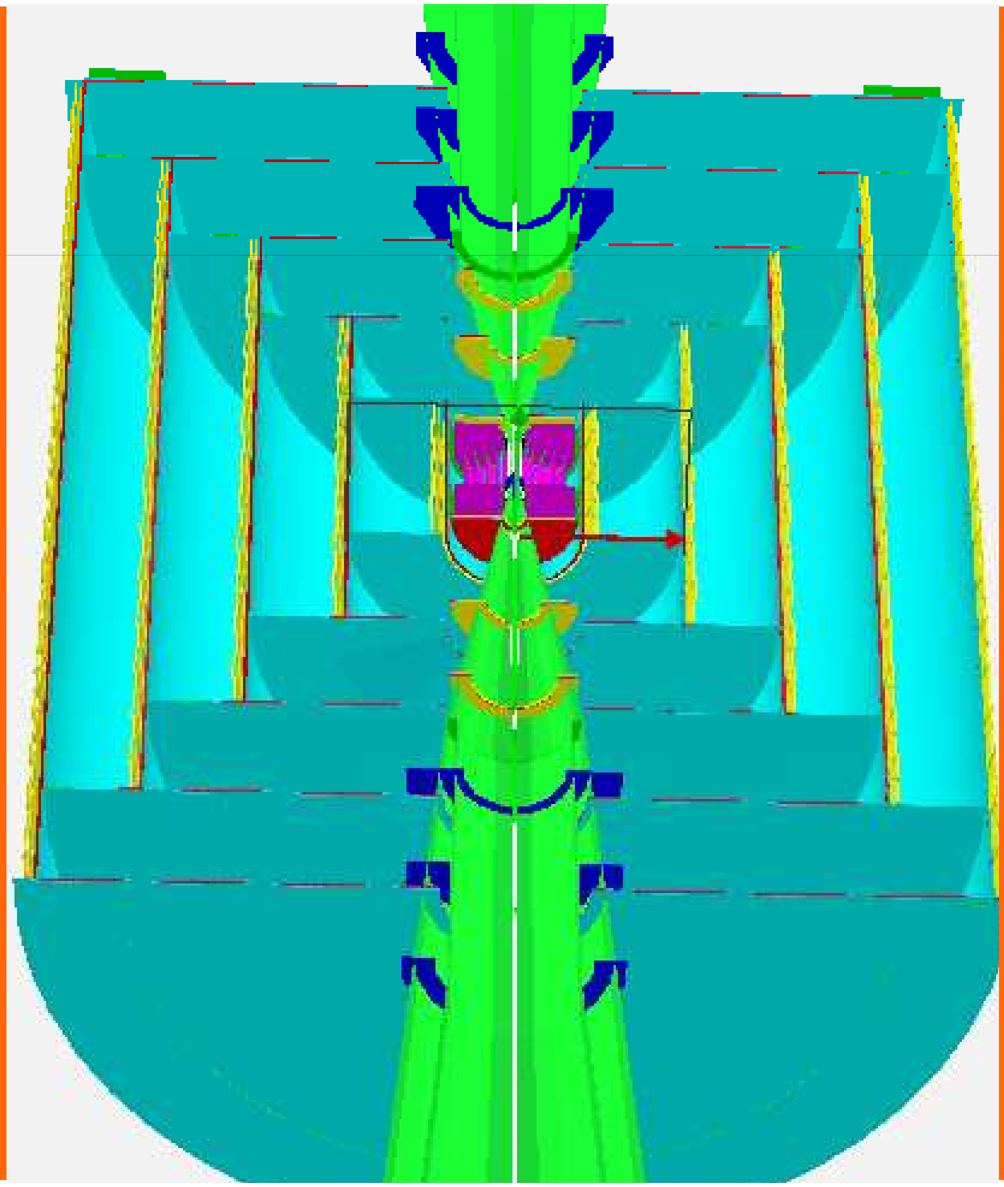
Working Group 1: Tracking for a Muon Collider



Tim Nelson - SLAC

Muon 2011 - Telluride

July 1, 2011

Lepton Collider Goals

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

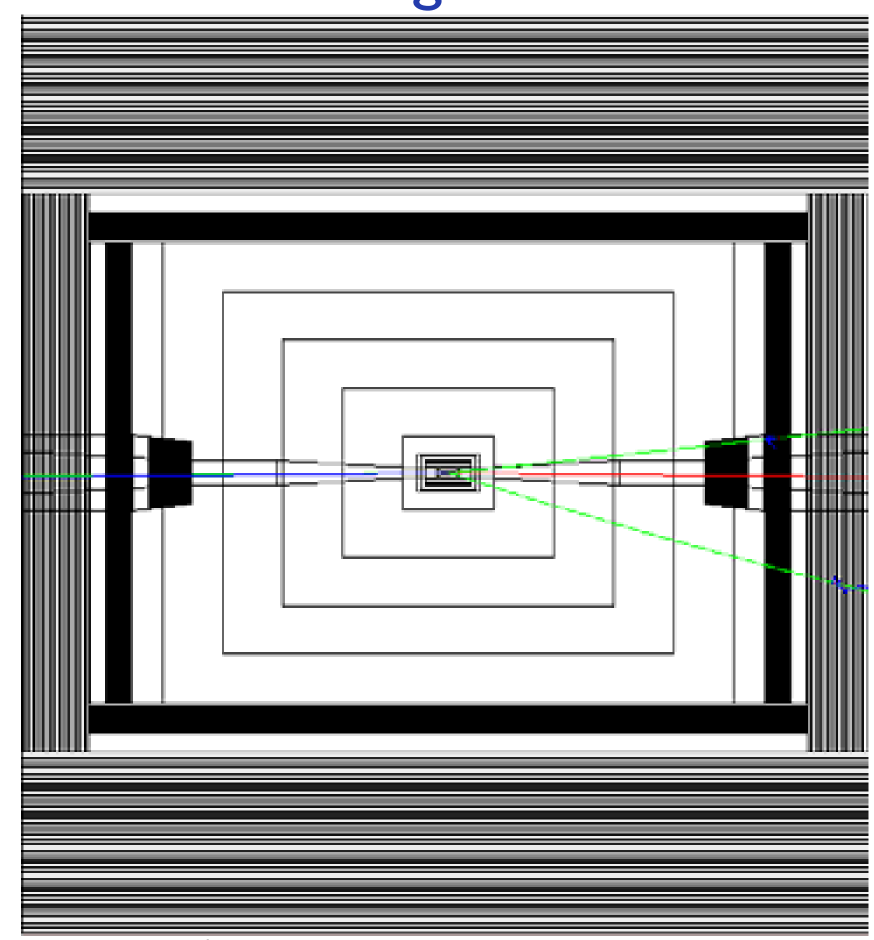
- A machine with much better defined initial-state kinematics and lower backgrounds than the LHC
- A detector capable of much more precise event reconstruction than LHC detectors. For tracking/vertexing:
  - far less mass than LHC trackers (~ 1/5-1/10 CMS): p_T res (< 50 GeV/c), tagging, ECal res
  - $d(1/p_T) < 5\times10^{-5}$ GeV^{-1} (~CMS/3): p_T res (> 100 GeV/c)
  - impact parameter $\sigma_{xy} = \sigma_z = 5 \oplus 10/(p \sin^{3/2}\theta)$ μm (~1/2 - 1/10 CMS): flavor tagging
  - excellent forward performance (to cosθ=0.99, θ=8°) : t-channel / fusion processes

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.

