ACHIEVEMENTS OF THE TEVATRON FIXED-TARGET PROGRAM

6/11/12

Heidi Schellman

Northwestern University

Tevatron II (1983-2000)

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

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

Achievements

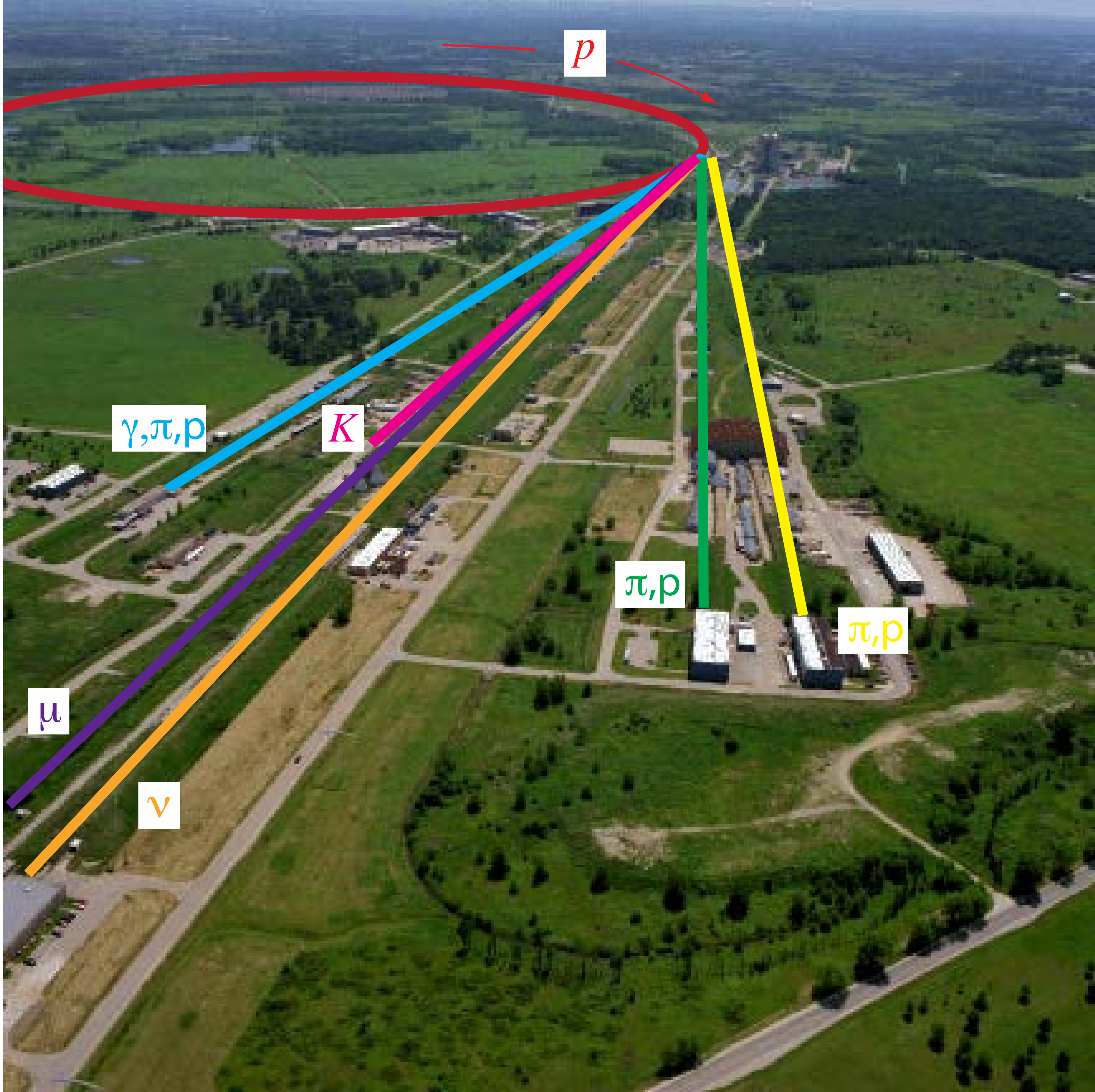
- Charm Physics and new technologies
- CP violation and rare kaon decays
- Nucleon spin and structure – anti-quarks and gluons
- QCD tests at many scales
- Hyperons galore
- Precision measurements of standard model parameters (V_{us}, V_{dc}, α_S, θ_W ...)
- Creation and detection of ν_τ

TeV II

Every minute
ramp from 0-800 GeV

Deliver up to 3×10^{13} protons/cycle

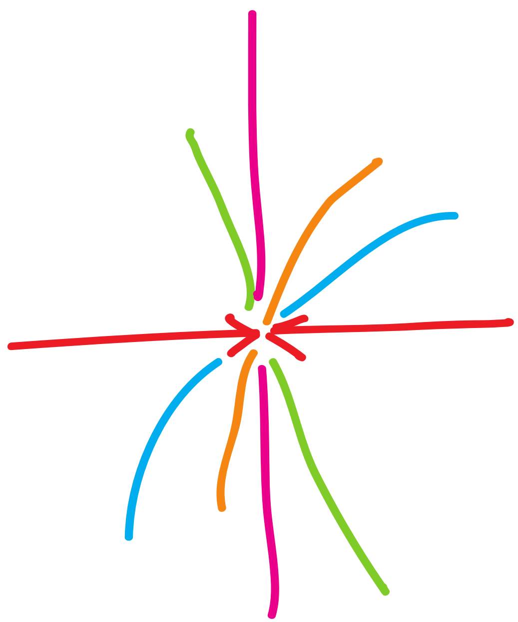
> 10 dipoles gave their lives for TeV II



Why fixed target?

