Fermilab

Operated by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Switchyard External Beamlines

From the past to the present

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1 July 2014

Switchyard External Beamlines

Items to be covered

1. Switchyard's History
2. Switchyard's Present
3. Delivery Method
4. Users
   - MTest
   - SeaQuest
   - MCenter

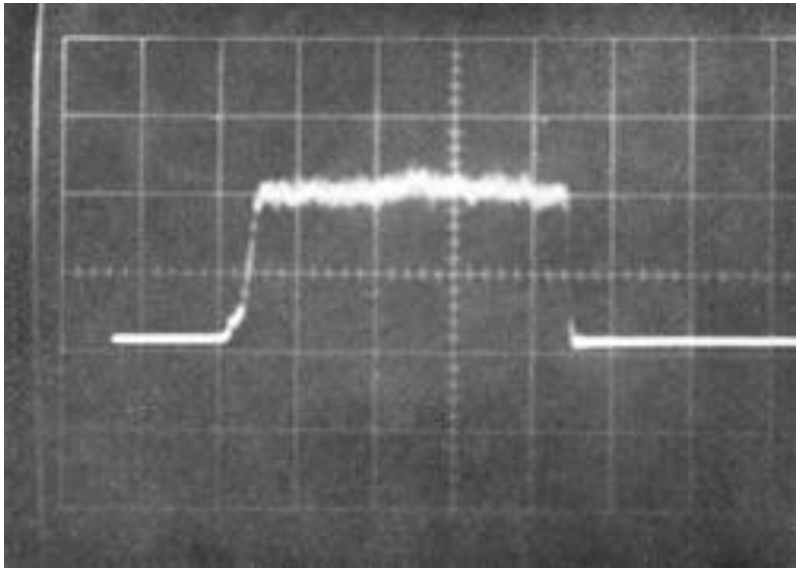
Switchyard's History – Begins with Fermilab's History

- NAL breaks ground Dec 1st 1968

Robert R. Wilson (l) and Glenn Seaborg (r) at the NAL Groundbreaking

Switchyard's History – Begins with Fermilab's History

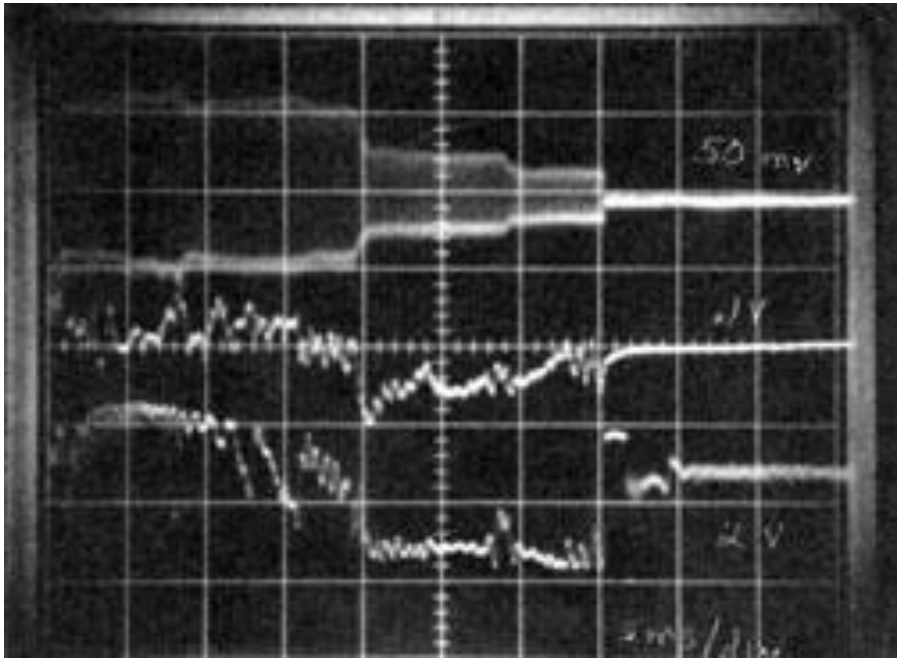
- NAL breaks ground Dec 1st 1968
- Linac beam (1970)



A photo of the early accelerated proton beam from NAL's pre-accelerator: 200 milliamperes during 80 microseconds pulse

Switchyard's History – Begins with Fermilab's History

- NAL breaks ground Dec 1st 1968
- Linac beam (1970)
- Booster beam (1971)



Scope display of first Booster beam to 8 GeV. Upper trace is beam intensity; middle trace is beam pulse

Switchyard's History – Begins with Fermilab's History

- NAL breaks ground Dec 1st 1968
- Linac beam (1970)
- Booster beam (1971)
- Main Ring (1972)

Main Ring machine

Switchyard's History – Begins with Fermilab's History

- NAL breaks ground Dec 1st 1968
- Linac beam (1970)
- Booster beam (1971)
- Main Ring (1972)
- Proton (1972)

Aerial view of Proton experimental area. Pagoda control center may be seen at right

Switchyard's History – Begins with Fermilab's History

- NAL breaks ground Dec 1st 1968
- Linac beam (1970)
- Booster beam (1971)
- Main Ring (1972)
- Proton (1972)
- Neutrino (1972)

Photo by Tim Fielding, NAL

Neutrino Dome Feb 24, 1972

Switchyard's History – Begins with Fermilab's History

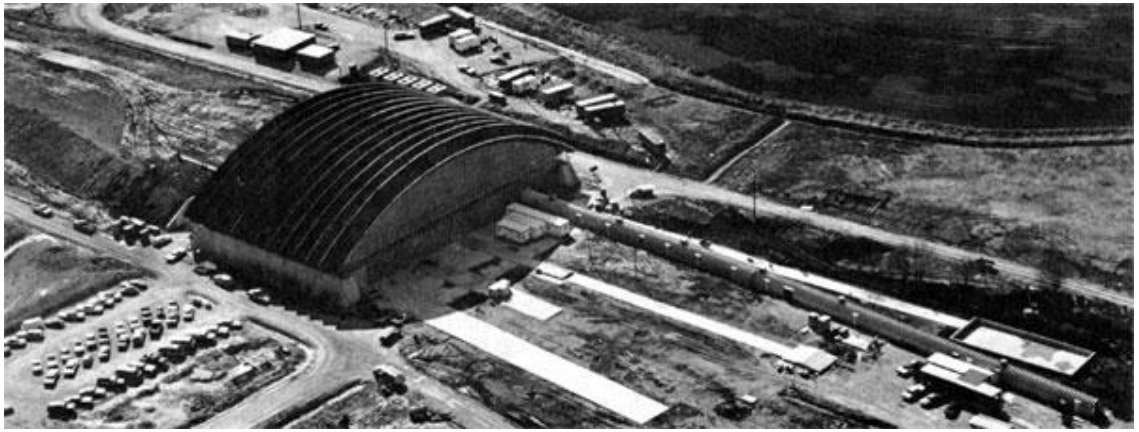
- NAL breaks ground Dec 1st 1968
- Linac beam (1970)
- Booster beam (1971)
- Main Ring (1972)
- Proton (1972)
- Neutrino (1972)
- NAL became FNAL May 11th 1974

Distinguished guests dedicate Fermilab

Switchyard's History – Begins with Fermilab's History

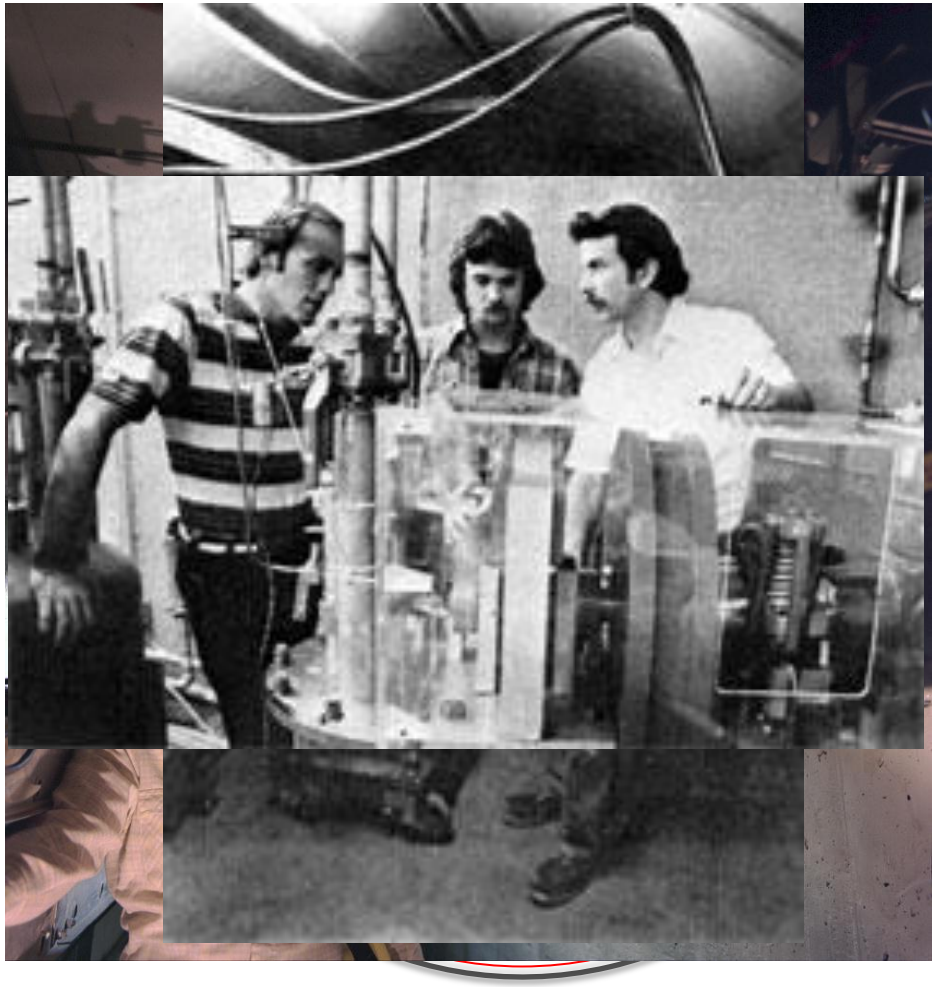
- NAL breaks ground Dec 1st 1968
- Linac beam (1970)
- Booster beam (1971)
- Main Ring (1972)
- Proton (1972)
- Neutrino (1972)
- NAL became FNAL May 11th 1974
- Meson (1977)

Meson Detector Building



Switchyard's History – Begins with Fermilab's History

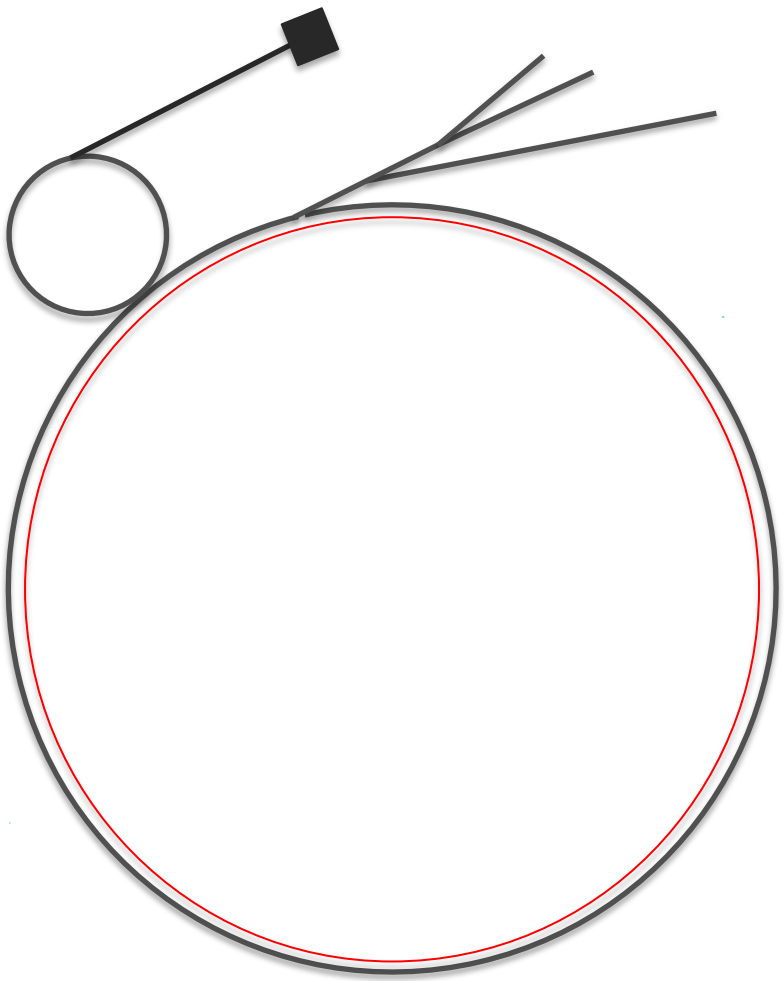
Switchyard's History – Begins with Fermilab's History



On July 3rd 1983 the Energy Doubler better known as the Tevatron reached 512 Gev.

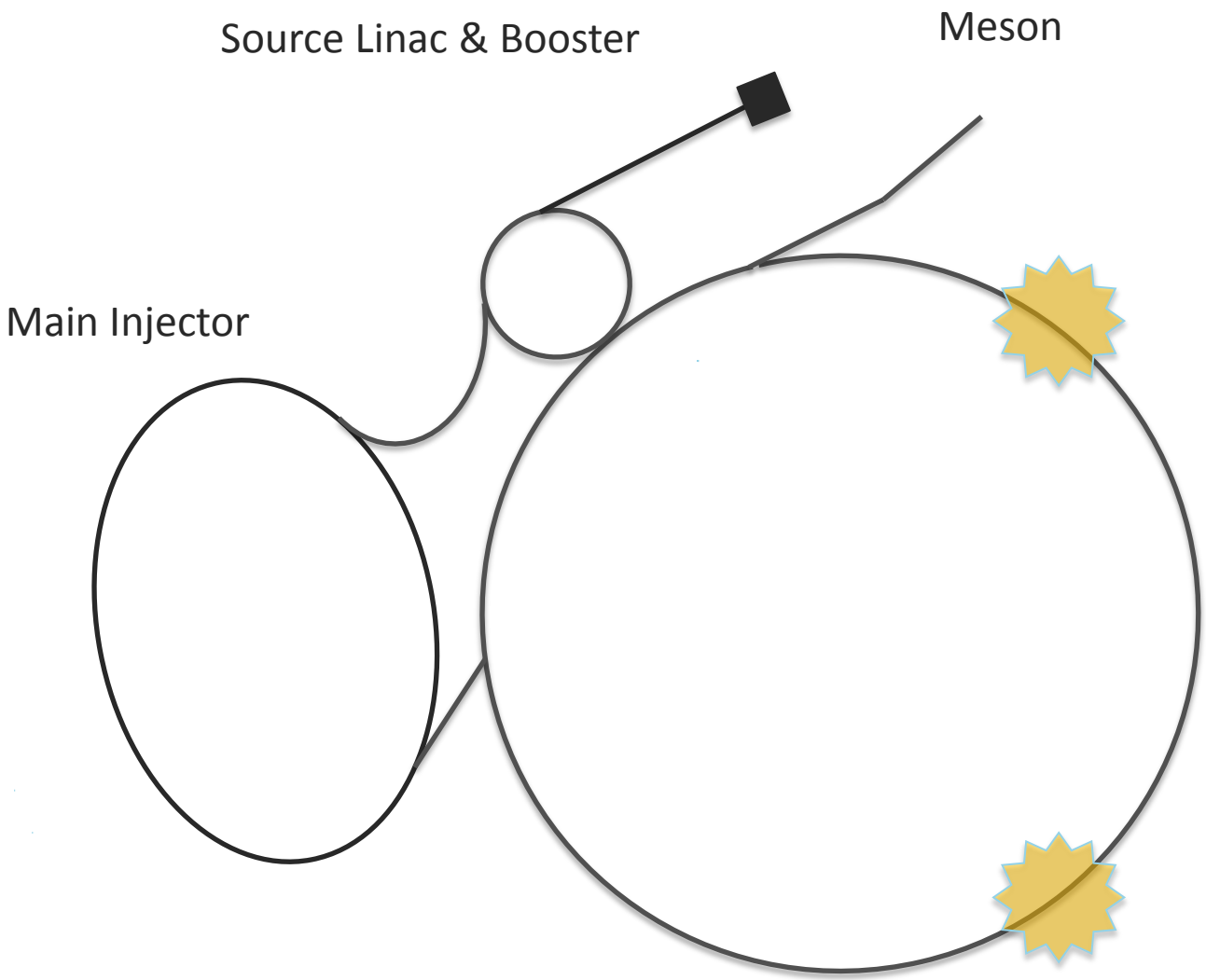
Feb 16th 1984 800 Gev was achieved and extracted towards the Switchyard area.

