Report on the UCSC/SCIPP BeamCal Simulation Effort

FCAL Collaboration Meeting
Vinca Institute, Belgrade, Serbia
September 3-4, 2017

Bruce Schumm
UC Santa Cruz Institute for Particle Physics

FCAL Collaboration
High precision design

Questions to Address

Two-photon backgrounds (to any physics with invisible final state particles: SUSY, dark matter…)

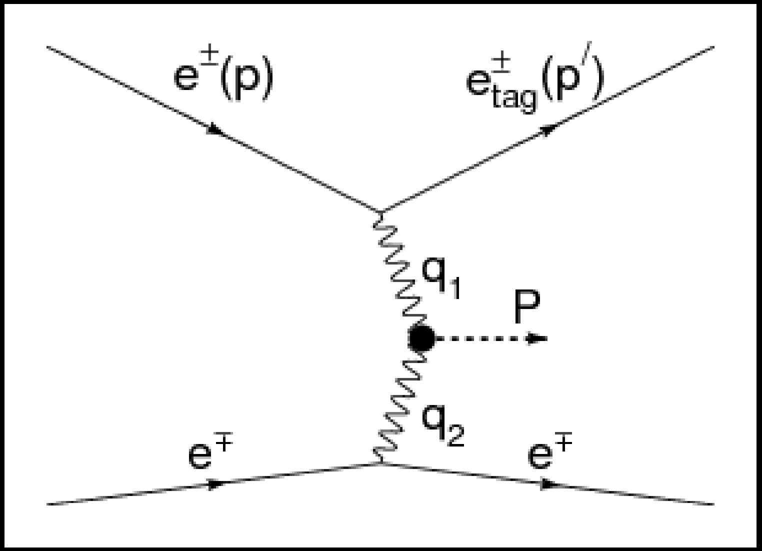
- **Simulation challenges (> 1 events per crossing, plus Bhabha, pairs, …)**
- **Effect of “central” detector coverage on BeamCal tagging & physics searches**

Use of the BeamCal to determine ILC IP parameters

- **Requirements placed on BeamCal geometry**

Two-Photon Event Facts

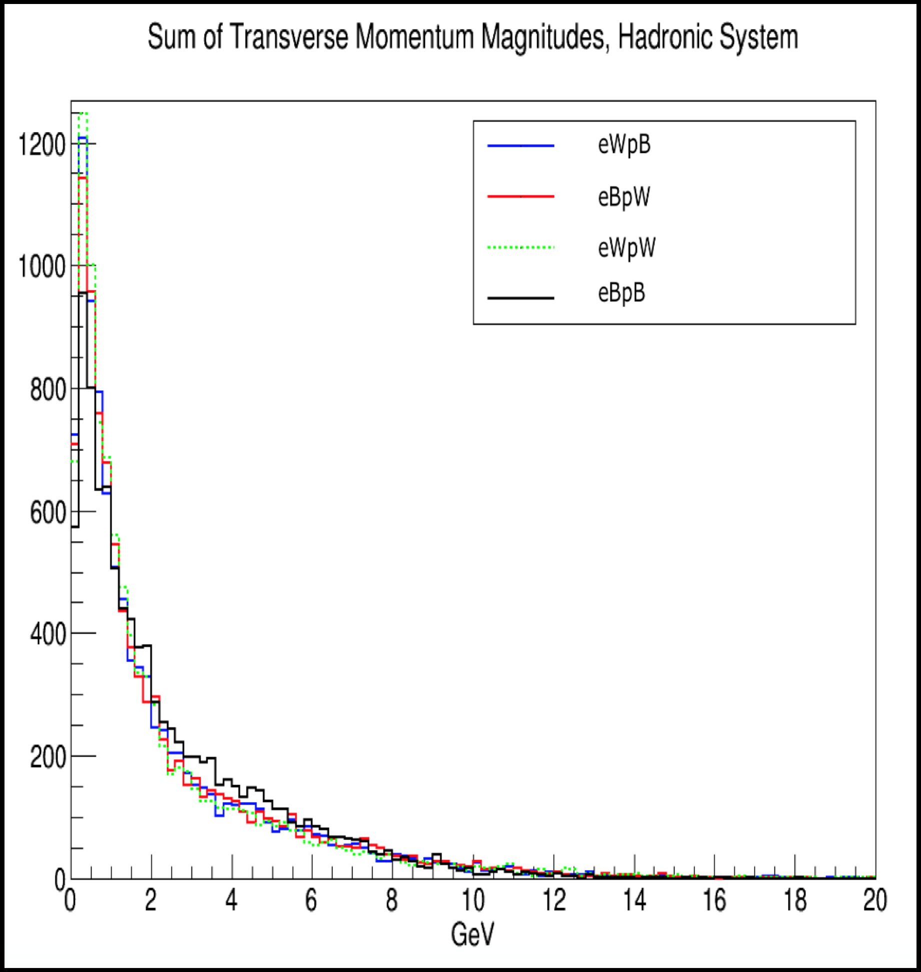
Tim Barklow has simulated $\gamma\gamma \rightarrow$ hadrons down to the $\pi\pi$ threshold

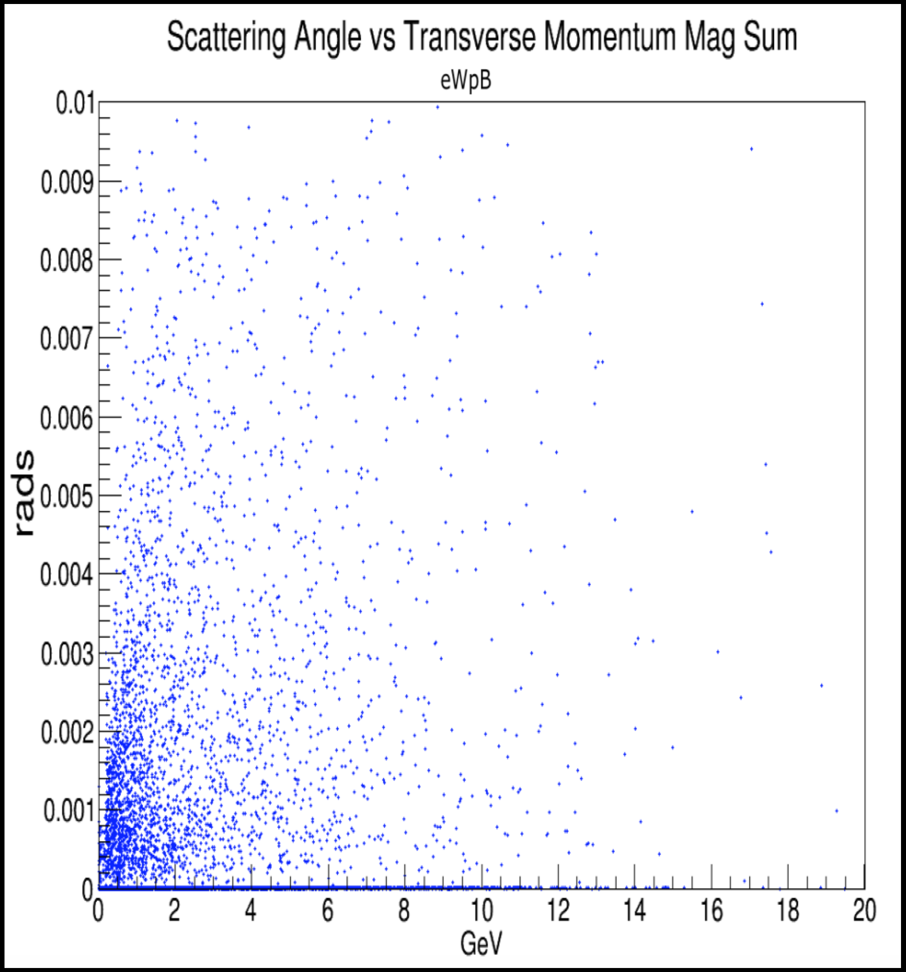


Photon flux from

- Beamstrahlung (B) ➔ no p_T kick for $e^{\pm}$
- Weiszacker-Williams (W) ➔ $e^{\pm}$ sometimes get p_T kick

In this simulation, only about 15% of $\gamma\gamma$ events does an $e^{\pm}$ get a p_T kick



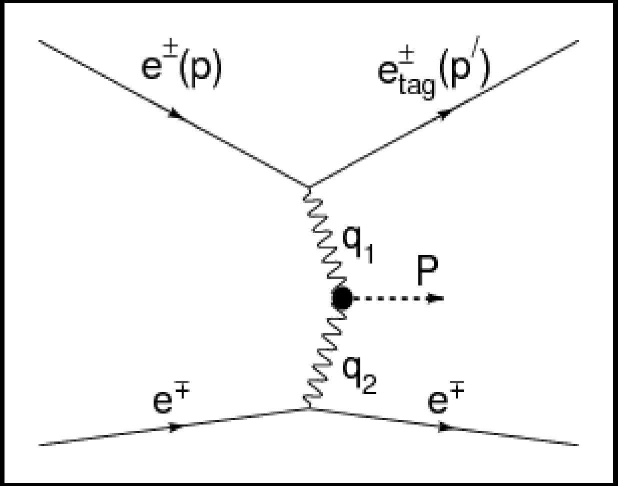


Most $\gamma\gamma$ events leave very little p_T in the detector, but for those that do, we'll need to know they were $\gamma\gamma$ events by finding the scattered $e^{\pm}$ if there is one.

The "Prediction Algorithm"

Jane Shtalenkova

Based on the properties of the hadronic ($\gamma\gamma$) system, can predict trajectory of deflected $e^{\pm}$ up to two-fold ambiguity (don't know if e^+ or e^- scattered)



Set transverse momentum e_T (p_T) of scattered e^- (e^+) to inverse of $\gamma\gamma$ system transverse momentum

Longitudinal momentum e_z (p_z) given by

Either electron…

$$e_z = -\frac{e_T^2 - \alpha^2}{2\alpha} \qquad p_z = \frac{p_T^2 - \beta^2}{2\beta}$$

Or positron.

$$\alpha = 500 - H - h_z \qquad \beta = 500 - H + h_z$$

H = $\gamma\gamma$ system energy; h_z = $\gamma\gamma$ system longitudinal momentum

Prediction Algorithm cont'd

Thus, each event gives us a prediction of where the e^- (e^+) would have gone if the e^- (e^+) got the entire p_T kick.

If this assumption is true, and the hadronic system is perfectly reconstructed, one of these is exactly correct and the other is wrong (the "wrong" particle in fact goes straight down the exhaust beam pipe).

Assumed veto strategy:

Case 1): If an e^+ or e^- is seen in either BeamCal (and is/are inconsistent with Bhabha event), veto event.

Case 2): If neither e^+ nor e^- inconsistent with Bhabha event are seen, veto if neither is "predicted" to hit the BeamCal.

Peril: If e^+ and/or e^- is "predicted" to hit the BeamCal, but none does ("hit/miss event"), may be mistaken for SUSY.

Why would prediction algorithm fail in this way?

- Both e^+ and e^- get p_T kick ("WW" events)
- One of incoming e^+ or e^- is significantly below E_{beam}
- Incomplete/inaccurate reconstruction of $\gamma\gamma$ system

Avoid first of these for now by looking at "WB" events (require at least $S = \Sigma\,|p_T| > 1$ GeV for hadronic system)

Look as a function of cut on $|z| = |\cos\theta|$ coverage of detector

Hit Status Prediction/Truth Averaged Over eWpB and eBpW Events

z_{max}	No Cut	0.999	0.99	0.95	0.9	0.8	0.5
H/H	0.118	0.112	0.084	0.059	0.048	0.037	0.019
H/M	**0.029**	**0.040**	**0.045**	**0.050**	**0.050**	**0.045**	**0.029**
M/H	0.014	0.019	0.047	0.072	0.083	0.095	0.112
M/M	0.839	0.823	0.824	0.848	0.819	0.822	0.839

Up to about 0.9 loss of coverage worsens "perilous" outcome. Beyond that, improvement counterbalanced by loss of information in SUSY discriminating variables (see below…)

Simulation Hurdle: Two-Photon Event Rate

For baseline pulse luminosity, approximately 1.1 $\gamma\gamma$ events per pulse

(10^7 seconds/year) x (10^4 pulse/second) ➔ 10^{11} $\gamma\gamma$/yr

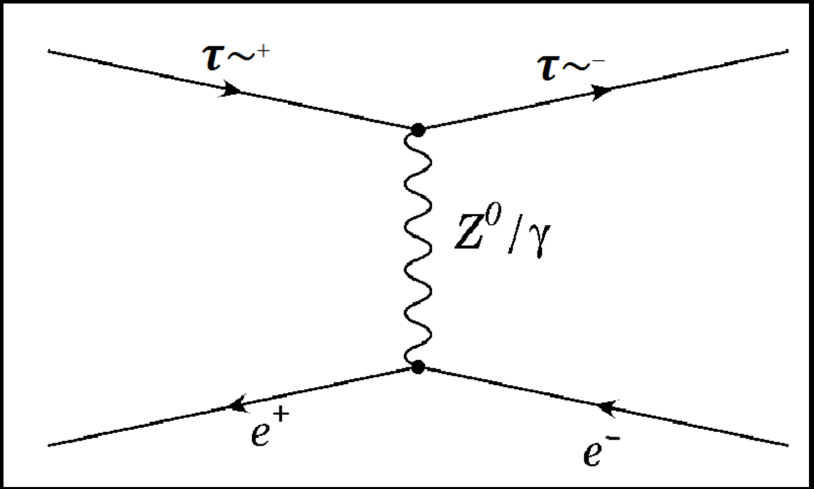
Simulation/storage capacity: 10^9 events is realistic.

➔ Helpful to develop “generator level” cut to reduce $\gamma\gamma$ rate by 10^{-2}.

But must be efficient for whatever signal you seek.
Use degenerate SUSY as study guide.

SUSY Signal Selection

At SCIPP, have simulated $e^+e^- \to \tilde{\tau}^+\tilde{\tau}^-$; $\tilde{\tau} \to \tau\chi^0$ over a range of $\tilde{\tau}$ mass and $\tilde{\tau}/\chi^0$ degeneracy



$m_{\tilde{\tau}}$ = 100, 150, 250 GeV

$\Delta_m = m_{\tilde{\tau}} - m_\chi$ = 20.0, 12.7, 8.0, 5.0, 3.2, 2.0 GeV

Exploring discriminating observables and the impact of limited detector coverage

Summer Zuber

Event Observables

Have explored the following observables so far ("S" is just the scalar sum of transverse momenta mentioned above)

$$S_{(\gamma\gamma)} = \sum_{(\gamma\gamma)} \sqrt{p_x^2 + p_y^2}$$

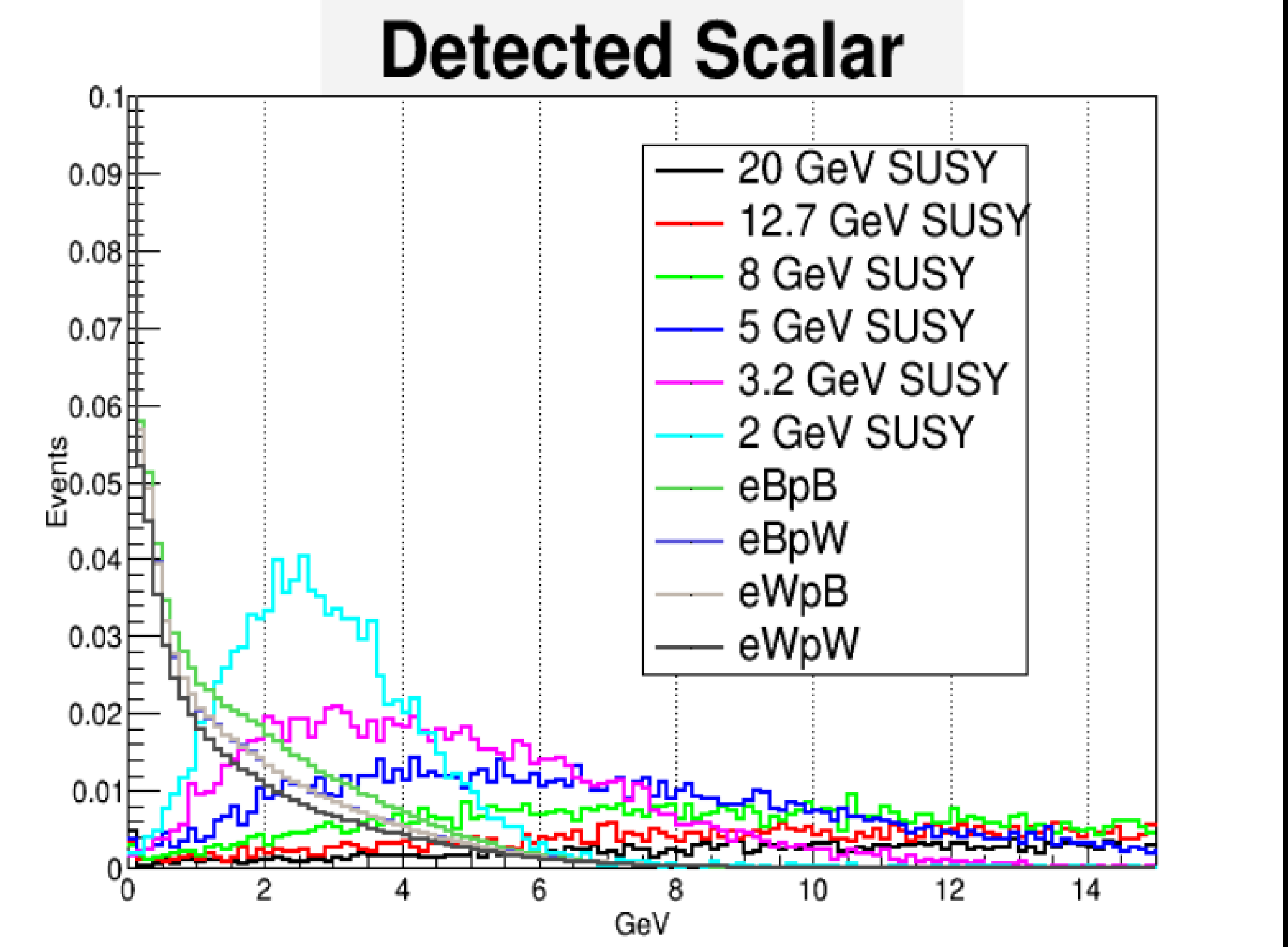
$$V_{(\gamma\gamma)} = \sqrt{(\sum_{(\gamma\gamma)} p_x)^2 + (\sum_{(\gamma\gamma)} p_y)^2}$$

$$M_{(\gamma\gamma)} = \sqrt{(\sum_{(\gamma\gamma)} E)^2 - \|\sum_{(\gamma\gamma)} \vec{p}\,\|^2}$$

