Ξ^0_c production in pp collision at $\sqrt{s} = 13$ TeV

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**Motivation**

- **QGP probe of Heavy quarks**
  - Charm and beauty quarks are heavier than light quarks (u,d,s) and are produced in initial hard-scattering processes with high $Q^2$, transported through the full medium created in the collisions.
  - Production cross sections calculable with perturbative QCD.
  - Traversing the medium while interacting with its constituents.
  - Study charm and beauty hadronization mechanisms using meson and Baryon production $D, \Lambda_c, \Xi_c, \ldots$

- **pp collisions**
  - Reference for p-Pb and Pb-Pb collisions.
  - Testing ground for perturbative QCD calculations.
Analysis flow

**STEP. 1**
Select e and $\Xi$ and Make pair of Right Sign and Wrong Sign

**STEP. 2**
Subtract the Wrong Sign spectra from Right Sign Spectra

**STEP. 3**
Using Unfolding technique to correct missing neutrino momentum

**STEP. 4**
Efficiency correction and event normalization
Detector

- ALICE Detector

**Inner Tracking System (ITS)**
- Vertexing, tracking
  - $|\eta| < 0.9$

**Time Projection Chamber (TPC)**
- Tracking, PID via $dE/dx$
  - $|\eta| < 0.9$

**V0**
- Trigger
  - $2.8 < \eta < 5.1$ (V0A)
  - $3.7 < \eta < -1.7$ (V0C)

**Time Of Flight Detector (TOF)**
- PID via time-of-flight
  - $|\eta| < 0.9$
- Dataset

- Dataset

**Data : LHC16k, pass1 ( pp collision, 13 TeV, 189M events, 165 runs)**

258537, 258499, 258477, 258456, 258426, 258393, 258391, 258387, 258359, 258336, 258332, 258307, 258306, 258303, 258302, 258301, 258299, 258278, 258274, 258273, 258271, 258270, 258258, 258257, 258256, 258204, 258203, 258202, 258198, 258197, 258178, 258117, 258114, 258113, 258109, 258108, 258107, 258063, 258062, 258060, 258059, 258053, 258049, 258045, 258042, 258040, 258039, 258019, 258017, 258014, 258012, 258008, 258003, 257992, 257989, 257986, 257963, 257960, 257957, 257939, 257937, 257936, 257892, 257855, 257853, 257851, 257850, 257849, 257848, 257847, 257846, 257844, 257841, 257822, 257819, 257817, 257814, 257812, 257808, 257807, 257805, 257804, 257803, 257800, 257799, 257798, 257797, 257773, 257765, 257757, 257754, 257737, 257735, 257734, 257733, 257730, 257727, 257725, 257724, 257697, 257694, 257692, 257691, 257689, 257688, 257687, 257685, 257684, 257682, 257644, 257642, 257636, 257635, 257632, 257630, 257606, 257605, 257604, 257601, 257595, 257594, 257592, 257590, 257588, 257587, 257566, 257562, 257560, 257541, 257540, 257539, 257537, 257531, 257530, 257492, 257491, 257490, 257488, 257487, 257474, 257468, 257457, 257433, 257364, 257358, 257330, 257322, 257320, 257318, 257260, 257224, 257209, 257206, 257204, 257144, 257139, 257138, 257137, 257136, 257100, 257095, 257092, 257086, 257084, 257082, 257080, 257077, 257028, 257026, 257021, 257012, 257011, 256944, 256942, 256941

**Data : LHC16l, pass1 ( pp collision, 13 TeV, 55M events, 58 runs)**

259888, 259868, 259867, 259866, 259860, 259842, 259841, 259822, 259789, 259788, 259781, 259756, 259752, 259751, 259750, 259748, 259747, 259477, 259396, 259395, 259394, 259389, 259388, 259382, 259378, 259342, 259341, 259340, 259339, 259336, 259334, 259307, 259305, 259303, 259302, 259274, 259273, 259272, 259271, 259270, 259269, 259264, 259263, 259261, 259257, 259204, 259164, 259162, 259118, 259117, 259099, 259096, 259091, 259090, 259088, 258964, 258962
Cut list

