Using energy deposition and pixel clusters in ILCroot Si VXD and Tracker for machine background rejection

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MAP 2014 Spring Workshop
Fermilab
27-31 May, 2014

Outline

- **MARS 1.5 TeV and Higgs Factory backgrounds**
- **ILCroot status and data**
- **Background rejection techniques in Si VXD and Tracker**
  - energy deposition
  - clusters of hits and pixels
- **Conclusions/Plans**

MARS 1.5 TeV and Higgs Factory backgrounds

- **MARS background simulation results for $\mu^+ \mu^-$ beams with $2*10^{12}$ μ/BX each (N. Mokhov, S. Striganov)**
  - MARS particle yields and thresholds for 1.5 TeV MC and 10^0 shielding nozzle, **total yield/BX ~ 2.2e+08 particles**

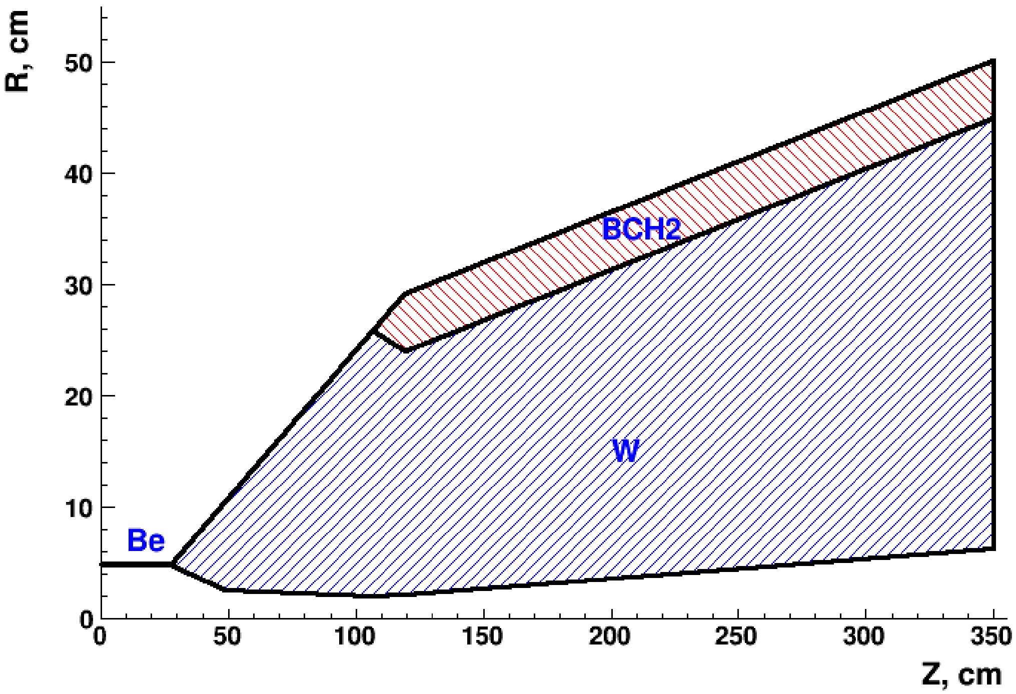
	γ	n	e±	p	π±	μ±
Yield/BX	**1.77e+08**	**0.40e+08**	**1.03e+06**	**3.13e+04**	**1.54e+04**	**0.80e+04**
E_{thr} , MeV	**0.2**	**0.1**	**0.2**	**1.0**	**1.0**	**1.0**

  - MARS particle yields and thresholds for Higgs Factory MC and 15^0 shielding nozzle (based on μ- beam data), **total yield/BX ~ 4.7e+08 particles**

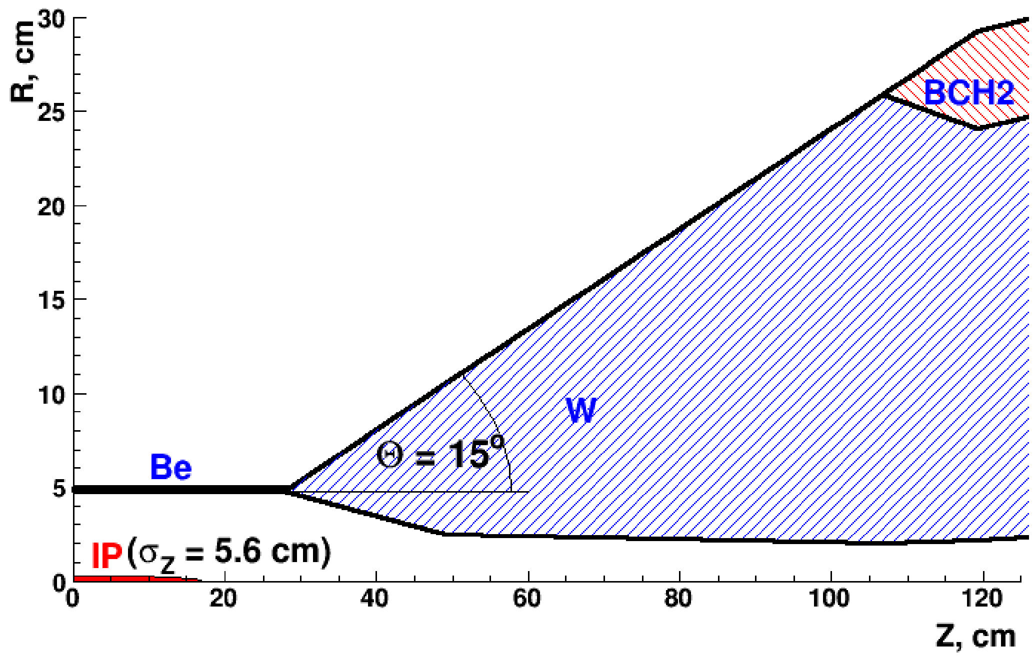
	γ	n	e±	p	π±	μ±
Yield/BX	**3.39e+08**	**1.30e+08**	**2.64e+06**	**1.67e+04**	**0.46e+04**	**0.25e+04**
E_{thr} , MeV	**0.1**	**1.0e-09**	**0.1**	**0.1**	**0.1**	**0.1**

