Single Event Effects and Their Mitigation at the Collider Detector at Fermilab

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Fermilab

Single Event Effects at CDF

CDF II Detector

Operational Problems (Single Event Effects)

- Radiation Related Failures
- Component Identification
- Operational Solutions

Radiation Sources and Shielding

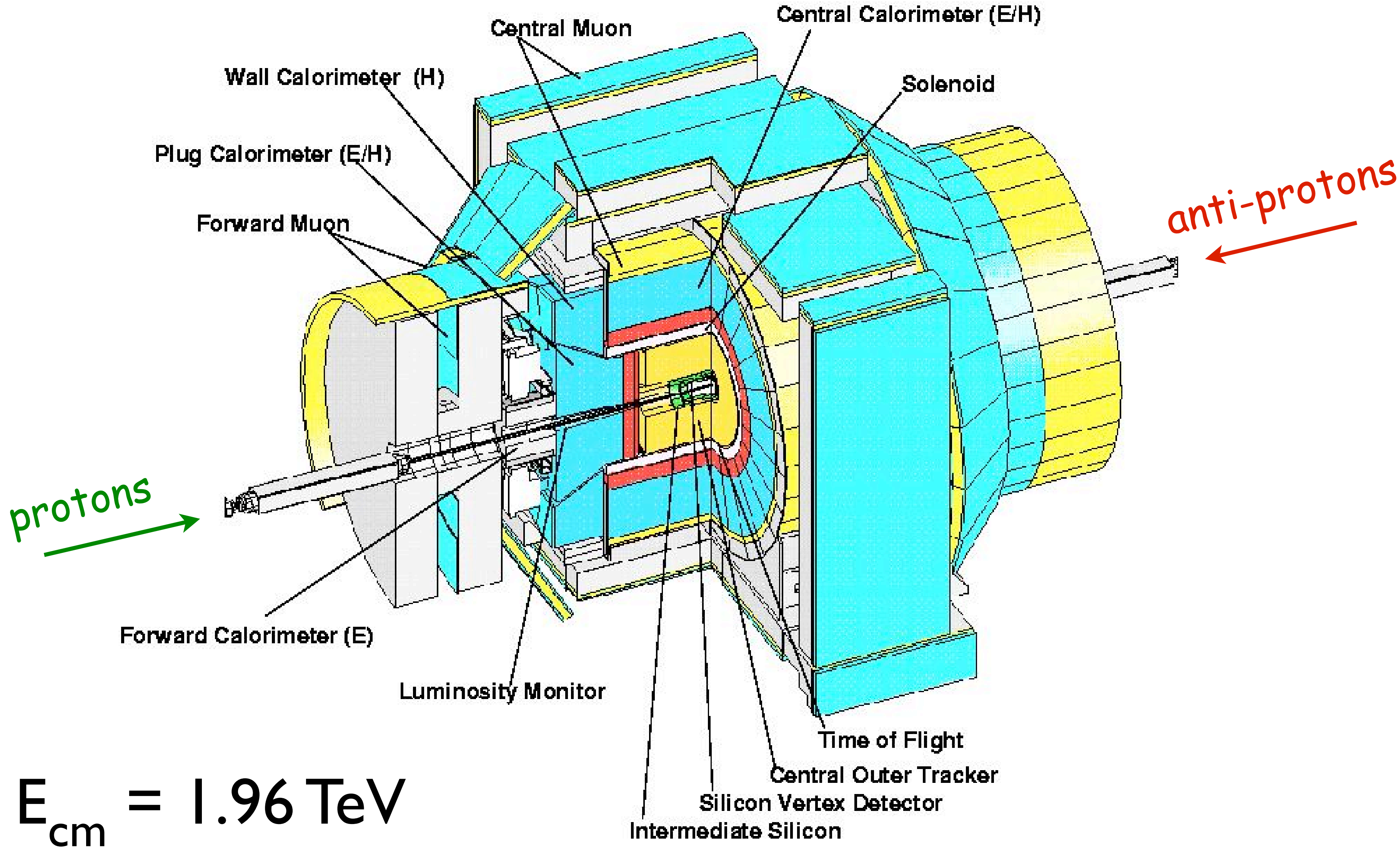
- Identifying Radiation Sources
- Shielding
- Measurement and Simulation

Improving Beam Conditions

Summary/Conclusions

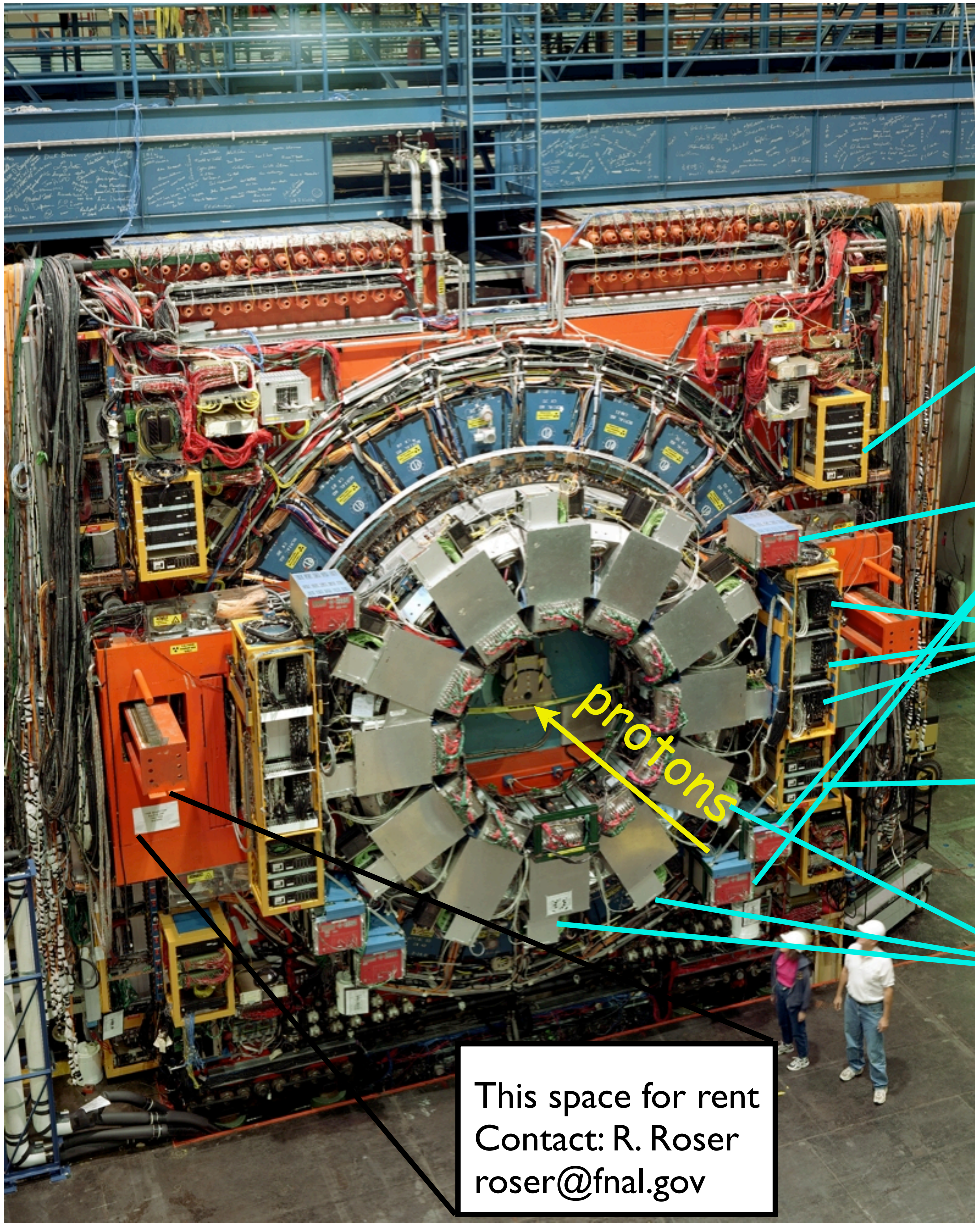
Work of many people, still in progress

CDF-II Detector (G-rated)



