MRPCs at work: Λ_c reconstustion with the ALICE TOF Detector

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Outlines

1) The ALICE Time of Flight Detector
   a) Detector operation
   b) The ALICE Experiment
   c) The ALICE TOF

2) Λ_c : a powerful QGP probe
   a) Heavy quarks
   b) Observable: Λ_c/D^0
   c) Λ_c reconstruction

PART 1:

The ALICE Time of Flight Detector

Detector operation

A **time of flight (TOF) detector** is a particle detector which identify the particles using their time of flight between two detectors.

The first detector activates a clock upon being hit while the other stops the clock.

If the particle momentum and the travelled distance are known, we can identify the particle:

$$\mathbf{p} = \gamma m \boldsymbol{v}$$

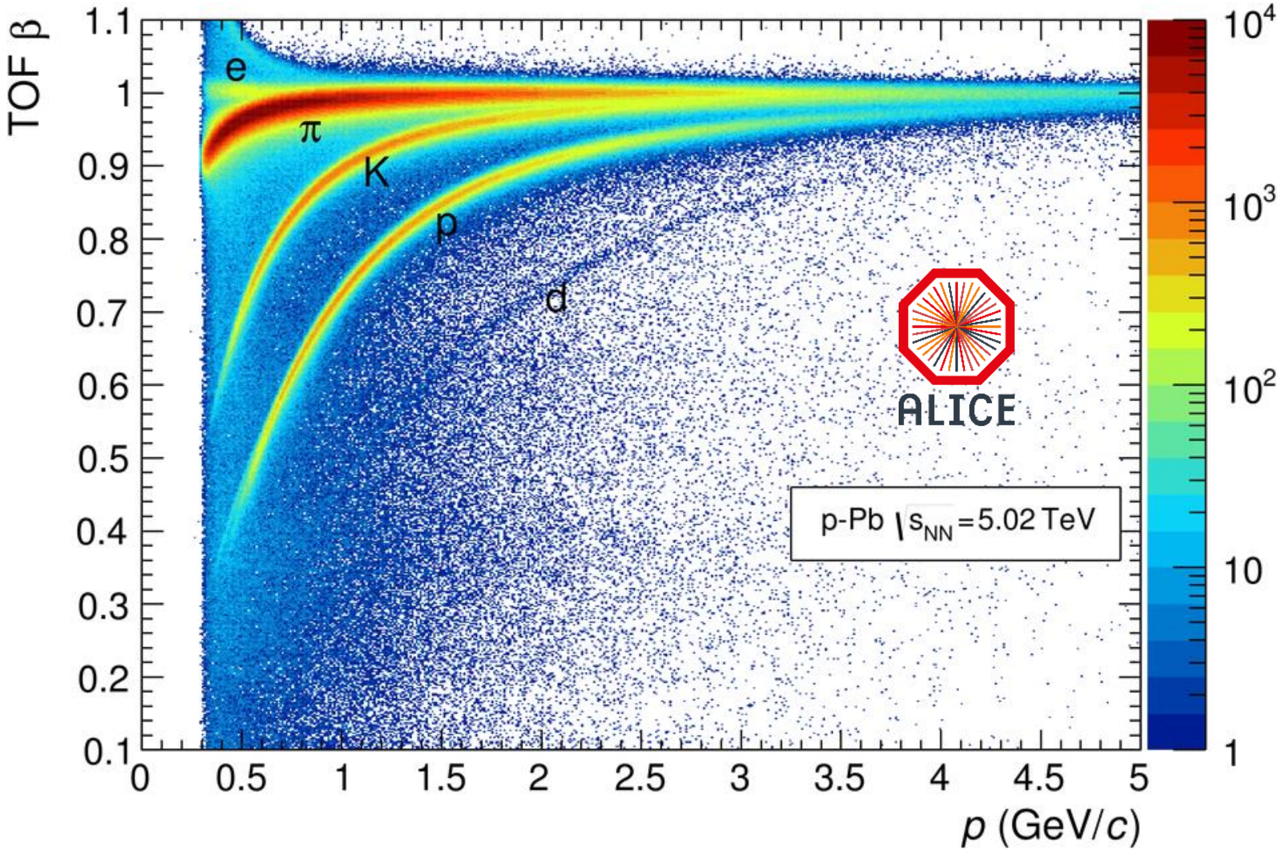
$$\gamma = (1 - v^2)^{-1} \qquad v = \frac{L}{t}$$

$$\boldsymbol{m = p\sqrt{\frac{t^2}{L^2} - 1}}$$

m = mass of the particle
$\boldsymbol{v}$ = particle speed
L = travelled distance
t = time spent on

TOF detector for particle identification

Many experiments at colliders use time of flight detectors to identify particles at intermediate transverse momentum.

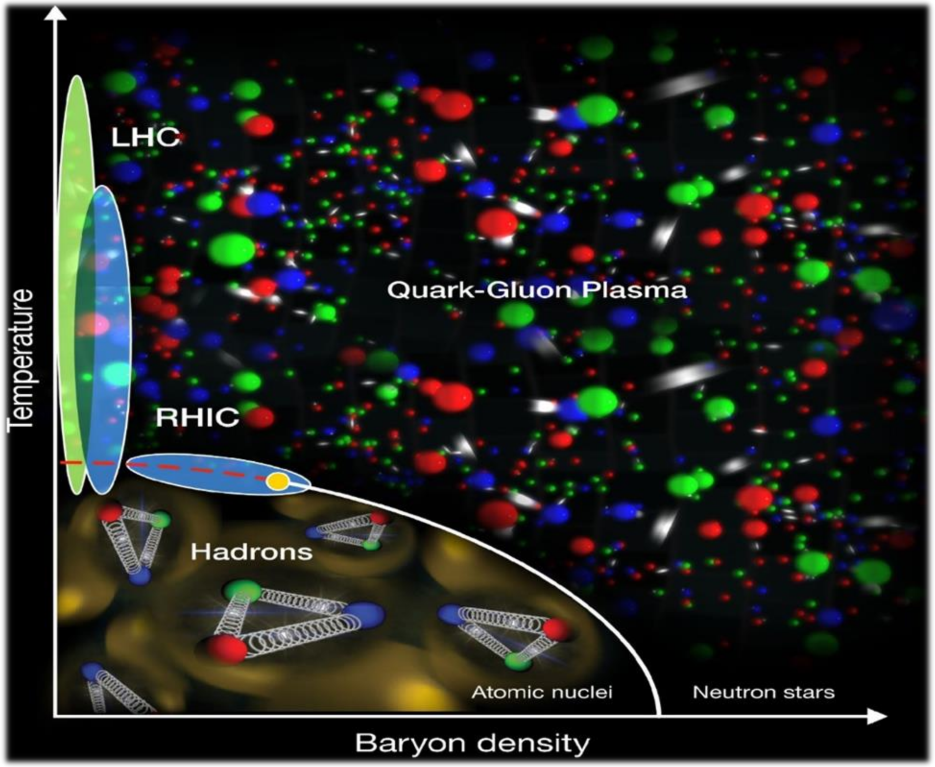


Identification until:

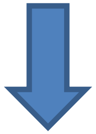
- 2GeV/c for pions and kaons
- 4GeV/c for protons

The ALICE experiment

The ALICE experiment is focused on QCD. It is designed to investigate the physics of strongly interacting matter and the QGP, product in heavy-ion collisions.



Phase Transition at very high temperature and/or baryon density.



New State of Matter:

Quark Gluon Plasma (QGP)

The ALICE Letter of intent dates 1993: theoretical models based on experimental results predict particle multiplicity per rapidity units ranging between 2000 and 8000.

ALICE TOF detector requirements

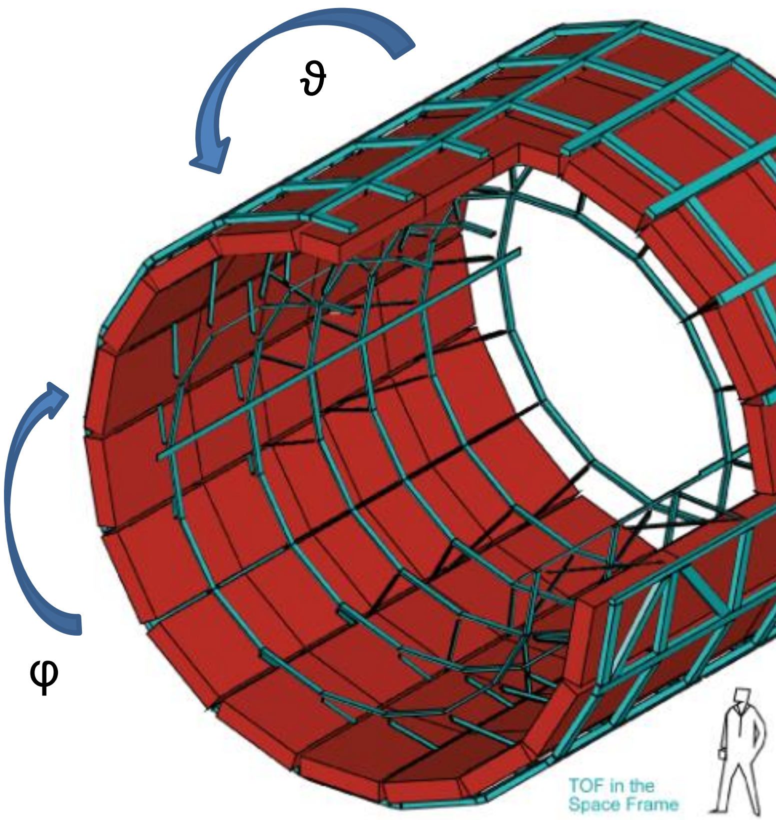
TOF detector is the most important ALICE detector for the particle identification. It was designed to detect the maximum expected particle multiplicity.

- High time resolution
- High rate capability
- Large area coverage
- High signal (without causing discharges)

Only two possibilities:
- Scintillator
- Gaseous detector

Gaseous Detector →
- Cheaper
- Modular structure

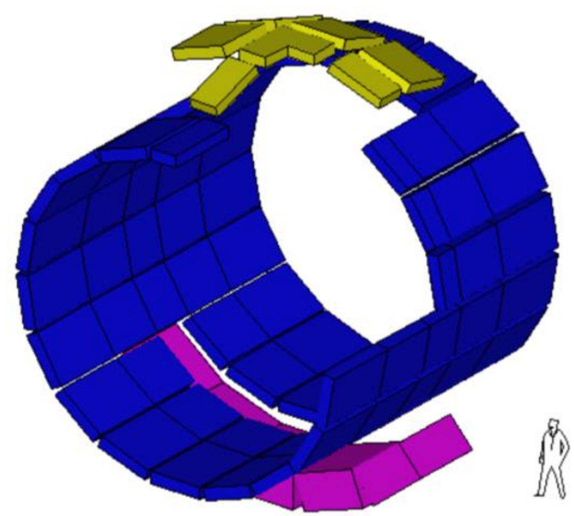
The ALICE TOF



Internal Radius: 370cm

External Radius: 400cm

Active Volume Length: 7.41m

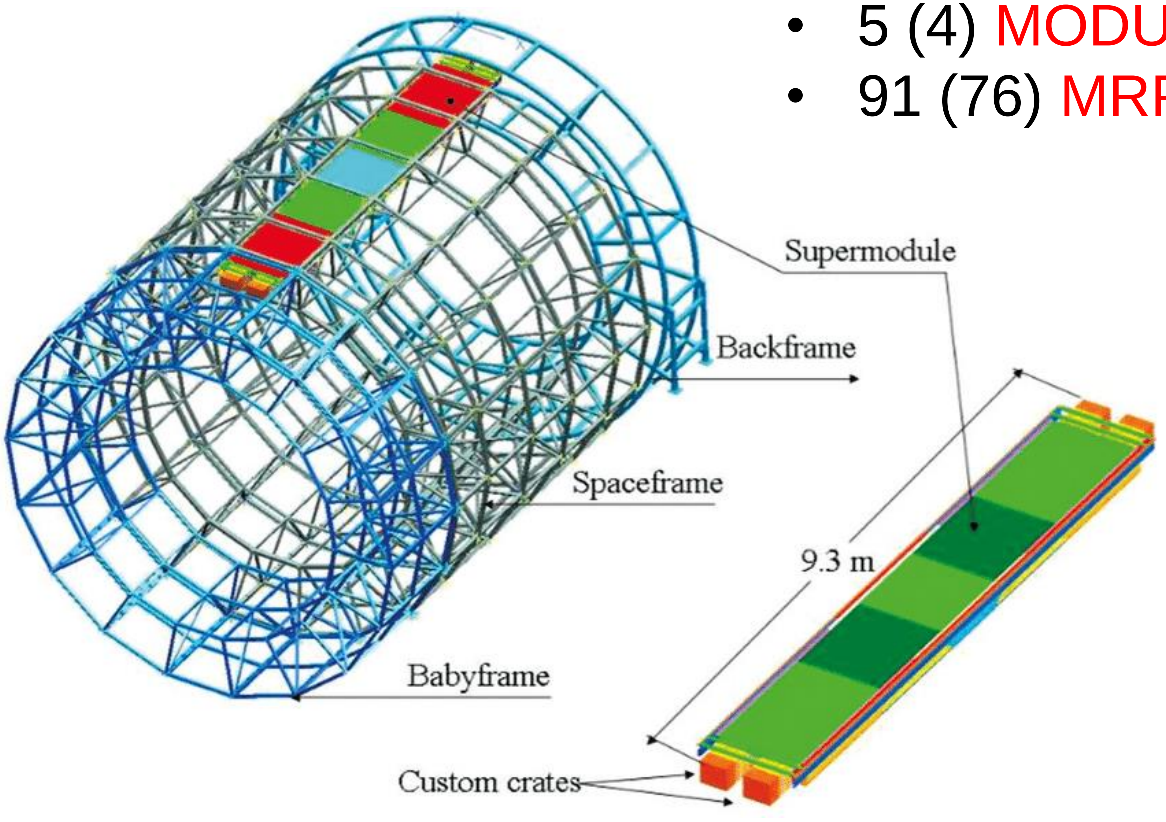


Polar angle covered: 45°< ϑ <135°

Azimuthal angle covered: 0°< φ <360°
(except the region 260°< φ <320° & |η|<0.12 in with PHOS detector is mounted)

Pseudo-Rapidity coverage: |η|<0.9

Modular stucture of TOF detector



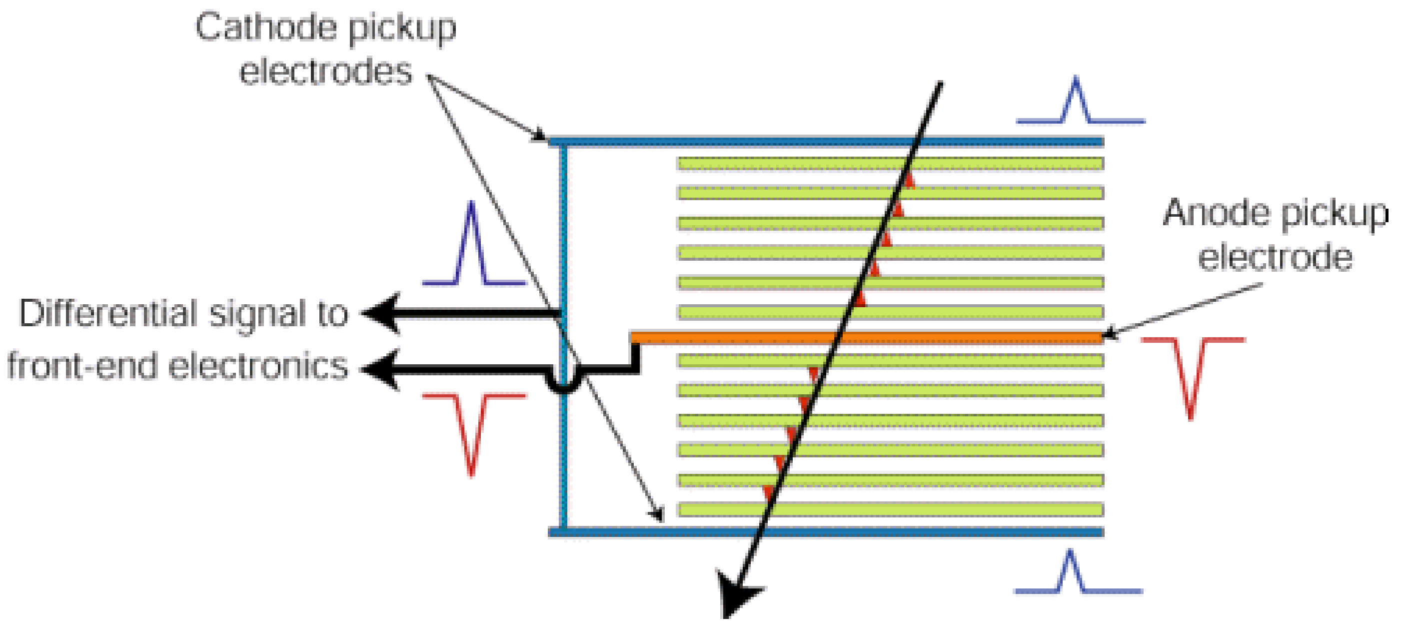
- 18 linear sector called SUPERMODULES.
- 5 (4) MODULES for each Supermodule.
- 91 (76) MRPC for each Supermodule.