- **15^0 shielding nozzle geometry for Higgs Factory Muon Collider**

General (1/2 RZ) view



Zoom in on beam pipe



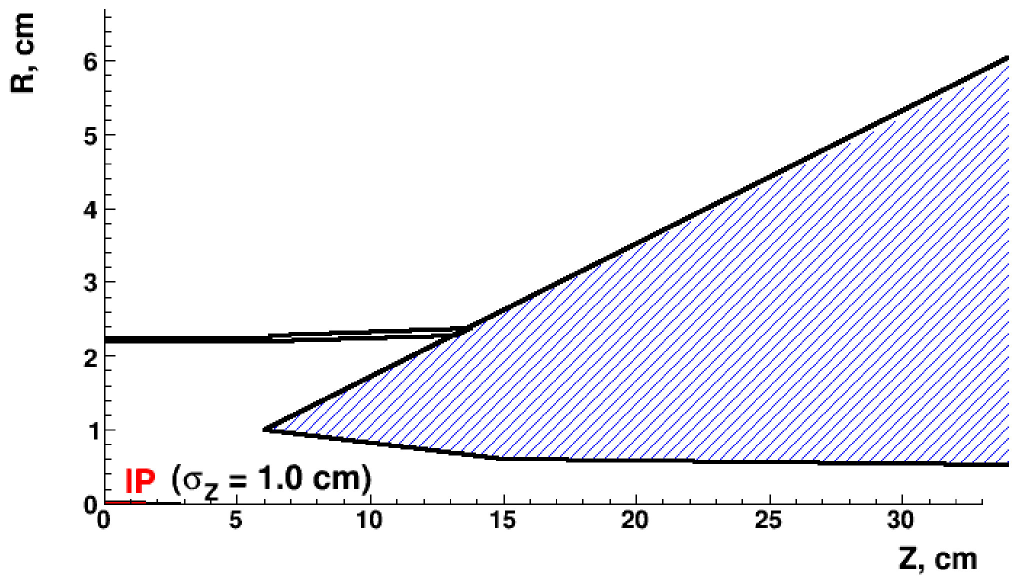
W – tungsten

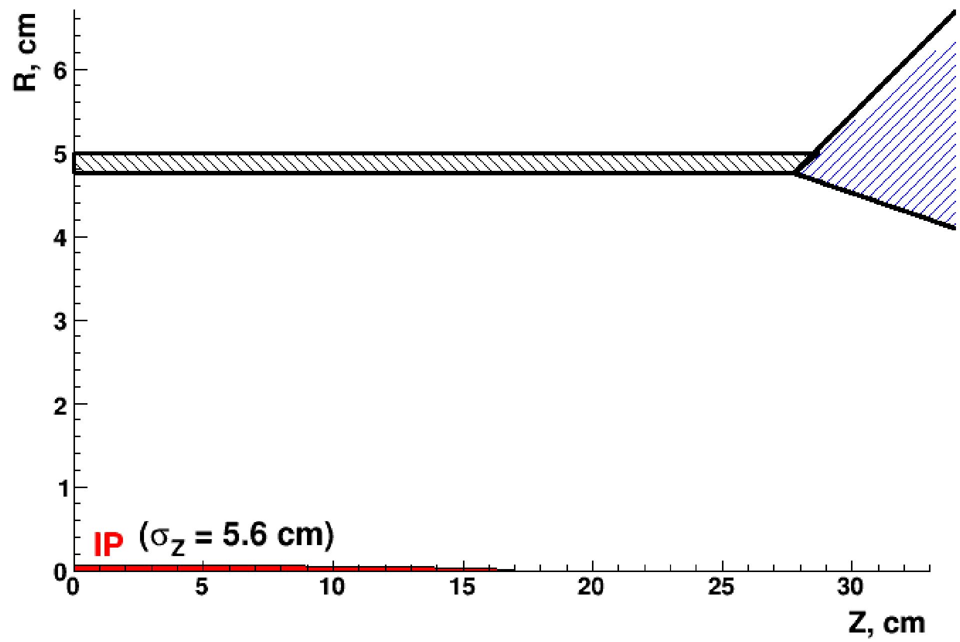
Be – beryllium

BCH2 – borated polyethylene

- **Shielding nozzle geometry (** zoom in on beam pipe**)**

10⁰ nozzle, 1.5 TeV MC — **15⁰ nozzle, HF MC**



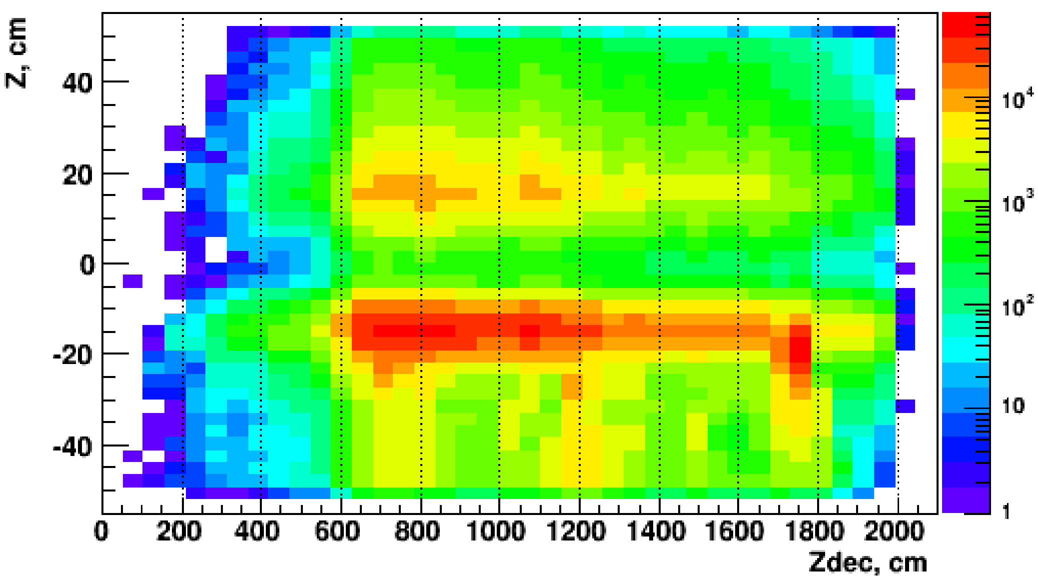


- **HF MC nozzle vs. 1.5 TeV MC nozzle – larger critical parameters**
  - **distance between tips ~ 5 times (due to IP σ_Z)**
  - **beam pipe radius ~ 2 times**

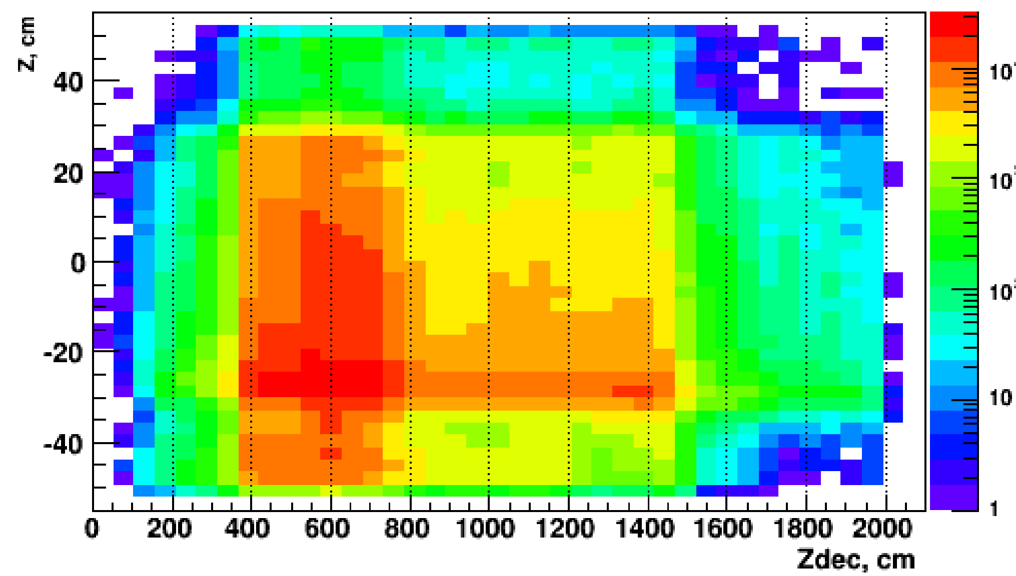
MARS 1.5 TeV and Higgs Factory backgrounds

- **Z coordinate of MARS background vs. Z_{dec} of beam μ^-**
  - main contribution from Z_{dec} outside of the shielding cone ($|Z_{dec}|>600$ cm for 1.5 TeV or $|Z_{dec}|>350$ cm for HF)
  - relative yield at the beam pipe Z is much larger for HF nozzle

10^0 nozzle, 1.5 TeV MC



15^0 nozzle, HF MC



ILCroot status and data

- **ILCroot4MuC - ILCroot June 2013 release (Vito Di Benedetto)**
  - GEANT4 v9.6.01 and ROOT v5.34.05
  - runtime switch between single and dual layer geometry, runtime geometry parameters for sub-detectors
  - detailed algorithms for light propagation and front-end electronics in the ADRIANO Dual-Readout calorimeter
  - was used by Vito for 1.5 TeV Muon Collider MARS background and IP muons simulations at 3.5T detector magnetic field
    - 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

ILCroot status and data

- **ILCroot4MuC in VXD and Tracker double layer geometry for 1.5 TeV MARS background simulation**
  - new physics list QGSP_BERT_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 layers in VXD and Tracker (as before)
  - four sets of geometry for VXD and Tracker to study double layer background rejection:
    1 mm and 2 mm space between sub-layers,
    3.5T and 7.0 T magnetic field
  - hit simulation was done also for IP muons, photons and neutrons

ILCroot status and data

- **ILCroot4MuCv4_1_0 is the newest release of ILCroot for Higgs Factory studies** (with help from Vito Di Benedetto)
  - different build procedure
  - Higgs Factory 15^0 shielding nozzle was inserted into geometry replacing 1.5 TeV 10^0 shielding nozzle
  - VXD barrel layers radii were increased to accommodate larger beam pipe radius, Si double layers thickness was left as before
  - using physics list QGSP_BERT_LIV
  - simulation was limited to hits in VXD and Tracker only, the rest of detectors as material
- **Used it for Higgs Factory MARS background from μ- beam simulation**
  - two geometry sets with magnetic field of 3.5T and 5T and sub-layer space 1 mm
  - at 3.5T field also IP μ+ and μ- simulation

