Silicon-tungsten calorimetry and the SiD forward region

David Strom
University of Oregon

Thanks to Tom Markiewicz(SLAC), Takashi Maruyama (SLAC), Mary Robinson (UO undergrad)

Introduction

- SiD is a silicon based detector
  - Silicon pixel vertex detector
  - Silicon strip tracking for the inner detector
  - Silicon-tungsten ECAL
  - Fine grained (RPC?) HCAL
- Cost optimization results in a relatively small radius of the inner detector of $R \simeq 1.25$m with large 5 T field

See Snowmass talks from Breidenbach and Weerts

Energy flow drives most of the design

Hermeticity is also important

- Processes such as

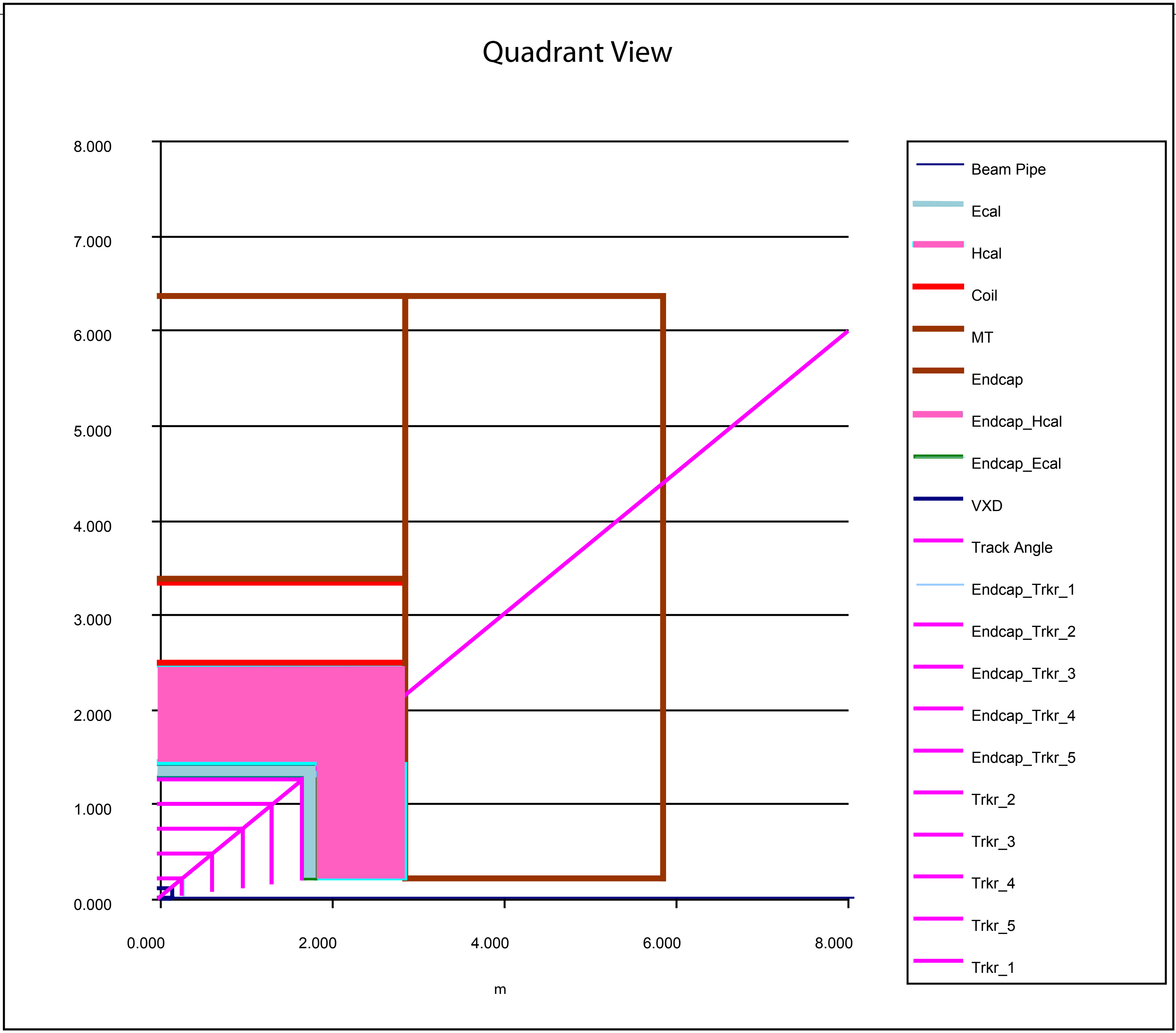
$$
\begin{aligned}
e^+e^- &\rightarrow \tilde{\tau}^+\tilde{\tau}^- \\
&\rightarrow \tau^+\tilde{\chi}^0\tau^-\tilde{\chi}^0
\end{aligned}
$$

are tagged using momentum imbalance

- Can be faked by

$$e^+e^- \rightarrow e^+e^-\tau^+\tau^-$$

with missing final state e^+ or e^- that carry p_t



Quadrant View
8.000
7.000
6.000
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3.000
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2.000
4.000
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8.000
m
Beam Pipe
Ecal
Hcal
Coil
MT
Endcap
Endcap_Hcal
Endcap_Ecal
VXD
Track Angle
Endcap_Trkr_1
Endcap_Trkr_2
Endcap_Trkr_3
Endcap_Trkr_4
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Trkr_2
Trkr_3
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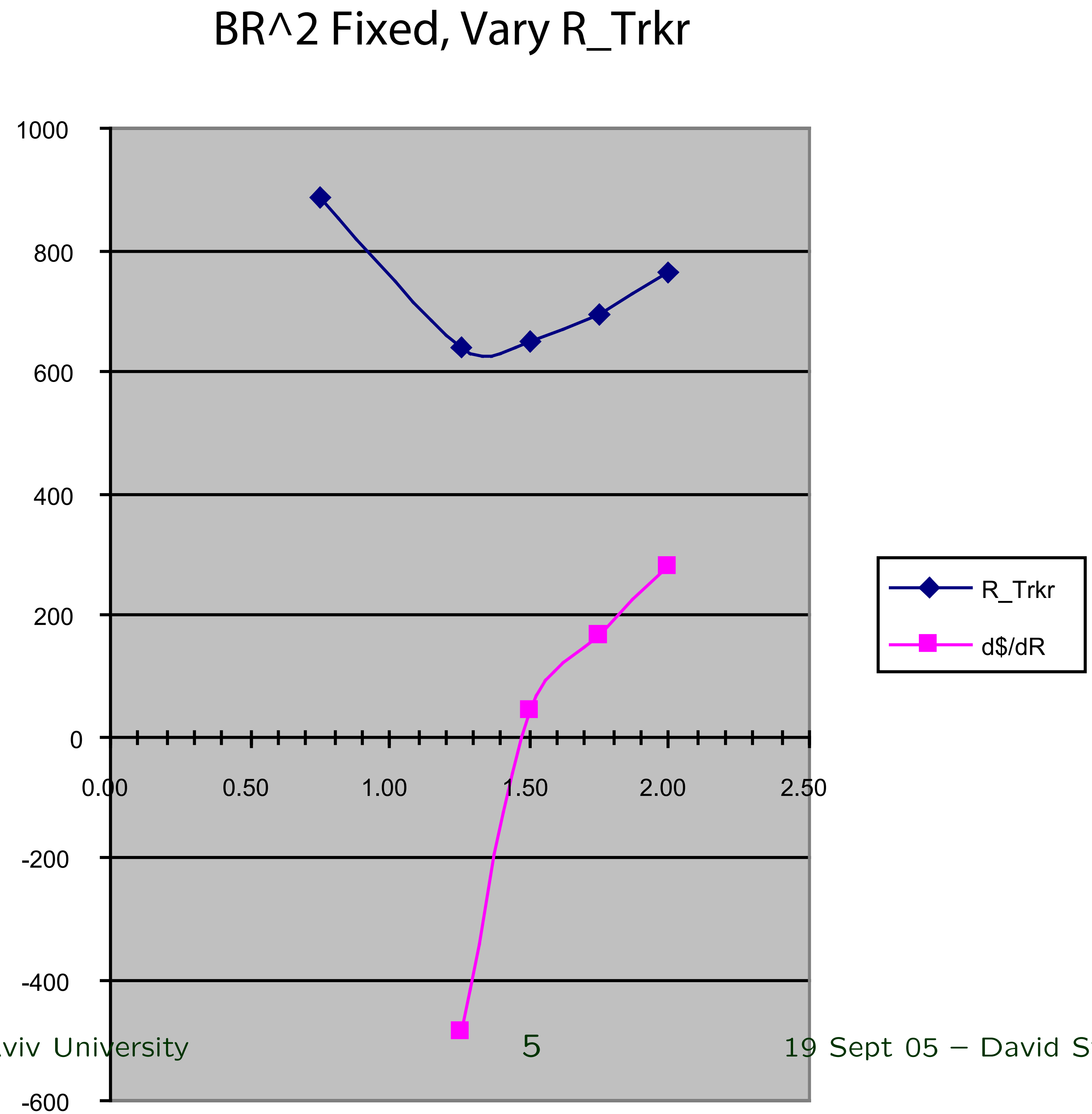
Trkr_5
Trkr_1