At the two edges of each Supermodule there are two crates for the readout electronics.

MRPCs DOUBLE-STACK

MRPC double-stack:

- Double the gaps without increasing the applied voltage.
- Better time resolution.



Efficiency : ~ 100%

Intrinsic time resolution: ~ 40ps

Read-Out electronics time resolution: ~40ps

Total time resolution: ~**80ps**

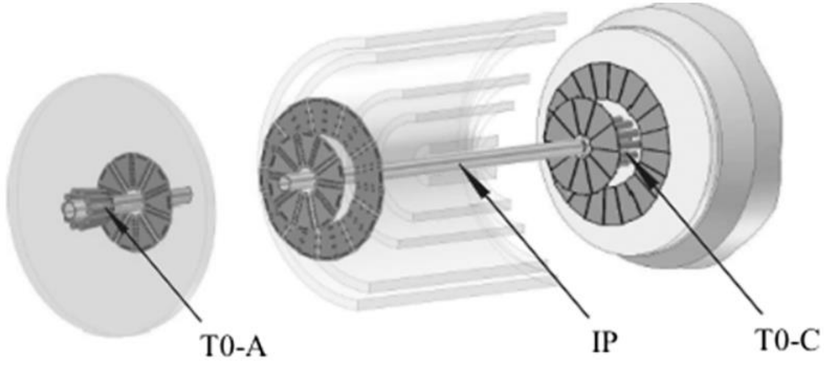
Start and Stop of the time counter

Stop: MRPCs double-stack signal

Start:
- T0 Detector
- χ^2 minimization procedure based on TOF

T0 Detector: 2 arrays of Cherenkov detector (T0A and T0C) located at the sides opposite to the collision zone at 370cm and 70cm away from the IP.

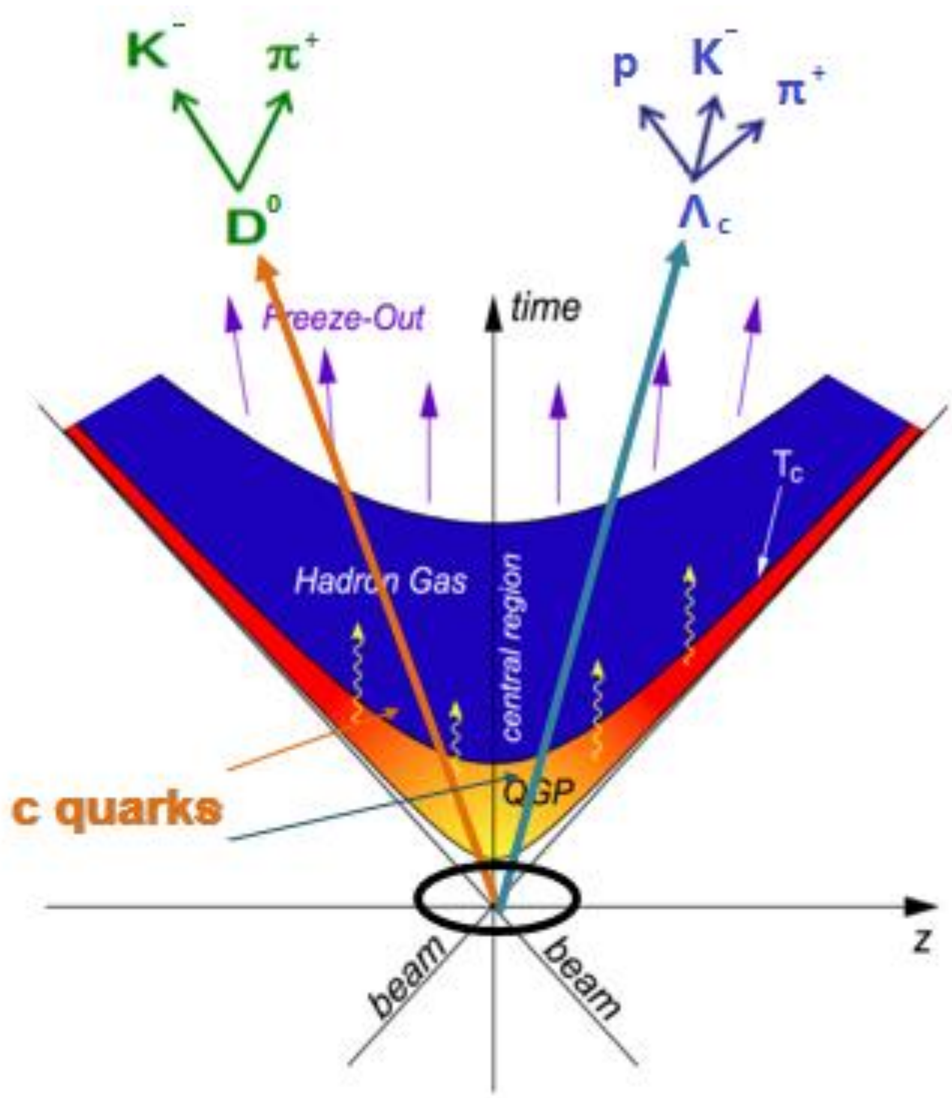
Limited Acceptance → Event time estimation non available for a fraction of the events (Hight centrality collision).



PART 2:

Λ_c : a powerful QGP probe

Heavy Quarks:
powerful probes for the Quark Gluon Plasma

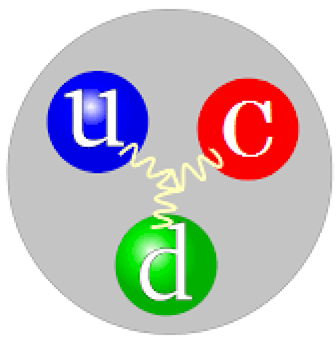


Heavy quarks are produced in the early stages of the collision, before the QGP formation. They experience the whole medium evolution.

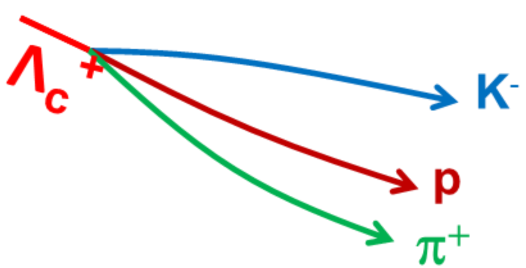
The relative abundances of baryons and mesons depend on the interactions with the hot medium.

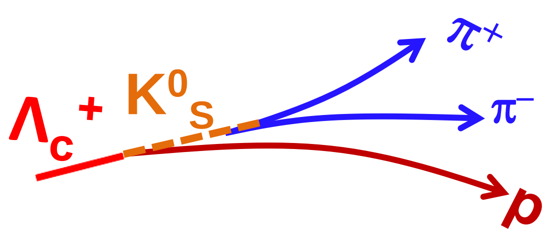
Who is Λ_c?

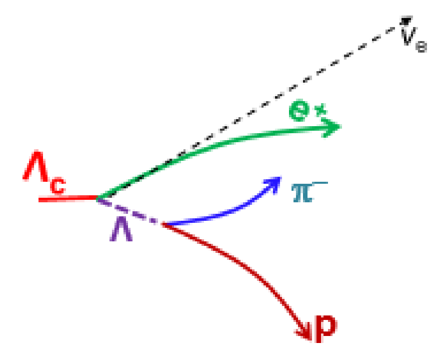
Λ_c is the lightest open charm baryon.



Quark content	m (MeV/c^2)	cτ (μm)
udc	2286.46 ± 0.14	**59.9**







BR = (6.23 ± 0.33)% BR = (1.09 ± 0.21)% BR = (2.30 ± 0.40)%

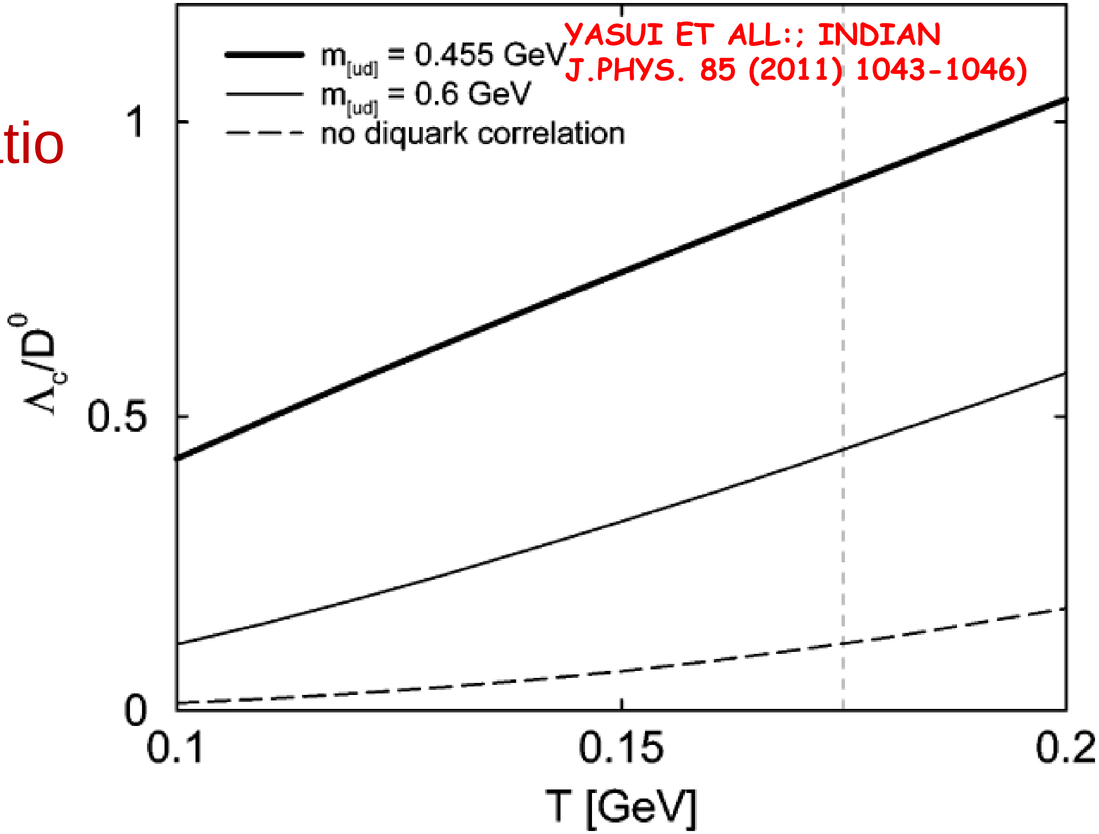
Motivations for Λ_c studies

In A-A collision

- The measurement of Λ_c in Pb-Pb collisions could give an insight into the hadronization mechanisms in QGP.

Measure of the baryon over meson ratio

Λ_c/D^0 ratio is strongly dependent on the medium created in the collision.



- Moreover, we need to understand heavy baryon production in elementary collisions (pp and p-Pb)

Motivations for Λ_c studies

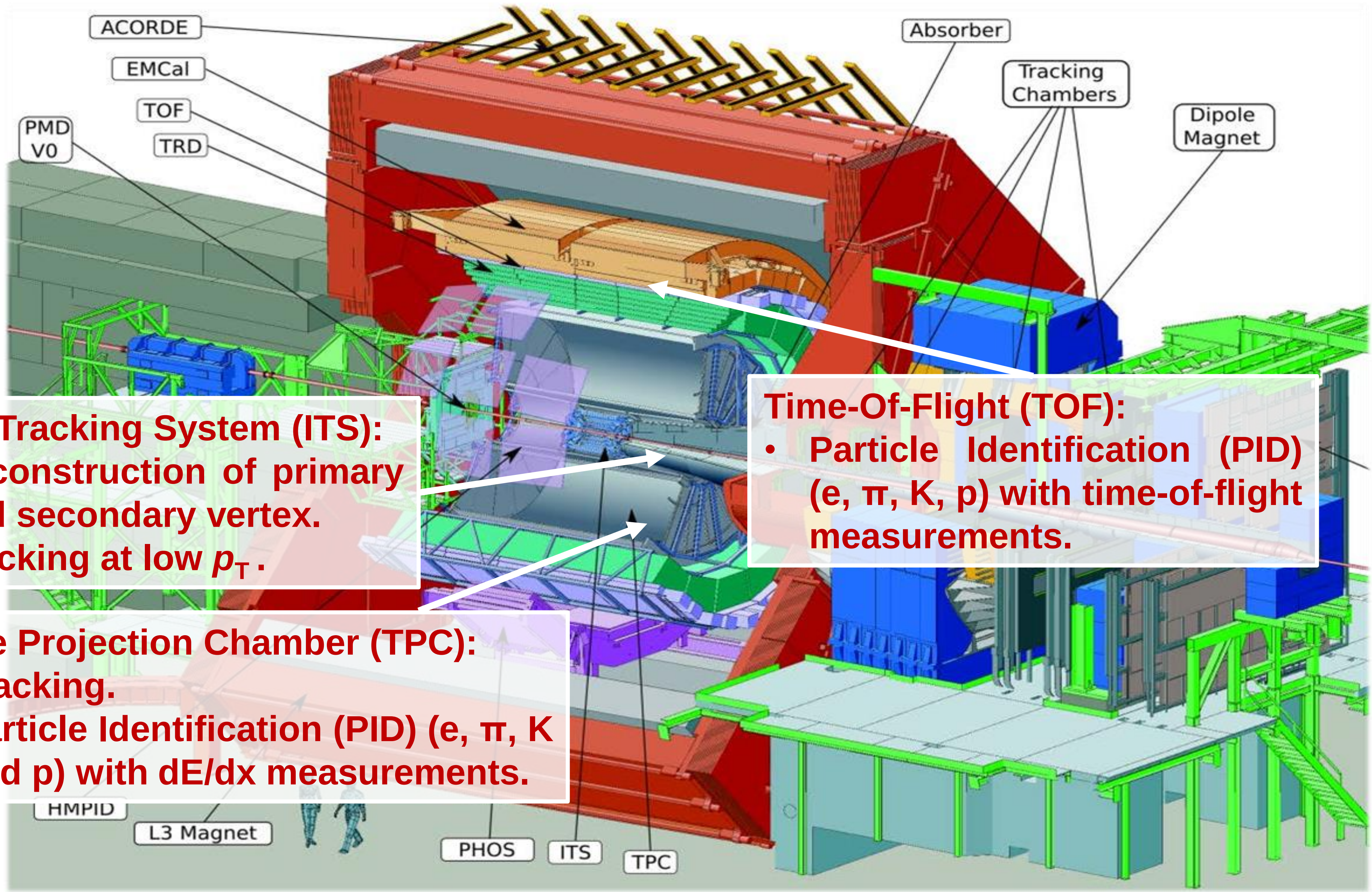
In pp collision

- Reference for A-A collision.
- Test of perturbative QCD (pQCD) calculation predictions at highest collision energies.

