Monte Carlo with pulser beam background

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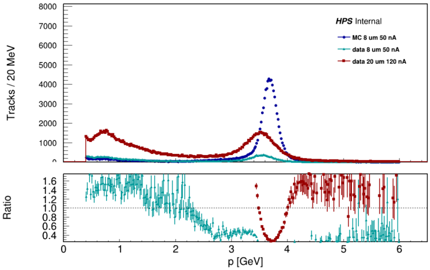
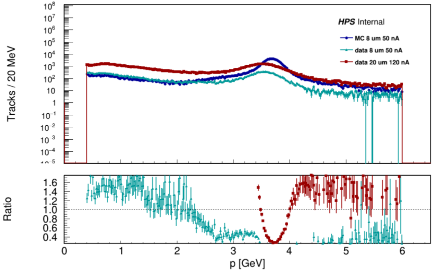
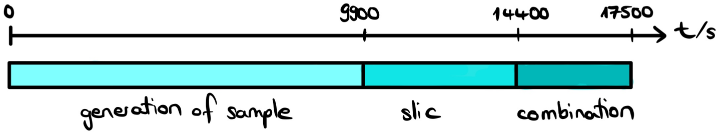
Motivation





- Fall 2022, early 2023: Tongtong and Cam show excess of FEEs in MC simulated beam
- Above: old plots from Cam
  - For thin ($8\,\mu$m) target: data and MC agree at low momenta; distributions diverge at FEE peak
  - Comparing to data taken with thick ($10\,\mu$m) target: thin target MC has more events in FEE peak

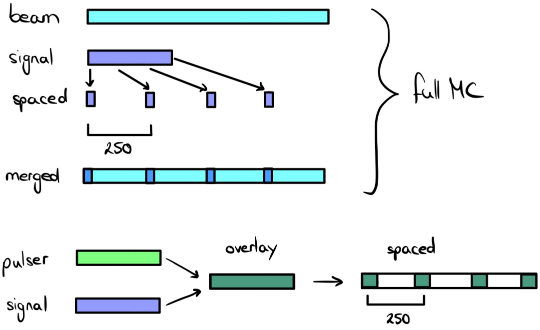
Motivation



- Generation of full MC sample (beam and signal simulated) takes a lot of time
  - Full simulation of beam and detector response takes about 4 hours
  - Merging of simulated beam and signal adds another $\sim 1\,\mathrm{h}$
- Overlaying simulated signal with random beam background (pulser) could be faster

MC methods – combination of signal+beam

SLAC

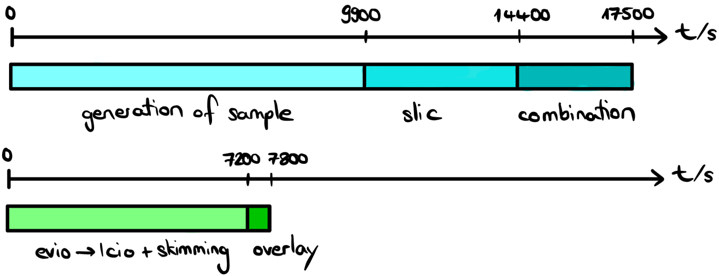


- full MC: generate continuous beam background, merge with spaced signal
- pulser: overlay signal and random beam, space in time, and expand

A'+beam MC sample production

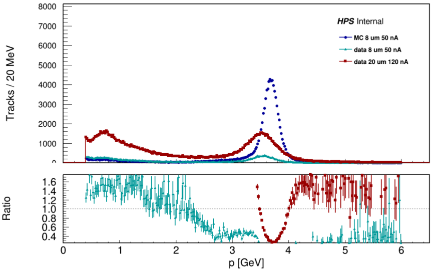
- Full MC
  - Beam and signal simulated
  - Signal spaced by event interval = 250
  - Using LCIOMerge to merge both samples
  - For more details see `hps-mc/python/jobs/signal_beam_merge_to_recon_job.py`
- Pulser data
  - Overlay random beam data and simulated signal
  - Space events with event interval = 250
  - For more details see `hps-mc/python/jobs/signal_pulser_overlay_to_recon_job.py`
- For both samples: run the same readout and reconstruction
  - Steering for readout: PhysicsRun2021TrigMultiSingles.lcsim and PhysicsRun2019TrigSinglesWithPulserDataMerging.lcsim
  - Both use singles2 and singles3 trigger
- Detector used: HPS_Run2021Pass1_v4; run number: 14229