BR^2 Fixed, Vary R_Trkr
1000
800
600
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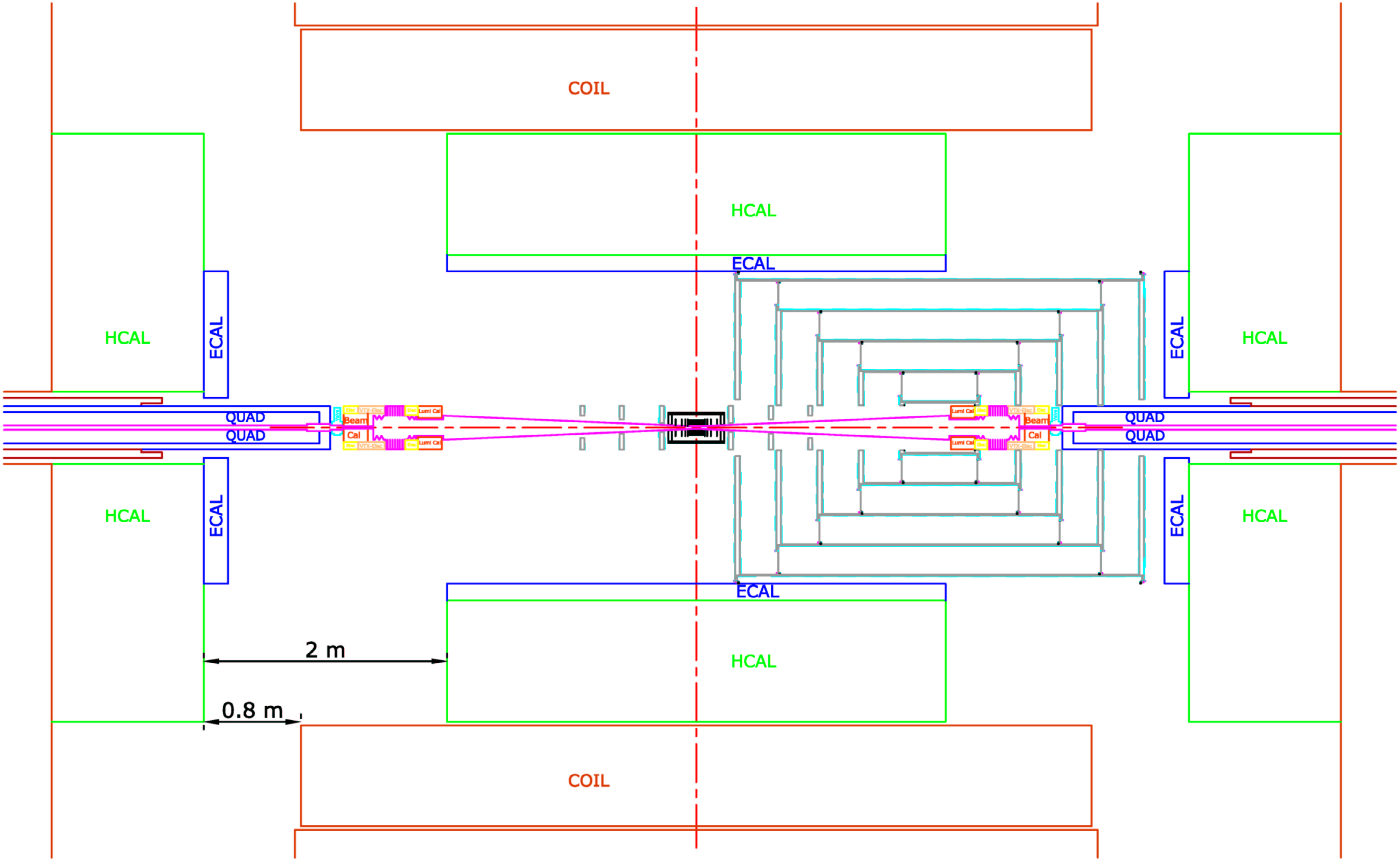
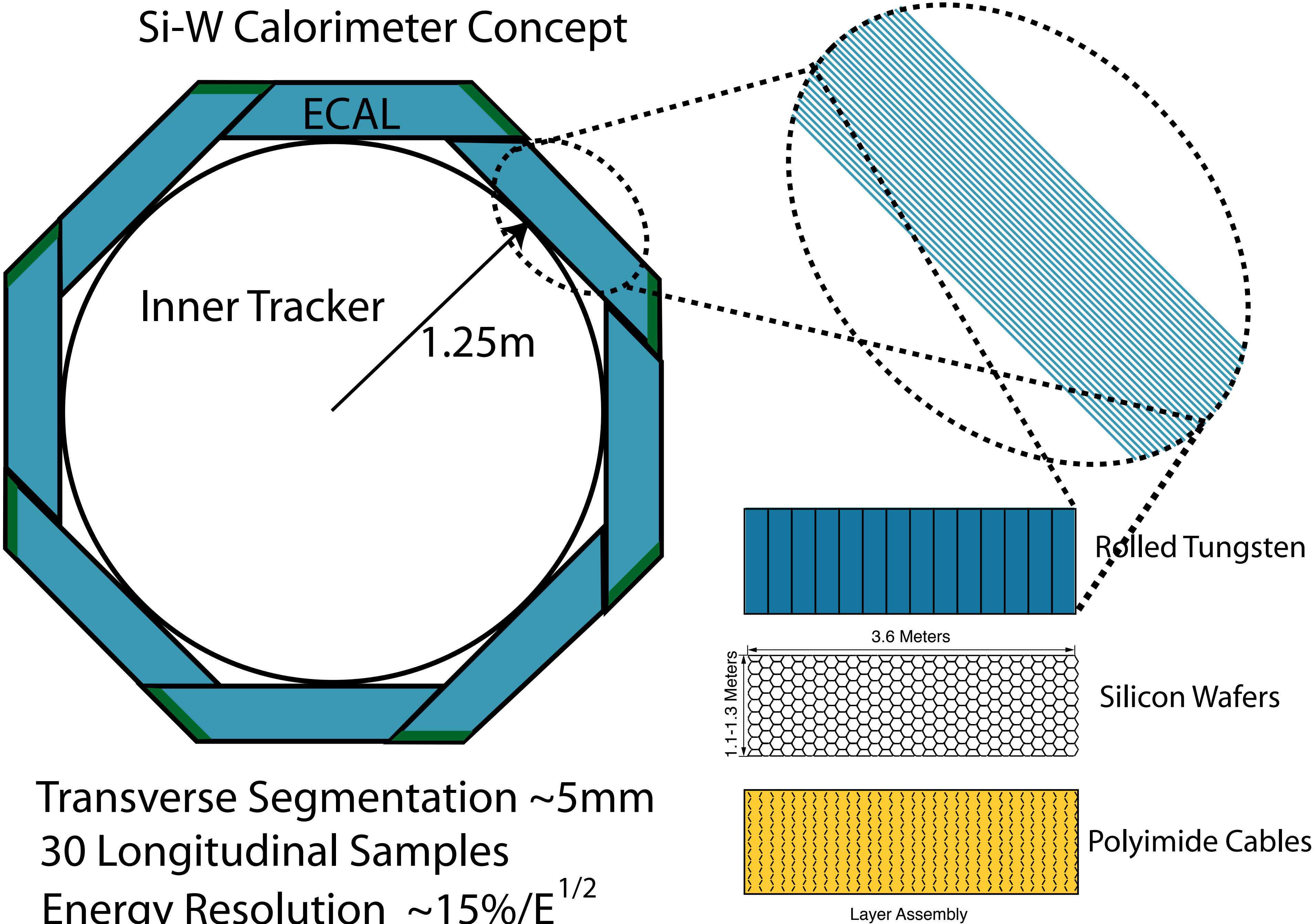
200
0
-200
-400
-600
0.00
0.50
1.00
1.50
2.00
2.50
R_Trkr
d$/dR

Bill Cooper's opening scheme (Endcap not split)



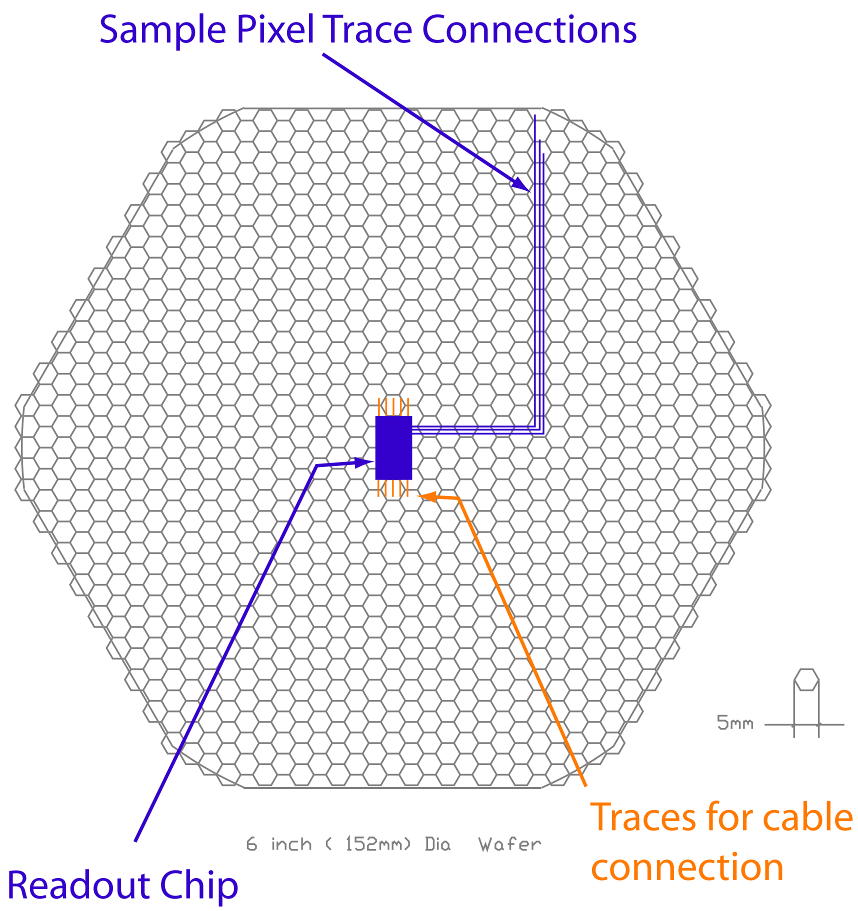
Si-W Calorimeter Concept



Transverse Segmentation ~5mm
30 Longitudinal Samples
Energy Resolution ~15%/$E^{1/2}$

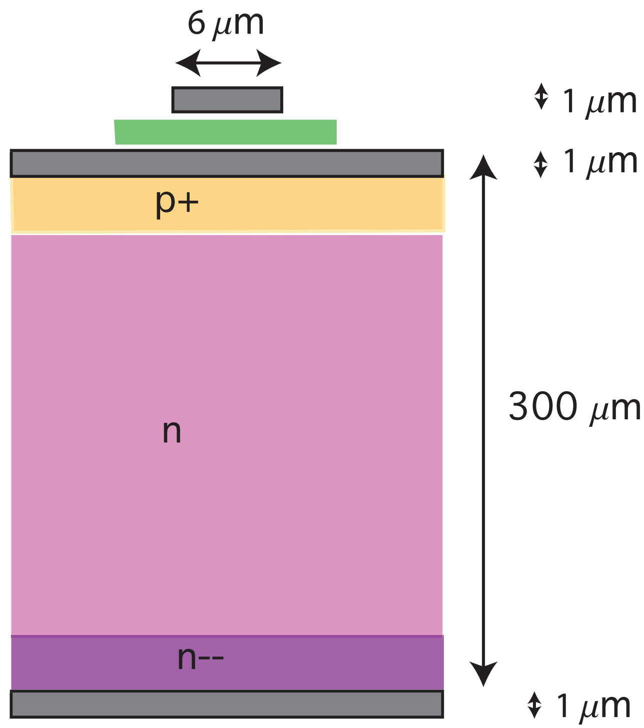
Silicon Concept

- Readout each wafer with a single chip
- Bump bond chip to wafer
- To first order cost independent of pixels /wafer
- Hexagonal shape makes optimal use of Si wafer
- Channel count limited by power consumption and area of readout end chip
- May want different pad layout in forward region



Silicon Detector Design

- DC coupled detectors (avoids bias resistor network)
- Two metal layers
- Keep Si design as simple as possible to reduce cost
- Cross talk looks small with current electronics design
- Trace capacitances (up to 30pF) are bigger than the 5 pF pixel capacitance

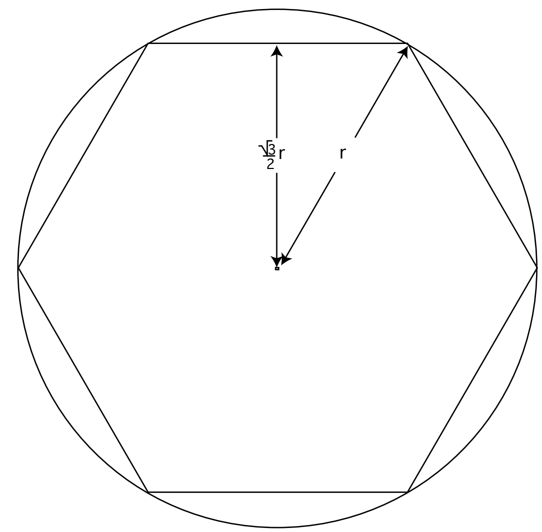


Notes on silicon based calorimetry

- For large projects, price depends on silicon area (perhaps 3/cm^2)

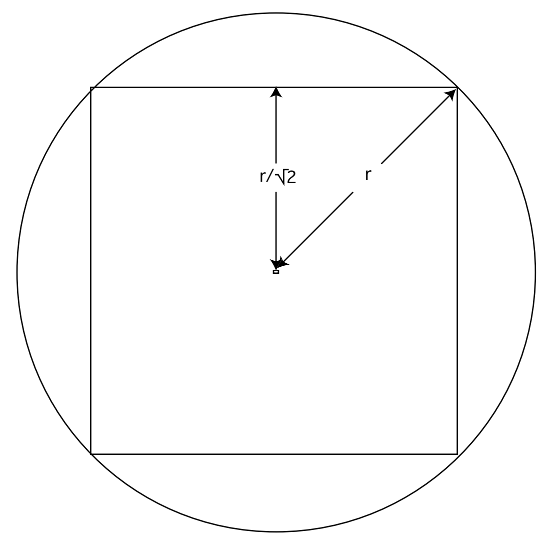
- Ratio of area a hexagon inscribed in a circle to a square inscribed in a circle:

$$\frac{3\sqrt{3}}{4} = 1.29$$



- Ratio of dead edge (e is edge width) space hexagon to square

$$\frac{\frac{4e}{\sqrt{3}r}}{\frac{2\sqrt{2}e}{r}} = \sqrt{\frac{2}{3}} = 0.81$$