Collider

Tevatron I

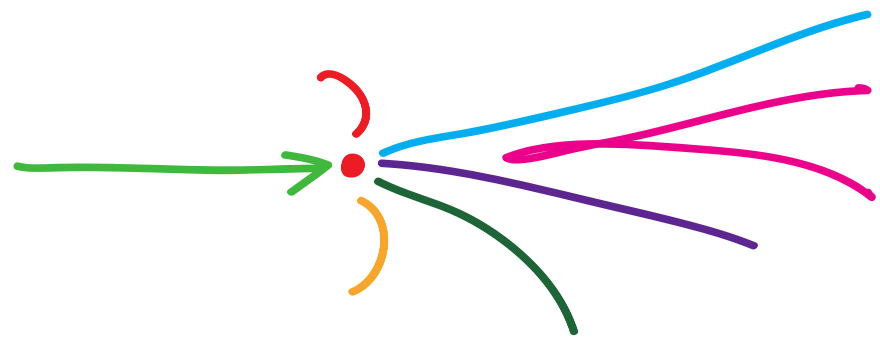


$$E_{CM} \simeq 2E_{beam}$$

~1960 GeV

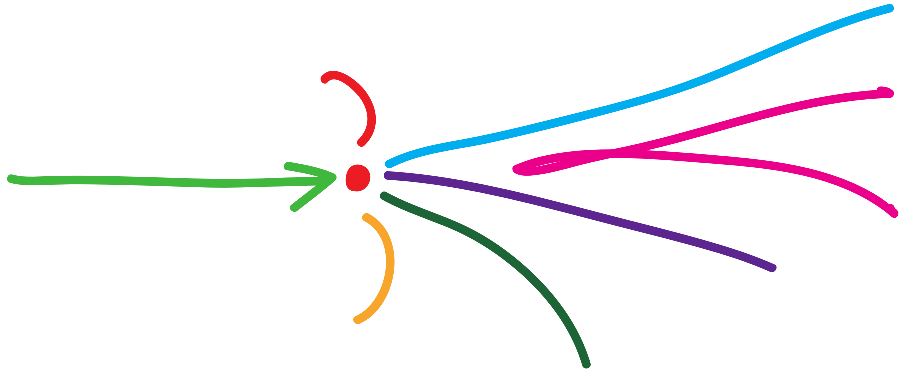
Fixed Target

Tevatron II



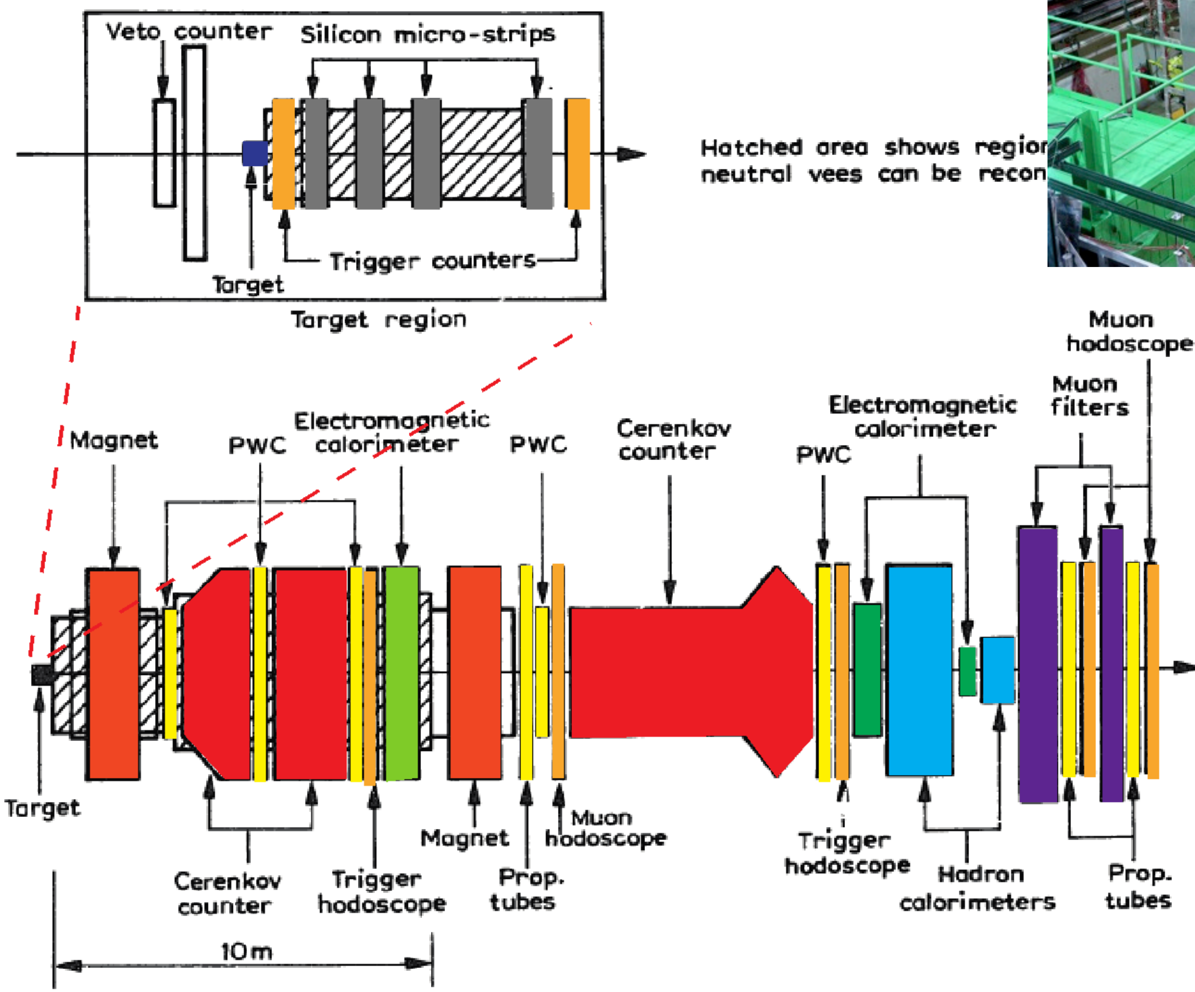
$$E_{CM} \simeq \sqrt{2ME_{beam}}$$

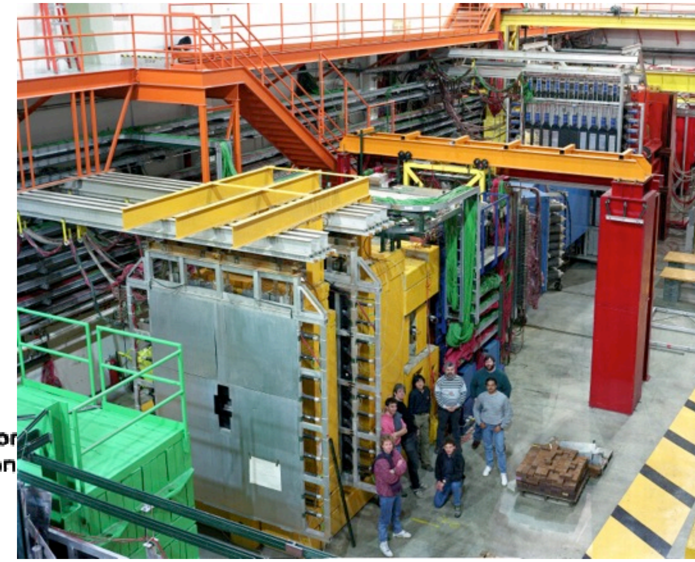
~40 GeV



- Advantages
  - Higher Luminosity
    - 10^{13} p/min instead of 10^{13} p/day
    - 10^{36}/cm^2/sec vs 10^{32}/cm^2/sec
  - Longer, more flexible detector designs
  - Hot and cold running exotic particle beams
  - Smaller groups

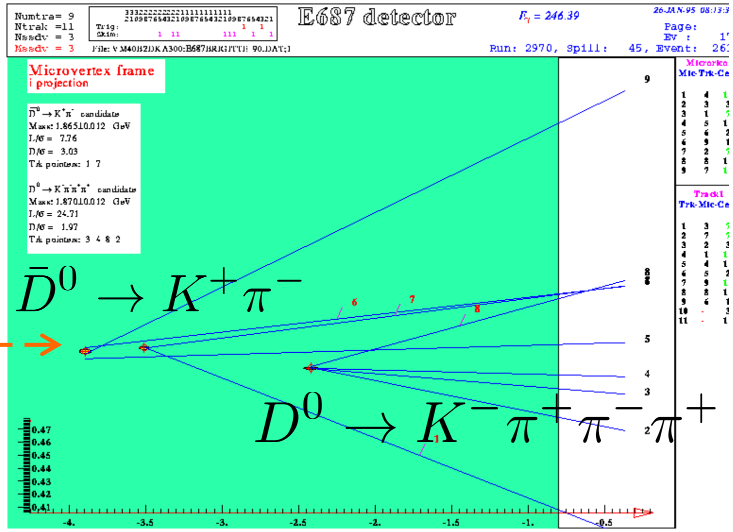
Generic detector (E687)

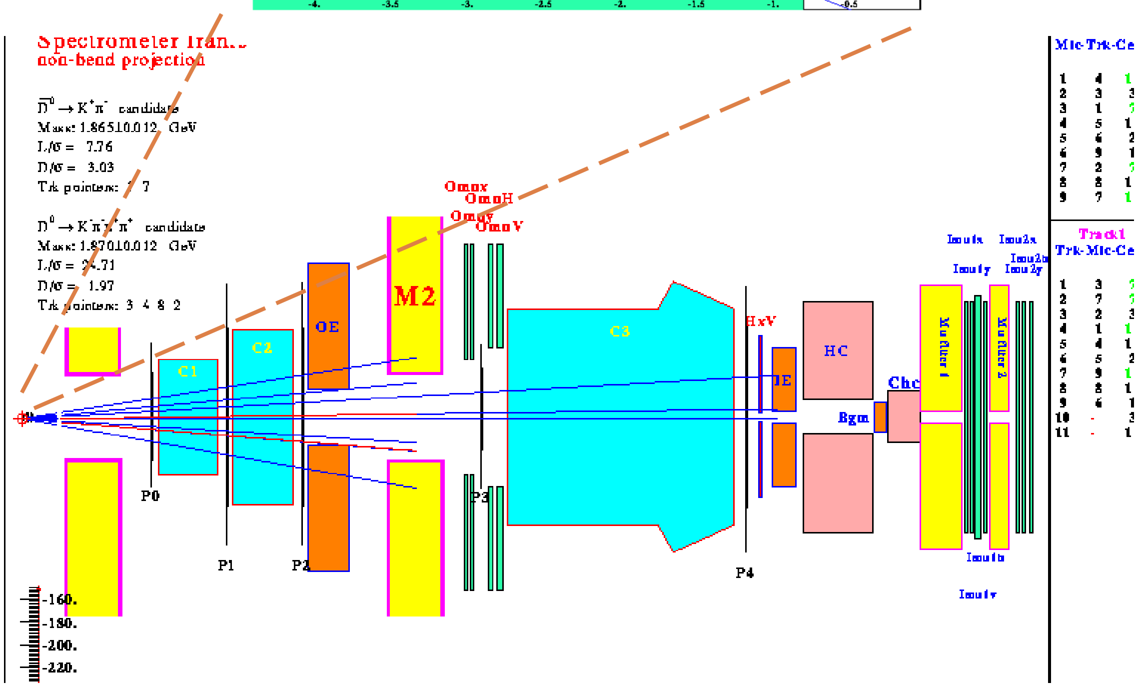


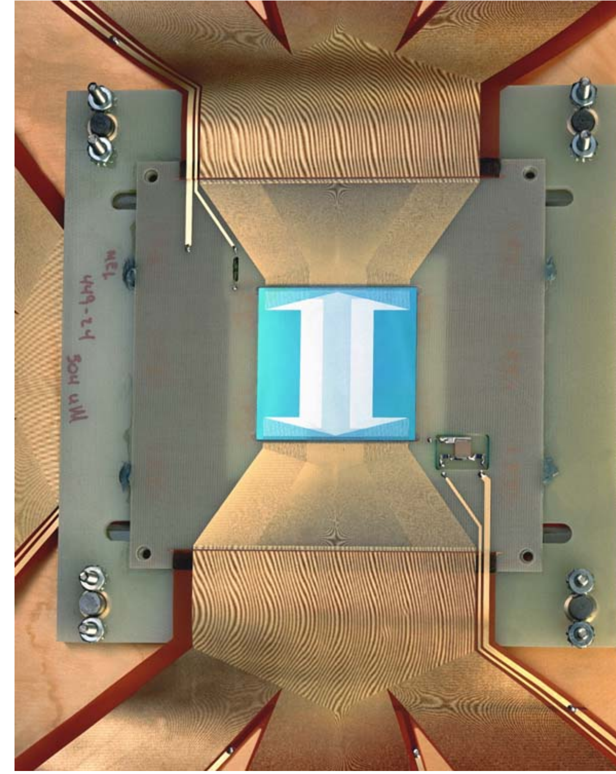


Target
Silicon microstrips
Scint. Counters
Tracking chambers
Particle ID
EM calorimeter
Hadron calorimeter
Muon detector

