Systematics from “old” muons

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Thanks to my Pienu colleagues for their input

GORDON AND BETTY MOORE FOUNDATION

Outline

- Brief description of the Pienu experiment
  - focus on the impact of “old” muons
    (drop the quotes on “old”)
- Sources of old muons for PIONEER
- Topologies of triggers and backgrounds
- Suppression of pileup
- Systematics considerations

The Pienu Experiment at TRIUMF

Beam:

60kHz pions @ 75 MeV/c

$\pi : \mu : e = 85 : 14 : 1$

Detector: [1]

Acceptance: 20%

Plastic Scintillators

NaI(Tl) + CsI Calorimeter

Wire Chambers

Silicon Strips

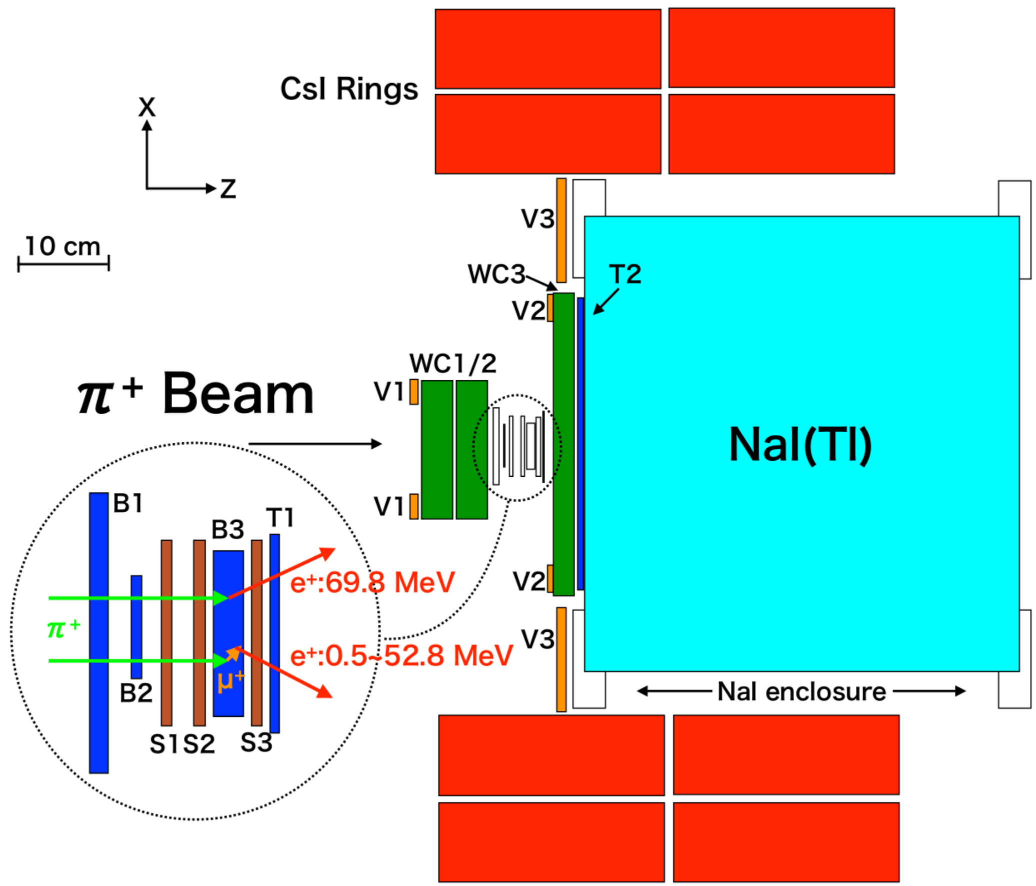
Energy resolution:

2.2% FWHM @ 70MeV

Temperature Stabilization

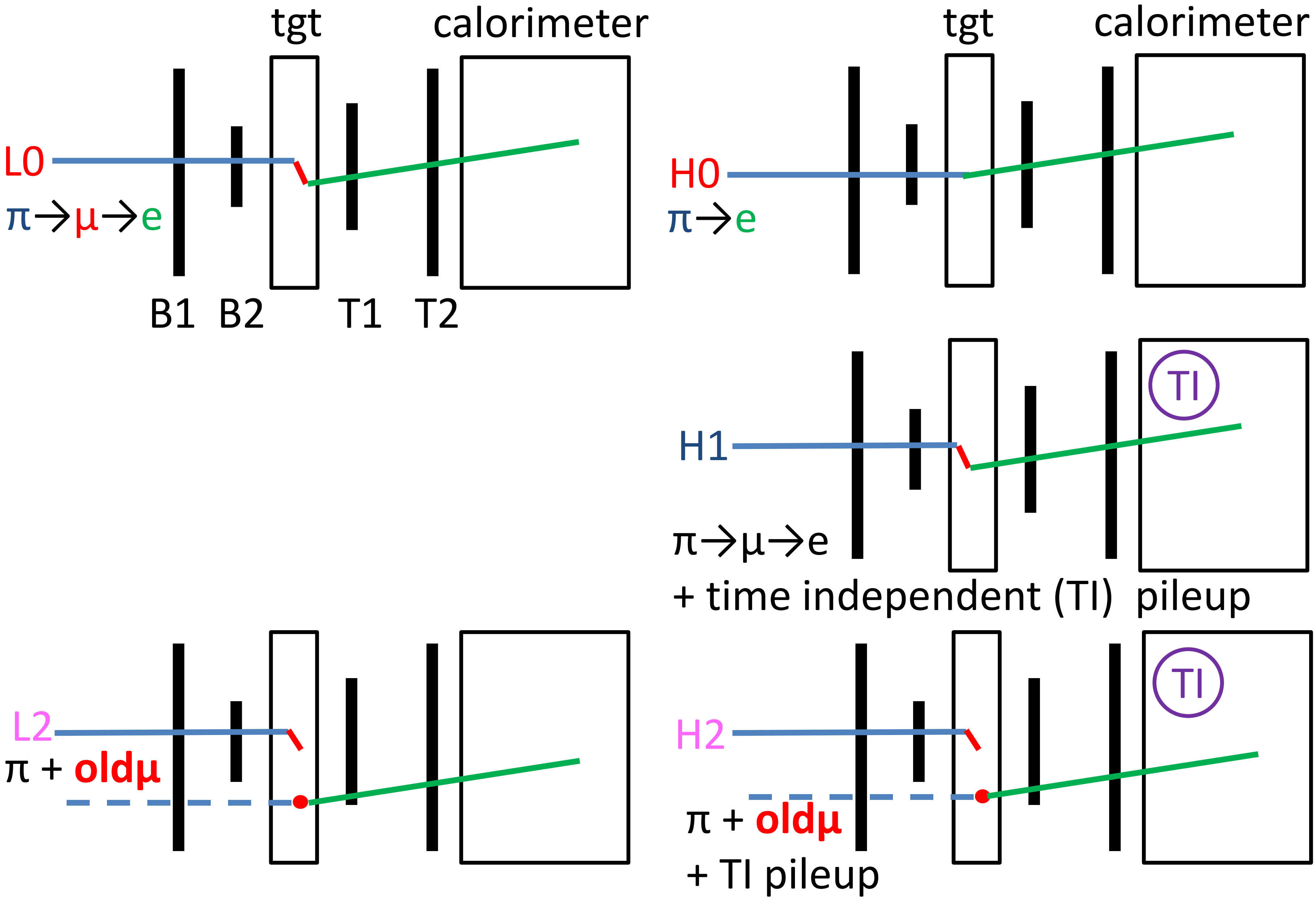
Data taking:

2009-2012

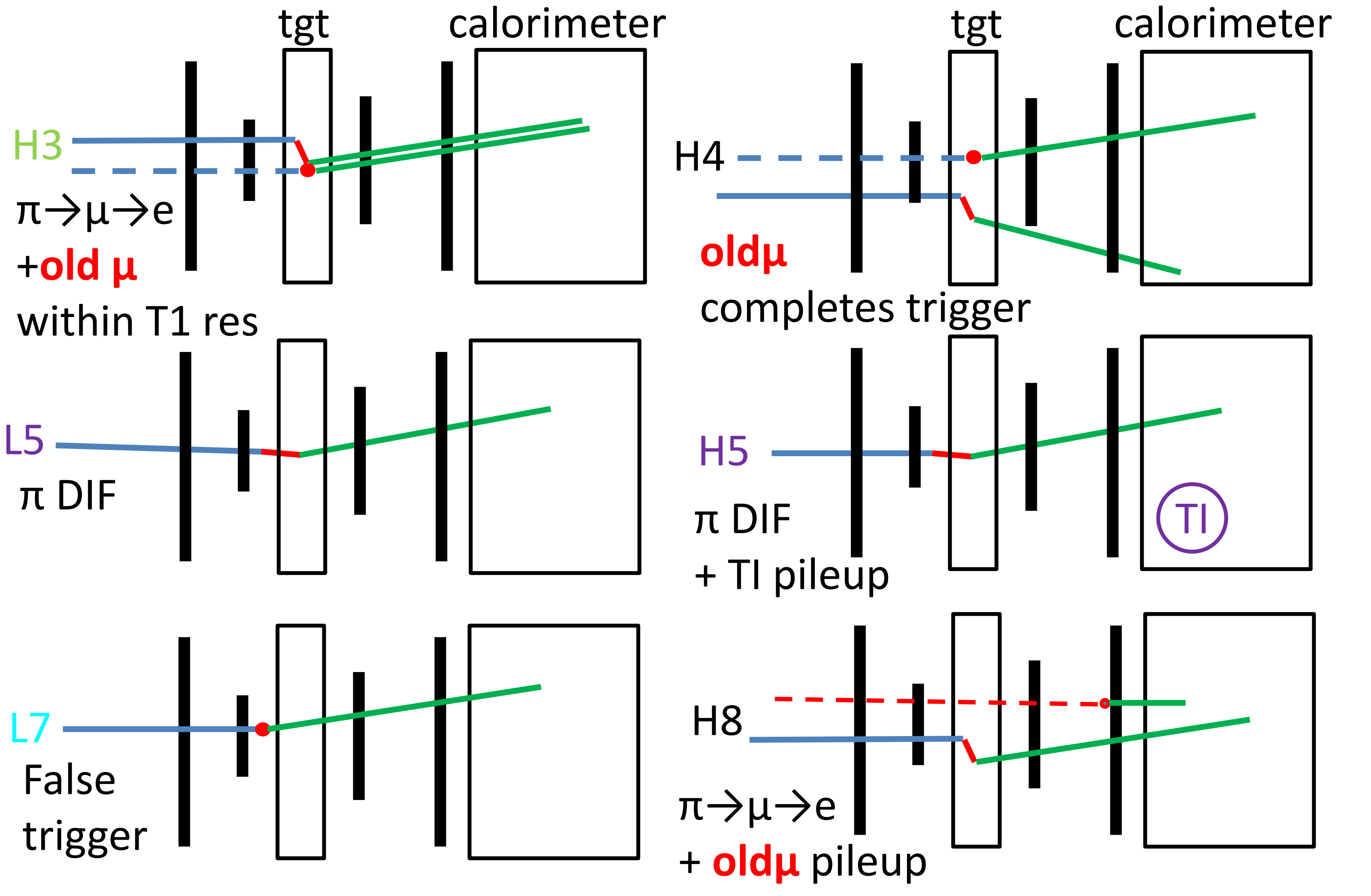


[1] A. Aguilar-Arevalo et al., Nucl. Instrum. Methods Phys.Res., Sect. A 791, 38 (2015).

