Offline Analysis of H4 Beam Line Instrumentation Data

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ProtoDUNE Analysis Workshop, CERN. January 27th, 2019

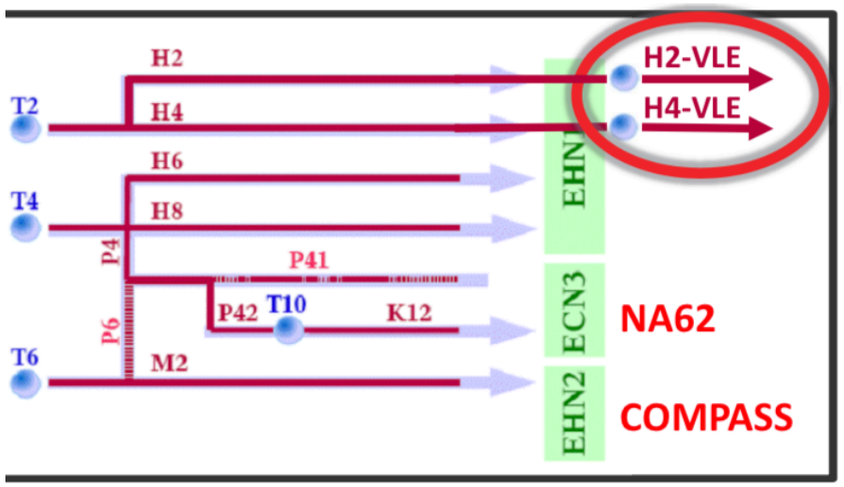
Overview

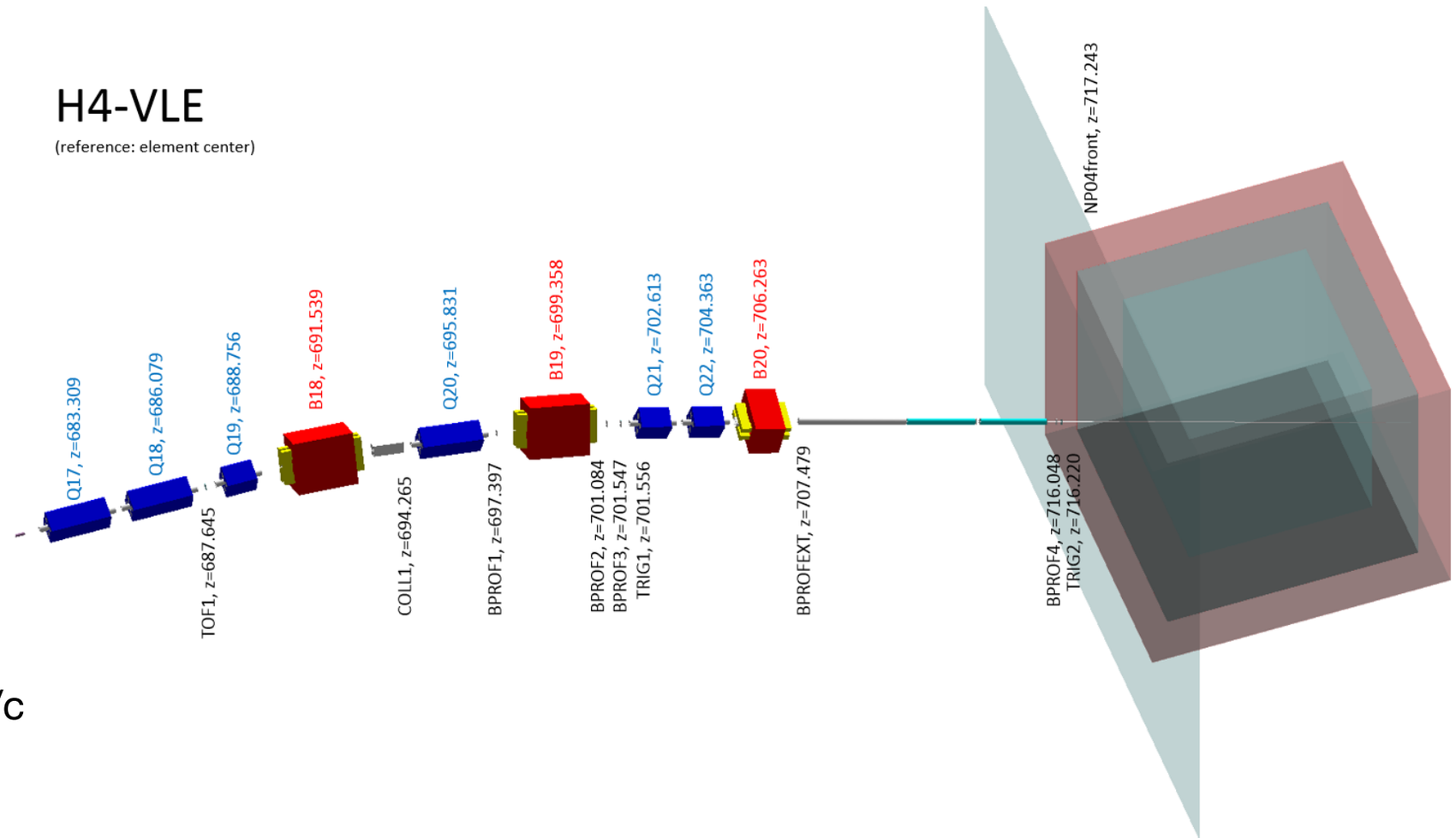
- Offline event tree.
  - Tool, raw beam line data —> match instrumentation event-wise to general trigger.
  - ROOT file for easy analysis.

- H4 beam line detectors.
  - Beam profile monitor (XBPF) performance. Hit multiplicities / efficiencies.
  - Correction to relative position of XBPF.

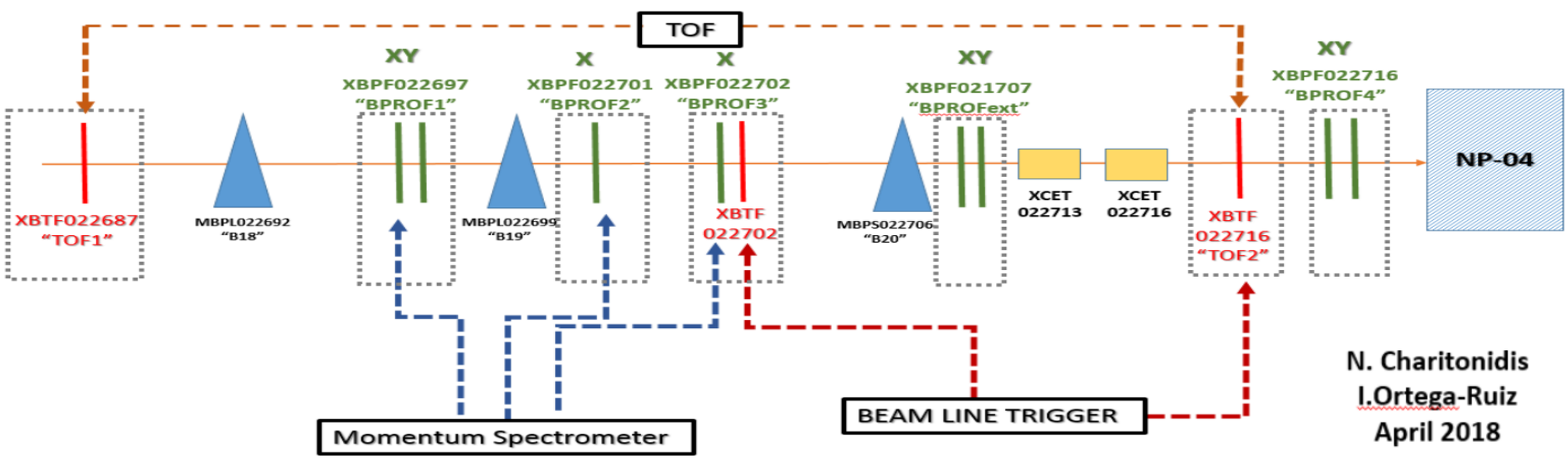
- Latest results.
  - Trigger rates & momentum spread.
  - Particle ID and beam composition.

H4 Beam Line





- SPS proton beam at 400 GeV/c directed to North Area.
- Secondary hadron beam at 80 GeV/c produced at primary target T2.
- Tertiary low energy beam, 0.3 - 7 GeV/c produced at secondary target.



Offline Event Tree

What is the Event Tree

- Tool to make event-by-event analysis of all beam line instrumentation more straightforward.
- C++ code, matches in time 34 variables by spill —> then by event.
- Done by defining a **search window** around general trigger.
- Identify the **same event** passing through **all detectors**.
- Each tree entry <-> 1 event (general trigger).
  - Event level variables: e.g. Time of flight, reconstructed momentum, etc.
  - Associated spill level variables: e.g. Cherenkov pressures, collimator positions, etc.
- Assigned ‘event rank,’ golden, silver.

Event tree ROOT files will soon be made available at FNAL & CERN for all ‘good runs’.

Addition of PID branches (TOF & Cherenkov signal) still needs to be validated.

What is the Event Tree

EventTree_2018-11-05_00:00_2018-11-05_02:00_Example.root
- EventTree
  - eventRank
  - spillTimeStamp
  - fractionComplete
  - XBH4.BEND.022.692_I_MEAS
  - XBH4.BEND.022.699_I_MEAS
  - XBH4.EXPT.NP04.001_COUNTS
  - XBH4.EXPT.NP04.002_COUNTS
  - XBH4.EXPT.NP04.003_COUNTS
  - XBH4.EXPT.NP04.004_COUNTS
  - XBH4.EXPT.NP04.009_COUNTS
  - XBH4.EXPT.NP04.010_COUNTS
  - XBH4.EXPT.NP04.011_COUNTS
  - XBH4.EXPT.NP04.012_COUNTS
  - XBH4.XCET.022.713_COUNTS_TRIG
  - XBH4.XCET.022.713_PRESSURE
  - XBH4.XCET.022.713_SIMPLE_COUNTS
  - XBH4.XCET.022.716_COUNTS_TRIG
  - XBH4.XCET.022.716_PRESSURE
  - XBH4.XCET.022.716_SIMPLE_COUNTS
  - XBH4.XCSH.022.694_POS_JAW1_MEAS
  - XBH4.XCSH.022.694_POS_JAW2_MEAS
  - XBH4.XSCI.022.680_COUNTS
  - SPS.T2_INTENSITY
  - XBH4GENERALTRIGGER_NCounts
  - XBH4XTDC022713_NCounts
  - XBH4XTDC022716_NCounts
  - XBTF022687A_NCounts
  - XBTF022687B_NCounts
  - XBTF022716A_NCounts
  - XBTF022716B_NCounts
  - XBH4GENERALTRIGGER_TimestampNS
  - XBH4GENERALTRIGGER_TimestampFracAccuracy
  - XBH4.XTDC.022.713_TimestampNS
  - XBH4.XTDC.022.713_TimestampFracAccuracy
  - XBH4.XTDC.022.716_TimestampNS
  - XBH4.XTDC.022.716_TimestampFracAccuracy
  - XBTF.022.687A_TimestampNS
  - XBTF.022.687A_TimestampFracAccuracy
  - XBTF.022.687B_TimestampNS
  - XBTF.022.687B_TimestampFracAccuracy
  - XBTF.022.716A_TimestampNS
  - XBTF.022.716A_TimestampFracAccuracy
  - XBTF.022.716B_TimestampNS
  - XBTF.022.716B_TimestampFracAccuracy
  - TOFChannel
  - TOF
  - XBH4.XTDC.022.713_On
  - XBH4.XTDC.022.716_On
  - XBH4.XBPF.022.697_TimestampNS
  - XBH4.XBPF.022.697_NFibresHit
  - XBH4.XBPF.022.697_Span
  - XBH4.XBPF.022.697_HitCoordinates
  - XBH4.XBPF.022.698_TimestampNS
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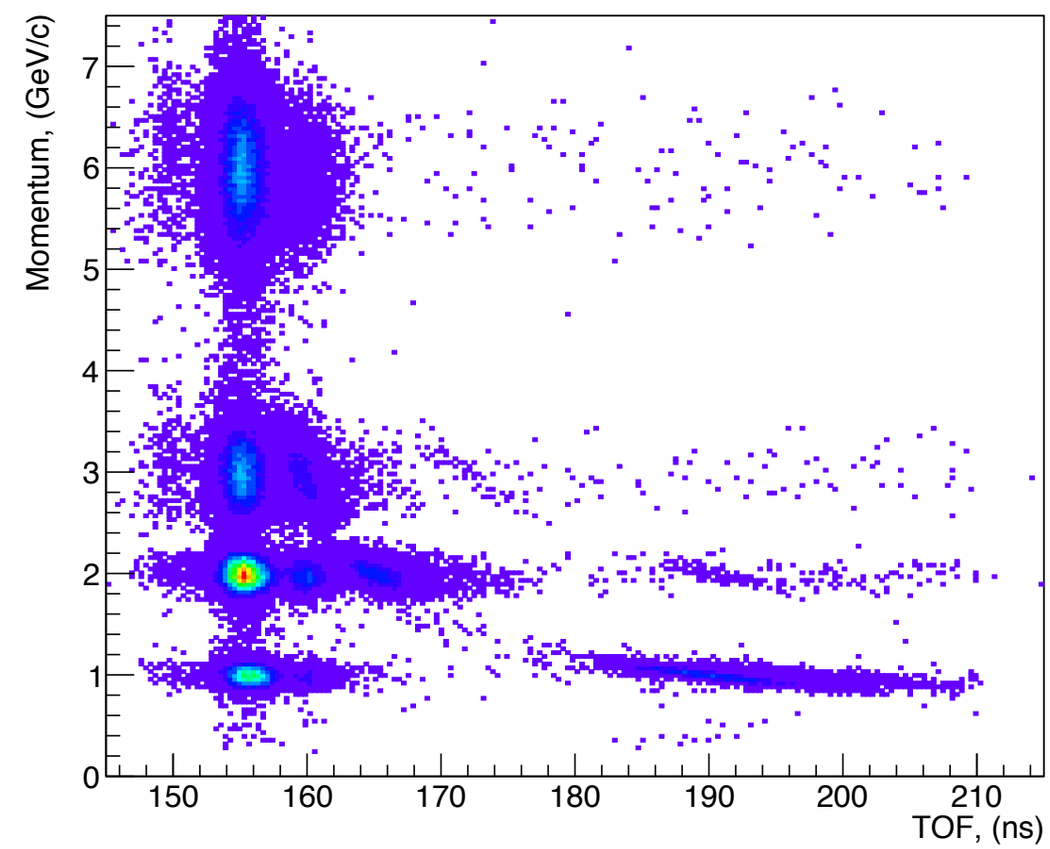
  - XBH4.XBPF.022.717_NFibresHit
  - XBH4.XBPF.022.717_Span
  - XBH4.XBPF.022.717_HitCoordinates
  - nPossibleMomenta
  - deflectionAngle
  - reconstructedMomentum

+Calibrated TOF.
+PID.

More detail in the backup slides of this talk: https://indico.fnal.gov/event/19270/contribution/0/material/slides/0.pdf

- How it works.
- What the variables actually are.

```
t->Draw("reconstructedMomentum:TOF","eventRank==1","COLZ")
```

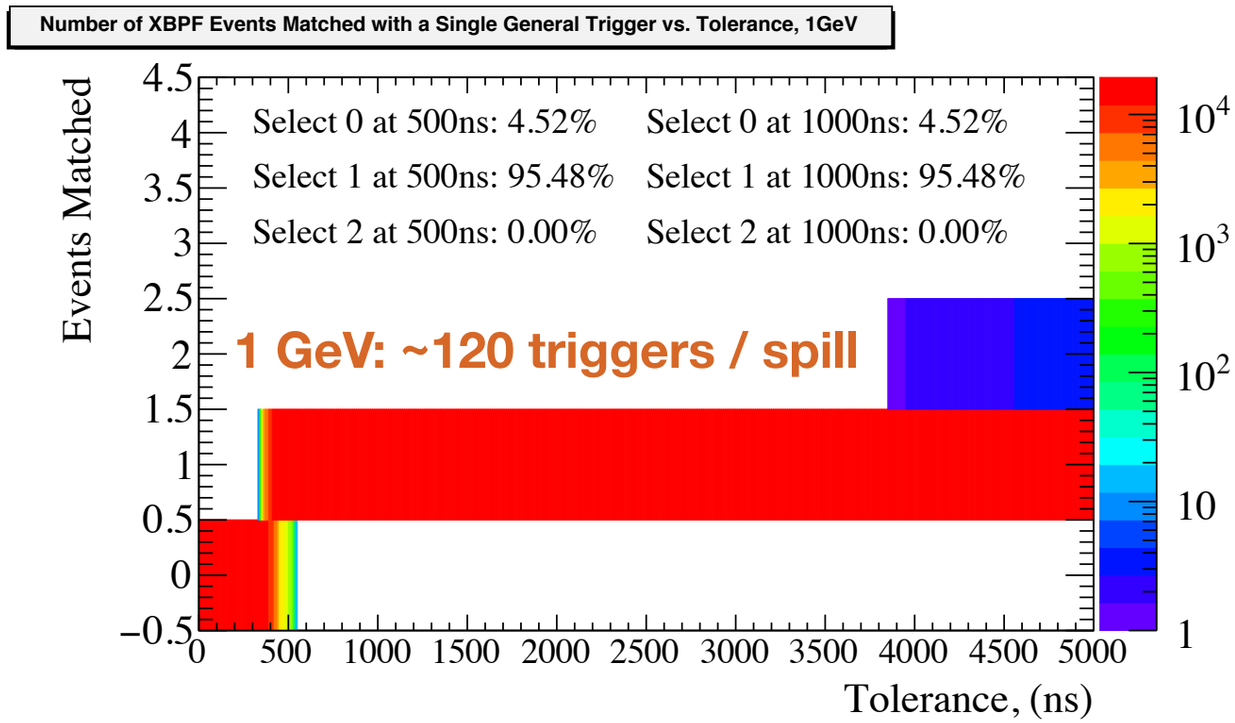


Key component, **size of search window.**

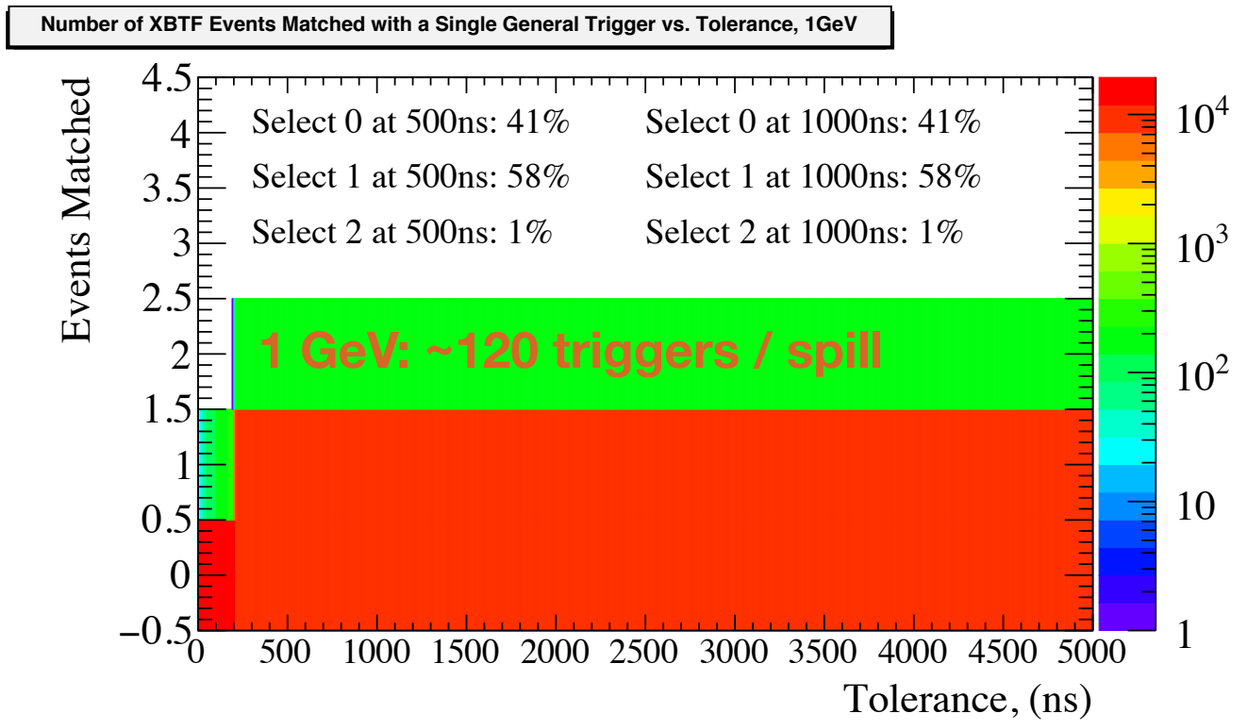
Back of envelop guess -> 500 ns.

