Radiation Monitoring at the Tevatron

R.J. Tesarek
Fermilab
11/30/04

11/04 Radiation Event

What is Radiation Monitoring?

If you know the enemy and you know yourself, you need not fear the result of a hundred battles -- Sun-Tzu (ca.400 BC)

Operational Definition:

Monitor any beam induced conditions which affect the performance, reliability, lifetime of detectors or infrastructure.

Methods adopted at CDF (D0):

- Record/Monitor beam conditions and radiation.
  - real time and samples
- Evaluate the radiation field.
  - measurements and simulation
- Modify conditions to reduce risk.
  - modify/abort the beam (beam position, tune, collimator positions)
  - modify the conditions in the monitored region (shielding)

Radiation Monitoring at CDF

Initial Goals:

- Measure distribution and rates of radiation
- Provide early estimate of Si tracker lifetime

Secondary Goals:

- Identify/evaluate radiation sources in/near CDF
- Eliminate/reduce failures in electronics
- Additional instrumentation for the accelerator

Monitoring Technologies:

- Thermal Luminescent Dosimeters (TLDs)
- Silicon PIN diodes
- Ionization chambers
- Silicon detectors
- Scintillation counters
- Other beam monitors

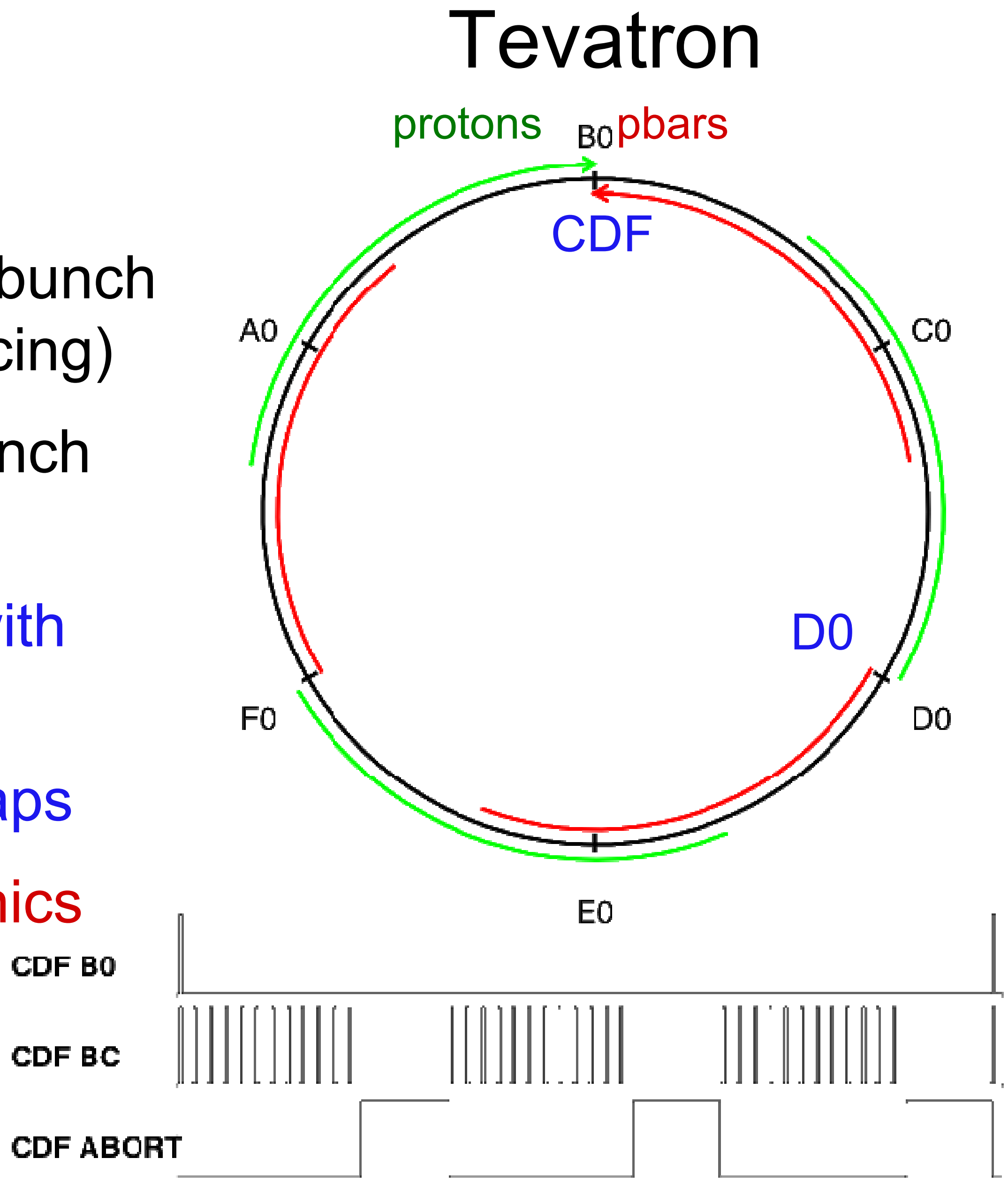
Beam Structure

- 36 1ns bunches in 3x12 bunch trains (396ns bunch spacing)
- 2.2μs space between bunch trains

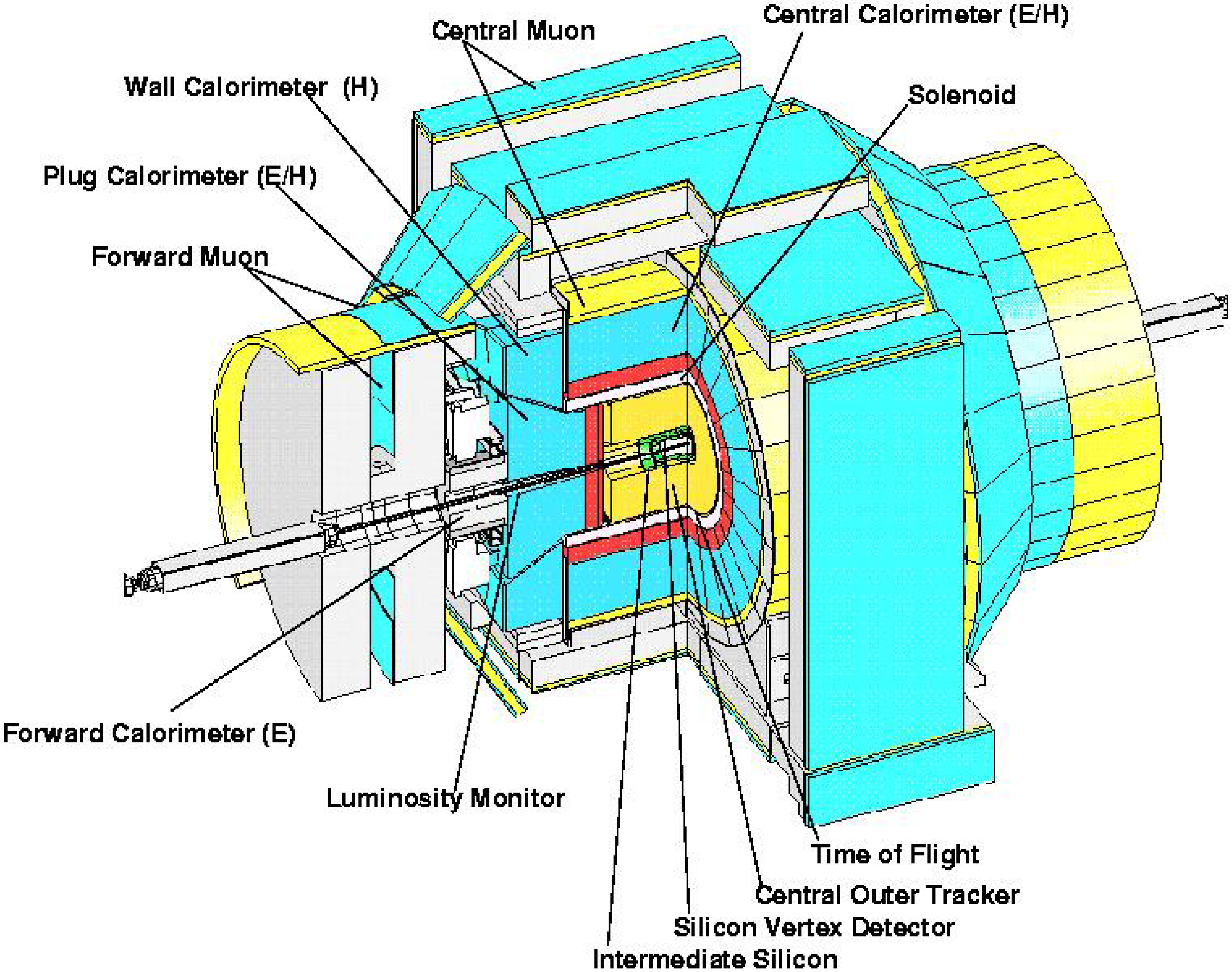
* Monitor losses (in time with beam)

* Monitor beam in abort gaps

> Fast detectors & electronics



CDF-II Detector (G-rated)

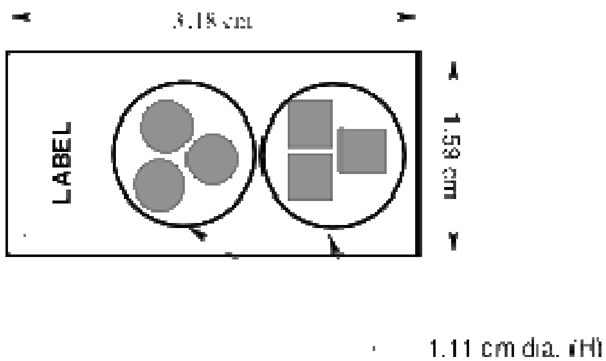


Measuring the Radiation Field

Thermal Luminescent Dosimeters (TLDs)

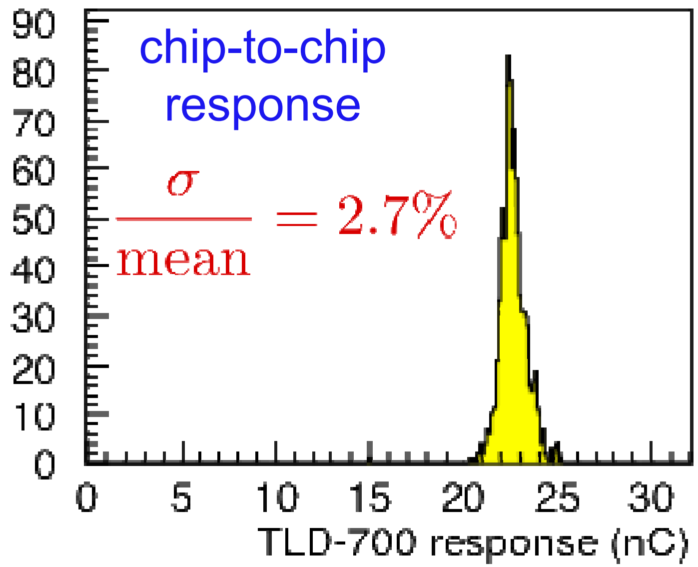
Advantages:

+ 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



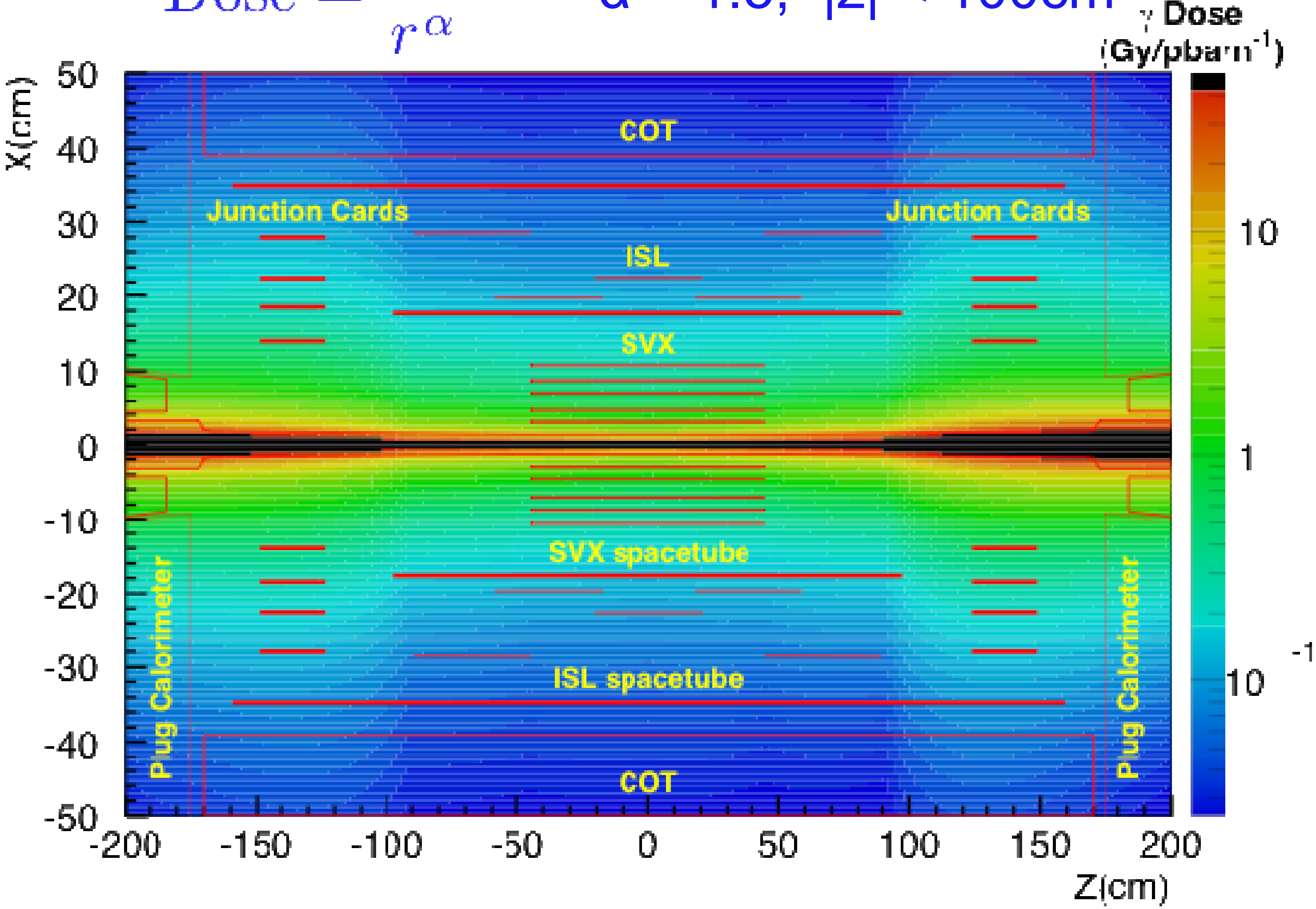
Good for accurate, low-medium dose evaluation

