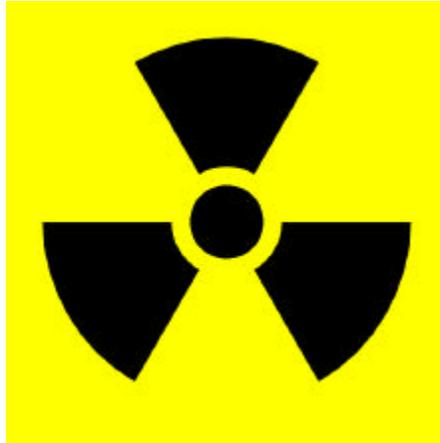


A Measurement of the Radiation Field in the CDF Tracking Volume



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(CDF Radiation Monitoring Group)

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CMS Tracker Week
CERN

Why Measure Radiation?

Motivation

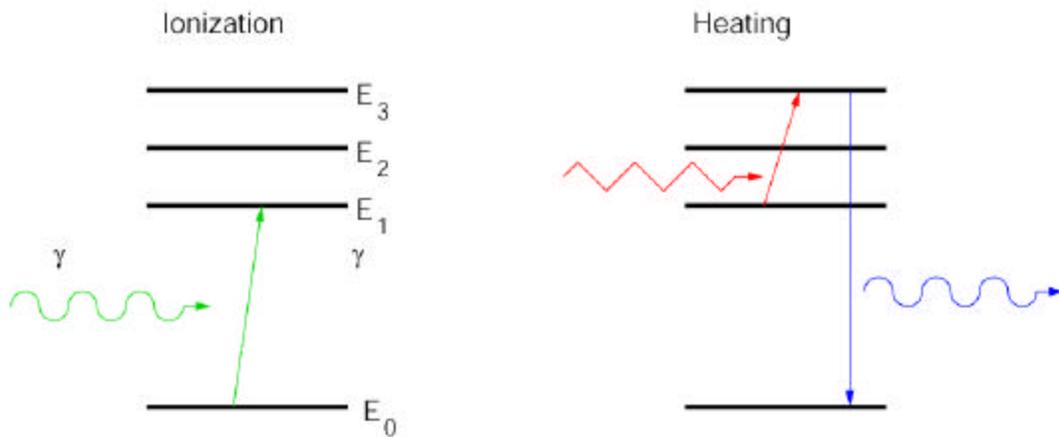
- Correlate information w/ beam
- Predict radiation damage to inner devices

Method: Thermal Luminescent Dosimeters

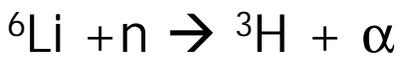
- TLD features
 - + Continuously integrates radiation
 - + Passive
 - + Large dynamic range 1mRad – 200kRad
 - + On-site TLD reader “fast turn around”
 - + Industry standard
 - Requires harvesting + reading individual dosimeters
 - Large amount of handling

Thermal Luminescence

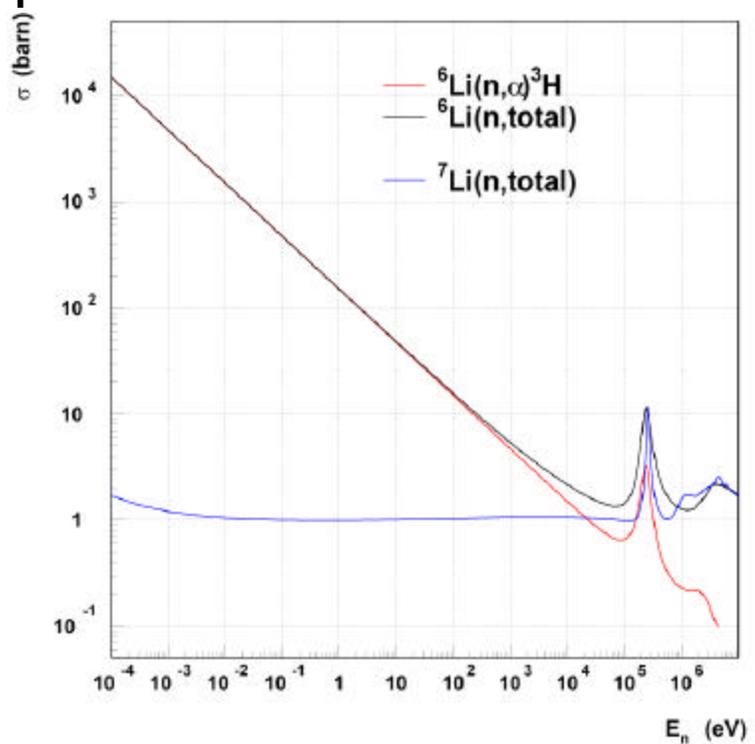
Ionizing radiation



Neutron absorption



Detect ionization
from ${}^3\text{H}$



Measurement Technique

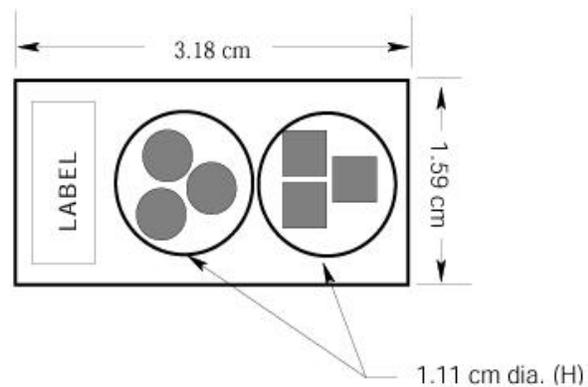
“The Devil is in the details...”

Considerations:

- Redundancy multiple measurements
- Low mass light materials
- Low profile thin materials
- γ , n meas. 2 types of dosimeters

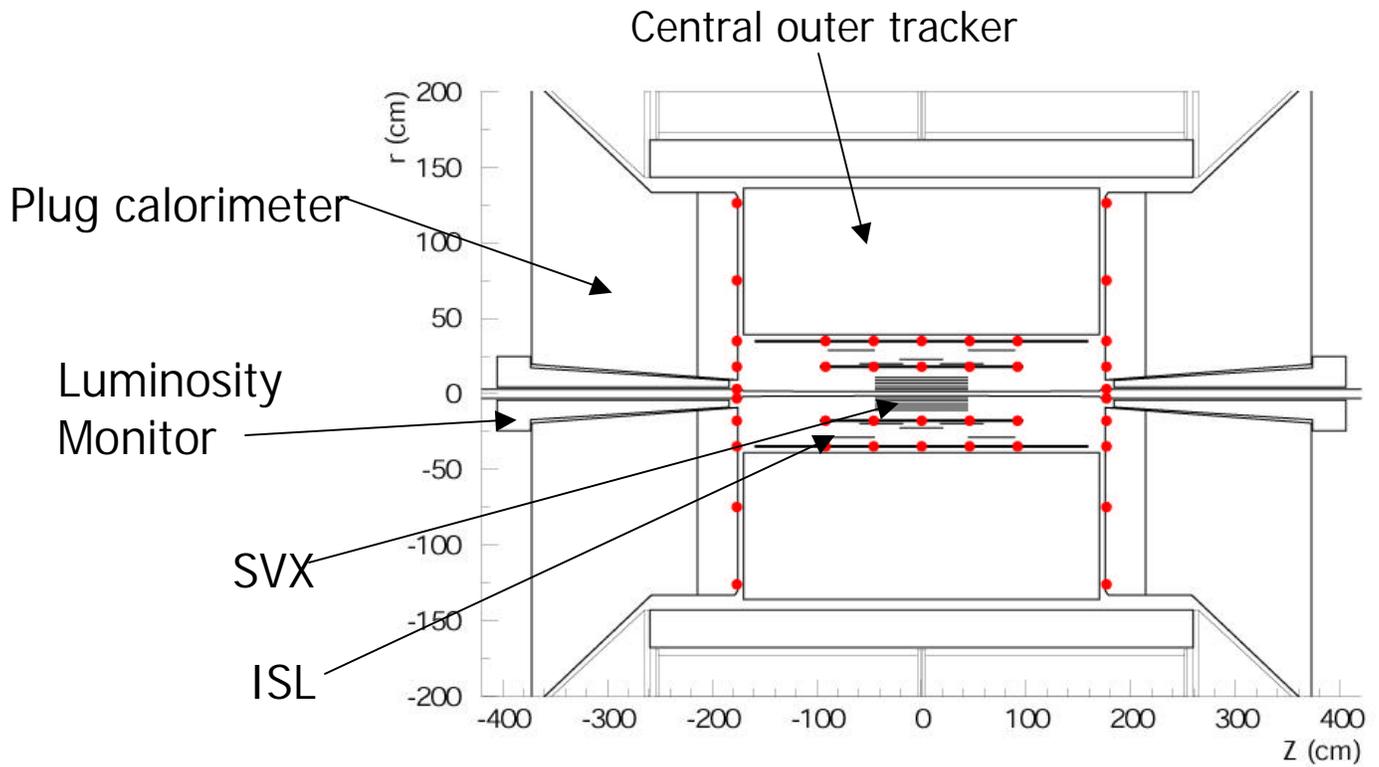
Implementation

0.8mm thick FR-4



- 2 types of dosimeters in a holder
 - TLD-700 ${}^7\text{LiF}$ γ sensitive
 - TLD-600 ${}^6\text{LiF}$ γ , n sensitive
- 3 TLD chips of each type per holder

