Timing and double layer criteria to suppress Si vertex and tracker hits for MARS/ILCRoot simulated muon beam backgrounds

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Outline

- **The MARS/ILCRoot modeling results**
- **Timing for vertex and tracker detector hits**
- **Double layer criterion**
- **Combining timing and double layer criteria**
- **Conclusion**

The MARS/ILCRoot modeling results

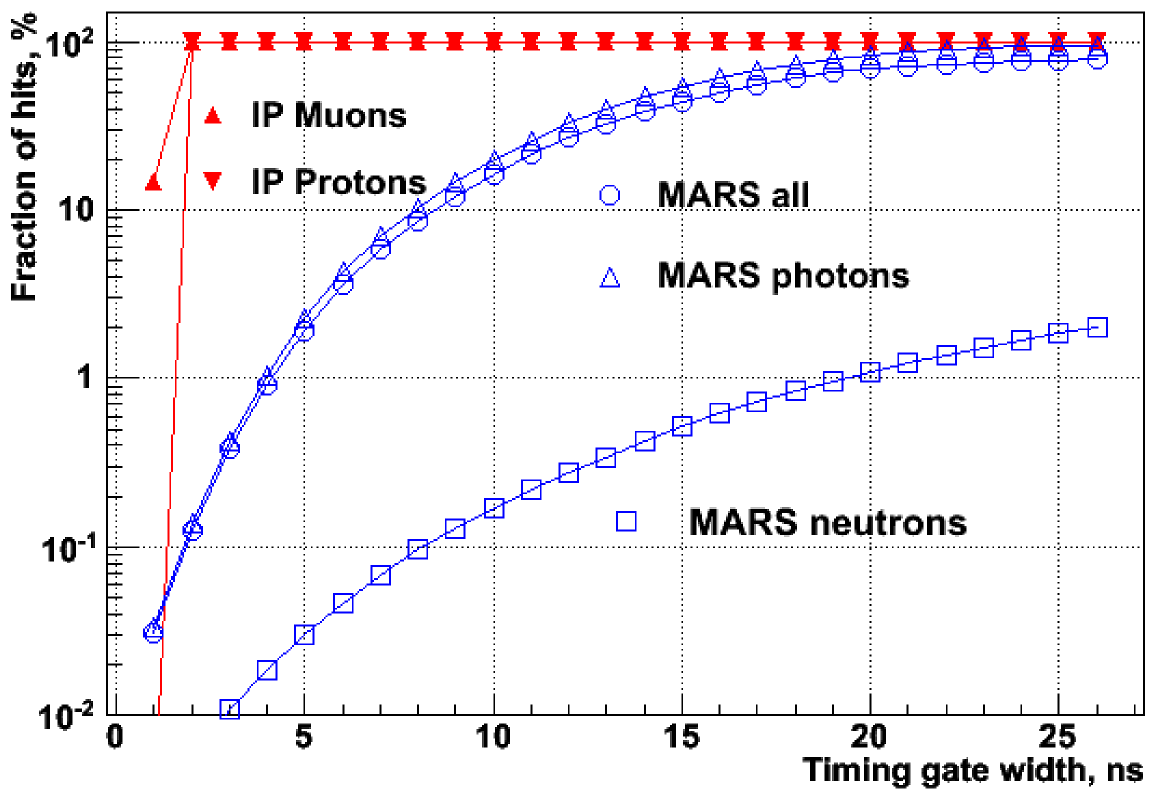
- **Working with MARS background simulation results for (750 + 750) GeV $\mu^+ \mu^-$ beams with $2*10^{12}$ muons/bunch each**
  - http://www-ap.fnal.gov/~strigano/mumu/mixture/
  - Background yields/bunch on 10^0 nozzle surface and MARS thresholds

	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 statistics (full bunch crossing, MARS weights included) was used as inputs for ILCRoot simulation of the Si vertex and tracker hits.**
  - Three separate inputs (all MARS particles, neutrons and photons)
  - Run ILCRoot_2.9.1 (latest release) simulation with latest GEANT4 (4.9.4.p01)
  - ILCRoot output files with hits were analyzed in standing alone code
  - Hits for tracks leaving sensitive volume (or stopping) are analyzed
  - Timing results were presented at Muon Collider 2011 workshop in Colorado

