Machine-Detector Interface and Background Studies

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U.S. DEPARTMENT OF ENERGY

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Outline

- Muon Collider Background Sources
- Suppressing Backgrounds
- MARS15 Simulations
- Comparing to CLIC & LHC
- Comparing to $\mu^+\mu^-$ Collisions
- Background Loads on Detector
- Feeding Detector Simulations

Detector Backgrounds

- Muon Collider (MC) detector performance is strongly dependent on the background particle rates in various sub-detectors.

- Deleterious effects of the background and radiation environment produced by muon decays is one of the fundamental issues in the feasibility study of MC ring, Interaction Region (IR) and detector.

Sources of Background at Muon Colliders

1. IP $\mu^+\mu^-$ collisions: Production x-section 1.34 pb at $\sqrt{S}$ = 1.5 TeV (negligible compared to #3).
2. IP incoherent e^+e^- pair production: x-section 10 mb which gives rise to background of 3×10^4 electron pairs per bunch crossing (manageable with the nozzle, TBC)
3. Muon beam decays: Unavoidable bilateral detector irradiation by particle fluxes from beamline components and accelerator tunnel – major source at MC: For 0.75-TeV muon beam of $2\text{x}10^{12}$, $4.3\text{x}10^5$ dec/m per bunch crossing, or $1.3\text{x}10^{10}$ dec/m/s for 2 beams.
4. Beam halo: Beam loss at limiting apertures; severe, but is taken care of by an appropriate collimation system far upstream of IP.

Suppressing Backgrounds

1. Collimating nozzles at IP, detector magnetic field assisted. Machine background reduction ~1000 times. Also can fully confine incoherent pairs if $B_z > 3$ T.

2. High-field dipoles in IR with 5-σ tungsten masks between and liners inside: further substantial reduction of loads on central detectors; also help reduce Bethe-Heitler muon flux at large radii.

3. Tungsten/iron/concrete shield at MDI and borated poly shells on the cones and detector inside (wherever possible).

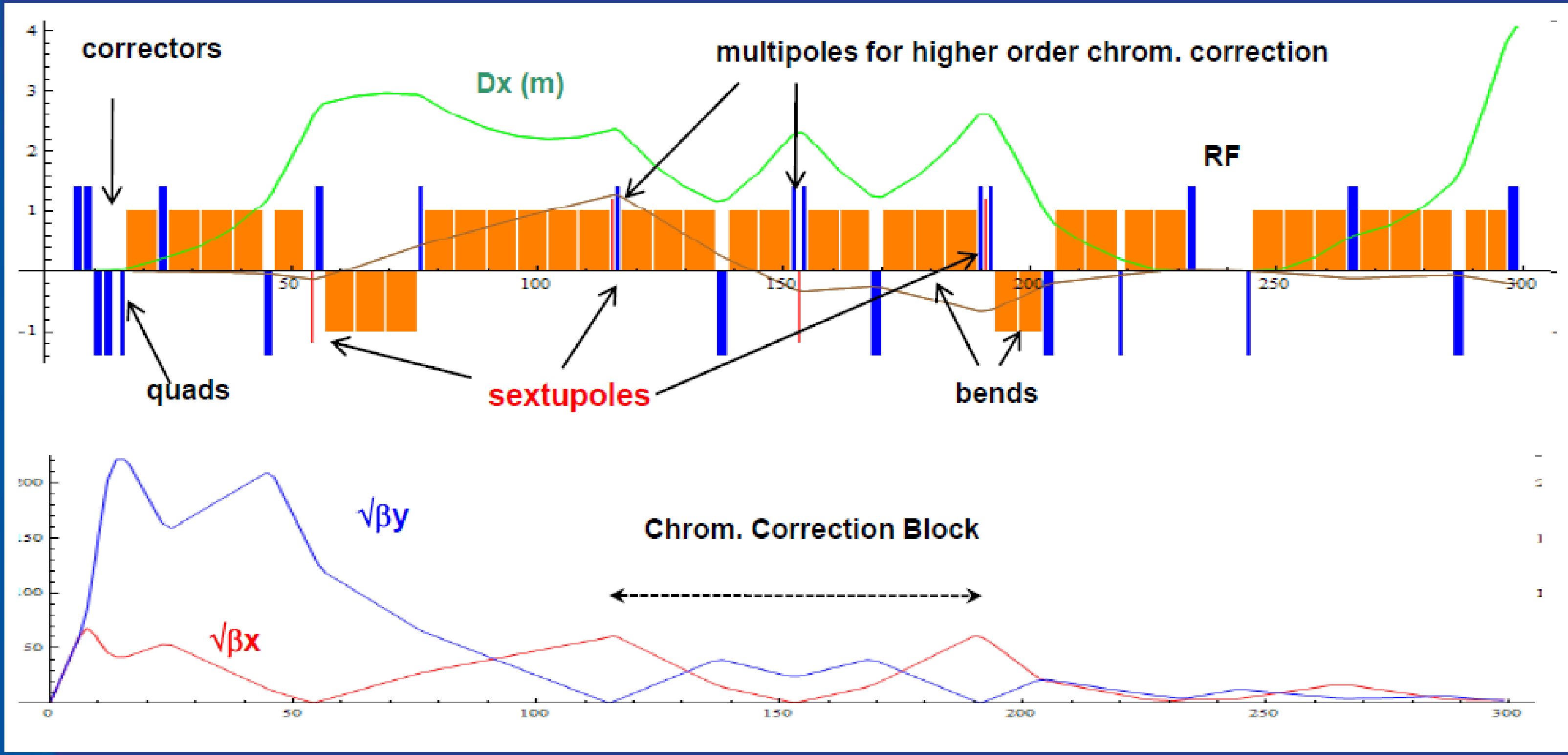
Muon Collider Parameters

E_{cms}	TeV	1.5	4
f_{rep}	Hz	12	6
n_b		1	1
Δt	μs	10	27
N	10^{12}	2	2
$\varepsilon_{x,y}$	μm	25	25
L	10^{34} $cm^{-2}s^{-1}$	1	4

Current MARS15 Simulations

- Compact lattice: C=2.5 km with B = 10 T
- Consistent IR design with realistic IR magnets and shielding
- Full MARS15 modeling to optimize shielding, with breakthrough in reduction of statistical weight spread
- Feeding detector simulators with new 1.5-TeV files

IR & Chromatic Correction Section



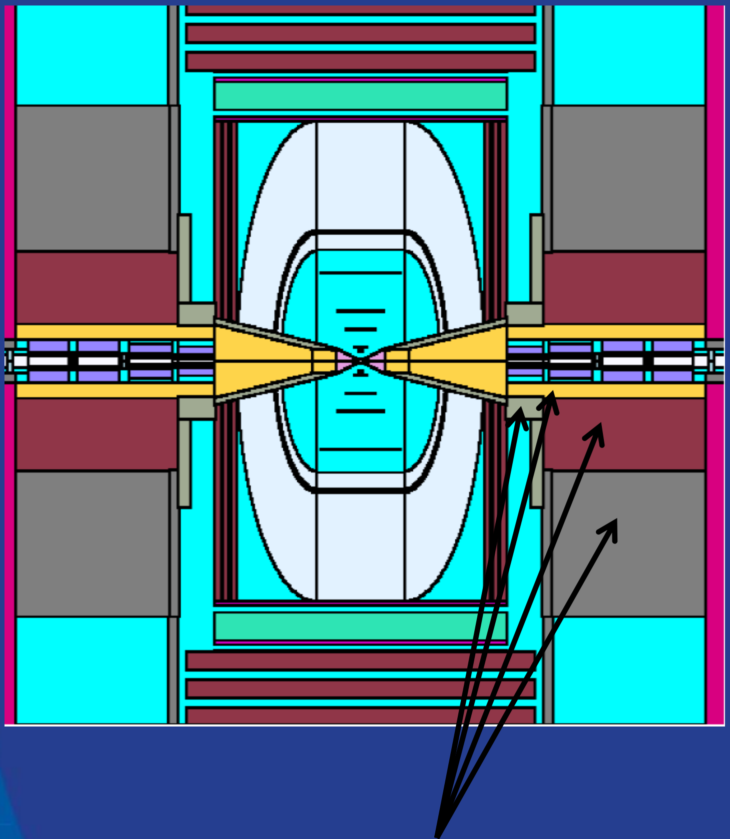
8-T dipoles in IR to generate large D at sextupoles to compensate chromaticity and sweep decay products; momentum acceptance 1.2%; momentum compaction factor of -1.5×10^{-5}; dynamic aperture sufficient for transverse emittance of 50 μm; under engineering constraints.