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 parameters
  - an adequate front-end technology does not exist yet
- **List of background rejection techniques**
  - timing, requires < 100 ps time resolution in front-end ROC
  - double layer geometry to reject space random neutral background and preserve IP charged tracks (in trigger software)
  - energy deposition of background vs. IP particles (in trigger)
  - new: number of having signal pixels in pixel clusters (in trigger)
  - new: patterns in pixel clusters (in trigger)
- **In this talk - preliminary results of study of energy deposition and hit/pixel clusters for MARS 1.5 TeV background and IP muons in single layer Si VXD and Tracker geometry**

Energy deposition in Si VXD and Tracker

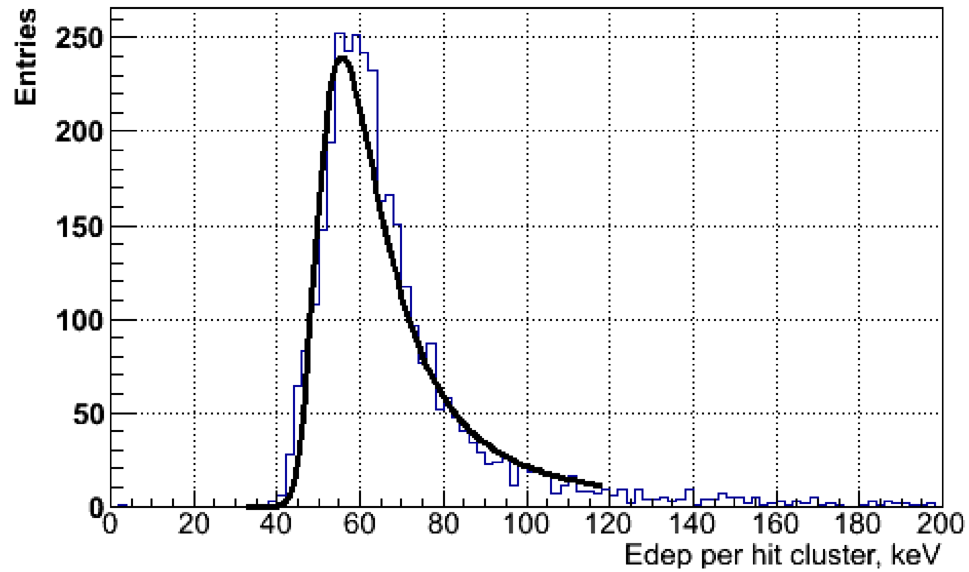
- **A hit in GEANT4**
  - "a snapshot of the physical interaction of a track in the sensitive region of a detector", defined for each step of the particle tracking
  - has X,Y,Z ,Time and P components (at begin and end of step), ID of the track, energy deposition in the step etc.
  - ILCroot keeps detailed 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 ended by final hit when track left the volume or stopped in it**
  - use it to sum energy deposition per cluster
  - corresponds to pixel cluster as a group of pixels crossed by the track in the hit cluster
  - will be used in double layer technique (cluster coordinate)

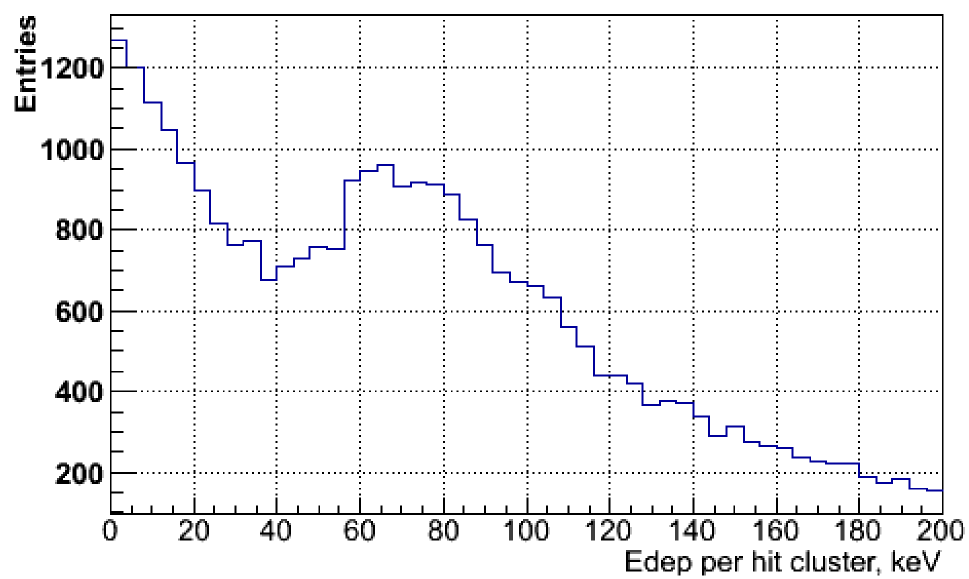
Energy deposition in Si VXD and Tracker

- **Energy deposition results are based on ILCroot4MuC simulation of 1.5 TeV MARS background, single layer geometry and QGSP_BERT_HP physics list**
- **Get Edep - sum of energy depositions in all hits of the hit cluster**
  - fit Edep distribution for IP muons with Landau function and define Edep cut (threshold) as (Landau peak position - 3*σ)
  - fraction of IP muon hit clusters having Edep higher than the cut gives IP muon hit cluster efficiency
  - find surviving fraction of MARS background hit clusters having Edep higher than the cut

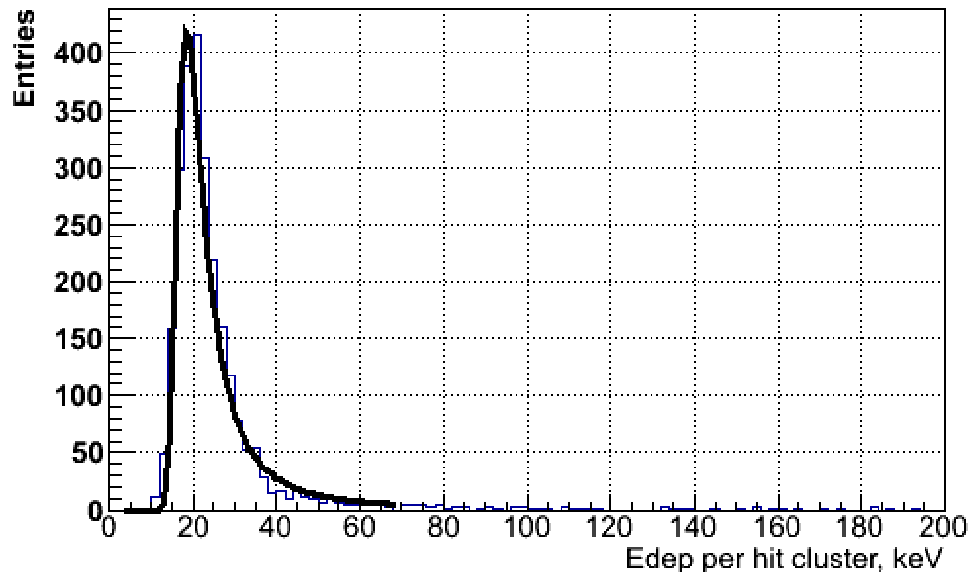
Energy deposition in Si VXD and Tracker

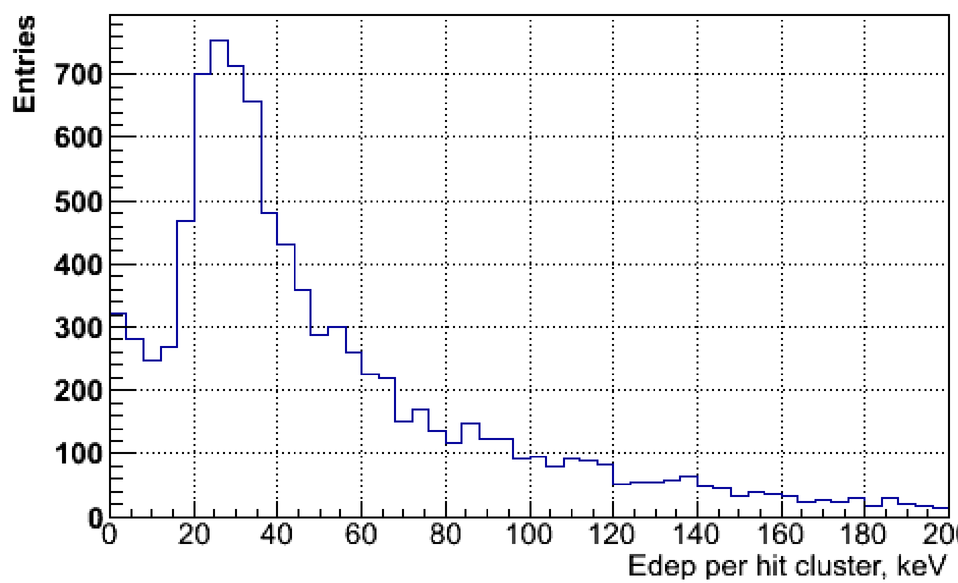
- **Hit cluster energy deposition for IP muons and MARS background in the innermost Tracker barrel layer at Z~0 (thickness 200 microns)**
  - IP muon
    - Landau peak at **~57** KeV, **σ~5** KeV,
    - Edep threshold **~40** KeV, IP efficiency ~**99.8%**
  - MARS background
    - mostly e- from n and g interacted in any point of Si layer
    - the second peak is for particles crossing layer
    - fraction of surviving background hit clusters **~70%** for threshold 40 KeV