TLD Locations



Location	# ϕ	# z	# r	Total # Holders
Plug faces	8	2	5	80
SVX	5	5	1	25
ISL	8	5	1	40
Control				11
Total # TLD chips				916

TLD Locations

How do we install holders?

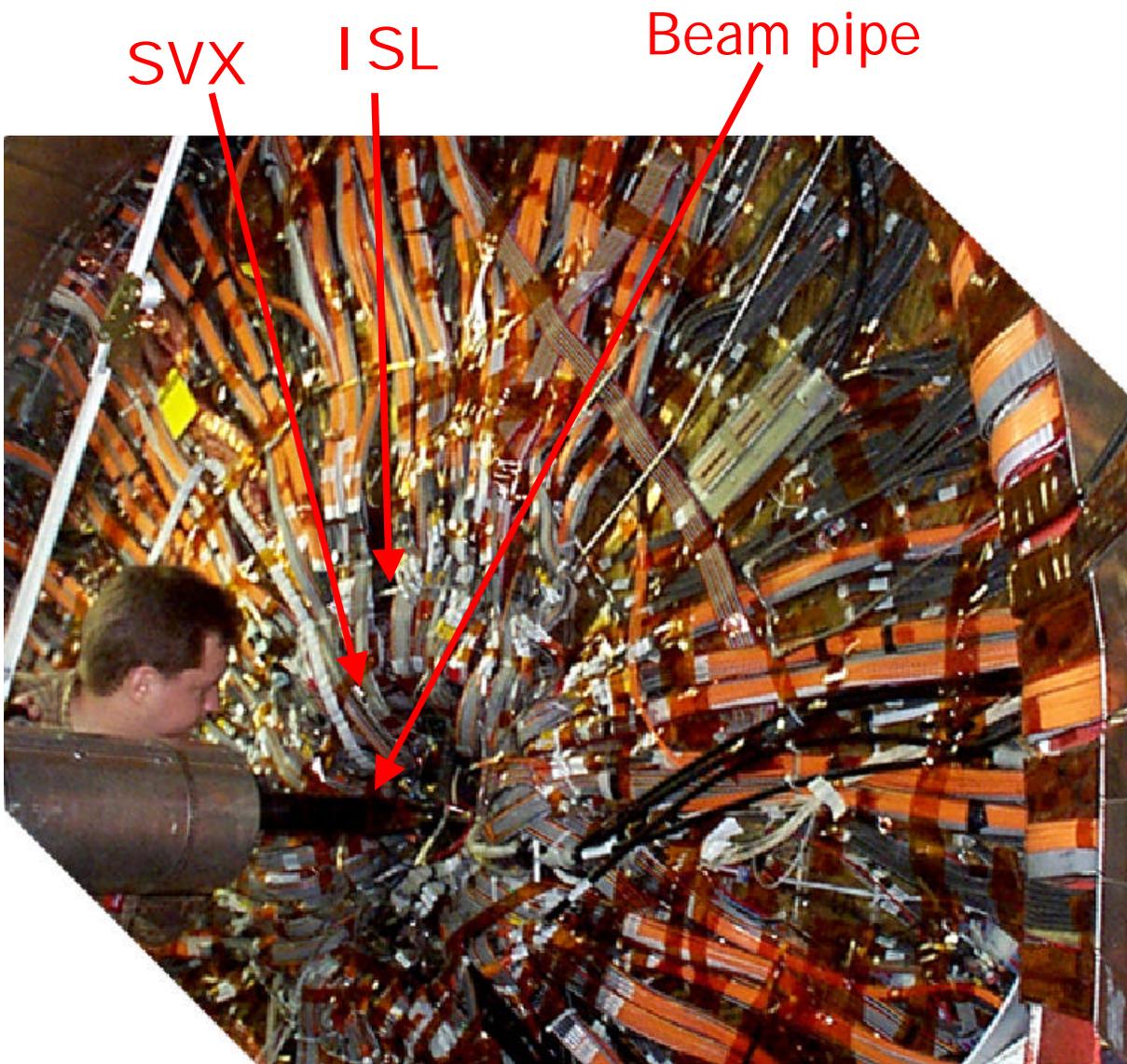


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Magnet Bore

Finding the leaders in CDF



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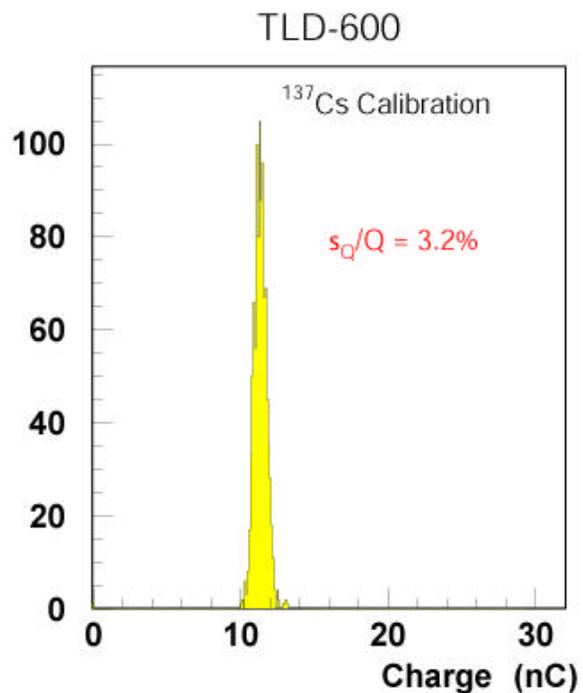
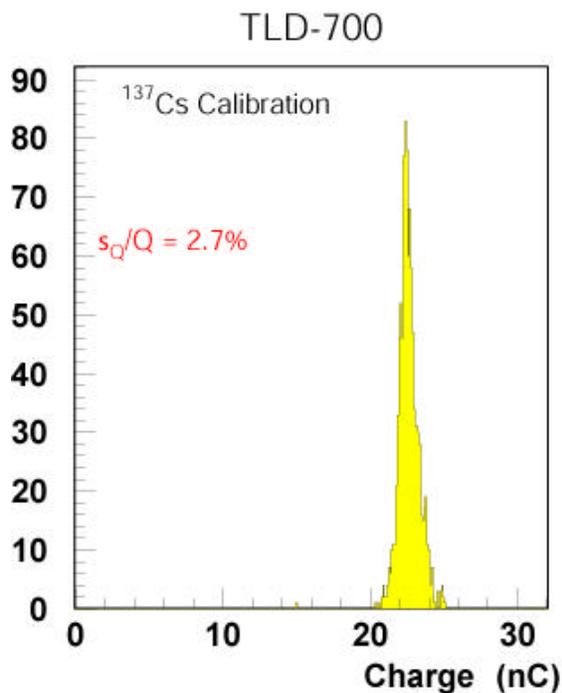
Calibration

