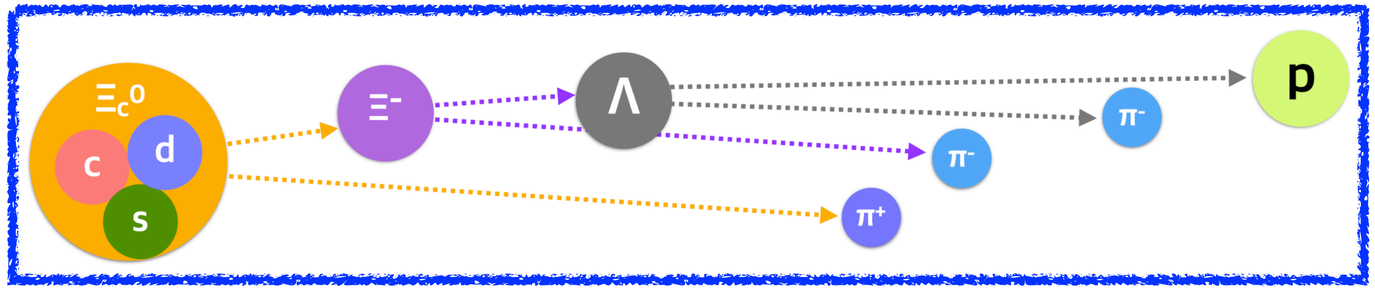
Run 4
2028 ~ 2030

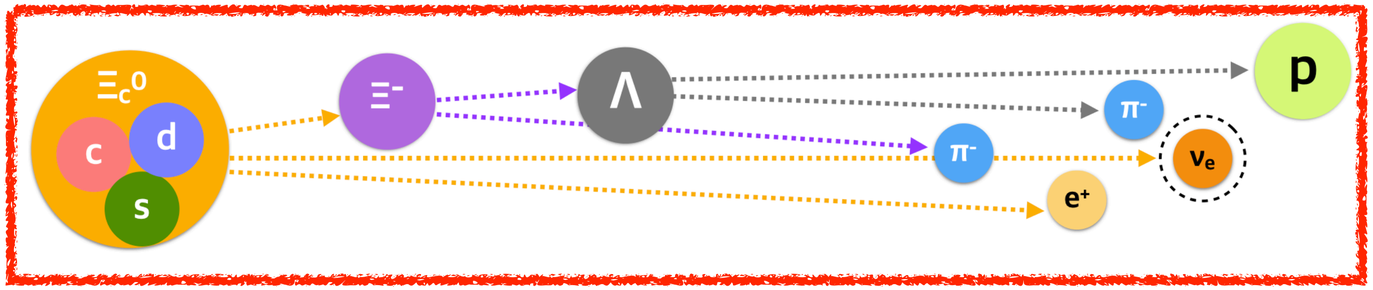
Run 5
2032 ~ 2034

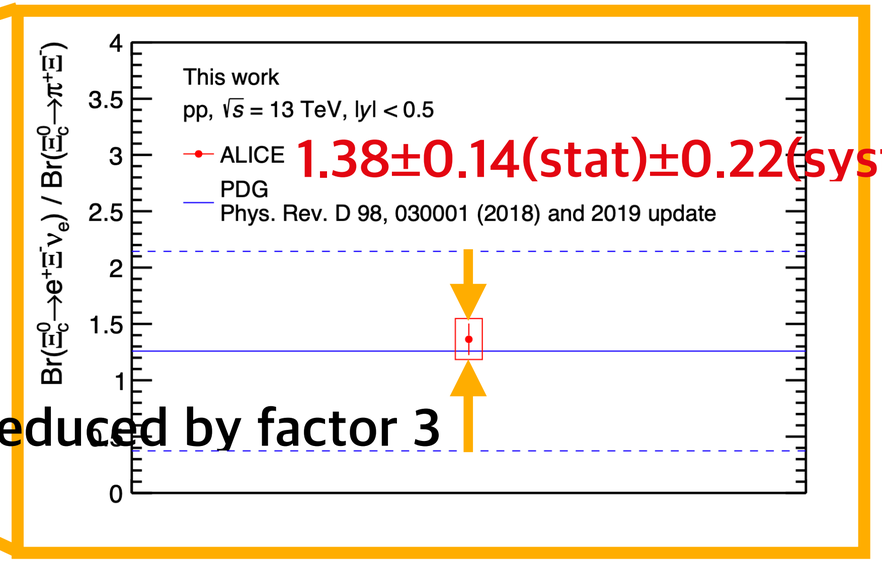

Inner Tracking System (ITS)
Vertexing, tracking
|η| < 0.9
P
P
Ξc0
c
d
s
Ξc0
c
d
s
Ξ-
Ξ-
Λ
Λ
π-
π-
e+
νe
p
p
π+
π-
π-
16m
16m
23m

$\Xi_c^{0,+}$ measurements in ALICE





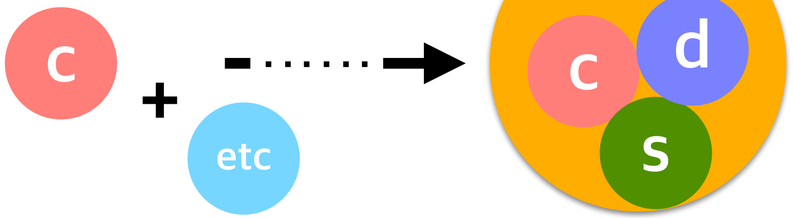




ALI-PUB-488898

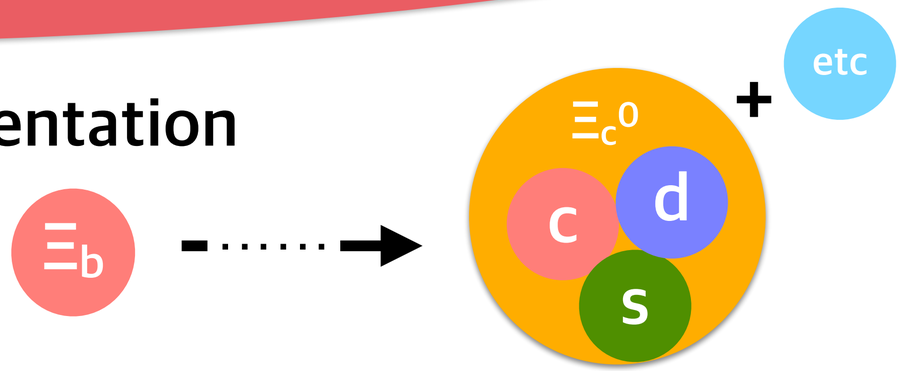
$\Xi_c^{0,+}$ measurements in ALICE

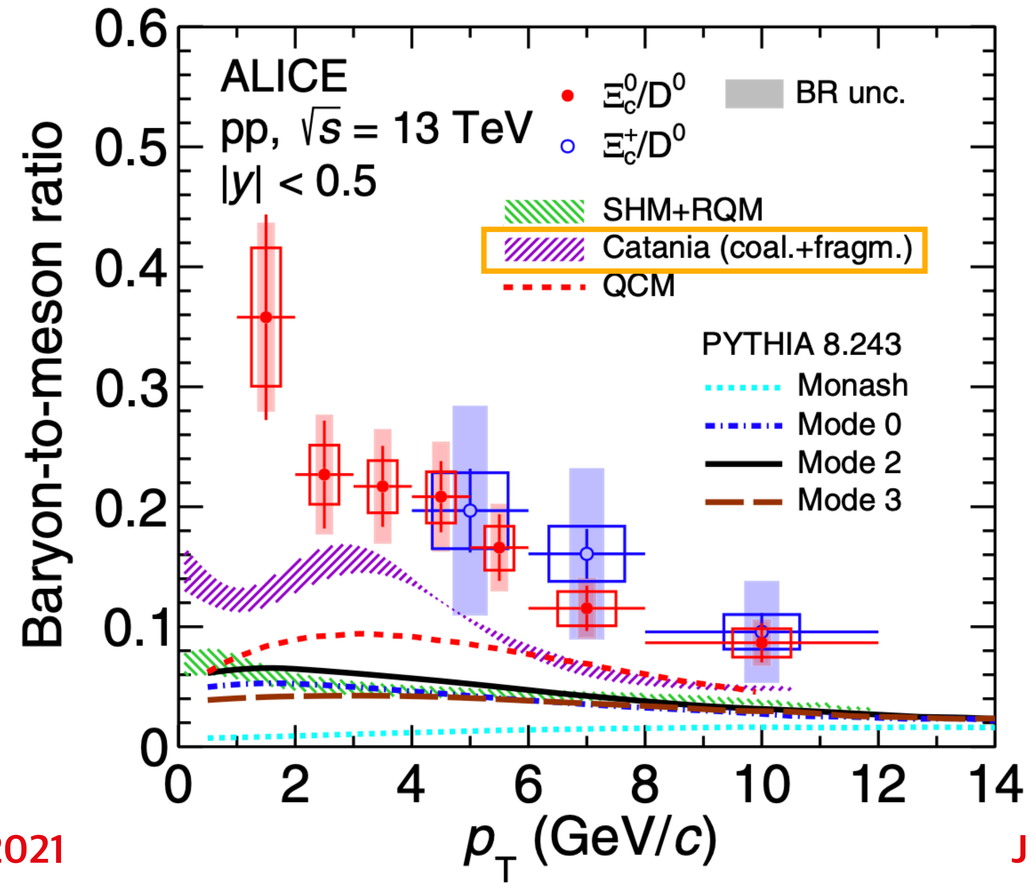
Coalescence

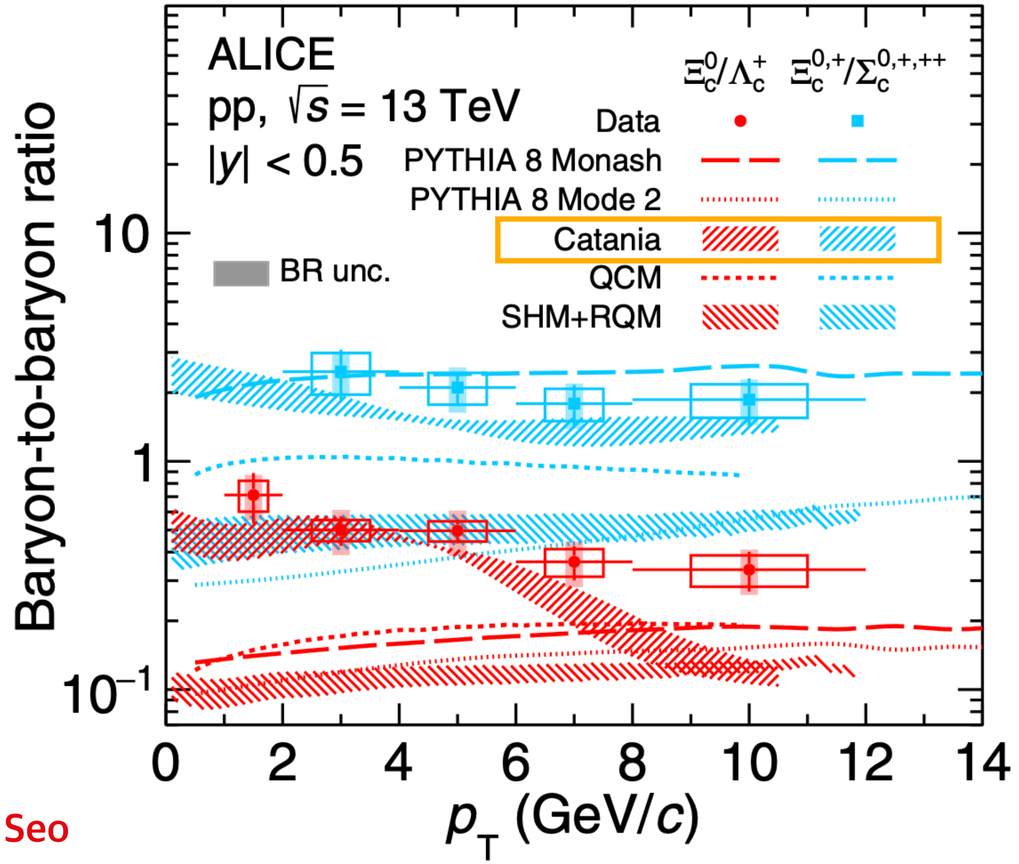


&

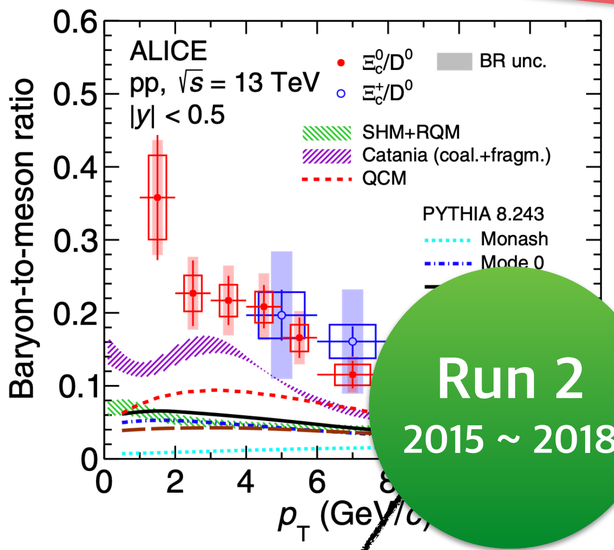
Fragmentation







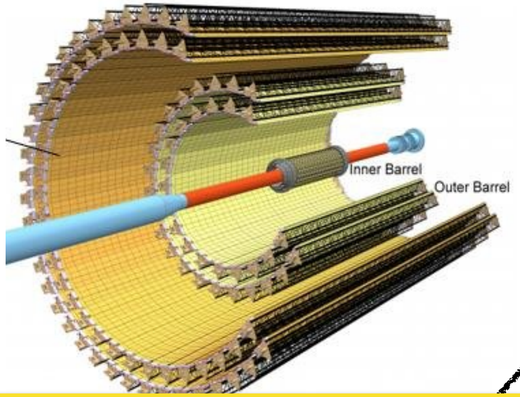
ALICE Overview



Run 2
2015 ~ 2018

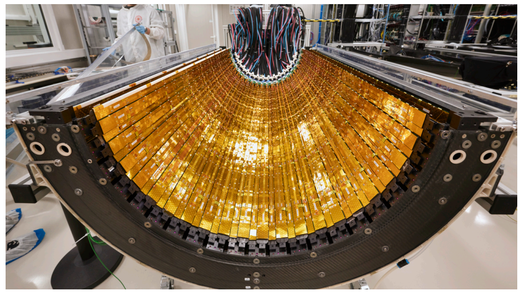
ALICE

Run 1
2009 ~ 2013



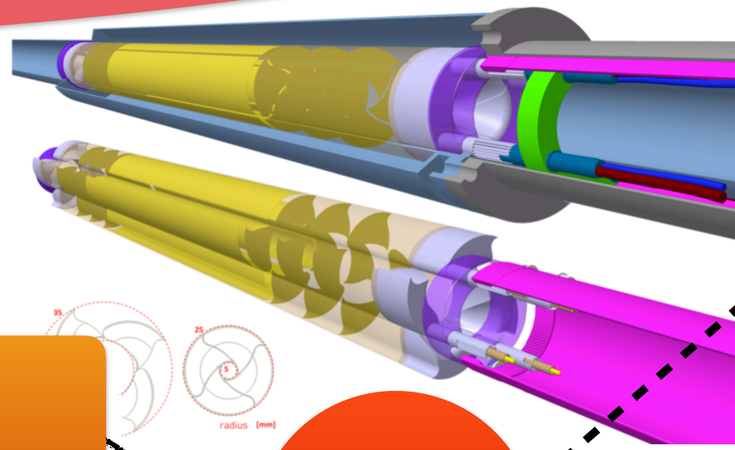
ALICE 2

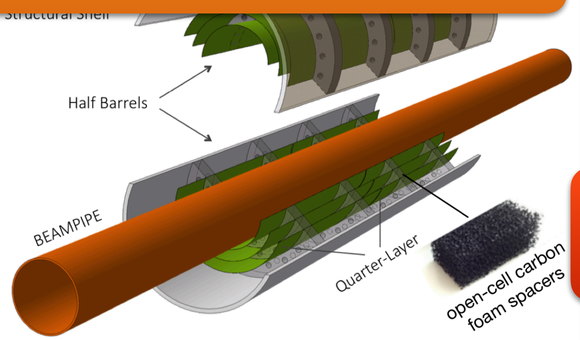
Run 3
2022 ~ 2024



Run 4
2028 ~ 2030

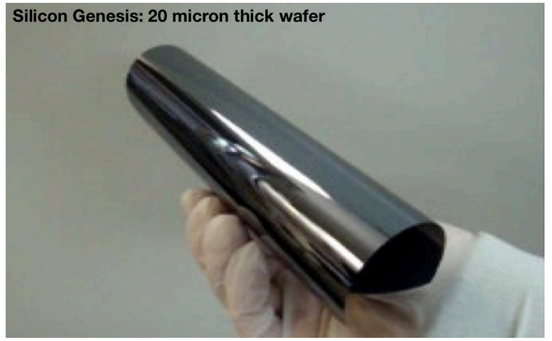
ALICE 2.1
(+ ITS 3 & FoCal)