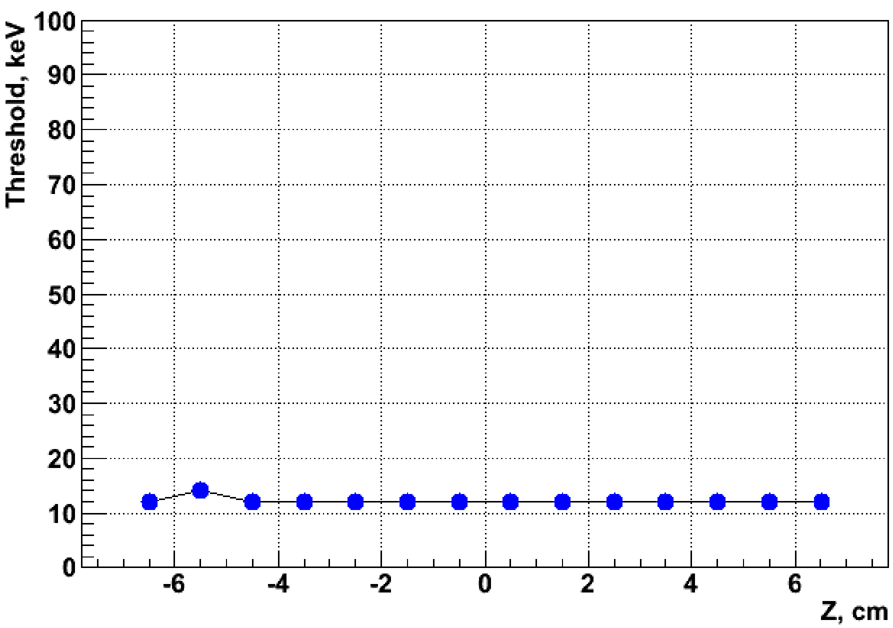
- **Hit cluster energy deposition for IP muons and MARS background in the outermost VXD barrel layer at Z~0 (thickness 75 microns)**
  - IP muon
    - Landau peak at **~19** KeV, **σ~2** KeV,
    - Edep threshold **~12** KeV, IP efficiency ~**99.6%**
  - MARS background
    - mostly e- from n and g interacted in any point of Si layer
    - the second peak is for particles crossing layer
    - fraction of surviving background hit clusters **~90%** for threshold **~12** KeV



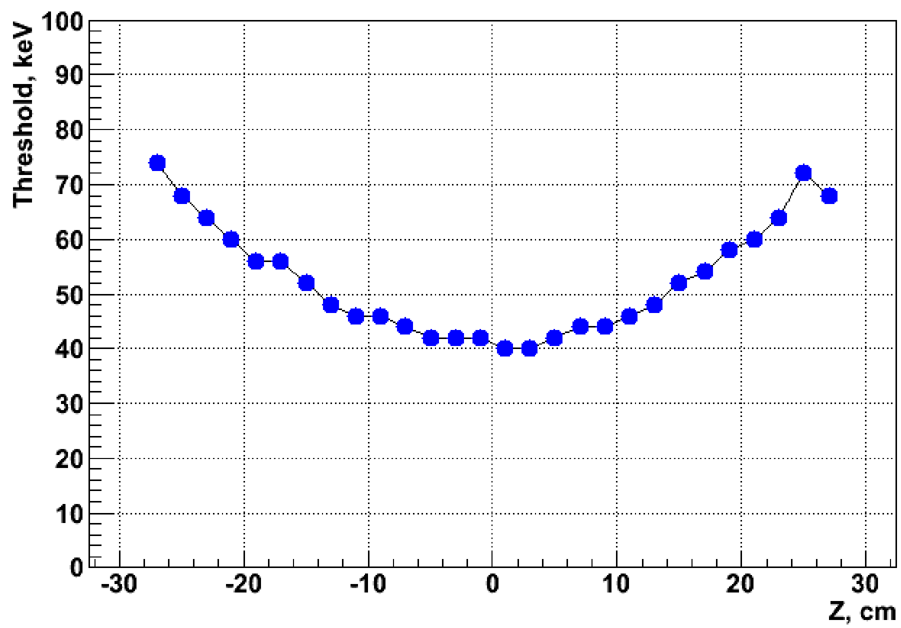


- **Landau peak position (and Edep threshold) for IP hit clusters depend on:**
  – sensitive volume thickness (75 µm for VXD barrel and 200 µm for Tracker barrel layers)
  – and IP muon track polar angle (~Z position of the track in the VXD or Tracker barrel layers)
  – thresholds for 99.5% IP muons hit cluster efficiency

