MARS15 Simulations of Detector Backgrounds

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Fermilab

Outline

- Muon Collider Background Sources
- Suppressing Backgrounds
- MARS15 Simulations
- Source Term Studies
- Feeding Detector Simulations

Sources of Background at Muon Colliders

1. IP $\mu^+\mu^-$ collisions: Production x-section 1.34 pb at √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).

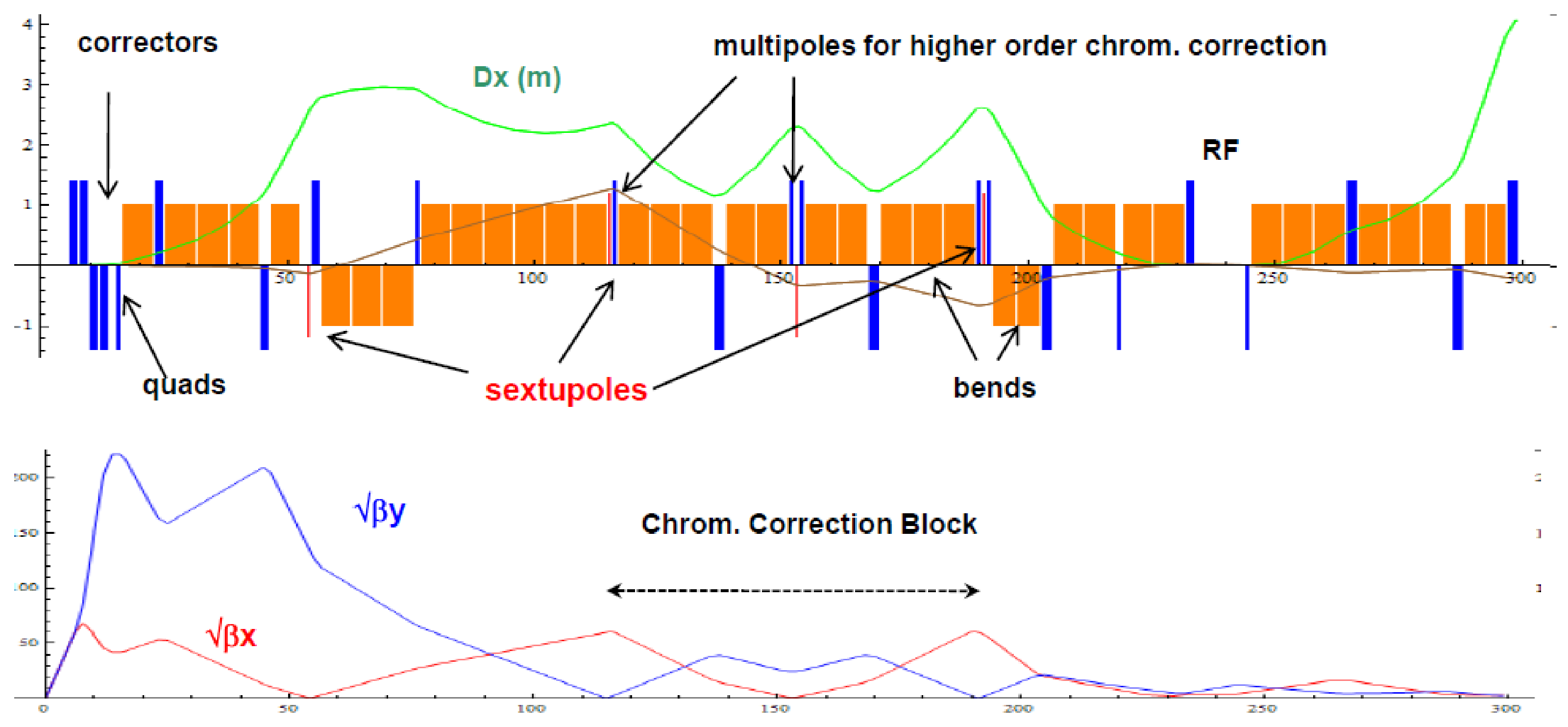
Recent MARS15 Simulations

- 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

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

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 -1.5x10^{-5}; dynamic aperture sufficient for transverse emittance of 50 μm; under engineering constraints.

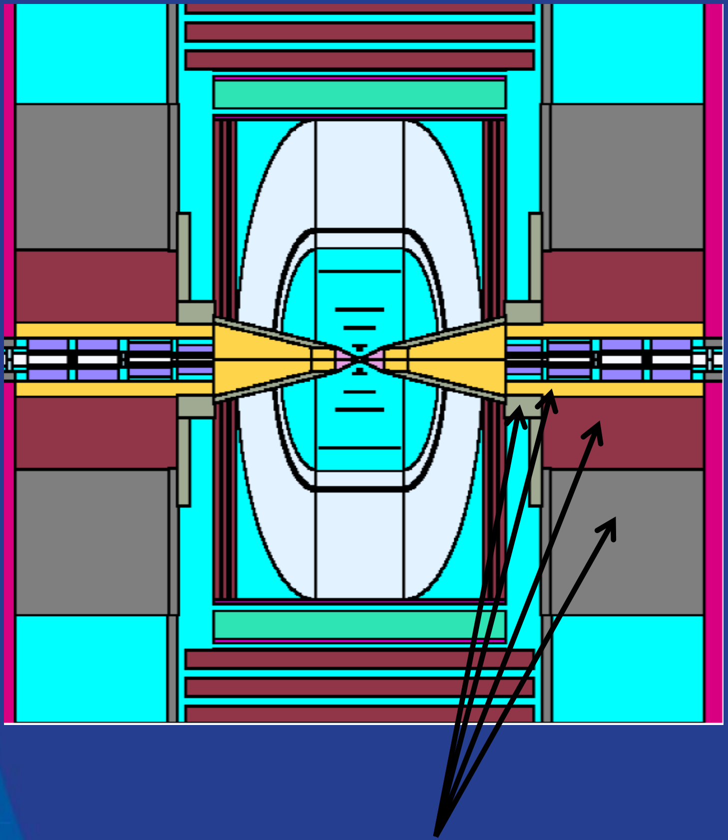
Iterative studies on lattice and MDI with magnet experts:

High-gradient (field) large-aperture short Nb_3Sn quads and dipoles.

