LC Detector Hadron ID: Cerenkov Detectors

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Outline

- Hadron ID
- PID Tools Package
- Cerenkov Detectors
    - Basics
    - BaBar DIRC
    - Focusing DIRC
    - Time-of-Propagation Counter
- Conclusions

Potential Roles for Hadron ID

- Flavor tagging e.g. neutral B meson in combination with vertex information
- Improved jet mass resolution
- Decays of Higgs into $s\bar{s}, c\bar{c}, gg$ that may be more difficult to isolate than $b\bar{b}$
- Multi-jet analyses (lower average momentum)
- Baryon composition as a tag for SUSY processes
- Exotica such as slowly moving massive particles

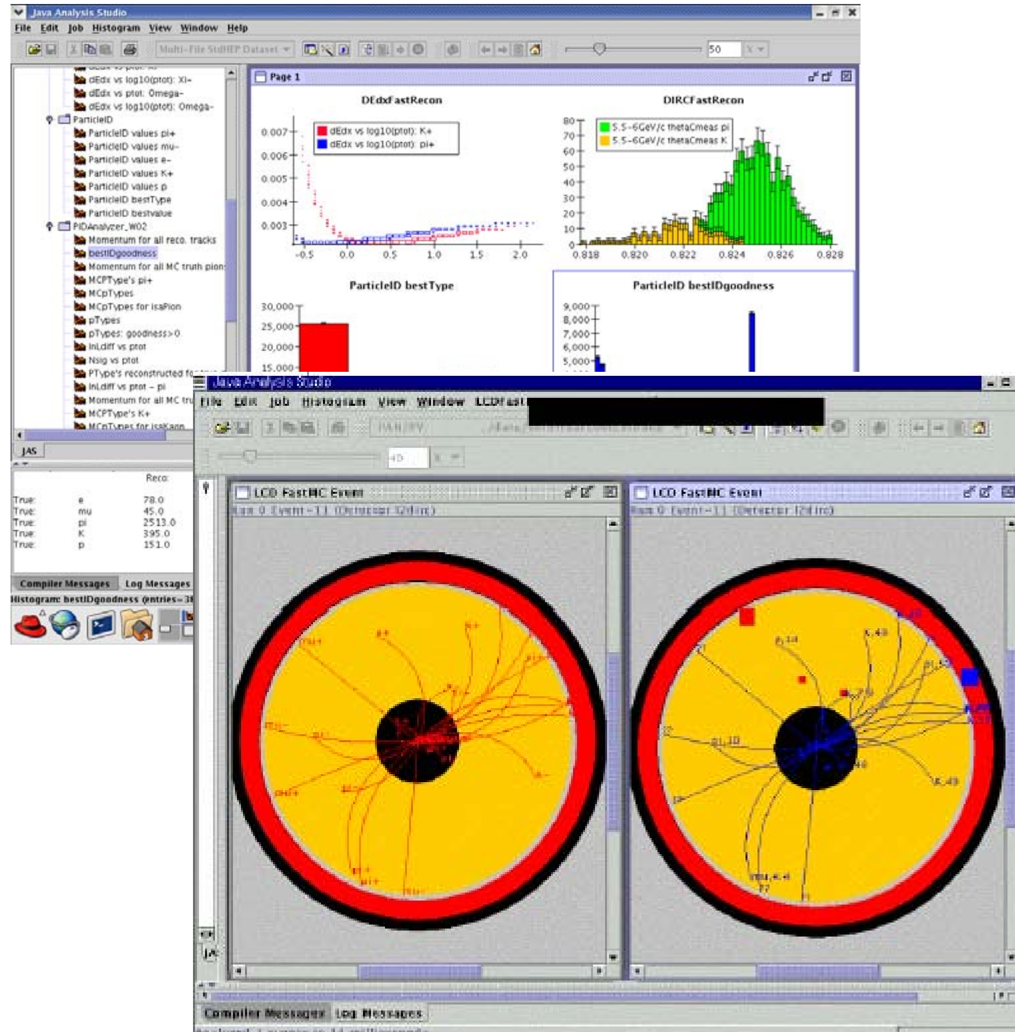
LC Hadron ID Analyses

- Probing SUSY R-parity and Baryon Number Violation with Hadron ID. (A. Soffer, CSU)
  - Marginal even w/ perfect ID, but protons ID qualitatively new info
  - Could be important handle if SUSY not seen at LHC in lepton modes
- Impact of PID on W+- Helicity Measurements at LC (A. Soffer, CSU)
  - Enhance with charm jet ID in hadronic decays
  - Up to 30% enhancement even with gas chambers
- Analyses of Long-lived Slepton NLSP (Mercadente & Yamamoto, UH)
  - Distinguish long-lived staus from mu background
  - Entire kinematic range needs dE/dx+DIRC
- Neutral B meson Flavor Tagging. (Robert J. Wilson)
  - In t tbar at 500 GeV < 30% tagged w/ perfect ID; TESLA TPC ~10%
- Jet-Jet Invariant Mass for ZH using Hadron ID. (Rolnick & Wilson, CSU)
  - Modest effect for pi/K
  - pi/K/p knowledge may be valuable for PFA

- Most of these should be re-done.

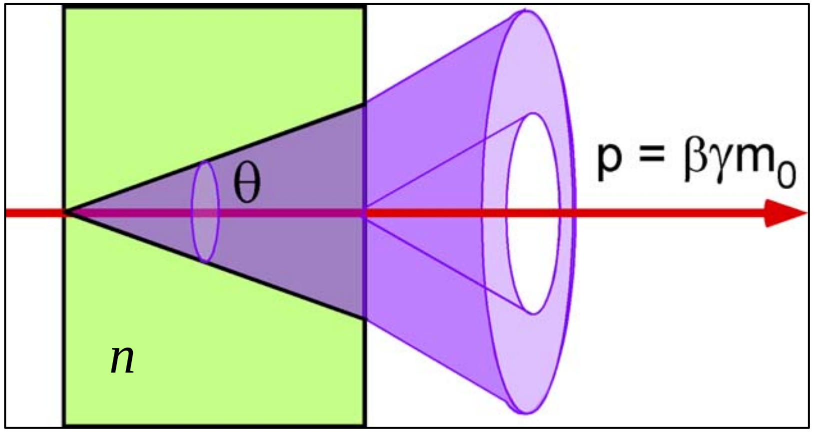
Particle ID in LCD/JAS Framework

- Particle ID fast simulation & reconstruction available in LCD/JAS2 framework
    - •Original framework due to Gary Bower/SLAC, modified and extended by Bob Wilson & Sky Rolnick/CSU.
- Simple, flexible, and fast tool to explore particle ID issues.
- Supports *lcd* or *stdhep* event data files.
- Can simulate multiple detectors “simultaneously” to aide comparisons (e.g., *l2, l2dirc, s2, s2dirc*).
- Source code and example files may be downloaded at
http://hep45.hep.colostate.edu/~rolnick/pid.htm
- **Conversion to JAS3?**