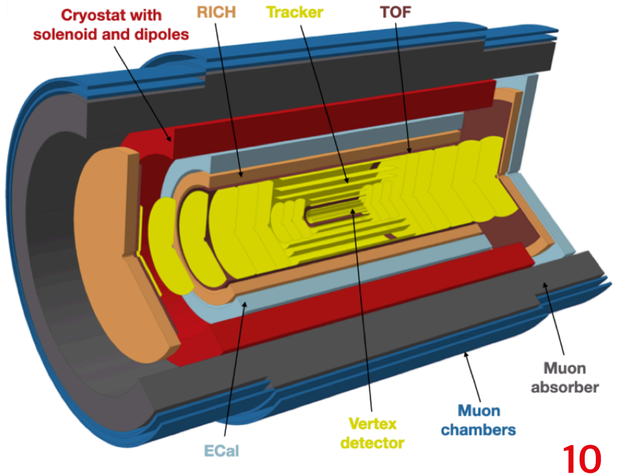




Run 5
2032 ~ 2034

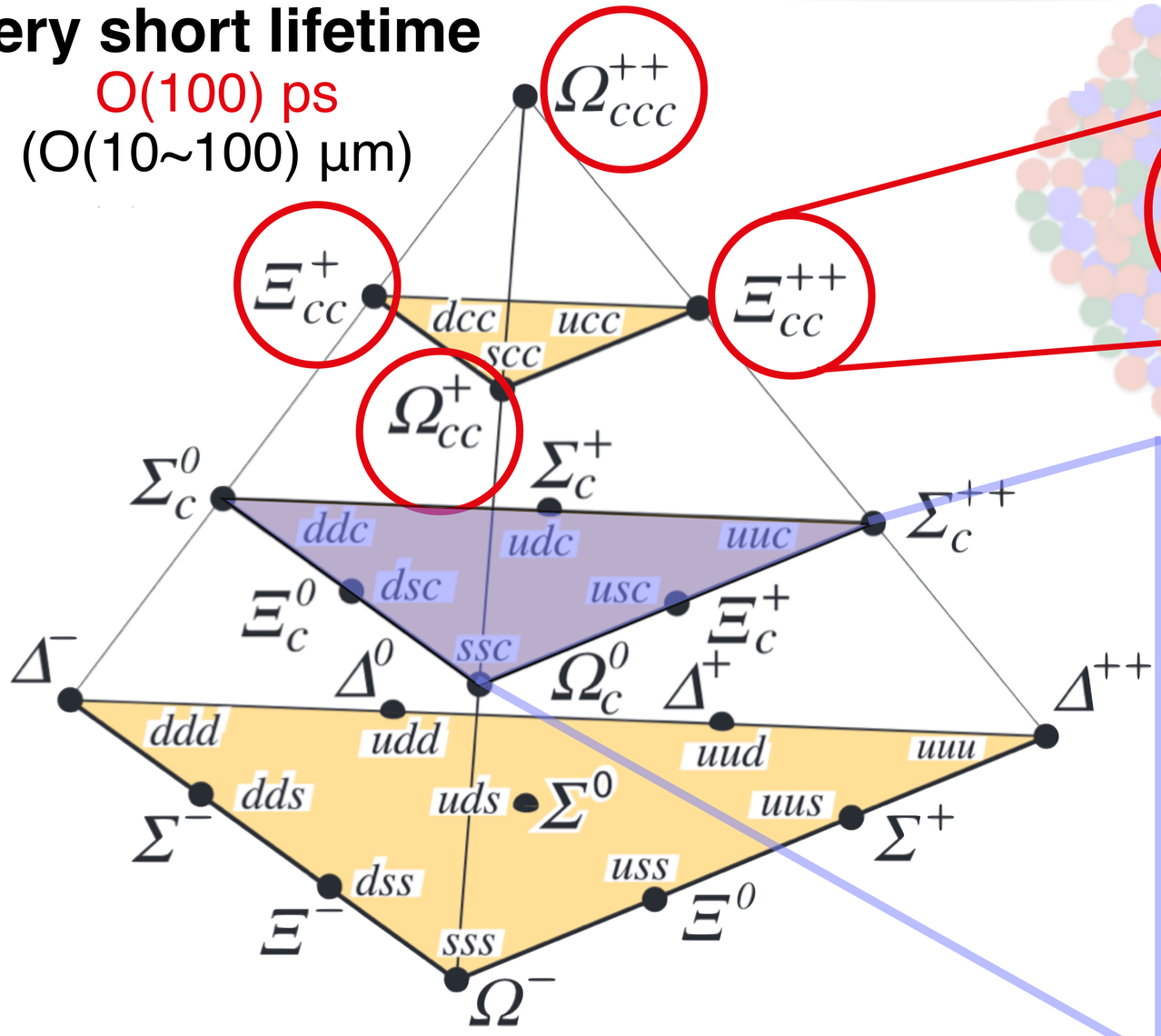
ALICE 3

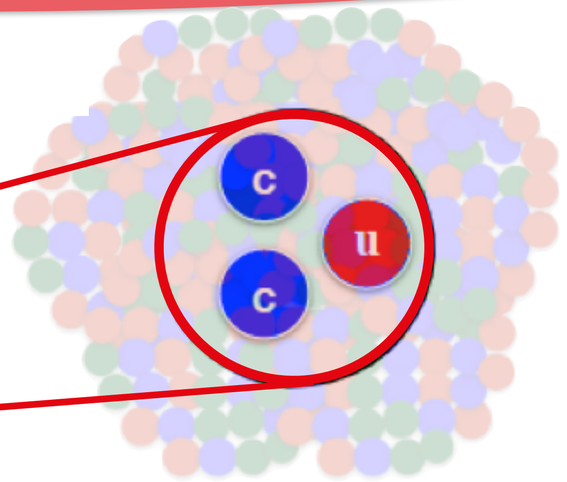




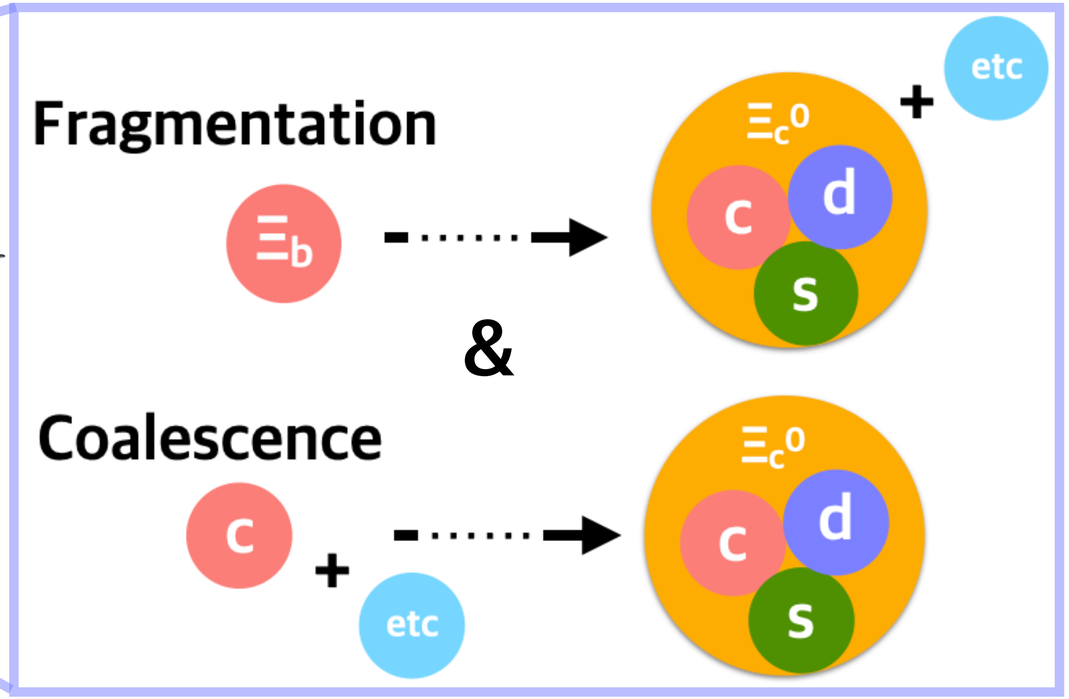
ALICE 3 Physics goal

Very short lifetime
O(100) ps
(O(10~100) μm)

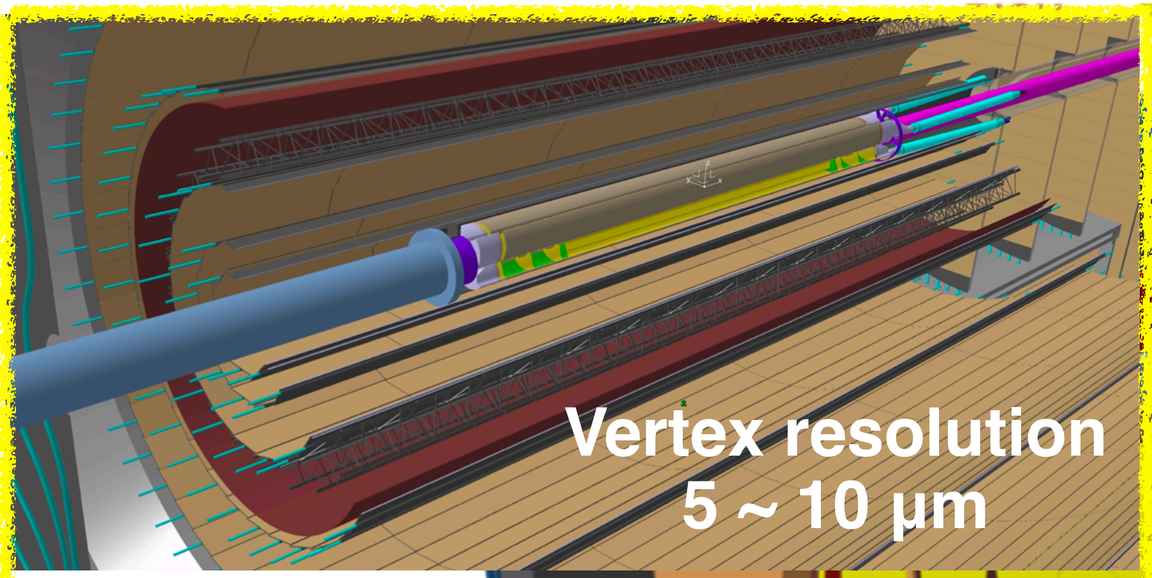




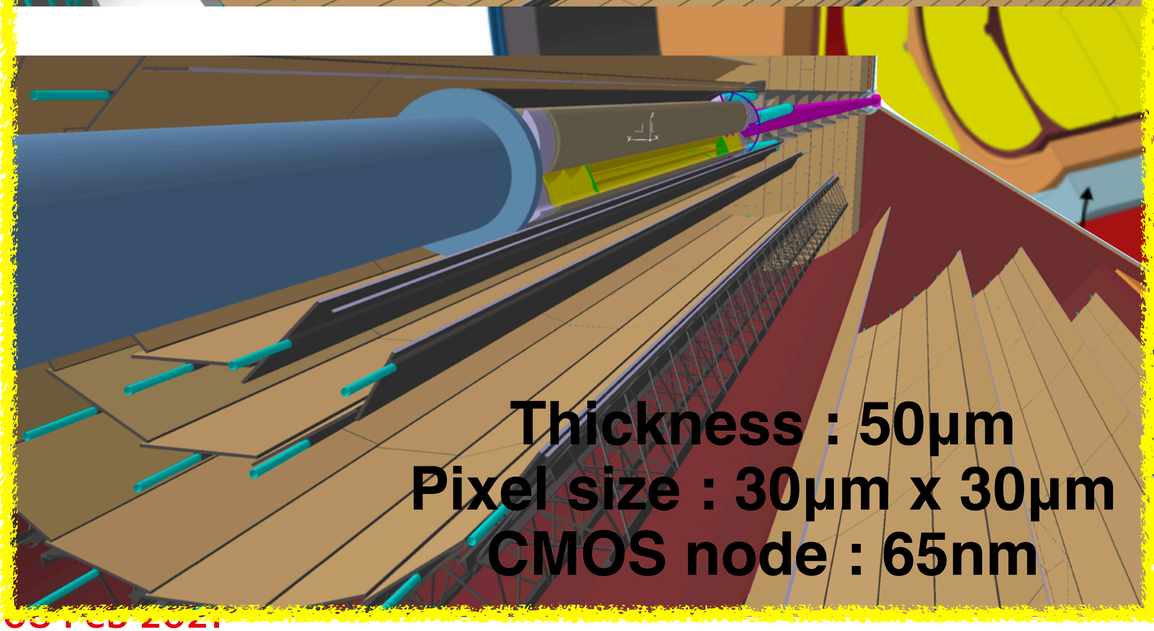
"Pure" coalescence particles



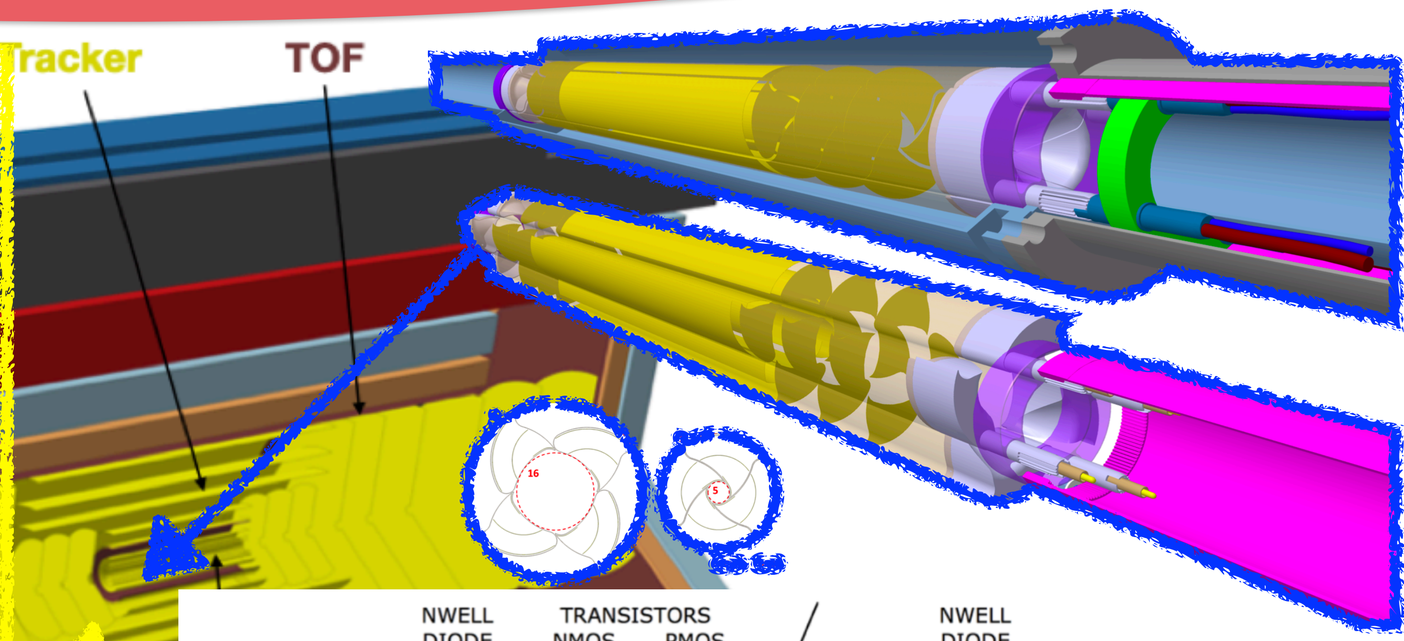
Tracker and Vertex detector

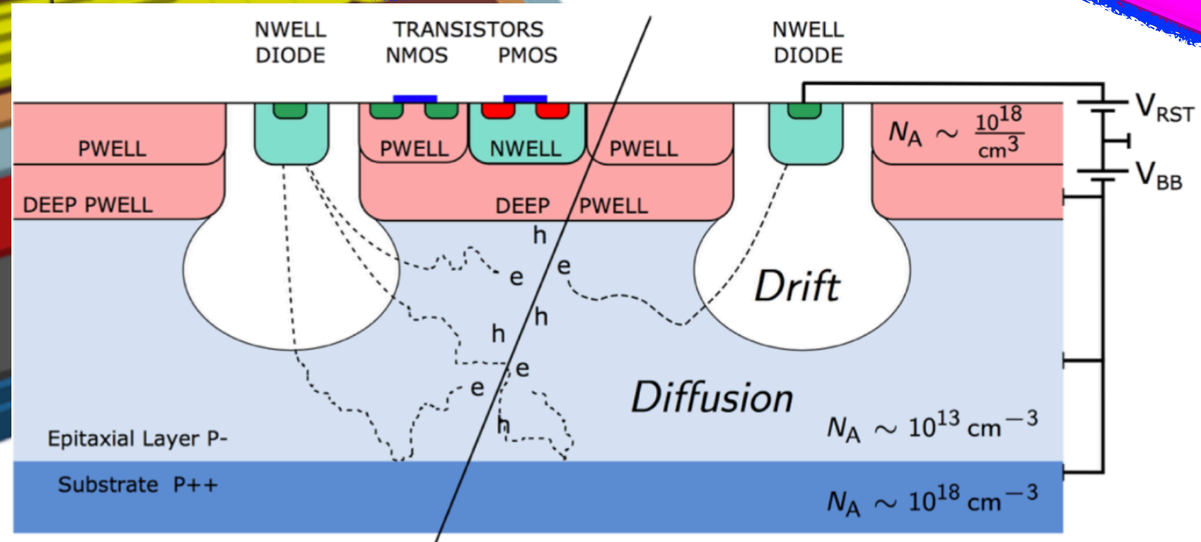


Vertex resolution
5 ~ 10 μm



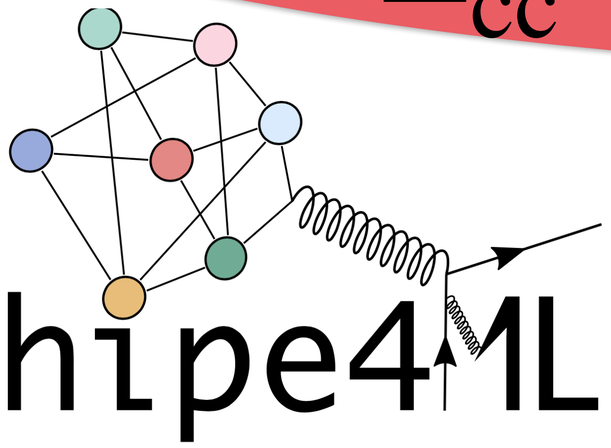
Thickness : 50μm
Pixel size : 30μm x 30μm
CMOS node : 65nm





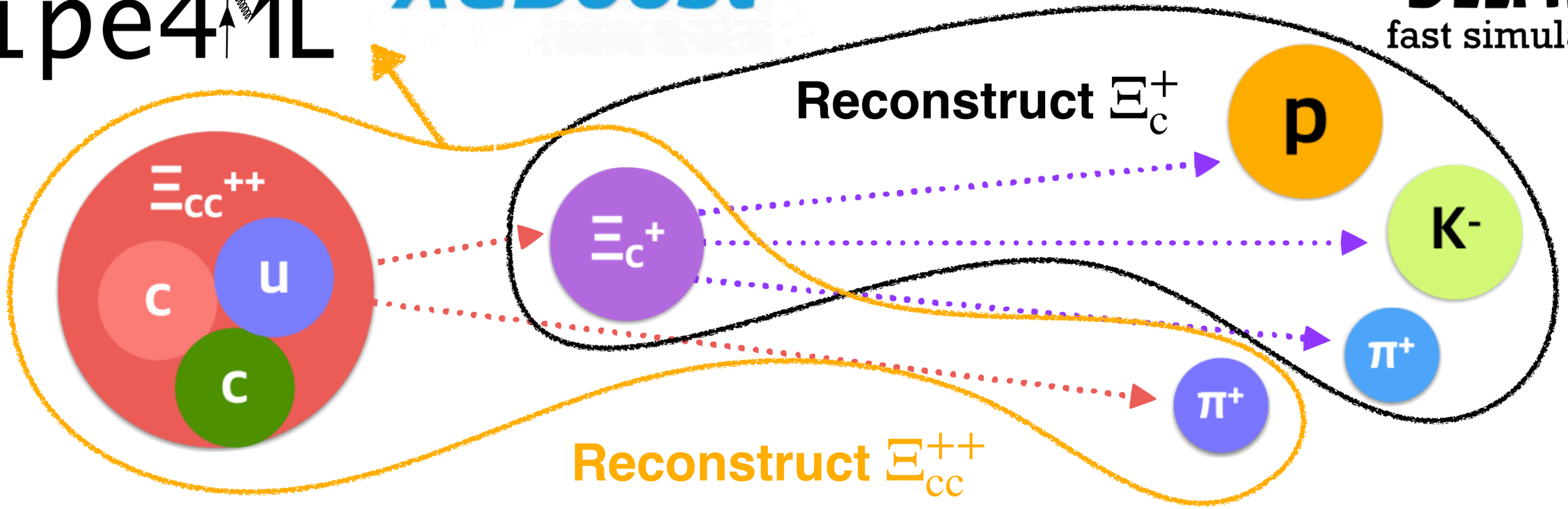
CMOS Monolithic Active Pixel Sensors (MAPS)

Ξ_{cc}^{++} Performance study with ML



dmlc XGBoost

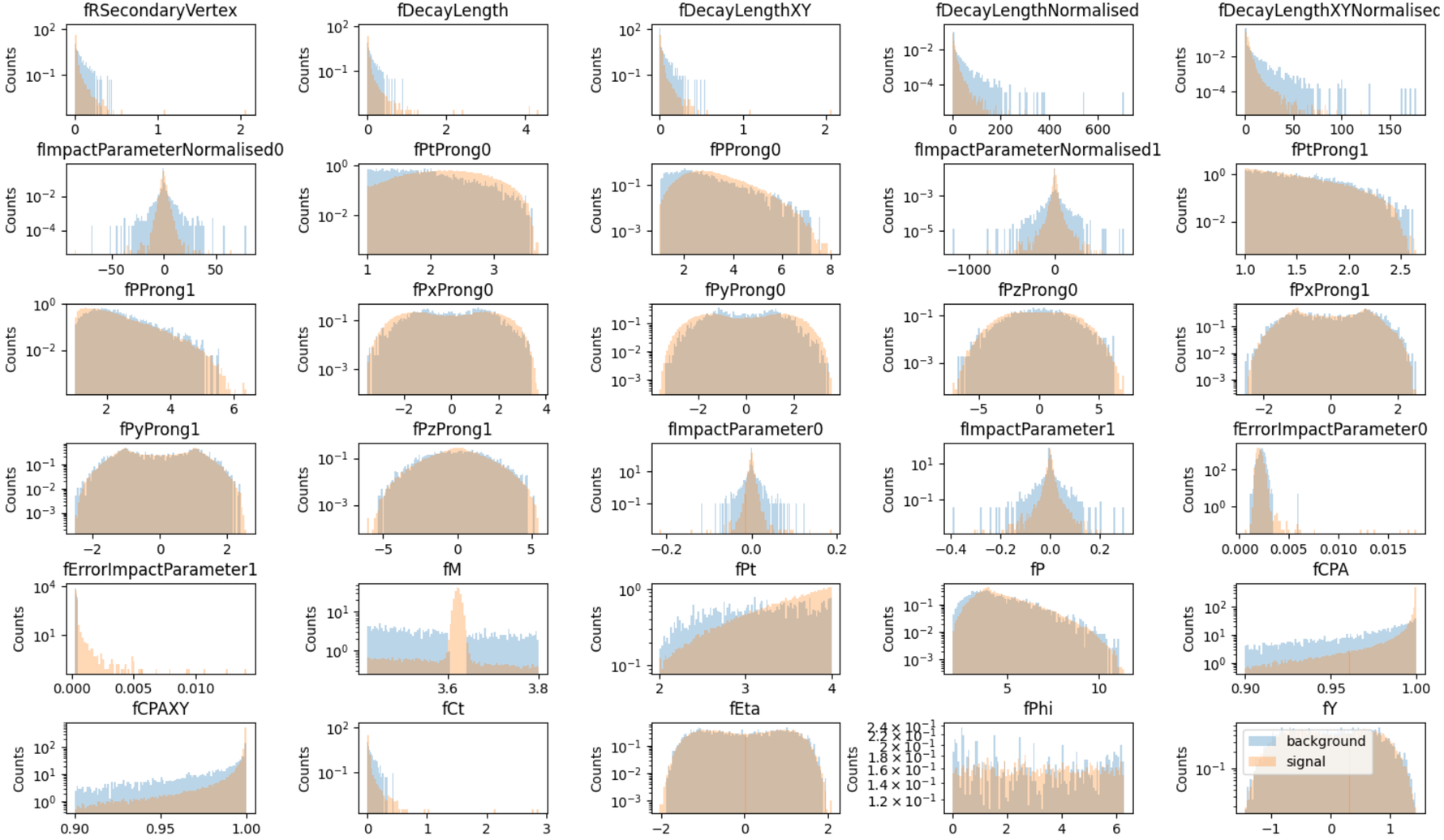
DELPHES fast simulation



Very Rare Signal
(1 signal for 1M pp collisions)

