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

Marcin Chrzaszcz

University of Zurich[UZH]

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

T.Lesiak(IFJ, Krakow), B.Nowak(IFJ, Krakow), M.Witek (IFJ, Krakow),
L.Pescatore(EPFL, Lousanne), M.Stamenkovic(EPFL, Lousanne),
M.Martinelli(EPFL, Lousanne)

Analysis and Software Week, CERN

April, 2017

Topics covered in this presentation

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

Yellow pages

- ⇛ Review started on 31.03.2017.
- ⇛ Reviewers: Tom Blake, Harry Cliff
- ⇛ Twiki:

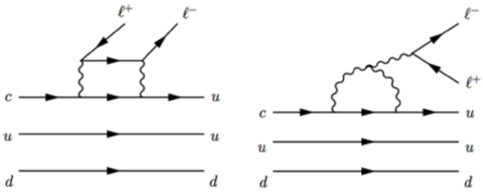
https://twiki.cern.ch/twiki/bin/view/LHCbPhysics/Lc2PMuMu

- ⇛ The newest version of the ANA note:

CLIC

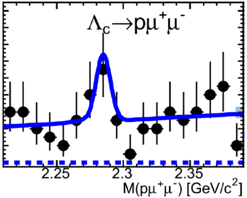
Physics of $\Lambda_c^+ \to p\mu\mu$

⇛ $\Lambda_c^+ \to p\mu\mu$ is a FCNC in the charm sector:



⇛ Current experimental situation:

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



⇛ SM prediction:

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

Strategy

⇛ We follow the strategy of previous analysis: $\tau \to \mu\mu\mu$ and $\tau \to \mathrm{p}\mu\mu$.

⇛ Analysis based on 2011 and 2012 data sets.

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

⇛ We start from stripping and loose pre-selection.

⇛ MVA:

- Signal MC.
- Background side-bands.

⇛ k-Folding technique applied.

⇛ Two BDT are used:

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

⇛ Final 3D optimization: $(\mathrm{BDT2}, \mathrm{ProbNNp}, \mathrm{ProbNNmu})$.

⇛ Calculate the UL with $\mathrm{CL_s}$.

Trigger

⇛ 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;

Stripping

StrippingTau23MuTau2PMuMuLine	
Condition	$\Lambda_c^+ \to \mathrm{p}\mu\mu$
$\mu^\pm$ and p	
P_T	$> 300\ \mathrm{MeV/c}$
Track χ^2/ndf	< 3
IP χ^2/ndf	> 9
PID $\mu^\pm$	PIDmu$>$ -5 and (PIDmu - PIDK) $>$ 0
PID p	PIDp$>$10
Λ_c^+	
Δm	$< 150\mathrm{MeV/c}^2$
Vertex χ^2	< 15
IP χ^2	< 225
$c\tau$	$> 100\mu m$
Lifetime fit χ^2	< 225

$\Rightarrow$ In Run2 we have a dedicated stripping/HLT2 lines for μ, e lepton flavours.

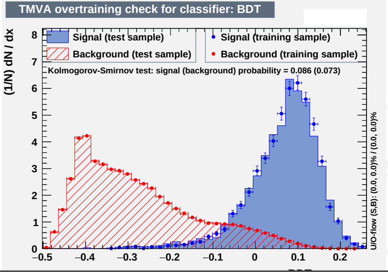
Futher preselection

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

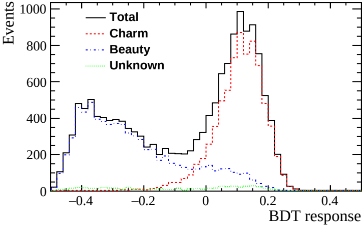
MVA Selection 1/2

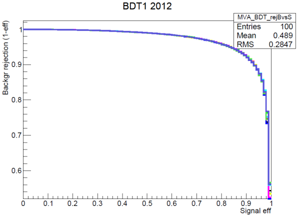
⇛ The BDT1 uses a small set of available variables related to Λ_c^+ candidate:

