Update on timing and double layer criteria in ILCRoot VXD and Tracker. A hit rates.

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Outline

- **Introduction**
- **Timing for MARS background particles and ILCRoot hits** (neutron contribution from previous BX)
- **Timing + Double layer criteria** (ladder overlapping hits excluded)
- **Hit rates estimation** (and comparison with CMS)
- **Conclusions/suggestions**

Introduction

- **Working with MARS background simulation results for (750 + 750) GeV $\mu^+ \mu^-$ beams with $2*10^{12}$ muons/bunch each**
  - http://www-ap.fnal.gov/~strigano/mumu/mixture/
  - Background yields/bunch on 10^0 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 (full bunch crossing, weights included) was used as input for ILCRoot simulation of the Si vertex and tracker hits.**
  - Run ILCRoot_2.9.1 release simulation with GEANT4 (4.9.4.p01)
  - ILCRoot output files with hits were analyzed in standing alone code

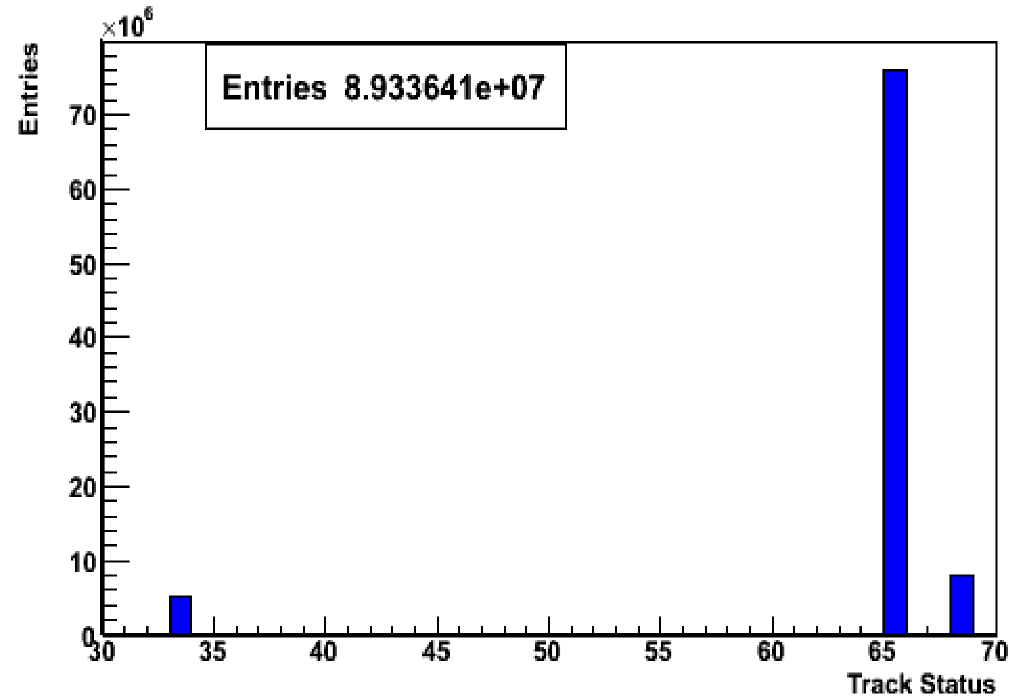
Introduction

- **Hit definition**
  - a snapshot of the physical interaction of a particle in the sensitive region of a detector (GEANT4 User Guide)
  - provided for each step (particle track propagation is simulated in steps) within a sensitive volume
  - includes the position and the time of the step, the momentum and energy of the track, the energy deposition of the step, etc.

- **For each hit ILCRoot stores in bits the status of the track at the time of creating this hit. Some of them are:**
  - Bit 1 (1) - track is inside the sensitive volume
  - Bit 3 (4) - track is exiting sensitive volume
  - Bit 6 (32) - track stopped
  - Bit 7 (64) - track is alive

