Beam Induced Power Supply Failures at CDF and D0

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Outline

CDF Experience

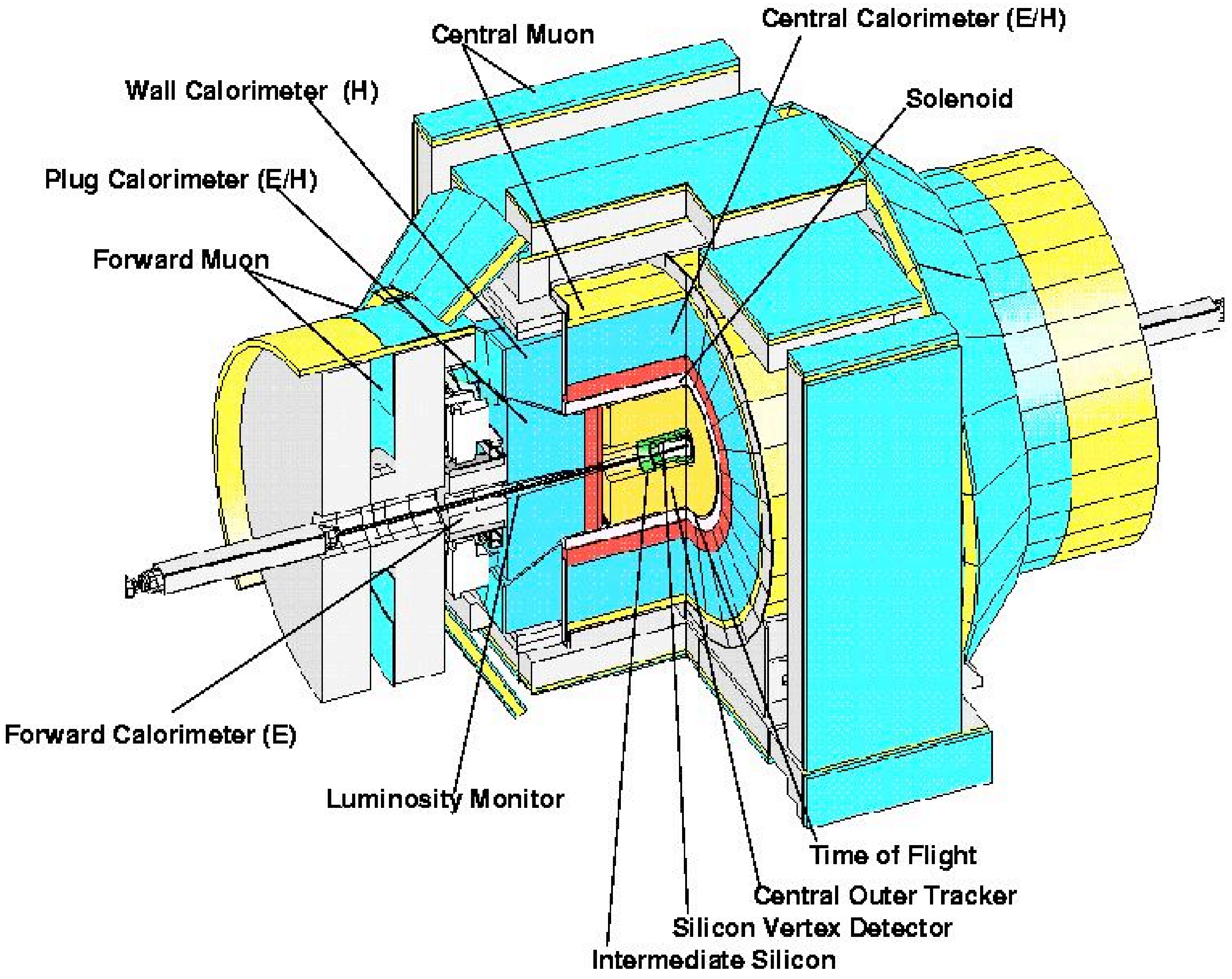
- CDF Detector
- Switching Power Supply Failures
- Failure Conditions/Mechanism
- Radiation Measurements
- Failure Mitigation

D0 Experience

- Switching Power Supply Failures
- Failure solutions

Avoiding Problems

CDF-II Detector (G-rated)

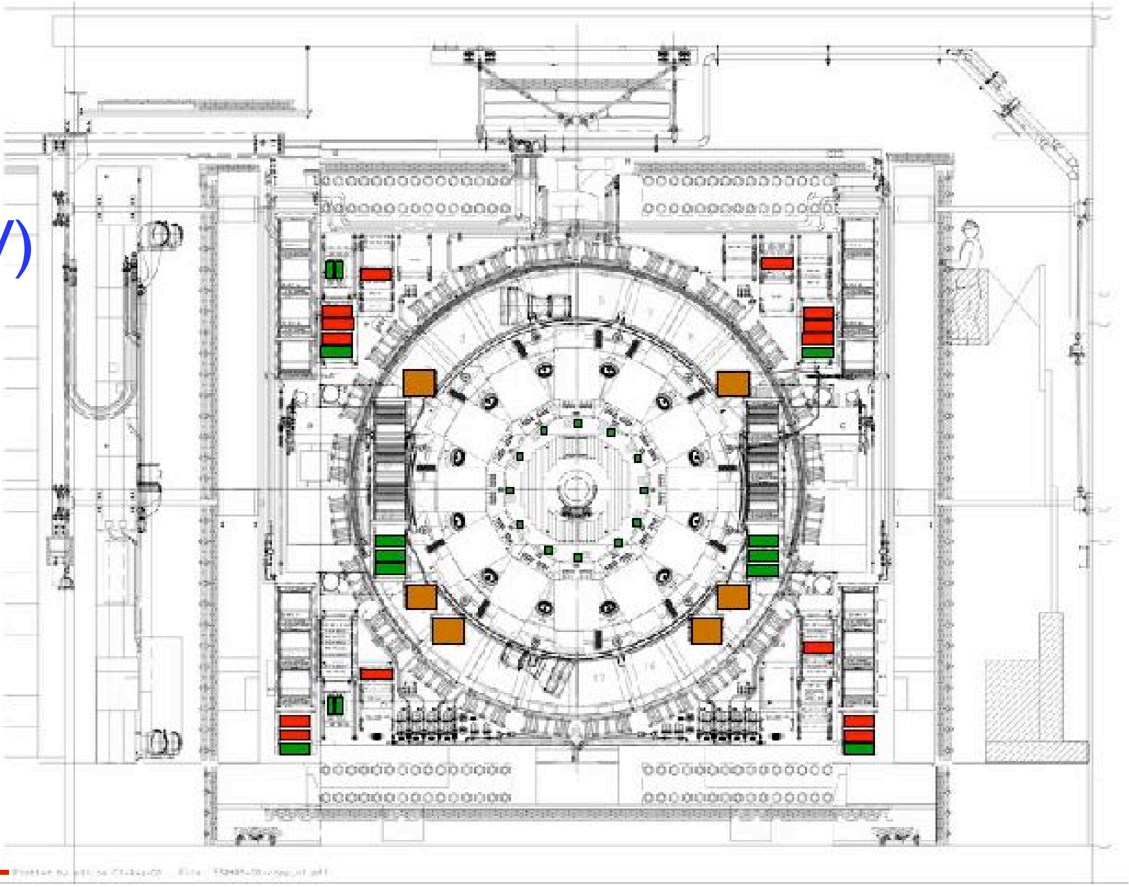


CDF Detector (Adults Only)

Power Supplies on the CDF Detector

- 36 switching supplies (5kW)
  - 28 "shielded"
- 38 linear supplies (1kW)
  - all "shielded"
- ~200 linear supplies (0.3kW)
  - all "shielded"

"shielded" means no line of sight to beam.



🟥 Switching Power Supplies (5kW)
🟩 Linear Power Supplies (1kW, 0.3kW)
🟧 HV Mainframe

