Evolution of the CLEO Detector & Its Impact

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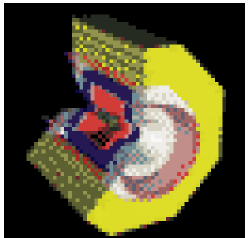
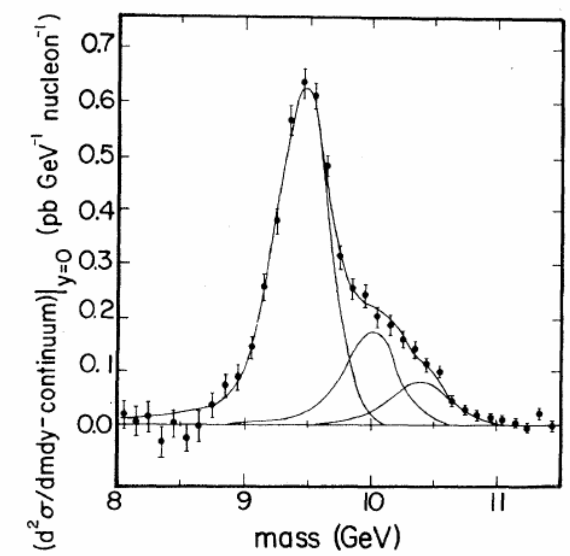


Introduction

- Context: Late 1970's, J/ψ had been discovered in Nov. 1974, we knew about open charm & τ, but not about existence of b, t, W or Z !
- Idea: explore e^+e^- collisions in 8 -16 GeV center-of-mass range, hope for something new
- Competition: PEP/Petra at higher energy (up to 32 GeV) at SLAC & DESY, later ARGUS at DESY
- CESR proposal May 1975 for single ring collider with $\mathcal{L}=10^{32}$ $cm^{-1}s^{-1}$
- Surprise – After detector design started discovery of b quark 1977 (Lederman) at FNAL via Υ(1S) & Υ(2S) (hint of Υ(3S)). Could there be a nice state for threshold $B\bar{B}$ production like the ψ(3770) for D's?

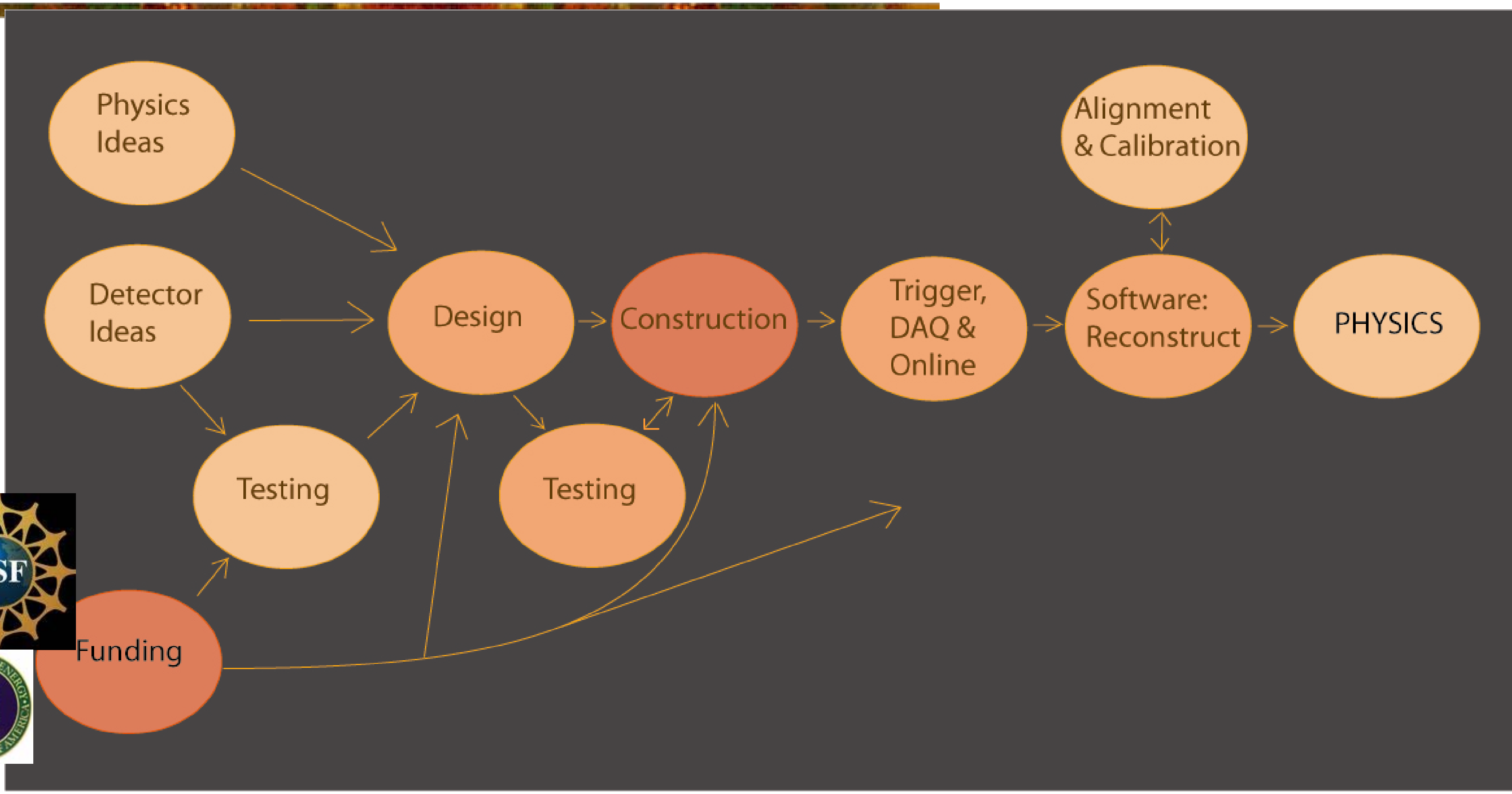


Uneno et. al, FNAL $\mu^+\mu^-$ mass, background subtracted (1979)

b Physics Goals

- Would b's decay as "predicted" or could we see new phenomena?
- Could we learn something seminal about QCD studying Upsilon transitions & decays?
- Was there anything to learn from charm decays, since $e^+e^- \to c\bar{c}$ is 1 nb, 40% of total?
- Is there anything unexpected?

What it Takes to Build a Detector



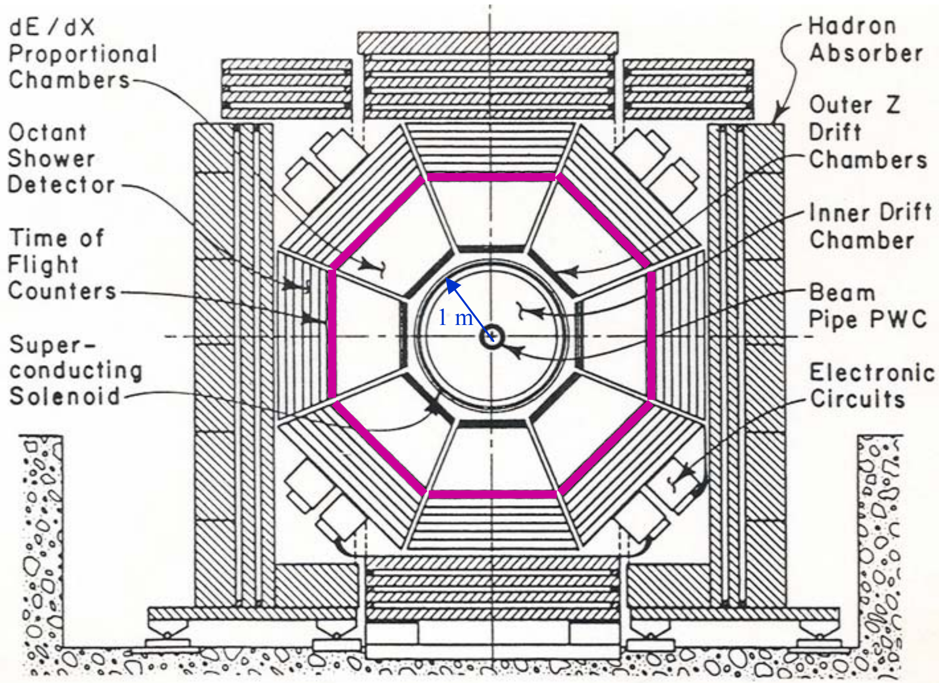
- I will not talk much about Trigger, DAQ, Online, Software, etc... even though they are critically important; apologies to Selen, Galik, Honscheid, Kreinick, Kutschke, Katayama, Hetsley, Skwarnicki, & many others (& other apologies...)

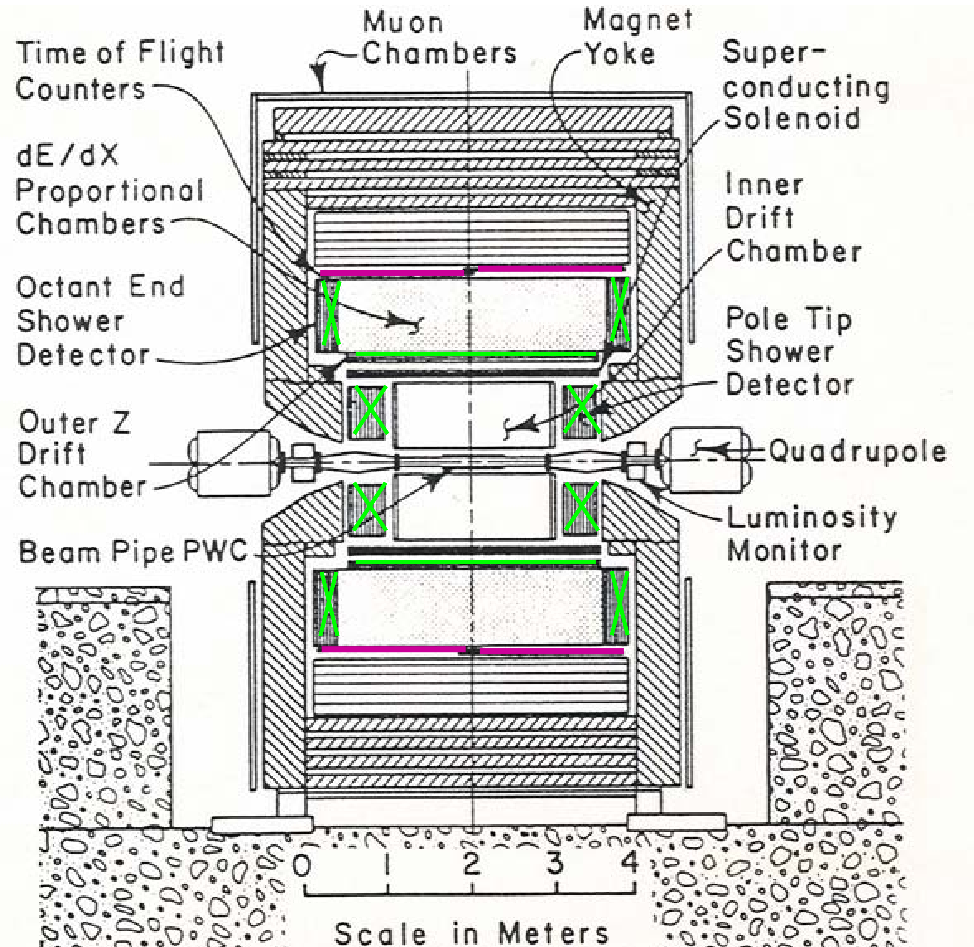
Detector Philosophy

- $e^+e^- \to$ hadrons: lots of charged tracks & γ's, $\approx$10 charged tracks & 10 γ's on average per event
- Maximize acceptance
- Have best possible p & E resolution
- Identify leptons: $e^\pm$ & $\mu^\pm$
- Identify charged hadrons
- Learned later: Detect vertices from short lived particles, e.g. D's
- Main detector design issues: cost, detector material, our understanding as detector was designed without knowing about $e^+e^- \to B\bar{B}$

CLEO I Detector

- Tracking components: DR, IZ, OZ
- γ detection: Octant Shower – choice over Pb-scintillator
- PID: TOF + dE/dx, originally High pressure Č 2/8 & atmos Č 2/8 (for e- only)
- μ id from muon chambers
- e id from shower & dE/dx
- Some parts never used



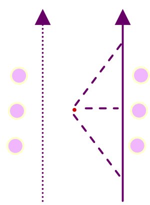


The Super-Conducting Coil

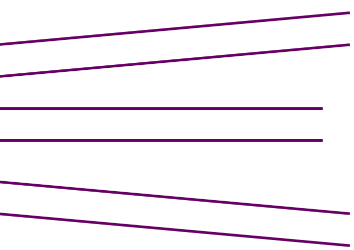
- We started for about 18 months with a 0.5T conventional coil
- Thin (0.7 r. l.) super-conducting coil at 1.0 T was critically important
  - TPC detector for PEP was building such a large coil
  - Dave Andrews studied their design made several crucial improvements. This was a typical CLEO adventure, in that he had almost no help (~ factor of 10 less manpower), & managed to get the thing to work. Unfortunately, TPC was delayed to some nasty failures.

The Drift Chamber

- Measure time for ionization to drift to sense wire



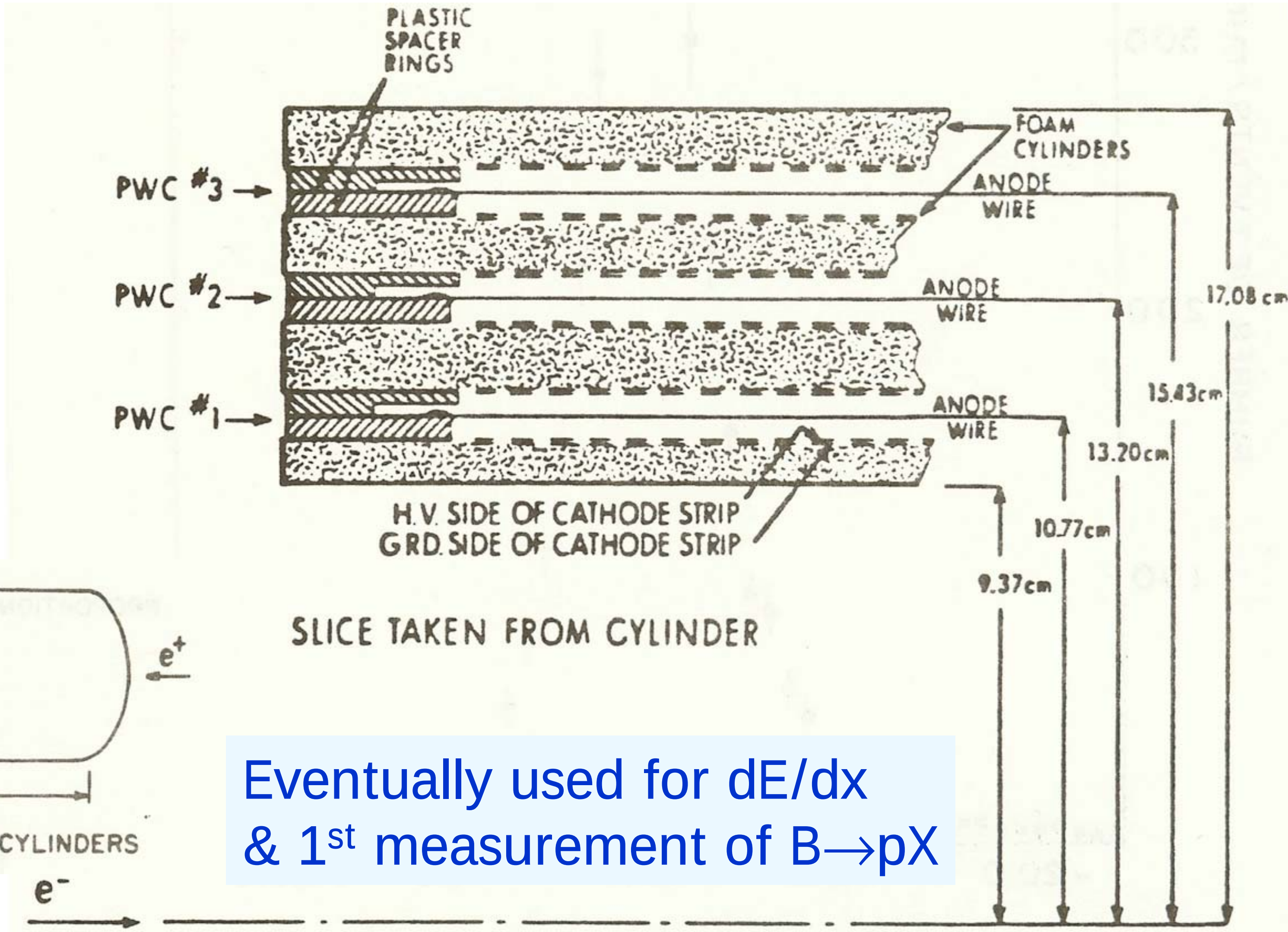
- z coordinate found using stereo wires, with 20x worse resolution

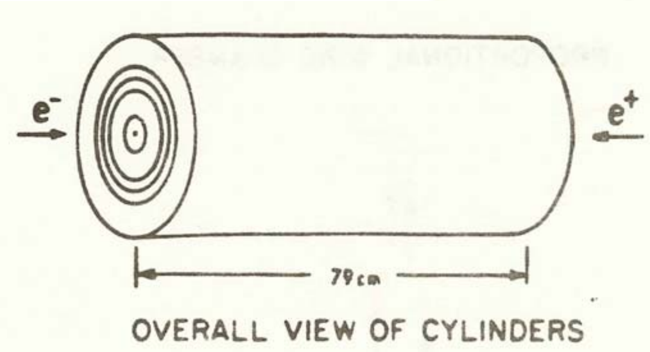


- Hartill, Larson...

IZ: Inner Chamber for Z Measurement

- Built at Syracuse (Horwitz) along with never used OZ (Others)

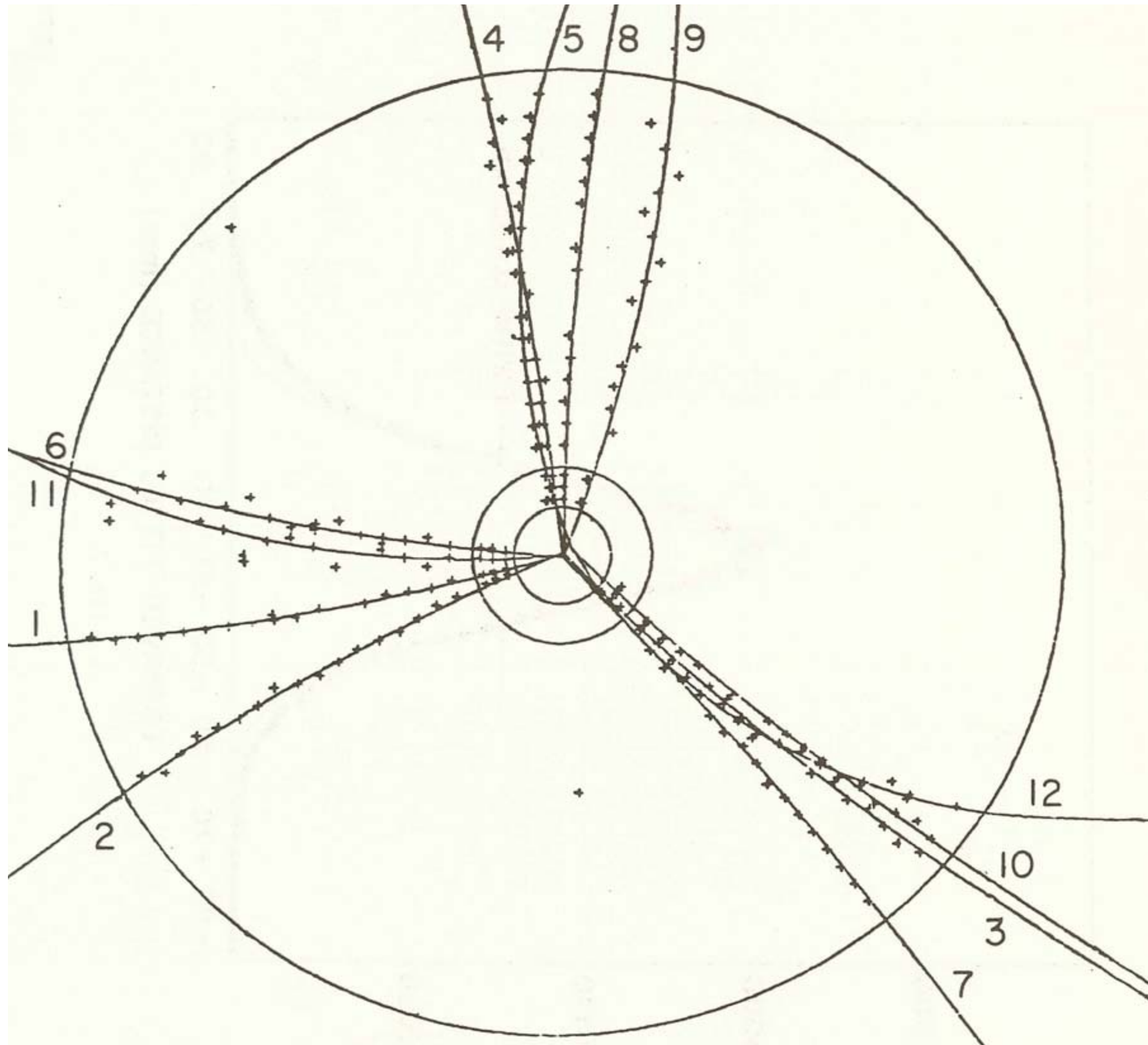




Eventually used for dE/dx & 1st measurement of $B \to pX$

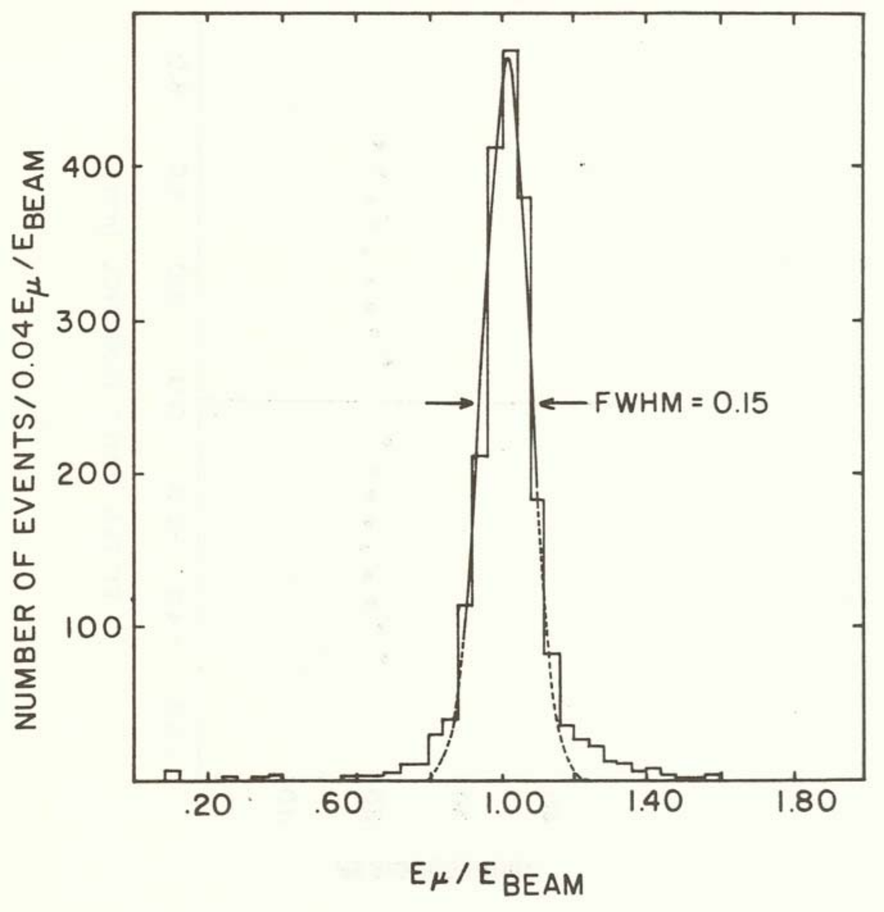
Charged Particle Tracking

- 17 Layers, hits are spread apart “non-local” ambiguity resolution
- Stereo for z
- No dE/dx
- IZ: 3 layers with cathode strips for z meas.



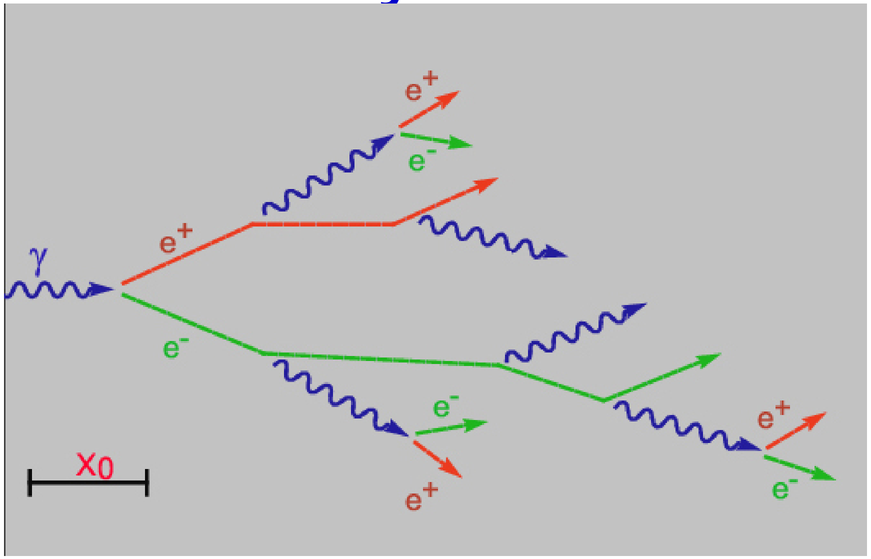
Performance

- DR resolution 250 μm
- Δp/p~12% at 5.2 GeV
- Problems
  - Efficiency was good but not great.
  - Left/Right ambiguities often solved incorrectly
- Eventually ~1985 "Solo" tracking (Berkelman) replaced by "Duet" (Ogg & Cassel)



Electromagnetic Calorimeter

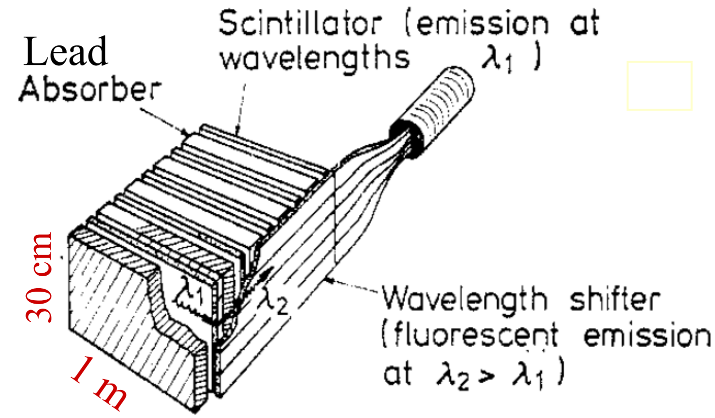
- Need to measure position and energy of γ's, most of which result from π^o decays
- Idea is to use the "electromagnetic shower" generated by high Z materials

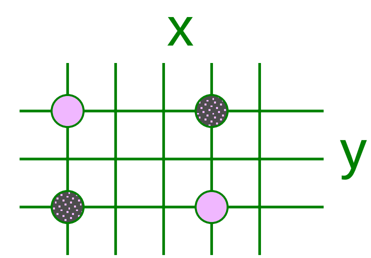


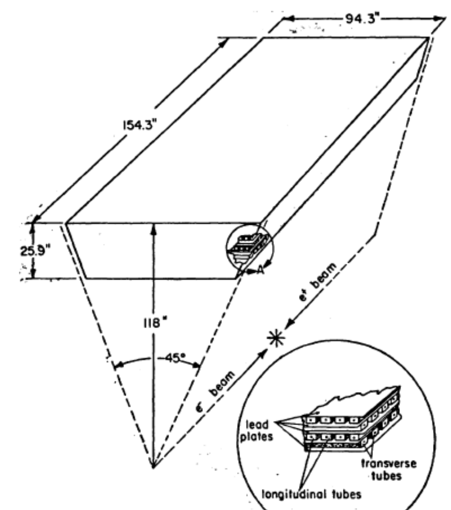
- Energy is proportional to the number of charged particles and these can be sampled

EM Calorimeter

- Choices
  - Pb-scintillator sandwich read out with waver shifter
  - Pb-proportional tube sandwich. This system had crossed x & y tubes that ran over the entire octant. Causes problems, when more than 1 track or γ is present
  - Energy resolution is ~17%/√E
  - This was our choice, called RS, for “Rutgers Shower,” F. Sannes...