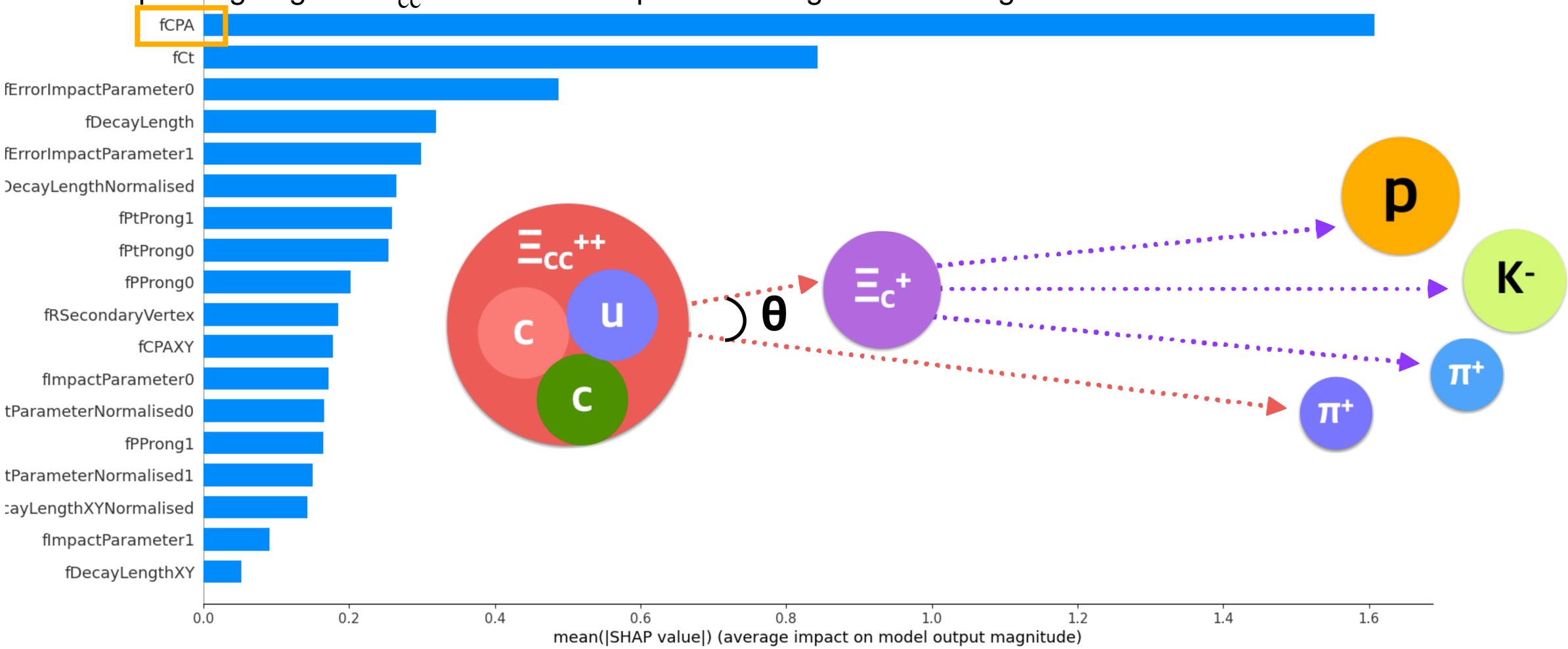
Signal vs Background

- **Signal vs background distribution** $(2 \leq p_{\mathrm{T}} < 4\,\mathrm{GeV}/c)$



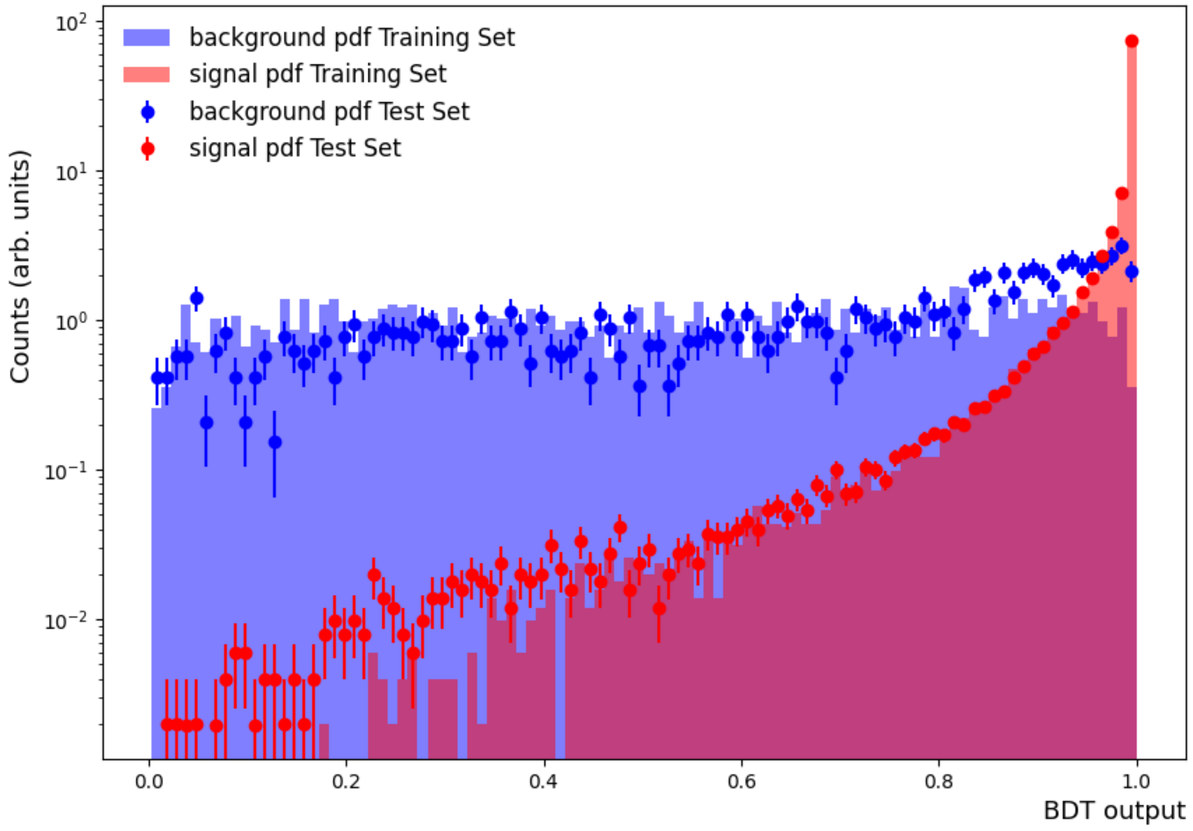
BDT model output

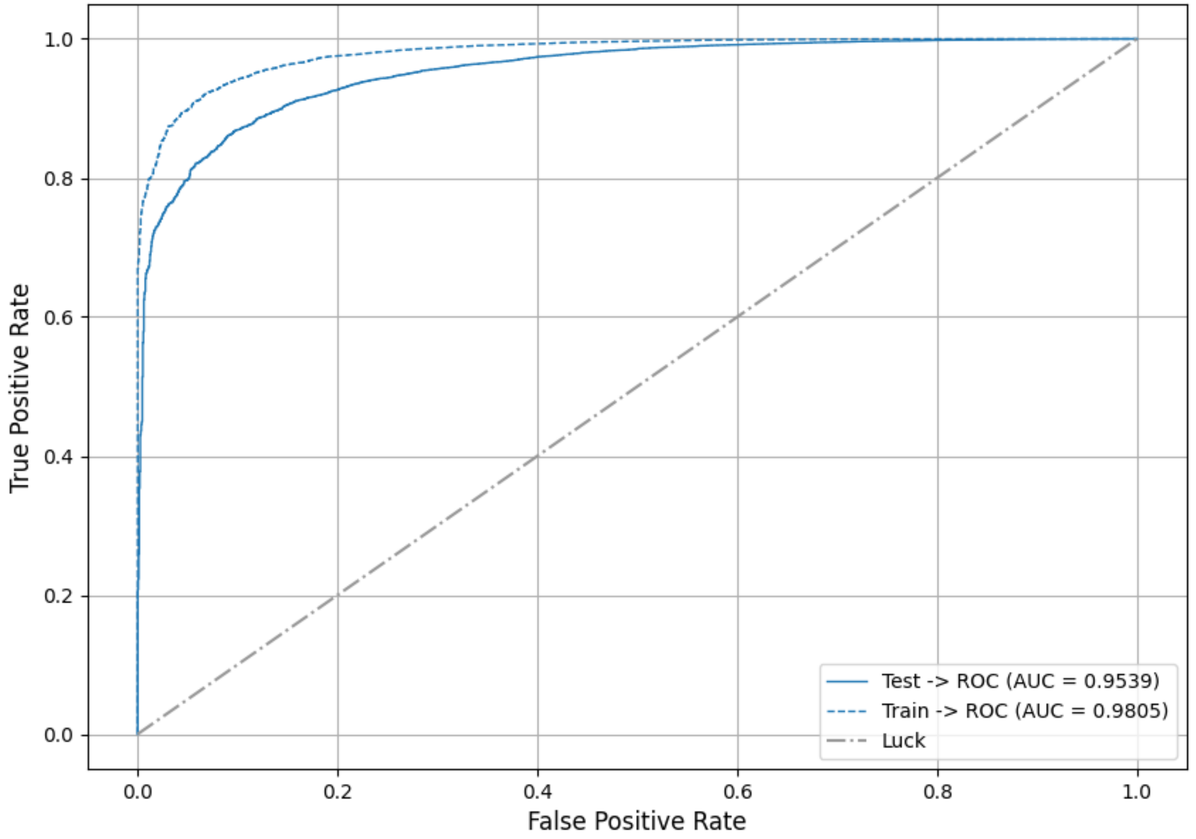
- **Feature importance** $(2 \leq p_{\mathrm{T}} < 4\,\mathrm{GeV}/c)$
  - Cosine of pointing angle of Ξ_{cc}^{++} is critical to separate the signal and background.



BDT model output

- **Model output** $(2 \leq p_{\mathrm{T}} < 4\,\mathrm{GeV}/c)$
  - **BDT output :** Kind of the probability of signal
    - 0.999 BDT output cut is applied to separate the signal and background.





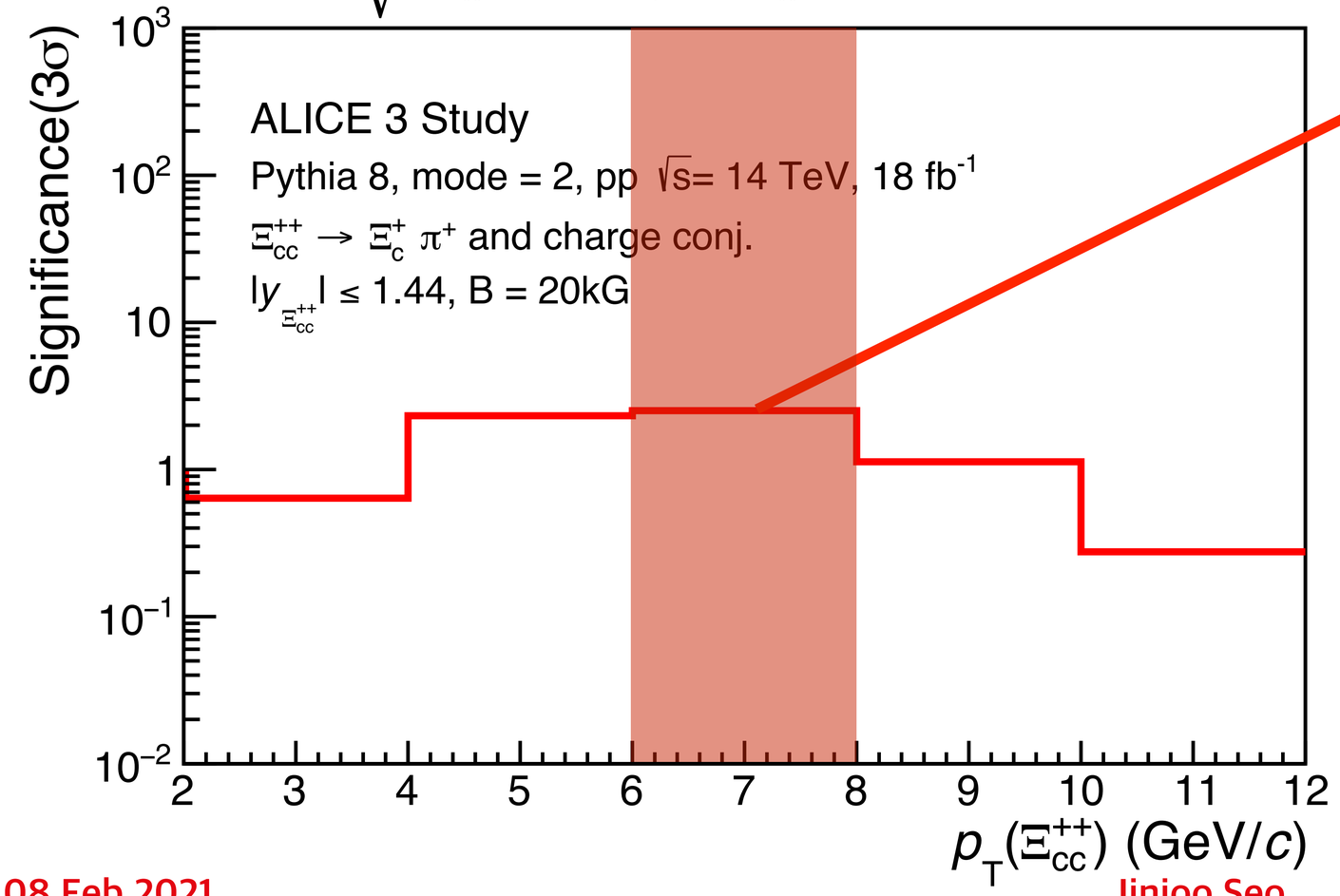
Ξ_{cc}^{++} Performance study with ML

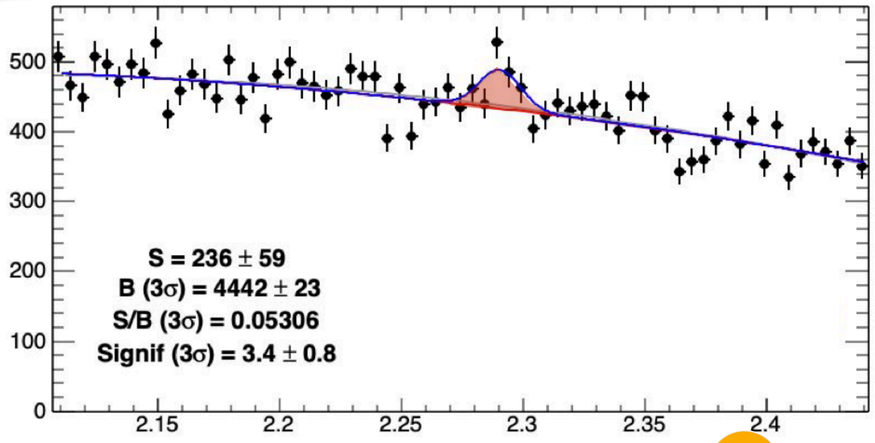
- **Significance of Ξ_{cc}^{++}**

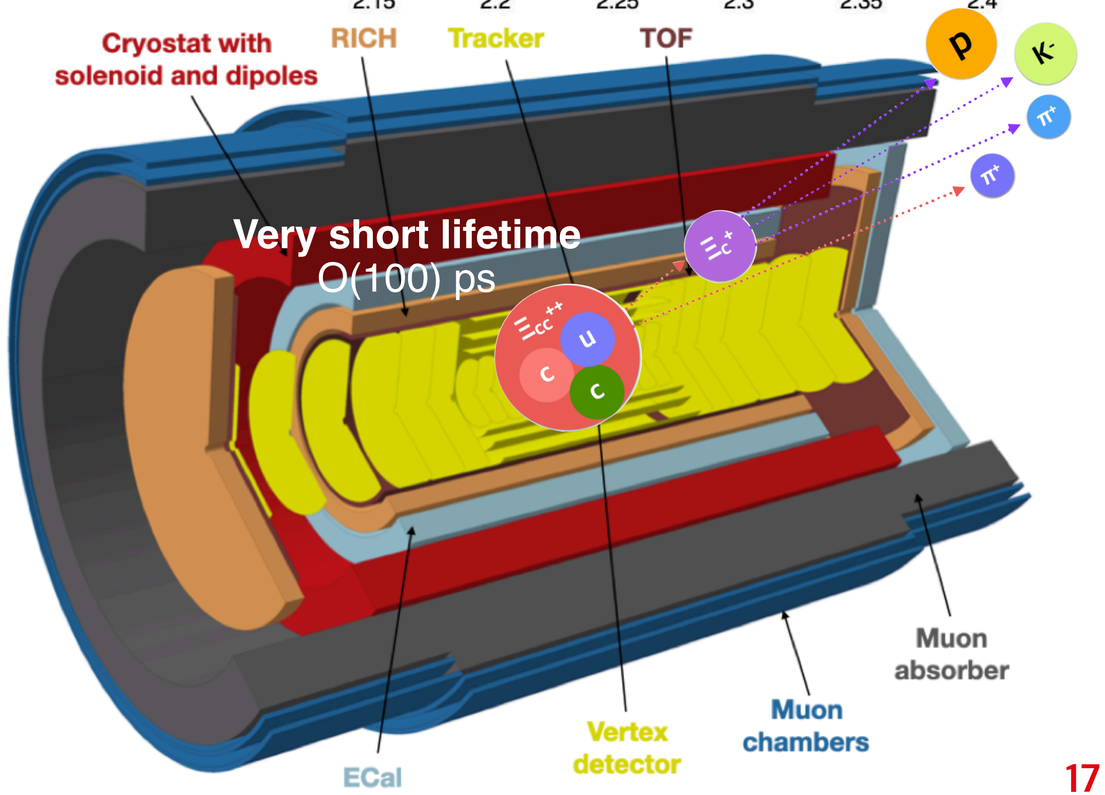
$$Significance = \frac{N_{\Xi_{cc}^{++}}}{\sqrt{N_{\Xi_{cc}^{++}} + N_{Background\,\Xi_{cc}^{++}}}}$$

$N_{\Xi_{cc}^{++}}$: Number of Ξ_{cc}^{++}

$N_{Background\,\Xi_{cc}^{++}}$: Number of Ξ_{cc}^{++} background







Summary of 2021 Activity

- **$\Xi_c^{0,+}$ production in pp collisions at 13 TeV**
  - Published 28 December 2021

PHYSICAL REVIEW LETTERS **127,** 272001 (2021)

Measurement of the Cross Sections of Ξ_c^0 and Ξ_c^+ Baryons and of the Branching-Fraction Ratio $\mathrm{BR}(\Xi_c^0 \to \Xi^- e^+ \nu_e)/\mathrm{BR}(\Xi_c^0 \to \Xi^- \pi^+)$ in pp Collisions at $\sqrt{s} = 13$ TeV

S. Acharya *et al.*[*]
(A Large Ion Collider Experiment Collaboration)

(Received 2 August 2021; revised 18 October 2021; accepted 19 November 2021; published 28 December 2021)

The p_T-differential cross sections of prompt charm-strange baryons Ξ_c^0 and Ξ_c^+ were measured at midrapidity ($|y| < 0.5$) in proton-proton (pp) collisions at a center-of-mass energy $\sqrt{s} = 13$ TeV with the ALICE detector at the LHC. The Ξ_c^0 baryon was reconstructed via both the semileptonic decay ($\Xi^- e^+ \nu_e$) and the hadronic decay ($\Xi^- \pi^+$) channels. The Ξ_c^+ baryon was reconstructed via the hadronic decay ($\Xi^- \pi^+ \pi^+$) channel. The branching-fraction ratio $\mathrm{BR}(\Xi_c^0 \to \Xi^- e^+ \nu_e)/\mathrm{BR}(\Xi_c^0 \to \Xi^- \pi^+) = 1.38 \pm 0.14(\mathrm{stat}) \pm 0.22(\mathrm{syst})$ was measured with a total uncertainty reduced by a factor of about 3 with respect to the current world average reported by the Particle Data Group. The transverse momentum (p_T) dependence of the Ξ_c^0- and Ξ_c^+-baryon production relative to the D^0 meson and to the $\Sigma_c^{0,+,++}$- and Λ_c^+-baryon production are reported. The baryon-to-meson ratio increases toward low p_T up to a value of approximately 0.3. The measurements are compared with various models that take different hadronization mechanisms into consideration. The results provide stringent constraints to these theoretical calculations and additional evidence that different processes are involved in charm hadronization in electron-positron (e^+e^-) and hadronic collisions.

