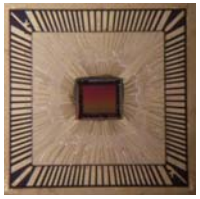
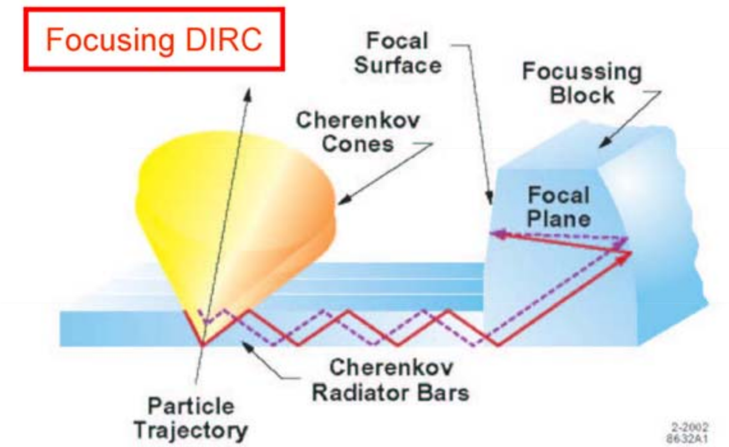
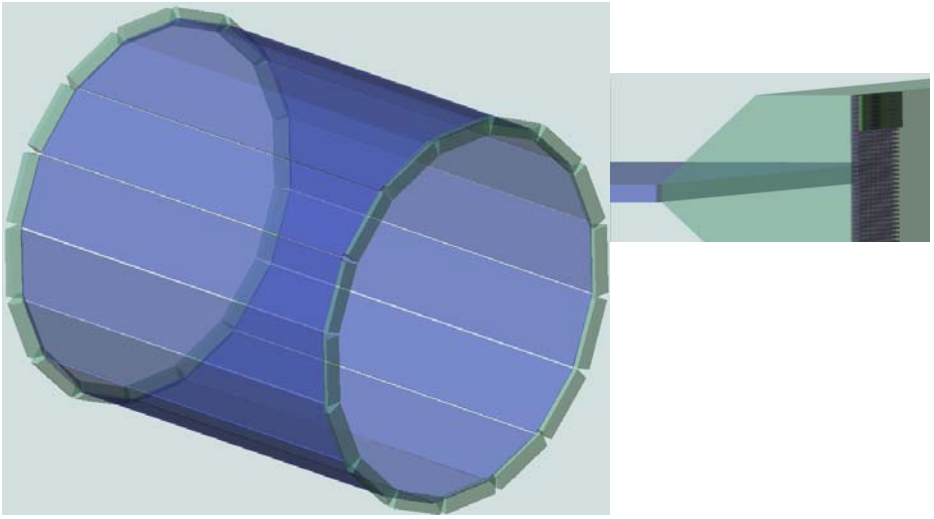
Alternative Detector Concepts for the PID Upgrade







- focusing DIRC (fDIRC)
- imaging TOP (iTOP)

Jose Benitez, David W.G.S. Leith, Gholam Mazaheri, Blair N. Ratcliff, Jochen Schwiening, Jerry Va'vra

SLAC

Matt Belhorn, Alexey Drutsukoy, Alan Schwartz

University of Cincinnati

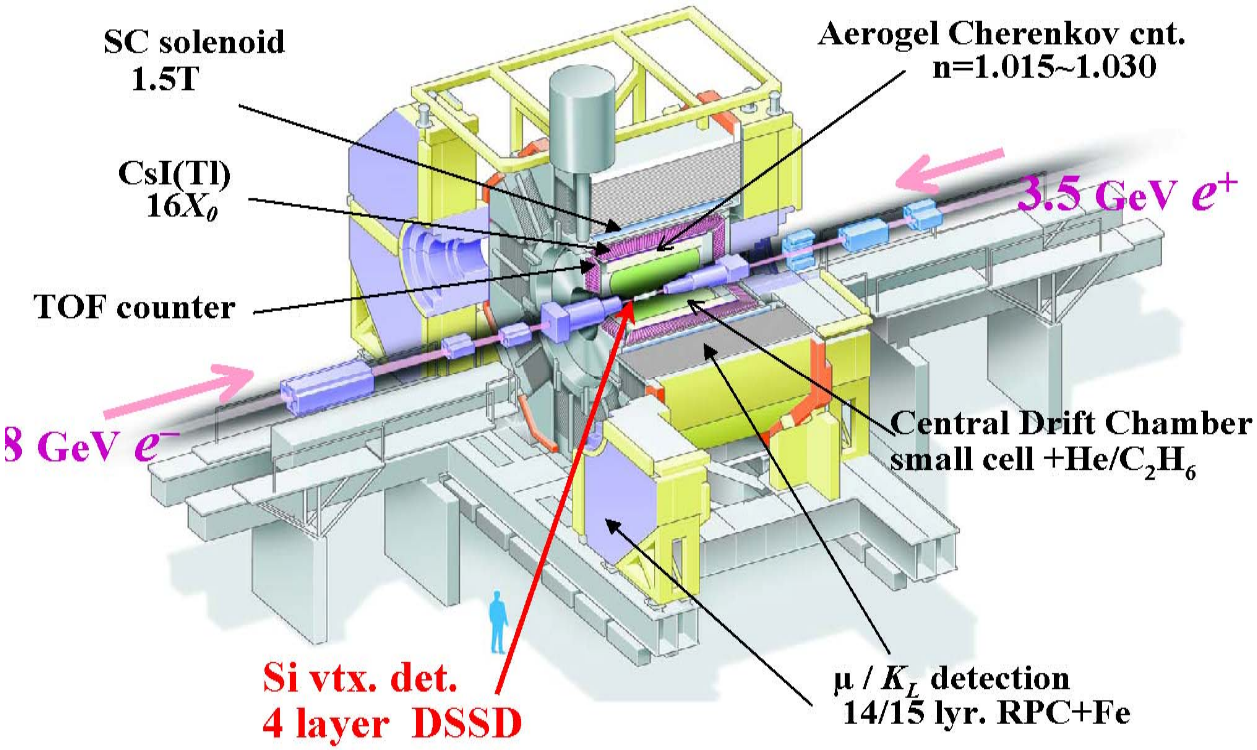
Tom Browder, James Kennedy, Kurtis Nishimura, Marc Rosen

University of Hawaii at MANOA

Larry Ruckman and Gary S. Varner

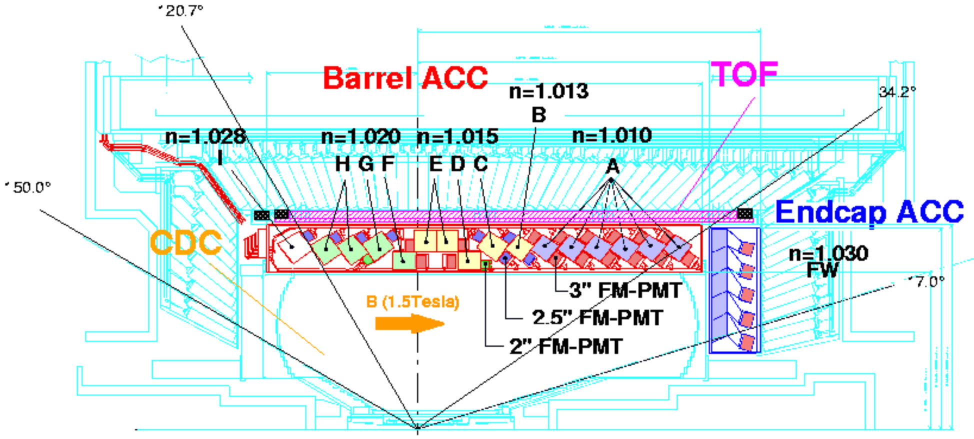
Proto-Collab. Meeting 20-MAR-08

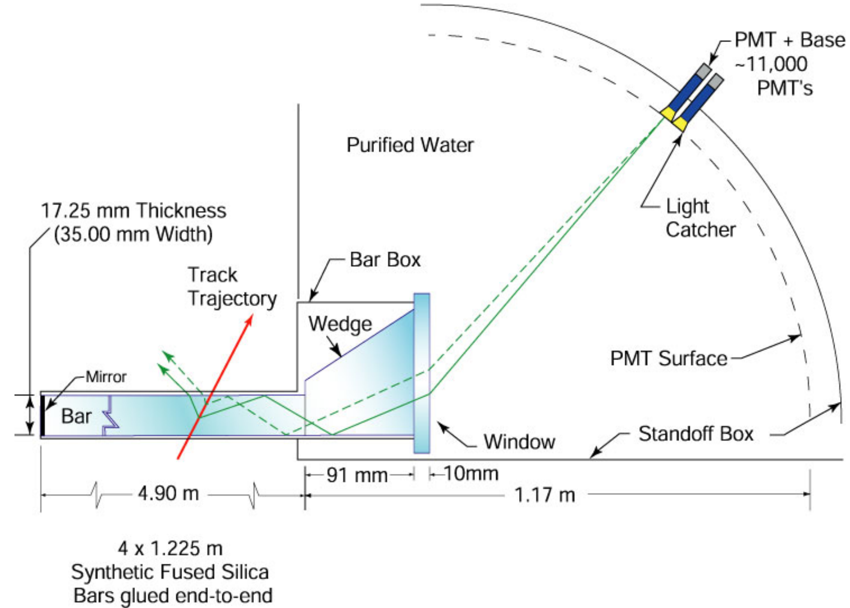
An Upgraded Detector

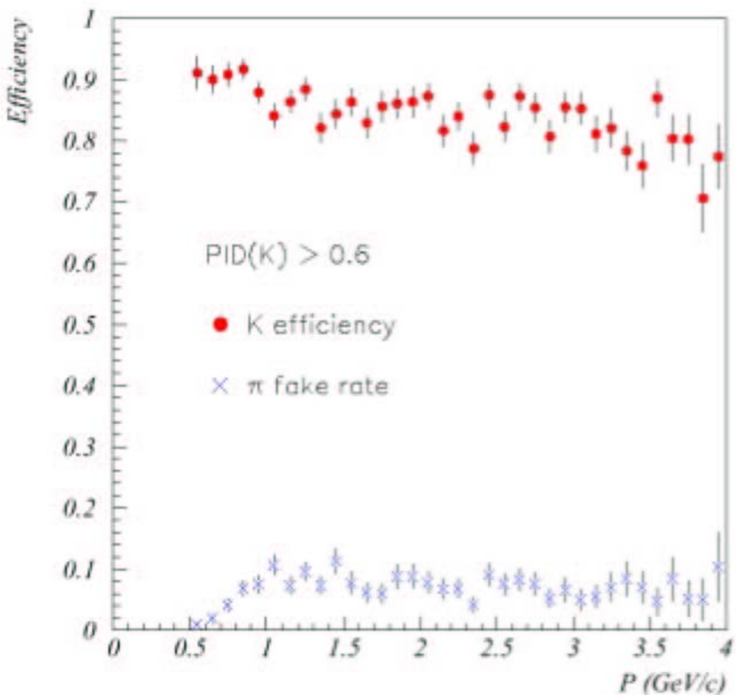


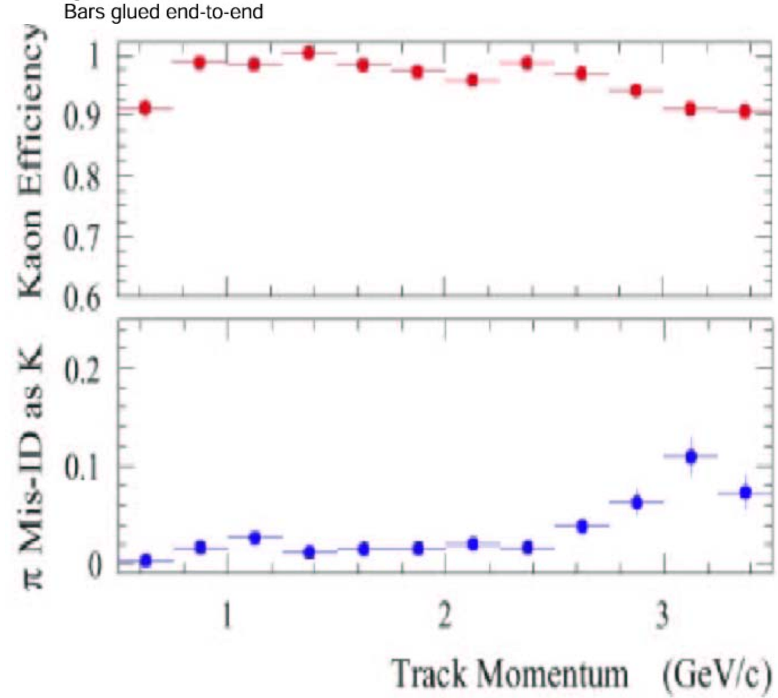
- 3 ways to improve:
  - Pixel detector
  - Hermiticity
  - Particle Identification

Particle ID at the B-factories

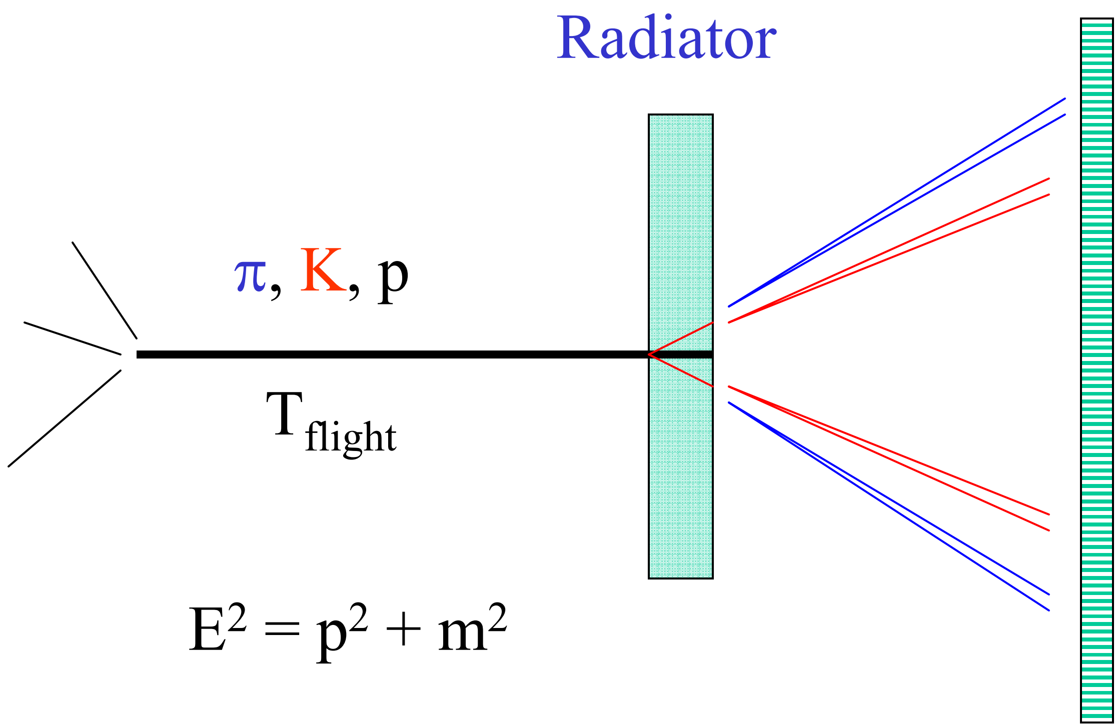








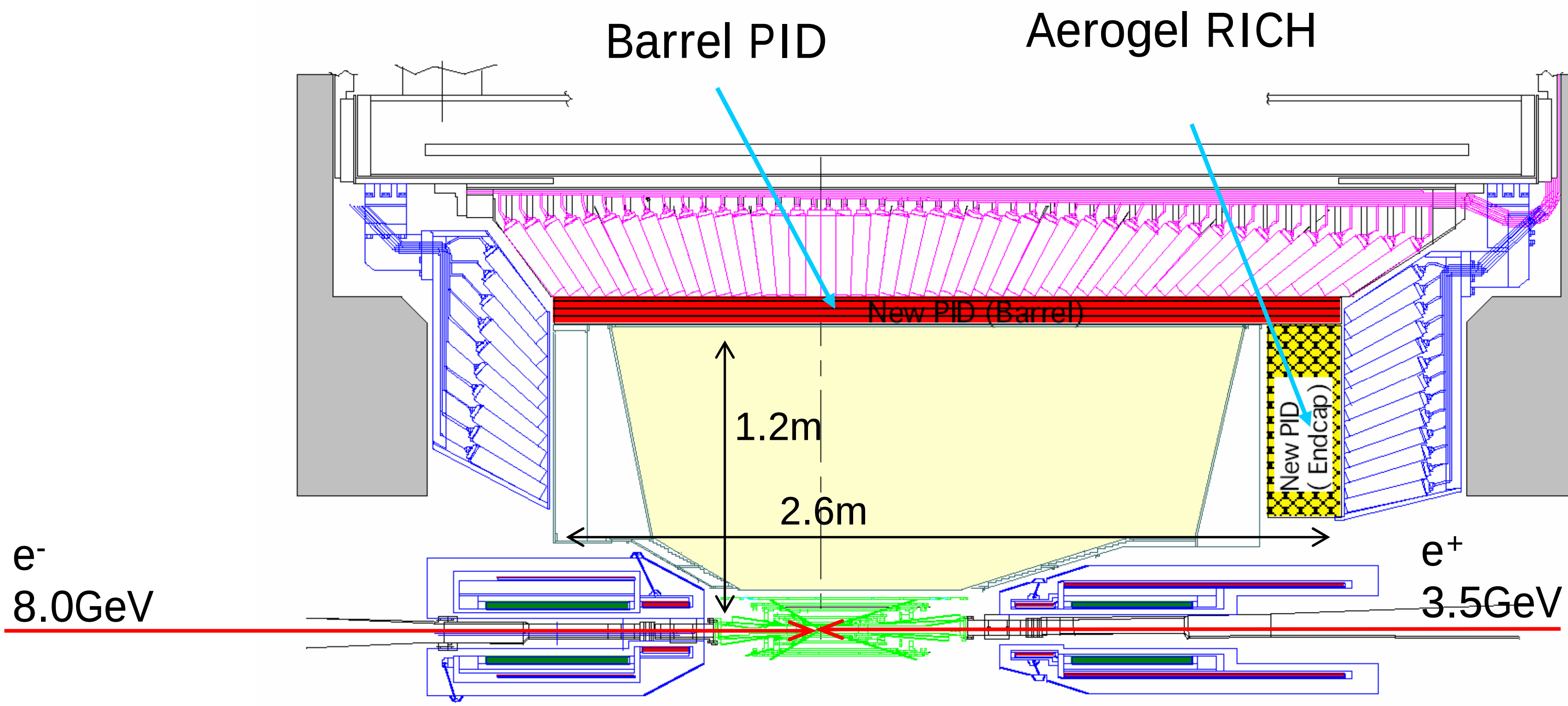
Particle ID observables



$E^2 = p^2 + m^2$

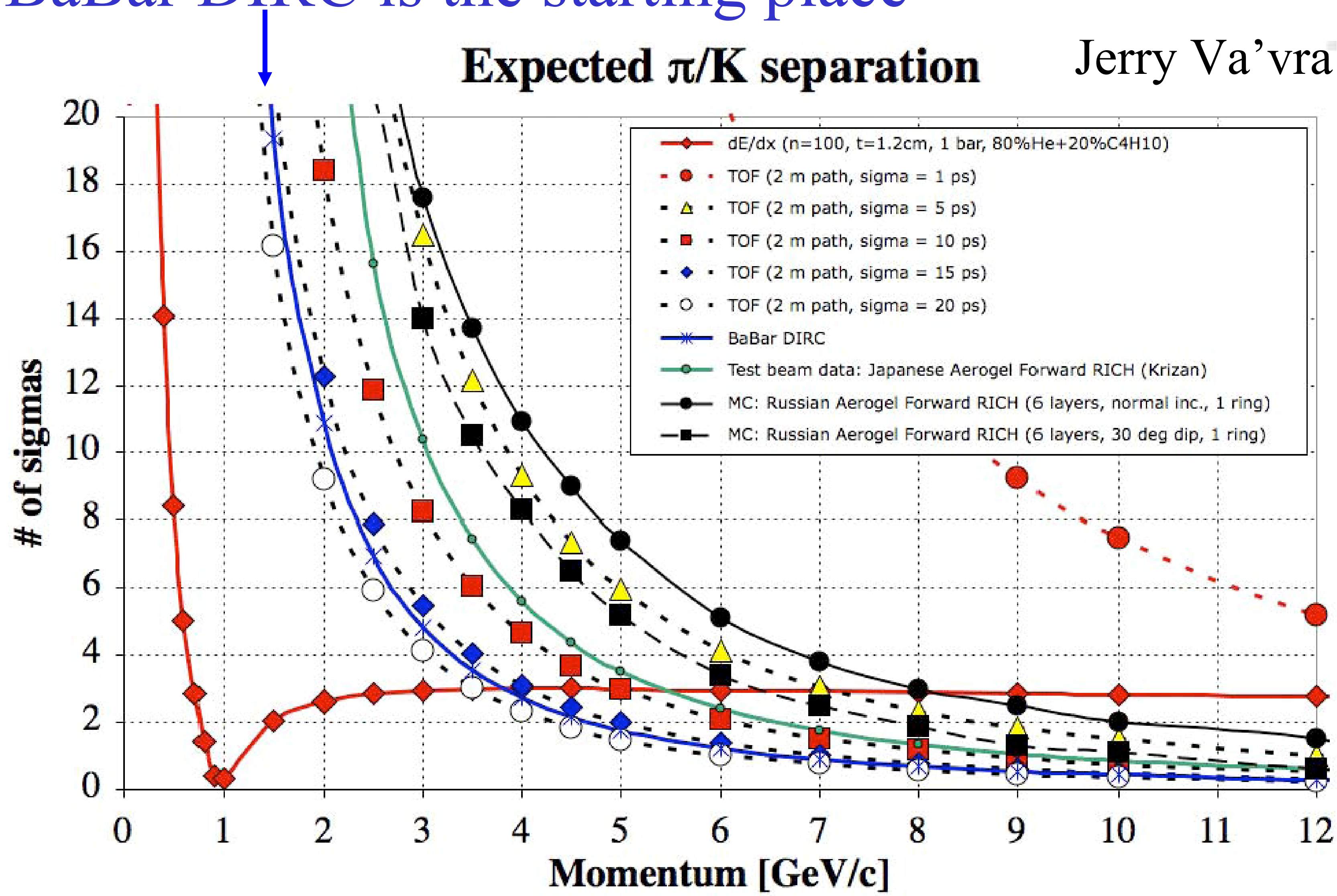
Upgraded detector

- PID (π/K) detectors
  - Inside current calorimeter
  - Use less material and allow more tracking volume
  - → Available geometry defines form factor
    -



Particle ID Techniques

- BaBar DIRC is the starting place



3-D Detector Concept (Blair Ratcliff)