Photon







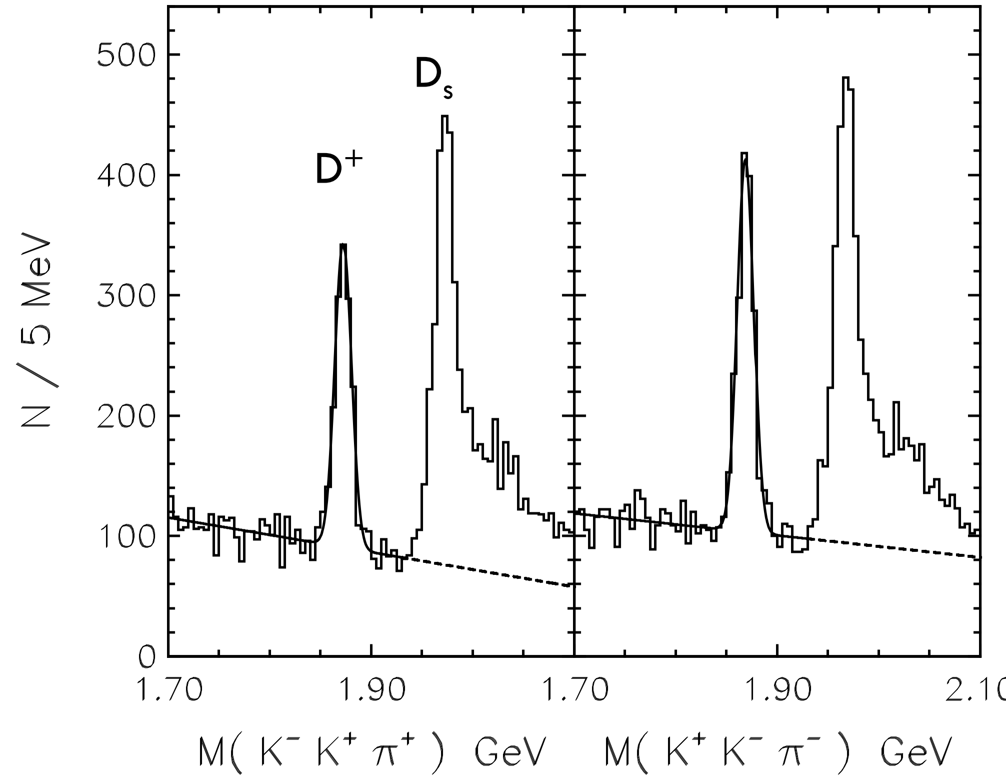
High statistics Charm physics

Use silicon strip detectors to identify charm in humungous background

E687 – photon beam

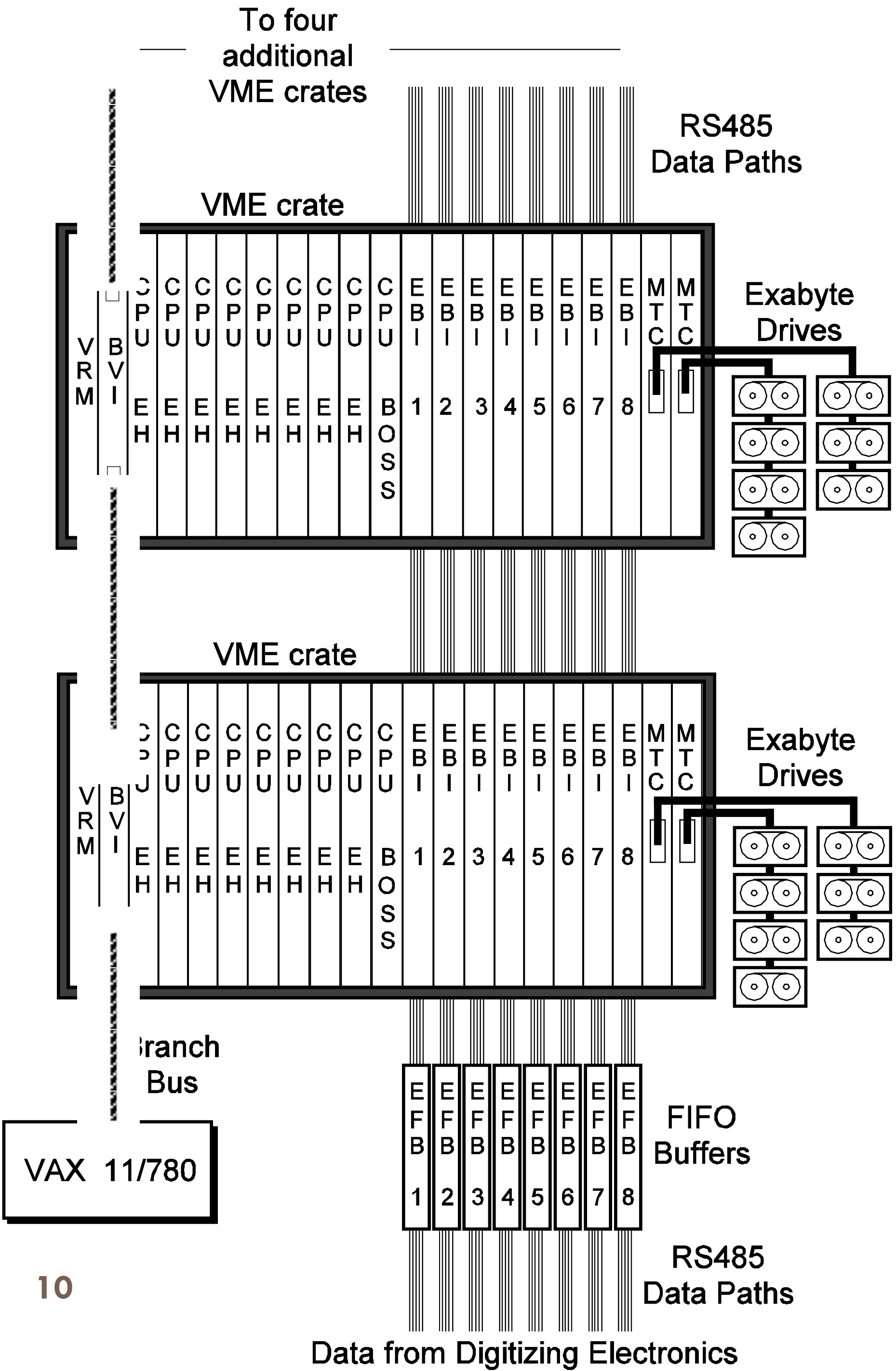
Charm rates at E791

- 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.

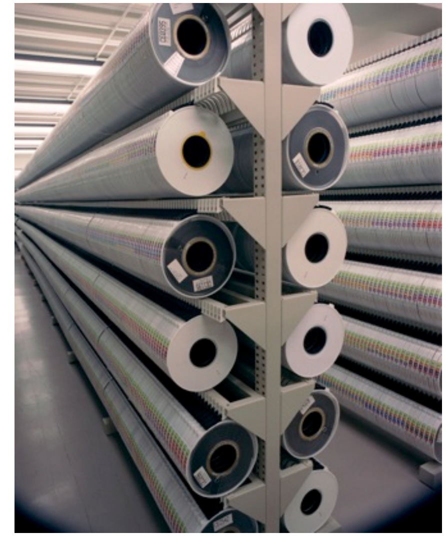


Slides from M. Purohit

E791 charm

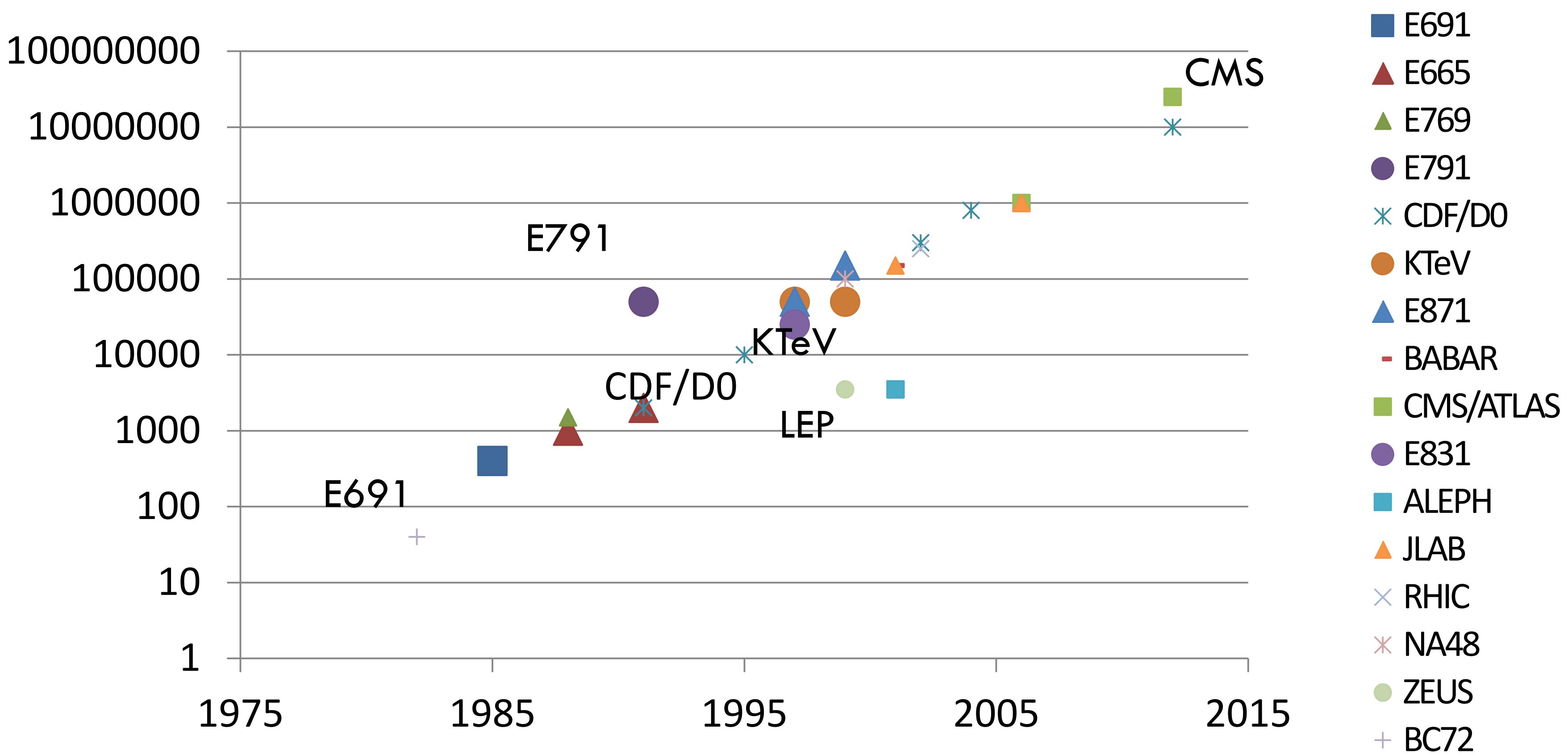


Before

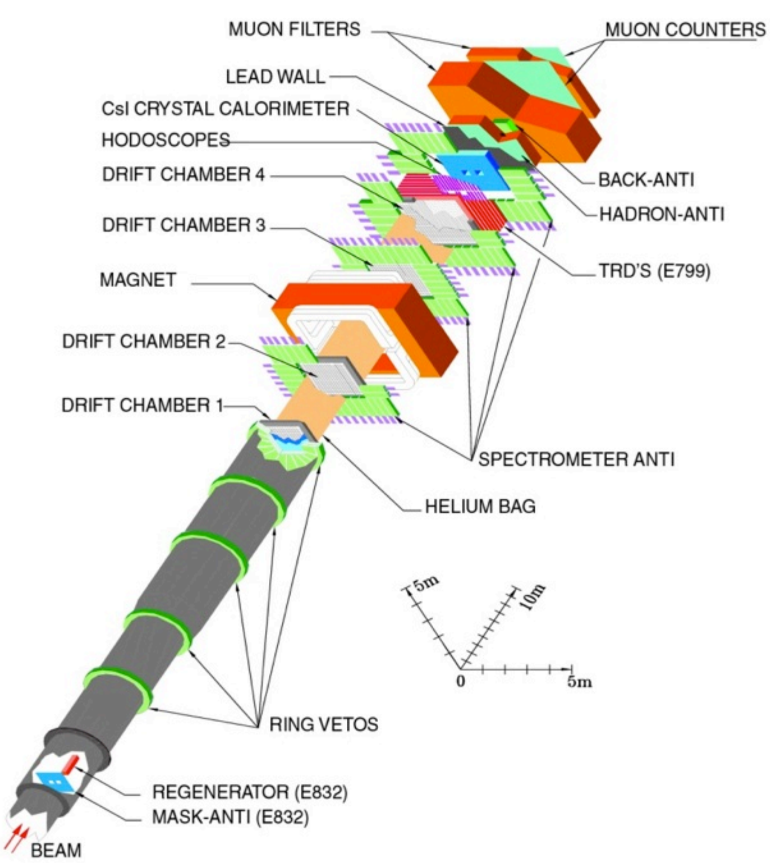


E791

Data Volume per experiment (in Gbyte)