- Lambda_cplus_IP_OWNPV
- Lambda_cplus_IPCHI2_OWNPV
- $\mathrm{TMath :: Exp}(-1000 * \mathrm{Lambda\_cplus\_TAU})$
- Lambda_cplus_ENDVERTEX_CHI2
- Lambda_cplus_PT
- Lambda_cplus_FD_OWNPV
- Lambda_cplus_FDCHI2_OWNPV

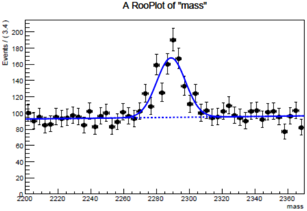


MVA Selection 2/2





⇒ We choose a loose cut $(\mathrm{BDT1} > -0.1)$ to clean up the sample:



$$\Lambda_c \to \mathrm{p}\phi(\mu\mu)$$

Normalization

$\Rightarrow$ $\Lambda_c \to \mathrm{p}\phi(\mu\mu)$:

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

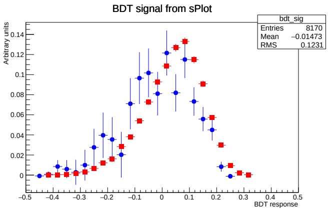
$\Rightarrow$ $\Lambda_c \to \mathrm{p}\pi\pi$:

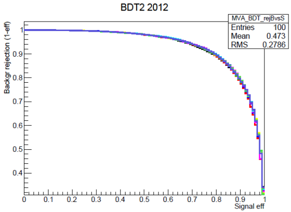
- Different final state!
- The systematics will not cancel in the ratio.
- Need to understand the $\pi\pi$ spectrum.
- High branching fraction: $Br(\Lambda_c \to \mathrm{p}\pi\pi) = (4.3 \pm 2.3) \times 10^{-3}$

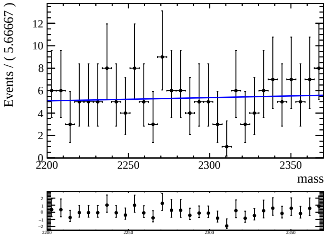
We have chosen the $\Lambda_c \to \mathrm{p}\phi(\mu\mu)$ as normalization channel.

MVA Selection II

- Added variables related to the daughter tracks.







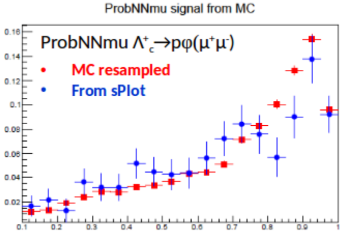
$\Rightarrow$ The BDT was checked against the correlation with mass on MC background.

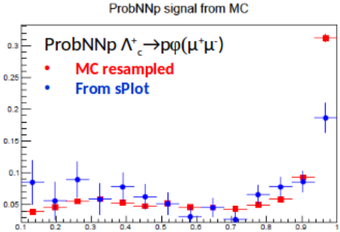
$\Rightarrow$ All cross-checks passed.

PID

⇛ 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 $\mathrm{D_s} \rightarrow \pi\phi(\mu\mu)$.
- The same procedure was used in the different analysis with this problem.
- The sample is currently being included to the standard sample from the PID WG.





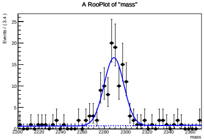
Optimization

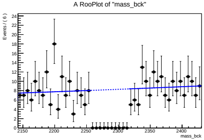
⇛ Optimization was performed on a TOY MC sample.

⇛ The toys were generated using PDF from signal MC and sideband sample.

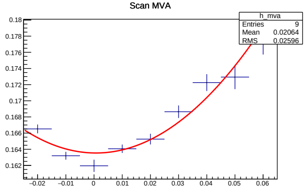
⇛ Optimization was done on grid of points, using 100 TOYs peer point.

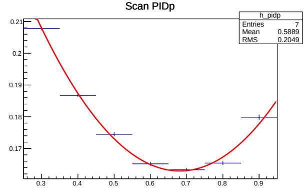
⇛ $\mathrm{CL_s}$ was used as FOM.