Event topologies

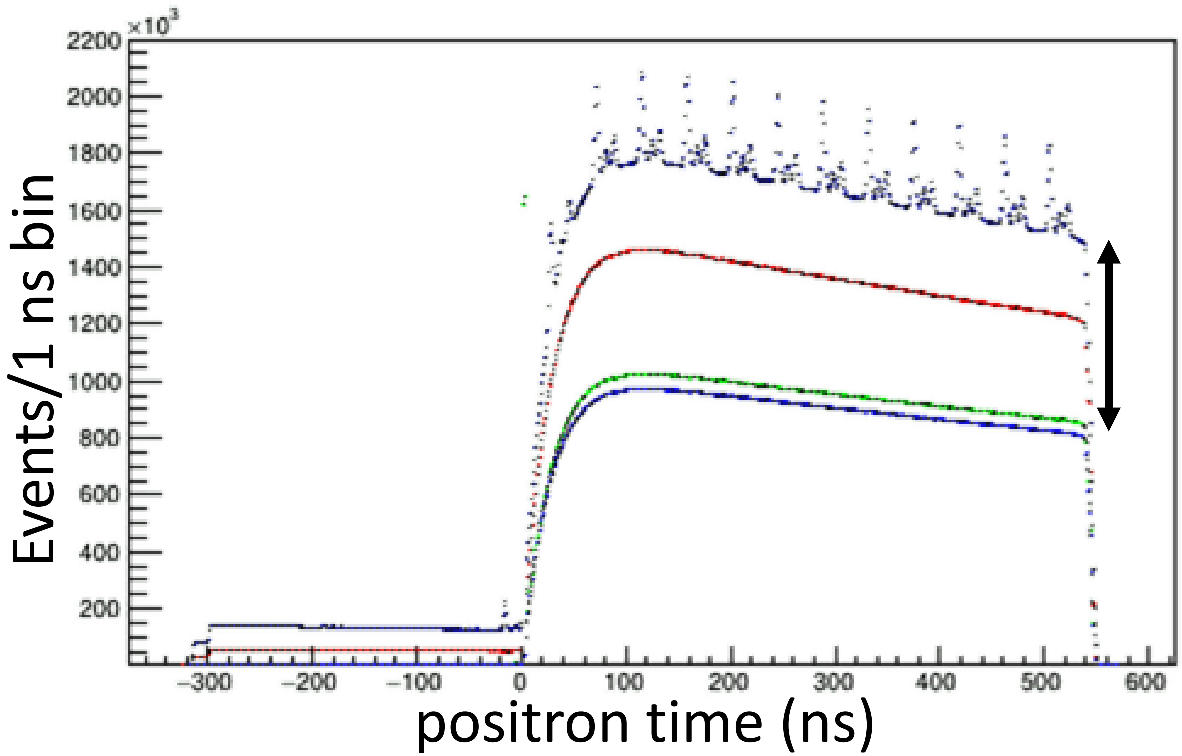


More event topologies



Effect of pileup cuts on the time spectrum

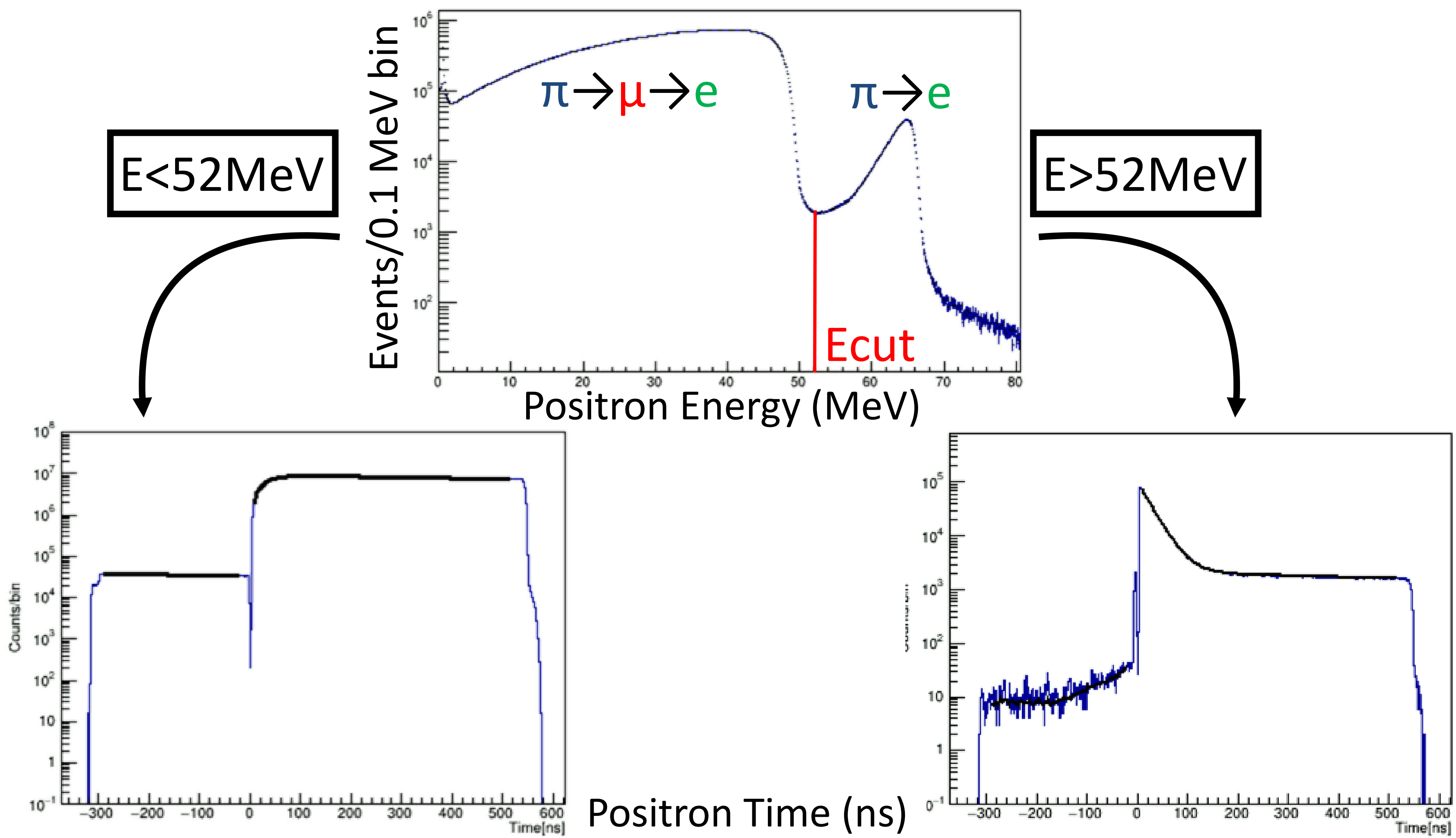
- The pileup cuts are severe: ~35% of events pass
  - Black: after cuts to select incident pions
  - Red: after pileup cuts in scintillators
  - Green: after cuts for early-time pileup
  - Blue: after all selection cuts



pileup
mostly due
to old muons

Extraction of the Branching Ratio

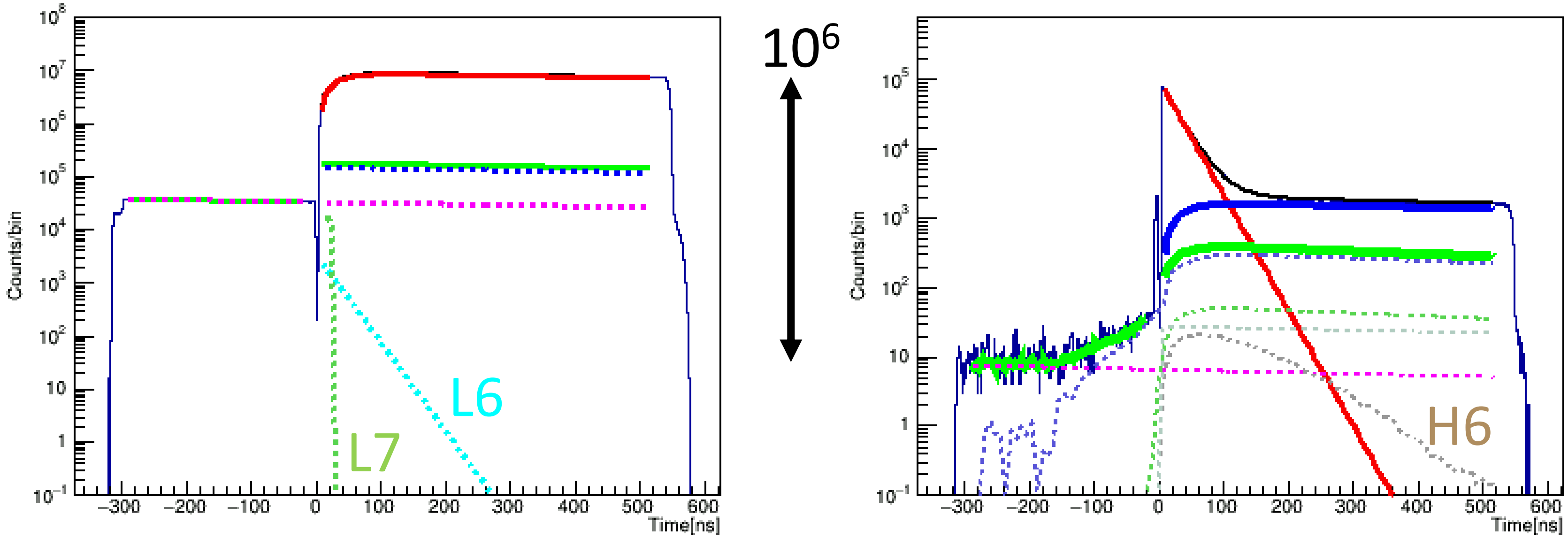
- The branching ratio for π→eν(γ)/π→μν(γ) is extracted from the data by first dividing the energy spectrum into low energy and high energy and then fitting the time spectra simultaneously