Outermost barrel VXD layer

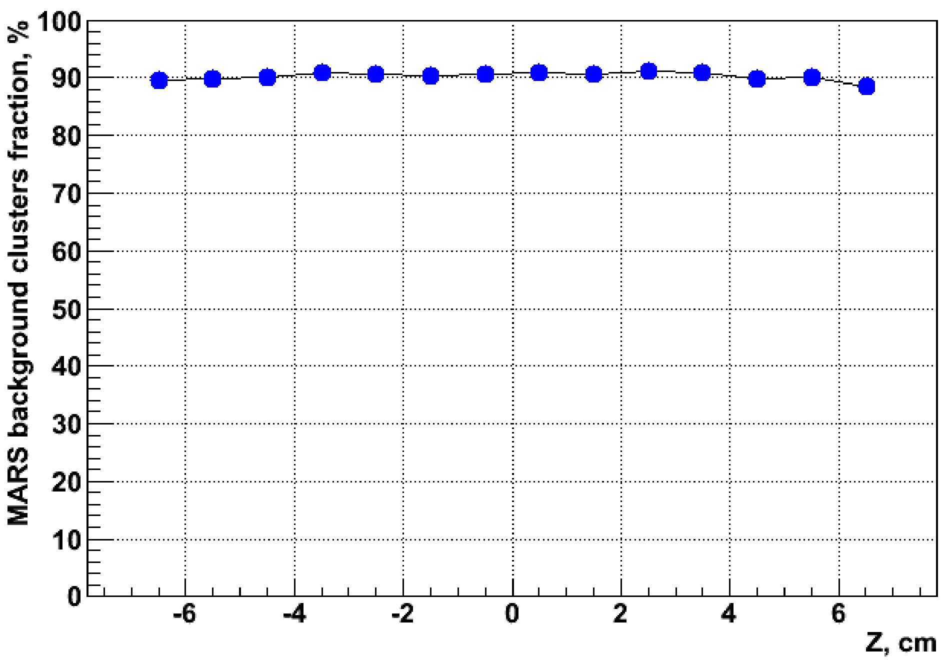


Innermost barrel Tracker layer

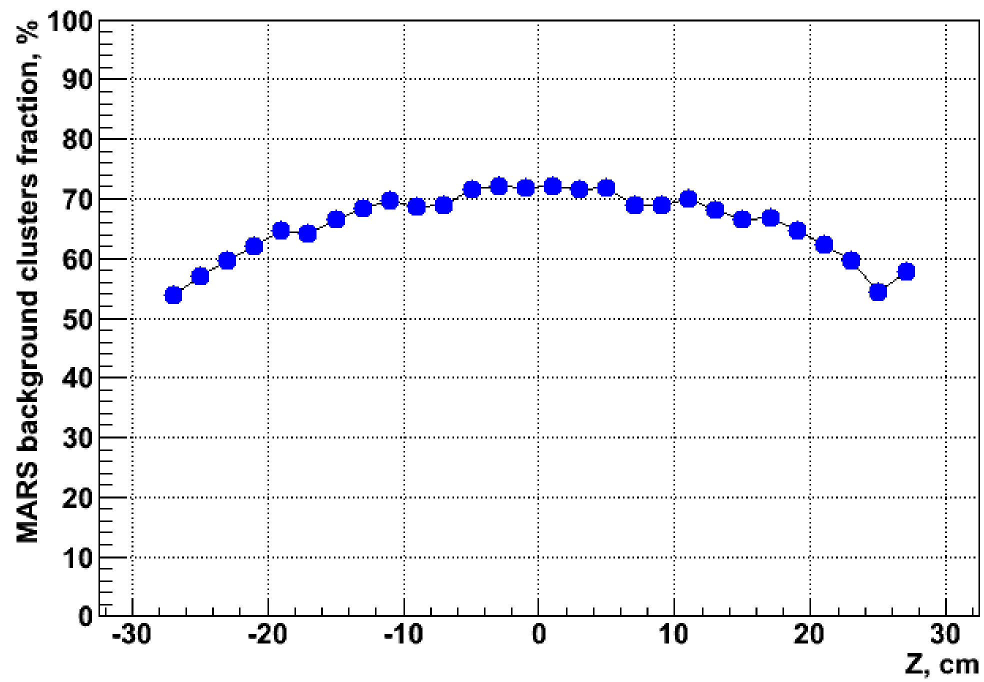


- **MARS background hit clusters surviving fraction vs. Z for Edep cuts providing ~99.5% IP muon hit cluster efficiency**

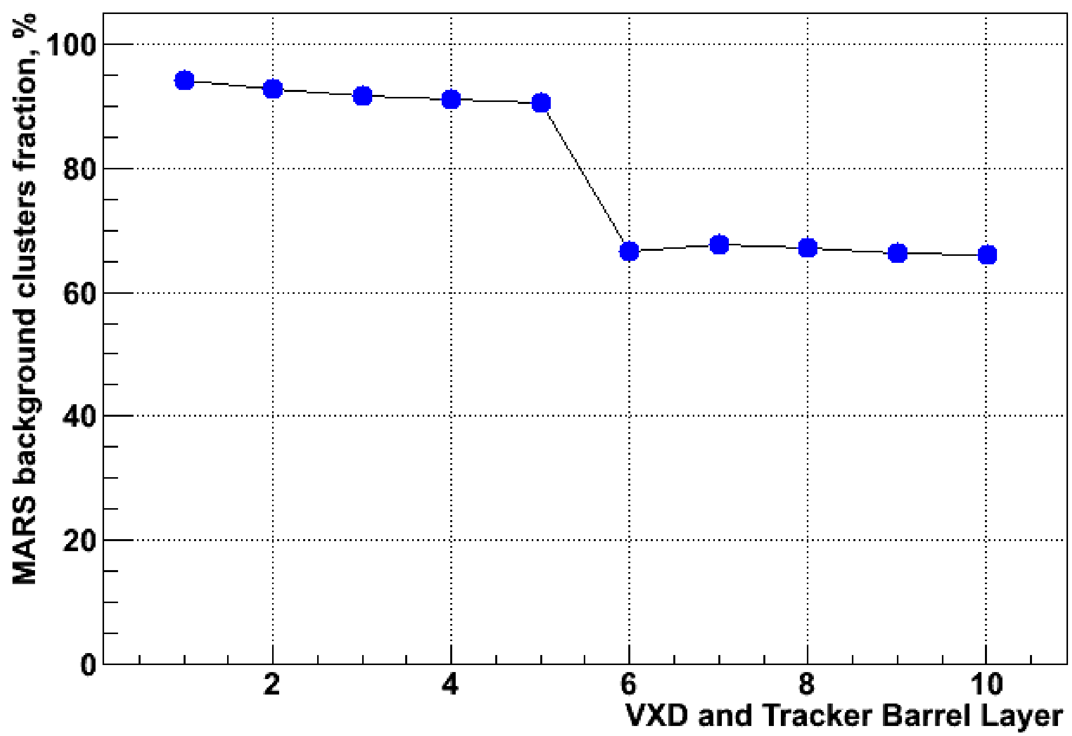
Outermost barrel VXD layer



Innermost barrel Tracker layer



- **MARS background hit clusters surviving fraction vs. VXD and Tracker barrel layers for Edep cuts providing ~99.5% IP muon hit cluster efficiency**
  - layers 1-5 are VXD barrel, layers 6-10 are Tracker barrel
  - MARS background hit clusters surviving fraction for **all VXD and Tracker barrel layers together ~ 70%**



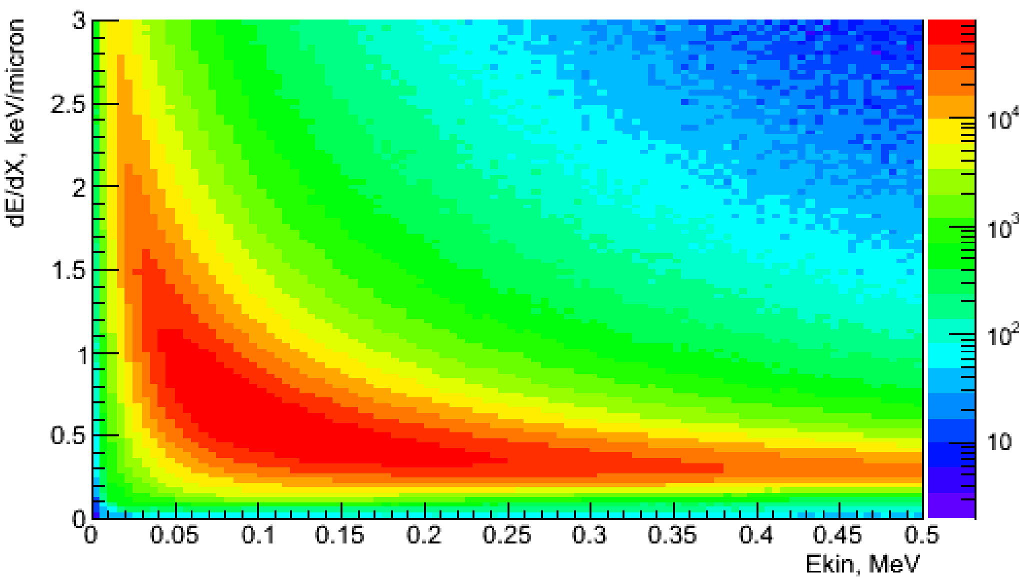
Energy deposition in Si VXD and Tracker

- **A modest improvement of the hit cluster energy deposition criteria – two sides cuts (at 97 - 98% IP efficiency)**

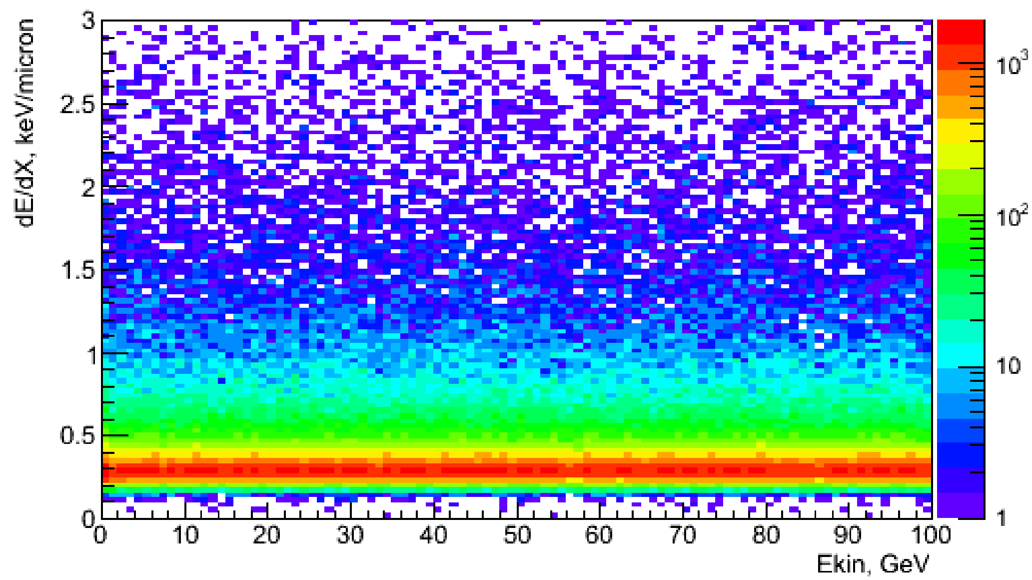
Layer	Cuts, KeV	MARS surviving fraction
VXD barrel outermost layer	12 < Edep < 100	76%
Tracker barrel innermost layer	40 < Edep < 160	54%

