# GLAST ACD Segmentation Trade Study
# March 6, 2001
## Analysis by Alex Moiseev and J. F. Ormes

**ACD Subsystem**

**ACD segmentation and the efficiency requirement at 300 GeV**

**March 13, 2001 IDT phone call**

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# Study Motivation

- **The goal is to understand the impact on the LAT effective area and geometry factor if the number of ACD tiles is reduced.**
- **Since the overall ACD dimensions are frozen, reducing the tile number implies using larger tiles.**
- **Larger tile area results in higher self-veto probability, which reduces the GLAST sensitivity, increasingly at higher energy. The goal of the study is to determine the importance of this effect in a specific case.**
- **Current ACD design has 145 tiles (290 channels).**
  - **An additional 16 (TBR) channels for scintillating fibers tapes if needed to seal the gaps.**
- **Reducing number of tiles would save**
  - **Money and time - handling, testing and integrating.**
  - **Power, parts and complexity (and a little mass)**
- **Remove any remaining concerns about "real estate" for electronics**

# Not a background study

- Eventually, the impact of any change is segmentation must be vetted in GLASTSIM.
  - There is no efficient way to do this at the present time.
  - Background rejection does have cuts on number of tiles hit but because of the way this cut is used, changing the segmentation will have a negligible impact (S. Ritz, 2000).
- Otherwise the segmentation in the bottom two rows is not currently used in the background cuts.
- Selection/background rejection cuts for high energy electrons are now being developed by Taro Kotani and Steve Ritz.
  - Need 0.9 from the tracker to go with 0.9997 ACD efficiency to reach required <1 false photon in $3 \times 10^4$ electrons
  - 0.9 is just the live fractional area of a tracker layer
    - Probably ok for top entry
    - Side entry requires some “fiducial volume” cut
      - No one has yet validated this number by simulation or determined the effect of this cut on effective area.

# Segmentation trade study

- **25 tiles on the top, 120 on the sides**
  - **Lower two rows dominate**
  - **80 tiles nearest calorimeter**
- **Do analysis at 300 GeV**
  - **The self-veto problem increases as a function of energy**
  - **The required depth of calorimeter to obtain a given energy resolution also increases as a function of energy**
- **Self-veto and hence ACD segmentation affects both projected effective area $A_p$ and geometry factor $A\Omega$, "G"**
- **Science most affected: search for gamma ray lines**
  - **Point sources of dark matter**
    - **Galactic center**
    - **Clumps in the halo**
  - **Isotropic high latitude diffuse component from galactic halo**

# Sensitivity to gamma-ray lines

GLAST sensitivity for the "dark matter point source" such as the Galactic Center

$$I_\gamma = \frac{n_\sigma}{0.68\sqrt{A_{cal}\, f_t T}} \sqrt{2\eta E_\gamma \left(F_{GC} + F_b \Delta\Omega\right)}$$

and for a high latitude diffuse component

$$I_\gamma = \frac{n_\sigma}{0.68} \sqrt{\frac{2 F_b \eta E_\gamma}{A_{cal} \Omega T}}$$

- The lower $I_\gamma$, the better.
- Off axis, calorimeter gets thicker, and $\eta$ decreases but so does A.

$I_\gamma$ and $E_\gamma$ are the line intensity and energy,
$n_\sigma$ is the desired significance (in $\sigma$),
$\eta = \Delta E / E_\gamma$ is the relative energy resolution (half width containing 68% of events),
$2\eta E_\gamma$ is the bin width,
$A_{cal}$ is the sensitive area,
T is the observation time,
$f_t$ is the fraction of time (~0.25) during which the source lies in a good direction,
$F_{GC}$ is the differential gamma-radiation from the source,
$F_b$ is the background flux,
$\Delta\Omega = 10^{-3}$ sr is the point-spread function for the calorimeter, and
$A_{ca\lambda}\Omega$ is the geometric factor.

# Tile segmentation requirement

- **Requirement flowdown from SRD**
  - **Effective area on axis: >8000 cm$^2$, goal >12,000 cm$^2$**
    - Peak, 1-10 GeV, including loss due to background rejection
    - Energy resolution: 0.1-10 GeV, <10%, goal 8%
  - **Energy resolution >60$^o$, >10 GeV: <6%, goal <3%**
    - SRD does not specify the effective area we need at >60$^o$
      - Explanatory footnote: "Effective area for side incidence is 0.1 to 0.2 that of normal incidence for high resolution measurements."
    - **$\Delta$E/E Goal implies calorimeter depth of 15-18 (TBR) Xo**
- **Don't forget electron background rejection**
  - **Selection: we must require at lease one tracker layer with "no- hit" be in the path of these events and the ACD must not be "hit" either.**

# LAT systems specification

- **LAT Performance Specification 5.2.1**

  **Energy range:** 20 MeV to >300 GeV,

  Aeff >300 $cm^2$ (TBR) at 20 MeV, >3000 $cm^2$ at 100 MeV, >6400 $cm^2$ (TBR) at 300 GeV.

  **Goal:** >1000 $cm^2$ at 20 MeV, >8000 $cm^2$ at 100 MeV and >9500 $cm^2$ at 1 TeV.

- **LAT Performance Specification 5.2.2**

  **Resolution:** normal incidence gamma rays

  <50% (TBR) 20 - 100 MeV, <10% 0.1 - 10 GeV, <20% (TBR) 10 - 300 GeV.

