Radiation Environment and Damage in the CDF Tracking Volume

R.J. Tesarek

Fermilab

(CDF Radiation Monitoring Group)

Y.C.Chow[3], S.D'auria[4], A.Hocker[5], K.Kordas[6], L.Nicolas[1,4], S.Mcgimpsey[1], R.J.Tesarek[1], R.Wallny[3], S.Worm[2]

[1]Fermilab, Batavia, IL USA

[2]Rutgers University, Piscataway, NJ USA

[3]University of California, Los Angeles, CA USA

[4]University of Glasgow, Glasgow UK

[5]University of Rochester, Rochester, NY USA

[6]University of Toronto, Toronto Ontario, CA

Outline

- Introduction
  - Accelerator environment
  - Detector environment
  - Why these measurements
- TLD Radiation Measurements
  - Thermal Luminescent Dosimeters
  - Exposure statistics
  - Data
  - Model
- Diode Radiation Measurements
  - PIN diodes
  - Calibration with TLD data
- Summary & Conclusions

Experiment Environment

Accelerator:

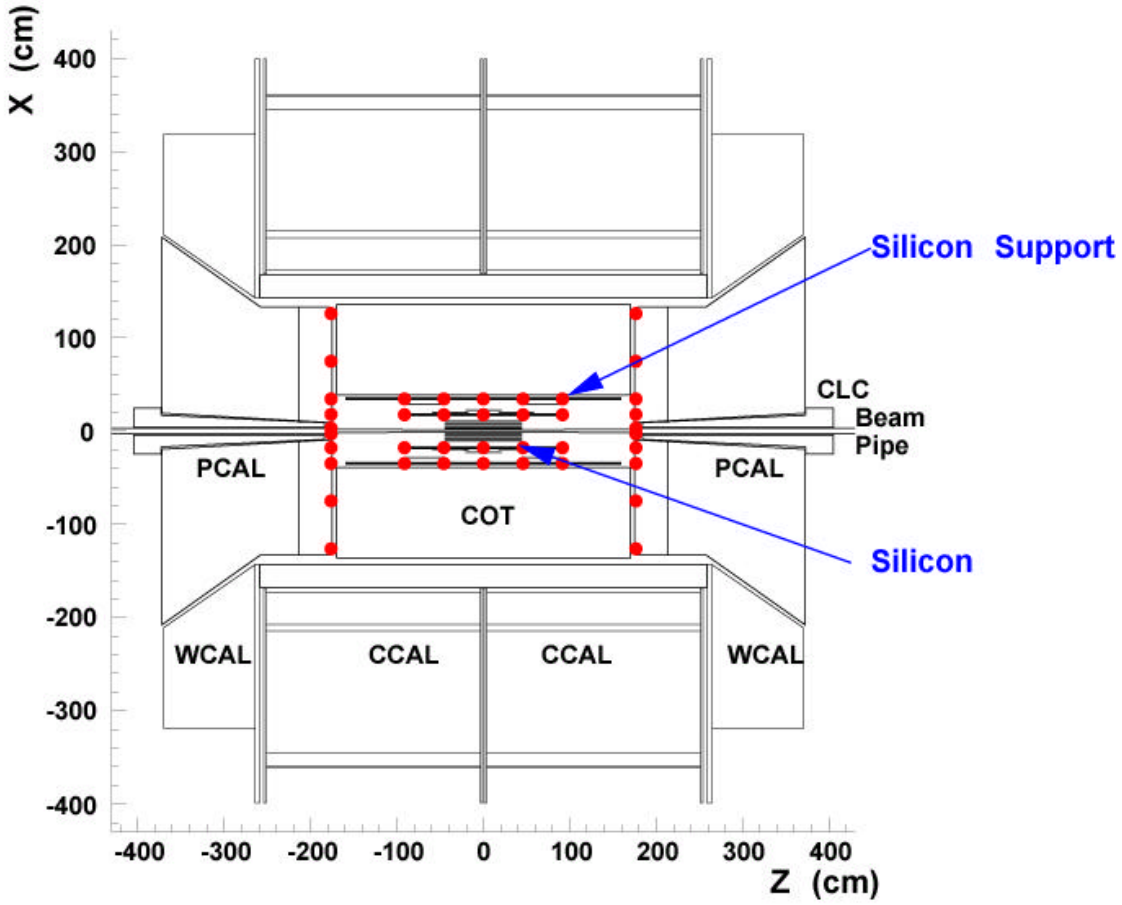
- 980 GeV proton(p)/antiproton(pbar) beams
- 36 bunches ~10^{10} part/bunch
- Beam currents p:pbar = 10:1
- Radiation from beam halo
  - Beam-gas collisions
  - Interactions in collimators

Experiment Environment

Detector:

Cylindrically symmetric detector at collision point.

- Collisions can occur every 396ns
- ~10 charged particles/collision
- Radiation from collisions
  - Ionizing radiation (γ,charge particles)
  - Neutrons



Radiation Measurement

Goal:

- Accurately measure radiation field
- ➔ Predict silicon detector's useful lifetime

Considerations:

- Redundancy
- Absolute Calibration
- Accuracy

Detector Technologies:

Thermal Luminescent Dosimeters (TLDs)

- + Industry standard
- + Good precision
- + Large dynamic range: (10μGy – 2kGy)
- + Calibrate with $^{137}Cs(\gamma)$, $^{252}Cf(n)$
- – Harvest & read each chip
- – Large amount of handling

PIN Diodes

- + Large dynamic range: (10Gy – 10MGy)
- + Remote readout
- – Temperature history
- – *In-situ* calibration

Measurement Technique

TLDs: (~1000 dosimeters in 145 locations)

- 2 types of dosimeters

  TLD-700 (^{7}LiF): ionizing radiation

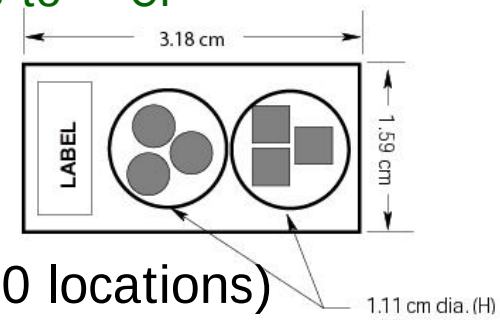
  TLD-600 (^{6}LiF): ionizing radiation & low energy neutrons (E_n<200keV)

- Calibration

  1% reproducibility, 3% chip-to-chip variation

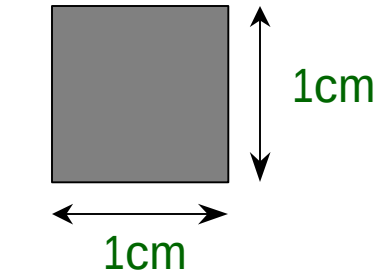
  Ionizing radiation: 10mGy exposure to ^{137}Cs