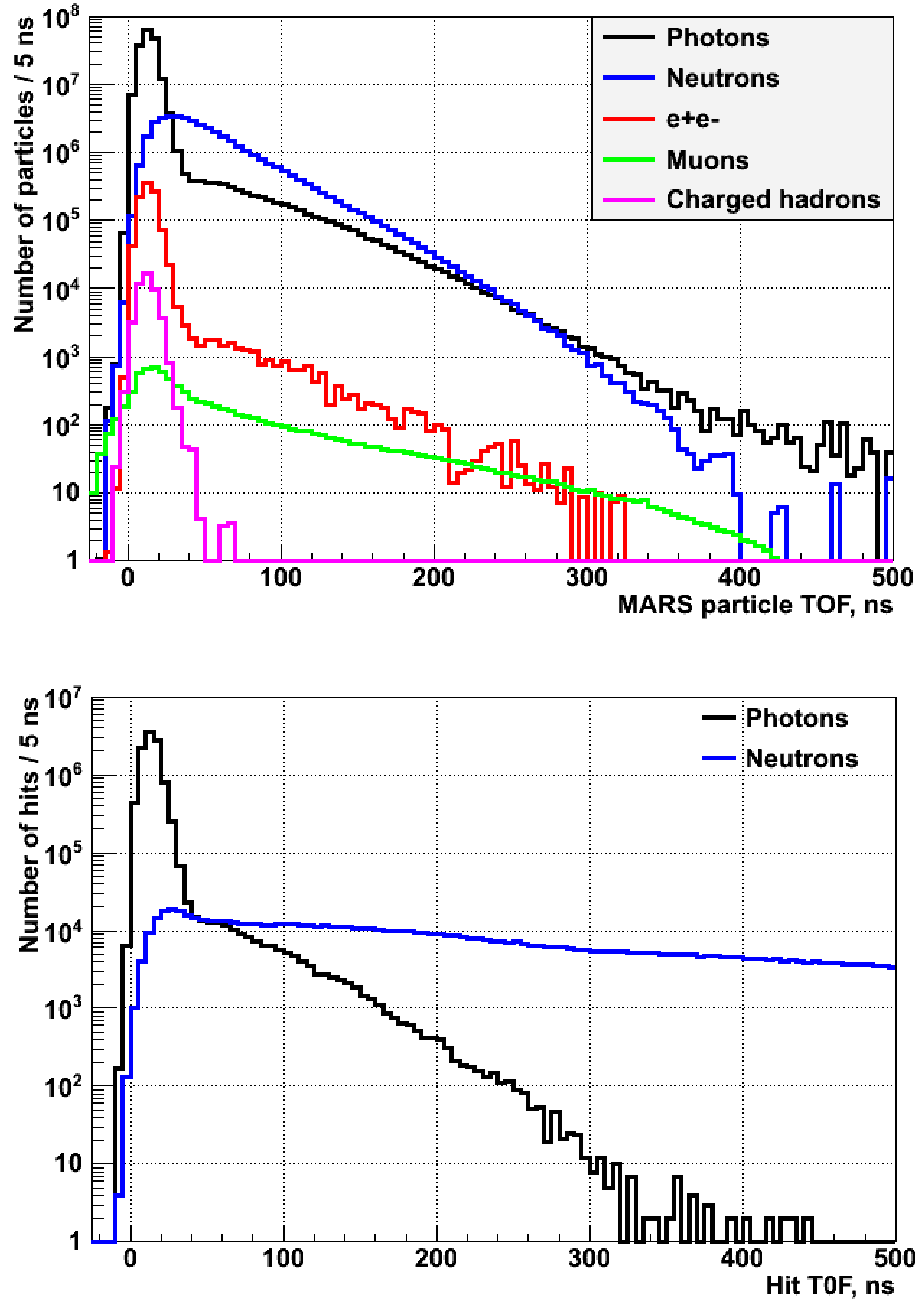
Introduction

- **Observed status of the tracks:**
  - 65=64+1 - alive and inside (most of the hits)
  - 33=32+1 - stopped inside
  - 68=64+4 - alive and exiting



- **For analysis of hits for timing, double layer and hit rate purpose use hits with track status != 65 (tracks exiting or stopped)**
  - hits with track status =65 (hits inside) are used by ILCRoot to sum the energy deposition in the steps along the track and digitize the signal from this track
  - 89.3M hits (all hits from all MARS background particles) reduced to 13.2M hits
  - 87.2M hits (all hits from MARS neutrons+photons) reduced to 12.6M hits
  - one (almost) such hit with track status != 65 represents one track in given sensitive volume

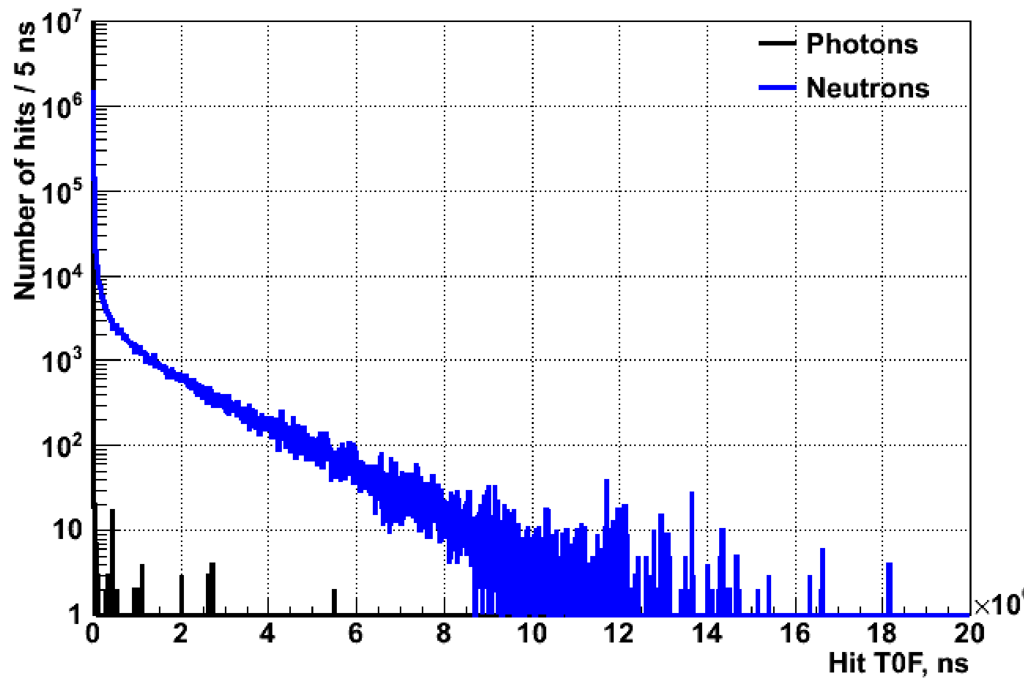
Timing



- **Timing for MARS background particles and ILCRoot hits**
  - MARS background is within ~500 ns w.r.t. a bunch crossing (BX)
  - ILCRoot hits for Si vertex and tracker in the same interval except hits from neutrons

Timing

- **Timing for MARS background particles and ILCRoot hits (cont'd)**
  - The neutron hits tail up to 20 ms (neutron "gas" in detector due to large elastic scattering?)
- **Checking contribution of neutron hits from previous BX. Assume 10 μs between BXs and constant beam intensity.**
  - Look back as far as 10^3 BXs using hits TOF distribution for one BX
  - Number of hits in given BX 10 μs interval is up by ~50% for hits from neutrons but only ~6% for hits from all background particles
  - Negligible contribution in interval of 0-150 ns (~4% for neutrons, ~0% for all particles), no impact on timing in this interval



Timing + double layer criteria update

- **Reminding**
  - A stacked layer design to reduce random neutral background occupancy based on inter-layer correlations
  - Use ILCRoot Si Tracker and Vertex hits and geometry to illustrate the method, see details and references in previous talk, https://indico.fnal.gov/conferenceDisplay.py?confId=4823
- **Update**
  - Corrected formulae to estimate the number of fake signals
  - Hits from overlapping regions of ladders are excluded
- **A new version of ILCRoot was released on Nov. 29 by Vito Di Benedetto**
  - New ROOT,GEANT4 and VMC packages
  - **Implementation of double layer geometry in the Si Vertex and Tracker detectors with runtime controlled parameters**
  - **Now ILCRoot is capable of simulating a realistic double layer geometry with ~mm interlayer distance** - will try it ASAP for current MARS neutral background data (not the subject of this talk)

Timing + double layer criteria update

- **Corrected formula to estimate the number of fake signals**
  - Assume flat uncorrelated random hits distributions in both layers
  - **N** - total number of all pixels per layer,
    n_1 - number of hits in layer 1,
    n_2 - number of hits in layer 2
  - Then using binomial distribution get