In p-A collision

- Reference for A-A collision.
- Study of the *cold nuclear matter effects* (CNM).

ALICE Detector



Inner Tracking System (ITS):
- **Reconstruction of primary and secondary vertex.**
- **Tracking at low p_T.**

Time Projection Chamber (TPC):
- **Tracking.**
- **Particle Identification (PID) (e, π, K and p) with dE/dx measurements.**

Time-Of-Flight (TOF):
- **Particle Identification (PID) (e, π, K, p) with time-of-flight measurements.**

Λ_c Analysis Purpose

Λ^+_c prompt differential cross-section estimation.

The Raw Yield is the sum between Λ^+_c and Λ^-_c while the cross section is given just for Λ^+_c .

Λ_c fraction produced by direct hadronization of the quark charm. Estimated on the MC.

Raw Yield (Λ^+_c + Λ^-_c) extracted from the invariant mass plot. Measured on data.

$$\left.\frac{d\sigma^{\Lambda^+_c}}{dp_T}\right|_{y<|0.5|} = \frac{1}{2}\frac{1}{\Delta y * \Delta p_{\mathrm{T}}}\frac{1}{Eff\ X\ Acc}\frac{f_{prompt} * N^{\Lambda_c}}{BR(\Lambda_c \rightarrow p\pi^+\pi^-) * L_{\mathrm{INT}}}$$

Rapidity range

Transverse momentum range

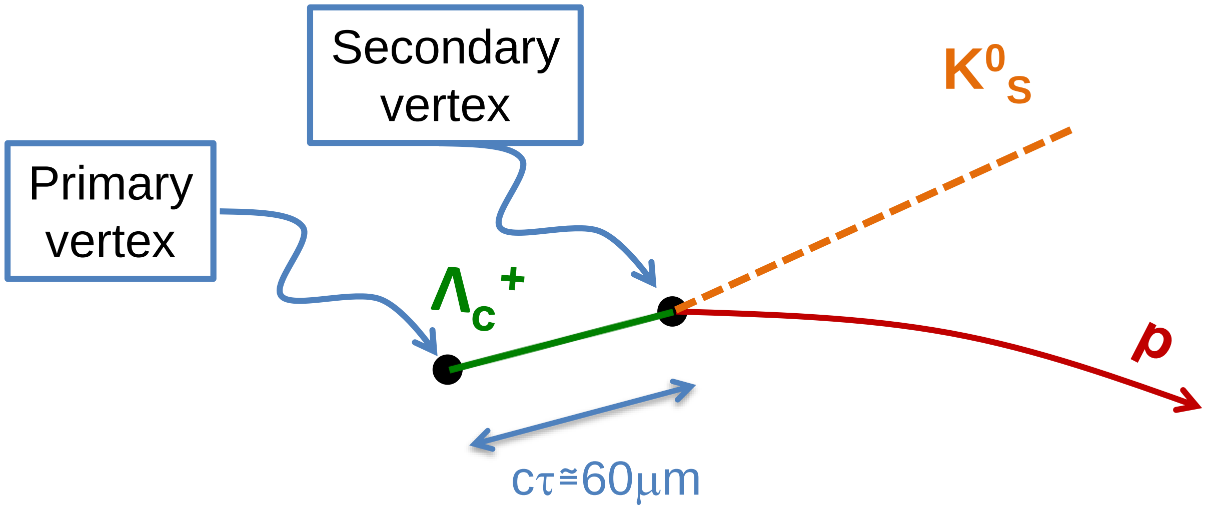
Efficiency x Acceptance product. Estimated on the MC.

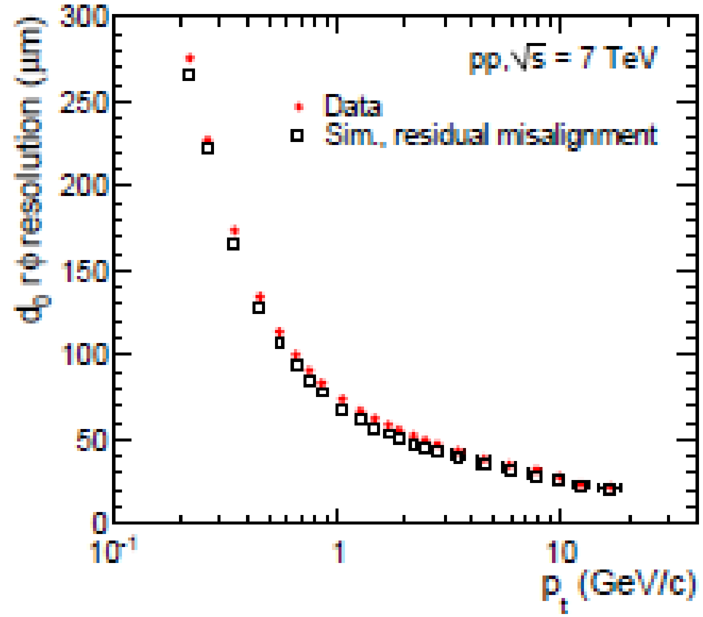
Branching ratio: (1.09 ± 0.21)%

Integrated Luminosity. (arXiv:1405.1849 [nucl-ex])

Λ_c reconstruction in the channel decay $\Lambda_c \rightarrow K^0_S + p$

Λ_c candidates are built by combining K^0_S candidates with proton candidates identified in each event.





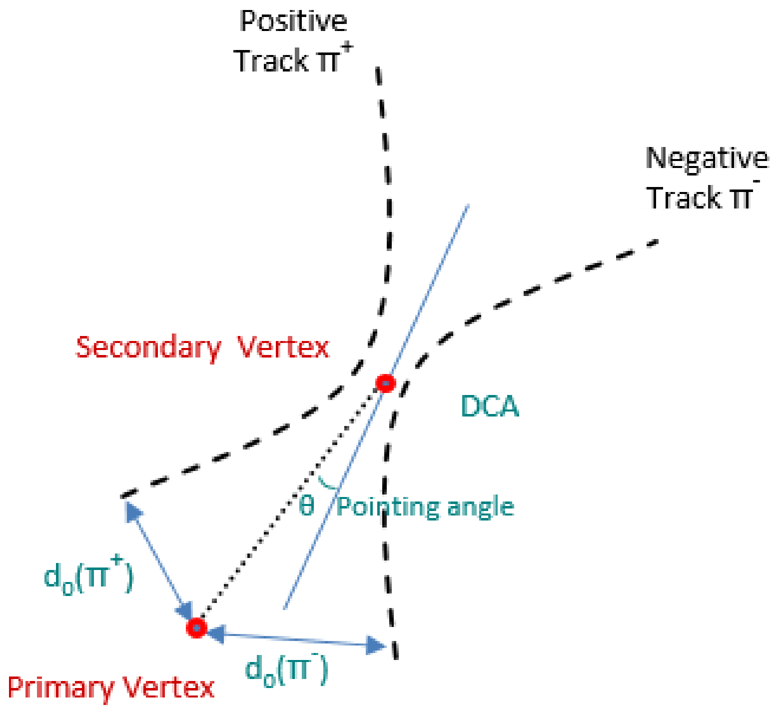
The resolution on vertices reconstruction is not sufficient to separate the production vertex (primary) and the decay one (secondary) of Λ_c baryons.

➔ It's not possible to select the Λ_c candidates using the decay topology.
(For the charmed mesons (D) it's possible to separate the two vertices)

Essential to select the best K^0_S and p candidates.

K^0_S candidates selection

"V" Decay reconstruction in π^+ and π^-.



Decay topology:

- Maximum value of the distance of closest approach between charged tracks (DCA)
- Pointing angle cosine, ϑ
- Radius of the fiducial volume

Quality in recostruction of charged tracks:

- Minimum value of pions transverse momentum
- Minimum value of impact parameter
- Minimum number of hit in TPC detector

Invariant mass selection:

- $m_{inv}(\pi^+ \pi^-)$ compatible with $m(K^0_S)$
- $m_{inv}(p\ \pi^-)$ and $m_{inv}(\pi^+ p)$ incompatible with $m(\Lambda)$
- $m_{inv}(e^+ e^-)$ incompatible with $m(\gamma)$

Proton (anti-proton) candidates selection

Quality in recostruction of charged tracks:

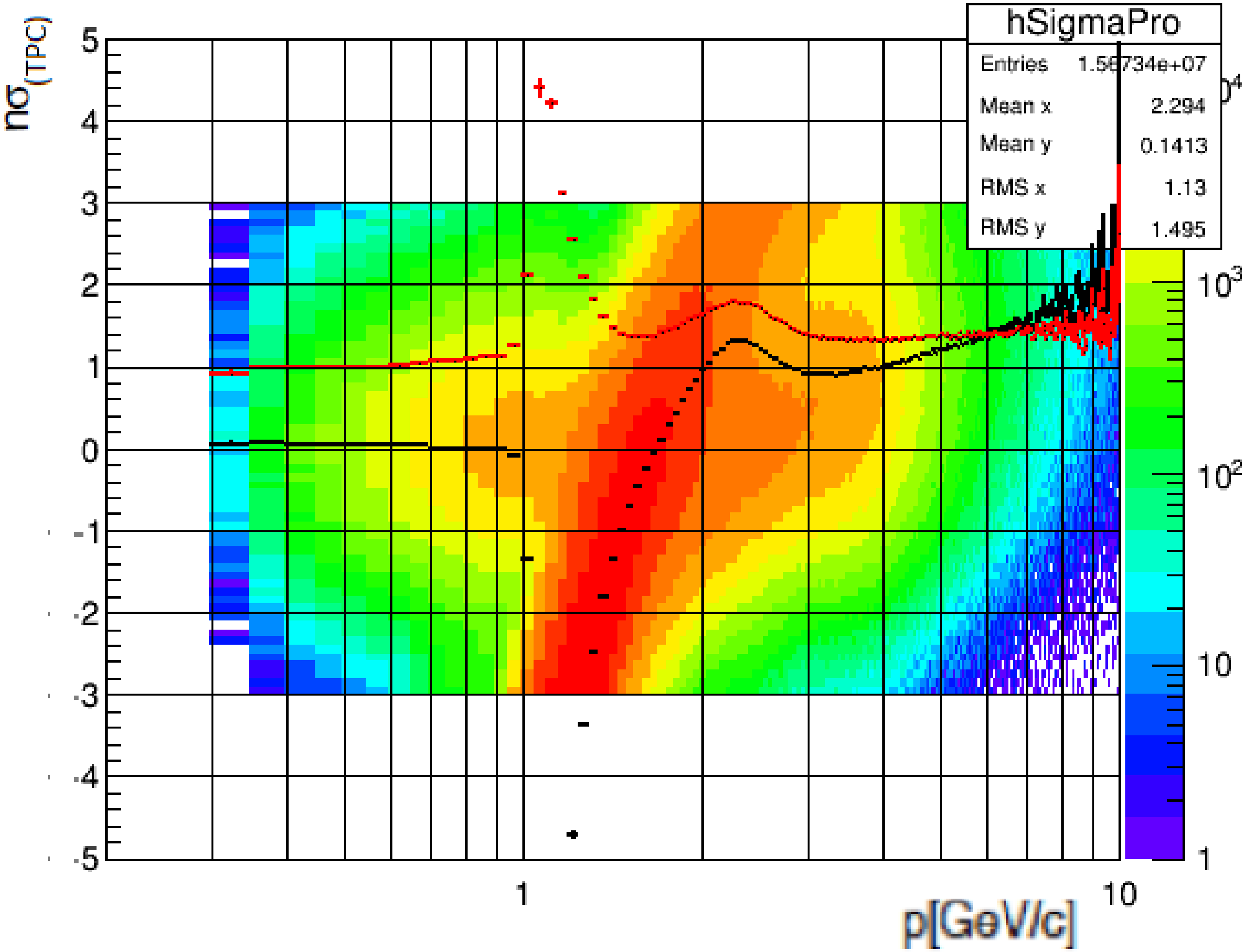
- Minimum value of transverse momentum
- Maximum value of impact parameter
- Minimum number of hit in TPC detector
- Minimum number of hit in ITS detector

Particle Identification (PID):

- Essential element to carry out this analysis
- Based on dE/dx measure (TPC) and on time of flight measure (TOF)
- Two selection levels:
  - dE/dx measure compatible with proton hypothesis
  - Combined measure of TPC and TOF compatible with proton hypothesis.

First PID level

$$(n\sigma)_{TPC} = \frac{\left(\frac{dE}{dx}\right)_{exp} - \left(\frac{dE}{dx}\right)_{th}(p)}{\sigma_{TPC}}$$