- Area of current detectors is $\frac{3\sqrt{3}r^2}{2} \simeq 118cm^2$

- Price of mask set for different shapes is likely a fixed cost of about 50K USD.
- 50K USD is equivalent to approximately 150 wafers at 3 USD/cm^2
- Price could be reduced if specialized pieces where built in-house.
- More than one small piece/wafer may be possible

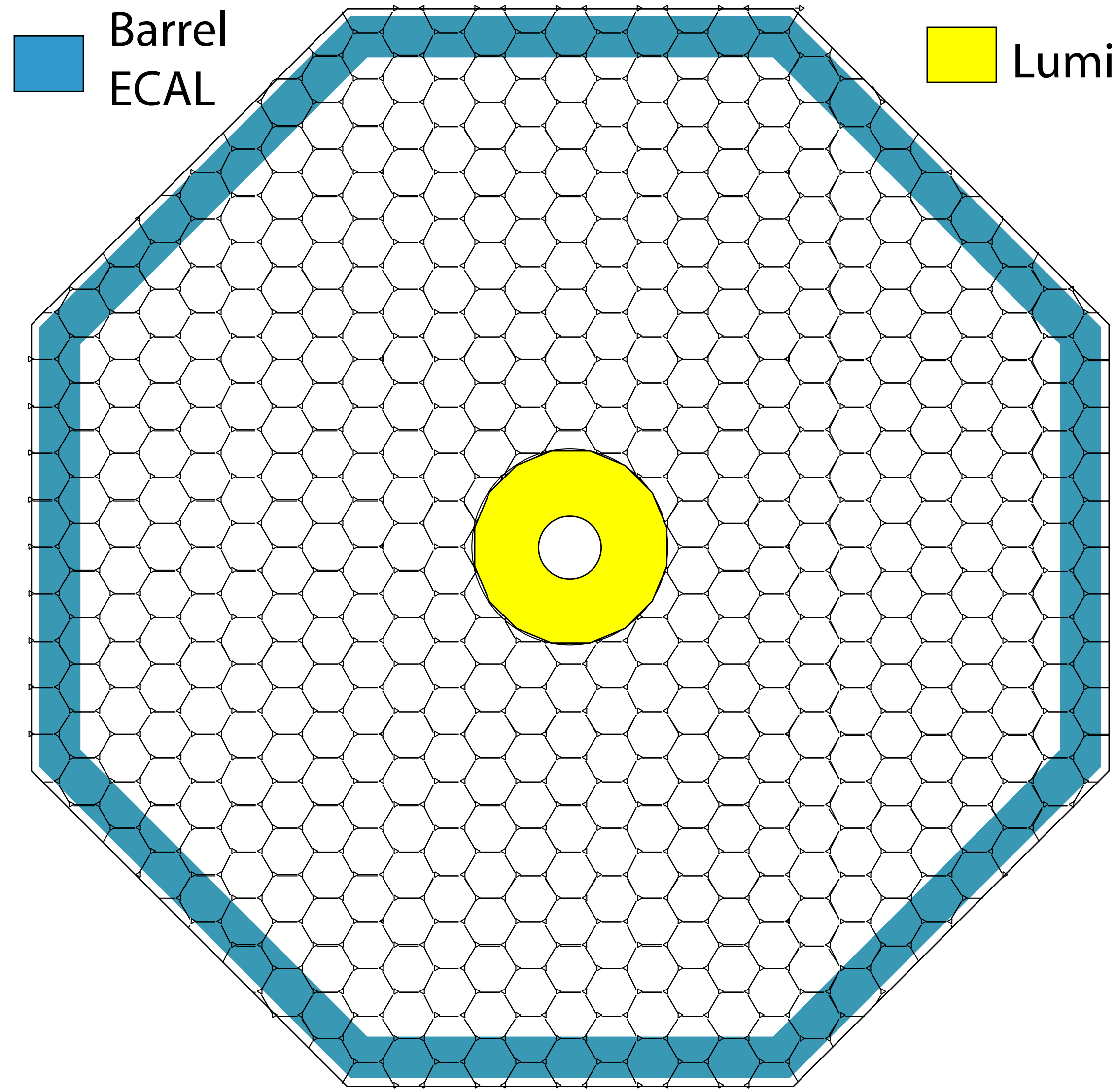
Possible endcap layout

- Requires $\sim$ 15 different mask sets for zero crossing angle

- Nearly twice as many are required if luminosity monitor is offset to be centered on outgoing beam

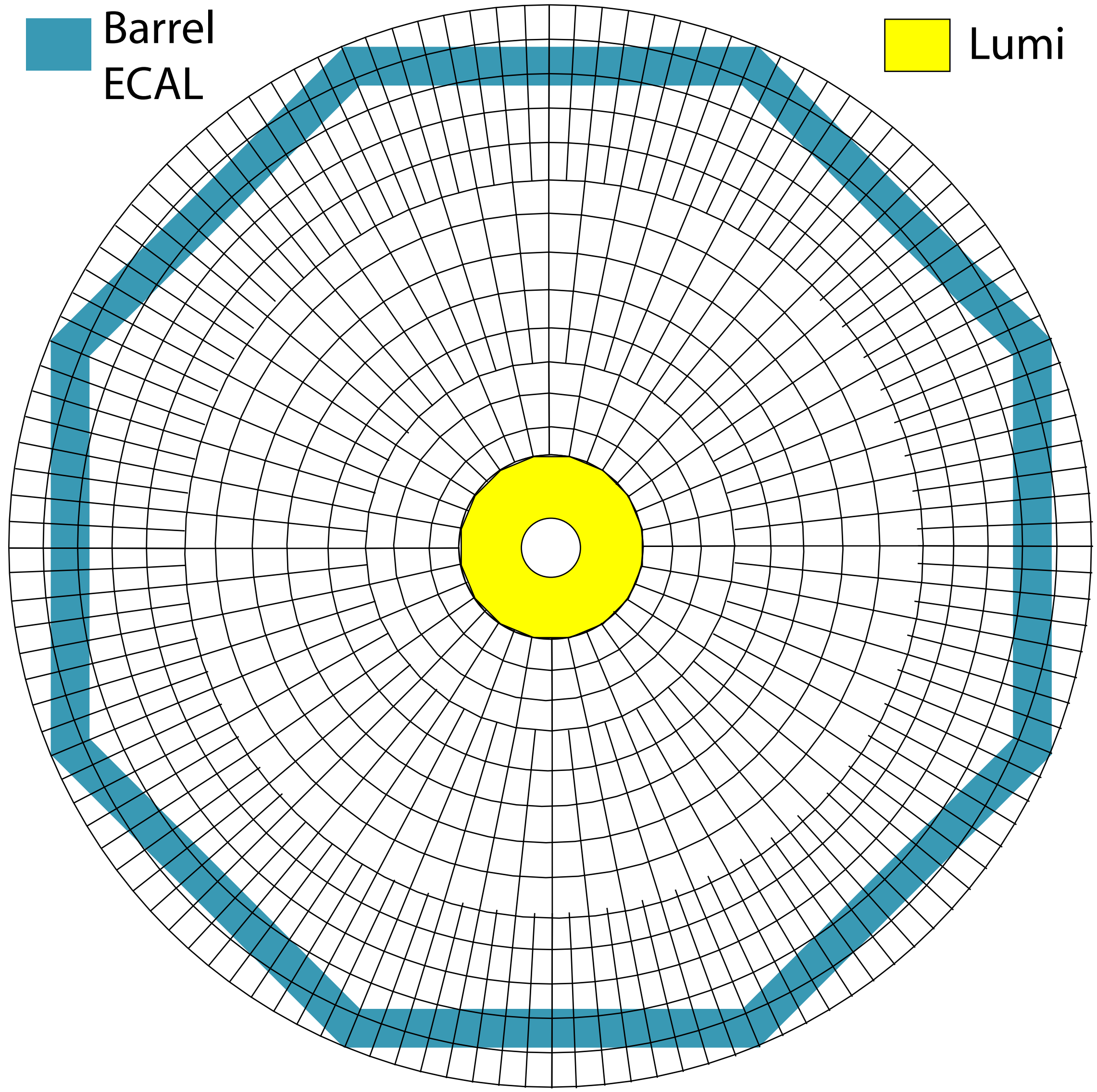
- Could rotate silicon pattern 45° on alternate layers

- Will need 1cm clearance between lumi and endcap.

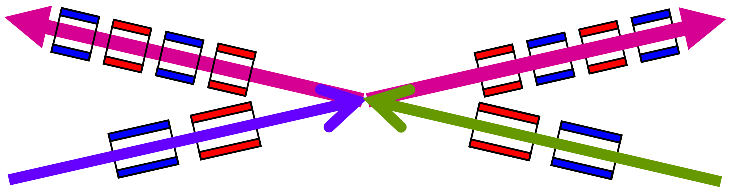


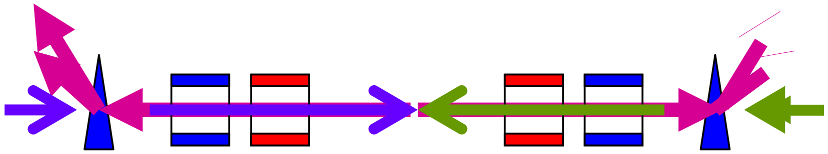
Alternative layout

- Radial design allows for radial pads on endcap
- Radial design would require at least 13 different masks
- Wedges make poor use of silicon area on a wafer
- For an Octagonal outer edge, many more masks needed



Crossing Angles – Two regimes





• Large crossing angle with separate input and exit apertures. *Minimum angle* limited by the magnet size.

• Minimum large angle could be as large as ~ 20 mrad

• Small crossing angle with shared input and exit apertures. *Maximum angle* limited by magnet bore (typically 8-9 cm)

• Maximum angle is ~ 2 mrad

For physics zero crossing angle is usually preferred.

For machine operation a large crossing angle is better.