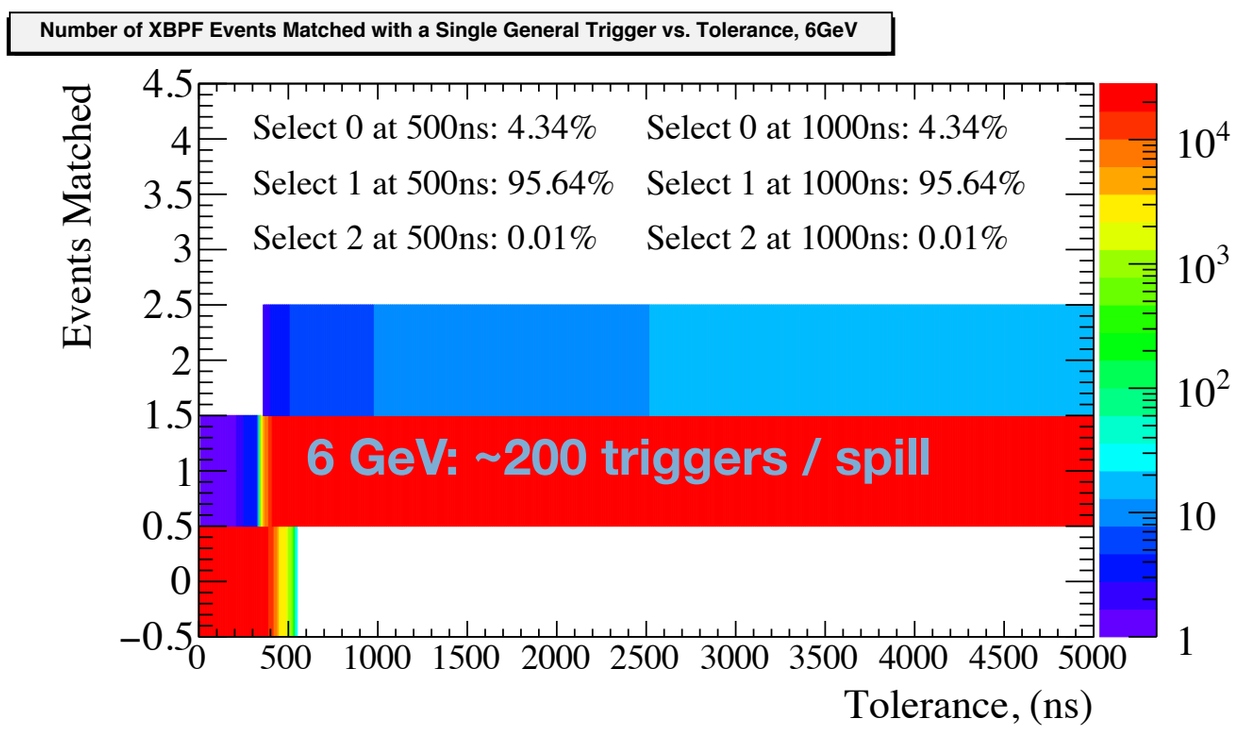
Timing Tolerance with General Trigger

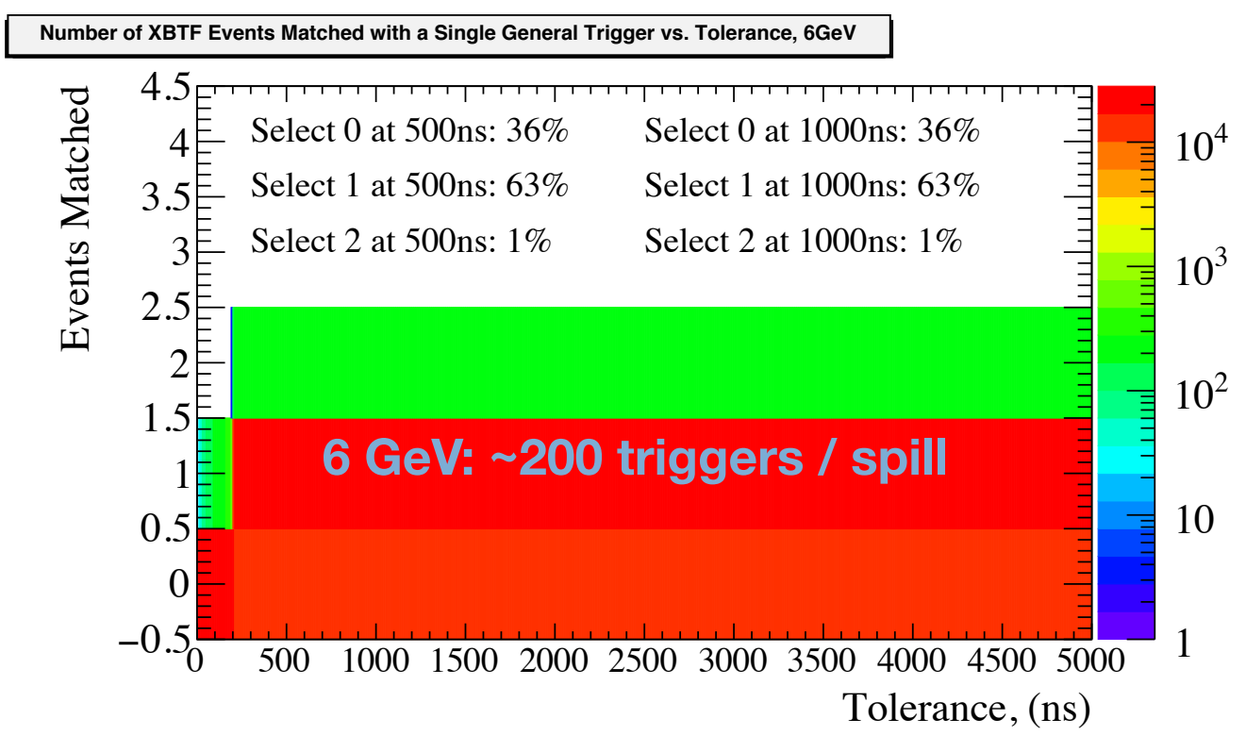
XBPF702 (Triggered)



XBTF687A (Not triggered)



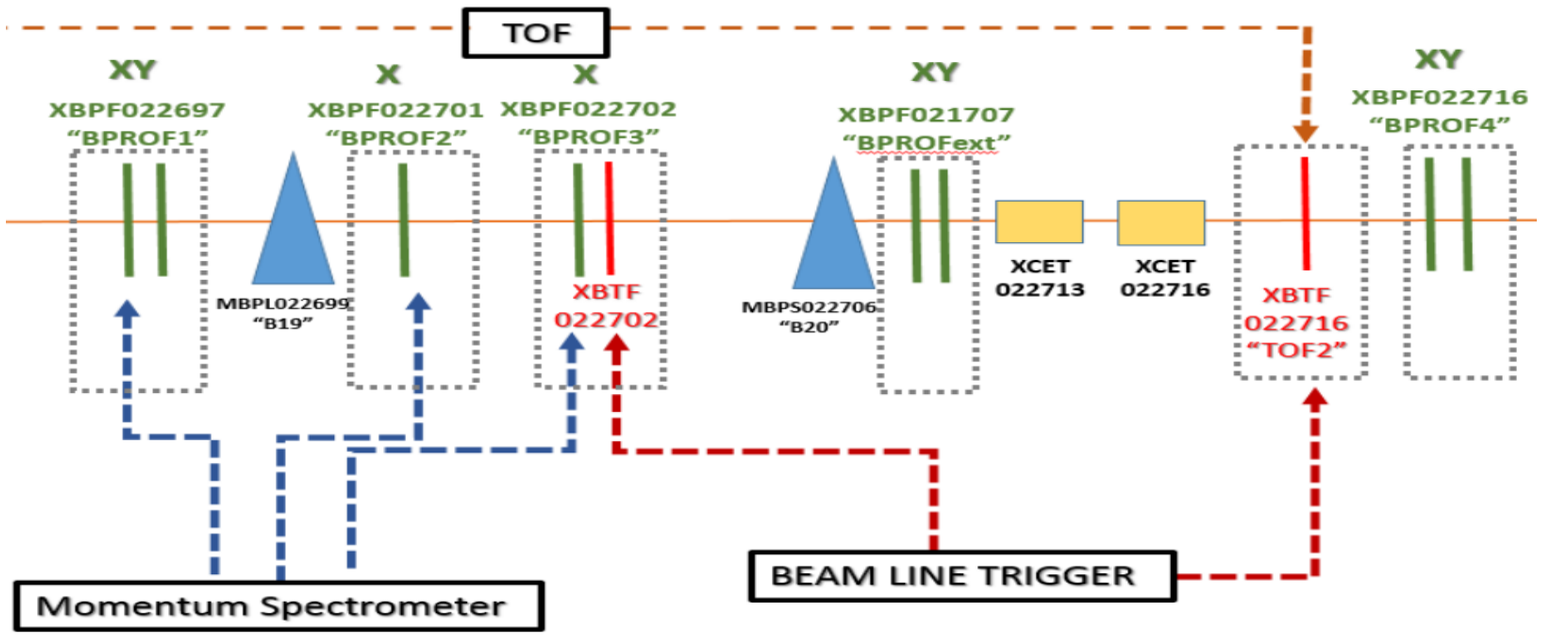


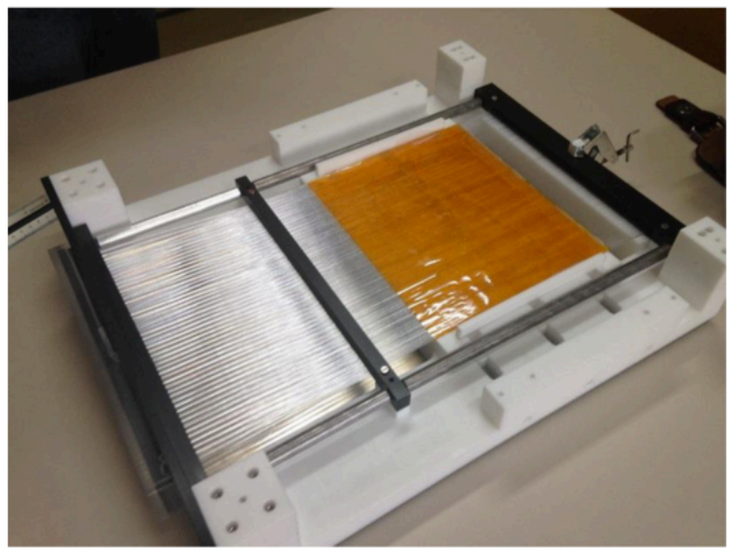


500 ns was a good choice! Don't loose events, don't double count.

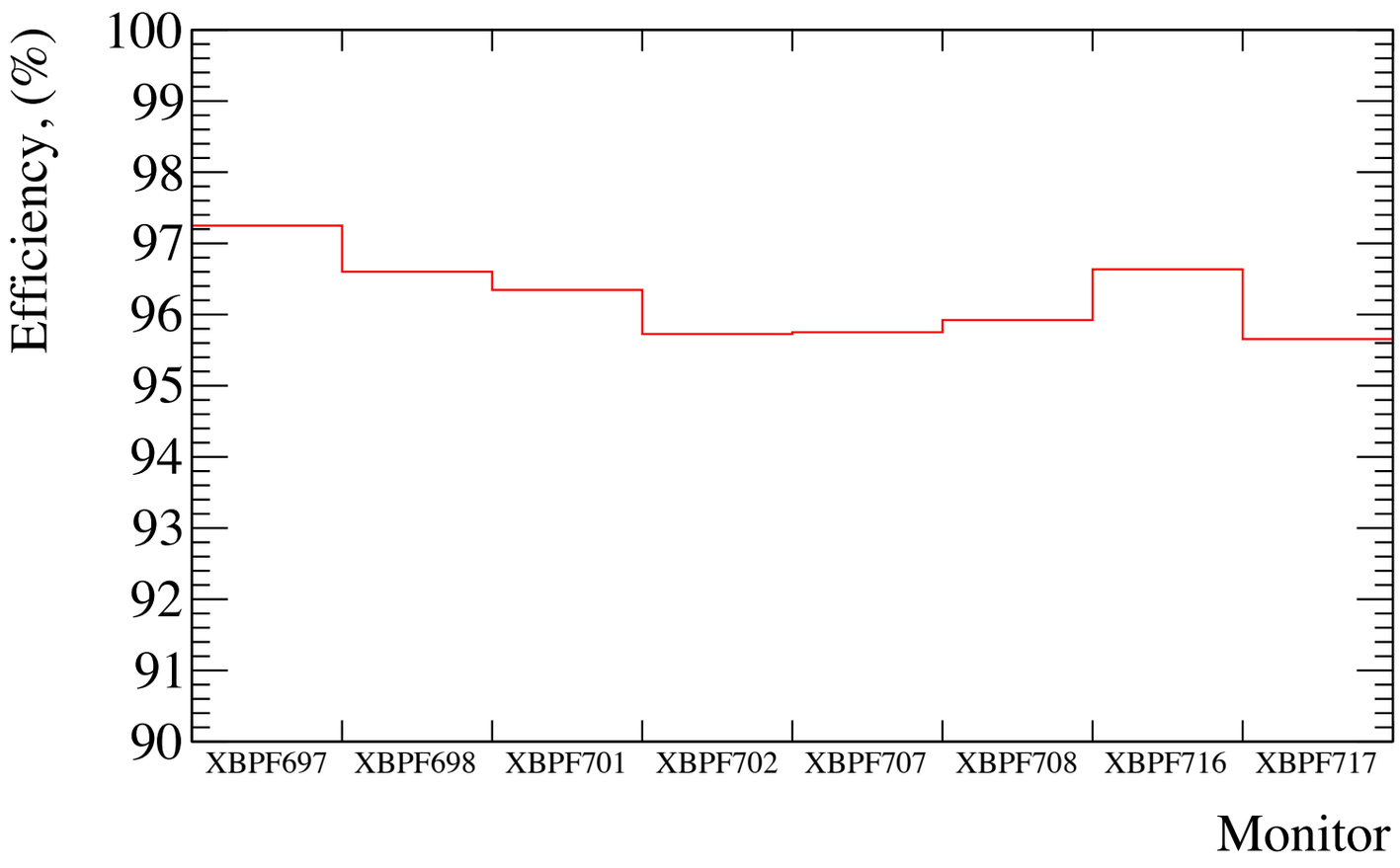
H4 Beam Line Detector Performance

XBPF Efficiencies





Profile Monitor Efficiency

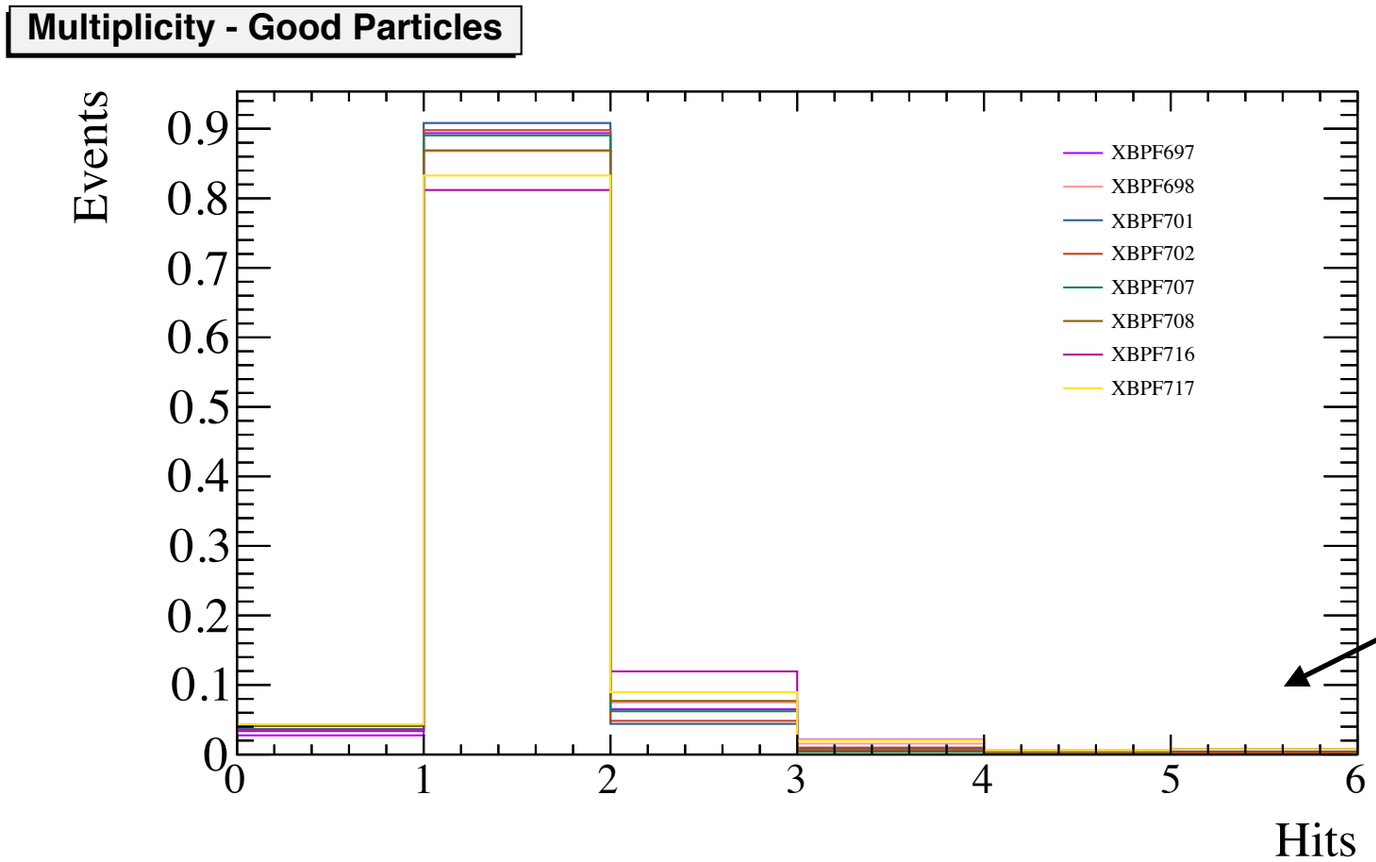


23 hours of data at various energies.

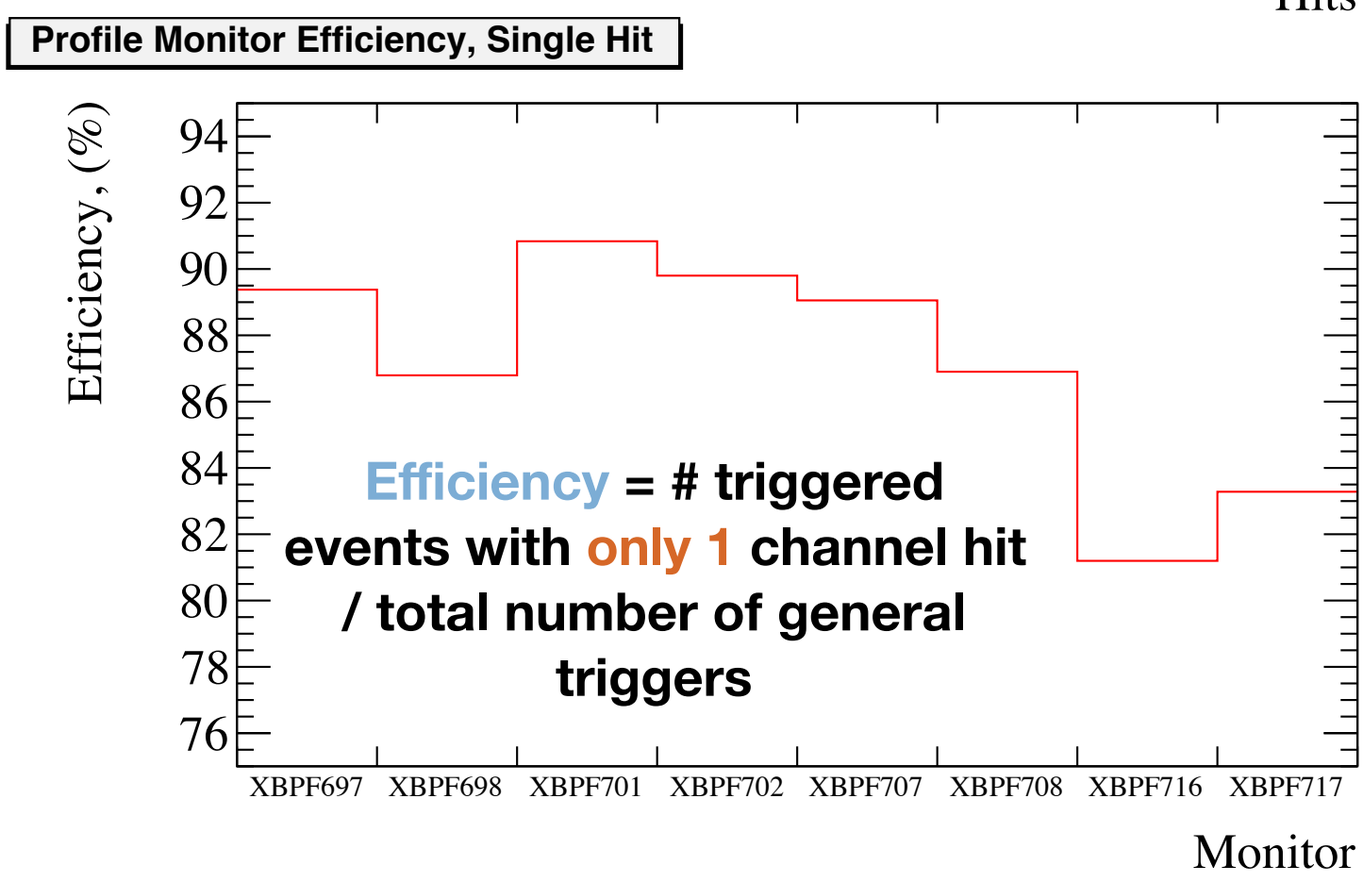
Efficiency = # triggered events with at least 1 channel hit / total number of general triggers

Measured XBPF efficiency > 95.5 % for all momenta.