    N_f – number of pairs of pixels with hits in both layers (fake signals)

    $$N_f = N * [1 - (1-1/N)^{n1}] * [1 - (1-1/N)^{n2}]$$

    N_1 – number of pixels with hits in layer 1

    $$N_1 = N * [1 - (1-1/N)^{n1}]$$

    N2 – number of pixels with hits in layer 2

    $$N_2 = N * [1 - (1-1/N)^{n2}]$$
  - Fraction of pixels with fake signal

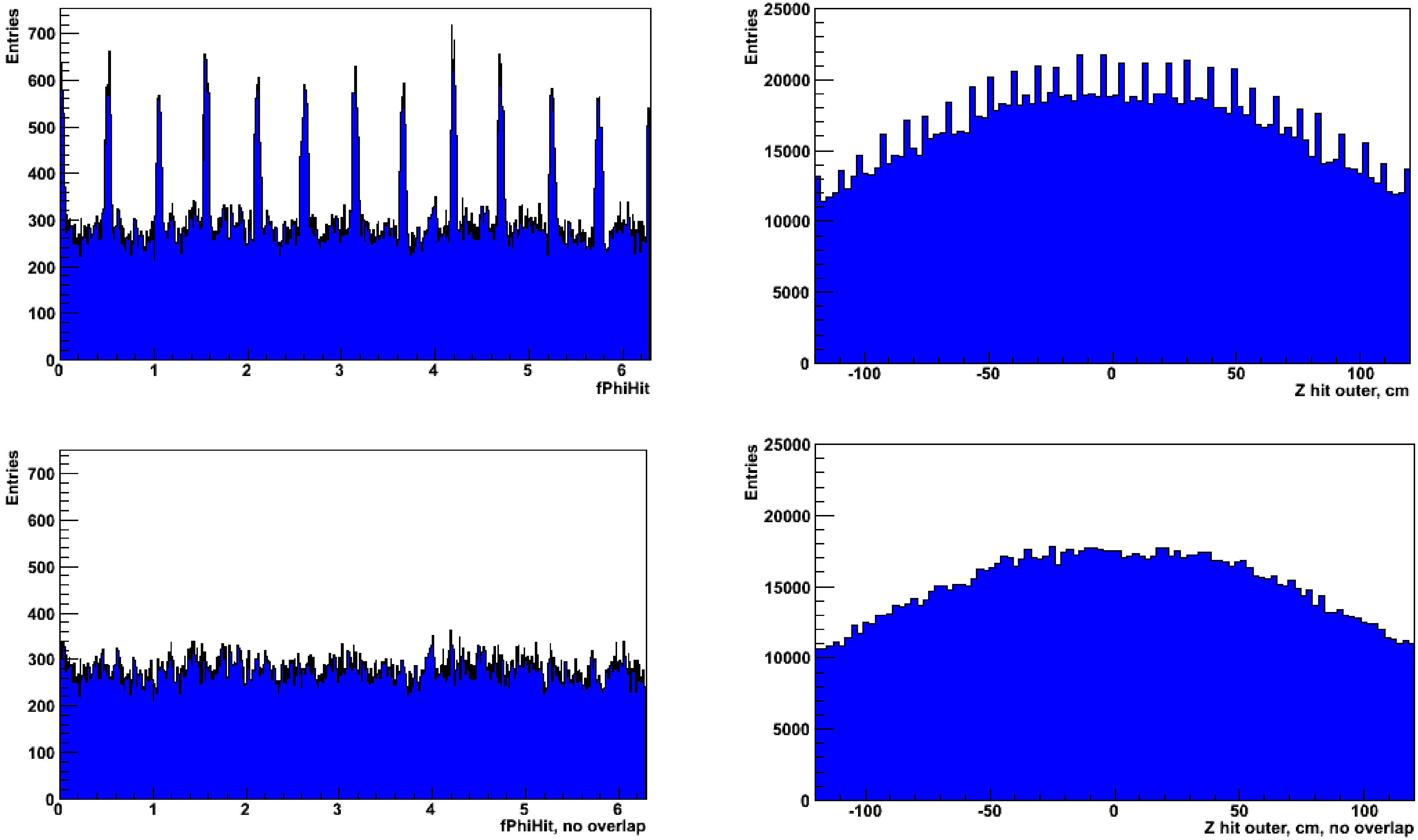
    $$N_f/N \sim (n_1/N) * (n_2/N) \quad \text{(if n1, n2 << N)}$$
  - Rejection **R** of pixels with hits in layers 1 and 2

    $$R_1 = N_1/N_f \sim 1/(n_2/N) \quad \text{(if n2 << N)}$$

    $$R_2 = N_2/N_f \sim 1/(n_1/N) \quad \text{(if n1 << N)}$$

Timing + double layer criteria update

- **Hits from overlapping regions of ladders are excluded**



Timing + double layer criteria update

- Number of hits and active 500 micron "pixels" vs. timing gate width before and after double layer criteria (for MARS background neutrons + photons), L1 – L2 VXD Barrel (layers 1-2)

Timing gate	None	25 ns	10 ns	3 ns
# of hits in L1 # of hits in L2	90036 86900	84551 81375	19148 18819	301 354
# of pixels in L1 # of pixels in L2	Np1=64556 Np2=62418	61476 59311	16887 16402	281 330
Timing rej. of pixels in L1 Timing rej. of pixels in L2	Np1/64556=1 Np2/62418=1	Np1/61476=1.05 Np2/59311=1.05	Np1/16887=3.8 Np2/16402=3.8	Np1/281=230 Np2/330=189
Nf, fake signals observ. Nf, fake signals predict. Predicted/Observed	26196 29414 1.12	23632 26720 1.13	1825 2073 1.14	2 1 0.5
Fake occupancy, Nf/N*	17%	15%	1.2%	0.001%
Comb. rej. Np1/Nf in L1 Comb. rej. Np2/Nf in L2	2.5 2.4	2.7 2.6	36 34	~32,000 ~31,000

* N = 153840 – number of 500x500 μ pixels per outer layer L2

Timing + double layer criteria update

- Number of hits and active 500 micron "pixels" vs. timing gate width before and after double layer criteria (for MARS background neutrons + photons), L4 – L5 Tracker Barrel (layers 17-18)

Timing gate	None	25 ns	10 ns	3 ns
# of hits in L4 # of hits in L5	1.55M 1.51M	1.09M 0.97M	0.224M 0.199M	4504 3923
# of pixels in L4 # of pixels in L5	Np1=1.49M Np2=1.45M	1.04M 0.93M	0.216M 0.191M	4355 3753
Timing rej. of pixels in L4 Timing rej. of pixels in L5	**Np1/1.49M=1** **Np2/1.45M=1**	**Np1/1.04M=1.4** **Np2/0.93M=1.6**	**Np1/0.216M=6.9** **Np2/0.191M=7.6**	**Np1/4355=342** **Np2/3753=386**
Nf, fake signals observ. Nf, fake signals predict. Predicted/Observed	29713 30938 1.04	13733 14075 1.02	522 601 1.15	0 0
Fake occupancy, Nf/N*	**0.04%**	**0.02%**	**~0.001%**	**0%**
Comb. rej. Np1/Nf in L4 Comb. rej. Np2/Nf in L5	**50** **49**	**109** **105**	**2860** **2780**	**>1.49M** **>1.45M**

