Forward Calorimetry DBD Activities

SiD Workshop
December 14-16 2011

Bruce Schumm
UCSC/SCIPP

Activities Underway

- **Measurement of stau in the degenerate regime (U. Nauenberg et al)**
- **BeamCal Shower reconstruction for different beam delivery scenaria**
- **Bean Chip Development**
- **Radiation Damage Studies**

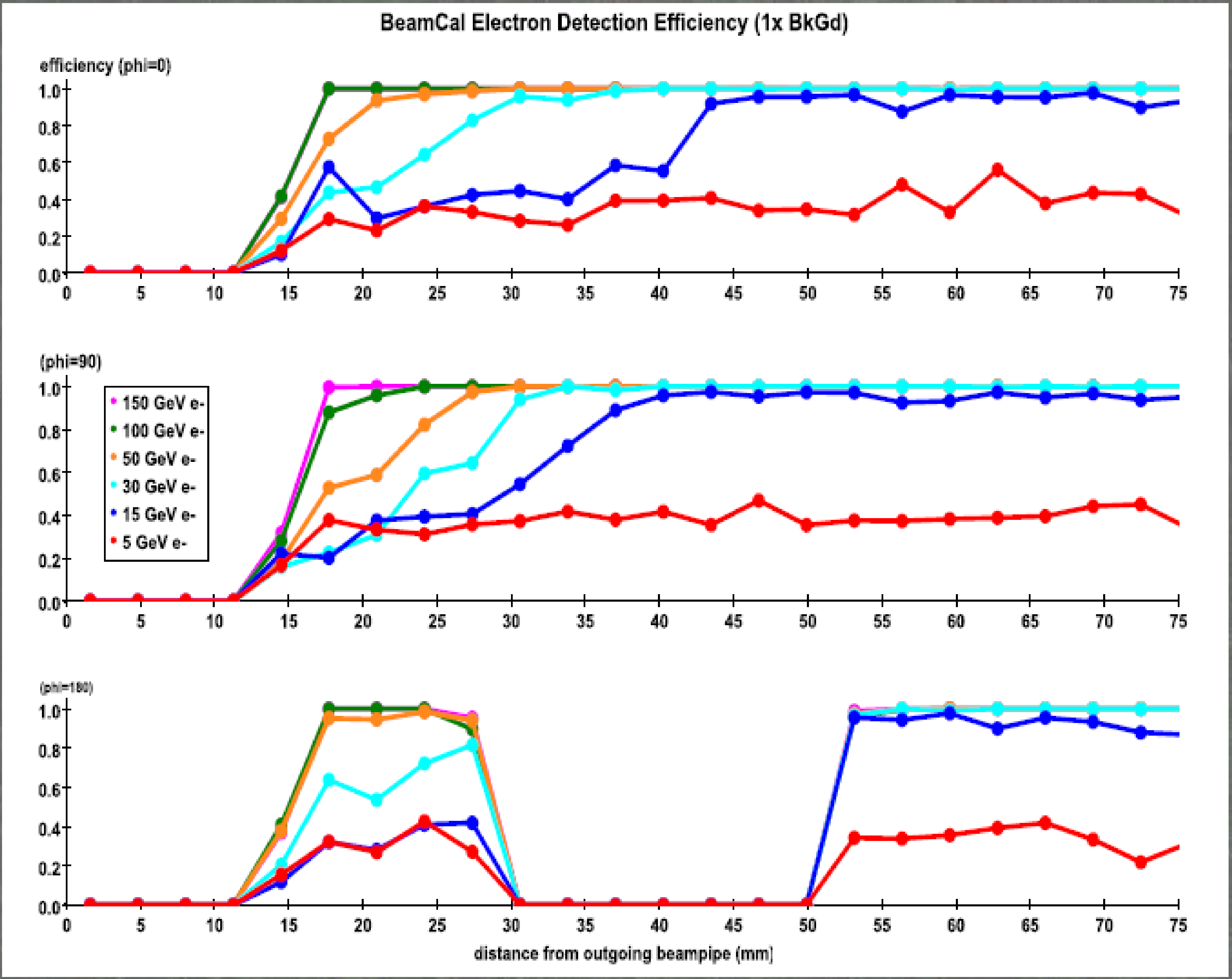
Stau Production and BeamCal Reconstruction

Colorado Study

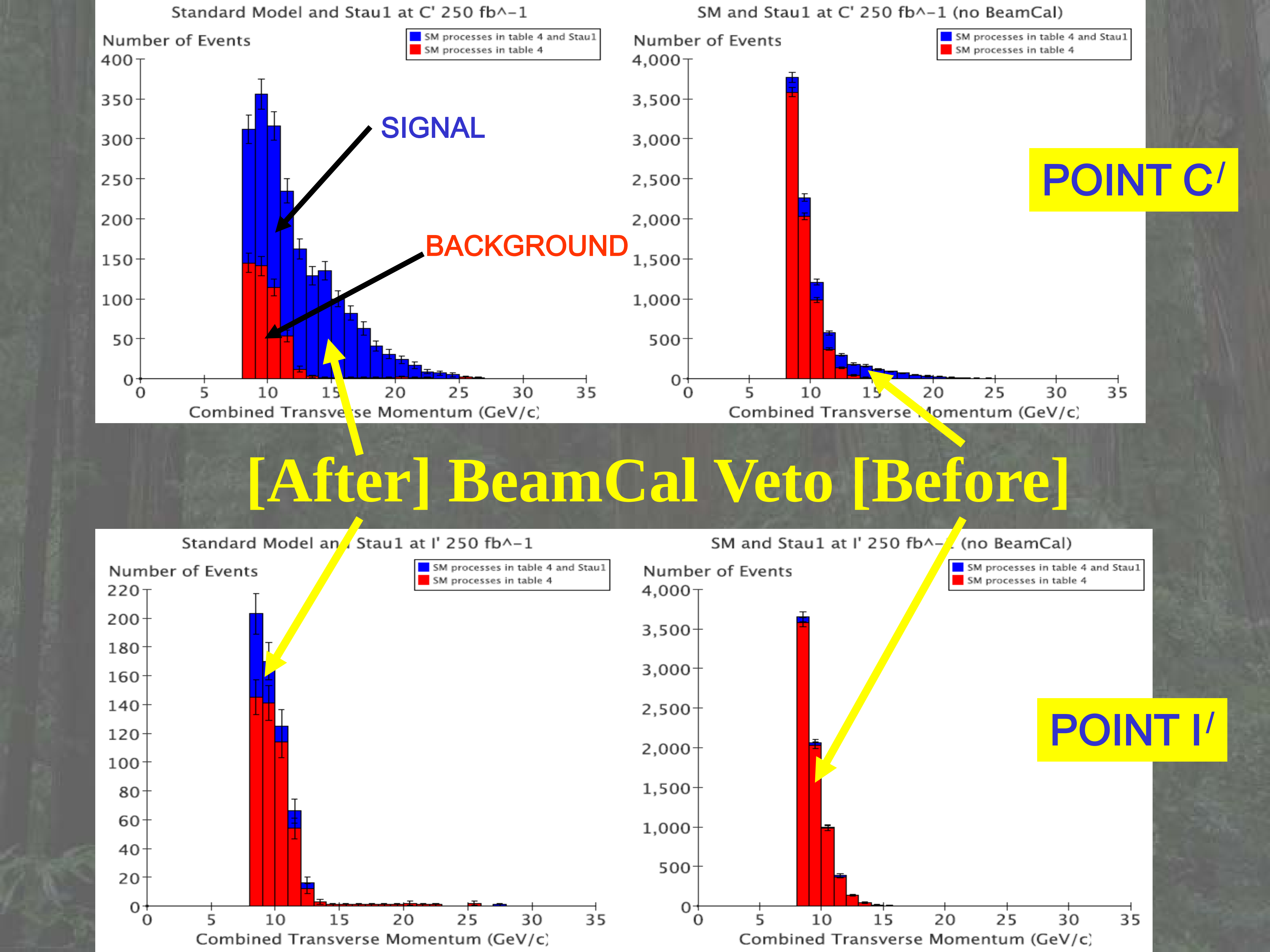
WMAP data prefers "co-annihilation" configuration with nearly-degenerate LSP (χ^0) and NLSP (stau)

Dominant two-photon background rejected by identifying $e^{\pm}$ in BeamCal

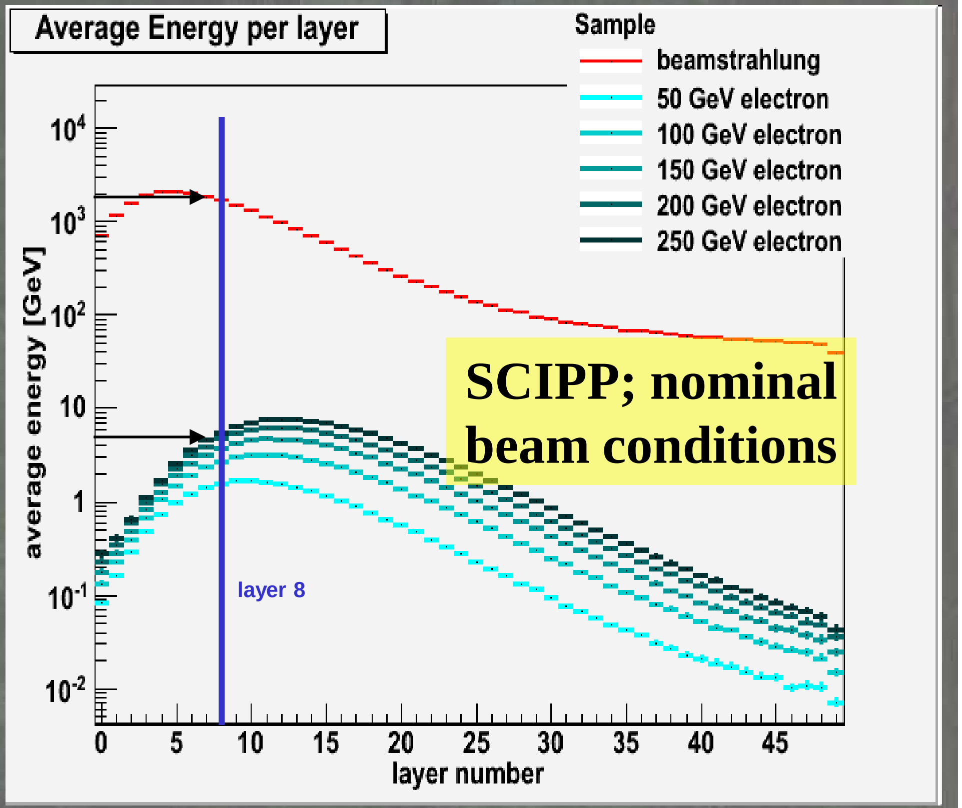
Model	B'	C'	D'	G'	I'	SPS1a'
W^+	80.4	80.3	80.3	80.3	80.3	80.4
h^0	110.0	114.1	115.3	114.5	113.9	112.1
H^0	377.7	587.3	755.0	525.9	440.0	424.7
A^0	377.2	586.9	754.7	525.8	440	424.5
H^+	386.0	592.7	759.3	532.2	447.8	432.2
$\tilde{d}_L$	565	863.4	1106.4	818.3	780.6	566.7
$\tilde{d}_R$	541.9	827.1	1058.5	784.5	749.7	543.7
$\tilde{u}_L$	559.5	859.8	1103.6	814.5	776.6	561.3
$\tilde{u}_R$	542.2	829.4	1062.2	786.4	751.3	544.0
$\tilde{s}_L$	565.0	863.4	1106.4	818.3	780.6	566.7
$\tilde{s}_R$	541.9	827.1	1058.5	784.5	749.7	543.7
$\tilde{c}_L$	559.5	859.8	1103.6	814.5	776.6	561.3
$\tilde{c}_R$	542.1	829.4	1062.2	786.4	751.3	544.0
$\tilde{b}_1$	514.2	788.2	1013	735.7	674.3	503.4
$\tilde{b}_2$	542.4	825.2	1053.3	776.9	728.1	542.7
$\tilde{t}_1$	410.1	648.1	852.0	613.5	580.1	365.9
$\tilde{t}_2$	583.2	841.6	1049.2	795.3	748.6	581.8
$\tilde{e}_L^-$	186.1	287.0	372.8	282.2	297.7	189.7
$\tilde{e}_R^-$	119.9	178.3	230.1	187.2	223.1	125.3
$\tilde{\nu}_e$	168.4	275.7	364.1	270.4	286.5	172.4
$\tilde{\mu}_L^-$	186.2	287.0	372.8	282.2	297.8	189.7
$\tilde{\mu}_R^-$	119.9	178.3	230.1	187.1	222.8	125.2
$\tilde{\nu}_\mu$	168.4	275.7	364.1	270.4	286.4	172.4
$\tilde{\tau}_1^-$	110.6	170.6	223.9	158.6	144.6	109.0
$\tilde{\tau}_2^-$	190.2	289.0	373.5	289.0	309.3	194.4
$\tilde{\nu}_\tau$	167.8	274.8	363.0	266.8	273.8	170.5
$\tilde{g}$	603.3	930.5	1196.2	877.2	824.9	604.0
$\tilde{\chi}_1^0$	96.5	161.0	216.4	150.9	140.8	97.6
$\tilde{\chi}_2^0$	178.6	303.5	413.5	284.5	265.1	183.5
$\tilde{\chi}_3^0$	−348.2	−527.6	−674.3	−493.7	−461.3	−400.4
$\tilde{\chi}_4^0$	367.5	542.6	680.2	507.5	475.0	413.9
$\tilde{\chi}_1^+$	178.1	303.5	413.7	284.5	265.2	183.3
$\tilde{\chi}_2^+$	368.4	543.1	682.5	508.6	476.4	415.3