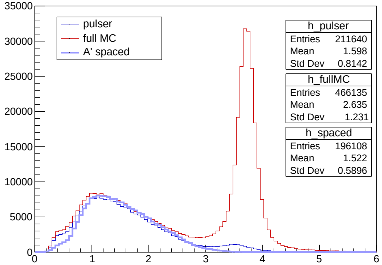
Comparison production times



- Generation of full MC sample
  - Full simulation of beam and detector response takes about 4 hours
  - Merging of simulated beam and signal adds another $\sim 1\,\mathrm{h}$
- Overlaying simulated signal with pulser
  - Converting files and skimming random + pulser triggers takes about 2h or less
  - Overlaying signal and pulser takes $\mathcal{O}(10\,\mathrm{s})$

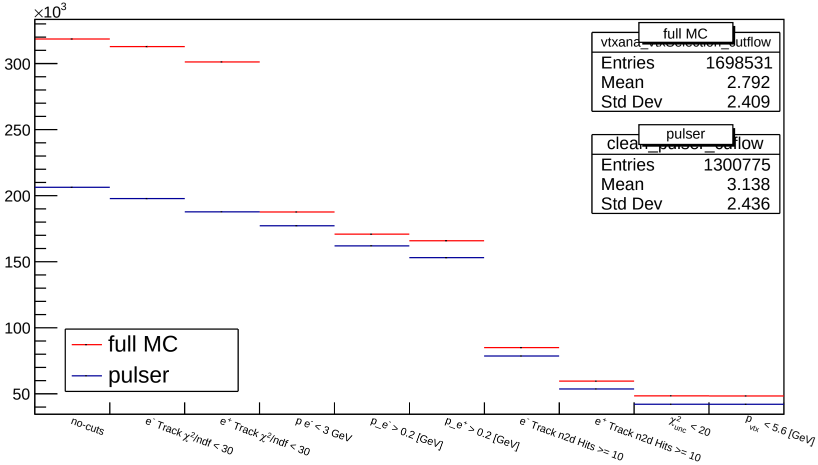
Comparing track momenta





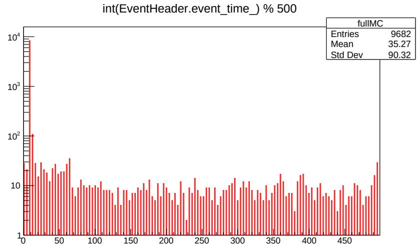
- Find tracks with $n_{\text{hits}} \geq 10$ and $\chi^2/\text{ndf} \leq 30$
- Comparing Cam's old plot to simulated and pulser track momenta
  - Distributions have low momentum peak from simulated A' signal
  - Full MC shows an excess of FEEs
  - Pulser data shows a much smaller peak at beam energy

Preselection cutflow

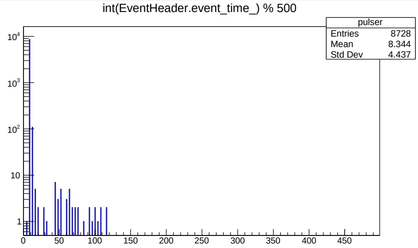


- Looking at the number of triggers: additional triggers for full MC
  - Are the additional events out of time backgrounds?