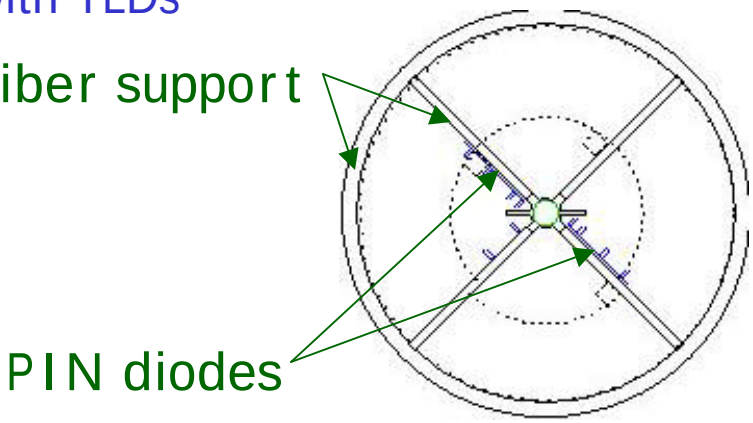
  Neutrons: 10mGy exposure to ^{252}Cf



PIN Diodes: (12 diodes in 10 locations)

Cross calibrated with TLDs





Exposure Conditions

Beam conditions:

- **Collisions(luminosity at CDF):**
  - Measured by Cherenkov radiation counters (A. Sukhanov N11-1)
- **Losses of incoming p and pbar:**
  - Monitored by scintillator counters near beam pipe on either side of CDF

Three TLD exposure periods

Period	Beam($x10^{18}$) P	Beam($x10^{18}$) Pbar	Losses ($x10^{9}$) P	Losses ($x10^{9}$) Pbar	Ldt ($pbarn^{-1}$)
Feb.– May 2001	0.702	0.082	15.3	2.02	0.058
May– Oct. 2001	15.6	1.37	40.9	10.2	12.3
Oct 2001 – Jan 2003	96.2	4.89	277.	35.1	167.

Feb. – May: p-loss/collision=$264x10^{9}/pbarn^{-1}$

May – Oct.: p-loss/collision=$3.3x10^{9}/pbarn^{-1}$

Oct. – Jan.: p-loss/collision=$1.6x10^{9}/pbarn^{-1}$

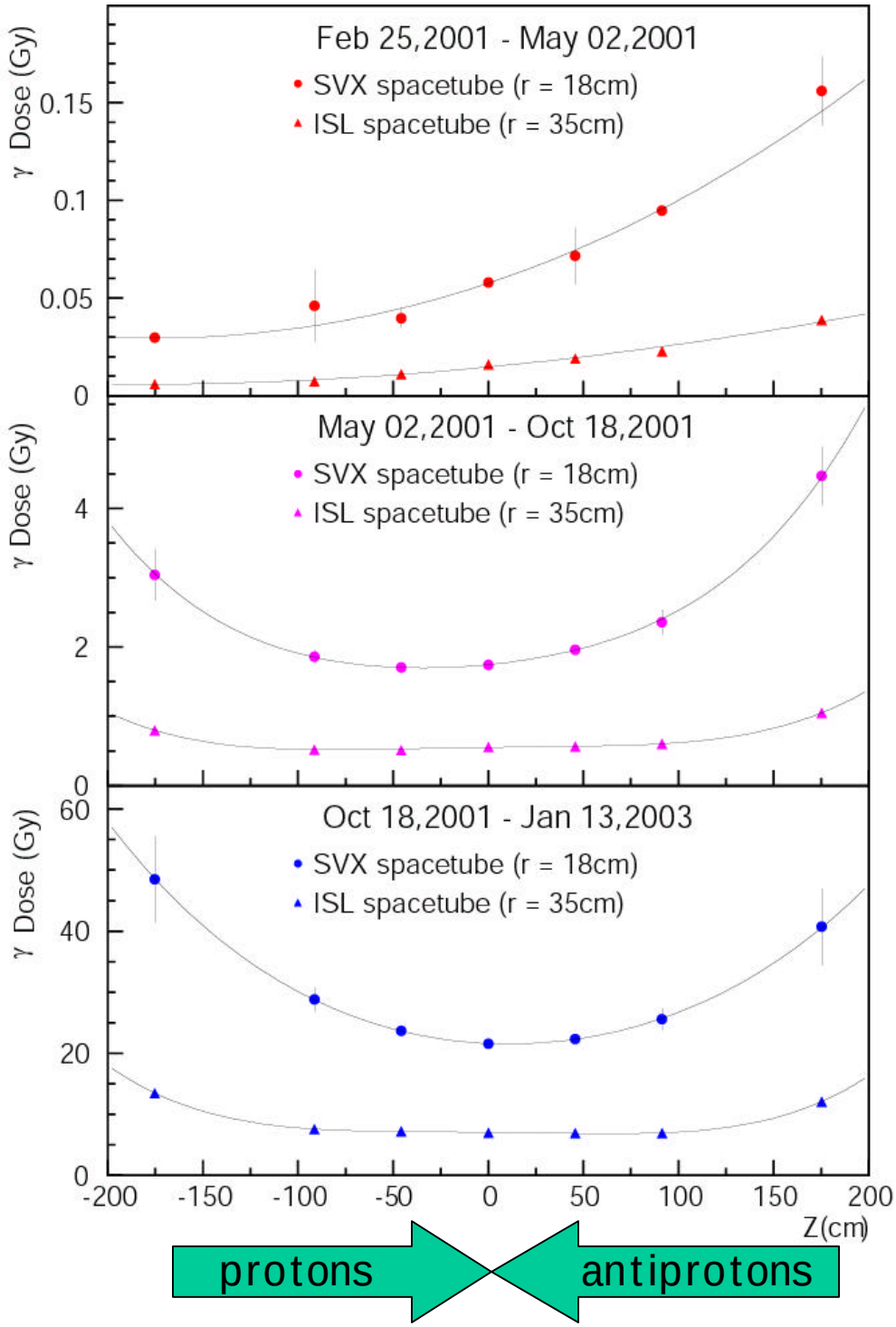
NOTE: 1 $pbarn^{-1}$ ~ $5x10^{10}$ p-pbar collisions

TLD Data (Ionizing Radiation)

