

# ***Simulation of Si Vertex and Tracker detectors hits response to machine background in the 1.5 TeV Muon Collider***

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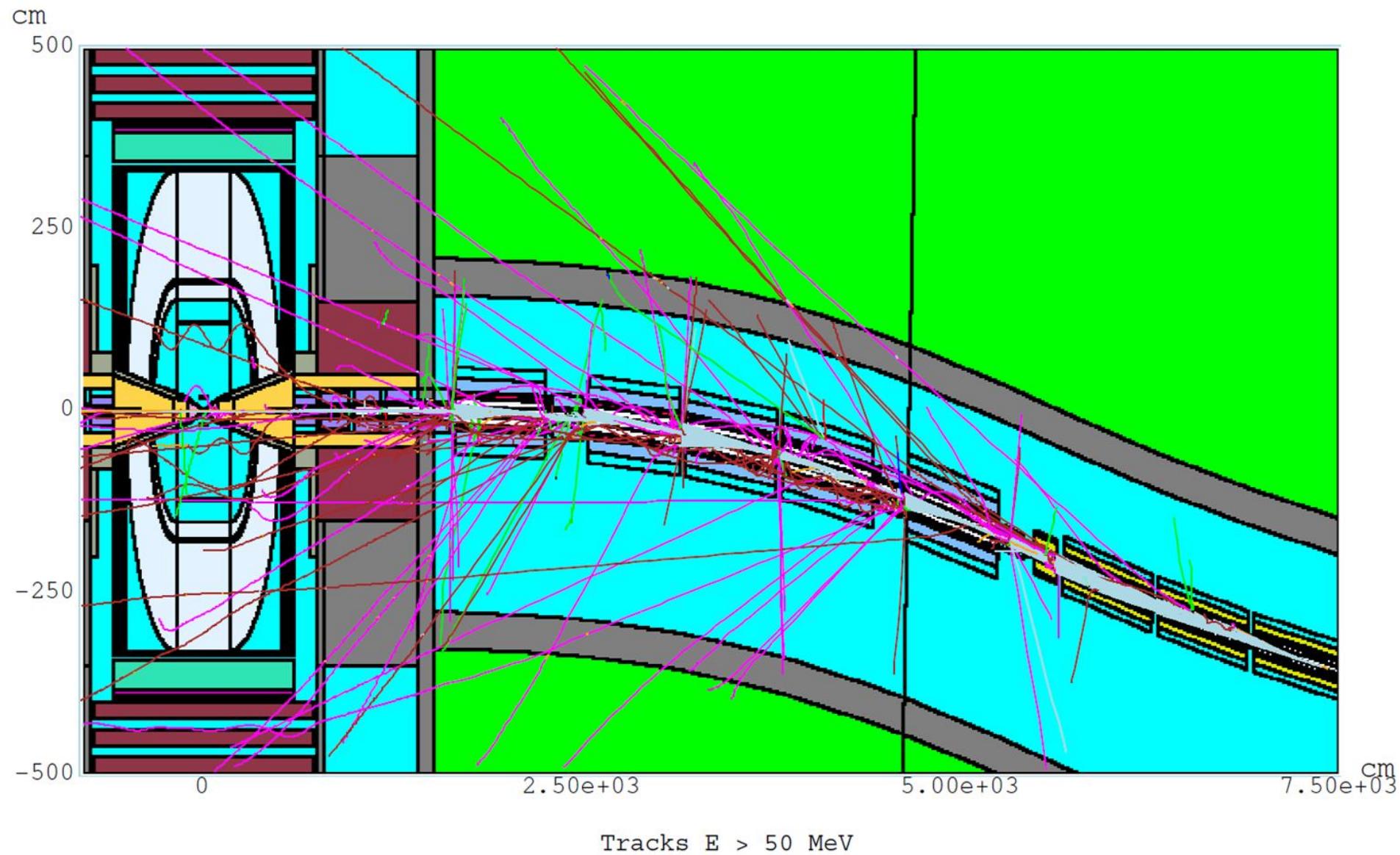
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(Fermilab)

MAP 2013 Collaboration Meeting  
Fermilab  
June 19-22, 2013

- **MARS simulation data for 1.5 TeV Muon Collider background**
- **ILCRoot simulation of the Si VXD and Tracker hits with MARS data and IP muons as input**
  - Timing based background rejection results
- **VXD and Tracker hits in SLIC simulation**
  - ILCRoot vs. SLIC (MARS background hit timing and energy deposition in VXD and Tracker)
- **Conclusion**

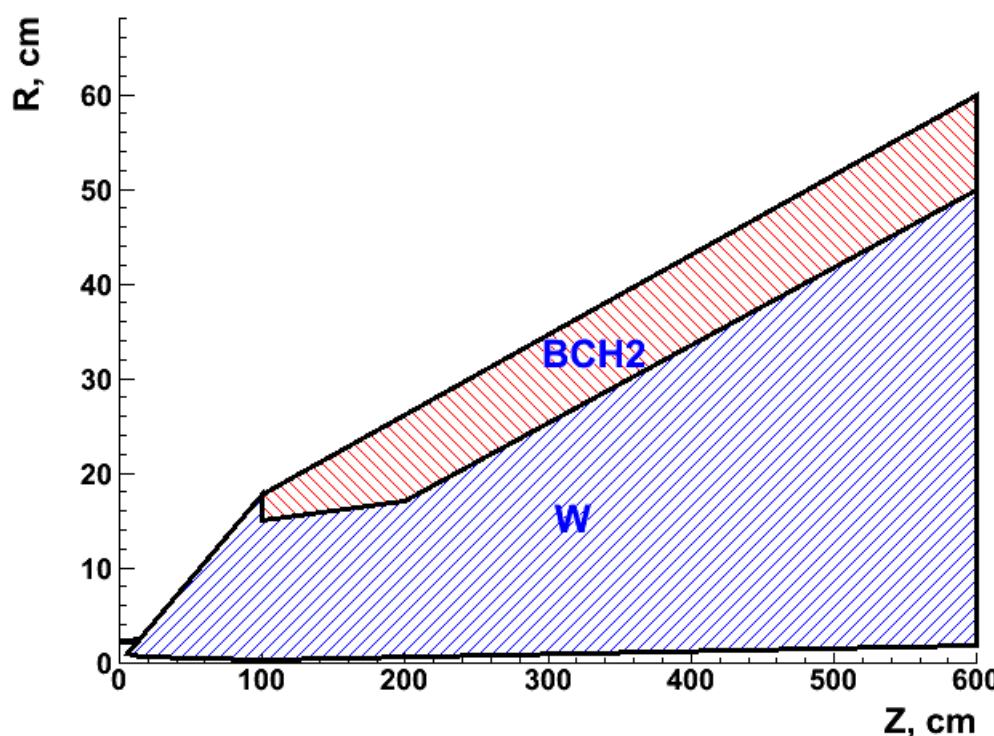
- **The major source of the detector background in Muon Collider – decays of the beam muons**
  - for two 750 GeV  $\mu^+$  and  $\mu^-$  beams, each  $2 \times 10^{12}$  muons/BX there are  $\sim 1.28 \times 10^{10}$  decays/(m\*sec)
  - the decay  $e^+$  and  $e^-$  with synchrotron photons produce EM showers in the collider components -> generate intense fluxes of low energy photons, neutrons,  $e^+$  and  $e^-$ , hadrons and muons
- **Recent extensive studies** (N. Mokhov et al, Fermilab) **show that the background can be reduced by three orders of magnitude for 1.5 TeV Muon Collider**
  - simulation was done with MARS15 framework
  - it required consistent design of the collider lattice and magnets
  - use of the  $10^0$  shielding nozzle in the detector

- **MARS background particle tracks near the detector in the 1.5 TeV Muon Collider (yellow – shielding nozzle)**