Radiation from Collisions

TLD measurements + model

r measured transverse to the beam

$$\mathrm{Dose} = \frac{A}{r^{\alpha}} \qquad \alpha \sim 1.5;\ |z| < 100\mathrm{cm}$$



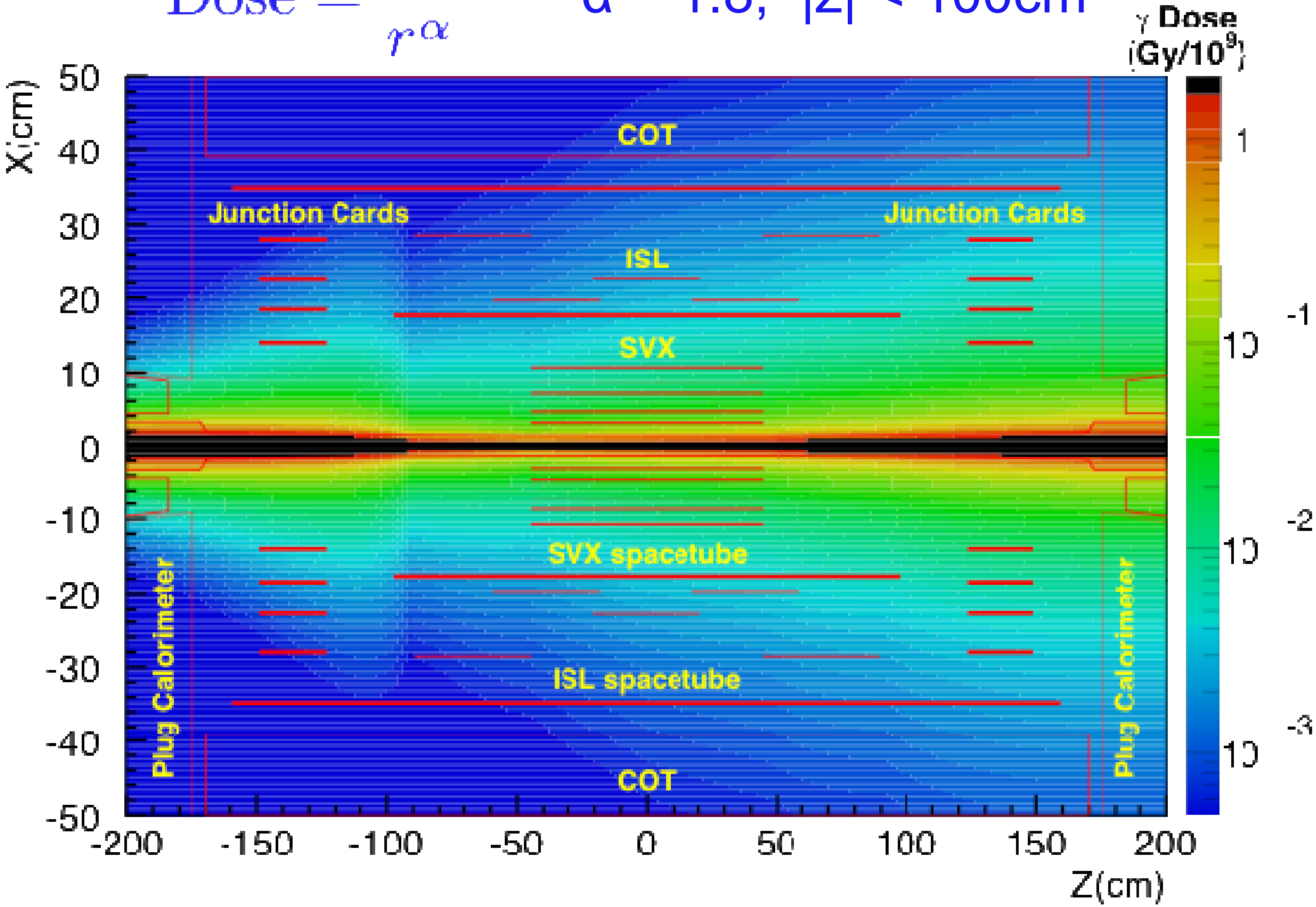
Radiation from Beam Losses

TLD measurements + model

r measured transverse to the beam

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

α ~ 1.8; |z| < 100cm



Silicon Detector Dose (Damage)

Measure I_{bias}

- correct Temp. to 20C
- α_{damage}=3.0x10^{17}A/cm

Early comparison with TLD Data

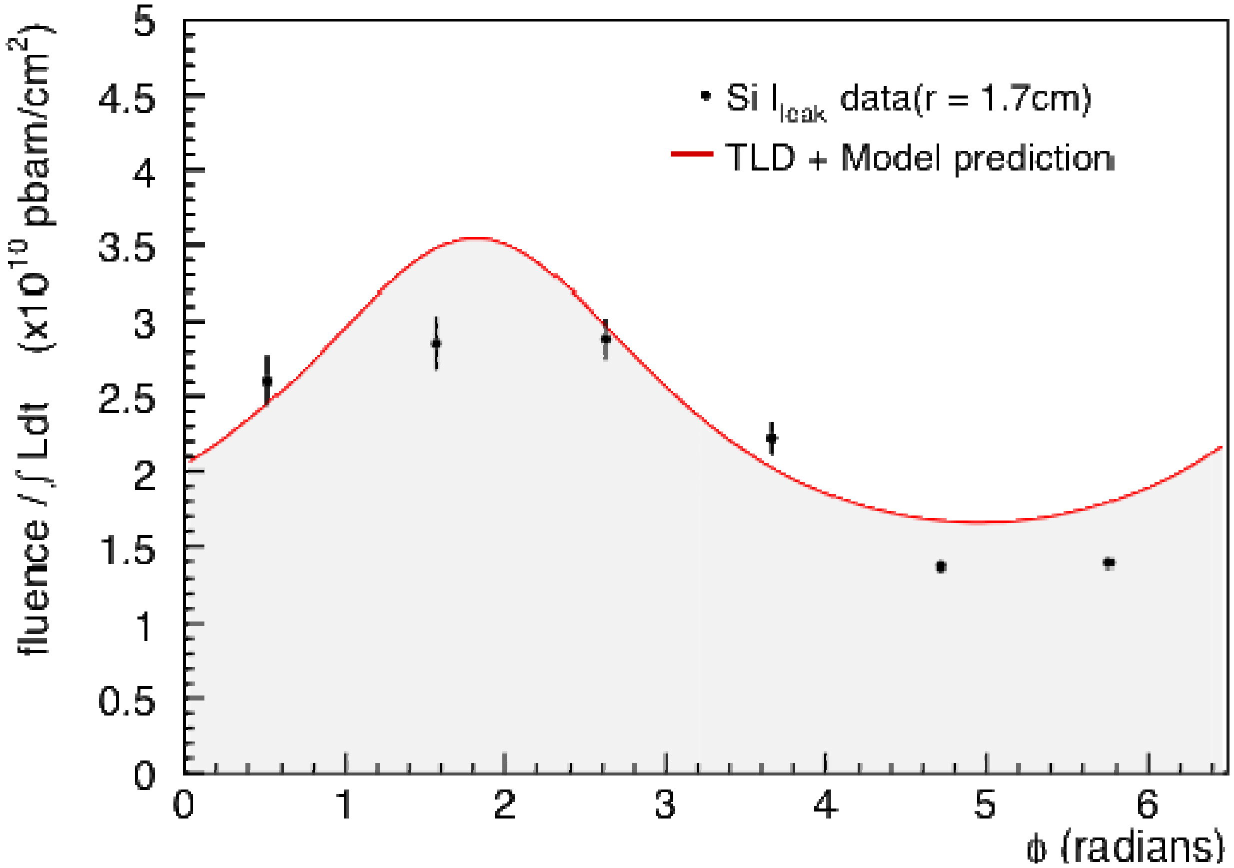
- Assume r^{α} scaling
- 1Gy=3.8x10^{9} MIPS/cm^{2}

Temp profile of SVX sensors poorly understood.

P. Dong

Update with full tracker in 2005.

L00 damage: 15 pbarn^{-1}



Note: Beam offset 5mm from detector axis

Simulated Ionizing Radiation

MARS simulation of CDF

- Collisions simulated by DPMJET
- Simulation scaled up 2x for plot (check shape)

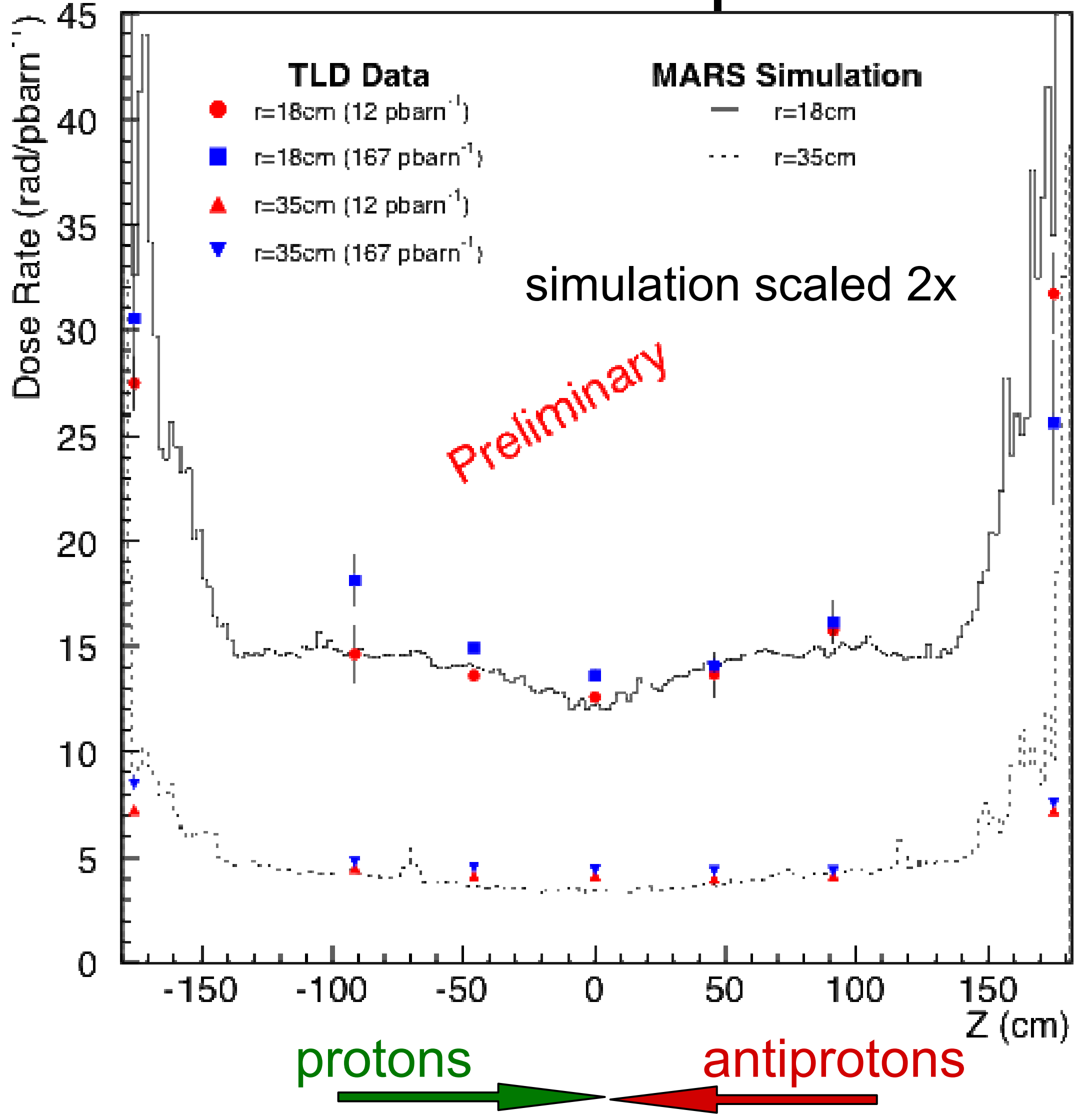
Missing Material?

- electronics
- cables
- cooling

+Qualitative understanding of collision dose (dominant)

-Losses not understood!