Loss dominated
20% collisions

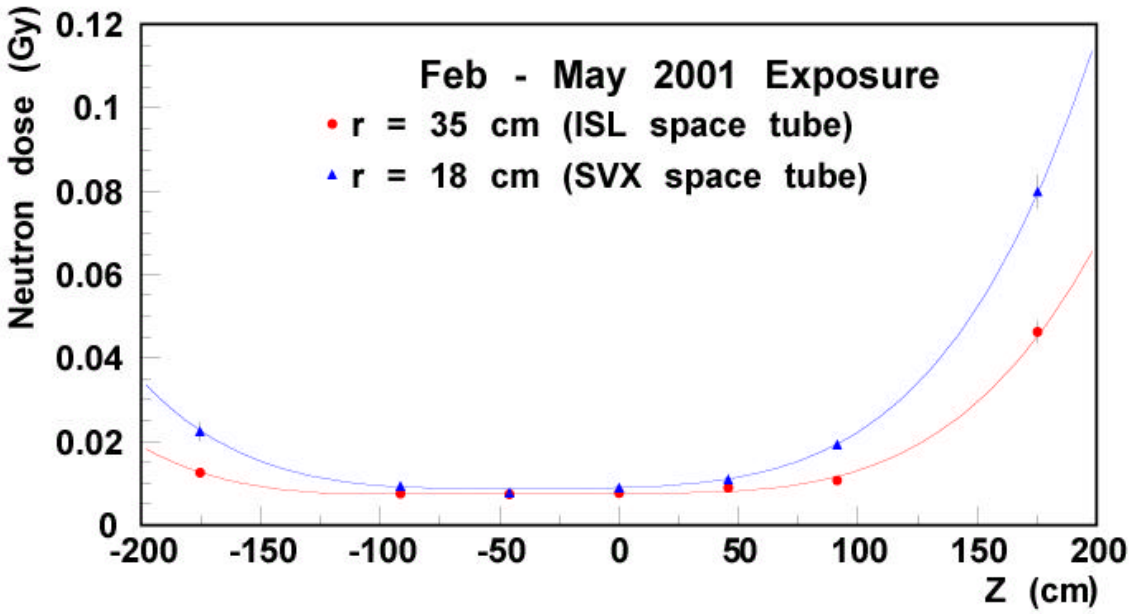
Collision dominated
82% collisions

Collision dominated
91% collisions

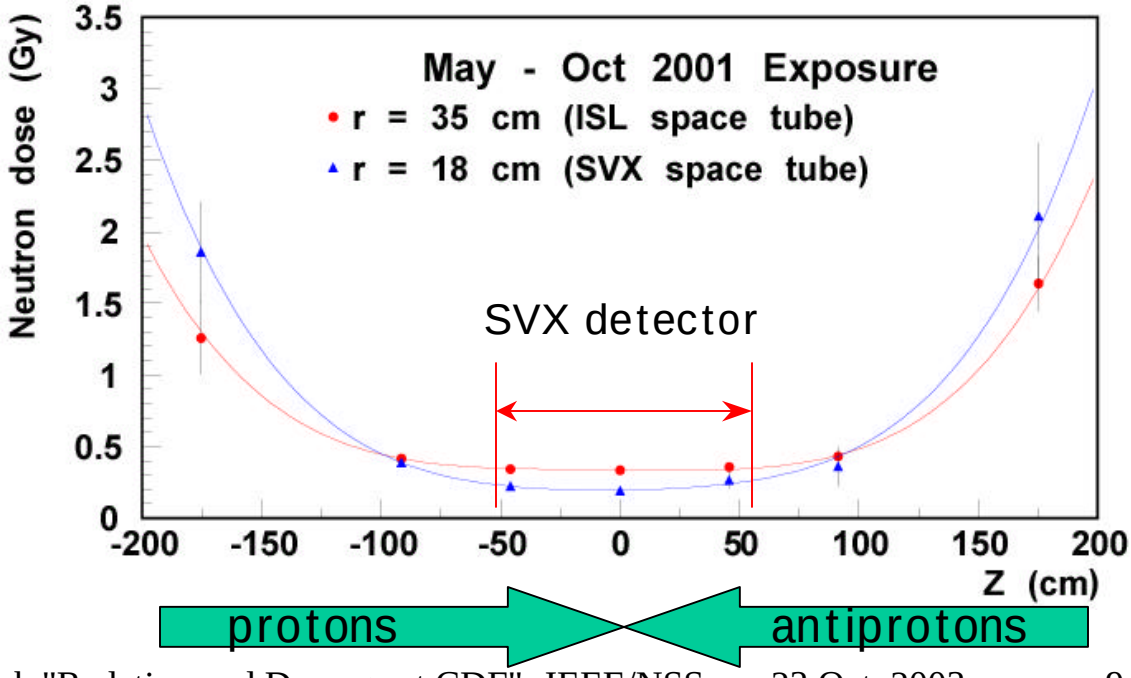


TLD Data (Neutrons)