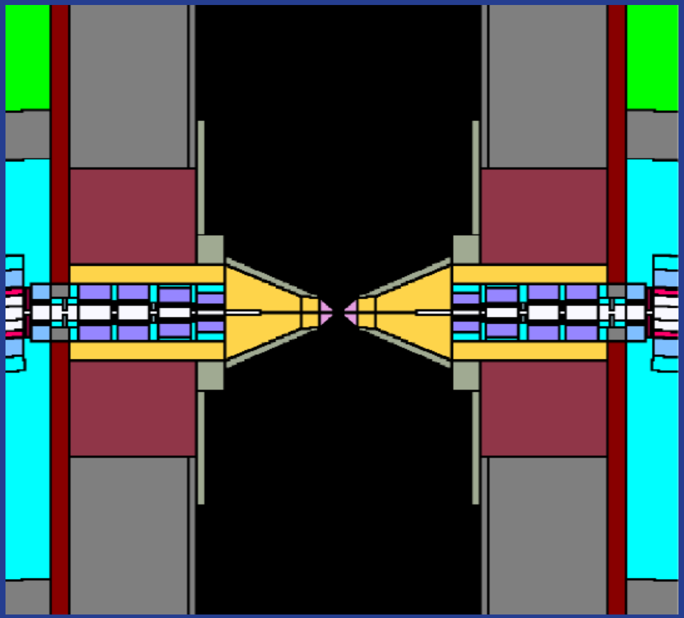
Iterative studies on lattice and MDI with magnet experts:
High-gradient (field) large-aperture short Nb_3Sn quads and dipoles.

MARS15 Modeling

- Segment of the lattice $|S| < S_{max}$, where $S_{max} = 250$ m, implemented in MARS15 model with Nb_3Sn quads and dipoles with masks in interconnect regions.
- Detailed magnet geometry, materials, magnetic fields maps, tunnel, soil outside and a simplified experimental hall plugged with a concrete wall.
- Detector model with $B_z = 3.5$ T and tungsten nozzle in a BCH_2 shell, starting at ±6 cm from IP with R = 1 cm at this z.
- 750GeV bunches of 2×10^{12} μ^- and μ^+ approaching IP are forced to decay at $|S| < S_{max}$, where $S_{max} = 25$ to 250 m at 4.28×10^5 / m rate.
- All physics processes with cutoff energies optimized for materials & particle types, varying from 2 GeV at ≥100 m to 0.025 eV in the detector.

Detector Model and Source Term





Sophisticated shielding:
W, iron, concrete & BCH_2

Source term at black hole to feed detector simulation groups: ILCRoot, lcsim and Fast MC

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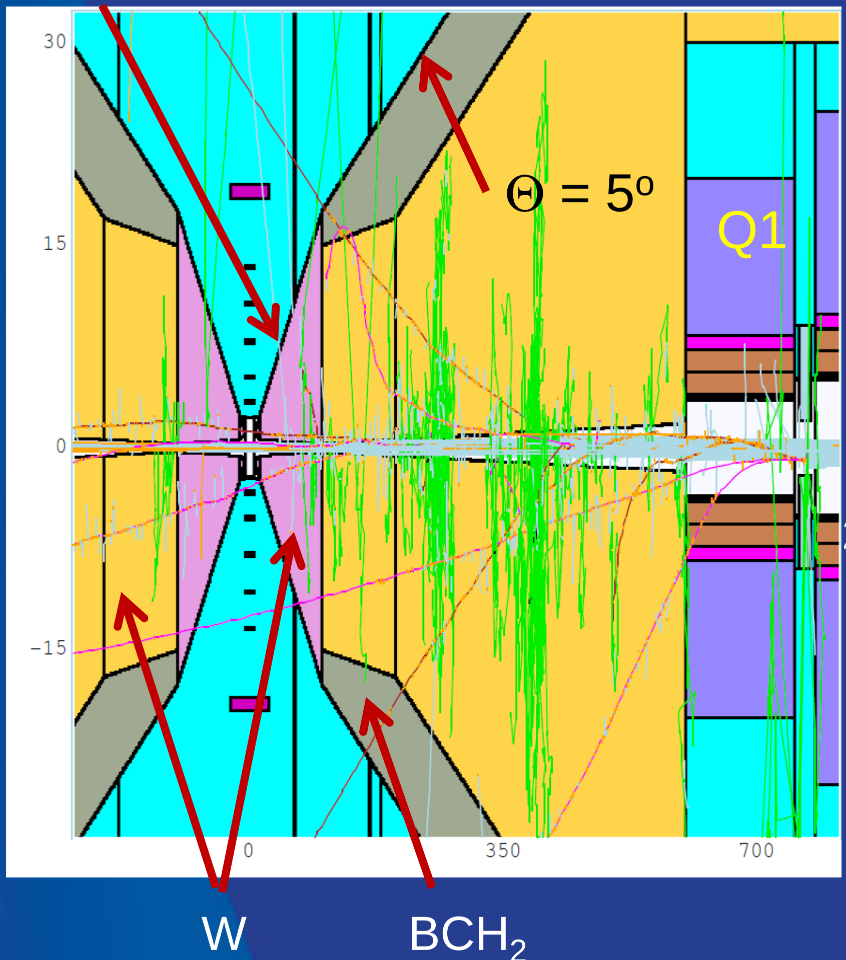
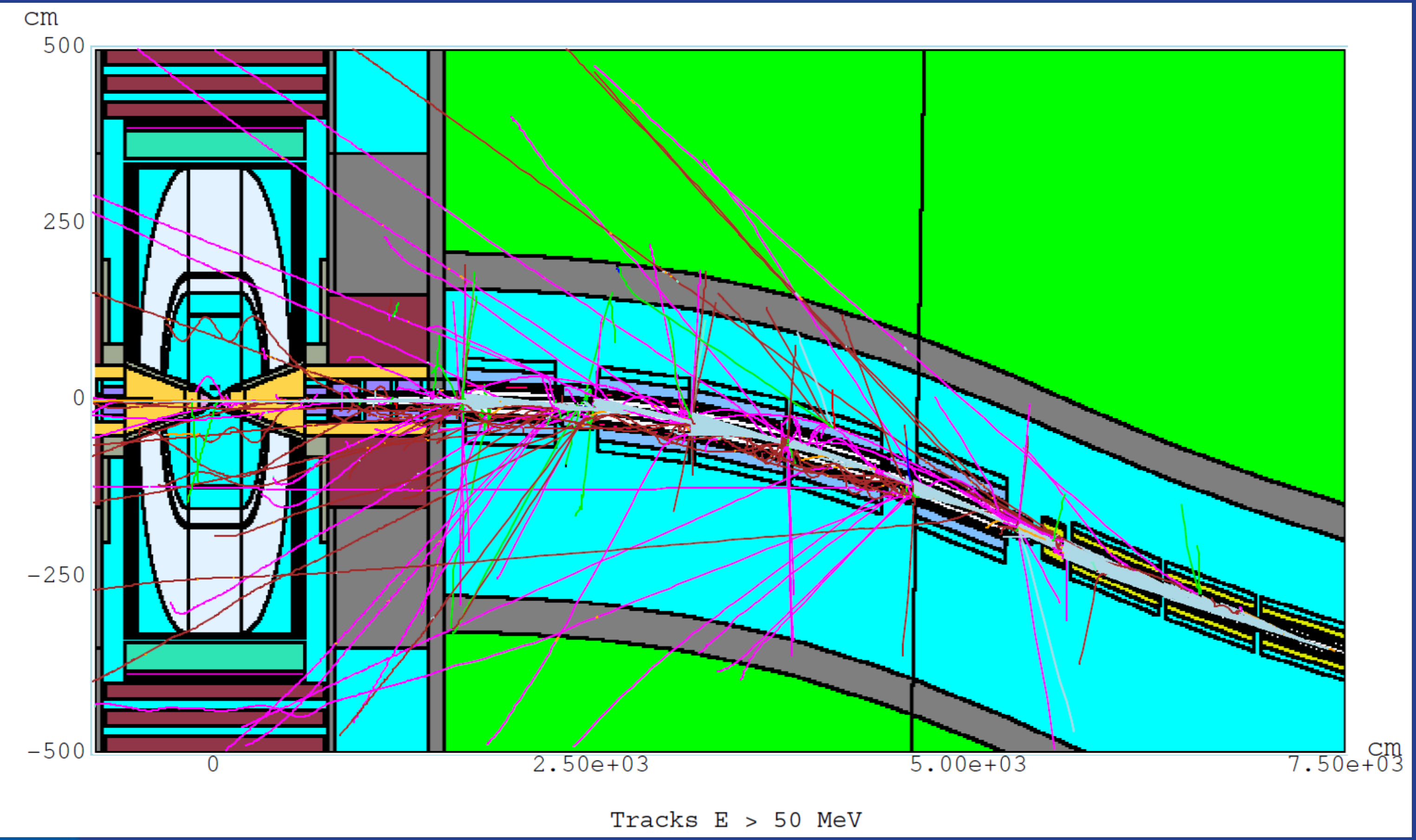
Tungsten Nozzle in BCH_2 Shell