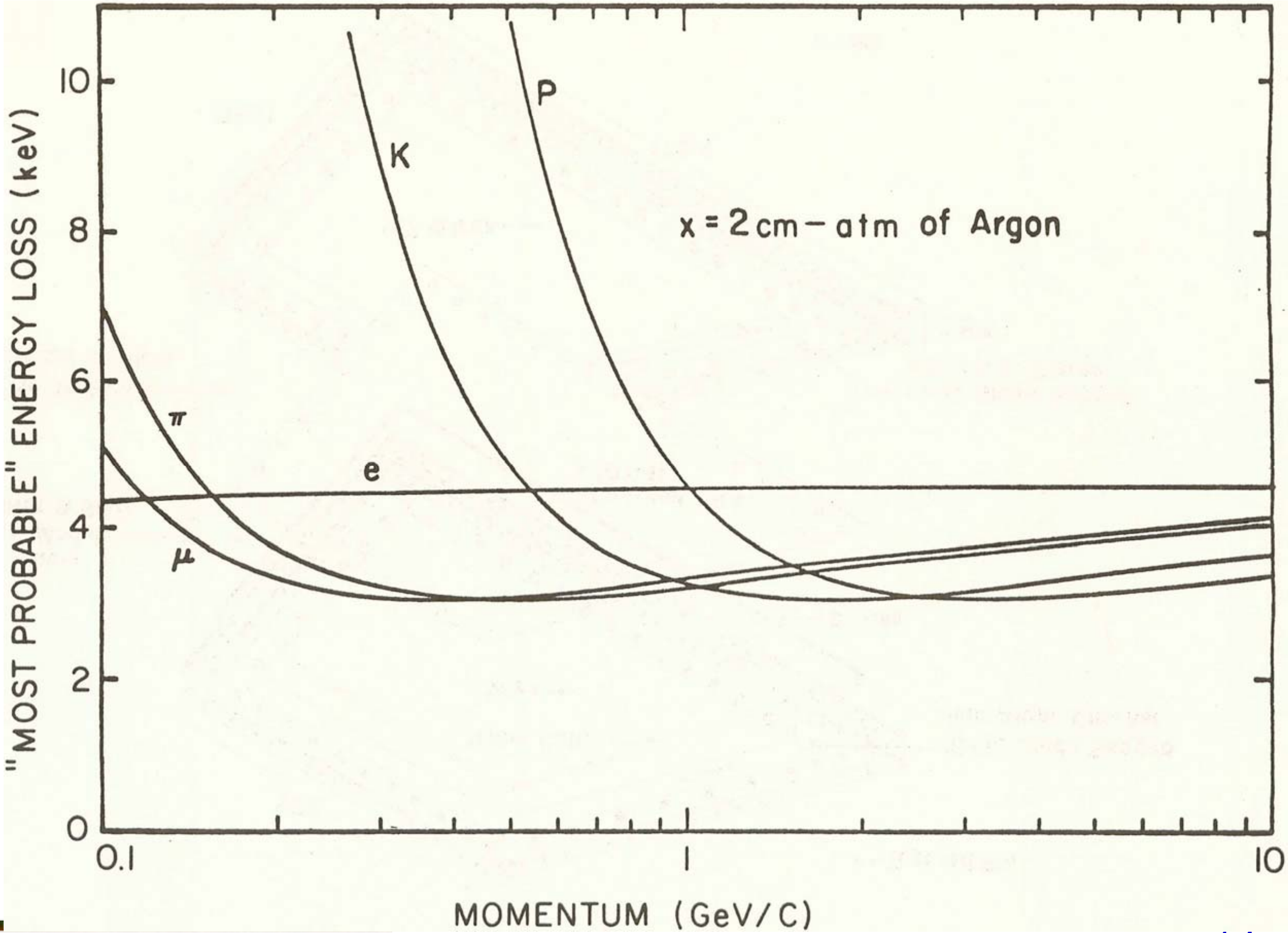






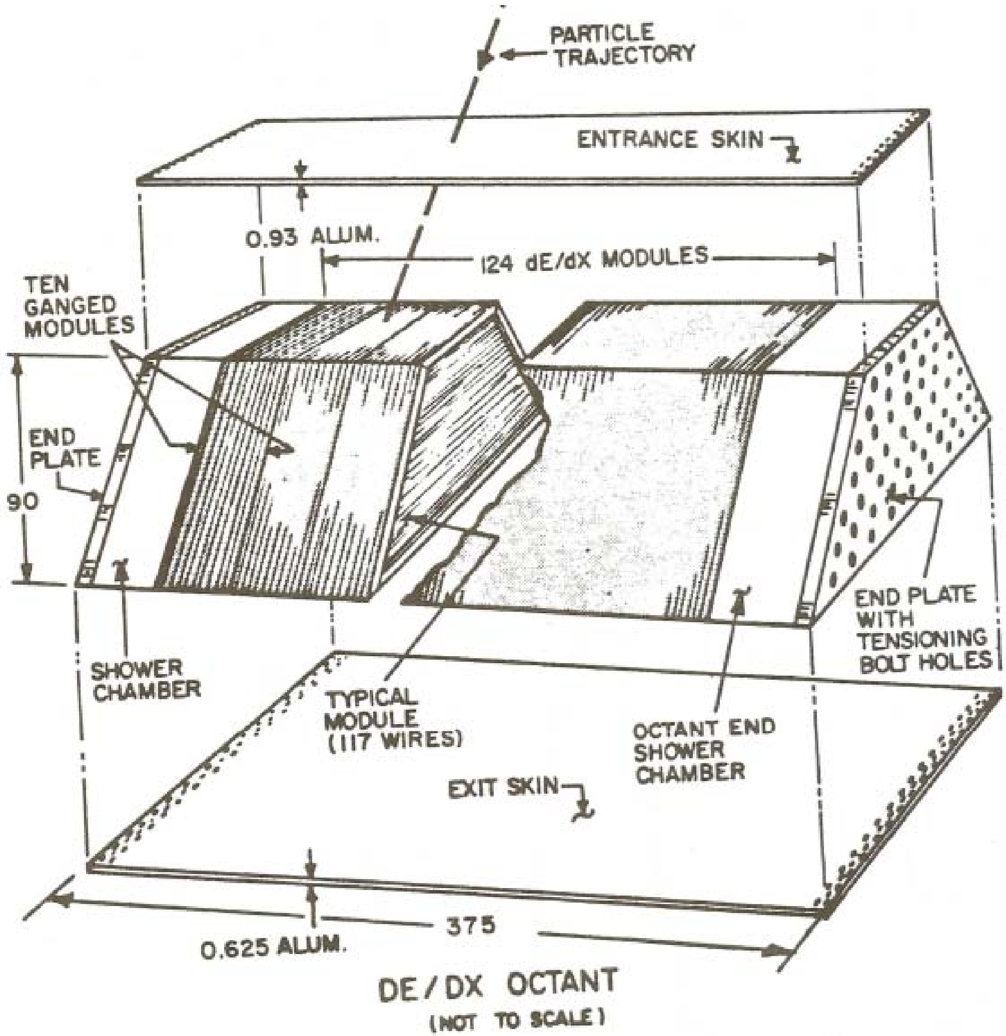
dE/dx: Expected Energy Deposit

- Ehrlich, Gentile, Talman, Stein, Stone + Vandy (Csorna & Panvini)

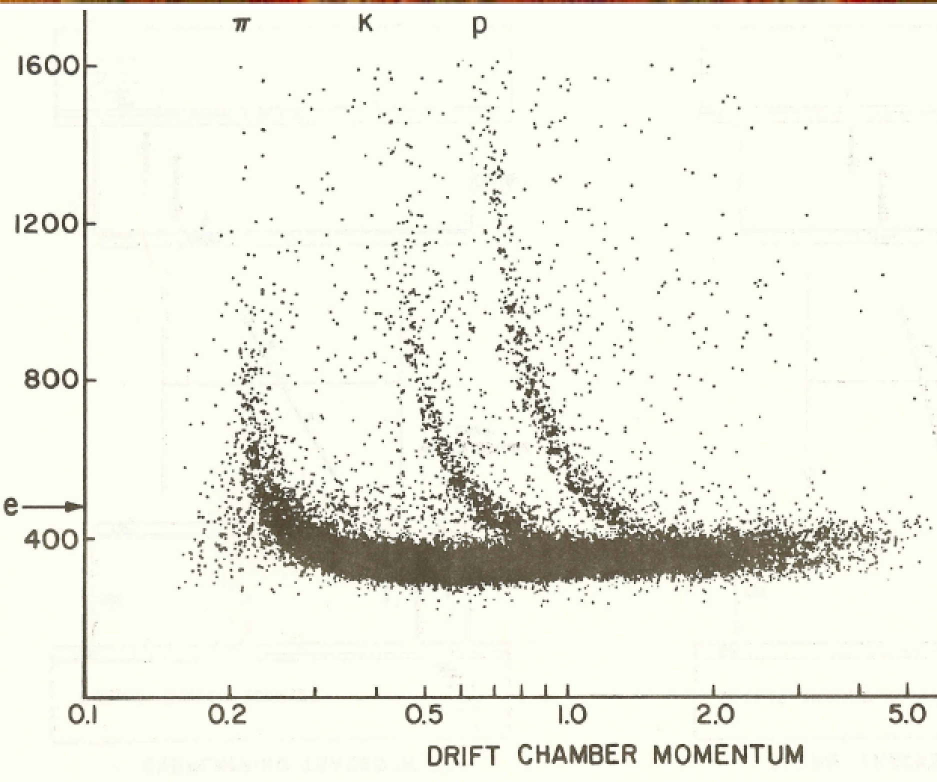


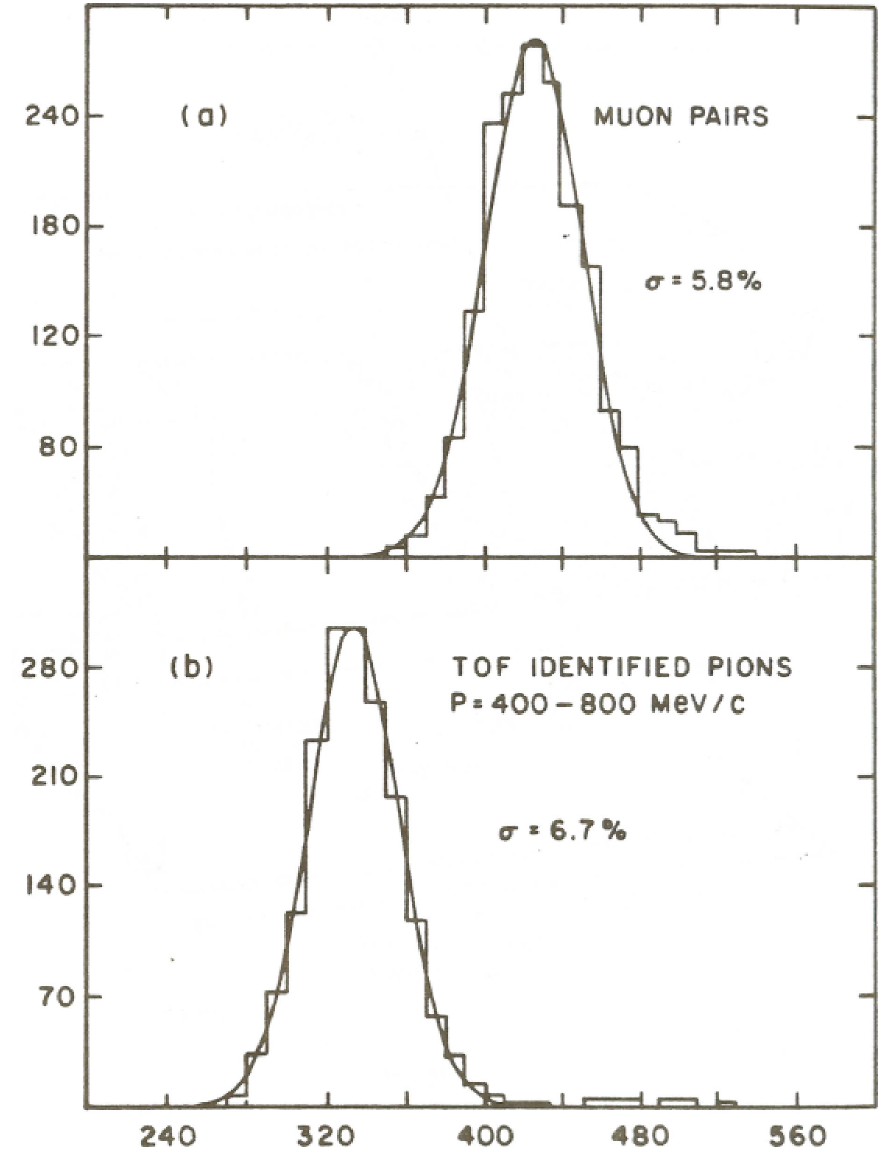
dE/dx Construction

- Consists of 124 1” thick modules
- Wires at same position in 10 modules ganged together
- Pressurized to 3 atm



dE/dx: Results

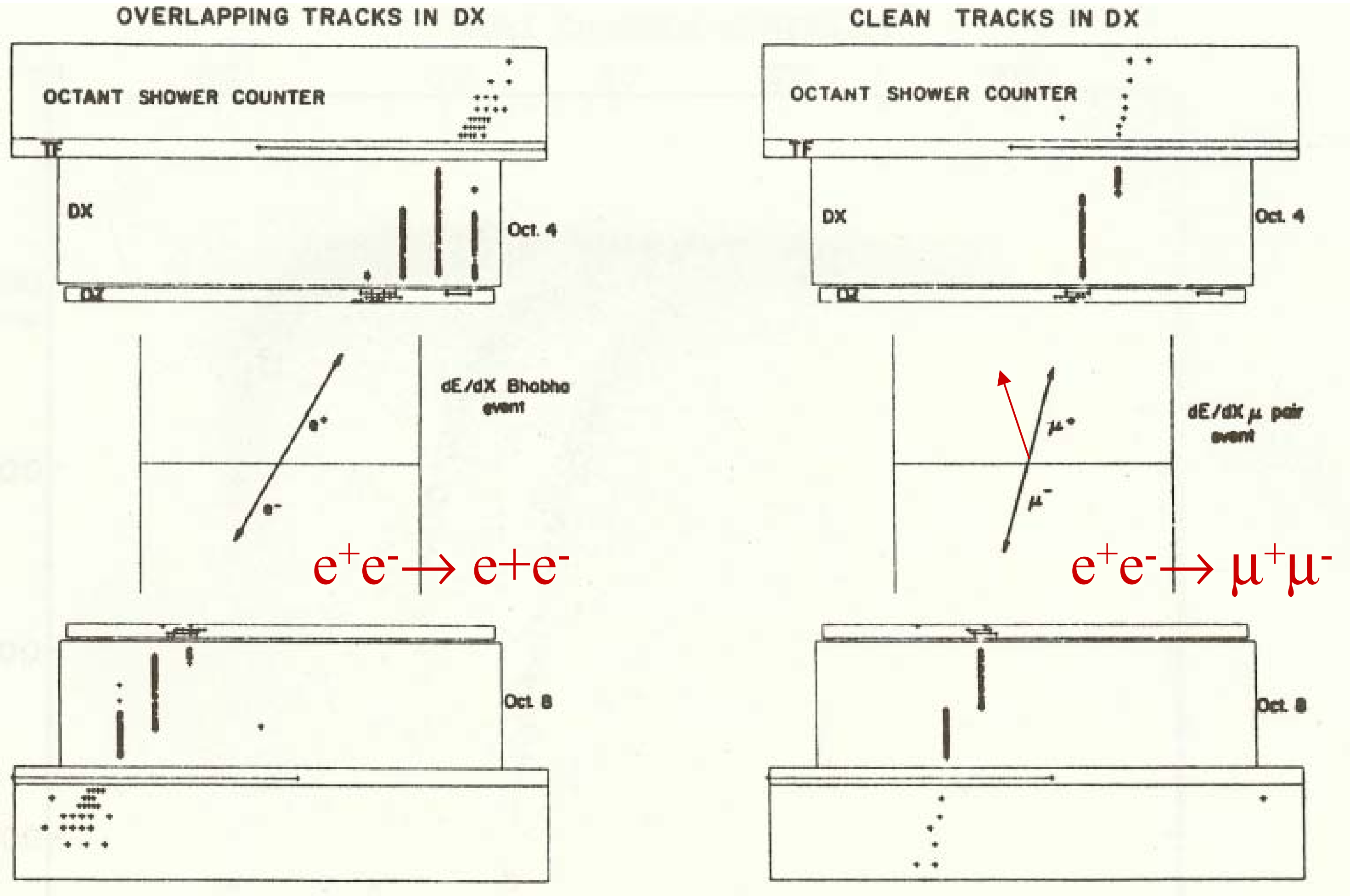




- A useful device, but compromised by material in coil

dE/dx & RS: Also e⁻ Identification

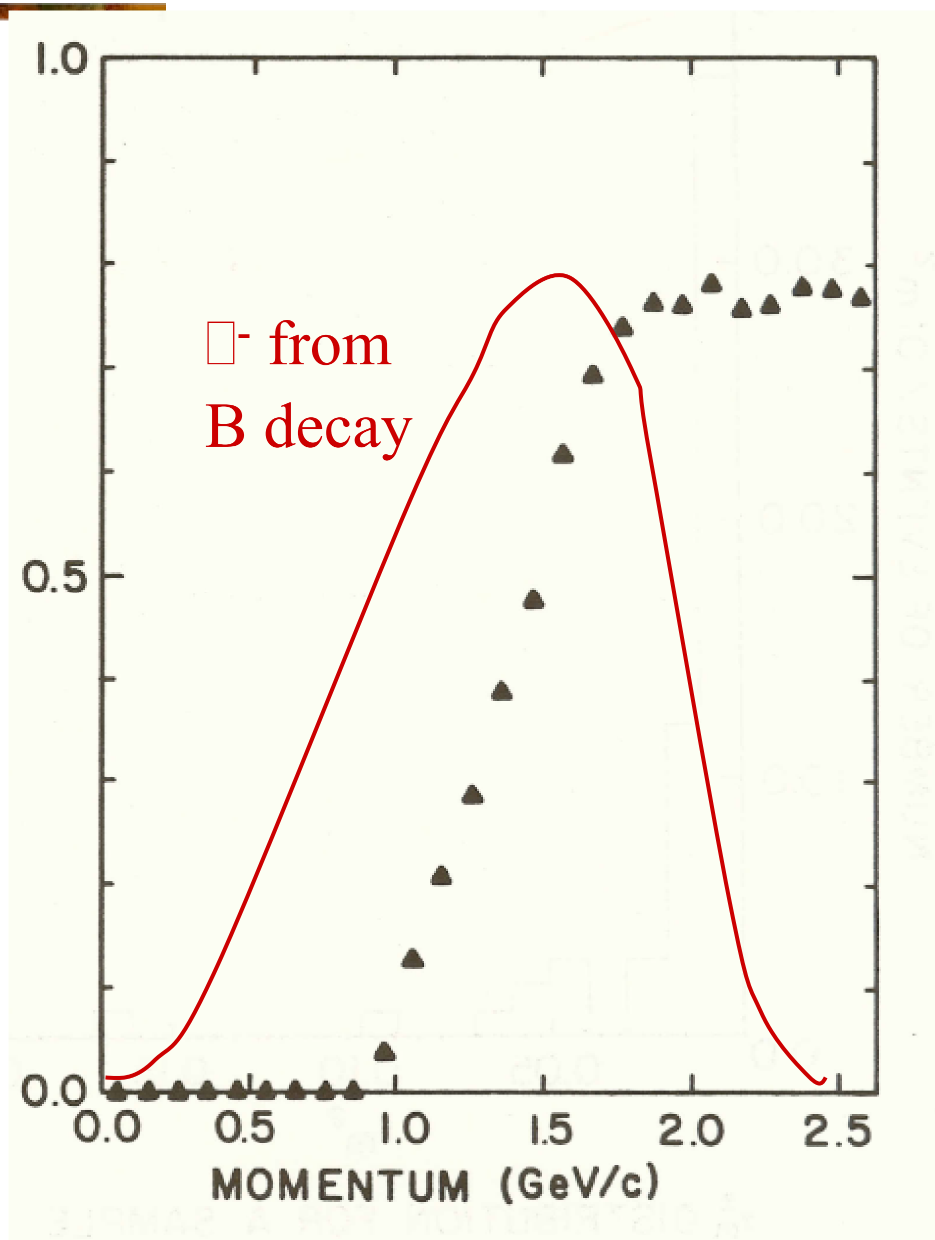
- Good for e^- detection
- RS match Energy with p
- dE/dx ask for large ionization



Ghost track problem

Muon System

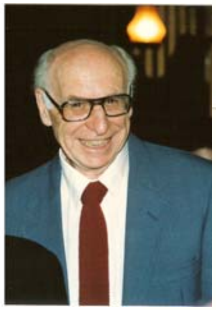
- Efficiency vs p
- Designed for high p tracks, before Y(4S) was found (by us). Acceptance not well matched to B decays
- Maximum efficiency was 54% for p>1.7 GeV/c
- Rochester group: Olsen, Thorndike, Melissinos, Poling,....



CLEO I Budget

- Maybe double for labor costs
- No contingency
- Inflation is 265%
- So maybe = 19.5 M$ in 2008 dollars
- *Absurdly cheap*
- Total for CESR + CLEO ~20 M$

CBX 77-5
A. Silverman



CLEO I Leader

Revised Cost Estimate for CESR Detector

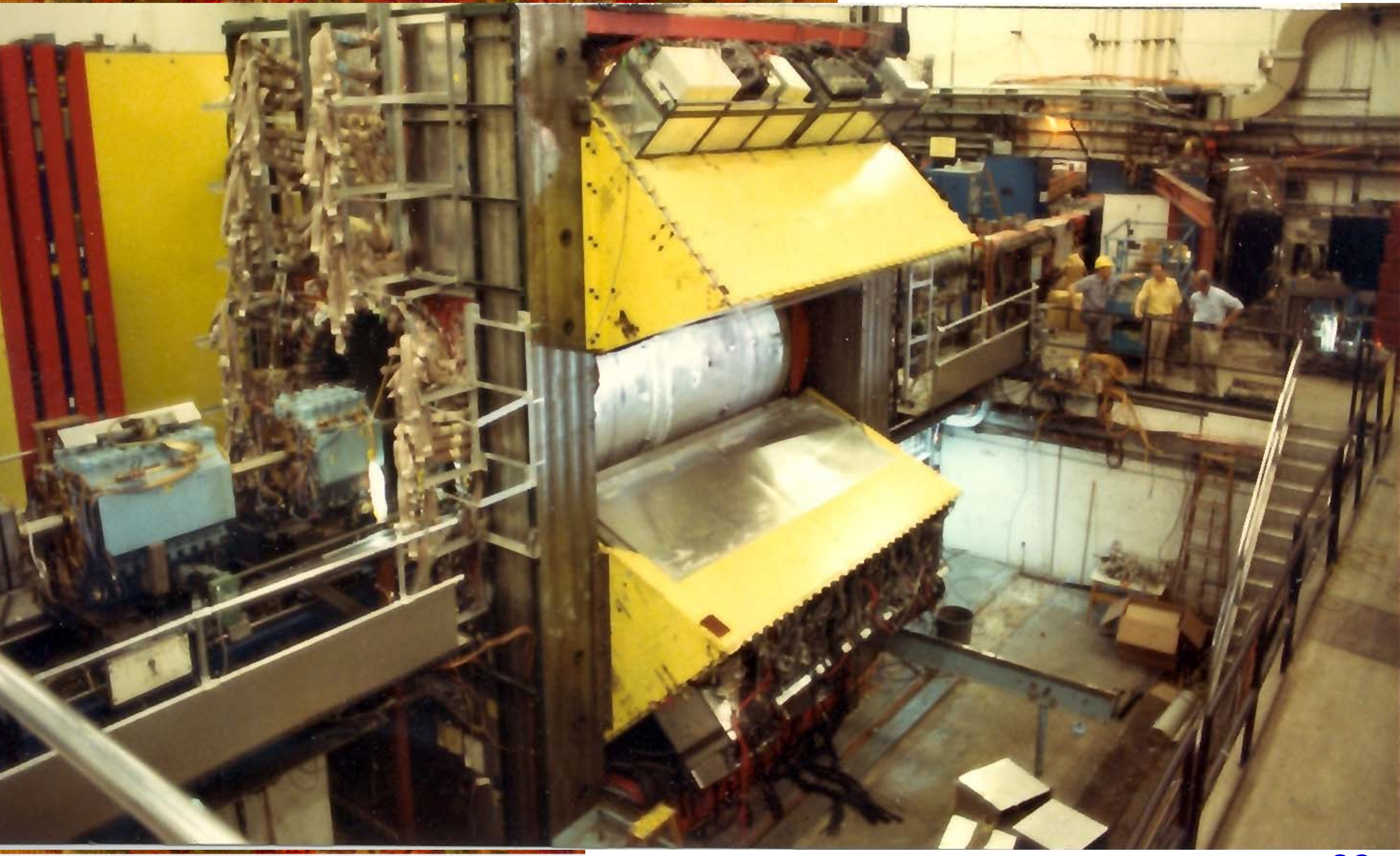
Table I*

Item	Cost	Oct. 1977	Oct. 1978
Al. coil	100	100	
Sc. coil	300	300	
Refrigerator	200	150	50
Cryostat	50	50	
Magnet iron	320K	320K	
μ-Iron	400K	100K	300K
wire chambers in μ-detector	100K	75K	25K
Central detector			
Drift chambers	200K	150K	50
Time of flight	400K	300	100
Other trigger counters	50K	50	
γ-Det.	220	170	50
$\frac{dE}{dx}$ drift chambers	175	125	50
End caps	150	100	50
Total	2.665M$	1.99M$	.675M$