All dosimeters of each type from a single batch

- Chip to chip response variation ~3%

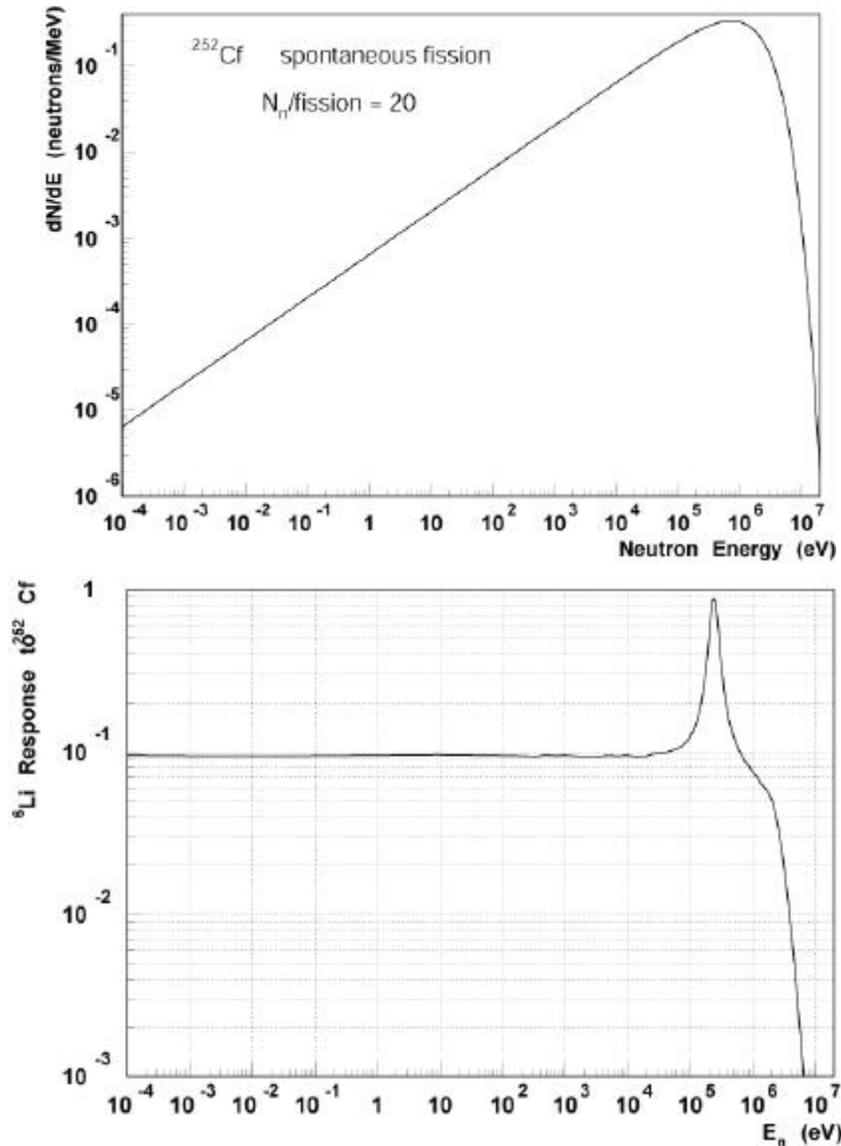
All dosimeters γ response calibrated w/ 1 Rad exposure to a ^{137}Cs source

- Reproducibility <1% variation
- Absolute scale ~1% uncertainty



Neutron Calibration

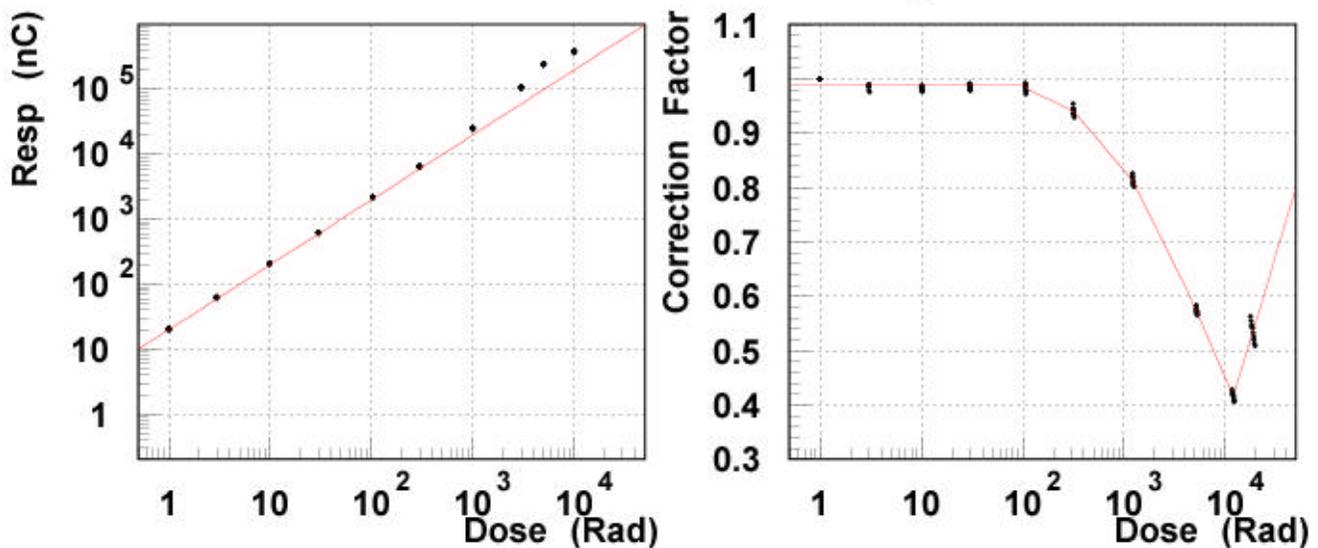
- 10 mRad exposure to ^{252}Cf
 - 15% variation
 - 10% scale uncertainty



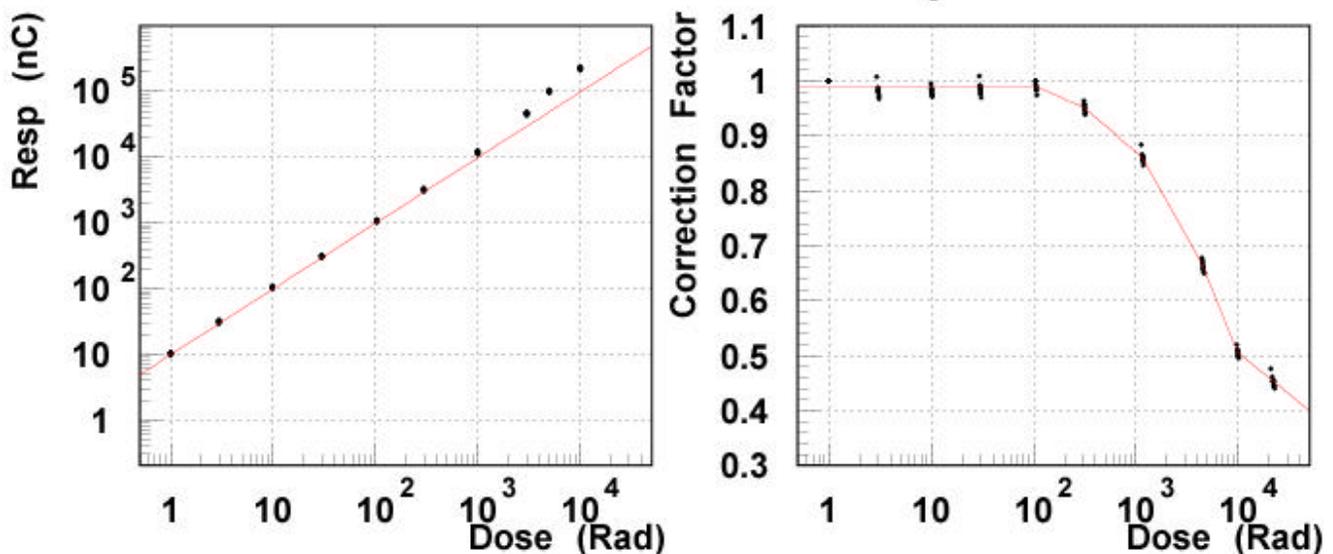
TLD Non-linearity

LiF exhibits super linearity $\sim 100\text{Rad}$

TLD-700 Linearity



TLD-600 Linearity



Dosimetry

Ionizing Radiation Dosimetry

$$D_{\gamma} = C(kR)kR - D_c$$

R	TLD reading (nC)
k	1/(1 Rad response) (Rad/nC)
C(kR)	non-linearity correction
D _c	control dose (Rad)