Cherenkov Basics

$$\cos\theta = \frac{1}{\beta n}$$



$$\gamma_{threshold} = \left(1 - \frac{1}{n^2}\right)^{-1/2}$$

$N_\gamma = N_0 L z^2 \sin^2\theta$

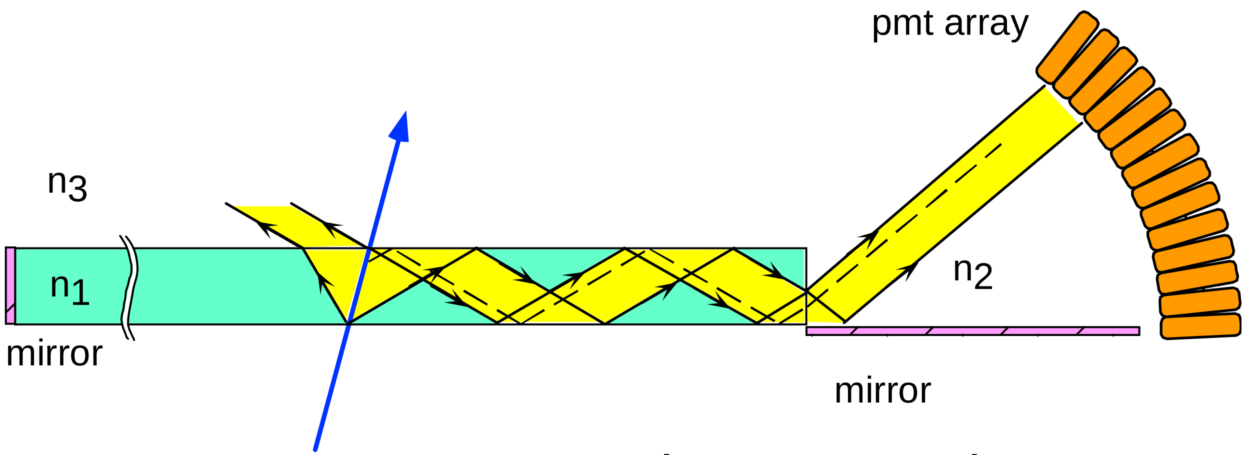
$N_0 \propto n$ (density)

In practice, like $\langle N_\gamma \rangle \approx 10$

Cherenkov Detector Options

- Low density/refractive index (gas, aerogel)
  - ☺ High momentum reach
  - ☺ Several collider examples – DELPHI, SLD, BELLE
  - ☹ Large radial extent – at expense of tracker or calorimeter radius ($$)
  - ☹ Complex - fluids, HV, active components inside fiducial volume
  - ☹ Non-uniform material in fiducial volume; separate from calorimeter face
  - ☹ PFA compromised significantly
  - ☹ Out of the question for LC detectors
- High density/refractive index (quartz)
  - ☹ Lower momentum reach
  - 😐 One example – BaBar DIRC
  - ☺ Small radial extent
  - ☺ Simple – no fluids, HV, active components inside fiducial volume
  - ☺ Uniform material in fiducial volume; close to calorimeter face
  - ☺ PFA okay?
  - ☺ Candidate for LC detectors?

Detection of Internally Reflected Cerenkov light



BaBar DIRC Nucl.Instrum.Meth.A538:281-357,2005

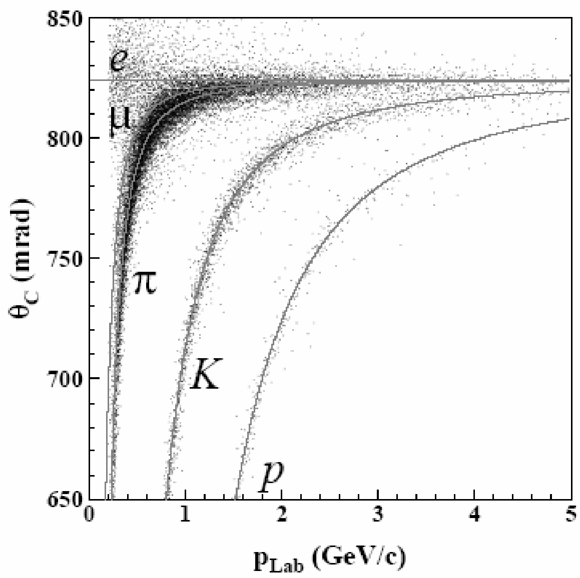
- quartz radiator, refractive index n=1.474
  - $\beta_{threshold}$ =0.68, γ = 1.36 $\Rightarrow$ $p_{threshold}$ = 0.92 $m_{\mu,\pi,K,p}$
  - N_γ (β~1, normal incidence, at the pmts) ~ 30
- radiator thickness, 17.5 mm
- radial extent including support structure, 8 cm
- avg. material in front of calorimeter incl. support structure, 21%X_0
- "standoff" distance of pmt array, 117 cm

BaBar DIRC Performance

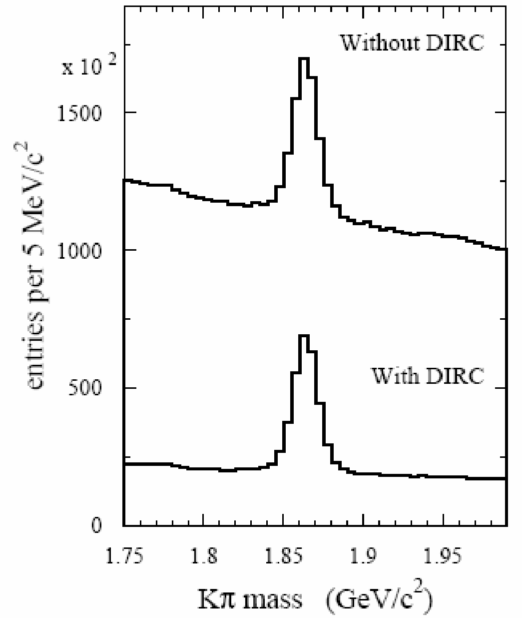
- Single photon resolution ~9.6 mrad
  - 1 mrad track error
  - 2-3 mrad photon transport along bar
  - 4.1 mrad bar thickness
  - 5.5 mrad PMT size
  - 5.4 mrad chromatic – n(λ)
- Avg. θ_c resolution per track ~2.4 mrad
- Photon time of arrival ~1.6 ns