DOI: 10.1103/PhysRevLett.127.272001

Measurements of heavy-flavor hadron production in high-energy proton-proton (pp) collisions provide important tests of quantum chromodynamics (QCD). The cross sections of heavy-flavor hadrons are usually computed using the factorization approach as a convolution of three factors [1]: (i) the parton distribution functions of the incoming protons, (ii) the hard-scattering cross section at partonic level, and (iii) the fragmentation function of heavy quarks into a given heavy-flavor hadron. The D- and B-meson cross sections in pp collisions at several center-of-mass energies at the LHC [2–7] are described within uncertainties by perturbative QCD calculations [8–12], which use fragmentation functions tuned on e^+e^- data, over a wide range of transverse momentum (p_T). Measurements of Λ_c^+-baryon production at midrapidity in pp collisions at the center-of-mass energy $\sqrt{s} = 5.02$ and 7 TeV were reported by the ALICE and CMS Collaborations in Refs. [13–15]. The measured Λ_c^+/D^0 ratio is higher than previous measurements in e^+e^- [16–18] and e^-p [19,20] collisions. A similar observation was drawn from the measurement of the inclusive Ξ_c^0-baryon production at midrapidity in pp collisions at $\sqrt{s} = 7$ TeV [21].

PYTHIA8.2 tunes including string formation beyond the leading-color approximation [22] and a statistical hadronization model (SHM) [23] including a set of higher-mass charm-baryon states as prescribed by the relativistic quark model (RQM) and from lattice QCD [24,25] qualitatively describe the measured $\Sigma_c^{0,+,++}/D^0$ and Λ_c^+/D^0 cross section ratios [15,26], but underestimate the Ξ_c^0/D^0 ratio [21]. The observed enhancement of the charm-baryon production can also be explained by model calculations considering hadronization of charm quarks via coalescence in addition to the fragmentation in pp collisions [27,28]. The increased yield of charm baryons makes it mandatory to include their contribution for an accurate measurement of the $c\bar{c}$ production cross section in pp collisions at the LHC [29].

In this Letter, the measurements of the cross sections of the prompt (i.e., produced directly in the hadronization of charm quarks and in the decays of directly produced excited charm states) charm-strange baryons Ξ_c^0 and Ξ_c^+ at midrapidity ($|y| < 0.5$) in pp collisions at $\sqrt{s} = 13$ TeV are reported. The Ξ_c^0 baryon was reconstructed via the decay channels $\Xi^- e^+ \nu_e$, $\mathrm{BR} = (1.8 \pm 1.2)\%$ and $\Xi^- \pi^+$, $\mathrm{BR} = (1.43 \pm 0.32)\%$ [30] together with their charge conjugates in the interval $1 < p_T < 12$ GeV/c. The Ξ_c^+ baryon was reconstructed via the decay channel $\Xi^- \pi^+ \pi^+$, $\mathrm{BR} = (2.86 \pm 1.21 \pm 0.38)\%$ [31], together with its charge conjugate, in the interval $4 < p_T < 12$ GeV/c.

[*]Full author list given at the end of the article.

Summary of 2021 Activity

- $\Xi_c^{0,+}$ **production in pp collisions at 13 TeV**
  - Published 28 December 2021

- Ξ_{cc}^{++} **Performance study**
  - Study is ongoing with machine learning

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

ALICE

CERN

CERN-LHCC-2021-xxx
ALICE-PUBLIC-2021-xxx

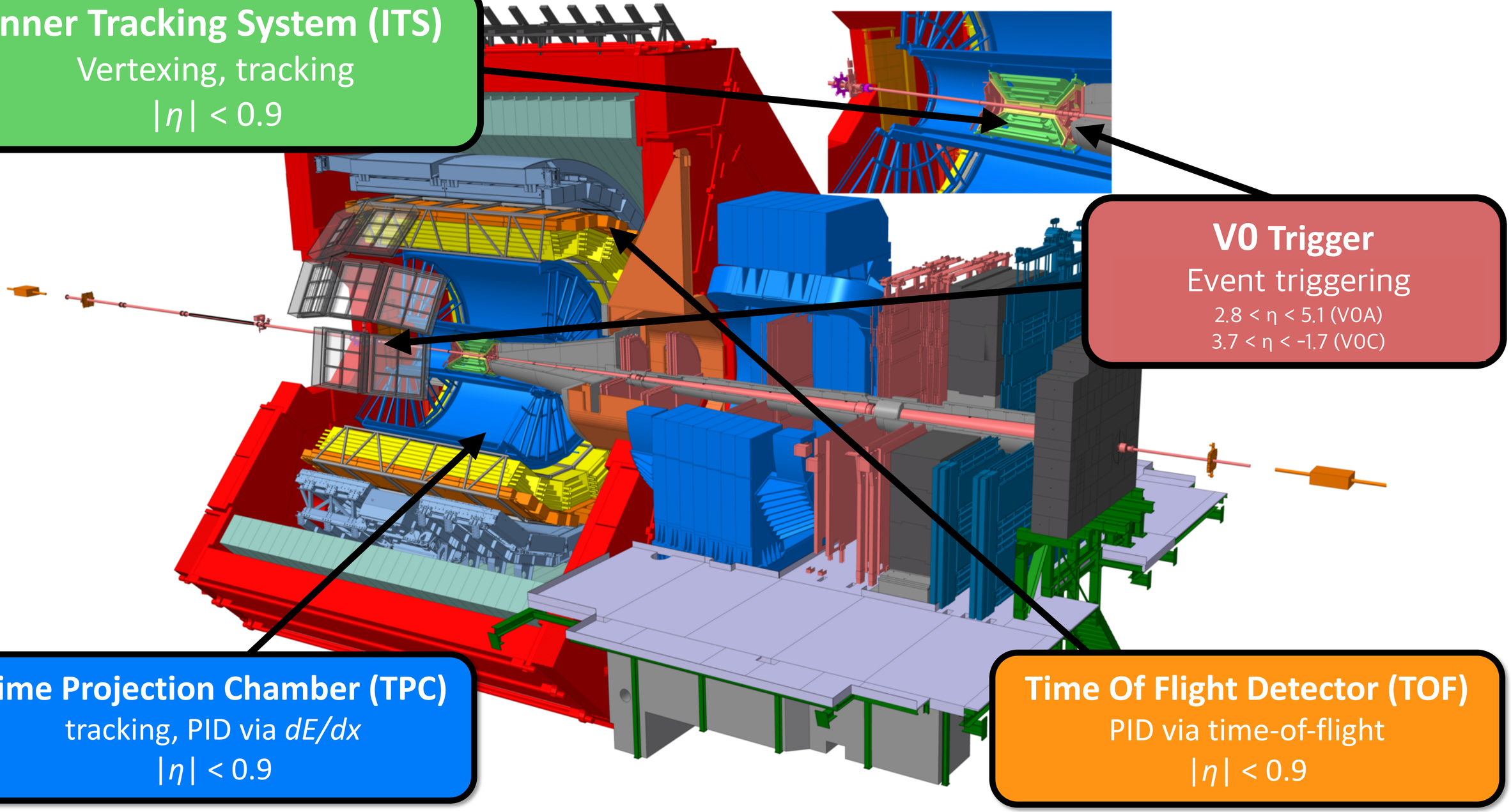
Letter of Intent:
ALICE 3

Draft v3

ALICE Collaboration*

*See Appendix ?? for the list of collaboration members

Back up


Inner Tracking System (ITS)
Vertexing, tracking
|η| < 0.9
V0 Trigger
Event triggering
2.8 < η < 5.1 (V0A)
3.7 < η < -1.7 (V0C)
Time Projection Chamber (TPC)
tracking, PID via dE/dx
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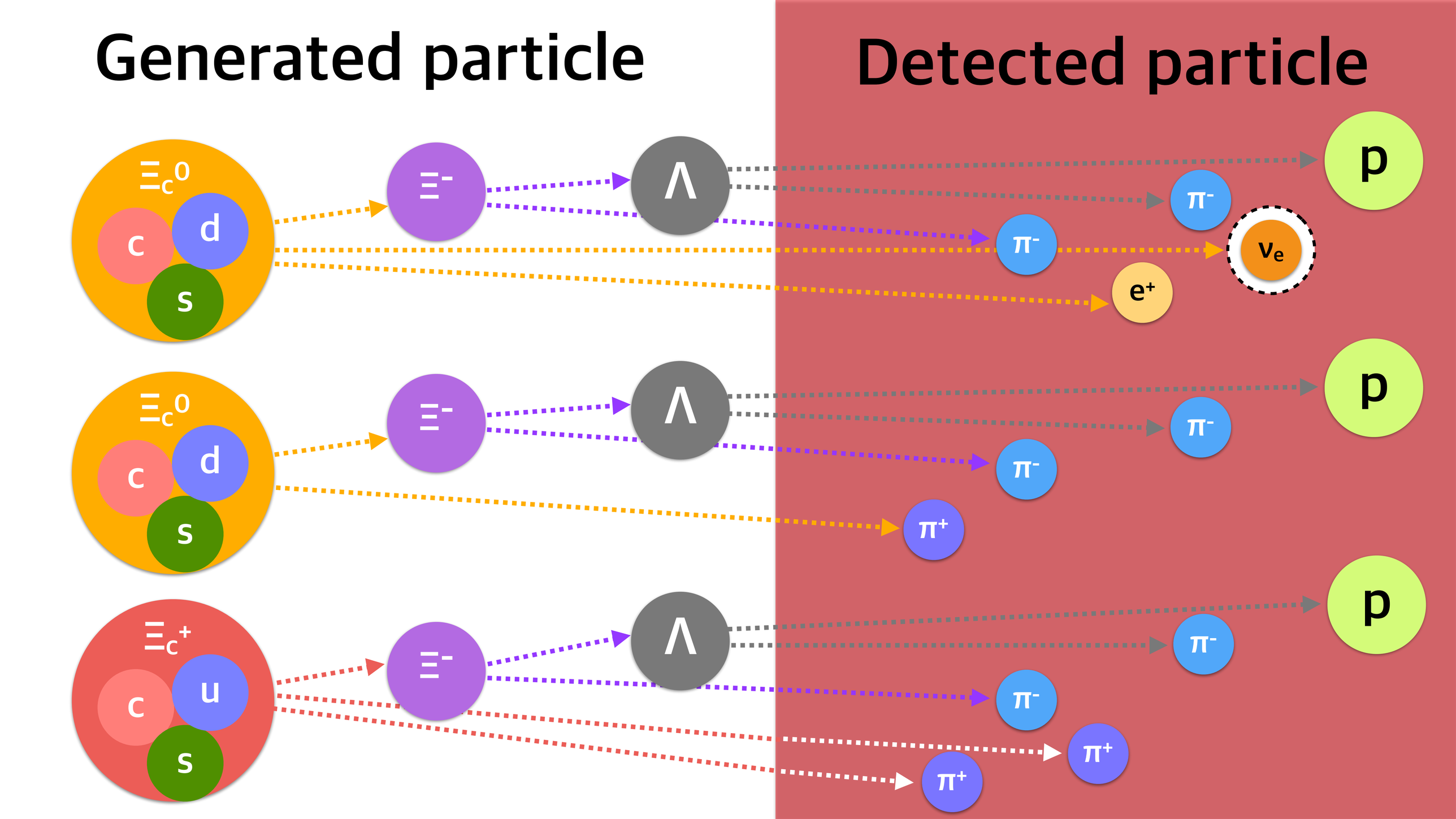
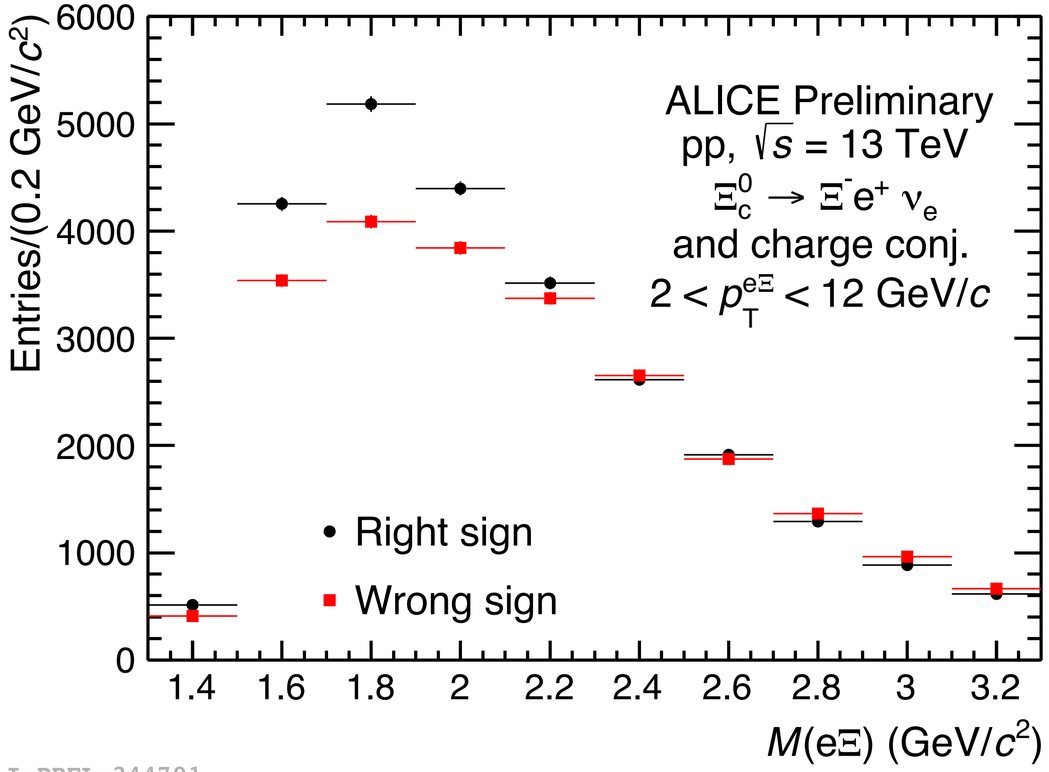
Time Of Flight Detector (TOF)
PID via time-of-flight
|η| < 0.9


Generated particle
Detected particle
Ξc0
c
d
s
Ξ-
Λ
p
π-
νe
e+
Ξc0
c
d
s
Ξ-
Λ
p
π-
π-
π+
Ξc+
c
u
s
Ξ-
Λ
p
π-
π-
π+
π+

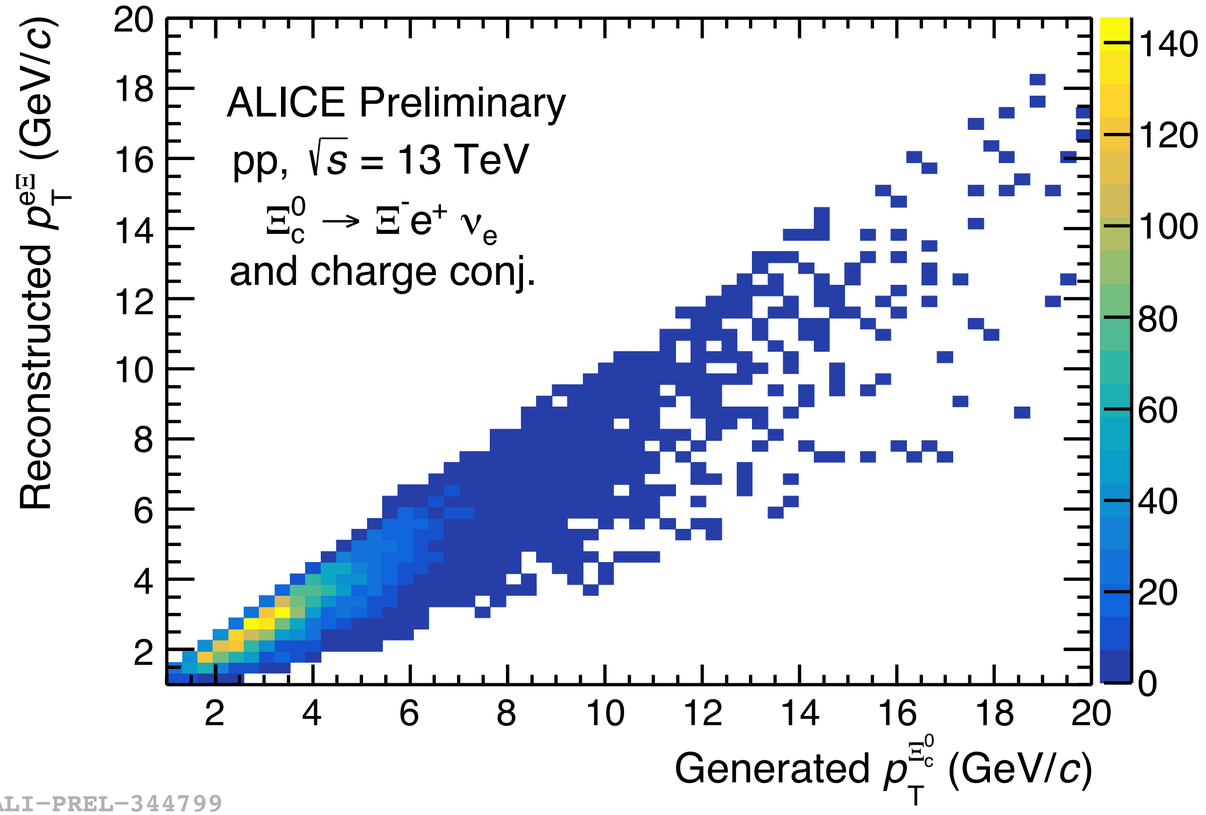
$\Xi^0_c \rightarrow e^+\Xi^-\nu_e$

- Unfolding

- **Unfolding**
  - The p_T of eΞ pairs is corrected for the missing momentum of the neutrino using unfolding techniques.
  - Convergence of the Bayesian unfolding is achieved after three iterations.