- **$10^0$  shielding nozzle geometry for 1.5 TeV Muon Collider**

General (1/2 RZ) view

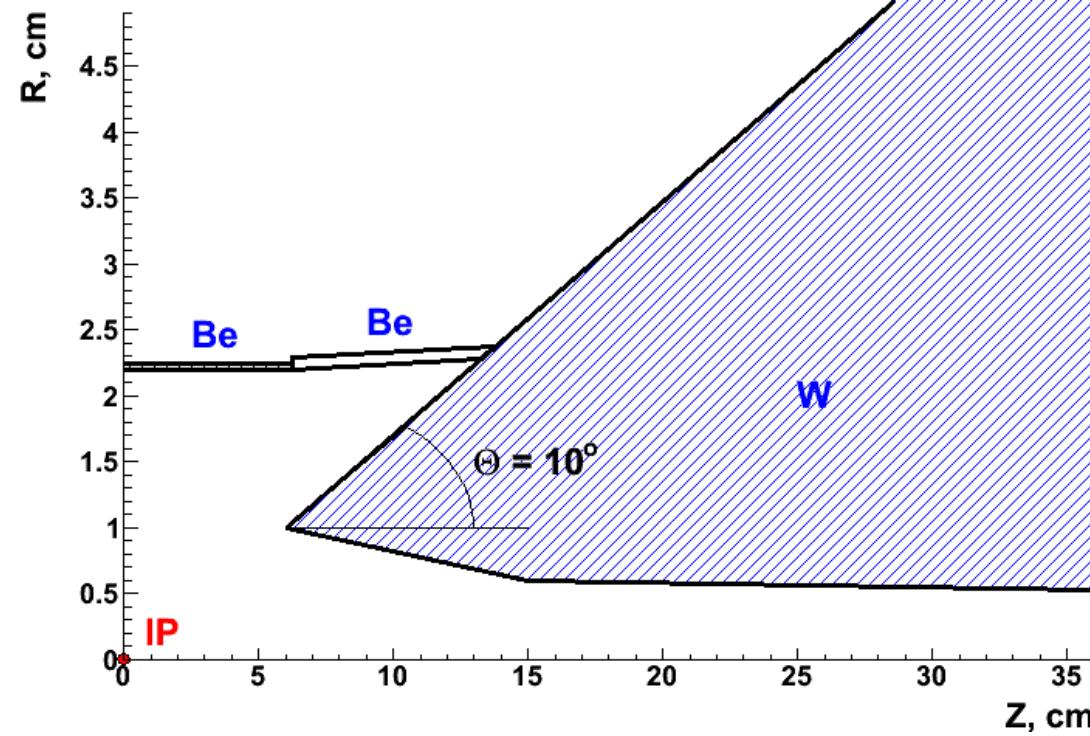


**W** – tungsten

**Be** – beryllium

**BCH2** – borated polyethylene

Zoom in beam pipe



- **Working with MARS background simulation results for 750 + 750 GeV  $\mu^+ \mu^-$  beams with  $2 \times 10^{12} \mu/\text{BX}$  each**
  - <http://www-ap.fnal.gov/~strigano/mumu/mixture/>
  - background yields/BX on  $10^0$  shielding nozzle surface and MARS thresholds (**2.18e+08 total yield/BX**, weights included)

	$\gamma$	n	$e^{+-}$	p	$\pi^{+-}$	$\mu^{+-}$
<b>Yield</b>	<b>1.77e+08</b>	<b>0.40e+08</b>	<b>1.03e+06</b>	<b>3.13e+04</b>	<b>1.54e+04</b>	<b>0.80e+04</b>
<b><math>E_{\text{thr}}</math>, MeV</b>	<b>0.2*)</b>	<b>0.1**)</b>	<b>0.2</b>	<b>1.0</b>	<b>1.0</b>	<b>1.0</b>

\*) lowest limit available in latest MARS15 code is now 0.001 MeV

\*\*) MARS code has  $E_{\text{thr}} = 1.0 \text{e-3 eV}$  for neutrons,  
currently 0.1 MeV threshold was chosen for muon collider background simulation

- **All MARS statistics (weights included) was used as input for ILCRoot simulation of the Si VXD and Tracker hits**
  - particles with weight N were smeared azimuthally to N particles (with preserved P and Pt)

- The **ILCRoot - software Infrastructure for Large Colliders based on ROOT and Alice's Aliroot with add-ons for Muon Collider studies** (see backup slides for details)
- **Available at Fermilab** (maintained by V. Di Benedetto)
  - presented results are based on ILCrootMuXDetV3 version
  - GEANT4 v9.5.1 (+ neutron timing patch) and ROOT v5.32.03
  - ILC SiD detector based geometry
  - implementation of double layer geometry in the Si Vertex and Tracker detectors + scalable magnetic field
  - QGSP\_BERT\_HP physics list for better neutron transport simulation

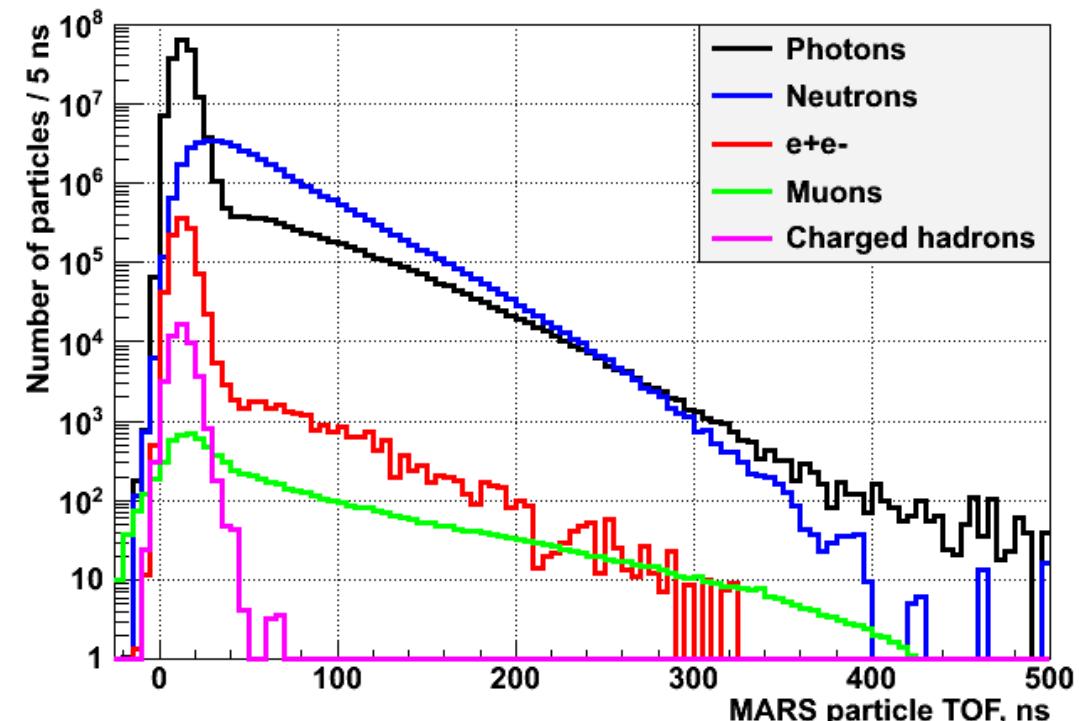
- **ILCRoot new release(ILCrootMuCv4)**
  - GEANT4 v9.6.01 and ROOT v5.34.05
  - runtime switch between single and dual layer geometry (since ILCrootMuXDetV3.1), runtime geometry parameters of sub detectors
  - detailed algorithms for light propagation and front-end electronics in the ADRIANO Dual-Readout calorimeter
  - will use for 1.5 TeV Muon Collider MARS background simulation in single layer geometry similar to SLIC with goal to compare with SLIC hits (now in progress, V. Di Benedetto)
- **Ongoing studies of a Heavy Higgs resonance with full beam background simulation for 1.5 TeV Muon Collider**  
(A. Mazzacane, V. Di Benedetto)

- **ILCRoot hits simulation for MARS background and IP muons at different geometry settings - completed**
  - only VXD and Tracker hits, the rest of detector as material (includes calorimeters, beam pipe,  $10^0$  shielding cone etc. – full layout)
  - the hits were simulated in four geometries for VXD and Tracker double layers
    - **200  $\mu$  thick Si sub-layer, 1 mm and 2 mm space between sub-layers**
    - **3.5 T and 7 T magnetic fields**

