THE FERMILAB FIXED TARGET PROGRAM

6/7/17

Heidi Schellman
Oregon State University

My qualifications to give this talk

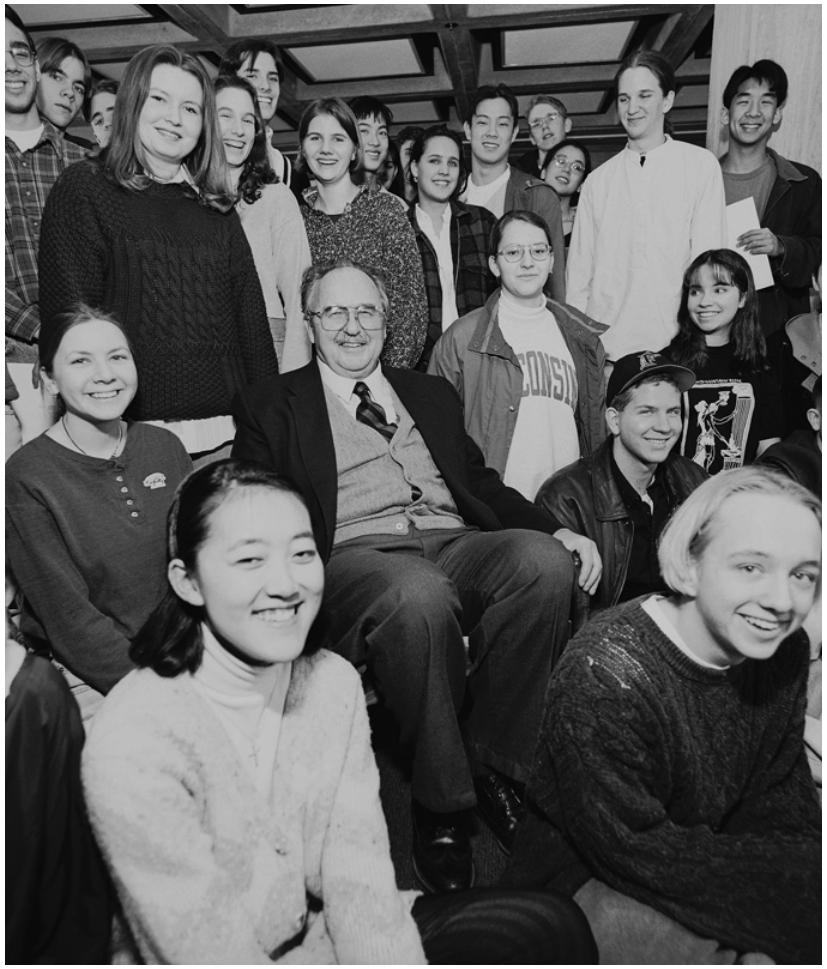
- I came to FNAL in early 1985 as a University of Chicago postdoc on the CCFR neutrino experiment
- I was a Wilson Fellow on the E665 muon scattering experiment
- I later worked on NuTeV and MINERvA alternating with the D0 experiment
- My knowledge of pre-TeVatron fixed target is limited to the historical record (Gallison etc.) and the oral tradition.

Outline

- The early days
- An aside on experiment #'s and series
- Upsilon
- TeV II overview
- Conclusions

Sources

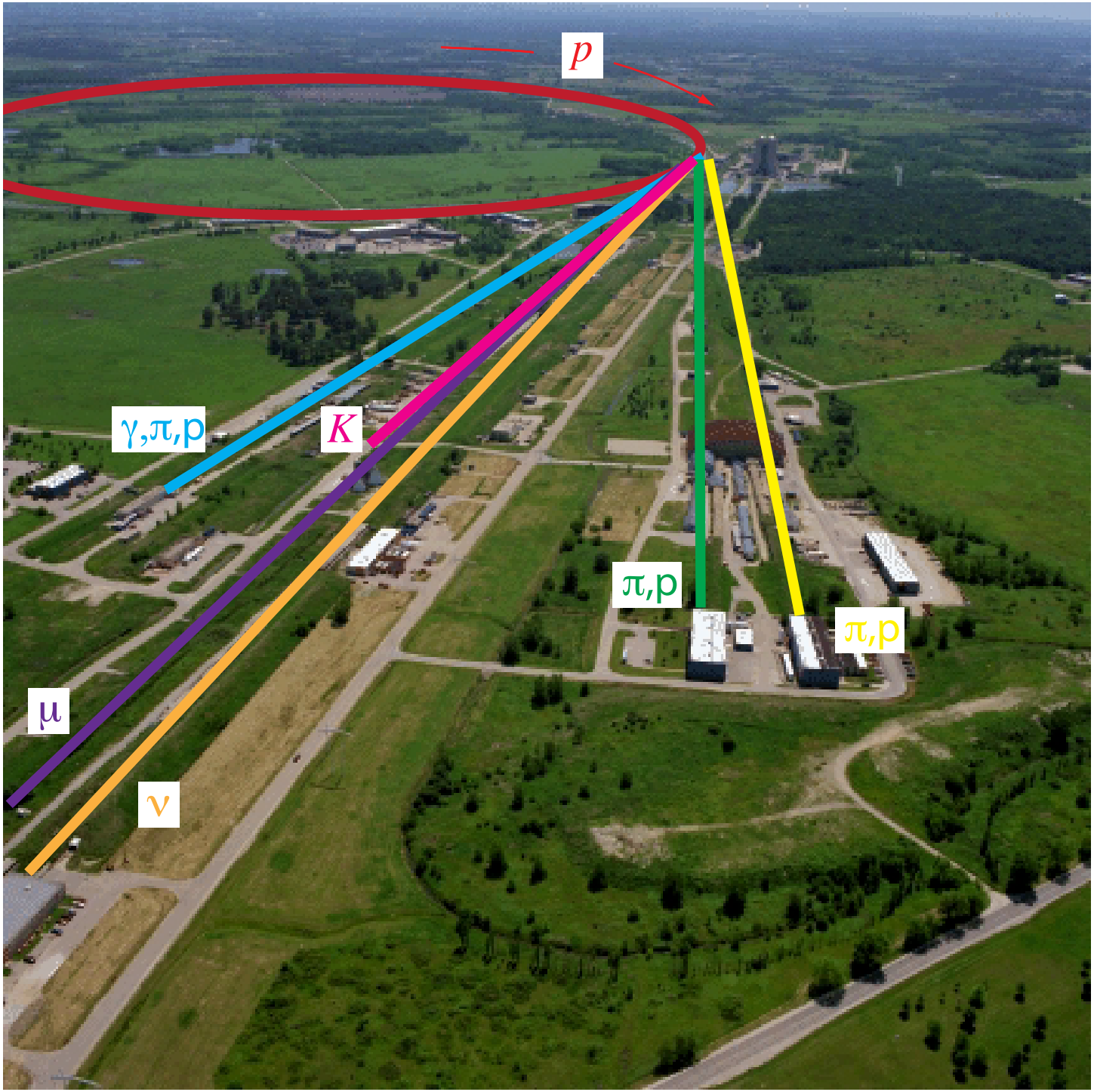
- Fermilab archives! Awesome resource
- Gallison's "How experiments end"
- INSPIRE list of experiments
- FNAL preprints/proposals/theses online
- http://conferences.fnal.gov/tevft/book/
- Visual Media Services
- Legends told by the elders (Drasko Yovanovitch)



Fixed Target

Every 20-60 sec ramp from 0-400/800 GeV

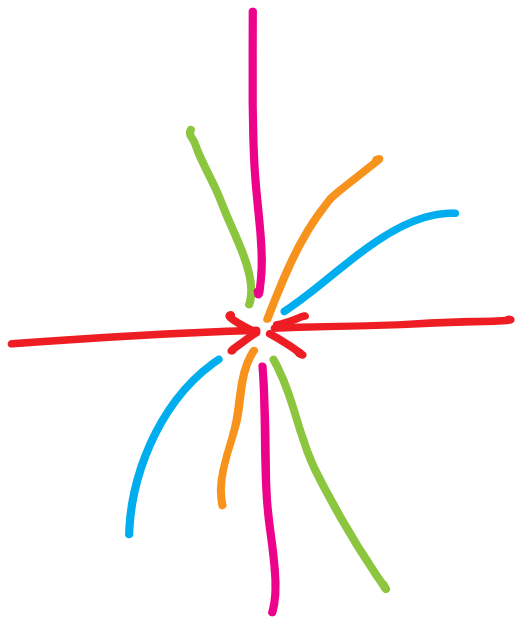
Deliver up to 3×10^{13} protons/cycle



Why fixed target?

Collider

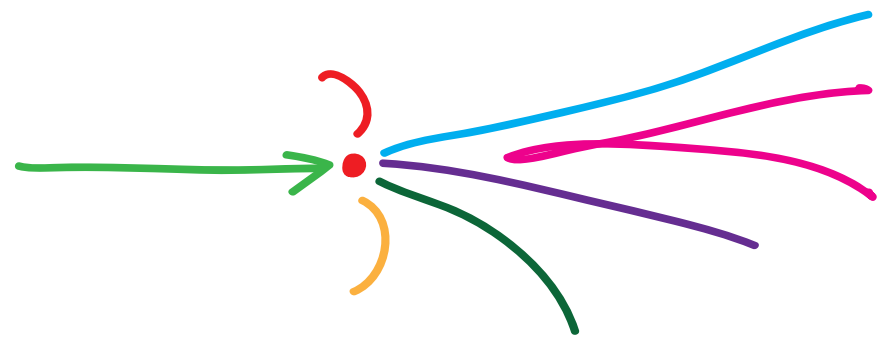
Tevatron I



$$E_{CM} \simeq 2E_{beam}$$

~1960 GeV

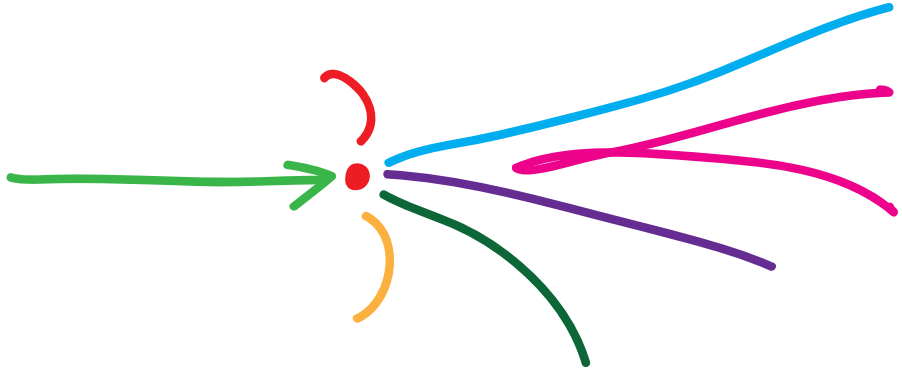
Fixed Target



$$E_{CM} \simeq \sqrt{2ME_{beam}}$$

~40 GeV TeV II

~ 30 GeV @500GeV



- Advantages
  - Higher Luminosity
    - 10^{13} p/min instead of 10^{13} pbar/day
    - $10^{36}/cm^2/sec$ vs $10^{34}/cm^2/sec$ @LHC
  - Longer, more flexible detector designs
  - Hot and cold running exotic particle beams
  - Smaller groups

Achievements

- Discovery – b quark and ν_τ, confirmation of neutral currents
- Nucleon spin and structure – anti-quarks and gluons
- QCD tests at many scales
- Fundamental constants (V_{us}, V_{dc}, α_S, θ_W,...)
- Charm Physics and new technologies
- CP violation and rare kaon decays
- Hyperons galore

Design phase 1968

Main Ring groundbreaking 1969

NAL PROPOSAL No. 1-A

Correspondent: D. Cline
Department of Physics
University of Wisconsin
Madison, Wisconsin

FTS/Commercial 608-262-5878

NAL NEUTRINO PROPOSAL

D. Cline, D. D. Reeder
Wisconsin

E. W. Beier, A. K. Mann
Pennsylvania

J. Pilcher, C. Rubbia
Harvard

June 1970

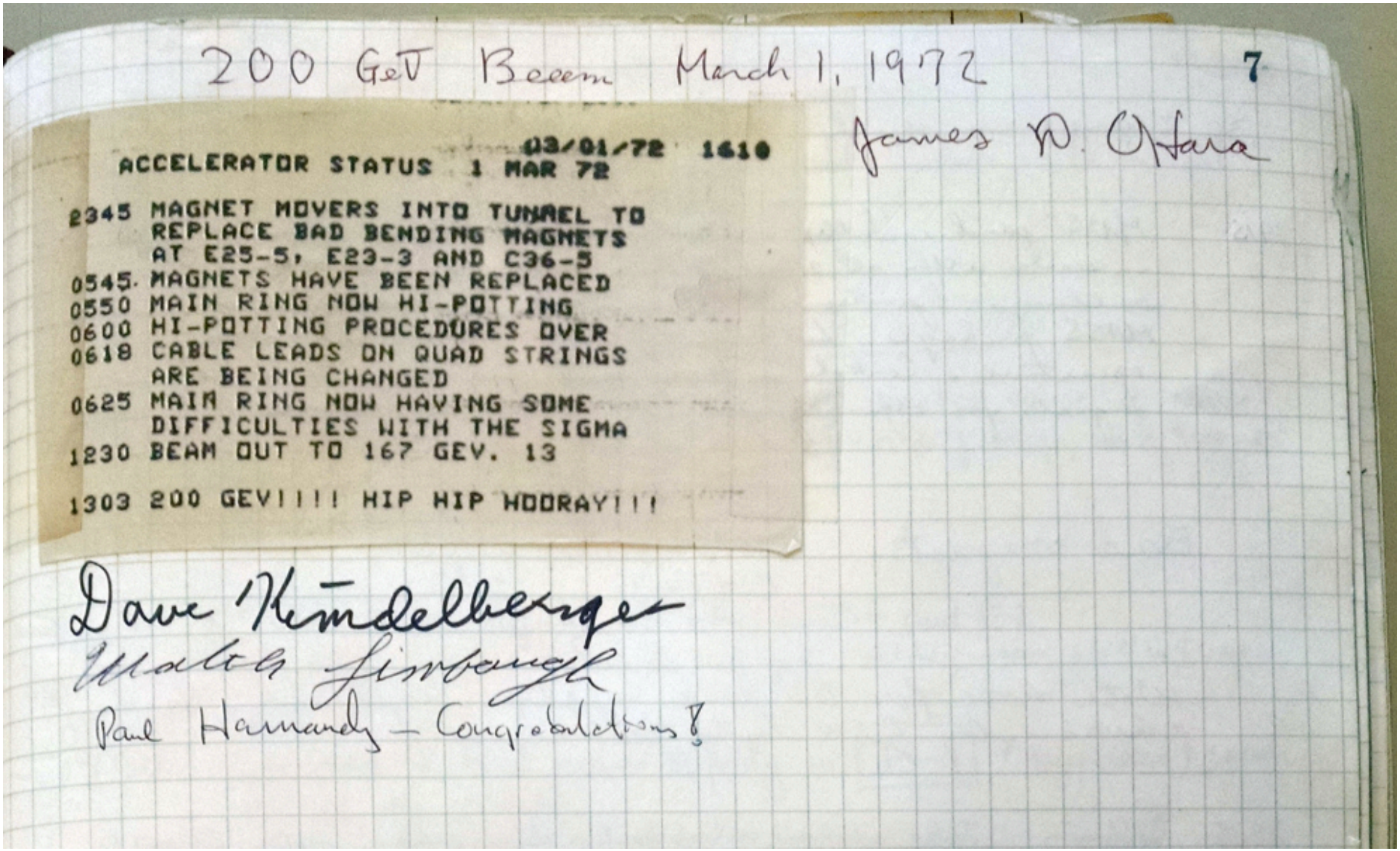
HARVARD - PENNSYLVANIA - WISCONSIN COLLABORATION*

NAL NEUTRINO PROPOSAL

ABSTRACT

We propose here an experiment, using neutrinos in the energy range 10 - 100 GeV, that will permit us to: (1) search for an intermediate vector boson W through the reaction $\nu_\mu + Z \rightarrow \mu^- + W^+ + Z$, up to a W mass of $\simeq$ 10 GeV/c^2 at 200 GeV operation of NAL; both the leptonic and hadronic decay modes will be detected; (2) measure the cross section for the diagonal 'point' four-fermion interaction $\nu_\mu + Z \rightarrow \mu^- \mu^+ \nu_\mu Z$; (3) measure $d^2\sigma/dq^2 d(E_\nu - E_\mu)$ in the region $q^2 \rightarrow$ very large, $(E_\nu - E_\mu) \rightarrow$ very large, i.e., the deeply inelastic scattering region; (4) measure $d^2\sigma/dq^2 d(E_\nu - E_\mu)$ and $\sigma_{tot}(E_\nu)$ for the reaction $\nu_\mu + p \rightarrow \mu^- +$ (anything). The device that will be used to accomplish these experiments consists of a large hydrogen target, a heavy metal, fine-grained total absorption calorimeter and a large iron core magnet.

200 GeV Beam arrives



200 GeV Beam March 1, 1972 7

James D. O'Hara

03/01/72 1610

ACCELERATOR STATUS 1 MAR 72

2345 MAGNET MOVERS INTO TUNNEL TO
REPLACE BAD BENDING MAGNETS
AT E25-5, E23-3 AND C36-5
0545 MAGNETS HAVE BEEN REPLACED
0550 MAIN RING NOW HI-POTTING
0600 HI-POTTING PROCEDURES OVER
0618 CABLE LEADS ON QUAD STRINGS
ARE BEING CHANGED
0625 MAIN RING NOW HAVING SOME
DIFFICULTIES WITH THE SIGMA
1230 BEAM OUT TO 167 GEV. 13

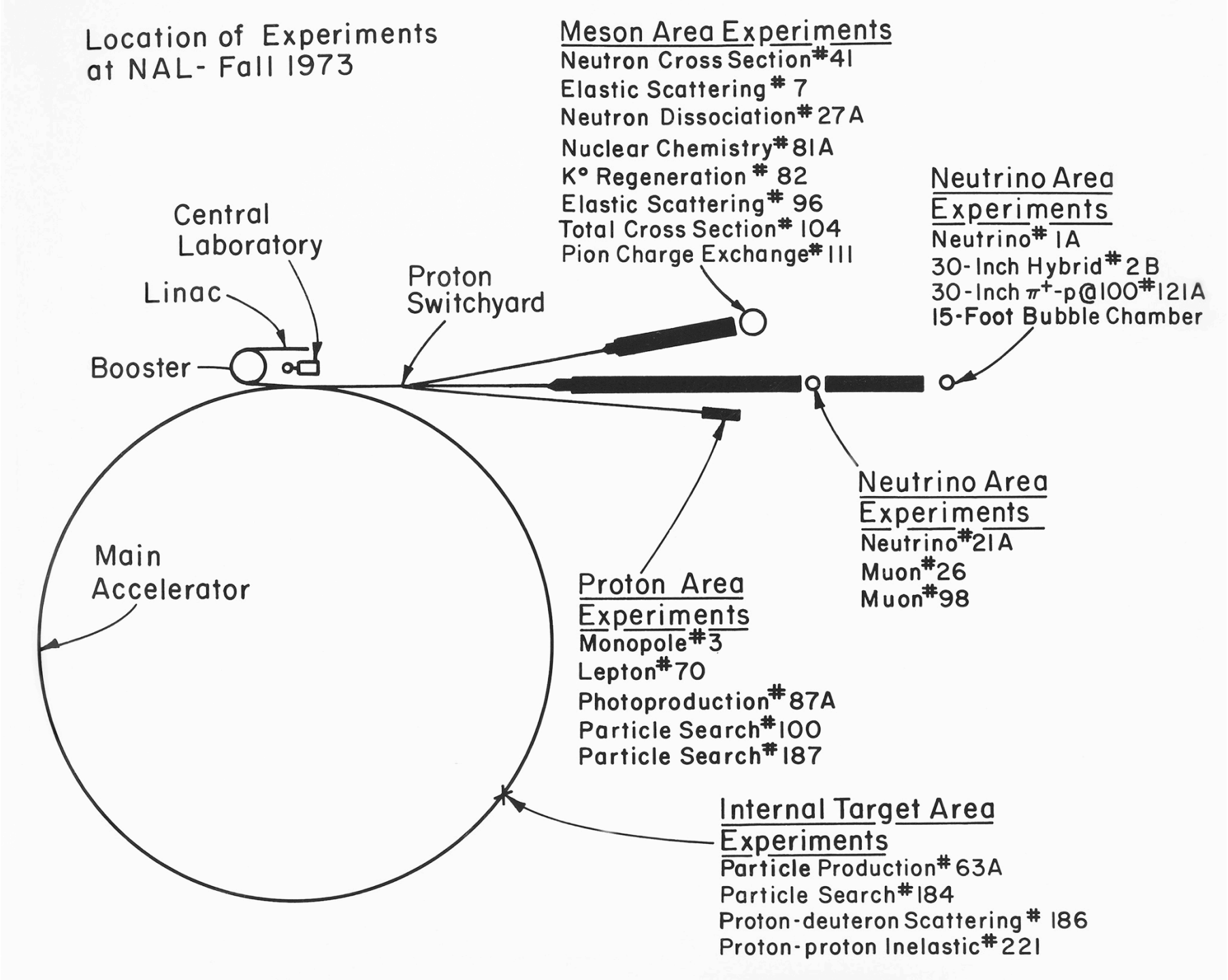
1303 200 GEV!!!! HIP HIP HOORAY!!!