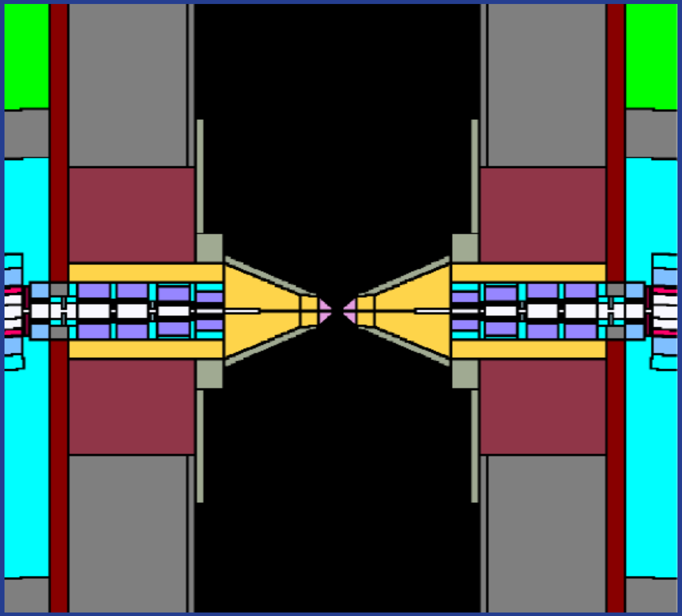
MARS15 Modeling

- 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

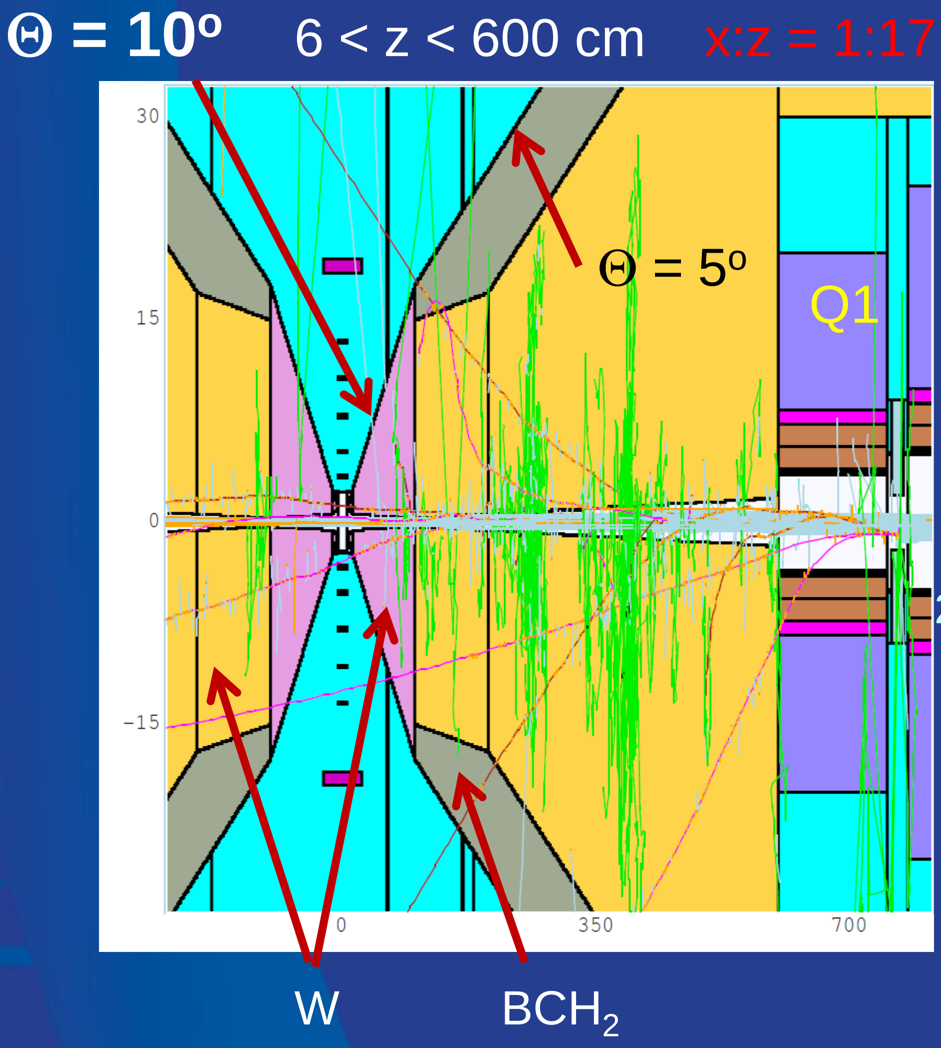


Sophisticated shielding:
W, iron, concrete & BCH_2



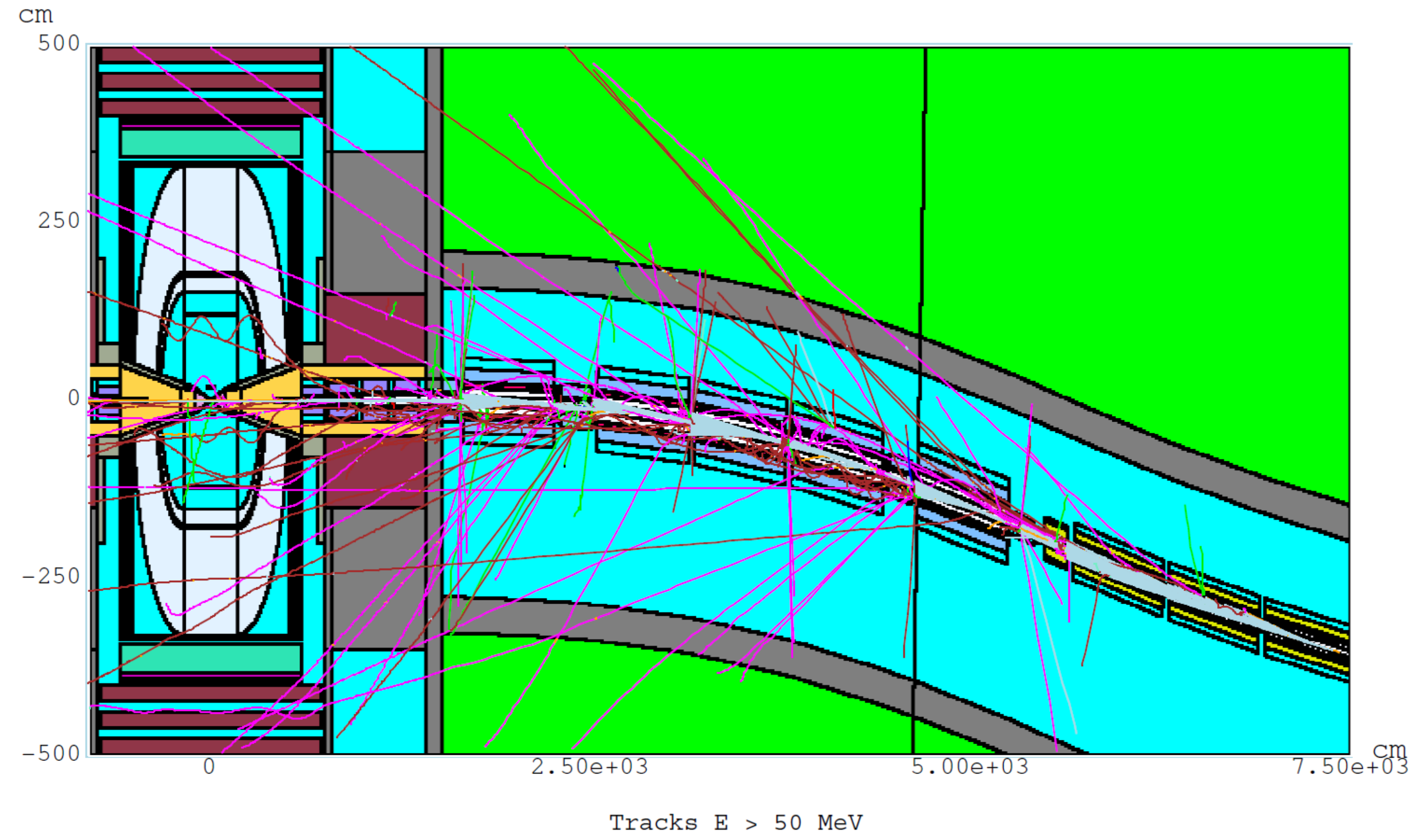
Source term at black hole to feed detector simulation groups: ILCRoot (INFN), Fast MC (FNAL) and lcsim