E_{cm} = 1.96 TeV

CDF Detector (Adults Only)



Readout, control and support electronics located on the detector:

- 5kW custom low voltage (LV) switching power supplies
- Commercial remotely operated high voltage (HV) switching power supplies
- Custom digitizing and readout electronics 9U VME crate (FPGA based)
- 1 kW commercial low voltage (LV) linear power supplies.
- Custom digitizing and readout electronics 6U VME crate (FPGA based)

Operational Problems

Custom low voltage switching power supplies

- catastrophic component failure only with beam present
- average ~3 failures/week
- 12 failures in single day (St. Catherine's day massacre)
- single event burnout (SEB) of power MOSFET

Commercial high voltage switching power supplies (CPU controlled)

- "soft" failure when beam present
- loss of communication/cpu hang
- loss of calibration constants
- 10% of non-accelerator down time due to problem+recovery

Custom detector readout electronics (Shower Maximum, SMX, system)

- soft failure when beam present
- only systems near beam line fail
- communication interrupt/hang
- 6% of non-accelerator down time due to problem+recovery

Single Event Effects

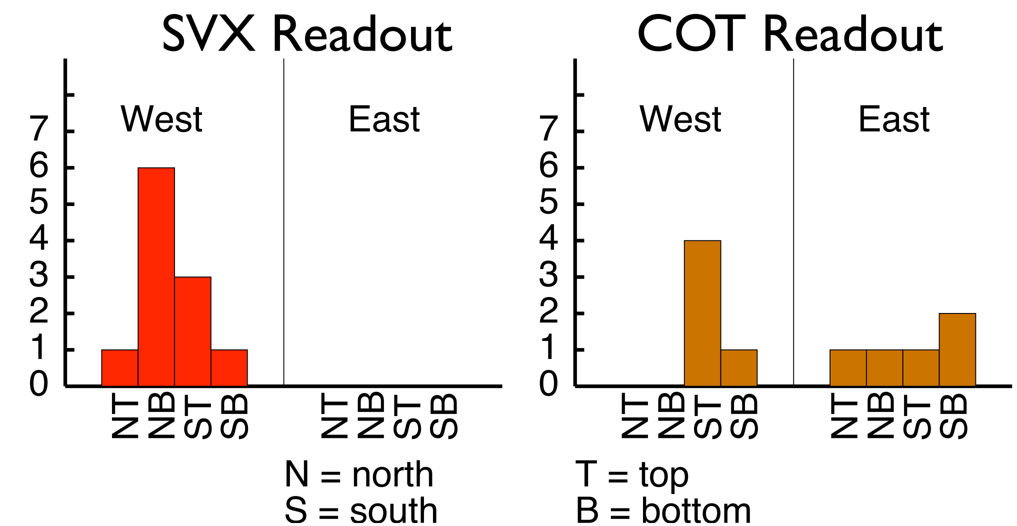
Low Voltage Power Supply Failures

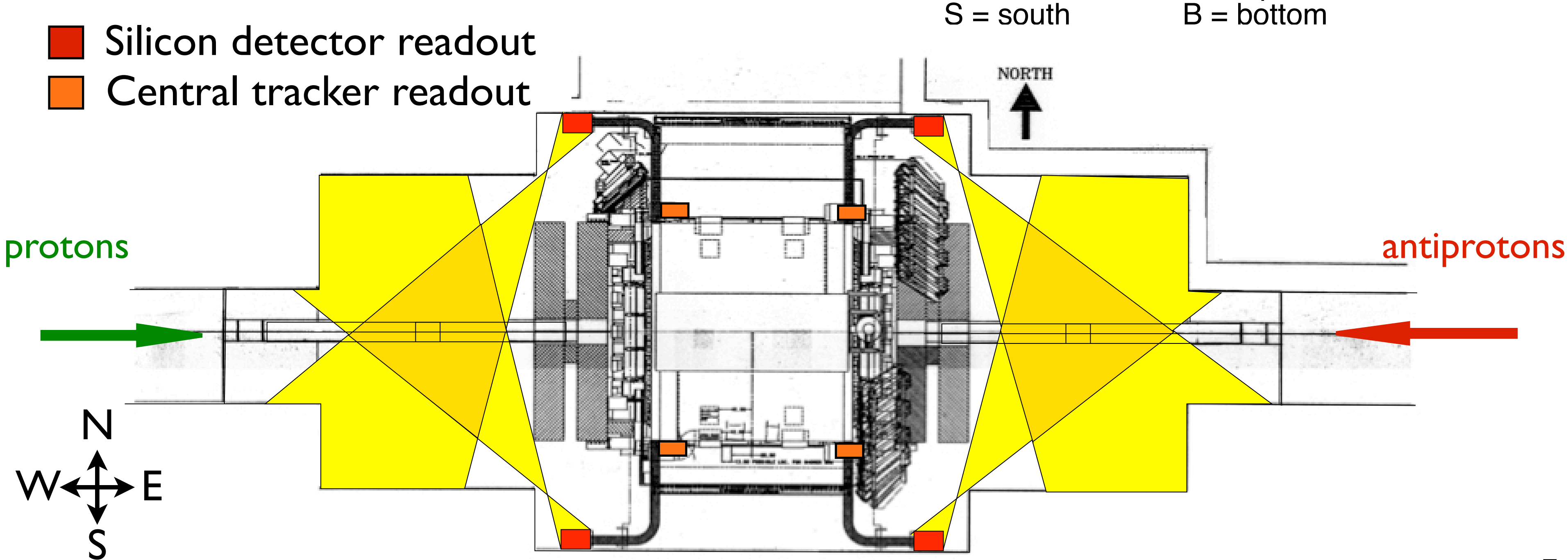
Failure Characteristics

- Position Dependent
- Beam Related

Experiments show focusing quads are a line source of radiation