Multiple hits / Triggered Event



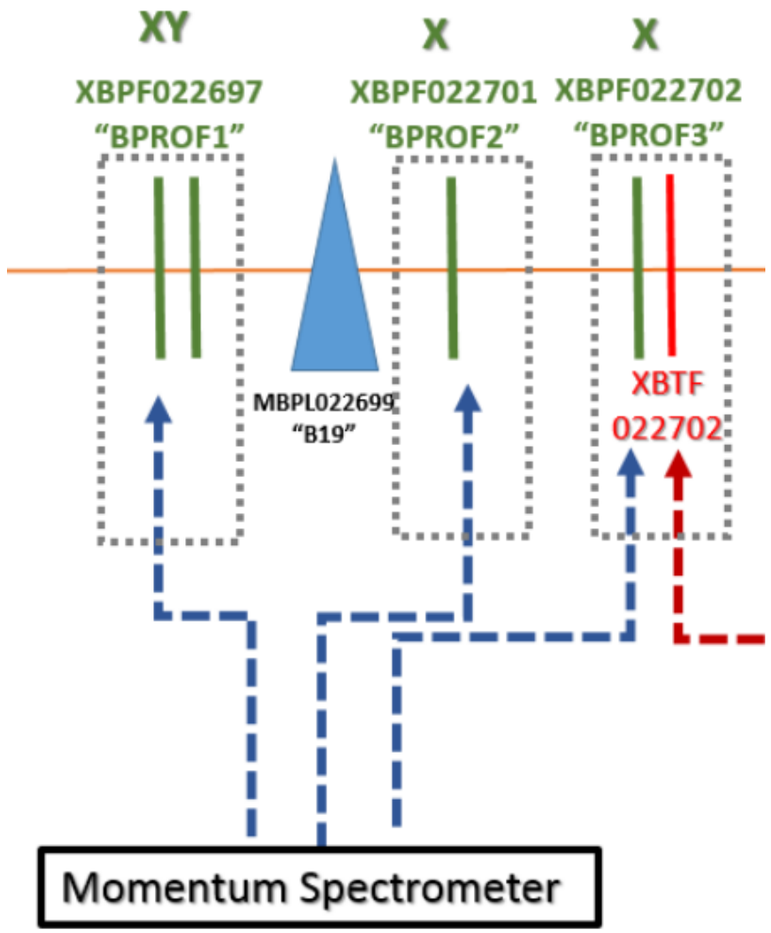
Contains all triggered events with 5 or more hits.

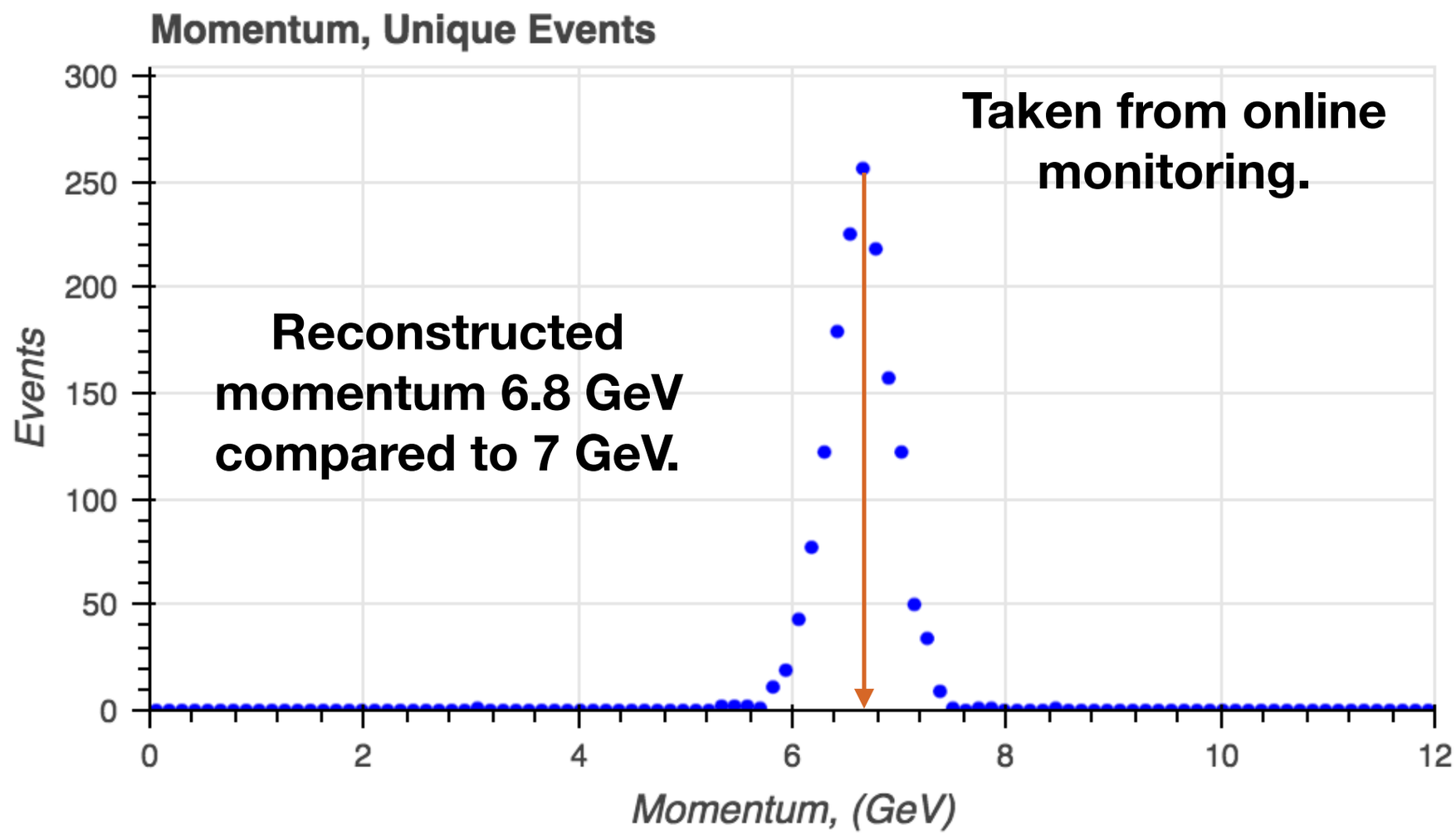


Side note: Can use XBPFs to examine time profile of spill -> homogenous as expected. See backup.

Momentum Reconstruction

- Technique to reconstruct momentum described in PhysRevAccelBeams.20.111001.
- Based on using known value of magnetic field.
- These magnets used for many years at CERN. Magnetic field and I -> BL is known well.





Small inconsistency (< 5%) and behaviour systematic at all energies —> **transverse misalignment of fibre planes, one with respect to another.**

Similar problems and inconsistencies with this method see in past. (Nikos for details).

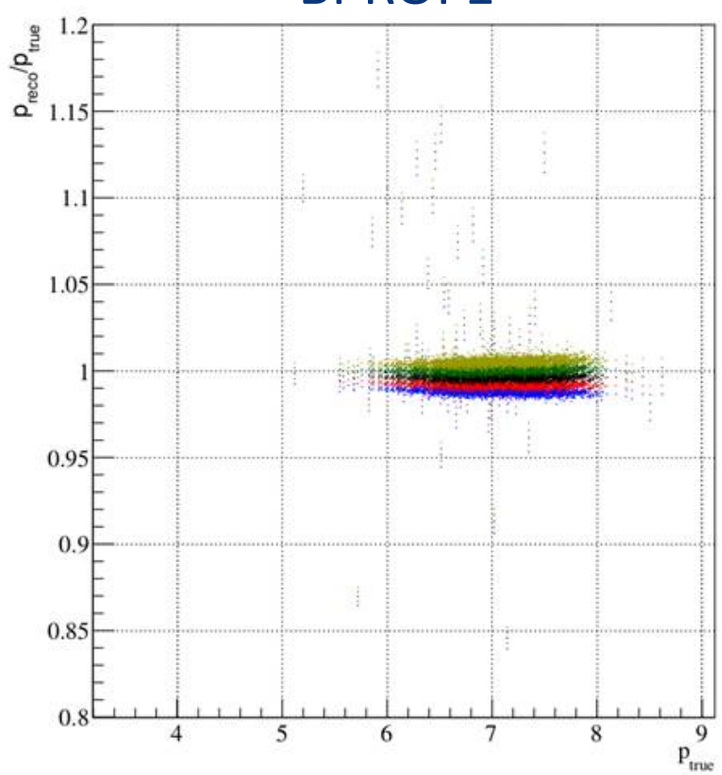
Still being investigated.

Quantifying Misalignment, Monte Carlo

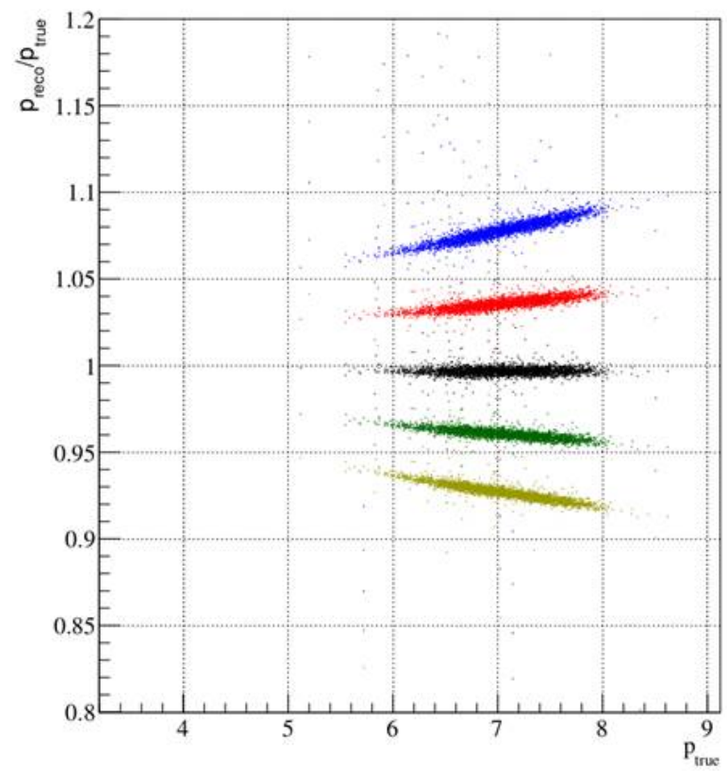
Momentum reconstruction studied in Monte Carlo.

x shift: +2 mm to -2 mm.

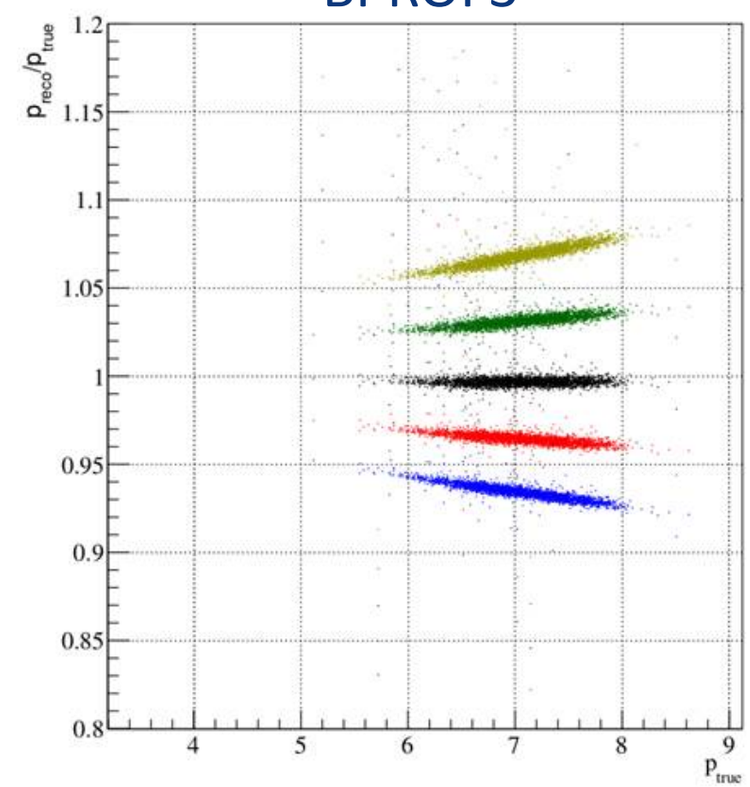
BPROF1



BPROF2



BPROF3



If BPROF3 is off by 1 mm -> 3.5% shift in reconstructed momentum at 7 GeV.

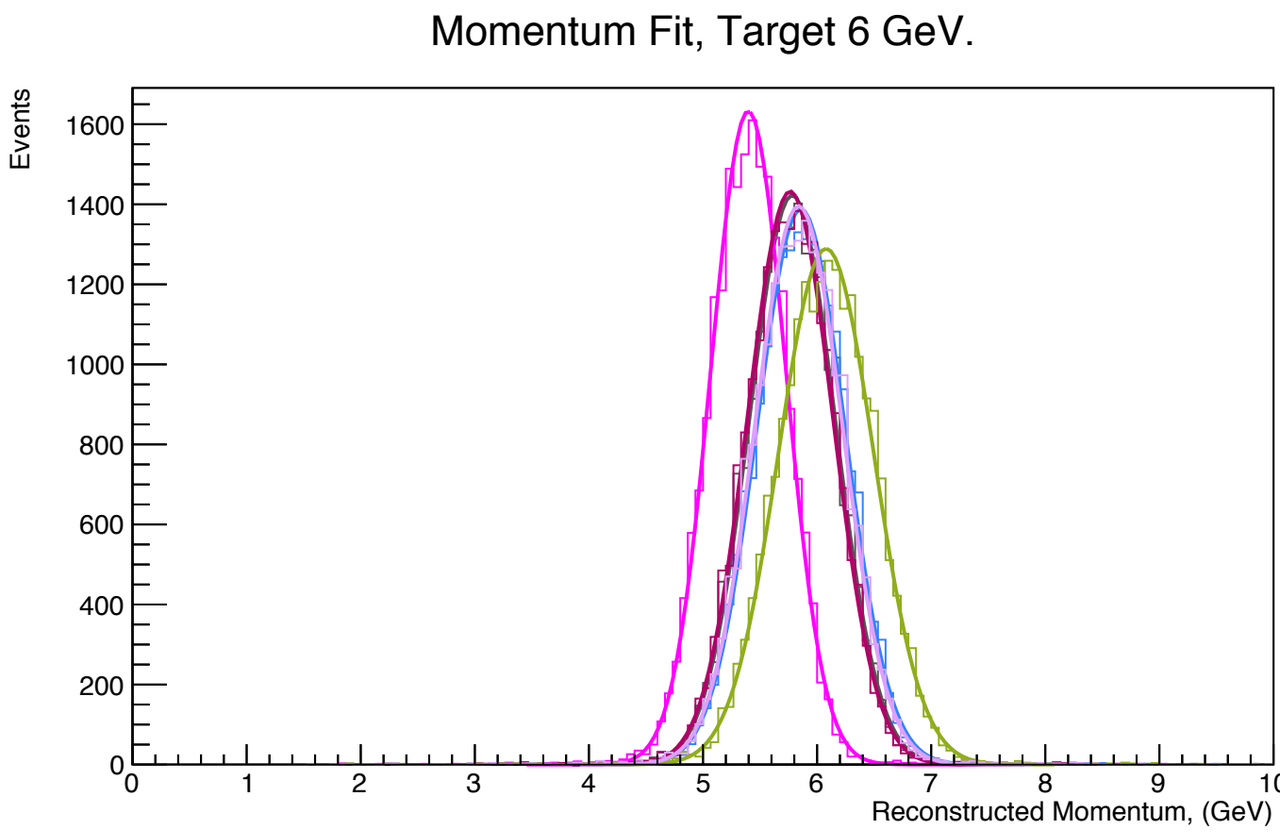
Quantifying Misalignment, Data

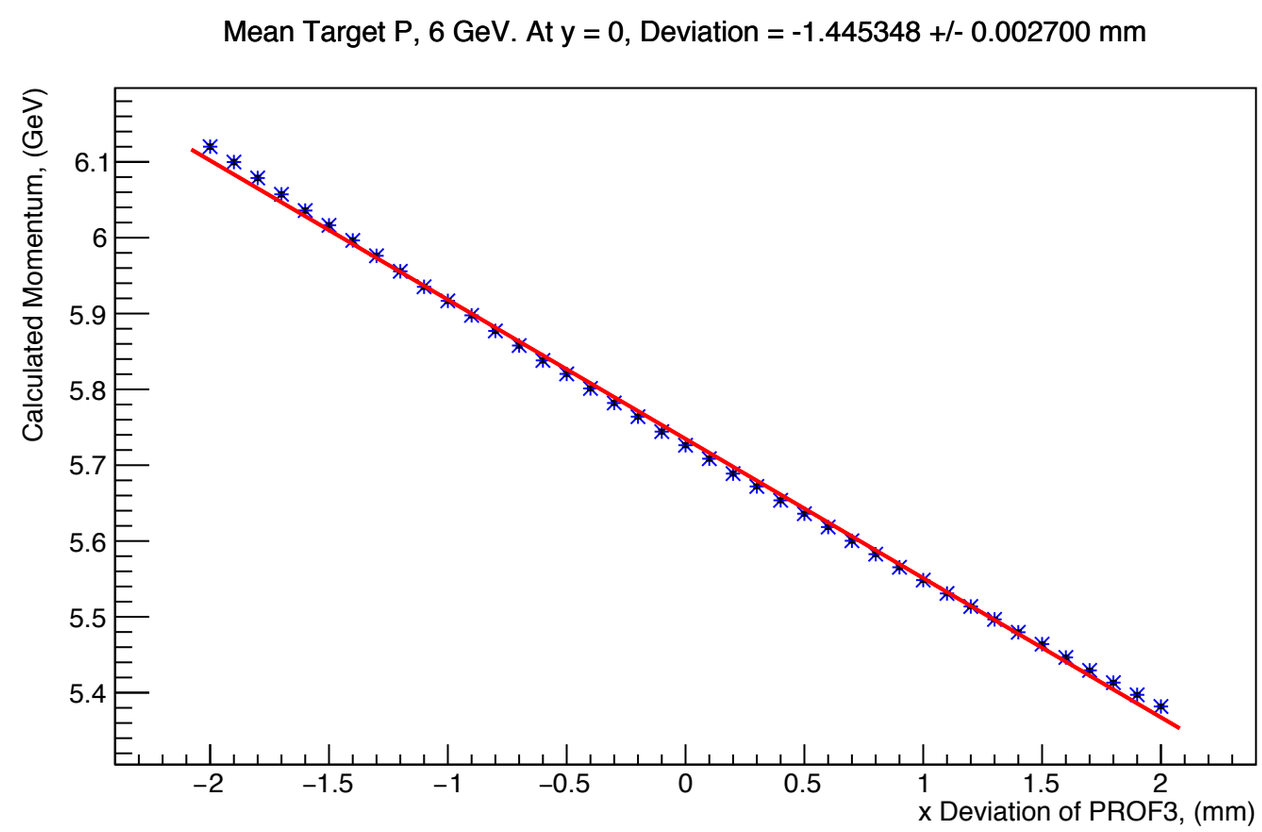
Showed in MC that misalignment must be ~O(few mm).

1) Take raw data at various momenta.

2) Rerun momentum calculation with BPROF3 at various x positions, (+/- 2 mm every 0.1 mm around nominal).

3) Fit gaussian to momentum distributions.



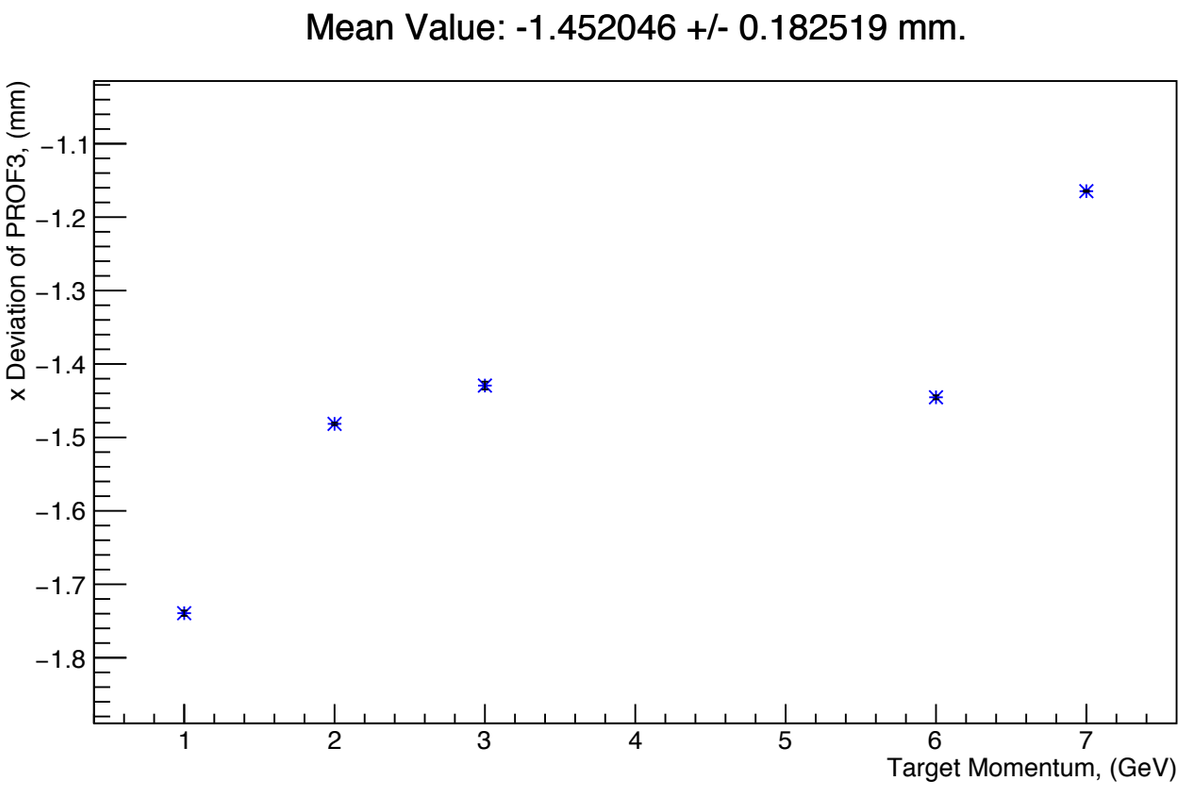


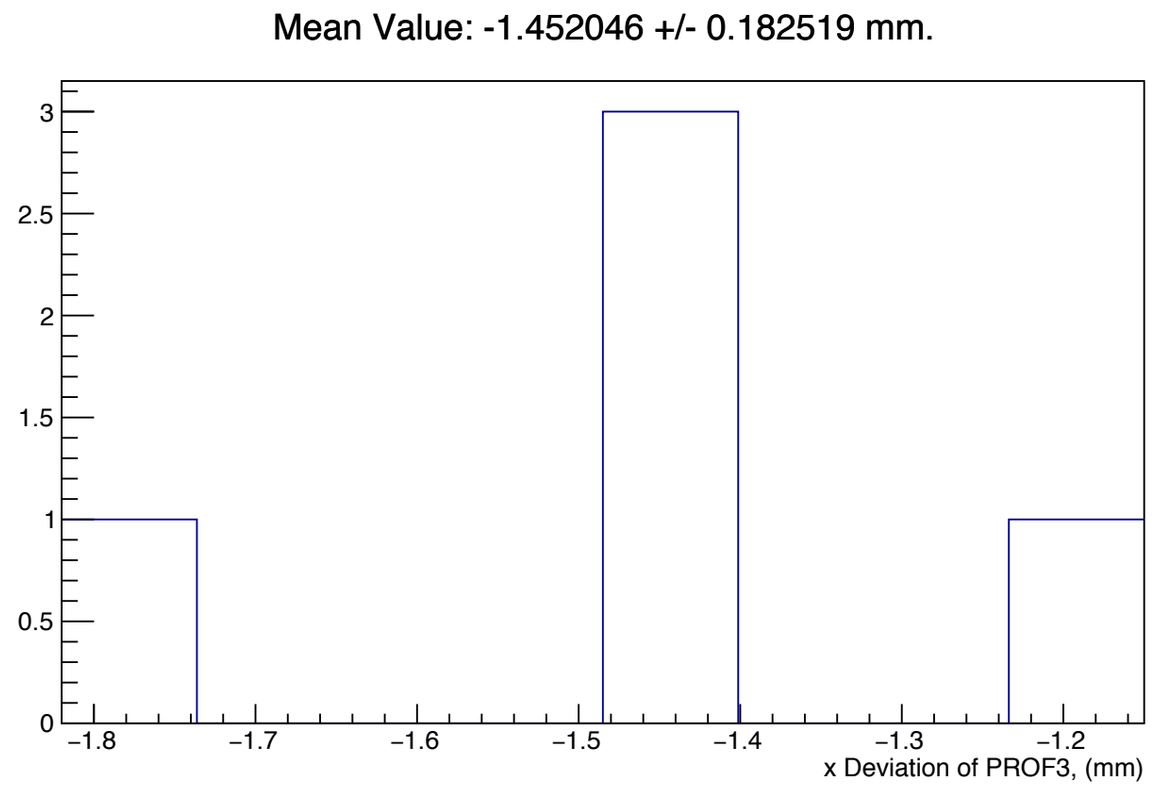
4) Plot mean of fits against corresponding deviation from nominal, make a linear fit.