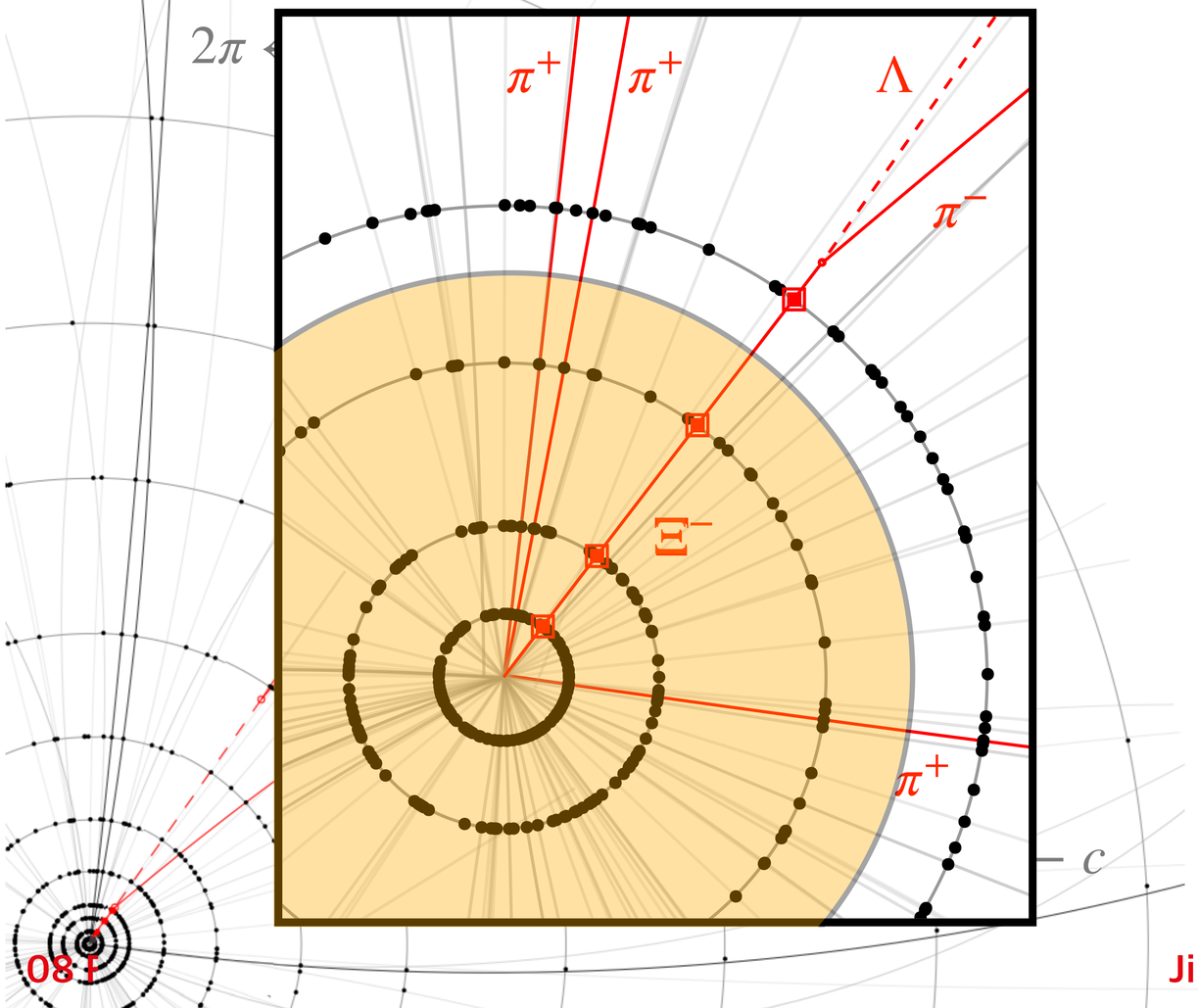
ALI-PREL-344791

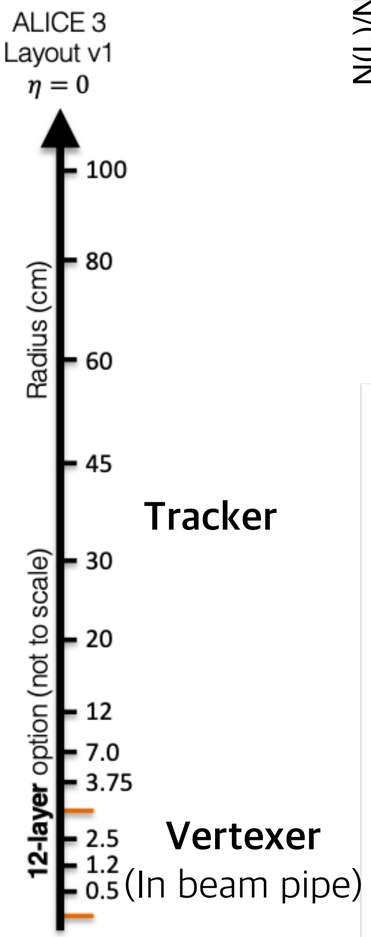


ALI-PREL-344799

Multi-Charm baryon

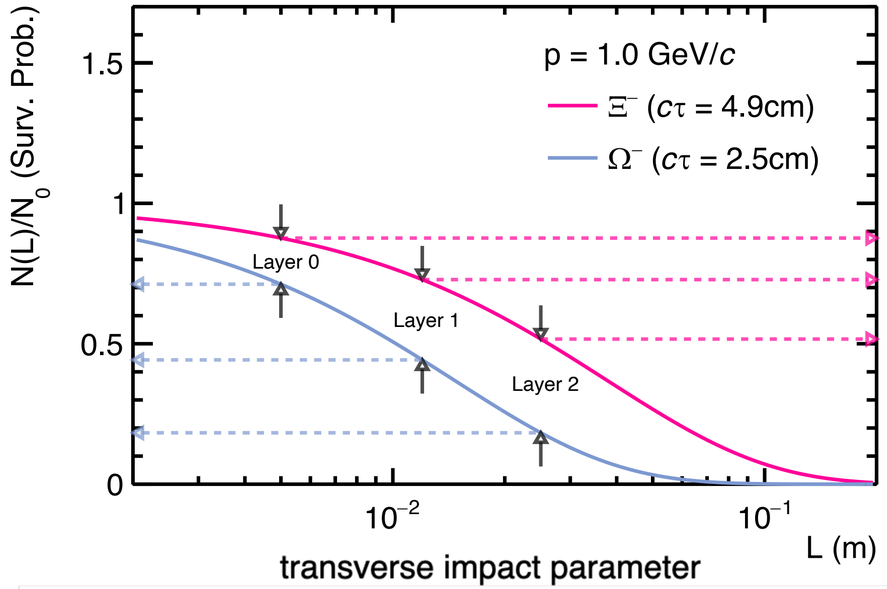
- **Performance study : strangeness-tracking**
  - $\Xi_{cc}^{++} \rightarrow \Xi_c^+\pi^+ \rightarrow (\Xi^-\pi^+\pi^+)\pi^+$ and $\Omega_{cc}^{+} \rightarrow \Omega_c^0\pi^+ \rightarrow (\Omega^-\pi^+)\pi^+$

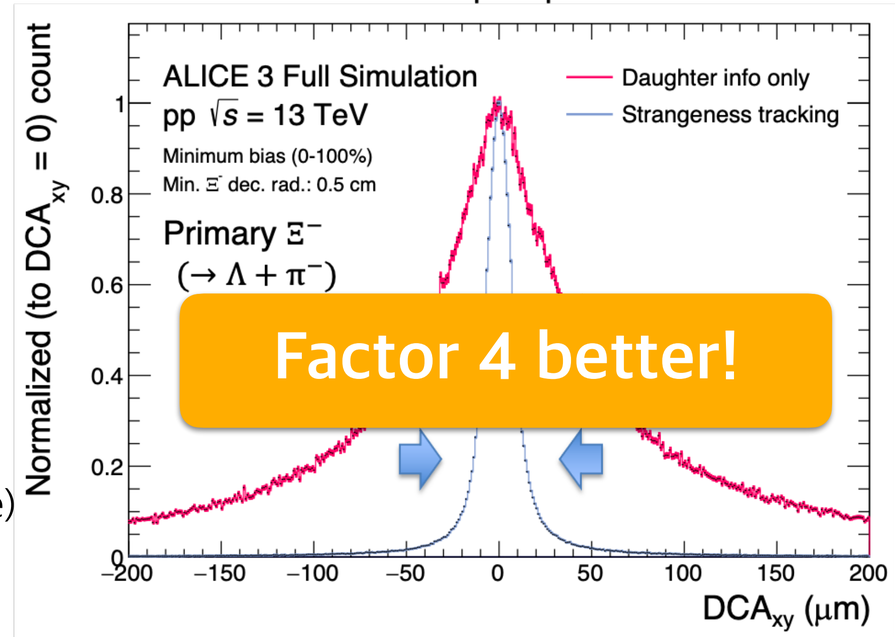




Tracker

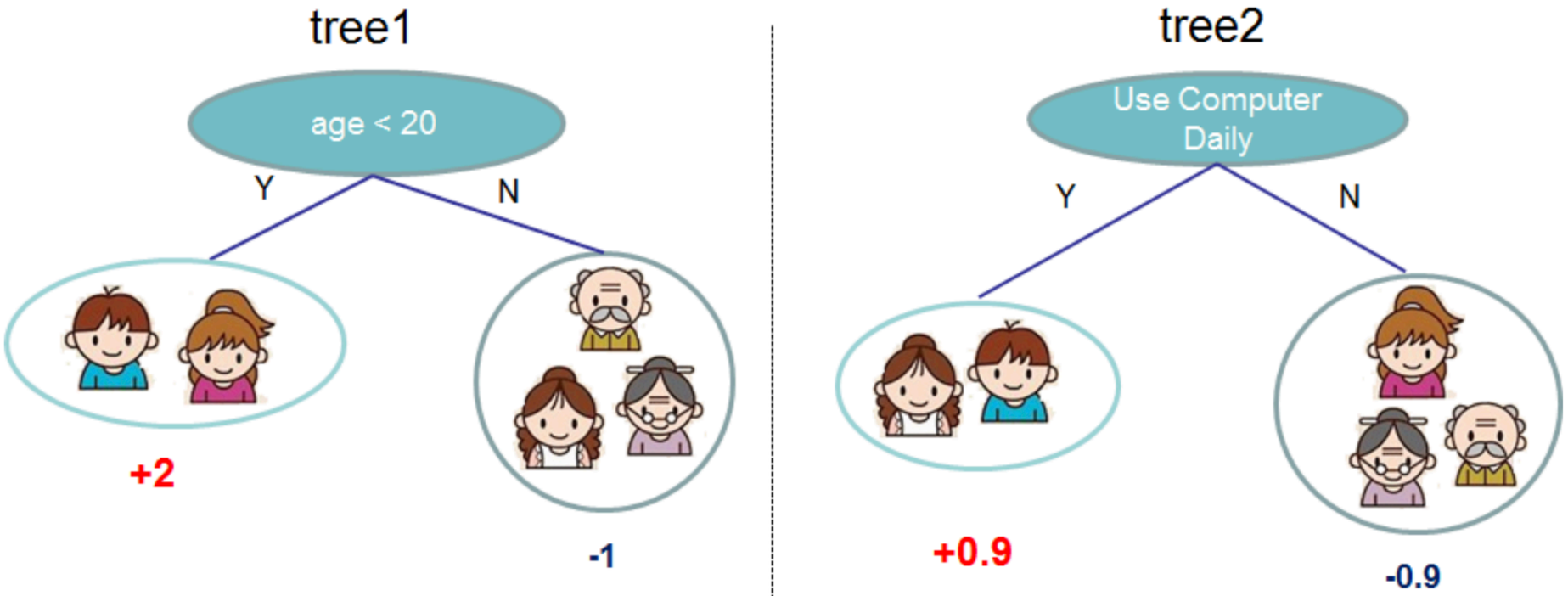
Vertexer
(In beam pipe)





Boost Decision Tree

- **Pre-selection and Training variable**
  - Ensemble algorithm + Gradient descent algorithm



f( ) = 2 + 0.9= 2.9 f( )= -1 - 0.9= -1.9

ML Preselection & Training variable

- **Pre-selection and Training variable**
  - Very loose cuts
    - lnSigmaTOFl < 3 & lnSigmaTOFCombinedl < 5 are already applied to reduce the tree output size
      - NOT considered nSigmaTOF and nSigmaTOFCombined as training variable -> will be added

Preselection

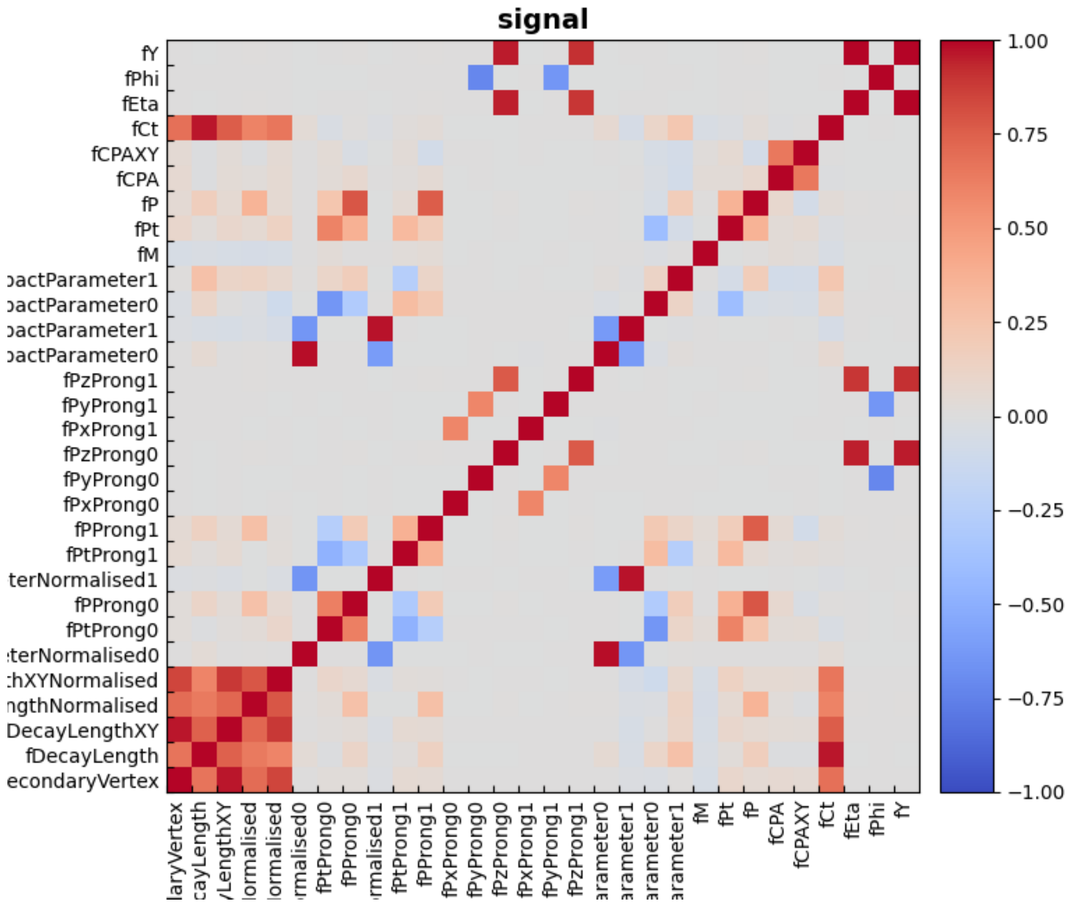
```
#loose preslection
preselection = [
    '-1.44 < fY < 1.44',
    '0.00 < fDecayLength < 10',
    '-10 < fImpactParameter0 < 10',
    '-10 < fImpactParameter1 < 10',
    '0.5 < fPtProng0 < 20',
    '1 < fPtProng1 < 20',
    '0.90 < fCPA < 1',
    '0.90 < fCPAXY < 1',
    '3.4 < fM < 3.8',
    '0 < fPt < 16'
]
```

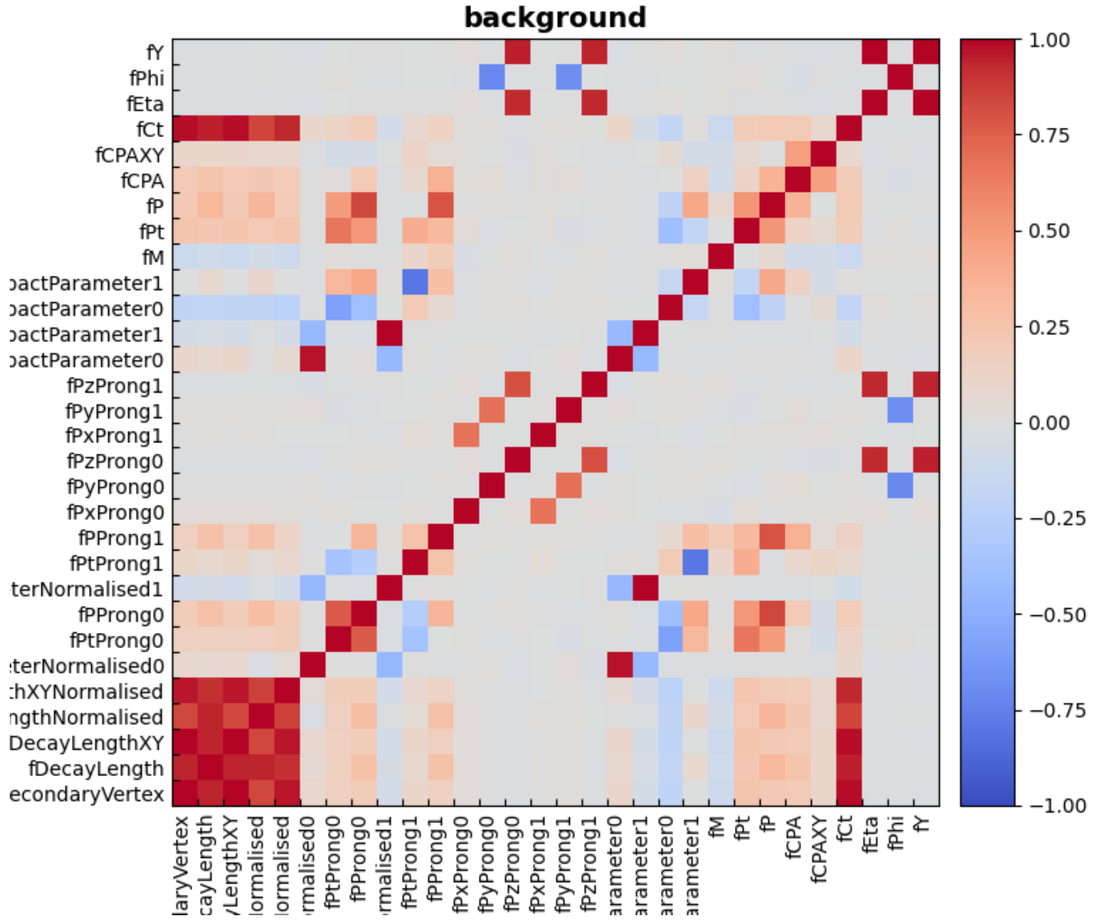
Training variable

```
("fDecayLength", &fDecayLength);
("fDecayLengthXY", &fDecayLengthXY);
("fDecayLengthNormalised", &fDecayLengthNormalised);
("fDecayLengthXYNormalised", &fDecayLengthXYNormalised);
("fImpactParameterNormalised0", &fImpactParameterNormalised0);
("fPtProng0", &fPtProng0);
("fPProng0", &fPProng0);
("fImpactParameterNormalised1", &fImpactParameterNormalised1);
("fPtProng1", &fPtProng1);
("fPProng1", &fPProng1);
("fImpactParameter0", &fImpactParameter0);
("fImpactParameter1", &fImpactParameter1);
("fErrorImpactParameter0", &fErrorImpactParameter0);
("fErrorImpactParameter1", &fErrorImpactParameter1);
("fCPA", &fCPA);
("fCPAXY", &fCPAXY);
```

Signal vs Background

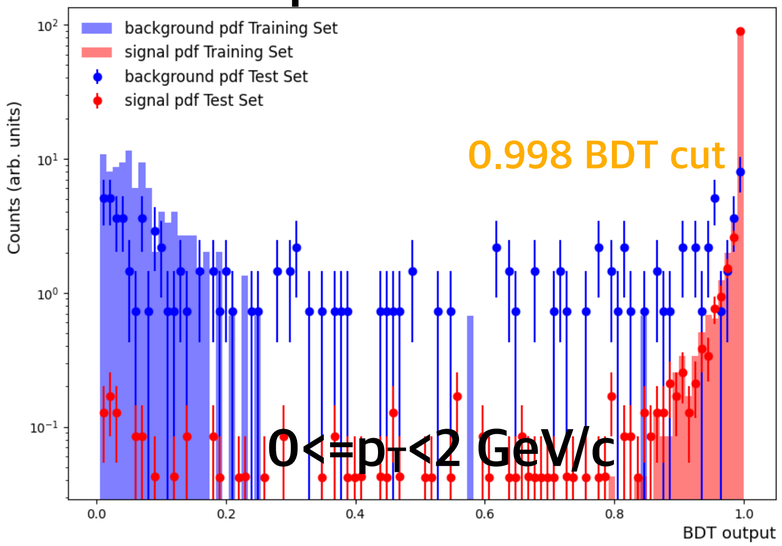
- **Signal vs background distribution** $(2 \leq p_{\mathrm{T}} < 4\,\mathrm{GeV}/c)$