Neutron Radiation Dosimetry

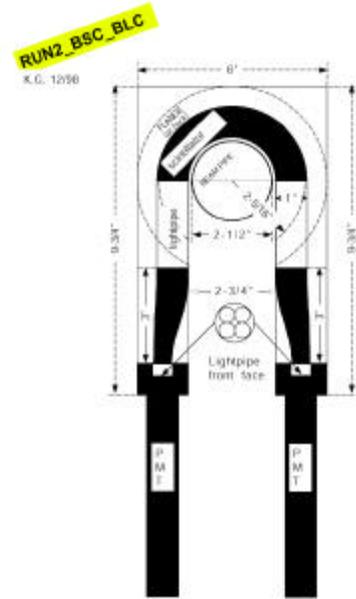
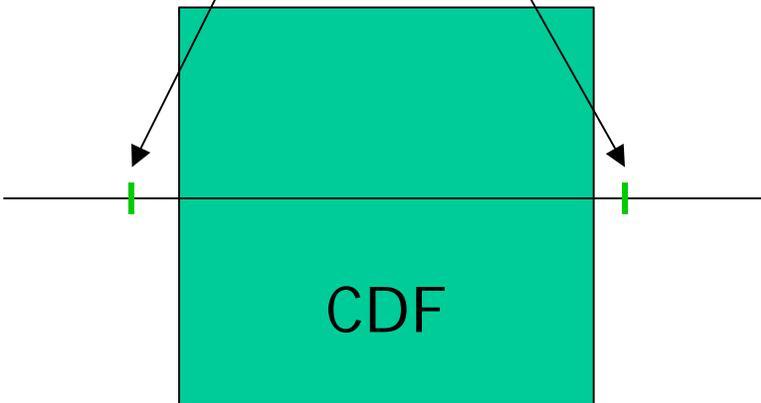
$$D_n = \{C(kR)kR - D_c\} - D_{\gamma}$$

R	TLD reading (nC)
k	1/(1 Rad response) (Rad/nC)
C(kR)	non-linearity correction
D _c	control dose (Rad)
D _γ	ionizing radiation dose (Rad)

Beam Monitoring

Losses (beam shower counters)

Scintillation counters



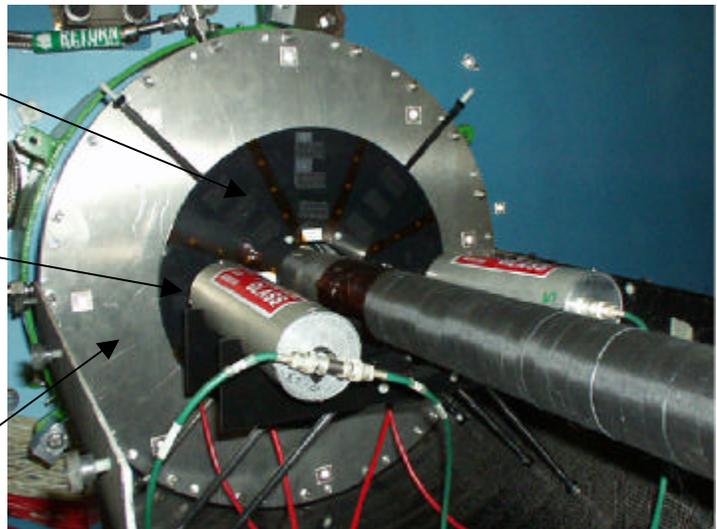
Radiation (beam loss monitors)

Ionization chambers

Wagon wheel (TLDs)

BLMs

Luminosity Monitor



Exposure Statistics

Beam Statistics

	Feb. – May	May – Oct.	Units
p	0.0703	1.56	10^{19}
Pbar	0.0082	0.137	10^{19}
P-losses	1.06	2.84	10^9
Pbar-losses	0.14	0.71	10^9
∫Ldt	0.058	10.7	pb⁻¹

Beam Loss Monitors

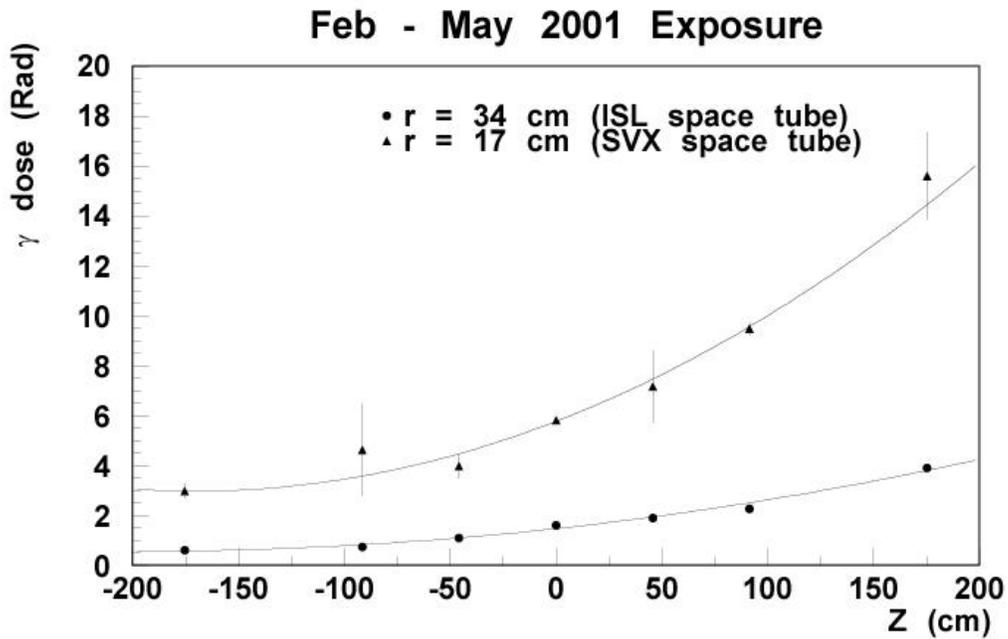
	Feb. –	May	May –	Oct.
	Inner	Outer	Inner	outer
Proton	7.0	6.1	85.4	14.0
Pbar	241	224	286	305

