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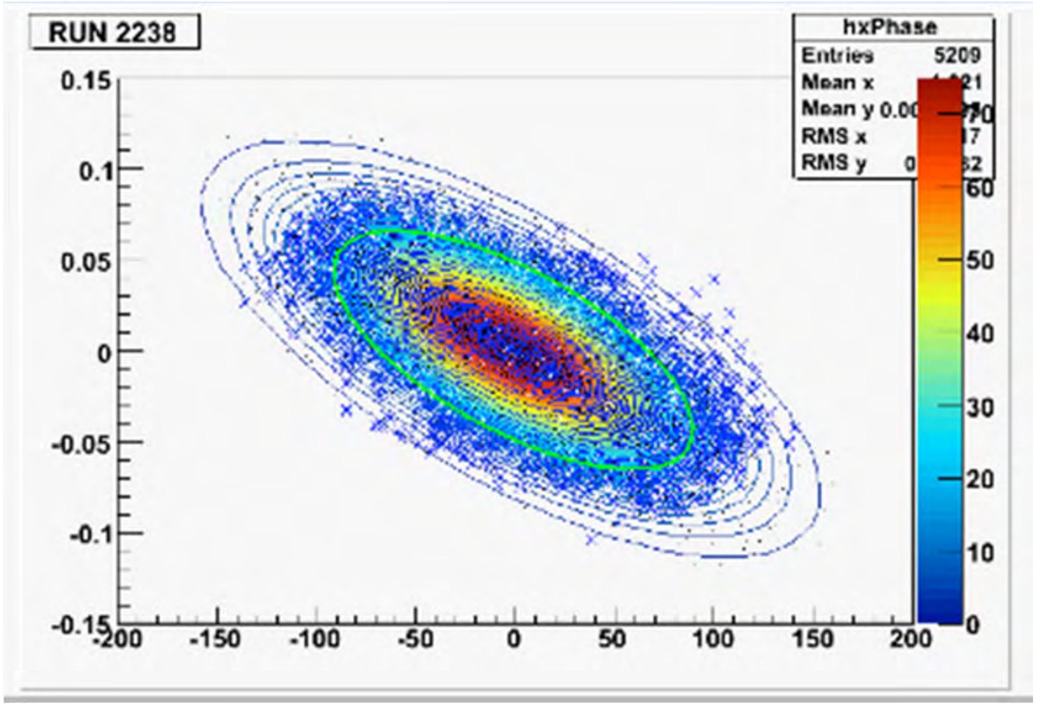
Muon Ionization Cooling Experiment at RAL

University of California, Riverside

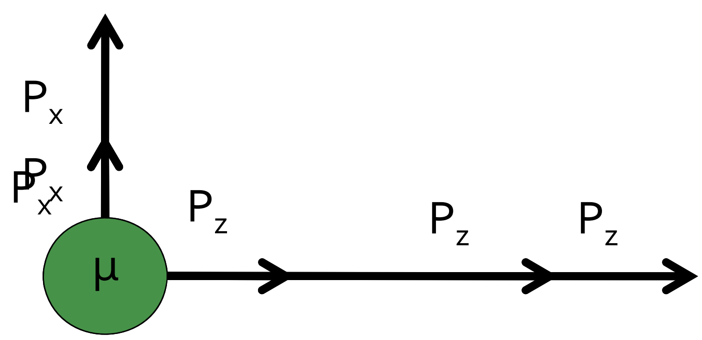
What do you mean by cooling?

- A particle in a beam has an *emittance* related to its position measured from the center of the beamline and its transverse momentum.
- When we plot these two values for each particle in the beam we get ellipses who's area is the emittance of the beam.
- Cooling is the reduction of this emittance, or making this area smaller.



Why Ionization Cooling?

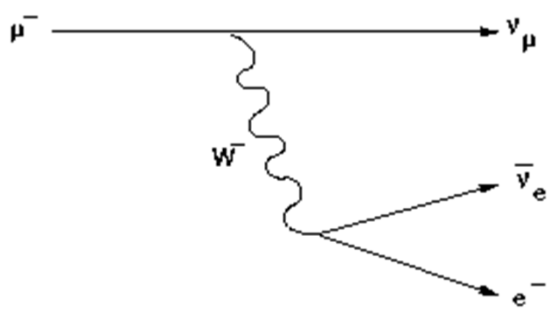
- Standard cooling methods are too slow for muons due to their short lifetime (~2.2μs).
- Ionization cooling works by allowing a muon beam to ionize liquid hydrogen removing momentum from the muons in all dimensions.
- Momentum is replaced in only the Z by RF.



Why Cold Muons?

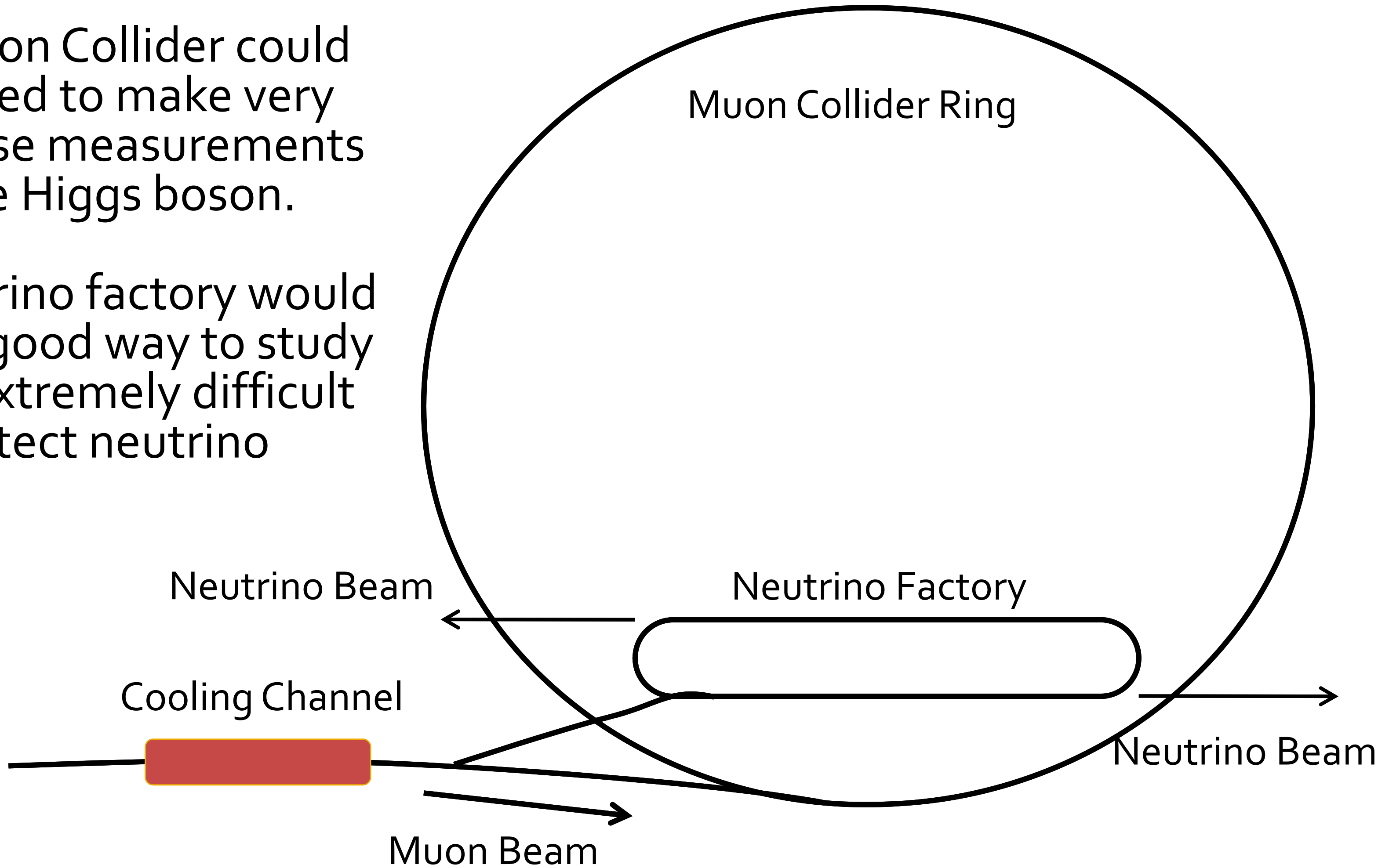
- Particle beams need to be cooled to “fit” into an accelerator

- Cooling of a muon beam would allow construction of new accelerator based experiments such as a Muon Collider and Neutrino Factory.



Muon Collider / Neutrino Factory

- A Muon Collider could be used to make very precise measurements of the Higgs boson.
- Neutrino factory would be a good way to study the extremely difficult to detect neutrino