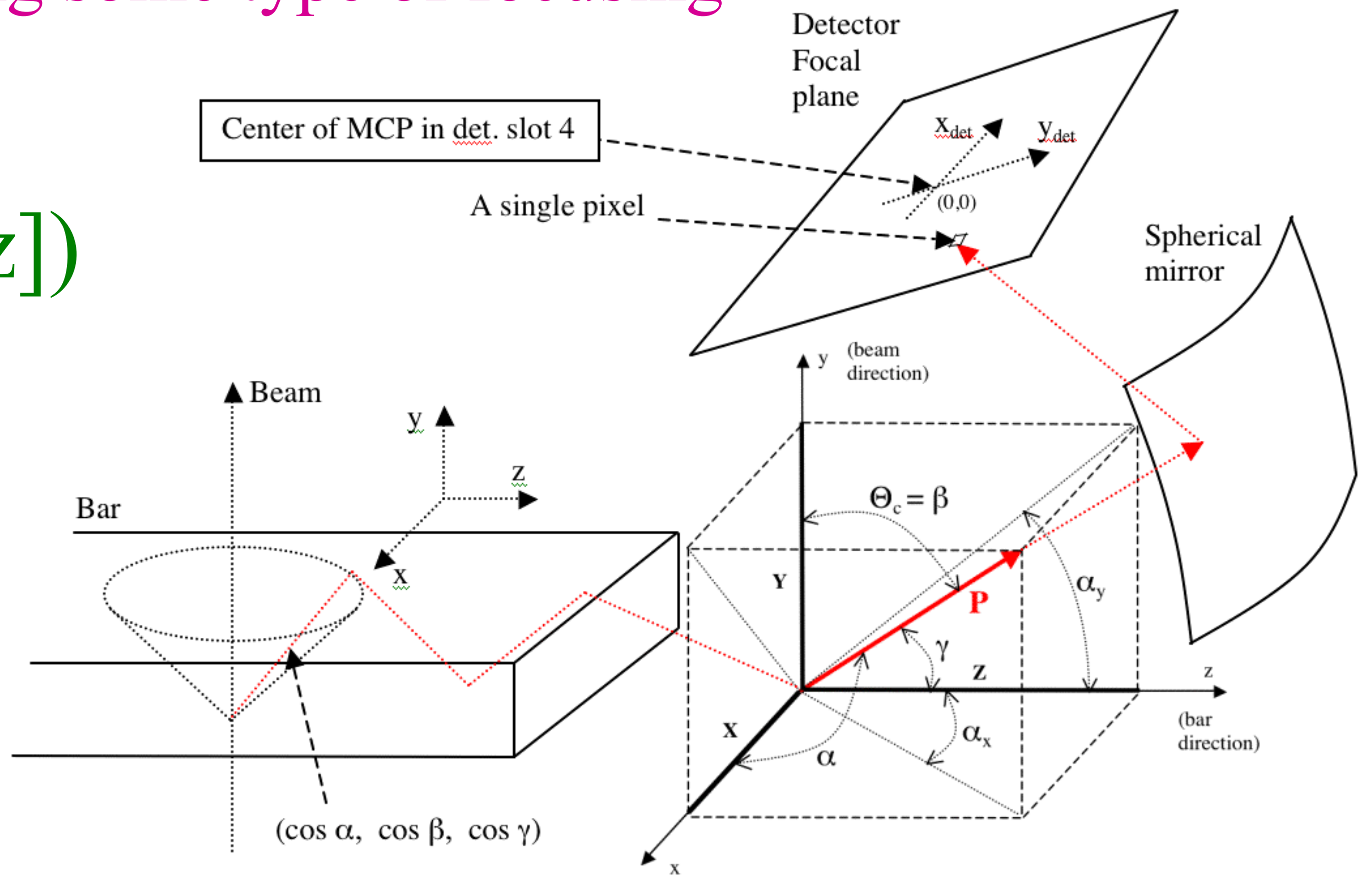
Precisely measured detector pixel coordinates and beam parameters.

→ Pixel with hit (x_{det}, y_{det}, t_{hit}) defines 3D propagation vector in bar and Cherenkov photon properties *(assuming average λ)*

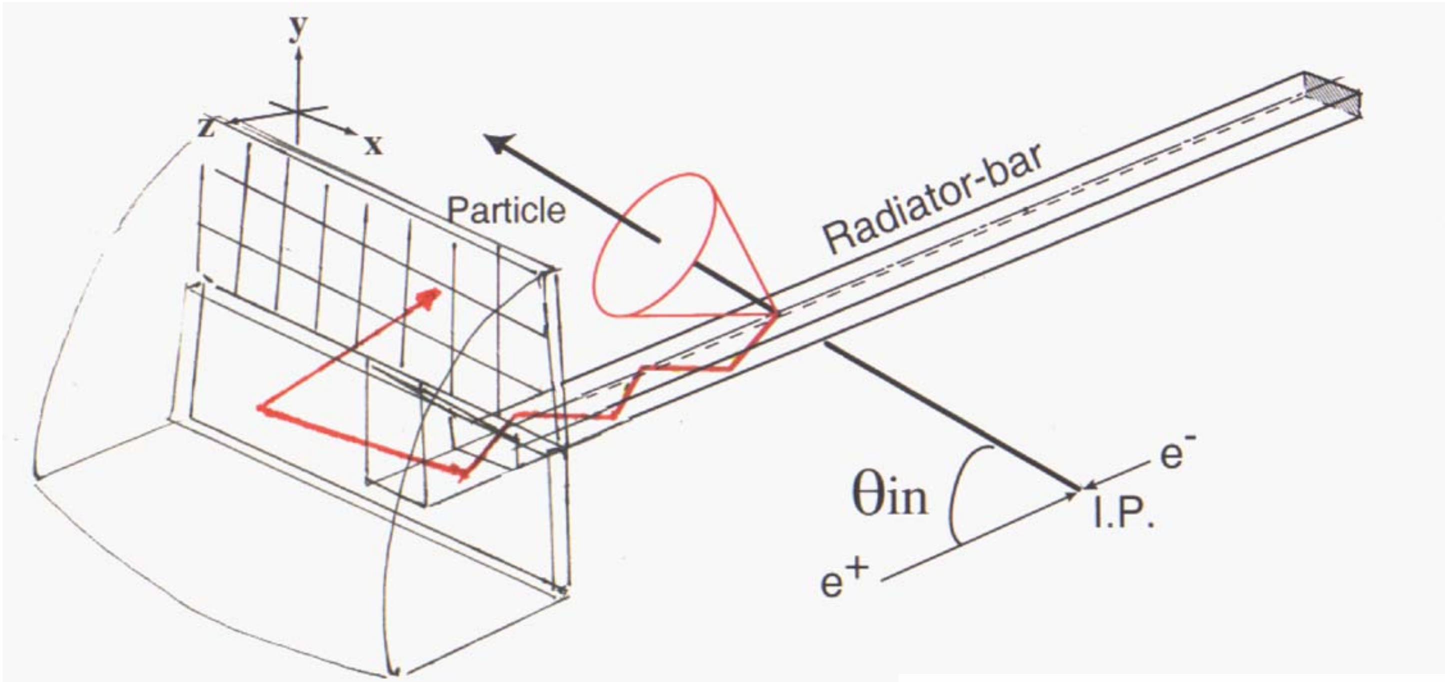
α_x, α_y, cos α, cos β, cos γ, L_{path}, $n_{bounces}$, θ_c, f_c , $t_{propagation}$

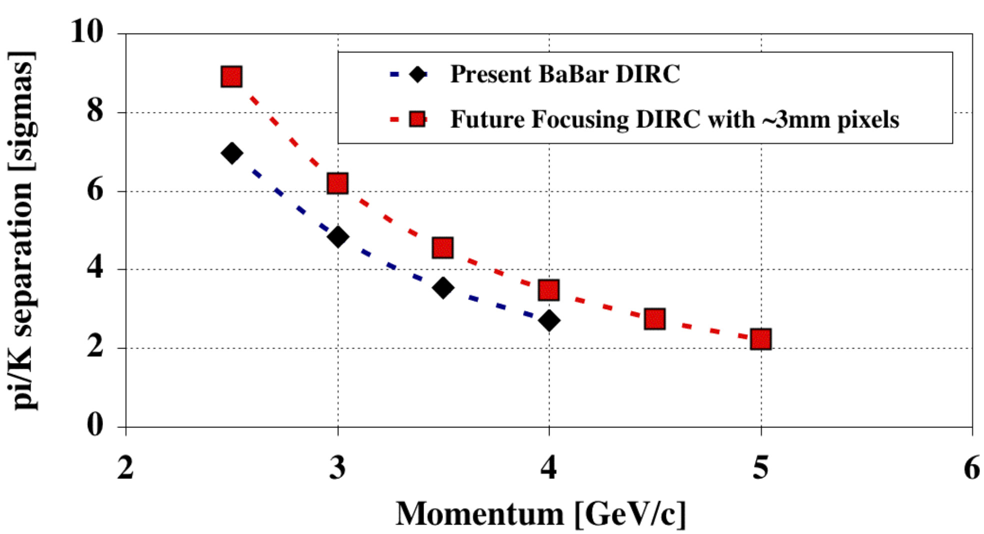
Always doing some type of focusing

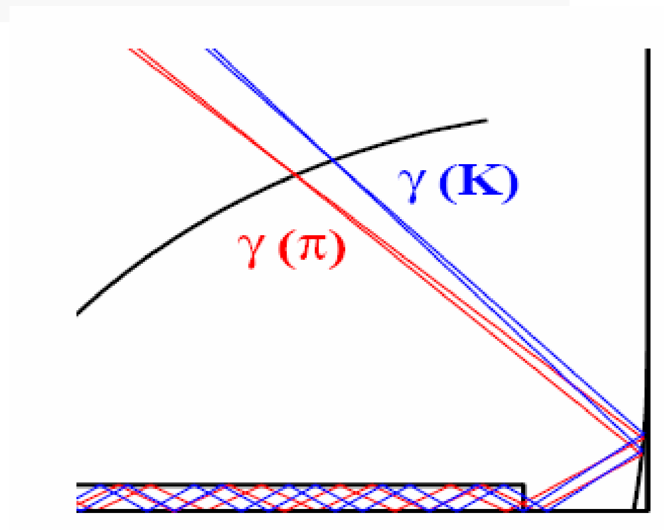
f(x.y.[t-z])



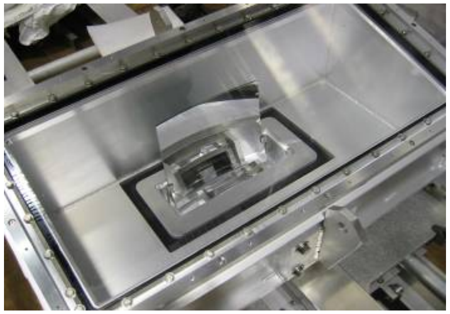
Fast Focusing DIRC Concept

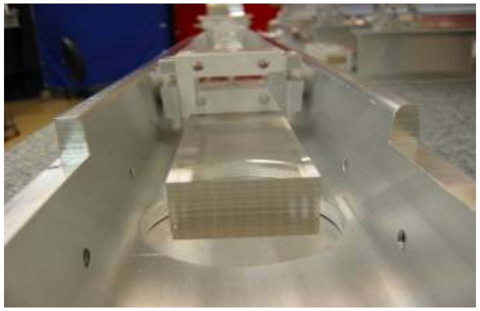


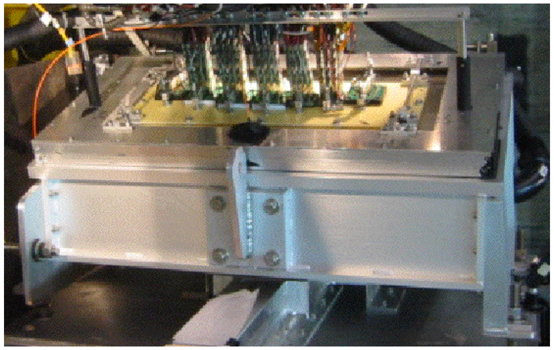


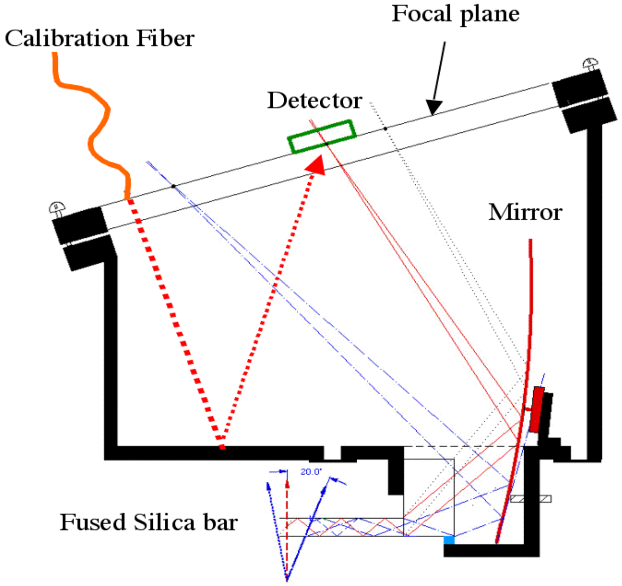


Focusing DIRC Prototype Optics





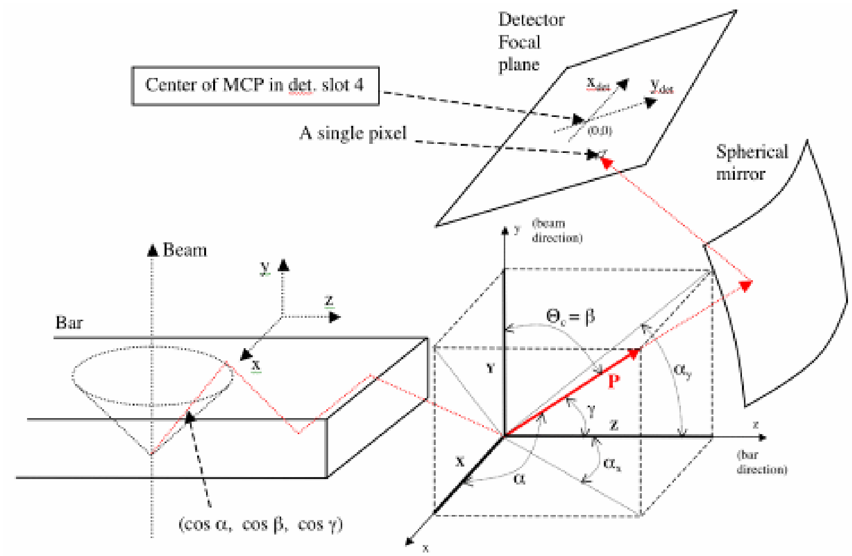




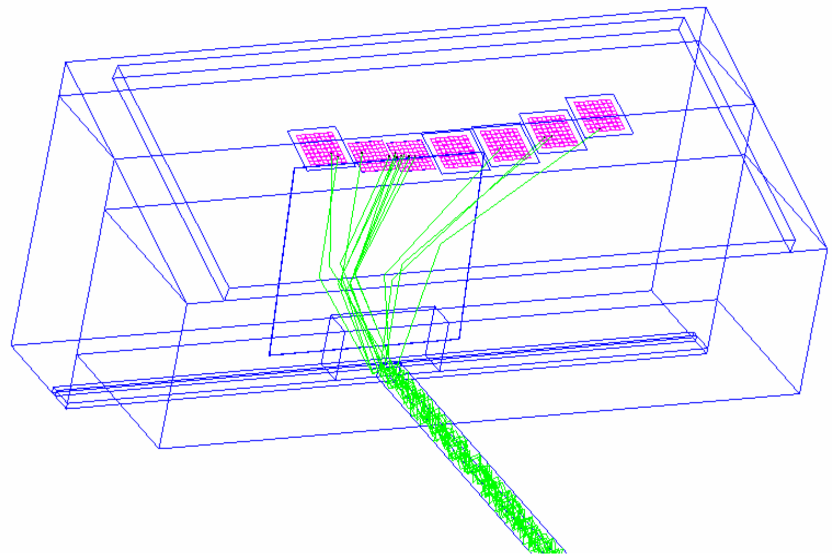
- Radiator:
  - 1.7 cm thick, 3.5 cm wide, 3.7 m long fused silica bar (spares from BABAR DIRC).
- Optical expansion region:
  - filled with a mineral oil to match the fused silica refraction index (KamLand oil).
  - include optical fiber for the electronics calibration (PiLas laser diode).
- Focusing optics:
  - a spherical mirror with 49cm focal length focuses photons onto a detector plane.

Focusing DIRC prototype reconstruction

Prototype coordinate systems:



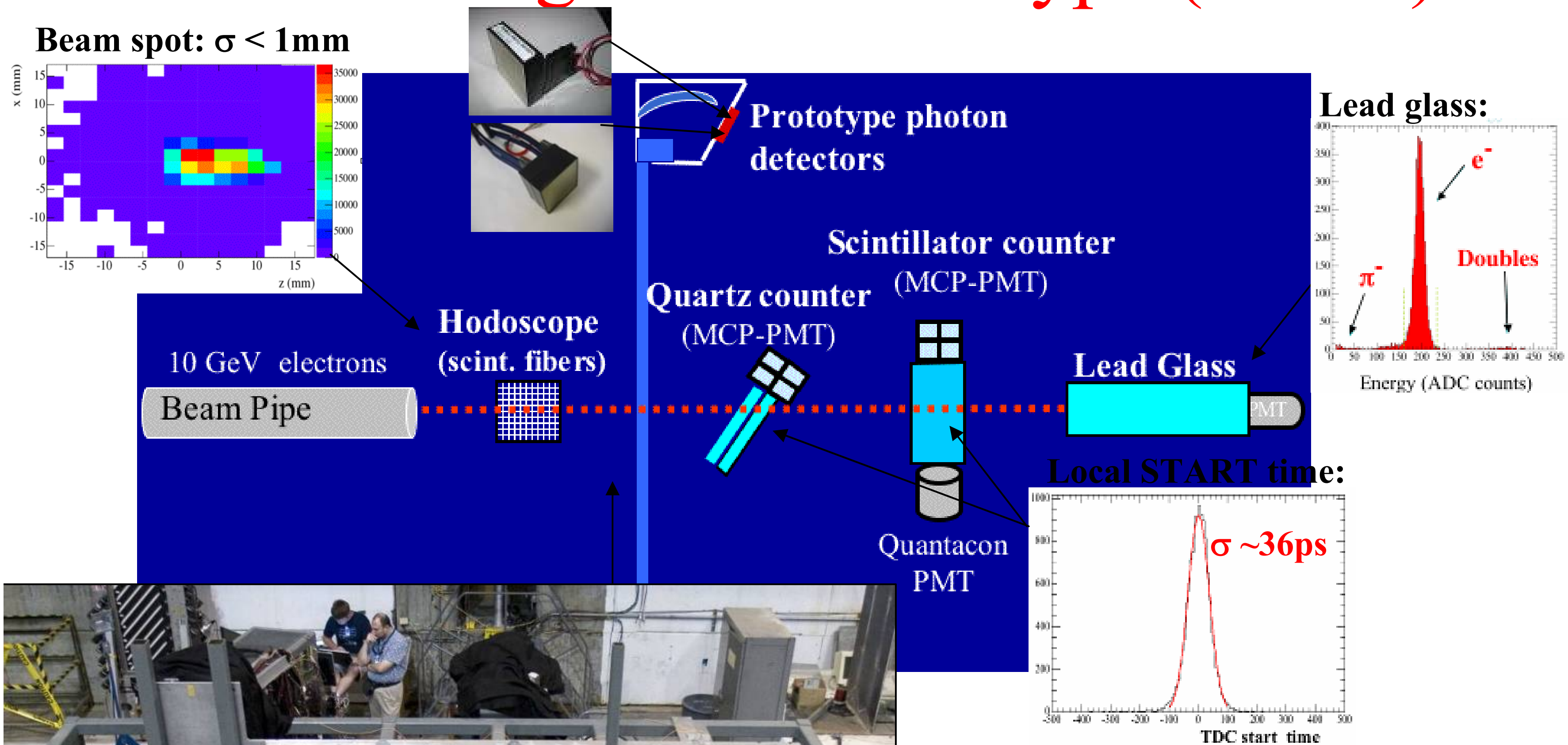
Geant 4 simulation of the prototype:

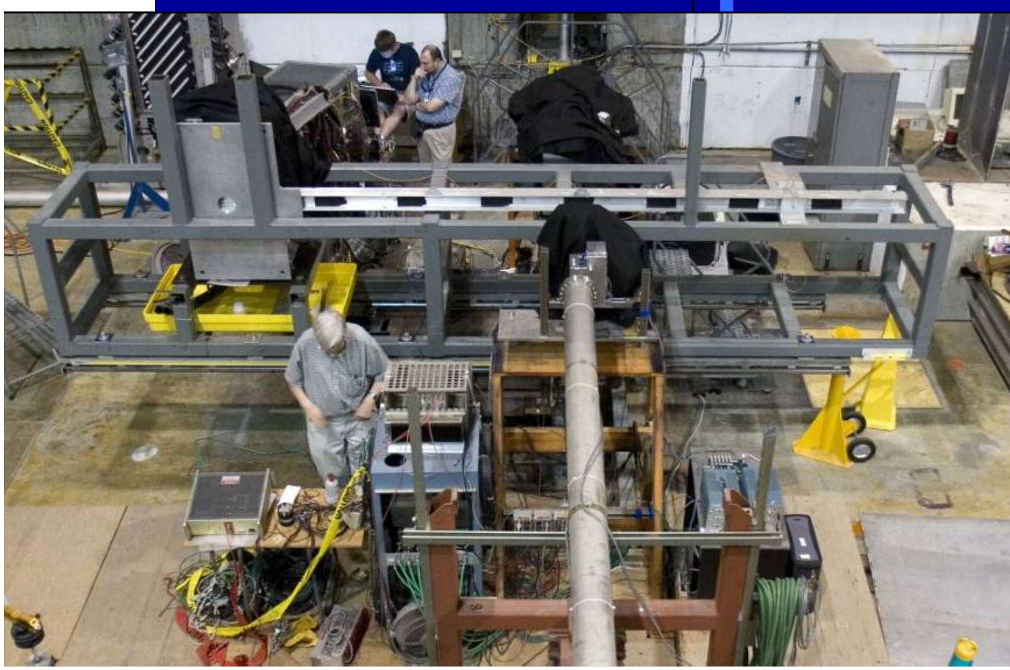


- Each detector pixel determines these photon parameters for average λ :
  θ_c, cos α, cos β, cos γ, Photon path length, time-of-propagation, number of photon bounces.