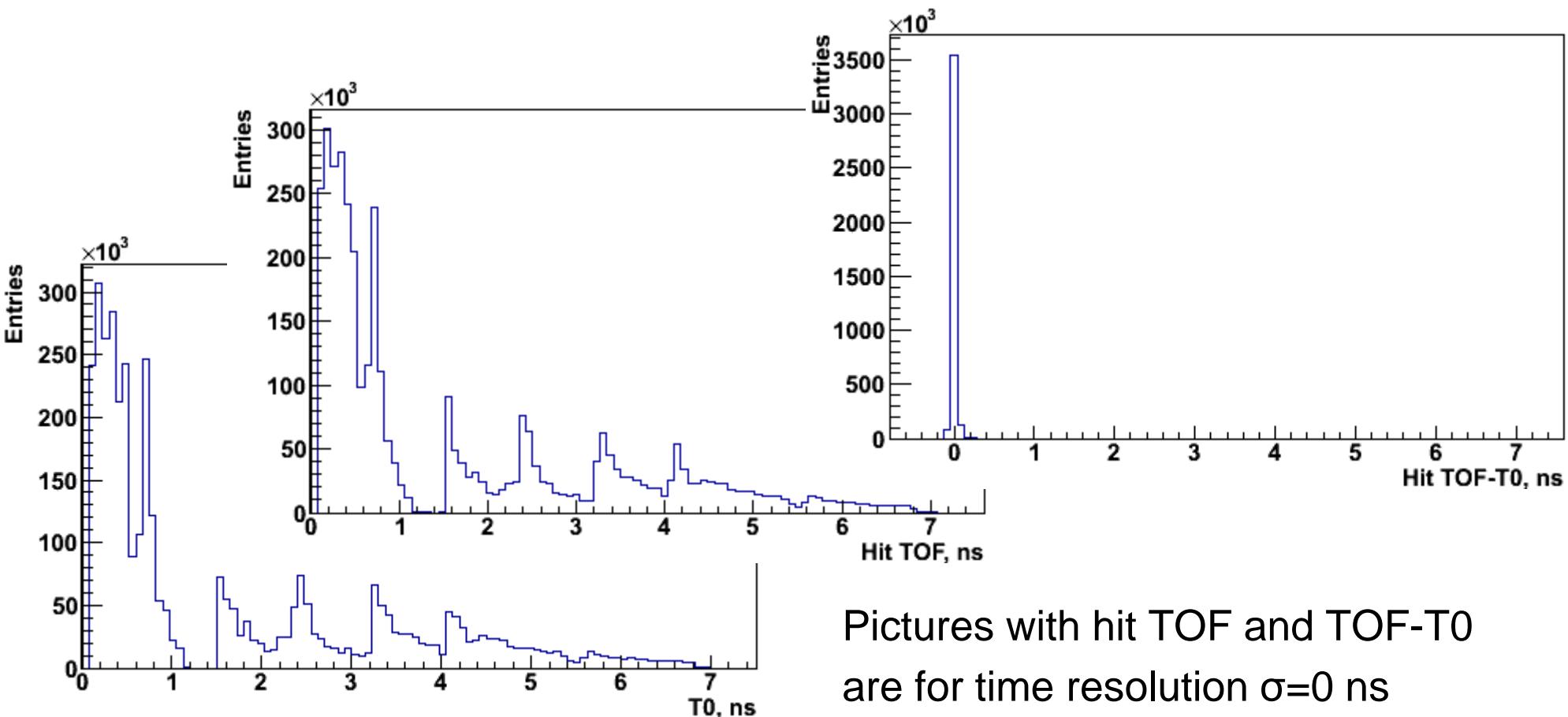
- **ILCRoot hits simulation for MARS background and IP muons in different geometry settings - completed**
  - IP smearing in  $Z_V$  (Gaussian  $\sigma = 1 \text{ cm}$ ) and  $X_V, Y_V$  (Gaussian  $\sigma = 6 \mu$ ) for  $\mu^+$  and  $\mu^-$  having flat  $P = 0.2 - 100 \text{ GeV}/c$  distribution
  - the goal is to study criteria for MARS background hit rejection
    - **using timing** (done for geometry set with two  $200 \mu$  thick Si sub-layers 1 mm apart, 3.5T magnetic field and hit time resolution in analysis for Gaussian  $\sigma=0.0, 0.2, 0.5$  and  $1.0 \text{ ns}$ )
    - **double layer criteria vs. different geometries** (in progress)
    - **energy deposition of the track in the Si sensitive volume** (in progress)

- **Timing for MARS background particles**

- time of flight (TOF) of MARS background particles (with respect to BX) is given on the detector side surface of the shielding cone
- most of the background particles are out of time of IP particles due to their spread in energy spectrum, large Z-distances of the point of origin from IP point and longer than beam  $\mu^-$  trajectories
- suggests to use the narrow timing cut which preserves hits from IP particles and reduces the volume of readout background



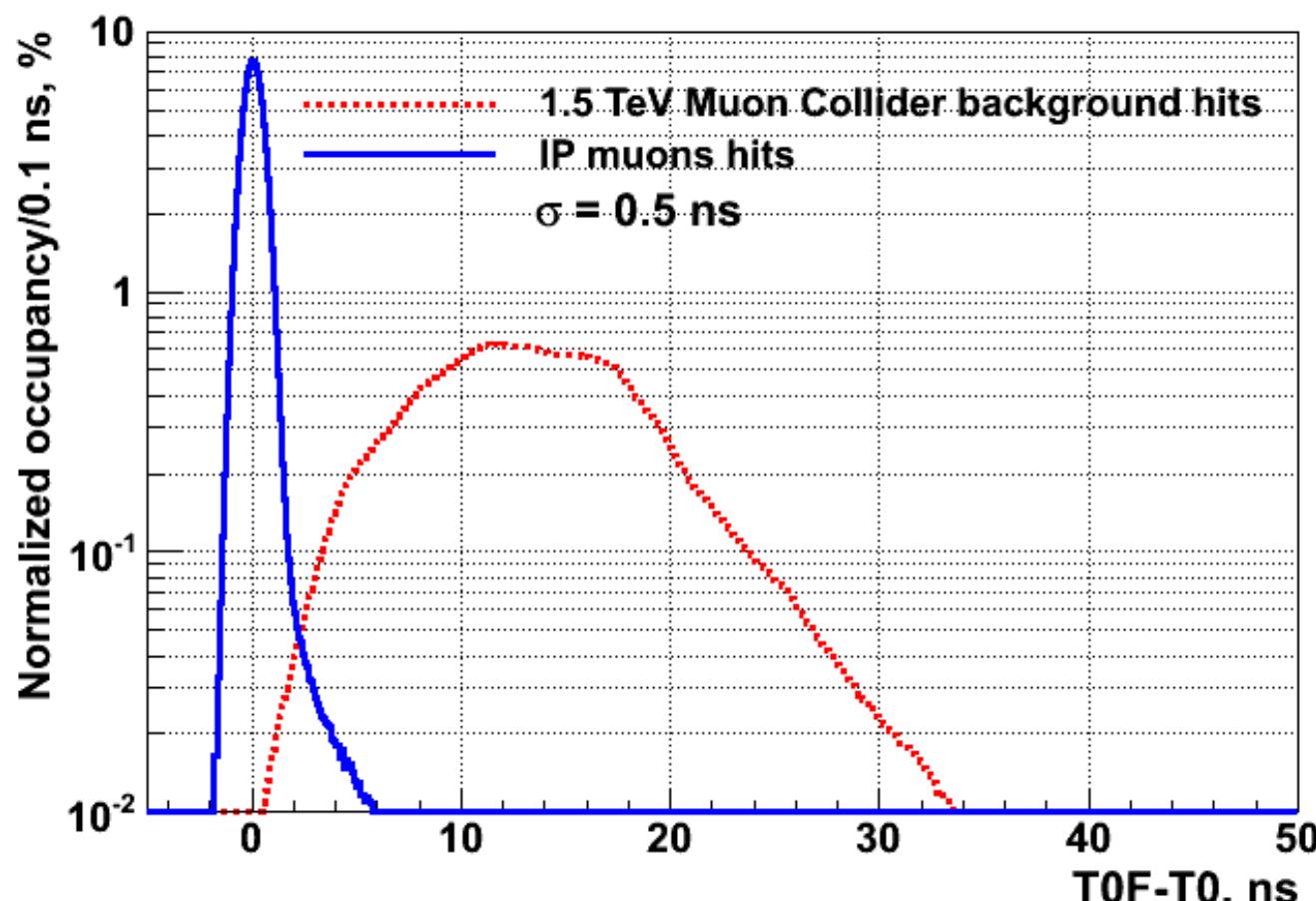
- **Timing of ILCRoot hits for IP and MARS background particles**
  - in analysis use instead TOF-T0 where T0 – time of flight of IP photon from interaction point IP ( $X=0, Y=0, Z=0$ ) to the point with IP muon or MARS background particle hit coordinates
  - this compensates the different TOF for IP particles making hits in different layers of VXD and Tracker at different R and Z coordinates of the hit



