Muon Collider background rejection in ILCroot Si VXD and Tracker detectors

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Outline

- **New MARS 1.5 TeV Muon Collider (MC) background data**
- **ILCroot status and data**
- **Background rejection techniques in Si VXD and Tracker (on the hit level)**
  - timing
  - energy deposition
  - double layer method
  - results for IP efficiency and MARS background surviving fraction
- **Conclusions**

MARS 1.5 TeV MC background data

- **New MARS background simulation results (July 2014) for 750+750 GeV μ^+ μ^- beams with $2*10^{12}$ μ/BX each**
  (N. Mokhov, S. Striganov, www-ap.fnal.gov/~strigano/mumu/2014)
  - new geometry of MC magnets
  - no weight fluctuation in interactions, intrinsic weight = 1
  - low energy electron-photon modules in the MARS code were rewritten
  - time of flight error fixed
- **Lower thresholds in new data**
  - files **mupl-1e3x500-26m-lowth-excl** and **mumi-1e3x500-26m-lowth-excl**
  - **100 keV** threshold for γ, **$e^\pm$, $\mu^\pm$** and charged hadrons, **0.001 eV** for **n**
- **MARS particle yields for 1.5 TeV MC and 10^0 shielding nozzle**
  - **~4.5%** decays were simulated on the **26m** length
  - it gives statistical weight **~22.3** which is taken into account in ILCroot simulation
  - correspondingly, **total yield/BX ~ 3.24e+08** particles into detector

	γ	n	$e^\pm$	p	$\pi^\pm$	$\mu^\pm$
Yield/BX	**1.72e+08**	**1.50e+08**	**1.50e+06**	**4.39e+04**	**1.65e+04**	**0.28e+04**

ILCroot status and data

- **ILCrootMuCv4-1-1, July 2014 release by Vito Di Benedetto**
  - minor changes in the code since ILCroot4MuC
  - the same versions GEANT4 v9.6.01 and ROOT v5.34.05
  - was used by Vito Di Benedetto for 1.5 TeV Muon Collider new MARS background and IP muons simulations at 3.5T detector magnetic field to study calorimeter response
    - full simulation (hits, digits etc.) in all sub-detectors
    - with physics list QGSP_BERT_HP
    - single layers Si VXD and Tracker geometry
    - 75 µm and 100 µm Si thickness for VXD barrel and disks
    - 200 µm Si thickness for Tracker barrel and disks
    - full MARS background was merged with physics events, tracking was done with hits surviving time cuts

ILCroot status and data

- **ILCrootMuCv4-1-1 with VXD and Tracker double layer geometry for 1.5 TeV MC new MARS background and IP muons simulation**
  - new physics list QGSP_BERT_HP_LIV (better EM description)
  - simulation was limited to hits (no digits and tracking) in VXD and Tracker only, the rest of detectors as material
  - 75μ, 100μ and 200μ Si sub-layers in VXD and Tracker layers
  - geometry for VXD and Tracker to study double layer background rejection:
    - 1 mm space between two sub-layers in layer
    - 3.5T magnetic field
  - hit simulation was done for IP muons with P = 0.2 - 10 GeV/c
  - timing, energy deposition and angle cuts were applied to the hits to get final IP muon tracks efficiency and MARS background surviving hit fraction (all for barrel layers of VXD and Tracker)

Background rejection techniques in Si VXD and Tracker

- **A study is limited to hits simulation and analysis**
  - the hit level study provides basis for future front-end electronics and readout parameters
  - an adequate front-end technology does not exist yet
- **List of background rejection techniques**
  - **timing**, requires 100-200 ps time resolution and < 1 ns timing gate width in front-end ROC to distinguish TOF (time of flight) of IP particles from TOF of random in time muon collider machine background
  - **energy deposition, as** Landau peak for IP particles crossing Si layer vs. wide energy deposition distribution for secondary e- produced by photons and neutrons in any point of the sub-layer, can be applied in a trigger level software or/and offline tracking
  - **double layer geometry** criteria to reject space random neutral background hits and preserve IP charged track correlated hits in both sub-layers (in the trigger software or/and offline tracking)

Background rejection techniques in Si VXD and Tracker

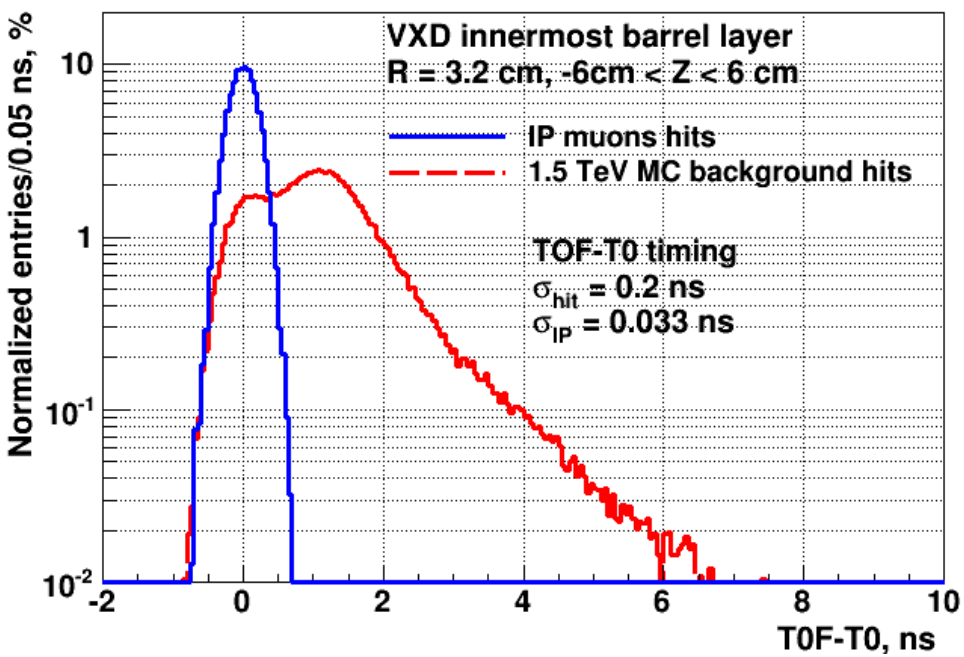
- **A hit in GEANT4**
  - "a snapshot of the physical interaction of a track in the sensitive region of a detector", defined for each step of the particle tracking
  - has X,Y,Z ,Time and P components (at begin and end of the step), ID of the track particle, energy deposition in the step etc.
  - ILCroot keeps detailed information about hits including status of the track (continues to be in sensitive volume, left the sensitive volume or stopped in it)
- **Define the hit cluster as a group of hits for given track in given sensitive volume (Si sub-layer) ended by final hit when track left the volume or stopped in it**
  - corresponds to pixel cluster as a group of pixels crossed by the track
  - use it to sum energy deposition per cluster, also for timing and position parameters
  - in following presentation use "hit" as "hit cluster" equivalent