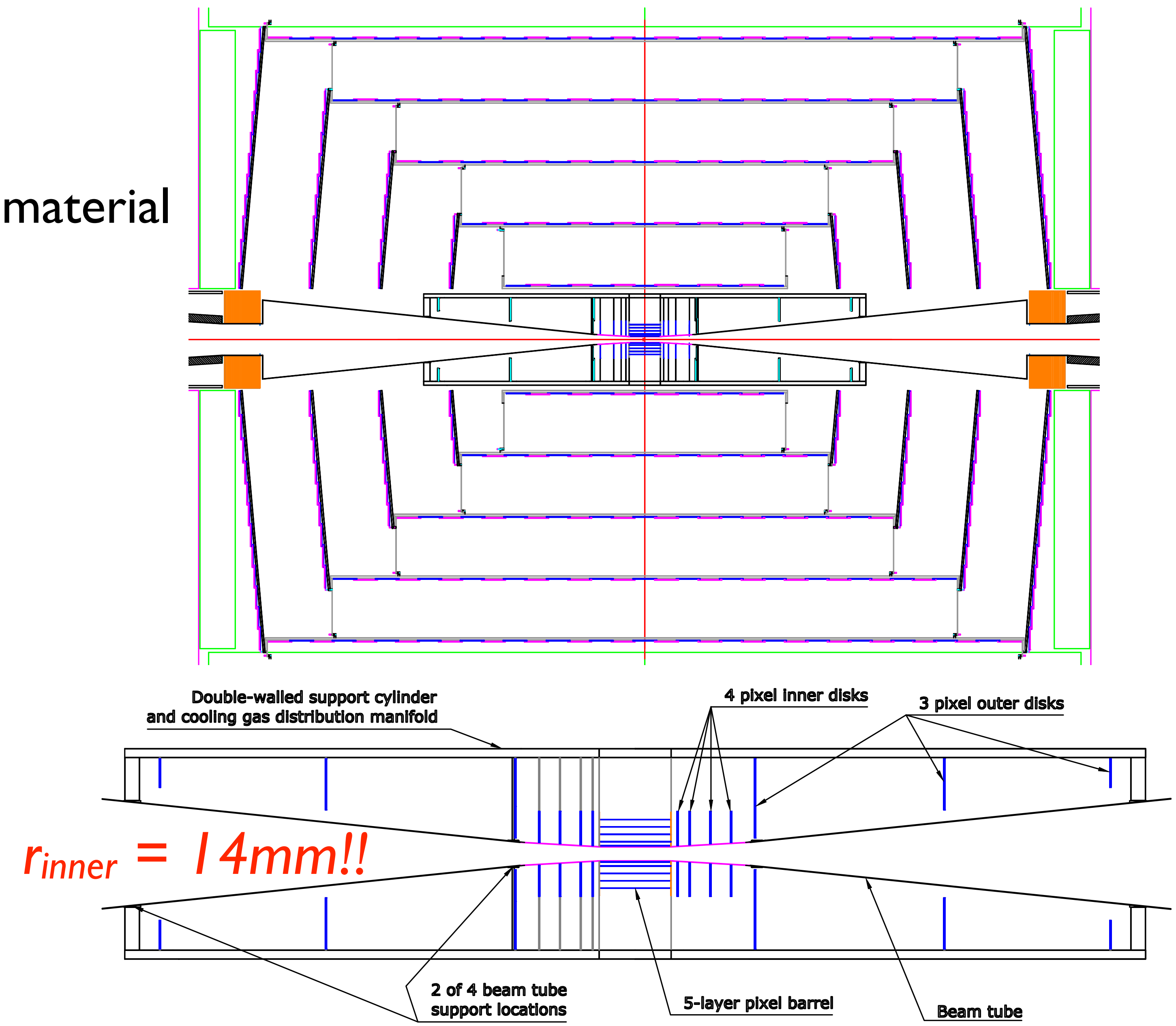
1 ILC background event



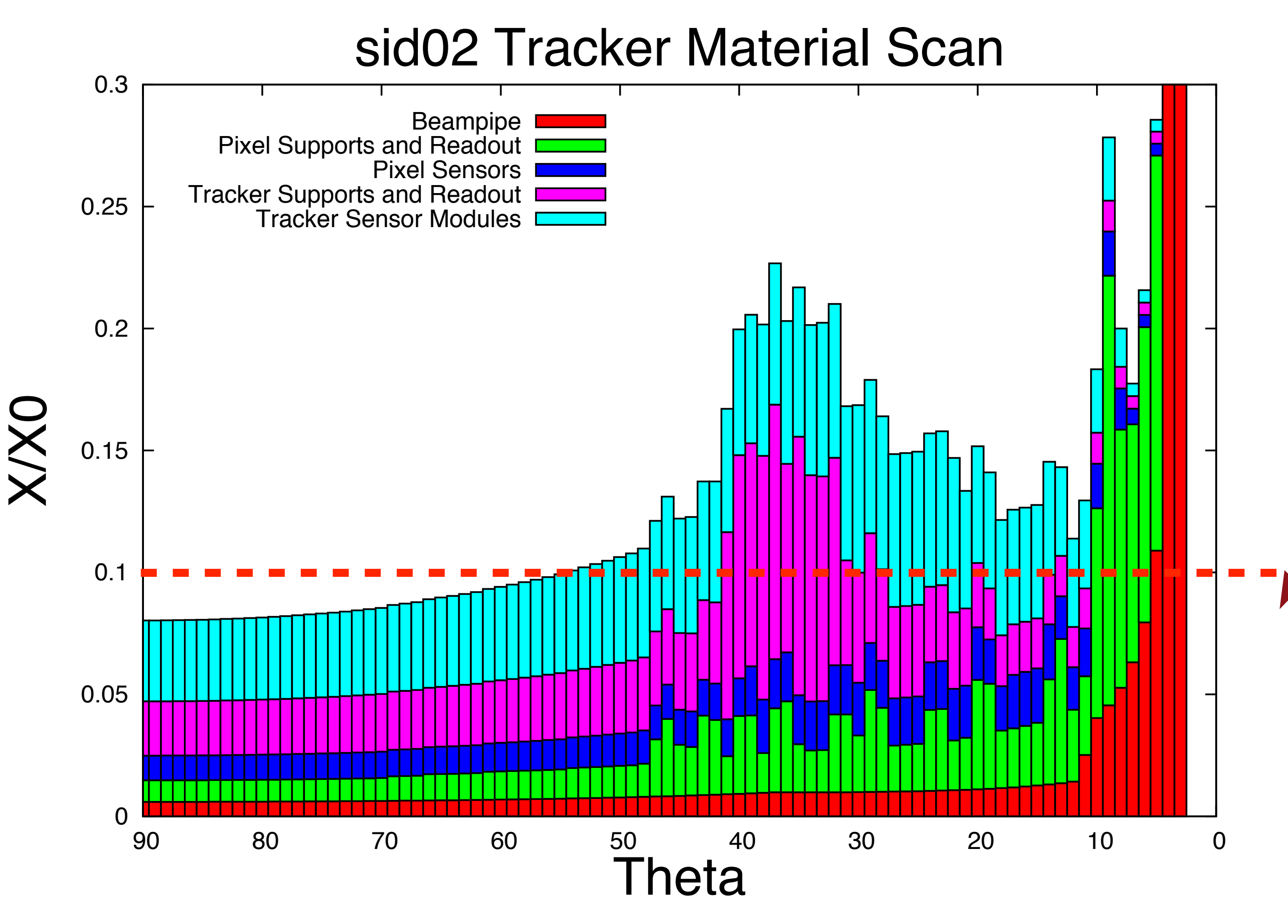
SiD Concept

- VXD
  - pixels ~(20 μm x 20 μm)
  - sensors w/integrated readout reduce material
  - best time tagging within gas cooled power budget (13 mW/cm^2)
  - time tagging from 1~150 bunches depending upon technology
- TKR
  - fine-pitch microstrip sensors
  - low-mass readout/support
  - single-bunch time tagging with low power consumption (0.5 mW/cm^2)
  - P_{tot} < 500W *just* allows gas cooling

CLIC-SiD substantially the same.



