Particle Identification at a super B Factory.

FRASCATI
WORKSHOP
DISCUSSION ON PID

“ Do no harm “ !

(The Hippocratic oath of detector designers, especially for those outside you).

- Keep a minimum thickness of material in front of the outer detectors ;
- Technology choices must survive in the background environment – the materials , and the photon detectors .[some of the systems are considering new devices, and ***must*** look at these issues !)

What the PID needs of the other systems :

- Good tracking information ;
- Good ‘start-time’ information ;
- Energy loss information to help low energy PID.

What technologies might do the job ?

- A BaBar DIRC ;
- A fast readout DIRC a la the SLAC R&D ;
- A variation of the Belle TOP Cerenkov system ;
- A proximity focusing aerogel system ;

DIRC

- BABAR-DIRC has been a very successful particle identification (PID) system
  - crucial to success of SLAC B-Factory
  - very reliable, robust, easy to operate
  - p/K separation ≥ 2.7σ up to 4.2GeV/c

- Potential ‘ Fast DIRC ’ for PID at future experiments?
  - • Super B-Factory
  - • Linear Collider
  - • Hadron spectroscopy (GlueX at JLab)
  - • Nuclear physics (PANDA at GSI.

PID at Super B Factory

- For the End Cap region, as usual, there is the complication of the geometry .
- Very good TOF (ie with resolutions of around 25 psec) would do a fair job, provided tracking gives adequate momentum resolution..
- Some kind of ring imaging device would be better ; e.g. an aerogel proximity focusing device could be an interesting choice, as would a Fast Dirc device, a la our R&D.

  [one must remember the detectors will have to live in a high magnetic field.environment.]

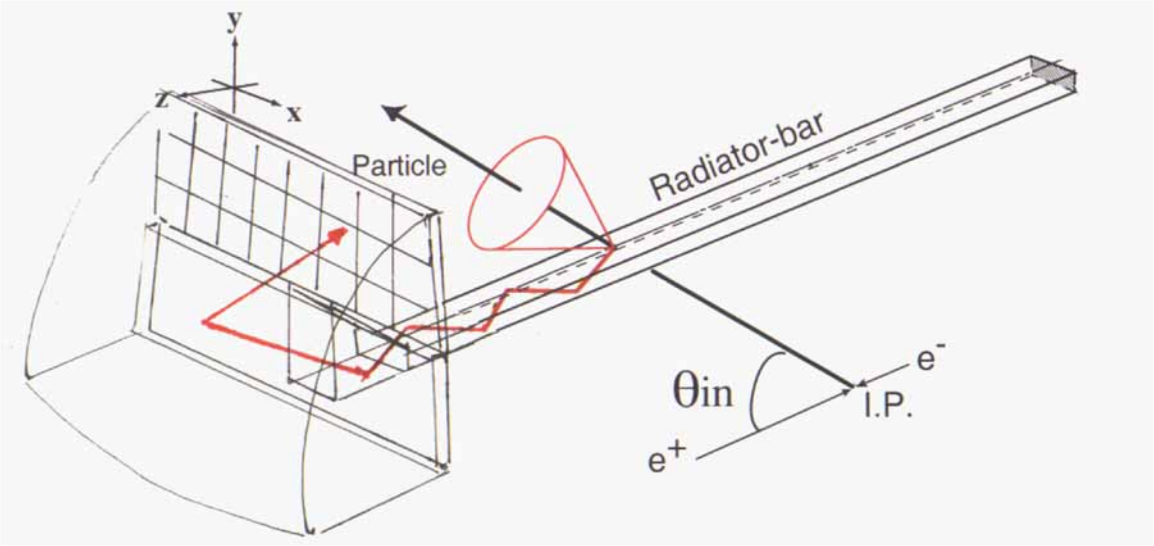
PID at a Super B Factory

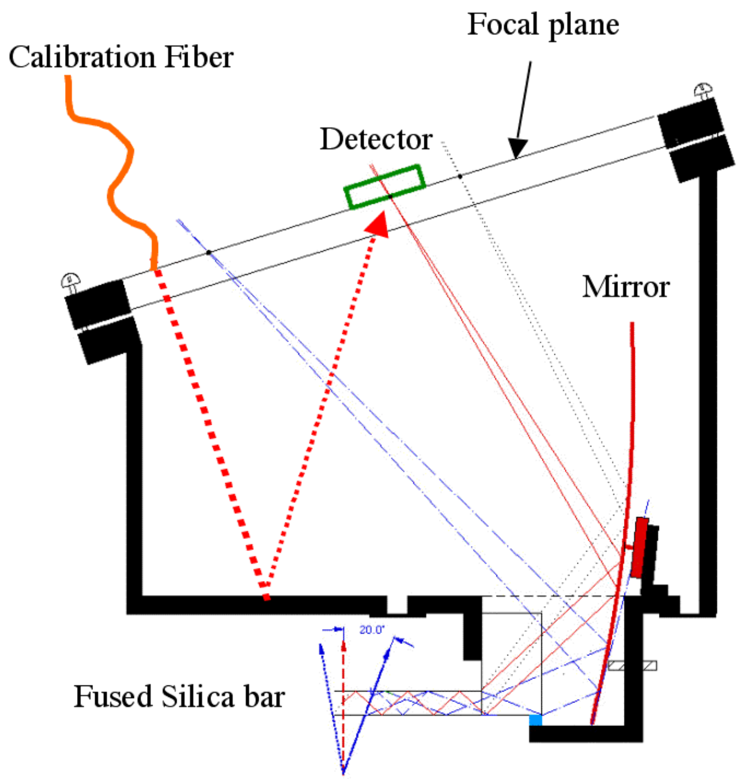
- DAQ will have to be pipe-lined for the PID device, and at a rather high data rate;
- The machine parameters should not present a challenge, other than bullet one above :
- Backgrounds should be OK for a Fast Dirc device, given that we are making a big (positive) jump in the time domain – but a detailed look at the background environment will be necessary, as the detected photon data will integrate over many, (say four or five) beam bunches.

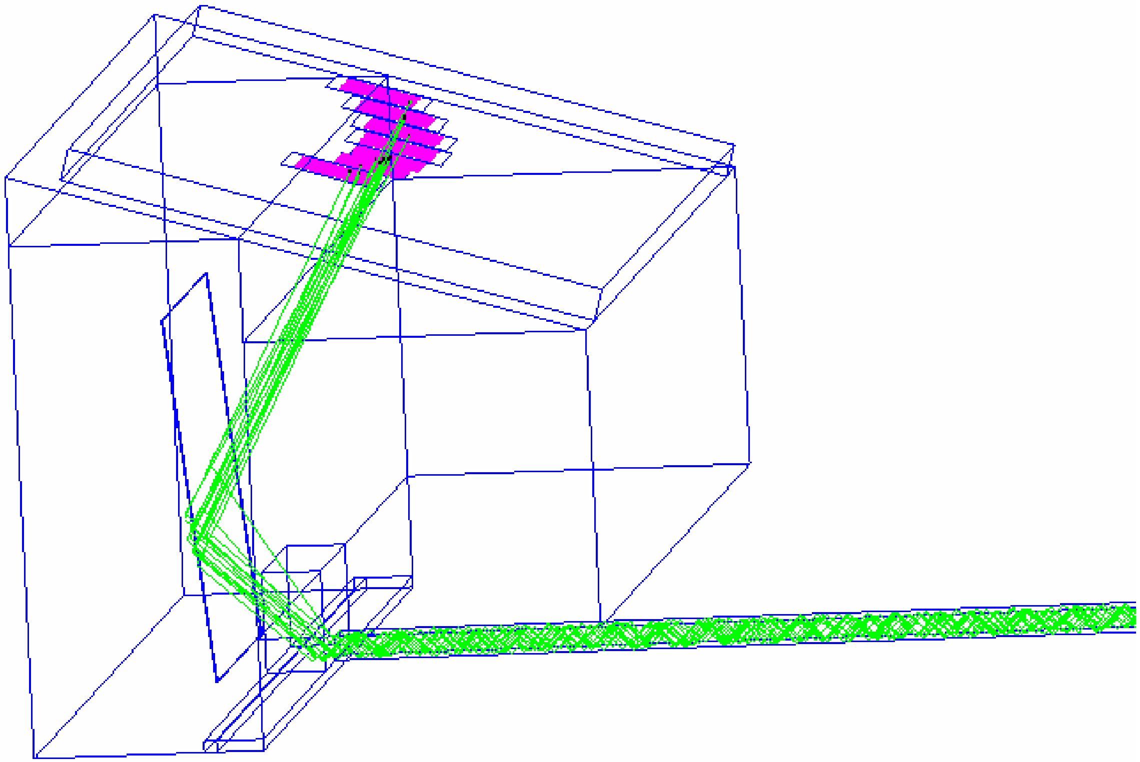
FOR A SUPER DIRC ……….

- For a super B factory, we need to further improve the momentum coverage, and make DIRC more background resistant
- → Improve single photon timing and angular resolution, decrease size of Cherenkov ring expansion region
- → SLAC R&D towards a fast Focusing DIRC, has been studying the performance of the prototype in test beam at SLAC.

