New proton samples for PIDCalib

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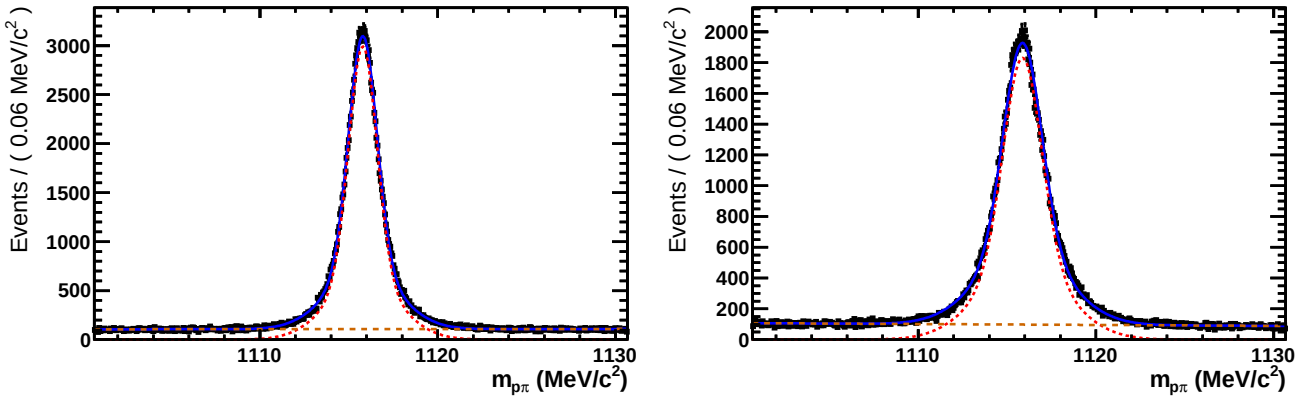
Current PIDCalib calibration samples

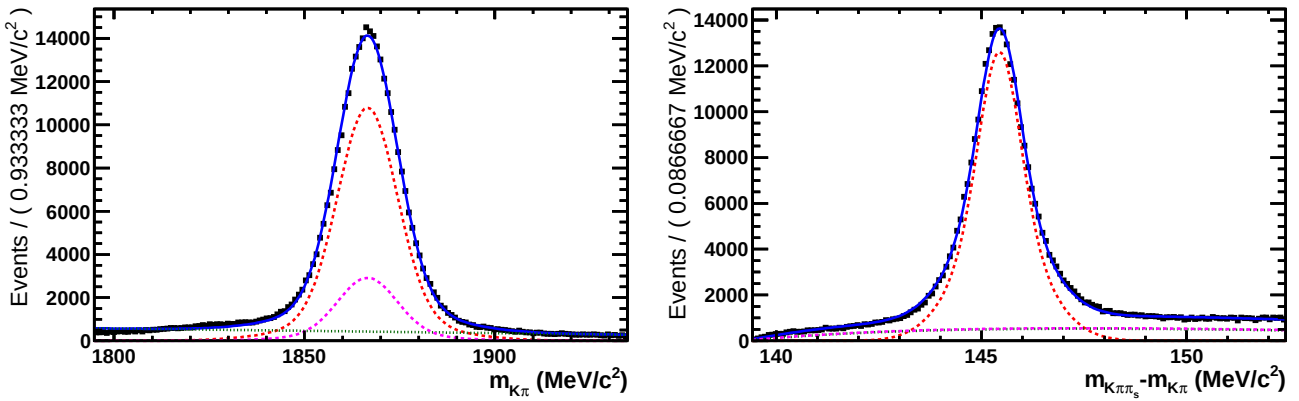
- PIDCalib technique relies on acquisition of charged tracks reconstructed without use of PID discriminants.
- Requires modes which can be reconstructed cleanly with just kinematics.
- Historically been done with:
  - $D^* \to D(K^-\pi^+)\pi_s$ for acquisition of K/π tracks.
  - $\Lambda^0 \to p\pi^-$ for p tracks.
  - $J/\psi \to \mu^-\mu^+$ for μ tracks.
  - And some other modes which are discontinued since Stripping17
    - $\phi \to K^-K^+$, $K^0_S \to \pi^+\pi^-$

PIDCalib mass fits

- Existing modes reconstructed very cleanly:
- Proton mass fits (left $p < 40\ \mathrm{GeV}/c$, right $> 40\ \mathrm{GeV}/c$):



- $D^* \to D(K^-\pi^+)\pi_s$ uses simultaneous fit of m(D^0), left, and δm, right (due to random slow pion contamination, purple):

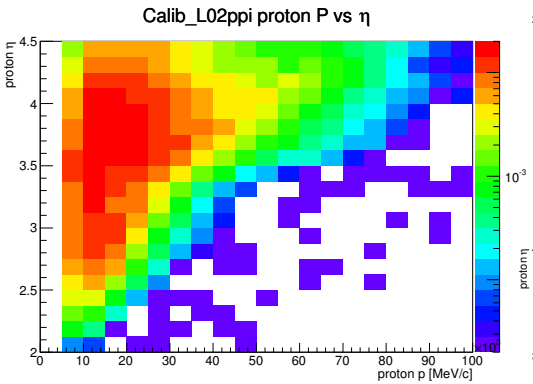


The PIDCalib proton predicament

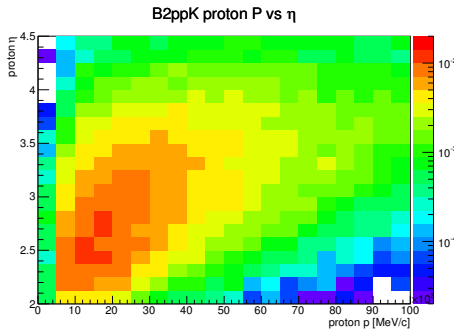
- So what is the problem with protons?
- PIDCalib technique involves binning tracks in suites of variables which characterise PID response:
  - p, p_{T}, η, N_{tracks}, N_{SPDhits}.
- Existing coverage of $\Lambda \to p\pi^-$ samples has poor kinematic overlap with heavy physics decays.
- Leads to regions of phase space where we can't accurately calibrate protons in physics analyses...