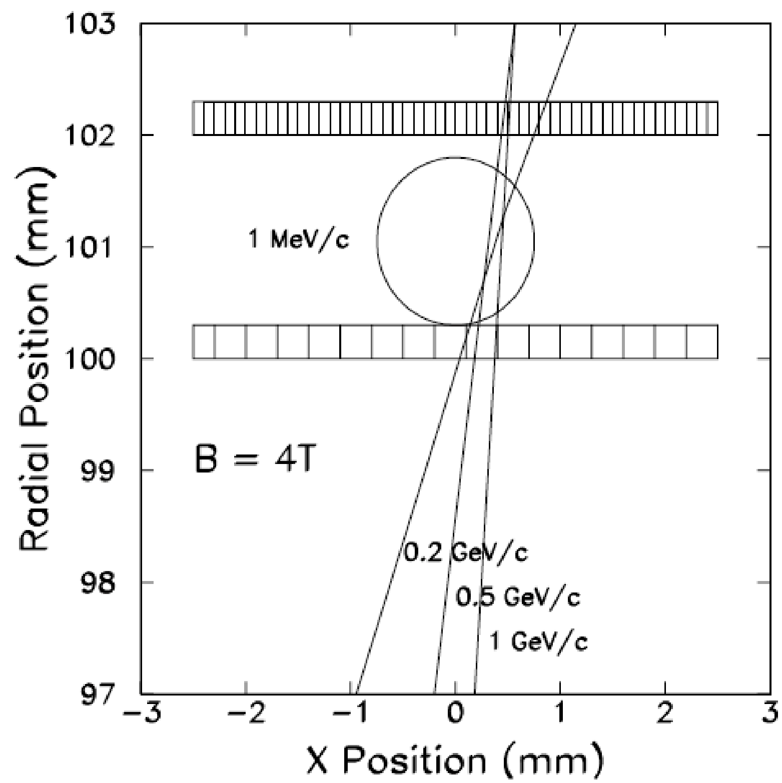
Timing for vertex and tracker detector hits

- **Si vertex and tracker hits timing**
  - Tune timing relative to expected arrival time of IP photon
  - Adjust timing gate width to detect hits from IP particles with ~100% efficiency
  - The hits from muon collider background particles will be suppressed due to their significant time spread (mostly neutrons)
  - With 3 ns gate rejection factor ~260 for all MARS particles, photons and more than 1000 for neutrons
  - For now ignore collection time and front-end resolution time in Si



Double layer criterion

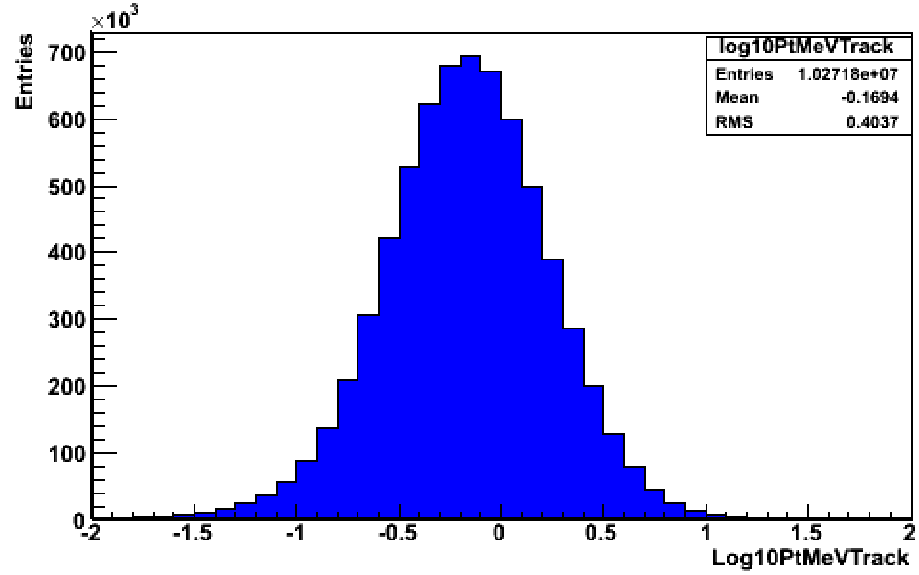
- **A stacked layer design to reduce random neutral background occupancy based on inter-layer correlations**
  - Suggested by S. Geer for the muon collider in 1996
  - A single layer replaced with two layers being 1-2 mm apart
  - Soft MeV tracks from background hit in one layer do not reach the second layer (B=4T)
  - IP physics track makes hits in both layers
  - Readout takes AND of appropriate pixel pairs in both layers suppressing background hits

