Technical Design Review
Studying the Proton ``Radius" Puzzle with μp Elastic Scattering: ``Trigger"

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- Beam FPGA PID System - a custom project from RU P&A electronics shop
- Main Trigger - largely a commercial project with CAEN v1495

The focus of this talk

$$\left[\frac{d\sigma}{d\Omega}\right] = \left[\frac{d\sigma}{d\Omega}\right]_{ns} \times \left[\frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} + \left(2\tau - \frac{m^2}{M^2}\right) G_M^2(Q^2)\frac{\eta}{1-\eta}\right]$$

$$\left[\frac{d\sigma}{d\Omega}\right]_{ns} = \frac{\alpha^2}{4E^2}\frac{1-\eta}{\eta^2}\frac{1/d}{\left[1 + \frac{2Ed}{M}\sin^2\frac{\theta}{2} + \frac{E}{M}(1-d)\right]} \qquad d = \frac{\left[1 - \frac{m^2}{E^2}\right]^{1/2}}{\left[1 - \frac{m^2}{E'^2}\right]^{1/2}}$$

$$\eta = Q^2/4EE'$$

$d\sigma/d\Omega(Q^2)$ = counts / ($\Delta\Omega$ N_{beam} $N_{target/area}$) x corrections x efficiencies

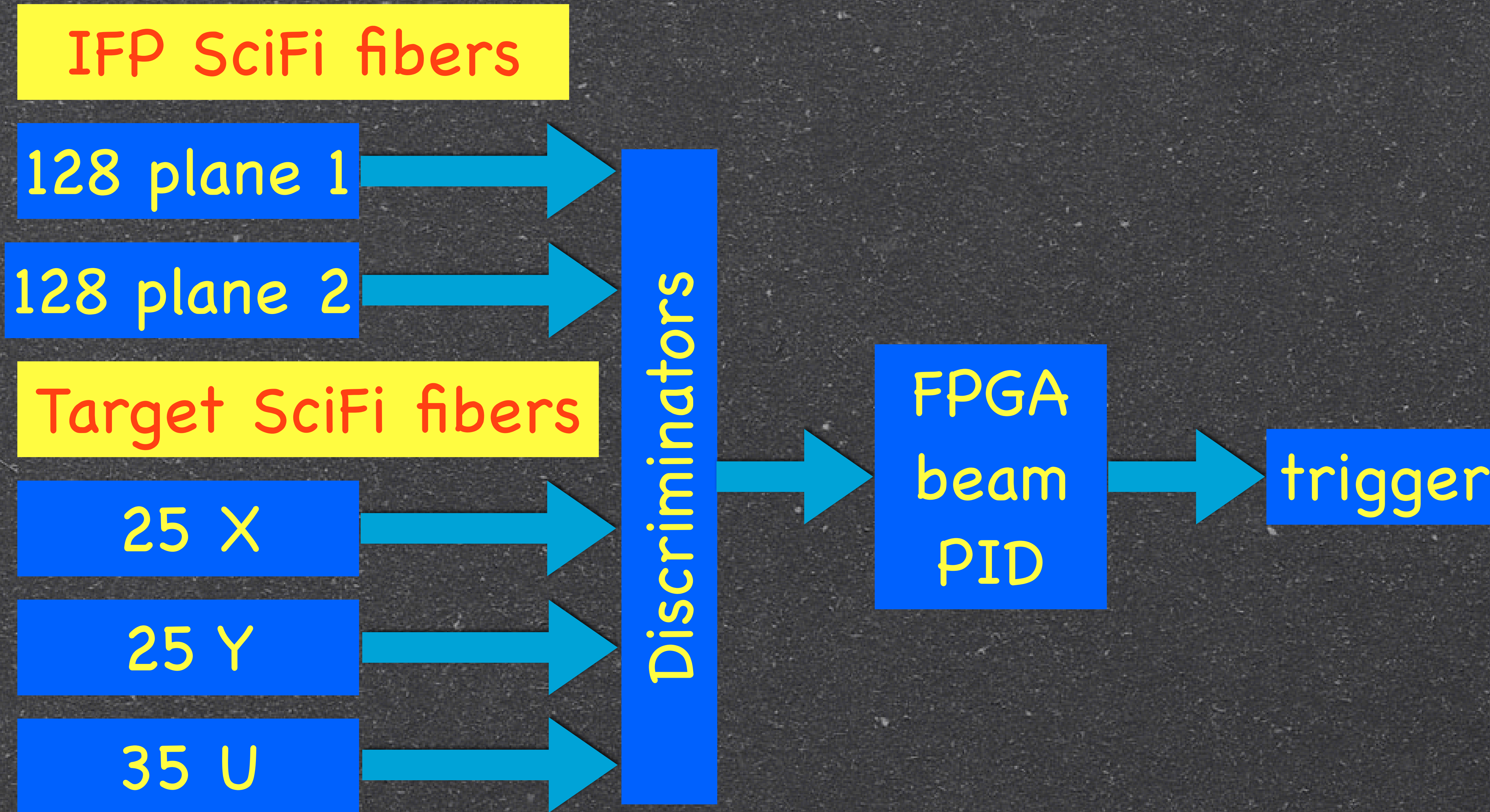
Beam PID system identifies beam μ's and e's and gets this number right

