ILCRoot VXD and Tracker hits timing study for MARS background from Muon Collider

N. Terentiev *
(Carnegie Mellon U./Fermilab)

V. Di Benedetto, C. Gatto, A. Mazzacane
(University of Lecce, INFN Naples, Fermilab)
N. Mokhov, S. Striganov
(Fermilab)

Muon Collider Higgs Factory Mini-Workshop
Nov. 13, 2012
Fermilab

Outline

- **2012 MARS15 developments for muon collider background simulation** (from N. Mokhov)
- **ILCRoot framework**
- **Mass production in ILCRoot VXD and Tracker hit simulation for IP particles and MARS background particles**
- **Results of hit timing study (TOF-T0 and TOF timing comparison, hit timing resolution impact)**
- **Conclusions**
- **Plans**

MARS15 Status

- **MARS is the framework for simulation of particle transport and interactions in accelerators, detectors and shielding components. The new release of MARS15 is available since Sept. 9, 2011 at Fermilab (www-ap.fnal.gov/MARS)**
- **MARS15 developments in 2012** (see backup for details)
  - Inclusive (weighted), Exclusive (all W=1) and Hybrid Modes
  - Particle Production Event Generators
  - Coupling to EGS5
    - the EGS5 code has been implemented in MARS15 for precise modeling of electromagnetic showers in the 1 keV - 20 MeV energy range (current MARS data have E_{thr} = 200 keV)
    - crucial for accurate description of transition effects in fine accelerator and detector structures, background studies and medical applications.

- **MARS15 developments in 2012 (cont'd)**
  - New model for neutron DPA (displacement per atom) in radiation damage - from 10^{-5} eV to 20(150) MeV (using NJOY99+ENDF-VII database, 393 nuclides)
  - Newest phenomenological MARS15 model for pion production in hadron-nucleus interactions
  - New and better approximations for elementary total, elastic, and inelastic cross sections for NN and πN interactions
  - Radiation Damage
  - GUI and Visual Editor, ROOT Geometry
    - 3D visualization
    - New ROOT-MARS Beam Line Builder

MARS simulation data

- **Working with MARS background simulation results for (750 + 750) GeV $\mu^+ \mu^-$ beams with $2*10^{12}$ μ/BX each**
  - http://www-ap.fnal.gov/~strigano/mumu/mixture/
  - background yields/BX on 10^0 shielding 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**
E_{thr} , MeV	**0.2*)**	**0.1**)**	**0.2**	**1.0**	**1.0**	**1.0**

*) Lowest limit available in current MARS code

**) Current MARS code has E_{thr} = 1.0e-3 eV for neutrons, 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)

ILCRoot framework

- **The ILCRoot - software Infrastructure for Large Colliders based on ROOT and Alice's Aliroot with add-ons for Muon Collider studies** (see also backup slides)
  - "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)
  - "Muon Collider Detector Studies in ILCroot", C. Gatto, Sep. 28, 2011, Granada (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)
- **Available at Fermilab**
  - latest ILCRoot release (ILCrootMuXDetV3 by V. Di Benedetto) with recent GEANT4 v9.5.1 (neutron timing patch was provided by GEANT4 team with help from V. Di Benedetto)
  - ILC SiD detector based geometry
  - implementation of double layer geometry in the Si Vertex and Tracker detectors with runtime controlled parameters (V. Di Benedetto)
  - using QGSP_BERT_HP physics list for better neutron transport simulation

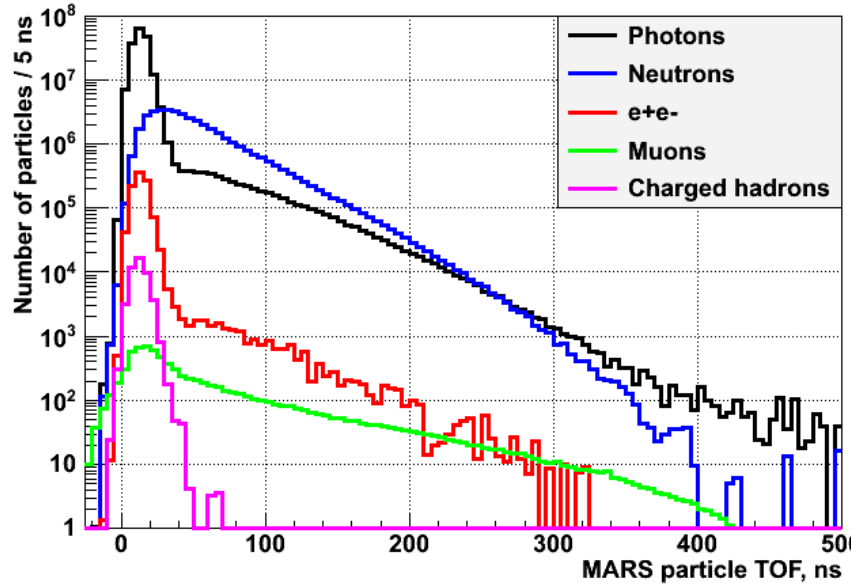
ILCRoot mass production simulation

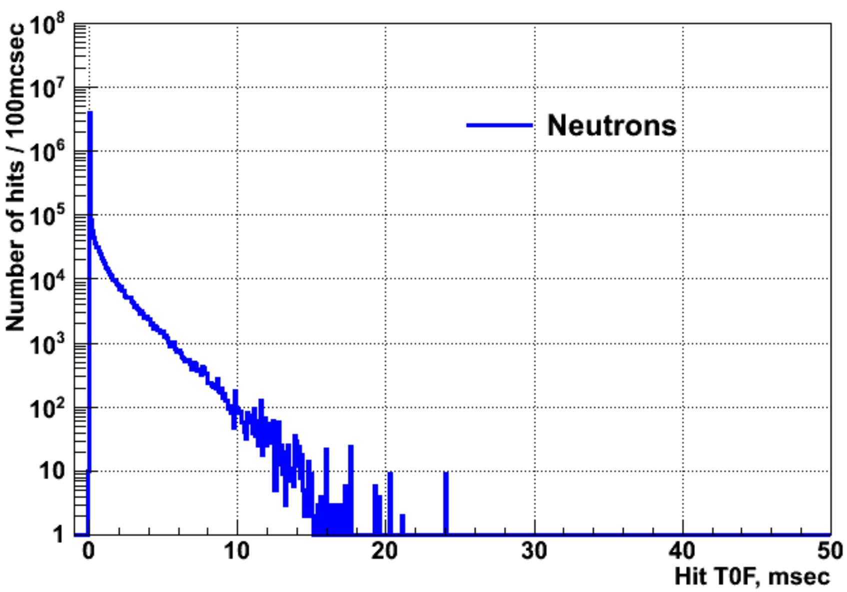
- **ILCRoot mass production of simulated hits for MARS background, IP muons and protons - <u>completed</u>**
  - only VXD and Tracker hits, the rest of detector as material (includes calorimeters, beam pipe, 10^0 shielding cone etc. – full layout)
  - the hits were simulated in four geometries with VXD and Tracker double layers
    - 200 μ thick Si sub-layer, 1 mm and 2 mm space between sub-layers
    - 3.5 T and 7 T magnetic fields
    - IP smearing in Z_V (Gaussian σ = 1 cm) and X_V,Y_V (Gaussian σ = 6 μ) for IP muons and protons having flat P = 0.2 - 100 GeV/c distribution
  - additional geometry sets were simulated (see https://indico.fnal.gov/conferenceDisplay.py?confId=5901), among them to try the new approach for fast Si tracking – use of SiPM (see R. Lipton's talk "Thin, Low Mass Si Trackers" on "Project X Physics Study" workshop, 14-23 June 2012, Fermilab , indico.fnal.gov/contributionDisplay.py?contribId=161&sessionId=11&confId=5276
    - 20 μ thick Si sub-layer, 1 mm and 20 μ space between sub-layers