Loss dominated data



Collision dominated data

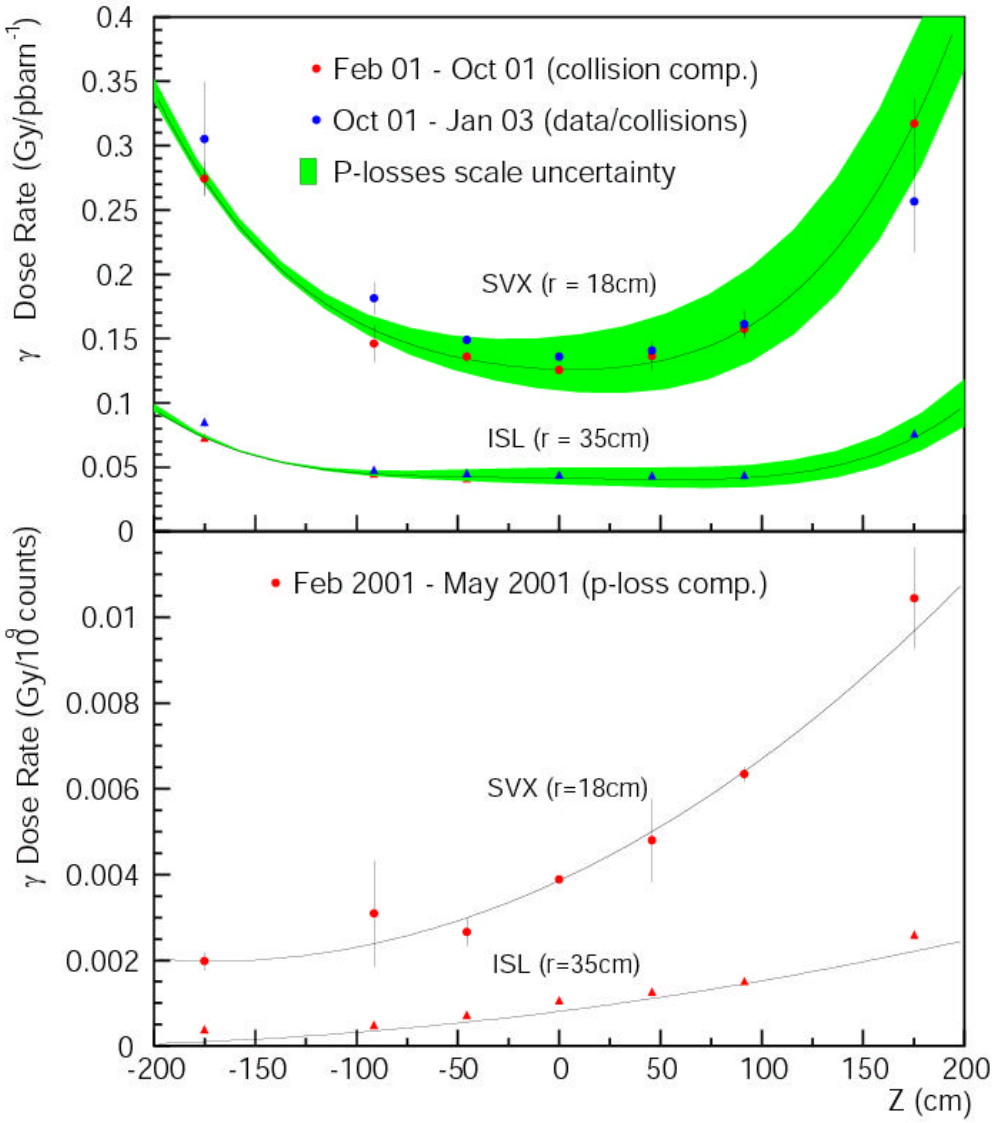


Separating Collision/losses

Assume radiation is a linear superposition of collisions and losses

$D_1(x,y,z) = I_1 L(x,y,z) + c_1 C(x,y,z)$

$D_2(x,y,z) = I_2 L(x,y,z) + c_2 C(x,y,z)$



A Simple Model

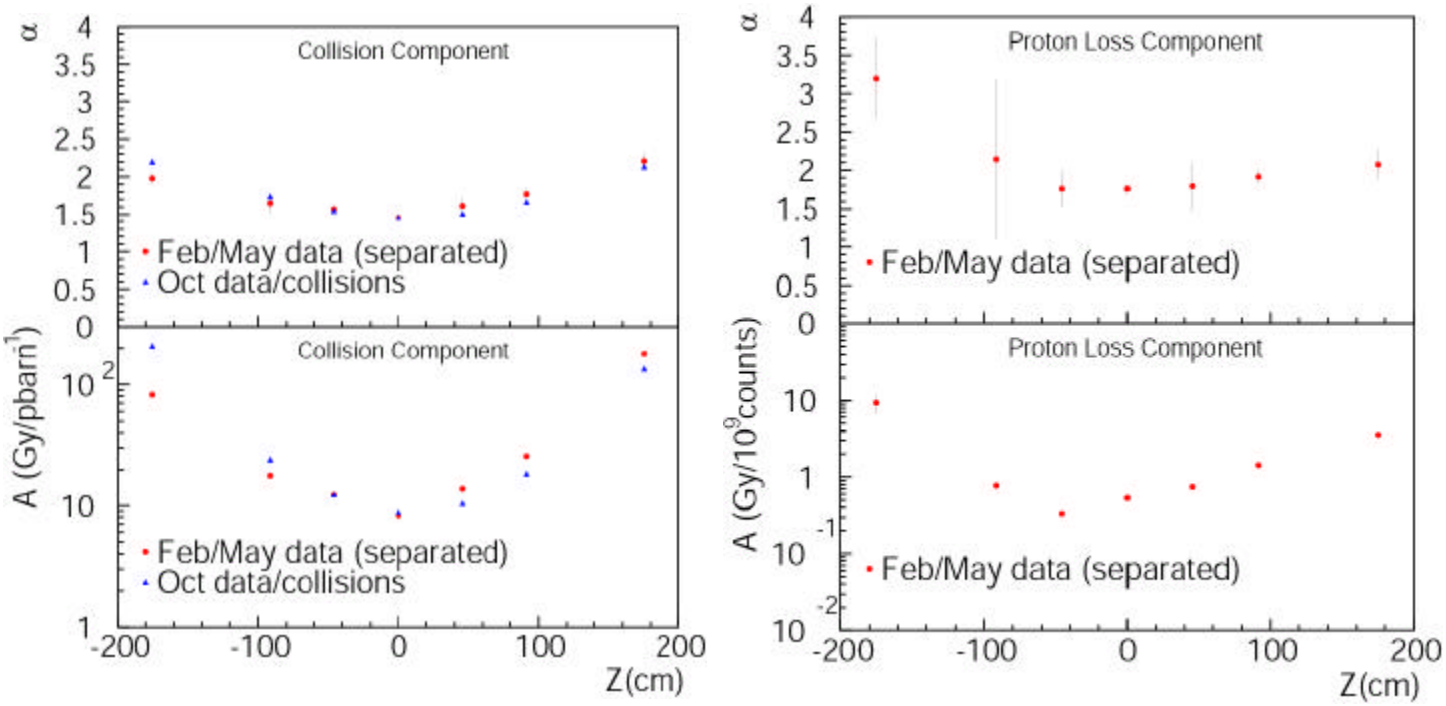
Use previous experience to build a simple model of the radiation field.*

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

- Assumptions:
  - Radiation has cylindrical symmetry about the beam
  - Field follows power law: $\mathbf{D \sim Ar^{-\alpha}}$