* N = 74.1M – number of 500x500 μ pixels per outer layer L5

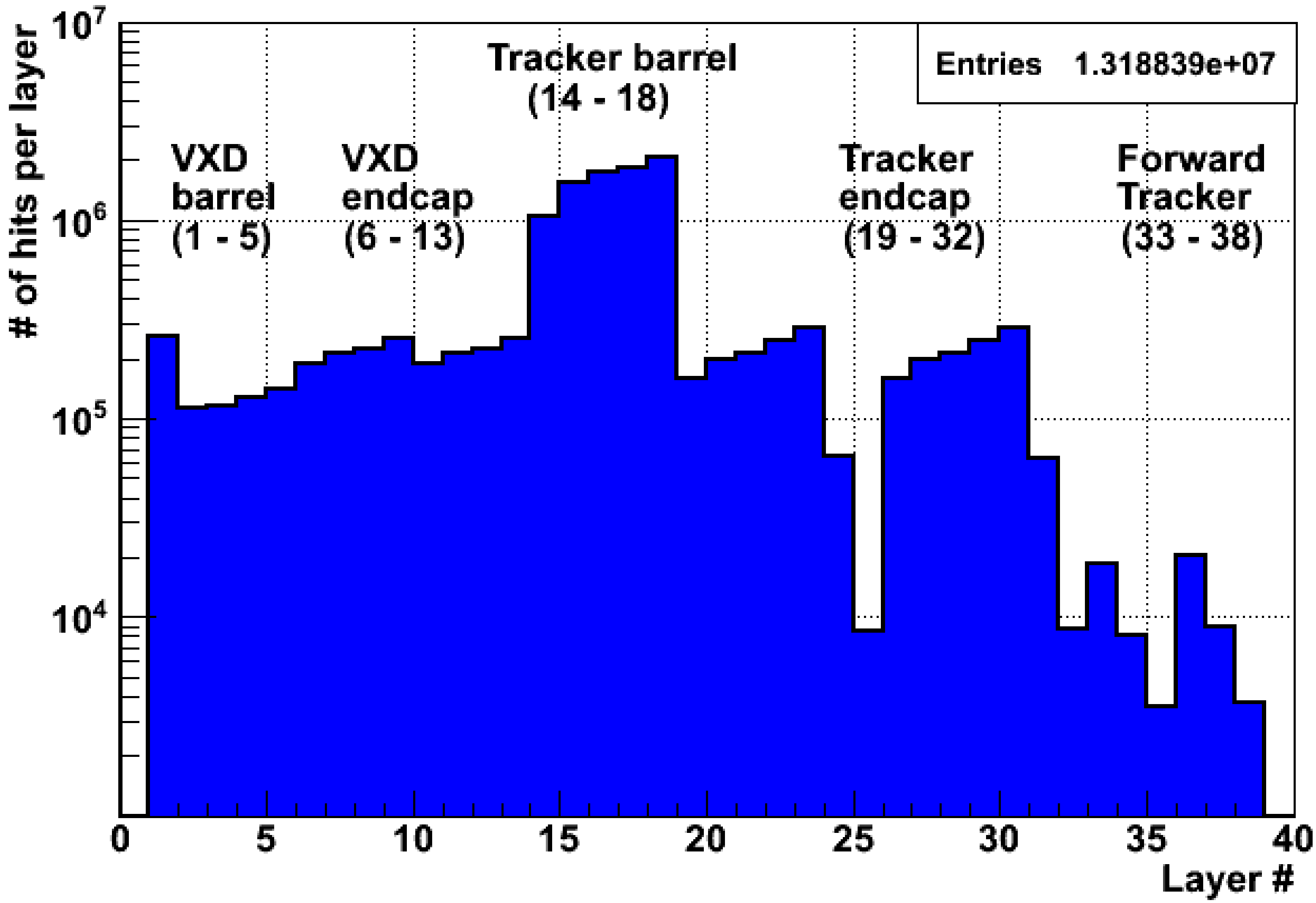
Timing+double layer criteria conclusion

- **Combination of timing and double layer criteria to reduce muon collider beam neutral background was studied using hits**
  - MARS full bunch crossing neutral background statistics as an input (~177M photons, ~40M neutrons)
  - ILCRoot Si vertex and tracker barrel detectors with 500x500 micron "pixel" segmentation and 3.5T magnetic field as an example, large distance between layers
  - The double layer approach can potentially provide large reduction of the number of pixels with neutral background hits:
    - at current ILCRoot geometry and MARS photon+neutron background after 10^0 shielding cone the 10 ns timing cut and double layer correlation gives:
      - rejection factor of ~30-40 and remaining "pixel" occupancy of 1-2% in first two layers of the vertex barrel detector
      - rejection factor of ~2800 in outer two layers of the tracker barrel detector
    - in realistic geometry (interlayer distance ~ mm) will be limited by fraction of secondary tracks reaching the second layer (function of magnetic field, layer orientation in magnetic field, track momentum distribution and space between layers) – subject of study in latest ILCRoot release