BaBar DIRC Performance

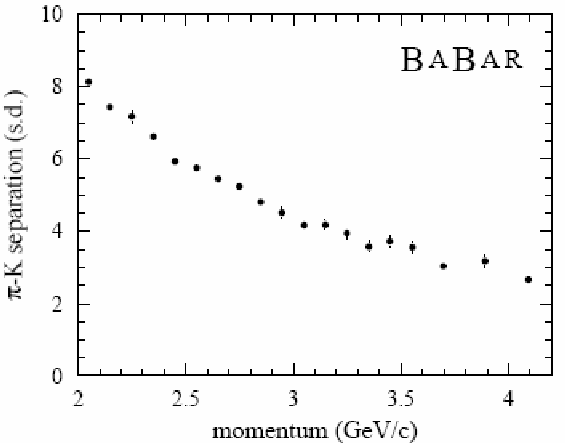
- B, D, τ, physics at asymmetric e^+(3.1 GeV) e^-(9.0 GeV) PEPII collider
- BR(B^0 -> K^+ X) ~ 78%



Fitted Cherenkov angle in multihadron events; solid lines are predictions

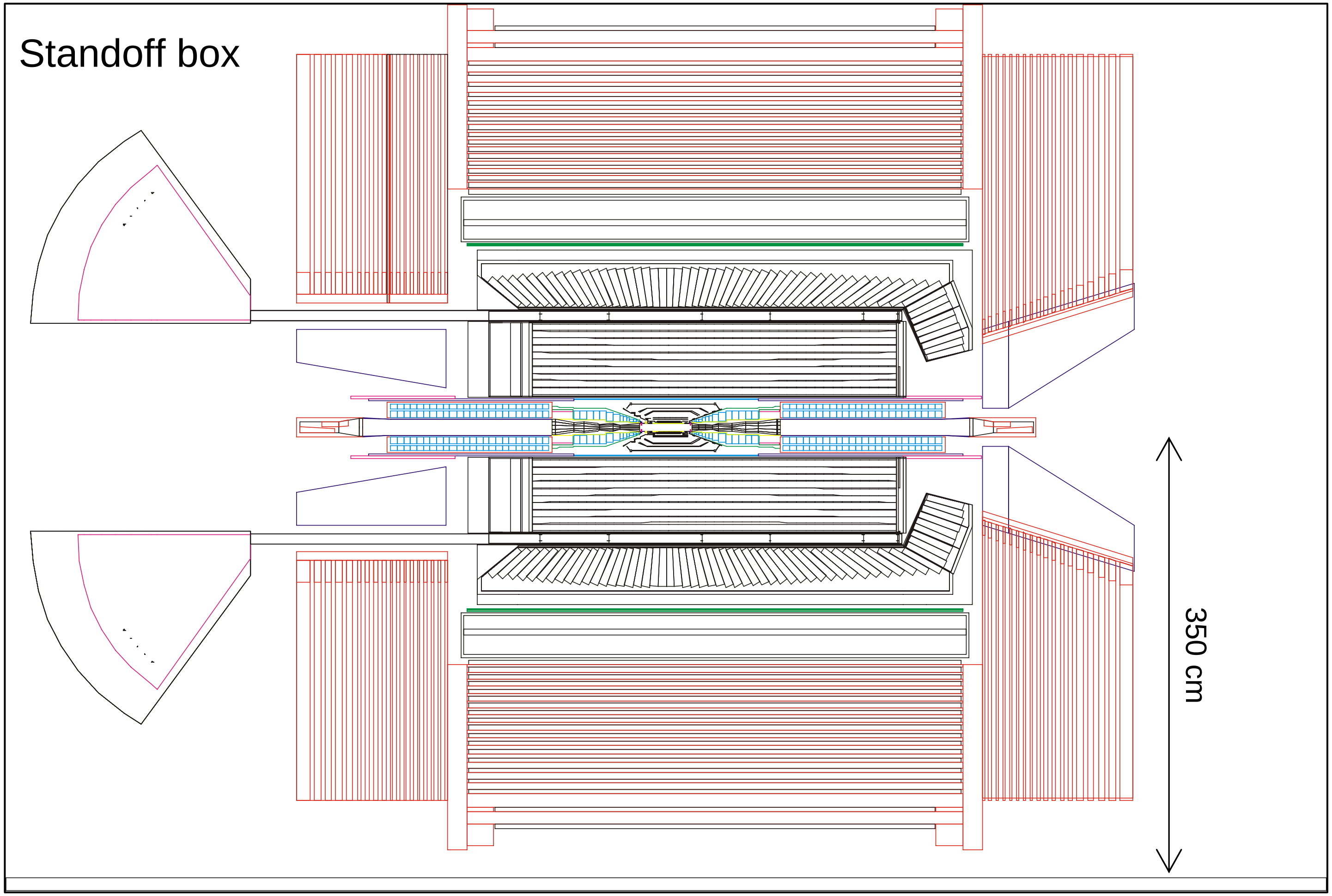


$K\pi$ invariant mass spectrum for kinematically reconstructed D^0 from $D^* \rightarrow D^0\pi$ w/ and w/o DIRC for kaon ID



K-π separation for tracks in kinematically reconstructed D^0 from $D^* \rightarrow D^0\pi$