Proton kinematics in heavy flavour

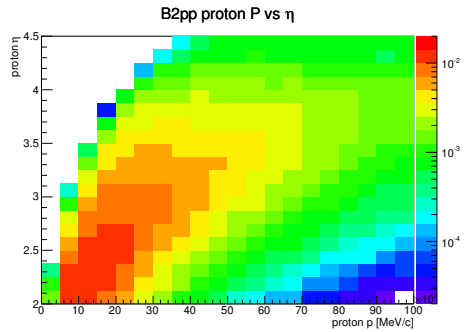
- Normalised proton kinematics for a variety of final selections shown.
  - From Λ_b^0, B and charm baryon decays.
  - MC truth matched or sWeighted data.
  - More info on these plots available in this talk from PID workshop on 28th Jan.



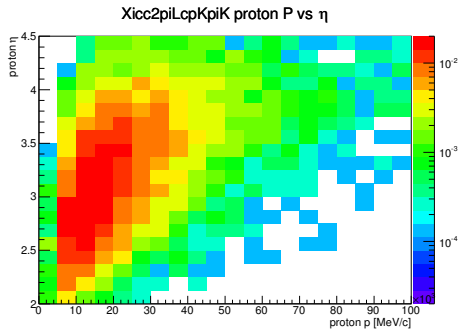
2011 $\Lambda \to p\pi^-$



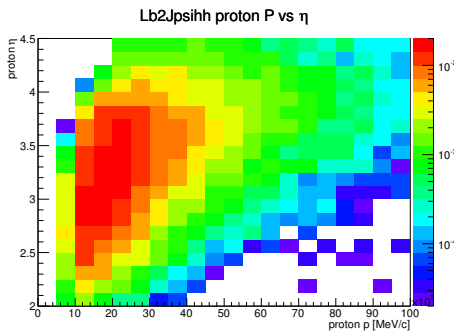
$B \to p\bar{p}K$



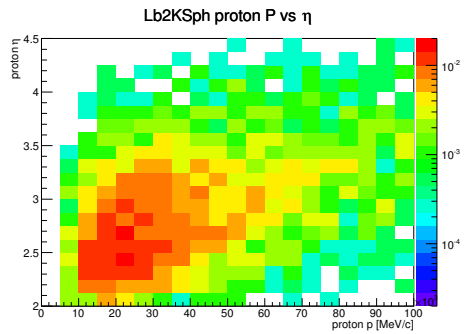
$B \to p\bar{p}$



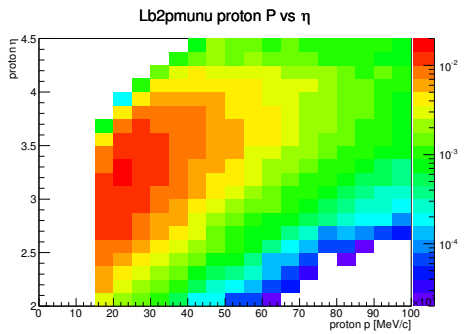
$\Xi_{cc}^+ \to \Lambda_c K^- \pi^+$



$\Lambda_b^0 \to J/\psi\, p\pi^-$



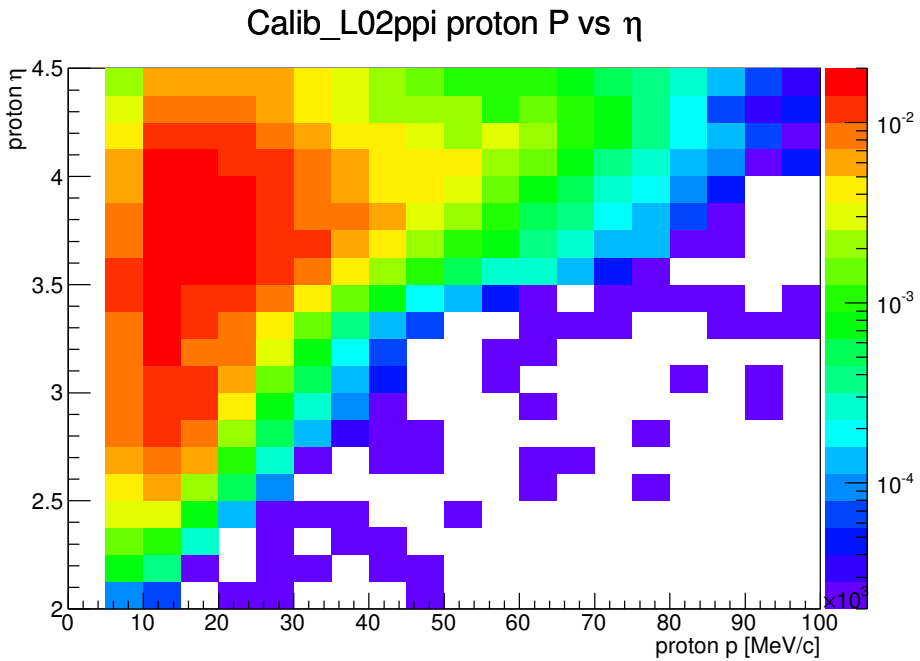
$\Lambda_b^0 \to K_S^0 p\pi^-$



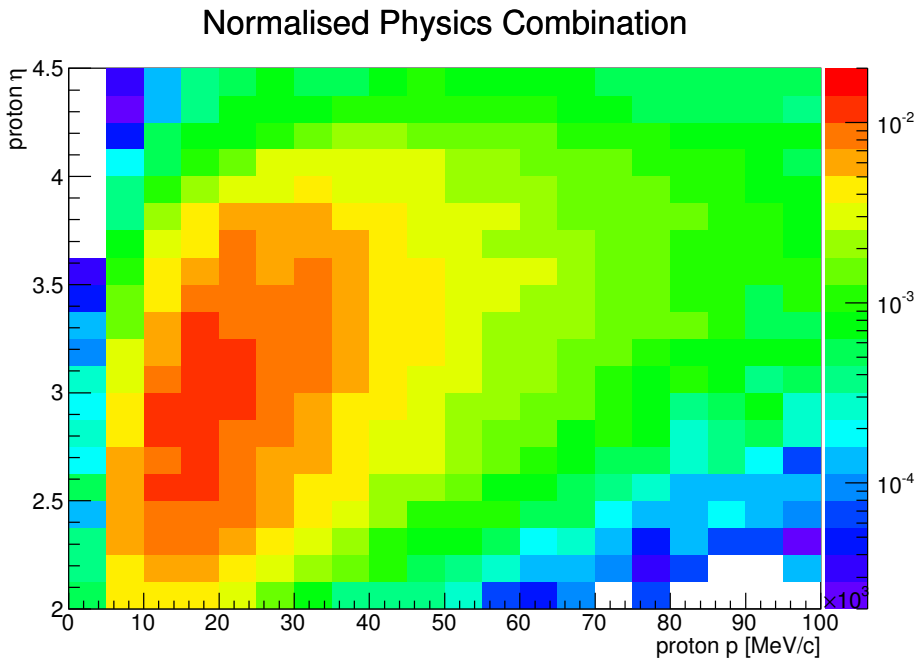
$\Lambda_b^0 \to p\mu\nu_\mu$

Proton kinematics in heavy flavour - summary

- Normalised combination of these physics channels shown right.
- We have physics protons nearly everywhere in the phase space.
- Therefore calibration data needed for full region of acceptance.



Calib $\Lambda \to p\pi^-$



Physics combination

- $\Lambda \to p\pi^-$ **samples on their own are inadequate for LHCb's physics performance.**

Solving this problem

A solution/new decay mode needs:

- Source of high momentum protons at LHCb, with wide kinematic coverage.
- A method of acquisition which places no PID requirements on the protons.
  - Utilise a trigger chain which is exclusively TOS on lines without PID on proton.
  - Alternately: exclusively TIS chain. Downside is much lower trigger efficiencies.
  - Utilise a stripping line which uses no PID cuts on proton.
- Other considerations which are not intractable, but are concerns:
  - High signal purity desirable.
