Update on sensitivity study for $B^- \to \Lambda \bar{p} \nu \bar{\nu}$ at phase 3

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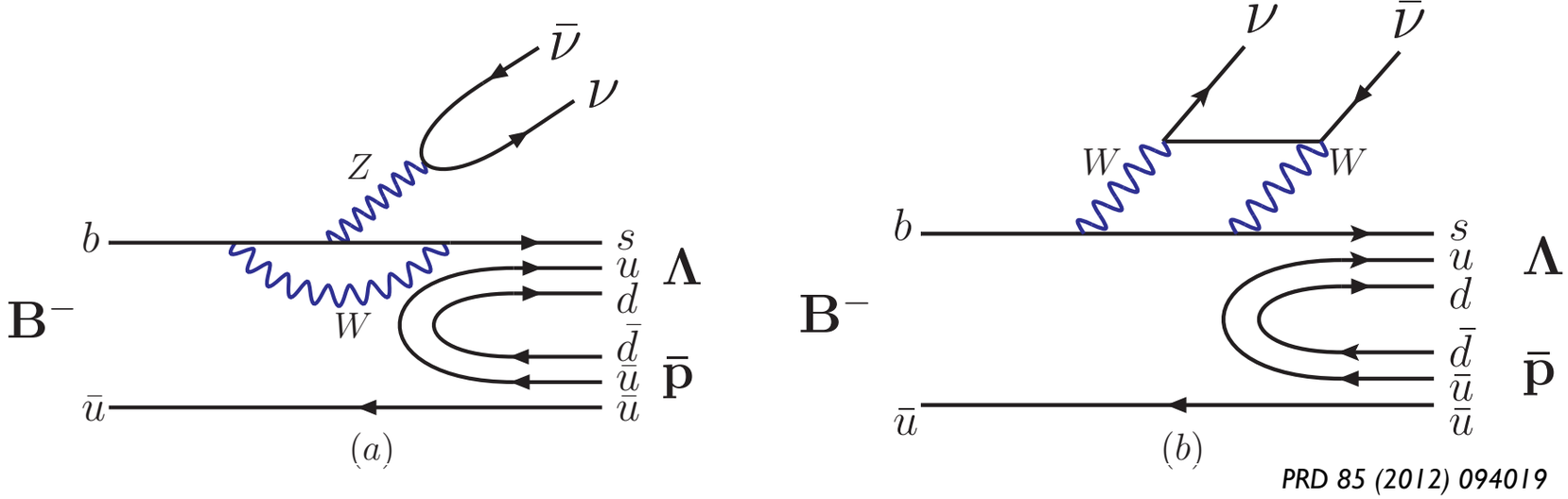
WG1 - (Semi-)Leptonic and Missing Energy Decays, Leptonic sub-group meeting
8th November 2018

Details and motivation



PRD 85 (2012) 094019

- Standard Model prediction: $\mathcal{B}(B^- \to \Lambda\bar{p}\nu\bar{\nu})$ = (7.9 ± 1.9) x 10^{-7} (Geng & Hsiao, PRD 85 (2012) 094019).
  - Rare, FCNC decay - suppressed by the standard model.
  - New physics potentially hiding in loops - will affect branching fraction.
  - Amenable to further study: angular asymmetries, T-odd observables *etc.*

- BaBar result (see backup slides for more detail)
  - Presented at ICHEP 2018: indico.cern.ch/event/686555/contributions/2986950/
  - First ever measurement of $B^- \to \Lambda\bar{p}\nu\bar{\nu}$. Results:

    BF central value: (0.4 ± 1.1(stat.) ± 0.6(sys.)) x 10^{-5}
    BF upper limit at 90% confidence level: 3.0 x 10^{-5}
    (Compare theory: (7.9 ± 1.9) x 10^{-7})
    No observation of signal or New Physics.

MC, FEI and skimming

- basf2 release-01-02-11

- Use MC9 FEI skim "feiHadronicBplus": skim of first 0.8 ab^-1 generic Ups(4S) BGx1 events

  Central FEI skim cuts
  - Mbc > 5.24 GeV
  - |deltaE| < 0.200 GeV
  - signal probability > 0.001

- SigMC: MC9, 10 M events, phase3, Ups(4S), BGx1
- Skim sigMC using same cuts

Scale background luminosity to BaBar

To give comparability with only existing experimental result. Scale down background luminosity from 0.8 ab^{-1} to 0.424254 ab^{-1}.

Reweight signal MC

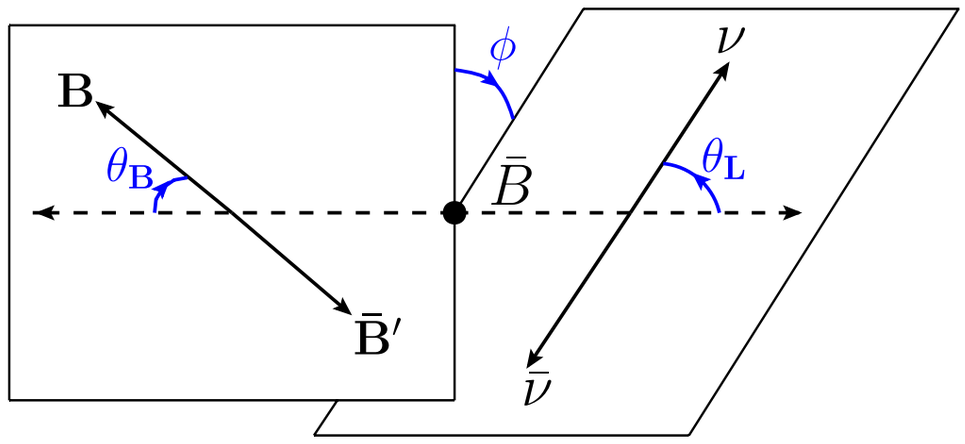


FIG. 2 (color online). Three angles $\theta_{\mathbf{B}}$, $\theta_{\mathbf{L}}$, and ϕ in the phase space for the four-body $\bar{B} \to \mathbf{B}\bar{\mathbf{B}}'\nu\bar{\nu}$ decay.