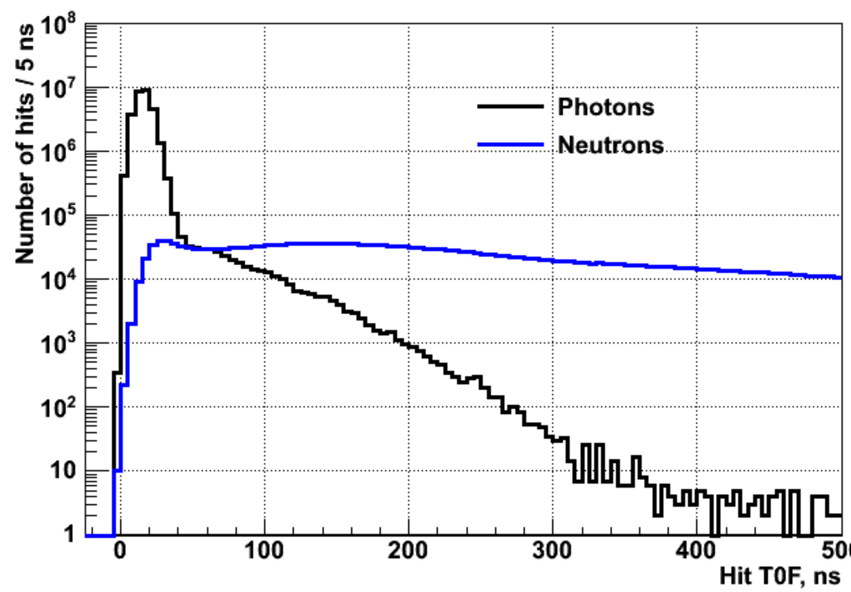
ILCRoot mass production simulation

- **ILCRoot mass production (cont'd)**
  - the goal – to study timing and double layer criteria for MARS background hit rejection
- **Double layer criteria for MARS background hit rejection**
  - suggested by J. Chapman and S. Geer for the muon collider ("The Pixel Microtelescope", J. Chapman, S. Geer, FERMILAB-Conf-96/375)
  - IP physics charged track makes hits in both sub-layers
  - readout takes AND of appropriate (IP oriented) pixel pairs in both sub-layers suppressing random neutral background hits
  - analysis is in progress
- **The timing study was done for geometry set with 200 μ thick Si sub-layers 1 mm apart and 3.5T magnetic field**
  - two timing modes (TOF-T0) and TOF are compared
  - time resolution impact
  - results are presented for layers in VXD and Tracker

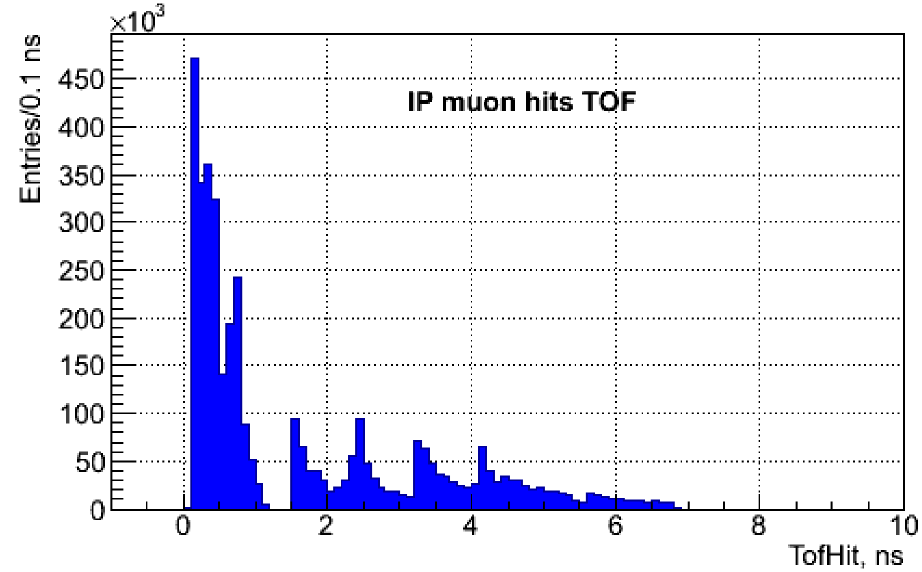
- **Timing for MARS background particles**
  - MARS background (on a surface of the shielding cone) is within ~500 ns of TOF (time of flight) w.r.t. a bunch crossing (BX)
- **Timing of ILCRoot hits in VXD and Tracker (from MARS background)**
  - TOF for neutron hits has long tale up to a few msec (due to “neutron gas”)

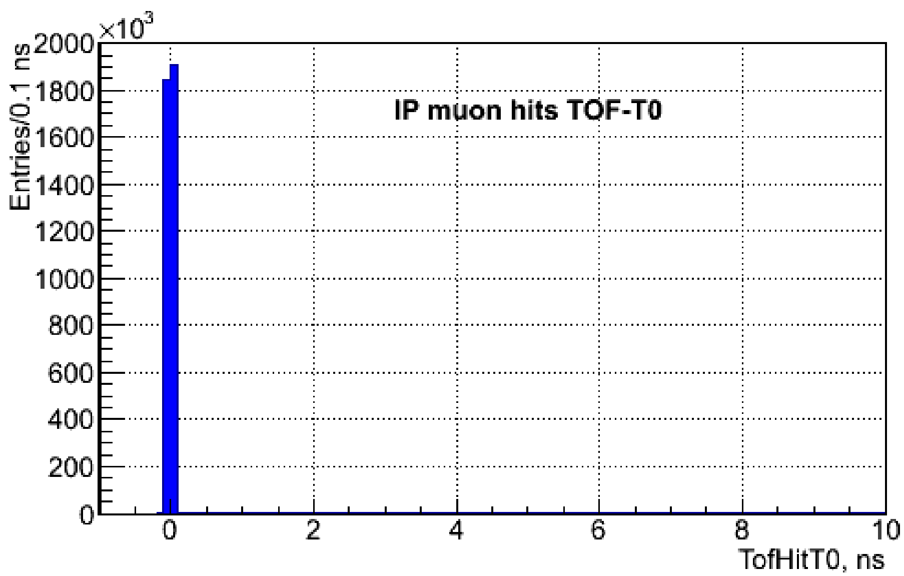


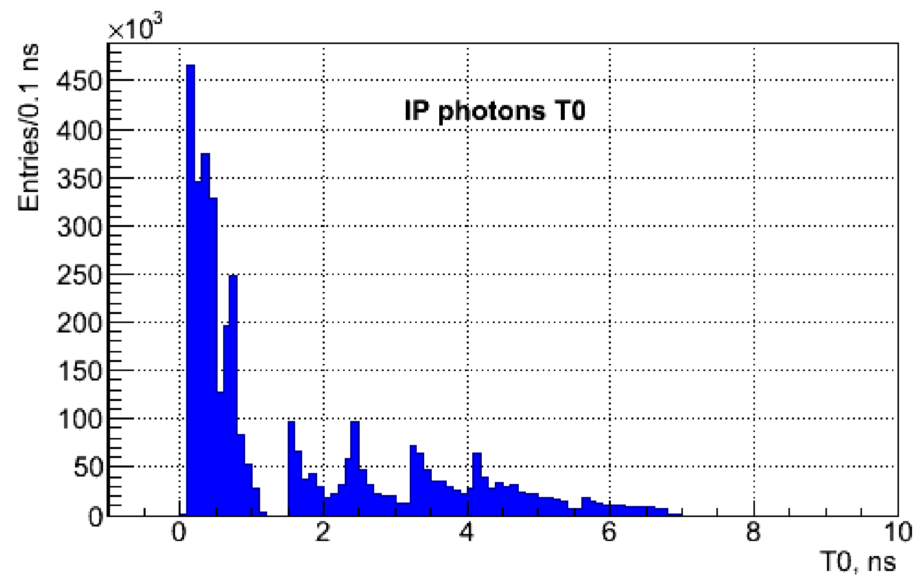




- **Choosing start and width of the timing gate to provide ~100% efficiency for IP tracks**
  - use IP muons and protons to simulate fastest and slowest tracks
  - to minimize the width of the timing gate recalculate TOF of hits in each VXD and Tracker layer relatively to T0 - arrival time of the photon coming from IP to the point with the hit coordinates
  - almost all TOF-T0 are within ~0.2 ns, if no timing resolution included

