Search for the suppressed $\Lambda_c^+ \to p\mu^+\mu^-$ decay and observation of the $\Lambda_c^+ \to p\omega$ decay

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With M. Jezabek, T. Lesiak, B. Nowak, M. Witek (IFJ PAN)

Tuesday meeting, CERN
September 26, 2017

Yellow pages

- ⇛ Reviewers: Tom Blake(chair), Harry Cliff, Simon Eydelman(EB)
- ⇛ Twiki:
`https://twiki.cern.ch/twiki/bin/viewauth/LHCbPhysics/Lc2PMuMu`
- ⇛ Review start: 01.04.2017
- ⇛ Three interactions with the review committee.
- ⇛ Unbinding: 18.07.2017
- ⇛ Minor changes to the analysis during the review.

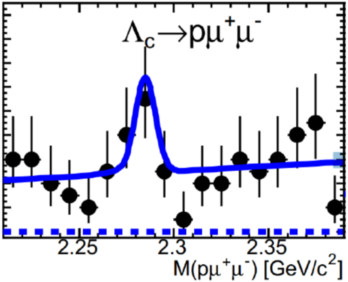
We would like to take this occasion and than Tom, Harry and Simon for fruitful, constructive and smooth review!

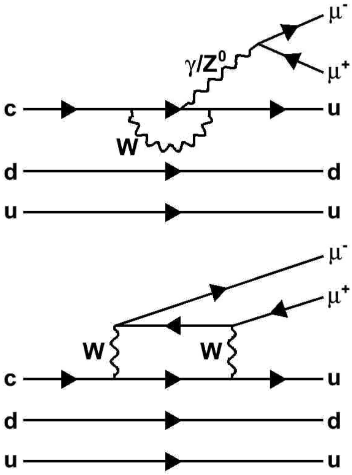
Motivation

⇛ SM predictions:
$\mathcal{O}(10^{-8})$

⇛ Long distance effects:
$\mathcal{O}(10^{-6})$

⇛ Previous measurement done by Babar:
$\mathrm{Br}(\Lambda_c^+ \to p\mu^+\mu^-) < 4.4 \cdot 10^{-5}$ at 90% CL





Should be able to improve by a factor of 100!

Analysis strategy

⇛ Normalization to $\Lambda_c^+ \to p\phi(\mu\mu)$.

⇛ Typical steps rare decays:

- Loose stripping selection.
- BDT1 used for first preselection.
- BDT2 used to further suppress the background.
- PID used to fight the peaking background.

⇛ Search performed in several dimuon mass windows.

⇛ Selection optimized on $\mathrm{CL_s}$.

⇛ Unblinding and calculate the UL of BR using $\mathrm{CL_s}$.

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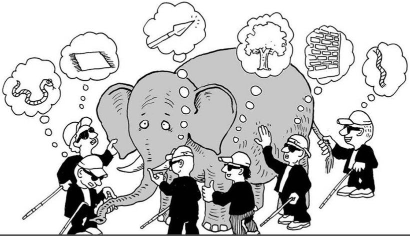

Normalization channel

Use the $\Lambda_c^+ \to p\phi(\mu\mu)$.

$\Rightarrow$ Same final state, same selection, a lot of systematics cancel.

$\Rightarrow$ The Branching fraction of $\Lambda_c^+ \to p\phi$ is know with $22\ \%$.

Use the $\Lambda_c^+ \to pK\pi$.

$\Rightarrow$ Precisely known branching fraction (precision: $6.4\ \%$).

$\Rightarrow$ A lot of additional systematics due to different final states, different selections

We choose the $\Lambda_c^+ \to p\phi(\mu\mu)$ option

$\Rightarrow$ In the most optimistic scenario where you assume the $22\ \%$ systematic to go town to $6.4\ \%$ the UL.

$\Rightarrow$ In this case the UL gets worse $7.8\ \%$.

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Data sets and Stripping

⇛ 2011+2012 (aka Run1) Stripping 20.