Trigger identifies μ and e scattering events

Scalers determine some of these

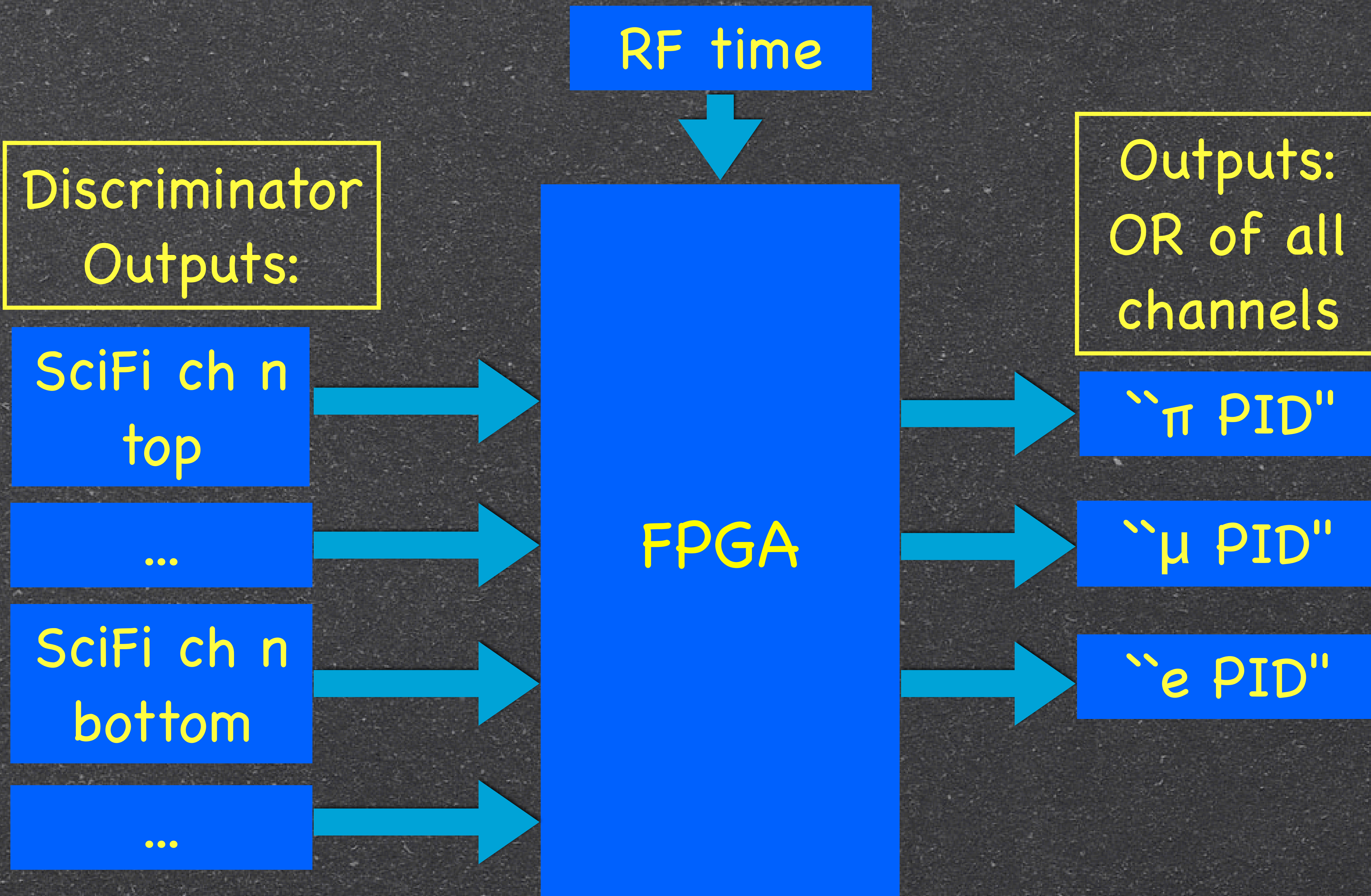
Wednesday, July 25, 2012

Beam FPGA PID System Cartoon