Advantages of large crossing angles for machine operation:

- $\sim$ 10% of 10 MW beam power in photons is brought directly to the beam dump

- Input and output beam optics can be adjusted with maximum flexibility

- Synchrotron radiation from soft bends in incoming beam can be blocked without interfering with outgoing beam

- Allows for operation at $\sqrt{s} > 1$ TeV

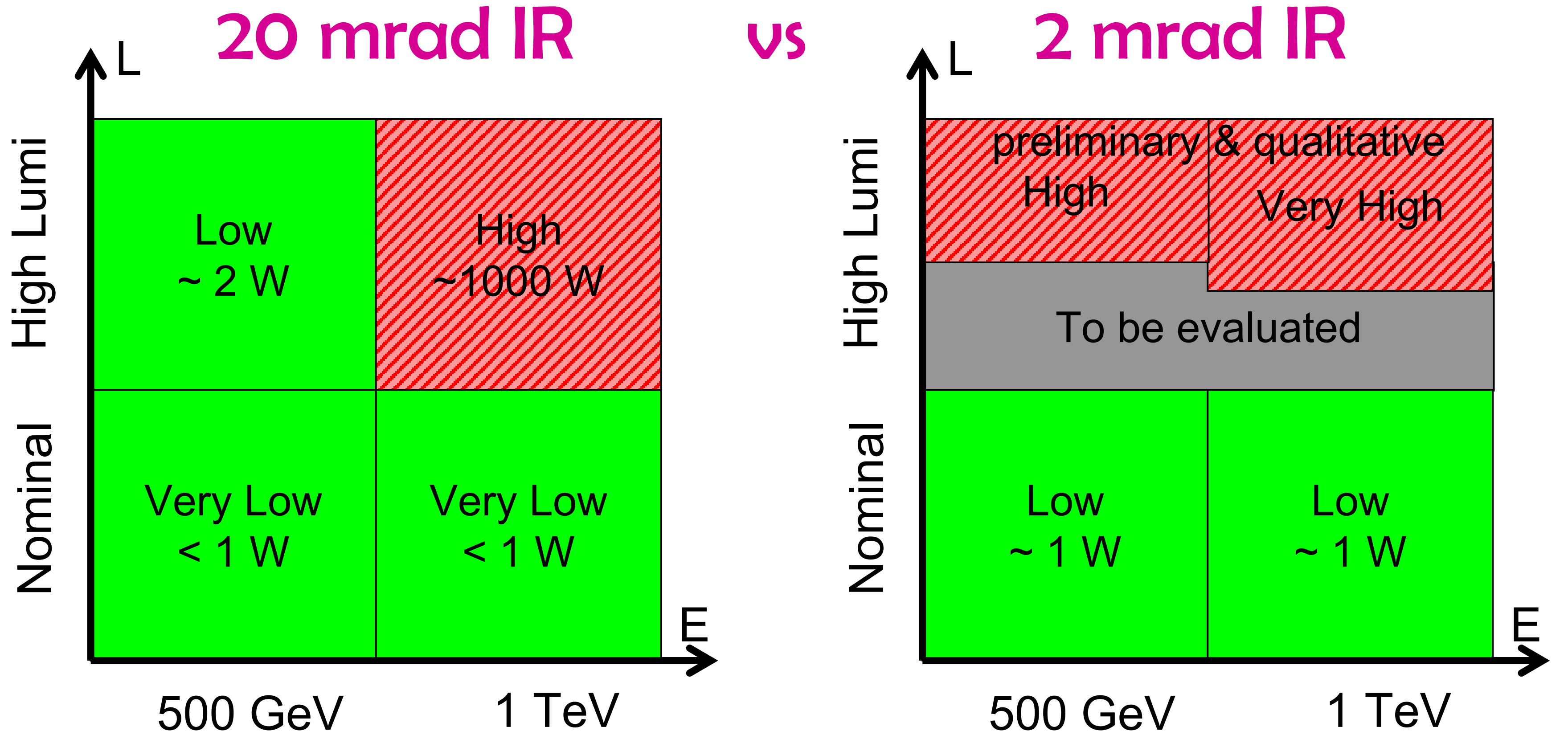
- Allows for small bore ($\sim$ 2 cm magnets)

- Allows for down-stream instrumentation for determining beam polarizations

Disadvantages of small cross angle for machine operation:

- Requires very large bore magnets for final elements
- 2 mrad bend imposes on CM energy limit from synchrotron radiation
- Shared function of magnets leads to less flexibility for the machine
- Large amount of energy dissipated in final magnets

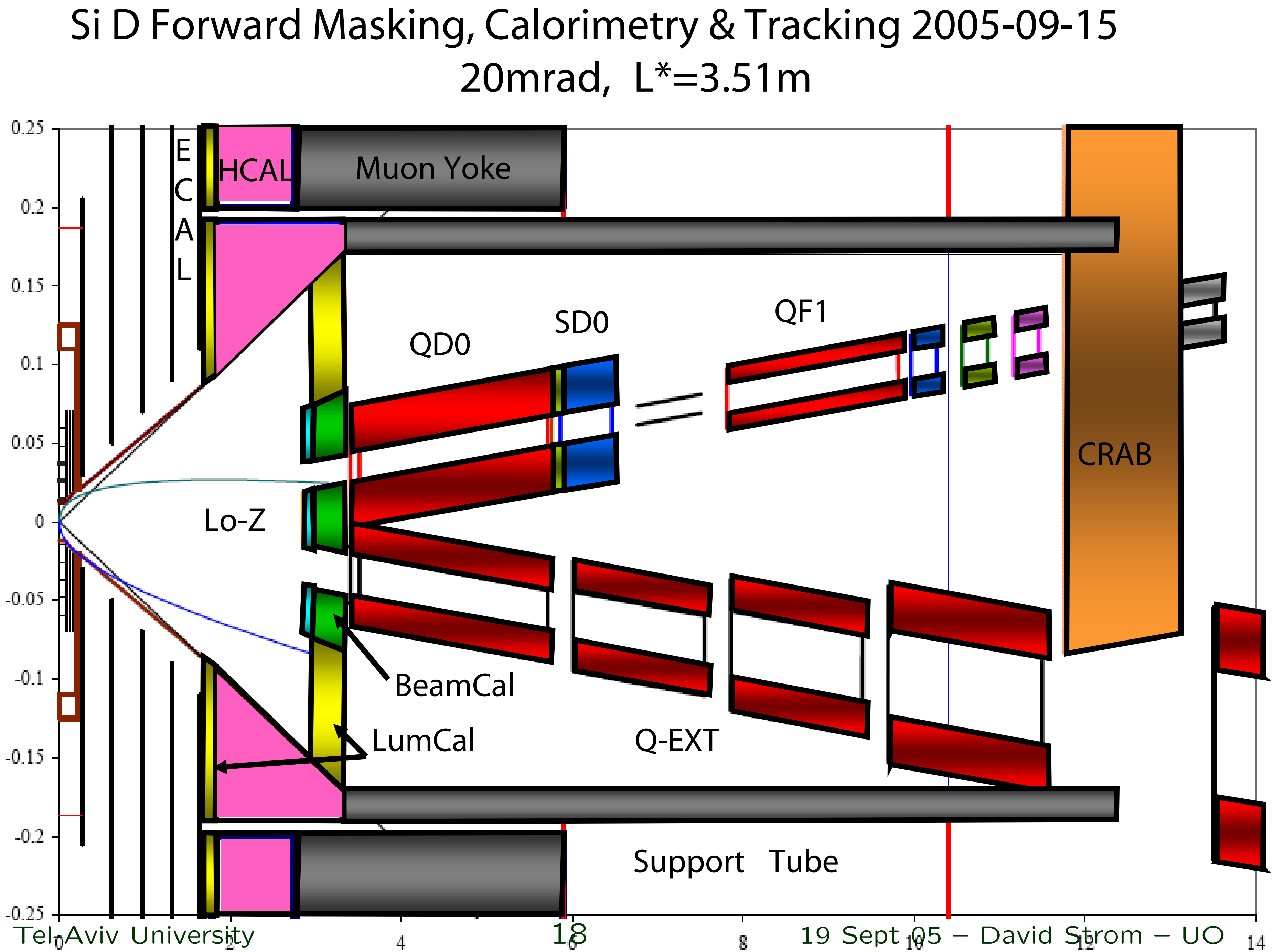
- Snowmass conclusion (Andrei Seryi)



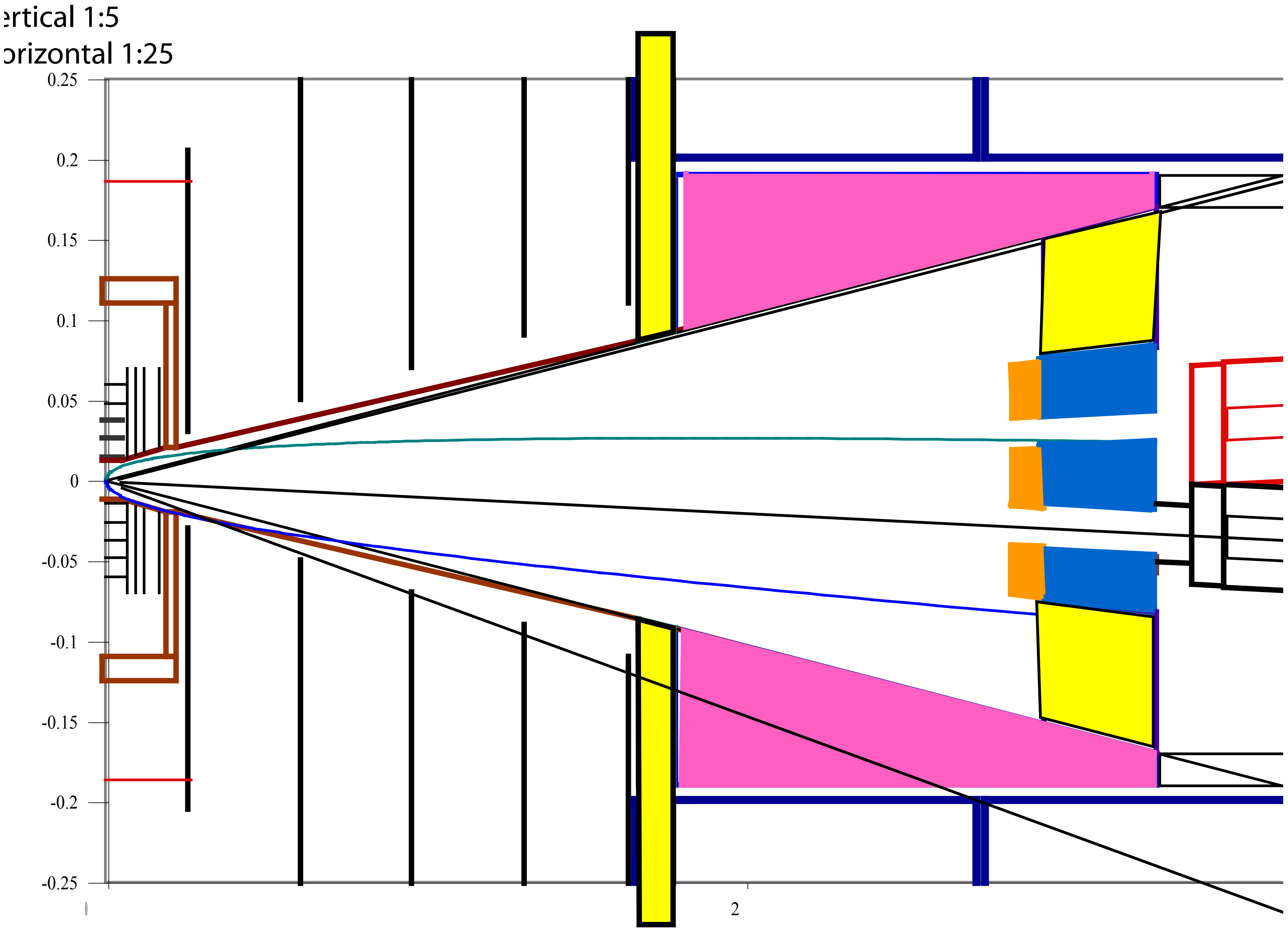
(Numbers in Watts show losses on SC FD magnets)

- **Optimization of design and evaluation will continue, but clear that disrupted beam losses on SC elements limit performance**
- **Better detector hermeticity & background of 2mrad IR comes together with lower luminosity reach**
- **(20mrad IR works well with New High L parameters)**
  (2mrad to be evaluated)