Switchyard's Present – Begins with Change



- Fermilab's Main Injector initial design started 1987
- Construction began 1993
- MI ready for HEP in 1999

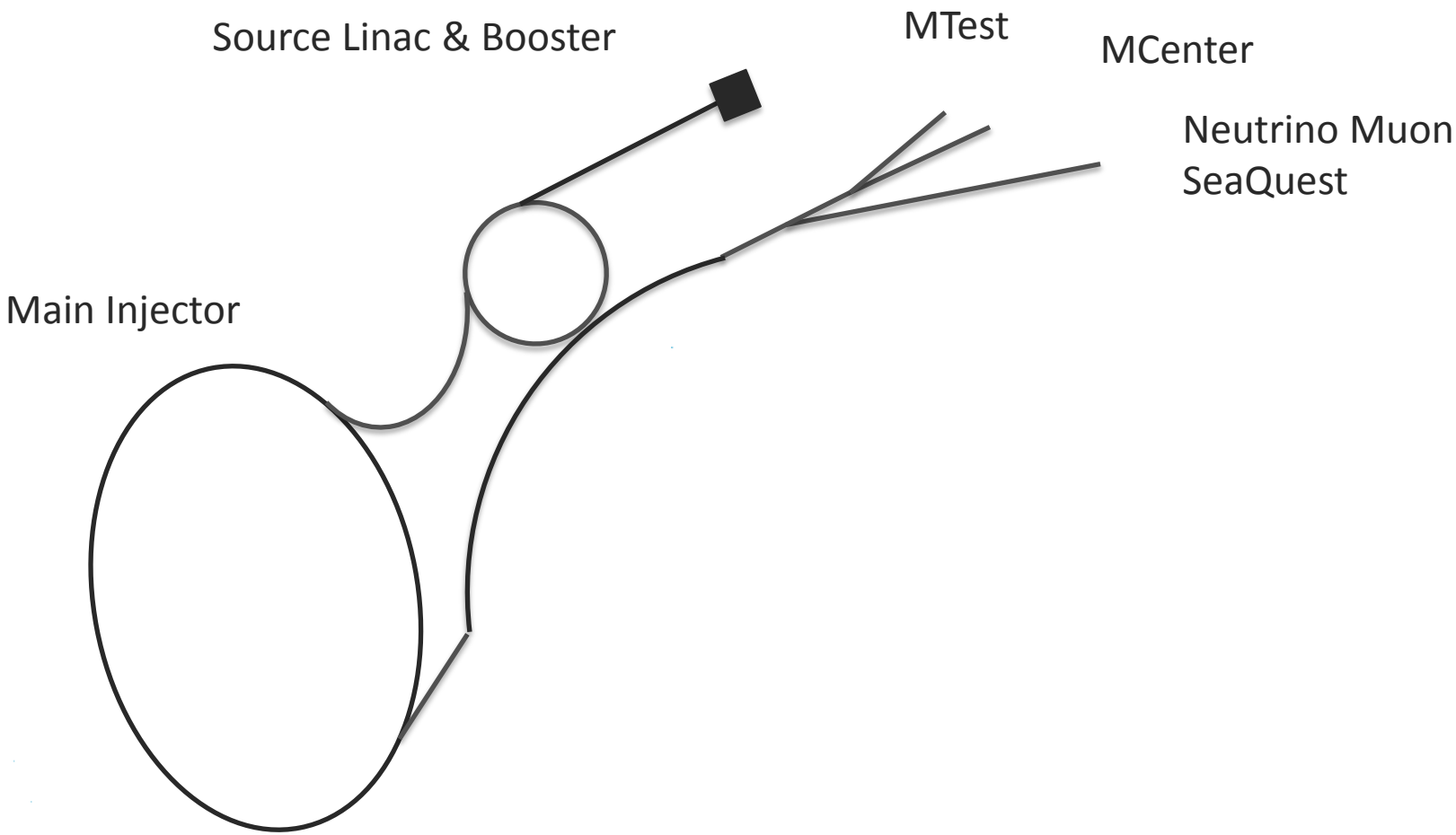
Switchyard's Present – Begins with Change



Switchyard's Present

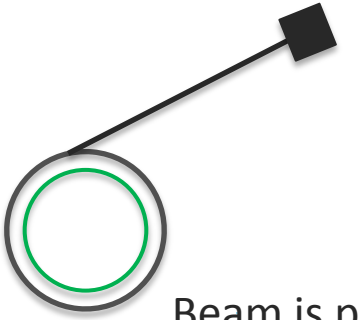
Things still changing…

Switchyard's Present



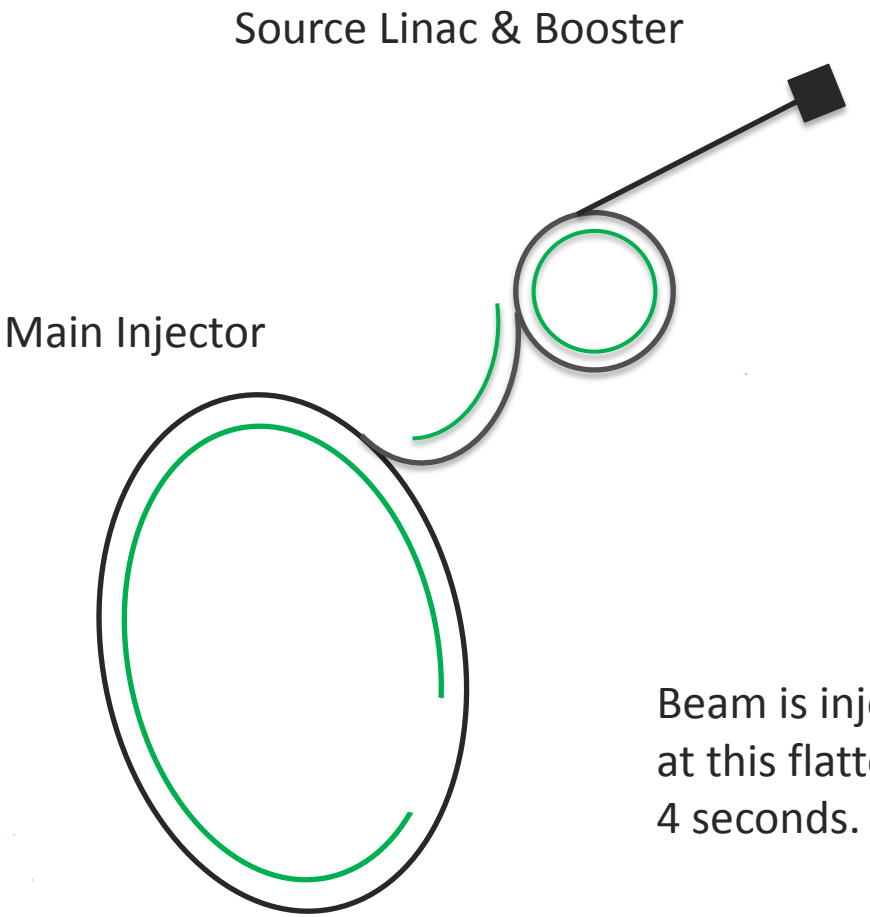
Switchyard's Delivery

Source Linac & Booster



Beam is produced from AD's Proton source which includes three machines. The Source, Linac and the Booster Ring.

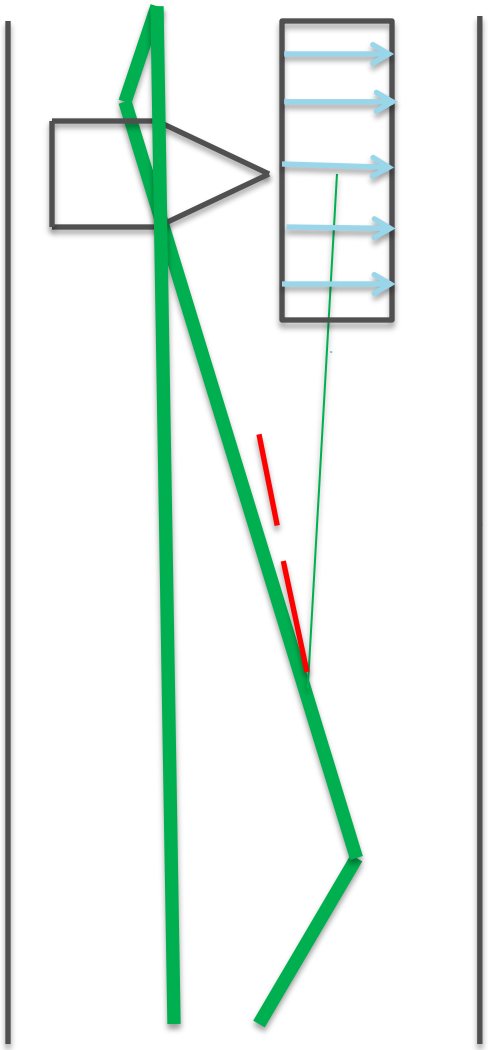
Switchyard's Delivery



Beam is injected at 8 and ramped to 120 Gev Beam is at this flattop value and is resonantly extracted over 4 seconds.

Switchyard's Delivery

Field Free Region

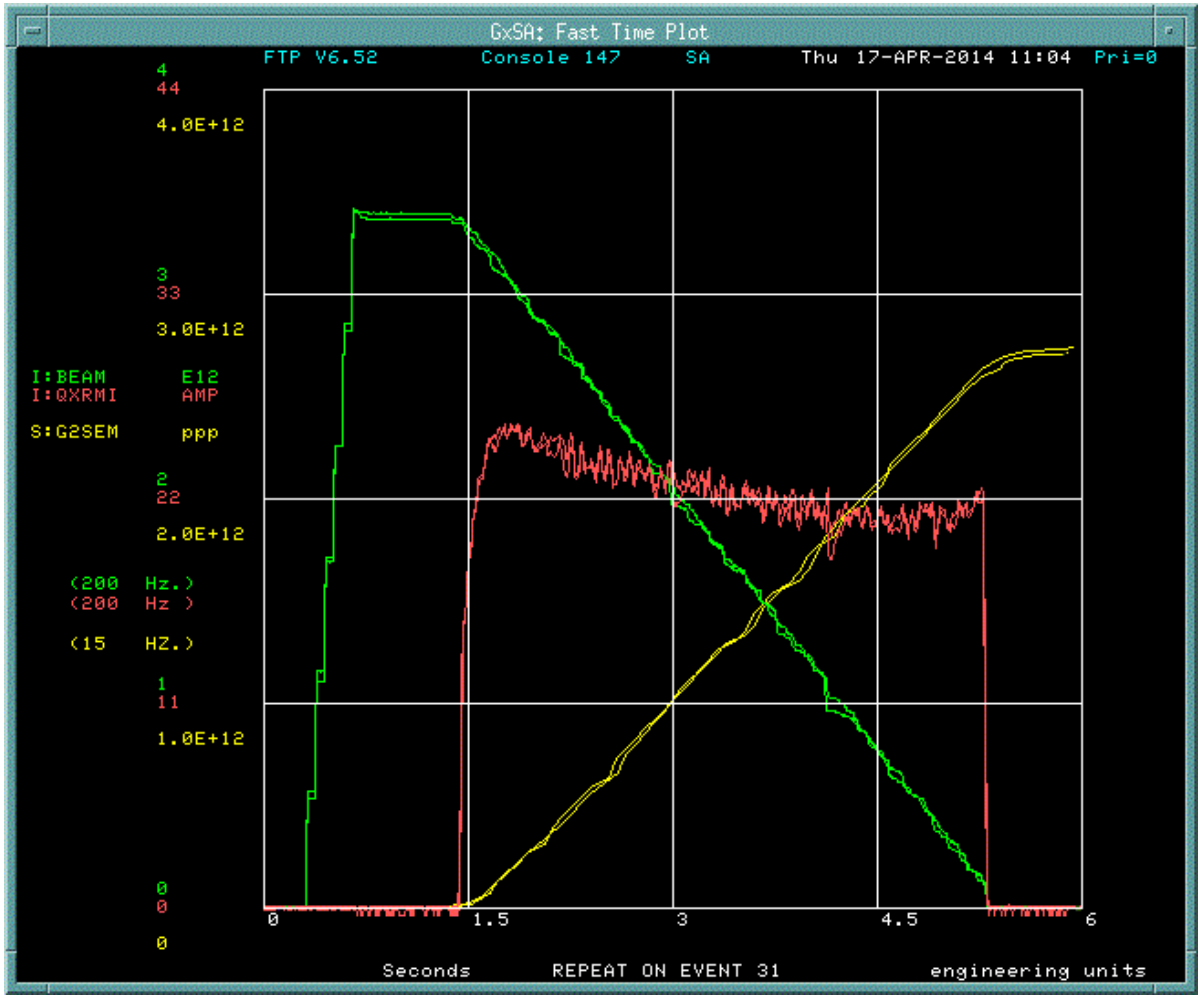


Field Region

2 Electrostatic Septa

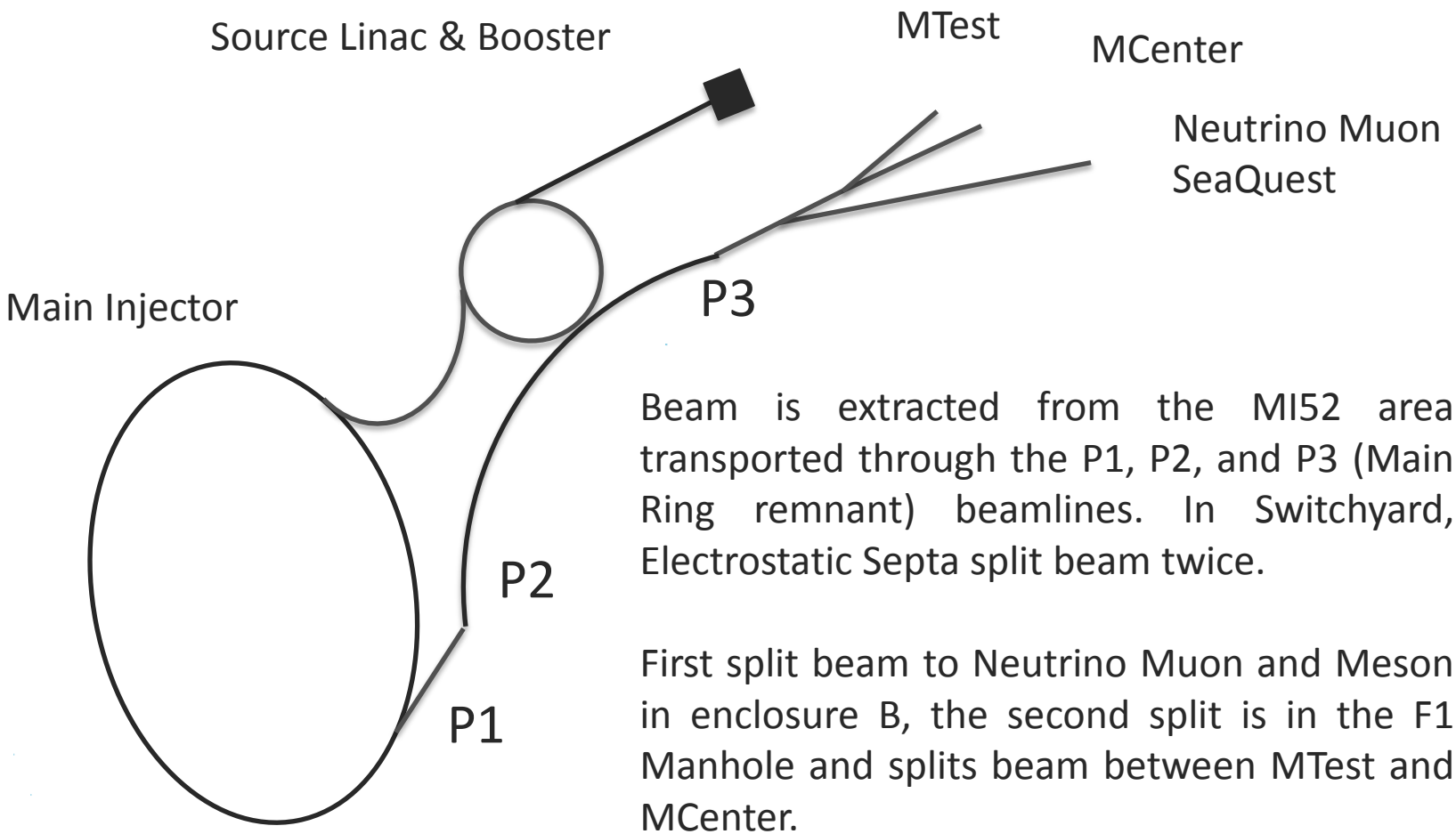
Not to scale*

Switchyard's Delivery



QXR regulates Slow Extraction

Switchyard's Present



Beam is extracted from the MI52 area transported through the P1, P2, and P3 (Main Ring remnant) beamlines. In Switchyard, Electrostatic Septa split beam twice.