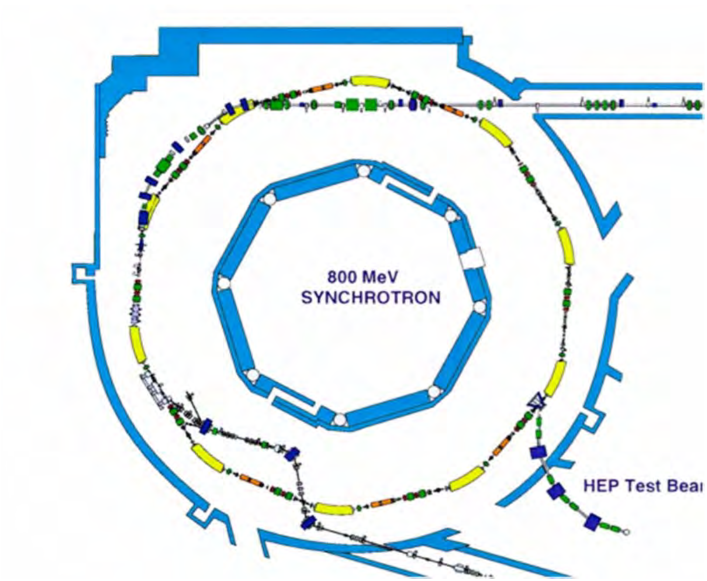


MICE Collaboration

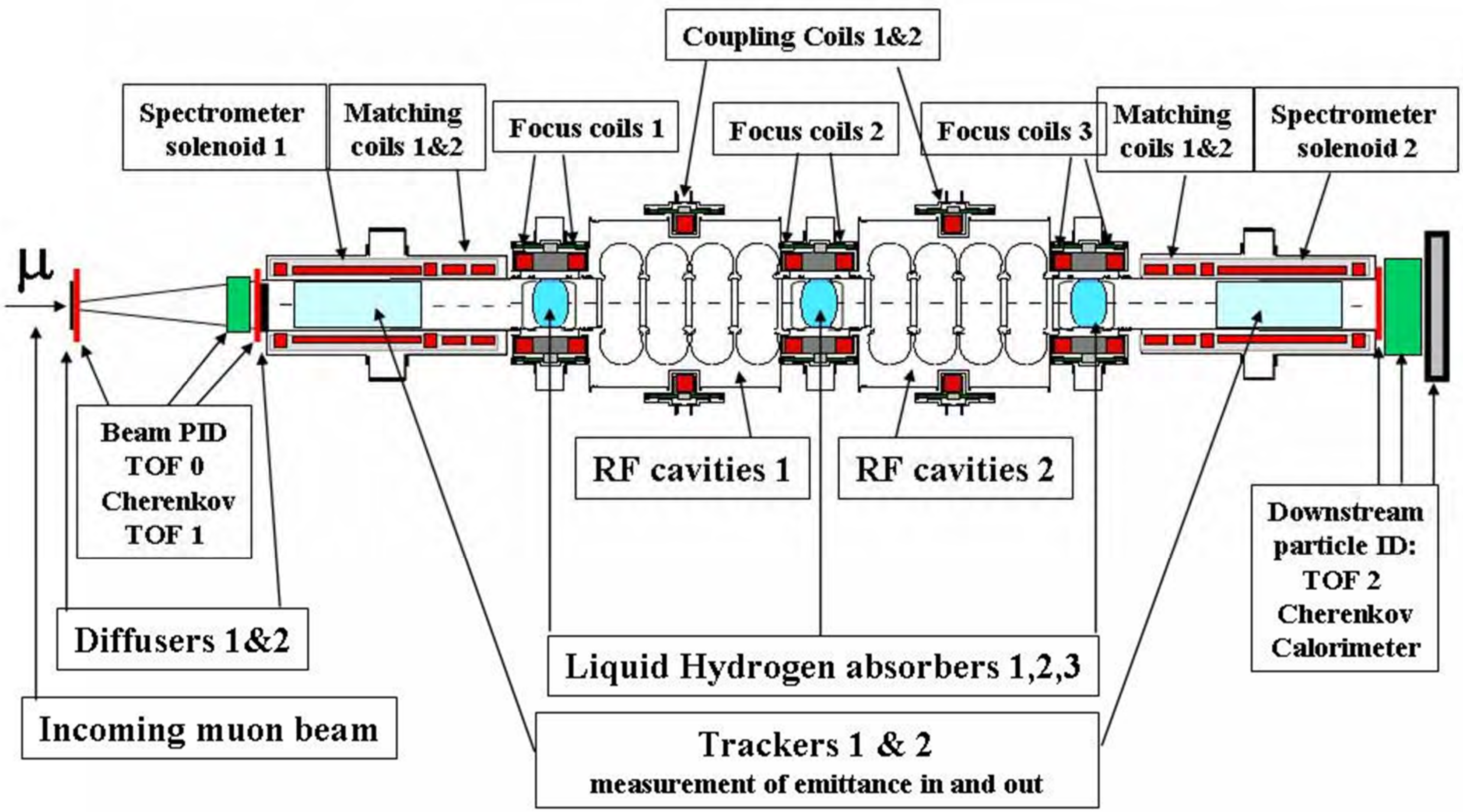
- International collaboration of physicists from 11 countries hosted by the Rutherford Appleton Laboratory in the United Kingdom

ISIS Proton Accelerator

- Located at the Rutherford Appleton Lab
- Used by MICE as a proton source



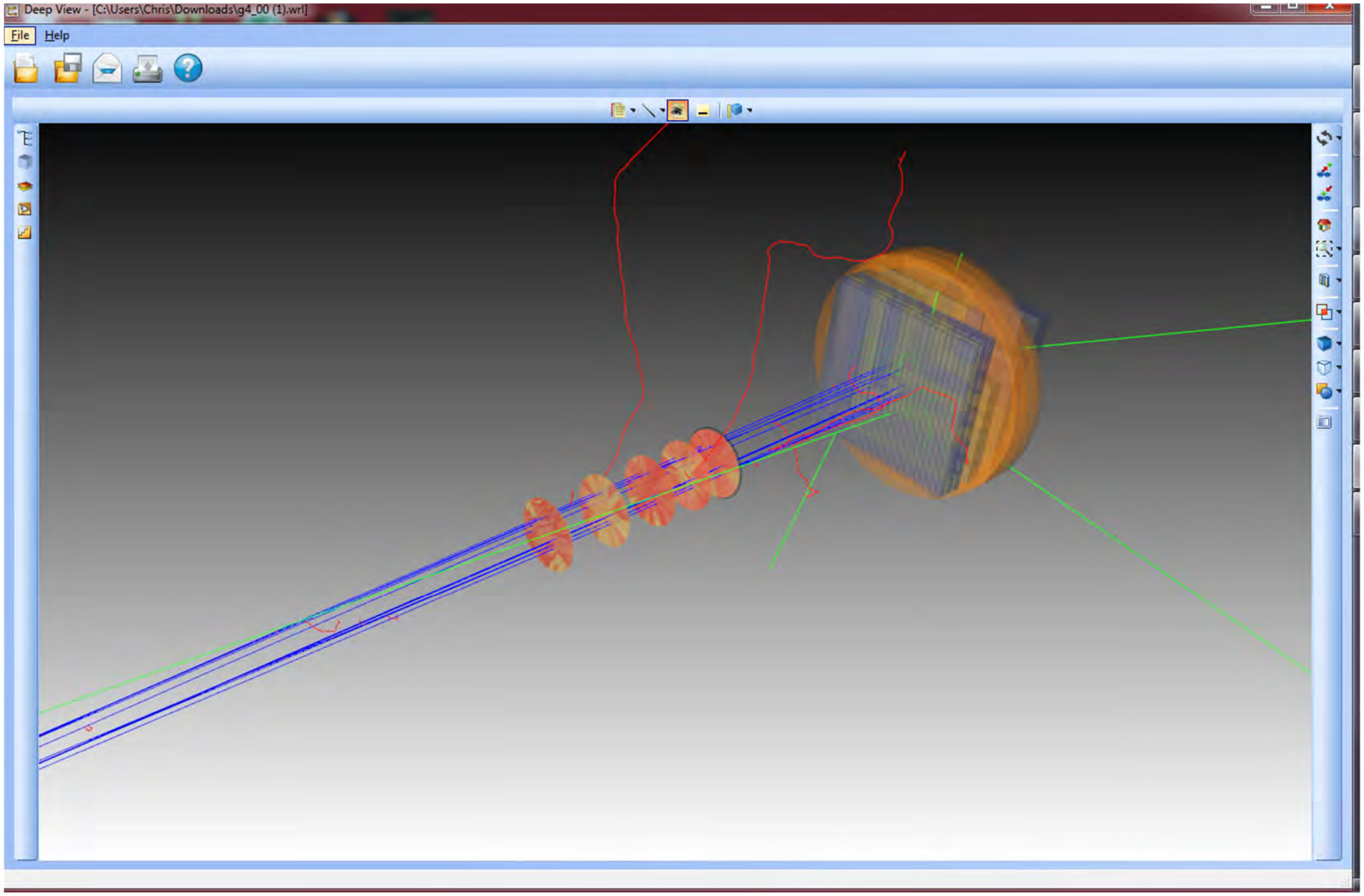
MICE Cooling Channel (Step VI)



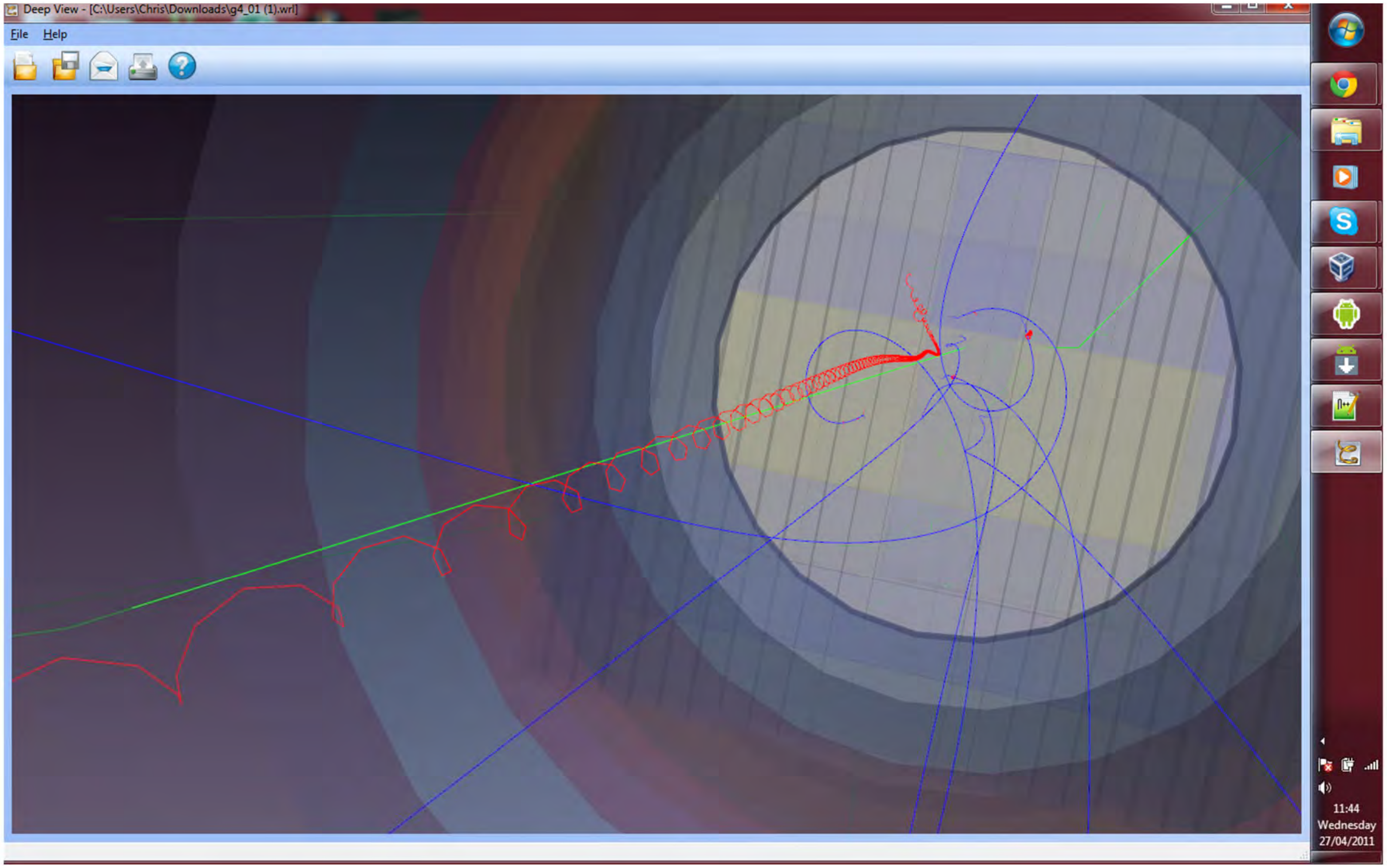
Sci-Fi Trackers

- Scintillating Fiber Trackers will be used as the main detectors for emittance measurements.
- Housed inside of a superconducting spectrometer solenoid.
- 5 Tracking stations made of 3 planes of fibers each

