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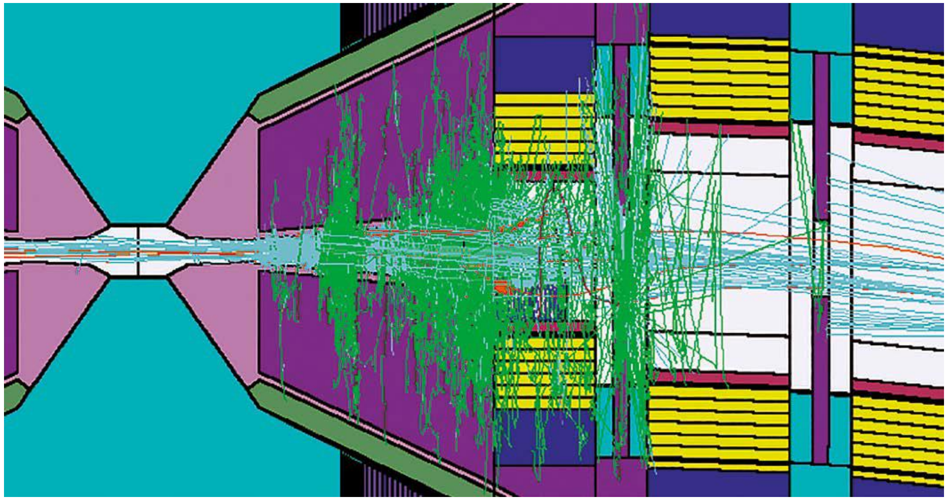
Machine-Detector Interface at Muon Colliders



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Outline

- Introduction
- MDI Basics with 1.5-TeV MC as an Example
- 125-GeV Higgs Factory MC
- Multi-TeV MC

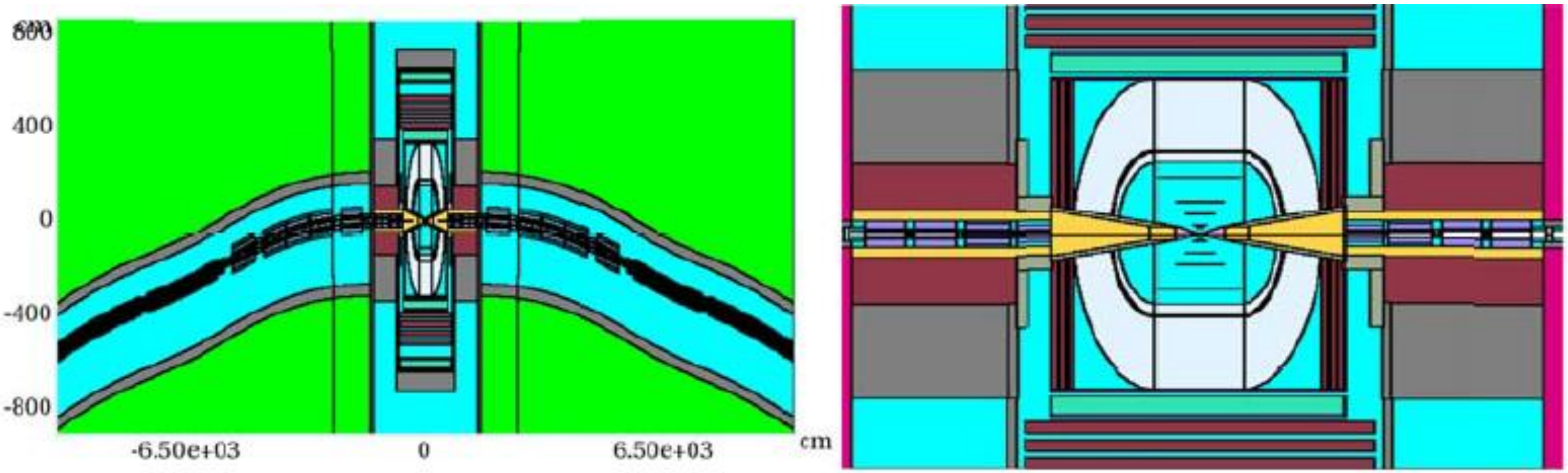
Introduction

The physics goals of a Muon Collider (MC) can only be achieved with appropriate, self-consistent designs of the ring, interaction region (IR), high-field superconducting magnets, machine-detector interface (MDI) and detector.

Our results of 1994 thru 2014 from realistic MARS simulations for 1.5-TeV and 125-GeV MC have shown that with carefully optimized protection elements implemented in IR, MDI and detector, the background rates in the detector can be suppressed by several orders of magnitude.