First split beam to Neutrino Muon and Meson in enclosure B, the second split is in the F1 Manhole and splits beam between MTest and MCenter.

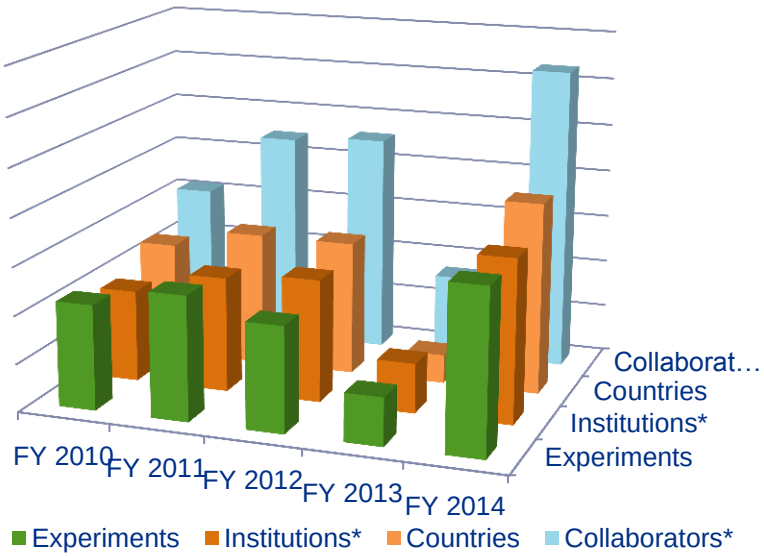
Switchyard's User – FTBF Location

Meson Detector Building – West

Switchyard's User – FTBF Users

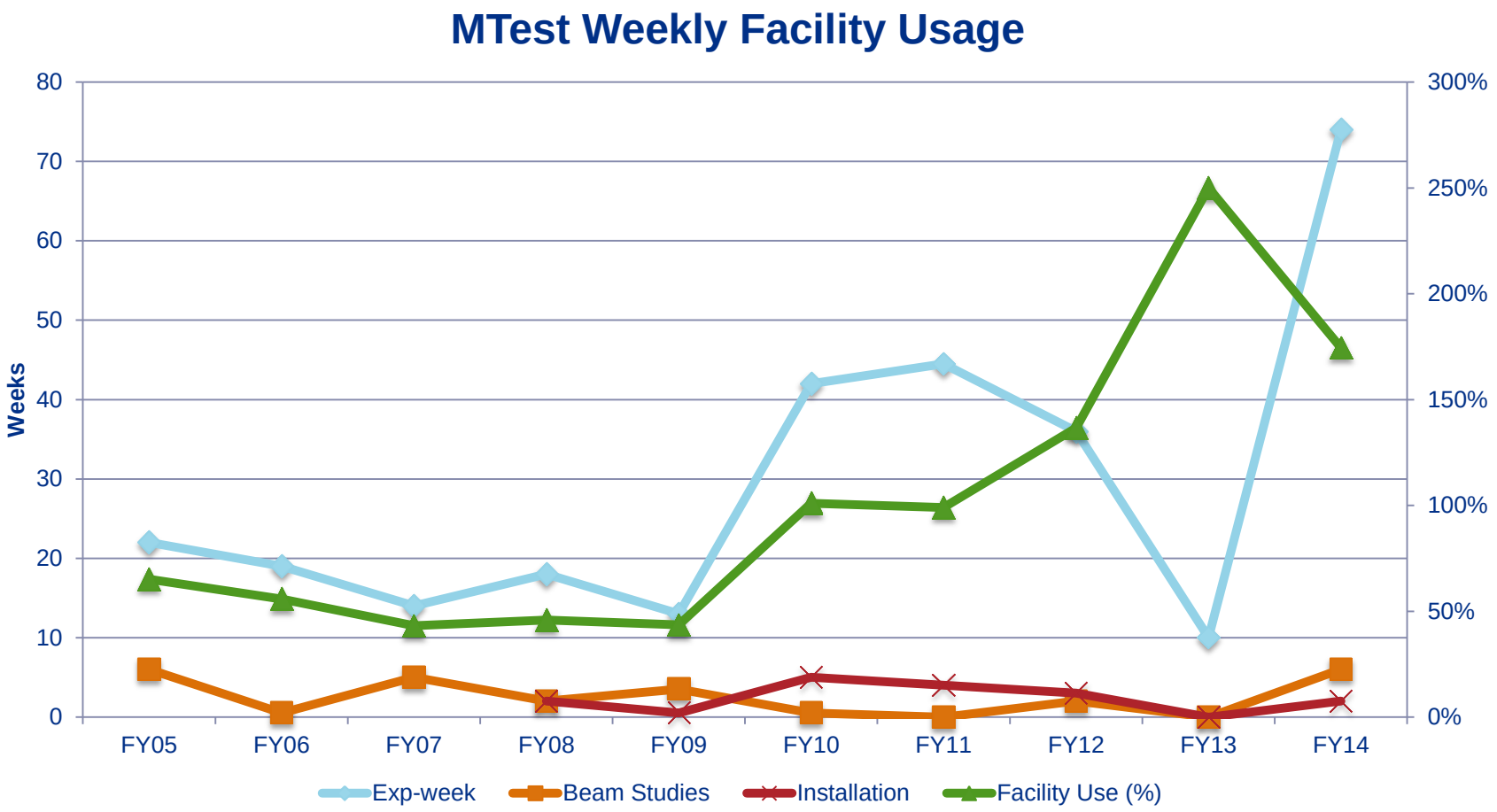
- World Class Facility
- The only U.S. HEP Test Beam
- Detector R&D focus
- In 2014:
  - 17 experiments
  - 316 collaborators
  - 85 institutions
  - 20 countries

Most Recent 5 Years



- *Number of *Collaborators* has been scaled to fit on plot
- *Number of *Institutions* has been scaled to fit on plot.
- Accelerator Shutdown FY12 & FY13

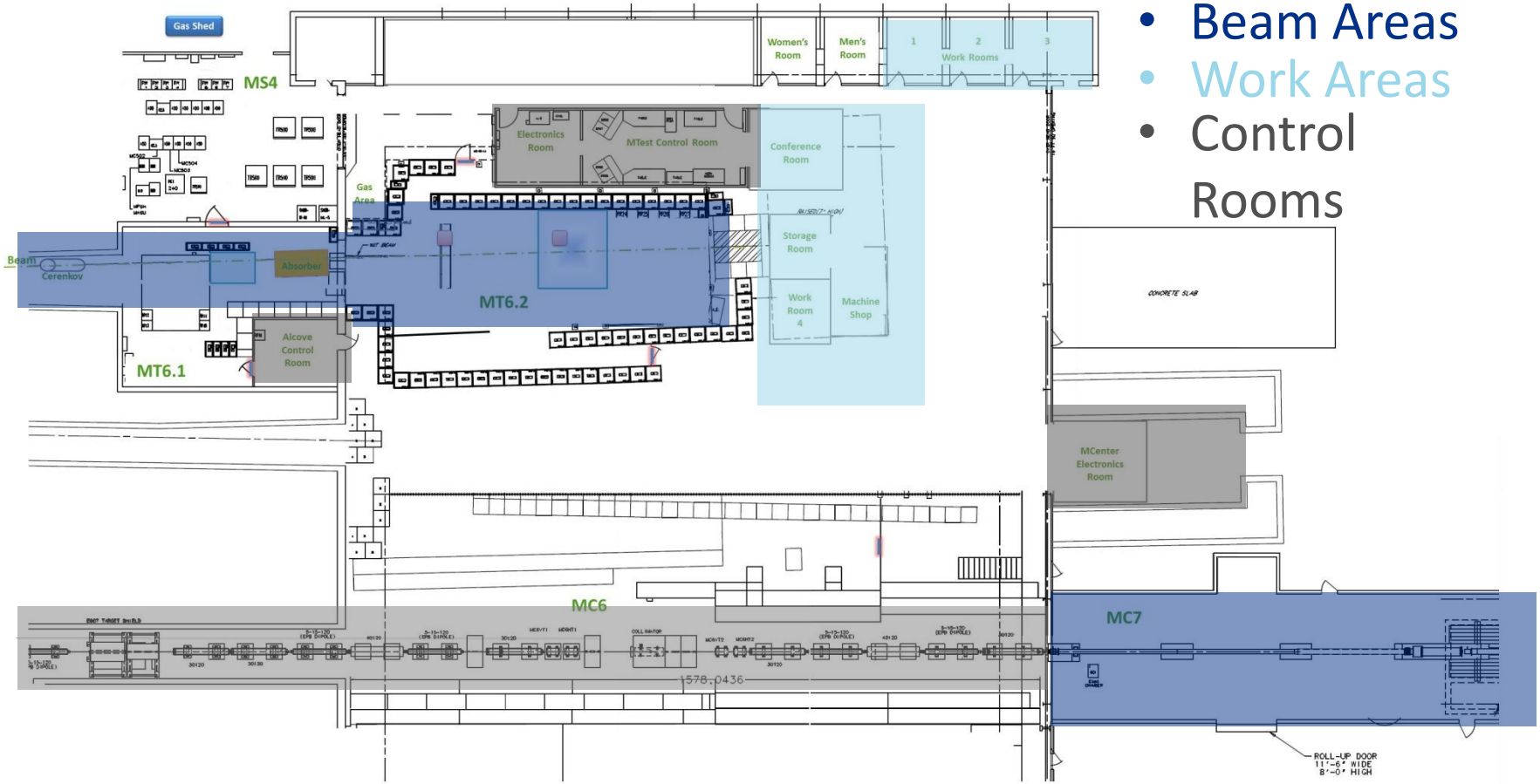
Switchyard's User –FTBF Weekly Usage



Switchyard's User – FTBF 2014 Experiments

- Dual Readout Calorimetry – General R&D
- Spacordian – Support of LHC experiment
- ATLAS Tile Electronics Test – Support of LHC experiment
- High Rate Pixel Detector for CMS Upgrade – Support of LHC experiment
- FlYSUB – General R&D
- CMS Forward Calorimetry R&D – Support of LHC experiment
- Muon g-2 Straw Tracker – Fermilab Experiment
- sPHENIX Calorimetry Tests – Nuclear Physics Experiment
- PHENIX Fast TOF – Nuclear Physics Experiment
- ATLAS large scale Thin Gap Chambers – Support of LHC experiment
- sPHENIX PreShower – Nuclear Physics Experiment
- ATLAS DBM Module Qualification – Support of LHC experiment
- FP420 Fast Timing Group – General R&D
- Fast Timing Counters for PSEC – General R&D
- DAMIC – Fermilab Dark Energy Experiment
- SLHC sensor tests – Support of LHC experiment
- JASMIN – Nuclear Physics Research

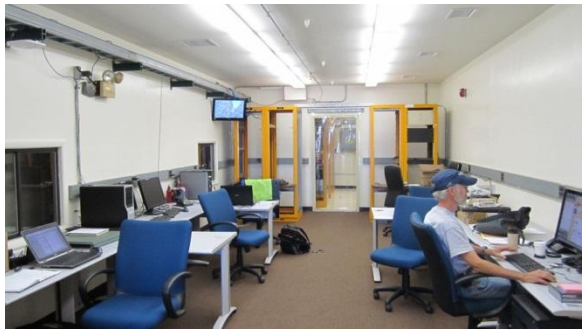
Switchyard's User – FTBF Facility Layout



- Beam Areas
- Work Areas
- Control Rooms

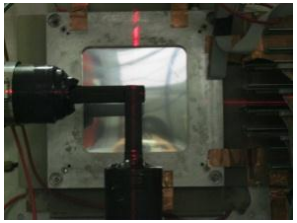
Switchyard's User – FTBF Rooms

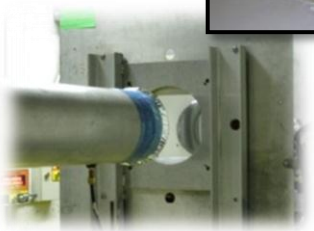
- Multiple Control Rooms
  - Mtest Ctrl Rm
    - Electronics Rm
  - Alcove Ctrl Rm
  - MCntr Ctrl Rm
- Video Conference Room
- Machine Shop
- Cosmic Test Area



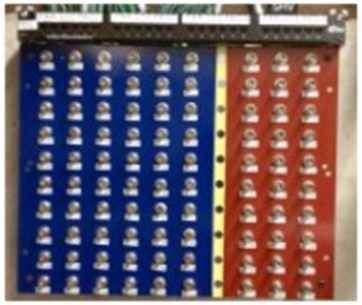
Switchyard's User – FTBF Infrastructure

- ACNET controlled Motion Tables
- Laser Alignment
- Helium Tubes





- State-of-the-Art, web-based Cameras
- Crane Coverage (30 tons)
- Climate controlled Huts
- Gas Patch panels
- Signal, Network, & High Voltage cable patch panels



Switchyard's User – FTBF Facility Instrumentation

- 2 Cerenkov Detectors
- 2 Pixel Telescopes
- 4 MWPC Tracking System
- Time of Flight System
- Lead Glass Calorimeters
- Assorted Trigger scintillators

Switchyard's User – FTBF High Rate Tracking Area

- Located in MTest beamline upstream of pinhole collimator (MT3 Alcove)
- 2.5 GHz/cm^2 Rates for protons
- Patch panels for signal, HV, and network link the enclosure alcove area with the MS3 service Building
- Acnet controlled table
- Pions also available

Switchyard's User – MTest Particles and Energies

- 120 Gev Proton Mode (primary beam)
  - Maximum intensity: 5E5 p/spill

p

- High Energy Pion Mode
  - + 60
  - + 50
  - + 40

π

- Muon Mode:
  - Every LE or HE Pion Mode with additional absorbers in MT6-1.