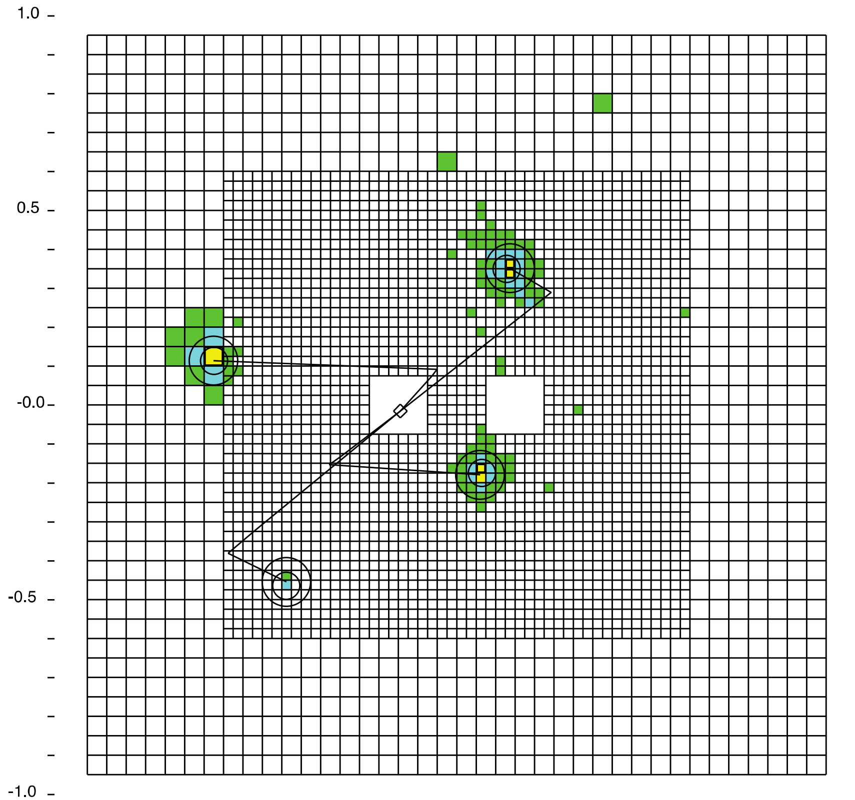


KTeV: high intensity kaon beams

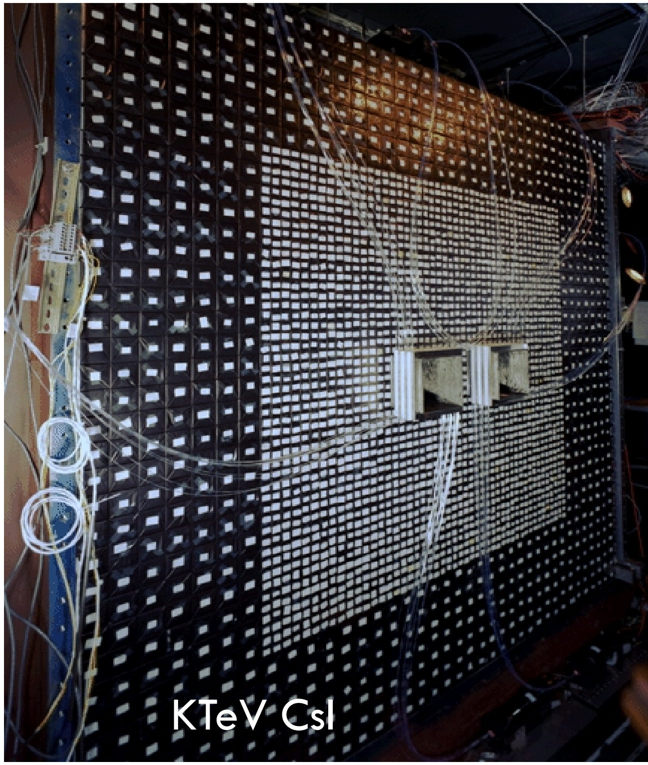


KTeV Pure CsI Calorimeter

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



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

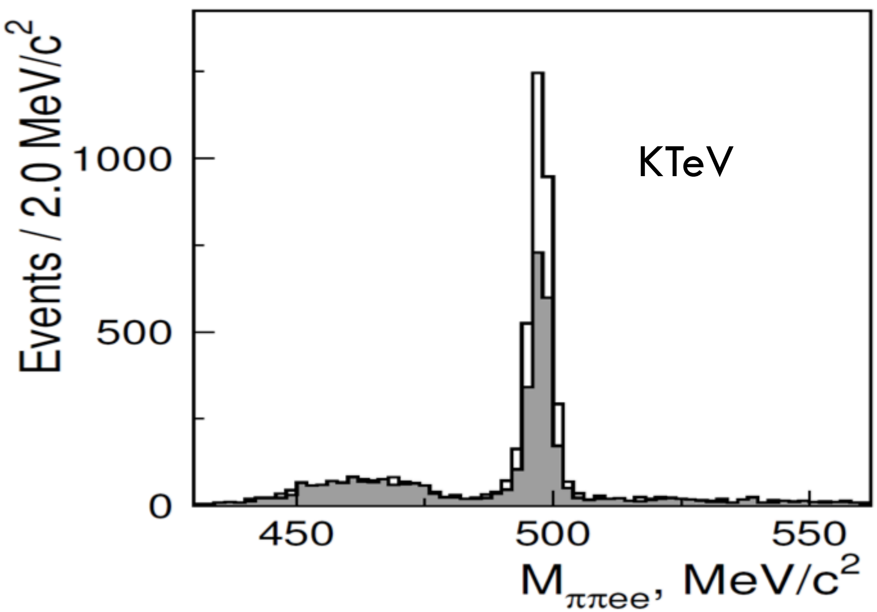


Example of Intensity

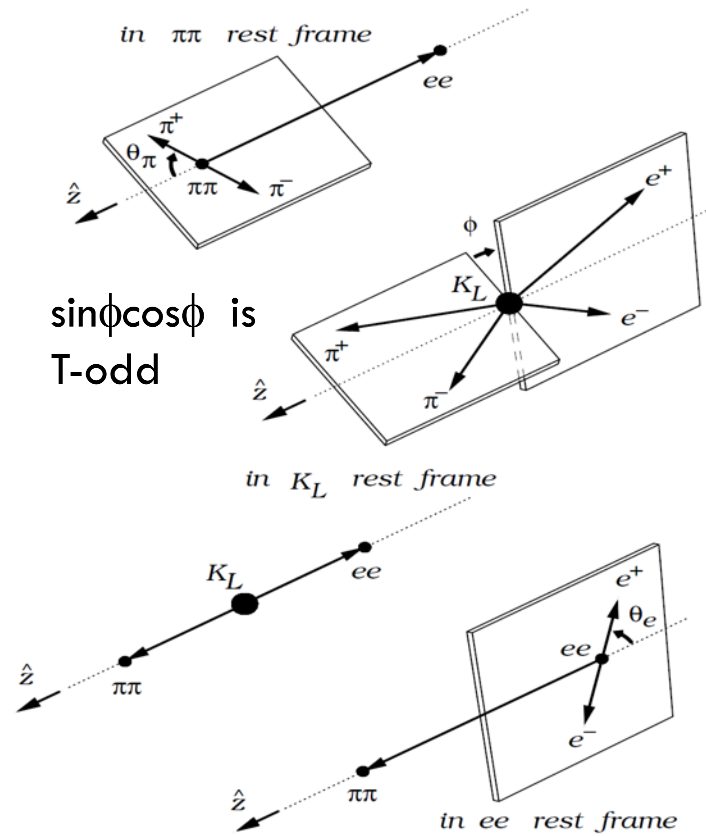
Discovery of $K_L \rightarrow \pi^+\pi^- e^+ e^-$