  - High statistics required.
  - Peaking backgrounds kept to a minimum.

$\Lambda_c^+ \to pK^-\pi^+$ decays

- What is the most plentiful source of protons from heavy flavour decays at LHCb?
- Probably $\Lambda_c^+ \to pK^-\pi^+$ decays.
  - $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = 5\ \%$
  - prompt $\sigma_{(\Lambda_c)} = 232\ \text{pb}^{-1}$ at LHCb.
- Problems:
  - Large combinatoric background due to short lifetime. $\tau_{(\Lambda_c)} = 0.2\ \text{ps}$.
  - Dedicated Hlt2 triggers for $\Lambda_c^+ \to phh'$ use PID cuts on protons.
- Solutions:
  - SL tagged decays from $\Lambda_b^0 \to \Lambda_c^+ \mu^- \overline{\nu}_\mu$.
    - Uses TOS chain based on muon, Mika's proton PID-less stripping line.
    - Lower backgrounds due to PV – Λ_c vertex separation and muon trigger.
    - Available in 2011 and 2012.
  - Tagged decays from $\Sigma^{0/++} \to \Lambda_c^+ \pi^{-/+}$.
  - Uses D^* and Σ_c triggers, and Laurence's PID-less stripping line.
  - Only avaliable for 700 pb^{-1} of 2012, when triggers were introduced.

Trigger chains

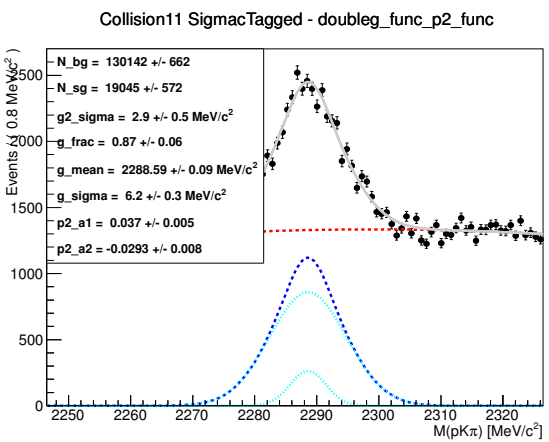
- SL tagged. TOS on:
  - μ^- - L0MuonDecision AND Hlt1TrackMuonDecision
  - Λ_b^0 - OR of Hlt2TopoMuNBodyBBDTDecision, N = 2,3,4
  - Thinking ahead to MC validation - this trigger chain reduces reliance on $\Lambda_c^+ \to pK^-\pi^+$ decay space, where the MC modelling is poor.
- Σ_c tagged. TOS on:
  - Σ_c - L0HadronDecision AND Hlt1TrackAllL0Decision AND (Hlt2CharmHadD02HHXDst_hhXDecision OR Hlt2CharmHadD02HHXDst_BaryonhhXDecision)
- At some point will investigate exclusively TIS chain, but know from $\Lambda_c^+ \to phh'$ $\mathcal{B}$ analysis that efficiencies are very low.