Sources of Beam-Induced Backgrounds

Three sources of beam-induced backgrounds (BIB) and radiation loads in MC: **incoherent e^+e^- pair production at the IP, beam halo loss on limiting apertures and muon beam decays.** The first source, with 10-mb X-section, gives rise to backgrounds in detector of 3×10^4 electron pairs per bunch crossing. The second source is taken care of by beam halo extraction far upstream of IR.



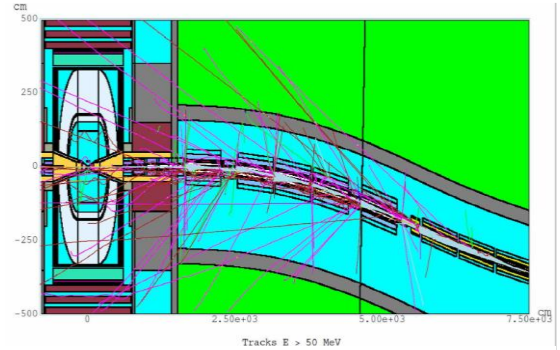
MARS15 model of IR and MDI at 1.5-TeV MC

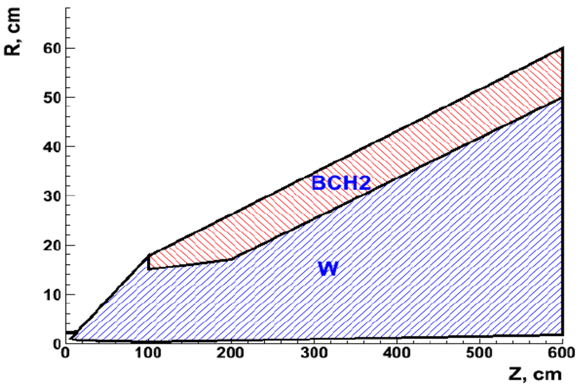
Muon Decays as the Major Source of BIB

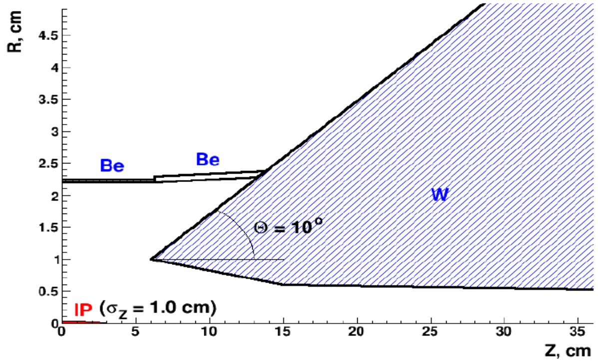
For the 0.75-TeV beam, with 2×10^{12} muons in a bunch, one has **4.28×10^5 decays per meter of the lattice in a single pass**. Electrons from muon decays have mean energy of approximately 1/3 of that of the muons. These ~250-GeV electrons, generated at the above rate, travel to the inside of the ring magnets, and radiate a lot of energetic synchrotron photons tangent to the electron trajectory.

Induced EMS create high background and radiation levels both in the detector and in the ring at the rate of 0.5-1 kW/m (compared to a few W/m in hadron colliders). **Without mitigation measures, the quench stability, cryogenic issues in superconducting magnets, background loads to a detector and neutrino-induced hazard would kill the idea of a high-energy muon collider.**