μ

- Low Energy Pion Mode
  - +/- 32
  - +/- 30
  - +/- 25
  - +/- 20
  - +/- 16
  - +/- 15
  - +/- 12
  - +/- 10
  - +/- 8
  - +/- 6
  - +/- 5
  - +/- 4
  - +/- 3.5
  - +/- 3
  - +/- 2.5
  - +/- 2
  - +/- 1.5
  - +/- 1

Some kaons

k

Mostly Electrons/ Positrons

e

Fermilab

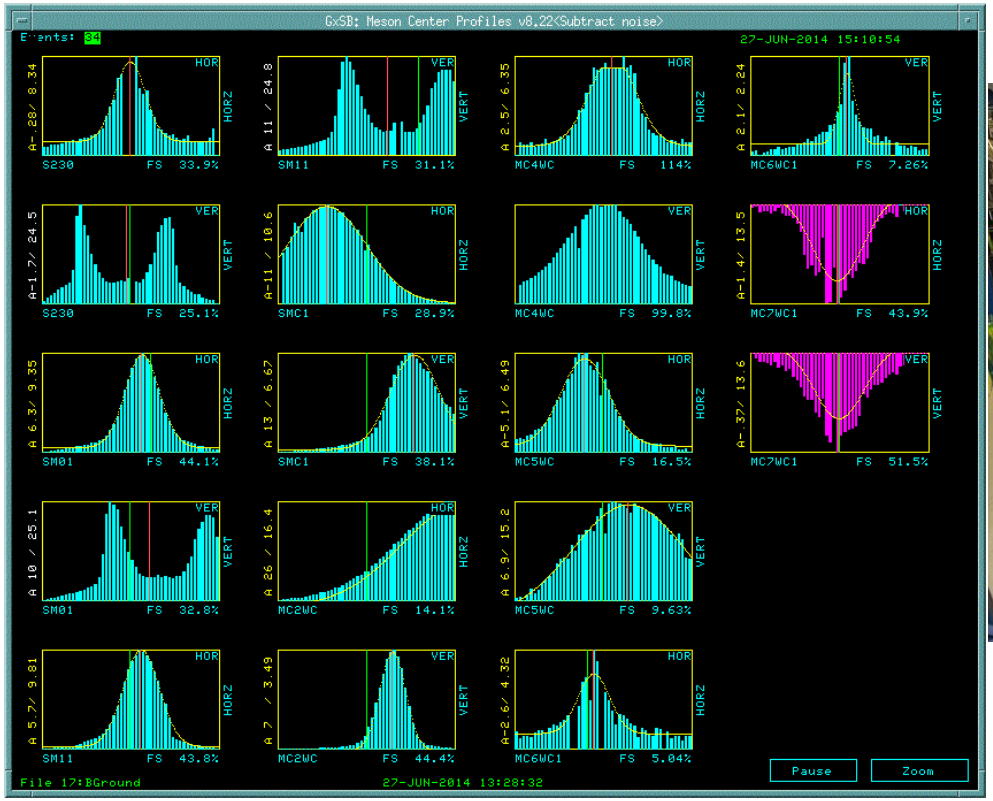
Switchyard's User – FTBF Summary

- Fermilab Test Beam Facility is an High Energy Beam facility for world-wide Detector R&D
- Extensive facility infrastructure & instrumentation
- Flexible beam delivery
  - Protons, pions, muons, electrons, kaons
  - 200 MeV – 120 GeV
  - 1 – 300 kHz intensities
- Beam time available!
  - http://www-ppd.fnal.gov/FTBF
  - Become a User

Switchyard's User – MCenter Summary

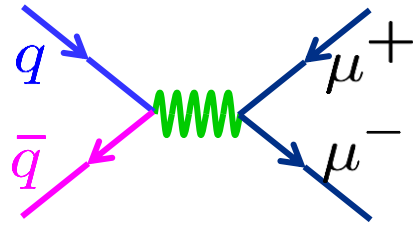
Primary Beam Commissioned April 8th

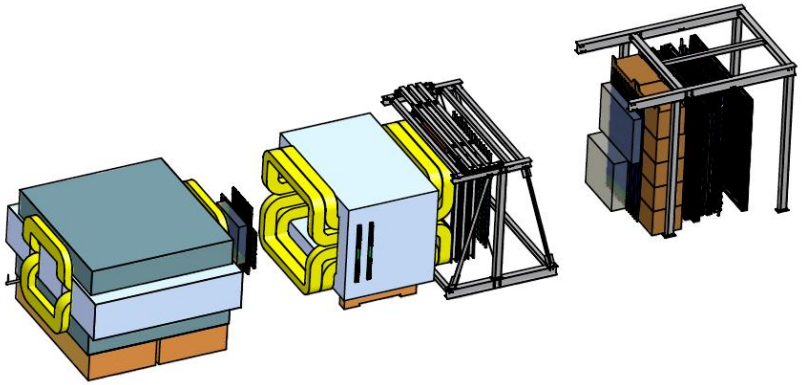
Secondary Beam continues to be commissioned

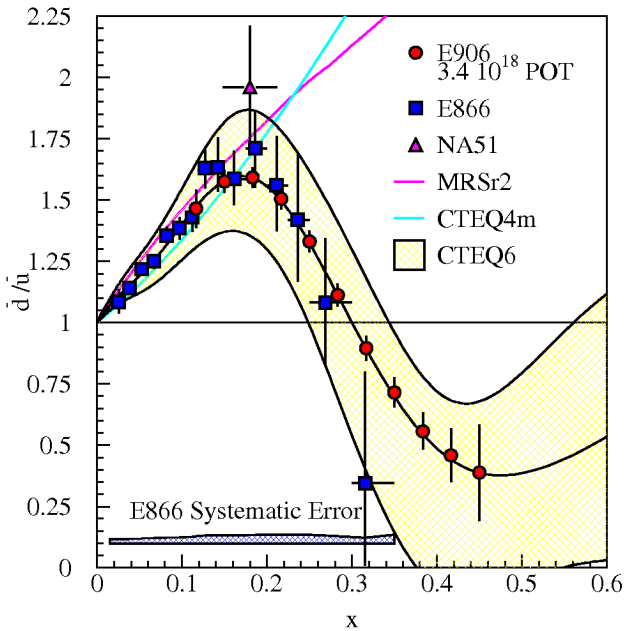


Switchyard's User - SeaQuest

- Paul E. Reimer
- Physics Division
- Argonne National Laboratory





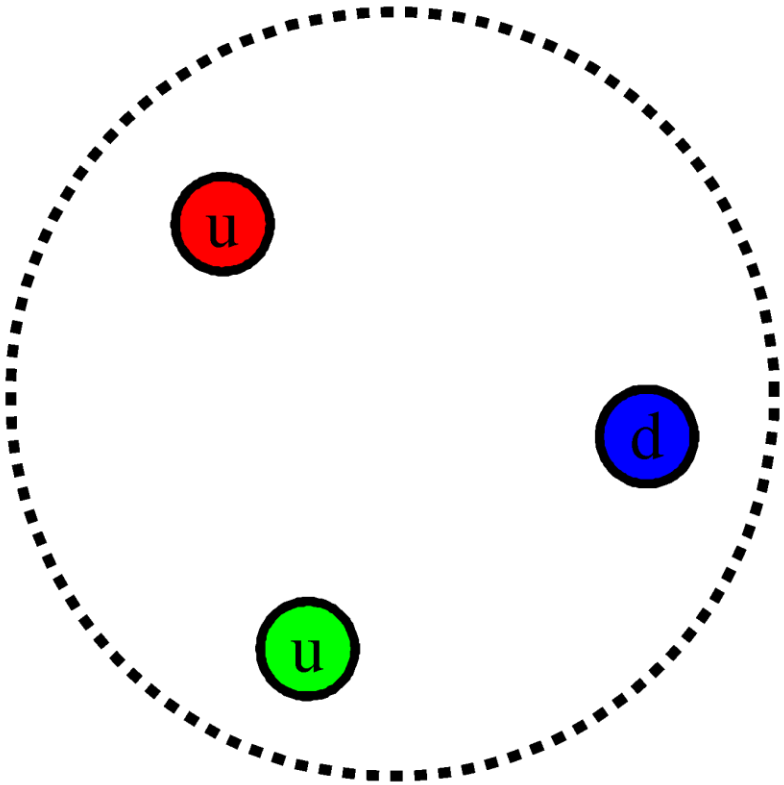


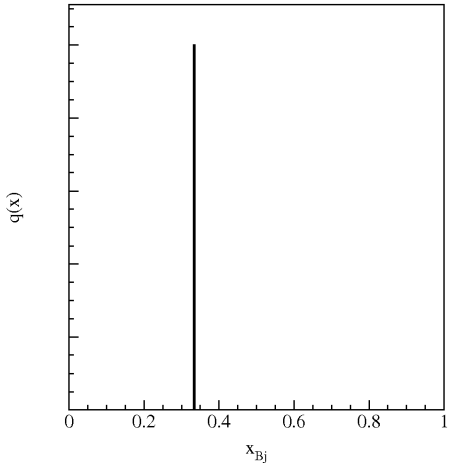
This work is supported in part by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357.

Switchyard's User - SeaQuest

Switchyard's User – SeaQuest The Proton's Sea

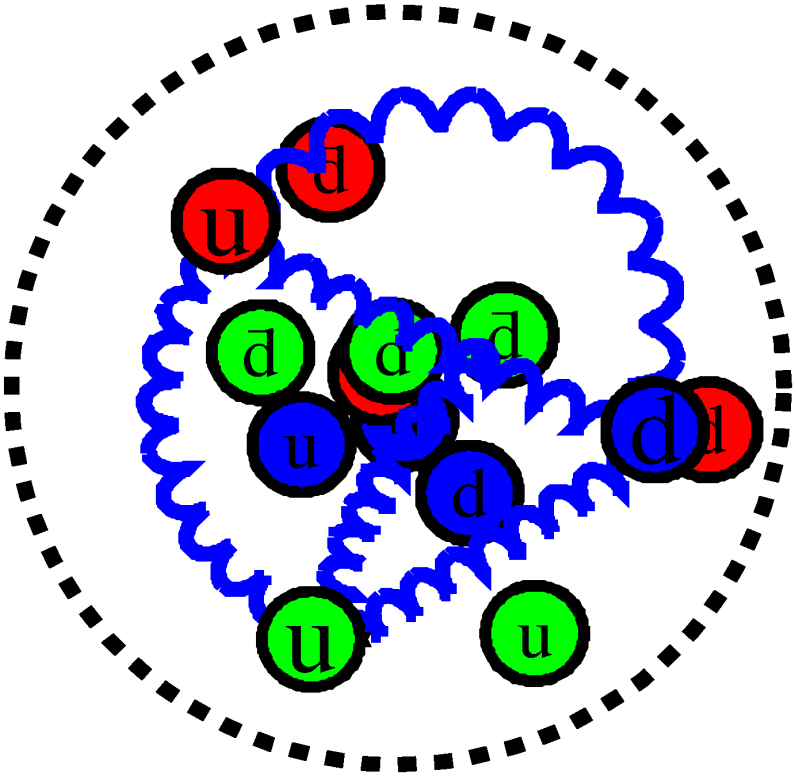
- Proton is 3 quarks—two up and one down
- Bjorken-x (x_{Bj}) represents the fraction of the total momentum carried by the interacting quark

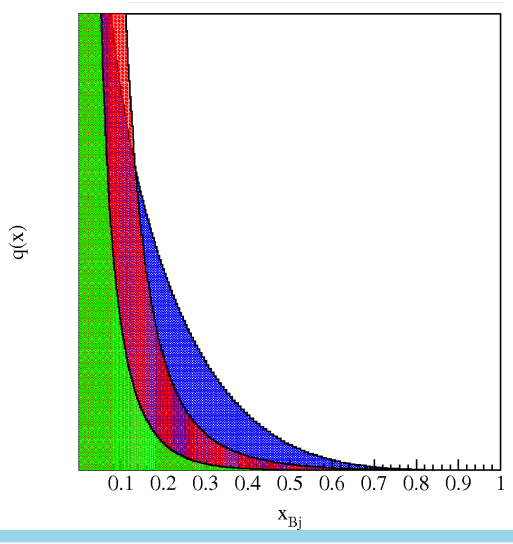




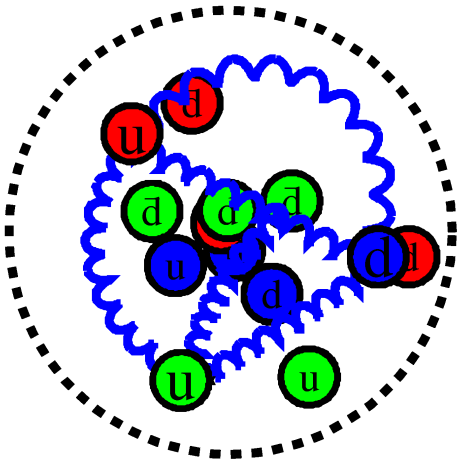
Switchyard's User – SeaQuest The Proton's Sea

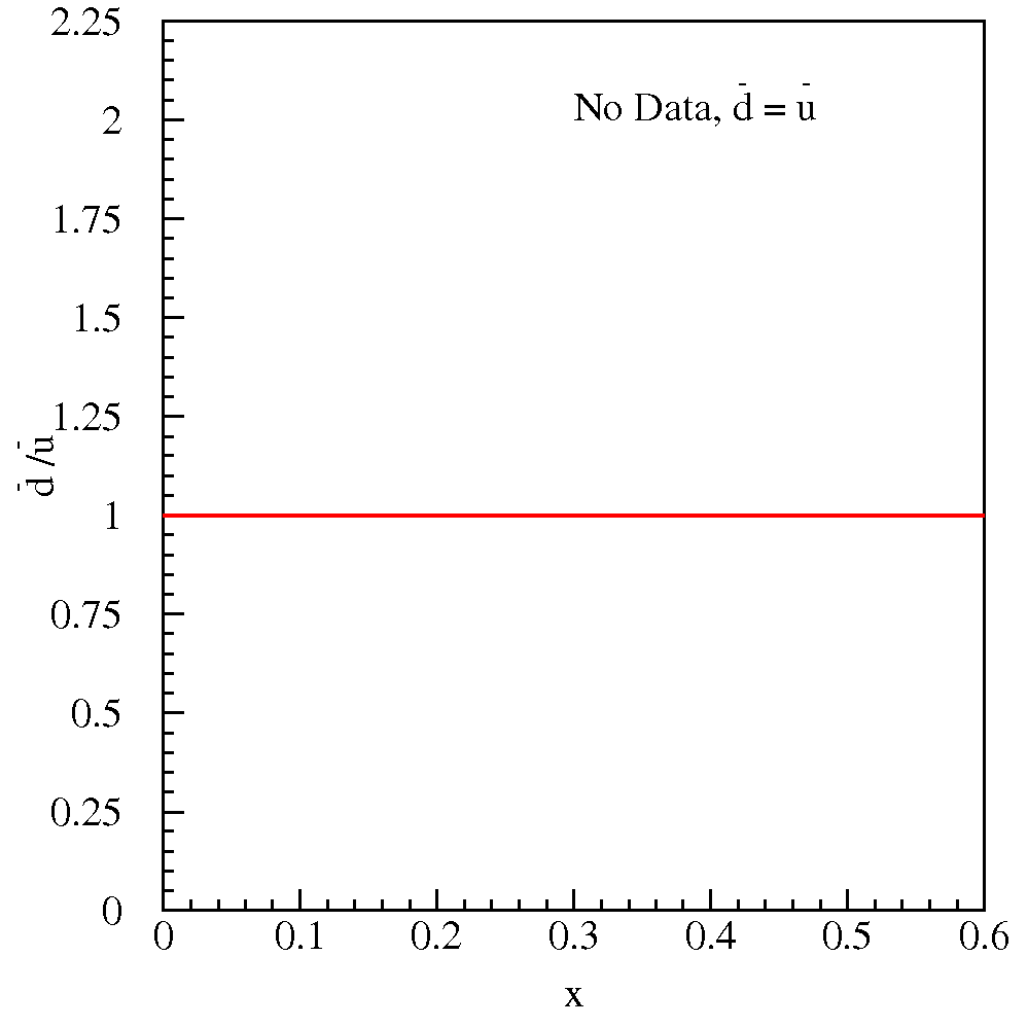
- Proton is 3 quarks—two up and one down
- Bjorken-x (x_{Bj}) represents the fraction of the total momentum carried by the interacting quark
- Glue at low relative momentum
- Sea quarks from gluon splitting





Switchyard's User – SeaQuest Light Antiquark Flavor Asymmetry:





- This picture produces

$$\bar{d}(x) \equiv \bar{u}(x)$$

  - Sea generated by gluon splitting.
  - Gluons couple to color, not flavor!
  - Strange Sea: similar shape and origin—M_s suppresses.