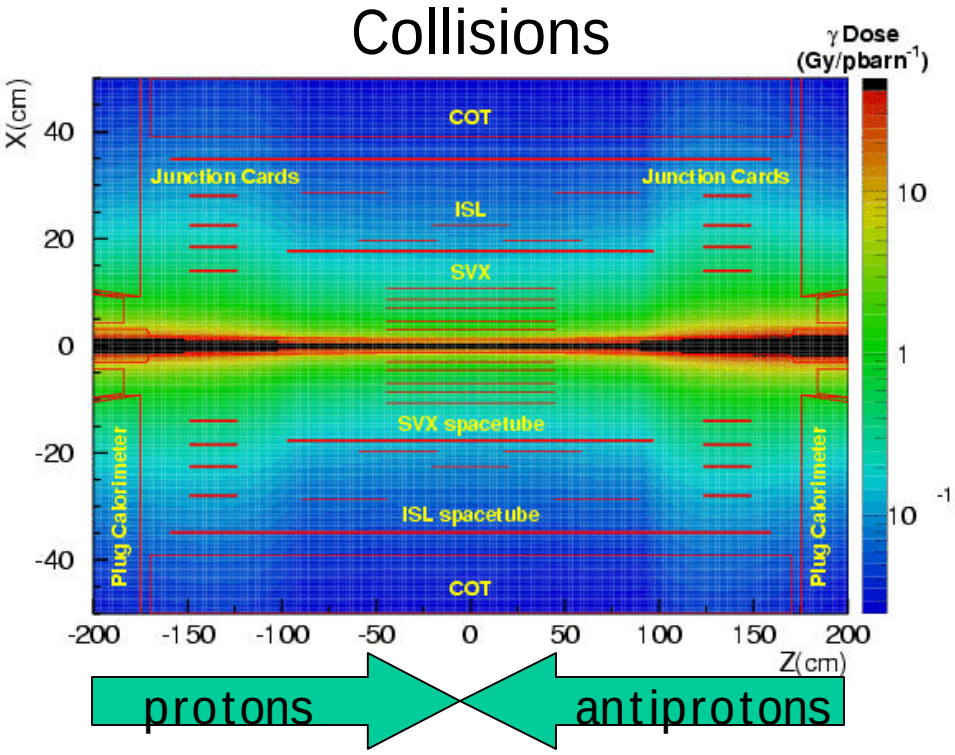
    α = power law exponent

    A = Normalization

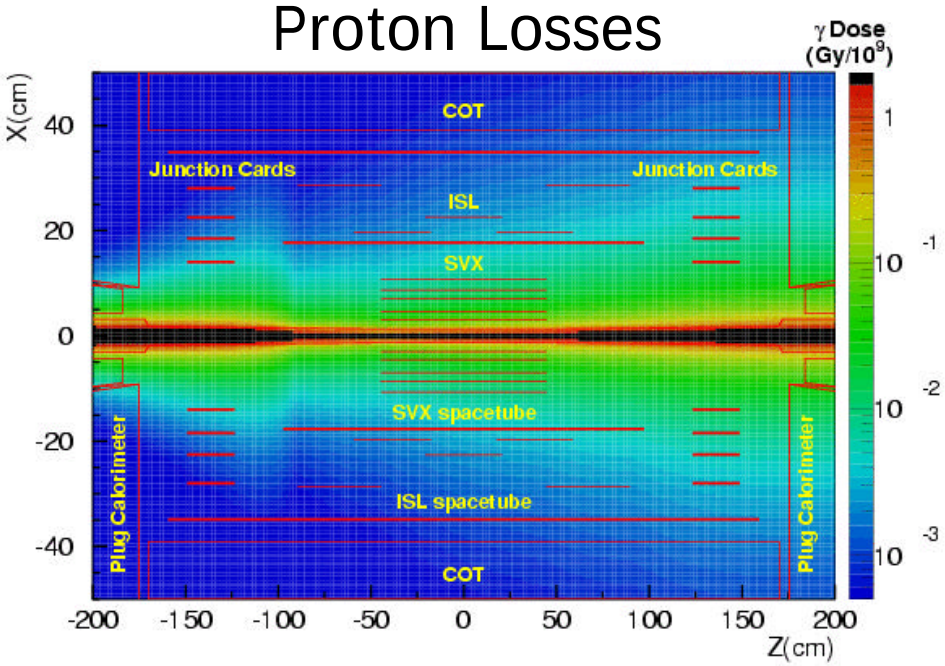


Ionizing Radiation Fields

Collisions

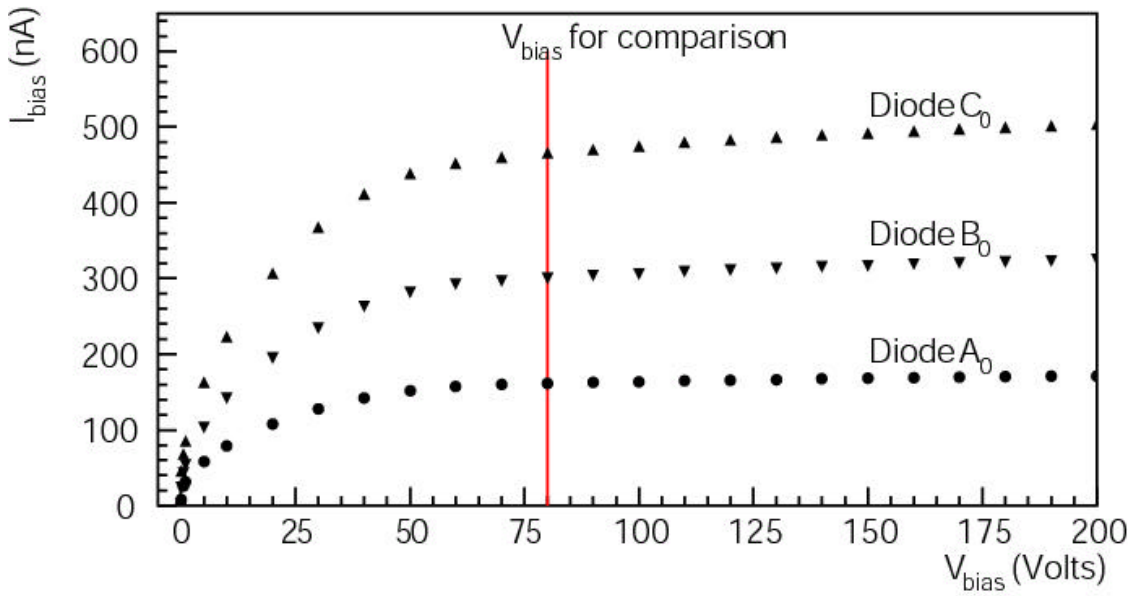


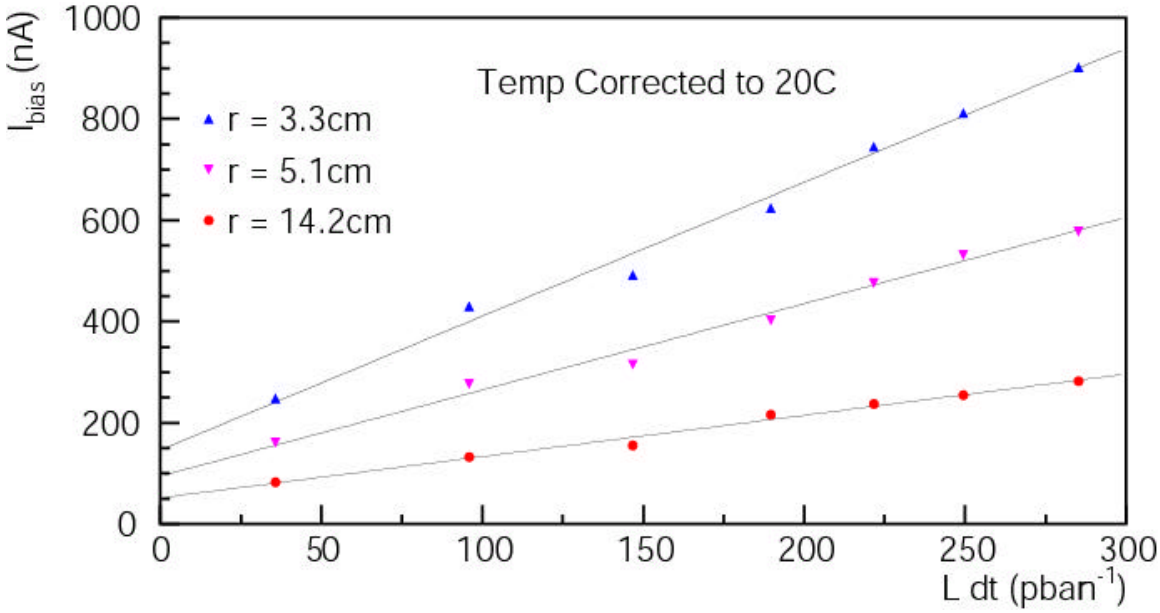
Proton Losses



PIN Diodes

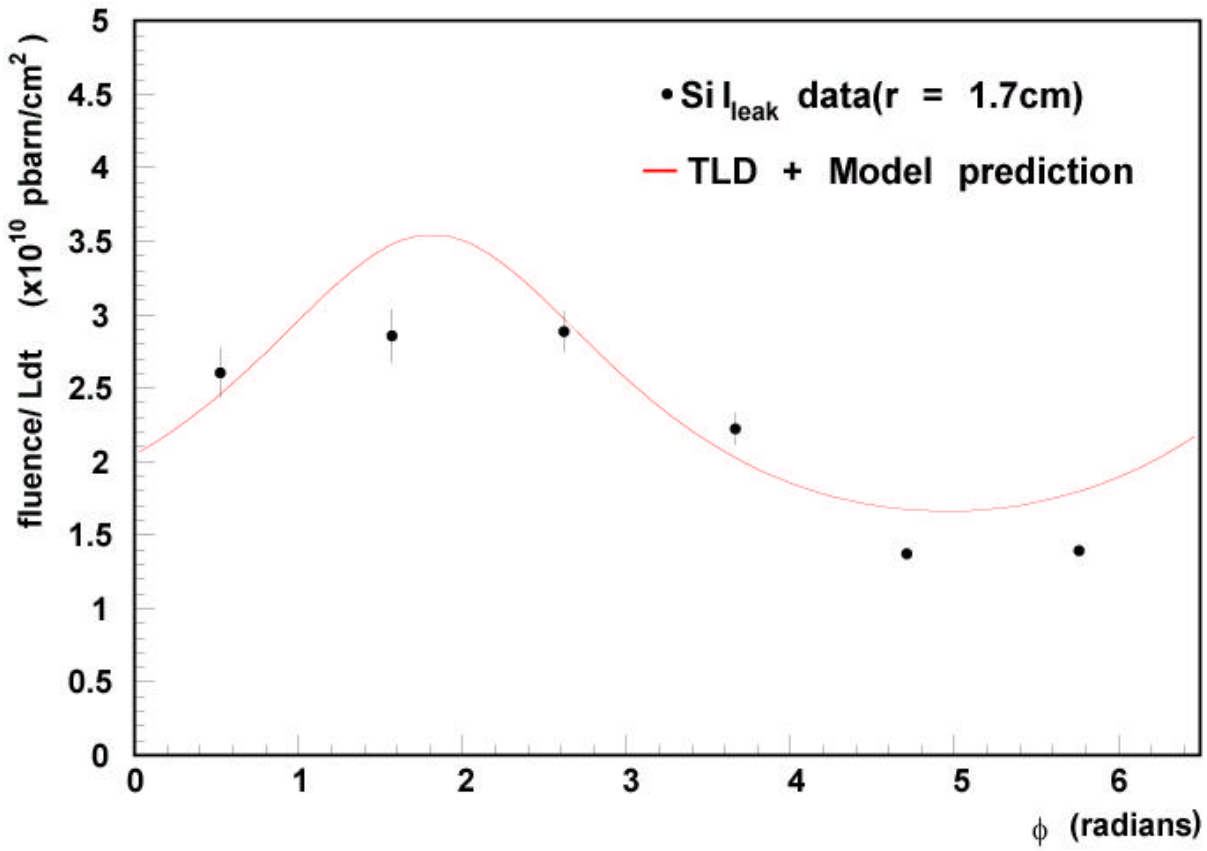
- TLDs ➔ Radiation field
- PIN diodes scale radiation





Comparison with Si Data

- Si bias current increase rate measurements
  - Correct for temperature (8→20C)
  - Include α_{damage}=3.0x10^{17} A/cm
  - Extrapolate TLD results 17cm→1.7cm