The components of the fit that involve old muons are L2, H2, H3, and H4

LE

HE



π→μν→eνν

L2 (π + oldμ)

L5 (πDIF)
L6 (π→eν tail)
L7 (False trigger)

π→eν(γ)

time (ns)

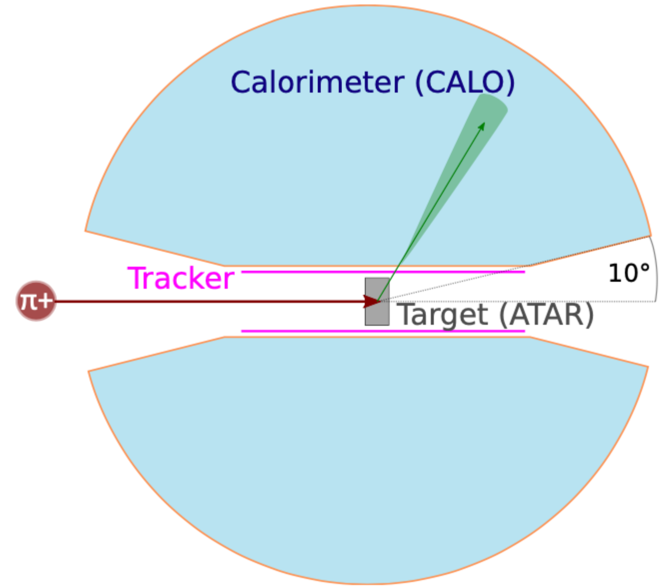
H1 (π→μν→eνν + TI pileup)
H2 (π + oldμ + T! pileup)
H3 (T1 res)
H4 (double muon)
H5 (πDIF + TI pileup)
H6 (π→μνγ)

Systematic uncertainties in Pienu

- Several of the systematic uncertainties in Pienu are related to old muons
- Cut uncertainties
  - in spite of the severe pileup cuts, significant contributions from pileup appear in the time spectra
  - relaxing the early-time pileup cut reveals the need for an additional term in the fit (H8)
- Fit uncertainties
  - Does the fit include all relevant topologies?
  - If the shape of a background term depends on simulation, is the Monte Carlo sufficiently accurate?
  - Are the values of fixed background terms correct?

PIONEER

Precision Measurement of Rare Pion Decays



- Some key differences between Pienu and PIONEER

	Pienu	PIONEER
Beam rate	60 kHz	300 kHz
Solid angle	20%	75%
CALO time window	1 μsec	0.2 μsec
Segmented active target	------	ATAR
Precision	0.1%	0.01%

Active target (ATAR)*

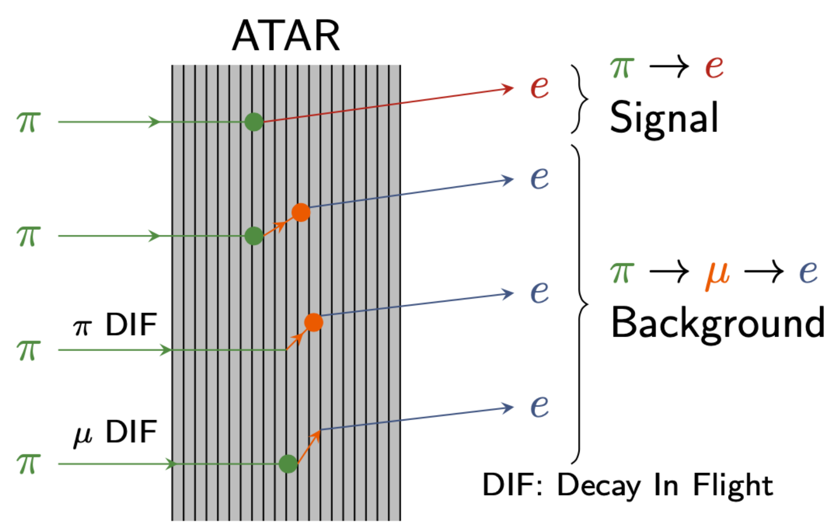
- The ATAR with high spatial and temporal resolution is a game-changer relative to previous experiments.
- Design concept: low-gain avalanche diode (LGAD)

  48 layers, each 120 μm thick

  100 strips per layer with 200 μm pitch

  alternating X/Y strips

  2 cm × 2 cm × 0.6 cm



*Fully discussed Friday afternoon in talks by Simone Mazza, et al.