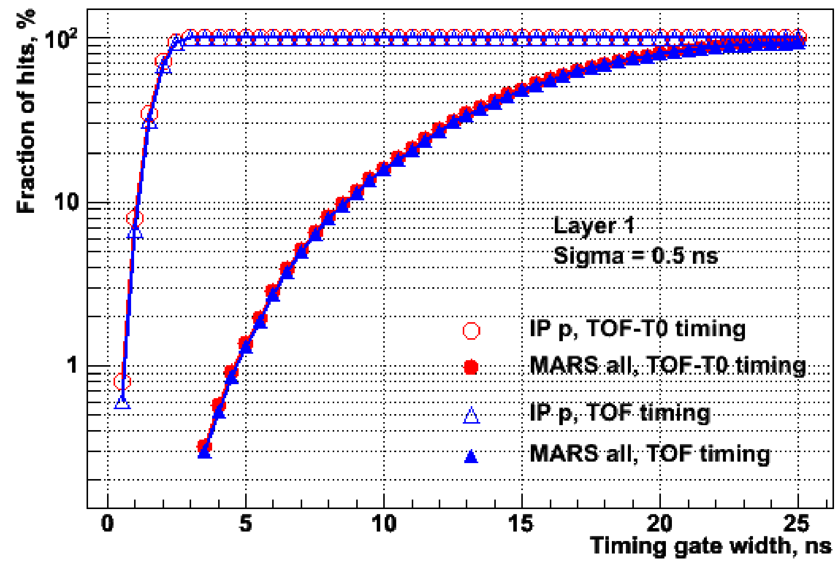






MARS background rejection and hit time resolution

- Introduce VXD and Tracker hit time resolution as Gaussian smearing with σ = 0.2 ns, 0.5 ns and 1.0 ns
- Compare TOF-T0 and TOF timing requesting ~99.7% efficiency per layer for IP protons
- Almost no difference for VXD (small distance from IP, small T0 < 1 ns)
- At resolution σ <= 0.5 ns MARS background rejection in VXD layer 1 >~ 500 for timing gate width of 3.1 ns

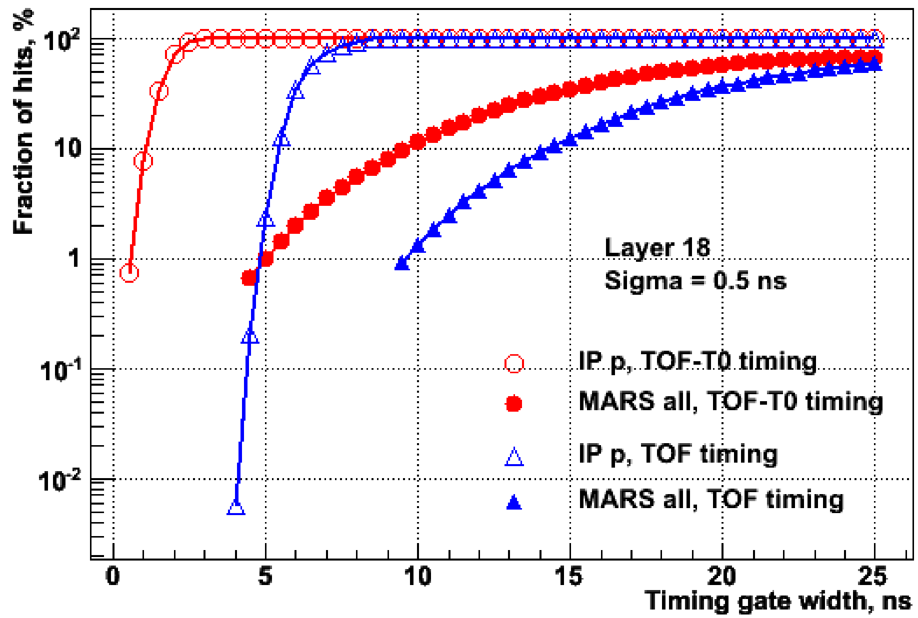


Timing gate widths and background rejection for VXD Barrel Layer 1

σ	Timing mode	Timing gate width	IP proton eff.	MARS all fraction
0.2 ns	TOF-T0 TOF	1.3 ns 1.4 ns	99.81% 99.64%	0.032% 0.026%
0.5 ns	TOF-T0 TOF	**3.1 ns** **3.1 ns**	99.70% 99.62%	**0.19%** **0.17%**
1.0 ns	TOF-T0 TOF	6.0 ns 6.1 ns	99.71% 99.71%	1.18% 1.11%

MARS background rejection and hit time resolution

- **Compare background rejection for TOF-T0 and TOF timing in Tracker layers**
  - the difference comes from Tracker outmost layers (barrel layer 18, large R ~ 120 cm, large T0 corrections ~4-7 ns)
- **At resolution σ <= 0.5 ns MARS background rejection > 100 in Tracker layer 18 if timing gate widths 4.1 ns (TOF-T0) or 9.4 ns (TOF)**



- **Timing gate widths and background rejection for Tracker Barrel Layer 18**

σ	Timing mode	Timing gate width	IP proton eff.	MARS all fraction
0.2 ns	TOF-T0 TOF	2.9 ns 8.1 ns	99.70% 99.71%	0.37% 0.58%
0.5 ns	TOF-T0 TOF	**4.1 ns** **9.4 ns**	99.71% 99.72%	**0.48%** **0.85%**
1.0 ns	TOF-T0 TOF	6.3 ns 11.7 ns	99.68% 99.68%	1.09% 1.71%

Conclusions

- **MARS15 code was substantially improved and extended allowing now even more consistent, reliable, efficient and user-friendly modeling of the machine-induced backgrounds**
- **The TOF-T0 and TOF timing modes were compared in terms of MARS background rejection at different hit time Gaussian resolutions σ of 0.2 ns, 0.5 ns and 1.0 ns in VXD and Tracker layers**
  - IP proton hits efficiency was set to be ~99.7% per layer (subject to a trade-off)
  - **for VXD layers both modes almost equivalent** (hits are close to IP point, T0 corrections are small, T0 < 1 ns)
  - the difference comes from Tracker outmost layers (large R, large T0 corrections)
  - in VXD barrel layer 1 at resolution σ <= 0.5 ns MARS background rejection >~ 500 for timing gate width ~3.1 ns
  - in Tracker barrel layer 18 at resolution σ <= 0.5 ns MARS background rejection >~ 100 for timing gate width ~4.1 ns (TOF-T0) and ~ 9.4 ns (TOF)

Conclusions

- **TOF-T0 mode gives modest improvement in background rejection in comparison with TOF**
  - TOF of the hit can be measured by the front end time stamp (relatively to BX)
  - implementation of TOF timing gate in the front-end (much easier than TOF-T0)
  - use TOF-T0 timing gate criteria in offline hit selection for tracking
- **High precision front end timing can provide significant reduction of the number of VXD and Tracker readout hits produced by muon collider background if it includes**
  - time stamping
  - time gating capabilities

Plans

- **MARS new version work in progress on new MDI and magnet models for the Higgs factory and high-energy muon colliders**
- **Analysis continues for ILCRoot VXD and Tracker hits made by MARS background**
  - the goals are to estimate timing and double layer criteria rejection for the MARS background hits (in different geometry sets)
- **Start to use LCSIM simulation for current MARS background (750 + 750 GeV $\mu^+ \mu^-$ beams with $2*10^{12}$ muons/bunch each)**
  - compare results for hits with ILCRoot in the same geometry
- **While waiting for the new MARS background data for 125 GeV Higgs muon factory --> for now we can try to merge LCSIM simulation results (hits) for current MARS background (for 750 + 750 GeV $\mu^+ \mu^-$ beams) with 125 GeV Higgs production in 125 GeV CM $\mu^+ \mu^-$ beams**

Backup slides

MARS15 Developments in 2012 (backup)

