Detector Design Considerations for a Symmetric τ/c Factory

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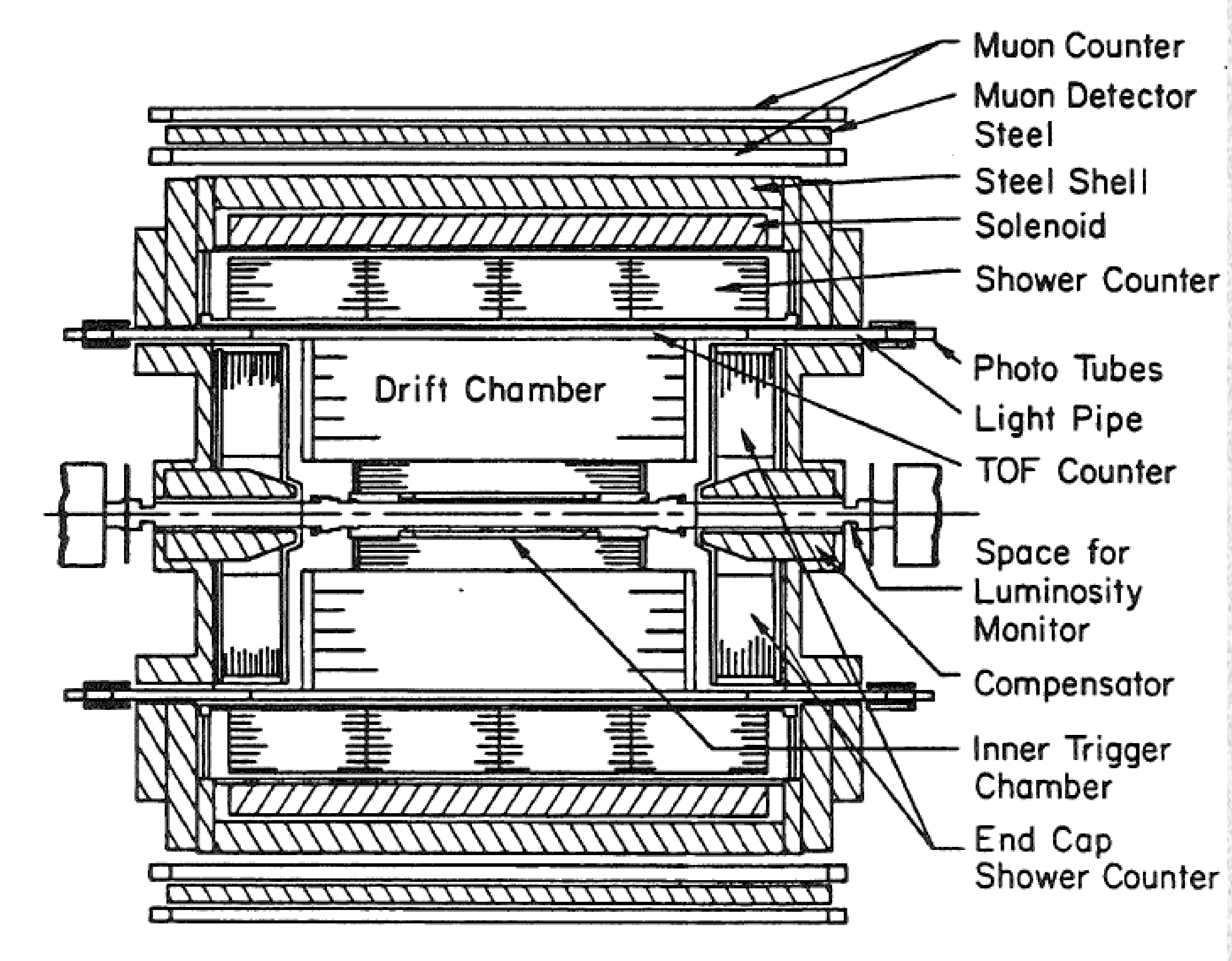
Elba τ/c Workshop

May 27. 2013

This feels like “déjà vu all over again” *

- The Mark III detector for SPEAR (1978)
  - Based on the flux return of the SPEAR Magnetic Detector (called Mark I, after the fact)
  - The solenoid coil was also to be reused, but was found to have been damaged in storage
  - Replaced with larger radius solenoid (normal-conducting (0.4T))
  - Compensating solenoids
  - Beam pipe 75mm radius (1.5mm Be)
  - Inner trigger chamber (4 wire layers)
  - DC 1.14m inner radius
    2.337m length
  - TOF scintillators
  - Pb/MWPC shower counter
    - Placed inside of coil
  - Al tube/wire muon counters (two layers)

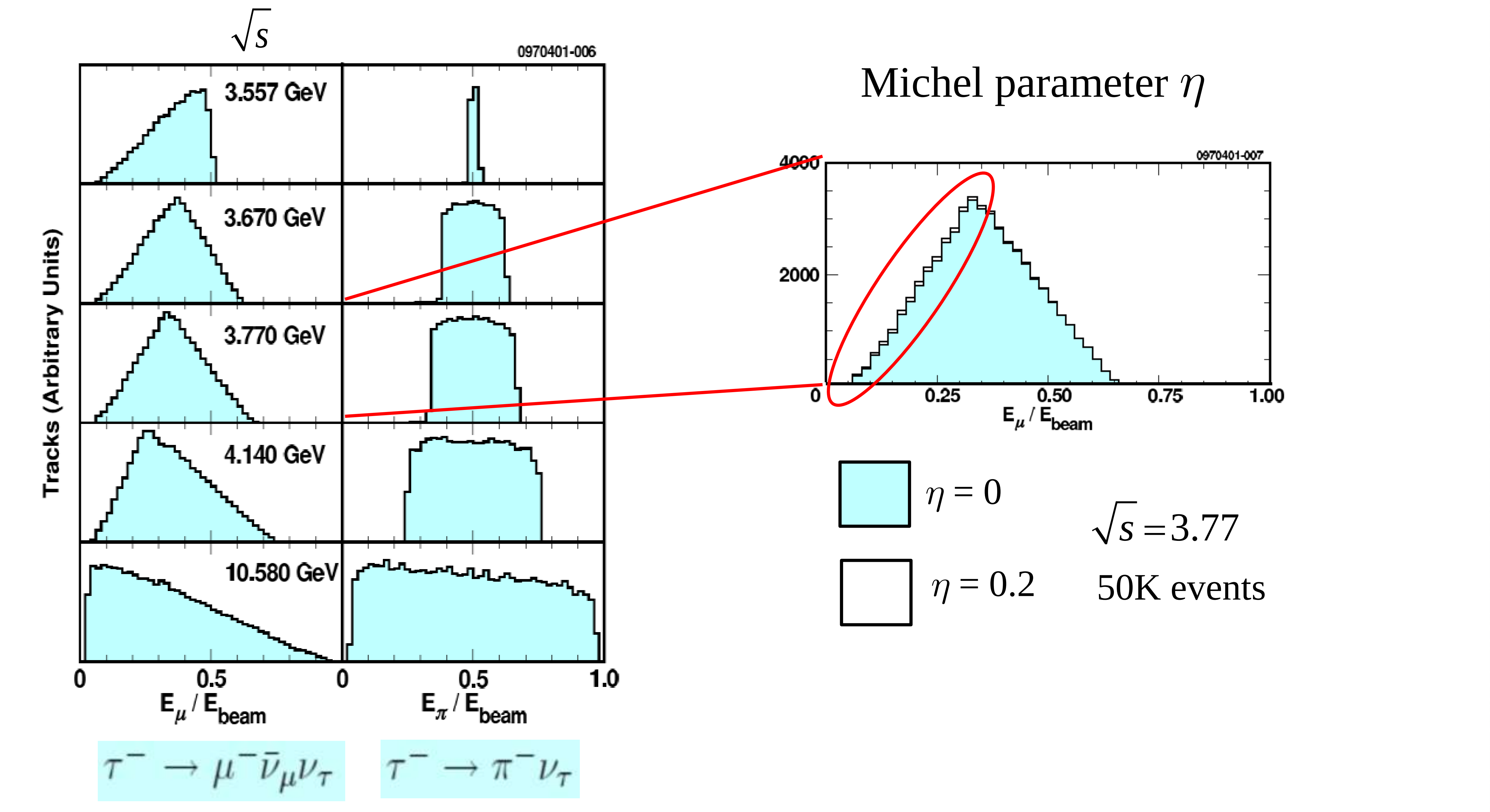


* Yogi Berra
(NY Yankees catcher and oft-cited philosopher)

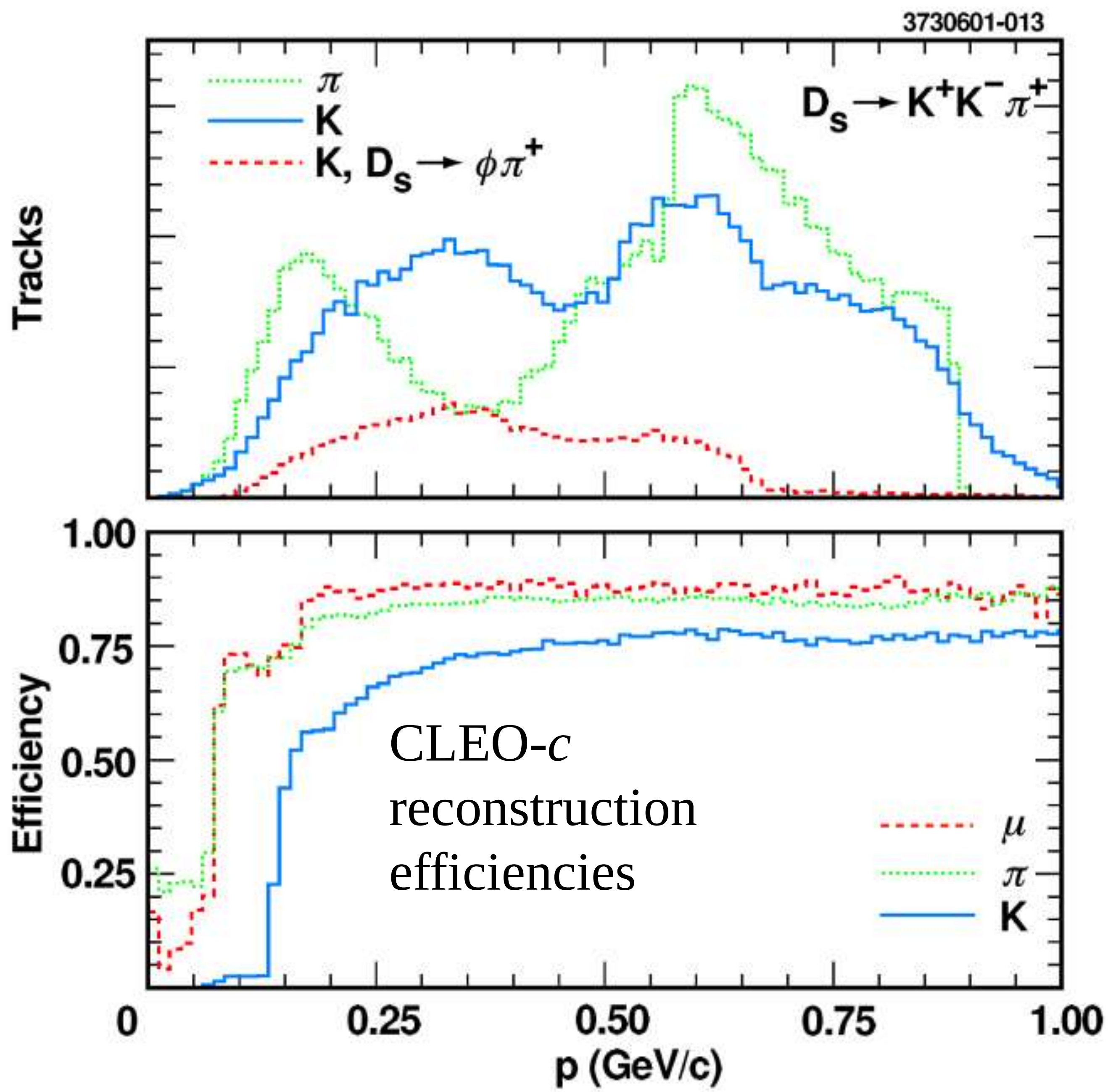
Event characteristics

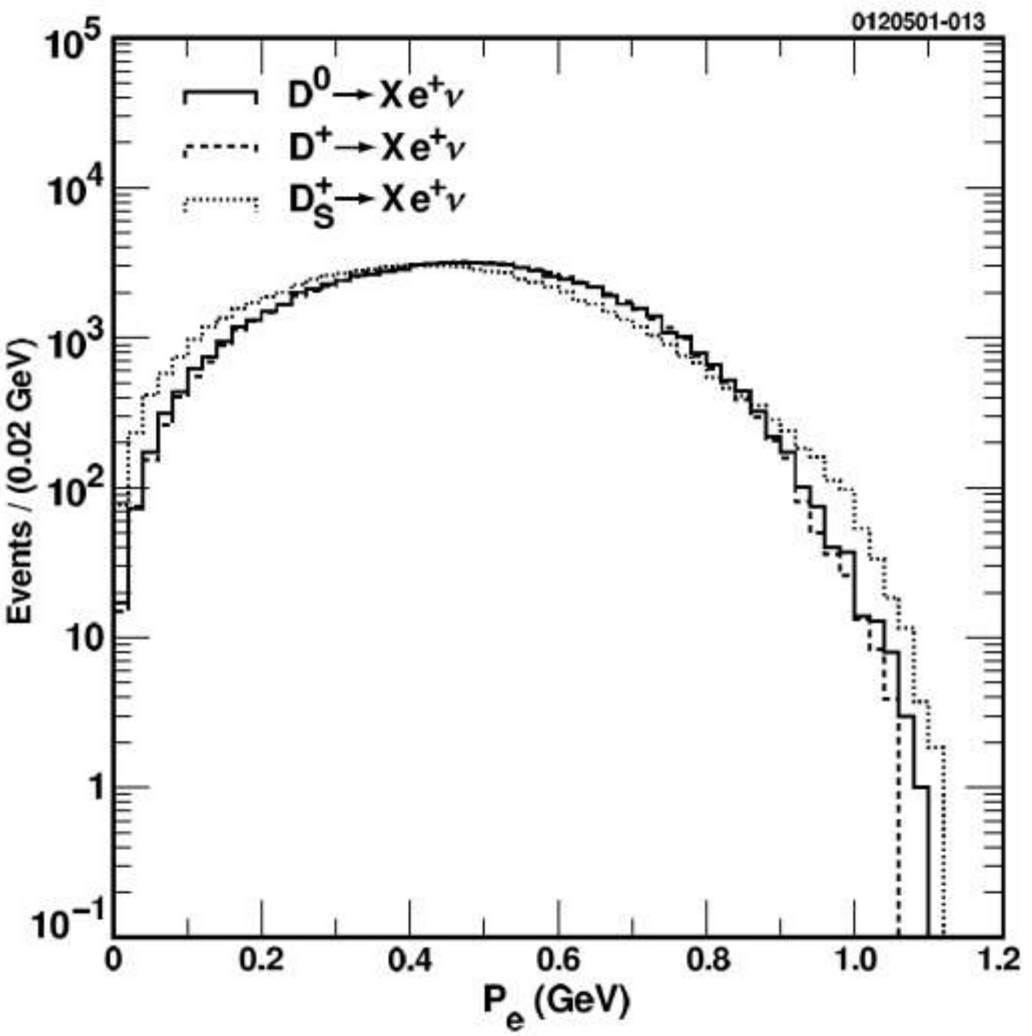
- Topics of interest (general)
  - Charmonium states (J/ψ, $\psi(2S)$, ……
  - Charm production and decay ($\psi(3770)$, 4.03, 4.16, (Λ_c ?)
  - Tau production and decay (for some modes below charm threshold, at best e^- polarization
- The operational situation is different from that at the *B* factories, where a large majority of running time was spent at the $\Upsilon(4S)$, with much less time at the other Υ resonances
  - At a τ/c factory different physics $\Rightarrow$ different CM energies $\Rightarrow$ prioritization of topics
- Detector requirements must be matched to event characteristics, with emphasis on what is required to attack the most important physics objectives (τ LFV, *CP*V in *D* decay, …….)
  - Efficient exclusive state reconstruction (+ tagging efficiency and purity) and background discrimination
    - Best possible solid angle coverage and resolution for
      - Vertex reconstruction (?)
      - Charged particle momentum measurement
      - Particle identification (dE/dx, TOF, Cherenkov, range)
      - Photon reconstruction (energy and position resolution)

τ decay two and three body momentum spectra



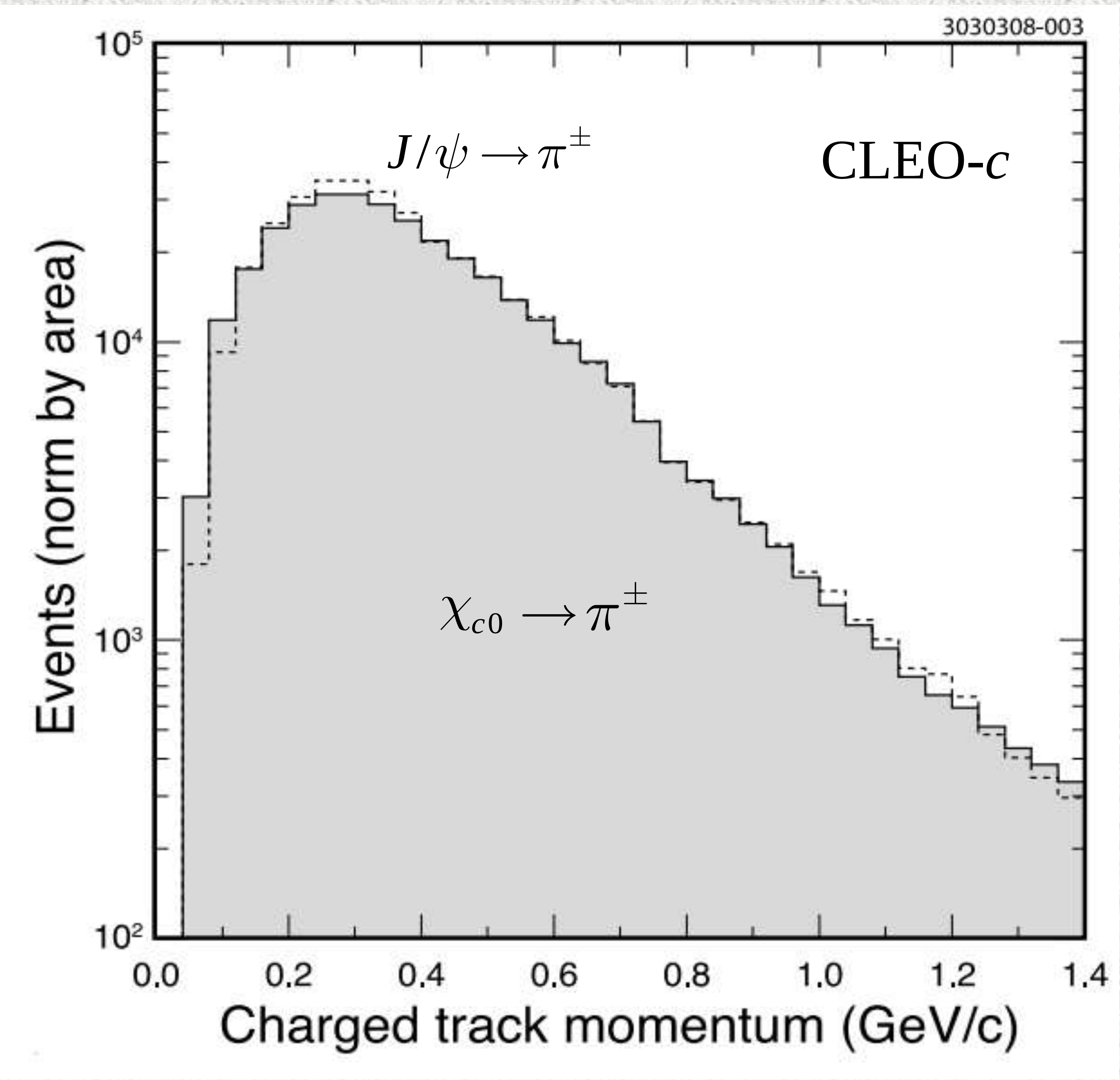
D_s^+ decays – typical momentum spectra





semileptonic D decay:
electron momentum spectra

Inclusive $\pi^{\pm}$ spectra from $J/\psi \to \pi^{\pm}$ and $\chi_{c0} \to \pi^{\pm}$ decay



Event characteristics

- Topics of interest ($\Rightarrow$ different CM energies $\Rightarrow$ prioritization of topics)
  - Charmonium states
  - Charm production and decay
  - Tau production and decay
- Detector requirements
  - Efficient exclusive state reconstruction (+ tagging)
    - Best possible solid angle coverage and resolution for
      - Charged particle momentum measurement: $.05 < p < 1.6$ GeV/c
      - Particle identification: $.05 < p < 1.6$ GeV/c
      - Photon, electron shower reconstruction: $0.02 < E_\gamma < 2.5$ GeV/c
    - Is vertex reconstruction important?