$\Theta = 10^o$ 6 < z < 600 cm x:z = 1:17

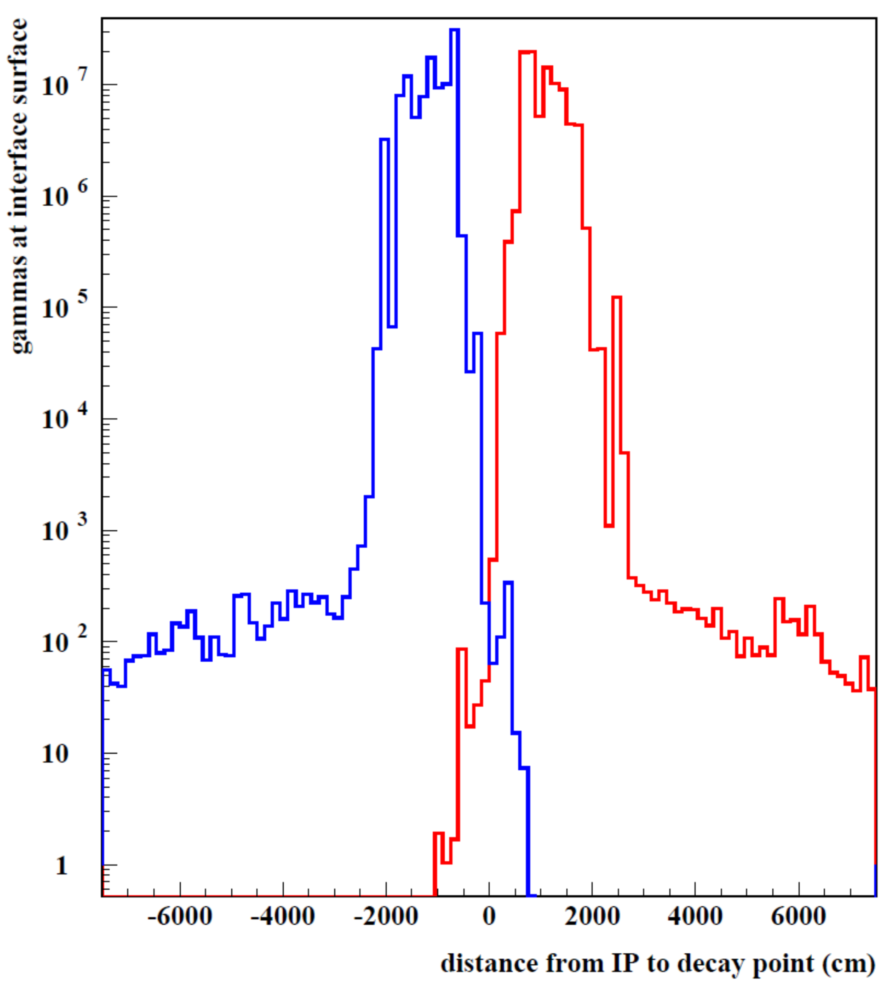


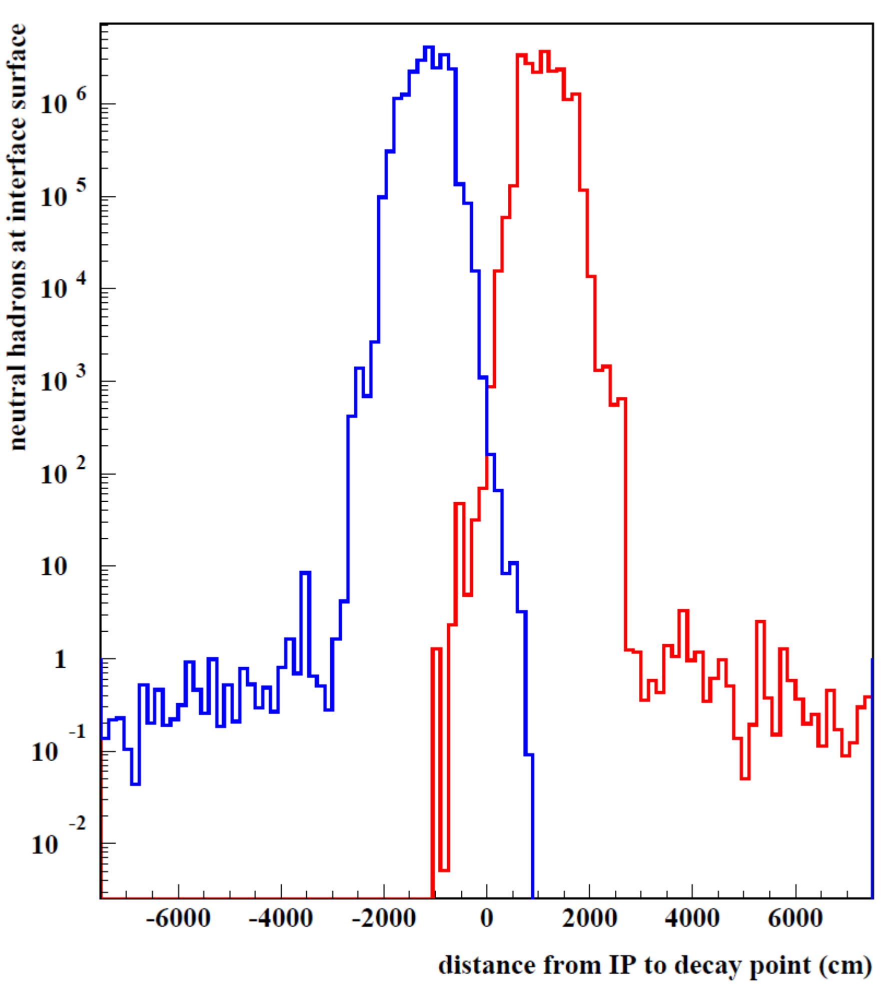
1. Minimize it ($20^0 \rightarrow 10^0$)
   - Top production in forward regions as CoM energy goes up
   - Asymmetries are more pronounced in forward regions
   - Z' → ttbar
   - Final states with many fermions (e.g. SM tt events) are hardly ever contained in the central detector
2. Instrument it
   - Forward calorimeter
   - Lumi-cal a'la ILC (40-140 mrad) for precise measurement of the int. luminosity ($\Delta L/L \sim 10^{-3}$)
   - Beam-cal at smaller angles for beam diagnostics