Feb. – May loss dominated

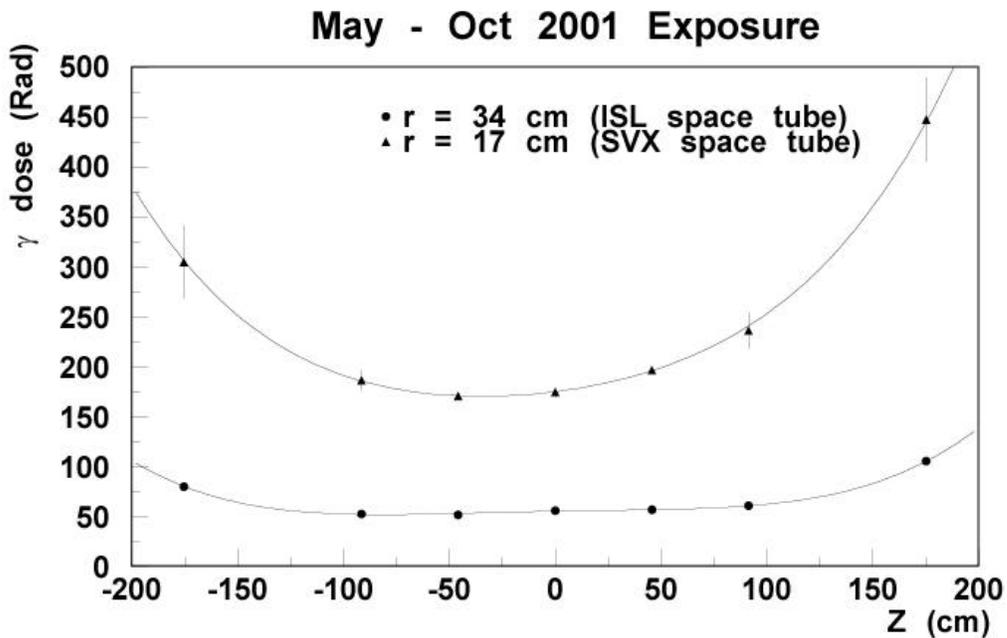
May – Oct. collision dominated

BLMs insensitive to collisions

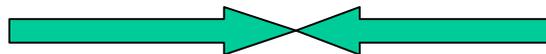
Data



protons



protons



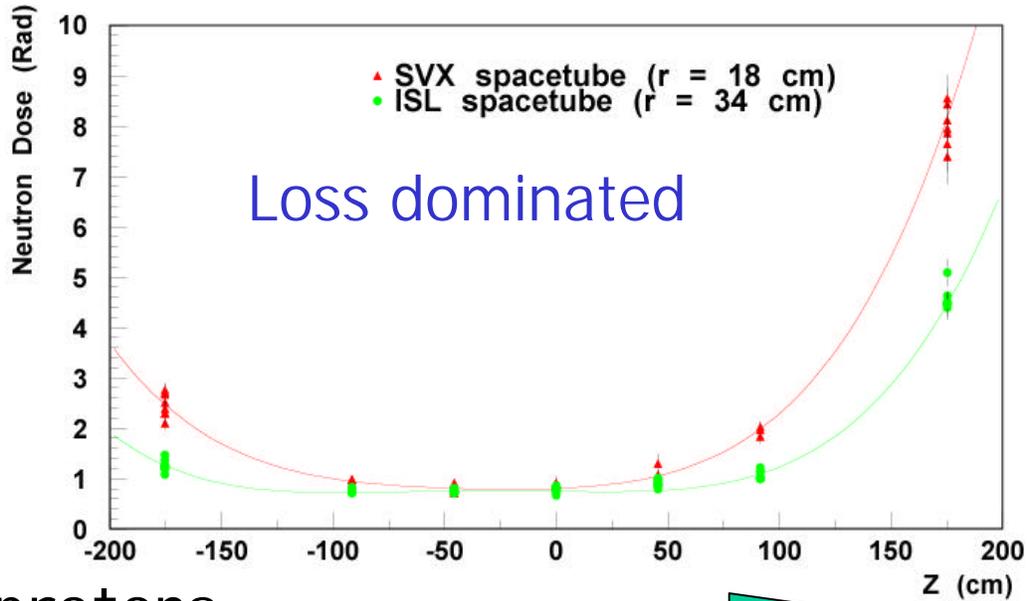
antiprotons

Neutrons

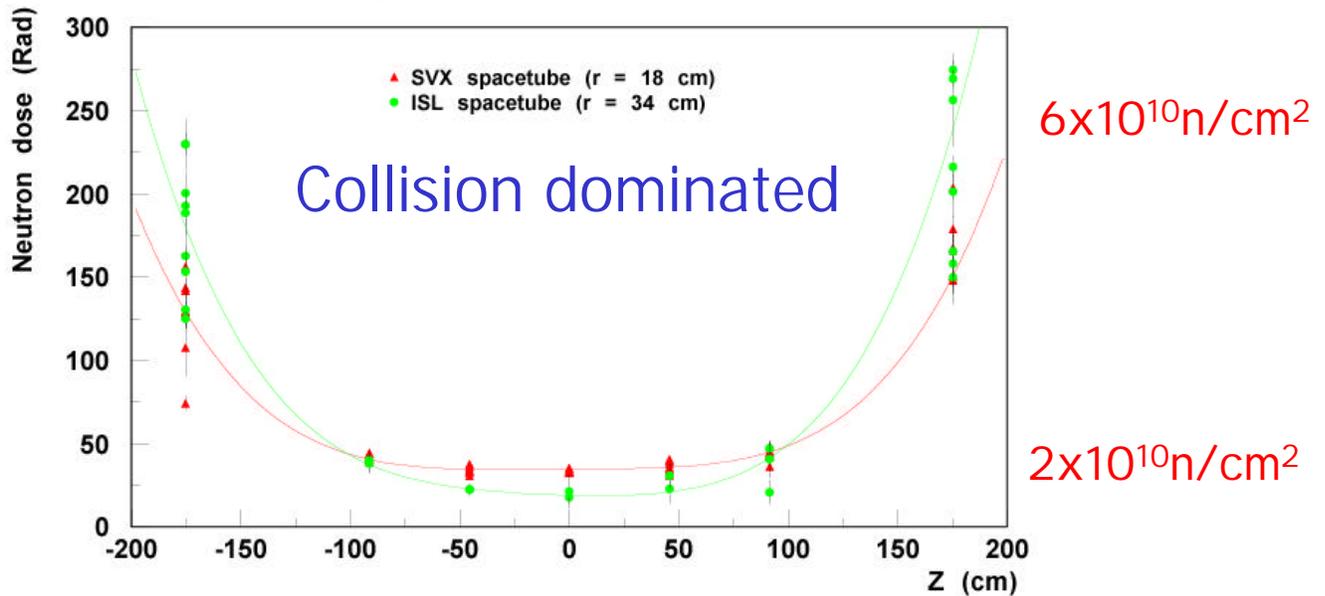
Scale

$$1\text{rad} = 3.2 \times 10^8 \text{n/cm}^2$$

Feb. – May 2001



May – Oct. 2001



Collisions & Losses

Motivation:

- Dose different for collisions/losses
 - Collisions should dominate losses even more in the future
- ⇒ Better prediction of radiation field

Method: Linear model

$$D_1 = L_1 d_L + C_1 d_C$$

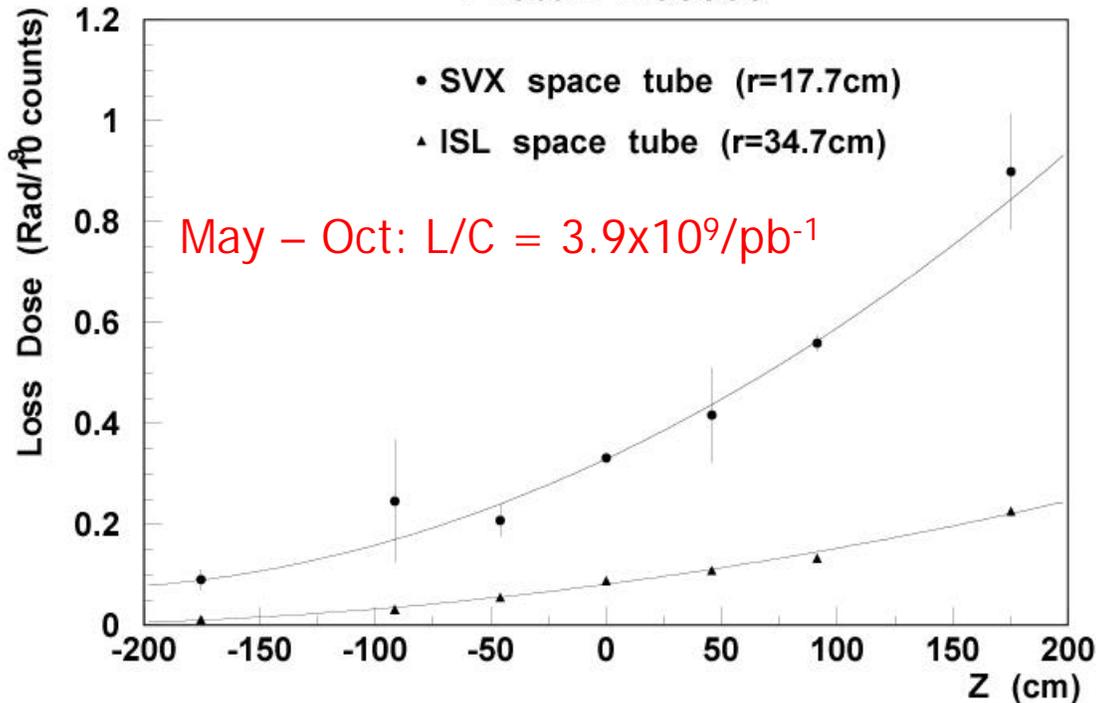
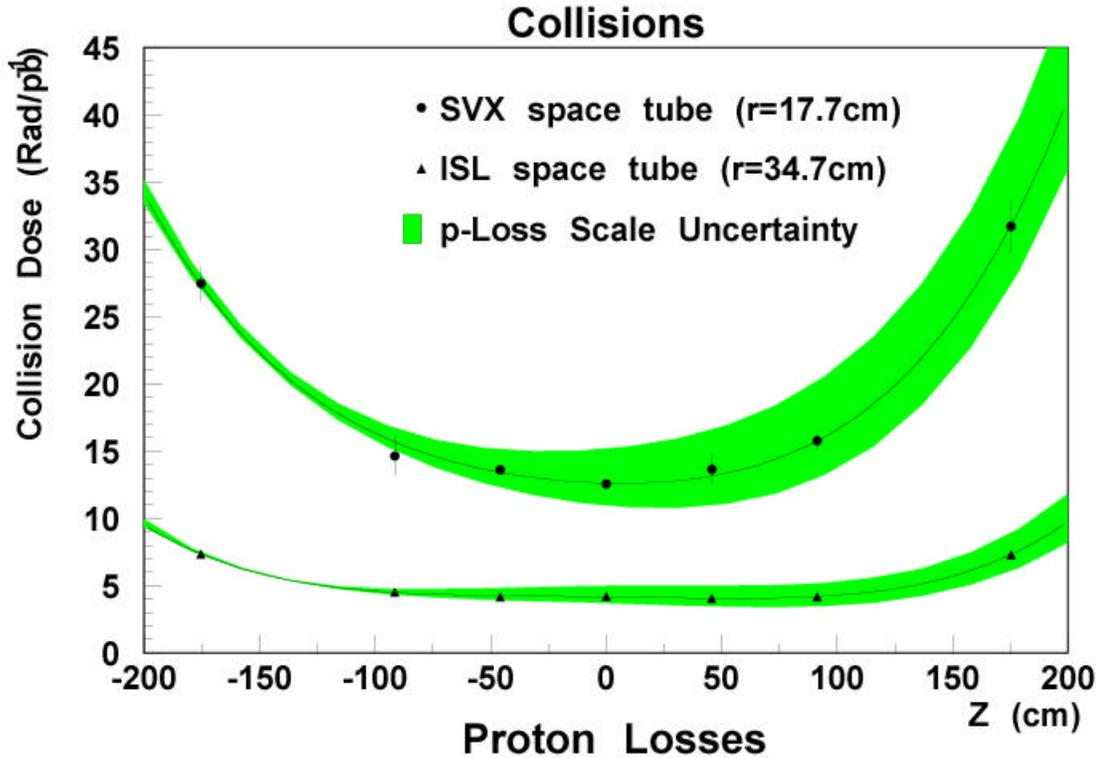
$$D_2 = L_2 d_L + C_2 d_C$$

