

$\Lambda_c^+ \rightarrow p\mu\mu$ Status Update and Plans for future



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on behalf of the $\Lambda_c^+ \rightarrow p\mu\mu$ team:

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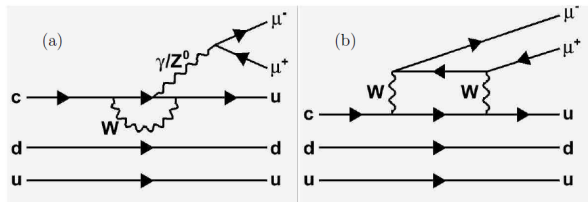
Analysis and Software Week, CERN
April, 2017

Topics covered in this presentation

1. Physics of $\Lambda_c^+ \rightarrow p\mu\mu$
2. Pre-Selection.
3. MVA selection.
4. PID.
5. Normalization.
6. Systematics.
7. Expected limits.
8. Run2 extensions.

Physics of $\Lambda_c^+ \rightarrow p\mu\mu$

$\Rightarrow \Lambda_c^+ \rightarrow p\mu\mu$ is a FCNC in the charm sector:

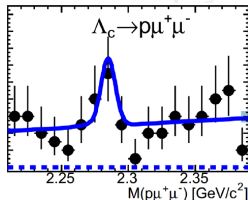


\Rightarrow Current experimental situation:

\Rightarrow SM prediction:

- Short distance
 $Br \sim \mathcal{O}(10^{-8})$
- Long distance
 $Br \sim \mathcal{O}(10^{-6})$
- Expected to improve
by $\mathcal{O}(10^2)$

- $Br(\Lambda_c^+ \rightarrow p\mu\mu) < 4.4 \times 10^{-5}$ at 90 %CL
arXiv:1107.4465



Strategy

⇒ We follow the strategy of previous analysis: $\tau \rightarrow \mu\mu\mu$ and $\tau \rightarrow p\mu\mu$.

⇒ Analysis based on 2011 and 2012 data sets.

⇒ Blind the signal window: $|m_{p\mu\mu} - m_{\Lambda_c^+}^{PDG}| < 40$ MeV

⇒ We start from stripping and loose pre-selection.

⇒ MVA:

- Signal MC.
- Background side-bands.

⇒ k-Folding technique applied.

⇒ Two BDT in used:

- BDT1 to first clean up the sample.
- BDT2 to further increase the sensitivity.

⇒ Final 3D optimization: (BDT2, ProbNNp, ProbNNmu).

⇒ Calculate the UL with CL_s .

⇒ We decided to based the analysis on muon triggers:

- L0
 - Lambda_cplus_L0MuonDecision_TOS
 - Lambda_cplus_L0DiMuonDecision_TOS
- HLT1
 - Lambda_cplus_Hlt1TrackMuonDecision_TOS
 - Lambda_cplus_Hlt1DiMuonLowMassDecision_TOS
 - Lambda_cplus_Hlt1TrackAllL0Decision_TOS
- HLT2
 - Lambda_cplus_Hlt2CharmHadD2HHHDecision_TOS;
 - Lambda_cplus_Hlt2DiMuonDetachedDecision_TOS;
 - Lambda_cplus_Hlt2CharmSemilep3bodyD2KMuMuDecision_TOS;
 - Lambda_cplus_Hlt2CharmSemilepD2HMuMuDecision_TOS;

Condition	$\Lambda_c^+ \rightarrow p\mu\mu$
μ^\pm and p P_T Track χ^2/ndf IP χ^2/ndf PID μ^\pm PID p	$> 300 \text{ MeV}/c$ < 3 > 9 PIDmu > -5 and (PIDmu - PIDK) > 0 PIDp > 10
Λ_c^+ Δm Vertex χ^2 IP χ^2 $c\tau$ Lifetime fit χ^2	$< 150 \text{ MeV}/c^2$ < 15 < 225 $> 100 \mu\text{m}$ < 225

