Hits timing and double layer criteria for MARS muon collider background reduction in ILCRoot simulation (Si VXD and Tracker)

N. Terentiev*
(Carnegie Mellon U./Fermilab)

V. Di Benedetto, C. Gatto, A. Mazzacane
(University of Lecce, INFN Naples, Fermilab)

N. Mokhov, S. Striganov
(Fermilab)

MAP 2012 Winter Meeting
March 04 - 08, 2012
SLAC

Outline

- **Introduction**
- **Background hits rate in ILCRoot Si vertex and tracker detectors**
- **Update on timing for MARS background particles and ILCRoot hits (neutron contribution from previous BX)**
- **ILCRoot new release with double layer geometry**
- **IP muons and MARS background hits in new ILCRoot simulation and analysis**
- **Conclusions, plans**

Introduction

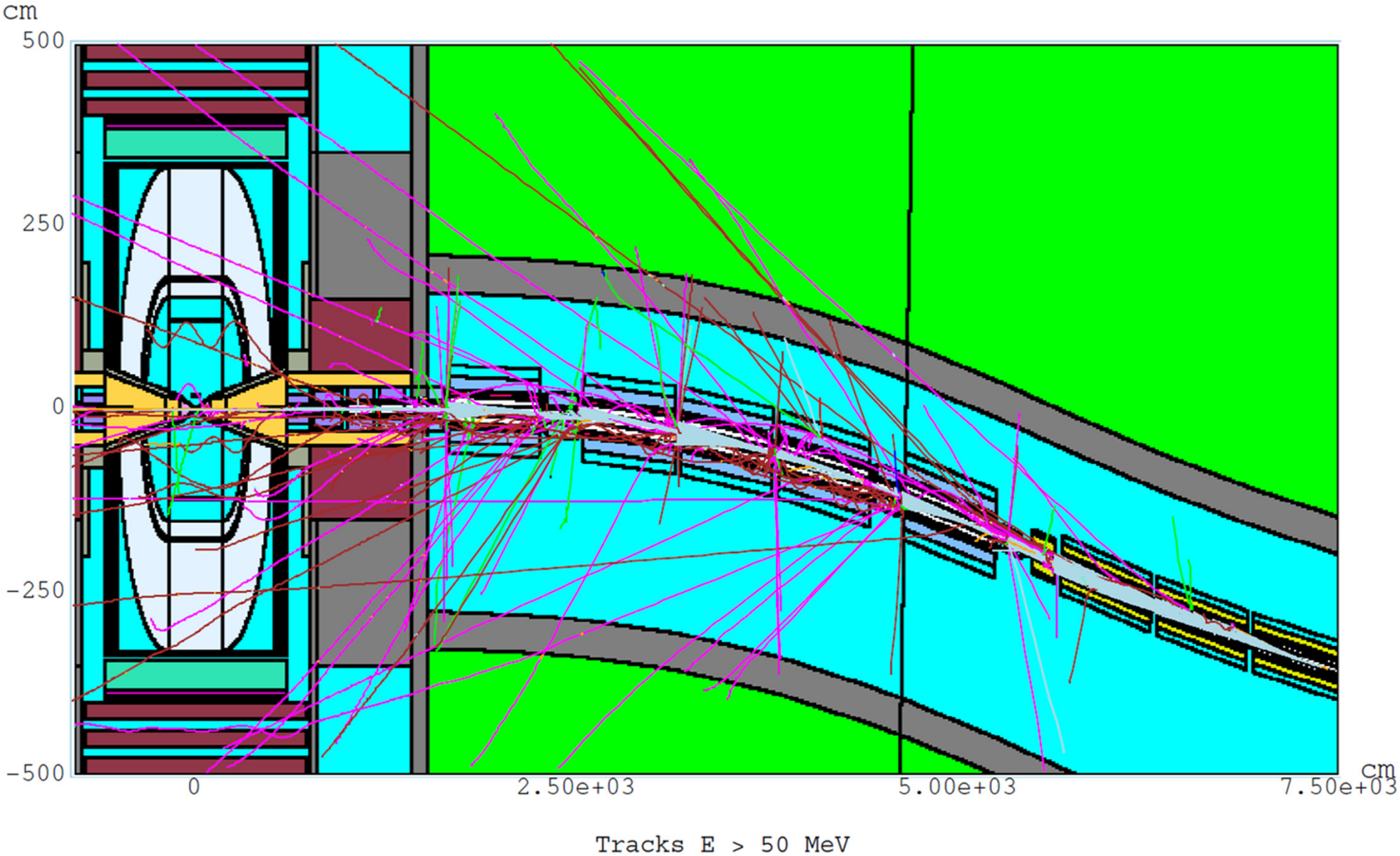
- **Working with MARS background simulation results for (750 + 750) GeV $\mu^+ \mu^-$ beams with $2*10^{12}$ μ/BX each**
  - http://www-ap.fnal.gov/~strigano/mumu/mixture/
  - Background yields/BX on 10^0 shielding nozzle surface and MARS thresholds

	γ	n	e^{+-}	p	π^{+-}	μ^{+-}
Yield	**1.77e+08**	**0.40e+08**	**1.03e+06**	**3.13e+04**	**1.54e+04**	**0.80e+04**
Ethr, MeV	**0.2**	**0.1**	**0.2**	**1.0**	**1.0**	**1.0**

- **All MARS statistics (weights included) was used as input for ILCRoot simulation of the Si vertex and tracker hits.**
  - Timing and hits rate results are based on previous ILCRoot_2.9.1 release simulation with GEANT4 (4.9.4.p01) – single Si layers, 100 μm
  - ILCRoot output files with hits were analyzed in standing alone code