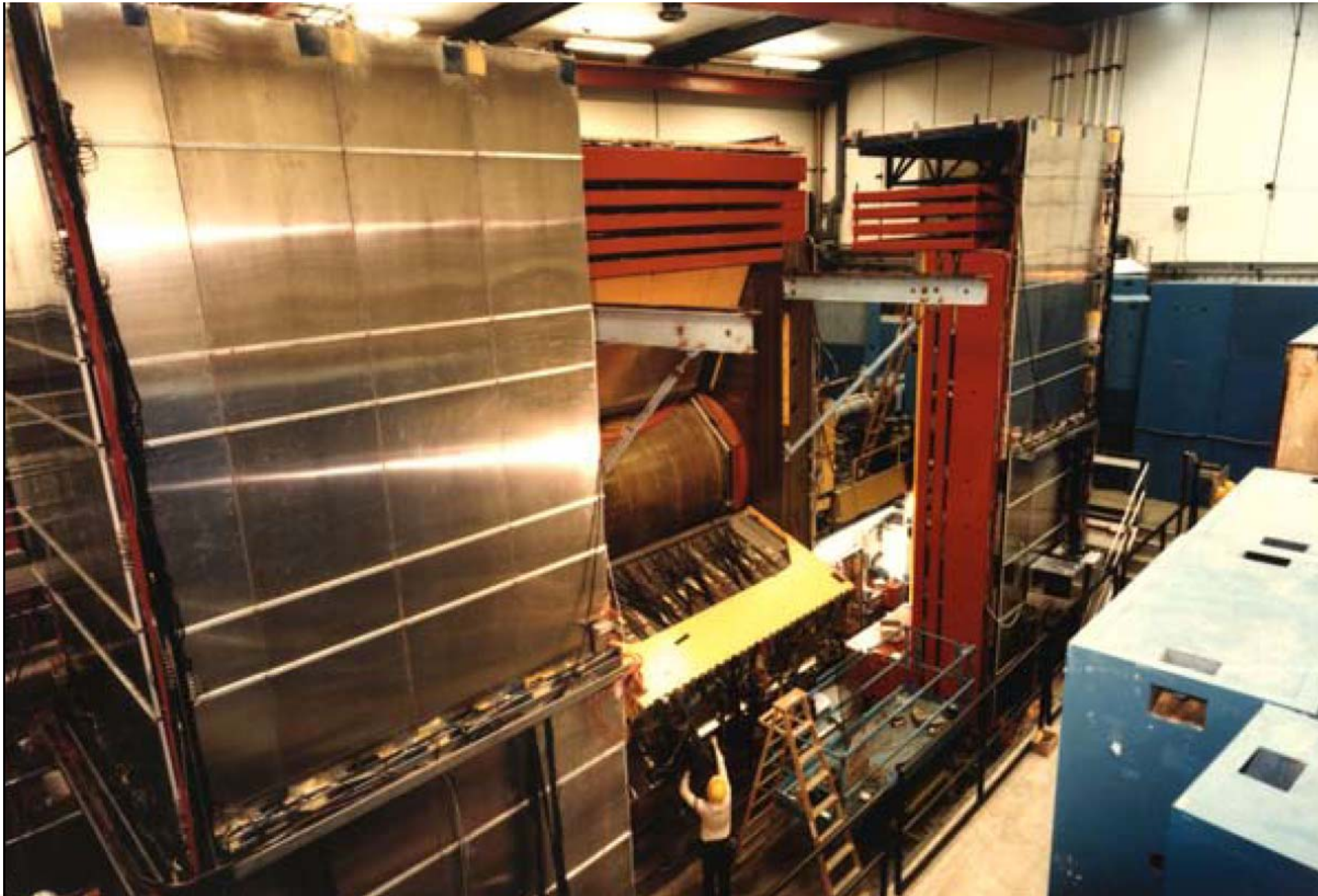
In The Beginning

Magnet Assembly

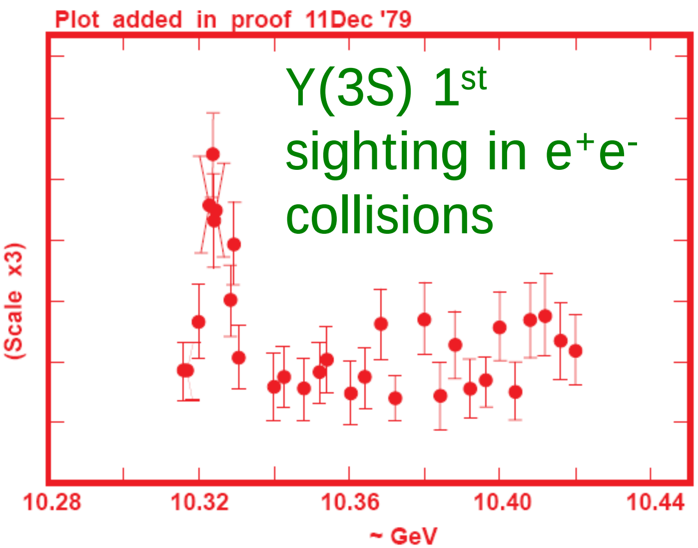
CLEO I During Assembly



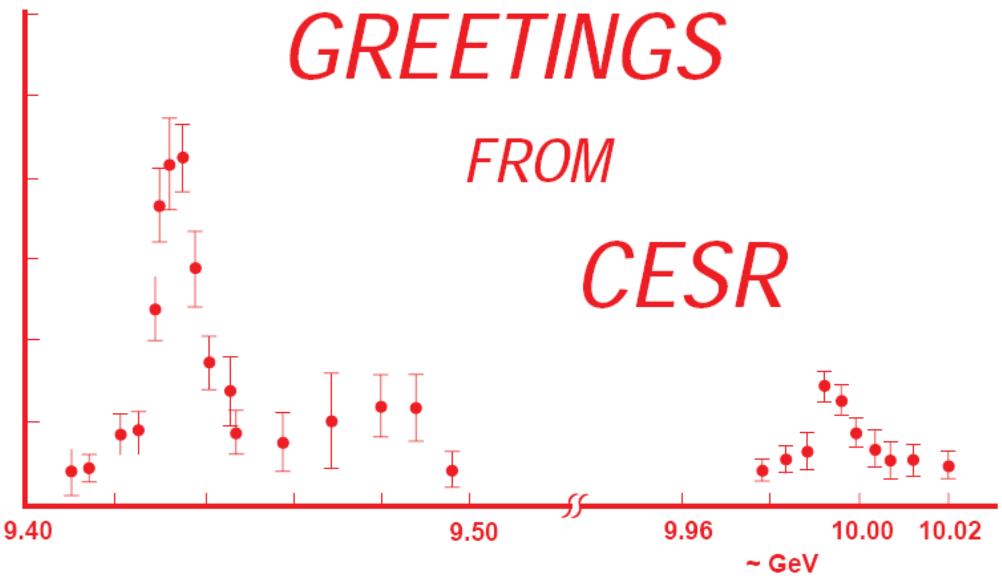
CLEO I Almost Together



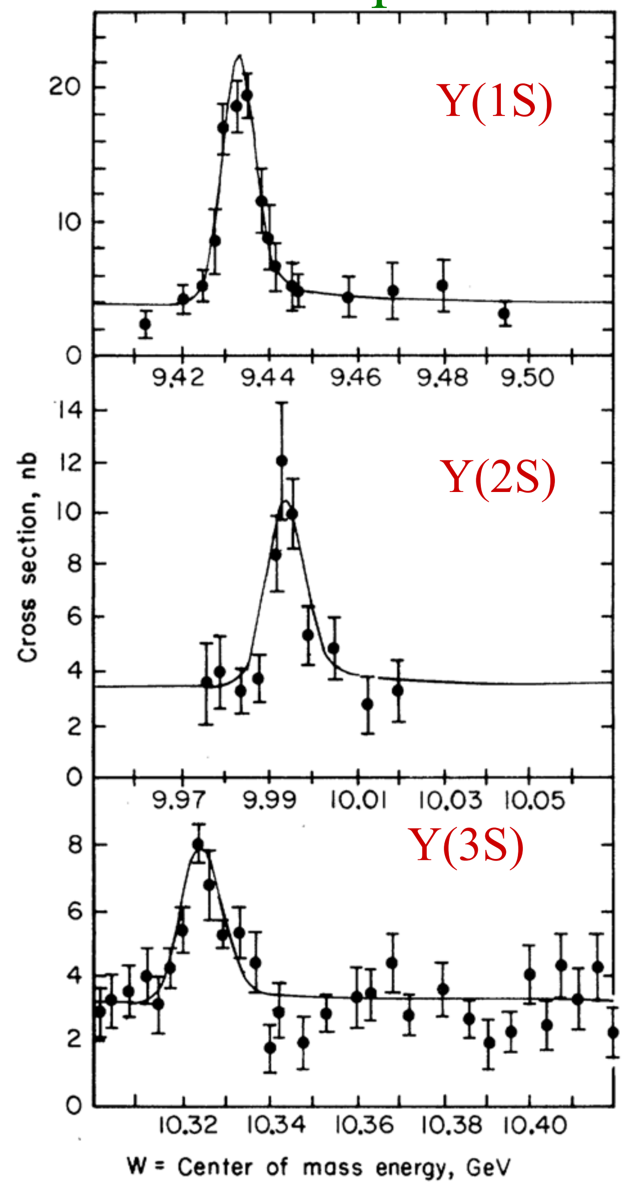
First Results (Narrow Upsilons)



Xmas card 1979



$\mathcal{L}$=0.4 pb^{-1}



VOLUME 45, NUMBER 4 PHYSICAL REVIEW LETTERS 28 JULY 1980

Observation of a Fourth Upsilon State in e^+e^- Annihilations

Discovery of Υ(4S)

$\mathcal{L}$=1.1 pb^{-1}

σ

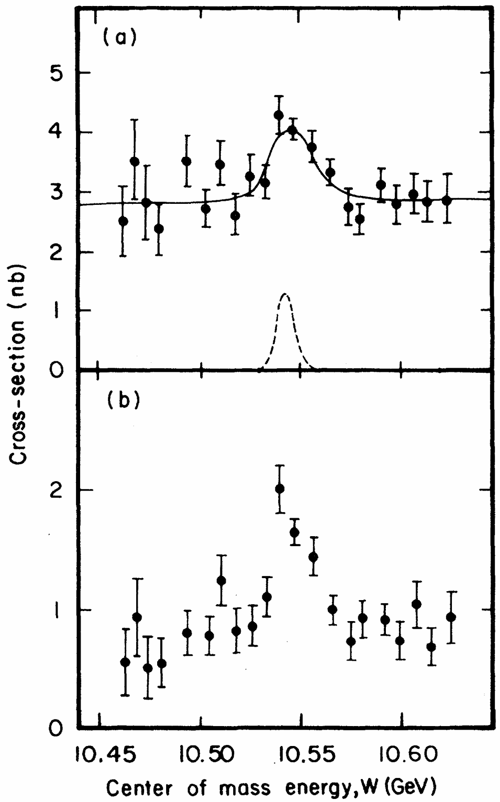
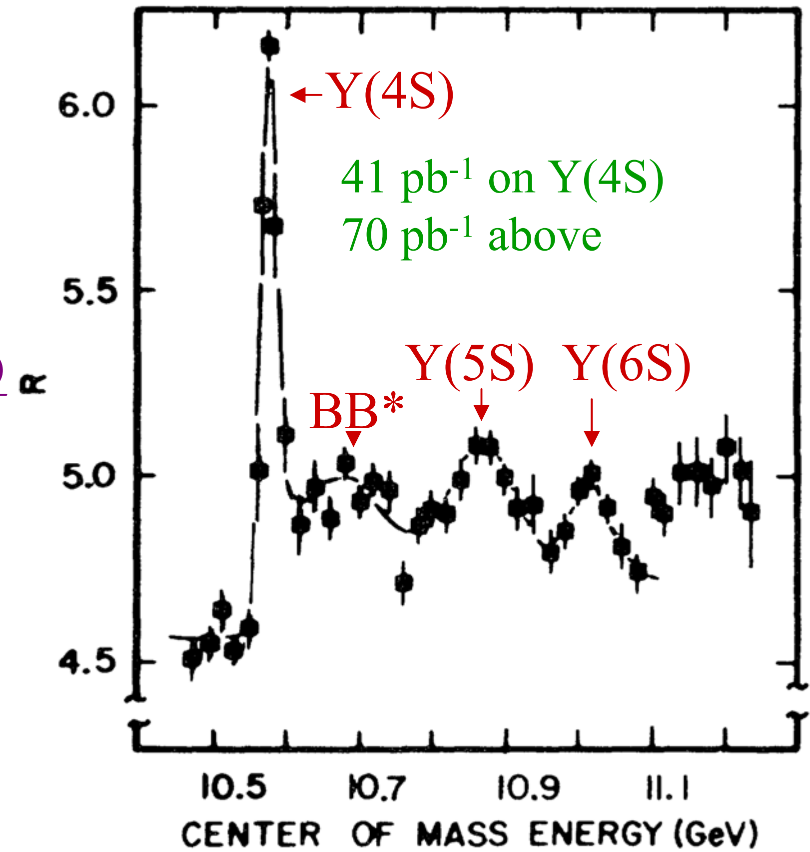


FIG. 1. Hadronic cross sections corrected for acceptance, as a function of center-of-mass energy, W. There is an additional overall systematic error of ±15%, arising mainly from the uncertainty in the detector acceptance. (a) Total hadronic cross section. The curve is a radiatively corrected Gaussian fit to the resonance above a smooth continuum varying as W^{-2}. The dashed curve indicates the beam energy resolution. (b) Partial cross section for events with $R_2 < 0.3$. (See text.)

$$R = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

In 1985, Υ(5S), etc..

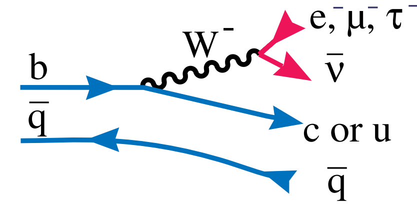


Mystery: mass differences: Υ(5S)-Υ(4S) > Υ(4S)-Υ(3S)

Further Expectations (~1983)

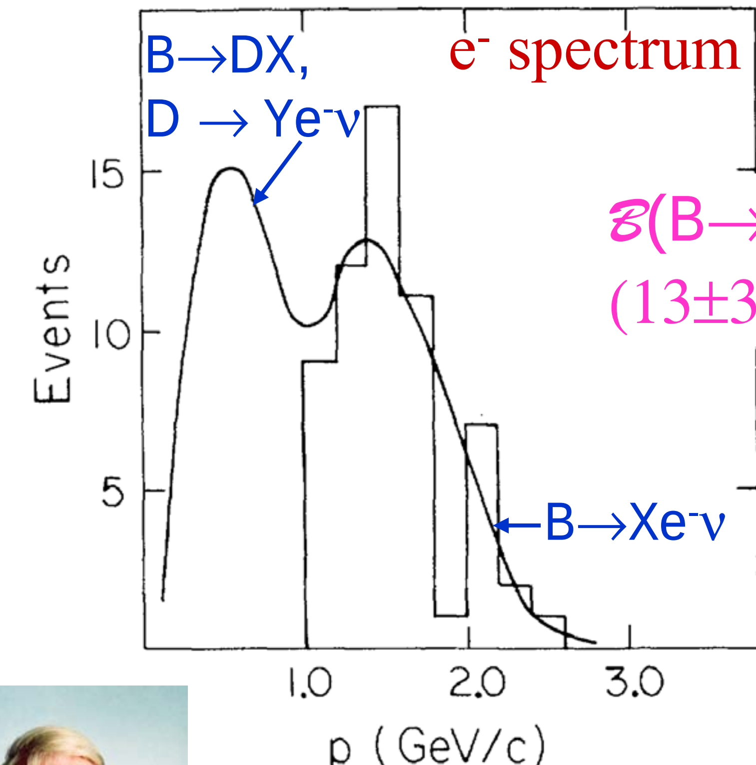
- B meson lifetime will be short
- B^o mixing will be small
- CP violation will be small
- B's will decay in very high multiplicities making full reconstruction difficult
- But in 1983, the B meson lifetime was measured as relatively long ~1 ps by PEP & PETRA experiments
- *We did have tracking & particle id to exploit measurements beyond cross-sections*

b-quarks Decay As Expected



- First observation of semileptonic decays
- Exotic decays not dominant – We are still looking for non-SM decays. New Physics, must produce these & their pattern will tell us a great deal about the NP.

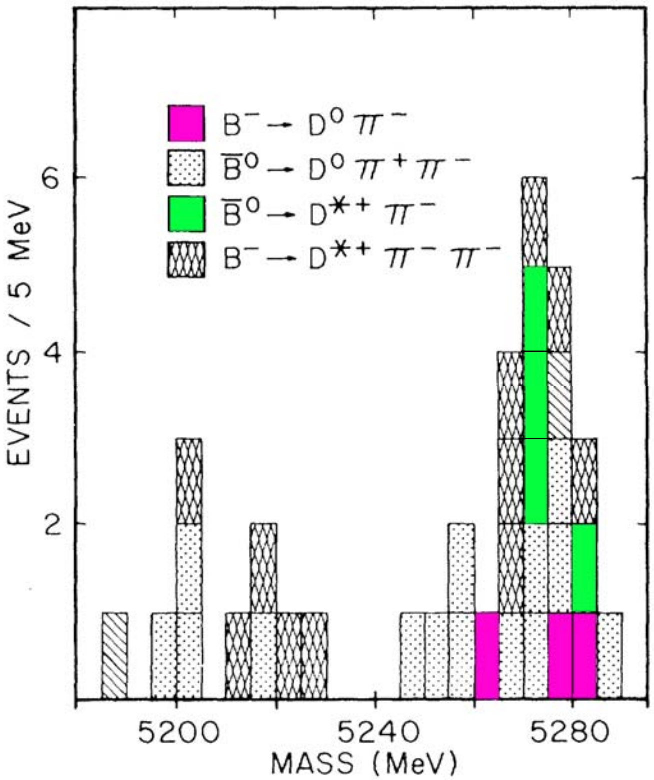
Evidence for New Flavor Production at the Υ(4S) - 1980



$\mathcal{B}(B \to X e^- \nu) = (13 \pm 3 \pm 3)\%$

DeWire, Gittleman, Thorndike....

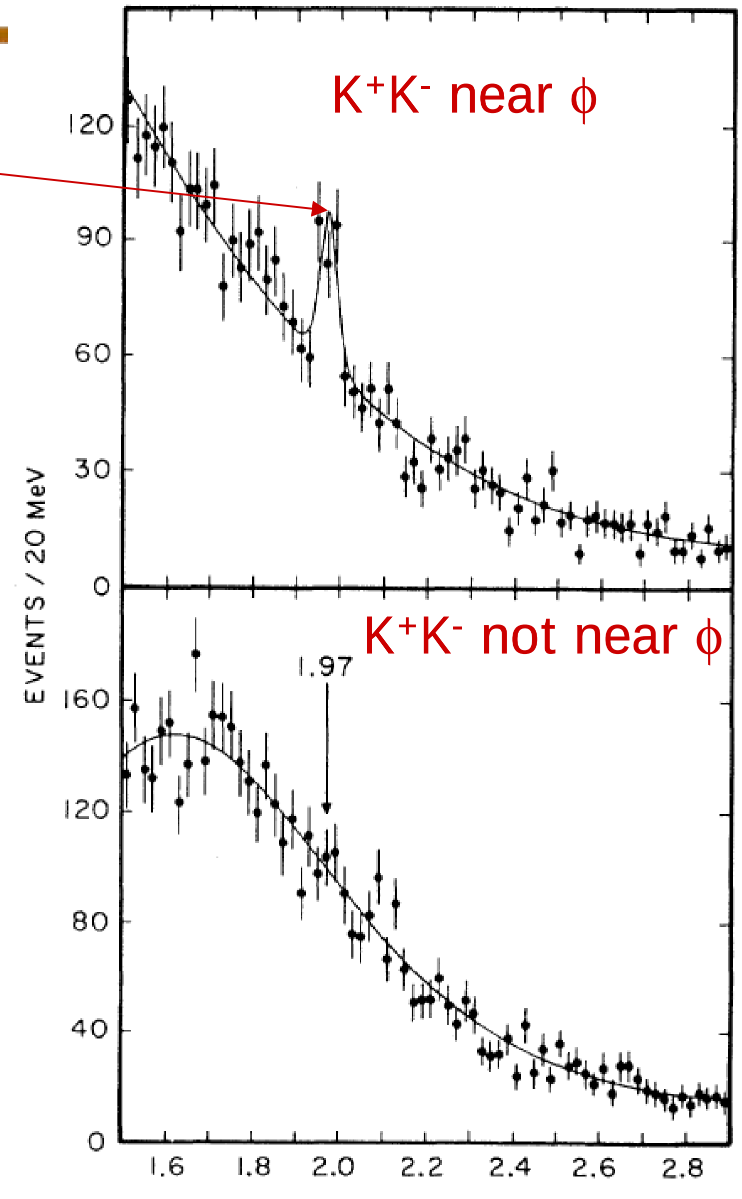
Fully Reconstructed B Mesons (1983)



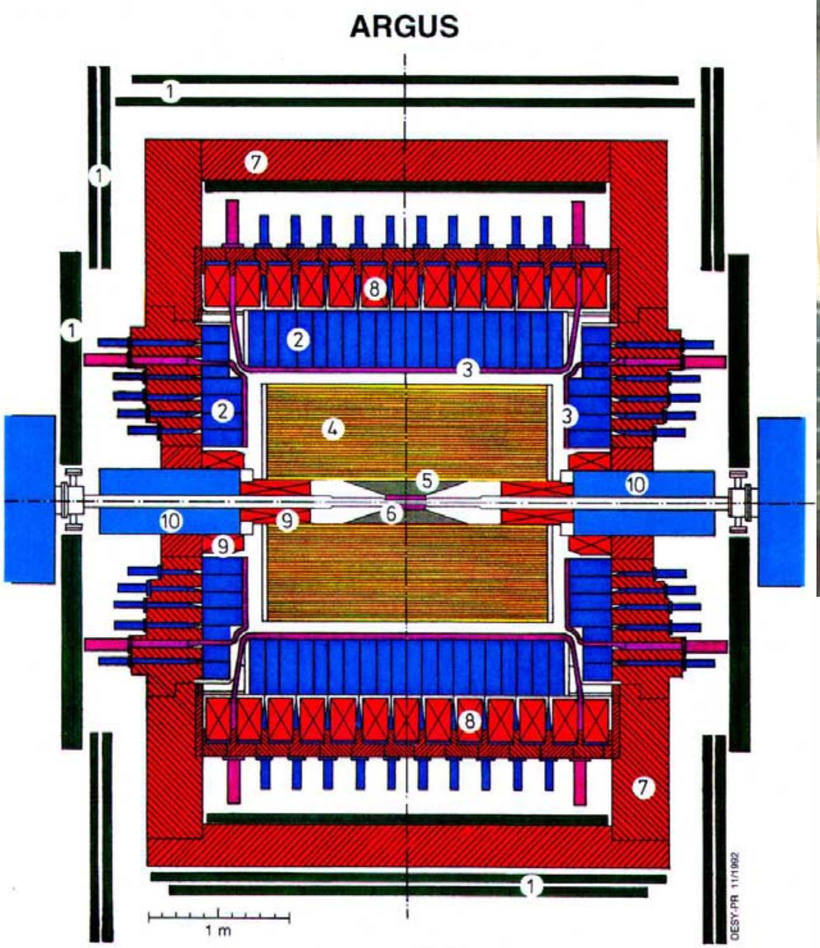
- Br's too large (partially due to ~x2 wrong D^o rate)
- Two-body modes had real events
- 3-body were wrong
- Many new techniques developed – learned better tracking software was in order

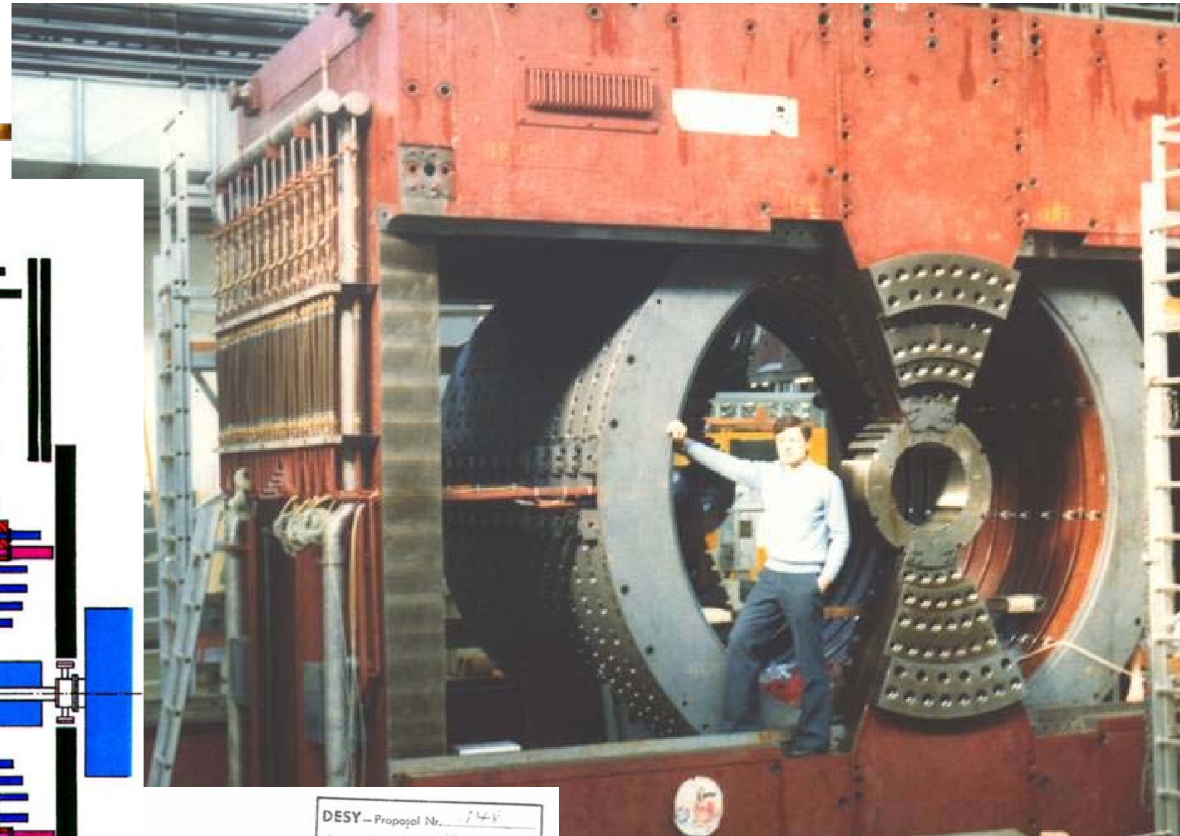
Discovery of the F≡D_s (Also in 1983)

- Mass of 1970 MeV Previously thought to be at 2020 MeV (See . arXiv:hep-ph/0010295 for details)
- Soon confirmed by ARGUS and HRS
- Beginnings of much charm & τ physics



ARGUS





DESY – Proposal Nr. 148

eingegangen am 19.10.1978

A R G U S

A New Detector for DORIS

by

A Russian-German-United States-Swedish Collaboration

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- Detector compact: not so many $K,\pi \to \mu$ fakes

ARGUS Calorimeter

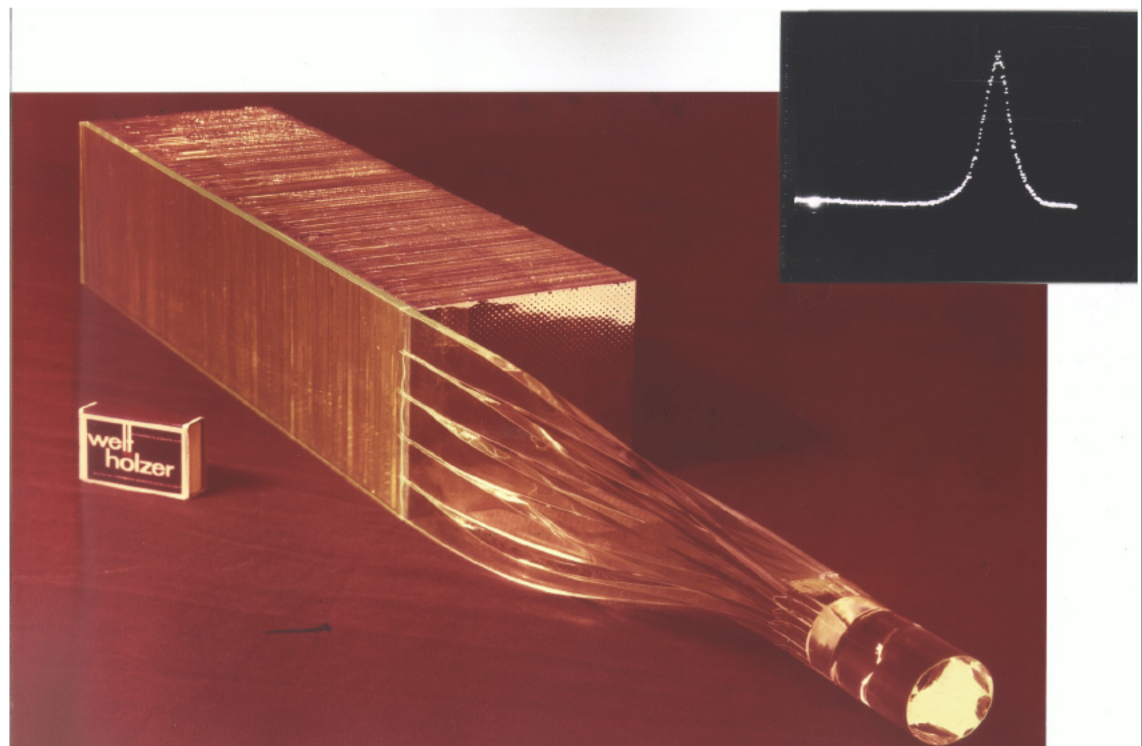
New shower counter
with BBQ readout at DESY test beam

ΔE/E= 7.5% at 1GeV in test beam

marvelous

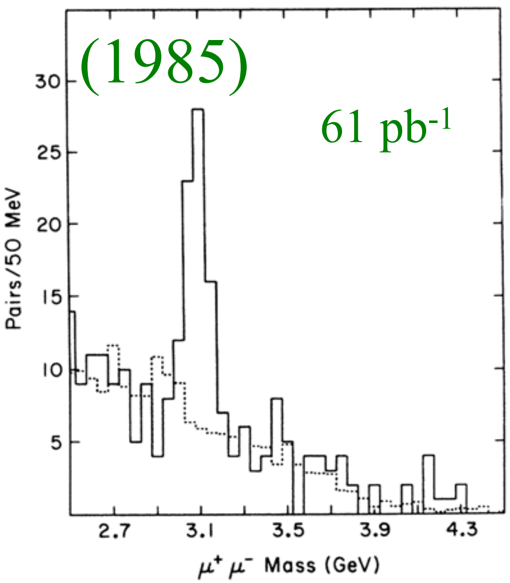
Can be used

before coil

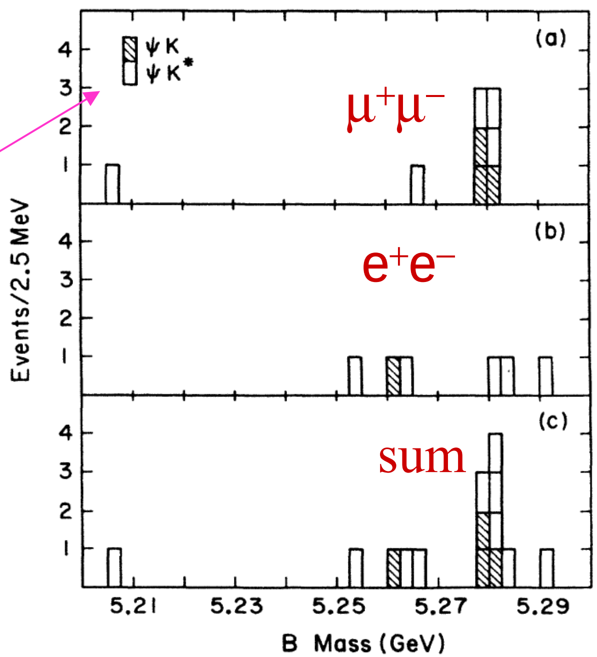


Better ℒ, Competition From ARGUS

- B physics
  - ARGUS has better lepton identification
  - CLEO made first observation of $B \rightarrow \psi X$, & $B \rightarrow \psi K^{(*)}$, (ARGUS just about simultaneously)



•In 1984: dE/dx in Drift Chamber, new 10 layer Vertex Detector (wires), a total of 119 pb^{-1}



CLEO I.V

- ARGUS promised real competition
- First upgrade CLEO I.V: In 1984 OSU group builds new VD 10 layers around same beam pipe, later in 1986 they add a VD insert (Kagan, Kass ...)
- Coupled to New Drift Chamber (1986)
  - 51 layers of tracking – big improvement
  - Full dE/dx capability
  - However end plates 3 cm of Al
  - Cornell+: M. Pisharody, D. Cassel, R. DeSalvo, J. Dobbins, R. Galik, M. Gilchriese, S. Gray, D. Hartill, J. Mueller, D. Peterson, D. Riley and K. Kinoshita
- Rest of CLEO II planned, but not finished until 1989. (Existence of ARGUS crucial approval.)