Comparison of τ/c and Super$B$ collider parameters

Parameter	Units	τ/c HER=LER	Super$B$ LER	Super$B$ HER
Luminosity	$cm^{-2}\ s^{-1}$	1.00E+35	1.00E+36	
CM Energy	GeV	4	10.58	
Beam Energy	GeV	2	4.18	6.7
Circumference	m	325.4	1183.2	
Boost		0	0.238	
β_x @ IP	cm	6	3.2	2.6
β_y @ IP	cm	0.06	0.0205	0.0253
σ_x @ IP	microns	17.69	8.87	7.21
σ_y @ IP	microns	0.088	0.036	0.036
Bunch length (full current, no IBS)	mm	4	5	5
Free space at IP	m	$\pm$0.3	$\pm$0.35	
Beam current	mA	1570	2440	1900
Bucket spacing	#	1	2	2
Bunch current	mA	3.10	2.66	2.06
Number of particles/bunch	#	2.11 E+10	6.6 E+10	5.1 E+10
Bhabha cross section (15-165°)	nb	871.7	124.6	
Beam lifetime (rough scaling for τ/c)	min	6.9	4.48	4.23
Depolarization time	sec	1435	1200	-
e^- Polarization	%	65	76	-

Overall dimensional constraints

Space between machine elements at the IP

- As β_y* and therefore bunch length has been decreased to increase luminosity, the closest focusing machine elements have been brought closer
- There is no apparent difference between symmetric and asymmetric machines

	SPEAR	TRISTAN	LEP	PEP-II	Super*B*	τ/c
β_y* (cm)	10	4-10	5	1.2	0.02	0.06
Free space (m)	±1.2	±2.3	±3.5	±0.2	±0.35	±0.3

"All airplanes have wings and all e^+e^- detectors have solenoids."

W. Toner

Coil aspect ratio

- Is the aspect ratio of the solenoid coil coupled to the symmetric/asymmetric configuration, requiring a different the partition of barrel/endcap technologies?

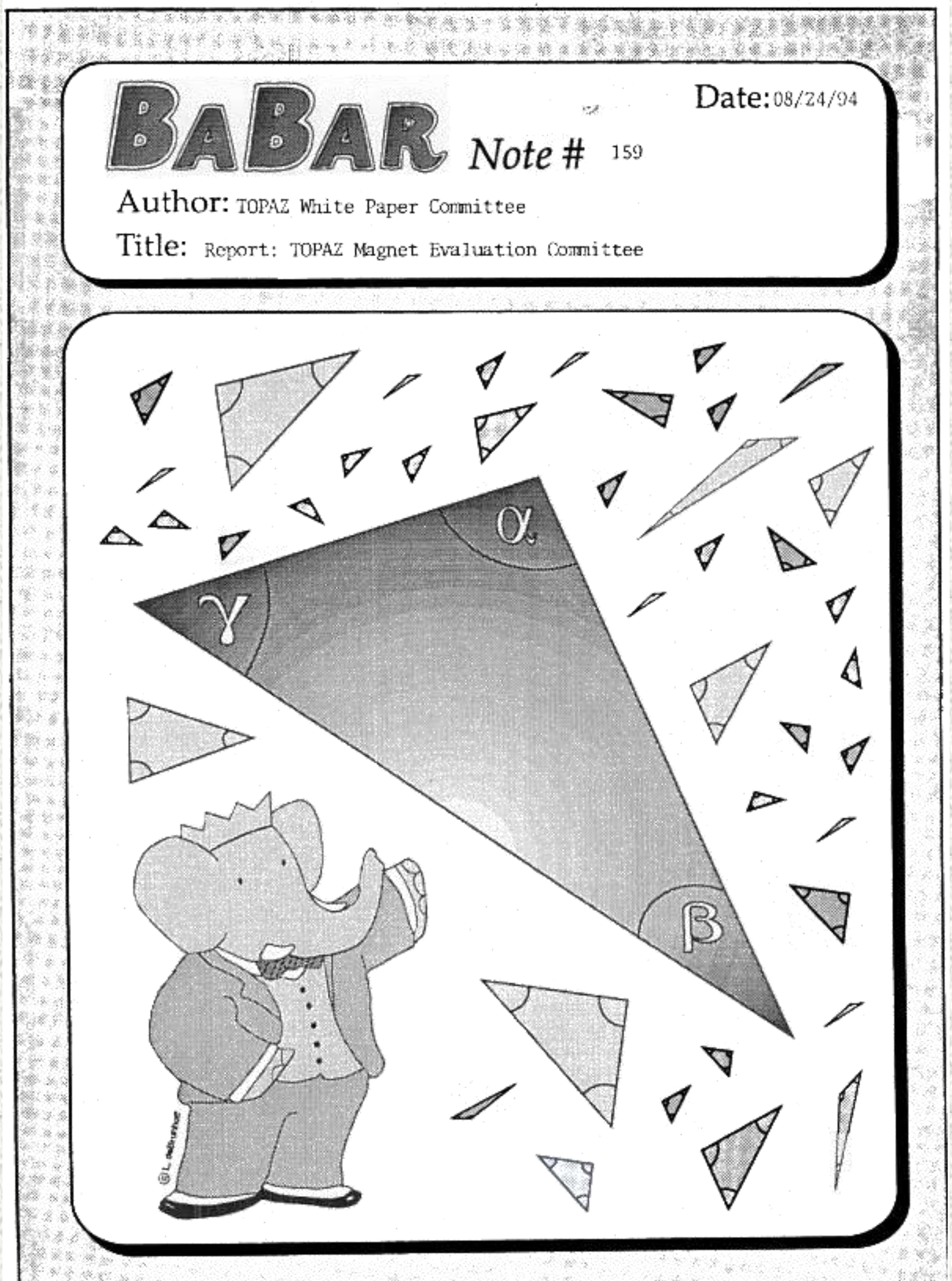
Cryostat dimensions	Mark III	BES III	CLEO-c	*BABAR*
Length (m)	3.47	3.91	3.5	3.85
Radius (m)	1.78	1.38	1.45	1.42

This feels like "déjà vu all over again", all over again

- In the early nineties, we were faced with the problem of designing, from scratch, *BABAR*, a detector for PEP-II, an asymmetric collider, under serious financial constraints
- The question then was whether an existing detector (read "solenoidal magnet and flux return") could be adapted as the basis of the new detector
  - All previous 4π detectors for e^+e^- colliders had been designed for symmetric collisions
- The current question is whether *BABAR*, designed for asymmetric collisions ($\beta\gamma$=0.56), can form the basis of a detector at a symmetric collider in the 3-4 GeV CM regime
- Much of the work done for the Super*B* detector in upgrading *BABAR* remains relevant

I will not present you with a "straw man" detector design, but will rather discuss the physics environment, survey detector system options and comment on geometry and integration questions

The *BABAR* TOPAZ White Paper Committee



BABAR Note # 159

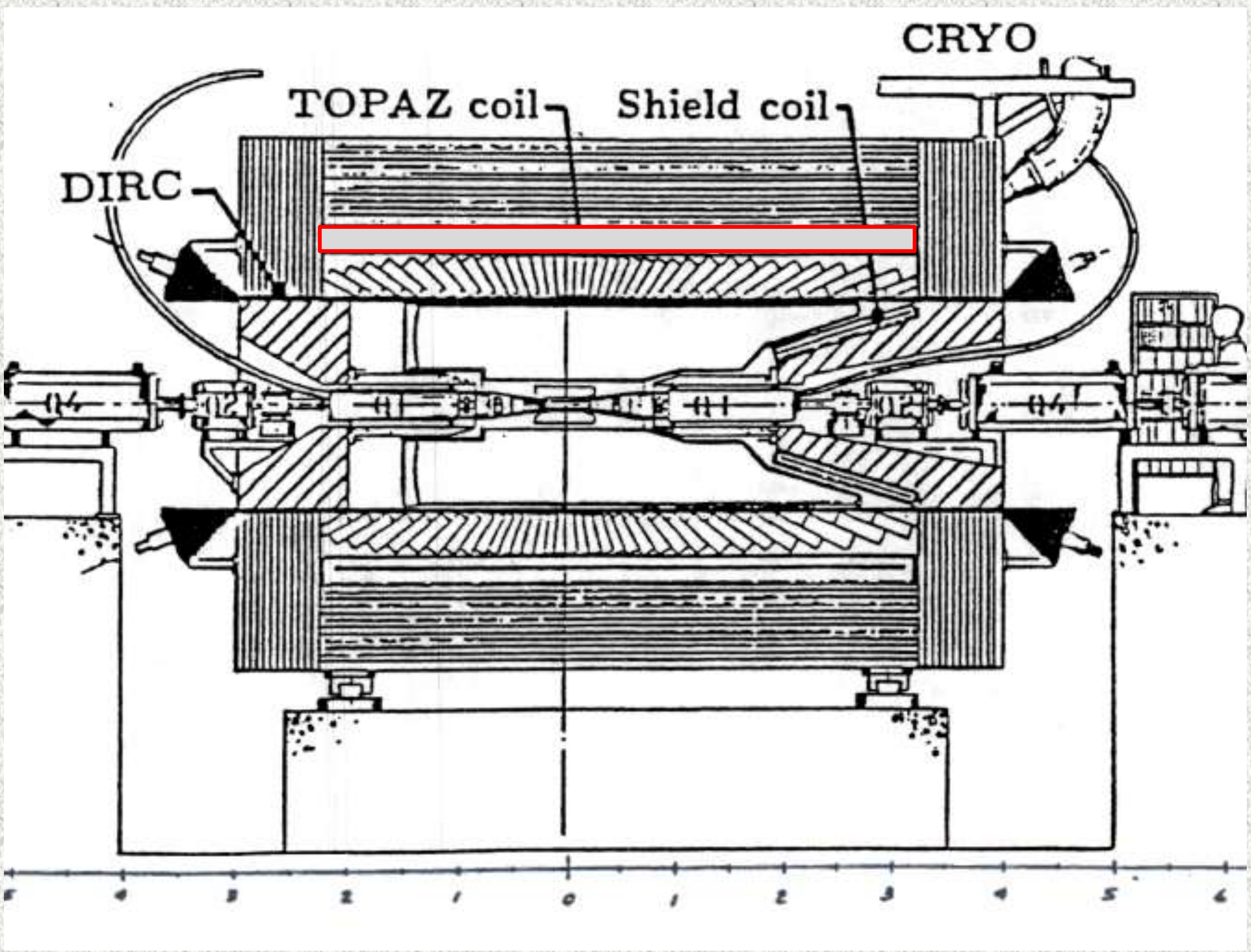
Date: 08/24/94

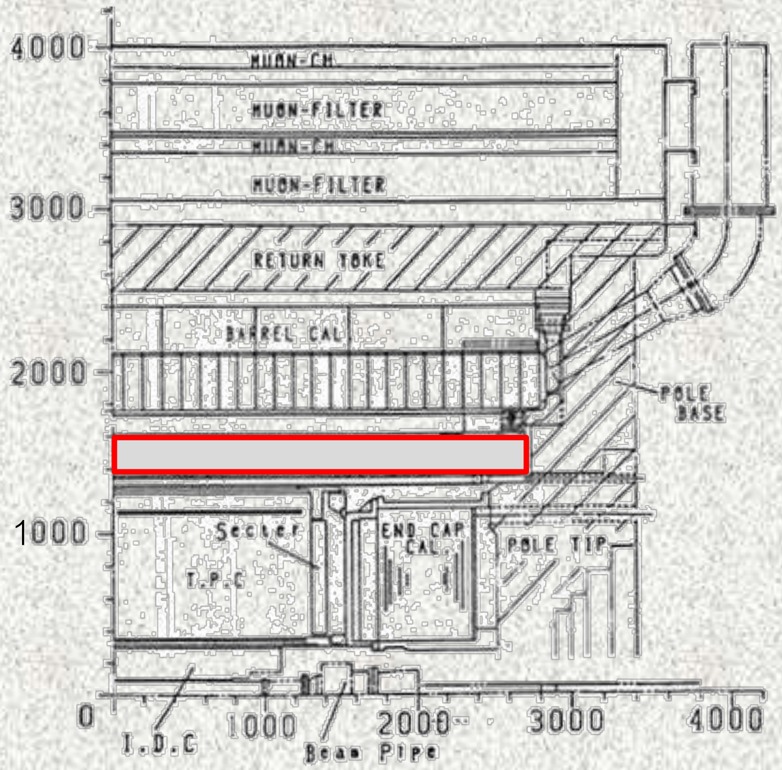
Author: TOPAZ White Paper Committee

Title: Report: TOPAZ Magnet Evaluation Committee

R. Aleksan
G. Bowden
W. Burgess
H. DeStaebler
W. Frisken
C. Hearty
V. Luth
B. Pedrotti
I. Peruzzi
F. Porter
J. Rasson
A. Seiden
W. Wenzel

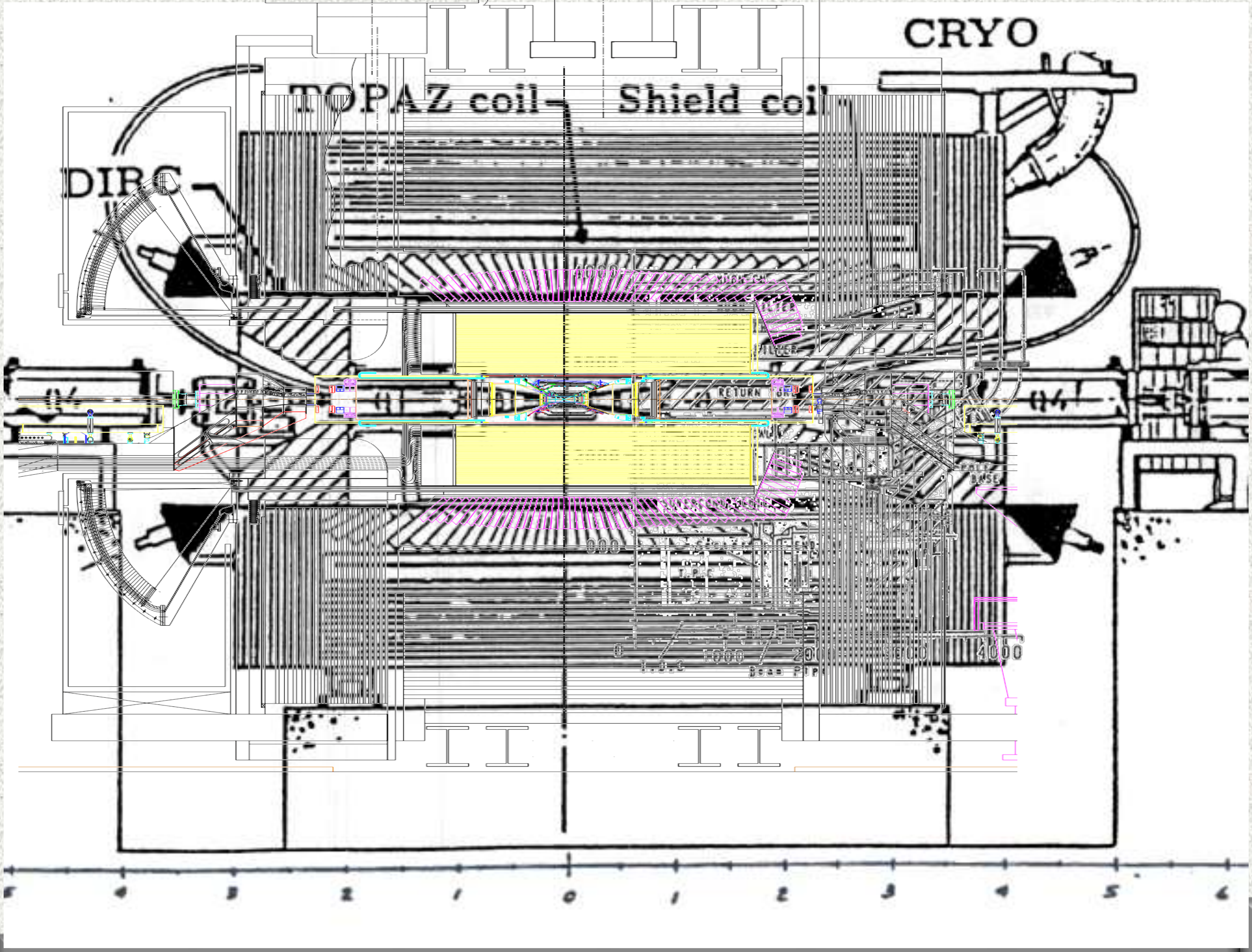
The White Paper Committer detector based on TOPAZ