- Cut list

## Event cut

<table>
<thead>
<tr>
<th>Cut variables</th>
<th>Cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics Selection</td>
<td>kINT7</td>
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<tr>
<td>Primary vertex</td>
<td>Within 10cm</td>
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<tr>
<td>Pile up</td>
<td>Rejection</td>
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## eID cut

<table>
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<th>Cuts</th>
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<tr>
<td>Number of TPC clusters</td>
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<tr>
<td>Number of TPC PID clusters</td>
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<td>Ratio to findable cluster</td>
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<tr>
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<tr>
<td>Number of ITS cluster</td>
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<tr>
<td>pt</td>
<td>&gt;0.5</td>
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<tr>
<td></td>
<td>η</td>
</tr>
<tr>
<td>SPD hit</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>TOF ησ</td>
</tr>
<tr>
<td>TPC ησ</td>
<td>-1.5 ~ 3</td>
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</table>

## Ξ cut

<table>
<thead>
<tr>
<th>Cut variables</th>
<th>Cuts</th>
</tr>
</thead>
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<tr>
<td>Number of TPC cluster</td>
<td>&gt;80</td>
</tr>
<tr>
<td>Λ Mass tolerance (MeV/c²)</td>
<td>7.5</td>
</tr>
<tr>
<td>Ξ Mass tolerance (MeV/c²)</td>
<td>8</td>
</tr>
<tr>
<td>DCAof V0 to PV(cm)</td>
<td>&gt;0.03</td>
</tr>
<tr>
<td>DCA f V0 daughters PV (cm)</td>
<td>&gt;0.073</td>
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<tr>
<td>V0 cosine pointing angle to Ξ vertex</td>
<td>&gt;0.983</td>
</tr>
<tr>
<td>DCA of bachelor track to PV (cm)</td>
<td>&gt;0.0204</td>
</tr>
<tr>
<td>V0 decay length (cm)</td>
<td>&gt;2.67</td>
</tr>
<tr>
<td>Ξ decay length (cm)</td>
<td>&gt;0.38</td>
</tr>
<tr>
<td>TPC ησ (proton)</td>
<td>&lt;4</td>
</tr>
<tr>
<td>TPC ησ (pion)</td>
<td>&lt;4</td>
</tr>
</tbody>
</table>
- Event cut

- **All** : All events in period
- **PS** : Physics selection + kINT7
- **PSpileup** : PS+ pile up rejection
- **Goodz** : PSpileup + Passed the SPD
- **Goodzcut** : Goodz + SPD primary vertex < 10cm.
- Event cut

<table>
<thead>
<tr>
<th>Energy</th>
<th>5 TeV</th>
<th>13 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>LHC17p : 1063M (kINT7, FAST)</td>
<td>LHC16k : 189M (kINT7, CENT)</td>
</tr>
<tr>
<td></td>
<td>LHC17q : 66M (kINT7, FAST)</td>
<td>LHC16l : 55M (kINT7, CENT)</td>
</tr>
<tr>
<td>Total event number</td>
<td>819M (after cuts)</td>
<td>48M (after cuts)</td>
</tr>
</tbody>
</table>

- 5TeV results is used in Andrea’s results.
  (https://indico.cern.ch/event/766082/contributions/3222028/attachments/1756106/2847189/20_11_2018_Xic.pdf)
- Compare the event number, at 13TeV, the number of events after the cut is too small.
- The lack of event number occurs the statistics problem.
- Select electrons

- Time-Of-Flight (TOF) and Time Projection Chamber (TPC) detector are used to identify the electron.
- The $n\sigma_{TOF}$ and $n\sigma_{TPC}$ distributions of electrons get from real data.
- eID Cuts applied in this analysis

TOF $n\sigma$ as function of $p_T$. The black line is the cut values.

TPC $n\sigma$ as function of $p_T$. The black line is the cut values.
- Select the $\Xi$
  
  • The $\Xi^{-}$ baryons are reconstructed from the decay chain $\Xi^{-} \rightarrow \pi^{-}\Lambda$, followed by $\Lambda \rightarrow p\pi^{-}$.
  
  • The $\Xi^{-}$ and $\Lambda$ candidates were selected based on AliAODcascade, where the pion produced from $\Xi^{-}$ and $\Lambda$ can be identified using mother particle's lifetimes ($c\tau$ of about 4.91 cm and 7.89 cm).
  