Failure Locations



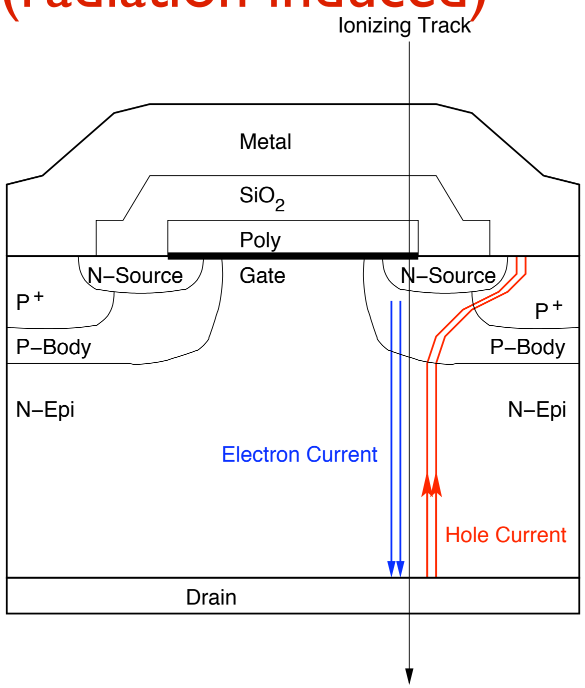


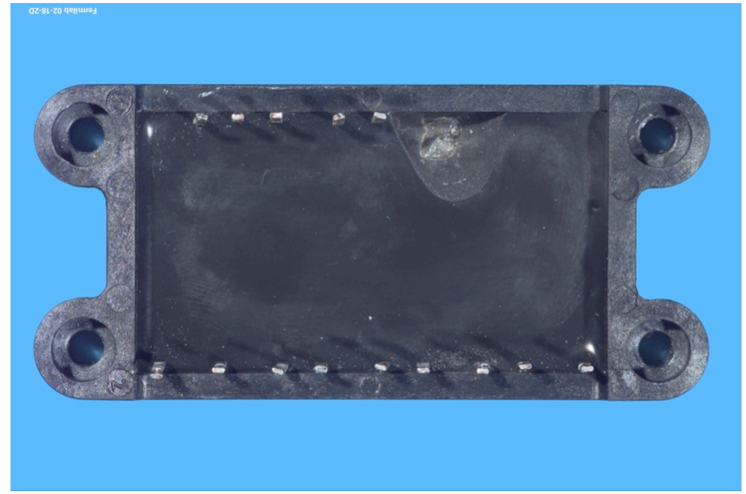
Low Voltage Power Supply Failures

Power Factor Corrector Circuit

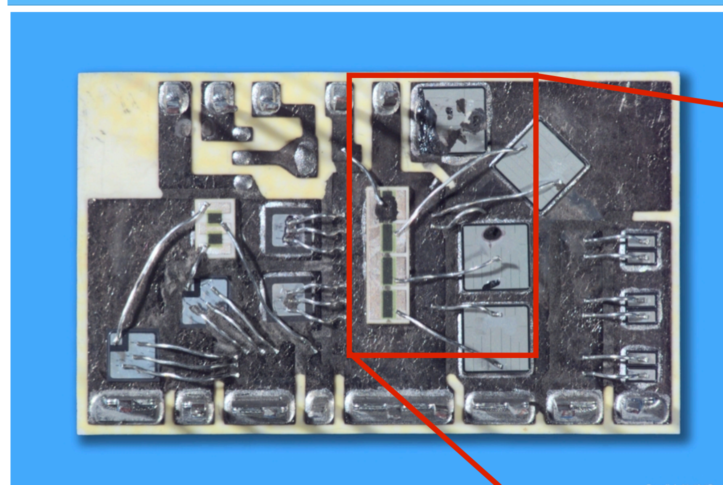
Most failures were associated with high beam losses or misaligned beam pipe

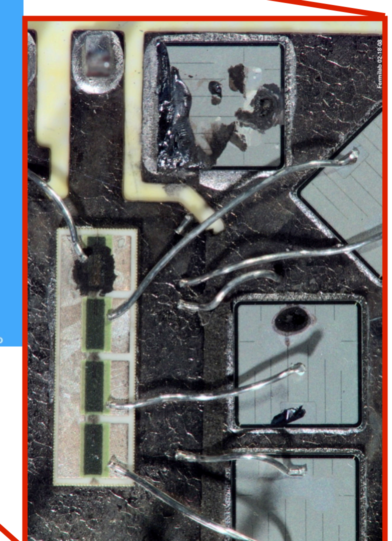
> Power MOSFET SEB (radiation induced)





epoxy covering fractured





silicon in MOSFET sublimated during discharge through single component

Single Event Burnout (SEB)

SEB Features

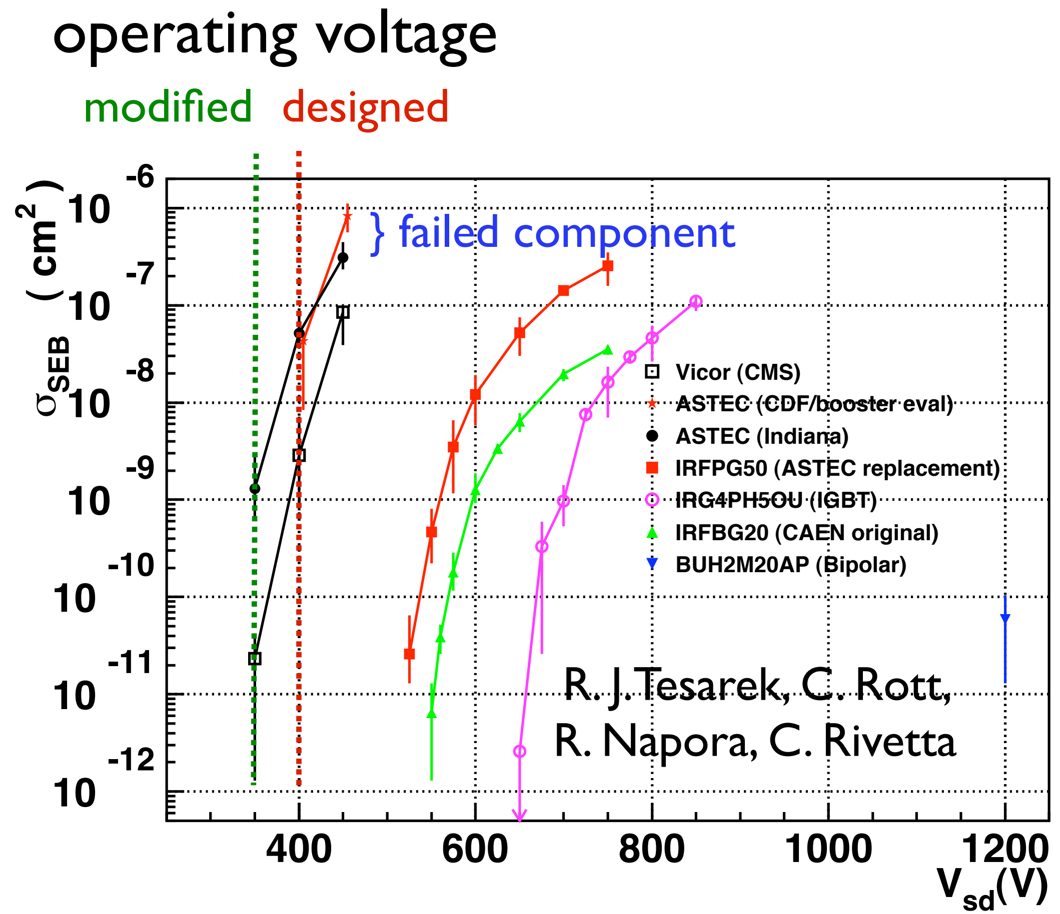
- catastrophic
- beam related
- damage at low doses
- depends on bias voltage

SEB cross section measurement

Solution (lower Vbias)

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

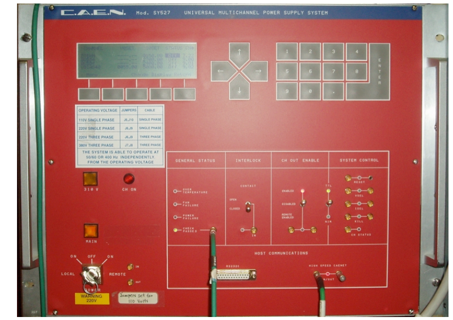
What about radiation?



Test beam data, 200 MeV protons

Indiana Cyclotron

High Voltage Power Supplies



Commercial system (CAEN SY527 mainframe)

Only systems in collision hall fail

Failure Modes:

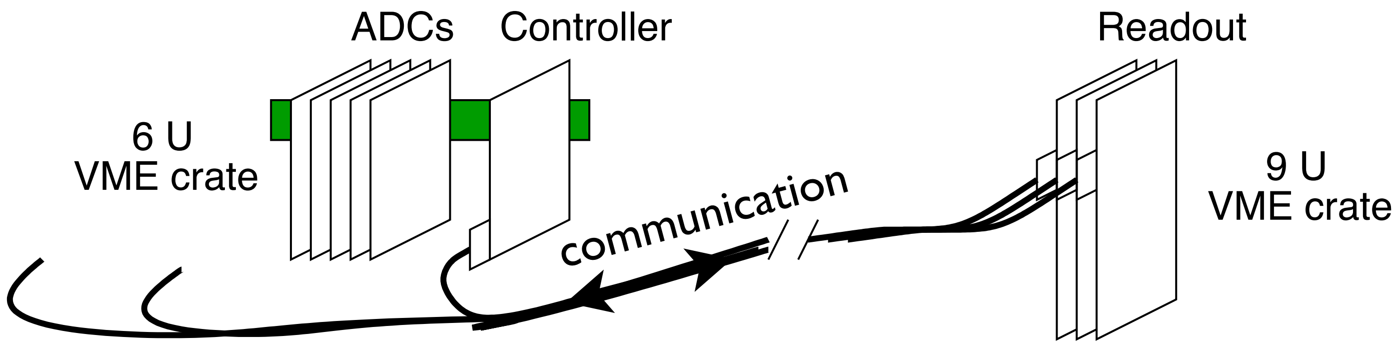
	Observed Failure	Recovery Action	Likely Problem
a.	Communication lost	CPU reset	SEU in CPU/EPROM
b.	Power supply modules spontaneously turn off	turn on HV	SEU in KILL logic (FPGA)
c.	Garbled information from crate (ie, voltage reads 10.0V, nominal 150.0V)	CPU reset	SEU in RAM memory
d.	Power supply module spontaneously turn on	turn off HV	??