5) Use fit line to calculate deviation that gives expect value of reconstructed momentum.

Quantifying Misalignment

Take the mean and standard deviation of these 'best fit' deviations.



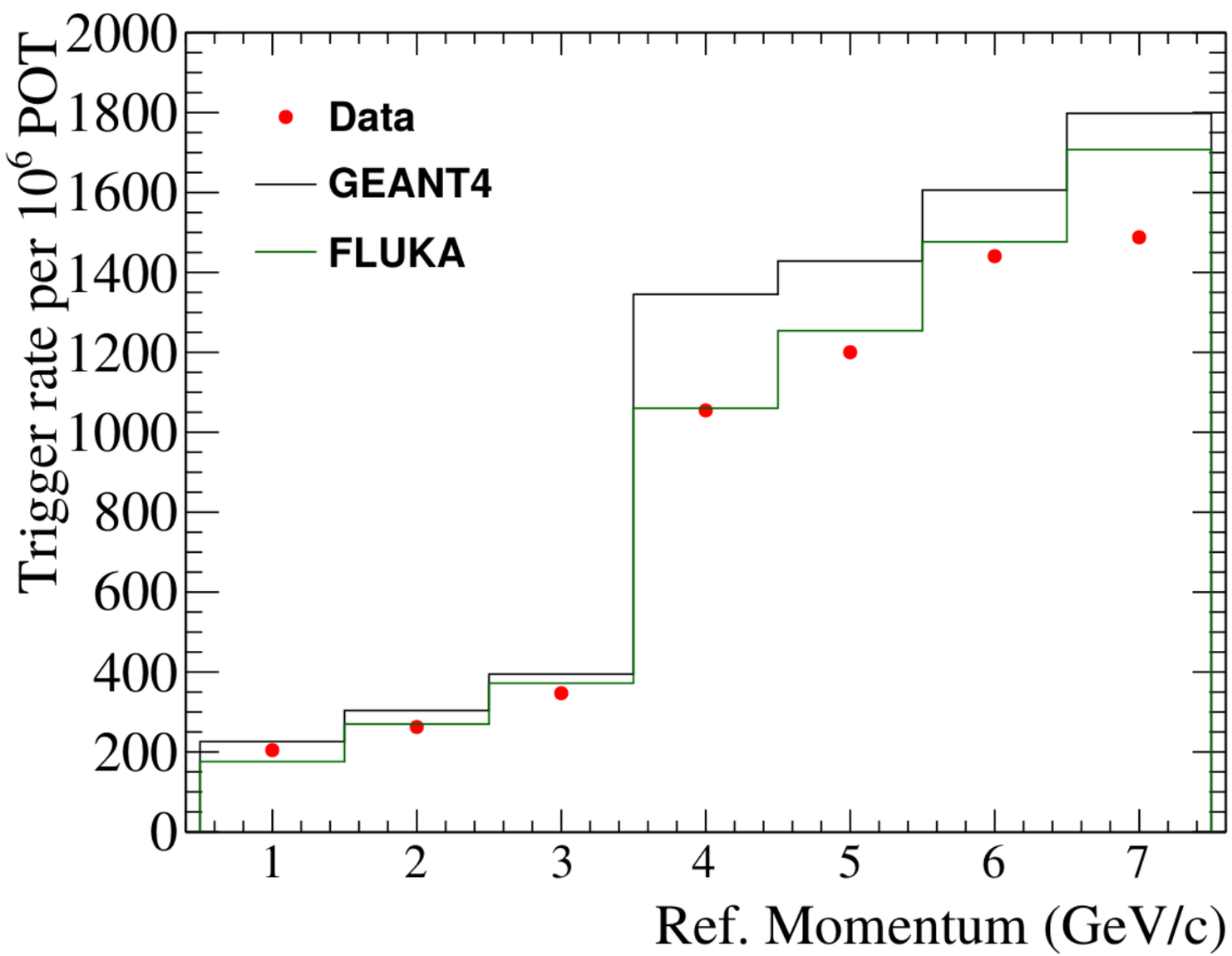


'Best fit' across range of Momenta: -1.45 +/- 0.18 mm

Latest Results: Trigger Rates & Momentum Spread

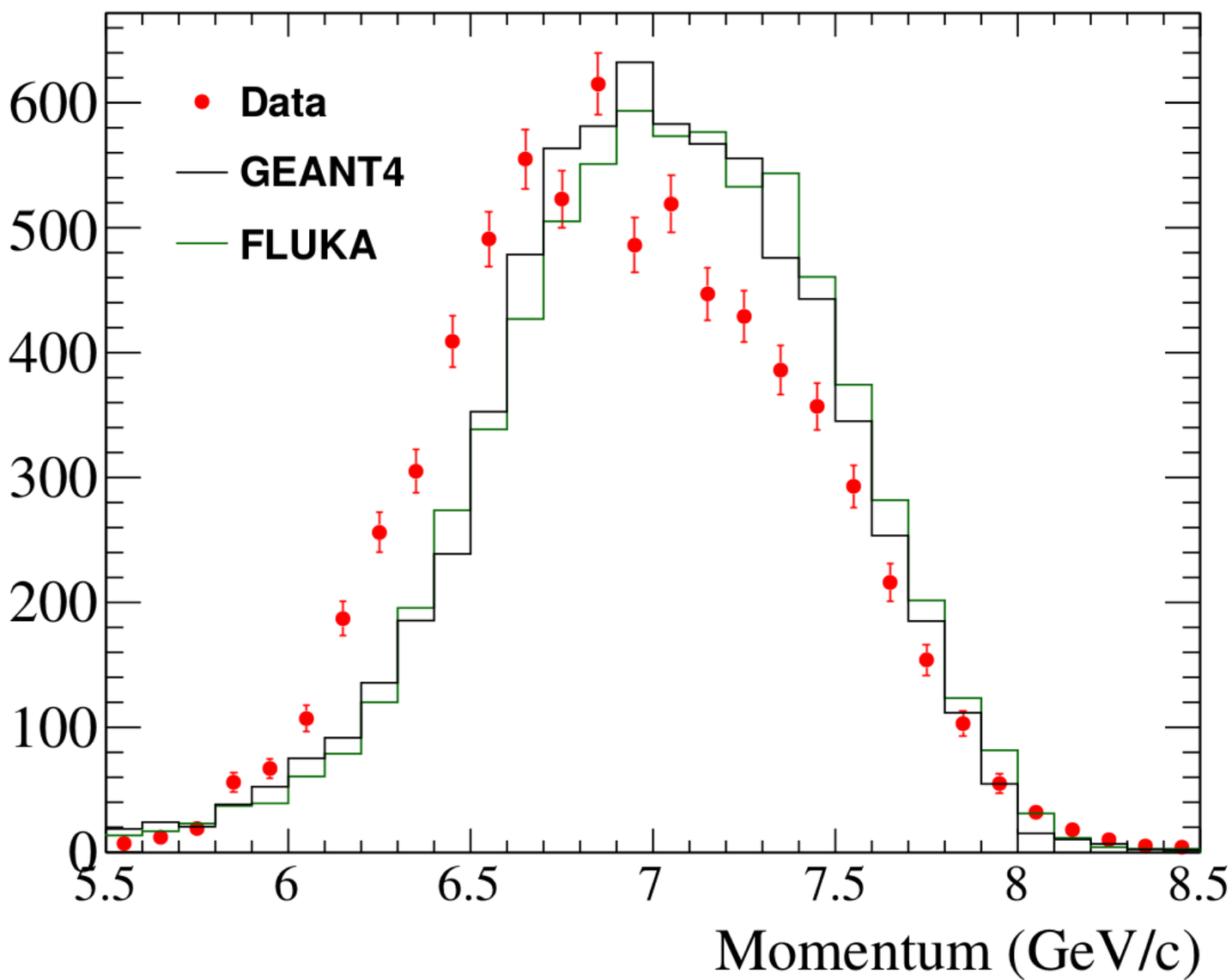
Trigger Rates

- Measured trigger rates compared to Geant4 and FLUKA simulations.
- Assume 95% efficiency for each plane.
- Data normalised to 1 million events on secondary target.
  - 1 - 3 GeV/c tungsten.
  - 4 - 7 GeV/c copper.



Momentum Spread

- Measured momentum distribution for “7 GeV/c” compared to Geant4 & FLUKA.
- Widest collimator opening (88 mm).
- Data normalised to same integral between 6 & 8 GeV/c.
- 1.45 mm systematic shift in x added to 3rd spectrometer plane.

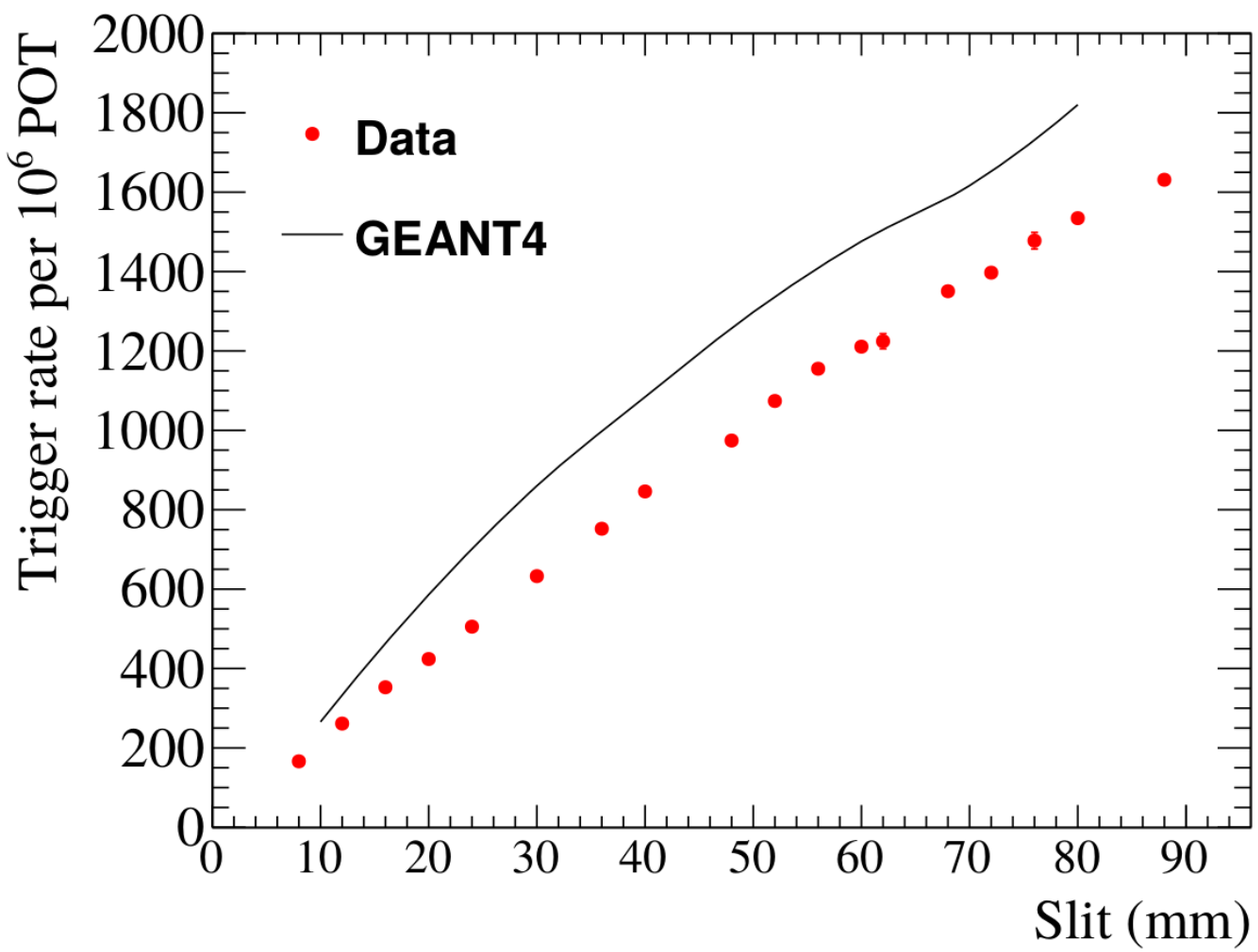


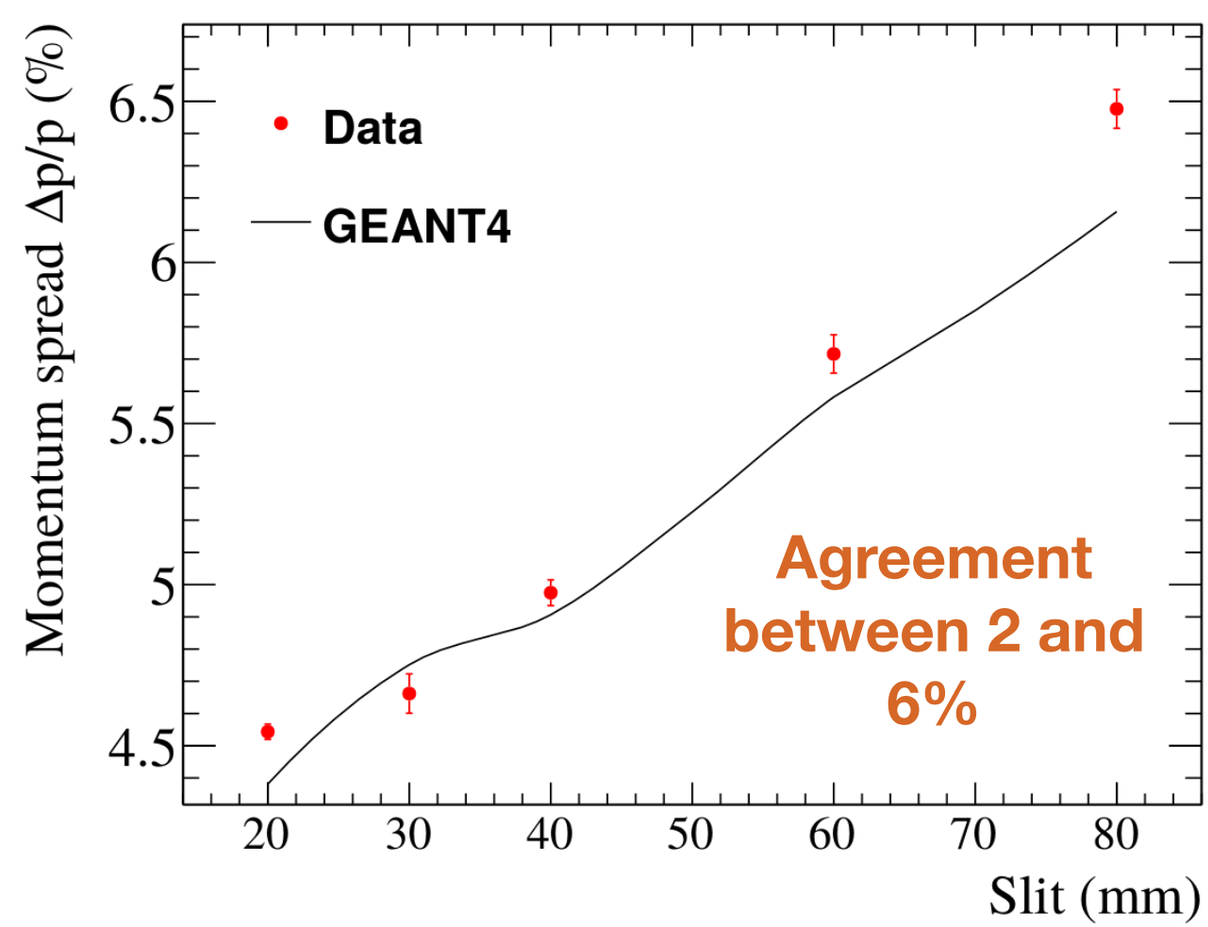
At widest collimator opening, some disagreement still.

Narrower opening, distributions sit more on top of each other.

Collimator Slit Dependence

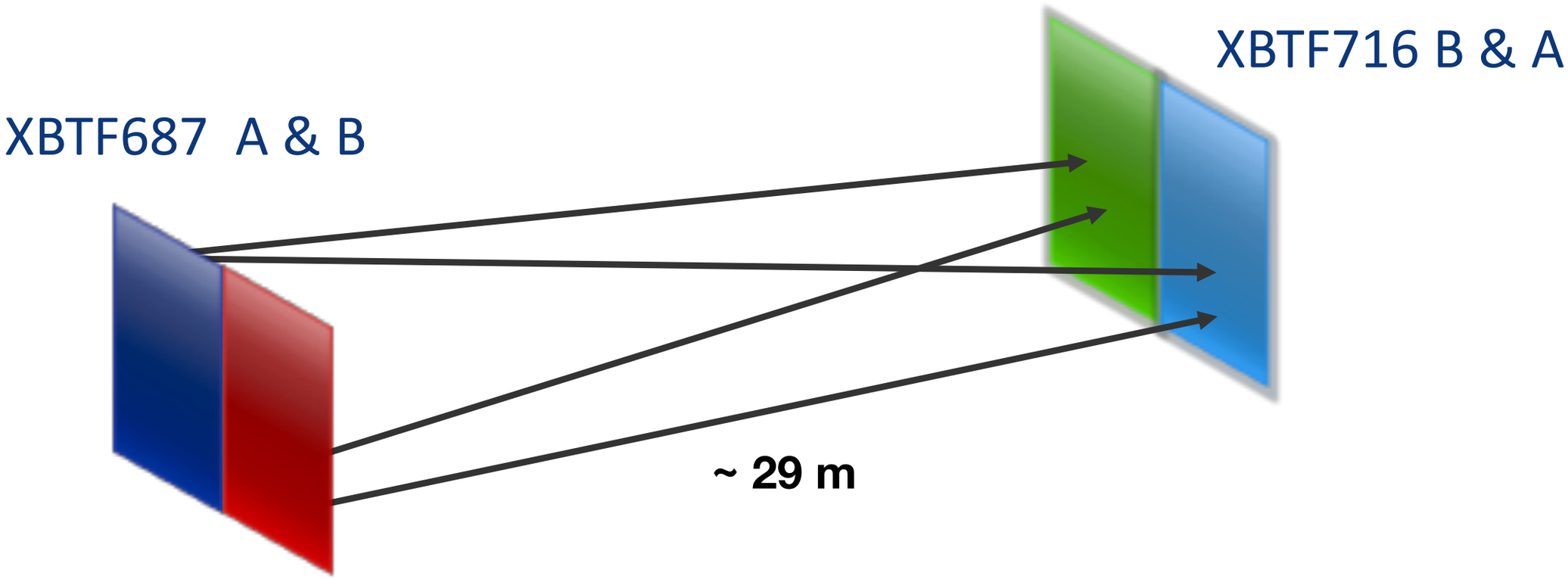
- Variation of trigger rate & momentum spread with different collimator openings studied at 7 GeV/c (95% efficiency per trigger plane).
- Expected Geant4 trigger rate slightly larger (normalisation, misalignments possible).
  - MC simulates ideal beam line.
- Observed momentum spread (RMS) variation similar to simulated values.





Latest Results: Particle Identification

PID Overview I



- Particle identification based on:
  - Time of flight between XBTF687 and XBTF706.
  - Cherenkov signal in Cherenkov 1 (C1, XCET713), and / or Cherenkov 2 (C2, XCET716).