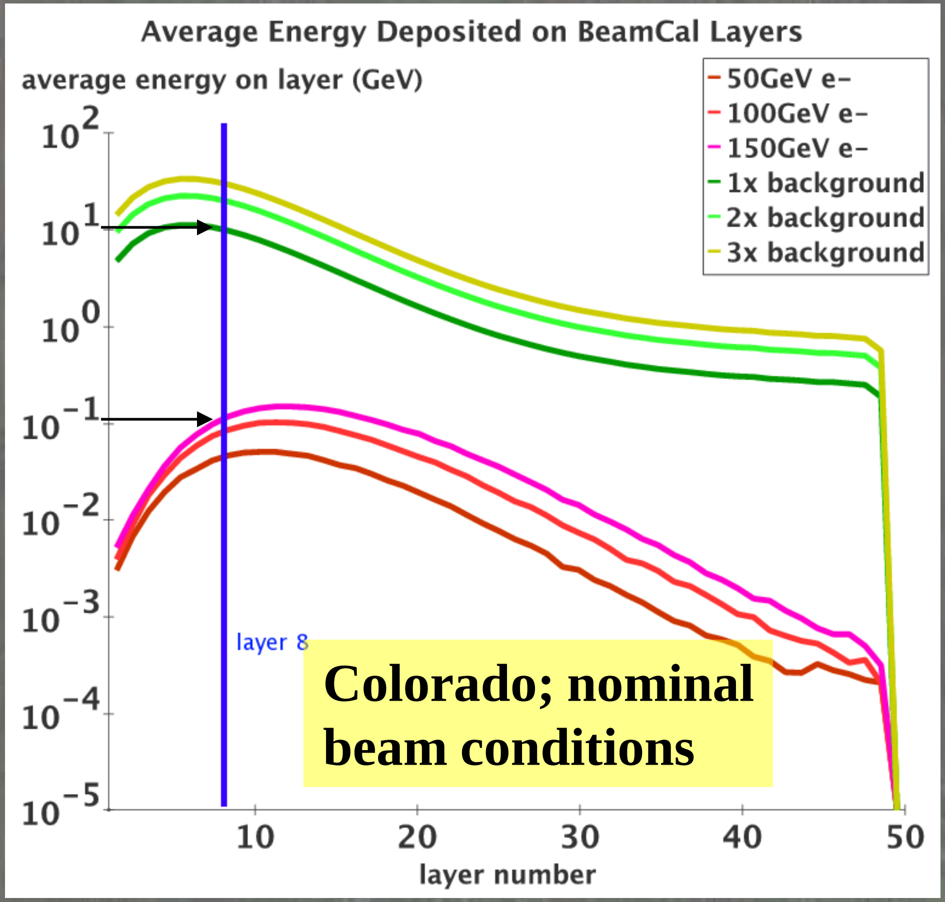


BeamCal Electron Detection Efficiency (1x BkGd)
efficiency (phi=0)
(phi=90)
(phi=180)
150 GeV e-
100 GeV e-
50 GeV e-
30 GeV e-
15 GeV e-
5 GeV e-
distance from outgoing beampipe (mm)


Standard Model and Stau1 at C' 250 fb^-1
Number of Events
SM processes in table 4 and Stau1
SM processes in table 4
SIGNAL
BACKGROUND
Combined Transverse Momentum (GeV/c)
SM and Stau1 at C' 250 fb^-1 (no BeamCal)
Number of Events
SM processes in table 4 and Stau1
SM processes in table 4
Combined Transverse Momentum (GeV/c)
POINT C/
[After] BeamCal Veto [Before]
Standard Model and Stau1 at I' 250 fb^-1
Number of Events
SM processes in table 4 and Stau1
SM processes in table 4
Combined Transverse Momentum (GeV/c)
SM and Stau1 at I' 250 fb^-1 (no BeamCal)
Number of Events
SM processes in table 4 and Stau1
SM processes in table 4
Combined Transverse Momentum (GeV/c)
POINT I/

SCIPP: Explore different beam conditions?





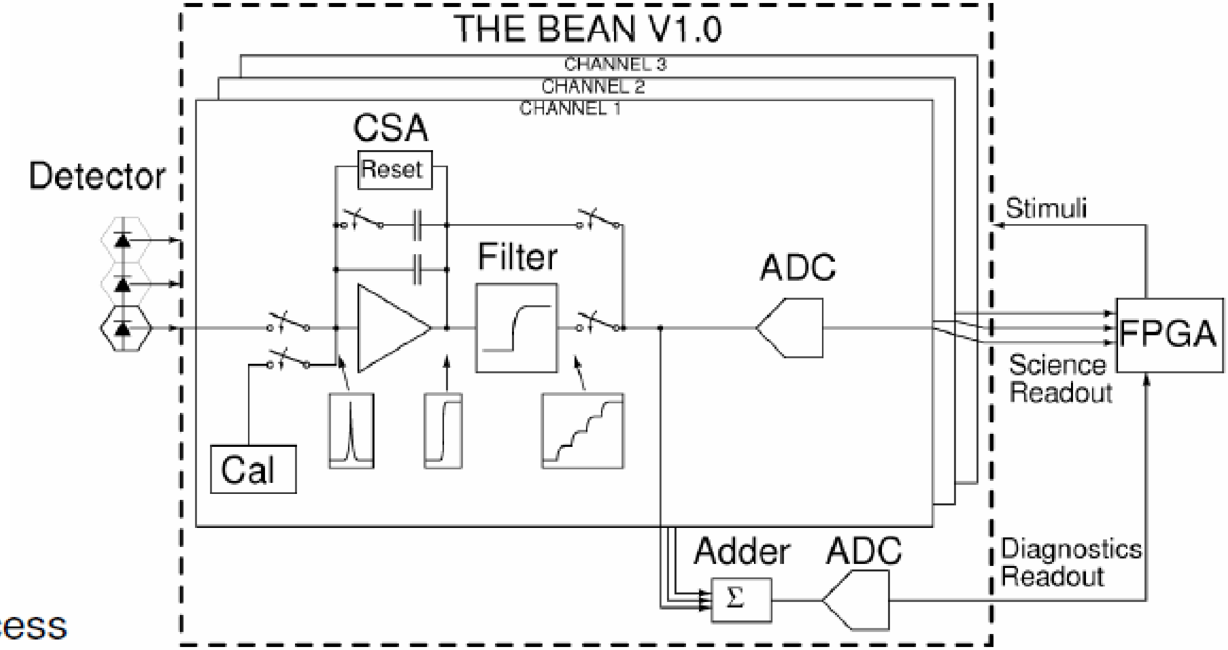
Colorado: Mean background is x100 mean signal

SCIPP: Mean background is x500 mean signal

Have been unable to understand what changed


BEAN ASIC
Development

The Bean Prototype: System-Level Design



- 180-nm TSMC process
- Fully independent channels
- Digital memory to store 32 channels x 2820 x 10-bit results per ASIC
- Precharge circuit for the charge-sensitive amplifier (CSA) to maximize output swing
  - CSA precharger doubles as on-chip pulser for electronics calibration
- SC adder followed by a dedicated ADC
- Gated reset for quick baseline restoration
  - This has noise consequences in DCal mode