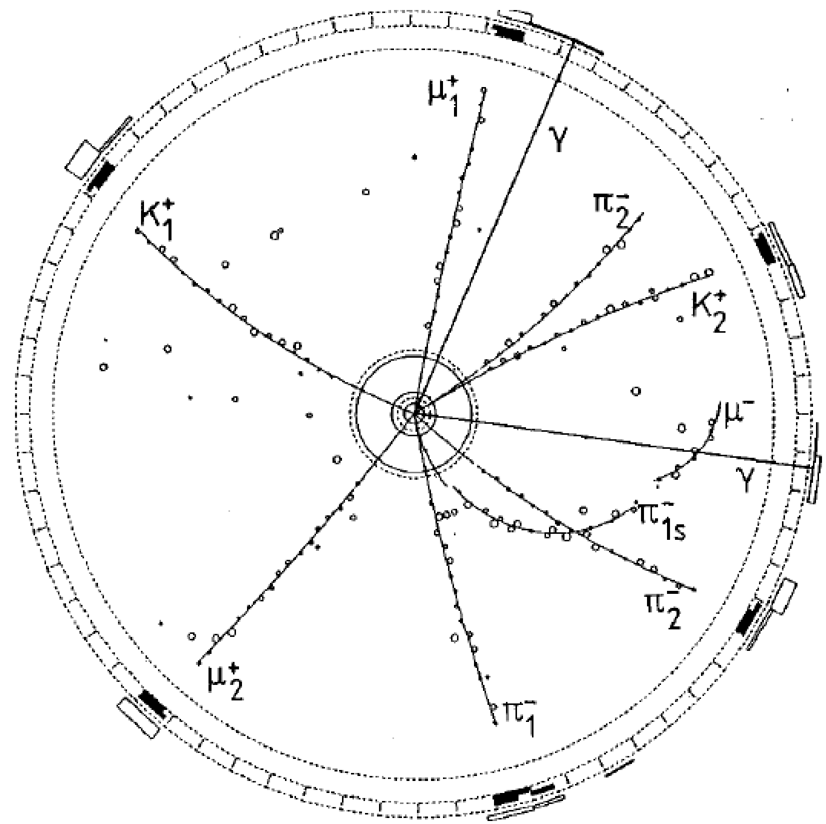
ARGUS: B^o-$\overline{B}^o$ Mixing Discovery

- In 1987 long before we can get CLEO II finished ARGUS finds $r = \frac{N(B^o B^o) + N(\overline{B}^o \overline{B}^o)}{N(\overline{B}^o B^o)} = 0.21 \pm 0.08$

- Consistent with our upper limit r<0.24 (Alice Bean)

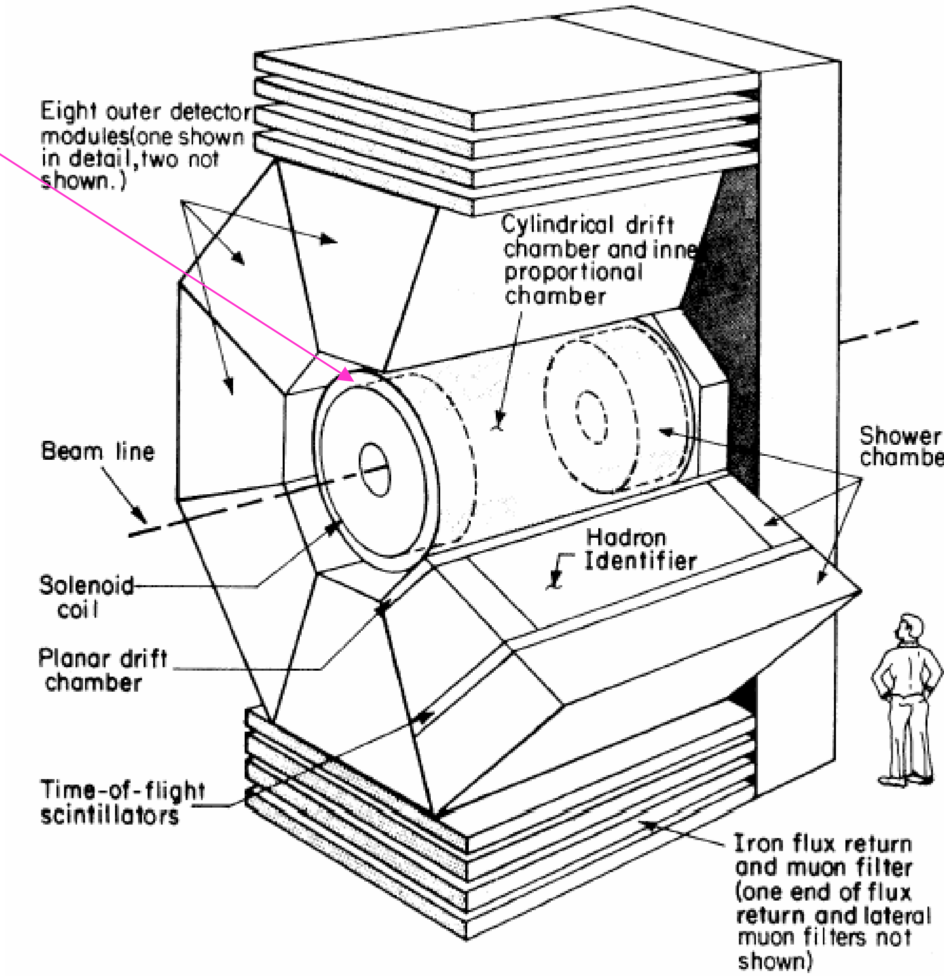
r

Decay	Mass(GeV/c^2)	P(GeV/c)	M^2_{Recoil}(GeV^2/c^4)
$B_1^0 \to D_1^{*-}\mu_1^+(\nu_1)$	4.393 ± 0.088*	1.090 ± 0.108*	-0.609
$D_1^{*-} \to \pi_1^- \overline{D}^0$	2.008 ± 0.001	1.196 ± 0.013	
$\overline{D}^0 \to K_1^+\pi_1^-$	1.873 ± 0.021	1.091 ± 0.012	
$B_2^0 \to D_2^{*-}\mu_2^+(\nu_2)$	3.969 ± 0.032*	1.244 ± 0.015*	-0.275
$D_2^{*-} \to \pi^0 D^-$	2.008 ± 0.005	1.611 ± 0.017	
$\pi^0 \to 2\gamma$	0.180 ± 0.028	0.136 ± 0.019	
$D^- \to K_2^+\pi_2^-\pi_2^-$	1.886 ± 0.015	1.478 ± 0.007	



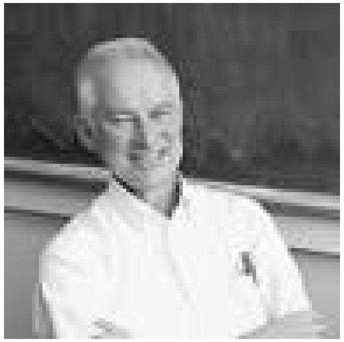
What we learned not to do

- Magnet coil is a thick barrier: put particle ID & EM cal inside
- Muon system is too thick at front, p acceptance full only >1.4 GeV/c; also too far away allows π, K decays
- EM calorimeter has too many cracks, not enough segmentation & poor Energy resolution ~17%/$\sqrt{E}$
- DR I Too few tracking layers: tracking problems, pid...



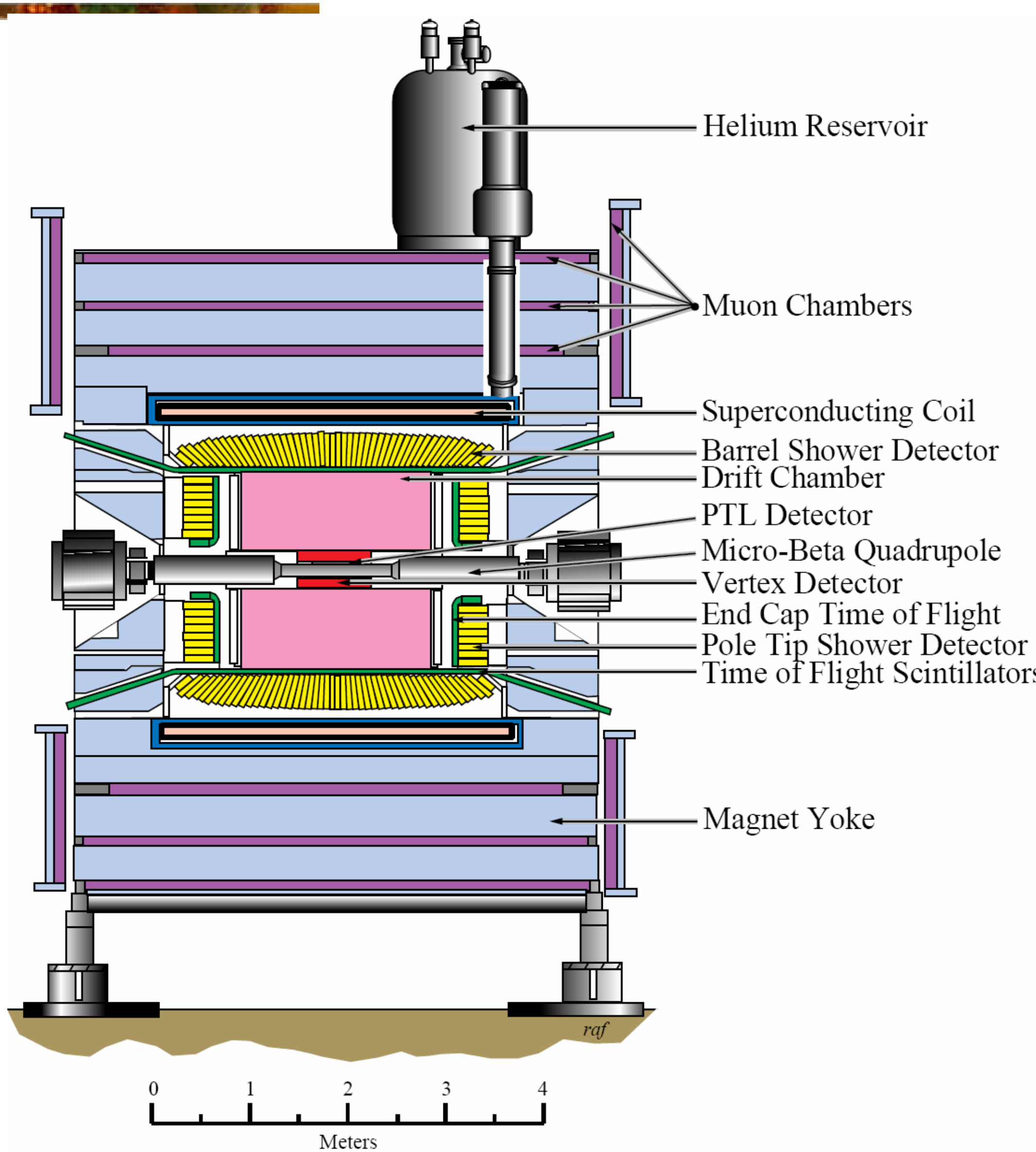
CLEO II Requirements

- Improve B physics capabilities
- Detect photons with ~same ability as charged tracks; identify e^- cleanly
- Improve momentum resolution on charged tracks B goes from 1.0 T to 1.5 T
- Improve dE/dx and tracking flaws by filling up Drift chamber gas with detection layers
- Lower muon id threshold & fake rate
- (Project Director: Bernie Gittelman)



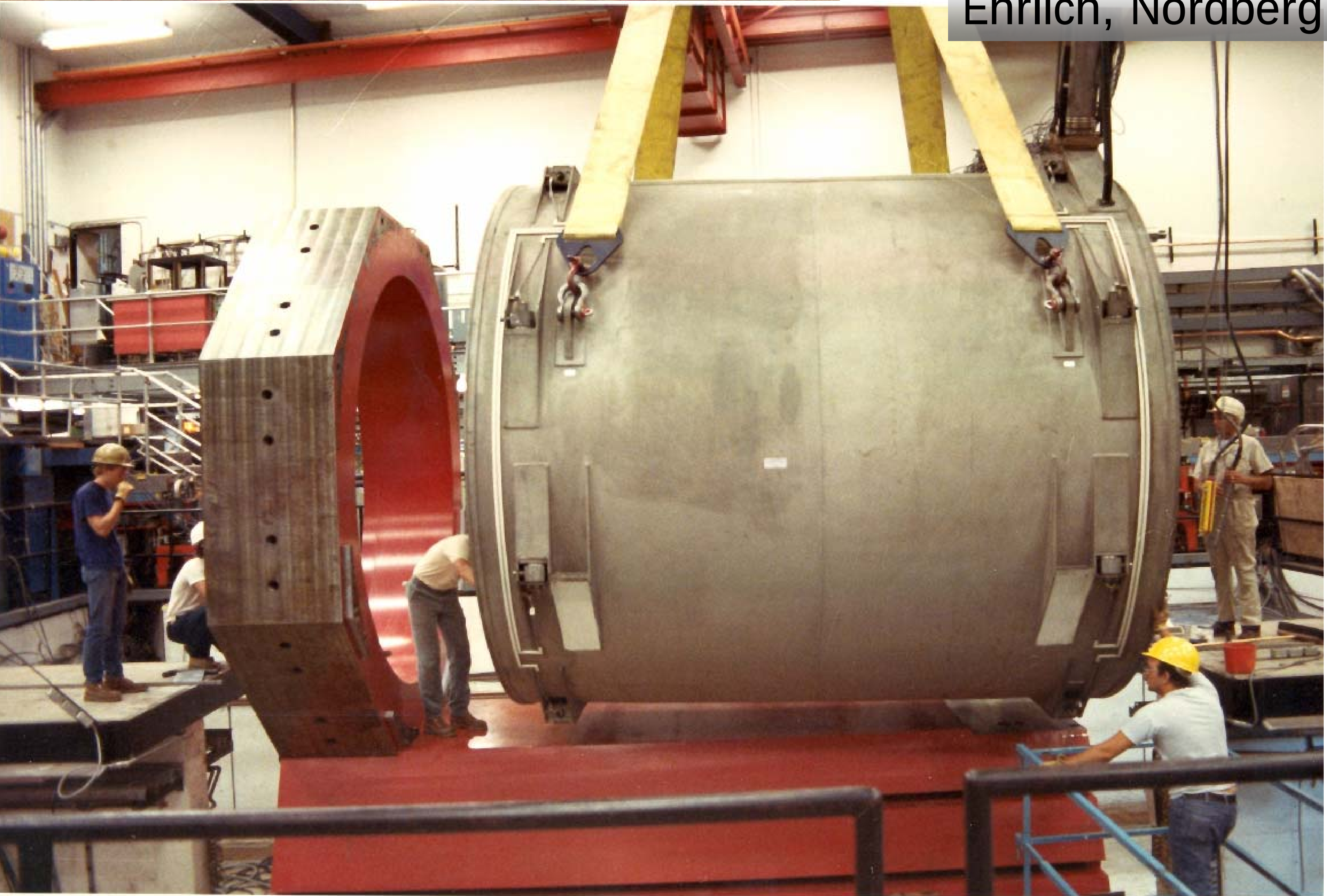
CLEO II

- All particle id: TOF & dE/dx inside coil
- CsI(Tℓ) inside coil
- Lower p threshold on muons to ~ 1 GeV/c



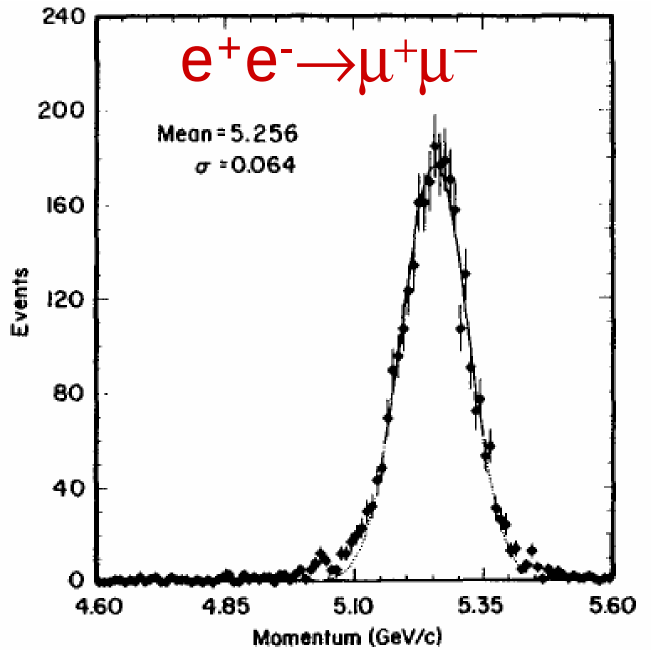
The 1.5 T Super-Conducting Coil

Ehrlich, Nordberg...



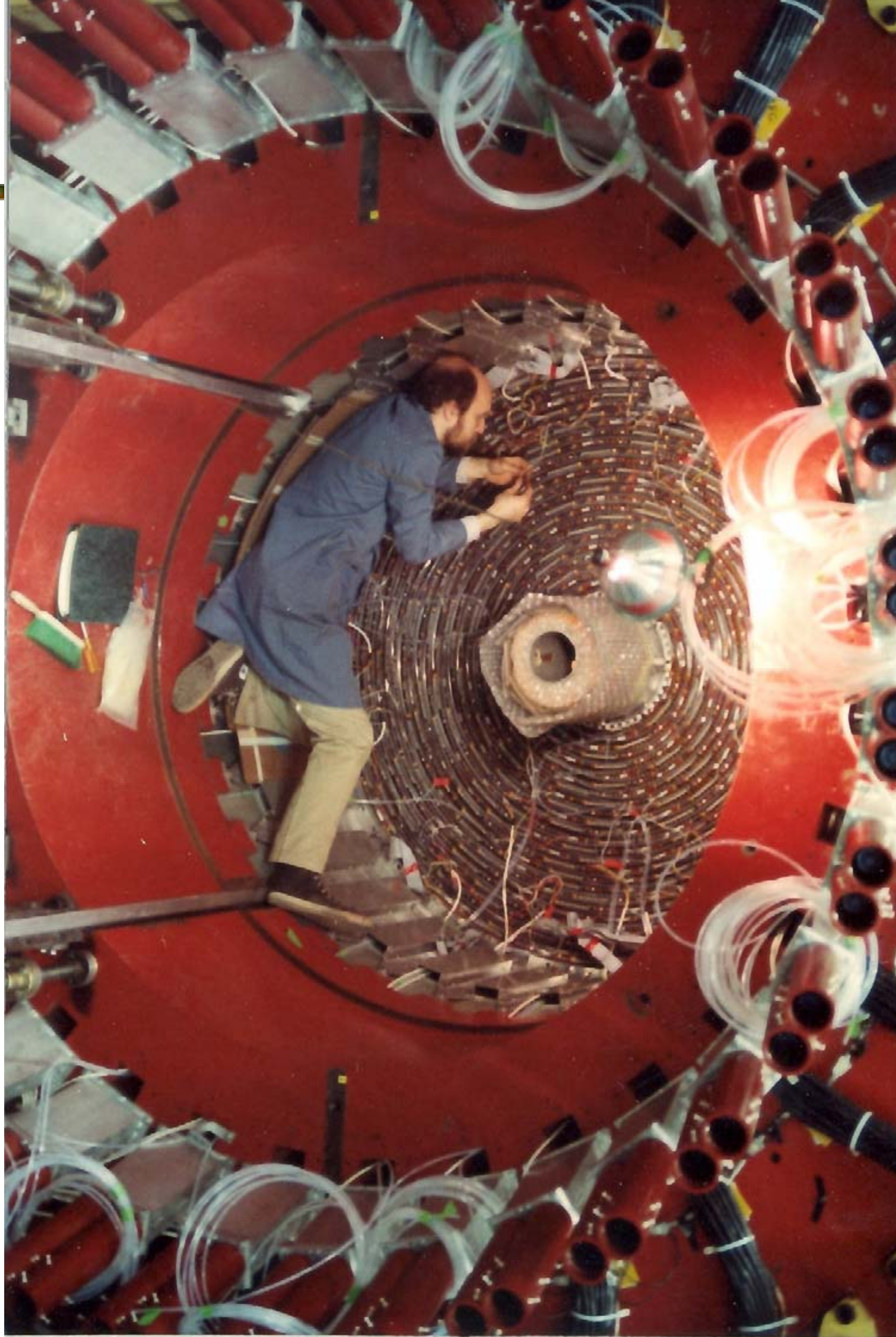
Tracking

- 3 tracking stations, DR, VD & PTL (6 layer straw tube device)
- beam pipe radius 3.5 cm



21 Observed momentum of muons from the reaction $e^+e^- \to \mu\mu$ at 5.280 GeV beam energy

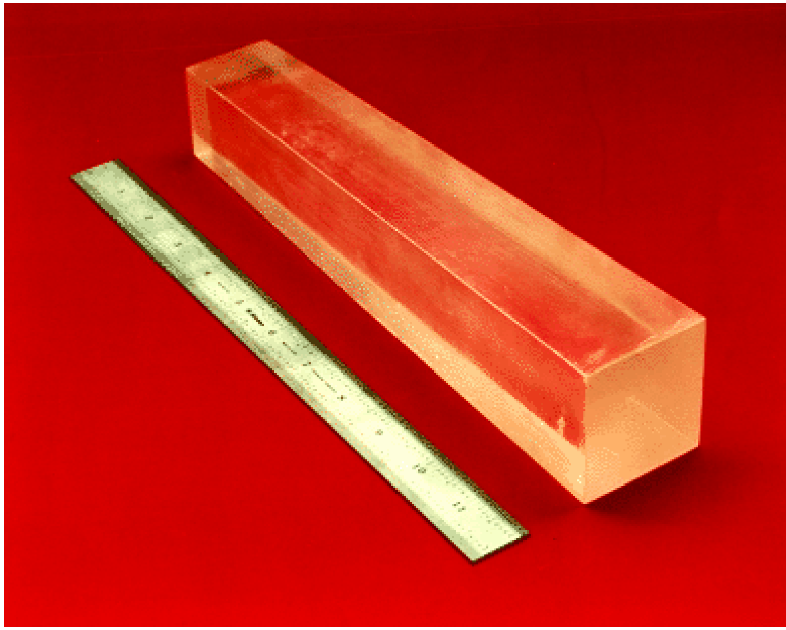
$\delta\phi = 1$mr
$\delta\theta = 4$ mr



Inner Detector Installation

Crystal Calorimetry

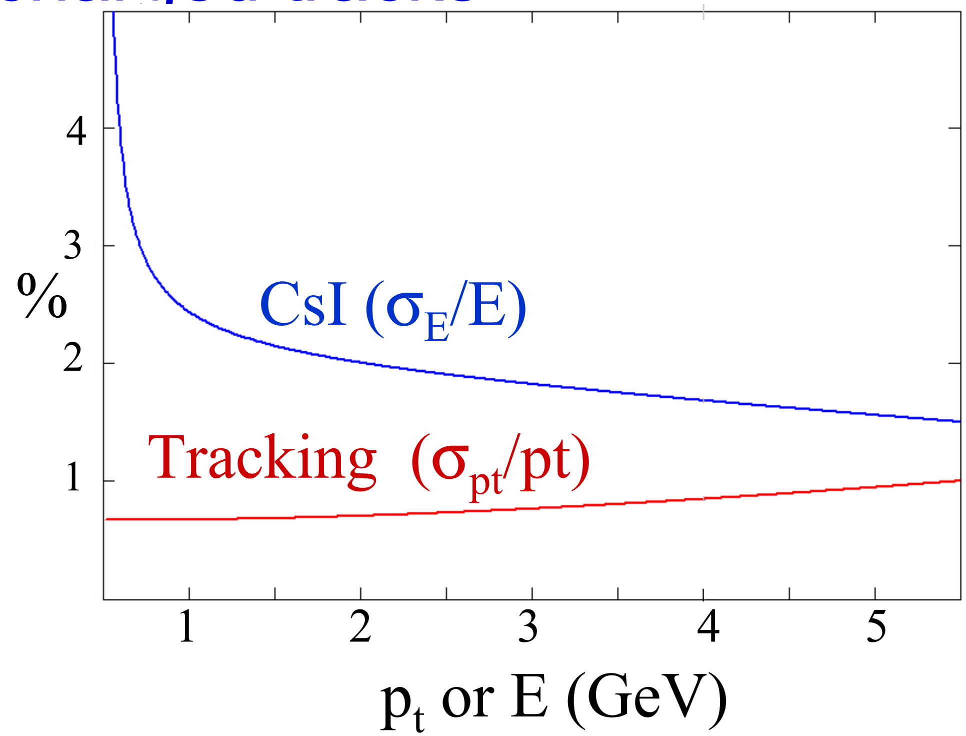
- Instead of sampling use "total" absorption. Need a high Z material that also produces a signal. Crystals scintillate, and energy is proportional to the amount of light generated
  - Need >16 radiation lengths to "fully" absorb all shower energy
  - In CsI($T\ell$) ~5000 γ's/MeV
  - Can detect light with photodiodes in B field, but gain=1



- Previous Crystal Calorimeters
  - Crystal Ball (NaI), small, used photomultiplier tubes
  - L3 (BGO), Light output $\approx$1/8 CsI very expensive, purchase helped by Chinese government, & also small in comparison
  - CUSB mostly NaI + small amounts BGO

CsI Calorimeter The New Part

- Idea: reconstruct γ, π^o's & η's, with "as good efficiency & resolution as charged tracks"
- Actually, not quite as good, but really useful (compare to 17%/√E)
- $\sigma(\theta,\phi)$=3mr at 5 GeV, 11 mr at 100 MeV
- Great Adventure, nothing this size had been attempted before
- Crystal co.: 2 in Ohio ~~(Bicron & Harshaw)~~, BDH England, Horiba Japan



"You will never get the crystals"

Crystal Contracts

CORNELL UNIVERSITY ITHACA, N.Y. 14853

GOVERNMENT CONTRACT
DEPT. REQUISITION COPY

DATE	ACCOUNT CODE	REQ. NO.	AGENCY	CONTRACT NO.	ORDER NUMBER
6/12/85	U82-8416-5021	5-2606	NSF	PHY 84-12263 EXPIRES:	5-84659

VENDOR SD1

TO: BDH Chemicals Ltd.
Broom Road
Poole BH12 4NN
England
Attn: R. H. M. Symons

SHOW ON ALL SHIPMENTS, BILLS, AND CORRESPONDENCE

SHIP TO: Cornell University.
See section 18 of Attachment I.

PREPAY ALL SHIPMENTS ADD TO INVOICE IF FOB SHIP. PT-
ATTACH PREPAID RECEIPT TO INVOICE
USE, UPS, PARCEL POST OR MOTOR FRT. IF NOT INDICATED

ITEM NO.	MATERIALS OR SERVICES	QUANTITY	UNIT PRICE	TOTAL
	Cesium iodide/thallium iodide crystals in accordance with this order, Attachment I, Attachment II, the Escrow Agreement, BCC-1 and -2 (both dated 4/24/85), figure 3 (dated 1/16/85) and the Light Output Specifications dated 1/16/85; all attached. (Attachments I & II are dated June 11, 1985; the Escrow Agreement is dated June 6, 1985)			

REQUESTED BY: S. Stone | PHONE EXT. | SHIP TO ARRIVE BY: Per schedule

C.U. BID REF.: CLEO II-10 | VENDOR REF. | FOB: Cornell. Duty extra | TERMS: Per Attach. I | TOTAL COST: $6,374,928.00

BIDDERS	DELIVERY	TERMS	FOB	UNIT PR.	TOTAL PRICE	BASIS OF AWARD
						( ) Price ( ) Delivery Time ... Business ( ) Handicapped Owned Bus. ( ) Small Bus. ( ) Large Bus.

EXPLANATION, COMMENTS, INSTRUCTIONS TO PURCHASING:
USE: CLEO II
Approved by NSF 6/18/85.

GOVT. PRIOR APPROVAL

INSTRUCTIONS FOR PREPARATION.
1. Use typewriter only.
2. If items will not fit in space provided, attach 5 copies of list.
3. After typing remove and retain top sheet, send other six copies to Purchasing.
4. Do not remove carbon or top stub.
5. Do not fold.

