Tracking for Lepton Colliders: from ILC to CLIC to MuC

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Goals

To dissect, *in much greater detail*, new physics discovered by the LHC: Higgs/EWSB, SUSY, Z′, Extra Dimensions, ??? This requires:

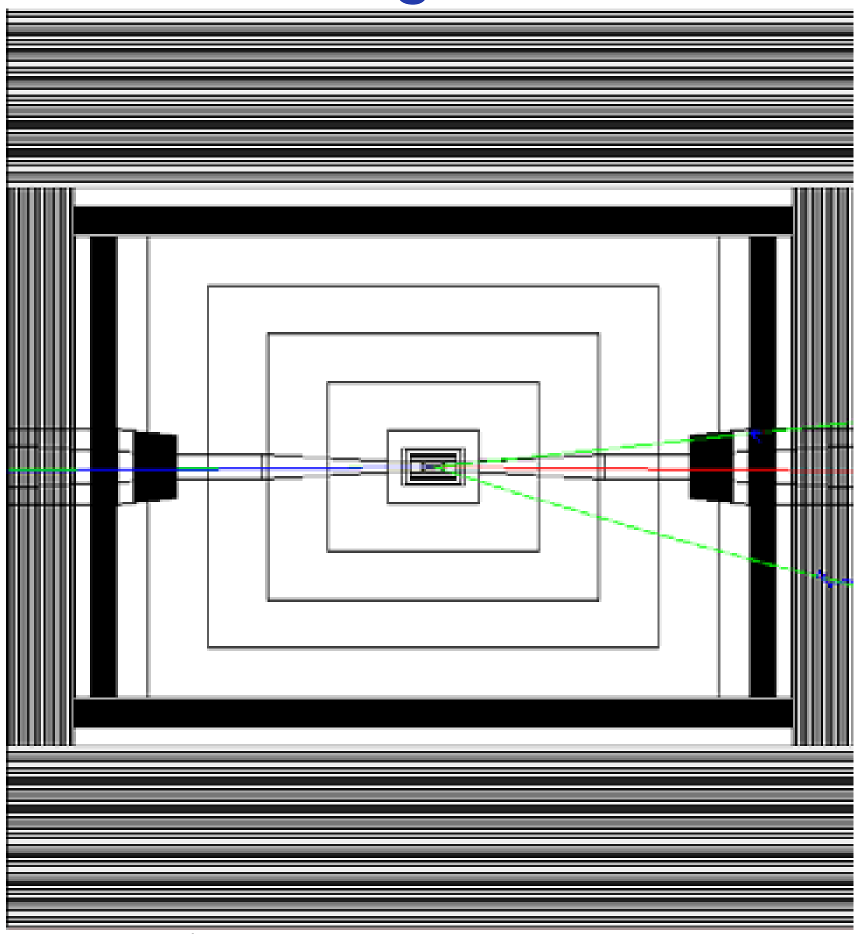
- A machine with much better defined initial-state kinematics and lower backgrounds than the LHC
- A detector capable of much more precise event reconstruction than LHC detectors. For tracking/vertexing:
  - much less mass than LHC trackers (~ factor of 5-10)
  - $d(1/p_T) < 5\times10^{-5}\ \mathrm{GeV}^{-1}$ (~CMS/3)
  - impact parameter $\sigma_{xy} = \sigma_z = 5 \oplus 10/(p \sin^{3/2}\theta)\ \mu m$
  - excellent forward performance (to $\cos\theta=0.99$, $\theta=8°$)

These requirements have driven development ILC/CLIC detectors and must be considered for any lepton collider that wants to have same physics capabilities.

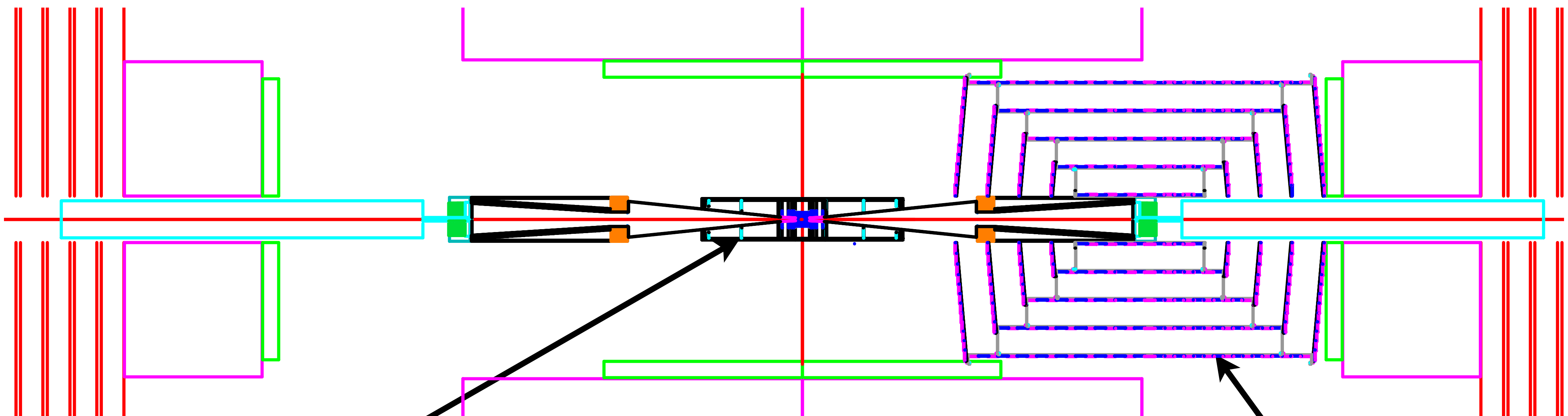
ILC Machine and Backgrounds

- Timing: trains at 5 Hz, 308 ns bunch spacing
  - pulsed power electronics: reduction ~100×
  - single bunch time tagging relatively easy
- Backgrounds: dominated by e+e- pairs
  - rate/bunch crossing is very small
  - can relax single-bunch timing to reduce power
- Radiation Environment: ~1/10000 LHC
  very few technologies excluded, even in VXD.

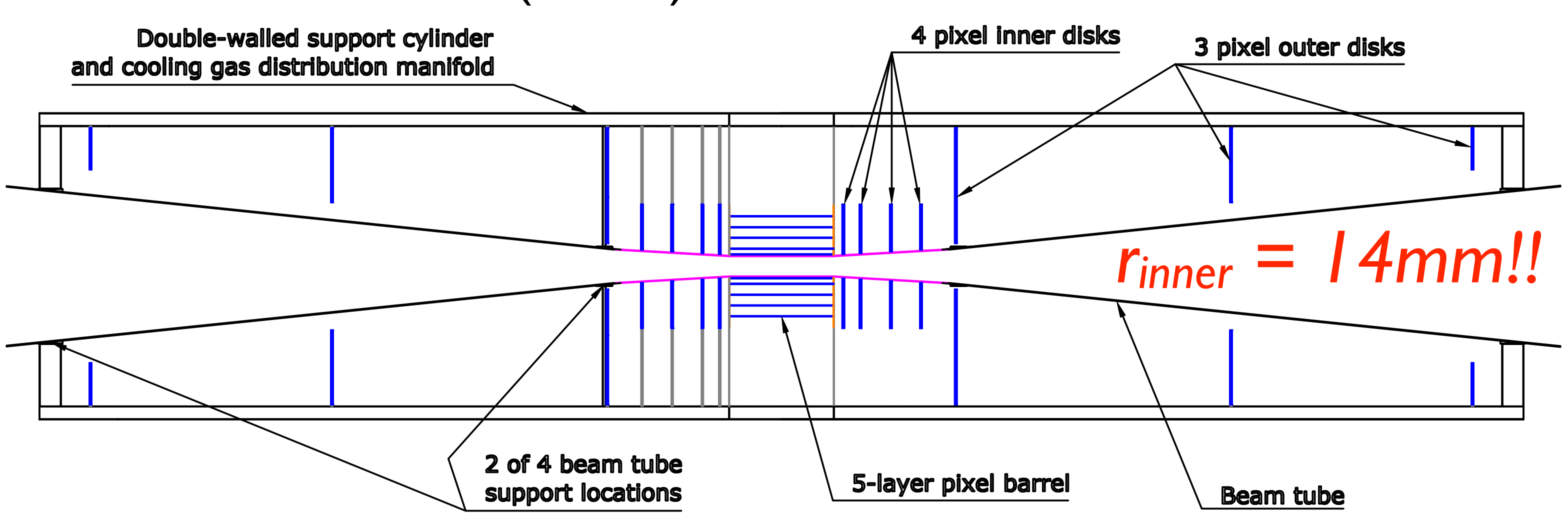
1 ILC background event



SiD Concept

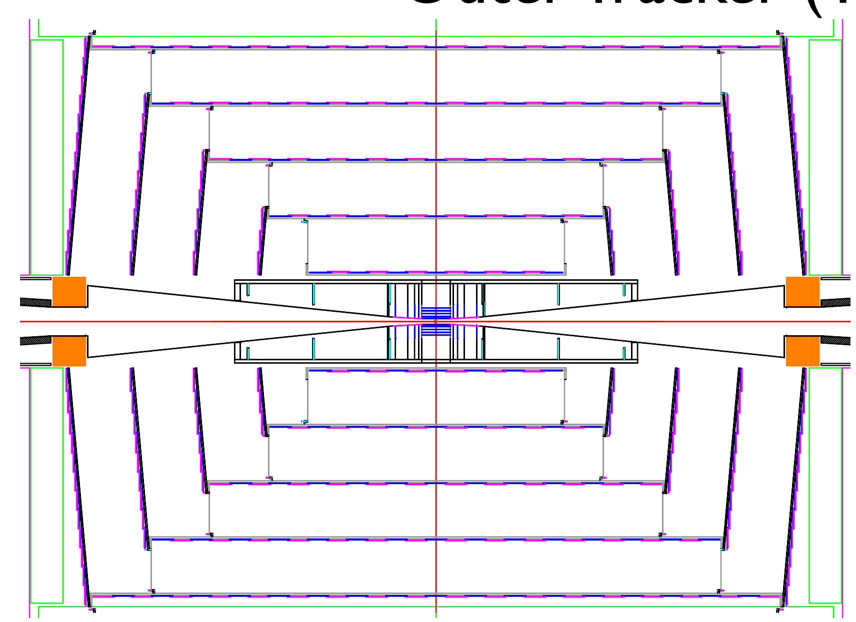


Vertex Detector (VXD)