DIRC at BaBar



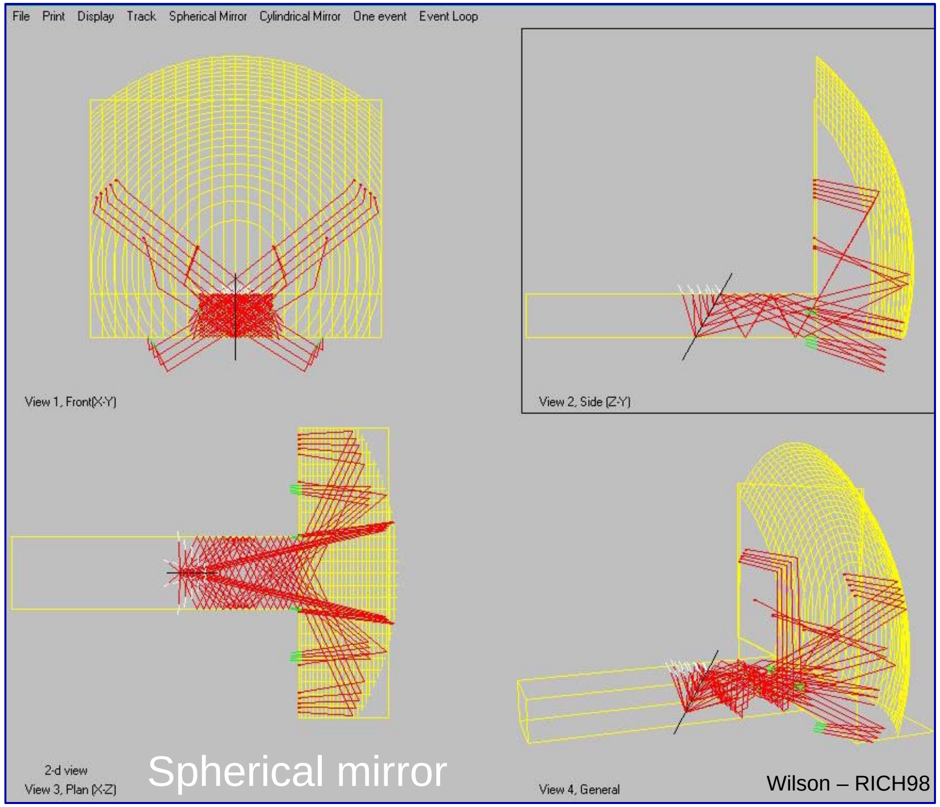
BaBar DIRC Drawbacks

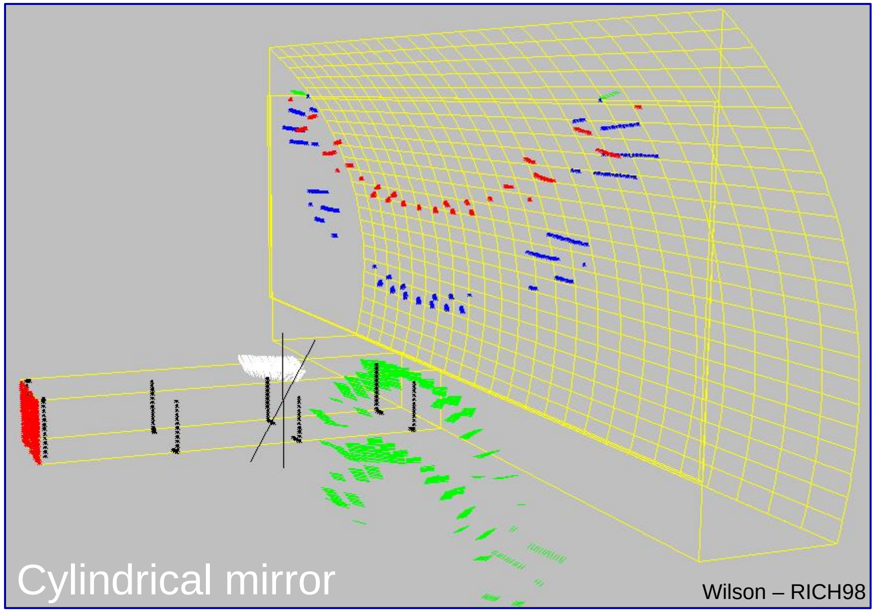
- Proximity focusing $\Rightarrow$ large “standoff” tank
  - Quartz penetrates flux return
  - PMTs require both compensating magnetic field and massive passive shielding
- Single photon angle and timing
  - Large PMT and bar size contributions to angle resolution
  - Timing resolution not sufficient to reduce large chromatic error – need 50-100 ps
- Large water tank $\Rightarrow$ background sensitivity
  - Okay up to luminosity 4×10^{34} $cm^{-2}s^{-1}$
  - Need design change for higher luminosity (SuperBaBar ~ 10^{36} $cm^{-2}s^{-1}$)

Focusing DIRC

- Focusing reduces imaging system size
- Focusing and smaller photodetector elements removes bar size contribution to the resolution
- Reduced time transit spread improves timing resolution; reduces chromatic uncertainty
- Investigated for BaBar/Belle upgrades and LC
  - T. Kamae *et al*. NIM A382 (1996) 430 - *TK96*
  - RJW (Colorado St.), NIM A433 (1999) 487 - *RW99*
  - Y. Enari *et al.* (Nagoya), NIM A494 (2002) 430 - *YE02*
  - B. Ratcliff (SLAC), ICFA Instr. Bull. 22, 03 (2001); NIM A502 (2003) 211 - *BR03*
  - J. Va'vra *et al.* (SLAC), NIM A518 (2004) 565 - *JV04*
  - A. Drutskoy *et al.* (Cincinnati), Super B Factory Workshop 2005 - *AD05*
- Very good time resolution allows direct Cerenkov angle measurement
  - Time of Projection (TOP) may remove need for focusing altogether (YE02)