- Use full GEANT4 simulation to obtain the photon track parameters for each pixel.
  (it is checked by a ray-tracing software)

Focusing DIRC Prototype (T-492)





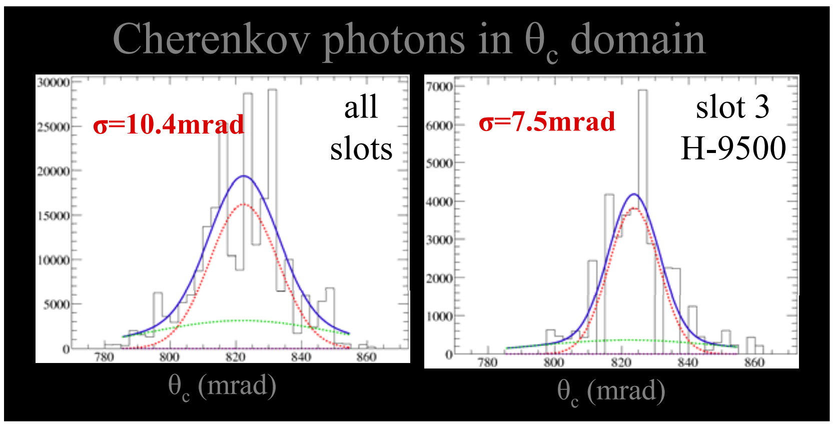
Focusing DIRC R&D effort at SLAC:

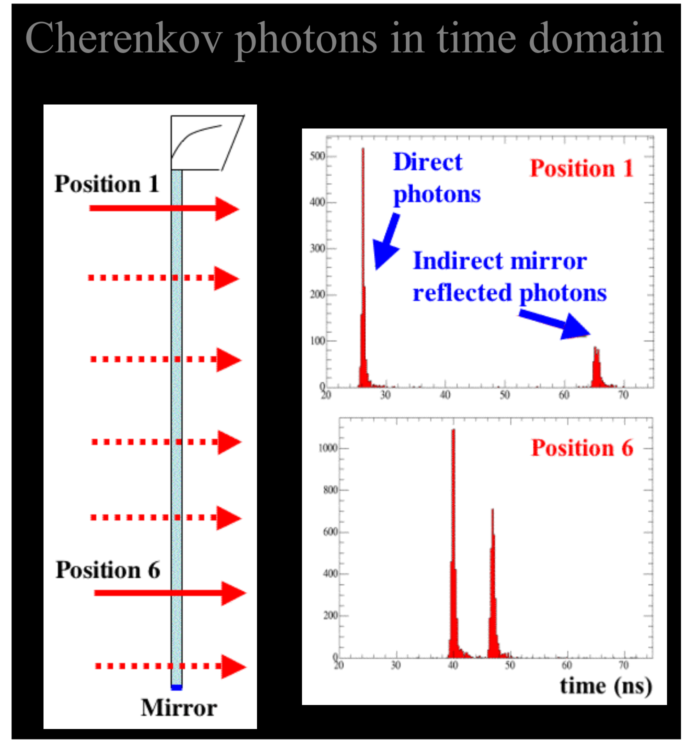
Jose Benitez # David W.G.S. Leith #
Gholam Mazaheri # Blair N. Ratcliff #
Larry L. Ruckman + Jochen Schwiening #
Gary S. Varner + Jerry Va'vra #

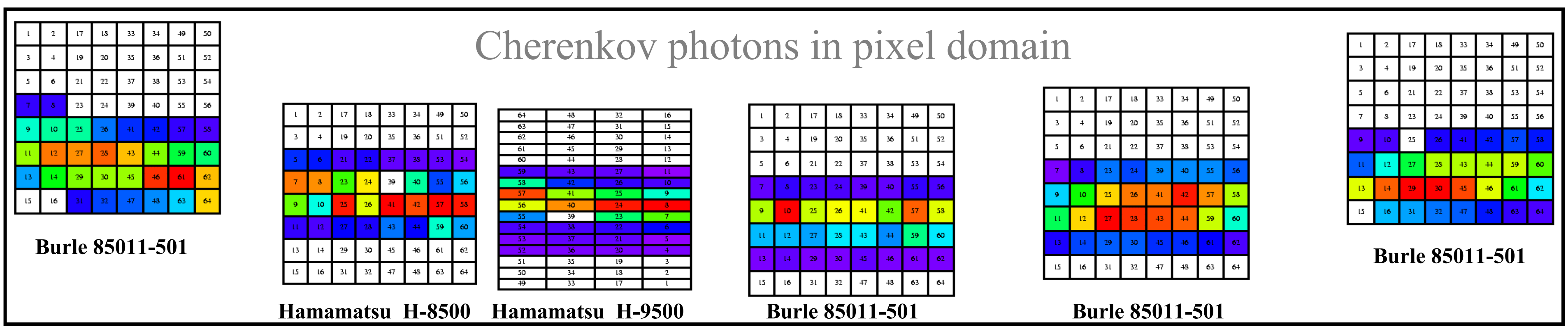
SLAC + University of Hawaii

Cherenkov Photon Signal (2006)

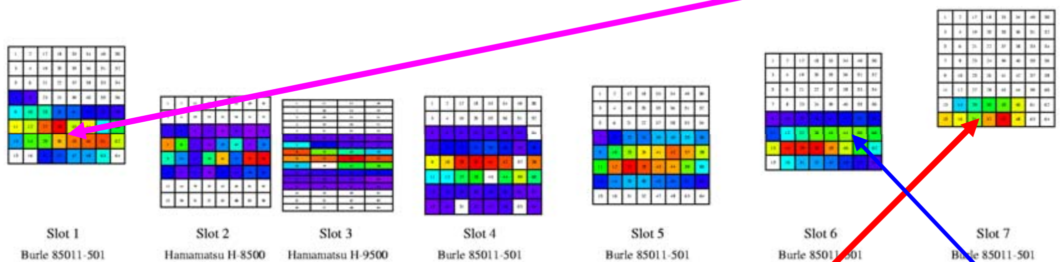
- 10 GeV/c electron beam data
- approx. 7.7M triggers, 560k good single e^- events
- ~ 200 pixels instrumented
- Ring image is most narrow in the 3 x 12 mm pixel detector (H-9500 in slot 3)



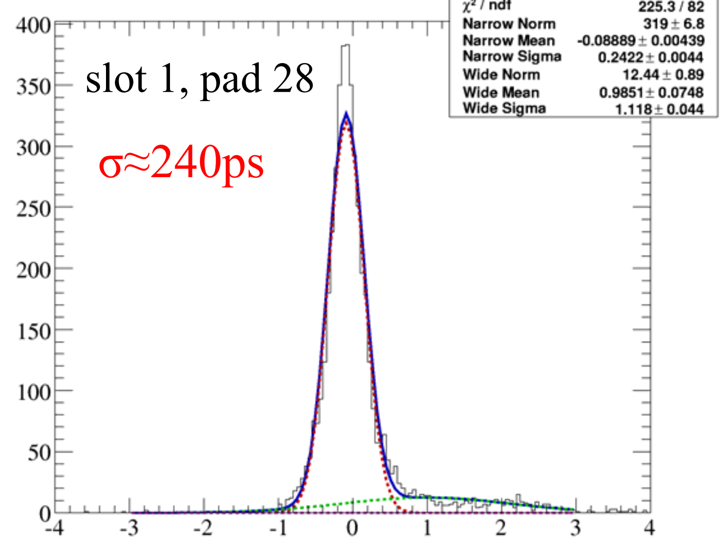




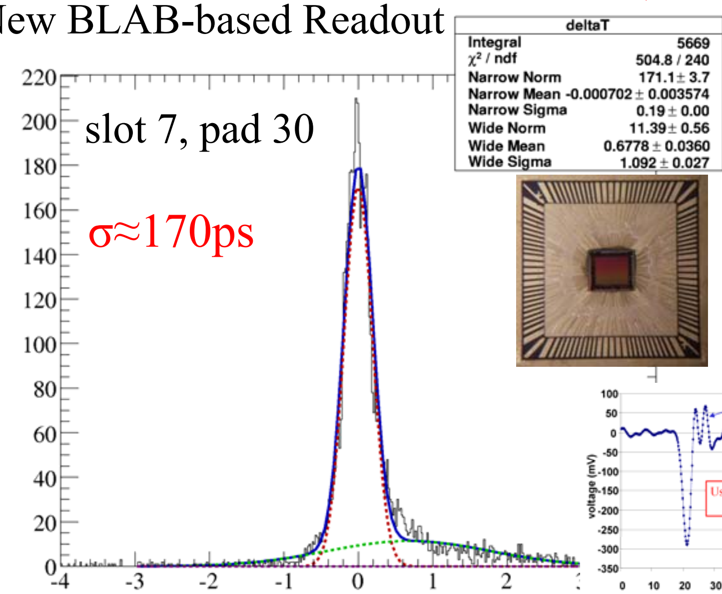
Aug 2007 Run: timing slot 7, pad 15
to Philips slot 1&6
for run 27, pos 1, direct photons

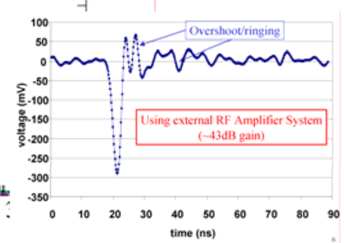


(symmetry partner in hit plane)

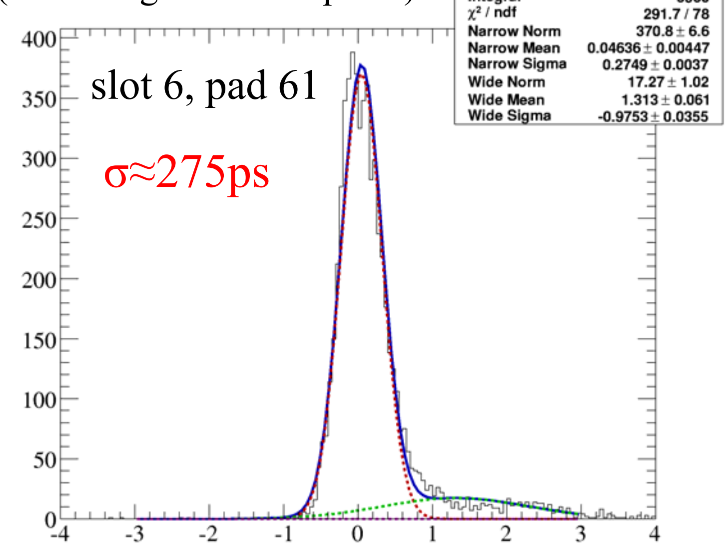


New BLAB-based Readout





(close neighbor in hit plane)



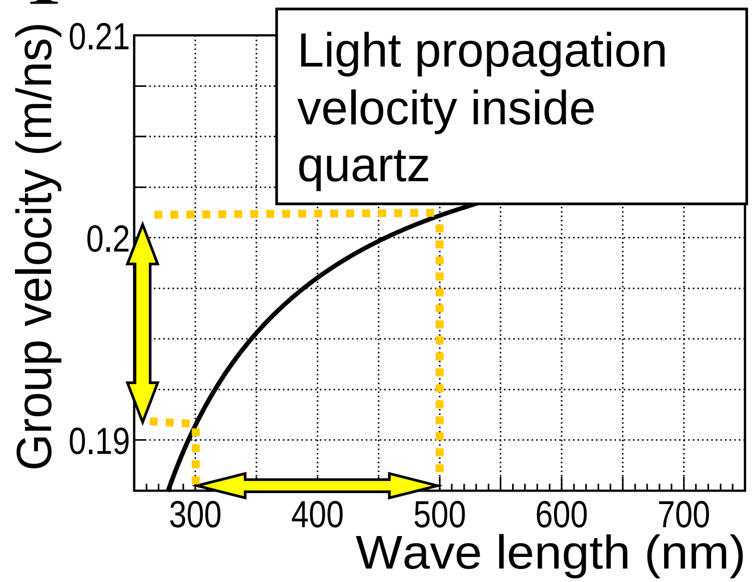
Future readout prototype

delta(time) (ns)

Chromatic dispersion

Variation of propagation velocity depending on the wavelength of Cherenkov photons

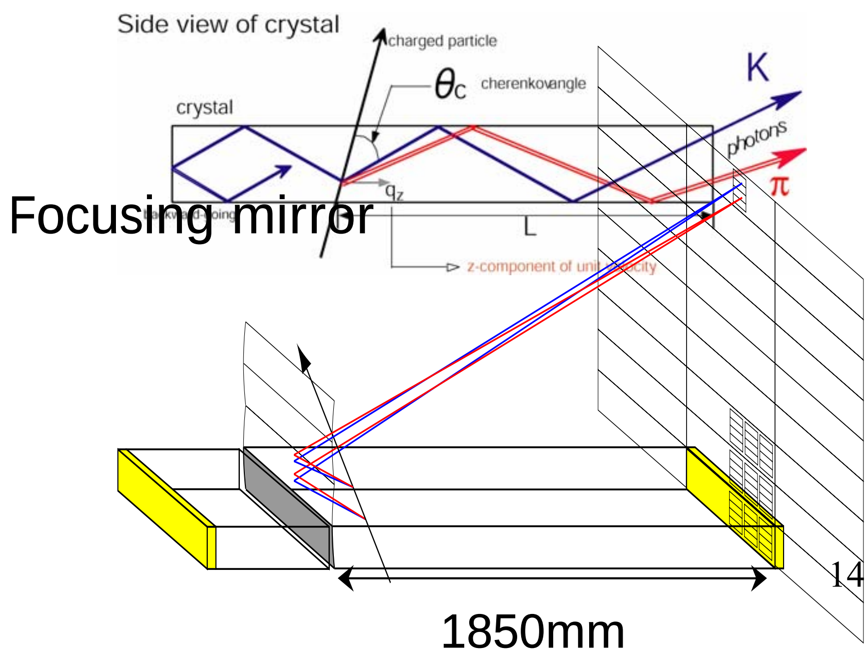
- Due to wavelength spread of detected photons
- → propagation time dispersion



- Longer propagation length

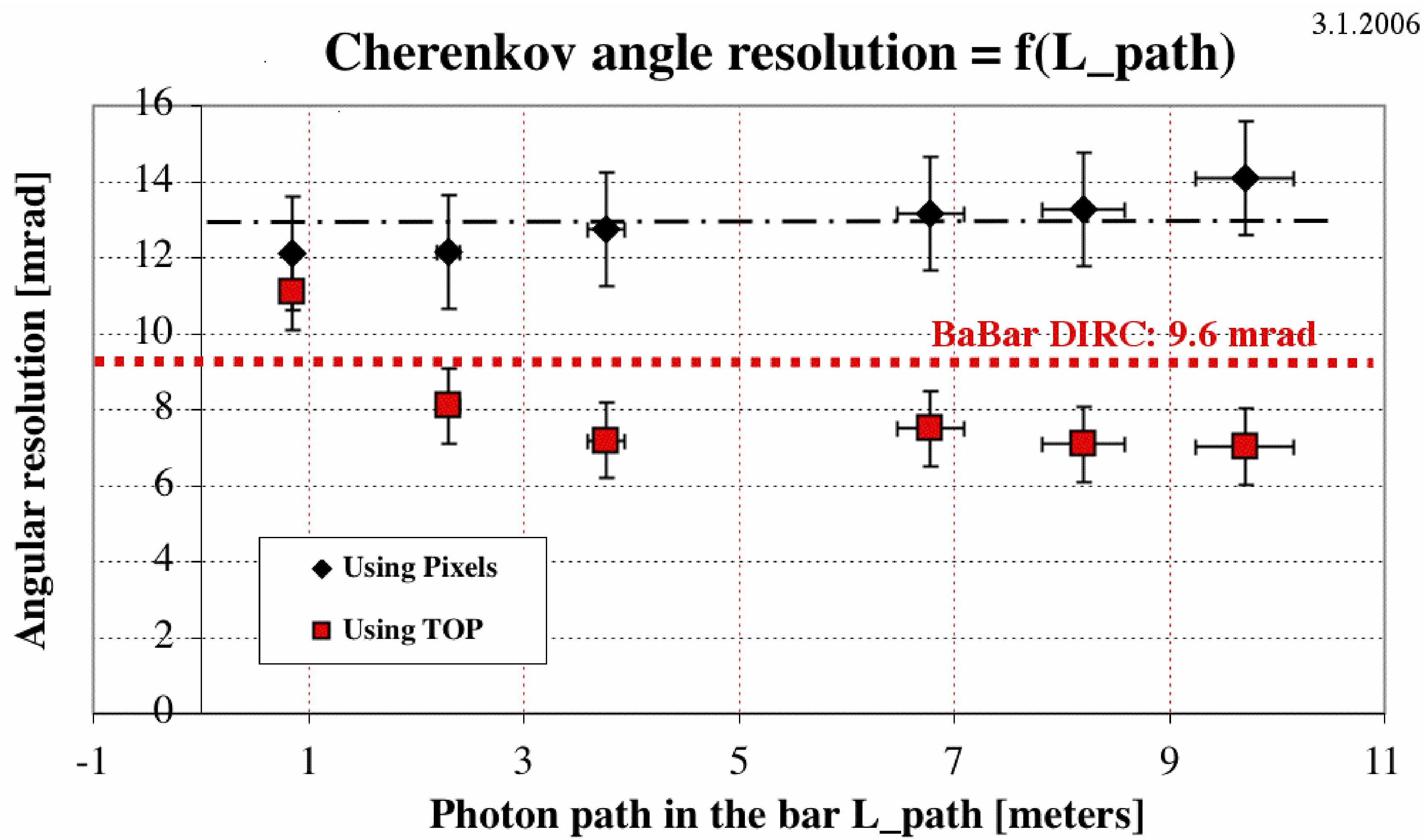
→ Improves ring image difference

But, decreases time resolution.



Techniques complement each other

Cherenkov Angle Resolution



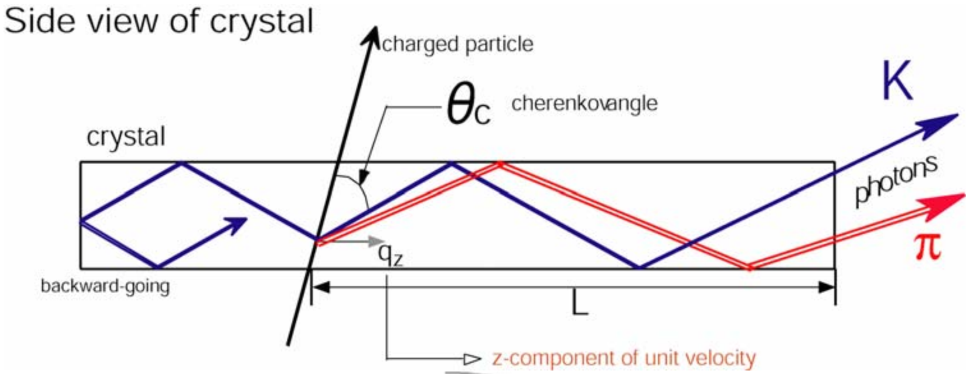
- Evidence: Timing improves imaging and vice-versa

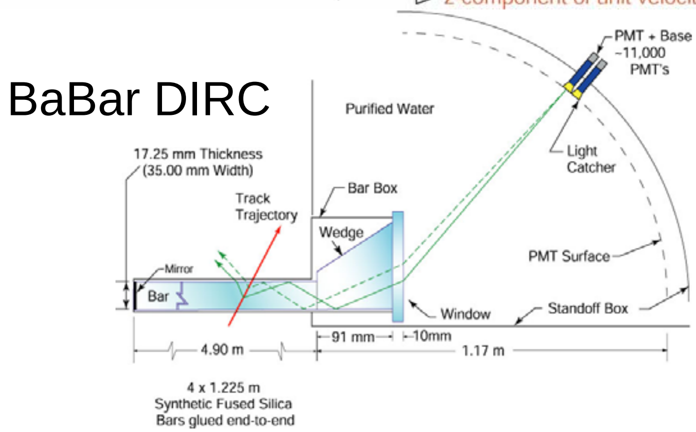
Issues with current PID options

- Basic TOP
  - Performance optimal ?
  - Robust against multiple particle hits
- Focusing TOP
  - Acceptance gap
  - Complicated image reconstruction
- Fast Focusing-DIRC
  - Works very well
  - Mirror(s): might not fit, additional aberrations(?)
- Some alternative?

