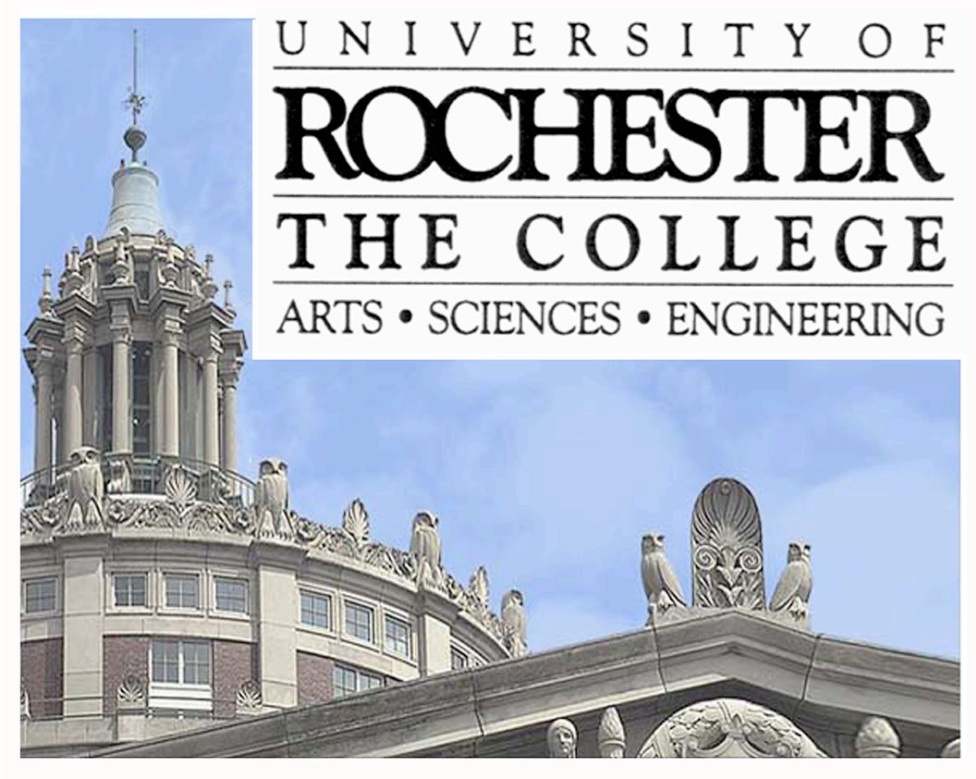
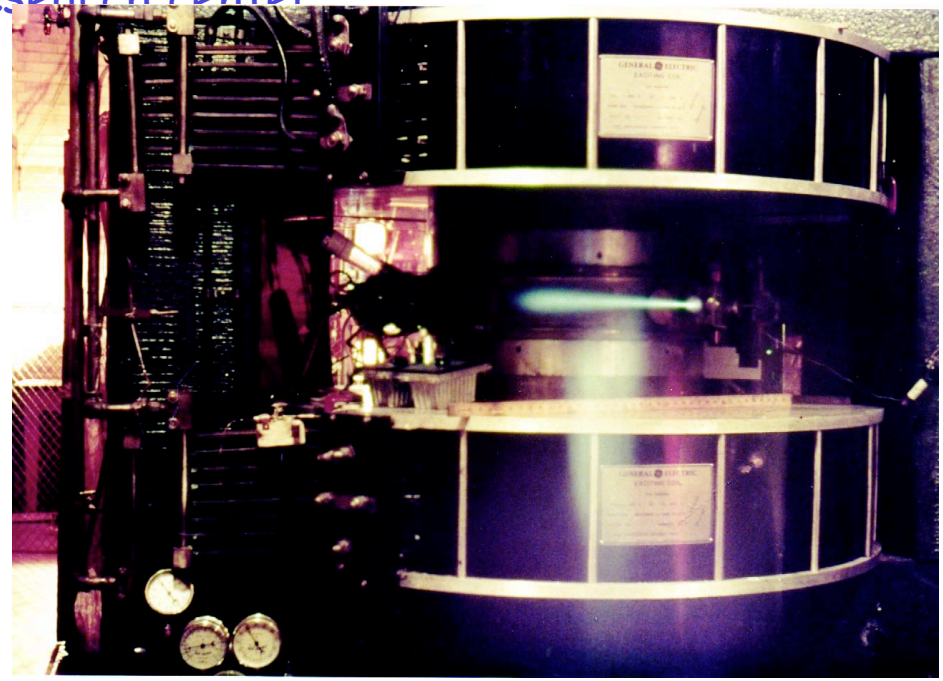



# High Energy Physics

## At the University of Rochester

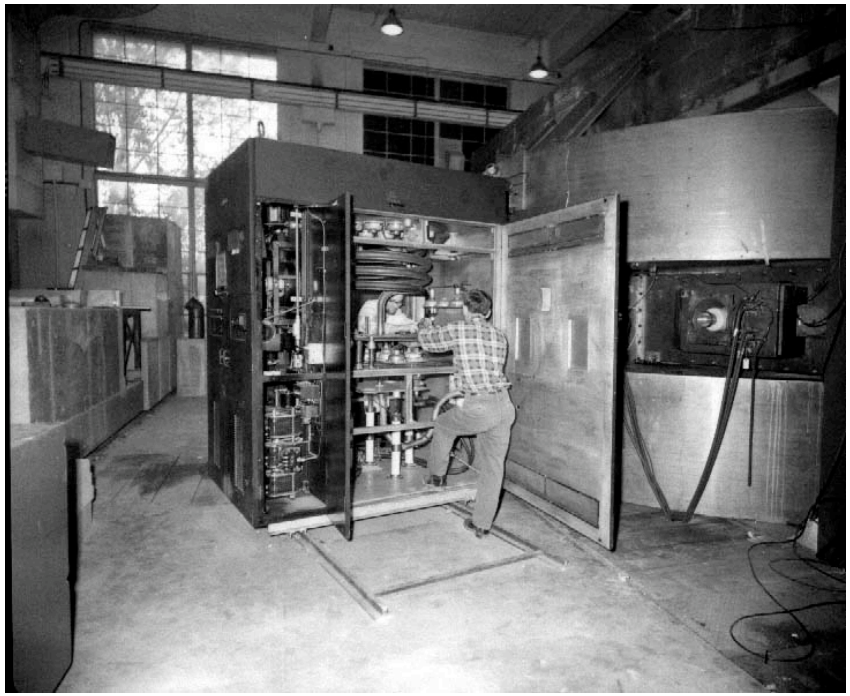
# Origins

- In 1932 George Eastman died, leaving much of his estate to UR.
- In 1934 UR President Rush Rhees hired Lee DuBridge to transform the Physics Department, then primarily focused on undergraduate teaching, into a world-class research center.
- DuBridge successfully sought funds from Kodak to build one of the world's first cyclotrons, which commenced operations in 1935.
- DuBridge hired outstanding faculty, including S. Barnes, F. Seitz, V. Weisskopf, R. Marshak and J. Platt



# The Post-WWII Period

- After the war, DuBridge returned briefly to UR (before becoming president of CalTech), obtaining funds from the ONR to build a larger cyclotron, which at the time of its commissioning in 1948 was (briefly) the highest energy particle accelerator in the world.



# Rochester Conferences

•In 1950 Marshak as department chair initiated the annual Rochester Conferences in High Energy Physics, which brought leading HEP physicists from around the world to campus **to both define and address the most important questions in the field.**

• Since 1960 these conferences (ICHEP) are still known informally as "Rochester Conferences."

8 Nobelists at the 1960 Rochester Conference

E. Segrè & O. Chamberlain [1959], C. N. Yang & T. D. Lee [1957], E. M. McMillan [1951 (Chemistry)], C. D. Anderson [1936], I. I. Rabi [1944], W. Heisenberg [1932]

# Evolution of the Program

- In 1950 the ONR contract was replaced by one from the Atomic Energy Commission, which subsequently led to funding from the Department of Energy. NSF funding of HEP at UR started in 1967.

- The department's two cyclotrons were phased out in the late-60s and UR experimental faculty became users at the world's laboratories: BNL, Cornell, SLAC, Fermilab, KEK, CERN

- Carrying on the tradition of Marshak, Weisskopf et al, we are still trying to <u>identify and address the most important questions in our field:</u>

  - How is electroweak symmetry broken?
  - Is the SM a low-energy approximation to a more exact theory?
  - Why three families?
  - Is the large top mass a clue as to what is behind the SM?

# Current UR Faculty

- 9 Experimentalists:
  - Arie Bodek
  - Tom Ferbel
  - Steve Manly (DOE Nuclear)
  - Adrian Melissinos
  - Kevin McFarland
  - Paul Slattery
  - Ed Thorndike (NSF)
  - Paul Tipton
  - Frank Wolfs (NSF Nuclear)

- 5 Theorists:
  - Ashok Das
  - Carl Hagen
  - Susumu Okubo
  - Lynne Orr
  - Sarada Rajeev

# Theory at Rochester

Additional motivating questions:

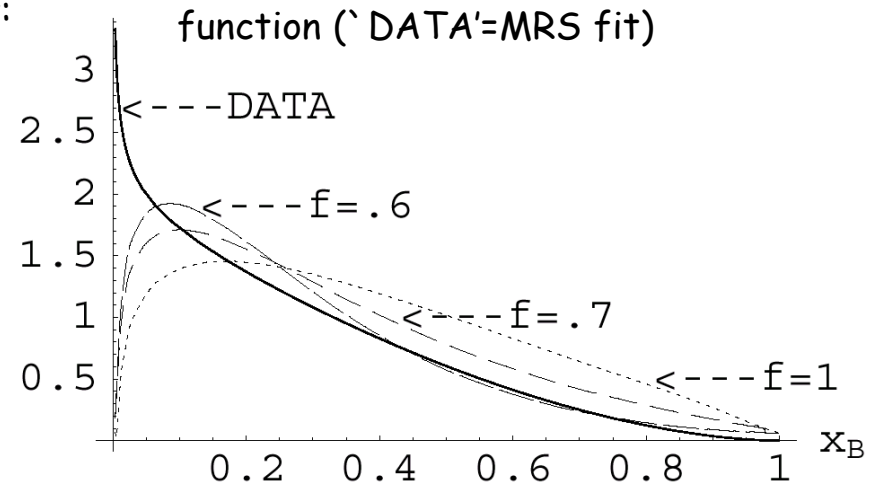
- Is there a theory of everything? What does it look like?
- What will future particle theories look like, in general?
- How can we test out theories experimentally?

To answer these questions, Rochester theorists study:

- M-theory dualities
- Matrix models
- Integrable systems, octonions
- New algebras underlying gauge and string theory
- Quantum field theory phenomena (Casimir effect, etc.)
- Field theory at finite temperature

- Large-N limit of gauge theories and matrix models, including first-principles computation of parton densities:

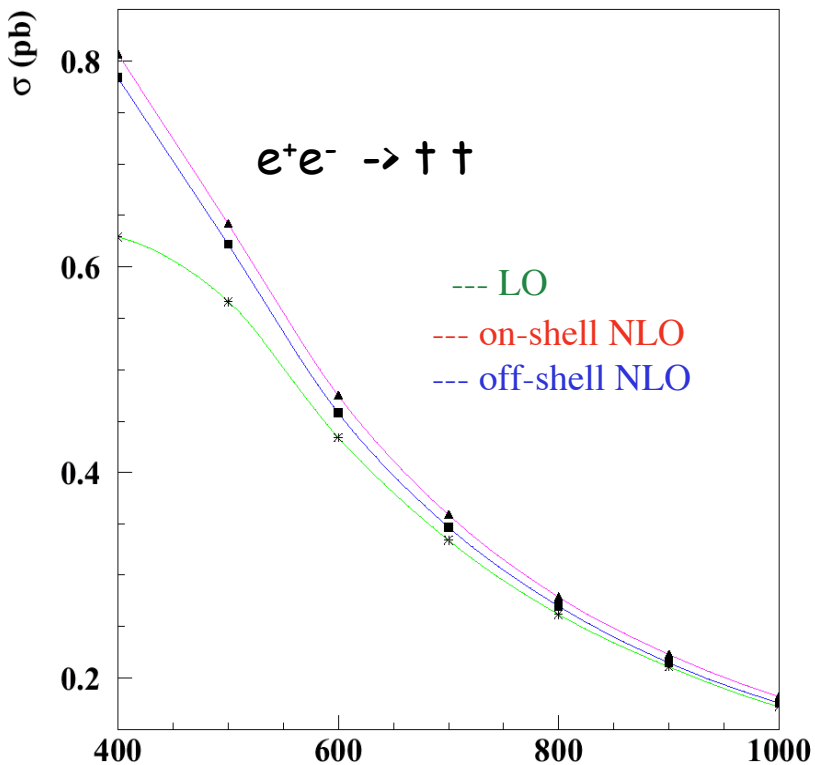
Valence quark parton density function (`DATA'=MRS fit)




G.Krishnaswami and S.Rajeev, Phys. Lett. **B441** (1998) 429.