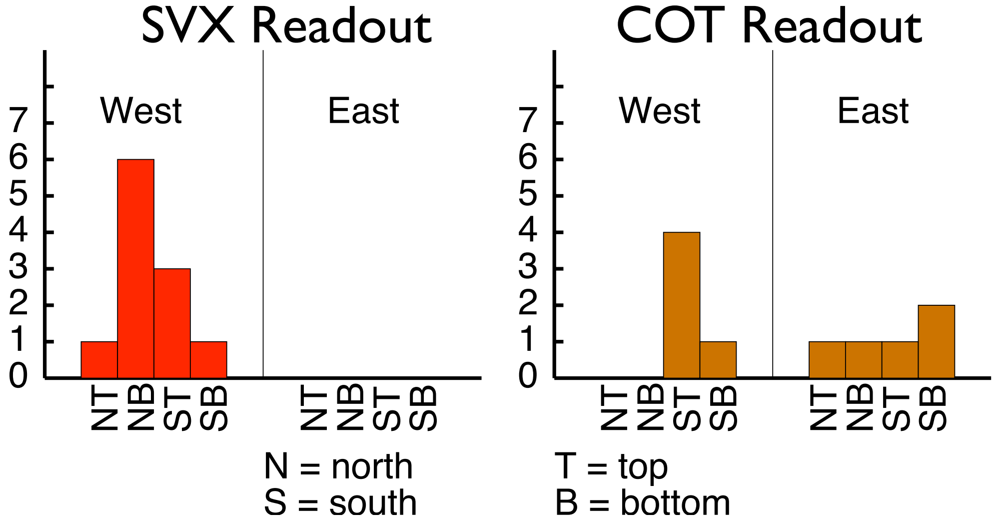
CDF VME Power Supply Failures

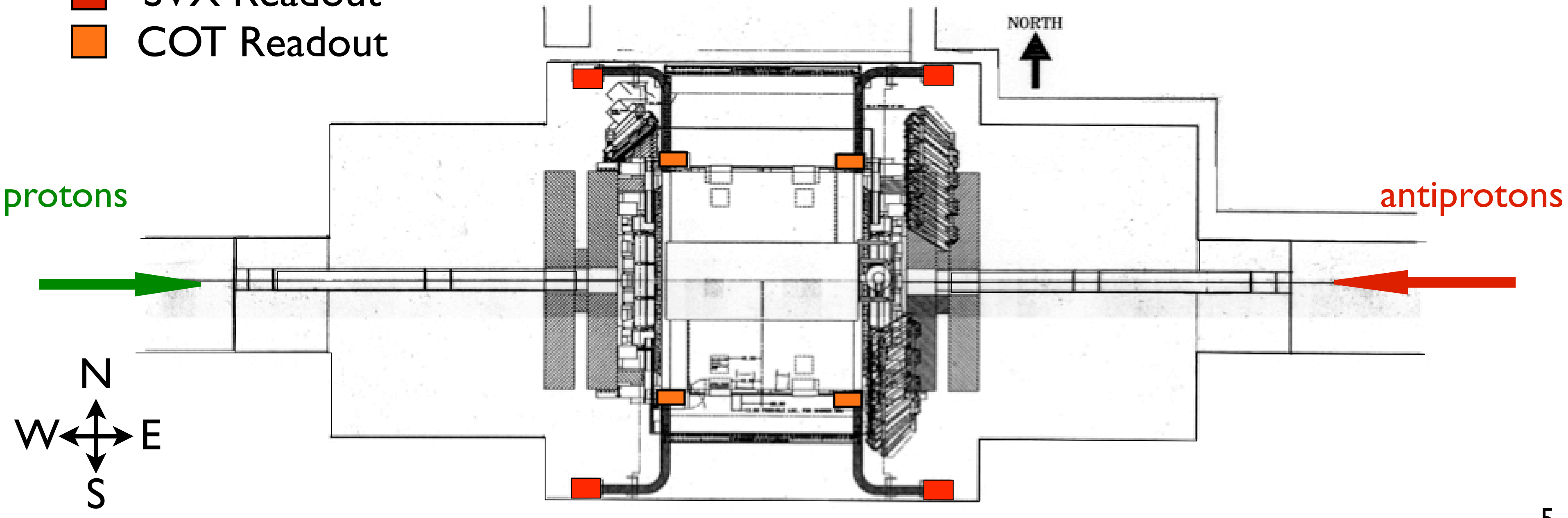
Failure Characteristics

- Position Dependent
- Beam Related
- Catastrophic
- Switching supplies only
- failure rate ~3/week
- 12 supplies failed in 1 day

🟥 SVX Readout
🟧 COT Readout

Failure Locations



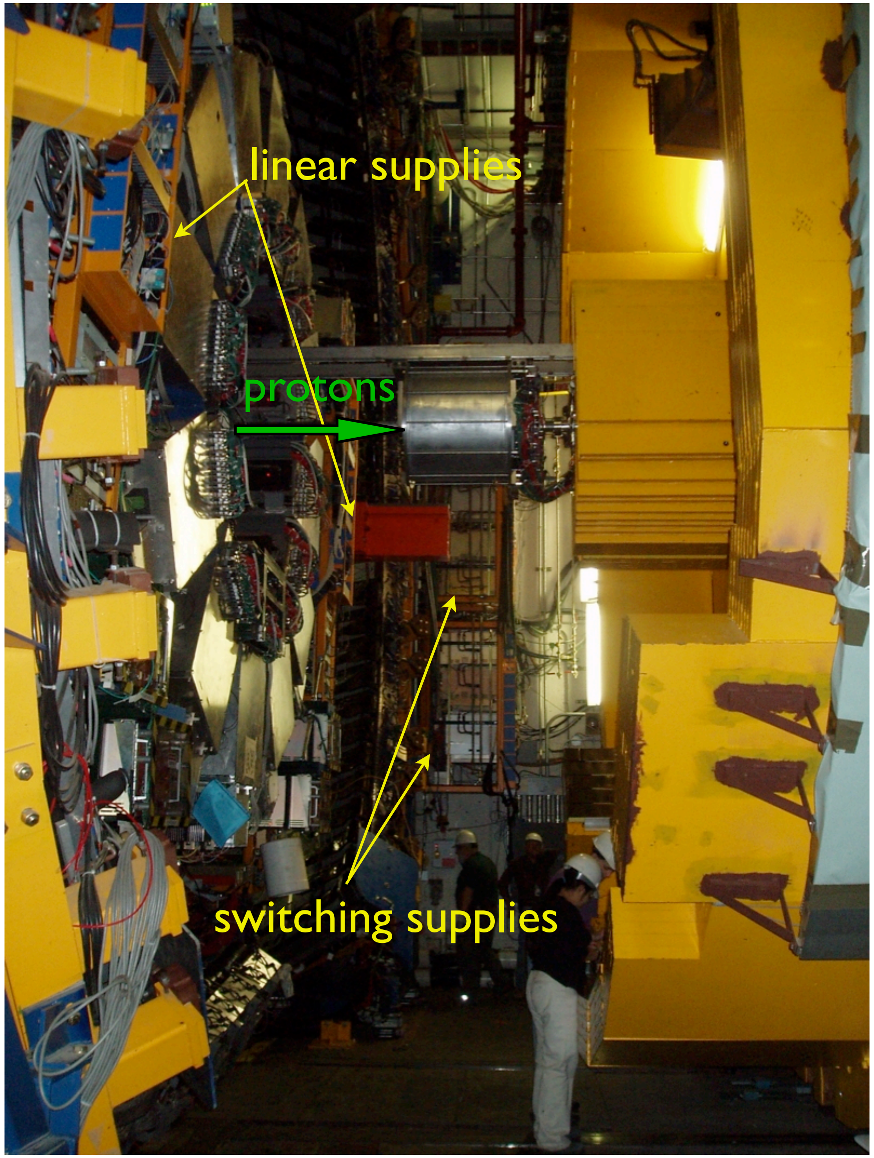


St Catherine’s Day Massacre

12 switching power supplies failed in an 8 hour period.

- only during beam
- only switching supplies
- failures on detector east side
- shielding moved out
- new detector installed
- beam pipe misaligned