Branching fraction of 4×10^{-7}

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



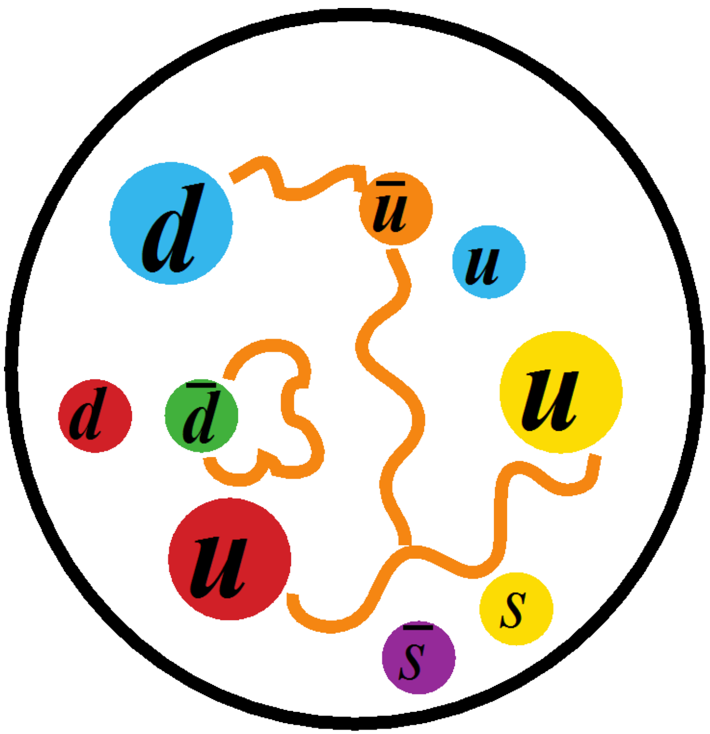
Gray: sinφcosφ<0; Clear: sinφcosφ>0



sinφcosφ is T-odd

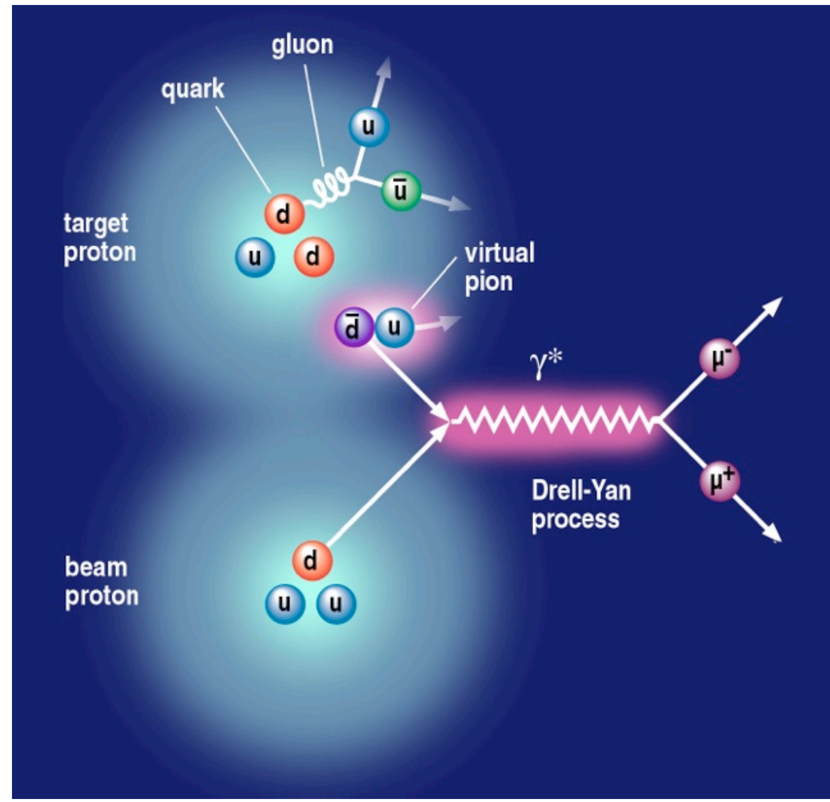
- 5000 events observed, sensitivity < 10^{-10}.
- Large T-odd, CP asymmetry observed.

Proton Structure



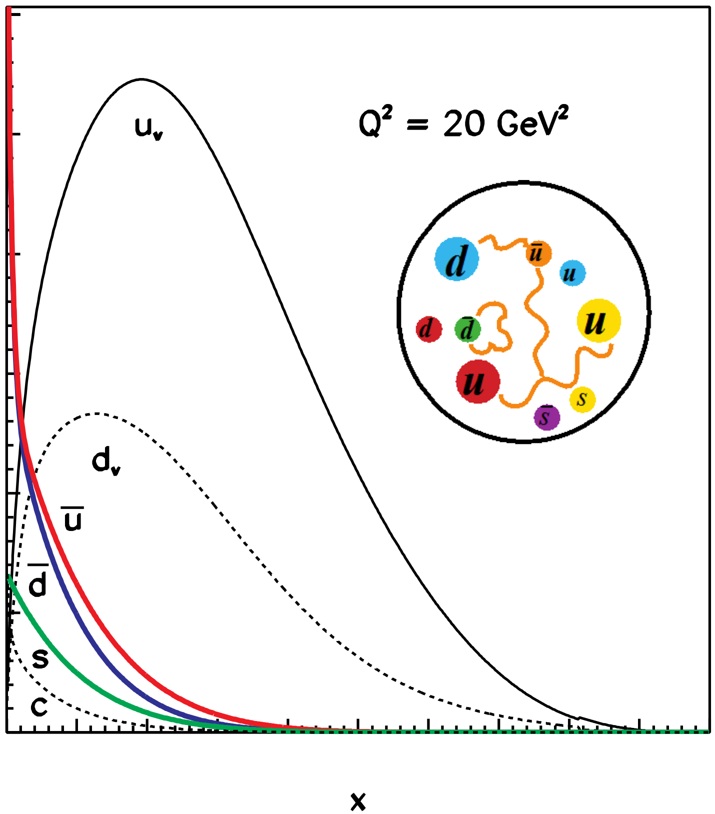
Naïve expectation
anti-u = anti-d = anti-s

NUSEA – proton on protons



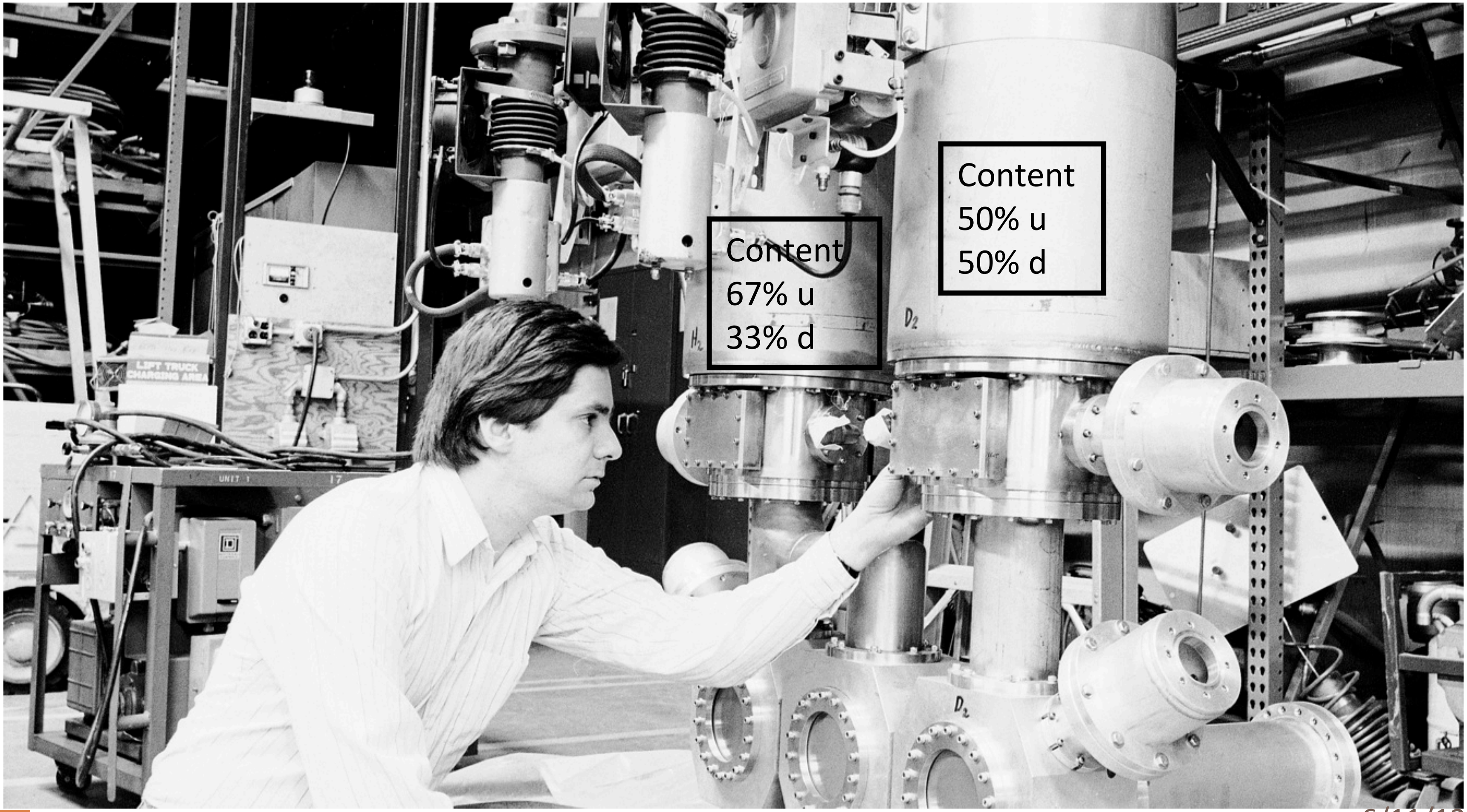
Collide protons on protons
Annihilate quarks and anti-quarks