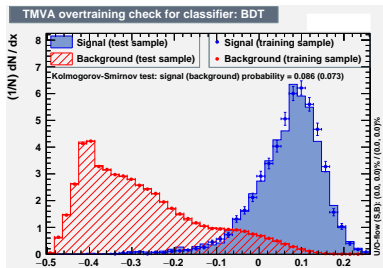
Futher preselection

Common cuts
$m_{\mu\mu} > 250 \text{ MeV}/c^2$ proton $ProbNNp > 0.1$ $\mu^+, \mu^- ProbNNmu > 0.1$ $10 \text{ GeV}/c < p_{\text{proton}} < 100 \text{ GeV}/c$
Signal channel
$ m_{\mu\mu} - m_{\omega} > 40 \text{ MeV}/c^2$ $ m_{\mu\mu} - m_{\phi} > 40 \text{ MeV}/c^2$
Normalization channel
$ m_{\mu\mu} - m_{\phi} < 35 \text{ MeV}/c^2$

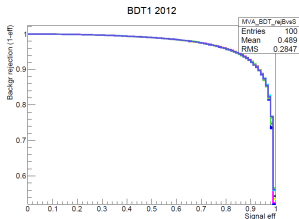
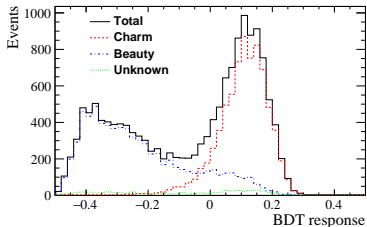
MVA Selection 1/2

⇒ The BDT1 uses a small set of available variables related to Λ_c^+ candidate:

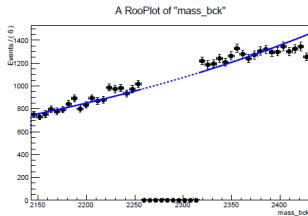
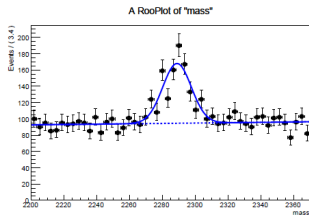
- Lambda_cplus_IP_OWNPV
- Lambda_cplus_IPCHI2_OWNPV
- TMath :: Exp(-1000 * Lambda_cplus_TAU)
- Lambda_cplus_ENDVERTEX_CHI2
- Lambda_cplus_PT
- Lambda_cplus_FD_OWNPV
- Lambda_cplus_FDCHI2_OWNPV



MVA Selection 2/2



⇒ We have choose a loose cut ($BDT1 > -0.1$) to clean up the sample:



$$\Lambda_c \rightarrow p\phi(\mu\mu)$$

Blinded data.

Normalization

$\Rightarrow \Lambda_c \rightarrow p\phi(\mu\mu)$:

- Same final state!
- Most of the systematics cancel in the ratio.
- Kinematics difference will only remain.
- Low Br: $Br(\Lambda_c \rightarrow p\phi(\mu\mu)) = (2.98 \pm 0.63) \times 10^{-7}$

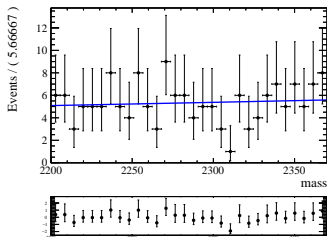
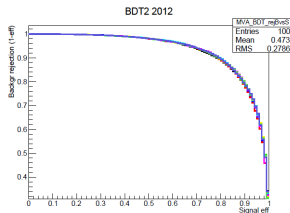
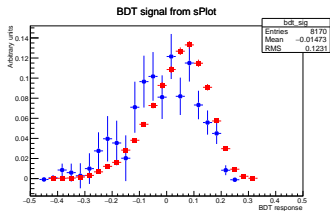
$\Rightarrow \Lambda_c \rightarrow p\pi\pi$:

- Different final state!
- The systematics will not cancel in the ratio.
- Need to understand the $\pi\pi$ spectrum.
- High branching fraction:
 $Br(\Lambda_c \rightarrow p\pi\pi) = (4.3 \pm 2.3) \times 10^{-3}$

We have chosen the $\Lambda_c \rightarrow p\phi(\mu\mu)$ as normalization channel.

MVA Selection II

- Added variables related to the daughter tracks.