Collision Component

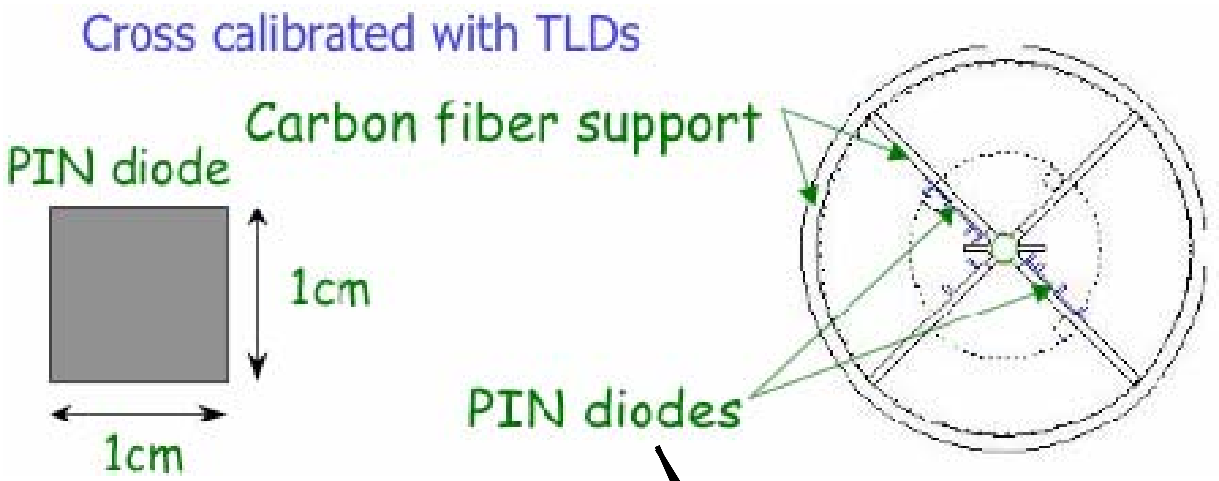


L.Nicolas

Measure Larger Accumulated Doses

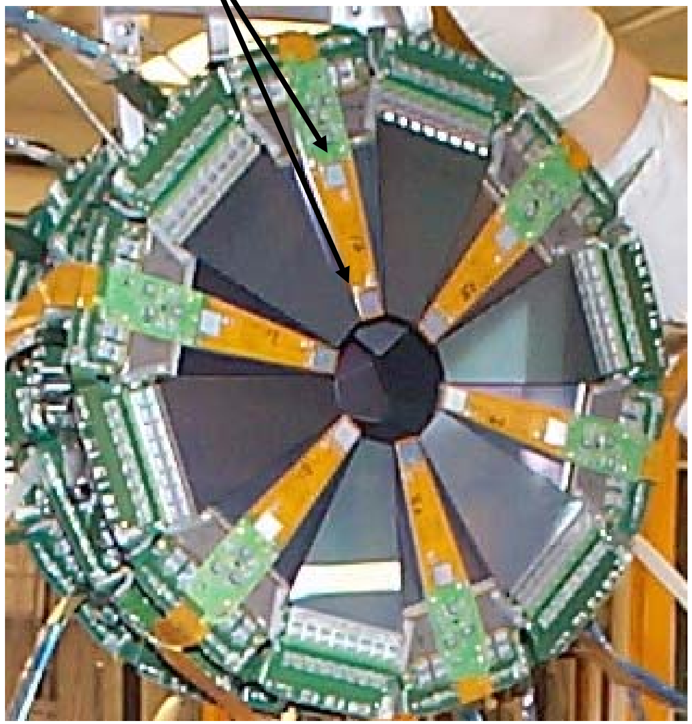
- PIN Diodes
- Advantages:
  - + passive/active
  - + in-situ readout
  - + large dynamic range (10^2 - 10^5Gy)
- Disadvantages:
  - - Temperature/history dependent
  - - Calibrate in-situ
  - - active operation needs periodic calibration

CDF



DØ

(Active)

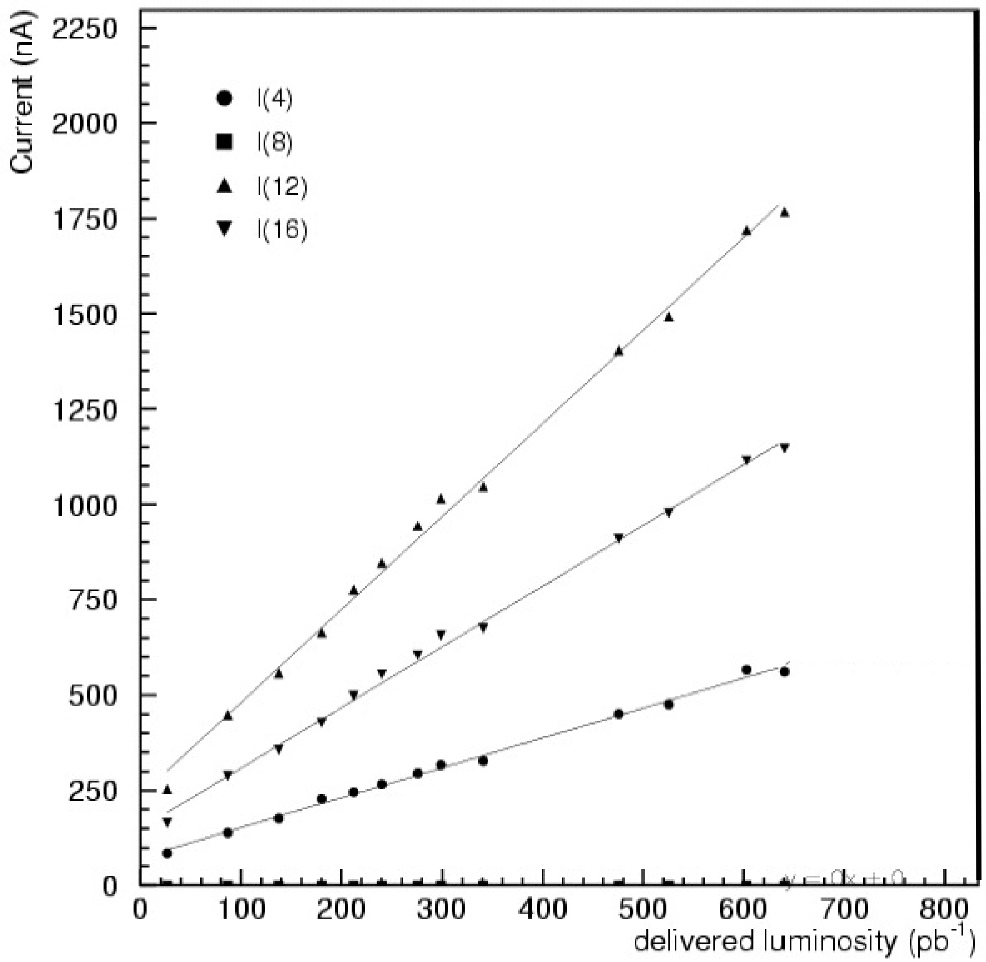


Monitor Dose to Si Tracker

TLD Data: Spatial distribution of ionizing radiation.

PIN Diodes: Use increase in bias current as scale to get delivered dose.

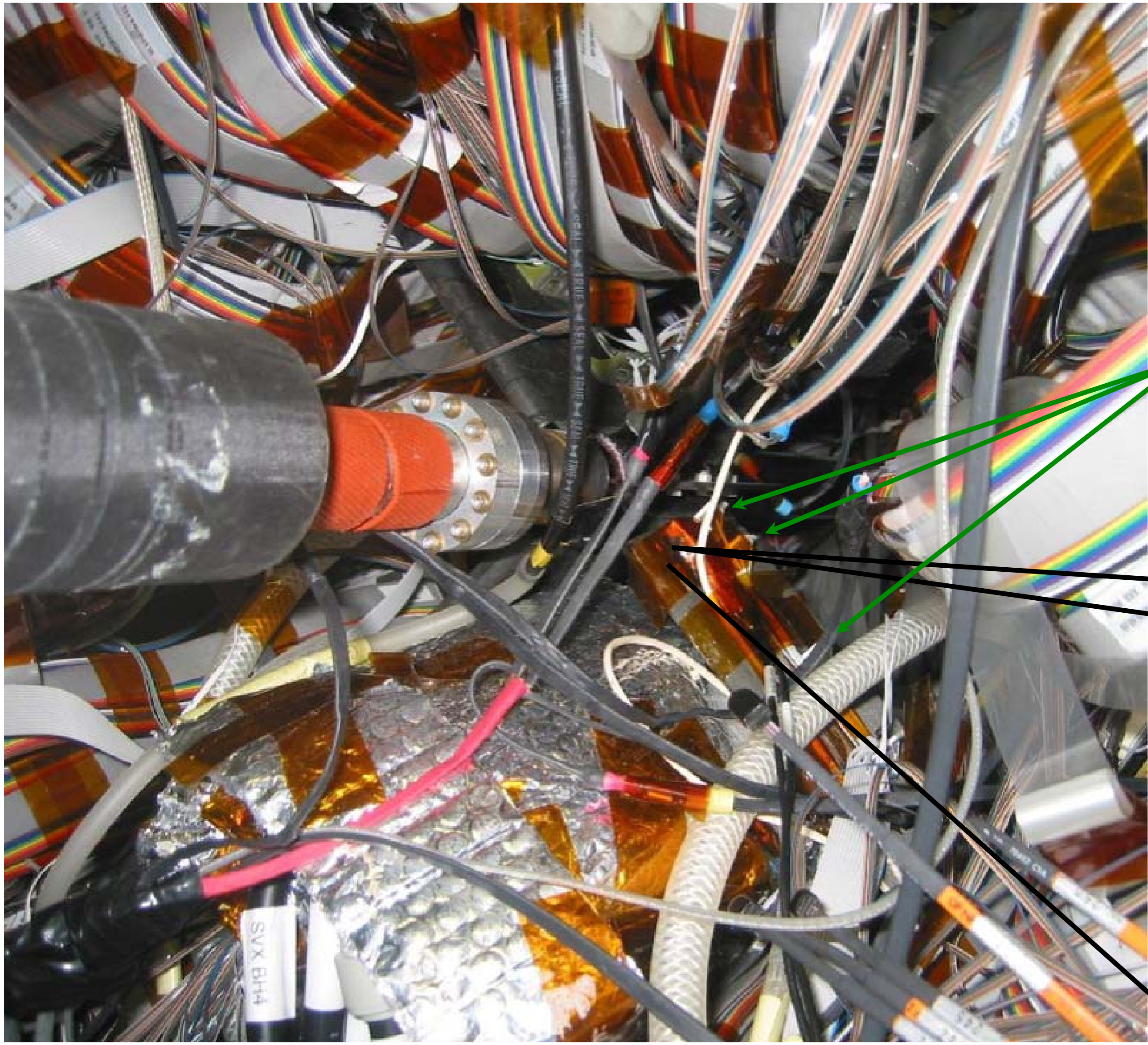
- T corrected to 20 C
- Diodes used passively
- I/V curves taken monthly
- Si dose ~2.1 kGy @ r=3cm



Dose rate and distribution as expected.

Real time monitor desirable

Diamond in CDF

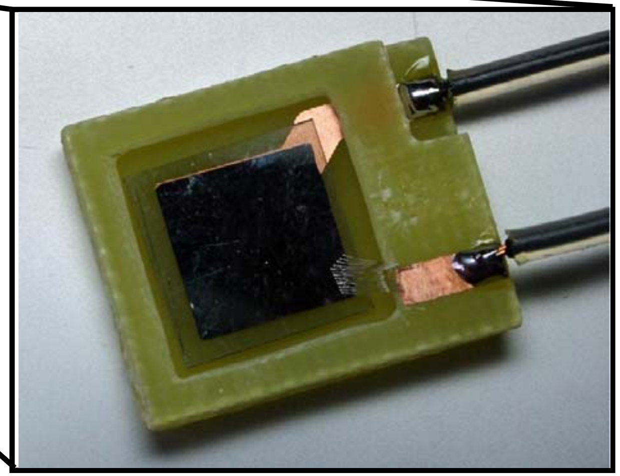


supplemental real time radiation measurement

Status: Installed 10/04
Leakage current measurement <1pA

diodes

diamond



R. Wallny, P. Dong

Measuring Beam Losses/Halo

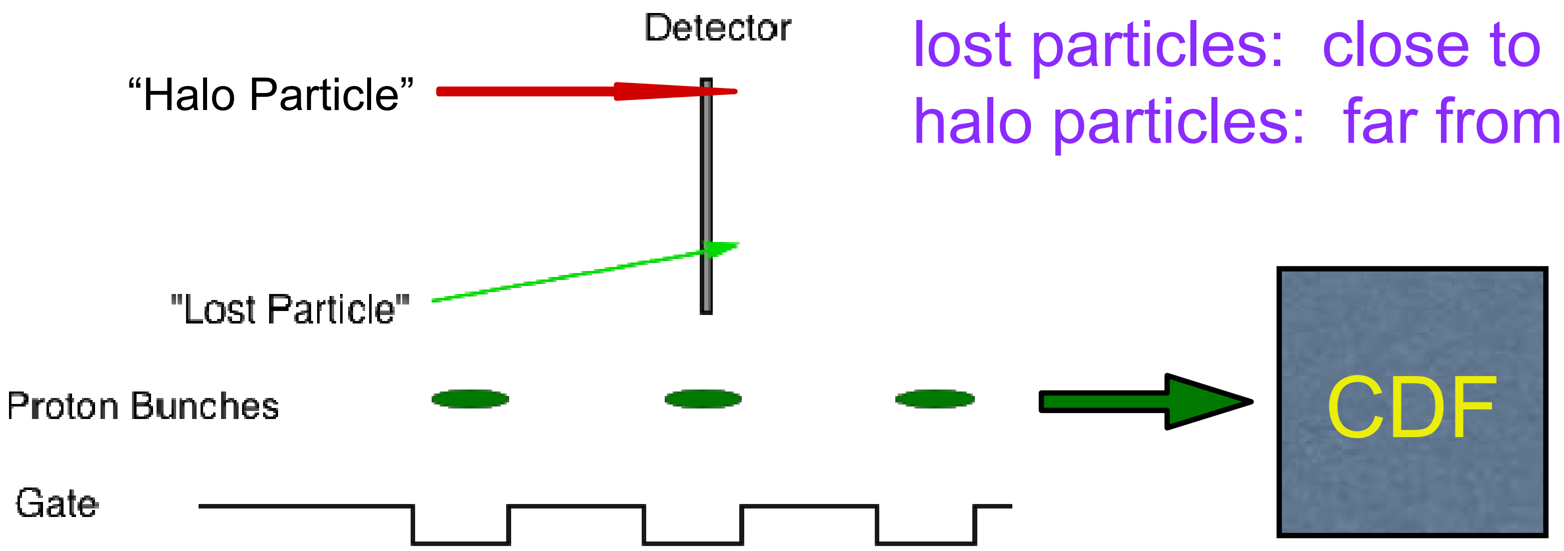
Beam Losses all calculated in the same fashion