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

e- from background g and n



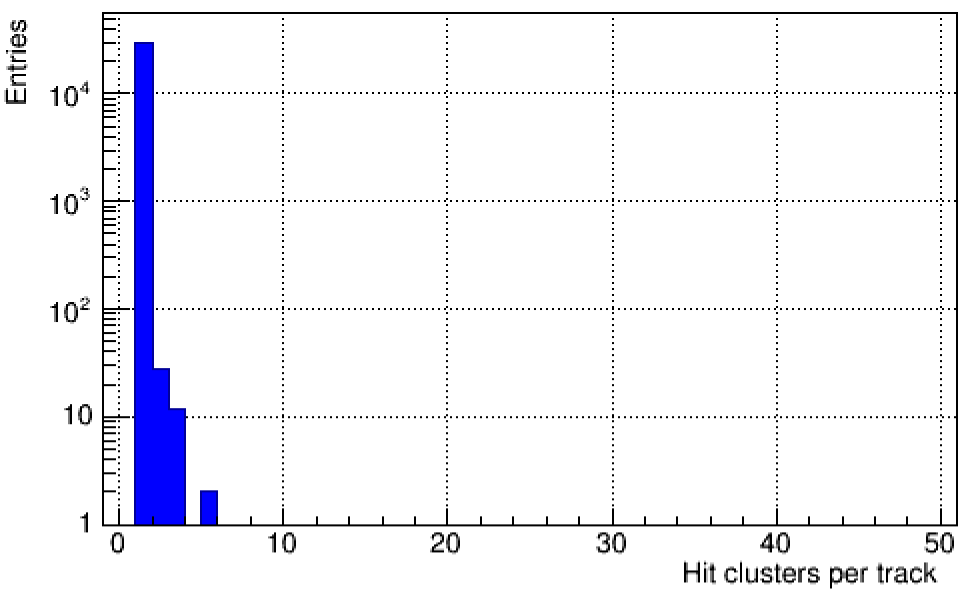
IP muons



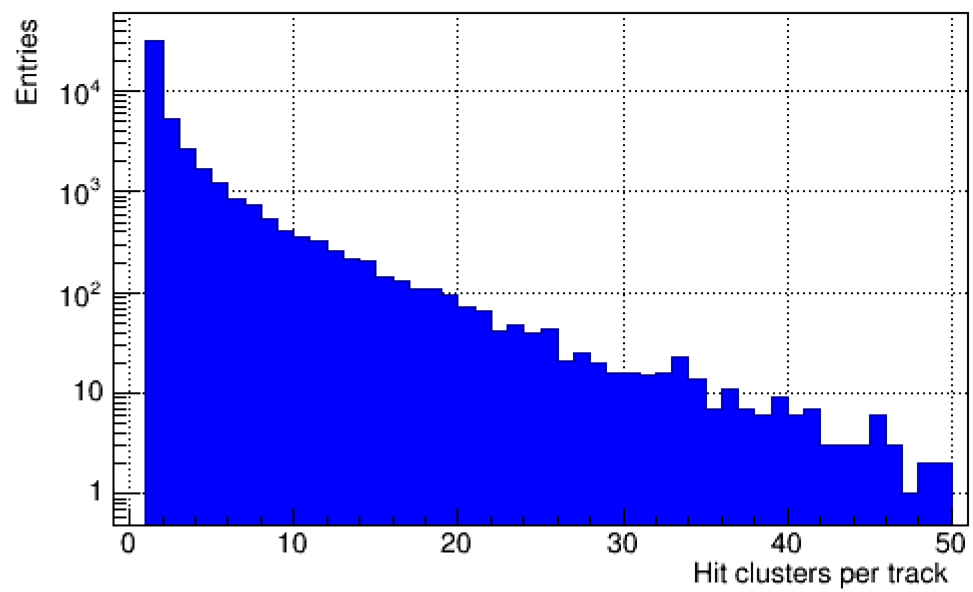
Hit and pixel clusters

- **MARS background tracks produce more hit clusters than IP tracks** (pictures are for barrel VXD layer 5)

IP muons

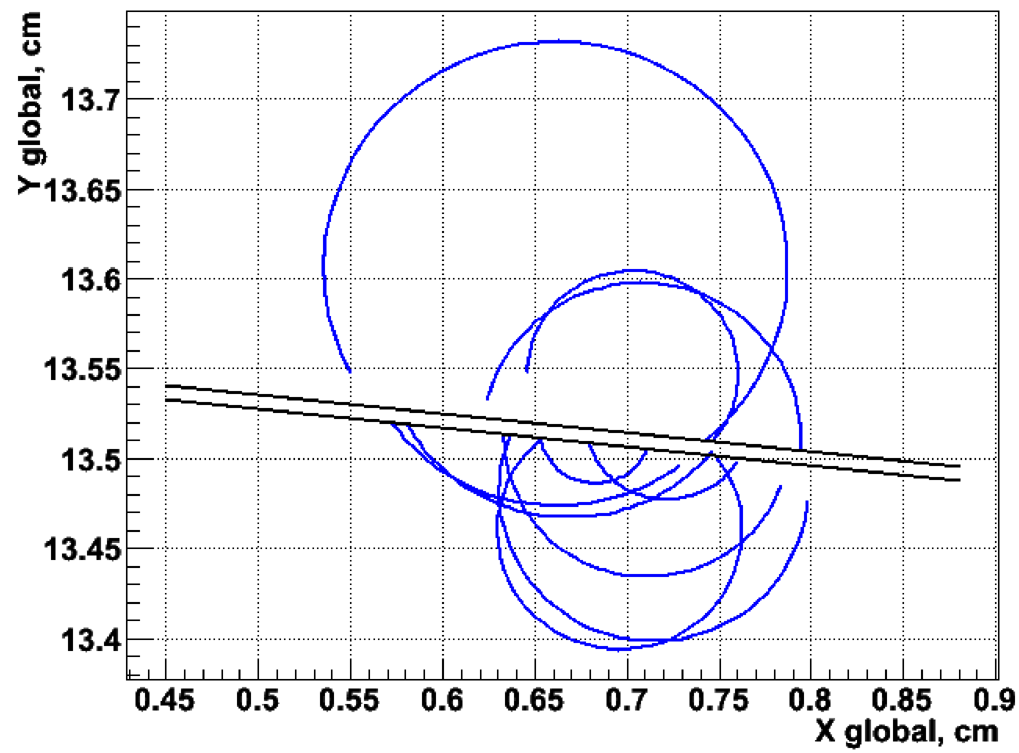


MARS background



Hit and pixel clusters

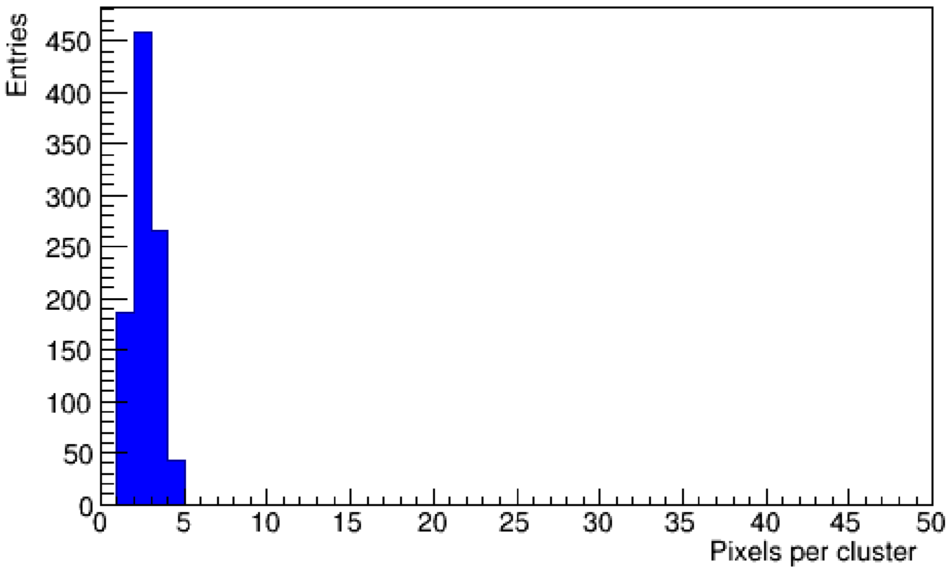
- **MARS background tracks producing many hit clusters**
  - some low energy secondary e- are trapped by magnetic field in sensitive volume of Si barrel layer crossing layer many times
  - example for barrel VXD 75 μm thick layer 5, module 66
  - in magnetic field B=3.5 T secondary e- (produced by MARS photon) with initial P_t ~ 1.4 MeV/c circles with R ~ 1.3 mm and crosses layer 14 times before to stop in the layer