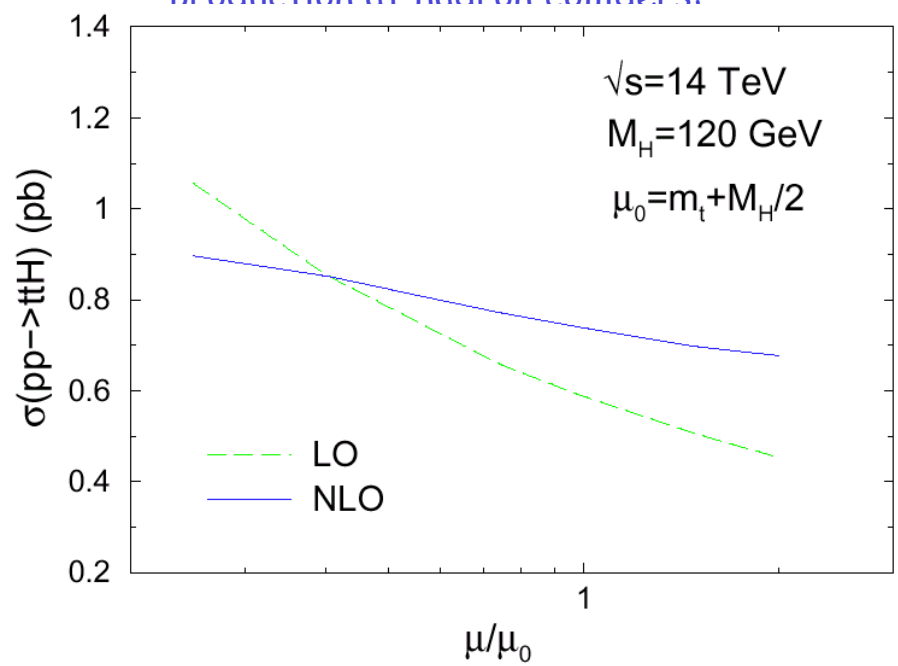
# Theory at Rochester, cont.

- SUSY phenomenology
- Top quark physics at hadron and lepton colliders, including QCD corrections:




C.Macesanu and L.Orr

- QCD and BFKL physics at colliders
- Higgs phenomenology: QCD corrections to top-tbar-Higgs production at hadron colliders:




S.Dawson, L.Orr, L.Reina, D.Wackeroth, in prep.

# The Present Experimental Program

- DOE-funded HEP group:
  - Tevatron Run 2 with CDF and DØ
  - NuTeV
  - Accelerator R&D for a LC at FNAL AØ and for Run 2b (electron cooling in the Recycler)
  - CMS at the LHC
  - Future Neutrino effort at FNAL/NUMI or JHF
- NSF-funded HEP group:
  - CLEO/CLEO-C
- High Energy Nuclear Physics funded by both NSF and DOE:
  - Phobos at RHIC

# UR Participation in CLEO

- PI's Lobkowicz, Olsen, Melissinos and Thorndike built the muon system and oversaw construction of magnet flux return for the original CLEO detector
- UR helped build the CLEOIII tracking chamber
- Thorndike has been spokesperson or co-spokesperson for 7 of the last 20 years
- Thorndike has been associated wit LEO results including:
  - First evidence of naked beauty
  - First observation of b->u
  - First observation of b->s gamma

# Precision $|V_{cb}|$ from $b \to c l \nu$

$$\Gamma_{SL} = c_0 |V_{cb}|^2 \left[ 1 + c_1 \frac{\bar{\Lambda}}{M_B} + c_2 \frac{\lambda_1}{M_B^2} + \cdots \right]$$

B lifetime, B semileptonic decay branching fraction give $\Gamma_{SL}$ to good (and improving) accuracy.

For precision $|V_{cb}|$, need the HQET parameters $\bar{\Lambda}$, $\lambda_1$

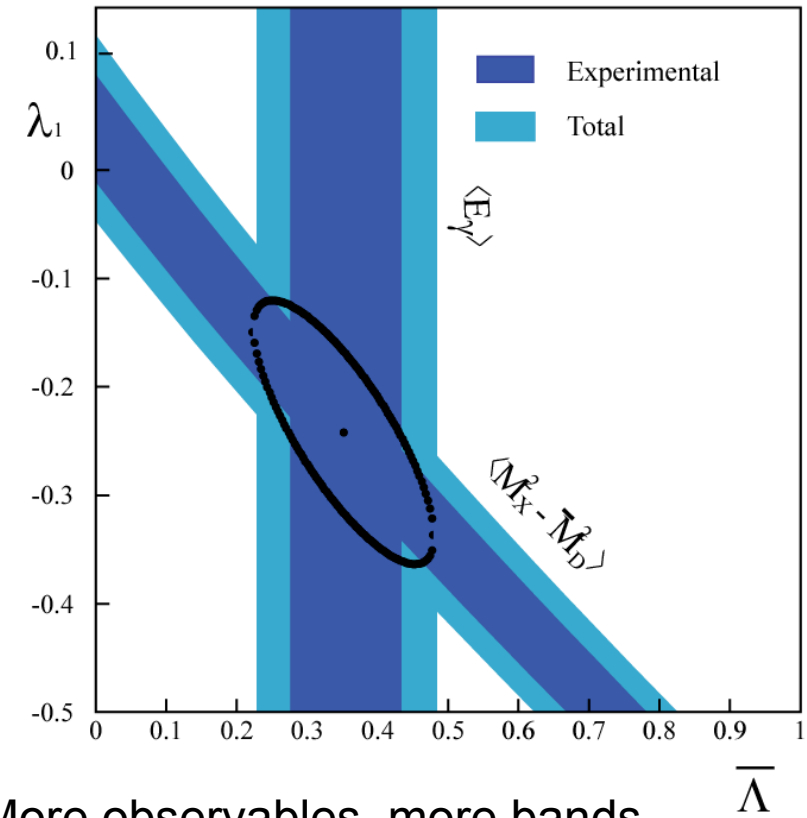
For ANY inclusive B decay observable

$$OBS = OBS_0 \left[ 1 + d_1 \frac{\bar{\Lambda}}{M_B} + d_2 \frac{\lambda_1}{M_B^2} + \cdots \right]$$

Measure 2 observables $\Rightarrow$ 2 bands $\Rightarrow$ $\bar{\Lambda}$, $\lambda_1$

$\langle E_\gamma \rangle$ in $b \to s\gamma$ [PRL 87, 251807 (2001)]

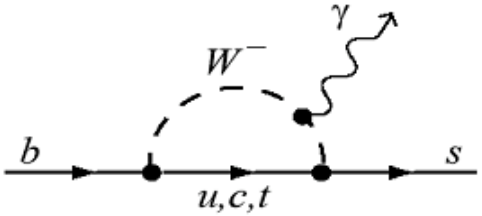
$\langle M_X^2 \rangle$ in $B \to X_c l \nu$ [PRL 87, 251808 (2001)]



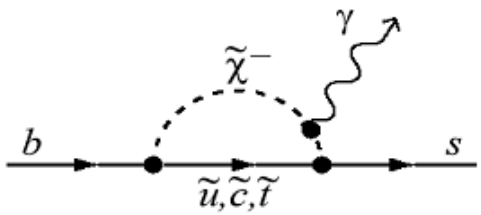

More observables, more bands, will allow these to be reduced

$\Gamma_{SL}$ $\quad$ $\bar{\Lambda}, \lambda_1$ $\quad$ theory $(1/M_B^3)$

$|V_{cb}| = (4.05 \pm 0.05 \pm 0.09 \pm 0.08) \times 10^{-2}$




# b □ s□




## Branching Fraction - Extremely sensitive to "New Physics"

CLEO's first b □ s□paper, PRL 74, 2885 (1995); (U. Roch. Ph.D. thesis, Jesse Ernst) is CLEO's most cited publication, 500+ citations.

In contrast, $E_{\square}$ spectrum very *insensitive* to New Physics. Provides information on *b* quark mass and Fermi momentum. Spectrum used to improve accuracy of $|V_{cb}|$ determination (previous transparency), and also $|V_{ub}|$.

M. Neubert; A.K. Leibovich, I. Low, I.Z. Rothstein

Fraction of b □ ul□ lepton spectrum above $E_0$, (some cut near endpoint) given by

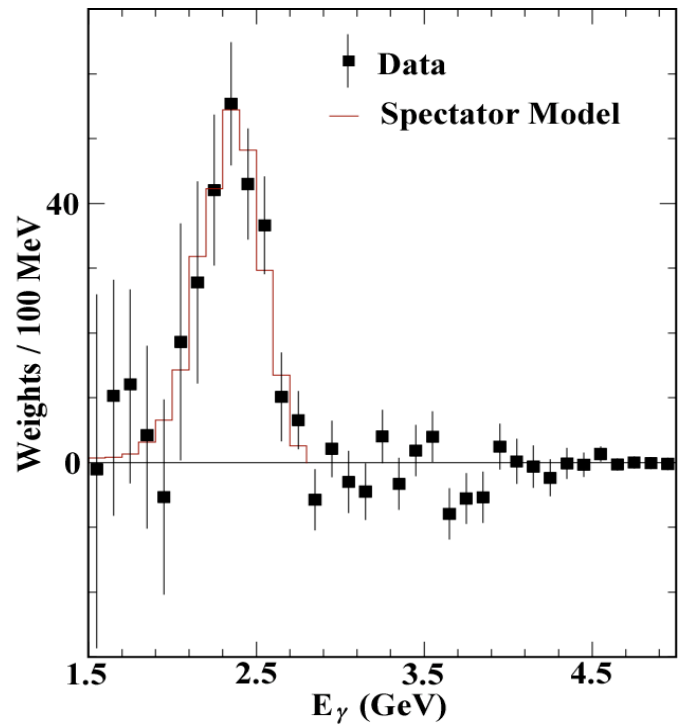
$$f_u(E_0) = \int_{E_0} w(E_{\square}, E_0) S(E_{\square}) dE_{\square}$$

Our measurement of $S(E_{\square})$, plus

Minnesota group measurement of □B(> $E_0$)

□ $|V_{ub}|$ PRL 88,231803 (2002)

Theorists now debating corrections

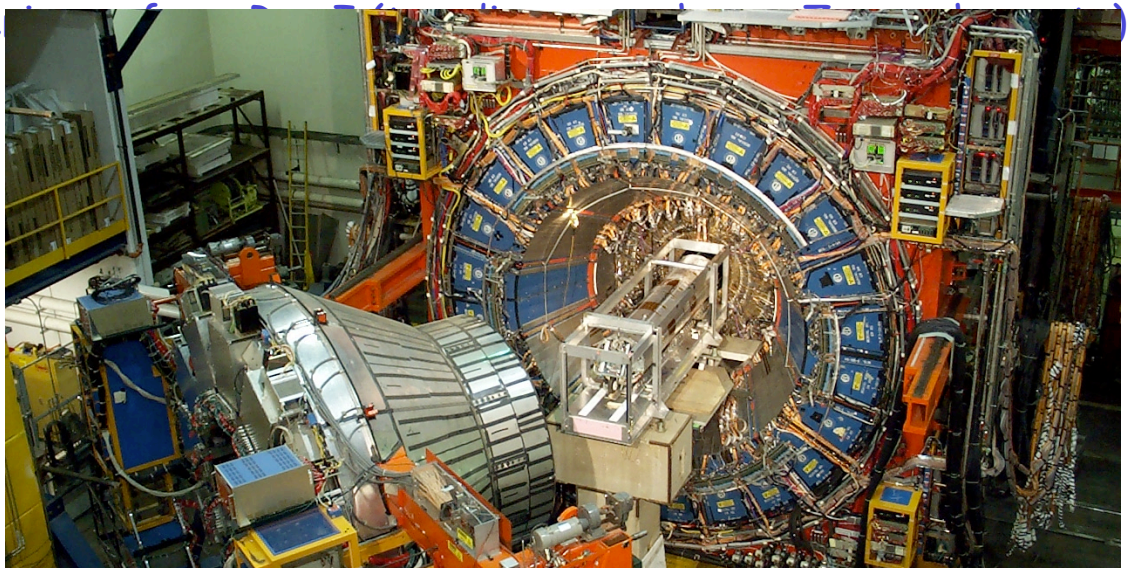


# CDF, DØ and Run 2

CDF effort led by Bodek, Tipton, McFarland

We are focused on:

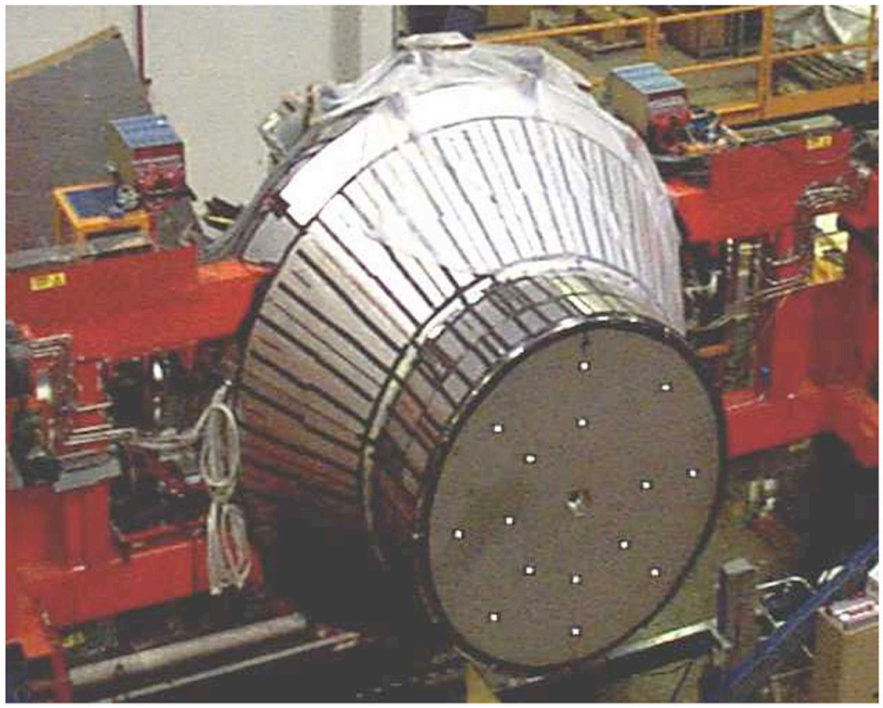
- Tests of the SM in and around the top candidate sample
- Production and decay parameters of the Top Quark
- Search for new W and Z Bosons
- Higgs Search
- Much expe



# CDF

Run 2 contributions to CDF focus on three areas:

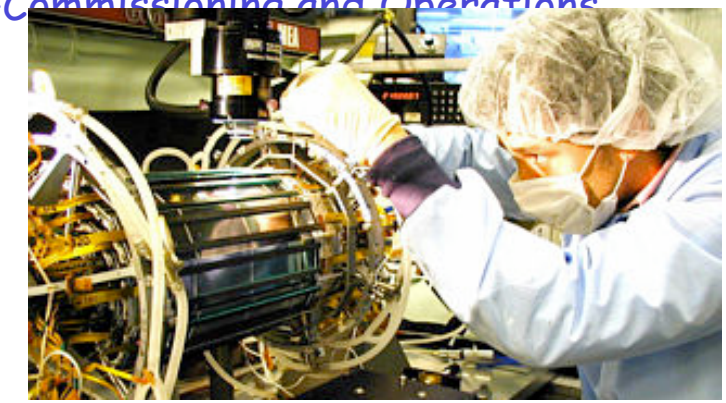
- Run 2 forward calorimeter -- 'endplug' (Bodek)
  - -Hadronic section a Rochester-led effort
  - -Constructed at FNAL with Rochester physicists and technicians doing fabrication, QA, testbeam, installation, commissioning and operations



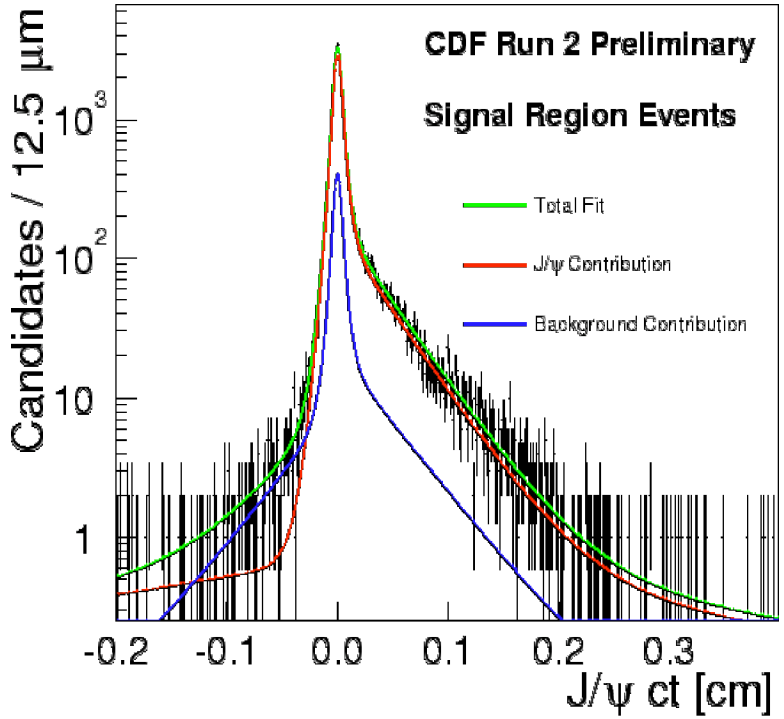
# CDF, cont.

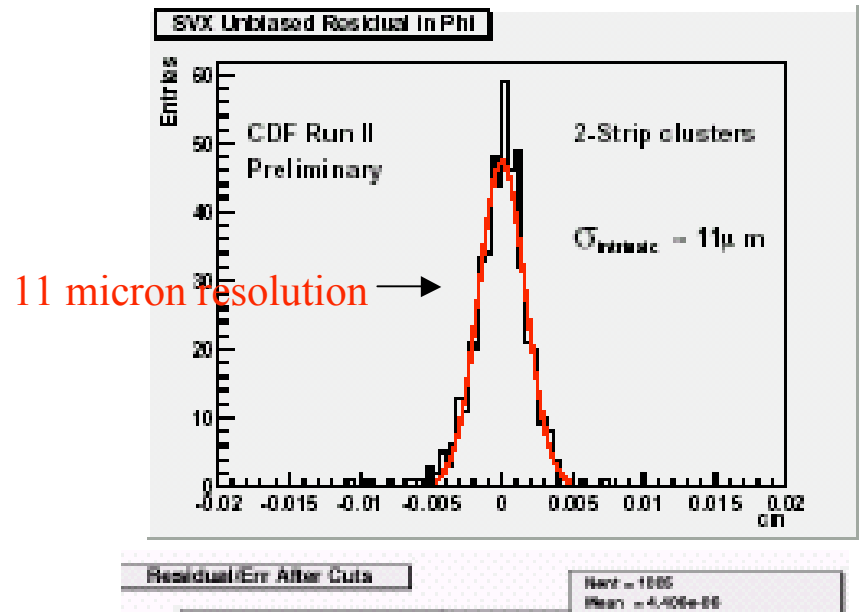
Second area of Focus: Silicon Tracking

- Run 2 SVXII (Tipton)
  - -Rochester group contributed to SVXII Ladder and Barrel fabrication
  - -Silicon Cooling and Interlocks
  - -Radiation Monitoring and Tevatron abort
  - -Commissioning and Operations

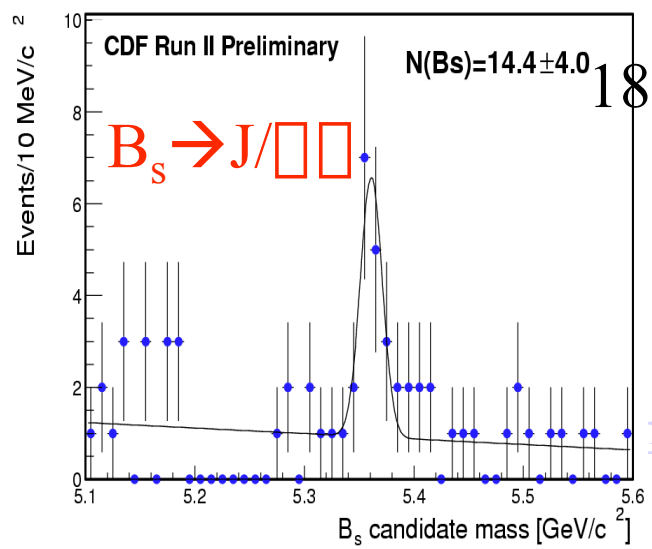


# Silicon Performance




11 micron resolution




$B_s \rightarrow J/\psi\phi$

18.4/pb

- Inclusive B lifetime with J/□'s

  $c\tau$=458±10$_{stat.}$ ±11$_{syst.}$ □m (PDG: 469±4 □m)

- Exclusive $B^+ \rightarrow J/\psi K^+$ lifetime

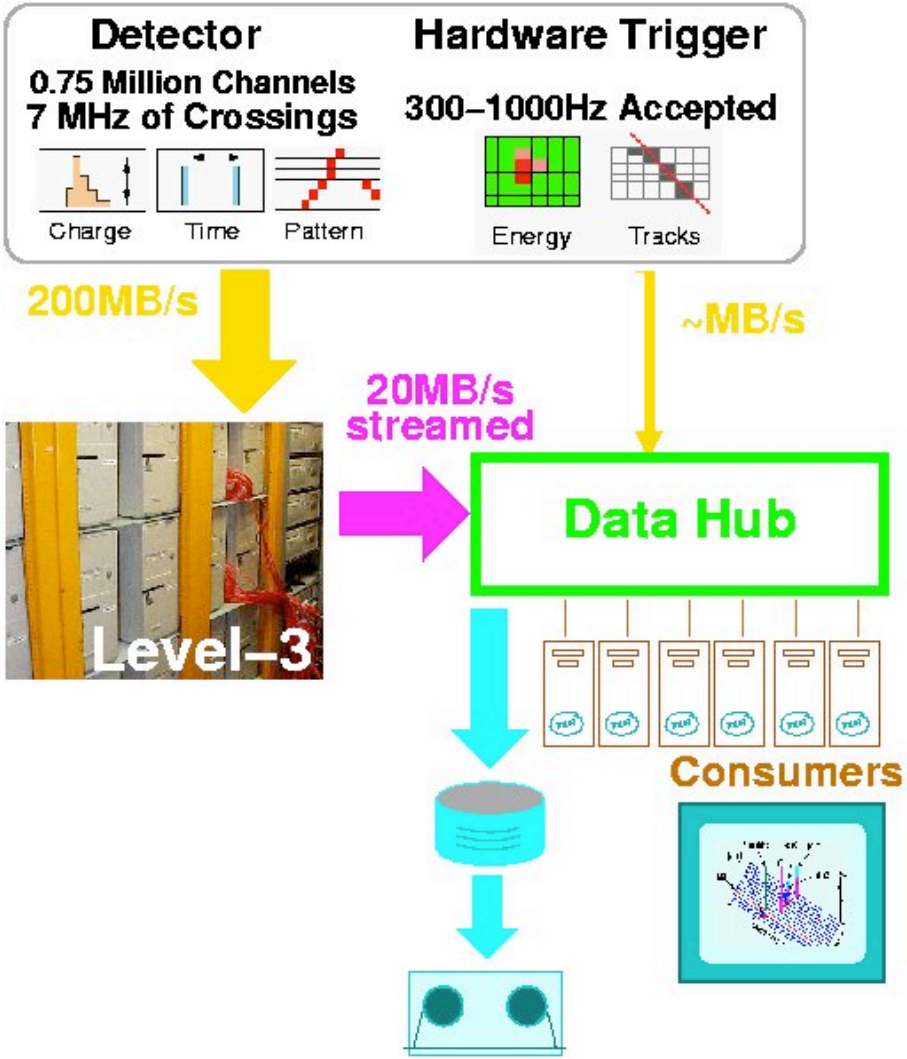
  $c\tau$=446 ±43$_{stat.}$ ±13$_{syst.}$ □m (PDG: 502±5 □m)