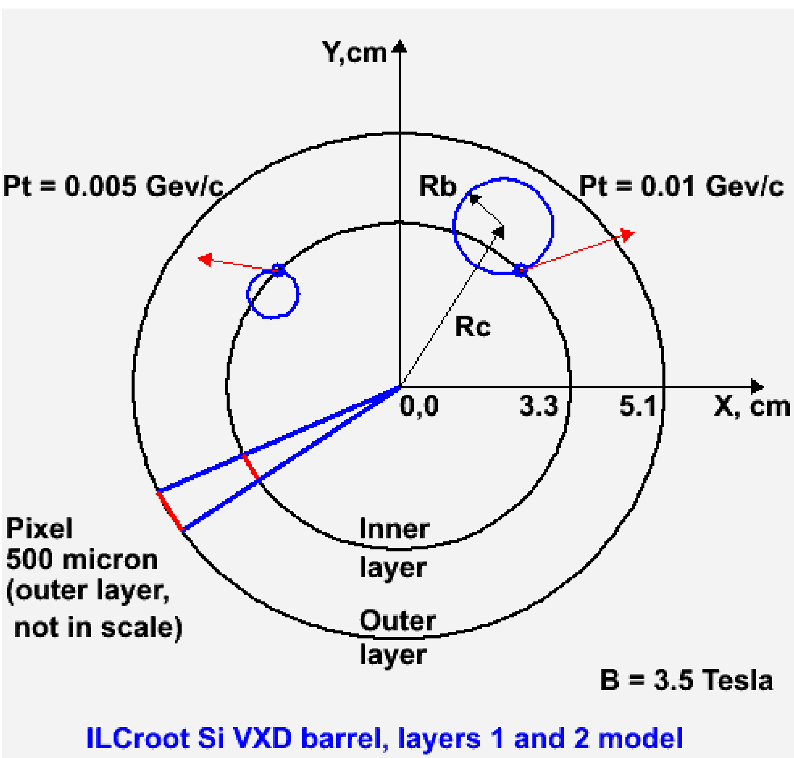


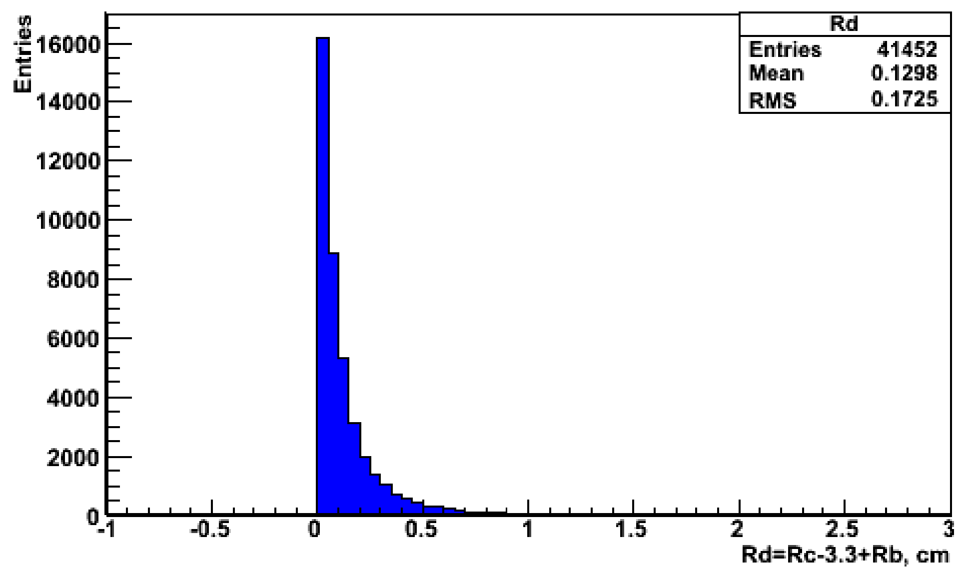
- **Fermilab is developing similar technology for the CMS upgrade,** see R. Lipton, "New Detectors for Muon Collider", http://conferences.fnal.gov/muon11