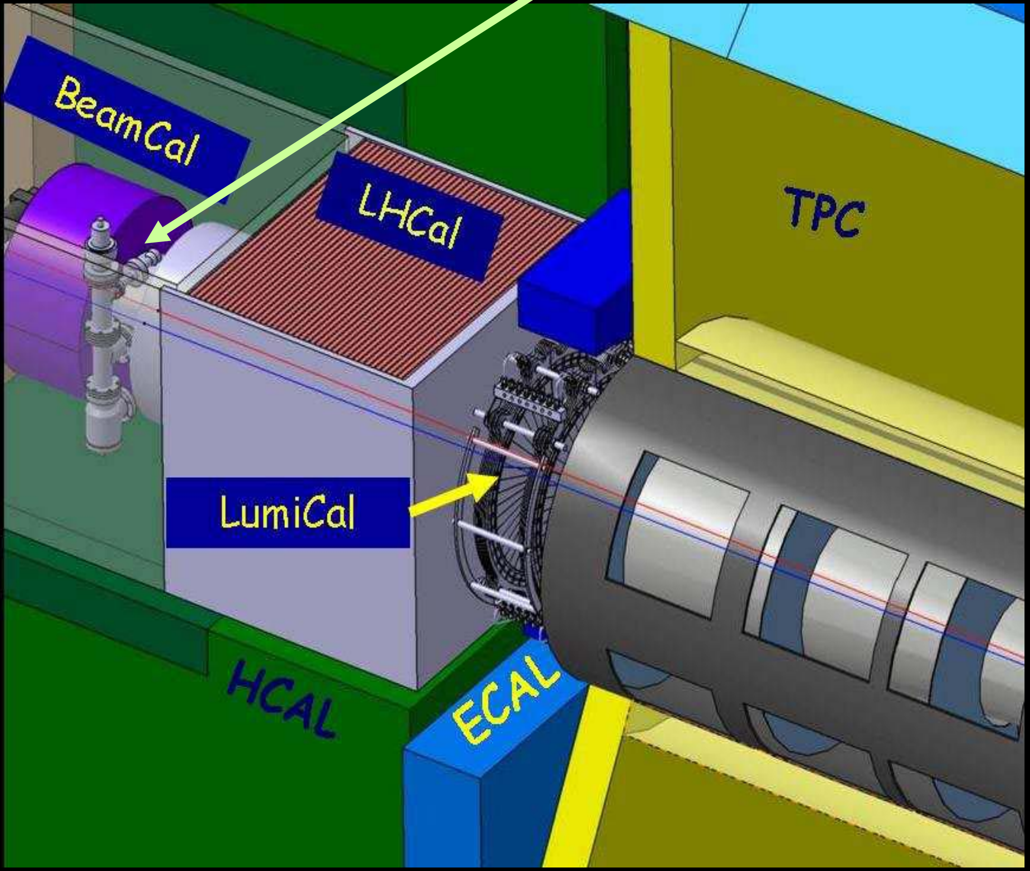
BEAN ASIC: Next Steps

- Incremental improvements to filtering strategy
- Scale from 3 to 32 channels
- Digital back-end (switched capacitor array) for storage of full beam-spill for quiescent readout
- Abusleme has obtained funding from Chilean government; SCIPP has some funding and interested engineer
- Structure in place to proceed to 2nd prototype design in ~6 months (?)

➔ Some support requested (confirm specs)

Radiation Damage in Electromagnetic Showers

The Issue: ILC BeamCal Radiation Exposure



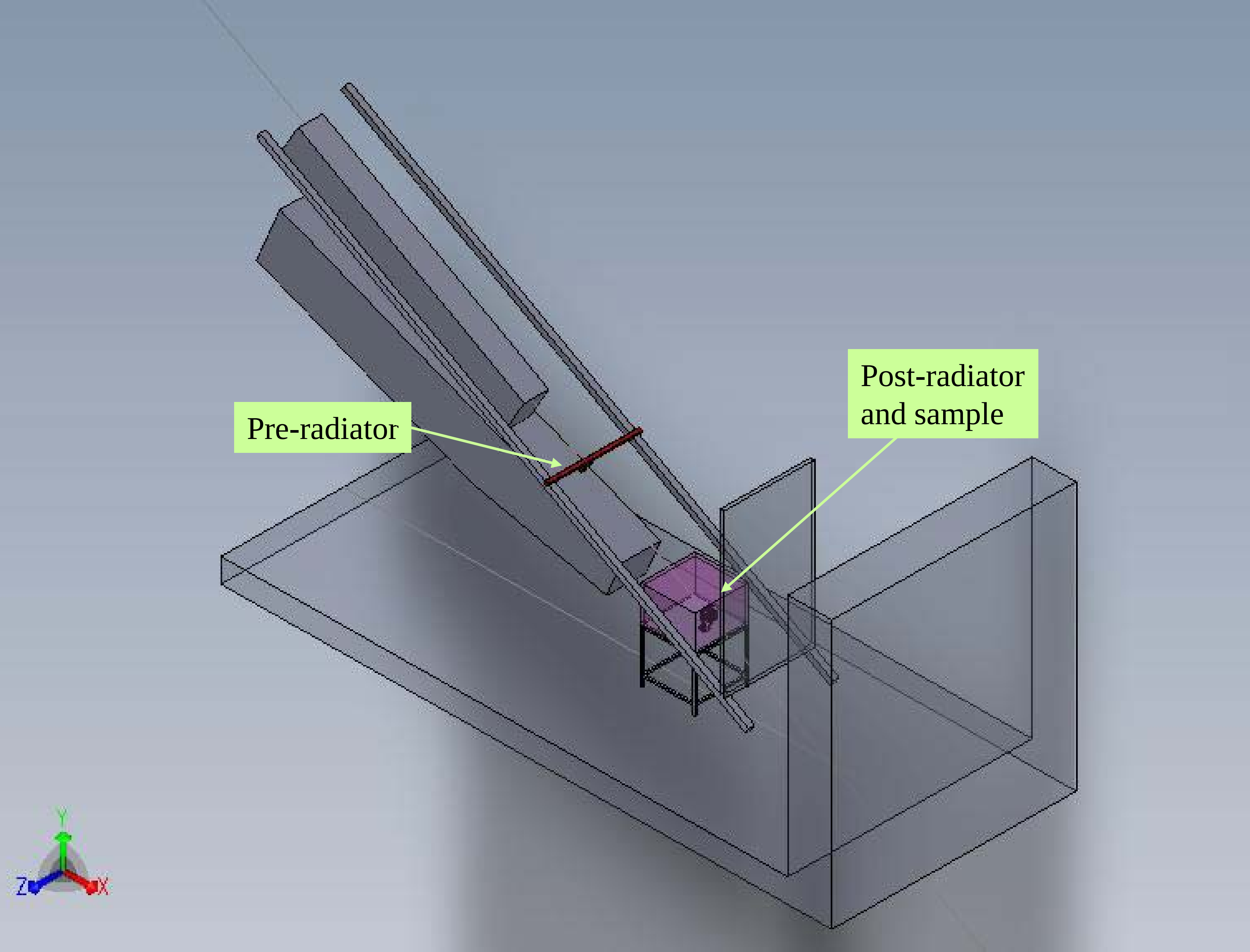
ILC BeamCal:

Covers between 5 and 40 miliradians

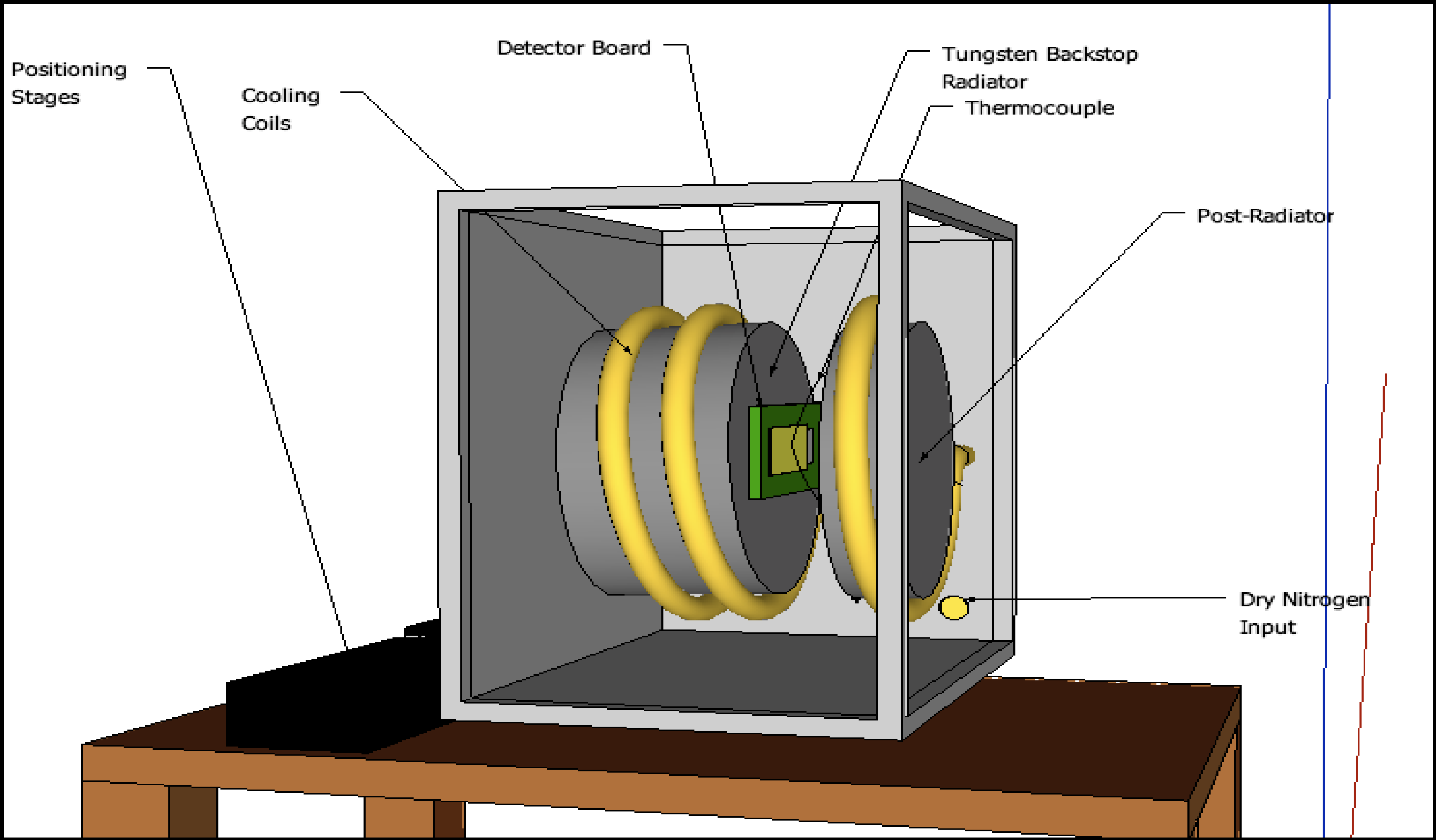
Radiation doses up to 100 MRad per year

Radiation initiated by electromagnetic particles (most extant studies for hadron – induced)

EM particles do little damage; might damage be come from small hadronic component of shower?


Pre-radiator
Post-radiator and sample
Y
Z
X

Hadronic Processes in EM Showers



Status: Thermal prototype under testing at SCIPP

Run Plan

To acheive uniform illumination over 0.25x0.75 cm region (active area of SCIPP's charge collection measurement apparatus), must raster in 0.05cm steps over 0.6x1.5 cm:

$$1\,GRad \approx \frac{650}{I_{beam}(nA)\bullet E_{beam}(GeV)}\,hours$$

e.g. 100 MRad at 1 nA 5 GeV e^- ➔ ~ 10 Hours

Will start with stepped runs up to 100 MRad accumulation. Under discussion w/ ESTB (Karsten) for Spring; keep fingers crossed.