PRD 85 (2012) 094019

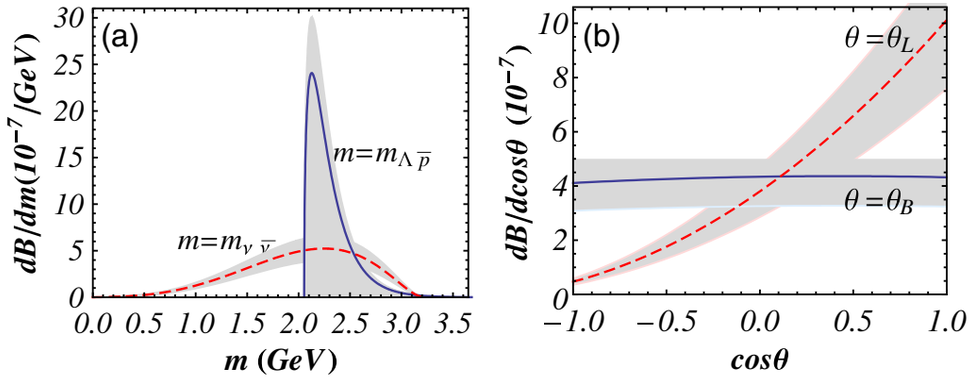
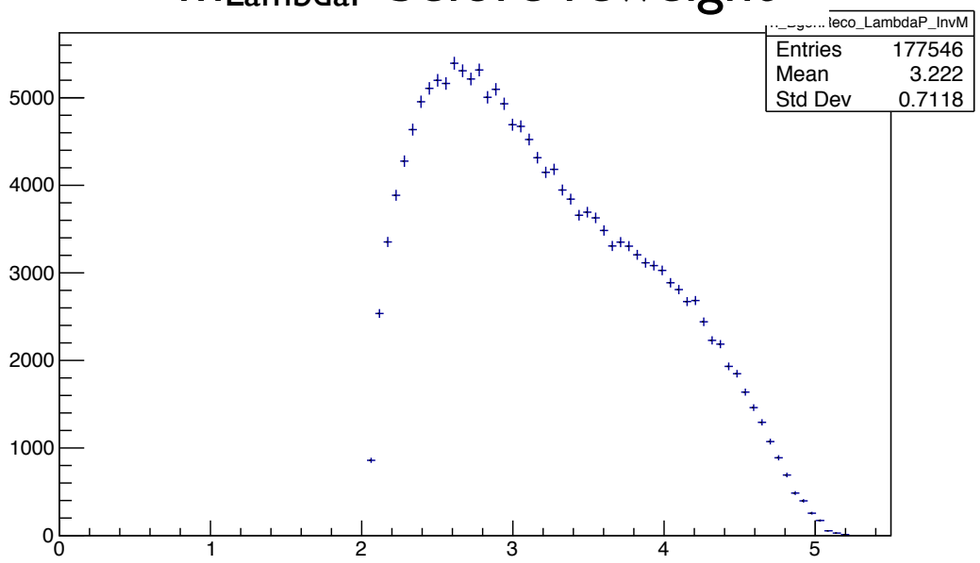


FIG. 3 (color online). Invariant mass spectra as functions of the invariant masses $m_{\Lambda\bar{p}}$ and $m_{\nu\bar{\nu}}$ and angular distributions as functions of $\cos\theta_{B,L}$ for $B^- \to \Lambda\bar{p}\nu\bar{\nu}$, respectively, where the shaded areas represent the theoretical uncertainties from the form factors and CKM mixings.

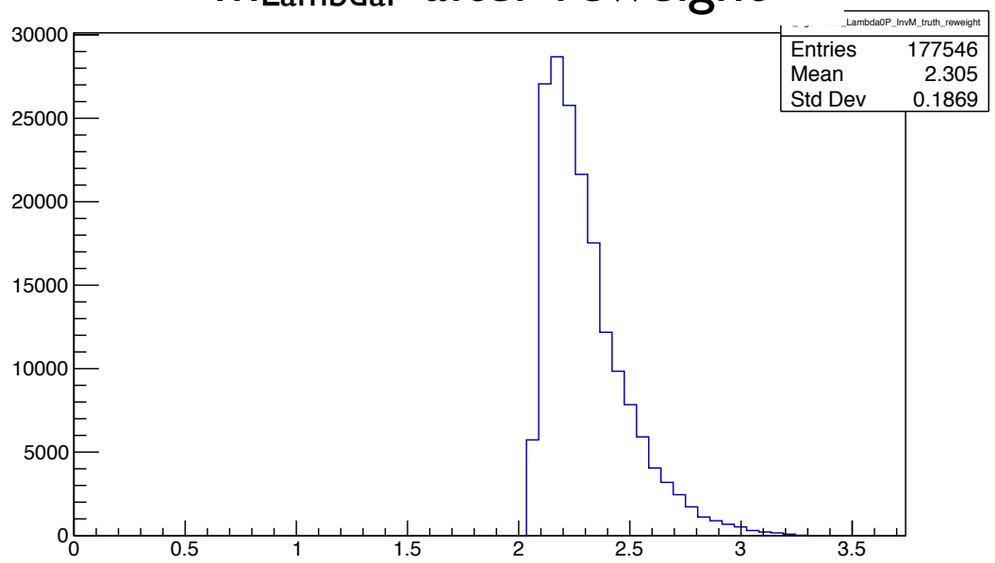
PRD 85 (2012) 094019

- Simultaneous reweight to all four variable is impossible.
- Try reweighting to each variable individually, one-by-one: only reweights that made a difference to final result are $m_{LambdaP}$ and m_{NuNu}, and they make the same difference.
- Reweight to $m_{LambdaP}$.

$m_{LambdaP}$ before reweight



$m_{LambdaP}$ after reweight



Signal selection cuts

$$B^- \to \Lambda \bar{p} \nu \bar{\nu}$$
$$\hookrightarrow p\pi^-$$

Btag

- remaining tracks in event after FEI == 3 (Lambda(p pi-)pbar)
- if >1 Btag candidate in an event, keep candidate with highest signal probability

