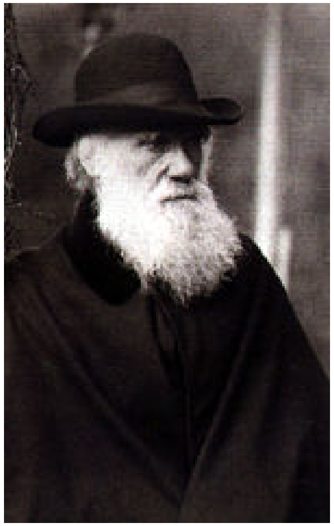
University of DØ
P. Grannis, April 8, 2010

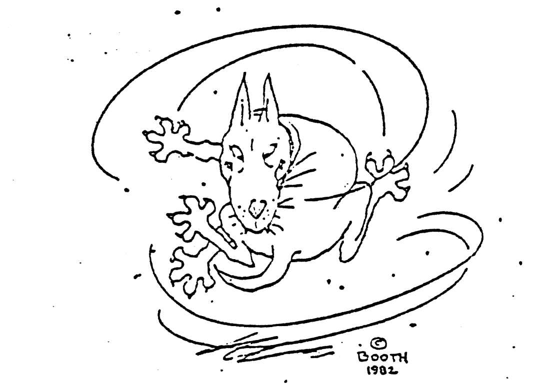
# The Voyage of the Beagle

… or

# On the Origin of Species



# The Voyage of the Beagle




… or

# On the Origin of ~~Species~~ DØ

From mid-1983 to end 1984, the DØ collaboration was formed and the experiment was shaped. From 1984 onward, many tests, studies, detector fabrication and commissioning were done, leading to Run 1 collisions from 1992 to 1996.

# Pre - 1983

- In 1981, Director Leon Lederman called for proposals for an experiment in the DØ IR. He asked for something 'small (<750 m$^3$), simple, and clever'. It must be moveable on and off the beam (fixed target beam extraction occurred in DØ).

- Aim for first operation in 1986. Fermilab offered financial contributions to the detector up to $1M!

- 19 proto-proposals of varying complexity resulted; 12 survived and were finally considered in the June 1983 PAC meeting.

- The result was disapproval of all proposals – and carte blanche Stage I approval (July 1, 1983) for a new consortium originally consisting of only one person (PG). The charge was to create a new experiment for high $p_T$ physics that was at least <u>no worse</u> than the proposed concepts.

Not very auspicious beginnings …

# Letters of intent

Rubbia: 4T SC dipole, hi press tracking, fine grained calorimeter

§ Pope: 2 Pb glass fwd arrays; MWPC tracking

Kennett: track chmbrs, 1.5T solenoid; PWC cal

Barish: PWC calorimeter egg around IP

Longo: PWCs and Cal in forward regions – 50 m long!

§ Marx.: LAPDOG; Pb glass, 600 tons

Diebold: Borrow large dipole; dE/dx, TOF, calorimeter. 200 tons

§ Green: Muon scint hodoscopes above ground

Rushbrook: Move UA5 streamer chamber

Garelick: non magnetic Fe, muon tracker

* Giacomelli: Roman pots elastic scattering

Frisken: 2000 ton detector for e-p collisions

W.Lee; e-p collision detector

* Price: Lexan stack monopole search

Devlin: $4\pi$ calorimeter

§ Ferbel: move ISR R807 axial field spectrometer

Thun: drift chambers, PWC and Pb glass calorimeter

§ Erwin: Forward calorimeters based on E609 fixed target detectors

S. Smith: Time expansion chamber, 10T SC solenoid, HCal, muons

* Ultimately approved and ran in other IRs.

§ Portions of these ultimately became DØ

Two became HERA-based

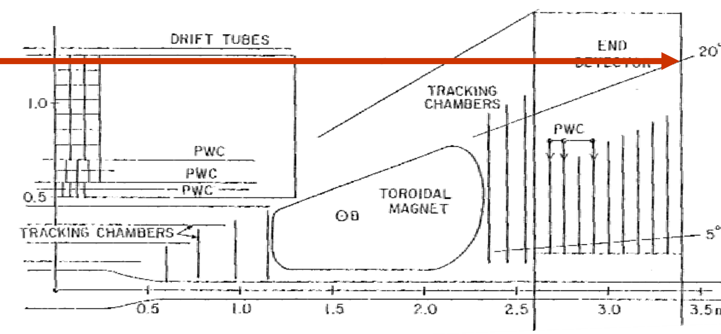
# Pre – 1983 : LAPDOG

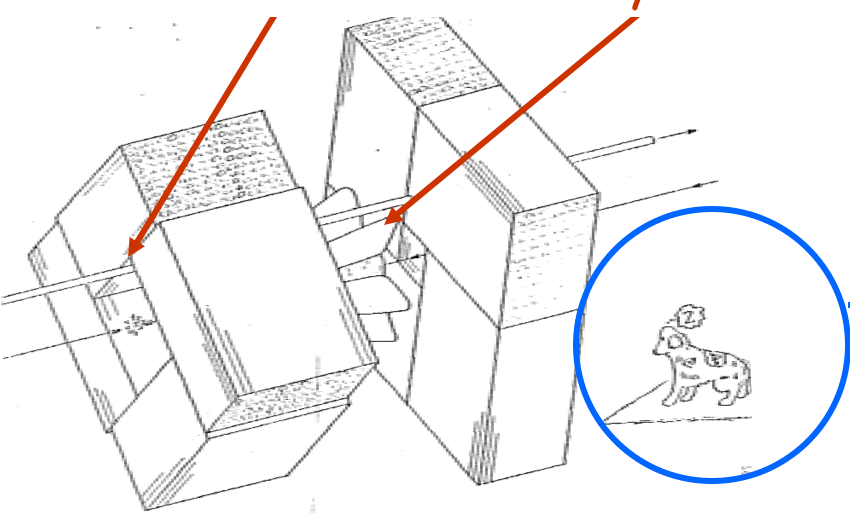
Large Angle Particle Detector Or Gammas

LAPDOG focussed on W/Z and high $p_T$ hadron physics with an (EM) calorimeter made from extruded lead glass bars.

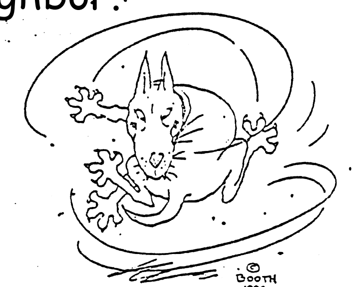
By 1983, it had merged with a proposal to build a muon spectrometer (in the berm) that morphed into a hadron calorimeter.

- Detector ~ 7m along beam (~1/3 of DØ)
- Central cal. rotated to accommodate MR.
- Note (ATLAS folks) the air toroids in the forward direction.
- Note advanced CAD system!



The “DØ døg” was born as the logo for LAPDOG, courtesy George Booth, my Stony Brook neighbor.



# 1983 : DØ proposal

Starting in summer 1983, a collaboration formed from portions of many of the earlier proposals. It should complement the CDF detector that started ~4 years earlier.

The first challenge was to settle on a name – GEM, BELLA, DØGBREATH, … we failed utterly to agree and settled on the lowest common denominator "DØ", our address in the lattice.

The guiding principle was the focus on high $p_T$ physics (electrons, muons, jets and MET) without a central magnet. The EM calorimeter was first scintillating glass bars (more light, more rad hard, more expensive than Pb glass).

In the 'September revolution', this scheme was seen as too complex and cumbersome (and under-performing). DØ switched to liquid argon calorimetry (ensuring delay while learning the LAr business).

# 1983 : DØ proposal

By the December PAC meeting a full proposal was presented and given Stage I approval (and a resounding ovation) but few $$.

71 collaborators, 12 institutions all in US.

THE DO COLLABORATION

B. Pifer
University of Arizona

L. Ahrens, S. Aronson, P. Connolly, B. Gibbard, H. Gordon, R. Johnson,
S. Kahn, M. Month, M. Murtagh, S. Protopopescu, S. Terada,
D. Weygand, D. H. White, and P. Yamin
Brookhaven National Laboratory

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P. Martin, P. Mazur, J. McCarthy, and R. Yamada
Fermi National Accelerator Laboratory

H. Goldman
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S. Kunori and P. Rapp
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S. Linn, D. Lloyd-Owen, M. Marx, R. McCarthy, L. Romero,
R. D. Schamberger, and H. Weisberg
State University of New York at Stony Brook

and

J. Ficenec
Virginia Polytechnic Institute

# 1983 : DØ proposal

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71 collaborators, 12 institutions all in US.