The Effects of Detectability

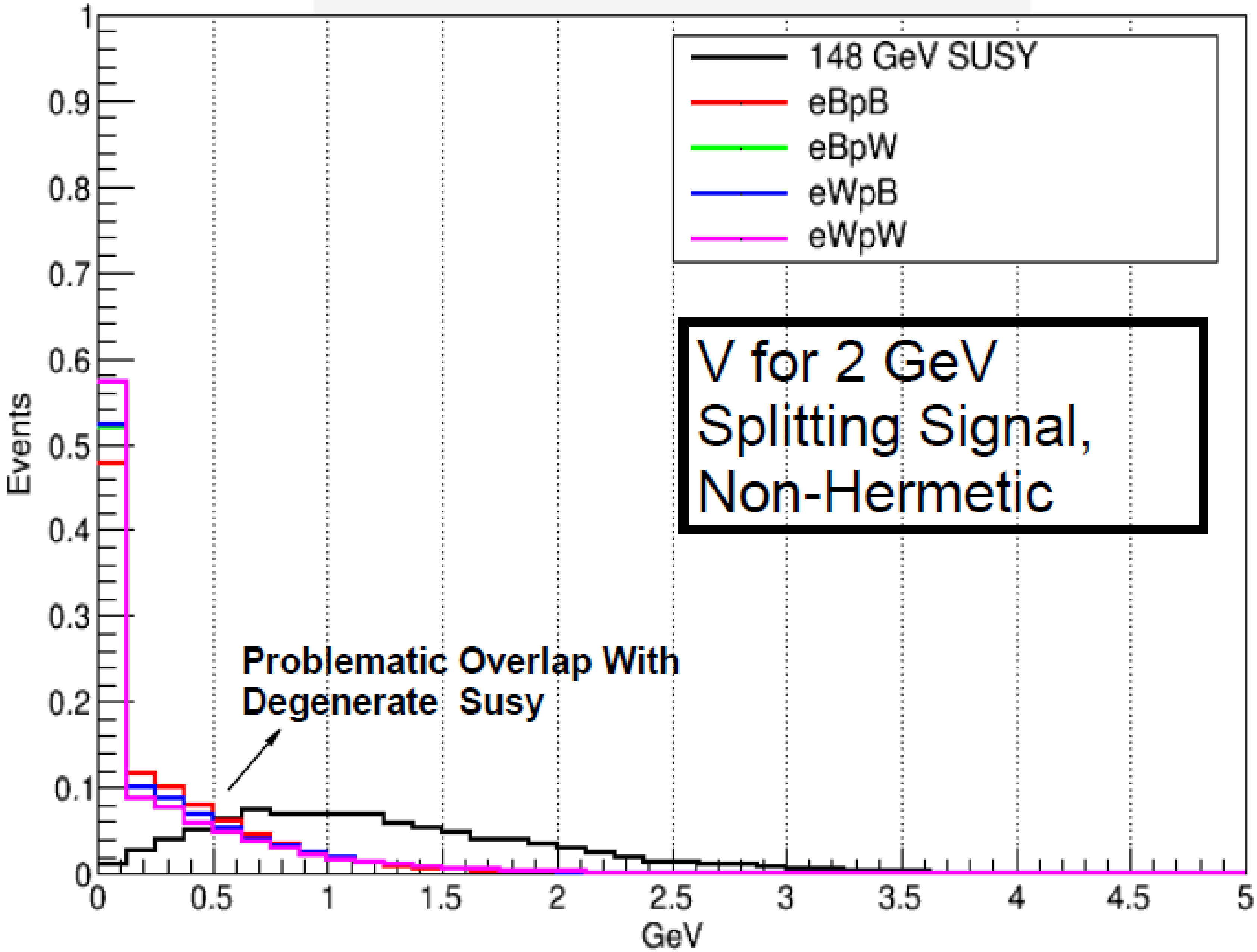
The Discriminating Power of Event Observables Can Depend on Coverage of the Detector

- Truth Level: All "final state" particles
- Detectable Level: excludes neutrinos/neutralinos (i.e. completely hermetic detector)
- Detected Level: excludes neutrinos/neutralinos and forward particles with $|\cos(\theta)|>\alpha$; we have initially chosen a conservative value of $\alpha = 0.9$

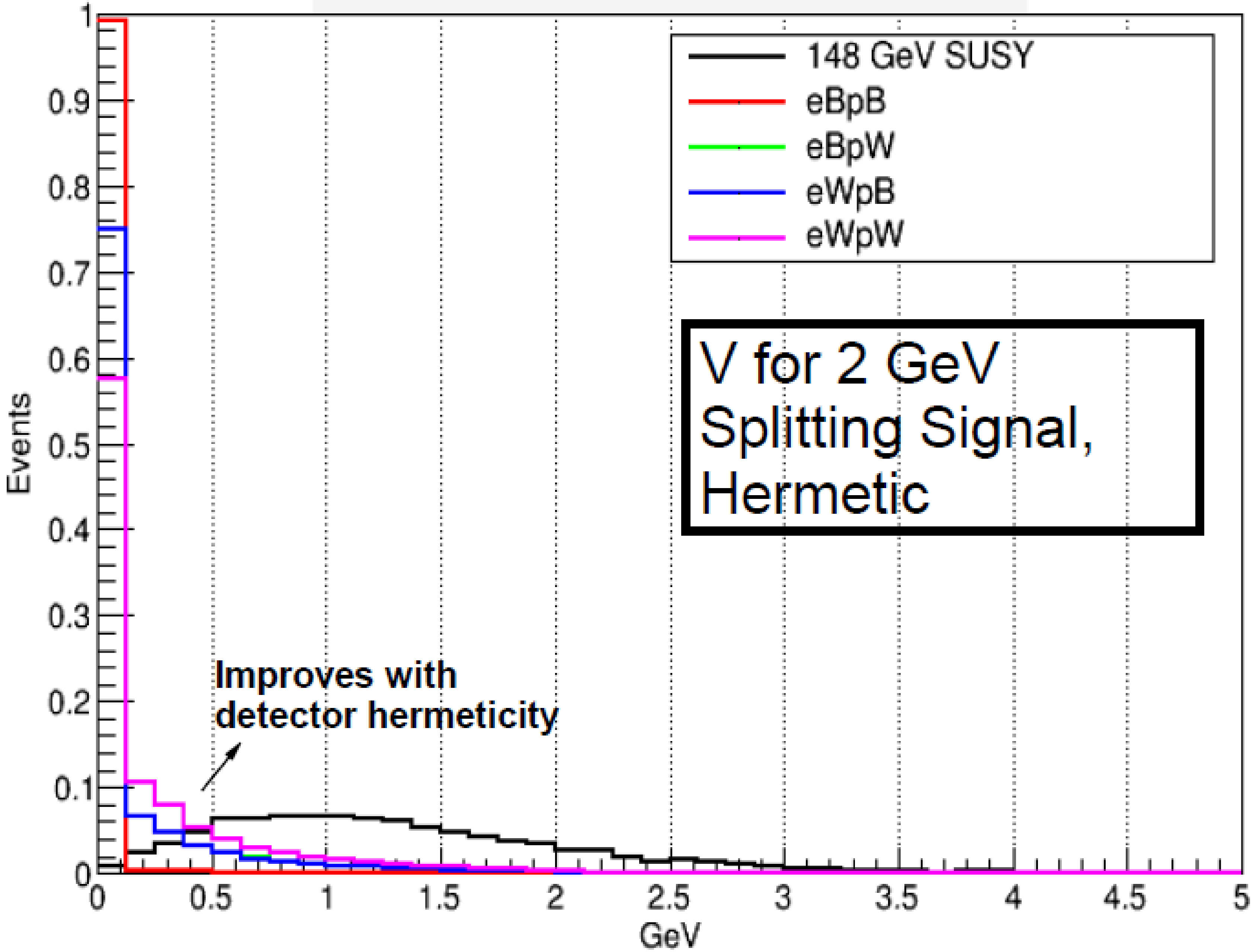


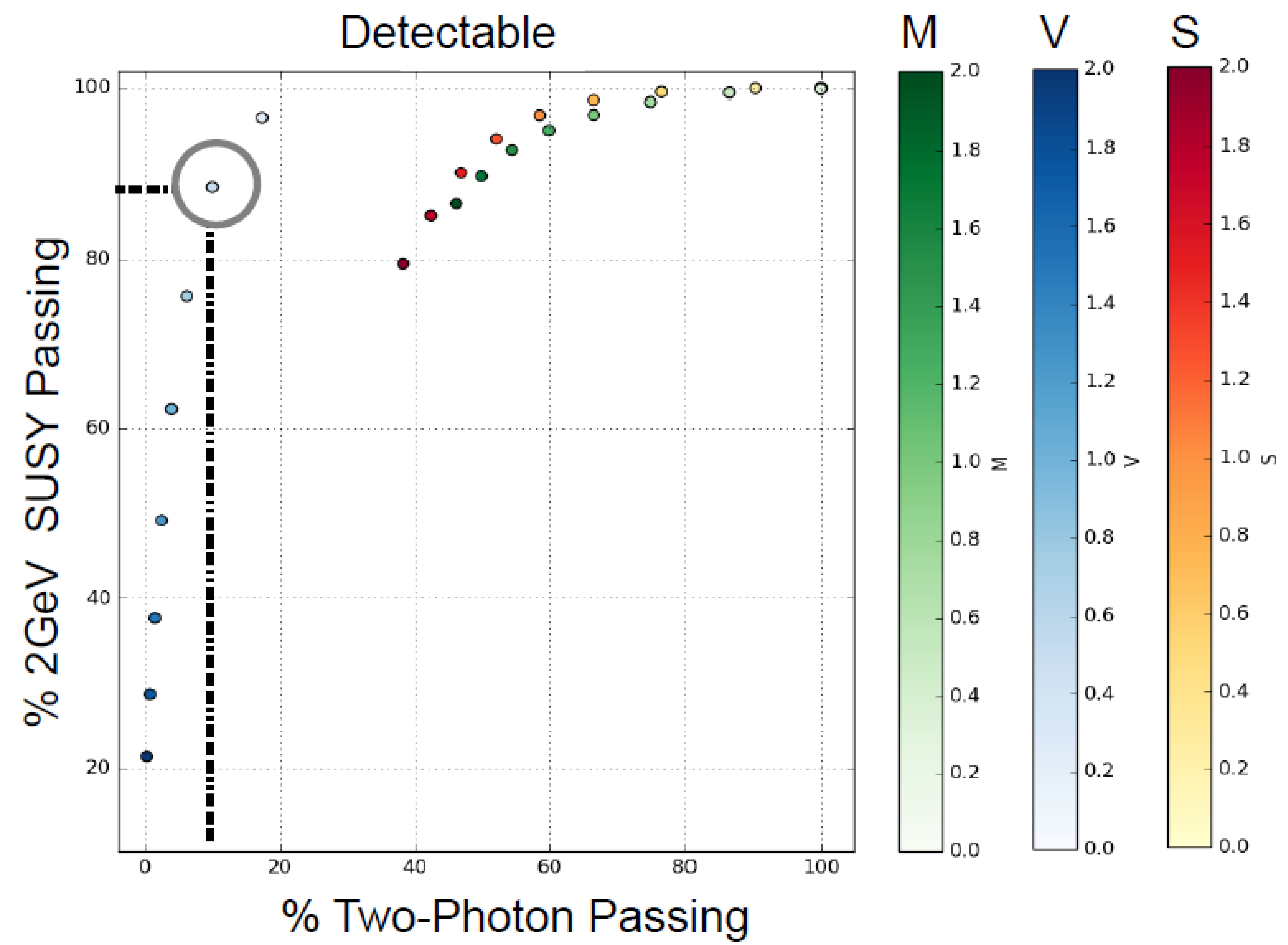
Detected Scalar
20 GeV SUSY
12.7 GeV SUSY
8 GeV SUSY
5 GeV SUSY
3.2 GeV SUSY
2 GeV SUSY
eBpB
eBpW
eWpB
eWpW
Events
GeV
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0
2
4
6
8
10
12
14

Detected Vector

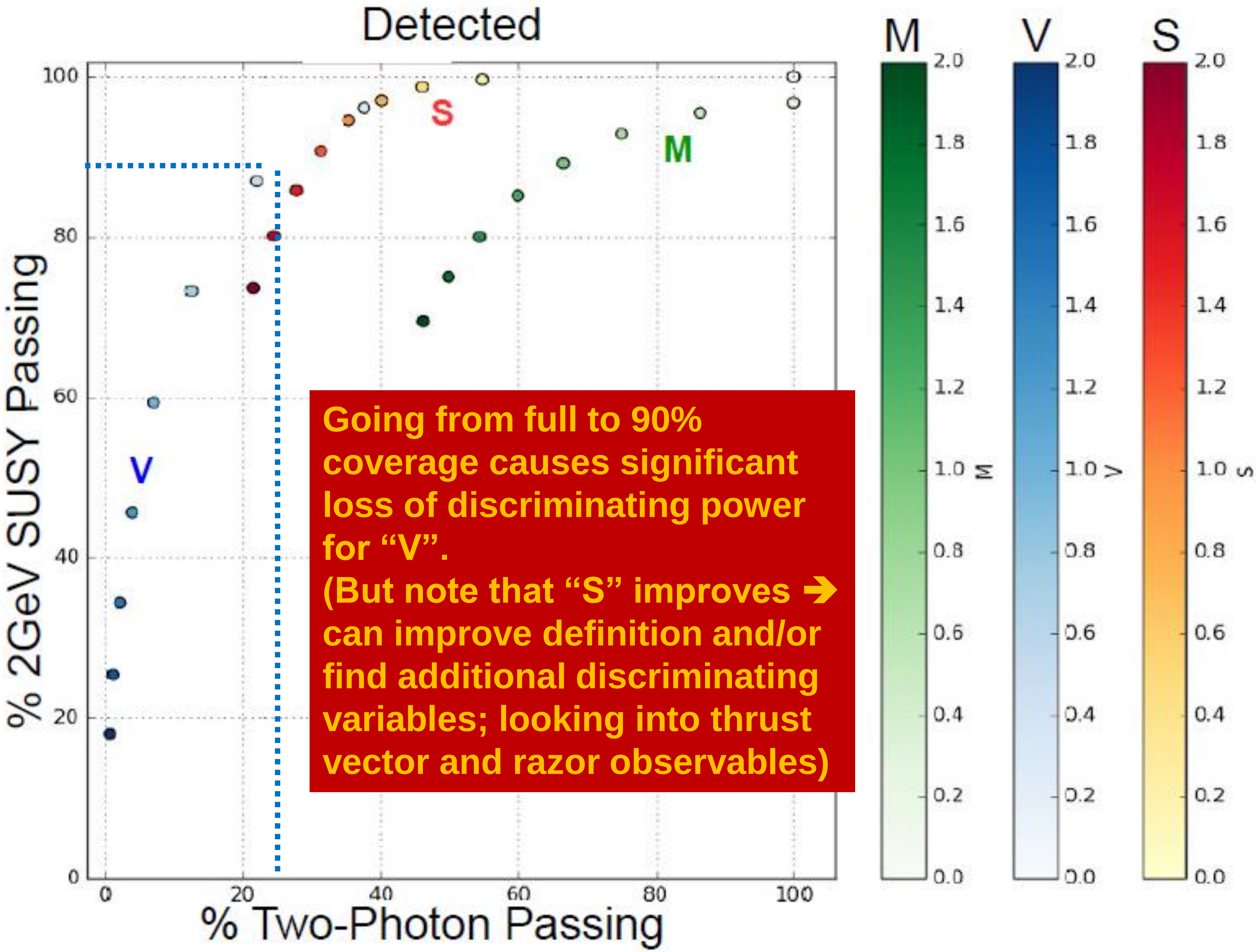


Detectable Vector





Detectable
M
V
S
% 2GeV SUSY Passing
% Two-Photon Passing
0
20
40
60
80
100
20
40
60
80
100
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0