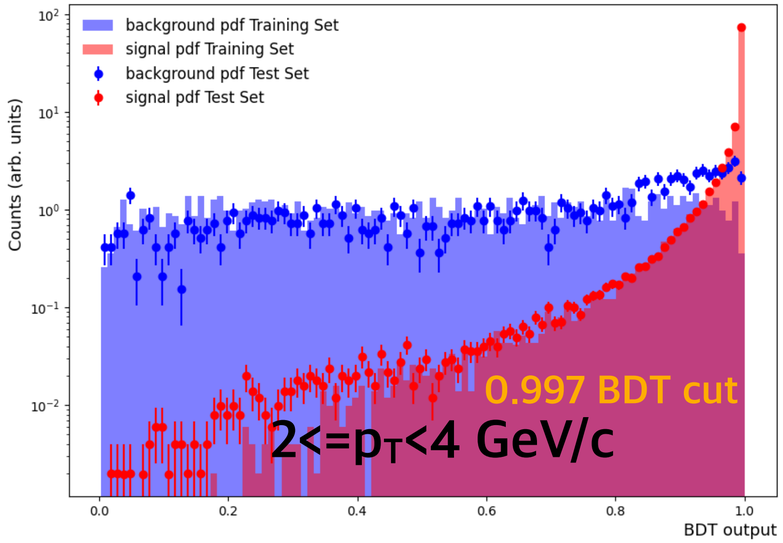


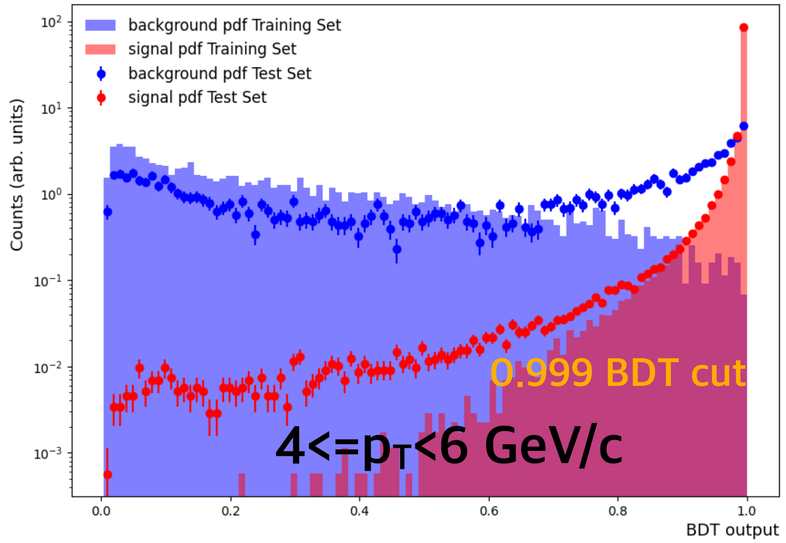


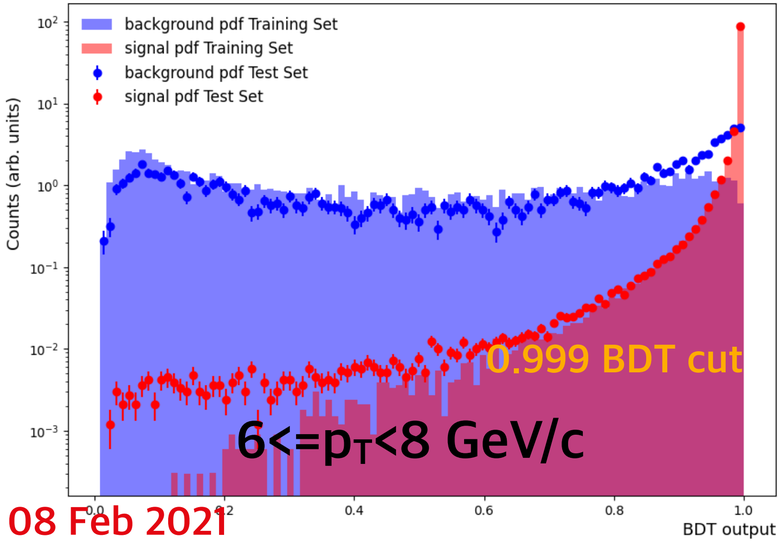
BDT model output

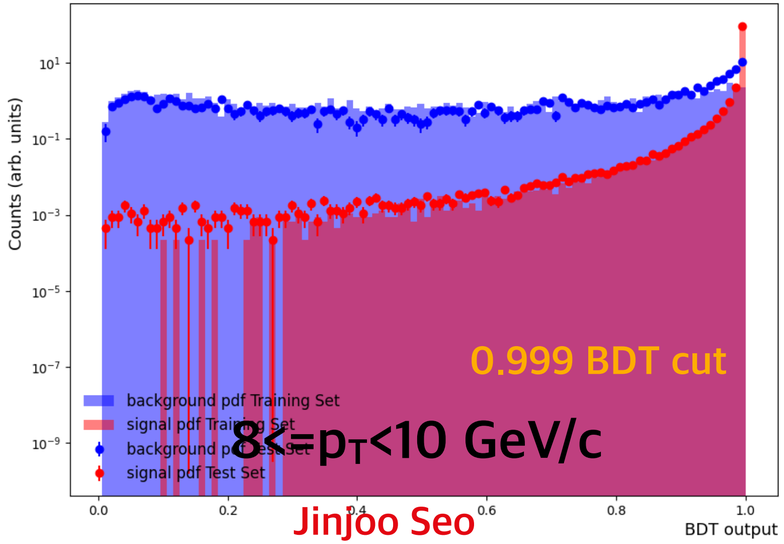
- **Model output**

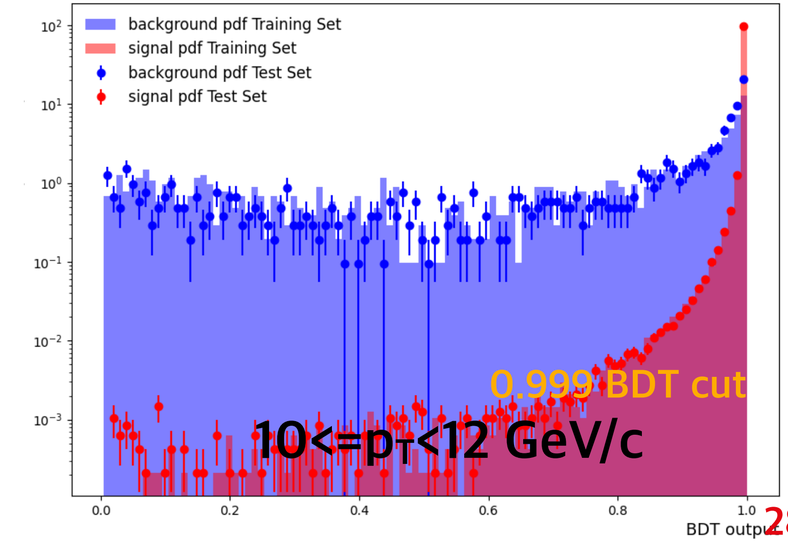






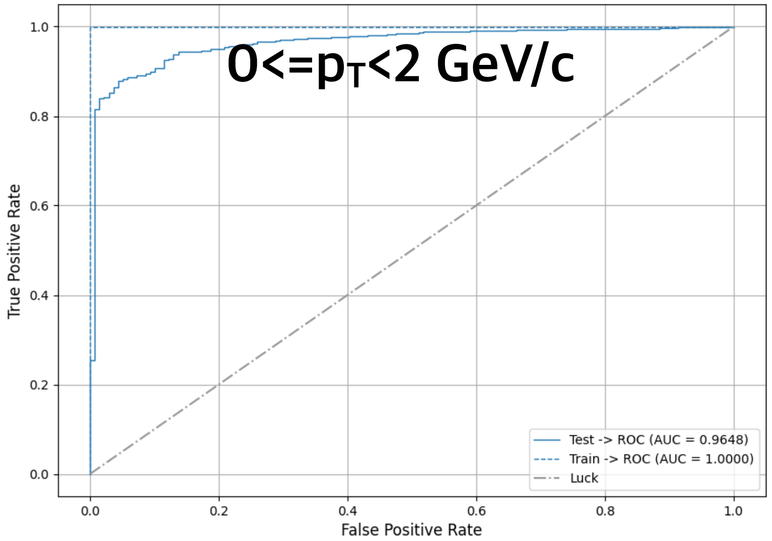


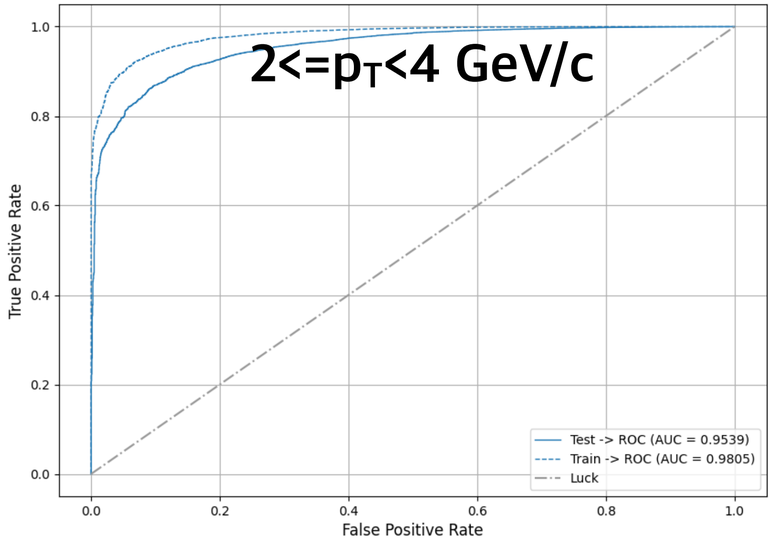


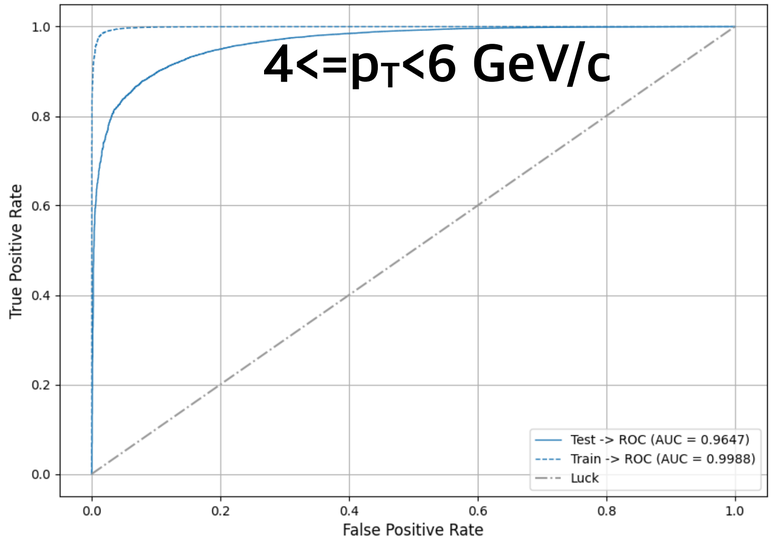


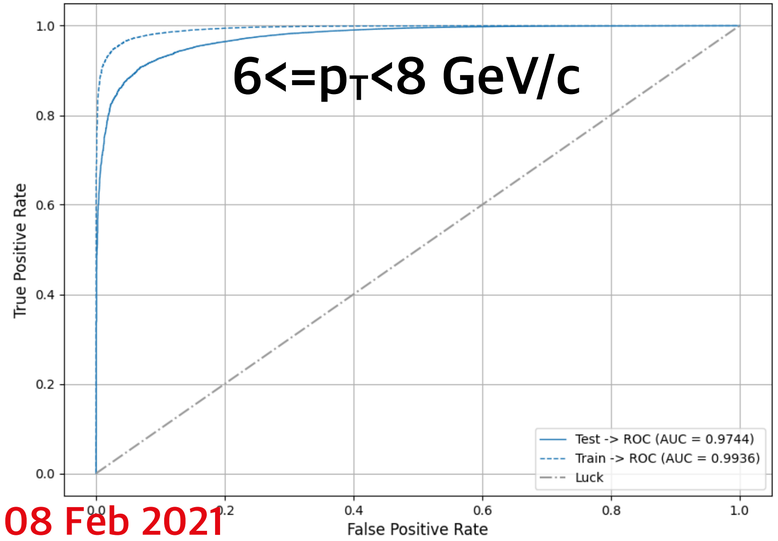
ROC curve

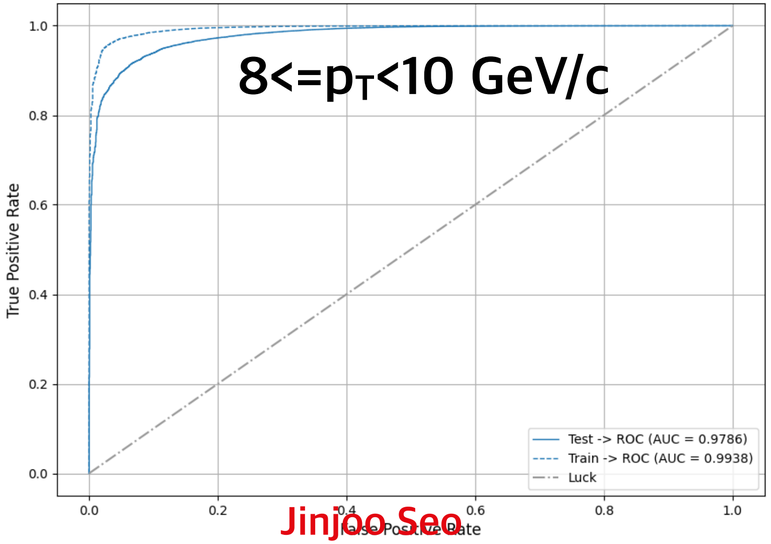
- **ROC curve**

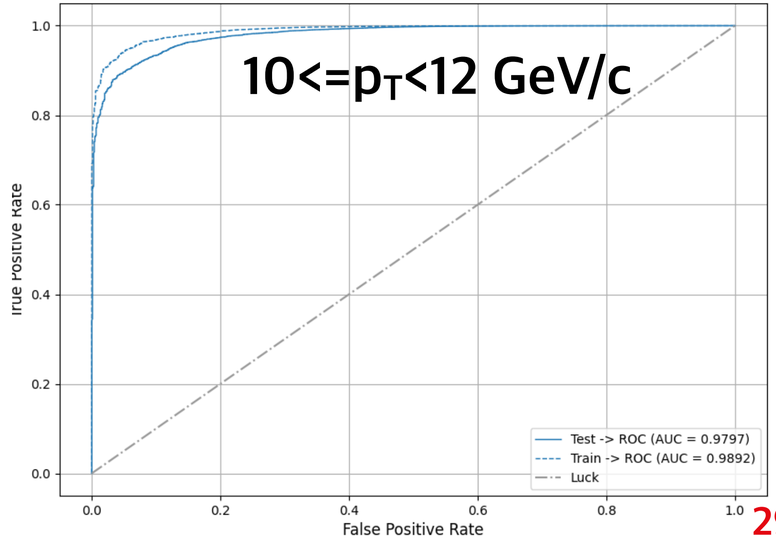






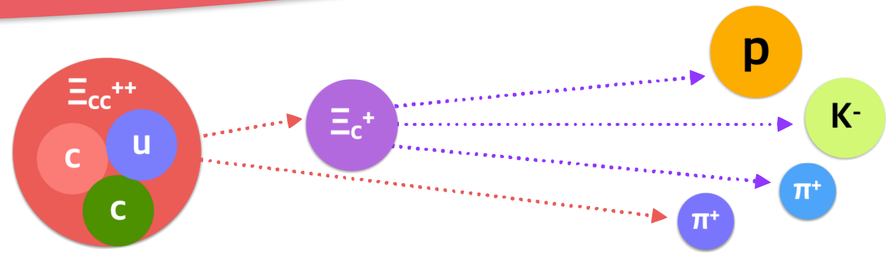




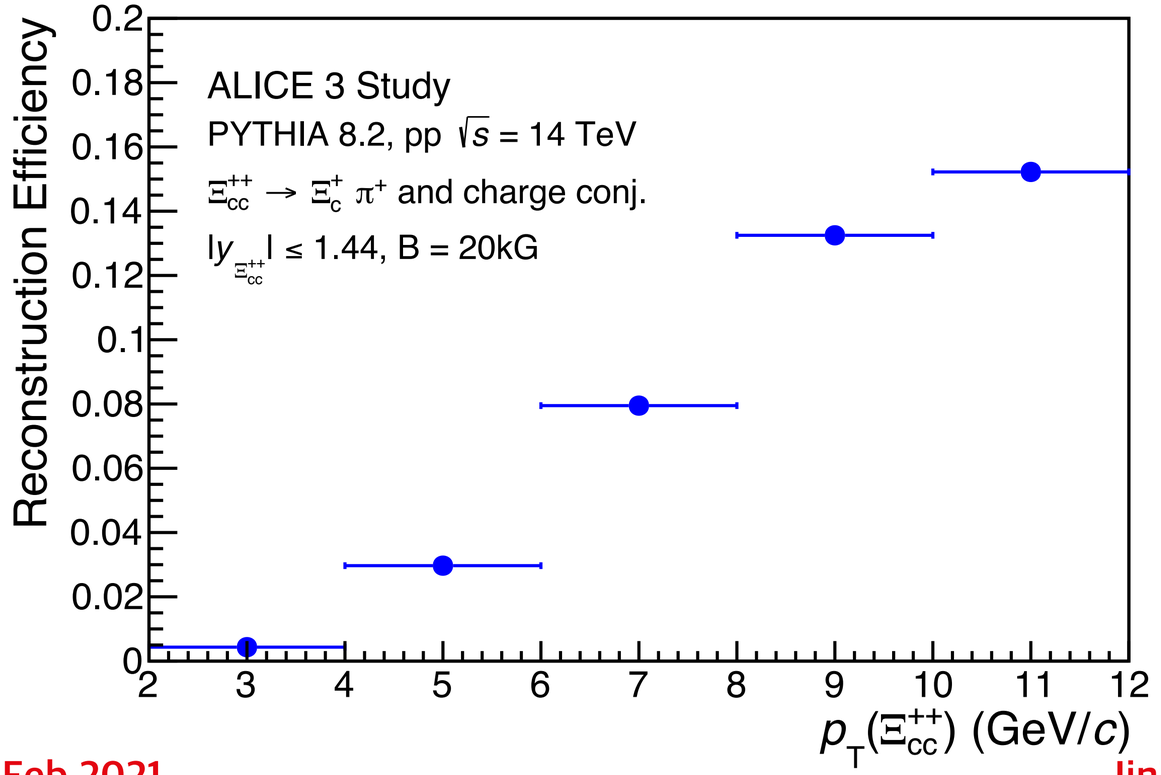


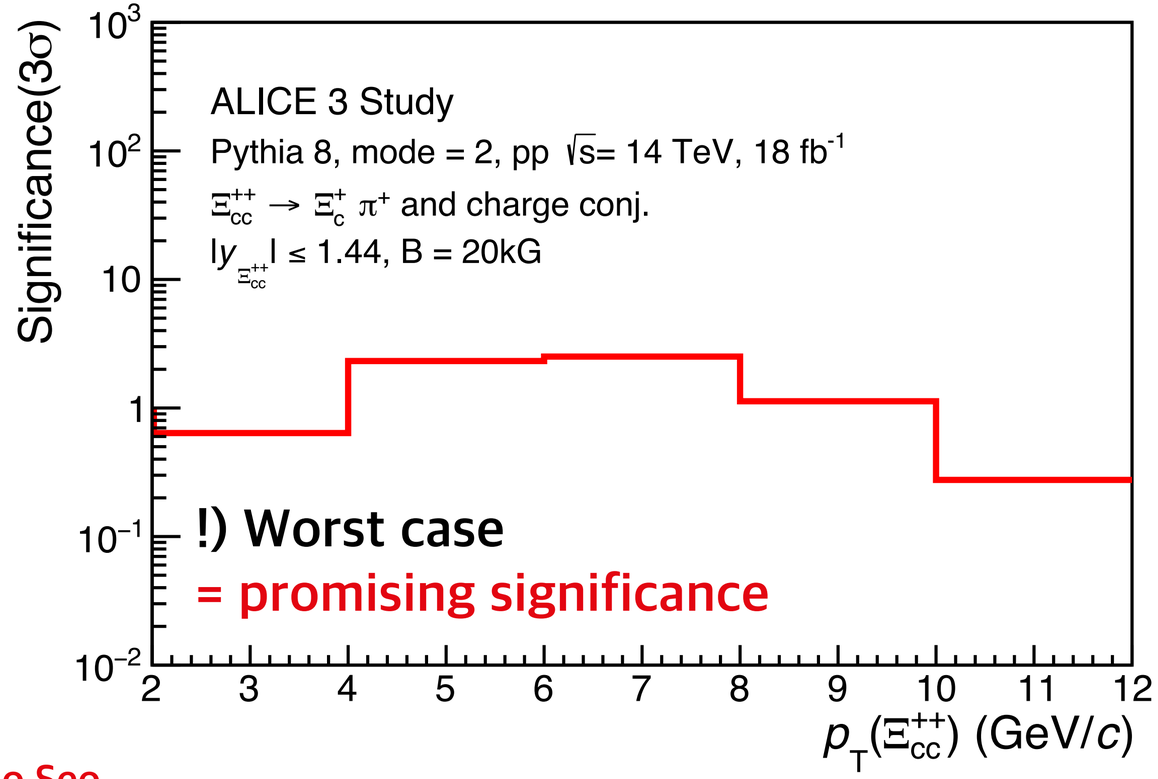
Results

- **Performance study : Ξ_{cc}^{++} on non-strangeness decay**
  - **Efficiency** : Increases with p_T due to higher momentum π^+
  - **Significance**
    - Signal/event : Theoretical expectation(cross section, 39 nb) + PYTHIA 8 (p_T shape) + efficiency + BR(0.03%)
    - Large uncertainty on production cross section(factor 200) and branching ratio(factor 5)



arXiv:hep-ph/9710339





Multi-HF hadron

$\Xi_{cc}^{++} \to \Lambda_c^+ + K^- + \pi^+ + \pi^-$ $\Lambda_c^+ \to p + K^- + \pi^+$	B.R.
	5%
	6.35%
	0.32%