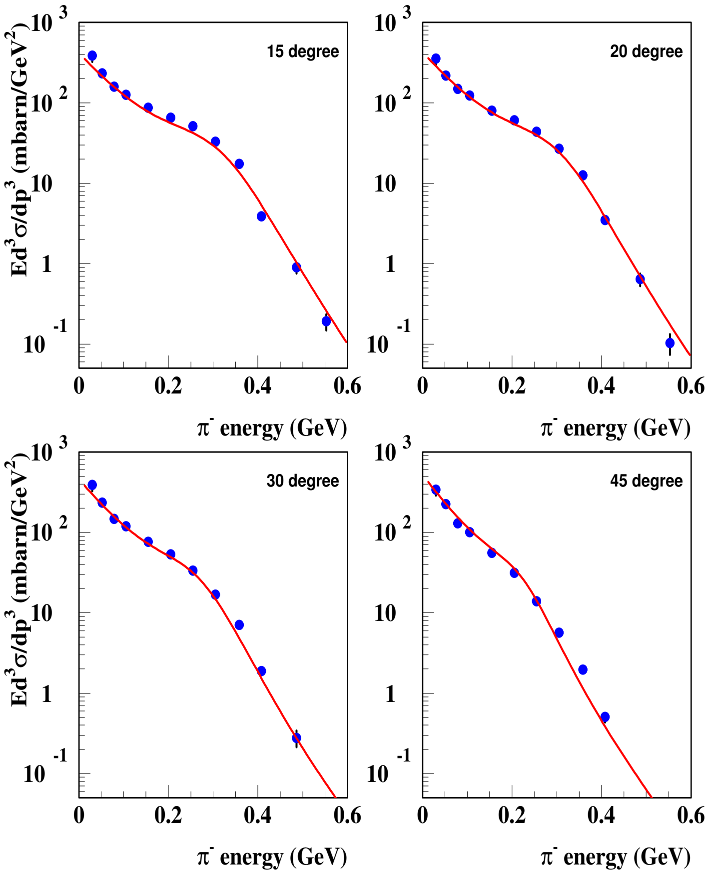
- Inclusive (weighted), Exclusive (all W=1) and Hybrid Modes
- Particle Production Event Generators
- Mean Stopping Power
- Coupling to EGS5: Electromagnetic showers down to 1 keV
- Nuclide Production, Decay and Transmutation
- Radiation Damage (DPA)
- GUI and Visual Editor
- ROOT Geometry

Inclusive Pion Production (backup)

Newest phenomenological MARS15 model for pion production in hadron-nucleus interactions. Extension of two-source model:

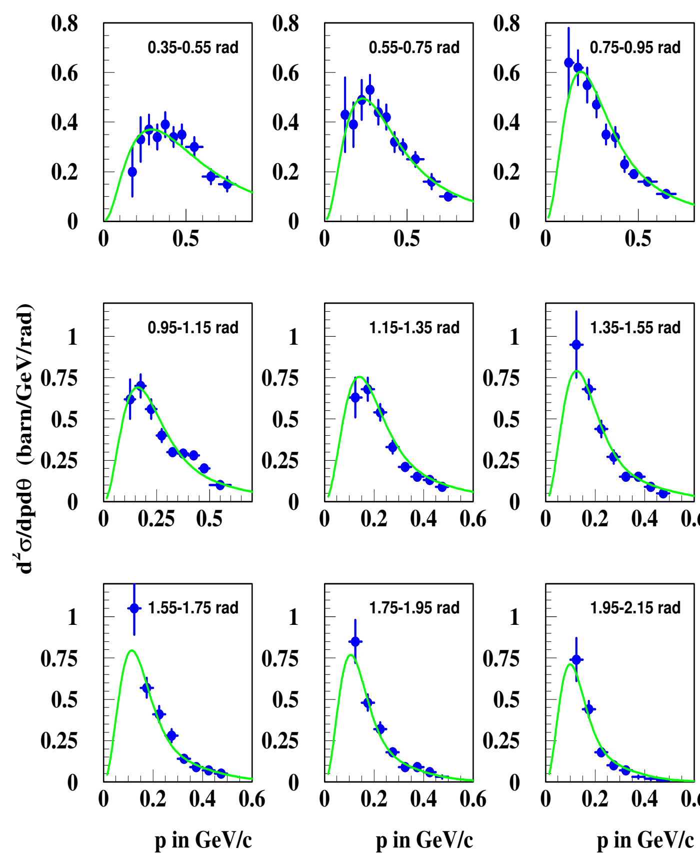
$$E\frac{d^3\sigma}{dp^3} = p_1(1+p_7\cos\theta)\exp(-\frac{T(1-p_2\cos\theta)}{p_3}) + \frac{p_9(1+p_8\cos\theta)}{1+p_4\exp(-T(1-p_6\cos\theta)/p_5)}$$

p+Pb→π⁻X vs. LANL at 0.7 GeV



π^- production in proton lead interaction at 730 MeV

p+Pb→π⁻X vs. HARP at 3 GeV/c



π^- production in p-Pb interaction at 3 GeV/c. HARP data.

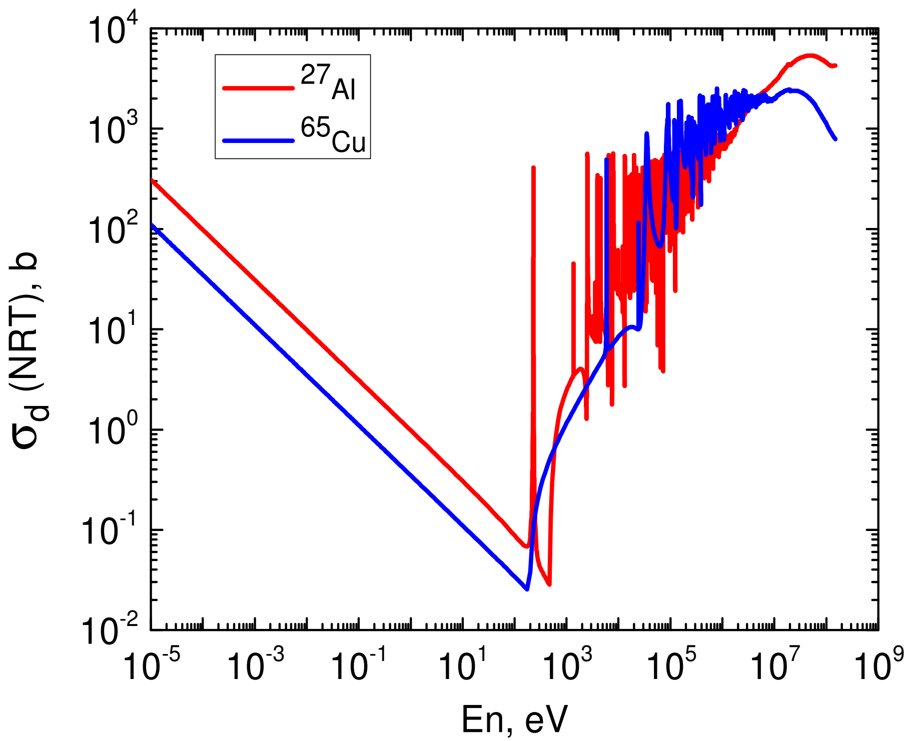
MARS15-LAQGSM Developments (backup)

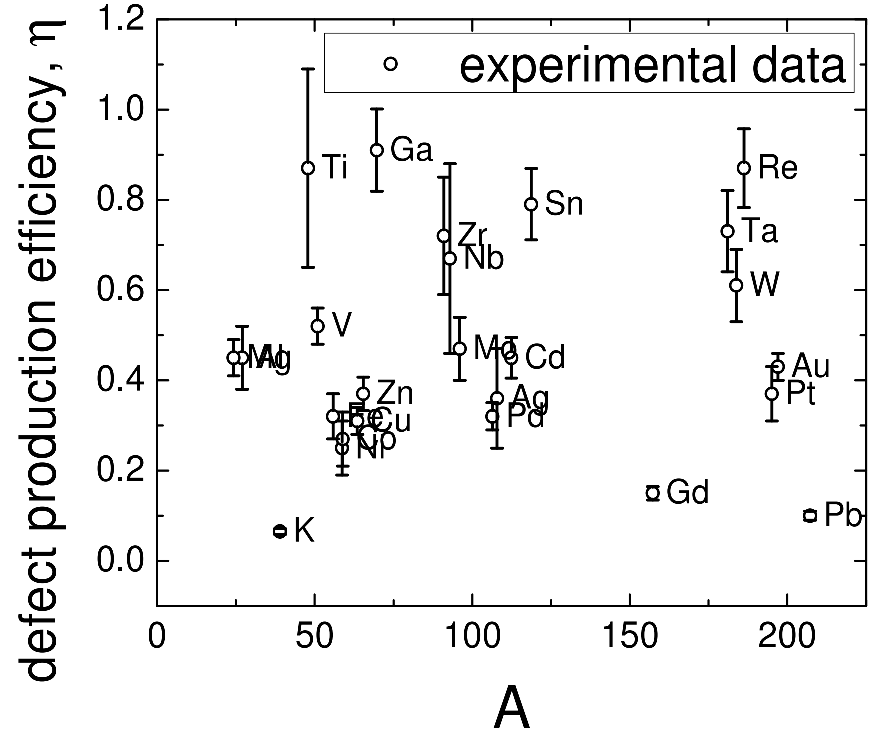
- New and better approximations for elementary total, elastic, and inelastic cross sections for NN and πN interactions
- Several channels have been implemented for an explicit description: N+N→N+N+mπ, π+N→N+mπ (m<5), B+B→B+Y+K, π+B→Y+K, Kbar+B→Y+π, and K+Kbar, N+Nbar pair production
- Combination of the phase space and isobar models and experimental data
- gA reactions extended down to GDR and below
- Arbitrary light nuclear projectile (e.g., d) and nuclear target (e.g., He)

EMS Inclusive/Exclusive 1 keV (backup)

- Inclusive, exclusive and hybrid modeling of electromagnetic showers at all energies is now controlled in a user-friendly way globally or for specified materials.
- The **<u>EGS5 code has been implemented in MARS15</u>** for precise modeling of electromagnetic showers in the 1 keV to 20 MeV energy range globally or in specified materials: crucial for accurate description of transition effects in fine accelerator and detector structures, background studies and medical applications.