Introduction

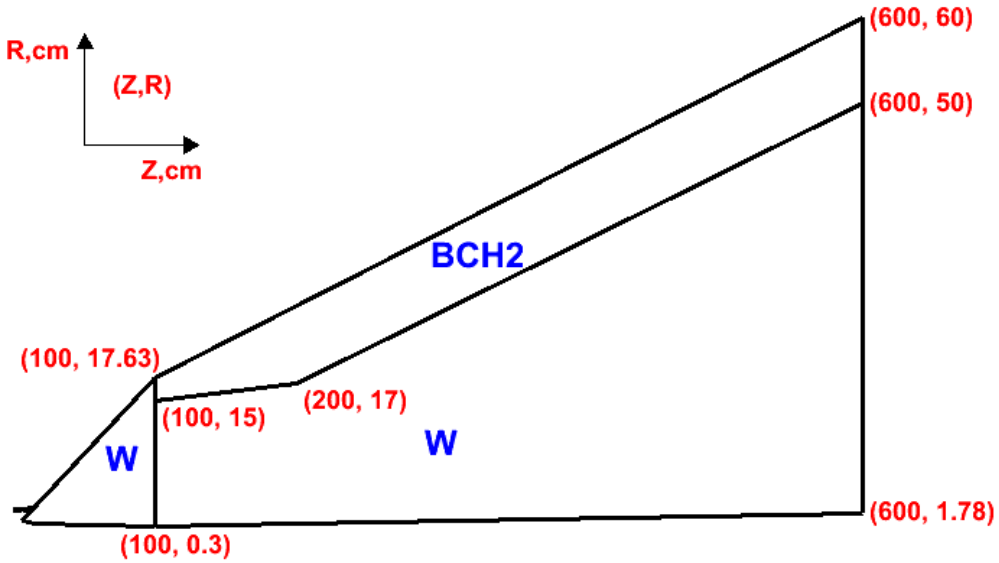
- **MARS background particle tracks in MC near the detector**