10 individuals remain from 1983 on the list of 449 on the current DØ masthead.

9 institutions remain among the 67 now participating.

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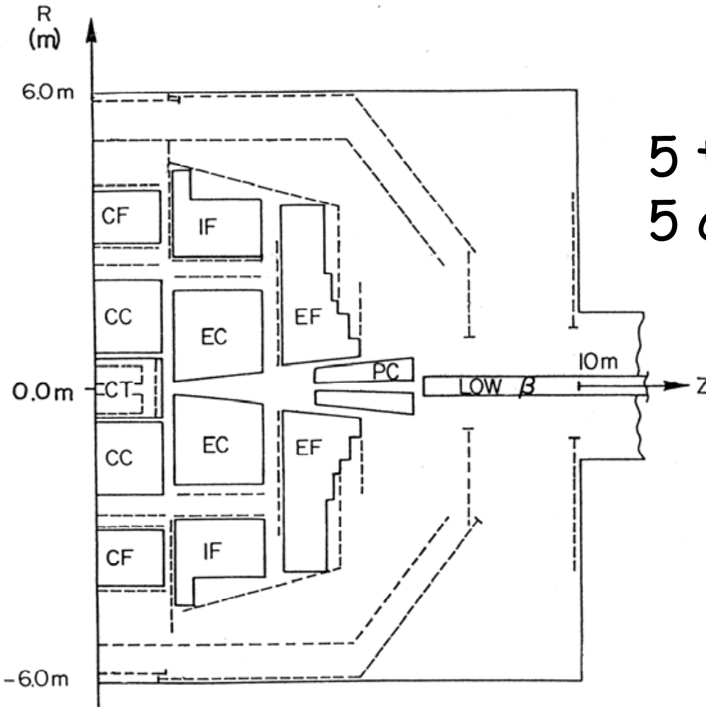
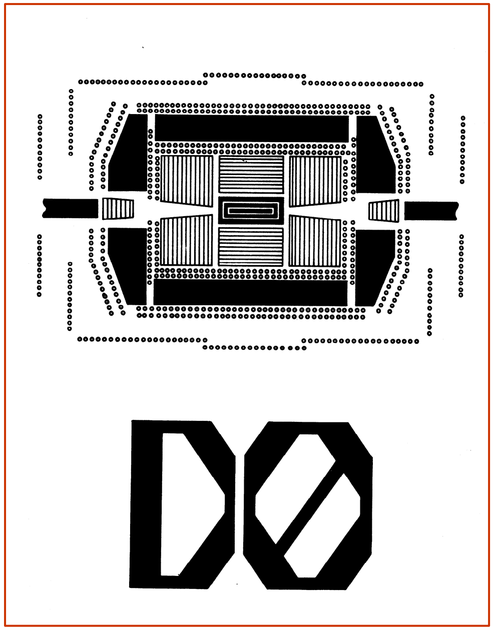
# Highlights of 1983 proposal

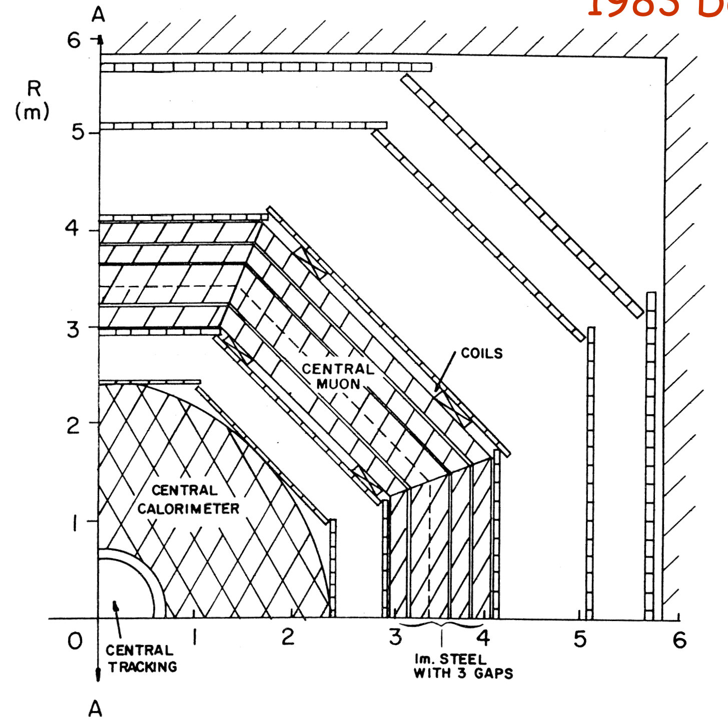



5 toroids (CF/IF/EF);
5 calorimeters (CC/EC/PC)

complex!



1983 Design Rept cover




Octagonal shape for toroids, muon chambers.

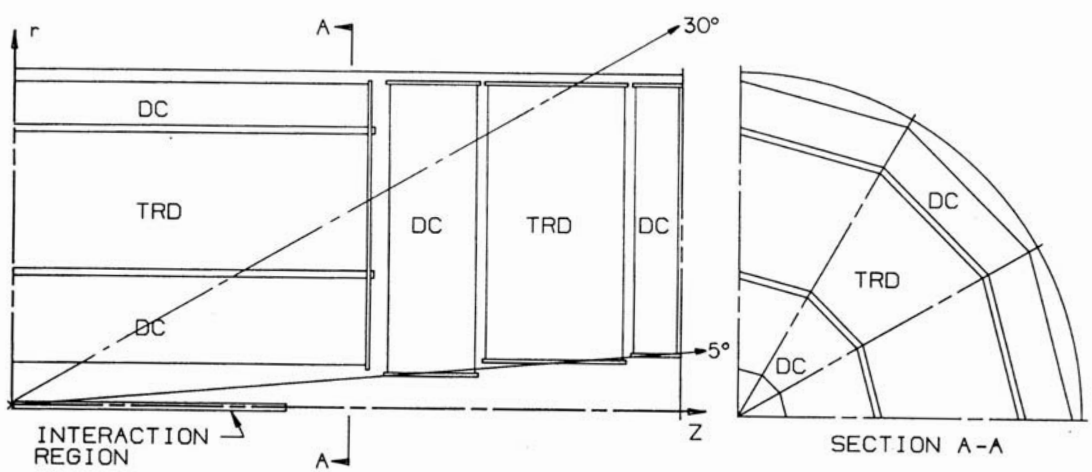
# Highlights of 1983 proposal

Tracking:

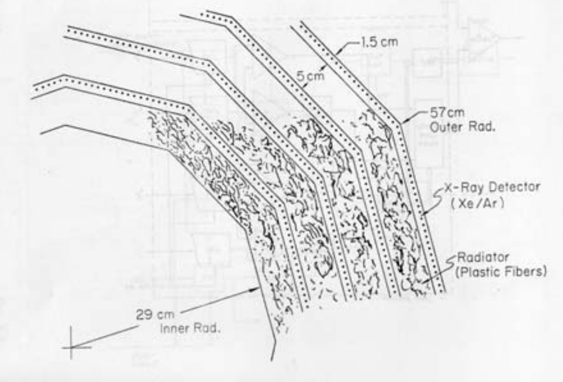
Inner and outer drift chambers; 4 layer Transition Radiation Detector in both central and forward region for electron ID.

Again a polygonal structure.