Lambda reconstruction

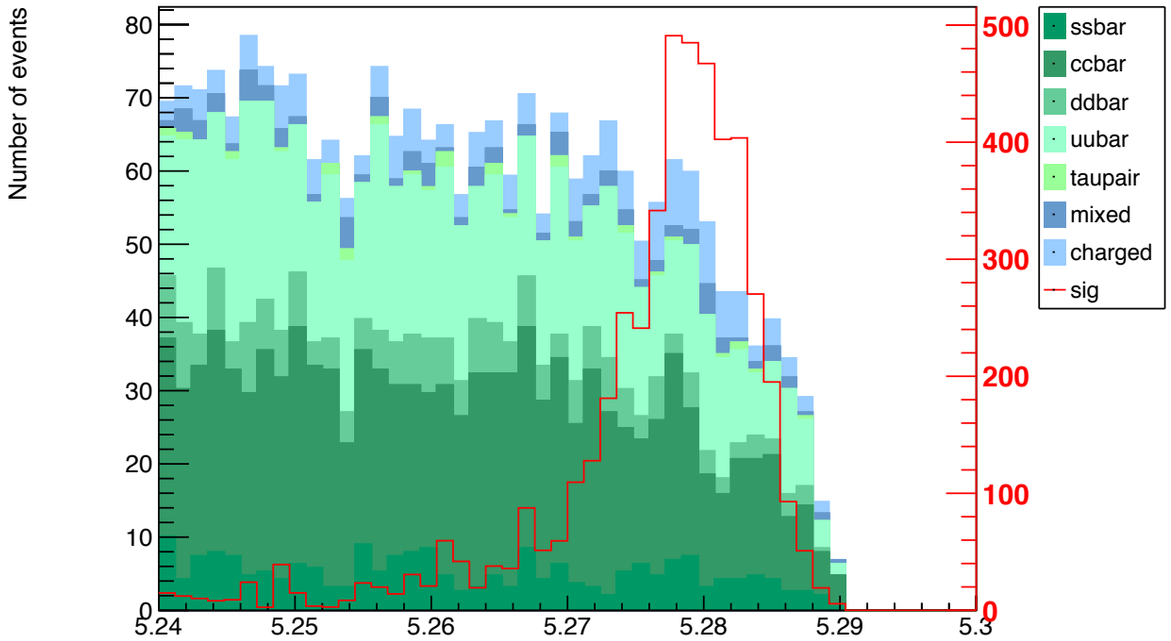
- 95% efficiency proton and pion ID on remaining tracks
- Lambda daughters must obey expected DOCA order (pbar < p < pi) (see backup slides for detail)
- Reconstruct lambda from PID'ed tracks, KFit
- Lambda mass: PDG ± 40 MeV
- If >1 lambda candidate, choose one with best significance-of-distance relative to IP

Other

- Reconstruct Bsig and Upsilon(4S) (imposes "no overlaps" and charge consistency)

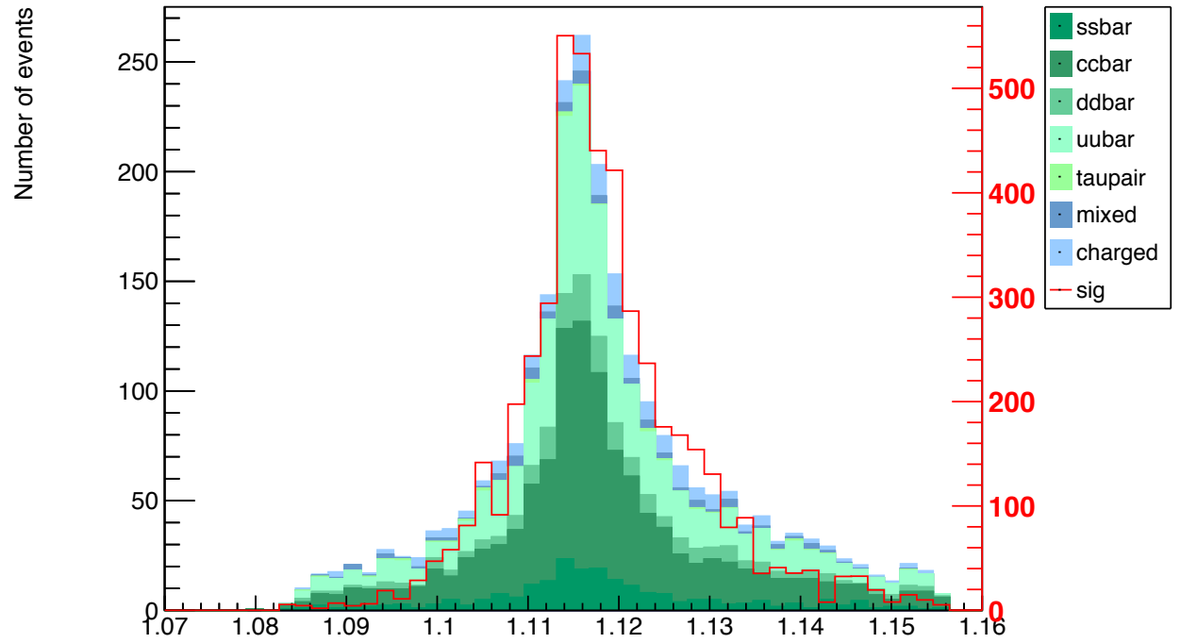
Signal selection cuts

Btag Mbc



Use Mbc > 5.27 GeV for final result.

Reconstructed Lambda mass



PDG Lambda mass = 1.116 GeV

Keep events with m_Lambda within PDG +/- 25 MeV.

Signal selection cuts

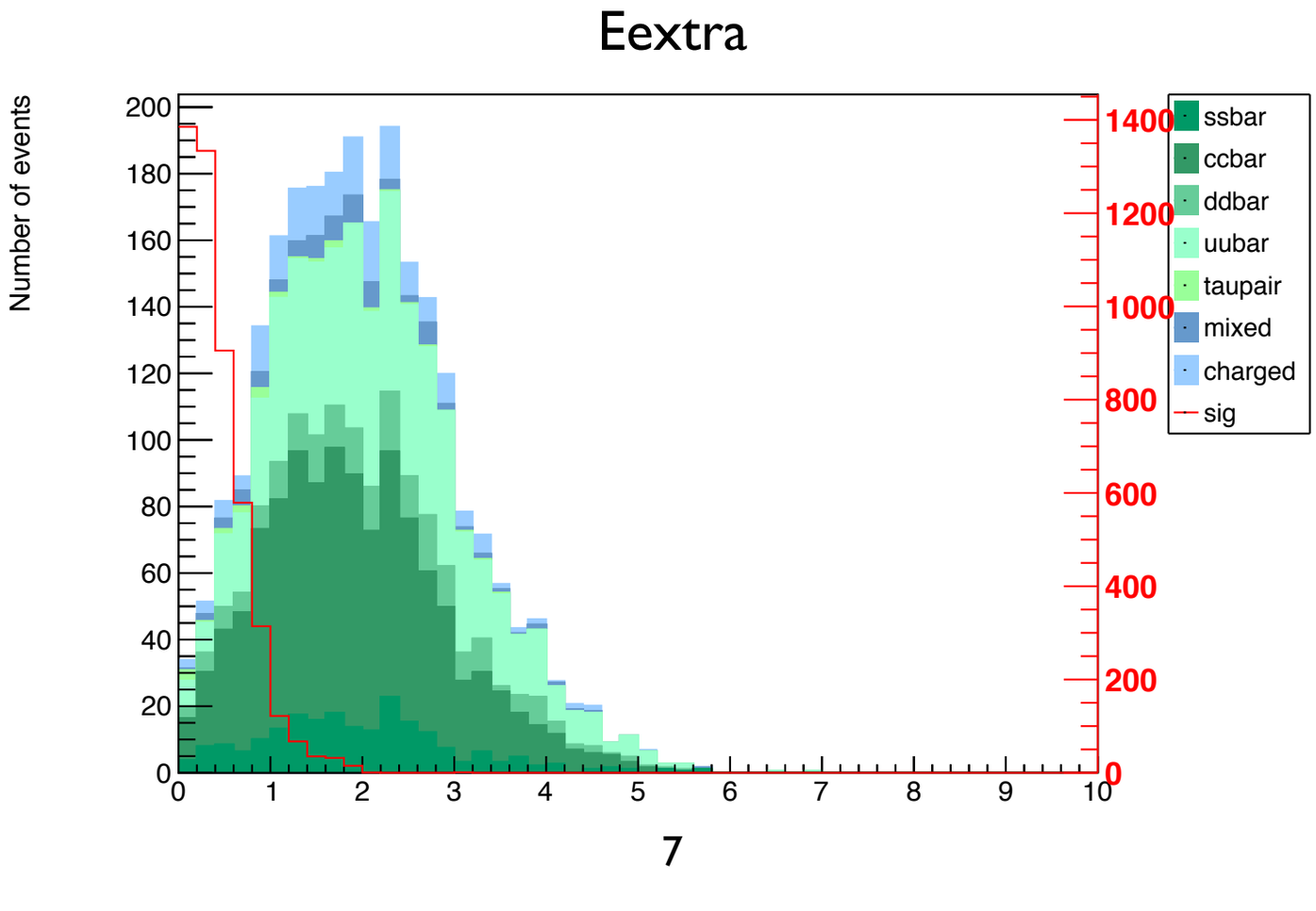
$$B^- \to \Lambda \bar{p} \nu \bar{\nu}$$
$$\hookrightarrow p\pi^-$$