Hit rate

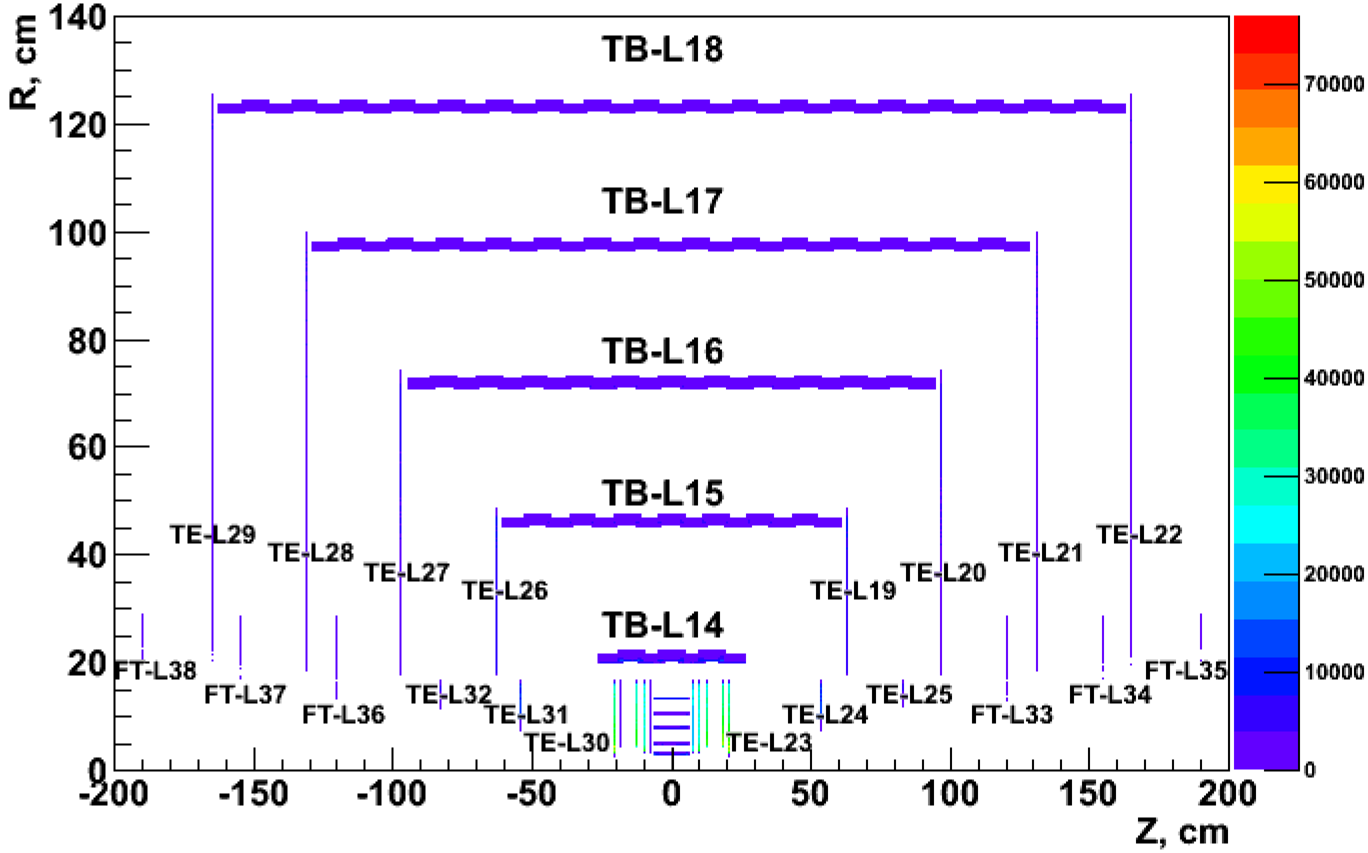
- **For a rough hit rate estimation**
  - no timing and double layer cuts
  - constant muon beams intensity
  - contribution of neutrons from previous bunch crossings included (matters for neutron hits, small for all hits)
  - barrel layers are approximated by cylinders
  - number of pixels is estimated as S_{layer}/S_{pixel}
  - no correction for Z and Phi overlapping of ladders in layers
  - ignore signals induced in adjacent pixels
- **A hit rate estimation is important**
  - electric power
  - hit dissipation