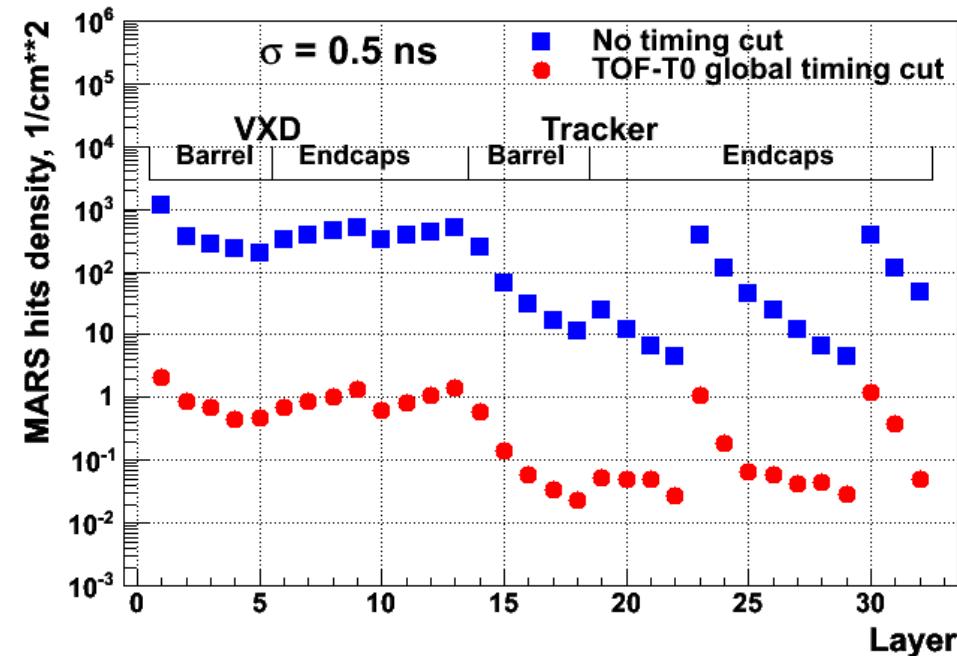
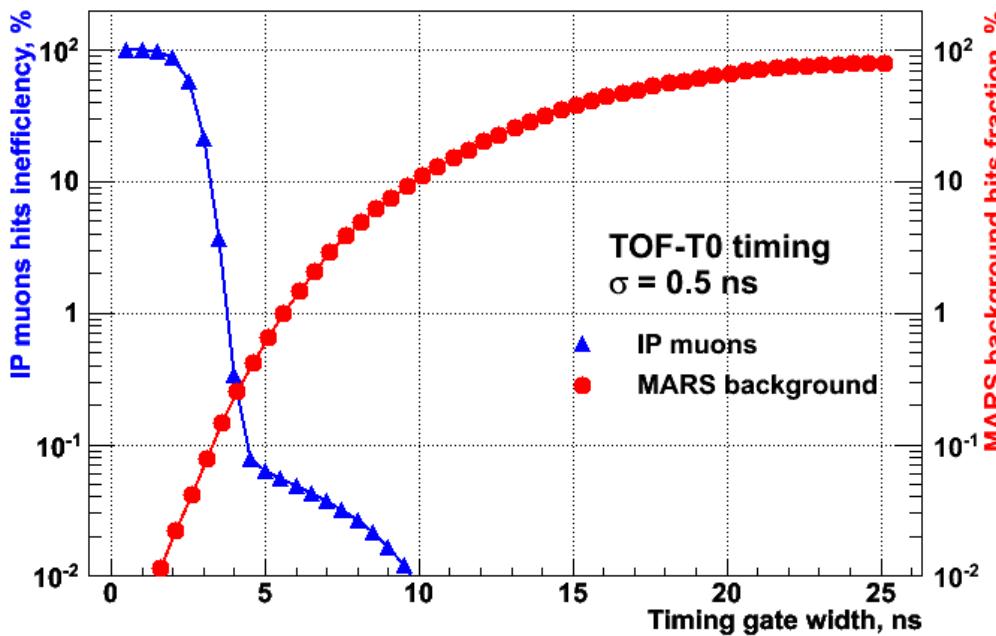
Pictures with hit TOF and TOF-T0  
are for time resolution  $\sigma=0$  ns

- **Timing of ILCRoot hits for IP and MARS background particles**

- in the front-end the corresponding time cuts (start of the timing gate and its width in each readout chip of each VXD and Tracker layer) will be defined to provide high efficiency of the hits for IP particles
- the width depends on the hit time resolution (figure for  $\sigma=0.5$  ns)



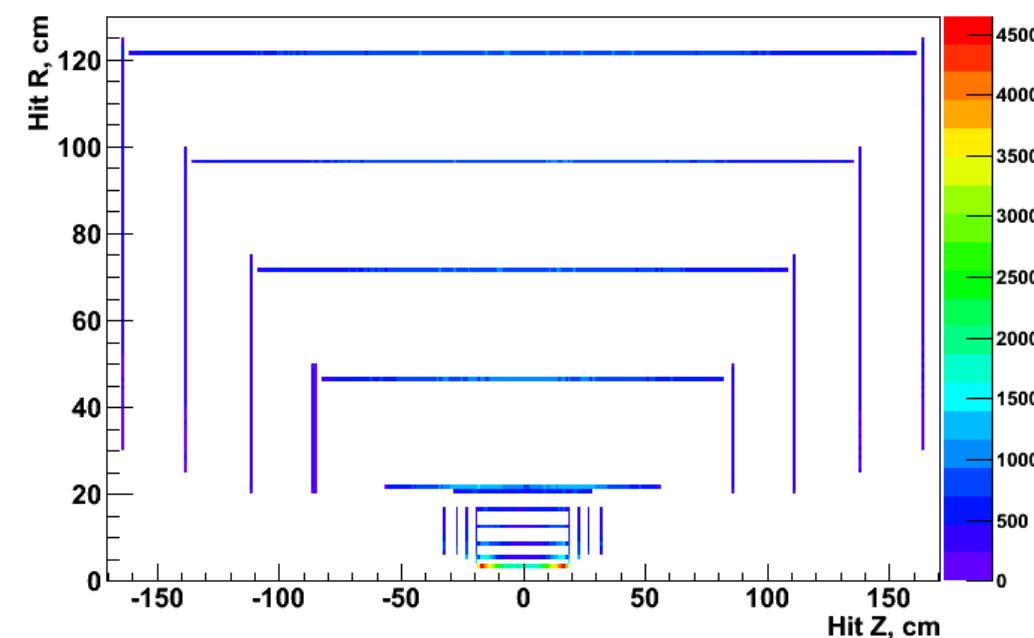
- **Timing of ILCroot hits for IP and MARS background particles**
  - timing gate width of 4 ns can provide a factor of 300-500 background rejection keeping efficiency of hits from IP particles higher than 99% at hit time resolution  $\sigma=0.5$  ns
  - max. MARS background hits density of  $\sim 10^3$  hits/cm<sup>2</sup> without timing cut (per sub-layer in the 1-st layer of VXD barrel) goes down to  $\sim 2$  hits/cm<sup>2</sup> readout at timing gate width of 4 ns