mass plots

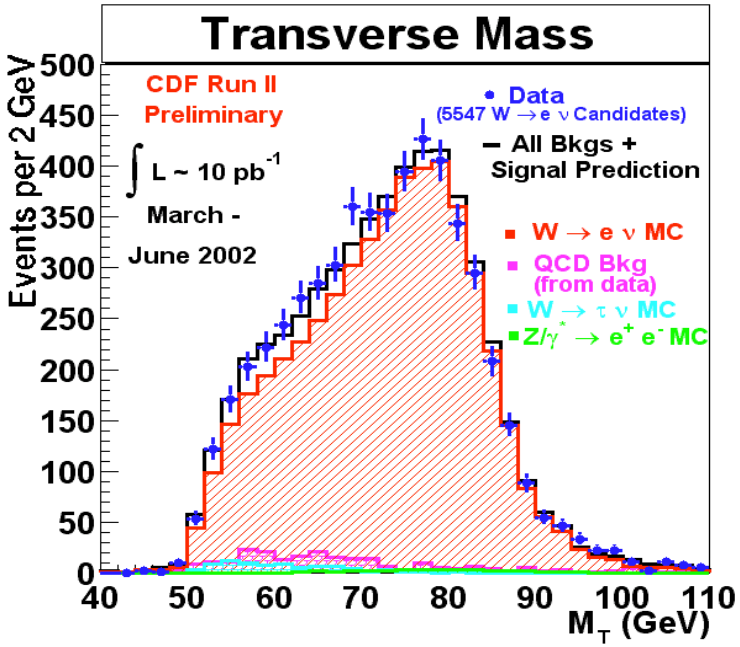
# CDF, cont

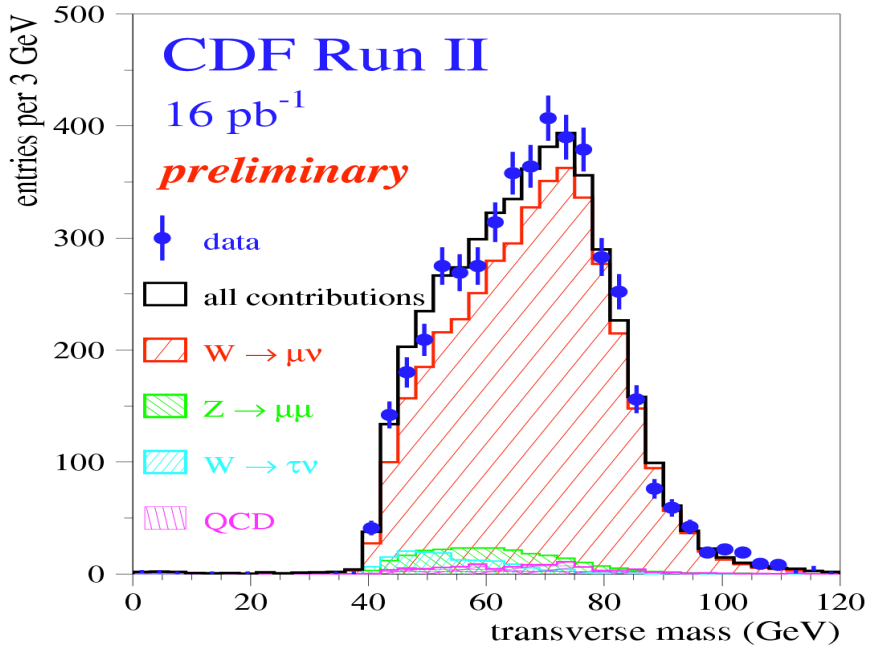
Third area of Focus: Level 3 Trigger/Data Hub

- Level 3 (McFarland)
  - -Responsible for software trigger based on offline reconstruction
  - -Current_Run2b Bandwidth
    - -Input rate: 80_200 MB/sec
    - -Output: 20_60 MB/sec
  - -"Data Hub" takes accepted Level-3 events, logs them and distributes to online monitoring system
  - -Level-3 selections determine offline datasets after processing
    - -Allows CDF to find events in its firehose of a datastream



# Run 2 Measurements of □□(W→e□, □□)




$M_T$

**5547 candidates in 10 pb$^{-1}$**

$\square_W$*BR(W→e□) (nb) =

$2.60 \pm 0.07_{stat} \pm 0.11_{syst} \pm 0.26_{lum}$

**4561 candidates in 16 pb$^{-1}$**

□·B(W→□□) =

$2.70 \pm .04_{stat} \pm .19_{syst} \pm .27_{lum}$

Run 1 scaled to 1.96 TeV: $2.72 \pm 0.02_{stat} \pm 0.09_{syst} \pm 0.10_{lum}$

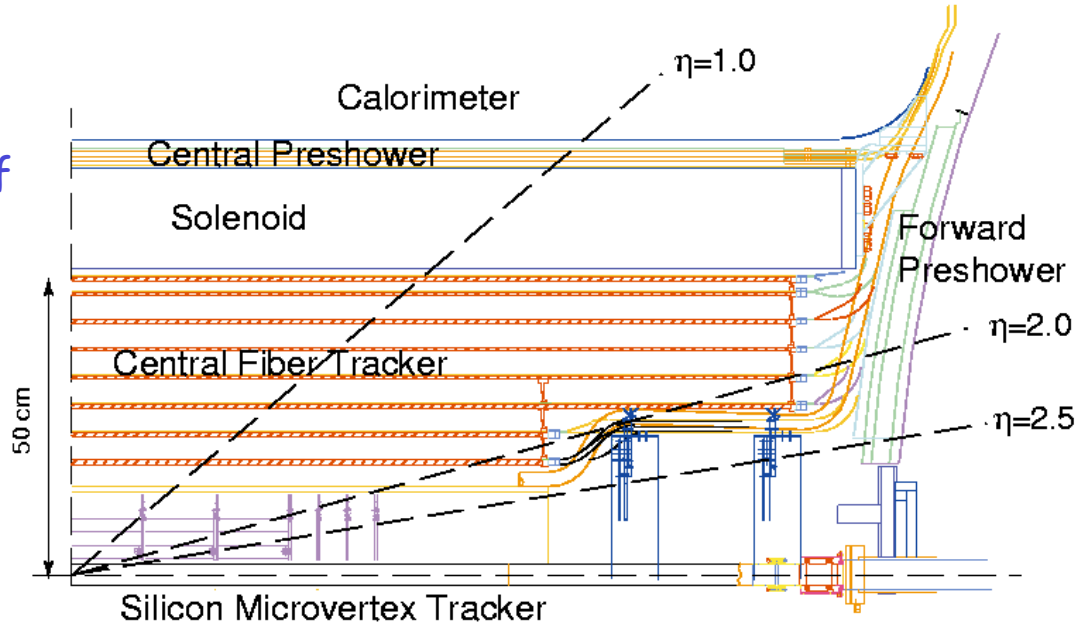
# Rochester's Participation in DØ

## PIs Ferbel and Slattery

- UR contributions to the DØ Run 1 detector included:
  - Supplying the calorimeter's LA purity and temperature monitoring systems
  - Coordinating the experiment's test beam effort
- Contributions to the Run 2 detector include:
  - Contributing to early R&D on the Fiber Tracker (FT)
  - Providing the VLPC (Visible Light Photon Counters) cassettes for the FT
  - Present leadership of the FT commissioning effort
  - Shared leadership of the Run 2a & 2b upgrades of the Online system
  - Providing the Run 2 luminosity data base and associated software tools
- Contributions to the Run 2 analysis software include:
  - Responsibility for the GEANT-based and fast (parameterized) calorimeter MCs
  - Developing Level-3 calorimeter cluster, electron, and jet ID algorithms
  - Providing the online display (EXAMINE) software for the calorimeter
- Contributions to the Run 1 and Run 2 physics analyses

# The DØ Tracker for Run 2

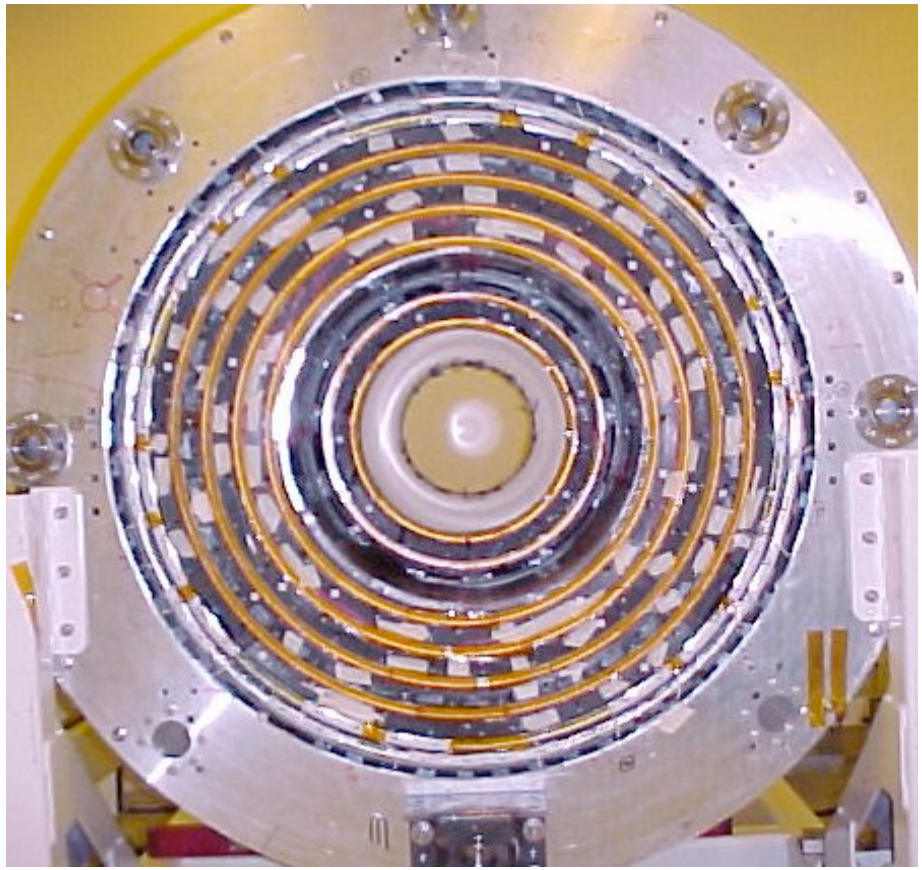
- The DØ tracker for Run 2 is a completely new system, consisting of a silicon microvertex tracker (SMT) enclosed by a central fiber tracker (CFT), both devices contained within a new solenoidal magnet.




- The central (CPS) and forward (FPS) preshower detectors are also new detector components used to restore the calorimeter's earlier performance in the presence of the additional pre-calorimeter material.

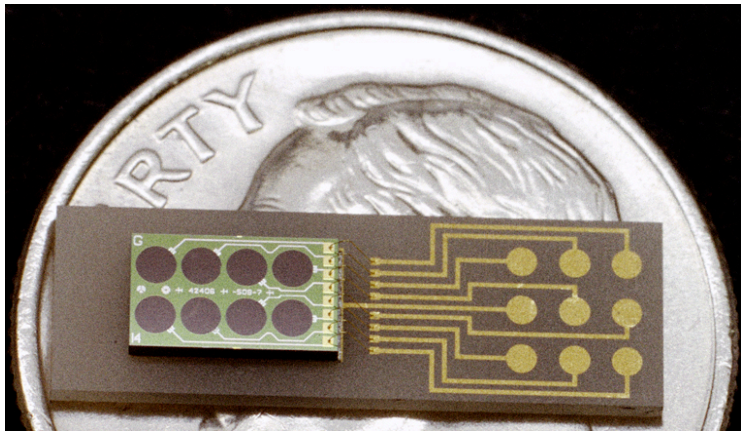
# The DØ Central Fiber Tracker (CFT)

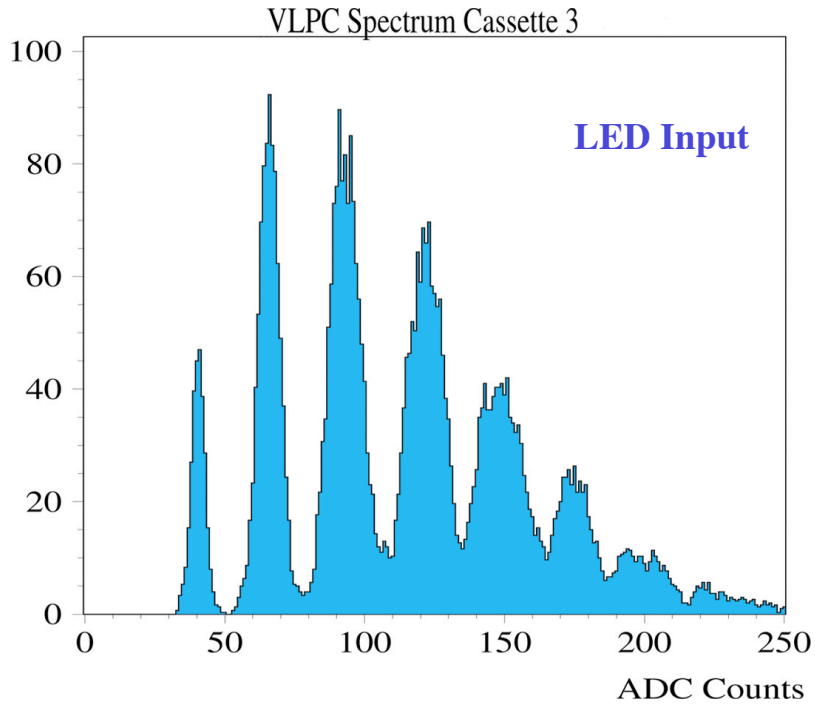
- The CFT consists of 8 concentric carbon fiber support cylinders on which are mounted pairs of ribbons of 835 μm scintillating fibers aligned in axial and 3° stereo orientations.
- The position resolution of a fiber doublet is ~100 μm. The CFT readout requires a total of 76,800 fibers.
- Rochester contributed to the development and construction of the DØ CFT in numerous ways, but principally by building the devices that detect the ~8 photons/MIP that reach the external readout.