Momentum fractions

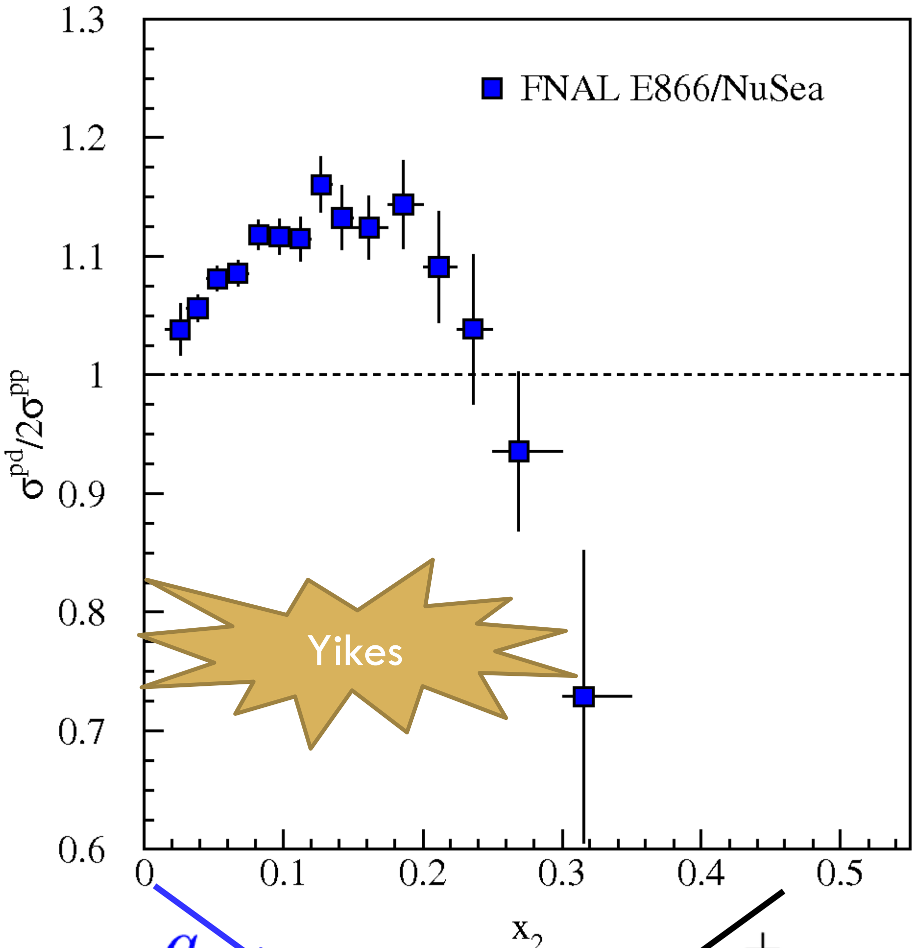


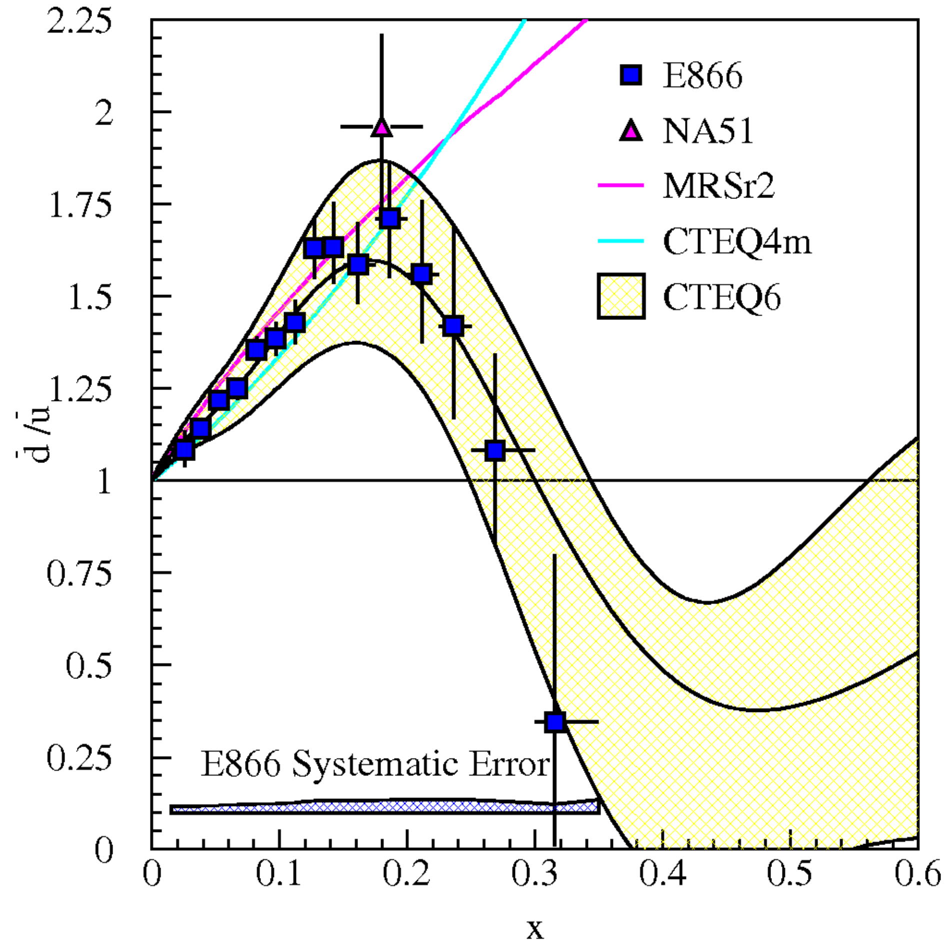
- If you can pick out a type of quark, you can measure its momentum fraction
- Vital input to almost all collider physics

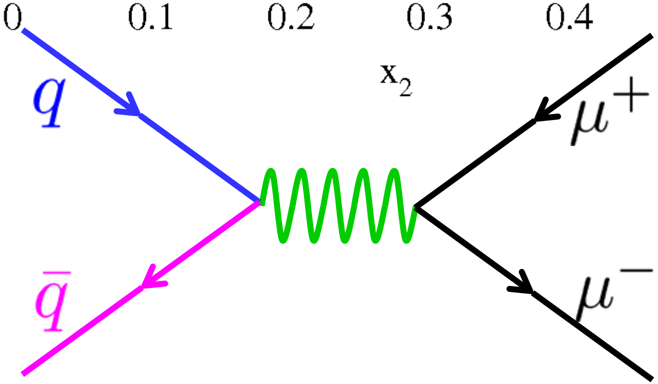
Hydrogen and deuterium targets



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

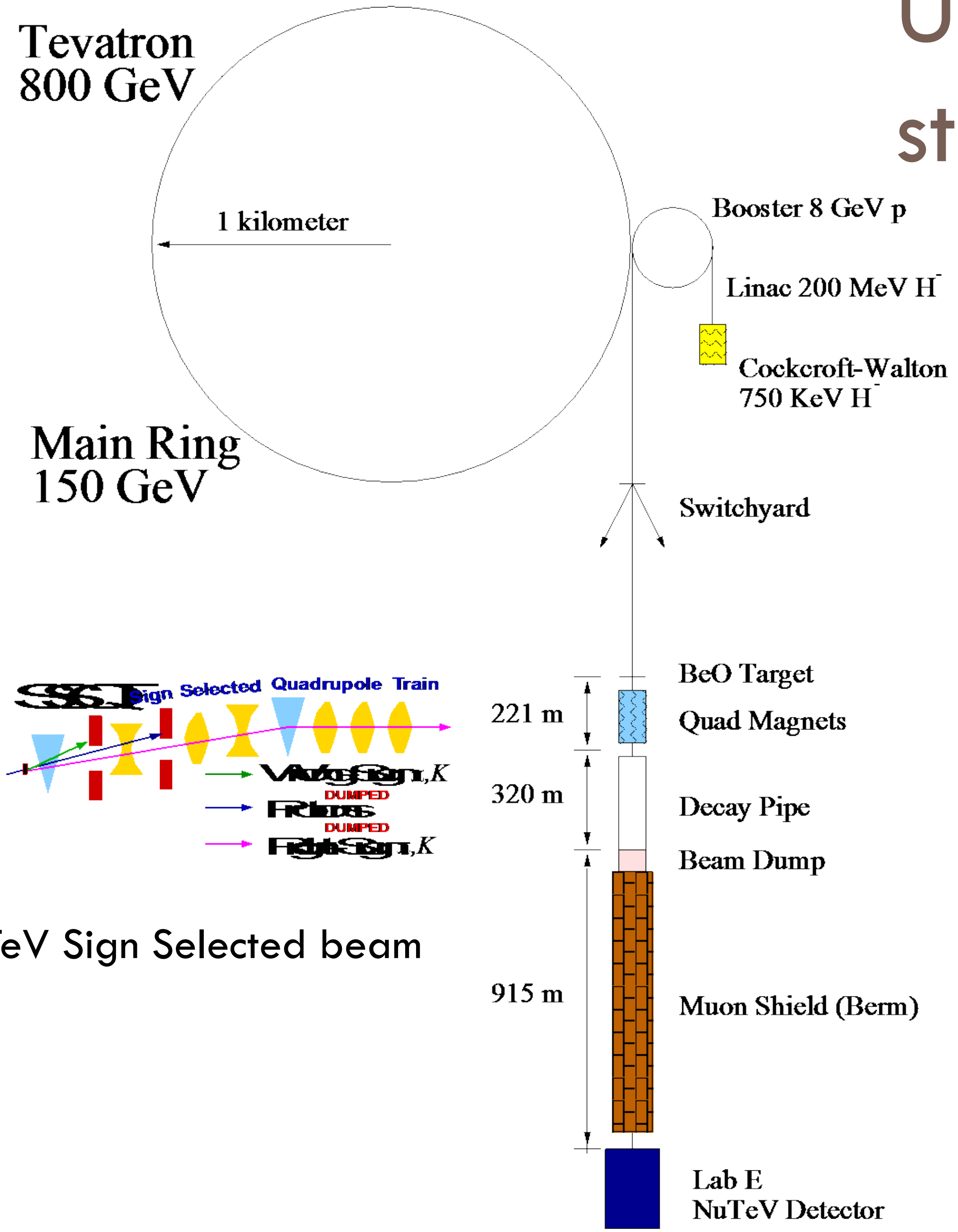




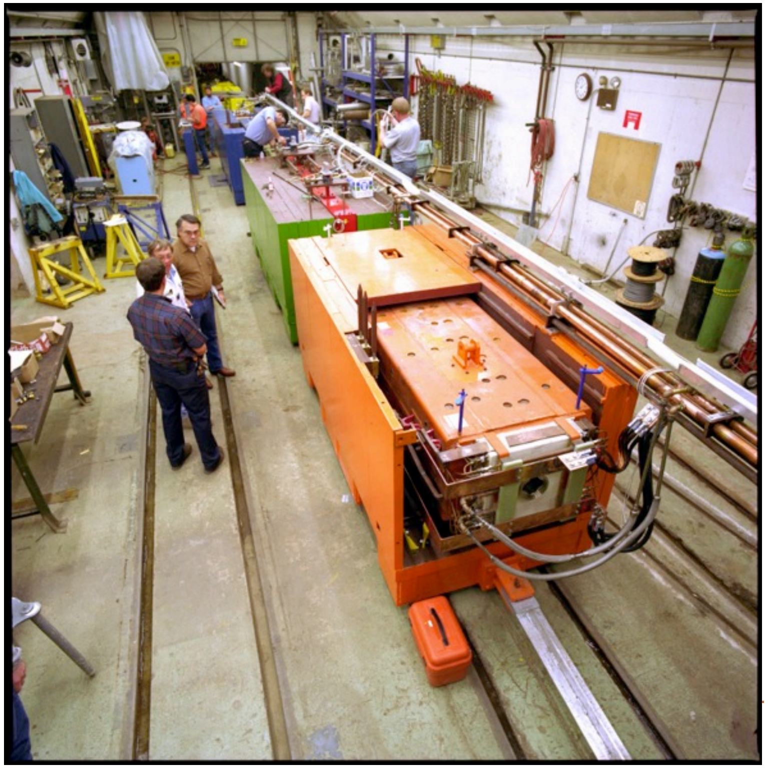


$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_b \gg x_t} \approx \frac{1}{2}\left[1+\frac{\bar{d}(x_t)}{\bar{u}(x_t)}\right]$$