Findings from 1994-2011 Studies on 1.5-TeV MC

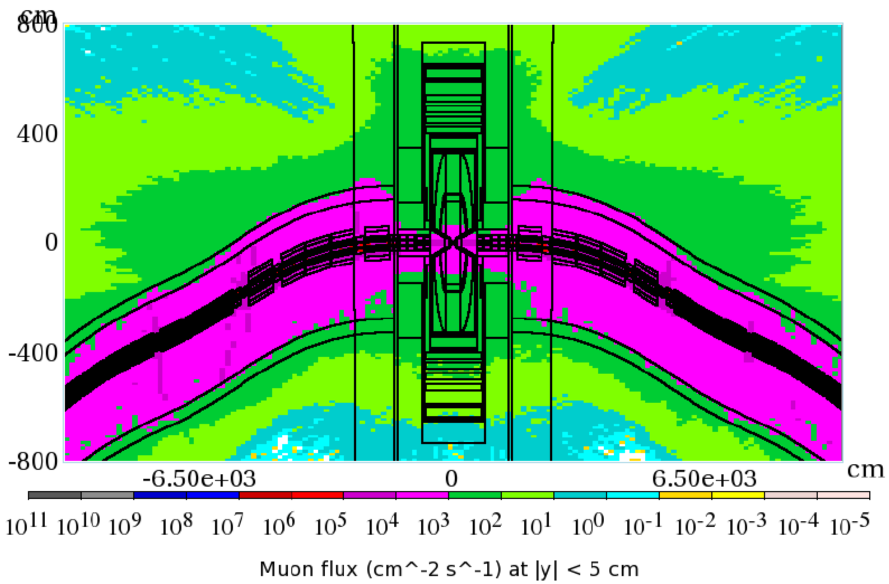


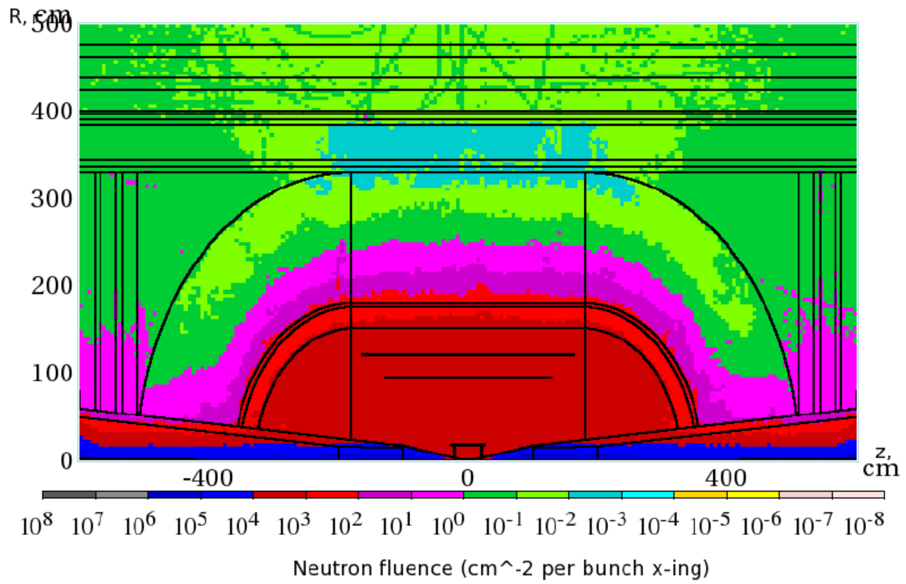




- High-field SC dipoles in IR and a dipole component in IR quads, along with tungsten liners inside magnets and masks in interconnect regions, provide substantial reduction of backgrounds.
- W-nozzles, starting a few centimeters from IP with ±20-deg outer angle, are a very effective way (~1/500) of further background suppression [WF & NM (1994)]. These nozzles can also fully confine incoherent pairs if the magnetic field of the detector solenoid is > 3 T.
- With such an IR design, the major source of BIB in a MC detector is muon decays in the IR itself, i.e. the region confined to about ±25 m from the IP.
- Time gates would allow substantial mitigation of remaining background problem in a MC detector.
- There are ways to mitigate neutrino hazard!