EventHeader event time

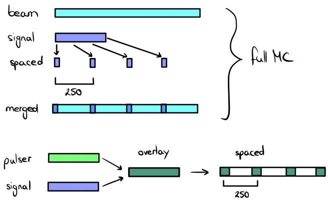


full MC



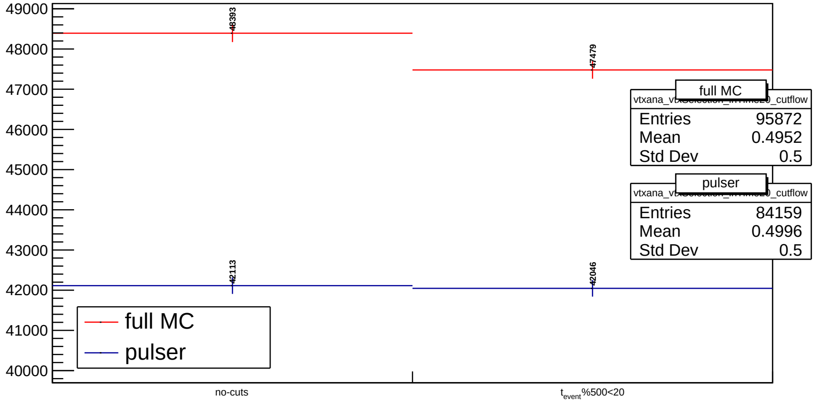
pulser

- Expect event time mod 500 to peak at low values
  - Can be seen in both distributions
  - Peak contains signal events (by construction)



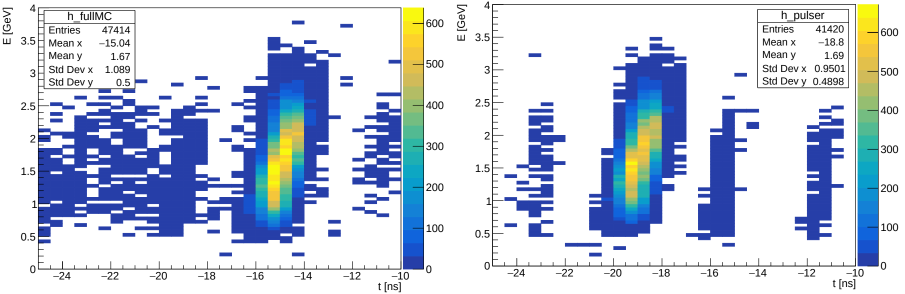
- Out-of-time background for full MC adds to the total number of triggers

Cut on event time $t_{\text{event}} \% 500 < 20$



- Cut on event time removes $\mathcal{O}(10^3)$ events from full MC and $\mathcal{O}(50)$ events from pulser

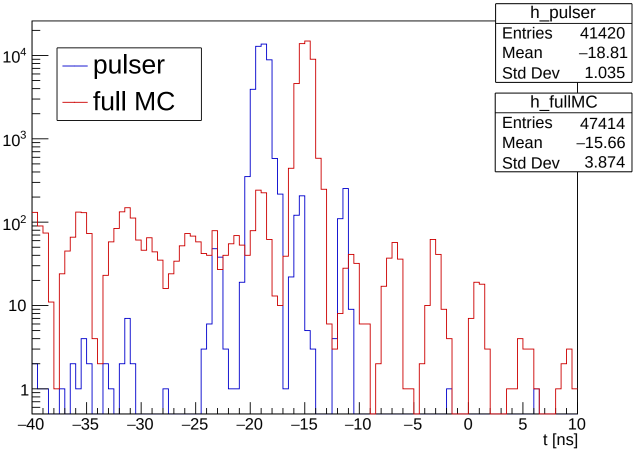
Positron clusters – no cut on event time



full MC   pulser

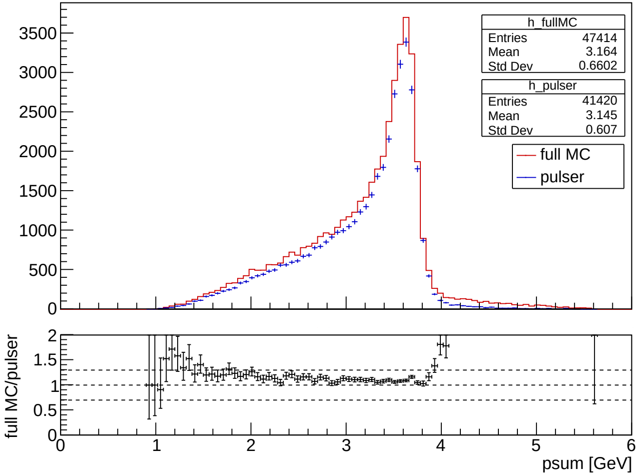
- Looking at positron cluster energy vs time
  - Bunch structure in time visible main peak at different times
  - Similar structure in energy distribution