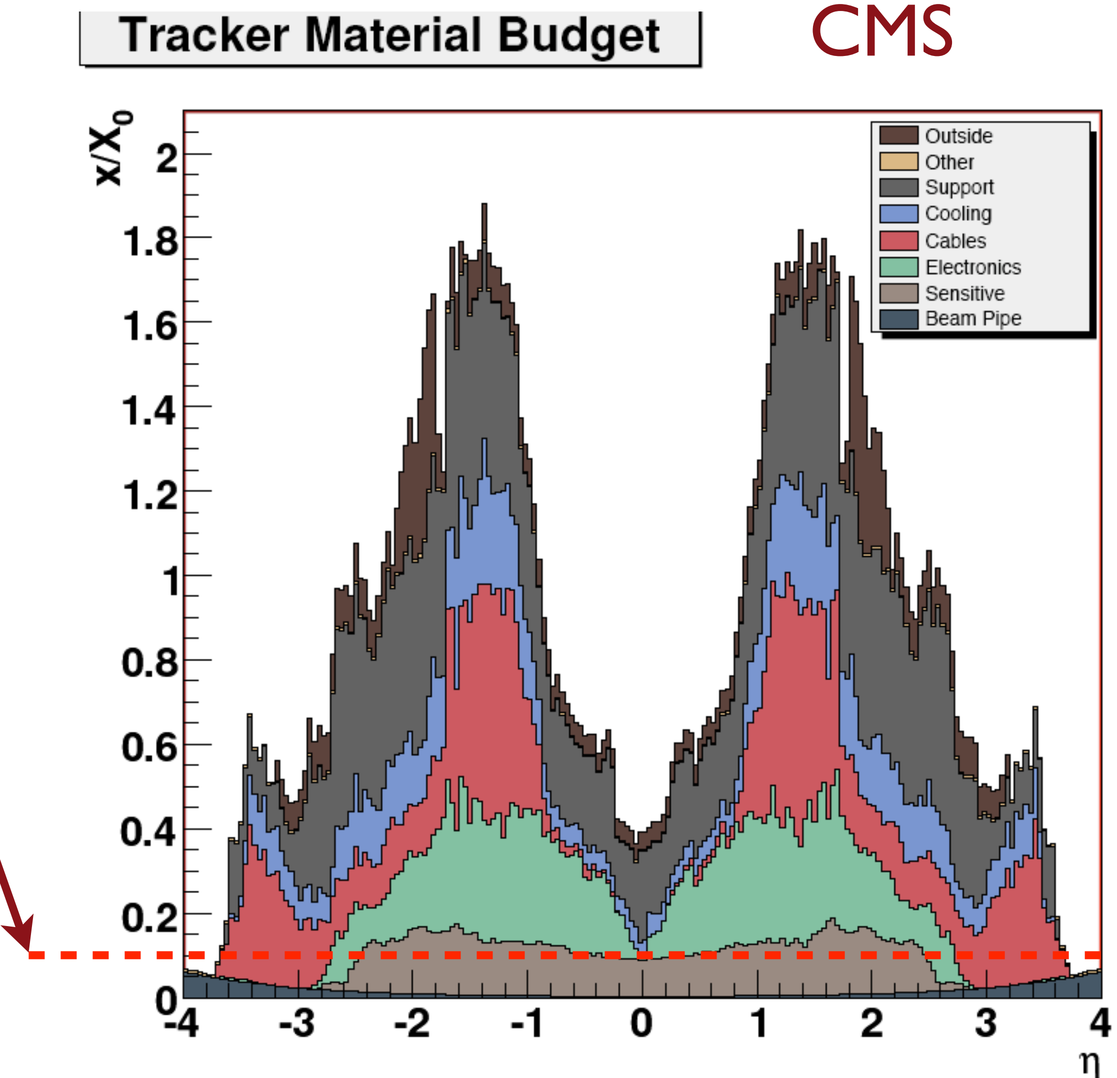
SiD Concept



VXD: ~0.1% X_0/layer

TKR: ~1.0% X_0/layer

CMS

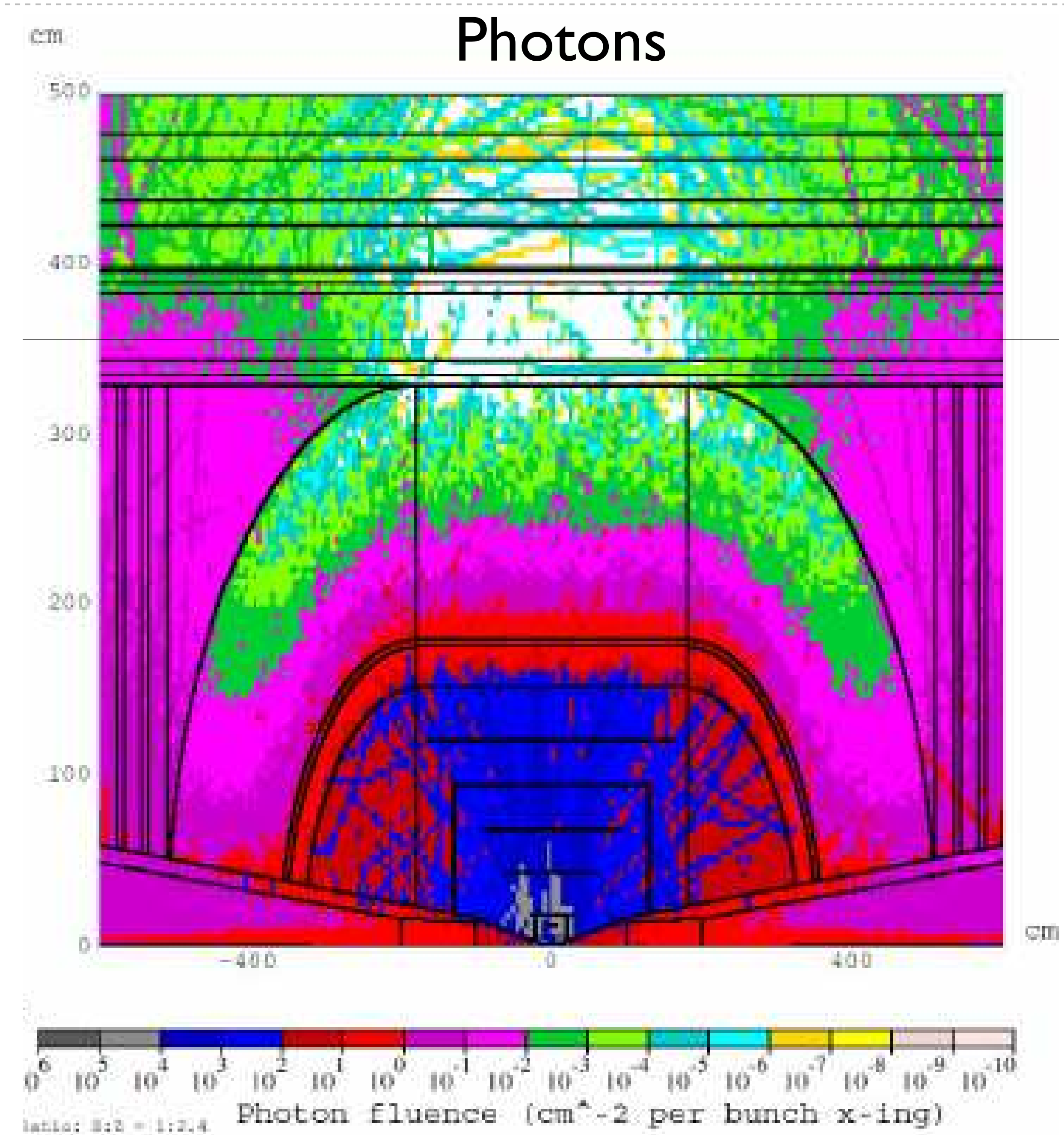


Calorimeter guys don’t like this!