Conclusion: Albedo radiation from new detector

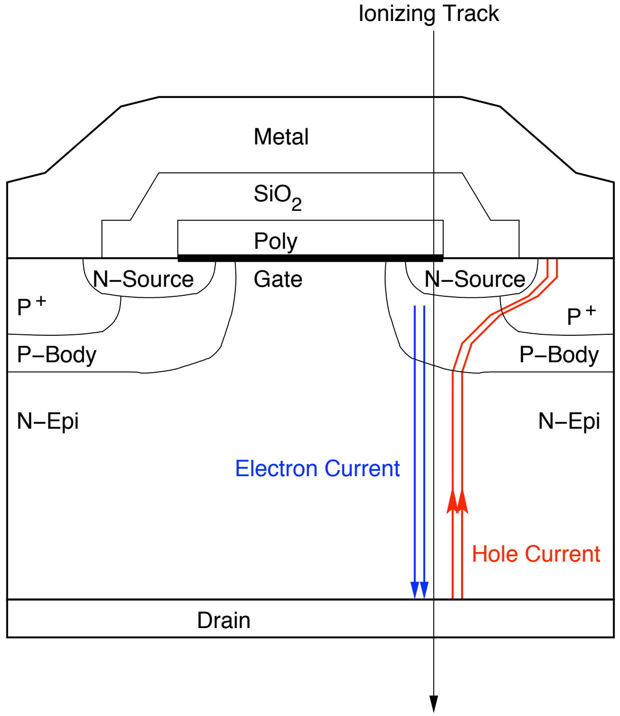


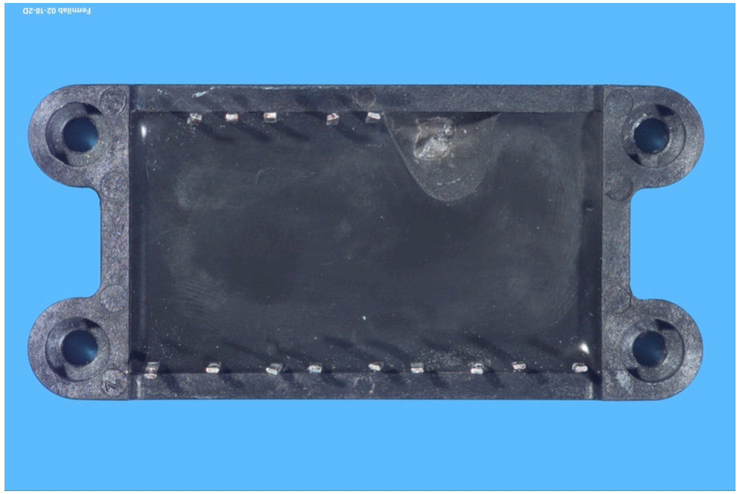
L.V. Power Supply Failures

Power Factor Corrector Circuit

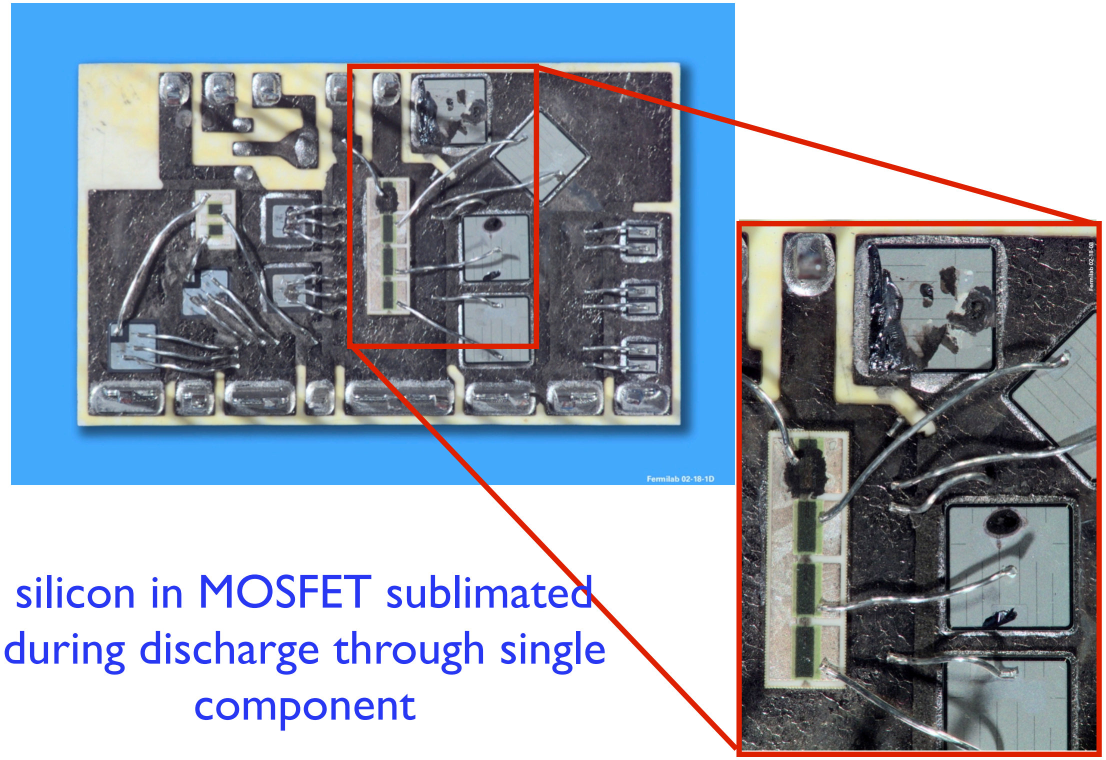
Most failures were associated with high beam losses or misaligned beam pipe

> Power MOSFET Single Event Burnout (SEB)





epoxy covering fractured



silicon in MOSFET sublimated during discharge through single component

Solution(s)

1. Align beam pipe
2. Measure SEB cross sections
    - Radiation tolerance of existing components
    - Identify candidate replacements
    - Modify operating conditions
3. Identify radiation sources
    - Locate sources of radiation (counter measurements)
    - Measure radiation field/composition
4. Shield supplies from the beam
5. Monitor/improve beam conditions
    - Install new monitors
    - Establish dialog with accelerator folk

Work is still in progress...

Single Event Burnout (SEB)

SEB Features

- beam related
- damage at low doses
- depends on bias voltage

SEB cross section measurement (Indiana University Cyclotron)

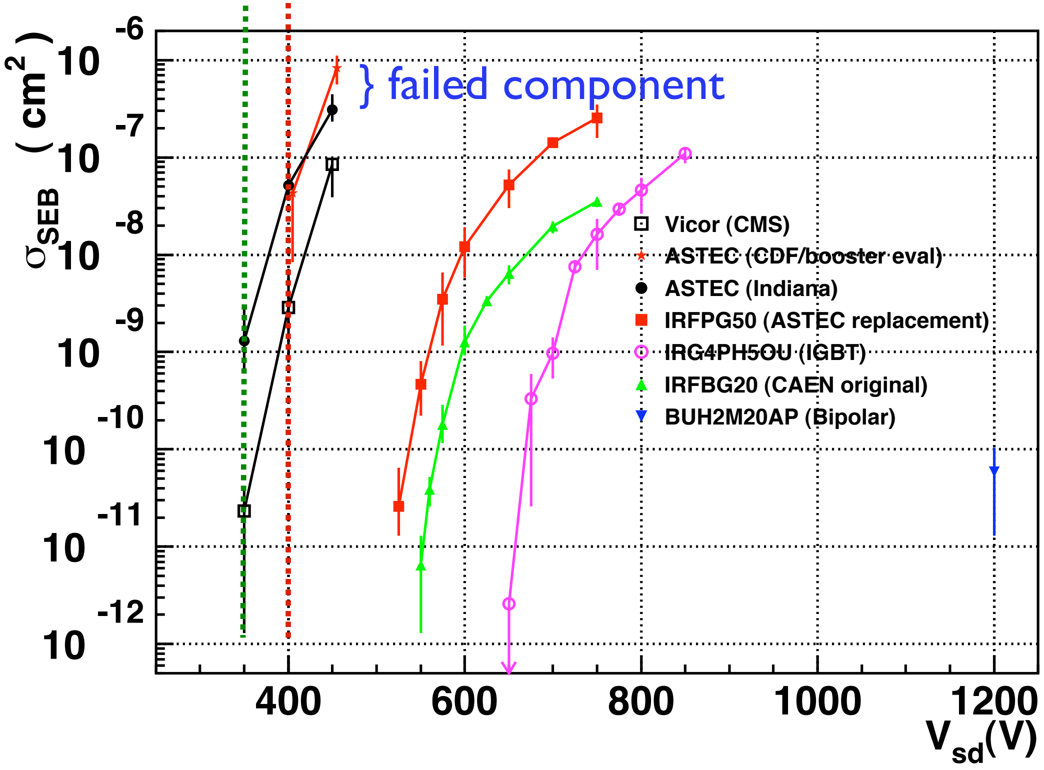
Solution: (lower Vbias)

- Factor of 50 reduction in radiation sensitivity
- No failures in > 2 years of operation

What about radiation?

operating voltage

modified designed



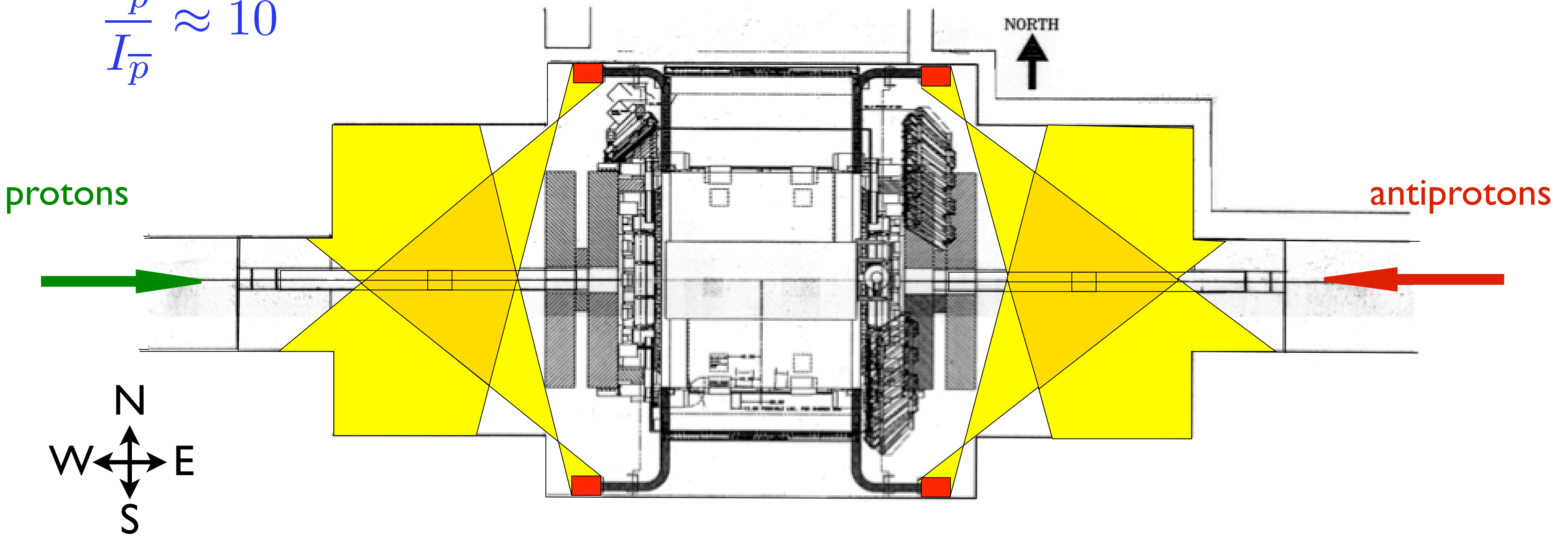
Test beam data, 20 MeV protons

Radiation Source?

- Counter measurements show low beta quadrupoles form a line source of charged particles.
- Power supply failure analysis shows largest problem on the west (proton) side of the collision hall.