Dave Kindelberger

Walter Limbaugh

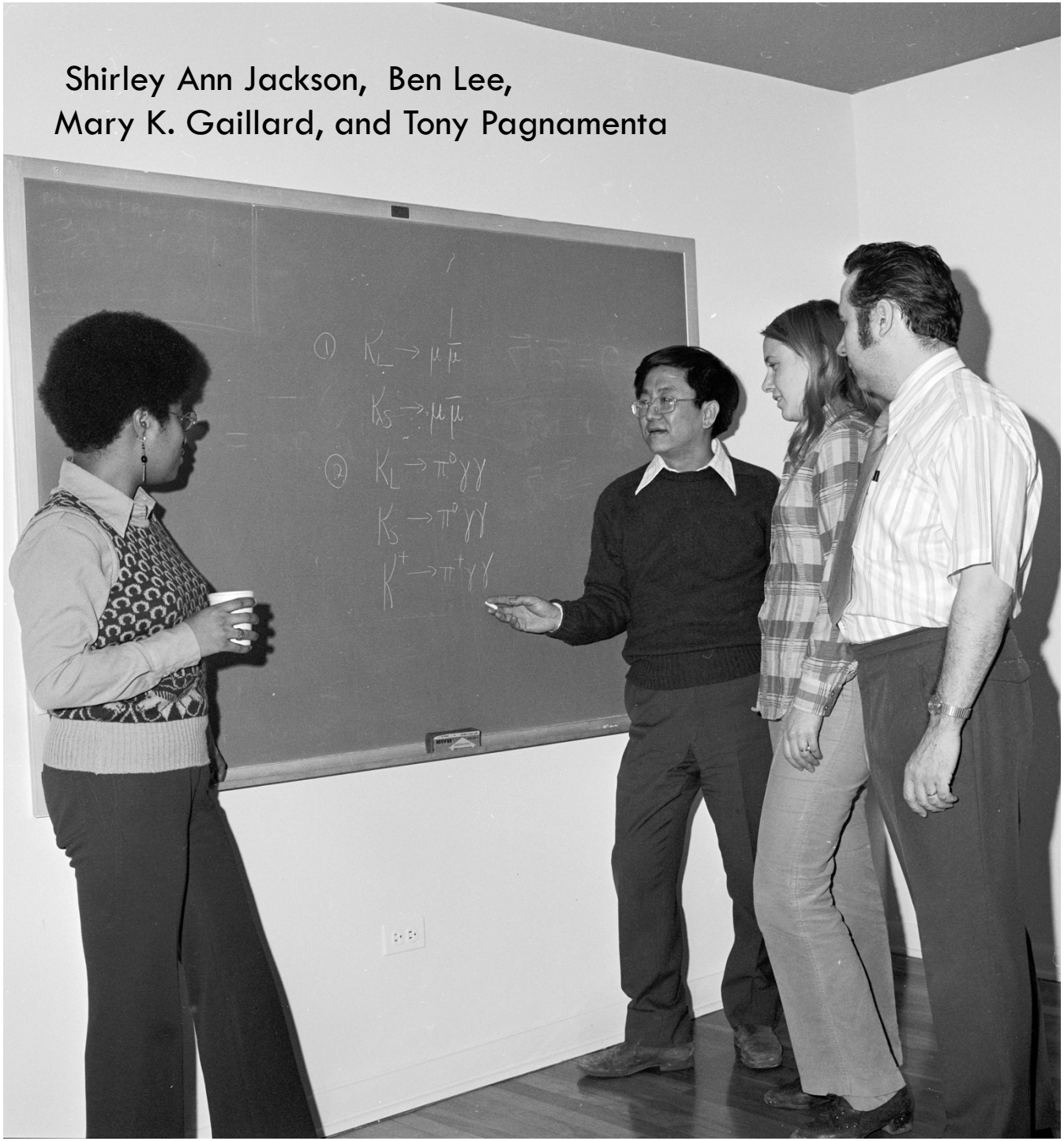
Paul Harnandy – Congratulations!

Neutrino Area construction 1973
HERLIHY

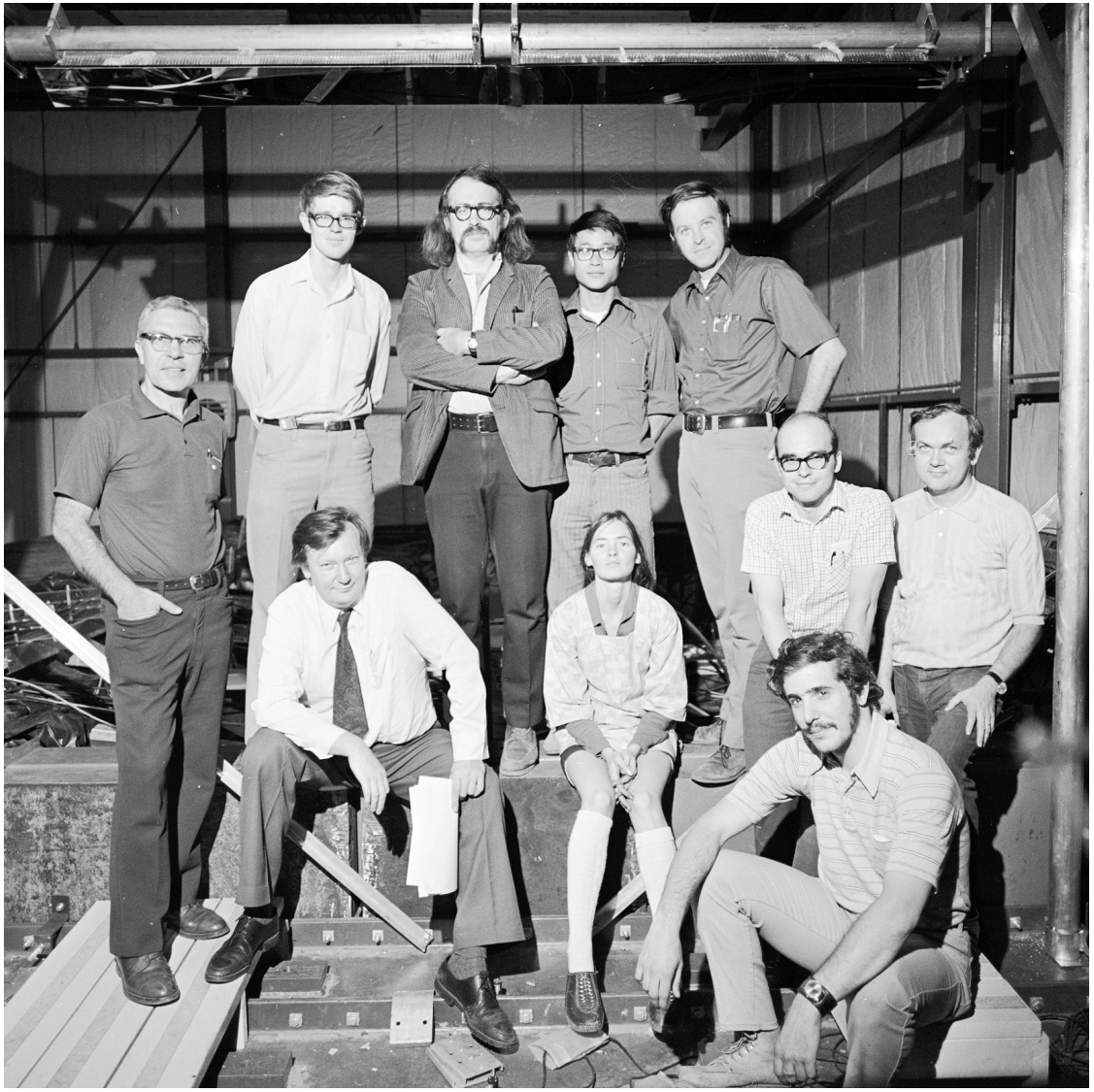

Location of Experiments
at NAL- Fall 1973
Meson Area Experiments
Neutron Cross Section #41
Elastic Scattering # 7
Neutron Dissociation # 27A
Nuclear Chemistry # 81A
K° Regeneration # 82
Elastic Scattering # 96
Total Cross Section # 104
Pion Charge Exchange # 111
Neutrino Area
Experiments
Neutrino # 1A
30-Inch Hybrid # 2B
30-Inch π^+-p@100 # 121A
15-Foot Bubble Chamber
Central
Laboratory
Linac
Booster
Proton
Switchyard
Main
Accelerator
Neutrino Area
Experiments
Neutrino # 21A
Muon # 26
Muon # 98
Proton Area
Experiments
Monopole # 3
Lepton # 70
Photoproduction # 87A
Particle Search # 100
Particle Search # 187
Internal Target Area
Experiments
Particle Production # 63A
Particle Search # 184
Proton-deuteron Scattering # 186
Proton-proton Inelastic # 221

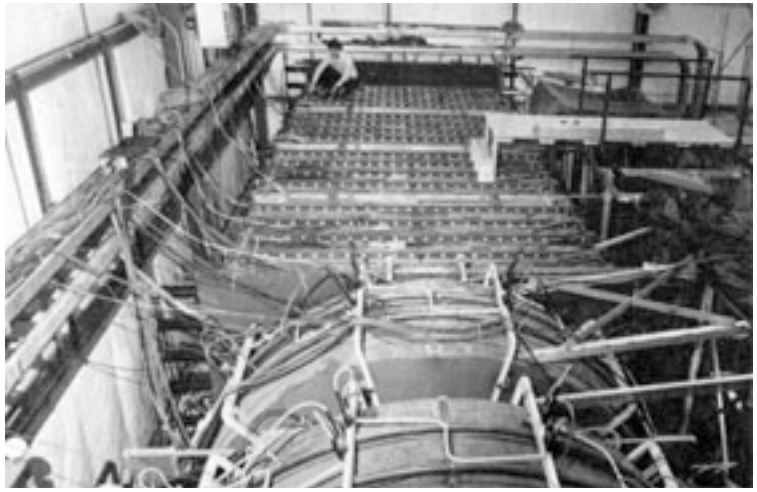
Raise the energy to 400 GeV

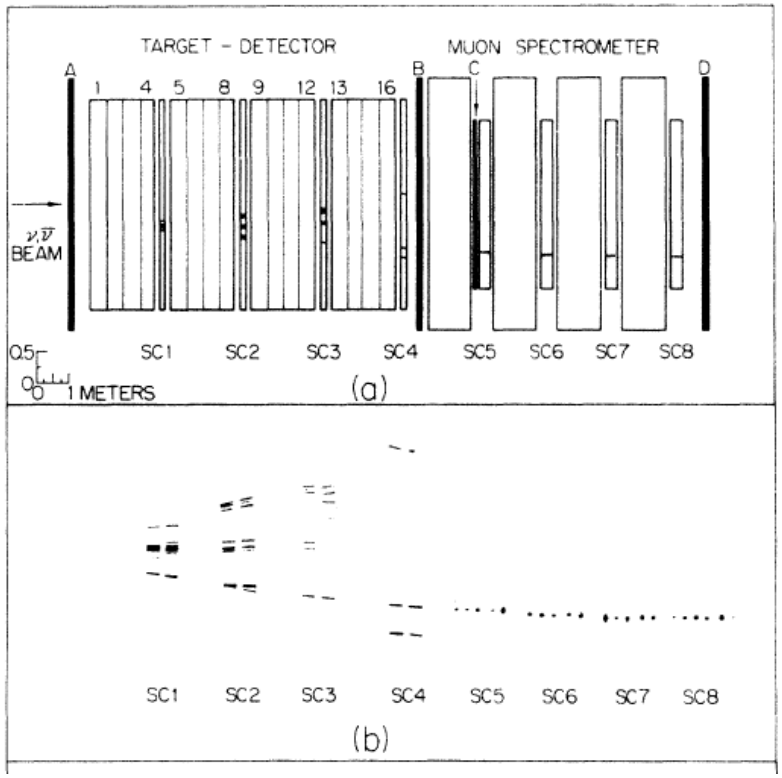
THEORY GROUP 1974



Fermilab Dedication 1974







E1A Collaborators in 1973

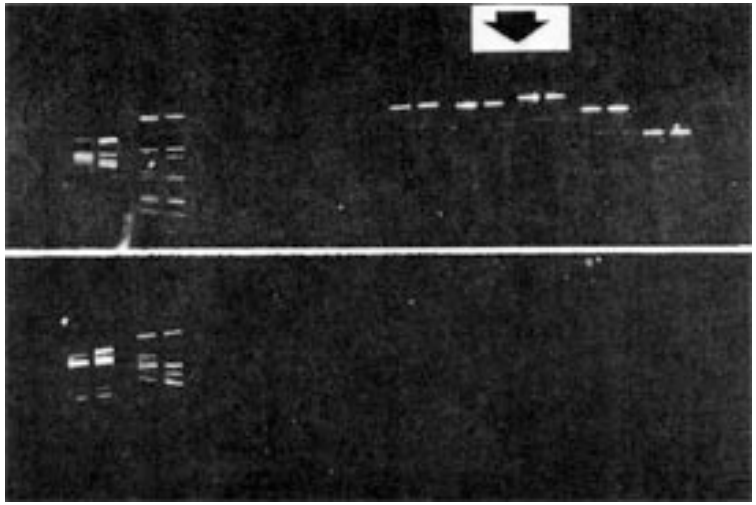
Observation of Muonless Neutrino-Induced Inelastic Interactions

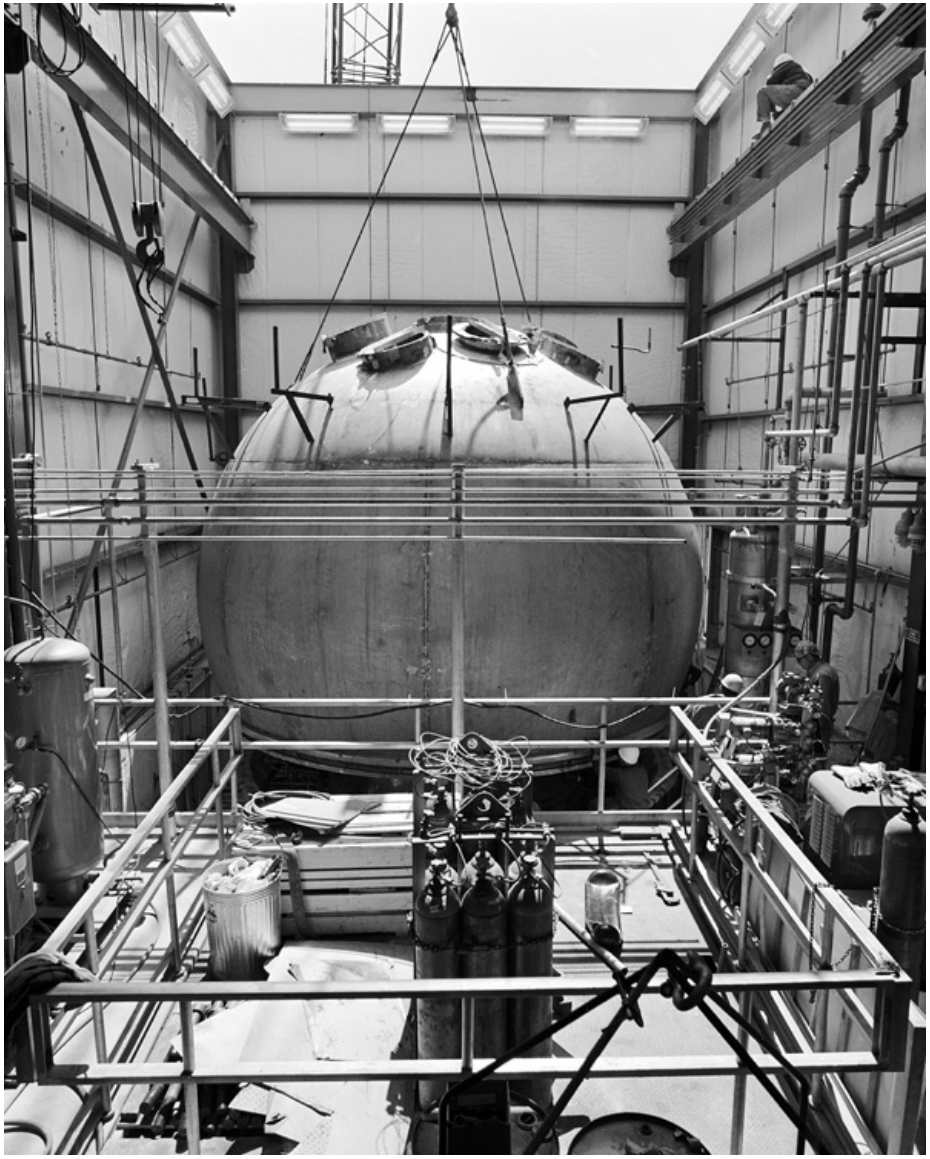
A. Benvenuti, D. C. Cheng,* D. Cline, W. T. Ford, R. Imlay, T. Y. Ling, A. K. Mann, F. Messing, R. L. Piccioni, J. Pilcher,† D. D. Reeder, C. Rubbia, R. Stefanski, and L. Sulak

Department of Physics, Harvard University,‡ Cambridge, Massachusetts 02138, and Department of Physics, University of Pennsylvania,‡ Philadelphia, Pennsylvania 19174, and Department of Physics, University of Wisconsin,‡ Madison, Wisconsin 53706, and National Accelerator Laboratory, Batavia, Illinois 60510

(Received 3 August 1973)

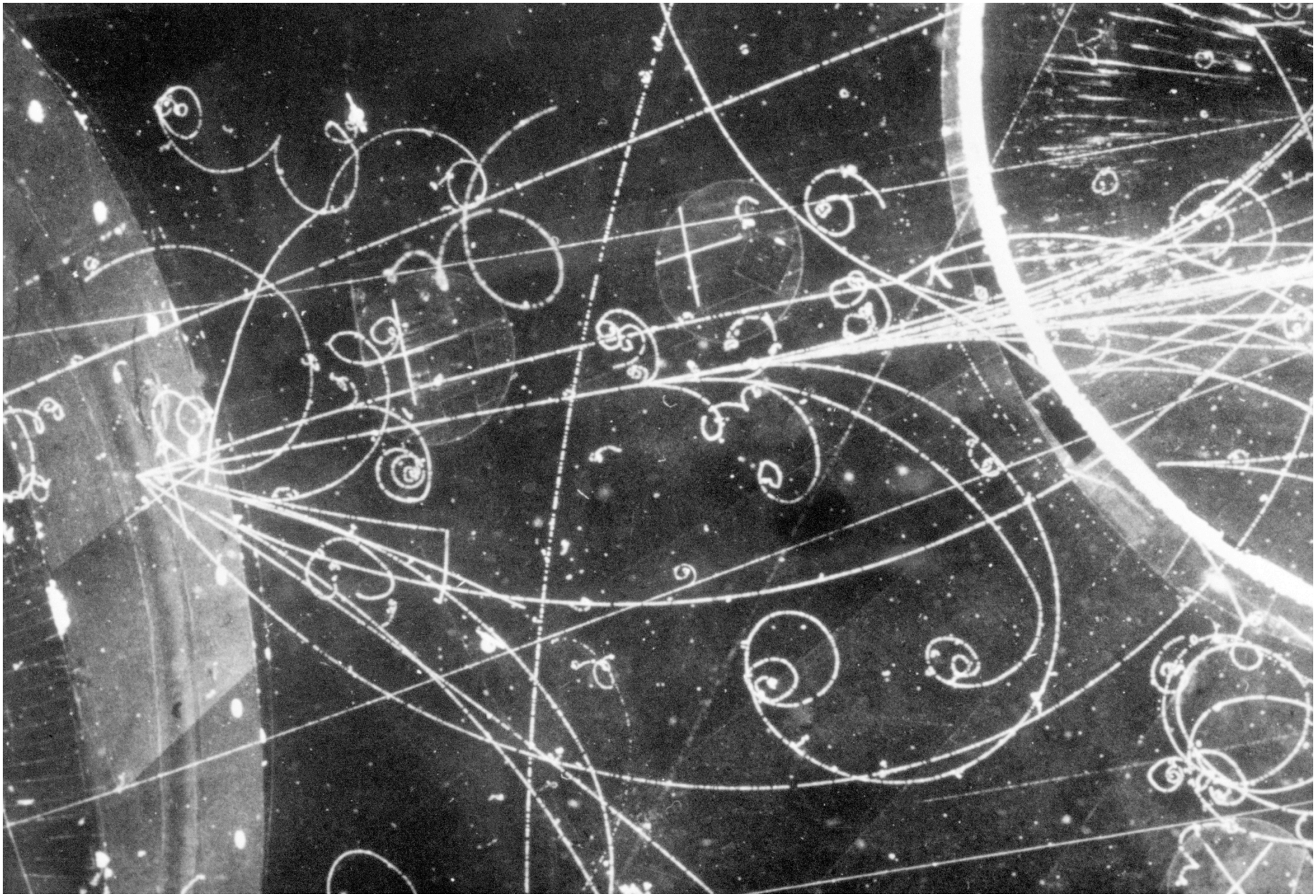
We report the observation of inelastic interactions induced by high-energy neutrinos and antineutrinos in which no muon is observed in the final state. A possible, but by no means unique, interpretation of this effect is the existence of a neutral weak current.