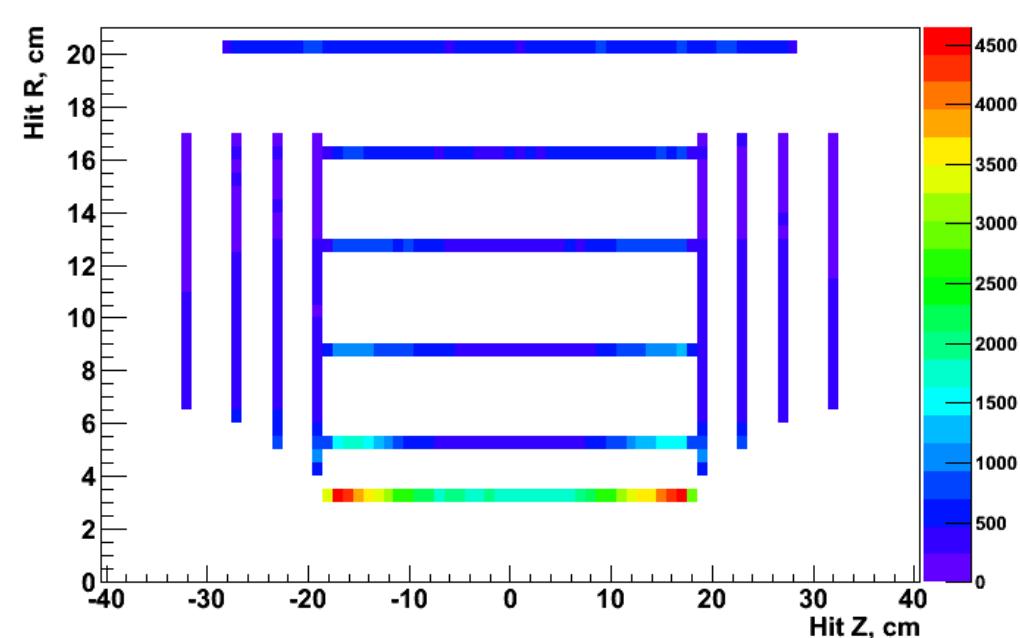
- **LCSim framework installed at Fermilab since 2011**  
(H. Wenzel, Fermilab, see update in H. Wenzel's talk)
  - GEANT4, v9.5.p01
  - detector response to MARS background for 1.5 TeV Muon Collider and  $10^0$  shielding cone was simulated by H. Wenzel in SLIC (Simulation for the Linear Collider), part of LCSim framework
  - mcdrcal00 detector (5T solenoid field, BGO calorimeters, SLAC Si  $20\mu$  VXD and  $300\mu$  Tracker)
  - no MARS particle statistics weight was taken into account, therefore actually ~5% of background was simulated
  - no shielding cone material included
- **SLIC output files (\*.slcio) were converted to \*.aida files and then to ROOT ntuples for analysis**

- Hit R vs. Z for MARS background

**VXD + Tracker**

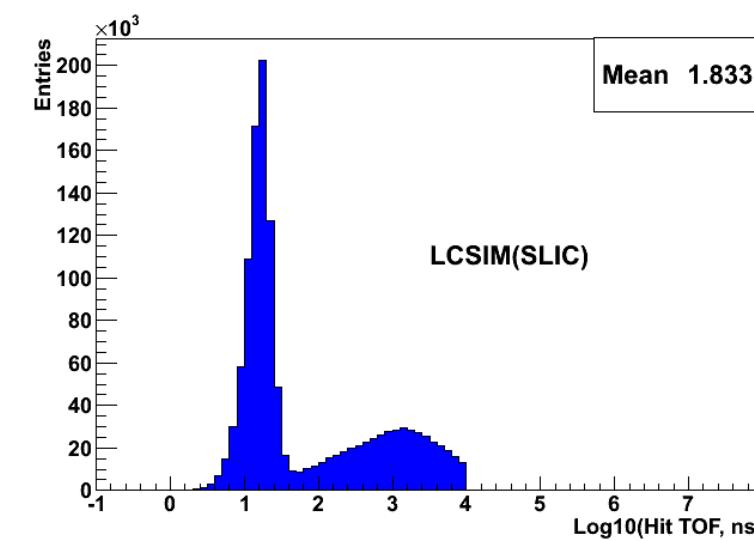
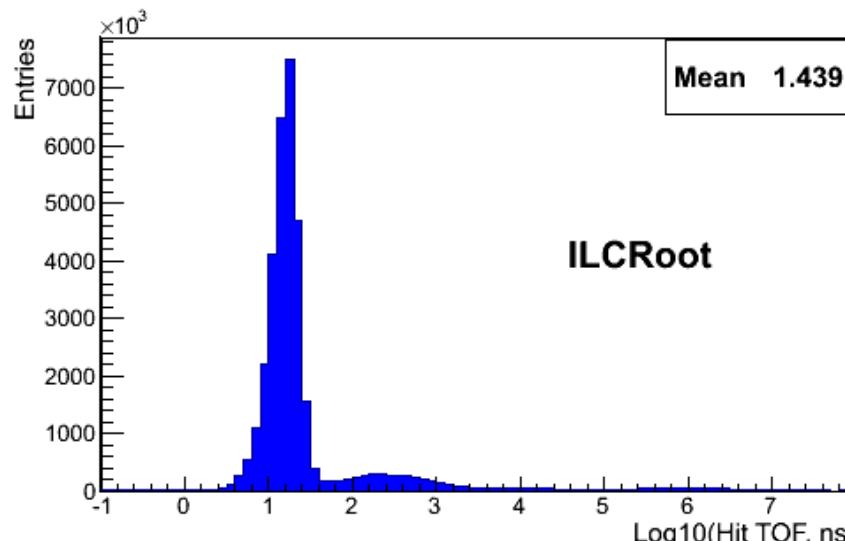
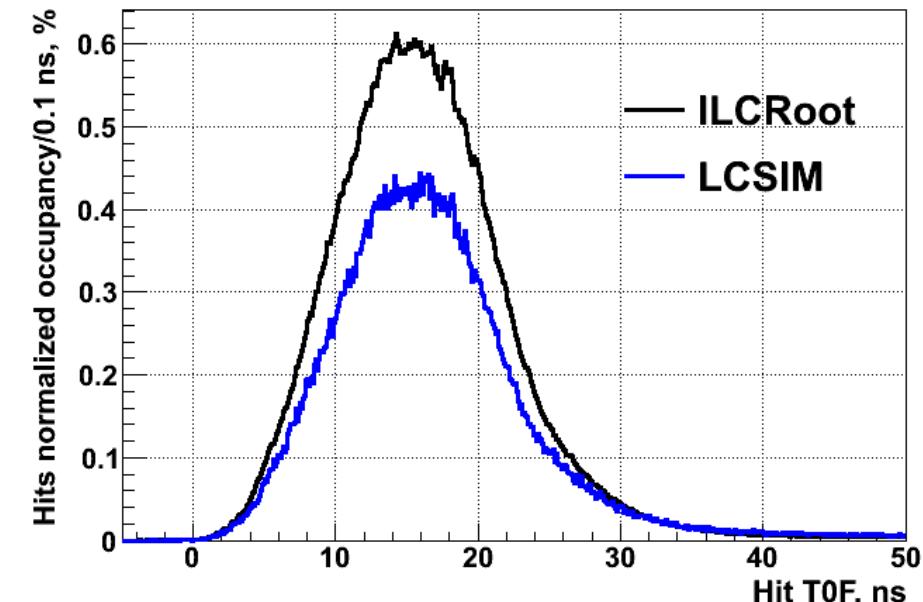