Eextra

- ECL energy from neutral particles that are not used in Btag reconstruction.
- Suppress beam background by requiring (https://confluence.desy.de/x/QGIHAg):

Detector region	forward	barrel	backward
Energy (MeV)	62	60	56
abs(cluster timing) (ns)	< 18	< 20	< 44

Optimise cut using BF upper limit as figure of merit → keep events with Eextra < 0.5 GeV

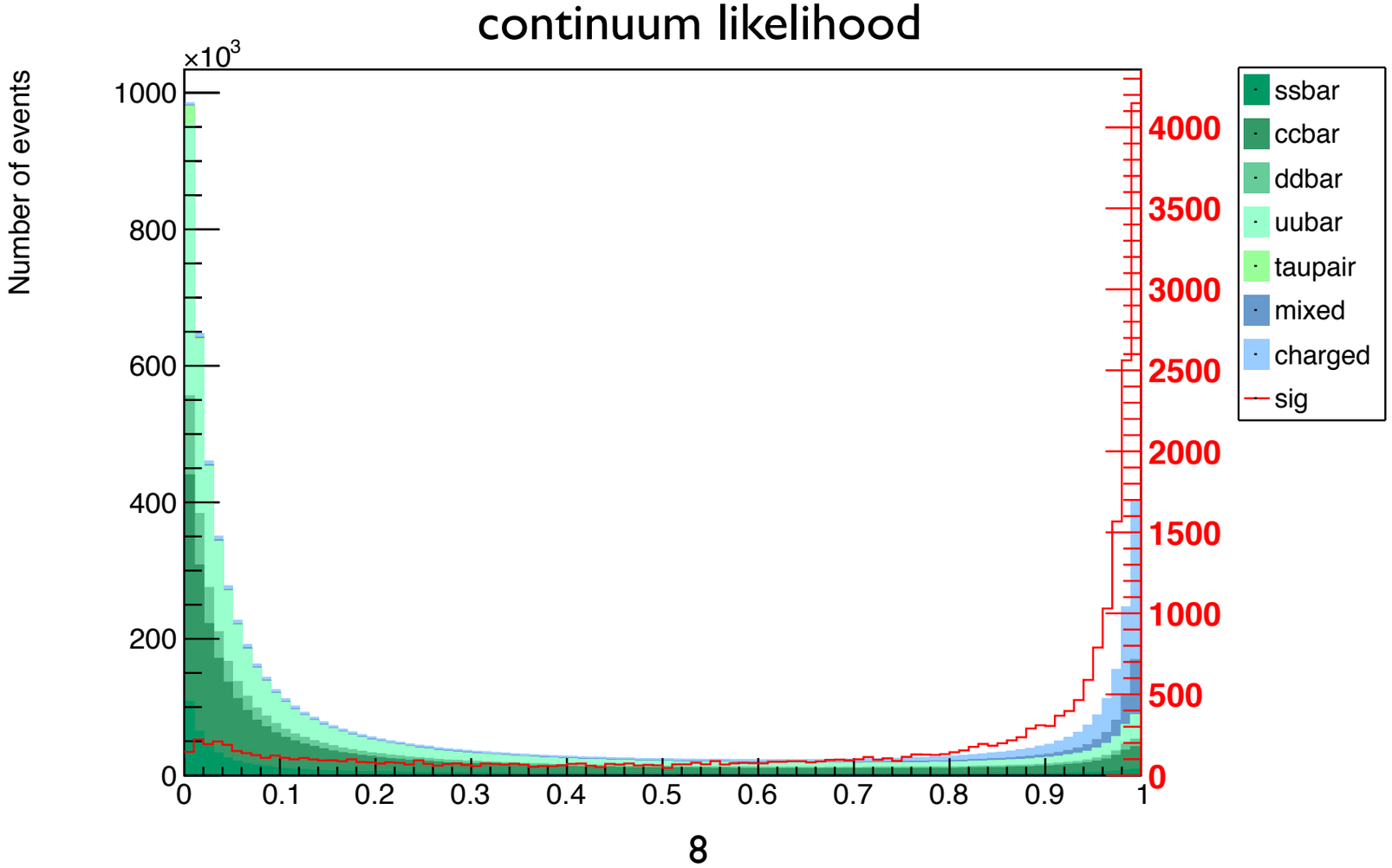


Continuum suppression

$$continuum\ likelihood = \frac{\prod_i P_{B\bar{B}}(x_i)}{\prod_i P_{B\bar{B}}(x_i) + \prod_i P_{cont}(x_i)}$$

where $P_{BB}(x_i)$ and $P_{cont}(x_i)$ are probability density functions describing BB and continuum events respectively for the variable x_i (see backup slides for list of variables).