Positron cluster time – no cut on event time



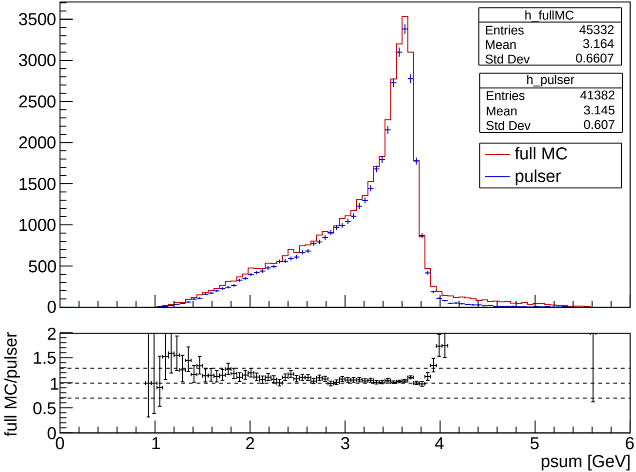
- Difference in timing for both models
  - Originating from readout simulation; different time shifts?
  - Full MC has more background at $t \lesssim 20\,\mathrm{ns}$

Comparison of psum distributions – no time cut



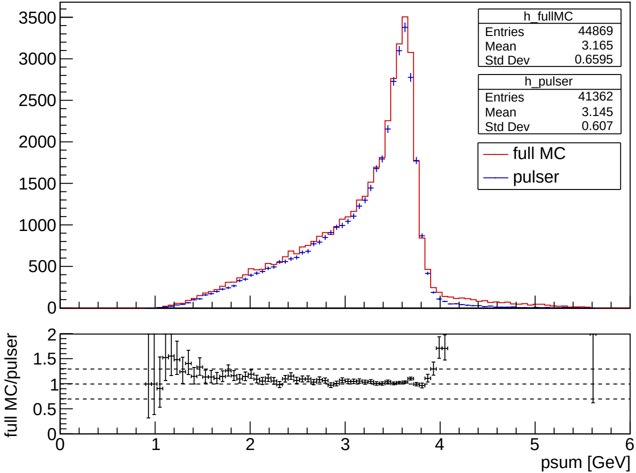
- More events in full MC; ratio $\sim$ constant around 1.1-1.2

Cut on positron cluster time $t_{\text{clust}} > -25$



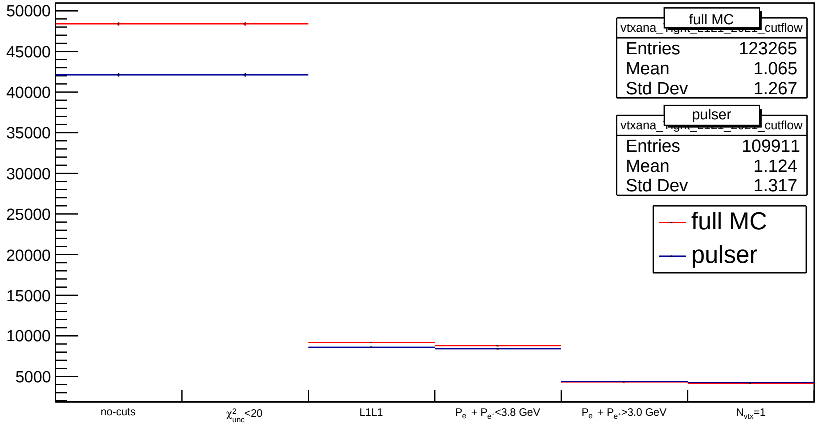
- Cut on positron cluster time, allowing $t_{\text{clust}} > -25$ for both samples
- Removes $\mathcal{O}(2000)$ events from full MC