# Visible Light Photon Counters (VLPCs)

- VLPCs are solid state devices capable of detecting single photons.
- The DØ devices consist of 1 mm pixels in a 2 ▯ 4 array operating at 9 K.
- Rochester physicists built the 99 VLPC cassettes need for the CFT and PS. Each contains 1024 channels. Achieved exceptional QC (< 0.15% defective channels).
- The plot displays the LED calibration of a typical VLPC cassette. Successive peaks are for 0, 1, 2, 3, … photoelectrons, respectively.
- <u>CFT performance</u>: Hit efficiency approximately 97%.

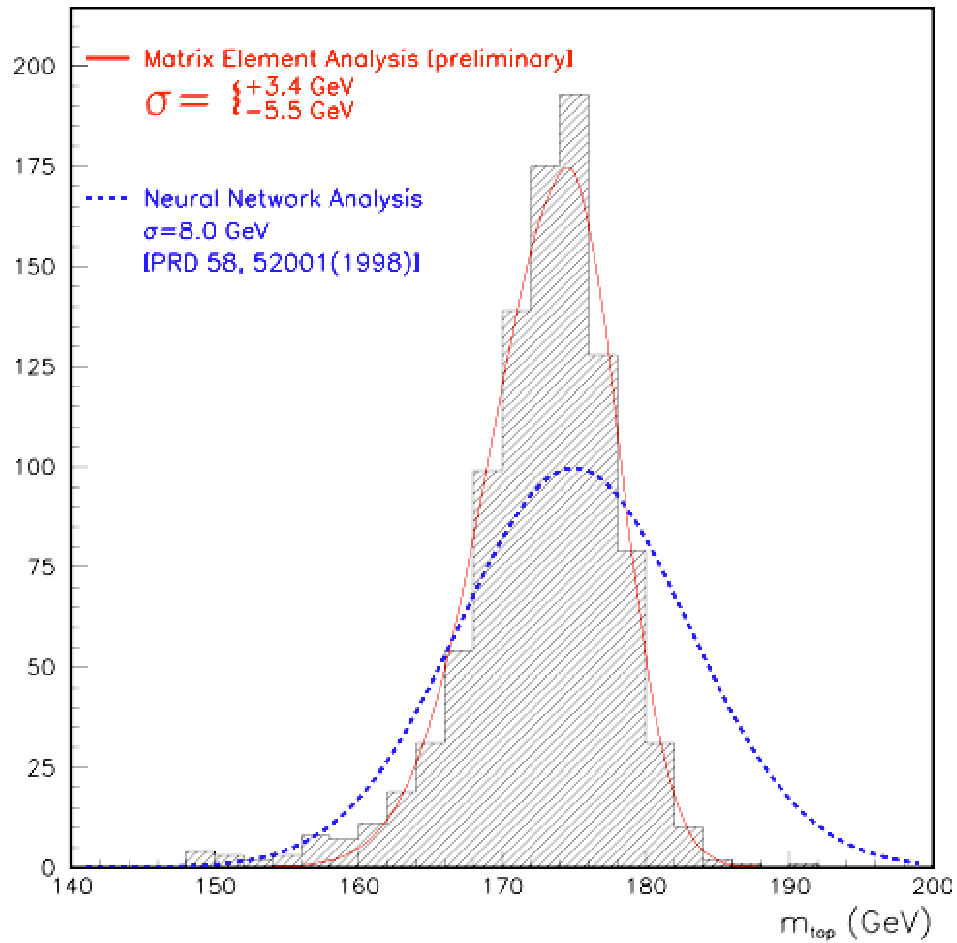




# Contributions to Top Analysis

Note that this slide does not print correctly!

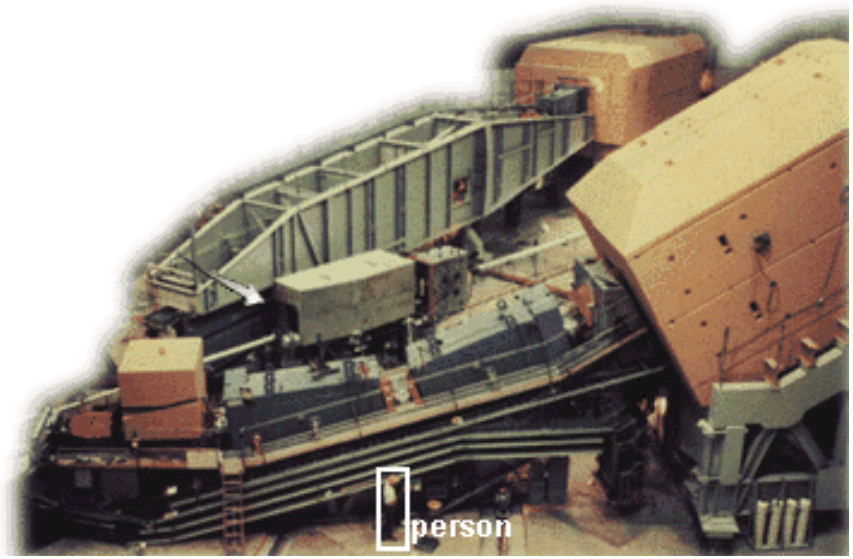
- Shared leadership of all Run 1 studies of top properties after the initial discovery
- Studies of the $t\bar{t}$ to all-jets channel
- Improved measurement of the top mass:
  - The plot compares preliminary results from a recent analysis of the *lepton + jets* Run 1 data set to the published results obtained in the original NN-based analysis
  - The new analysis employs a novel matrix element based technique developed by Rochester and Fermilab physicists
  - The histogram displays the top mass results obtained from a Monte Carlo ensemble of experiments having comparable statistics (in both signal & background) to the data, while the curve depicts the published uncertainty in the measured top mass



# UR Lepton Scattering Program

## PIs Bodek, McFarland

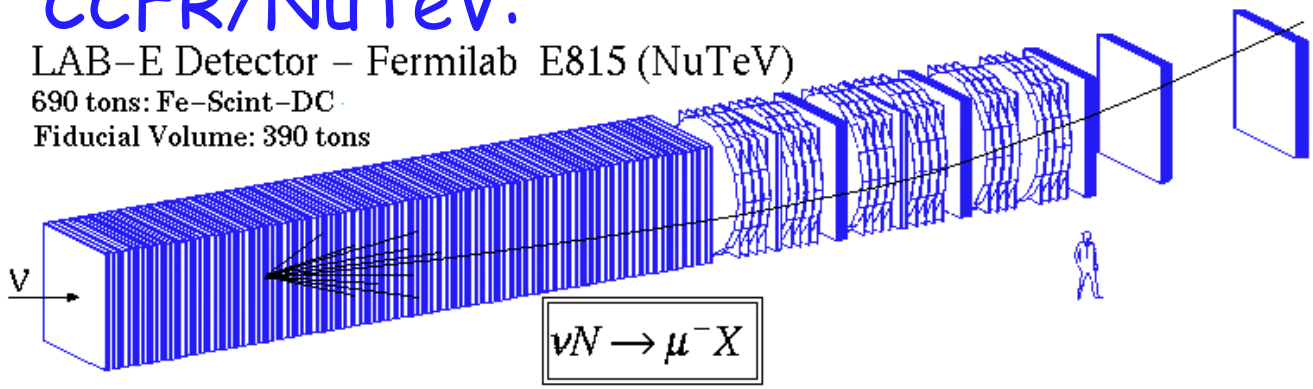
- Rochester upgrade to the spectrometer at SLAC for the E140 electron scattering experiment (1983-1993)
- Enabled a series of precision electron-scattering experiments
- Measured structure functions F1,F2 and nuclear effects

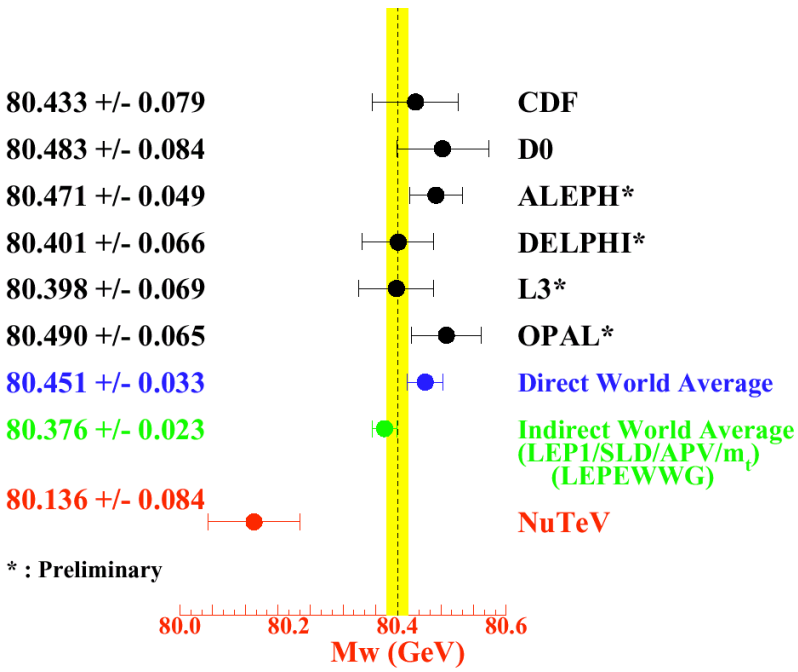



- In Parallel, measure structure functions at high energies with neutrinos on iron at FNAL with CCFR/NuTeV

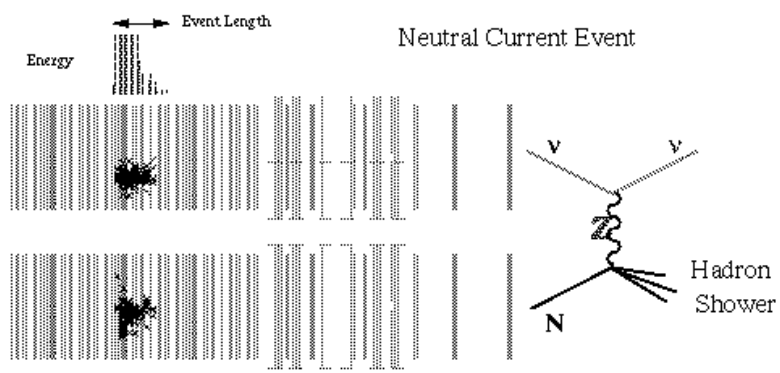
# UR Lepton Scattering Program, cont.