Tungsten Nozzle in BCH_2 Shell



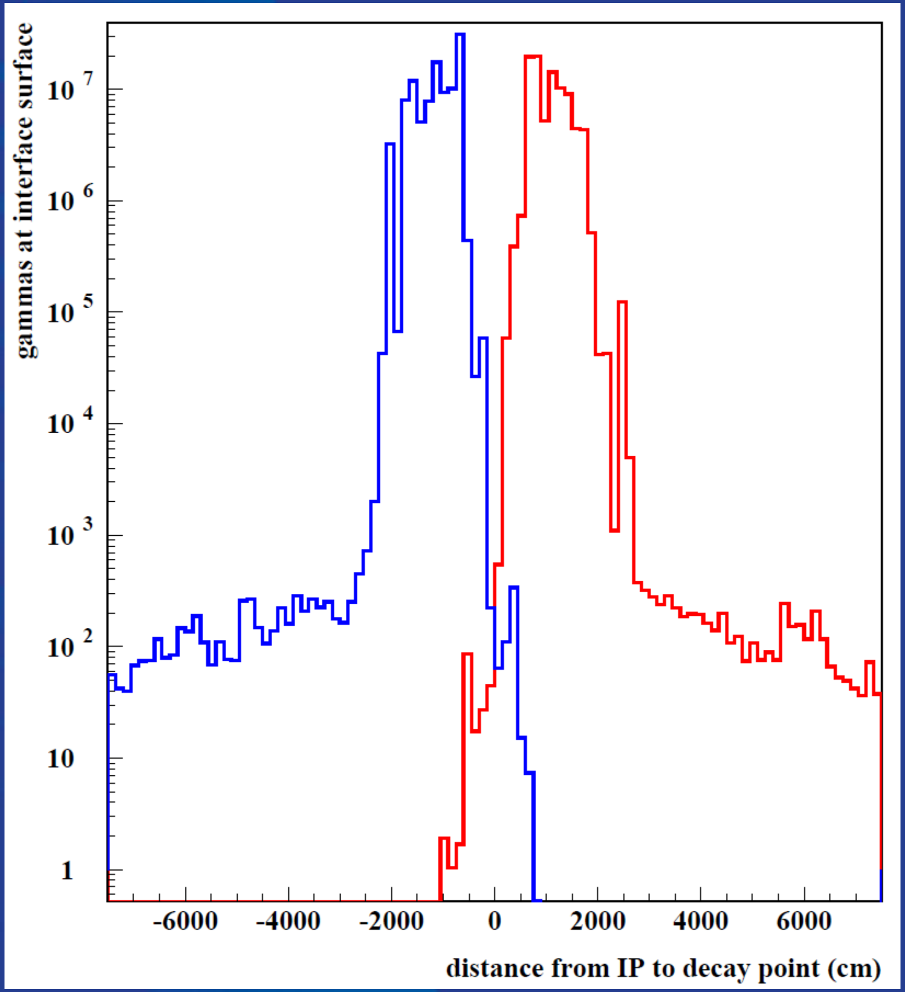
1. Minimize it (20^0 → 10^0)
   - Top production in forward regions as CoM energy goes up
   - Asymmetries are more pronounced in forward regions
   - Z' → ttbar
   - Final states with many fermions (e.g. SM tt events) are hardly ever contained in the central detector
2. Instrument it
   - Forward calorimeter
   - 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