Plans for new work into DBD

- Colorado WMAP-aware stau study (but with caveat)

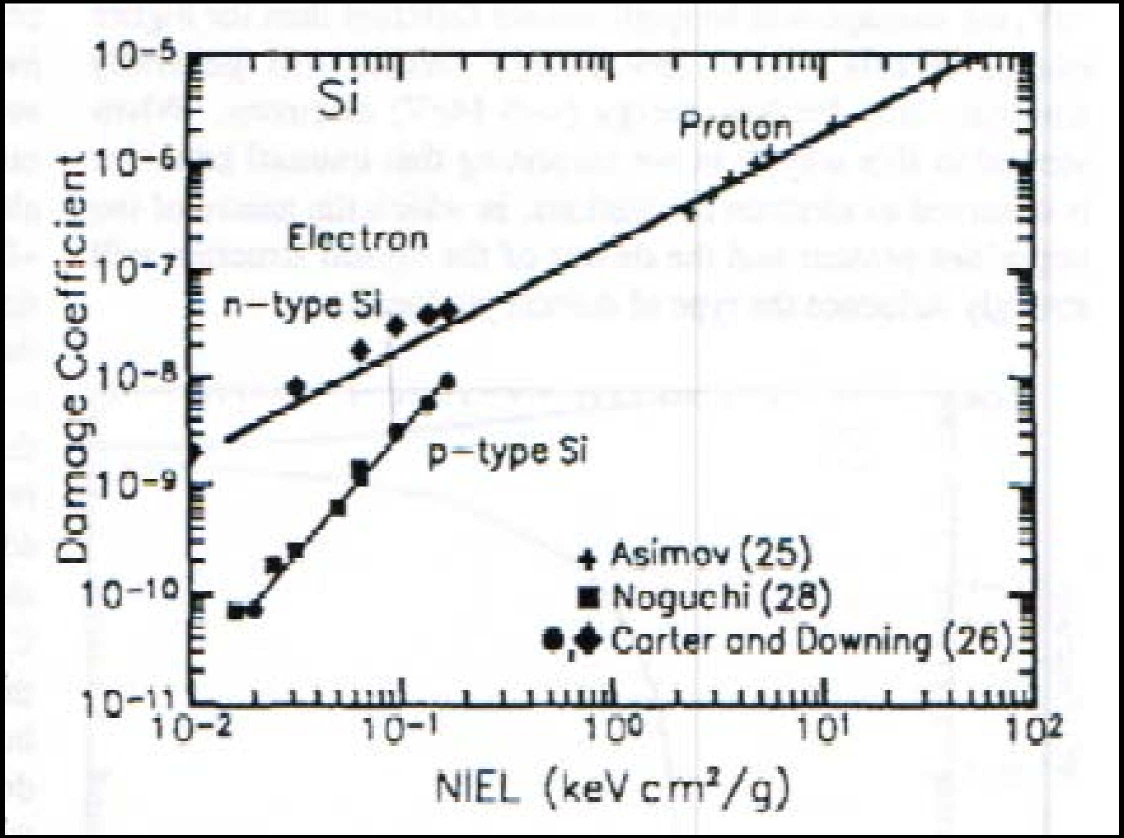
- BeamCal efficiencies for various beam delivery scenarios (beset by same caveat)

- Design of second BEAN (BeamCal resdout ASIC) prototype

- ESTB willing, first set of radiation damage studies with silicon sensors

- Not much of this in hand yet (some mild attention/ support from larger SiD group indicated)

G.P. Summers et al., IEEE Trans Nucl Sci **40**, 1372 (1993)



NIEL	e^- Energy
$2x10^{-2}$	0.5 MeV
$5x10^{-2}$	2 MeV
$1x10^{-1}$	10 MeV
$2x10^{-1}$	200 MeV

Damage coefficients less for p-type for E_{e-} < ~1GeV (two groups); note **critical energy** in W is **~10 MeV**

But: Are electrons the entire picture?

Hadronic Processes in EM Showers

There seem to be three main processes for generating hadrons in EM showers (all induced by **photons**):

• Nuclear (“giant dipole”) resonances

Resonance at 10-20 MeV (~$E_{critical}$)

• Photoproduction

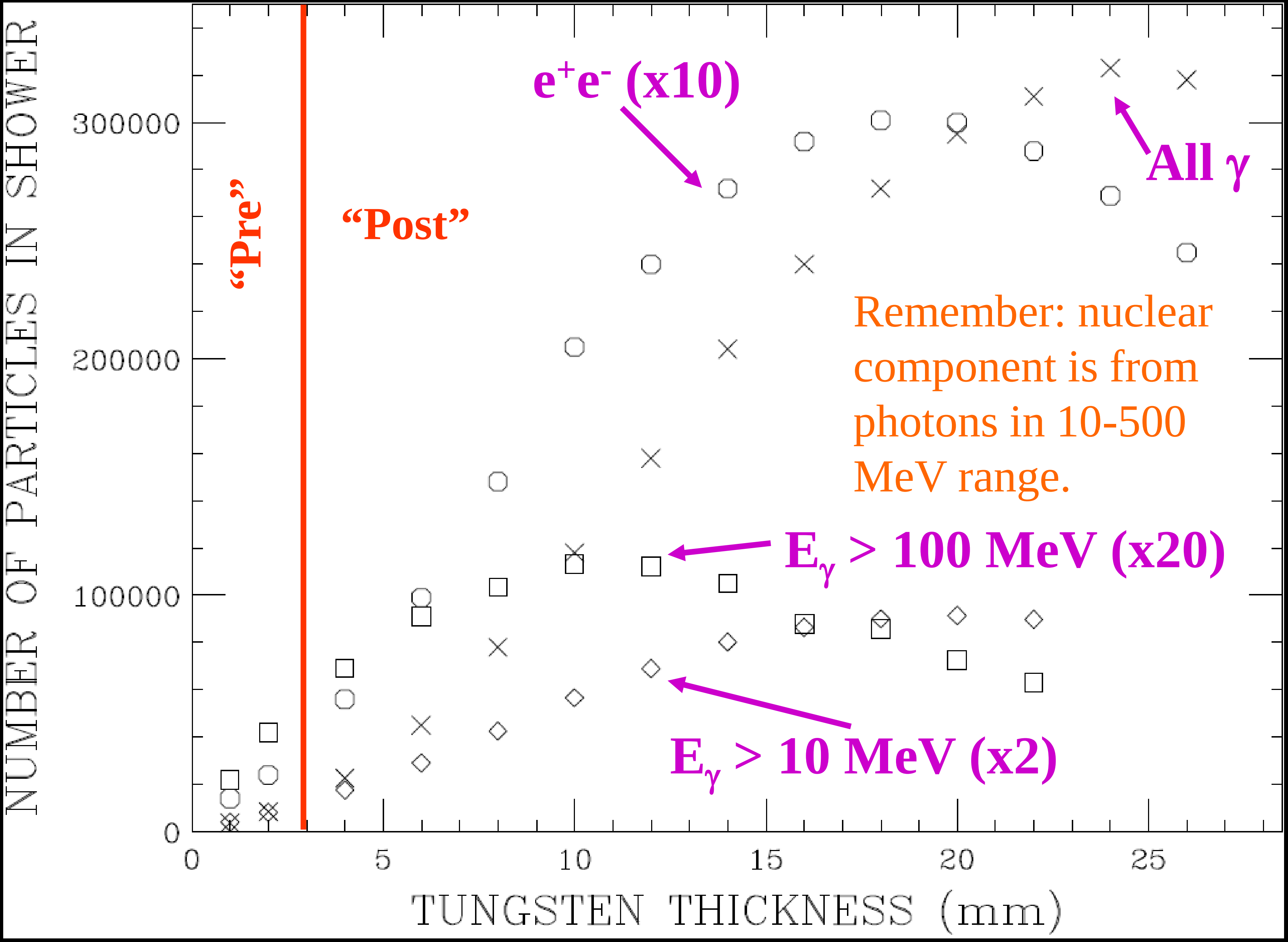
Threshold seems to be about 200 MeV

• Nuclear Compton scattering

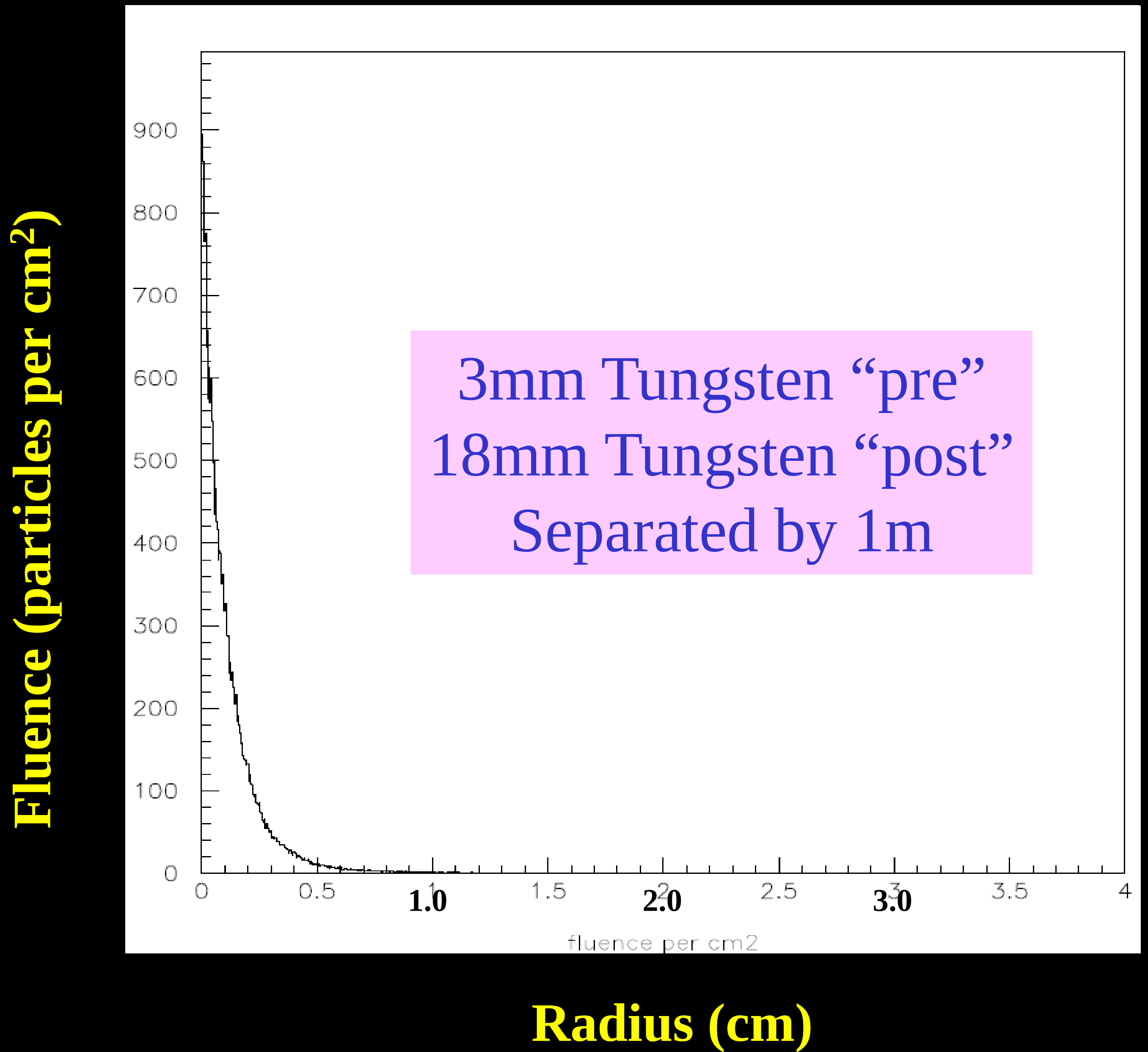
Threshold at about 10 MeV; Δ resonance at 340 MeV