## CCFR/NuTeV:



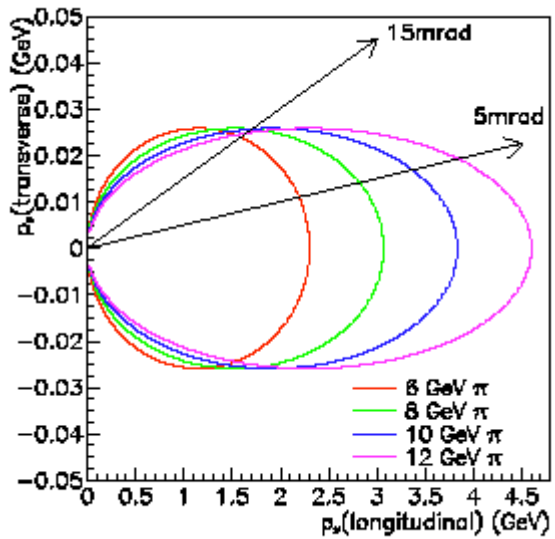

- $\sin^2(\theta_W)$ is extracted from the measurement of ratio of neutral-to-charged current interactions



# UR Lepton Scattering Program, cont.

Proposed off-axis Neutrino Scattering (Bodek, Manly, McFarland, Slattery)

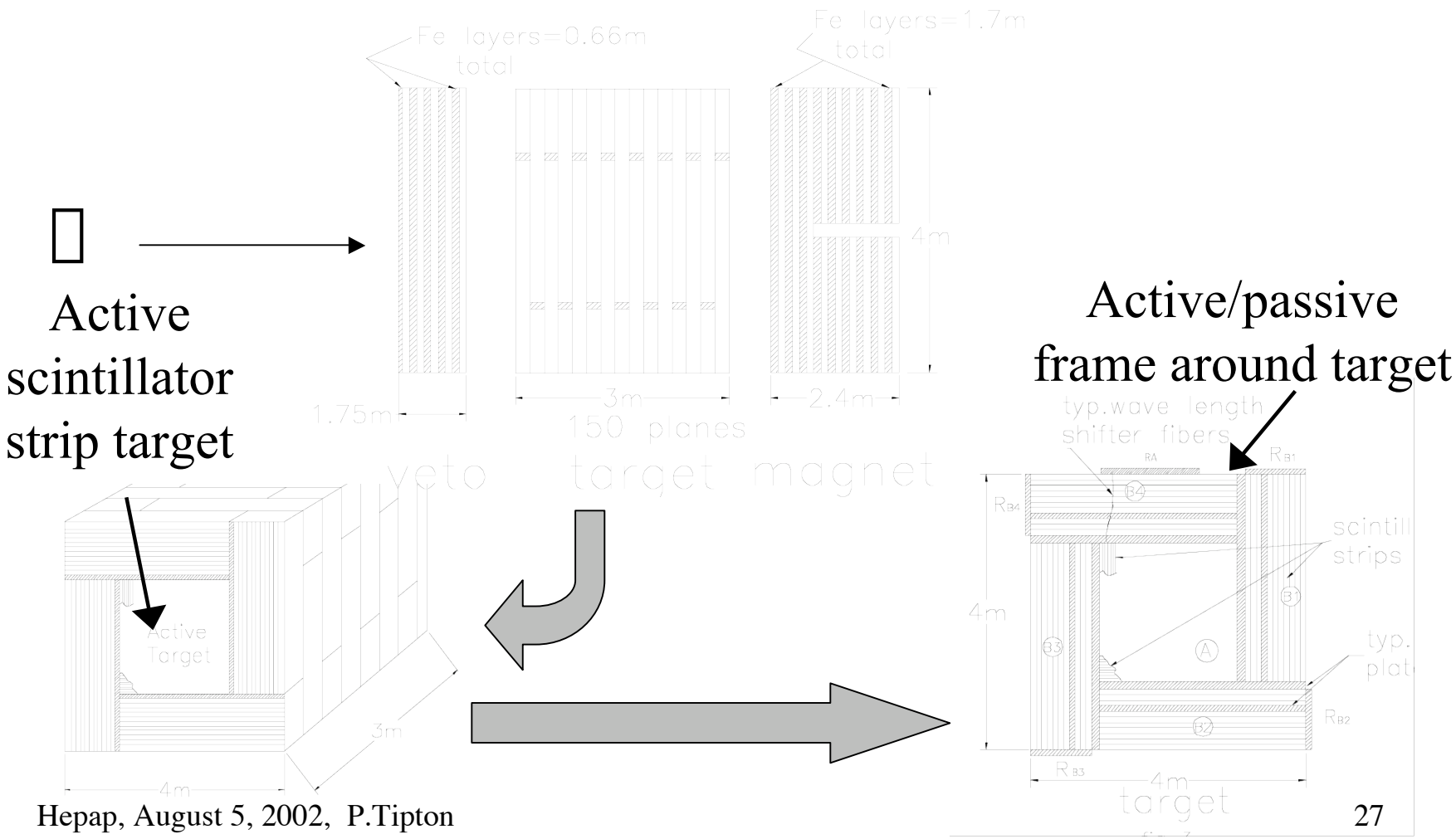
- Goal is to observe electron-appearance in muon neutrino beam
- Off-axis gives 'mono-energetic' low-energy neutrinos which minimizes cc background from high energy neutrinos
- Near detector is key in understanding both the beam and the backgrounds
- Near detector technology will mimic the far detector but with no passive material
- EOI at FNAL, awaiting decision on JHF




- Numi/JHF offer 2 orders of magnitude increase in neutrino rates at lower energy over existing data
- QCD with low energy neutrinos (J-lab with neutrinos)…duality, nuclear effects…

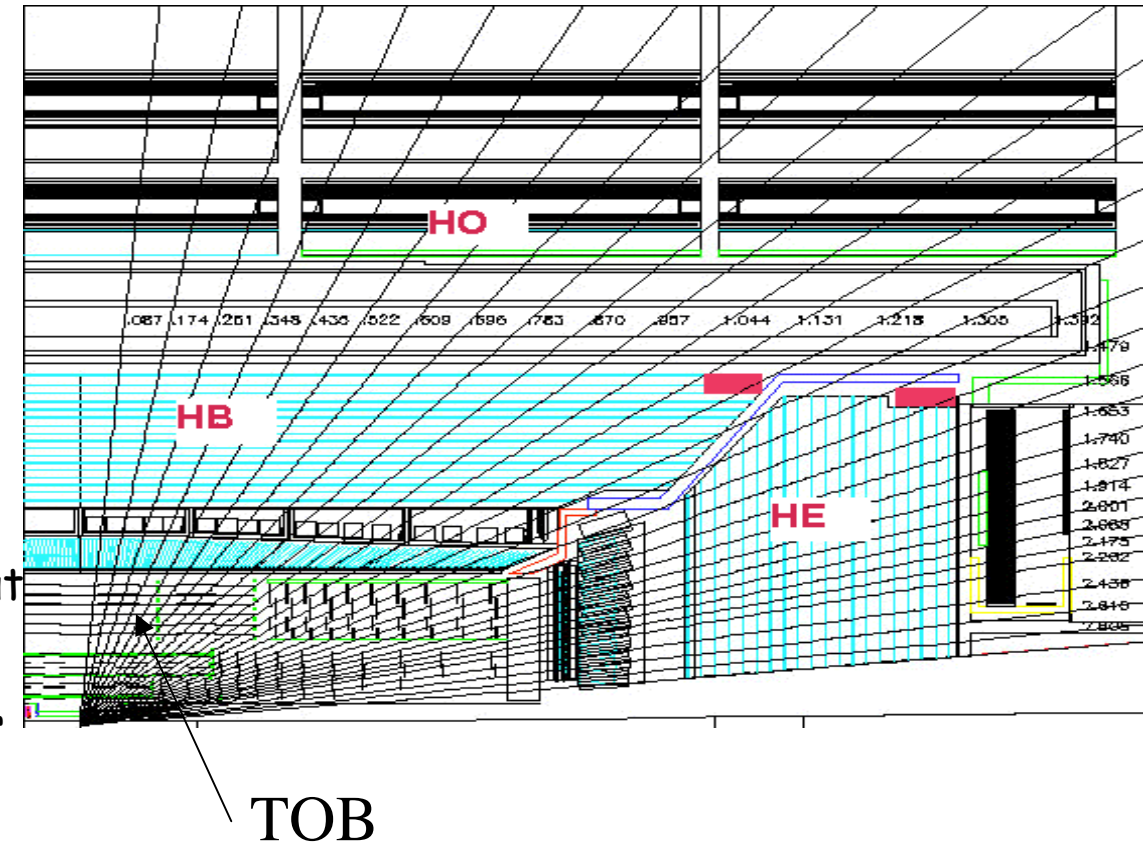
# Fully-Active Off-Axis Near Detector (Conceptual)

2 ton fiducial volume



# UR CMS Responsibilities

- HCAL (Bodek, Slattery)
  - Construction of the Hadron Barrel (HB) Calorimeter
  - Optical Readout System for HB Calorimeter
  - Assembly&Integration of Readout boxes for HB, HE and HO
  - Construction of Motion Table for H2 test beam at CERN




- Tracker (Tipton)
  - Burn-in system, mechanical QA, transportation boxes for Tracker Outer Barrel, TOB

# CMS Optics Factory

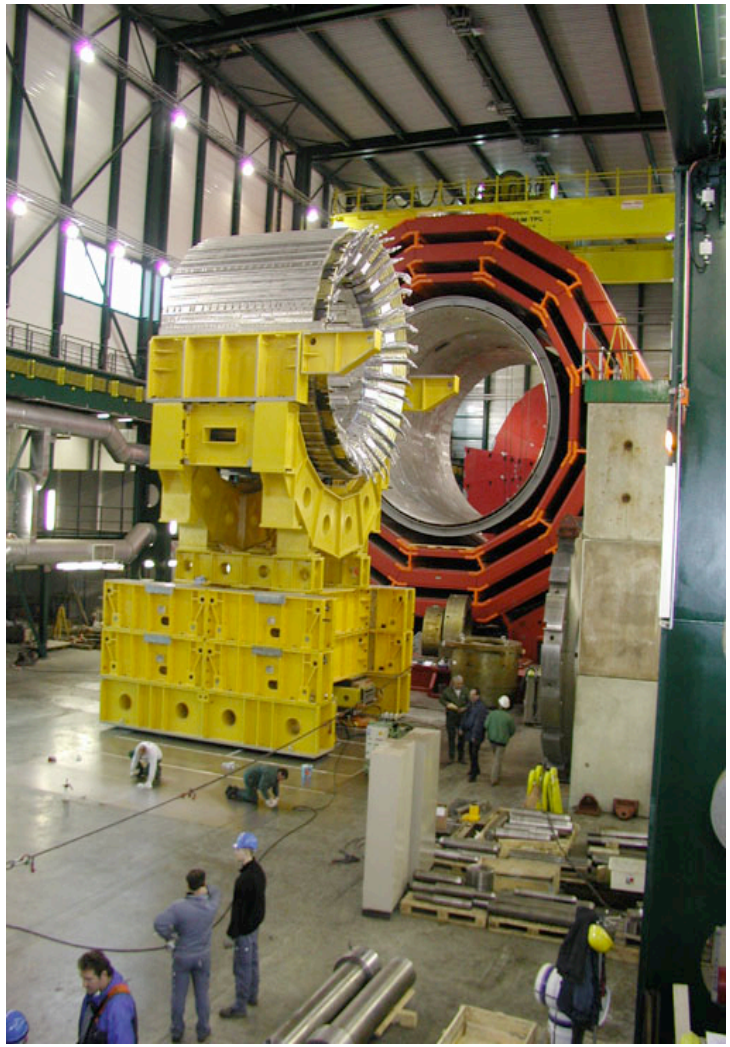
## At FNAL:

- P. de Barbaro is L3 manager responsible for HCAL Optics ($3.7M project)
- Supervise crew of 12 Rochester technicians at Fermilab and are responsible for scintillator machining and fiber/connector production, QA

## At CERN:

- Scintillators installed into HB wedges at bldg 186
- All HB wedges tested with radioactive source system, pronounced "ready"
- Wedges transported to SX5 for installation into cradle..

# HB- Assembly at SX5

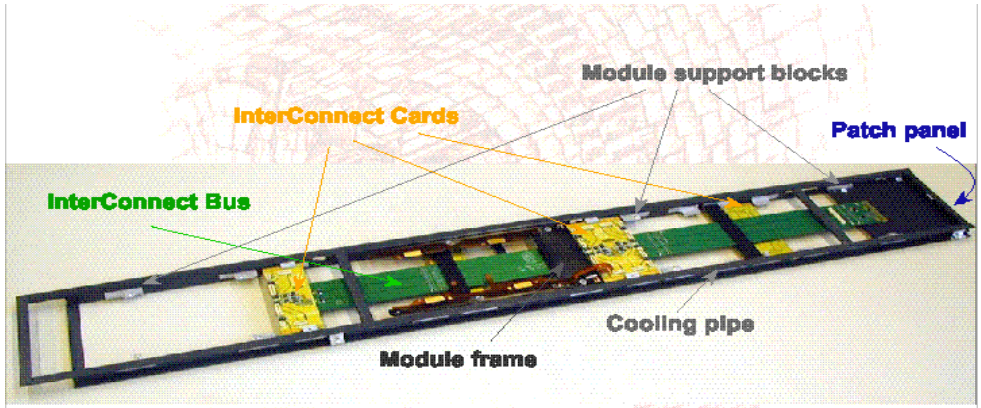


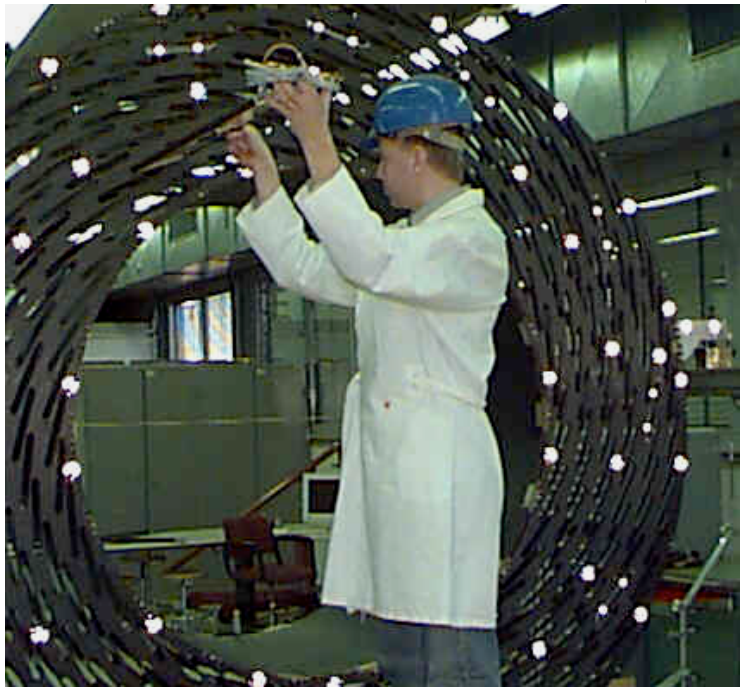
- Assembly of HB- completed in Fall of 2001
- Assembly of HB+ into cradle will be completed in Sep 02.