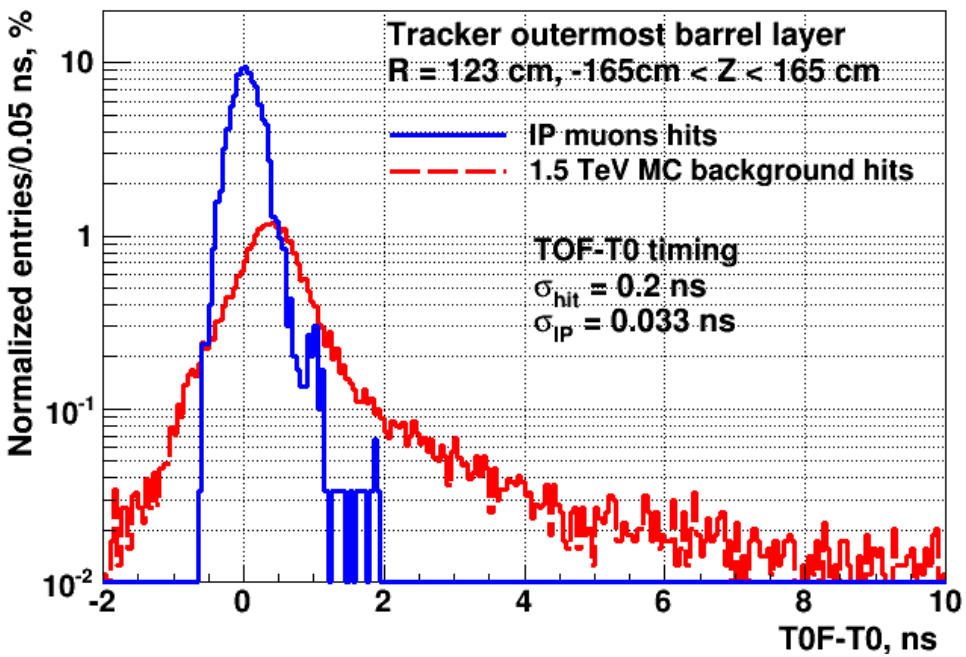
Background rejection techniques in Si VXD and Tracker

- **Timing**
  - time of flight (TOF) of MARS background particles (with respect to bunch crossing BX) is given on the detector side surface of the shielding cone
  - 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 in sub-layer
  - 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

Background rejection techniques in Si VXD and Tracker

- **Timing (cont'd)**
  - the TOF of the IP muon hits and MARS background particles hits was smeared with Gaussian time resolution of 200 ps
  - IP TOF-T0 distribution is fitted by Gaussian to determine start and width of the timing gate for given IP efficiency
  - MARS background hits timing different from layer to layer, therefore different rejection if keep one and the same IP efficiency



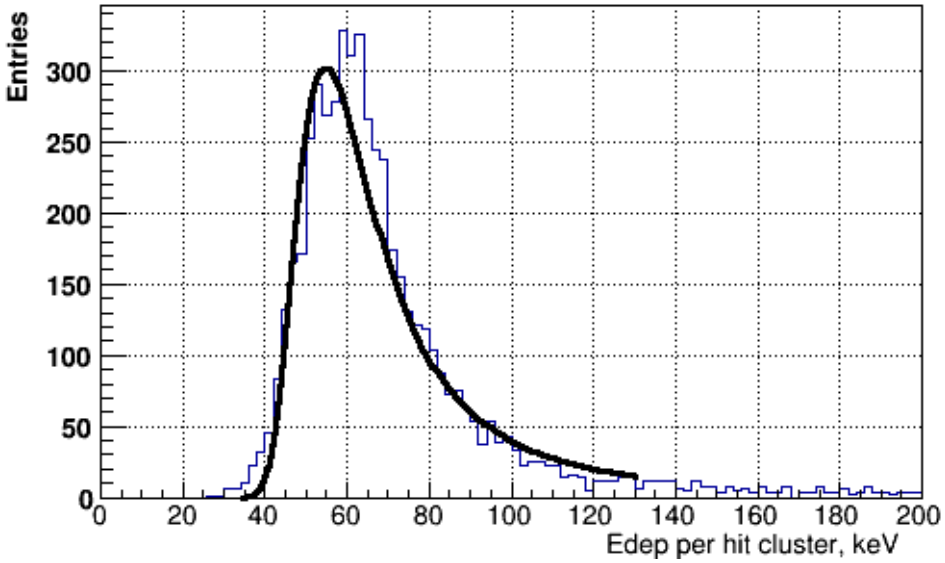


Background rejection techniques in Si VXD and Tracker

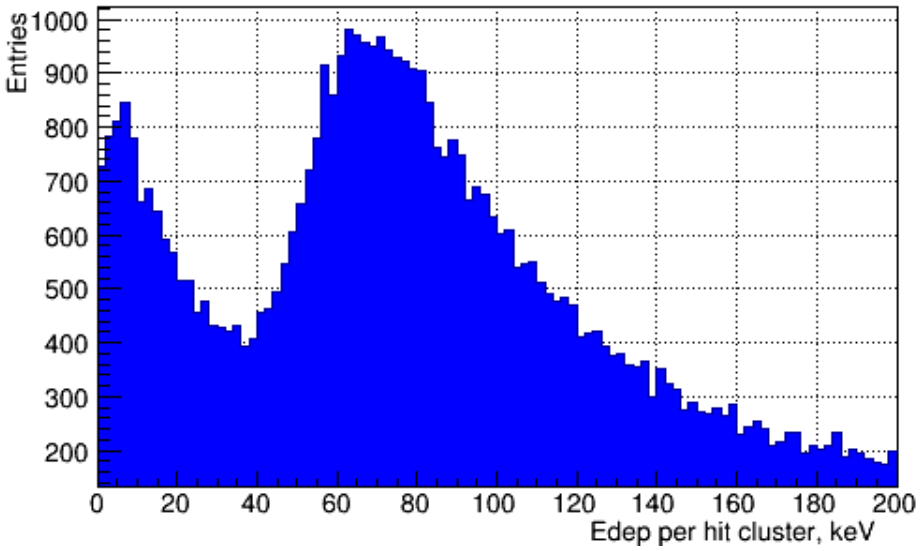
- **Energy deposition**
  - Edep - sum of energy depositions in all hits of the hit cluster for given track in given sub-layer
    - Edep resolution was introduced (Gaussian σ_{res} = 2 keV for VXD and 5.6 keV for Tracker) as 1/10 of Landau peak position at Z=0 cm
    - fit Edep distribution for IP muons with Landau function and define Edep cut (threshold) = (Landau peak position – 2.5*σ) where σ is the fit parameter
    - corresponding IP muon track efficiency per layer with hit clusters having Edep higher than the threshold is 95-97%
    - Edep threshold depends on sub-layer thickness (75μm or 200 μm) and Z-position of the IP hit in the sub-layer (θ angle)
    - find surviving fraction of MARS background hit clusters having Edep higher than the threshold, per sub-layer