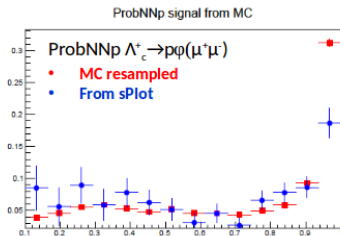
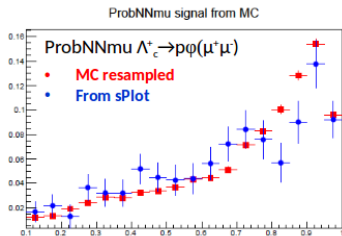
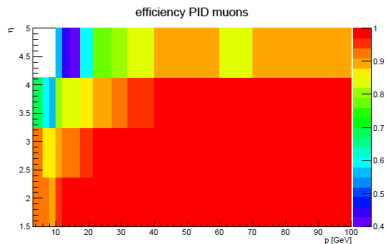


⇒ The BDT was checked against the correlation with mass on MC background.

⇒ All cross-checks passed.

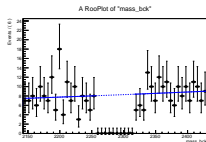
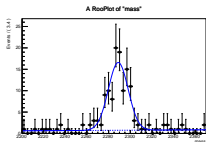
⇒ The PID in this analysis is done using re sampling the PID distributions.

- PIDCalib for muons does not cover the low p_T muons (10 %) of the sample.
- We used the $D_s \rightarrow \pi\phi(\mu\mu)$.
- The same procedure was used in the different analysis with this problem.
- The sample is currently being included to the standard sample PID sample by PID WG.

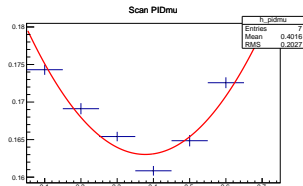
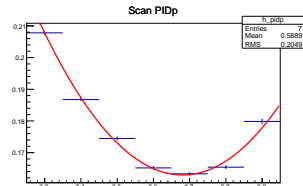
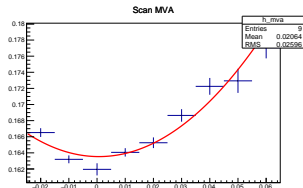


Optimization

- ⇒ Optimization was performed on a TOY MC sample.
- ⇒ The toys were generated using PDF from signal MC and sideband sample.
- ⇒ Optimization was done on grid of points, using 100 TOYs peer point.
- ⇒ CL_s was used as FOM.



Variable	Cut
BDT2	> 0.0
ProbNNp	> 0.68
ProbNNmu	> 0.38



Peaking backgrounds 1/2

⇒ There are several sources of peaking background:

Resonance	$\text{BF}(\Lambda_c^+ \rightarrow pX)$	$\text{BF}(X \rightarrow \mu\mu)$	Total BF
η	-	$(5.8 \pm 0.8) \times 10^{-6}$	-
ρ	-	$(4.55 \pm 0.28) \times 10^{-5}$	-
ω	-	$(9.0 \pm 3.1) \times 10^{-5}$	-
ϕ	$(1.04 \pm 0.21) \times 10^{-3}$	$(2.87 \pm 0.19) \times 10^{-4}$	$(2.98 \pm 0.63) \times 10^{-7}$

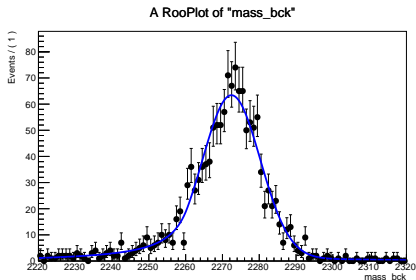
Resonance	$\text{BF}(\Lambda_c^+ \rightarrow pX)$	$\text{BF}(X \rightarrow \mu\mu\gamma)$	Total BF
η	-	$(3.1 \pm 0.4) \times 10^{-4}$	-
η'	-	$(1.08 \pm 0.27) \times 10^{-4}$	-

⇒ Unfortunately not all of the BF are known...