A big caveat regarding Σ_c

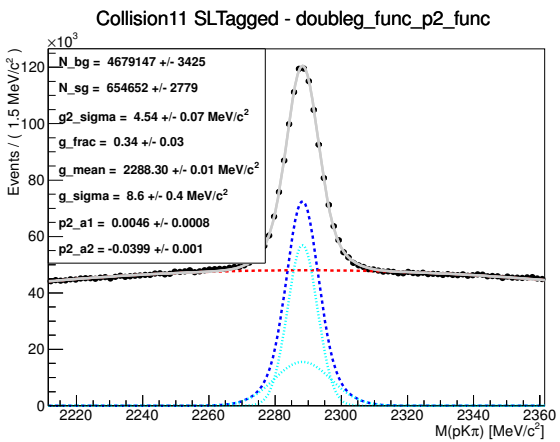
- Something appears to have gone wrong with my DV processing of the Σ_c line output.
- Statistics presented here are lower than the 9 pb^{-1} test samples provided to me by Laurence in January.
- Below 1k found, around 173k expected. Investigating this now.
- Σ_c mass plots here are indicative only of expected purities, and signal and background shapes.
- **Should not be taken as indication of expected signal statistics!**

Stripping output

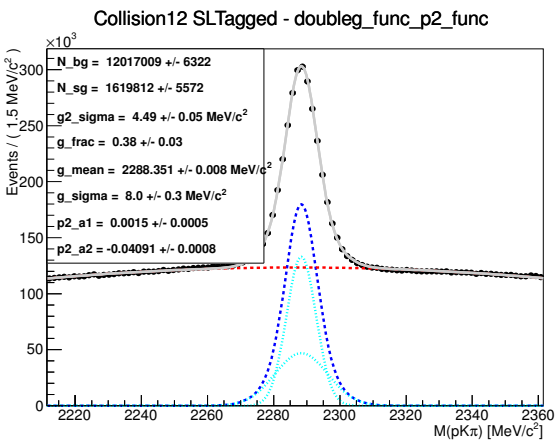
- Output of stripping lines below, without trigger cuts.
- 5-10 % of each processing failed on grid, final stats will rise correspondingly.
- *Very* rough fits to estimate statistics:
  - D reflections abundant with complicated shapes
  - Fit pulls are correspondingly bad
- Double Gaussian function signal models, N=2 Chebychev polynomial backgrounds.



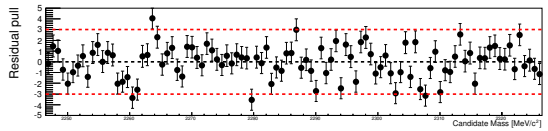
2012 Σ_c tagged

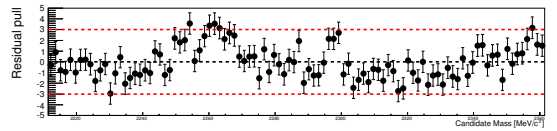


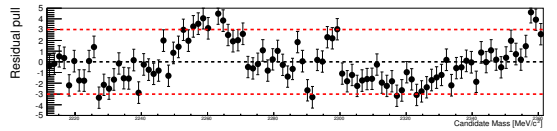
2011 SL tagged



2012 SL tagged

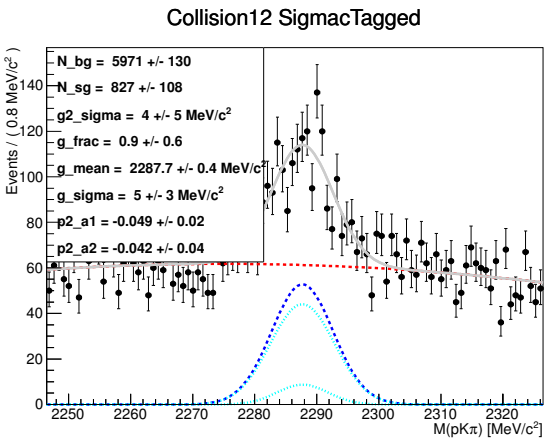




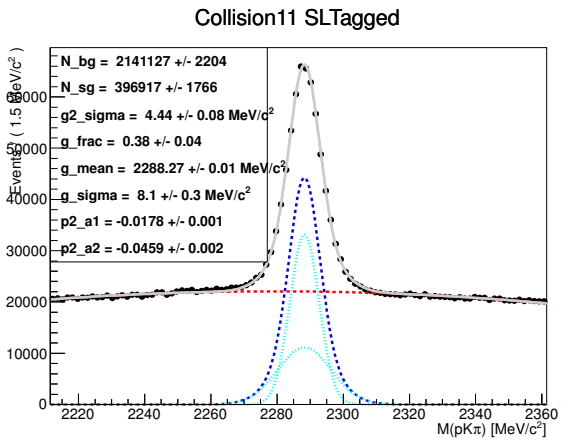


Output after triggers

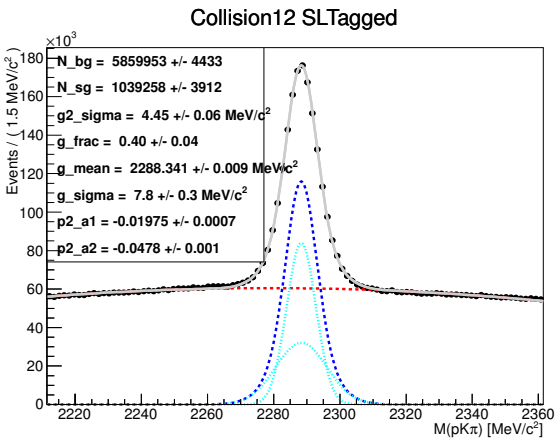
- SL tagged: around 400k candidates in 2011, 1m (!) in 2012.
- Purity at this stage is poor, perhaps "not good enough" for `PIDCalib`.
- Need to properly understand backgrounds to employ ${}_s\mathcal{P}lots$ technique.