Double layer criterion

- **Pt and R distributions of the secondary charged tracks produced by MARS background particles (photons) in ILCRoot vertex and tracker detectors**
  - All Pt are less than 10-30 MeV/c
  - Maximum distance of the secondary track trajectory at B=3.5 T relatively to the layer 1 of the vertex barrel detector < 1 cm

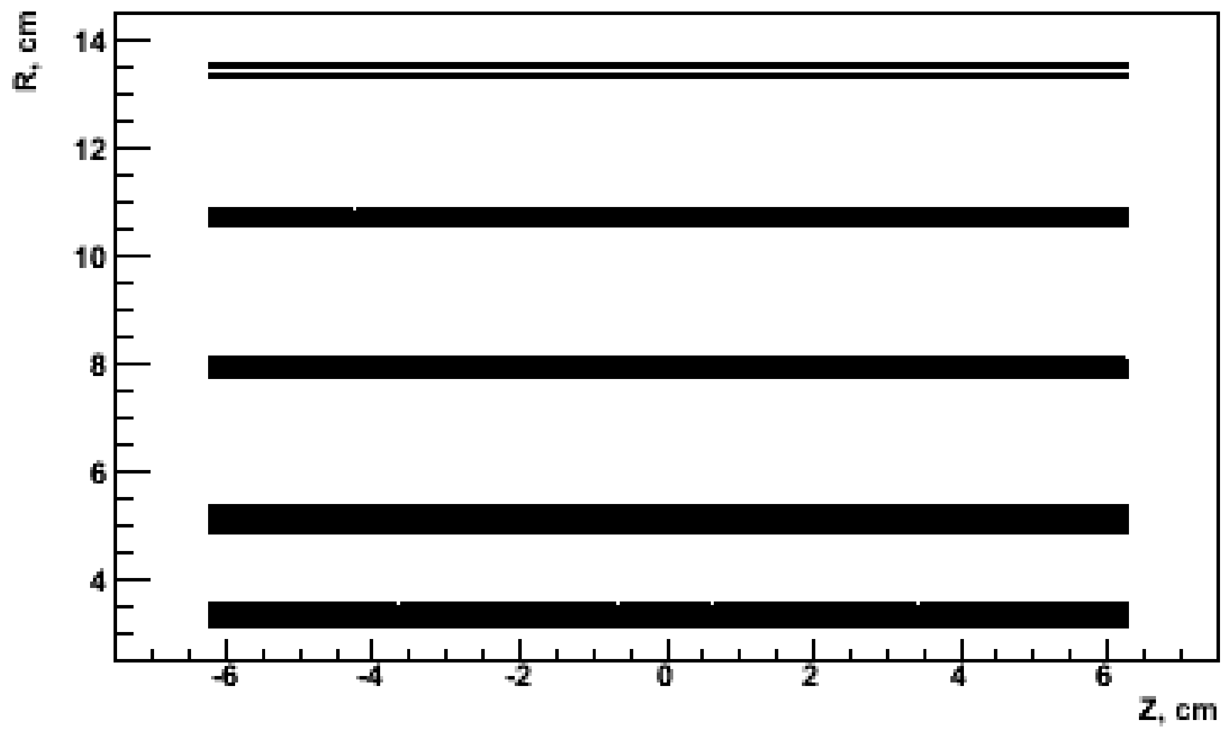






Double layer criterion

- **Illustrate it in ILCRoot for Si vertex detector and MARS full bunch crossing background statistics**
  - Direct implementation (e.g. 1-2 mm between layers) not possible without rewriting the ILCRoot hard coded geometry
  - Use instead the 1-st and 2-nd layers of the vertex barrel Si detector in their existing geometry as having minimal radial distance between them (R1~3.2 cm, R2~5.1 cm, -6 cm < Z < 6 cm)