  **Resolution goal:** >60 degrees off-axis: <3% above 10 GeV.

- **LAT Performance Specification 5.2.3**

  **Peak effective area:** >8000 $cm^2$ after background rejection

  **Peak effective area goal:** >10000 $cm^2$ after background rejection

# ACD Level 3 specification

**As of today, the DRAFT ACD Level 3 subsystem specification says:**

- **5.6: False VETO due to Calorimeter Backsplash**
  - **<20% of otherwise accepted gamma-ray events at 300 GeV shall be rejected by false VETOs due to calorimeter backsplash**

  **Can meet the LAT Requirement: $A_{eff}$ >6400 cm$^2$ (TBR) at 300 GeV.**

  **Goal: >9500 cm$^2$ at 1 TeV.**

- **If peak $A_{eff}$ at 10 GeV meets 8000 cm$^2$ spec, then 0.8 x 8000 = 6400 cm$^2$.**
  - **This led to >0.8 ACD Level 3 specification**

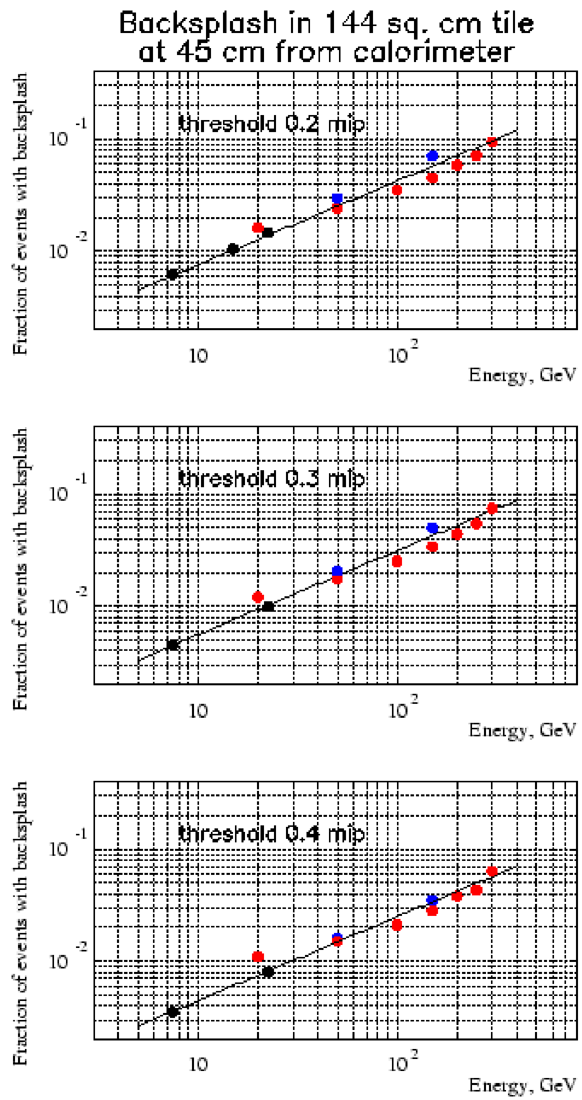
# ACD: Backsplash Measurements

- **Backsplash measured from 5 to 300 GeV (SLAC and CERN)**
- **Agrees with simulations to approximately factor of 2**
  - **Spectra are different**
  - **Angular distributions are different**

$$P_{Backsplash} = \left\{0.85 * \frac{0.3}{E_{thr}} + 0.15\right\} * 10^{-3} * \frac{A}{144} * \left(\frac{55}{x+10}\right)^2 * E^{0.75}$$

Where E is the energy of incident electron/photon in GeV
$E_{thr}$ is the threshold value in units of *mip*
X is the distance from the top of calorimeter
A is area in $cm^2$
$P_{backsplash}$ is the probability that there was an energy deposition above $E_{thr}$ in 1cm scintillator

- SLAC-97
- CERN-99
- CERN-99 (ACCESS calorimeter)