Sources of old muons in PIONEER

- Pions stopping in the ATAR
  - the rates are such that vetoing is not practical
- Beam muons
  - these can stop in material downstream of the ATAR
- Cosmic rays
  - could be a significant source of time-independent pileup
- Pions missing the ATAR
  - these are a particular worry
  - a Gaussian beam spot with $\sigma = 10$ mm would leave 33% of pions outside the ATAR
  - another large source is pion decay-in-flight (πDIF)

Old muons from πDIF

- πDIF is a significant source of muons that will miss the ATAR
- For 75 MeV/c pions, the decay rate is 20%/m
- Distribution of muons from πDIF at Z = 0
  - ~75% of muons miss the ATAR

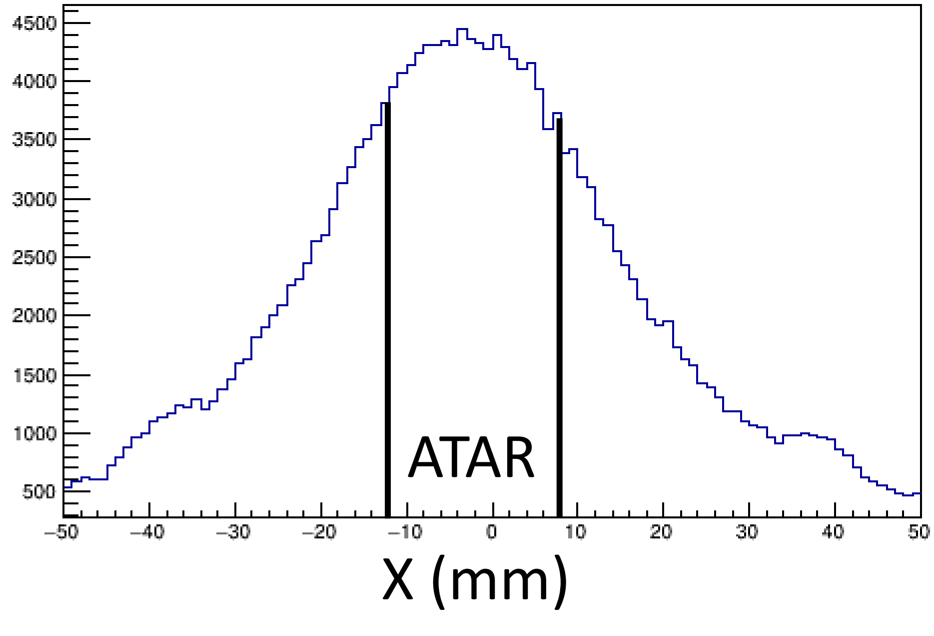
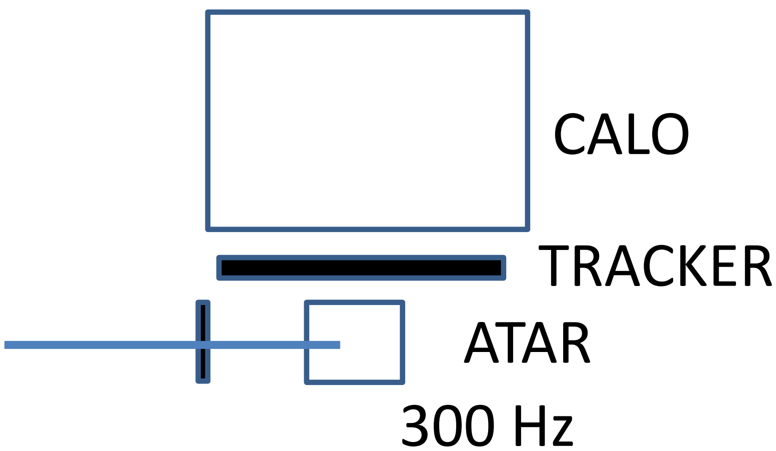