Cut on positron cluster time and event time



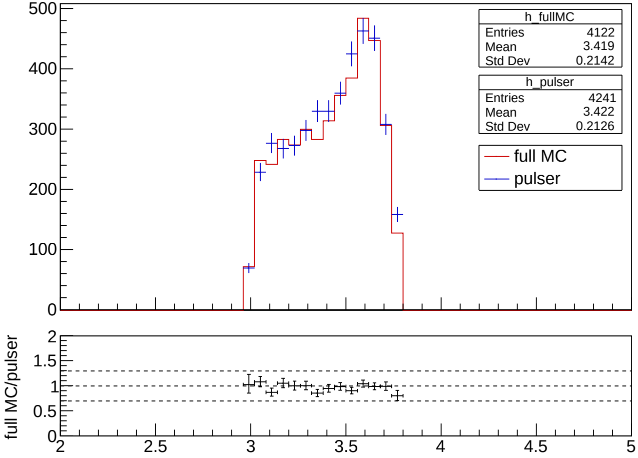
- Event time $t_{\text{event}}\%500 < 20$ and positron cluster time $t_{\text{clust}} > -25$
- Full MC still has more events in high psum tail

Tight selection



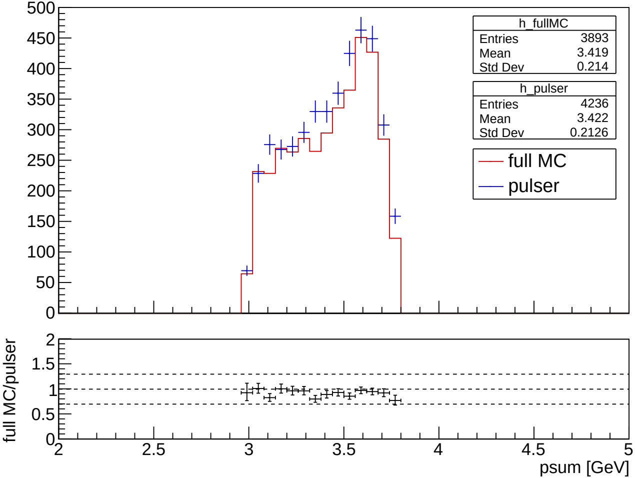
- Number of events that pass tight selection similar for both methods
- L1L1 requirement has a big impact on both samples

Psum after preselection



- Distributions match; slightly fewer events in full MC

Psum after preselection – time cuts



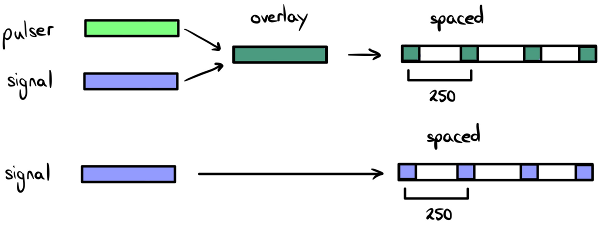
- $t_{\text{clust}} > -25$ and $t_{\text{event}}\%500 < 20$
- Cuts back on full MC event number

Conclusion I

- Using pulser and randomly triggered data enables us to correctly reproduce the beam background.
- Apart from differences in timing (event time and cluster time), the two MC versions are very similar.
  - Full MC has extra, out-of-time events
  - Positron cluster time peak is shifted by about 5 ns
- After preselection, including time cuts, psum distributions match
  - Small excess of events in high psum tail for full MC
- Tight selection yields matching psum distributions for both methods
- Note: investigation of pulser overlay led to (minor) bug fix
  - Previously only singles3 trigger was used in the readout simulation for pulser overlay
  - Now: singles2 and singles3, matching full MC trigger simulation

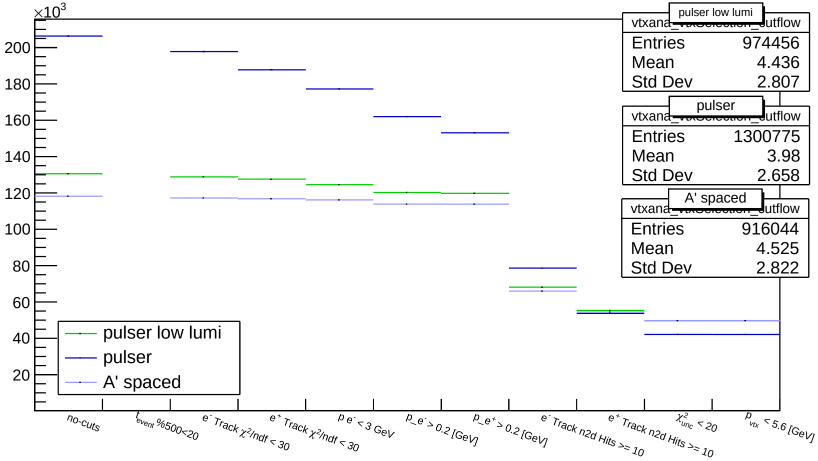
Moving on: first analysis of pulser + signal MC