No magnet for tracking volume – enabling compact high quality calorimetry



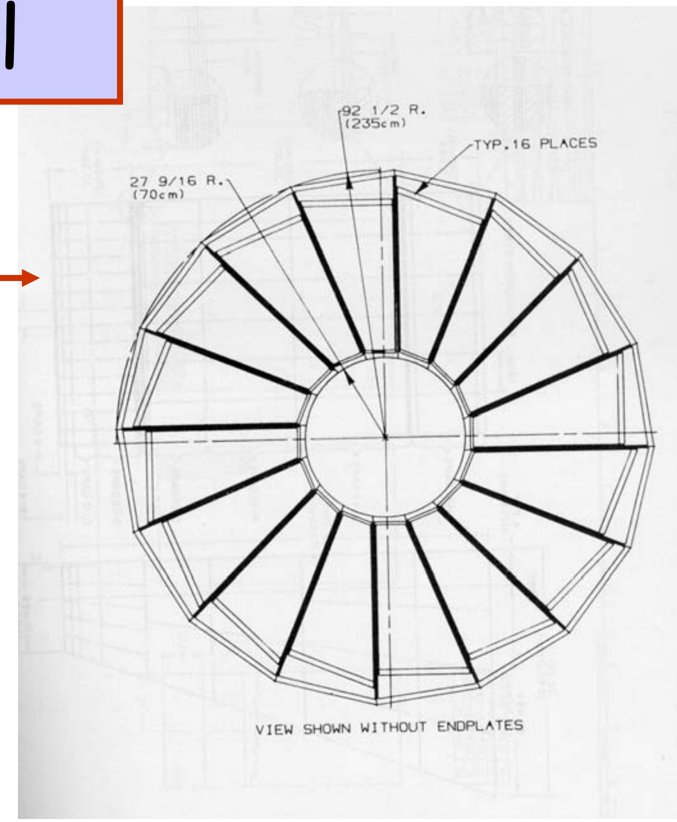

TRD schematic

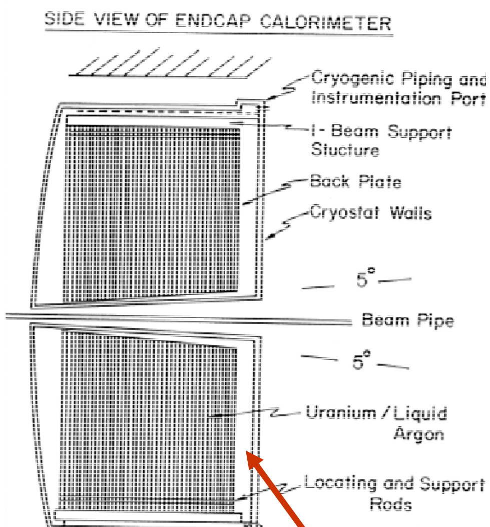


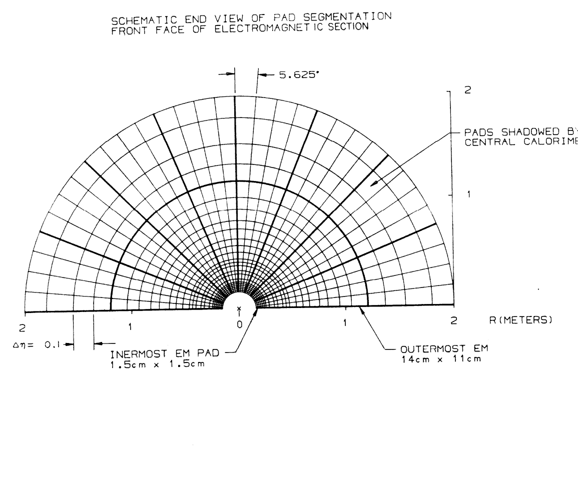
# Highlights of 1983 proposal

Calorimetry:

Interesting CC pinwheel modules!




Single, very heavy, EC module with tapered hole for a plug calorimeter within $\Theta < 5^{o}$

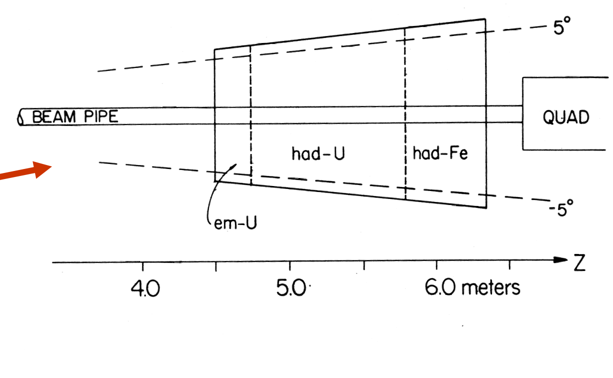
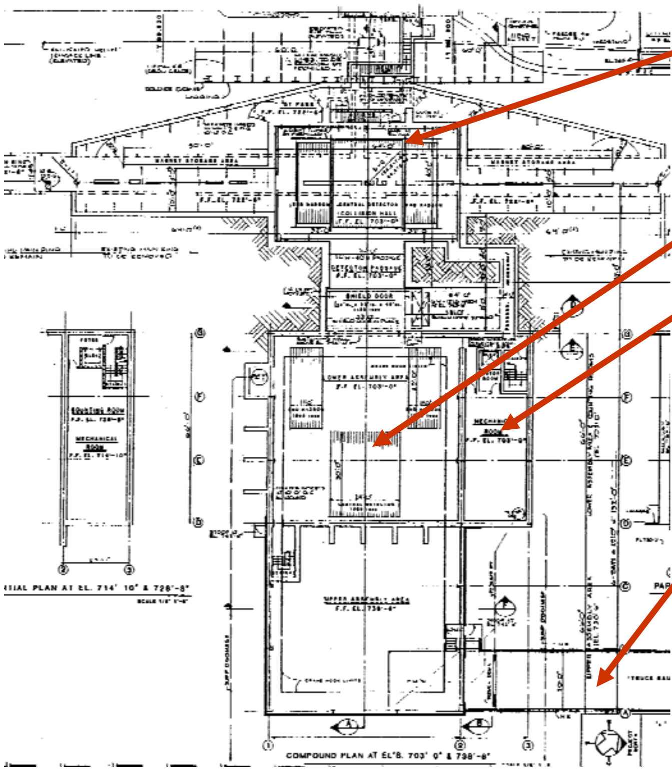



Fig. 7.2

# Highlights of 1983 proposal

Considerable work was done on DAB design; the collision hall size was frozen, so it constrained the detector design. FNAL decreed that there would be no movable door to allow rolling the detector into collision hall. Also decreed that Main Ring accelerator (400 GeV) could not be lifted all the way above our hall, as in CDF.



Collision hall
Assembly hall
Control room
Very few offices

(Pretty much as built, but office bldg later extended.)

A Director with an over-developed imagination suggested a turntable with detector & shield wall on it that could be twirled from In to Out positions…

or a vertical piston elevator to the surface.

We decided that a stackable concrete block wall was simpler!

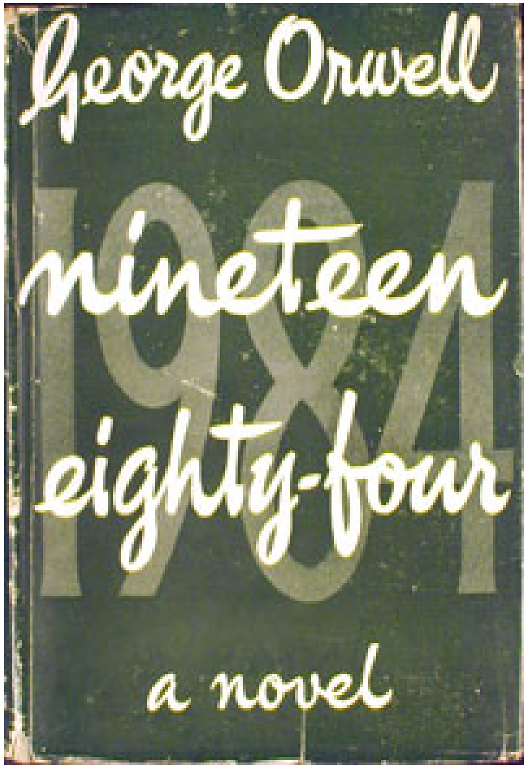
# On to 1984

Feb. 1984 DOE (Big Brother) charged HEPAP to advise on the relative priority of SLD and DØ (not enough funds to start both).

In a split vote of HEPAP, SLD was favored (desire to beat LEP was the reason). Big Brother however recognized the case for DØ and did allocate some funds for R&D, and scheduled a Temple (a.k.a. Lehman) review for November.

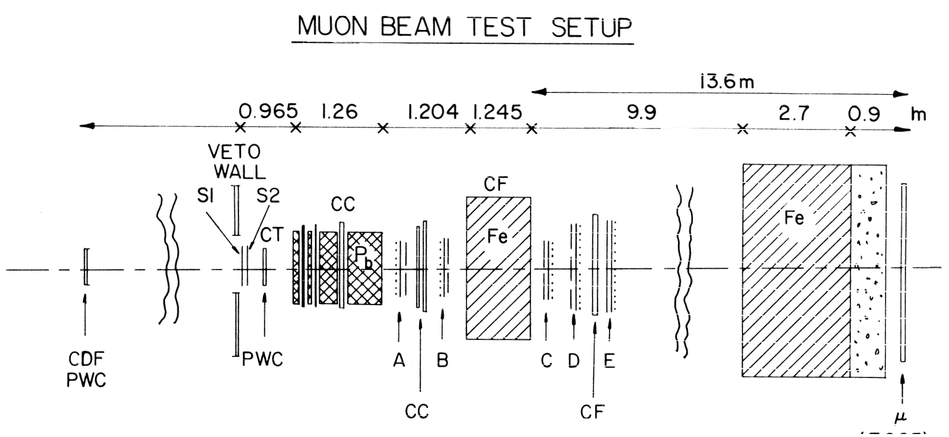
This meant that a real design, cost estimate, schedule with milestones, management plan etc. was needed (in the end, the total accounted cost was $75M, not the $1M offered by Lederman).