New Neutron DPA Model (backup)



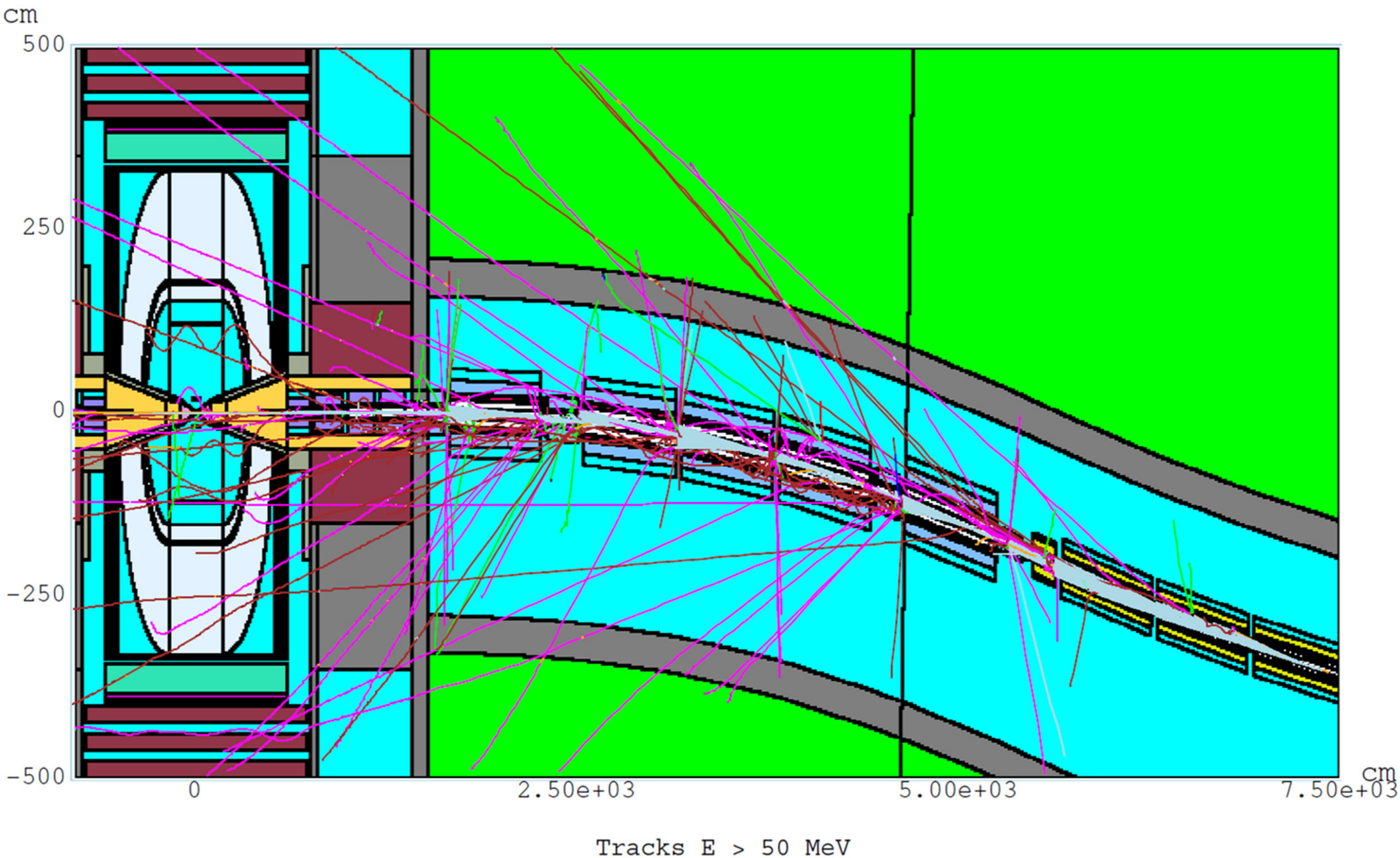


<u>**New for neutrons from 10^{-5} eV to 20(150) MeV**</u>: NJOY99+ENDF-VII database, for 393 nuclides: NRT (industry standard) corrected for experimental defect production efficiency η (Broeders, Konobeyev, 2004), where η is a ratio of a number of single interstitial atom vacancy pairs (Frenkel pairs) produced in a material to the number of defects calculated using NRT model

ROOT Geometry Mode in MARS15 (backup)

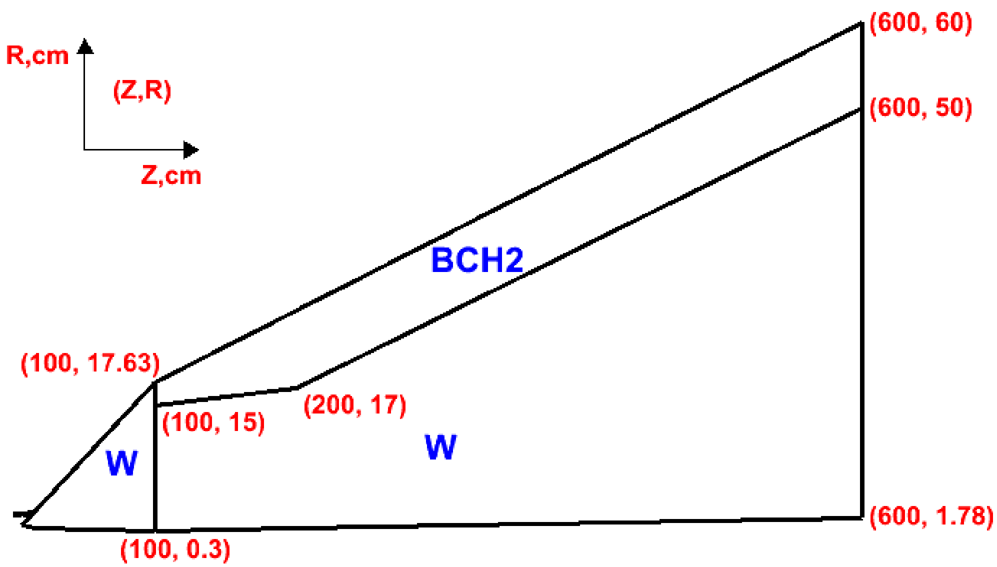
- Powerful ROOT Geometry and visualization implemented.
- Geo models created for MARS15 can be used with other MC codes (e.g., Geant4 and ILCroot).
- One can use the ROOT models created for Geant4 (CMS model as an example) with MARS15.
- ROOT provides large set of geometrical elements (primitives) along with a possibility to produce composite shapes and assemblies.
- 3D visualization.
- New ROOT-MAD-MARS Beam Line Builder (RMMBLB).