Particle Tracks in IR

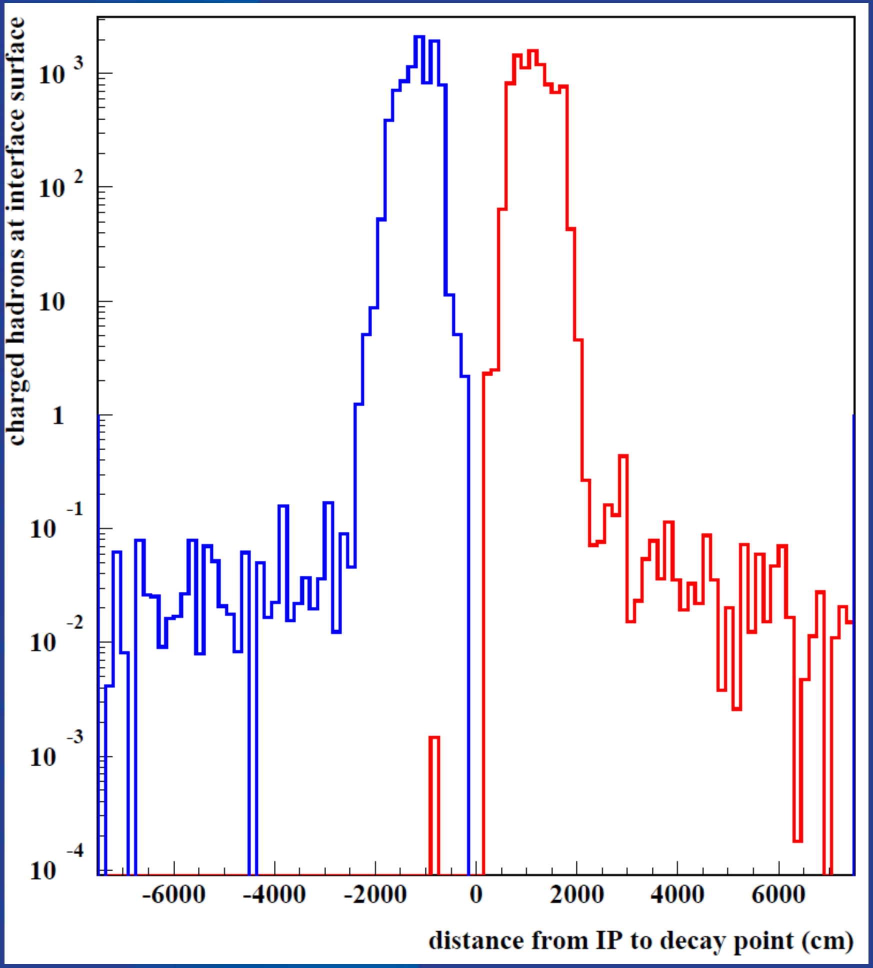


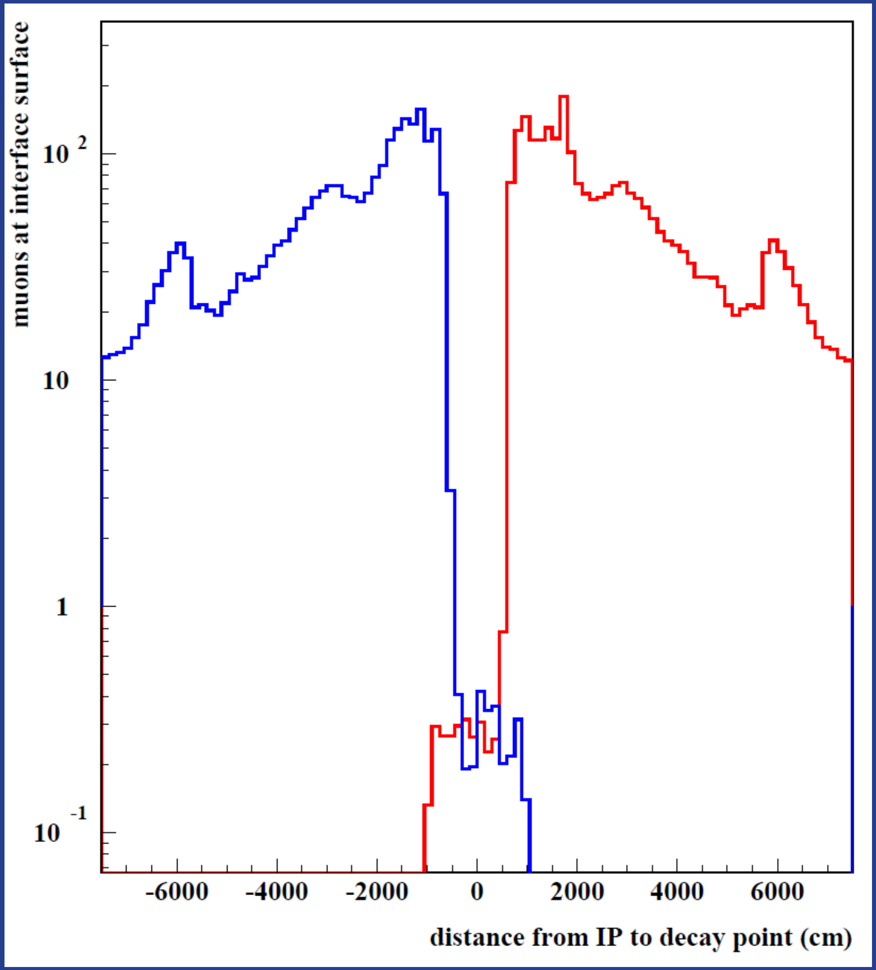
Source Tagging: Photons and Neutrons





Source Tagging: Charged Hadrons & Muons



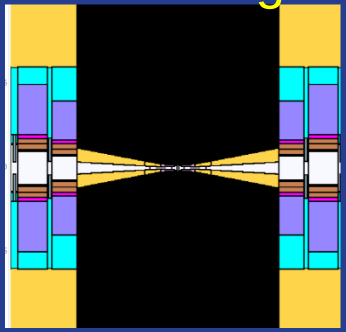


Load to Detector: Optimizing Nozzle

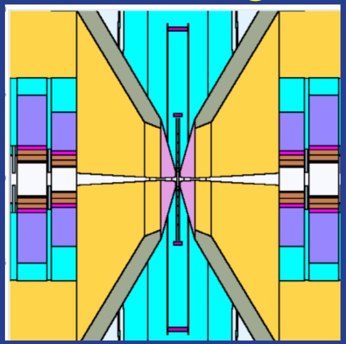
Number of particles per bunch crossing entering detector, starting from MARS source term for S_{max}=75m

Particle	Minimal 0.6-deg	10-deg
Photon	1.5×10^{11}	1.8×10^{8}
Electron	1.4×10^{9}	1.2×10^{6}
Muon	1.2×10^{4}	3.0×10^{3}
Neutron	5.8×10^{8}	4.3×10^{7}
Charged hadron	1.1×10^{6}	2.4×10^{4}

0.6-deg



10-deg



No time cut applied, can help substantially

X:Z=1:20

Vertex Detector Hit Density

- Layer of Silicon at a radius of 10 cm (earlier results) per bunch x-ing:

750 photons/cm^2	$\rightarrow$ 2.3 hits/cm^2
110 neutrons/cm^2	$\rightarrow$ 0.1 hits/cm^2
1.3 charged tracks/cm^2	$\rightarrow$ 1.3 hits/cm^2
TOTAL	3.7 hits/cm^2

$\rightarrow$ 0.4% occupancy in 300x300 μm^2 pixels (10 times better with nowadays 50x50 μm^2)

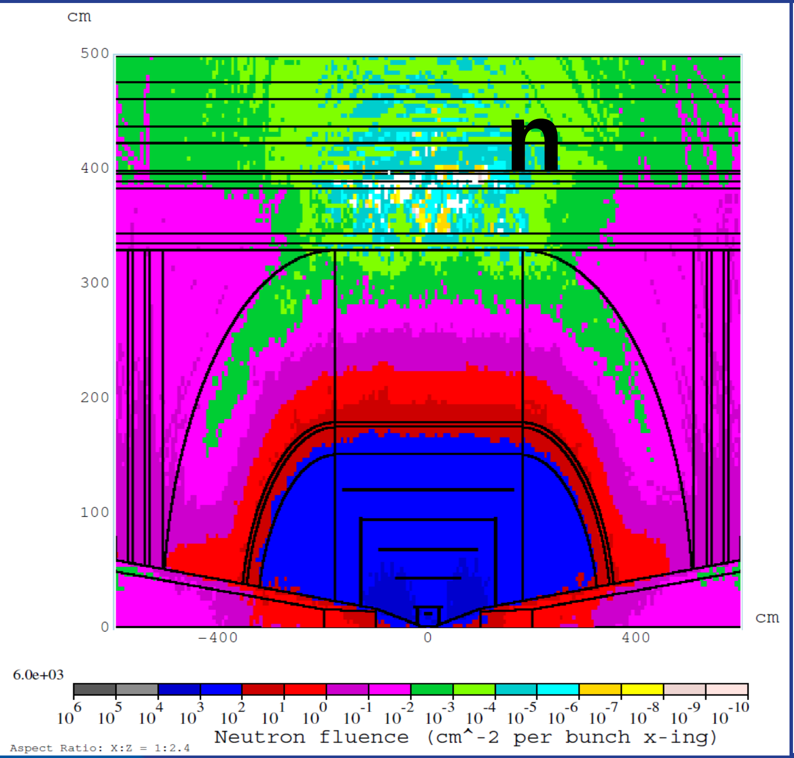
- At 5cm radius: 13.2 hits/cm^2 $\rightarrow$ 1.3% occupancy (again, better with current technologies)

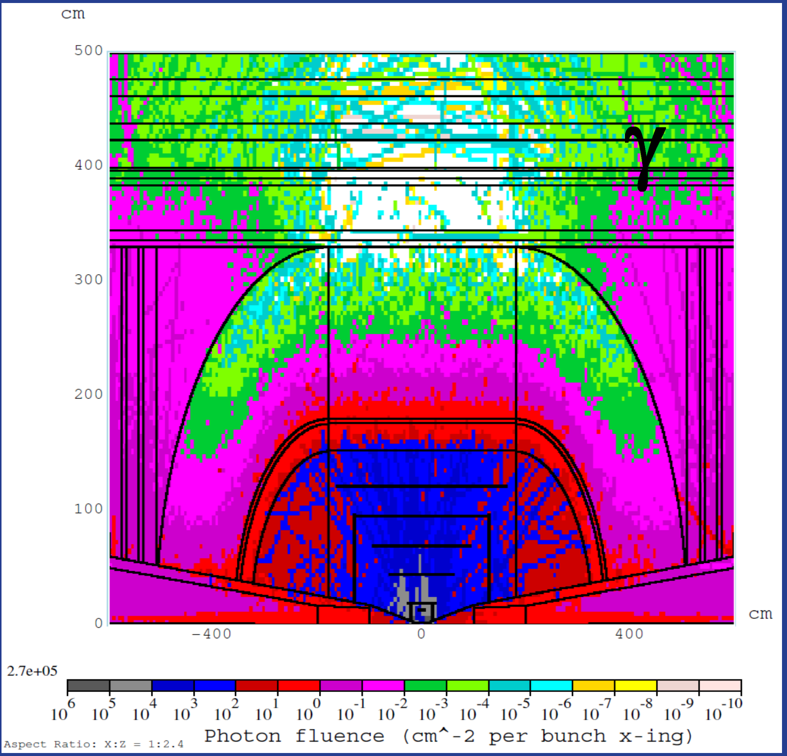
- For comparison with CLIC
  - At r = 3cm hit density about ×2 higher than at 5cm $\rightarrow$ ~20 hits/cm^2 $\rightarrow$ 0.2 hits/mm^2 per bunch x-ing (MC) vs ~1 hit/mm^2/bunch train (CLIC)
  - Shielding cone: 10^o (MC) vs 7-9^o (CLIC)
  - Bunch crossing time: CLIC 0.5ns (signal formation in Si much longer) MC: 10μs (lots of time for readout, backgrounds don't pile up)

Neutron and Photon Fluence

Fluence per bunch crossing, starting from MARS source term for S_{max} = 75 m. Compared to best 20-deg '96 configuration, peak values are down 5-10 times for all particles but photons.