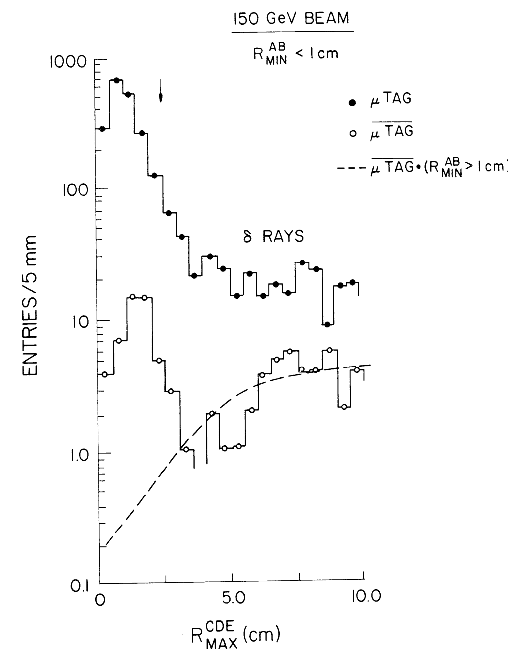
DØ moved administratively to Accel Div (to promote competition between CDF/PPD and DØ/AD) and into quarters in a series of leaky portakamps around the Booster pond . AD knew little about experiments and this adventure was abandoned in several years.




# Some 1984 activities

Fig. 6.23




Test beam run to measure the poorly known hadron punchthrough – Pb block simulating CC.

MC simulations – jet trigger cross sections

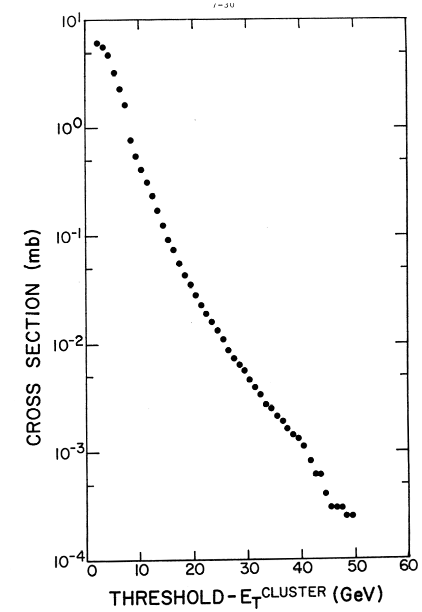
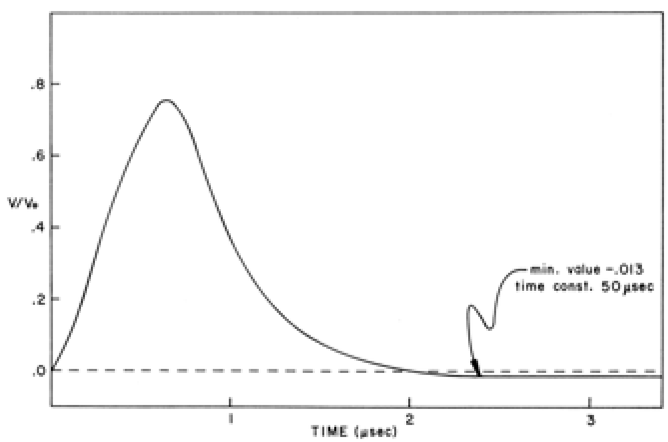