Going from full to 90% coverage causes significant loss of discriminating power for "V".
(But note that "S" improves ➔ can improve definition and/or find additional discriminating variables; looking into thrust vector and razor observables)

Realistic ILC Beam Crossing Samples

- **An ILC beam crossing is not a single $\gamma\gamma$ of Bhabha event:**

Event Type	BB	BW	WB	WW
Crossing (fb)	134427168.3	93474234.88	94353013.33	81276125.5867
Events/Crossing	0.368855	0.256484181	0.2588954634	0.2230137589

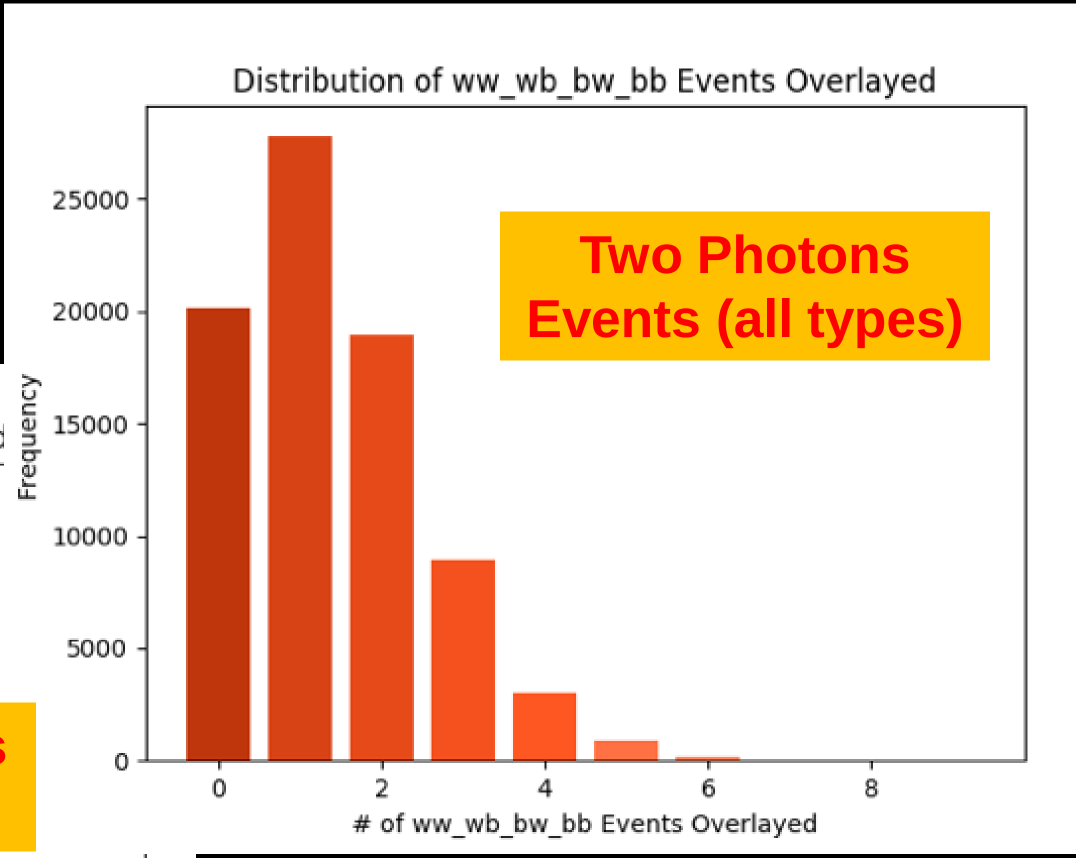
Secondary Radiation	e^+e^-	$e^+e^-\gamma$	$e^+e^-\gamma\gamma$
Crossing (fb)	278555100.0	853356.41.88	15389.98.33
Events/Crossing	0.764327339	0.002341525	0.000042229

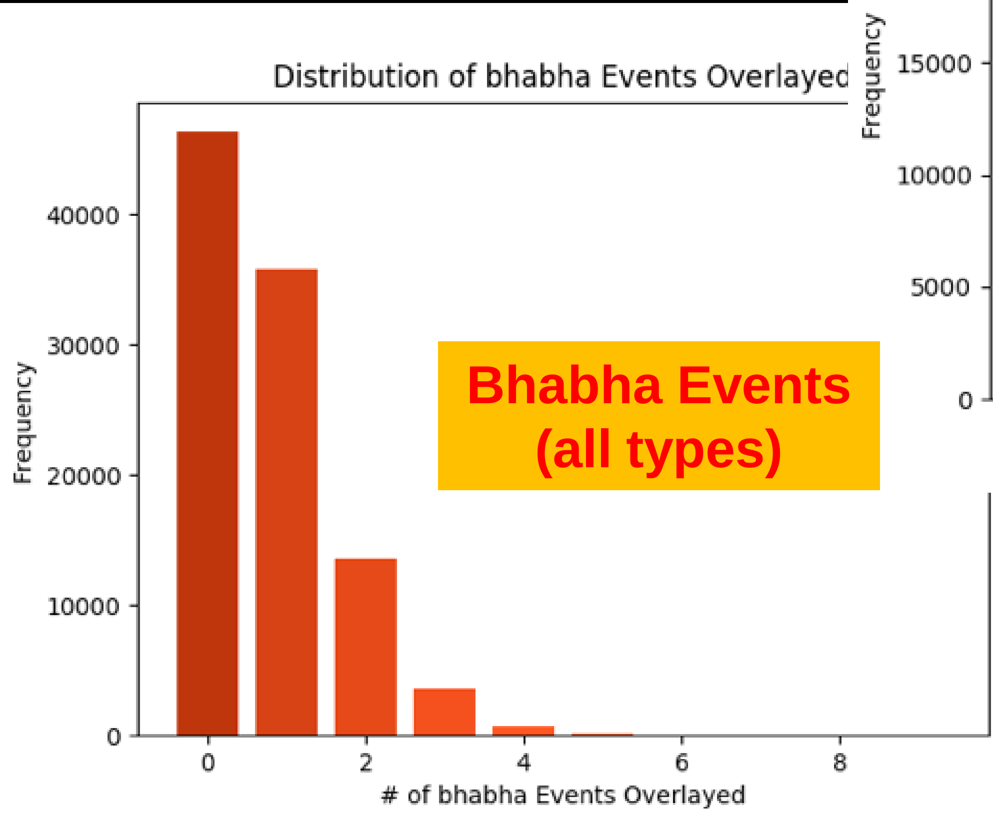
Events rates from cross sections for

- **$\gamma\gamma$ down to di-pion mass threshold**
- **Bhabhas down to virtuality of $\sqrt{Q^2} > 1$**

Nominal Event Number Distributions

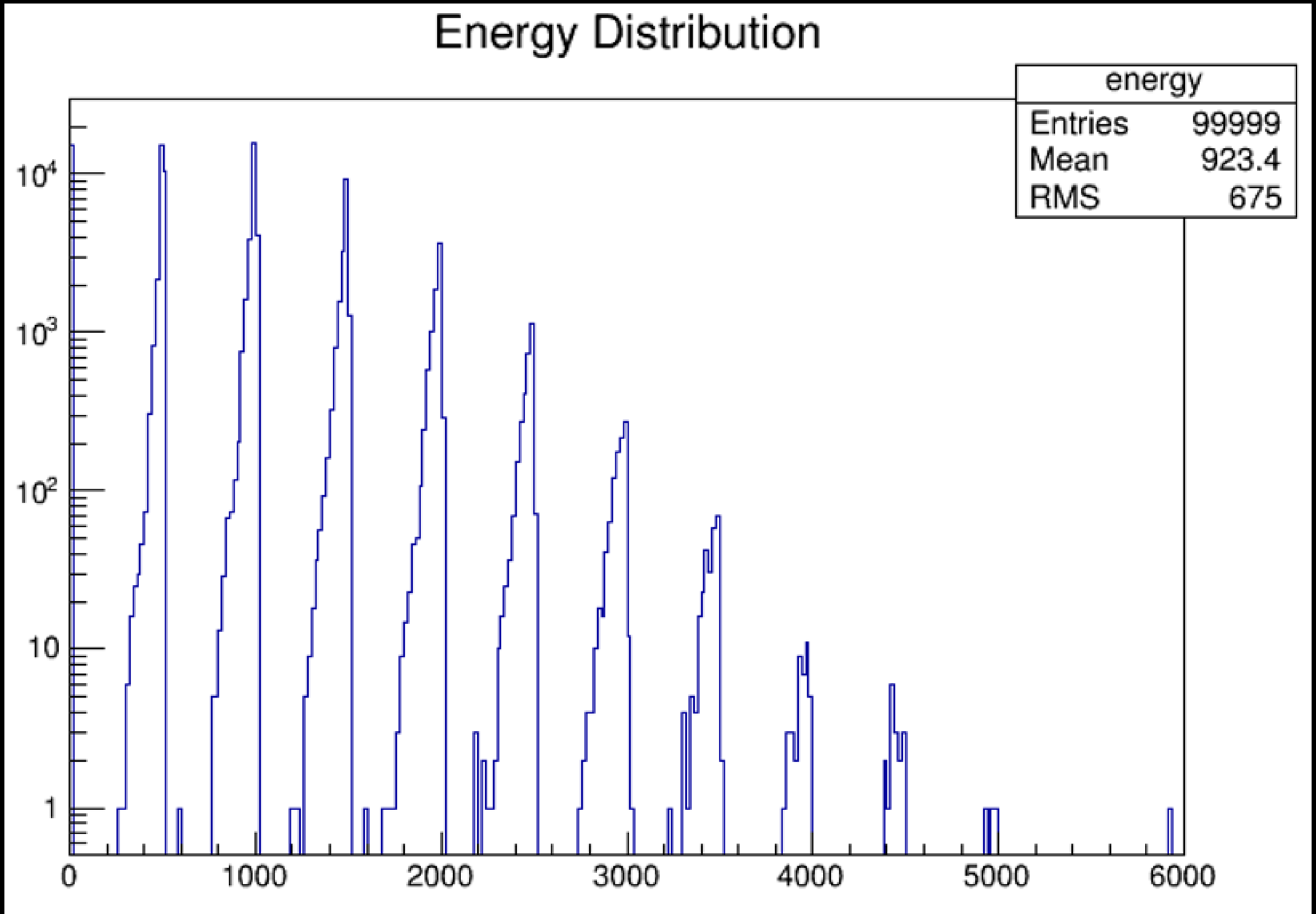
These are input to simulation





Realistic Beam Crossing Simulation

Total energy (visible & invisible) for 100,000 nominal ILC beam crossings



Using the BeamCal to Obtain Information about Collision Parameters, and Impact of BeamCal Geometry Options

Contributors

- Luc D'Hauthuille, UCSC — Undergraduate (thesis)
- Anne Schuetz, DESY — Graduate Student
- Christopher Milke, UCSC — Undergraduate

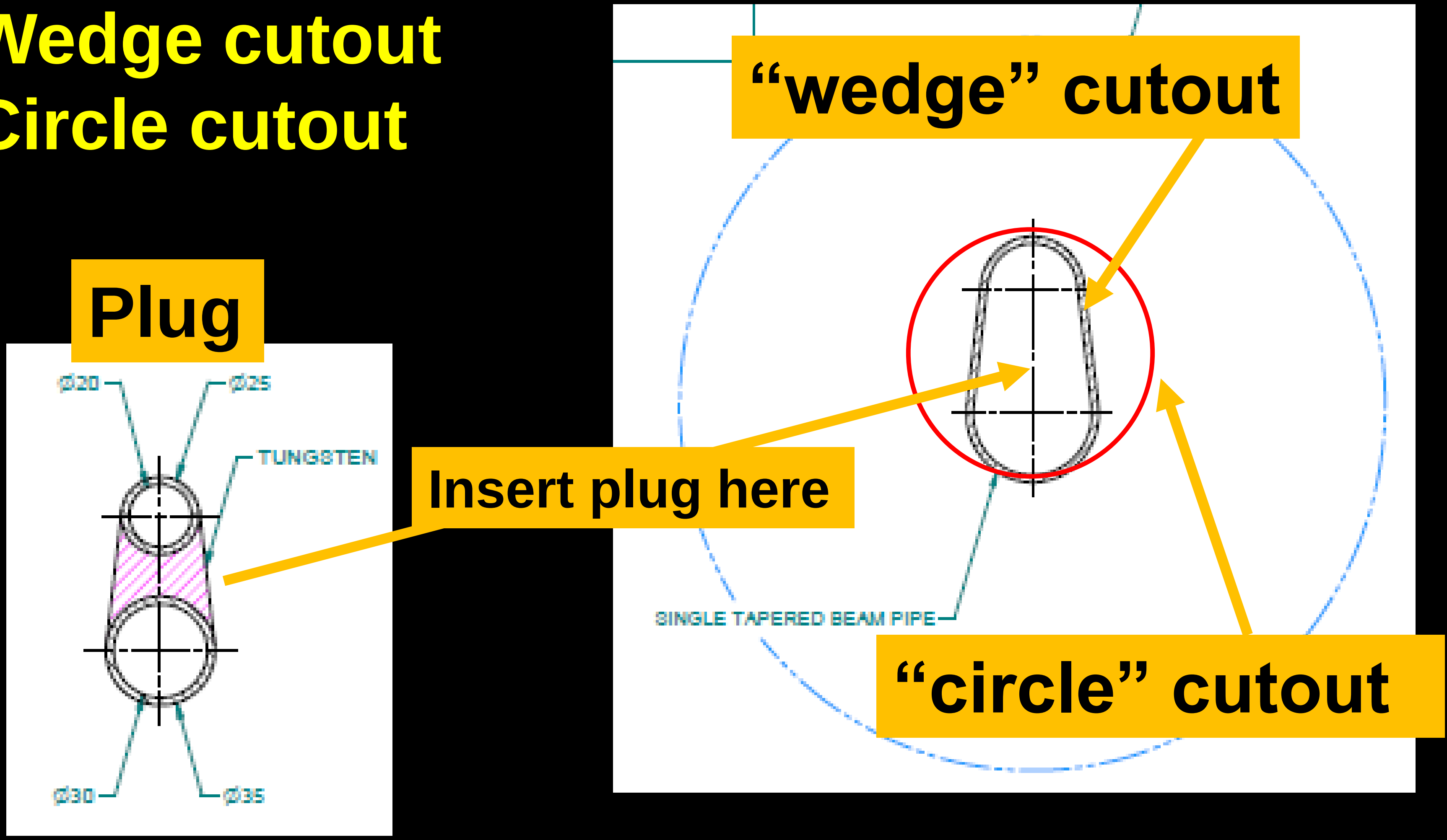
With input from Glen White, Jan Strube, B.S.

Goal

Idea is to explore the sensitivity of various beamstrahlung observables, as reconstructed in the BeamCal, to variations in IP beam parameters. The sensitivity will be explored with various different BeamCal geometries.

BeamCal Face Geometry Options

- “plugged”
- Wedge cutout
- Circle cutout



Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee

RECONSTRUCTION OF IP BEAM PARAMETERS AT THE ILC FROM BEAMSTRAHLUNG *

G. White, SLAC & Queen Mary, University of London

OBSERVABLES

There are three sources of experimental observables considered here; the energy and number weighted distributions of the electron-positron pairs; the energy weighted photon distribution and the beam-beam kick (each beam experiences a strong transverse kick as it passes through the field of the colliding beam).

Using the ILC BeamCal [1,3], situated just downstream of the final Quadrupole magnet (3.65m from the IP in the TESLA TDR design), event shape variables are formed based on the hits by electron-positron pairs. Event shape variables are also formed for the photons using a photon detector about 200m downstream from the IP. The list of event shapes variables considered for the photon and pair detectors are as follows: Total Energy deposition; r and 1/r moments; 'Thrust' axis and value (how 2-lobe like the radiation is); Angular spread; Ratio of radiation in inner and outer parts of the detector; left-right, top-bottom and diagonal asymmetries and ratio of Number of hits to total energy deposition for the BeamCal only. Together with the beam-beam deflection and splitting the variables into average and difference quantities between left and right-side detectors, this provides a total of 44 observables.

