Doubly Charmed Baryons in COMPASS

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Workshop on Future Physics at COMPASS

- Basics on CCQ
- Experimental Setup
- Trigger Scenario
- Simulations
- Rate Estimates
- Questions and Conclusions

Simulations by Roland Kuhn
SU4 Baryon Multipletts

Masses and Lifetimes

<table>
<thead>
<tr>
<th></th>
<th>Likhoded</th>
<th>Tong</th>
<th>Ebert</th>
<th>Roncaglia</th>
<th>Körner</th>
<th>Itoh</th>
<th>Kaur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ξ_{cc}</td>
<td>3.48</td>
<td>3.74</td>
<td>3.66</td>
<td>3.66</td>
<td>3.61</td>
<td>3.65</td>
<td>3.71</td>
</tr>
<tr>
<td>Ξ^+_{cc}</td>
<td>3.61</td>
<td>3.86</td>
<td>3.81</td>
<td>3.74</td>
<td>3.68</td>
<td>3.73</td>
<td>3.79</td>
</tr>
<tr>
<td>Ω_{cc}</td>
<td>3.59</td>
<td>3.76</td>
<td>3.76</td>
<td>3.74</td>
<td>3.71</td>
<td>3.75</td>
<td>3.89</td>
</tr>
<tr>
<td>Ω^+_{cc}</td>
<td>3.69</td>
<td>3.90</td>
<td>3.89</td>
<td>3.82</td>
<td>3.76</td>
<td>3.83</td>
<td>3.91</td>
</tr>
</tbody>
</table>

Masses in GeV

<table>
<thead>
<tr>
<th></th>
<th>Ξ^+_{cc}</th>
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<th>Ω^+_{cc}</th>
</tr>
</thead>
<tbody>
<tr>
<td>τ, ps</td>
<td>0.46 ± 0.05</td>
<td>0.16 ± 0.05</td>
<td>0.27 ± 0.06</td>
</tr>
</tbody>
</table>

Lifetimes in ps

Hadronic decay channels

ξ_{cc}^+ → \Lambda_c^+ K^- \pi^+  (3%)  \quad  Ω_{cc}^+ → Ω_{cc}^0 \pi^+  (5%)

Ξ^+_{cc} → D^+ \Lambda \pi^+  (2.5%)  \quad  Ω^+_{cc} → Ω^+_{cc} K^- \pi^+  (5.5%)

Σ_{cc}^0 \rightarrow Σ_{cc}^+ (2%)  \quad  Ξ^0_{cc} → Ξ^0_{cc} K^- \pi^+  (4%)

ρ_{cc}^0 \rightarrow Γ_{cc}^0 \pi^+  (1.5%)  \quad  Ξ_{cc}^+ \rightarrow Ξ_{cc}^+ K^- \pi^+  (1.5%)

Δ_{cc}^- \rightarrow Δ_{cc}^0 (1%)  \quad  Ξ_{cc}^+ \rightarrow Ξ_{cc}^+ K^- \pi^+  (5%)

Δ_{cc}^0 \rightarrow Δ_{cc}^+ (5%)  \quad  Ω_{cc}^0 \rightarrow Ω_{cc}^0 K^- \pi^+  (4%)

Δ_{cc}^+ \rightarrow Δ_{cc}^+ (5%)  \quad  Ξ_{cc}^0 \rightarrow Ξ_{cc}^0 K^- \pi^+  (4.5%)

Δ_{cc}^++ \rightarrow Δ_{cc}^++ (2.5%)  \quad  Ω_{cc}^0 \rightarrow Ω_{cc}^0 K^- \pi^+  (5%)

Measurements

SELEX (FNAL E781): Ξ_{cc}^+ → Λ_c^+ K^- \pi^+, 15.9 events, m=3519 MeV, τ < 33 fs (90% CL)
Double Charm Setup: Modified COMPASS