- 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

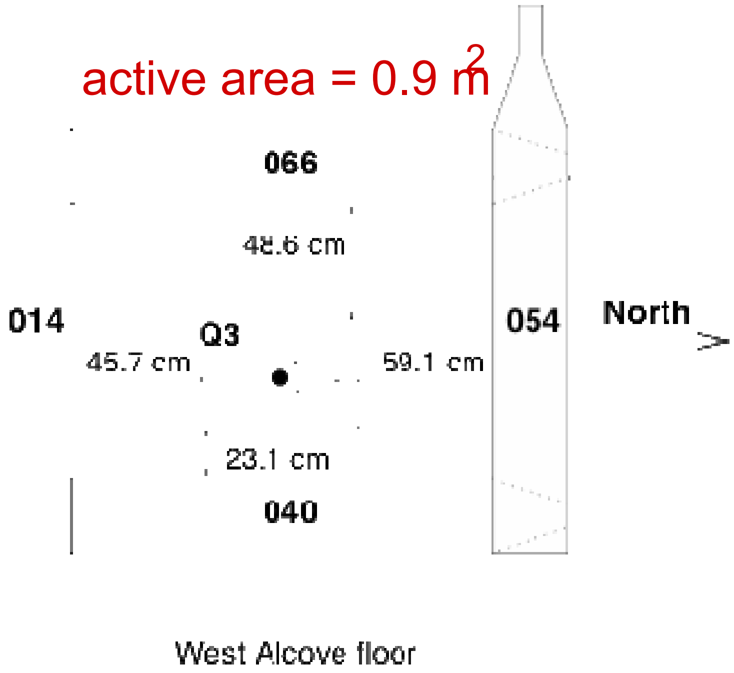
halo particles: far from beam



Detectors

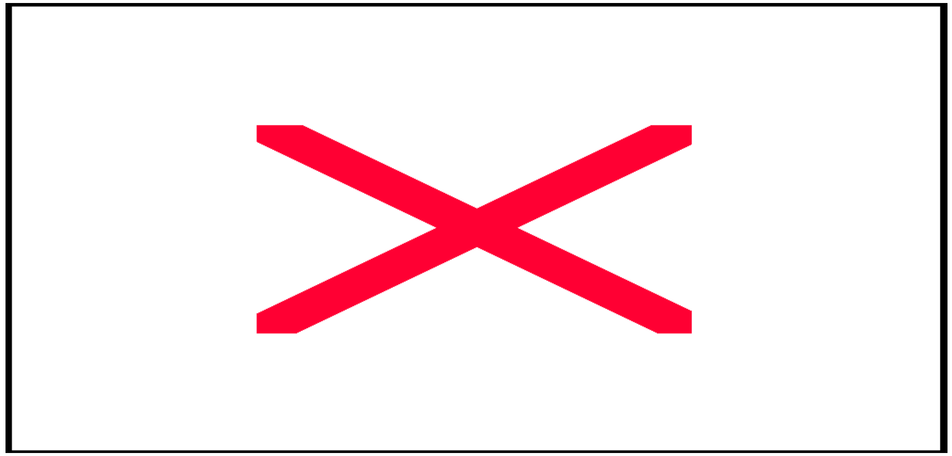
Halo Counters

active area = 0.9 m^2



Beam Shower Counters

active area = 77 cm^2

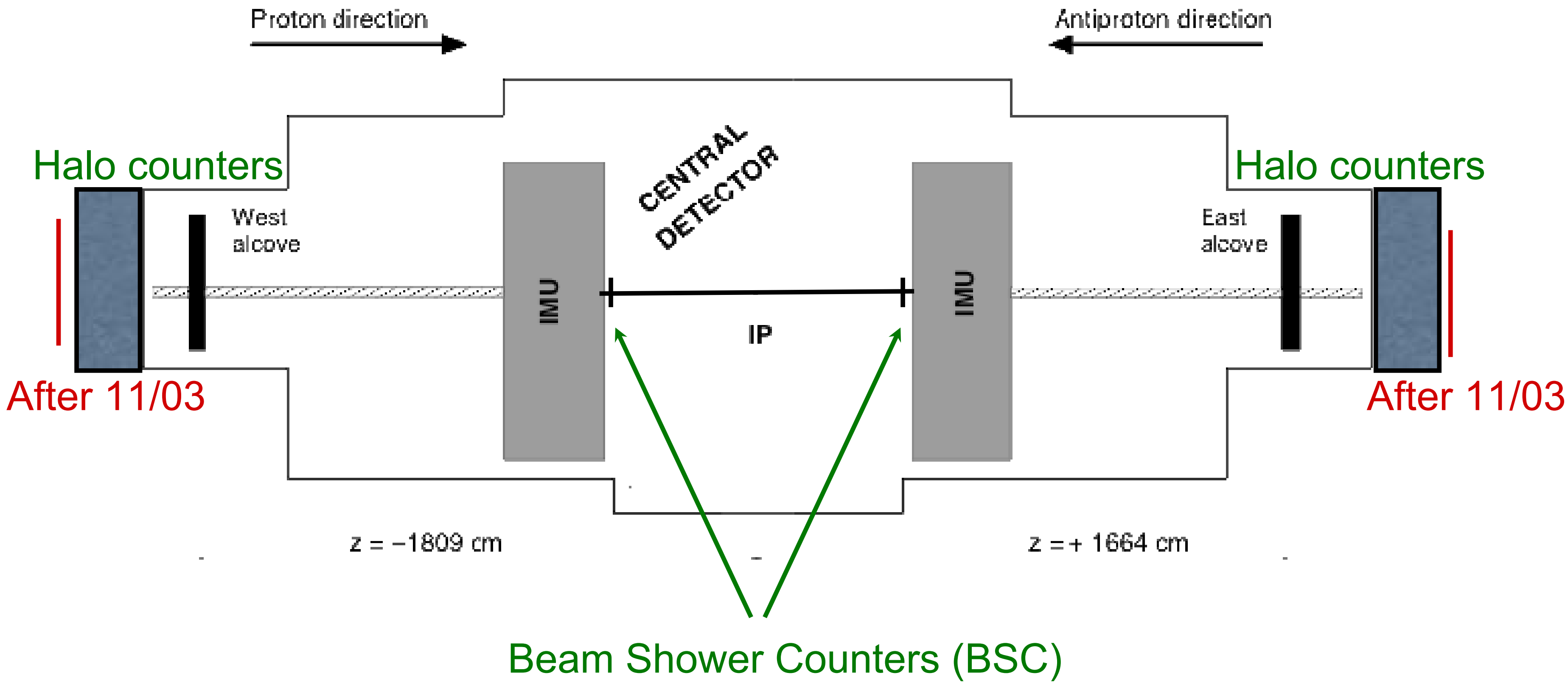


ACNET variables:

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)

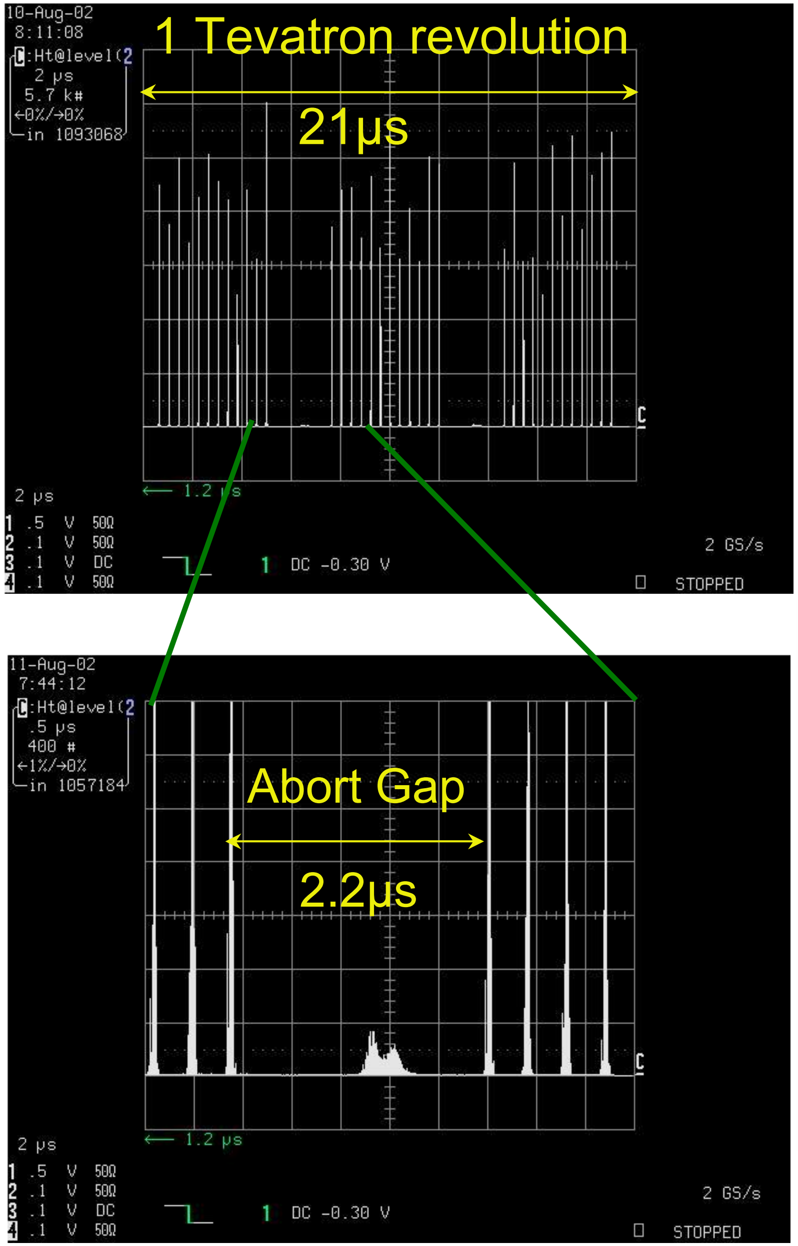
Beam Monitors



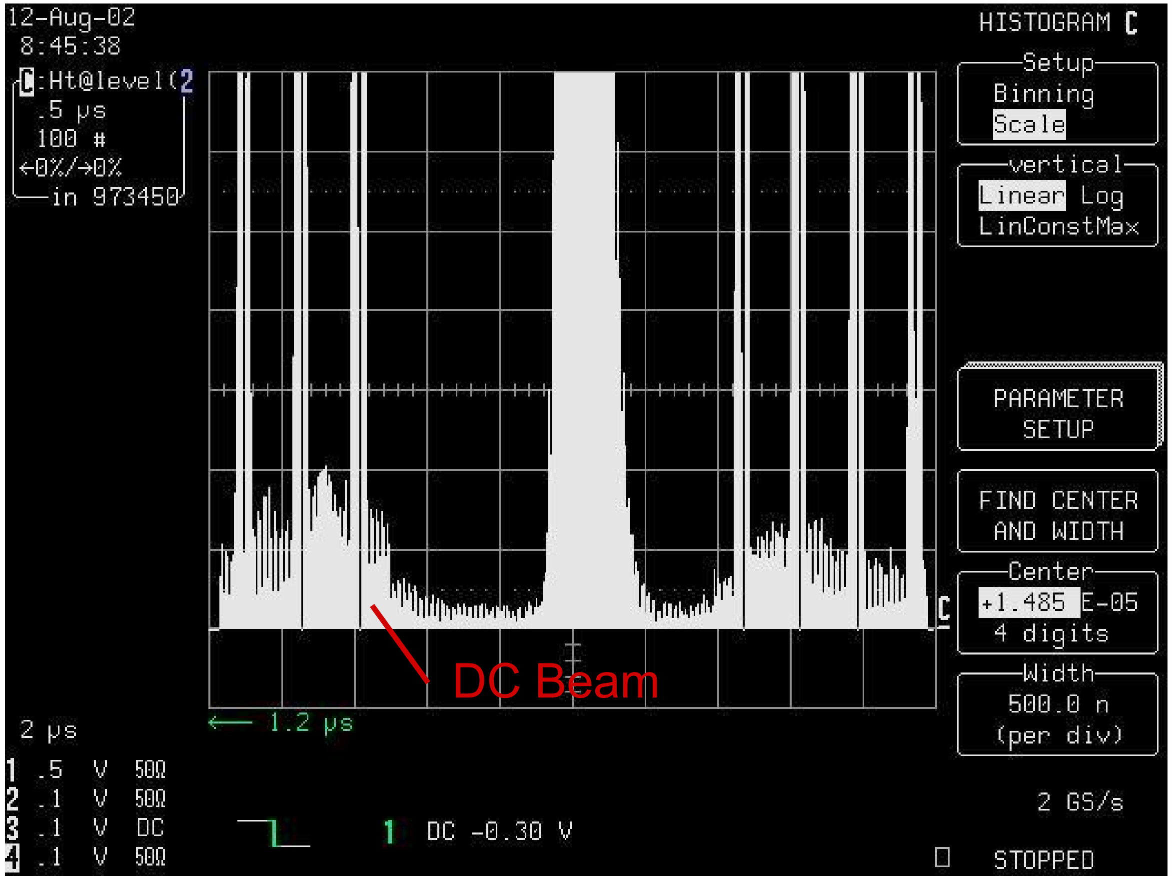
BSC counters: monitor beam losses and abort gap

Halo counters: monitor beam halo and abort gap

Recording "Fast" Signals



Diagnose beam problems
Reduce risk of accident!