- TDC timestamps of XCET signals and XBTF hits are matched to a general trigger within some time tolerance. (Event tree).

- Optimum case, ‘golden event’:
  - One possible TOF combination matched to one general trigger.
  - One or no XCET timestamp matched to one general trigger.

PID Logic Summary

Example: 3 GeV.

CH1 ~ 1.2 bar (low), CH2 ~ 3.4 bar (high).

At 3 GeV 1.2 bar, see only positron. At 3.5 bar see mu / pion / positron. Never see K or P.

Signal from CH1-> electron.

Signal from CH2, nothing from CH1 -> mu / pion.

Nothing from either -> K or P. Check TOF. TOF > Cut -> proton. Else K.

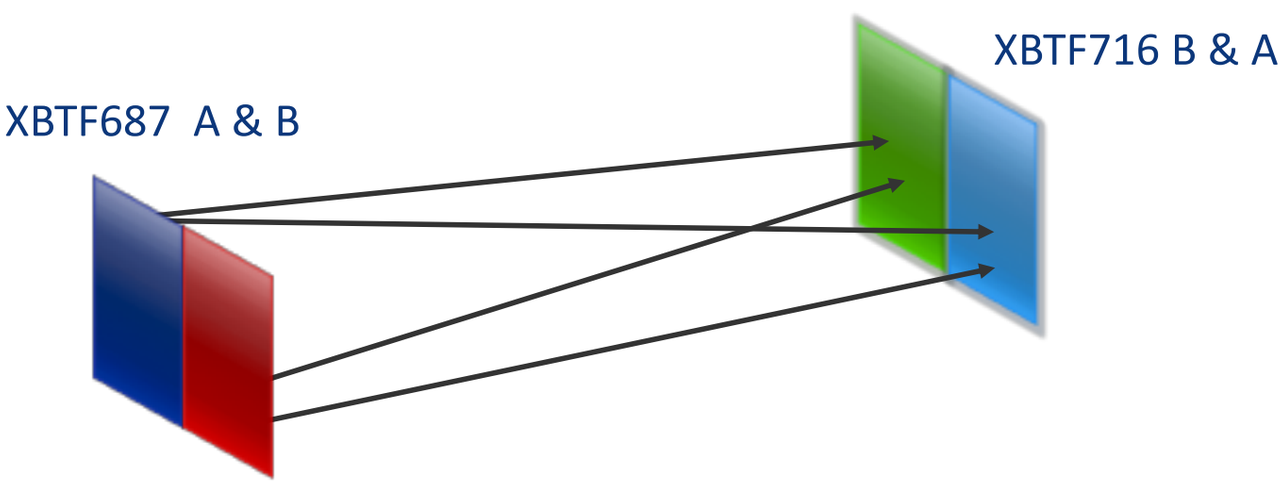
When CH2 is involved, it is the higher pressure CH.

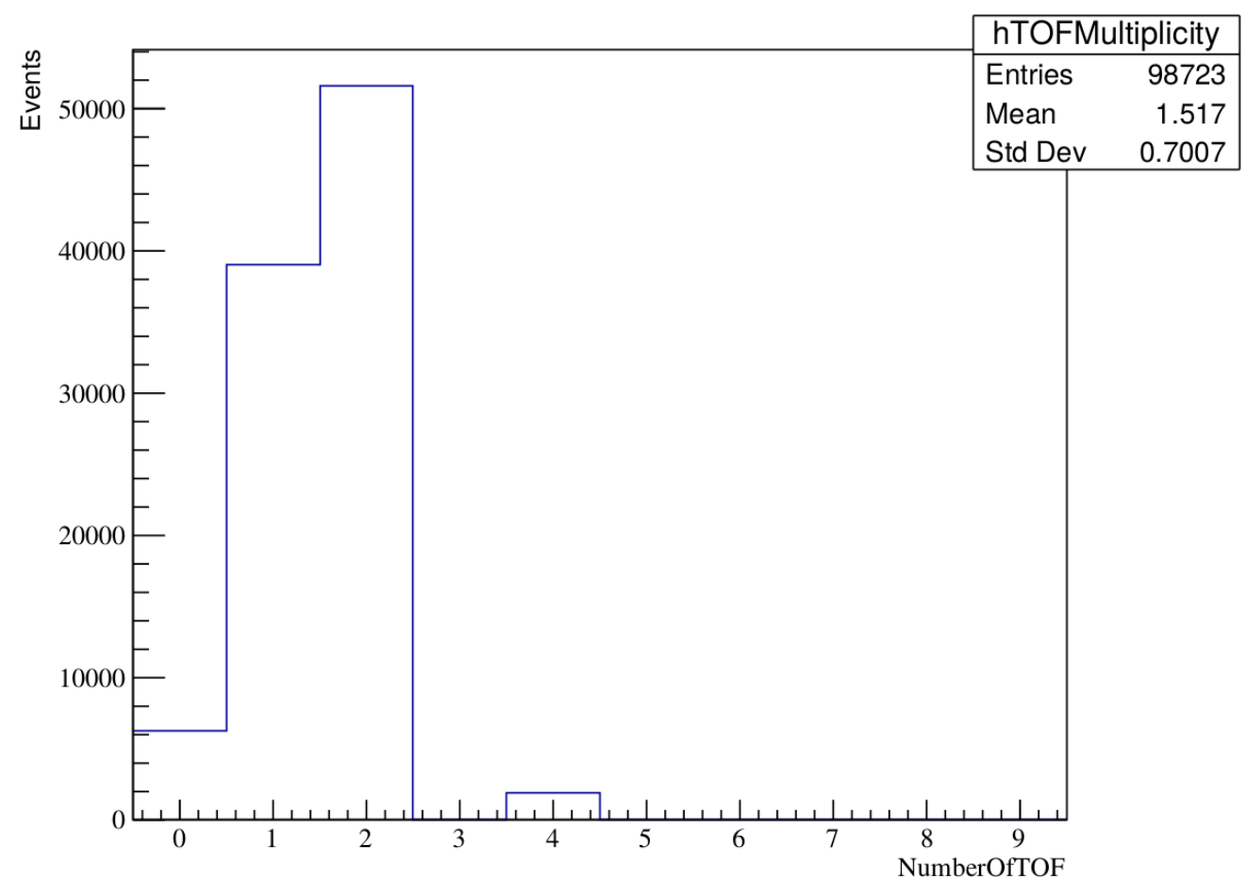
p (GeV/c)	e	μ	π	K	p
1	CH1	TOF	TOF	/	TOF
2	CH1	TOF	TOF	/	TOF
3	CH1	CH2	CH2	TOF	TOF
4	CH1	CH2	CH2	TOF	TOF
5	CH1	CH1	CH1	CH2	!CH
6	CH1	CH1	CH1	CH2	!CH
7	CH1	CH1	CH1	CH2	!CH

Time of Flight

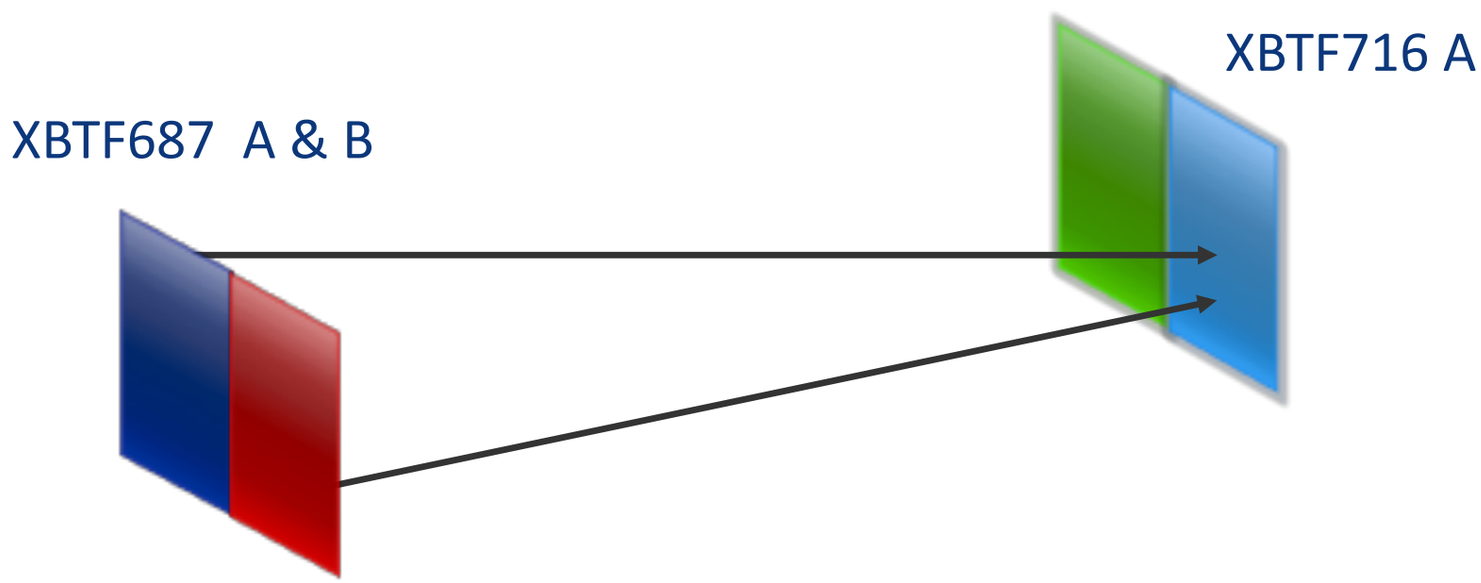
- Problem: observed many trigger events allow for multiple possible TOF times in defined time window.

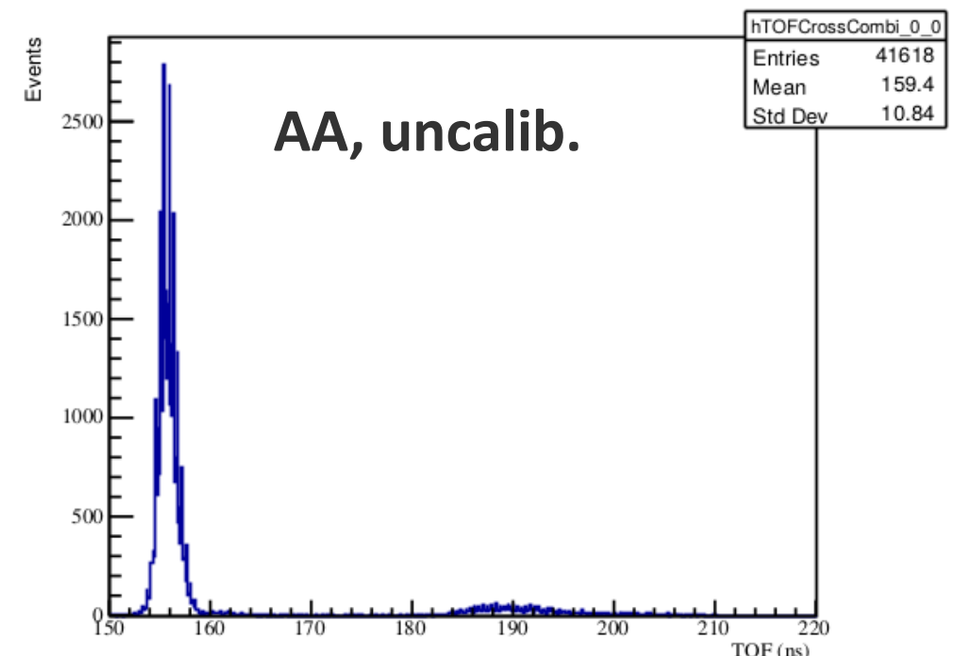
- Four channels: (XBTF687A, XBTF687B), (XBTF716A, XBTF716B)
  - 0/1 total timestamps → 0 TOF combinations
  - 1 timestamp, 1 timestamp → 1 TOF combination (golden)
  - 2 timestamp, 1 timestamp → 2 TOF combinations
  - 1 timestamp, 2 timestamp → 2 TOF combinations
  - 2 timestamp, 2 timestamp → 4 TOF combinations

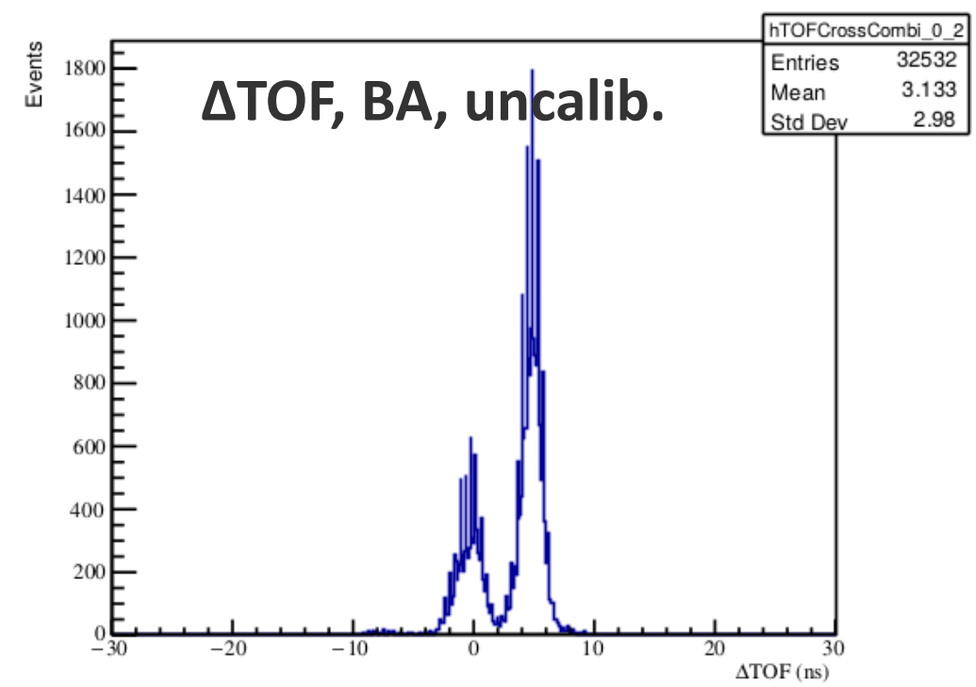




Time of Flight (Channel-wise Study)





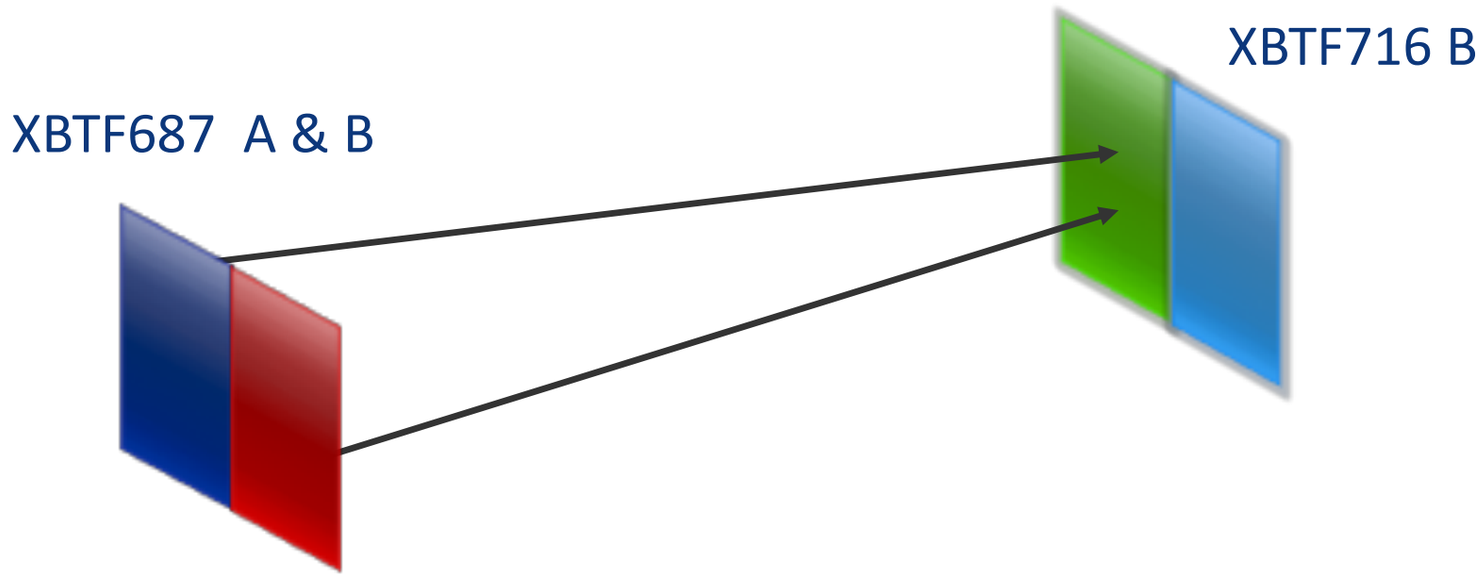


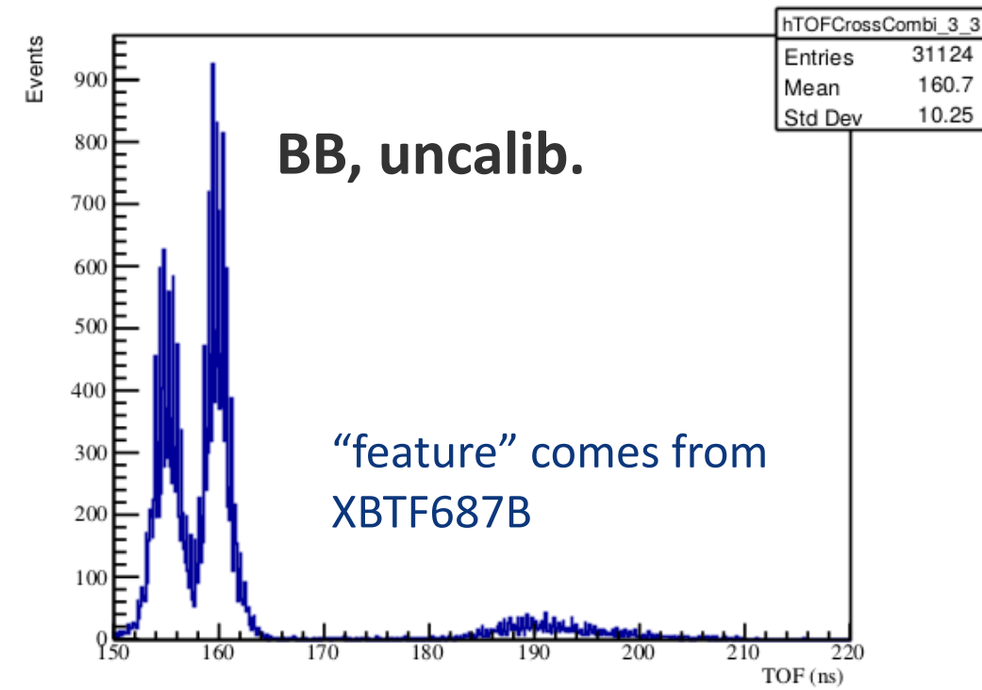
- **Question:** If AA has a valid TOF combination, does BA also provide a valid TOF combination for same event?

Answer: Very often, yes!

- Timestamp in XBTF716A is usually the same for both calculated TOF.
- Signal from XBTF687B comes simultaneous ΔTOF ≈ 0ns, or
- Signal from XBTF687B comes 4-5 ns earlier: ΔTOF ≈ +4-5ns with respect to XBTF687A.

Time of Flight (Channel-wise Study)

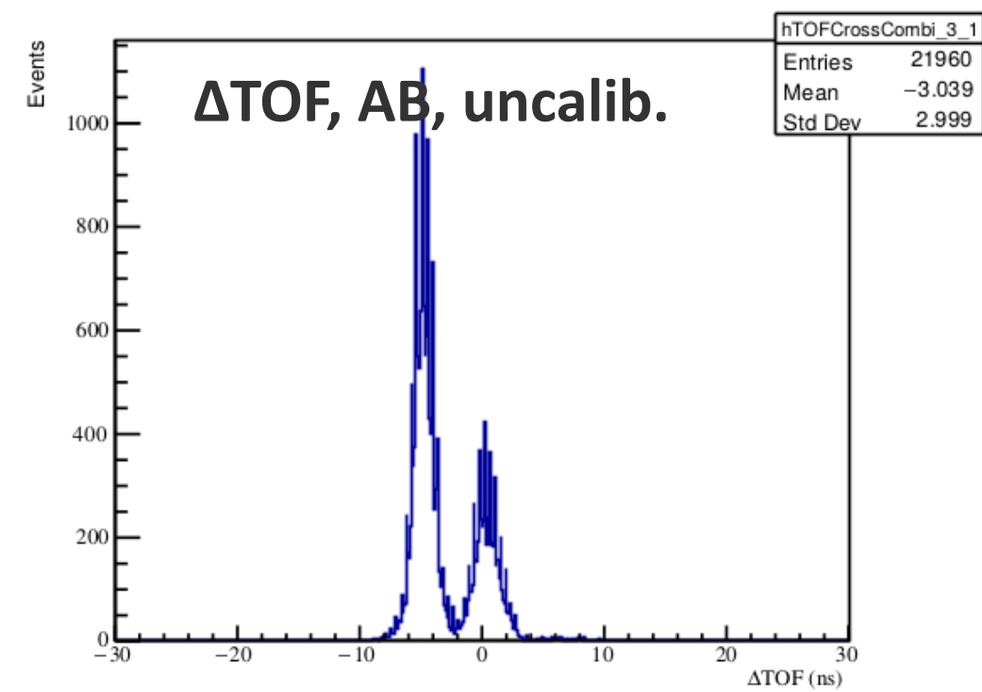




- **Question:** If BB has a valid TOF combination, does AB also provide a valid TOF combination for same event?

Answer: Very often, yes!