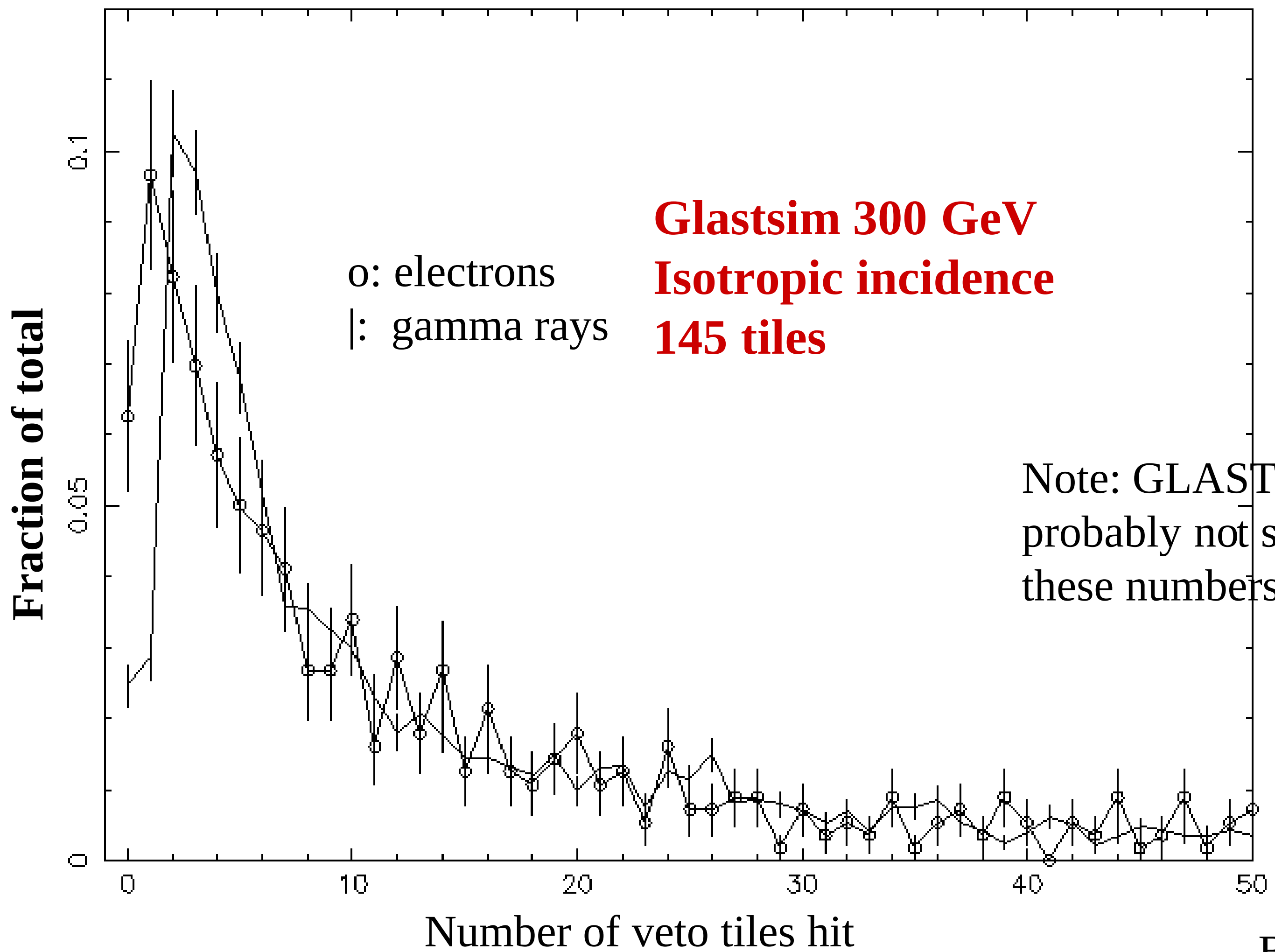


# Simulation studies

- GEANT-3 and GLASTSIM studies were made to compare with measurements of backsplash ($E_{deposit}$ > 200 keV)
  - Unresolved differences at high angle (90$^o$ to beam):
    - GEANT sims give 2 x more than observed
  - GLASTSIM gives 2.5 times fewer photons crossing the ACD than GEANT
  - Unresolved differences near beam in GLASTSIM (ok in GEANT)
    - Did not produce observed isotropic distribution
    - Did not produce energy dependence
- GEANT-3 studies by Alex
  - SLAC beam test '97
    - Sims 40% below measured
    - Reproduce proper angular distribution within 60$^o$ of beam
  - CERN test with deeper 40Xo Pb/SciFi calorimeter
    - Sims ~25-40% low at 20 GeV decreasing to 10% at 1 TeV
    - Sims suggest steeper slope than observed
- GEANT self-veto probabilities are <40% low.
  - GLASTSIM would be even lower

Design segmentation to measurements.

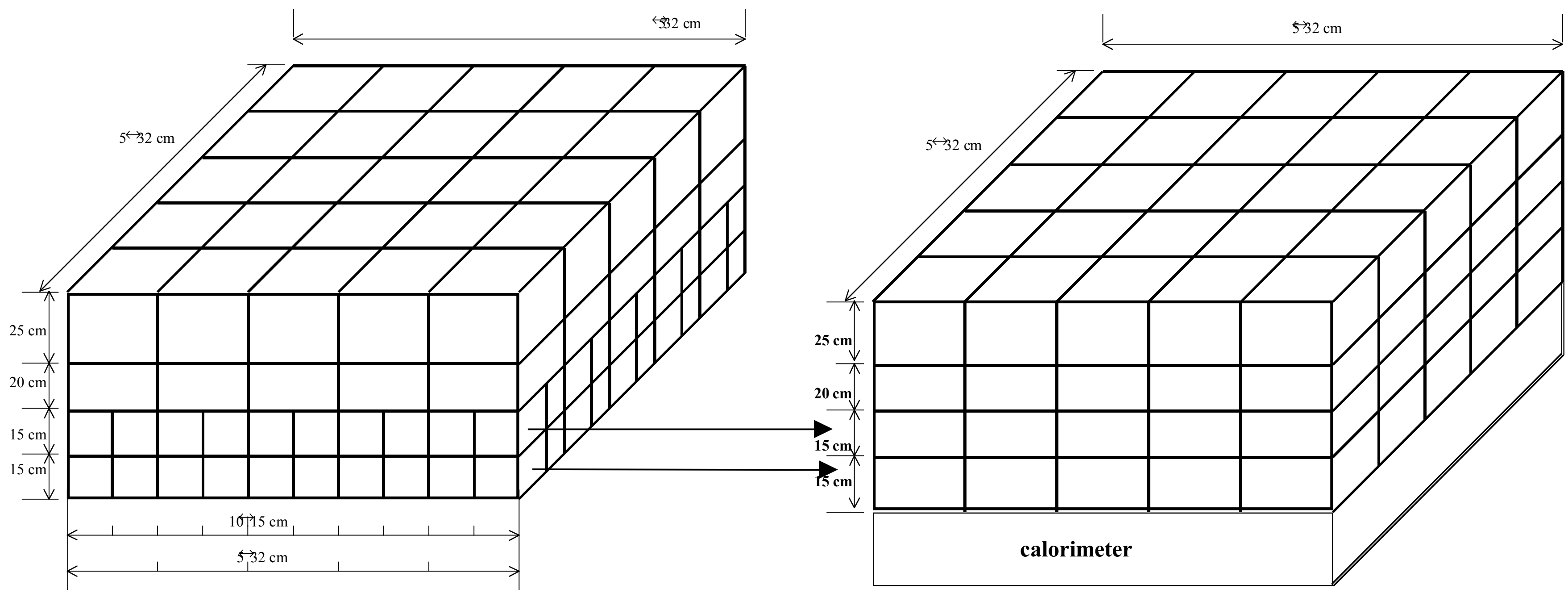
# Distribution of number of tiles hit




Note: GLASTSIM is probably not simulating these numbers correctly.