TA

CORNELL UNIVERSITY ITHACA, N.Y. 14853

GOVERNMENT CONTRACT
PURCHASE ORDER

DATE	ACCOUNT CODE	REQ. NO.	AGENCY	CONTRACT NO.	ORDER NUMBER
6/12/85	U82-8416-5021	5-2607	NSF	PHY 84-12263 EXPIRES:	5-84658

VENDOR SD1

TO: Horiba International Corp.
A Wholly-owned subsidiary
of Horiba Ltd. of Kyoto Japan
1021 Duryea Ave.
Irvine, CA 92714
Attn: Robert D. Gafford
5-84658

SHOW ON ALL SHIPMENTS, BILLS, AND CORRESPONDENCE

SHIP TO: Cornell University. See section 18 of Attachment I.
6-21-85 BP
5-84658

PREPAY ALL SHIPMENTS ADD TO INVOICE IF FOB SHIP. PT-
ATTACH PREPAID RECEIPT TO INVOICE
USE, UPS, PARCEL POST OR MOTOR FRT. IF NOT INDICATED

ITEM NO.	MATERIALS OR SERVICES	QUANTITY	UNIT PRICE	TOTAL
	Cesium iodide/thallium iodide crystals in accordance with this order, Attachment I, Attachment II, the Escrow Agreement, BCC-1 and -2 (both dated 4/24/85), figure 3 (dated 1/16/85) and the Light Output Specifications dated 1/16/85; all attached. (Attachments I & II and the Escrow Agreement are all dated June 11, 1985.)	Sheldon ←		

REQUESTED BY: S. Stone | PHONE EXT. | SHIP TO ARRIVE BY: Per schedule

C.U. BID REF.: CLEO II-10 | VENDOR REF. | FOB: Cornell. Duty extra. | TERMS: Per Attach. I | TOTAL COST: $6,315,086.19

TERMS AND CONDITIONS

1. Exempt from Federal Excise Tax - IRS Reg. No. 16-73-0034-F and N.Y.S. Sales and Use Tax EX-106514.

...pments, and

Crystals were delivered on time for contract price

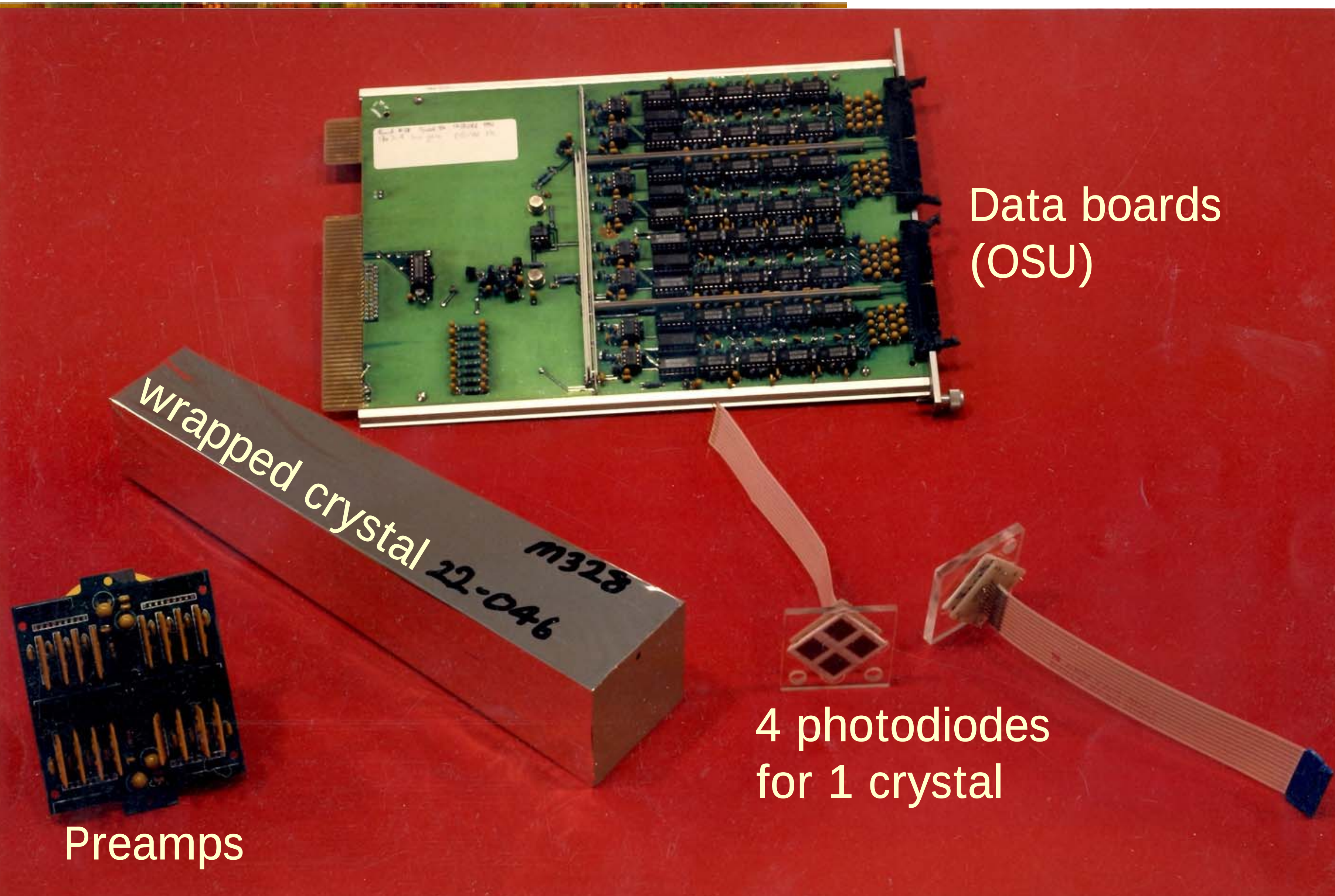
4. Partial shipments and invoices are acceptable.
5. Follow shipping instructions accurately. Delivery to any location other than that stipulated in the "Ship To" block on this order will not constitute delivery to Cornell University. Vendor will be held accountable for any and all expense resulting therefrom.
6. No changes in this order as to quantity, quality or other specifications shall be made unless authorized in writing by the Purchasing Manager or an authorized agent. Any deviation from this requirement will result in a refusal to accept seller's goods and/or services at seller's expense.
7. By acceptance of this order, seller agrees not to assign this order or any interest therein without the written authorization of the Purchasing Manager or an authorized agent.

(Continued on reverse side)

CORNELL UNIVERSITY
PURCHASING DEPARTMENT
120 MAPLE AVENUE
ITHACA, N.Y. 14850
(607) - 256-3804

By [signature]
PURCHASING AGENT
(Submit written acceptance of order to Purchasing Agent)

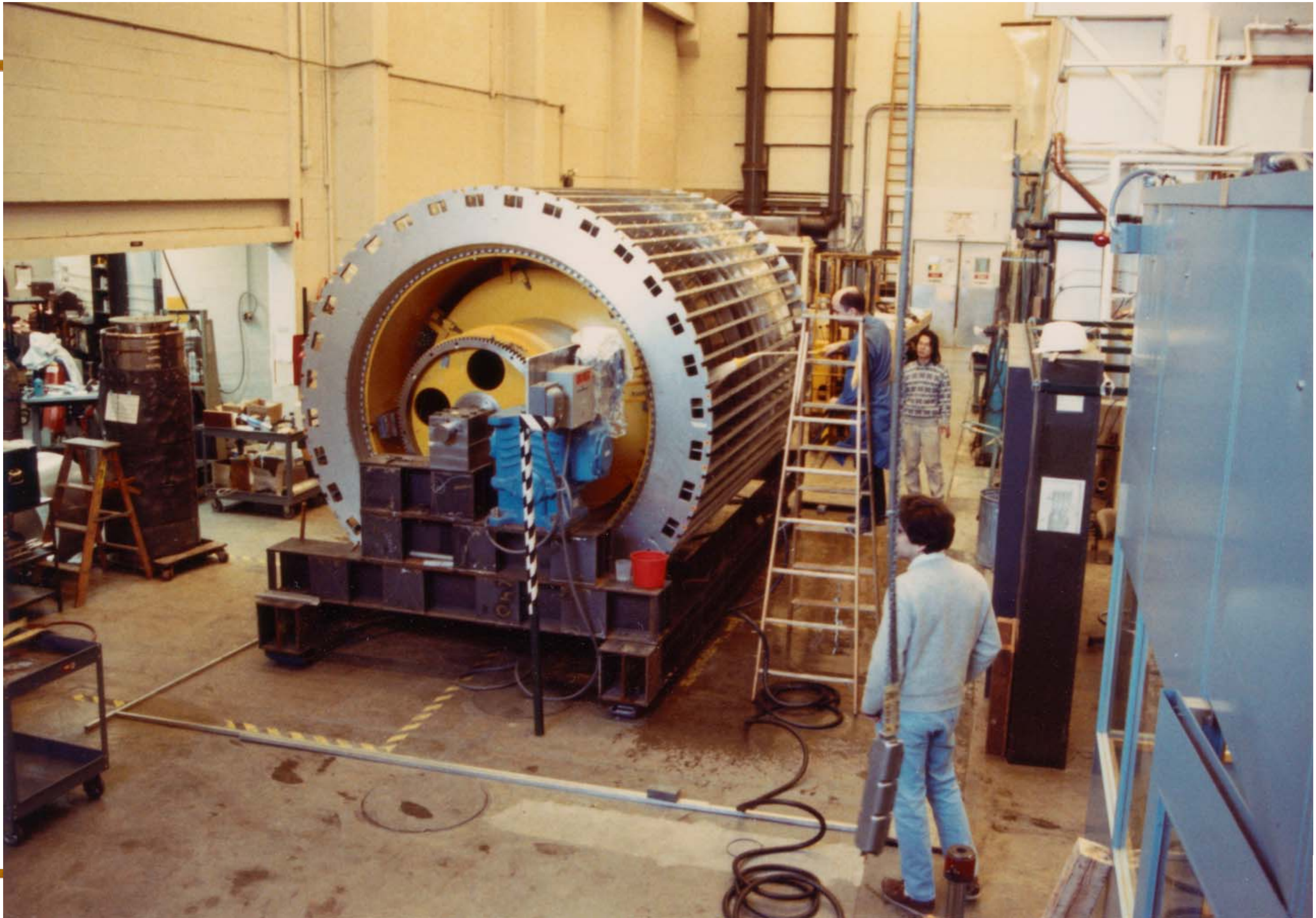
The Parts


Data boards
(OSU)
wrapped crystal
m328
22-046
4 photodiodes
for 1 crystal
Preamps

The Crystal Holder

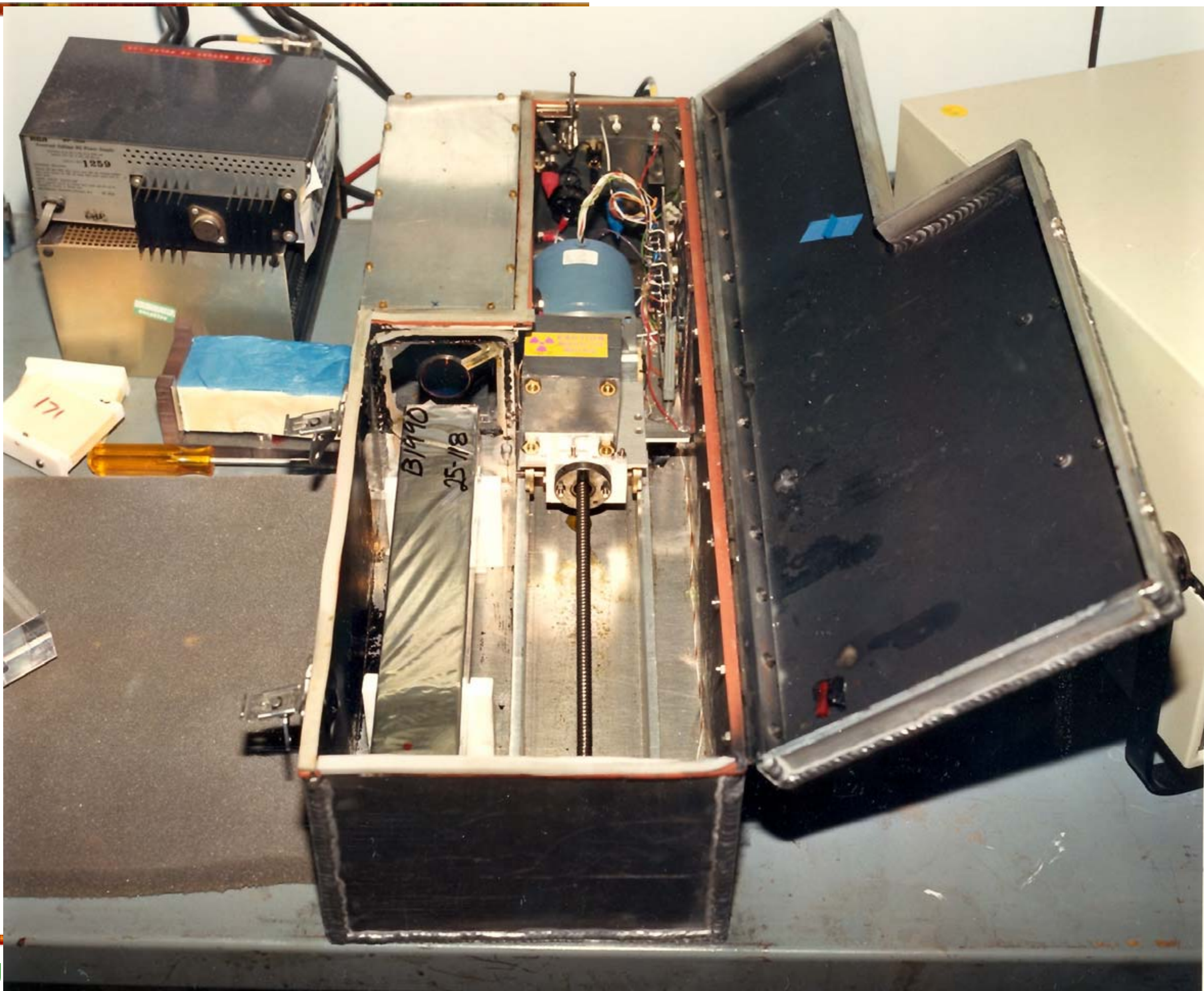
- Designed by McDaniel
- Others in Crystal Project: E. Blucher, B. Gittelman, B. Heltsley, J. Kandaswamy, B. Kowalewski, Y. Kubota, N. Mistry, S. Stone, H. Worden

Completed Holder



Light Output Testing Apparatus

- Had to test 8000 crystals for Light output & Size
- Glue on photo-diodes…
- Ed Blucher, Bob Kowalewski, Helen Worden...

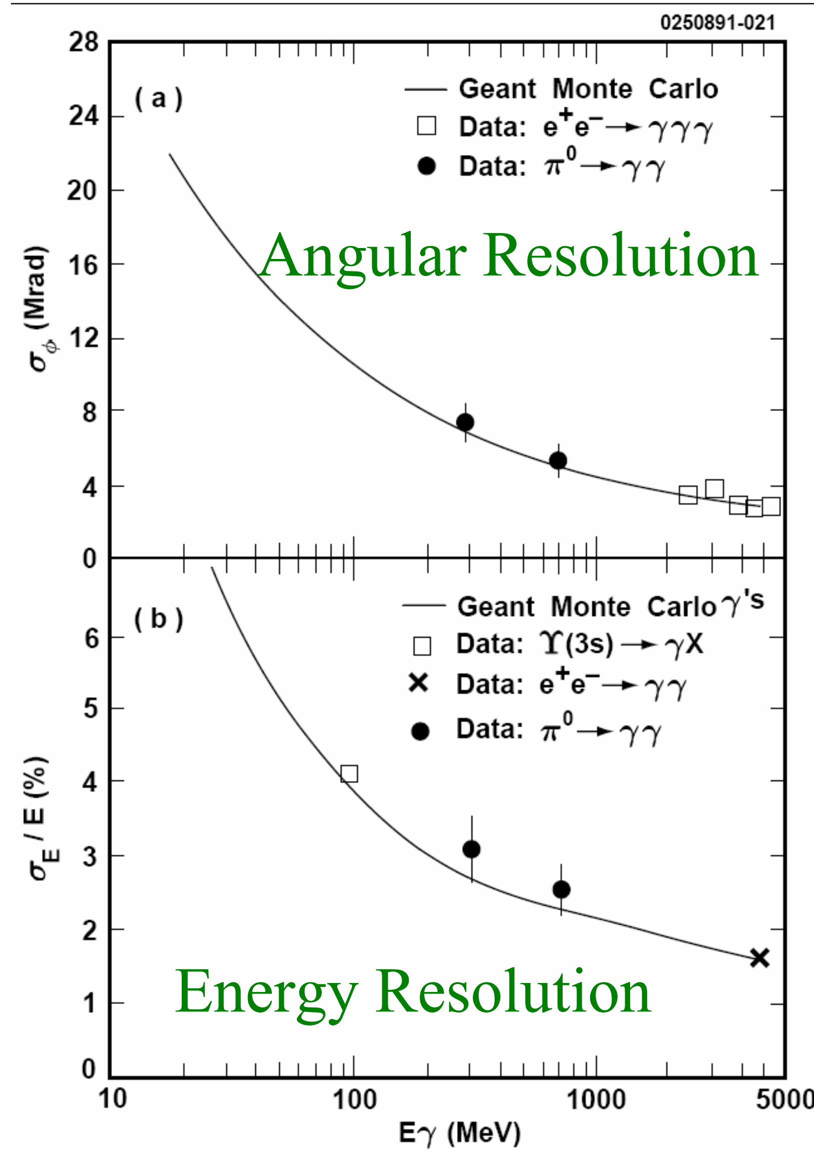


Assembly

CsI Performance

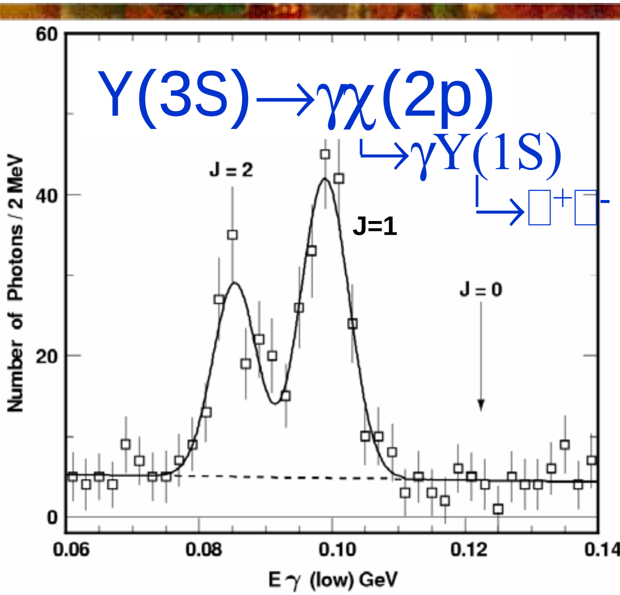
- CsI angular resolution & energy resolution close to MC prediction

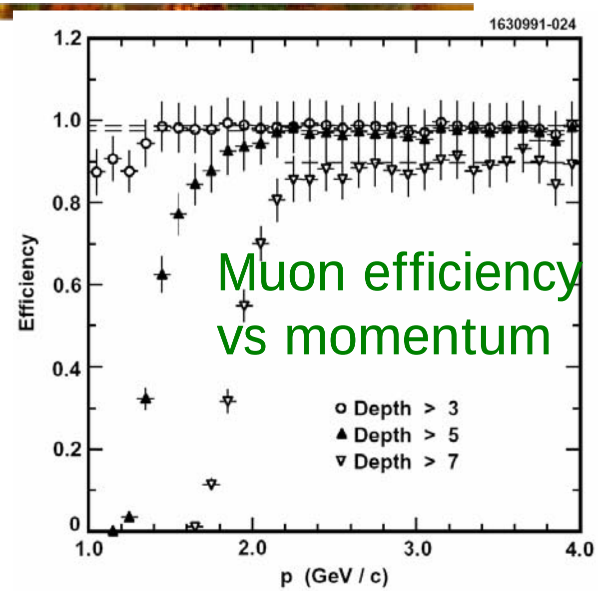
Endcap assembly



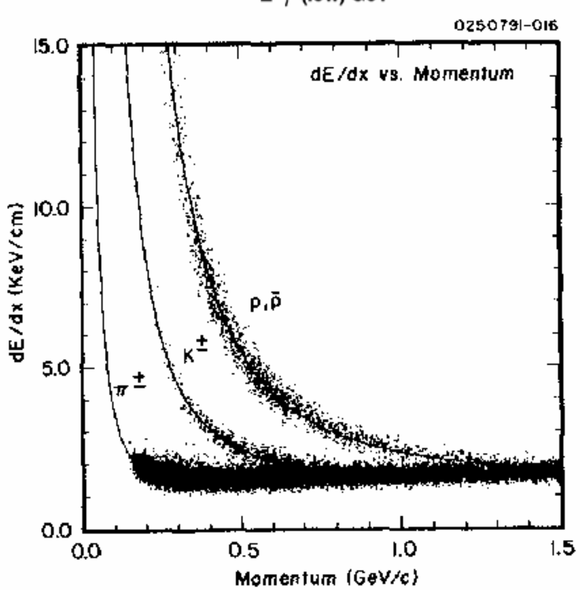
2008

CLEO II Performance Benchmarks

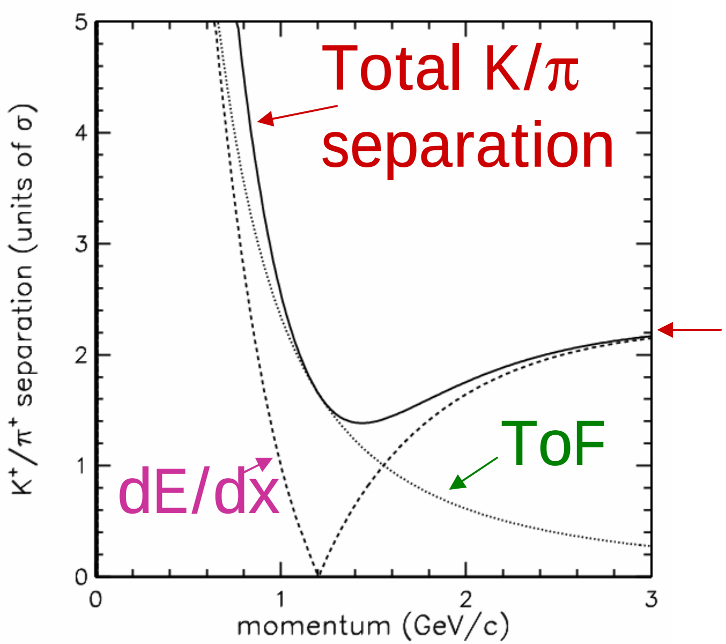




- Excellent overall detector performance



20 Specific Ionization vs Track Momentum for Hadrons



Not very good at high momentum

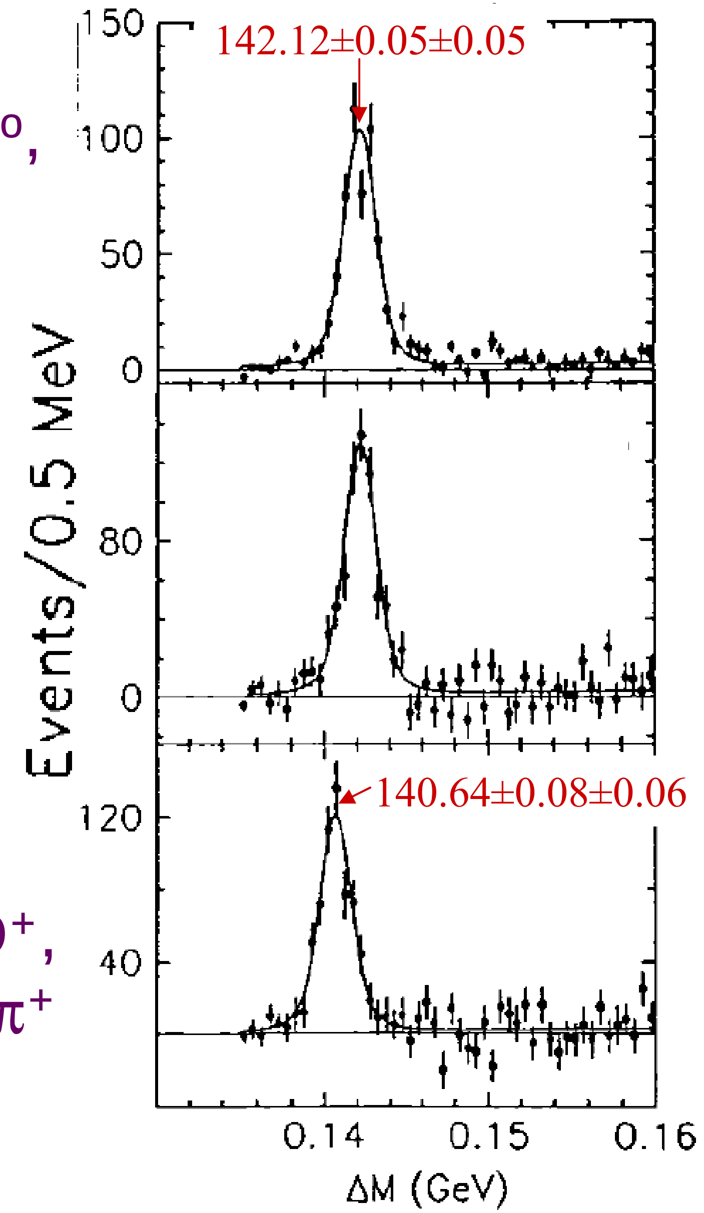
Example of π^o Resolution

- D*-D mass differences≡ΔM
- σ=0.9 MeV for π^o modes
- σ=0.7 MeV $D^{*+}\to\pi^+D^o$ (no Si vetex dectector)
- Calorimeter is very good on π^o's

$D^{*o}\to\pi^oD^o$, $D^o\to K^-\pi^+$

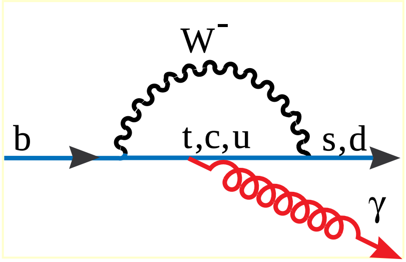
$D^{*o}\to\pi^oD^o$, $D^o\to K^-\pi^+\pi^o$

$D^{*+}\to\pi^oD^+$, $D^+\to K^-\pi^+\pi^+$

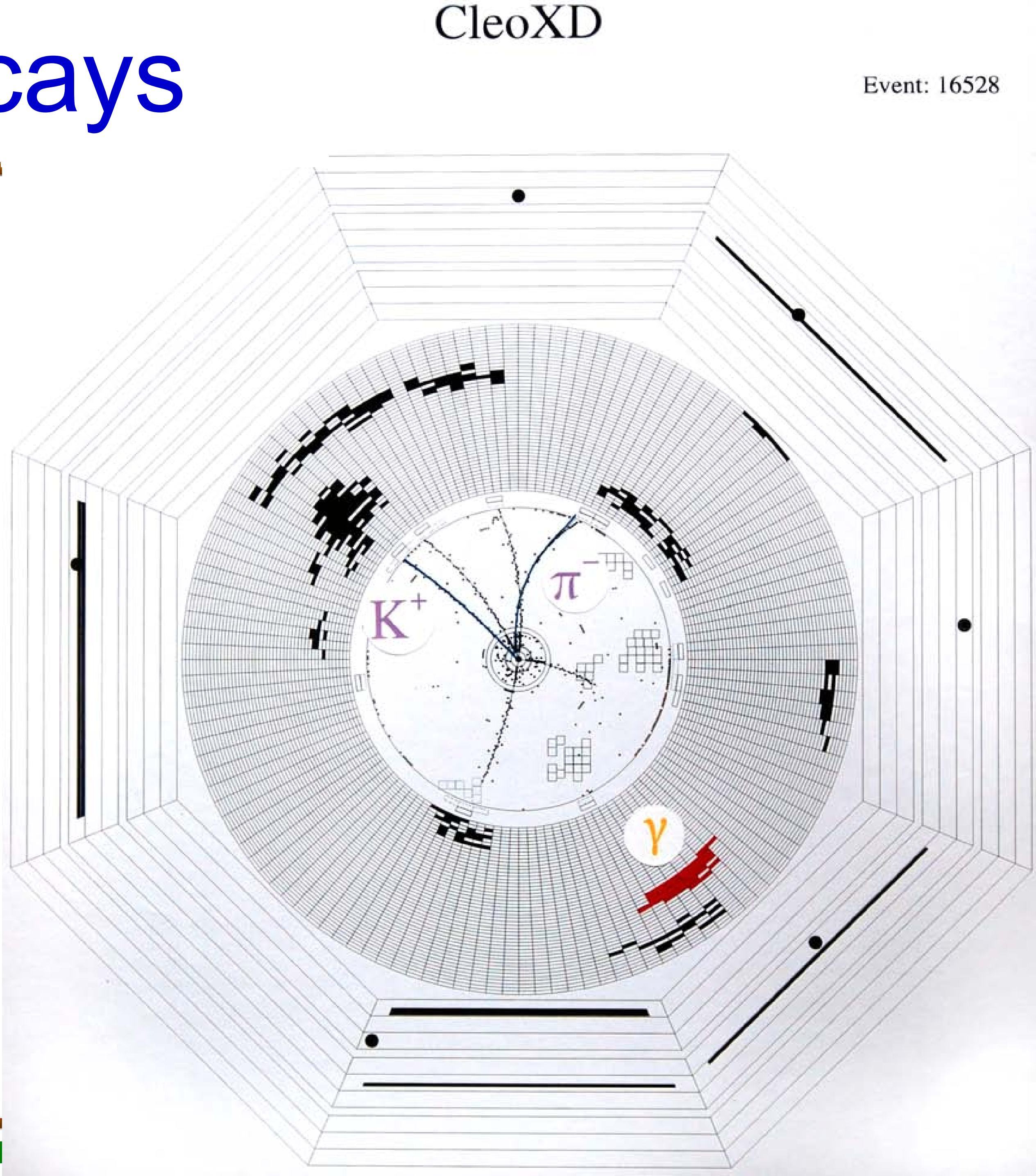


Rare B Decays

- $B \rightarrow K^*\gamma$
  - Rozen & Horwitz, Thorndike & Kim
- Later $b \rightarrow s\gamma$
  - +Skwarnicki, Ernst