Of these, we believe the following can be reconstructed in the BeamCal:

- Total energy and its r, 1/r moment
- Mean depth of shower
- Thrust axis and value (relative to barycenter; could also use mode of distributions.)
- Mean x and y positions
- Left-right, top-bottom, and diagonal asymmetries

IP Parameter Scenarios & Observables

IP parameter variations thanks to Anne Schuetz, GuneaPig expert

Relative to nominal:

- Increase beam envelop at origin (via β-function), for electron and positron beam independently, by 10%, 20%, and 30%
- Move waist of electron and positron beam (independently) back by 100μm, 200 μm, 300 μm.
- Change angle φ of orientation of transverse electron and positron beam profile (independently) by 5 mrad and 20 mrad

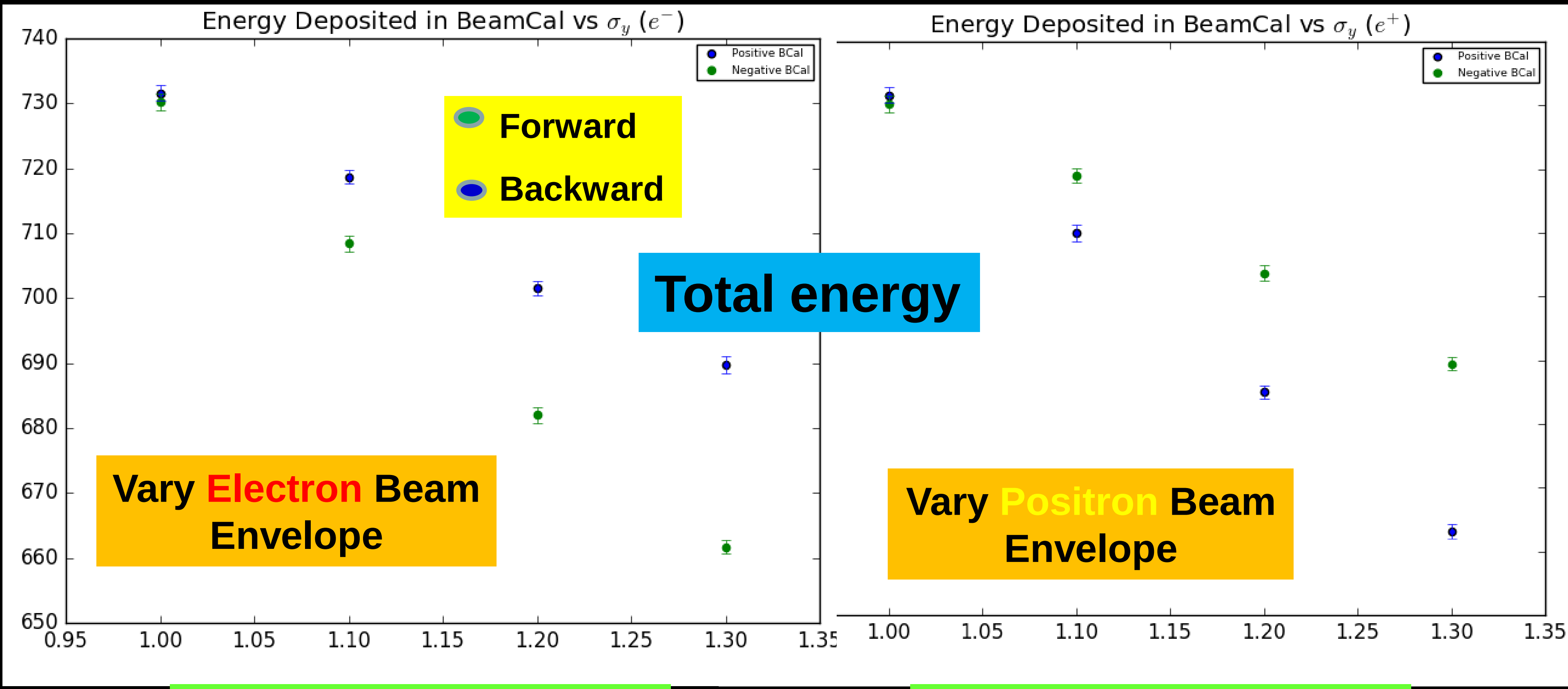
Details at https://wikis.bris.ac.uk/display/sid/GuineaPig+simulations+for+BeamCal+study

Observables reconstructed (differing dependencies on IP pathologies)

Total deposited energy	Mean depth of deposited energy
R moment	1/R moment
Barycenter (BC)	Modecenter (MC)
Left-right asymmetry*	Top-down asymmetry*
+45^0 diagonal asymmetry*	-45^0 diagonal asymmetry*
Thrust value*	

*With respect to both BC and MC

Size of beam envelope σ_y gives noticeable total energy dependence

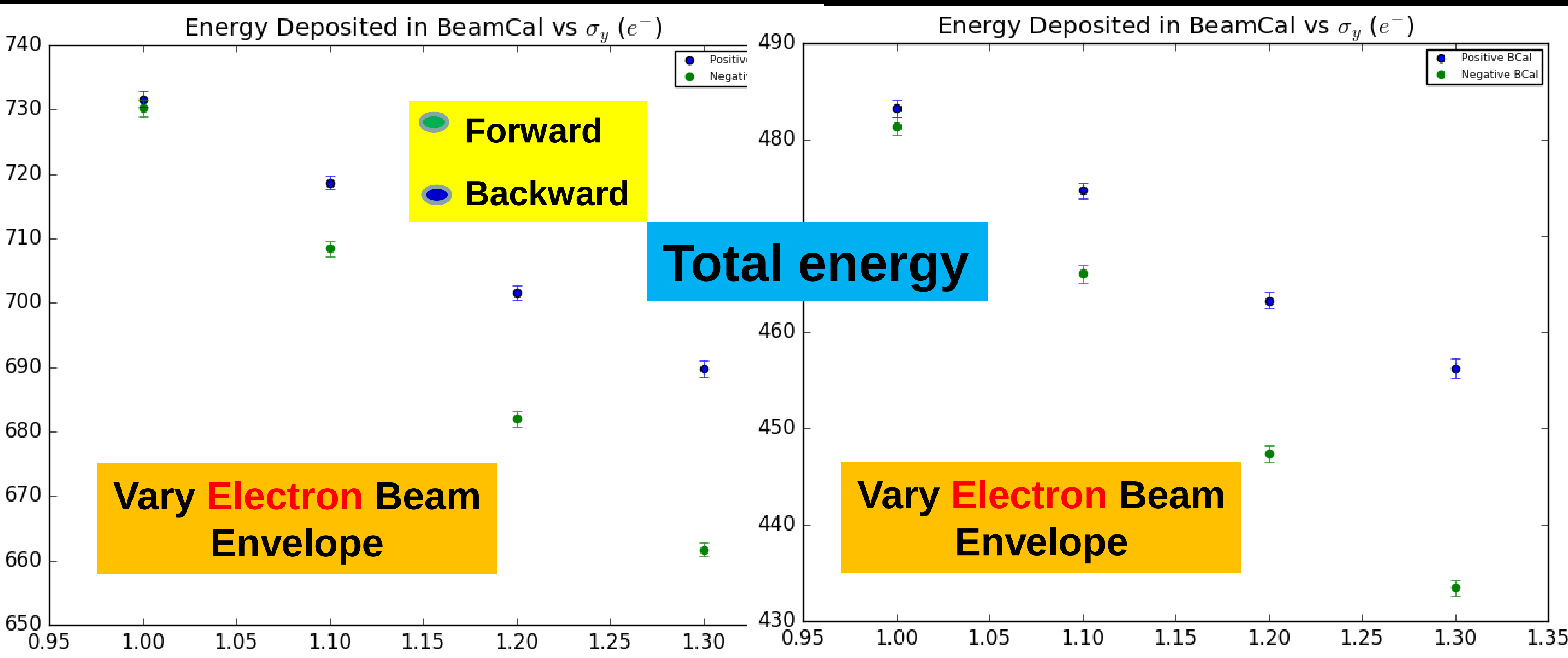


Nominal Geometry

Nominal Geometry

100 Beam Crossings

But for beam envelope size, information from wedge is not important for total energy deposition



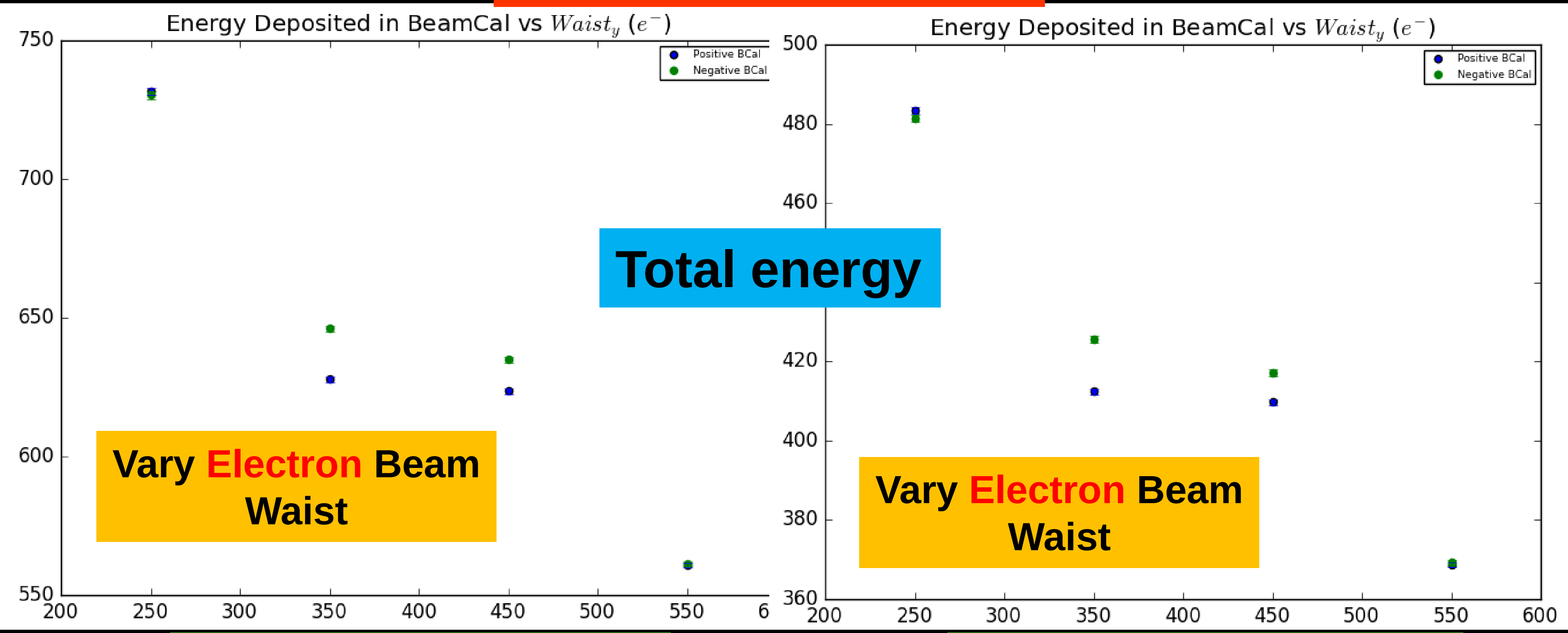
Nominal Geometry

With Wedge Cutout

100 Beam Crossings

Waist error produces very characteristic dependence of BeamCal energy deposition

100 Beam Crossings



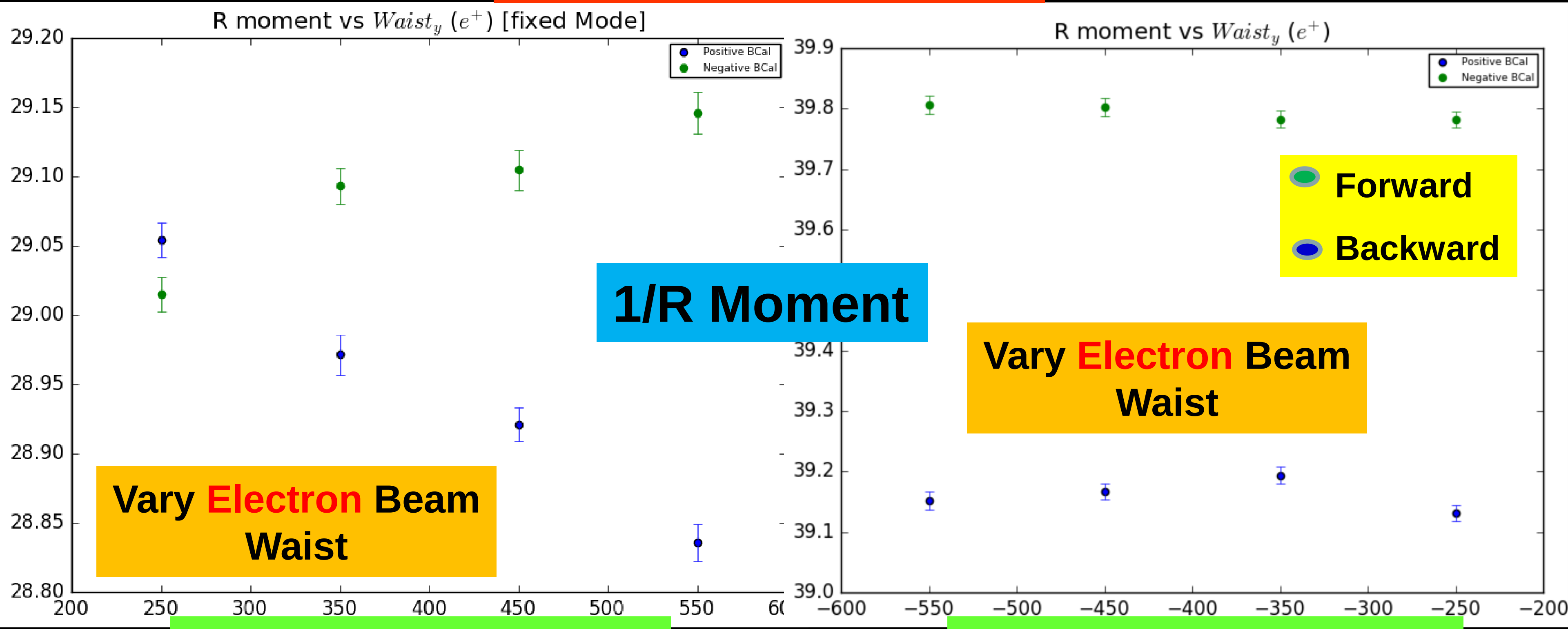
Nominal Geometry

With Wedge Cutout

That again doesn't particularly require the wedge region.

Waist error also produces clear dependence in the BeamCal 1/R profile

100 Beam Crossings



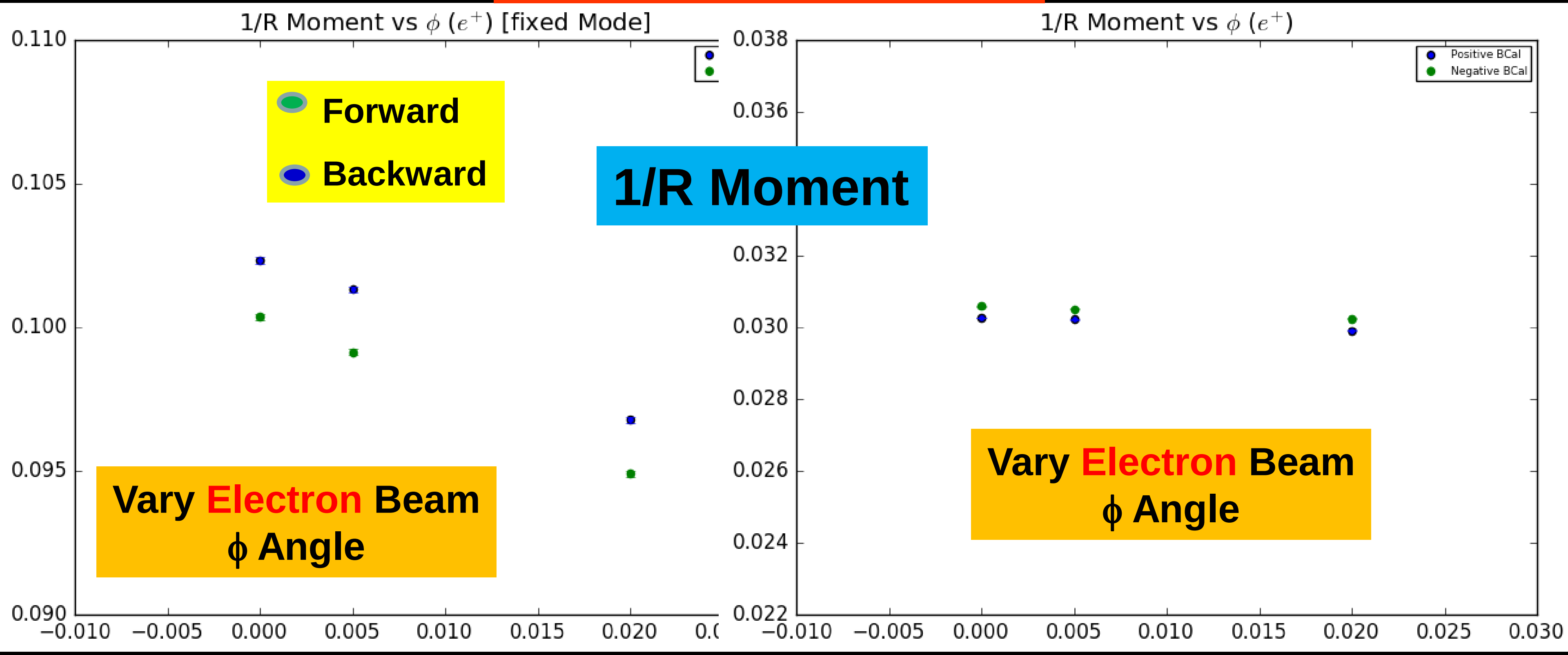
Nominal Geometry

With Wedge Cutout

But this time, the effect comes entirely from the wedge region

ϕ Rotation also detectable via 1/R moment

100 Beam Crossings



Nominal Geometry | **With Wedge Cutout**

And again, wedge region is essential

Studies continue

- More beam parameter variations (especially phase space correlations
- Is wedge important for particular types of beam parameter variation
- Are there other observables (in addition to 1/R moment) for which wedge is important?