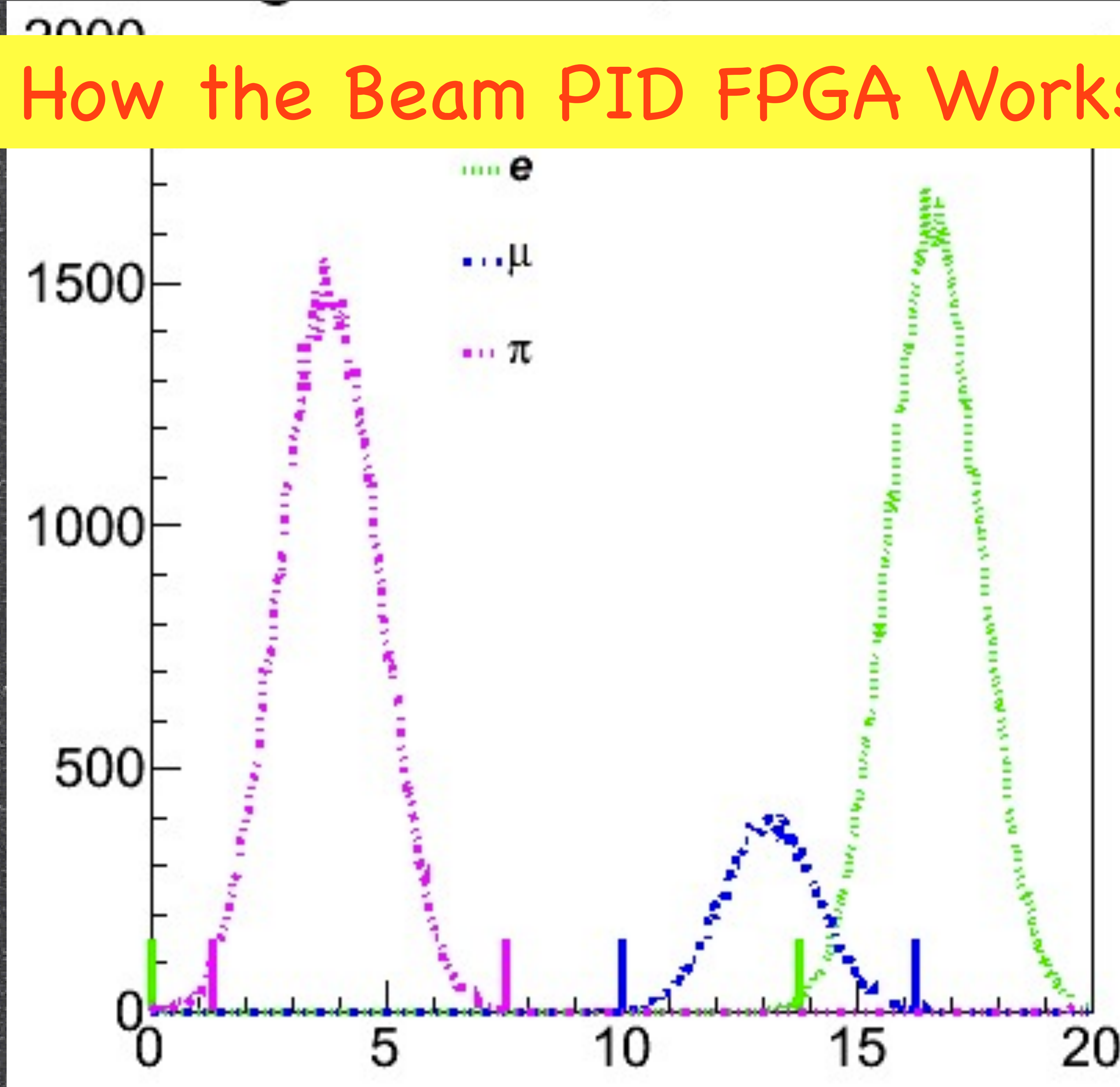


Fibers are read out at both ends, so 682 total SciFi channels.
Planning on 23 (24?) 6U VME boards, each with 32 inputs.