- From now on: ignore full MC sample, focus on comparing pulser+A' to pure A' sample
  - Pure A' sample is spaced and extended in time, just not overlayed with pulser data



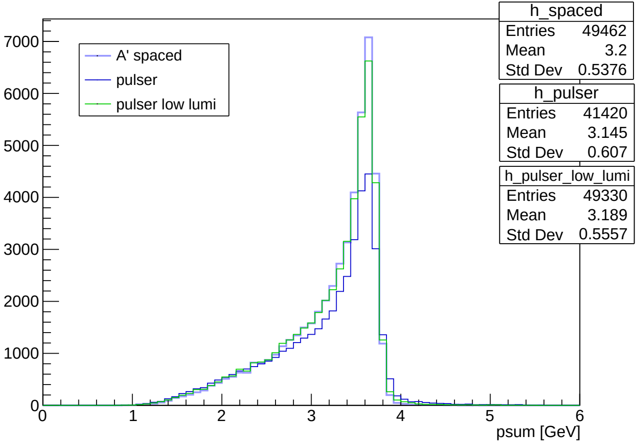
- Additionally: look at low luminosity pulser overlay
  - Using 2021 low lumi run 14166
  - Expect less background for low lumi overlay – reconstruction performance similar to pure A' sample
  - Same overlay, readout, reconstruction pipeline as for 'normal' pulser

Preselection cutflow



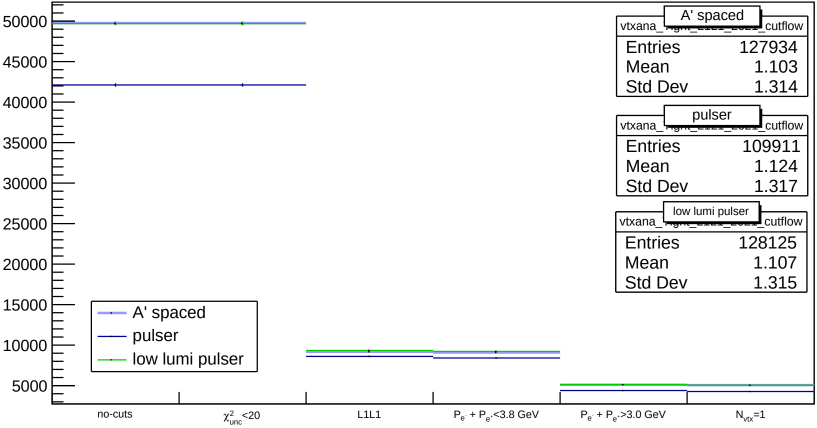
- Pulser has more simulated triggers after readout
- $\chi^2_{\rm unc}$ cut reduces the number of events for pulser relative to pure A' and low lumi pulser

Psum distribution after preselection



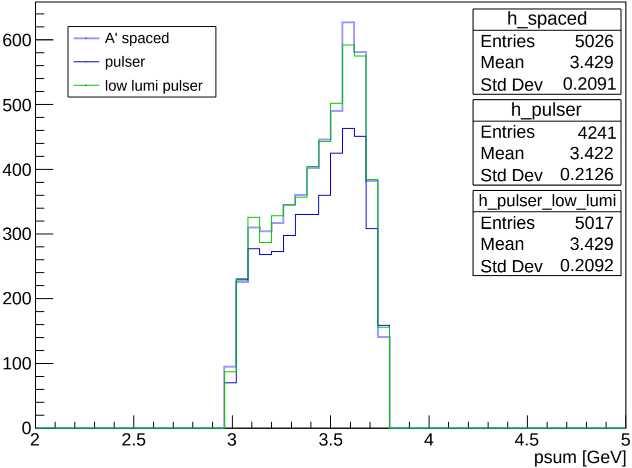
- ‘Normal’ pulser fewer events than low lumi and pure A’
- Pulser low momentum tail matches but peak doesn’t