$\Xi_{cc}^{++} \to \Xi_c^+ + \pi^+$ $\Xi_c^+ \to p + K^- + \pi^+$	B.R.
	5%
	2.2 ± 0.8% (1)
	0.11%

Ξ_{cc} decays: BR from 1703.09086 (authors claim ~1% < BR < ~10%)

$\Omega_{ccc}^{++} \to \Xi_{cc}^{++} + \overline{K}^0$ $\Xi_{cc}^{++} \to \Lambda_c^+ + K^- + \pi^+ + \pi^-$ $\Lambda_c^+ \to p + K^- + \pi^+$ $\overline{K}^0 : 50\,\% K_s^0 \to \pi^+ + \pi^-$	B.R.
	5% x 0.5
	5%
	6.35%
	70%
	0.0055%

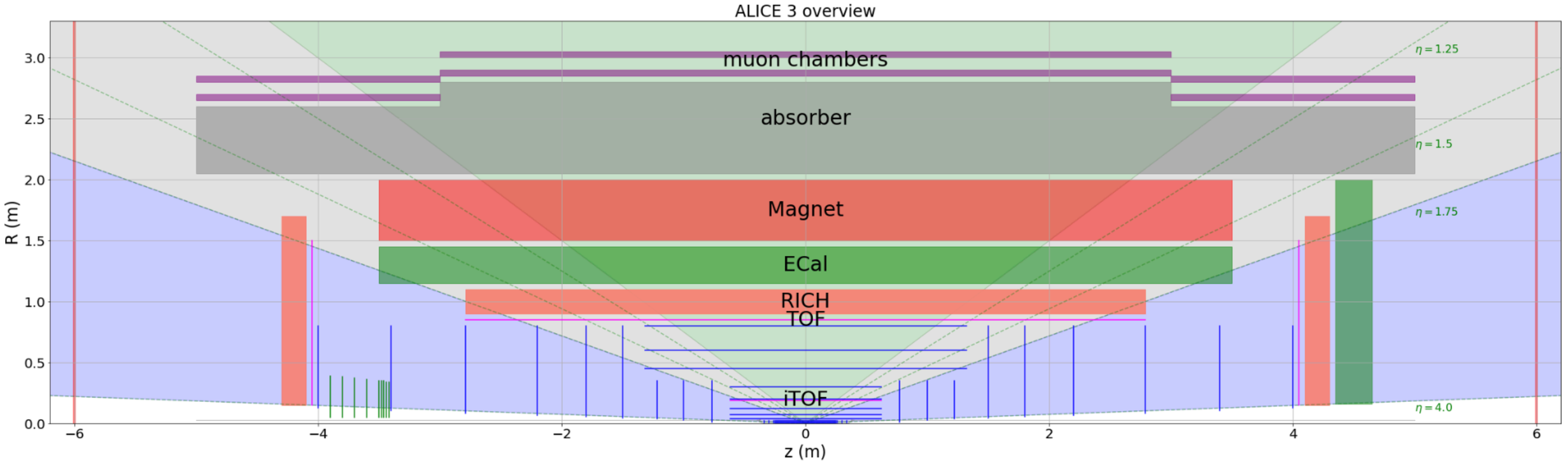
$\Omega_{ccc}^{++} \to \Xi_{cc}^{++} + \overline{K}^0$ $\Xi_{cc}^{++} \to \Xi_c^+ + \pi^+$ $\Xi_c^+ \to p + K^- + \pi^+$ $\overline{K}^0 : 50\,\% K_s^0 \to \pi^+ + \pi^-$	B.R.
	5% x 0.5
	5%
	2.2 ± 0.8% (1)
	70%
	0.0019%

$\Omega_{ccc}^{++} \to \Xi_c^+ + \mathrm{D}^+$ $\Xi_c^+ \to p + K^- + \pi^+$ $\mathrm{D}^+ \to K^- + \pi^+ + \pi^-$	B.R.
	5%
	2.2 ± 0.8% (1)
	9%
	0.0099%

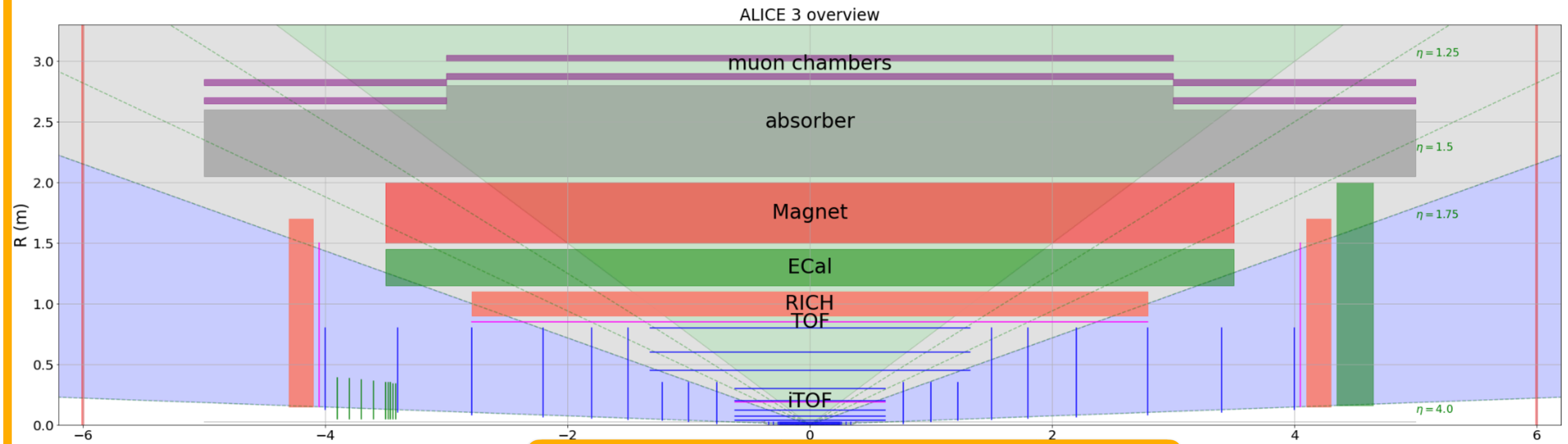
$\Omega_{ccc}^{++} \to \Omega_{cc}^+ + \pi^+$ $\Omega_{cc}^+ \to \Omega_c^0 + \pi^+$ $\Omega_c^0 \to \Omega^- + \pi^+$ $\Omega^- \to \Lambda + K^-$ $\Lambda \to p + \pi^-$	B.R.
	5%
	5%
	5%
	67.8%
	63.9%
	0.0054%