illustration using the Pienu MC

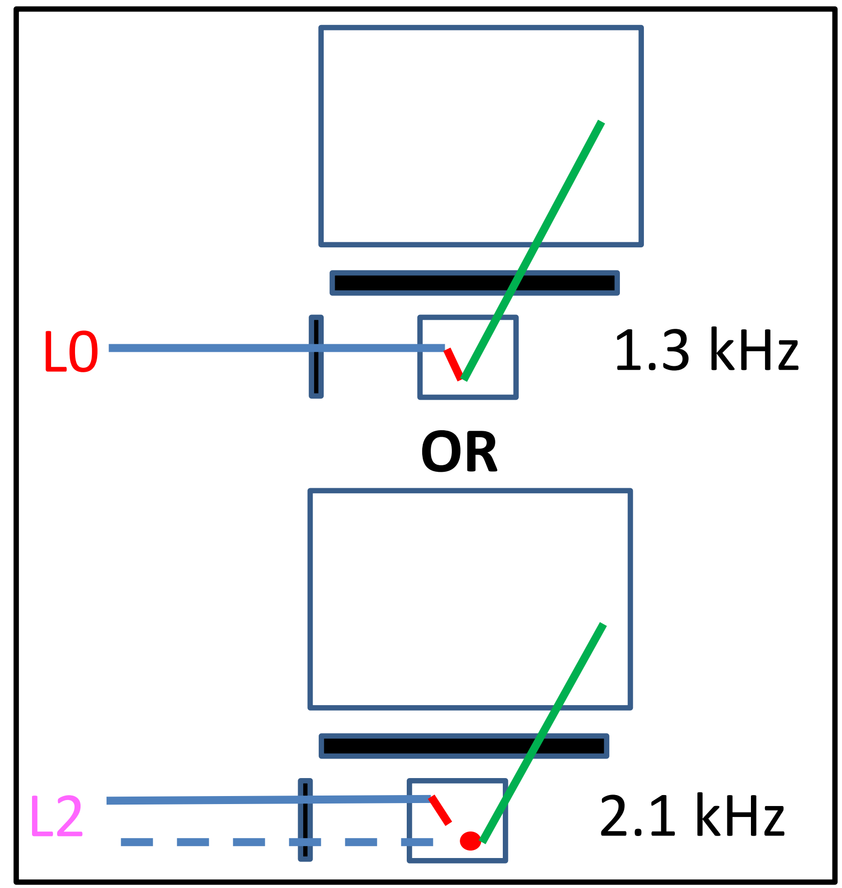
PIONEER triggers

PI/1000 (prescale factor)