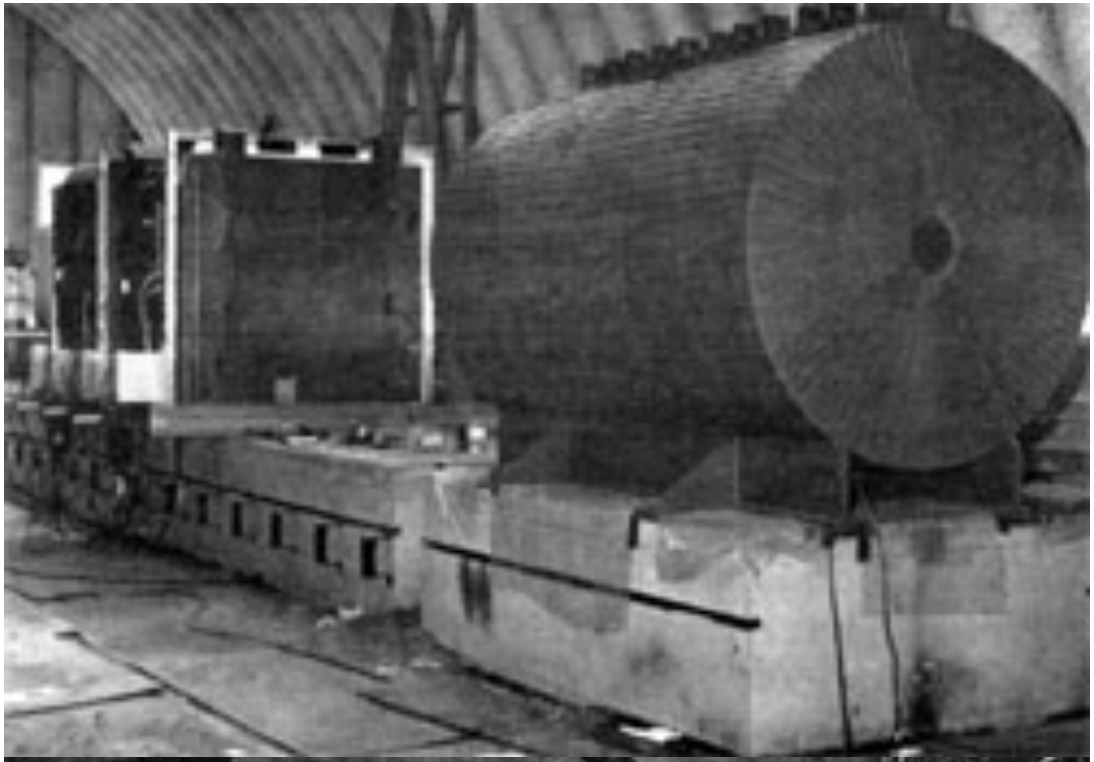
15’ Bubble chamber being assembled

Bubble Chamber experiments are still a major source of information on neutrino interactions



E21
Caltech-FNAL

Begat
CCFR
NuTeV



Neutrino begats

E21 | 356 | 482 | 616 | 701 | 744 770 | NuTeV

594 | 733

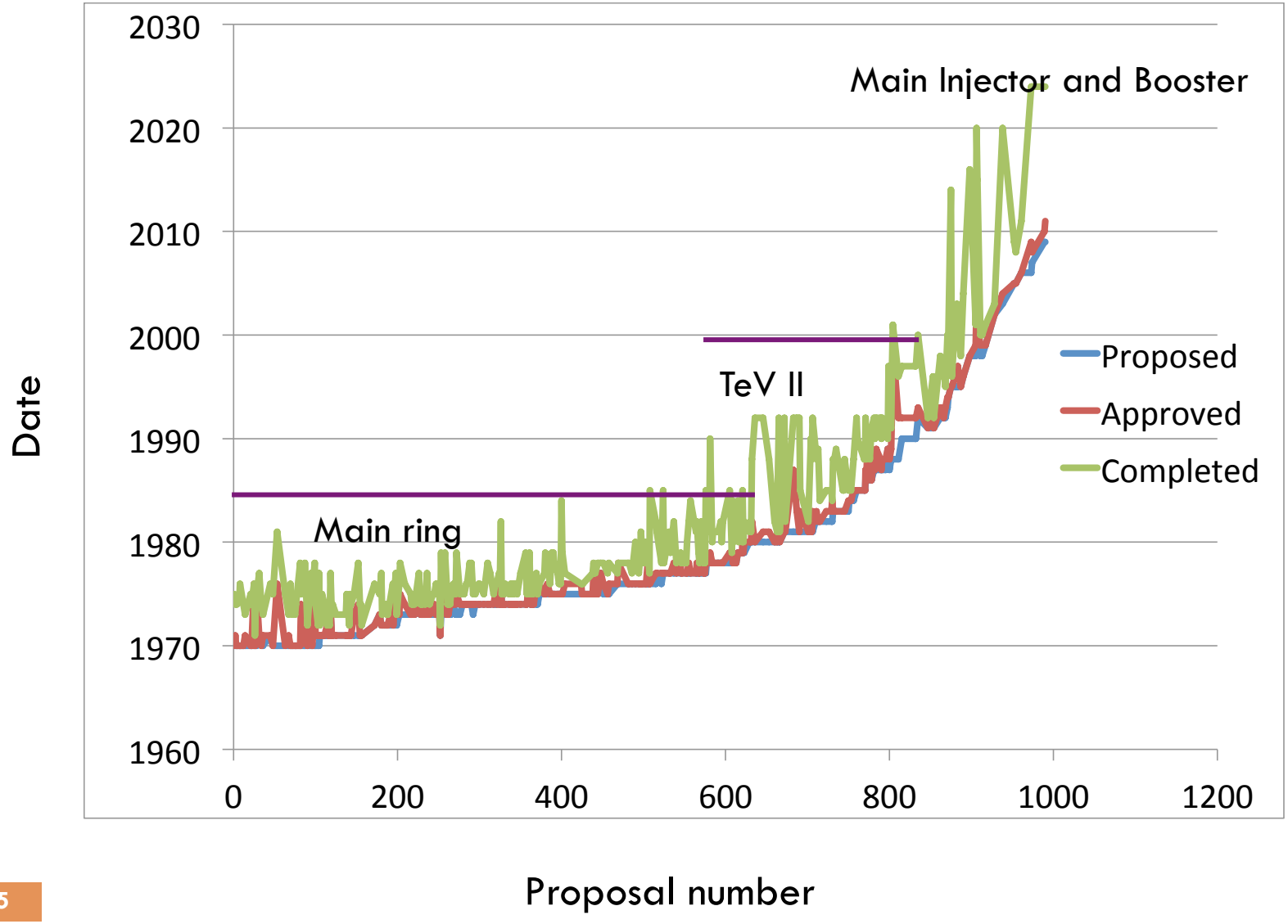
E1A | 255

DONuT

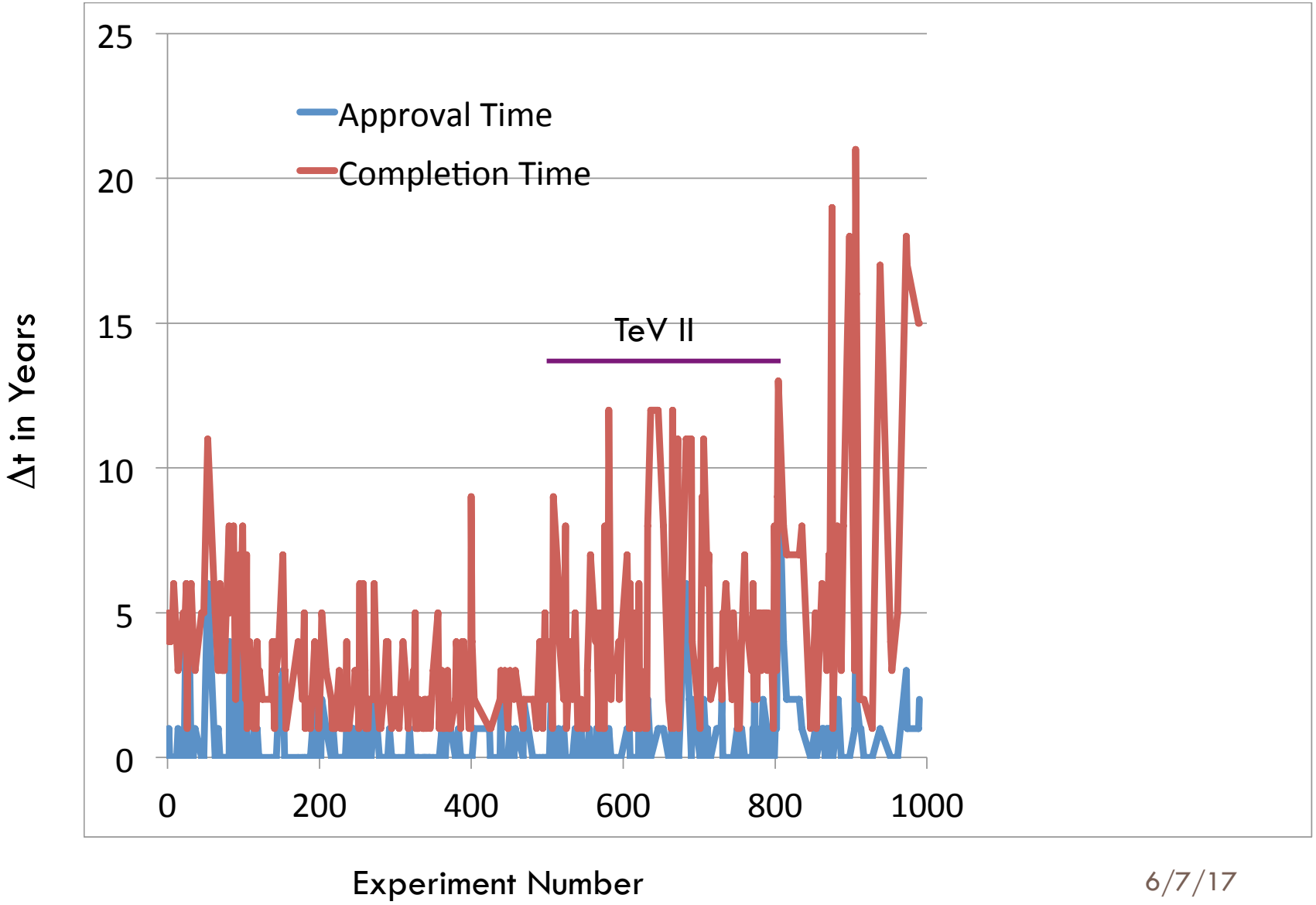
MINOS | MINERvA | NOvA

Mini BooNE | Sci BooNE | Micro BooNE

Fermilab Proposals 1-1000



Time scales


Approval Time
Completion Time
TeV II
Δt in Years
Experiment Number
0
5
10
15
20
25
0
200
400
600
800
1000

E288 proposal, Feb 1974

ADDENDUM TO PROPOSAL 70

"Study of Lepton Pairs from Proton-Nuclear Interactions;
Search for Intermediate Bosons and Lee-Wick Structure"

L.M. LEDERMAN, W. LEE, J. APPEL, D. SAXON

Columbia University, New York, N.Y.

M. TANNENBAUM, Harvard University, Cambridge, Mass.

L. READ, J. SCULLI, T. WHITE, T. YAMANOUCHI

National Accelerator Laboratory, Batavia, Ill.

3. Double Arm Study of Lepton Pairs. This is a larger aperture study of the continuum distribution of effective masses of the dilepton produced in (1). It is complementary to reactions of deeply inelastic scattering

$$e + p \rightarrow e + \text{anything} \tag{4}$$

and clashing e^+e^- beams

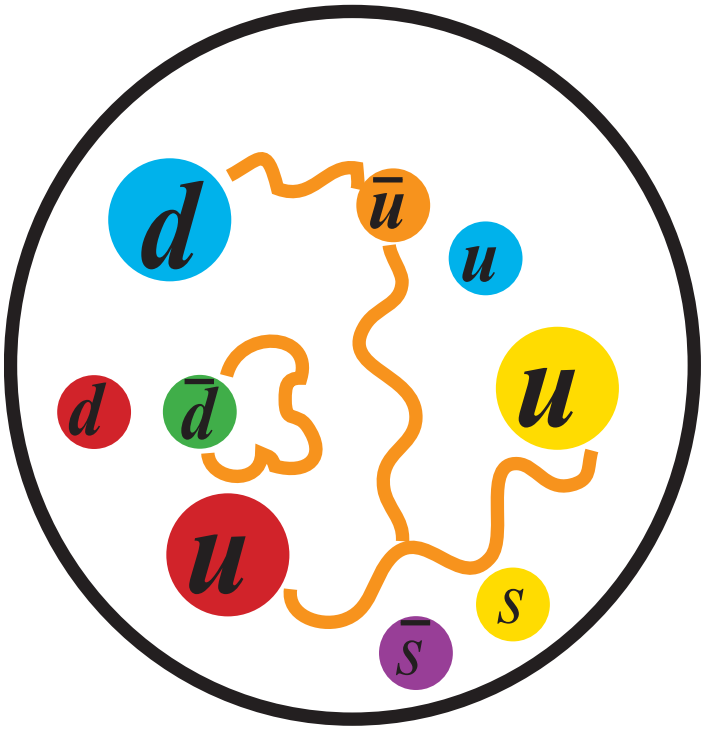
$$e^+ + e^- \rightarrow \text{anything} . \tag{5}$$

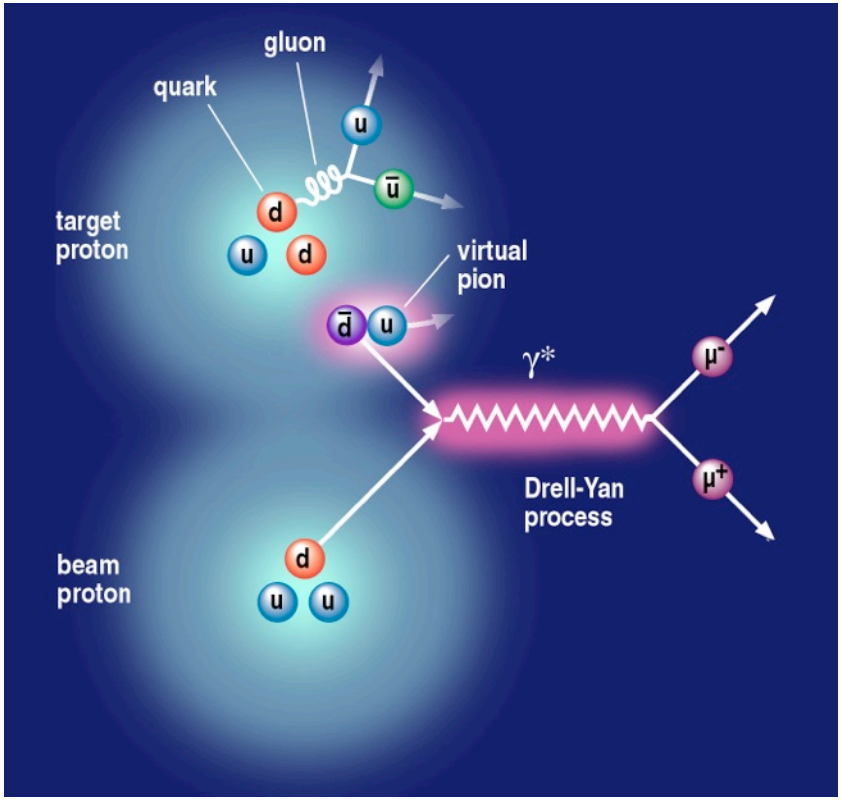
Recent theoretical analysis of (1) indicates that the rather special diproton initial state can be handled and the range of variables s and $m_{e^+e^-}^2$ far surpasses those available in the timelike "competition" of reaction (5).

The continuum serves also to "measure" the theoretical production cross section for weak charged bosons via the CVC arguments of Yamaguchi etc.

However, the major thrust is to search for new physics however weakly coupled to hadrons via the 1^- state we are studying. The larger apertures here would extend the sensitivity of the single arm search by an order of magnitude.