By Taro Kotani

# Design configurations




Baseline (145)

Reduced segmentation (105)

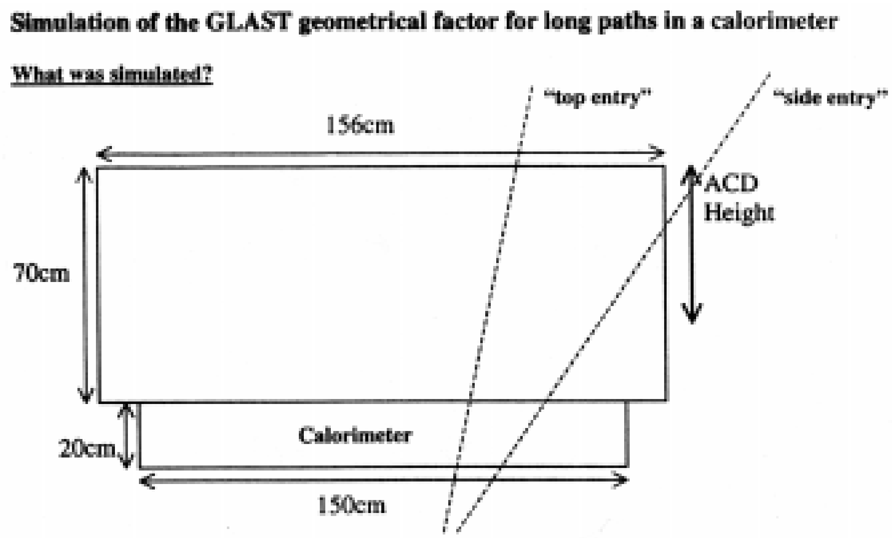
# Study Approach

- **Designs being compared**
  - **"baseline design" (aka Proposal design)**
  - **"reduced segmentation design" (aka design "A")**
- **Configurations were illuminated by muons**
  - **muons exclude interactions**
    - **studying only geometric effects**
  - **uniform flux over the ACD**
- **2 cases were studied:**
  - **isotropic flux to study the Geometric factor, $G = A\Omega$**
  - **parallel flux (as function of zenith angle $\Theta$ and for $\Phi=0^o$ and $45^o$) to study effective area A**
- **Illumination was separable into events entering the instrument through the top of the ACD (Tracker) and separately through each side tile row.**

# Study Approach (cont.)

- The events were required to enter >6 cm above the bottom of ACD (top of the calorimeter). This reflects the requirement for the events to pass at least 2 Si planes.
- The self-veto of false hit probability was calculated using the formula obtained by beam tests at SLAC and CERN (Moiseev and Ormes, in preparation).
- For every event the path in the calorimeter, the distance between the entry points to the ACD and the calorimeter were calculated. This distance corresponds to x in the formula. An energy of 300 GeV and a VETO threshold of 0.3 mip were used in the simulations.
- Calorimeter was assumed to be 20cm (8.5Xo) thick. Paths were required to traverse both the top and bottom surfaces of the calorimeter.
- Probability of backsplash was calculated for known tile area.

# Impact on Area and Geometry




Row heights on side
Front to Back
Aka Top to Bottom
25, 20, 15, 15 cm

- **Total height of side = 70 cm above calorimeter.**
- **Entry must be >6cm above top of calorimeter to traverse 2 tracker layers.**