- Timestamp in XBTF716A is usually the same for both calculated TOF.
- Signal from XBTF687B comes simultaneous ΔTOF ≈ 0ns, or
- Signal from XBTF687B comes 4-5 ns earlier: ΔTOF ≈ +4-5ns with respect to XBTF687A.



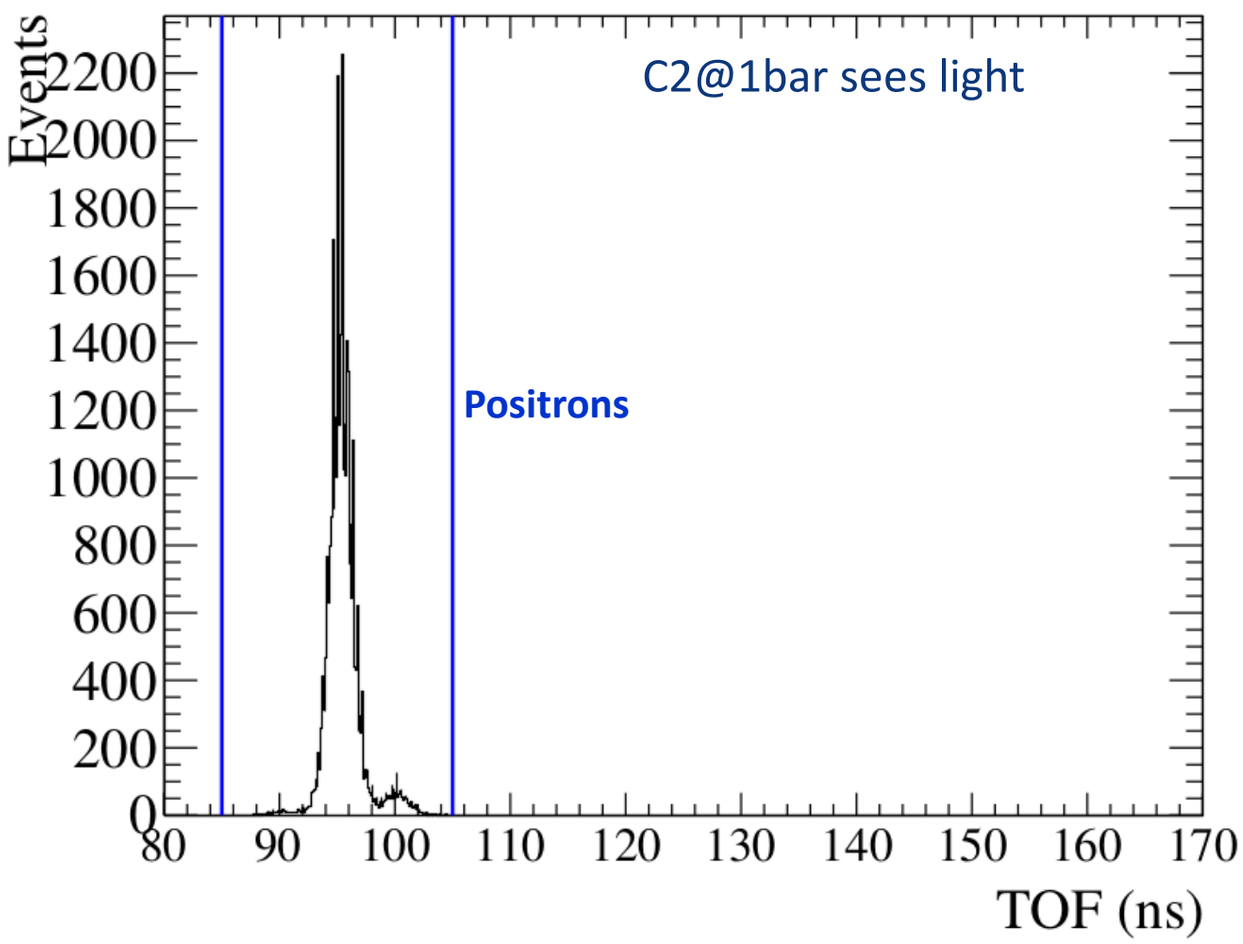
Mitigation

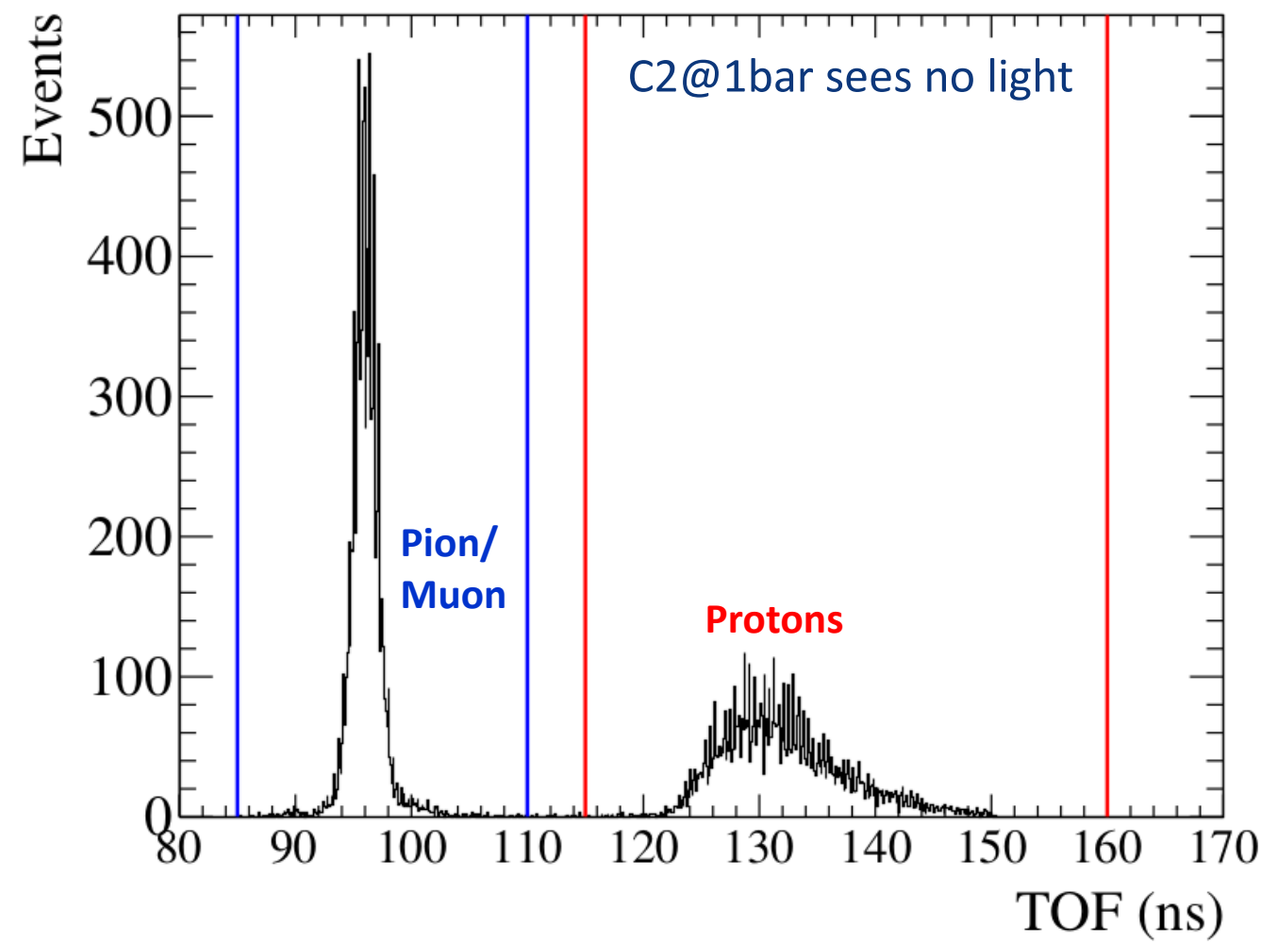
Combine TOF information with Cherenkov information to choose a 'valid TOF'.

- **Example:** 1 GeV/c: C1 not used, C2 @ 1 bar for positron tagging.
  - C2 sees light → assume the particle is a positron:
    - In case of multiple TOF, check if valid calib. TOF between 85-110 ns exists → Positron.
  - C2 no light → assume particle is either pion/muon or proton.
- Proton significantly slower (calib. TOF: 115ns – 160ns).
- Multiple TOF? Check if valid calib. TOF between 115ns – 160ns exists → Proton.
- ELSE: In case of multiple TOF, check if valid calib. TOF between 85-110 ns exists → Pion/Muon.

Results: 1 GeV/c

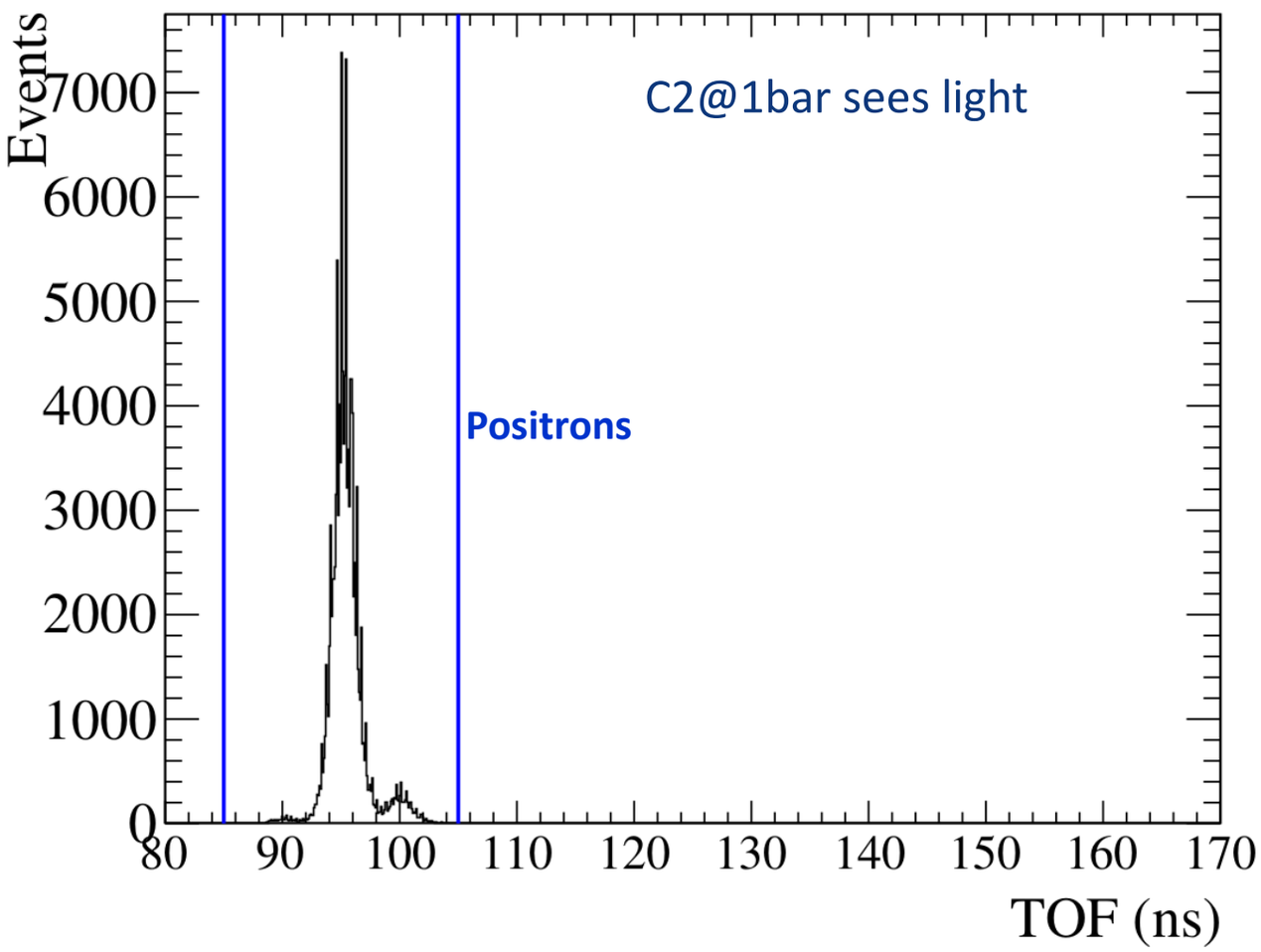
- Calibration of TOF depending on channel AA, AB, BA or BB.
- Between 65.5 and 66.5 ns subtracted from each channel.
- C1 is not used.
- C2 sees light only for positrons.

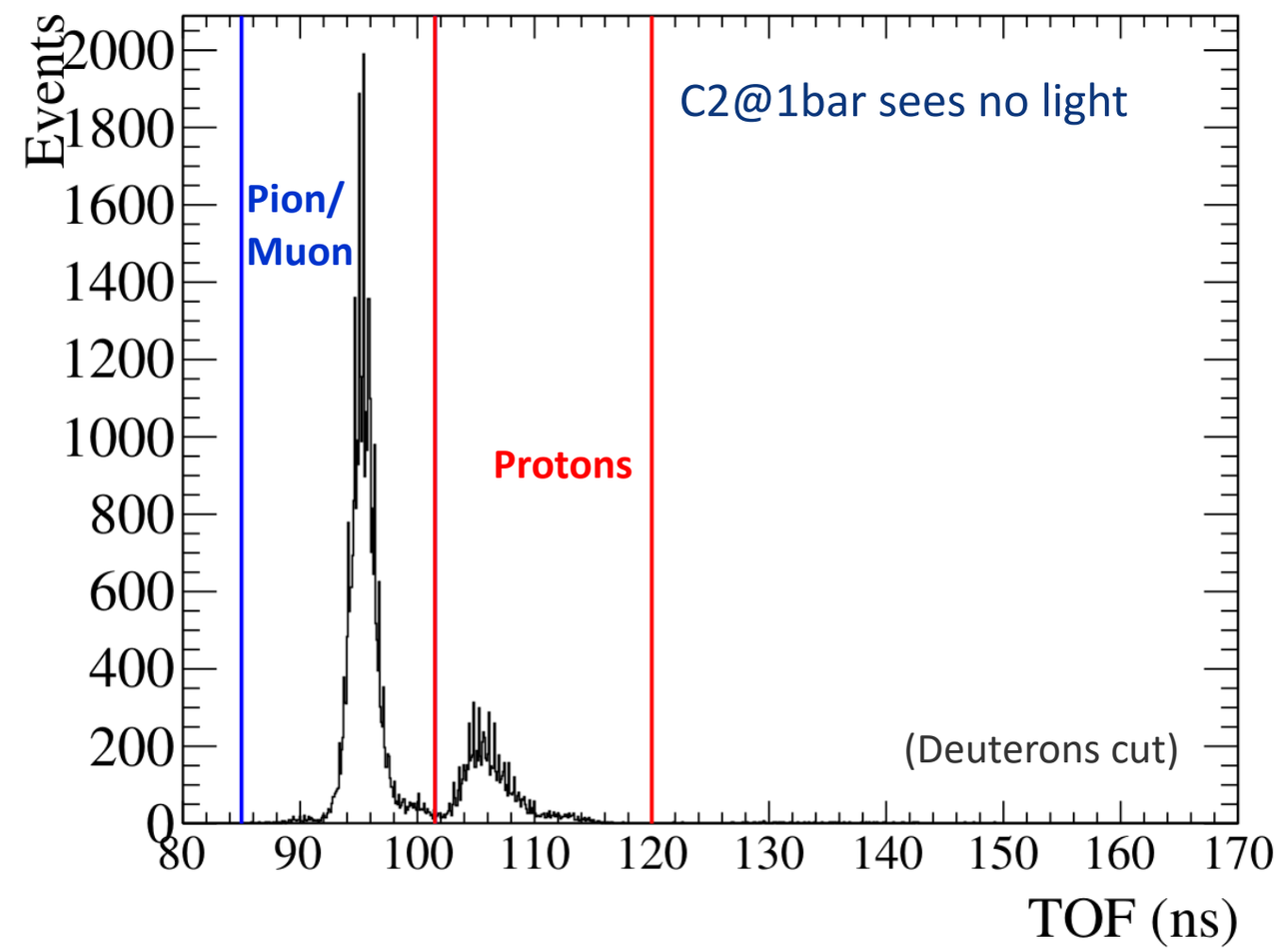




Results: 2 GeV/c

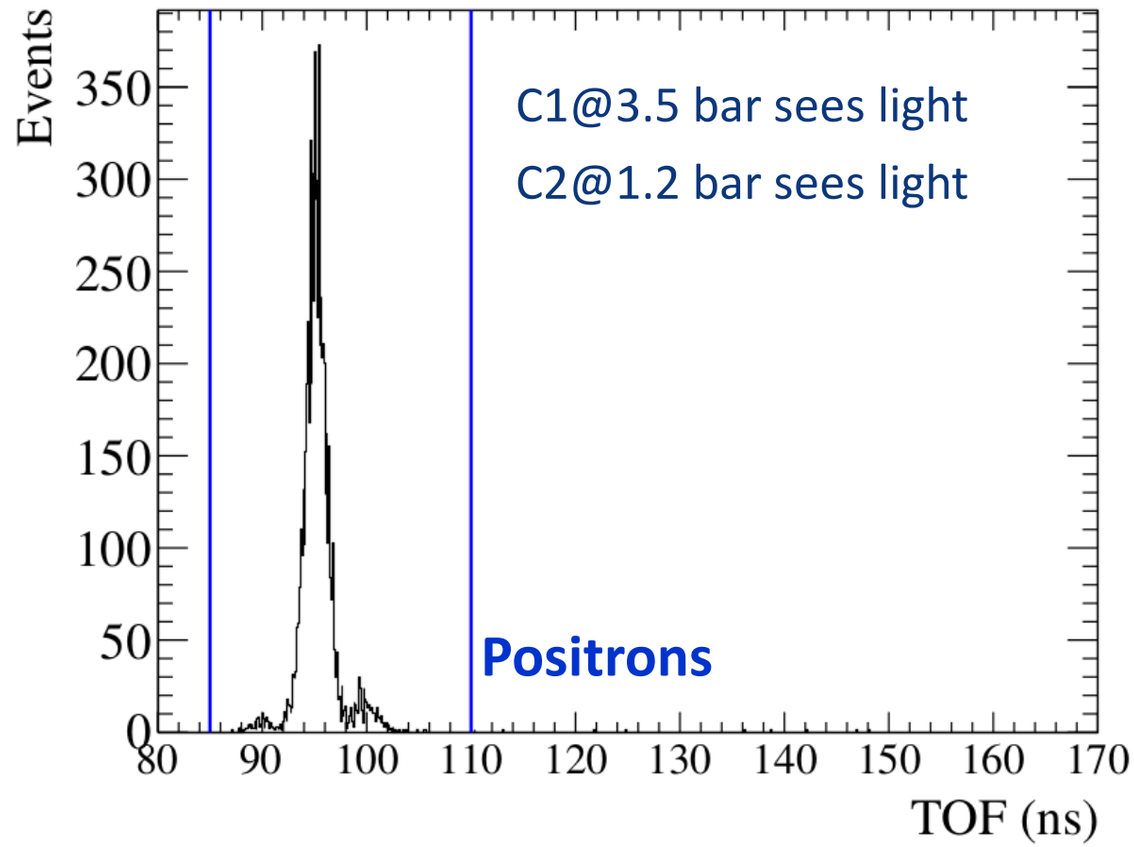
- C1 is not used.
- C2 sees light only for positrons.