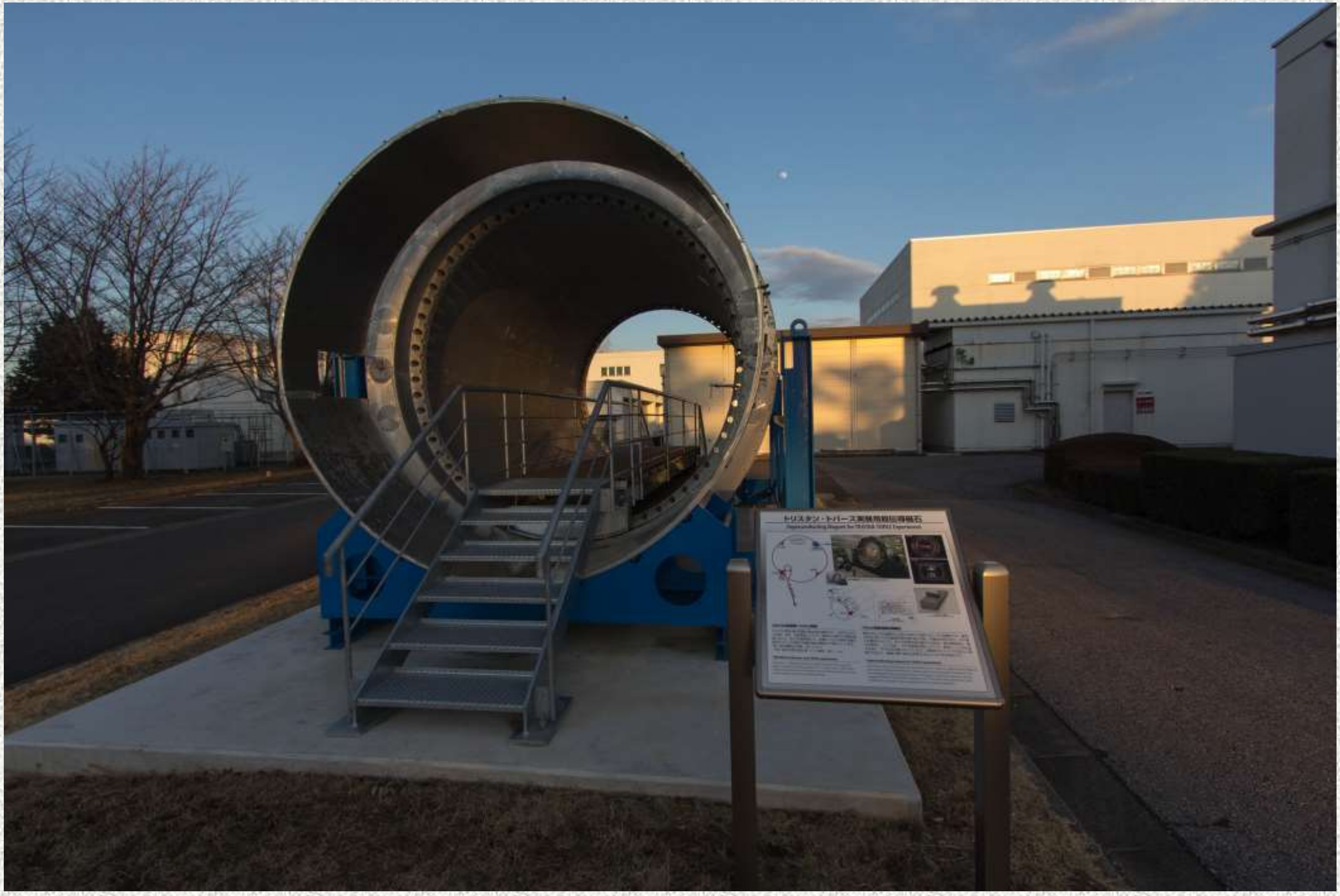


TOPAZ

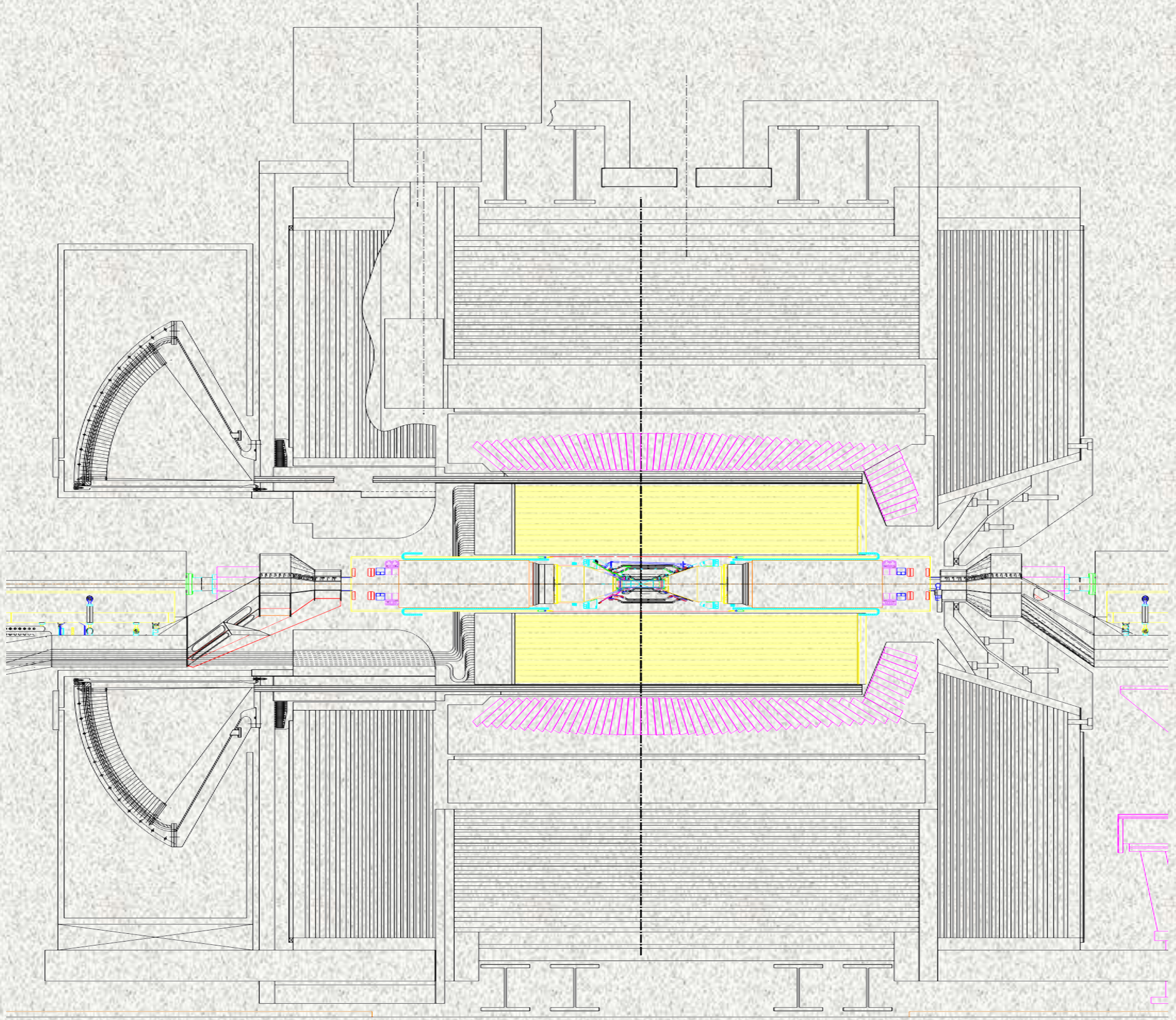
The White Paper Committee detector and *BABAR*