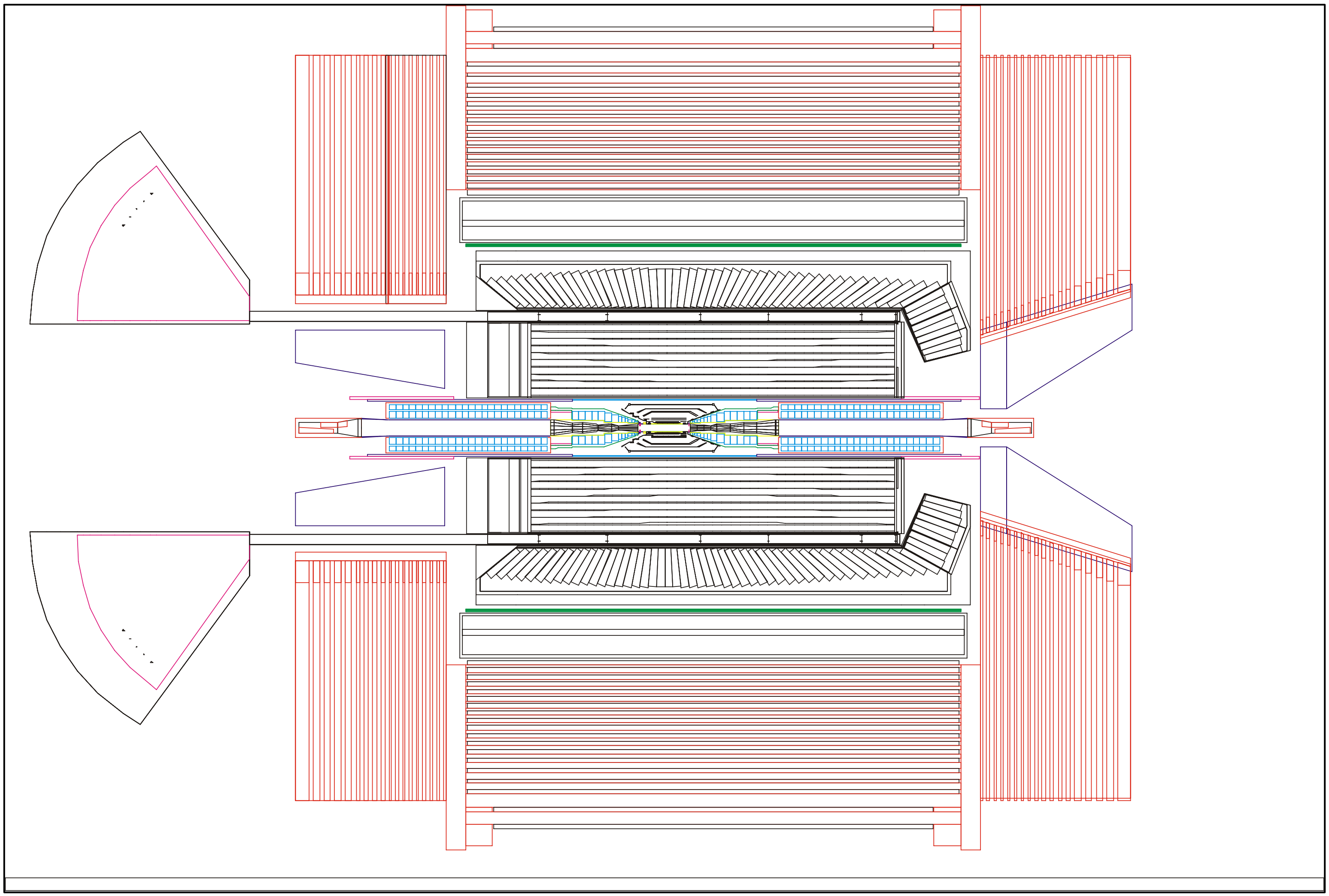
Focusing DIRC Concept



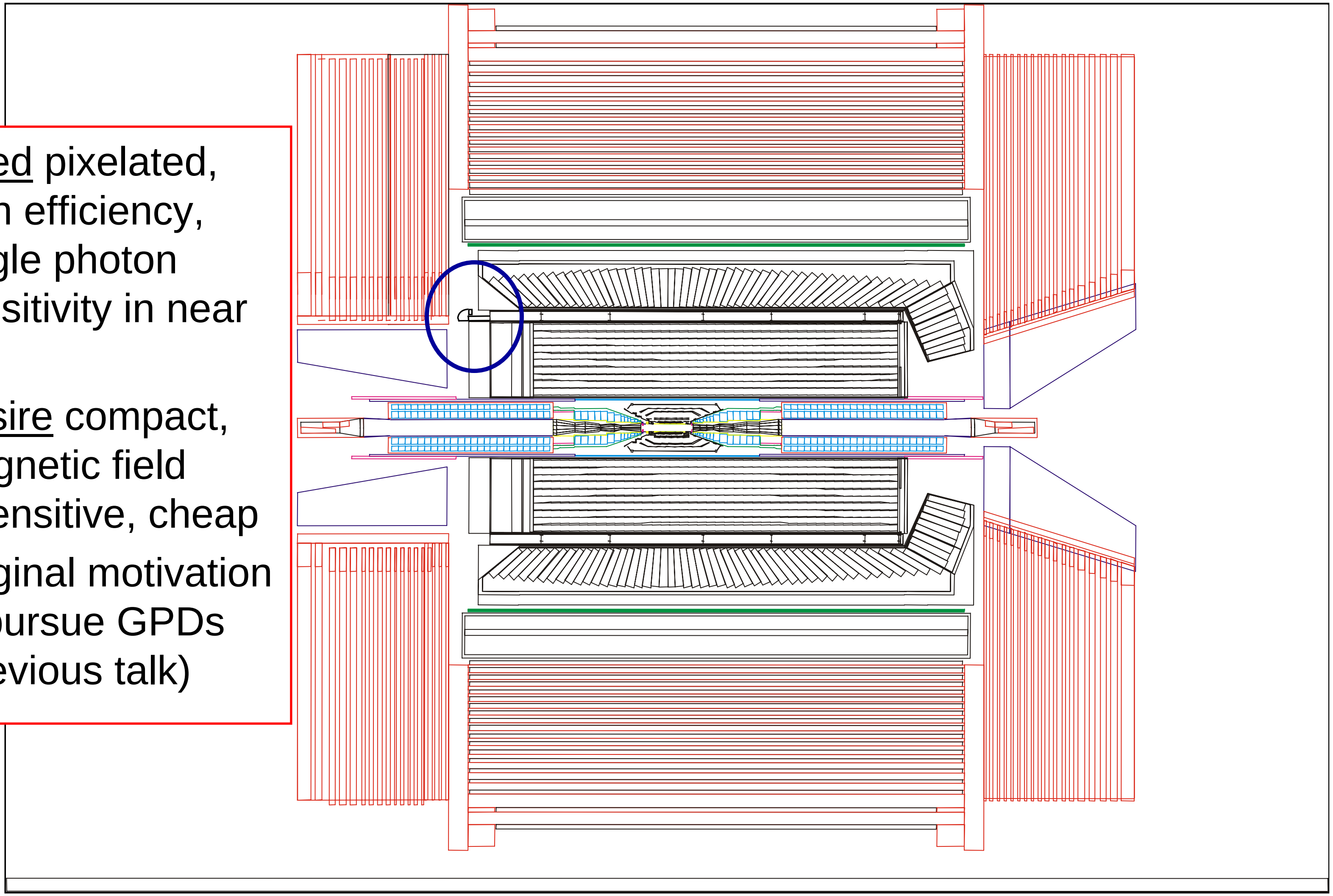


- Two position measurements and timing over-constrain two Cherenkov angles at single p.e. level
- Focusing structure – back-silvered quartz block

DIRC at BaBar



Focusing DIRC in BaBar



- Need pixelated, high efficiency, single photon sensitivity in near UV
- Desire compact, magnetic field insensitive, cheap
- Original motivation to pursue GPDs (previous talk)

Focusing DIRC Performance Limit

- Maximum momentum for separation by n_σ standard deviations:

$$p_{\max} = \left(\frac{\beta^2 \Delta m^2 \beta_t \gamma_t N_\gamma^{1/2}}{2 n_\sigma \sigma_\theta} \right)^{1/2}$$

- E.g. for 3σ π-K separation in 18 mm quartz

$$p_{\max} = 0.14 \left(N_\gamma^{1/4} \big/ \sigma_\theta^{1/2} \right)$$

BaBar-DIRC (N_γ~50; σ_θ~9.6 mrad) $\Rightarrow p_{max} \approx$ 3.8 GeV/c for

  - Similar to measured value

- JV04 estimate σ_θ~4 mrad achievable in principle with 50-100 ps timing, if also assume bar thickness (N_γ) increase by ~50%