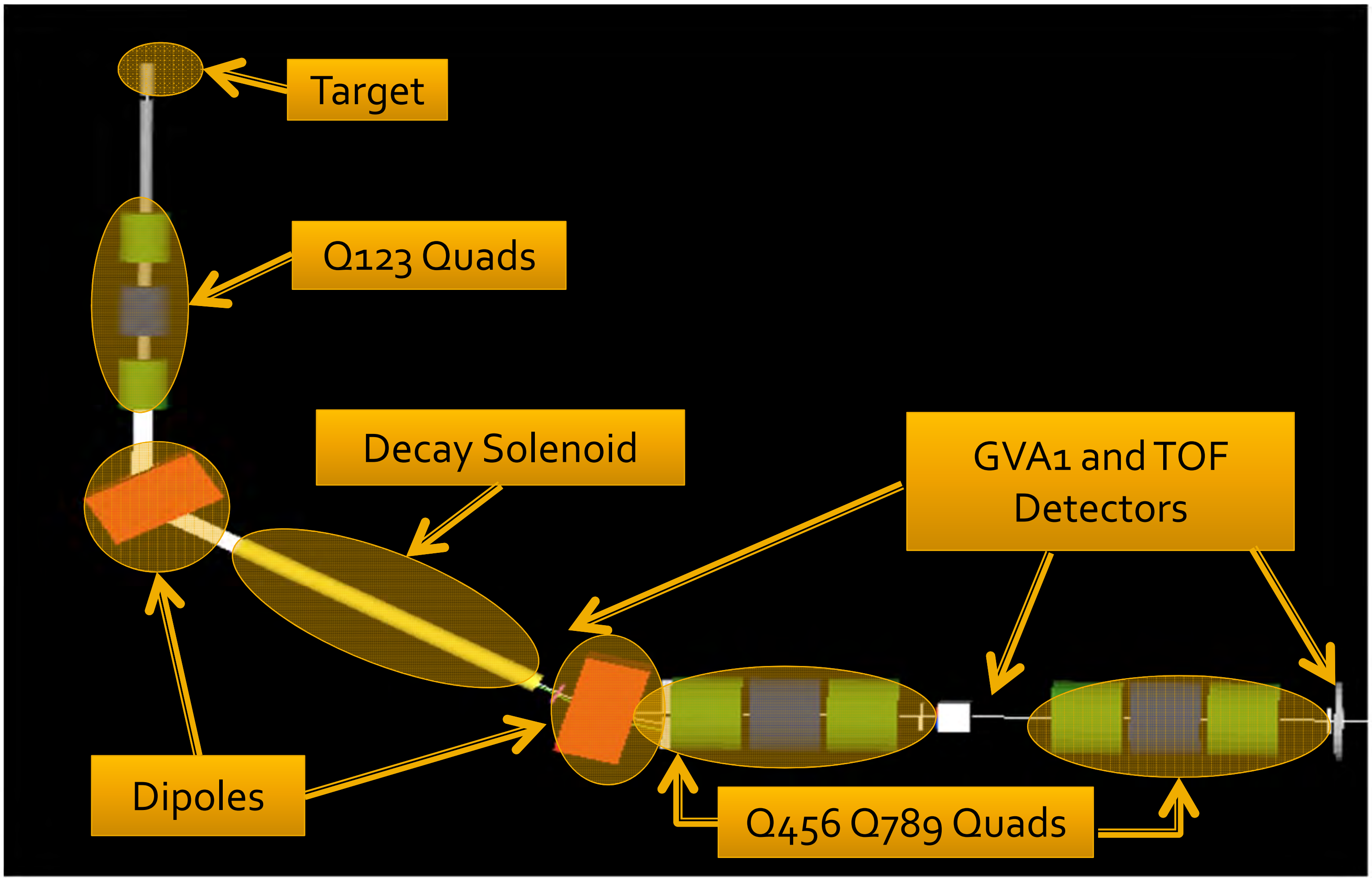
Sci-Fi Trackers



Sci-Fi Trackers

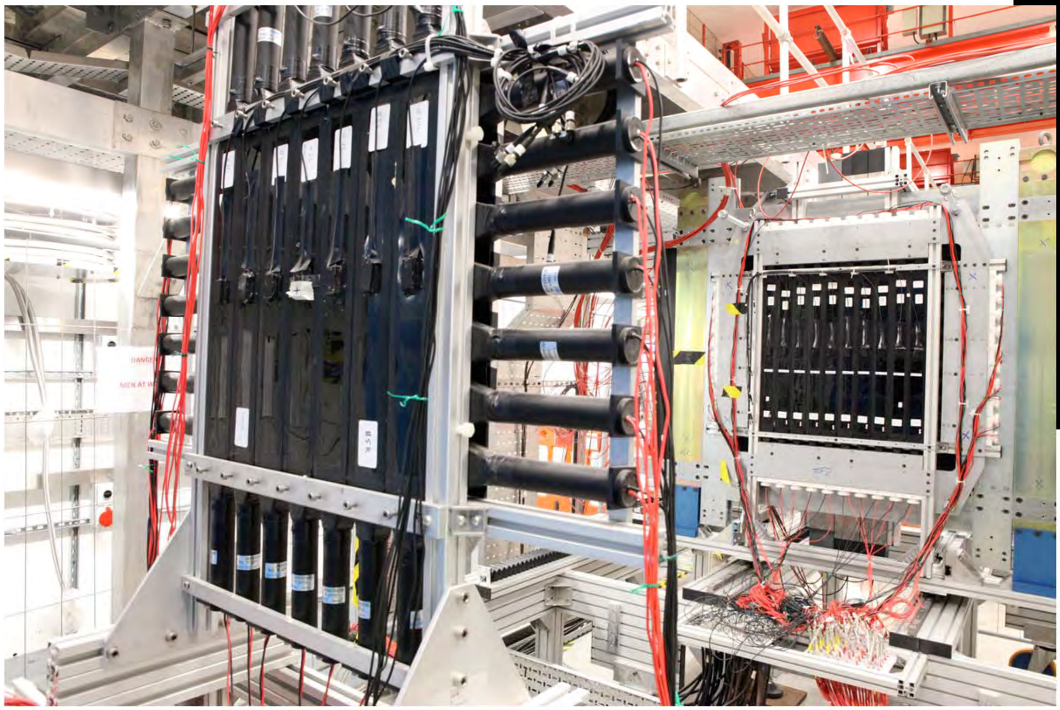


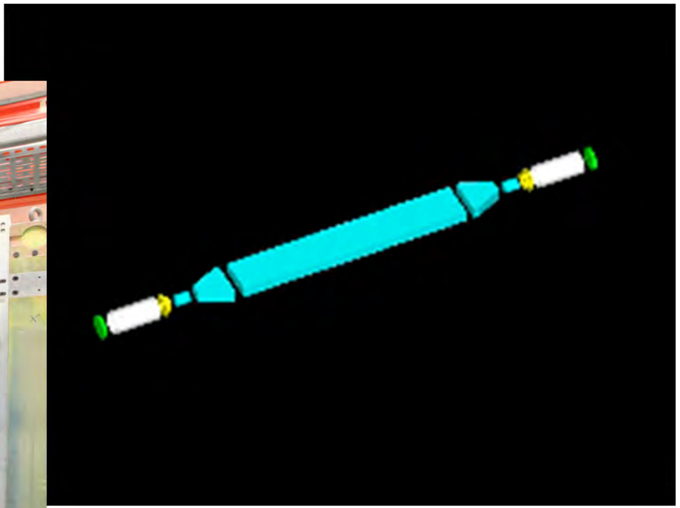
MICE Currently



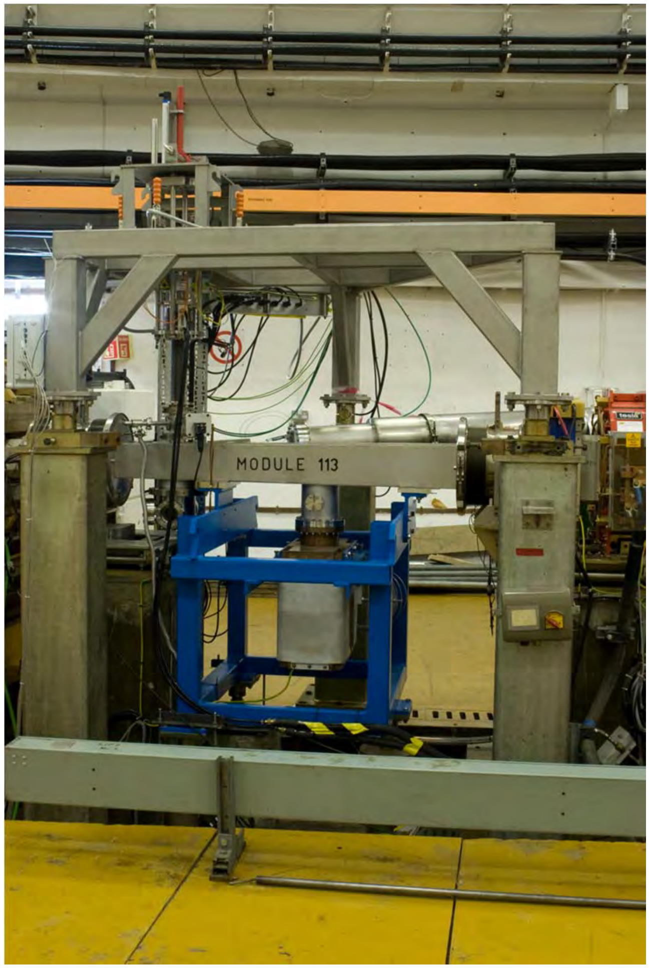
Time Of Flight Detectors

- Measures time of flight between two detectors to determine momentum
- Made of two planes of orthogonal slabs to determine a rough transverse position measurement