Of course physics studies themselves may well justify including the wedge, but it's interesting to see the strength of the motivation from the machine-control angle!

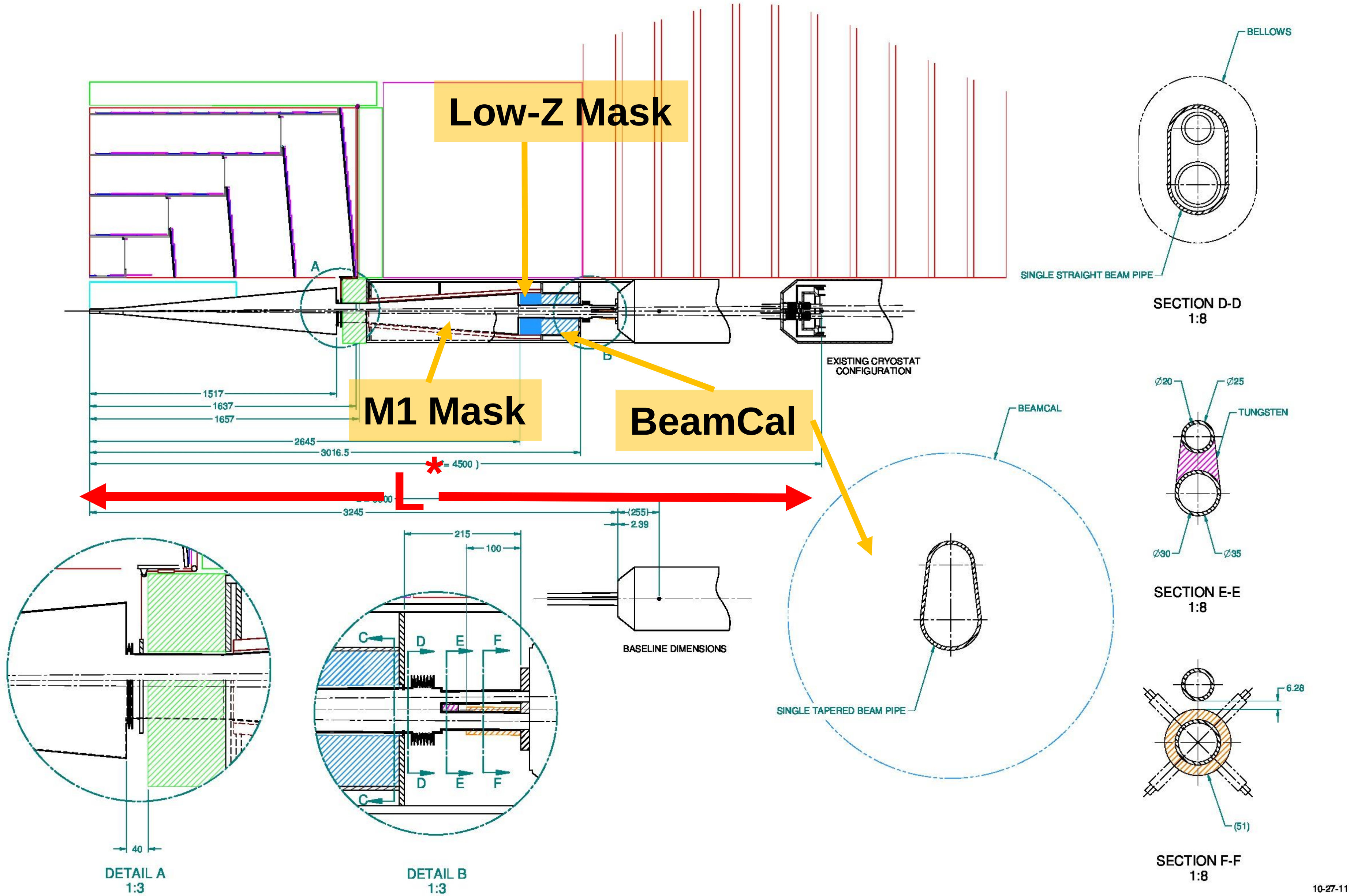
Summary and Outlook

- Slowly chipping away at degenerate SUSY studies
  - Initial "realistic beam crossing" simulation developed
  - Still need to include pairs (need to think about this) and perhaps also lower-cross-section processes
  - Can only generate about 0.01 yr of crossings; still need to develop generator cut with ~10^{-2} rejection
- Starting to understand effects of hermeticity
  - Gains observed for hadronic coverage with $|\cos\theta|$ substantially greater than 0.9
  - Started to work with Kiev group on LHCAL; need to restart
- IP Parameters and Beamcal Geometry
  - Wedge region important for 1/R moment observable; are there others?

BackUp…

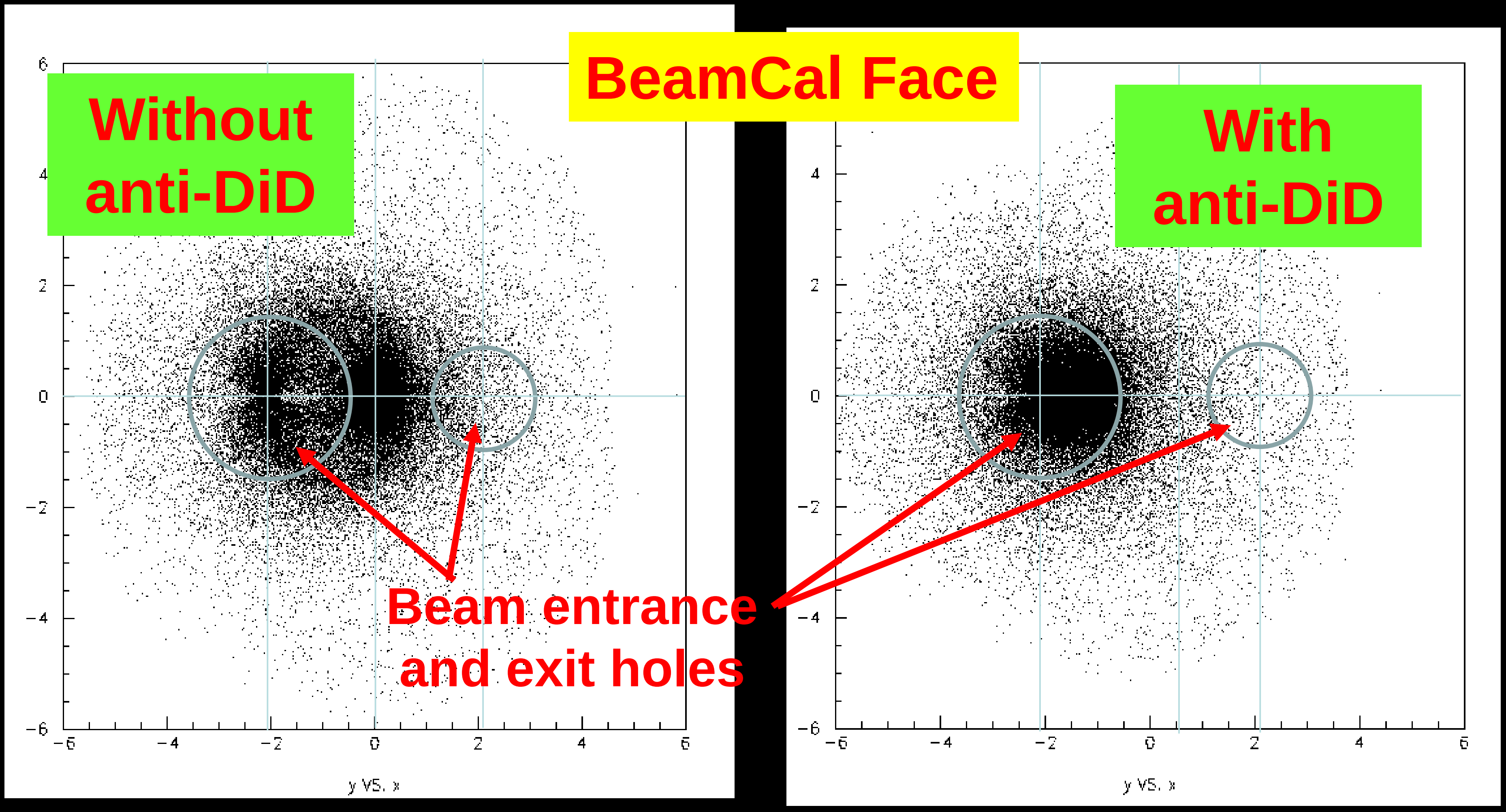
Effect of L*, Anti-DID, and BeamCal geometry on Vertex Detector Occupancy from BeamCal Backsplash

IR Layout



Low-Z Mask
M1 Mask
BeamCal
BELLOWS
SINGLE STRAIGHT BEAM PIPE
SECTION D-D
1:8
EXISTING CRYOSTAT CONFIGURATION
BEAMCAL
TUNGSTEN
Ø20
Ø25
Ø30
Ø35
SECTION E-E
1:8
SINGLE TAPERED BEAM PIPE
BASELINE DIMENSIONS
1517
1637
1657
2645
3016.5
= 4500)
L*
3245
(255)
2.39
215
100
6.28
(51)
40
DETAIL A
1:3
DETAIL B
1:3
SECTION F-F
1:8
10-27-11

Incidence of pair backgrounds on BeamCal with and without “anti-DiD” field



Tom Markiewicz, SLAC

Configurations Explored

Nominal: L^* = 4.1m; no antiDiD; plug in place

Then, relative to Nominal:

Small L*: L* = 3.5m

AntiDID: Include antiDiD field

Small L* AntiDID: L^* = 3.5m with antiDiD field

Wedge: Remove BeamCal plug

Circle: Remove additional BeamCal coverage as shown in prior slide.

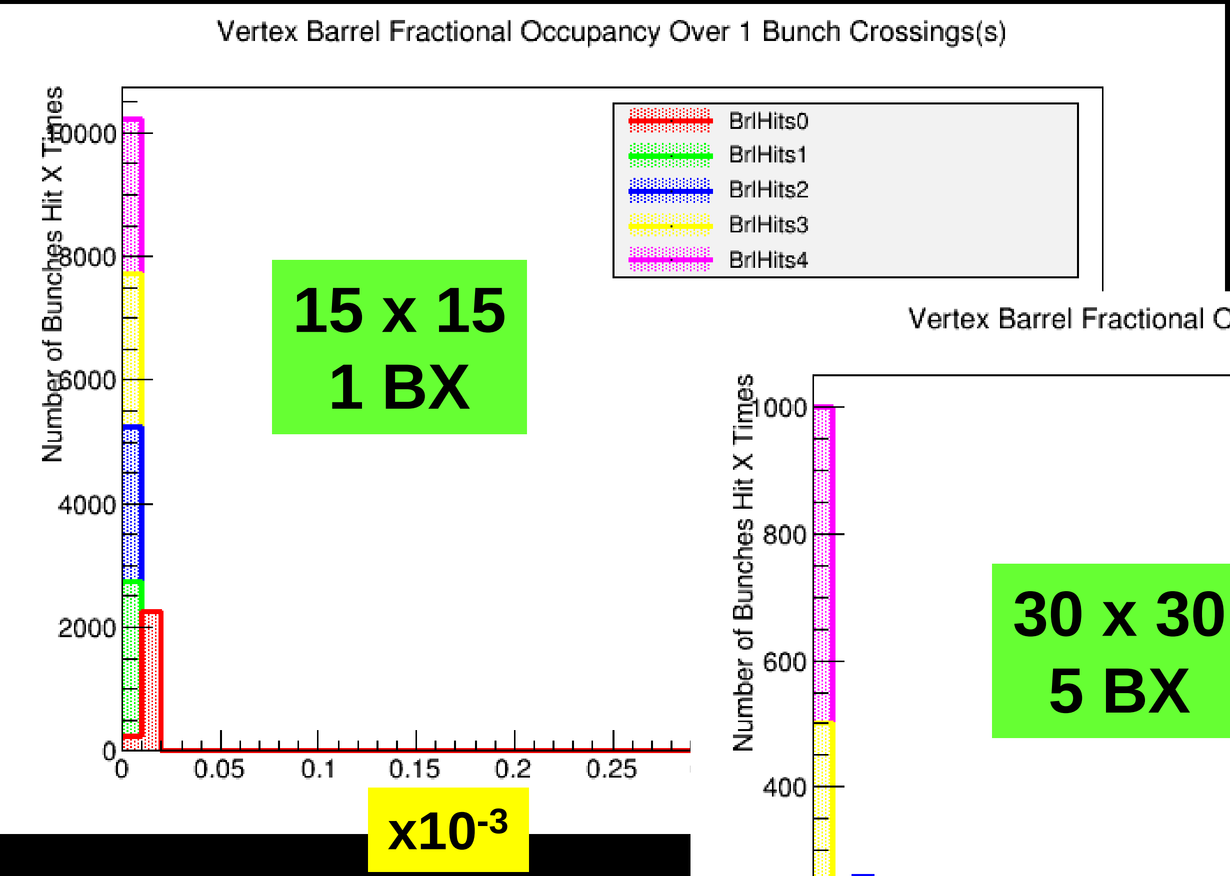
Vertex Detector Configurations

We have studied occupancy as a function of two aspects of the VXD readout architecture

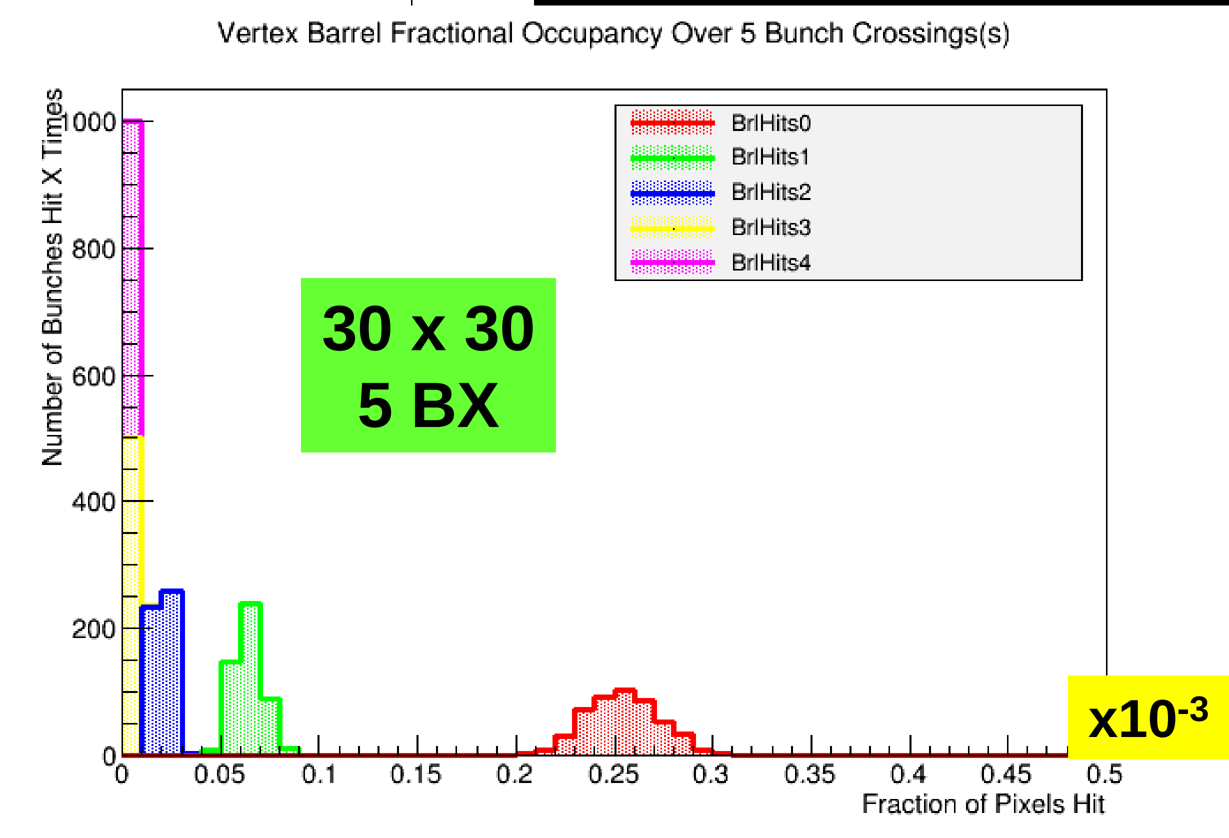
- **Pixel size**
  - **15 x 15 microns^2**
  - **30 x 30 microns^2**