Assistance from manufacturer: modify firmware to shorten recovery time

- enable CPU watchdog
- enhance error checking

Anticipate order of magnitude reduction of down time

Shower Maximum (SMX) Readout



Custom designed system

Communication lost in system

- only occurs for systems in highest radiation areas
- requires power cycle to recover
- ram based calibrations must be restored (re-calibration)
- 30 minute recovery time
- failing component not yet identified (2700 FPGAs)

Modify procedures to always write calibrations to non-volatile (FRAM) memory

- recovery time reduced to few minutes.

Radiation

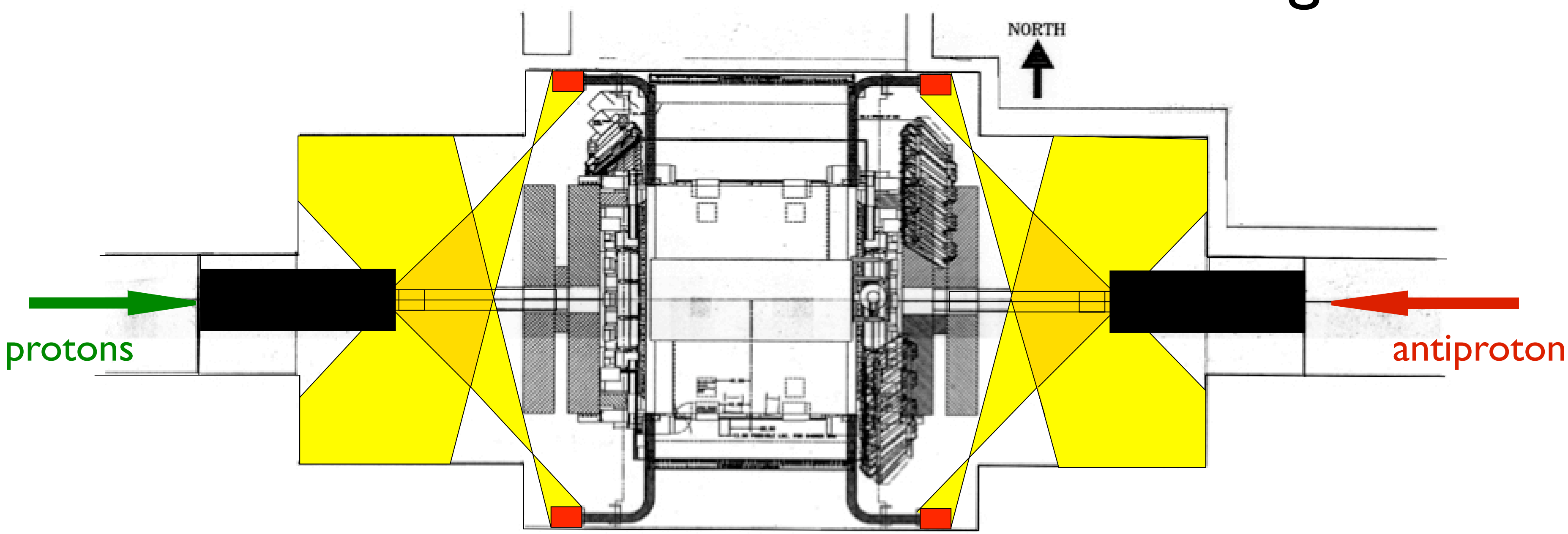
Radiation and Shielding?

Scintillation 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.

Shielding reduces ionizing radiation by 25%

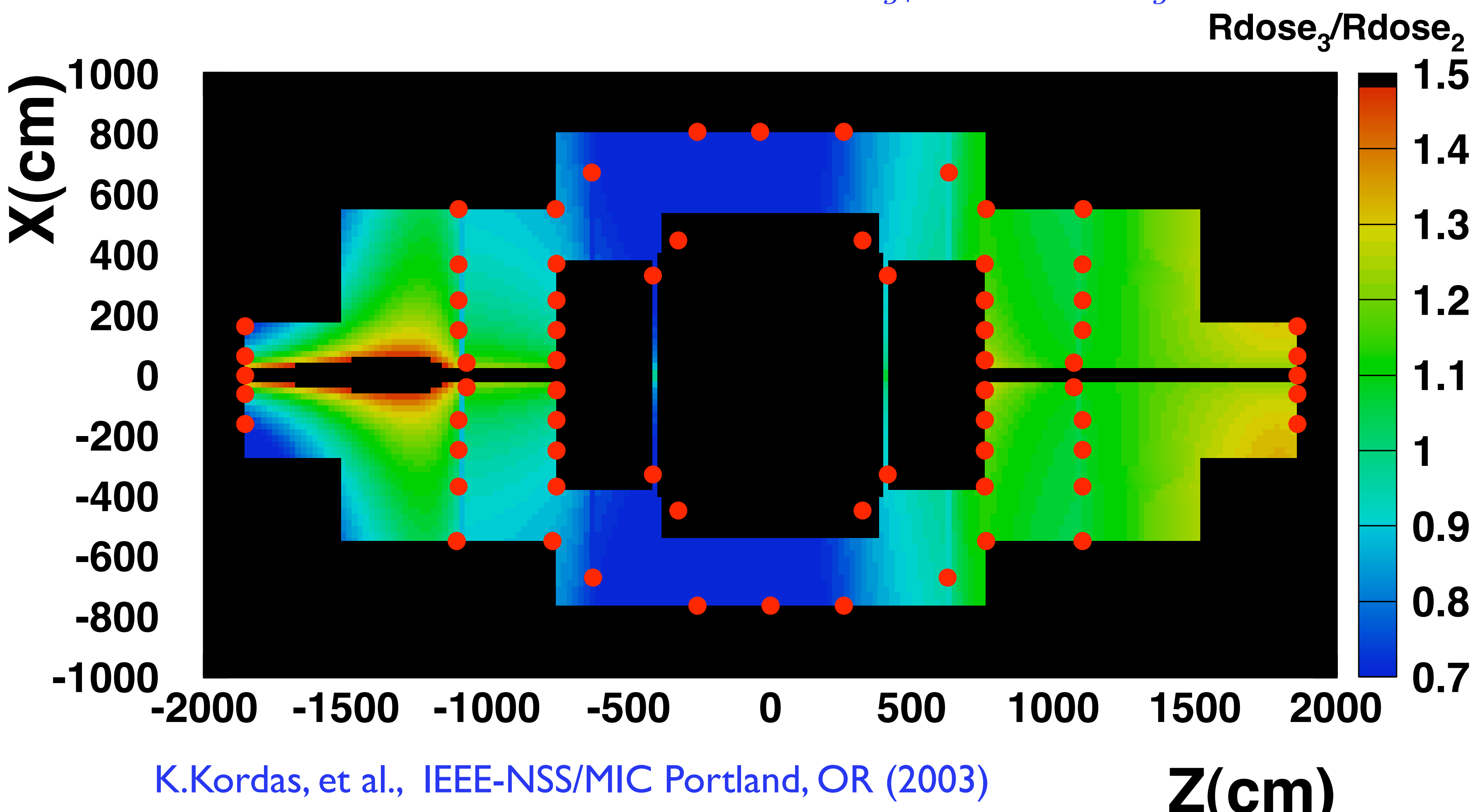
CDF Detector w/ additional shielding



Collision Hall Ionizing Radiation Field

Thermal luminescent dosimeter (TLD) measurements
Shielding installed on proton side only.