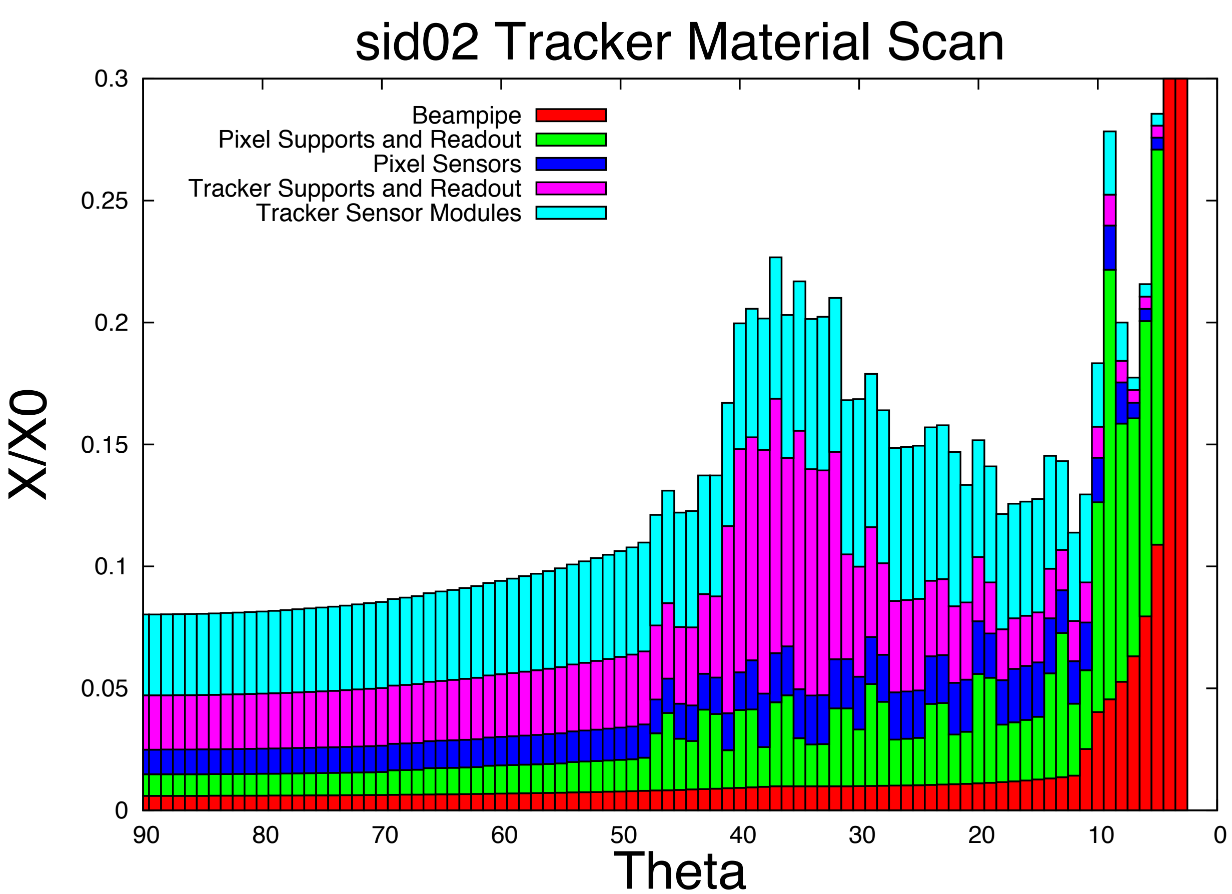


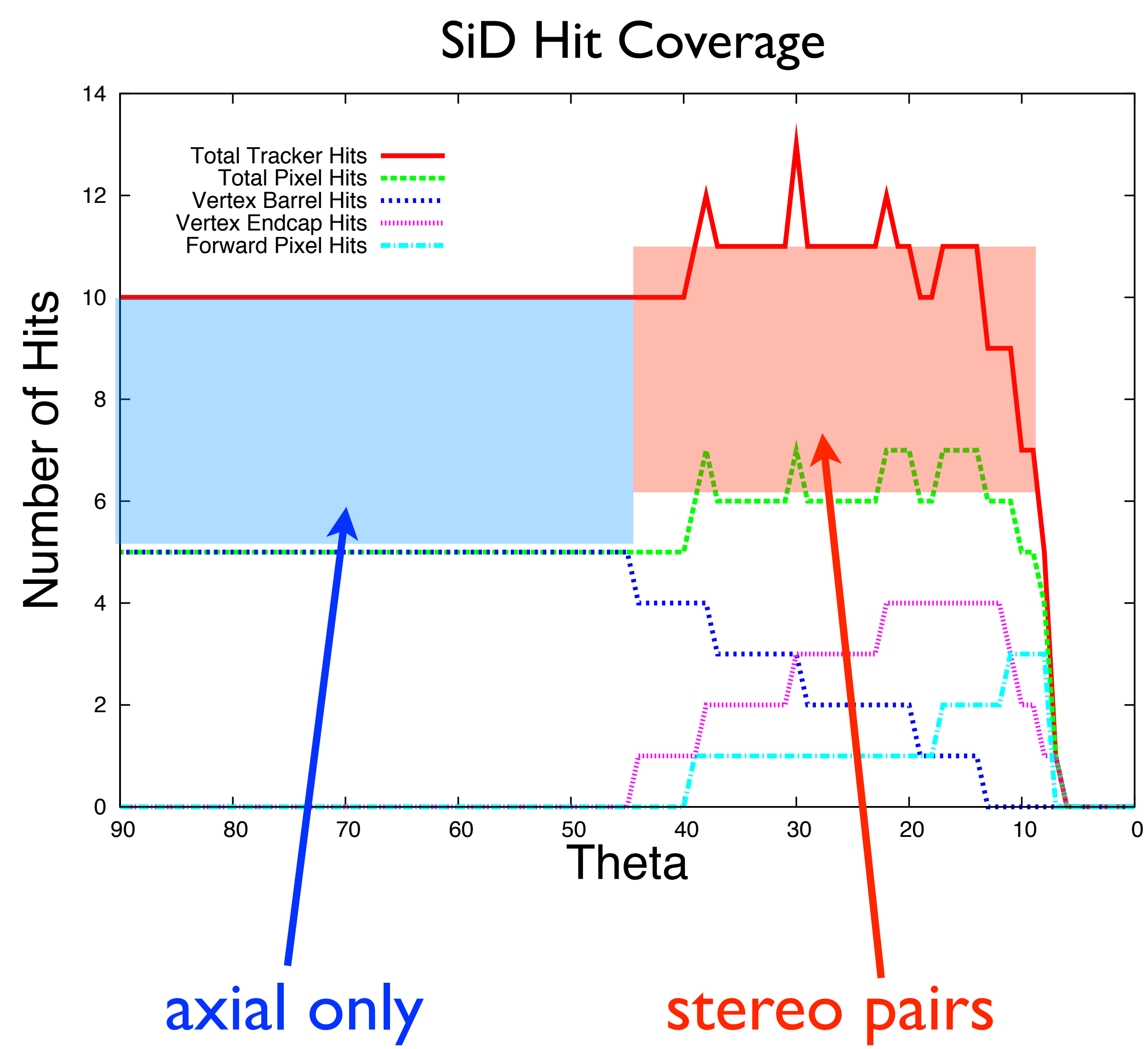
r_{inner} = 14mm!!

Outer Tracker (TKR)



SiD Concept





VXD: ~0.1% X_0/layer

TKR: ~1.0% X_0/layer

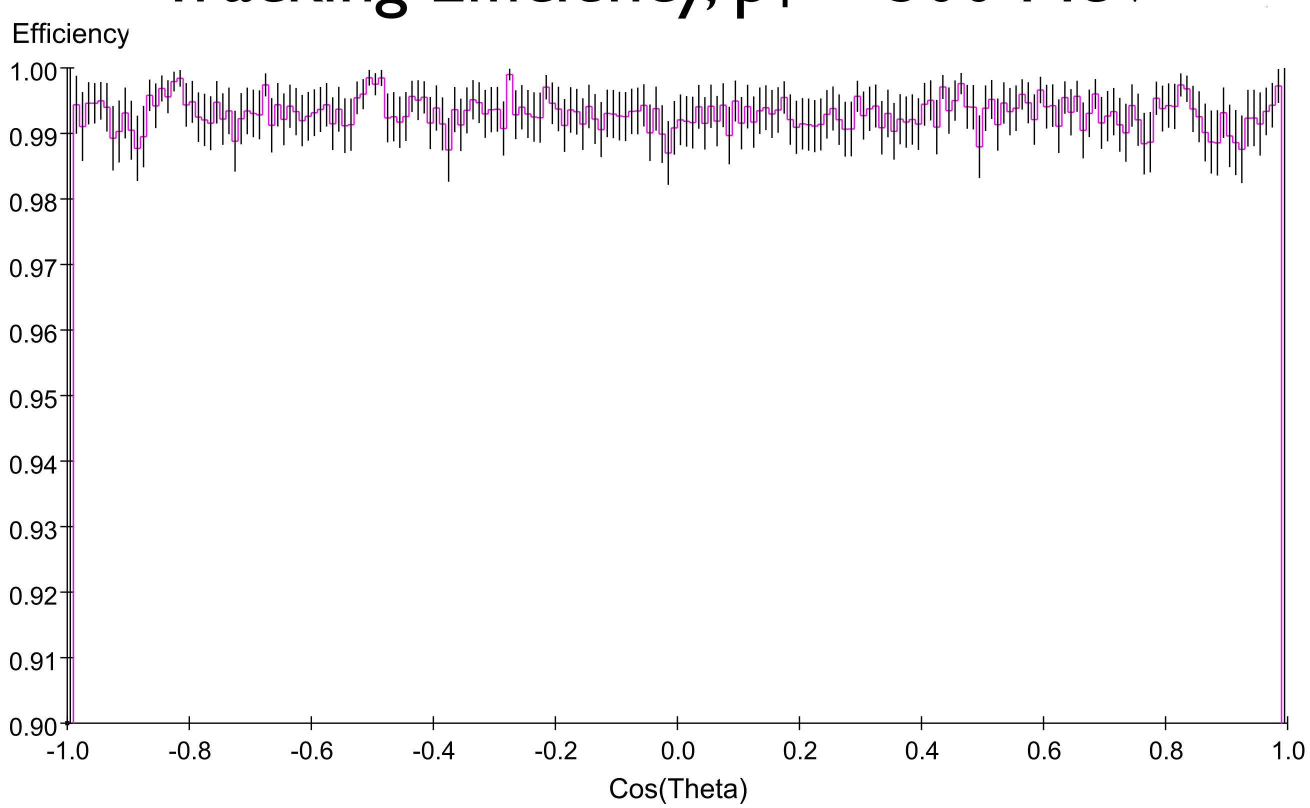
SiD Technologies

- VXD
  - fine pixels (of order 20 microns x 20 microns)
  - readout electronics integrated with sensor to reduce material
  - best time tagging available within gas cooled power budget (13 mW/cm^2)
  - time tagging from 1~150 bunches depending upon technology
- TKR
  - conventional single-sided microstrip sensors (double-sided modules in endcaps)
  - low-mass readout electronics and support structure
  - single-bunch time tagging with low power consumption (0.5 mW/cm^2)
  - total power <500W allows gas cooling