- **Number of hits per layer**

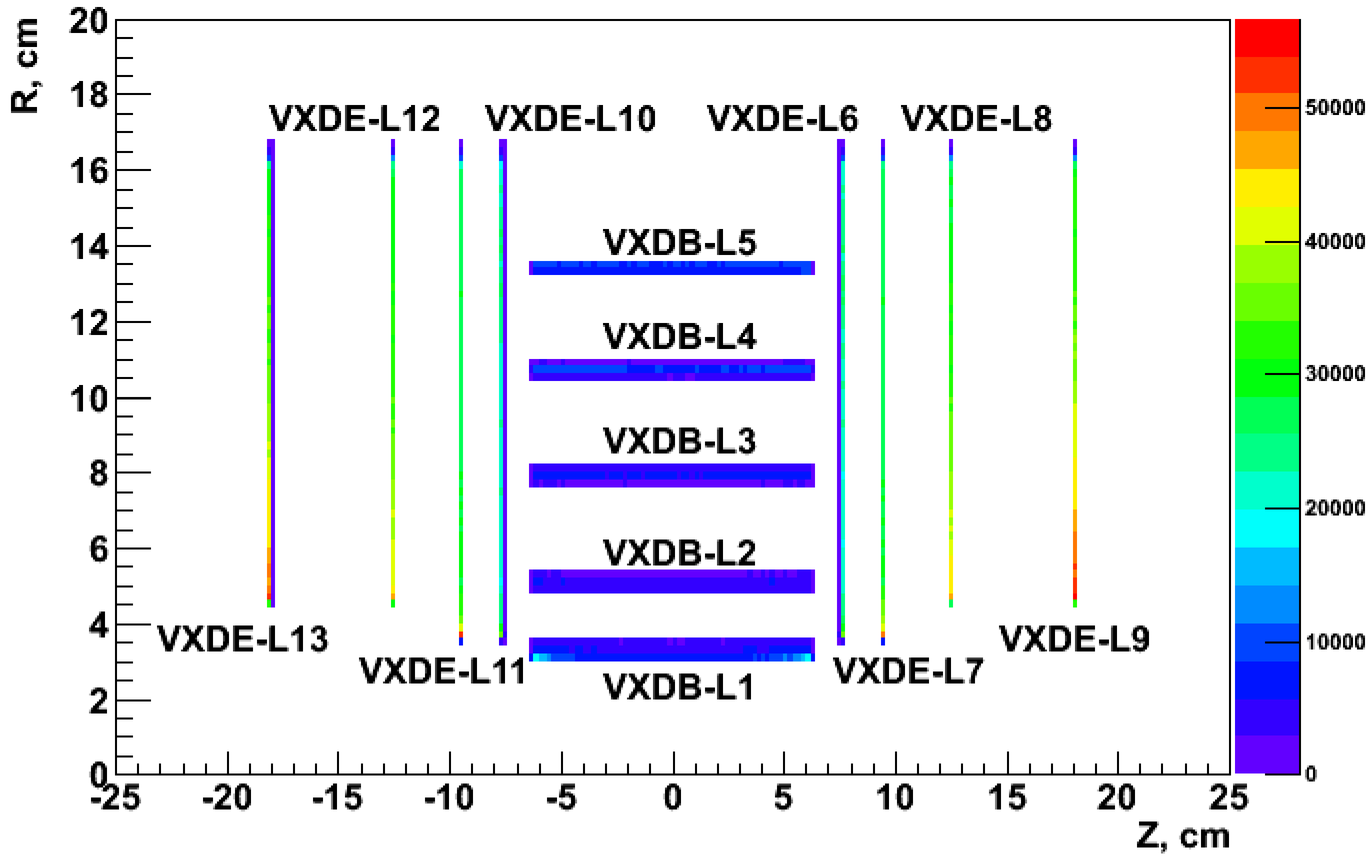


Hit rate

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

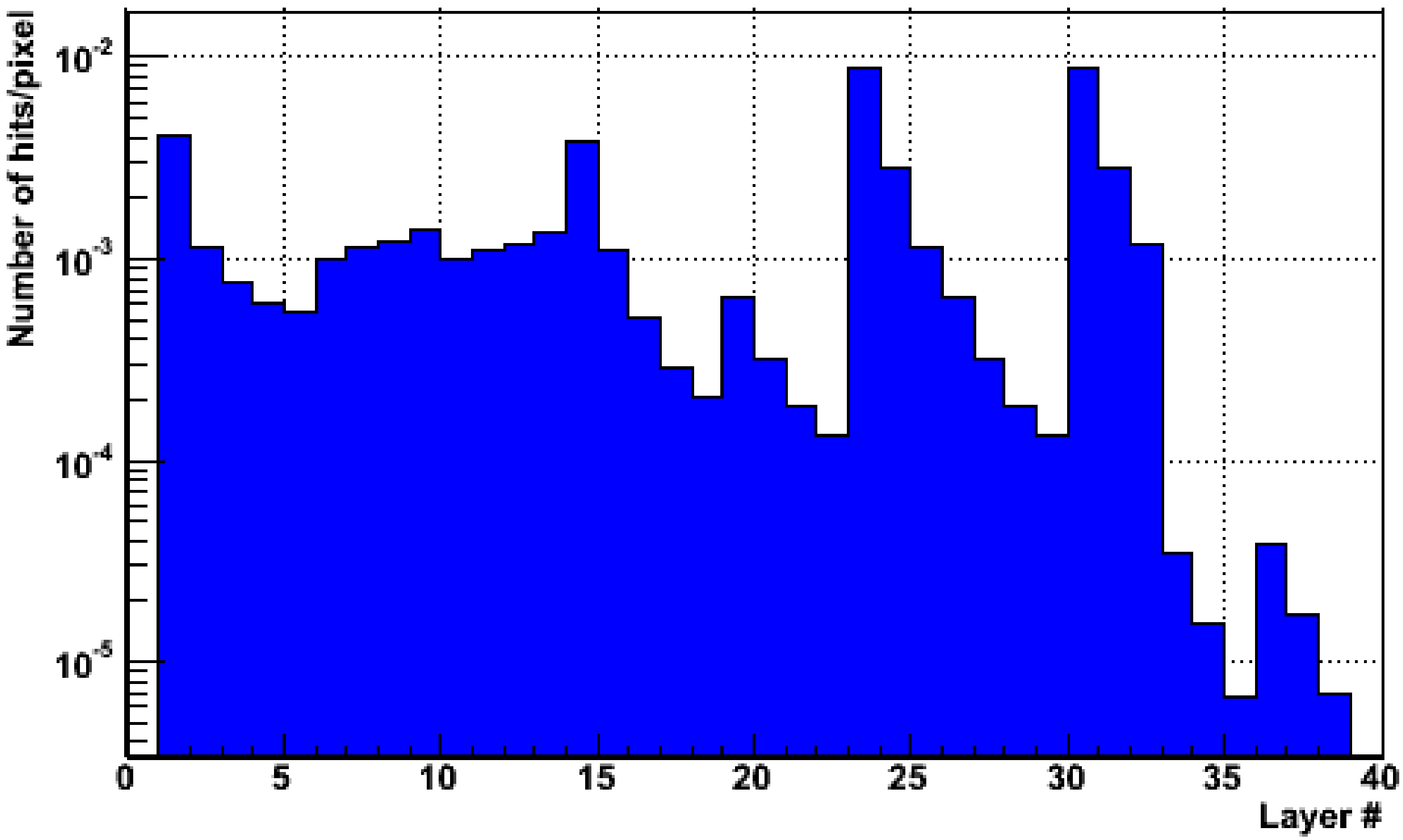


- **Hit R vs. Z for ILCRoot vertex detector (VXD) layers**
  - VXDB – VXD Barrel, VXDE – VXD Endcap