**Our effective area**

- **Point sources**

**or geometry factor**

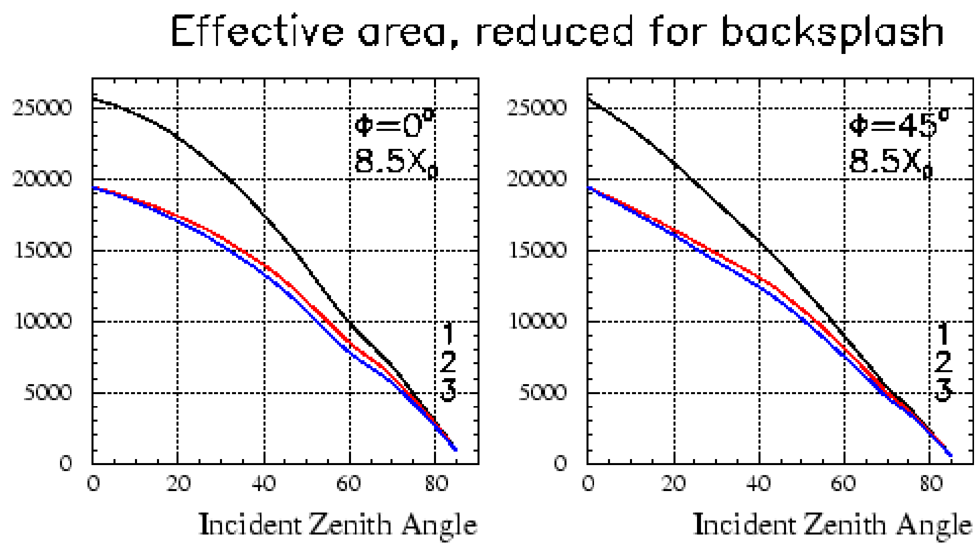
- **Isotropic source**

**at a given energy resolution**

- **depends on the depth of calorimeter desired.**

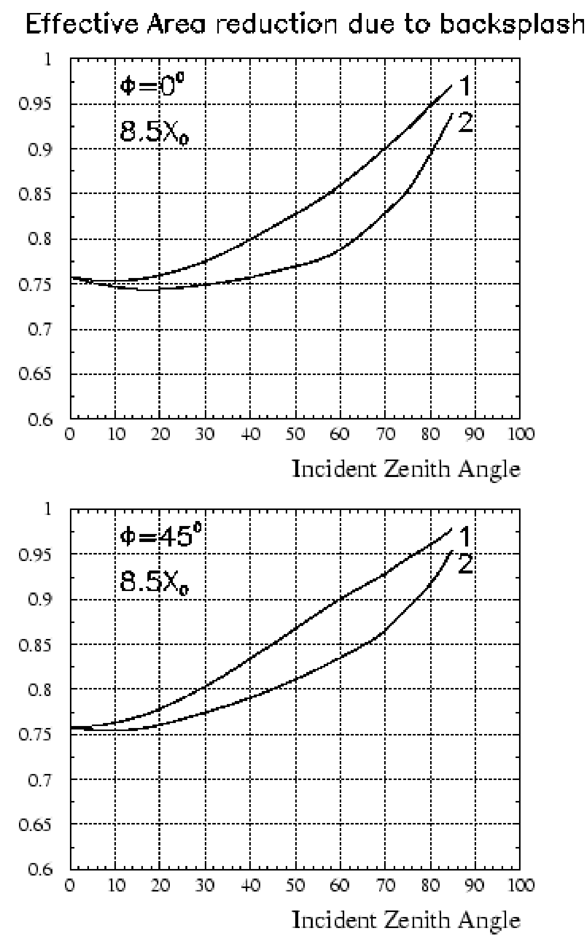
# Projected area, top + side entry

- **Line 1 (black) - projected area vs.. Incident angle**
  - **Azimuthal angle extremes**
  - **>8.5 Xo and >15Xo**
- **Line 2 (red) - same, reduced for backsplash**
- **Line 3 (blue) - same as red, reduced segmentation in 3-rd and 4-th rows**



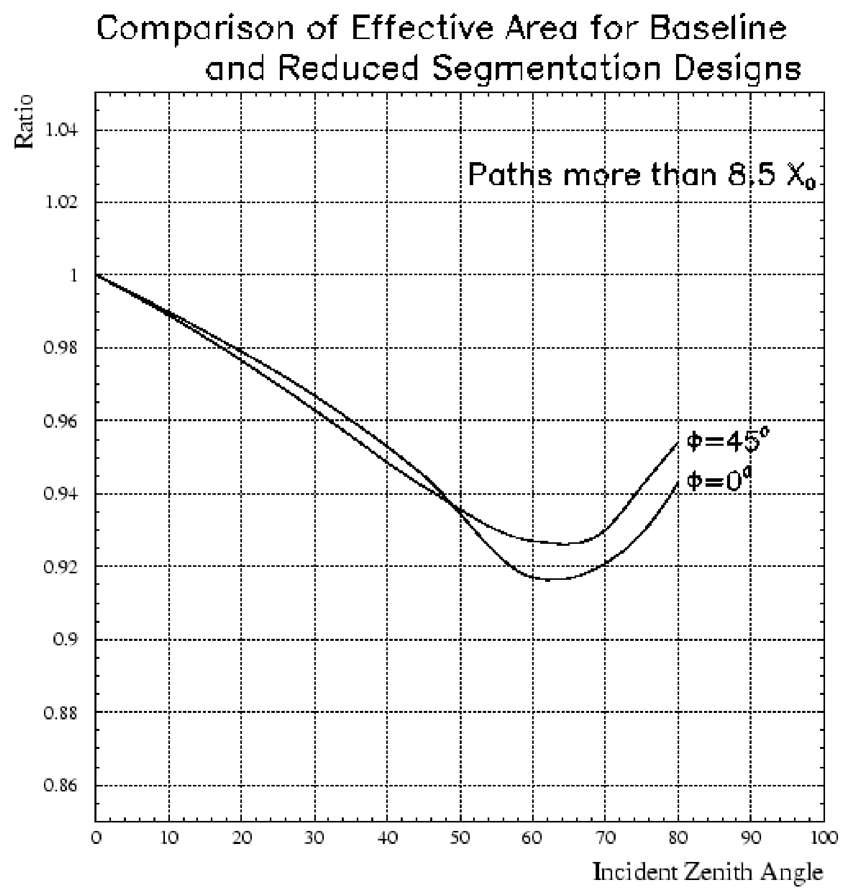
# Projected area reduced for self-veto: 300 GeV

- Top plus all 4 ACD side rows are used; events are required to enter 6 cm above the calorimeter.
- Line 1 - baseline
- Line 2 - reduced segmentation