# US CMS TOB Project

- 6 Layers covering |Z|<1.1m at 0.6m<R<1.0m
- layers 5-10.

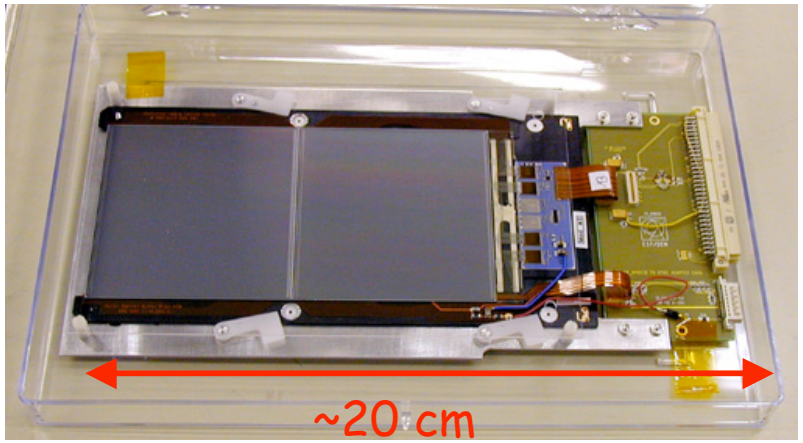
- Basic building block of TOB is a rod comprised of

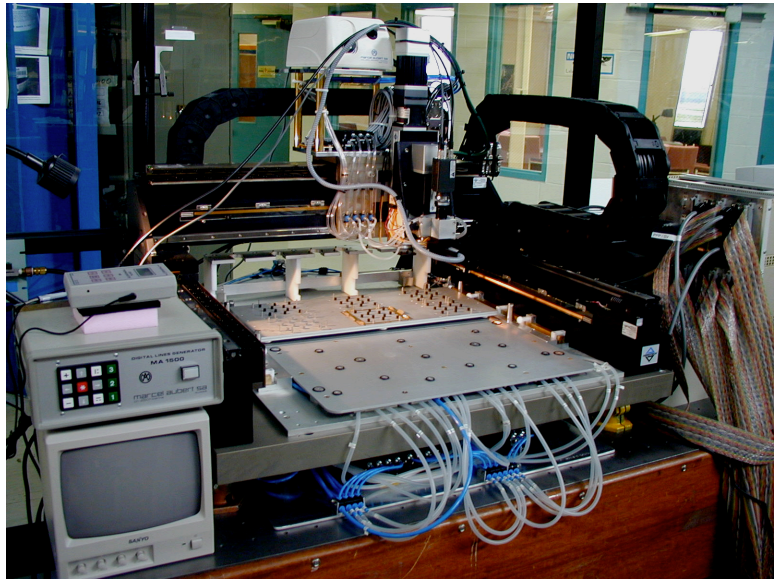


# US CMS TOB project, cont.

- TOB consists of 6,000 modules to be built at FNAL and UCSB using 'gantry' robotics
- We subsequently place modules into 700 rods
- After burnin, testing and thermal-cycling we ship completed rods to CERN
- Rochester responsible for
  - Burn-in/thermal-cycling facility for rods
  - Mechanical inspection and QA for module production

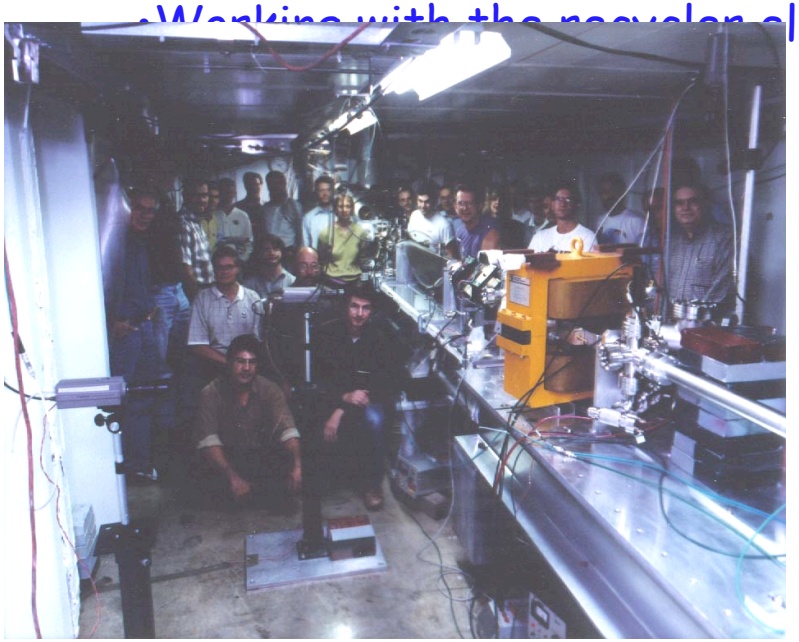


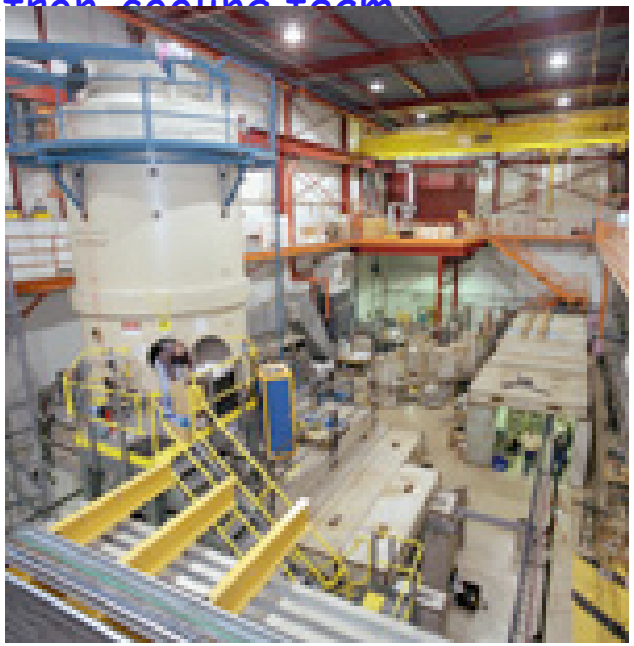



# UR Accelerator R&D

## PI Melissinos:

- Responsible for the laser in the AØ photoinjector project
- Responsible for the drive laser in the Northern Illinois-led collaboration (NICADD) LOI for high-brightness 3rd generation photoinjector
- Working with the recycler electron cooling team



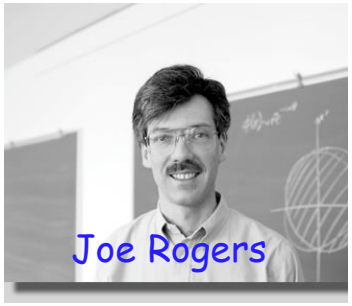


# Maintaining our Strength

- We have a very supportive administration
- A new experimental hire is authorized for this calendar year
- We have established a Marshak Postdoctoral Fellowship, partially endowed, to compete with similar Fermi, Millikan Fellowships

# Producing Scientists as well as Science

- Since 1980:
- 104 Ph.Ds,  34 now in faculty positions, 25 at national labs or similar research institutions
- 96 Post-docs, 37 now faculty, 28 at national labs or similar research institutions



# HEP Research Recognition

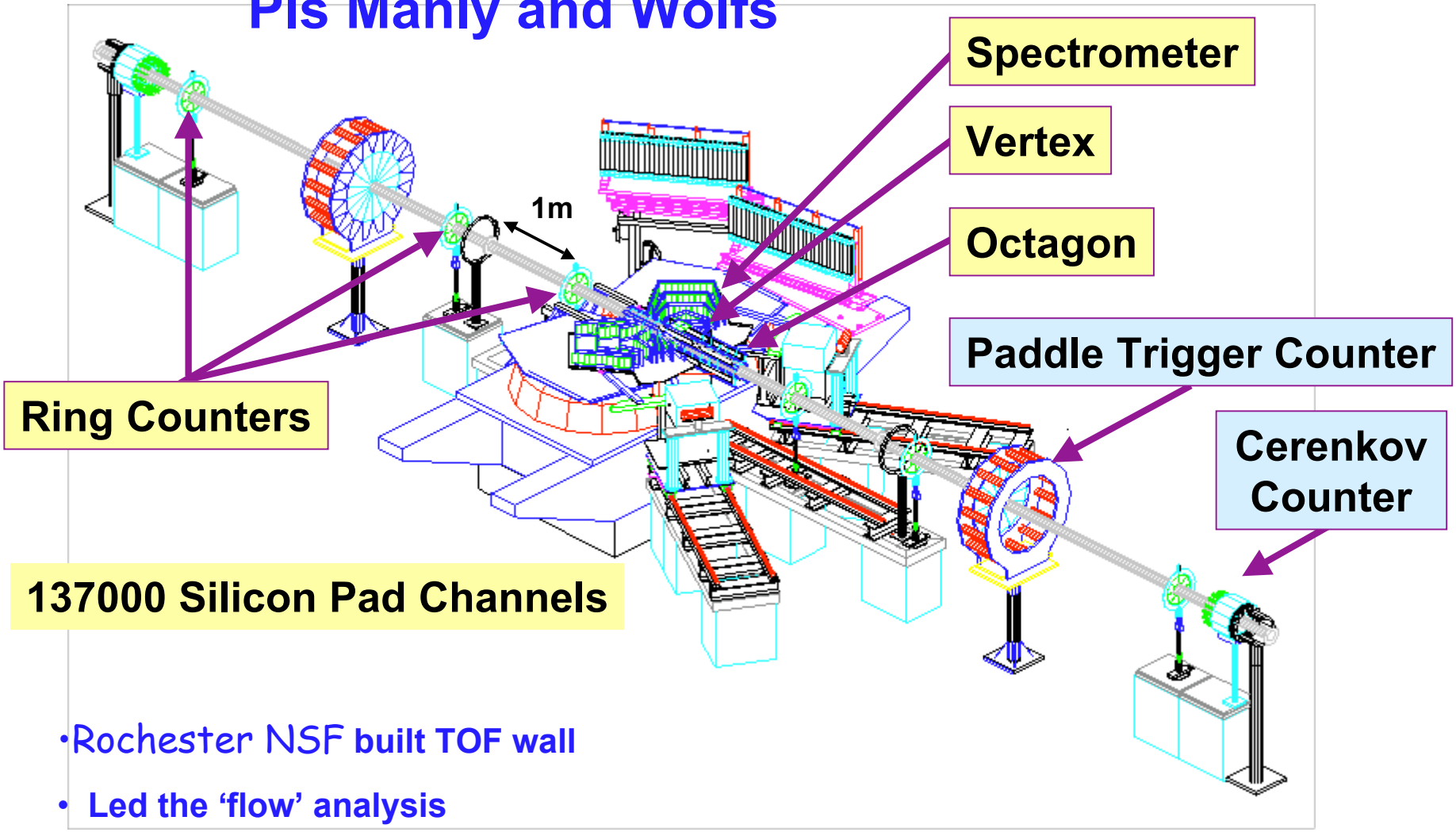
- Many HEP faculty have received individual recognition for their research
  - Panofsky Prize of American Physical Society — Thorndike
  - Nishina Foundation Award (Japan) — Okubo
  - Guggenheim Fellowships — Okubo; Ferbel; Olsen; Thorndike; Slattery
  - Humboldt Fellowships — Lobkowicz; Ferbel
  - Fulbright Fellowship — Das
  - Sloan Fellowships — Ferbel; Bodek; McFarland
  - NSF Presidential Young Investigator Award — Tipton
  - NSF Career Awards — Orr; McFarland
  - DOE Outstanding Junior Investigator Awards — Das; Tipton; Orr; McFarland
  - Cottrell Scholar Award — McFarland