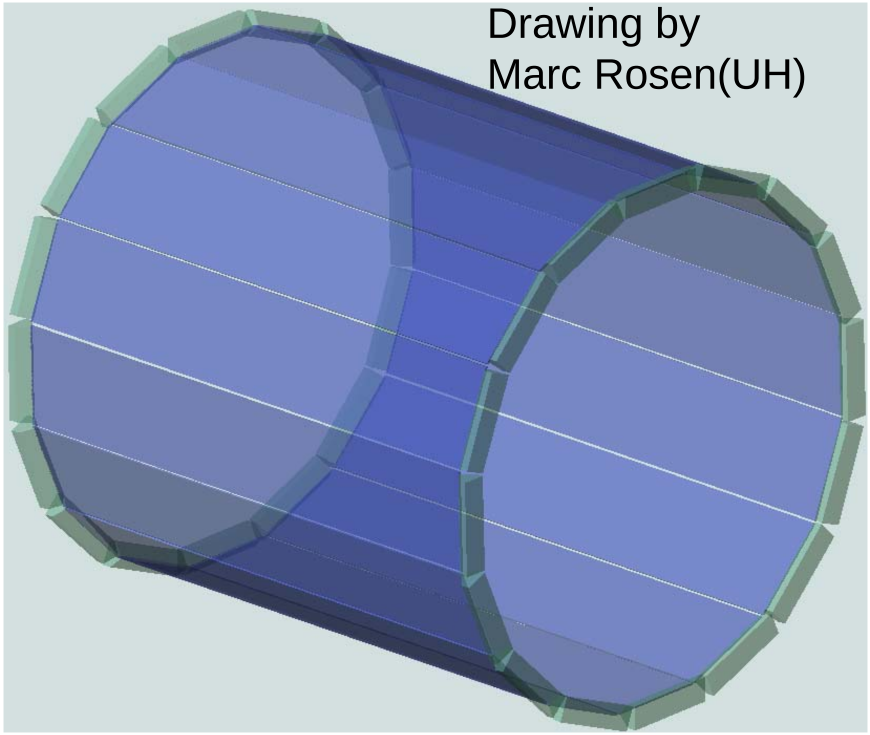
imaging TOP (iTOP)

Concept: Use best of both TOP (timing) and DIRC and fit in Belle PID envelope





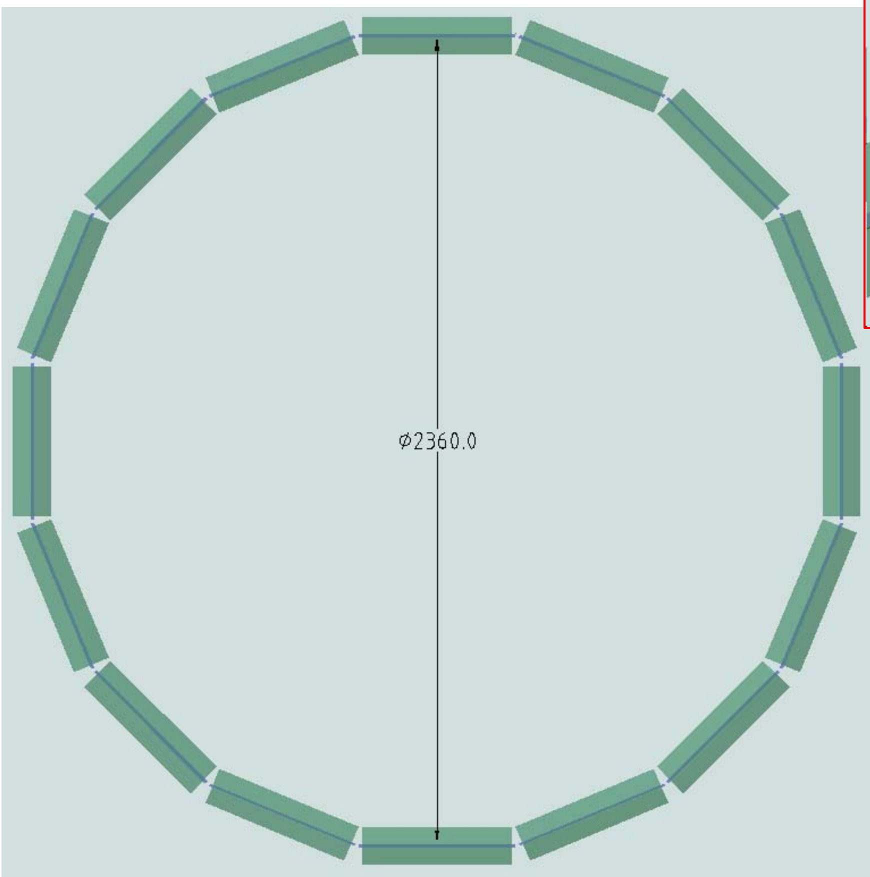
Bars compatible (though thinner) with proposed TOP counter

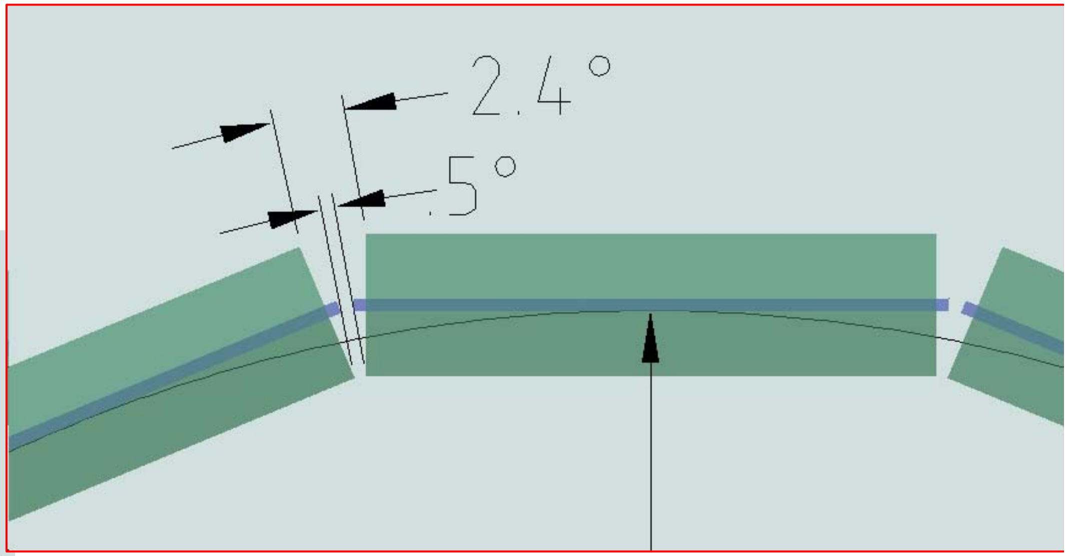


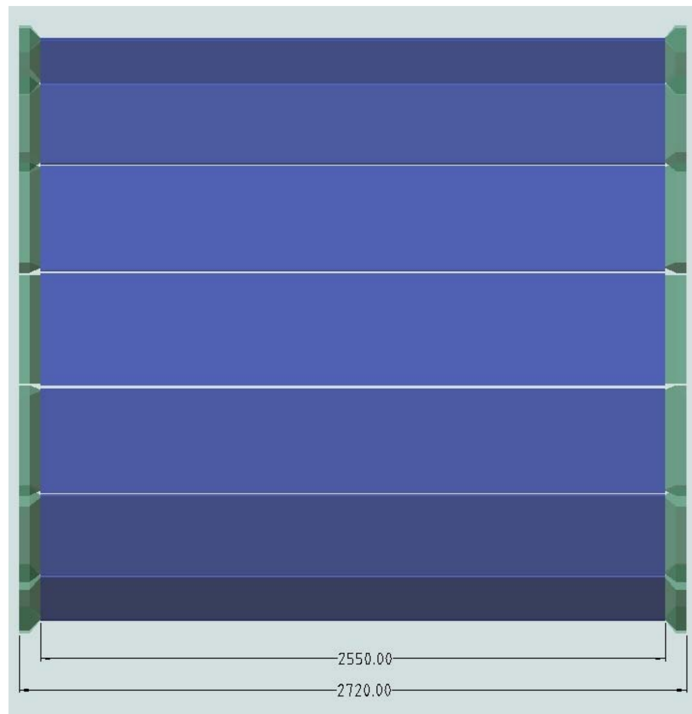
- Use new, compact solid-state photon detectors, new high-density electronics
- Use simultaneous T, θc [measured-predicted] for maximum K/π separation
- Keep pixel size comparable to DIRC

imaging TOP (iTOP)