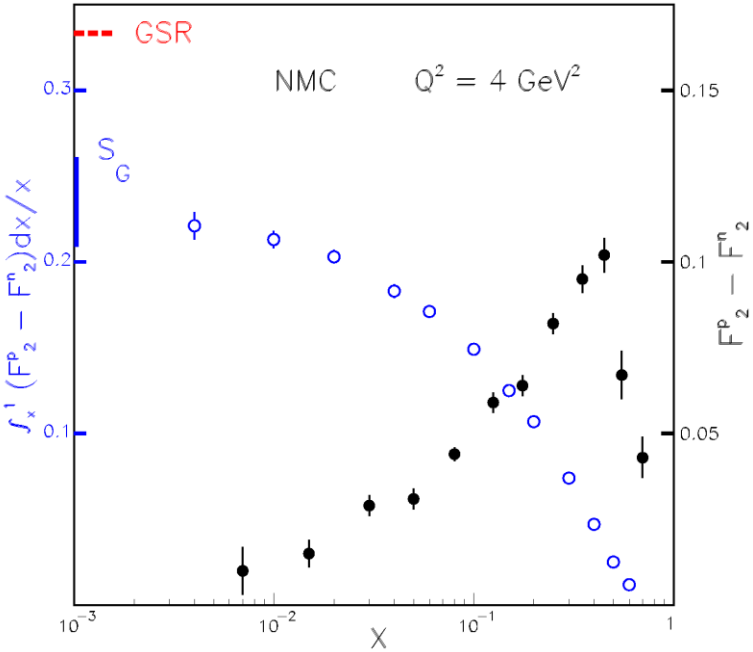
Switchyard's User – SeaQuest Light Antiquark Flavor Asymmetry:

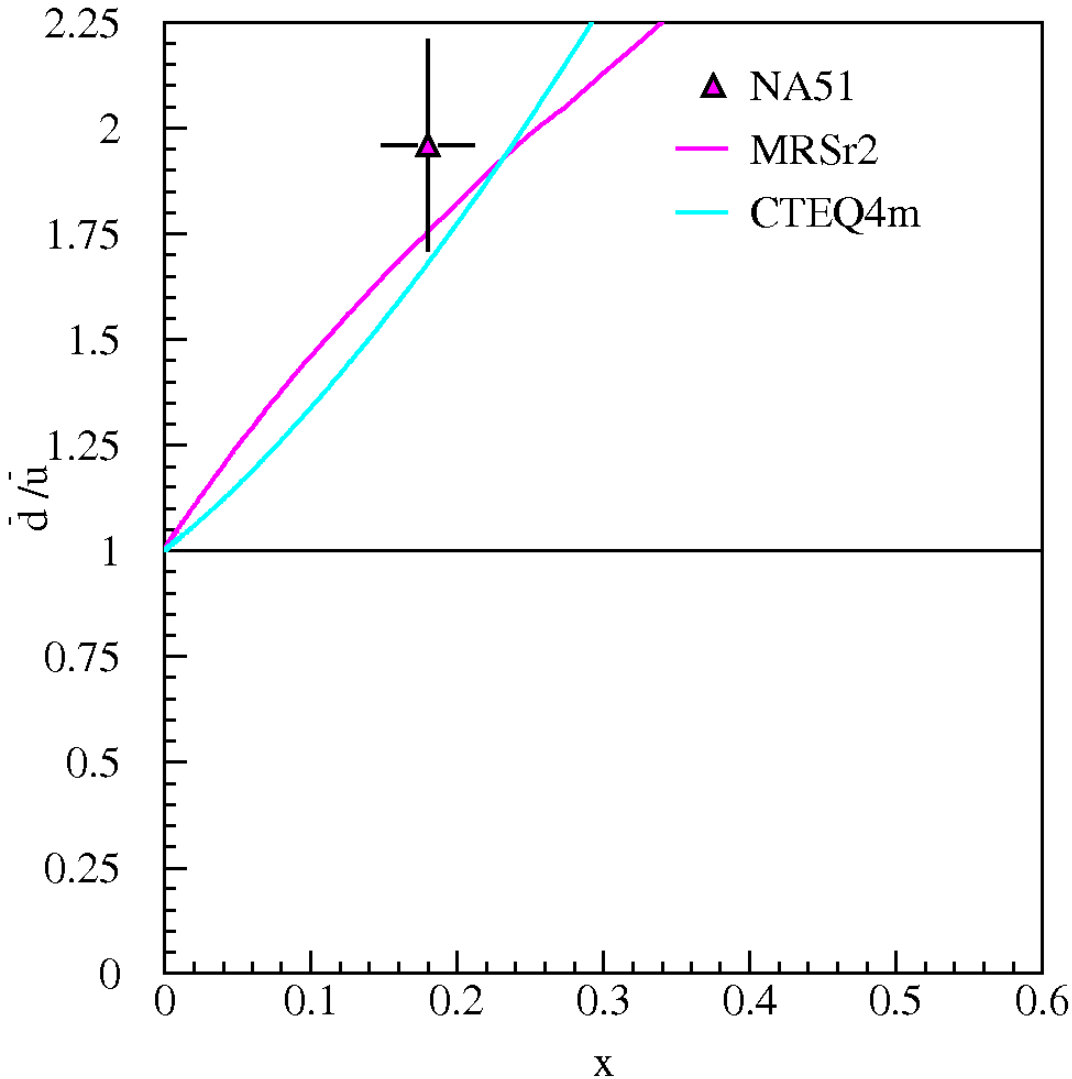
- NMC (Gottfried Sum Rule)

$$\int_0^1 \left[\bar{d}(x) - \bar{u}(x)\right] dx \neq 0$$

- NA51 (Drell-Yan)

$\bar{d} > \bar{u}$ at $x = 0.18$





Switchyard's User – SeaQuest Light Antiquark Flavor Asymmetry:

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$$\int_0^1 \left[\bar{d}(x) - \bar{u}(x)\right] dx \neq 0$$

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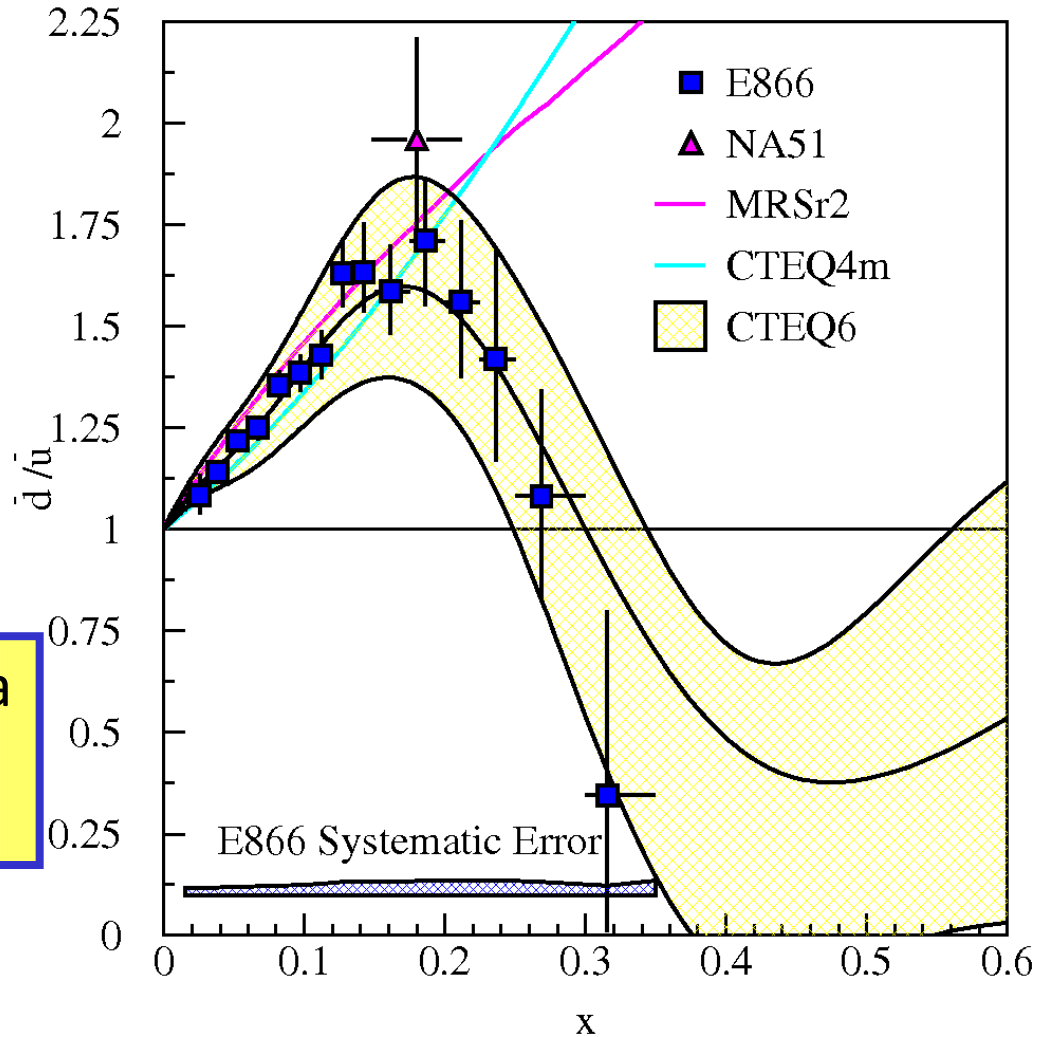
$\bar{d} > \bar{u}$ at $x = 0.18$

- E866/NuSea (Drell-Yan)

$\bar{d}(x)/\bar{u}(x)$ for $0.015 \leq x \leq 0.35$

- Knowledge of sea dist. are data driven
  - Sea quark distributions are difficult for Lattice QCD
- Non perturbative QCD models can explain excess d-bar quarks, but not return to symmetry or deficit of d-bar quarks



Switchyard's User – SeaQuest Early Pair Data

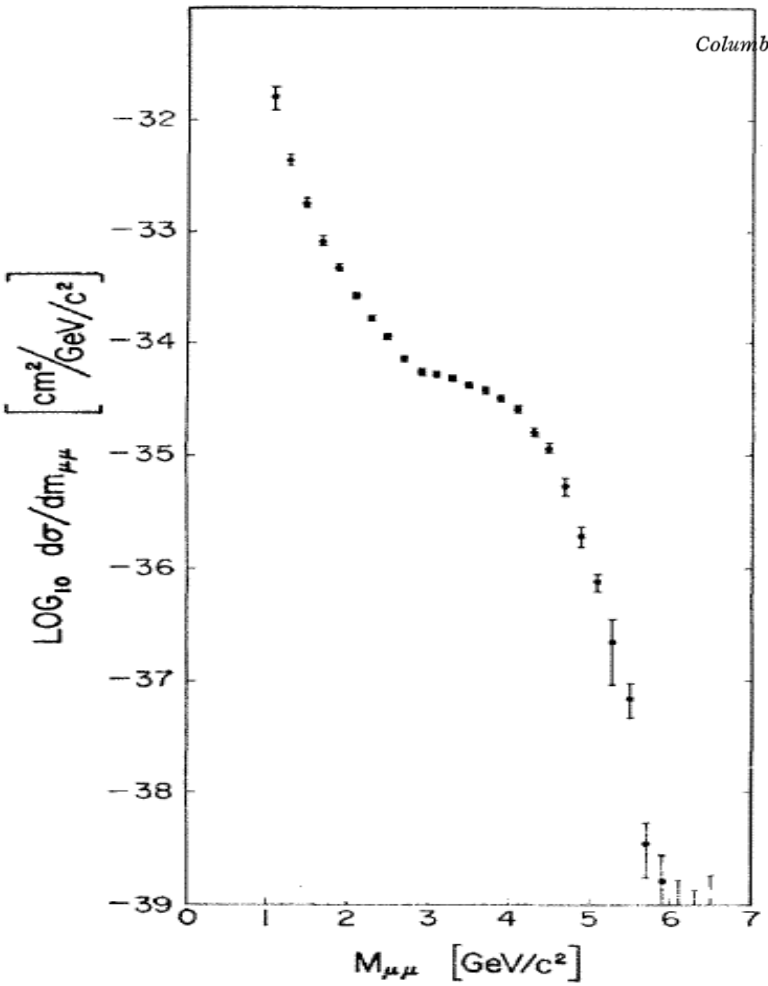
VOLUME 25, NUMBER 21 PHYSICAL REVIEW LETTERS 23 NOVEMBER 1970

Observation of Massive Muon Pairs in Hadron Collisions*

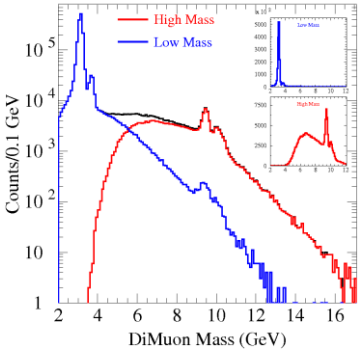
J. H. Christenson, G. S. Hicks, L. M. Lederman, P. J. Limon, and B. G. Pope
Columbia University, New York, New York 10027, and Brookhaven National Laboratory, Upton, New York 11973

and

E. Zavattini
CERN Laboratory, Geneva, Switzerland
(Received 8 September 1970)



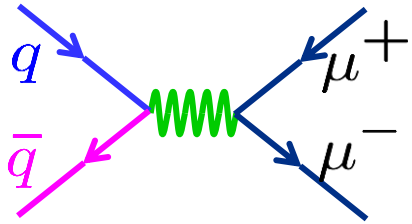
Muon Pairs in the mass range $1 < m_{\mu\mu} < 6.7$ GeV/c^2 have been observed in collisions of high-energy protons with uranium nuclei. At an incident energy of 29 GeV, **the cross section varies smoothly as $d\sigma/dm_{\mu\mu} \approx 10^{-32} / m_{\mu\mu}^5$ cm^2 (GeV/c)$^{-2}$ and exhibits no resonant structure.** The total cross section increases by a factor of 5 as the proton energy rises from 22 to 29.5 GeV.