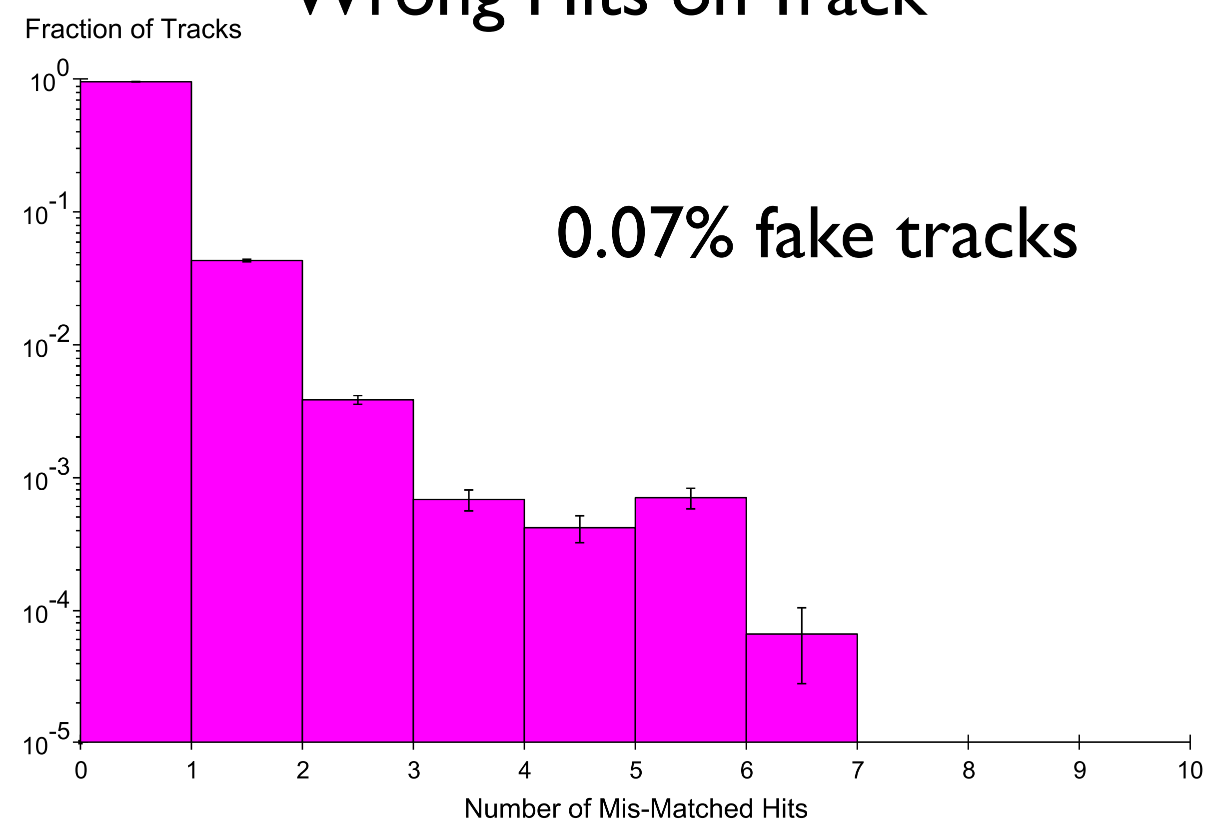
SiD Performance

500 GeV $e^+e^- \rightarrow t\bar{t}$

Tracking Efficiency, p_T > 500 MeV



Wrong Hits on Track



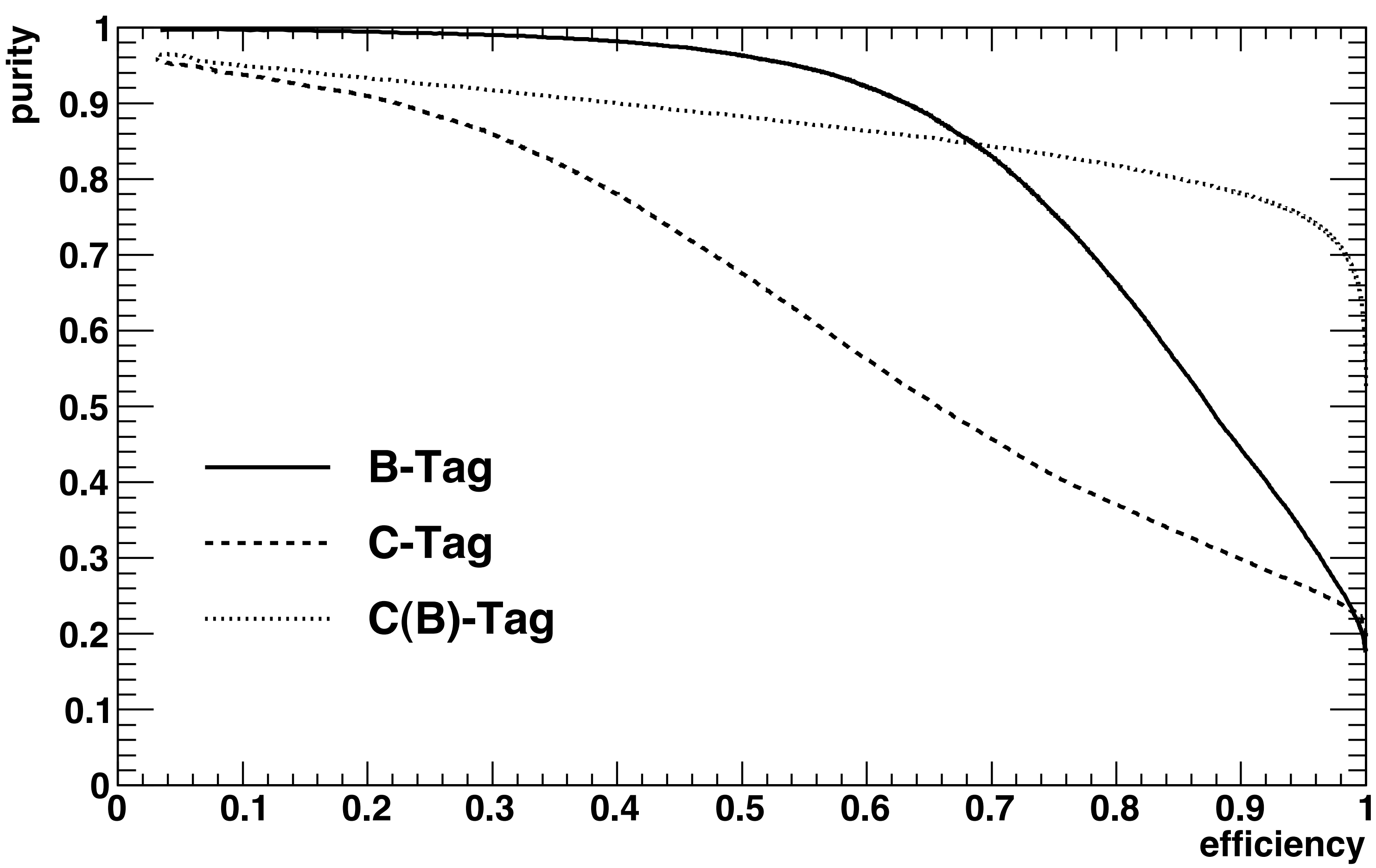
0.07% fake tracks

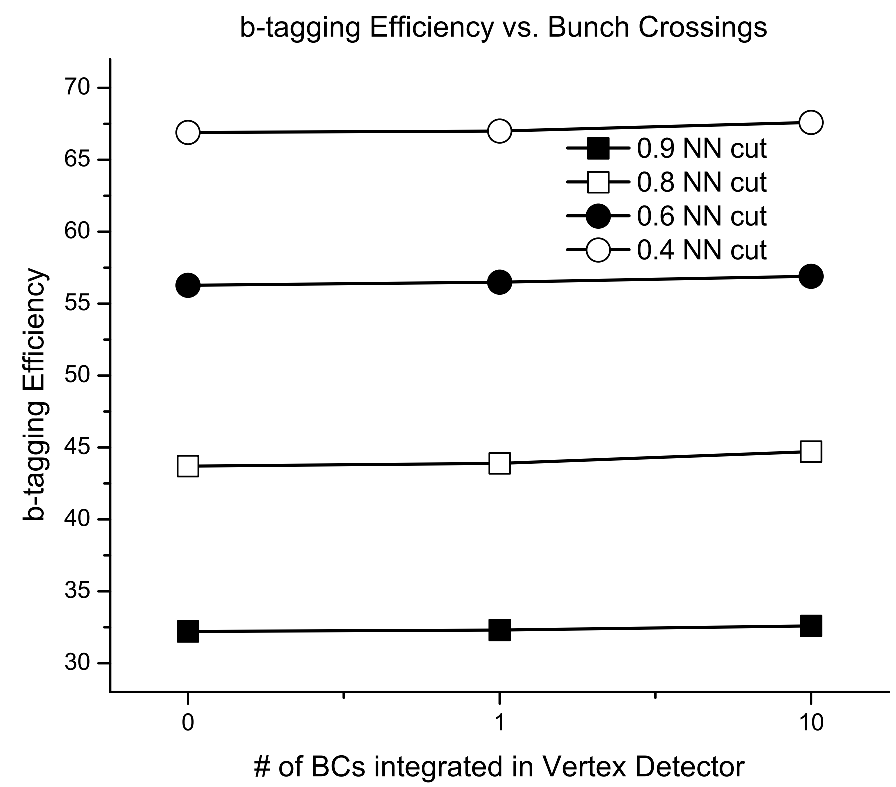
Newer studies at 1 TeV confirm performance of SiD at higher energy.

Performance with longer integration times in pixels is similar.