Tracking: Silicon, GEM and Straw chambers, Micromegas (or new GEM), DCs and MWPC

PID: RICH 1, RICH 2, ECAL

Trigger: ECAL 1 and HCAL 1 $\rightarrow E_T$

Muon Wall 1, Hodoscopes $\rightarrow$ semi-lept. decays

Proton beam: $10^8$/spill, $1.5 \times 1.1 \text{ mm}^2$, 280 GeV (beamline max.)
Target Setup

Target Region

- Silicon/SciFi for beam definition
- Segmented target, 2% $\lambda_{int}$
- Silicon vertex telescope
  → study resolution
- SciFi for track multiplicity trigger and timing

Charm Decay Detector

- Charm decay within detector array (mostly $D$'s)
- Trigger on multiplicity jump, charm track (2nd level)
  → cf. secondary vertex trigger
- More difficult
Detector requirements

- Fluences up to $5 \times 10^{14}$ ptc/cm$^2$
- Resolution $\sim 100\mu$m
- Good timing resolution ($\sim 2$ ns)

Detector optimisation

- Monolithic target-vertex-cryostat
- Pitch size (25 $\mu$m vs 50 $\mu$m)
- Lever arm vs. acceptance

Readout and triggering

- Readout speed up to 100 kHz
- ADC for resolution, timing, sec. interactions
- 2nd/3rd level trigger information
**Trigger Scenario**

**Starting point:** $2 \times 10^6$ int. per spill

**First Level Trigger**
- Simple track multiplicities $> 4$
  - SciFi for fast counting
  - factor $2 \varepsilon = 100\%$
- Transverse energy $E_T$ cut 3-5 GeV
  - ECAL1/HCAL1 sufficient
  - factor 3–5, $\varepsilon = 70 − 55\%$
- Muon trigger from semi.lept. $D$ decays
  - MF1 hodoscopes similar to DIS MF2
  - factor 30, $\varepsilon = 10\%$
- Envisage OR of $N \times E_T(med) \times \mu$ and $N \times E_T(hi)$

Total reduction: factor 4–10 at $\varepsilon \sim 60\%$

**Next step:** $2 \times 10^5$ triggers per spill

**Second/Third Level Trigger**
- **Detector:** Frontend
  - Hit multiplicity
  - Suppression of sec. interactions
  - Decay detector: mult. jump
- **Tracks:** Super ROB / 2nd level
  - Track angles
  - Track multiplicity
  - High impact tracks
- **Vertex:** Super ROB / 3rd level farm
  - Secondary vertex
  - Vertex separation
- **PID:** 3rd level farm
  - RICH reconstruction
  - Secondary tags ($K^0$, $\Lambda$, $\Xi$ etc.)
Transverse Energy

- High charm mass $\rightarrow$ high $Q$-value, high $p_T$ tracks
- Simulation of charm shows many tracks with high $p_T$
  $\rightarrow$ transverse energy from long decay chains
- Used e.g. by E791 (rather soft) and E831 at FNAL

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Multiplicities and Muon Trigger

Multiplicity cut as high as 10!

- Trigger on muon from semileptonic $D$ decays
  $\text{BR}(D^0 \to \mu X)=7\%$, $\text{BR}(D^+ \to \mu X)=10\%$,
- Strong reduction from $\sigma_{\text{tot}}$ (1/30)
- $p_T$ cut possible

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Online Filter Schemes

Filtering on EVBs:
12–16 dual CPU PCs
- At 40 kHz: 2-3 ms/evt
  → little room for complicated tasks

Frontend Preprocessing:
SGADC++, GeSiCA++
- Clusters
- Timing cuts
- Hit multiplicities
- Secondary interaction (second threshold)

Super ROB / 2nd level:
Quad-CPU, DSP coprocessors
- Track multiplicities
- High impact tracks
- DATE EDM

Filter Farm:
Server blades, ~300 CPUs
- Topical reconstruction:
  - Secondary vertices
  - Decay tags
  - RICH reconstruction