**VXD**



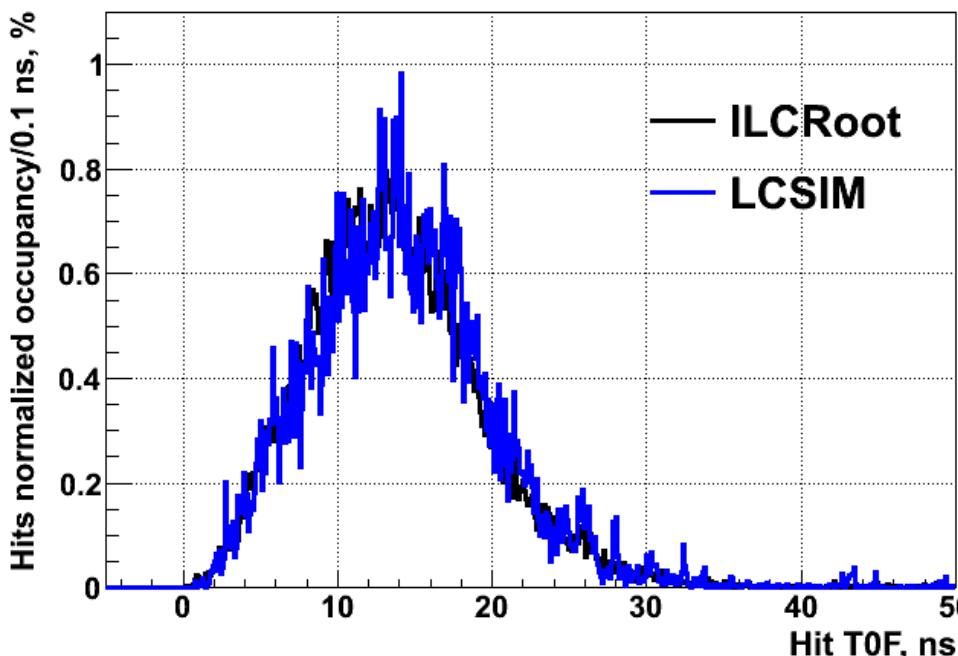
- Hit timing for MARS background in ILCRoot and SLIC**

- SLIC seems to produce smaller fraction of hits than ILCRoot at  $\text{TOF} < 50 \text{ ns}$  (e.g. larger tail at  $\text{TOF} > 50 \text{ ns}$ ), however:
  - small difference in geometries for VXD and Tracker
  - SLIC simulation – ignores the stat. weight of MARS particles, 5T magnetic field (3.5T in ILCRoot), different physics list (neutrons)
- for adequate comparison have to provide similar conditions

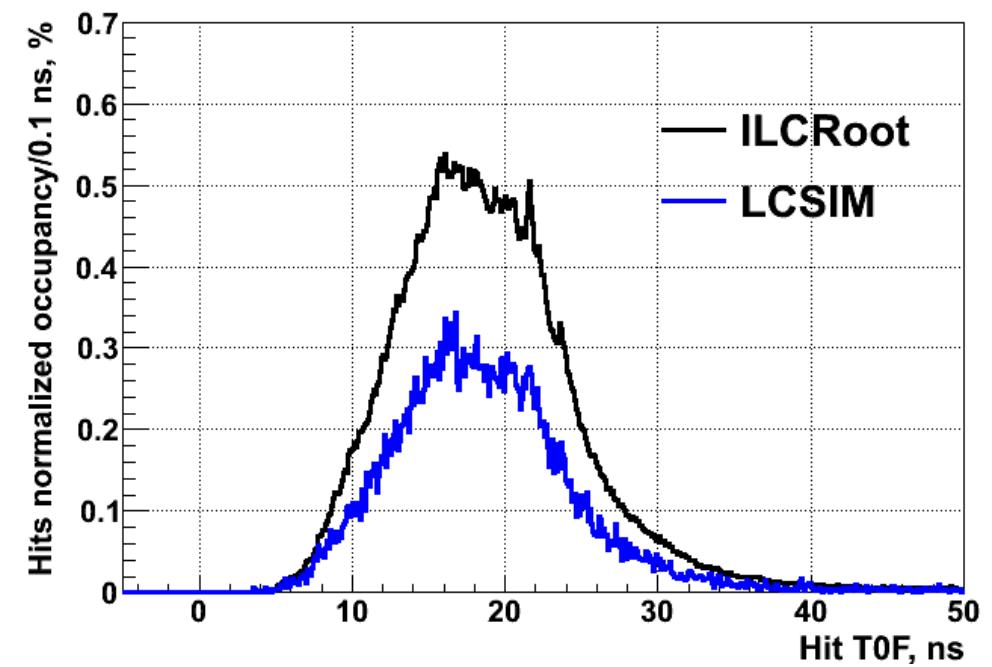


- **Hit timing for MARS background in ILCRoot and SLIC (cont'd)**
  - difference comes mainly from Tracker outmost barrel layers