10mm thick bars





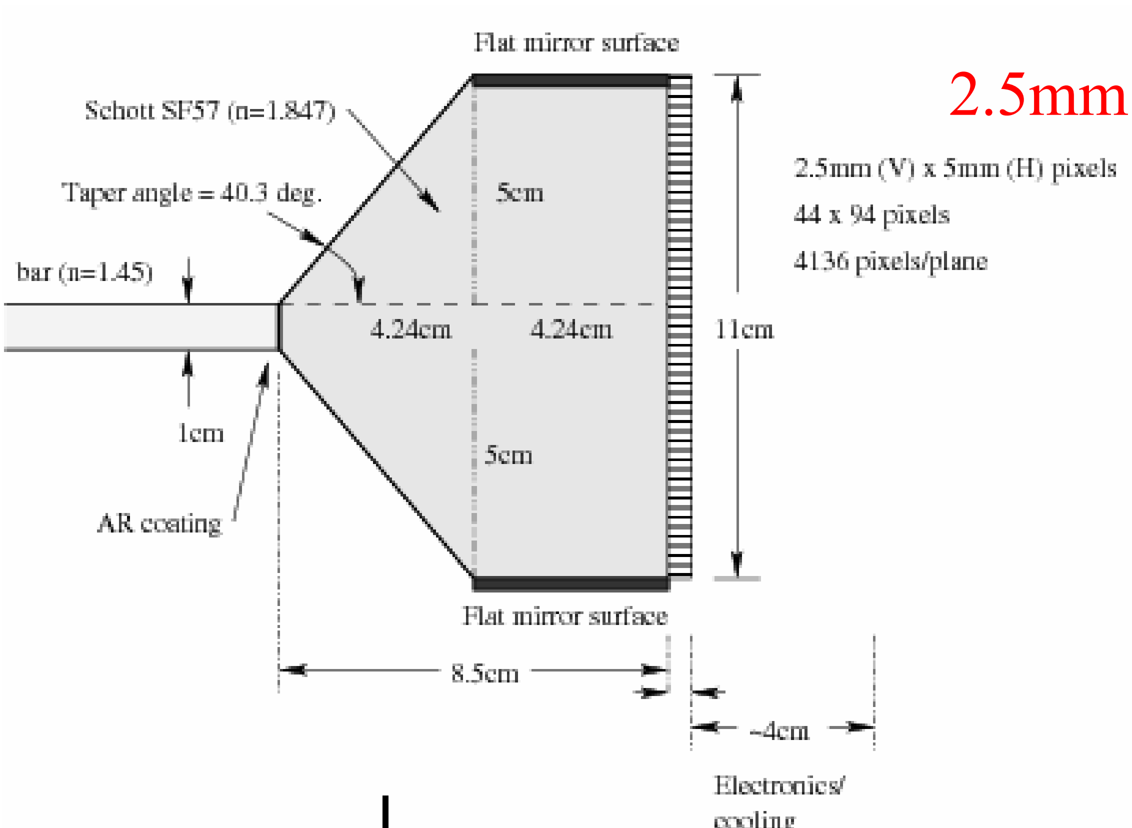


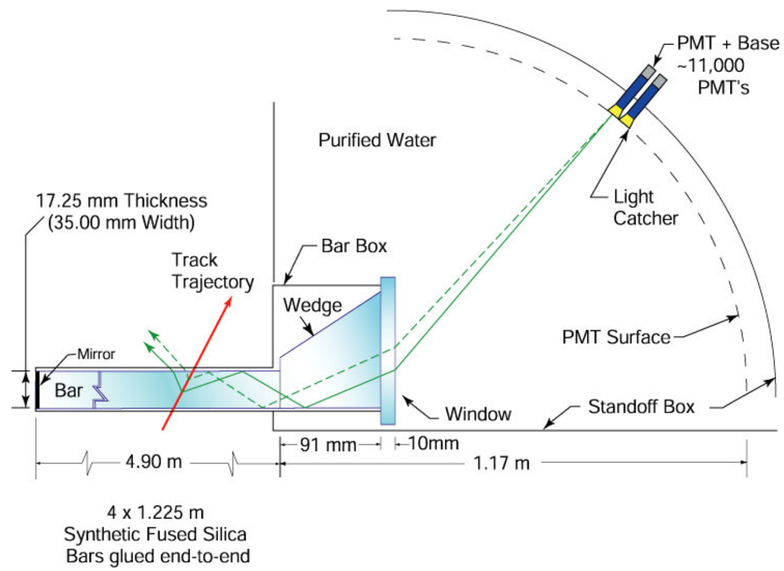
Acceptance gap: 2.4%

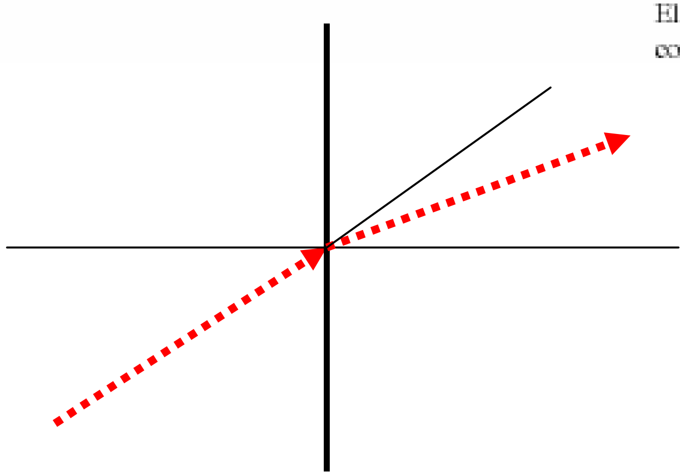
Simple refractive focusing

29mm

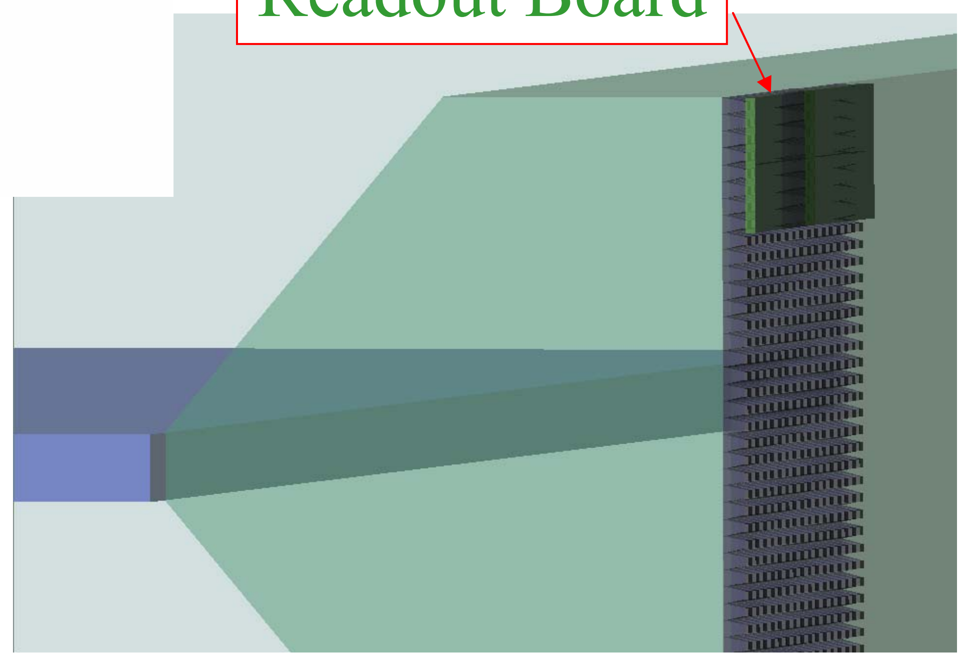
2.5mm



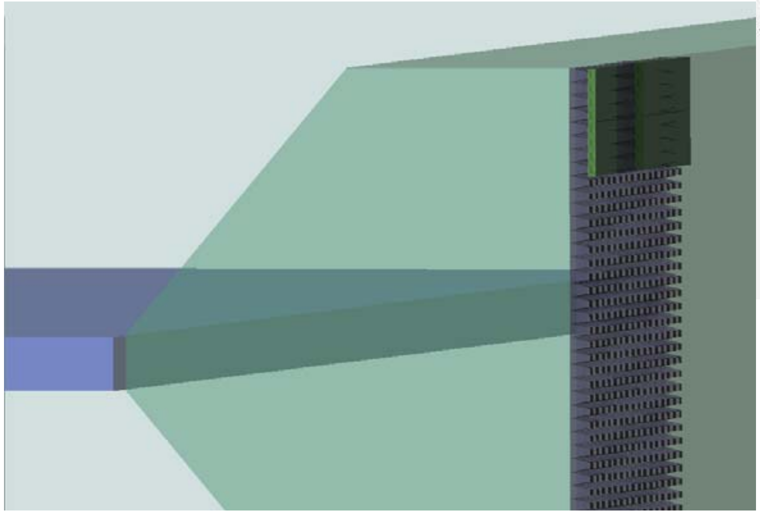


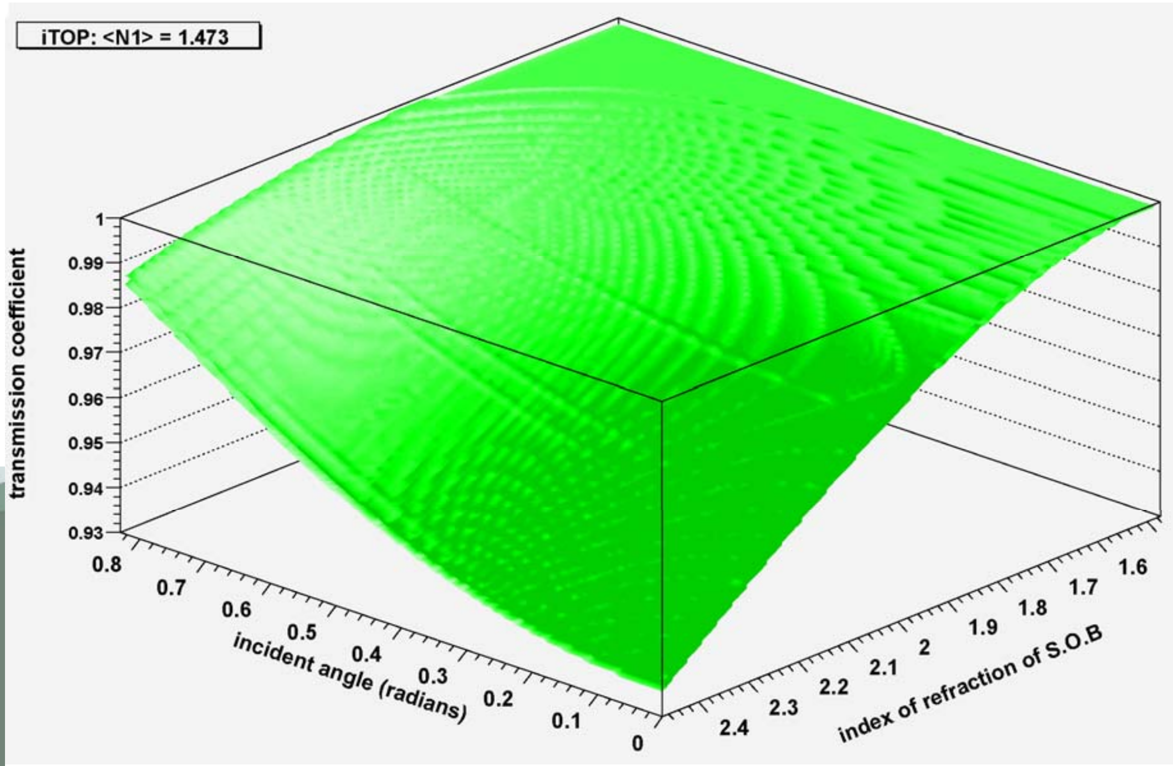


Readout Board



Stand-Off Block (SOB) Coupling

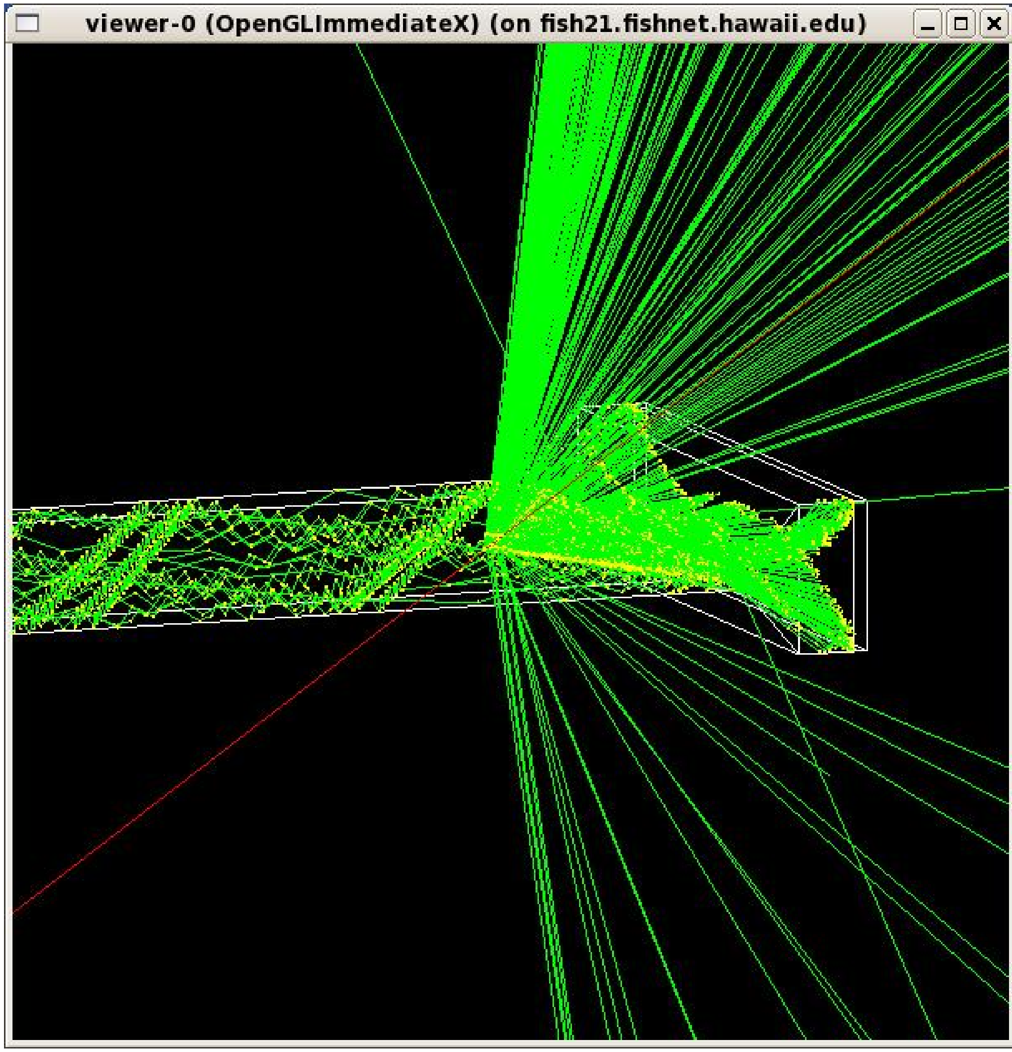


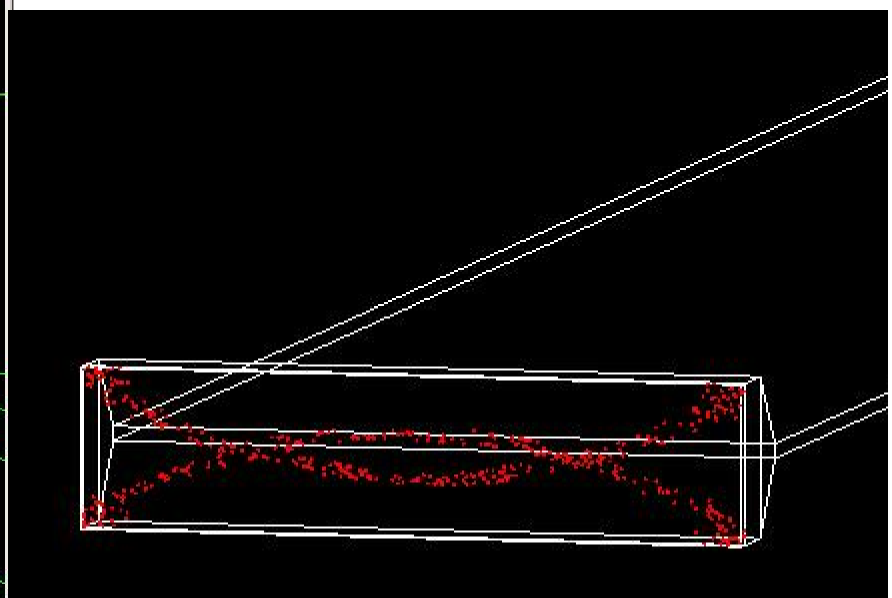


44 x 92 pix/plane = 4048 channels
16 bars x 2 ends x 4048 = ~130k channels

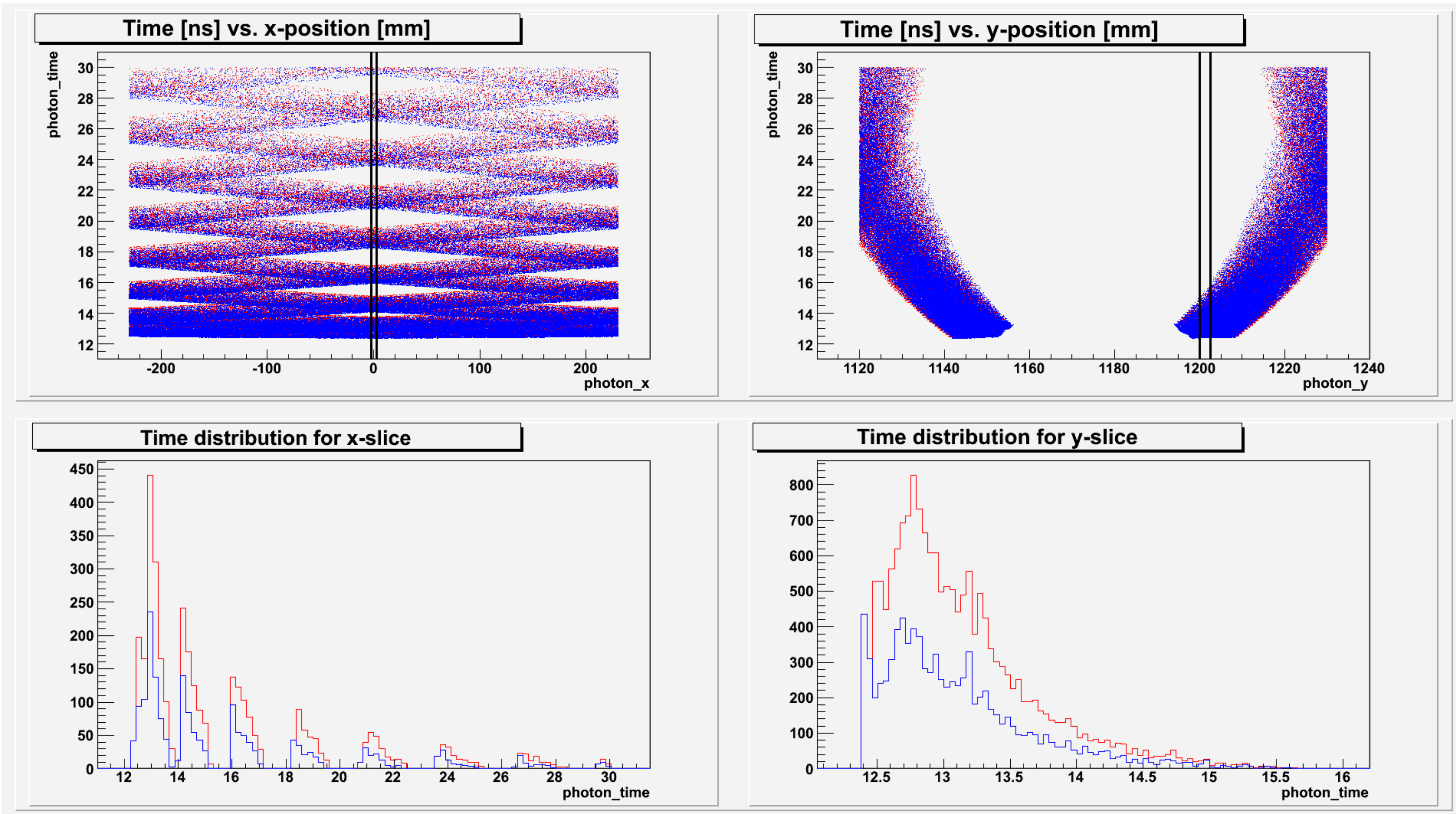
GEANT4 Simulation

Kurtis Nishimura



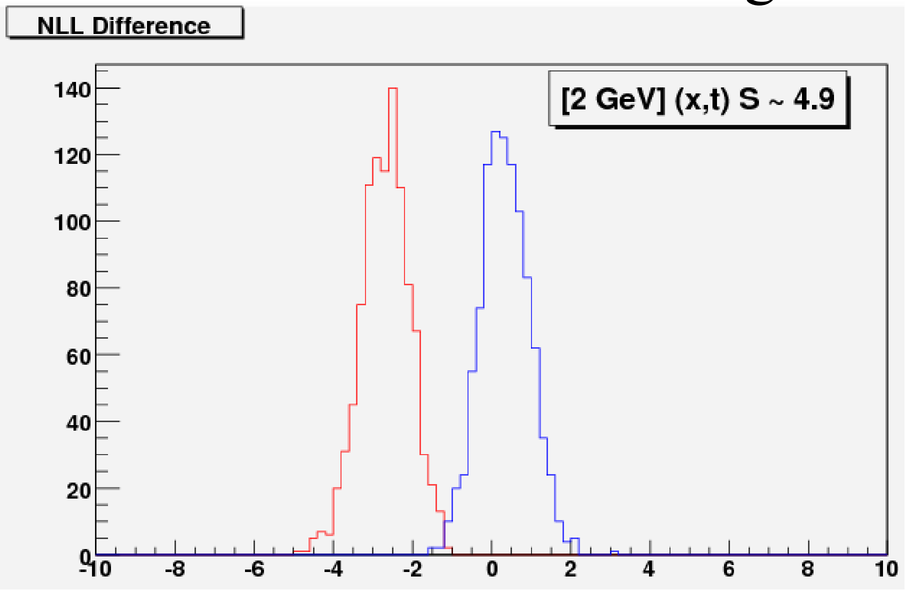


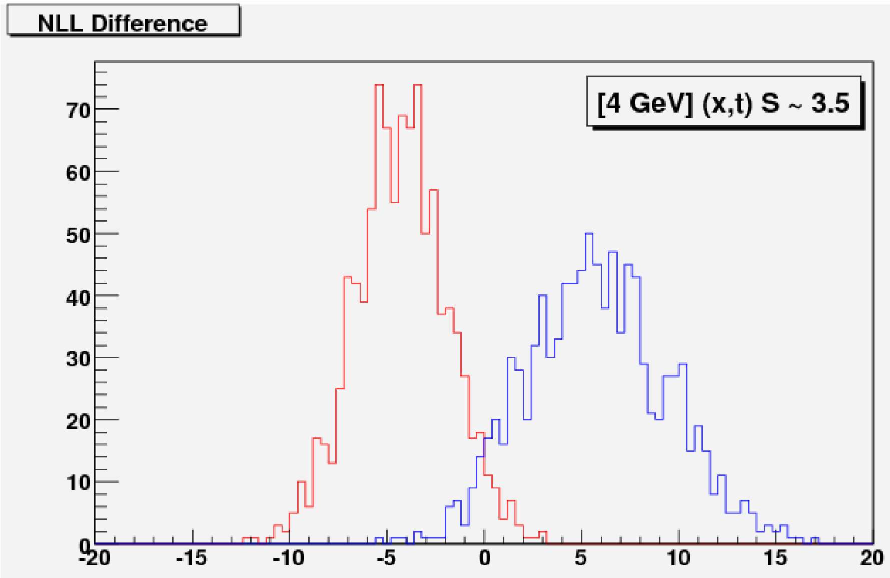
Timing comparison

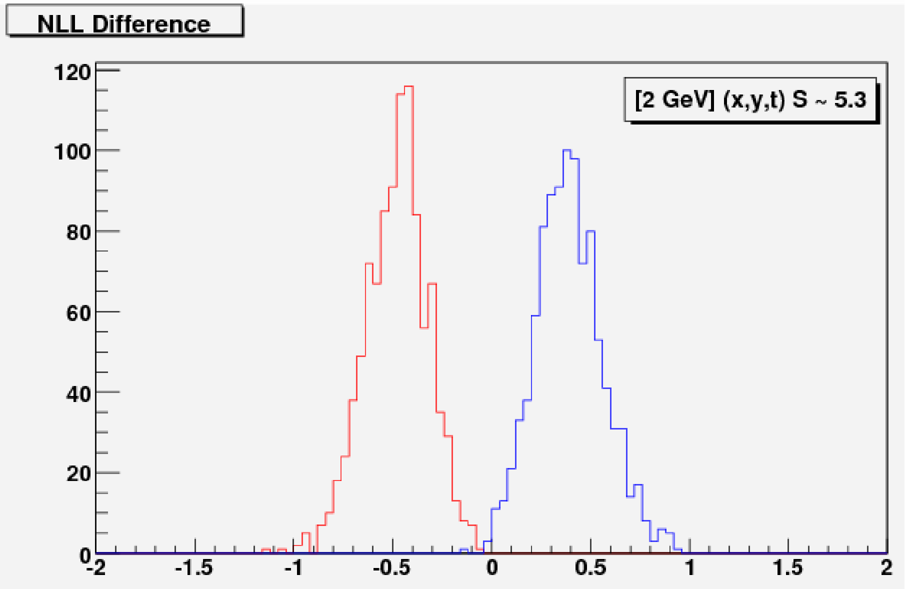


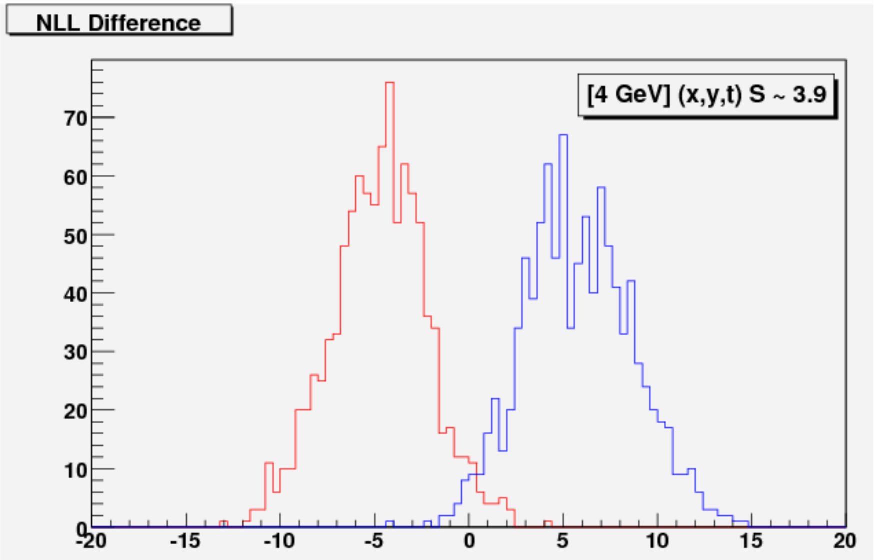
Separation Concept using Log $\mathcal{L}$

90 degrees (normal incidence)

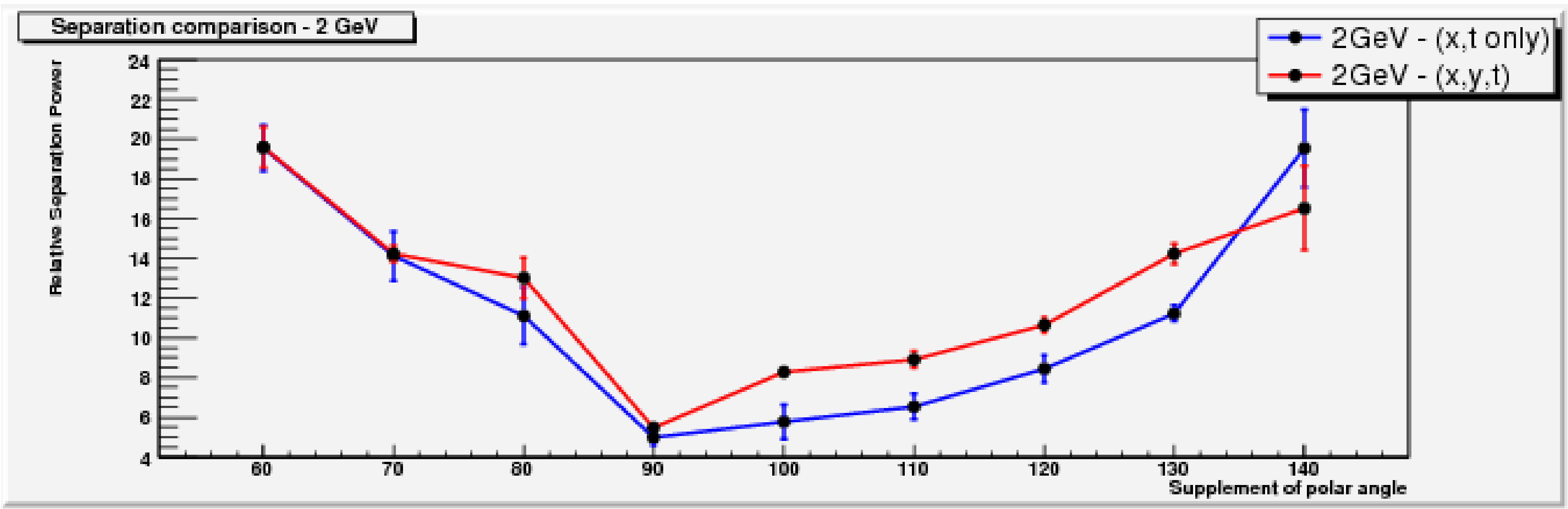


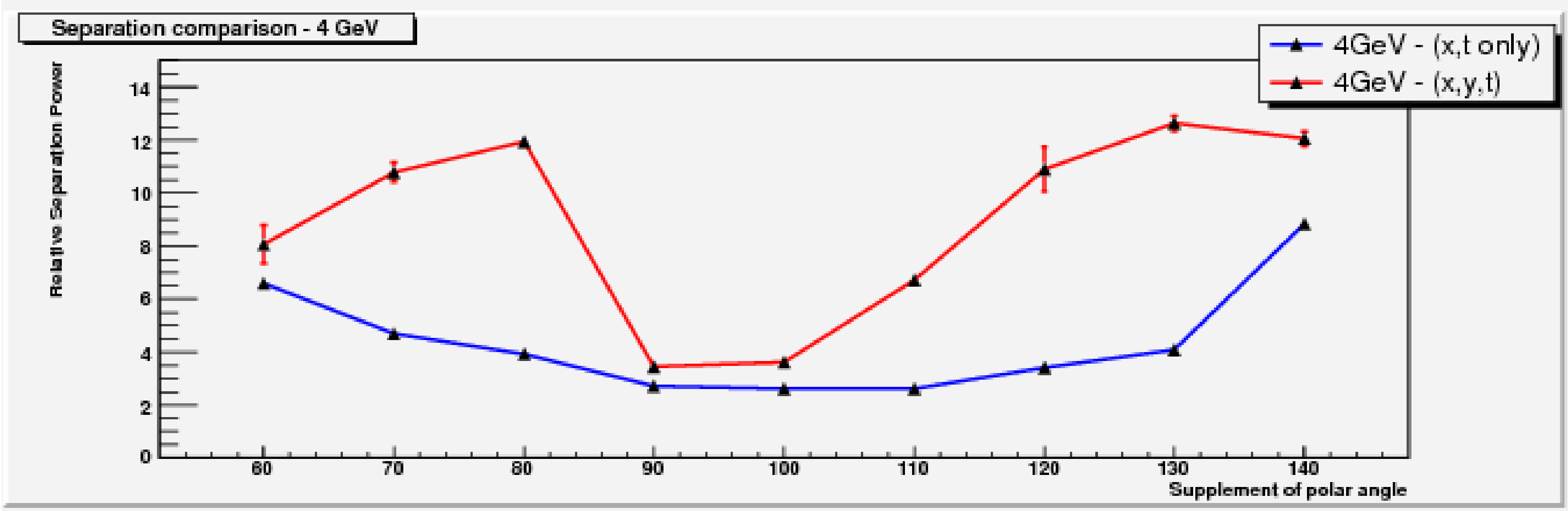






Quantitative Separation using Log $\mathcal{L}$

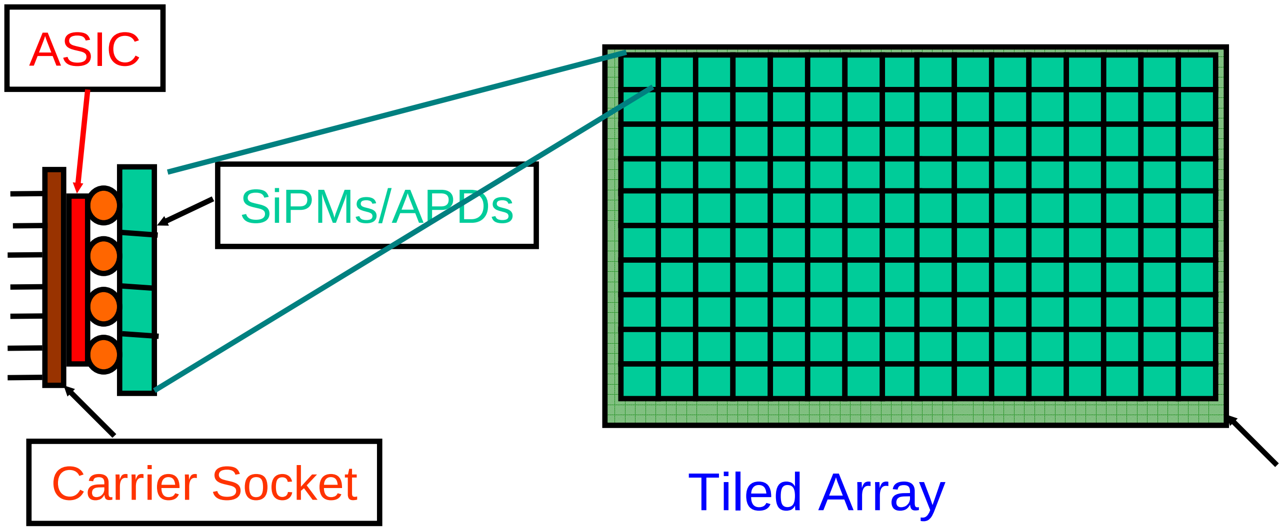


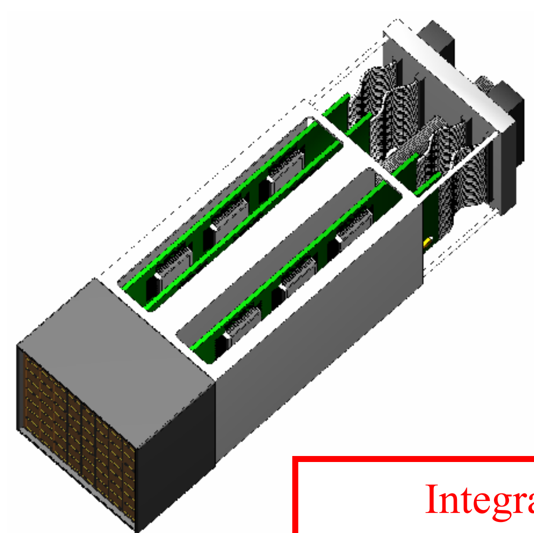


Key (common) PID R&D Items

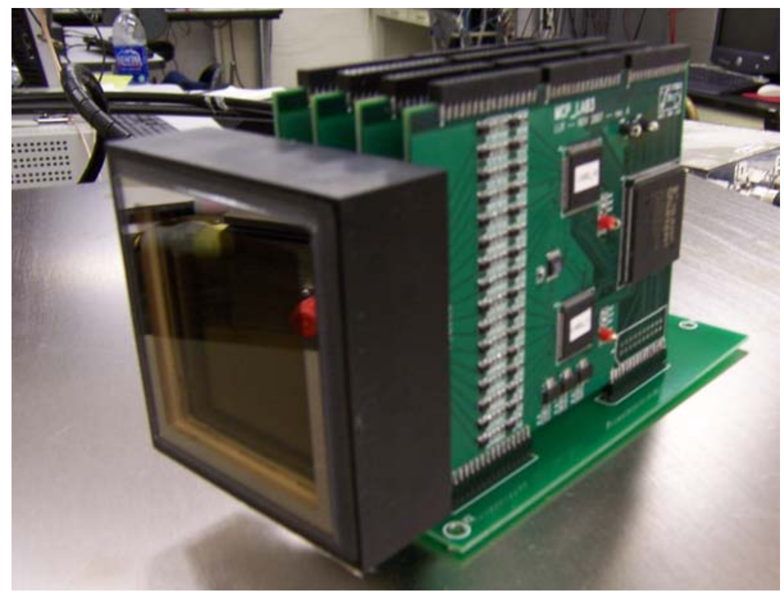
- Quartz (crystal) radiator bar production
- High performance Timing readout
- Good single photon timing detector
  - 1.5T field operation
  - Radiation hardness
  - <50ps Transit-Time Spread
- Triggering possibility?
  (ToF trig replacement)

Highly Integrated Readout





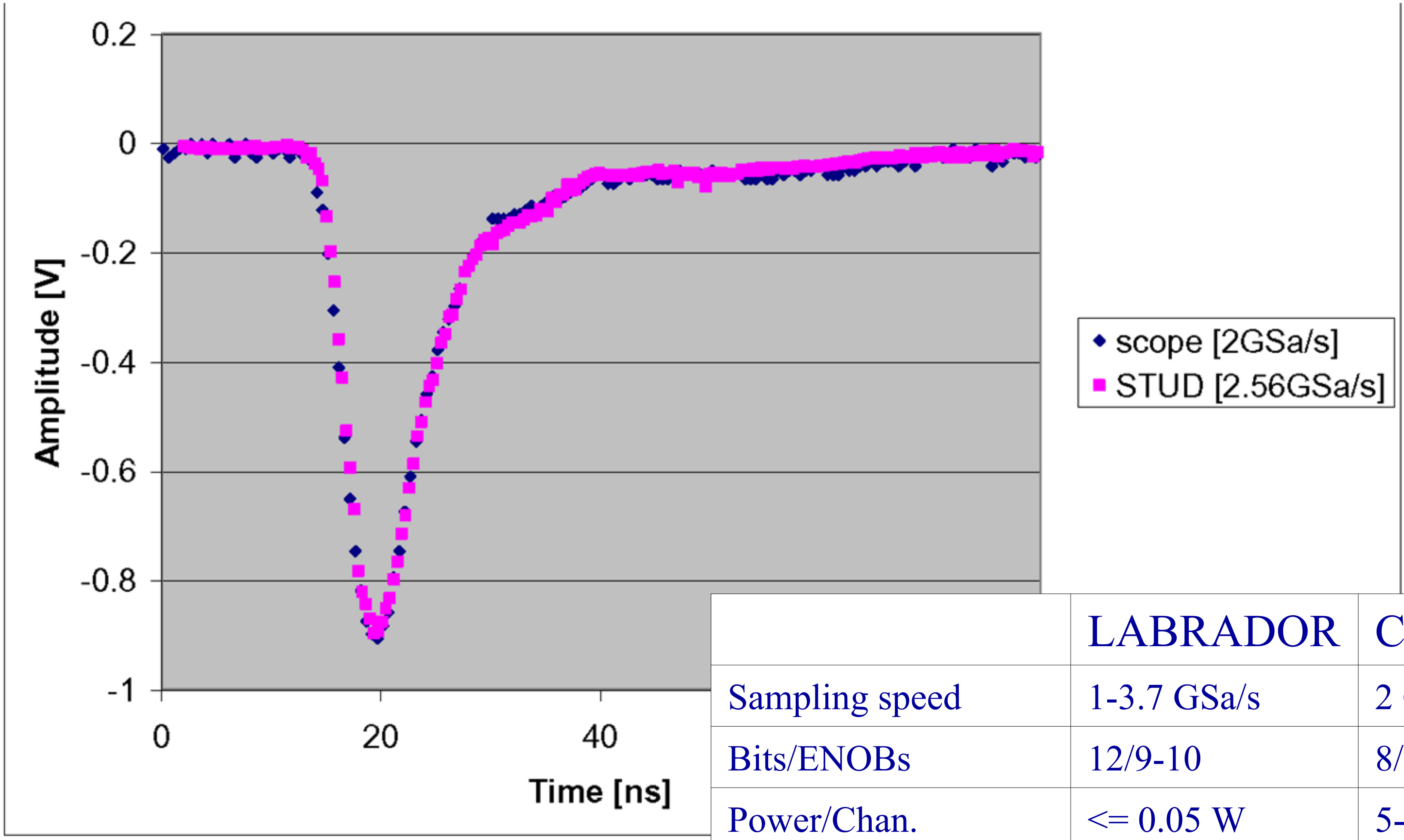
Integrated Photodetector packaging



Gen. 0 Prototype (LAB3-based)