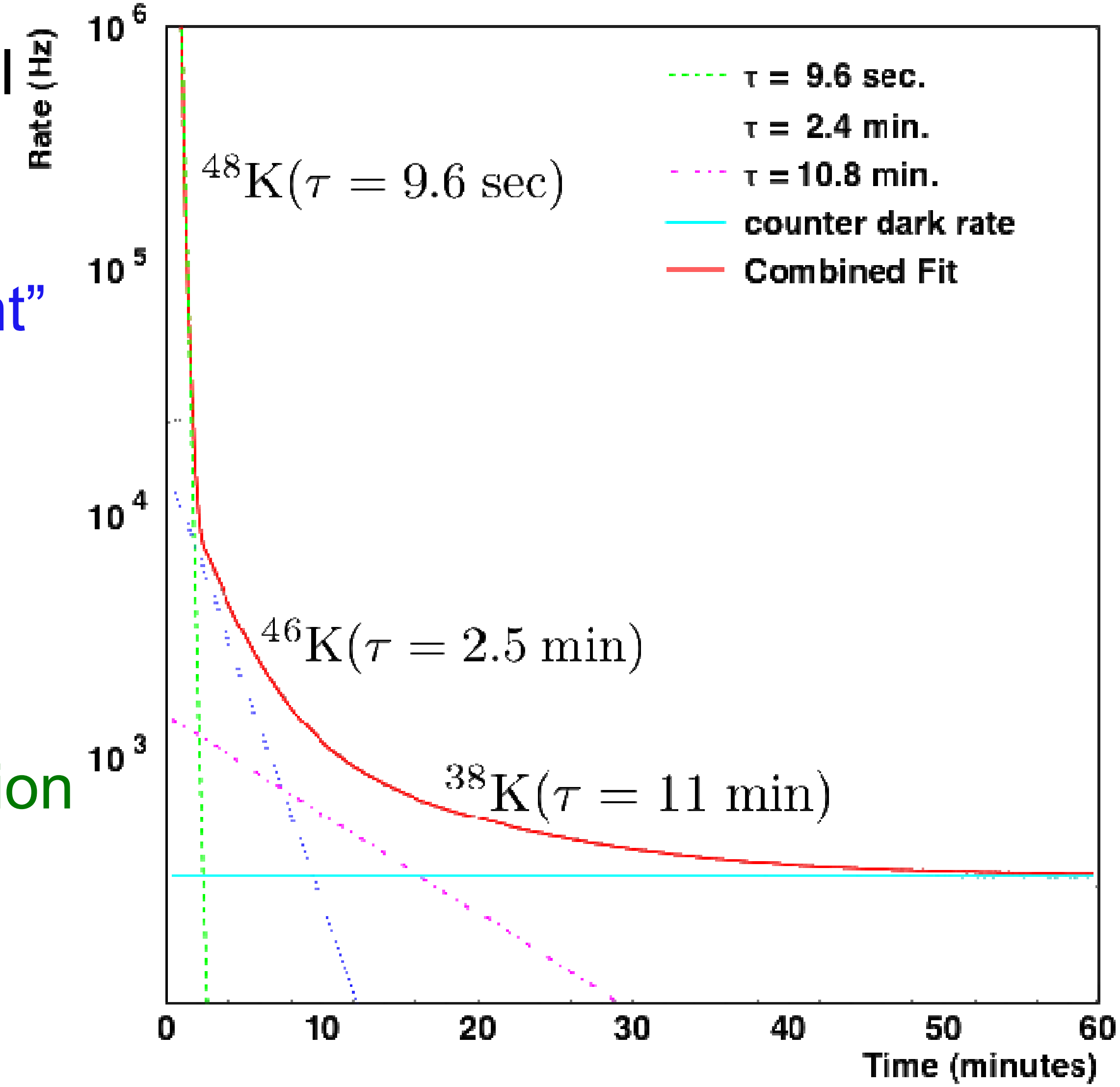
Activation Background in Counters

Activated quadrupole steel

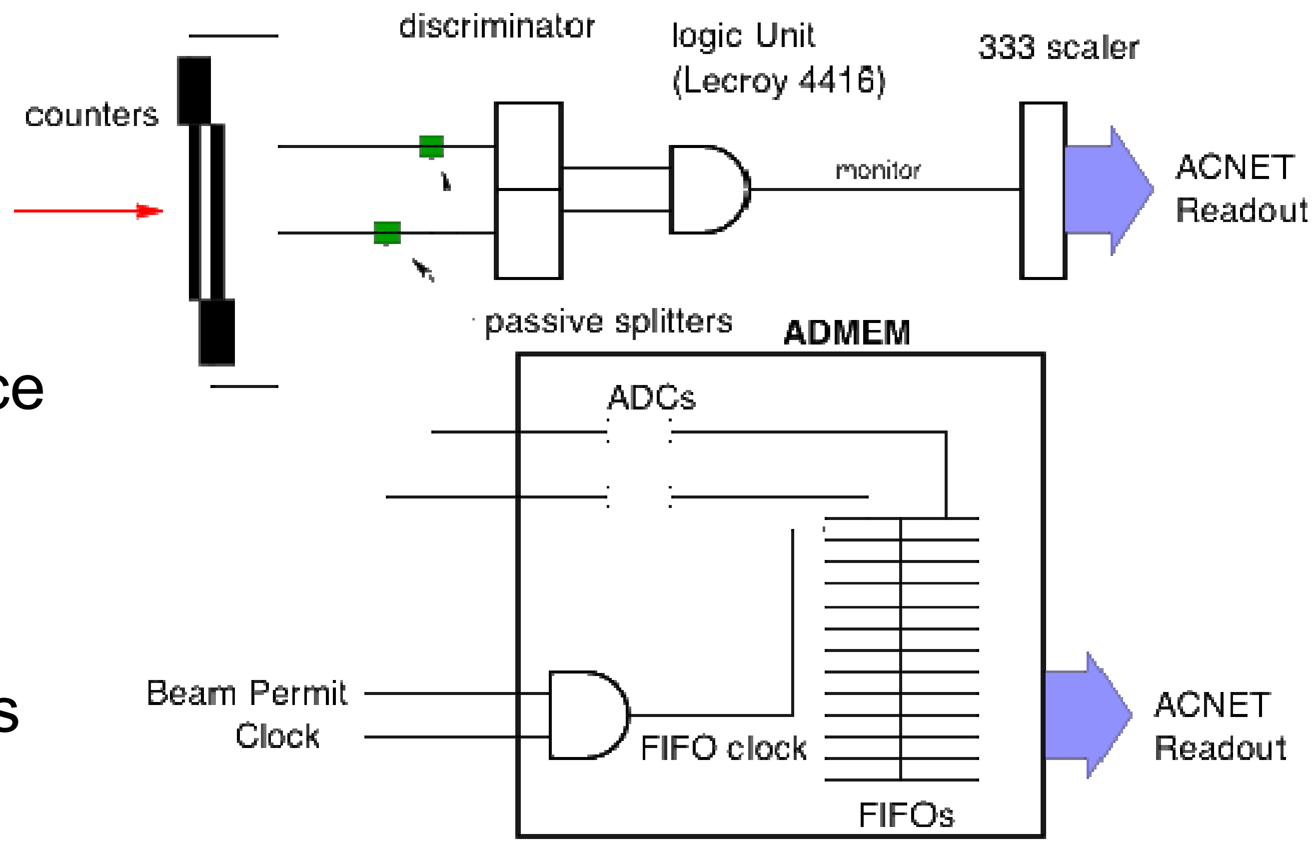
- Periods of sustained high losses
- Large beam “accident”
- β radiation mostly
- Lose timing info
- Contaminate measurement

Majority 2/4 coincidence

+ Reduces contamination
+ Reduces overall rate
- Insensitive to single particles



New Halo/Loss System in 2005



2 Counter coincidence

- Suppress backgrounds
- Calibrate *in situ*

Additional Electronics

- Digitize every bunch
- Deep FIFO (record several revolutions)

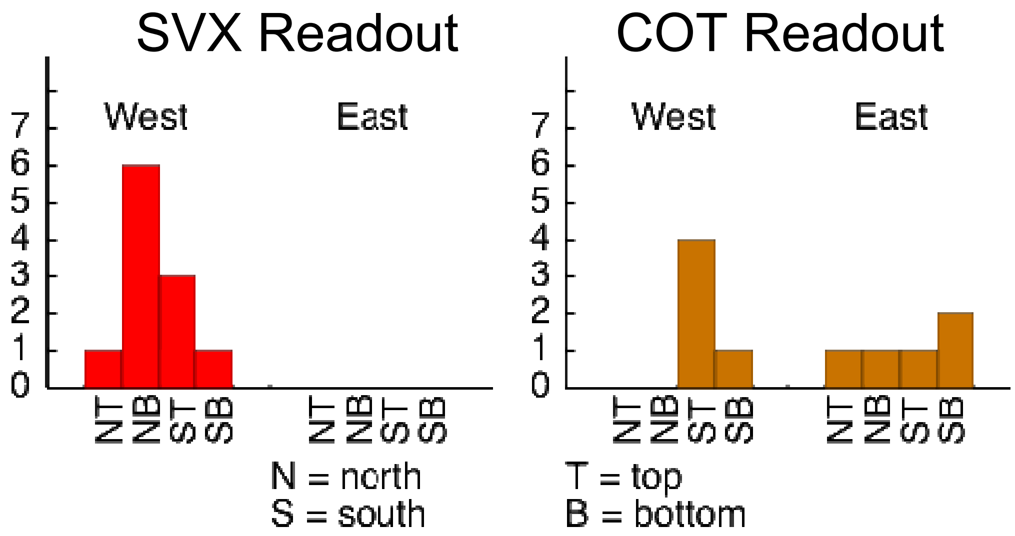
Reconstruct “accidents”

CDF VME Power Supply Failures

Failure Characteristics

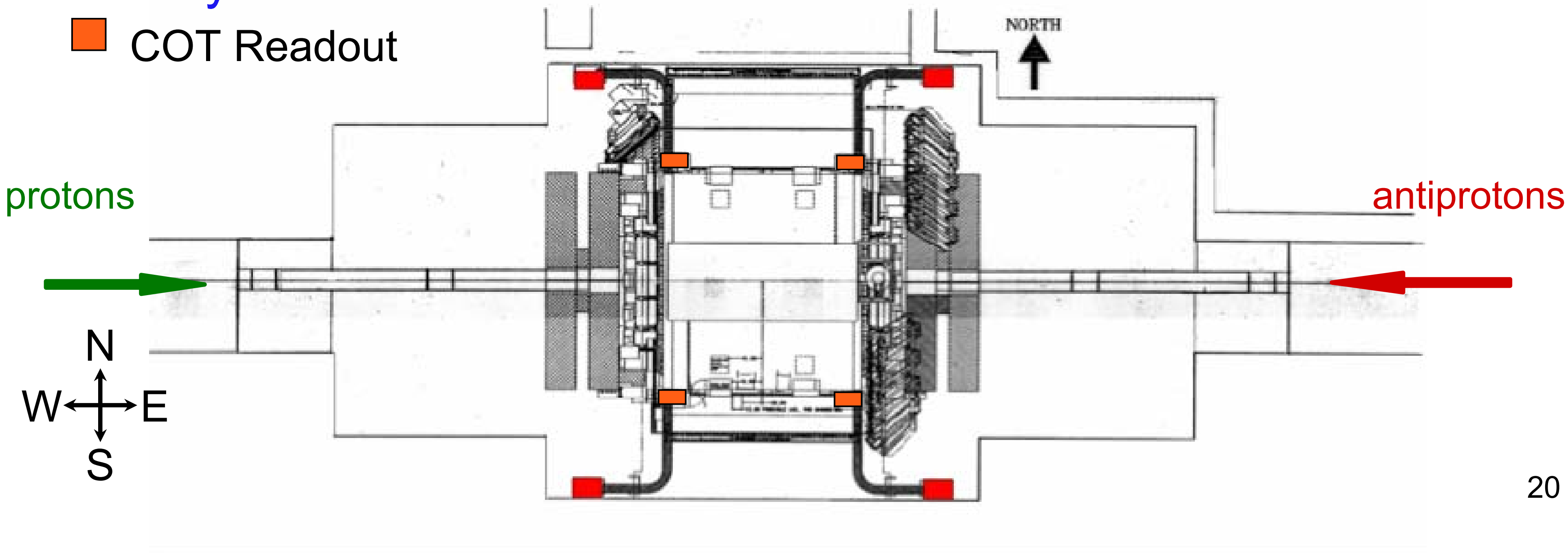
- Position Dependent
- Beam Related
- Catastrophic
- Switching supplies only
- failure rate ~3/week
- 12 supplies failed in 1 day

Failure Locations



SVX Readout

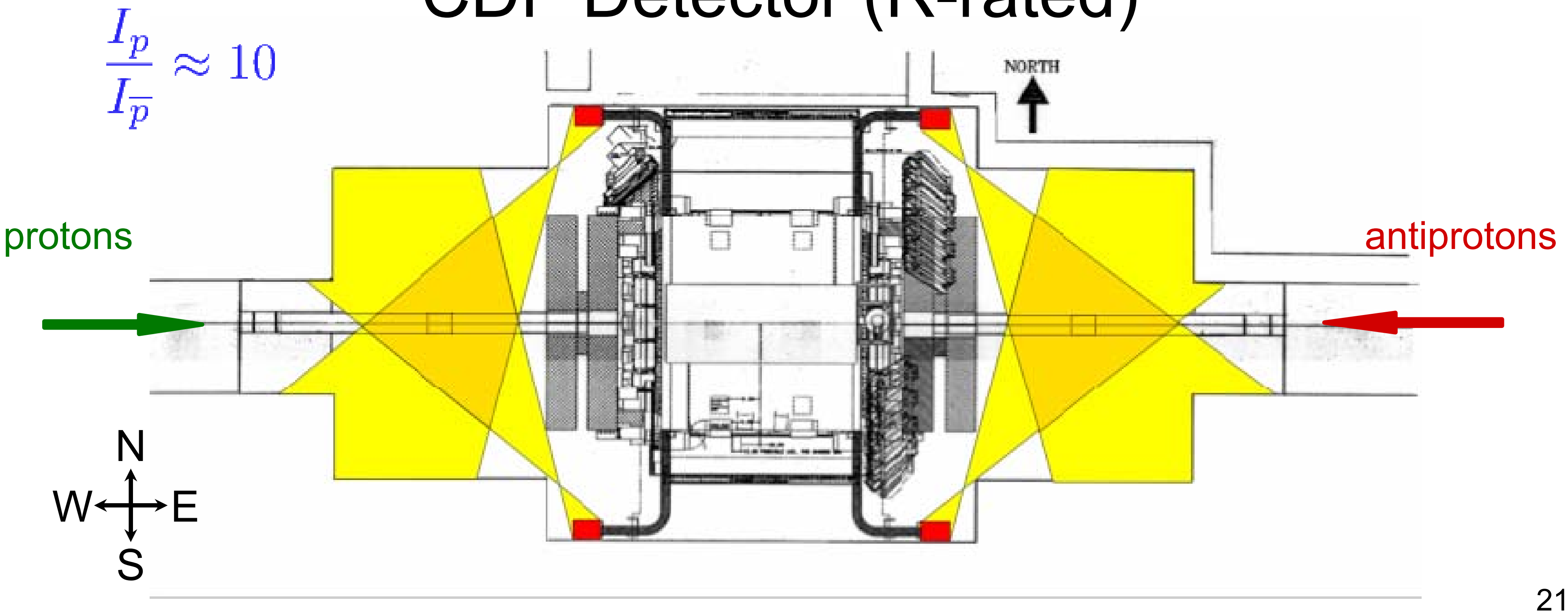
COT Readout



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)