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

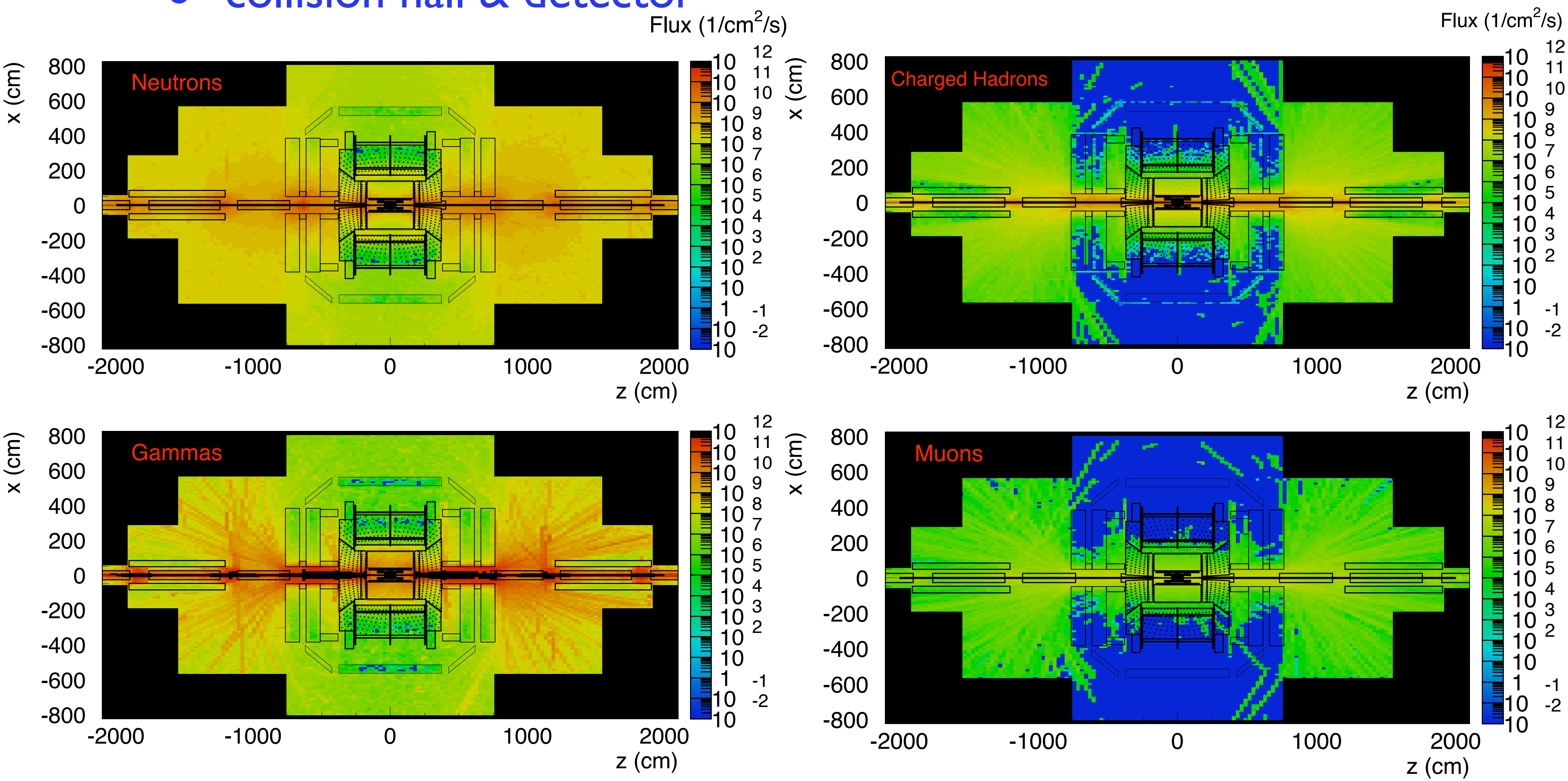


K.Kordas, et al., IEEE-NSS/MIC Portland, OR (2003)

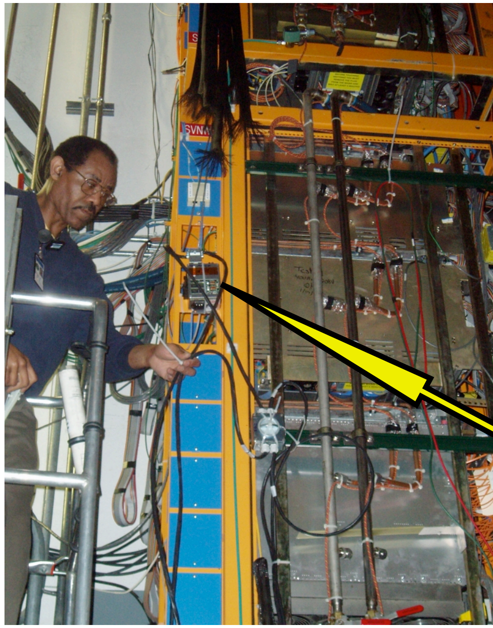
Simulated Radiation Environment

Detailed MARS simulation of:

- accelerator & beam transport
- collision hall & detector

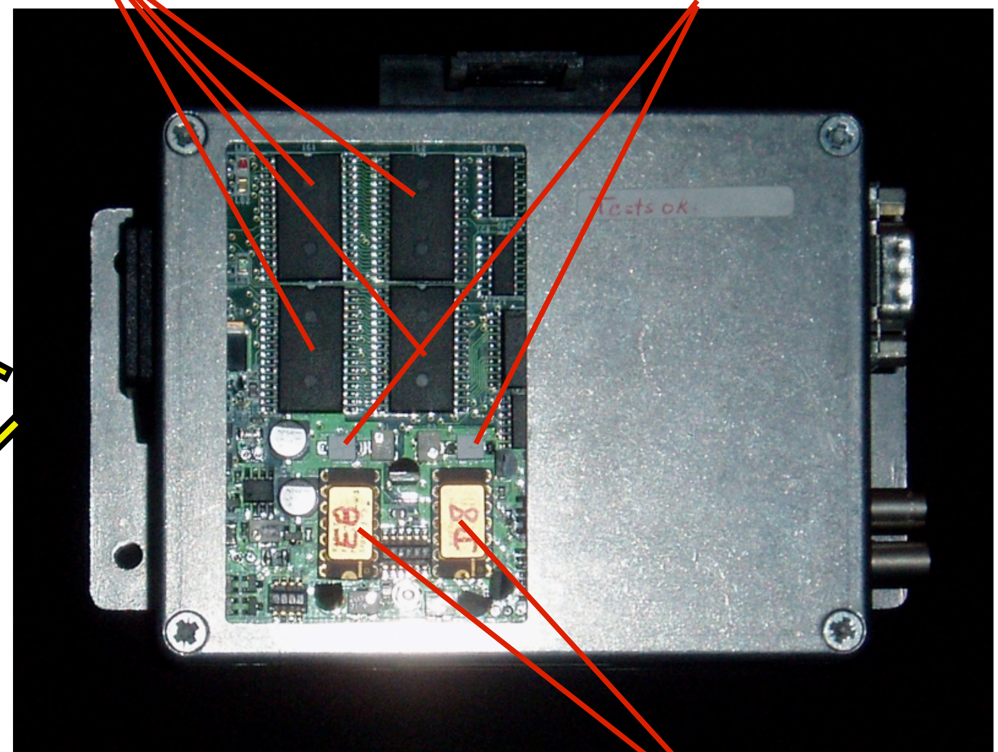


Active Dosimeters



SEU counters (memories)
>20 MeV hadrons

PIN diodes
1 MeV n equivalent



Thijs Wijnands, Christian Pignard

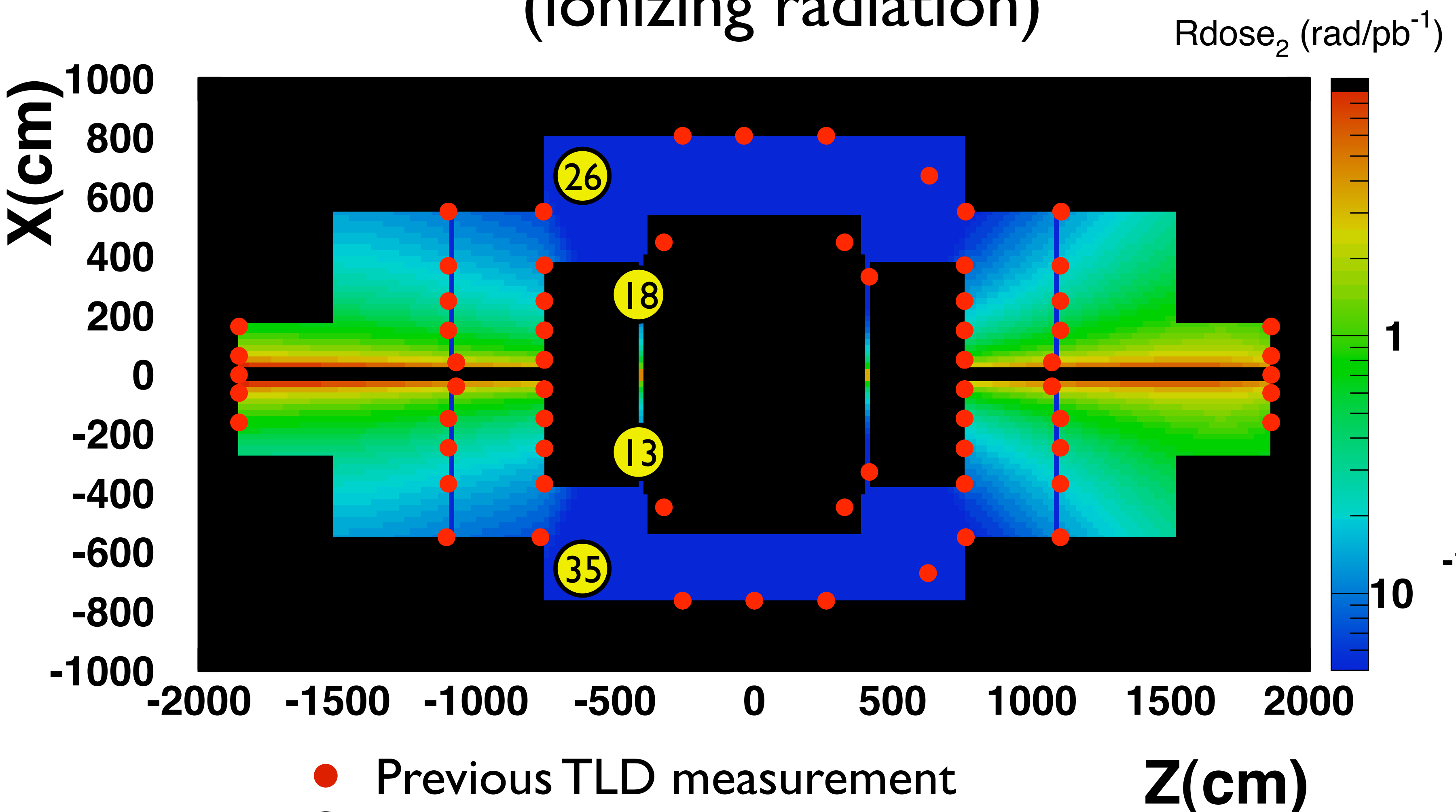
RadFETs
γ–e dose

Located near sensitive electronics

Readout at ~0.1 Hz

LHC prototype

CDF Radiation Field
(ionizing radiation)