Neutron peak/yr = 0.1xLHC@10^{34}





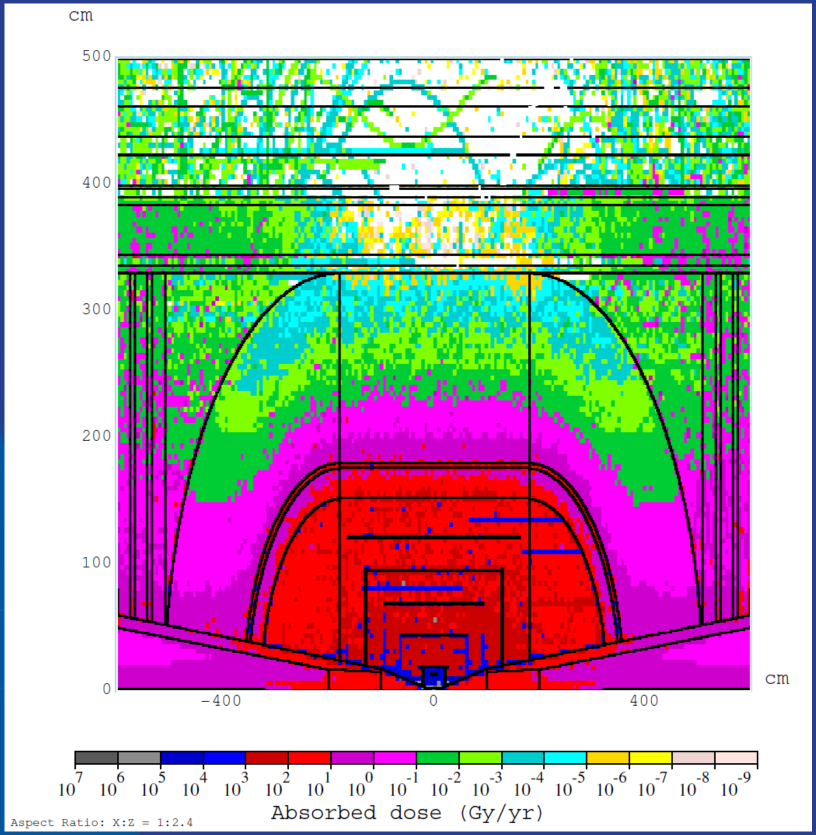
Absorbed Dose (vs LHC)

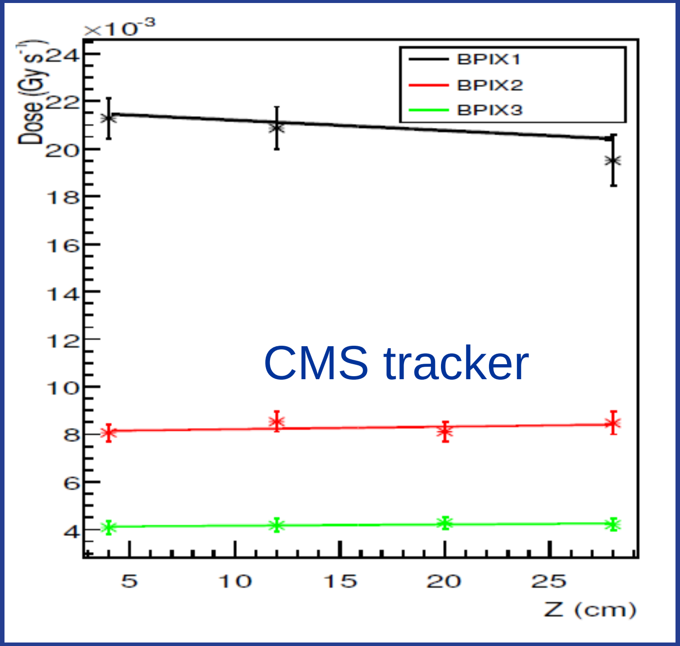
Total absorbed dose in Si

Peak at r=4 cm:

MC: 0.1 MGy/yr

CMS: 0.2 MGy/yr @10^{34}





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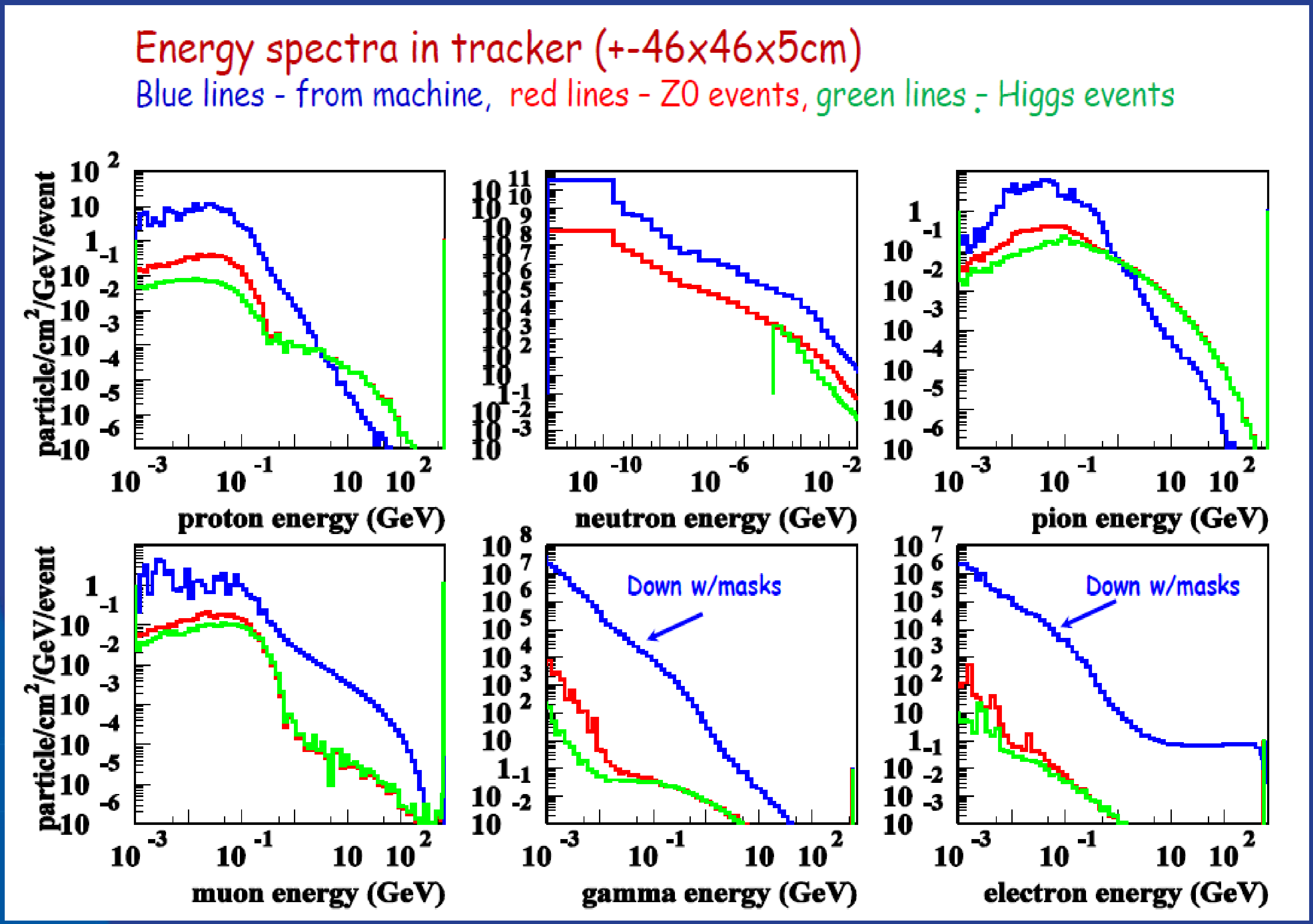
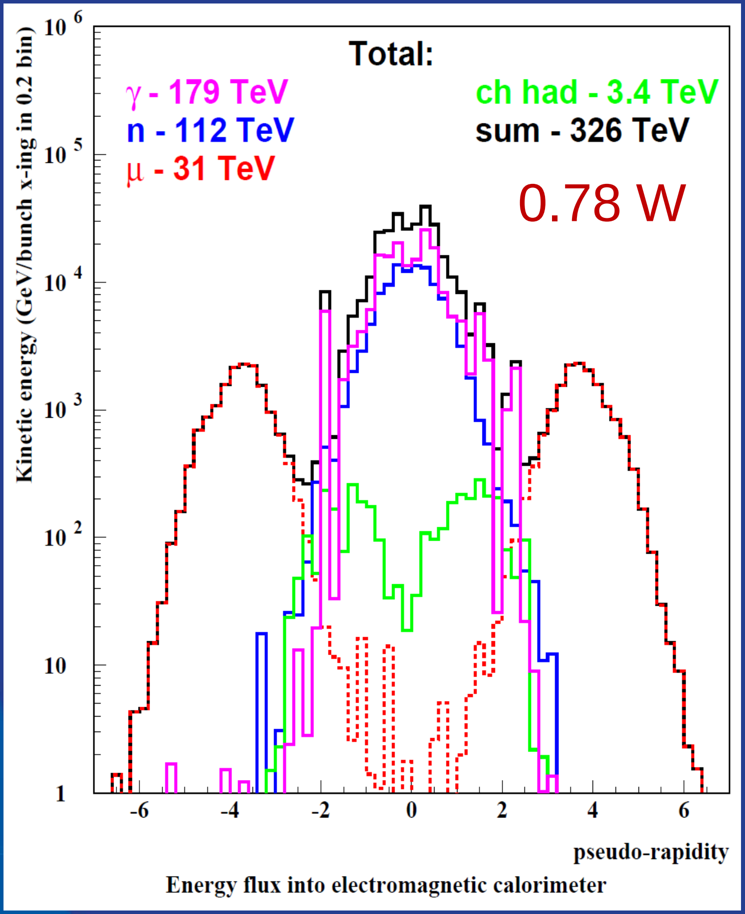
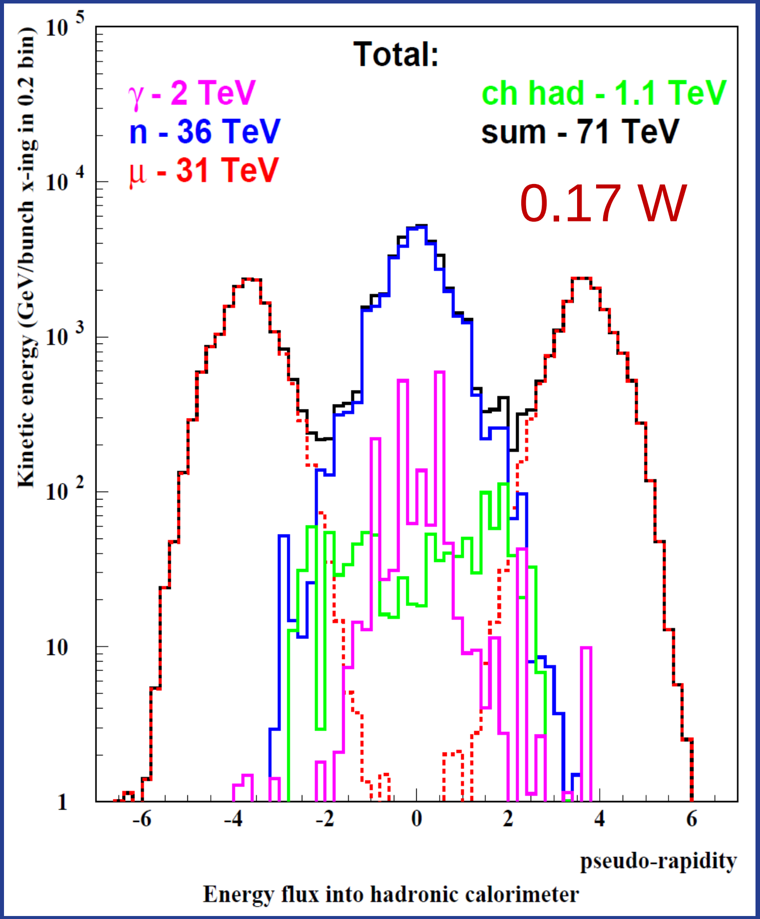
Machine vs IP Backgrounds in Tracker