SiD Performance

500 GeV $e^+e^- \rightarrow$ *dijets*

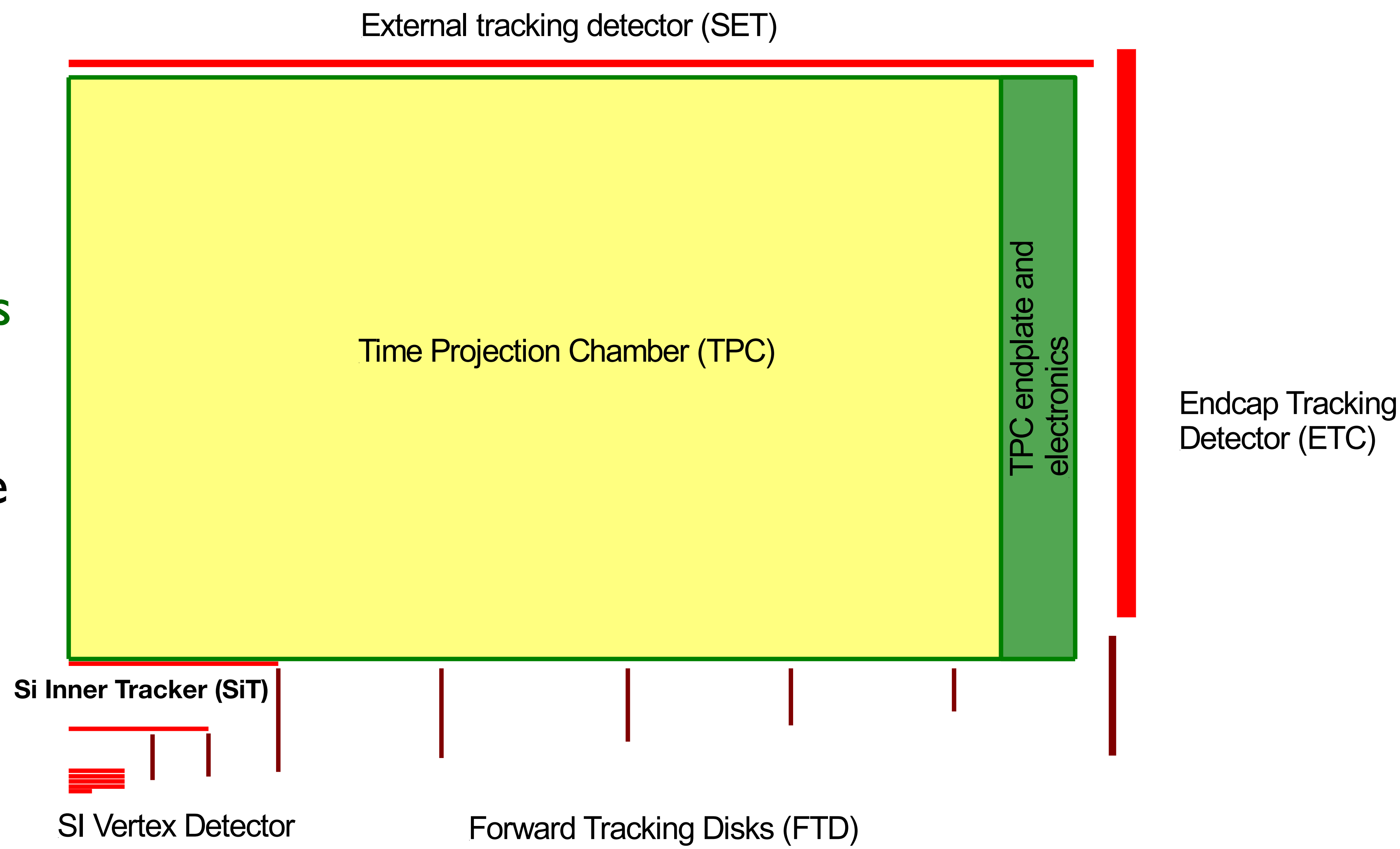




Little change with longer timing windows

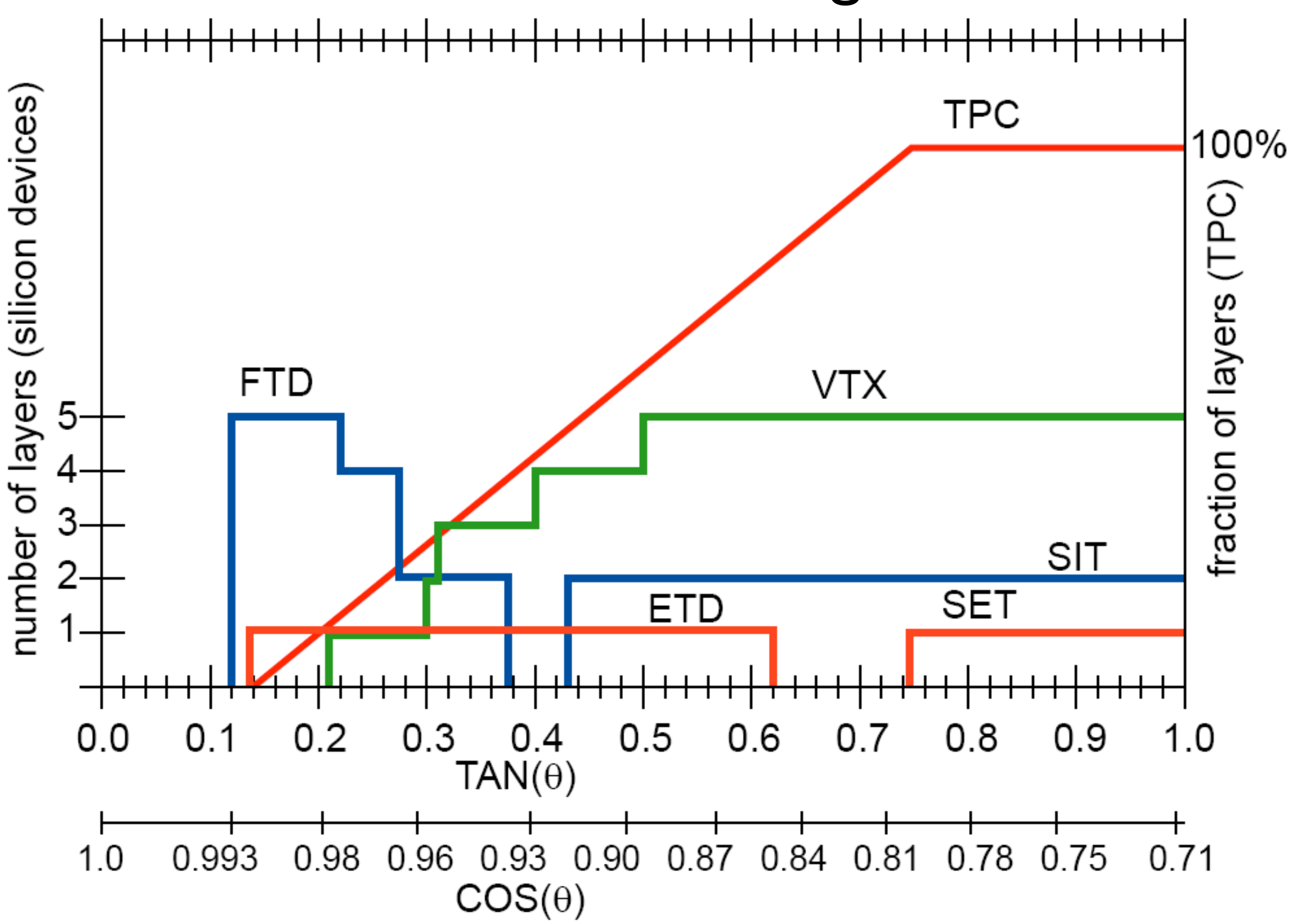
ILD Concept

- TPC core provides pattern recognition for all kinds of tracks
- Silicon on all sides necessary to provide timing information and achieve desired p_T resolution

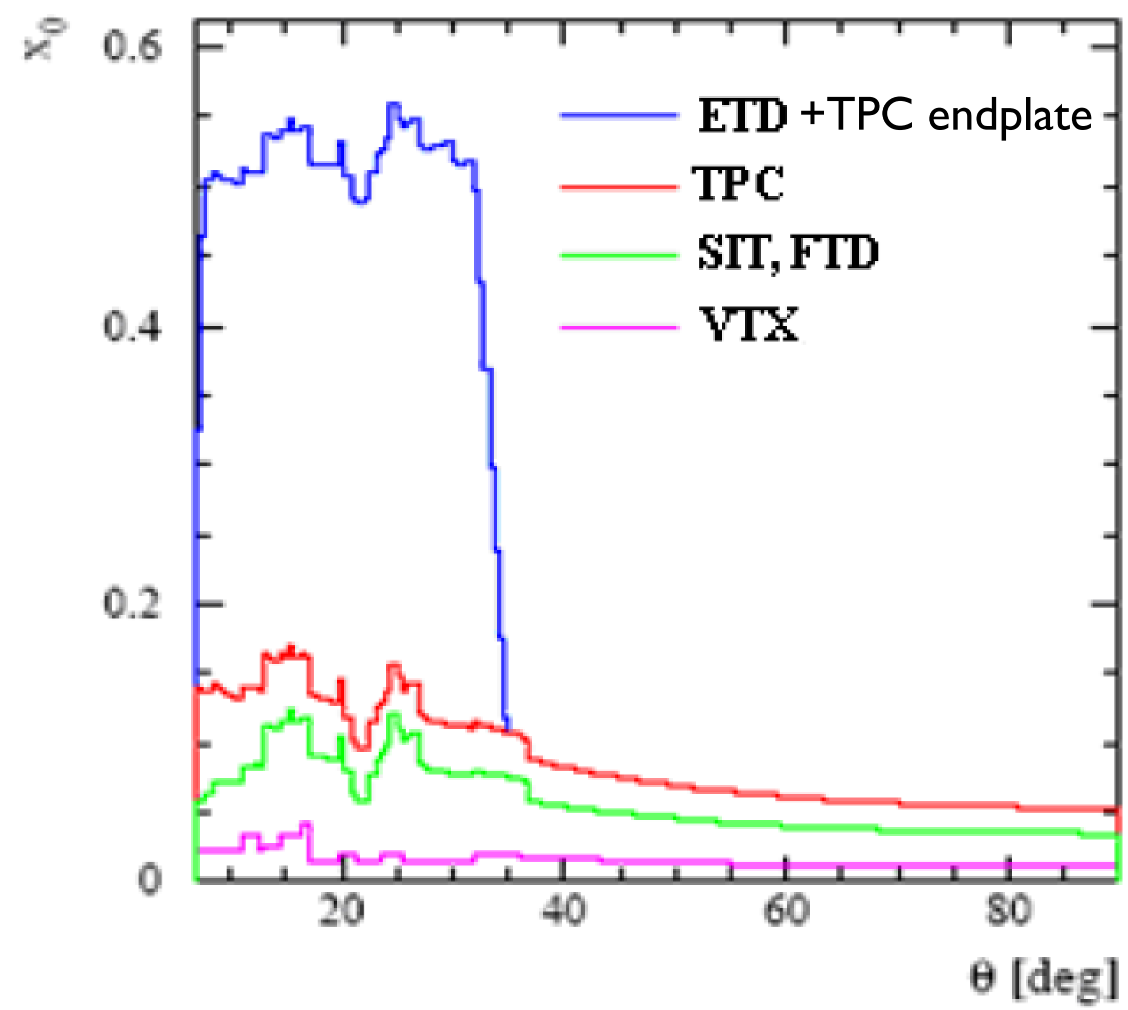


ILD Concept

ILD Hit Coverage



ILD Material Scan



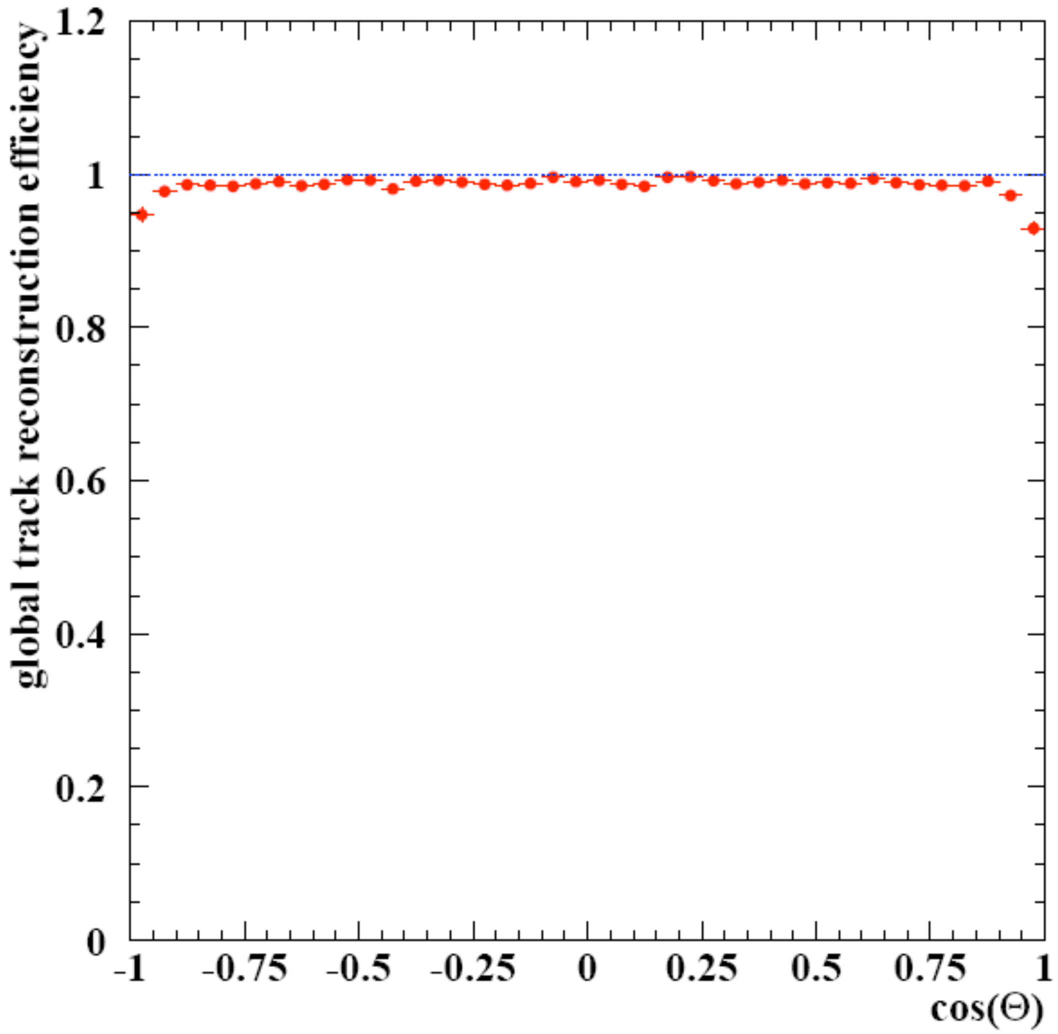
ILD Technologies

- VXD: basically the same options as SiD
- TPC:
  - low-mass endplate
  - gas with high drift velocity (>50 micron/nm)
  - gating grid to sweep out ion layer
  - Pad/FADC readout or CMOS pixel readout as cooling/material allow
- FTD, ETD, SIT, SET: undetermined mix of Si pixels, Si strips (single or double sided), GEMs, straw tubes.
- Readout ASIC for Si microstrips envisioned to provide timing in two ranges:
  - "coarse": 500 ns for bunch tagging
  - "fine": <1ns for position measurement along strip.
    Not yet proven. Power/channel of prototypes is 50x that for SiD readout chip.