L_i	measured losses
C_i	measured collisions (luminosity)
d_L	dose/unit losses
d_C	dose/unit luminosity

Solve for d_L and d_C

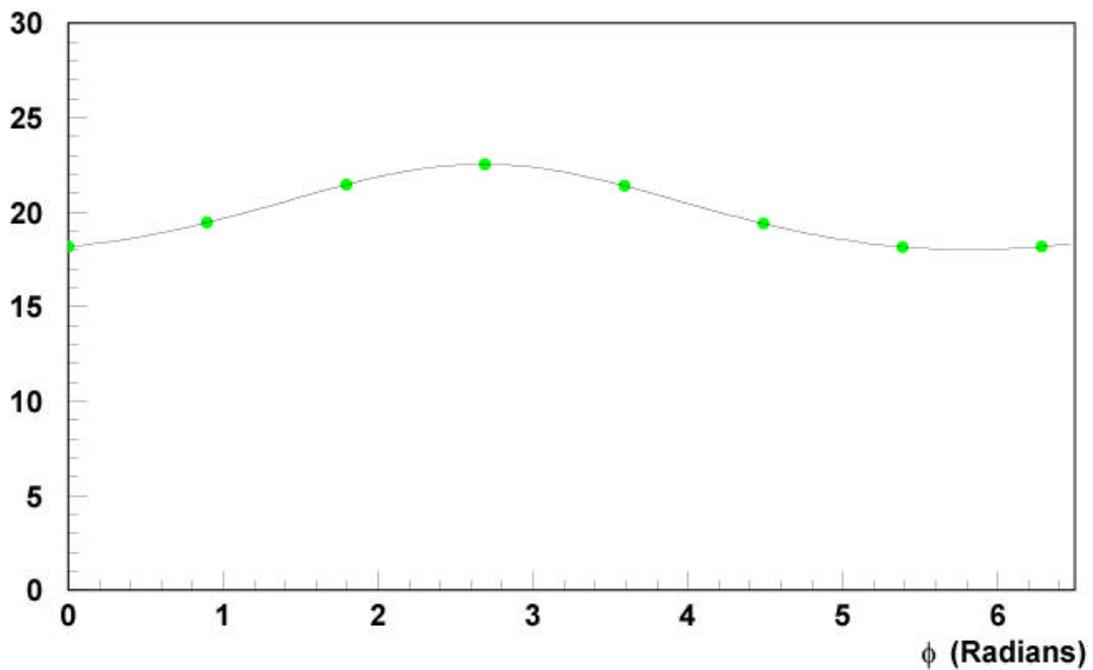
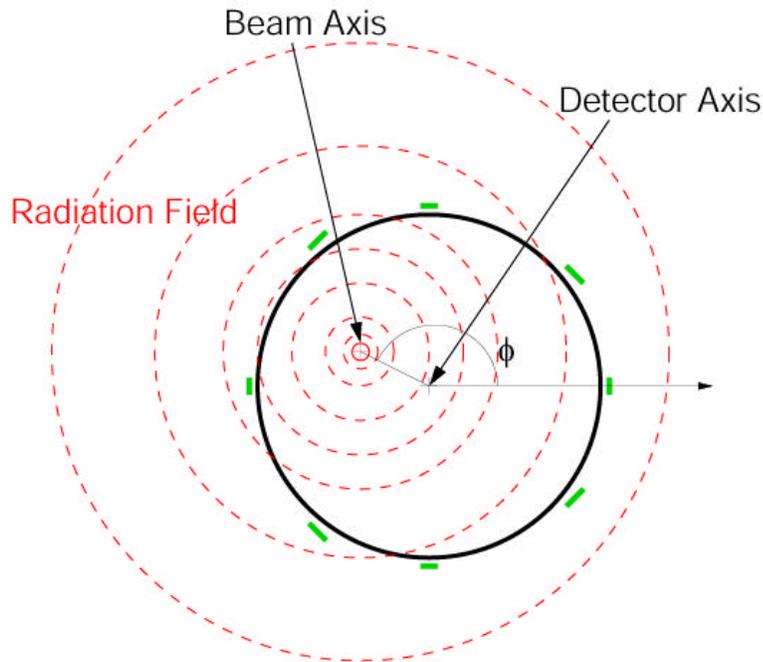
⇒ Unnecessary for neutrons