Energy Flux into Ecal and Hcal vs Rapidity





Peak: ~1 GeV / 2x2 cm^2 cell with σ_E ~ 30 MeV

Peak: ~1.5 GeV / 5x5 cm^2 cell with σ_E ~ 80 MeV

Reducing Weight Fluctuations

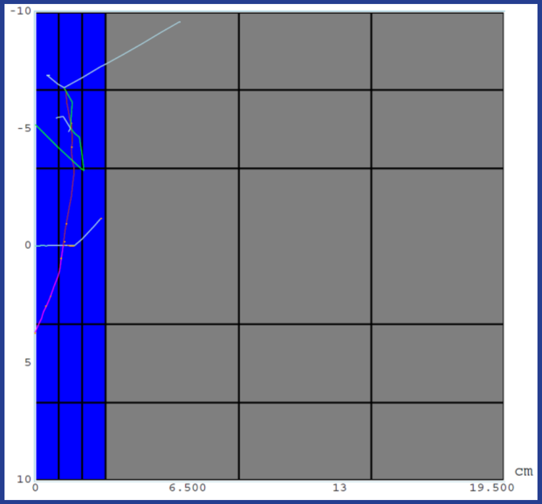
Statistical weight spread has been substantially reduced over last three months. Internal MARS weight fluctuations came predominantly from modeling of low-energy electromagnetic and hadronic showers as well as from photo- and electro-nuclear hadron and muon production algorithms.

Now these are user-controlled by material-dependent switches between exclusive, inclusive and hybrid modes.