CDF Detector (R-rated)

$$\frac{I_p}{I_{\overline{p}}} \approx 10$$



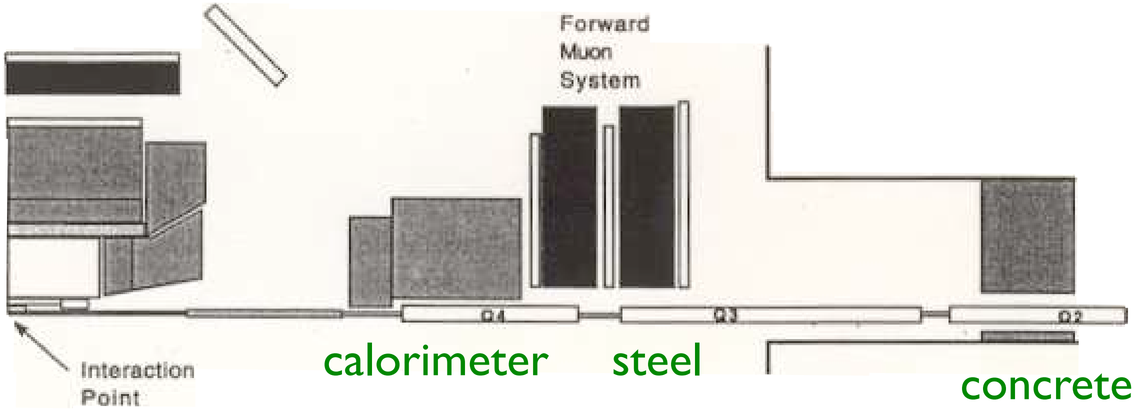
Run I Shielding

Detector configuration different in Run II

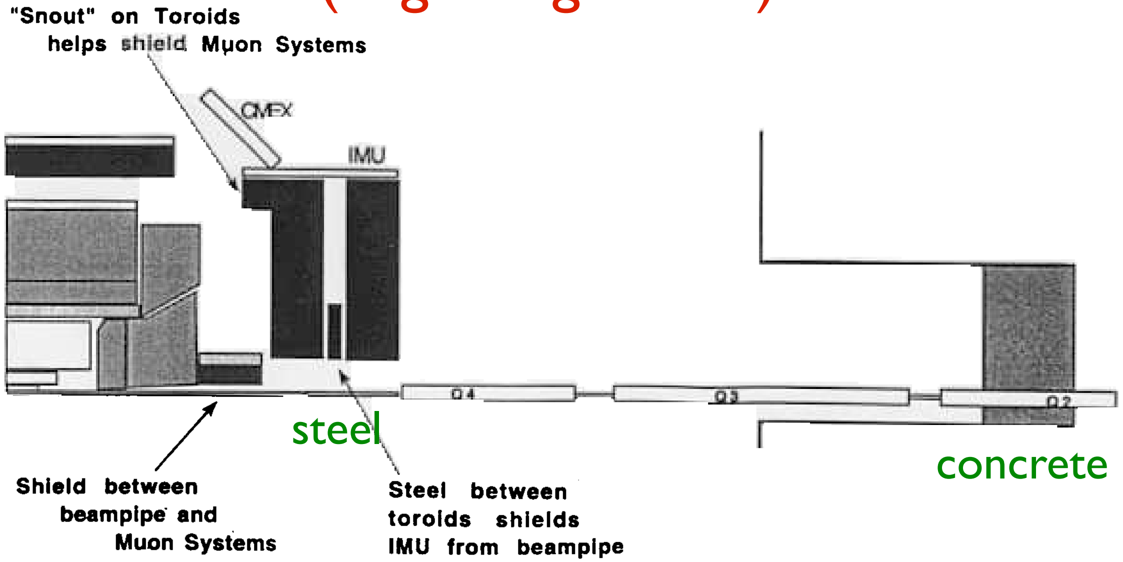
- Run I detector “self shielded”
- Additional shielding abandoned (forward muon system de-scoped).
- Shielding installed surrounding beam line.

Evaluation of shielding continues

Run I Shielding



Run II Shielding (beginning of run)



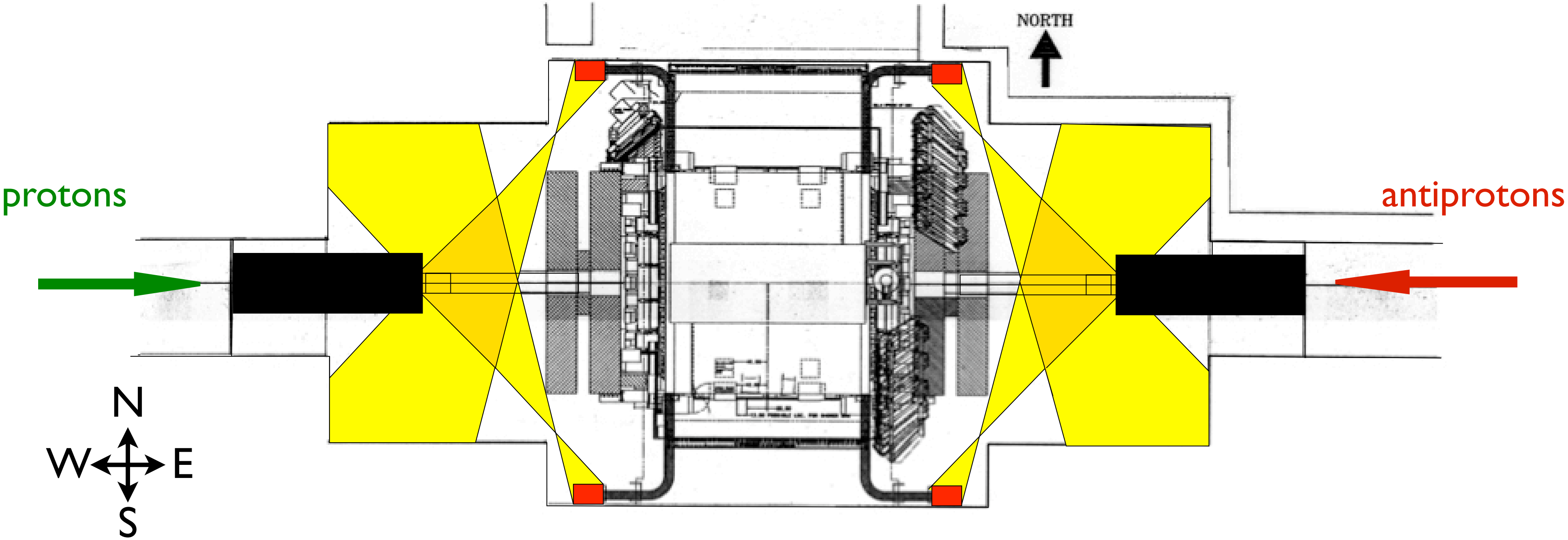
Radiation Shielding?

Install shielding to reduce radiation from low beta quadrupoles.

Reduces solid angle seen by power supplies by 25%

What do measurements tell us?

CDF Detector w/ additional shielding

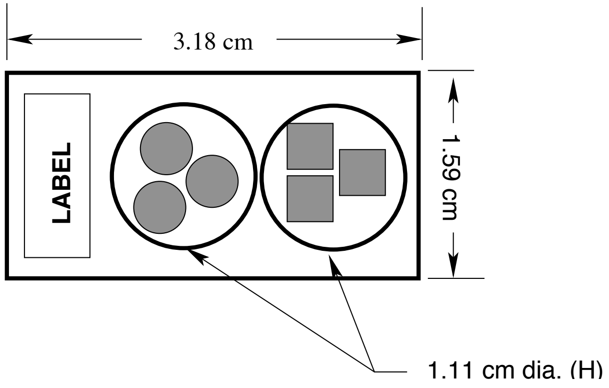


Measuring the Radiation Field

Thermal Luminescent Dosimeters (TLDs)

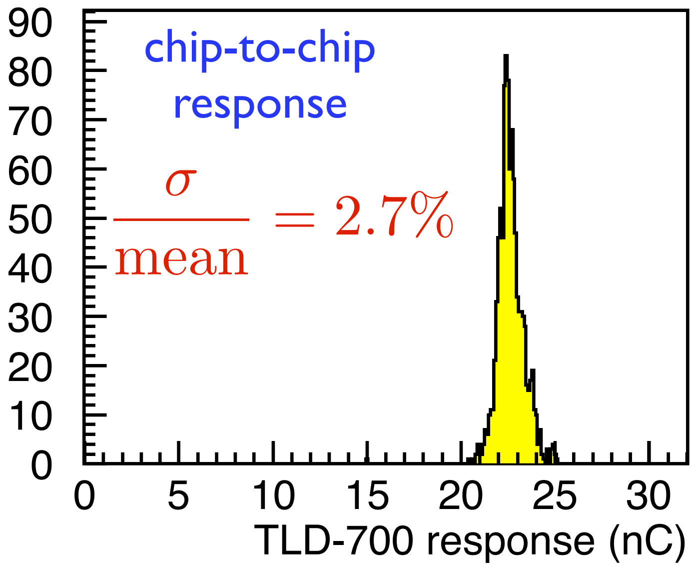
Advantages:

- \+ passive
- \+ large dynamic range(10-3-102 Gy)
- \+ good precision (<1%)
- \+ absolute calibration
- \+ γ,n measurements
- \+ redundancy



Disadvantages:

- \- harvest to read
- \- large amount of handling
- \- non linearity at high doses
- \- only measure "thermal" neutrons