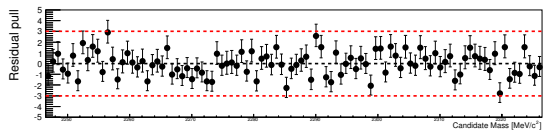
2012 Σ_c tagged

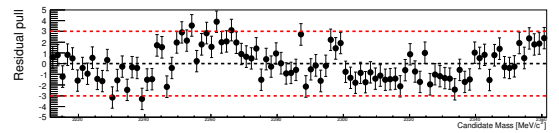


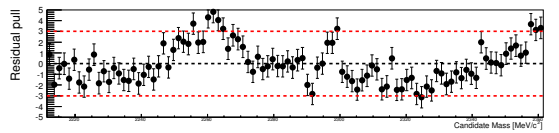
2011 SL tagged



2012 SL tagged





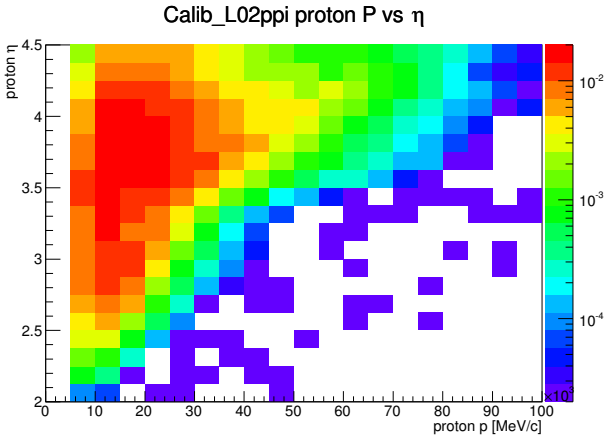


Sample kinematics

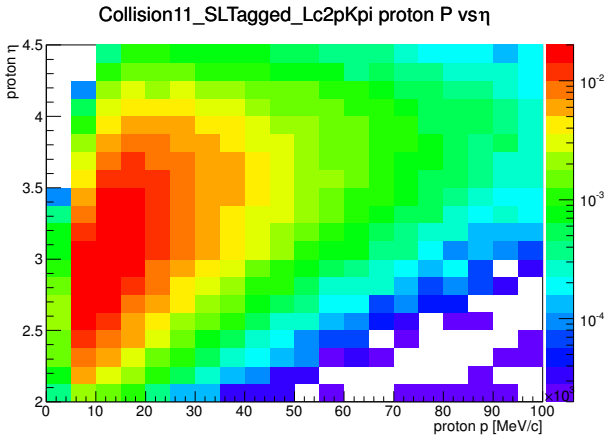
- Will focus on just SL tagged samples until issues with Σ_c processing is resolved.
- How do these samples look in terms of the variables discussed earlier?
- Fits sufficient at this stage for rough sideband subtraction.

Sample kinematics - p vs. η

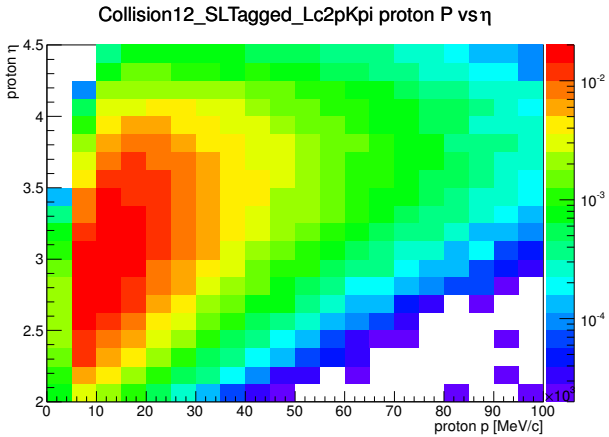
- p vs η for existing and SL tagged samples.
- sWeighted for sideband subtraction.
- Improved coverage over a broad range of the phase space.



2011 $\Lambda \to p\pi^-$



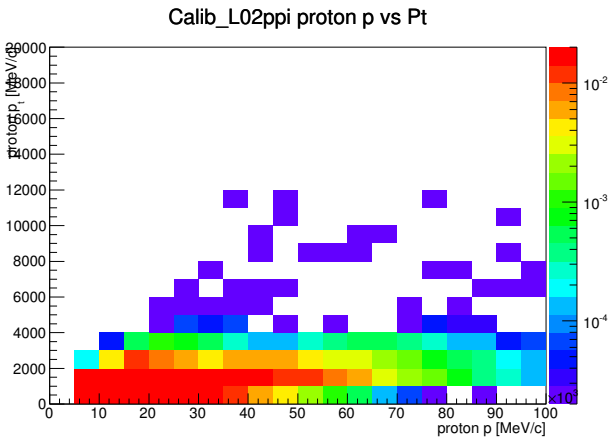
2011 SL Tagged



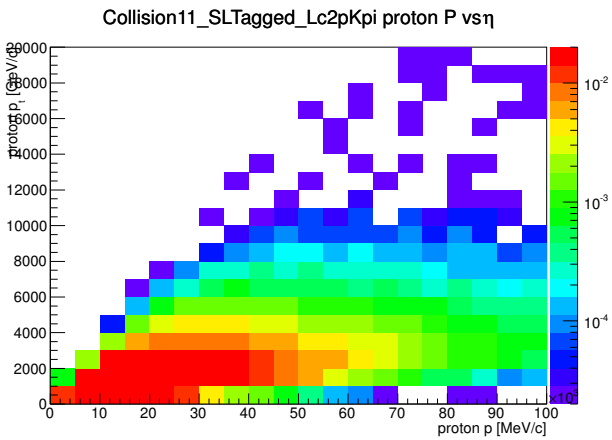
2012 SL Tagged

Sample kinematics - p vs. p_{T}

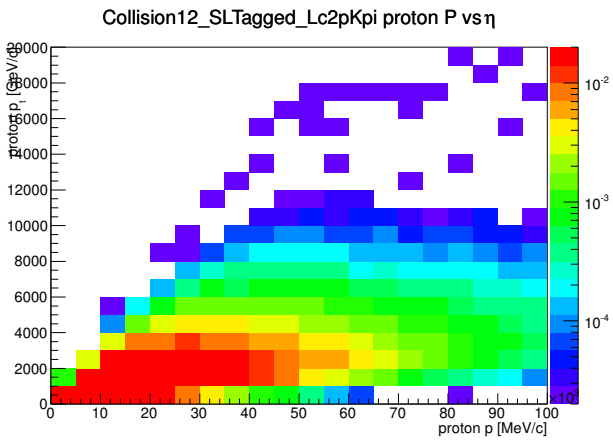
- p vs p_{T}.
- sWeighted for sideband subtraction.