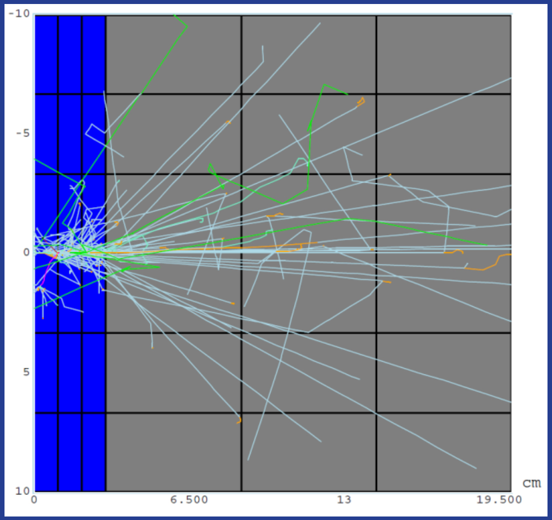
Example: EMS

One 10-GeV e^+ on 3cm W + 17cm concrete

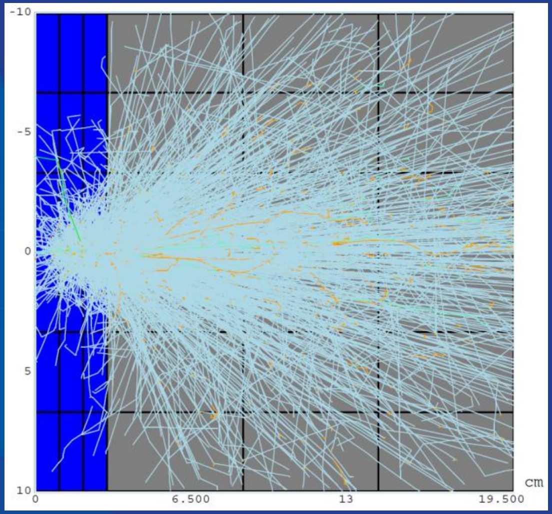
Inclusive



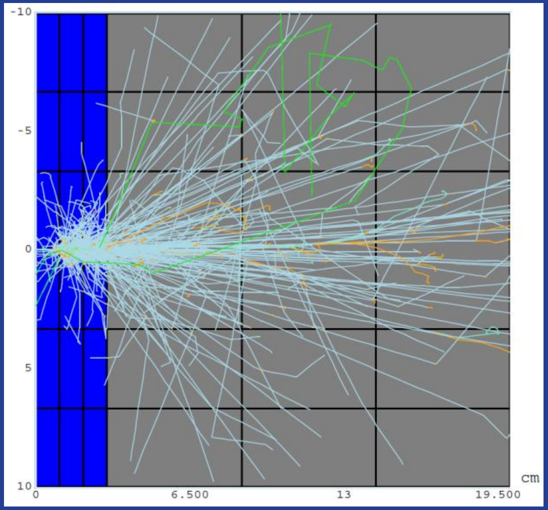
Hybrid-10



Exclusive

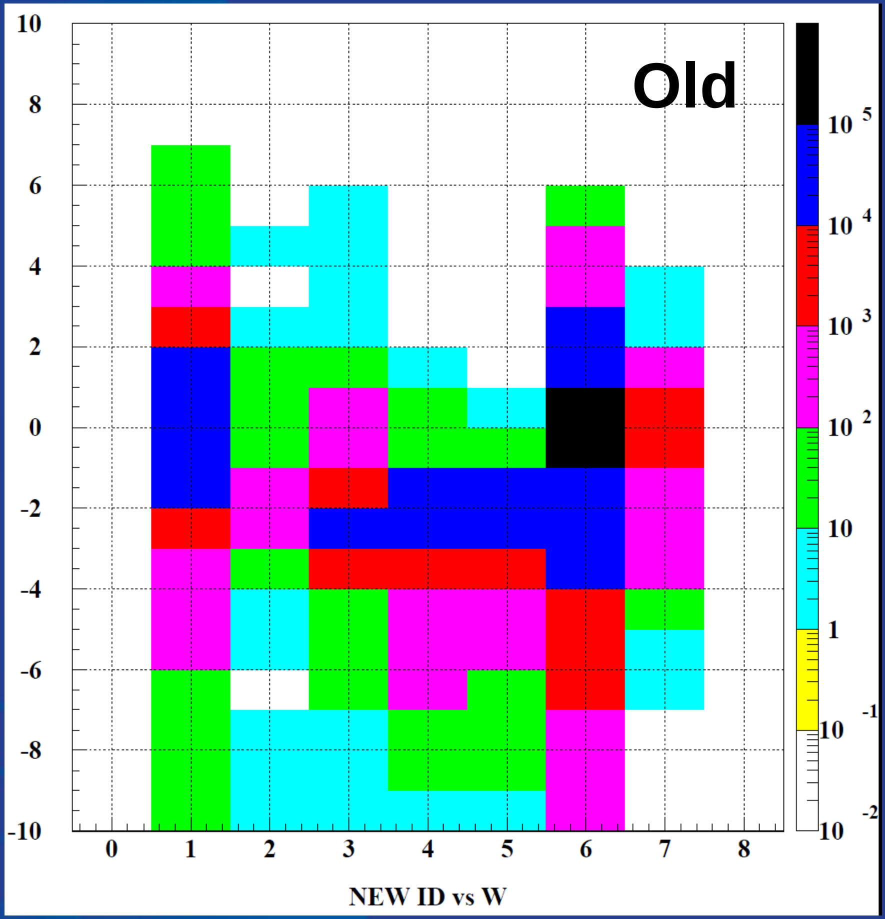


Hybrid-20

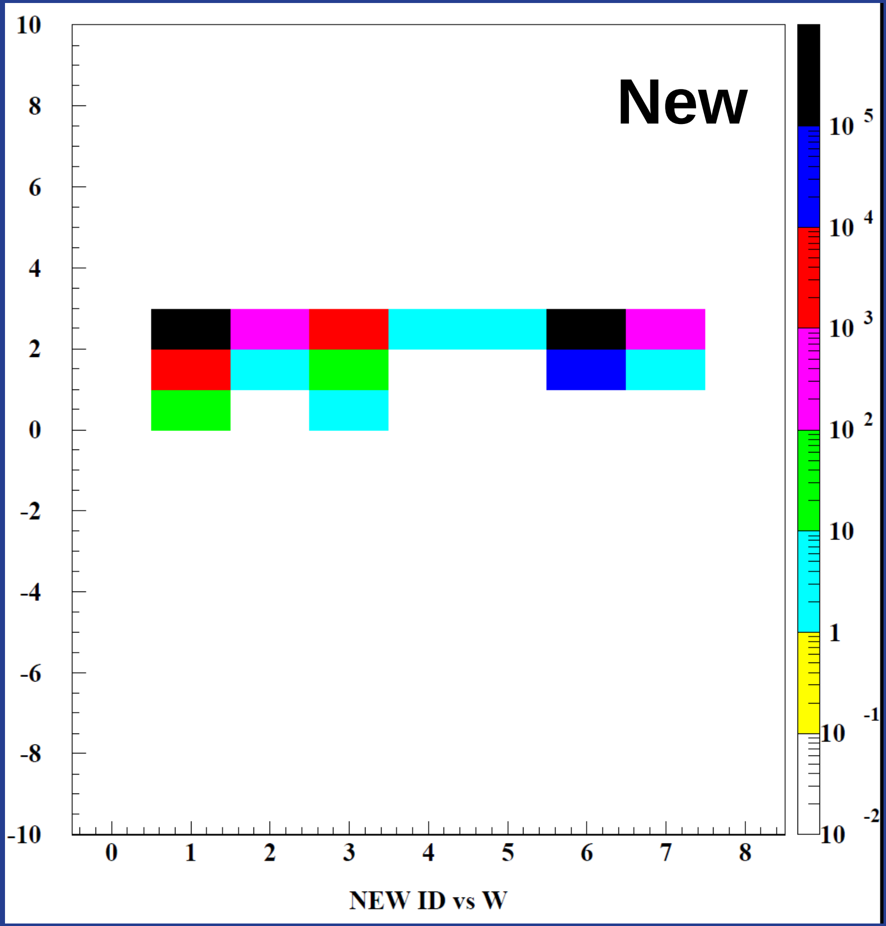


$Log_{10}W$ vs Particle ID

Divide by 5.1



Divide by 139



ID: 1=γ, 2=e^+, 3=e^-, 4=μ^+, 5=μ^-, 6=n, 7=ch.hadr

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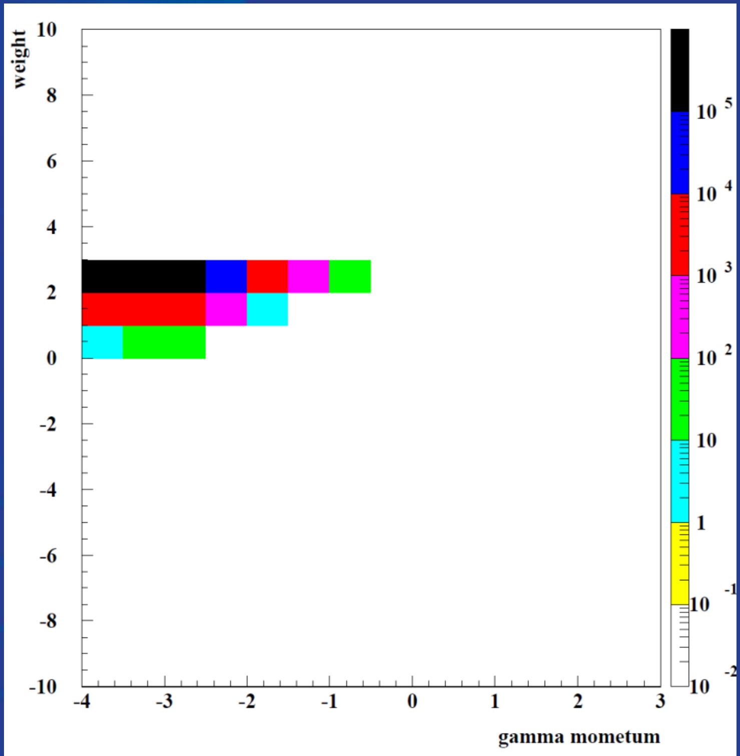
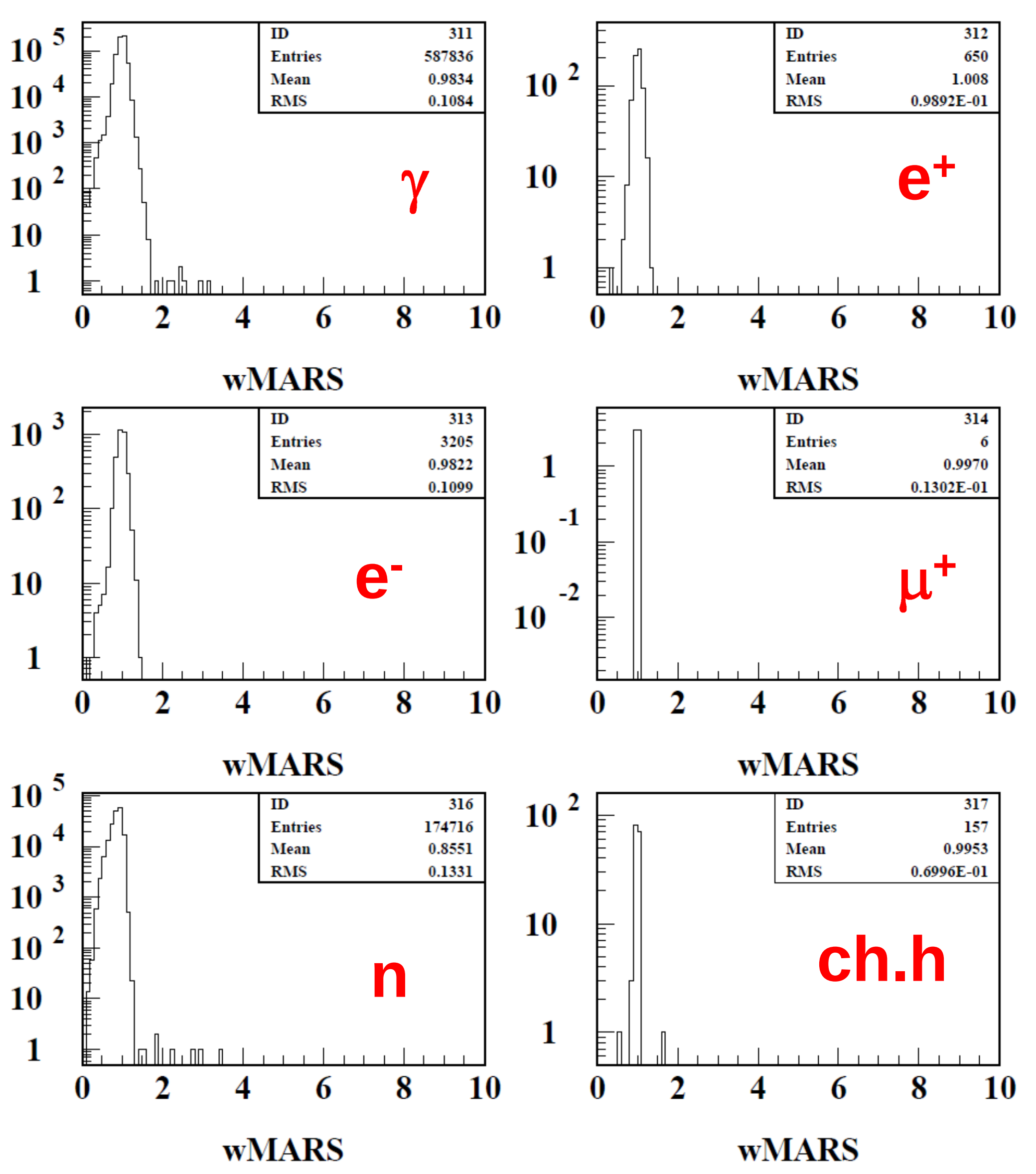
Weight Distributions