Summary

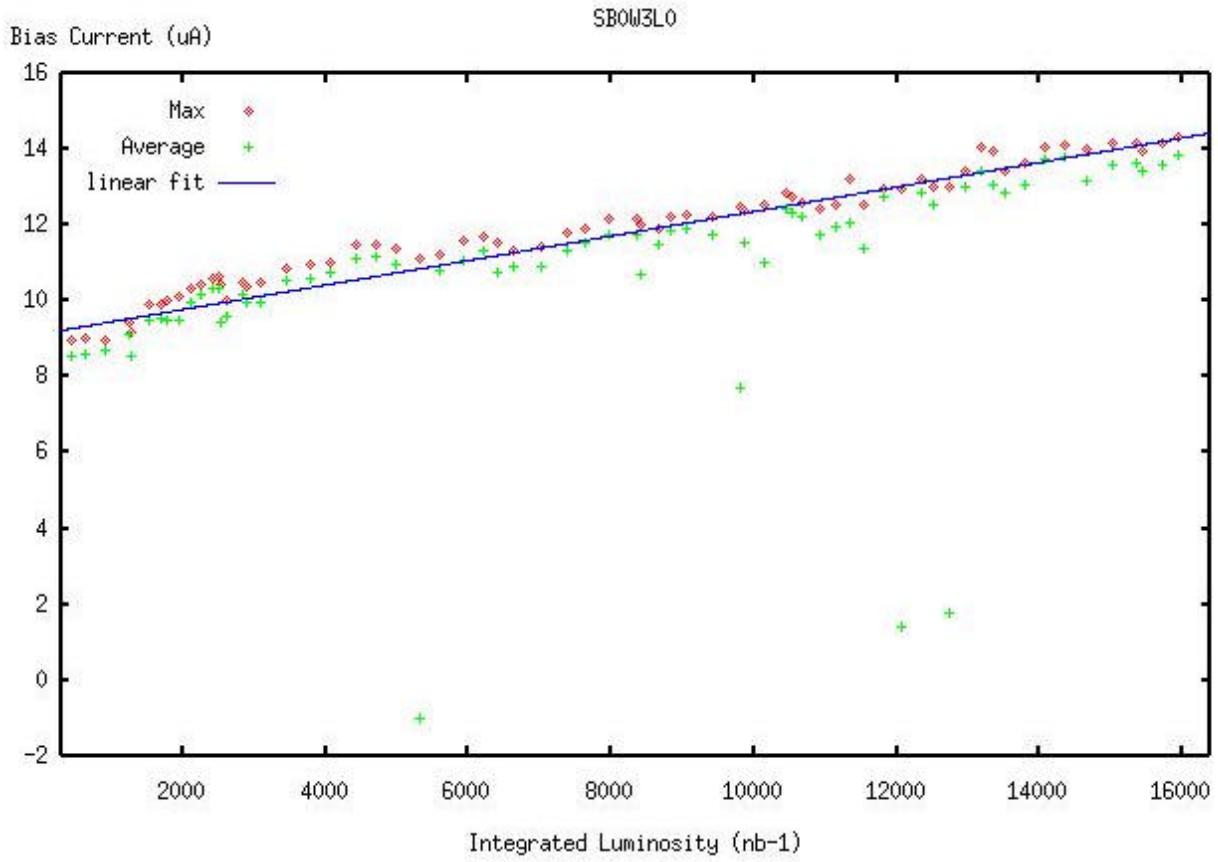
- Installed ~1000 TLDs, 12 diodes in CDF.
  - Photon & neutron measurements.
  - Bias current increase calibrated with TLDs.
- TLDs yielding accurate measurements of radiation environment in CDF.
  - γ radiation ~5% uncertainty.
  - Multiple measurements internally consistent
  - Separate fields from collisions and losses.
- New details
  - Predict radiation for given beam conditions
  - PIN diodes to scale radiation field
  - Early prediction of detector lifetime
- Quantitative agreement between Si detectors and TLD data.