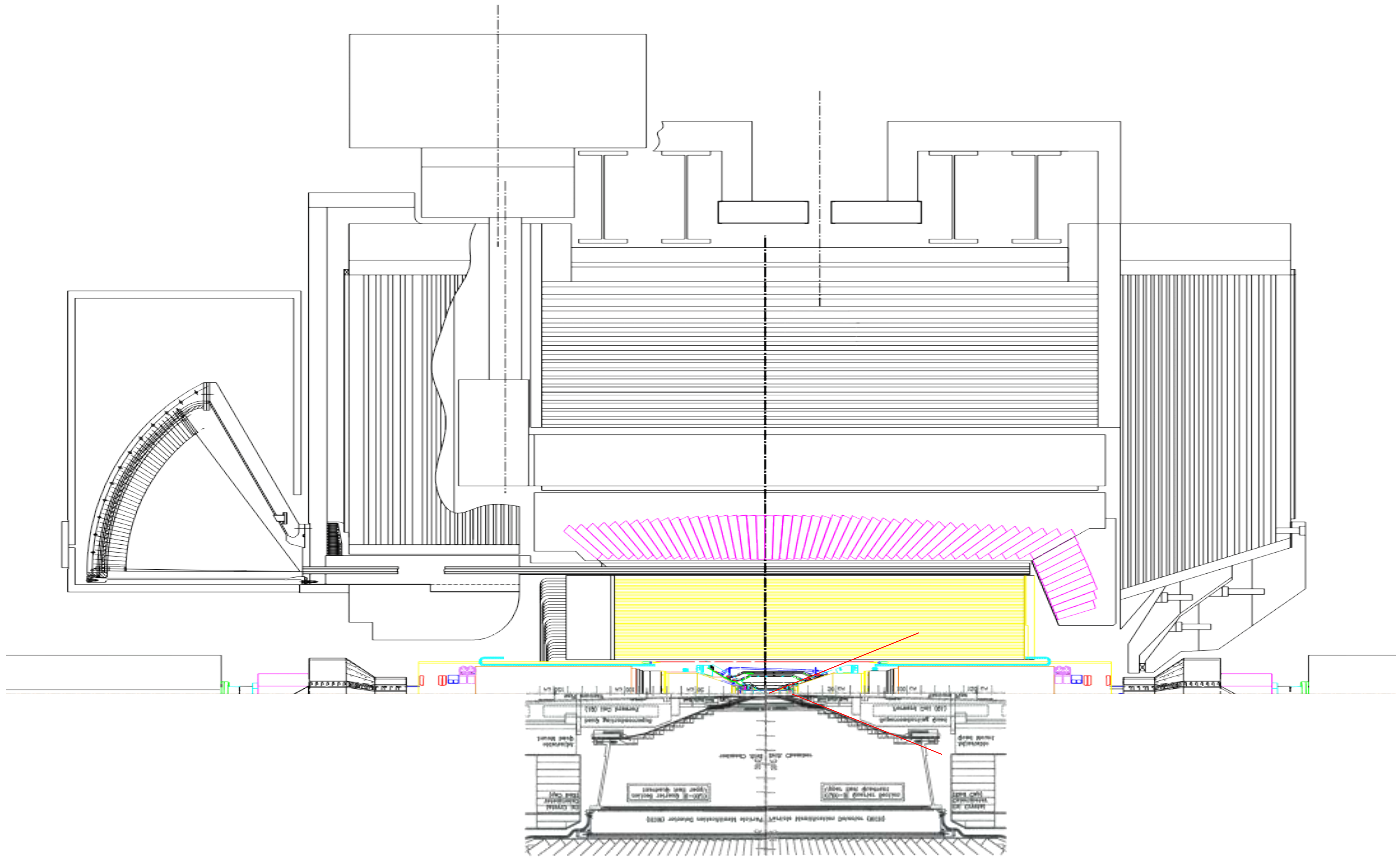
Current home of the TOPAZ solenoid



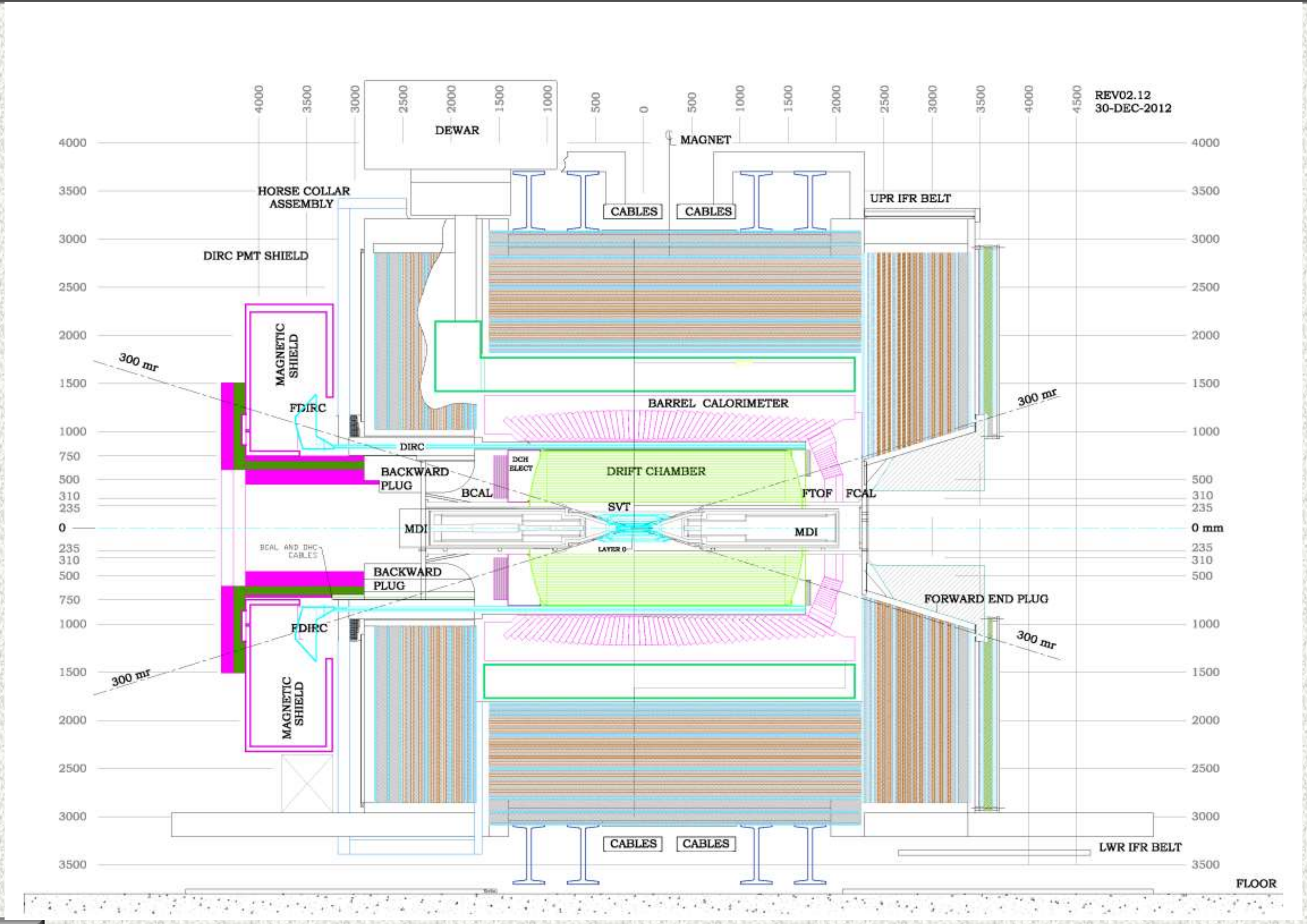
The actual *BABAR* detector



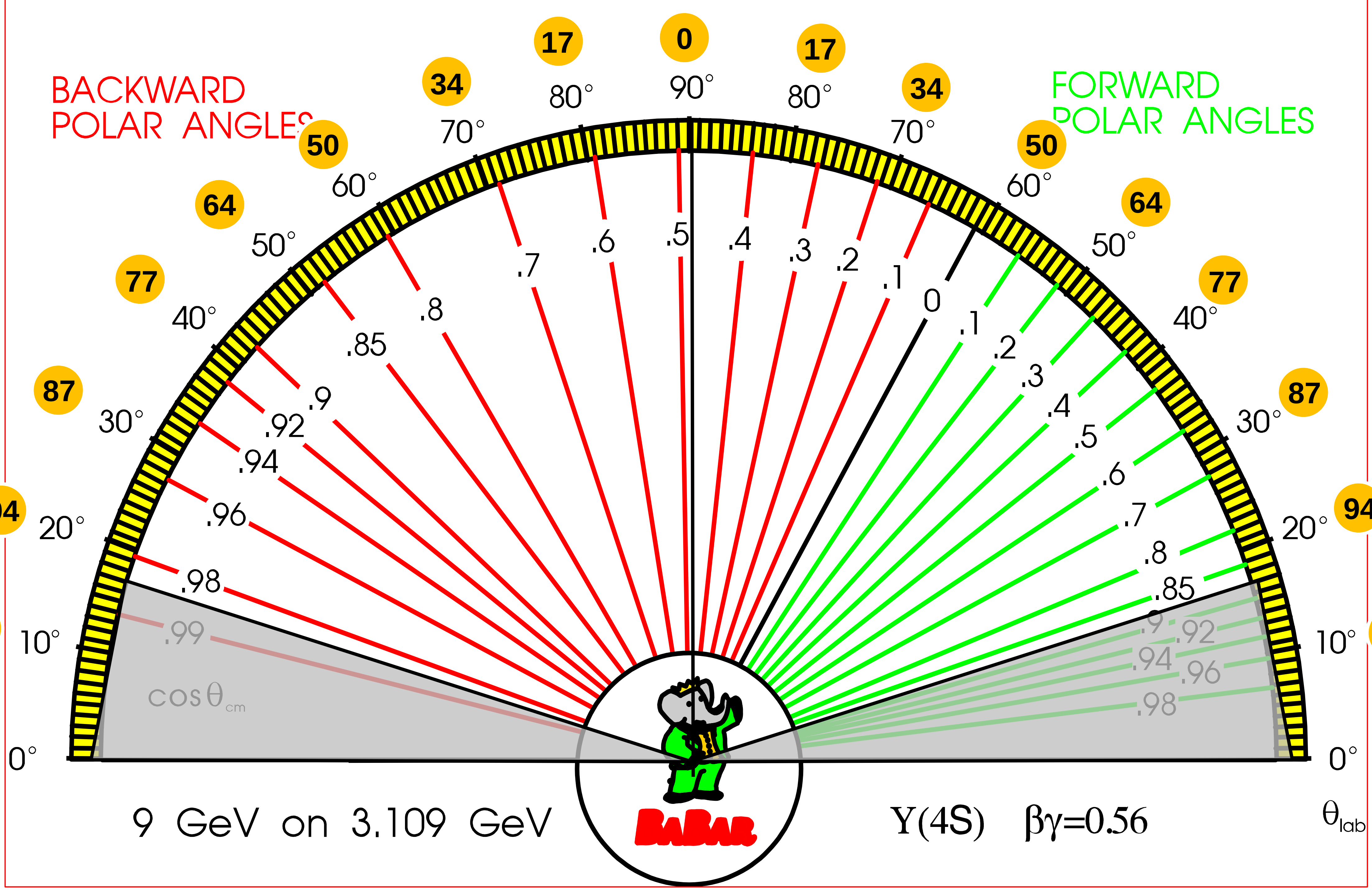
BABAR compared to CLEO-*c*



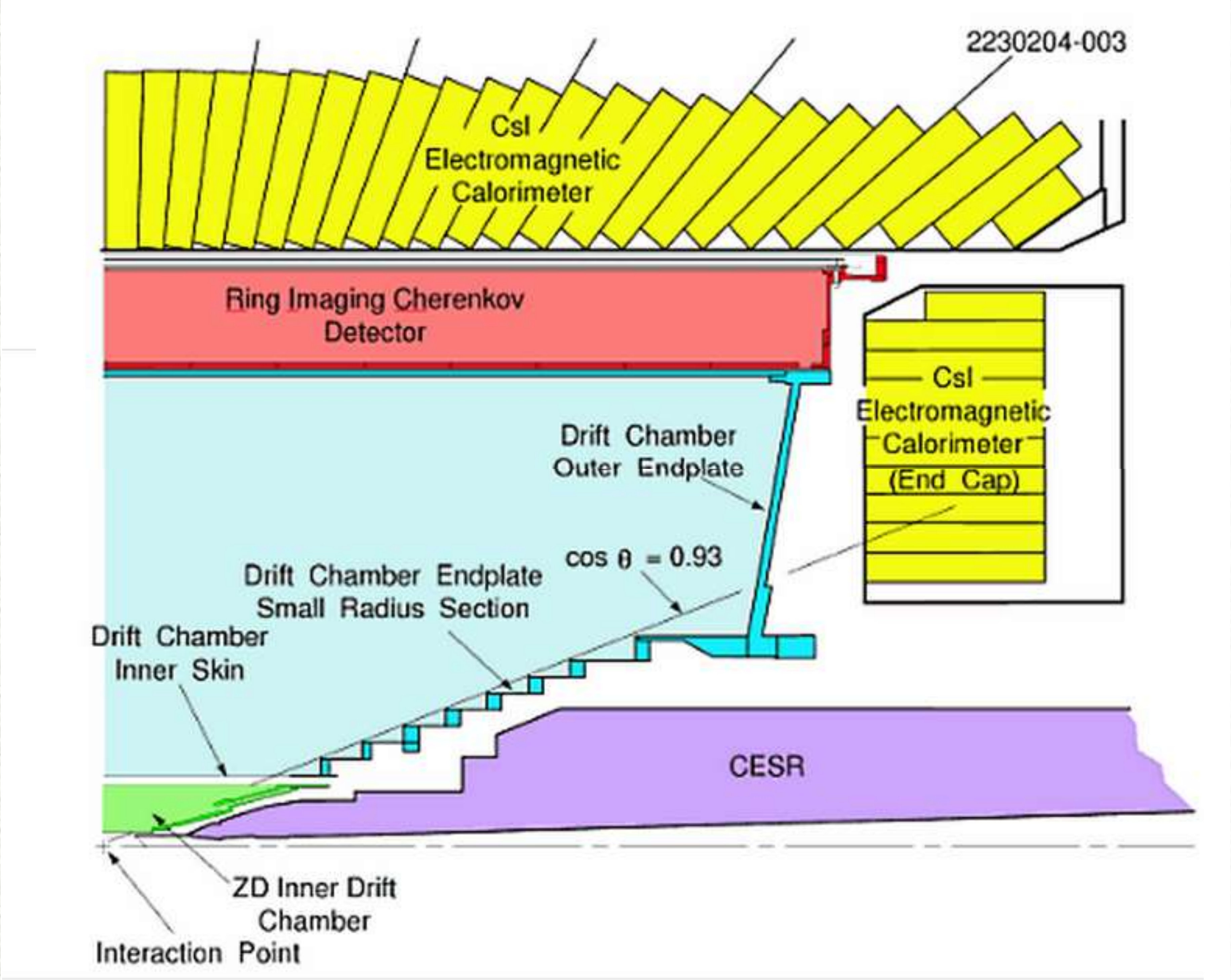
Upgrade of *BABAR* to Super*B*



Detector Protractor - γ's

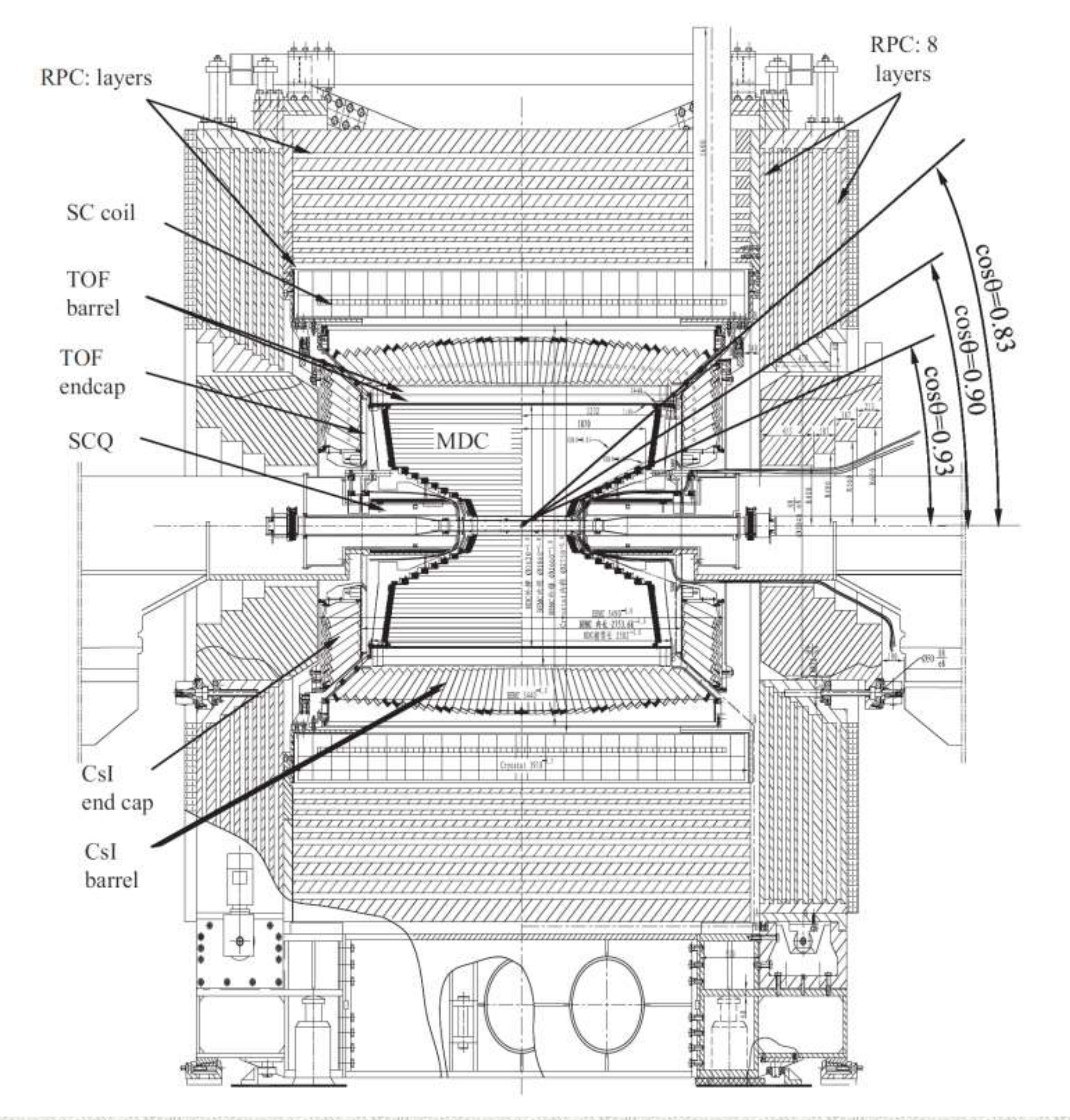


CLEO-*c*

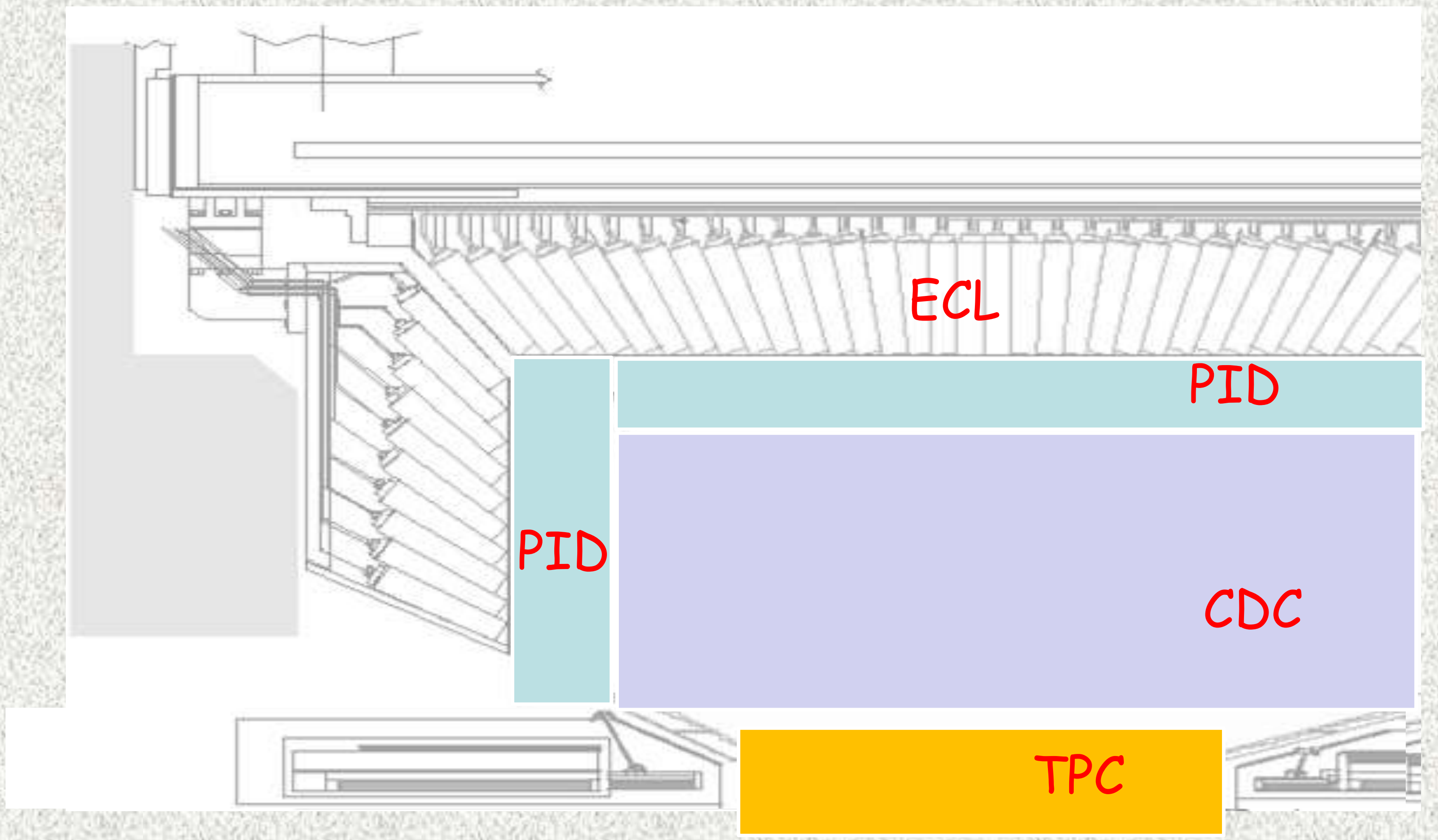


2230204-003
CsI
Electromagnetic
Calorimeter
Ring Imaging Cherenkov
Detector
CsI
Electromagnetic
Calorimeter
(End Cap)
Drift Chamber
Outer Endplate
cos θ = 0.93
Drift Chamber Endplate
Small Radius Section
Drift Chamber
Inner Skin
CESR
ZD Inner Drift
Chamber
Interaction Point

BES III

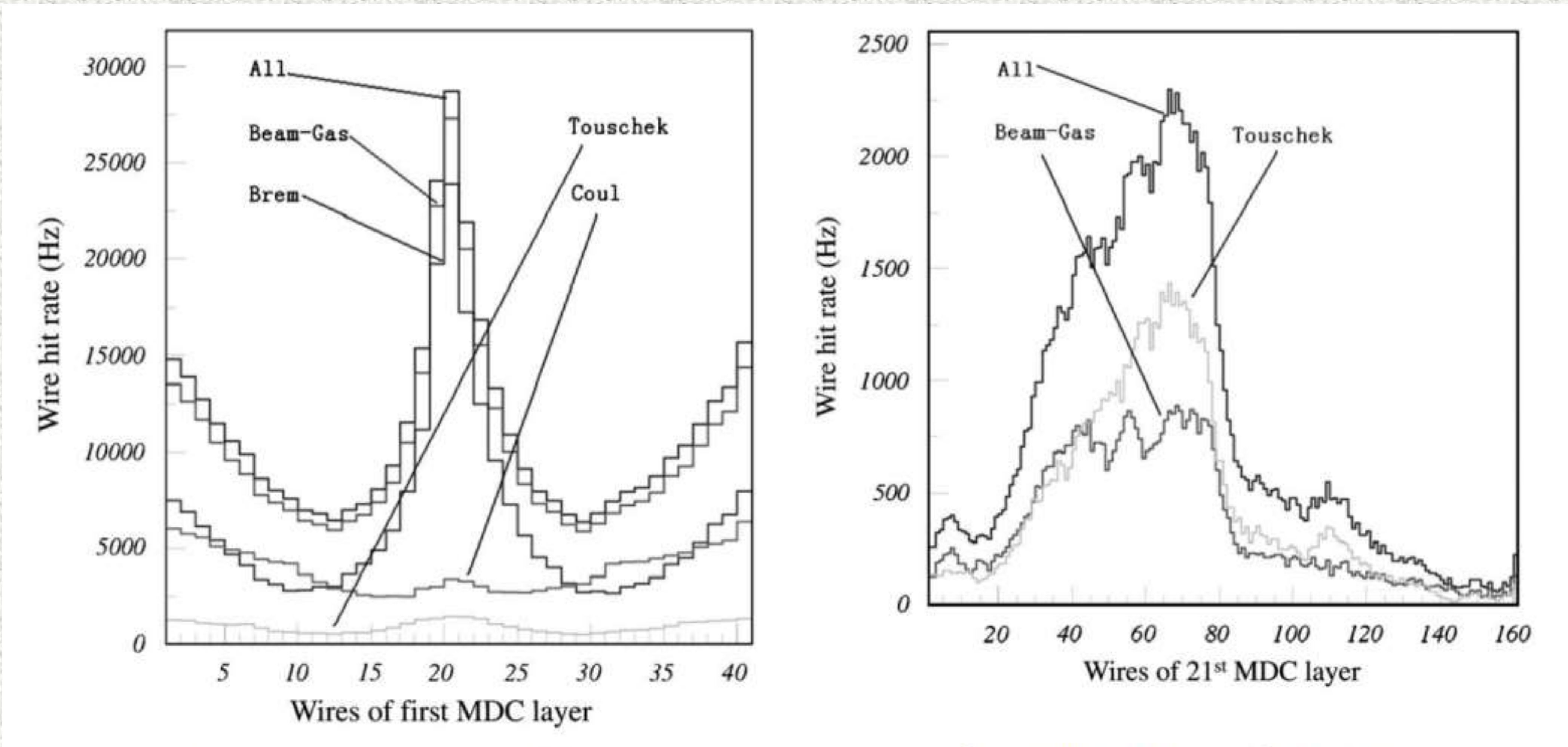

RPC: layers
RPC: 8 layers
SC coil
TOF barrel
TOF endcap
SCQ
MDC
CsI end cap
CsI barrel
cosθ=0.83
cosθ=0.90
cosθ=0.93

Novosibirsk c/τ detector

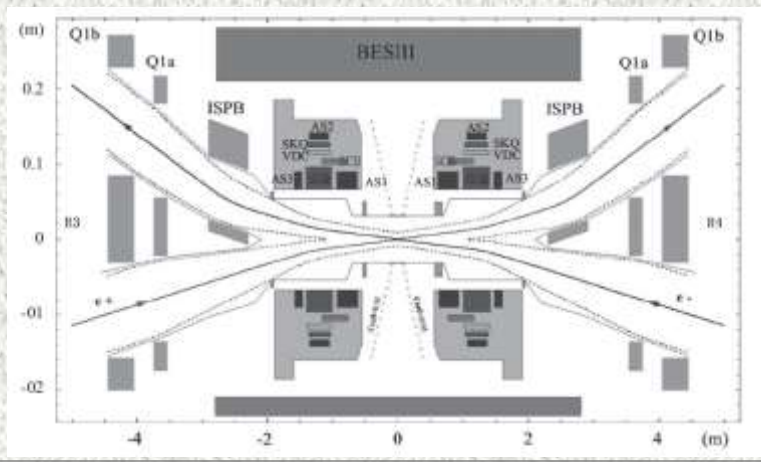


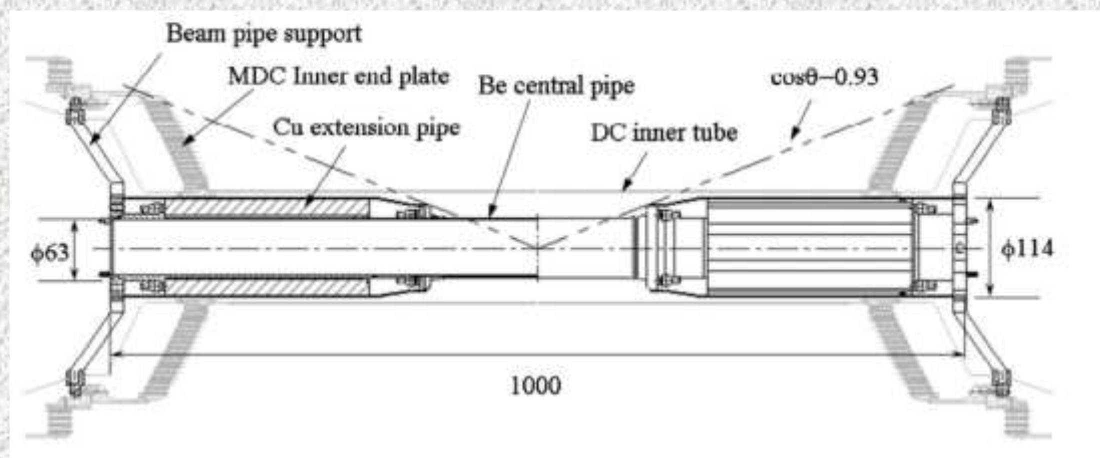
Backgrounds (BES III)

- Machine-related backgrounds at the IP: Coulomb, Touschek, bremsstrahlung, beam gas, ..



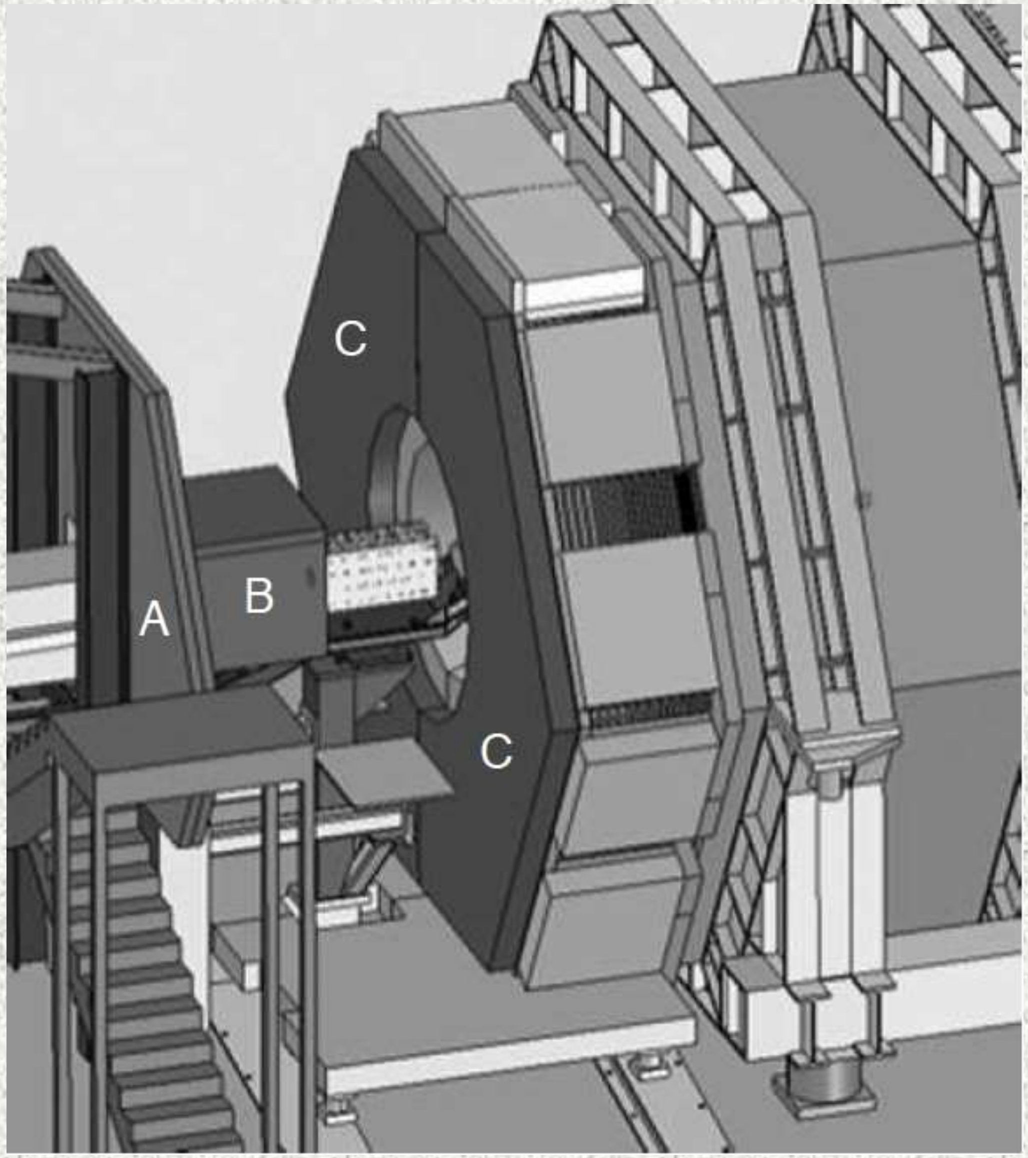
- These may or may not scale to 10^{35} in a new ring, but provide a benchmark for simulation