Optimise cut using BF upper limit as figure of merit → keep events with contLH > 0.35 GeV



Results and outlook

<u>Results</u>

- Final background: 10.6 ± 2.4(stat.)
  - BaBar MC : 2.3 ± 0.7(stat.) ± 0.6(sys.)
  - BaBar data: 3

- Final sig eff (incl. Lambda -> p pi- BF):
  - (1.44 ± 0.07(stat.))e-04
  - BaBar: (3.42 ± 0.08(stat.) ± 0.80(sys.))e-04

- BF upper limit at 90% CL (Barlow): 1.2e-4
  - BaBar: 0.30e-4
  - Theory: (7.9 ± 1.9)e-7

<u>Constraints</u>

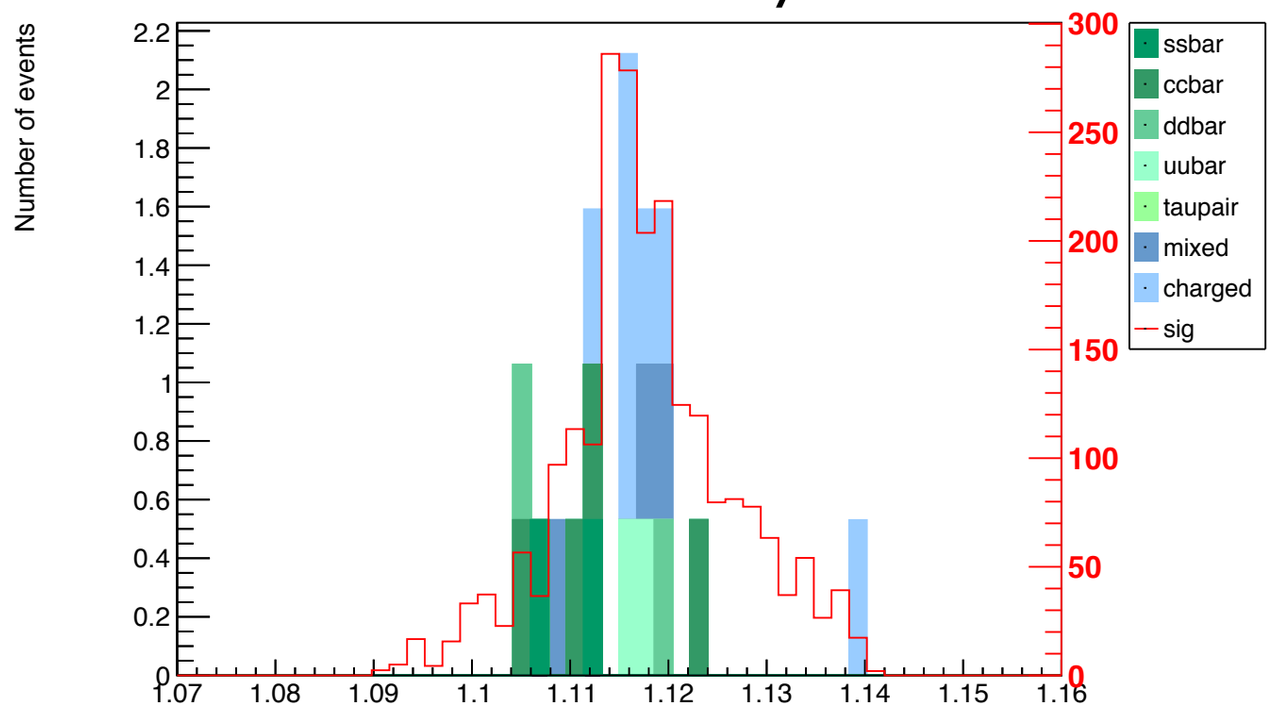
- FEI in phase 2: efficiency is factor of two lower in data than MC:
  - https://docs.belle2.org/record/1111 → §3.1.1
- Lambda reco in phase 2 prod 5 is factor of two lower in data than MC:
  - https://confluence.desy.de/x/dyWdAw → 4 Sep → Updates of proton-ID with Λ

→ Phase 2 results suggest MC and data disagree by factor of four…

<u>Outlook</u>

- Graduating soon, so minimal/no more work from me on this analysis.
- This is a very early sensitivity study (basf2 rel-01, MC9 with MC7 FEI training) - lots of room for future improvements.

Reconstructed Lambda mass
at end of analysis



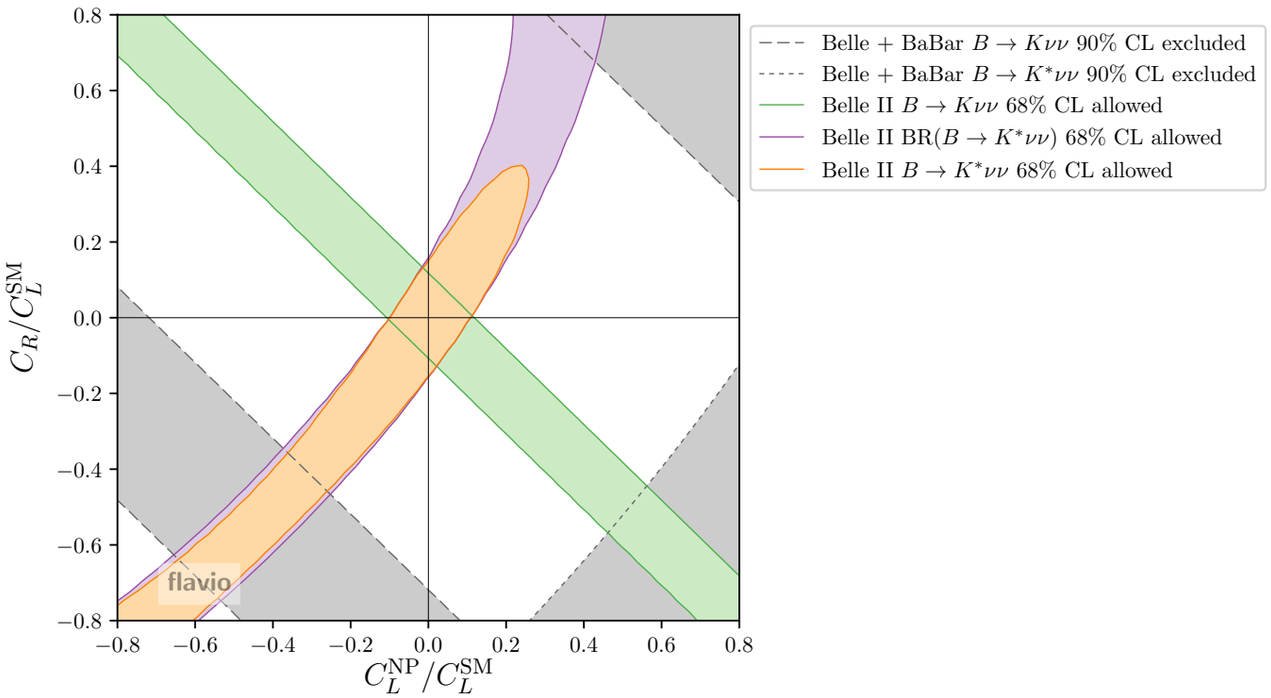
Backup

Details and motivation

- Baryonic equivalent of $B^- \to K^- \nu\bar{\nu}$
  - Predicted: (4.5 ± 0.7) x 10^{-6} (JHEP 2009, 022).
  - Measured:
    BABAR (hadronic): <3.7 x 10^{-5} (PRD 87 (2013) 112005),
    BABAR (semi-leptonic): <1.3 x 10^{-5} (PRD 82 (2010) 112002),
    Belle (hadronic): <5.5 x 10^{-5} (PRD 87 (2013) 11110).