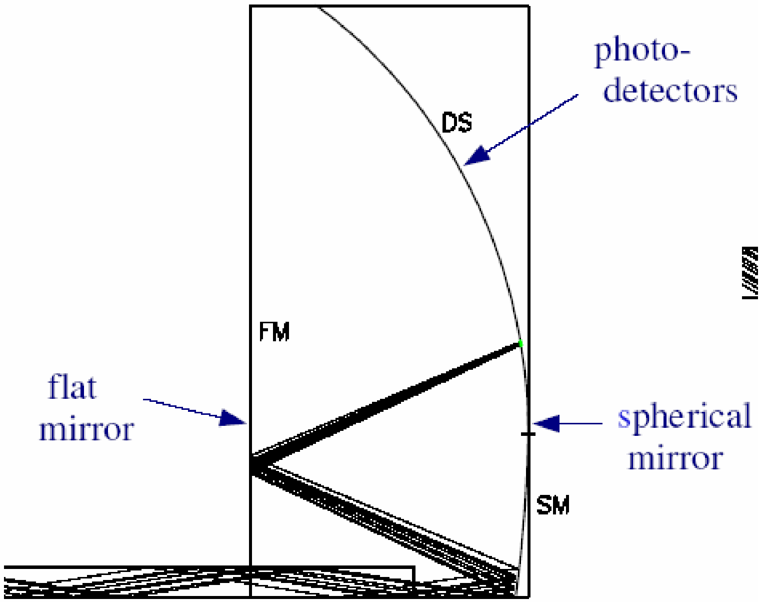
$\Rightarrow$ 3σ π-K separation limit ~ 6-7 GeV/c

SuperBelle Concept

Drutskoy/Kinoshita/Markus/Schwartz (Cincinnati), Super B Factory Workshop 2005

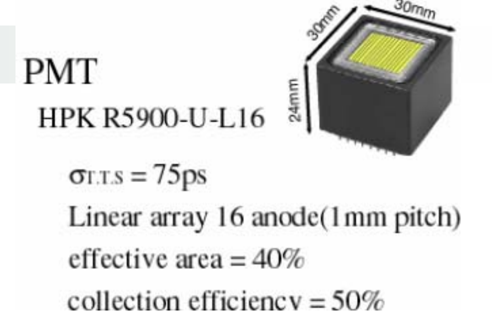
- 16 x 34 x 42 cm^3 boxes filled w/ 20l water
- 12 boxes in azimuth
- 12 BaBar-like quartz bars per box
- 10 x 42 cm^2 spherical mirror
- Wall of 6 x 6 mm^2 PMTs (3000/box)

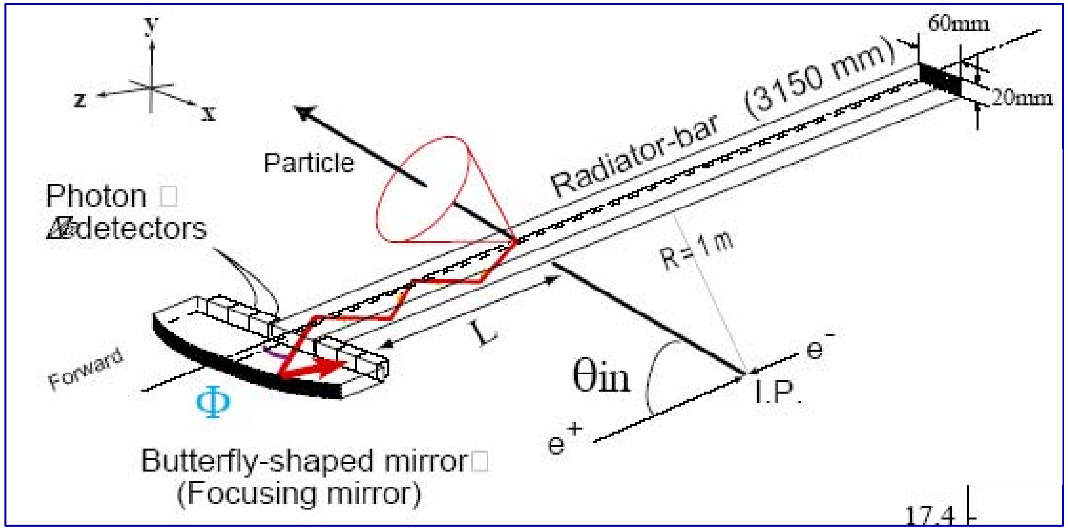
- Simulation:
  σ_t~50 ps; group velocity known to 0.5%;
  <1% noise/channel
  $\Rightarrow$ > 4σ π-K separation at 4.5 GeV/c