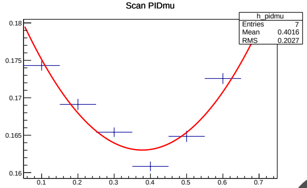




Variable	Cut
BDT2	> 0.0
ProbNNp	> 0.68
ProbNNmu	> 0.38







Peaking backgrounds 1/2

$\Rrightarrow$ There are several sources of peaking background:

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

$\Rrightarrow$ Unfortunately not all of the BF are known...

$\Rrightarrow$ 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).

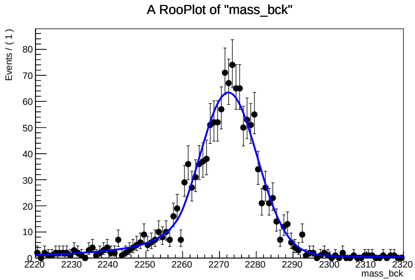
Peaking backgrounds 2/2

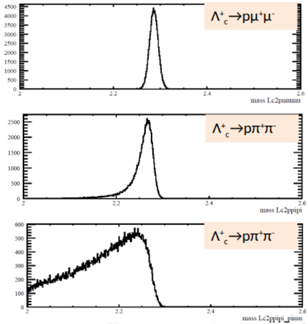
⇛ The other peaking background is a harmonic decay $\Lambda_c^+ \to p\pi\pi$.

⇛ Estimated from MC sample

⇛ Used the resampled PID response.

⇛ Observed number of events in the signal window.





⇛ Estimated: $N_{\Lambda_c^+ \to p\pi\pi} = 1.96 \pm 1.13$

⇛ Took into account in background estimation.

Normalization

⇛ Master equation:

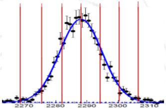
$$\frac{Br(\Lambda_c \to \mathrm{p}\mu\mu)}{Br(\Lambda_c \to \mathrm{p}\phi(\mu\mu))} = \frac{\epsilon_{\mathrm{norm}}{}^{\mathrm{TOT}}}{\epsilon_{\mathrm{sig}}{}^{\mathrm{TOT}}} \times \frac{N_{\mathrm{sig}}}{N_{\mathrm{norm}}},$$

where

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

⇛ Signal window divided in 6 equal bins (7 $\mathrm{MeV}/\mathrm{c}^2$)

⇛ Many of the ratios close to one:

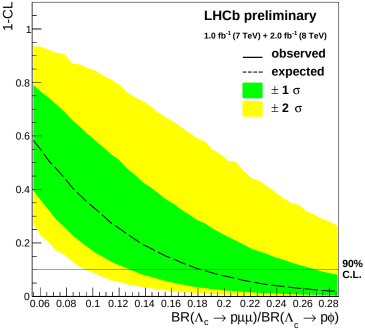


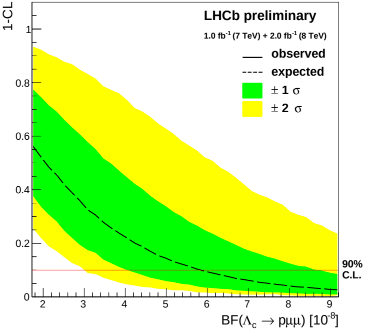
Systematics

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 %
$\Lambda_c \to \mathrm{p}\phi(\mu\mu)$	21.5 %
Variation of signal decay model	15.3 %

Expected limits

⇛ Putting all together one gets:





The expected limits:

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

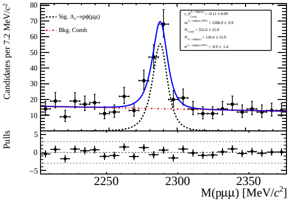
⇛ The RC started looking at the ANA note.

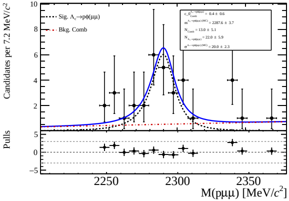
Run 2 plans

$\Rrightarrow$ We already started working on Run2 analysis.

$\Rrightarrow$ The program is expanding:

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





$\Rrightarrow$ Λ_c^+ is a exciting system that is not fully explored!

$\Rrightarrow$ We have a rich physics program to be studied with Run2 data.

Backup