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. ("MuCk"?)
  - r_{inner} ~3x that for ILC? (effects tagging?)
  - need timing >1 (>>1?) generation beyond current pixels: *power+cooling*.
- Radiation Environment: ~1/10 LHC
  need rad-hard technologies and *actively cooled sensors*

Looks like a very aggressive
sLHC tracker (sLHC++)



Mars15/ILCroot Group

“MuC-SiD”

Mars15/ILCroot Group

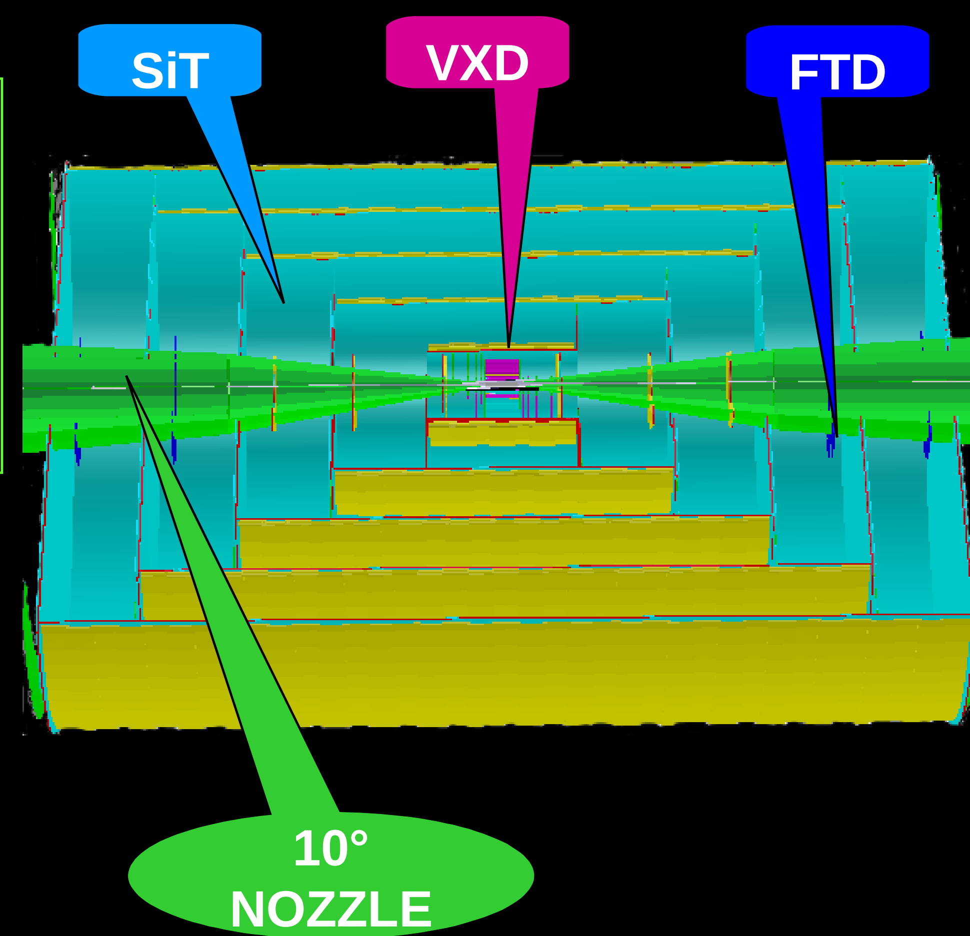
Silicon Tracker (SiT) and Forward Tracker Detector (FTD)

SiT

- 100 μm thick Si layers
- 50 μm x 50 μm Si pixel (or Si strips or double Si strips available)
- Barrel : 5 layers subdivided in staggered ladders
- Endcap : (4+3) + (4+3) disks subdivided in ladders
- R_{min}~20 cm R_{max}~120 cm L~330 cm

FTD

- 50 μm x 50 μm Si pixel
- Endcap : 3 + 3 disks
- Distance of last disk from IP = 190 cm



- Silicon pixel for precision tracking amid up to 10^5 hits
- Tungsten nozzle to suppress the background

A. Mazzacane (Fermilab)

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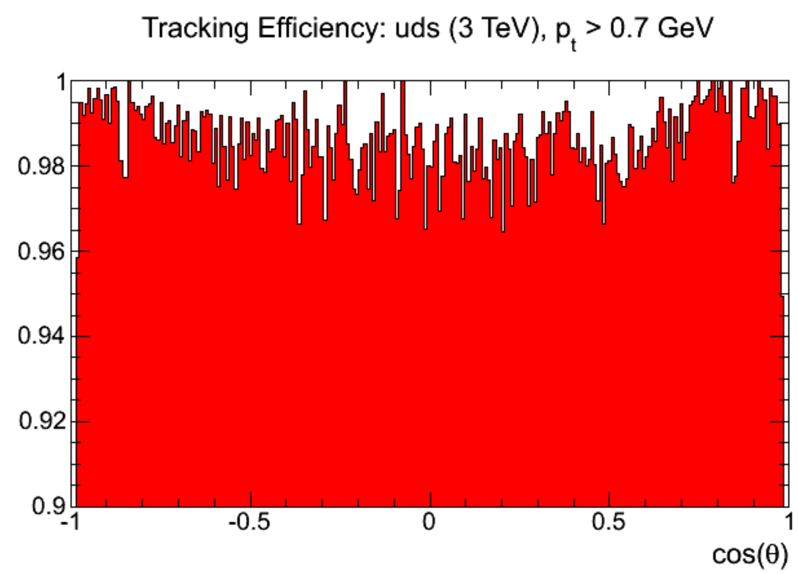
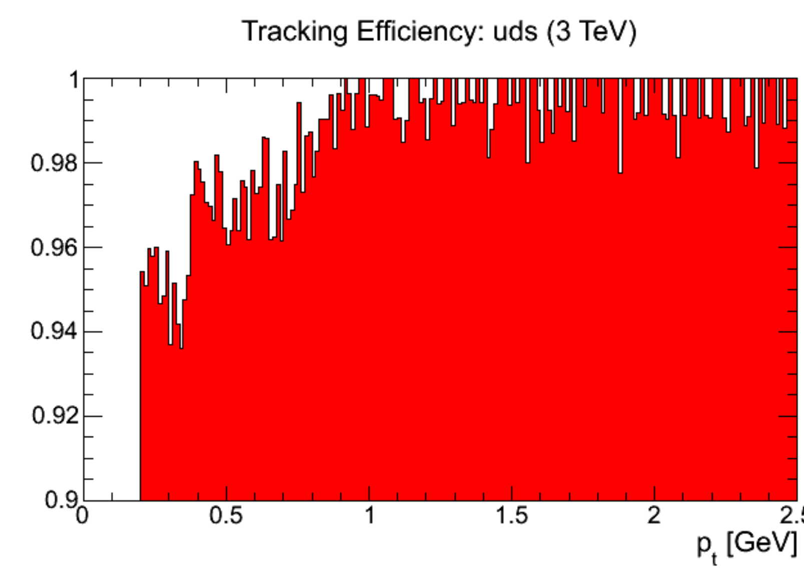
MuC-SiD Tracker

- This modified SiD tracker is a good first guess.
- Pixels with phenomenal timing are needed everywhere, so material budget is unrealistic.
- Single muons with no backgrounds look OK.
- How much does efficiency loss from cones hurt physics?