- **MARS background particle tracks near the detector**

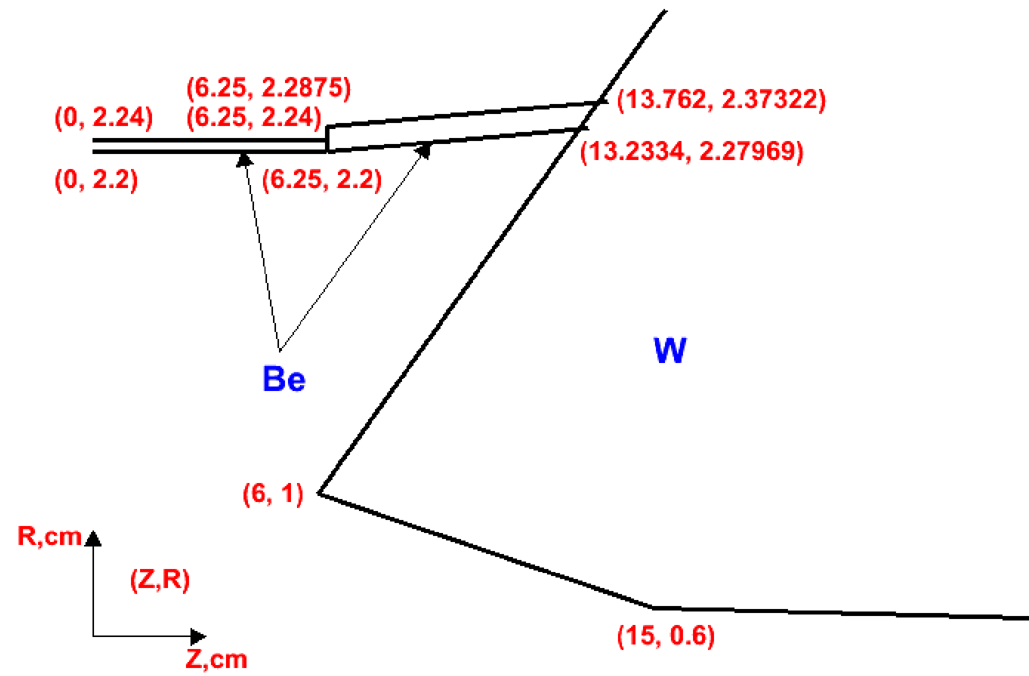


- **10^0 nozzle geometry**

General (1/2 RZ) view



Zoom in beam pipe



W – tungsten

Be – beryllium

BCH2 – borated polyethylene

Backup

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-allignement with latest Aliroot version every 1-2
- 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*

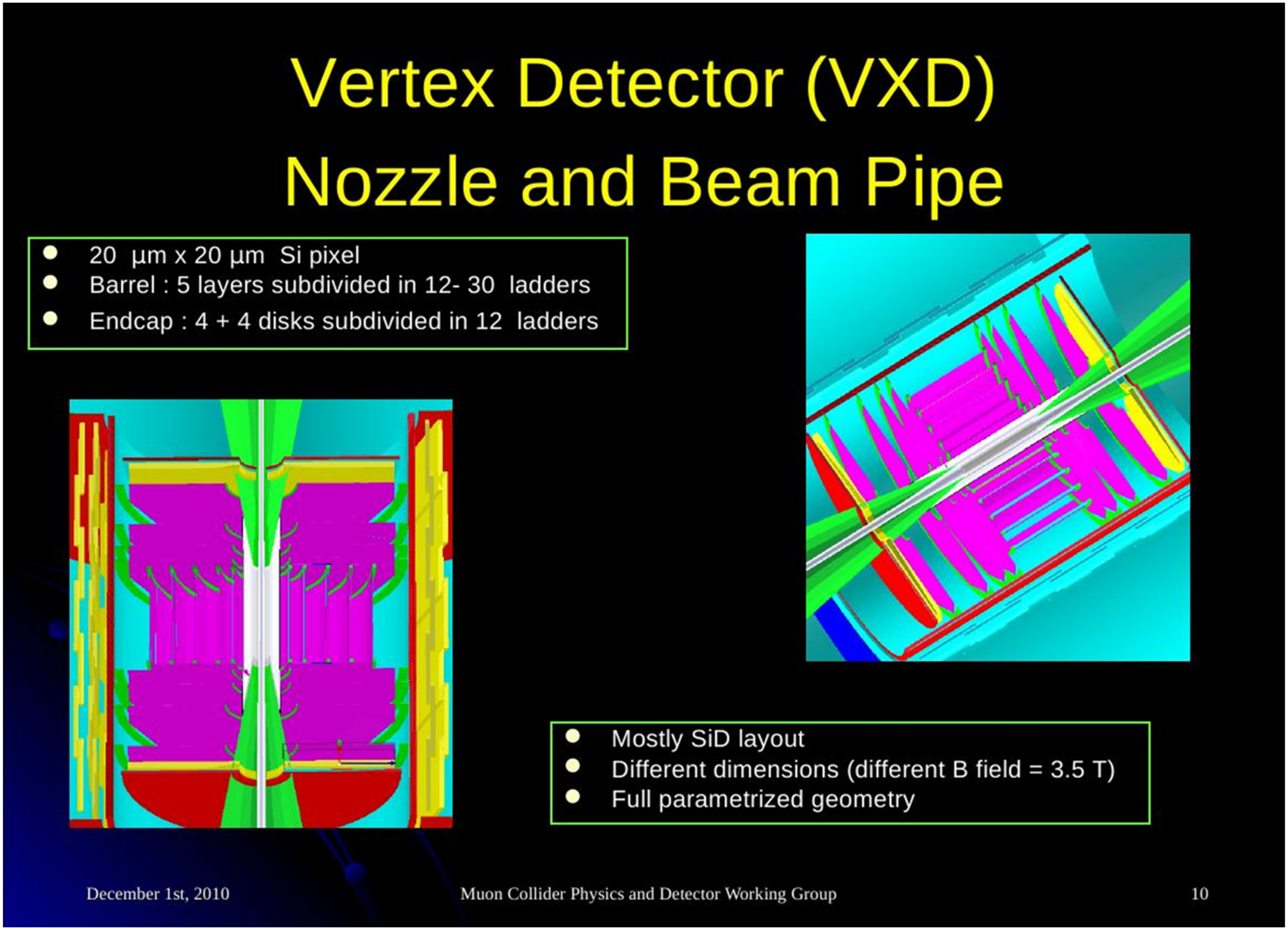
The Virtual Montecarlo (VMC) Concept

- 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 descripted 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 = 7.5m
  - 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 7.5m
  - Events are finally passed through the usual simulation (G4)-> digitization->reconstruction

Backup



Vertex Detector (VXD)
Nozzle and Beam Pipe
20 µm x 20 µm Si pixel
Barrel : 5 layers subdivided in 12- 30 ladders
Endcap : 4 + 4 disks subdivided in 12 ladders
Mostly SiD layout
Different dimensions (different B field = 3.5 T)
Full parametrized geometry
December 1st, 2010
Muon Collider Physics and Detector Working Group
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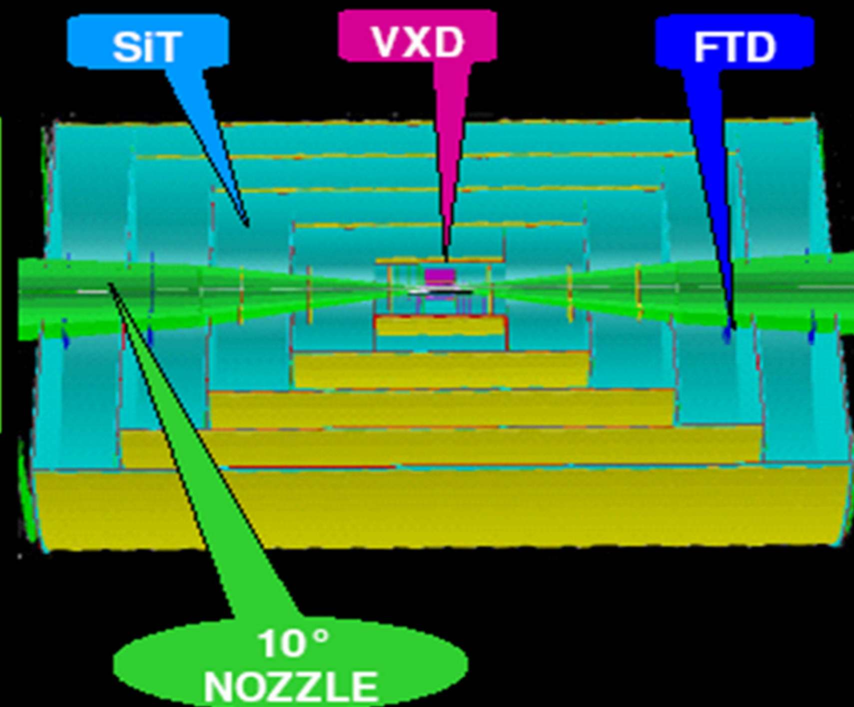
Silicon Tracker (SiT) and Forward Tracker Detector (FTD)