Background rejection techniques in Si VXD and Tracker

- **Energy deposition for IP muons and MARS background in the Tracker outermost barrel sub-layer (200 μm)**
  - IP muon
    - Landau peak **~56** KeV at Z=0
    - Edep threshold **~40** KeV, IP efficiency ~**98.5%** per sub-layer

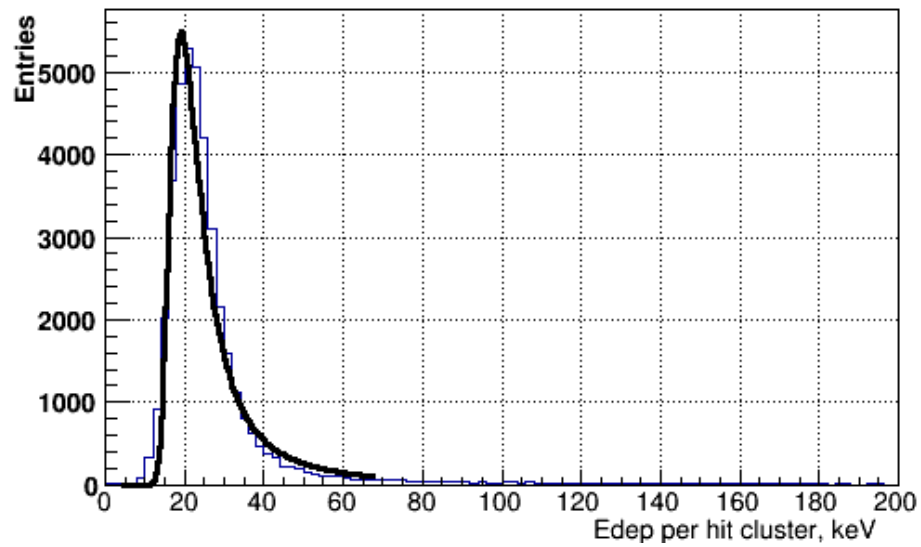


  - MARS background (all Z)
    - mostly e- from n and g interacted in any point of Si layer
    - the second peak is for particles crossing sub-layer

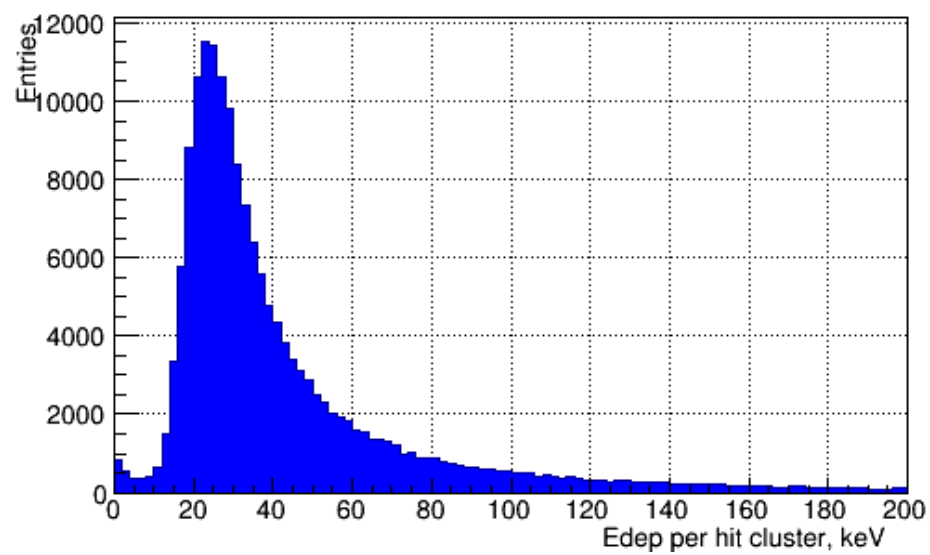


Background rejection techniques in Si VXD and Tracker

- **Energy deposition for IP muons and MARS background in the VXD innermost barrel sub-layer (75 μm)**
  - IP muon
    - Landau peak **~20** KeV at Z=0
    - Edep threshold **~13.5** KeV, IP efficiency ~**98%** per sub-layer



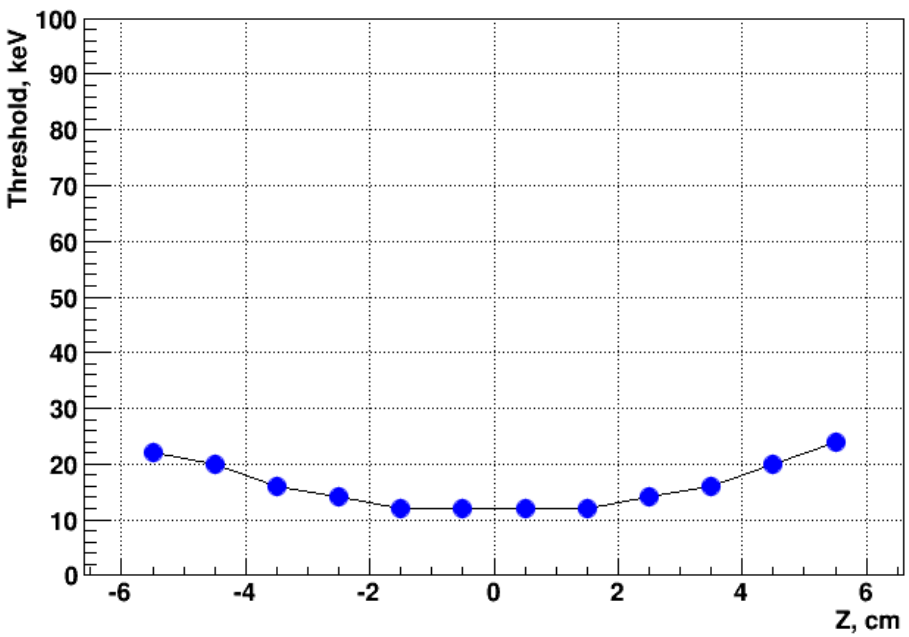
  - MARS background (all Z)
    - mostly MARS e+,e-