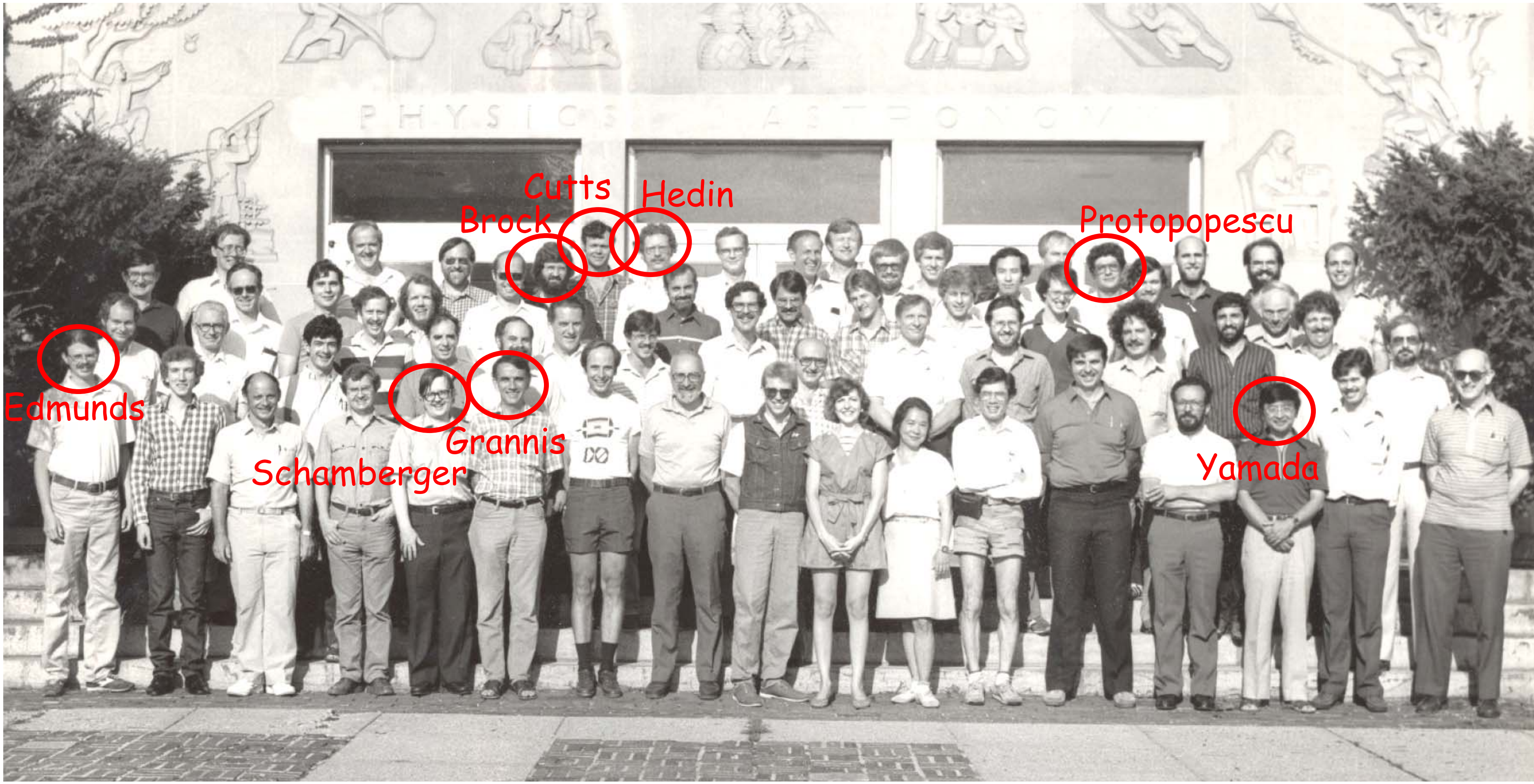

Fig. 7.3




Calorimeter preamp shaping electronics prototypes

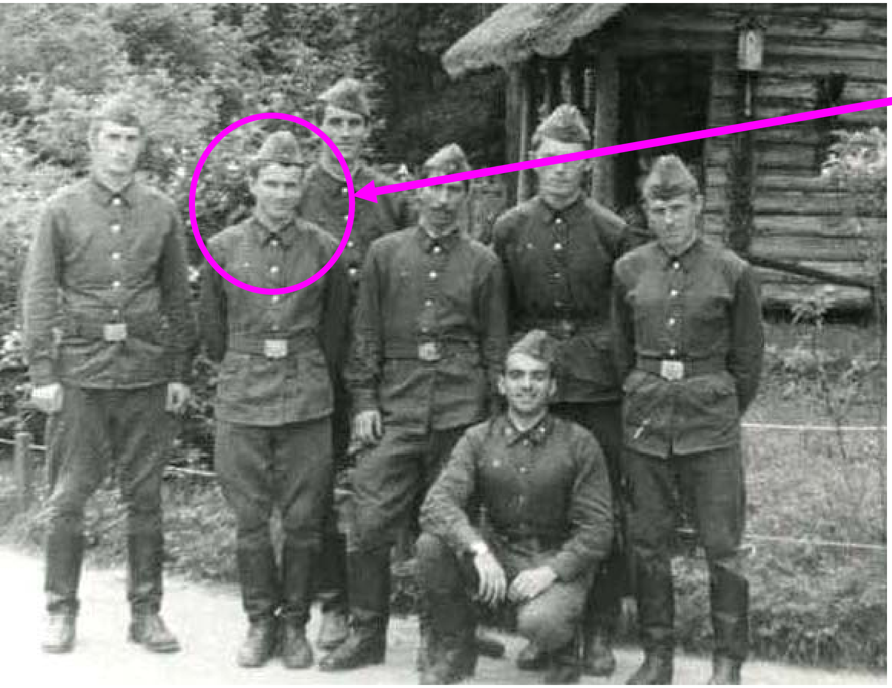
# 1984 MSU Workshop

# 1984 MSU Workshop



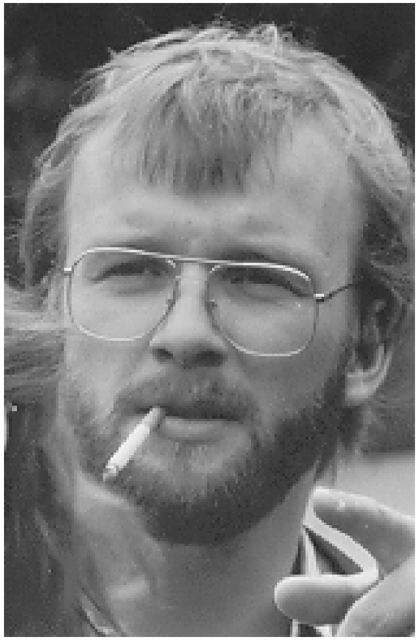

For some there has been a noticeable aging process.

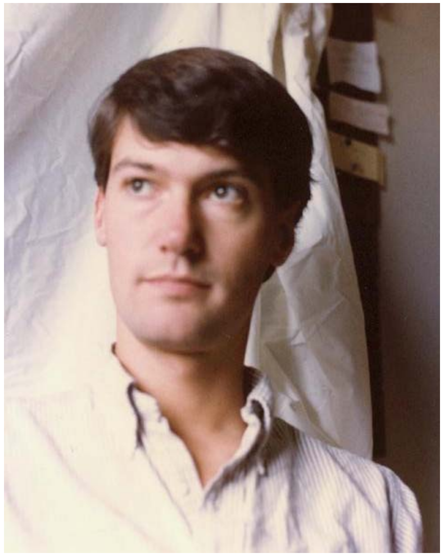
But if you think <u>we</u> looked young, what about the babies now running DØ, as seen in 1984 ?



Dmitri Denisov in USSR boot camp

Dashing Stefan Soldner-Rembold, old enough to have a beard





Darien Wood in grad school in Berkeley

# 1984 Design Report

Now 91 members (added 20)

14 institutions
(add Rochester, LBNL, Saclay;
drop Arizona)


THE DO COLLABORATION

S. Aronson, B. Gibbard, H. Gordon, W. Guryn, S. Kahn, M. Month, M. Murtagh,
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University of Pennsylvania

T. Ferbel, F. Lobkowicz, and P. Slattery
University of Rochester

Y. Ducros, R. Hubbard, P. Mangeot, B. Mansoulié, J. Teiger,
H. Zaccone, and A. Zylberstejn
CEN Saclay

M. Adams, R. Engelmann, G. Finocchiaro, P. Grannis, D. Hedin, J. Kirz,
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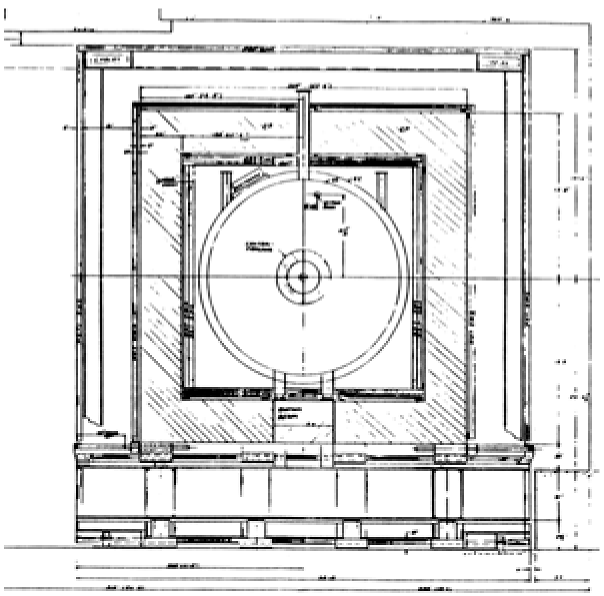
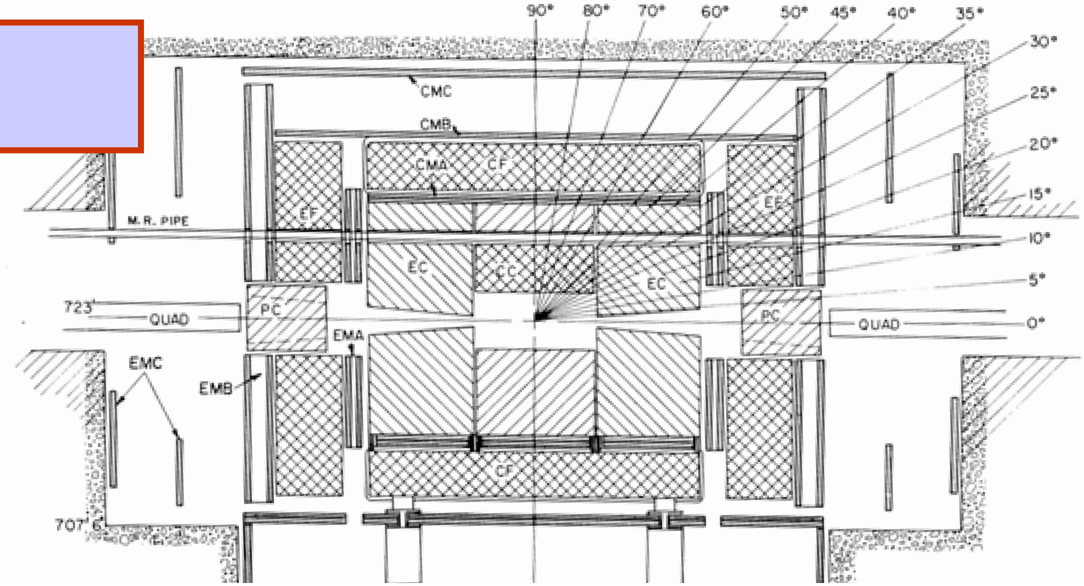
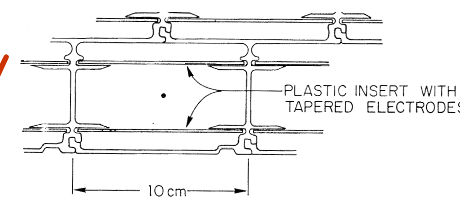
# 1984 DR muon



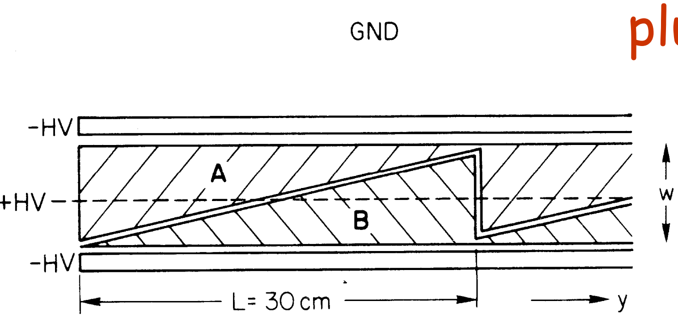



Still had plug calorimeter. Squared up the toroids (re-use Newport News cyclotron steel). Eliminated intermediate toroid. Detector rolls on movable platform.