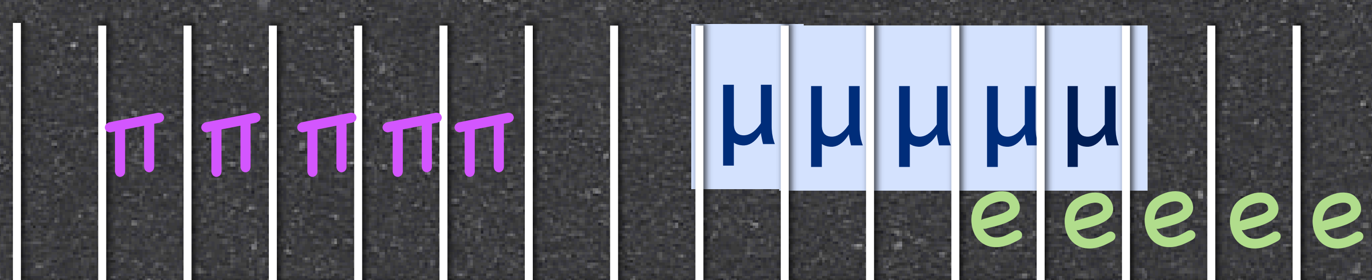
How the Beam PID FPGA Works I



How the Beam PID FPGA Works II



RF time



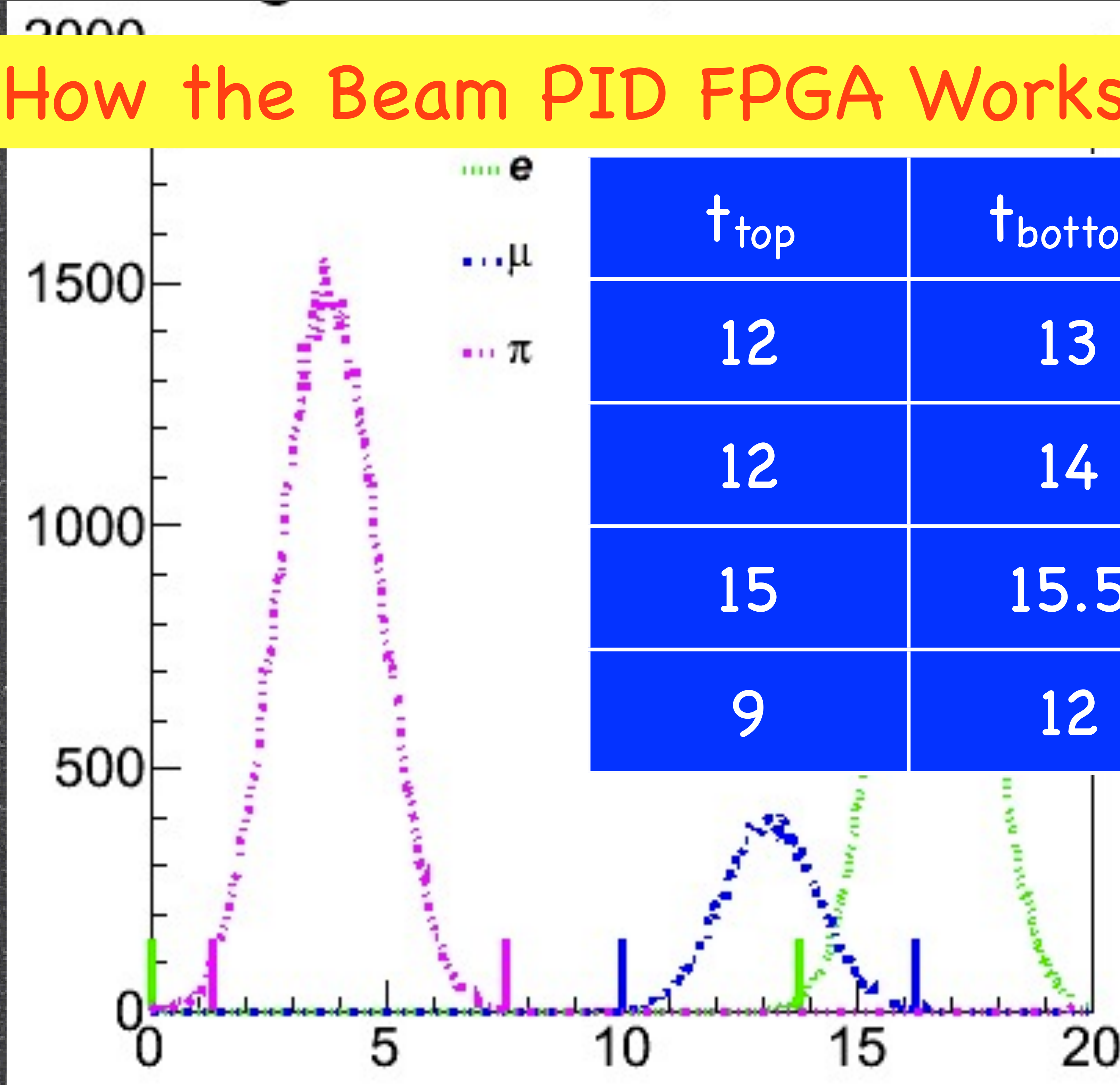
PID window

16 1.25-ns bins

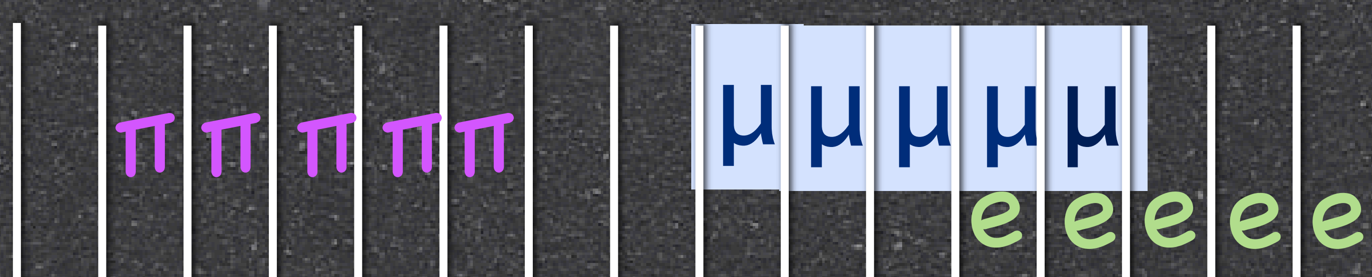
How the Beam PID FPGA Works III

t_{top}	t_{bottom}	output(s)
12	13	μ
12	14	μ
15	15.5	μ AND e
9	12	-

RF time



PID window



16 1.25-ns bins

Comments from Rutgers Eshop

- It would be easier to do as an ASIC, if we had another 150k.
- It should be doable.
- The key thing will be prototyping, to make sure we choose the right FPGAs, and being careful with timing within the chip.

In discussions on the beam PID FPGA, we have considered having 2 or 3 sets of outputs, perhaps with different timing (timed to input signals vs to window vs to RF) for different purposes, but this appears to not be needed.