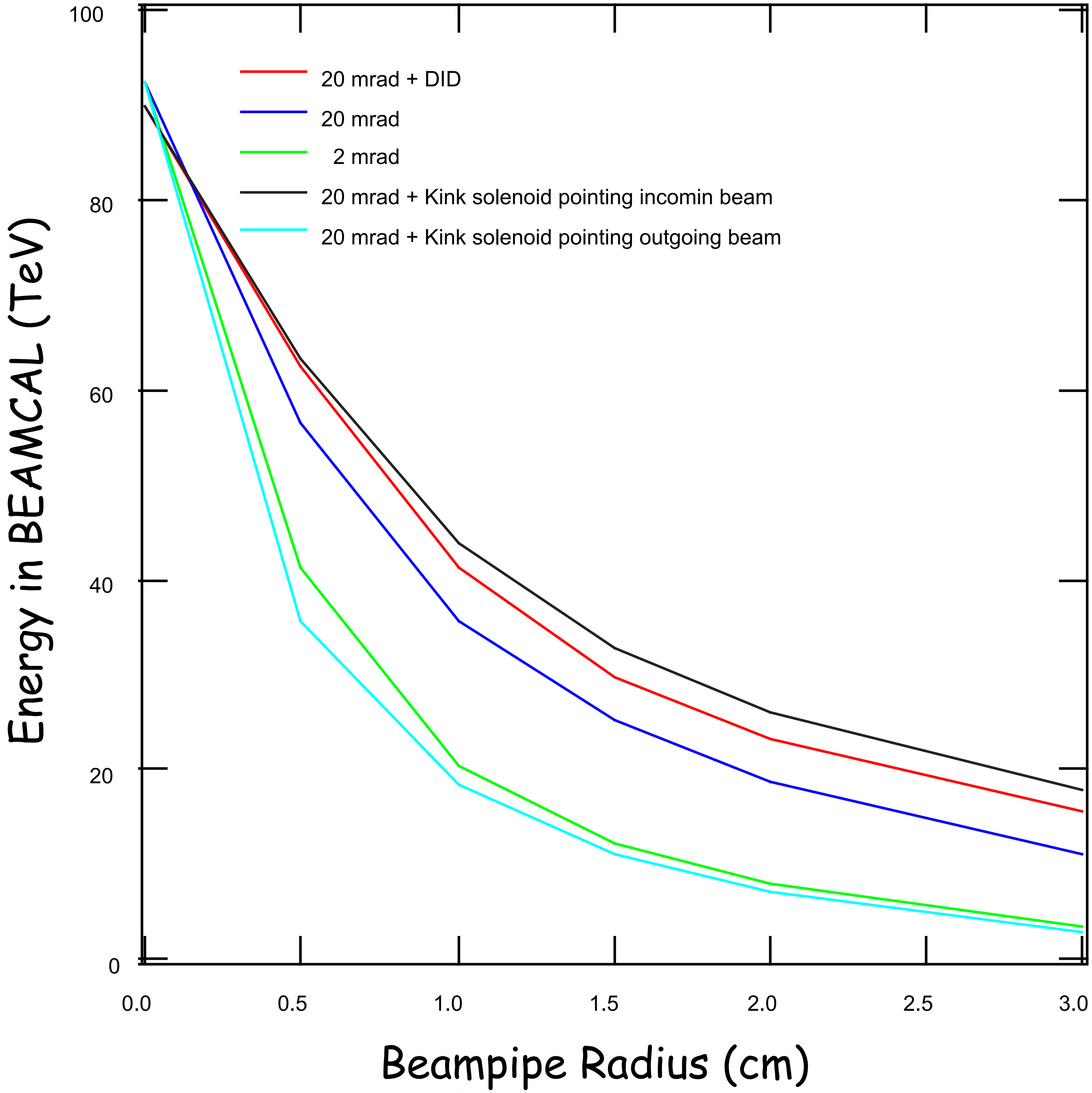
- SiD designed to accommodate a 20 mrad crossing angle



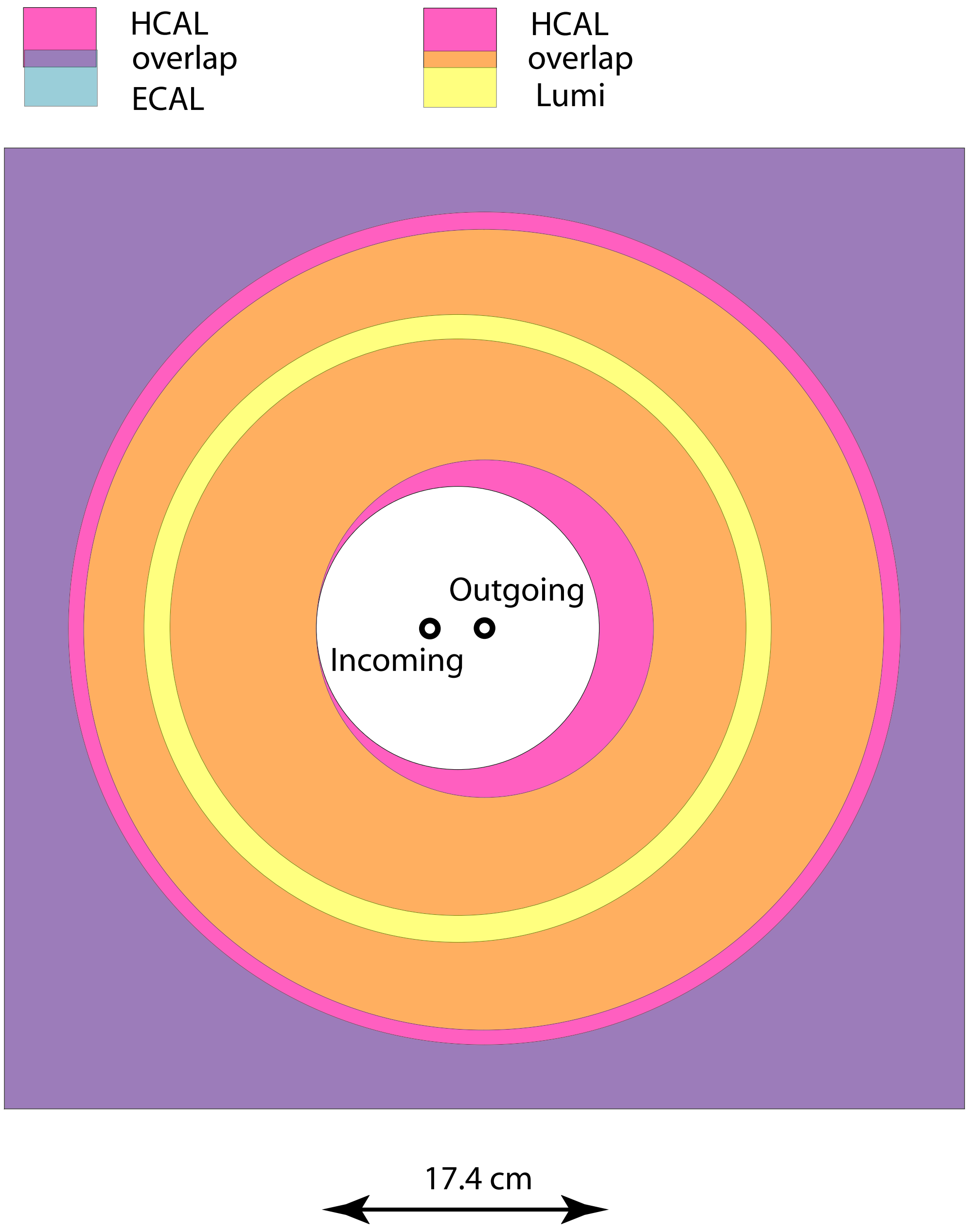
Probably best to center luminosity monitor on outgoing beam



How does a kink in the solenoid effect the background?



- Detail showing clearance between lumi and endcap.
- Note that HCAL is centered on the detector axis.
- Some electrons will be tagged by the HCAL
- Must support luminosity monitor with a minimum of material outside of detector



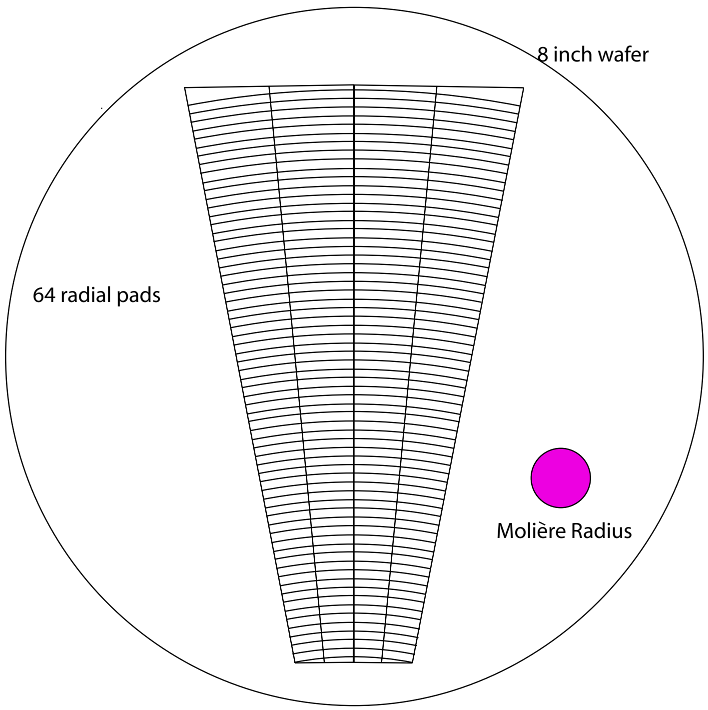
Lumi Detector Geometry

• It is essential to survey the detector at the micron level with cosmic ray muons or test beam.

⇒ Electronics must have MIP sensitivity even if it is not needed by the luminosity measurement

⇒ MIP sensitivity needed for possible muon veto (See Graham Wilson's Calorimeter talk).

• Detectors should fit on a single wafer



• SiD geometry

$R_{min} \simeq$ 8.7 cm ($\sim$ 50mrad)

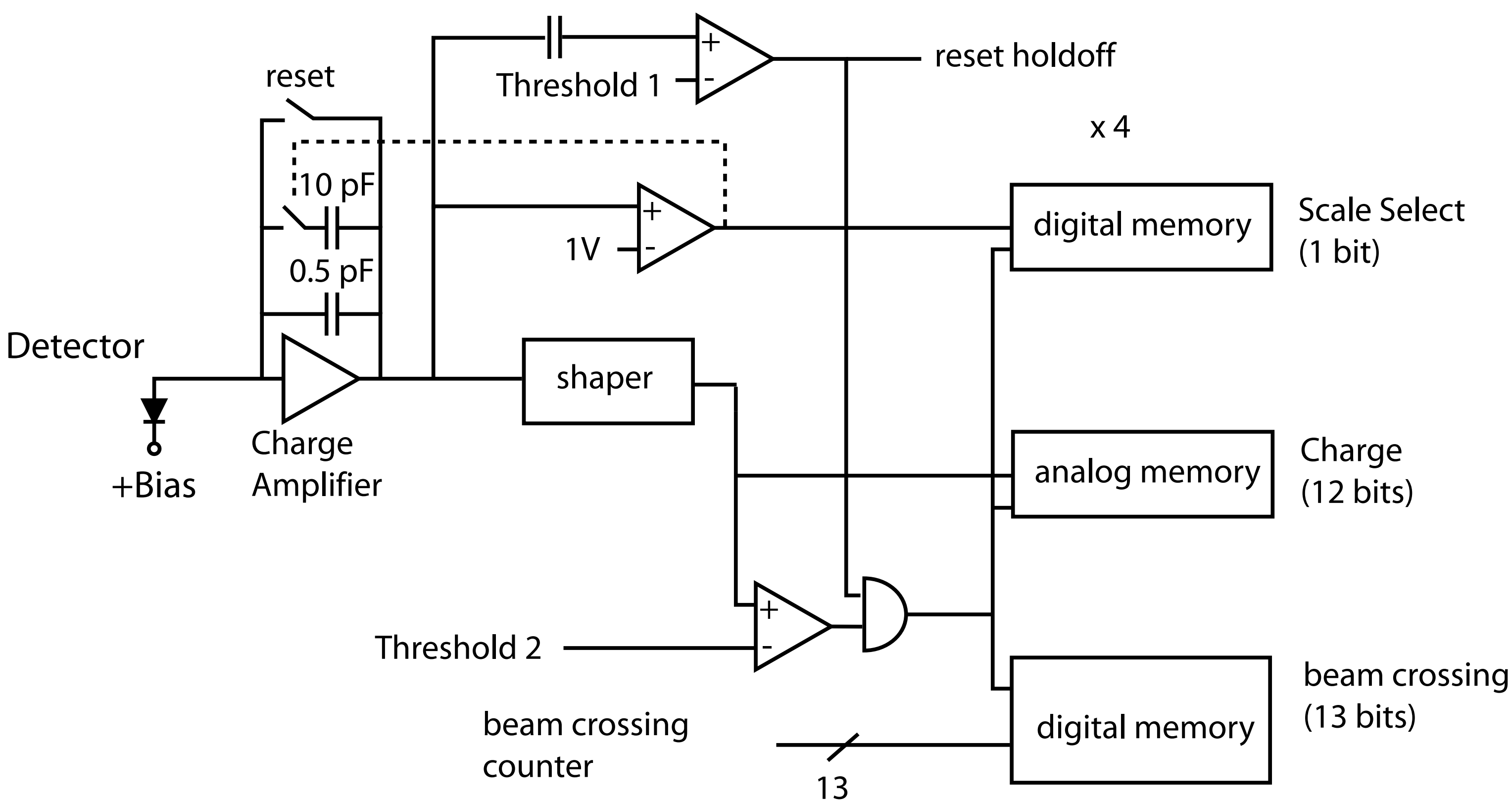
$R_{max} \simeq$ 24.7 cm($\sim$ 150mrad)