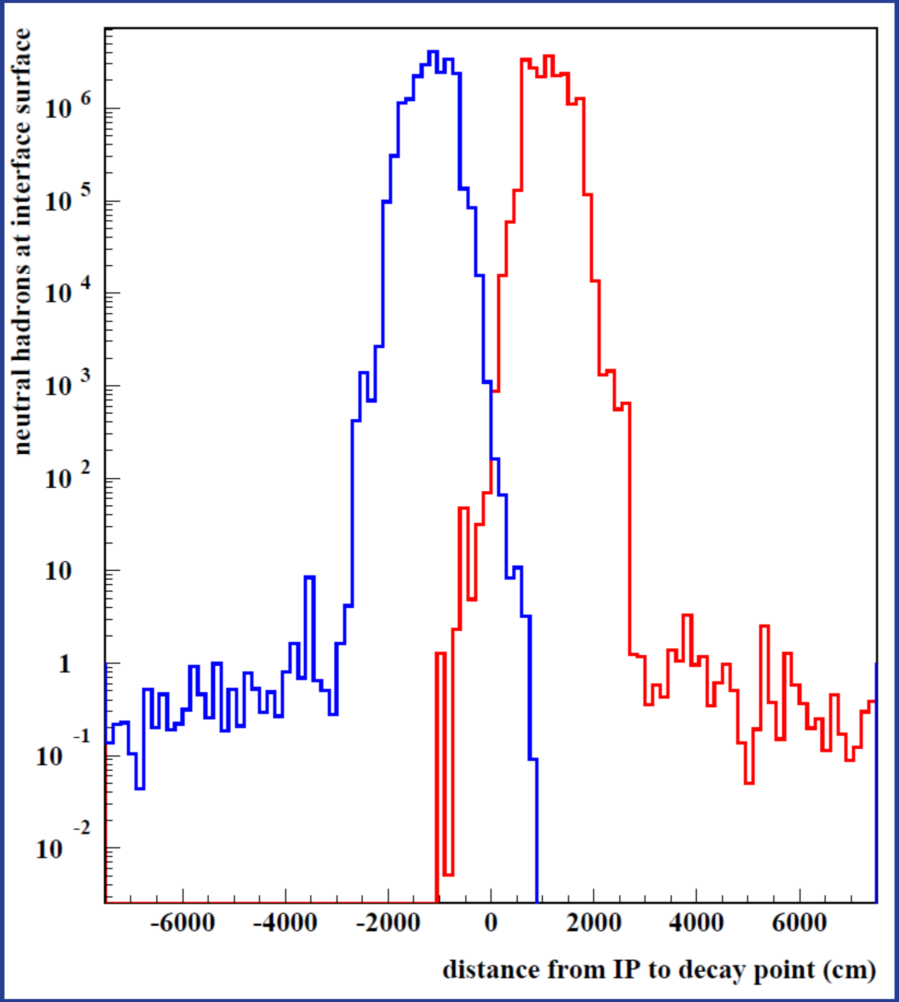
Particle Tracks in IR



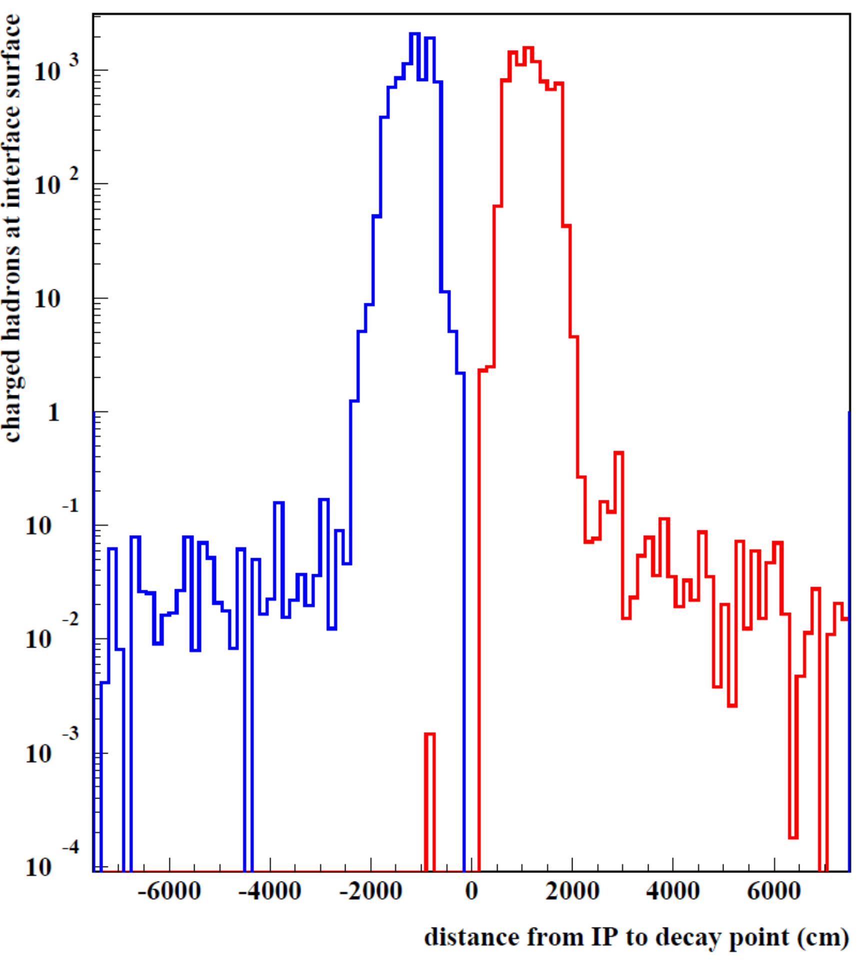
Tracks E > 50 MeV

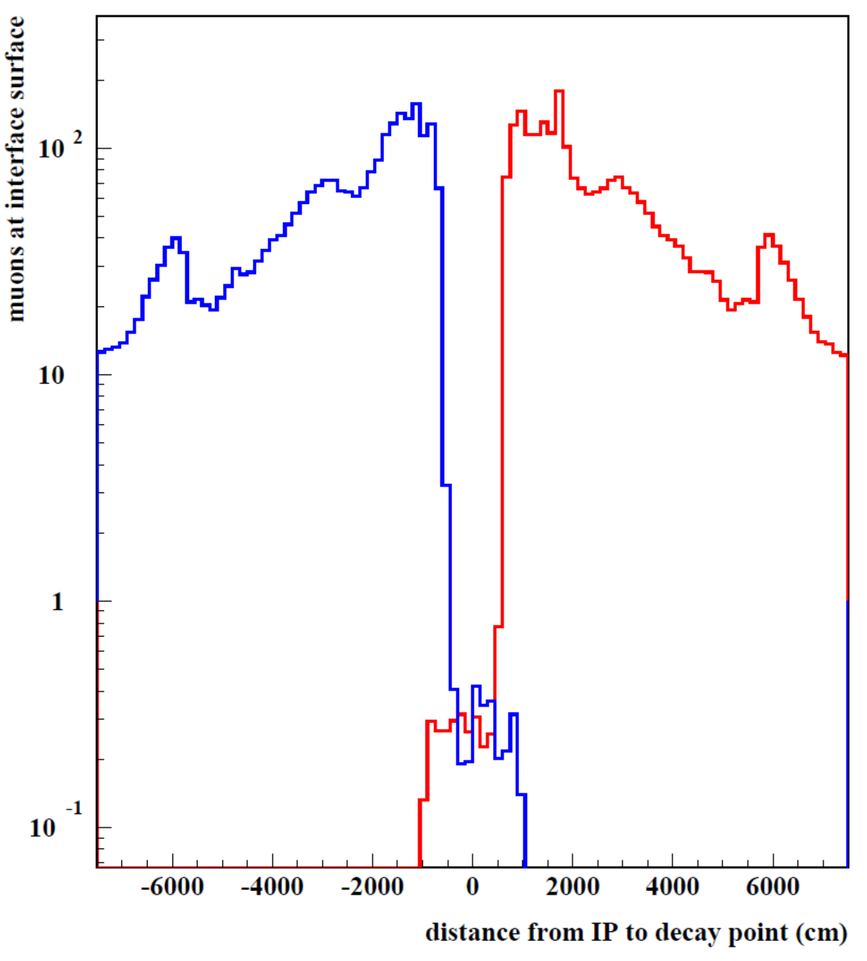
Source Tagging: Photons and Neutrons





Source Tagging: Charged Hadrons & Muons



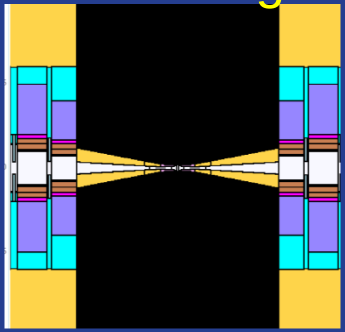


Load to Detector: Optimizing Nozzle

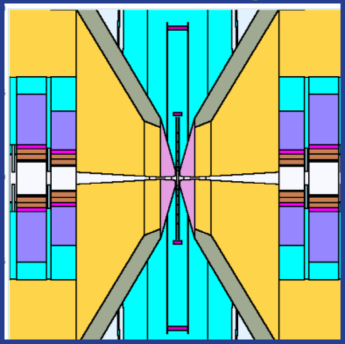
Number of particles per bunch crossing entering detector, starting from MARS source term for S_{max}=75m

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



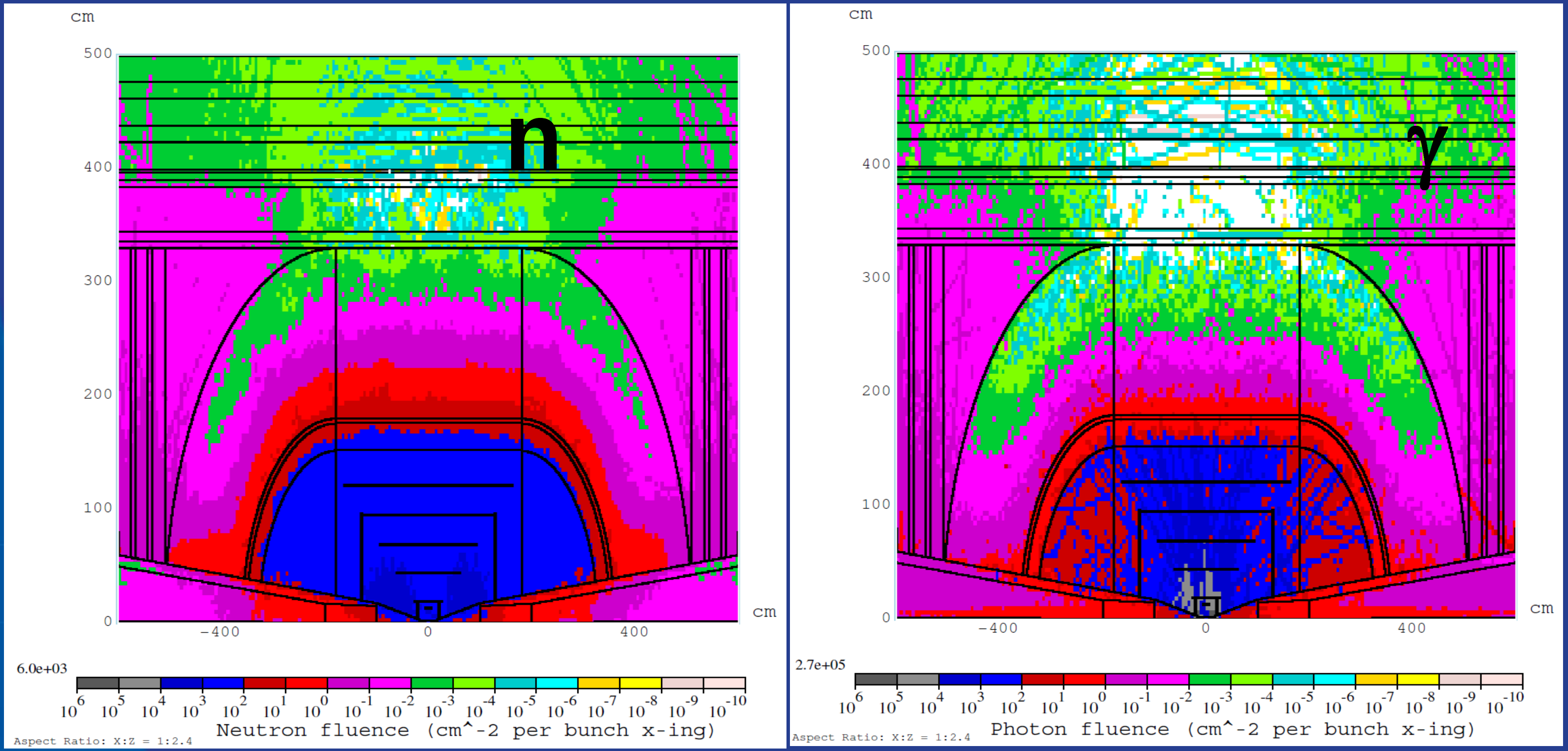
No time cut applied, can help substantially