  • $\Xi$ cuts are applied to remove the background.
- Remove background electrons

- There are the background electrons that come from gamma conversion and Dalitz decay in the selected electron (photonic electron) after the cuts.

- The background electrons can be identified using a technique based on the invariant mass of $e^+e^-$ pairs.

- The electron tracks are paired with opposite-sign tracks from the same event passing “loose selection criteria” ($|\ln \sigma_{TPC}| < 5$ without TOF requirement) and are identified as photonic electrons if there is at least one pair with an invariant mass smaller than 50 MeV/c$^2$. 

![Graph showing electron pair mass distribution](image)

- Photonic electron

- $e^+ e^-$ (unlike sign)

- $e^\pm e^\pm$ (like sign)
Analysis status

- Make eΞ pair and subtraction

  • Make pairs of e±Ξ∓(RS), e±Ξ∓(WS), e±Ξ∓(WS) when they satisfy the following two conditions
    1) The opening angle between e and Ξ is less than 90 degrees
    2) The invariant mass of pair is less than 2.5 GeV/c².

  • Due to the missing momentum of neutrino, the invariant mass distribution of the e±Ξ∓ and e±Ξ∓ pair does not have a peak at the Ξ⁰ c mass.

  • The background in the e±Ξ∓ pair distribution is estimated by exploiting the fact that Ξ⁰ c baryons decay into RS, but not into WS, while the most of the background sources contribute equally to RS and WS pairs. (RS-WS)
- Correct for the efficiency loss caused by prefilter

- The prefilter can reject the photonic electrons and also reject the non-background electrons.

- This efficiency correction is done separately from other efficiency corrections because it is expected to depend on the event multiplicity and topology, which could be different in data and MC.
**Further step**

- **Correct for the efficiency loss caused by prefilter**

  - The prefilter can reject the photonic electrons and also reject the non-background electrons.
  - This efficiency correction is done separately from other efficiency corrections because it is expected to depend on the event multiplicity and topology, which could be different in data and MC.

\[
\epsilon_{\text{prefilter}} = \frac{N_{e\Lambda}(\Xi) \text{ (same-sign prefilter on)}}{N_{e\Lambda}(\Xi) \text{ (prefilter off)}}
\]

**Electron pair mass distribution**

**$e^+ e^-$ (unlike sign)**

**$e^\pm e^\pm$ (like sign)**

**$p_t$ (GeV/c)**

**$\epsilon_{\text{prefilter}}$ in $e\Xi$ analysis**
Further step

- Correct for the over subtraction caused by bottom baryon contributions

  - In the WS spectra, there are contributions from bottom baryons, such as $\Xi_b \rightarrow e^- \Xi^- \nu_e X$.

  - The $\Xi_b$ baryons are not measured at LHC energies. Therefore two assumptions are made to estimate the contributions in $e\Xi$ analysis.
    1) The shape of $p_T$ spectrum is same as $\Lambda^0_b$ ( $\Lambda^0_b \rightarrow e^- \Lambda^+ c X \rightarrow e^- \Lambda X$ )
       This measurement is extrapolated to $p_T = 0$ using the Tsallis function.
    2) The $B(b \rightarrow \Xi_b) B(\Xi_b \rightarrow e\Xi X)/(B(b \rightarrow \Lambda_b) B(\Lambda_b \rightarrow e\Lambda X))$ ratio is the same in $ee$ and $pp$ collisions.

![The efficiency of $\Xi_b$ as a function of $p_T^{\Xi_b}$](image1)

![Response matrix of $\Xi_b \rightarrow e\Xi$](image2)
Further step

- Using Unfolding technique to correct missing neutrino momentum

- The response matrices are prepared to convert reconstructed $e\Xi$ pair $p_T$ into true $\Xi_0^c p_T$

- The matrices are calculated in two step
  1) The response matrix is obtained with the $p_T$ distribution generated with PYTHIA 6.
  2) The resulting $\Xi_0^c$ momentum distribution is used to produce the response matrix.

- The unfolding is performed with the RooUnfold implementation of the Bayesian unfolding technique.