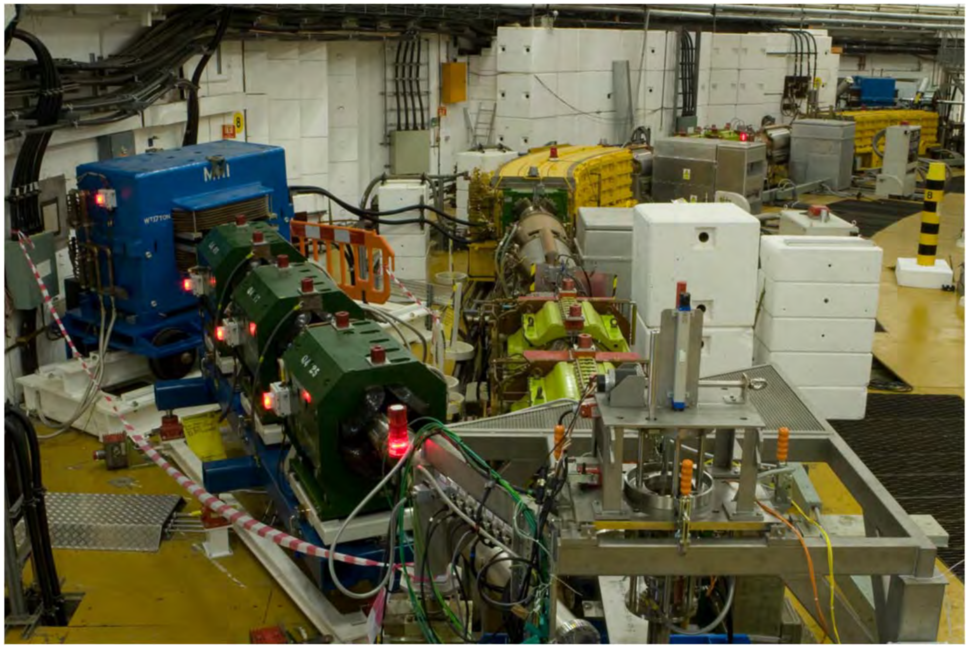




Target

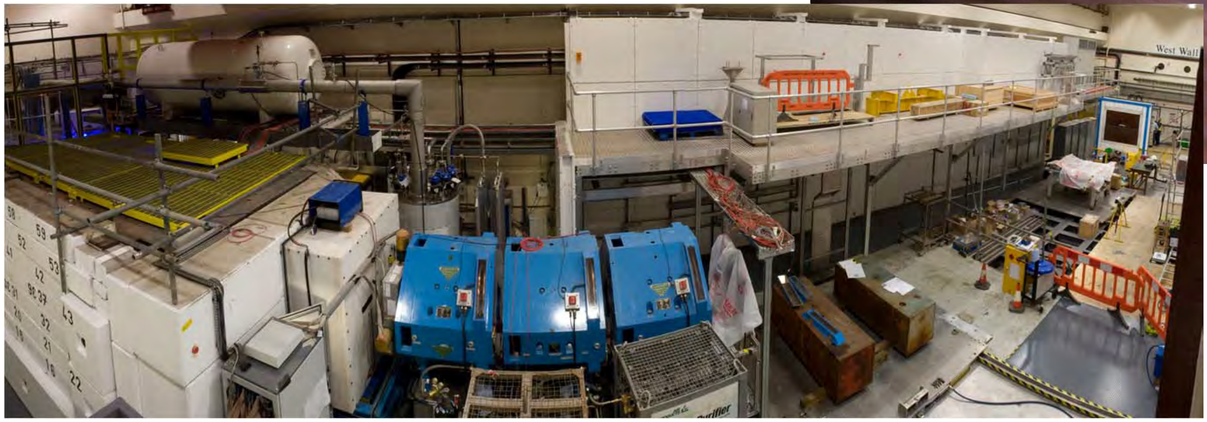


- A metal shaft that is dipped into the ISIS proton beam
- Protons collide with our target producing pions



Quadrupole Magnets

- Work very similar to optical lenses except they focus in one direction and defocus in the other
- Must be implemented in sets (Triplets in our case).

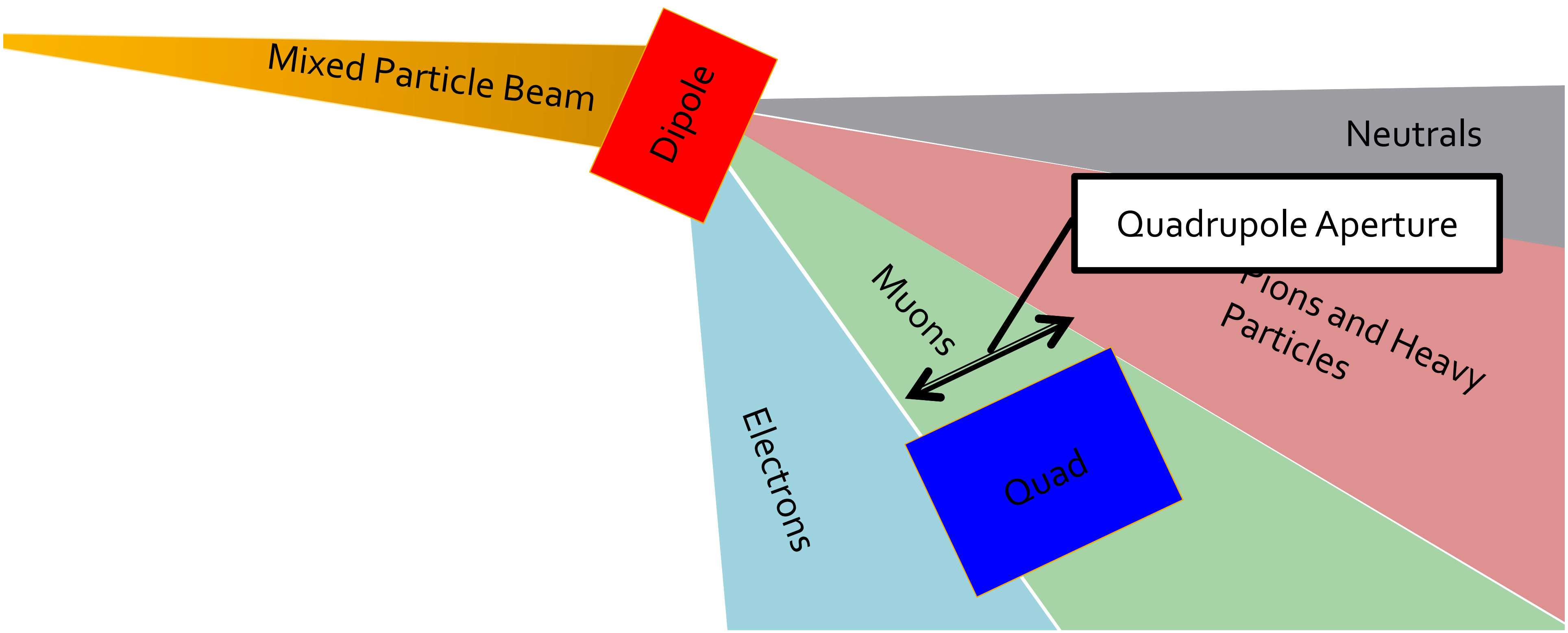


Decay Solenoid

- Very high field superconducting magnet (~5T)
- Causes charged particles to pass through in a helical path increasing the path length.
- Allows time for pions to decay to muons

Dipole Magnets

- Also known as bending magnets
- Used to 'select' particle momentum



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My Contributions to MICE this summer

University of California, Riverside

Tuning the Upstream Optics

- The MICE cooling channel will have several 'input' emittances determined by a diffuser.
- All 12 of the upstream magnets must be tuned to output a matching emittance.

(ε,P) matrix

ε (mm rad) / P (MeV/c)	2.8	6.0	10.0
140	t_{11}	t_{12}	..
200	..	t_{22}	..
240	..	..	t_{33}

Tuning the Upstream Optics

- Achieved by running Monte Carlo simulations many times.
- After each iteration, software calculates covariance matrices and normalized emittance.

$$
V_{6D} = \begin{pmatrix}
\sigma_{xx} & \sigma_{xx'} & \sigma_{xy} & \sigma_{xy'} & \sigma_{xt} & \sigma_{xt'} \\
\cdot & \sigma_{x'x'} & \sigma_{x'y} & \sigma_{x'y'} & \sigma_{x't} & \sigma_{x't'} \\
\cdot & \cdot & \sigma_{yy} & \sigma_{yy'} & \sigma_{yt} & \sigma_{yt'} \\
\cdot & \cdot & \cdot & \sigma_{y'y'} & \sigma_{y't} & \sigma_{y't'} \\
\cdot & \cdot & \cdot & \cdot & \sigma_{tt} & \sigma_{tt'} \\
\cdot & \cdot & \cdot & \cdot & \cdot & \sigma_{t't'}
\end{pmatrix}
$$

$$
V_{4D} = \begin{pmatrix}
\sigma_{xx} & \sigma_{xx'} & \sigma_{xy} & \sigma_{xy'} \\
\cdot & \cdot & \cdot & \sigma_{y'y'}
\end{pmatrix}
$$

$$
\varepsilon_{4D} = \sqrt[4]{\left|V_{4D}\right|}
$$

$$
\begin{pmatrix} x \\ x' \\ y \\ y' \end{pmatrix} \rightarrow \begin{pmatrix} x \\ p_x \\ y \\ p_y \end{pmatrix}
$$

$$
\varepsilon^{N}_{4D} = \frac{P_z}{m_\mu c}\varepsilon_{4D}
$$

Tuning the Upstream Optics

- Previous optimization scheme was a FORTRAN genetic algorithm.
- Covariance and emittance calculations done by ECalC9.
- This is VERY slow. 3-4 days per optimized setting.