Double layer criterion

- **Illustrate it in ILCRoot for Si vertex detector and MARS full bunch crossing background statistics (cont'd)**
  - ILCRoot collects signals coming within an area of ~200x200 microns
  - Assume 500x500 microns "pixels" on the surface of the outer layer (layer 2) projected in Z and Phi onto the inner layer (layer 1) to keep one and the same number of pixels in both layers (but resulting in smaller R*Phi pixel size in the inner layer):
    - Outer layer: 500x500 microns, 152960 pixels
    - Inner layer: 500x320 microns, 152960 pixels
- **If a pair of pixels with the same Z and Phi in both layers has at least one hit in each pixel accept this pair as pixels with signals from physics charged track (fake signal)**

Double layer criterion

- **Illustrate it in ILCRoot for Si vertex detector and MARS full bunch crossing background statistics (cont'd)**
  - Assume that background hit distributions in two layers with ~2 cm distance between them are not very much different from one in double layer structure with layer separation of 1 - 2 mm (less than 10%, see tables in the next slides)
  - The rejection power of the double layer idea will be overestimated – almost none of the secondary tracks make through a 2 cm distance to reach the second layer at the magnetic field of 3.5T
  - Do not look at efficiency of having hits from IP physics track in a pair of pixels with the same Z and Phi in both layers - irrelevant in this background study
  - Results are presented separately for photons and neutrons for illustration, but the making sense final result should be obtained for photon+neutron data (available and update will follow)

Combining timing and double layer criteria

- Number of hits and active 500 micron "pixels" vs. timing gate width before and after double layer criteria (for background photons), L1 - L2 VXD

Timing gate	None	25 ns	10 ns	3 ns
L1, # of hits L2, # of hits	104303 94614	98776 89715	22421 20582	357 400
L1, # of pixels L2, # of pixels	Np1=70289 Np2=65437	67612 62911	19430 17725	333 372
L1, timing rejection L2, timing rejection	Np1/70289=1 Np2/65437=1	Np1/67612=1.04 Np2/62911=1.04	Np1/19430=3.6 Np2/17725=3.7	Np1/333=211 Np2/372=176
Nf, # of fake signals	30759	28418	2365	2
Fake signal occupancy, Nf/152960*	20%	19%	1.5%	0.001%
L1, comb. rej. Np1/Nf L2, comb. rej. Np2/Nf	2.3 2.1	2.5 2.3	29.7 27.7	35144 32718