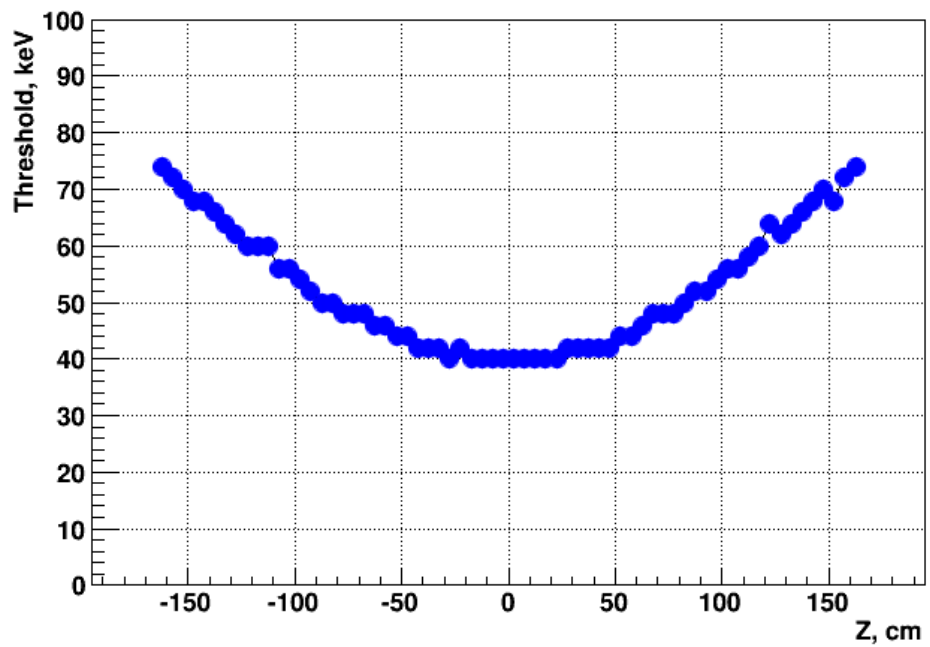
Background rejection techniques in Si VXD and Tracker

- **Edep threshold for IP hit clusters depends on:**
  - sensitive volume thickness (75 µm for VXD barrel and 200 µm for Tracker barrel sub-layers)
  - and IP muon track polar angle (~Z position of the track in the VXD or Tracker barrel sub-layers)

Innermost barrel VXD layer



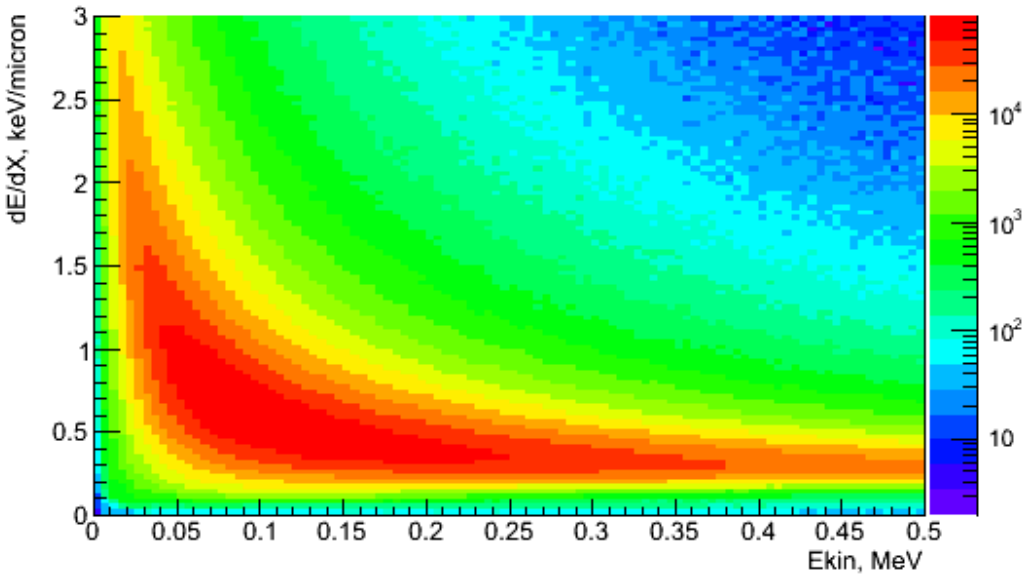
Outermost barrel Tracker layer



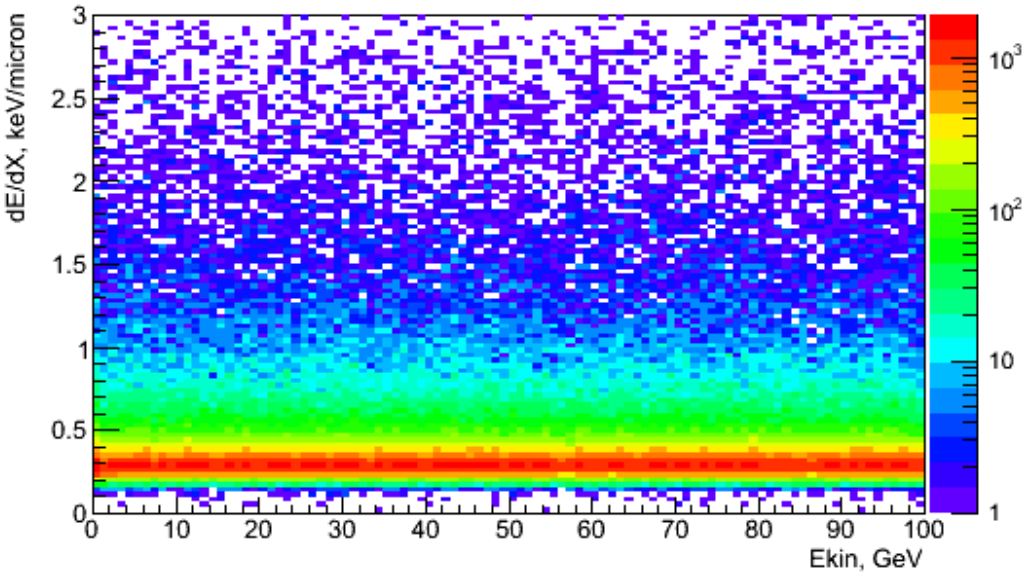
Background rejection techniques in Si VXD and Tracker