Tuning the Upstream Optics

- Wrote a new optimizer using ROOT's Minuit minimizer and C++
- Optimizes by minimizing χ^2

$$\chi^2 = \frac{(\varepsilon_c - \varepsilon_t)^2}{\sigma^2}$$

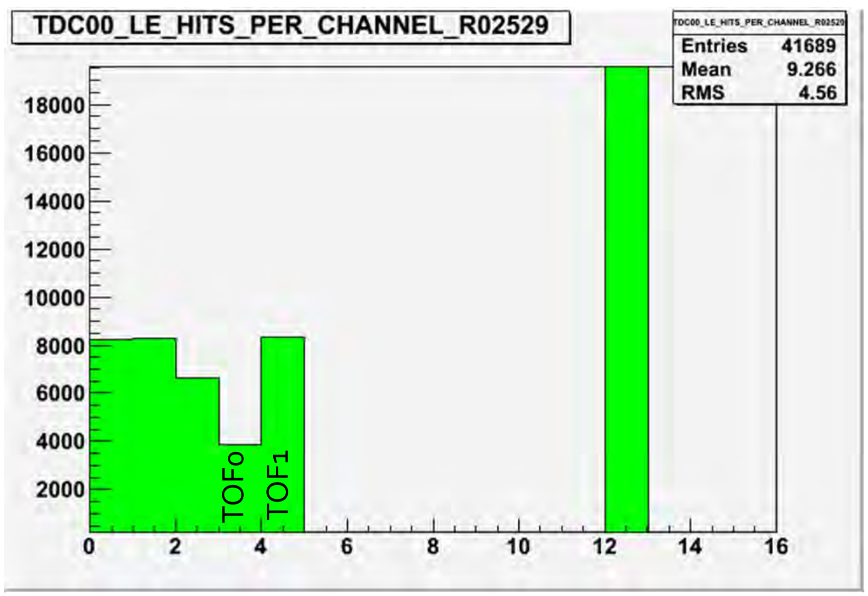
- Currently finds minimum with simplex and then MIGRAD method

Conclusions and Future Work

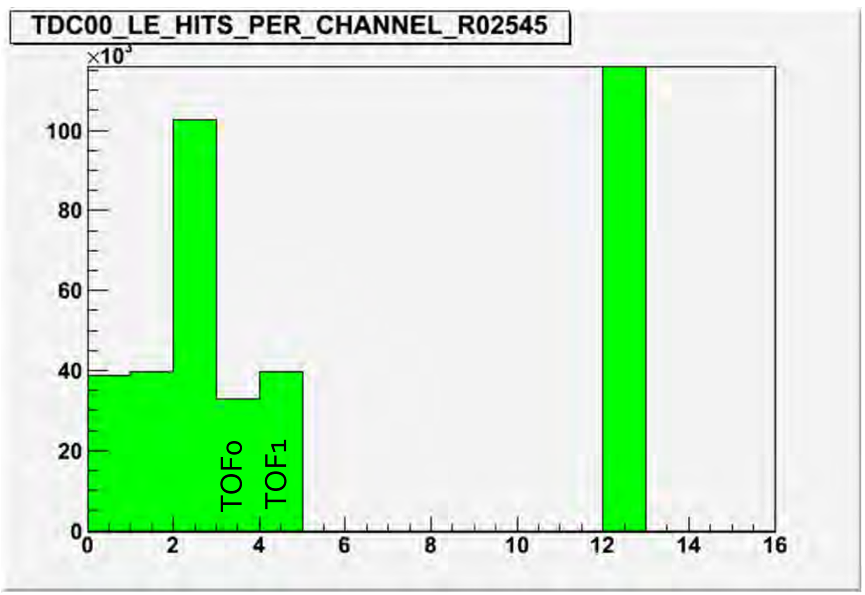
- Now takes only ~10 hours to produce an optimized setting
- All new optimized currents were within ~3% of values produced with old optimizer
- Will be modifying the optimizer to use Newton's method
- Program will be made to run on the GRID to reduce calculation time significantly

Neutrals In the Beamline

- Observed as an apparent TOFo inefficiency however positive beamline settings suggested otherwise.