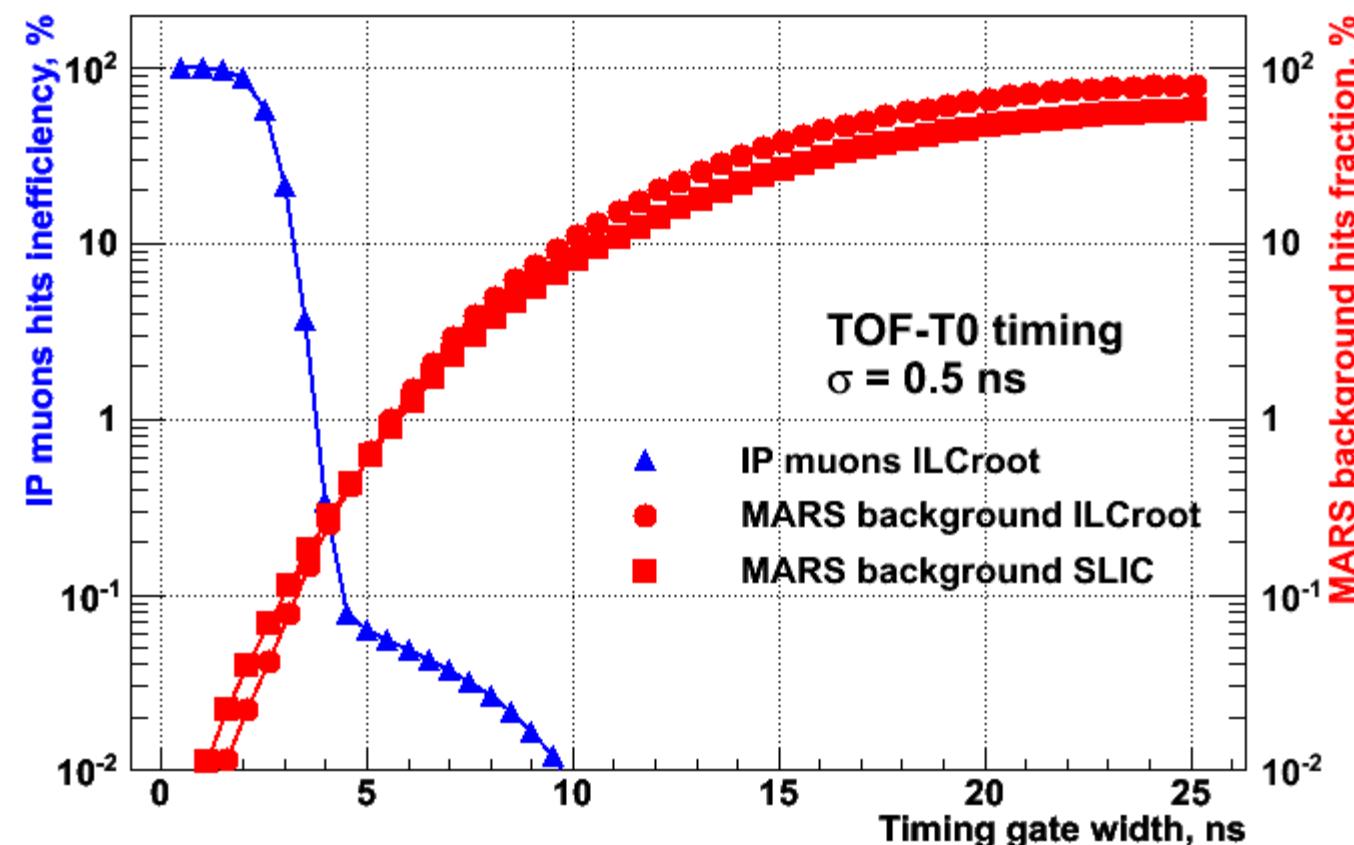
VXD barrel layer, R~5 cm



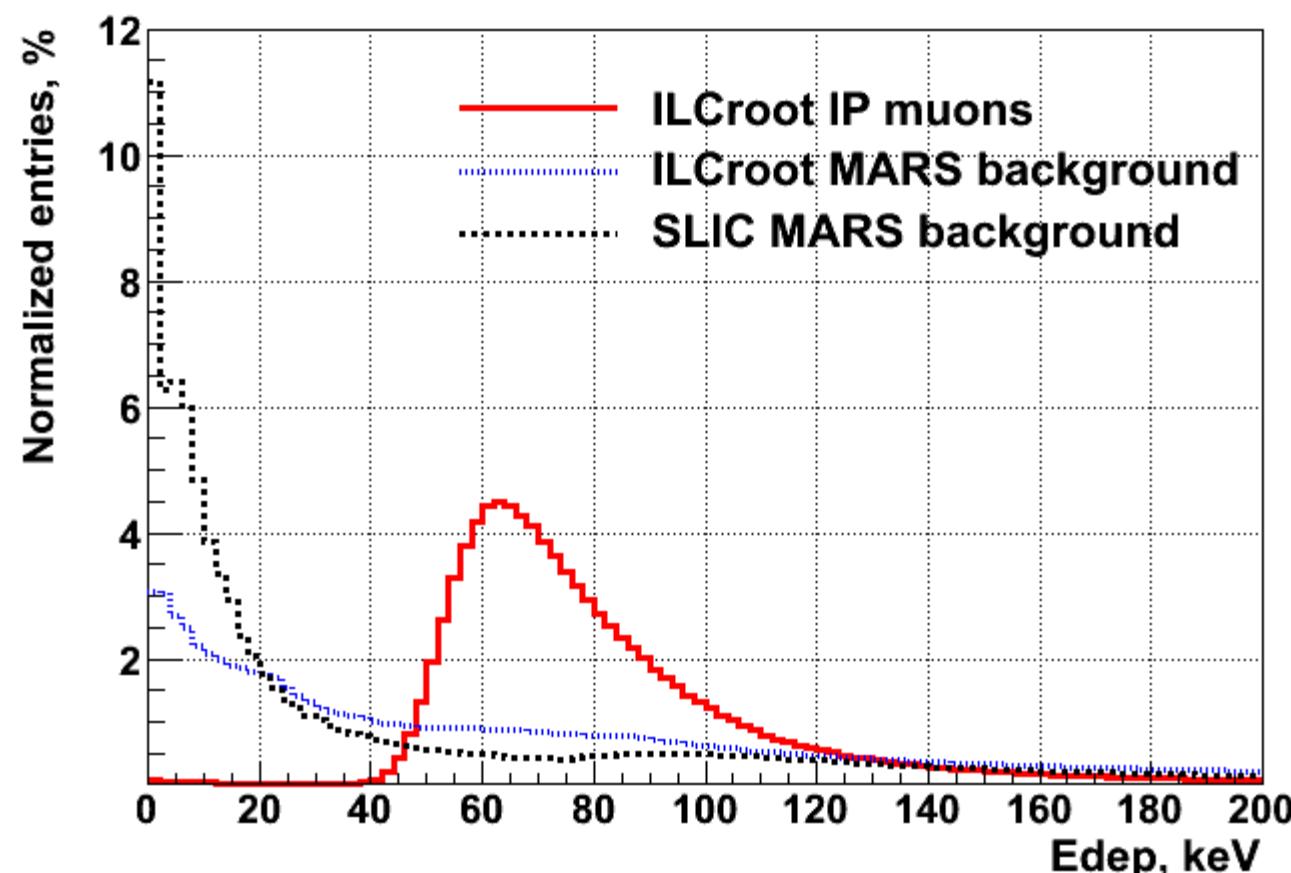
Tracker barrel layer, R~122 cm



- **Timing of ILCroot and SLIC hits for IP muons and MARS background particles**



- **Energy deposition of ILCroot and SLIC tracks for IP muons and MARS background particles**
  - Different Si thickness
  - ILCRoot – 200  $\mu$  per sub-layer in VXD and Tracker barrel
  - SLIC – 20  $\mu$  for VXD and 300  $\mu$  for Tracker



- **The ILCRoot VXD and Tracker hits timing study for 1.5 TeV Muon Collider MARS background was done at hit time resolution  $\sigma=0.2, 0.5$  and  $1.0$  ns, and the results illustrate that:**
  - a factor of  $>=100$  in the readout background hits rejection can be feasible with efficiency of hits from IP particles higher than 99%
- **Hit timing and energy deposition in ILCRoot and SLIC VXD and Tracker were compared first time for 1.5 TeV Muon Collider MARS background**
- **Plans**
  - will continue comparison for newest versions of ILCRoot and SLIC, having similar geometries and simulation conditions for 1.5 TeV Muon Collider (in progress)
  - simulate VXD and Tracker hit response for MARS background for Higgs Factory 126 GeV Muon Collider (in SLIC)

- **The timing study was limited to simulated hits only**
  - no front-end and readout details were included
  - the corresponding read-out chip (ROC) technology for Si detectors is not available yet (see, however, R. Lipton's talk)
    - time stamping with at least 1 ns wide bin
    - time resolution of order 0.2 - 0.5 ns
    - time gate with controlled start and width
- **The yield of background particles simulated in MARS will increase when lower thresholds for photons and neutrons (currently 0.2 MeV for photons and 0.1 MeV for neutrons) are implemented**
- **Having timing as the most powerful rejection tool we likely will need other two (in case of increased background yield or/and larger timing gate width)**
  - energy deposition threshold (to be implemented in front-end)
  - double layer criterion (in trigger software)
  - or/and tracking with timing as fitted parameter (in trigger software)

# BACKUP

- **The ILCRoot - software Infrastructure for Large Colliders based on ROOT and Alice's Aliroot with add-ons for Muon Collider studies**
  - “Recent developments on ILCroot”, V. Di Benedetto, May 18, 2011, Fermilab ([indico.fnal.gov/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=4455](https://indico.fnal.gov/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=4455))
  - “Muon Collider Detector Studies in ILCroot”, C. Gatto, Sep. 28, 2011, Granada ([ilcagenda.linearcollider.org/contributionDisplay.py?contribId=27&sessionId=33&confId=5134](https://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=27&sessionId=33&confId=5134))
  - “Detector and Physics Studies for High Energy Lepton Colliders with ILCroot Simulation Framework”, A. Mazzacane, Dec. 1, 2011, Fermilab, ([beamdocs.fnal.gov/AD-public/DocDB>ShowDocument?docid=4019](https://beamdocs.fnal.gov/AD-public/DocDB>ShowDocument?docid=4019))

## ILCroot: root Infrastructure for Large Colliders

- **Software architecture based on root, VMC & Aliroot**
  - All ROOT tools are available (I/O, graphics, PROOF, data structure, etc)
  - Extremely large community of users/developers
- **Re-alignment with latest Aliroot version every 1-2 years**
- **It is a simulation framework and an Offline Systems:**
  - Single framework, from generation to reconstruction and analysis!!
  - It naturally evolves into the offline systems of your experiment
  - Six MDC have proven robustness, reliability and portability
- **It is Publicly available at FNAL on ILCSIM since 2006**

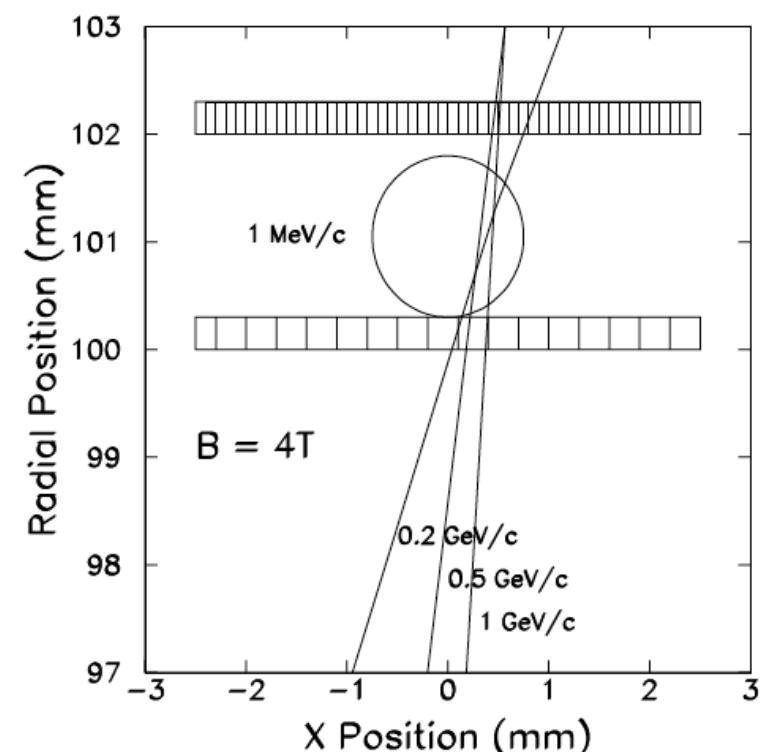
## The Virtual Montecarlo (VMC) Concept

- Virtual MC provides a **virtual interface to Monte Carlo**
- It allows to run the same user application with all supported Montecarlo's
- The real Monte Carlo (**Geant3, Geant4, Fluka**) is selected and loaded at run time