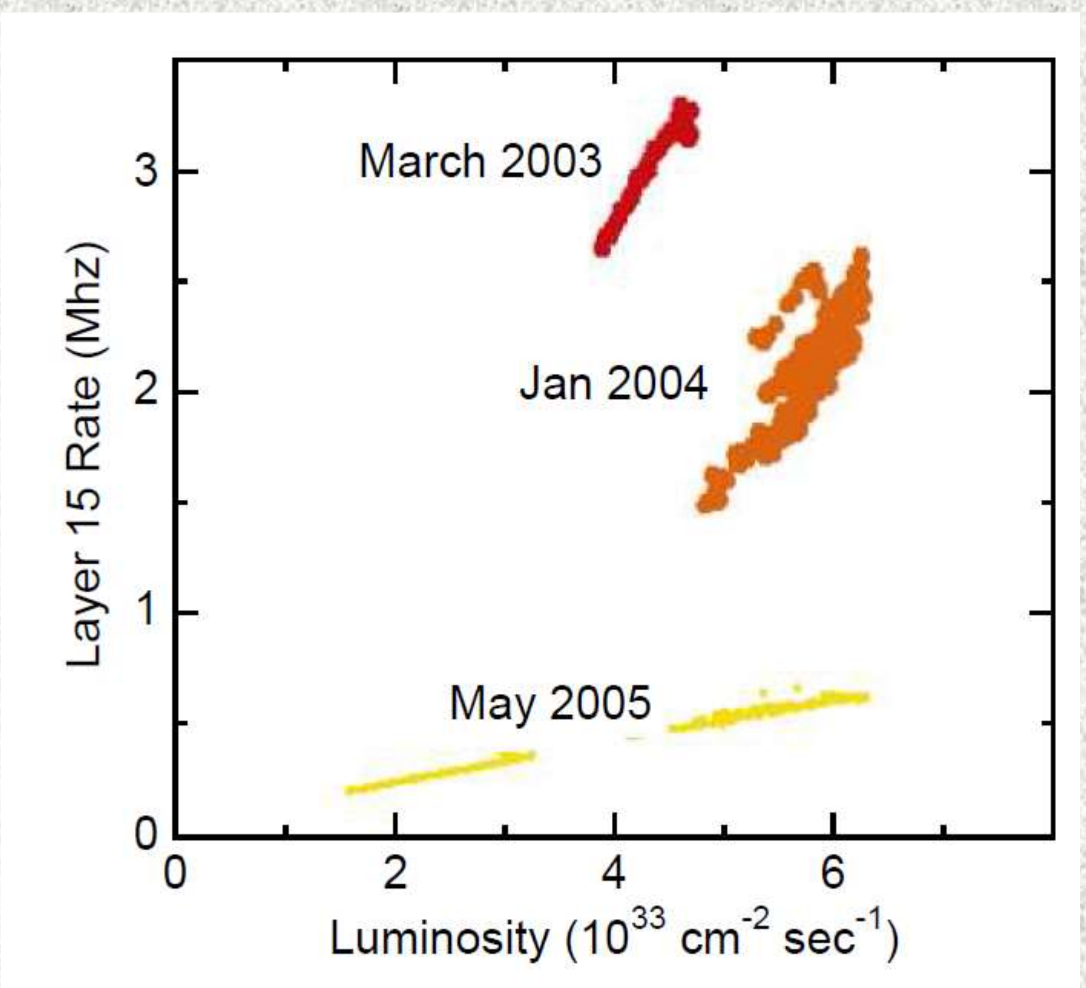




Upstream and downstream shielding (*BABAR*/PEP-II)

- Proper shielding of regions upstream and downstream of the detector is crucial





Endcap IFR rates

- Details of such shielding are machine-specific, but it is important to leave both physical space and room in the budget for proper up- and downstream shielding

To vertex or not to vertex?

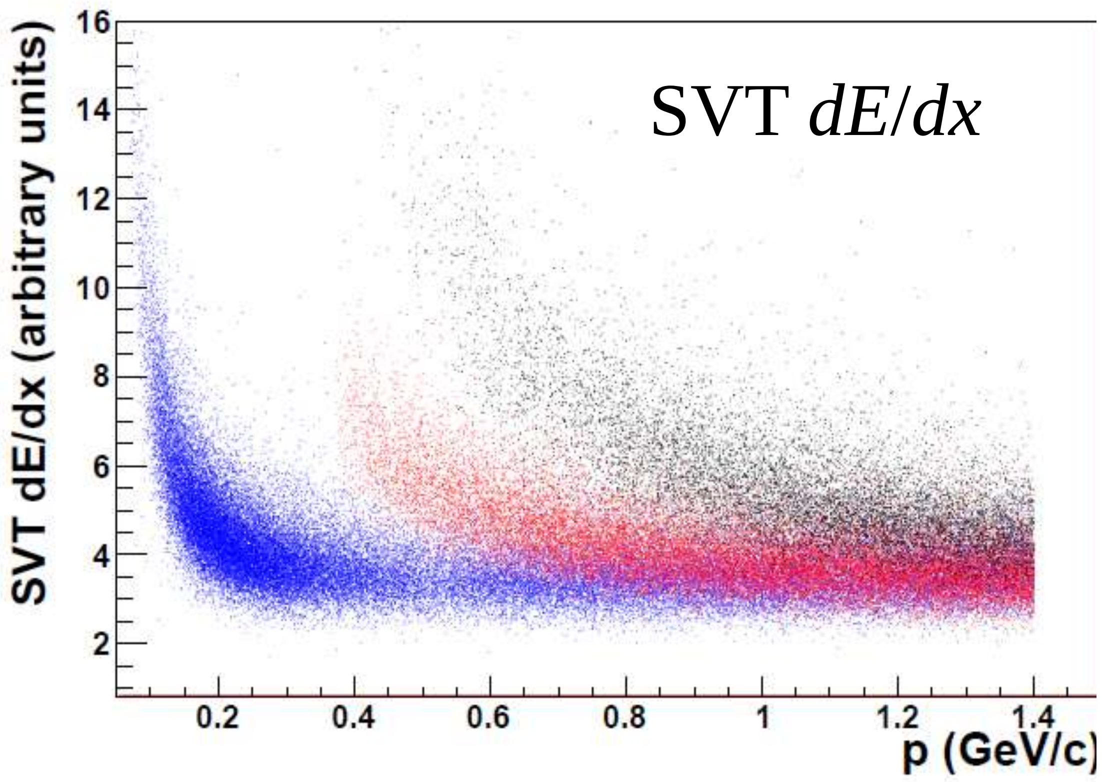
- $\tau(D^0)$ [4.1×10^{-13} s] is ~$3.7 \times$ shorter than $\tau(B^0)$ [1.53×10^{-12} s]
- $p(D^0)$ from $\psi(3770)$ decay is 288 MeV/c
- It appears that no practical boost of the $\psi(3770)$ at a threshold e^+e^- collider allows clean time-ordering of D^0 and $\bar{D}^0$ decay vertices by measurement in an SVT
  - One of the motivations for considering a symmetric machine at this workshop
- However, given the very small beam spot, having precise D decay vertices may be of use in background rejection
- Three directions:
  - A silicon vertex detector
  - A conventional low-mass drift chamber – might be integrated with main tracking chamber
  - A small TPC
    - (Déjà vu)^3 – Guy Wormser's min-TPC proposal for *BABAR*

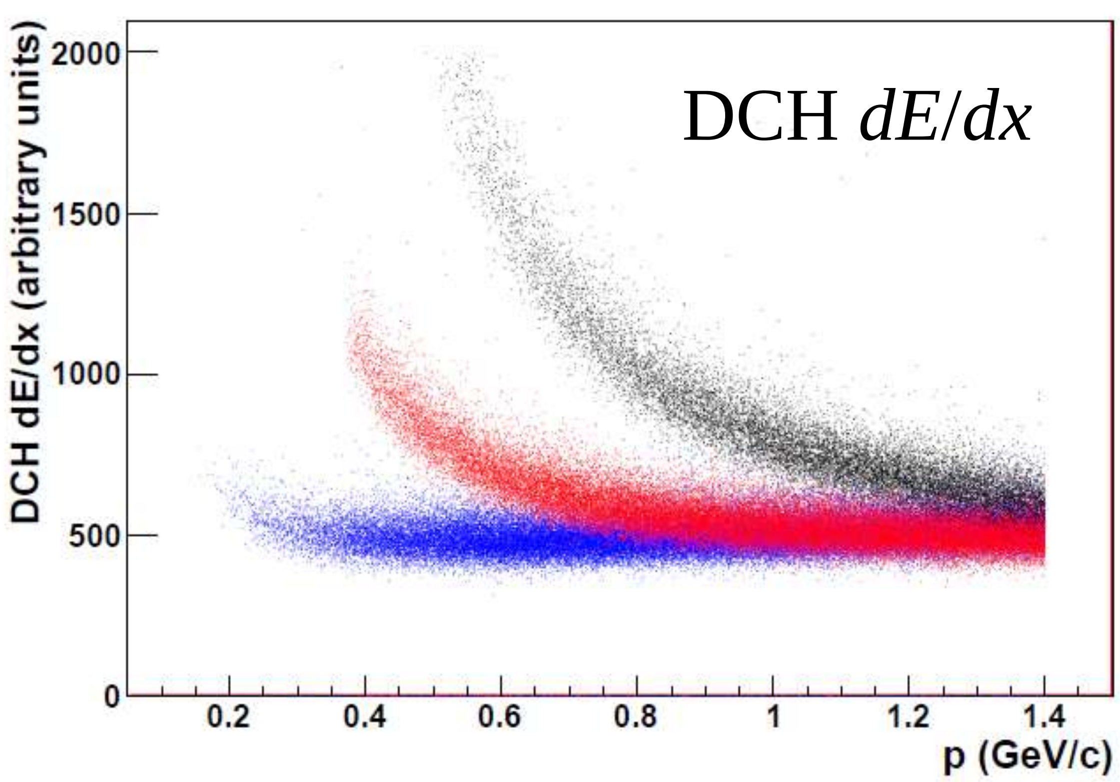
Main tracker

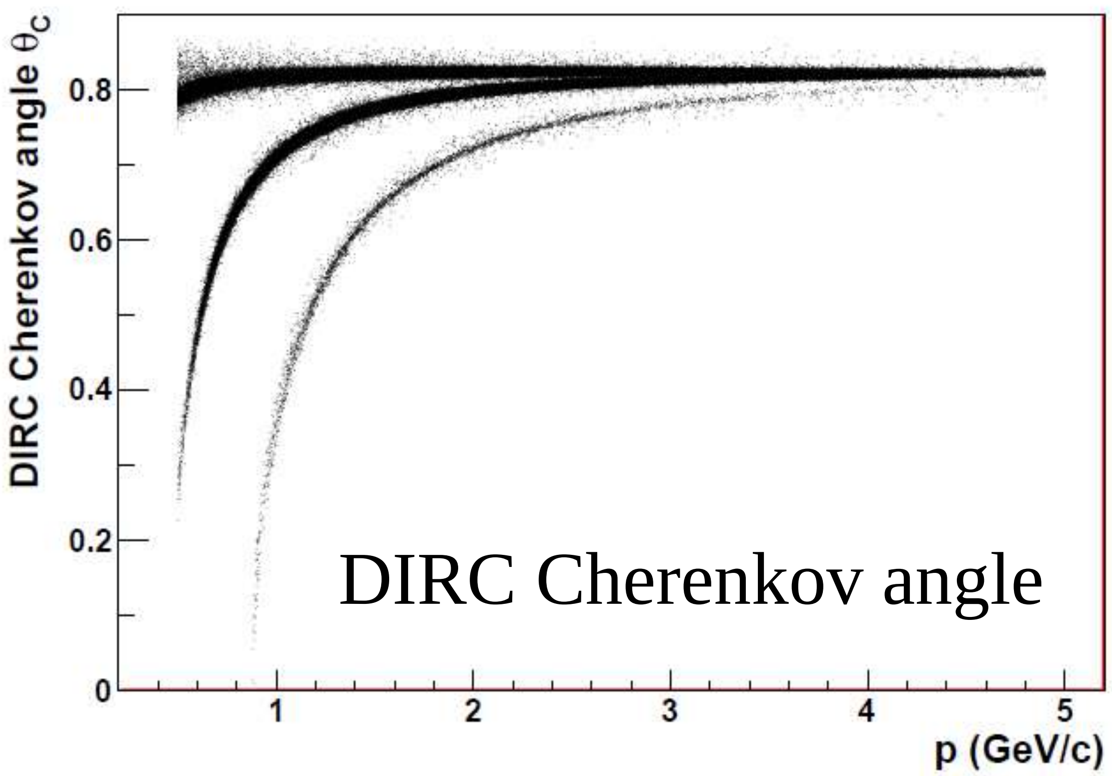
- Must balance momentum resolution with curling of low momentum tracks
  - Lower *B* field (~1T) is required, Should be re-optimized
  - Typical resolution $\Delta_t p/p_t$ = 0.5% at 1 GeV/*c*. Can one do better?
- Multiple coulomb scattering is an important determinant of momentum resolution
  - $\Rightarrow$ low mass helium-based gas, wires
  - Small cells are needed for speed – more wires in tension with low mass
  - Carbon fiber support structure to minimize effect on PID, EMC behind the DC endplates
- Detailed shape of the chamber interacts with the vertex tracker decision

- Particle ID via *dE/dx* assumes increasing importance at lower momenta
  - *BABAR* *dE/dx* resolution was 6%
  - With cluster counting, which was intensively studied for Super*B*, resolution using both *dE/dx* and cluster counting, can be ~3%
    - Improves particle separation at low momenta and extends usable range to higher momenta
    - Electronics is more complex and increase in data stream is substantial

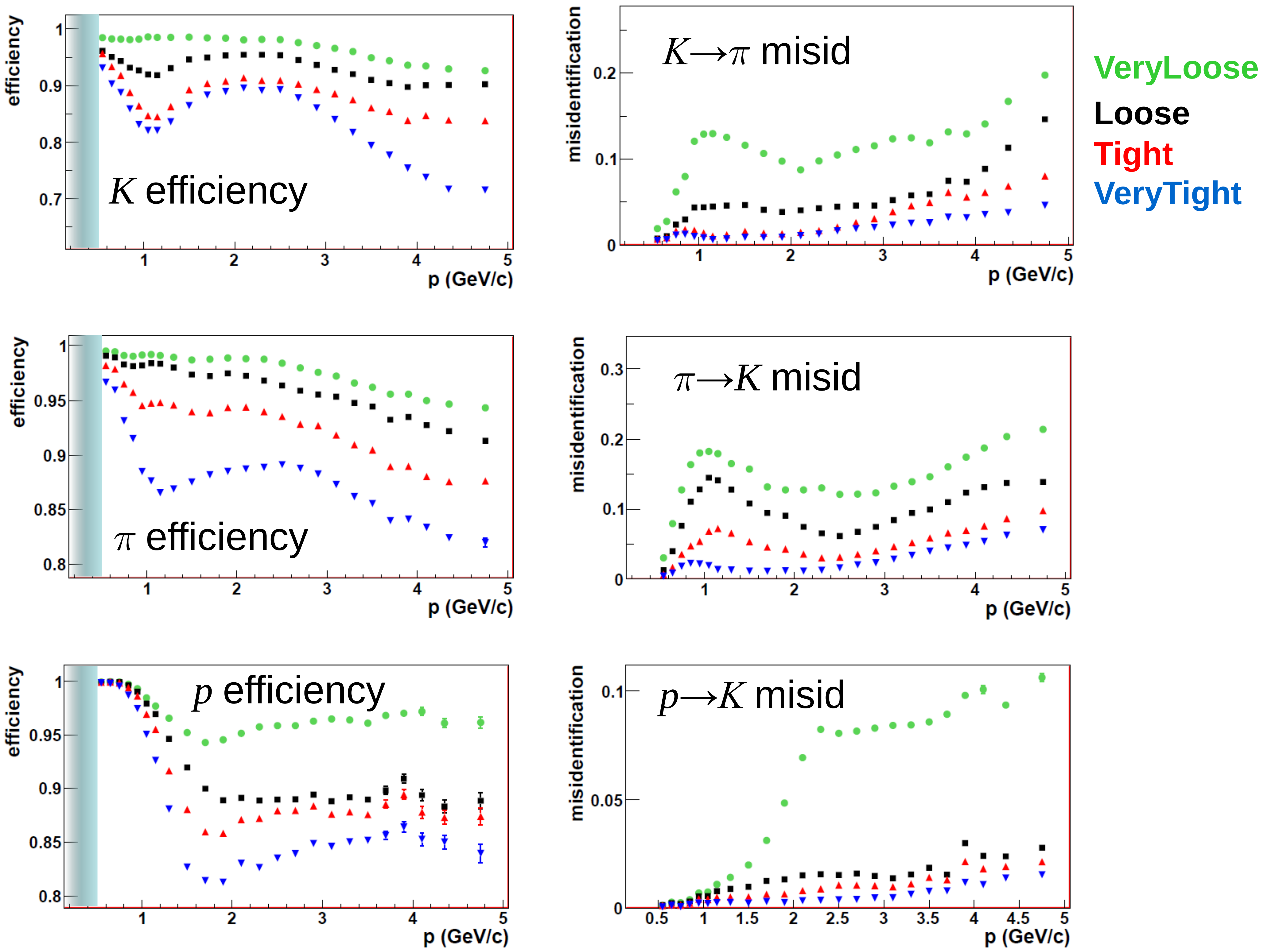
BABAR $\pi/K/p$ identification



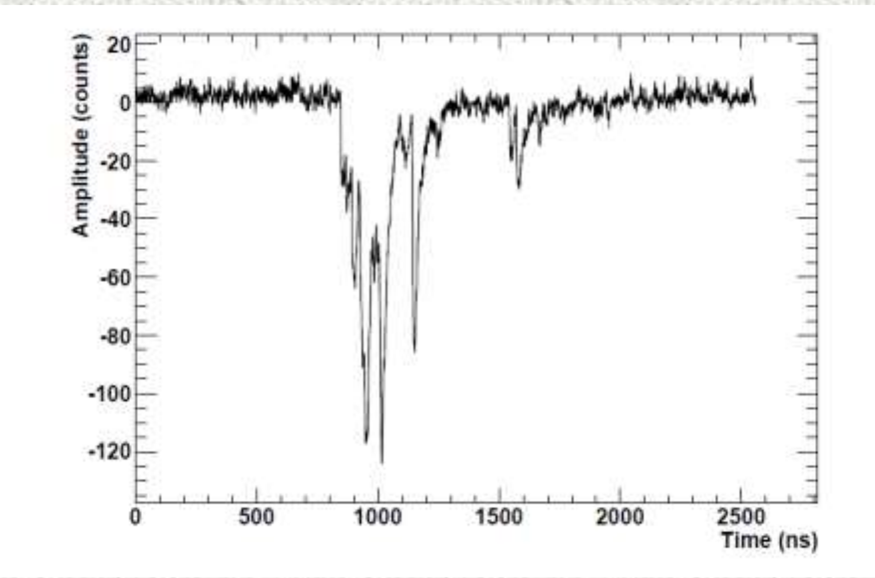




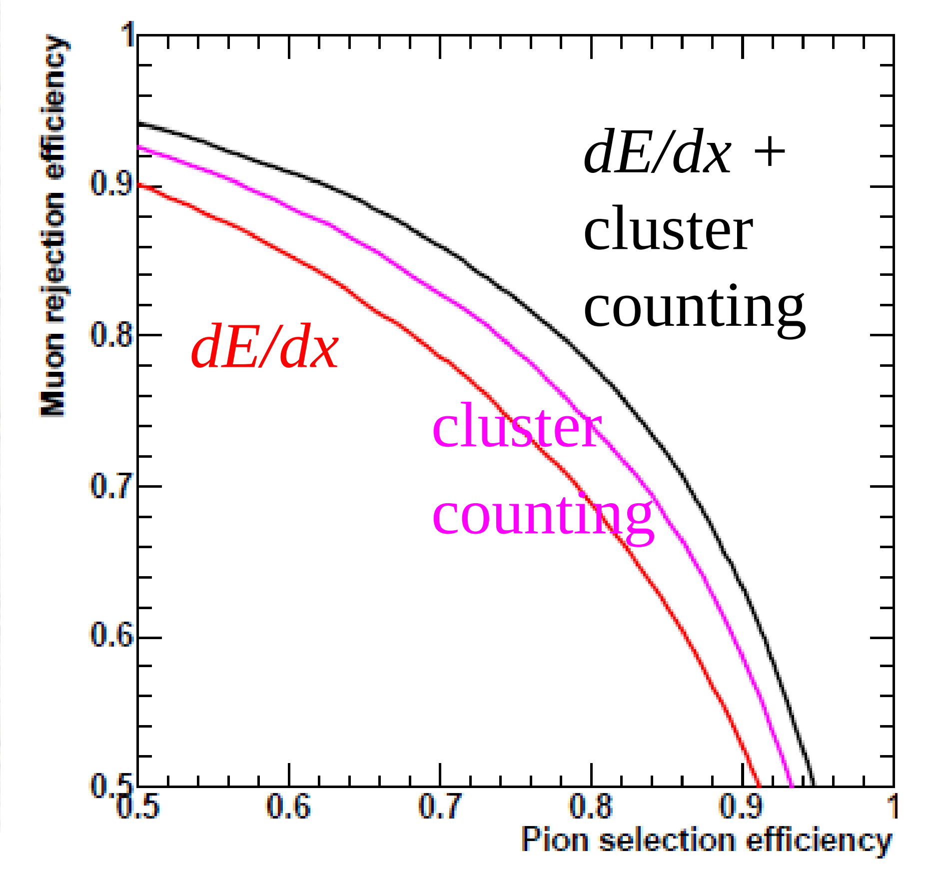
BABAR ECOC particle identification performance