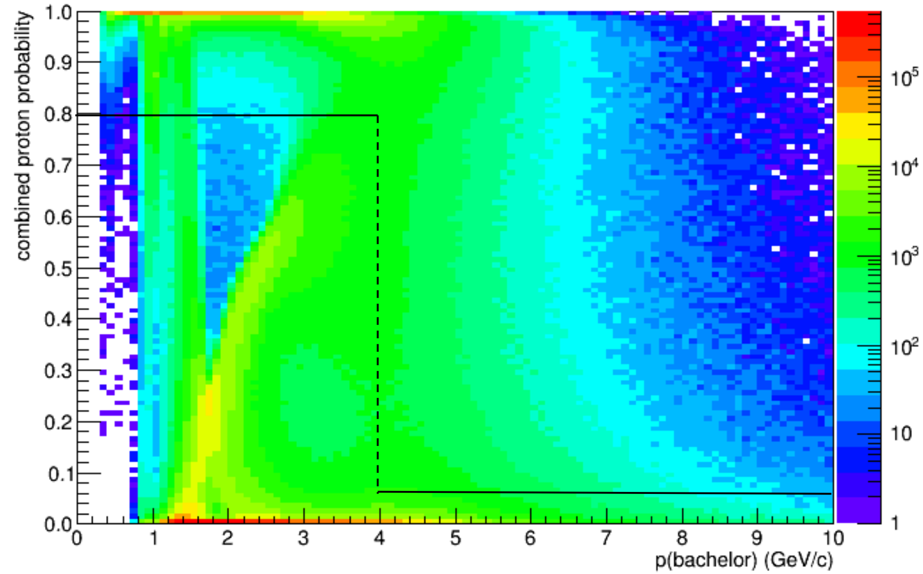


A 3σ cut is applied on dE/dx measures

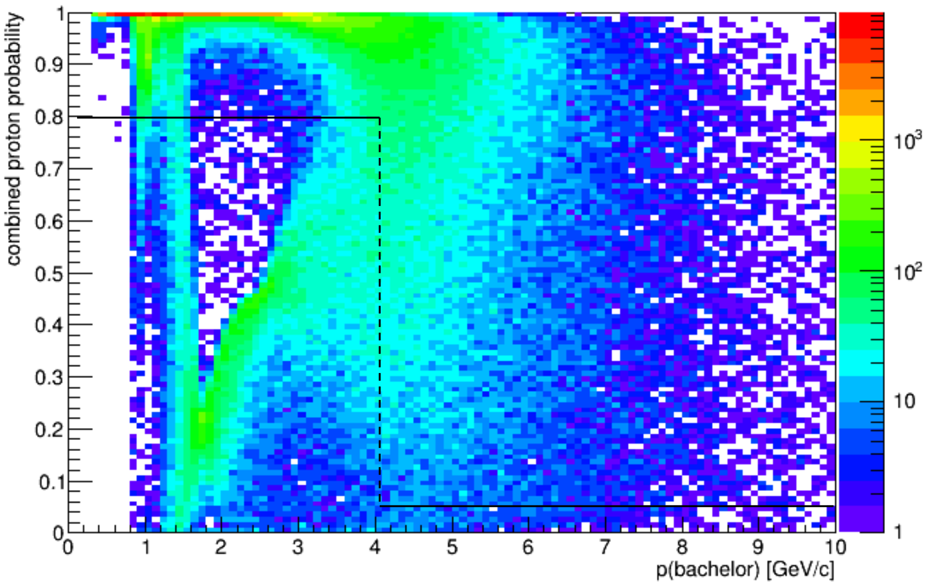
Second PID level

Proton identification with
TPC and TOF

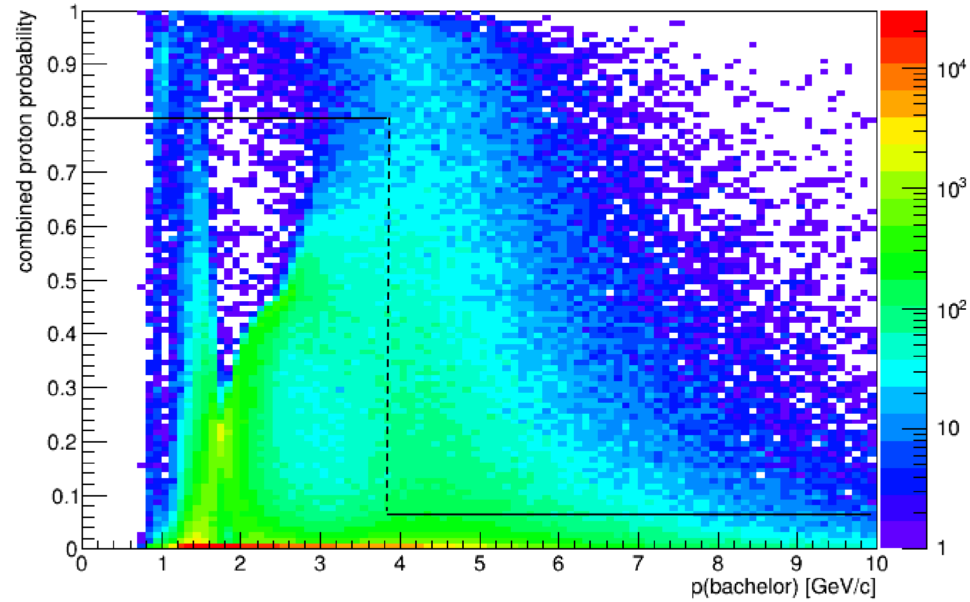
Data



Proton by MC



Non Proton by MC

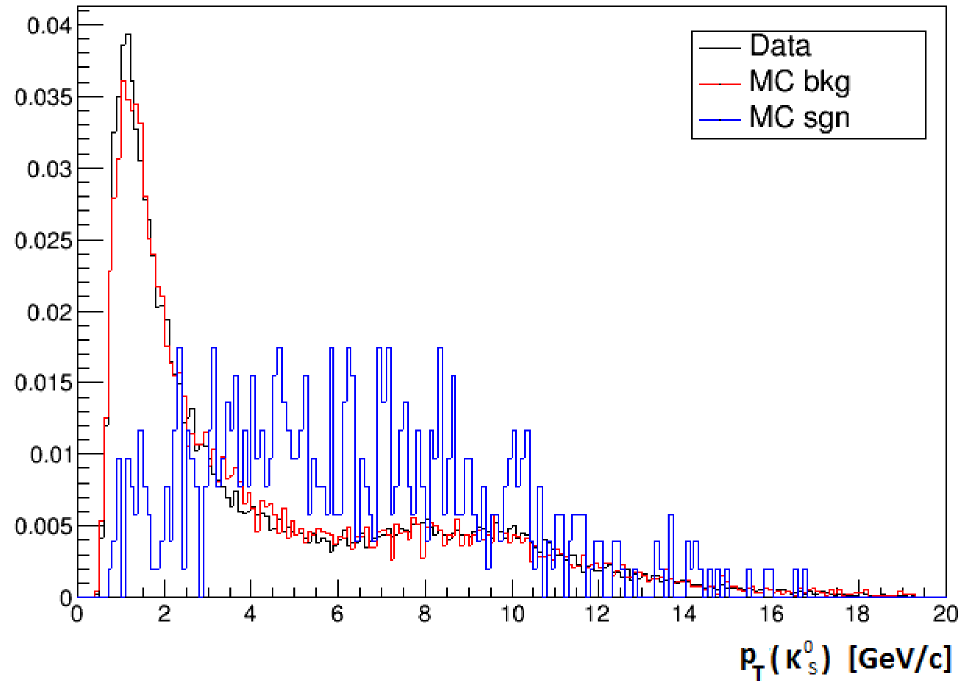


PID = p(proton)<4 GeV/c CombinedProb > 0.8
p(proton)≥4 GeV/c CombinedProb > 0.05

Cut Optimization

Choice of cutting variables:

- p, $\pi^{\pm}$,K^0_s transverse momentum
- proton impact parameter
- invariant mass $m(\pi^+\pi^-)$

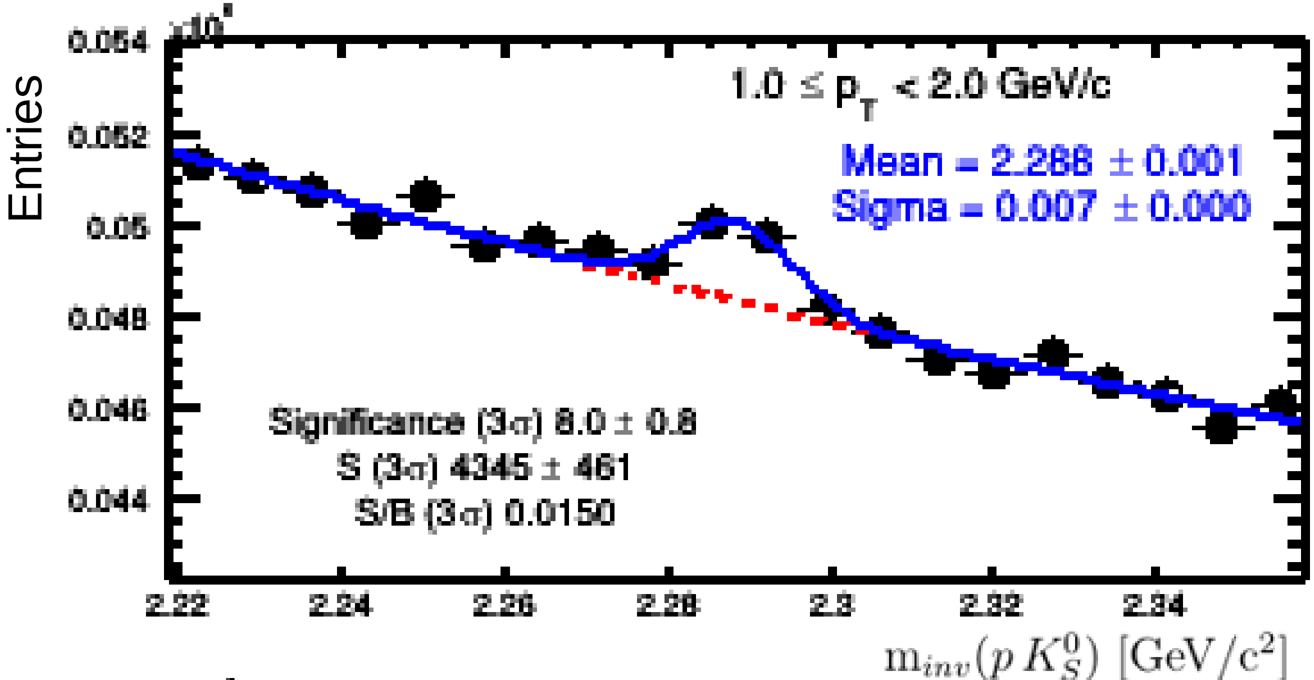


Cut variation in order to:

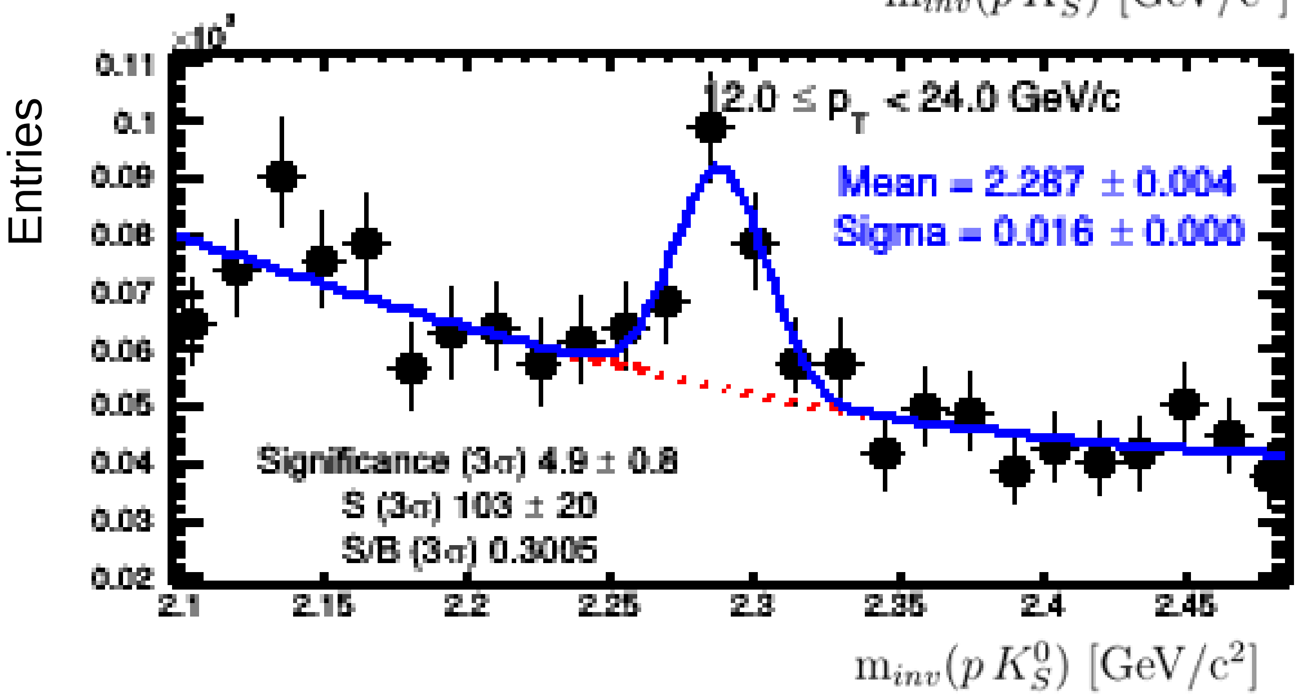
- maximize the Signal-Background ratio
- obtaining a good fit
- having a *Significance* at least grater than 3