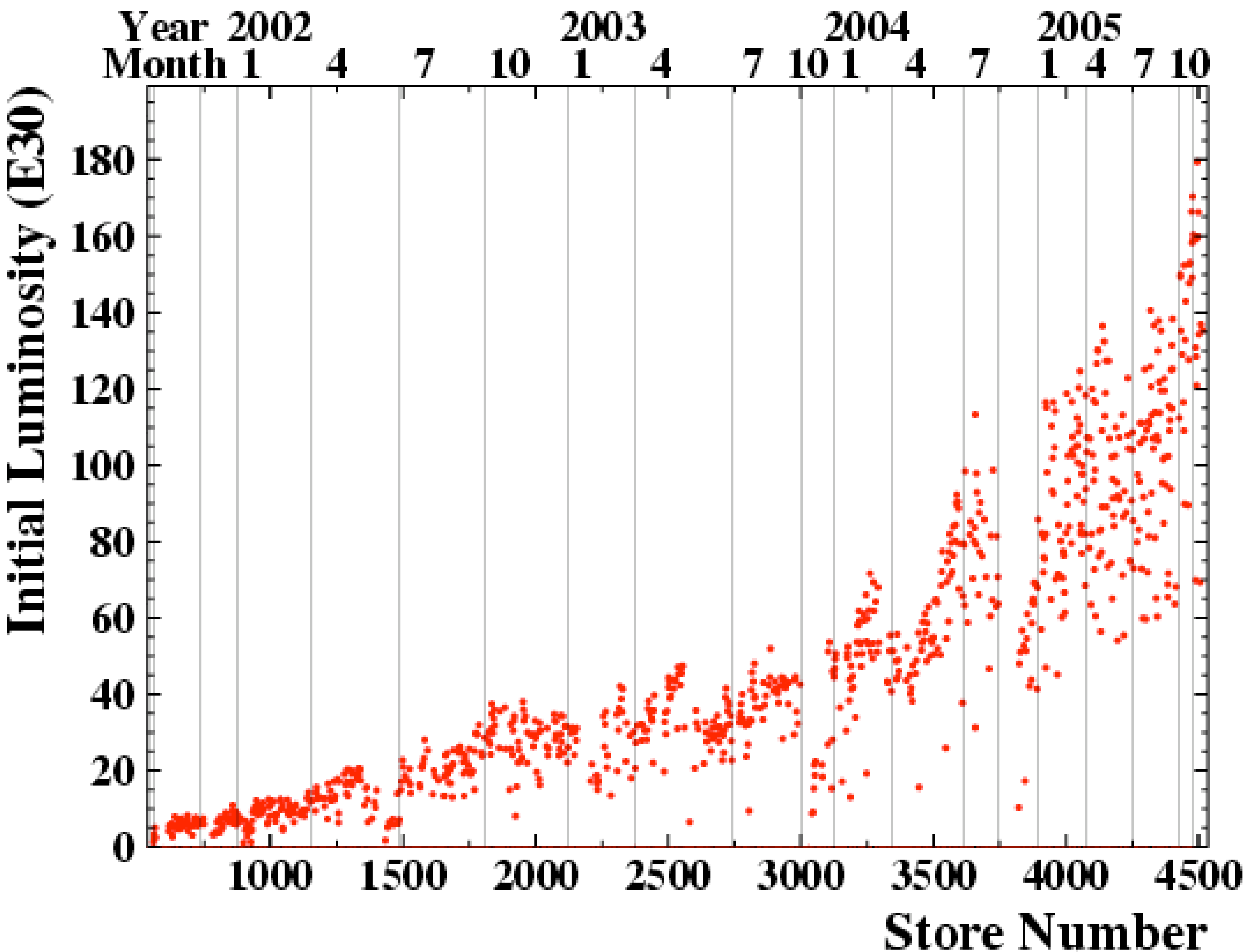


- Previous TLD measurement
- CERN Dosimeter Location/ no. SEU

Exposure Period: 27 April - 28 September 2005

Accelerator Performance

Accelerator Performance



Halo (Beam Loss) Reduction

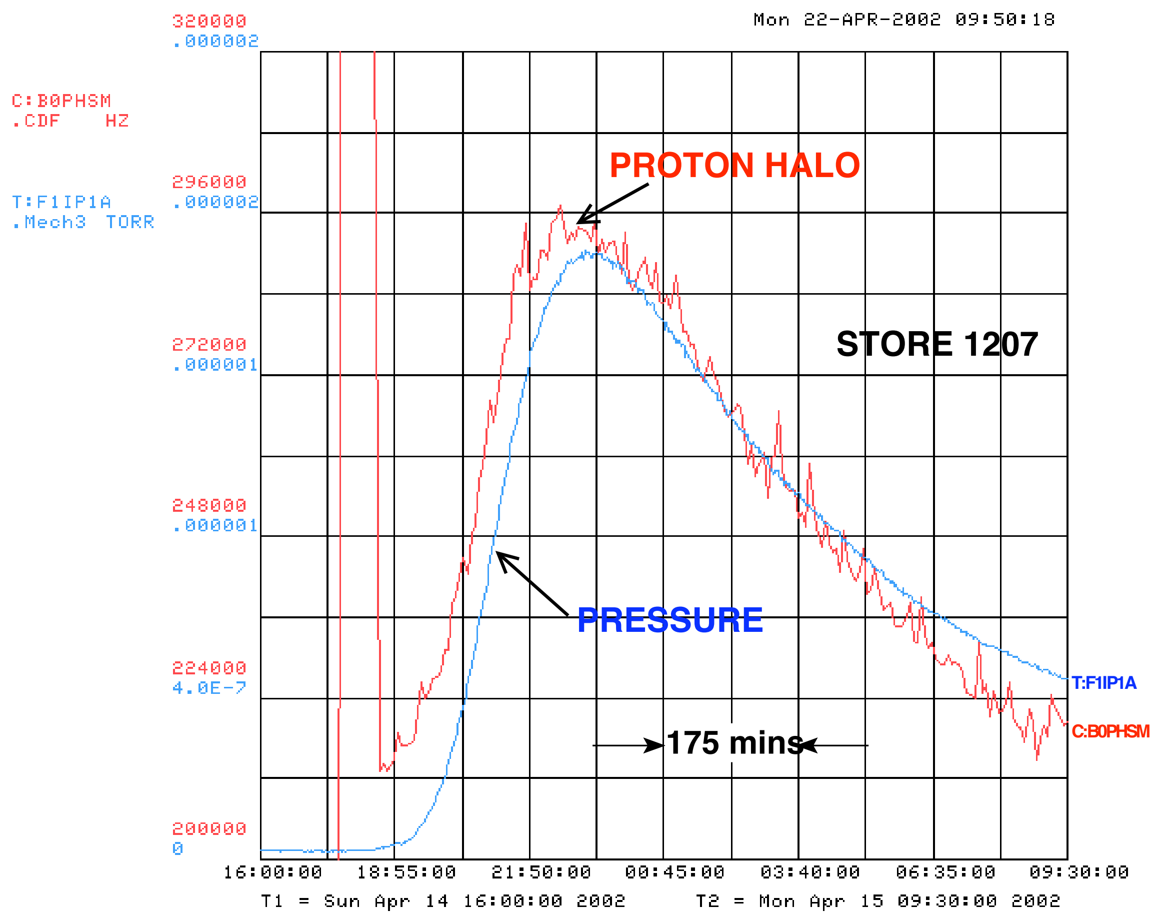
Vacuum problems identified in 2m long straight section of Tevatron (F sector)

Improved vacuum (TeV wide)

Commissioning of collimators to reduce halo

- Halo/proton reduced by factor of 10.
- Physics backgrounds reduced by ~40% in some triggers

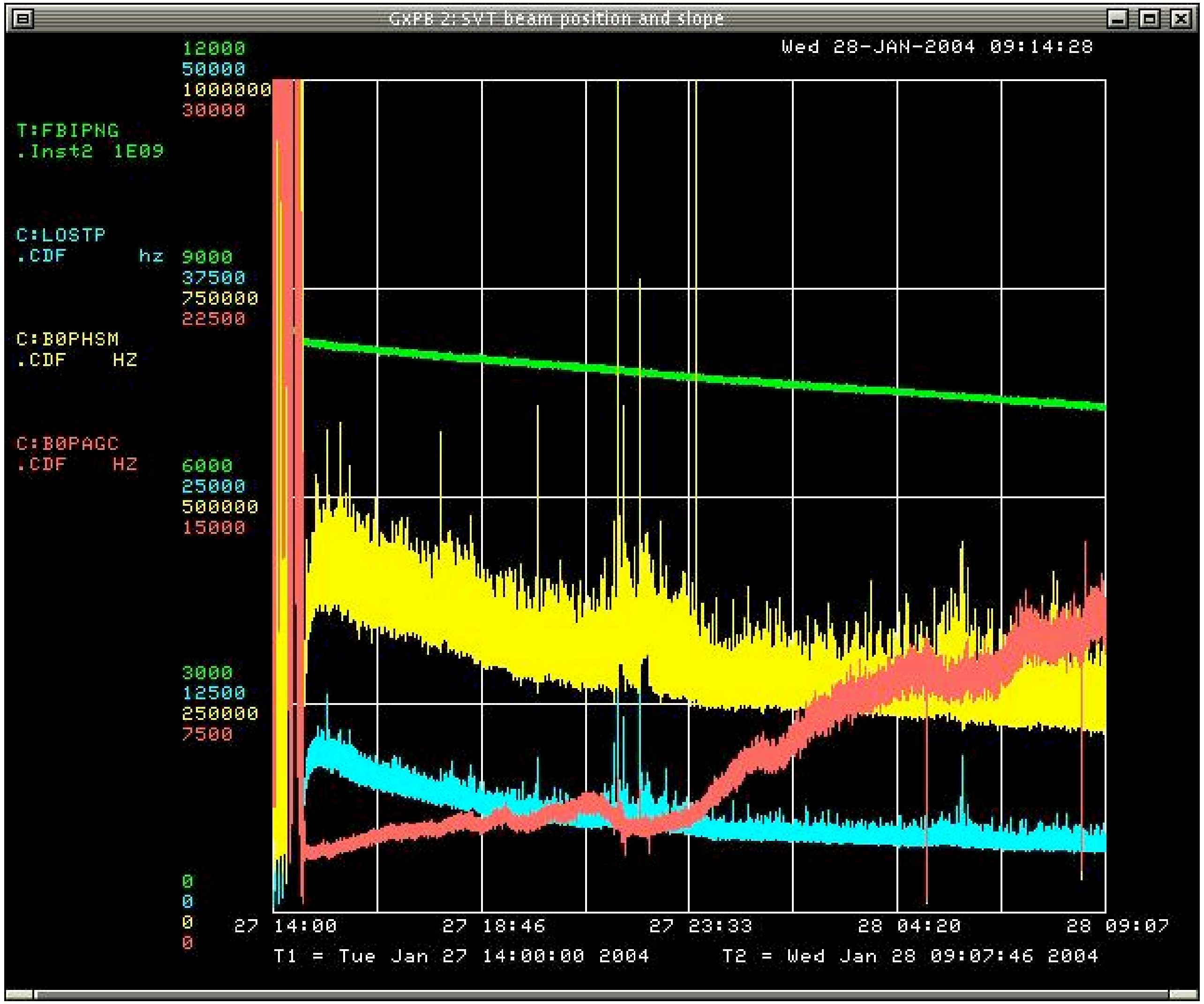
Requires good beam quality monitoring



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

Beam Improvements

"Typical good store (Jan 2004)"