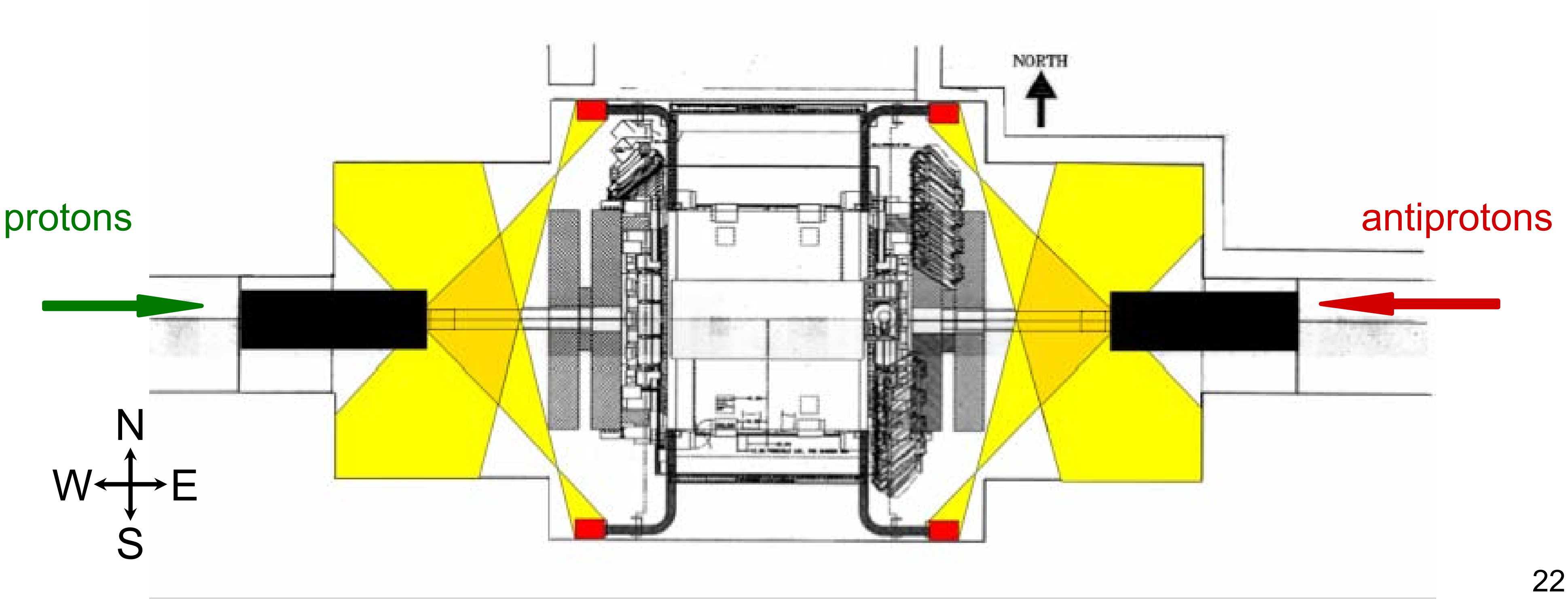
Radiation Shielding?

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



Collision Hall Ionizing Radiation Field

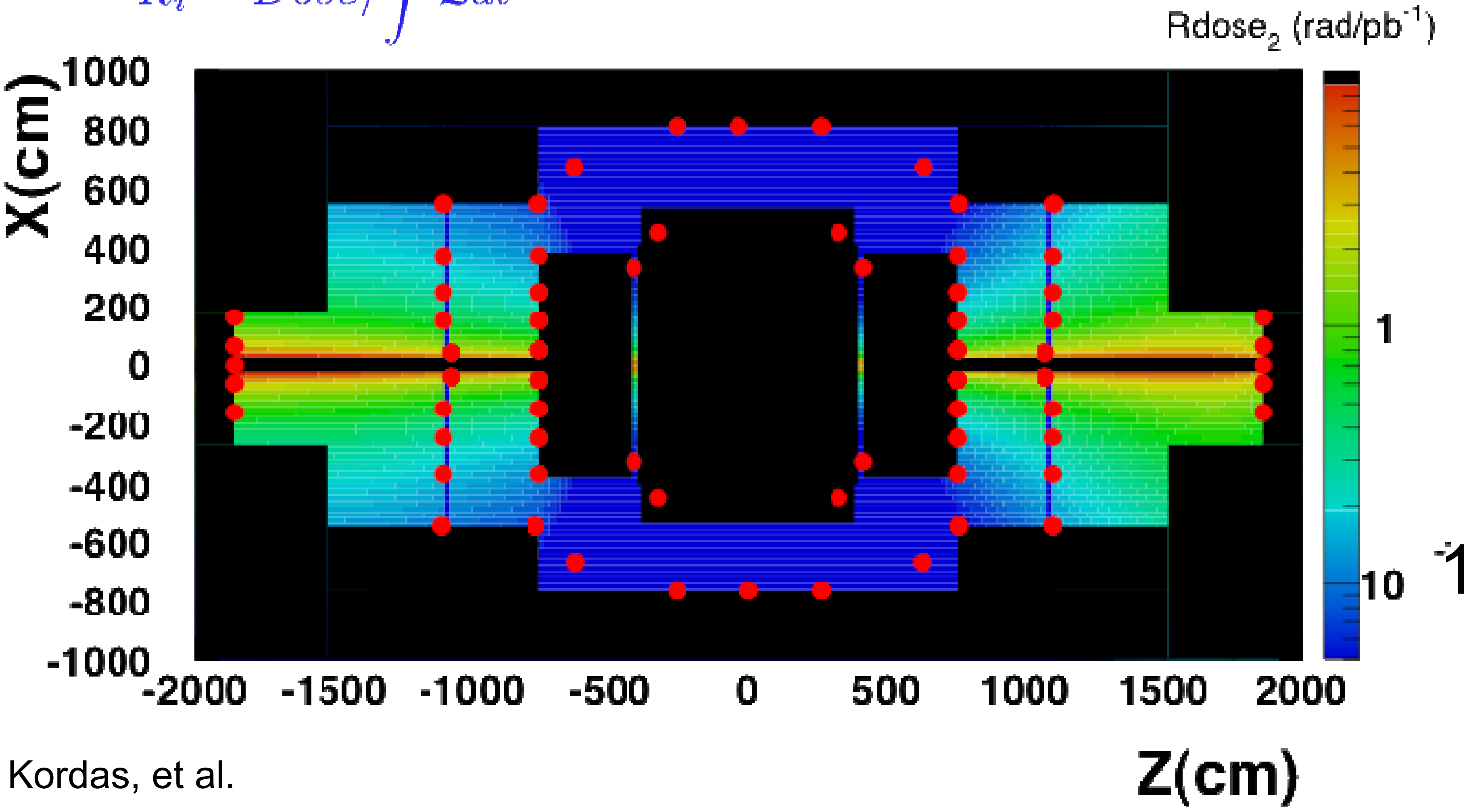
960 dosimeters installed in 160 locations

Radiation field modeled by a power law

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

r is distance from beam axis

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



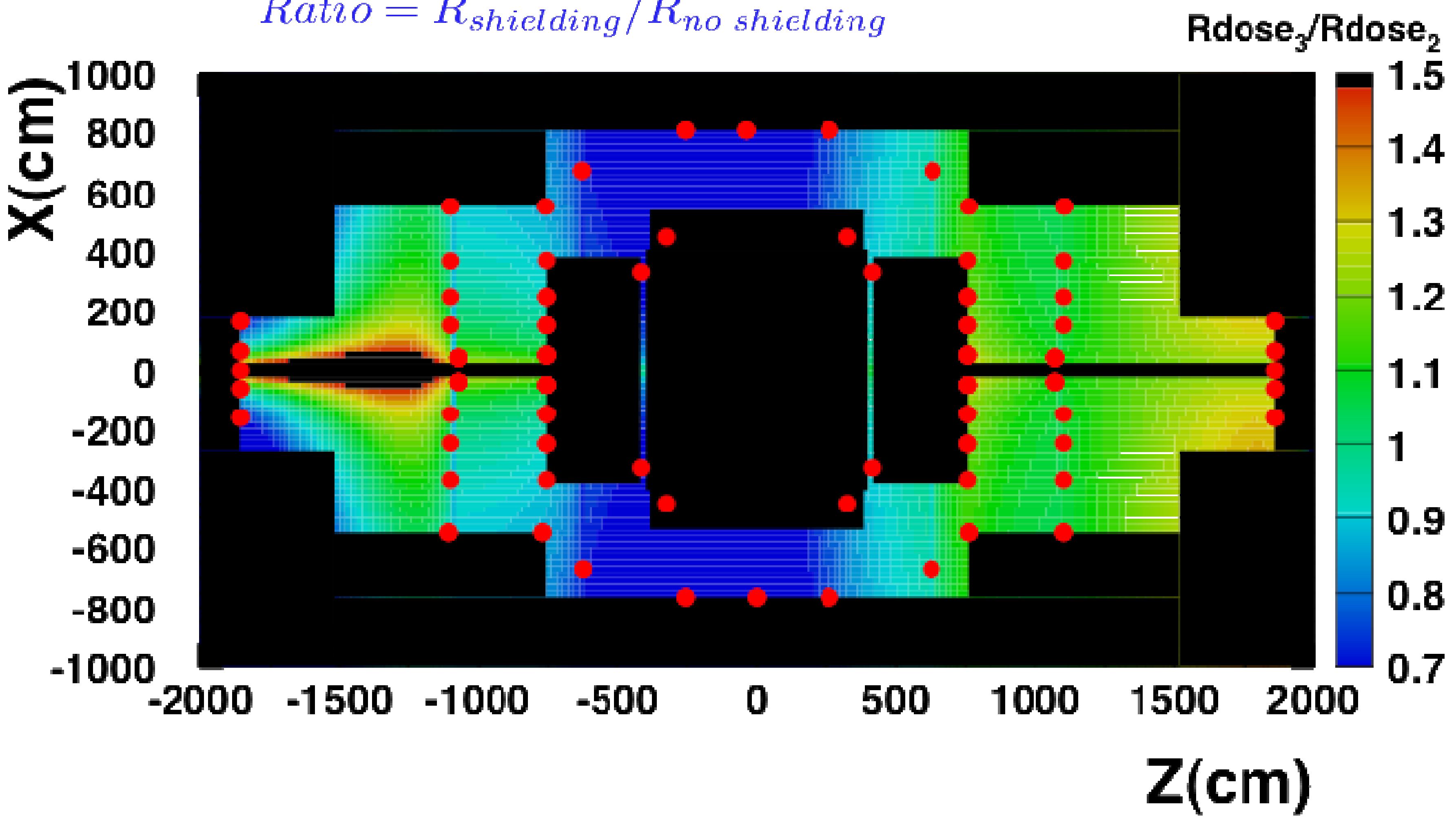
K. Kordas, et al.

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

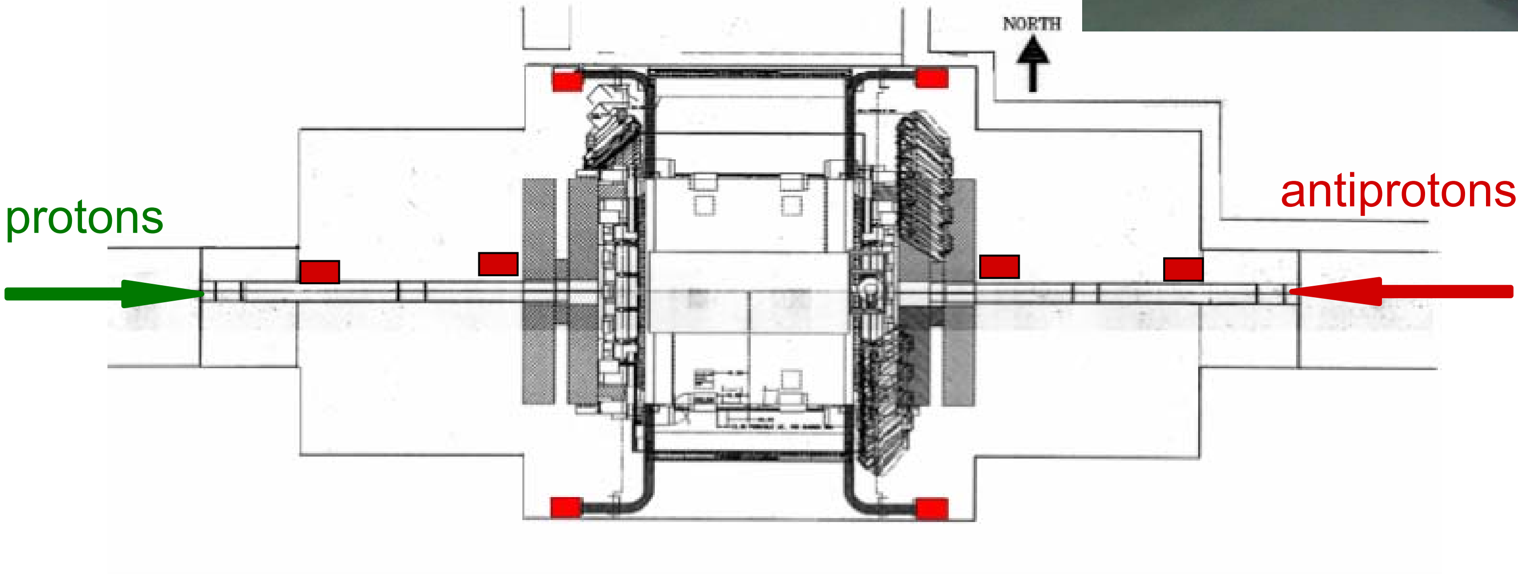
- Bonner spheres + TLDs
- ~1 week exposures
- Shielding in place

Measuring neutrons is hard!