- **$Edep_{thr}$ for the hit clusters does not provide good rejection of the muon collider background**
  - large dE/dX at the end of range for low energy e- coming from background photon and neutron interactions, exceeds dE/dX of IP muons crossing sub-layer (data for all barrel layers)

e- from background g and n



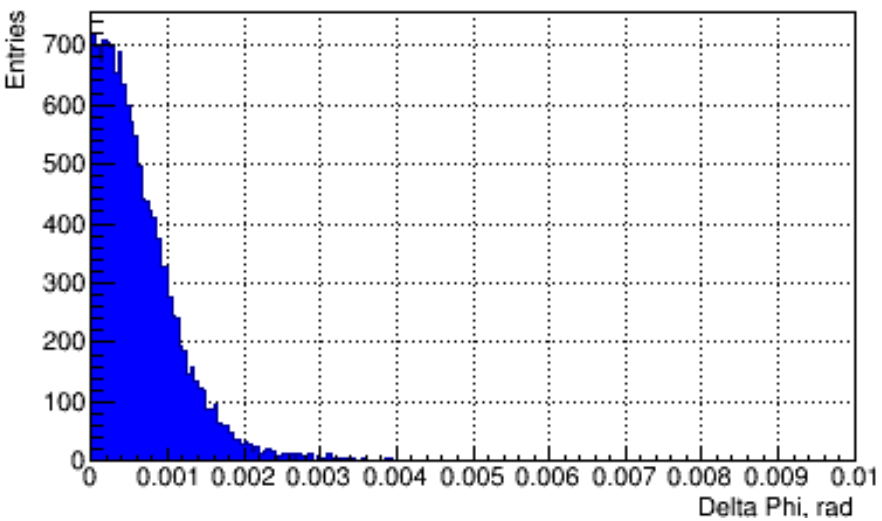
IP muons



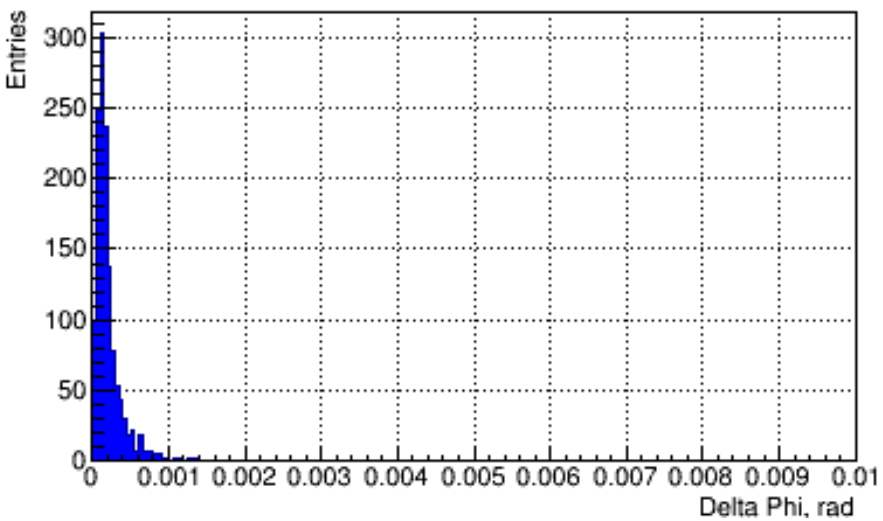
Background rejection techniques in Si VXD and Tracker

- **Double layer angle cuts**
  - smear hit cluster coordinates in each sub-layer in local Z and X with Gaussian σ_{res} = 15 μm for VXD and 40 μm for Tracker
  - define Delta Phi and Delta Theta as differences between Phi and Theta angles (relatively to IP) of the hit cluster coordinates in two sub-layers of the given layer
- **Delta Phi for IP**