➔ These are largely isotropic; must have most of hadronic component develop near sample

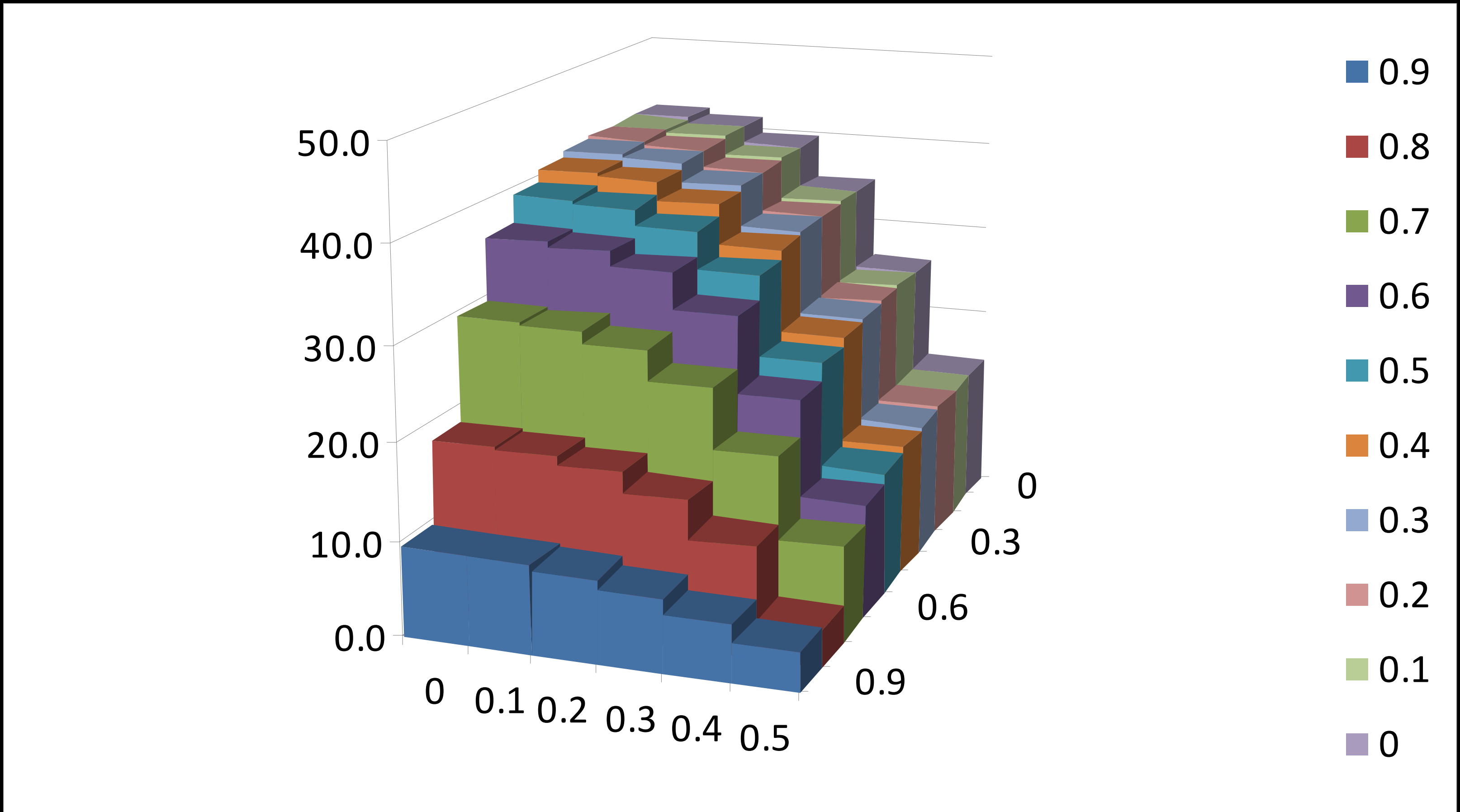
5.5 GeV Shower Profile



Proposed split radiator configuration

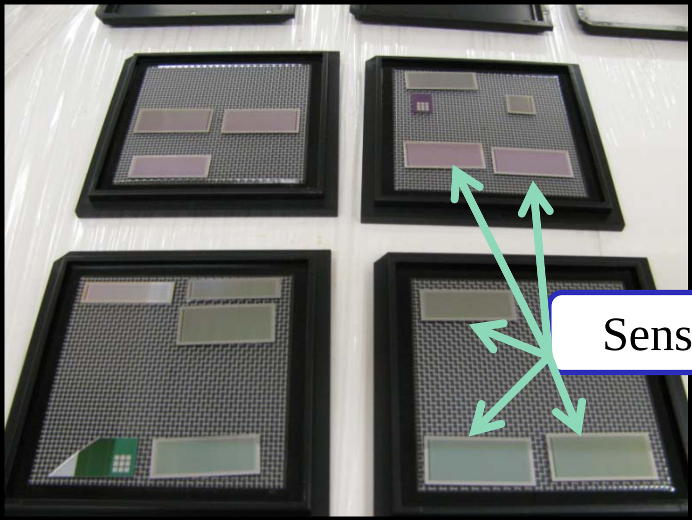


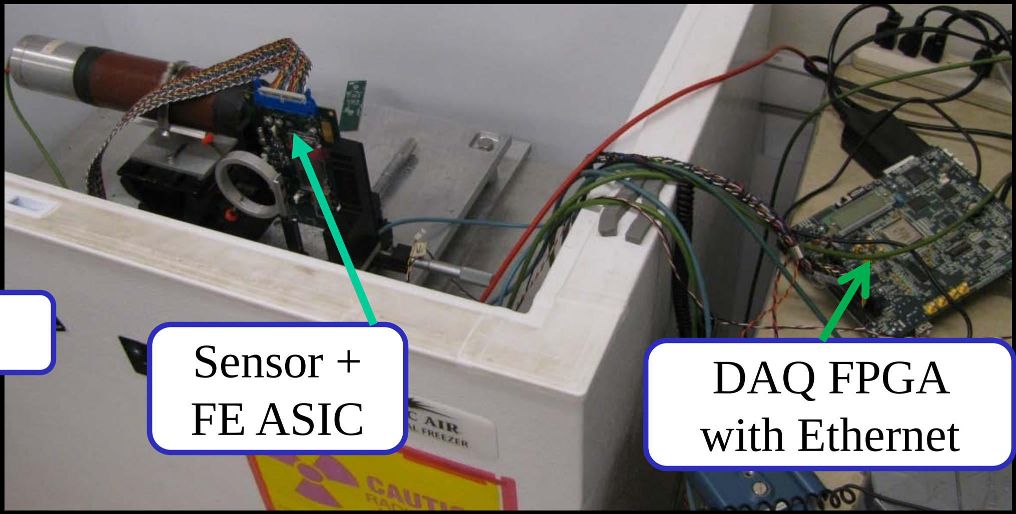
Illumination Profile



Uniform to ± 10% over (3x6)mm area

Charge Collection Apparatus





Need to upgrade CC Apparatus for multiple samples

- New detector board to modularize system (connector rather than bonds)
- Two pitch adapters (lithogaphic) to accommodate different detector pitches
- Modications to ASIC board
- Design review Monday 12/19

The BEAN (Beamcal) Chip

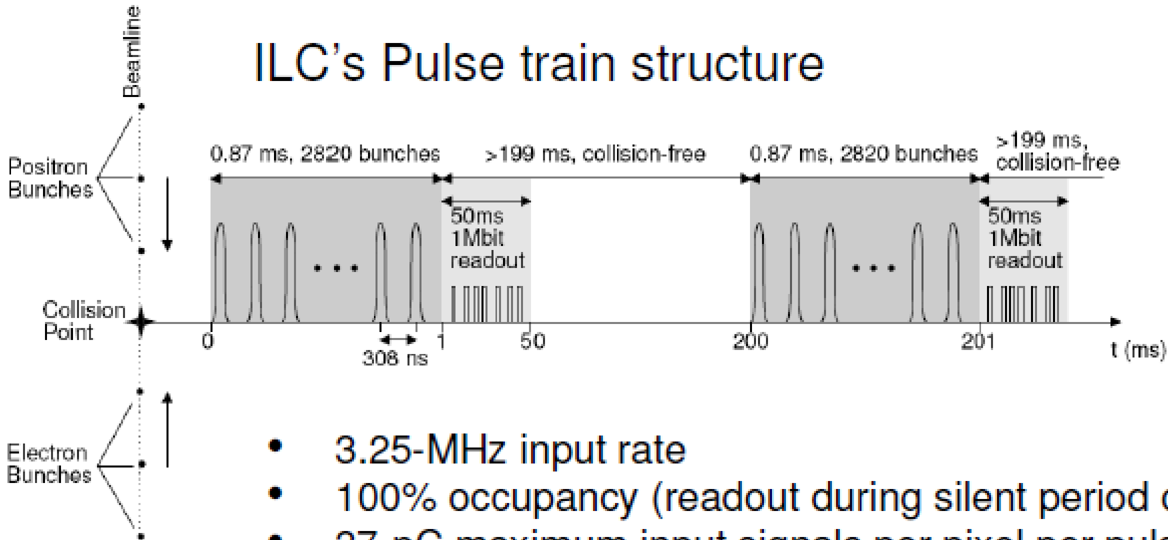
Main Proponent:

Angel Abusleme, Prof. of Electrical Eng.