Switchyard's User – SeaQuest Drell-Yen

Drell-Yan Process

- In leading order



$$\frac{d^2\sigma}{dx_{\mathrm{b}}dx_{\mathrm{t}}} = \frac{4\pi\alpha^2}{x_{\mathrm{b}}x_{\mathrm{t}}s} \sum_{q\in\{u,d,s,\ldots\}} e_q^2 \left[\bar{q}_{\mathrm{t}}(x_{\mathrm{t}})q_{\mathrm{b}}(x_{\mathrm{b}}) + \bar{q}_{\mathrm{b}}(x_{\mathrm{b}})q_{\mathrm{t}}(x_{\mathrm{t}})\right]$$

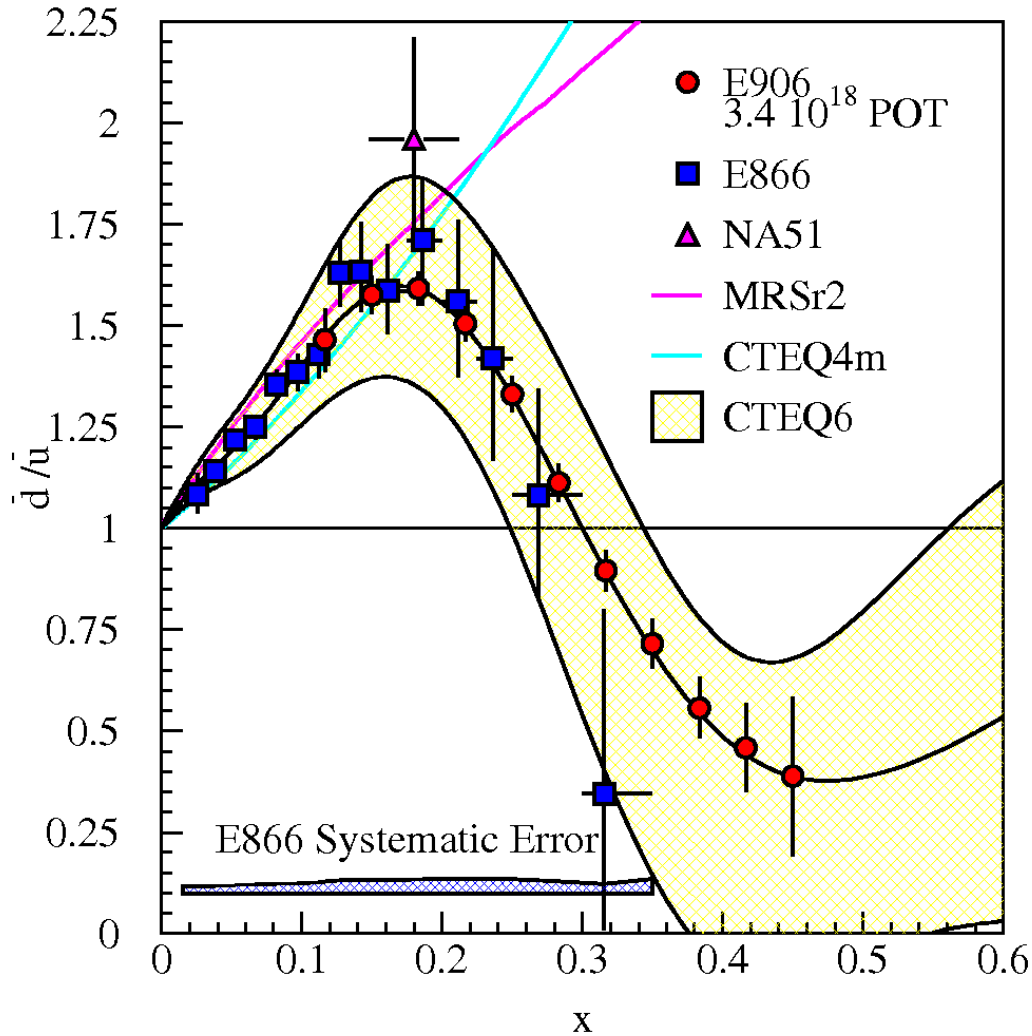
- u-quark dominance
- Forward x_F spectrometer acceptance

$$\frac{\sigma^{\mathrm{pd}}}{2\sigma^{\mathrm{pp}}} = \frac{1}{2}\left[1 + \frac{\bar{d}(x)}{\bar{u}(x)}\right]$$

- Suggested by Martin, Stirling and Roberts Phys.Lett. B308 (1993) 377

Switchyard's User – SeaQuest Extracting d-bar/u-bar

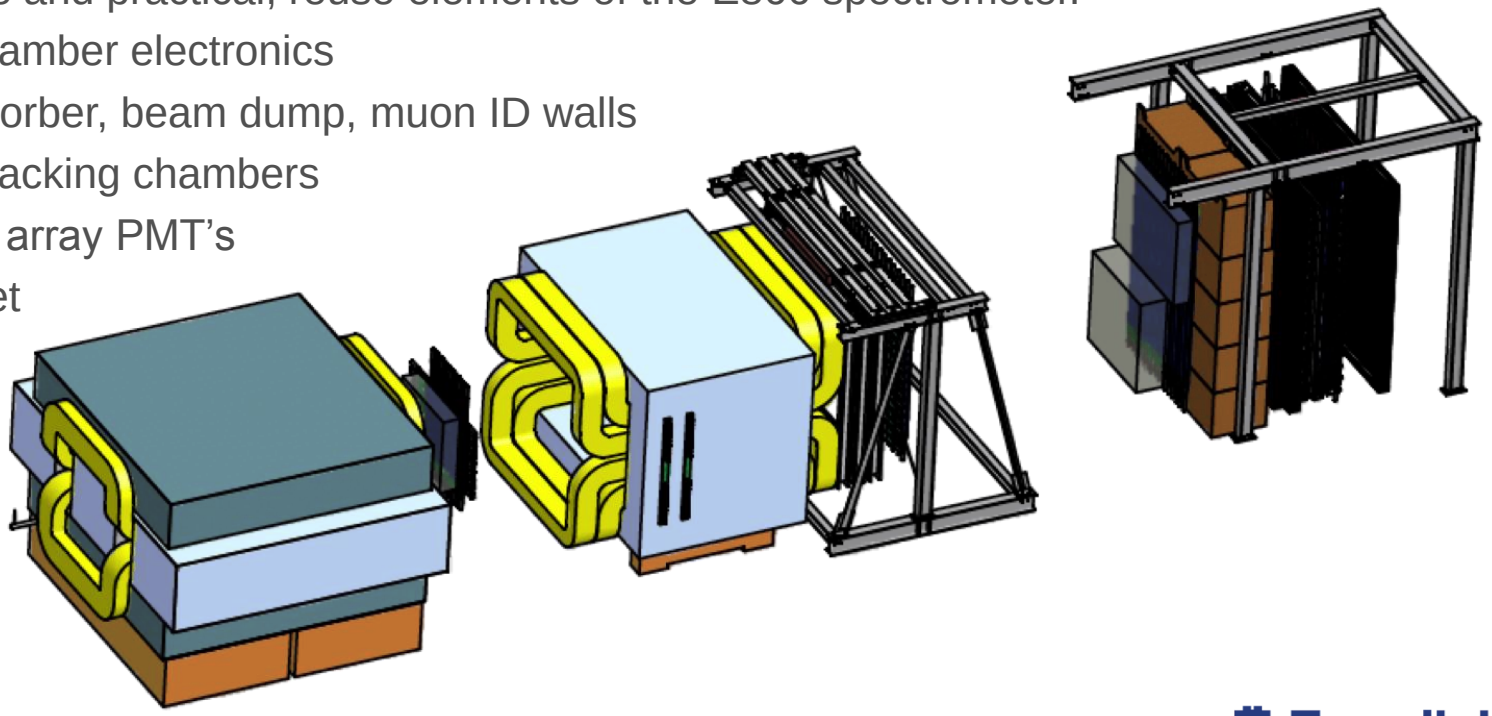
- E906/Drell-Yan will extend these measurements and reduce statistical uncertainty.
- E906 expects systematic uncertainty to remain at approx. 1% in cross section ratio.



Switchyard's User – SeaQuest Spectrometer Guiding Principles

- Follow basic design of MEast spectrometer (don't reinvent the wheel):
  - Two magnet spectrometer
  - Bean dump within first magnet
  - Hadron Absorber within first magnet
  - Muon-ID wall before final element

- Where possible and practical, reuse elements of the E866 spectrometer.
  - Tracking chamber electronics
  - Hadron absorber, beam dump, muon ID walls
  - Station 2 tracking chambers
  - Hodoscope array PMT's
  - SM3 Magnet



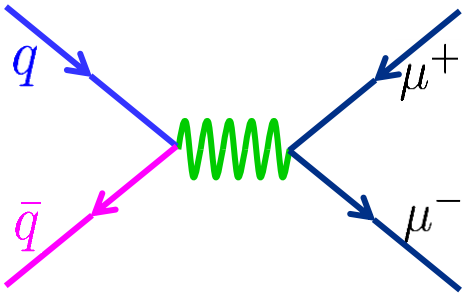
Switchyard's User – SeaQuest Event Reconstruction

- We measure
  1. Direction of particles
  2. Absolute momentum of particles

  } momentum vector

  } Relativistic energy-momentum vector ***p***

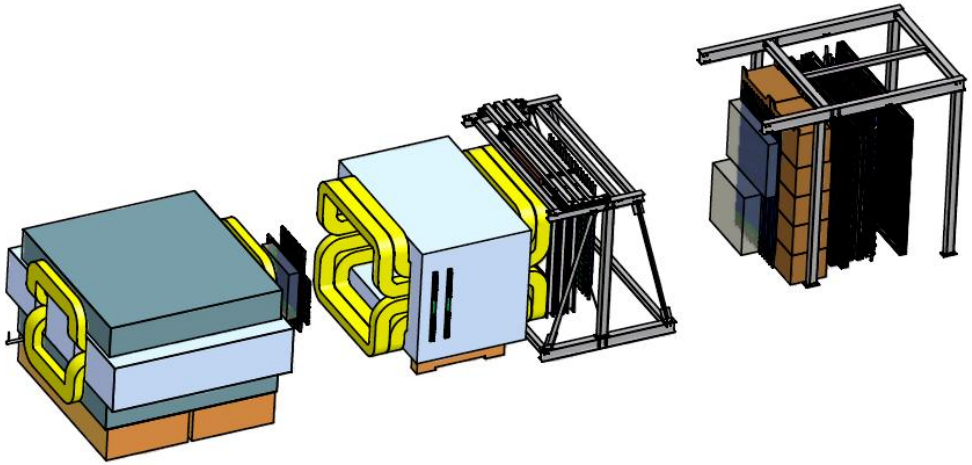
- We assume
  3. Particles are muons



- Add 4-vectors of muons to get 4-vectors of virtual photon ***p***
  - Now we know everything

$$\vec{P}^2 \equiv m_\gamma^2 = x_t x_b s$$

$$\frac{p_l}{p_l^{\text{max.}}} = x_{\text{Feymann}} = x_b - x_t$$

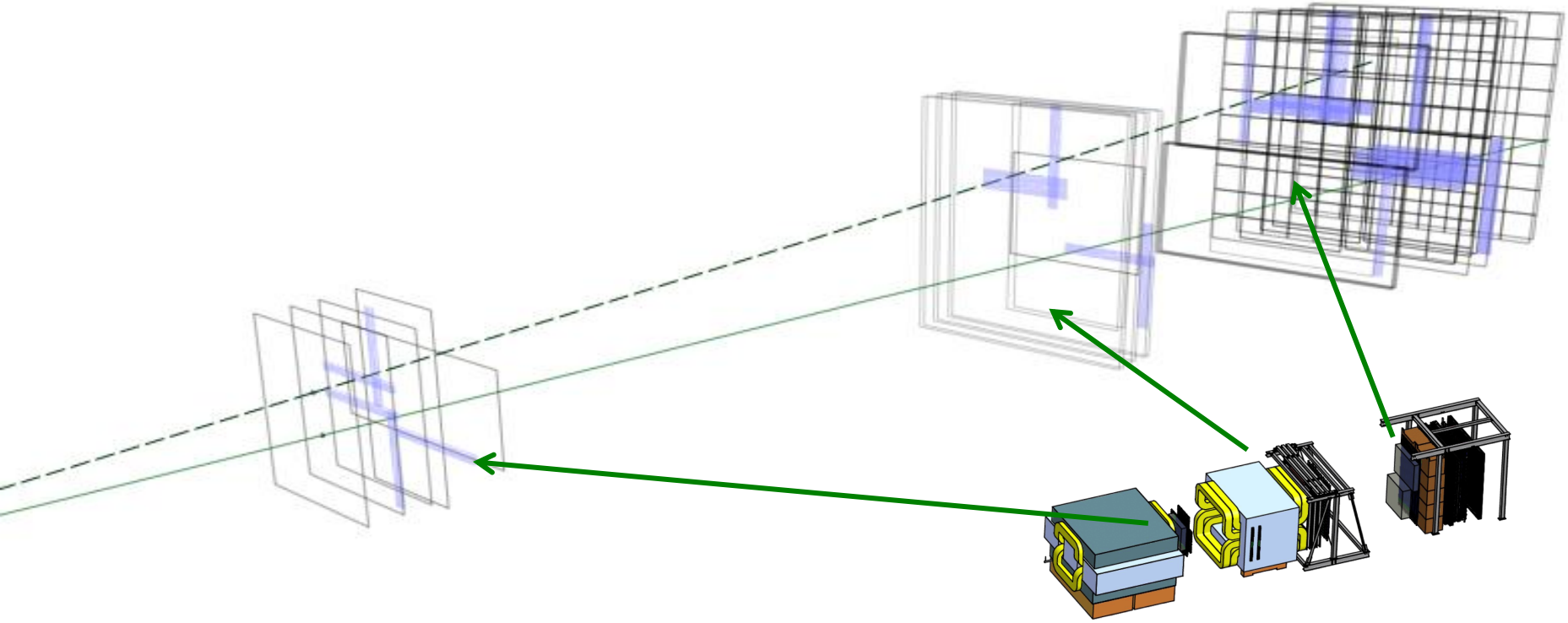


Switchyard's User – SeaQuest

- SeaQuest is dominated by random combinations that form triggers
  - Protons interact more than neutrinos
- Tevatron—Decades to develop
- MI—SeaQuest is the first significant demand on duty factor
  - very significant progress

Switchyard's User – SeaQuest Event Display and Trigger

- Trigger on pattern of hodoscopes that show likely high p_T tracks
  - Number of protons in Rf bucket increases number of hodoscopes
  - Trigger looks at **all combinations** of hodoscopes
  - Additional Hodoscope hits greatly increase combinatorics



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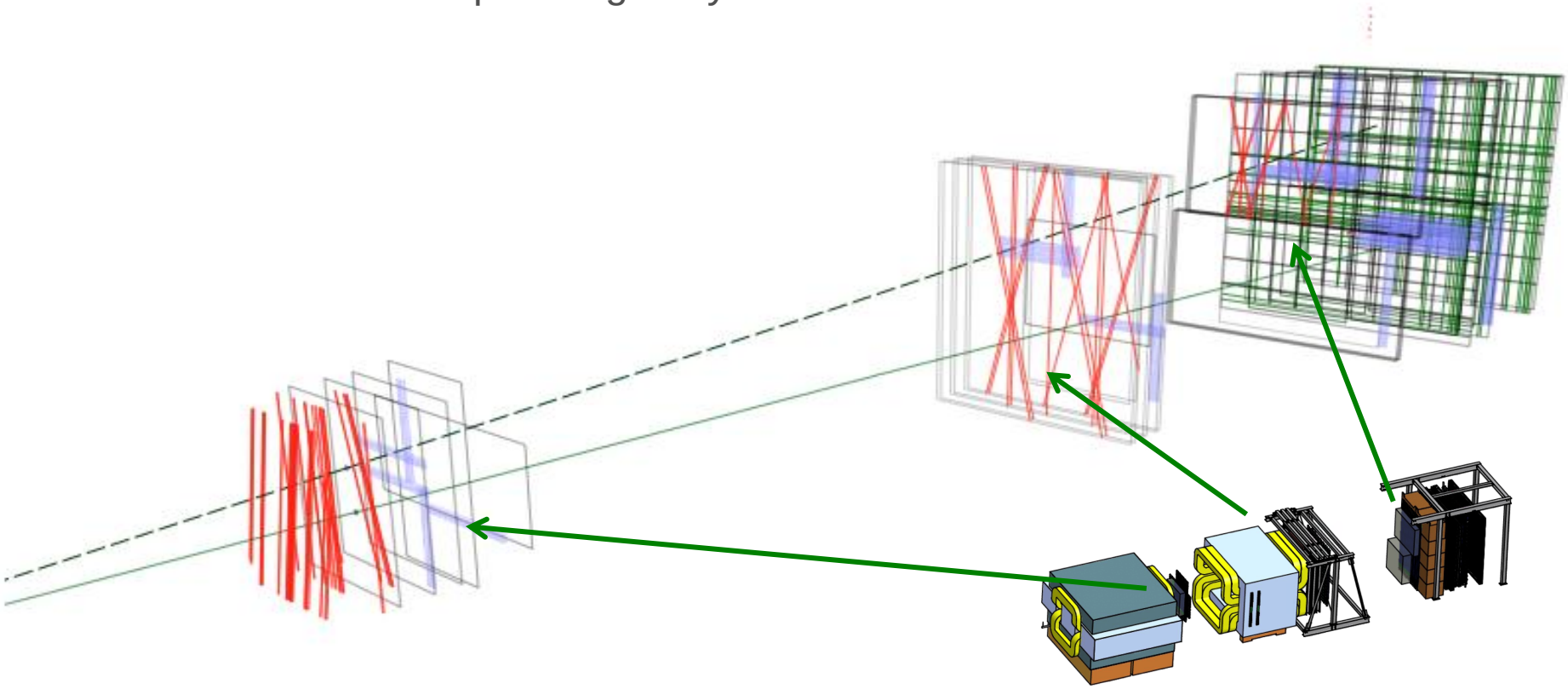