Backup Slides

Si Bias Current Data

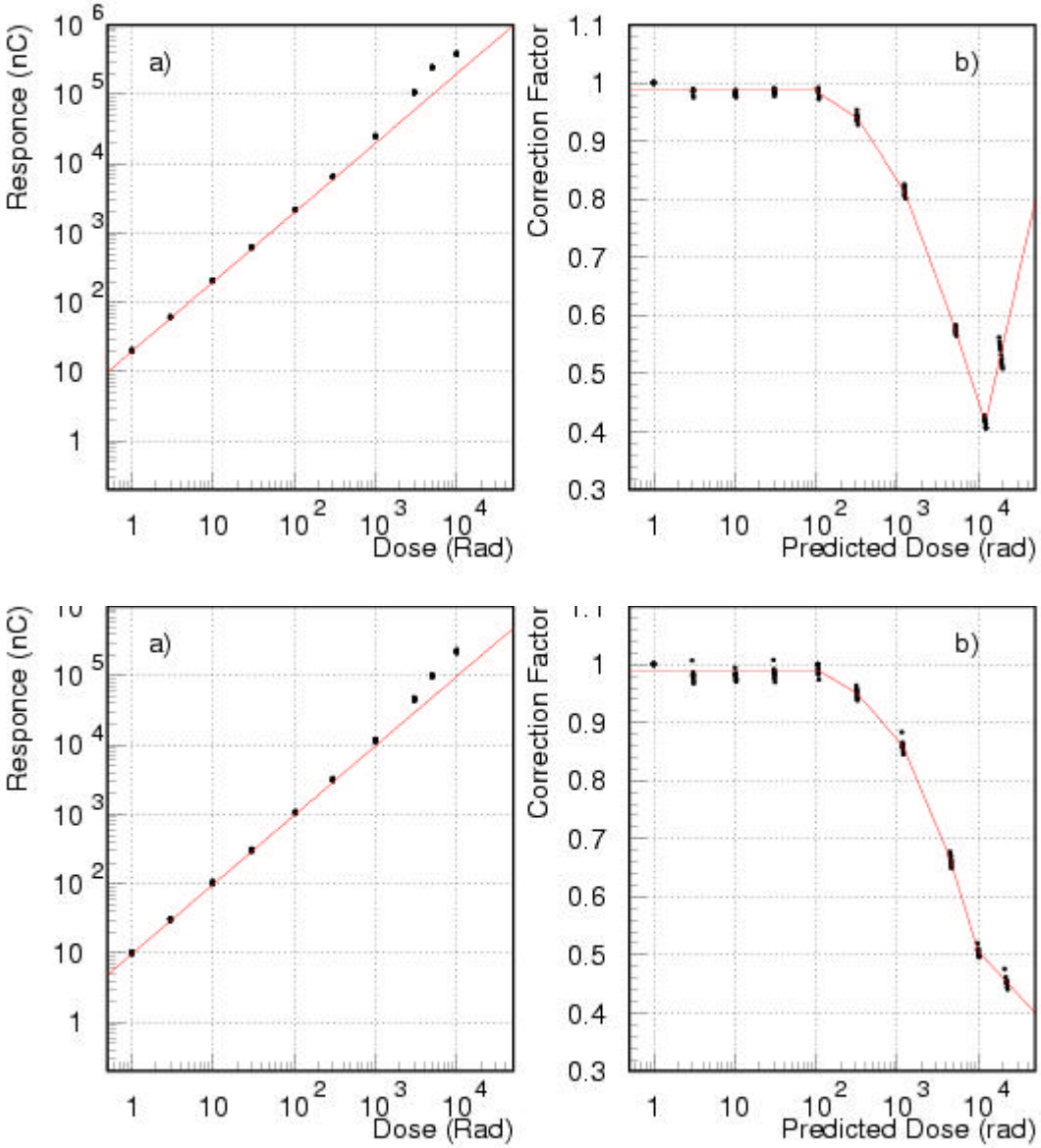
Si detector bias current vs collisions

- Calculate I_{bias}/volume of each sensor
- Correct to 20C