FAST DIRC PRINCIPLES




Focal plane
Calibration Fiber
Detector
Mirror
Fused Silica bar



BEAM TEST CONDITIONS

- For 2005 beam test read out two Hamamatsu Flat Panel PMTs and three Burle MCP-PMTs (total of 320 pads).
- Elantec 2075EL amplifier (130x) on detector backplane
- SLAC-built constant fraction discriminator
- Eight Philips 7186 TDCs (25ps/count) for 128 channels
- Four SLAC-built TDC boards: TAC & 12 bit ADC (~31ps/count) for 128 channels
- Connect only pads close to expected hit pattern of Cherenkov photons

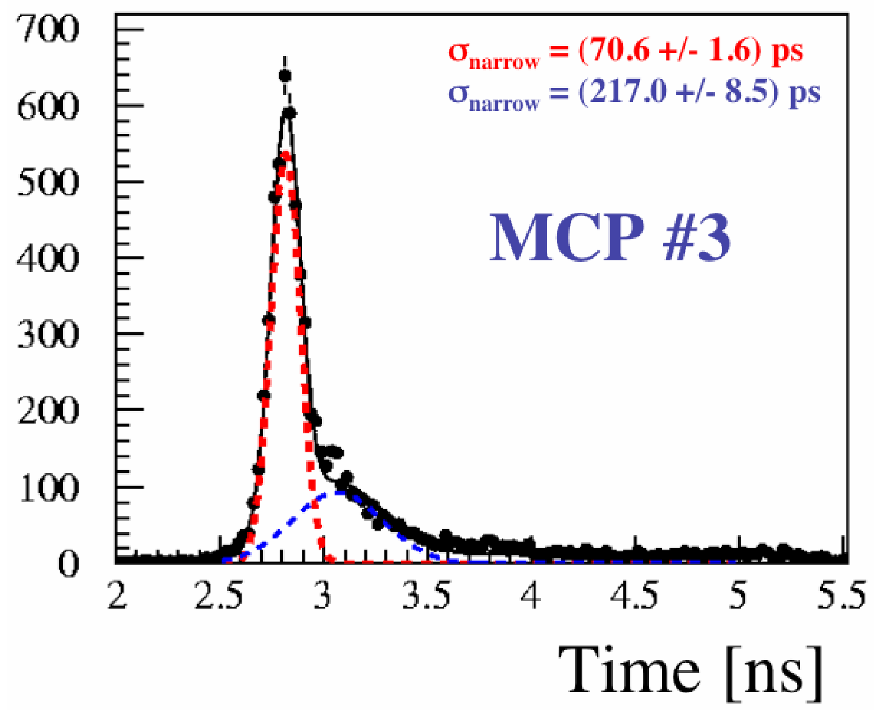
FAST DIRC R&D RESULTS

- IN OUR R&D AT SLAC WE HAVE CLEAR INDICATIONS OF SUCCESS IN MEASURING THE CHROMATIC EFFECTS IN RING IMAGING DETECTION ;

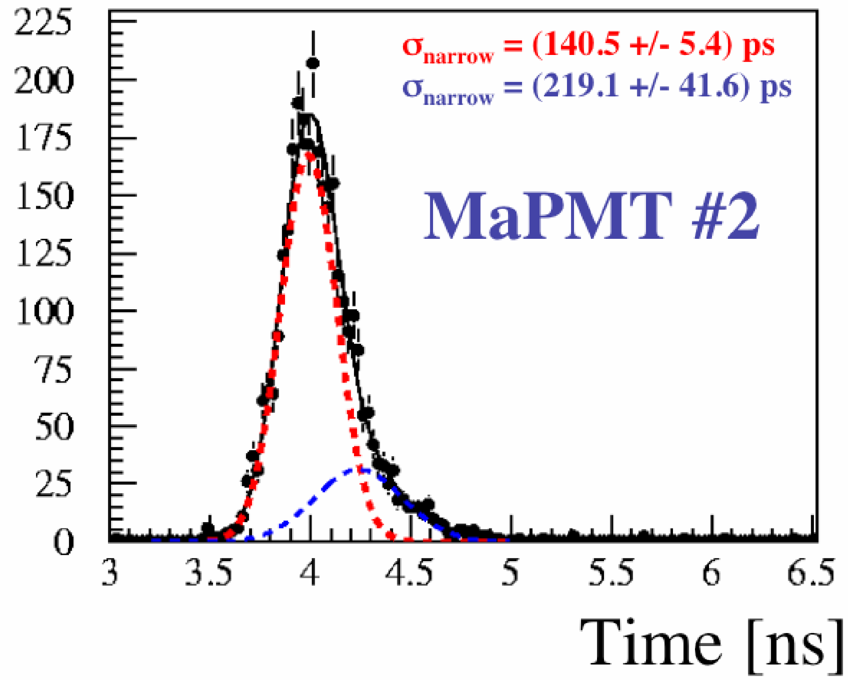
- WE HAVE ALSO DEMONSTRATED AN MCP DEVICE WORKING ADEQUATELY IN 15 KGAUSS MAGNETIC FIELDS ;

- R&D CONTINUES WITH THE DEVICE MAKERS TO IMPROVE THE PERFORMANCE AND ROBUSTNESS

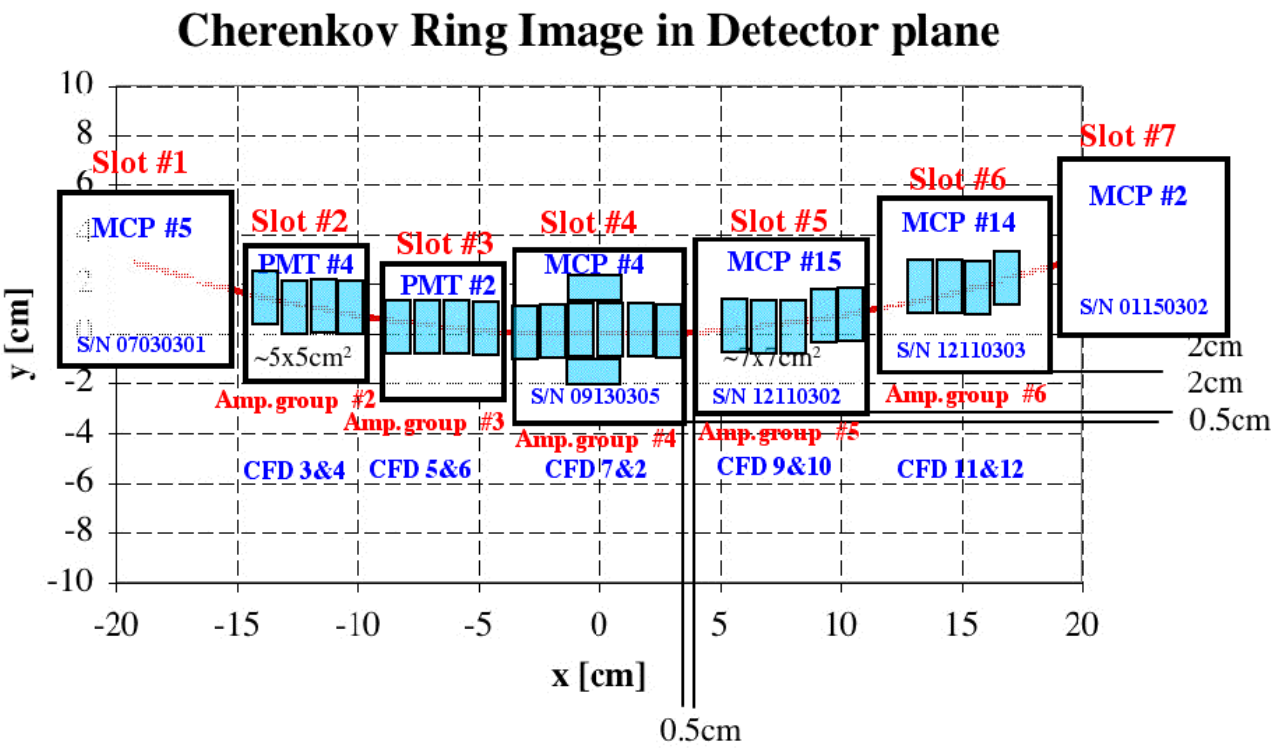
Burle 85011-501 MCP-PMT:



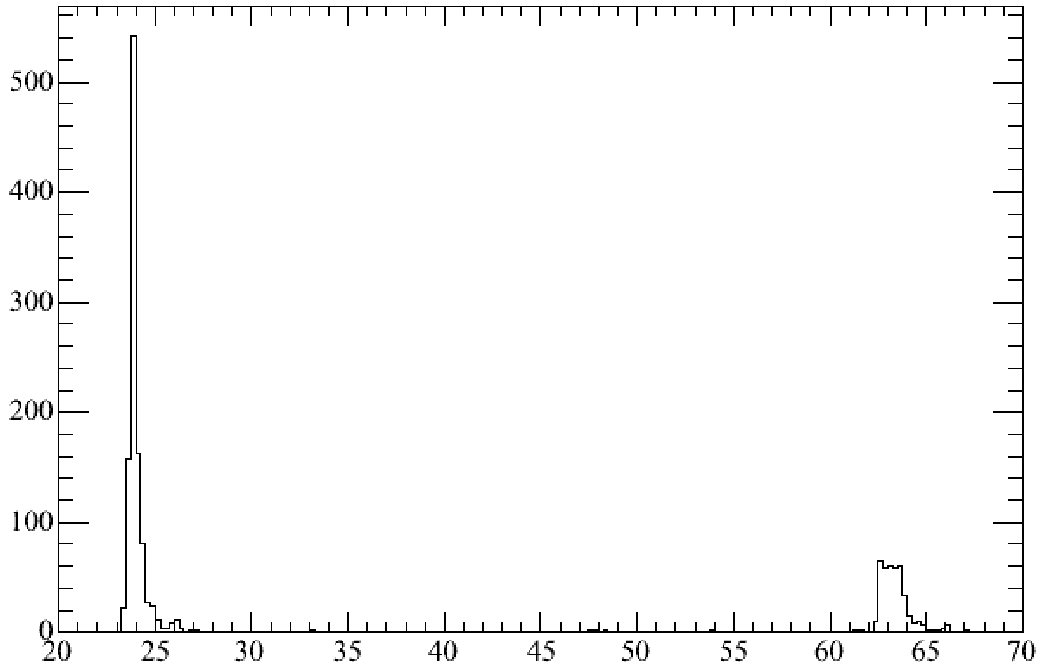
Hamamatsu Flat Panel H8500 PMT:



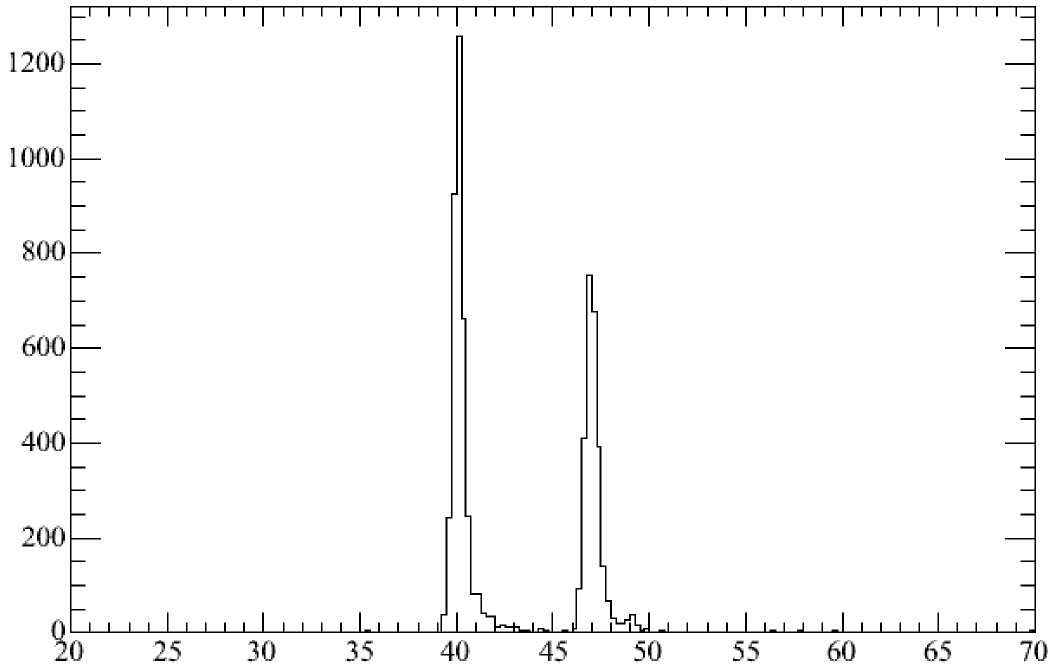
We will learn of cathode QE from the ‘ N-subO ‘ determined from the cerenkov ring studies.



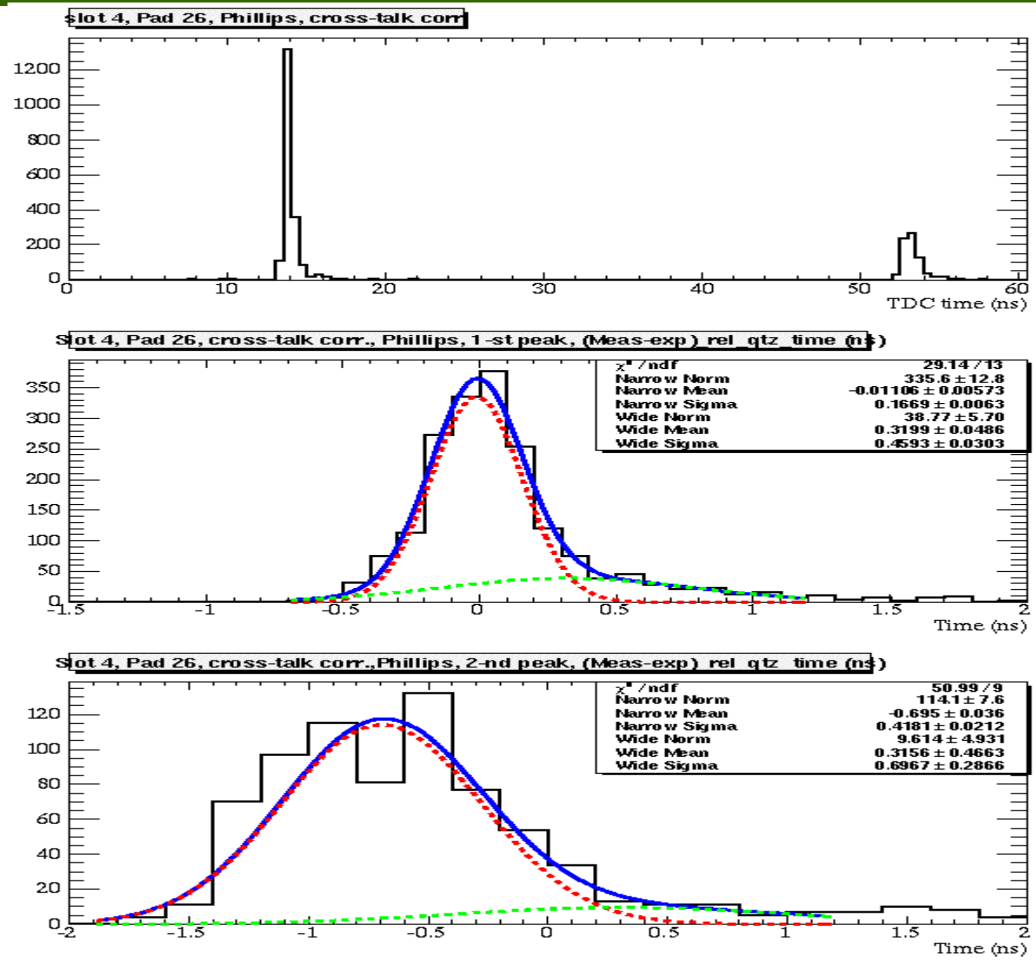
Beam position near the detector.



Beam position near centre of bar.



Close peak width is ~ 165 psec;
Far peak width is ~ 418 psec.



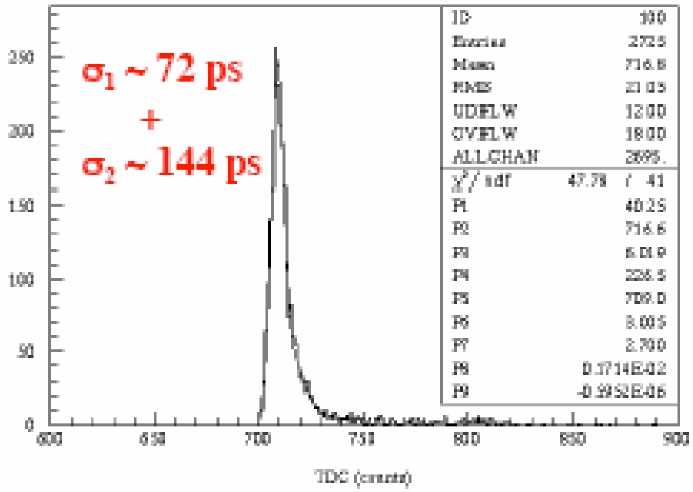
MAGNETIC FIELD TESTS

Summary:

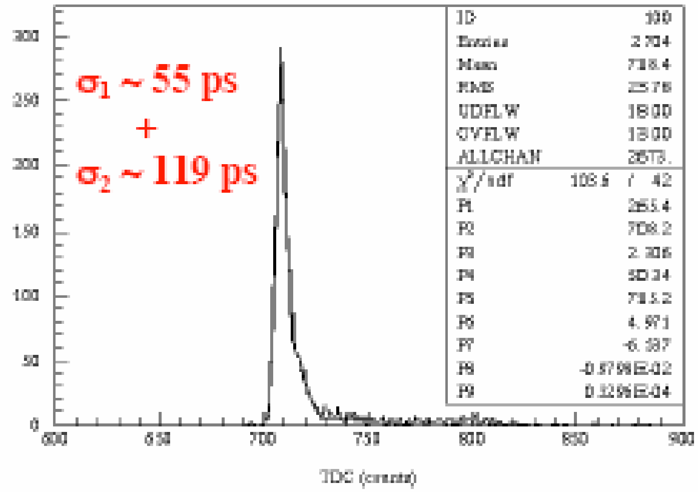
- At 15 kG, MCP with 10μm hole diameter can achieve a timing resolution of σ ~60 ps per single photon if one operates it at a voltage of 2.7kV, which exceeds the maximum recommended voltage by 300 Volts.
- At 10kG and 2.4kV, which is a maximum recommended voltage by Burle, one achieves a timing resolution of σ ~50ps per single photon.
- To make this type of MCP viable option for our application at 15kG, the internal MCP design should be modified to allow a high voltage operation up to 2.7kV, which means that a maximum allowed voltage should be 2.8-2.9kV. If the micro-channel plate itself would not allow such maximum voltage, than I would say the present design allows a maximum magnetic field of 10kG.
- One needs to use an amplifier with less than 1ns rise time to get a full response with this type of MCP. I had a good experience with Ortec VT120A amplifier.
- At 15kG and 2.65kV, a tilt of 3-5 degrees has no effect on a pulse height. At a tilt of 10 degrees, the pulse height decreases by ~30%, but one still get a decent response, which would allow a good operation for many applications. However, at a tilt of 15 degrees, the response is killed.
- At higher magnetic field, the tail of the timing distribution is somewhat suppressed. This means that the magnetic field suppresses the long trajectories of recoiling photoelectrons from the MCP surface.

- **Runs 4, 5, 6 (B = 10.1 kG, vary MCP voltage):**
  Ortec VT120A amp., **200x gain**, no splitter. Philips CFD with **1.5ns delay** and **25mV th.**, no ADC
  24ps/count, PiLas at 12.2%, 635nm, <10% probability to get an event, single photoelectrons.

Run 4 (B = 10.1 kG, V_{MCP} = -2.2kV):



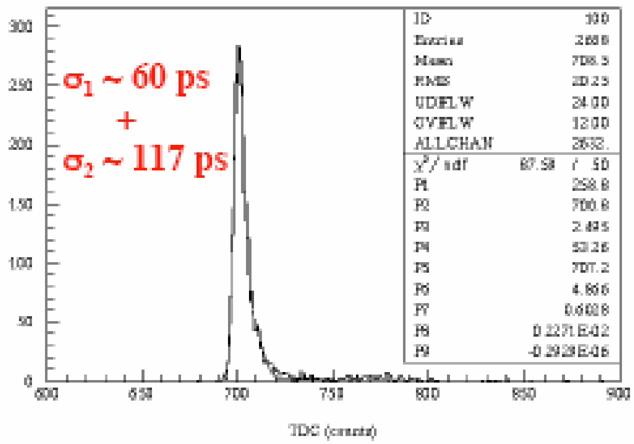
Run 5 (B = 10.1 kG, V_{MCP} = -2.3kV):



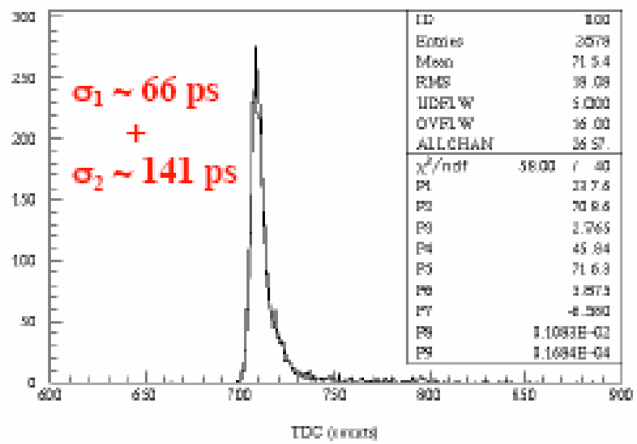
5 degree tilt – no effect ;
10 degree tilt – 30 % drop ;
15 degree tilt - dead .

- **Runs 7, 8, 9, 10 (B = 15 kG, vary MCP voltage):**
  Ortec VT120A amp., **200x gain**, no splitter. Philips CFD with **1.5ns delay** and **25mV th.**, no ADC, 24ps/count, PiLas at 12.2% (runs 7 &8) and 15% (runs 9&10) – change was necessary to increase the photon rate at smaller voltages of 2.65 & 2.6 kV.

Run 7 (B = 15 kG, V_{MCP} = -2.7kV):



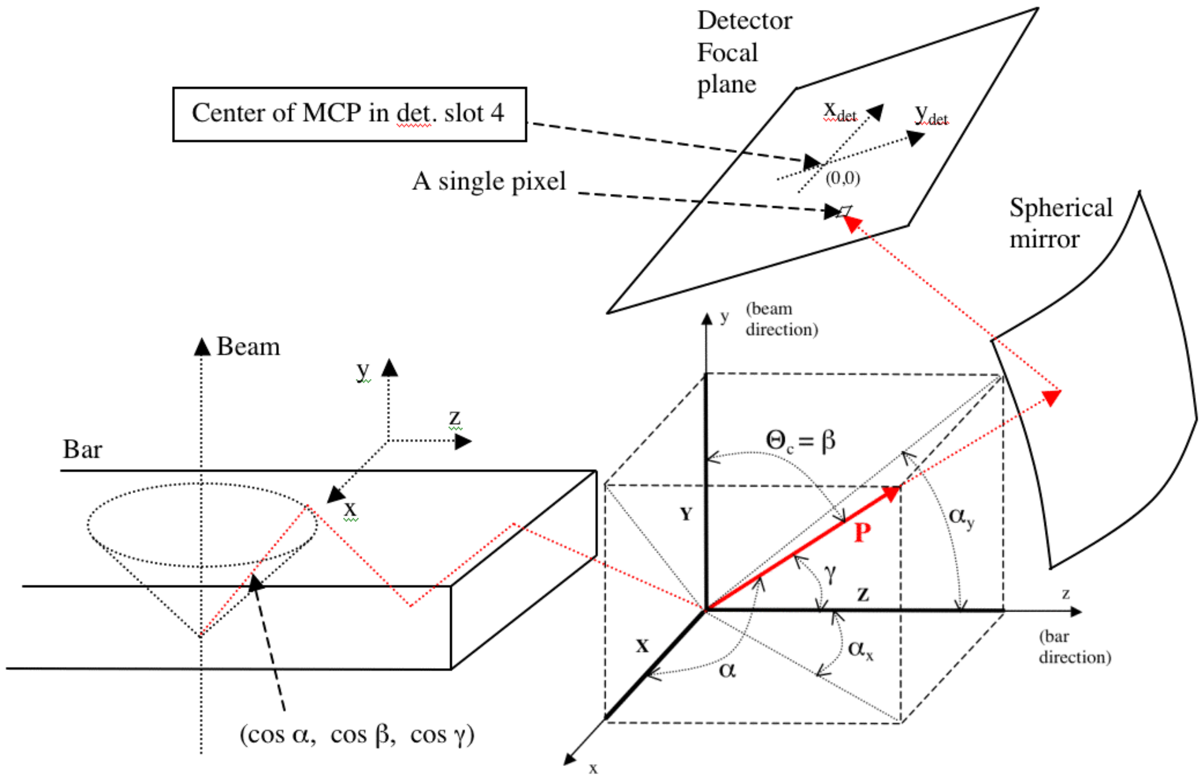
Run 10 (B = 15 kG, V_{MCP} = -2.65kV):