- **Integration time**
  - **1 beam crossing**
  - **5 beam crossings**

Nominal IR Geometry Occupancy Distributions (Barrel)

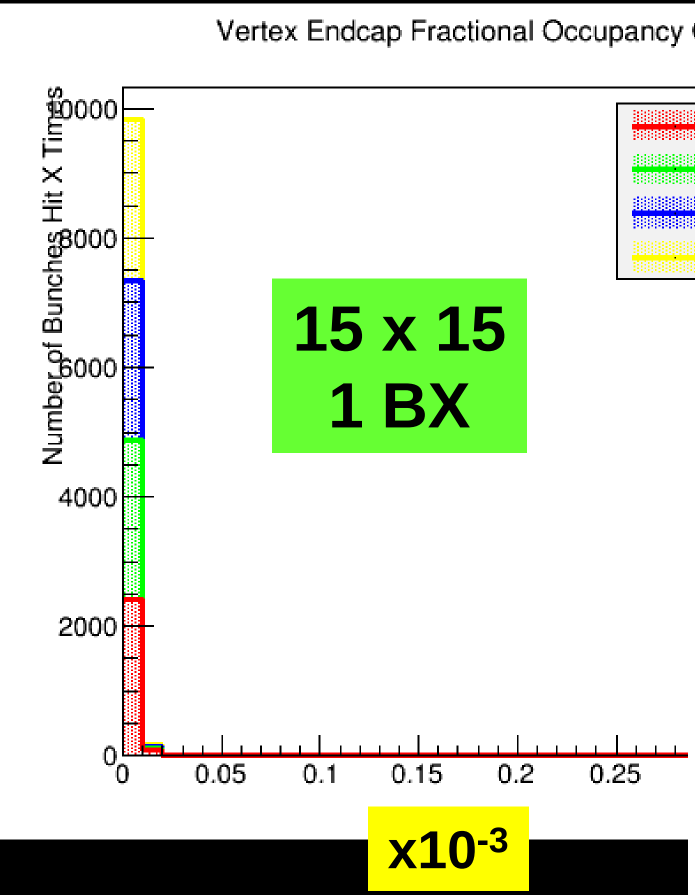


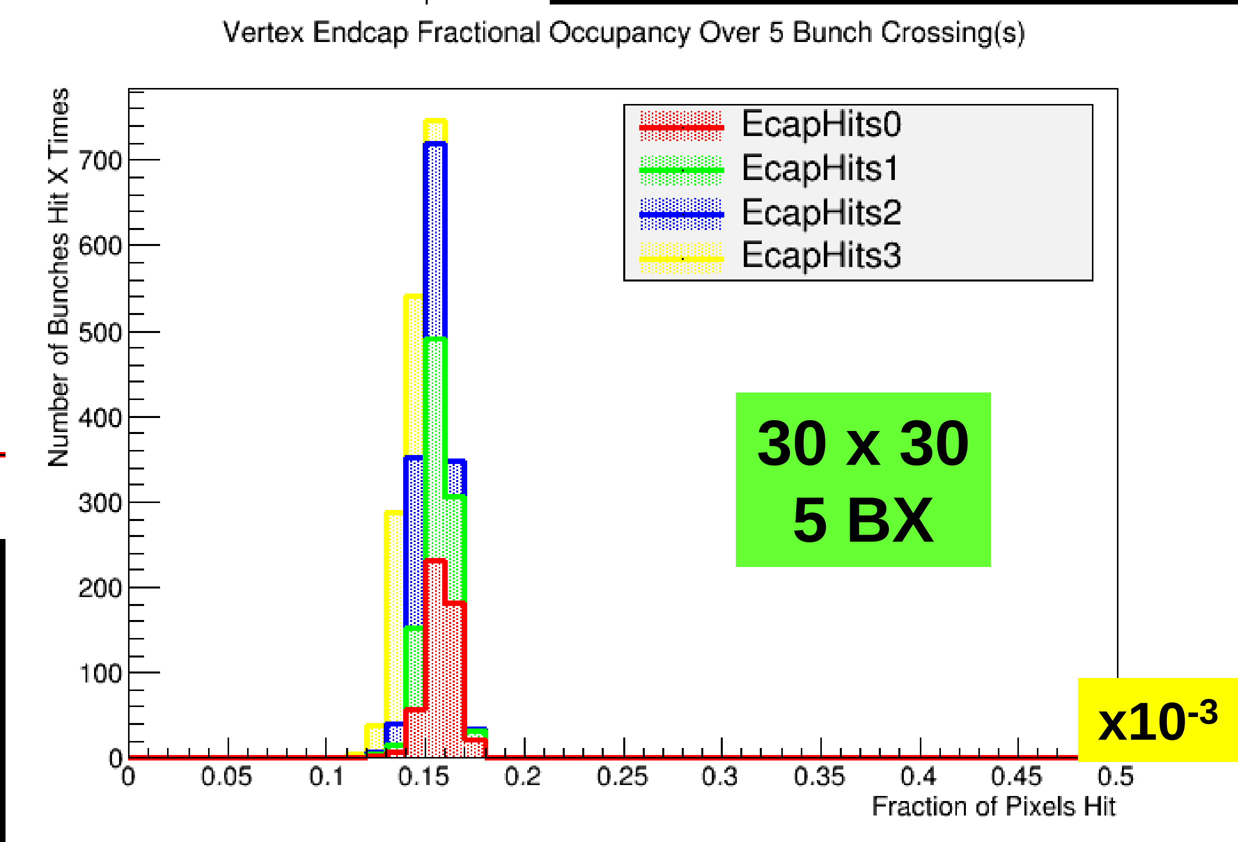
Stacked histograms!



Nominal IR Geometry Occupancy Distributions (Endcap)

Stacked histograms!





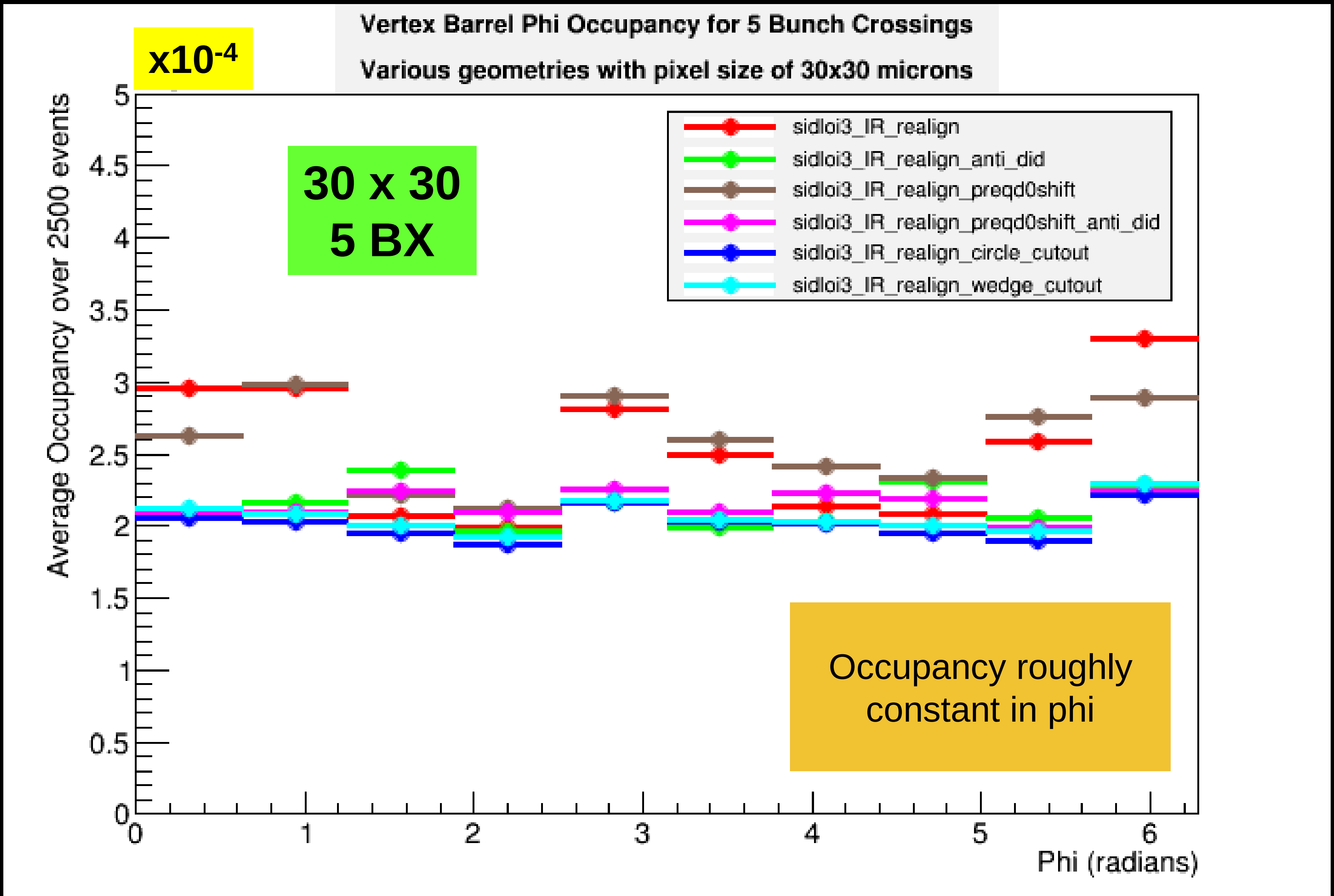
We note that:

- Pulse-by-pulse variation is small
- Occupancy only appreciable for largest pixel size (30x30) and greatest integration time (5 Bx)
- Inner layer (0) dominates occupancy in barrel
- Inner layer (0) characteristic of occupancy in endcap

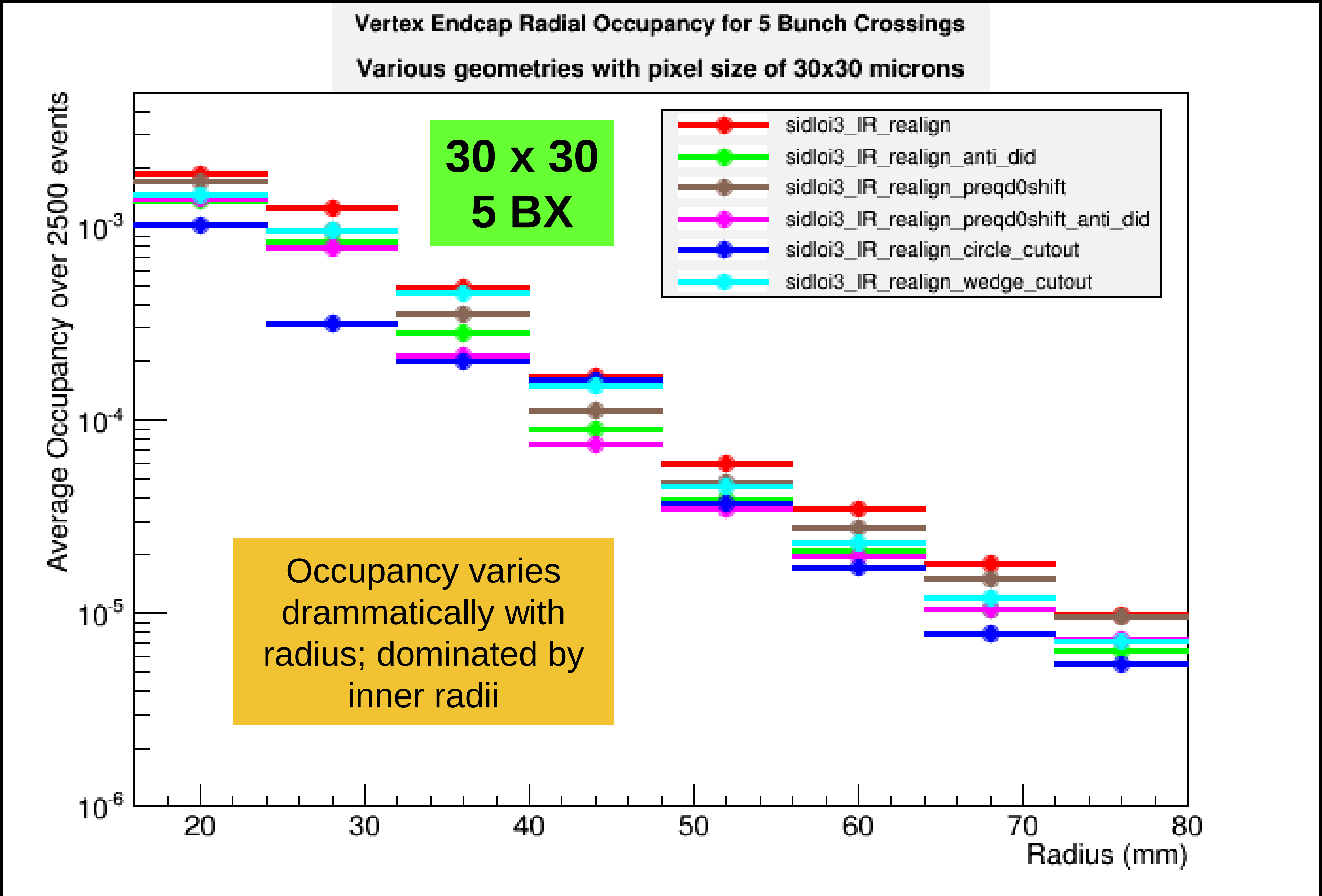
→Study IR configuration dependence with layer 0 (both endcap and barrel) for 30x30 pixel integrating over 5 Bx.