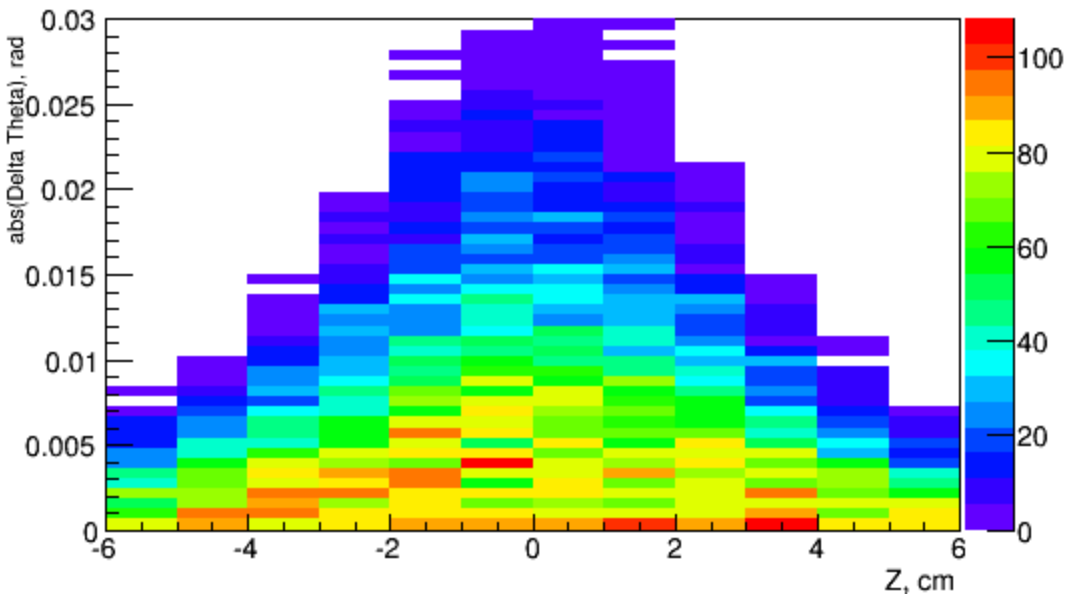
VXD innermost barrel layer

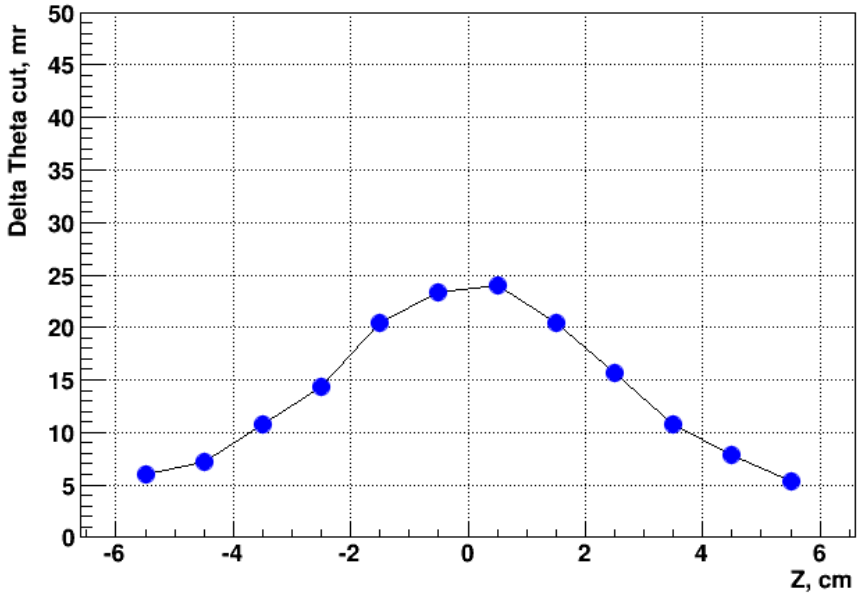


Tracker outmost barrel layer



- **Delta Theta for IP**
  - for layers close to IP (example for layer 1 of VXD) Delta Theta depends on Z due to IP smearing in Z (σ = 1 cm)



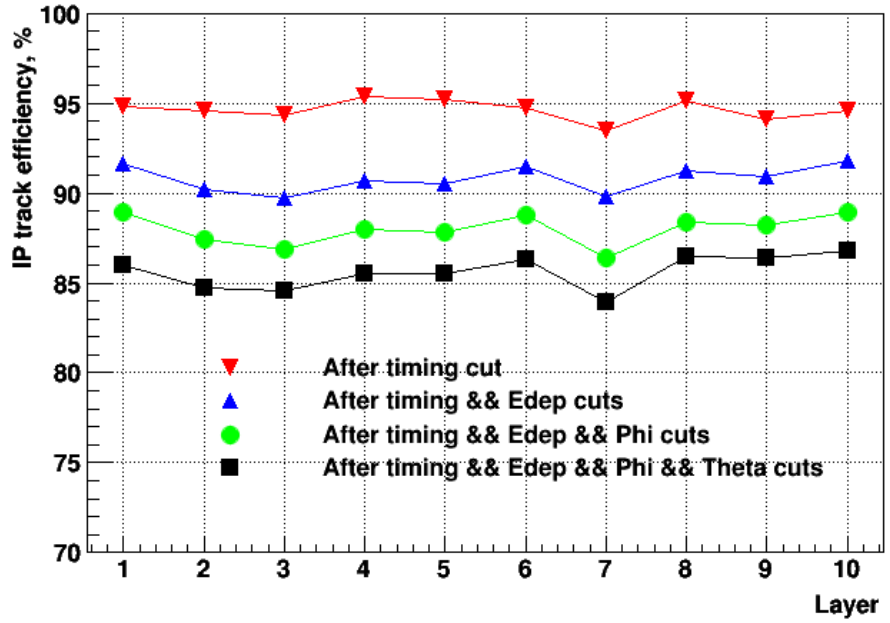


Background rejection techniques in Si VXD and Tracker

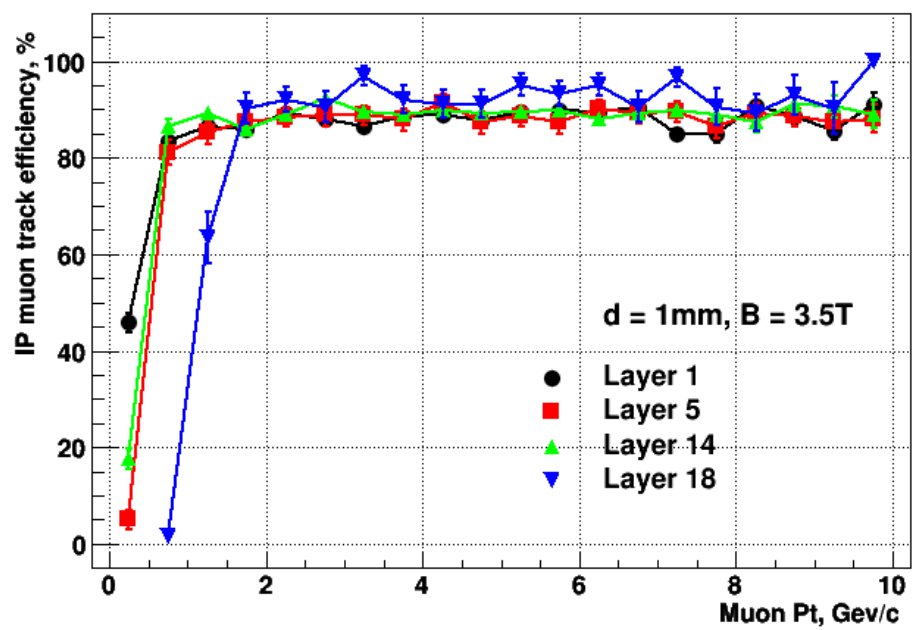
- **Summary of used resolutions in VXD and Tracker barrel sub-layers**
  - 0.2 ns for timing
  - 2 keV (VXD) and 5.6 keV (Tracker) for energy deposition as 1/10 of Landau peak position
  - 15 µm (VXD) and 40 µm (Tracker) X,Z for double layer method
- **Summary of used cuts in VXD and Tracker barrel sub-layers**
  - timing gate width 0.9 ns (VXD) and 0.9 ns – 1.05 ns (Tracker)
  - energy deposition, depends on Z and layer
  - Delta Phi, 1.95 mr - 1.15 mr (VXD), 1.65 mr - 0.7 mr (Tracker)
  - Delta Theta, depends on Z and layer

Results for IP efficiency and MARS surviving fraction

- **IP muon tracks efficiency vs. cuts and layer (1-5 are VXD barrel, 6-10 are Tracker barrel)**
  - overall IP efficiency ~85%