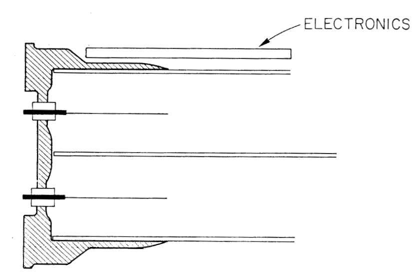
Ultimately plug cal replaced by plug toroid/muon detector




a.) INTERLOCKING EXTRUDED CELLS



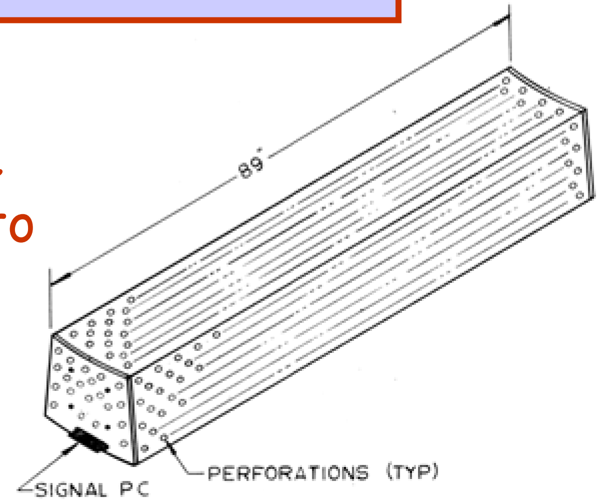

Muon PDT cells, with vernier pads for z-coordinate. PDT placement about as built.

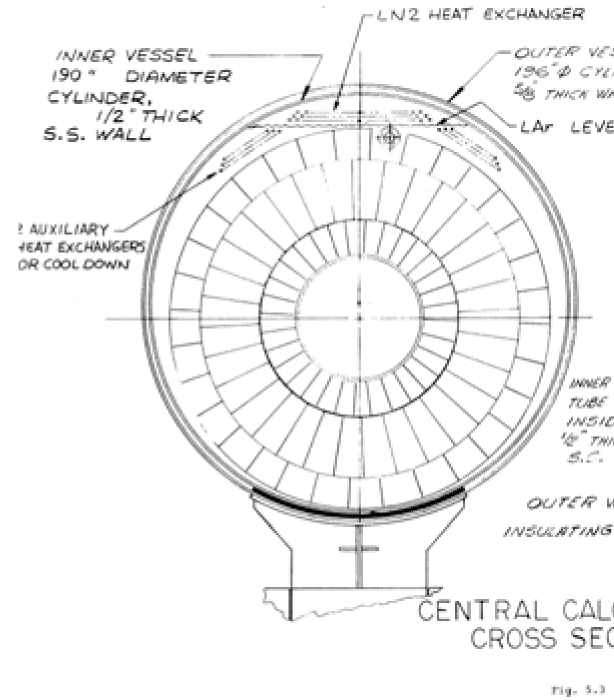


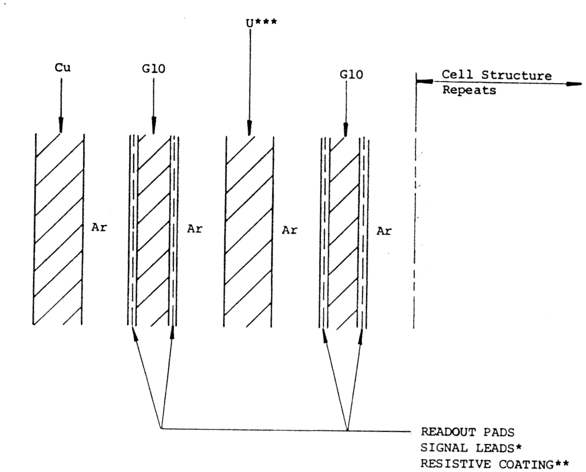

b.) END EXTRUSION

# 1984 DR calorimeter

Calorimeter module design was similar to as built.

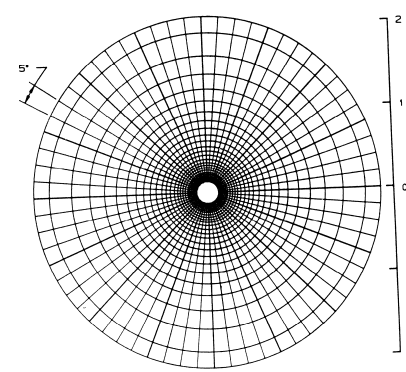


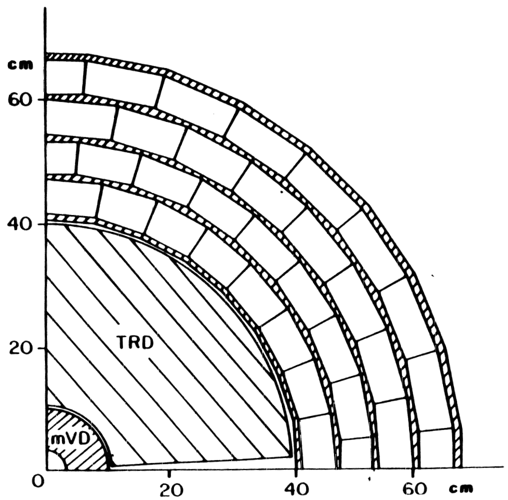

LAr readout structure defined: G10 readout boards with signal pads under resistive coat, signal boards for sending longitudinally ganged signals.

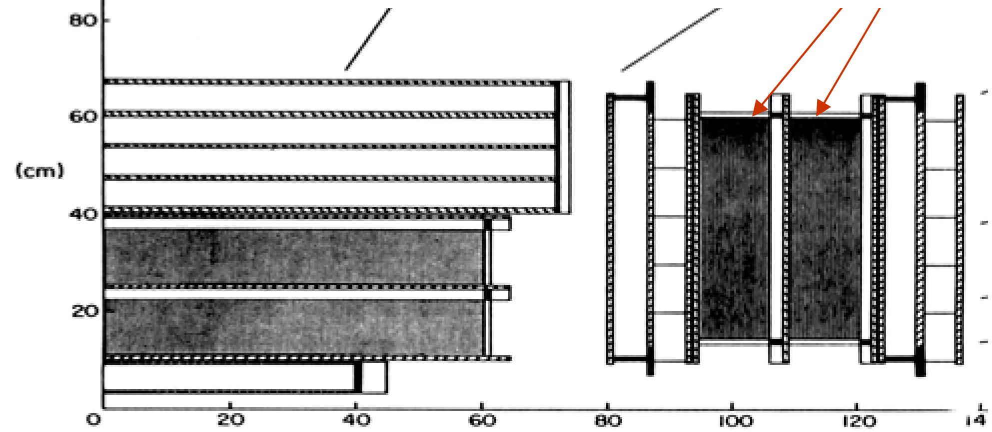
Pad segmentation fixed



# 1984 DR tracking

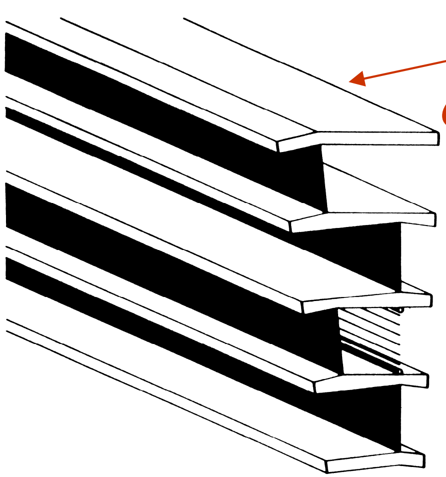
Run I tracking layout was as built apart from the forward TRD later dropped for lack of space (and large track density).

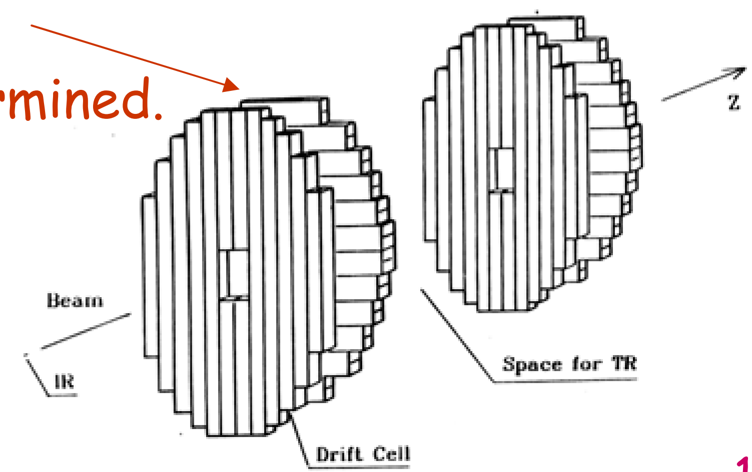



D0 Endcap Drift Chambers

CDC and FDC
cell structures determined.