Log$_{10}$W

Divide by 139



Log$_{10}$ p$_\gamma$



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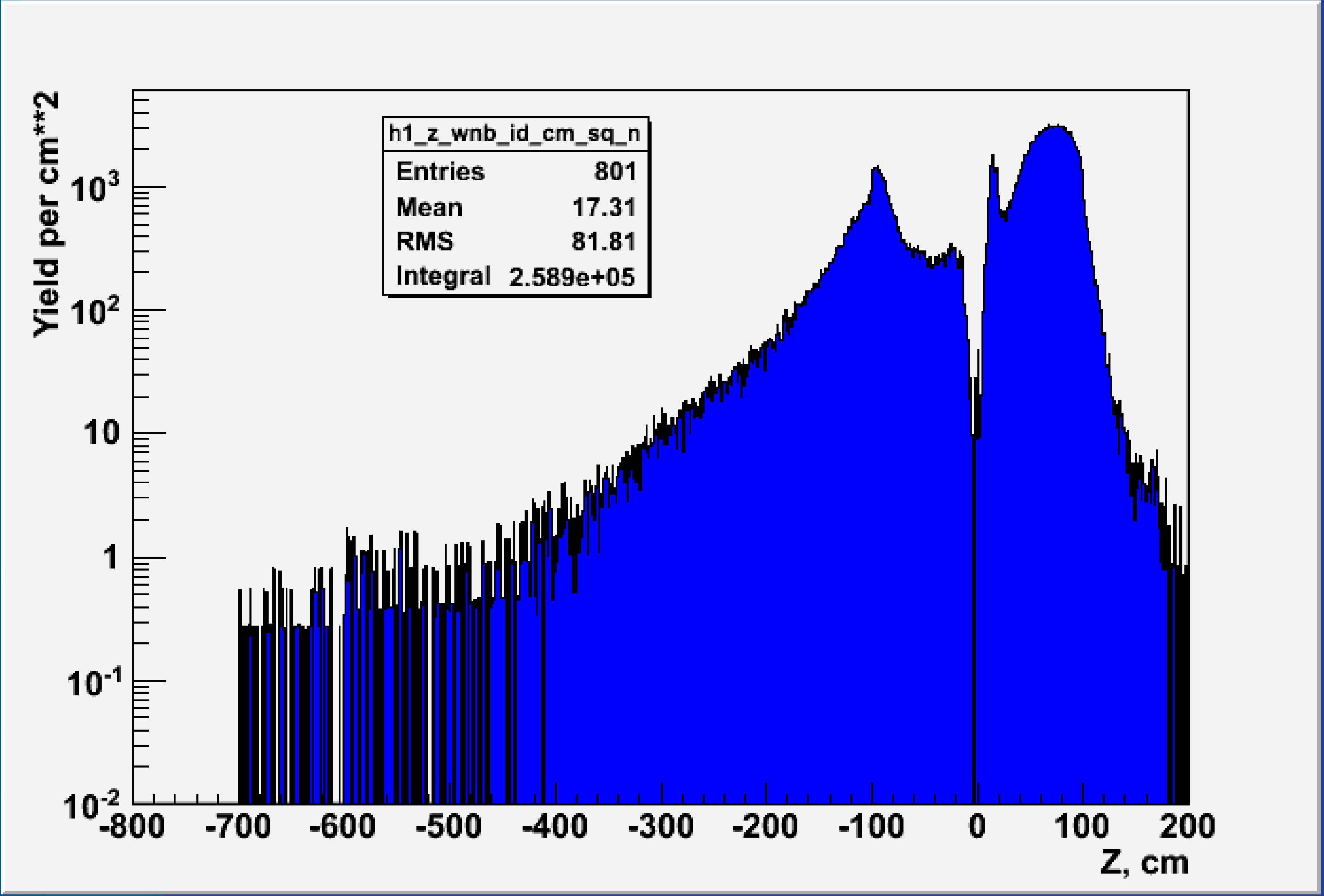
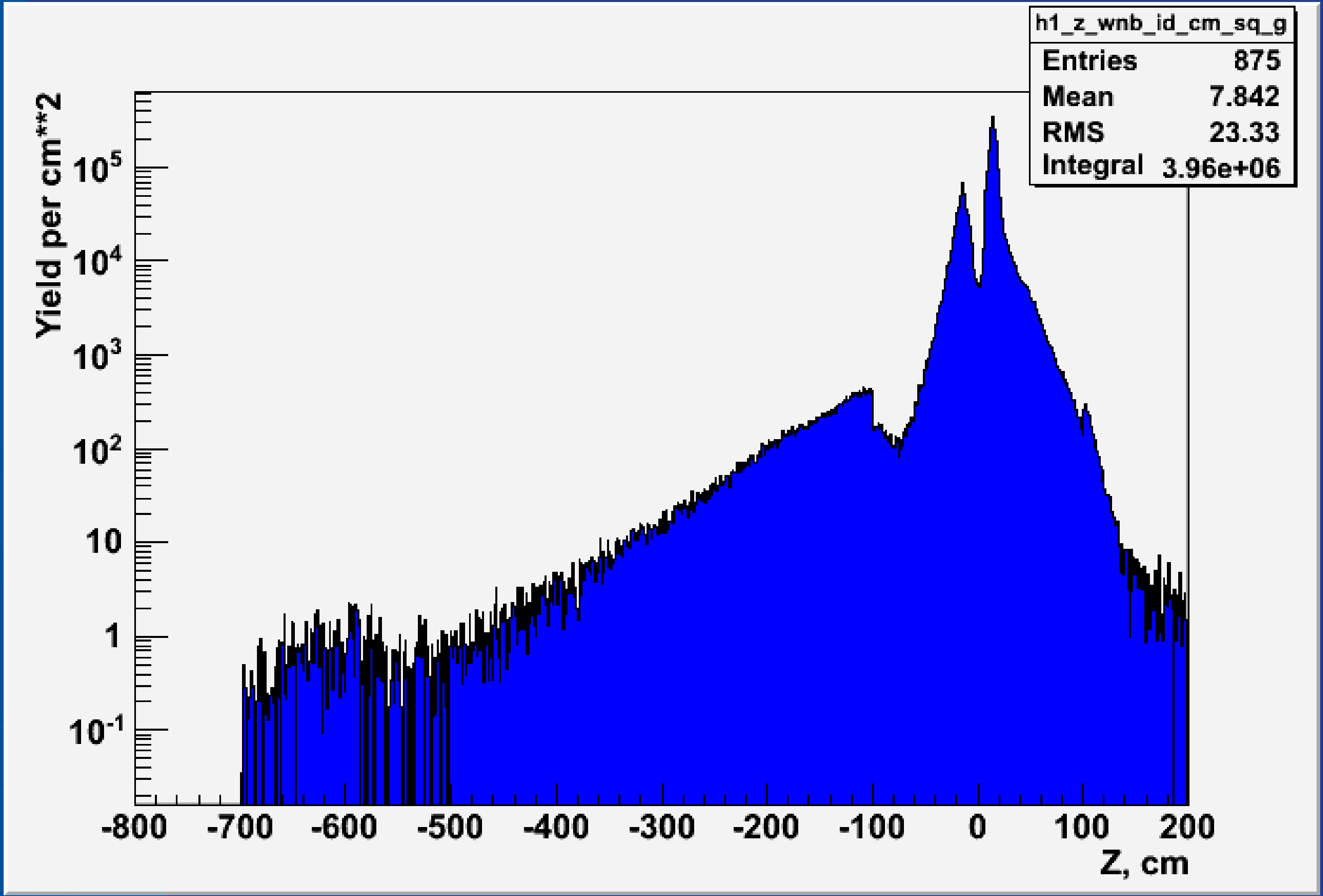
Neutrons/cm^2 Entering Detector vs Z



Muon beam approaching IP from the left

Photons/cm² Entering Detector vs Z



Muon beam approaching IP from the left

MDI Activities

- IR lattice, magnet design, MARS15 developments and modeling, optimization of shielding for detector and magnets, source term modeling on the MDI surface:

  N. Mokhov, Y. Alexahin, E. Gianfelice-Wendt, V. Kashikhin, S. Striganov, N. Terentiev, A. Zlobin

- Feeding detector simulation (so far):

  ILCRoot (C. Gatto group) and Fast Monte-Carlo (S. Mrenna)

Summary

- MARS15 model for a consistent IR design with realistic IR magnets and optimized shielding is up and running, with encouraging results on 1.5-TeV MC detector backgrounds
- Breakthrough in reduction of statistical weight spread allows for much easier analysis and feeding detector simulators
- New high-statistics files will be available to the detector community in October 2010
- Detector model to be adjusted to match the cone