It would be useful to use a second set of outputs as inputs to scalers to provide a check on the performance of each of the beam FPGA boards.

At this stage of the design, multiple outputs remains an option.

The Beam PID Determination

Determining the beam PID requires both IFP and target SciFi results.

We send all 69 e, μ, and π signals output from our custom FPGA boards into a single CAEN v1495 FPGA unit to do the logical combinations - this unit has 64+2 standard inputs, 32 standard outputs, and expansion slots for up to 96 additional I/O channels (no more than 64 additional inputs). The v1495 inputs can operate at up to 200 MHz. We will use the 50 MHz beam RF as a clock.

The Beam PID Determination

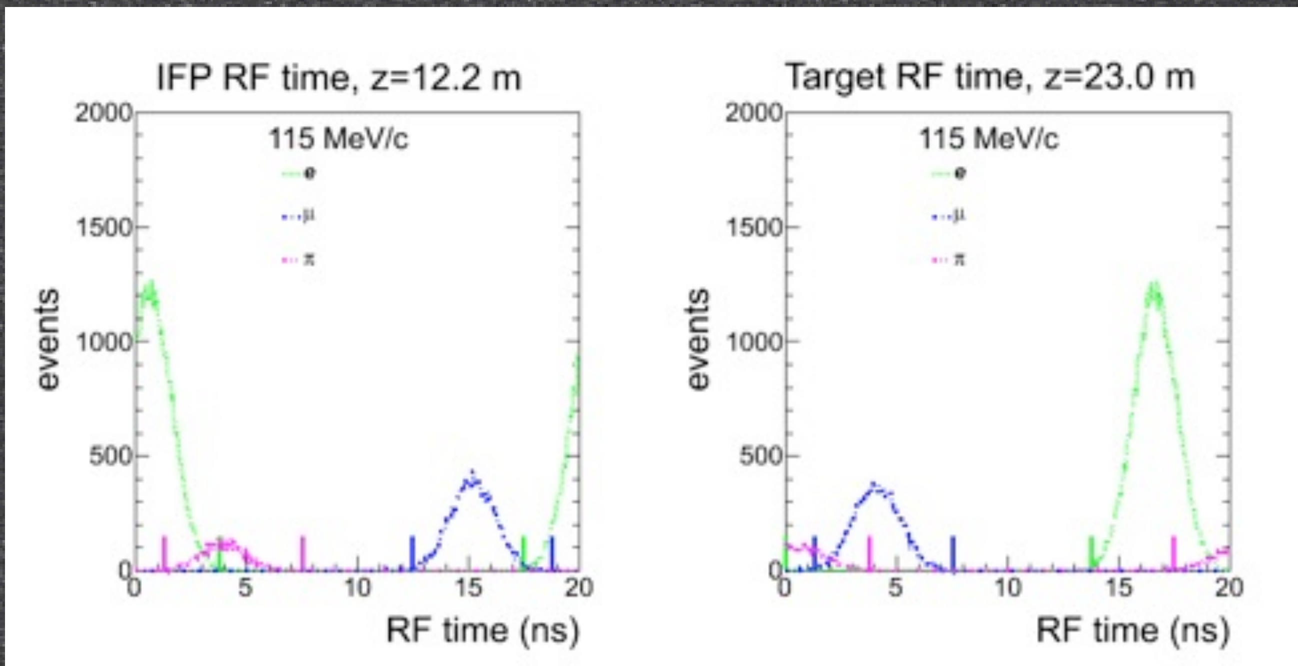
For efficiency purposes, we plan to require only 1 of 2 planes in the IFP SciFi and 1 of 3 planes in the target SciFi.