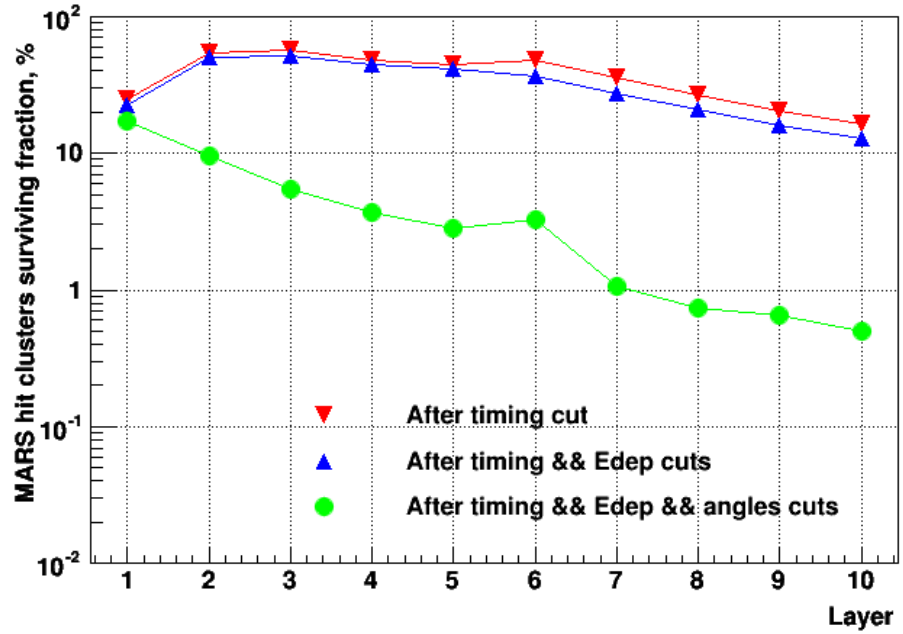


- **IP muon tracks efficiency vs. Pt (1,5 are VXD barrel, 14(6),18(10) are Tracker barrel)**

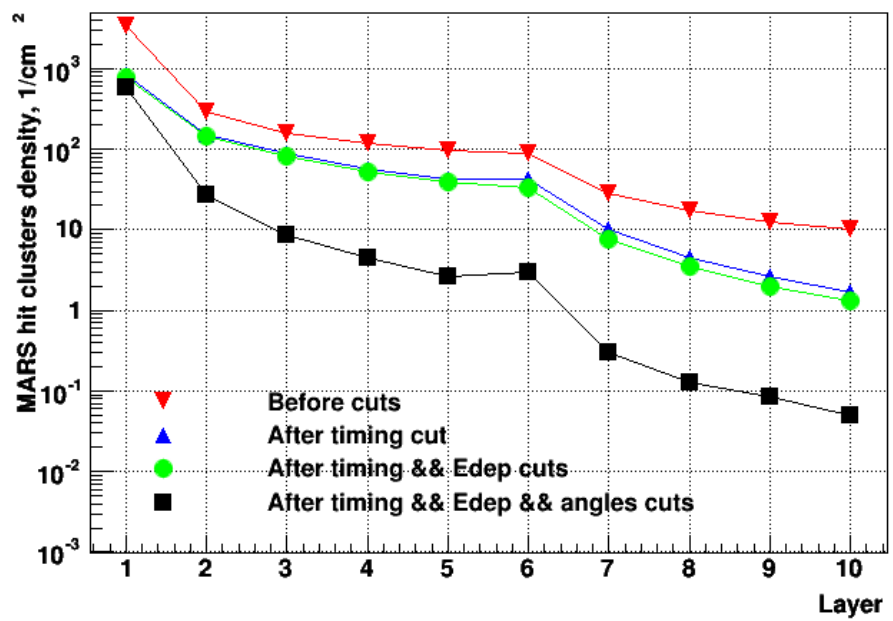


Results for IP efficiency and MARS surviving fraction

- **MARS hit clusters surviving fraction per sub-layer vs. cuts and layer (1-5 are VXD barrel, 6-10 are Tracker barrel)**
  - overall MARS surviving fraction ~2.7%



- **MARS hit clusters density per sub-layer vs. cuts and layer (1-5 are VXD barrel, 6-10 are Tracker barrel)**



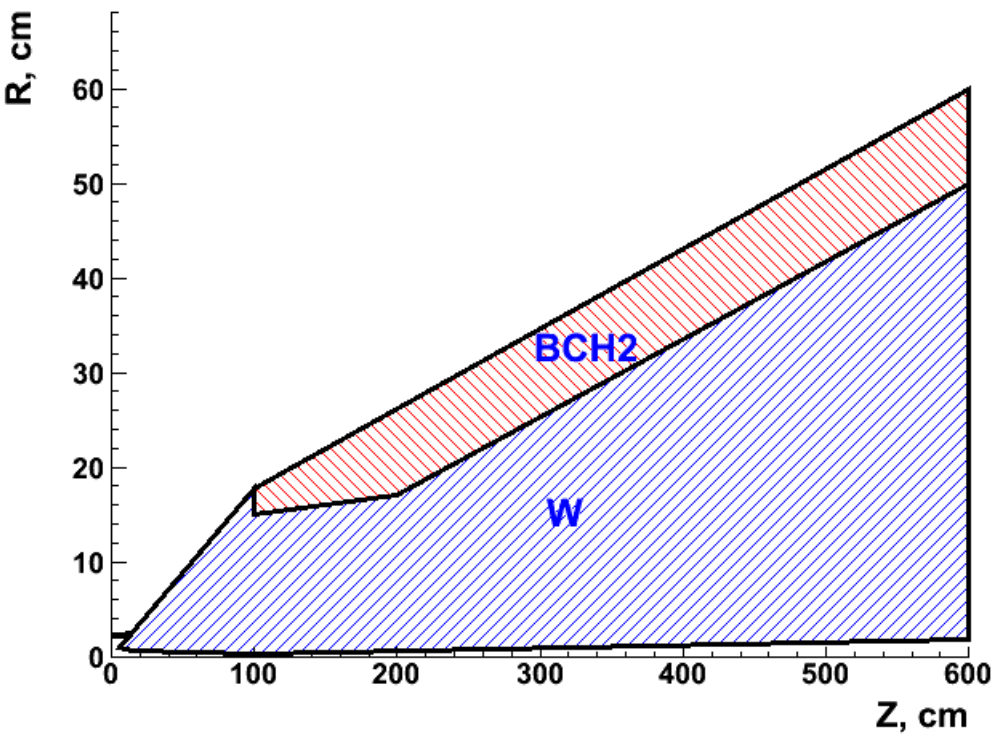
Conclusions

- **The new MARS 1.5 TeV muon collider background data were simulated on the hit level in ILCroot framework with double layer geometry in Si VXD and Tracker barrel layers.**
- **All four background rejection criteria (timing, energy deposition, Delta Phi and Delta Theta) were implemented to estimate per layer IP muon track efficiency and MARS background hit cluster surviving fraction per sub-layer.**
- **At IP muon efficiency ~85% the surviving MARS background fraction is ~17% in the innermost VXD layer and ~0.5% in the outermost Tracker layer.**
- **The overall MARS background surviving fraction is ~2.7% at IP efficiency of ~85% in VXD and Tracker barrel layers.**
- **The density per sub-layer of MARS surviving hit clusters is ~580 cm^{-2} for innermost VXD barrel layer and ~0.05 cm^{-2} for outmost Tracker barrel layer.**