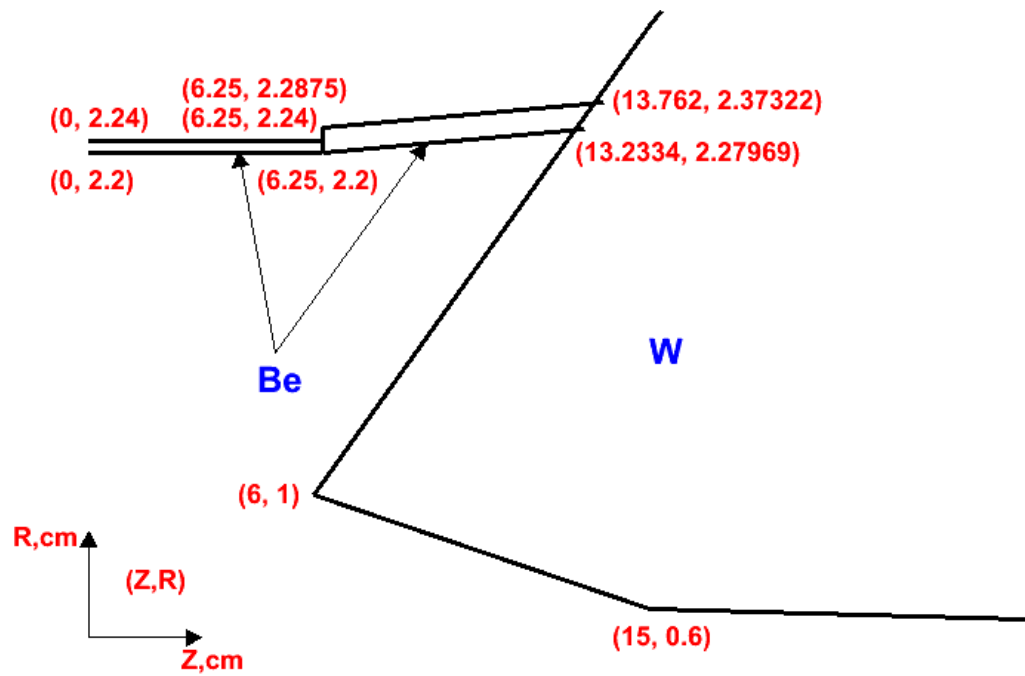
Introduction

- **10^0 nozzle geometry**

General (1/2 RZ) view



Zoom in beam pipe



W – tungsten

Be – beryllium

BCH2 – borated polyethylene

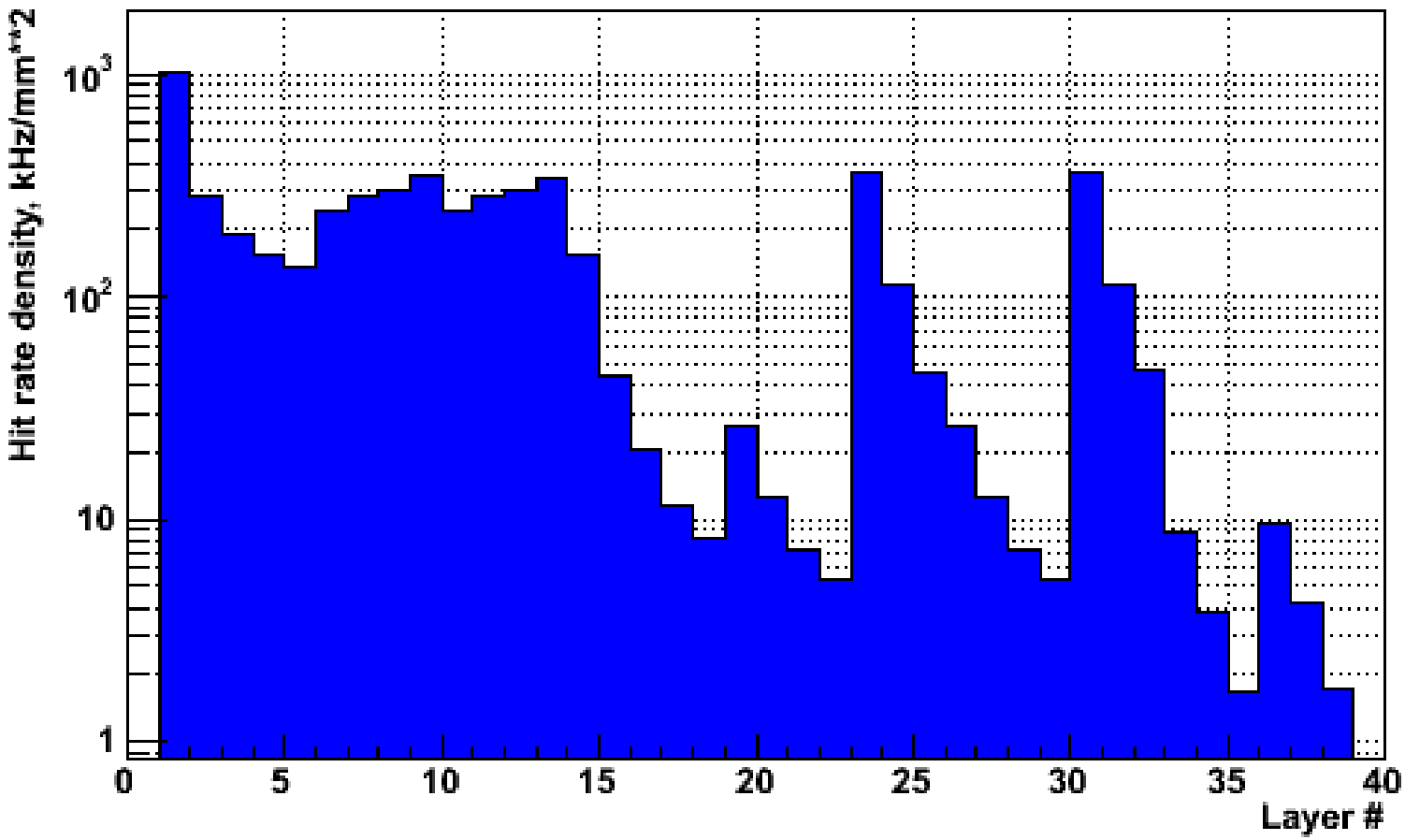
Background hits rate

- **Hits rate estimation is important for detector**
  - Electric power
  - Heat dissipation
  - Radiation hardness etc.
  - Timing and double layer criteria to reduce readout rate are useless if failed above

- **For the hits rate estimation**
  - 10 μs between BXs for μ+ μ- beams
  - Count one hit per track in given Si layer
  - No timing and double layer criteria cuts
  - Barrel layers are approximated by cylinders to calculate the rate density

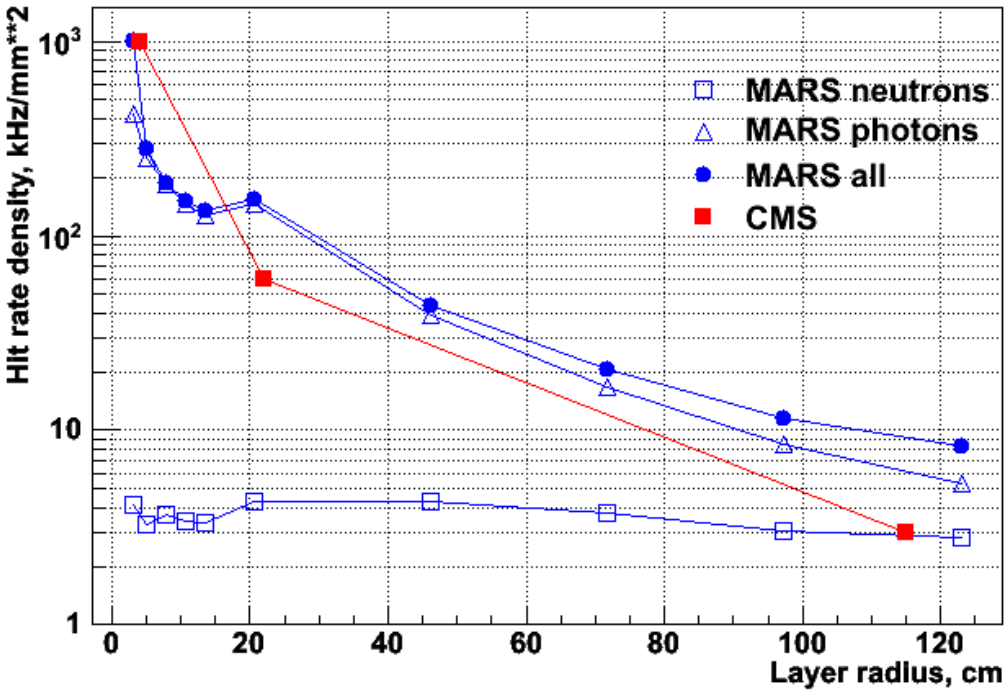
Background hits rate

- **Hit rate average density in layers**
  - VXD (layers 1 – 13), Tracker (layers 14 – 38), see backup slides
  - Maximum rate density in the first layer of VXD ~ 1 MHz/mm^2



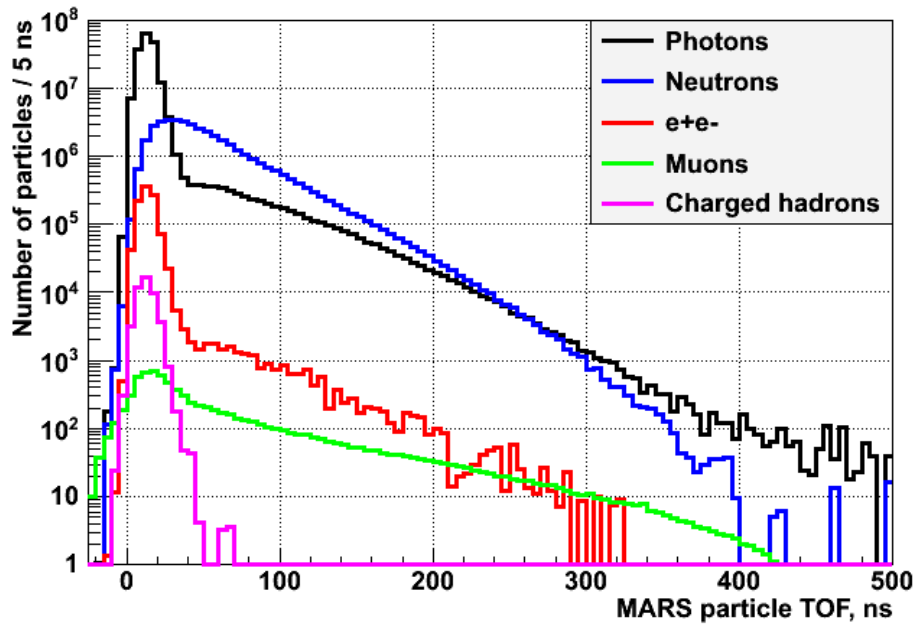
Background hits rate

- **Hit rate average density vs. radius in ILCRoot VXD and Tracker Barrels**
  - CMS data at the LHC designed luminosity of 10^{34} cm^{-2} s^{-1}, 7+7 TeV and 25 ns bunch crossing (from "The CERN Large Hadron Collider: Accelerator and Experiments", vol. 2, pp. 26-29, CERN 2009)
- **Expect higher rate in more realistic simulation. Currently:**
  - 100 μm Si single layers
  - Low material infrastructure (and no cooling)
  - New MARS results with lower thresholds are coming