Collisions & Losses



Finding the Beam w/ TLDs

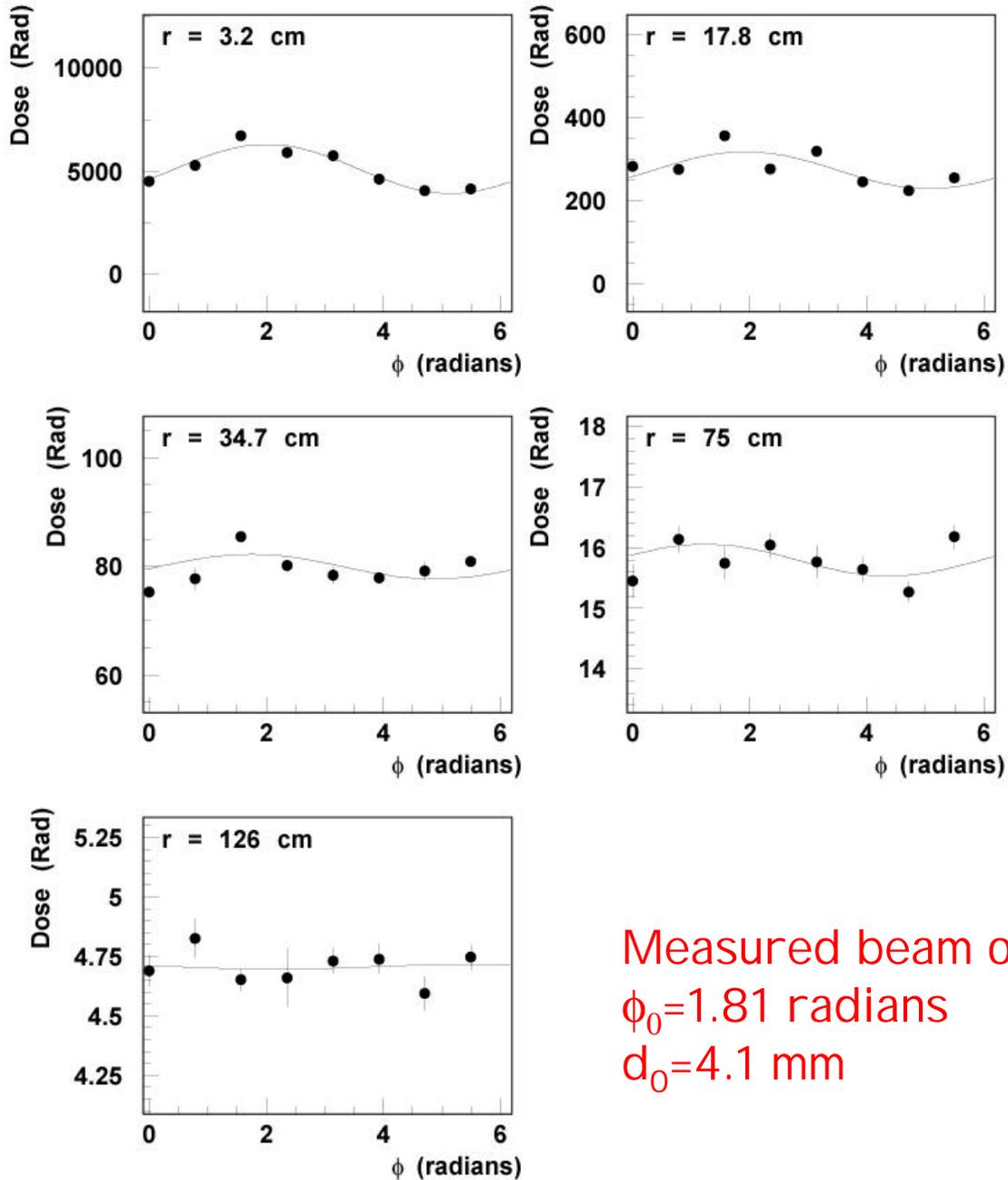
Beam and Detector cylindrically symmetric



Data (Φ)

Fit $\text{Acos}(\phi - \phi_0) + D_{\text{avg}}$ $\phi_0: 1.7\text{--}2.0$

West Plug



Measured beam offset
 $\phi_0 = 1.81$ radians
 $d_0 = 4.1$ mm

Modeling

Use previous experience to build a simple model of the radiation field*

*D.Amidei, et al NIM **A320** (1994) 73.

Assumptions

- Radiation has cylindrical symmetry about the beam.
- Field follows a power law in $1/r$.

Fit the data to the following form:

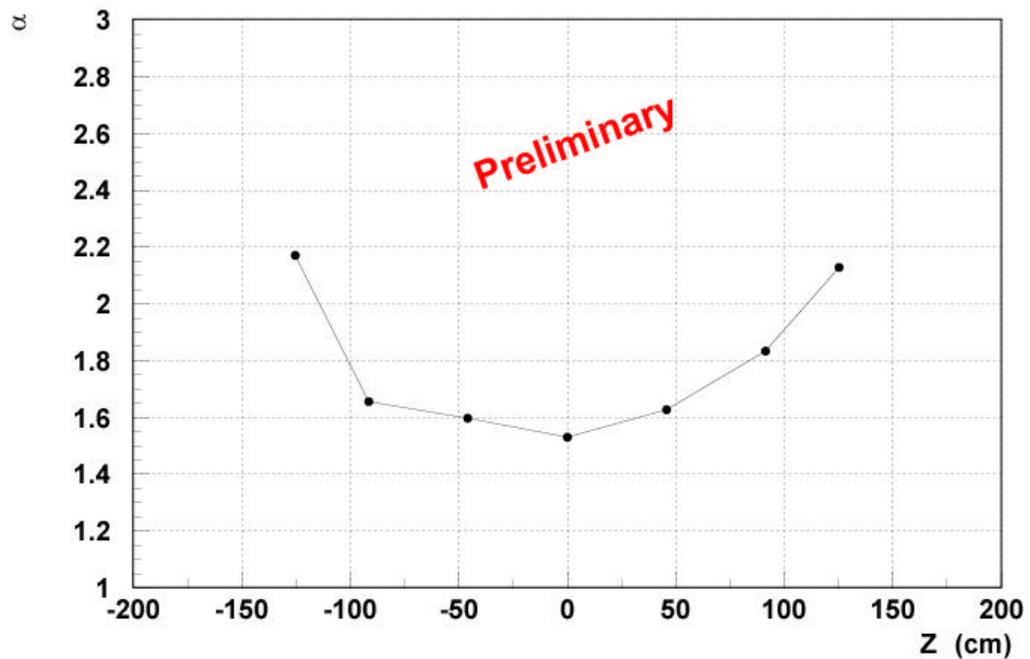
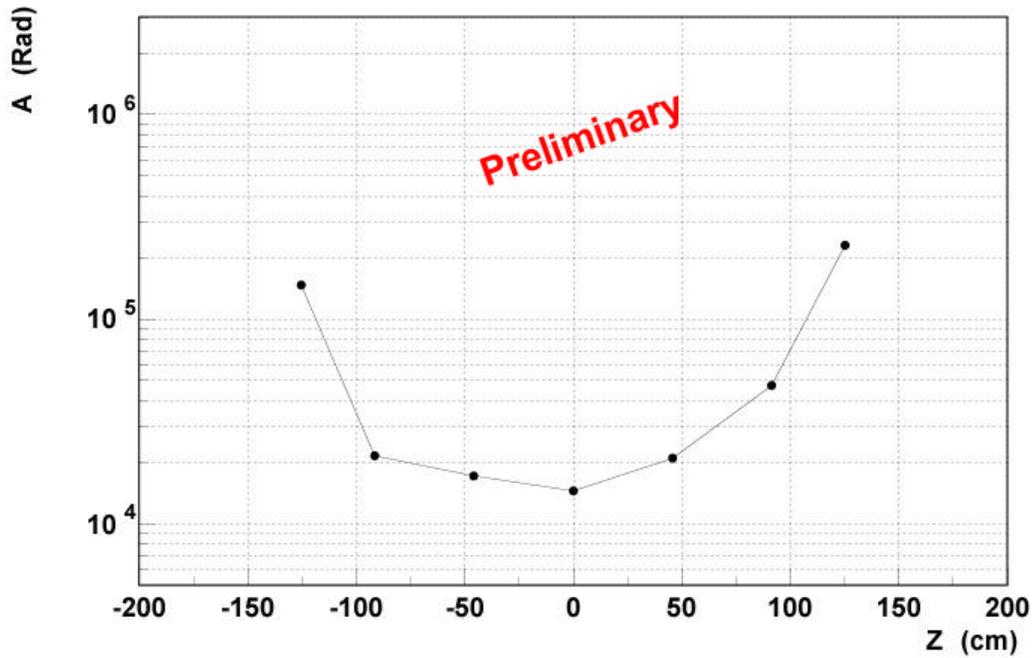
$$D(x,y) = A * \{ (x-x_0)^2 + (y-y_0)^2 \}^{-\alpha/2}$$

$D(x,y)$	radiation dose
A	absolute normalization
(x_0, y_0)	beam position offset
α	power law exponent

Note: Run I radiation damage profile yields
 $\alpha = 1.6 - 1.7$.