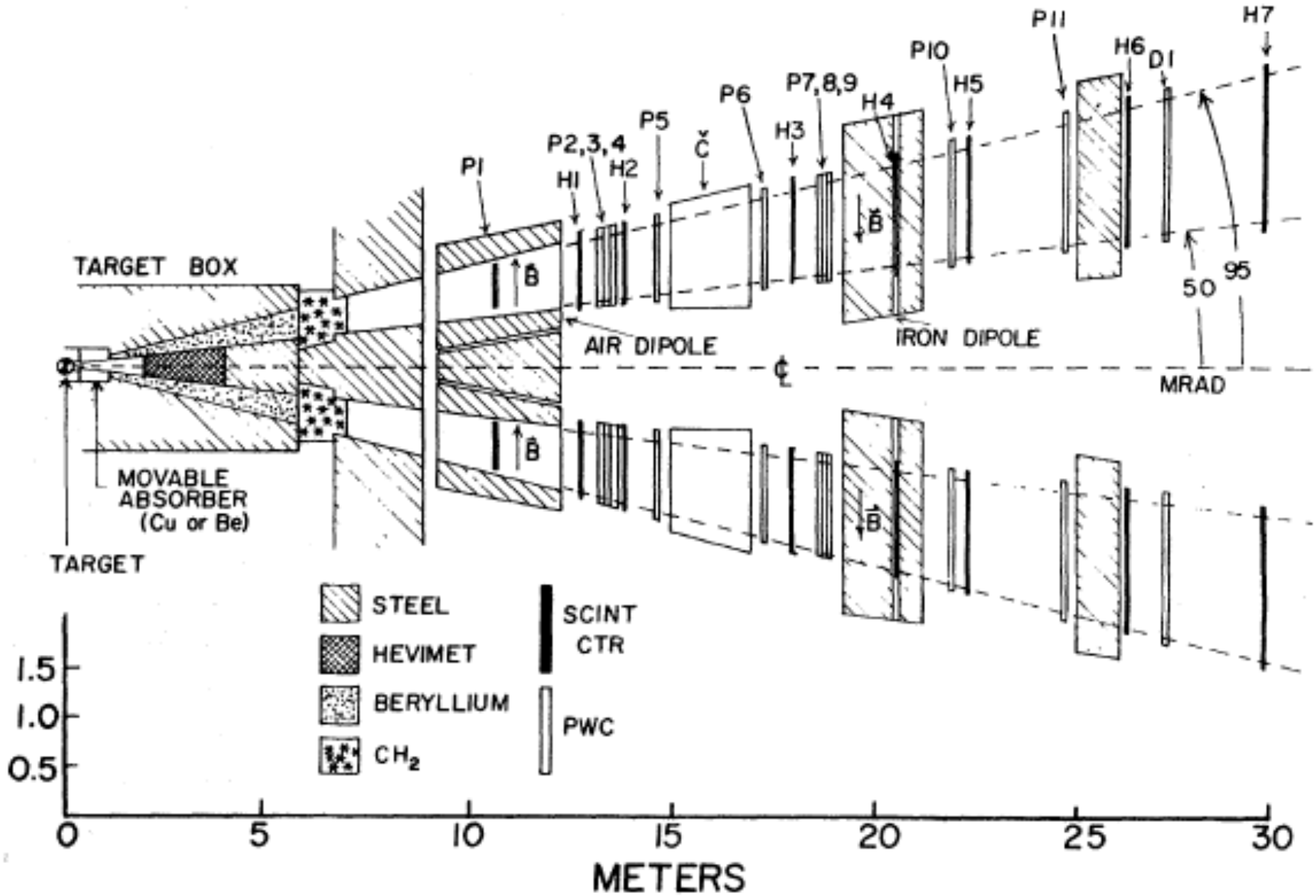
“Drell-Yan” process

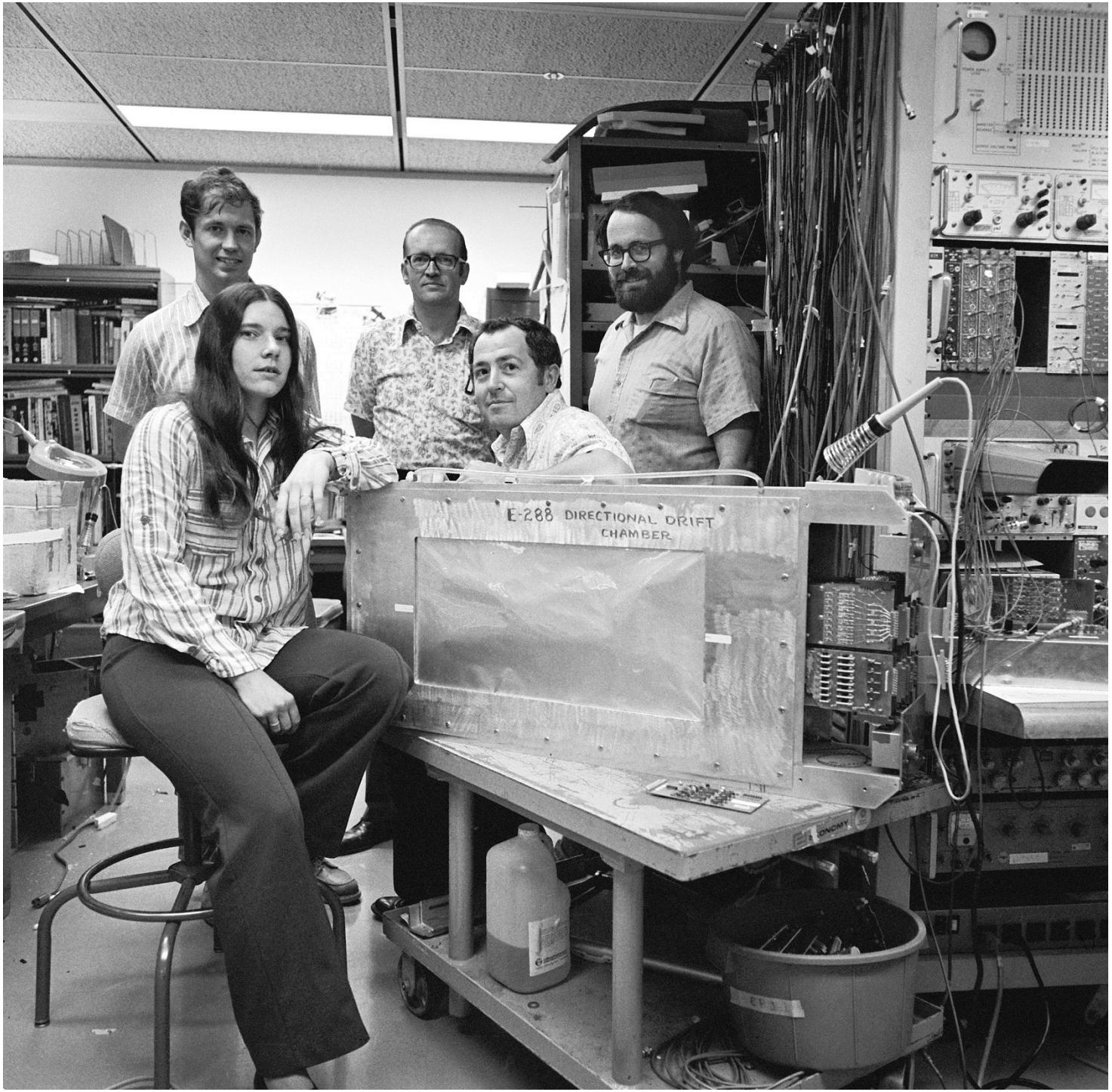




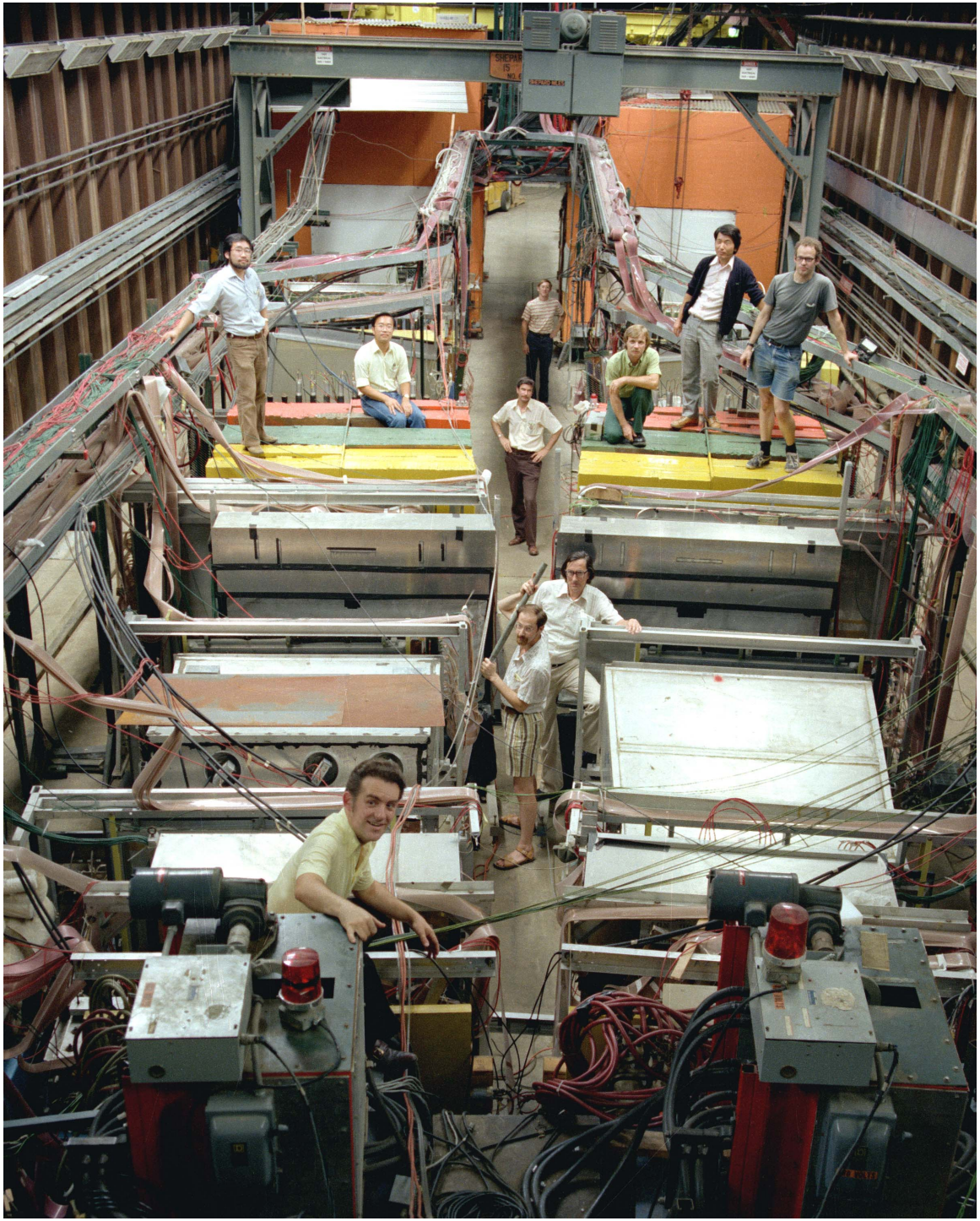
Collide protons on protons
Annihilate quarks and anti-quarks,
much higher luminosity than in e+e-

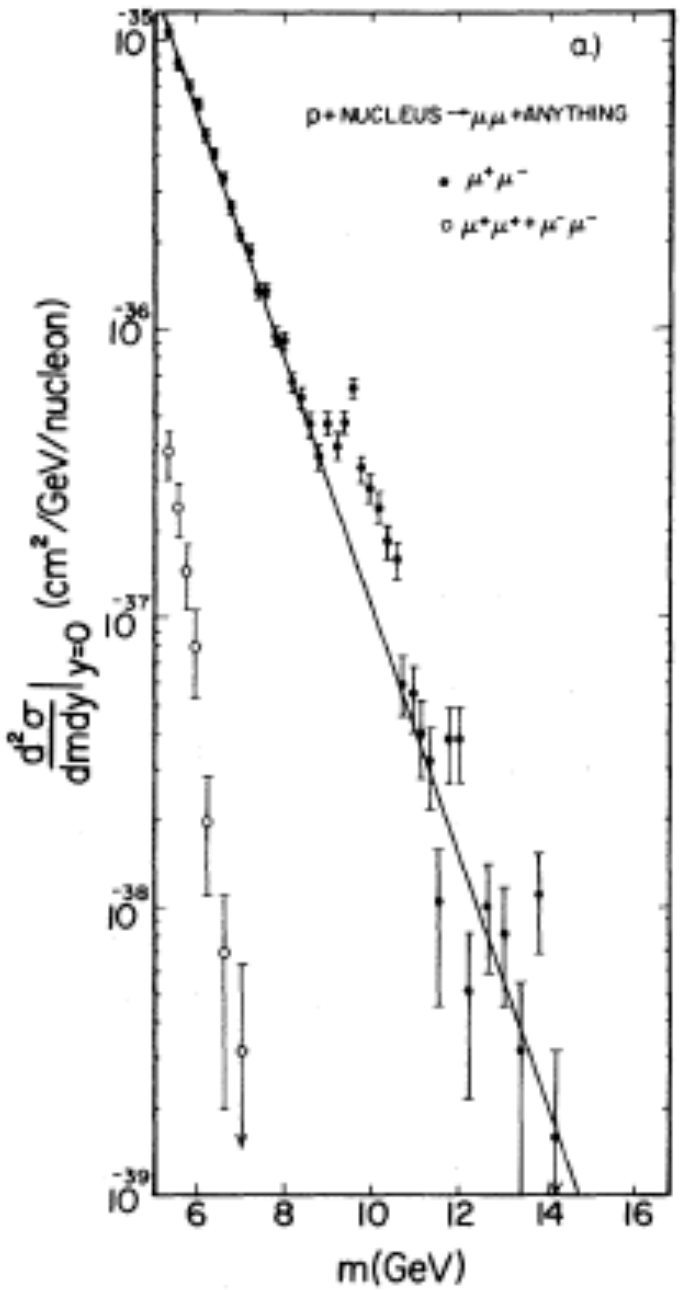
E288


TARGET BOX
TARGET
MOVABLE ABSORBER (Cu or Be)
P1
P2,3,4
H1
H2
P5
Č
P6
H3
P7,8,9
H4
P10
H5
P11
H6
D1
H7
B
AIR DIPOLE
IRON DIPOLE
50
95
MRAD
STEEL
HEVIMET
BERYLLIUM
CH2
SCINT CTR
PWC
1.5
1.0
0.5
0
5
10
15
20
25
30
METERS



6/7/17





Observation of a Dimuon Resonance at 9.5 GeV in 400-GeV Proton-Nucleus Collisions

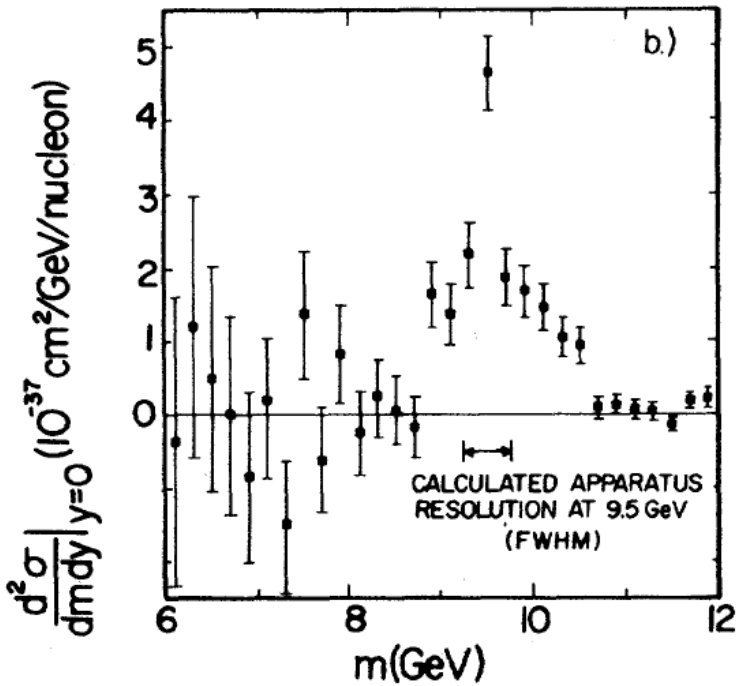
S. W. Herb, D. C. Hom, L. M. Lederman, J. C. Sens,[a] H. D. Snyder, and J. K. Yoh
Columbia University, New York, New York 10027

and

J. A. Appel, B. C. Brown, C. N. Brown, W. R. Innes, K. Ueno, and T. Yamanouchi
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

and

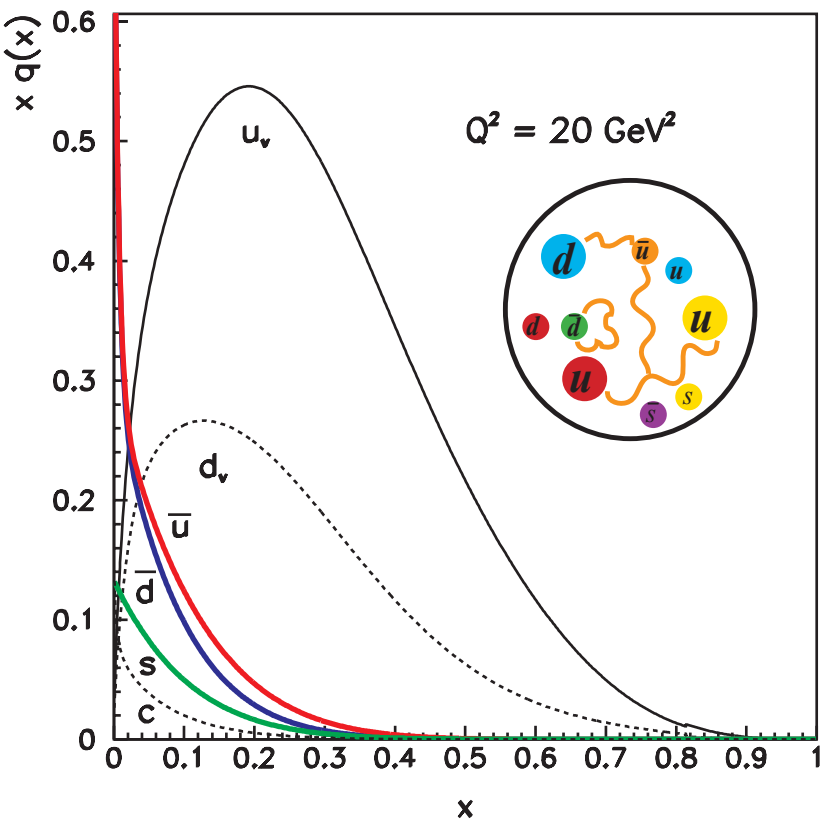
A. S. Ito, H. Jöstlein, D. M. Kaplan, and R. D. Kephart
State University of New York at Stony Brook, Stony Brook, New York 11974
(Received 1 July 1977)



NL-8485

Physics beyond the Upsilon…

Parton Momentum Fractions

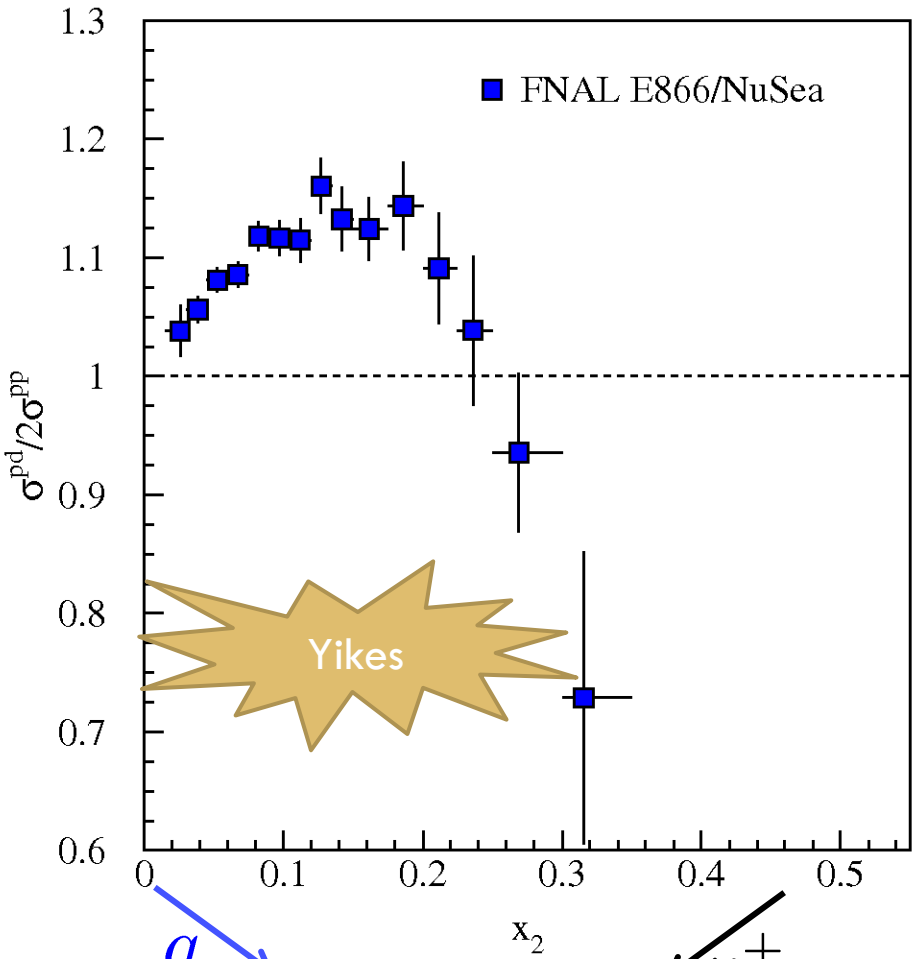


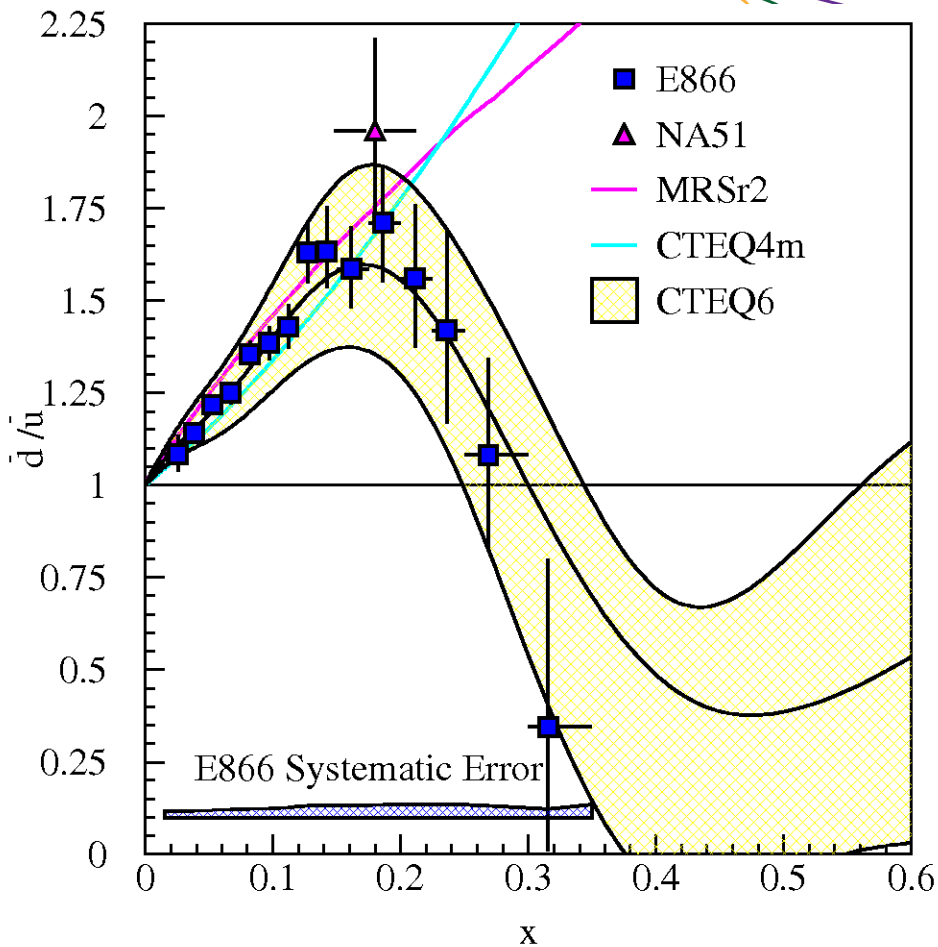
- If you can pick out a type of quark, you can measure its momentum fraction
- Vital input to almost all collider physics

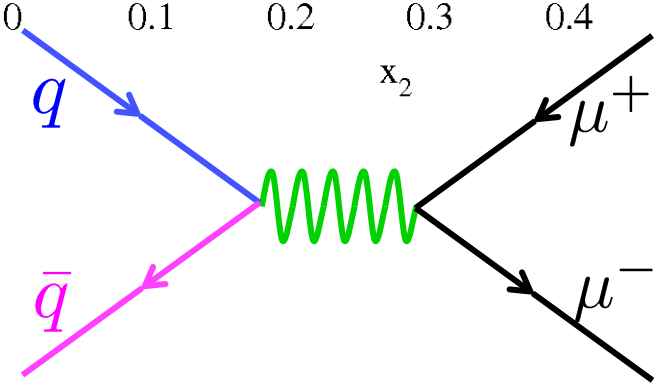
EHLQ

The adventure continues
NUSEA(TeVII) and SEAQUEST(MI)

Drell-Yan Cross Section Ratio and dbar/u-bar







$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_b \gg x_t} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x_t)}{\bar{u}(x_t)}\right]$$

The "Doubler"

- Build the TeVatron
- Not just for collider physics
- 800 GeV high intensity beams
  - Muons at 500 GeV
  - Hyperons
  - Neutrinos up to 500 GeV
  - Protons and pions galore
  - High intensity photon beams for charm production

1979 Funding for the "Energy Saver!"

Tevatron II (1983-2000)

- 43 experiments in many different beamlines
- > 400 doctorates from >100 Universities in 18 countries
- More than 300 publications as of 2012

http://conferences.fnal.gov/tevft/ has it all

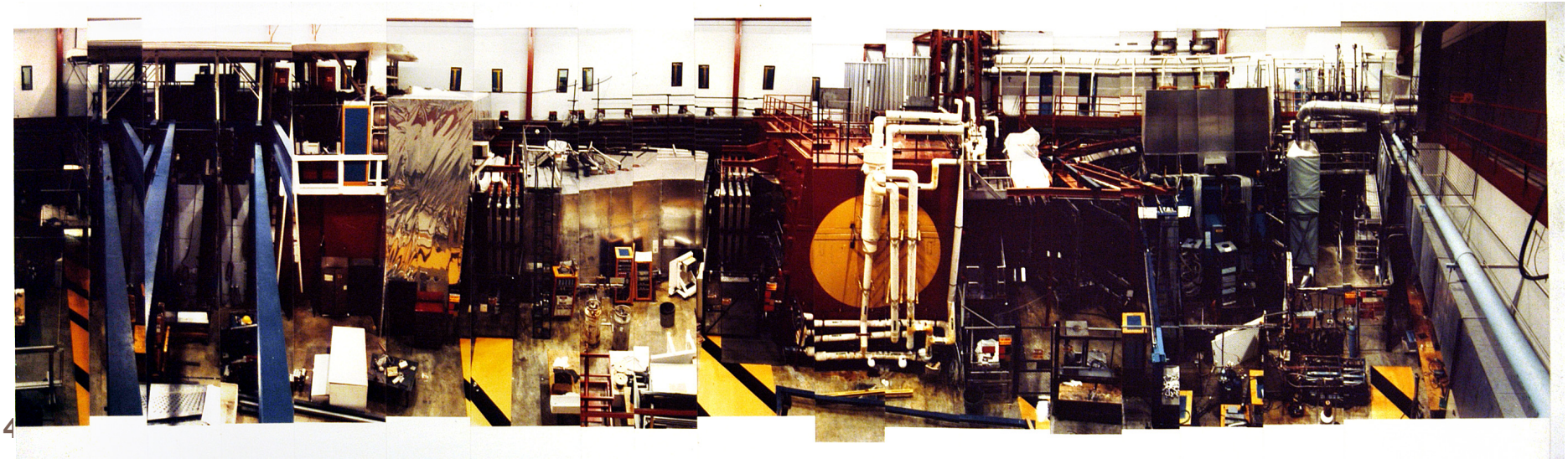
Chicago Cyclotron moves again!