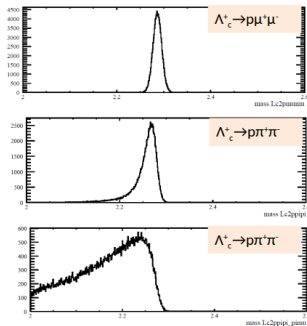
⇒ We took the adequate decay of D mesons. We ended up with BF $\mathcal{O}(10^{-9})$ for not vetoed decays, which is much below our sensitivity (see further slides).

Peaking backgrounds 2/2

- ⇒ The other peaking background is a harmonic decay $\Lambda_c^+ \rightarrow p\pi\pi$.
- ⇒ Estimated from MC sample
- ⇒ Used the resampled PID response.
- ⇒ Observed number of events in the signal window.



- ⇒ Estimated: $N_{\Lambda_c^+ \rightarrow p\pi\pi} = 1.96 \pm 1.13$
- ⇒ Took into account in background estimation.



Normalization

⇒ Master equation:

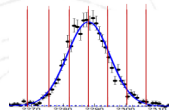
$$\frac{Br(\Lambda_c \rightarrow p\mu\mu)}{BR(\Lambda_c \rightarrow p\phi(\mu\mu))} = \frac{\epsilon_{\text{norm}}^{\text{TOT}}}{\epsilon_{\text{sig}}^{\text{TOT}}} \times \frac{N_{\text{sig}}}{N_{\text{norm}}},$$

where

$$\frac{\epsilon_{\text{norm}}^{\text{TOT}}}{\epsilon_{\text{sig}}^{\text{TOT}}} = \frac{\epsilon_{\text{norm}}^{\text{STRIP}}}{\epsilon_{\text{sig}}^{\text{STRIP}}} \times \frac{\epsilon_{\text{norm}}^{\text{COMM}}}{\epsilon_{\text{sig}}^{\text{COMM}}} \times \frac{\epsilon_{\text{norm}}^{\text{SPEC}}}{\epsilon_{\text{sig}}^{\text{SPEC}}}$$

⇒ Signal window divided in 6 equal bins (7 MeV/c²)

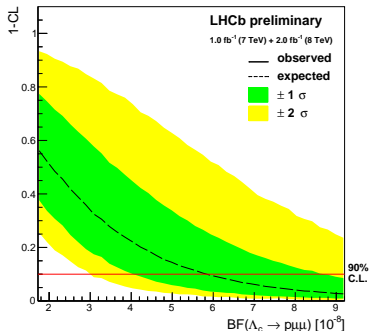
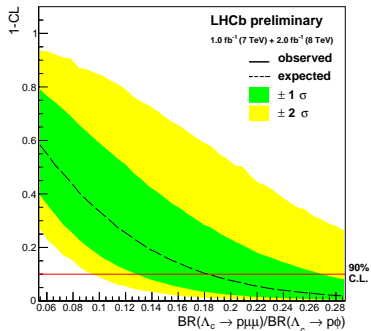
⇒ Many of the ratios close to one:



Uncertainty source	Value
Efficiency ratio R_{strip} (statistical)	0.2 %
Efficiency ratio R_{comm} (statistical)	3.37 %
Efficiency ratio R_{comm} (BDT2 cut)	0.4 %
Efficiency ratio R_{comm} (PIDCalib samples)	0.71 %
Width of the signal peak	0.55 %
Yield of normalization channel	11.8 %
Dedicated PID resampling	0.26 %
$\Lambda_c \rightarrow p\phi(\mu\mu)$	21.5 %
Variation of signal decay model	15.3 %

Expected limits

⇒ Putting all together one gets:



The expected limits:

$$Br(\Lambda_c \rightarrow p\mu\mu) < 5.9 \times 10^{-8} \text{ at } 90\% \text{ CL}$$

⇒ The RC started looking at the ANA note.

Run 2 plans

⇒ We already started working on Run2 analysis.

⇒ The program is expanding:

- $Br(\Lambda_c^+ \rightarrow p\mu\mu)$
- $R(\Lambda_c^+) = \frac{Br(\Lambda_c^+ \rightarrow p\mu\mu)}{Br(\Lambda_c^+ \rightarrow p\mu e)}$
- LFV: $\Lambda_c \rightarrow p\mu e$
- and maybe more ideas?