Pontificia Universidad Católica de Chile

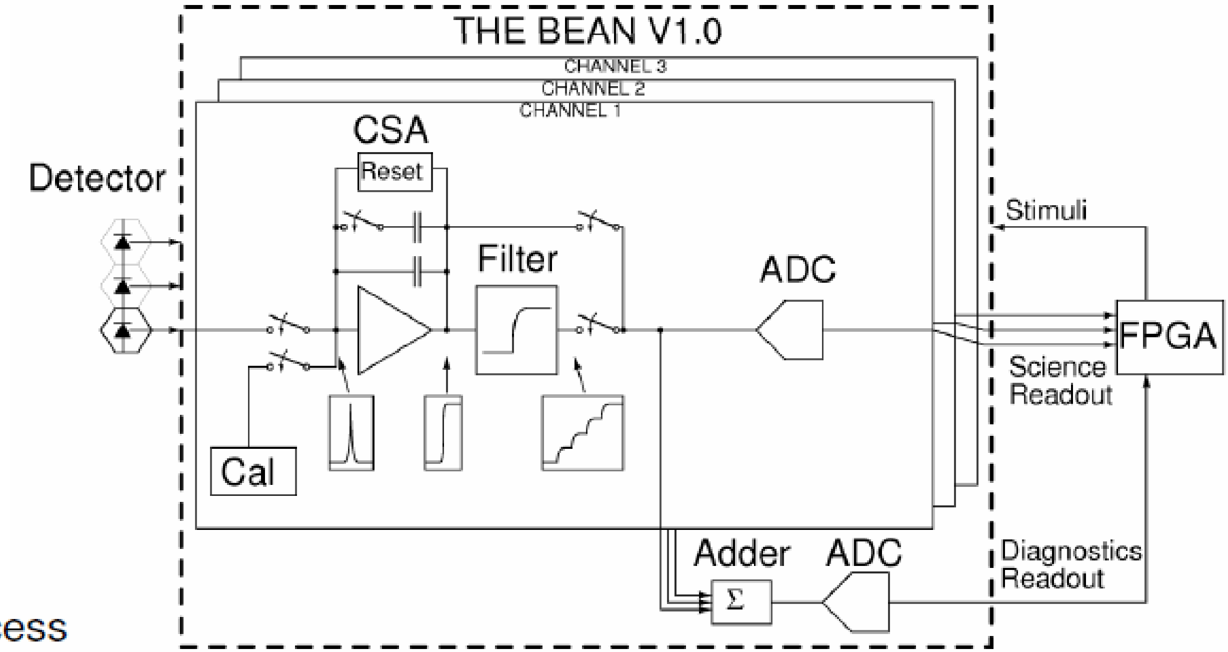
BeamCal Instrumentation ASIC Specs

ILC's Pulse train structure



- 3.25-MHz input rate
- 100% occupancy (readout during silent period of pulse trains)
- 37-pC maximum input signals per pixel per pulse[1]
- 40-pF input capacitance[1]
- 10-bit resolution
- Dual gain (50x) for different modes of operation: standard data taking (SDT) and detector calibration (DCal)
  - SDT: large input signal; slew rate, bandwidth and adder challenges
  - DCal: smaller input signal; noise, baseline restoration and linearity challenges (tighter design space)
- 32 channels per chip
- Full-chip output (8-bit, 1-μs latency) for beam diagnostics
- Radiation tolerance to 1 Mrad total dose

The Bean Prototype: System-Level Design



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- Fully independent channels
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- Precharge circuit for the charge-sensitive amplifier (CSA) to maximize output swing
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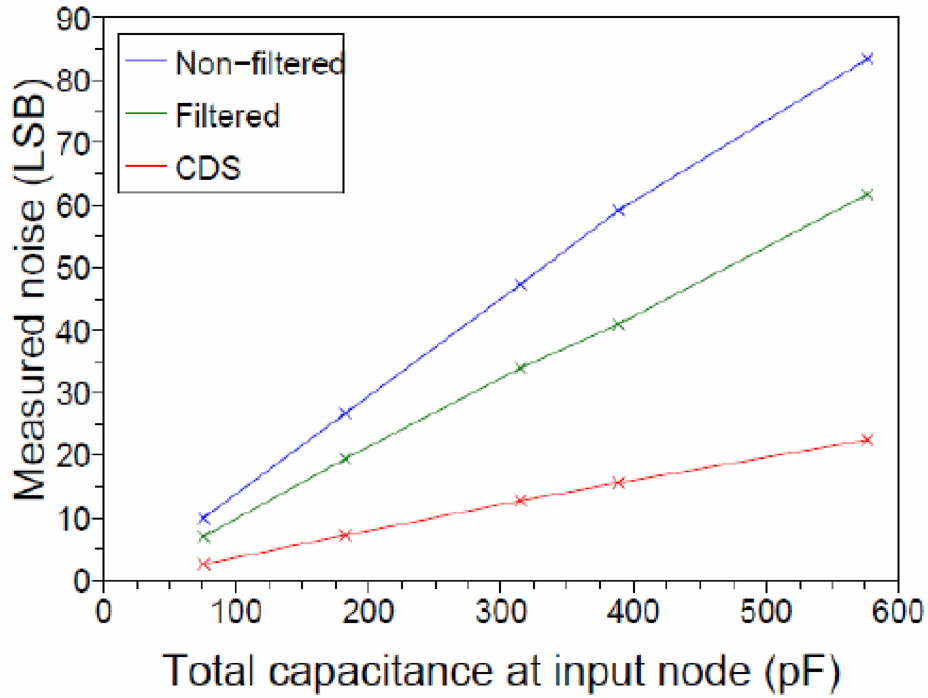
  - This has noise consequences in DCal mode

Noise Filtering, Increasing Input Capacitance

Test done at 1.63 MHz clock (32x slower than nominal speed)

- Filter reduces series noise by 26% (fixed reset scheme)
- Filter + digital CDS reduces series noise by 73%
- Measurements deviate 0.52% from weighting functions calculations



CDS → Correlated double sampling

BEAN ASIC: Next Steps

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- Scale from 3 to 32 channels
- Digital back-end (switched capacitor array) for storage of full beam-spill for quiescent readout
- Abusleme has obtained funding from Chilean government
- Schumm has interested SCIPP consulting engineer
- Mode of collaboration discussed

➔ Awaiting updating of readout specs

BeamCal Simulations

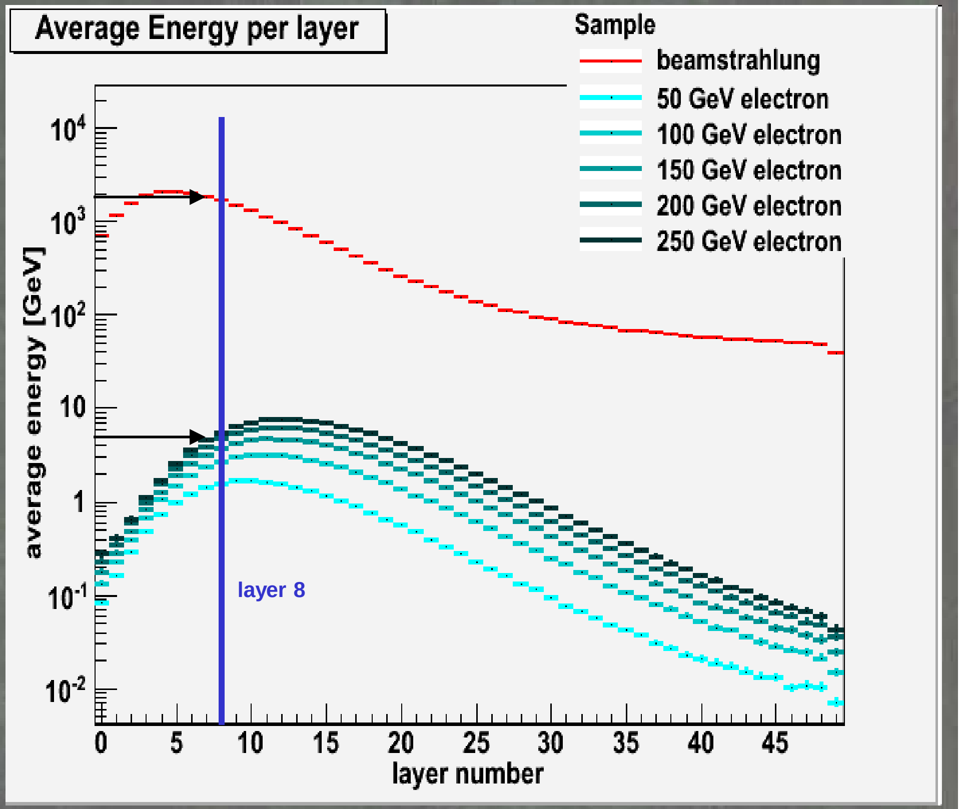
Goal:

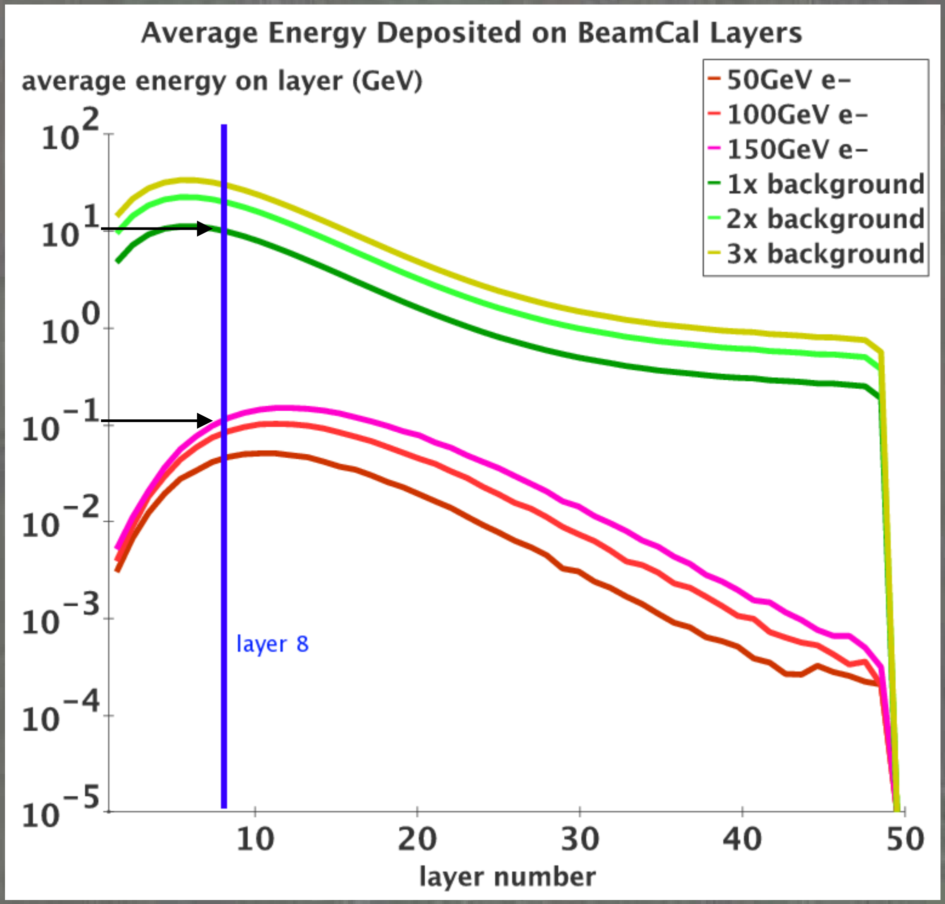
- **Reproduce Colorado studies of BeamCal electron ID efficiency/purity**
- **Determine sensitivity to increased/decreased background accumulation rates (different beam-delivery configurations)**

Reconstruction Algorithm

- Choose seed layer
- Subtract mean background from all pixels
- Sum energy in sliding window (“tile”) of NxN beamcal pixels (N is optimized)
- Chose highest 50 tile depositions in layer [determine efficiency that electron is one of them]
- Reject spurious tiles via longitudinal patterns

Signal to Noise Comparison





Colorado: Mean background is x100 mean signal

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Have been unable to understand what changed

BeamCal Simulations: Next Steps

- Any thoughts on nature/origin of discrepancy between Colorado/SCIPP signal/background files?
  - Calibration
  - Configuration
  - Beam conditions…