New Muon Lab

TeV II Experiments featured

Actual floors
Indoor plumbing
Hot and cold running Helium

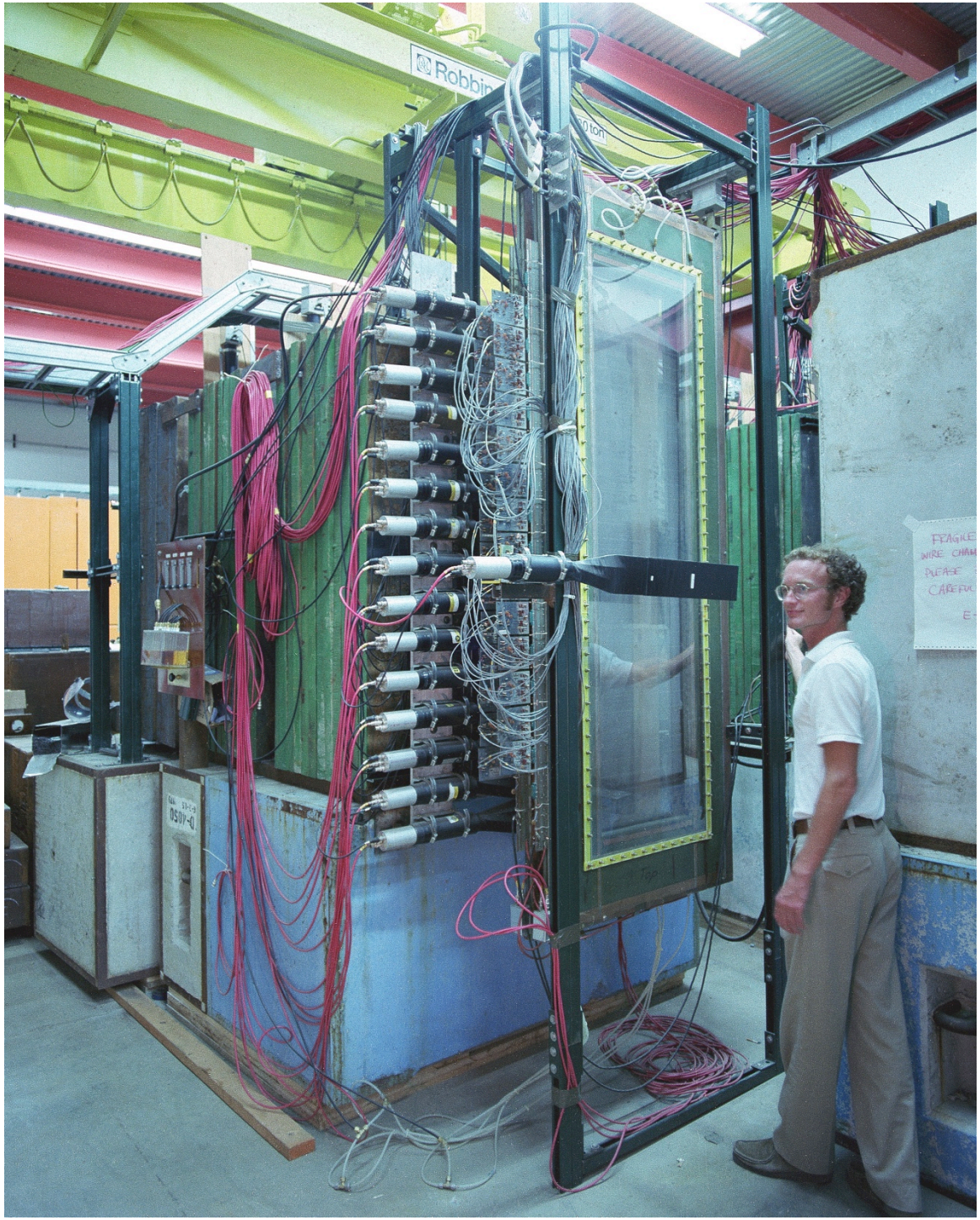
Composite Photo of E665 in the Muon Lab 1991



CHARM Physics

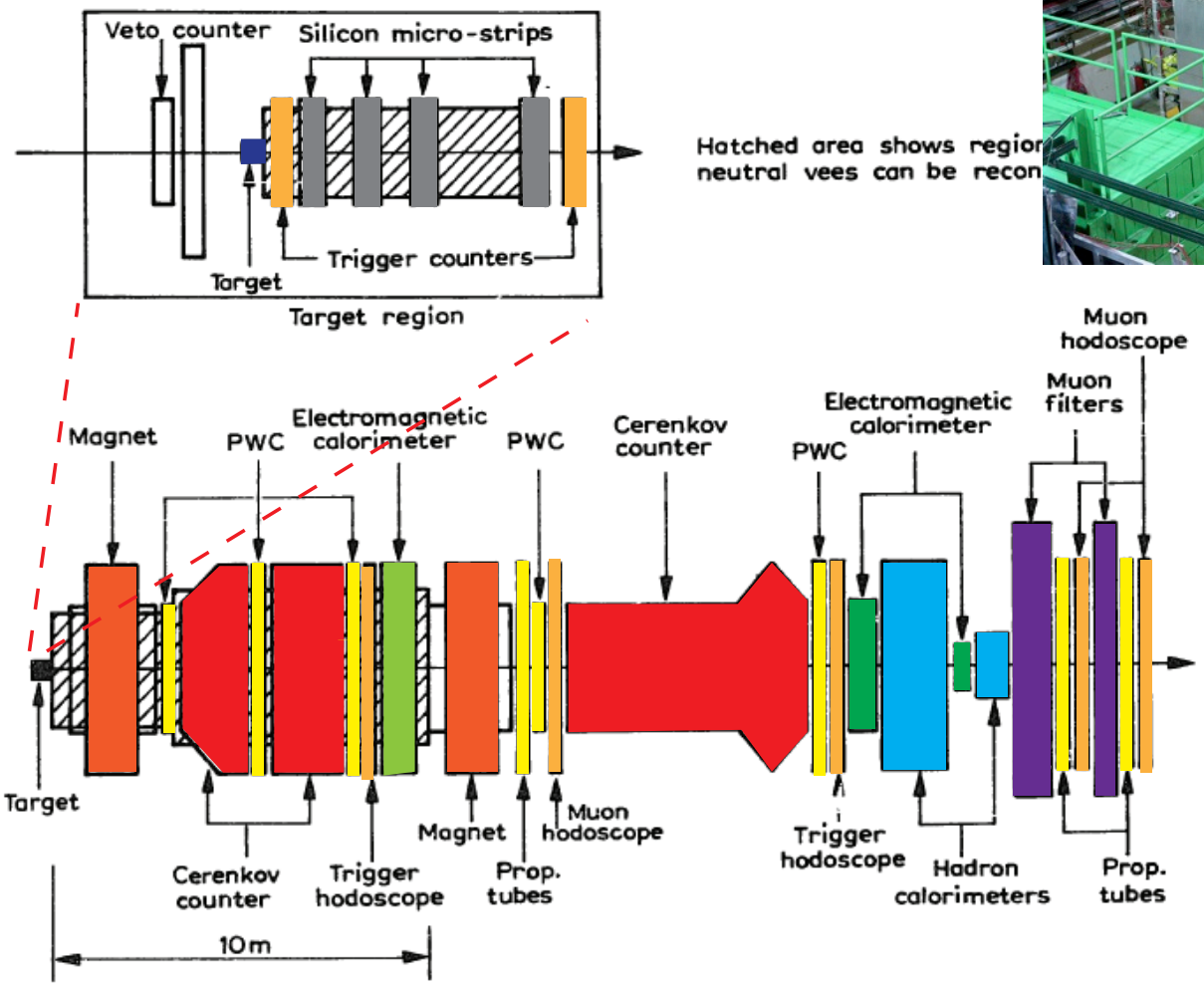
Silicon Detectors

Computing

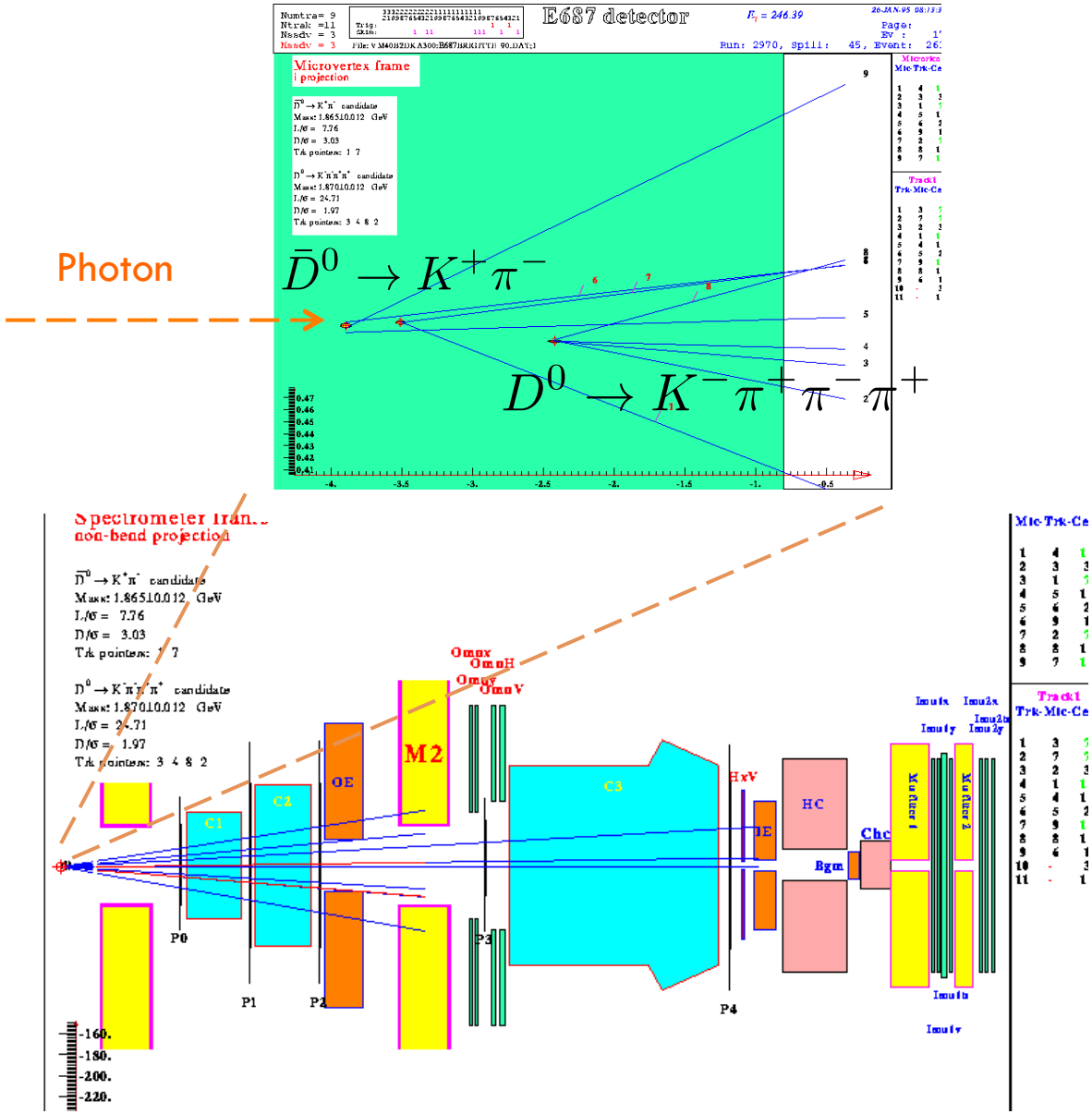


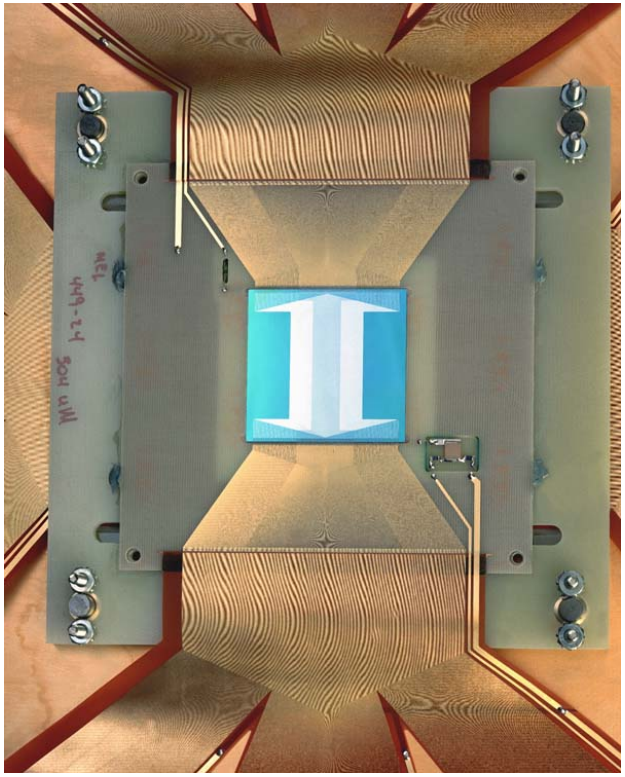
Mike Witherell in the tagged photon lab in 1999

Generic detector (E687)



Target
Silicon microstrips
Scint. Counters
Tracking chambers
Particle ID
EM calorimeter
Hadron calorimeter
Muon detector





High statistics Charm physics

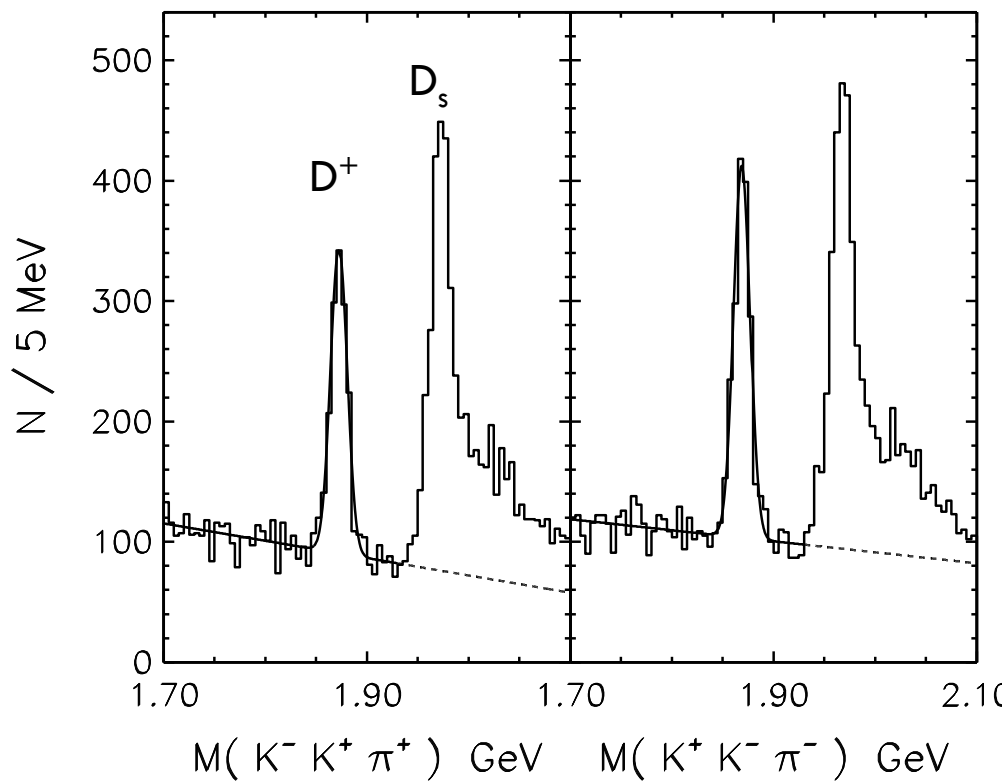
Use silicon strip detectors to identify charm in humungous background

E687 – photon beam

E691?

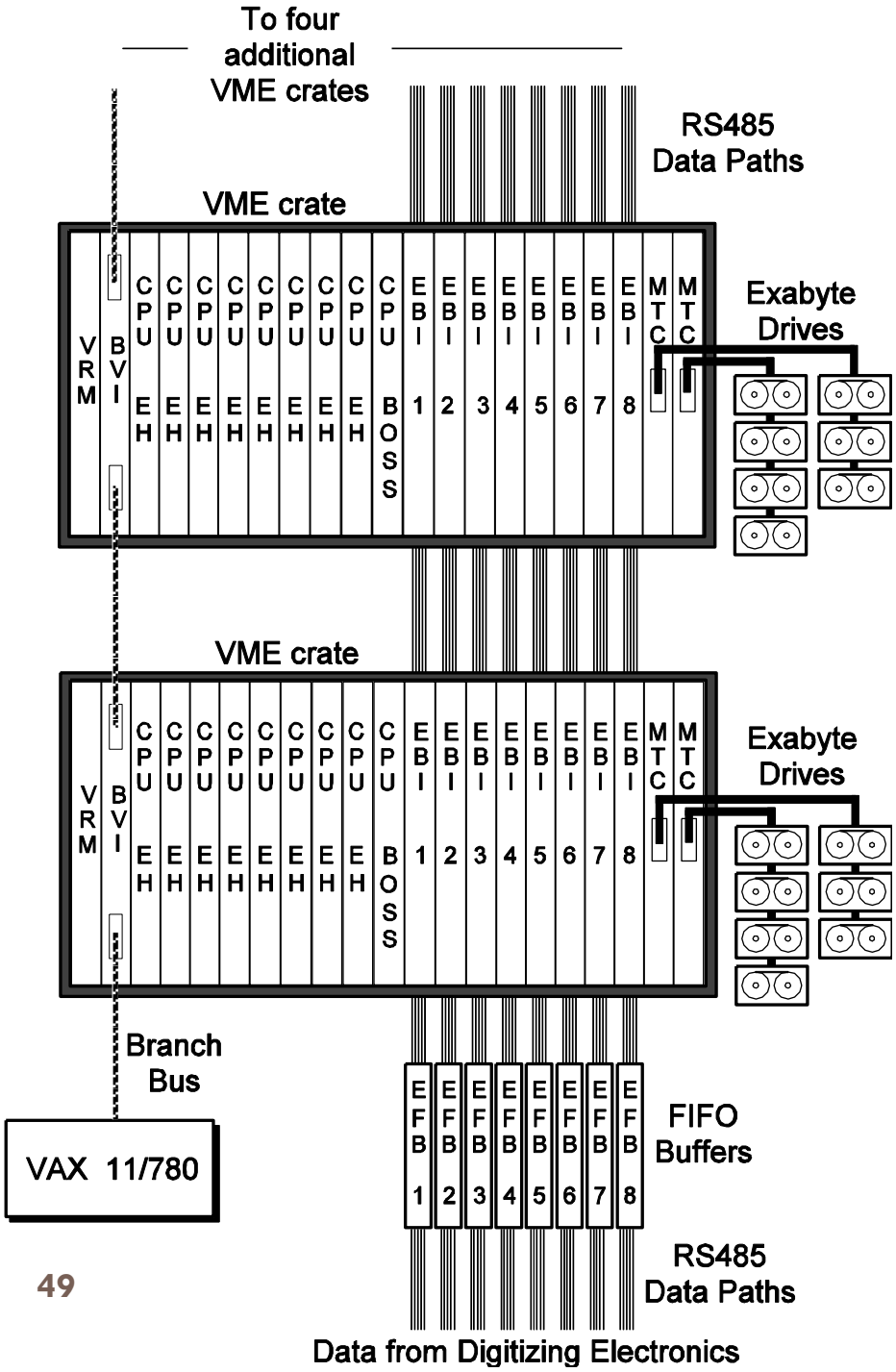
Charm rates at E791

- Pion beam at 2 MHz
- The target consisted of 5 foils:
  - A 0.5 mm Pt target and
  - Four 1.6 mm C (diamond) targets
- Interaction rate of 40 kHz – 10 kHz written to tape
- Only 1/1000 of the events were charm
- A total of 2 x 10^{10} events were recorded.