<u>New Physics</u>

· Branching fraction measurement can provide constraints on Wilson coefficients for left- and right-handed weak currents, as already done by Belle and BaBar B -> Knunu analyses.

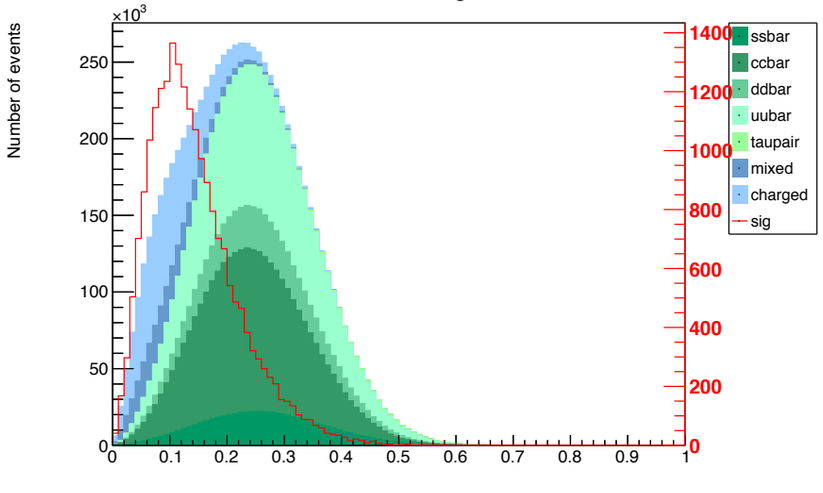


The Belle II Physics Book

Continuum suppression

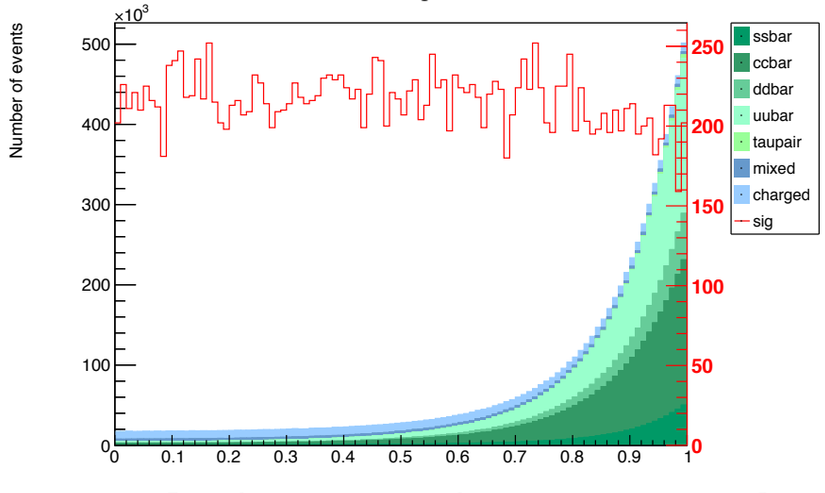
- Build a mutlivariate likelihood from:

R2



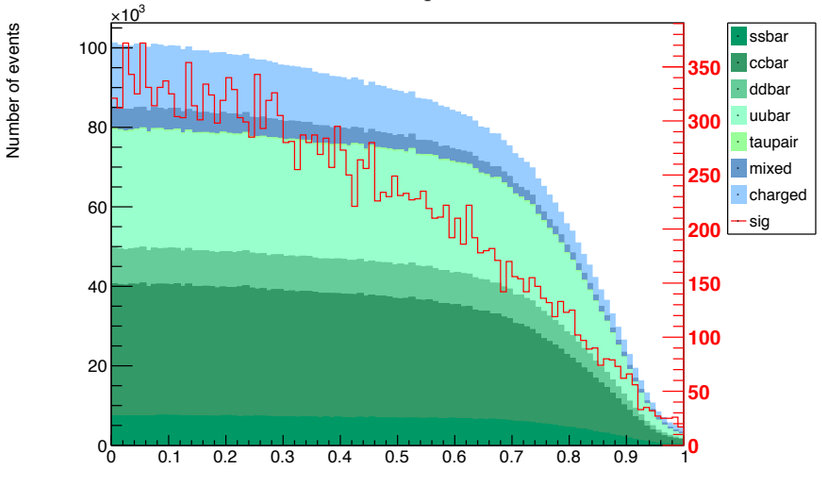
Reduced Fox-Wolfram moment

cos(TBTO)



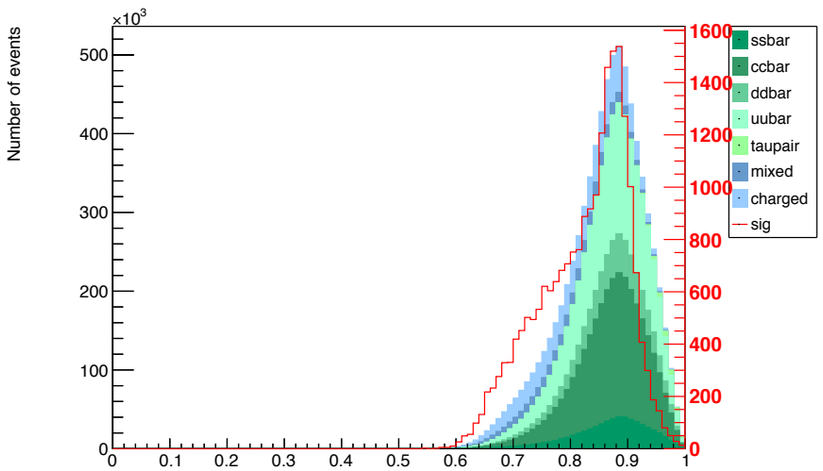
angle between thrust axis of Btag and thrust axis of ROE

cos(TBz)