⇒ 8 inch wafers would be needed

• Rate at 500 GeV is $\sim$ 8 bhabhas bunch train – Inner radius could be much larger and 6 inch wafers used

Electronics

• The ECAL electronics (Kpics) have chips with 1024 channels and store up to 4 hits/bunch train:



A note on a shaping times

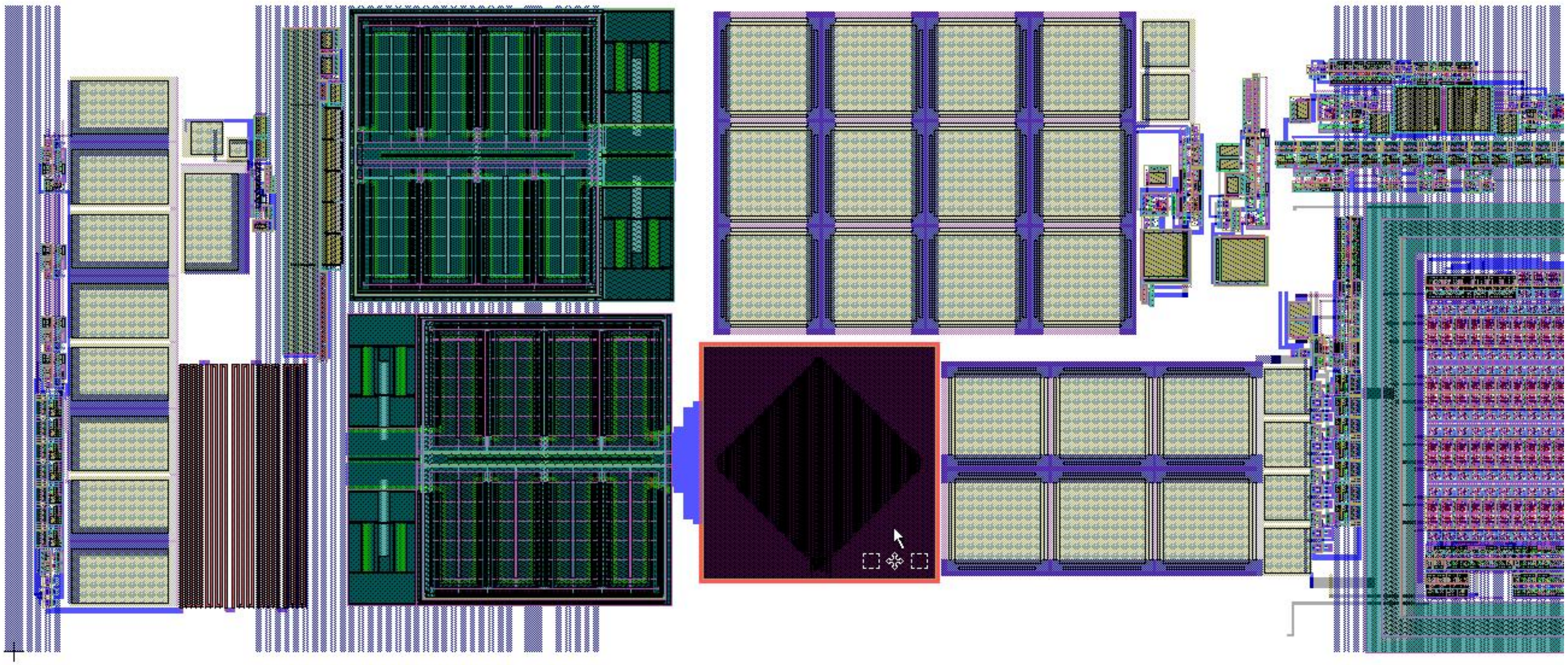
- For the ECAL calorimeter, maximum leakage current from radiation is expected to be < 10nA. $\Rightarrow$ Gives negligible contribution to noise (< 500 electrons)

- In the lumi-detector, this number could be a factor of 30 higher or more.

- At 300nA, 1 μs integration, shot noise is ~ 1400 electrons.

- A shorter shaping time may be needed.

• Calorimeter approach could be extended to include a large number of buffers for each channel, e.g. 128 Channels Chip each with 128 capacitors for storing charges for up to 128 bunches would fit into the same area as is presently used for the calorimeter:



Single Cell Layout

- A more likely scenario would be to readout every bunch crossing. This would require a different digitization technique, either SAR or a pipelined ADC with 12 stages. 128 channels would probably fit into the space presently used by the 1024

- Assume Successive Approximation ADC with 12 bits + range, digitizing at 3MHz (internal clock is 36MHz). Data rate is 576 MBytes/s/chip during bunch train ($\sim$ 3.0MBytes/s sustained)

- On-detector electronics cost will be dominated by development costs (very similar to run needed for test beam)

- Won't save much money by reducing channels/wafer

- Power consumption should be reasonable, but no design yet for cooling in the endcap in SiD. LDC will be easier.

Conclusion

- SiD thinking about forward region is in very early stages – your input is needed and welcome

- Precision luminosity measurement with cross angle seems possible

- Main lumi worry is potential background from machine and physics backgrounds

⇒ **Main overall challenge is to engineer luminosity monitor and endcap without large areas with dead material**

- Many costs in the forward region will be fixed by R&D rather than part count – keep this in mind when designing detectors

Issues from the Tel Aviv FCAL meeting relevant to SiD

- Investigation of the properties of diamond radiation detectors, K. Afanaciev, I. Emeliantchik, A. Ignatenko, E. Kouznetsova, W. Lohmann (mainly NCPHEP, Minsk)

- CVD diamonds, Christian Grah (DESY-Zeuthen)

- Backgrounds studies from K.Buesser/Desy HH, presentations at snowmass, extended by Christian Grah (DESY-Zeuthen)

- Comparison of BeamCal performance at Different ILC Designs, Vladimir Drugakov NC PHEP, Minsk / LAL, Orsay.

Many more talks available at:

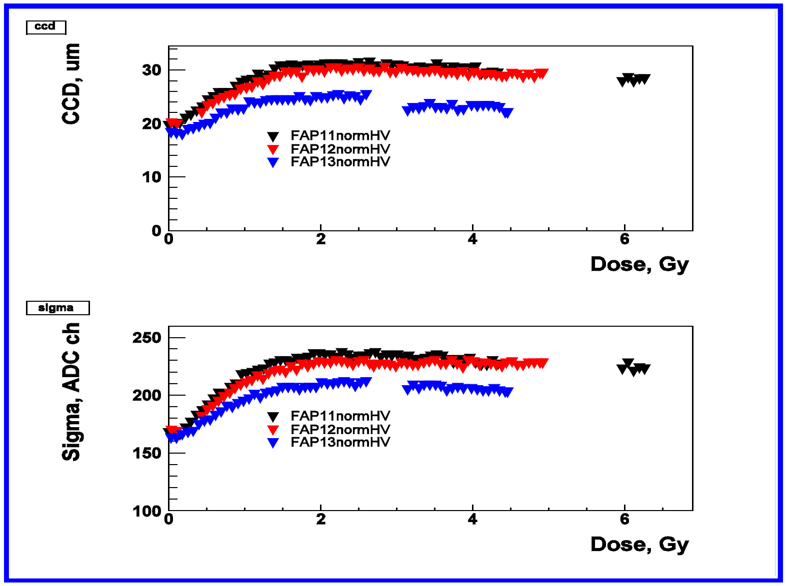
http://alzt.tau.ac.il/~fcal/

Investigation of the properties of diamond radiation detectors, K. Afanaciev (Minsk)

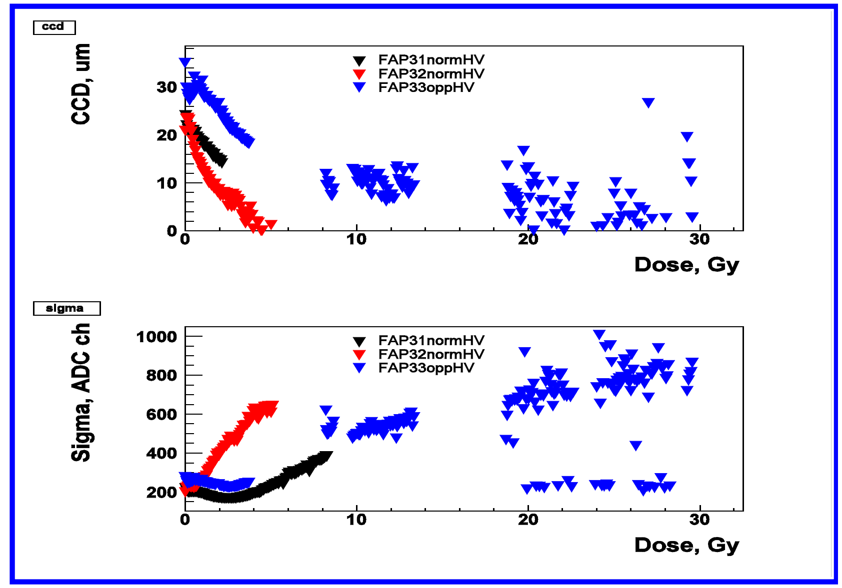
Work based on:

- Chemical vapor deposited (CVD) polycrystalline samples (IAF)
- 12x12 mm plates with thickness 200 - 700 μm
- Metallization: 10 nm Ti + 400nm Au

Example of radiation behavior of good detectors



Example of radiation behavior of bad detectors

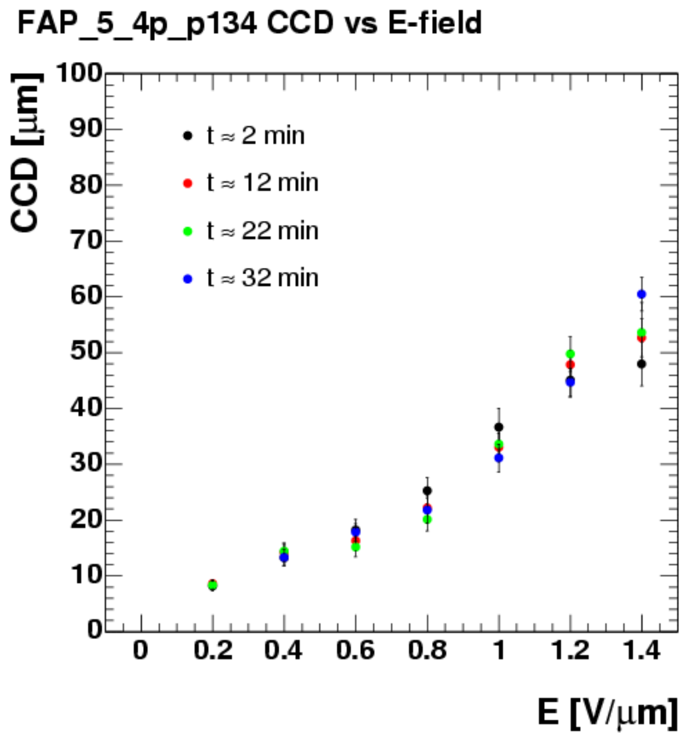


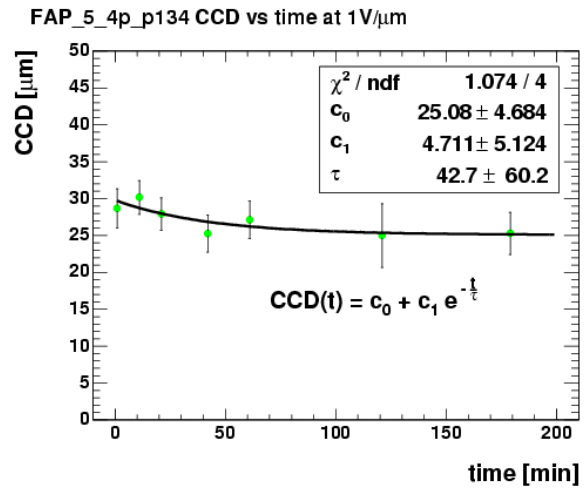
Currently exploring photoluminescence spectra of different samples to find correlation with behavior