Good for accurate, low-medium dose evaluation

Collision Hall Ionizing Radiation Field

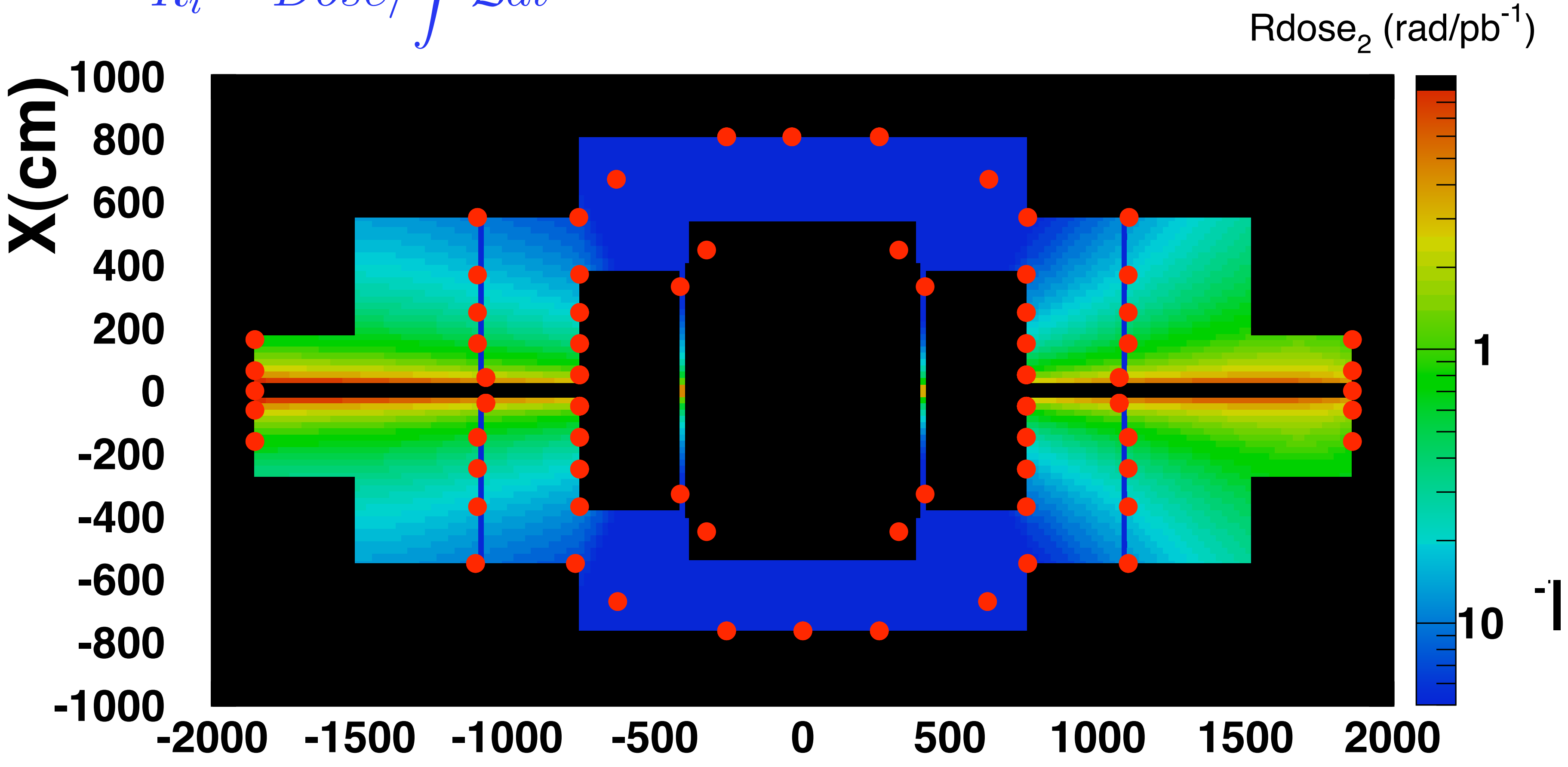
960 dosimeters installed in 160 locations

Radiation field modeled by a power law

$$Dose = \frac{A}{r^{\alpha}}$$

r is distance from beam axis

$$R_i = Dose / \int \mathcal{L} dt$$



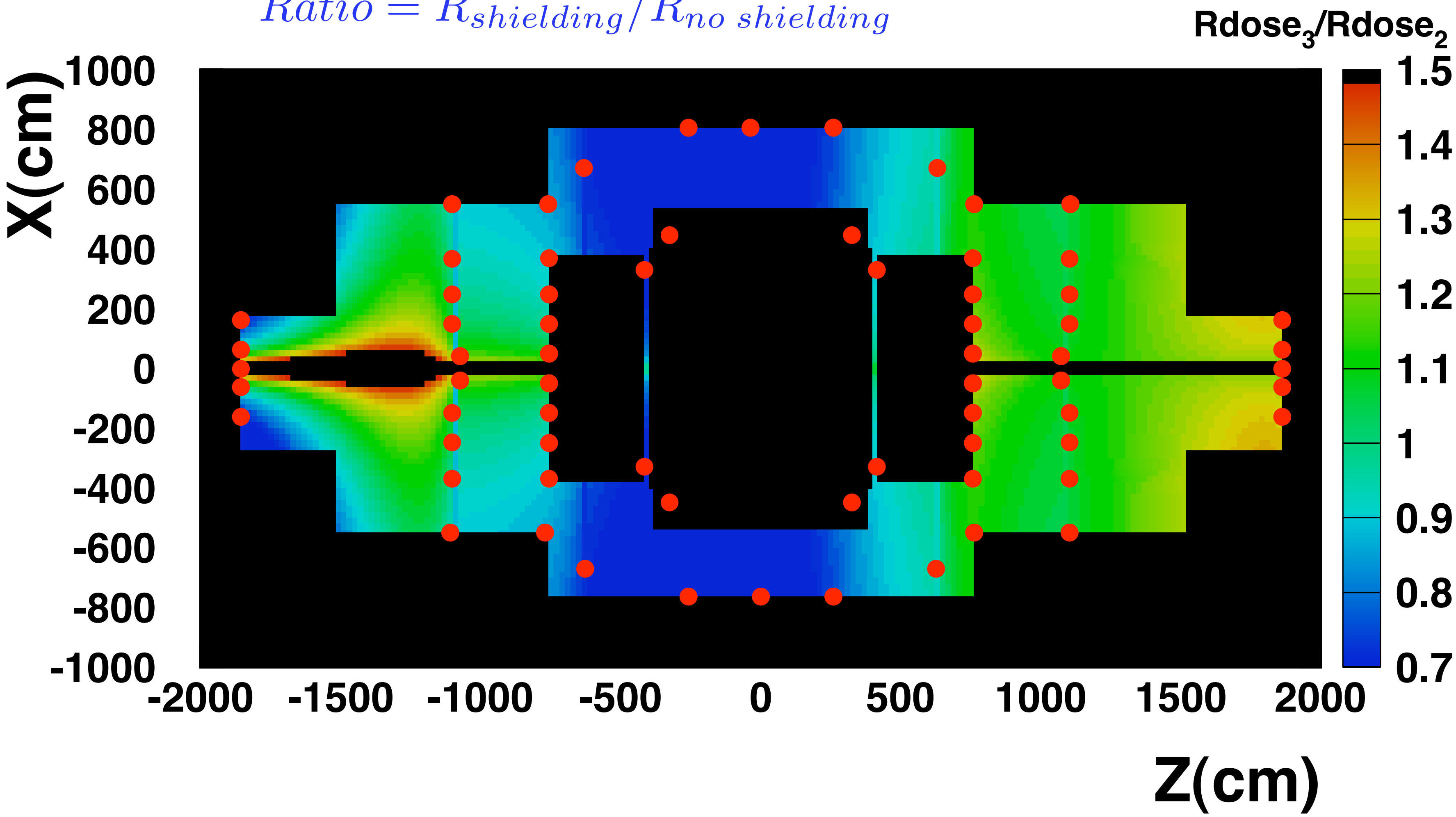
K. Kordas, et al.

Collision Hall Ionizing Radiation Field

Shielding effectiveness

- Ionizing radiation reduced by 20-30% near affected power supplies
- What about neutrons?

$$Ratio = R_{shielding}/R_{no\ shielding}$$



Neutron Spectrum Measurement

Evaluate Neutron Energy Spectrum

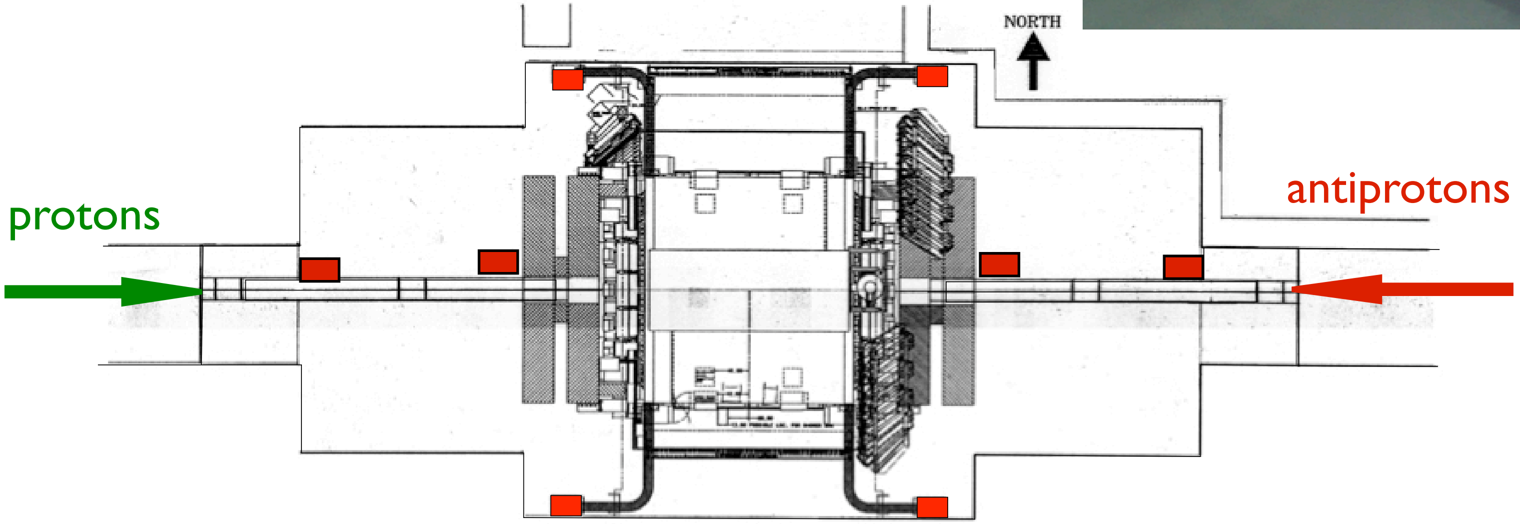
- Bonner spheres + TLDs
- ~1 week exposures
- Shielding in place

Measuring neutrons is hard

Work in progress...