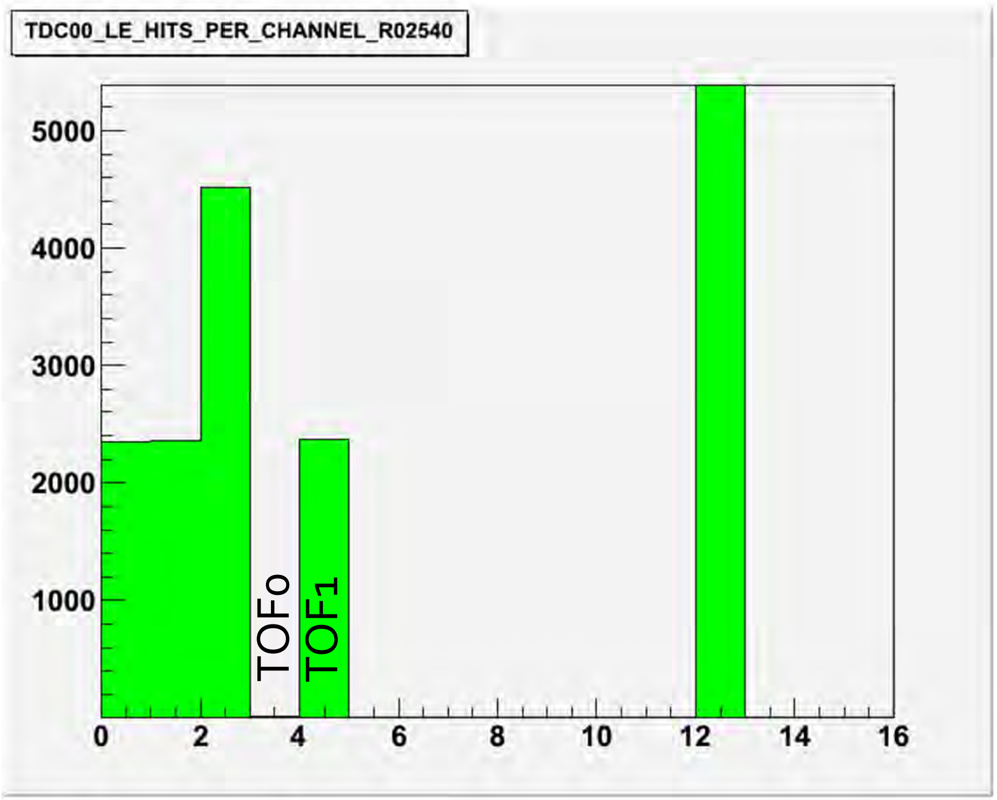


Negative Beamline



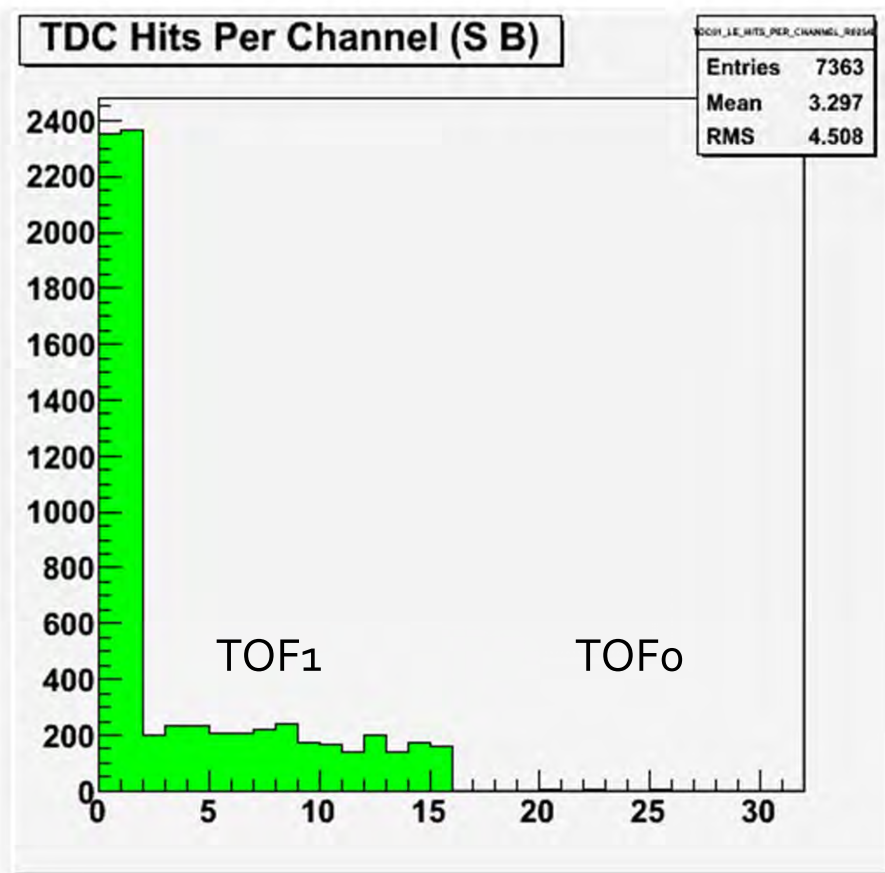
Positive Beamline

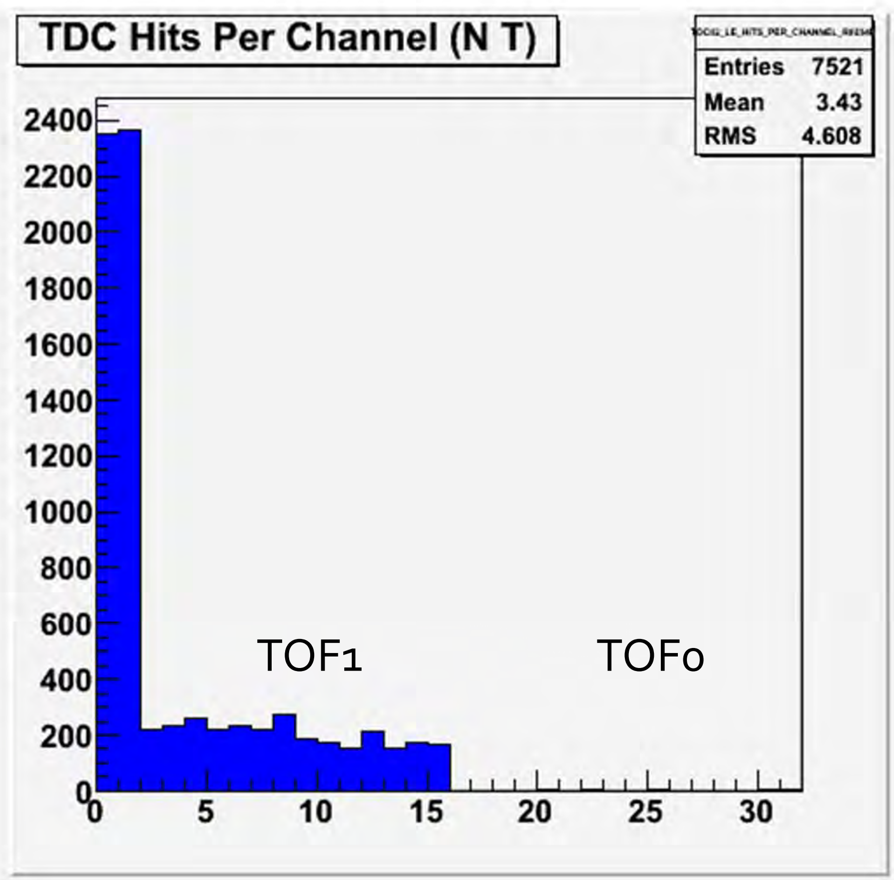
Positive BL with D2 off



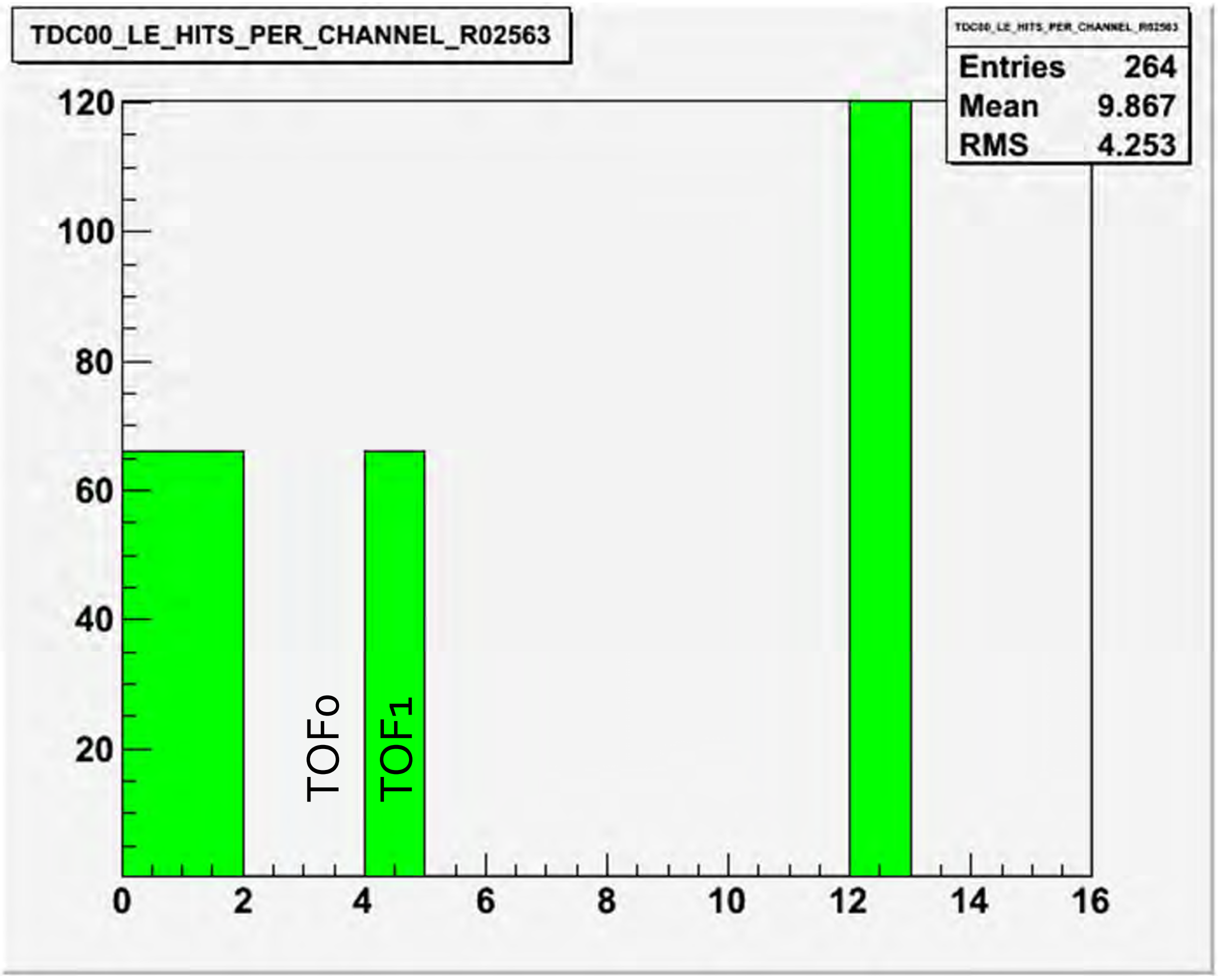
- No charged particles will make it to the detectors.
- All particles must either be neutrals or cosmics

Positive BL with D2 off

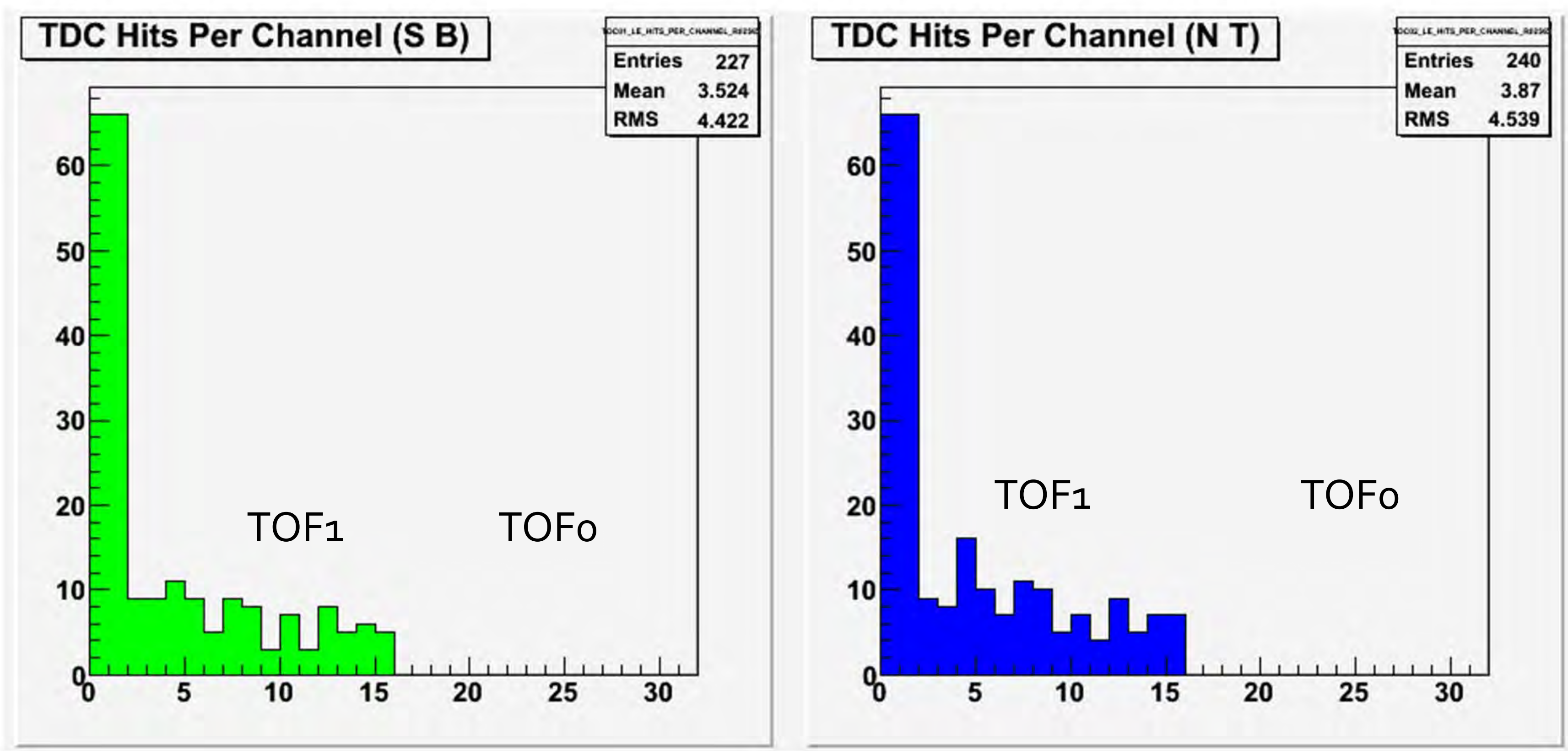




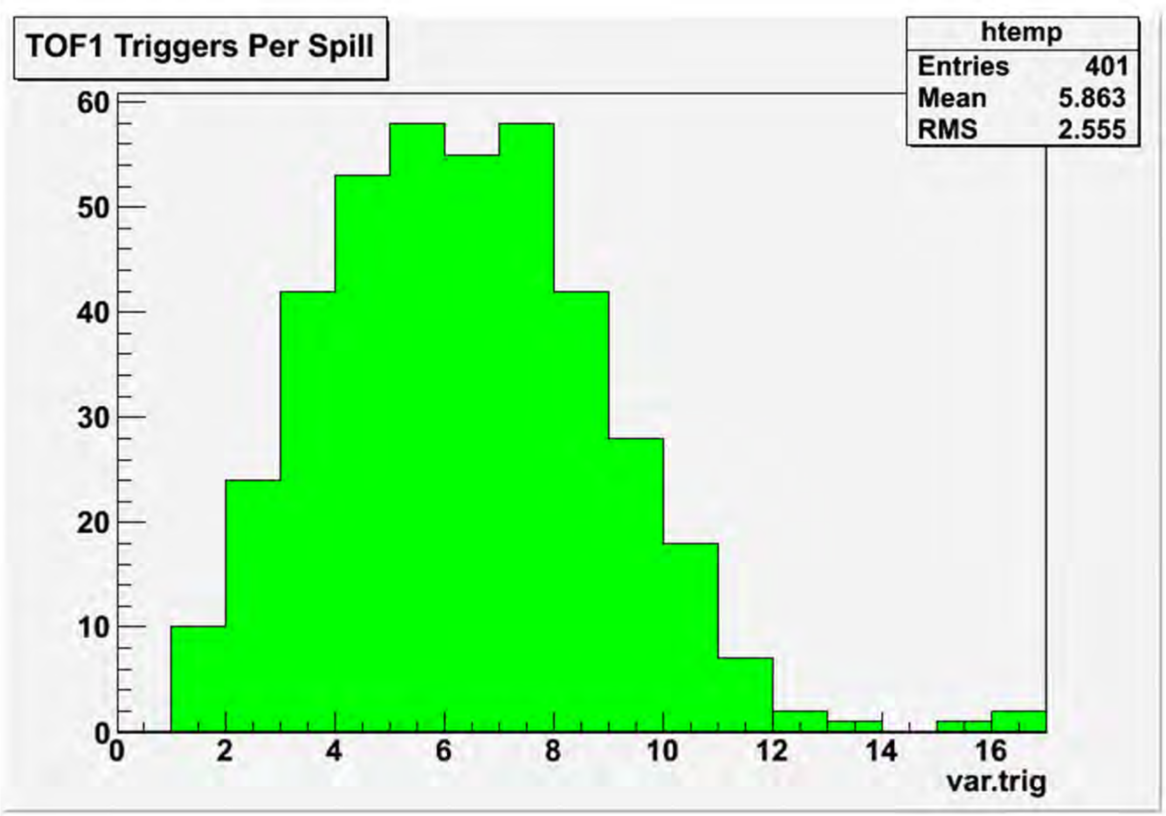
Target Frame Raised
Avg Triggers per spill: 0.2 (negligible)