Condition	$\Lambda_c^+ \to p\mu^+\mu^-$
$\mu^\pm$ and p	
p_T	$> 300 MeV/c$
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	$< 150 MeV/c^2$
Vertex χ^2	< 15
IP χ^2	< 225
$c\tau$	$> 100 \mu$m
Lifetime fit χ^2	< 225

Preselection

⇛ Additional cuts:

Common cuts
$m_{\mu\mu} < 1400\ MeV/c^2$
proton $ProbNNp > 0.1$
$\mu^+, \mu^-\ ProbNNmu > 0.1$
$10\ GeV/c < p_{proton} < 100\ GeV/c$

⇛ We define couple of dimuom mass regions:

$m(\mu\mu)$ region	$\left[MeV/c^2\right]$
ϕ region	$[985, 1055]$
ω region	$[759, 805]$
non resonant	$[210, 747] \cup [817, 980] \cup [1060, 1400]$

Trigger

⇛ We require the following triggers (all are TOS):

- L0
  - L0MuonDecision
- HLT1
  - Hlt1TrackMuonDecision
  - Hlt1DiMuonLowMassDecision
  - Hlt1TrackAllL0Decision
- HLT2
  - Hlt2DiMuonDetachedDecision
  - Hlt2CharmSemilep3bodyD2KMuMuDecision
  - Hlt2CharmSemilepD2HMuMuDecision

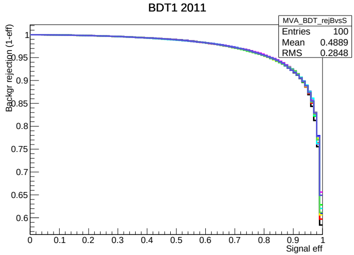
⇛ The TIS increase the signal yield by $< 10~\%$ and were asked to be removed at the WG review stage.

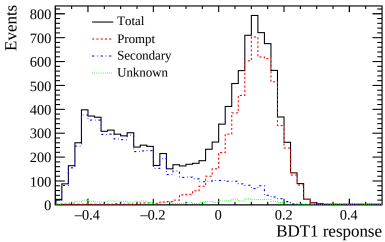
BDT1 training

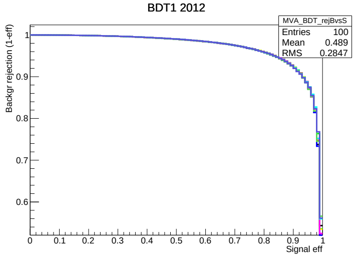
$\Rrightarrow$ The normalization channel is also a rather "rare decay":

$\mathrm{Br}(\Lambda_c^+ \to p\phi) \cdot \mathrm{Br}(\phi \to \mu\mu) = 3.1 \cdot 10^{-7}$

$\Rrightarrow$ After the previous preselection a simple BDT is trained using variables that are well simulated in the MC. k-folding used ($k = 10$) $\Rrightarrow$ The BDT1 (not surprisingly) likes the prompt Λ_c rather the secondary ones.





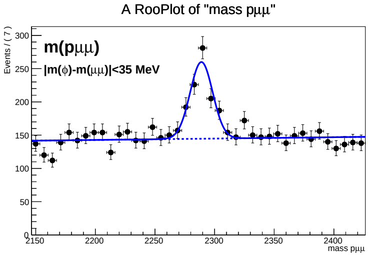


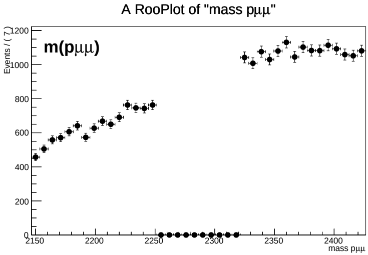
BDT1 selection

⇛ The selection based on BDT1 is not optimised.