Tight selection cutflow



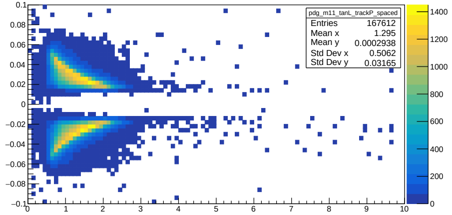
- Low lumi and spaced A' number of events match at each cut level
- L1L1 cut equalizes event numbers

Psum distribution after tight selection

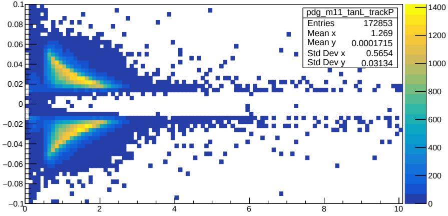


- Seems like pulser has relatively fewer events in peak

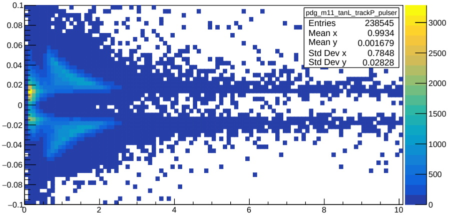
tanL vs momentum – positron tracks



A' spaced



low lumi pulser

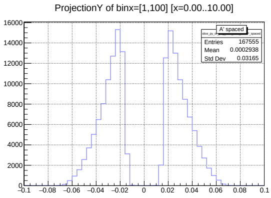


pulser

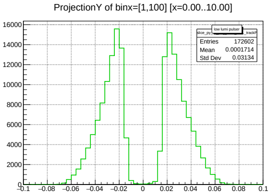
- No (pre-)selection – showing positron tracks after reconstruction

Conclusion II

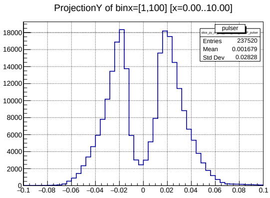
- As expected: reconstruction of vertices influenced by background
  - Low luminosity pulser events mix in less background – better vertex reconstruction
  - L1L1 requirement powerful for removing misreconstructed/mismatched tracks
- Pulser tracks show high momentum tails and asymmetric $\tan\lambda$ distribution in 2D
  - Asymmetry doesn't show in the projection



A' spaced



lowlumi

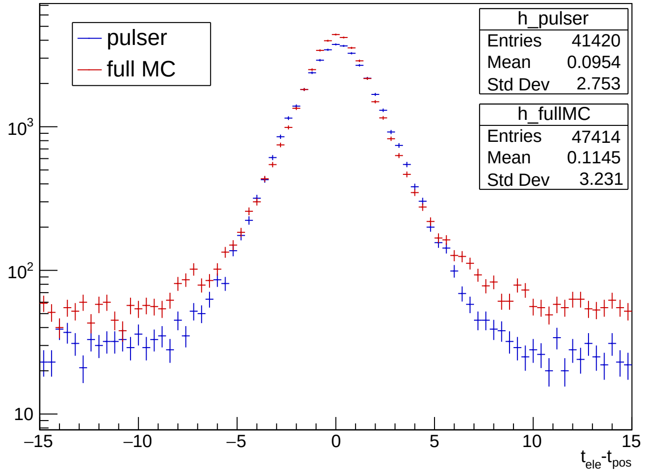


pulser

Summary

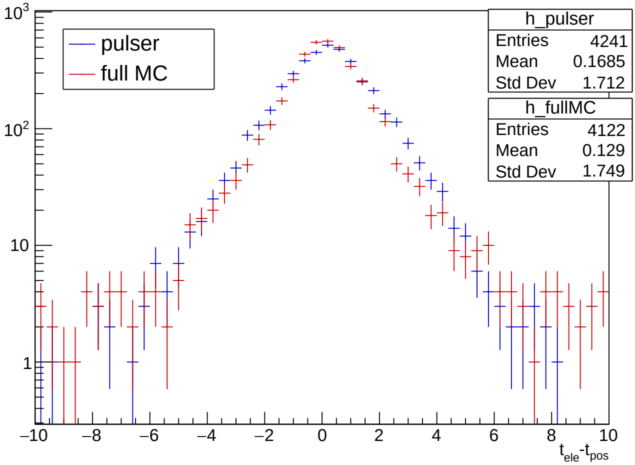
- Using pulser and randomly triggered data enables us to correctly reproduce the beam background.
- Apart from differences in timing (event time and cluster time), the two MC versions are very similar.
  - After preselection, including time cuts, psum distributions match
  - Tight selection yields matching psum distributions for both methods
- Further analysis of pulser MC needed to understand systematics
- Other things
  - Pulser overlay for 2016: hps-java PR