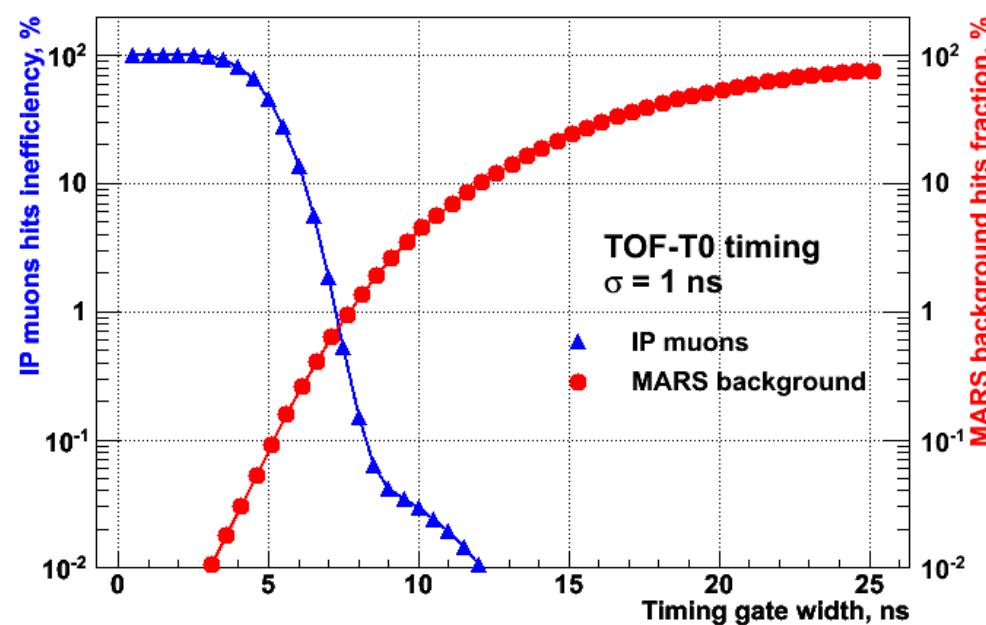
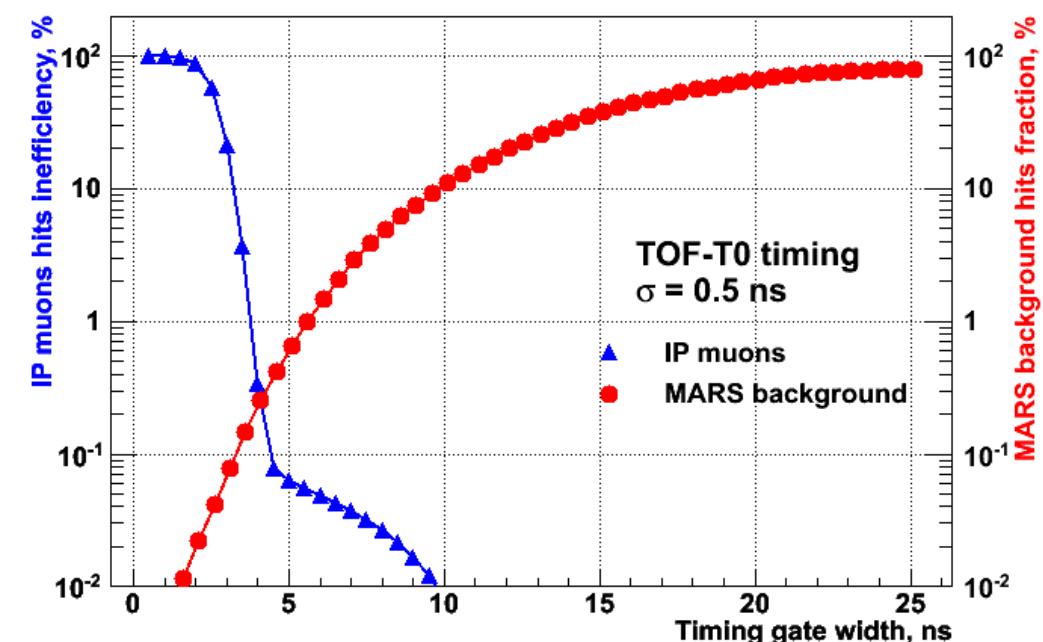
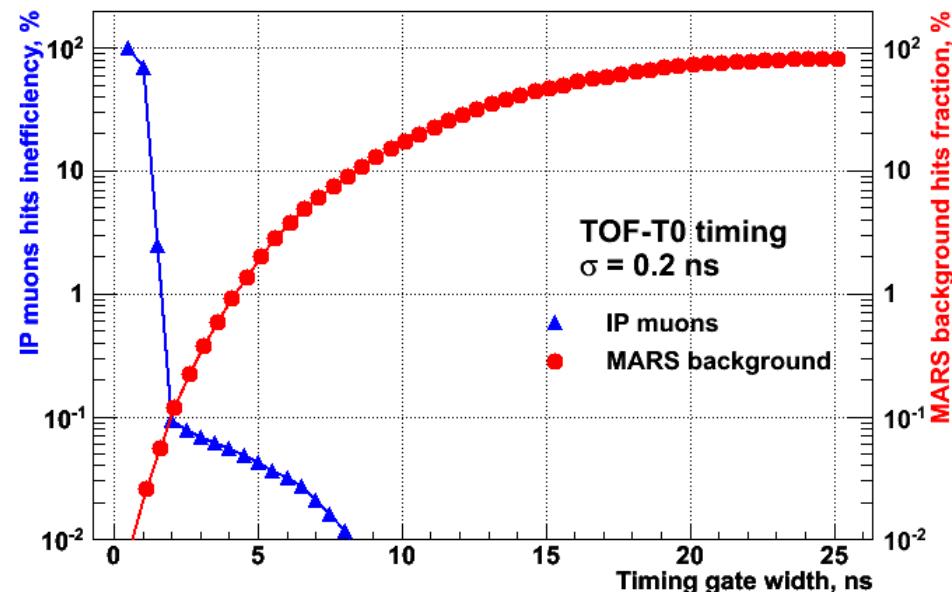
## MARS + ILCroot (Oct. 2009) Dedicated ILCroot framework for MUX Physics and background studies (in collaboration with N. Mokhov group)

- **The ingredients:**
  - Final Focus described in MARS & ILCroot
  - Detector description in ILCroot
  - MARS-to-ILCroot interface ([Vito Di Benedetto](#))
- **How it works**
  - The interface ([ILCGenReaderMARS](#)) is a *TGenerator* in ILCroot
  - MARS output is used as a config file
  - [ILCGenReaderMARS](#) creates a STDHEP file with a list of particles entering the detector area at  $z = 7.5\text{m}$
  - MARS weights are used to generate the particle multiplicity for G4
  - Threshold cuts are specified in Config.C to limit the particle list fed to G4
  - Geant4 takes over at  $7.5\text{m}$
  - Events are finally passed through the usual simulation (G4)-> digitization->reconstruction

- **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 both layers suppressing background hits



- IP muons hits inefficiency and MARS background hits fraction vs. timing gate width at hit time resolution 0.2 ns, 0.5 ns, 1.0 ns**



- MARS background hits density w/0 timing cut and with timing cut at hit time resolution  $\sigma=0.2$  ns, 0.5 ns and 1.0 ns and IP  $\mu$  hits efficiency ~99.7%**