- For now, trying to develop Colorado-like analysis with degraded S/N

- Outcome not clear

➔ Plea for support

Conclusions

- **Gearing up for radiation damage studies in realistic setting (Spring? Under consideration)**
- **Resources in place for further development of BEAN BeamCal readout ASIC; need to review specs**
- **Trouble reproducing canonical BeamCal reconstruction efficiency/purity traced to degraded signal/noise in the simulation (?)**

➔ Support sought on latter two issues

Backup

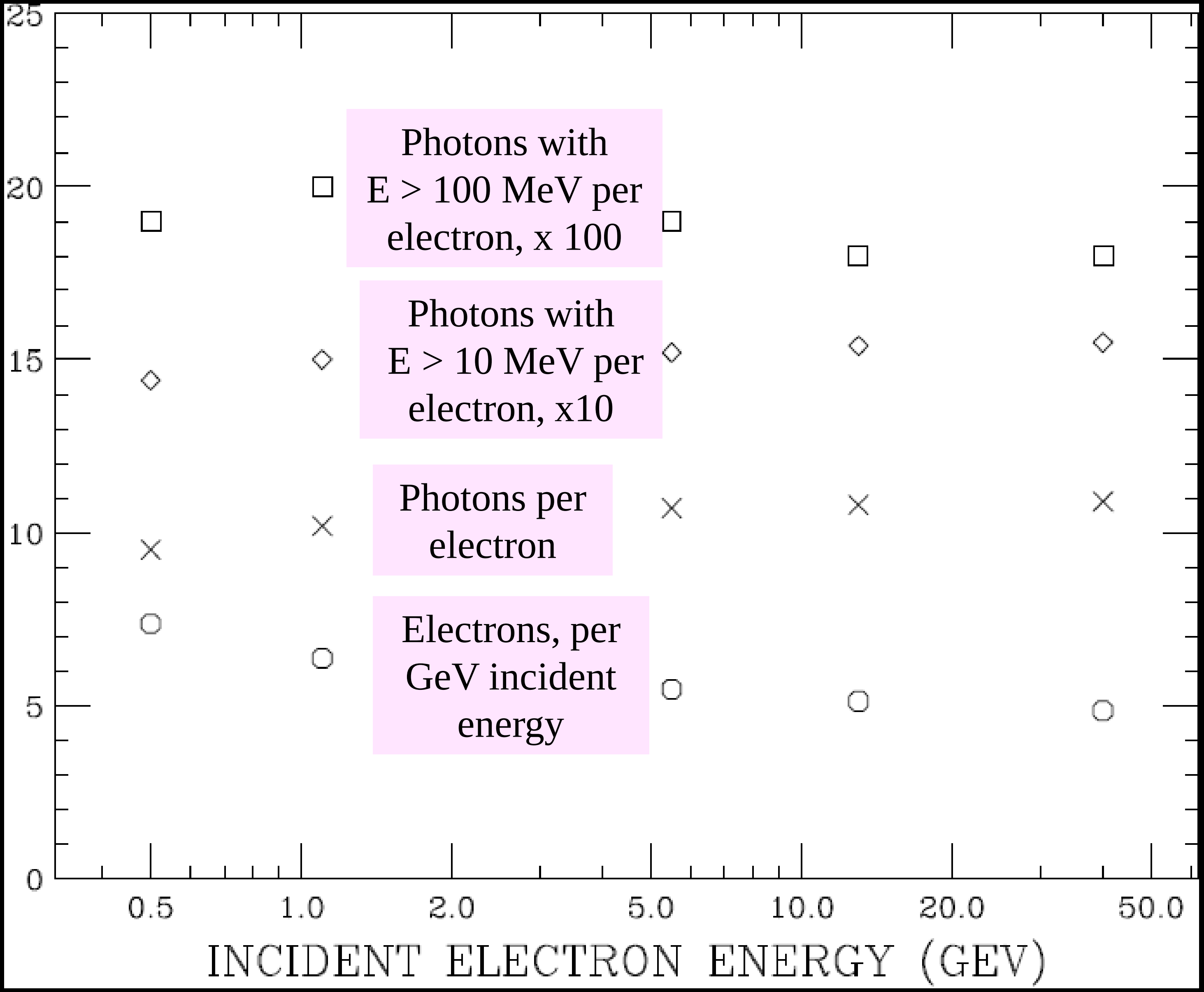
Parameters required for Beam Tests

To the presenter at the ESTB 2011 Workshop: please, fill in the table (at best) with the important parameters needed for your tests

Beam parameters	Value	Comments
Particle Type	electron	
Energy	Maximum	
Rep Rate	Maximum	
Charge per pulse	Maximum	
Energy Spread	Not a concern	
Bunch length rms	Not a concern	
Beam spot size, x-y	Large is helpful	Up to ~1 cm rms
Others (emittance, …)	Not a concern	

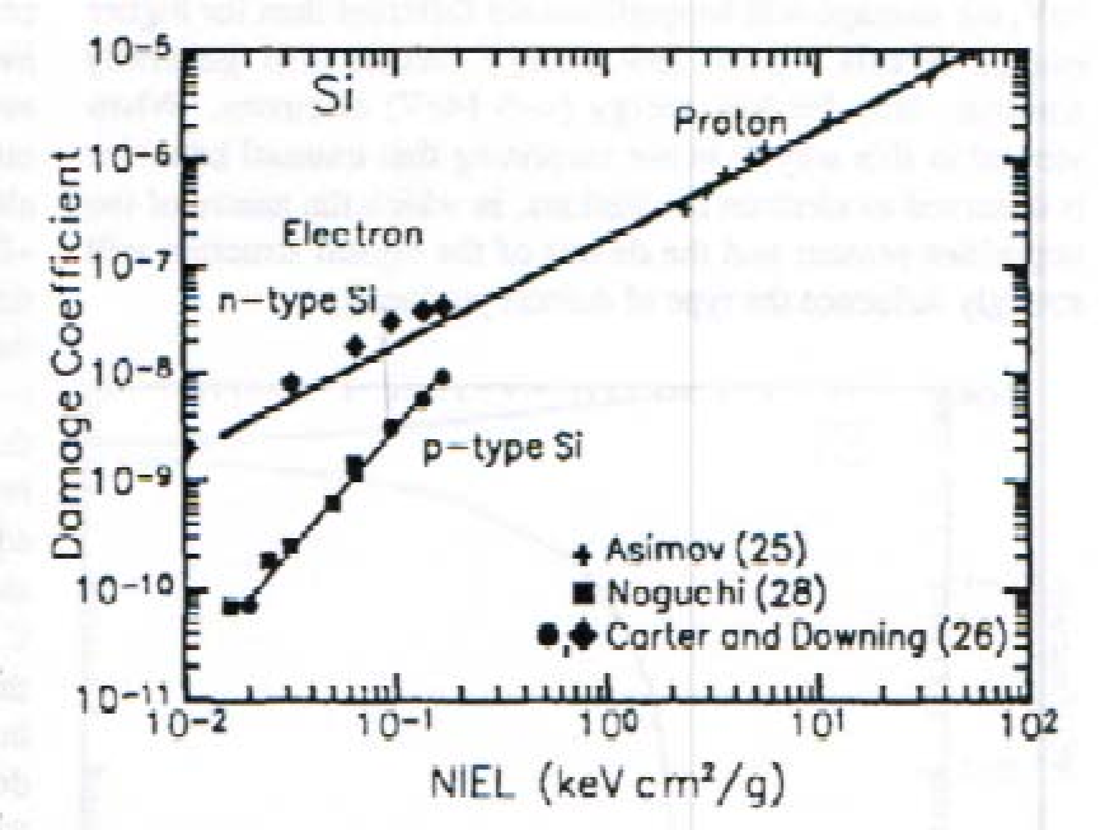
Logistics	Requirements
Space requirements (H x W x L)	1m x 1m x 1m (plus 20cm x 20cm x 20cm 1-2 meters upstream)
Duration of Test and Shift Utilization	Depends on available current
Desired Calendar Dates	CY 2012 (flexible)

Shower Max Results



➔ **Photon production ~independent of incident energy!**

G.P. Summers et al., IEEE Trans Nucl Sci **40**, 1372 (1993)



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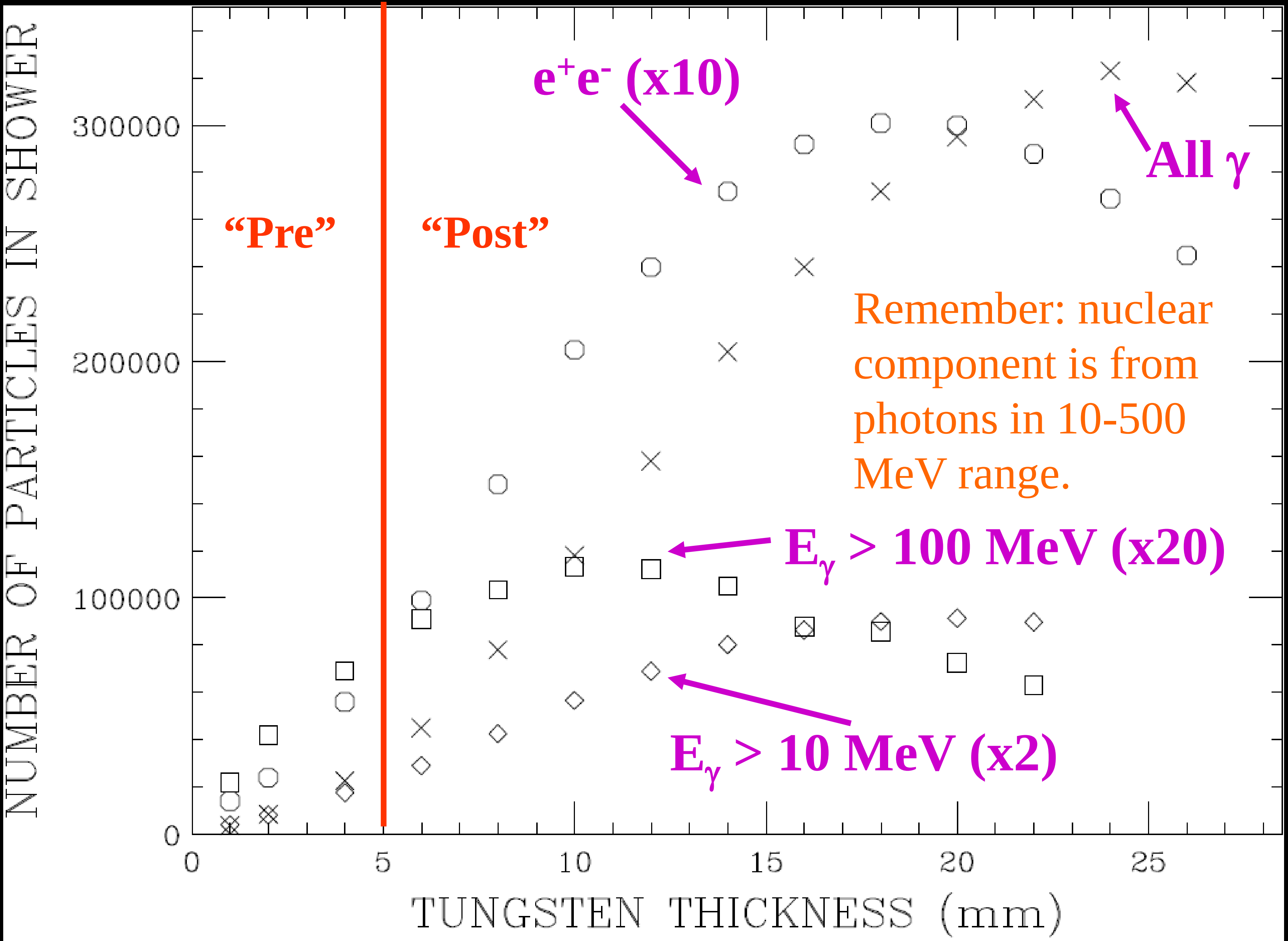
Damage coefficients less for p-type for E_{e-} < ~1GeV (two groups); note **critical energy** in W is **~10 MeV**

But: Are electrons the entire picture?