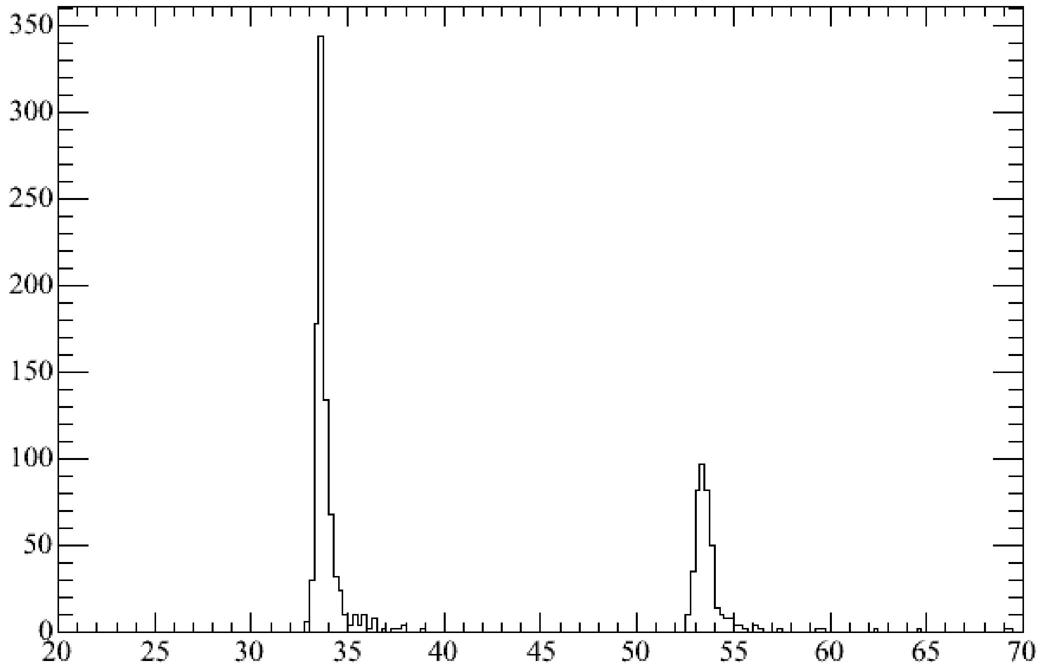


SUMMARY

- PID SHOULD NOT BE A PROBLEM AT SUPER-B ;
- A FAST DIRC LOOKS ATTRACTIVE, BUT OTHER SYSTEMS NEED TO BE EVALUATED ;
- END CAP REGION IS A SEPARATE EVALUATION;
- R&D IS NEEDED ON ALL OPTIONS ;
- DAQ IS A CHALLENGE, BUT NOT VERY DIFFERENT FROM OTHER SYSTEMS ;
- HERMITICITY NEEDS A NEW, SERIOUS CONSIDERATION ;
- A VERY GOOD CROSSING TIME SIGNAL IS REQUIRED FOR EACH DAQ DATA-TRAIN PACKET, (~ 50 TO 10 PSEC).

BACKUP SLIDES


Detector Focal plane
Center of MCP in det. slot 4
x_{det}
y_{det}
(0,0)
A single pixel
Spherical mirror
Beam
y
z
x
Bar
(cos α, cos β, cos γ)
y (beam direction)
$\Theta_c = \beta$
Y
P
γ
Z
α_y
α_x
X
α
z (bar direction)
x



350
300
250
200
150
100
50
0
20
25
30
35
40
45
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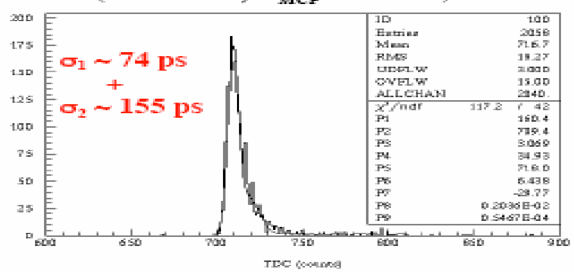
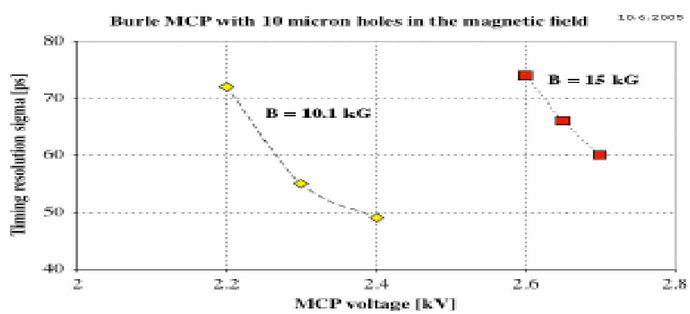
55
60
65
70

J.Va'vra, 10.12. 2005

Run 9 ($B = 15$ kG, $V_{MCP} = -2.6$kV):





Summary:

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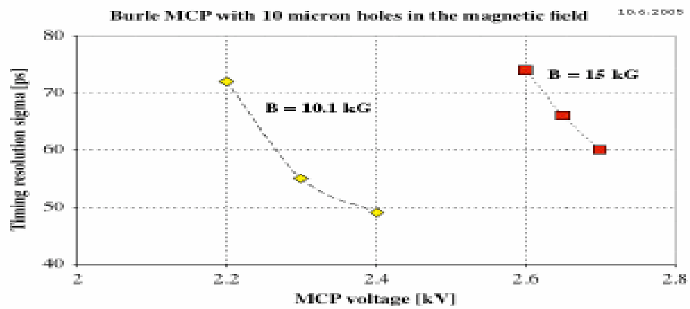

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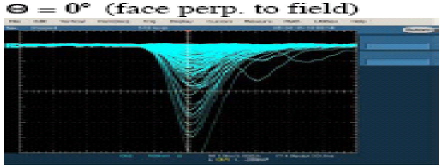
- One needs to use an amplifier with less than 1ns rise time to get a full response with this type of MCP. I had a good experience with Ortec VT120A amplifier.
- At 15kG and 2.65kV, a tilt of 3-5 degrees has no effect on a pulse height. At a tilt of 10 degrees, the pulse height decreases by ~30%, but one still get a decent response, which would allow a good operation for many applications. However, at a tilt of 15 degrees, the response is killed.
- At higher magnetic field, the tail of the timing distribution is somewhat suppressed. This means that the magnetic field suppresses the long trajectories of recoiling photoelectrons from the MCP surface.

ROTATION IN FIELD

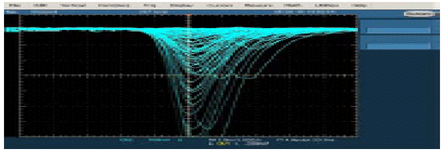
<u>Check if we are sensitive to misalignment (B = 15 kG):</u> 10.5.2005

- Ortec VT120A amp., 200x gain, no splitter, -2.65kV on MCP, PiLas at 12.2%, 635nm, <10% probability to get an event, trigger the scope with PiLas trigger, setup in the magnet, vary angle Θ between the magnetic field axis and a line perpendicular to the MCP face. Explore two possible tilts.
- B = 15 kG, scope setting: 100mV/div, 1ns/div.

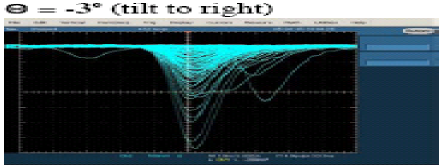
Θ = 0° (face perp. to field)



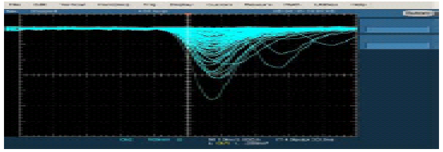
Θ = +3° (tilt to left)



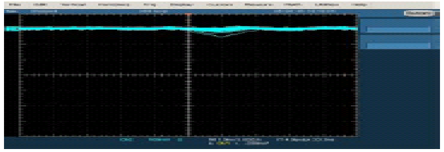
Θ = -3° (tilt to right)



Θ = -10° (tilt to right)

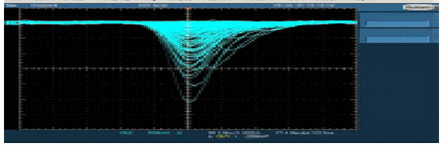


Θ = -15° (tilt to right)



Θ = -20° (tilt to right)

Θ = 0° (face perp. to field again)



The MCP can be tilted by 3-5° before pulse height is affected. At 10°, one sees a clear reduction of pulse height, but the tube can still be used. At 15° and above, the response is killed entirely.

DIRC Performance

- 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: mrad per photon → 2.4mrad per track

PATH FORWARD

Timing resolution   Pixel size
Single photon efficiency

timing resolution σt < 200ps required small pixels
allow reduction of size of expansion

need quantum efficiency ~20-30% and >70%
for chromatic correction region without
compromising angular resolution packing

efficiency to keep DIRC photon yield

Chromatic effect in Cherenkov detection

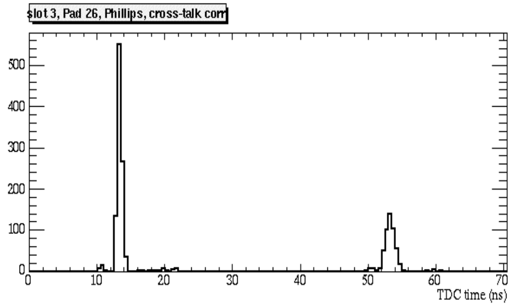
- Chromatic effect at Cherenkov photon production cos qc = 1/n(λ) b
  n(λ) refractive (phase) index of fused silica
  n=1.49…1.46 for photons observed in BABAR-DIRC (300…650nm)
  → qcγ = 835…815mrad
  Larger Cherenkov angle at production results in shorter photon path length
  → 10-20cm path effect for BABAR-DIRC *(UV photons shorter path)*
- Chromatic time dispersion during photon propagation in radiator bar
  Photons propagate in dispersive medium with group index ng
  for fused silica: n / ng = 0.95…0.99
  Chromatic variation of ng results in time-of-propagation (ΔTOP) variation
- ΔTOP= | –L l dl / c0 · d2n/dl2 |
  (L: photon path, dl: wavelength bandwidth)
  → 1-3ns ΔTOP effect for BABAR-DIRC *(net effect: UV photons arrive later)*

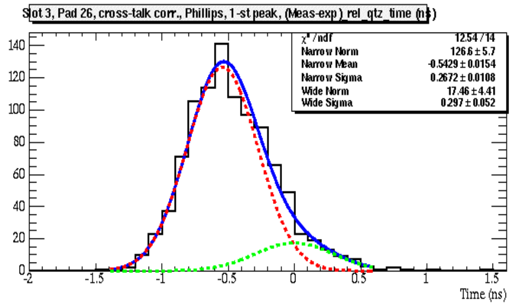
- In July and August 2005 we took beam data during four periods,
  lasting from few hours to several days.
- Total of 2.6M triggers recorded, 10 GeV/c e–
- Beam entered the radiator bar in 7 different locations.
- Recorded between 100k and 700k triggers in each beam location.
- Photon path length range: 0.75m – 11m.
- DAQ writes ASCII raw format (372 channels per event),
  converted offline to ROOT ntuples.