Time difference between tracks – preselection



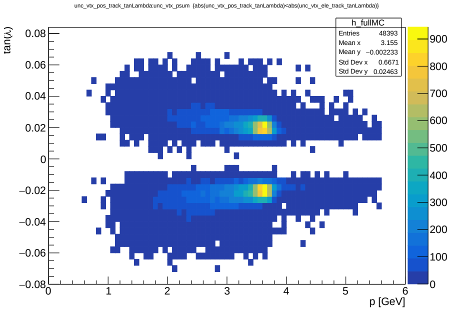
- Electron and positron track time difference after preselection

Time difference between tracks – tight selection

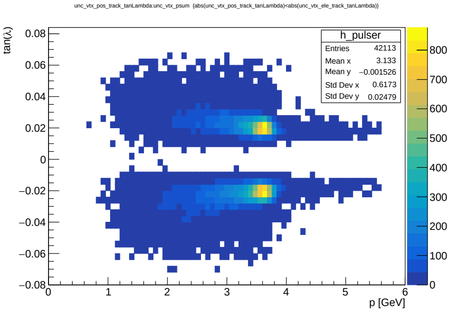


- Electron and positron track time difference after tight selection

tanL vs track momentum



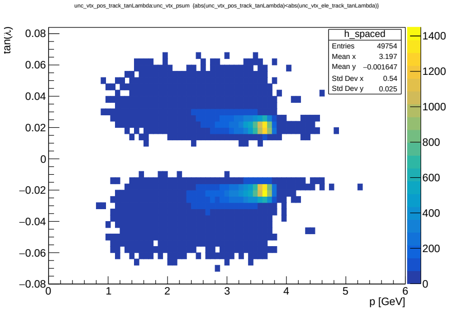
full MC



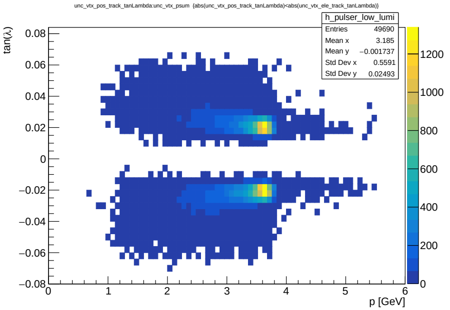
pulser

- Fill track with lower tanL, don't care about charge

tanL vs track momentum



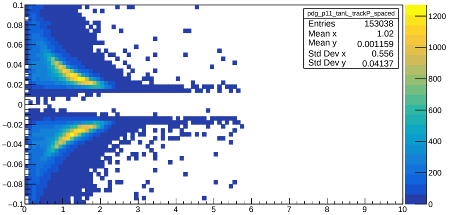
A' spaced



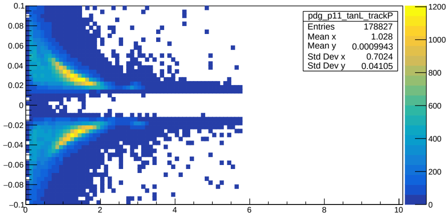
low lumi pulser

- Fill track with lower tanL, don't care about charge

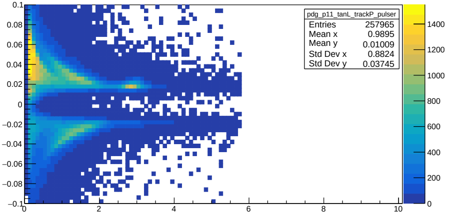
tanL vs momentum – electron tracks



A' spaced



low lumi pulser



pulser

- No (pre-)selection – showing electron tracks after reconstruction