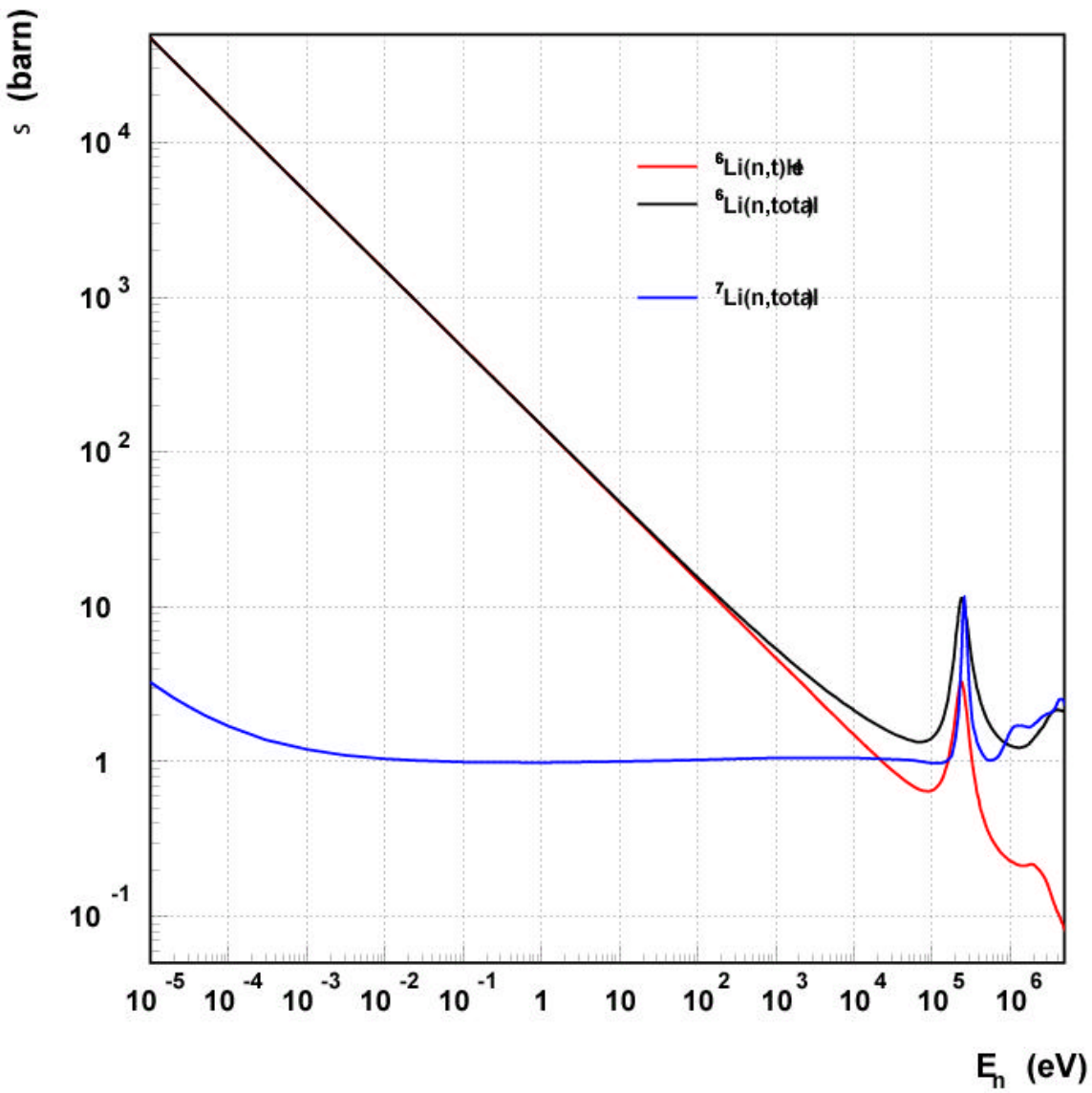
TLD Calibrations

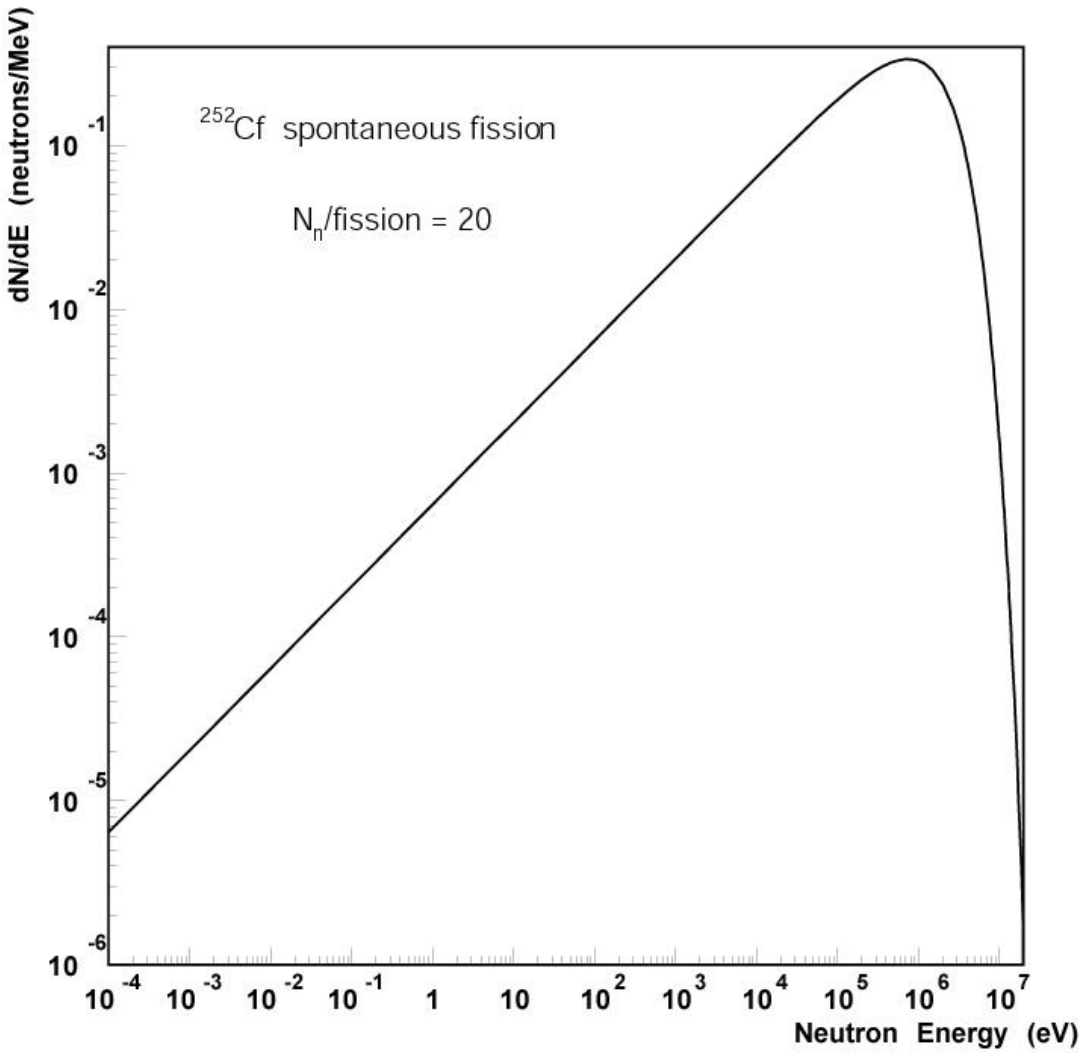
- TLD non-linearity calibration



Neutron Calibration

$^{6}Li(n,t)^{4}He$



Neutron Calibration

- 252 Cf Spectrum