⇛ A loose cut:

$$\mathrm{BDT1} > -0.1$$



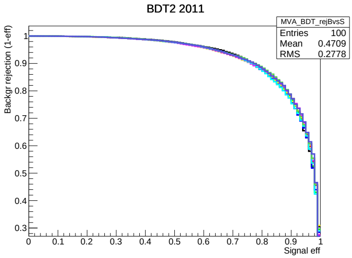


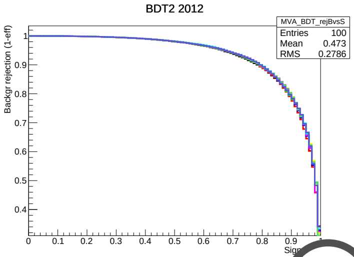
⇛ The normalization channel peak is observed.

BDT2 selection

⇛ Variables used:

- flight distance - the one between the production and decay points.
- χ^2 of flight distance,
- transformed decay time - $T = \exp(-1000 \cdot \tau/\mathrm{ns})$,
- IP - impact parameter with respect to primary vertex,
- χ^2 of IP of Λ_c^+
- $\log(\chi^2_{DTF})$,
- p_T - transverse momentum of Λ_c^+,
- minimum of χ^2 of p, μ^+, μ^- w.r.t. primary vertex,
- transverse momenta

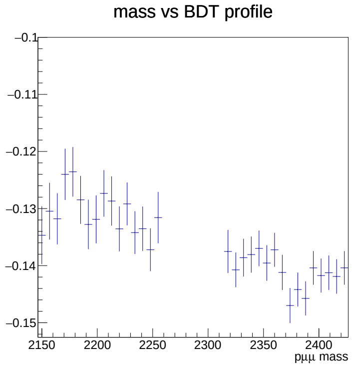


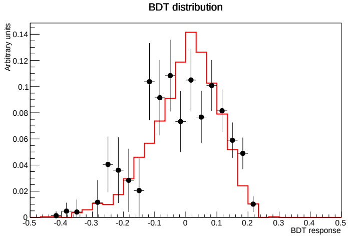


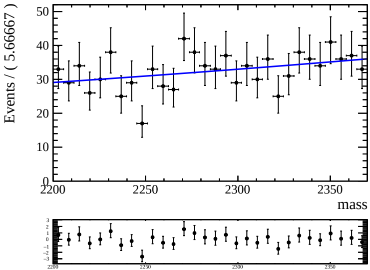
BDT2

⇛ After correcting the DATA/MC differences the BDT distribution shows a a good DATA/MC agreement.

⇛ No mass correlation observed.



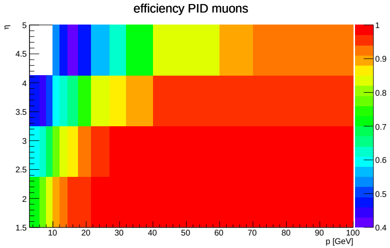


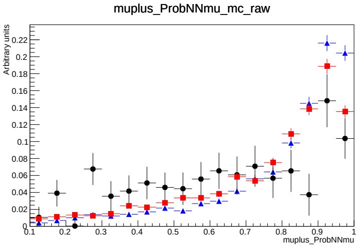


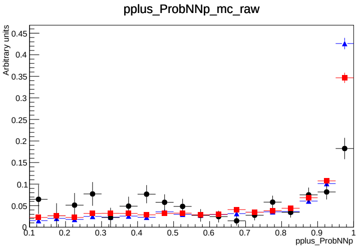
PID

⇛ MC re sampling is choose to correct the PID distributions:
For MC samples the ProbNNp and ProbNNmu are drawn from the PIDCalib distributions.

⇛ The PIDCalib doesn't cover to low p_T muons (10%).
⇛ Decided to use for them the $D_s \rightarrow \phi(\mu\mu)$ sample.