2011 $\Lambda \to p\pi^-$



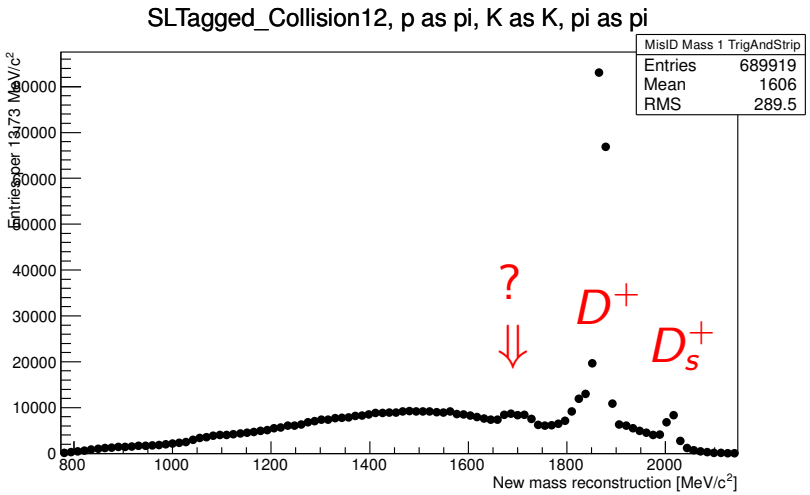
2011 SL Tagged



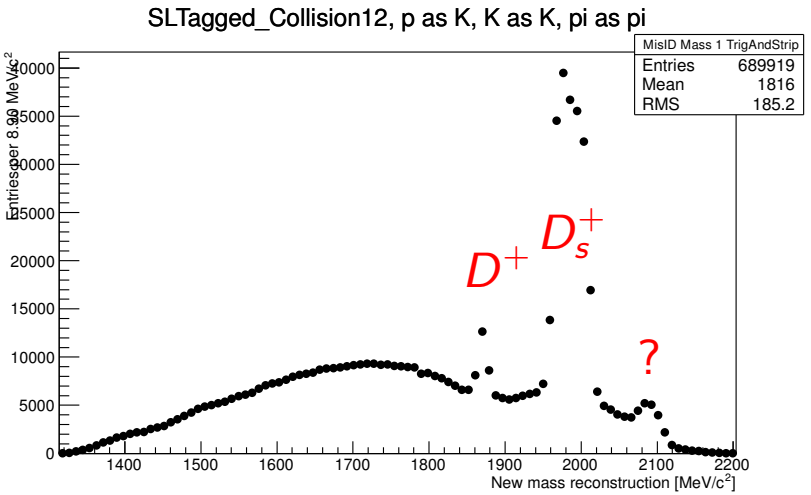
2012 SL Tagged

2012 data $D^+ \to hhh$ reflections

- Check for reflections from $D^0 \to hhh$, $D_s^+ \to hhh$ by reassigning the proton mass hypothesis as either a K or π, then recompute the candidate mass.
  - These check for $D^+/D_s^+ \to h^+K^-\pi^+$ (h $= \pi/K$), high $\mathcal{B}$ decays and only proton mis-ID necessary to manifest.
- Clear peaking structures at the D^+, D_s^+ masses, and 2100 MeV/c^2.