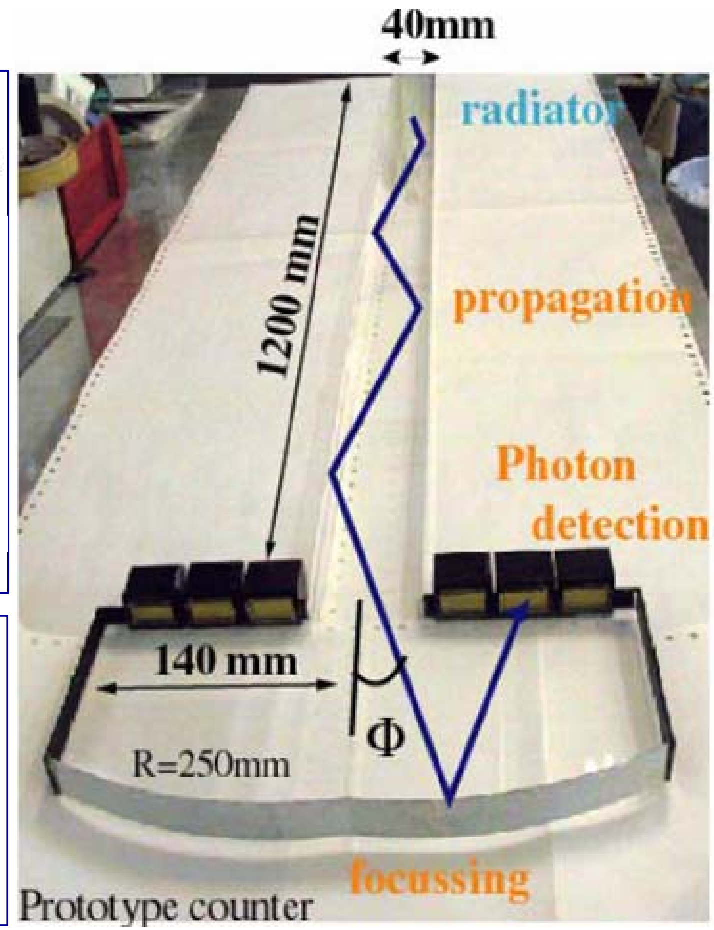


Time of Propagation Counter

Y. Enari et al. NIM A 494 (2002) 430-435







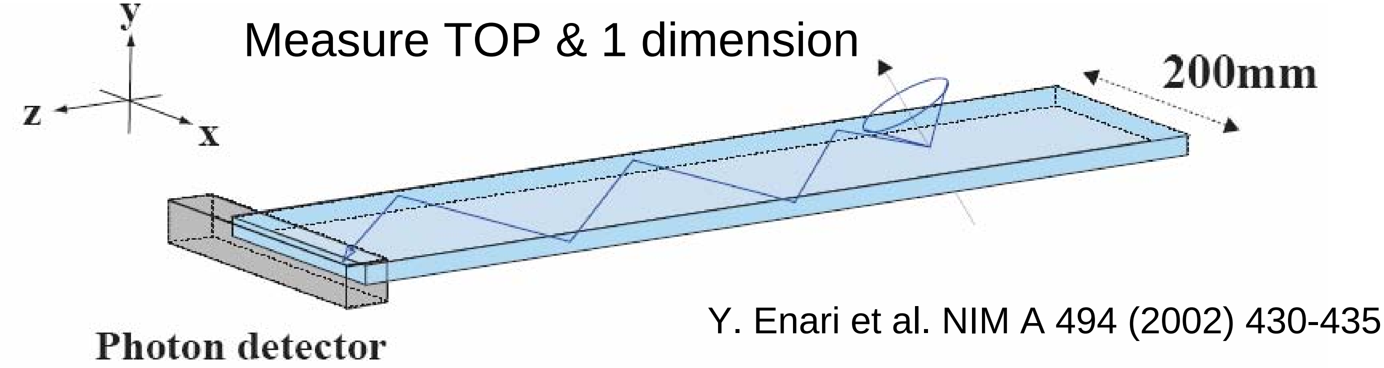
Beam test: σ_θ~10.6 mrad at 3 GeV/c with limited acceptance

Expect produce N_γ ~ 30 ⇒ σ_t~1.9 mrad

~ 6σ at 3 GeV/c

~ 3.4σ at 4 GeV/c

Simplified TOP



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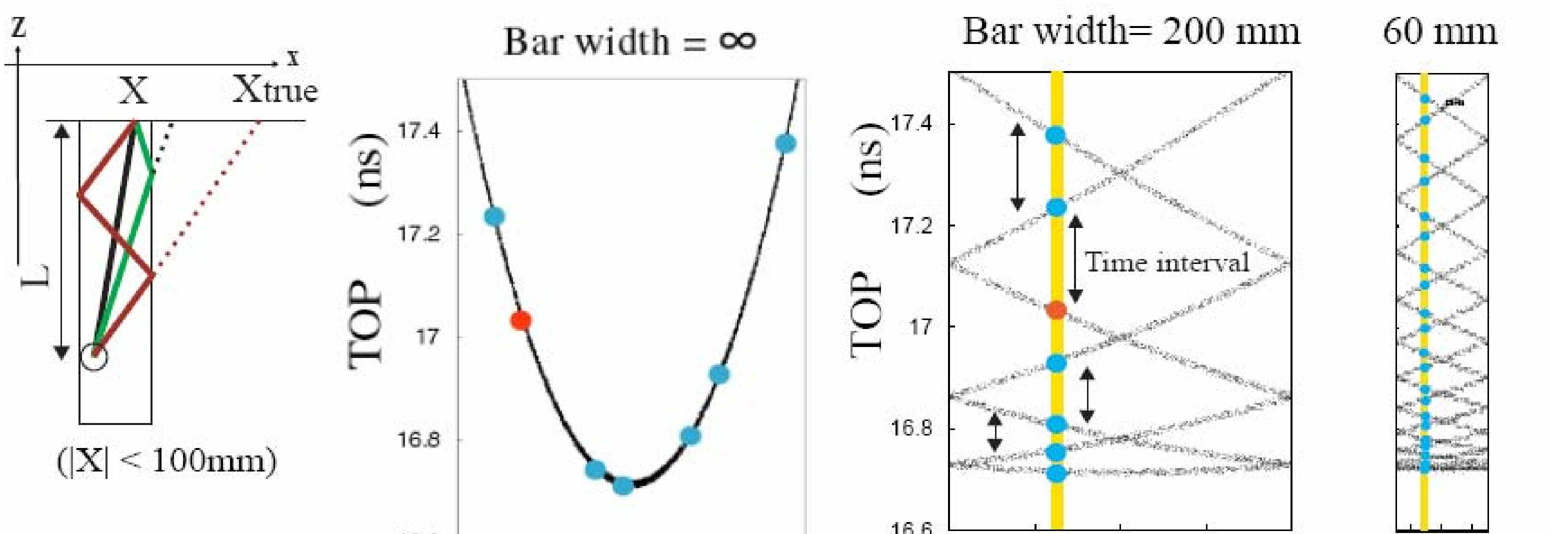
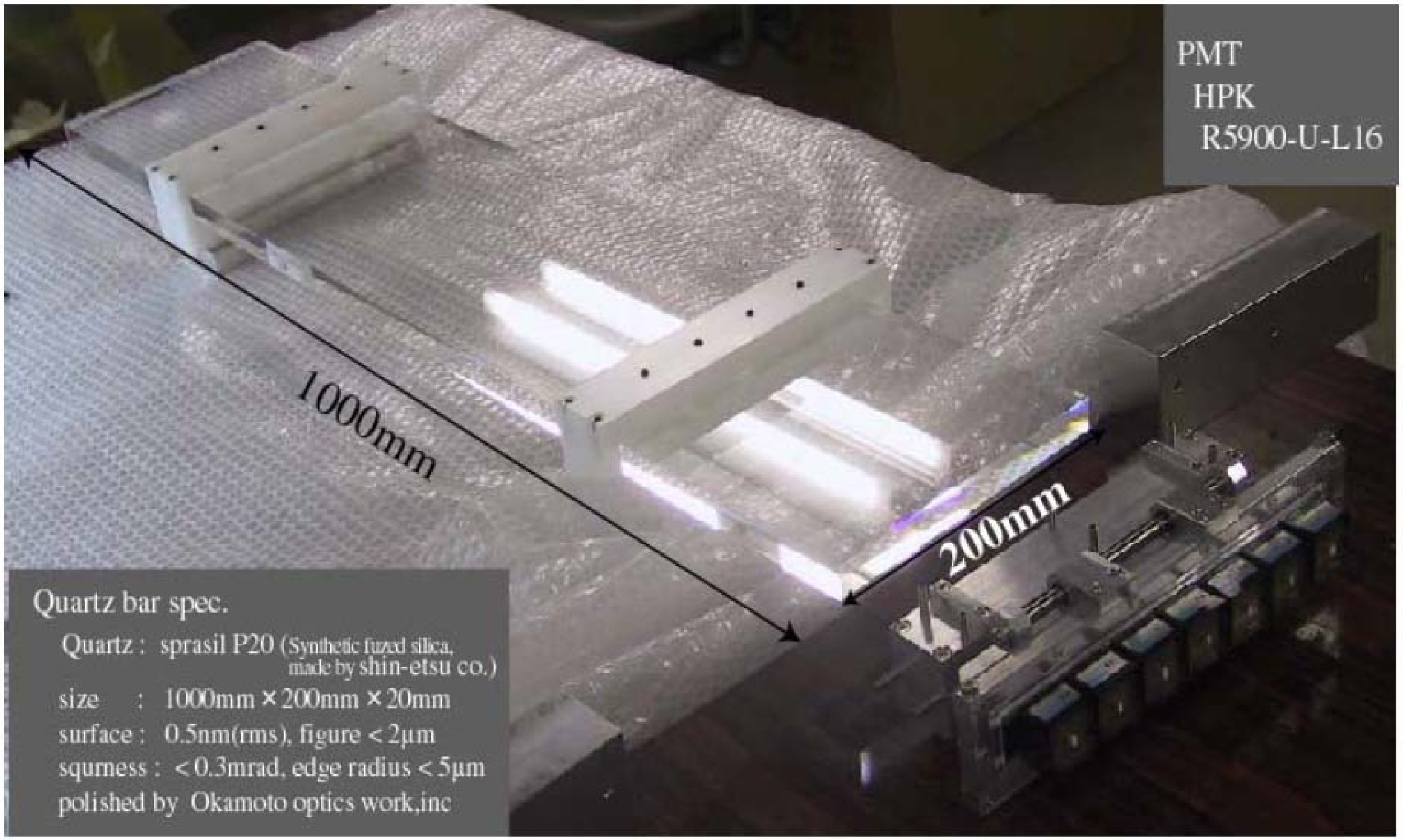