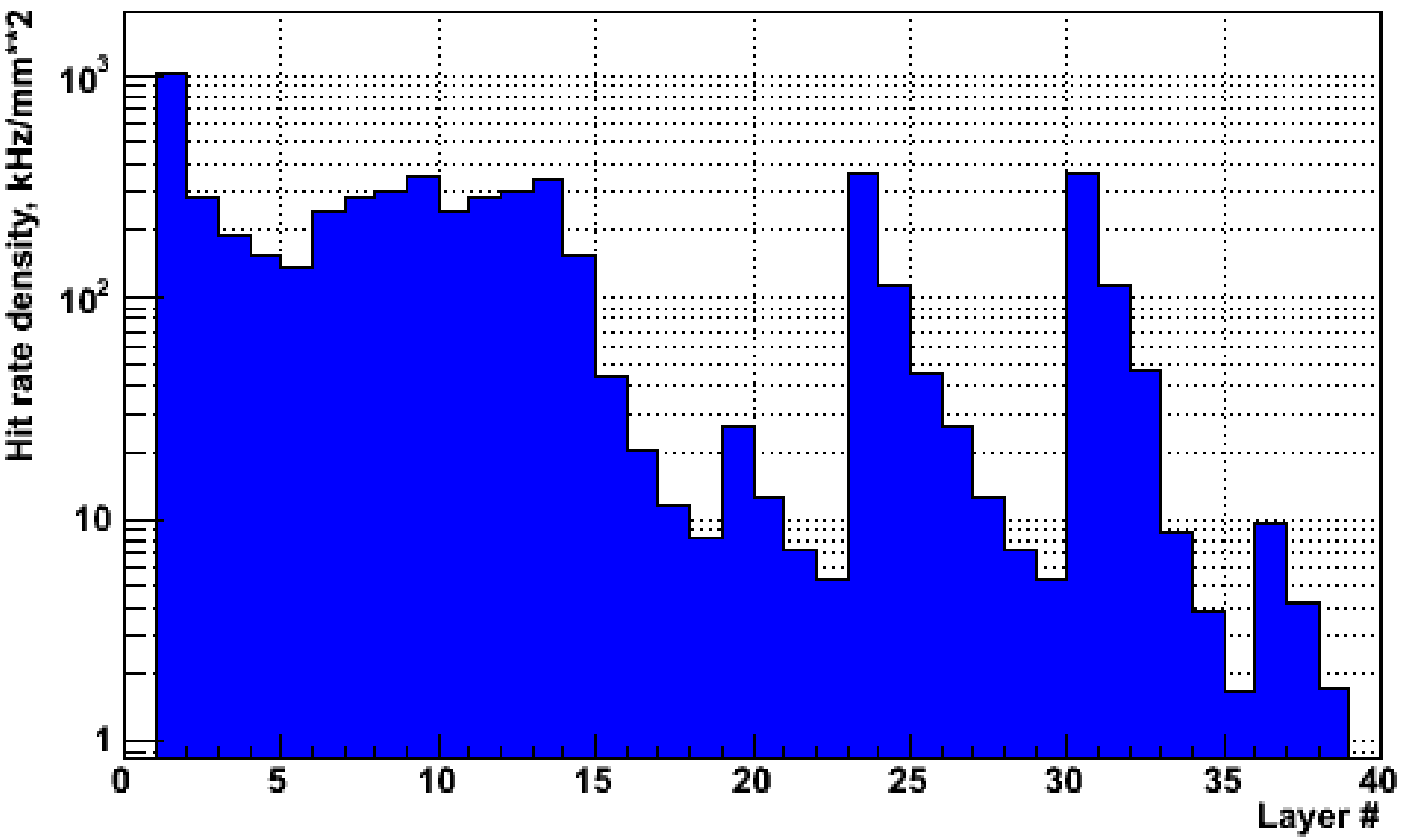
Hit rate

- **Number of hits per pixel vs. layer**
  - 3.5e+10 pixels in 38 layers of ILCRoot VXD and Tracker (calculated as S_{layer}/S_{pixel} and therefore overestimated), 20 and 50 micron pixels
  - Total area S ~ 75 m^2



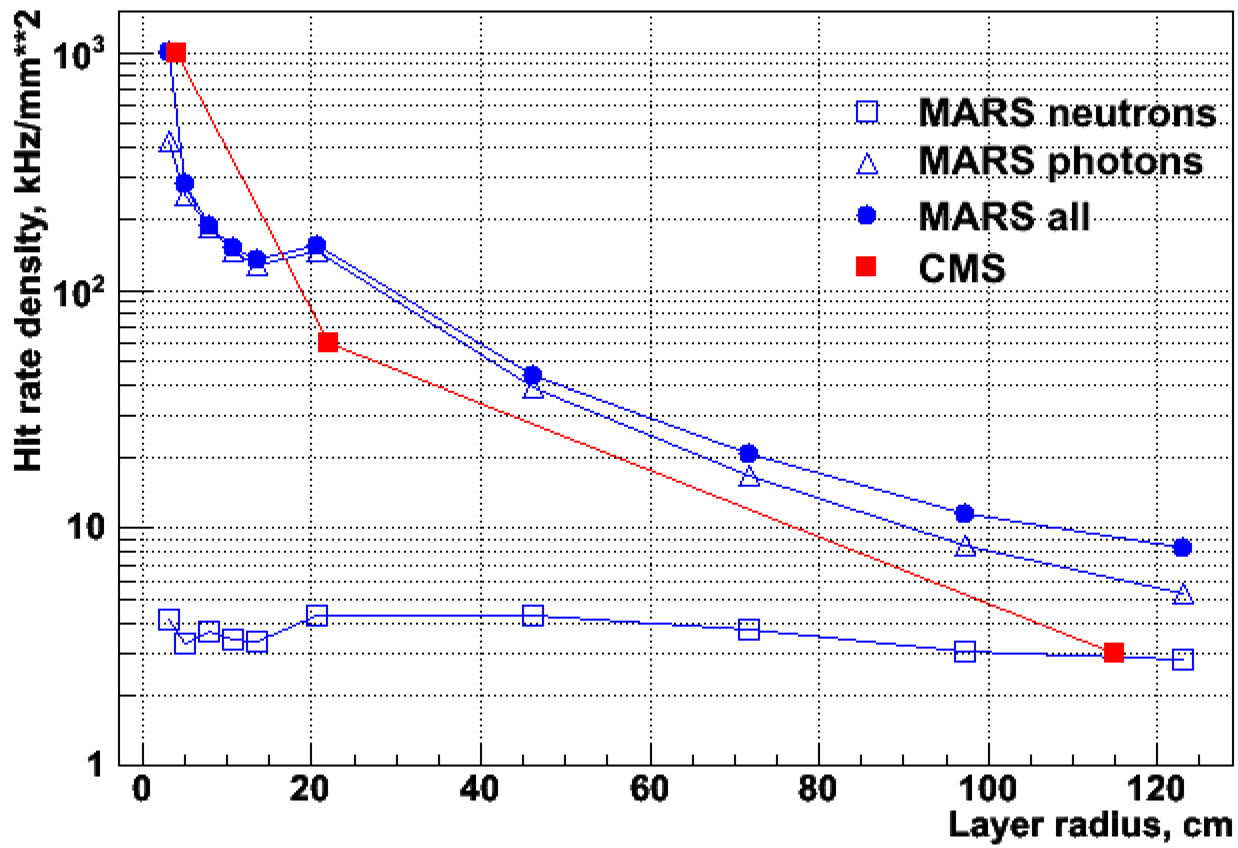
Hit rate

- **Hit rate average density per layer**
  - As N * (number of hits per layer) / (area of layer), $N=10^5$ for 10 μs bunch crossing



Hit rate

- **Hit rate average density vs. radius (ILCRoot VXD and Tracker Barrels)**



- **CMS data**
  - at the LHC designed luminosity of 10^{34} cm^{-2} s^{-1} and 7+7 TeV ~ 1000 particles from more than 20 overlapping pp interactions are traversing the CMS tracker for each 25 ns bunch crossing ("The CERN Large Hadron Collider: Accelerator and Experiments", vol. 2)
  - disclaimer: assume the similar "hit" definition in CMS simulation (?) data, e.g. one hit per track in given layer (however, this gives ~2.5 times less rate at R=4 cm and L~40 cm)