In terms of: azimuthal dependence in barrel; radial dependence in endcap

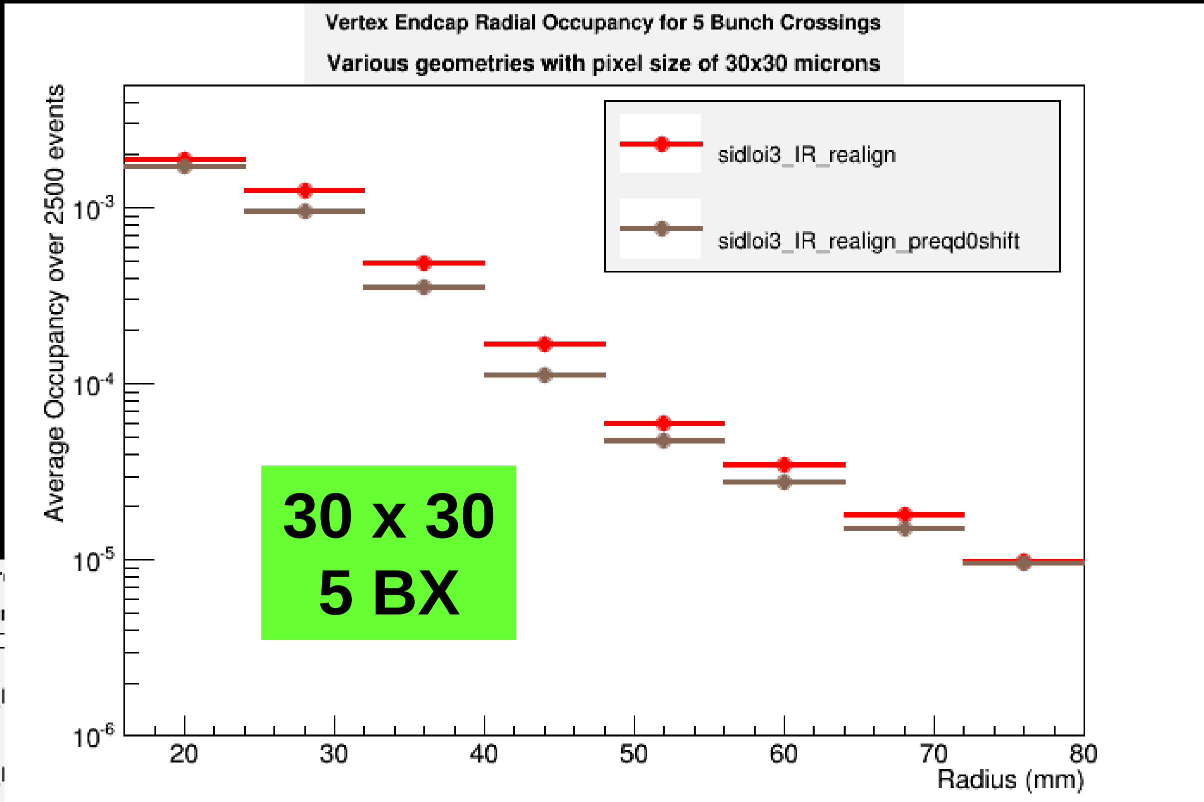
Barrel L0: Mean Occupancy vs. Phi

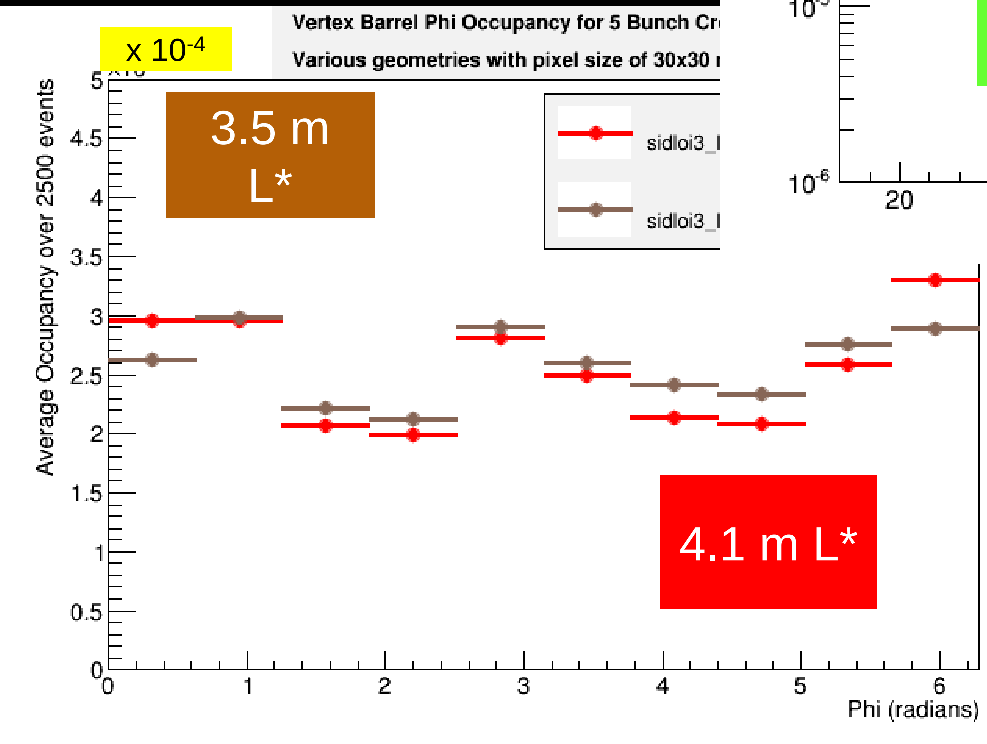


Endcap: Mean Occupancy vs. R



Vertex Occupancy Dependence on L* Configuration

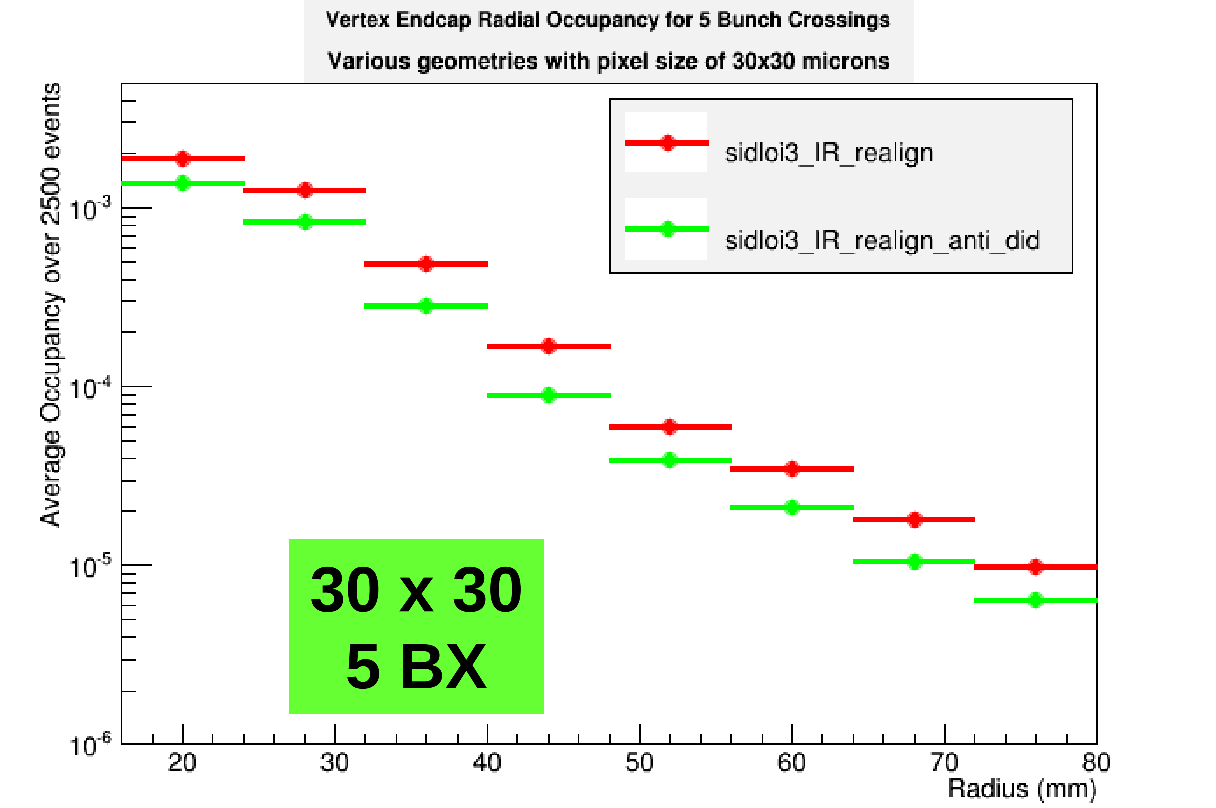


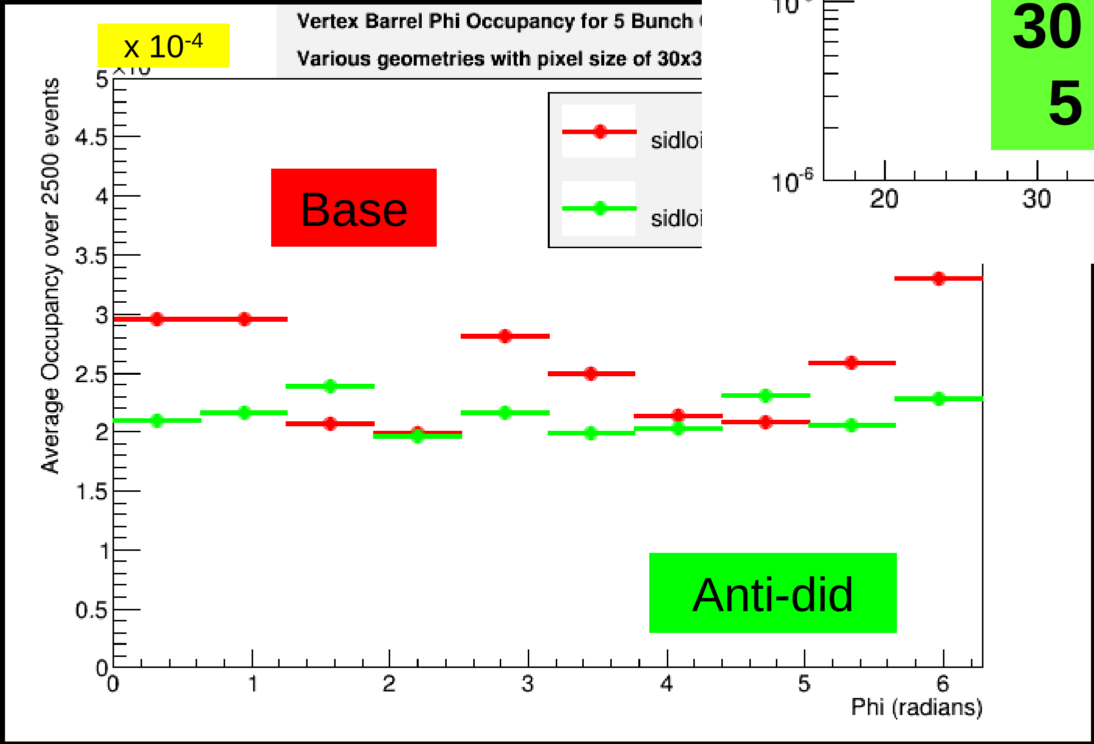


L* occupancy differences appear to depend on backscatter deflection angle

Vertex Occupancy Dependence on Anti-did Field

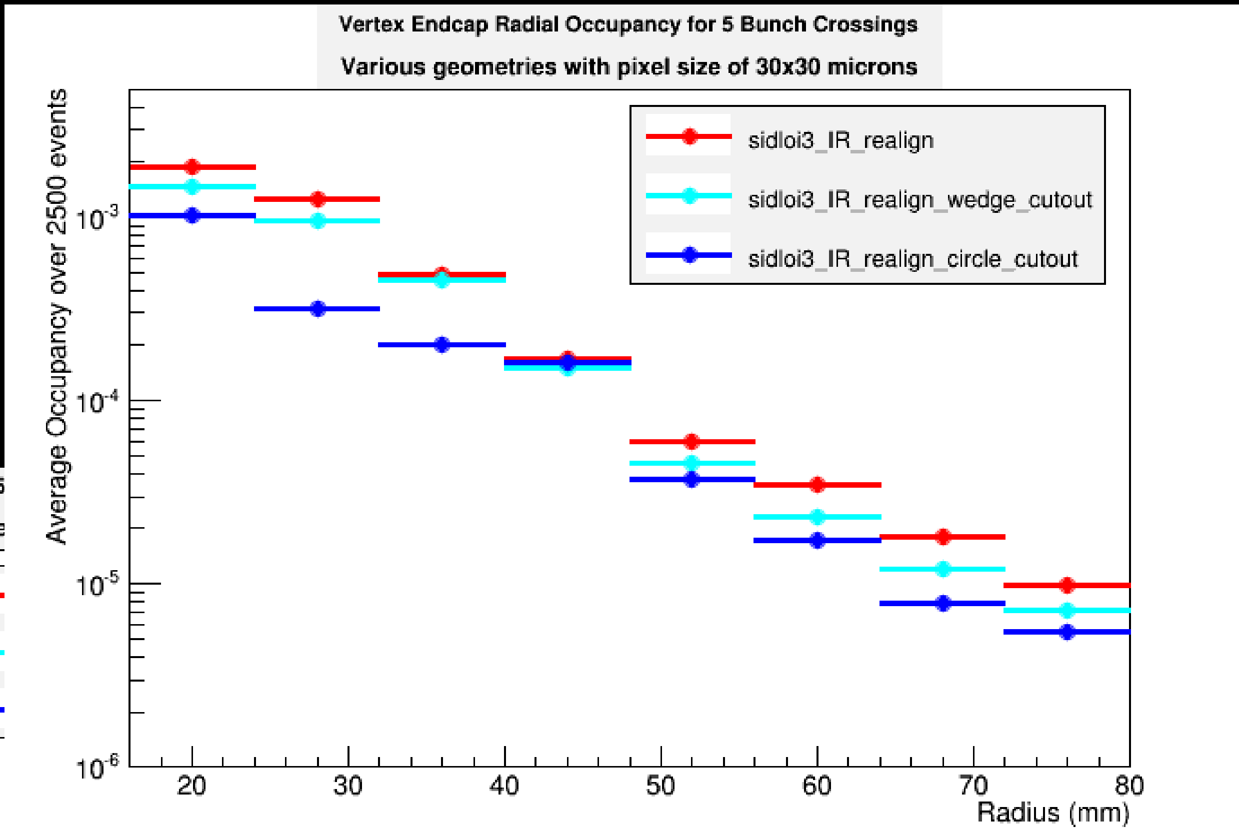
Plug is in place!

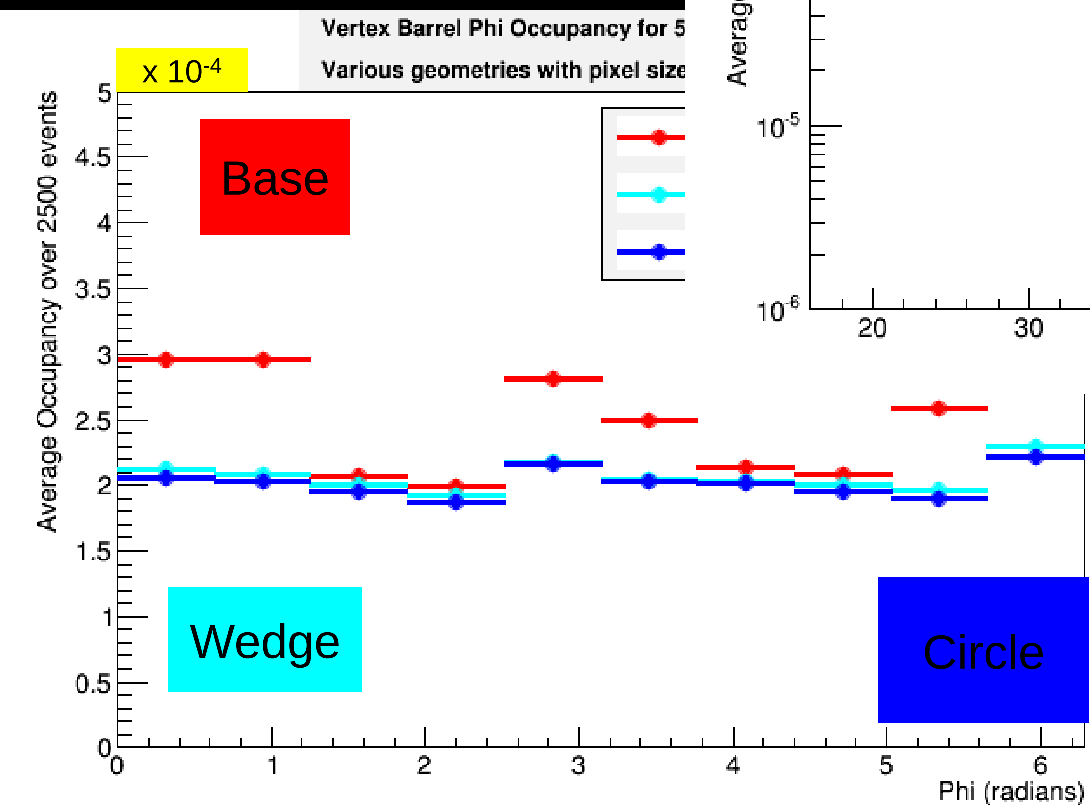




Anti-did field generally improves occupancy in barrel and consistently improves occupancy in endcap