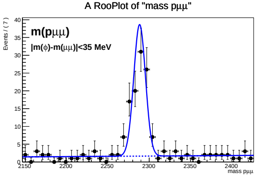


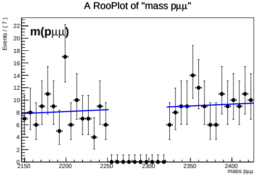


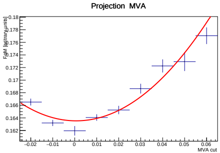
Selection optimization

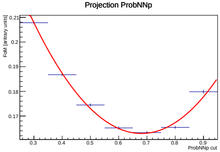
- ⇛ The final selection of the analysis is optimized!
- ⇛ $\mathrm{CL_s}$ method used.
- ⇛ KDE used to sample toy experiments.

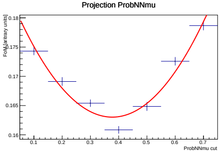
Variable	Condition
BDT	> 0.0
$ProbNNp(p)$	> 0.68
minimum $ProbNNmu(\mu^{\pm})$	> 0.38







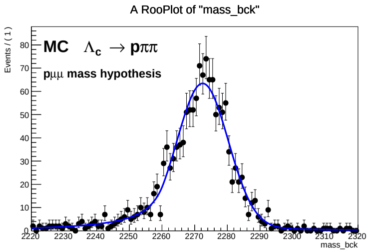


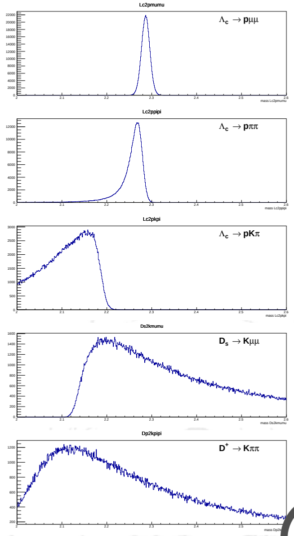


Peaking backgrounds

⇛ The tight PID cuts essentially kill the peaking bkg!

⇛ The only bkg left is the $\Lambda_c^+ \to p\pi\pi$.





⇛ Estimated contamination:

1.96 ± 1.13 ⇛ assigned as systematic

Normalization

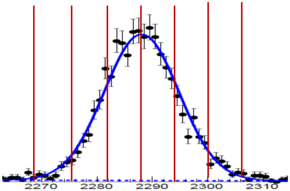
⇛ The gold equation:

$$\frac{\mathcal{B}(\Lambda_c^+ \to p\mu^+\mu^-)}{\mathcal{B}(\Lambda_c^+ \to p\phi(\mu\mu))} = \frac{\epsilon_{\text{norm}}^{\text{TOT}}}{\epsilon_{\text{sig}}^{\text{TOT}}} \times \frac{N_{\text{sig}}}{N_{\text{norm}}},$$

⇛ We take advantage of the cancellation that:

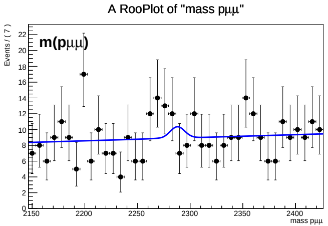
$$\frac{\epsilon_{\text{norm}}^{\text{TOT}}}{\epsilon_{\text{sig}}^{\text{TOT}}} = \frac{\epsilon_{\text{norm}}^{\text{STRIP}}}{\epsilon_{\text{sig}}^{\text{STRIP}}} \times \frac{\epsilon_{\text{norm}}^{\text{COMM}}}{\epsilon_{\text{sig}}^{\text{COMM}}} \times \frac{\epsilon_{\text{norm}}^{\text{SPEC}}}{\epsilon_{\text{sig}}^{\text{SPEC}}}, \quad \frac{\epsilon_{\text{norm}}^{\text{i}}}{\epsilon_{\text{sig}}^{\text{i}}} \simeq 1$$

⇛ In addition we have added 6 mass bins to increase the sensitivity.
⇛ Signal is modelled by a double Gaussian.