X:Z=1:20

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}

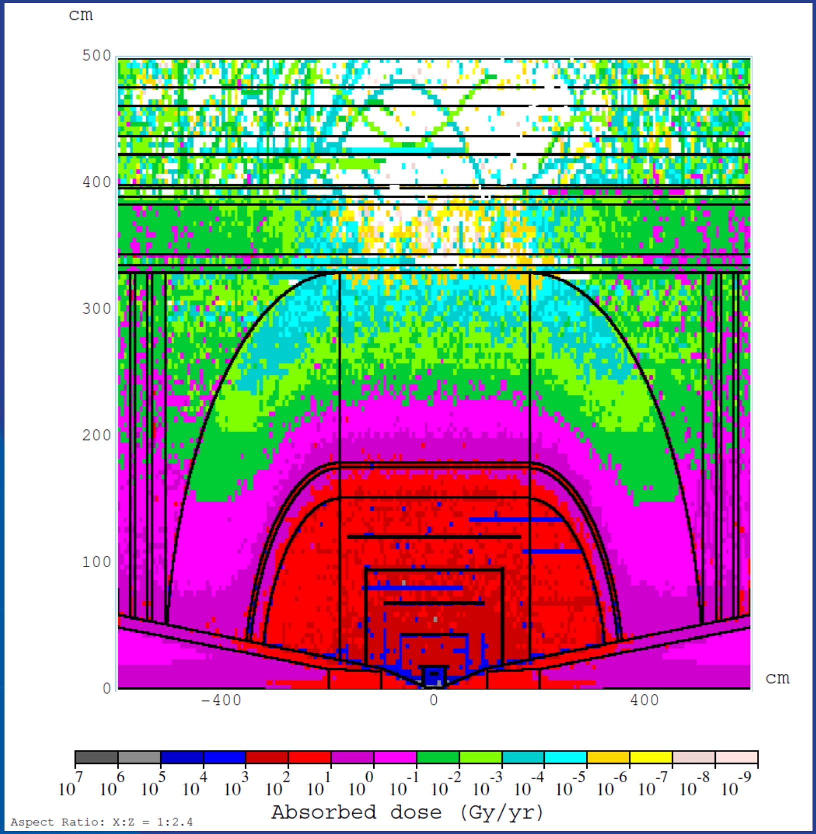


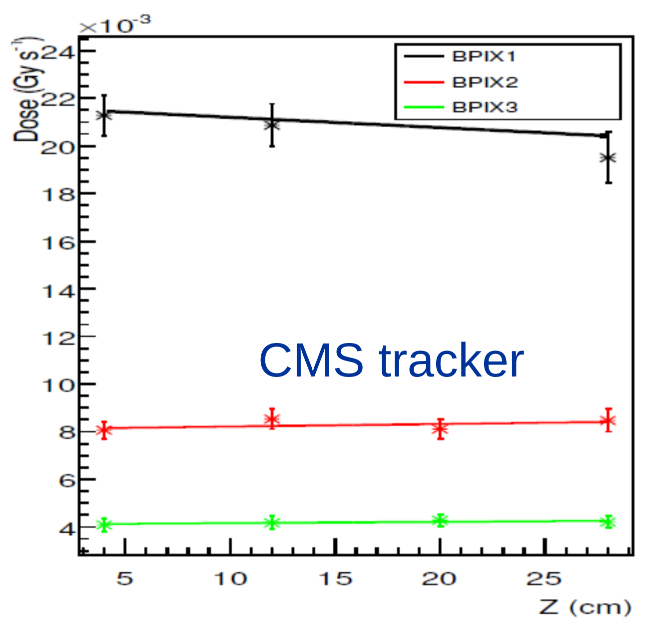
Absorbed Dose (vs LHC)

Total absorbed dose in Si

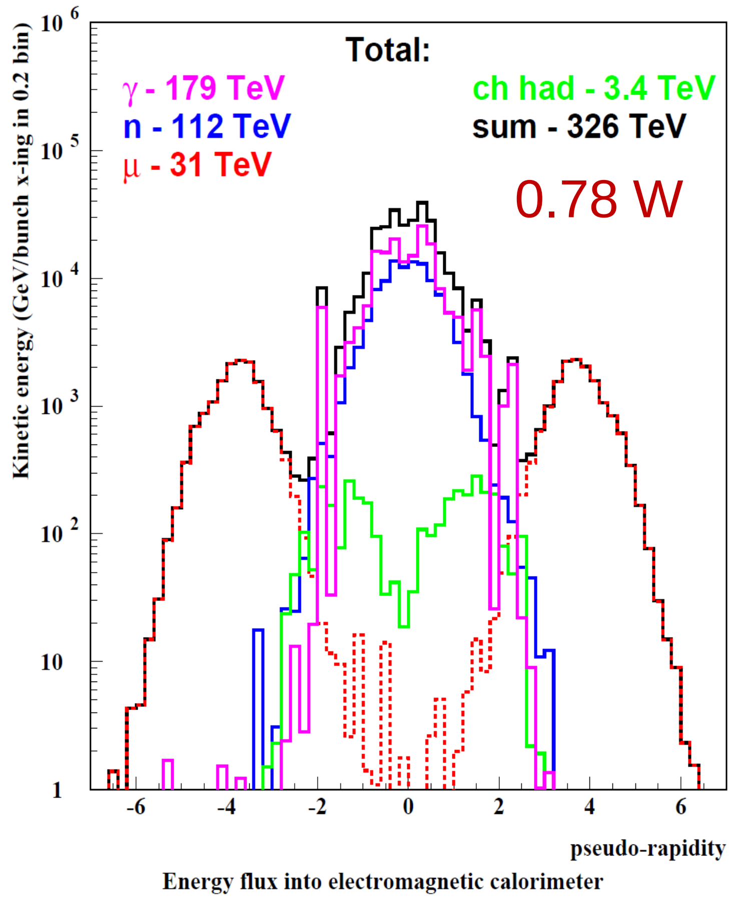
Peak at r=4 cm:

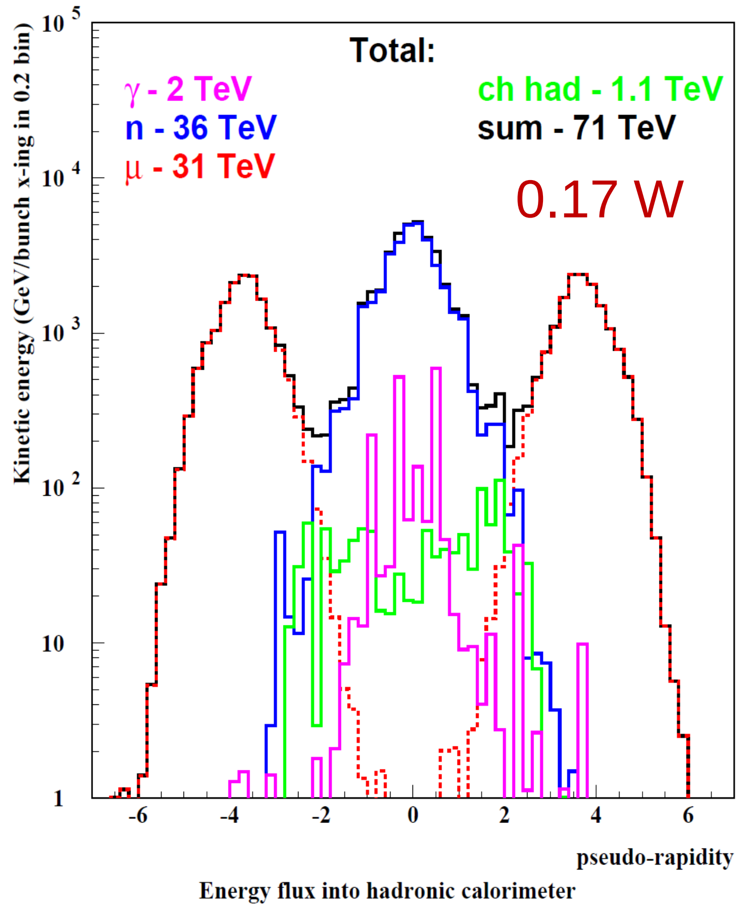
MC: 0.1 MGy/yr
CMS: 0.2 MGy/yr @10^{34}





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

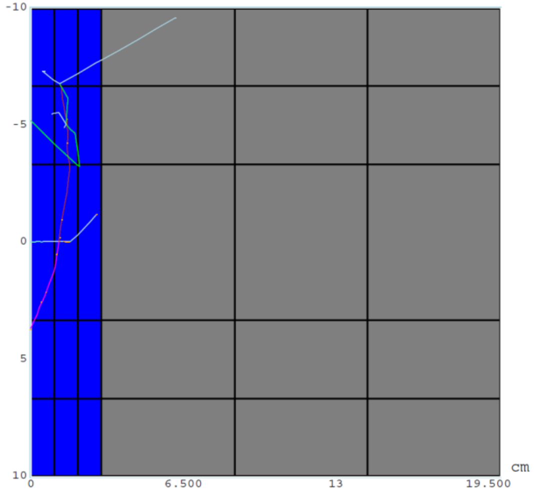
Statistical weight spread has been substantially reduced over last three months. Internal MARS weight fluctuations came predominantly from modeling of low-energy electromagnetic and hadronic showers as well as from photo- and electro-nuclear hadron and muon production algorithms.