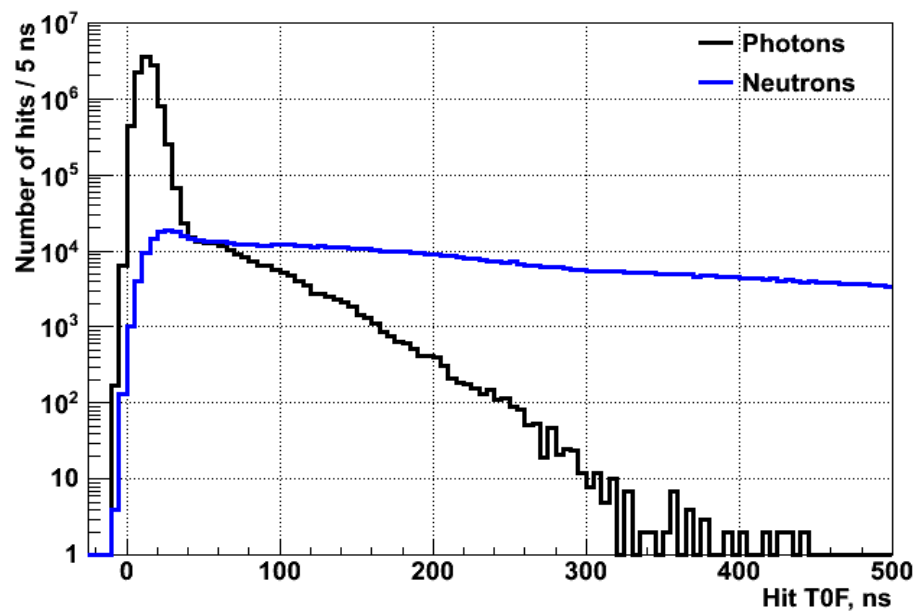


Timing for vertex and tracker detector hits

- **Timing for MARS background particles**
  - MARS background is within ~500 ns of TOF w.r.t. a bunch crossing (BX)

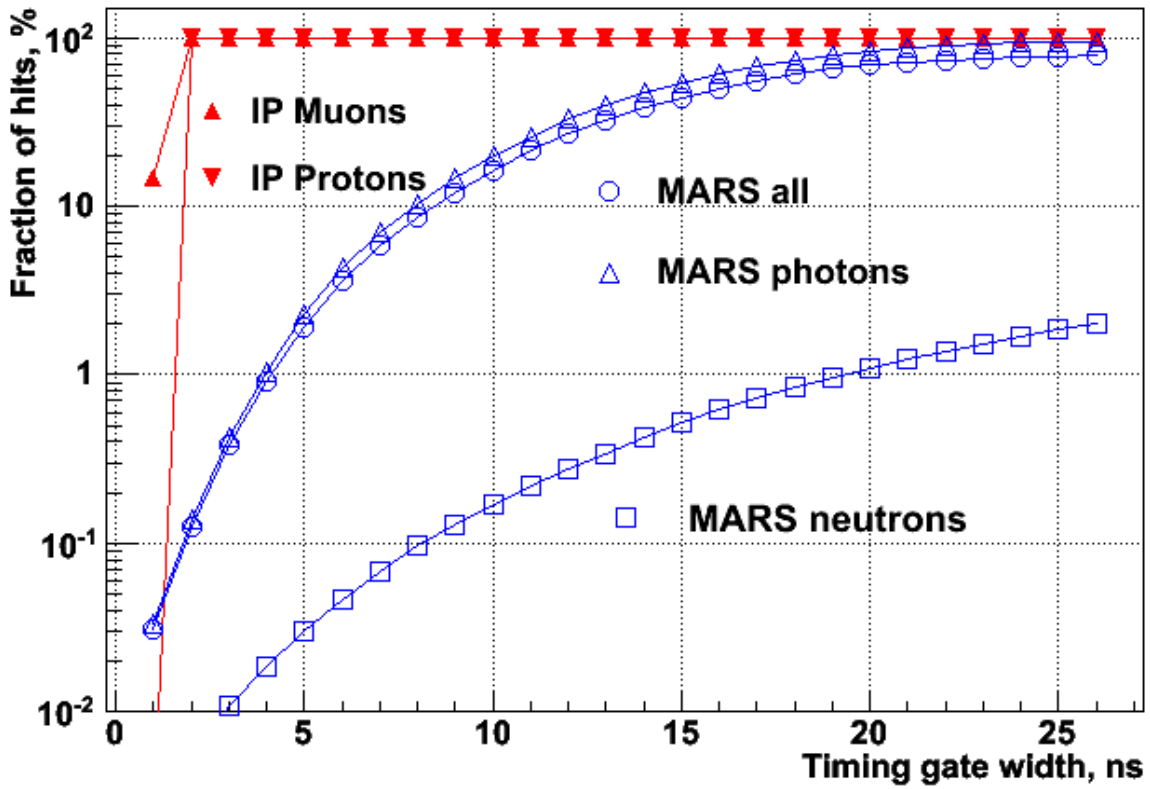


- **Timing of ILCRoot hits**
  - ILCRoot VXD and Tracker hits in the same interval except hits from neutrons
  - Neutron hits tail up to ~ ms due to "neutron gas"
  - Contribution of neutron hits from 10 μs apart previous BXs is small (a few %) in interval of 0 -150 ns, almost no impact on timing rejection



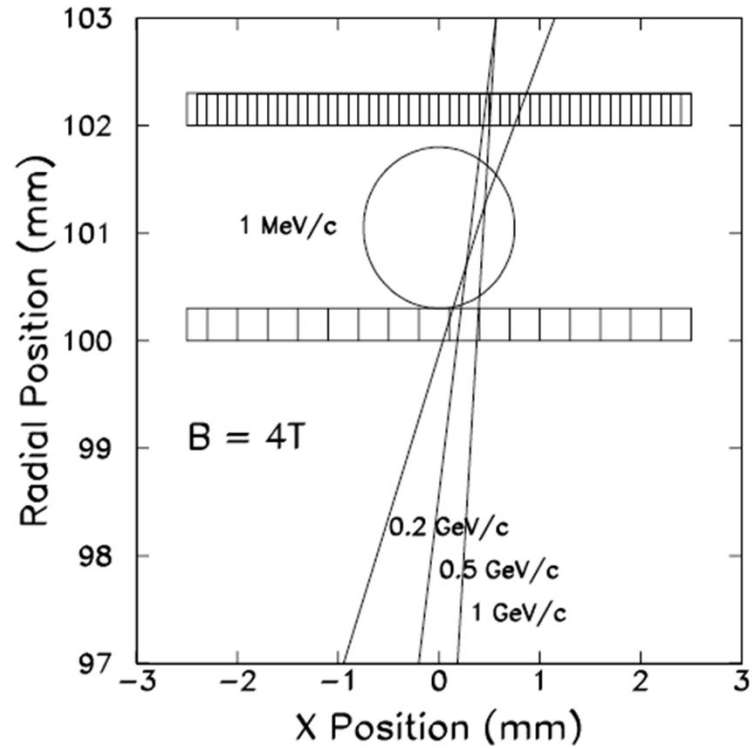
Timing for vertex and tracker detector hits