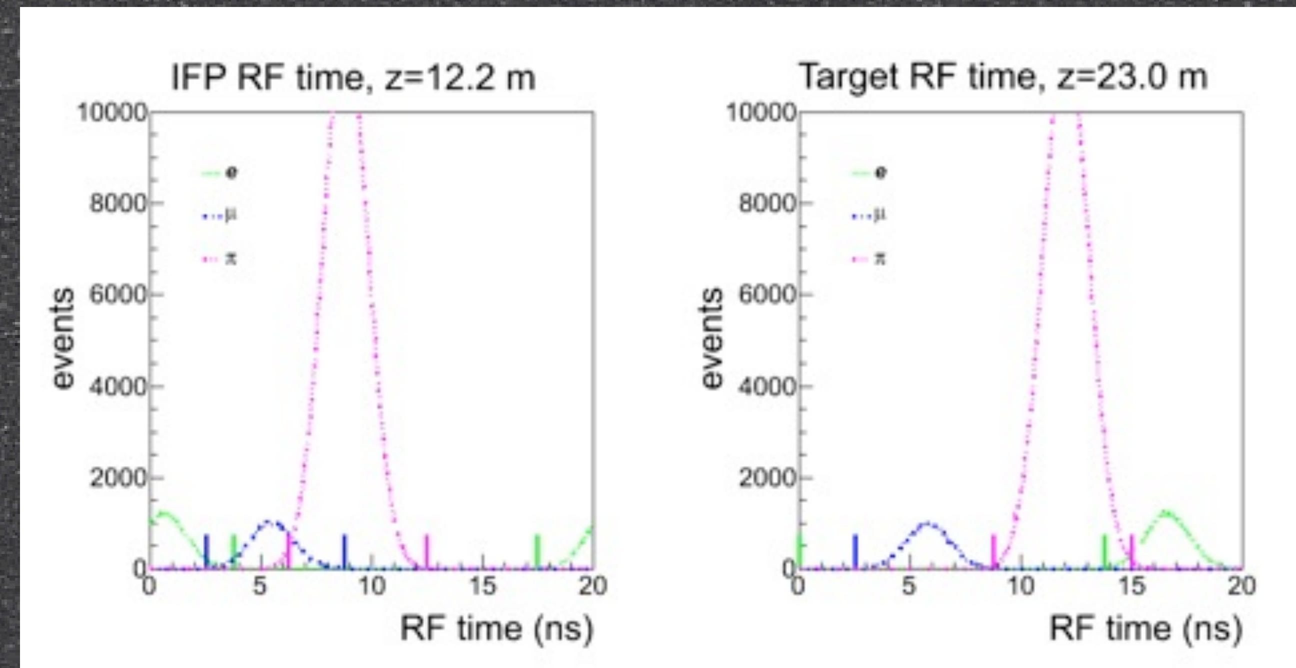
We will generally be unable to determine if there are multiple particles of the same type in the same RF pulse if they are in the same section of the 8 sections of the IFP Sci-Fi array. We will be able to determine e-only, μ-only, e AND μ, to some degree if there are 2e's or 2μ's , and if there is a π - a π acts as a veto, we do not want to count e's or μ's or trigger if there is a π.