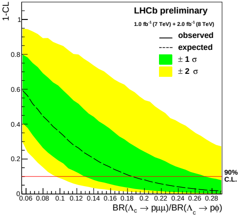


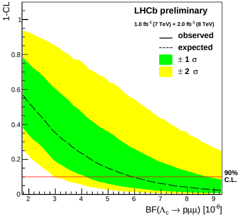
Expected background

⇛ Background modelled with a linear function.



bin	no events
bin1	8.56136 ± 0.540302
bin2	8.60318 ± 0.536917
bin3	8.64582 ± 0.536561
bin4	8.6887 ± 0.539208
bin5	8.7304 ± 0.544752
bin6	8.77226 ± 0.553162





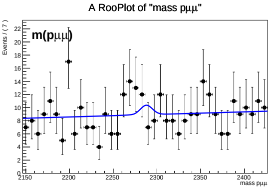
⇛ Expected upper limits: $\mathcal{B}(\Lambda_c^+ \to p\mu^+\mu^-) < 5.91 \times 10^{-8}$ at 90 % CL

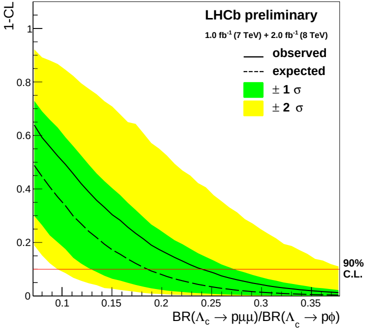
Observed Upper limits

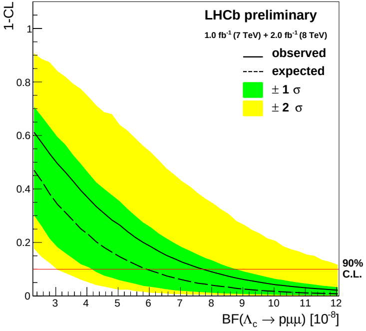
⇛ After the green light from RC we have unblinded we did not observed a significant access of events.

⇛ We have set an UL:

$$\mathcal{B}(\Lambda_c^+ \to p\mu^+\mu^-) < 7.68{\times}10^{-8}\ \mathrm{at}90\,\%\ \mathrm{CL}$$







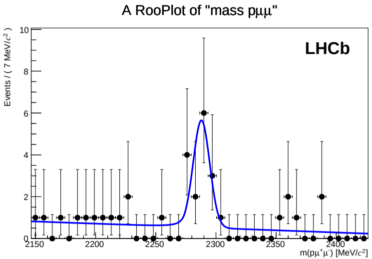
By product :)

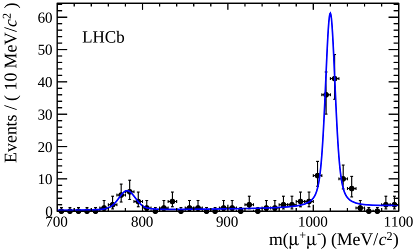
$\Rrightarrow$ We also looked at the ω dimuon region.

We observed an access

Using Wilks theorem we have calculated the significance to be $5.0\ \sigma$!

$\Rrightarrow$ This is the first observation of this decay!!!
$\mathcal{B}(\Lambda_c^+ \to p\omega) = (7.6 \pm 2.6\ (stat) \pm 0.9\ (syst1) \pm 3.1\ (syst2))\ \times 10^{-4}$





Conclusion

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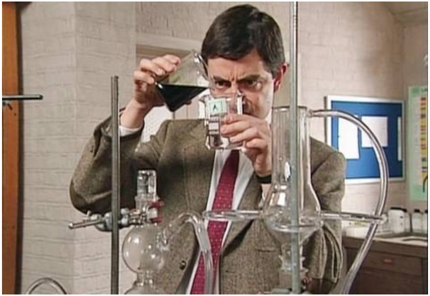

- First time observed the decay $\Lambda_c^+ \to p\omega$!!
- Paper is beeing prepared, aiming PRL
- We would like to ask the collaboration for approving this analysis.

Backup