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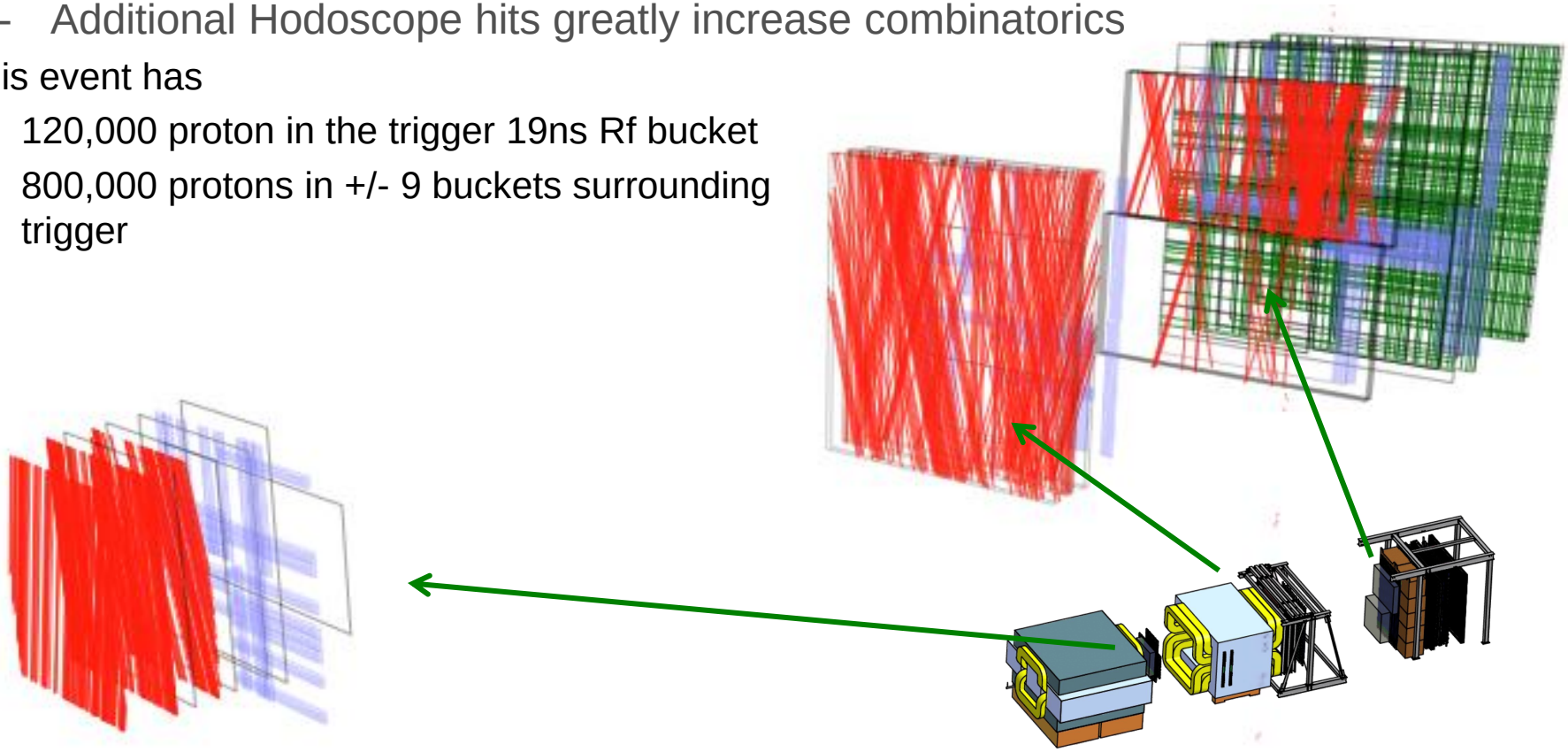
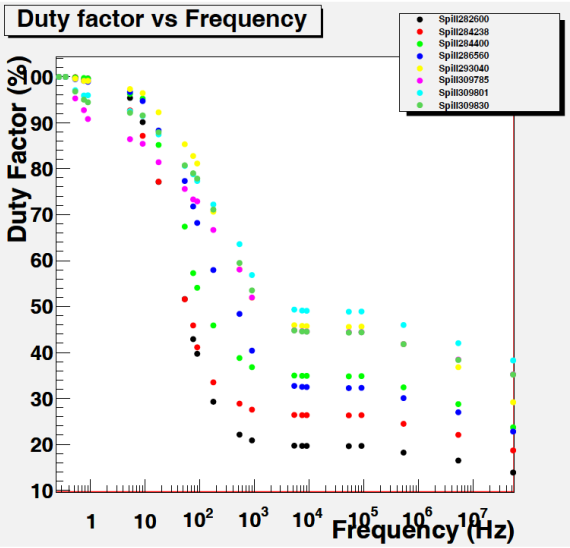
This event has

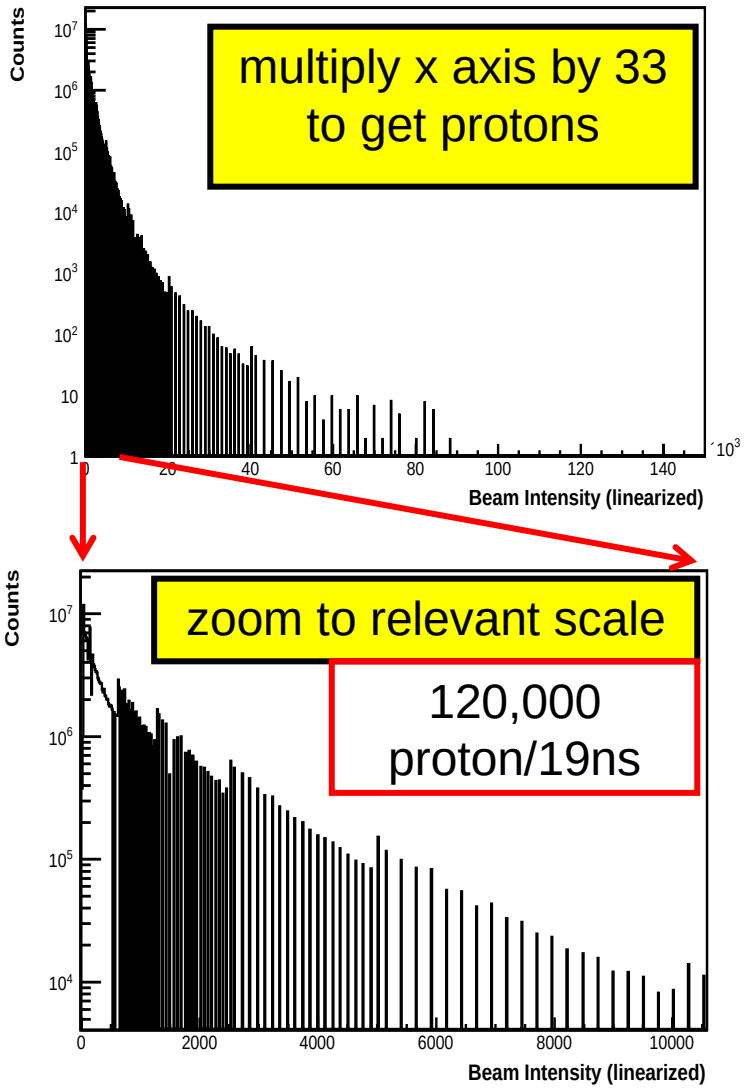
- 120,000 proton in the trigger 19ns Rf bucket
- 800,000 protons in +/- 9 buckets surrounding trigger



Switchyard's User – SeaQuest Proton spectra within a spill

- Present beam spill structure:
  - approx 3.5 x 10^{12} protons/4 sec spill
  - 20,000 protons/19 ns
- Goal
  - approx 10 x 10^{12} protons/4 sec spill
  - 50,000 protons/19 ns
- Measurement with beam line Cherenkov
- dependent on frequency at which measurement is made

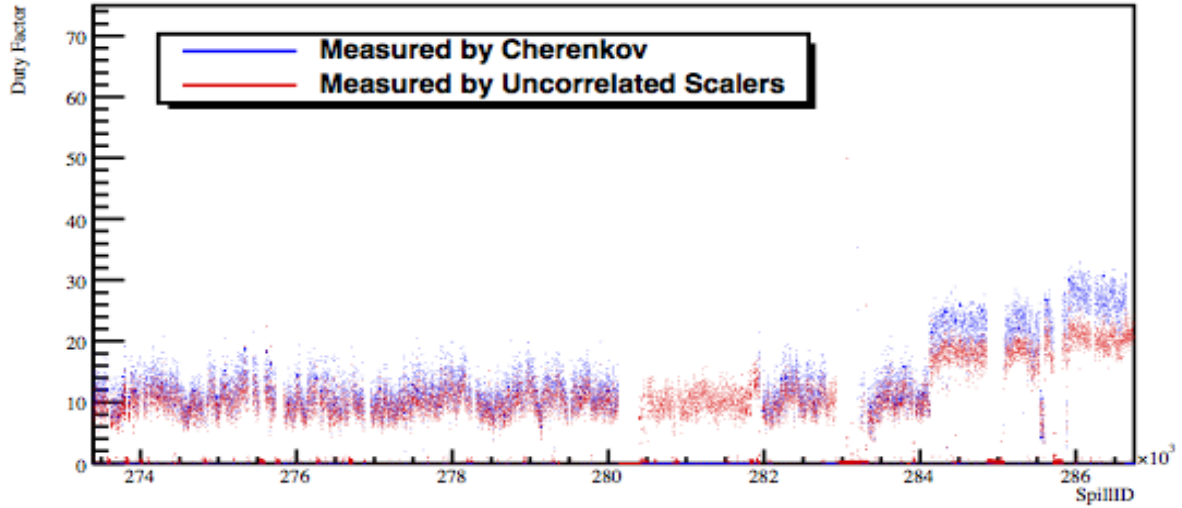


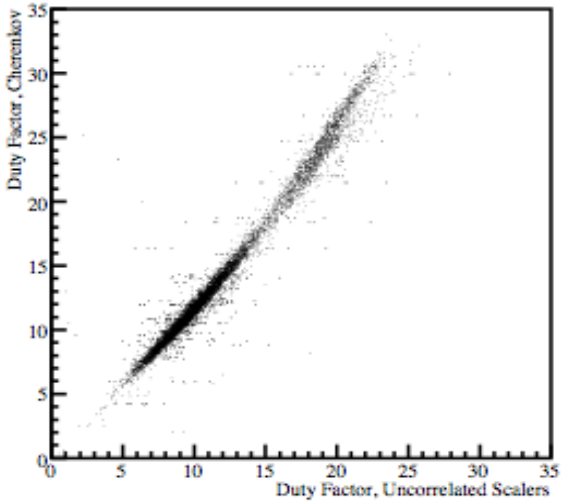


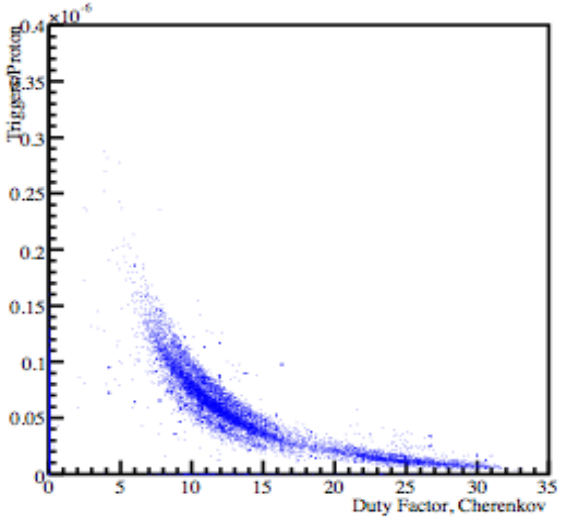
Switchyard's User – SeaQuest

Switchyard's User – SeaQuest Duty Factor

- Duty factor strongly correlated with triggers/proton due to pileup of random coincidences