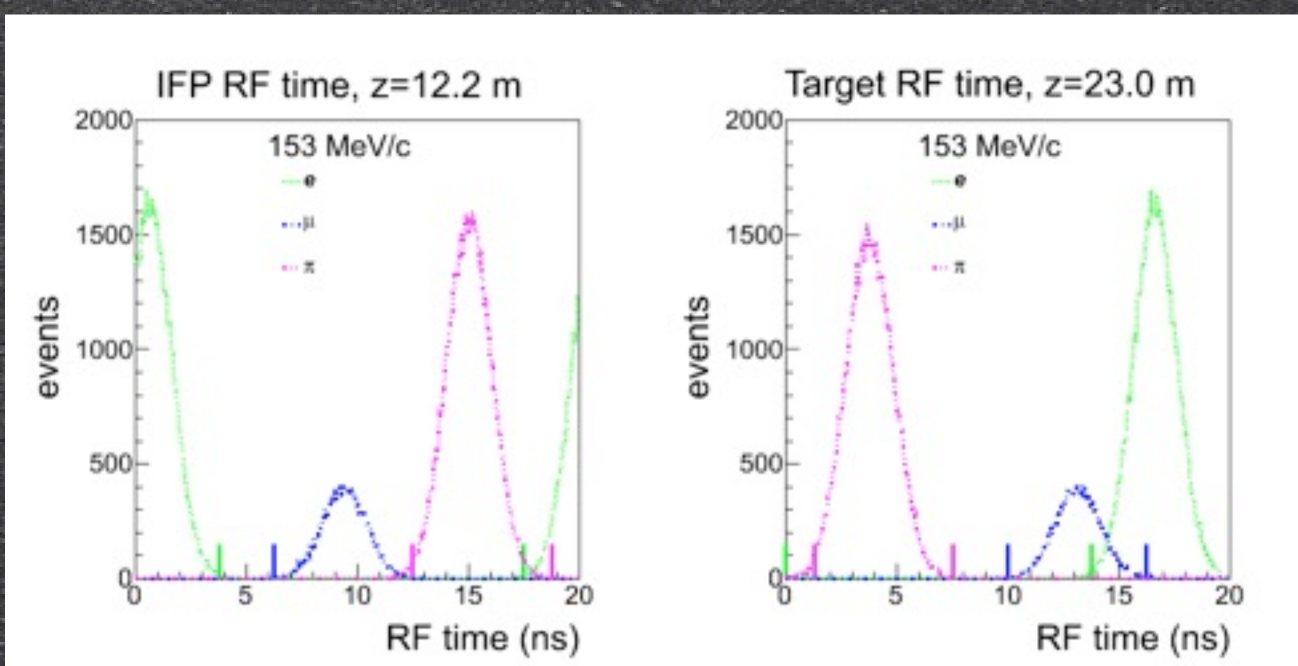
The various logical combinations will be output to the trigger and to scalers.

The three combinations count the numbers of beam particles, giving N_{beam} in the cross section formula.

Estimated Performance: Simulated RF Time Spectra







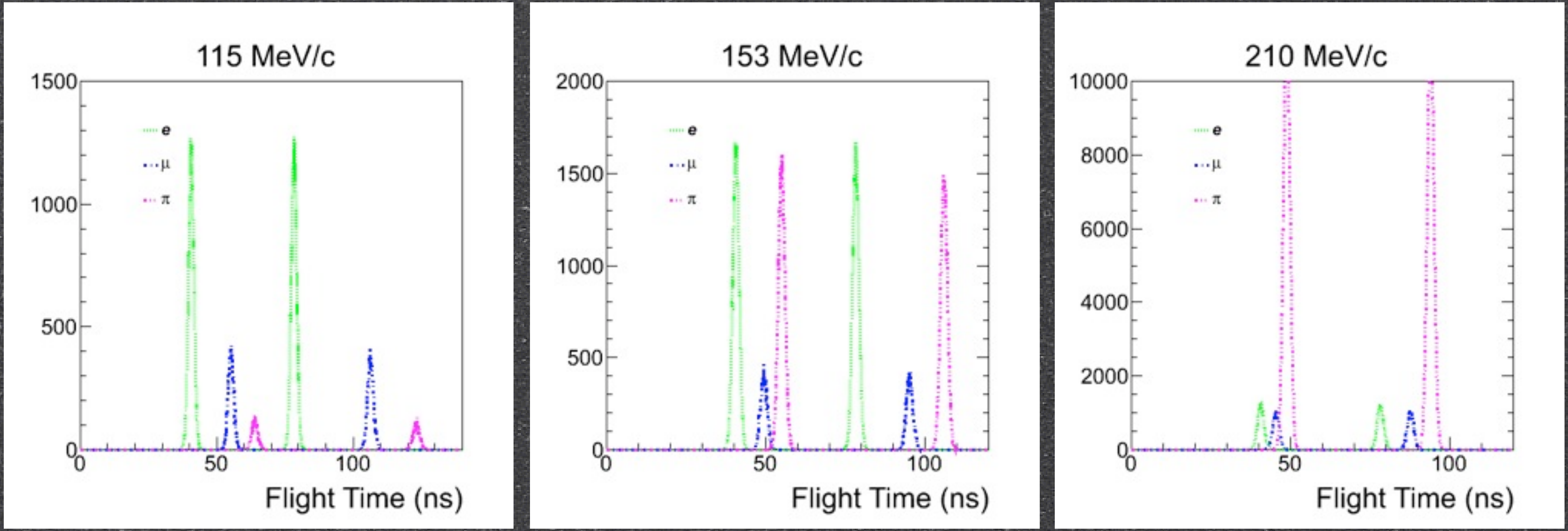
- Uses rates, σ ≈ 1 ns, Gaussian peaks, simple non-optimized 5-bin algorithm
- π peak generally separated, except π/e at 115 MeV/c at at IFP at 210 MeV/c
- But ...