Target Frame Raised

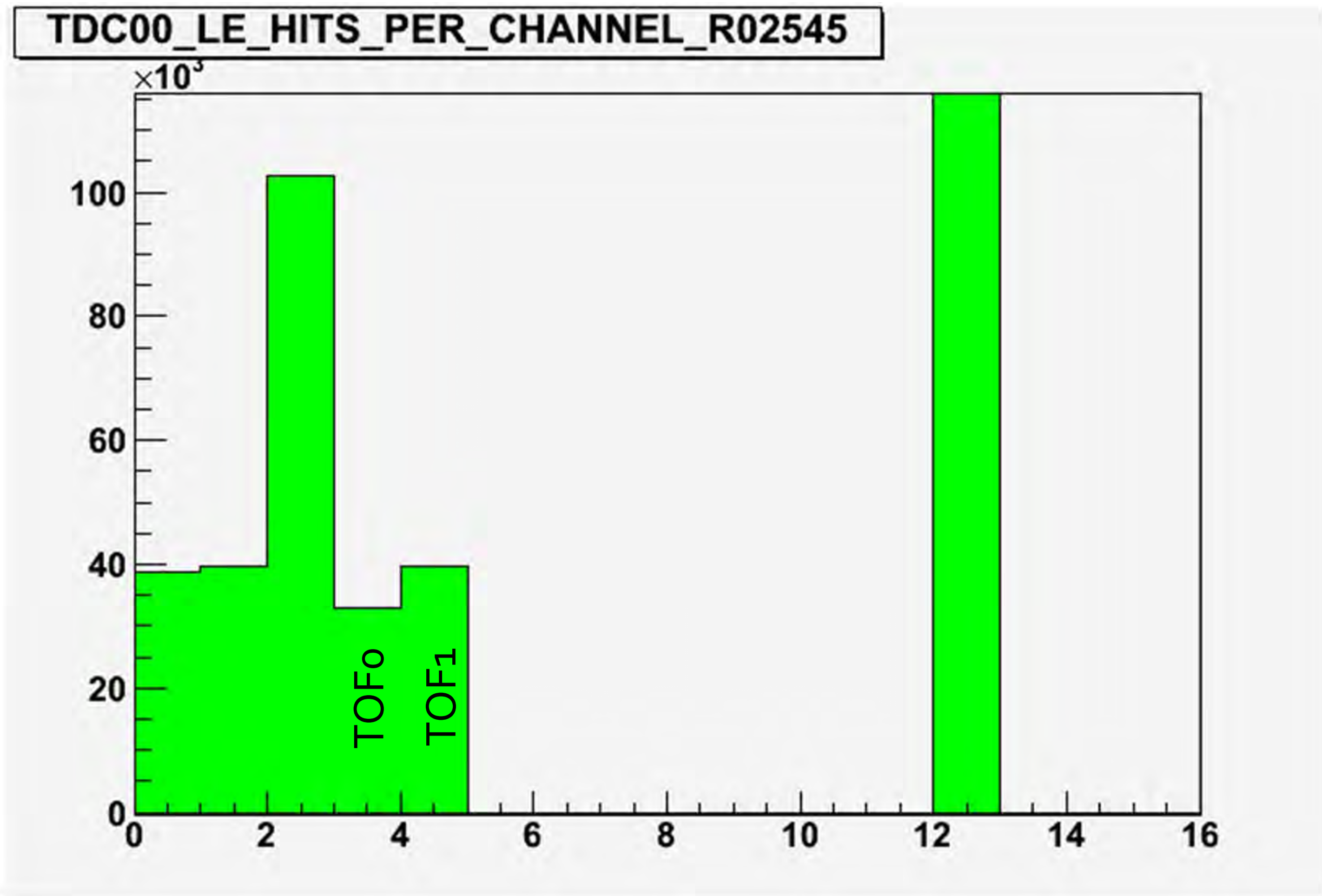


Positive BL with D2 off

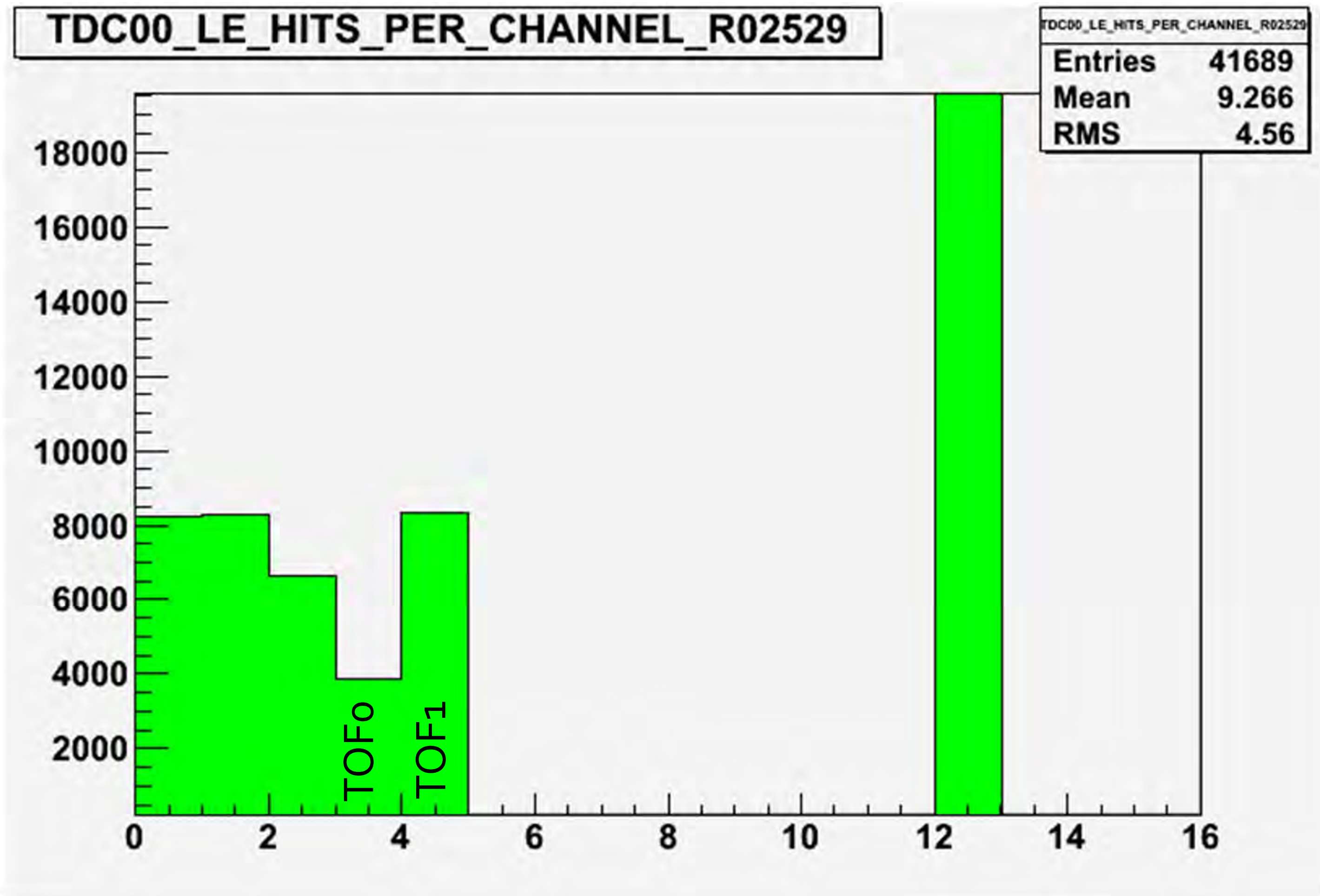


- Mean position tells us the most likely particle rate.
- RMS gives us an approximate spread.

Positive BL
Avg # of Tof1 w/o Tofo : 5.3 per spill



Negative BL
Avg # of Tof1 w/o Tofo : 6.3 per spill



Preliminary on New Data

- Rate is about the same with all magnets switched off.
- Scales with beam loss.
- Rate falls off to that of cosmics with beam stop up.

Conclusions and Future Work

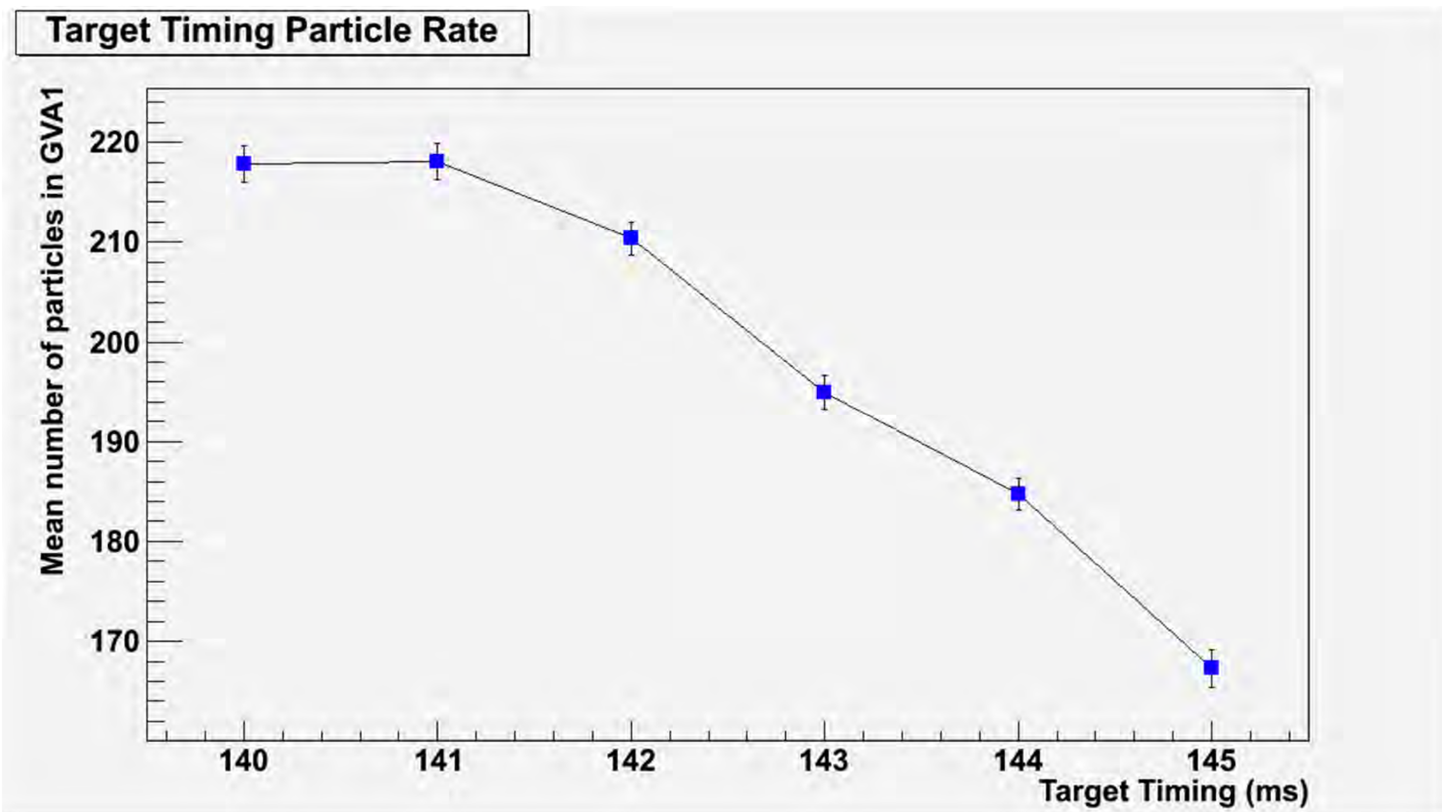
- Apparent TOFo and reconstruction inefficiency caused by neutrals in the beamline.
- Can expect around 6 neutrals per spill.
- At the current beam losses will not saturate the TOF's.
- Will be using 'MIP' to develop an energy calibration for the PMT's that will allow us to identify neutrals and ignore them in the reconstruction