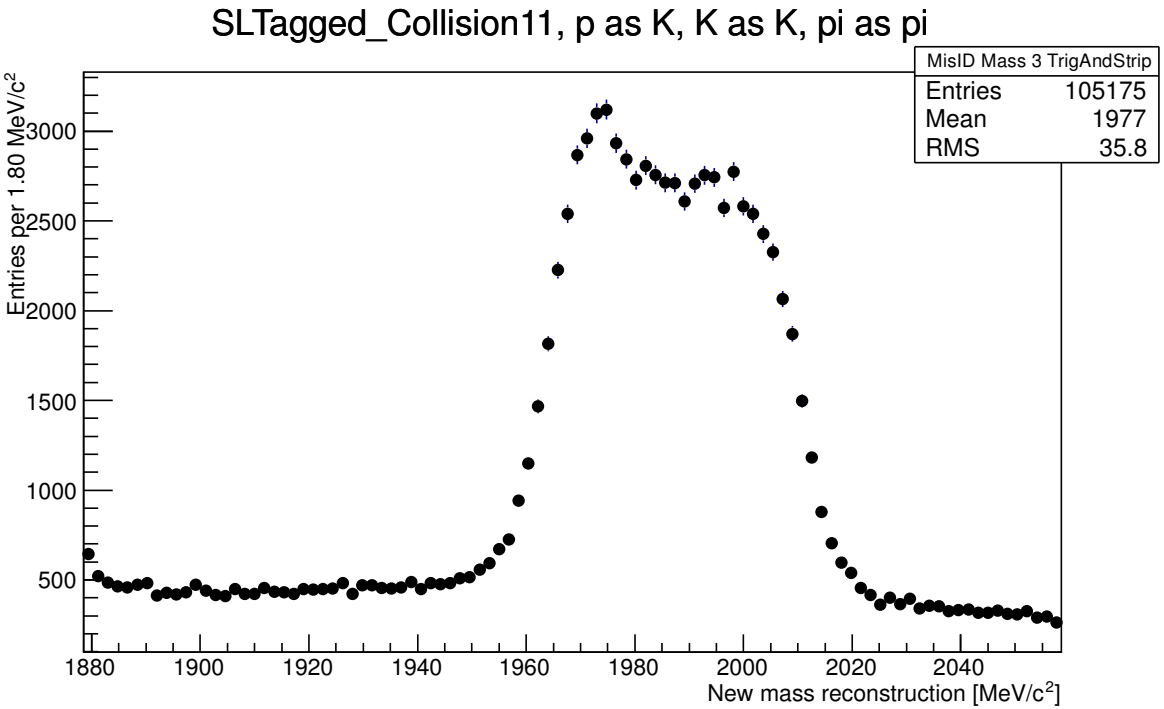
$p\ K^-\ \pi^+ \to \pi^+\ K^-\ \pi^+$



$p\ K^-\ \pi^+ \to K^+\ K^-\ \pi^+$

2012 data $D^+ \to hhh$ reflections - closeups

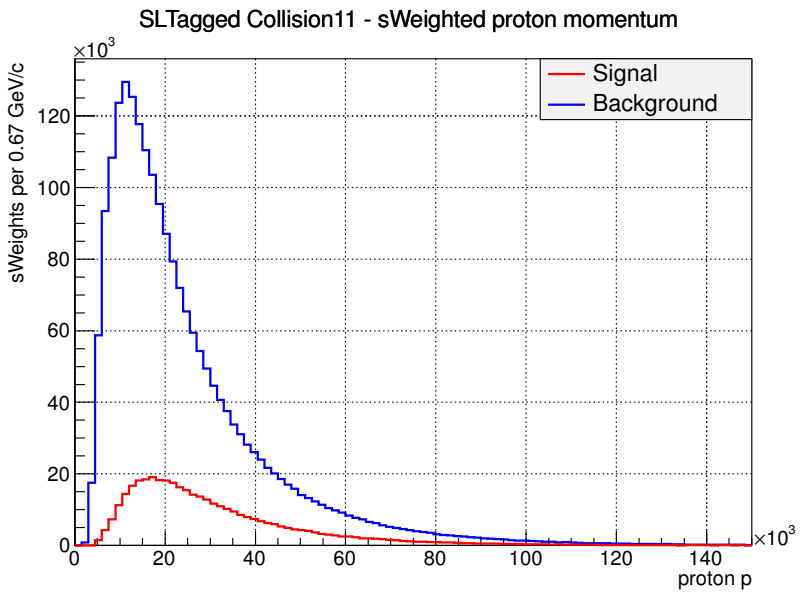
- Close up of the D_s^+ mass region with final state mass hypotheses of K^+ K^- π^+:
- Two peaking structures in close proximity?
- More work required to understand these peaking backgrounds.
- Possible veto needed across this whole region.
- 2011 not shown but similar backgrounds observed.



$$p\ K^-\ \pi^+ \to K^+\ K^-\ \pi^+$$

SL Tagged DLL(p – K) at high/low p

- Asked to produce plots showing the DLL(p– K) distributions for signal/background at either side of $p = 10\,\mathrm{GeV}/c$.
- Aerogel above K theshold, other radiators below K threshold, all radiators below p threshold at $p < 10\,\mathrm{GeV}/c$.
- Can inform aerogel performance discussions.
  - Any differences in signal and background distributions below $p = 10\,\mathrm{GeV}/c$ necessarily comes from aerogel discrimination.
  - Require that the proton momentum is above the K aerogel threshold.
- Momentum distributions shown below.