Use neutrinos to see strange quarks

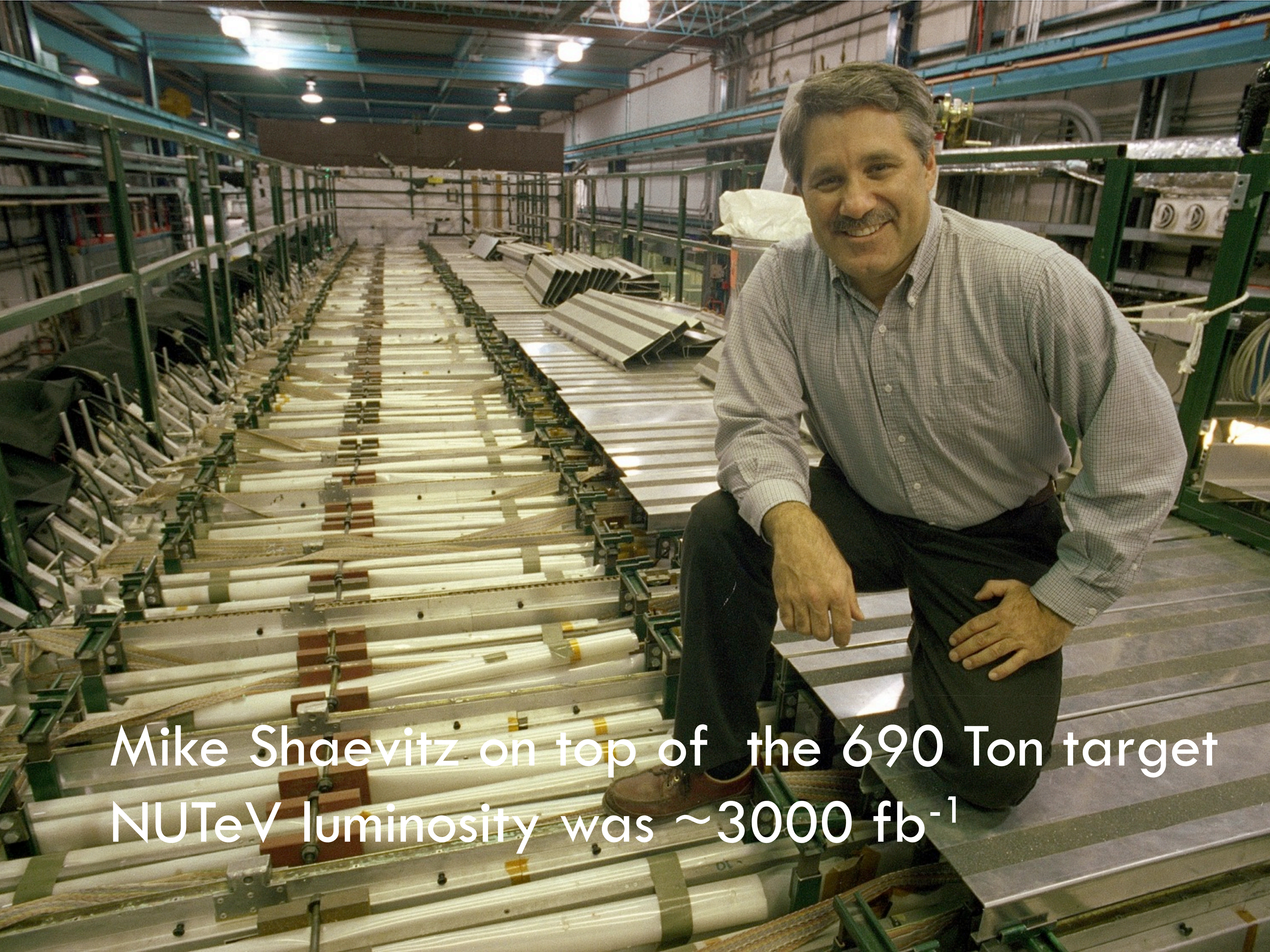


NuTeV Sign Selected beam



< 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

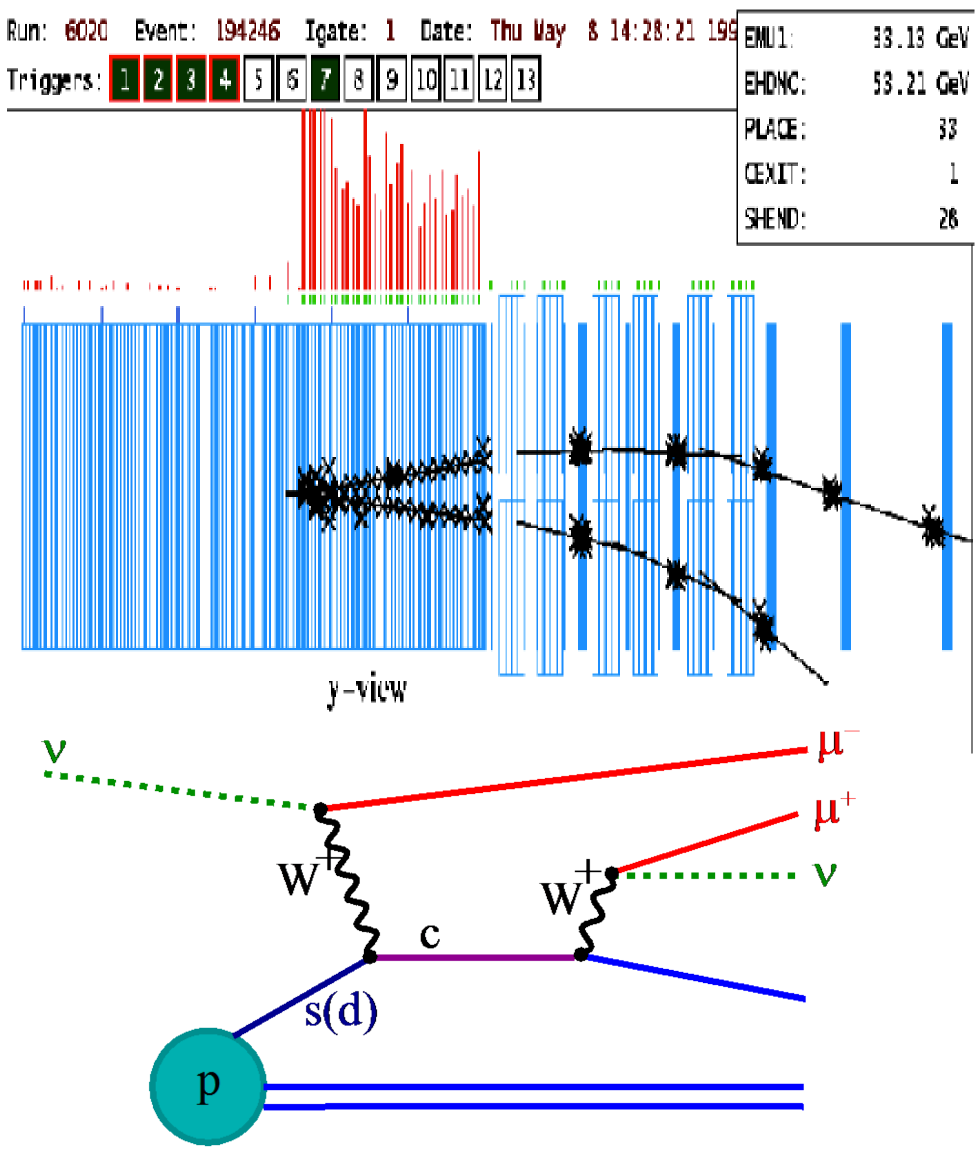
Neutrinos scattering can pick out strange quarks through the process