$$Significance = \frac{Signal}{\sqrt{Signal + Bkg}}$$

Signal Extraction



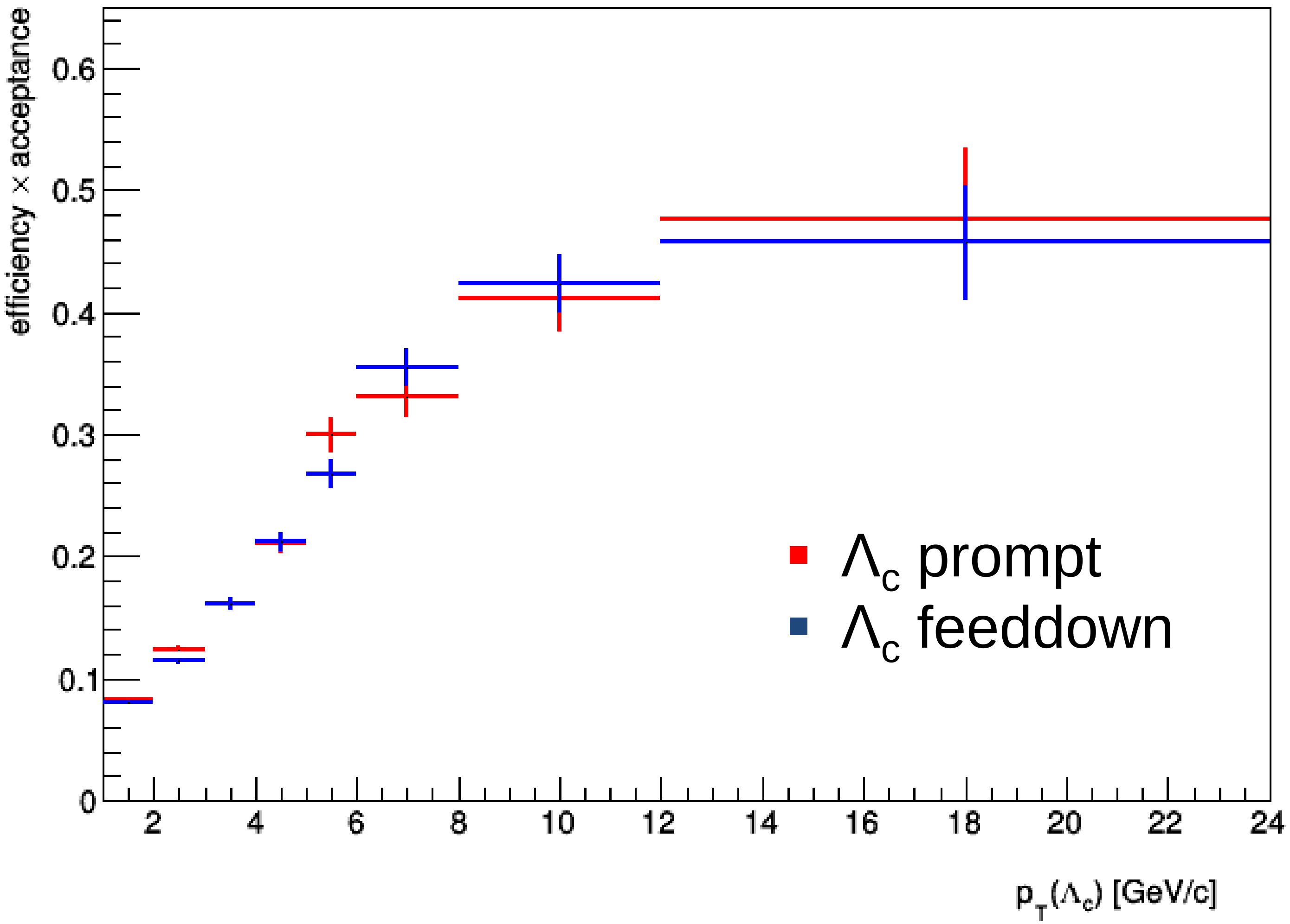
$1 \leq p_T(\Lambda_c) < 2$ GeV/c



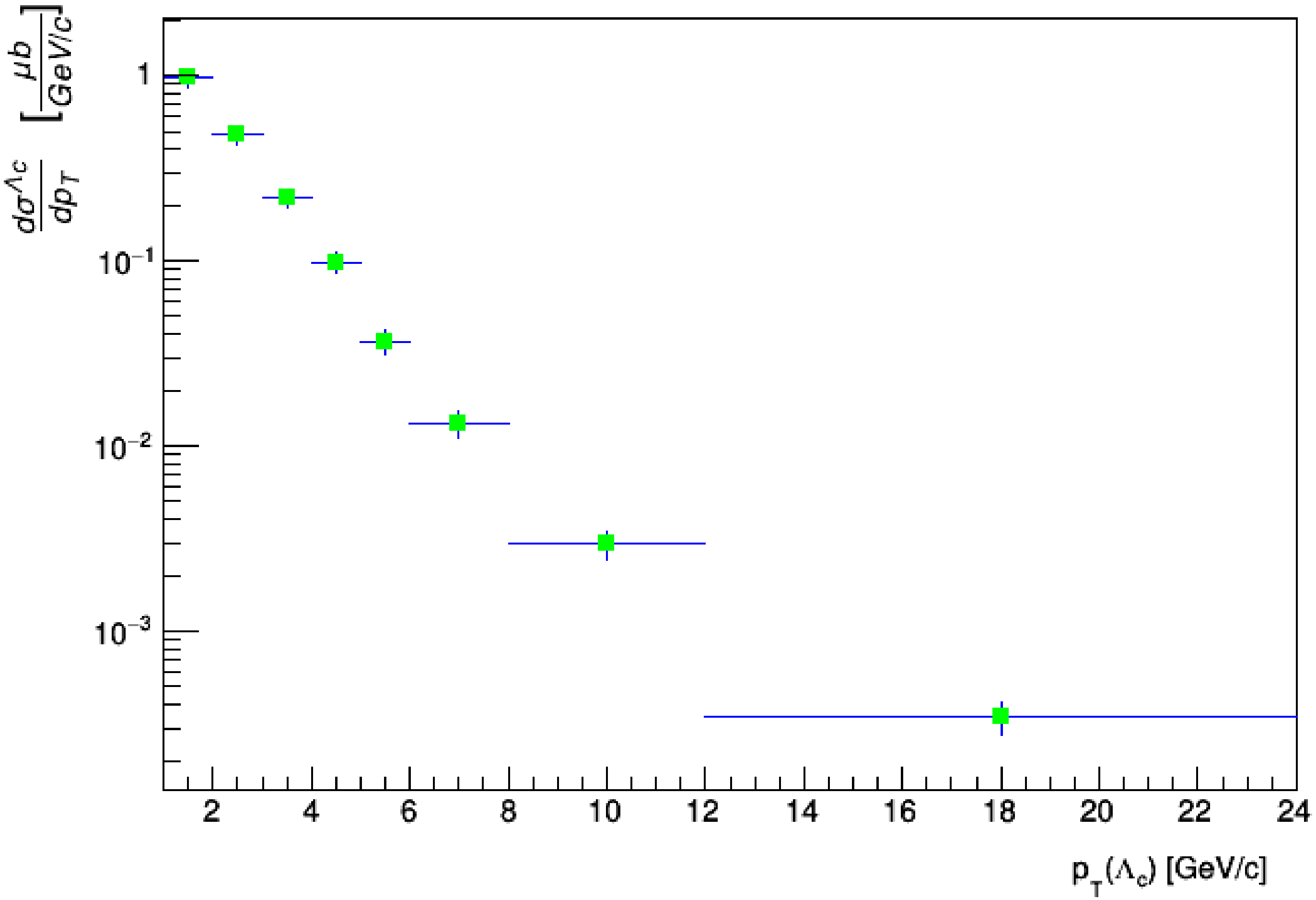
$12 \leq p_T(\Lambda_c) < 24$ GeV/c

Efficiency x Acceptance product estimate

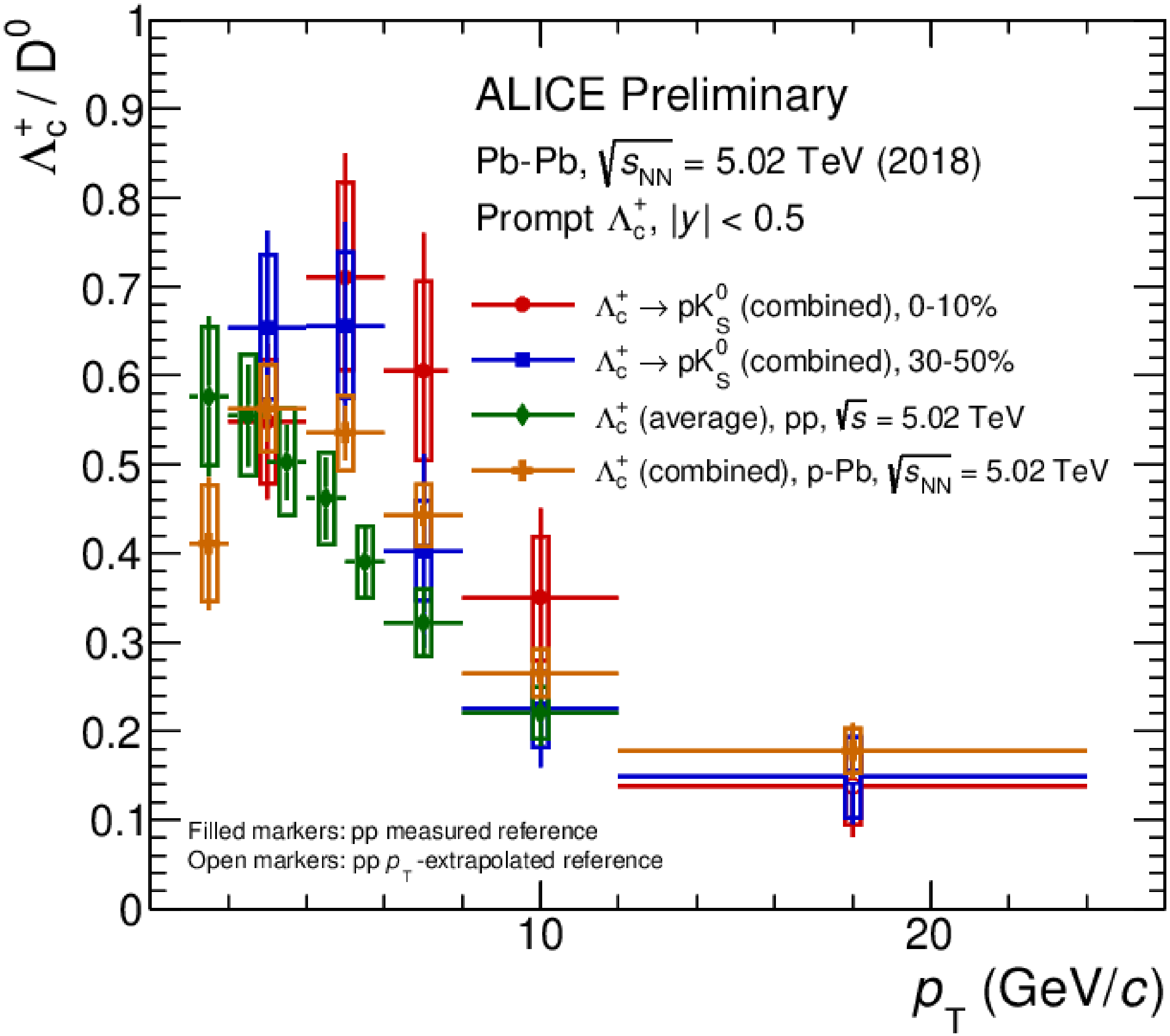
$$\textbf{Efficiency x Acceptance} = \frac{n^\circ\ of\ \Lambda_c\ candidates\ successfully\ reconstructed}{n^\circ\ of\ \Lambda_c\ \ generated\ in\ |y| < 0.5}$$



Differential Cross-section estimate



Λ_c/D^0 ratio



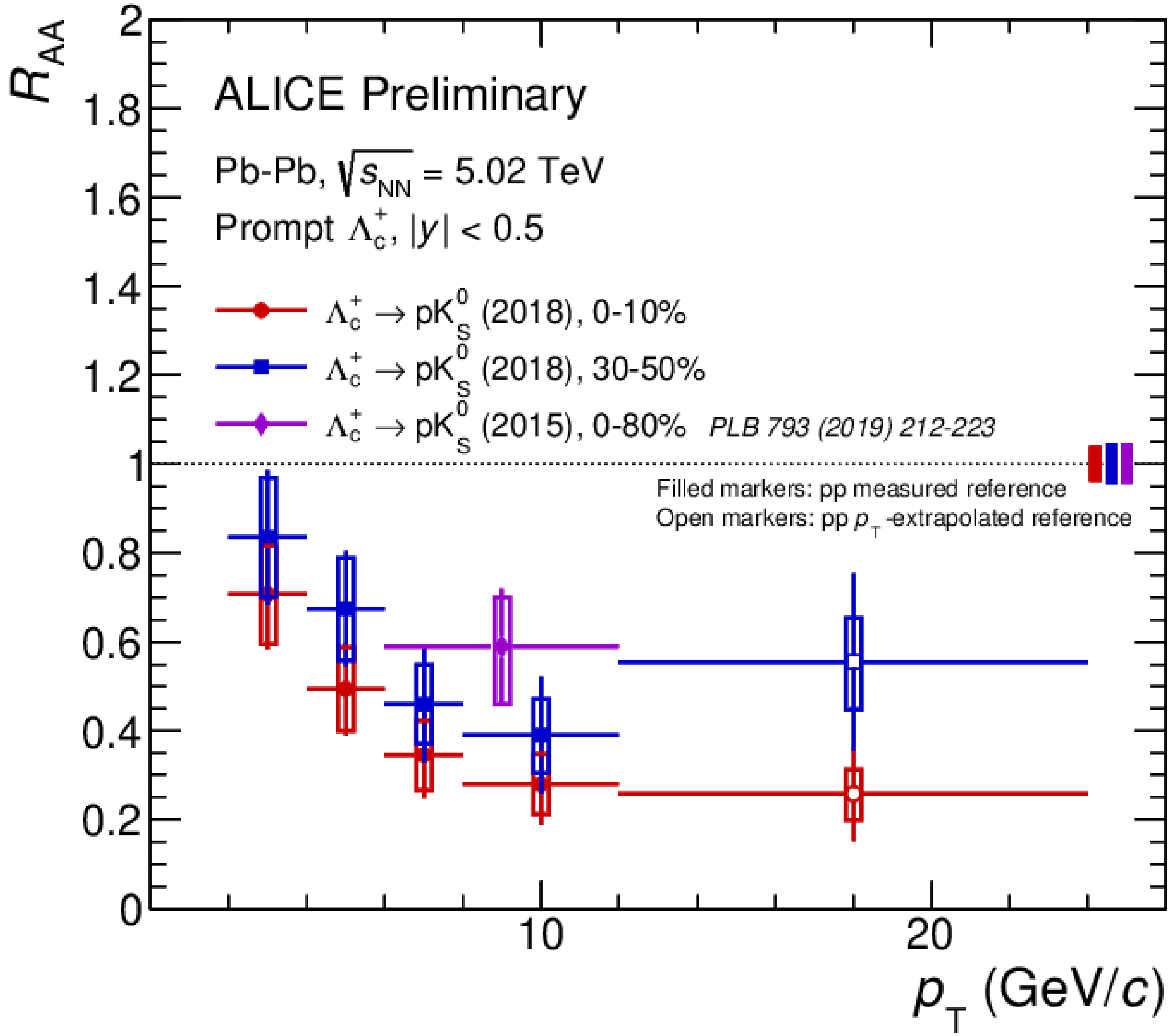
In Pb-Pb Λ_c/D^0 ratio increases at intermediate p_T

Summary

- TOF detector is a powerful instrument for particle identification.
- TOF is the principal ALICE detector. Thanks to the double-stack MRPCs it guarantees an efficiency near to 100% and a time resolution of 85ps.
- TOF is essential in the Λ_c reconstruction.
- Better Λ_c reconstruction in RUN III with TOF and ITS improvements.

Thanks for the attention

Nuclear modification factor



2) χ^2 minimization procedure: for a track j, the start event time t_{ev} is estimated using all the other track in the event, considering all the possible mass combinations (*i=p,K,π*).

$$\chi^2 = \sum_{n_{tracks},i} \frac{\left[(t_{TOF} - t_{ev}) - t_{exp}(m_i)\right]^2}{\sigma_{TOF}^2}$$

t_{TOF} = Stop time measured with TOF
t_{ev} = Start time (UNKNOW)
$t_{exp}(m_i)$ = Flight time expected for the mass m_i
σ_{TOF} = error on the TOF time mesurement

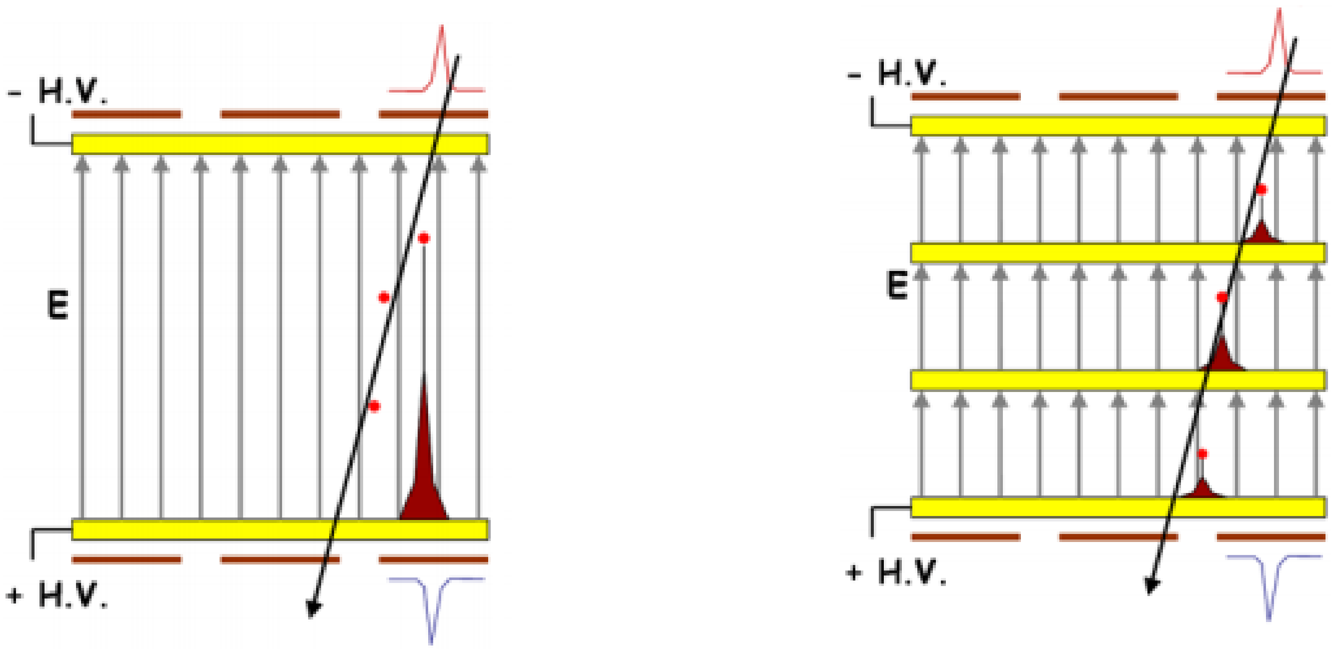
This procedure is repeated for each track, making the determination of t_{ev} independent of the TOF measured time of the track.