Work in progress...

Polyethylene “Bonner” spheres

Bonner sphere locations



Neutron Data

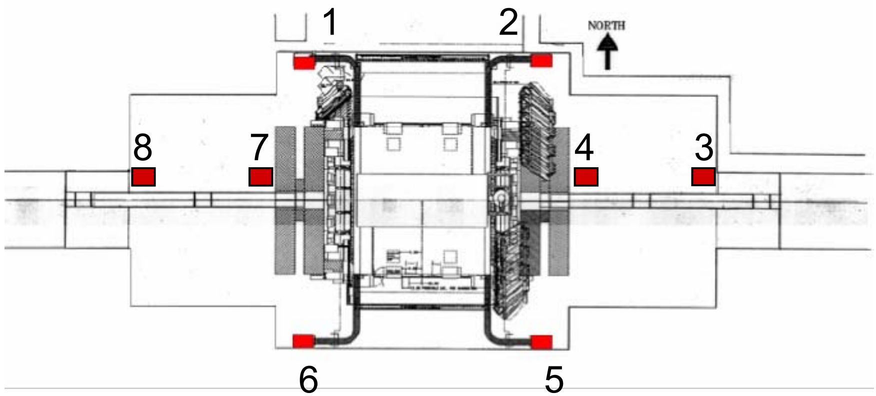
Compare data with ^{252}Cf

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

Data show average $E_n < 2$ MeV

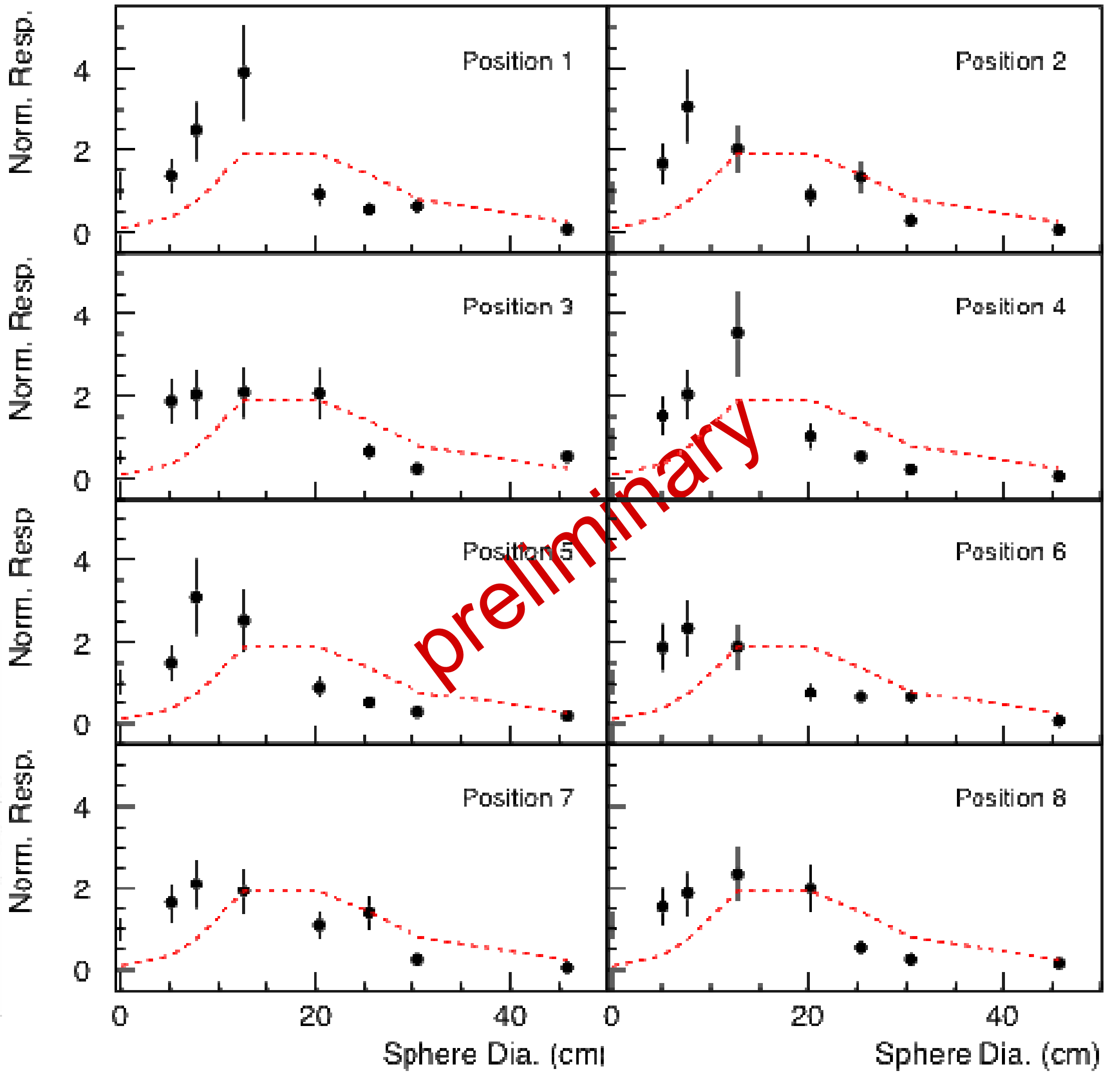
To do:

- understand E_n distribution
- neutron fluence



W. Schmitt, *et al.*

● Collision hall data
---- ^{252}Cf (calibration)



Summary

Multiple techniques to monitor radiation

- TLDs
- Silicon diodes
- Ionization chambers
- Scintillation counters
- Complimentary and redundant information

New systems to supplement information

- Diamond detector
- New counters & electronics

References (Incomplete List)

General:

- http://ncdf67.fnal.gov/~tesarek
- http://www-cdfonline.fnal.gov/acnet/ACNET_beamquality.html

Single Event Burnout:

- R.J. Tesarek, C. Rivetta, R. Nabora, C. Rott, *CDF internal note,* **CDF 5903**.
- C. Rivetta, B. Allongue, G. Berger, F. Faccioi, W. Hajdas, **FERMILAB-Conf-01/250E,** September 2001.
- J.L. Titus, C.F. Wheatly, *IEEE Trans. Nucl Sci.*, **NS-43,** (1996) 553.

CDF Instrumentation:

- M.K. Karagoz-Unel, R.J. Tesarek, *Nucl. Instr. and Meth.*, **A506** (2003) 7-19.
- A.Bhatti, *et al., CDF internal note*, **CDF 5247**.
- D. Acosta, *et al., Nucl. Instr. and Meth.,* **A494** (2002) 57-62.

Beam Halo and Collimation:

- A. Drozhdin, *et al., Proceedings: Particle Accelerator Conference(PAC03),* Portland, OR, 12-16 May 2003.
- L.Y. Nicolas, N.V. Mokhov, *Fermilab Technical Memo:* **FERMILAB-TM-2214** June (2003).

Radiation:

- D. Amidei, *et al., Nucl. Instr. and Meth.,* **A320** (1994) 73.
- K. Kordas, *et al., Proceedings: IEEE-NSS/MIC Conference,* Portland, OR, November 19-25 (2003).
- R.J. Tesarek, *et al., Proceedings: IEEE-NSS/MIC Conference,* Portland, OR, November 19-25 (2003).
- http://ncdf67.fnal.gov/~tesarek/radiation

Backup Slides

Typical Store

Beam Parameters:

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

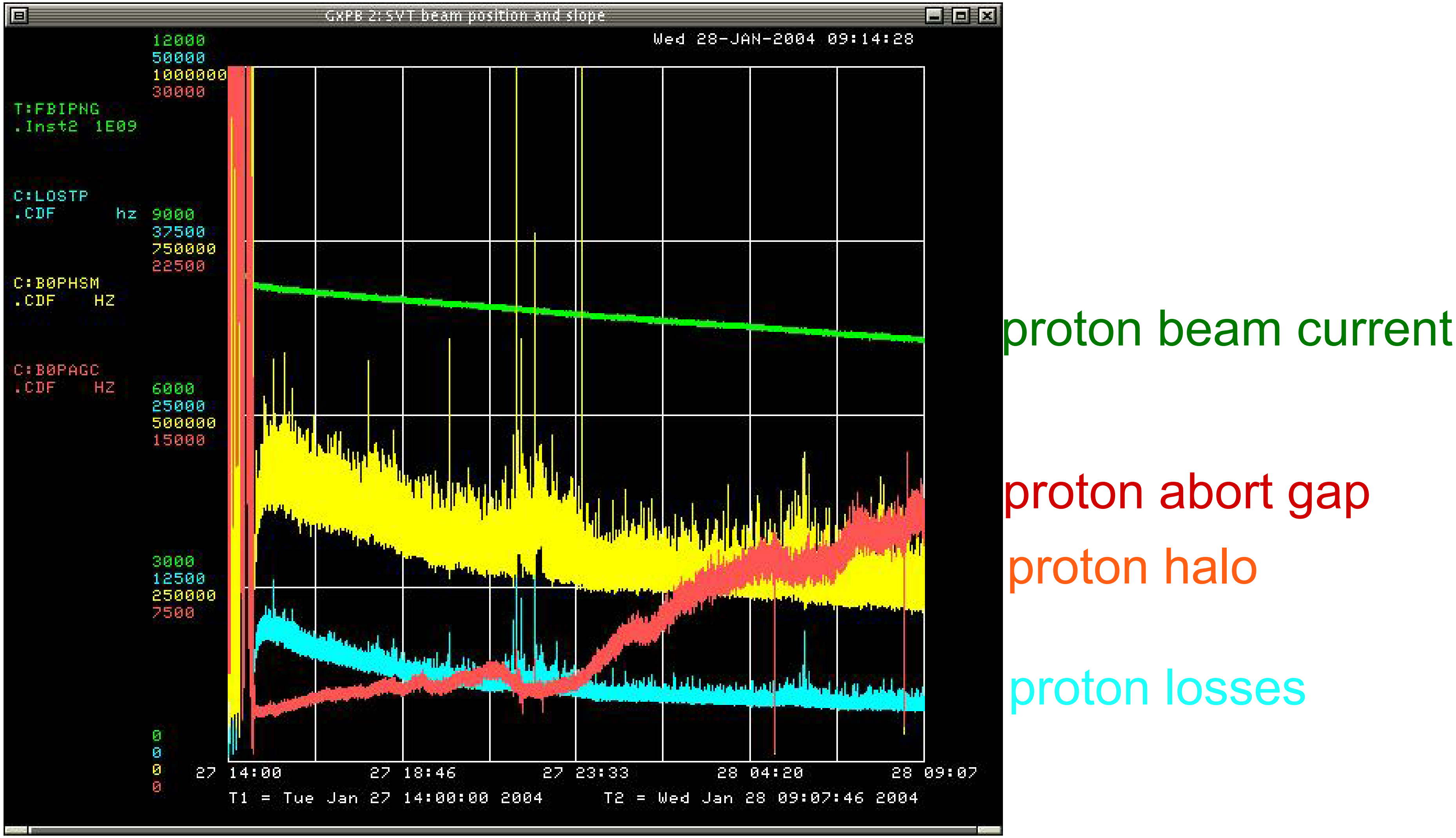
Losses and Halo:

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.

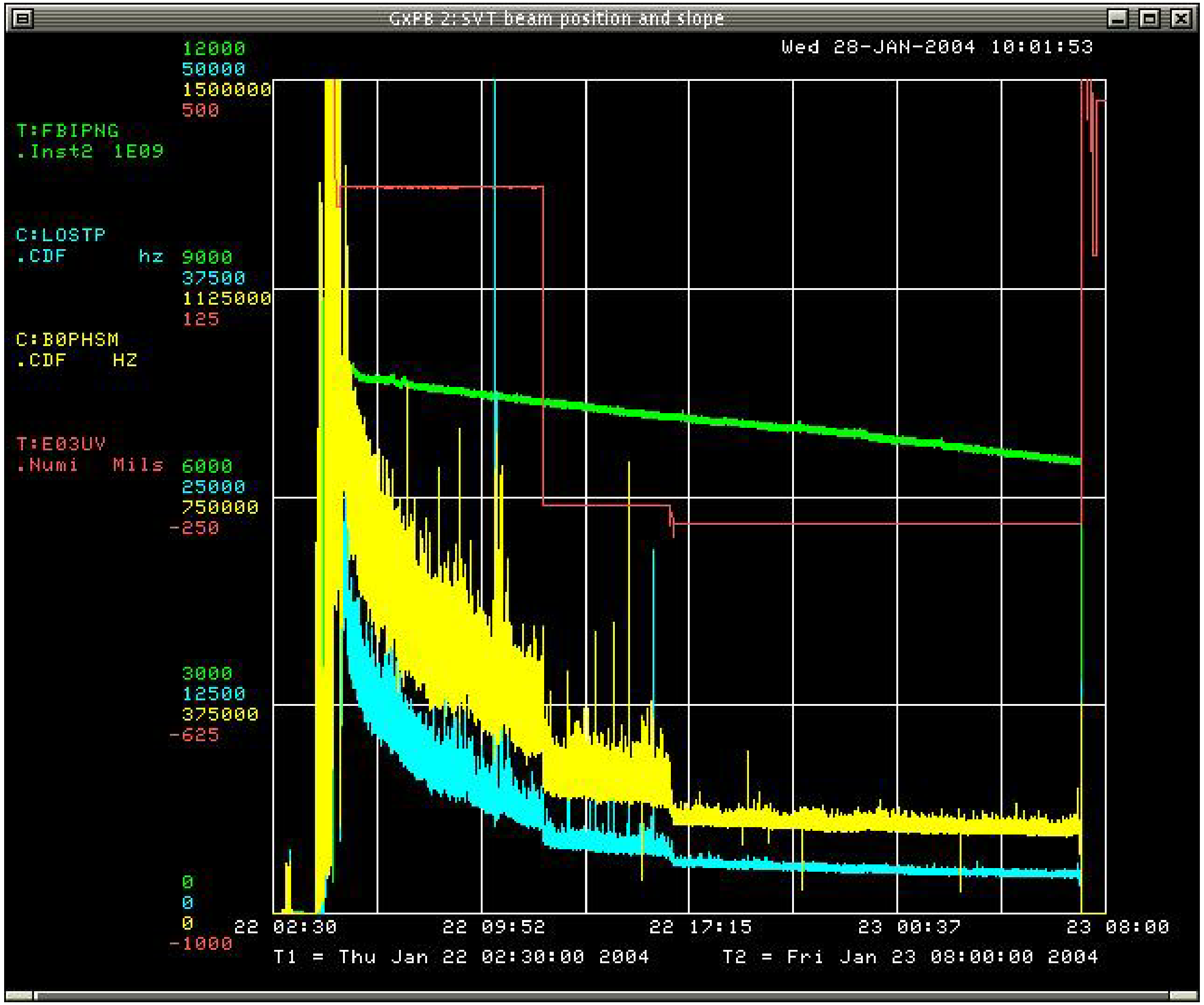
Monitor Experience

"Typical good store"