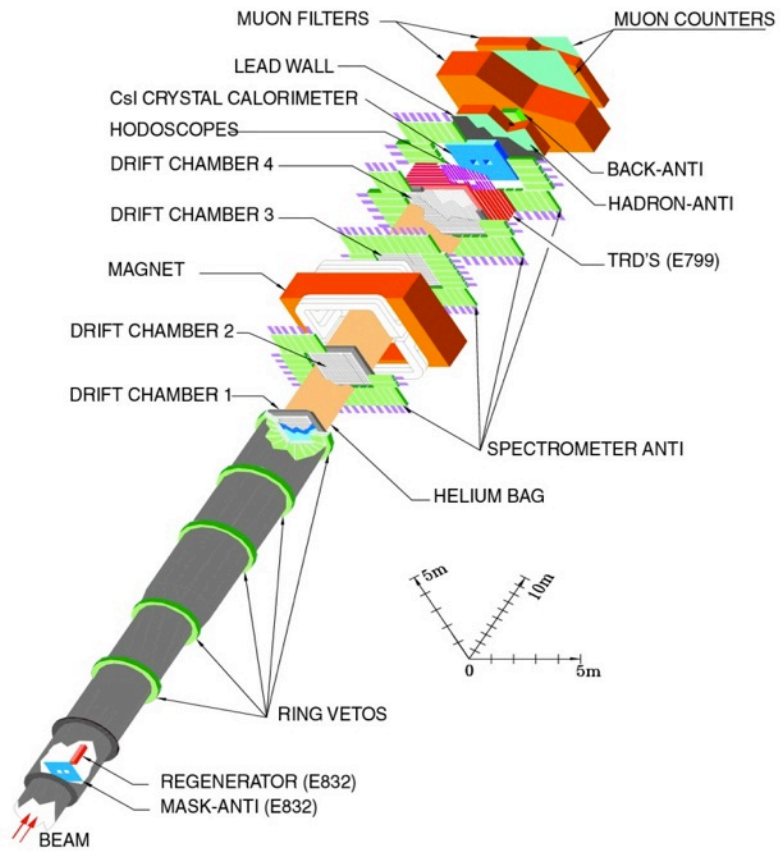
Slides from M. Purohit

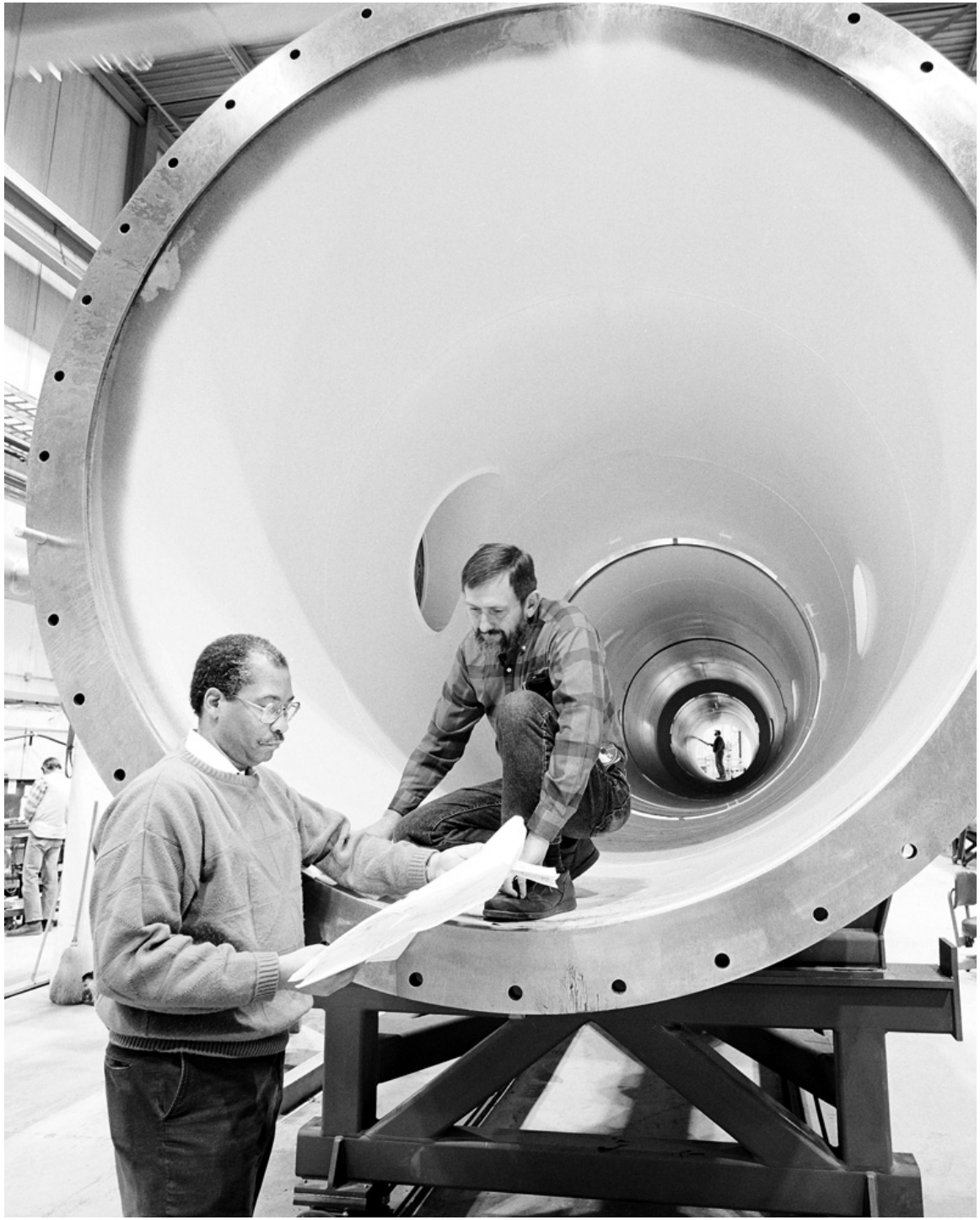
E791 charm



Before

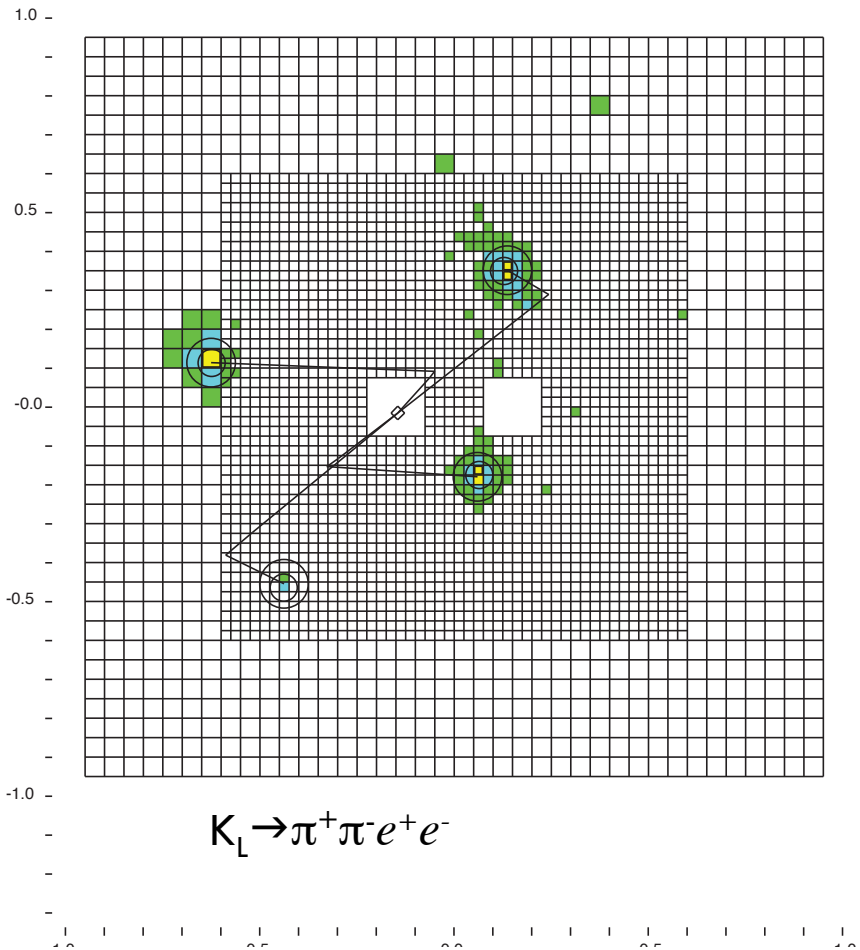
KTeV: high intensity kaon beams



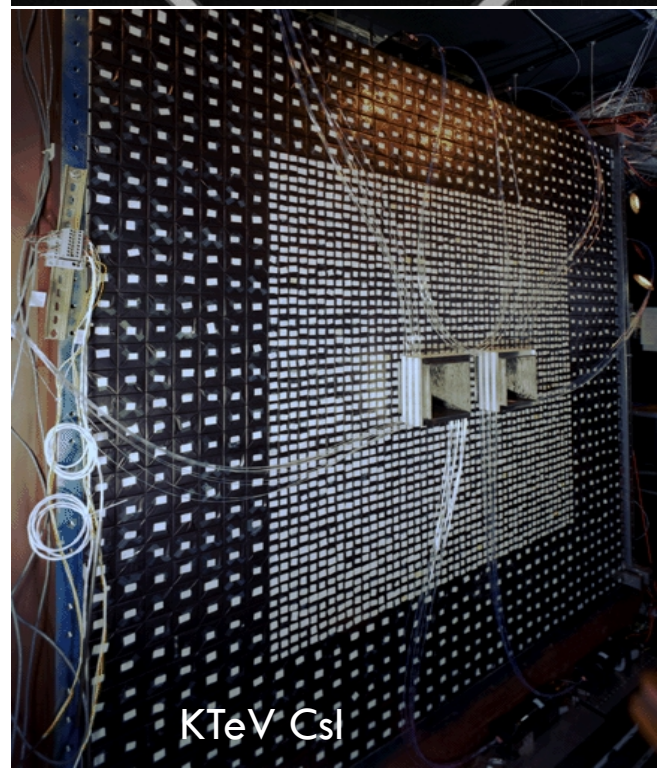


KTeV Pure CsI Calorimeter

- 3100 crystals, 1.9mx1.9m
- 27 X_0 deep (50cm)
- 0.6% energy resolution

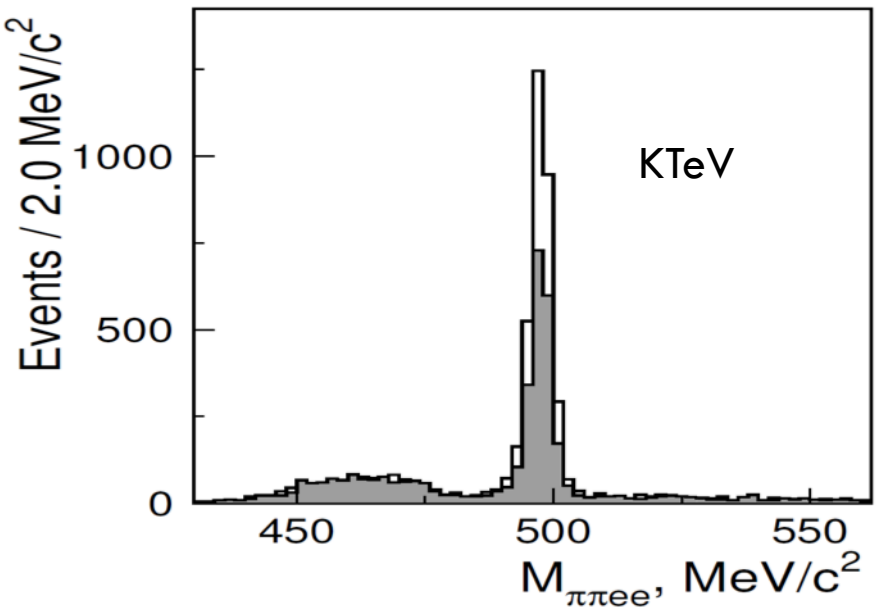


$K_L \rightarrow \pi^+\pi^- e^+ e^-$



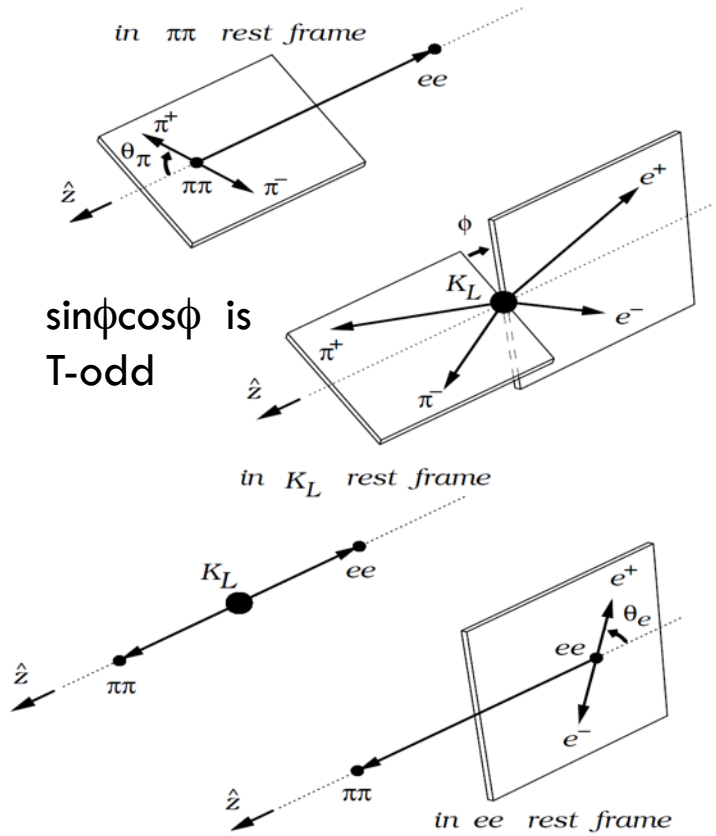
Example of Intensity Discovery of $K_L \rightarrow \pi^+\pi^-e^+e^-$ Branching fraction of 4×10^{-7}

Phys. Rev. Lett. 96, 101801 (2006).



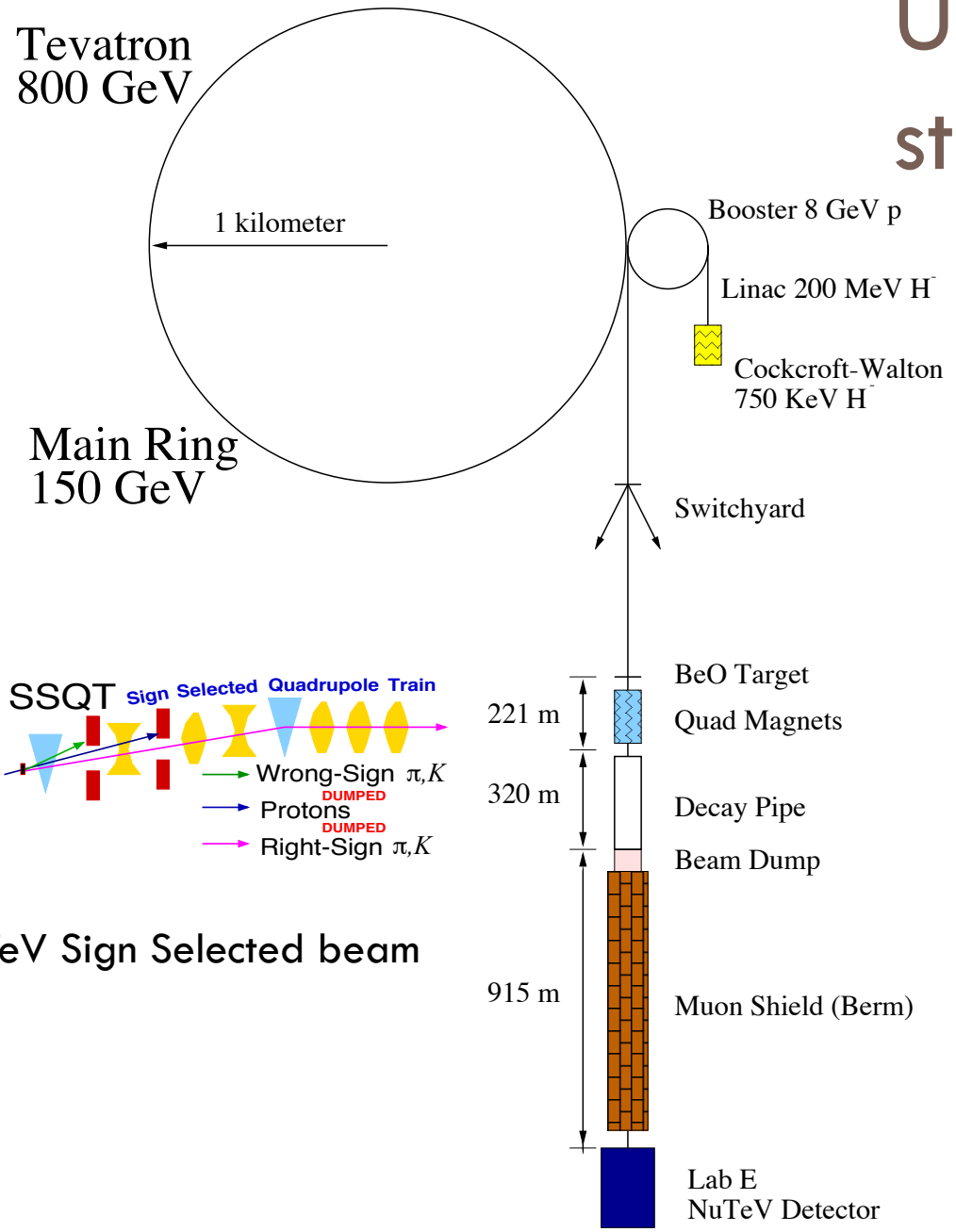
Gray: $\sin\phi\cos\phi<0$; Clear: $\sin\phi\cos\phi>0$

- 5000 events observed, sensitivity < 10^{-10}.
- Large T-odd, CP asymmetry observed.