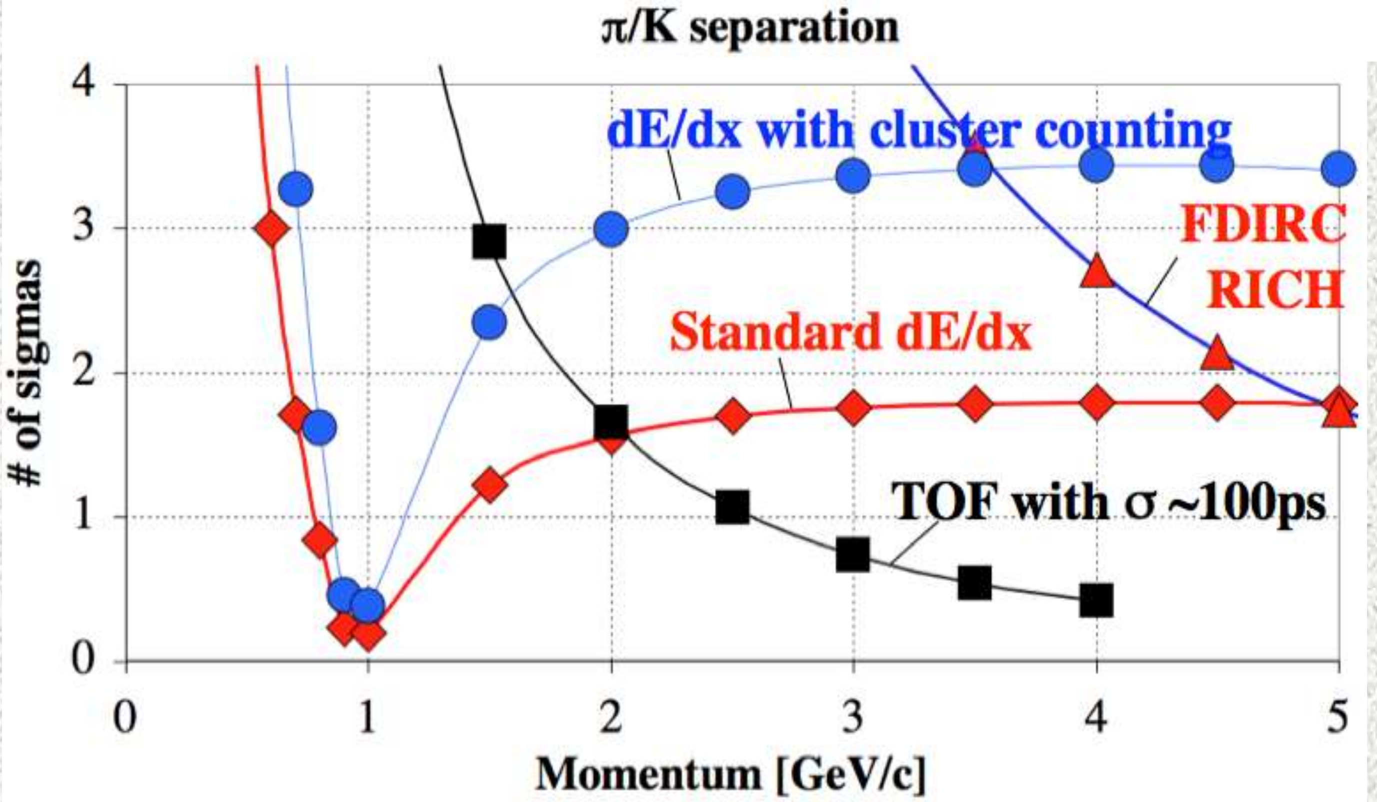
Cluster counting



Super*B*: TRIUMF test beam 140 MeV/c
90% He/10% C_4H_{10} gas

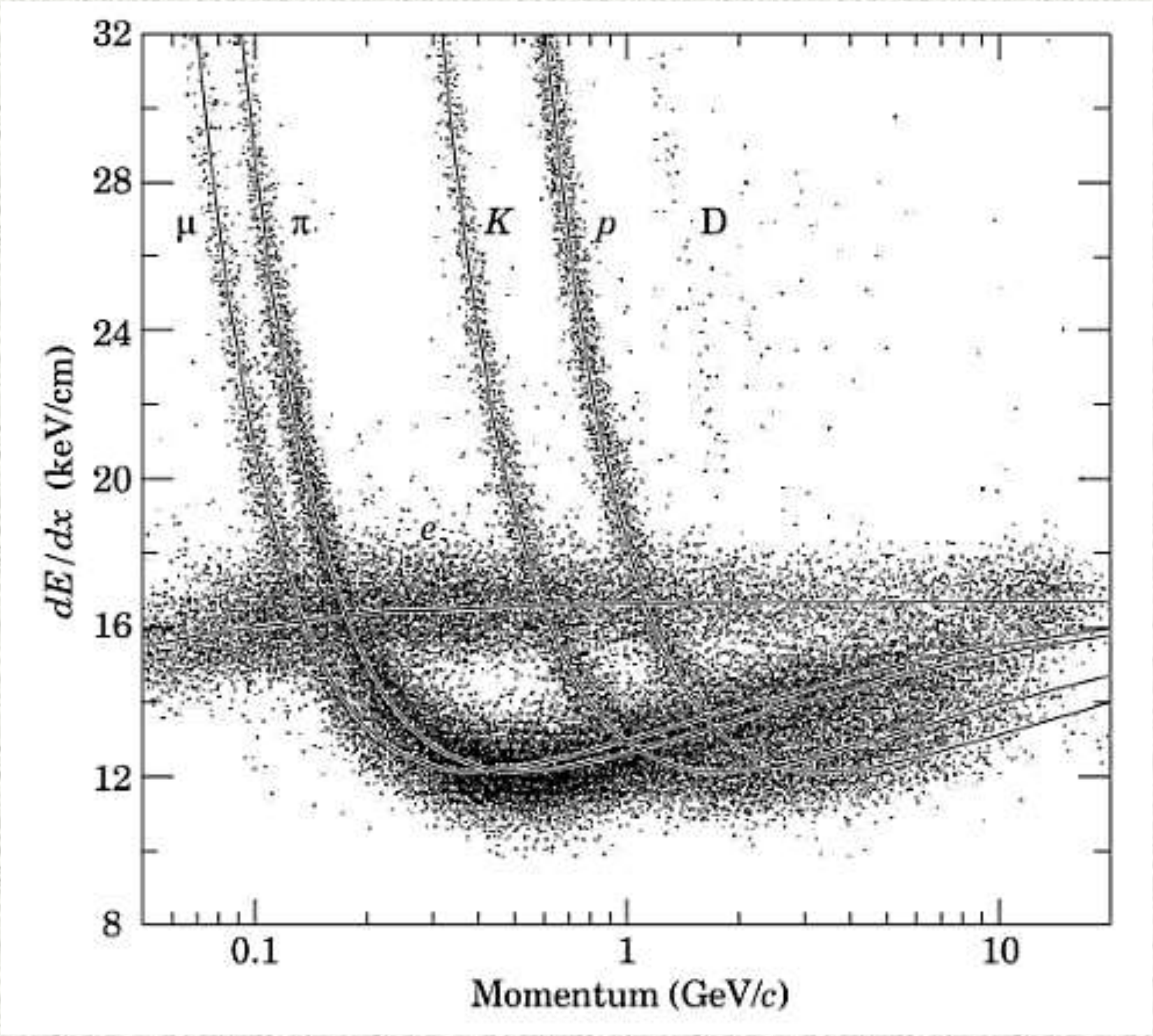


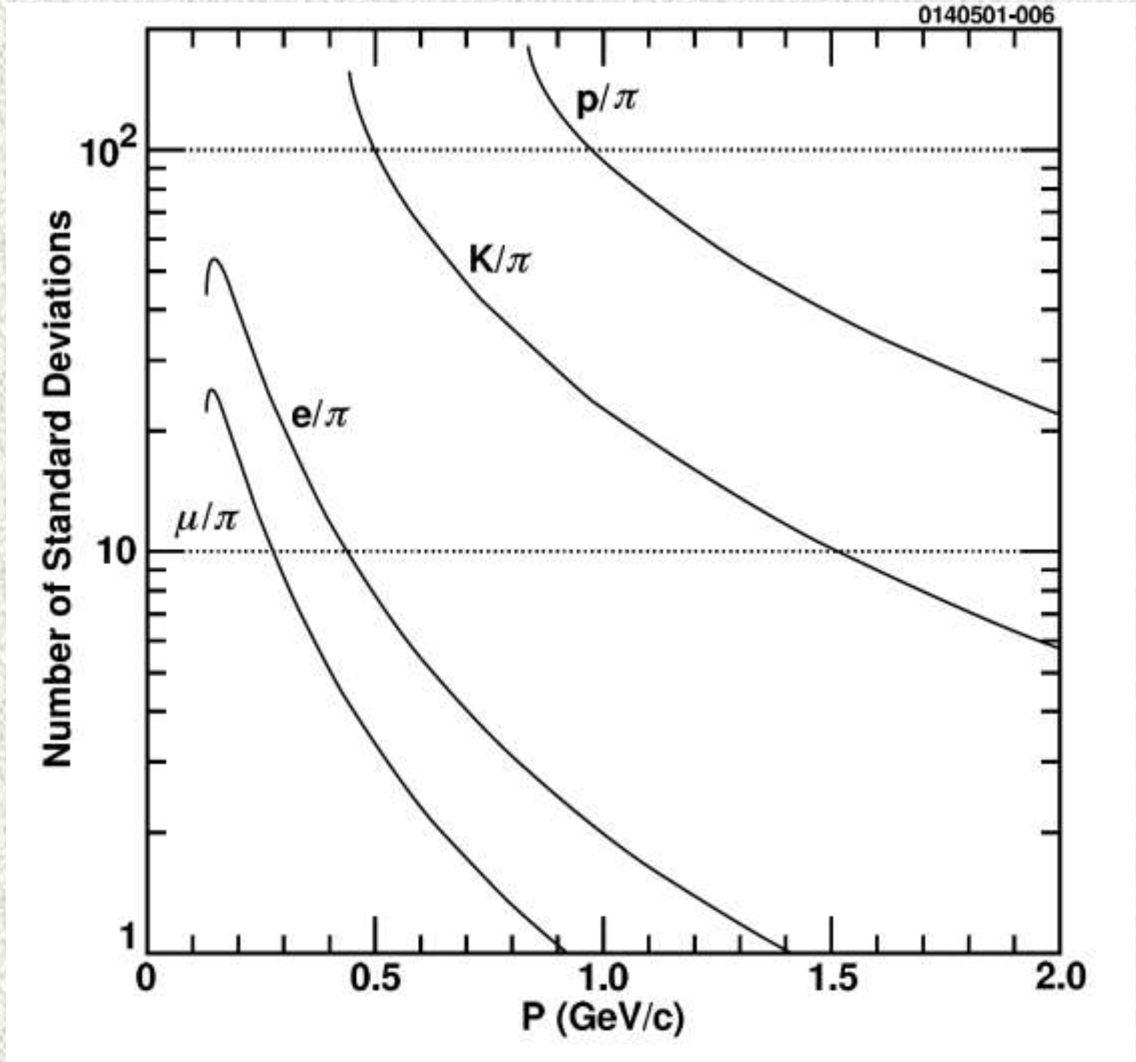
210 MeV



CLEO-III *dE/dx*, RICH

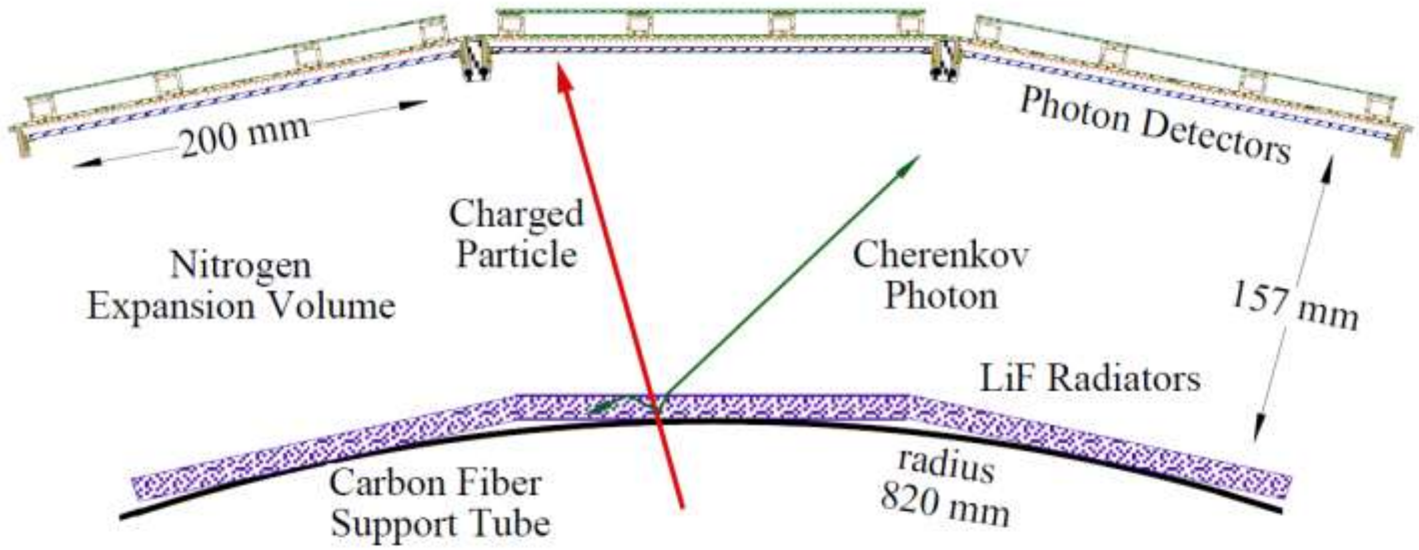
- Particle ID by *dE/dx* in DC and RICH with LiF radiator

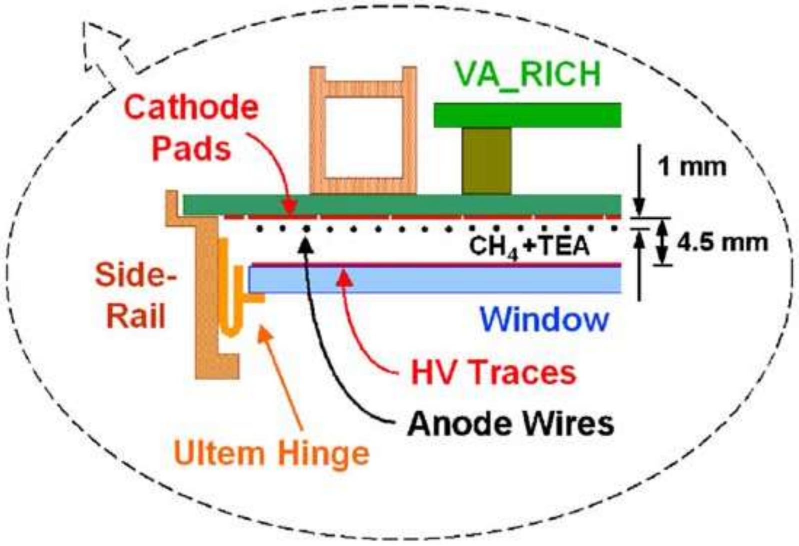


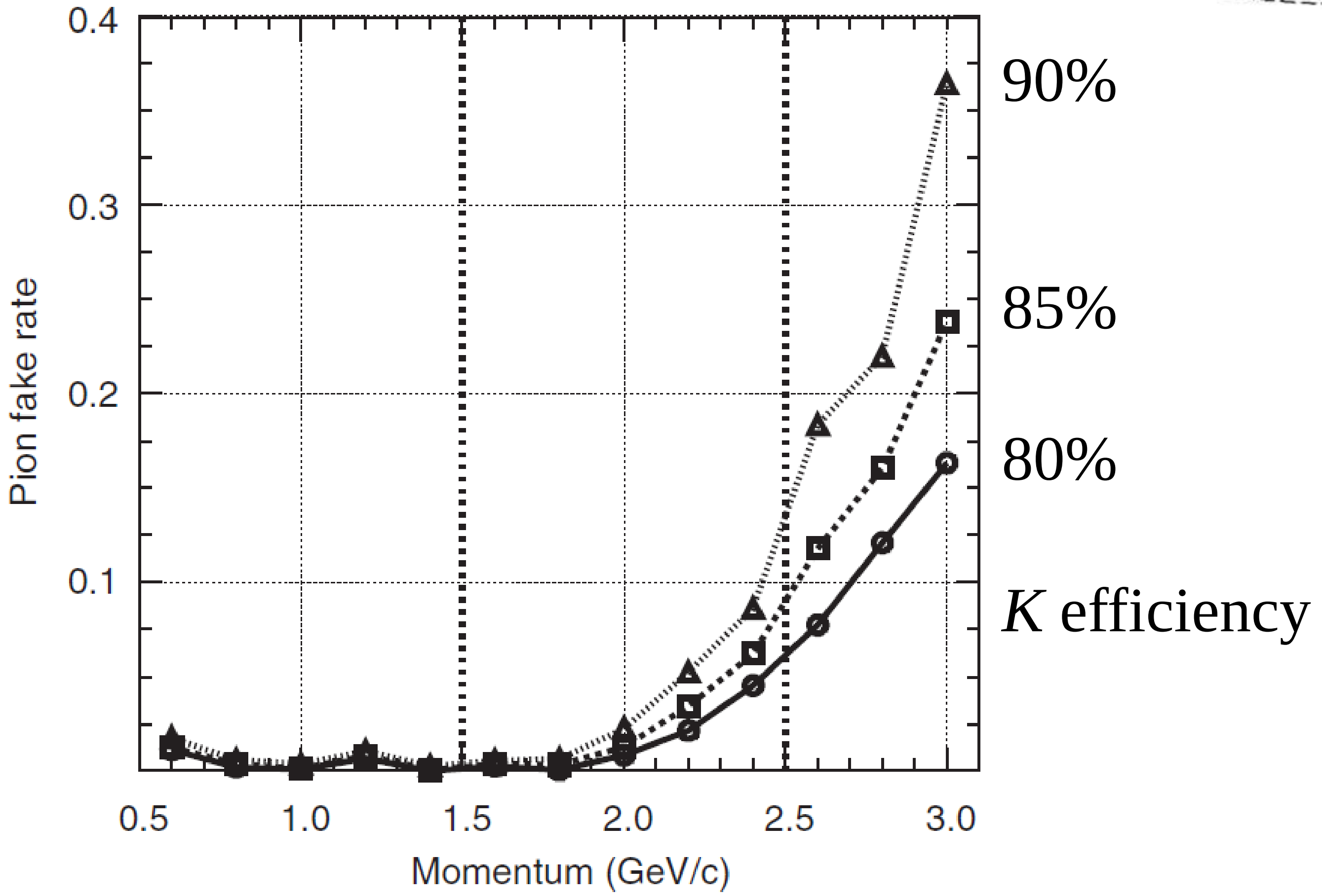


- μ/π separation at low momentum (below 1 GeV) is crucial for $\tau\to\mu\gamma$ sensitivity
  - μ tagging at low momentum can nearly double the tagging efficiency
  - $\tau\to\pi\pi^0\nu$ is largest background. Requires efficient, clean pion ID