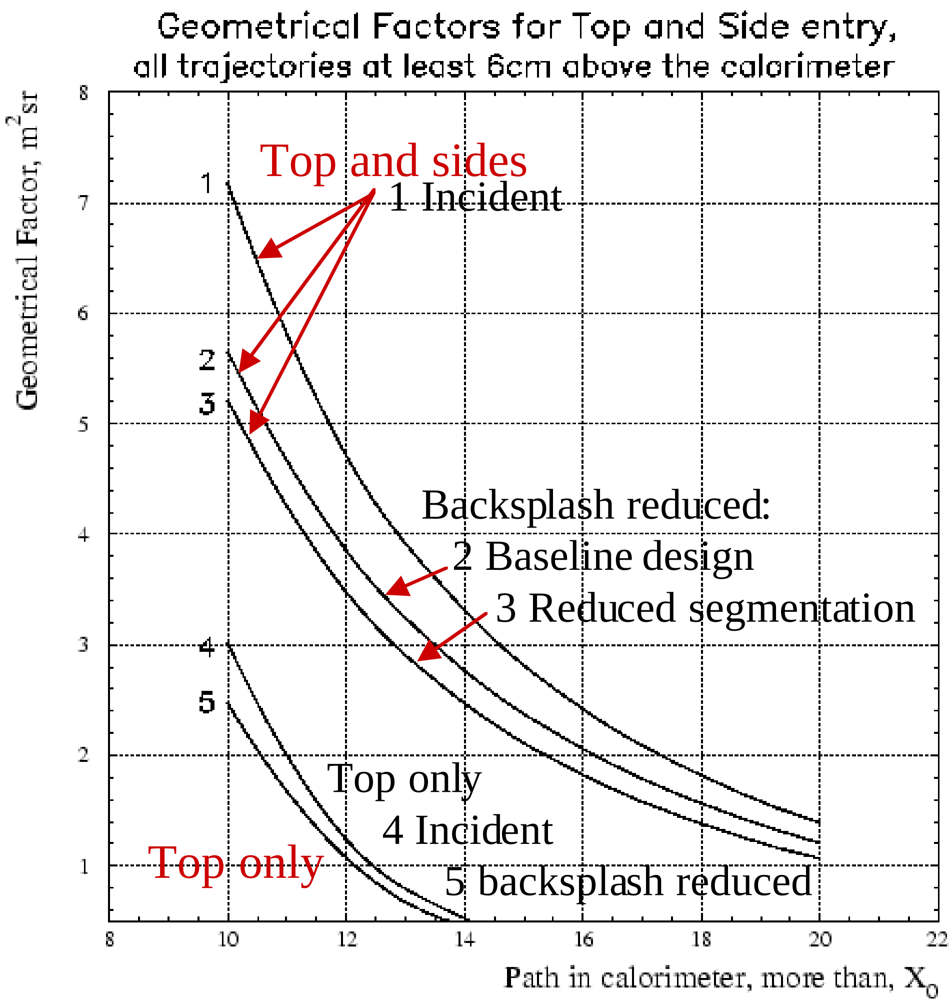


# Effective Area reduction

- **Ratio of effective area of reduced segmentation design to that for baseline design as function of incidence angle.**
- **Backsplash is included.**
- **Required path in calorimeter is 8.5$X_0$.**
- **All events entering GLAST through the top and sides.**
- **All 4 ACD side rows are used**
- **Events are allowed to enter 6cm above the calorimeter.**
- **Azimuthal angle**
  - **$\Phi = 0^0$**
  - **$\Phi = 45^0$**