- **Timing remains the main rejection factor for background**
  - The hits from muon collider background particles can be suppressed in readout due to their significant time spread (mostly neutrons)
  - Neutron tail from previous BXs – expect almost no impact on timing rejection
  - With 3 ns gate a rejection factor ~260 for all MARS particles and photons and more than 1000 for neutrons (result and picture from MAP 2011)



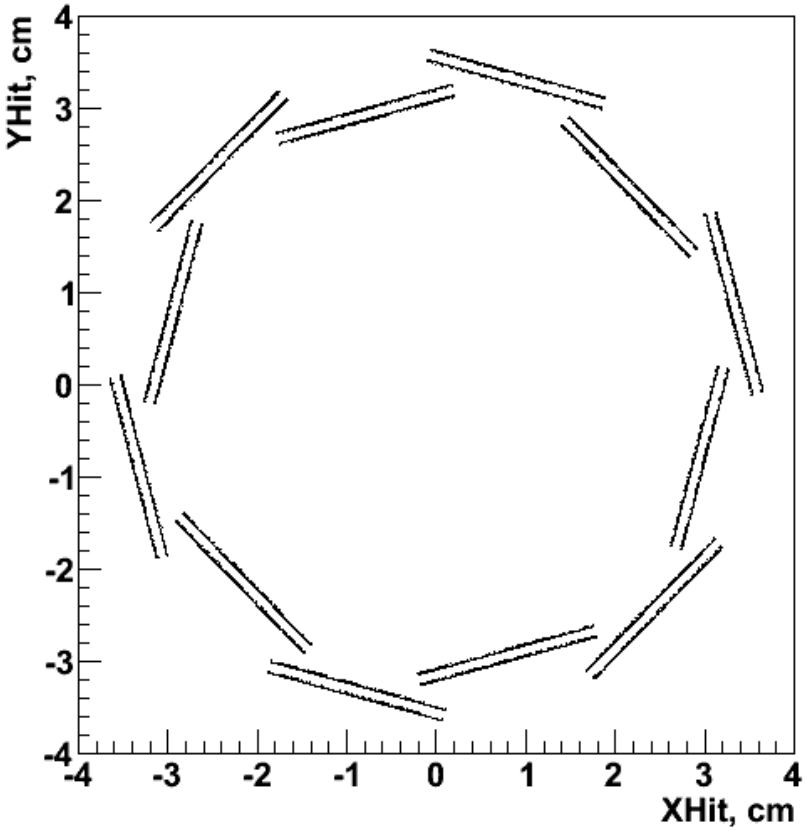
Double layer criterion

- **A stacked layer design to reduce random neutral background occupancy based on inter-layer correlations**
  - Suggested by S. Geer for the muon collider in 1996
  - A single layer replaced with two layers being 1-2 mm apart
  - Soft MeV tracks from background hit in one layer do not reach the second layer (B=4T)
  - IP physics charged track makes hits in both layers
  - Readout takes AND of appropriate pixel pairs in both layers suppressing background hits
- **Fermilab is developing similar technology for the CMS upgrade,** see R. Lipton, "New Detectors for Muon Collider", http://conferences.fnal.gov/muon11



New ILCRoot release with double layer geometry

- **A new version of ILCRoot was released recently by Vito Di Benedetto (INFN-Lecce)**
  - Implementation of double layer geometry (two sub-layers in each layer) and magnetic field scaling in the Si Vertex and Tracker detectors with runtime controlled parameters
  - Example – X and Y of IP muon hits in VXD Layer 1 with sub-layers 1 mm apart



New ILCRoot simulation with new geometry

- **A new ILCRoot simulation for IP muons and MARS muon collider background was done with the following four geometry sets:**
  - 1 mm and 2 mm sub-layer space at 3.5 T and 7 T magnetic field, each Si sub-layer has thickness of 200 μm
  - Only VXD and Tracker
- **IP μ+ and μ- simulation to define cuts for double layer criteria**
  - At P = 0.2 - 100 GeV/c
  - IP smearing in Z (gauss σ = 1 cm) and X,Y (gauss σ = 6 μm) according to the current design of 750+750 GeV muon collider
  - Total 20,000 muons
- **Three types of all statistics MARS background (all particles, photons and neutrons) to implement timing and double layer cuts**
- **Analysis is in progress**