Polyethylene "Bonner" spheres

Bonner sphere locations



Neutron Data

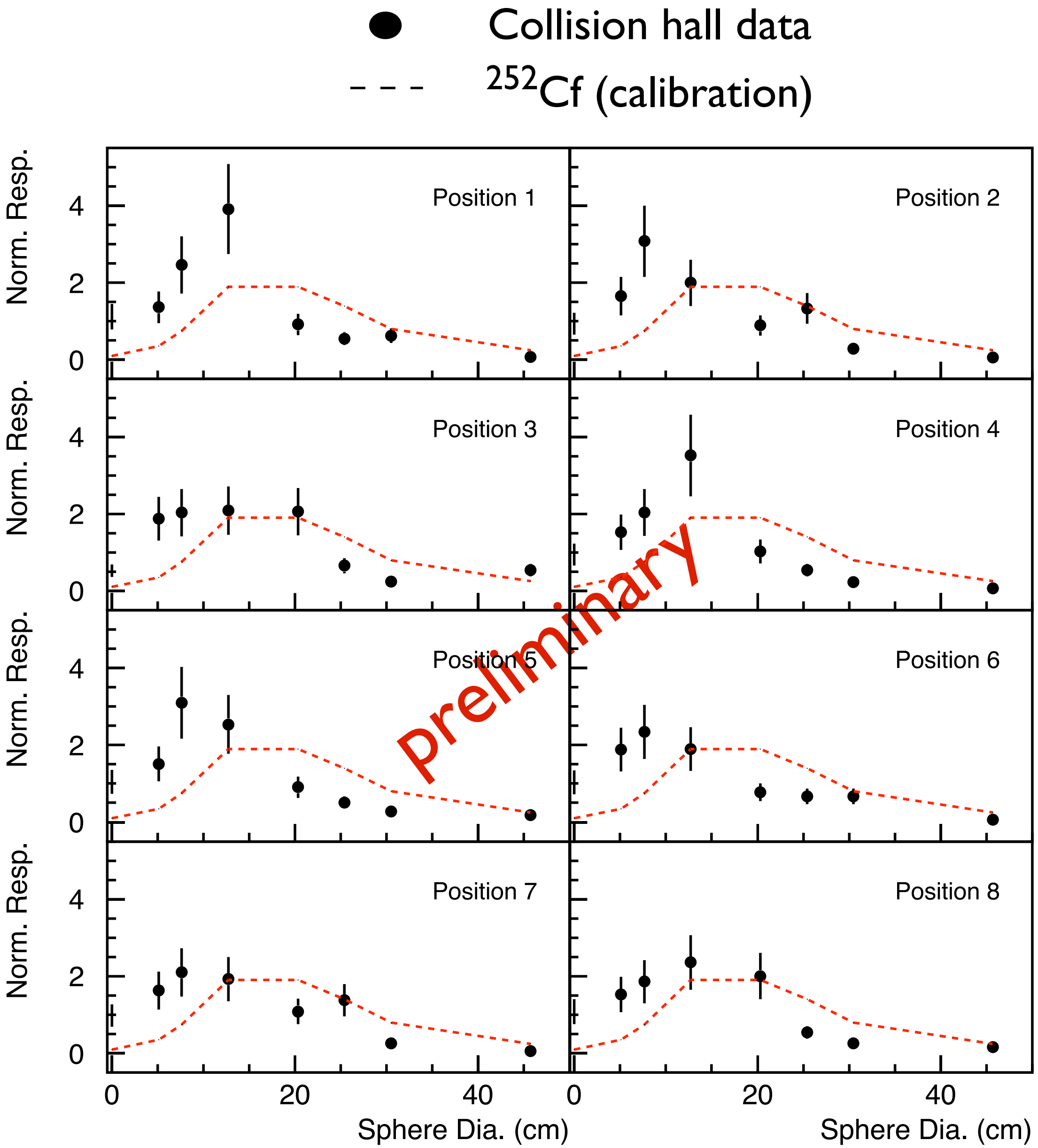
Compare data with ^{252}Cf

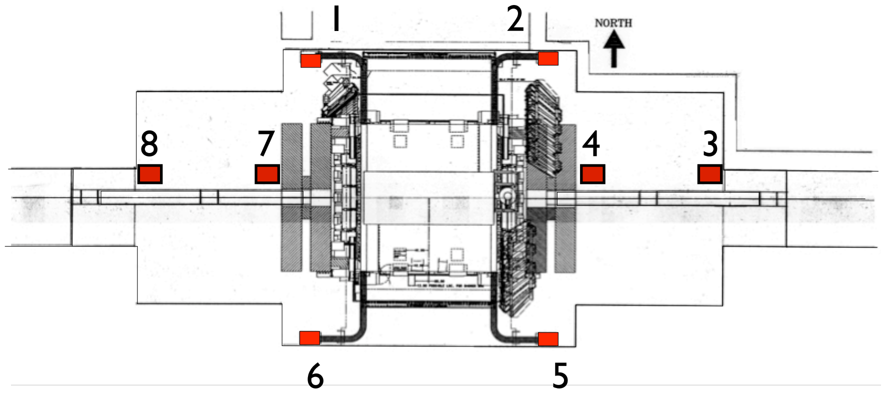
- spontaneous fission
- ~20 n/decay
- $\langle E_n \rangle$ ~2 MeV

Data show average $E_n < 2$ MeV

To do:

- understand E_n distribution
- neutron fluence



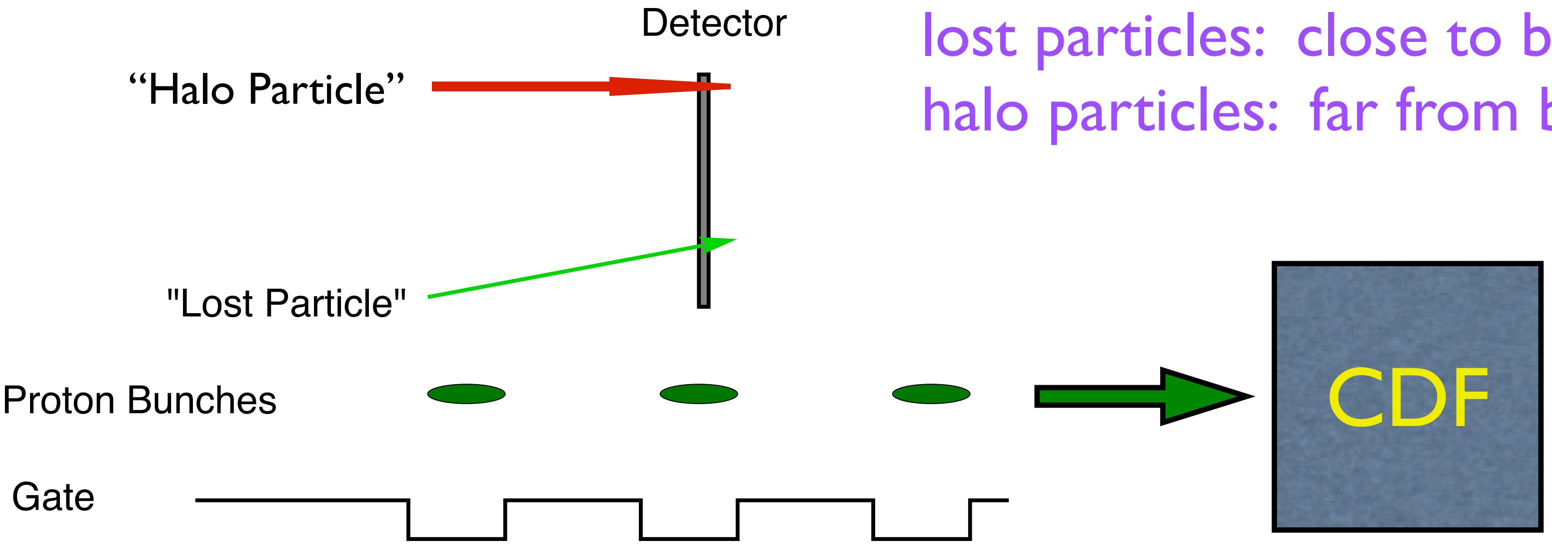


W. Schmitt, *et al.*

Measuring Beam Losses/Halo

Beam Losses all calculated in the same fashion

- Detector signal in coincidence with beam passing the detector plane.
- ACNET variables differ by detector/gating method.
- Gate on bunches and abort gaps.