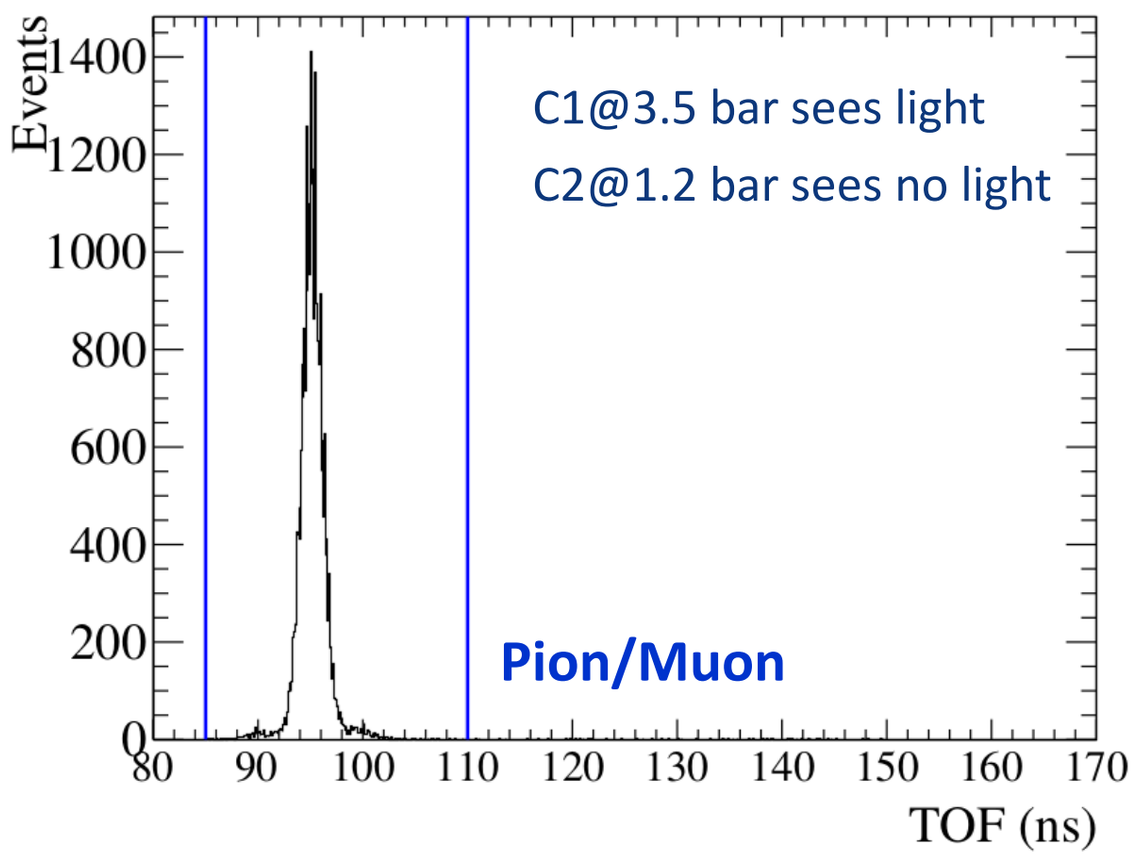


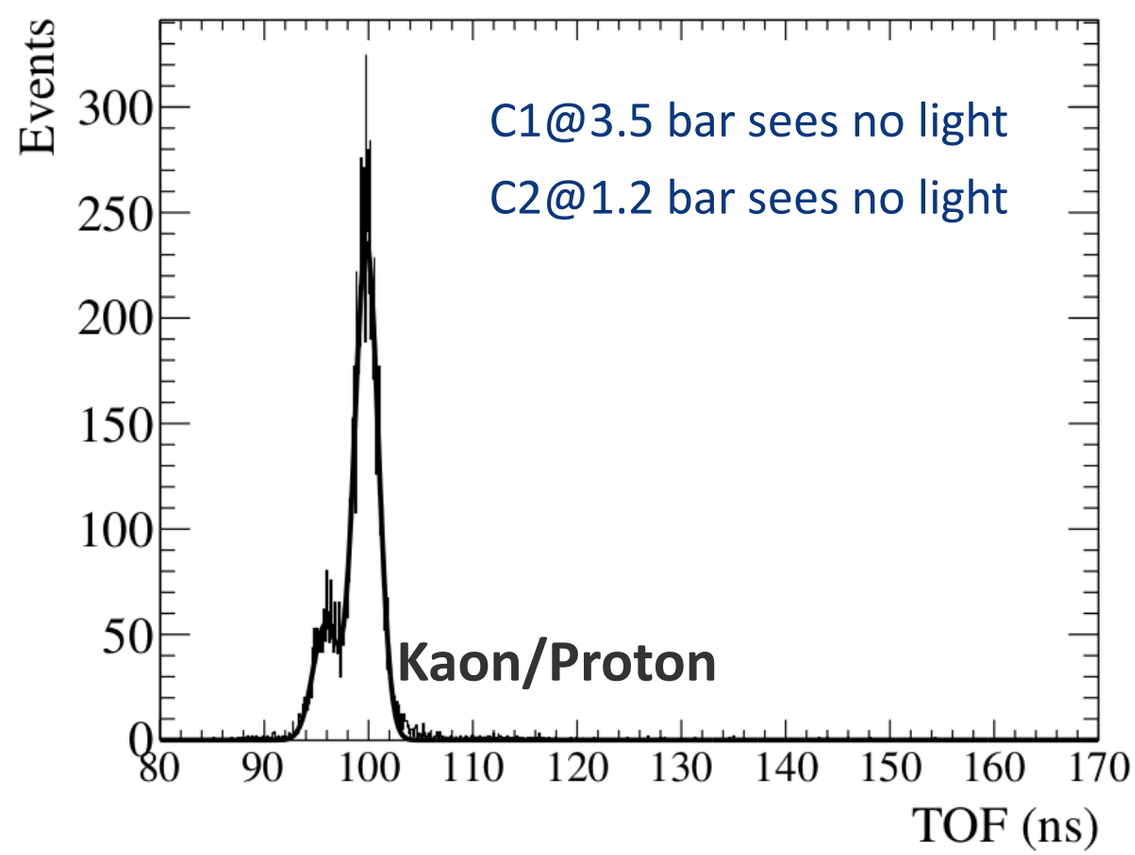


Results: 3 GeV/c

- C1 (high pressure) sees light for positrons, pions and muons.
- C2 (low pressure) sees light only for positrons.

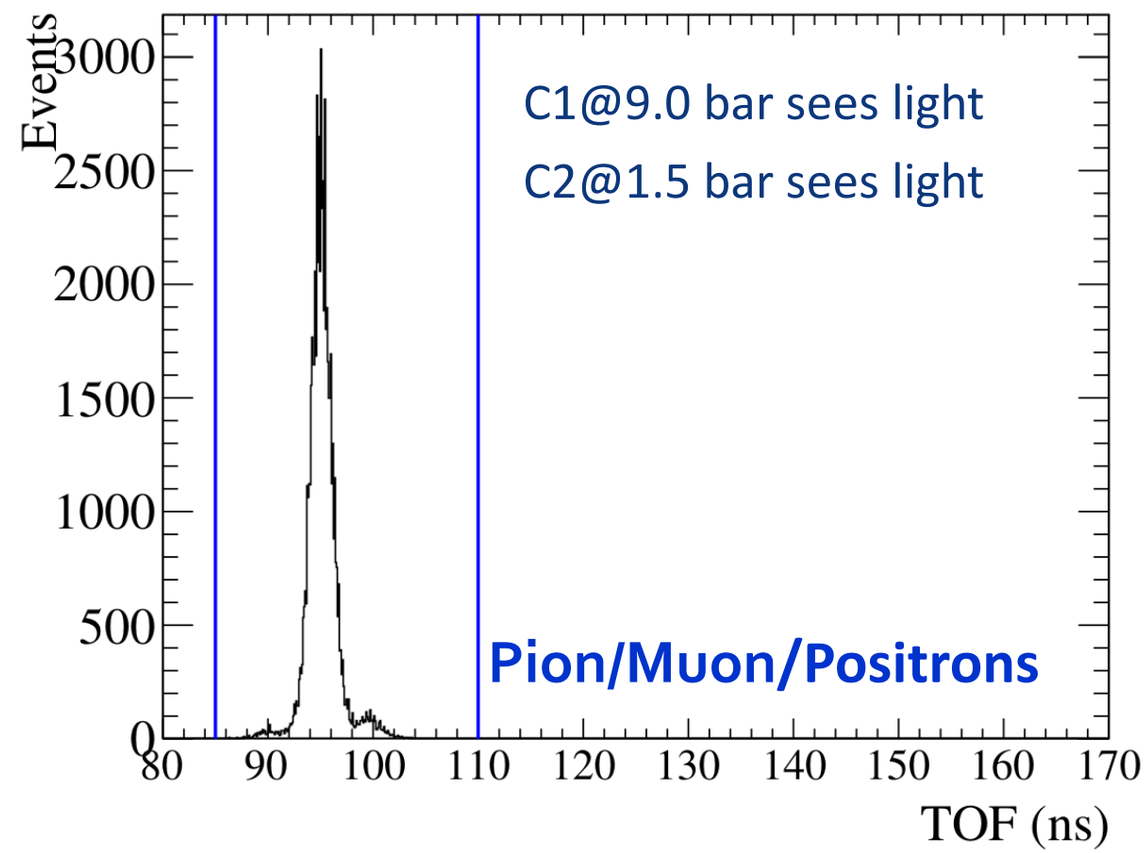


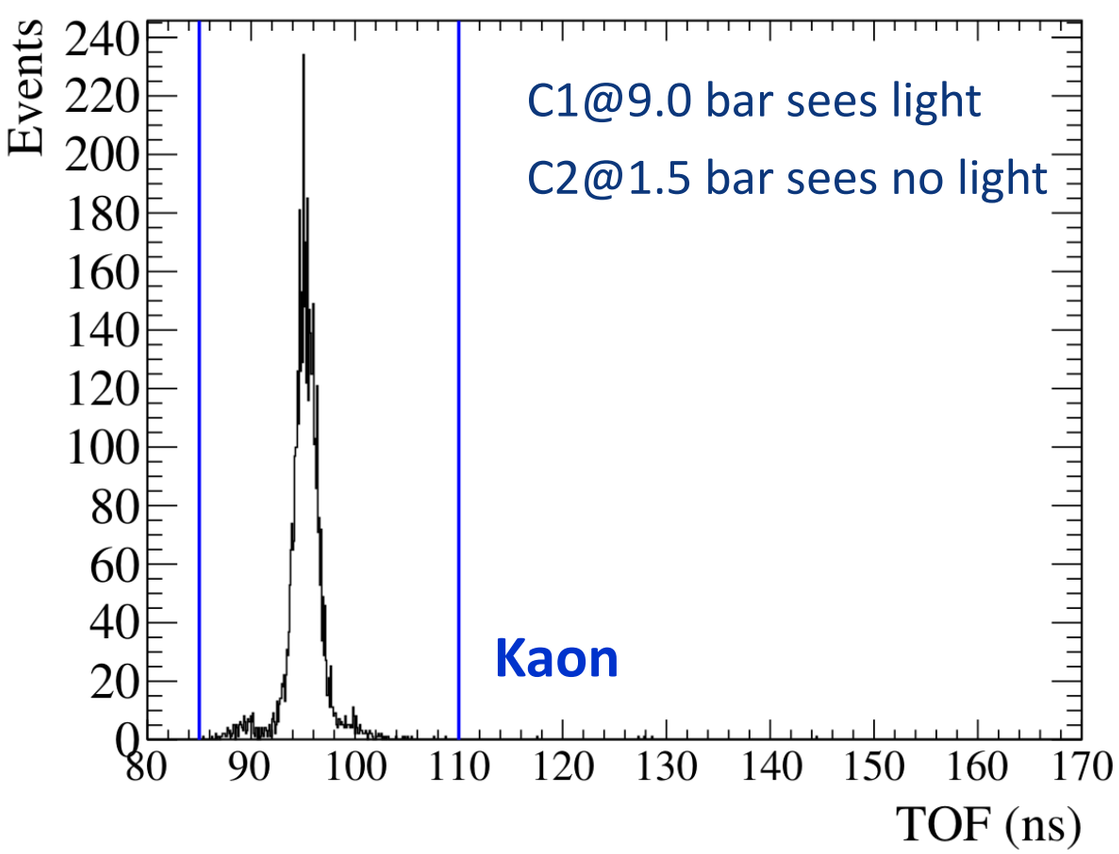


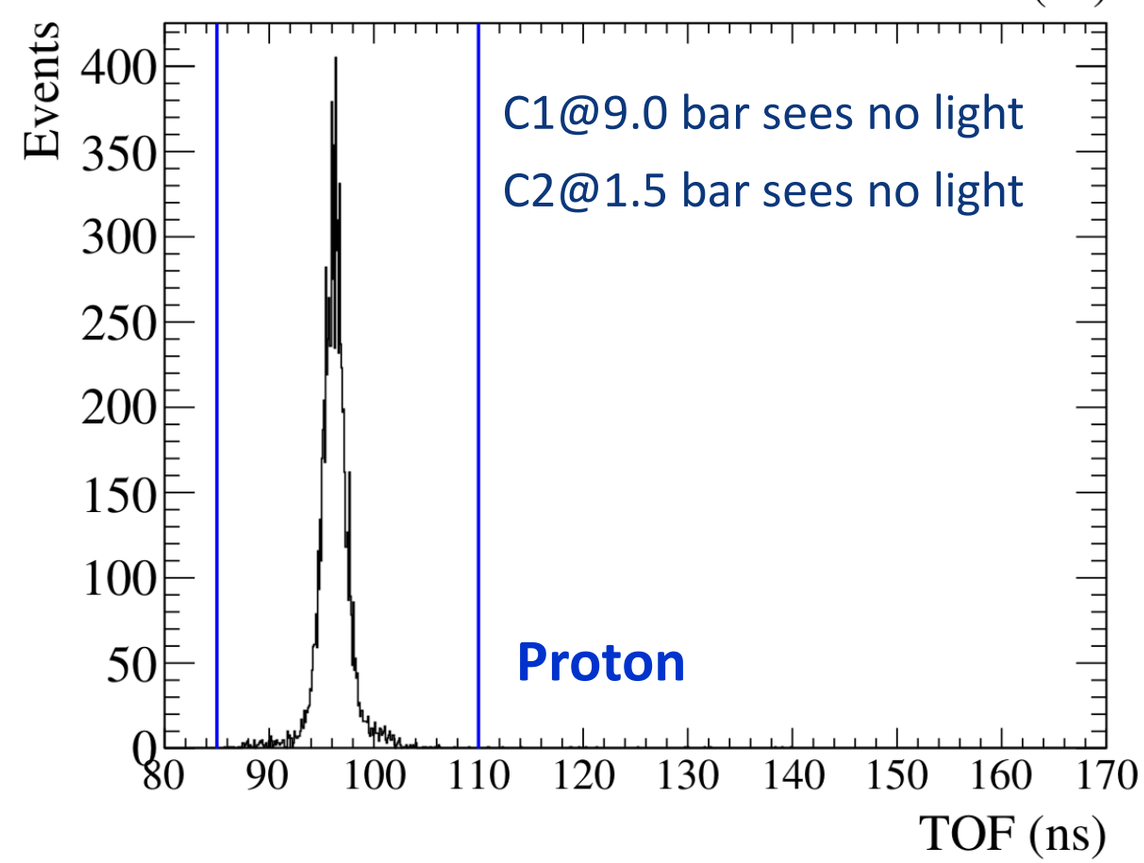


Results: 6 GeV/c

- C1 (high pressure) sees light for pions, muons, positrons and kaons.
- C2 (low pressure) sees light for pions, muons and positrons.

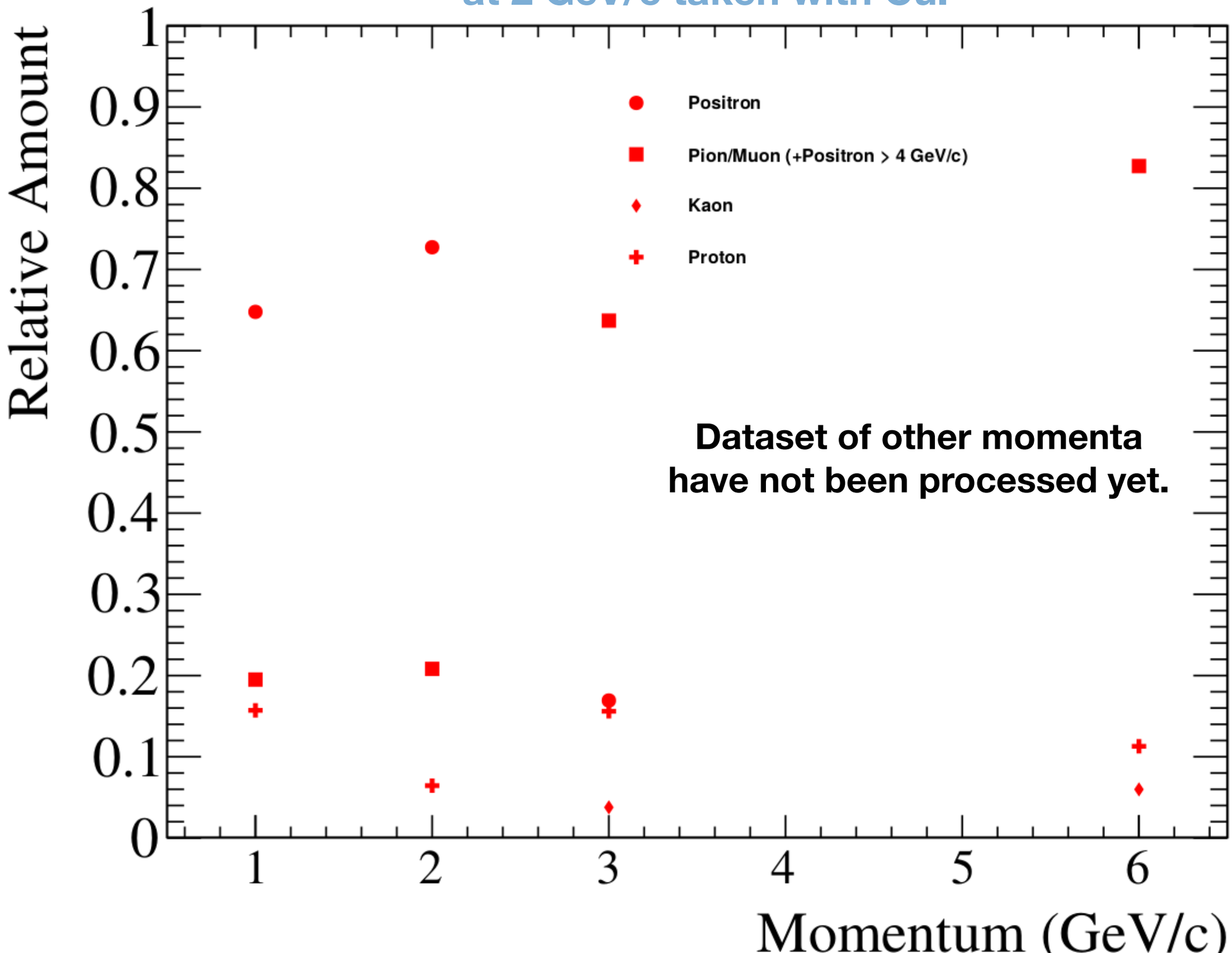






Beam Composition Summary

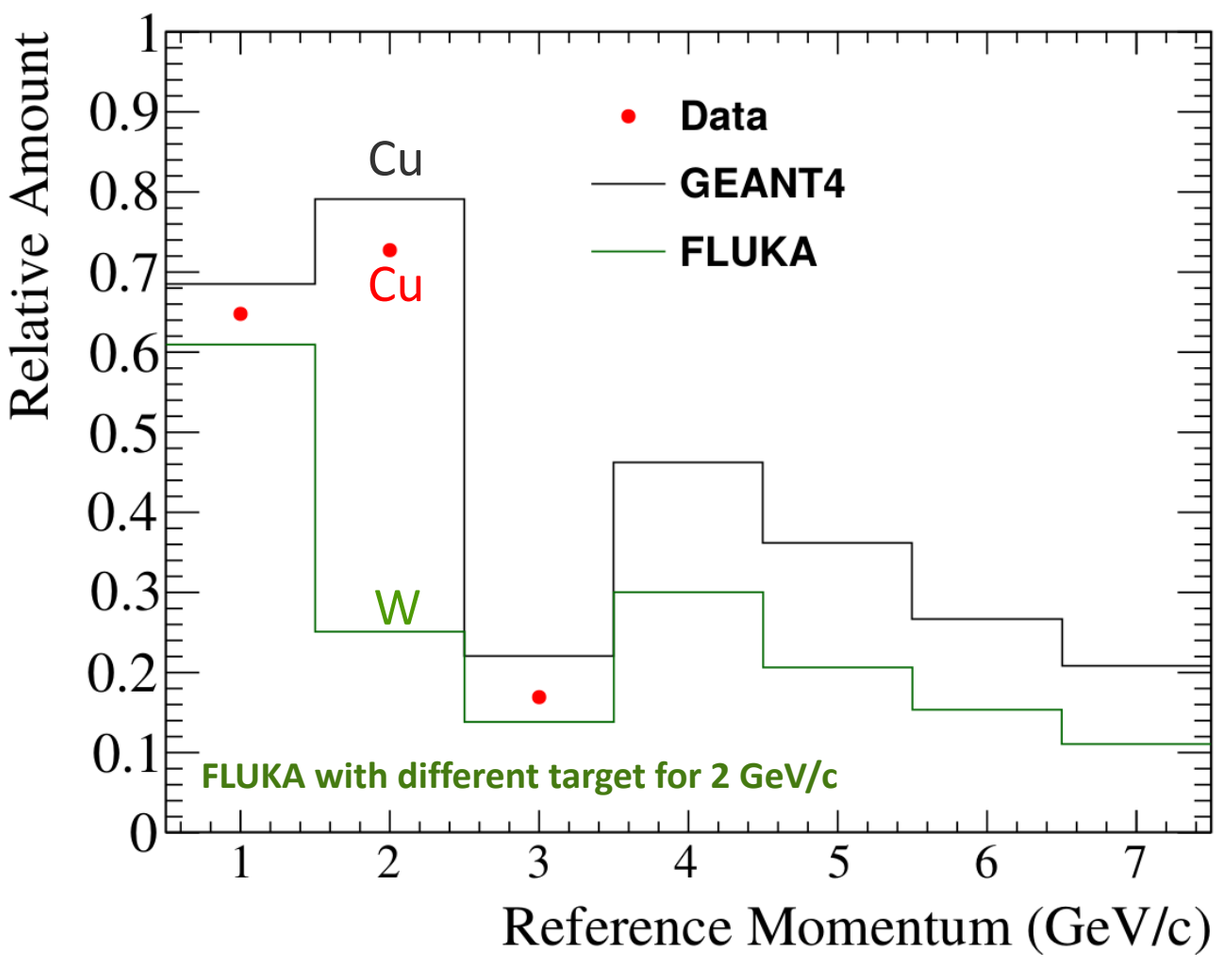
Default target: W for 1 - 3 GeV/c, Cu for 4 - 7 GeV/c. Measured data at 2 GeV/c taken with Cu.