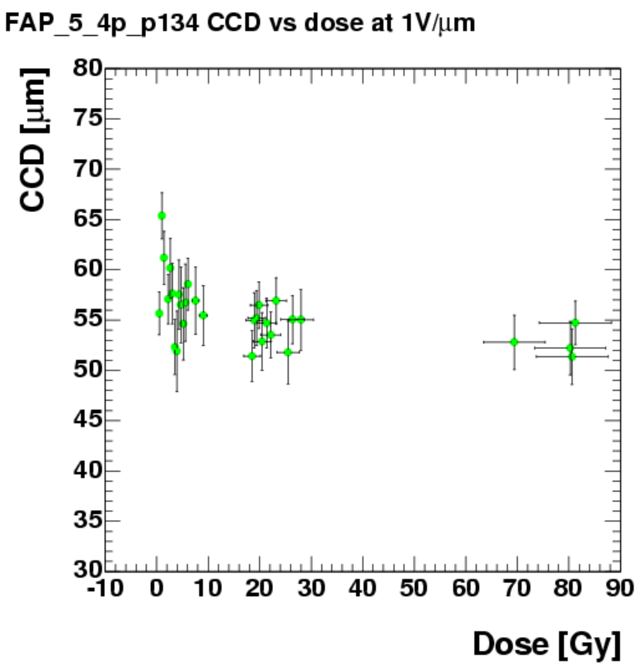
CVD Diamond Sensors for the Beam Calorimeter of the ILC (C. Grah)

Work based on polycrystalline CVD diamond from Freiburg Fraunhofer Institute (IAF)

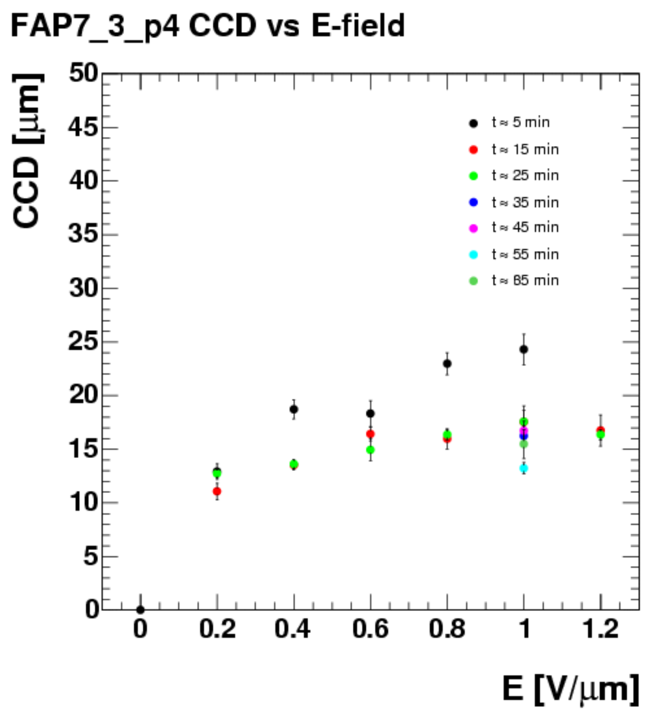
Some samples look good:

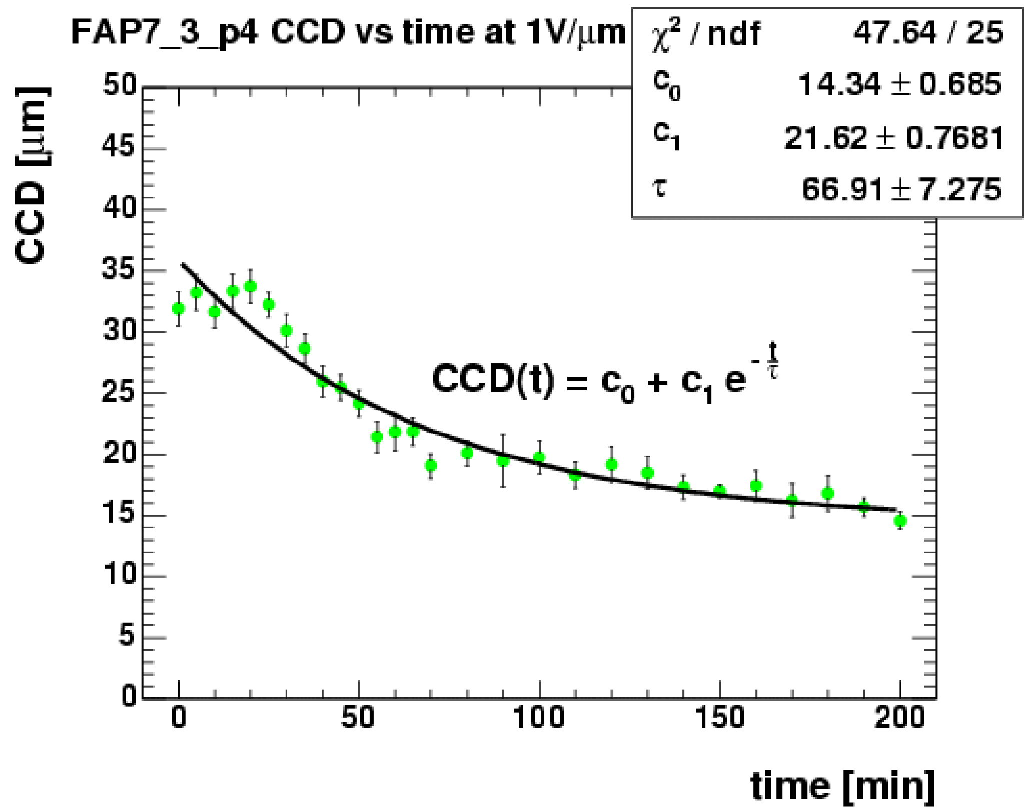




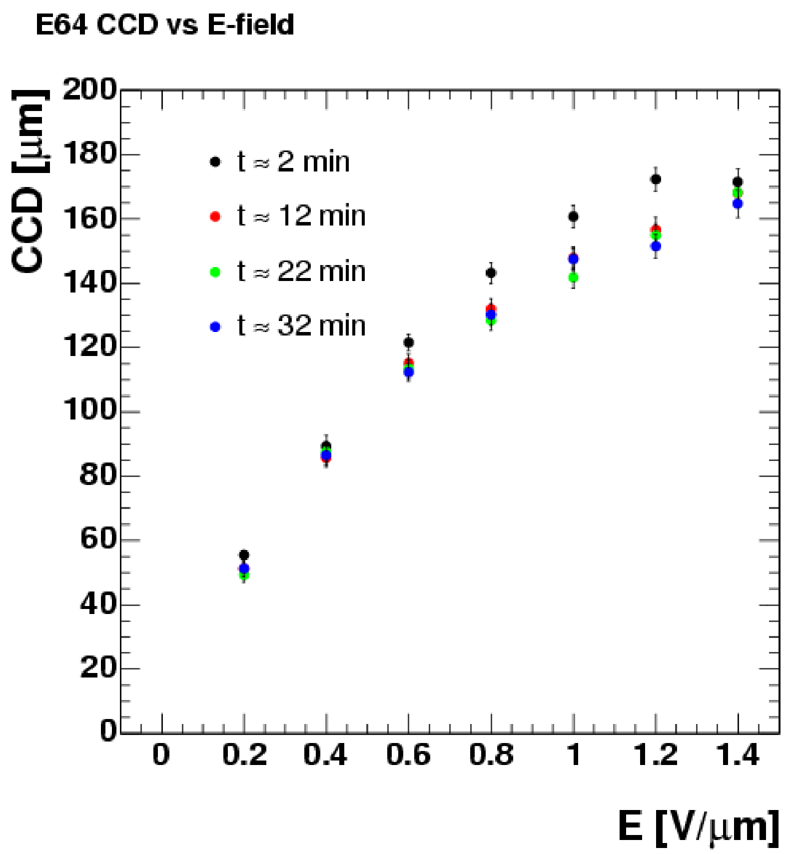


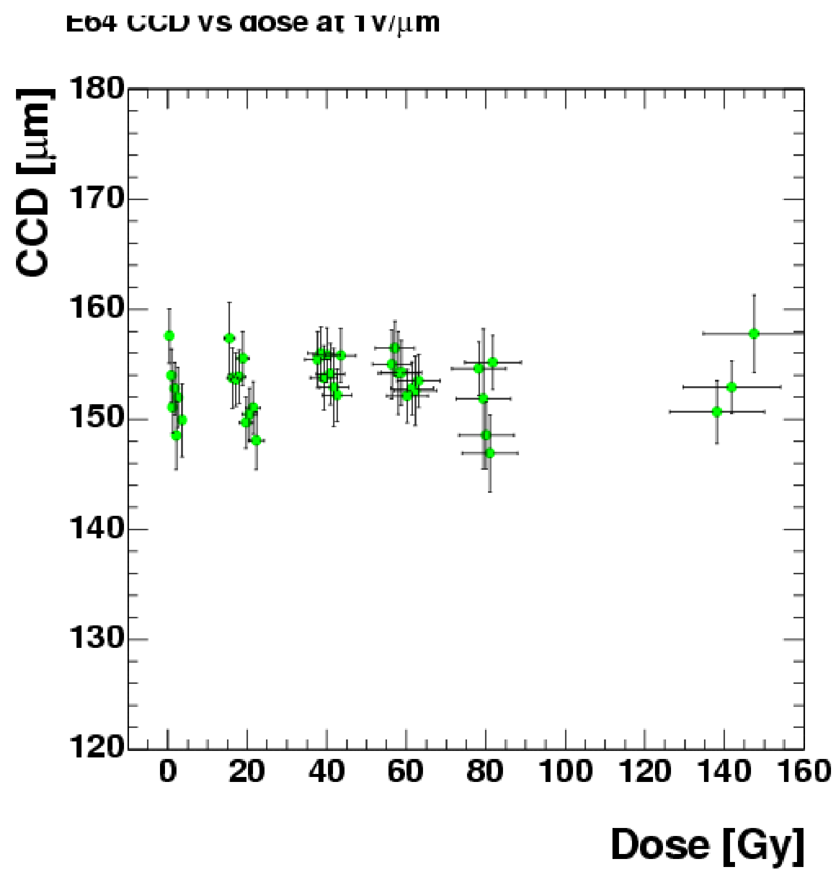
Others not so good (different batch):





Diamonds from Element Six also good (De Beers)