Target Delay Study

- Determine overall particle rate as a function of target delay
- Find ratio of muons to electrons as a funtion of target delay
- Develop a time tag calibration for all 6 TDC's
- Show trigger rate within a spill gate

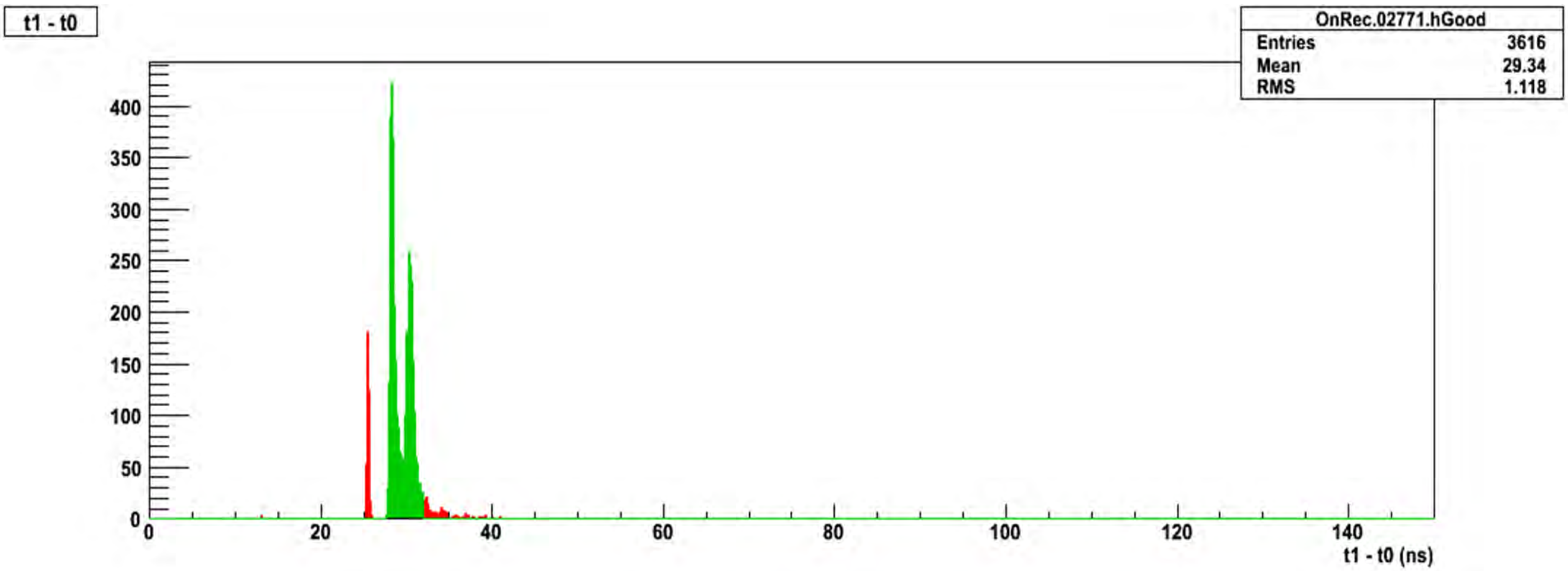
Target Delay Study

- Overall particle rate tells us how many triggers to expect
- Need to know this because the trigger has a rate limit



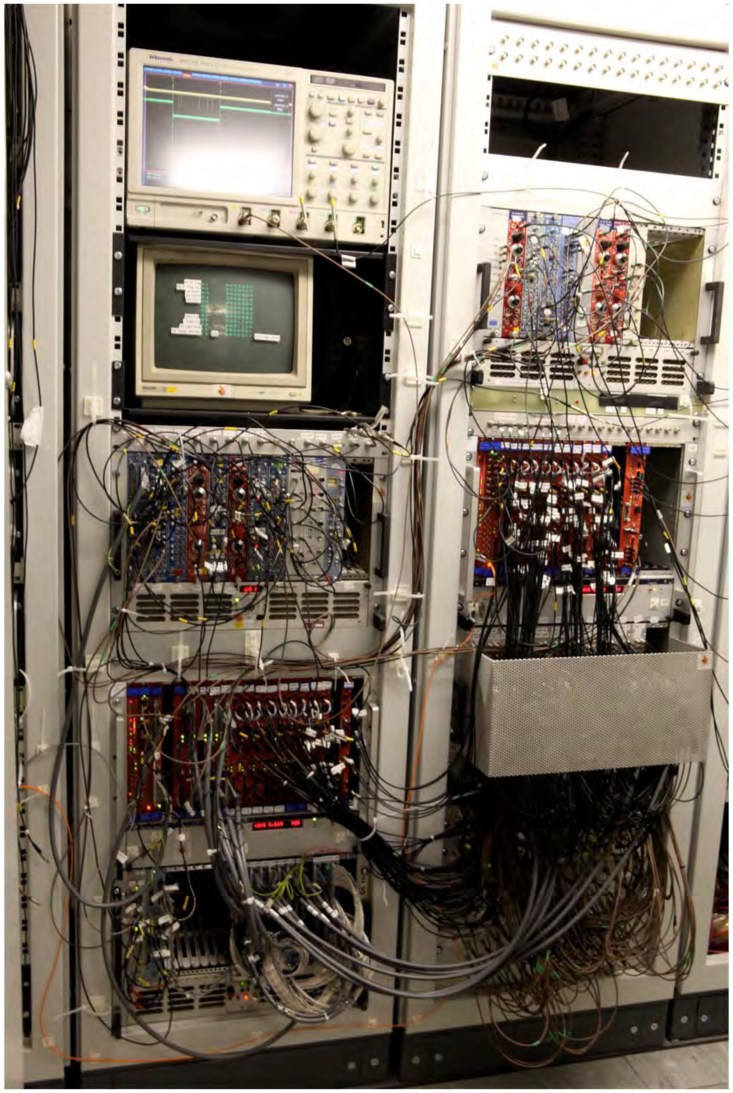
Target Delay Study

- Time of Flight distribution allows particle identification
- Must separate peaks and add all bin counts



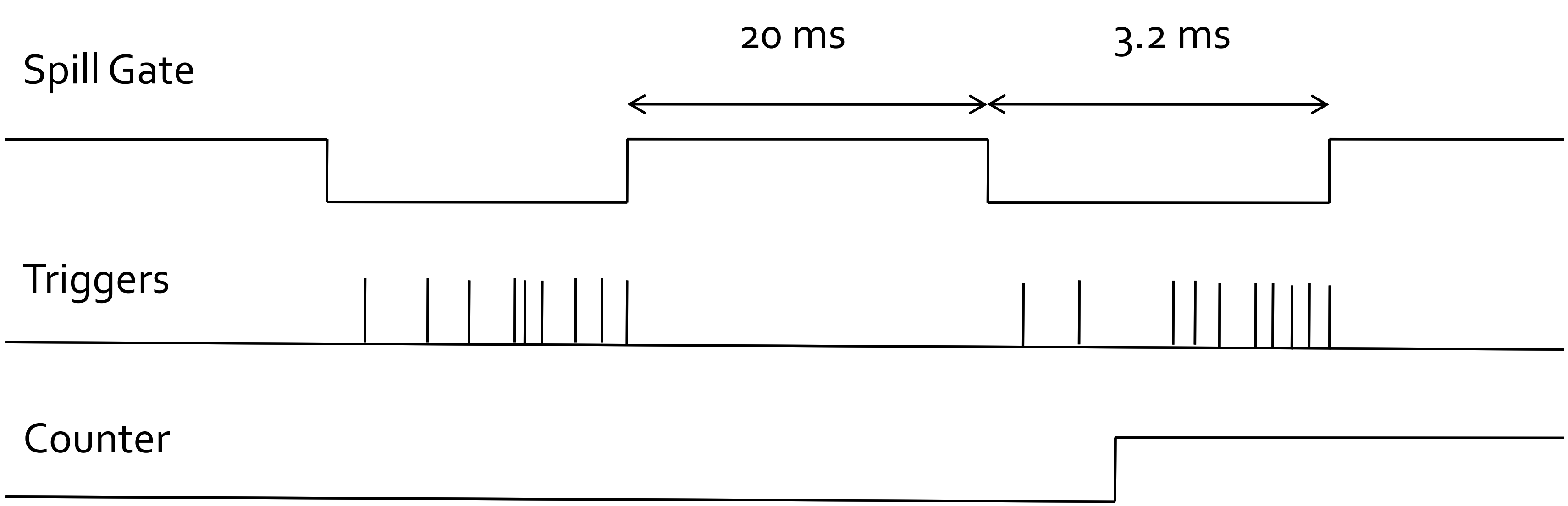
Target Delay Study

- A time tag is associated with a trigger by the time-to-digital converters (TDC)
- There are 6 TDC's each with their own 27 bit counters
- These counters are not reset at the same time nor have the same period as the MICE spill rate
- A calibration must be developed to look at timing within a single spill



Target Delay Study

- Must find the end of the first spill gate
- Make successive approximations using the last trigger time tag in all spills
- Counter does not start at zero and could reset anywhere in the spill or outside of it



Conclusions and Future Work

- Repeat this process for each TDC for every data file
- This calibration will allow me to ‘map’ each trigger time tag into the first spill gate and produce a time distribution within the gate
- Timing distributions can be used for locating our target in the ISIS beam and to better understand the arrangement of dead time, then to minimize it

Final Conclusions

- Wrote a new optimizer to decrease calculation time significantly
- Identified neutral particles in the beam line and showed it was not a detector inefficiency
- Developed a method and software to calculate a TDC calibration used for analyzing data

Thanks…

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