incident pion only
minimum bias

TRACK/50

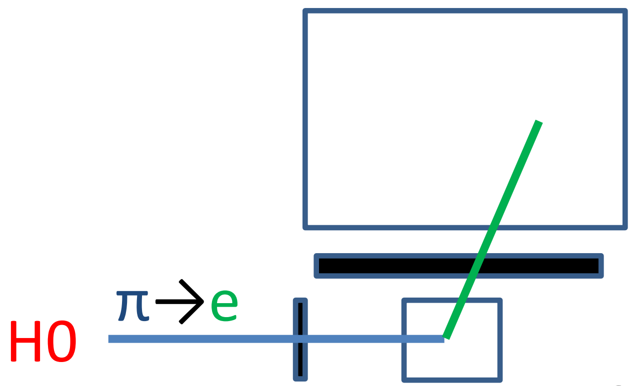


add TRACKER in coincidence
accidentals with old muons dominate

PIONEER triggers

CaloH

E > 58 MeV



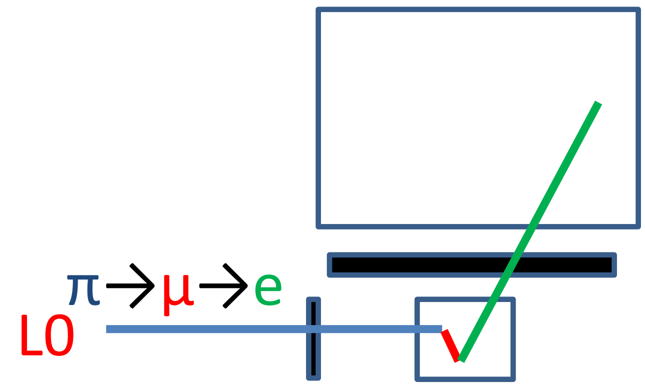
~100 Hz

100% efficient for π→e

rate dominated by backgrounds

PROMPT

2 – 32 ns



5 kHz

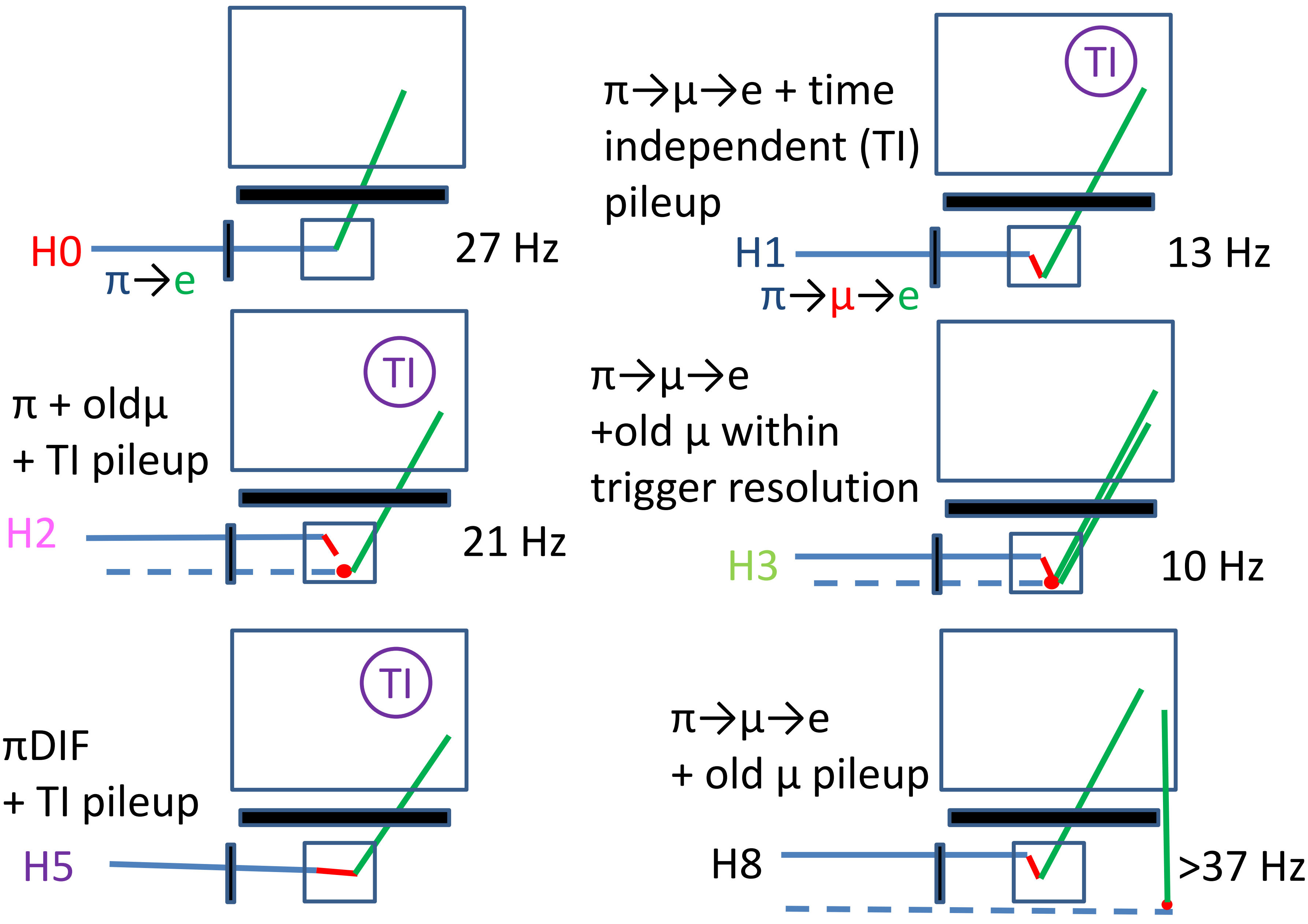
high efficiency for π→e

rate dominated by accidentals

H0 + H1 + H2 + H8 + …

27 + 13 + 21 + 34 + ? Hz

Event topologies for CaloH trigger



Suppression of pileup in the ATAR

- The pileup rates will not allow suppression of triggers
- Pileup can be suppressed in the analysis by requiring the outgoing positron to meet the stopped muon from the incident pion (or the stopped pion)
  - $\pi \rightarrow e$ and $\pi \rightarrow \mu \rightarrow e$ topologies are different in the ATAR
  - suppression can be applied for L2, H2, and H3
- The granularity of the ATAR may allow safe discrimination at the level of 1% of its volume
  - given the concentration of tracks in the center of the volume, the suppression factor will be less than 100

More suppression of pileup

- Early-time pileup in PIONEER
  - high-threshold hits in the ATAR will be recorded for 10 μsec before an event
  - this will yield an average of 3 early tracks/event
  - given the ATAR suppression by matching tracks, the early time info will be of limited help
- The good time resolution and spatial separation of particles in the TRACKER will be used to identify pileup
- Separation of showers in the CALO in time and space will also help to reject backgrounds; how well depends on the technology adopted
- Care must be taken as ~10% of the events may include a Bhabha scattered second particle

Systematics considerations for PIONEER

- Some background shapes will need to be simulated
  - limitations on the accuracy of the MC simulation will contribute to systematic uncertainties
  - the amplitude for H3 (tracker time resolution) will be suppressed by the spatial resolution of the TRACKER, but the shape must come from simulation
- The time structure of the beam may be important for simulating accidentals rates
  - at PSI protons hit the production target every 20 ns
  - for Pienu, the number of instances of two pions was 0.1%, but was twice that expected for evenly populated buckets

Systematics considerations for PIONEER

- Imperfections in the detector can lead to systematic uncertainties
  - ATAR: dead strips can be tolerated if sufficient info is available to fit the pion, muon, and positron tracks
  - TRACKER: two layers gives minimal redundancy and imperfections become important, especially cracks that could let positrons from muons that missed the ATAR add energy to CALO (mitigated by good separation of showers in CALO)
  - CALO: understanding the efficiency of pileup rejection over the full volume of CALO will be difficult

Systematics considerations for PIONEER

- Are there unidentified background topologies?
  - the analog of the geometry-dependent background (H4) in Pienu has not been identified or included
- Understanding the effects of pileup is critical
  - suppression of pileup in the analysis will help significantly
  - the raw BR must be stable as the amount of pileup is varied
  - aggressive rejection of pileup can result in errors
  - reducing systematic uncertainties by a factor of 10 relative to the current generation will be challenging