- The final event time is determined combining the t_{ev} estimated by TOF and T0 detectors, weighted by the respective resolutions.

RPC vs MRPC

RPC problems:

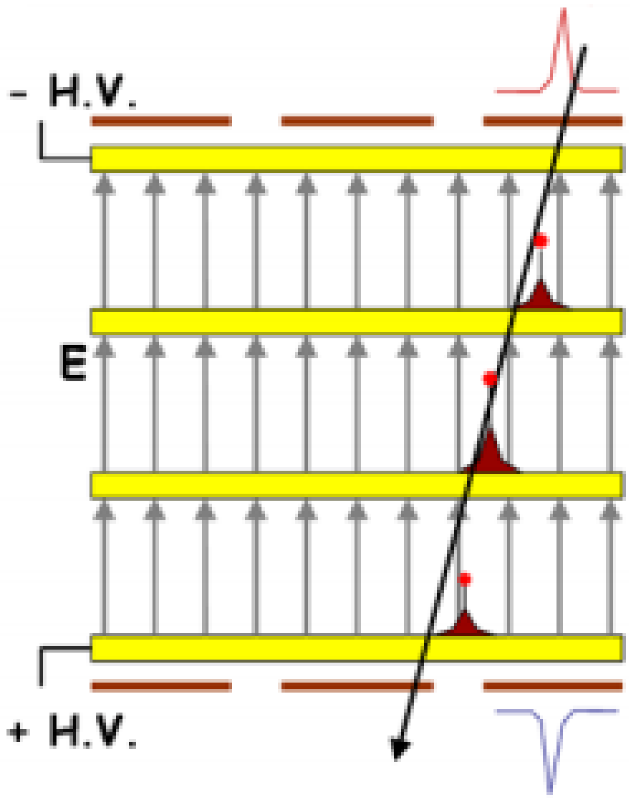
- Small gap → Avalanche generated near the anode can't grow
- Big gap → Strong dependence on the area in which the avalanche is formed.
  → Discharges danger if the avalanche is formed near the cathode.



MRPC. RPC gap is divided with resistive plates. Advantage:

- Time jitter reduction
- Independence on the area in which the avalanche is formed.
- Avalanche stopped by resistive plates. No discharge.

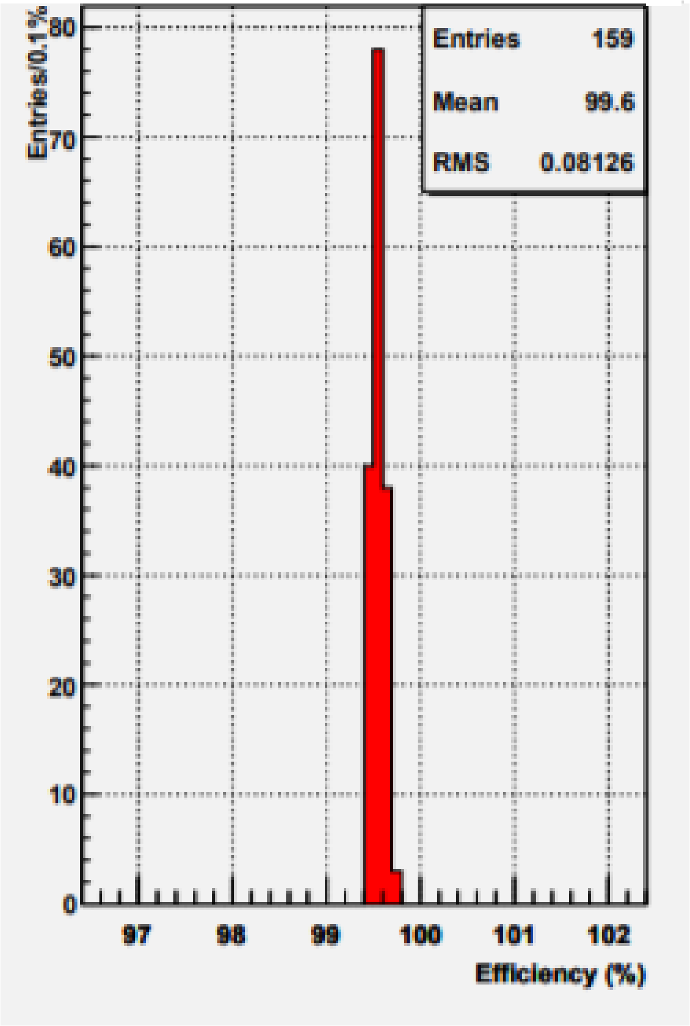
MRPC → DOUBLE-STACK

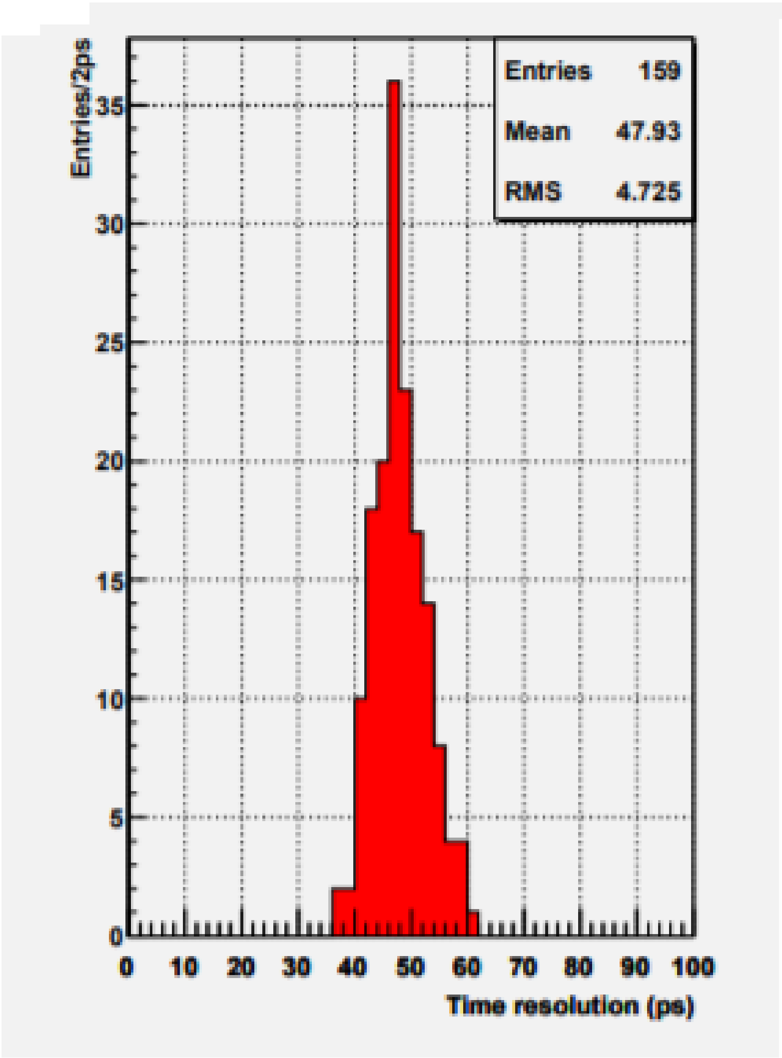


Intrinsic time resolution of MRPCs : ~ 65ps
Efficiency of MRPCs: ~ 97%

Not enough

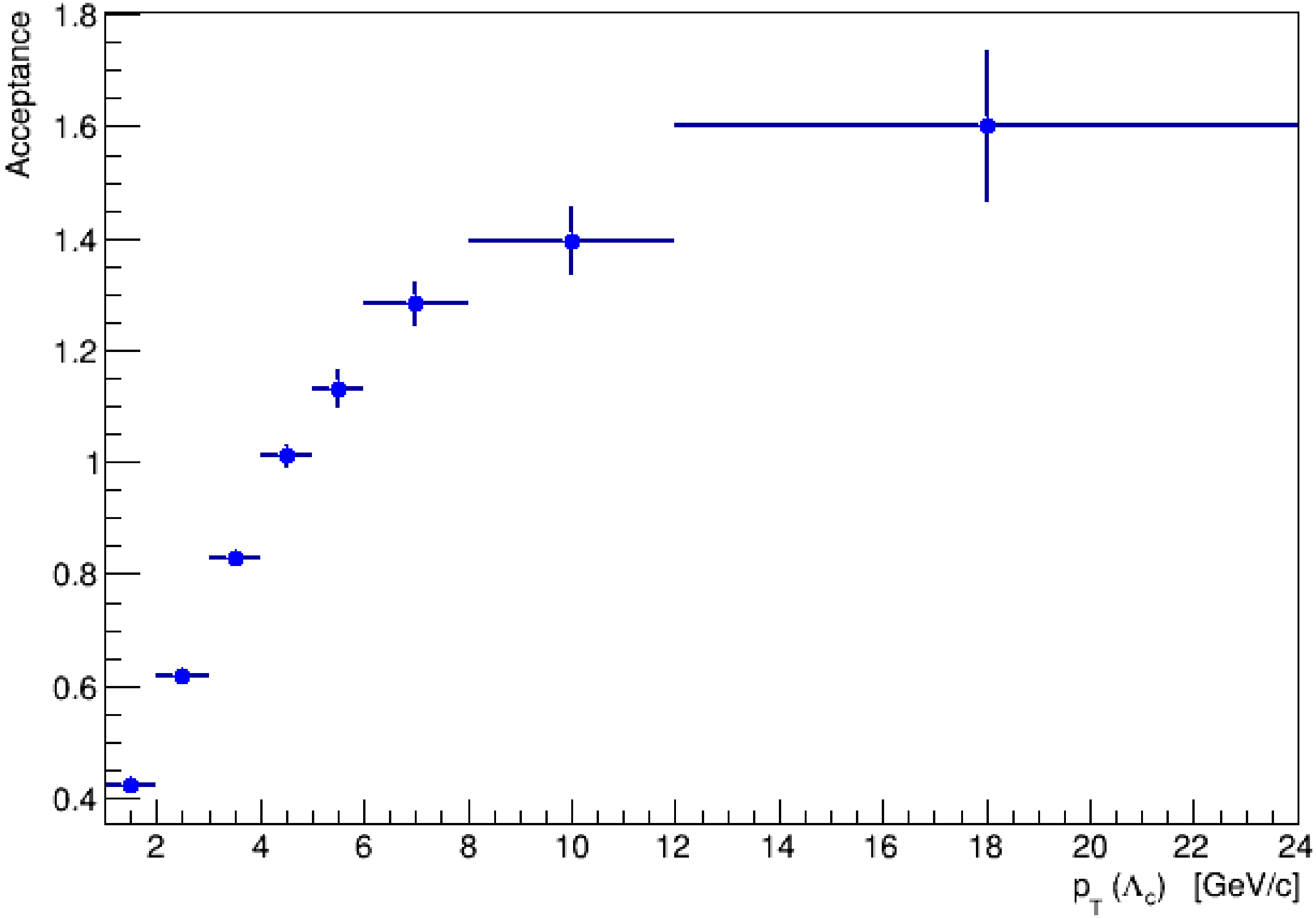
$C_2F_4H_2$ (90%)
$i\text{-}C_4H_{10}$ (5%)
SF_6(5%)





3) Stima di accettanza

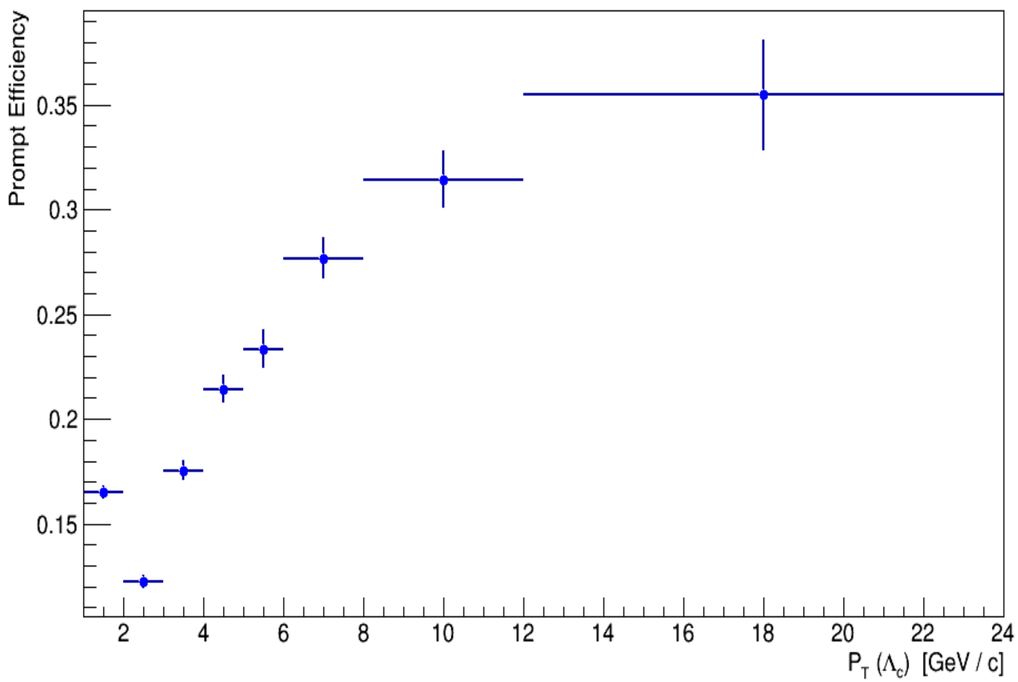
$$\boldsymbol{Accettanza = \frac{n^\circ\ di\ \Lambda_c\ generate\ nell'accettanza\ fiducial e\ |y| < yfiducial\ (p_T)}{n^\circ\ di\ candidate\ \Lambda_c\ generate\ nell'accetanza\ |y| < 0.5}}$$



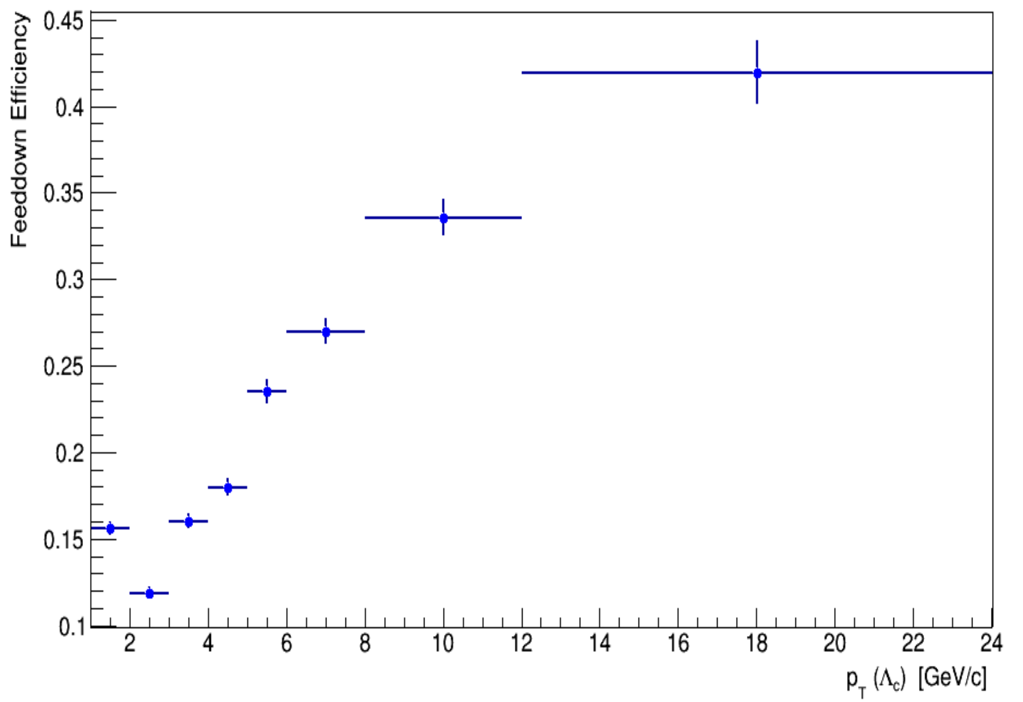
3) Stima di efficienza

$$\textbf{Efficienza} = \frac{n^\circ\ di\ candidate\ \Lambda_c\ ricostruite\ con\ successo}{n^\circ\ di\ \Lambda_c\ \ generate\ nell'accettanza\ fiduciale\ |y|<yfiducial(p_T)}$$