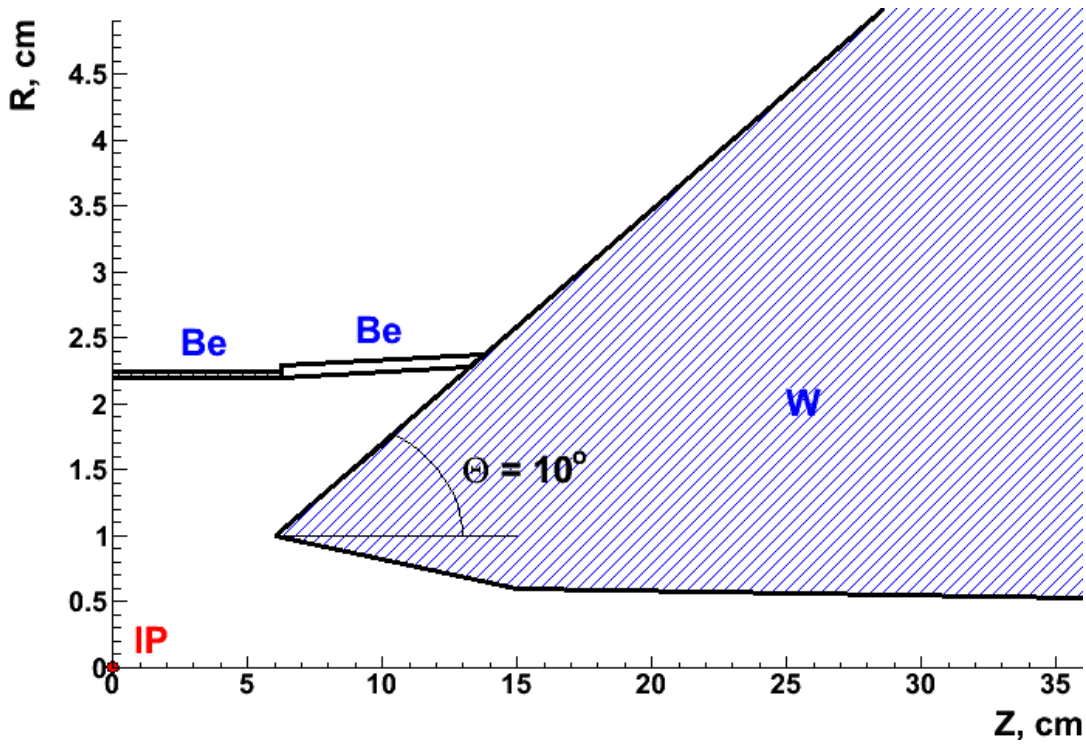
Backup slides

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

General (1/2 RZ) view



Zoom in beam pipe



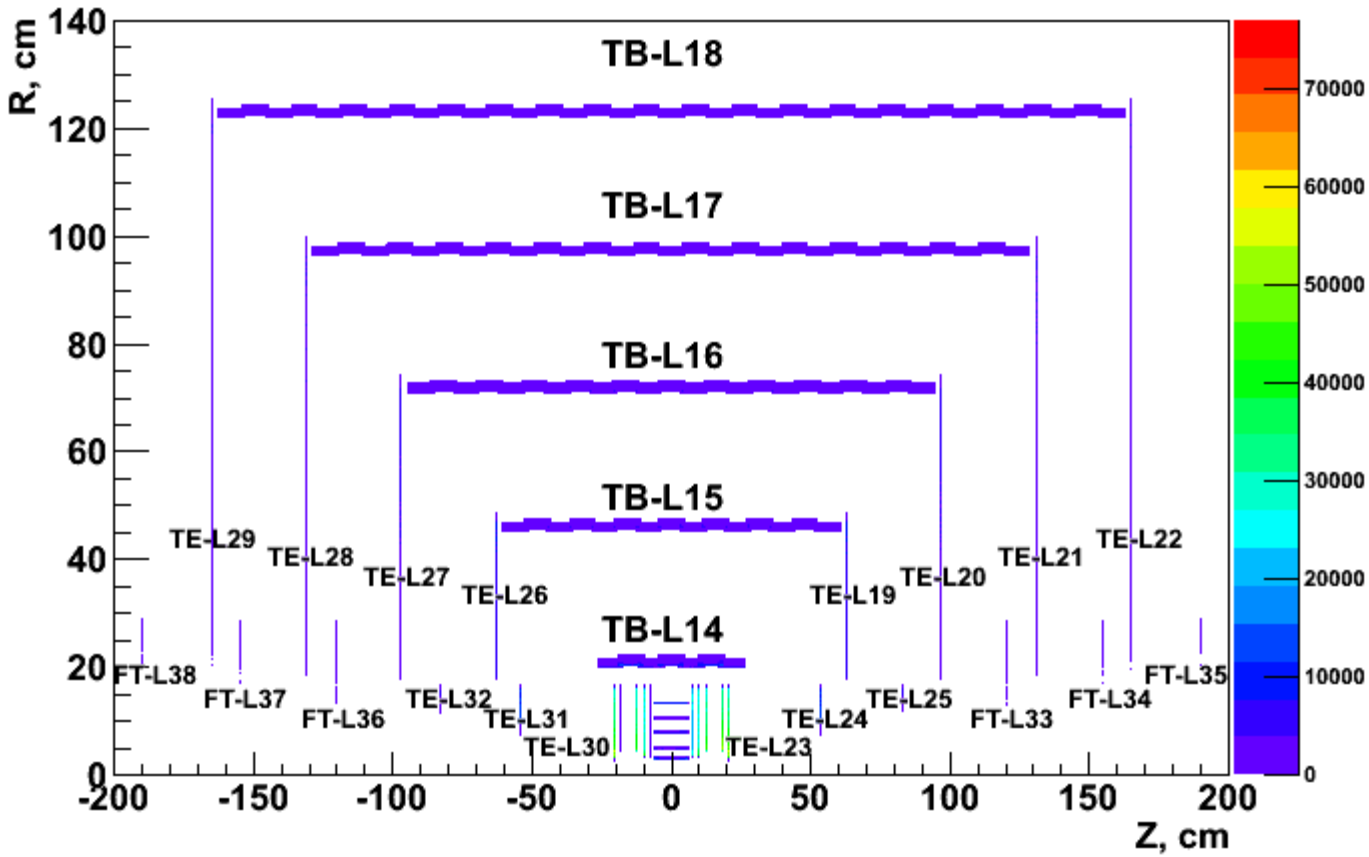
W – tungsten

Be – beryllium

BCH2 – borated polyethylene

Backup slides

- **Hit R vs. Z for ILCRoot VXD and 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