SiT

- 100 μm thick Si layers
- 50 μm x 50 μm Si pixel (or Si strips or double Si strips available)
- Barrel : 5 layers subdivided in staggered ladders
- Endcap : (4+3) + (4+3) disks subdivided in ladders
- R_{min}~20 cm R_{max}~120 cm L~330 cm



FTD

- 20 μm x 20 μm Si pixel
- Endcap : 3 + 3 disks
- Distance of last disk from IP = 190 cm

A. Mazzacane (Fermilab)

- Silicon pixel for precision tracking amid up to 10^5 hits
- Tungsten nozzle to suppress the background

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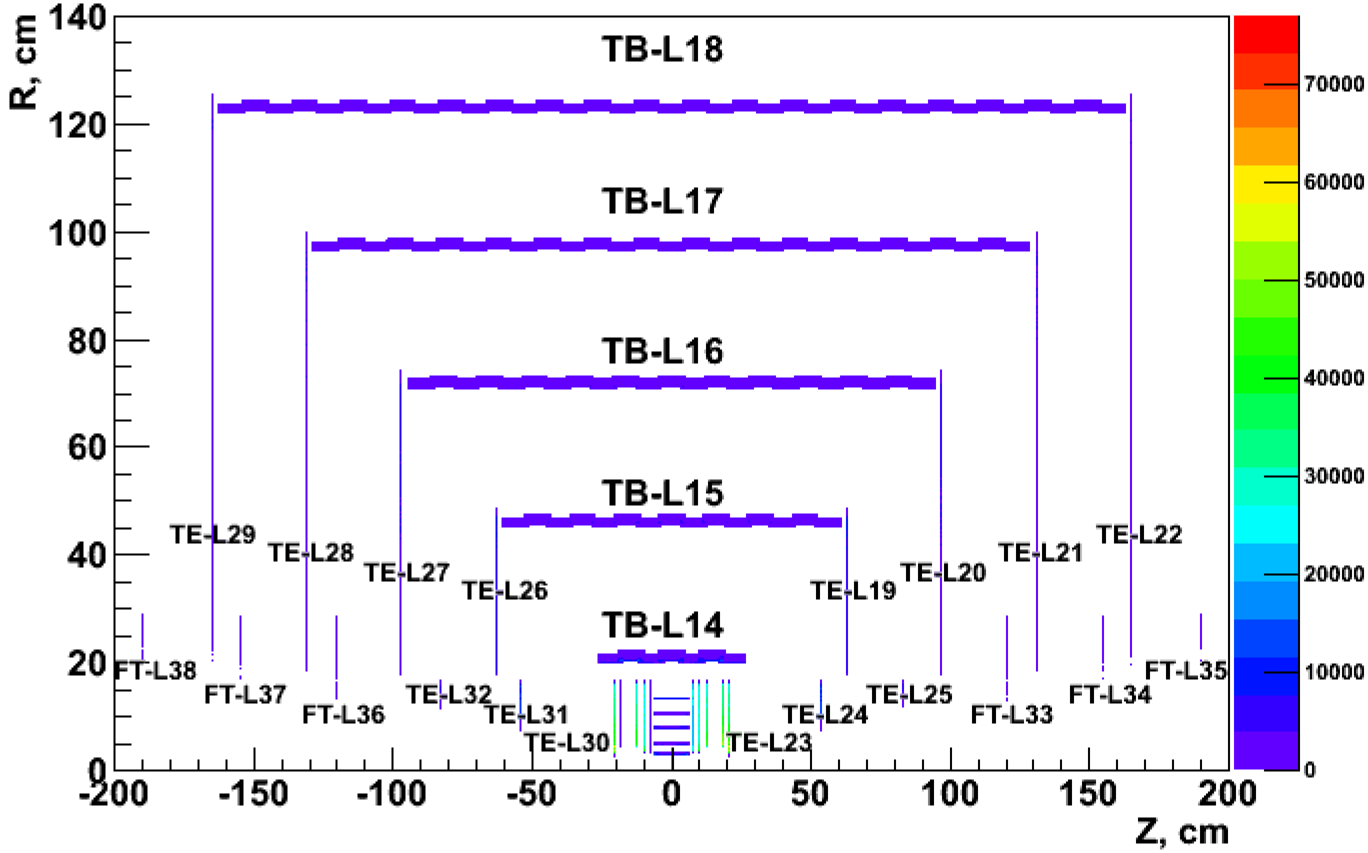
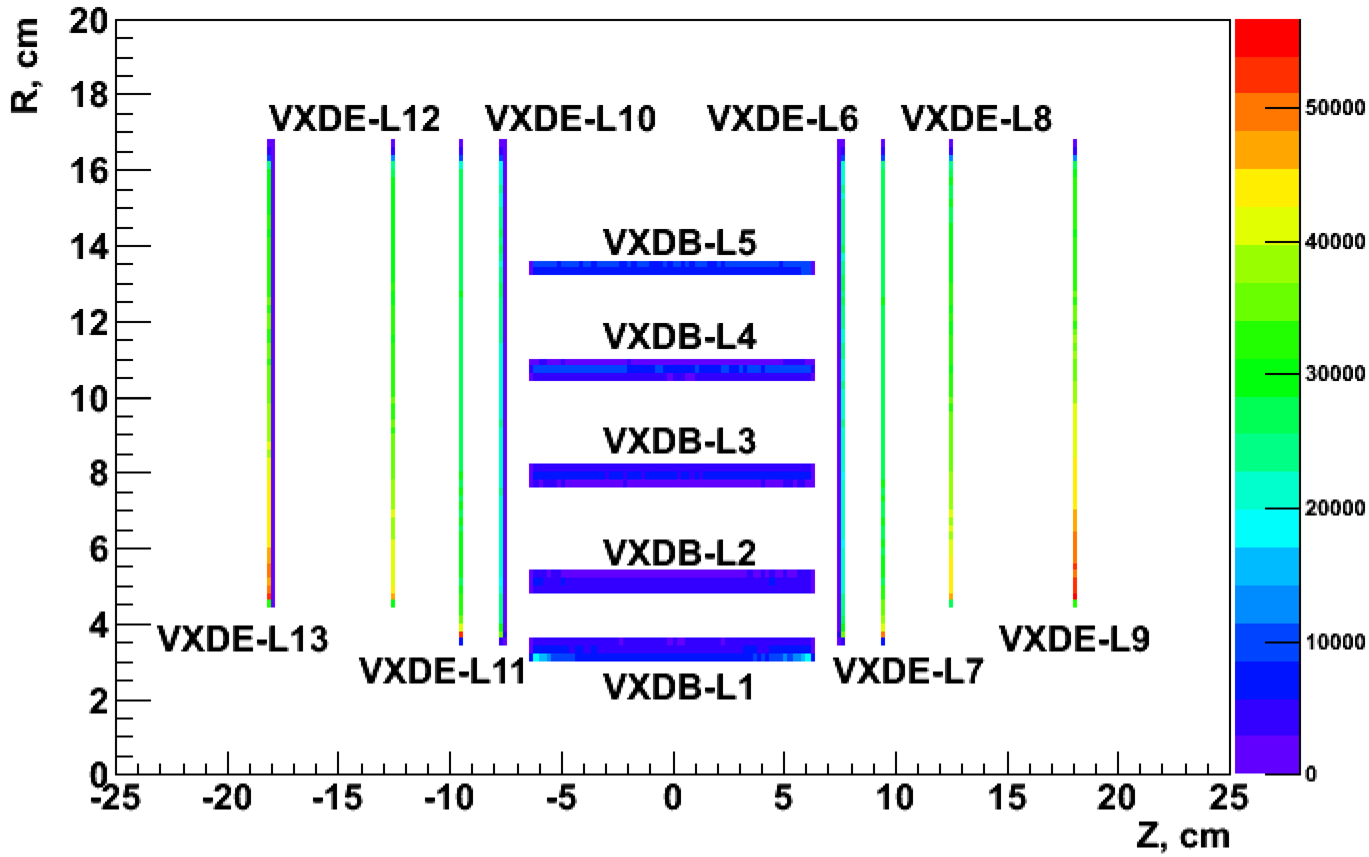
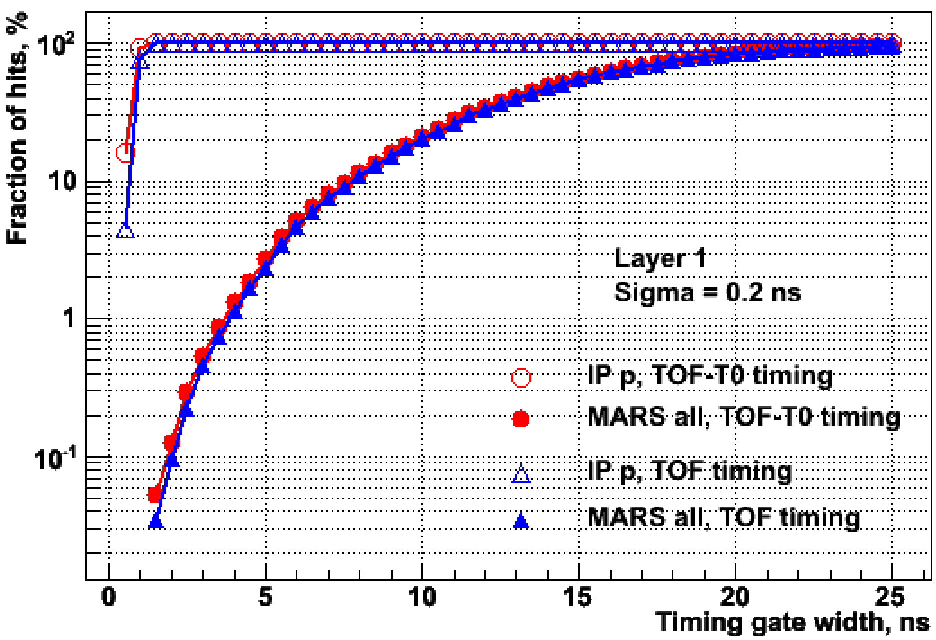
- **Hit R vs. Z for ILCRoot tracker detector layers**
  - TB – Tracker Barrel, TE – Tracker Endcap, FT – Forward Tracker