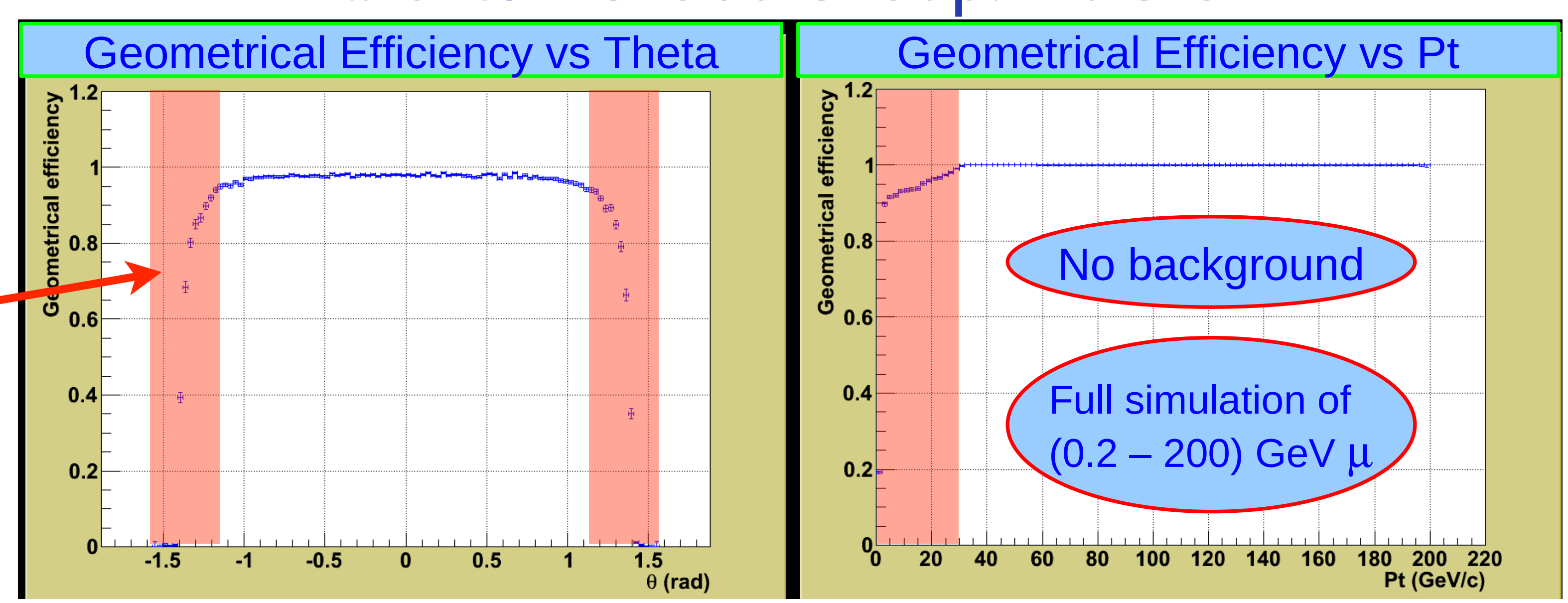
CLIC-SiD: efficiency vs. cos(θ)