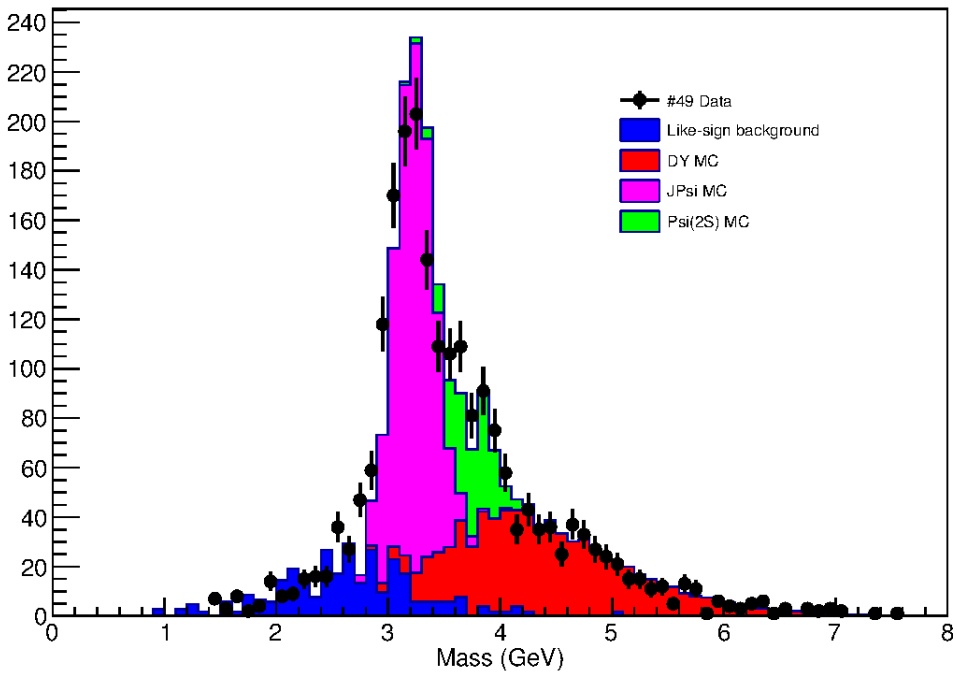


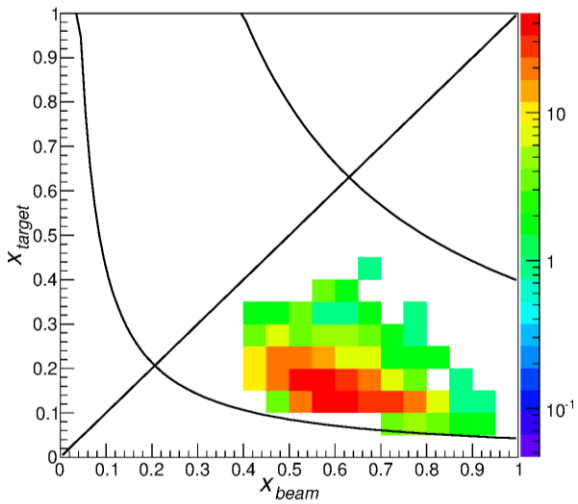


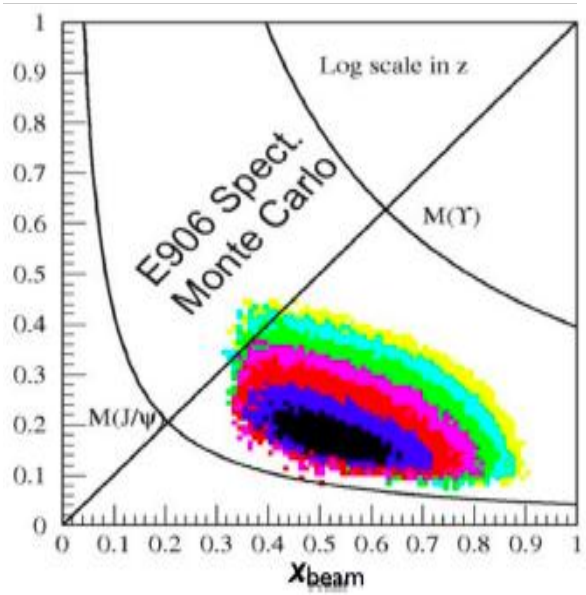


Switchyard's User – SeaQuest

- Reconstructed Kinematic distributions match Monte Carlo predictions

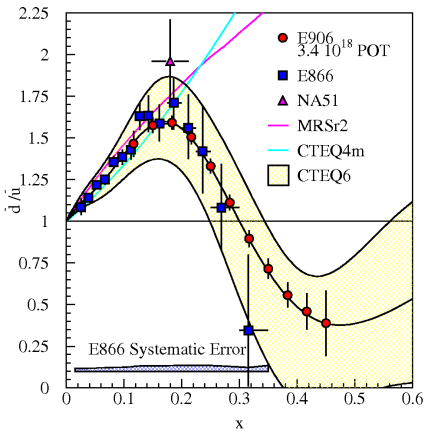




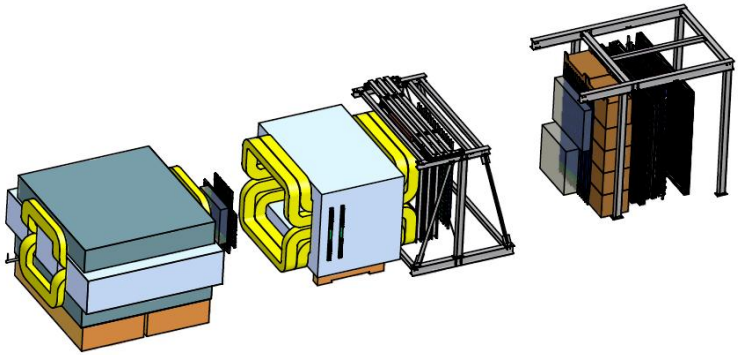


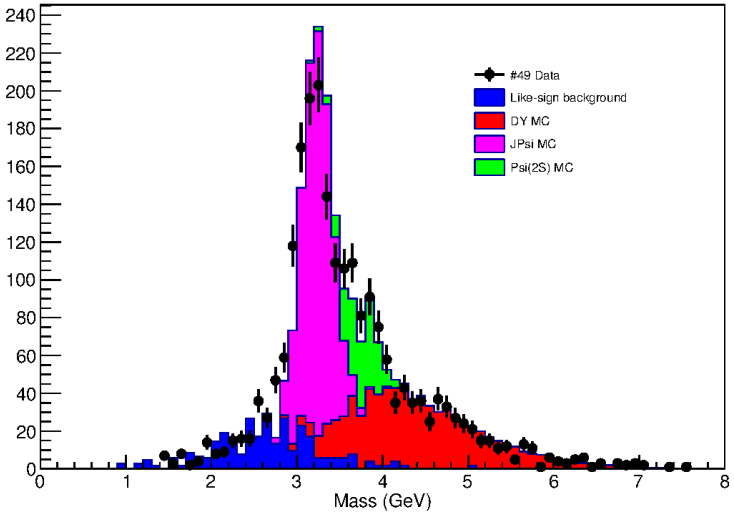
Switchyard's User – SeaQuest Summary

- Knowledge of parton distributions is data driven and
  - The sea quarks surprise us every time we look at them



- SeaQuest is running!
- SeaQuest is very sensitive to instantaneous beam intensity
  - AD (especially MI) have been working hard on this
- Data looks good, need statistics





Switchyard External Beamlines

Items covered

1. Switchyard's History
2. Switchyard's Present
3. Delivery Method
4. Users
   - MTest
   - SeaQuest
   - MCenter

Thanks to Fermilab's History & Archives Project
Valerie Higgins & Adrienne Kolb

Switchyard External Beamlines

Backup slides

Slow Extraction to MTest – Running Modes

120 Gev Proton Mode

High Energy Pion Mode

- + 60
- + 50
- + 40

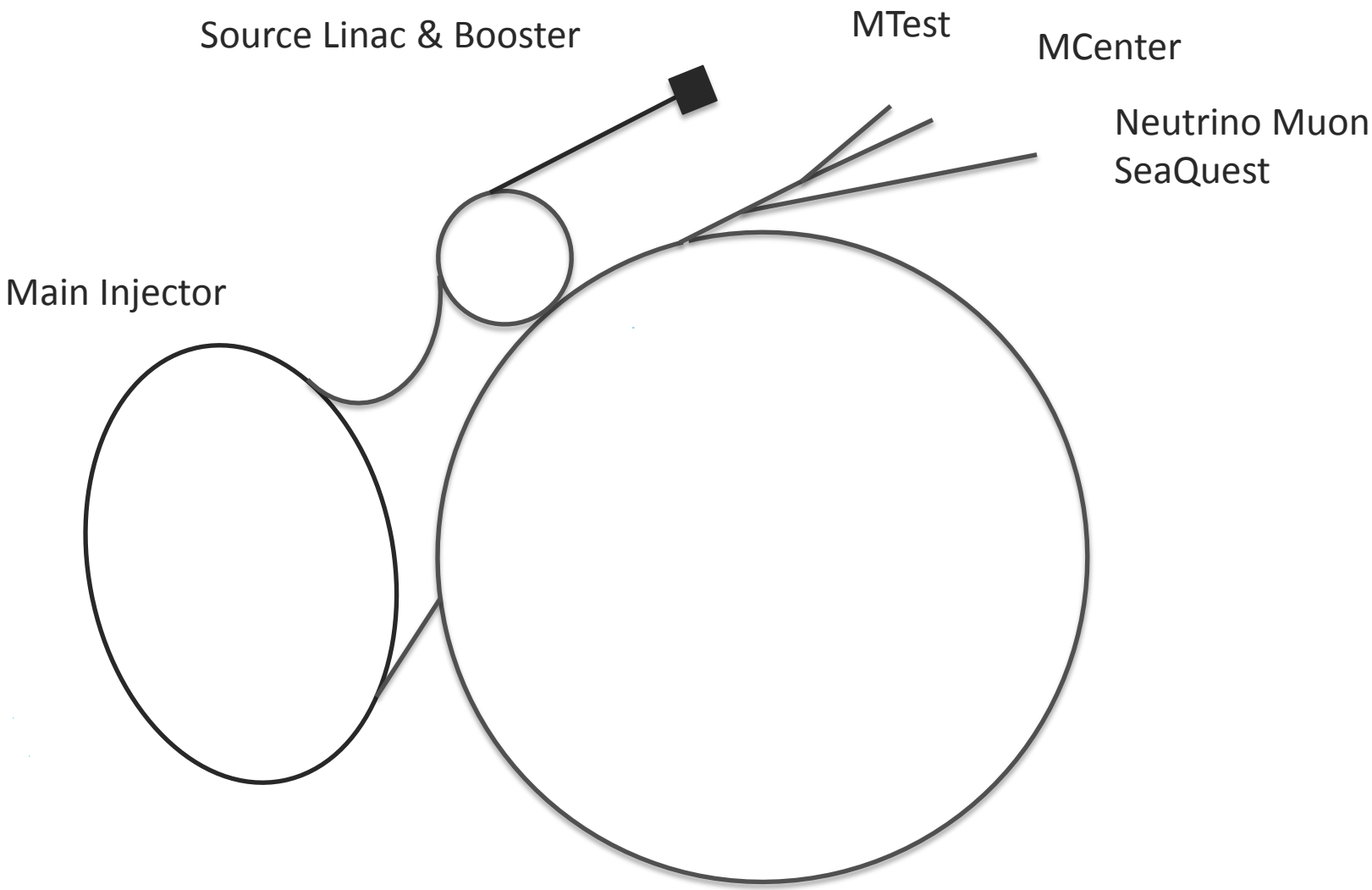
Muon Mode

Every LE or HE Pion Mode with additional absorbers in MT6-1.

Low Energy Pion Mode

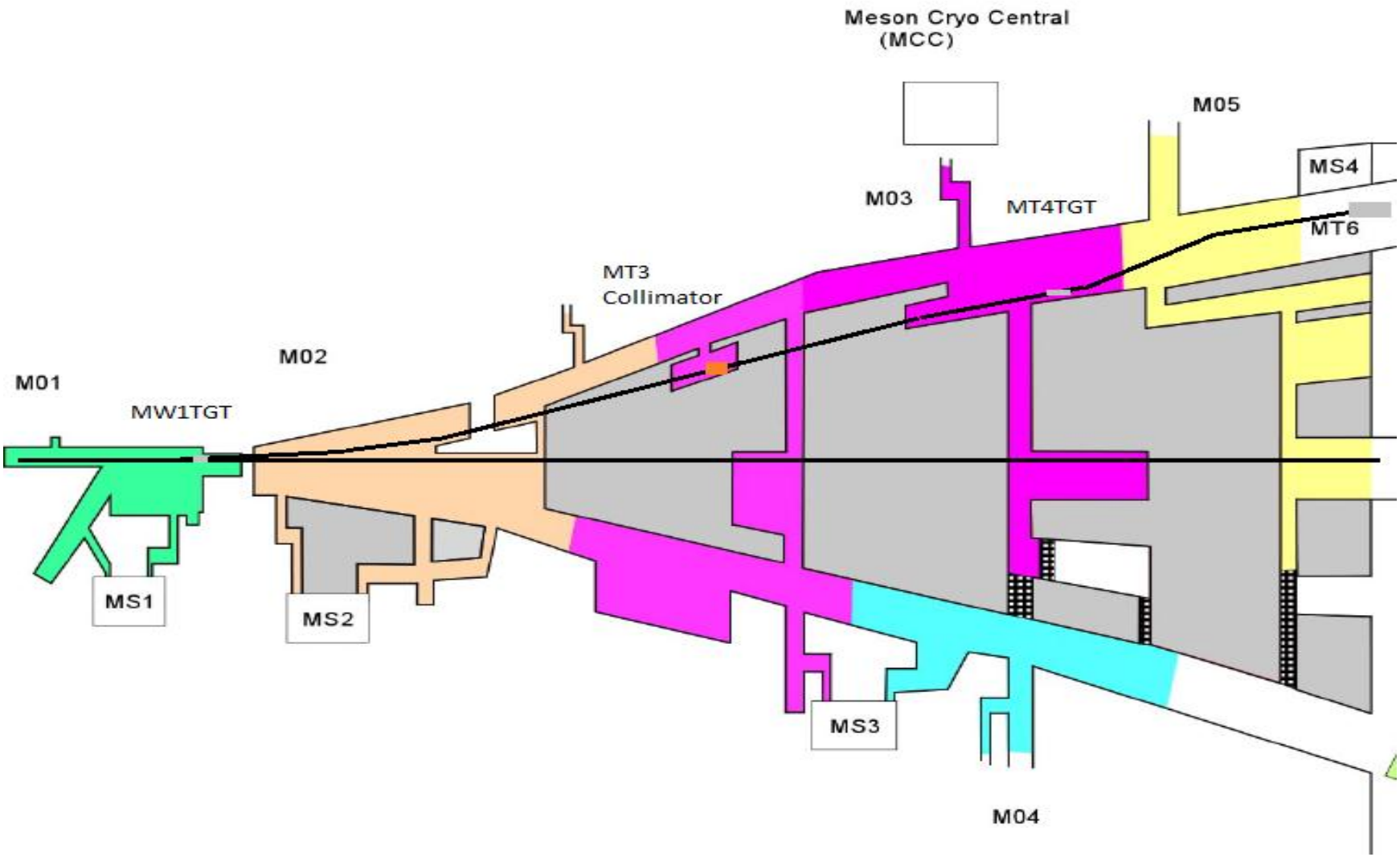
- +/- 32
- +/- 30
- +/- 25
- +/- 20
- +/- 16
- +/- 15
- +/- 12
- +/- 10
- +/- 8
- +/- 6
- +/- 5
- +/- 4
- +/- 3.5
- +/- 3
- +/- 2.5
- +/- 2
- +/- 1.5
- +/- 1

Switchyard's Present – Begins with Change



Switchyard's Pictures

Slow Extraction to MTest – Running Modes



Switchyard's Delivery

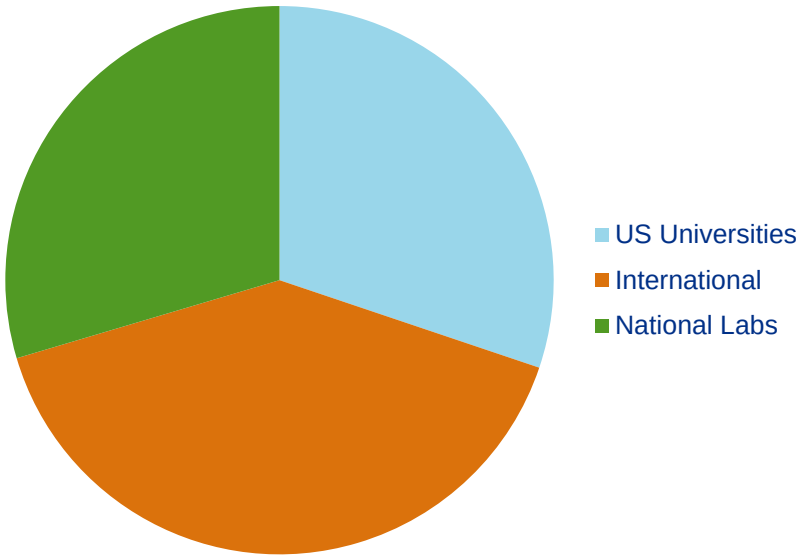
- 1 RF Bucket (53 MHz) = 19 nanoseconds
- Booster = 1.6 microsecond (84*19ns)
- Main Injector = 11.2 microsecond (1.6*7)
- Length of spill 4 seconds
- 4E6 / 11.2 microseconds = 357,143 revolutions
- One slow spill event is equivalent to 175 million RF buckets of possible beam*

**That assumes 492 buckets in MI occupied*

MCenter Beamline

- Beamline Now Operational!
  - Similar beam to MTest
  - Long dwell time experiments
  - Overflow/make-up experiments
- Supports Liquid Argon (Under development)
- Tertiary beamline Option
  - Protons & Pions
  - 200 MeV – 1 GeV range
- Large Dipole Magnets
  - ~ 1 Tesla
  - 1 meter bore

Experiments

2014 Institutions

- National Labs: 103 occurrences
- US Universities: 105 occurrences
- International: 140 occurrences