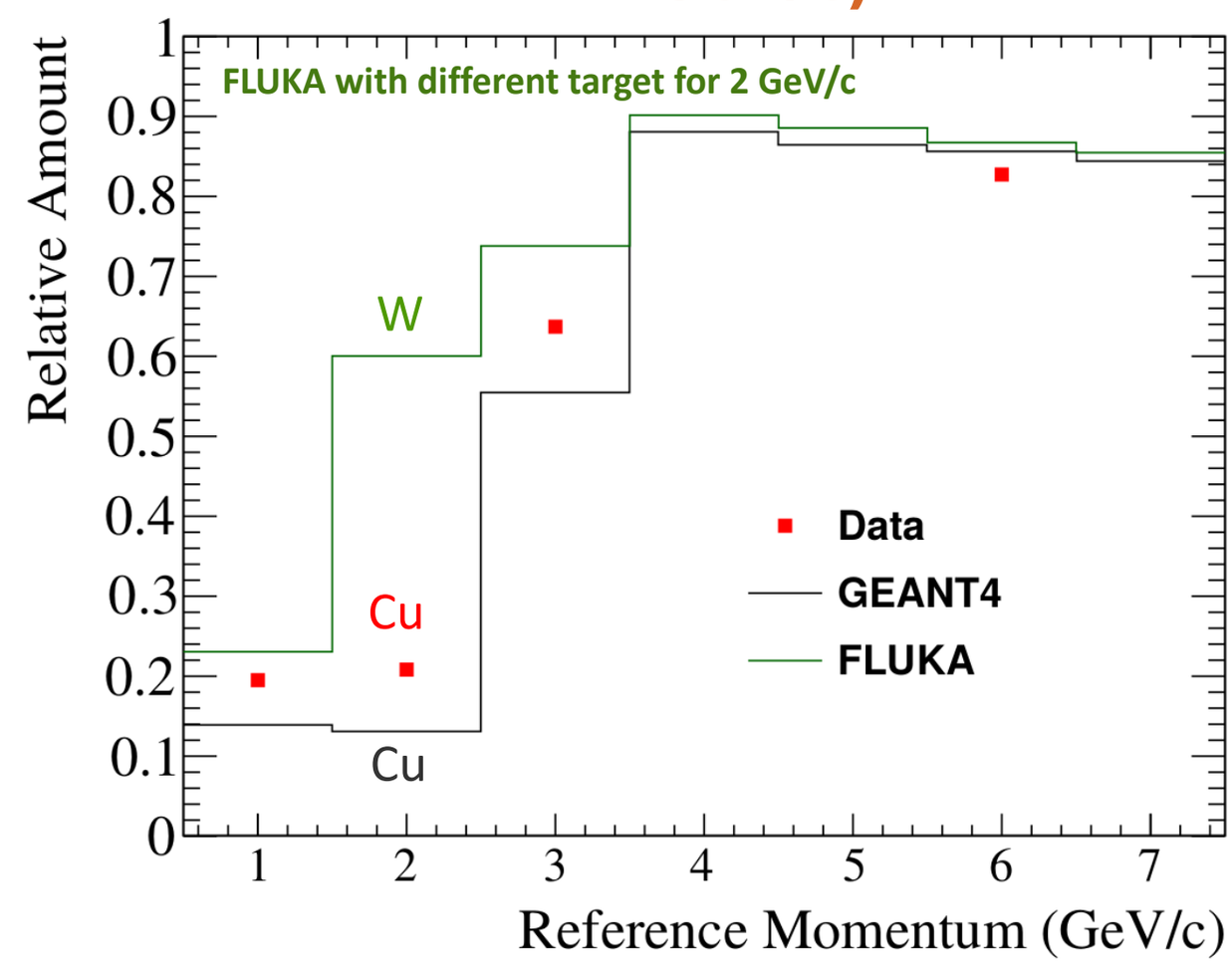
Monte Carlo Comparison

Default target: W for 1 - 3 GeV/c, Cu for 4 - 7 GeV/c. Measured data at 2 GeV/c taken with Cu.

Positrons



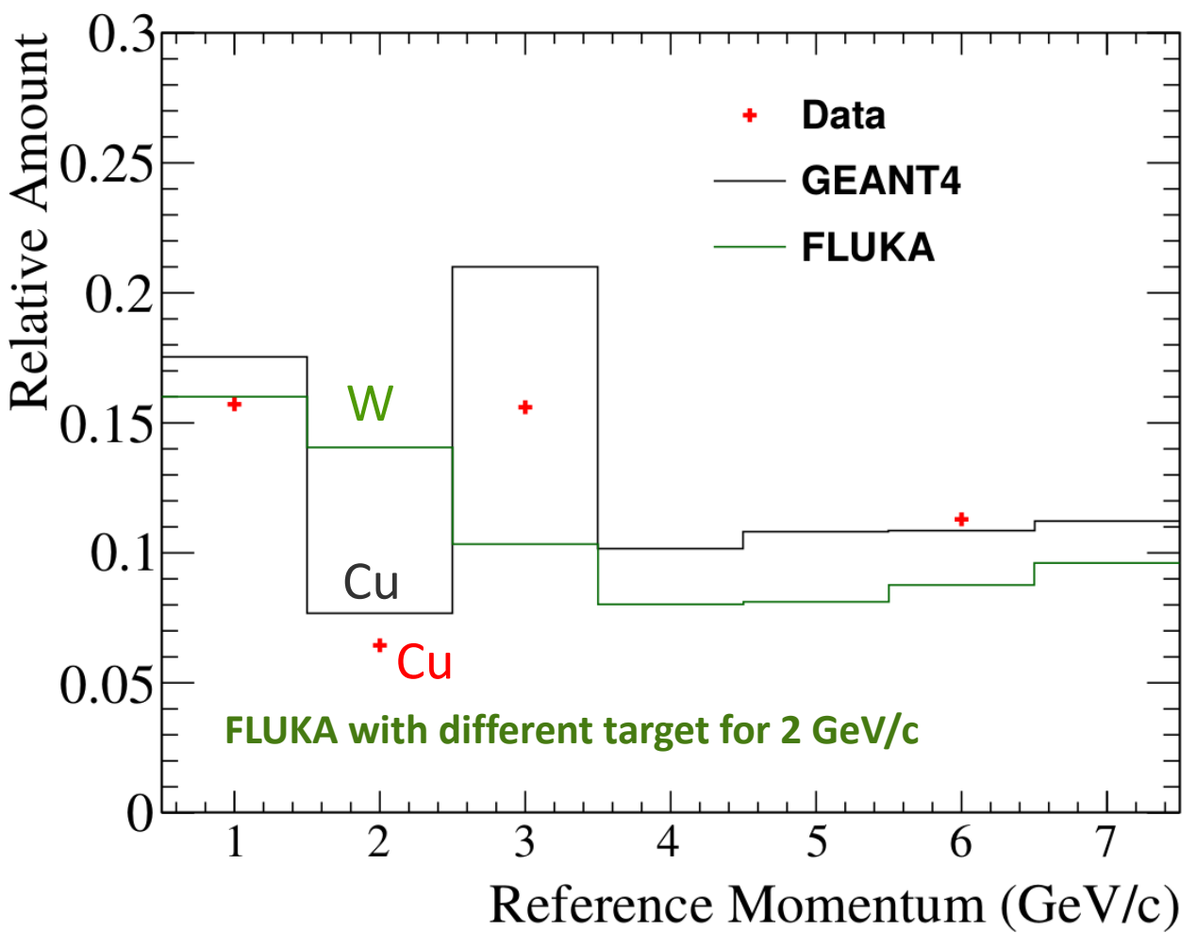
Pions / Muons (+ positrons > 4 GeV/c)



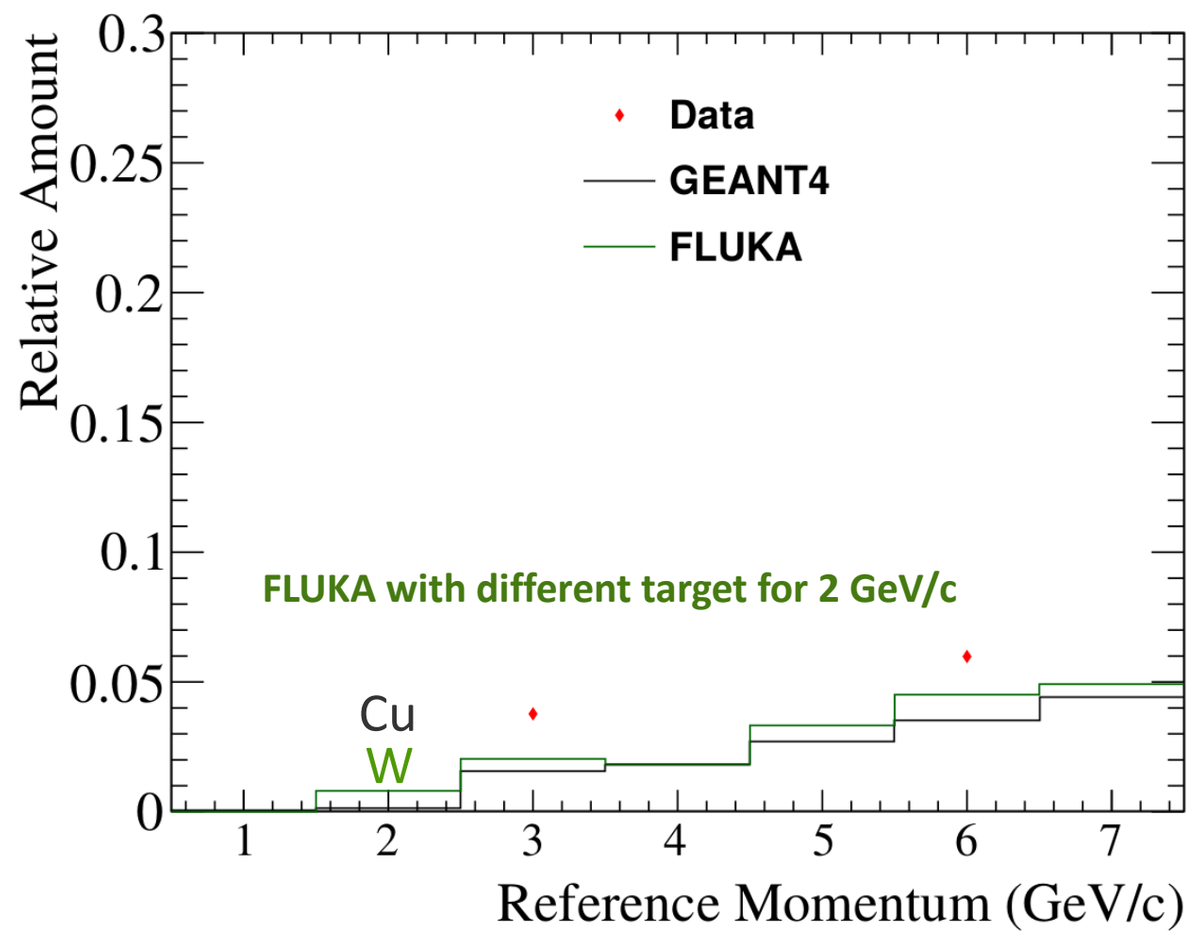
Monte Carlo Comparison

Default target: W for 1 - 3 GeV/c, Cu for 4 - 7 GeV/c. Measured data at 2 GeV/c taken with Cu.

Protons



Kaons



Summary I

- **Event tree:**
  - Code to produce an off-line ‘event tree’ has been written. 1 entry <-> 1 general trigger.
  - Written to ROOT file, making event-by-event analysis more straightforward.
  - Chosen a good window (500 ns) around general trigger to look for events in BI. Will rerun analyses with 1000 ns, check for stability.

Putting finishing touches to event tree generation, ROOT files for all good runs will be made available at CERN & FNAL soon.

- **Beam line detector performance:**
  - Beam profiler (XBPF) efficiencies are as expected. Spill shape stable across various momenta.
  - Systematically low reconstructed momenta can be account for with a 1.45 mm shift of 3rd profiler.
  - Advanced studies of observed trigger rates and momentum spread.
  - Measured rates and spread similar to expected values from Geant4 and FLUKA.

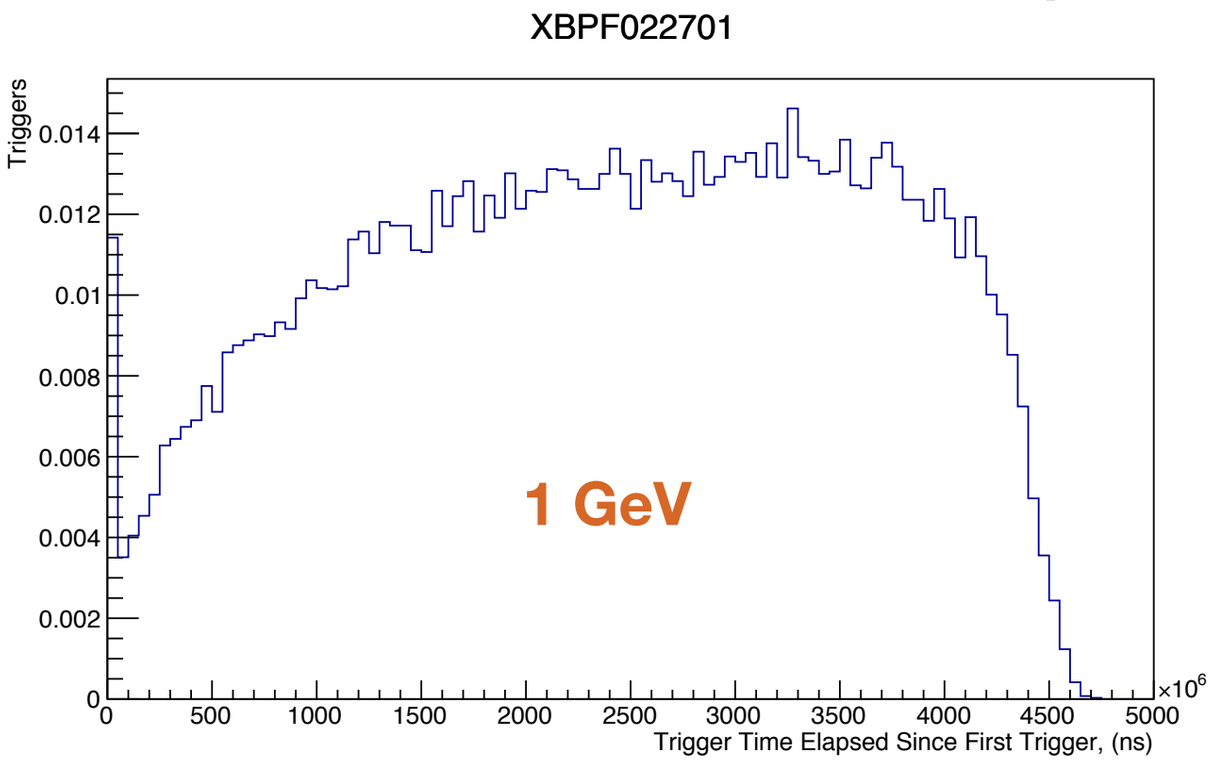
Summary II

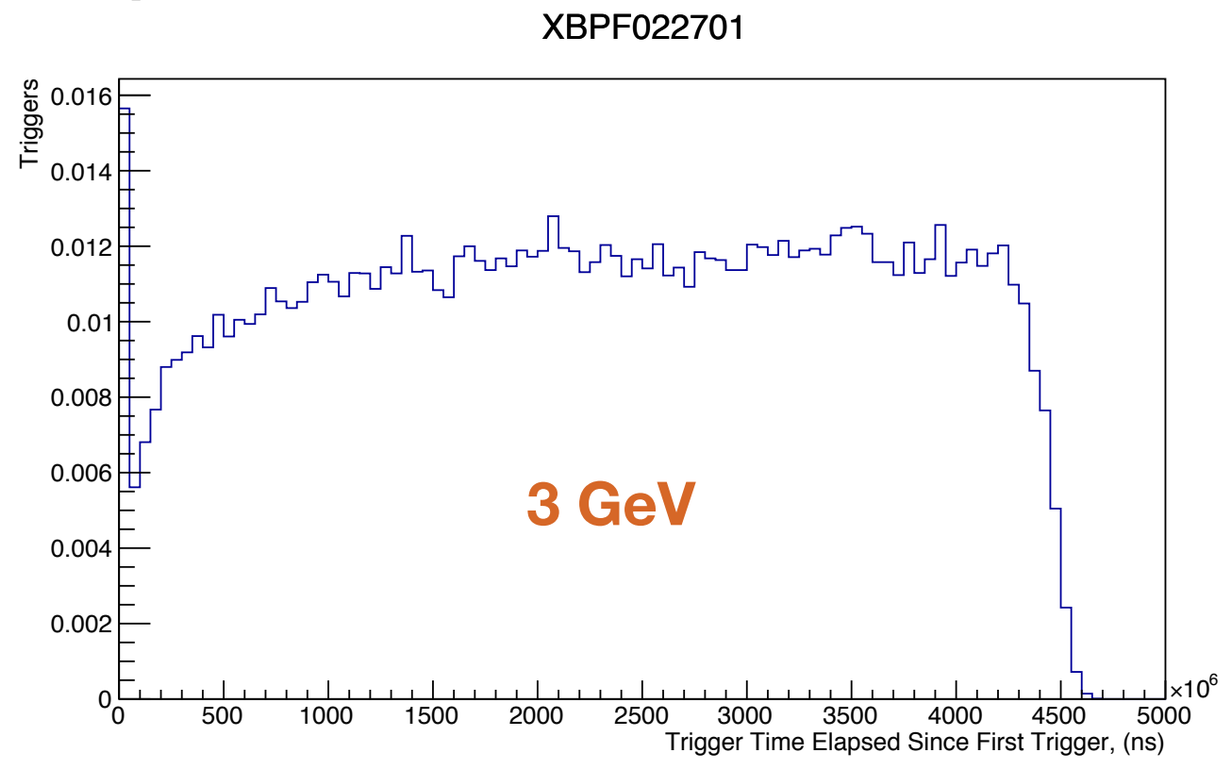
- **Particle Identification:**
  - Analysis combines Cherenkov signals and time of flight on event by event basis.
  - Identified ‘4 ns problem,’ probably related to XBTF687B detector / TDC channel.
    - Often (not always) simultaneous TOF events in combinations AA & BA or AB & BB. (2 TOF / event).
    - TOF reconstruction in channels BA or BB often 4 - 5 ns longer than in AA or AB.
    - To mitigate, chosen ‘valid TOF’ by using a combination of TOF and Cherenkov information to identify particle species.
  - Measured beam composition similar to expected values from Geant4 and FLUKA simulations.

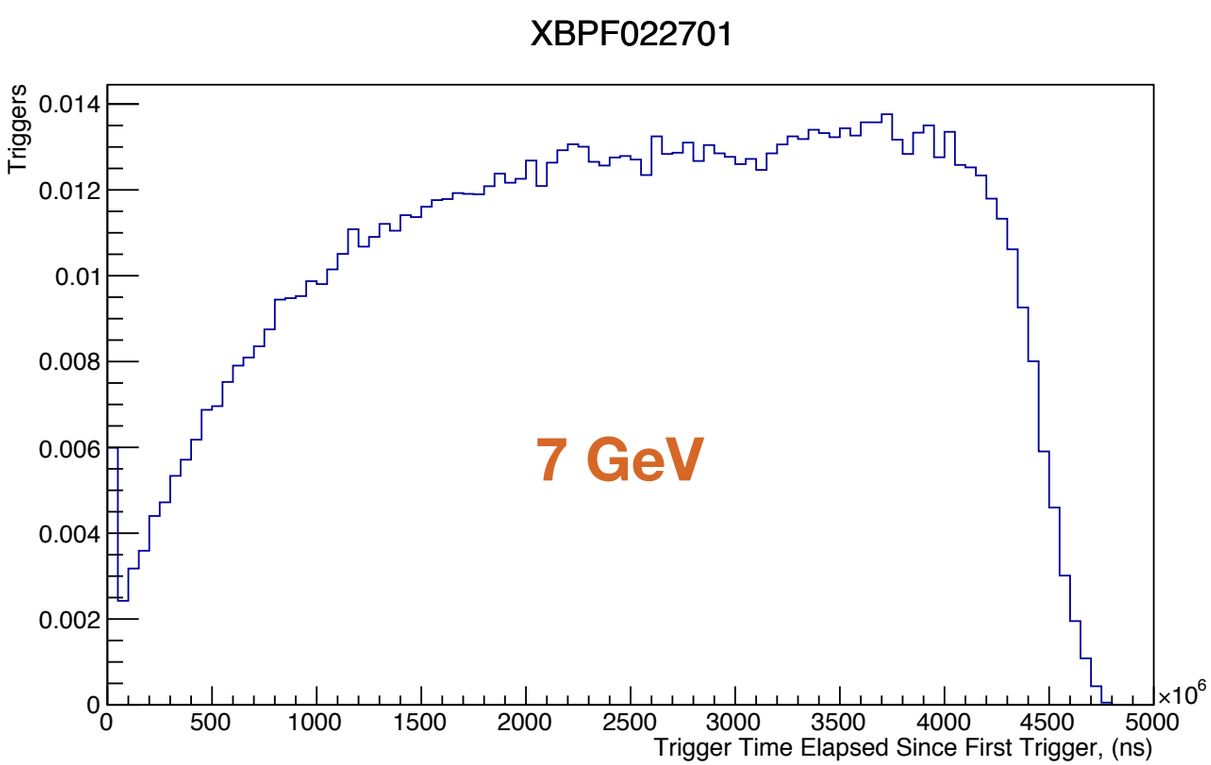
Backup Slides

Spill Shape

Can use time between any XBPF event in spill and first XBPF event in spill to see time profile of spill.







Pretty homogenous spill structure during extraction, as expected.

PID & Beam Composition Logic

At 1 & 2 GeV, with 1 bar can only see electrons.
XCET 713 ~ 0.1 bar (low), XCET 716 ~ 1 bar (high).
Signal from XCET 716 -> electron. No signal -> mu/pi/K/proton.
Check TOF. TOF > Mean + 4 sigma -> proton. Else mu/pi/K.

At 3 GeV 1.2 bar, see only electrons. At 3.5 bar see mu / pion / electron. Never see K or P.
XCET 713 ~ 3.4 bar (high), XCET 716 ~ 1.2 bar (low).
Signal from XCET 716 -> electron.
Signal from XCET 713, nothing from XCET 716 -> mu / pion.
Nothing from either -> K or P. Check TOF. TOF > Cut -> proton. Else K.

At 6 GeV 1.5 bar, see e / mu / pi, never K or P. At 9 bar e / mu / pi / K.
XCET 713 ~ 9 bar (high), XCET 716 ~ 1.5 bar (low).
XCET 713, 0 and XCET 716, 1 -> e / mu / pi.
XCET 713, 0 and XCET 716, 0 - > proton.
XCET 713, 1 and XCET 716, 1 -> e / mu / pi / K.
XCET 713, 1 and XCET 716, 0 -> K.