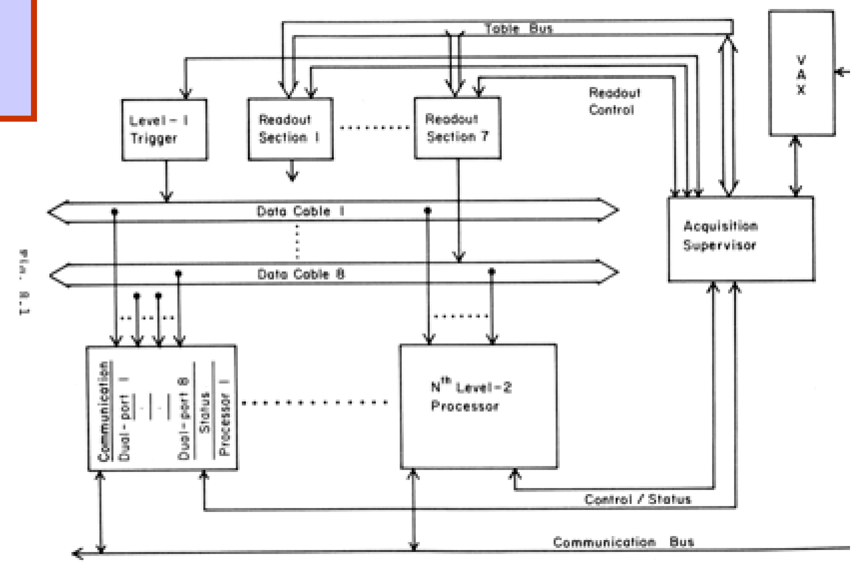




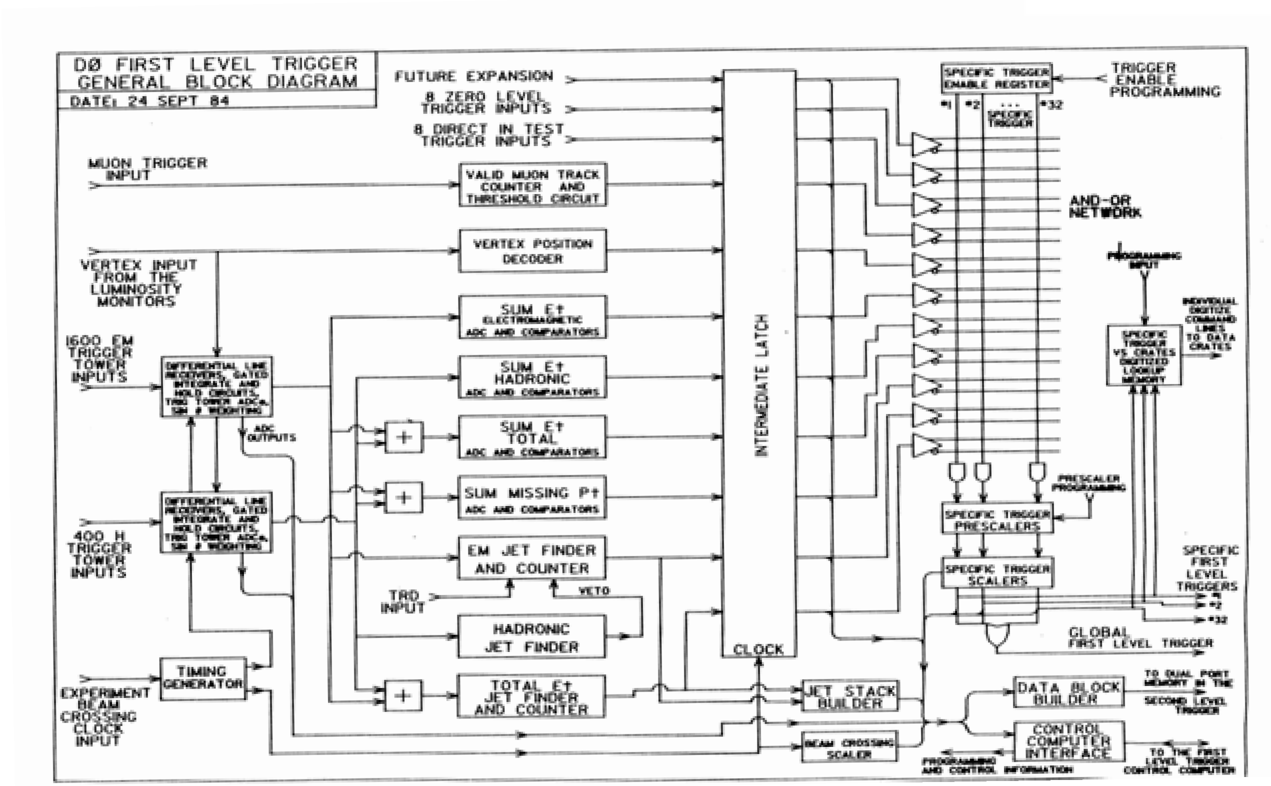
# 1984 DR trigger/DAQ

Level 0 interaction trigger +

2 level trigger and data acquisition design fixed




Processor-based Level 2 trigger and data acquisition.




Level 1 trigger (muon & calorimeter) block diagram.

# 1984 DOE Review

<u>November 1984 DOE review:</u>

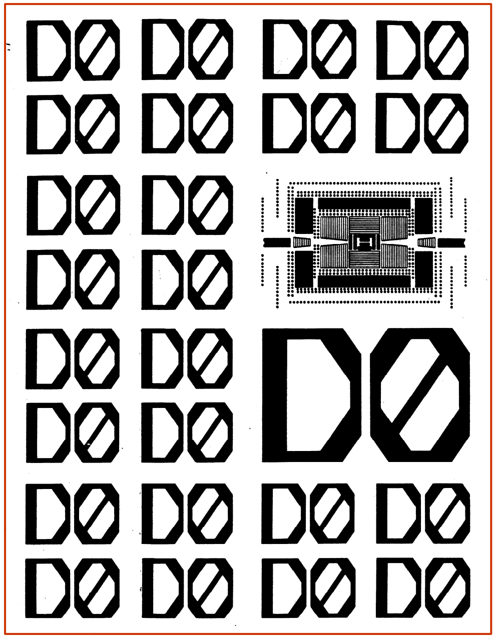
Gave baseline approval (equivalent to CD1 in today's DOE jargon).

Added contingency to the cost estimate.

Some funding started in FY1985.

About 4-5 years behind CDF

(CDF recorded first collisions at BØ early in 1985 with an unfinished detector; first physics run in 1987).




1984 Design Report cover – multiple 'DØ's

One collaborating institution said "Run by 1988 or we quit". First collisions were in April 1992 with this group still with us (and still with us today!)

# Physics Landscape in 1984

A decade of discovery!

1974: J/Ψ discovery (BNL/SLAC)

1975: SLAC/SPEAR: jets observed

1976: Open charm, tau discoveries (SPEAR)

1977: Upsilon discovery (FNAL)

1982: Open beauty meson discovery (CLEO)

1983: W/Z discoveries (CERN)

1984: High $p_T$ jets seen at UA2

UA1: Monojets (jets with large missing $E_T$) ??

UA1/UA2: anomalous $Z \rightarrow \ell^+ \ell^- \gamma$ ??

UA1: $W \rightarrow t\ b$ top evidence ??

Sidebar: T. Wyatt's first UA1 assignment was to 'confirm' the 40 GeV top quark discovery in the new data sample - which he failed utterly to do (for good reason ! ).

H. Montgomery to Terry on the occasion of 2007 DØ evidence for single top: "Well, you killed the last single top signal. I hope you worked hard to try to kill this one!"

There was a sense of excitement and discovery in the air.
Scepticism about tantalizing fluctuations was largely suspended.

# DØ Physics Program (Run 1)

DØ central goal was to explore high $p_T$ phenomena with three major themes:

1. Precision tests in the intermediate vector boson sector
2. High pT studies of QCD through jets and photons
3. Searches beyond the Standard Model

- Top quark, b-physics, Higgs search were not mentioned.

Physics studies assumed a run at $\mathcal{L} = 1 \times 10^{30}$ $cm^{-2}$ $s^{-1}$ each year for 5 $pb^{-1}$ (~1500 $Z \rightarrow ee$, 15,000 $W \rightarrow e\nu$). We probably imagined about three years of running. John Peoples: "Tevatron cannot exceed $\mathcal{L} > 3 \times 10^{30}$ ".