CLIC-SiD: efficiency vs. p_T



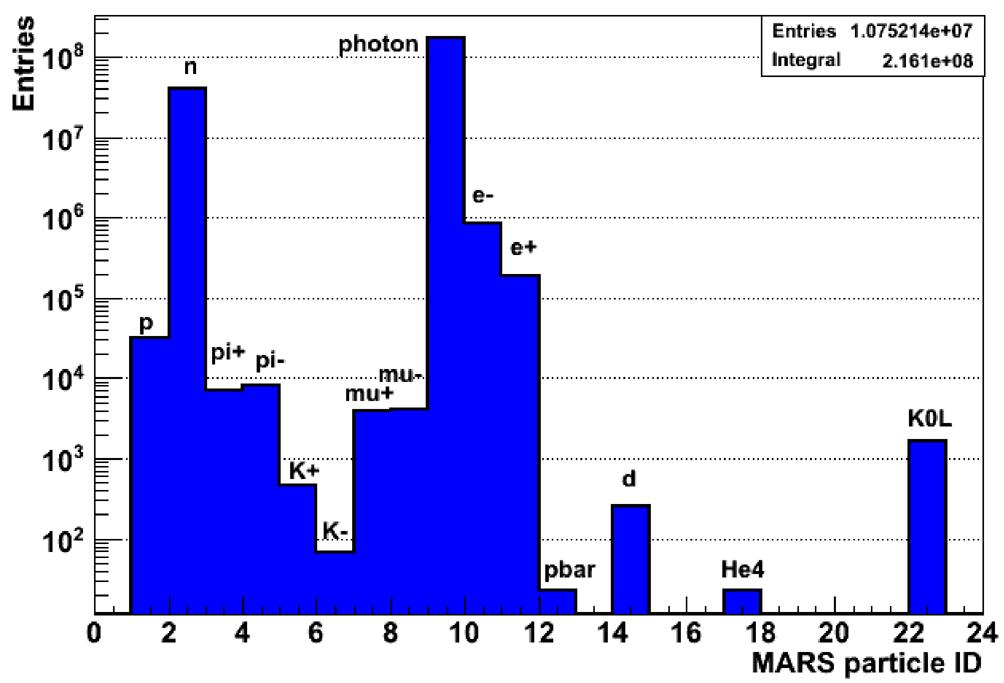
Mars15/ILCroot Group: MuC-SiD

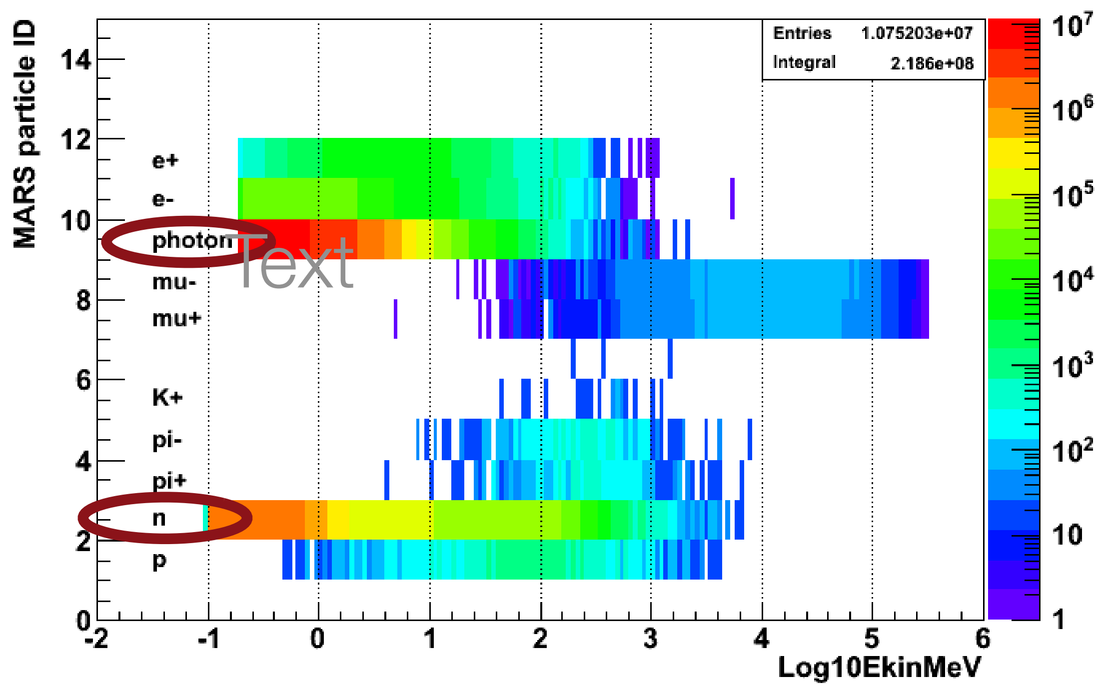


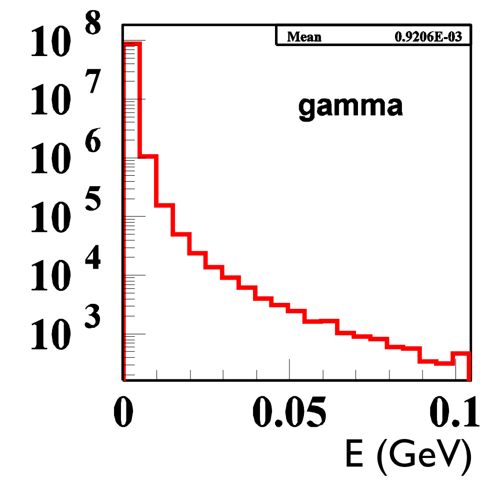
MuC Backgrounds

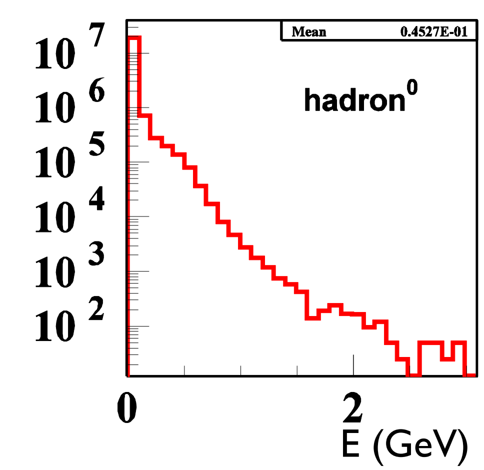
Mars15/ILCroot Group

- 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}

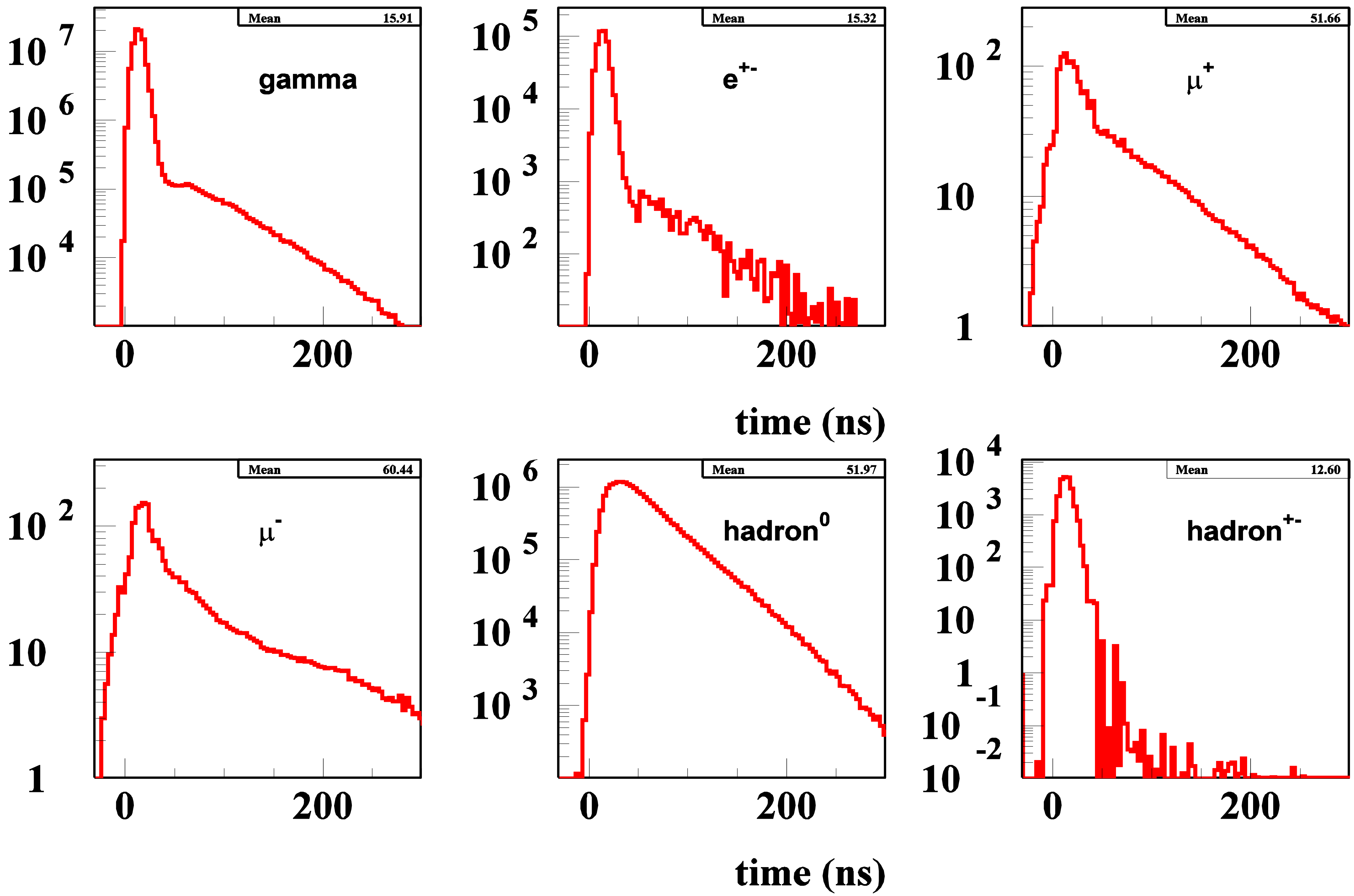
MuC Backgrounds

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 $\times 10^{?}$	0.24e+06 $\times 10^{?}$	0.44e+06

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

Time Distribution wrt Bunch crossing at Detector Entrance

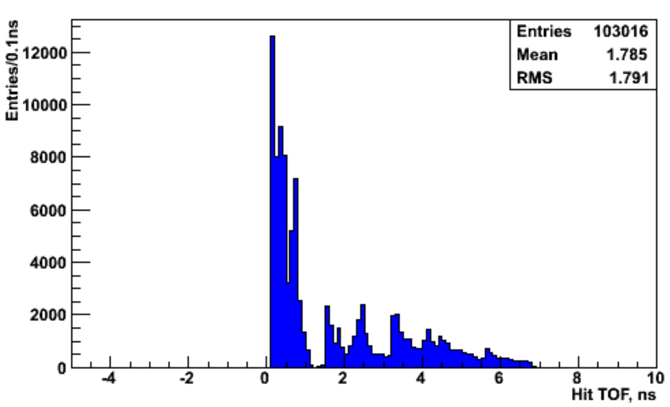


Timing Cuts

Mars15/ILCroot Group

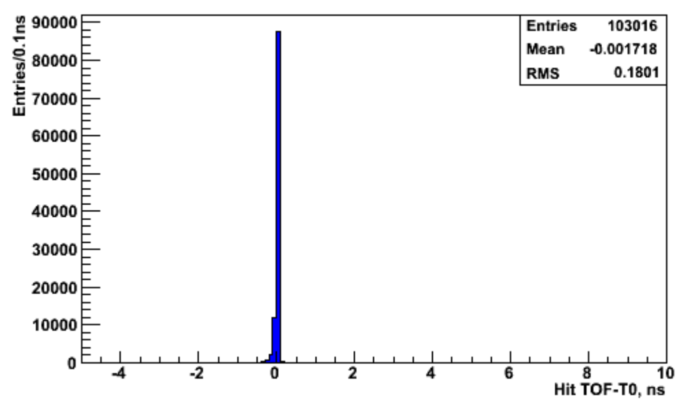
- **Vertex and tracker timing for IP muons** (mostly stiff tracks)