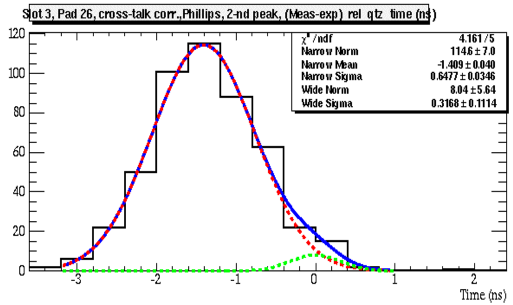
- Calculate expected time-of-propagation (TOP) of Cherenkov photon from photon hit location (assuming average wavelength of 440nm)
- Measure TOP of Cherenkov photon with high precision
- Calculate difference between measured and expected TOP: ΔTOP
- According to ng variation blue/UV photons arrive ~0.5-1ns earlier than 440nm “average photon”, red photon arrives ~0.5-1ns later.
- ΔTOP measurement corresponds to wavelength determination
- Need ~100-200ps timing resolution to perform meaningful determination of photon wavelength
- Better timing also allows tighter timing cuts for background rejection
- Fast timing would allow classic TOF measurement to contribute to PID (mostly for short photon path length)

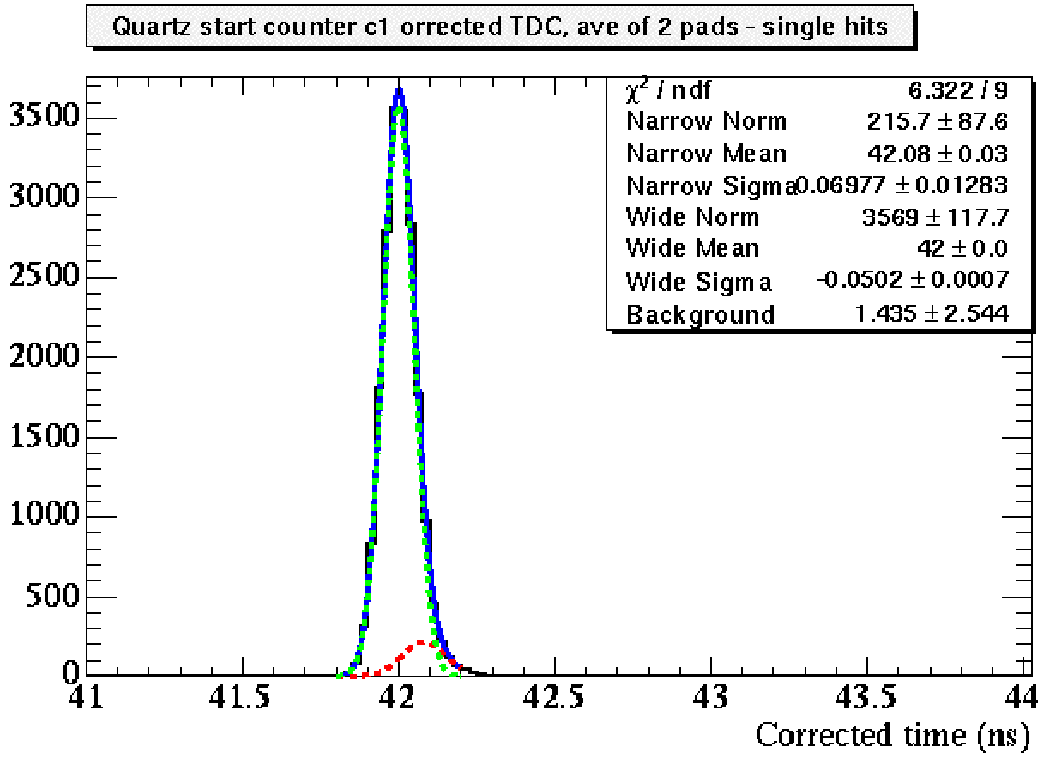
- The largest chromatic effect is in the position 1
- Peak 1 was was first adjusted with Joe's constants based on the PiLas calibration. Then it was adjusted arbitrarily adjusted to zero by a constant $C_{pad26,slot4,run7}$.
- Peak 2 was adjusted using the calculated offse using my spreadsheett, and assuming a TDC calibration of 23 ps/count.
- The 2-nd peak does not come to zero. It is off by ~.65ns at present.
- Corrected for the MCP cross-talk and for time drift using the Start counter 1.
- Assume that the detector plane is shifted down by 1.5cm in this analysis.

- Hamamatsu MaPMT does not have as large tail as the Burle MCP, but it is good enough to correct the chromatic error
- Peak 1 was was first adjusted with Joe’s constants based on the PiLas calibration. Then it was adjusted arbitrarily adjusted to zero by a constant $C_{pad26,slot4,run7}$.
- Peak 2 was adjusted using the calculated offset, and assuming a TDC calibration of 23 ps/count.
- The 1-st peak does not come to zero. It is off by ~.54ns at present. The 2-nd peak is off by 1.4ns.
- Corrected for the MCP cross-talk and for time drift using the Start counter 1.
- Assume that the detector plane is shifted down by 1.5cm in this analysis.

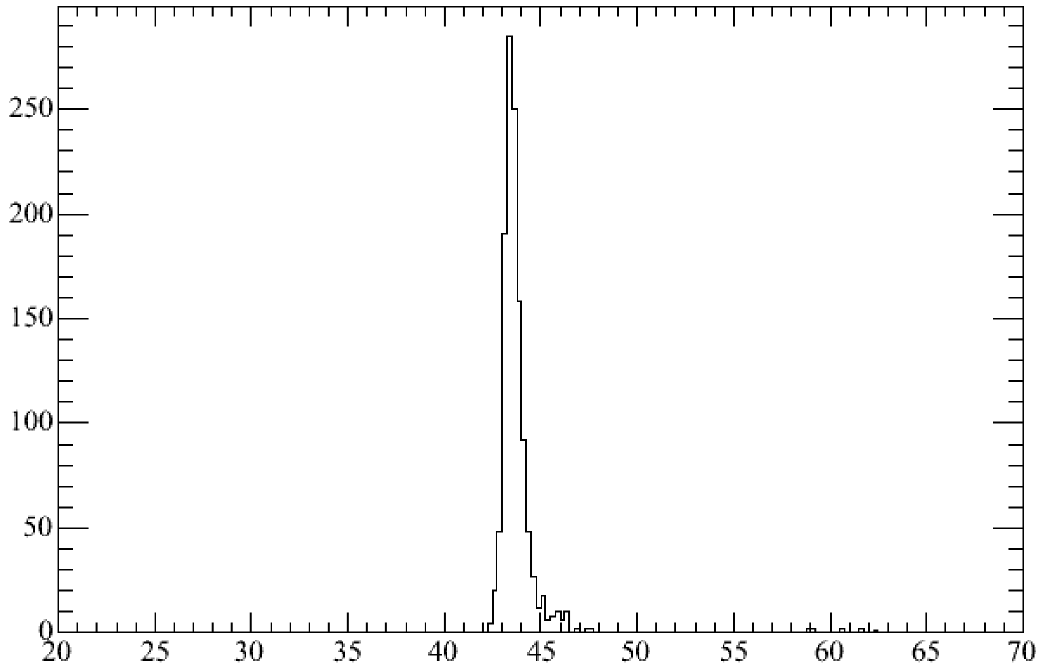

Slot 3, Pad 26, Phillips, cross-talk corr
TDC time (ns)


Slot 3, Pad 26, cross-talk corr., Phillips, 1-st peak, (Meas-exp) rel_qtz_time (ns)
χ² / ndf 12.54 / 14
Narrow Norm 126.6 ± 5.7
Narrow Mean -0.5429 ± 0.0154
Narrow Sigma 0.2672 ± 0.0108
Wide Norm 17.46 ± 4.41
Wide Sigma 0.297 ± 0.052
Time (ns)


Slot 3, Pad 26, cross-talk corr.,Phillips, 2-nd peak, (Meas-exp) rel_qtz_time (ns)
χ² / ndf 4.161 / 5
Narrow Norm 114.6 ± 7.0
Narrow Mean -1.409 ± 0.040
Narrow Sigma 0.6477 ± 0.0346
Wide Norm 8.04 ± 5.64
Wide Sigma 0.3168 ± 0.1114
Time (ns)