Expected Performance: TDR Table V

Momentum (MeV/c)	115	153	210
e efficiency (%)	99.6	99.6	99.6
μ efficiency (%)	99.1	99.5	99.6
π efficiency (%)	98.7	98.4	99.2
π ID-ed as e (%)	**13.2!**	≈0.01	≈0
π ID-ed as μ (%)	≈0	≈0	≈0.03
e ID-ed as μ (%)	≈0	≈0	≈0
μ ID-ed as e (%)	≈0.01	≈0	≈0

Using default non-optimized 5-bin algorithm.

But… What TDR Table V Misses



The two peaks of each particle type show the flight time to the IFP and target detectors. Because the particles separate as they propagate in time, misidentifications are suppressed. For example, a 115 MeV/c π overlaps e's from 1 RF pulse later at the IFP, and e's from 2 RF pulses later at the target.

This suppresses any misidentifications as e's (and misidentified π/μ except at 210 MeV/c) as long as we can tell the RF pulses apart.

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e efficiency (%)	99.6	99.6	99.6
μ efficiency (%)	99.1	99.5	99.6
π efficiency (%)	98.7	98.4	99.2
π ID-ed as e (%)	**0.5!**	0!	0!
π ID-ed as μ (%)	≈0	≈0	≈0.03
e ID-ed as μ (%)	≈0	≈0	≈0
μ ID-ed as e (%)	≈0!	0!	0!

Accidental coincidences still lead to some misidentifications, but at a much lower rate.

Calibration / Commissioning

As indicated in other talks, the main issues are:

- Do we efficiently identify e's and μ's? This is important as we do not want to lose statistics.
- Do we efficiently reject π's? This is important as the higher π cross section would lead to large DAQ rates.
- Are the e and μ signals really e's and μ's? This is important as the cross section is proportional to $1/N_e$ and $1/N_\mu$.
- All of these facets of the system get commissioned / calibrated / set / tested with direct beam measurements, using a high-precision scintillator after the target to unambiguously identify the particle type, and varying the incident rate to test the rate-dependent corrections.

Calibration / Commissioning

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- Are the e and μ ... the cross sectio...
- All of these fac... calibrated / tes... h- precision scintill... the particle typ... - dependent corre...

- If we miss an e and μ, we lose statistics, and
- If we miss a π, we get an extra background event to reject in analysis, but
- If we misidentify something else as an e or μ, we mis-normalize the cross section. It is this misidentification probability that we need to keep small and precisely known.
- Scalers count # of μ's that could trigger system, need to correct for fiducial cuts

CAEN v1495 Trigger

These Trigger FPGAs will generate a trigger when:

- both phototubes of a front plane paddle fire AND
- both phototubes of a back plane paddle fire AND
- the two paddles roughly point back to the target AND
- there is a good beam PID signal - (e .OR. μ) .AND. !π.

We expect to have other prescaled secondary triggers for diagnostics, depending on DAQ rates.

The 186 scintillator signals are too many for a single v1495. We will instead have LEFT and RIGHT v1495s, each taking in 88 scintillator signals and a set of beam PID signals.

Scintillator Timing

Because of the geometry of the scintillators, the flight distance for electrons from the target to the scintillators varies from about 50 - 130 cm, corresponding to flight times of 1.7 - 4.3 ns.

The rear scintillators are 2-m long, so the signal timing variation from light propagation time is about 6.7 ns x n ≈ 10.4 ns from one end of scintillator to the other. Thus, for a given beam particle type, the 2 scintillator signals can vary by ±5.2 ns from their average time and from the beam PID signal.

With leading edge timing, we get about ±7-8 ns variation in the arrival of the scintillator signals to the FPGA that we have to take into account in forming the coincidence between the beam PID signal and the scintillator signals.

For reading out the DAQ and vetoing π events, we only need to consider the closest in time π peak - we do not need to consider 2 RF periods.

Cost / Manpower
Beam FPGA System

The beam FPGA will be developed by Ed Bartz of the Rutgers P&A electronics shop. Ed is an experienced designer, and the main issue will be competition for his time from LHC projects.

The development time scale is about 6 months, and could start in 2013 as soon as we have some money to spend. We pay about $30/hour for Ed's time, so the development cost will be about $40,000.

Constructing the system (23 boards, spares, 1 VME crate, 1 CPU for the crate) will be about $60,000.

This the total cost is about $100,000.

Cost / Manpower
Trigger

The trigger system requires 1 VME crate + CPU, and 3 CAEN v1495 boards plus additional I/O cards and 1 spare v1495. The v1495s with additional cards are about $5000 each, so the trigger will cost about $30,000. (RU owns much of this system already, but we expect it to remain committed to FNAL E906.)

Programming the v1495 will be done largely by a postdoc and/or grad student, and will require about 1 year. There are great similarities to the E906 trigger, and an experienced student from 906, for example, could finish in ≈6 months.