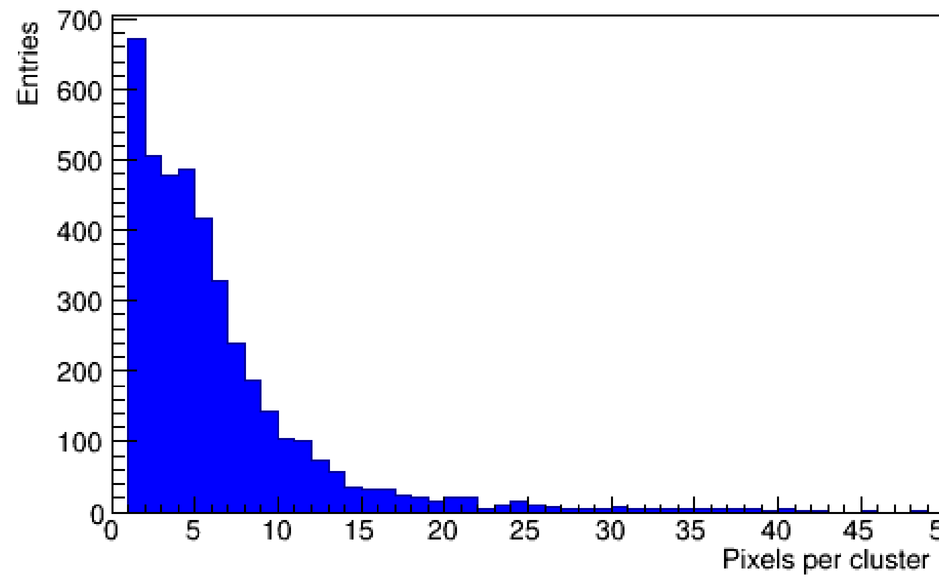
- **Number of pixels crossed by track**

(per cluster of 20μ pixels in VXD barrel layer 5, module 66)

IP muon primary tracks
(MEAN ~ 2 pixels)



Tracks from MARS background
(MEAN ~ 6 pixels)



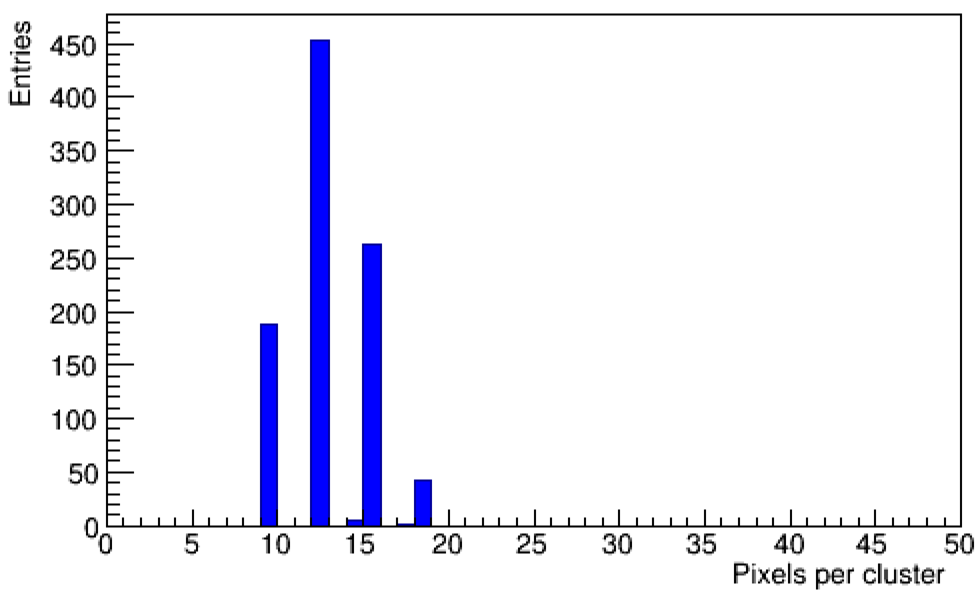
– IP tracks are crossing the whole Si layer in 1-4 pixels (P_t , ϴ)

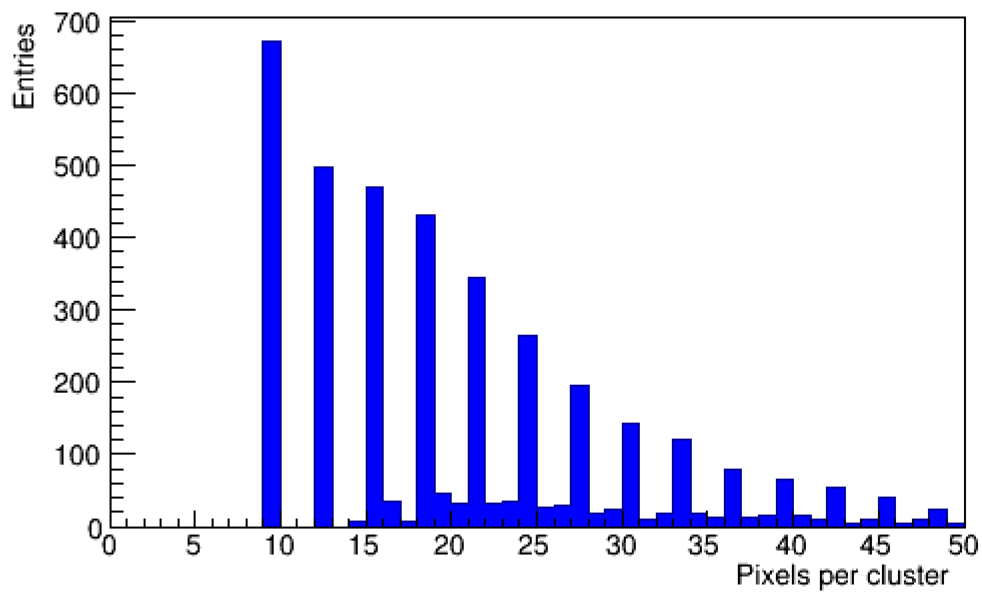
– e- produced by MARS ɣ and n are emerging in the Si layer and travel in all directions, can cross many pixels (100 KeV e- has range of ~85 μm, and ~90% of e- are in 0<Ekin<500 KeV region)

- **Number of pixels crossed by track + neighbors per cluster of pixels** (VXD barrel layer 5, module 66)

IP muon primary tracks
(MEAN ~ 12 pixels)

Tracks from MARS background
(MEAN ~ 20 pixels)





Hit and pixel clusters

- **Number of 20μ pixels per cluster crossed by track + neighbors as MARS background rejection criteria** (VXD barrel layer 5, module 66)