In the end, 3.5 years Run I netted 120 $pb^{-1}$ and peak $\mathcal{L} = 2 \times 10^{31}$. But the 1984 Design Report was remarkably optimistic on trigger/selection efficiencies, and was quite cavalier in documenting expected precisions. One would not get away with this today!

# Des. Rept Program: W/Z physics

1. W and Z masses: Design report outlined W mass methods – the newly-devised transverse mass, and from the W/Z ratio by ignoring one lepton from Z and measuring the transverse mass distribution for each.

   Estimated $\delta M_W \sim 400$ MeV via transverse mass (achieved 84 MeV in Run 1 !!) $\sin^2\theta_W = 0.0025$ (syst limited; radiative corrections, energy scale; top quark effects).

2. Z and W width. $\Gamma_Z$ constrains $N_\nu$ (at the time, $N_\nu < 44$!)

   $\delta\Gamma_Z \sim 130$ MeV $\rightarrow \delta N_\nu \sim 0.7$. $\delta\Gamma_W \sim 200$ MeV would constrain low mass top (expect $W \rightarrow tb$ but little $Z \rightarrow tt$ ; recall top mass of 30 - 40 GeV was indicated then).

3. Narrow states ($Z \rightarrow X\gamma$) (UA1/UA2 had seen several unexpected $ee\gamma$ & $\mu\mu\gamma$ events so there was a prospect for new states.)

   Use longitudinal EM cal segmentation to distinguish $\gamma$ and $\pi^0$ ($2\gamma$).

# Des. Rept Program: W/Z physics

1. W and Z masses: Design report outlined W mass methods – the newly-devised transverse mass, and from the W/Z ratio by ignoring one lepton from Z and measuring the transverse mass distribution for each.

   Estimated $\delta M_W$ ~ 400 MeV via transverse mass (achieved 43 MeV in 1 fb$^{-1}$ !!) $\sin^2\theta_W$ = 0.0025 (syst limited; radiative corrections, energy scale; top quark effects).

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**LEP/SLC did $\Gamma_Z$ ; left $\Gamma_W$ for Tevatron/LEP2**

3. Narrow states (Z→Xγ) (UA1/UA2 had seen severa eeγ & μμγ events so there was a prospect for new s

   Use longitudinal EM cal segmention to distinguish γ

**didn't exist but used this trick for γ ID**

# Des. Rept Program: W/Z physics

4. Asymmetry in W production & decay: (only muons without solenoid)

   1% measurement in <cos$\theta$*>; measure pdf's.

5. Trilinear gauge boson couplings:

   Expect ~ 20 W($\ell\nu$) $\gamma$, establish WW$\gamma$ coupling. Pious hope to see effect of the radiation amplitude zero!

6. W/Z production cross sections

   Small-x parton distribution functions; $p_T$ distribution in W+jet production to probe $\alpha_S(Q^2)$

7. W/Z$\rightarrow$ qq

   Can observe "if QCD jet backgrounds controlled" (!!). Can flavor tag using semileptonic decays.

   Seek W $\rightarrow$ tb (150 events for $m_t$ = 60 GeV)

# Des. Rept Program: W/Z physics

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   1% measurement in <cosθ*>; measure pdf

**CDF with B field better in Run 1 ; DØ caught up in Run 2**

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**Got the RAZ only in Run 2**

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**Chutzpah! Only now might see Z → bb, W→qq**

# Des. Rept Program: QCD

1. Jet production; "observe jets up to 500 GeV"; probe high $q^2$ QCD; look for compositeness through deviations.

2. Ratio of 3 to 2 jets: measure $\alpha_S(q^2)$

3. Ratio qqg/ qq$\gamma$: Measure $\alpha_S/\alpha_{EM}$ Separate single photons from $\pi^0$, $\eta$, $\omega$ through the distribution of first conversion points in CCEM.

4. Diphoton production: complementary parton structure info to Drell Yan dilepton.

5. Quark gluon plasma: Observe by excess $\gamma/\pi$ ratio at low $E_T$ (~100 MeV !!)

# Des. Rept Program: QCD

1. Jet production; "observe jets up to 500 GeV"; probe high $q^2$ QCD; look for compositeness through deviations.

**No $\alpha_s$ in Run 1; theory not controlled. Only in Run 2 did we get $\alpha_s$**

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**Insufficient energy density**

5. Quark gluon plasma: Observe by exces (~100 MeV !!)

# Des. Rept Program:  New Phenomena

1. Heavy W/Z:  sensitivity – Z' to 230 GeV;  W' to 150 GeV.

2. Heavy leptons:  $W \rightarrow L^{\pm}\,\nu_L$ or $Z \rightarrow L^{+}\,L^{-}$.

3. SUSY:  $p\bar{p} \rightarrow \tilde{g}\tilde{g}X$ ($\tilde{g} \rightarrow q\bar{q}\tilde{\gamma}$) should reach m(gluino)~ 100 GeV. Seek C-non-invariant $\tilde{g} \rightarrow g\tilde{\gamma}$

4. Heavy quarks <u>beyond top</u>; if inaccessible in $W \rightarrow Q_u\,Q_d$, seek $Q \rightarrow W\,q$ up to $m_Q$ = 120 GeV in a six-jet final state.

5. Discover toponium up to 55 GeV (we still expected bound state of  t tbar)

6. Technicolor: Techni-eta to 250 GeV;  Leptoquarks to 150 GeV.

7. UA1/UA2 anomalies:   Monojets;   $Z\,\ell^{+}\,\ell^{-}\,\gamma$;   $\gamma$ + MET; dijet bumps; anomalous multi-muons …   A whole zoo seemed waiting to be explored.

# Des. Rept Program: New Phenomena

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**LEP got there first**

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**Did it, but it was top**

5. Discover toponium up to 55 GeV (we still exp of t tbar)

**No bound toponium**

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7. UA1/UA2 anomalies: Monojets; $Z\,\ell^{+}\,\ell^{-}\,\gamma$; dijet bumps; anomalous multi-muons ... A who waiting to be explored.

**None of it was real**

# DØ Physics Program: Comments

❖ The stress on jets, leptons and missing $E_T$ paid off.

❖ Don't be too confident in predicting what you will do – Nature has devious ways.

❖ The possibility that top was very heavy was not foreseen. We were brainwashed by the successes of SPEAR and UA1 preliminary 'result'.

❖ The dominant role in Z physics that LEP was to play was not well understood (by us).

❖ The importance of b-tagging was underestimated. The possibility of important b-physics in a hadron collider was not articulated.

❖ No mention made of the Higgs. (lets fix that !)

❖ None of the UA1/UA2 zoo turned out to be real. The new physics terrain was more barren than we had hoped in the euphoric 1980's.

# 20-20 Hindsight

What might we have done differently?

I don't regret the initial non-magnetic design – Run I was successful, but the physics subsequently took us to a magnet in Run 2.

Choosing LAr gave us heartburn for years, but served us well (and we have even learned to deal with 400 ns bunch crossings in Run 2).

More tracking volume would have been good. DØ tracking has always been on the edge. The vertex drift chamber was almost unused (one study of J/$\Psi$ production by Indiana group). But the small radius allowed the superb calorimeter.

That damned main ring! Lost 10% of $\mathcal{L}$ due to blanking – never did find a clever detector to put in that hole in Run 2.

Lessons:

- You get to choose one very difficult detector challenge per experiment – biting off more is a recipe for disaster.
- Bright people and clever ideas can solve lots of problems.
- We were lucky that the Tevatron luminosity growth only came after DØ came on line.

# Final notes

- The broad outlines of the early DØ design were sound – stress on high $p_T$ physics with good lepton/parton recognition served us well.
- The detector worked well considering the ~100 fold increase in Run 1 accumulated luminosity over the expectations.
- The Design Rept. physics studies and detector simulations were extremely qualitative and crude by today's standards.
- Many of the physics objectives were addressed, and many new topics arose.
- The Run 2 upgrade we now know and love was actually proposed in 1990 before Run 1 began, with a much more detailed simulation and more careful scrutiny over 5 years!

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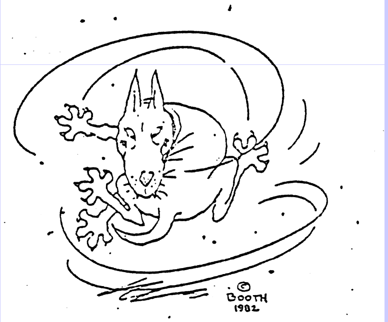
That beagle did have fleas, and we've been scratching hard for 27 years – a pretty good run.




Hope for more discoveries to come !