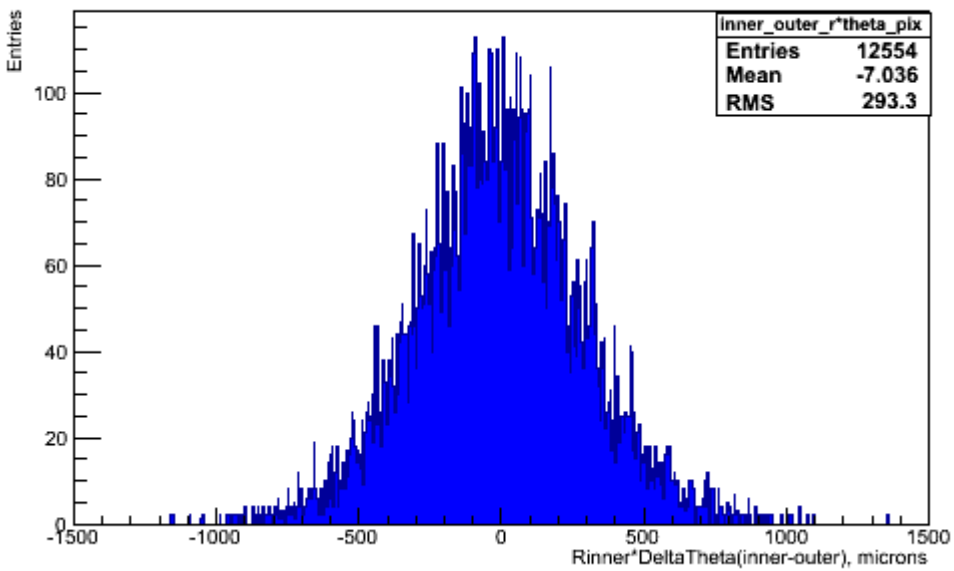
Analysis of IP muon hits

- **Use R*Delta(Phi) and R*Delta(Theta) variables for hits in both sub-layers of barrel layers**
  - In R, Phi and Theta calculations set IP to be at XYZ (0,0,0)
- **Cut on Rxy * Delta(Phi)**
  - Rxy is the radius of the hit position in XY in inner sub-layer
    Delta(Phi) = Phi(inner-outer) for azimuthal angles of the hits in inner and outer sub-layers
  - Rxy * Delta(Phi) distribution depends on muon Pt, magnetic field, layer radius and distance between sub-layers
- **Cut on Rxyz * Delta(Theta)**
  - Rxyz is the radius of the hit position in XYZ in inner sub-layer
    Delta(Theta) = Theta(inner-outer) for polar angles of the hits in inner and outer sub-layers
  - Rxyz * Delta(Theta) depends on Z smearing of IP, layer radius and distance between sub-layers
- **Tune the cuts to provide high efficiency for IP muons with small Pt and use them in double layer criteria to reduce background hits in readout (see backup slide)**

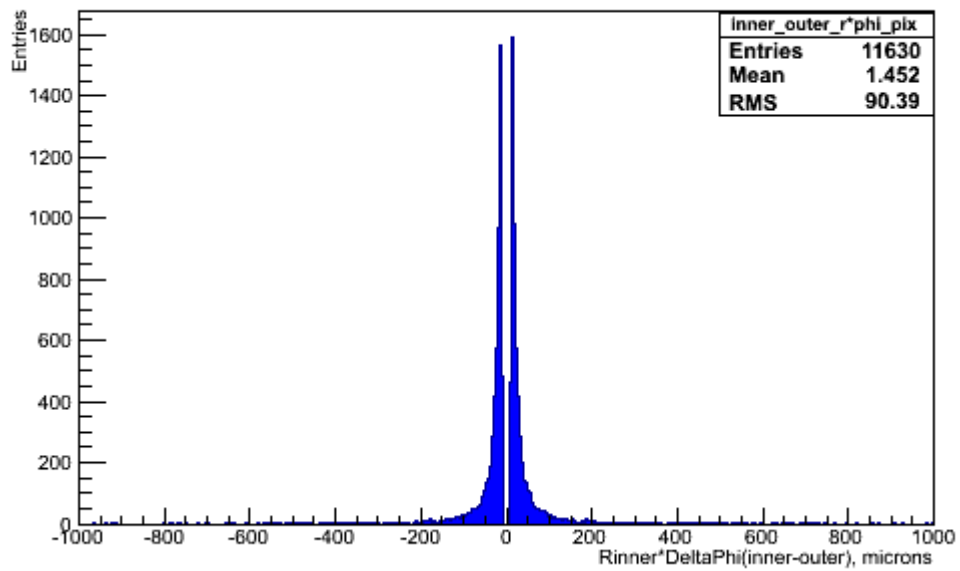
Analysis of IP muon hits

- **Rxyz * Delta(Theta) and Rxy * Delta(Phi) in geometry with 1 mm distance between sub-layers and 3.5T magnetic field**

Rxyz * Delta(Theta) in most inner layer of VXD barrel



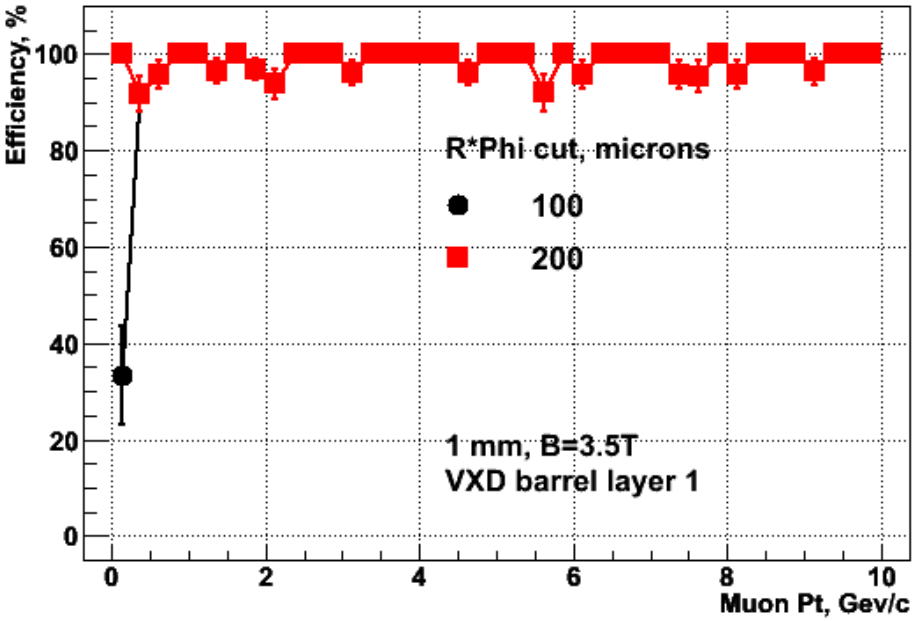
Rxy*Delta(Phi) in most outer layer of Tracker barrel