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

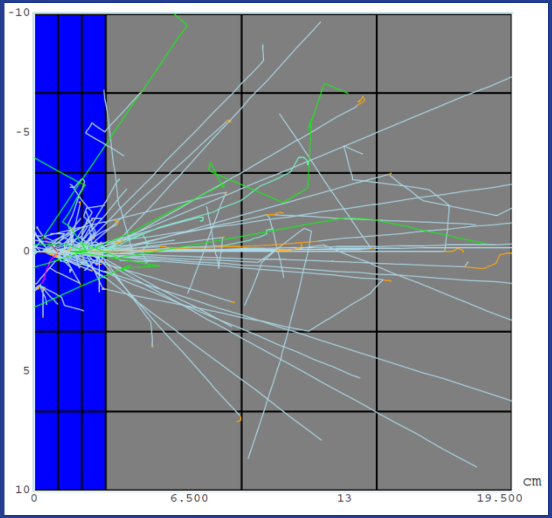
Example: EMS

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

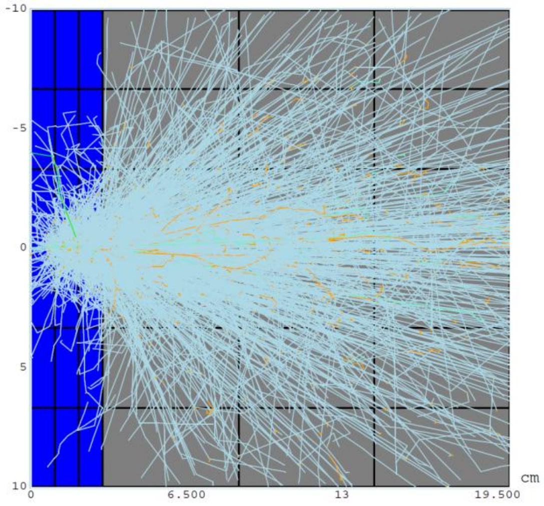
Inclusive



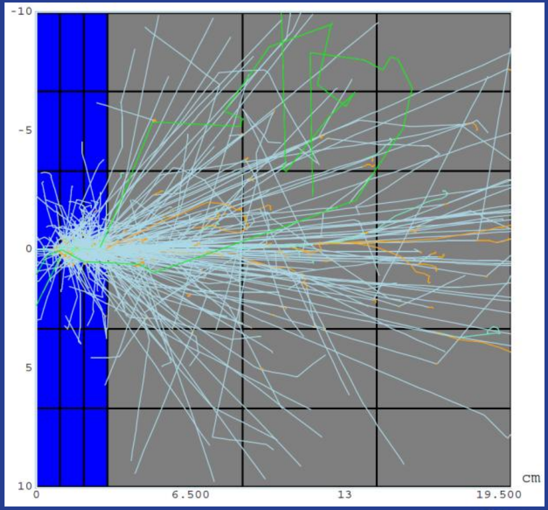
Hybrid-10



Exclusive

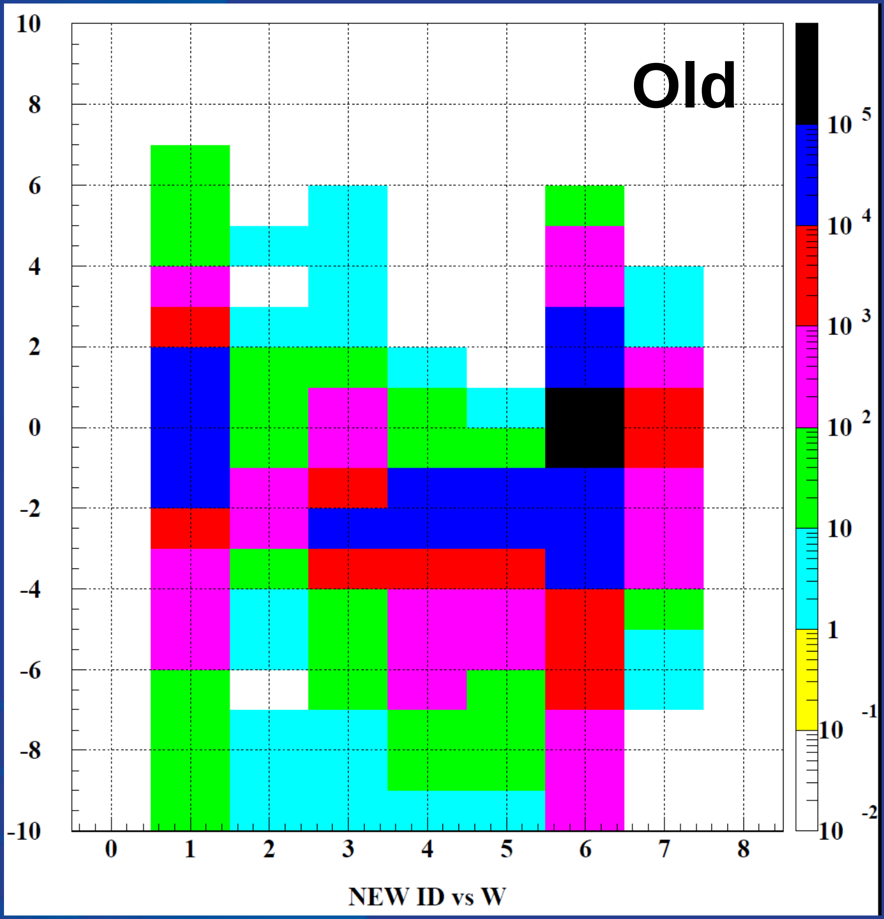


Hybrid-20

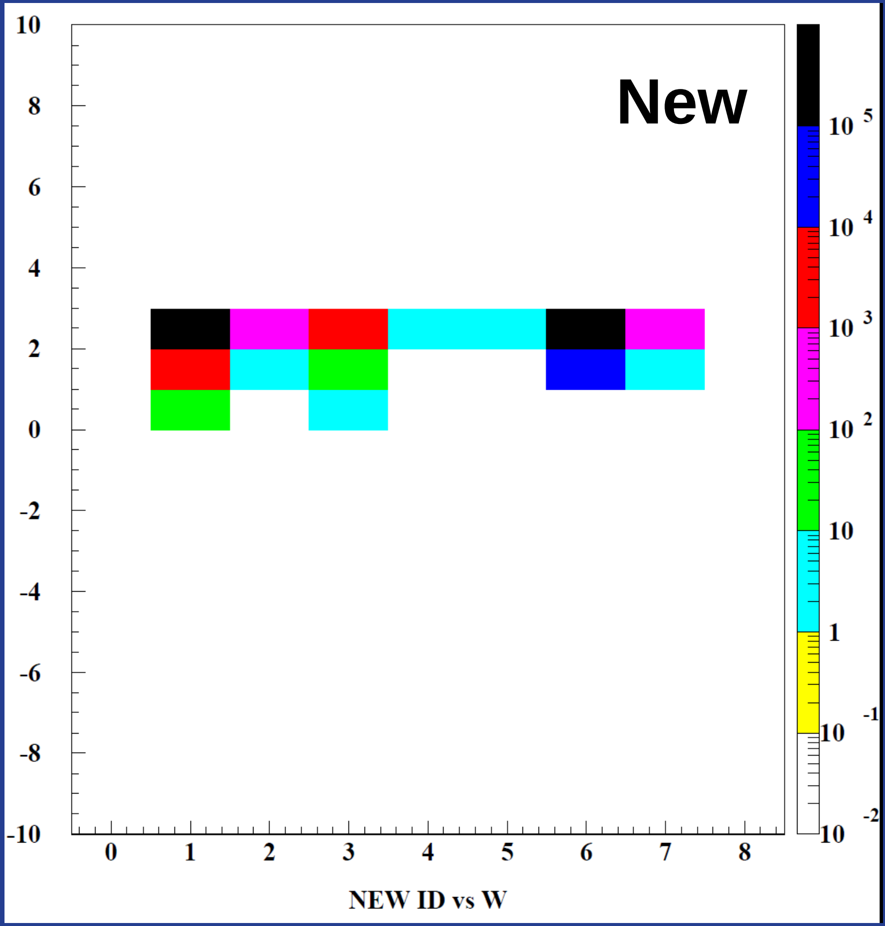


Log_{10}W vs Particle ID

Divide by 5.1



Divide by 139

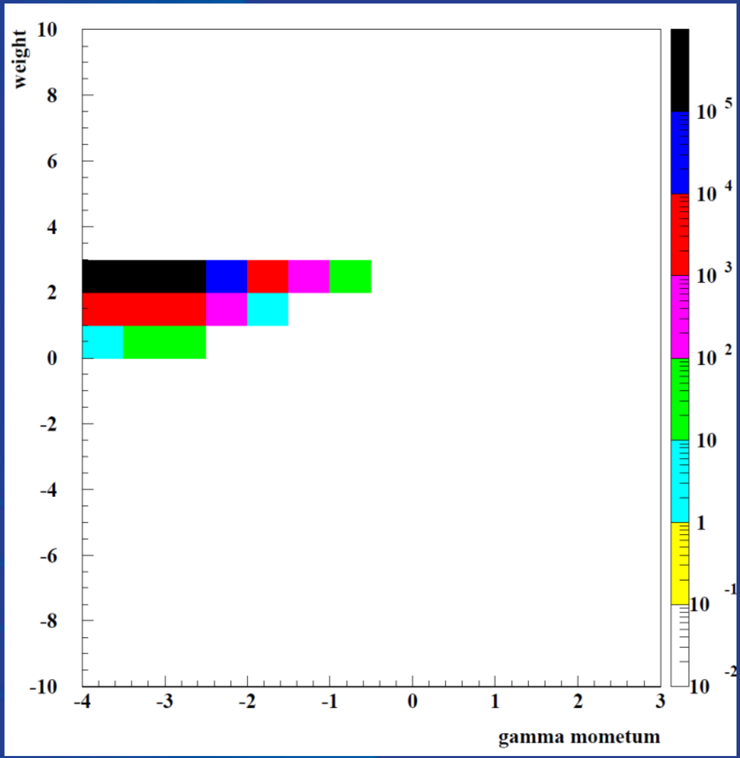


ID: 1=γ, 2=e^+, 3=e^-, 4=μ^+, 5=μ^-, 6=n, 7=ch.hadr