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

c decays to μ^+

Dimuons at NuTeV measure

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

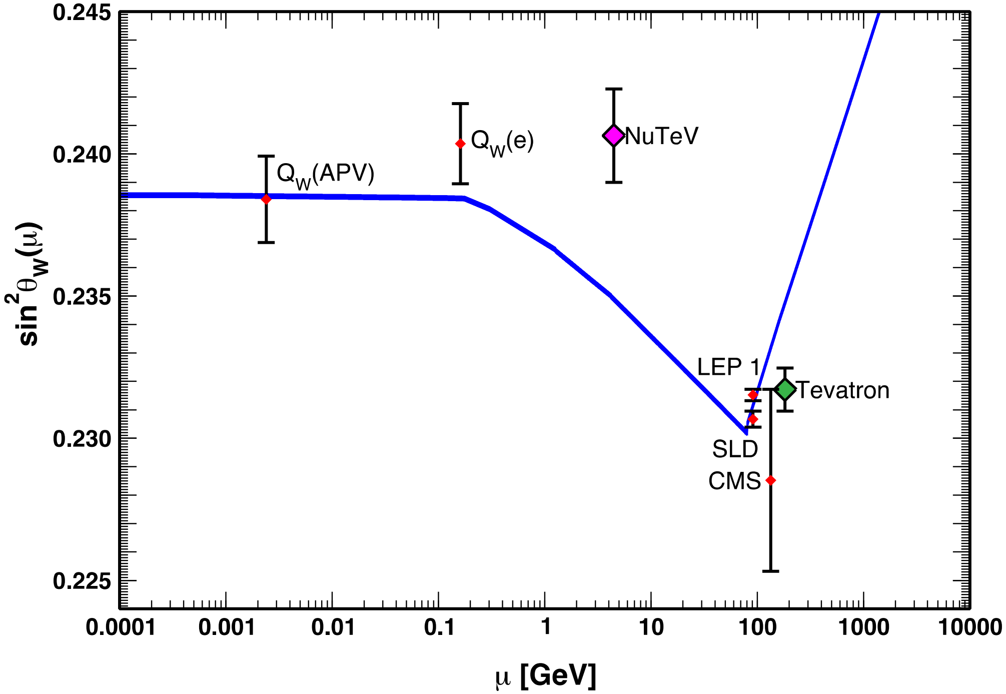


NuTeV Weinberg Angle

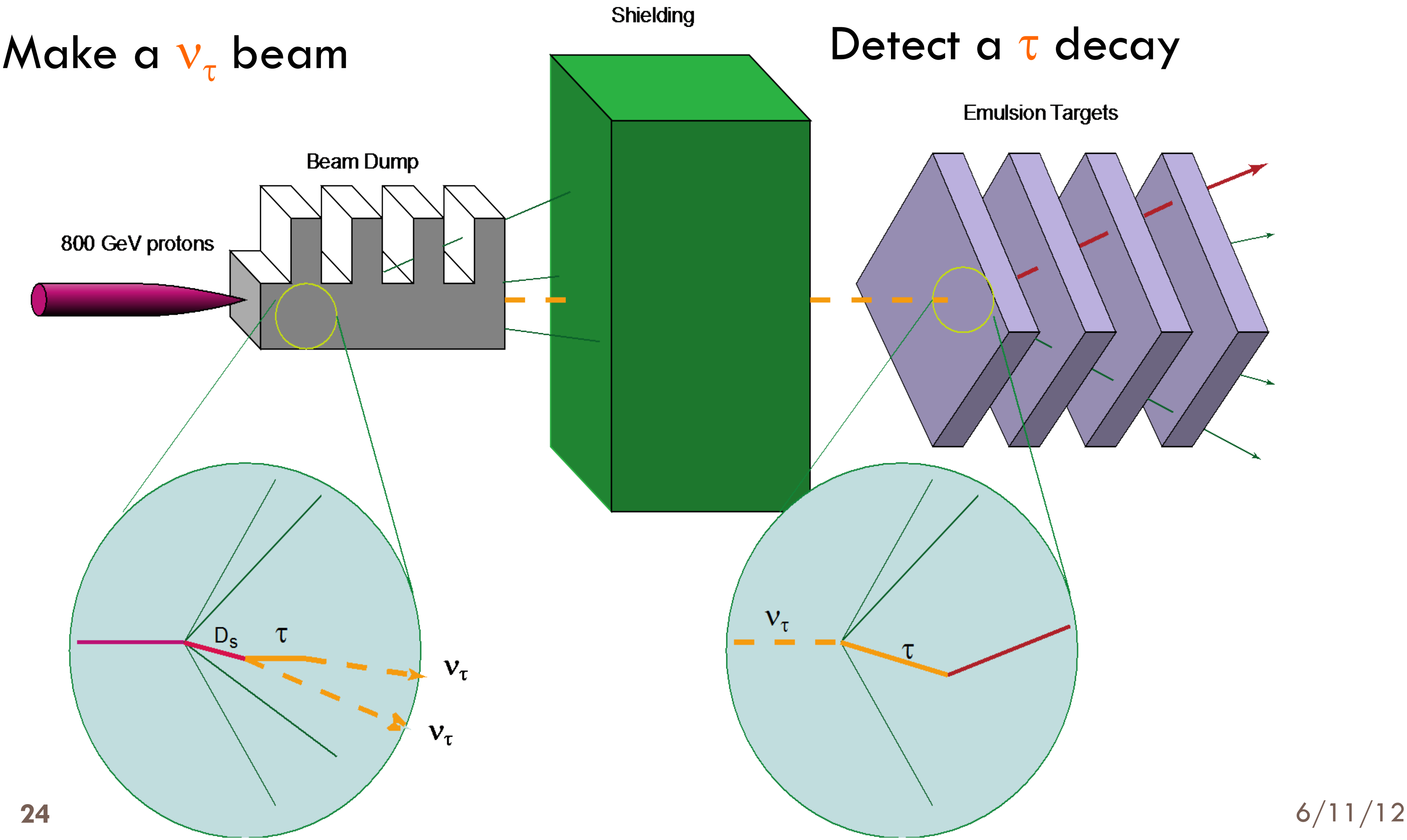
$$\sin^2\theta_W = \frac{1}{2} - \frac{\sigma(\nu_\mu N \to \nu_\mu X) - \sigma(\bar{\nu}_\mu N \to \bar{\nu}_\mu X)}{\sigma(\nu_\mu N \to \mu^- X) - \sigma(\bar{\nu}_\mu N \to \mu^+ X)}$$

Ratio of neutral to charged current interactions

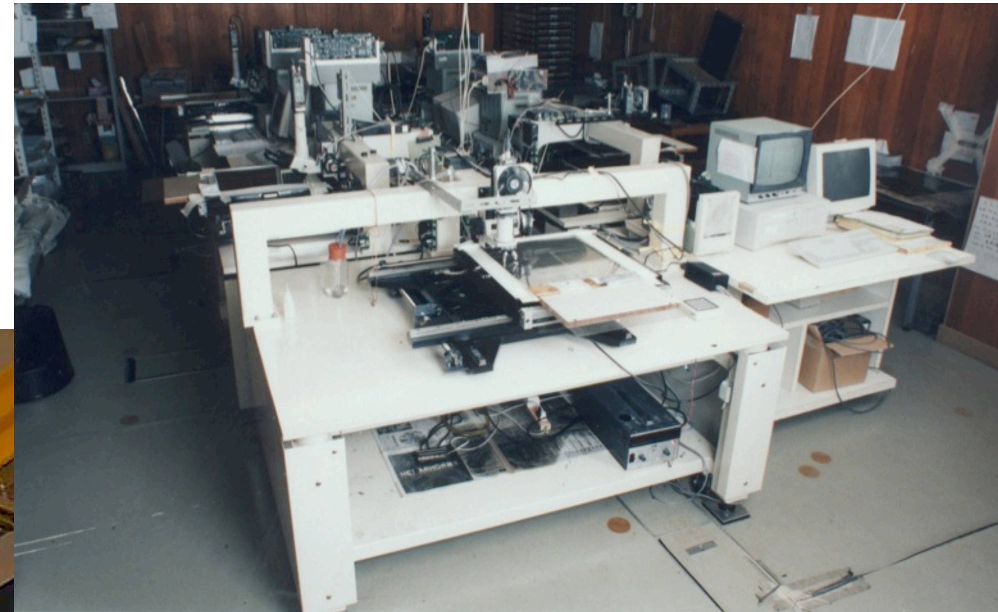
Need the sign selected beam



Discovery of the tau neutrino (DONUT)



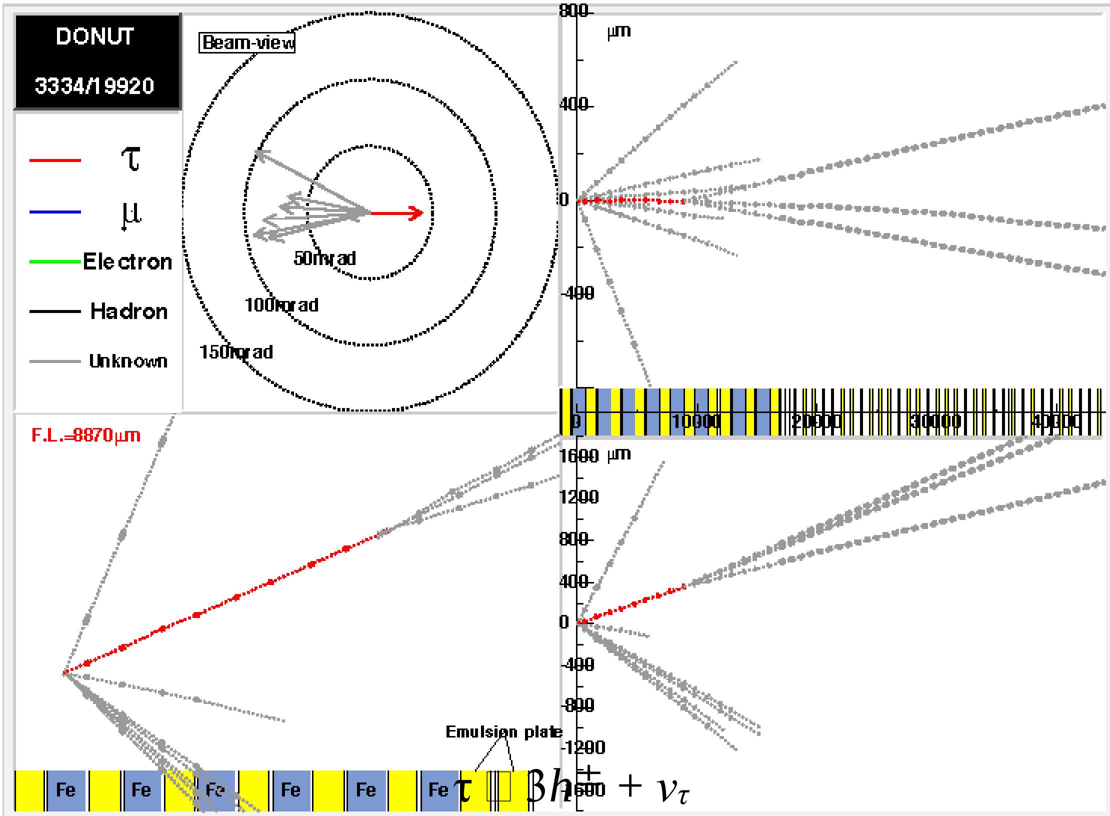
Emulsion modules and drift chambers



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

Recycled drift chamber electronics

Saw 9 candidates 7.52 ν→τ + 1.48 background



~80 GeV τ : τ probability 0.99+

~9mm decay length

digitized emulsion information shown

Conclusions

- Tevatron II 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
    - Discovery of 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, LBNE …..)
  - ???
- Kaon Physics with ORKA
- Proton Physics
  - SEAQUEST – son of NUSEA
- Your idea here

The beginning