Readout Electronics using *"Oscilloscope on a Chip"*

NIM **A583** (2007) 447



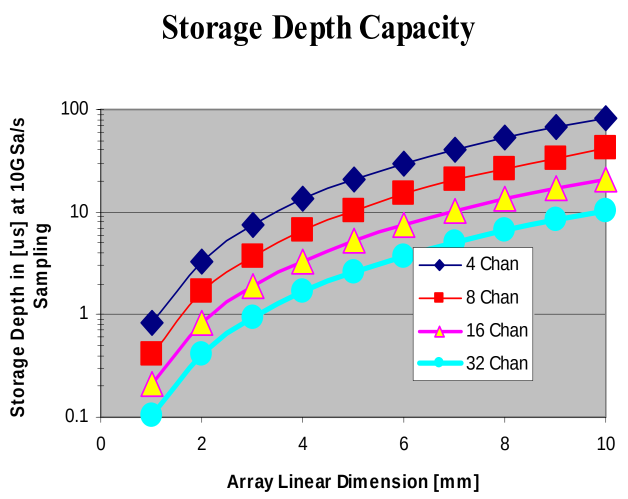
LABRADOR ASIC

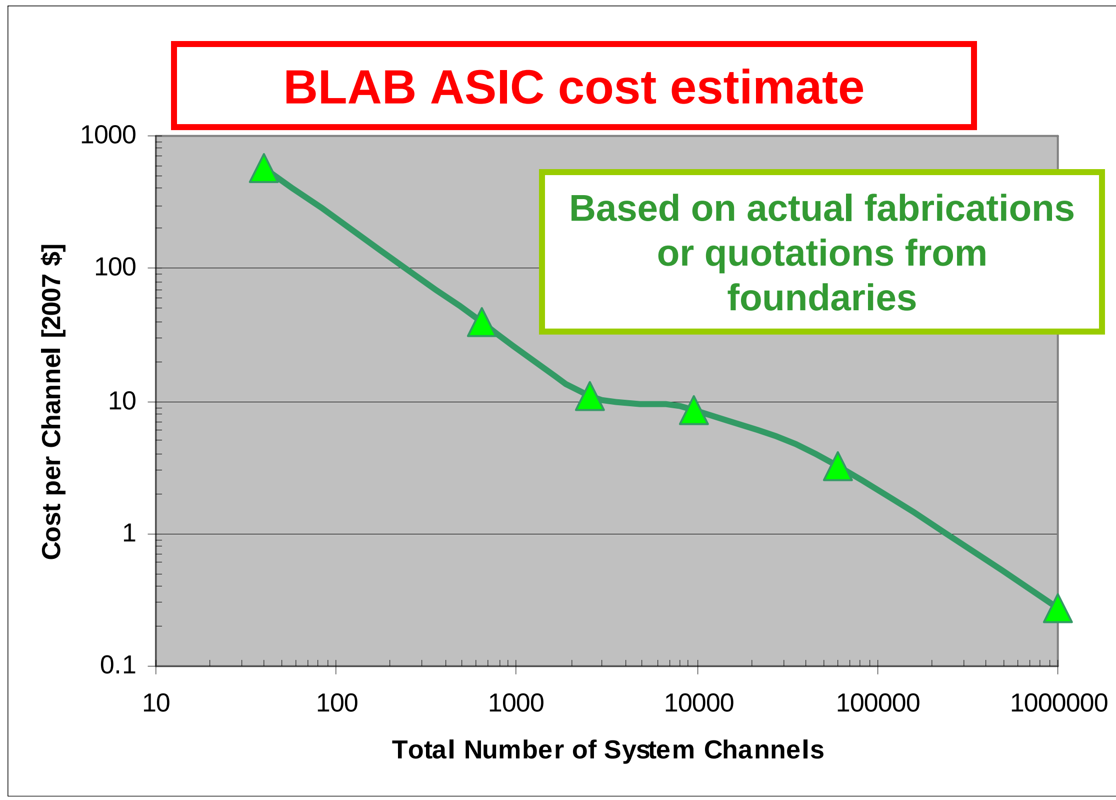
	LABRADOR	Commercial
Sampling speed	1-3.7 GSa/s	2 GSa/s
Bits/ENOBs	12/9-10	8/7.4
Power/Chan.	<= 0.05 W	5-10 W
Cost/Ch.	$10	> 1k$

Cost Estimates

- ASIC costing well understood, very competitive!

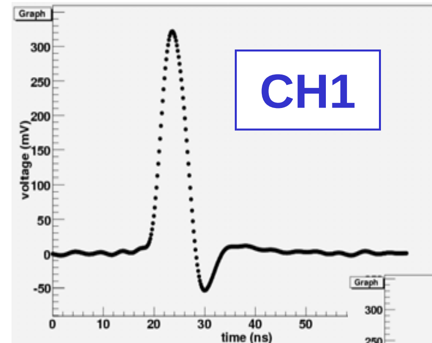
arXiv:0802:2278 (NIM in press)

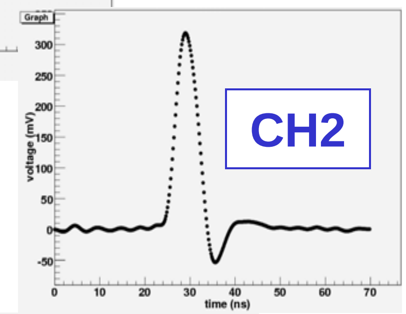


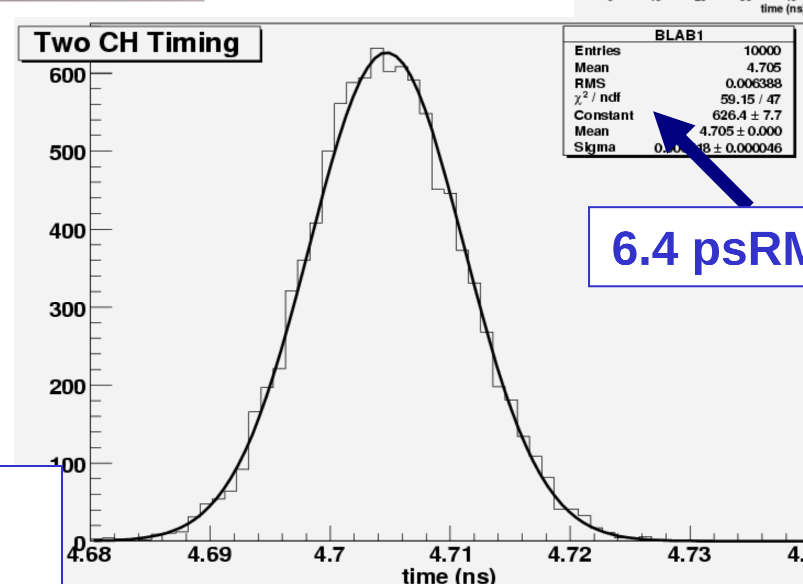


BLAB improved timing performance: Agilent Pulse Cross-Correlation Method

- Comparable performance to best CFD + HPTDC
- MUCH lower power, no need for huge cable plant!
- Using full samples significantly reduces the impact of noise
- Photodetector limited



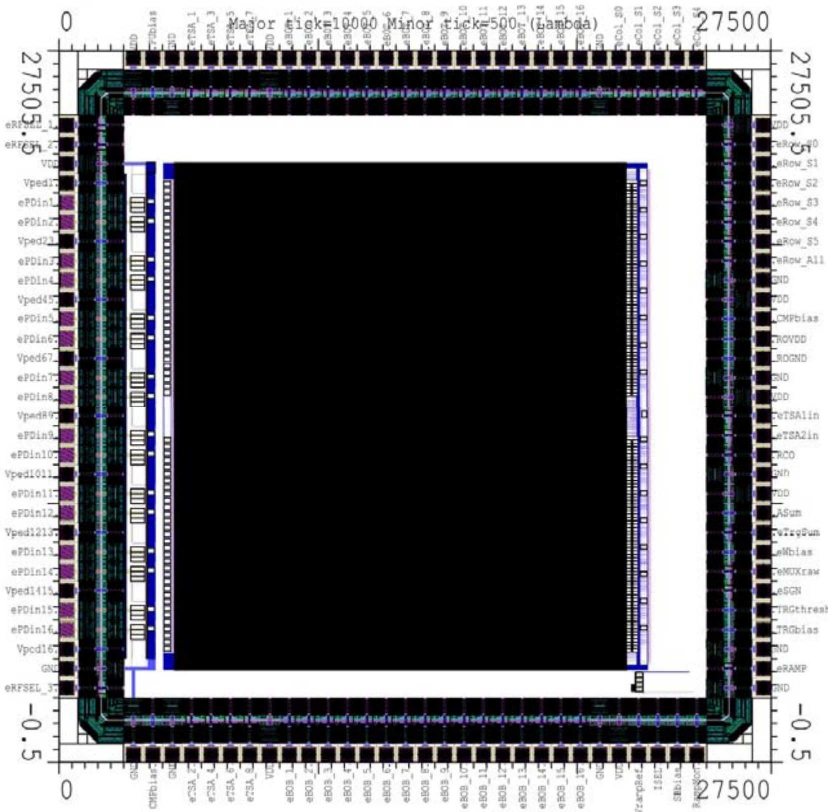


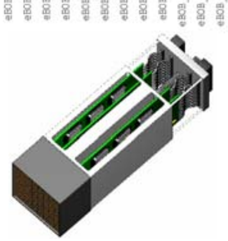


~4.5 ps per waveform

Triggering Capability

Currently TOF system provides precision timing trigger





- To reduce window size (silicon readout deadtime), a fast trigger with good timing performance and high efficiency is desired

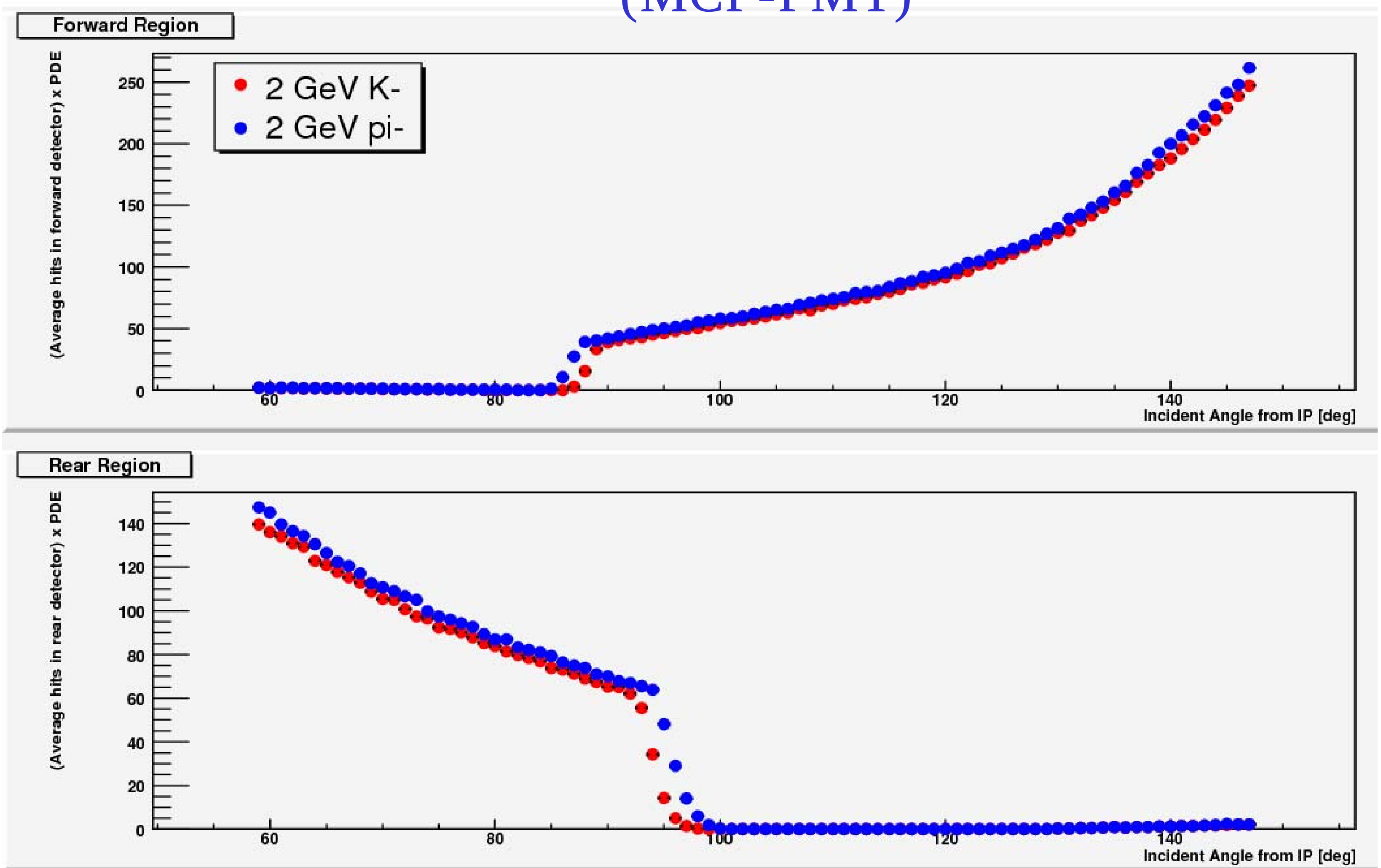
- Can do with new iTOP detector?

- Easy to include trigger functionality to BLAB2 ASIC

Trigger Simulations

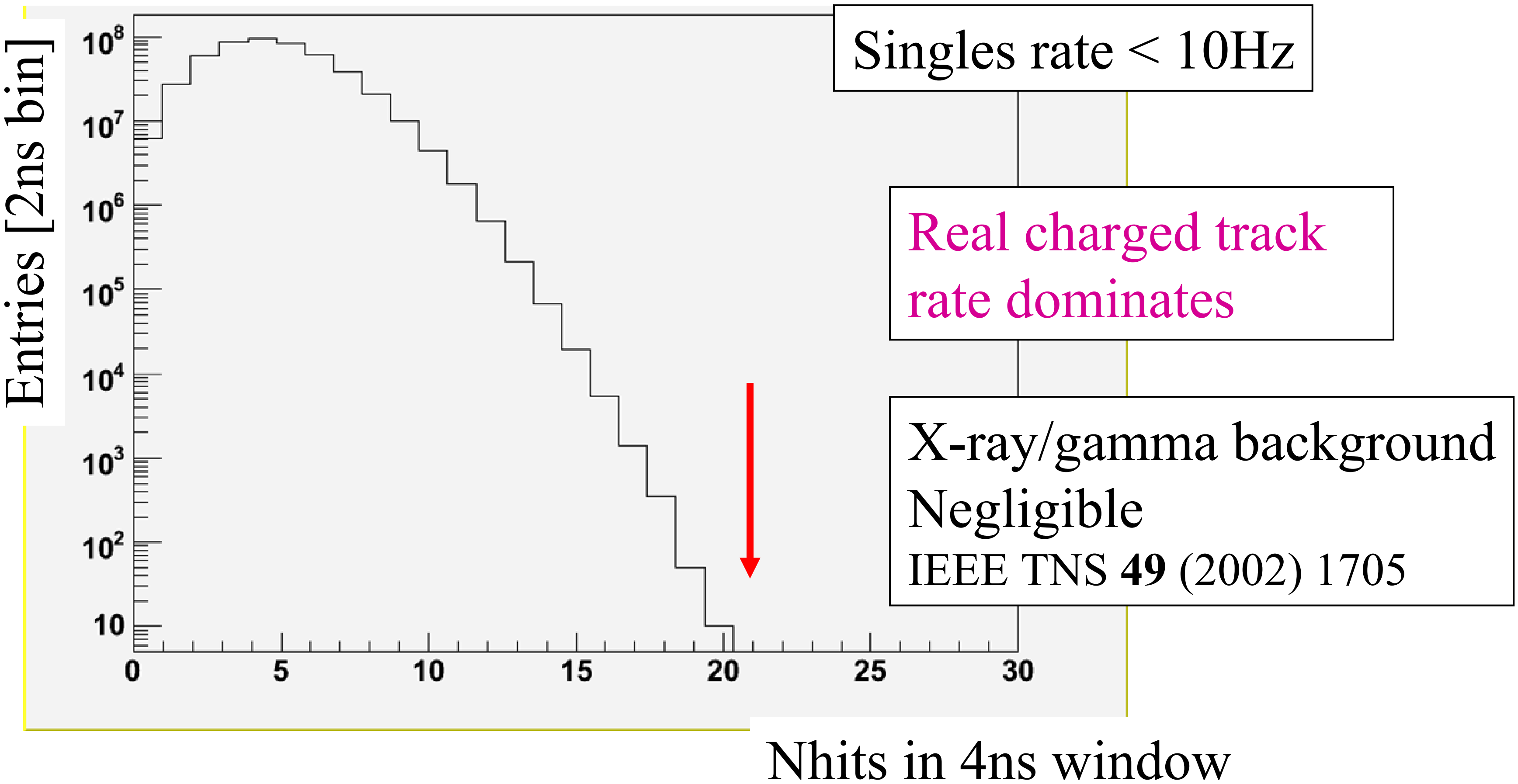
- 50% PDE
  - 350nm UV cutoff
  - Perfect bar

- To be conservative, use much lower threshold in estimates (MCP-PMT)



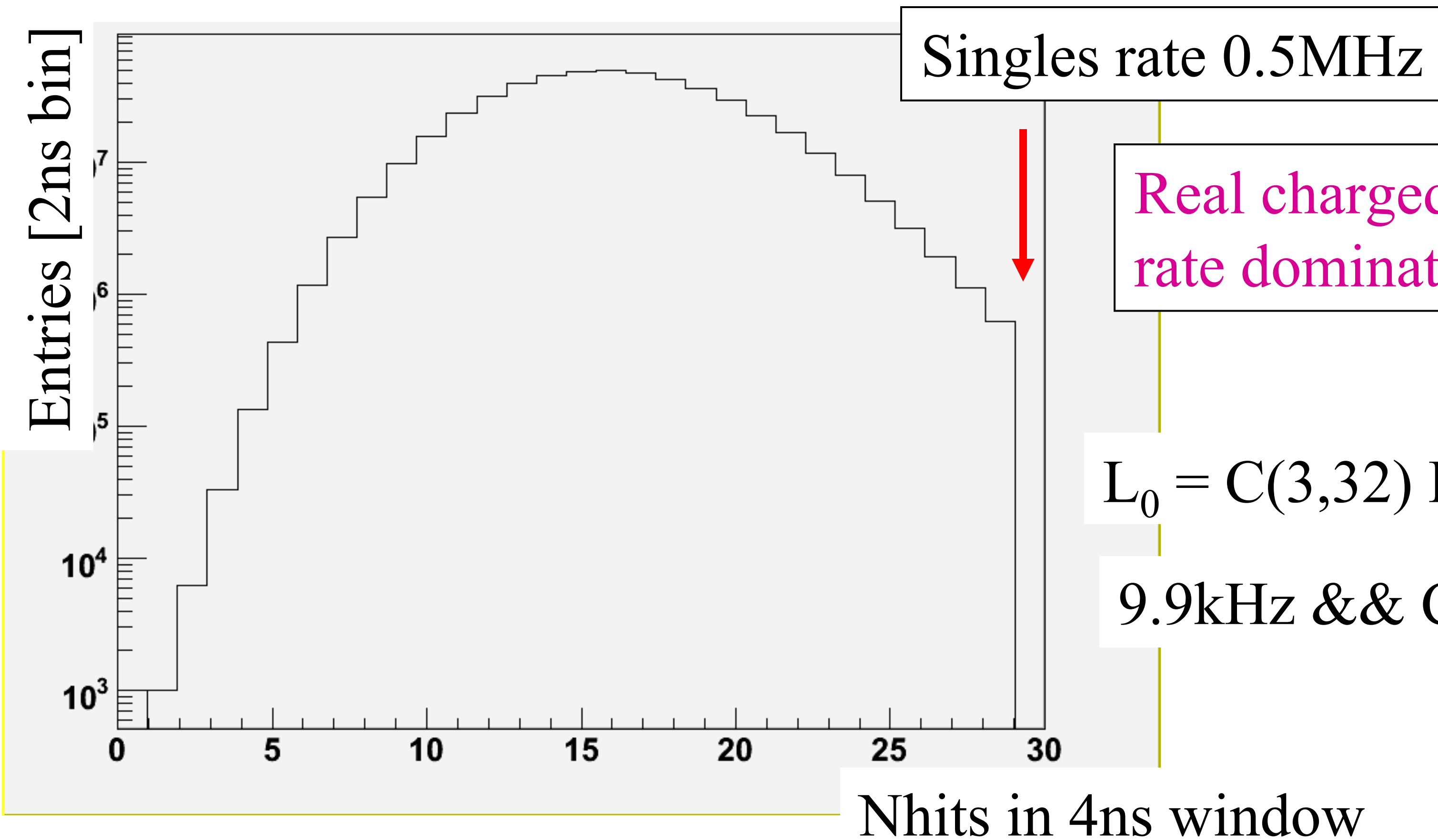
Trigger Simulations

- Assume 50um pixel (MPPC) as reference
  - 270kHz dark count rate
  - 44 x 92 = 4048 pixels/plane (2 planes/bar)
  - If require Nhits >20 (in 4ns window), 2ns pipeline



Trigger Simulations (better TTS)

- Rate can increase
  - 1MHz dark count rate
  - 44 x 92 = 4048 pixels/plane (2 planes/bar)
  - If require Nhits >30 (in 4ns window), 2ns pipeline



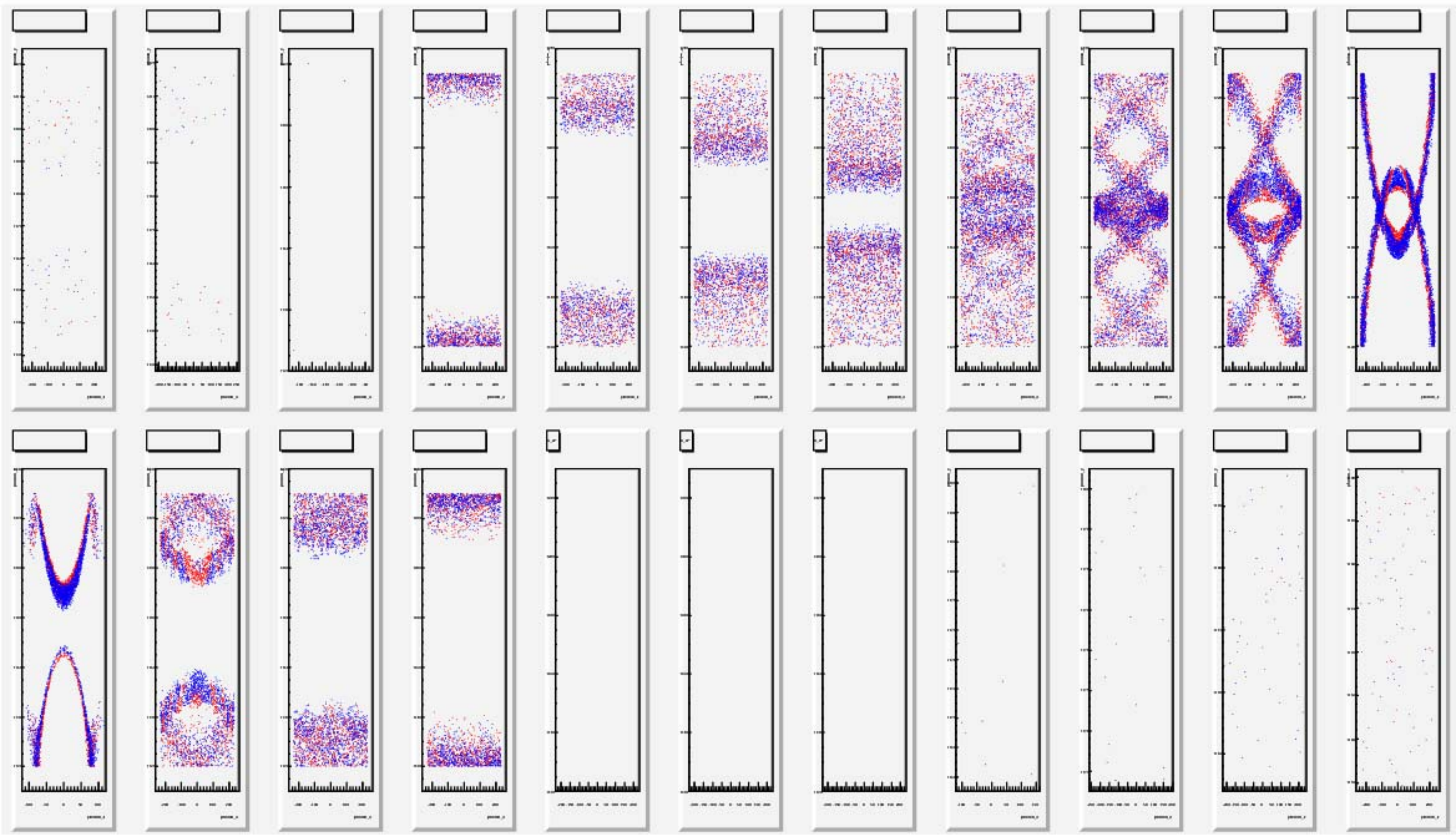
Real charged track rate dominates

$L_0 = C(3,32)\ L_s^3\ \tau^2$

9.9kHz && CDC

Trigger Timing?