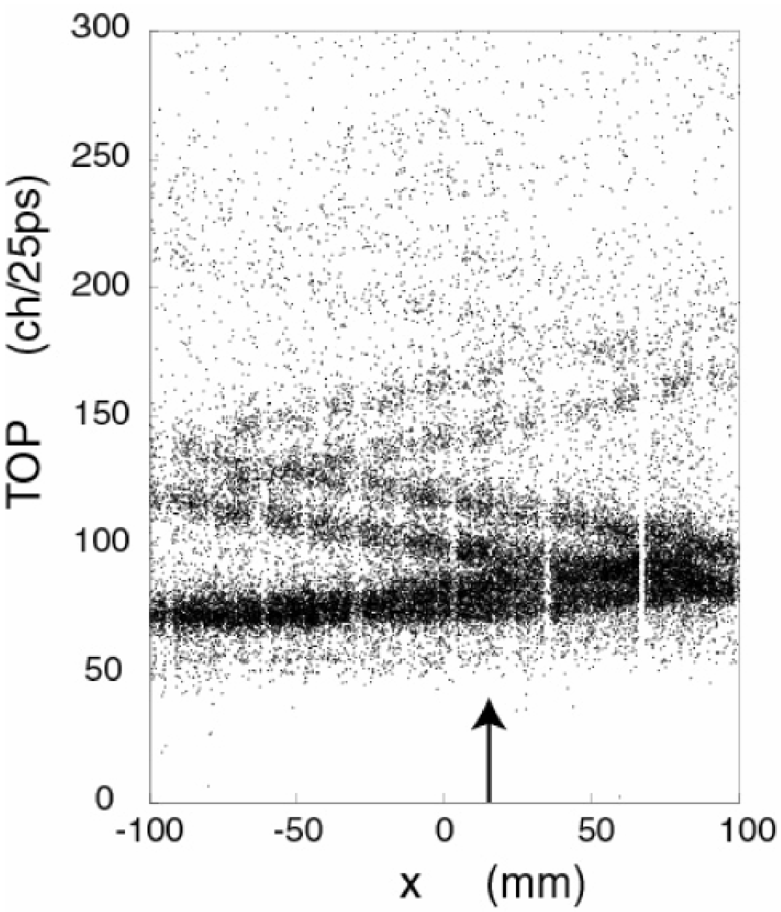
To measure
X instead of Φ

TOP Prototype



Y. Enari et al. NIM A 494 (2002) 430-435

TOP Prototype Beam Test

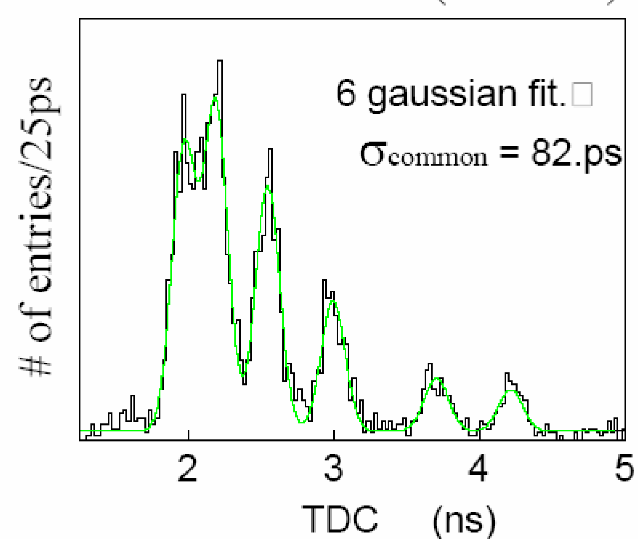


Beam test @ KEK-PS $\pi 2$ line

momentum p = 3GeV/c, π^-

L = 0.3m, $\theta_{in} = \phi_{in} = 90°$

TDC distribution (x=11.3mm)



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LC Detector Performance: dE/dx - DIRC

500 GeV ttbar	L2 (TPC)	S2+DIRC
2-σ Kaon eff./purity, %	38/73	48/96
3-σ Kaon eff./purity, %	13/86	42/99
2-σ proton eff./purity, %	19/71	63/99
3-σ proton eff./purity, %	12/90	61/100

- From an old study; crude generator level simulation
- Old US concepts: Large (TPC tracker – 4.5% dE/dx)
  and Small (Silicon tracker – no dE/dx)
- S2+DIRC considerably better than L2 TPC, especially for protons

Conclusions

- Renewed interest in hadron ID at this meeting – used with vertex charge?
- Still no strong motivation but most previous studies are old and crude
- Very good experience with BaBar DIRC
- State of the art in photodetectors has advanced
- Focusing or TOP DIRC could provide a compact system with good hadron ID over limited momentum range
- Should pursue physics justification & detector development (especially photodetectors, which overlap with muon system and calorimetry)