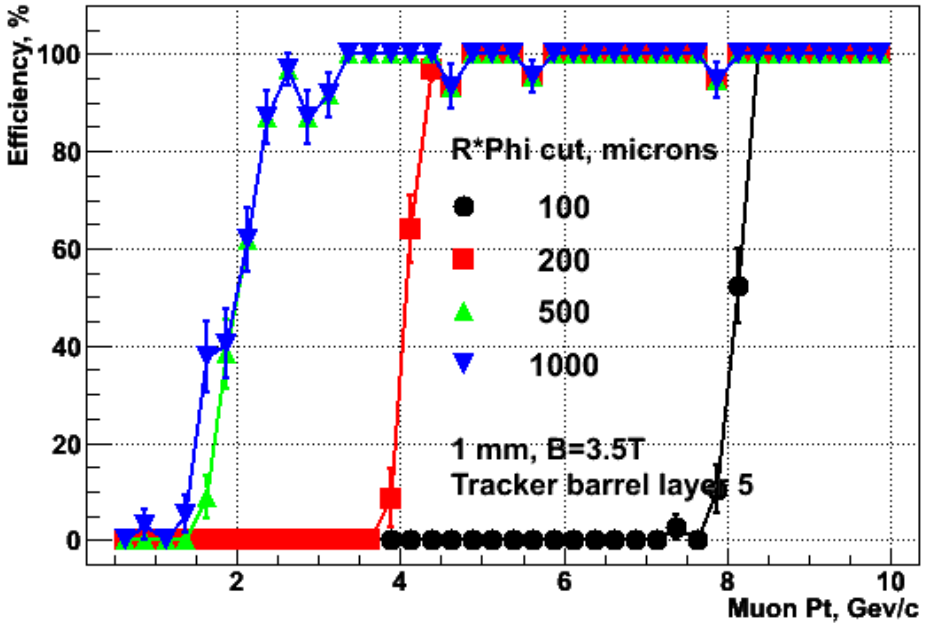
Analysis of IP muon hits

- **Efficiency of Rxy * Delta(Phi) cut vs. Pt in geometry with 1 mm distance between sub-layers and 3.5T magnetic field**

In most inner layer of VXD barrel



In most outer layer of Tracker barrel



Irregularities on plateau are due to 98% efficient cut on Rxyz*Delta(Theta)

Timing and double layer criteria for MARS background

- **In geometry with 1 mm distance between sub-layers and 3.5T magnetic field, "pixels" 200*200 μm, neutrons + photons**

Layer **# of pixels** **R, cm**	**VXD Layer 1** **819000** **3**	**Tracker Layer 1** **28,000,000** **20**	**Tracker Layer 5** **832,500,000** **125**
# pixels with hits (inner + outer)/2	~122,000	~1,400,000	~2,644,000
Occupancy before timing cut	~15%	~5%	~0.3%
Occupancy after **10 ns** timing cut	~3.4%	~1%	~0.04%
R*Delta(Theta) cut R*Delta(Phi) cut	715 μm 200 μm	150 μm 500 μm	150 μm 500 μm
Occupancy after timing, R*Delta(Theta) and R*Delta(Phi) cuts	**~2%**	**~0.1%**	**~ 0.001%**

Timing and double layer criteria for MARS background

- **In geometry with 1 mm distance between sub-layers and 3.5T magnetic field, "pixels" 200*200 μm, all MARS particles**

Layer **# of pixels** **R, cm**	**VXD Layer 1** **819000** **3**	**Tracker Layer 1** **28,000,000** **20**	**Tracker Layer 5** **832,500,000** **125**
# pixels with hits (inner + outer)/2	~215,000	~1,420,000	~2,661,000
Occupancy before timing cut	~26%	~5%	~0.3%
Occupancy after **10 ns** timing cut	~6%	~1%	~0.04%
R*Delta(Theta) cut R*Delta(Phi) cut	715 μm 200 μm	150 μm 500 μm	150 μm 500 μm
Occupancy after timing, R*Delta(Theta) and R*Delta(Phi) cuts	**~4%**	**~0.1%**	**~ 0.001%**

Conclusion

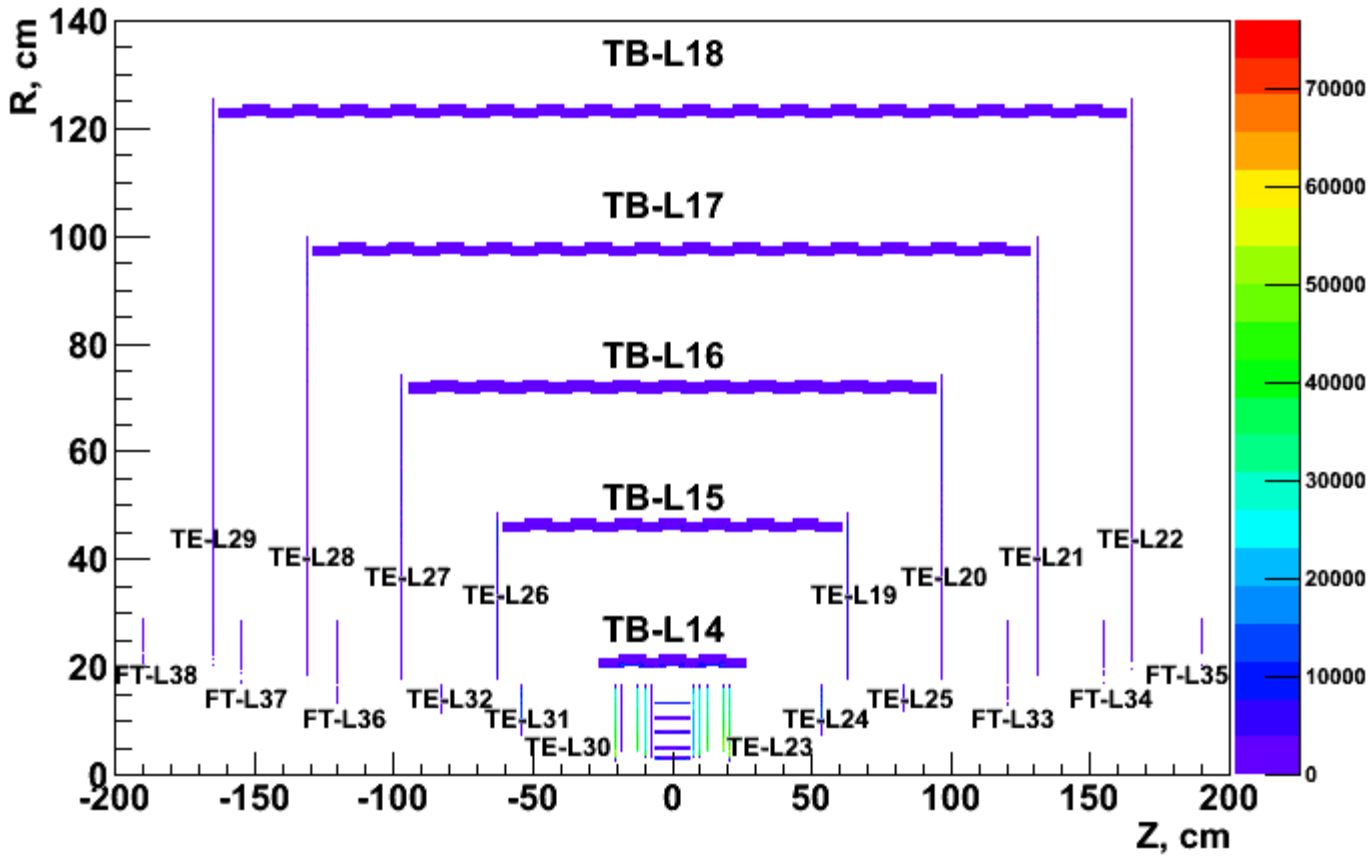
- **First implementation of combined timing and double layer criteria in simulation and analysis of ILCRoot hits produced by MARS muon collider background particles**
- **Preliminary results for geometry with 1mm double layer space and magnetic field of 3.5T in ILCRoot VXD and Tracker barrels with 200*200 μm "pixels" and 10 ns timing cut:**
  - ~4% occupancy in first layer of VXD for cuts R*Delta(Theta)~700μm and R*Delta(Phi)~200μm (a half comes from charged background particles)
  - << 1% occupancy in Tracker layers for cuts R*Delta(Theta)~150μm and R*Delta(Phi)~500μm (mostly neutral background)
- **Timing and double layer criteria requirements for front-end**
  - Fast to handle precise timing of ~ns
  - Double layer criteria to be used AFTER timing criteria
  - Smart, e.g. capable of finding coordinates of 2D position of hit (cluster) in sub-layers and making IP oriented selection of hits (patterns ?) for readout