Prompt



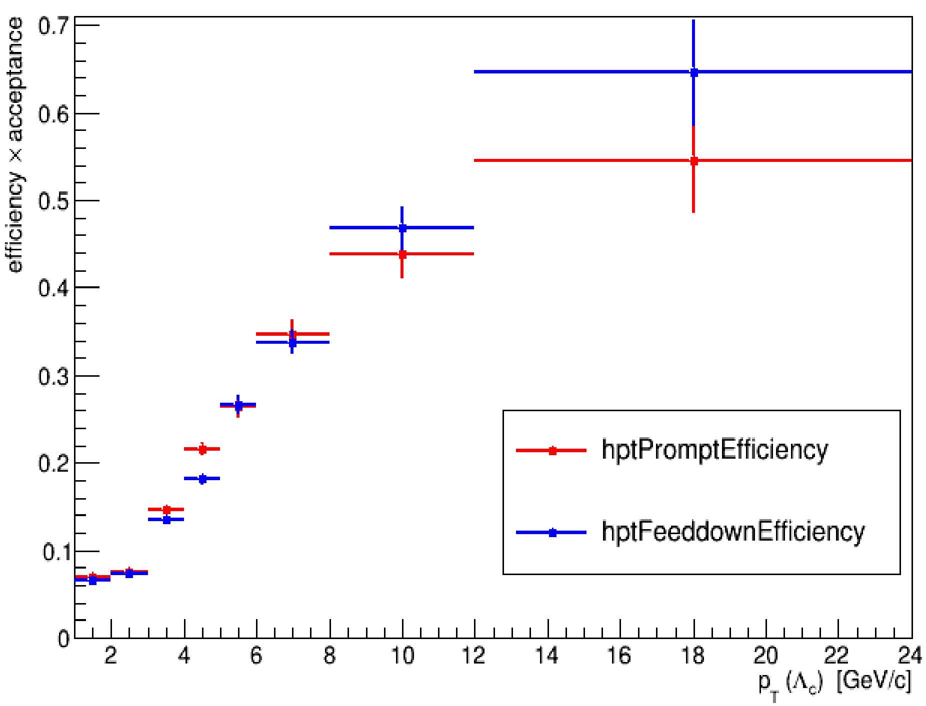
Feeddown



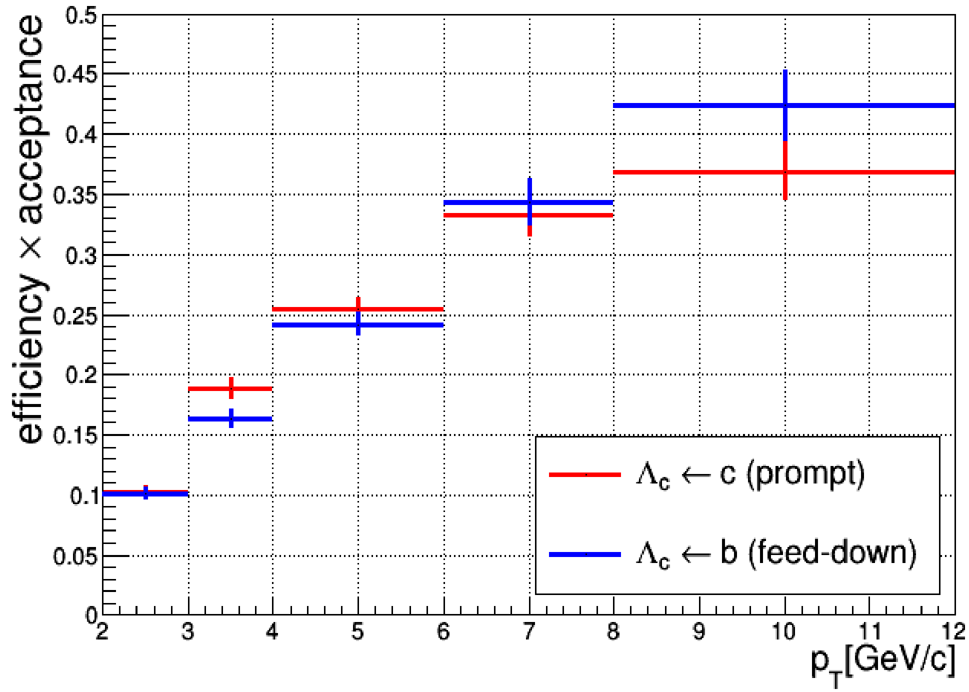
Calcolo del prodotto Efficienza X Accettanza

Il prodotto Efficienza x Accettanza è uno dei parametri necessari per la conoscenza del numero effettivo di Λ_c prodotte nella collisione, fondamentale per il calcolo della sezione d'urto.

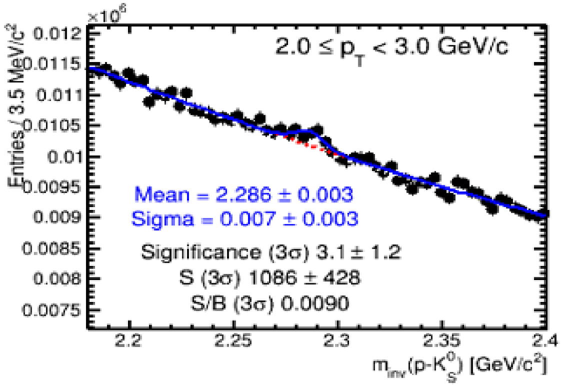
RUN 2

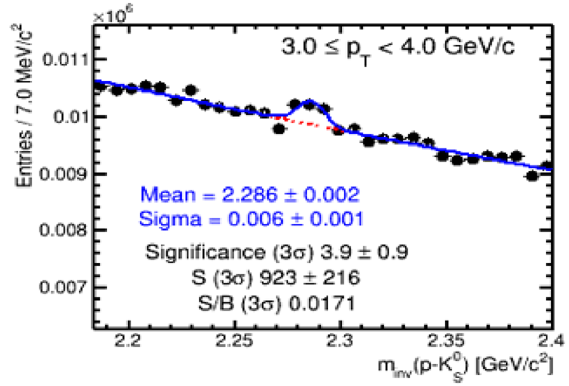


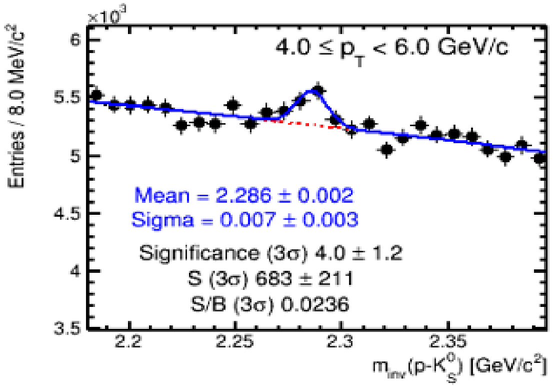
RUN 1

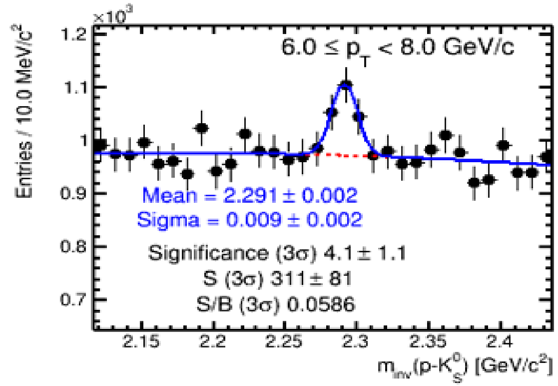


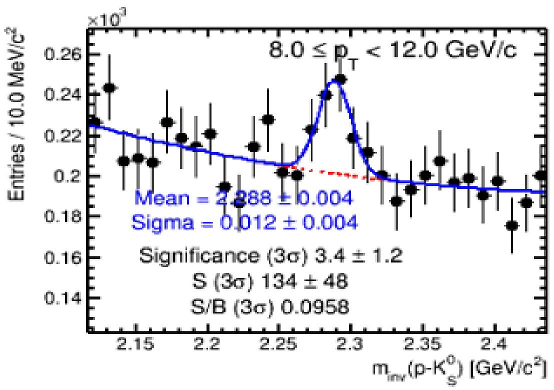
$\Lambda_c \rightarrow pK^0_S$ signal extraction in p-Pb











$\sqrt{s_{NN}} = 5.02$ TeV (2013)
1.0×10^8
Minimum Bias events

Clear signal extraction in 5 p_T bins,
in [2,12] GeV/c

Obiettivo analisi

Stima della sezione d'urto differenziale di produzione di Λ^+_c prompt.

Il Raw Yield è la somma di Λ^+_c e Λ^-_c mentre la sezione d'urto è data per sole Λ^+_c

Frazione di Λ_c da adronizzazione diretta del quark charm stimata sul MC

Segnale (Λ^+_c + Λ^-_c) misurato sui dati estratto da grafici di massa invariante

$$\left.\frac{d\sigma^{\Lambda_c^+}}{dp_T}\right|_{y<|0.5|} = \frac{1}{2}\,\frac{1}{\Delta y * \Delta p_{\mathrm{T}}}\,\frac{1}{Eff\ X\ Acc}\,\frac{f_{prompt} * N^{\Lambda_c}}{BR(\Lambda_c \to p\pi^+\pi^-) * L_{\mathrm{INT}}}$$

Intervallo di rapidità

Intervallo di momento trasverso

Prodotto Efficienza x Accettanza stimato sul MC

Luminosità integrata. (arXiv:1405.1849 [nucl-ex])

Branching ratio: (0.8 ± 0.21)%

Analysis Purpose

Λ^+_c prompt differential cross-section estimation.

The Raw Yield is the sum between Λ^+_c and Λ^-_c while the cross section is given just for Λ^+_c .

Λ_c fraction produced by direct hadronization of the quark charm. Estimated on the MC.

Raw Yield (Λ^+_c + Λ^-_c) extracted from the invariant mass plot. Measured on data.

$$\left.\frac{d\sigma\Lambda_c^+}{dp_T}\right|_{y<|0.5|} = \frac{1}{2}\,\frac{1}{\Delta y * \Delta p_T}\,\frac{1}{Eff\ X\ Acc}\,\frac{f_{prompt} * N^{\Lambda_c}}{BR(\Lambda_c \to p\pi^+\pi^-) * L_{\mathrm{INT}}}$$

Rapidity range

Transverse momentum range

Efficiency x Acceptance product. Estimated on the MC.

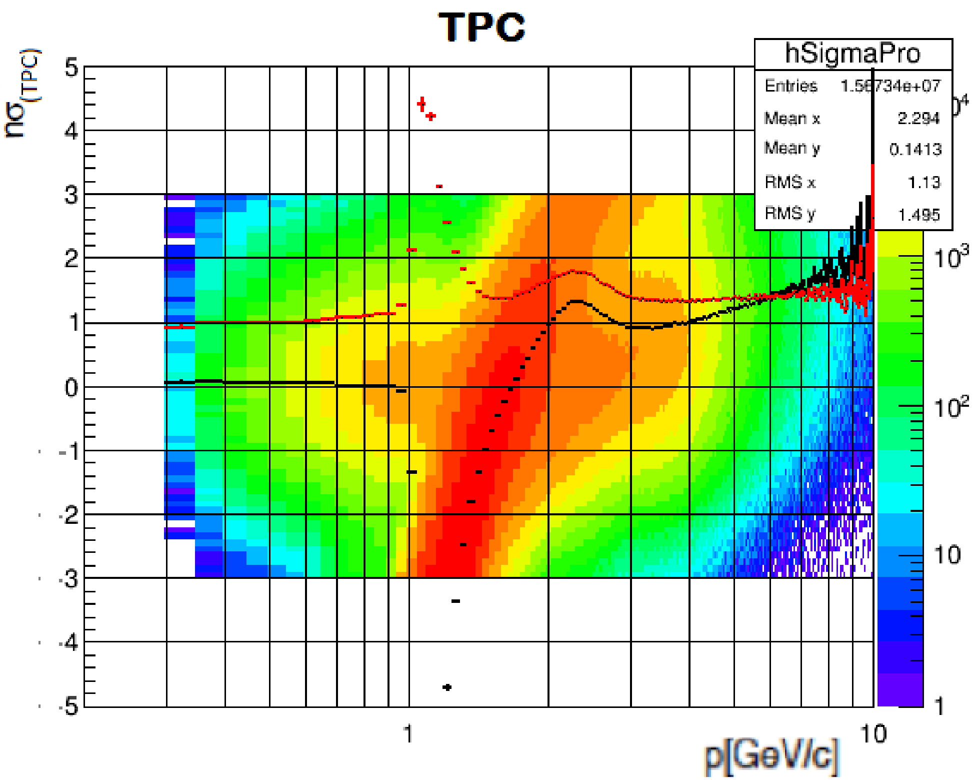
Integrated Luminosity. (arXiv:1405.1849 [nucl-ex])

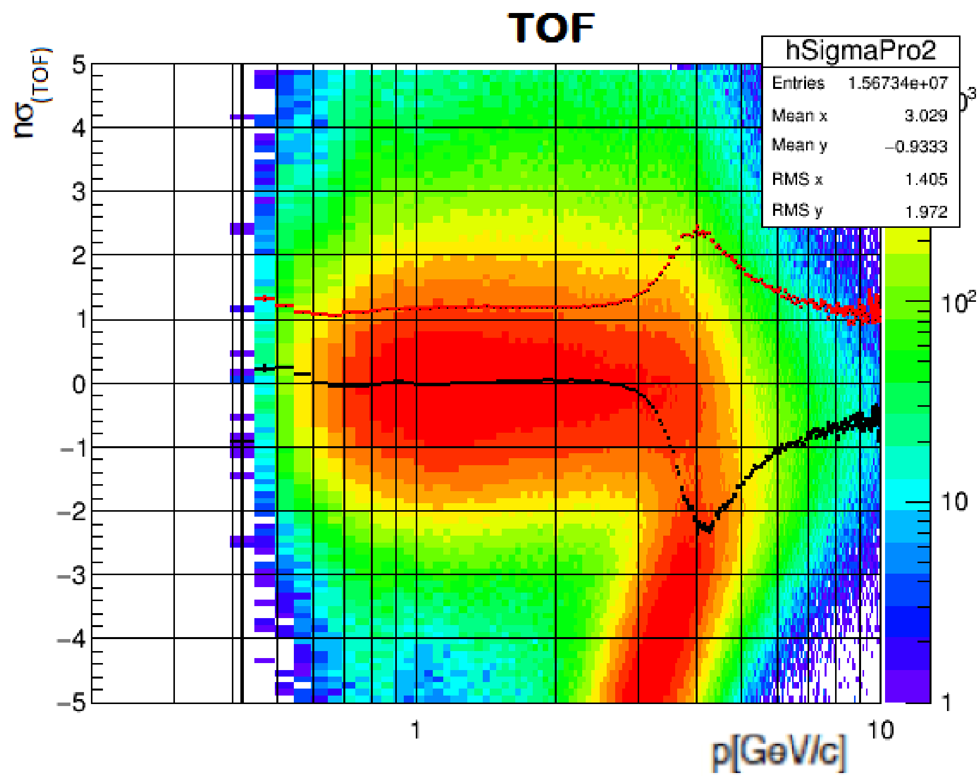
Branching ratio: (1.09 ± 0.21)%

Primo livello di PID

$$(n\sigma)_{TPC} = \frac{\left(\frac{dE}{dx}\right)_{exp} - \left(\frac{dE}{dx}\right)_{th}(p)}{\sigma_{TPC}}$$