5.5 GeV Shower Profile



Fluence (e^- and e^+ per cm^2) per incident 5.5 GeV electron (5cm pre-radiator 13 cm post-radiator with 1m separation)

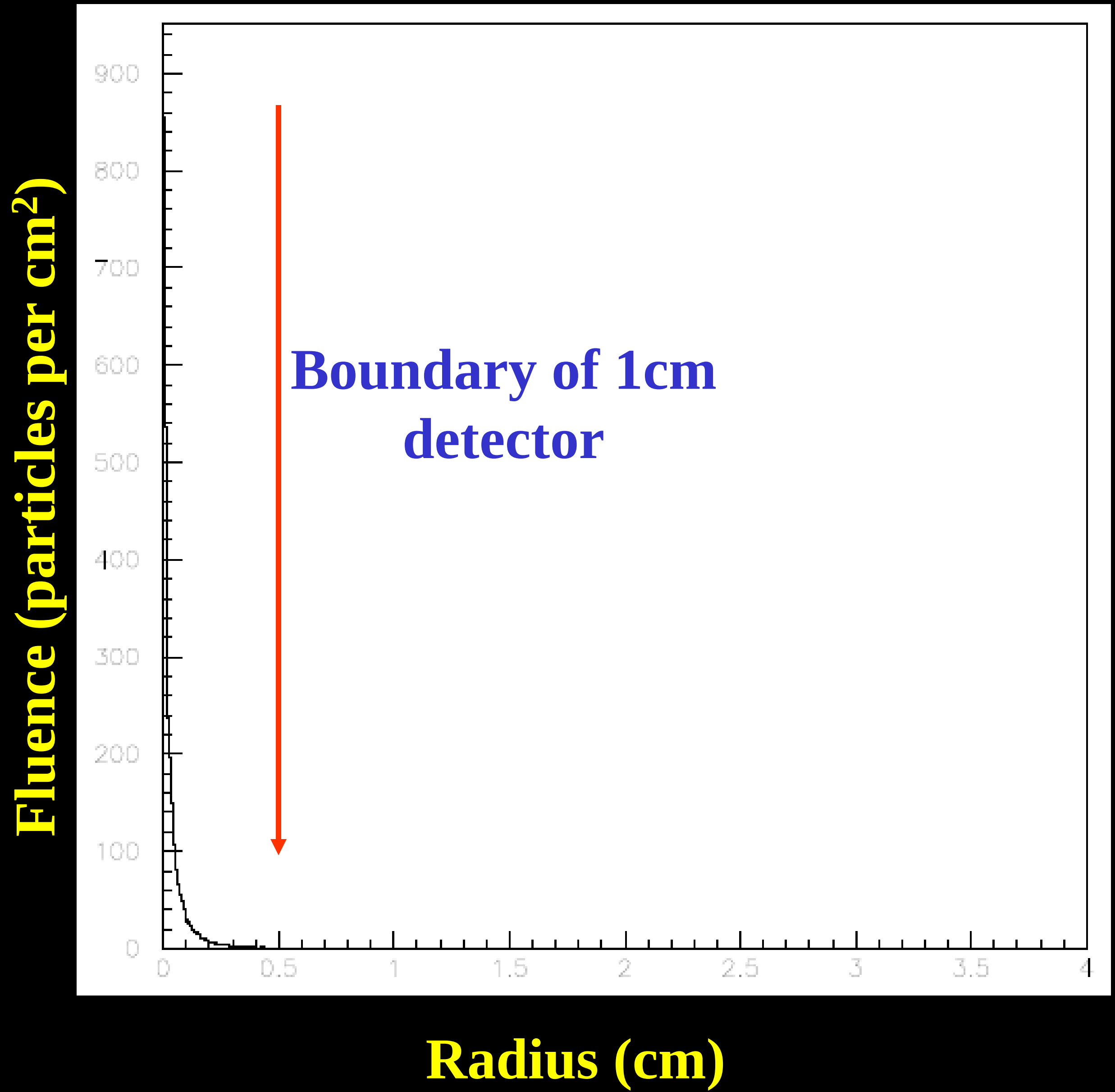
Center of irradiated area

¼ of area to be measured

¼ of rastoring area (0.5mm steps)

mm from center	0	1	2	3	4
0	13.0	12.8	11.8	9.9	8.2
1	13.3	12.9	12.0		
2	13.3	12.9	12.0		
3	13.1	12.8	11.8		8.2
4	13.0	12.6	11.7		
5	12.3				
6	11.6		10.7		
7	10.4				
8	8.6		8.0		6.4

5.5 GeV Electrons After 18mm Tungsten Block



Not amenable for uniform illumination of detector.

Instead: split 18mm W between "pre" and "post" radiator separated by large distance

Caution: nuclear production is ~isotropic ➔ must happen dominantly in "post" radiator!

NIEL (Non-Ionizing Energy Loss)

Conventional wisdom: Damage proportional to Non-Ionizing Energy Loss (**NIEL**) of traversing particle

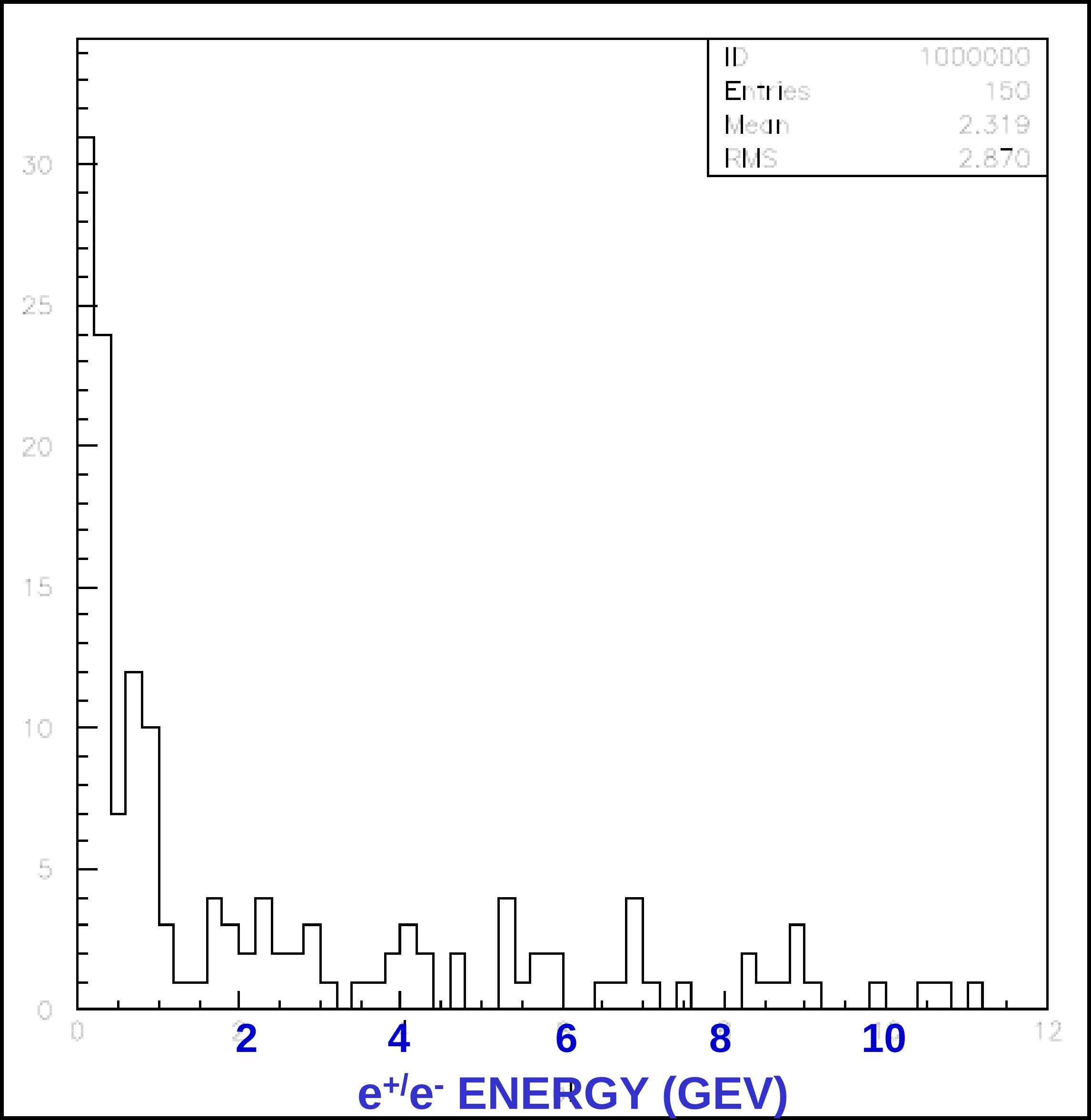
NIEL can be calculated (e.g. G.P. Summers et al., IEEE Trans Nucl Sci **40**, 1372 [1993])

At $E_c^{Tungsten} \sim 10$ MeV, **NIEL** is 80 times worse for protons than electrons and

- **NIEL** scaling may break down (even less damage from electrons/positrons)
- **NIEL** rises quickly with decreasing (proton) energy, and fragments would likely be low energy

➔ Might small hadronic fractions dominate damage?

BeamCal Incident Energy Distribution



Wrap-up

Worth exploring Si sensors (n-type, Czochralski?)

Need to be conscious of possible *hadronic* content of EM showers

Energy of e^- beam not critical, but intensity is; for one week run require E_{beam}(GeV) x I_{beam}(nA) > 50

SLAC: Summer-fall 2011 ESA test beam with E_{beam}(GeV) x I_{beam}(nA) $\geq$ 17 – is it feasible to wait for this?

Rates (Current) and Energy

Basic Idea:

Direct electron beam of moderate energy on Tungsten radiator; insert silicon sensor at shower max

For Si, 1 GRad is about 3 x 10^{16}/cm^2, or about 5 mili-Coulomb/cm^2

➔ Reasonably intense moderate-energy electron or photon beam necessary

What energy…?