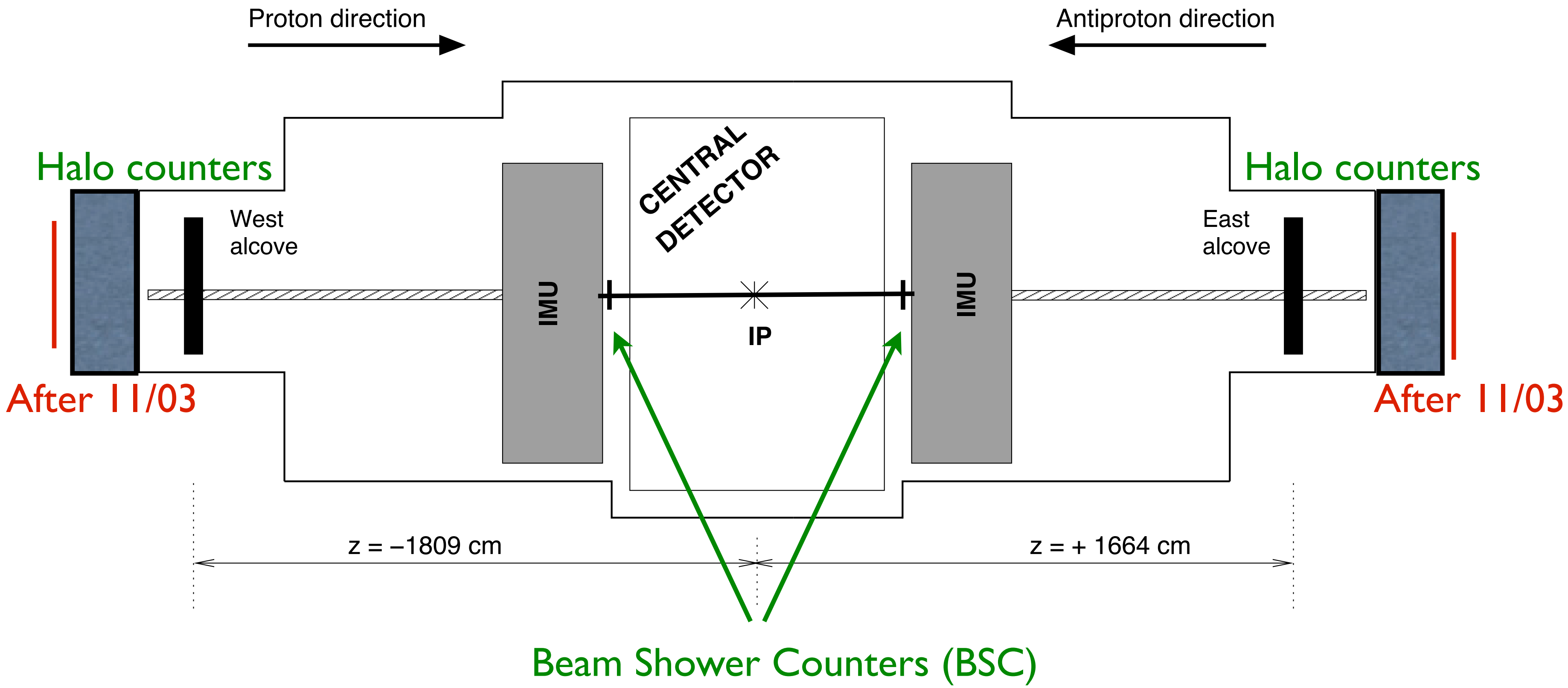


Definitions:

lost particles: close to beam

halo particles: far from beam

Beam Monitors



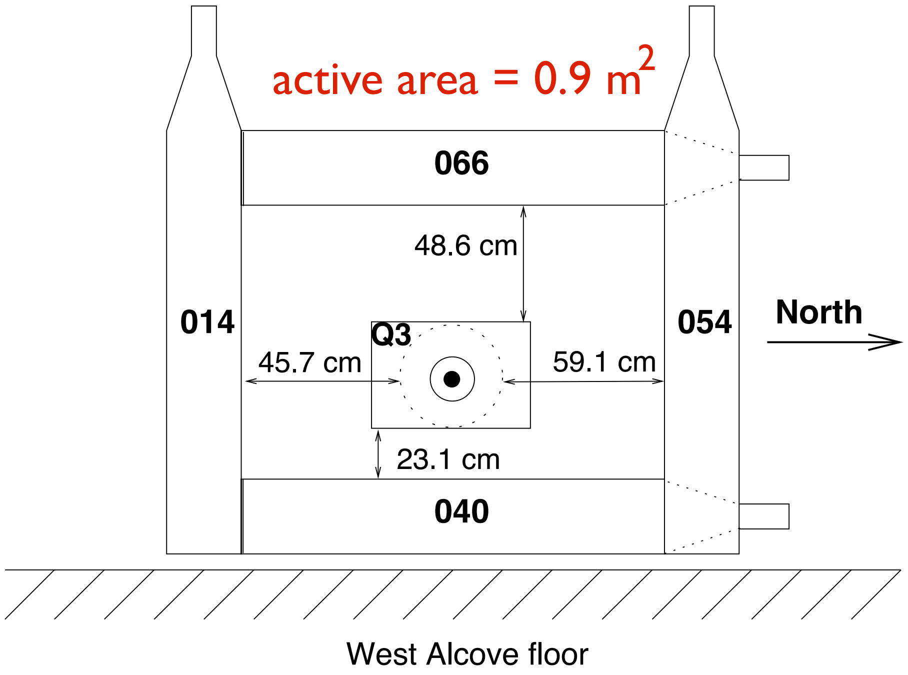
Beam Shower Counters (BSC)

BSC counters: monitor beam losses and abort gap

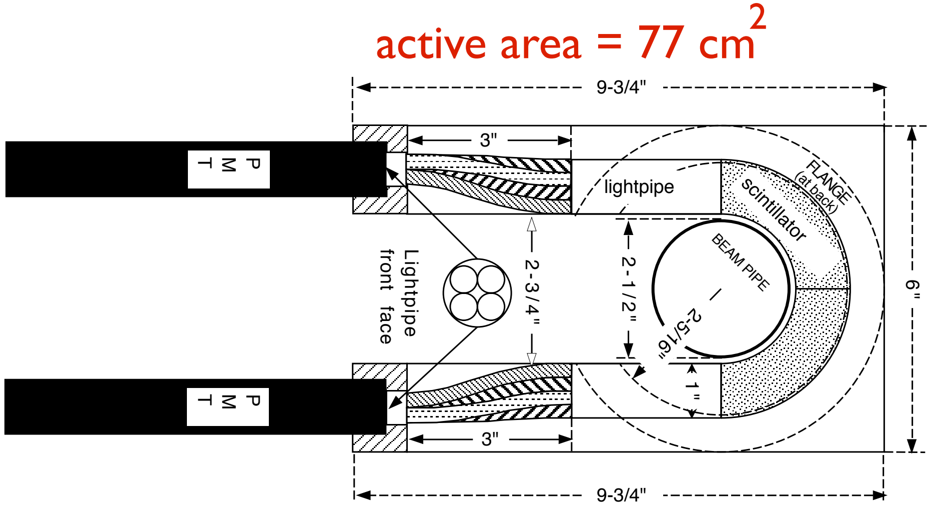
Halo counters: monitor beam halo and abort gap

Detectors

Halo Counters


active area = 0.9 m^2

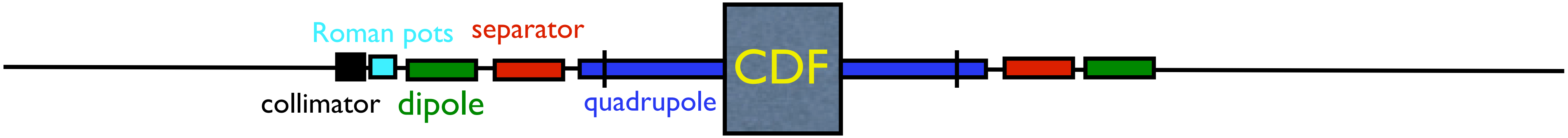
Beam Shower Counters


active area = 77 cm^2

ACNET variables:

B0PHSM: beam halo
B0PBSM: abort gap losses
B0PAGC: 2/4 coincidence abort gap losses
B0PLOS: proton losses (digital)
LOSTP: proton losses (analog)
B0MSC3: abort gap losses (E*W coincidence)

Beam Halo Counters



Typical Store

Beam Parameters:

Protons:	5000 - 9000	10^9 particles
Antiprotons:	100-1500	10^9 particles
Luminosity:	10 - 100	$10^{30}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
Duration	10-30	hours

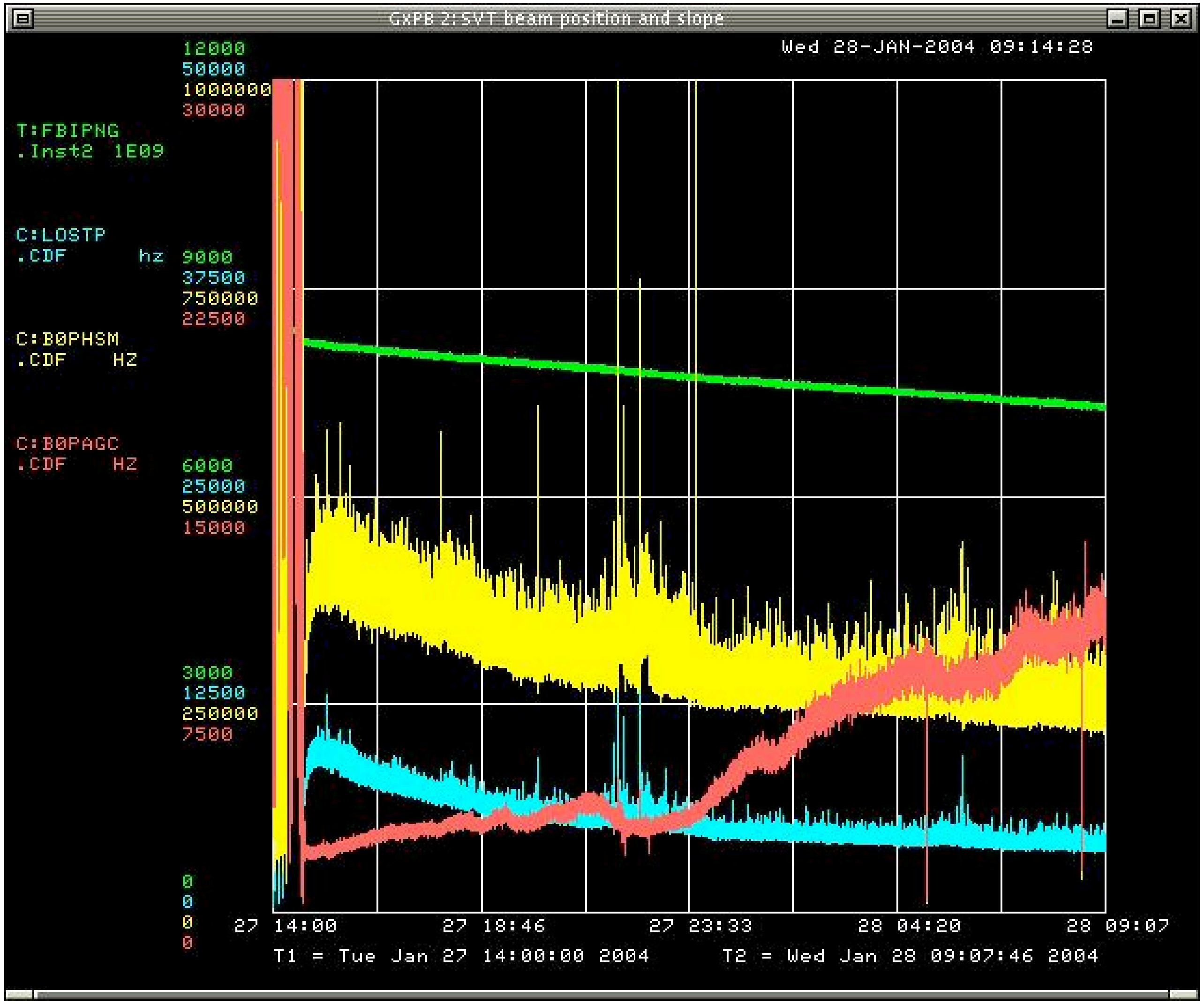
Losses and Halo:

Quantity	Rate (kHz)	Limit (kHz)	comment
P Losses	2 - 15	25	chambers trip on over current
Pbar Losses	0.1 - 2.0	25	chambers trip on over current
P Halo	200 - 1000	-	
Pbar Halo	2 - 50	-	
Abort Gap Losses	2 - 12	15	avoid dirty abort (silicon damage)
L1 Trigger	0.1-0.5		two track trigger (~1 mbarn)

Note: All number are taken after scraping and HEP is declared.

Monitor Experience

“Typical good store”



proton beam current

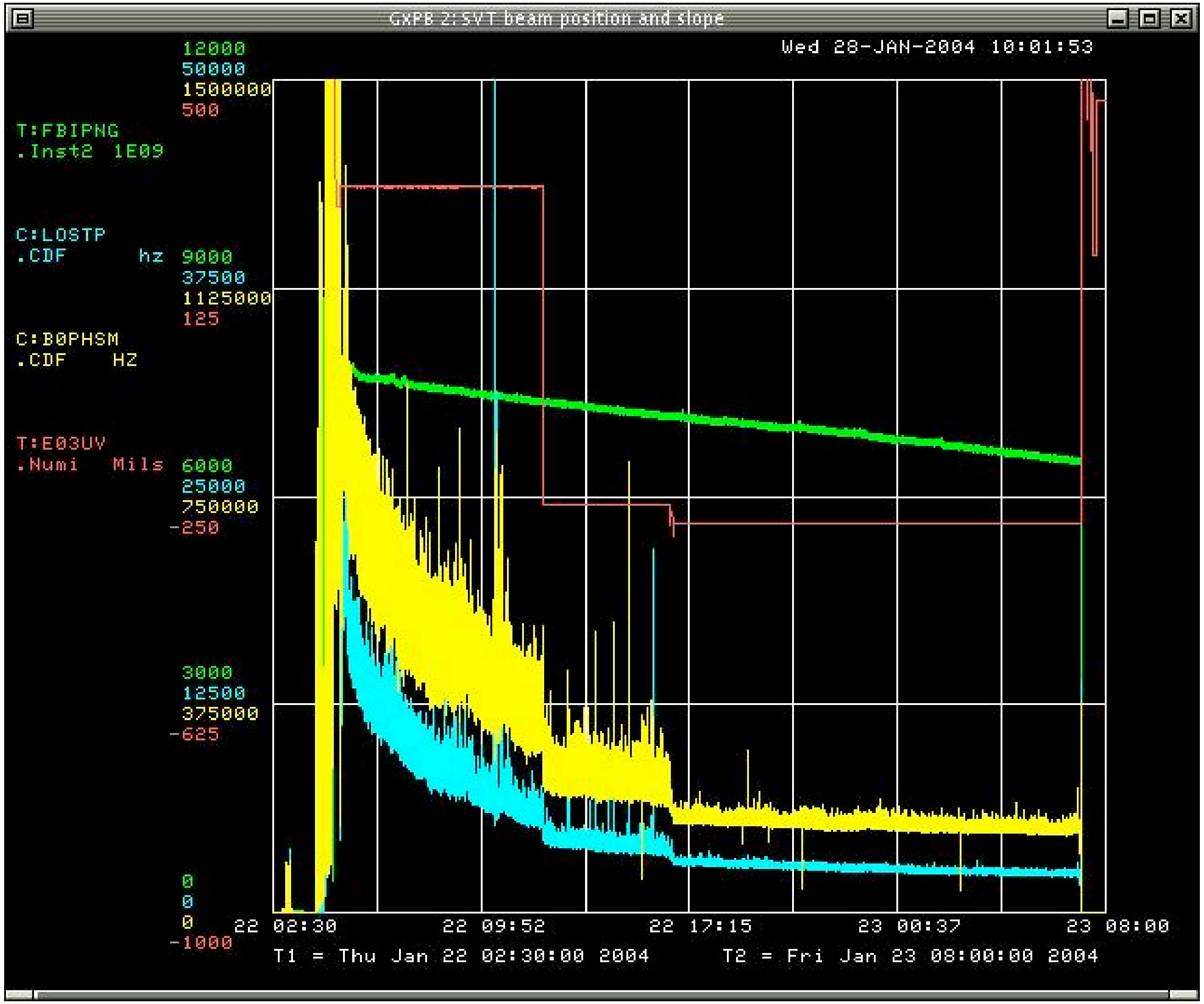
proton abort gap

proton halo

proton losses

Beam Collimation

Background reduction at work



E0 collimator

proton beam current

proton halo

proton losses

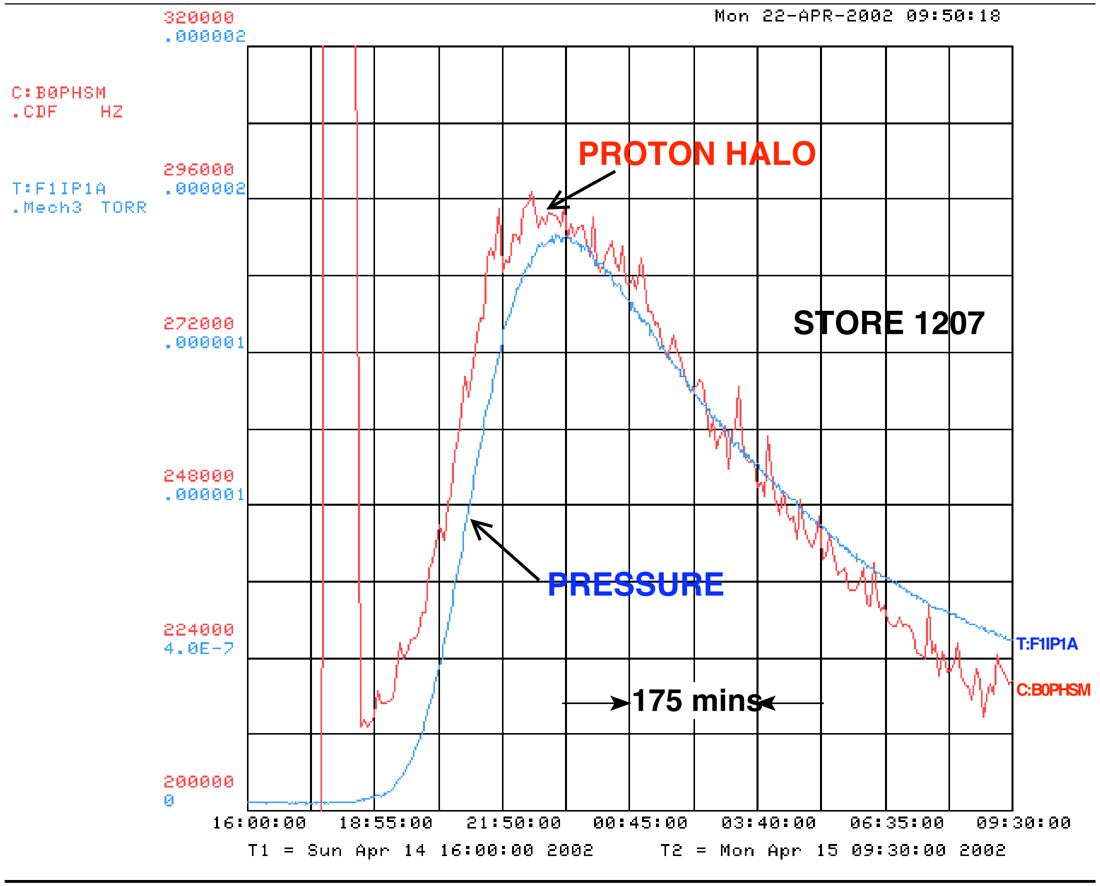
Halo Reduction

Vacuum problems identified in 2m long straight section of Tevatron (F sector)

Improved vacuum (TeV wide)

Commissioning of collimators to reduce halo

> Physics backgrounds reduced by ~40%



R. Moore, V. Shiltsev,
N.Mokhov, A. Drozhdin

Eliminating Failures

Evaluate radiation early

- Question "past experience"
- Simulations of the radiation environment
- Measurements in early, low beam current conditions

Design radiation tolerant devices

- Measure component radiation tolerances
- Avoid parallel structures holding off common stored energy

Monitor beam conditions

- "Fast" real time monitors
- Maintain dialog between experimenters and accelerator operators

Shielding

- Beam collimation system puts losses where tollerable
- Design shielding solutions based on measurements **and** simulation

References (Incomplete List)

General:

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