Plans

- **Using ILCRoot version with double layer geometry and magnetic field scaling**
  - Continue hits timing and double layer rejection criteria study for current muon collider background MARS data at different sub-layer distances and magnetic fields
  - Repeat simulation and analysis for coming new MARS data at 1.5 TeV and 3 TeV
- **Comparison of ILCRoot results with simulation in LCSIM**

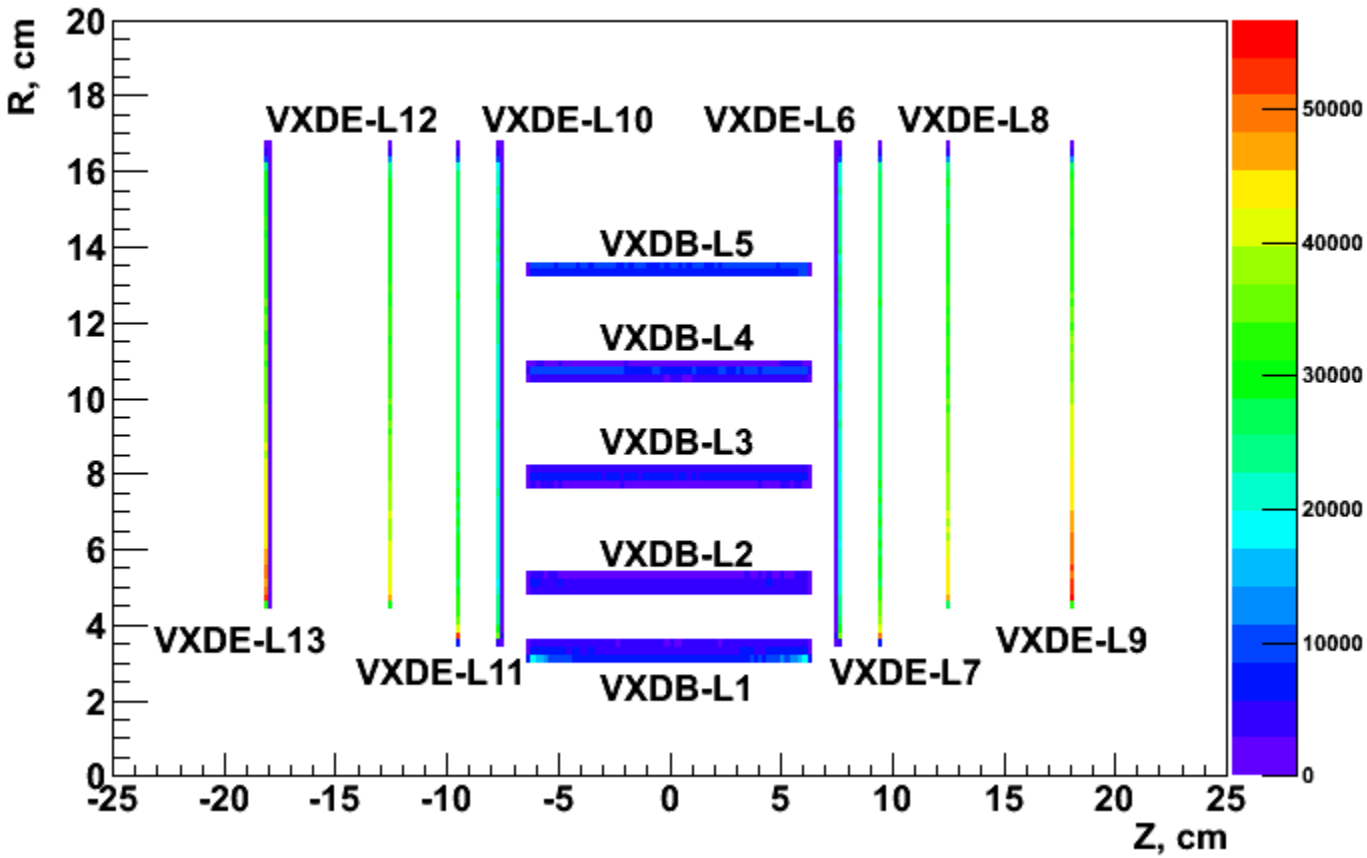
Backup slides

- **Hit R vs. Z for ILCRoot tracker detector layers**
  - TB – Tracker Barrel, TE – Tracker Endcap, FT – Forward Tracker



Backup slides

- **Hit R vs. Z for ILCRoot vertex detector (VXD) layers**
  - VXDB – VXD Barrel, VXDE – VXD Endcap



Backup slides

- **Choice of appropriate pixel pairs in both sub-layers for AND readout of background hits**
  - Use IP point with (0,0,0) coordinates and hit position in the inner sub-layer to find the direction (Phi, Theta)
  - Accept the hit in outer sub-layer if it lies in vicinity of this direction within the distance limited by R*Delta(Phi) and R*Delta(Theta) cuts
  - Readout "pixels" with these hits in both sub-layers for tracking
  - The R*Delta(Phi) and R*Delta(Theta) cuts are defined in analysis of IP muon hits (X, Y and Z smearing of IP included) as cuts providing the high efficiency of IP muons detection at low Pt
- **In this study the "pixel" size of 200*200 μm corresponds (approximately) to the size of cluster of pixels used in ILCROOT tracking algorithms**