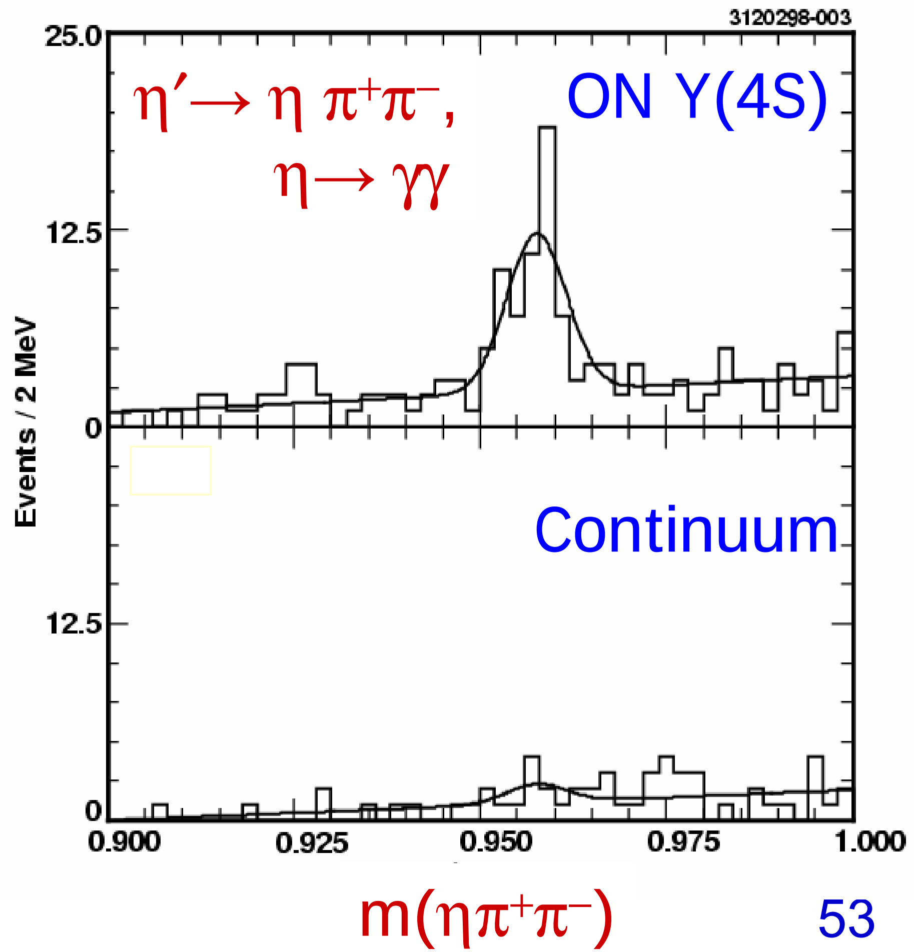


aka' “Penguins”



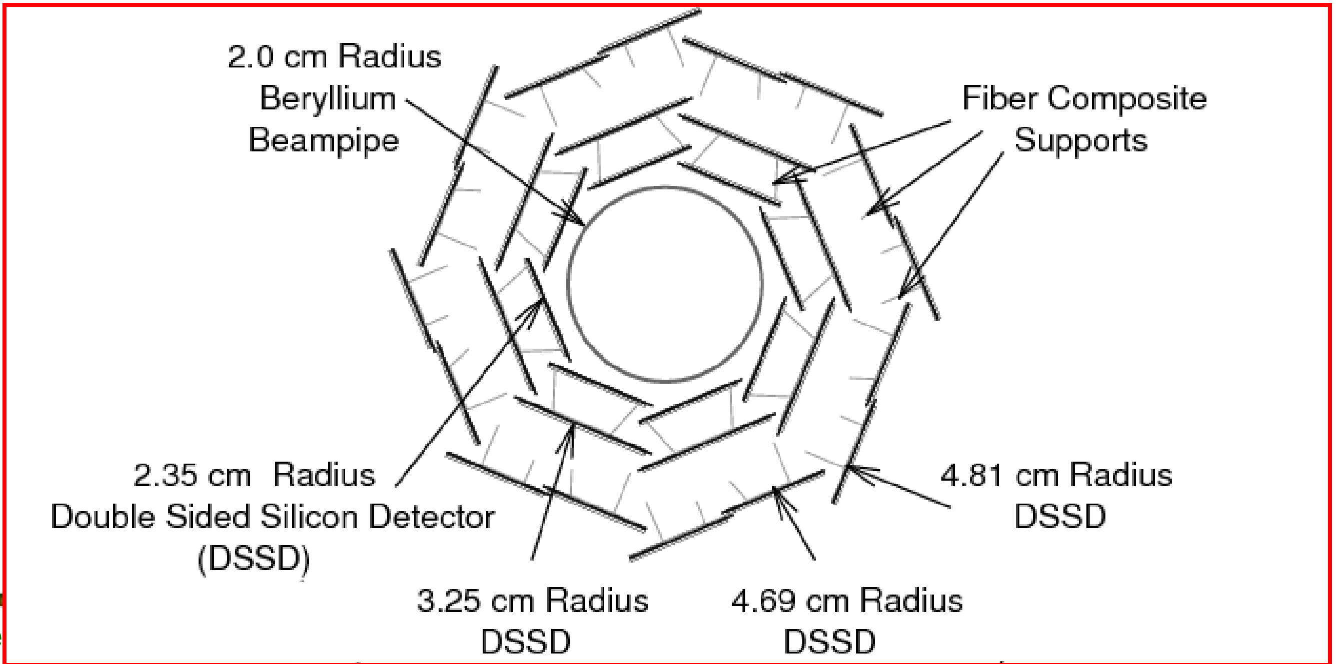
More Penguins

- $B \to \eta' X$, where X is a light hadron
- $p_{\eta'}$ between 2 & 2.7 GeV/c
- Huge rate found (Browder)
- $\mathcal{B}(B \to \eta' X)$ $=(6.2 \pm 2.5) \times 10^{-4}$
- Compare with e.g. $\mathcal{B}(B^o \to K^- \pi^+) = 1.8 \times 10^{-5}$



Another Upgrade: CLEO II.V

- Replace wire chamber with Silicon strip VD to get precision vertex information
  - Best upper limits for a long time on D^o mixing
  - Lifetime measurements of charm particles
  - Alexander, Artuso, Nelson, Morrison, Jaffe, Soffer, Asner, Cinabro, Henderson ...+...+

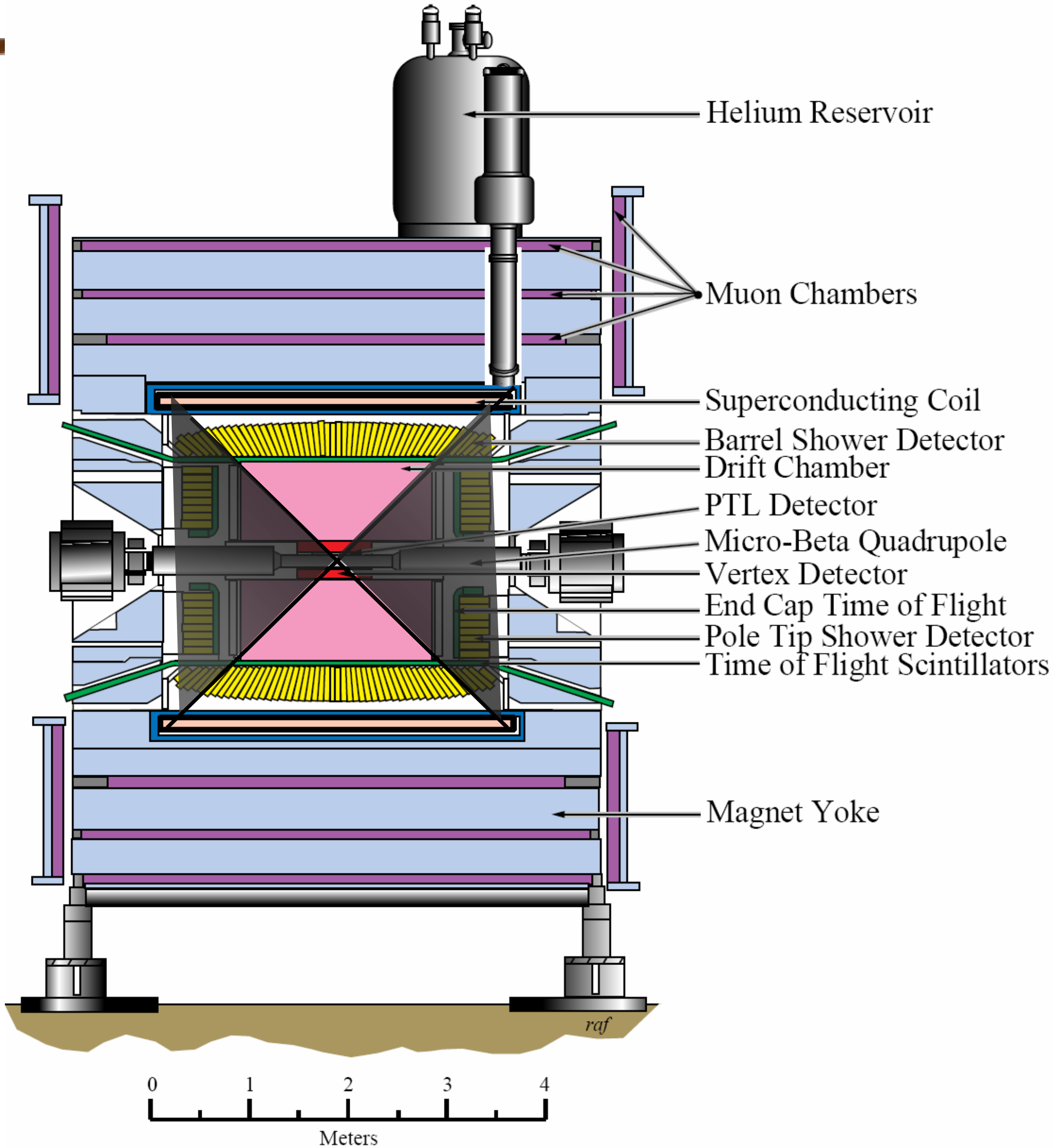


B Factory Era

- CESR-B proposal versus B factories
  - Ended in SLAC & KEK building high $\mathcal{L}$ two-ring machines
  - It was thought CESR could compete on time-independent measurements, that the $\mathcal{L}$ after an upgrade would be $\approx$the same
- Inner Detector Task Force Slogan: "Its the material, stupid." (Alexander, Bebek, Kagan, Kubota, Miller, Peterson, Stone, Witherell...)
- CLEO III
  - Space for interaction region dipoles close to collision point $\Rightarrow$ new DR
  - New technology possible for particle id: RICH
  - New Si vertex detector

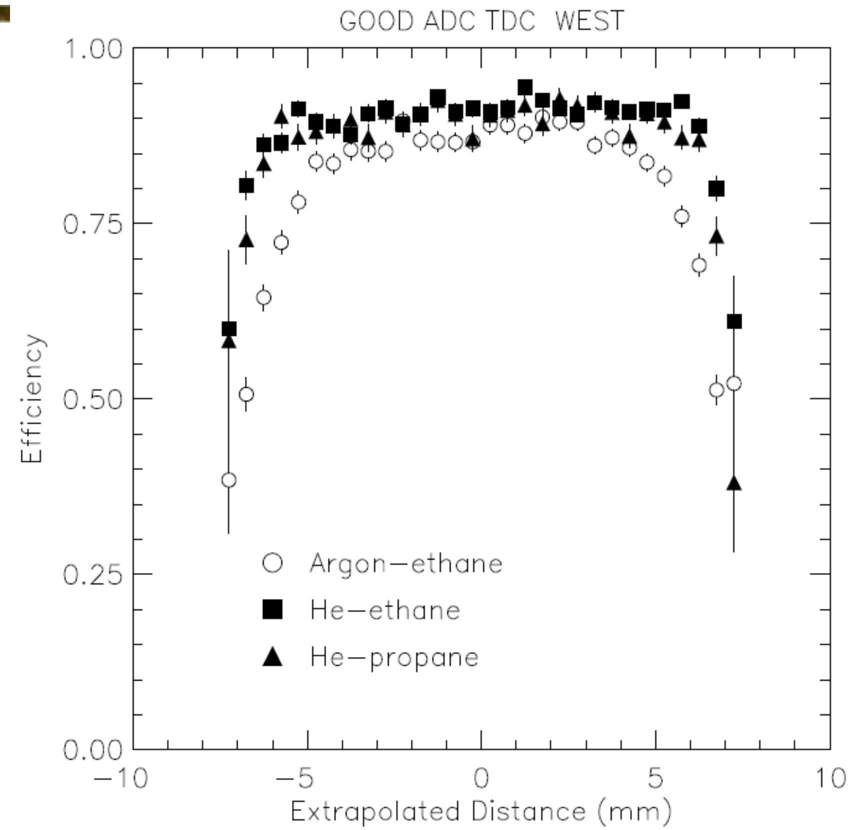
Some Problems with CLEO II

- Poor K/π separation for p > 0.9 GeV/c (some with dE/dx)
- DR endcaps too thick & DR not quite long enough$\Rightarrow$ $|\cos\theta|\leq 0.71$ for γ's



DR Gas Change

- He – Propane mixture (60:40)
  - Improves hit efficiencies
  - Improves dE/dx performance
- Test Chamber results (Kagan, Kass, Gan..)
- Tests in B field (Peterson & Tung Lee)



Gas Mixture	resolution at drift distance 2 mm to 4 mm (μm)	resolution averaged over full cell (μm)
Ar-ethane(50:50)	138	203
He-propane(60:40)	102	135

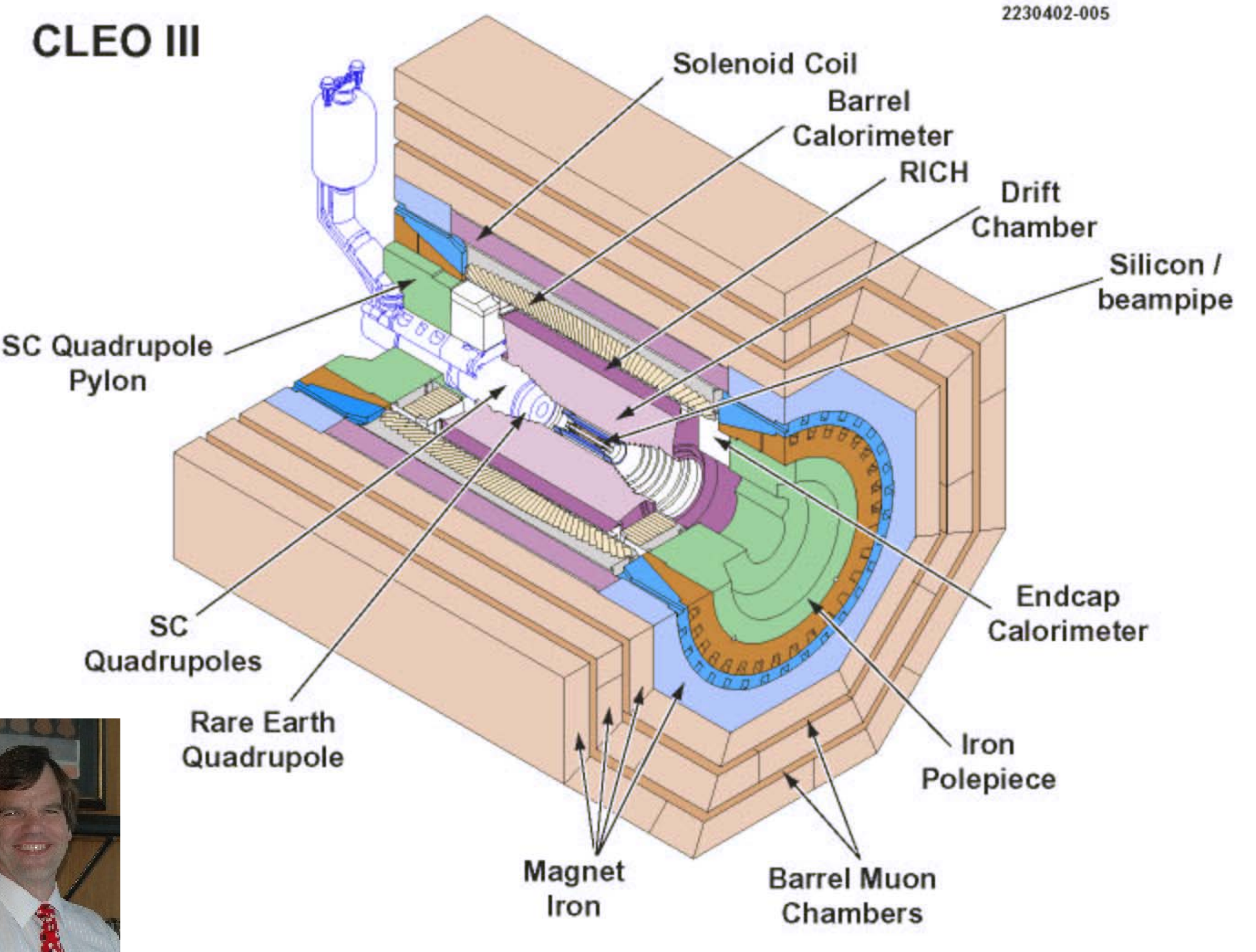
Detector Impact

- CsI was copied by B factory detectors
  - BaBar resolution slightly worse
  - Belle resolution slightly better
  - Acceptances both worse due to asymmetric beams
- DR used as model by other detectors
  - Construction techniques adopted
  - dE/dx became standard
- Other Si vertex detectors built on CLEO II.V experience

CLEO III

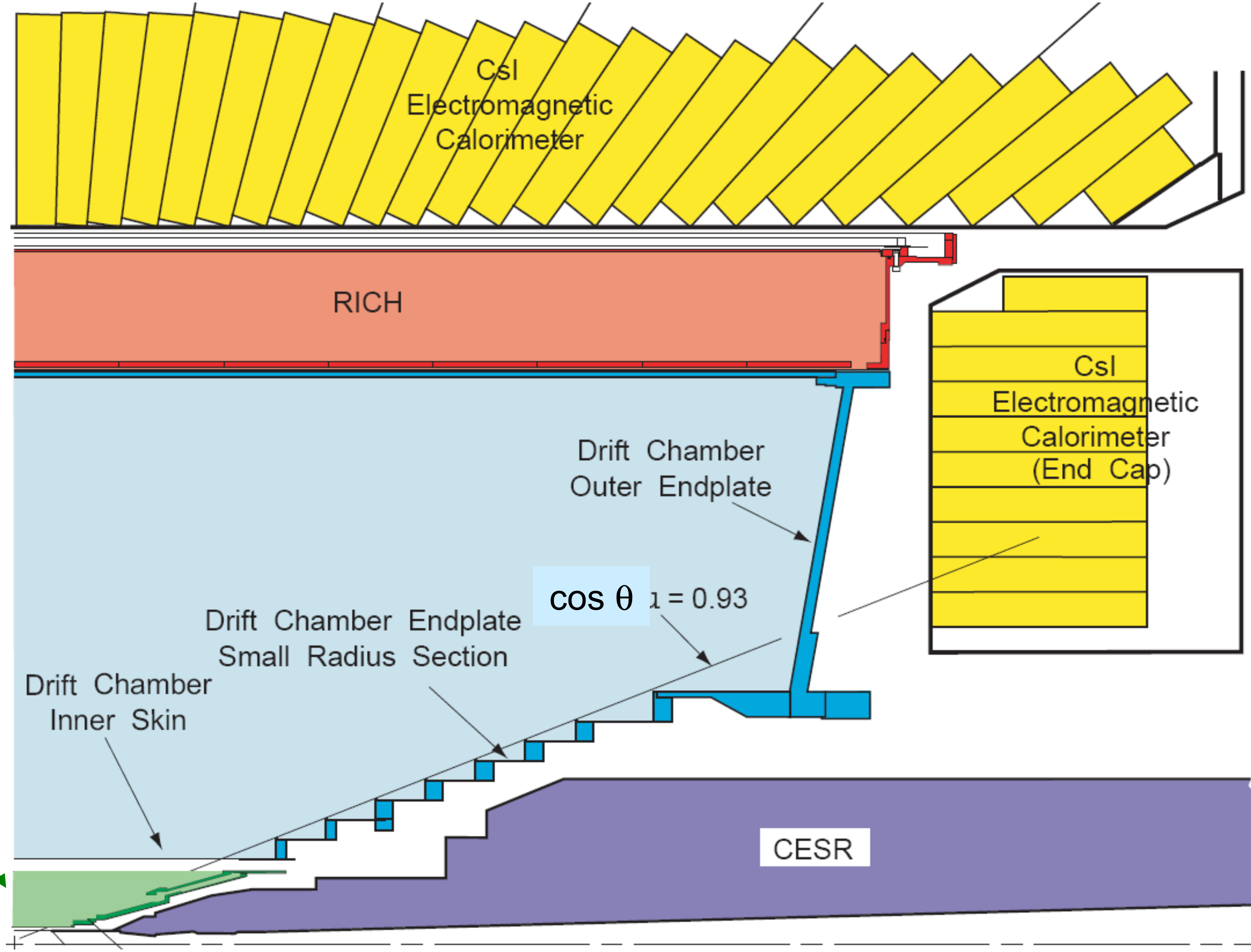
- Chris Bebek project leader

- Huge contributions from our mechanical engineer Jeff Cherwinka



Dipoles inside Detector

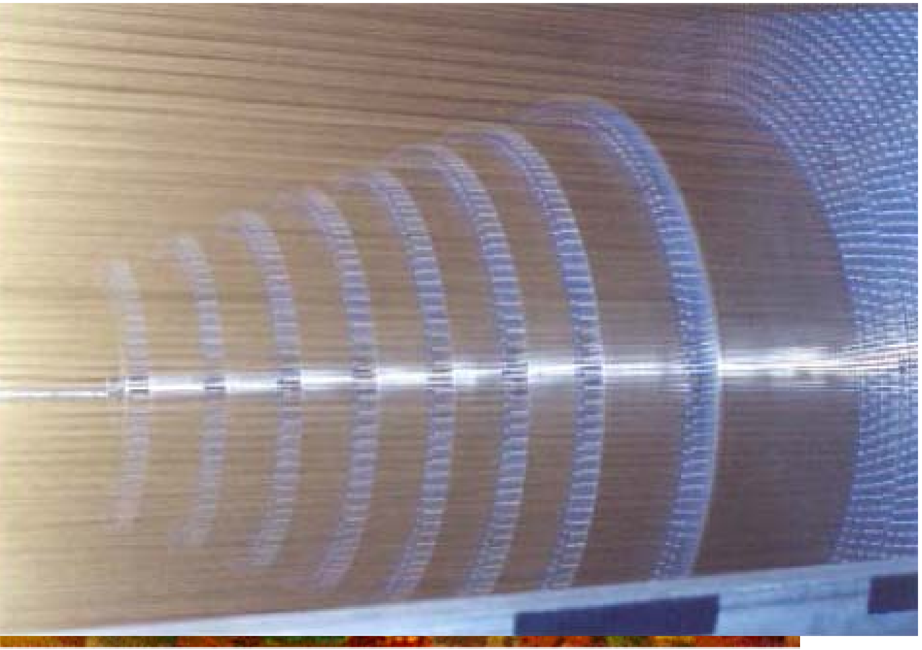
- Needed to increase *Luminosity*
- DR construction more complicated
- p_t resolution goes as track length^2, so must make up for RICH
- New Si Vertex det (OSU, Cornell, Purdue)

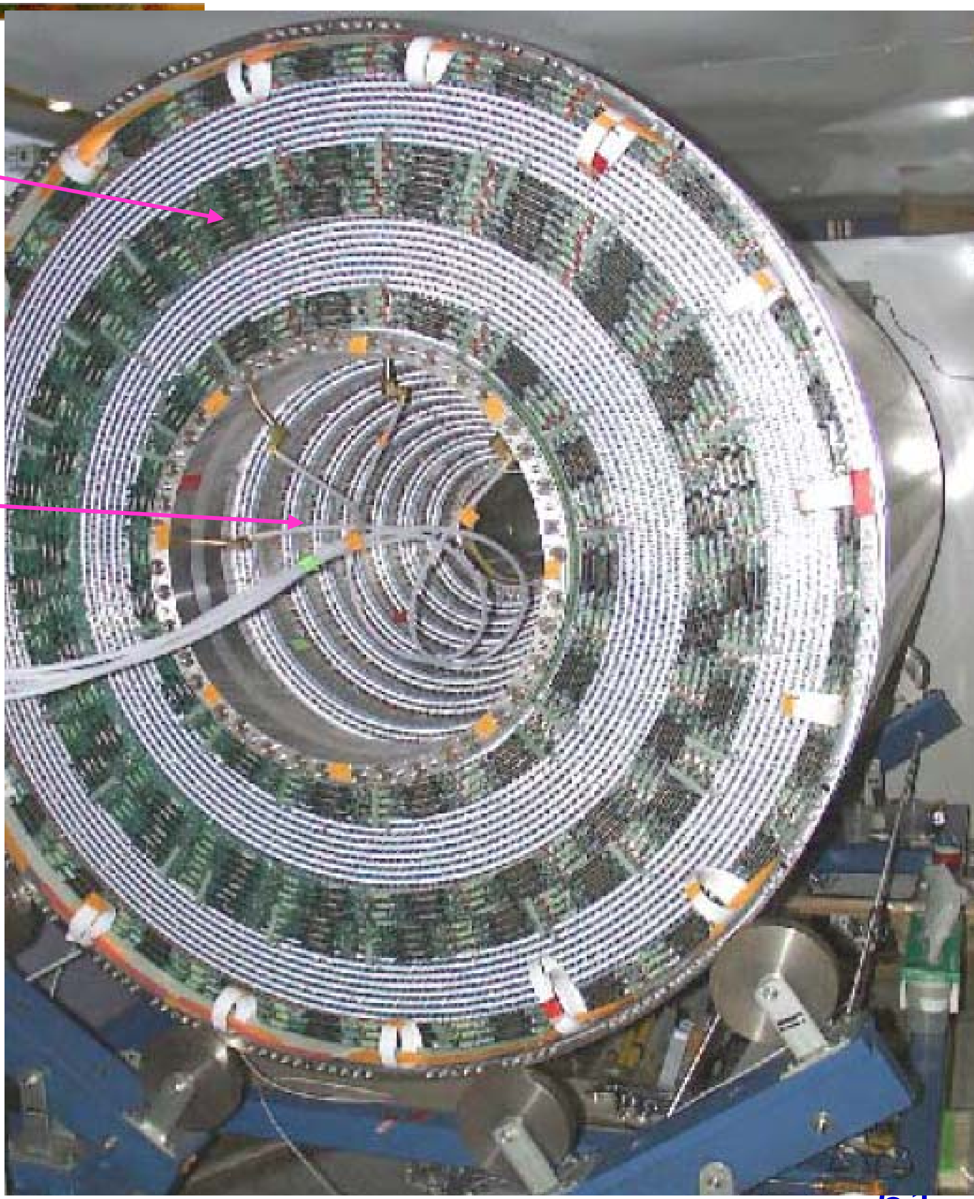


DR III

Peterson, Ecklund, Patterson, Briere, Cronin-Hennessy Lyon, Meyer Urner, Thorndike, Sadoff...