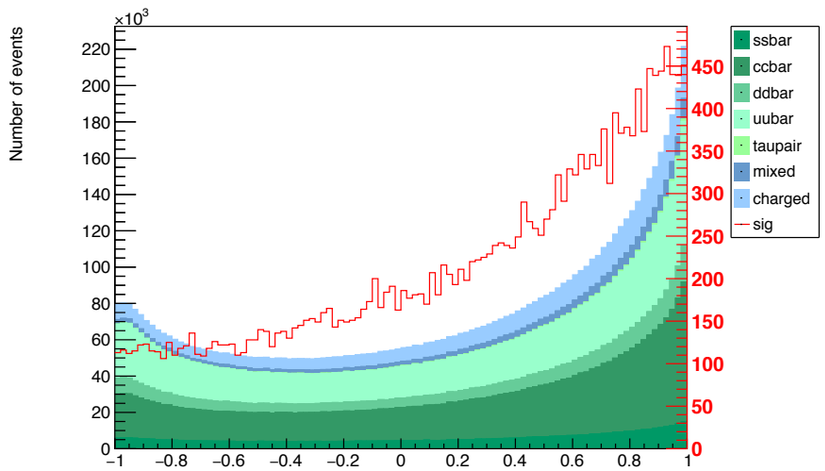
angle between thrust axis of Btag and z-axis

thrustBm



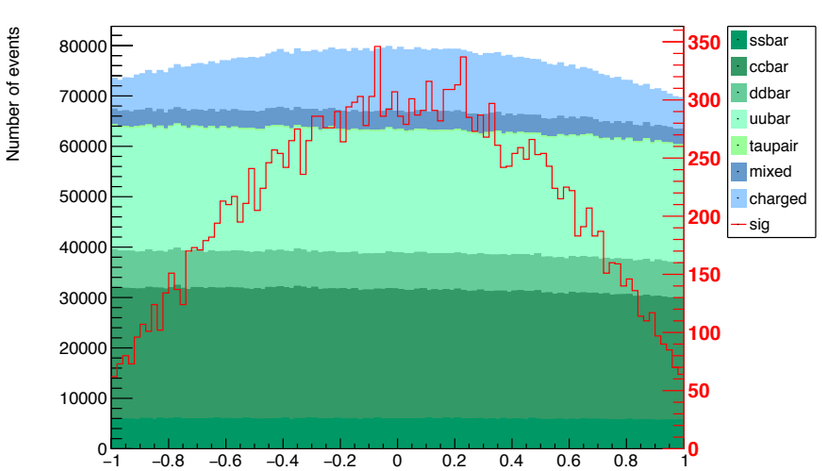
Magnitude of the Btag thrust axis

cos(missP), CM frame



angle between missing momentum and z-axis in CM frame

Btag_cosTheta_CM

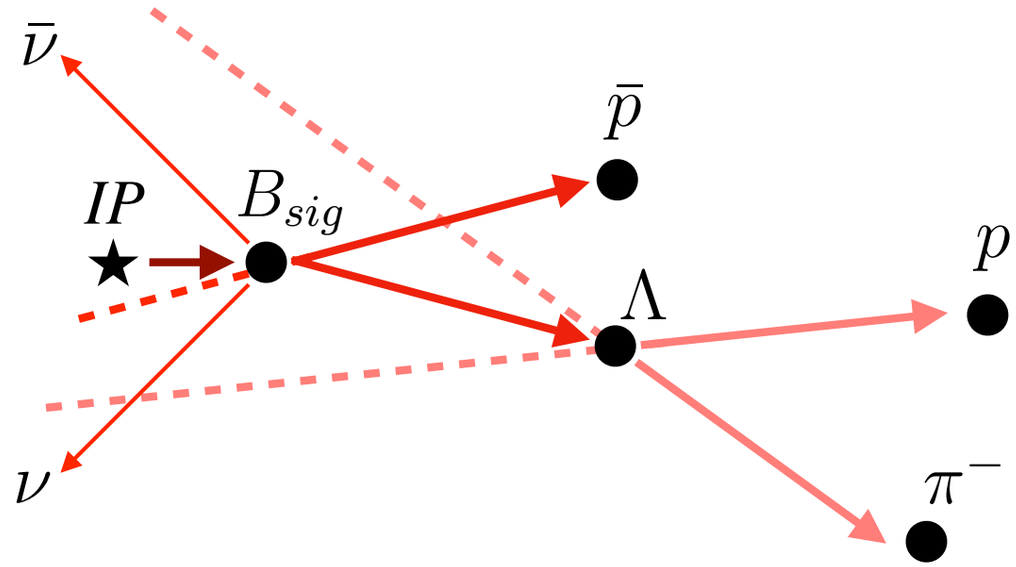


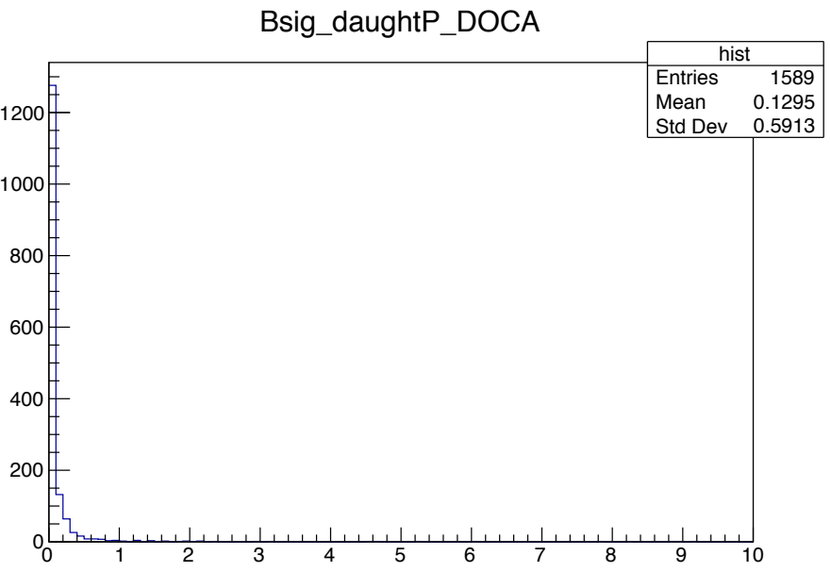
angle between Btag momentum and z-axis in CM frame