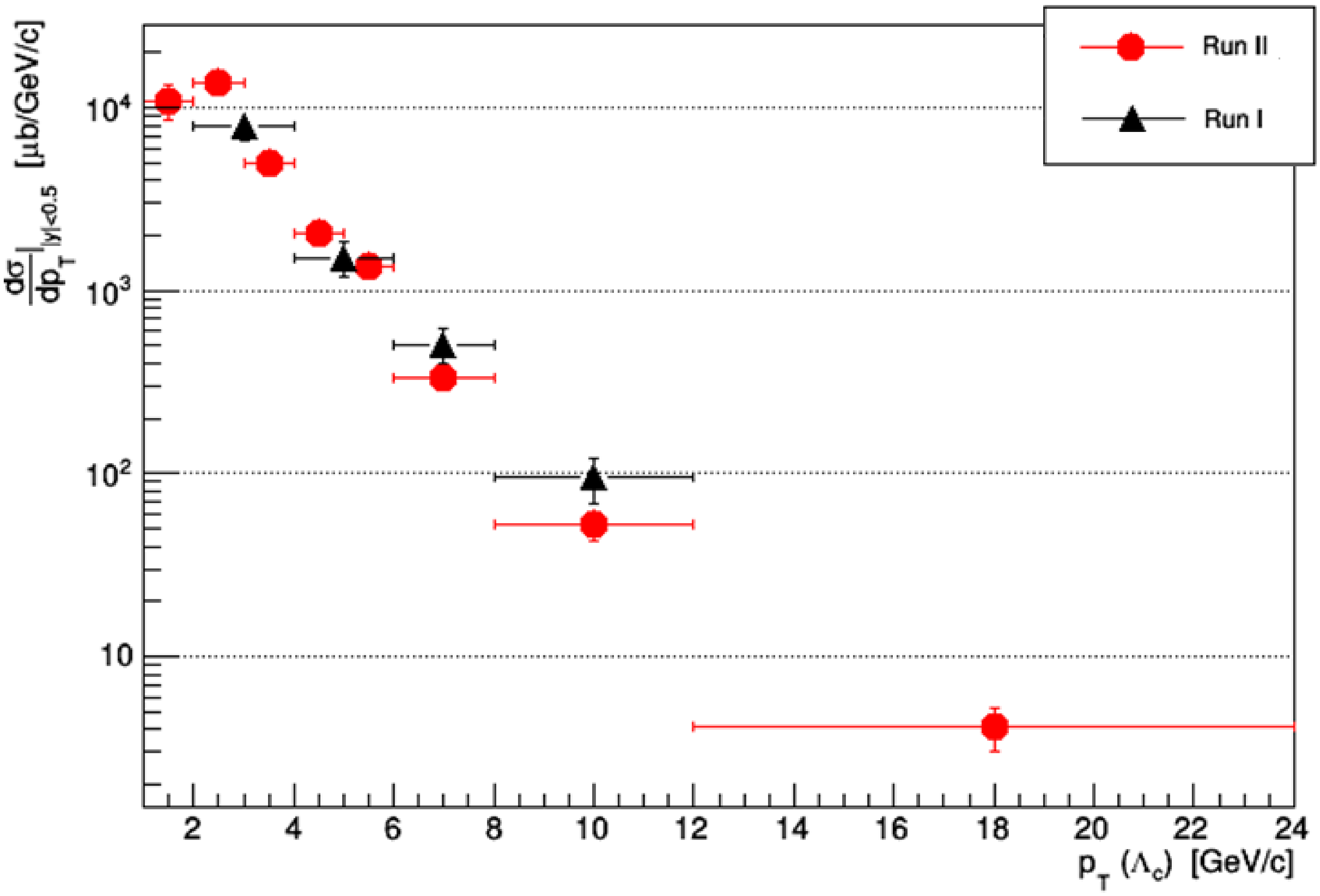
$$(n\sigma)_{TOF} = \frac{t_{exp} - t_{th}(p)}{\sigma_{TOF}}$$





Si applica un taglio a 3σ sulla TPC

Stima della sezione d'urto (RUN 2 VS RUN 1)



The time of flight difference between two particle with the same momentum ***p*** is given by:

$$\Delta t = L\left(\frac{1}{v_1} - \frac{1}{v_2}\right) = \frac{L}{2p^2}\left(m_1^2 - m_2^2\right)$$

If the particle momentum and the travelled distance are known we can identificate the particle:

$$\mathbf{p} = \gamma m \boldsymbol{v}$$

$$\boxed{\boldsymbol{m} = \boldsymbol{p}\sqrt{\frac{\boldsymbol{t}^2}{\boldsymbol{L}^2} - \mathbf{1}}}$$

$$\gamma = (1 - v^2)^{-1}$$

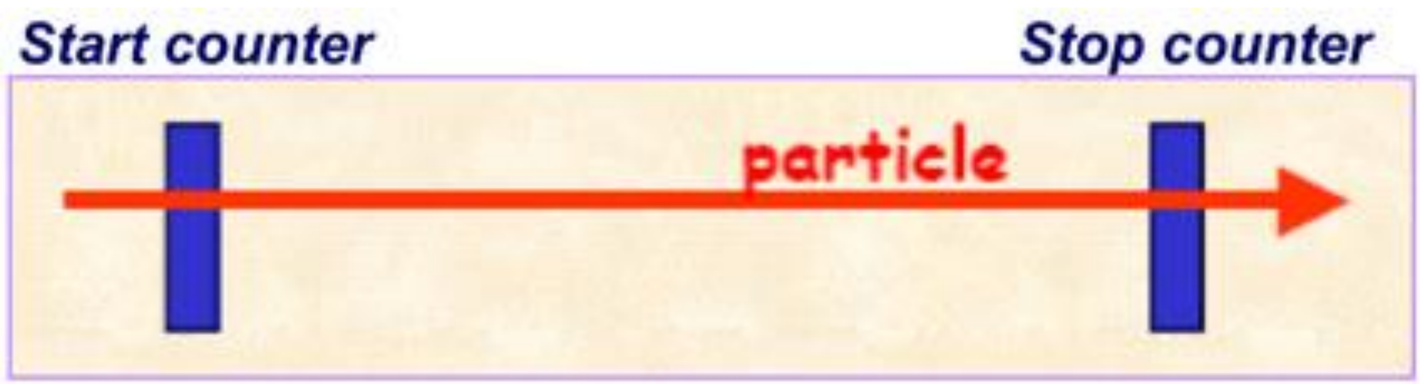
$$v = \frac{L}{t}$$

m = mass of the particle
$\boldsymbol{v}$ = particle speed
L = travelled distance
t = time spent on

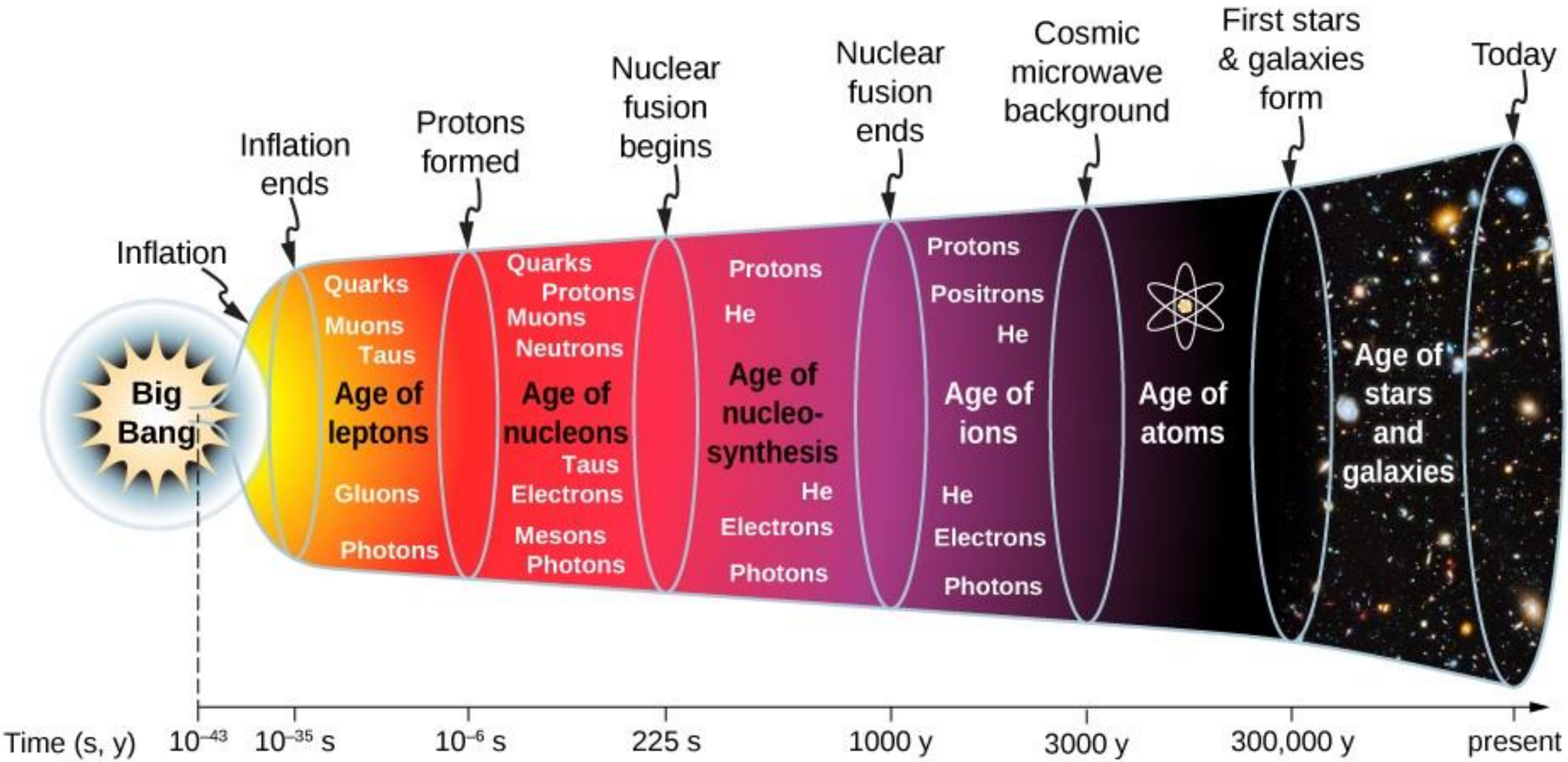
Detector operation

A **time of flight (TOF) detector** is a particle detector which can discriminate between a lighter and a heavier elementary particle of same momentum using their time of flight between two detectors (usually scintillators).

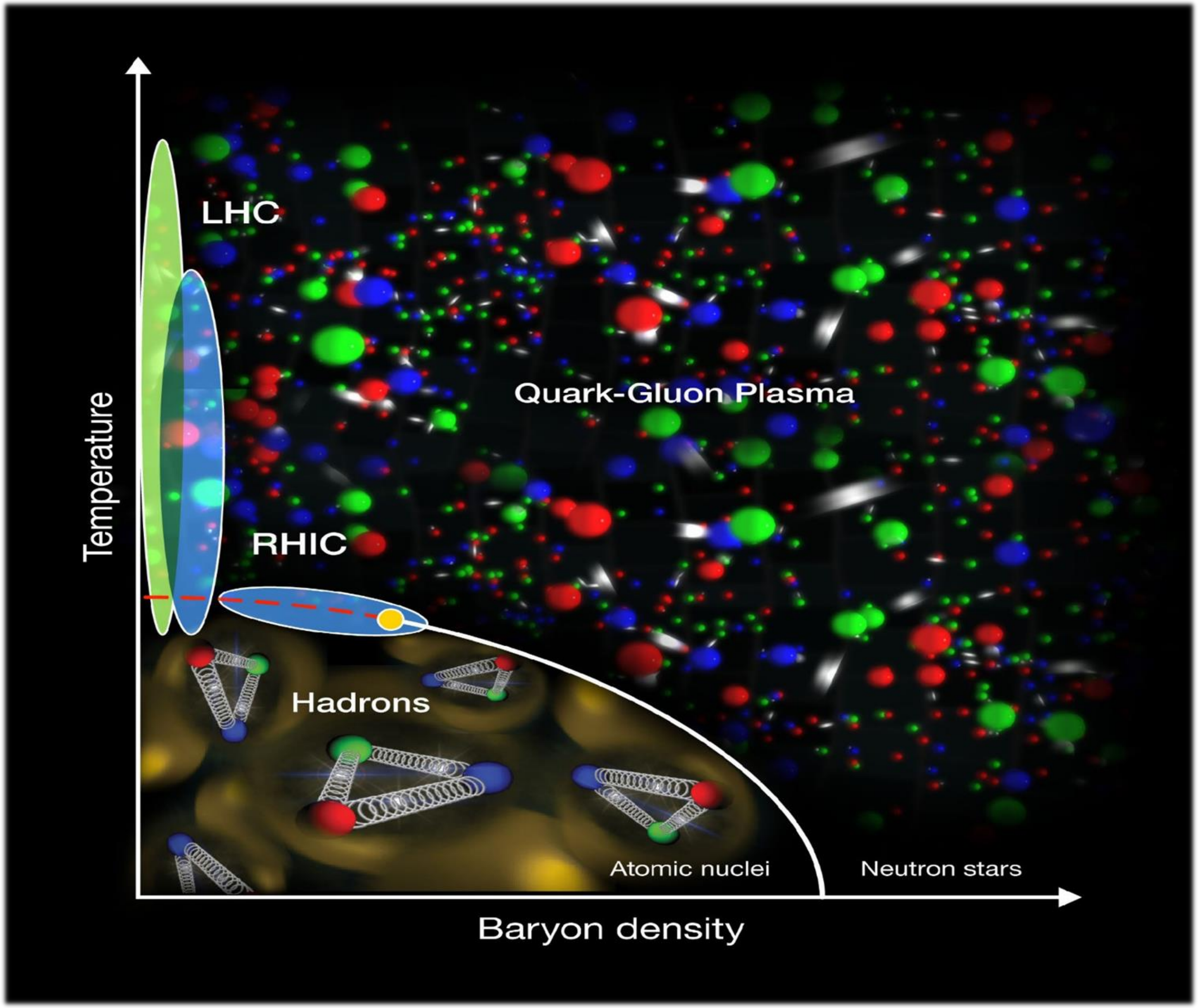
The first of the detector activates a clock upon being hit while the other stops the clock upon being hit.



How the universe looked like at the very beginning?



Hadronic matter phase diagram



Phase Transition at very hight temperature and/or baryon density.

New State of Matter:
Quark Gluon Plasma (QGP)

QGP is studied experimentally with ultra-relativistic heavy-ion collisions:
SPS, RHIC, LHC