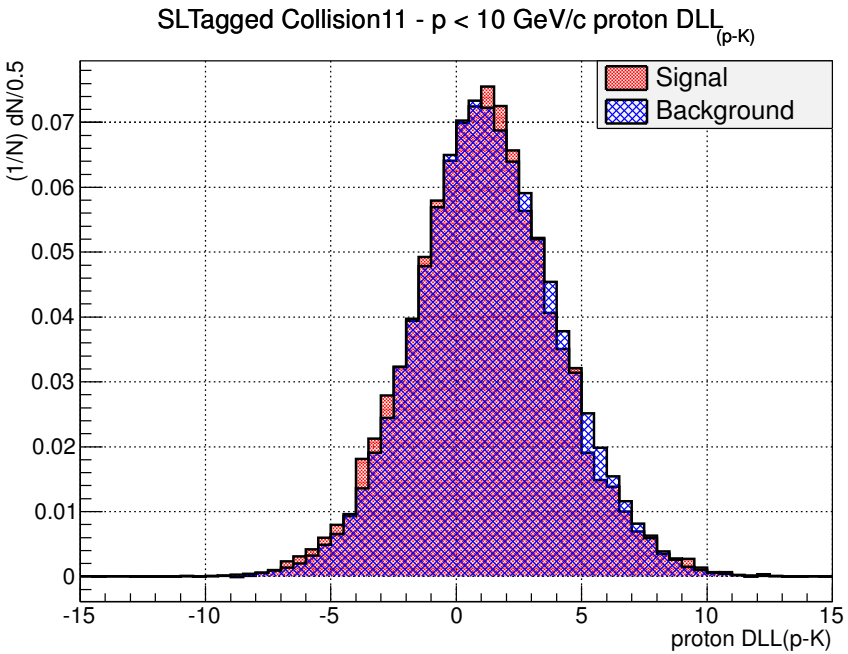


2011 data

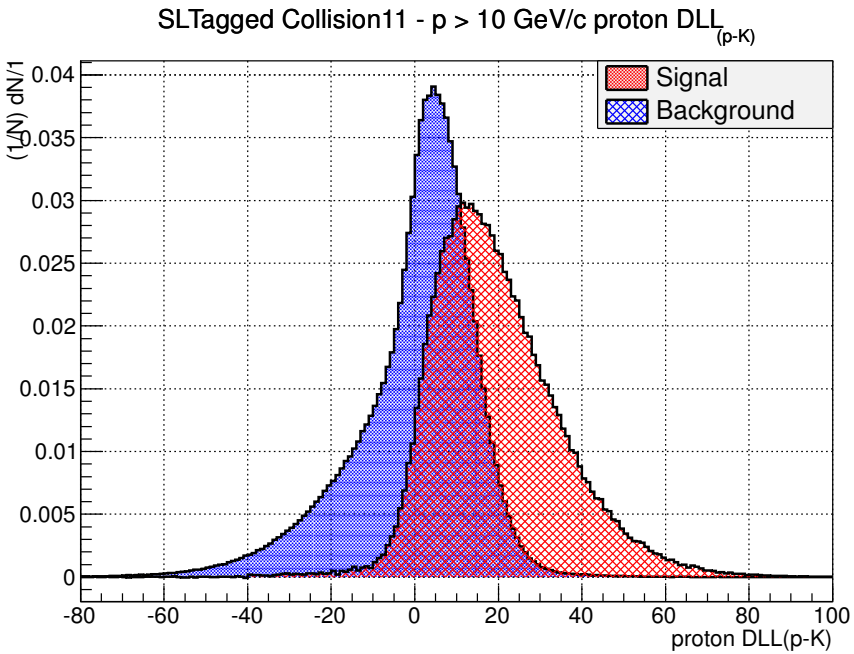
2012 data

2011 SL Tagged DLL($p - K$)

- sWeighted plots of DLL($p - K$) distributions shown below.
- No $p - K$ discrimination in 2011 below P $= 10$ GeV/c.



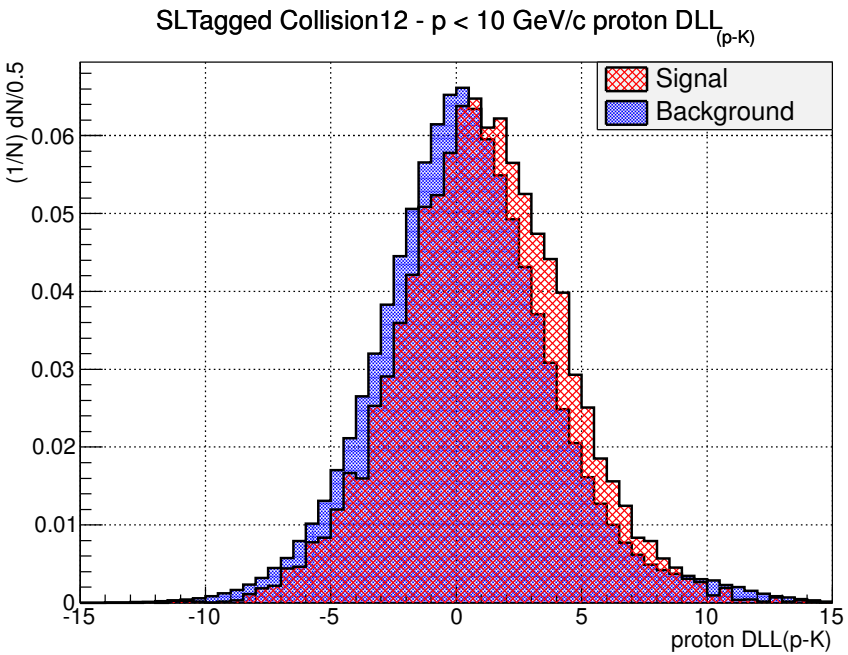
$p < 10$ GeV/c



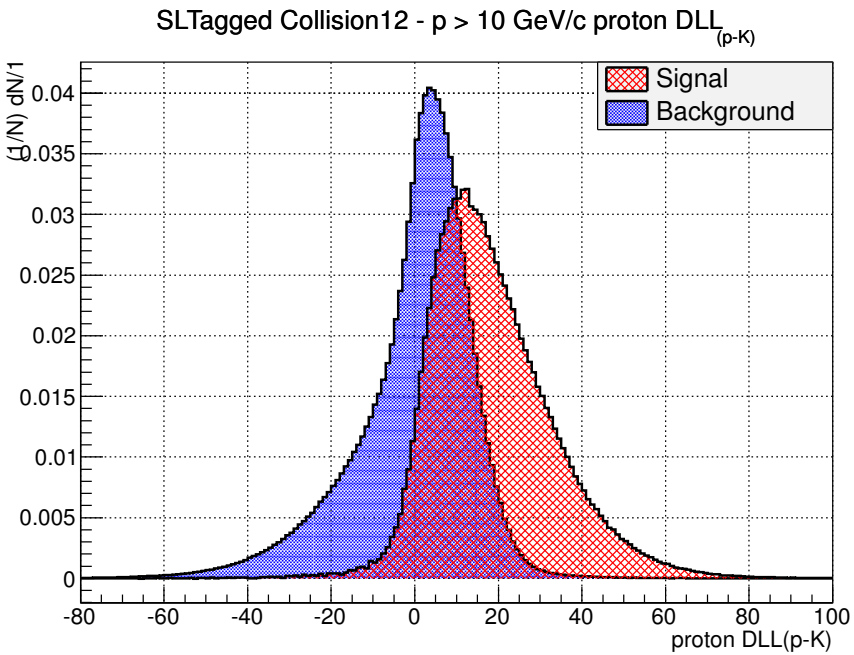
$p > 10$ GeV/c

2012 SL Tagged DLL(p– K)

- Minor improvement in performance compared to 2011 below P $= 10$ GeV/c.
- Possible effect of the aerogel box installed in 2012?



$p < 10$ GeV/c



$p > 10$ GeV/c

Future proton sample work

- Vetoes on D reflections to be implemented.
- Now beginning the optimisation of the offline selection to improve purity.
  - MVA has proven useful in $\Lambda_c^+ \to phh'$ analysis.
  - Plenty of signal to work with, can sacrifice a little to get the backgrounds down.
- MC needed for validation, and for systematic studies on physics user end.
- When samples are optimised and validated, can be swiftly implemented in the expert side of the `PIDCalib` package.
- Should drastically improve heavy flavour proton calibration.