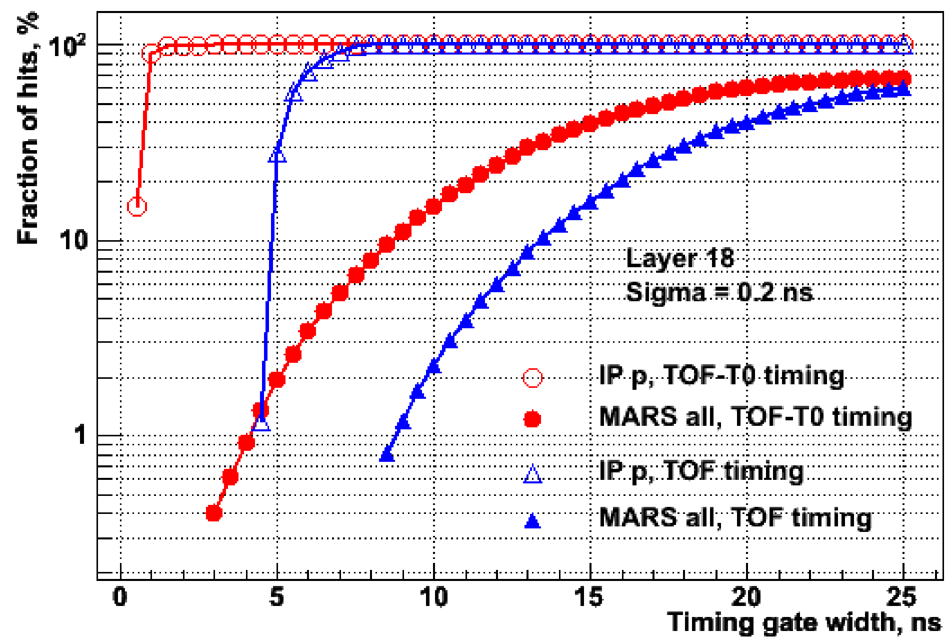


- **Hit R vs. Z for ILCRoot vertex detector (VXD) layers**
  - VXDB – VXD Barrel, VXDE – VXD Endcap

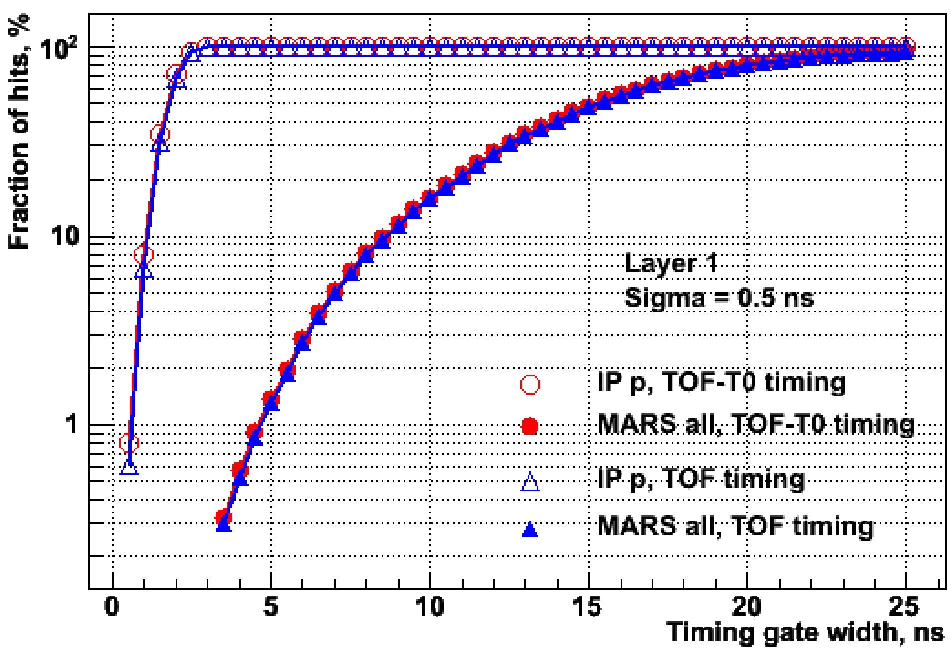


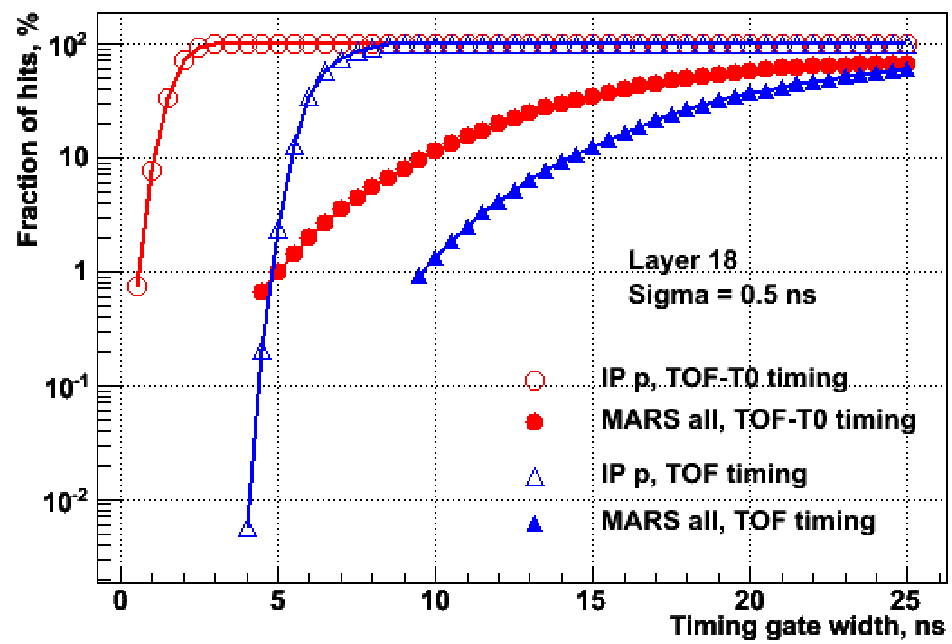
- **VXD barrel layer 1 and Tracker barrel layer 18, σ = 0.2 ns**





- **VXD barrel layer 1 and Tracker barrel layer 18, σ = 0.5 ns**





- **VXD barrel layer 1 and Tracker barrel layer 18, σ = 1.0 ns**