Quartz start counter c1 orrected TDC, ave of 2 pads - single hits
χ^2 / ndf 6.322 / 9
Narrow Norm 215.7 ± 87.6
Narrow Mean 42.08 ± 0.03
Narrow Sigma 0.06977 ± 0.01283
Wide Norm 3569 ± 117.7
Wide Mean 42 ± 0.0
Wide Sigma -0.0502 ± 0.0007
Background 1.435 ± 2.544
3500
3000
2500
2000
1500
1000
500
0
41
41.5
42
42.5
43
43.5
44
Corrected time (ns)



250
200
150
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50
0
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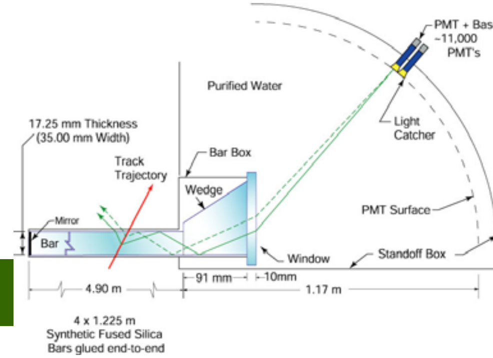
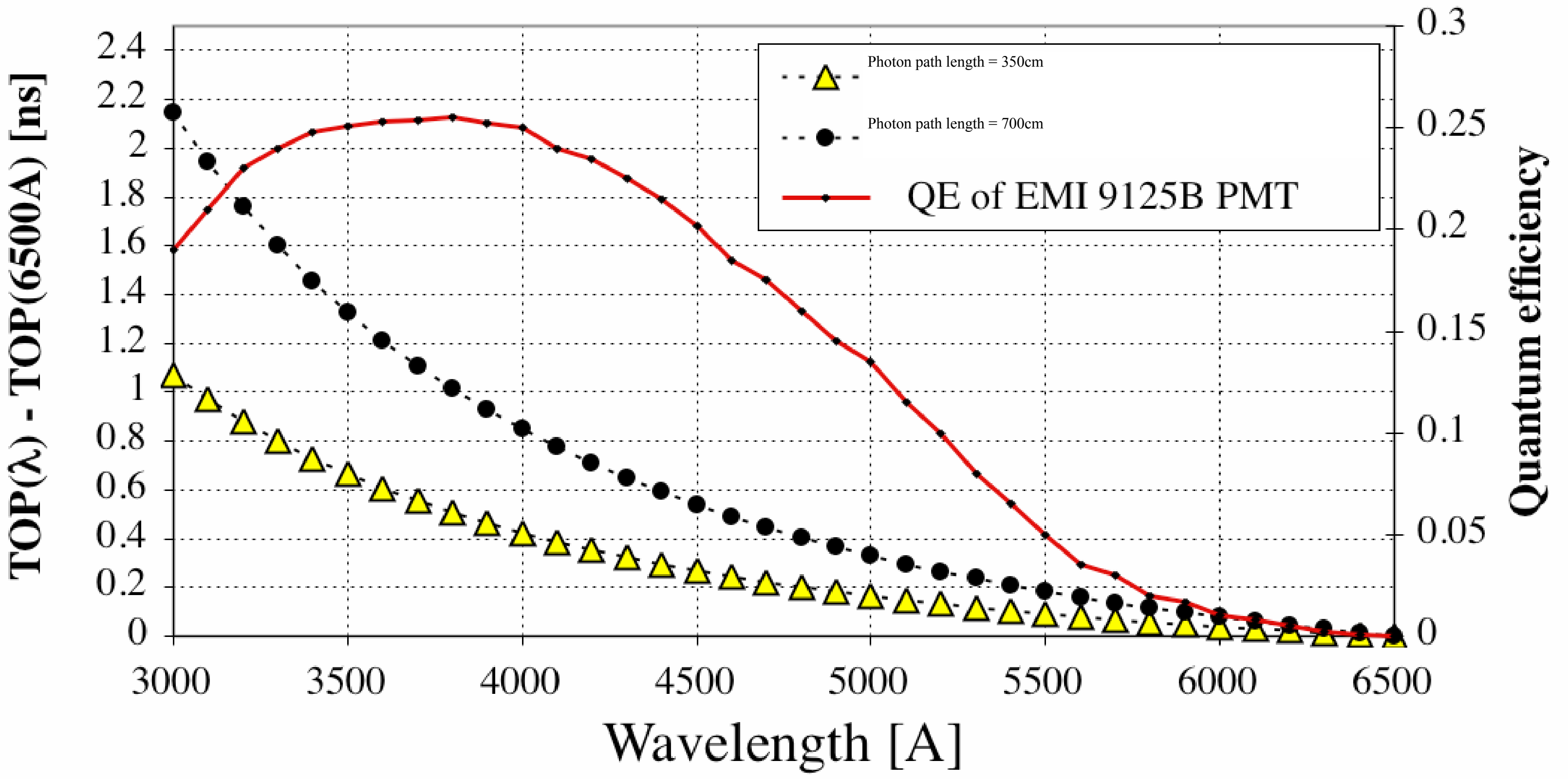
30
35
40
45
50
55
60
65
70