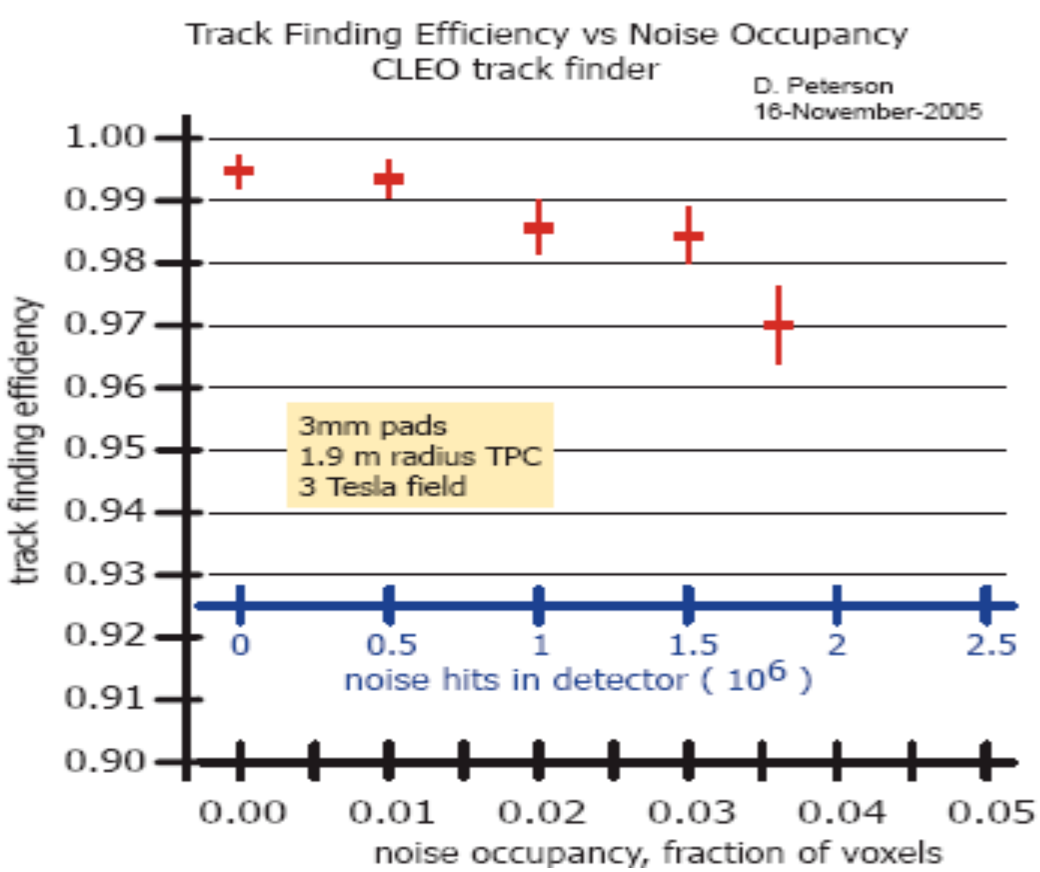
ILD Performance

$$e^+e^- \rightarrow Z \rightarrow q\bar{q}$$

Tracking Efficiency, p_T > 300 MeV

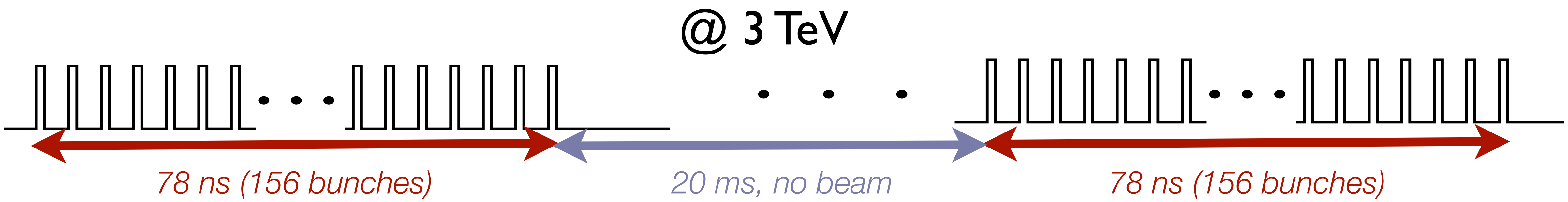


Background Sensitivity



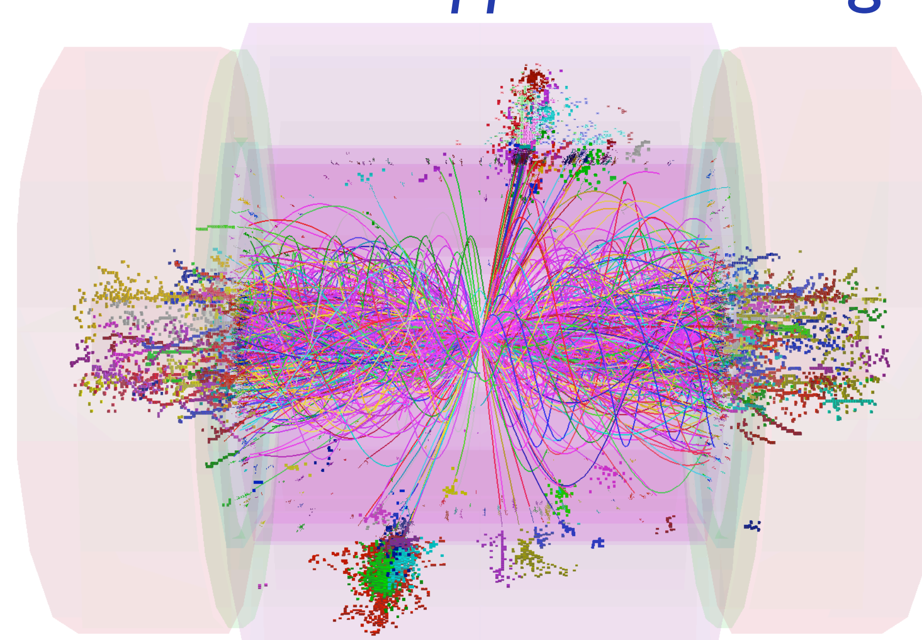
hits added in random voxels: ~(2mm)^3

CLIC Machine and Backgrounds



- Timing: trains at 50 Hz, 0.5 ns bunch spacing
  - pulsed power electronics: reduction ~50-100×
  - time tagging 5-10 ns possible (power tradeoff)
- Backgrounds: dominated by e+e- pairs
  - rate requires r_{inner} ~2x ILC
  - cannot relax timing to reduce power
- Radiation Environment: ~1/1000 LHC
  few technologies excluded, even in VXD.

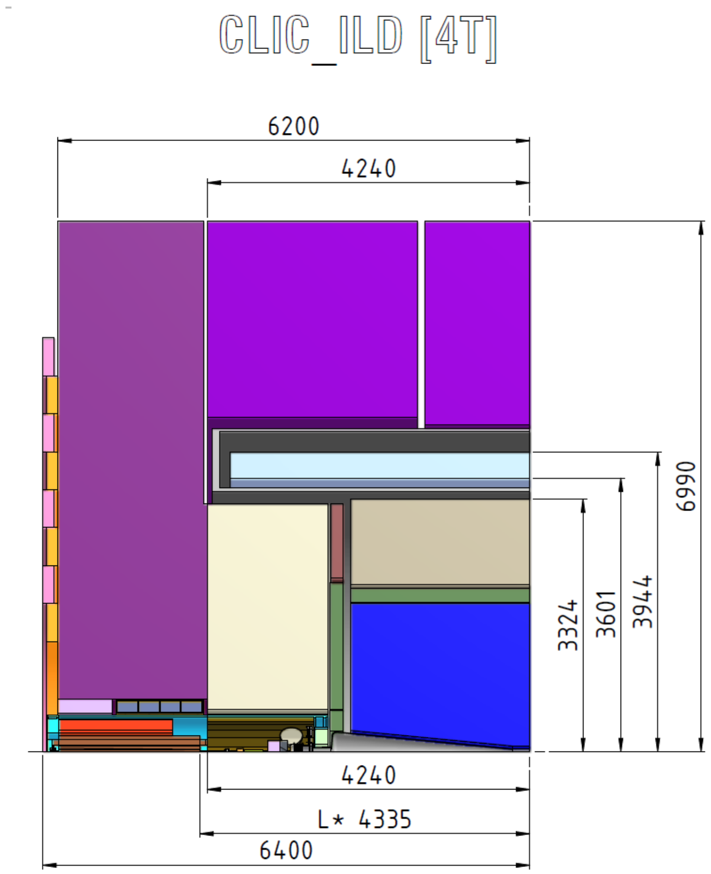
$e^+e^- \rightarrow Z \rightarrow qq$ + 30 ns bkgd

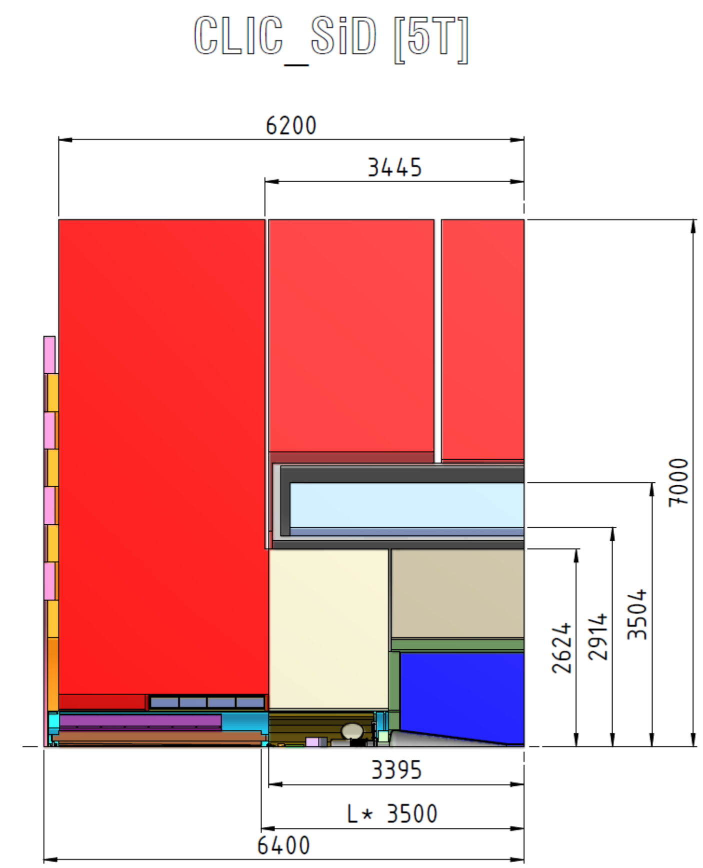


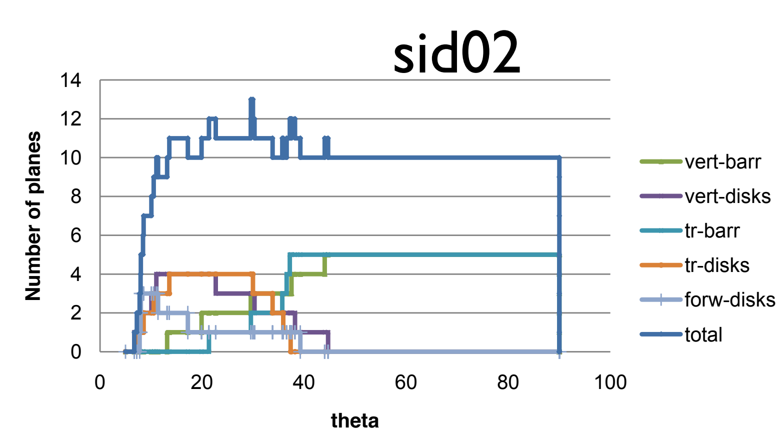
reconstructed objects

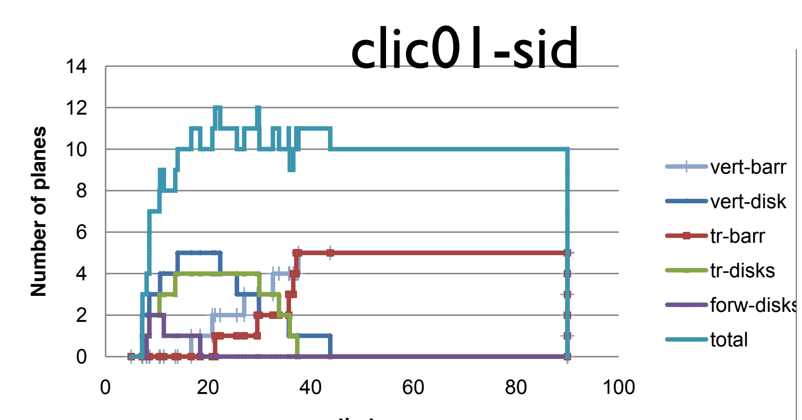
CLIC-SiD and CLIC-ILD

- Modified versions of SiD and ILD
- r_{inner} of VTX increased to ~3 cm
- Increase HCal to 7.5λ
- Minor shuffling of detector placements