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Based on SELEX Channel:

\[ \Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+ \]

with associated \( \bar{D}^0 \) and \( D^- \)

Production parameters:

\[ \sigma \sim (1 - x_F)^3 \]
\[ \sigma \sim \exp(-1.2p_t^2) \]

COMGEANT Setup:

- Downstream part as for DIS
- SM1 field map for 132 cm
  \( \rightarrow \) go to 82 cm when available
- Target setup as shown
  \( \rightarrow \) room for optimisation

Assumptions and Cuts:

- SELEX lifetime \( \tau(\Xi_{cc}^+) \sim 25 \) fs
- Main GEANT cuts at 100 MeV
- No RICH simulation, only thresholds, but PID for all \( K \)'s and proton
- Require any secondary vertex outside target
Acceptance and Resolution

Geometrical acceptance and tracking capability: 5%

- $\sigma(\Lambda_c) = 8$ MeV
- $\sigma(\Xi_{cc}) = 13$ MeV

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Momenta and track efficiencies

\[ \Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+ \]
\[ \rightarrow p K^- \pi^+ \]

- \[ L_1 \]
- \[ p \]
- \[ K^- \]
- \[ \pi^+ \]
- \[ \Lambda_c^+ \]

**momentum distribution**

**track efficiency**

- first pion
- first kaon
- second pion
- second kaon
- proton

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Muons trigger: $\mu > 2$ GeV

Multiplicity trigger: more than 10 charged tracks

1st level trigger: $\text{Multiplicity} \land ((E_T > 5.8 \text{ GeV}) \lor (E_T > 5.8 \text{ GeV} \land \mu))$

2nd level trigger: Some vertex activity

Charm/Fritiof: 29.5% / 11.7%

100% / 85%

57.7% / 20%

41.5% / 4.6%
Rate Estimates

**Beam rate:** $10^8$/spill

**Target:** 2% $\lambda_{int}$
- $10^{12}$ interactions in 100 d
- Luminosity $\int \mathcal{L} = 250$ pb$^{-1}$

**Based on SELEX:**
- From 1600 $\Lambda_c$ get 50 CCQ
- Considering cuts and BR: 50% of $\Lambda_c$ from CCQ
  $\implies$ assume: $\sigma(\text{CCQ}) \sim 1$ µb
  $\implies$ produce: 250 Mio.

**Simulation and BR:**
- Detectable channels for CCQ and daughters: $10\% \times 20\% = 2\%$
- Acceptance $\times$ Trigger = 0.8%
- Reconstruction $\times$ vertex separation = 20–40 %
  $\implies$ detect: 8000–16000

This scenario would allow CCQ spectroscopy

**Pessimistic estimate:**
- $\sigma(\text{CCQ}) \sim \sigma_{\text{tot}} \times (10^{-3})^2$
- i.e. factor 1000 down from $\sigma_c$
  $\implies$ assume: $\sigma(\text{CCQ}) \sim 10$ nb
  $\implies$ produce: 2.5 Mio.
  $\implies$ detect: 80-160
Open Questions

- Optimized setup: vertex detector, spectrometer, trigger detectors
- Design work needed

- Studies of trigger eff., reduction factors:
  → rejection of minimum bias from data
- More simulation studies
- Best filter algorithm

- Cross section and production mechanism
- Double charm or single charm plus double charm bonus?
Conclusions

Charm physics in COMPASS

- Hardware requirements
  - Good vertex detector
  - ECAL1/HCAL1 for $E_T$ trigger
  - Muon hodoscope in first spectrometer
  - RICH 2 helps
- Trigger requirements
  - First level trigger is achievable:
    - Multiplicity, $E_T$, muons
  - Filter farm and maybe second level (Super ROB) needed
- Double charm in particular:
  - Even higher $E_T$ and multiplicities
  - Momenta in average lower
  - Cross sections and lifetimes are still a question mark