* - 152960 – number of 500x500 micron pixels per layer

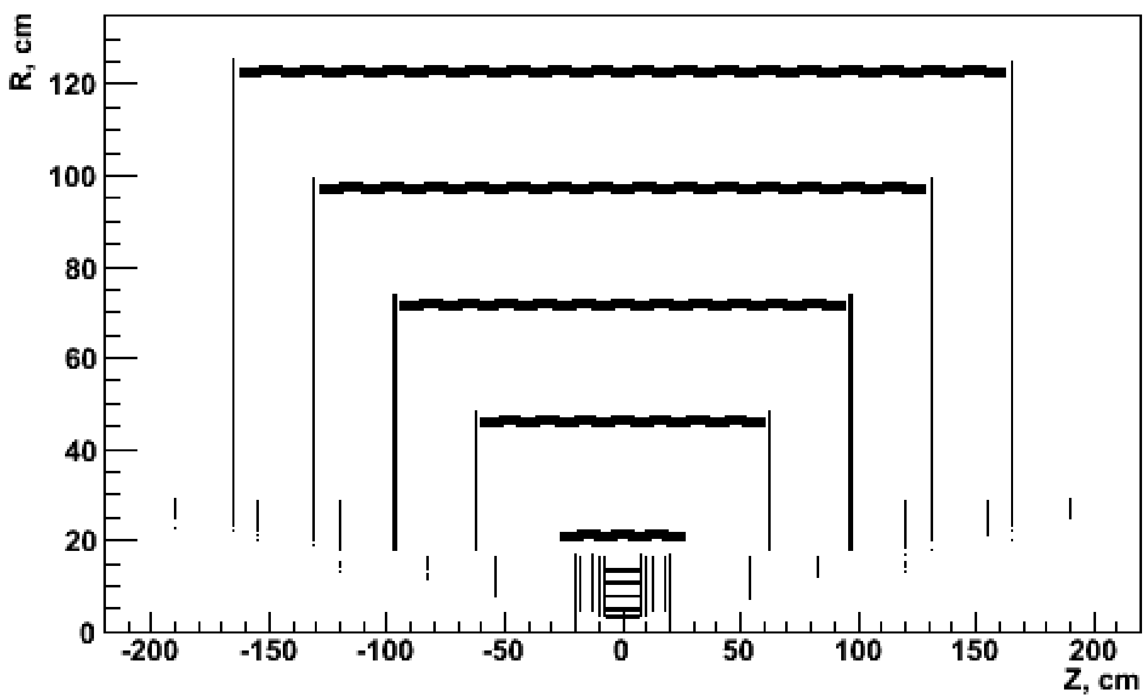
Combining timing and double layer criteria

- **Number of hits and active 500 micron "pixels" vs. timing gate width before and after double layer criteria (for background neutrons), L1 – L2 VXD**

Timing gate	None	25 ns	10 ns	3 ns
L1, # of hits L2, # of hits	1020 1254	59 77	2 0	0 0
L1, # of pixels L2, # of pixels	Np1=975 Np2=1224	59 75	2 0	0 0
L1, timing rejection L2, timing rejection	Np1/975=1 Np2/1224=1	Np1/59=16 Np2/75=16	Np1/2=487	
Nf, # of fake signals	11	0	0	0
Fake signal occupancy, Nf/152960*	0.007%	0%	0%	0%
L1, com. rej. Np1/Nf L2, com. rej. Np2/Nf	89 111			

* - 152960 – number of 500x500 micron pixels per layer

- **For comparison consider also layers 4 and 5 of the Si tracker barrel**
  - R4 ~ 97 cm,   R5 ~ 123 cm,   -120 cm < Z < 120 cm
  - Assume 500x500 microns "pixels" on the surface of the outer layer (layer 5) projected in Z and Phi onto the inner layer (layer 4) to keep one and the same number of pixels in both layers (but resulting in smaller R*Phi pixel size in the inner layer):
    - Outer layer: 500x500 microns, 74.12M pixels
    - Inner layer: 500x400 microns, 74.12M pixels



Combining timing and double layer criteria

- Number of hits and active 500 micron “pixels” vs. timing gate width before and after double layer criteria (for background photons), L4 – L5 Tracker

Timing gate	None	25 ns	10 ns	3 ns
L4, # of hits L5, # of hits	1.29M 1.16M	1.21M 1.08M	0.25M 0.22M	5001 4421
L4, # of pixels L5, # of pixels	Np4=1.23M Np5=1.10M	1.16M 1.03M	0.24M 0.21M	4839 4228
L4, timing rejection L5, timing rejection	Np4/1.23M=1 Np5/1.10M=1	Np4/1.16M=1.06 Np5/1.03M=1.07	Np4/0.24M=5.1 Np5/0.21M=5.2	Np4/4839=254 Np5/4228=260
Nf, # of fake signals	19455	17093	677	1
Fake signal occupancy, Nf/74.12M*	0.026%	0.023%	0.001%	0%
L4, com. rej. Np4/Nf L5, com. rej. Np5/Nf	63 57	72 64	1817 1624	1.23M 1.10M