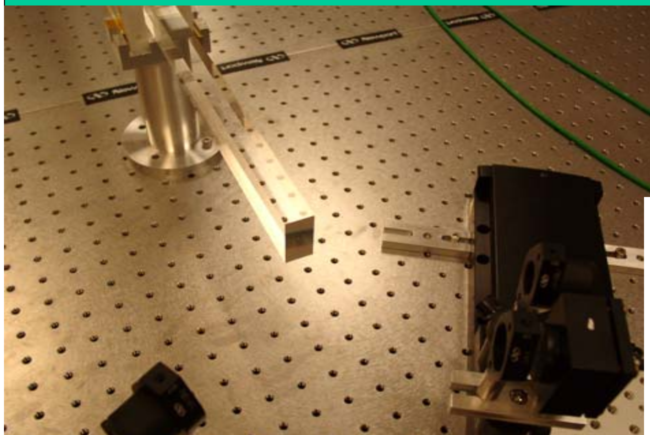
- Use FPGA (simple) pattern recognition to improve

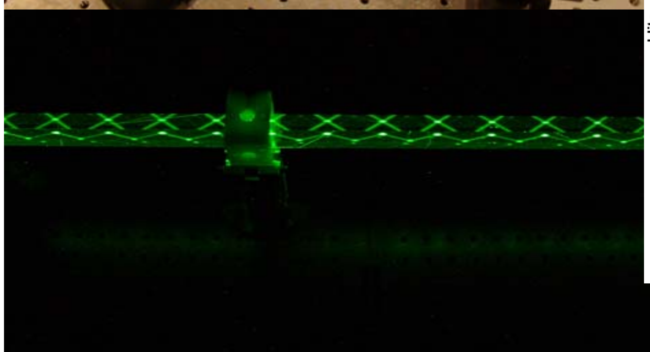


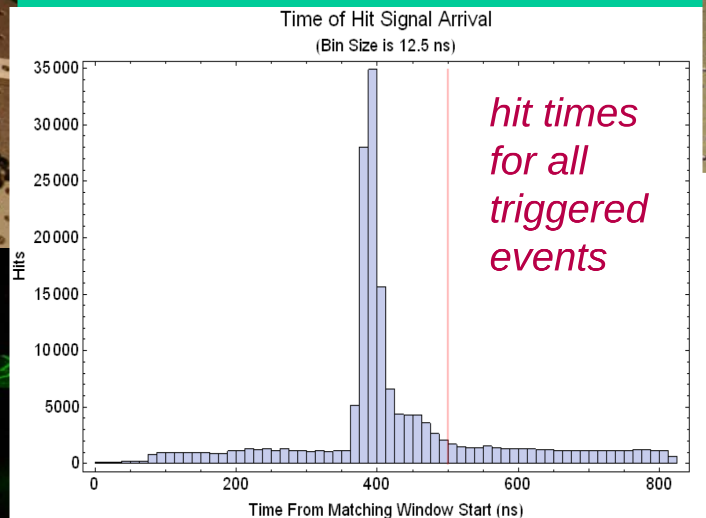
- 25cm segments ~ 2ns trigger timing, within 200ns

Cosmic Set-ups

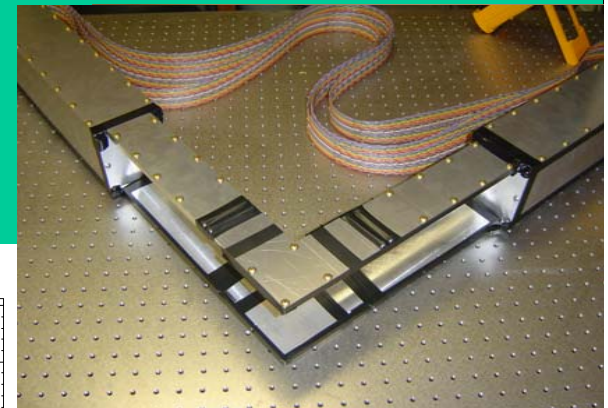
Studying Mirror/reflective optics for a tight space requirement





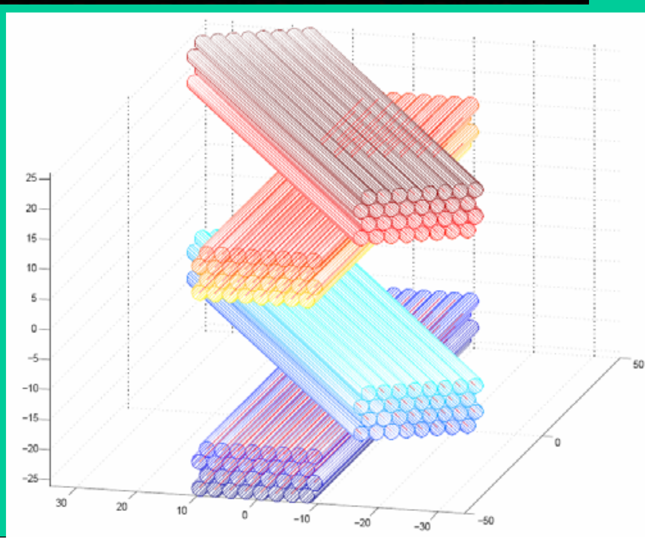


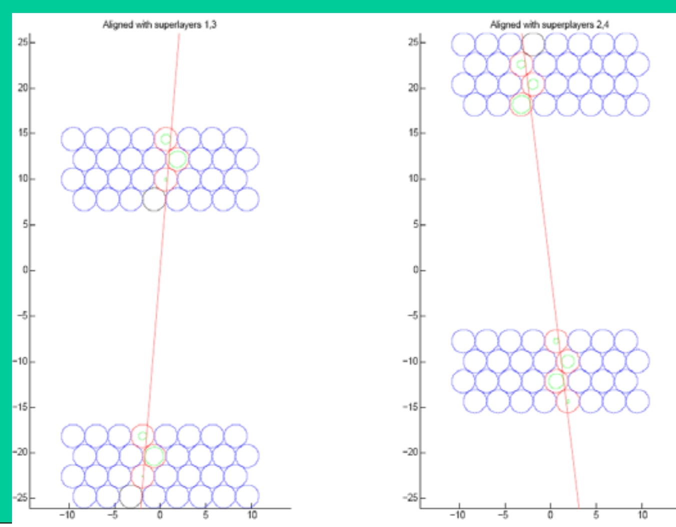
Cincinnati

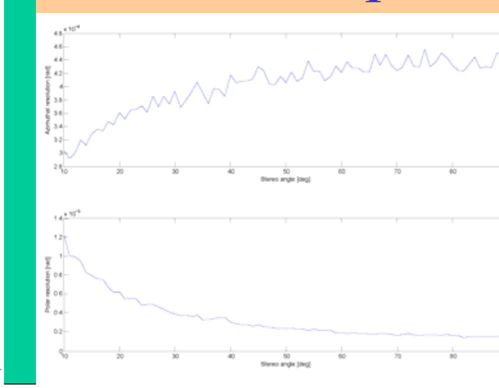


Hawaii

High-n SOB /refractive optics

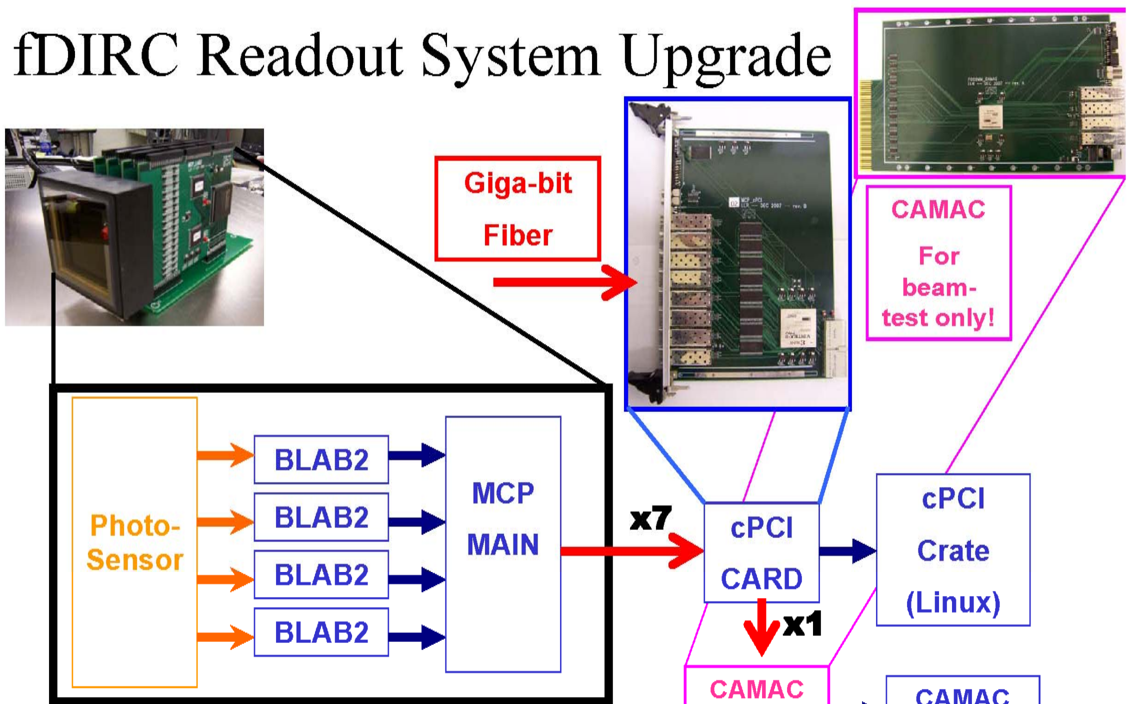






Beam test plans

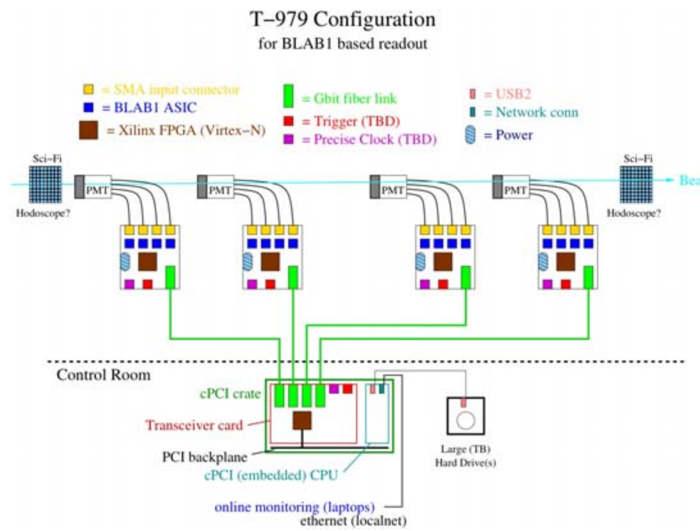
fDIRC Readout System Upgrade



- Up to 7x64 channels per cPCI card
- CAMAC card for SLAC beam test
- Up to 32,256 channels/cPCI crate

Very cost effective, board hardware already exists

- T-979 [FNAL]
  - ps TOF (June)



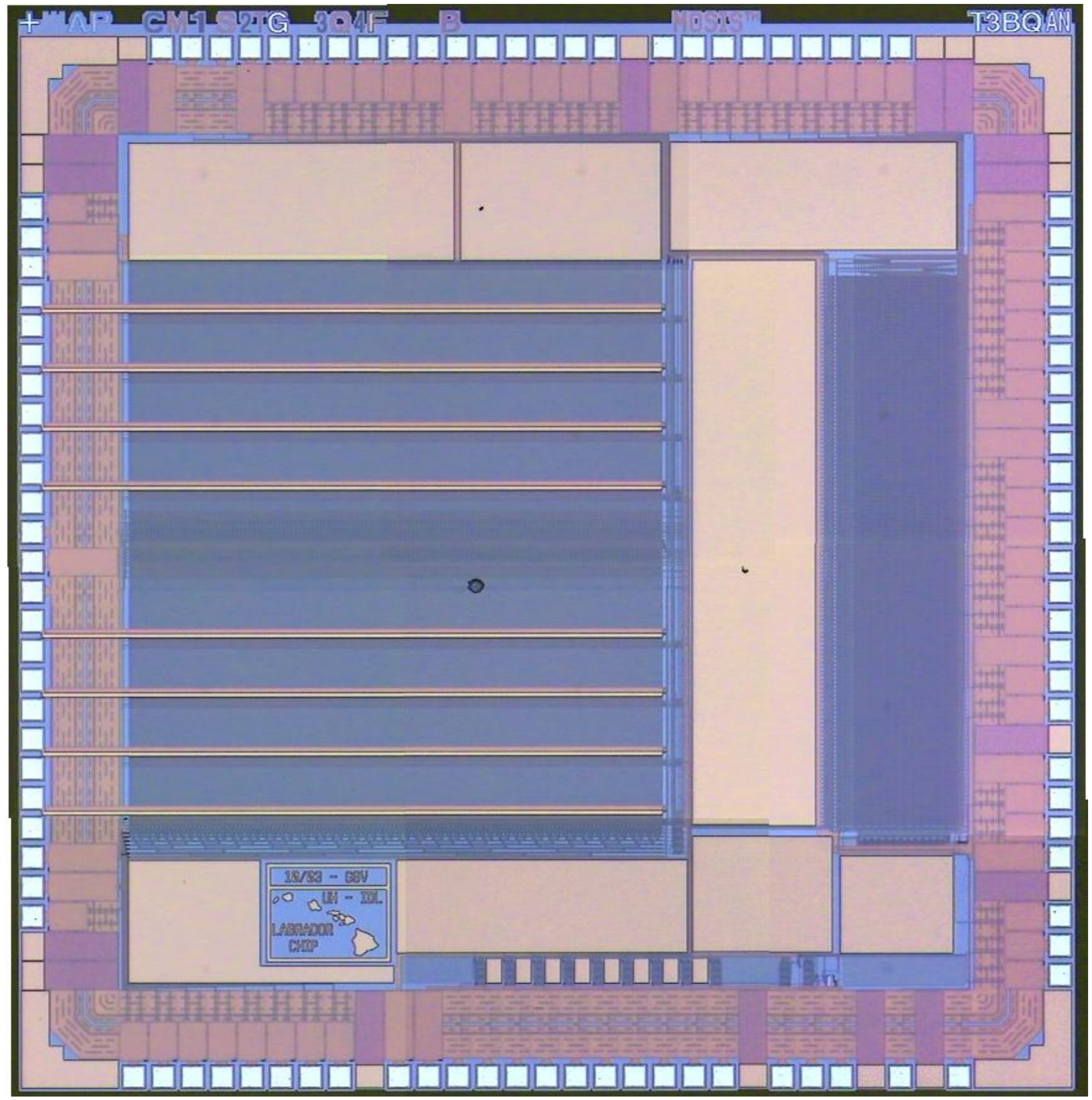
- T-492 (ESA/SLAC)
  - TOF (July)
  - Full (~500 chan) fDIRC [autumn]
- Fuji beamline
  - iTOP prototype [autumn]

Summary

Barrel geometry leads logically to some type of stave/bar configuration

- R&D this next year on optimal configuration
- Critical issues are radiator and photo-detector
- Plan to test 640 channel readout system by fall – extendable readily to 10-100k system
- Precision timing trigger from PID @ T=0
- Cosmic/beam tests in preparation for TDR / PID Shoot-out

Back-up slides

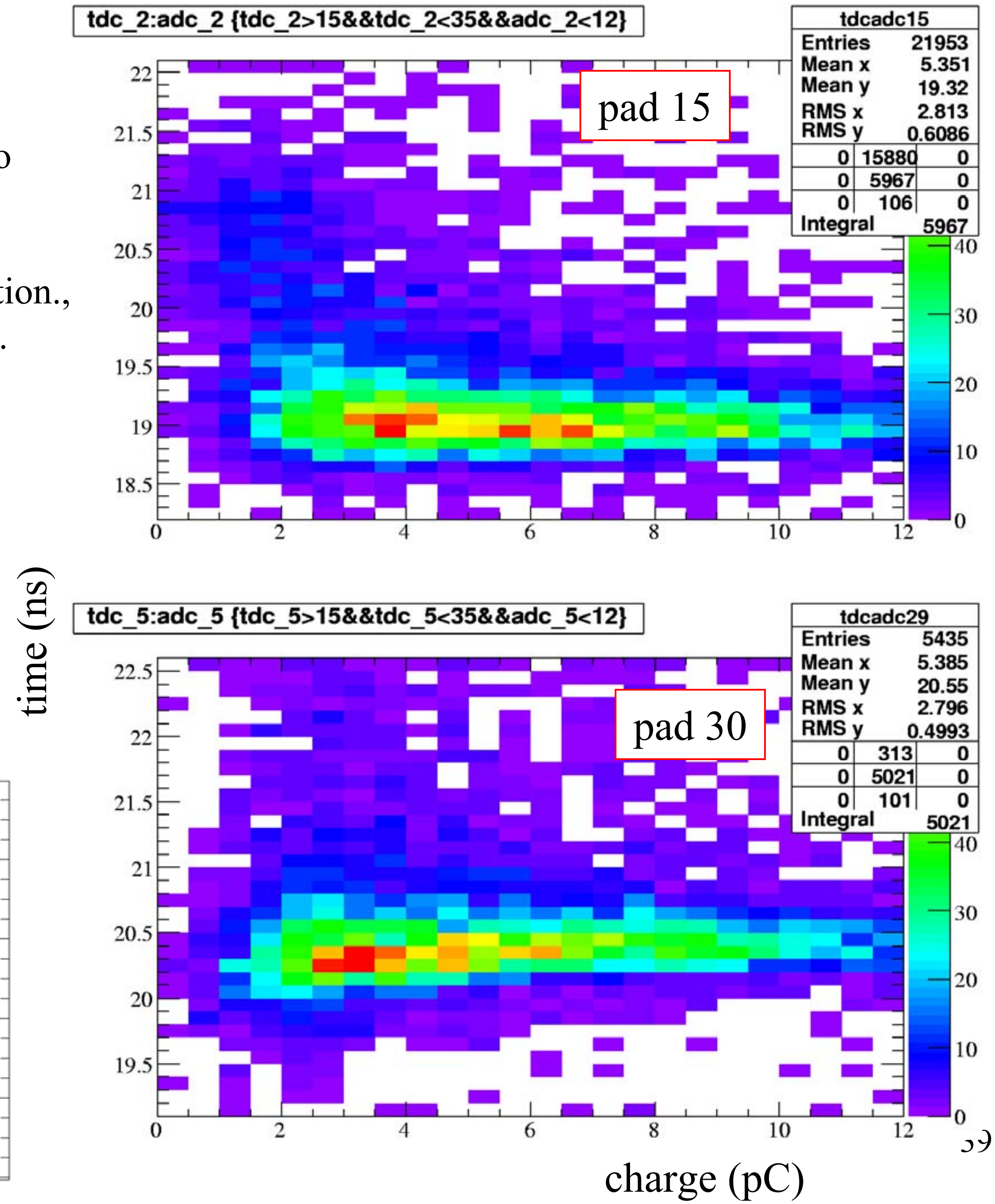


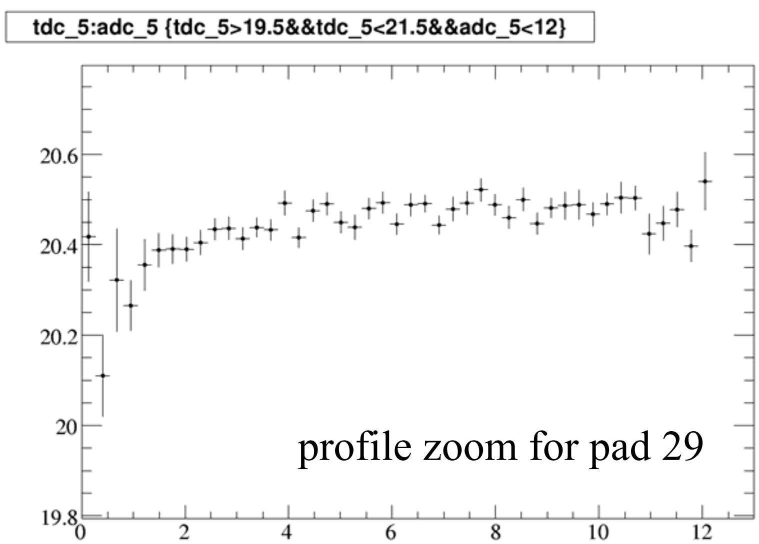
TDC vs. ADC for signal in run 27

Larry's offline correction method seems to come close to correcting time walk.