Correlation between the generated $\Xi_0^c$ baryon $p_T$ and the reconstructed $e^+\Xi^-$ pair $p_T$
- Summary

- Summary
  - $\Xi^0_c$ production is being studied via semi-leptonic decay in pp collision at 13 TeV.
  - Electrons are identified using Time-Of-Flight (TOF) and Time Projection Chamber (TPC).
  - The $\Xi^-$ peak in the $\pi^-\Lambda$ invariant-mass distribution integrated over $p_T$ is found ($1321.71 \pm 8$ MeV/c$^2$).
  - Background electrons are removed to use electron pair mass information.
  - Make Right Sign (RS) pair and Wrong Sign (WS) pair and WS was subtract from RS to remove background.

- Outlook

- Outlook
  - To increase statistics, we are considering to add another periods of the runs
  - The efficiency correction will be done, and the over subtraction effect due to bottom baryon contribution also will be corrected.
  - Unfolding procedure will be done considering also the missing neutrino momentum.
Thank you
Back up
- Make $e\Xi$ pair and subtraction
Analysis status

- Make $e\Xi$ pair and subtraction
Invariant-mass distribution of $\Xi^- \rightarrow \pi^- \Lambda$ (and charge conjugate) candidates integrated over $p_T$.

The arrow indicates the world average $\Xi^-$ mass and the dashed lines indicate the selected interval for the $\Xi^-$ candidates.

Invariant-mass distributions of right-sign and wrong-sign (and charge conjugate) pairs integrated over the whole $p_T$ interval.

Invariant-mass distribution of $\Xi^0_c$ candidates obtained by subtracting the wrong-sign pair yield from the right-sign one compared with the signal distribution from the simulation, which is normalized to the measured RS–WS yield. The arrow indicates the $\Xi^0_c$ mass.
- Cascade_c production in pp collision at 7TeV

Product of acceptance and efficiency \((A \times \epsilon)\) of \(\Xi^0_c\) baryons generated in \(|y| < 0.8\) decaying into \(e^+\Xi^-\nu_e\) as a function of \(p_T\), determined from simulations PYTHIA 6.

Inclusive \(\Xi^0_c\)-baryon \(p_T\)-differential production cross section multiplied by the branching ratio into \(e^+\Xi^-\nu_e\), as a function of \(p_T\) for \(|y| < 0.5\), in pp collisions at \(\sqrt{s} = 7\) TeV. The error bars and boxes represent the statistical and systematic uncertainties, respectively. The contribution from \(\Xi_b\) decays is not subtracted.
- Cascade_c production in pp collision at 7TeV

Ratio of the $p_T$-differential cross sections of $\Xi^0_c$ baryons (multiplied by the branching ratio into $e^+\Xi^-\nu_e$) and $D^0$ mesons as a function of $p_T$ for $|y| < 0.5$, in pp collisions at $\sqrt{s} = 7$ TeV. The error bars and boxes represent the statistical and systematic uncertainties, respectively. Predictions from theoretical models, (a) PYTHIA 8 with different tunes (b) DIPSY and HERWIG 7, are shown as shaded bands representing the range of the currently available theoretical predictions for the branching ratio of the considered $\Xi^0_c$ decay mode.
\begin{itemize}
\item $N_{\text{gen}}^{\Xi_0}$: The number of $\Xi^0$ baryons within $\Delta y$ decaying into $e\Xi\nu$ counted at the generation level in the MC simulations.
\item $N_{\text{reco}}^{\Xi_0}$: The number of $\Xi^0$ baryons decaying into $e\Xi\nu$ counted at the reconstruction level in the MC simulations.
\item The elastic cross section of anti-proton in GEANT3 is known to be inaccurate, therefore, further correction based on GEANT4 is applied.
\end{itemize}

\[ (\text{Acc} \times \varepsilon \times \varepsilon_{\text{tag}}) = \frac{N_{\text{MC, reco}}^{\Xi_0}}{N_{\text{MC, gen}}^{\Xi_0}} \]

Efficiency correction and event normalization

The product of efficiency, acceptance and the $\Xi$ tagging efficiency as a function of $p^\Xi_{T}$

Ratio of the $\Xi^0_{c}$ spectra with and without the GEANT4 correction