# Baseline geometry factor, “G”

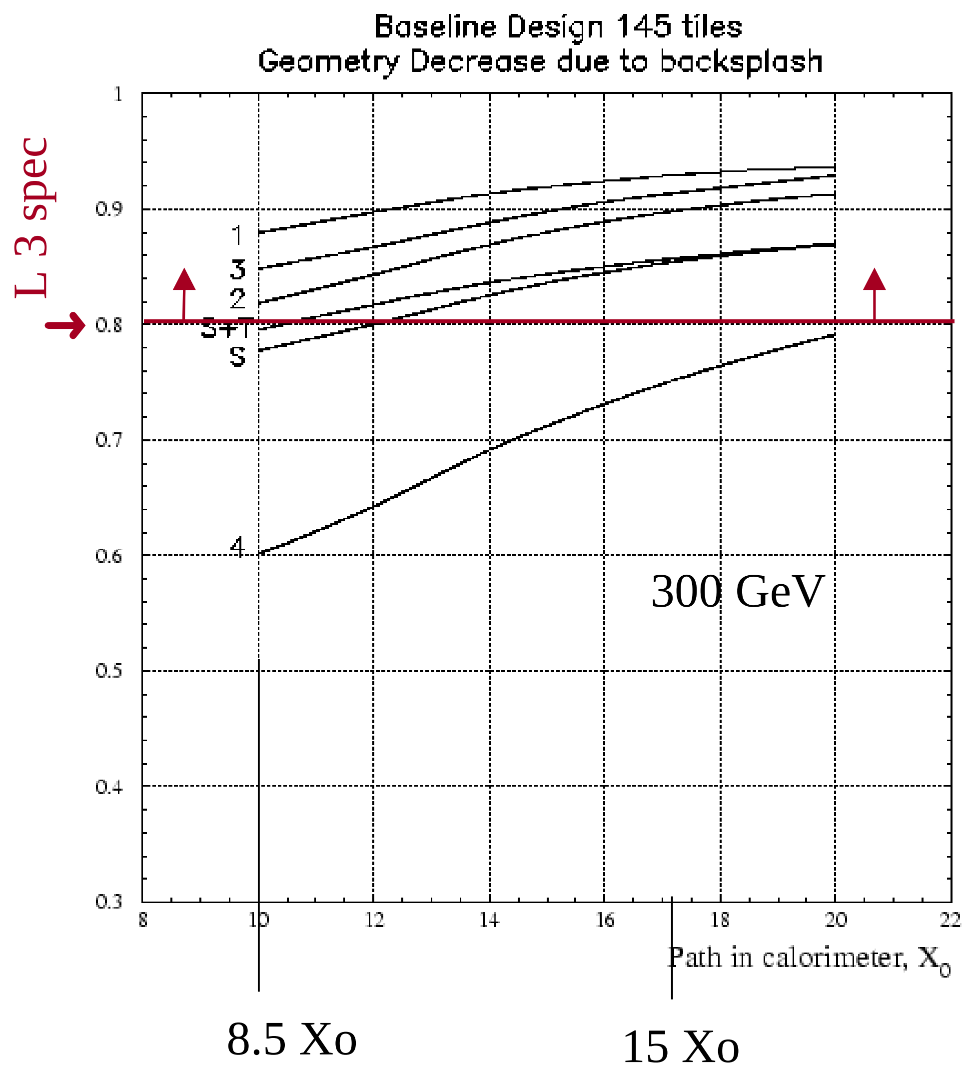



$$G(Xo) = A\Omega(Xo)$$

Integral geometry factor (area x solid angle) for LAT for paths greater than Xo as a function of path length in Xo (radiation lengths).

Note that more than 1/3 of LAT’s “G” has Xo > 16 radiation lengths.

# Baseline design: loss due to self veto



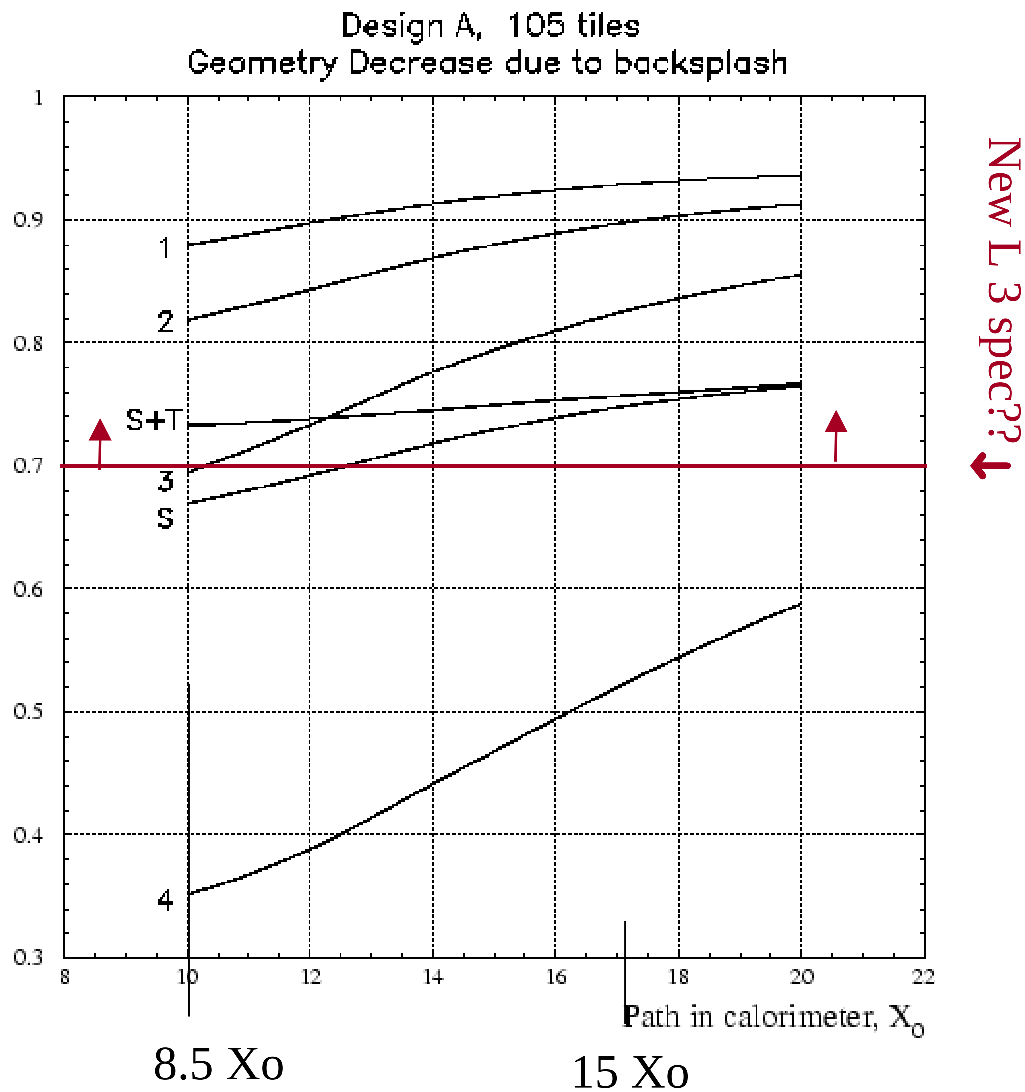

Overall geometry through side and top (S+T) meets the requirement of 80% acceptance.

The loss through the side is worst through the bottom row of tiles nearest to the calorimeter.