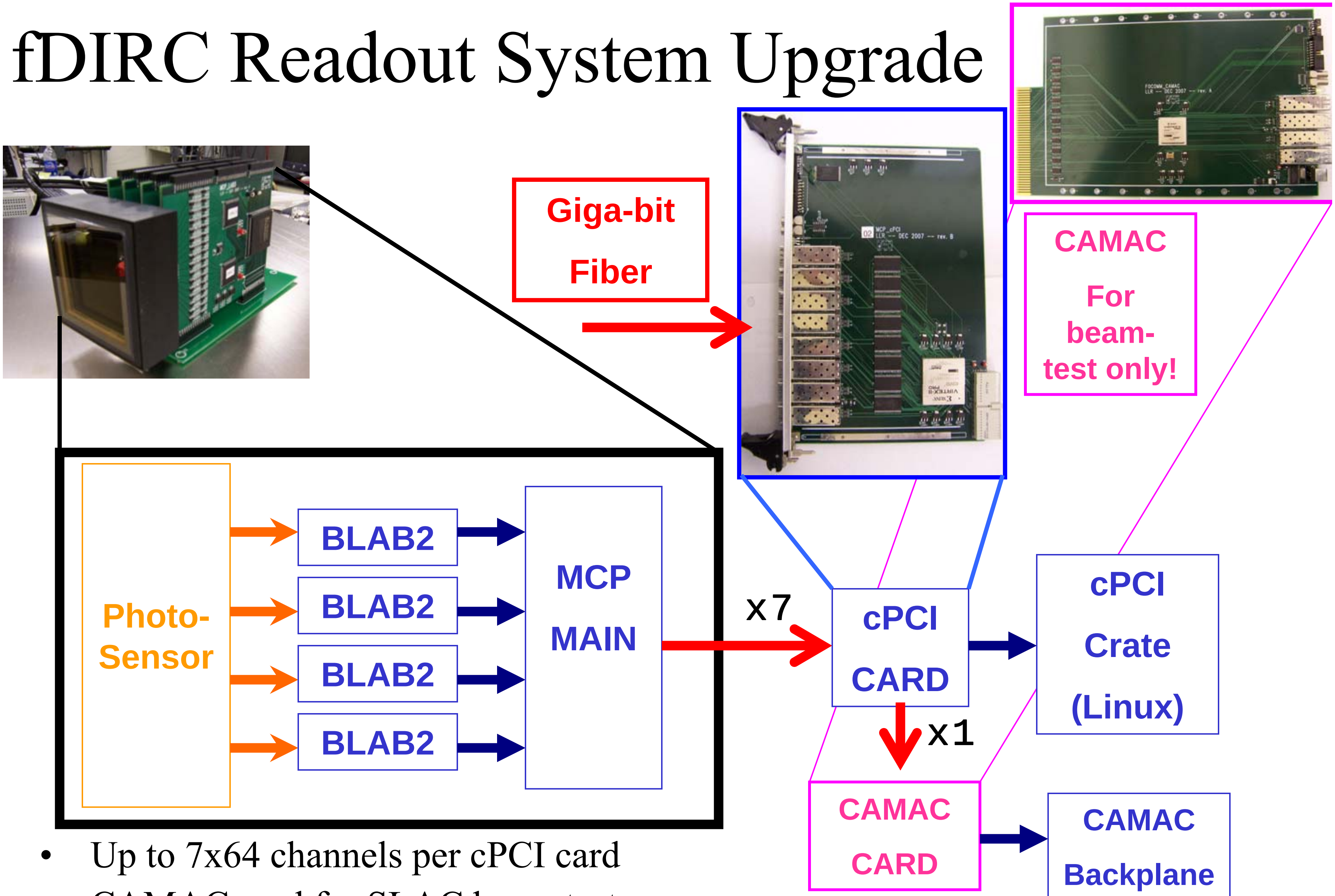
Some over-correction, some under-correction., more can be done offline with charge info.

Jochen Schwiening analysis (preliminary)





fDIRC Readout System Upgrade

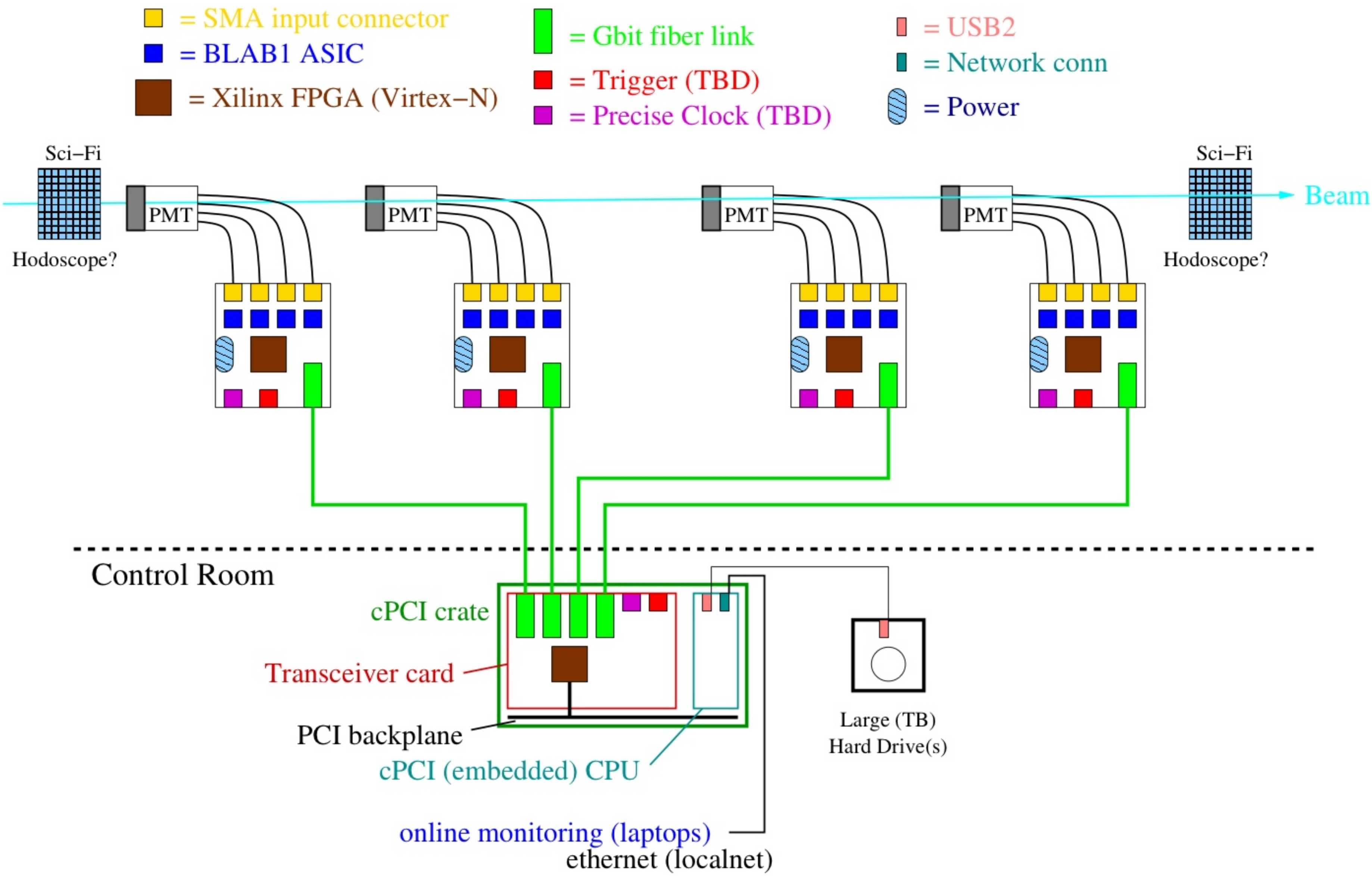


- Up to 7x64 channels per cPCI card
- CAMAC card for SLAC beam test
- Up to 32,256 channels/cPCI crate

Very cost effective, board hardware already exists

T–979 Configuration

for BLAB1 based readout

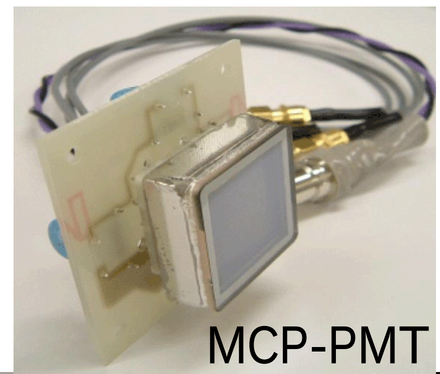


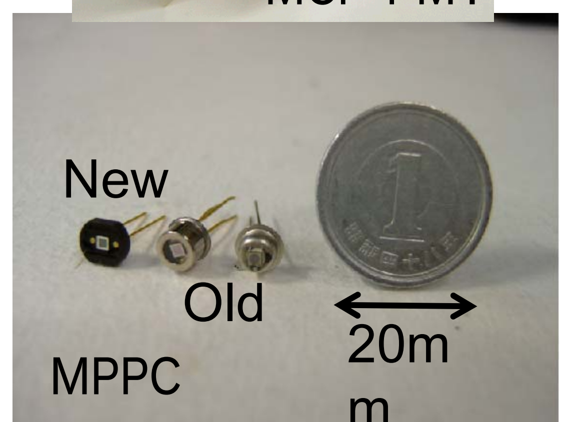
Photon detector options

- HAPD
  - Good result from test bench with ASIC readout
  - Stability? Need more production R&D

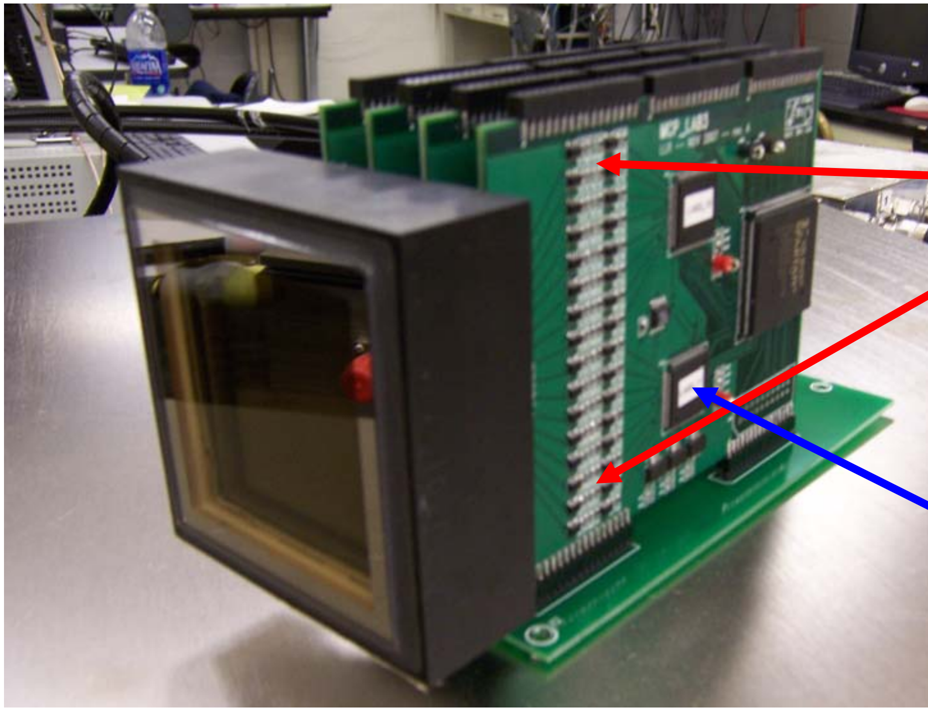
- MCP-PMT
  - Good TTS for TOF information
    - <20ps TOF resolution
    - Good ability for low momentum PID
  - Need lifetime estimation

- SiPM/MPPC
  - Good stability, Enough gain but only 100ps TTS
  - Need large effective area or light guide to make ~5x5mm^2 anode
  - Need gated readout because of high dark count (<~MHz)
  - Radiation hardness?





Gain Needed



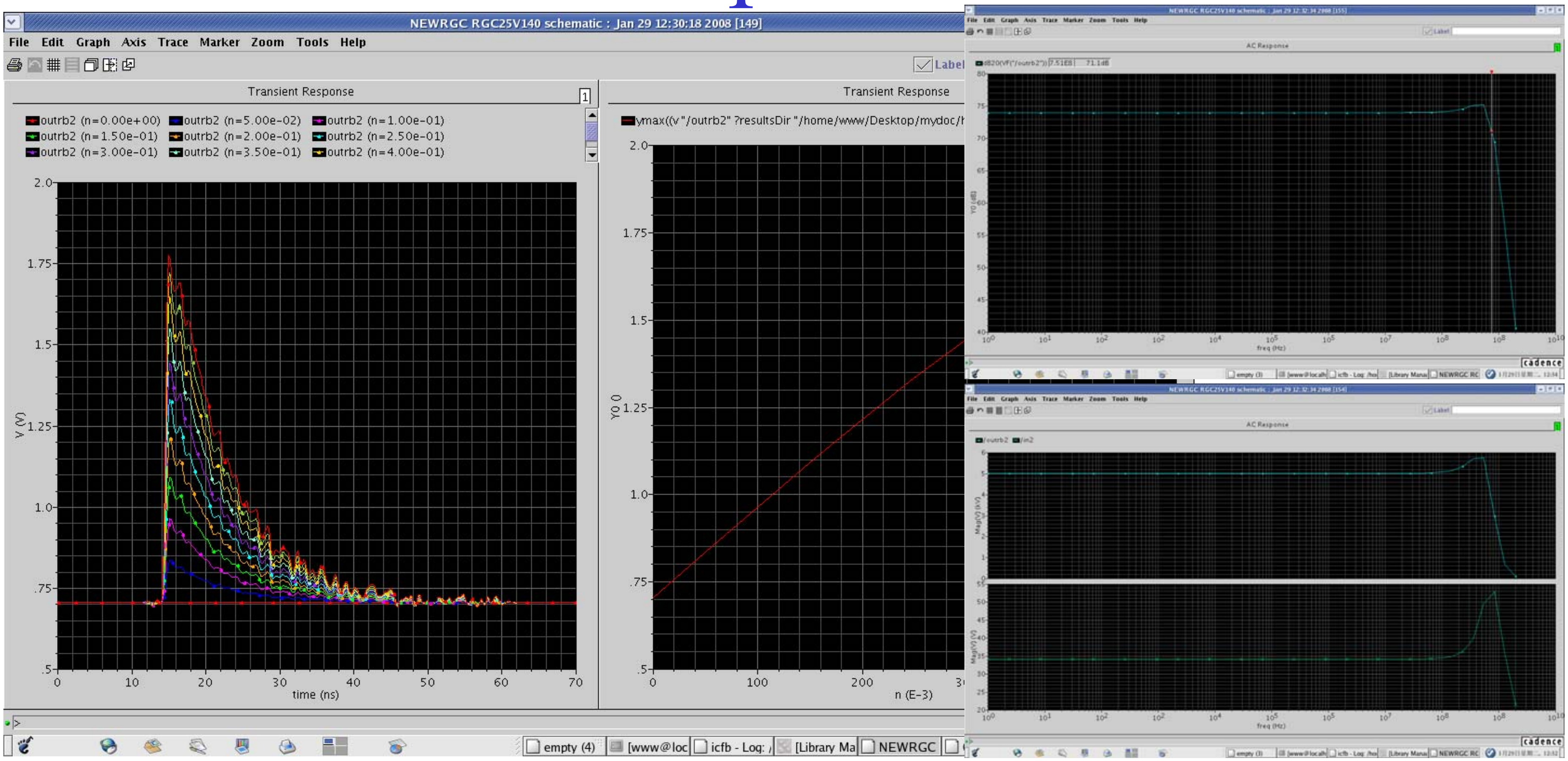
Amplifiers dominate board space

Readout ASIC tiny (14x14mm for 16 channels)

- What gain needed?
  - At 10^6 gain, each p.e. = 160 fC
  - At 2×10^5 gain (better for aging), each p.e. = 32 fC
  - In typical ~5ns pulse, Vpeak = dQ/dt * R = 32uA * R = 32mV * R [kΩ] (6.4mV)

Gain Estimate	
Rterm	**1 p.e. peak**
50	1mV
1k	20mV
20k	400mV

Simulated amplifier Performance



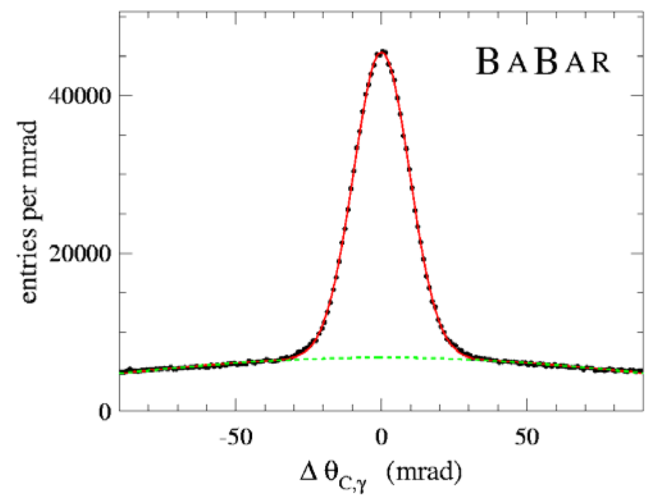
- Meets specs on previous slide
- 5k → ~100mV
- Sample noise ~2mV, if match input noise: 12pA/sqrt(Hz)
- SNR is then 50:1

BABAR-DIRC Resolution Limits

Photon yield:	18-60 photoelectrons per track *(depending on track polar angle)*
Typical PMT hit rates:	200kHz/PMT *(few-MeV photons from accelerator interacting in water)*
Timing resolution:	1.7ns per photon *(dominated by transit time spread of ETL 9125 PMT)*
Cherenkov angle resolution:	9.6mrad per photon → 2.4mrad per track

Limited by	*BABAR-DIRC*	*Improvement strategy*
Size of bar image	~ 4.1mrad	Focusing optics
Size of PMT pixel	~ 5.5mrad	Smaller pixel size
Chromaticity ($n=n(\lambda)$)	~ 5.4mrad	Better timing resolution

Focusing DIRC prototype designed to achieve
- 4-5mrad θ_c resolution per photon,
- 3σ π/K separation up to ~ 5GeV/c



Chromatic Effects

Chromatic effect at Cherenkov photon production $\cos\theta_c = 1/n(\lambda)\,\beta$

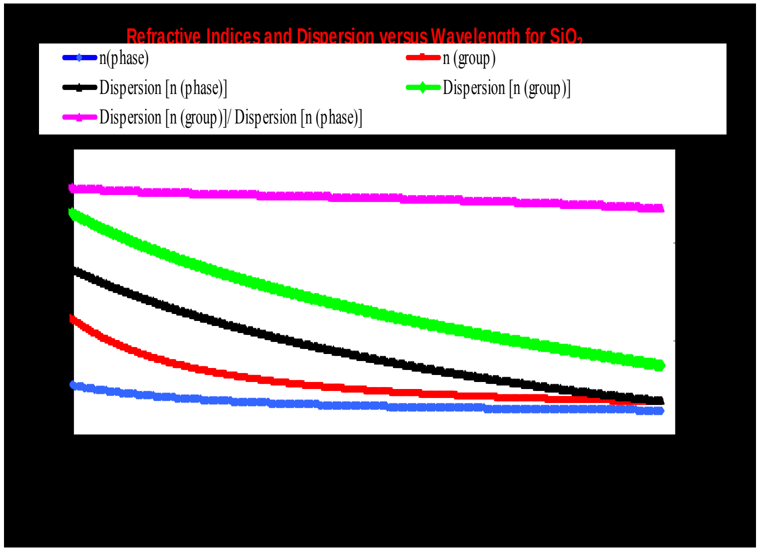
n(λ) refractive (phase) index of fused silica

n=1.49…1.46 for photons observed in BABAR-DIRC (300…650nm)

→ θ_c^γ = 835…815mrad

Larger Cherenkov angle at production results in shorter photon path length

→ 10-20cm path effect for BABAR-DIRC *(UV photons shorter path)*



Chromatic time dispersion during photon propagation in radiator bar

Photons propagate in dispersive medium with group index n_g

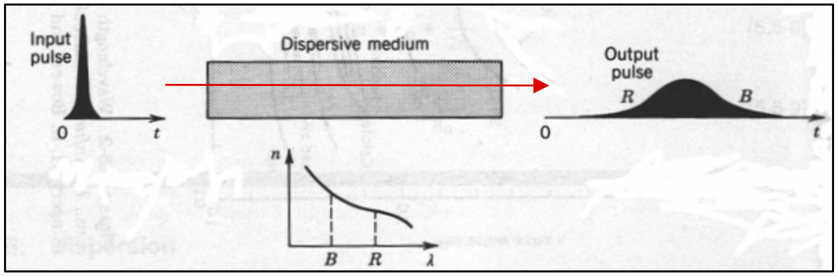
for fused silica: n / n_g = 0.95…0.99

Chromatic variation of n_g results in time-of-propagation (ΔTOP) variation

$$\Delta TOP = | -L\,\lambda\,d\lambda / c_0 \cdot d^2n/d\lambda^2 |$$

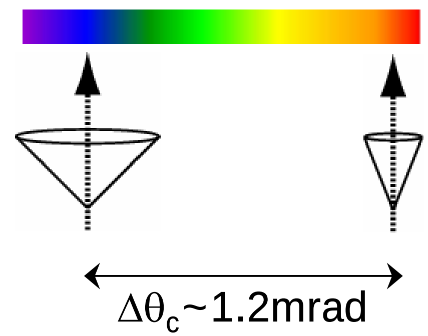
(L: photon path, dλ: wavelength bandwidth)

→ 1-3ns ΔTOP effect for BABAR-DIRC *(net effect: UV photons arrive later)*



Focusing TOP

- Use λ dependence of Cherenkov angle to correct chromaticity
  - Angle information → y position
  - Reconstruct Ring image from 3D information (time, x and y).



- $\Delta\theta_c$~1.2mrad over sensitive λ range
- → Δy~20mm (~quartz thickness)
  - We can measure λ dependence and obtain good separation even with narrow mirror and readout plane, because of long propagation length.