(1) Belle, B.R. = 0.45 ± 0.22%, PRD 100 (2019) 031101

ALICE 3 Detector



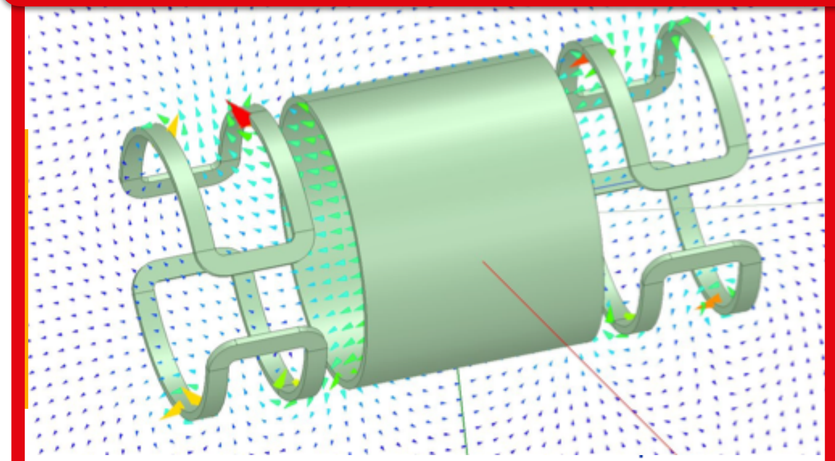
ALICE 3 Detector

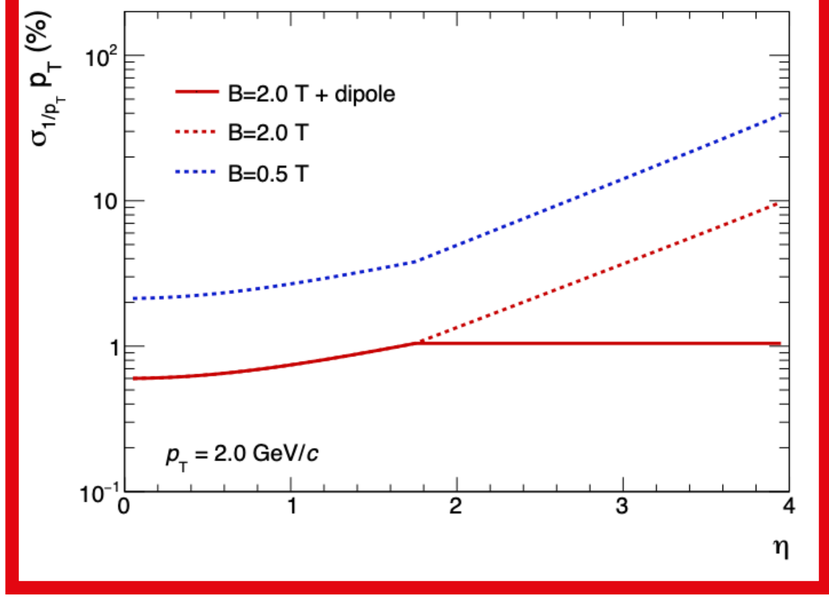


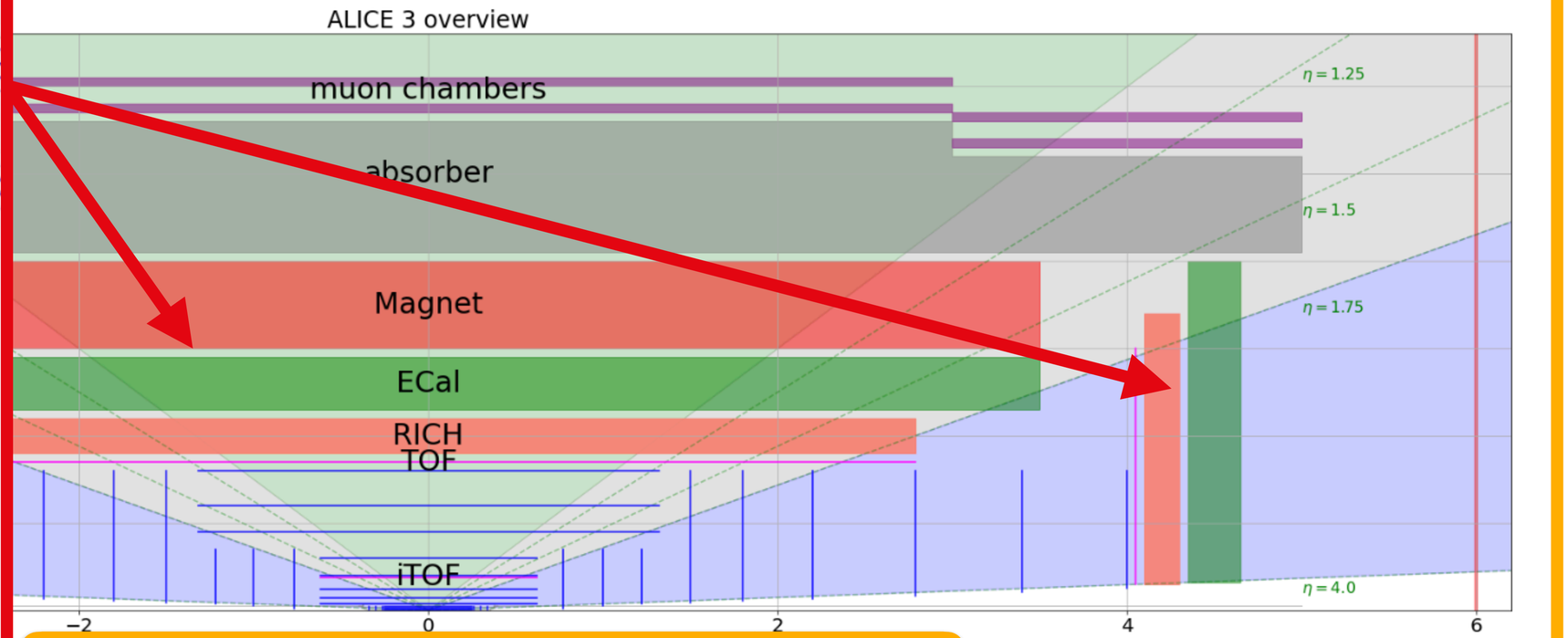
Large acceptance coverage

ALICE 3 Detector

~1% over full η range



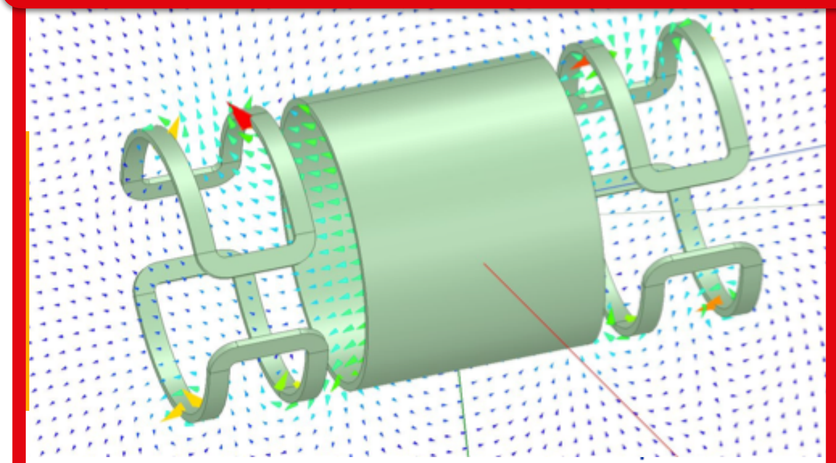


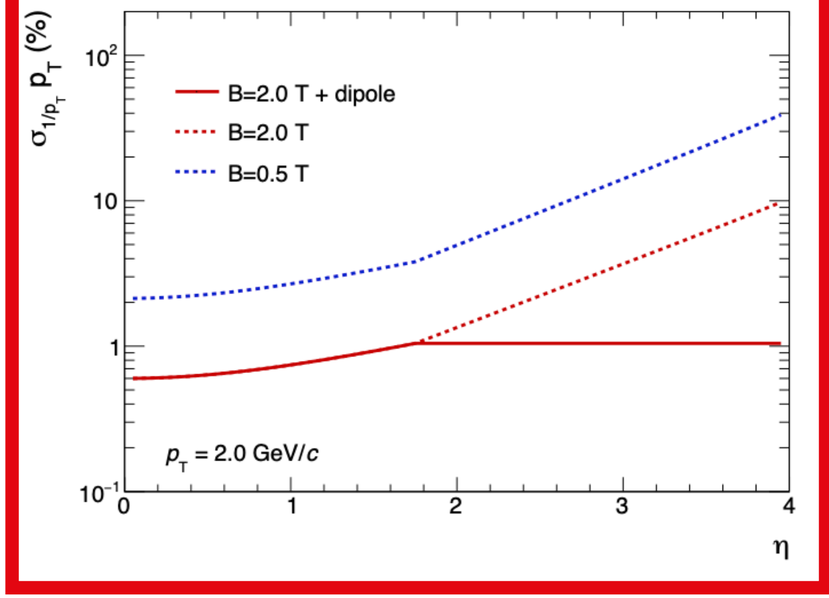


Large acceptance coverage

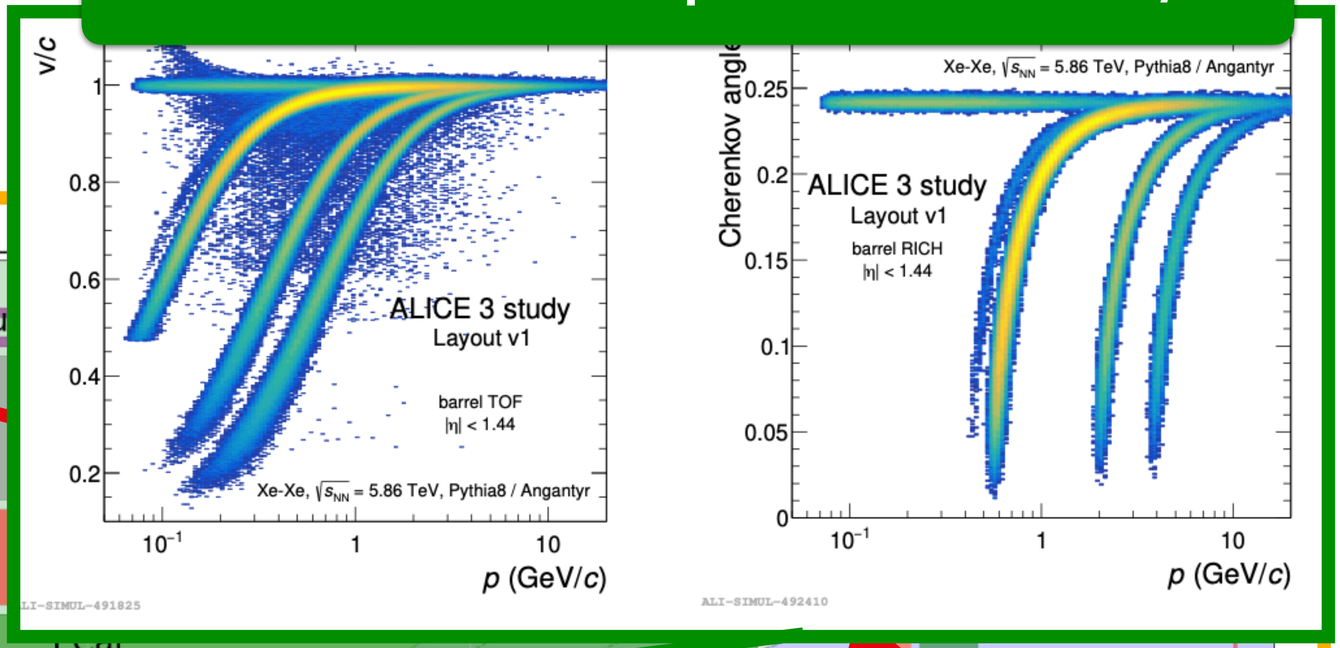
ALICE 3 Detector

~1% over full η range



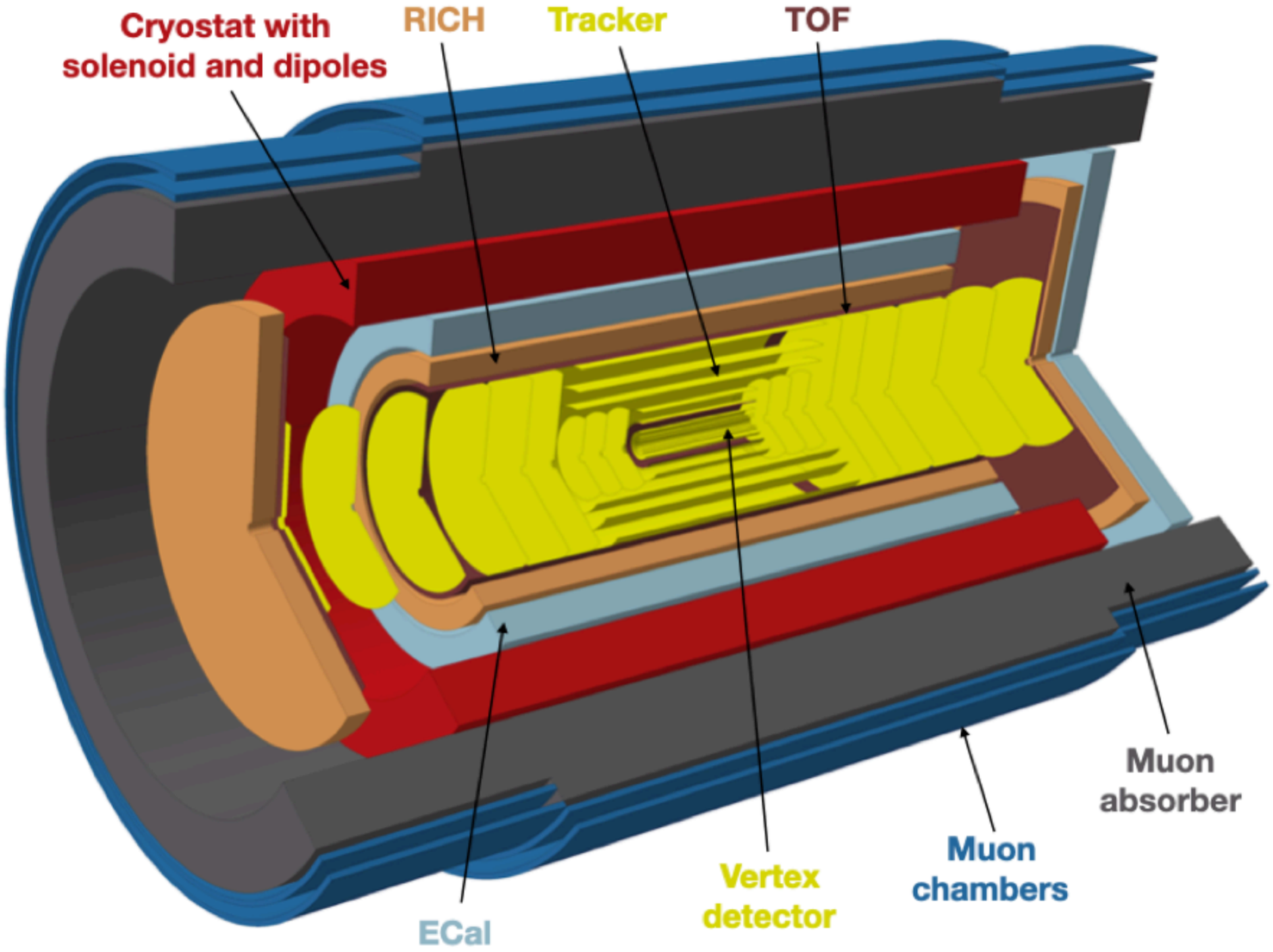


Hadron PID from p ~ 0.1 to 8 GeV/c

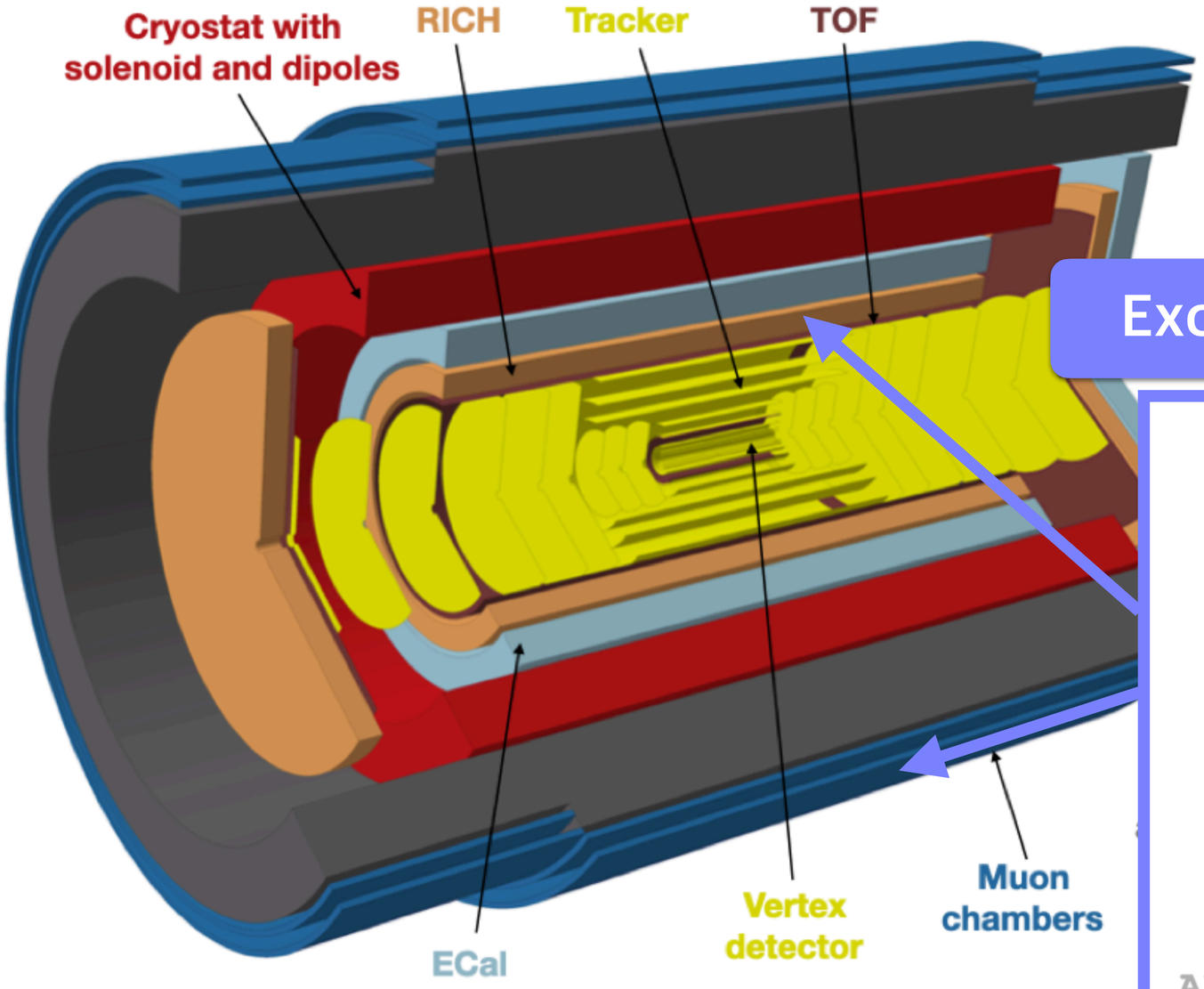


Large acceptance coverage

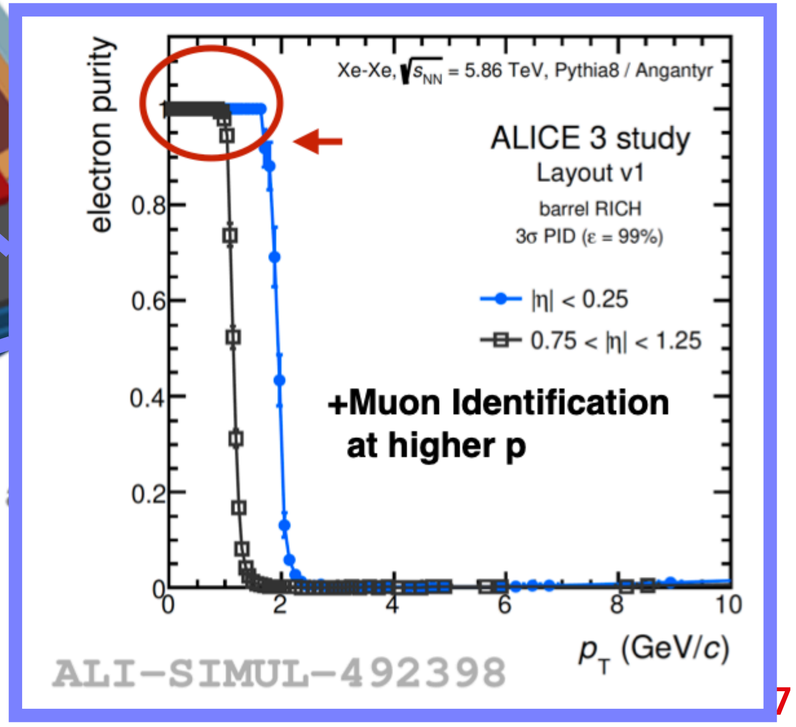
ALICE 3 Detector



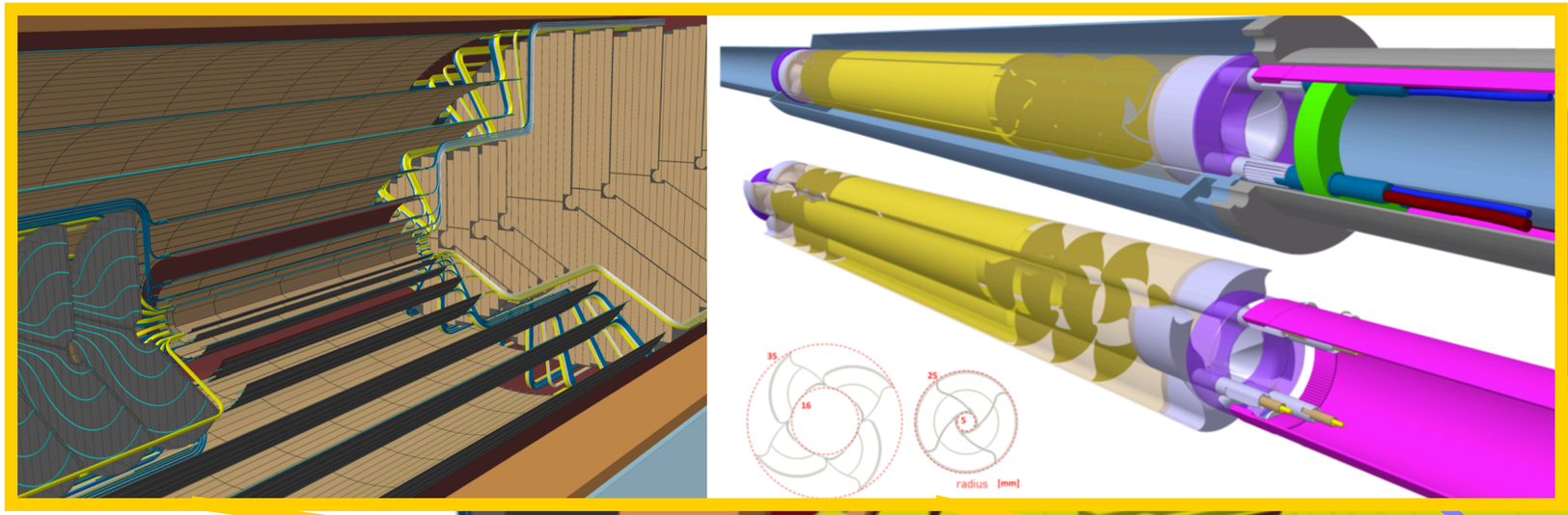
ALICE 3 Detector



Excellent e/π separation



ALICE 3 Detector

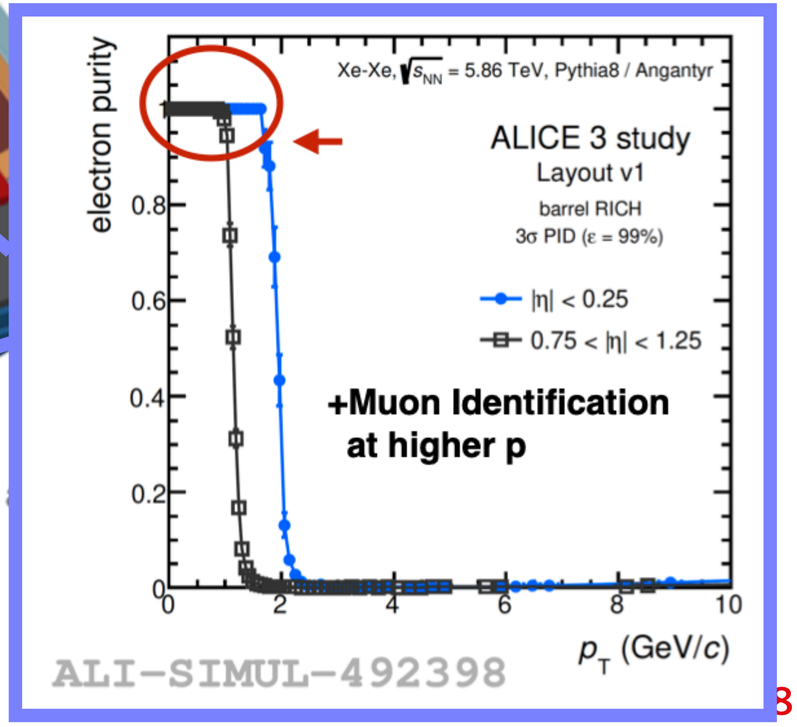


ECal

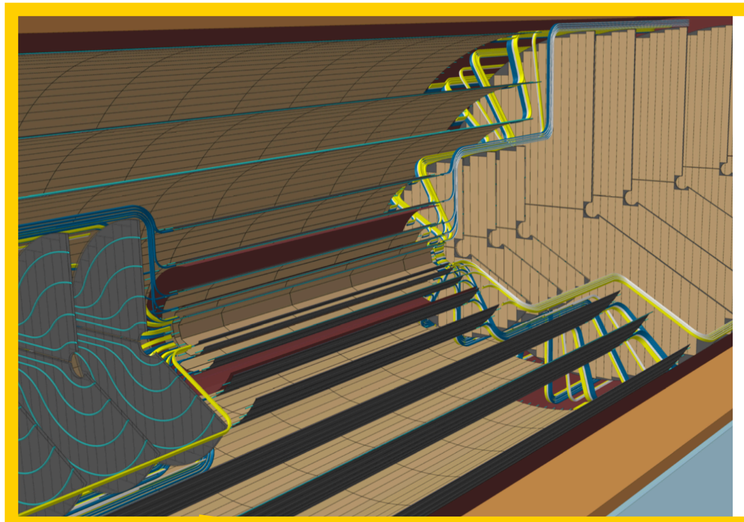
Vertex detector

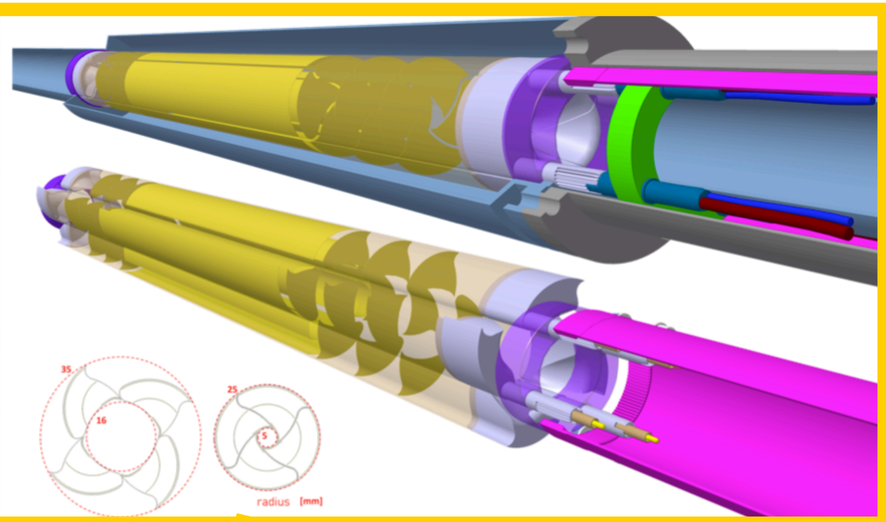
Muon chambers

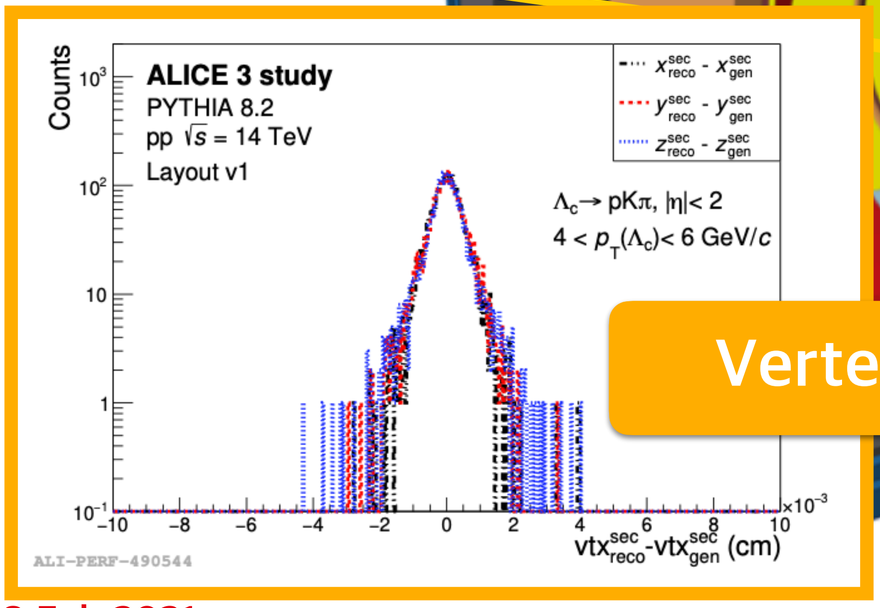
Excellent e/π separation



ALICE 3 Detector

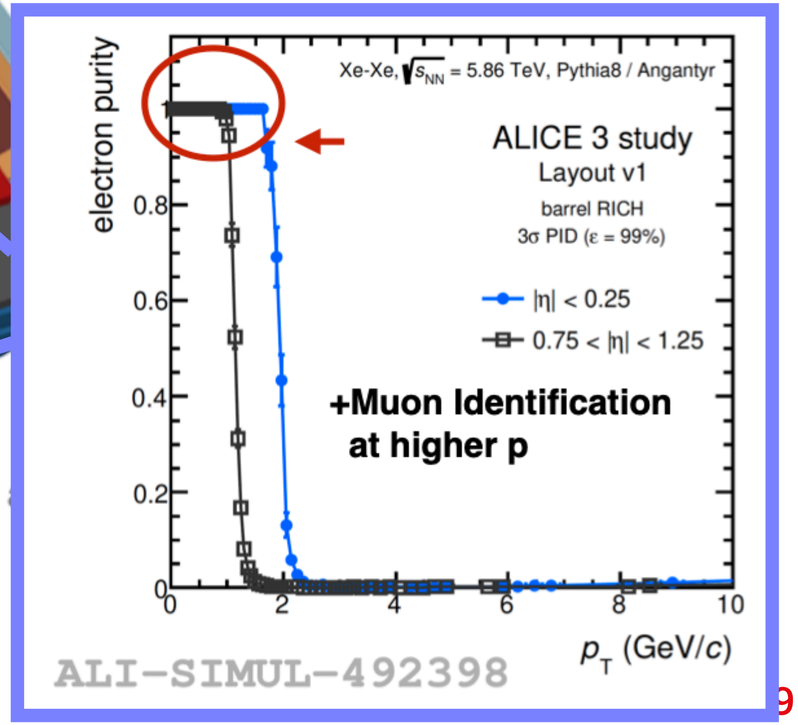






Vertex resolution < 5-10 µm

Excellent e/π separation



ECal

Vertex detector

Muon chambers