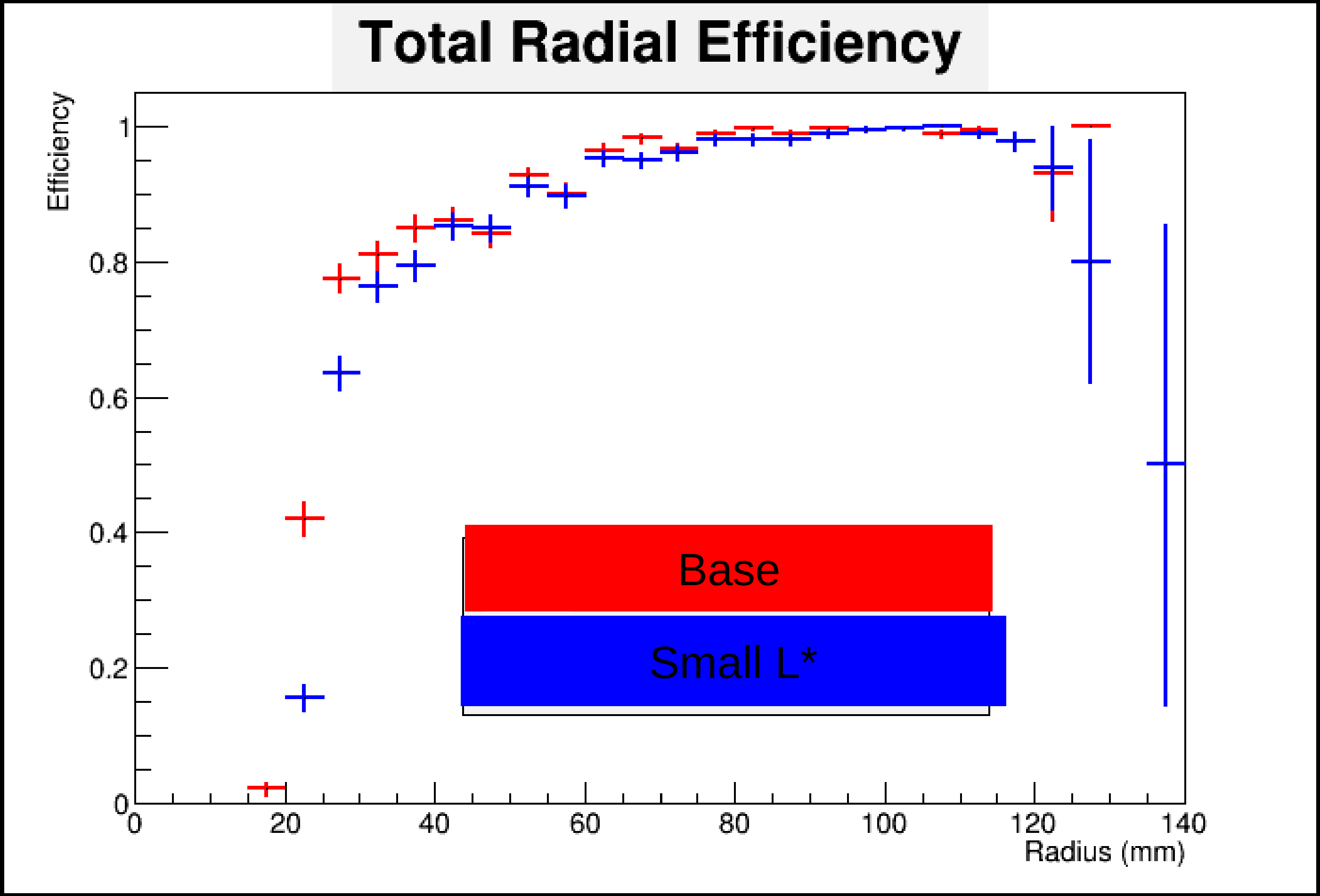
Occupancy Dependence on Plug Geometry





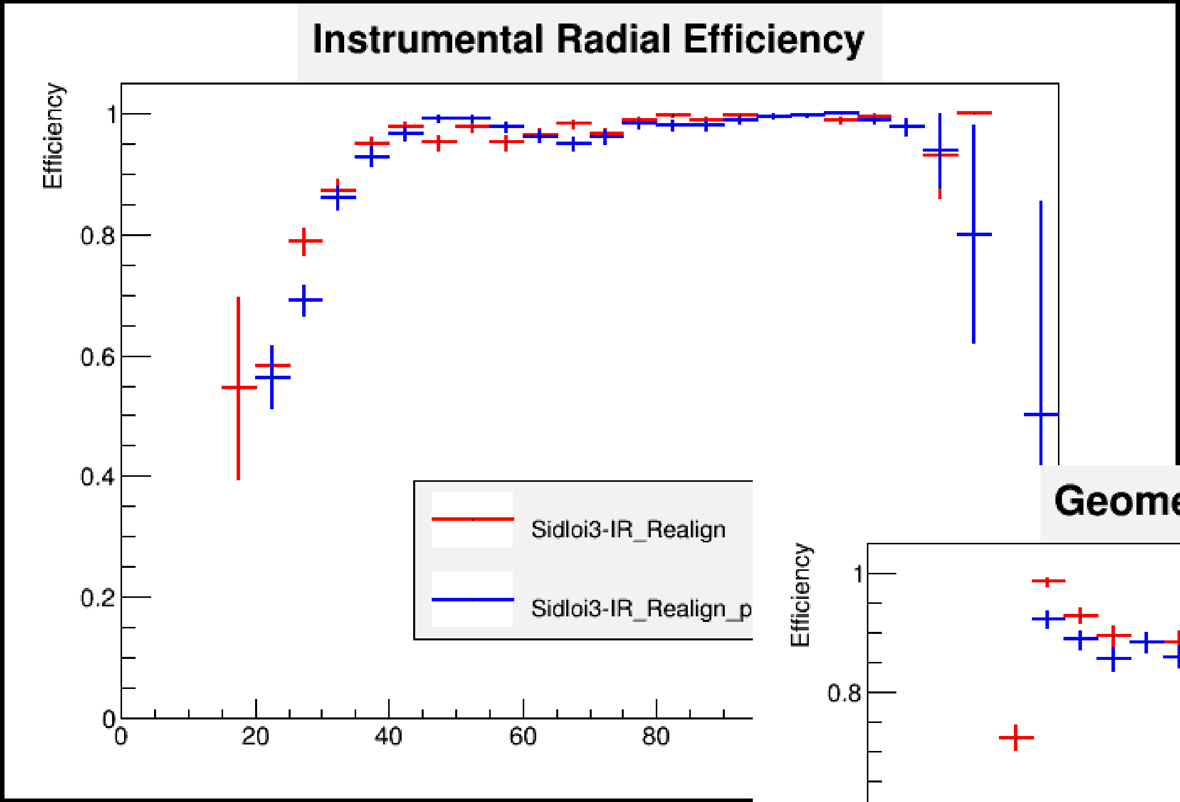
As expected, occupancy gets progressively lower as more of the BeamCal plug is cut away

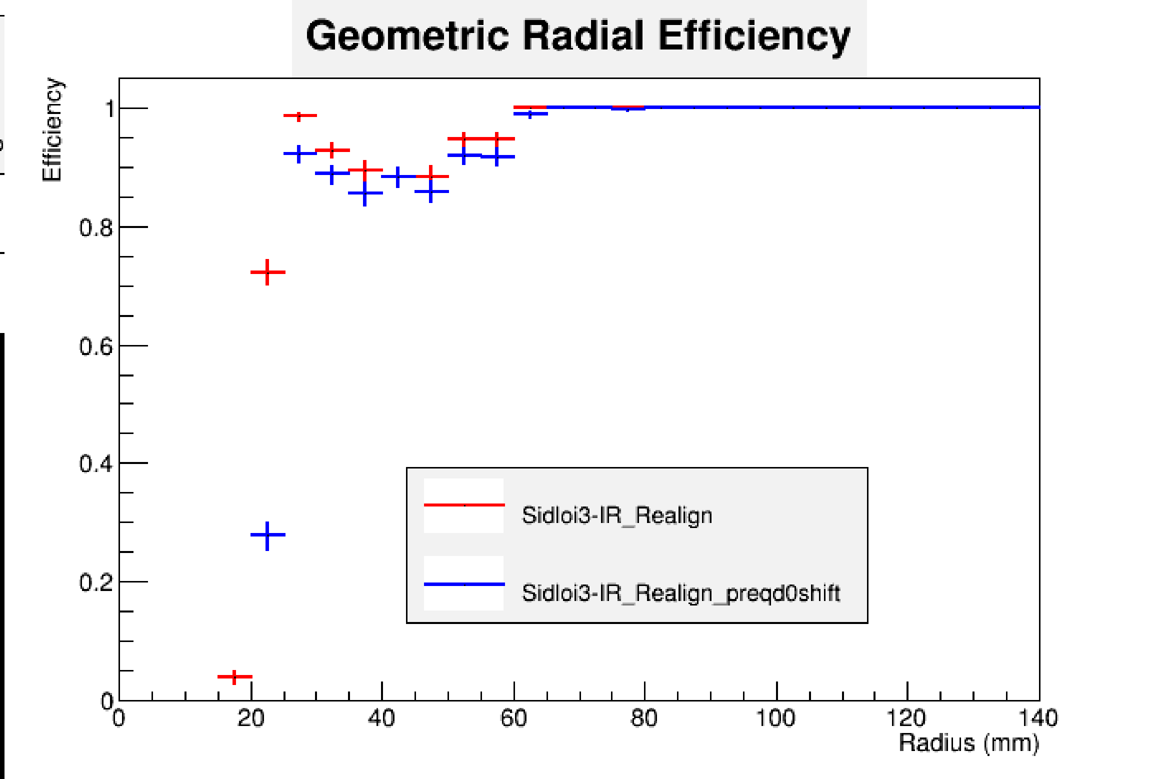
BeamCal Efficiency L* Dependence



larger L* consistently displays higher efficiency

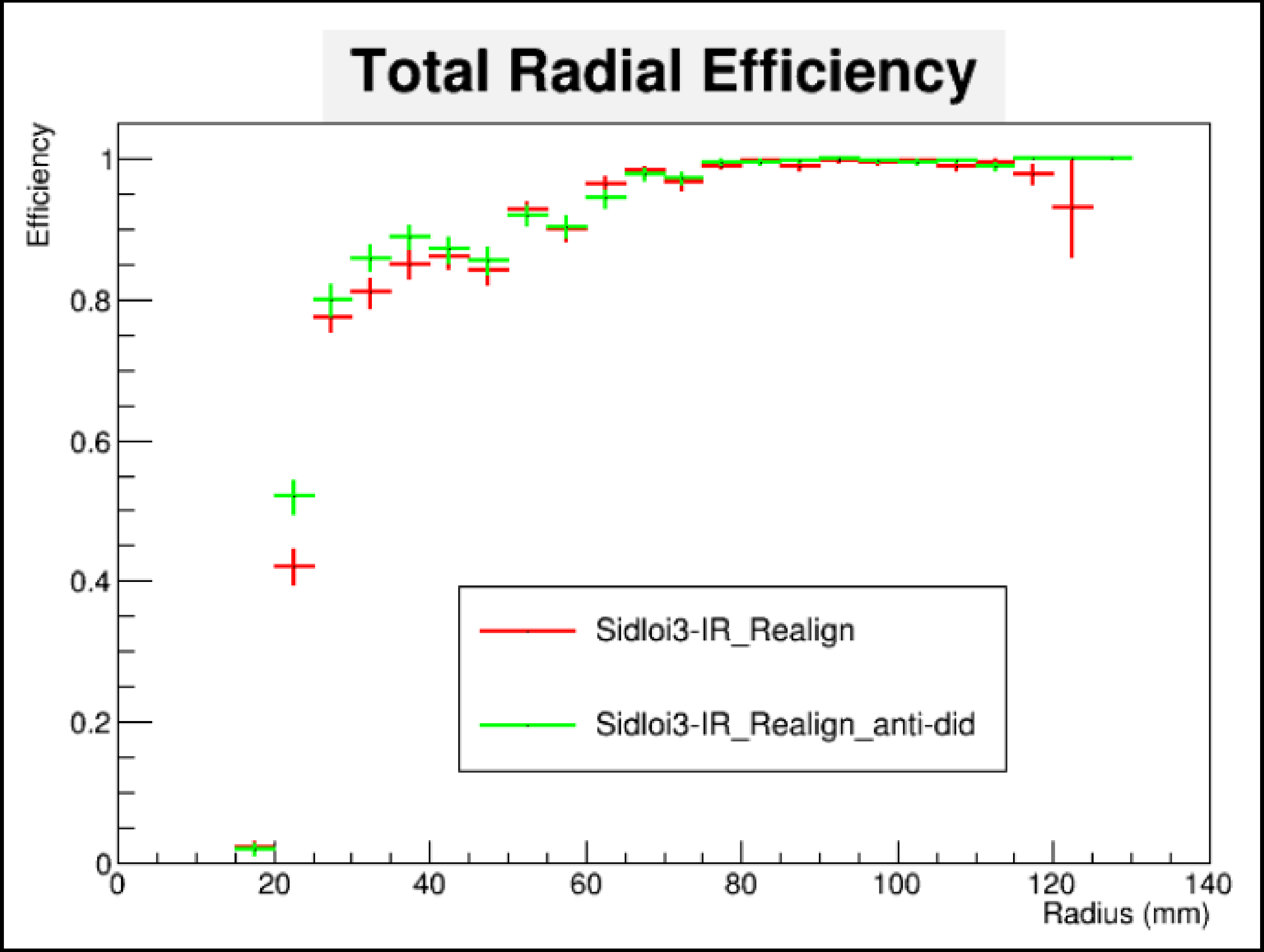
BeamCal Efficiency L* Dependence Factorized





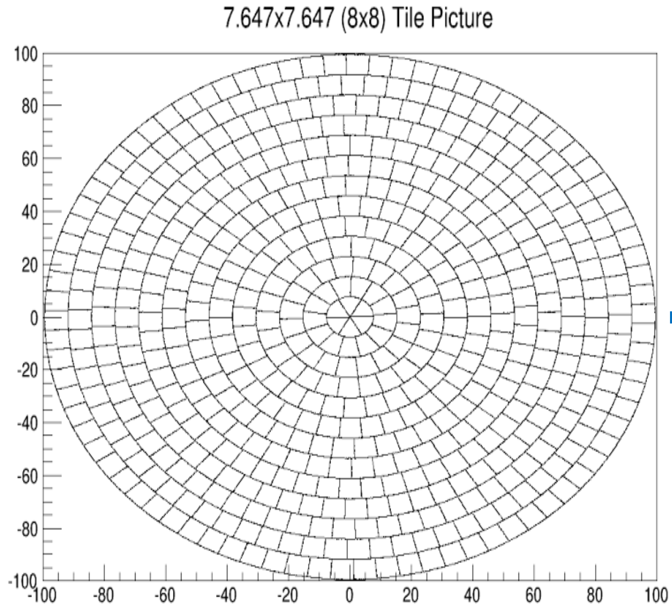
Difference is largely geometric

BeamCal Efficiency and the Anti-DiD Field



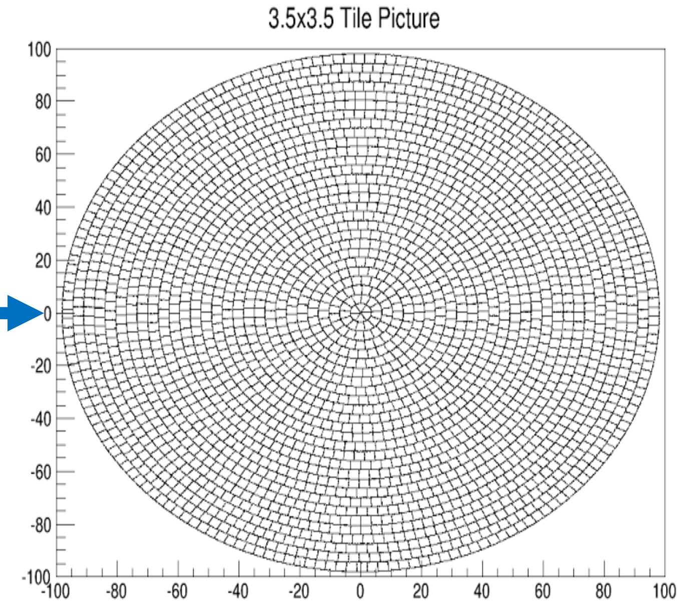
Noticeable but small effect

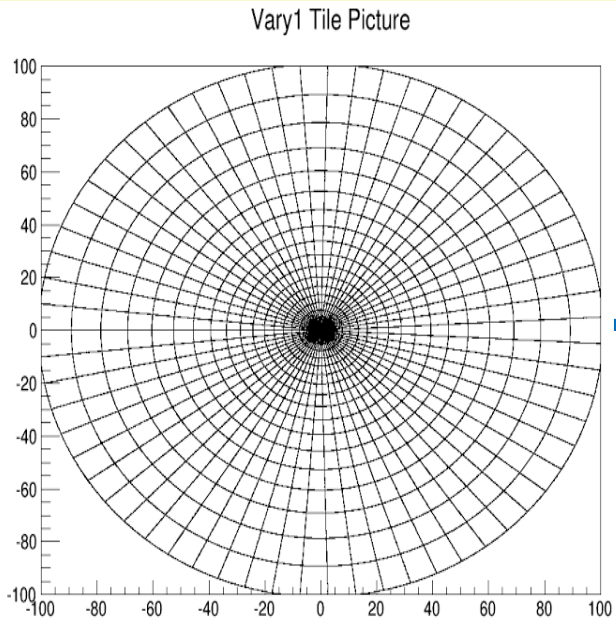
Tiling strategy and granularity study



Constant

7.6x7.6
5.5x5.5
3.5x3.5





Variable

Nominal
Nominal/√2
Nominal/2