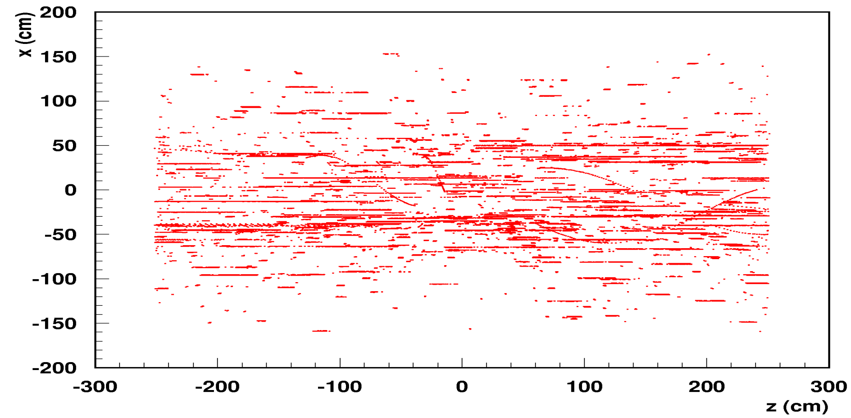




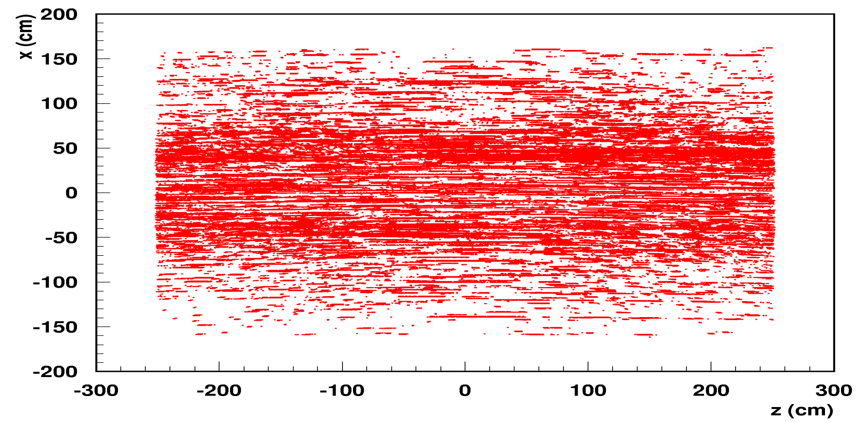
Backgrounds problem (see earlier discussion):

- The detector integrated dipole steers pairs along the incoming beam
- The luminosity monitor (instrumented mask) must be centered on the outgoing beam
- Pairs hit luminosity monitor giving a big background in the TPC

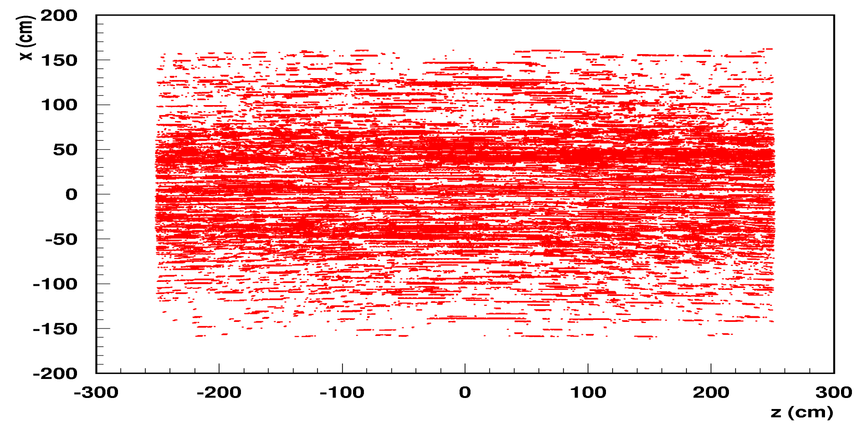
Solenoid field:
3304 ± 704 Hits/BX



Solenoid+DID field:
18145 ± 2518 Hits/BX

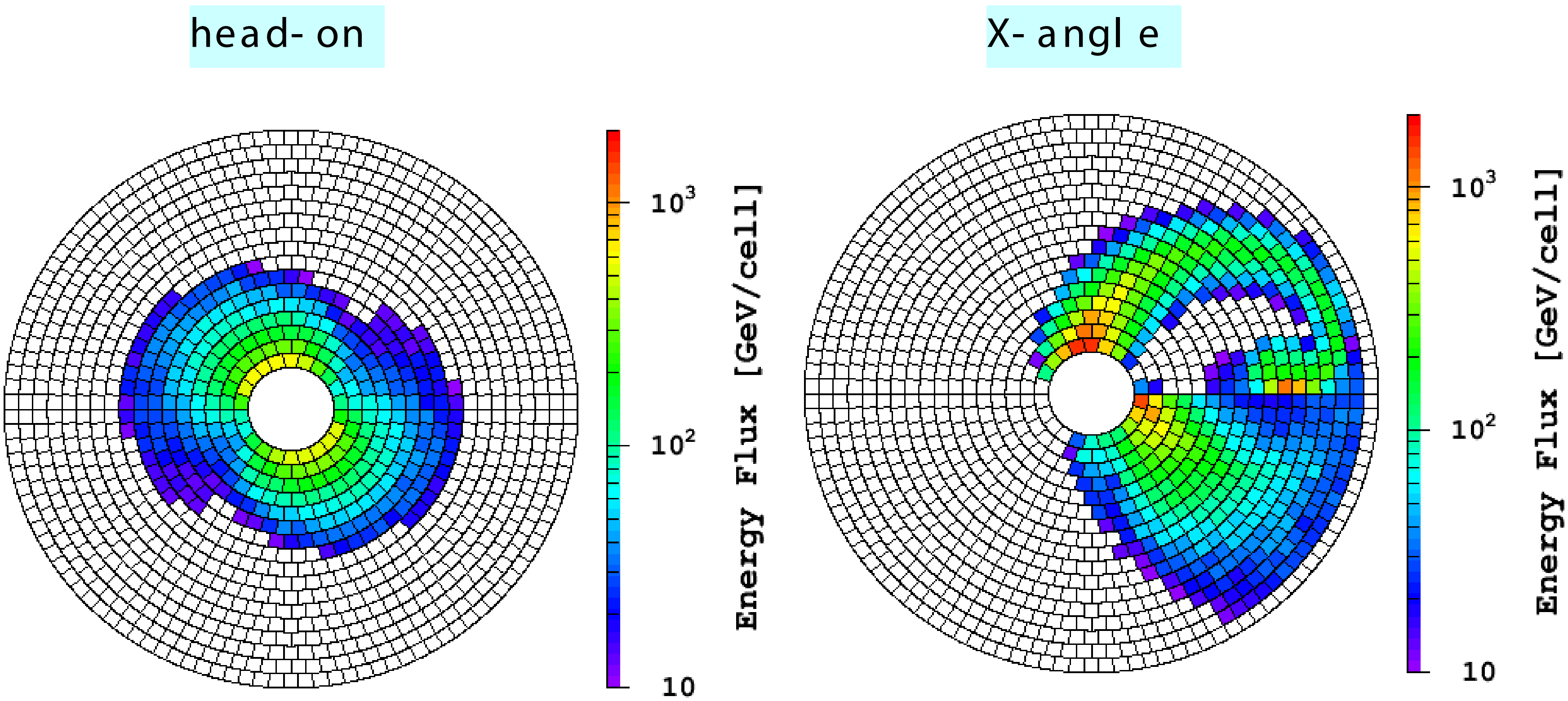


Larger opening in luminosity Monitor + Solenoid+DID field:
10861 ± 1840 Hits



Comparison of BeamCal performance at Different ILC Designs
Vladimir Drugakov NC PHEP, Minsk / LAL, Orsay

Effect on crossing angles on veto performance:

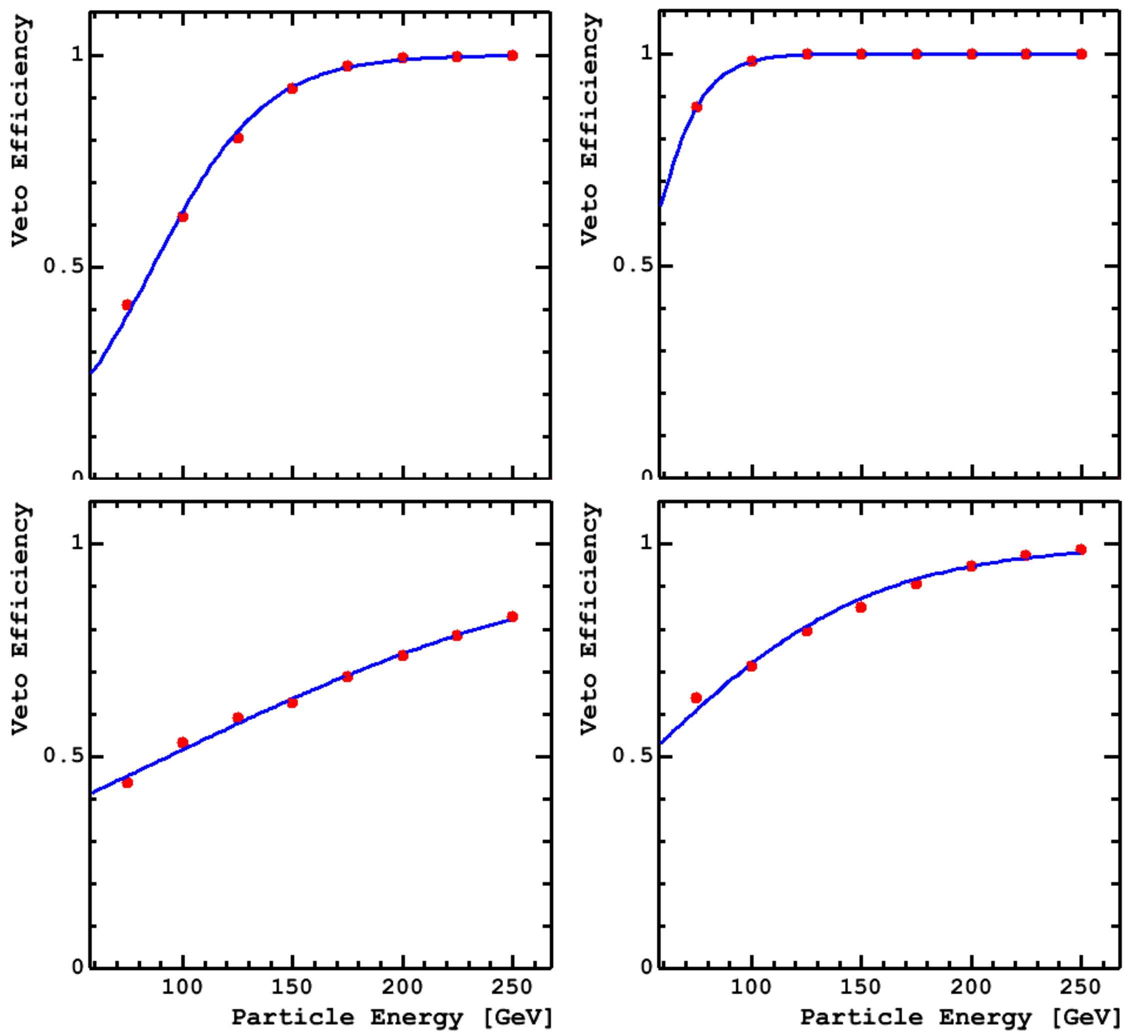


• efficiency calculation: per ring instead of per cell
⇒smaller statistical error

Results

Head-On

X-angle



Geant 4 – Fake rate 5% ?

Important issues for SiD to address:

- How much can the electron tagging be improved if the direction of the missing p_t is restricted?

- What will the false tag rate from Bhabhas be?
  $\Rightarrow$ FCAL claims this will be a $\sim$ 10% effect in the crossing angle geometry.
  $\Rightarrow$ Radiative Bhabhas will be important.

- How does the anti-DiD affect the tagging efficiency? Would it be possible to run with a crossing angle and a low background in order to get a better tagging efficiency for the the SUSY searches?