TOF



RMS ~ 1.8 ns

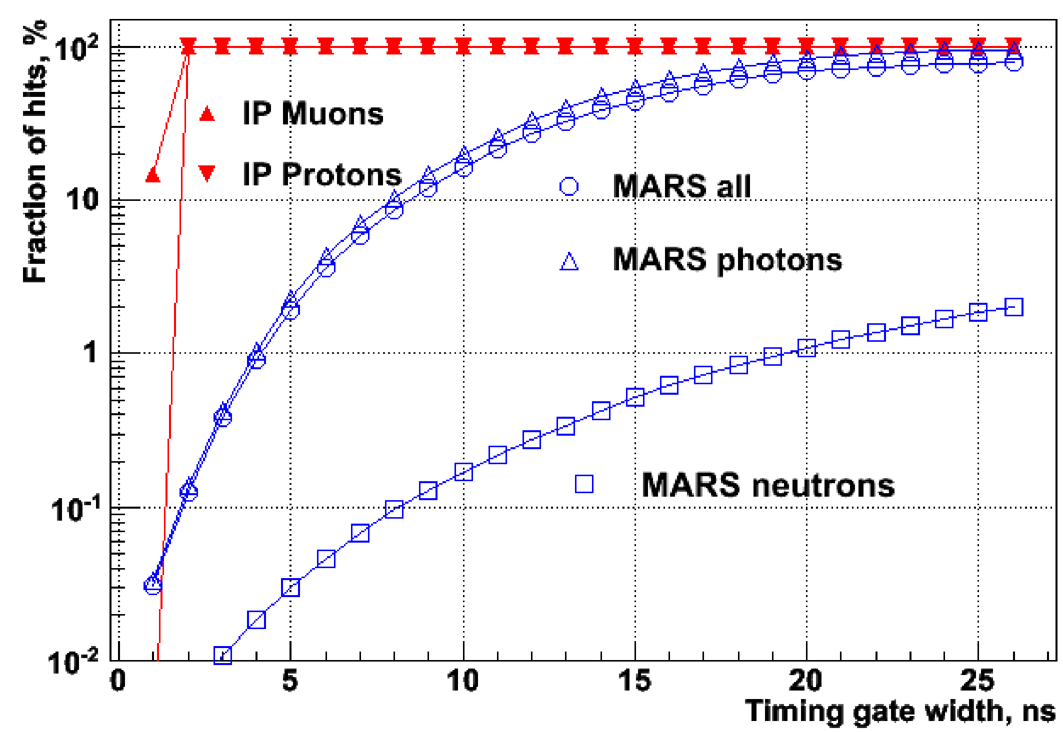
TOF – T0



RMS ~ 0.18 ns

cut on timing in each element of detector relative to expected arrival time of light speed particle from IP. “adjustable gate”

See also talk discussing general principles and applications by R. Raja



Timing Cuts

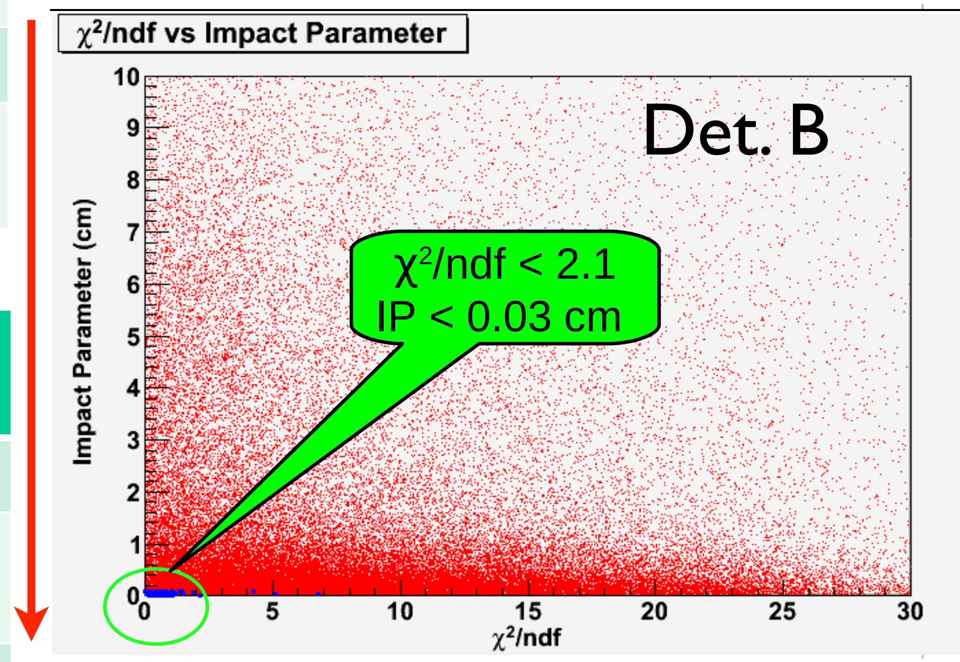
Mars15/ILCroot Group

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

one background event, no signal (all tracks are fakes)