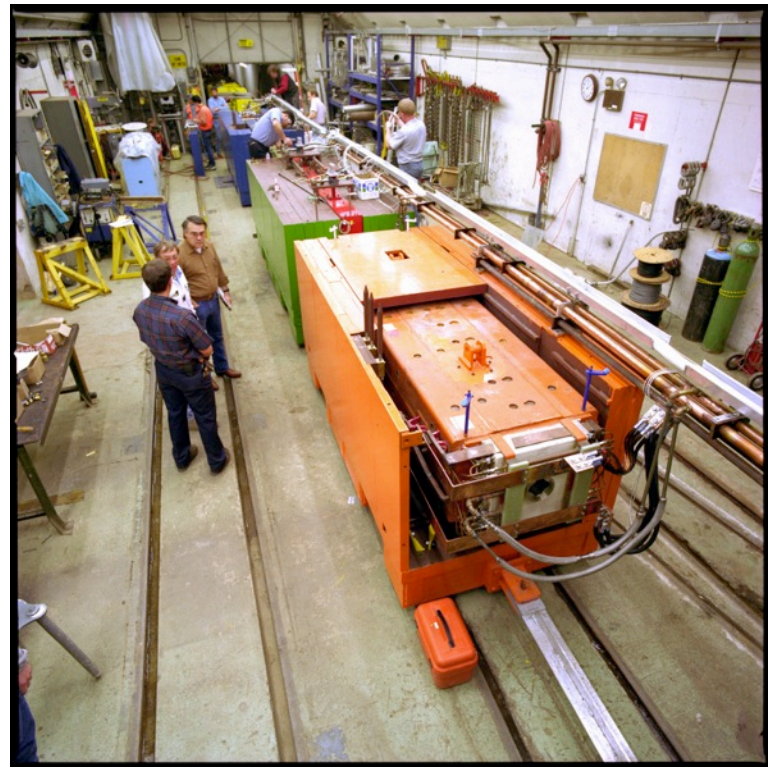


$\sin\phi\cos\phi$ is T-odd

Use neutrinos to see strange quarks

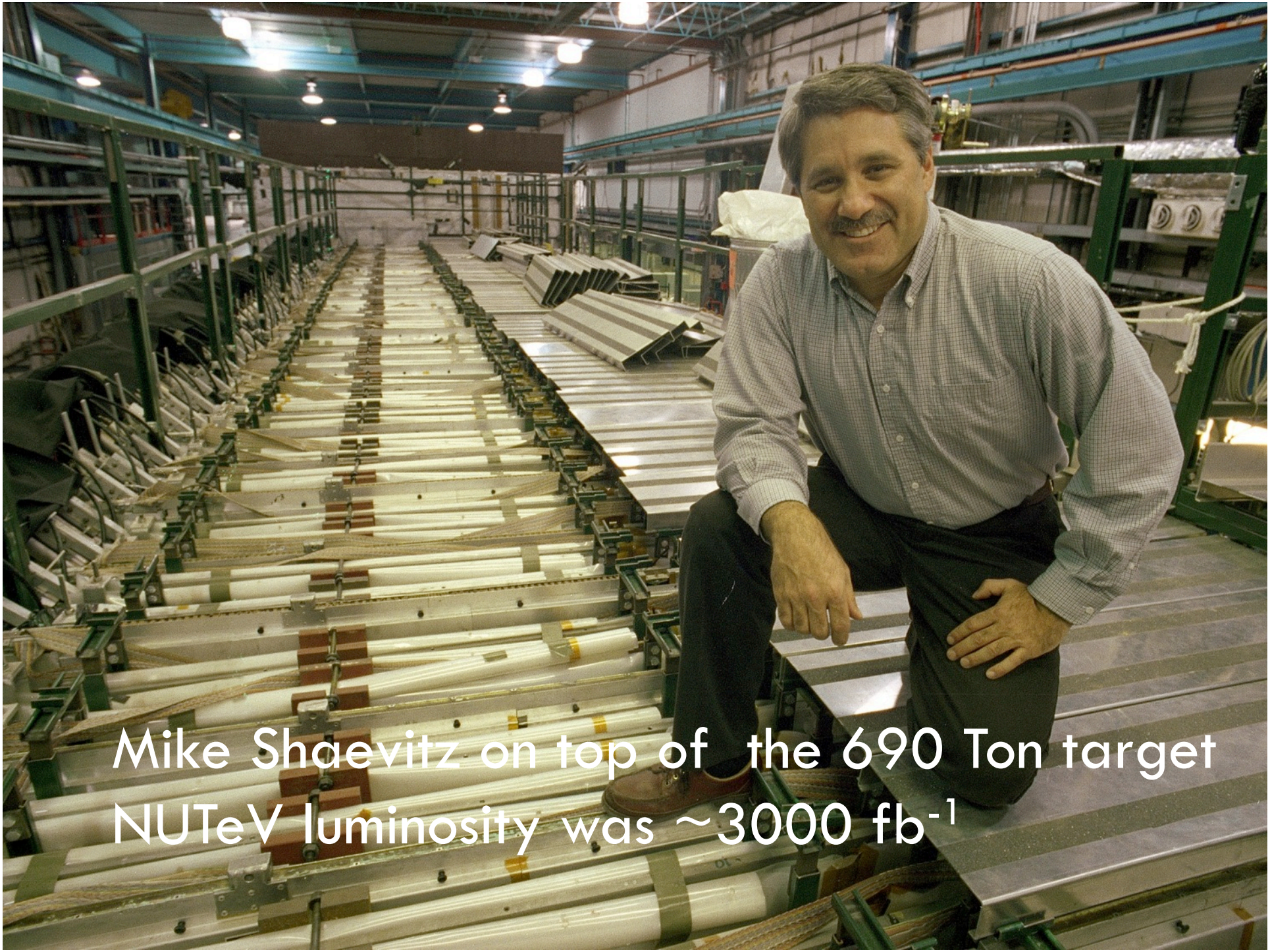


NuTeV Sign Selected beam



< 0.1% anti-ν in ν

< 0.3% ν in anti-ν


Mike Shaevitz on top of the 690 Ton target
NUTeV luminosity was ~3000 fb^{-1}

Strangeness

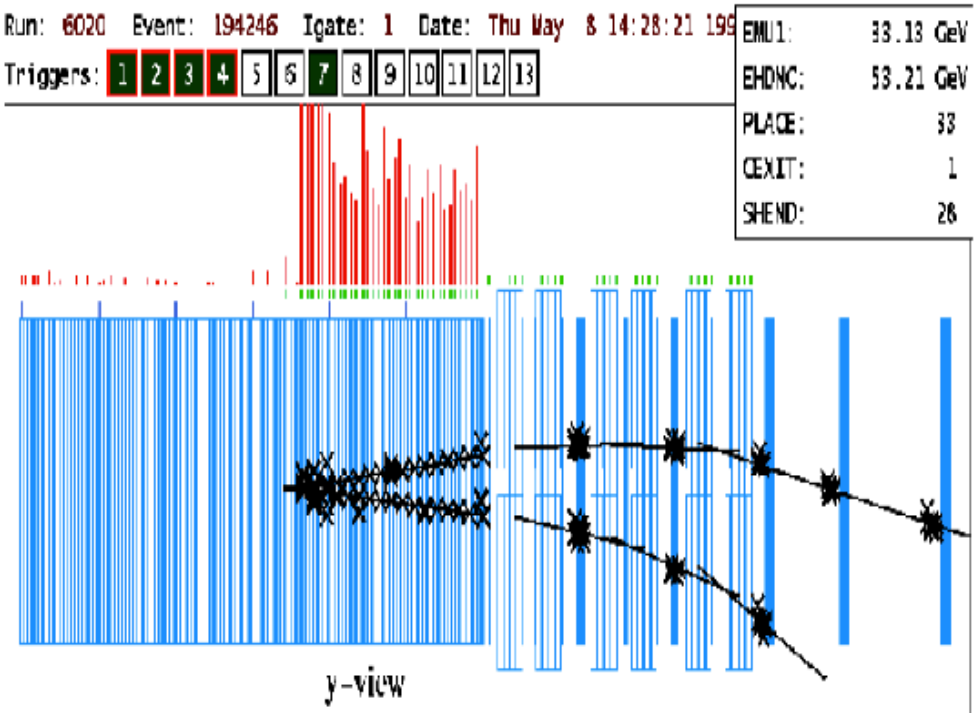
Neutrinos scattering can pick out strange quarks through the process

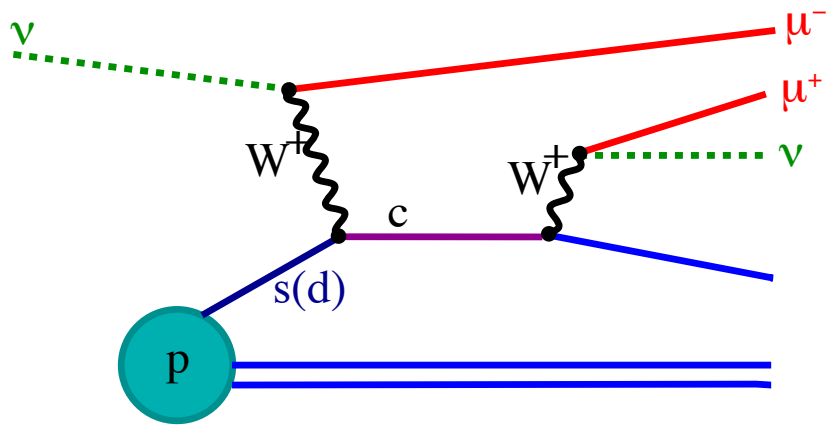
$\nu + s \rightarrow \mu^- + c$

c decays to μ^+

Dimuons at NuTeV measure

- Strange content s(x)
- s/anti-s difference
- V_{sc}/V_{dc}





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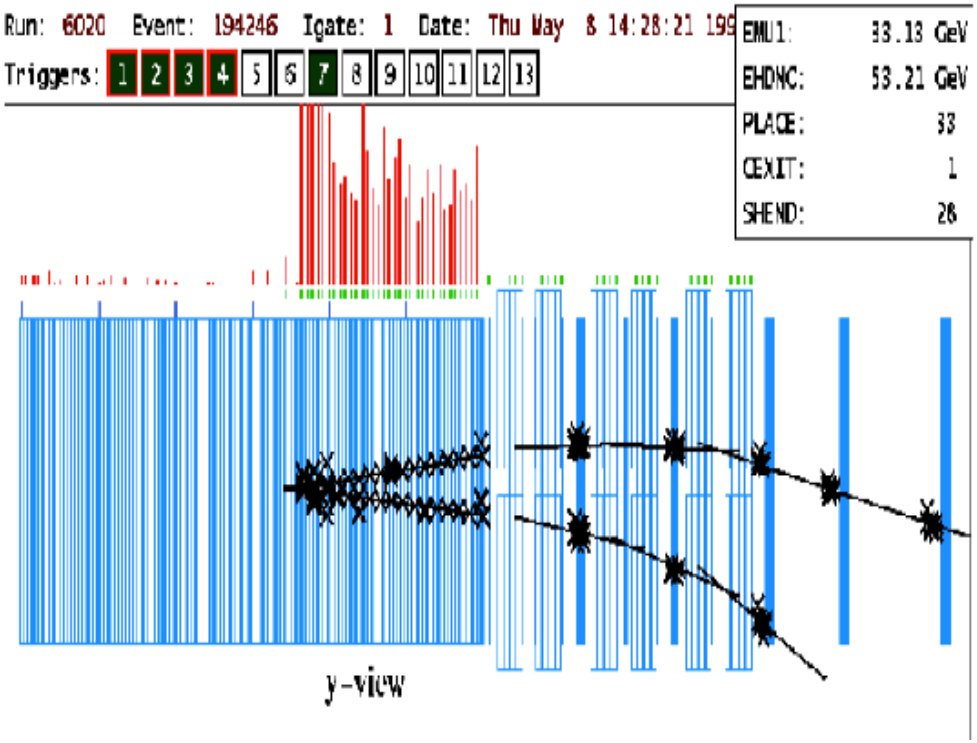


Dimuons at NuTeV measure

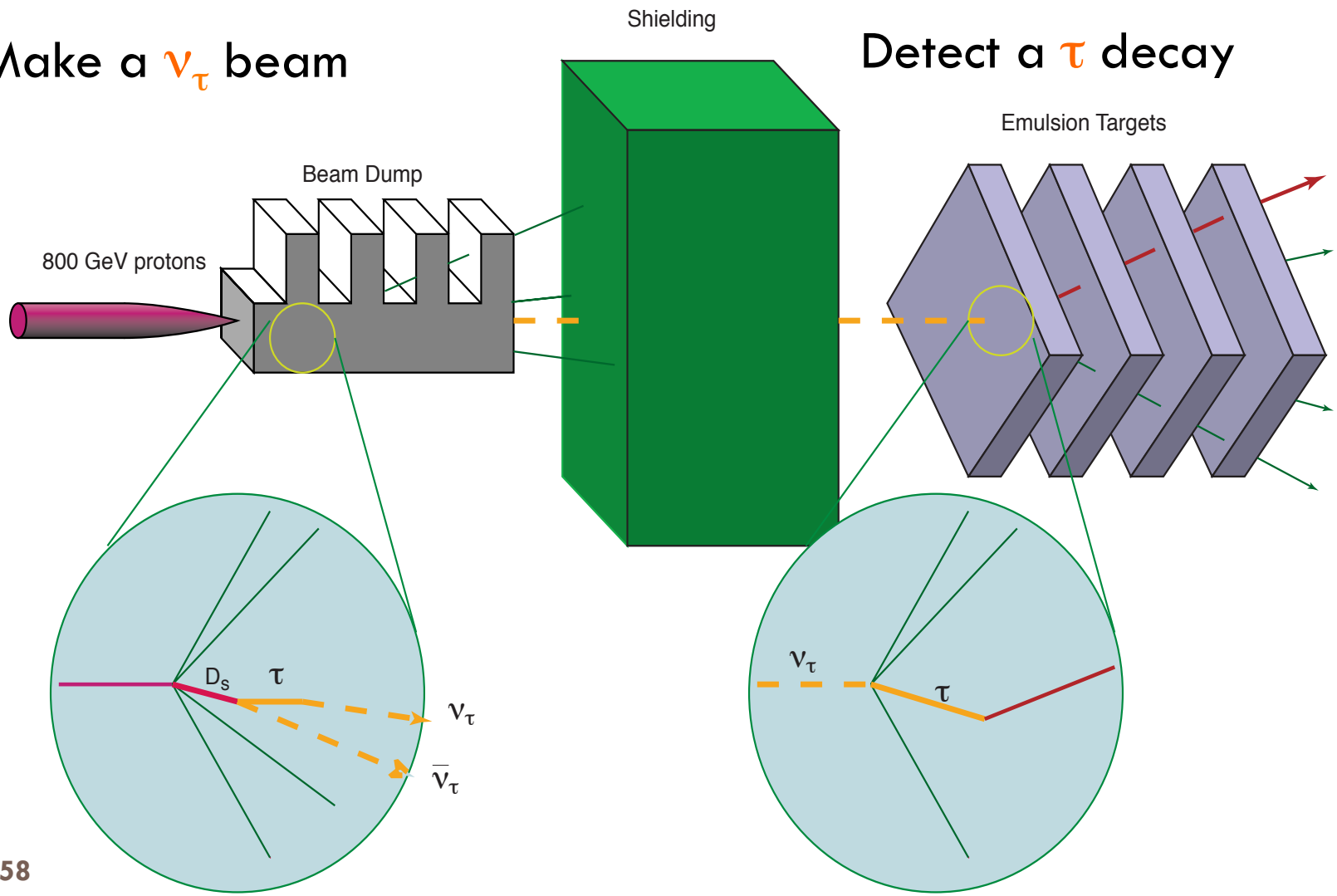
- Strange content s(x)
- s/anti-s difference
- V_{sc}/V_{dc}

Fun fact, we're all about 5% strange

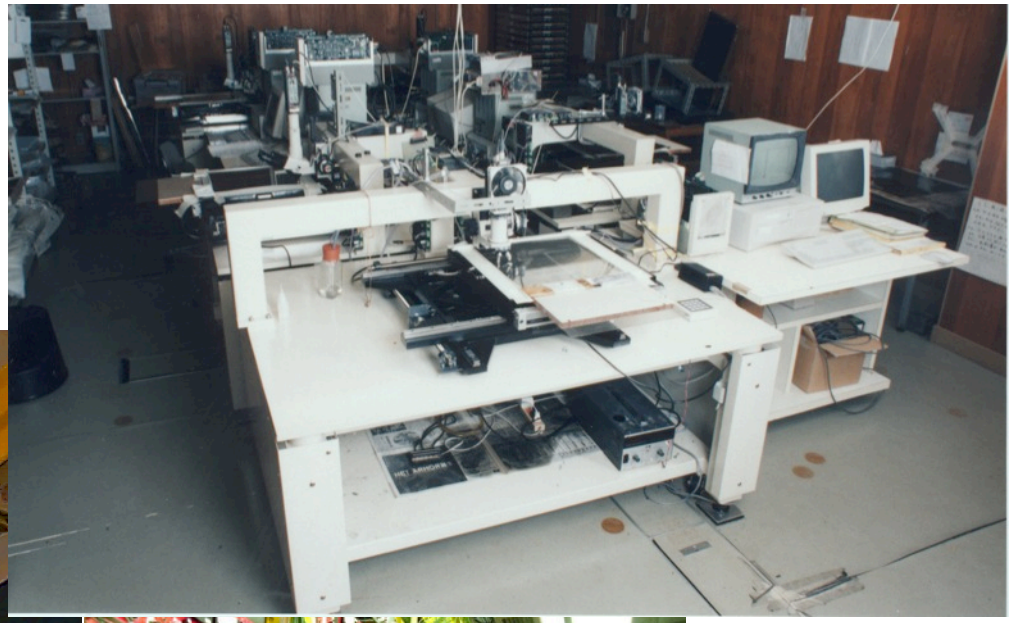
Discovery of the tau neutrino (DONUT)

Make a ν_τ beam

Detect a τ decay



Emulsion modules and drift chambers

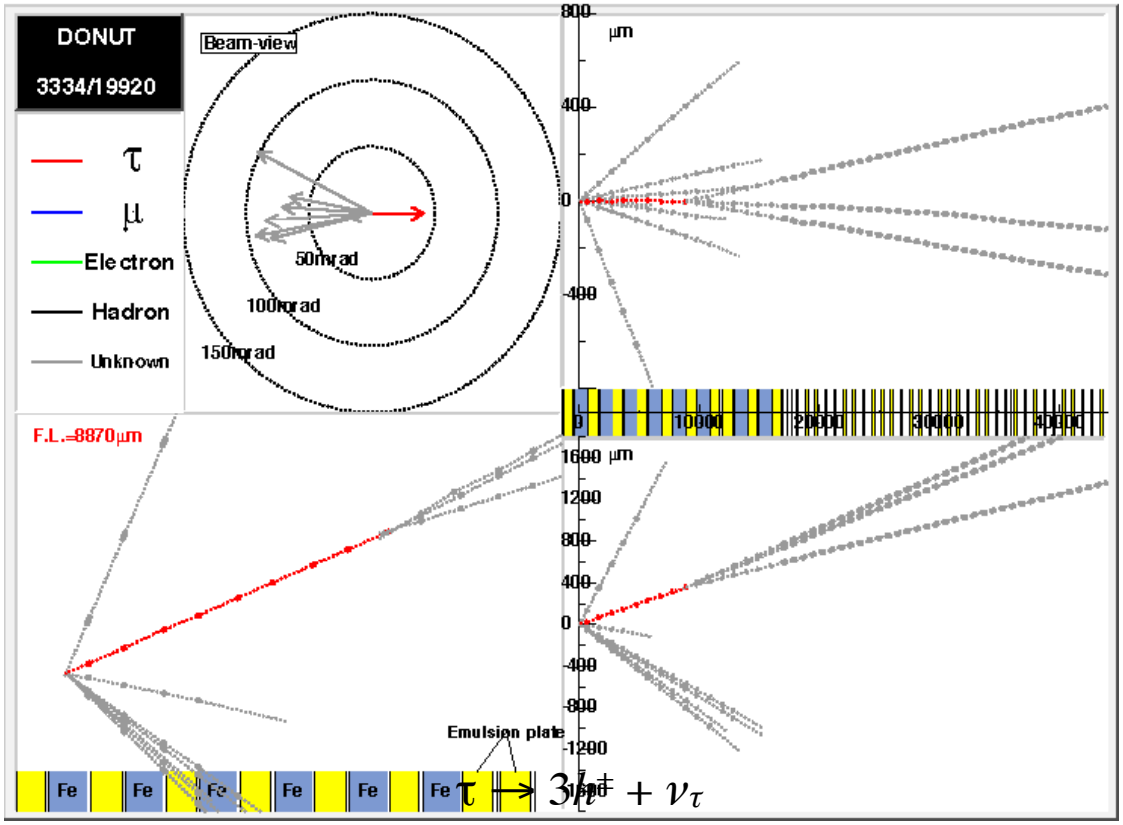


Emulsion plates interleaved with 1mm steel plates: total target mass 260 kg (not kt !)