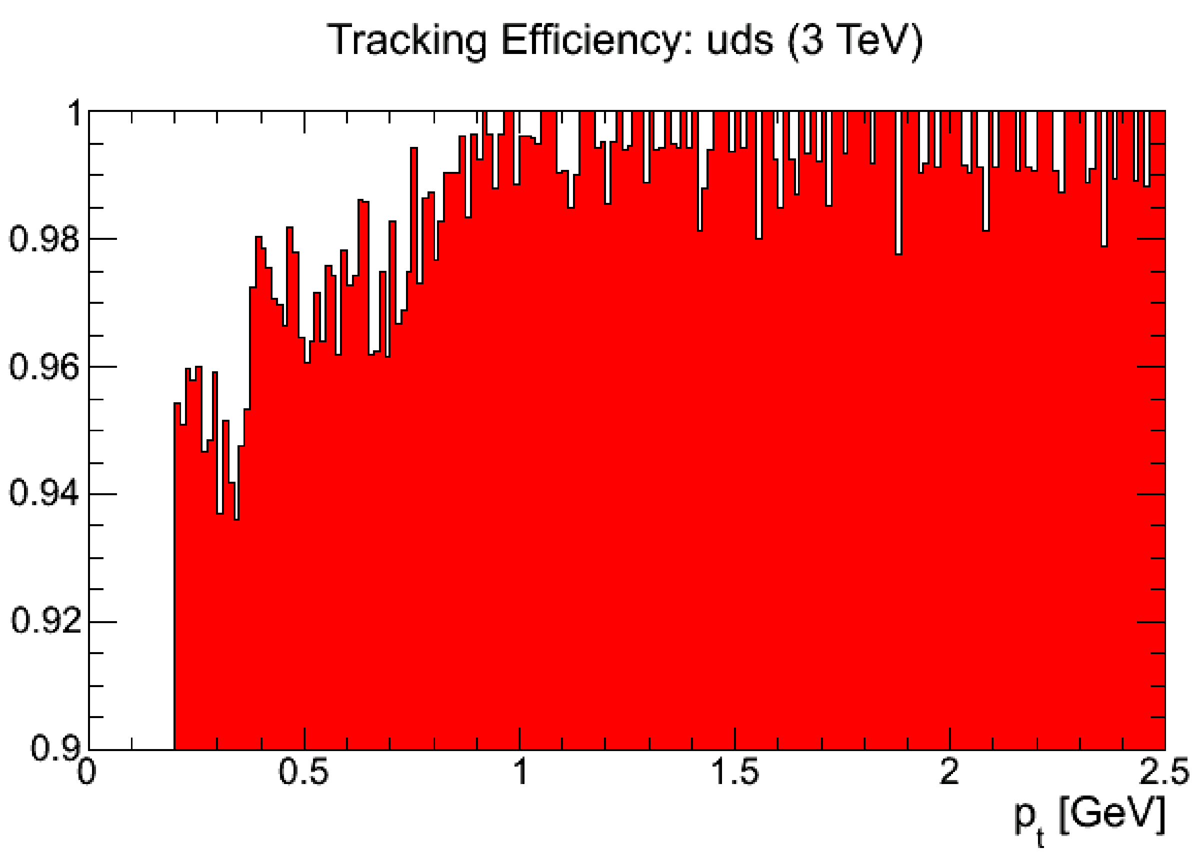




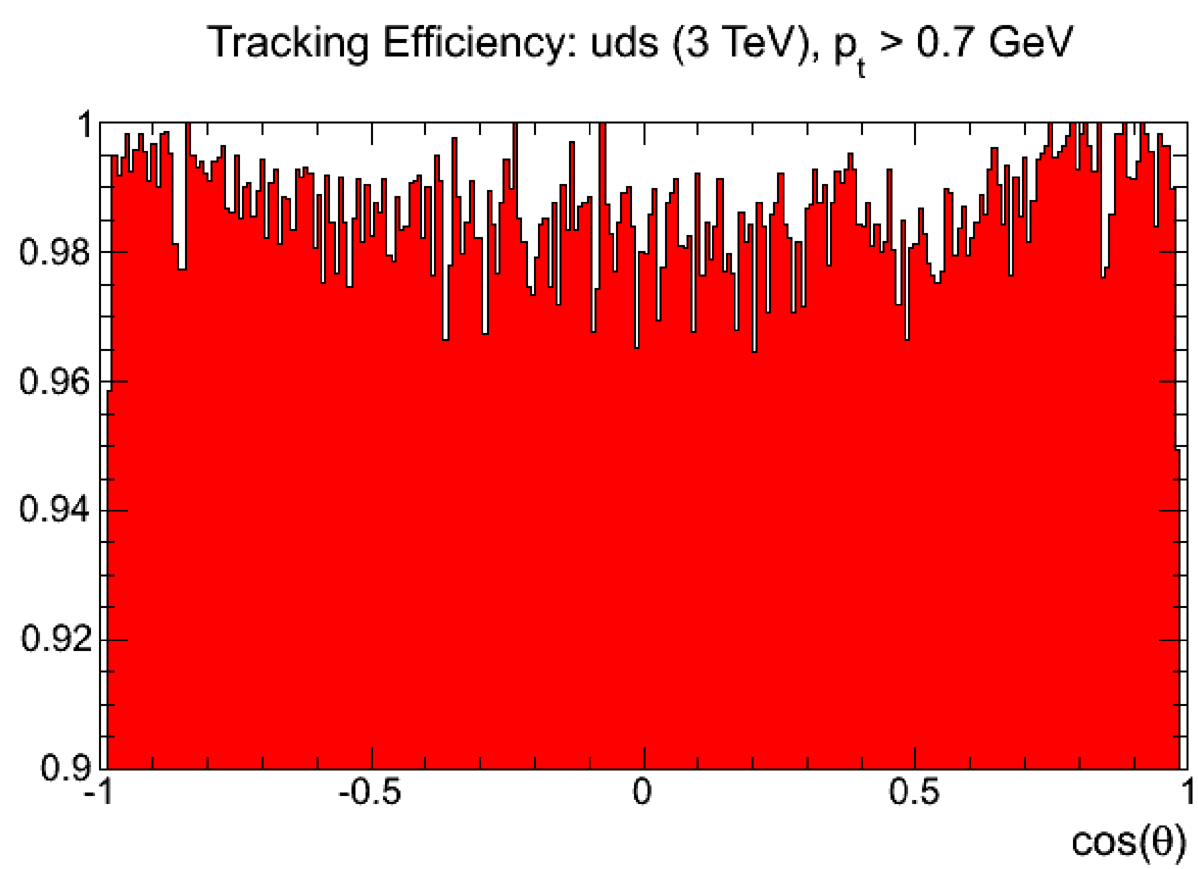


CLIC-SiD Detector Performance

efficiency vs. p_T



efficiency vs. cos(θ)

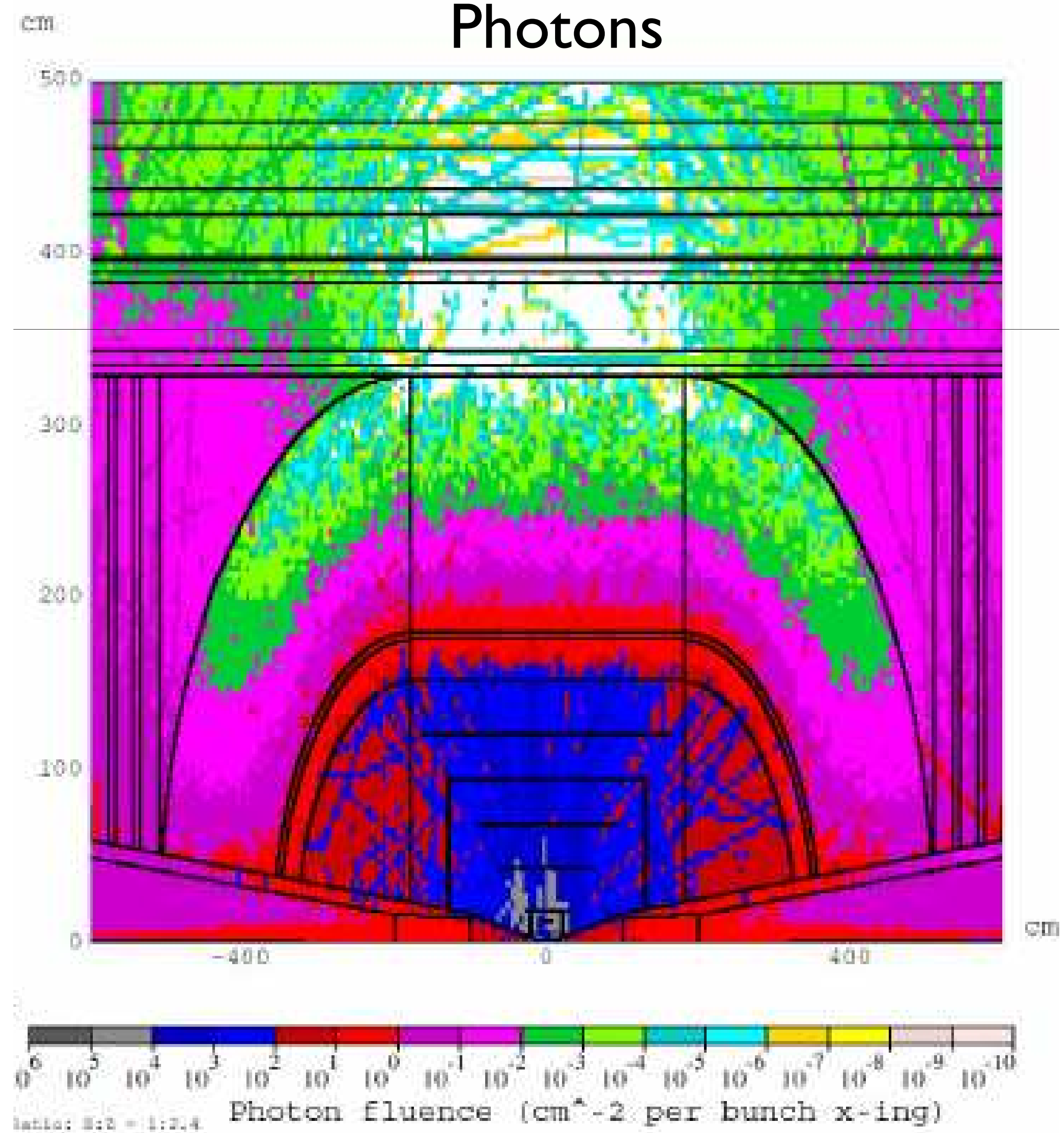


Both CLIC-SiD and CLIC-ILD retain good performance

MuC Machine Parameters

- Timing: single bunches every ~10 μs
  - no power pulsing
  - time tagging bunch a non-issue
- Backgrounds: photons, neutrons, muons, hadrons, kitchen sinks.
  - r_{inner} ~3x that for ILC? (effects tagging?)
  - need timing >1 (>>1?) generation beyond current pixel devices: *cooling*.
- Radiation Environment: ~1/10 LHC
  need rad-hard technologies and actively cooled sensors