CLEO-III RICH has 10 fold symmetry

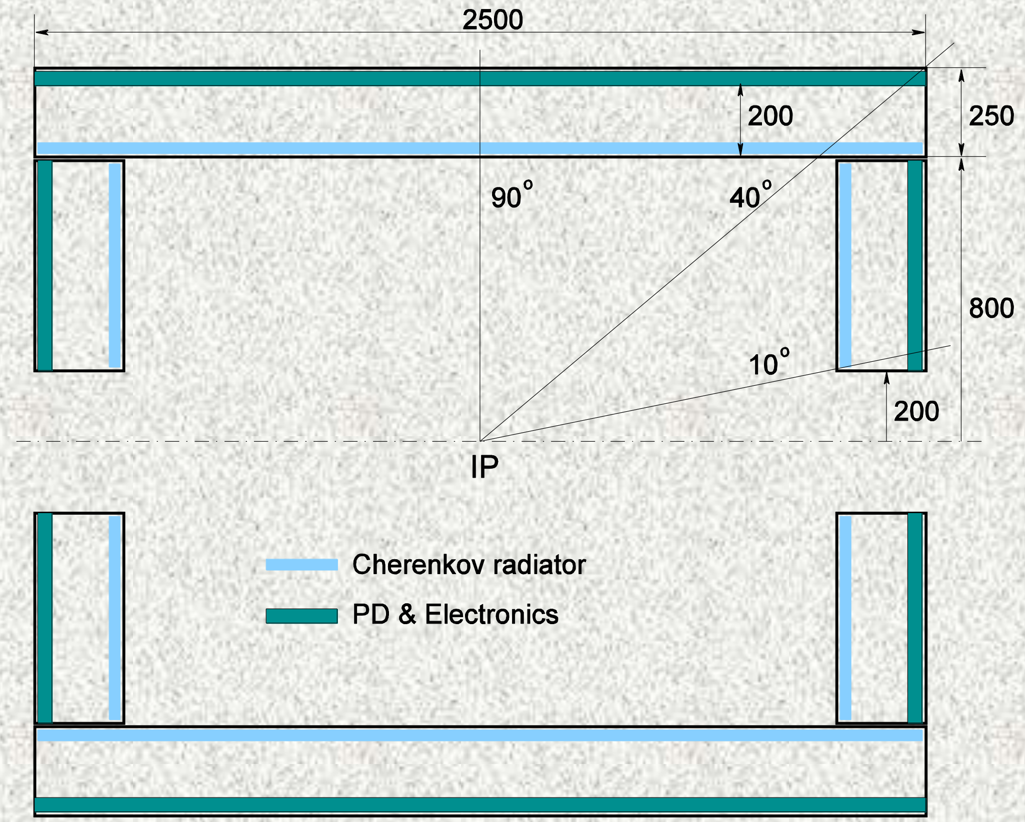


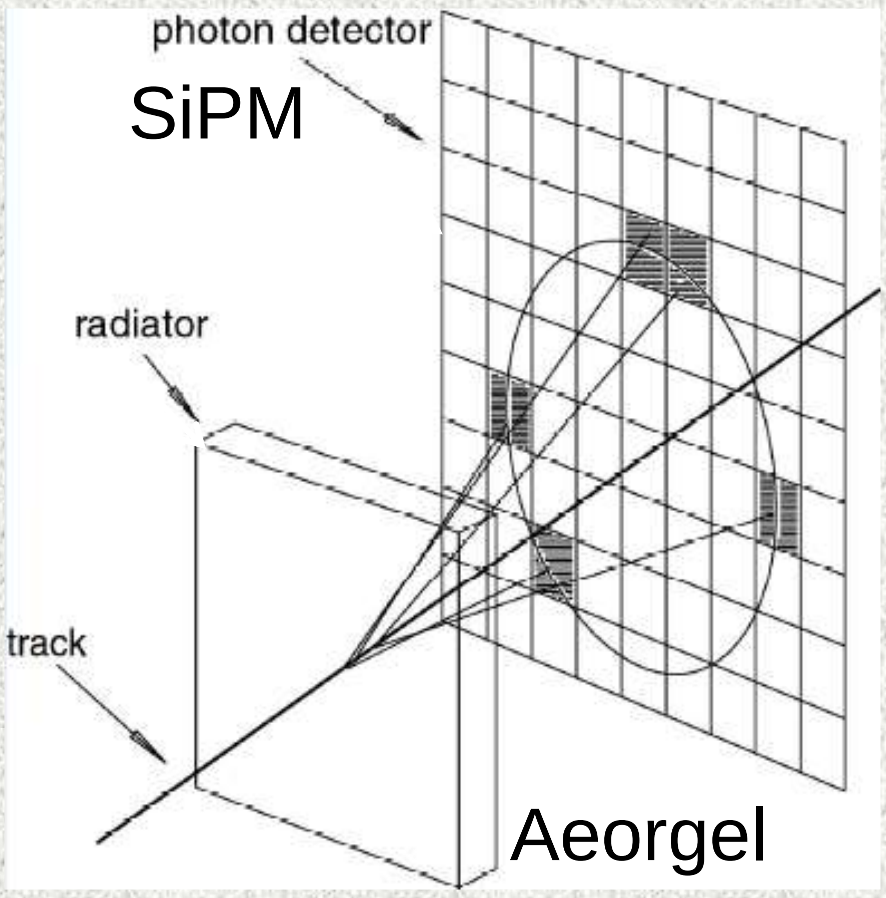




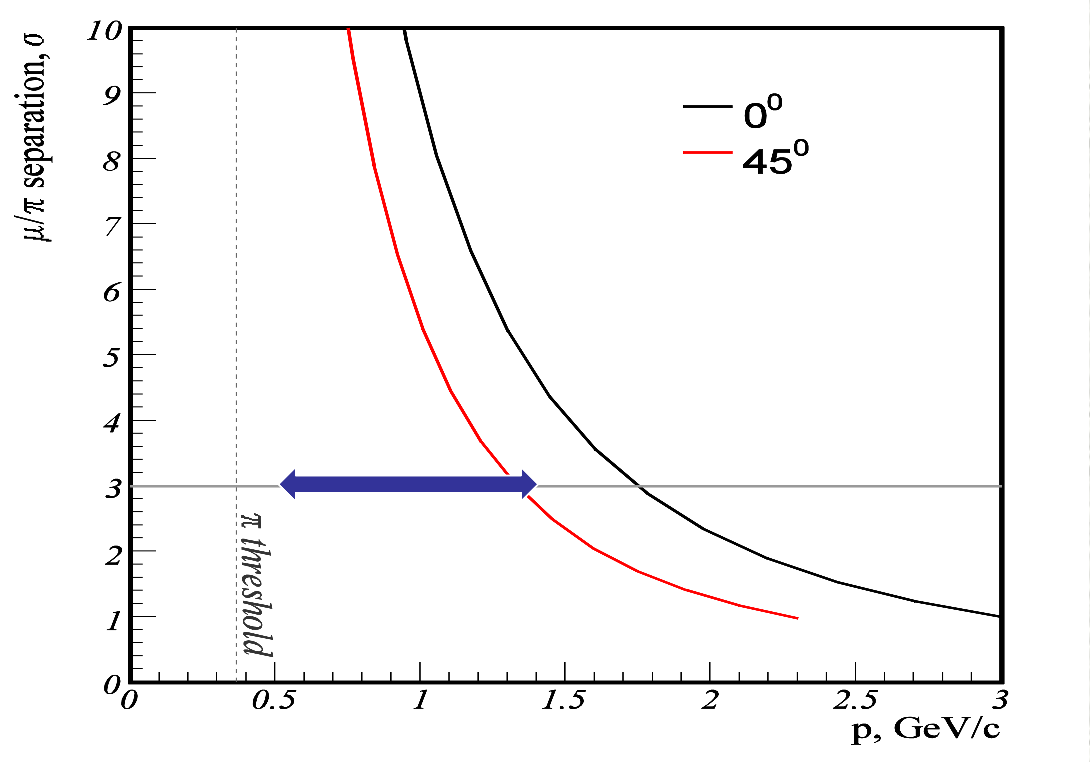
FARICH for Super c/τ detector at BINP

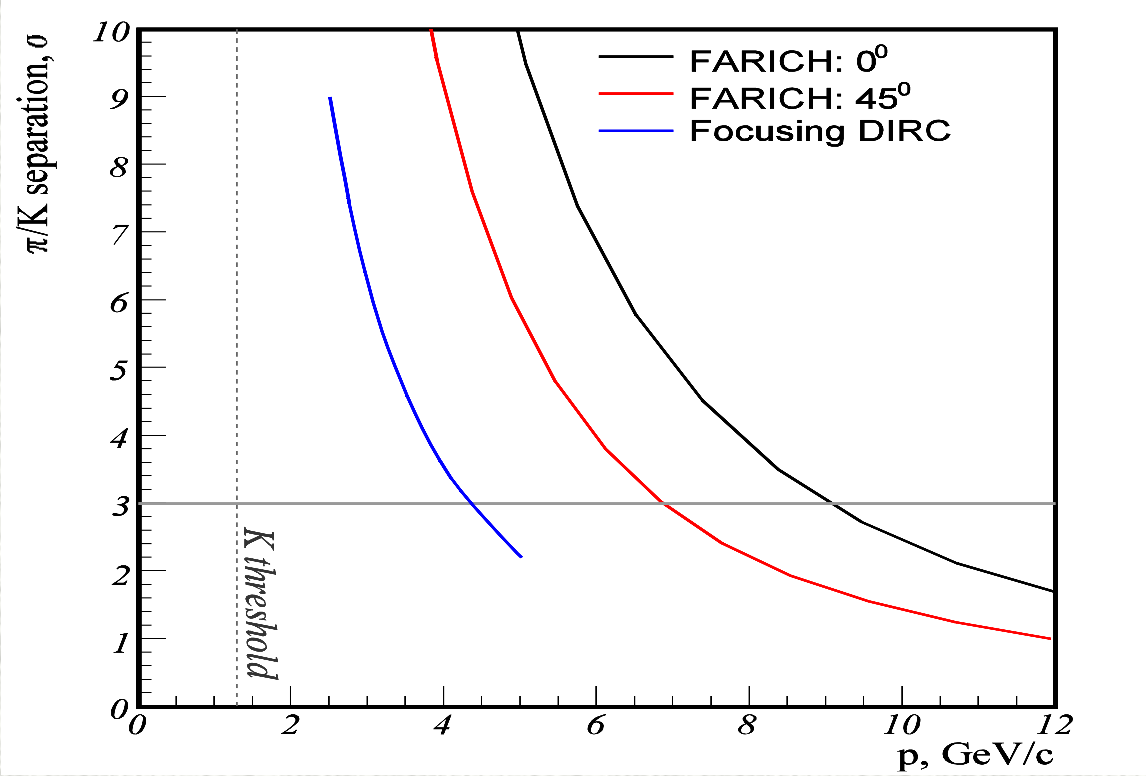
- Was considered for Super*B*
- Uses aerogel radiator
- Can provide 4π geometry
- 20 m^2 of radiator and photon detectors
- Requires 10^6 channels
- SiPMs are the main candidate for the photon detector