Recycled drift chamber electronics

6/7/17

Saw 9 candidates 7.52 $\nu \rightarrow \tau$ + 1.48 background



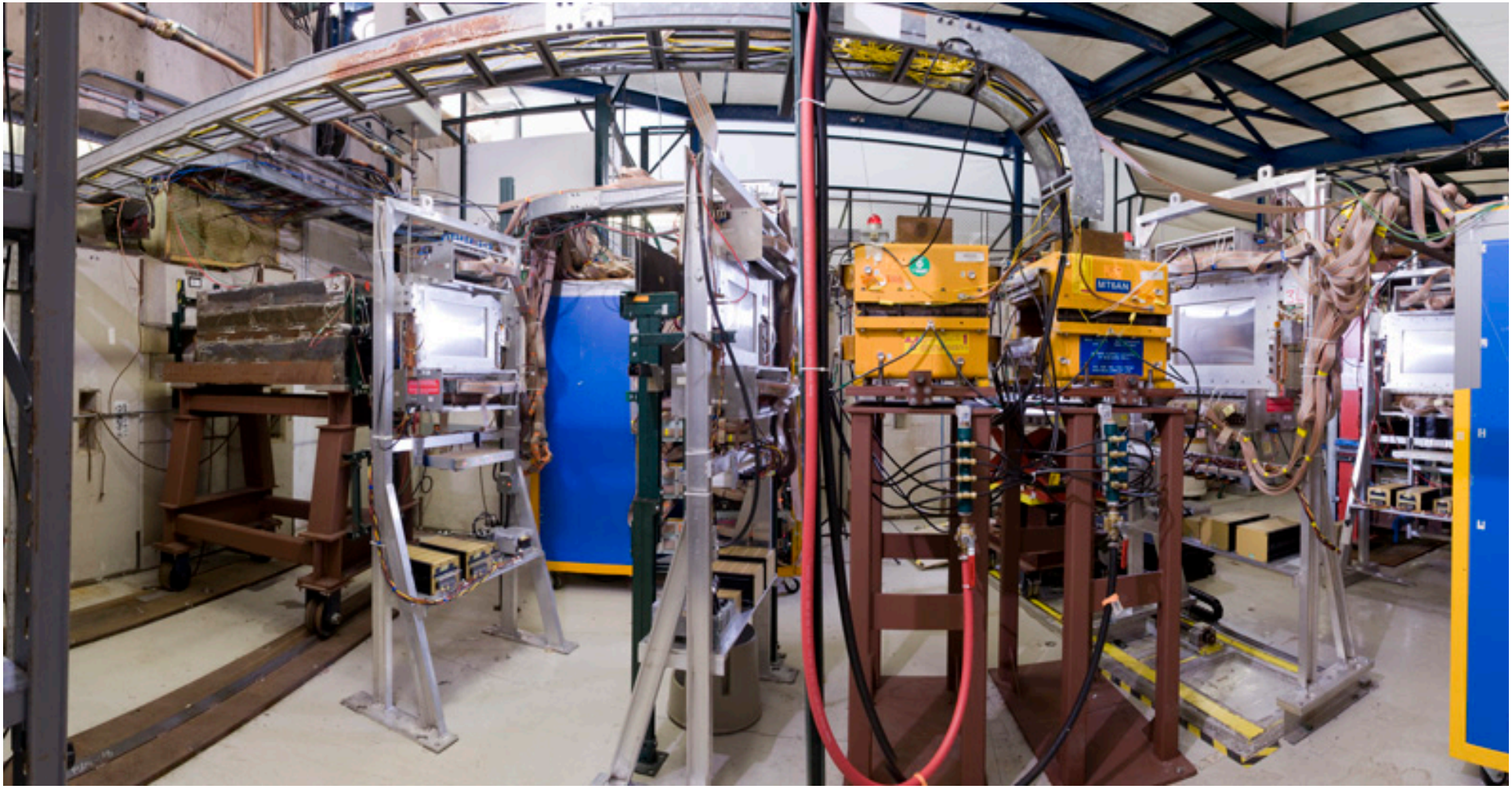
~80 GeV τ : τ probability 0.99+

~9mm decay length

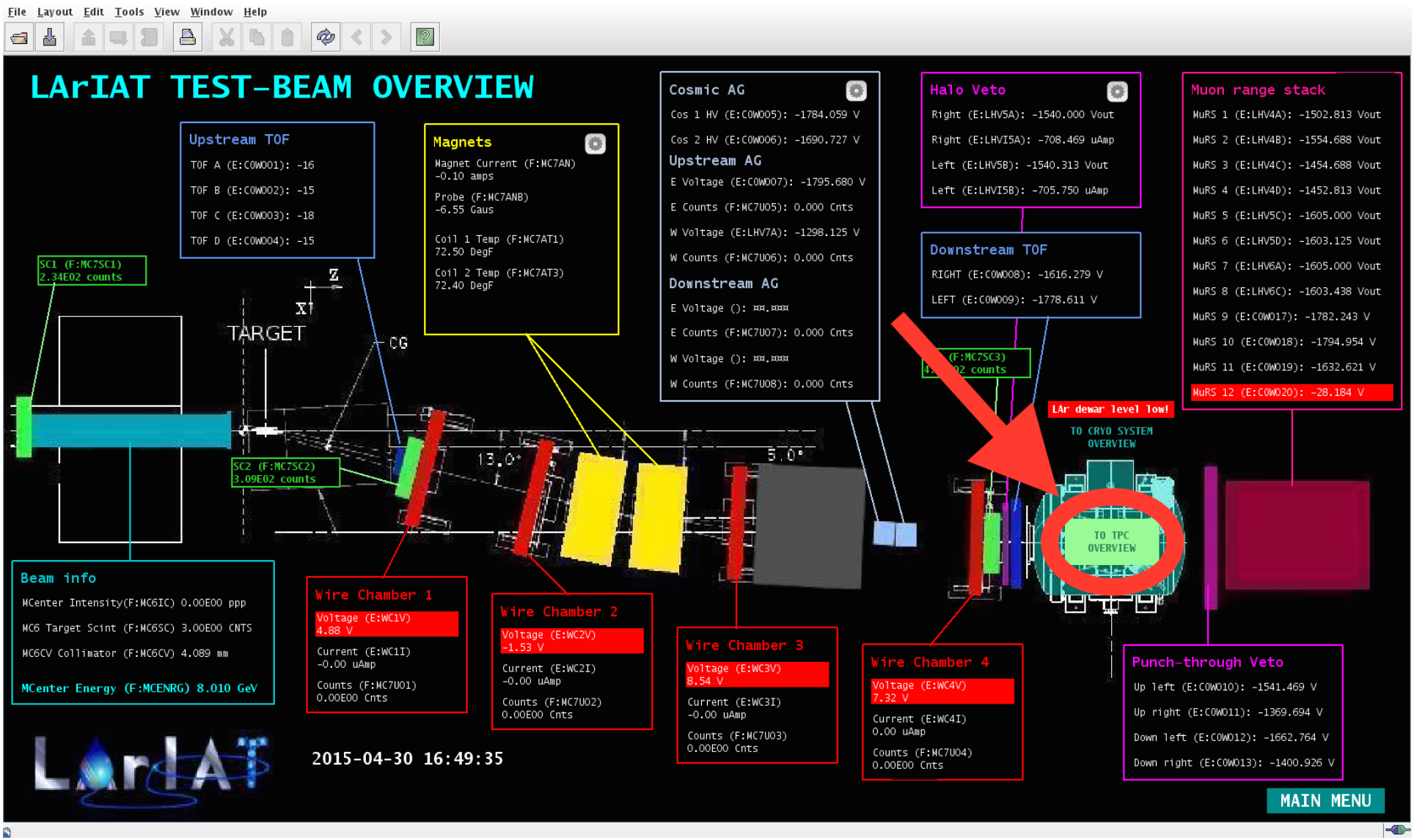
digitized emulsion information shown

Test Beams!!

- Facility upgraded in 2005
- 38 experiments as of 2005-2015



LArIAT test beam



Conclusions

- FNAL Fixed Target Legacy
  - Led to detectors and computing used in all modern experiments
  - High intensity and highest energy ever in fixed target
    - Charm physics
    - Kaon physics to 10^{-10}
    - Proton Structure
    - Precision Standard Model Parameters
  - Discoveries
    - Discovery of **Upsilon** and ν_τ

Not over yet

- Fermilab fixed target lives at 8 and 120 GeV
- Neutrino physics at 8 and 120 GeV
  - Cross sections (MINERvA)
  - Oscillations (MINOS, NOvA, MiniBooNE, MicroBooNE, SBND, Icarus DUNE …..)
  - ???
- Proton Physics
  - SEAQUEST – son of NUSEA
- Test beams !!!!
- Your idea here

E 715 IS HONORED AND PROUD TO BE

THE FIRST ENERGY SAVER USER

OCTOBER 1, 1983

Peter S Cooper

Ed McClimond

Roland Winston

John Marriner

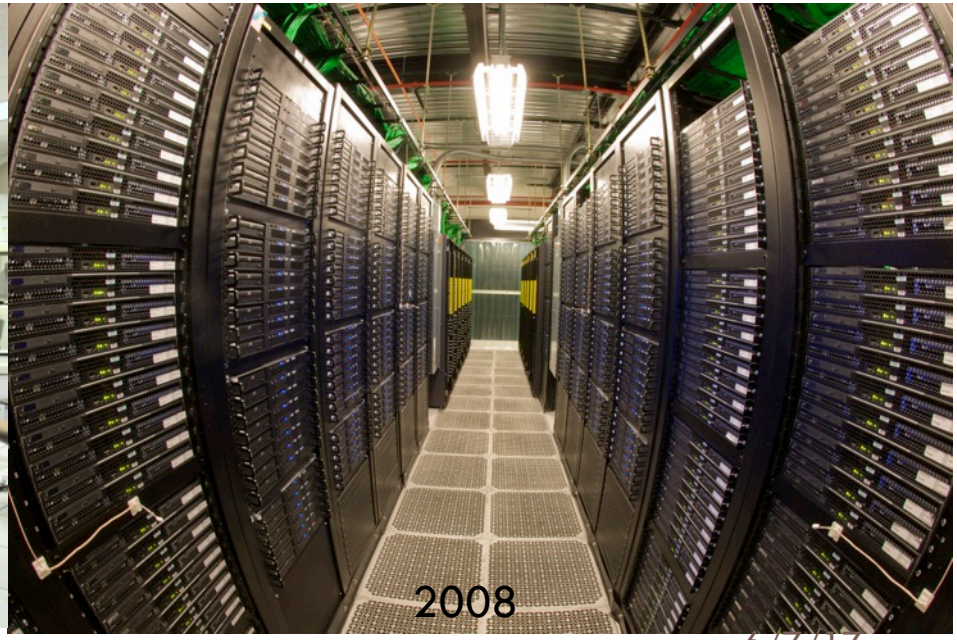
Nordie Zapalac

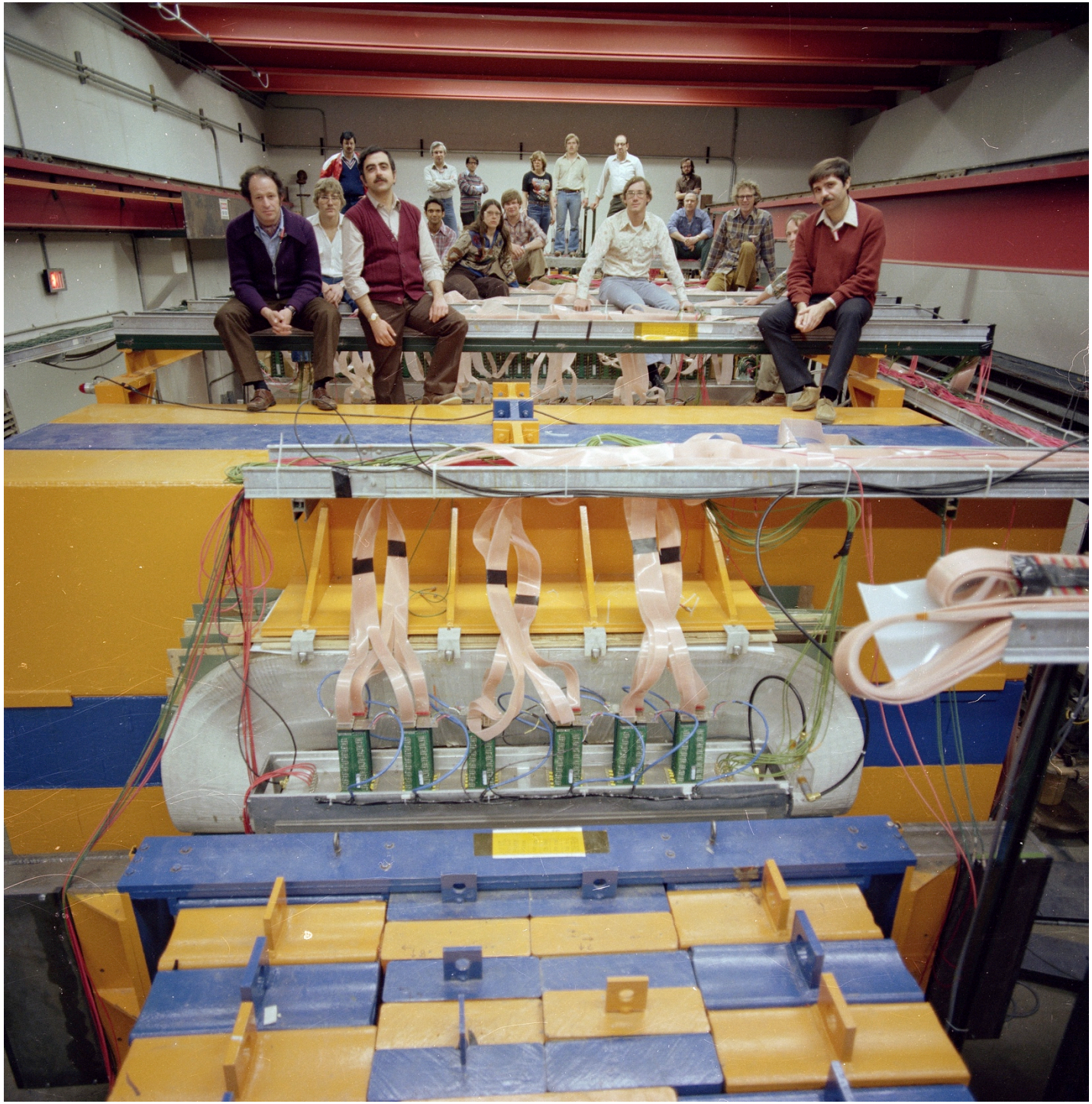
THANK YOU FERMILAB!

1990

1992

1999

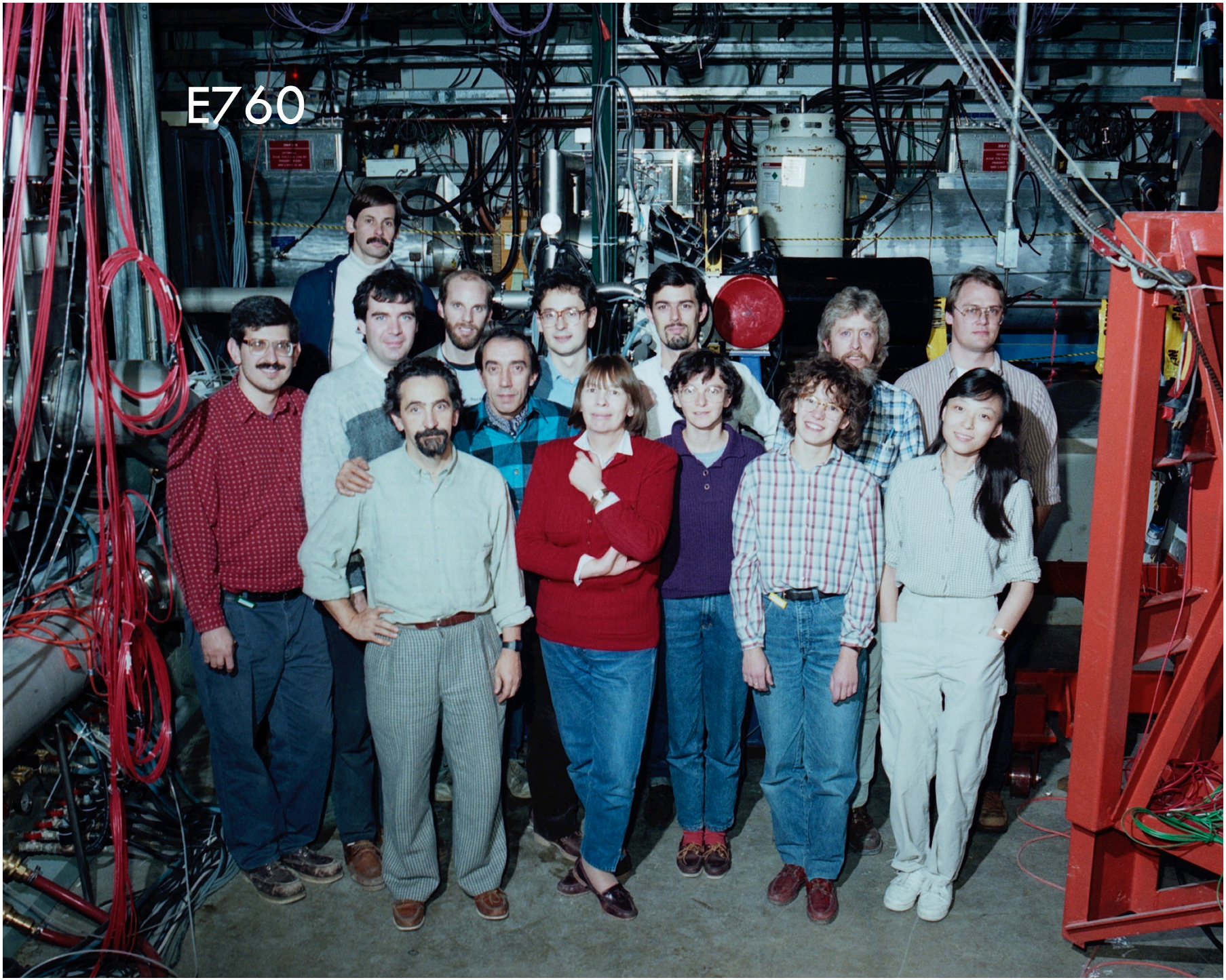

2008



E98

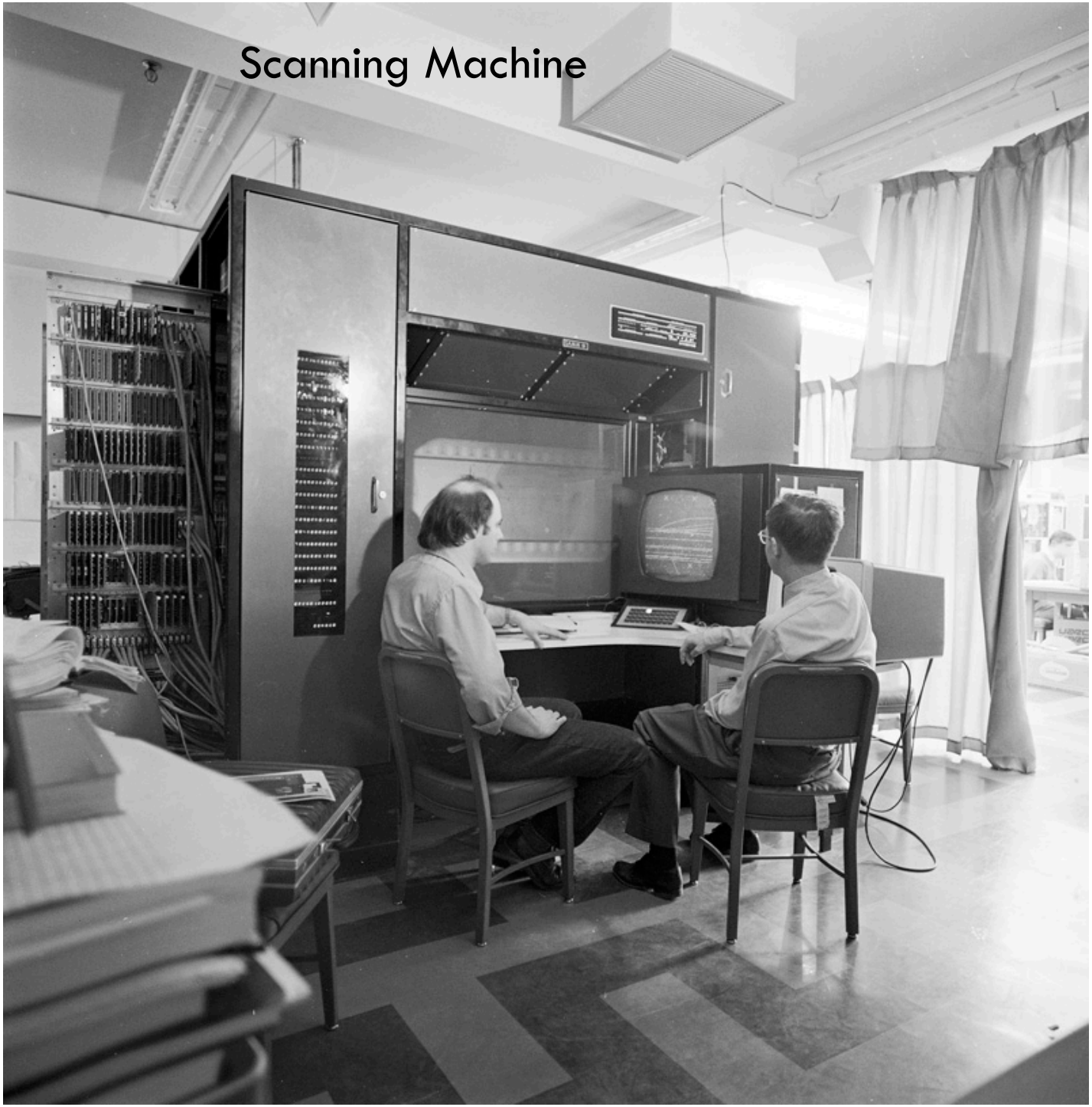
DANGER
MAGNETIC AREA
IF YOU VALUE
WATCH
TAKE IT OFF
YOU ARE IN AT LEAST
1 KILOGAUSS
MUON
98

DoNuT


E760

Meson building construction

Scanning Machine



Safety

ARE YOU
DOING ALL
YOU CAN
TO PREVENT
ACCIDENTS ?
TO HELP
APPROPRIATE FORM BELOW

LINAC construction

Fermilab Dedication 1974

6/7/17

E653

Dan Green

E186
CO