- Conical section 1.5 cm thick
- "Wedding cake" section to allow dipoles

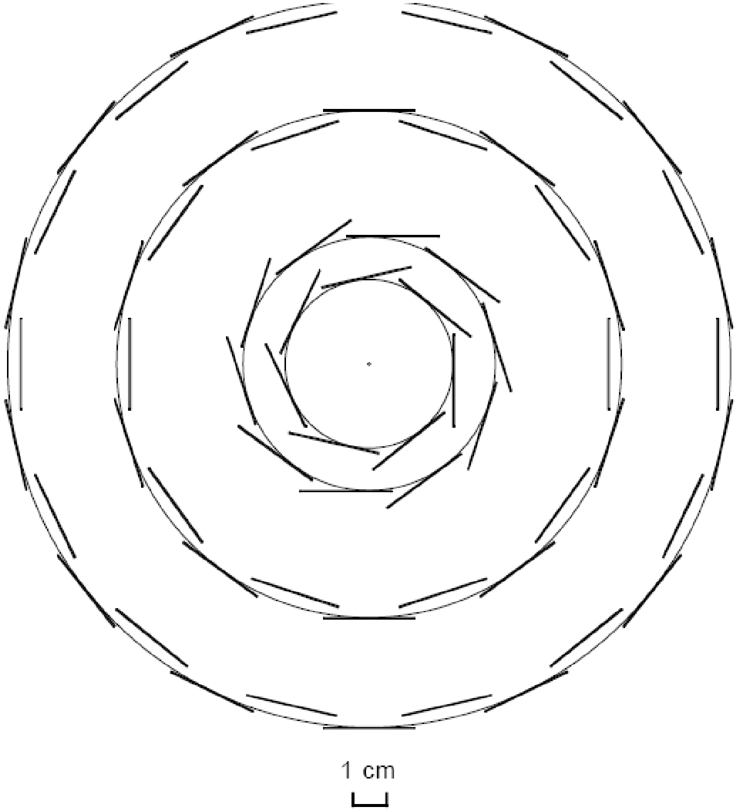


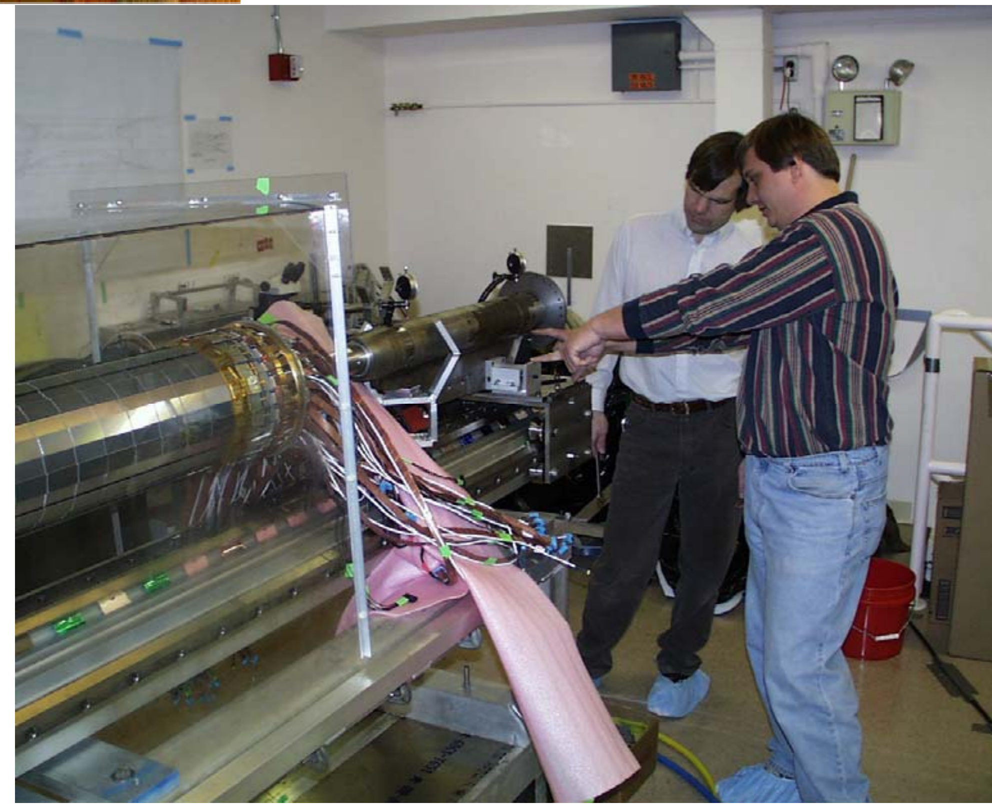


Si III Design

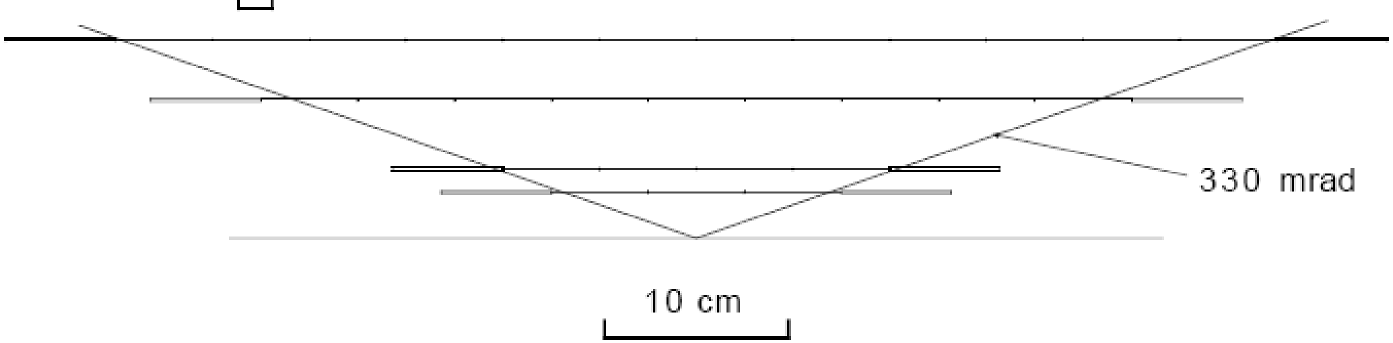
r-ϕ view

r(cm)
2.50
3.75
7.50
10.75





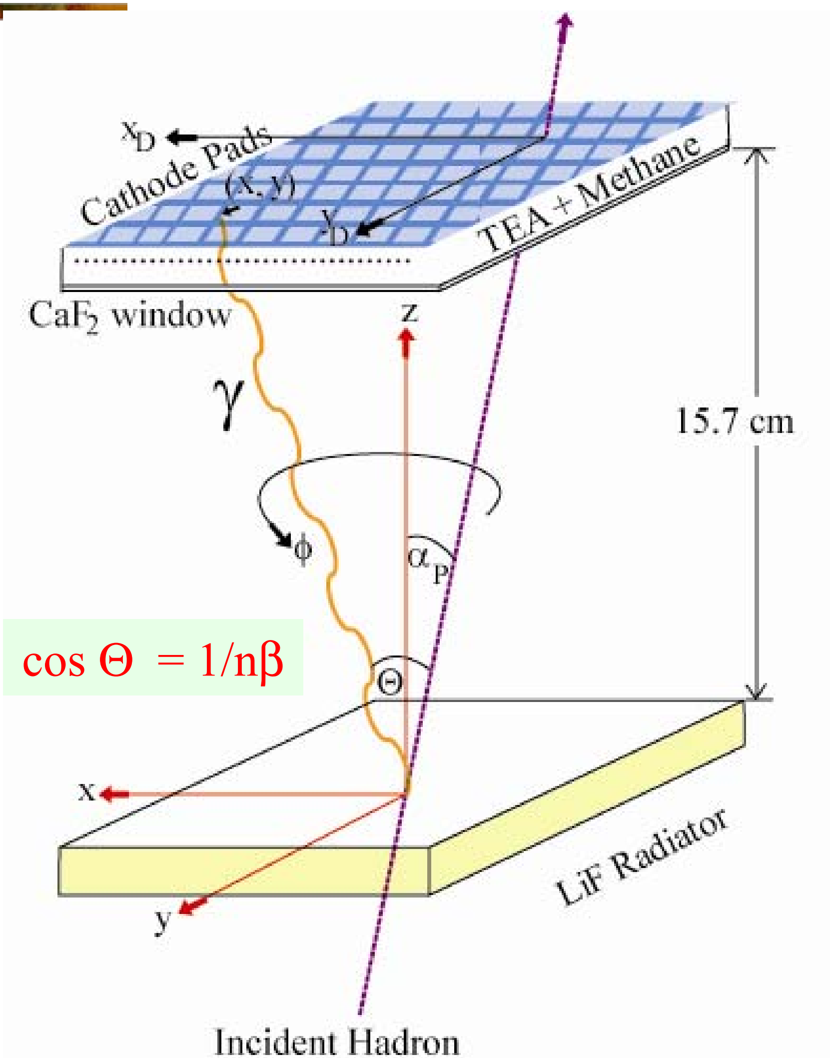
r-z view



RICH Fundamentals

- Use CH_4-TEA gas to detect single photons. Sensitive in VUV 135-165 nm
- Use LiF radiators
- Use N_2 volume 15.7 cm thick to allow Cherenkov cone to expand
- Use MWPC with pad readout to measure γ positions
- Original idea T. Ypsilantis & J. Séguinot , collaboration with Artuso & Mountain...
- Minimize material; goal

  < 12% r.l. (achieved 13% r.l.)

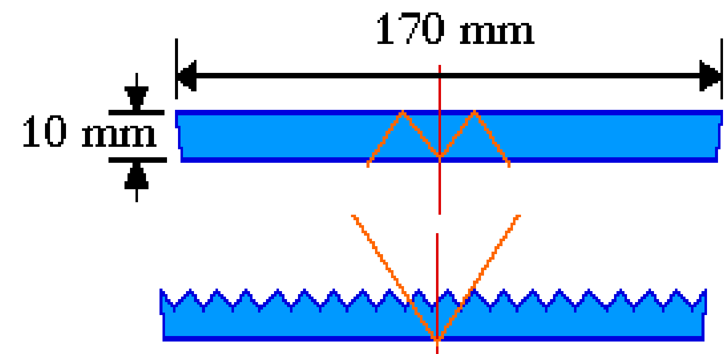


$\cos\Theta = 1/n\beta$

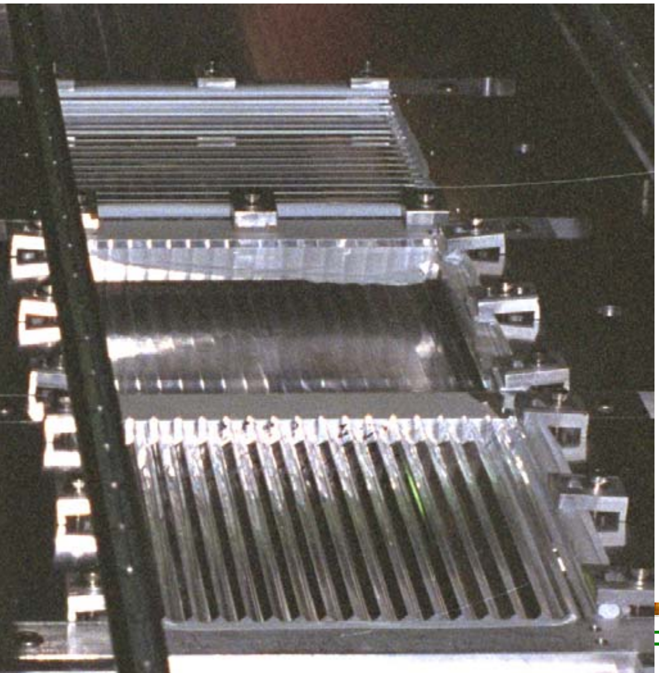
Measure β & p, so get mass

RICH Mechanical

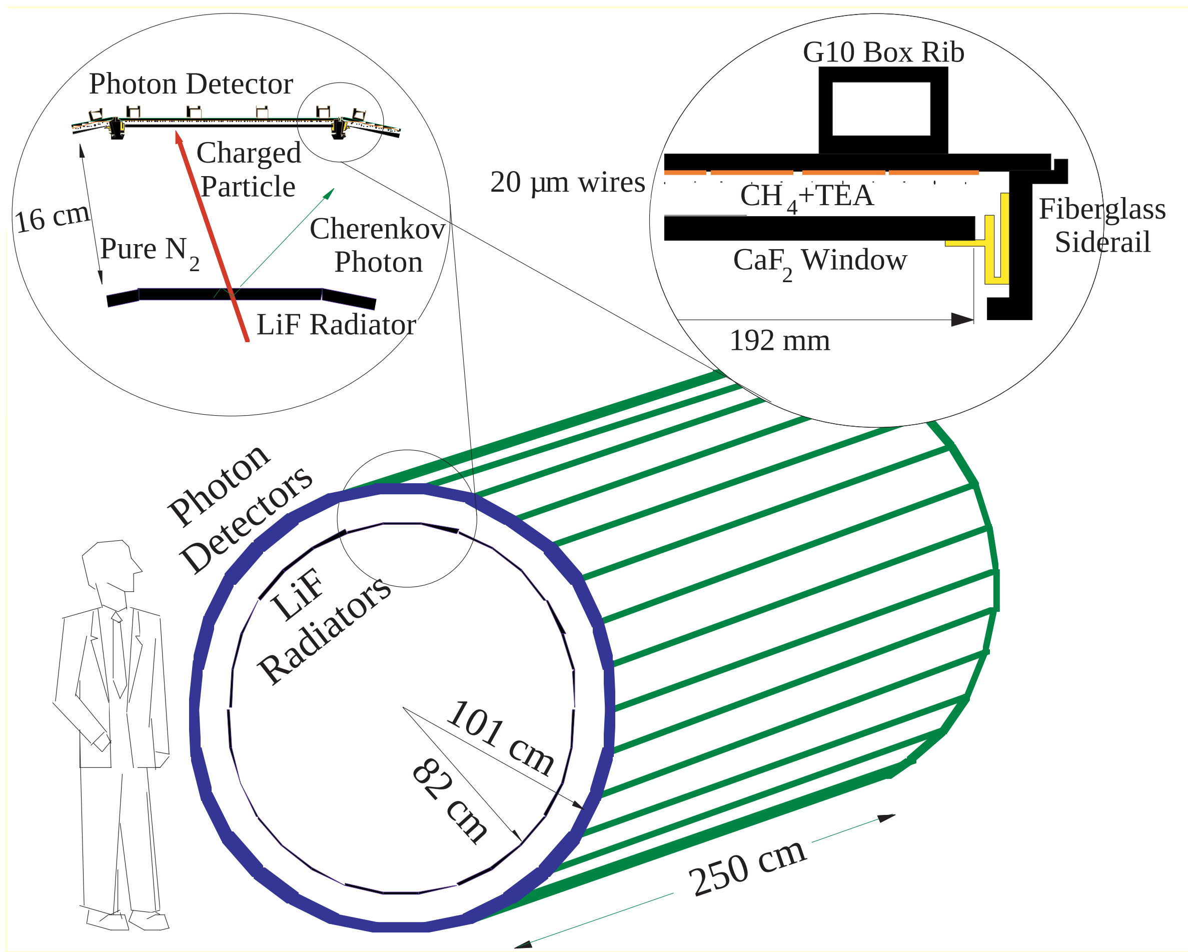
Radiators



A. Efimov & S. Stone NIM A371, 79 (1996)

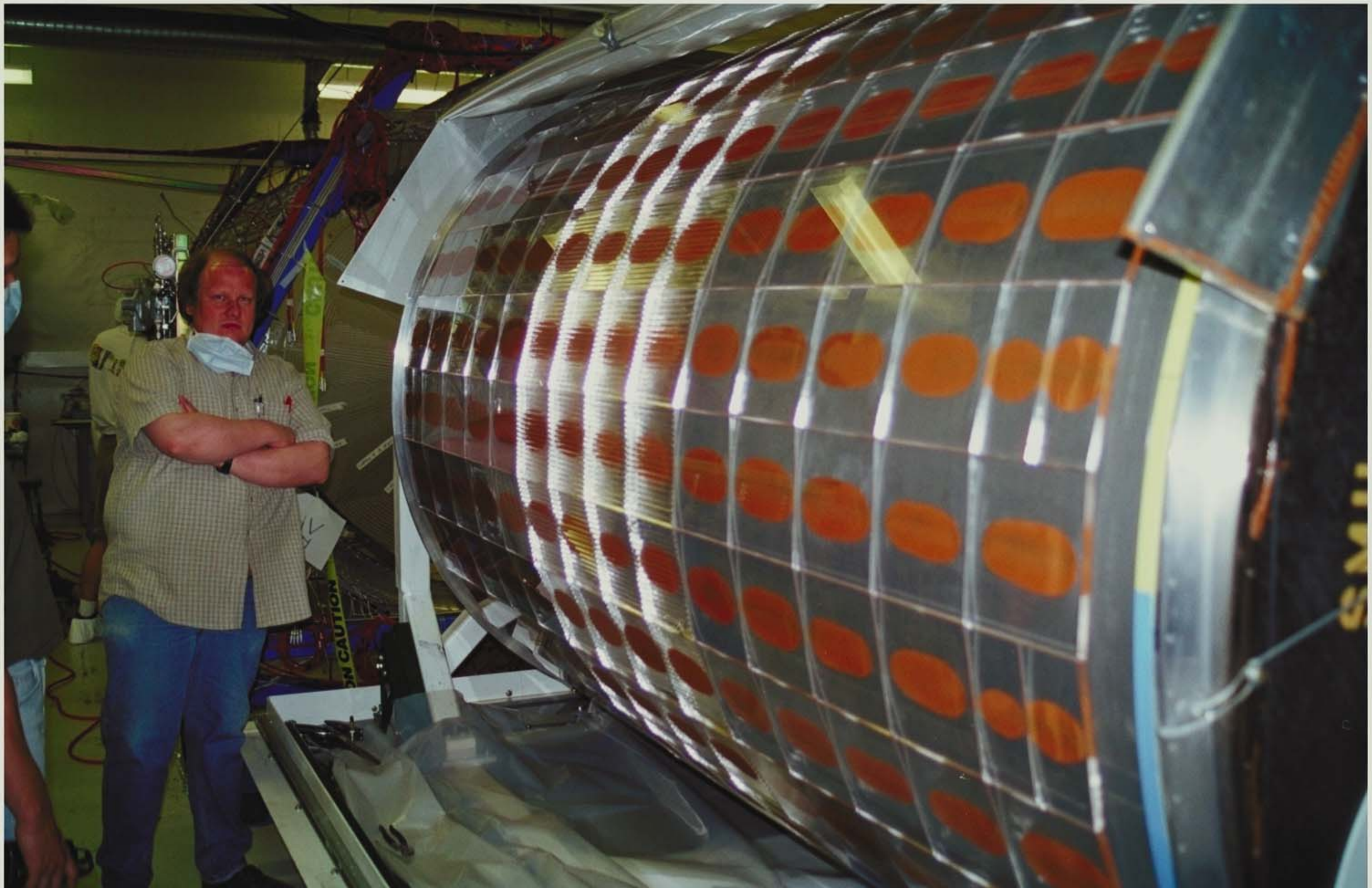


Overview



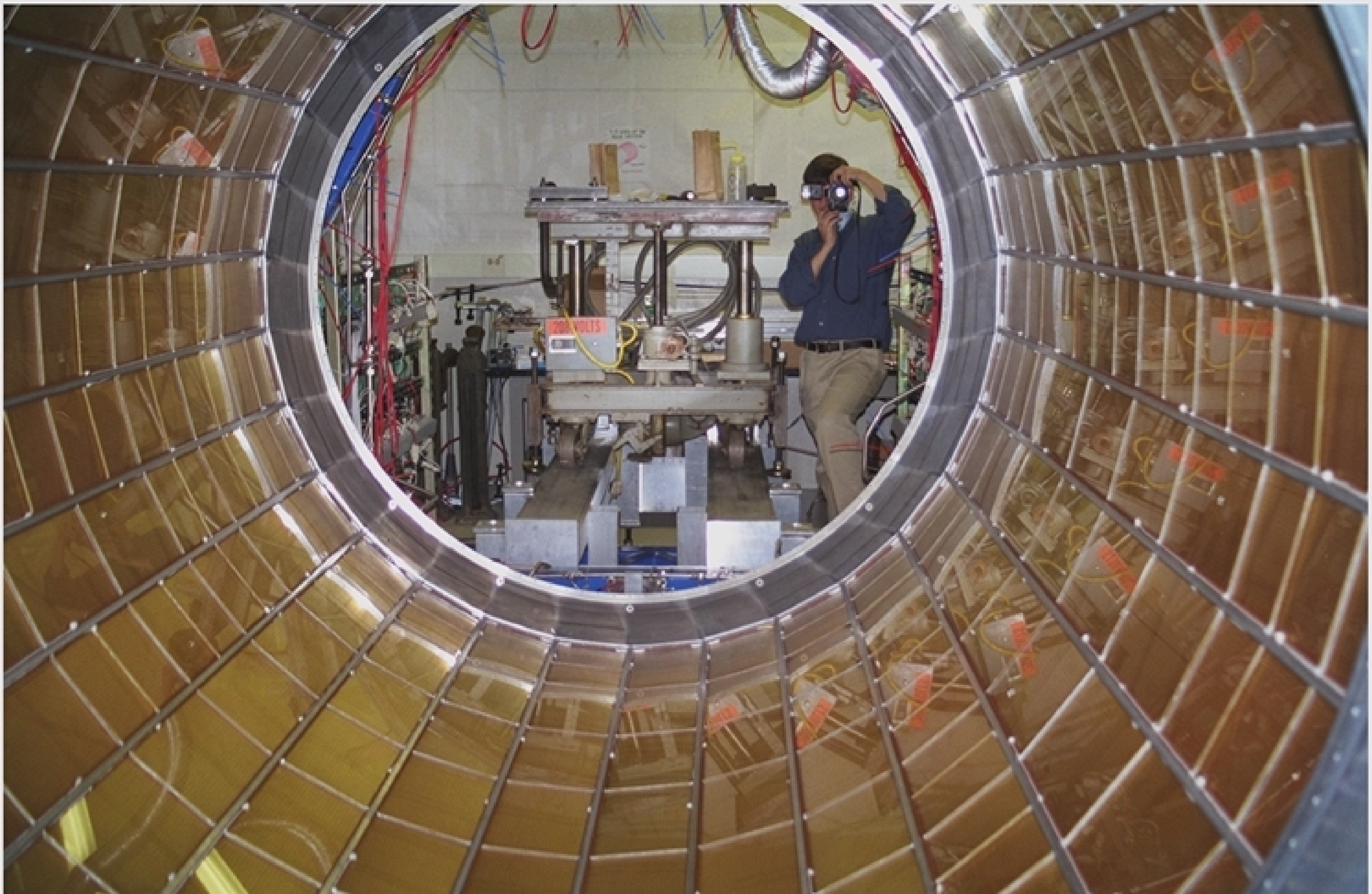
Completed Radiator Assembly

- Assembled at SMU: T. Coan, Y. Maravin....



Photon Detectors

- Syracuse: Ayad, Kopp, Mountain, Skwarnicki, Viehhauser ....



Gas system Minnesota:
A. Smith &
S. Anderson

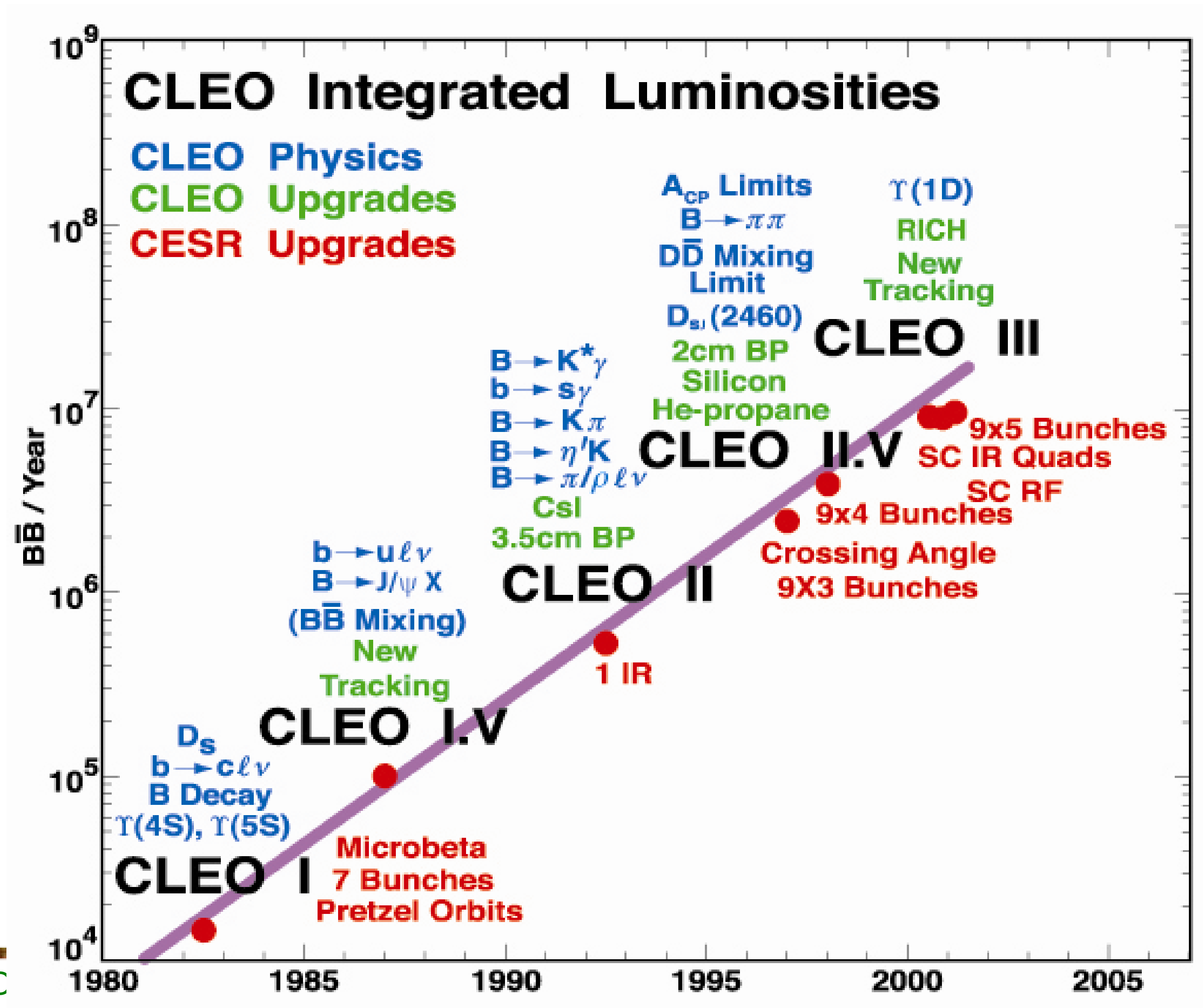
Electronics

- New chip developed: low noise a big deal
- Big fight with Bebek & Si
- Artuso, Schuh, Wang..

Outer Electronics Noise Shield

Most Import Results

- But in 2000 KEK-B & PEP II win $\mathcal{L}$ contest
- Each with 3xCESR



A New Proposal → CLEO-c

SYRACUSE UNIVERSITY
DEPARTMENT OF PHYSICS
201 PHYSICS BUILDING
SYRACUSE, NEW YORK USA 13244-1130
phone (315)-443-5972
fax (315)-443-9103
Email-Internet: Stone@phy.syr.edu

June 14, 2000

Prof. Maury Tigner
Director, Laboratory of Nuclear Studies
Newman Laboratory
Ithaca, NY

Dear Maury,

We are writing to you to express our concern with the status of CESR/CLEO and to explore with you the possibilities that running at a different center-of-mass energy could present. Currently, the asymmetric b-factories at SLAC and KEK are doing quite well. BABAR has accumulated almost as much integrated luminosity that had taken with CLEO II. BELLE is not far behind. We view this situation as potentially disastrous. Our competing with these machines on Υ(4S) physics with CLEO III was predicated on our starting at least one year before them and then accumulating at least as much luminosity per year. Unfortunately, we are running at ~1/3 the integrated luminosity and we started late.

Syracuse and other University groups have spent a great of time effort and money, more accurately in our case: blood, sweat and tears, in creating the components of CLEO III. We spent five years building the RICH and now that it is working we want to do some physics with it and the rest of the detector. Having the third best measurement will not make it. We also fear that we cannot present a proposal to the NSF that is based on CLEO running on the Υ(4S), in that it will review poorly. The physics justification just doesn't exist for a 3rd rate measurement.

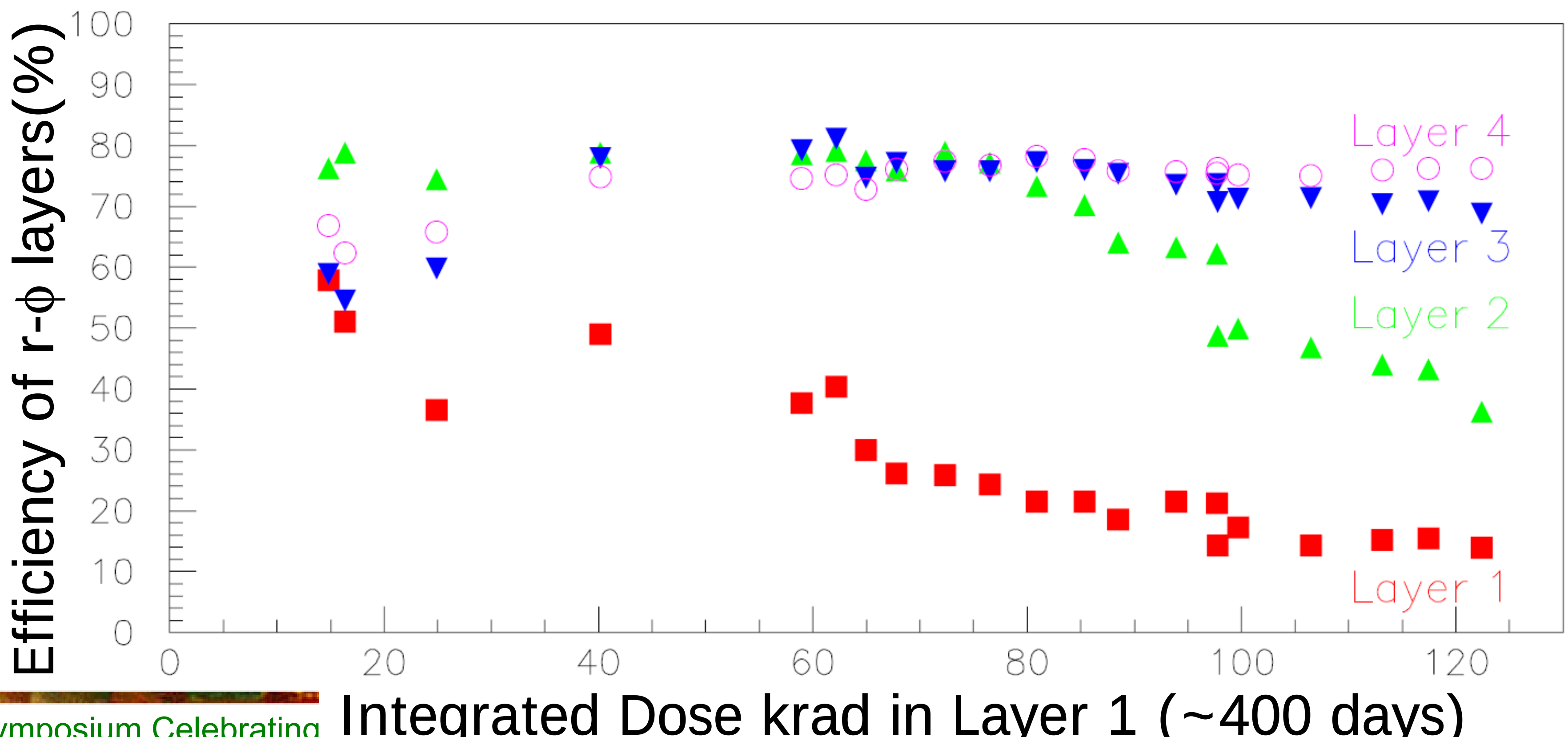
Still we want to do good, fundable physics with CLEO III. So we now suggest other places to run CESR that will allow us to do unique and interesting physics.