proton beam current

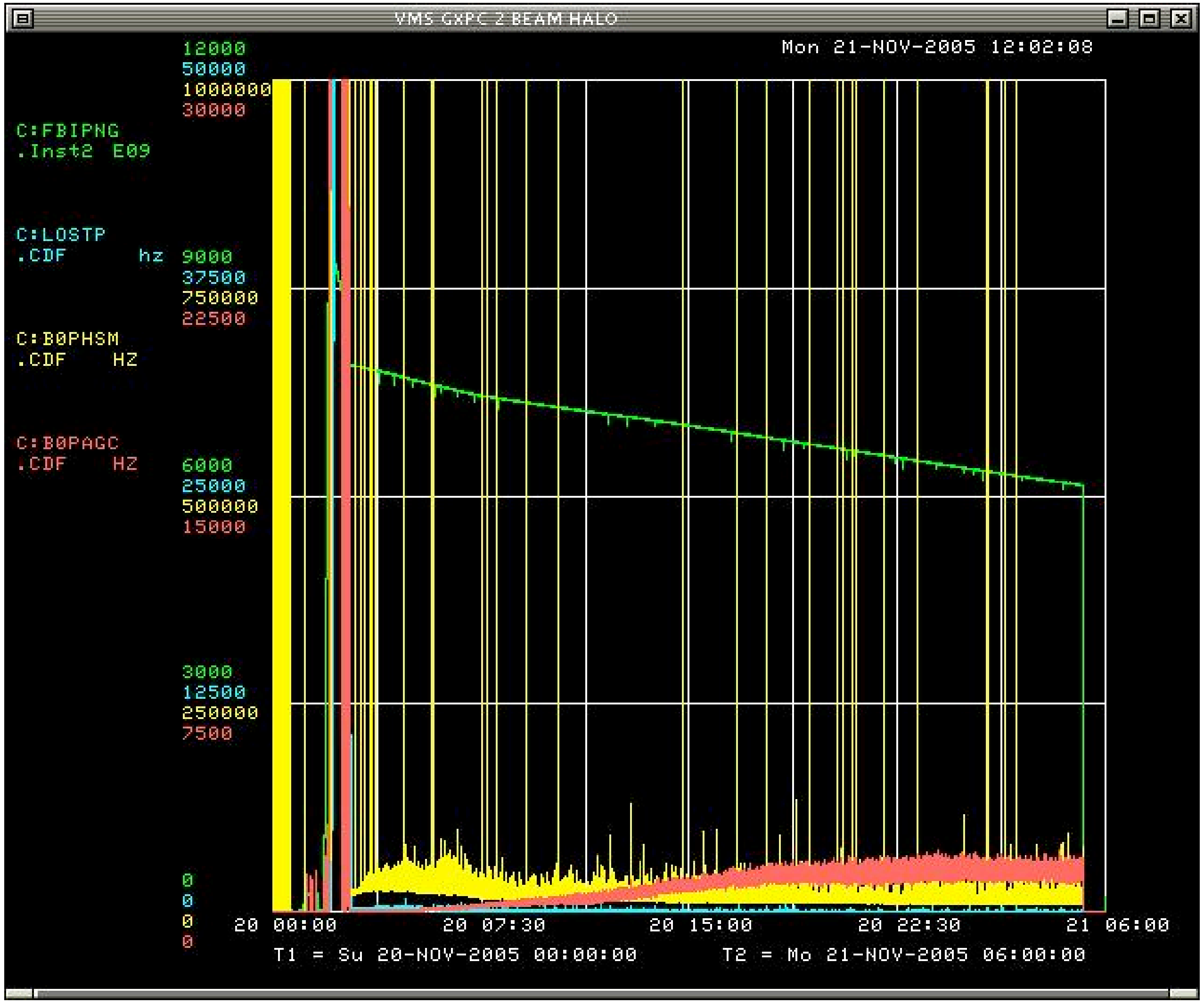
proton abort gap

proton halo

proton losses

Beam Improvements

"Typical good store (Nov. 2005)"



NOTE: "spikes" in proton halo are a readout artifact

proton beam current

proton abort gap

proton halo

proton losses

Summary

Single event effects (S.E.E.) observed at CDF in multiple systems/components

At present ~16% of non-accelerator down time traced to S.E.E.

Attack problems on multiple fronts:

- identify problem component
- modify operating conditions
- understand radiation and shield where possible
- reduce radiation from accelerator (collimation, improved accelerator operation)
- modify software/firmware to make system failure tolerant
- modify system/procedures to reduce recovery time after failure

Work continues...

References (Incomplete List)

General:

- http://ncdf67.fnal.gov/~tesarek

Single Event Effects

- R.J. Tesarek, *et al.*, Proceedings IEEE-NSS/MIC Conference, El Conquistador Resort, Fajardo, Puerto Rico, October 22-30 (2005).

Beam Quality and Instrumentation:

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- 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.
- 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.
- S. d'Auria, *et al.*, *Nucl. Instr. and Meth.*, **A513** (2003) 89-93.
- 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).

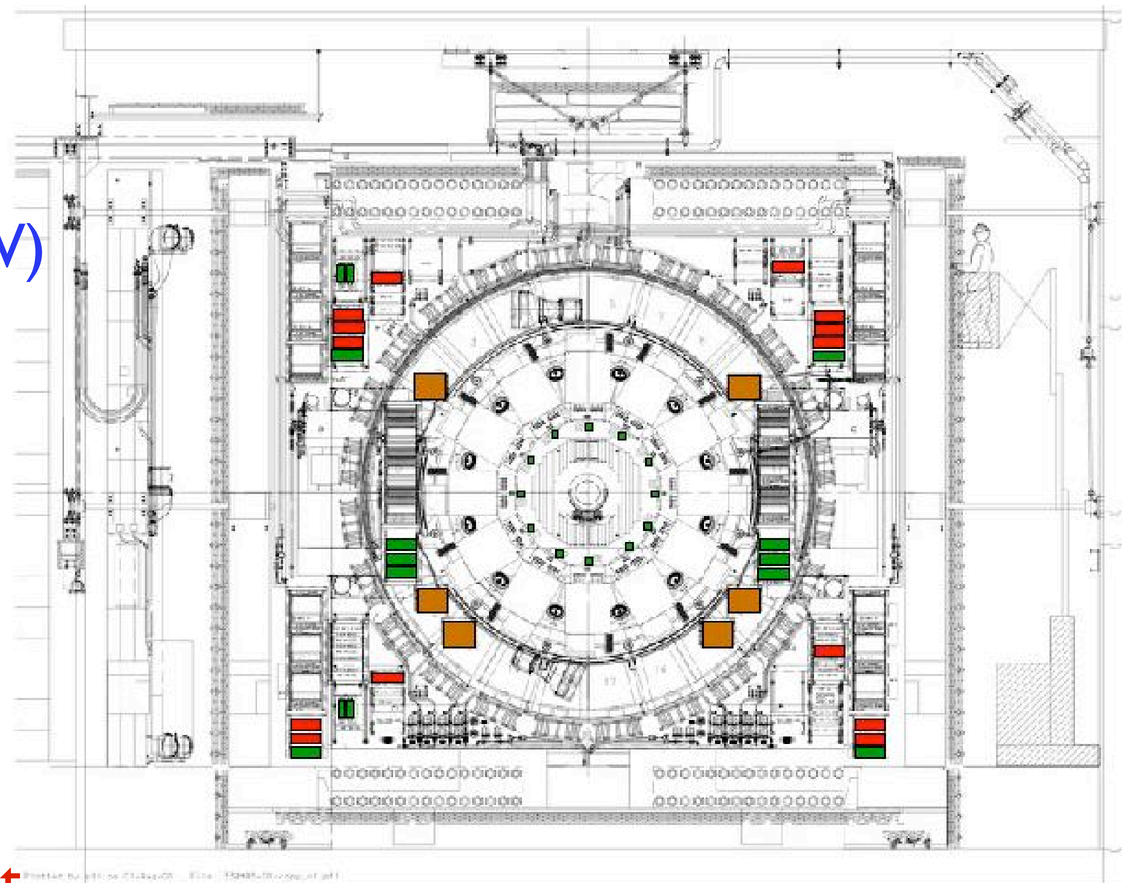
Backup Slides

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

Typical Store (2004)

Beam Parameters:

Protons:	5000 - 9000	10^9 particles
Antiprotons:	100 - 1500	10^9 particles
Luminosity:	30 - 70	$10^{30}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

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.

Typical Store (2005)

Beam Parameters:

Protons:	5000 - 10000	10^9 particles
Antiprotons:	500-1800	10^9 particles
Luminosity:	50 - 170	$10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Color Codes

better than 2004
worse than 2004
no change

Losses and Halo:

Quantity	Rate (kHz)	Limit (kHz)	comment
P Losses	0.1 - 0.5	25	chambers trip on over current
Pbar Losses	0.1 - 3.0	25	chambers trip on over current
P Halo	15 - 18	-	
Pbar Halo	20 - 100	-	
Abort Gap Losses	0.1 - 15	25	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.