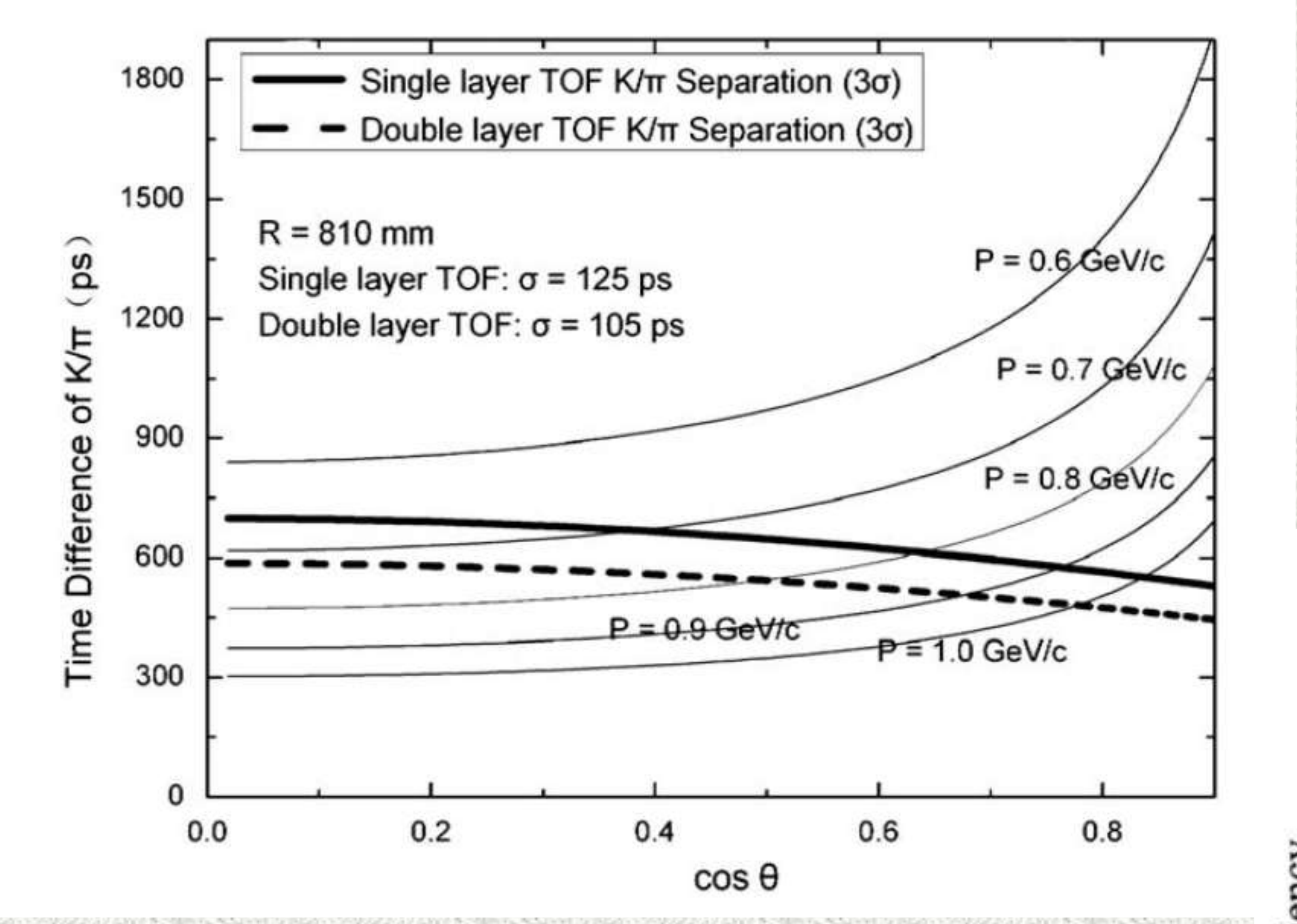
FARICH performance

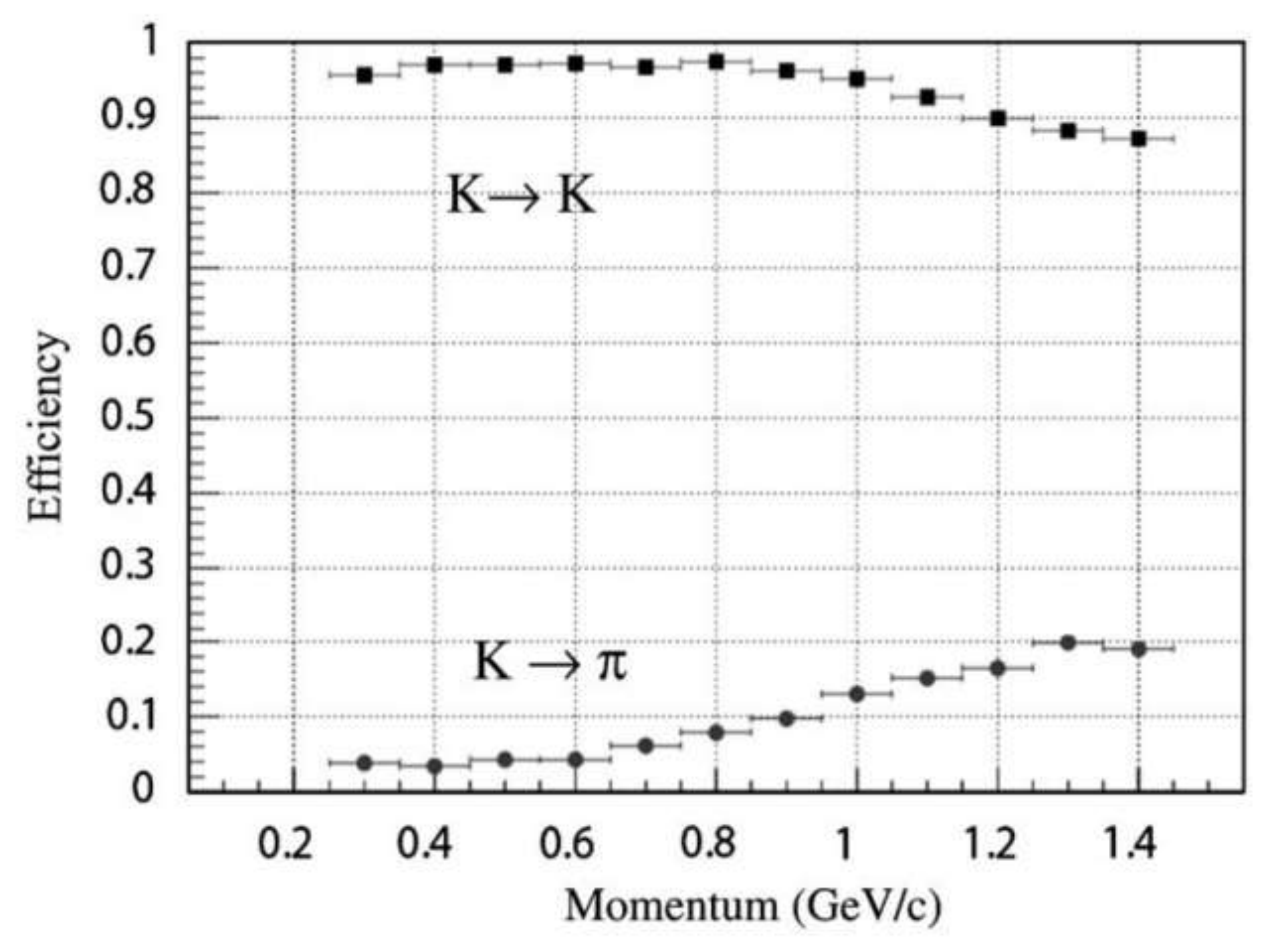




μ momentum range in $\tau \rightarrow \mu\gamma$

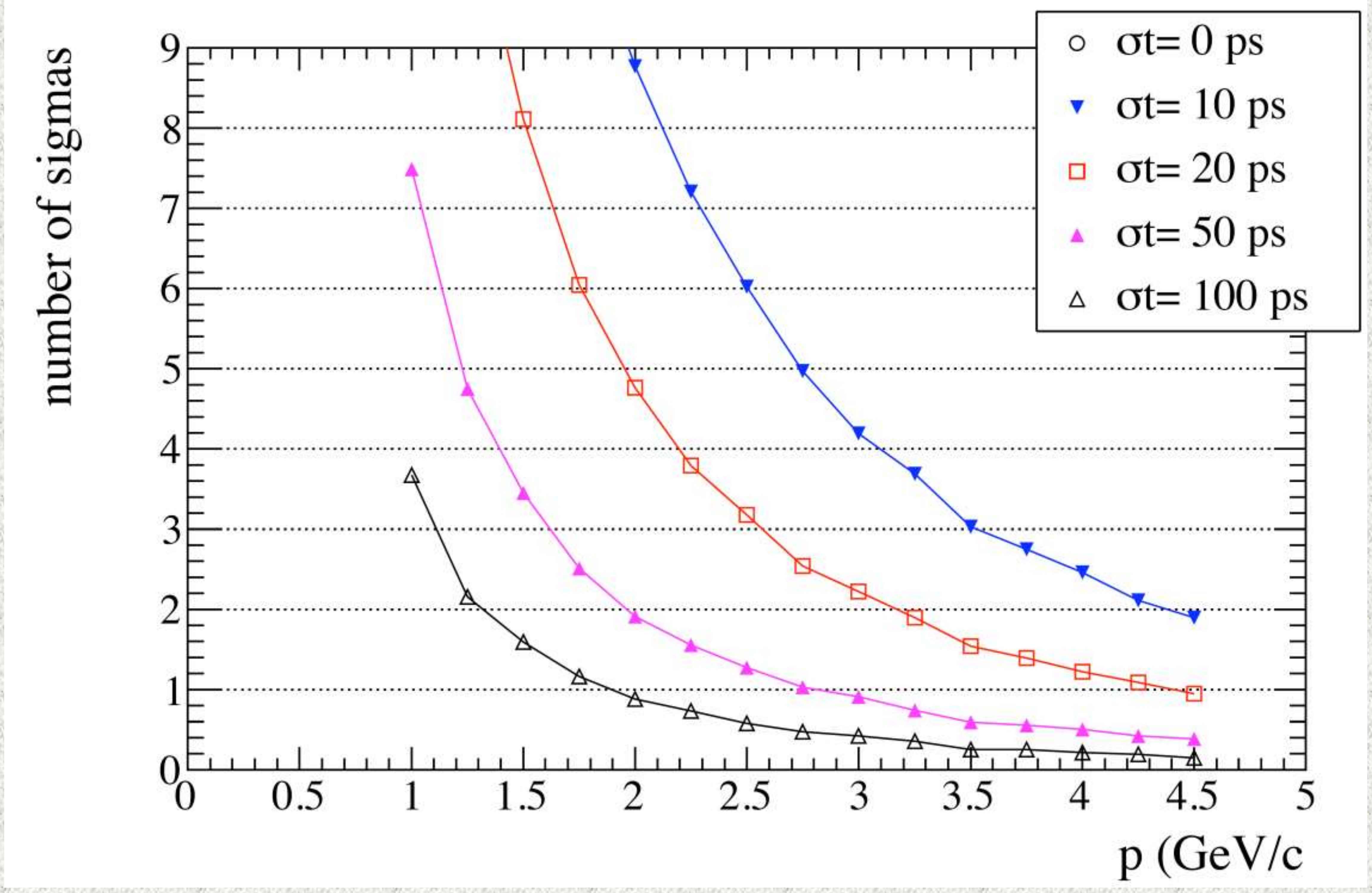
BES III TOF performance





Parameters	BESIII
Polar angle coverage	
Barrel	$\lvert\theta\rvert > 35°$
End cap	$18° < \lvert\theta\rvert < 32°$
Inner radius (m)	0.81
Time resolution for 1 GeV muon	
Barrel (ps)	~90
End cap (ps)	~120
3 σ K/π/ separation (GeV/c)	< 0.9

Super*B* backward endcap calorimeter PID



Electromagnetic calorimeter

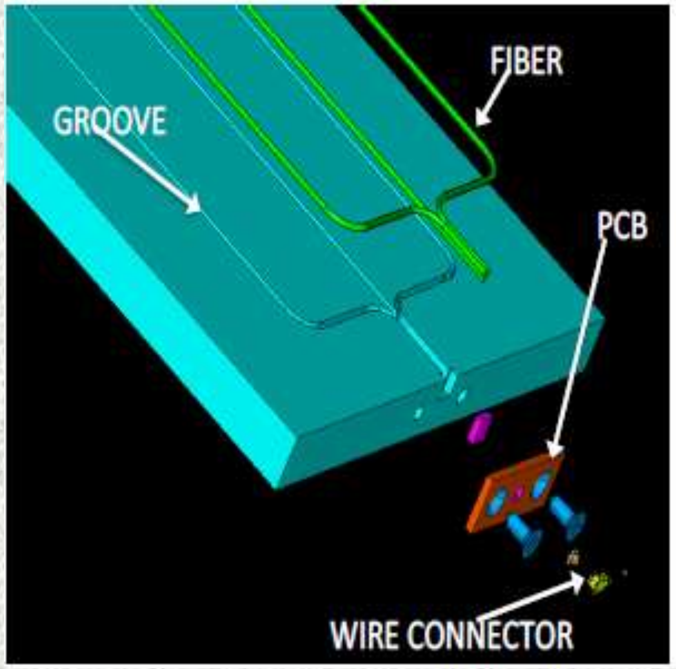
- Existing CsI(Tl) calorimeters (*BABAR*, BES-III, CLEO-*c*) are a reasonable first-order match to a 10^{35} collider in the 4 GeV region

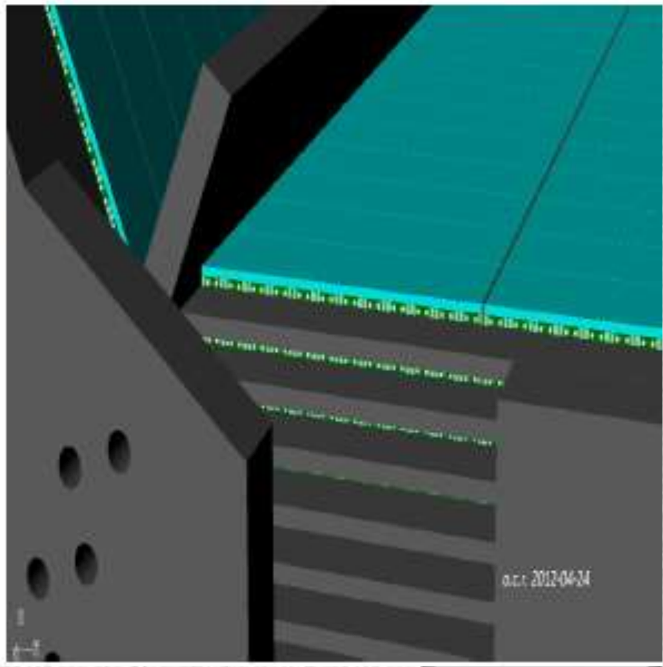
Parameter	BESIII	CLEO-c	BaBar	Belle
$\Delta\Omega/4\pi$ (%)	93	93	90	91
Active media	CsI(Tl)	CsI(Tl)	CsI(Tl)	CsI(Tl)
Depth (X_0)	15	16	16–17.5	16.2
σ_E at 1 GeV (MeV)	~25	~20	~28	~17
σ_E at 100 MeV (MeV)	3.3	4	4.5	4
Position resolution at 1 GeV/c (mm)	6	4	4	6

- The situation is similar to that of Super*B*
  - With adjustments to electronics time constants, the **barrel** calorimeter may be adequate
  - The **forward endcap** will see a rate comparable to Super*B*, but with reduced energy deposit from lower energy Bhabhas
    - In Super*B*, it was found necessary to replace the six inner rings of the forward endcap (out of nine total) with LYSO
    - Other alternatives, such as pure CsI, which were considered for Super*B*, could be re-evaluated. In this case the outstanding issue is the need for a fast, efficient readout device that works in a magnetic field.
  - The **rear endcap** region is relatively more important in a symmetric situation
    - If the *BABAR* DIRC were to be replaced, it would be possible to reconfigure the rear flux return door to make it possible to build a high-quality rear endcap

Muon identification in the flux return

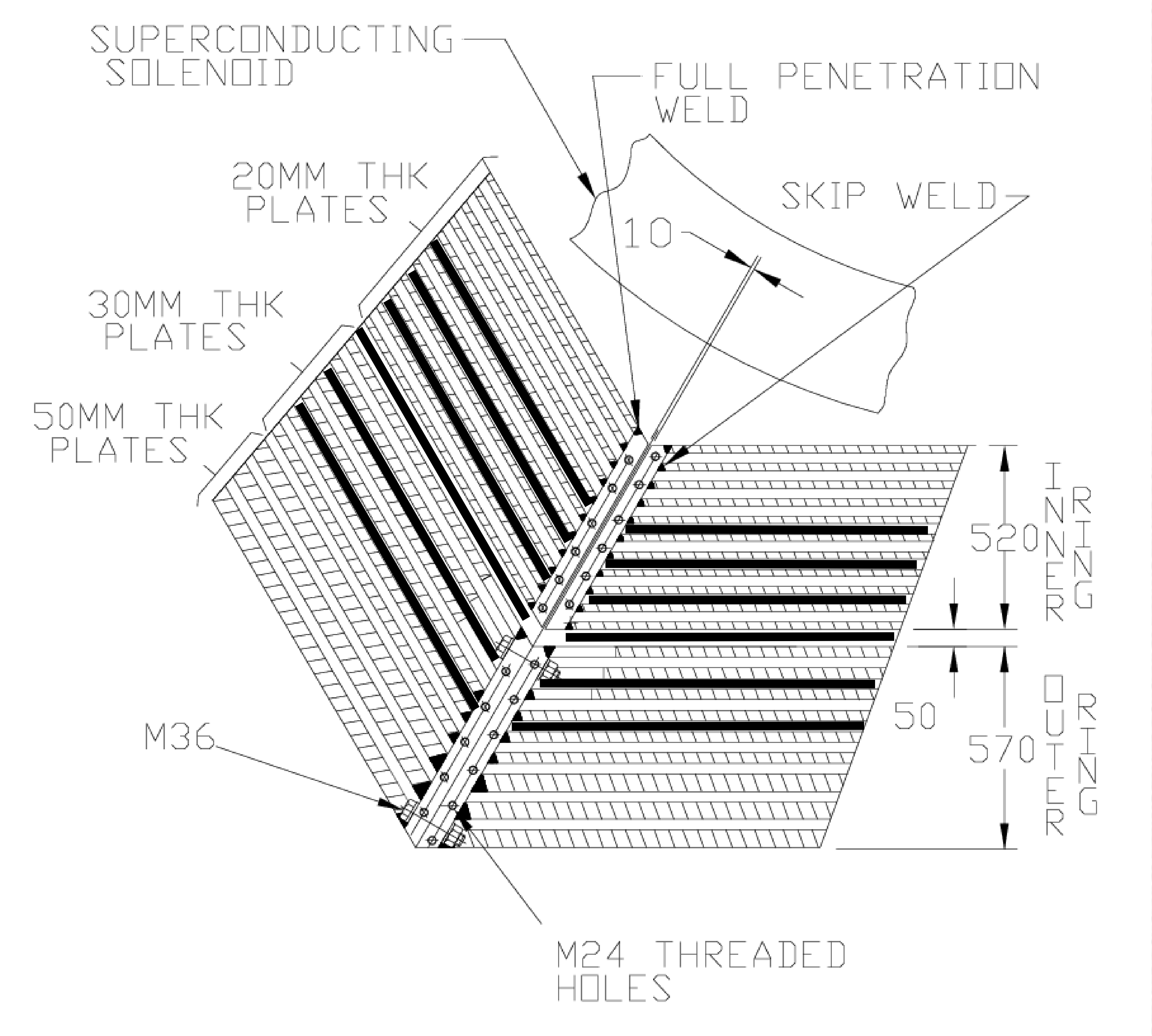
- A low momentum threshold is important
- Examples
  - Highly segmented *B*A*B*AR flux return is well-suited to the task
  - BES-III flux return is also highly segmented (not quite as well)
  - CLEO-*c* flux return is not, due to original use at higher energy
- At low momenta misidentification due to pion decay is a problem, and is difficult to deal with (see above)
  - Kink-finding in the main tracker can help, but is rarely done efficiently
    - A TPC could provide some advantage for kink-finding
- Current and past generations typically used some type of large area wire chamber, such as RPCs, LSTs as the sensitive device
- At Super Factory intensities, it is necessary to use faster technology, such as extruded scintillator strips with wavelength shifting fiber and pixelated APD or SiPM readout



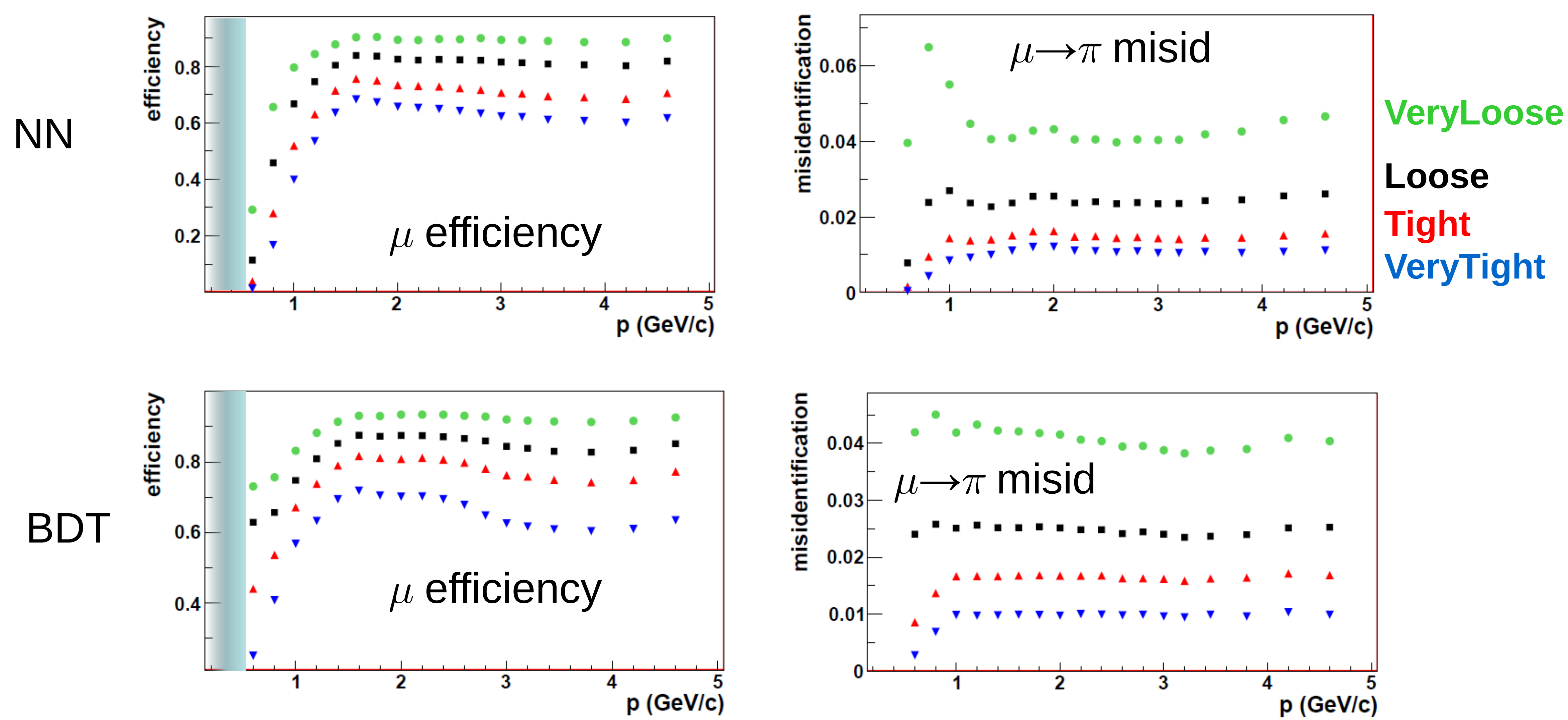


BABAR flux return plate structure

- Front layers of 20 and 30 mm plates, originally designed with emphasis on good energy and position resolution for K_L^0 from $B^0 \to J/\psi K_L^0$ decay, are a good configuration for low momentum muon ID with best possible efficiency
- Optimization against muon spectra from *D* semileptonic decay and $\tau \to \mu$ decay is required
- Likely will not have to fill all rear layers with sensors



BABAR NN and BDT muon identification performance



Detector Element	CLEO-c	BESII
Tracking Resolution		
at 1 GeV/c	0.5%	1.2%
Maximum momentum for π/K Separation	1.5 GeV/c	600 MeV/c
dE/dx Resolution	4.9%	9%
Photon Energy Resolution		
at 1 GeV	21.5 MeV	220 MeV
at 100 MeV	3.9 MeV	70 MeV
Minimum Photon Energy	30 MeV	80 MeV
Solid Angle for Tracking	0.93	0.8
Solid Angle for Photons	0.93	0.75

Bottom line τ/c detector issues

- **Exclusive state reconstruction** is the game being played
  - Functional solid angle coverage for each system must be optimized
- **Vertex detection**: is it needed? Low radius tracking is required, whether with SVT, low mass DCH or TPC. Is SVT precision beneficial?
  - Can low radius tracking be integrated with the main tracking?
- **Main tracking**
  - Lower *B* field (~1T) is required. Multiple coulomb scattering is an important determinant of momentum resolution - low mass gas, wires, support structure
  - Small cells needed for speed
- **Particle ID**
  - It is important to extend hadron/muon PID to lower momenta: improved *dE/dx* via cluster counting, TOF, Fast RICH, FARICH
- **EM calorimetry**
  - Existing CsI(Tl) barrels are likely OK, with performance somewhat compromised by need to shorten integration time
  - Forward endcap performance is on the edge, may need at least partial replacement with a faster, more radiation hard crystal

Bottom line τ/c detector issues - continued

- **EM calorimetry** – continued
  - If *BaBar* is the basis of τ/c detector, and DIRC is retained, rear endcap will inevitably be compromised, but "rear" region is more important in a symmetric configuration
    Were DIRC not to be retained, rear flux return door could be rebuilt to accommodate a proper high quality endcap EM calorimeter
- **Muon Identification**
  - A highly segmented flux return is needed to extend muon ID to lowest possible momentum
  - *BaBar* design is a good match
- **Data acquisition and computin**g were not discussed
  - The event rates are similar to those studied for SuperB
  - Event size is somewhat smaller due to lower average multiplicity
  - Offline computing task is also similar, but somewhat ameliorated by smaller event size

Other relevant wisdom from Yogi Berra

- The future ain't what it used to be.
- It ain't over 'til it's over.
- If you don't know where you're going, you might end up some place else.
- If the people don't want to come out to the ballpark, nobody's going to stop them.
- When you come to a fork in the road, take it.

- In theory there is no difference between theory and practice. In practice there is.
- Always go to other people's funerals, otherwise they won't go to yours.
- I didn't really say everything I said.