CLEO-c Task Force

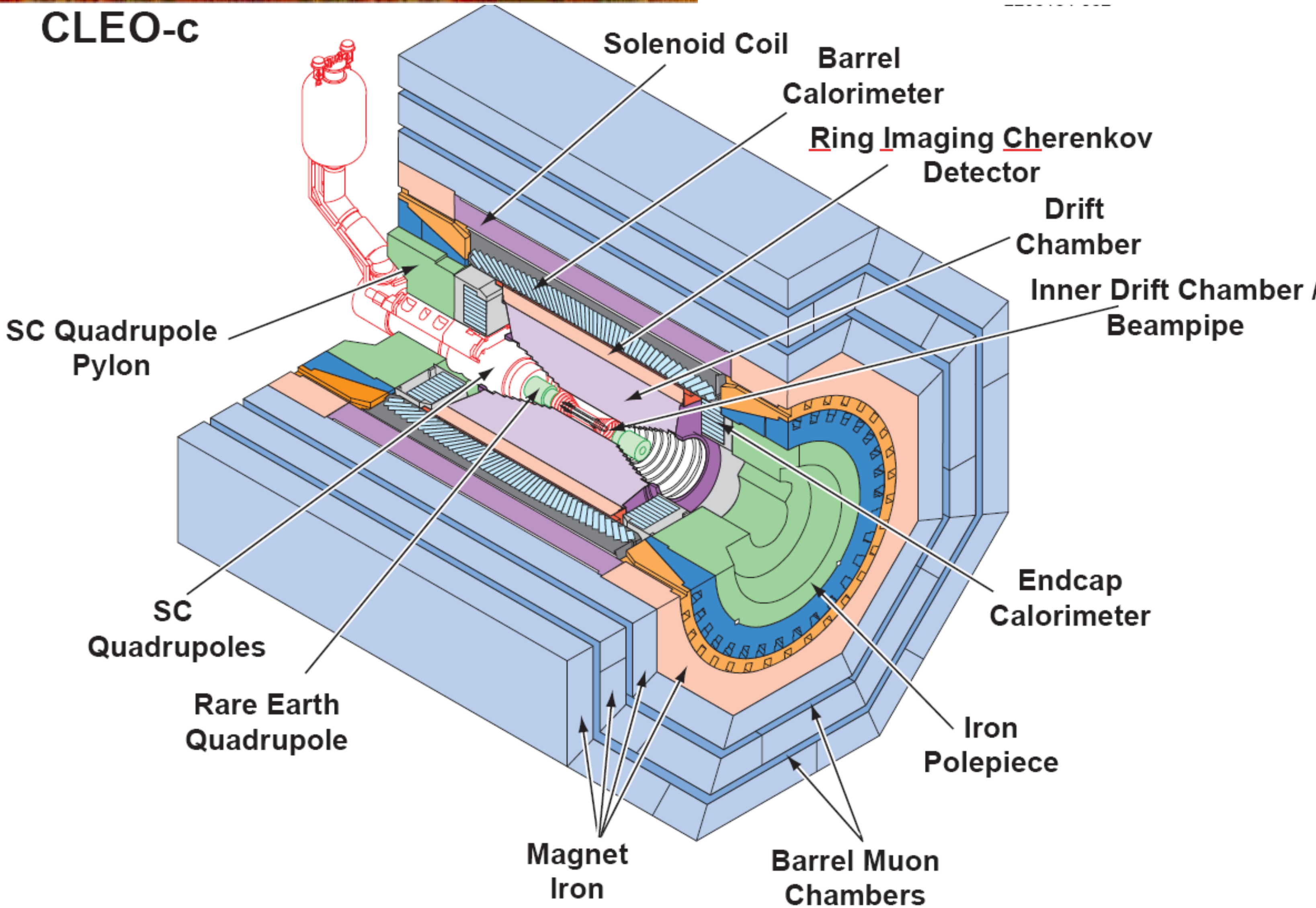
- CLEO leaders Marina Artuso & Ian Shipsey
  - Made Physics Case
  - Supervised simulations to show physics reach
  - Interacted with CESR-c group
- Accelerator Design: Dave Rice
  - Wigglers (N. Mistry)
  - Optics
  - Beam Stability
- Proposal Writing: Persis Drell

One More Detector Upgrade

- Replace Si III with low mass wire drift chamber (Ecklund, Galik, Peterson & Pivarski)
- Due to premature radiation damage



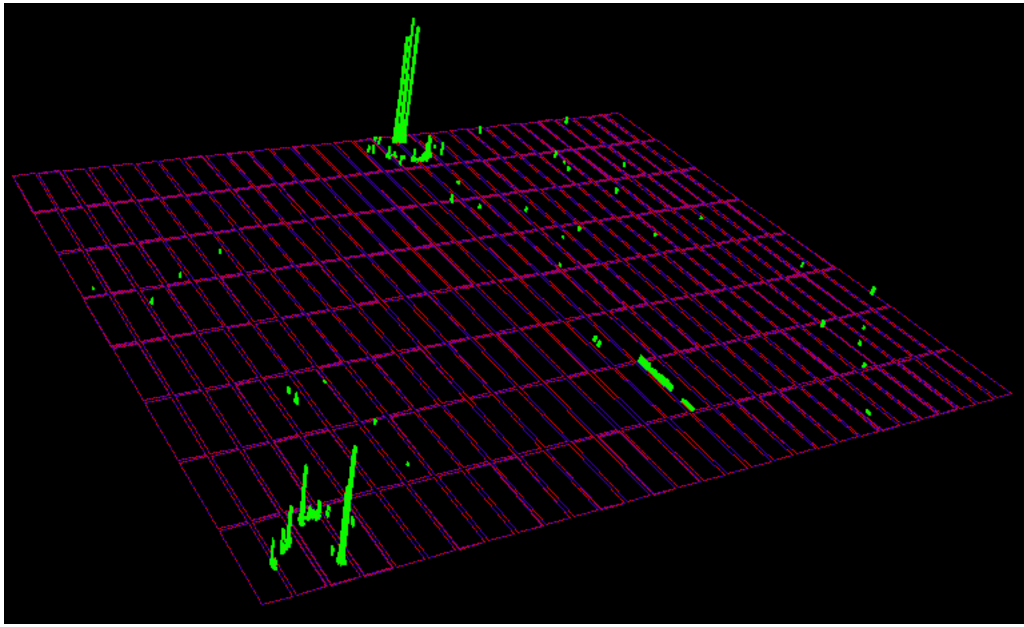
CLEO-c



CLEO-c
Solenoid Coil
Barrel
Calorimeter
Ring Imaging Cherenkov
Detector
Drift
Chamber
Inner Drift Chamber /
Beampipe
SC Quadrupole
Pylon
SC
Quadrupoles
Rare Earth
Quadrupole
Endcap
Calorimeter
Iron
Polepiece
Magnet
Iron
Barrel Muon
Chambers

RICH Performance in CLEO-c

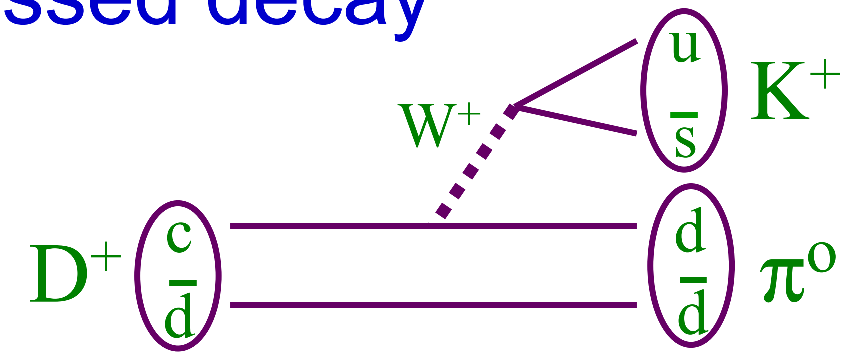
- Efficiency for Pions = (97.3±0.3)%
- Efficiency for Kaons = (90.6±0.7)% - difference due to decays in flight
- Rate for π faking K = $\left(1.2 \pm 0.4^{+0}_{-0.1}\right)\%$
- Rate for K faking π = $\left(2.6 \pm 0.5^{+0}_{-0.1}\right)\%$
- Over entire time period Oct. 2003 – July 2007

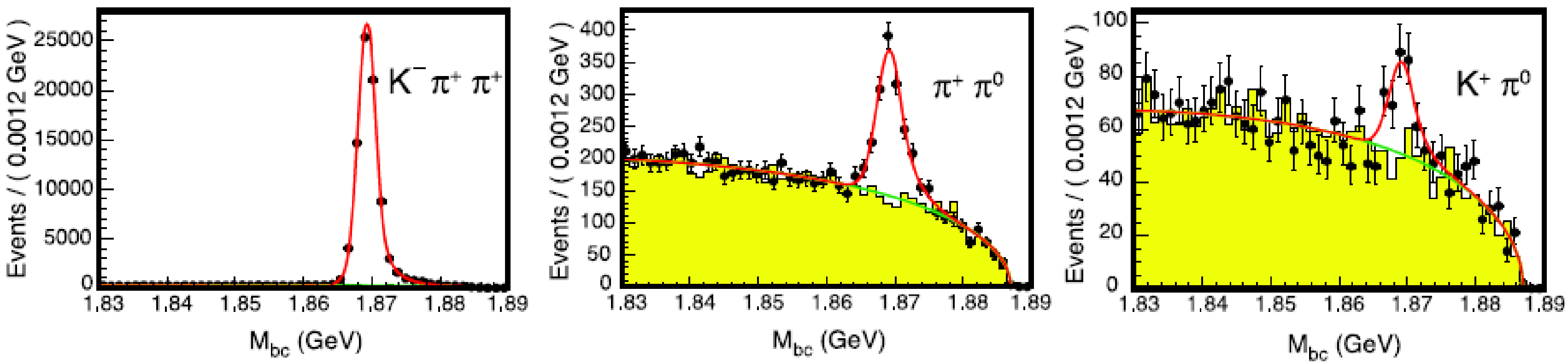


May be best performance ever of a RICH!

RICH Use Example

- Double Cabibbo Suppressed decay $D^+ \rightarrow K^+\pi^o$

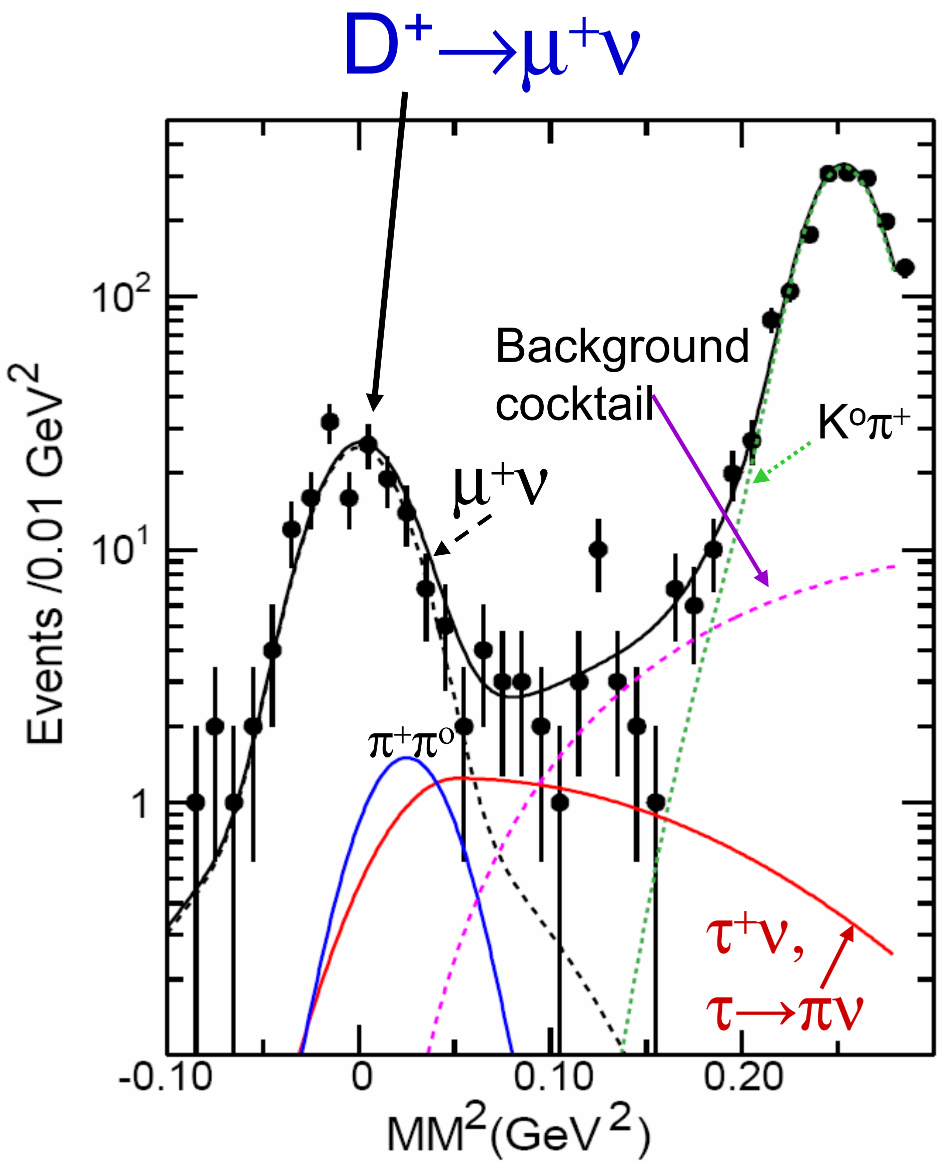


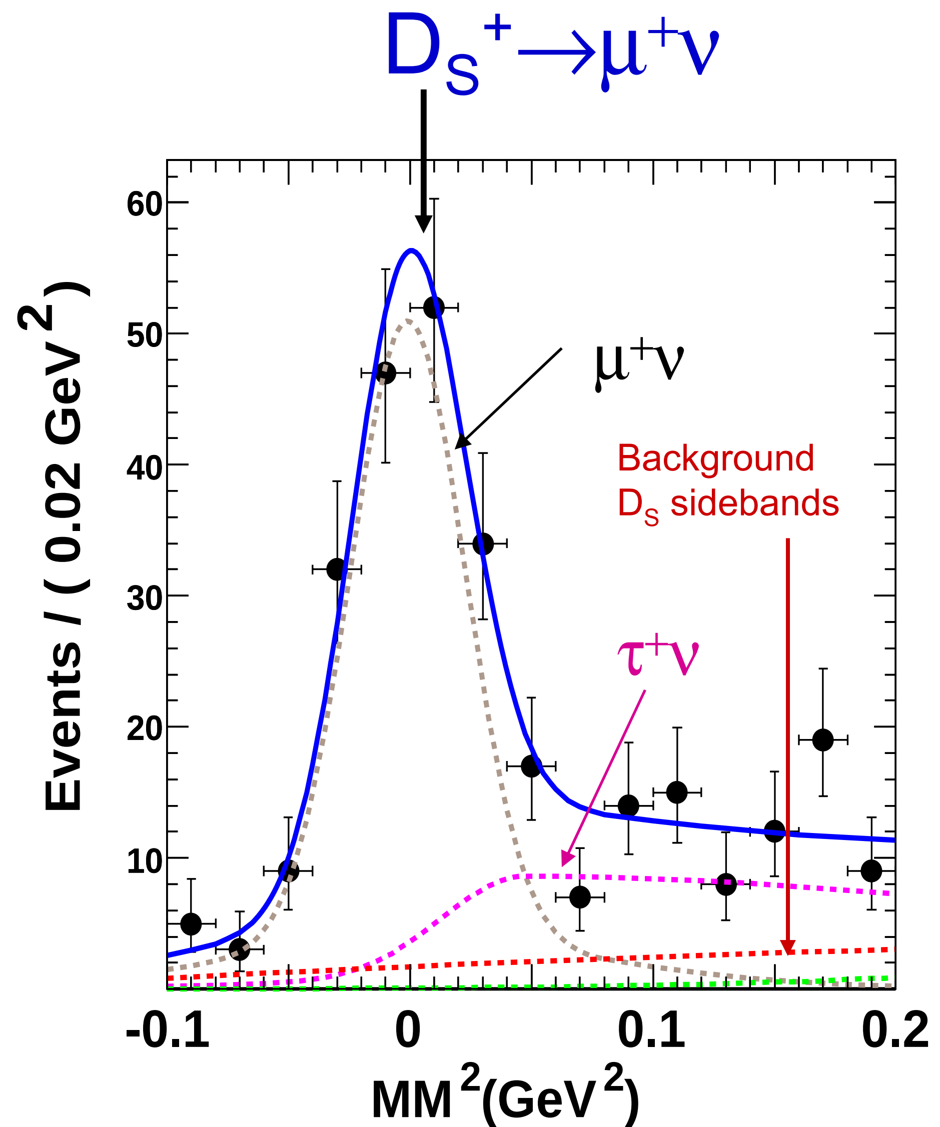


- We find nice signals without reflections, due to RICH $\mathcal{B}(D^+ \rightarrow K^+\pi^o) = (2.28 \pm 0.36 \pm 0.15 \pm 0.08) \times 10^{-4}$

Physics in CLEO-c

Fully reconstruct the D & then can measure D final states with a missing ν

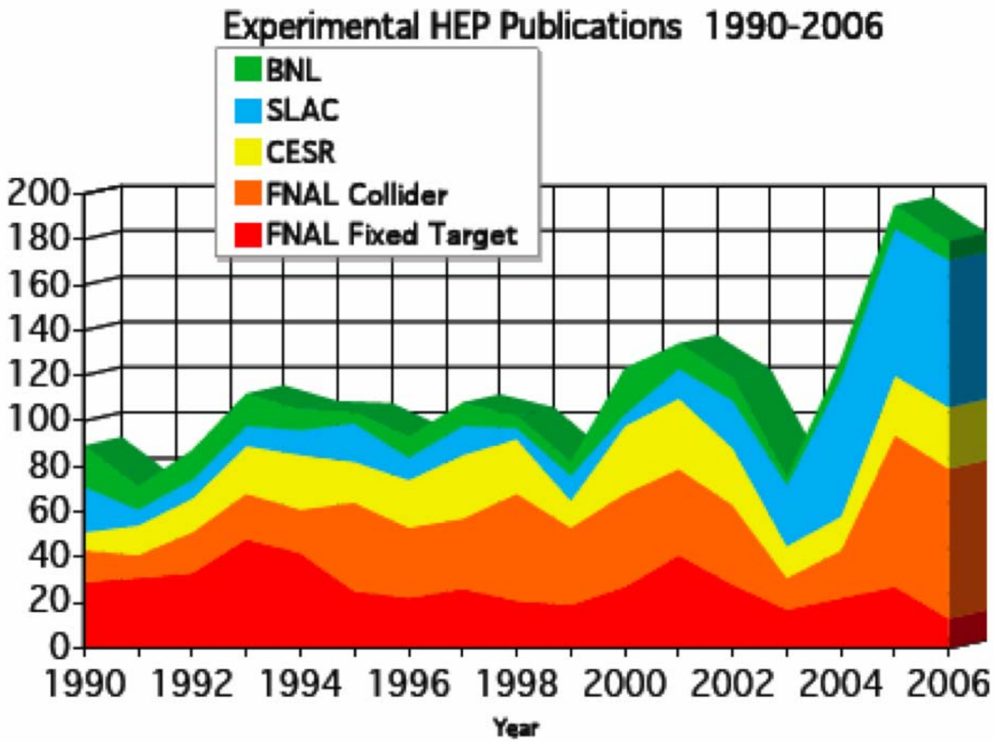


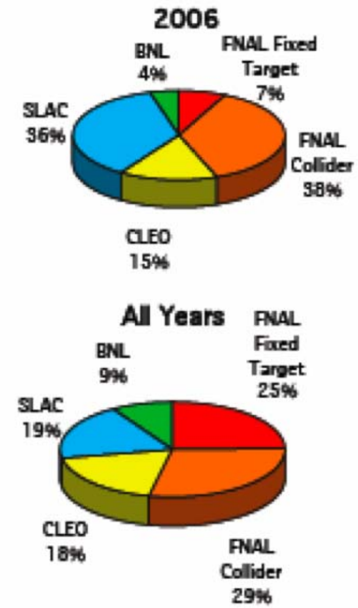


Detector Themes

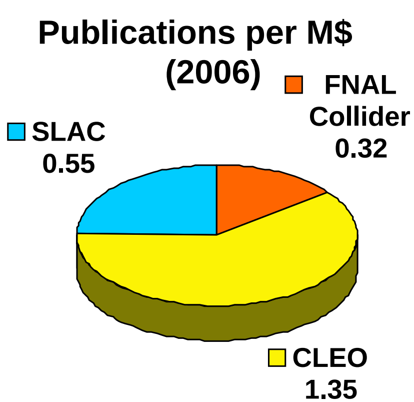
- Developing technologies widely adopted applied to upgraded detectors CLEO I.5, II, II.V, III
  - Example: PID in outer dE/dx $\rightarrow$ in DR $\rightarrow$ RICH
  - Example: Ever shrinking inner beampipe radius; IZ started at 9.4 cm
- These lessons were adopted by others

U.S Experimental Publications





Information compiled by Fermilab



Most support for CLEO/CESR program provided by NSF, with important contributions from the DOE

Conclusions

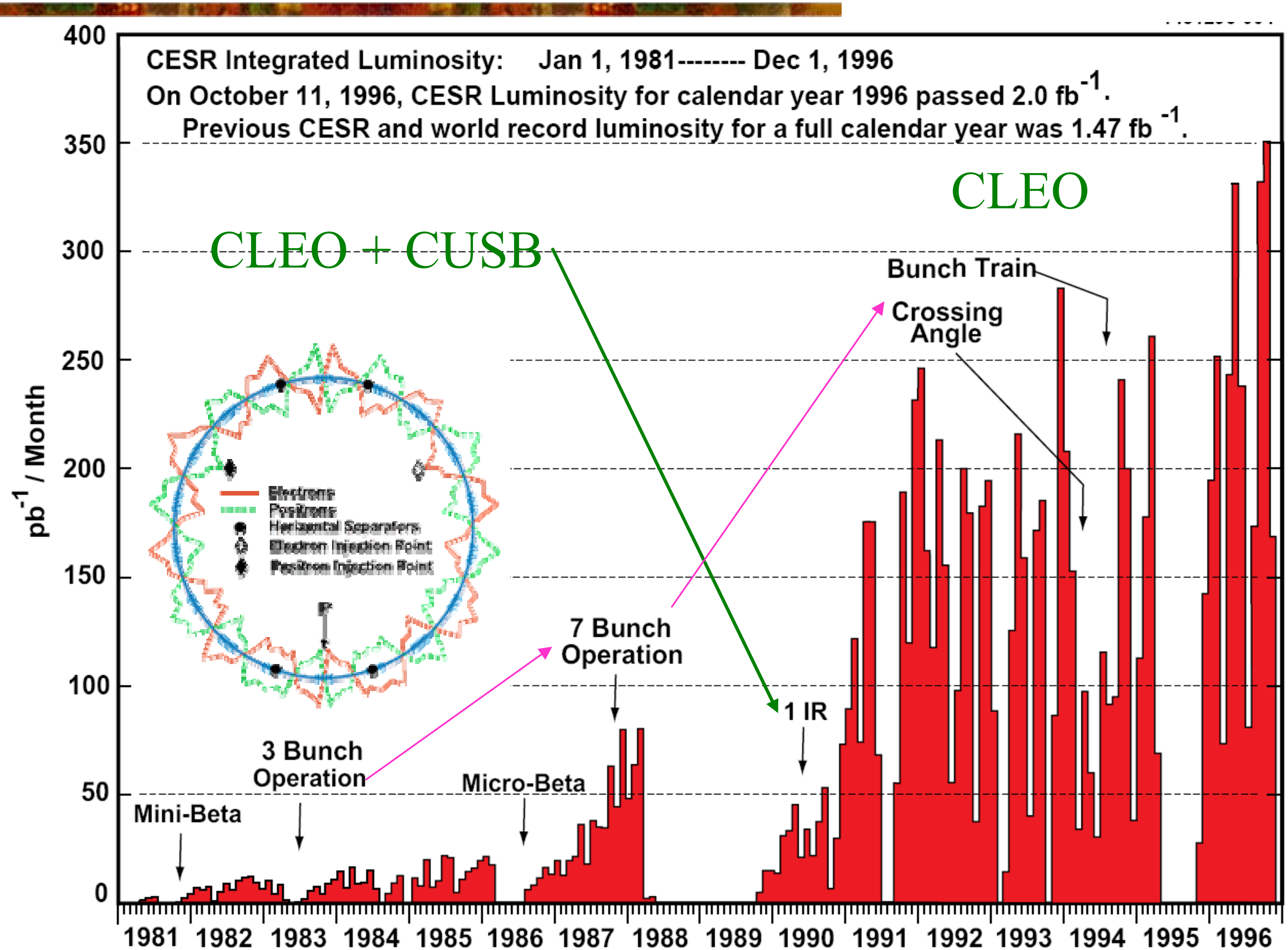
- Pioneering efforts in detector technology
  - Particle ID: dE/dx, RICH
  - Large scale crystal calorimetery coupled with excellent charged particle detection
  - Tracking & Vertex Detection at e^+e^- colliders
- All of the above led to CLEO Physics: pioneering efforts in heavy quark decay, many discoveries leading to future studies of CP violation and a path toward finding or classifying new physics (unless CLEO-c has found it already in leptonic decays)
- Pursuit of Science, pursuing new detector technologies, & physics analysis techniques has been very rewarding

All in all, its been FUN!

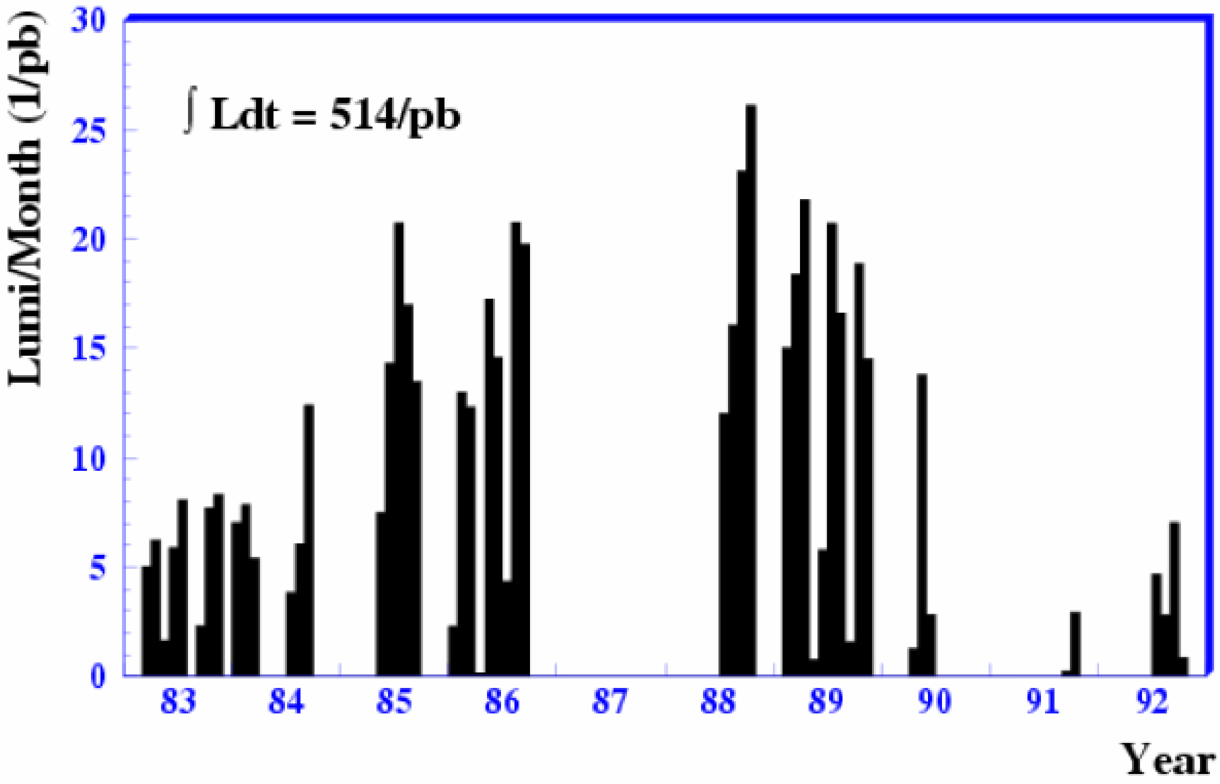
The

End

Luminosity Progress: Early Years



Argus Luminosity



Progression in Flavor Physics