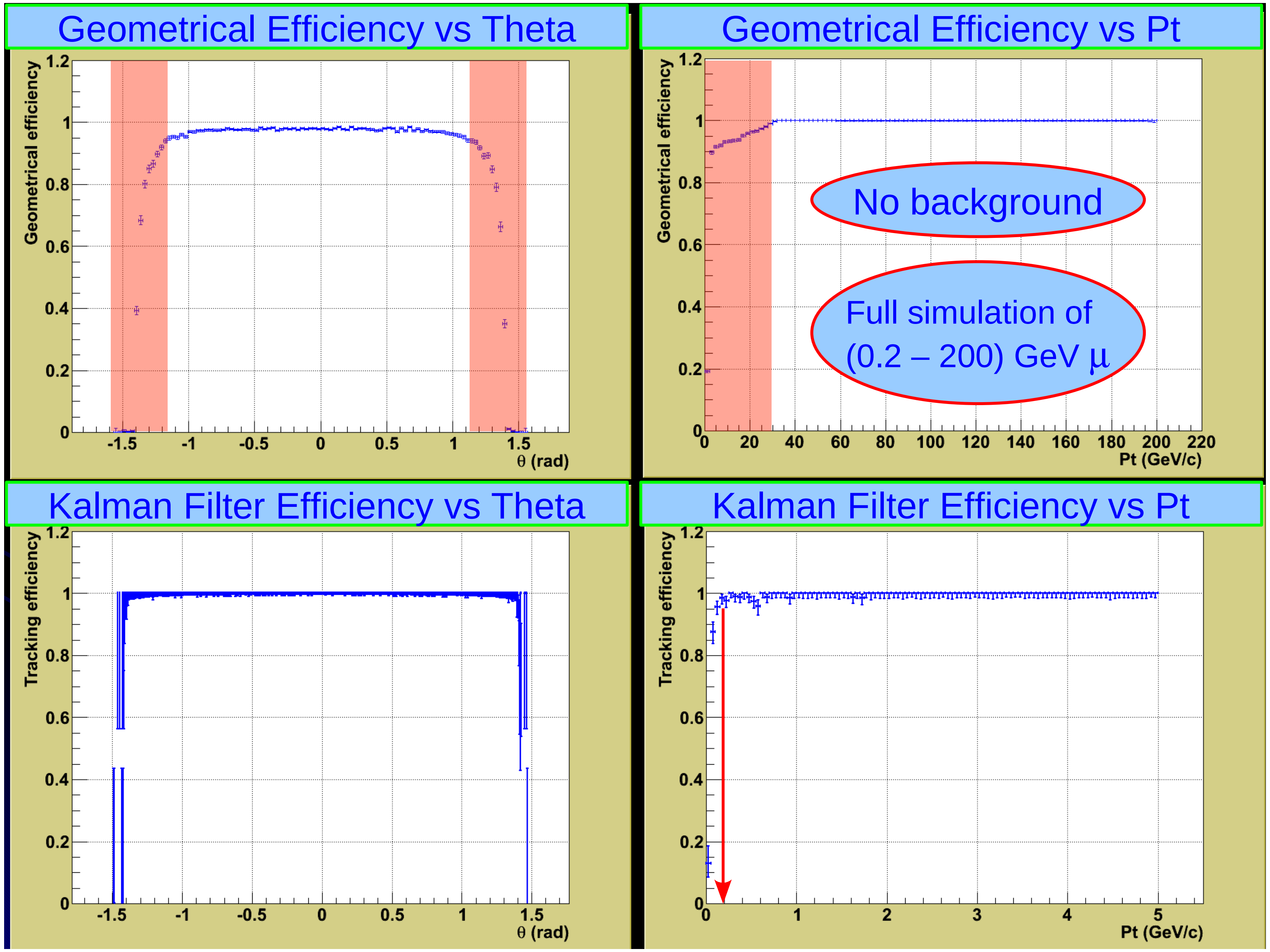
Photons



Mars15/ILCroot Group

MuC-SiD?

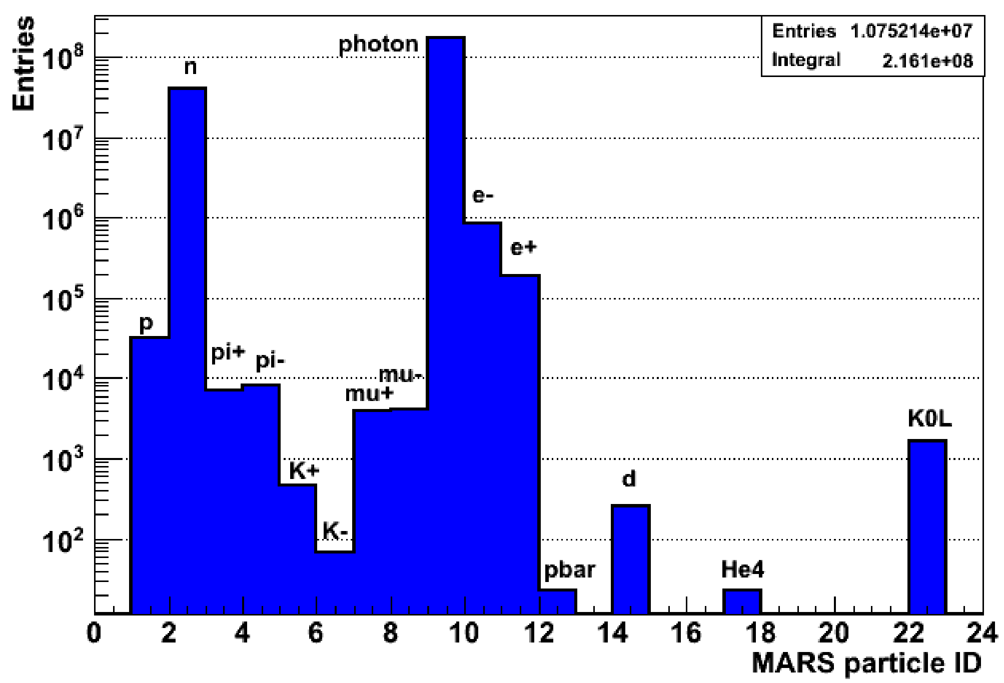
- Modified 4th concept detector is a good first guess
- Pixels are obviously needed everywhere (no point in discussing ILC tracker technologies in detail)
- Single muons with no backgrounds look OK.
- How much does efficiency loss from cones hurt physics?

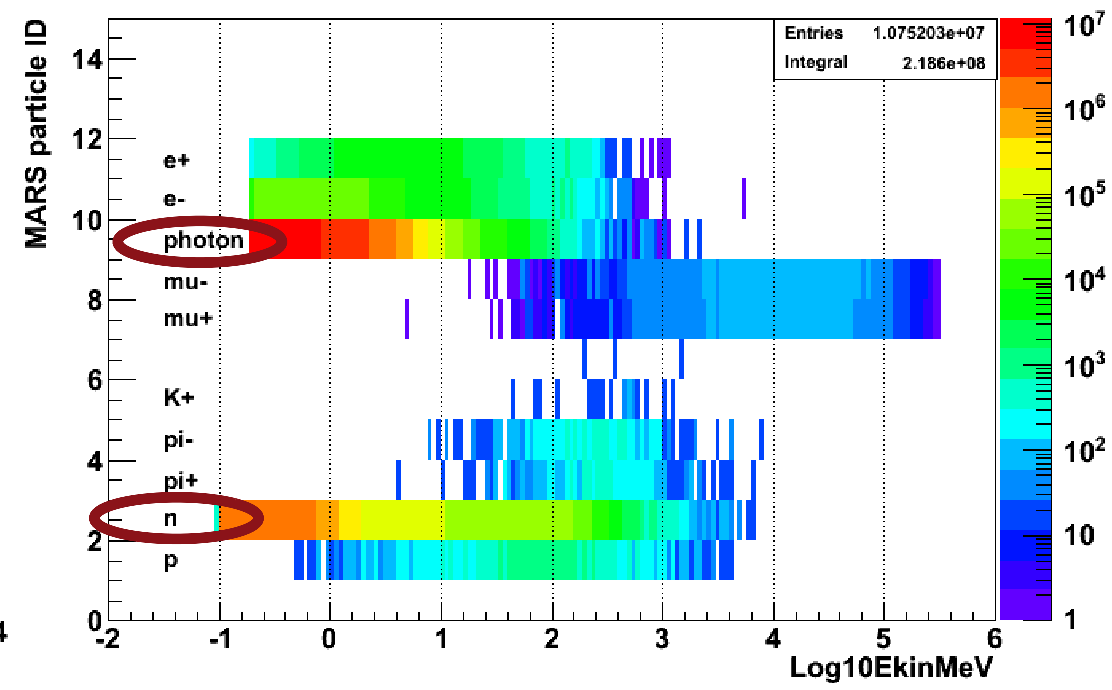


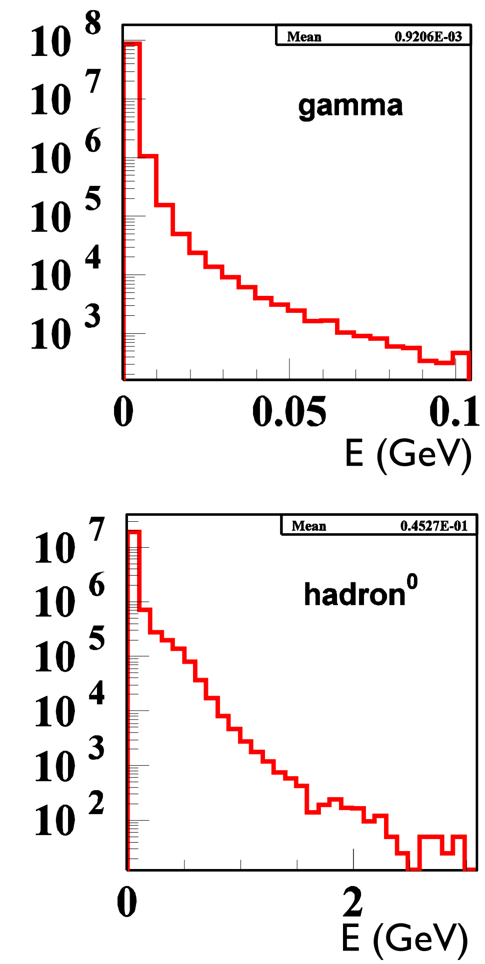
MuC Backgrounds

Mars15/ILCroot Group

- MARS background particle ID's yields for 750 GeV $2*10^{12}$ muons/bunch







- Background yields/bunch on 10^0 nozzle surface and MARS thresholds

	γ	n	e^{+-}	μ^{+-}
Yield	1.77e+08	0.40e+08	1.03e+06	0.80e+04
Ethr, MeV	0.2	0.1	0.2	1.0