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

Timing cut is clearly critical

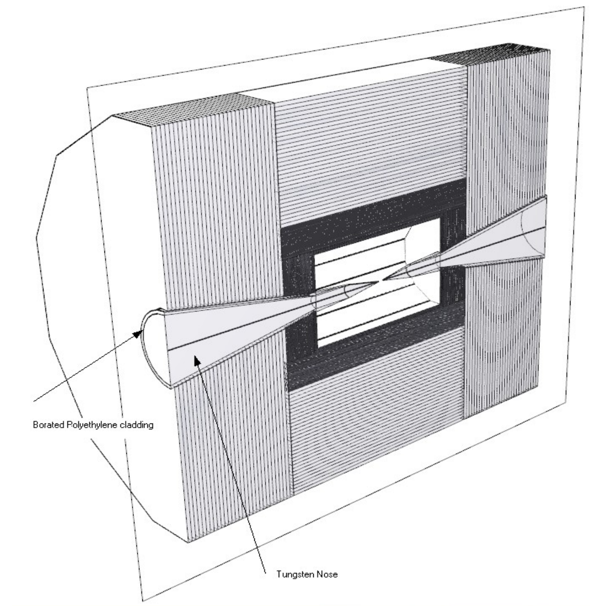


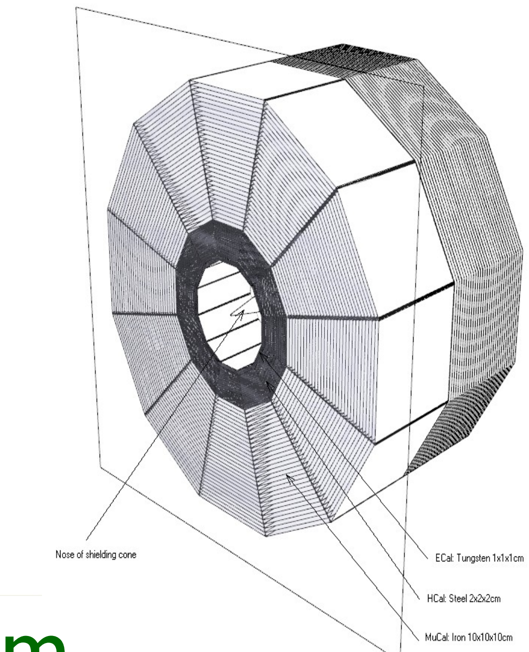
Track quality also important

but IP cut very restrictive

Simulation and Data Proceessing

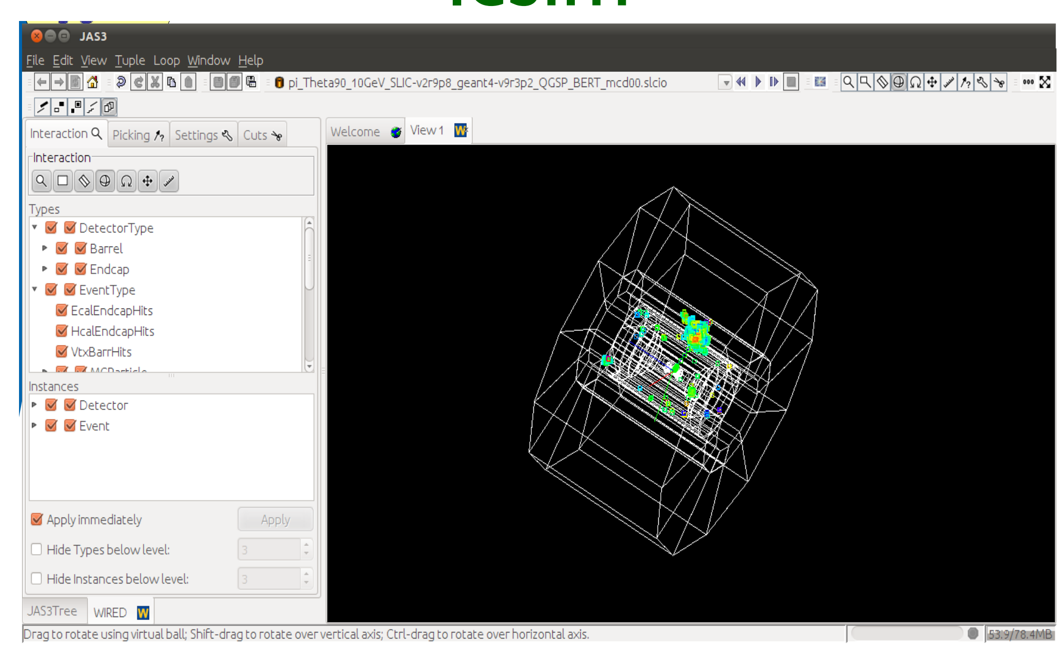
- Mars15/ILCroot is a powerful tool
- Para: CPU and data storage are staggering.
  For 1M events signal mixed with background
  - 2.2×10^6 CPU days
  - 100 petabytes data
  - Need a way to filter data to eliminate particles before simulating
- Wenzel:
  - Mars15 now interfaced to lcsim
    (used for SiD and CLIC-SiD simulations)
  - Brings with it many tools and an active community of developers





Norman Graf

lcsim



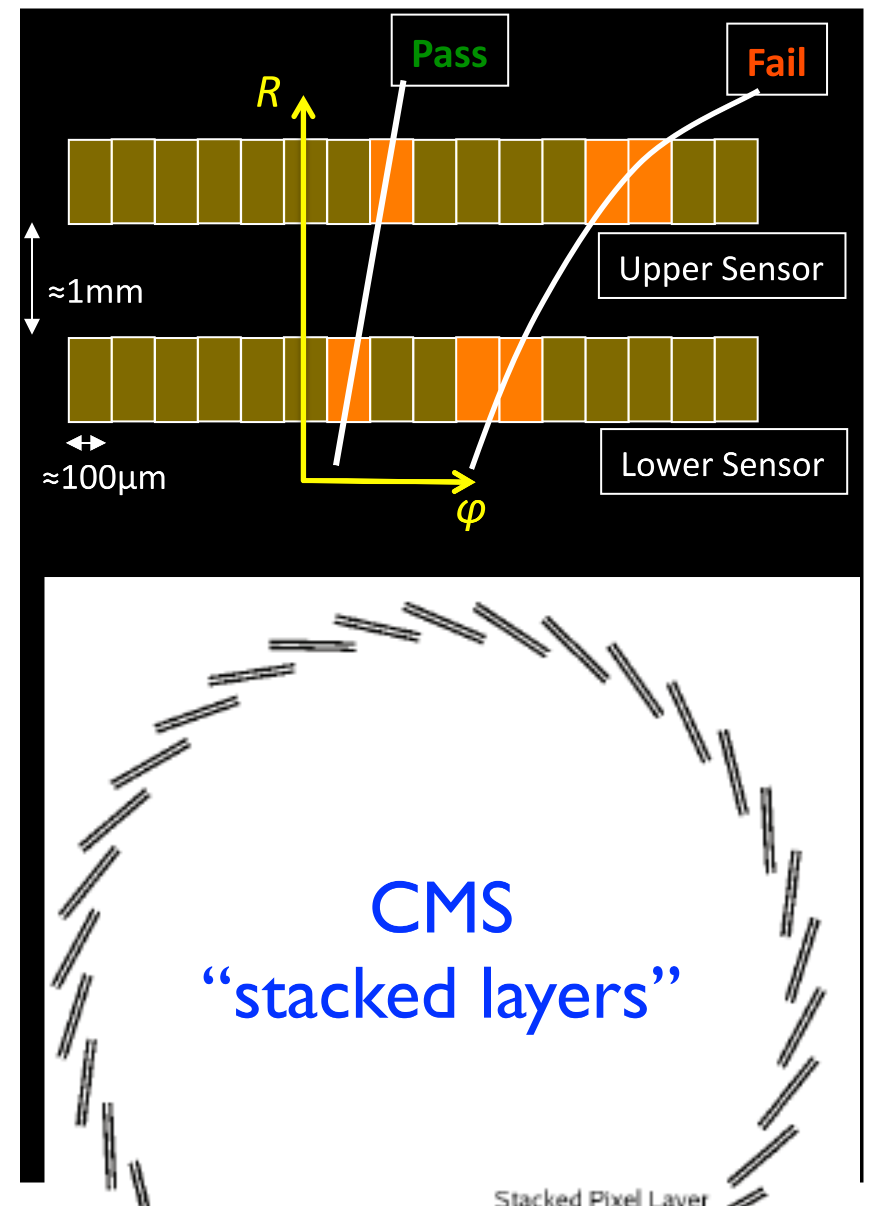
Summary of Ideas/Issues

Neither SiD nor SiD-CLIC is close; need to invent, simulate more realistic detector:

- Timing:
  - Model two resolutions; 5ns (~CLIC), 1ns (~CLIC++); each with some assumed power budget?
  - Develop models of detector material for each, given expected relative power consumptions.
- Spatial Correlations:
  - Back-to-back paired layers can select against random noise hits at cost of more power/material.
  - Need new tracking code to take full advantage of this configuration (try after timing exhausted)
- List of things to do and discuss further:
  - fix a bug found in readout thresholds. (yes... someone DID do work at this workshop!)
  - need to lower gamma, neutron simulation thresholds to get full background loads.
  - apply broad time cut to background before simulating? Requires agreement across detectors.
  - try other levers to eliminate noise hits and fake tracks. (e.g. cluster properties, track t_0 fitting)
  - develop apples/apples comparison with SiD/SiD-CLIC tracking (informs benchmarking efforts): repeating previous studies for a more massive detector a good start while we figure out how to streamline simulation with full backgrounds to begin looking at physics quantities.

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
- Has not checked been checked carefully but quick calculations indicate that TPC is a lost cause here by orders of magnitude.