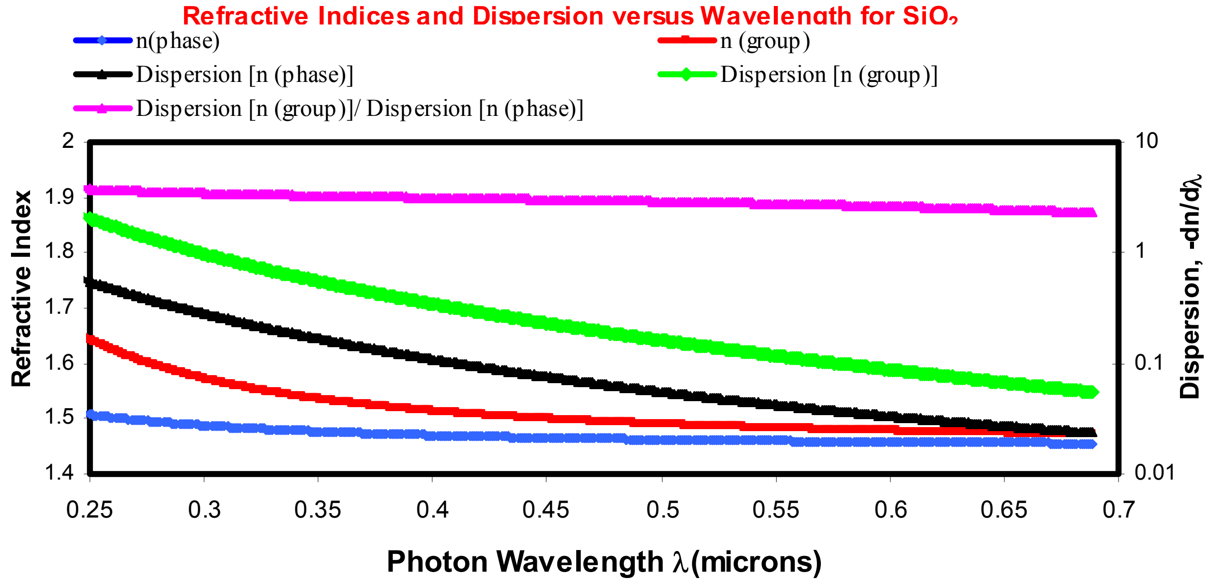


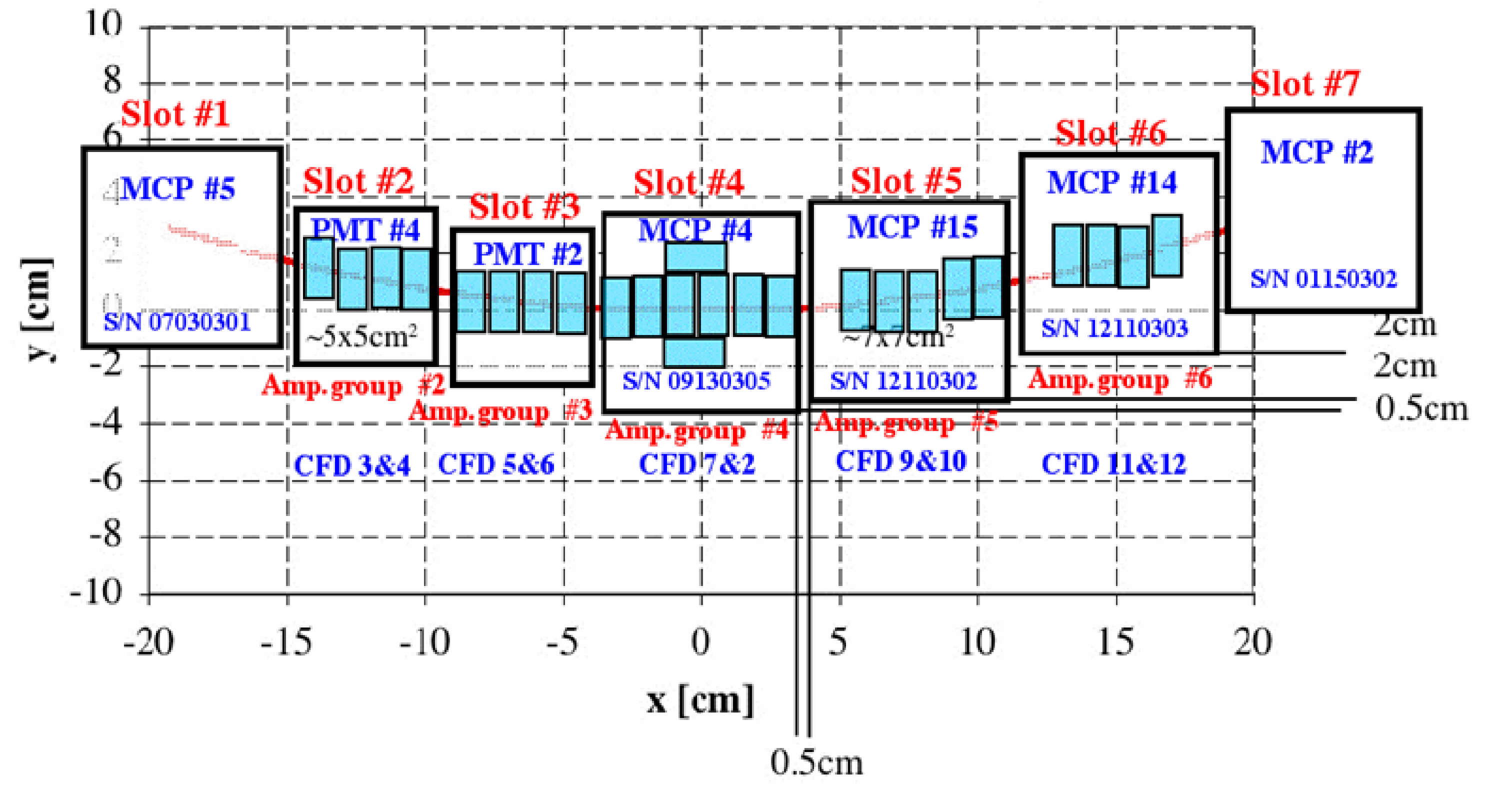
- **A charged particle traversing a radiator with refractive index n(λ) with b = v/c > 1/n(λ) emits Cherenkov photons on a cone with half opening angle cos qc = 1/n(λ) b.**
- **If n>√2 some photons are always totally internally reflected for b≈1 tracks.**
- **Radiator and light guide: Long, rectangular Synthetic Fused Silica (“Quartz”) bars**
- **Photons exit via wedge into expansion region (filled with 6m3 pure, de-ionized water).**
- **Pinhole imaging on PMT array *(bar dimension small compared to standoff distance).***
- **DIRC is a 3-D device, measuring: x, y and <u>time</u> of Cherenkov photons,**

  defining qc, fc, tpropagation of photon.

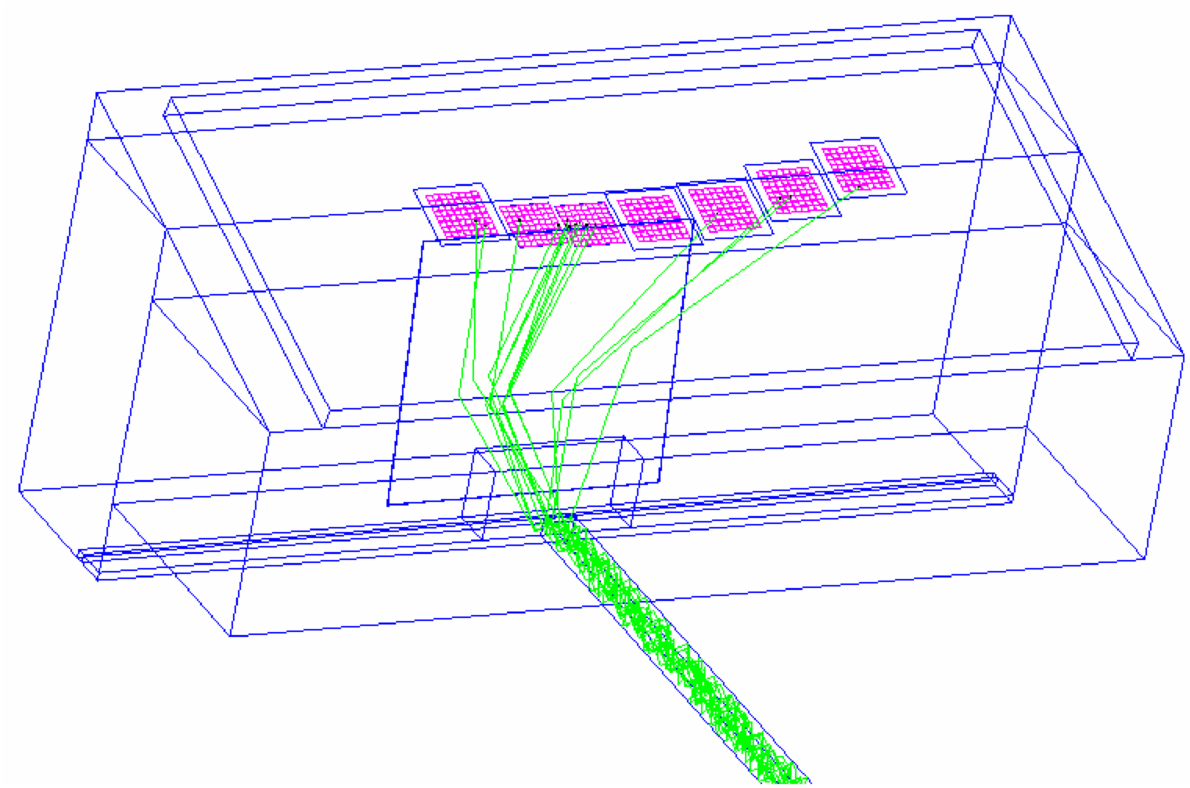

Photon path length = 350cm
Photon path length = 700cm
QE of EMI 9125B PMT
TOP(λ) - TOP(6500A) [ns]
Quantum efficiency
Wavelength [A]
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.3
0.25
0.2
0.15
0.1
0.05
0
3000
3500
4000
4500
5000
5500
6000
6500

Understanding chromatic effect (I)

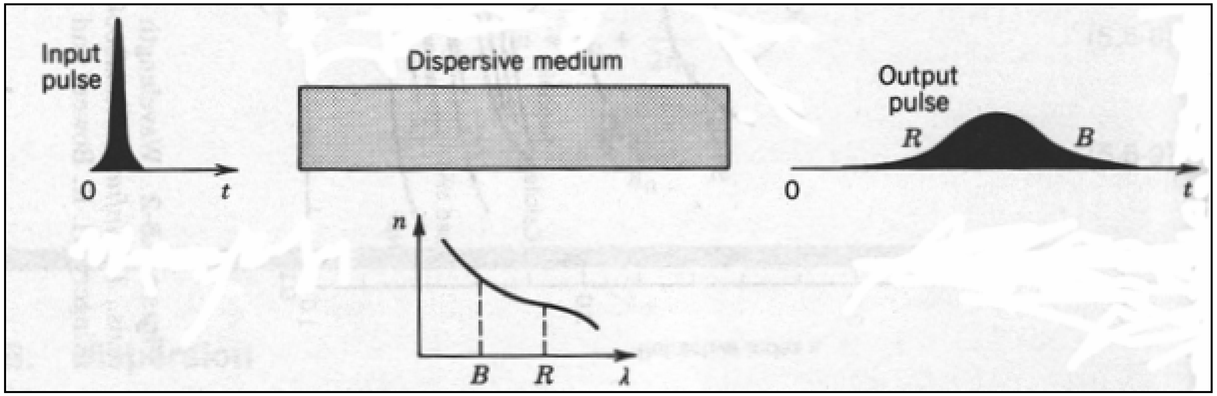




Slot #1
MCP #5
S/N 07030301
Slot #2
PMT #4
~5x5cm²
Amp.group #2
CFD 3&4
Slot #3
PMT #2
Amp.group #3
CFD 5&6
Slot #4
MCP #4
S/N 09130305
Amp.group #4
CFD 7&2
Slot #5
MCP #15
~7x7cm²
S/N 12110302
Amp.group #5
CFD 9&10
Slot #6
MCP #14
S/N 12110303
Amp.group #6
CFD 11&12
Slot #7
MCP #2
S/N 01150302
2cm
2cm
0.5cm
0.5cm
y [cm]
x [cm]



Understanding chromatic effect (II)



Path to Performance Improvement

- Improve single photon Cherenkov angle resolution
  - use smaller photon detector pixels
  - correct chromatic production term via precise timing
  - use focusing optics to decrease bar size term
- Decrease size of expansion region
  - smaller expansion region will decrease background rate (caused by conversion of few-MeV accelerator-induced photons in expansion region)