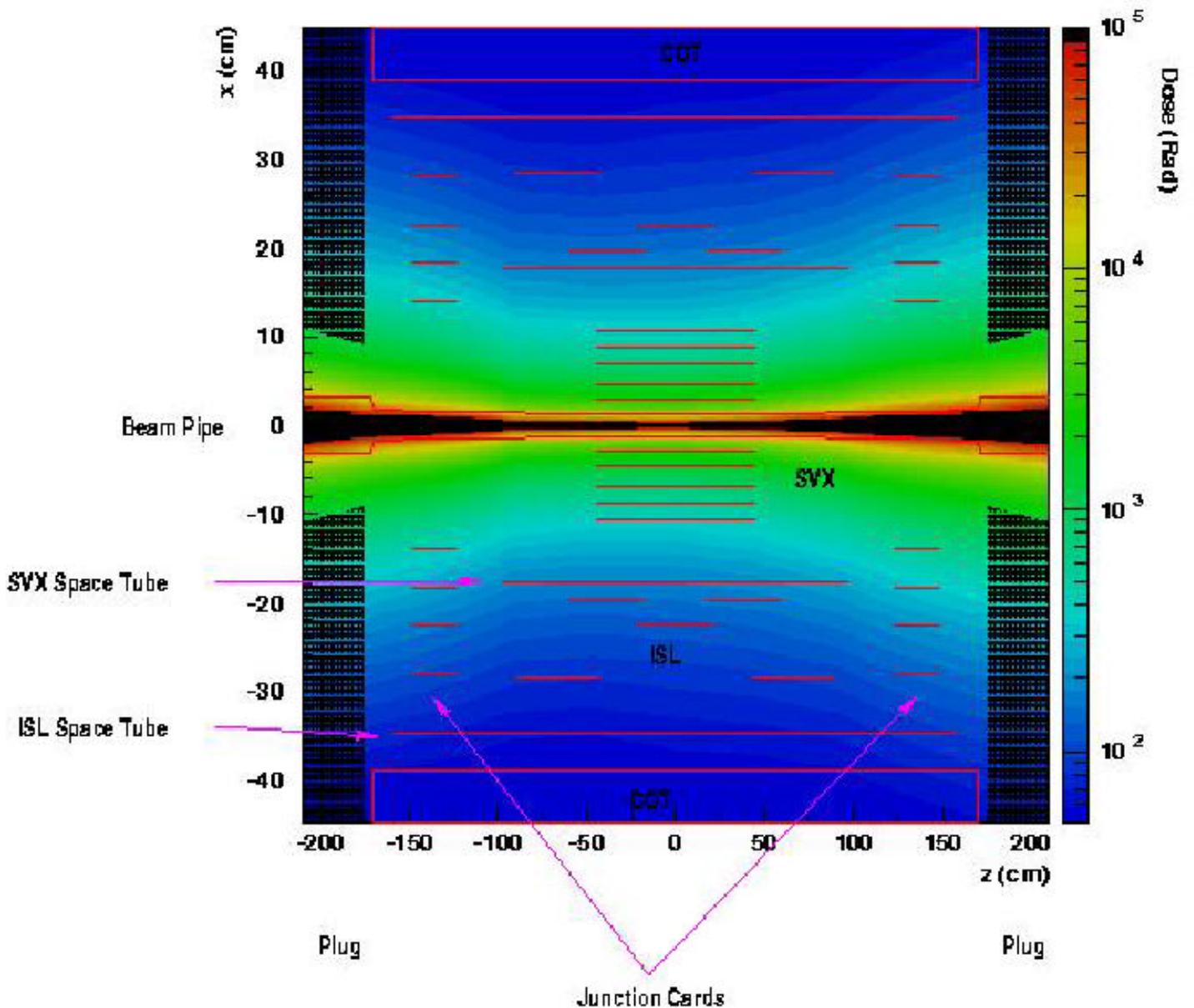
Results

Statistical uncertainties only!



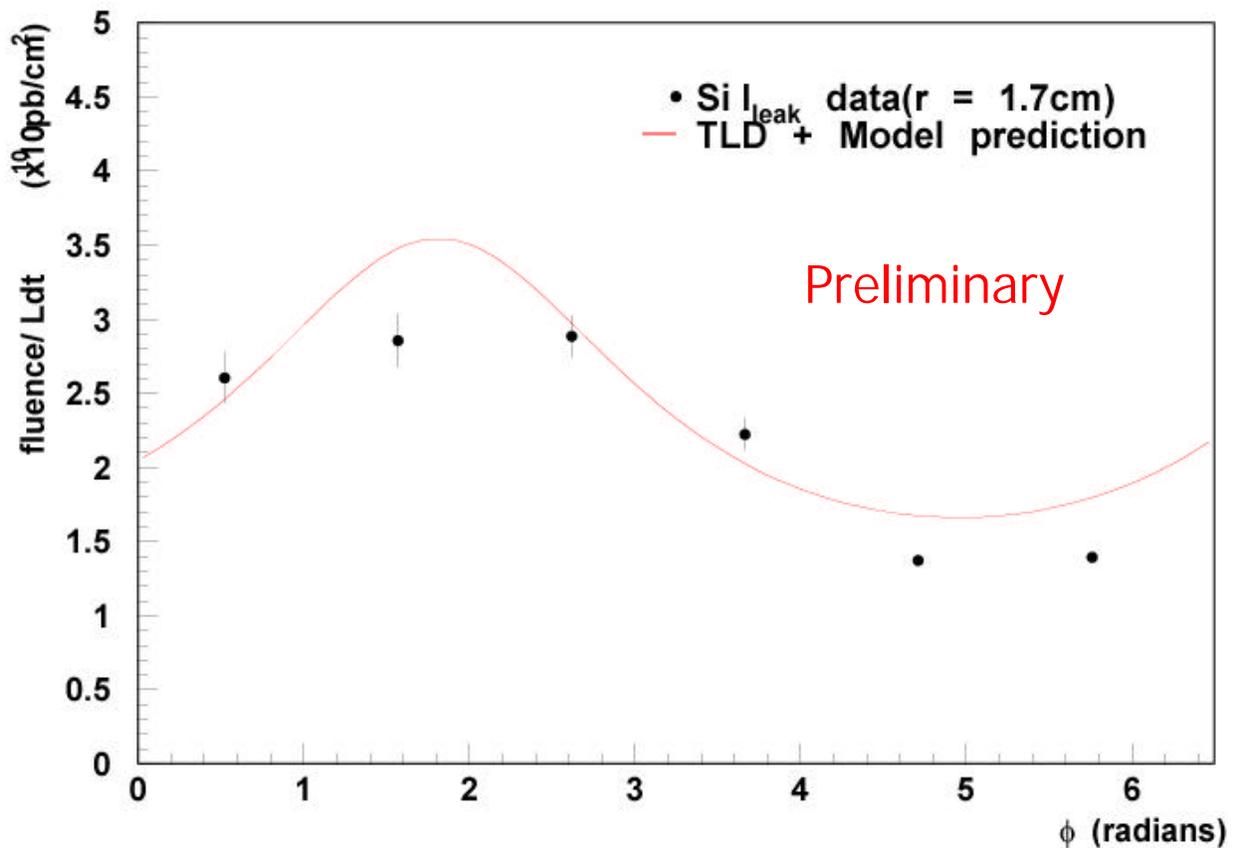
Ionizing Radiation Map

10.7 pb⁻¹ delivered luminosity



Silicon Leakage Currents

- Leakage Si current increase rate measurements
 - Correct for temperature (8 → 20 C)
 - Include $\alpha_{\text{damage}} = 3.0 \times 10^{-17}$ A/cm



CMS Projections

Conversion Factors

$$\gamma: 1 \text{ rad} = 3.8 \times 10^7 \text{ MIPs/cm}^2$$

$$n: 1 \text{ rad} = 3.2 \times 10^8 \text{ n/cm}^2 \text{ (thermal)}$$

Assumptions:

- Scaling of CDF measurements
- $L = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- 10^7 sec/year

CMS expected dose/year

Inner PIXEL detector ($r=4.3\text{cm}$)

$$\gamma: 6.6 \times 10^{14} \text{ MIPs/cm}^2$$

$$n: 1.9 \times 10^{14} \text{ n/cm}^2 \text{ (thermal)}$$

Summary

- Installed ~1000 TLDs in CDF
 - Photon and neutron measurements
- TLDs yield accurate measurements of radiation environment in CDF
 - γ radiation ~5% uncertainty
 - Separate fields from collisions and losses
 - N radiation ~20% uncertainty
- Qualitative agreement with expectations
 - Beam losses & collisions
 - Neutrons field
- New details emerging
 - Predict radiation for given beam conditions
 - Early prediction of detector lifetime
 - Naïve model from early experience (Tevatron Run I) needs update
- Semi quantitative agreement with Si data