Beam Collimation

Background reduction at work



E0 collimator

proton beam current

proton halo

proton losses

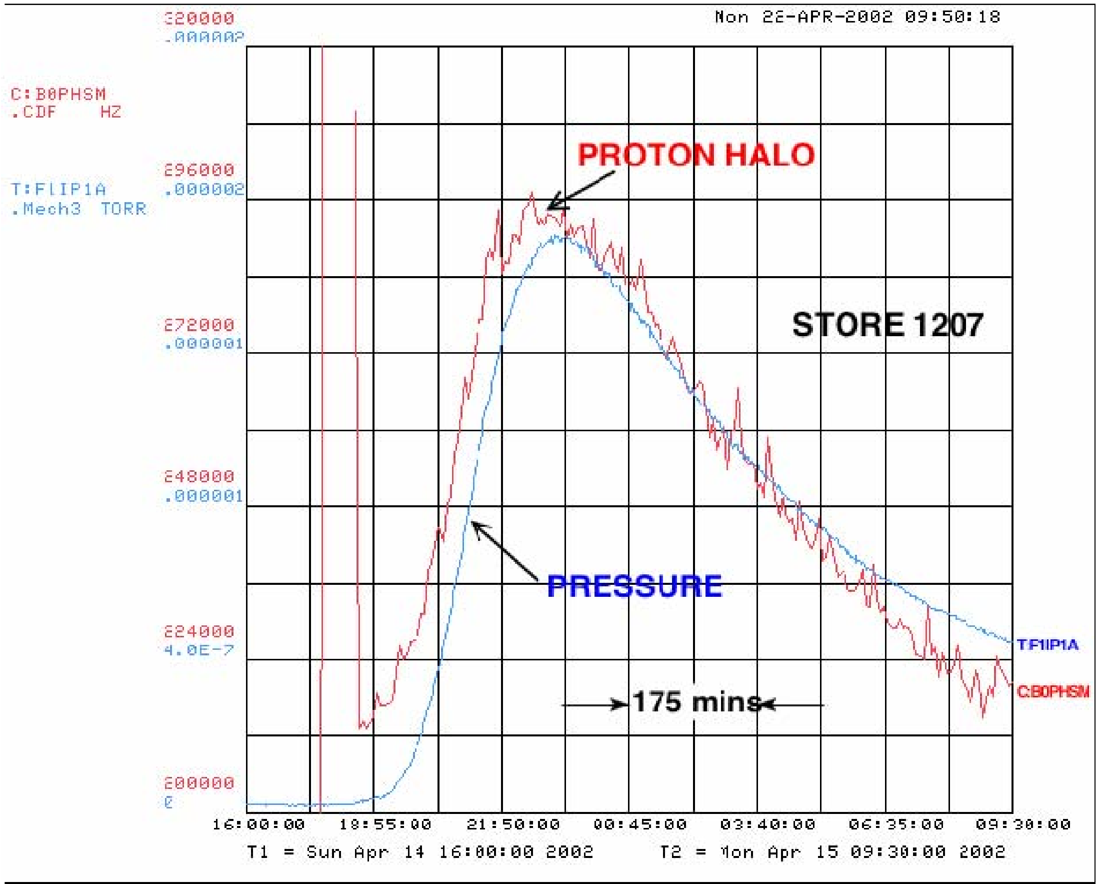
Halo Reduction

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

Improved vacuum (TeV wide)

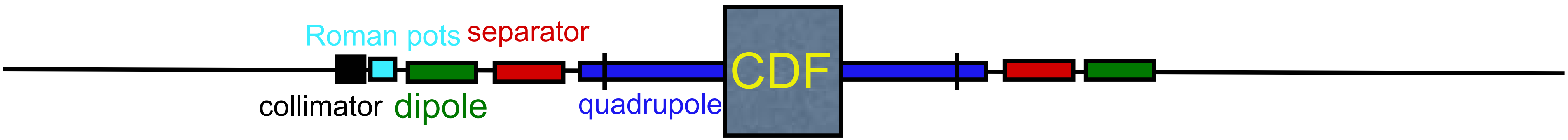
Commissioning of collimators to reduce halo

>Physics backgrounds reduced by ~40%



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

Beam Halo Counters



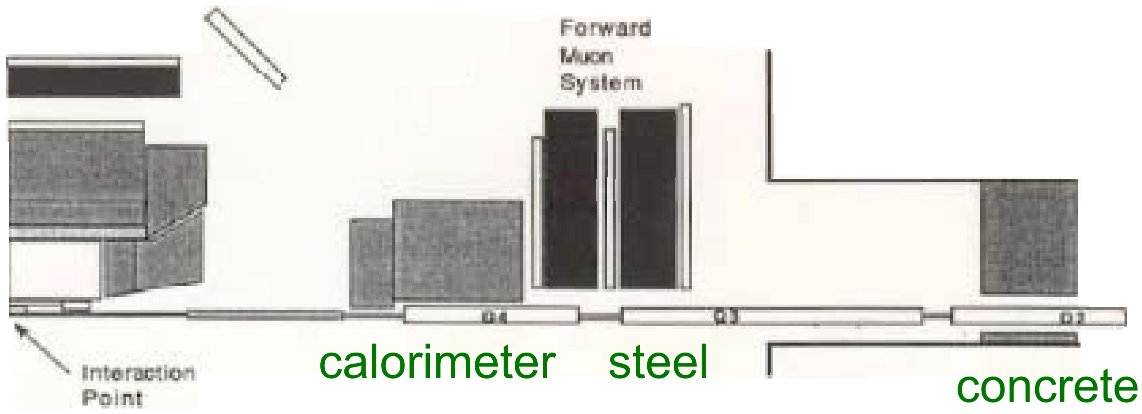
Run I Shielding

Detector configuration different in Run II

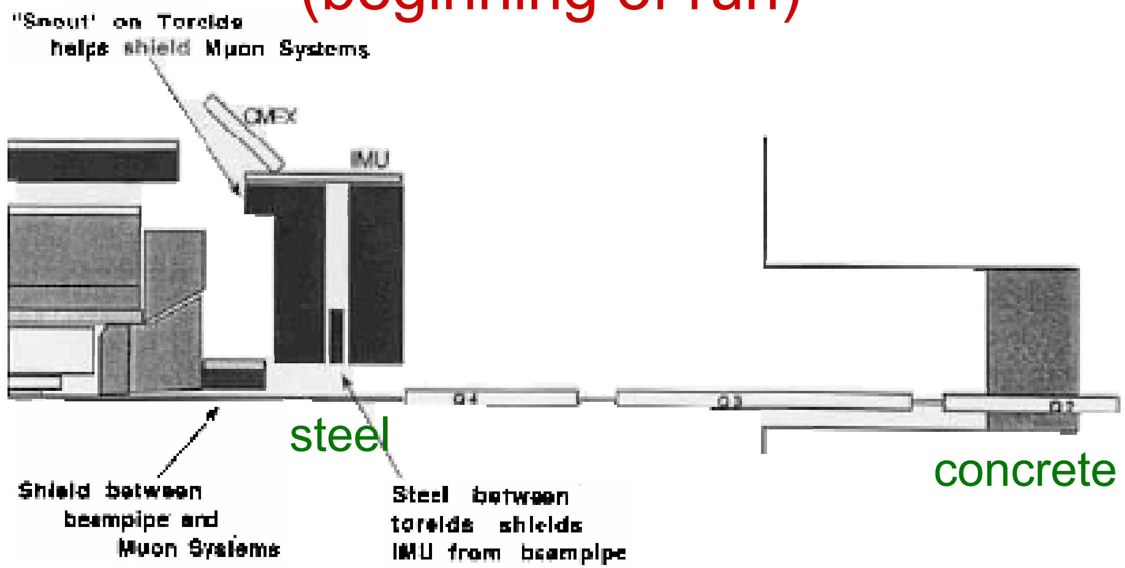
- Run I detector “self shielded”
- Additional shielding abandoned (forward muon system de-scoped).
- Shielding installed surrounding beam line.

Evaluation of shielding continues

Run I Shielding



Run II Shielding (beginning of run)

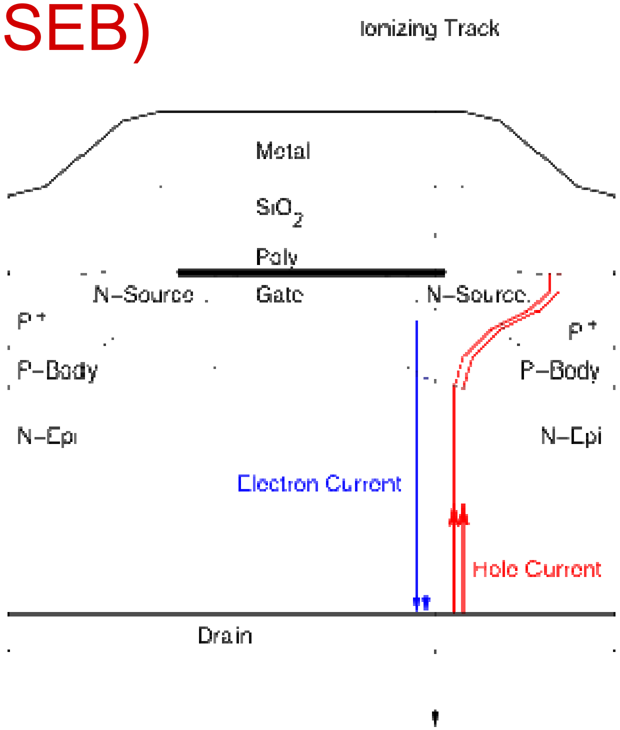


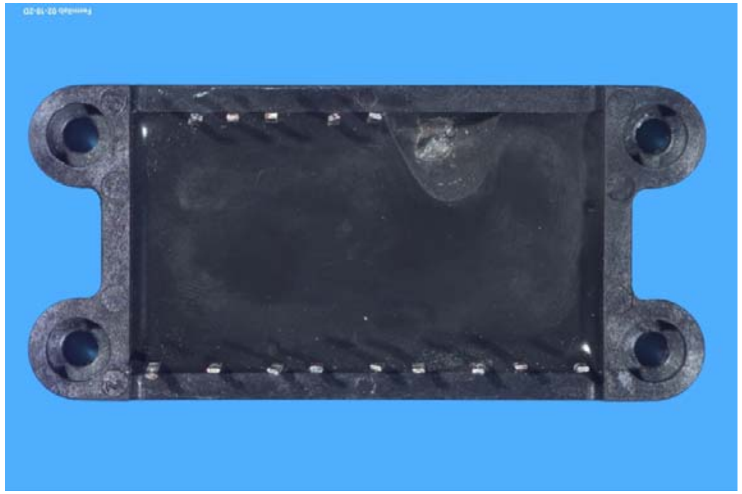
L.V. Power Supply Failures

Power Factor Corrector Circuit

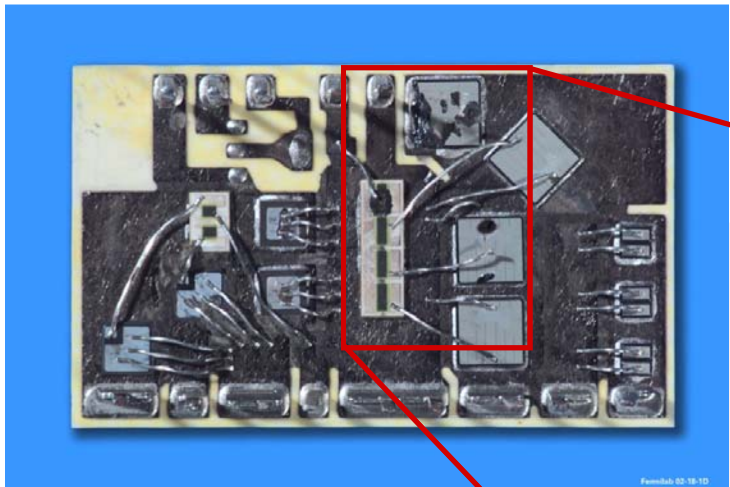
Most failures were associated with high beam losses or misaligned beam pipe

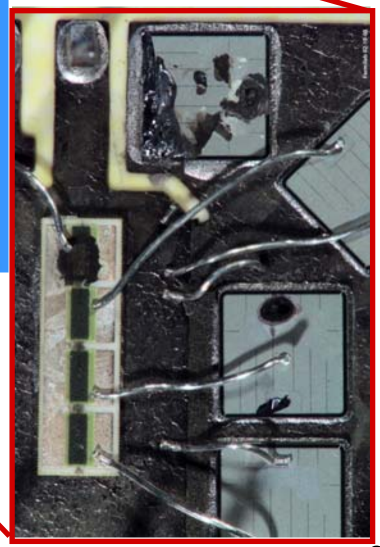
>Power MOSFET Single Event Burnout (SEB)





epoxy covering fractured





silicon in MOSFET sublimated during discharge through single component

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