typical Si threshold corresponds to 10-20 KeV E_{dep}

MuC Backgrounds

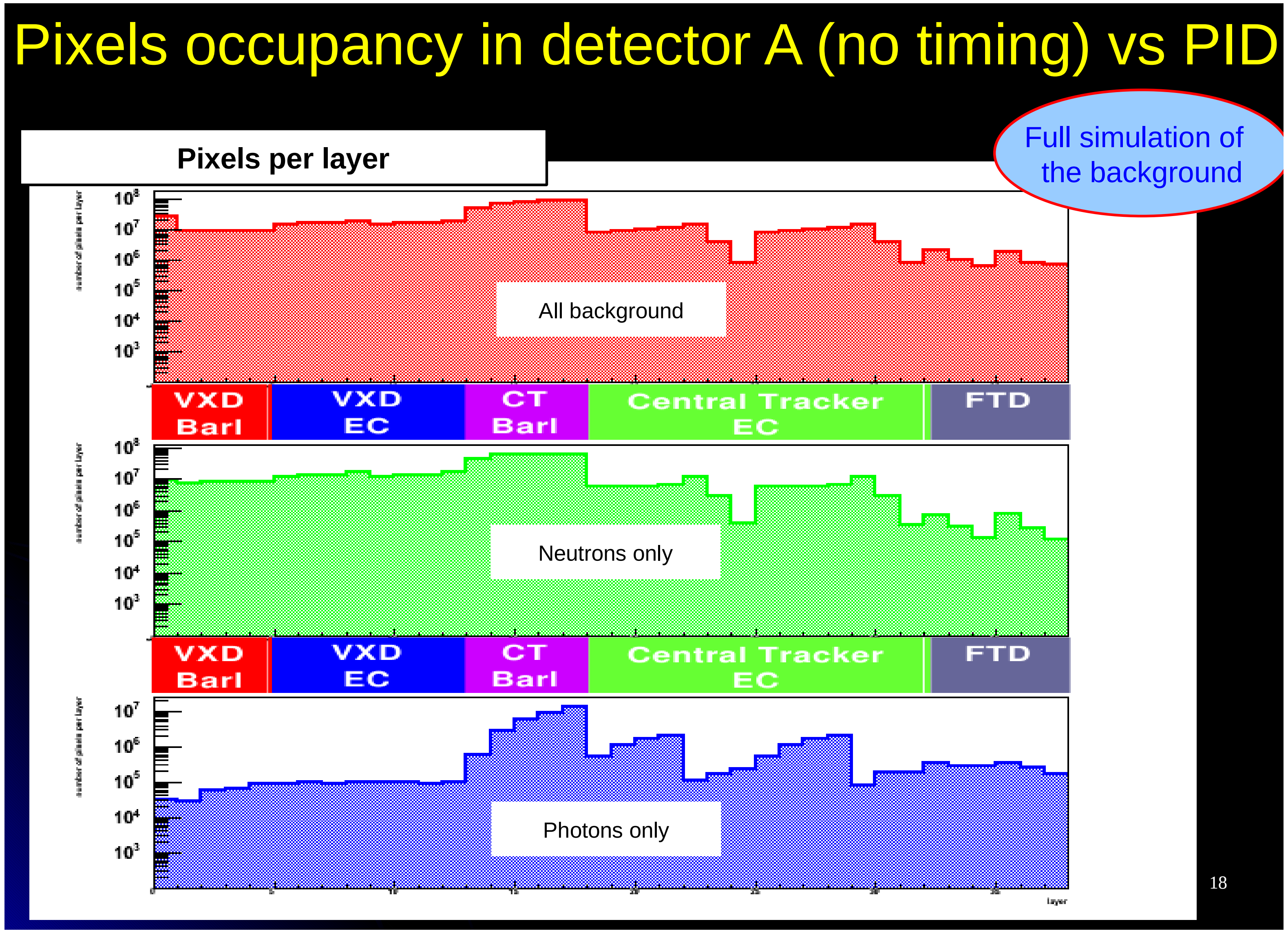
Mars15/ILCroot Group

	photons	neutrons	e^+e^-
Absolute MARS yields, # of particles (weight included, both beams)	1.77e+08	0.40e+08	1.03e+06
Fraction of particles producing hits in CT sensitive volumes	~2.8%	~0.6%	~43%
# of MARS particles "seen"	5.0e+06	0.24e+06	0.44e+06

- Photons Ekin ~ 0.2 – 100 MeV
  Neutrons Ekin ~ 0.1 – 1000 MeV
  e^+e^- Ekin ~ 0.2 – 100 MeV

Cluster Properties?

- Photon hits outnumber neutron hits 20:1.
- Pixels hit by neutrons outnumber those hit by photons by a huge factor in most layers.
- Are neutrons creating huge clusters in the pixel detectors that could be thrown away?
- What about cluster shapes?



Mars15/ILCroot Group

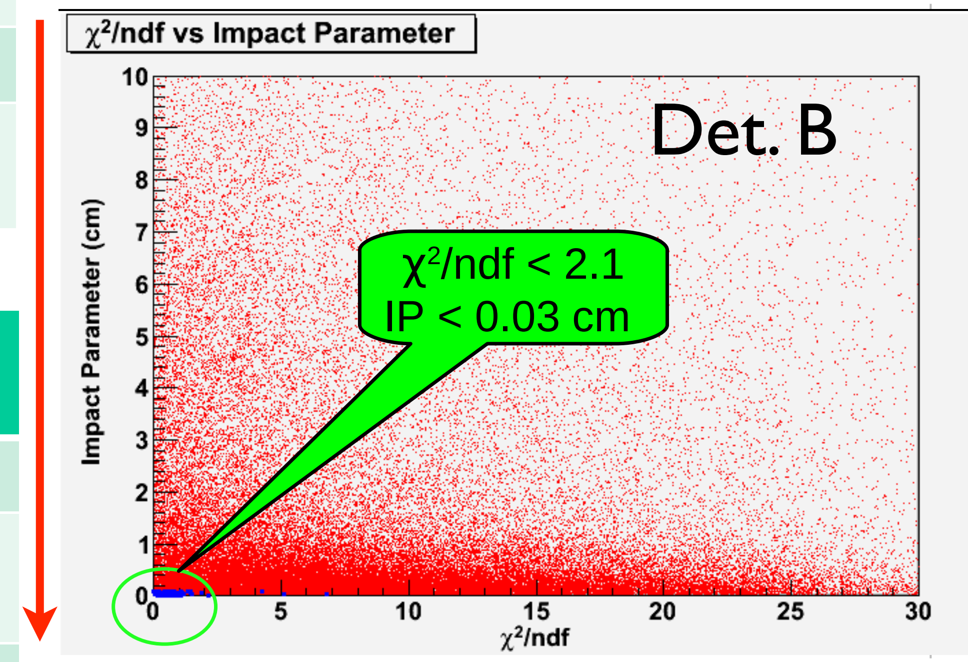
Timing Cuts

Mars15/ILCroot Group

Detector type	Reconstructed Tracks (full simu)	Reconstructed Tracks (fast simu)
Det. A (no timing)	Cannot calculate	Cannot calculate
Det. B (7 ns fixed gate)	75309	64319
Det. C (3 ns adjusteble gate)	6544	4639
Det. D (1 ns adjusteble gate)	1459	881

Timing cut is clearly critical

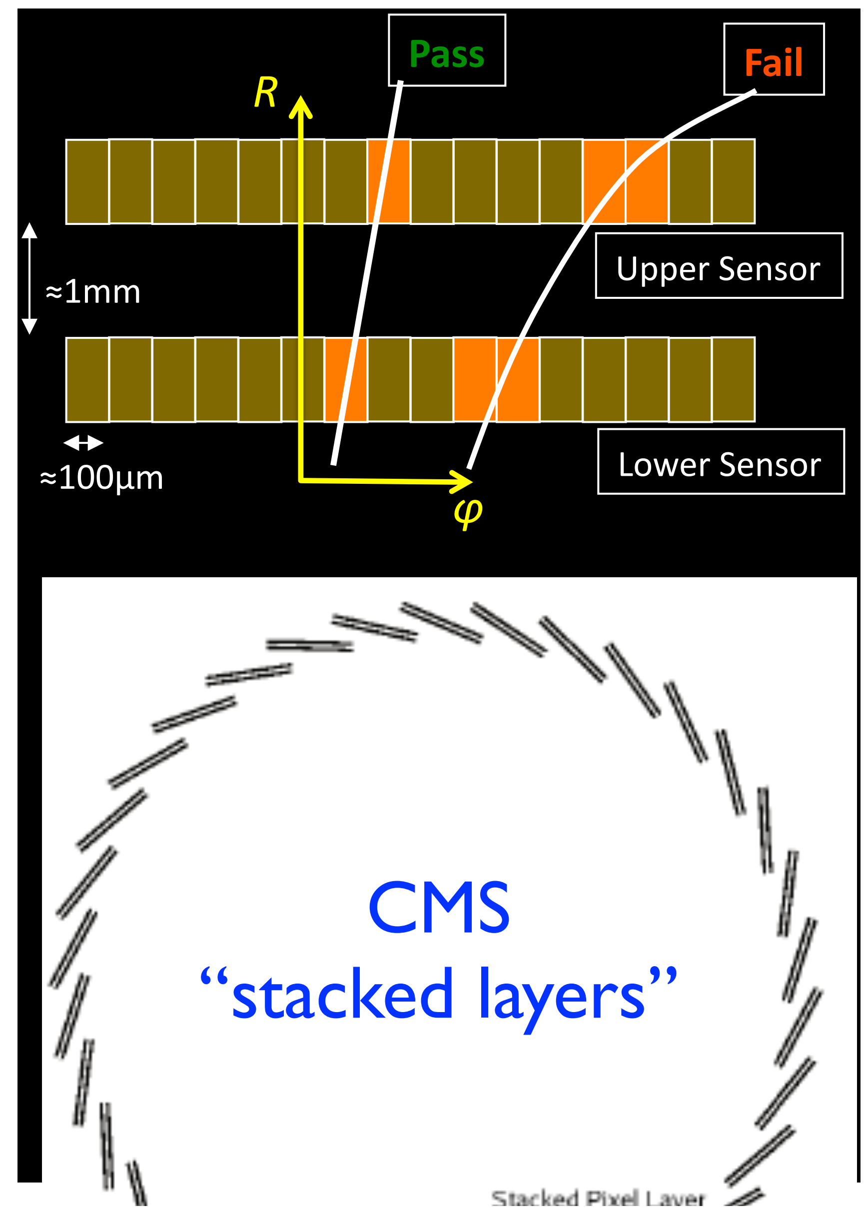
Detector type	Reconstructed Tracks (full simu)	Reconstructed Tracks (fast simu)
Det. A (no timing)	Cannot calculate	Cannot calculate
Det. B (7 ns fixed gate)	475	405
Det. C (3 ns adjusteble gate)	11	8
Det. D (1 ns adjusteble gate)	3	1



Track quality also important but IP cut very restrictive

Paired Layers

- Use of paired silicon layers in high density environments has become a very popular concept (e.g. sLHC tracking concepts.)
- Together with time this can be a very powerful discriminator
- Requires layer spacing << hit density or low-momentum tracking suffers: more useful in inner layers
- Increases power/material challenges



MuC-ILD?

- ILD TPC gases integrate ~40 bunches at MuC
- No way to reject backgrounds based upon timing
- ILC TPC gas presents ~1% X_0 to backgrounds
  - photon conversion rate not negligible: TPC is a nice x-ray detector
  - significant fraction of background hits can affect large regions (many voxels/hit)
- Although I have not checked carefully, quick calculations indicate that TPC is a lost cause here by orders of magnitude.

Summary of Ideas/Issues

Neither ILD nor SiD is close; need to invent, simulate a more realistic detector:

- Timing:
  - Two models of timing; 5ns, 1ns; each with some assumed power budget
  - More realistic models of detector material for each given power consumptions
- Spatial correlations:
  - Try paired layers at some reasonable spacing (~1mm)
  - Need specialized tracking code to take advantage of this configuration
- Studies:
  - need to lower gamma, neutron thresholds
  - need to stop simulating backgrounds beyond some broad time gate (5ns?)
  - need to investigate cluster properties
  - need to strive for apples/apples comparison with ILC/CLIC tracking performance: p_T resolution, IP resolution, eff. vs. pT and θ for more massive detector a good start.