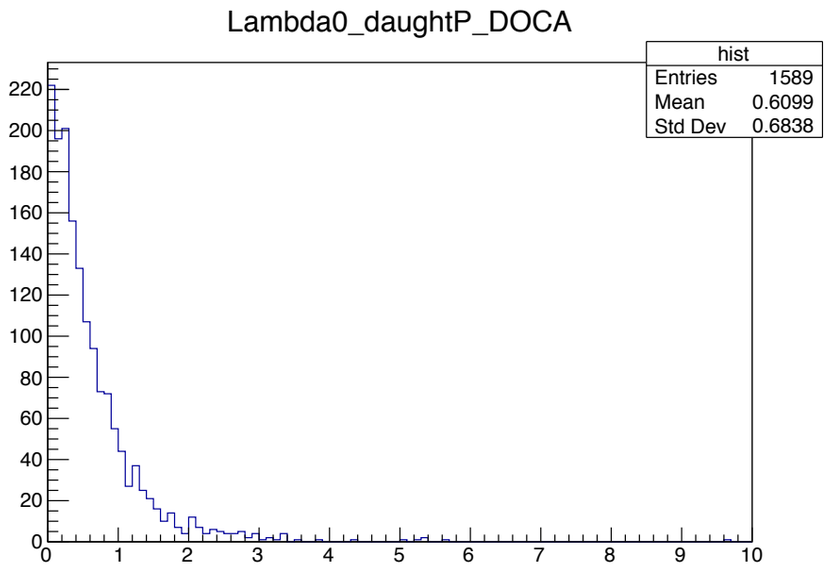
DOCA

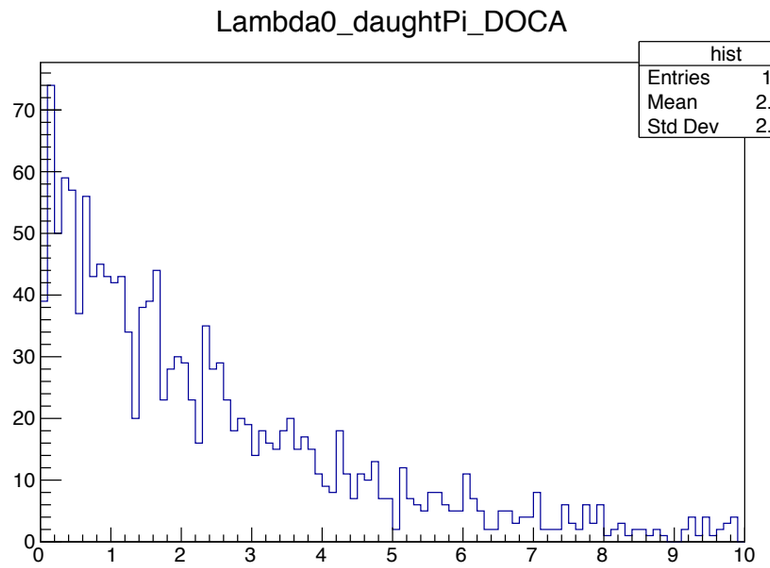
- **D**istance **o**f **C**losest **A**pproach of a track to the IP

Expect: Lowest DOCA - proton from B
Middle DOCA - proton from lambda
Highest DOCA - pion





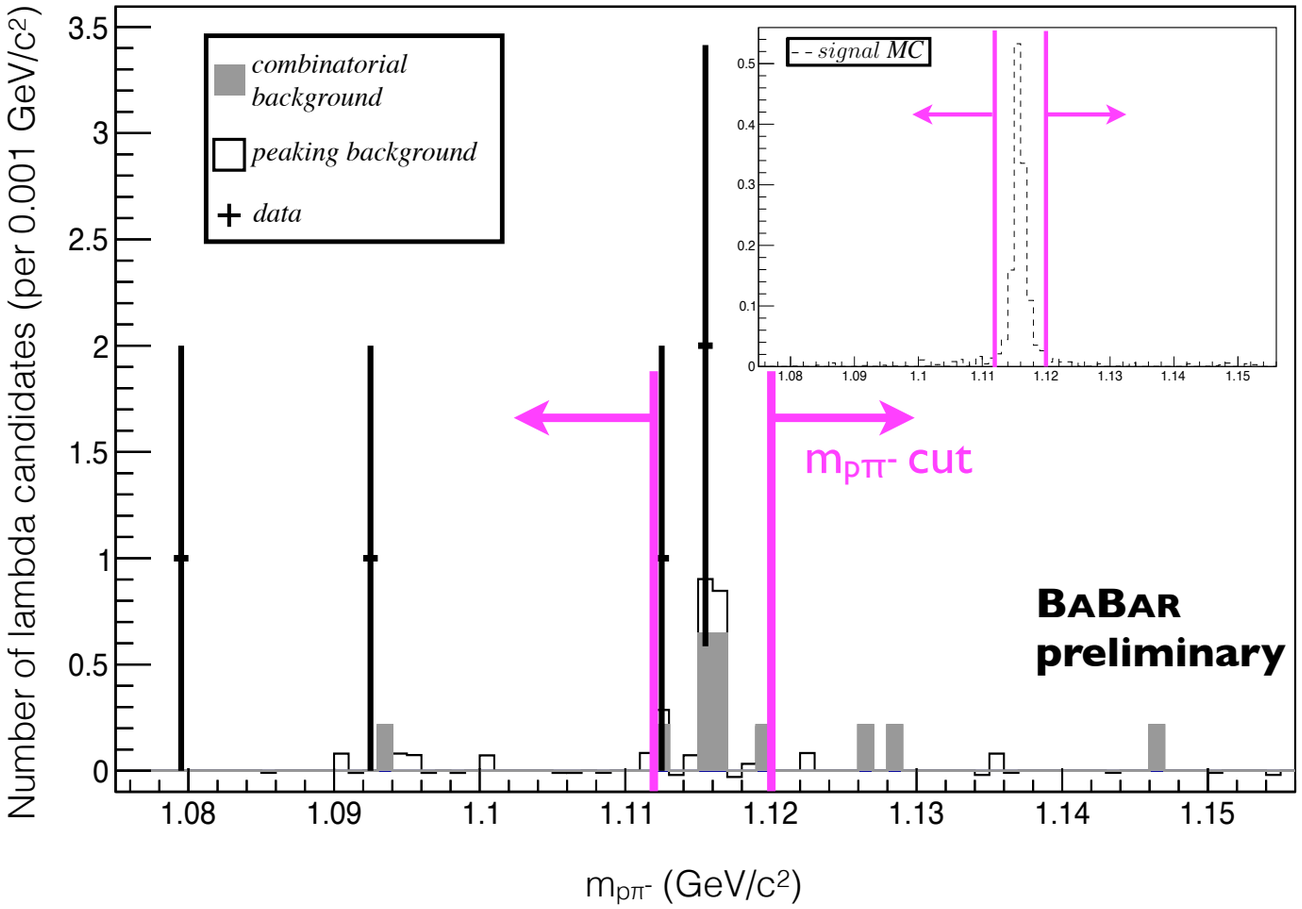




Preliminary tests show that at an intermediate stage of the selection, the DOCA cut causes 13% drop in signal efficiency but 60% drop in background.

BaBar result

- Presented at ICHEP 2018: indico.cern.ch/event/686555/contributions/2986950/



Data in signal region: 3 events

Final background estimate:
2.3 ± 0.7(stat.) ± 0.6(sys.)

Final signal efficiency:
(3.42 ± 0.08(stat.) ± 0.80(sys.)) x 10^{-4}

- First ever measurement of $B^- \to \Lambda\bar{p}\nu\bar{\nu}$. Results:

  BF central value: (0.4 ± 1.1(stat.) ± 0.6(sys.)) x 10^{-5}
  BF upper limit at 90% confidence level: 3.0 x 10^{-5}
  (Compare theory: (7.9 ± 1.9) x 10^{-7})

- No observation of signal or New Physics.