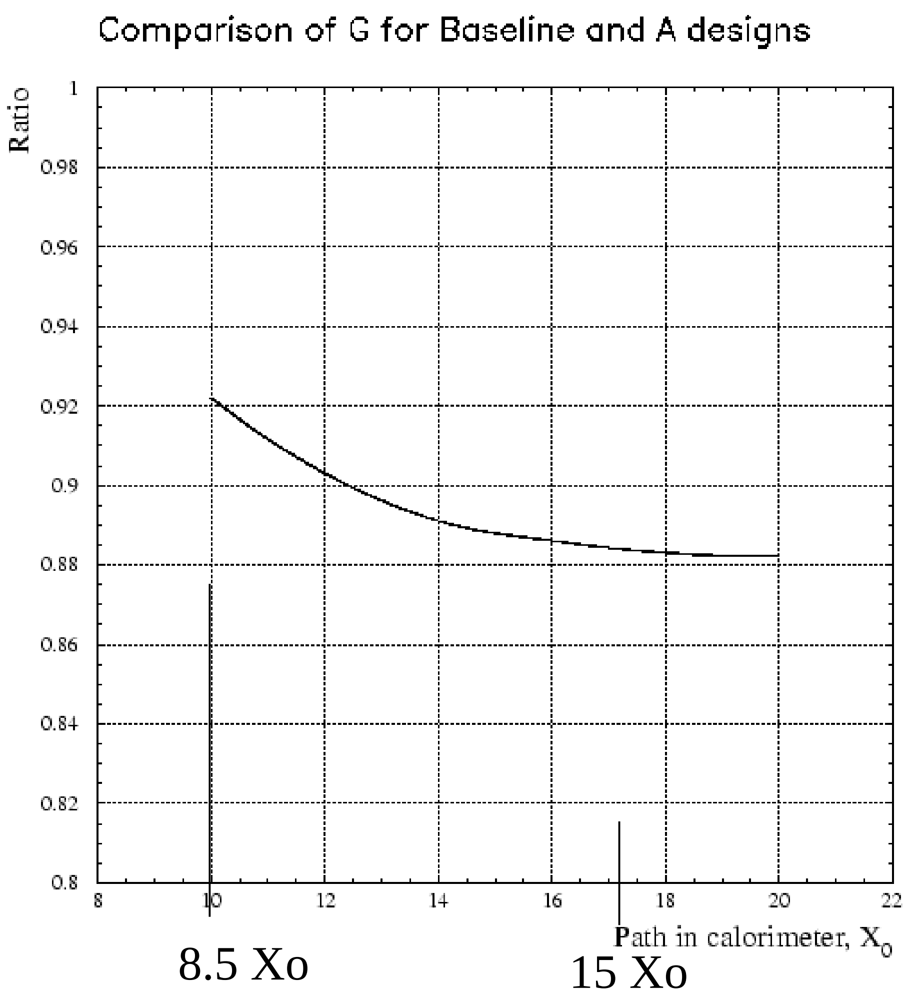
# Reduced segmentation: loss due to self veto

Tile size on bottom two rows is doubled in reduced segmentation design.

The overall effect is to reduce the effective geometry at 300 GeV **<27%** relative to that when there is no self-veto effect.



# Reduced segmentation design relative to baseline




Conclusion:

Doubling the size of the tiles on the lower two rows will decrease the geometry factor of LAT to an isotropic background by 10±2%.

LAT would still have >1/3 of its "G" with >16 Xo.

# ACD Level 3 specification

**As of today, the DRAFT ACD Level 3 subsystem specification says:**

- **5.6: False VETO due to Calorimeter Backsplash**
  - **<20% of otherwise accepted gamma-ray events at 300 GeV shall be rejected by false VETOs due to calorimeter backsplash**
- **Assuming peak $A_{eff}$ (at ~10 GeV) >8000 cm$^2$**

  **Baseline meets LAT Requirement: $A_{eff}$ >6400 cm$^2$ (TBR) at 300 GeV.**

  **Cannot reach the Goal: >9500 cm$^2$ at 1 TeV.**
- **Showed >0.73 can be attained w/ reduced segmentation proposed**
  - **To meet all requirements as stated, the**

  **Effective area at 10 GeV would have to be >6400cm$^2$/0.73 = 8770 cm$^2$**
- **Therefore I recommend changing Level 3 spec to read:**
- **5.6: False VETO due to Calorimeter Backsplash**
  - **<30% of otherwise accepted gamma-ray events at 300 GeV shall be rejected by false VETOs due to calorimeter backsplash**
  - **Implies $A_{eff}$ could be as low as 5600 cm$^2$**

# Summary

- For baseline design, the geometric area self-veto reduction is <25%.
- Reduced segmentation design further reduces the effective area by less than an additional 8.5% (worst case).
- With Baseline design we meet “20% self-veto reduction at 300 GeV” requirements.
- Reduced segmentation design reduces GLAST geometry factor by less than 10% additional at 300 GeV.
  - For longer paths in the calorimeter the new design has slightly more G reduction (about 12%).

# Conclusions

- Change the L3 additional loss specification from 20% to 30%
- In LAT Performance Specification 5.2.1
  - Change: “>6400 $cm^2$ (TBR) at 300 GeV”
  - To: “>5600 $cm^2$ at 300 GeV”
- Proceed to PDR with reduced segmentation in bottom two rows on side
  - 105 tiles instead of 145 tiles
  - Each side row would have 5 tiles
- No way to reach goal of $A_{eff}$ >9500 $cm^2$ at 1 TeV.
  - Estimate 60% self-veto at 1 TeV
  - Meeting Peak $A_{eff}$ goal of 10,000 $cm^2$ ⇨ 4000 $cm^2$ at TeV
    - Since electrons are relatively less of a problem at higher energies, we might do better by using the tracker as a self-shielded device.

# Further work

- Determine calorimeter depth necessary to get required off-axis energy resolution of 6% (goal 6%).
- Validate use of “calorimeter only” events entering through the back 15 cm.
- Determine off-axis energy resolution as function of path length in calorimeter.
- Electron background rejection and loss of effective G and $A_{eff.}$
  - 10 GeV worst case
  - Higher energies as electron flux decreases relative to $\gamma$s
- Study use of tracker as a self-shielded device at energies above 300 GeV.
  - Self-veto becomes 2.2 x more serious at 1 TeV
  - Use very fine segmentation of tracker
- Assure simulations correctly reproduce backsplash results.