  – cut on number of pixels per cluster vs. efficiency

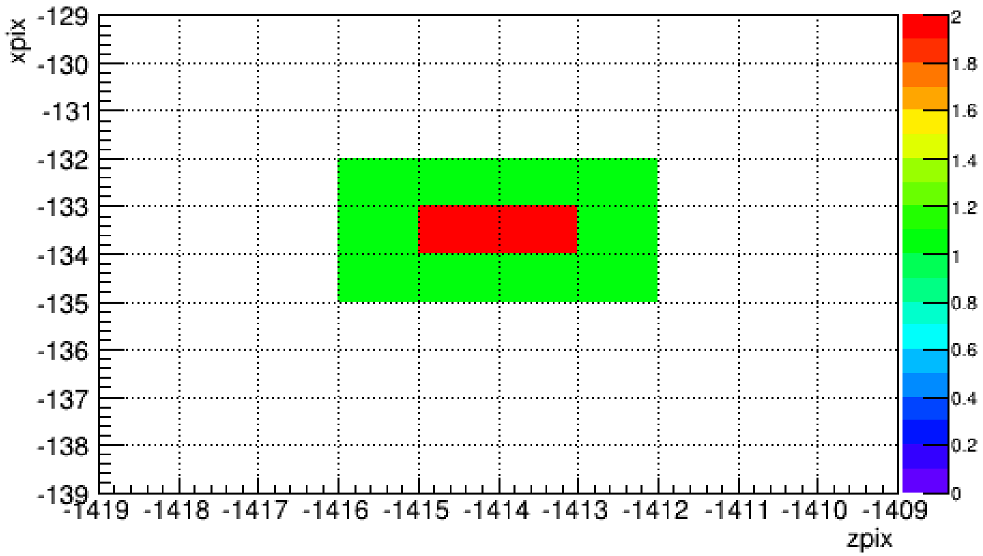
# of pixels	IP	MARS background
<=12	67%	29%
<=15	95%	40%
<=18	100%	52%

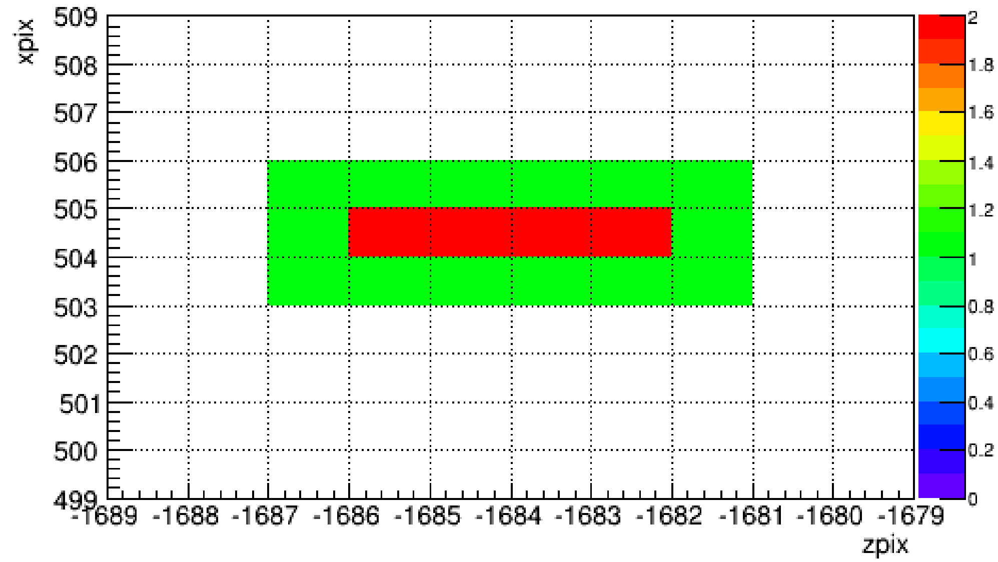
- **Pixels pattern as rejection criteria ? Next slide – patterns after cut on number of pixels in the cluster.**

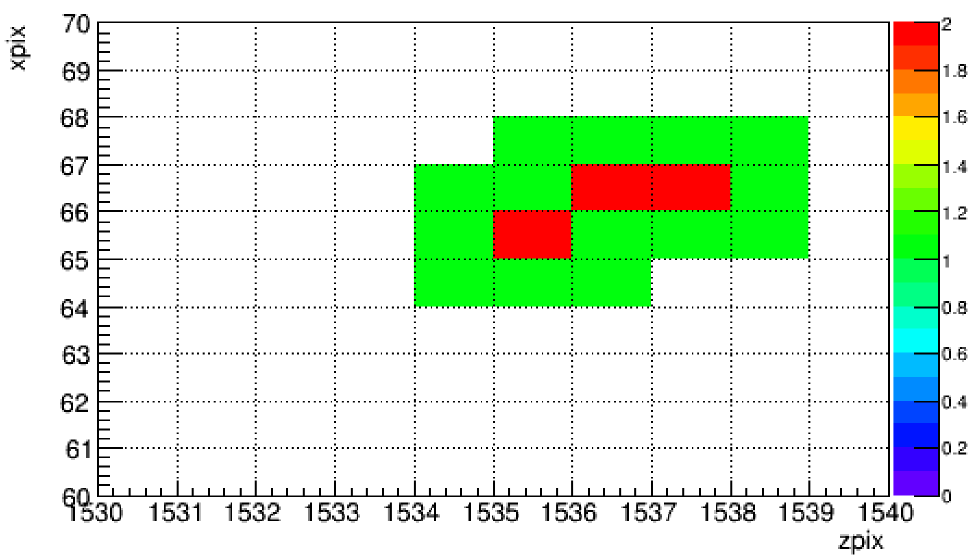
Hit and pixel clusters

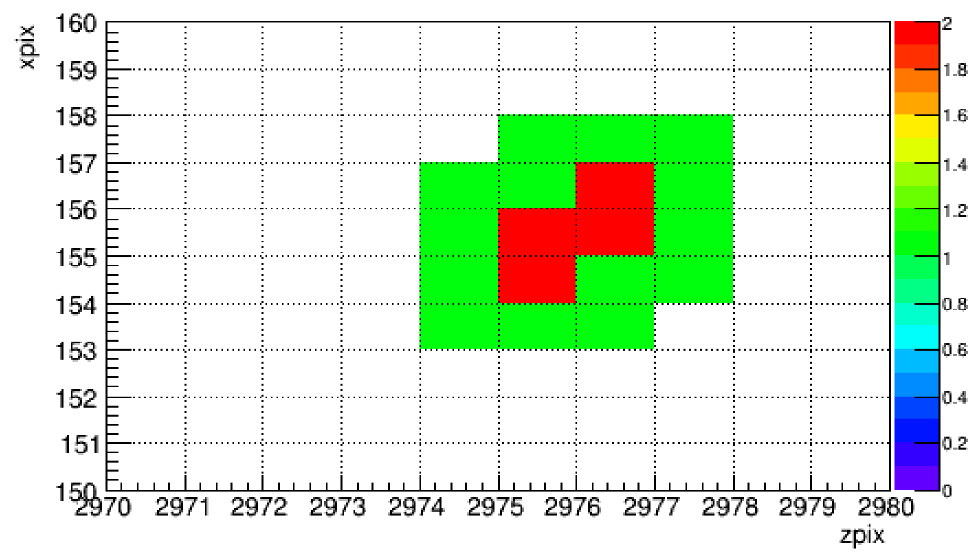
- **Patterns of pixels crossed by track + neighbor pixels**

IP muons | **MARS background**









Conclusions/Plans

- **The muon collider background rejection power of the energy deposition threshold was studied using IP muon and MARS background tracks simulated in barrel layers of Si VXD and Tracker in ILCroot**
  - hit cluster method was introduced to estimate energy deposition per hit cluster
  - fraction of survived background hit clusters is only ~50% in the best case (at large Z of the Tracker barrel layer) at the IP muon hit cluster efficiency of ~99.5%
  - overall background hit cluster surviving fraction is ~70% for VXD and Tracker barrel layers (at the IP muon hit cluster efficiency of ~99.5%)
  - small improvement if use two sides cut
- **Low rejection of MARS background is due to:**
  - large dE/dX of low energy secondary e-
  - some low energy secondary e- are trapped by magnetic field in sensitive volume of Si barrel layer and leave large energy depositions when crossing the layer

Conclusions/Plans

- **Number of pixels per cluster as background rejection method was introduced (example - for barrel layer 5 of VXD, 20μ pixels)**
  – background tracks cross ~3 times more pixels than IP track
  – ~2.5 background rejection factor at 95% IP efficiency if adding adjacent pixels
- **Disclaimer comments:**
  – signal amplitude resolution, front-end electronics noise, charge sharing and cross-talks were not included
- **Plans**
  – double layer criteria study based on hit cluster concept
  – after 3 TeV MARS background is available
    - **insert 3 TeV shielding nozzle into ILCroot geometry**
    - **ILCroot simulation of 3 TeV MARS background in double layer Si VXD and Tracker geometry**
    - **combine timing, double layer, energy deposition and number of pixels per cluster techniques to get overall background rejection**