Hit rate

- **Hit rate average density vs. radius (cont'd), kHz/mm^2**

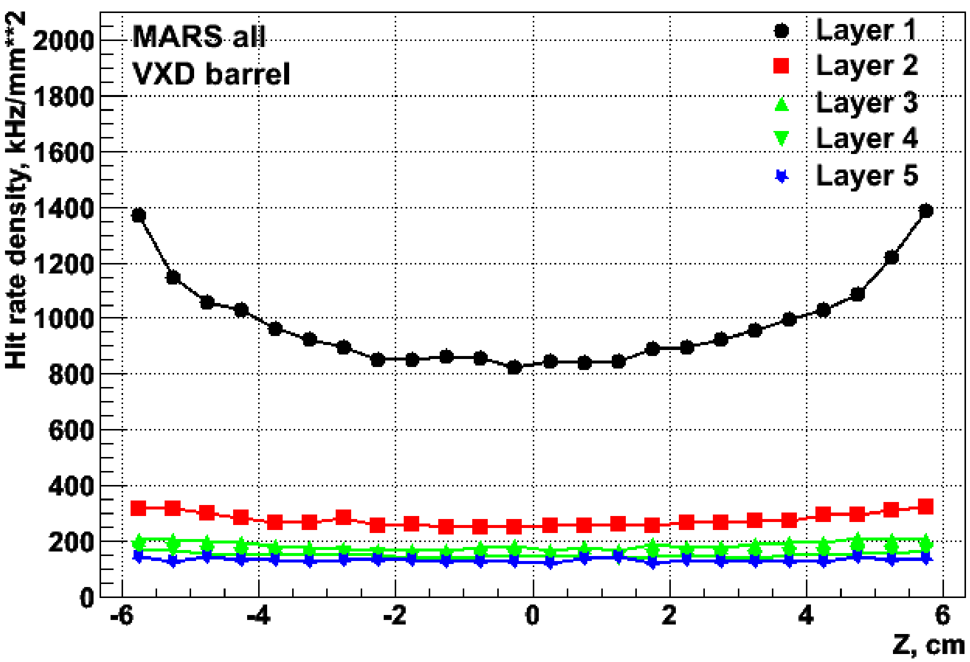
R, cm	3.3	4.0	5.1	7.9	10.7	13.4	20.7	22.0	46.2	71.7	97.3	115	123
ILCRoot	1010		281	188	152	134	153		44	21	12		8.2
CMS		1000						60				3	

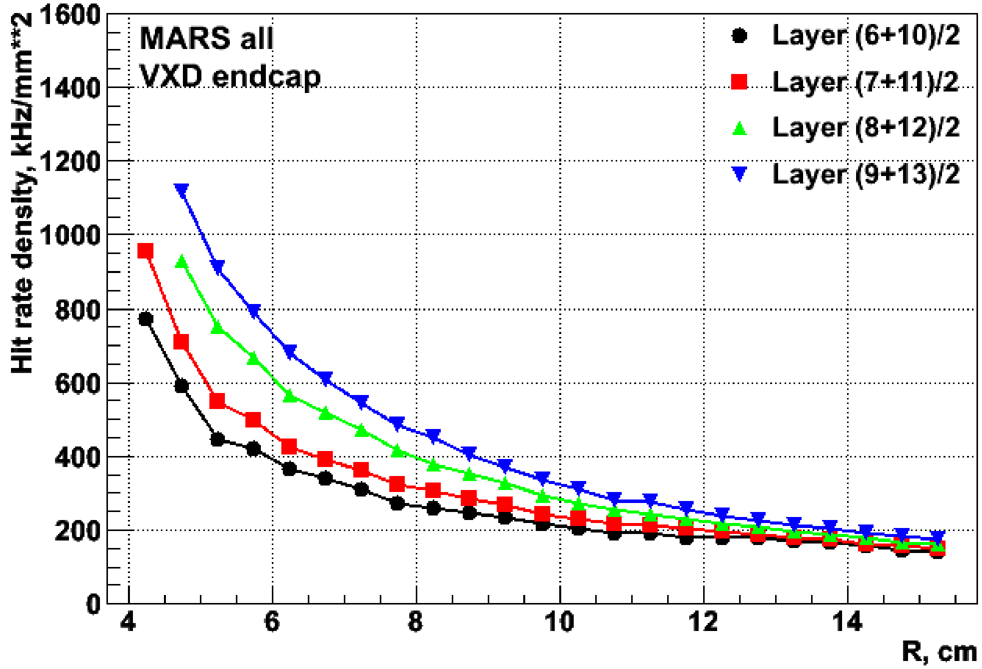
- **ILCRoot (VXD+Tracker) and CMS inner Si tracker parameters**

	ILCRoot	**CMS**
Total number of channels	~35,000M pixels	66M pixels, 9.3M strips
S, m^2	75	200
Si sensitive thickness, μ	100	300-500
Pixel size, μ	20, 50	100x150 for pixels 80-180 for strips
Radiation length (X_0) at $\eta = 0$	? (to be estimated)	0.4
Electric power, kW		60

Hit rate

- **Hit rate density vs. Z (barrel) and R (endcaps) for MARS background in VXD**
  - Large in VXD barrel layer 1 due to e-e+ contribution (3.5T magnetic field)
  - Irregularities are caused by overlapping of ladders in layers
  - 0.5 cm wide bin in Z, R, averaged over Phi





Conclusions

- **Timing – almost no MARS neutron hit contribution from previous BXs to all hits in an interval of 0 - 150 ns**
- **Timing + Double layer criteria were illustrated in current ILCRoot geometry with ladder overlapping excluded**
  - have a good potential of neutral background rejection
  - new ILCRoot release provides more realistic geometry with a few mm distance between sublayers, plan is to try it ASAP
- **A hit rate average density estimation for MARS muon beam background in ILCRoot vertex and tracker detector barrels**
  - ~1 MHz/mm^2 in the 1-st VXD layer at R = 3.3 cm (~the same for IP tracks in CMS tracker at R = 4 cm)
  - ~150 kHz/mm^2 and ~10 kHz/mm^2 at R~22 and 115 cm correspondingly (2-3 times higher than in CMS for IP tracks at the same radii)
  - main contribution comes from photons (and e+e- for the 1-st VXD layer)
  - hits from neutrons have about the same rate average density of 3 - 4 kHz/mm^2 for all barrel layers (R = 3 - 120 cm)
  - observed MARS background **signal** rate will be higher due to charge induced in adjacent pixels

Plans (suggestions for discussion)

- **Simulation + analysis**
  - test the latest ILCRoot release with double layer VXD and Tracker geometry
  - run ILCRoot simulation for current MARS data and IP muons at different interlayer distances and magnetic fields (parameters to be determined, scaling factor for magnetic field?)
  - run ILCRoot simulation for coming MARS new data and get results on the hit level (timing and double layer criteria, rates)
- **We need to continue with ILCRoot development**
  - to include timing into SDigits and Digits and implement double layer criteria?
  - realistic signal in front-end (collection and resolution time, induced signals etc) and corresponding background rejection after timing and double layer cuts on the SDigits/Digits level – expect less optimistic results than on the hit level
  - manpower ?