# Conclusions

- Despite diminished resources we have an excellent, well-rounded program
  - Energy frontier at Run 2 and LHC
  - Precision low-energy $e^+e^-$
  - Neutrino program
  - Accelerator R&D for LC and Run 2
  - RHIC
  - Well-rounded theory/phenomenology program
- We have a proven track record of producing great science and excellent scientists
- We are making every effort to maintain and improve our program

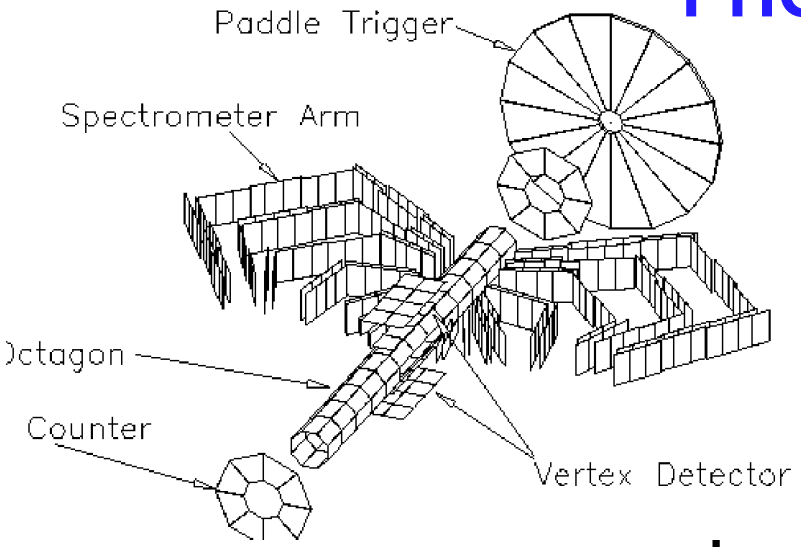
# The PHOBOS Detector (2001 run)

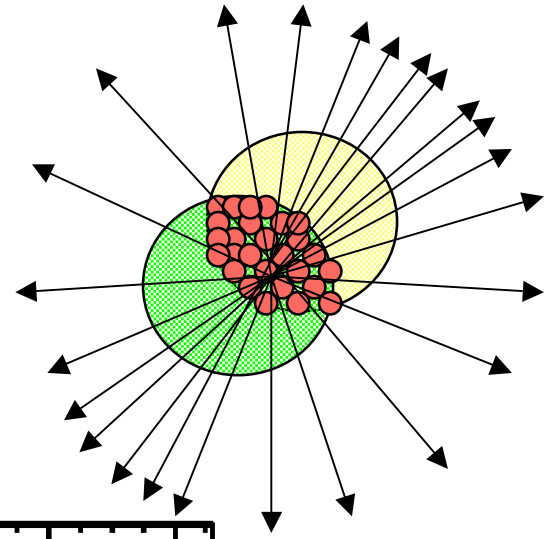
**Pls Manly and Wolfs**

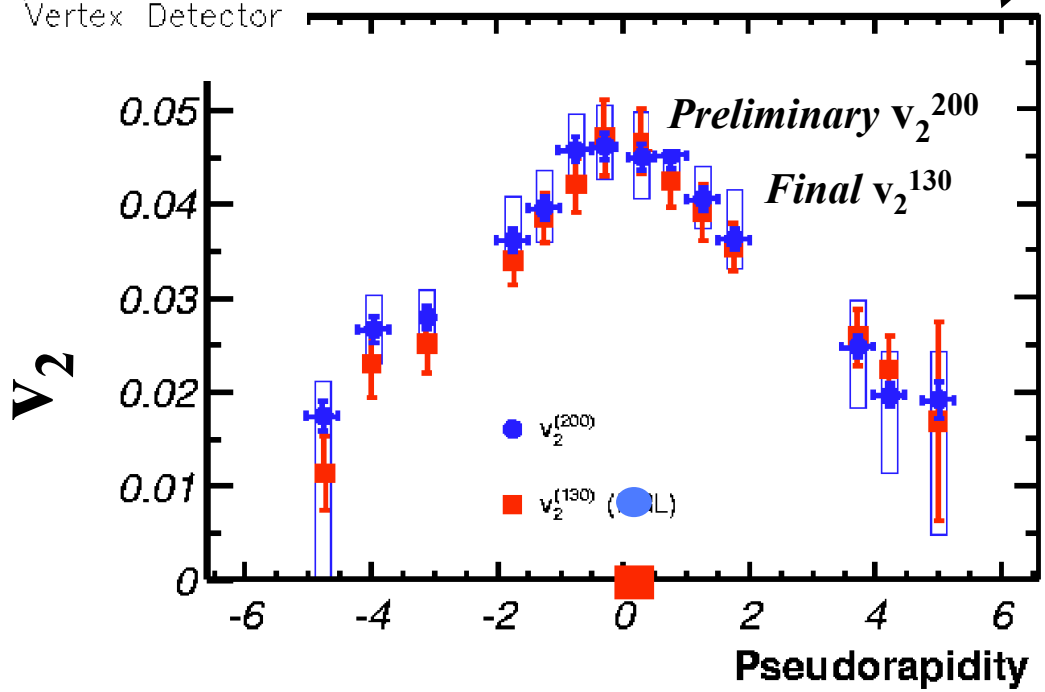



- Rochester NSF **built TOF wall**
- **Led the 'flow' analysis**

# PHOBOS, cont.

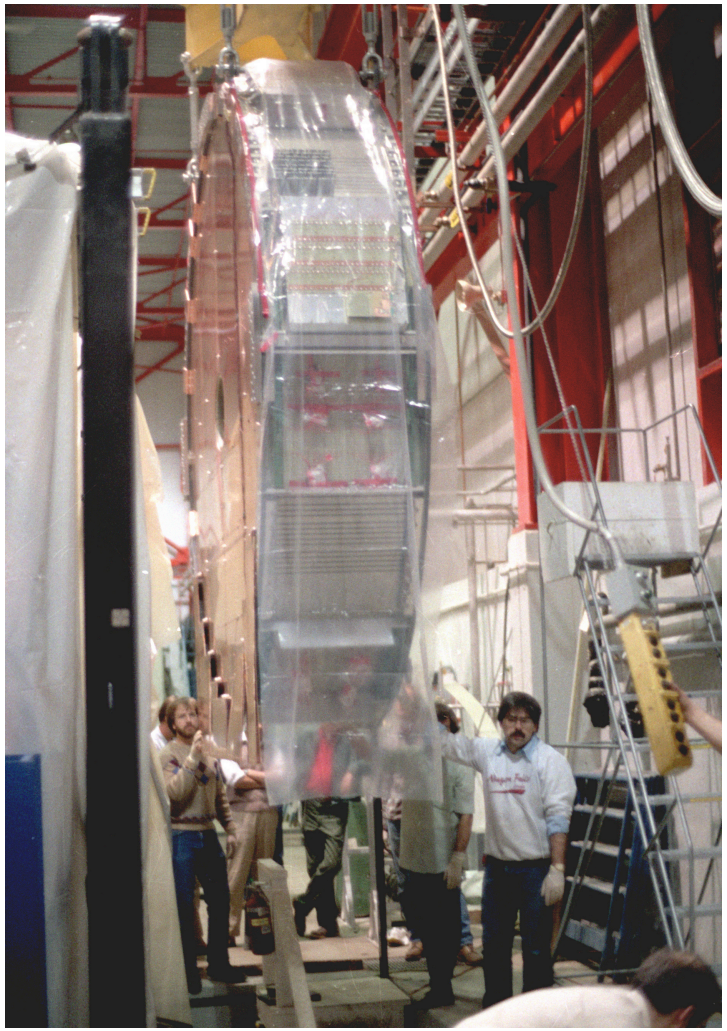

Paddle Trigger
Spectrometer Arm
Octagon
Counter
Vertex Detector




Preliminary $v_2^{200}$
Final $v_2^{130}$
$v_2$
0.05
0.04
0.03
0.02
0.01
0
-6
-4
-2
0
2
4
6
Pseudorapidity

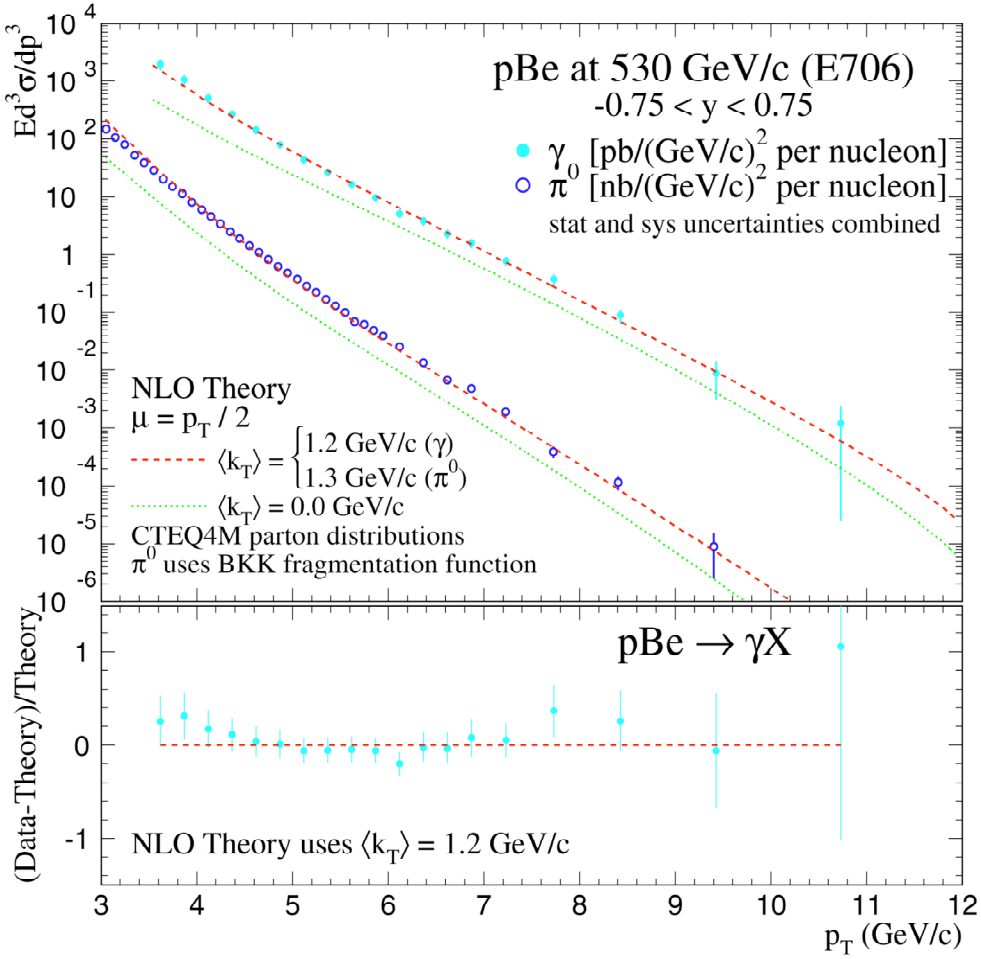
# Fermilab Experiment E706

- E706 measured high-$p_T$ inclusive direct-$\gamma$, $\pi^0$ & $\eta$ production for p (530 & 800 GeV/c) and $\pi^\pm$ (515 GeV/c) beams on H, Be & Cu targets.
- These processes provide sensitive probes of perturbative QCD.
- Rochester physicists proposed and led the experiment, including guiding the E706 physics analysis, which resulted in 34 PhDs being awarded.
- Rochester provided the primary E706 detector element, a 3 m diameter Pb/LAr electromagnetic calorimeter, shown here being transported from the assembly area to the MWEST beamline by UR physicists.



# Representative Physics Results From E706

- E706 observed large deviations from PQCD, even at NLO, for both direct-$\gamma$ & neutral meson production at high-$p_T$.
- These have been interpreted as being due to initial state gluon radiation not included in the NLO calculation.
- Good agreement between theory and data was obtained using a phenomenological model featuring initial state $k_T$.
- Rigorous "resummation" techniques have been used to confirm that soft gluon radiation must be included when comparing PQCD and data at these intermediate energies.
- E706's wide reach in $p_T$ and well-understood systematics made this unanticipated result credible.




Essentially identical results were obtained at 800 GeV/c