* - 74.12M – number of 500x500 micron pixels per layer

Combining timing and double layer criteria

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

Timing gate	None	25 ns	10 ns	3 ns
L4, # of hits L5, # of hits	0.45M 0.53M	5298 5765	296 281	14 12
L4, # of pixels L5, # of pixels	Np4=0.44M Np5=0.52M	4959 5395	271 259	12 11
L4, timing rejection L5, timing rejection	Np4/0.44M=1 Np5/0.52M=1	Np4/4959=89 Np5/5395=96	Np4/271=1623 Np5/259=2007	Np4/12=36700 Np5/11=47300
Nf, # of fake signals	3023	0	0	0
Fake signal occupancy, Nf/74.12M*	0.004%	0%	0%	0%
L4, comb. rej. Np4/Nf L5, comb. rej. Np5/Nf	146 172			

* - 74.12M – number of 500x500 micron pixels per layer

Combining timing and double layer criteria

- **For double layer criterion the number of fake signals can be estimated**
  - Assume flat uncorrelated random pixels distributions in both layers
  - **N** - total number of all pixels per layer,
    n1 - number of pixels with random hits in layer 1,
    n2 - number of pixels with random hits in layer 2
  - Then using binomial distribution
    get **Nf** – number of pairs of pixels with hits in both layers

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

  - Corresponding occupancies **Nf/N ~ (n1/N) * (n2/N)**
    and rejections **R1=n1/Nf ~ 1/(n2/N),**
    R2=n2/Nf ~ 1/(n1/N)

Combining timing and double layer criteria

- **Compare prediction and data for layers 1 – 2 of VXD, N=152960 “pixels”**
  - Photons

Timing gate	None	25 ns	10 ns	3 ns
n1 n2	70289 65437	67612 62911	19430 17725	333 372
Nf observed	30759	28418	2365	2
Nf predicted	19614	18427	1996	1

Ladders overlapping in Phi? High MeV tracks to the 2-nd layer?

  - Neutrons

Timing gate	None	25 ns
n1 n2	975 1224	59 75
Nf observed	11	0
Nf predicted	8	0

Combining timing and double layer criteria

- **Compare prediction and data for layers 4 – 5 of tracker, N= 74.12M “pixels”**
  - Photons

Timing gate	None	25 ns	10 ns	3 ns
n1 n2	1.23M 1.10M	1.16M 1.03M	0.24M 0.21M	4839 4228
Nf observed	19455	17093	677	1
Nf predicted	17970	15884	678	0

Better agreement for layers in tracker (large layers)

  - Neutrons

Timing gate	None	25 ns	10 ns	3 ns
n1 n2	0.44M 0.52M	4959 5395	271 259	12 11
Nf observed	3023	0	0	0
Nf predicted	3067	0	0	0

Conclusion

- **Combination of timing and double layer criteria to reduce muon collider beam background was studied**
  - MARS full bunch crossing background statistics as an input (~177M photons, ~40M neutrons)
  - ILCRoot Si vertex and tracker barrel detectors with 500x500 micron segmentation and 3.5T magnetic field as an example
  - The double layer approach can potentially provide large reduction of the neutral background hits:
    - must be implemented AFER timing cuts
    - depends on remaining occupancy
    - limited by fraction of secondary tracks reaching the second layer (function of magnetic field, track momentum distribution and space between layers)
    - dual layer (in current ILCRoot geometry) combined with time gate of 10 ns:
      - can reduce neutron background to a level of a few hits per layer
      - suppresses photon background by factor of ~30 in inner layers of VXD (with remaining occupancy of 1-2%) and by factor of ~1000 in outer layers of tracker
    - results for (photon+neutron) data are available, update will be made (it is the same for first layers of VXD, different for outer layers of tracker)

Conclusion

- **We need a realistic simulation which**
  - implements original dual layer geometry (1-2 mm layers distance) and is flexible enough to provide easy change in the geometry
  - has timing in digits and applies timing cuts in clusters used for tracking algorithm (to move from timing in hits to timing in front-end signal)
- **All this will require significant efforts and time from ILCRoot team**
- **Results will help to reevaluate:**
  - the timing cuts (possible increase of the gate width?)
  - …..
- **New MARS simulation is needed as well, with low thresholds for photons and neutrons**