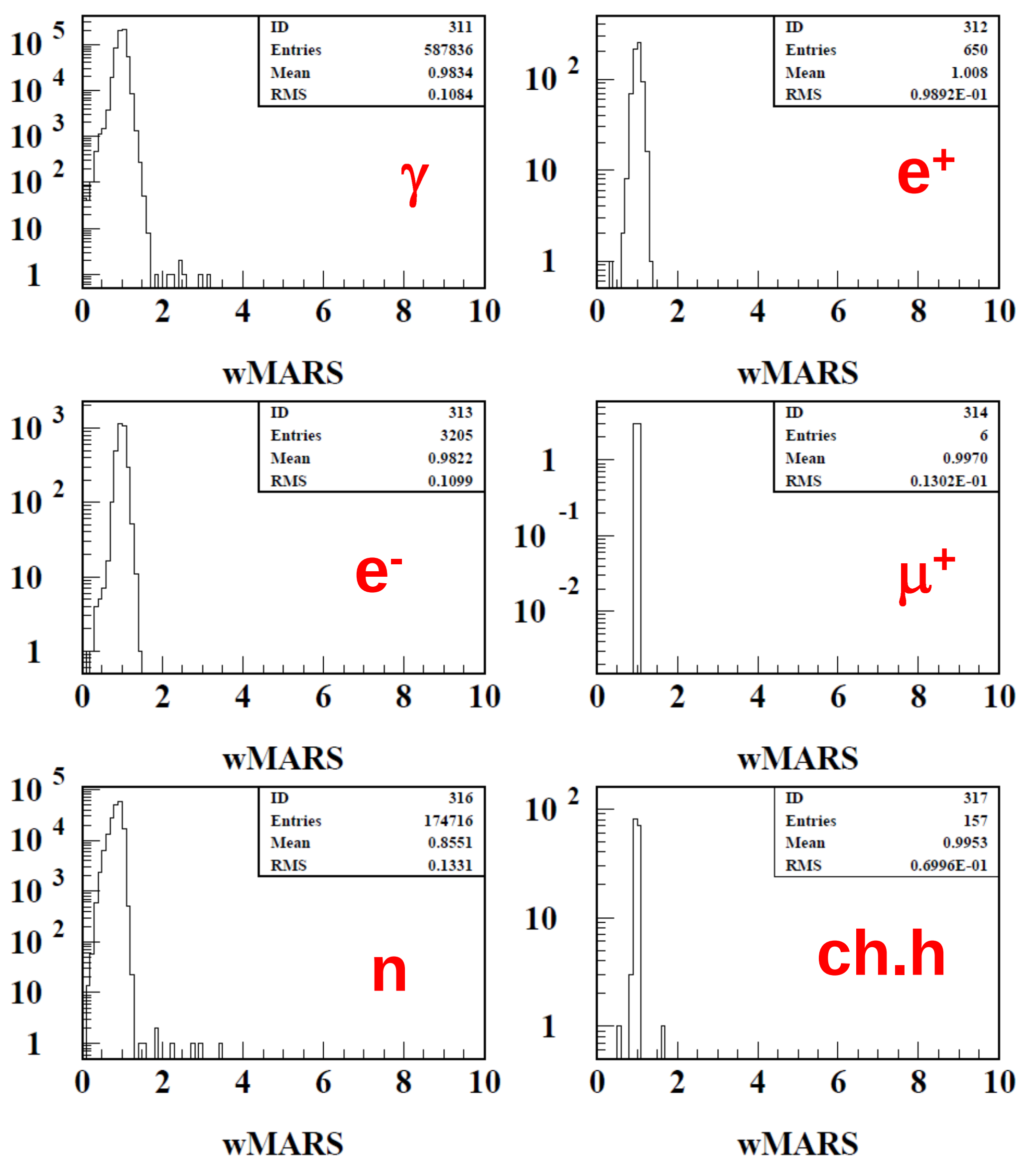
Weight Distributions

$\log_{10} W$

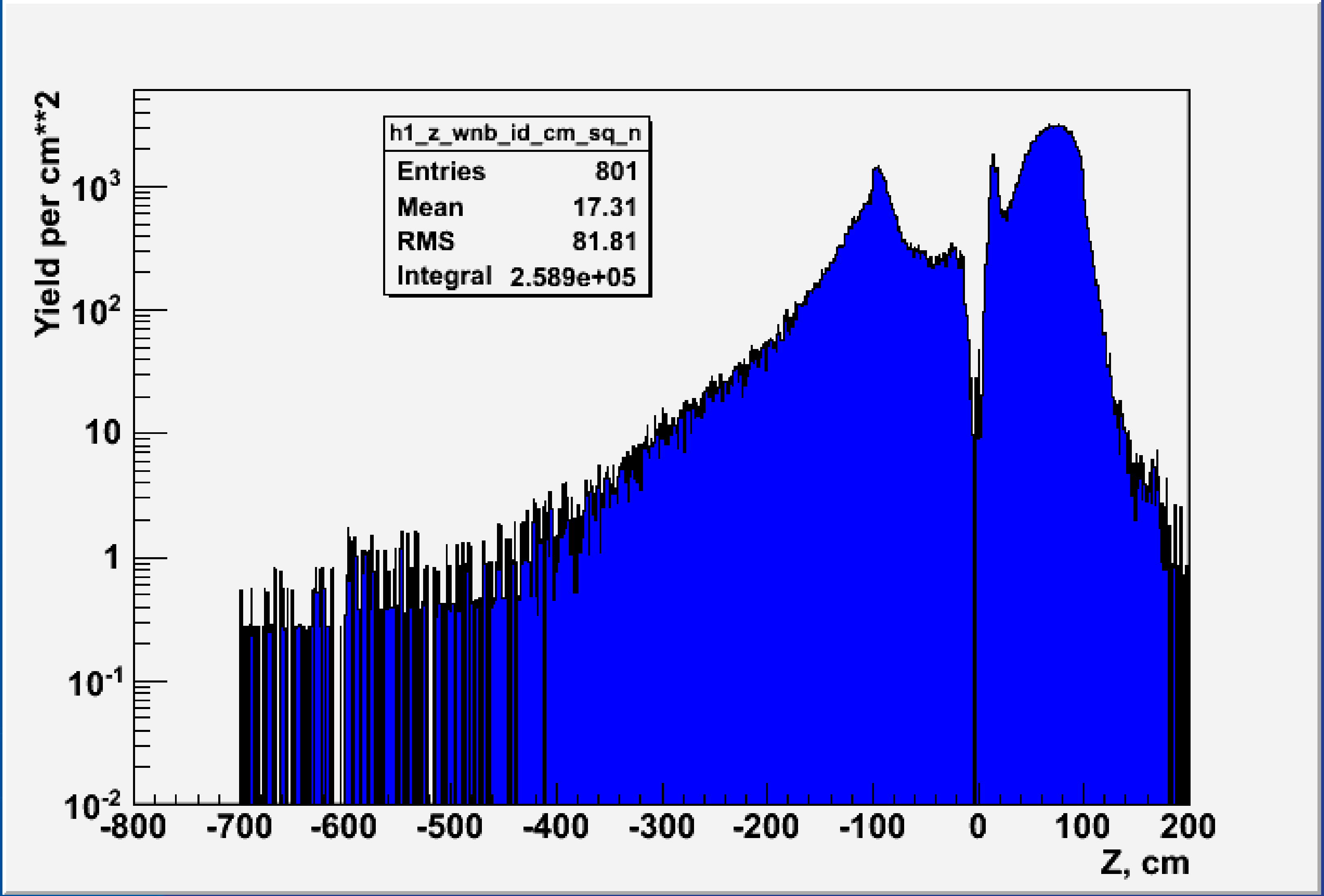
Divide by 139



$\log_{10} p_\gamma$

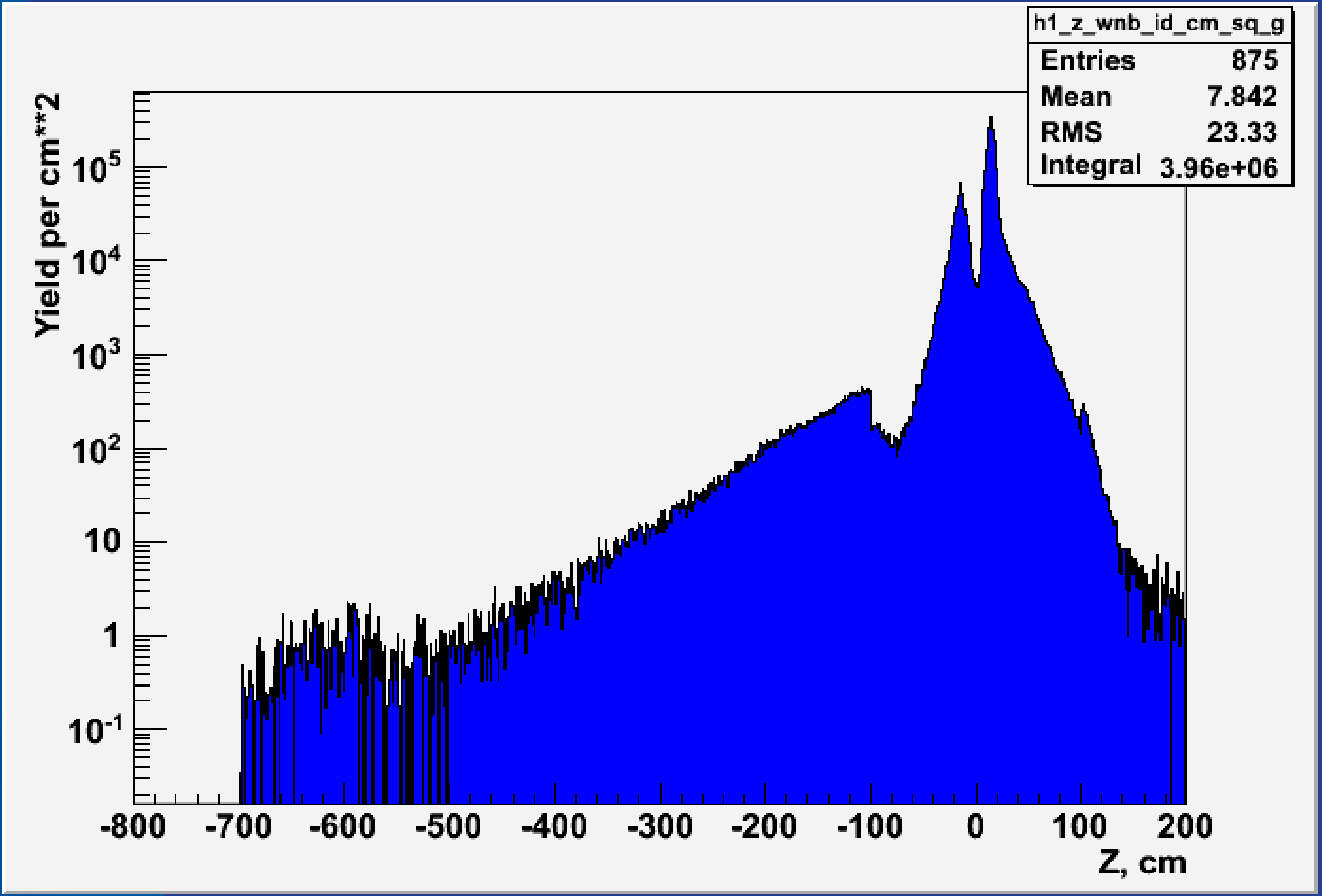


Neutrons/cm^2 Entering Detector vs Z



Muon beam approaching IP from the left

Photons/cm^2 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, A. Zlobin

- Feeding detector simulation (so far):

  ILCRoot 4th concept (C. Gatto group & N. Terentiev) 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 in October 2010
- Detector model to be adjusted to match the cone