Muon and Neutron BIB at 1.5-TeV MC

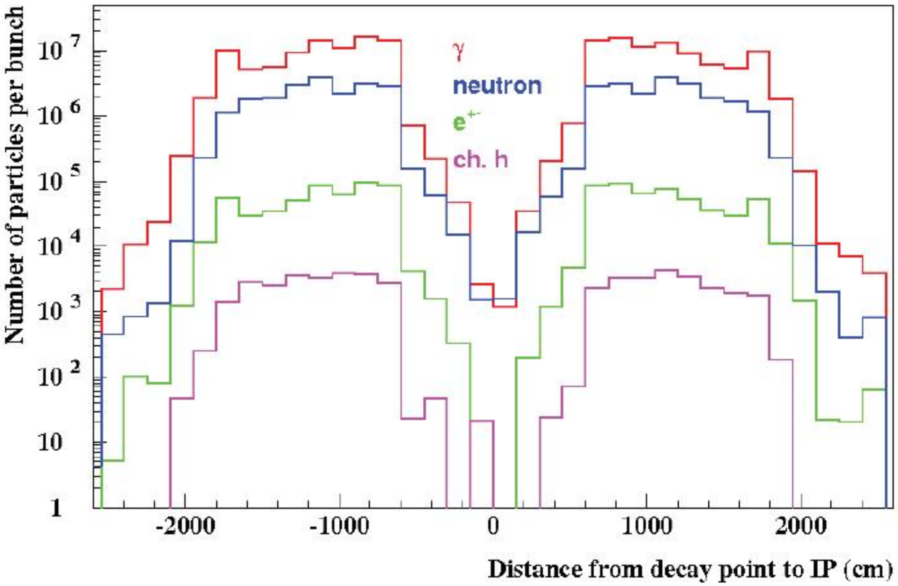


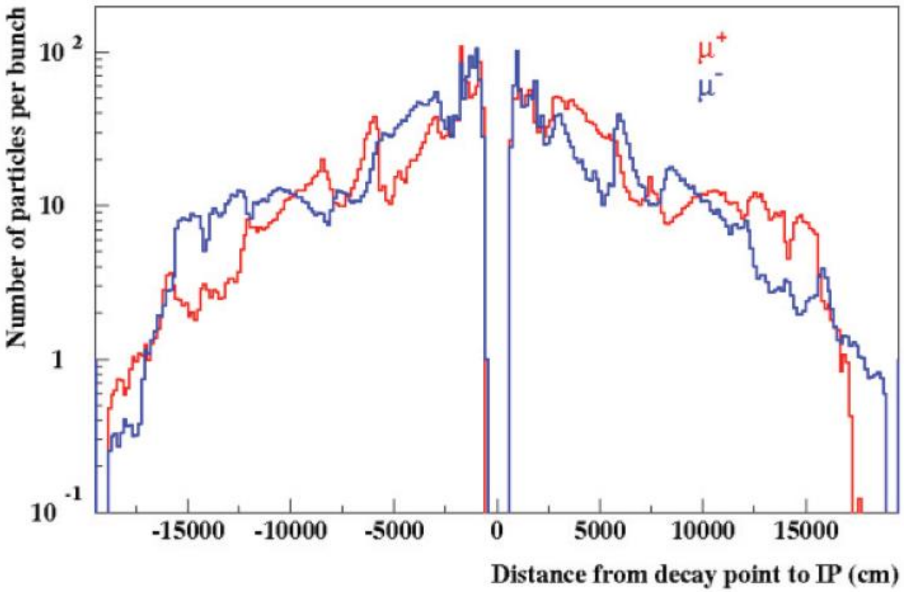


Muon flux isocontours in IR.
Muons – with energies of tens and hundreds GeV – illuminate the whole detector. They are produced as Bethe-Heitler pairs by energetic photons in EMS originated by decay electrons in lattice components.

The neutron isofluence inside the detector.
Maximum neutron fluence and absorbed dose in the innermost layer of the Si tracker for a one-year operation are at a 10% level of that in the LHC detectors at the nominal luminosity. High fluences of photons and electrons in the tracker and calorimeter exceed those at LHC, and need more work to suppress them.

Decay Origin of BIB Entering MDI

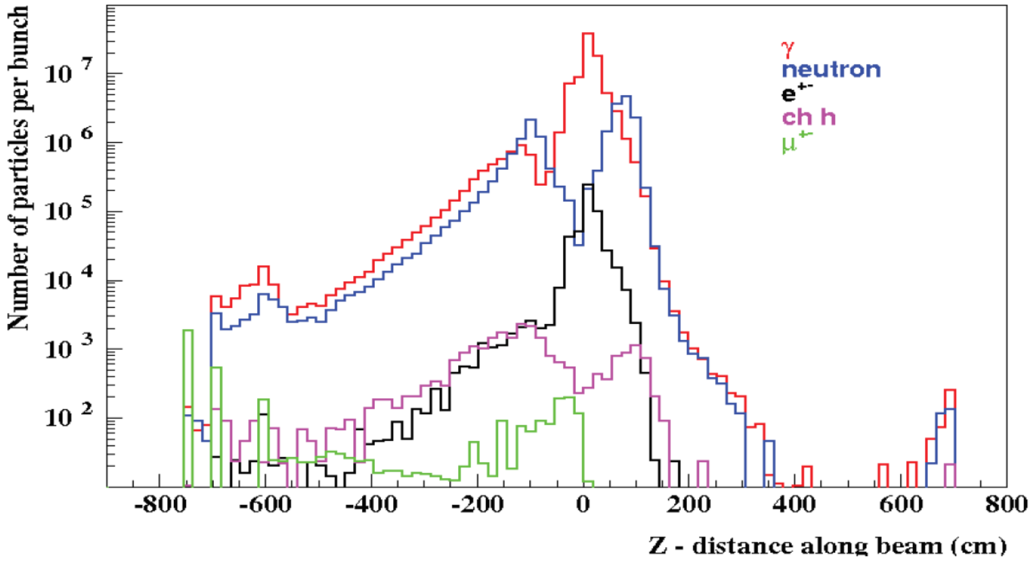




Quite similar to that at the HF MC

Very different from that at the HF MC

BIB Particles Entering MDI at 1.5-TeV MC



BIB particles per bunch X-ing entering detector via MDI surfaces *vs* the entry point z coordinate for the μ^+ beam moving from the left

Mean numbers, momenta and energy flow (540 TeV) of BIB particles per bunch X

Particle (E_{th}, MeV)	<n>	<p>, MeV/c	<EF>, TeV
Photon (0.2)	1.8×10^8	0.91	164
Neutron (0.1)	4.1×10^7	45	172
Electron/positron (0.2)	1.0×10^6	6.0	5.8
Charged hadron (1)	4.8×10^4	513	12
Muon (1)	8.0×10^3	23030	184

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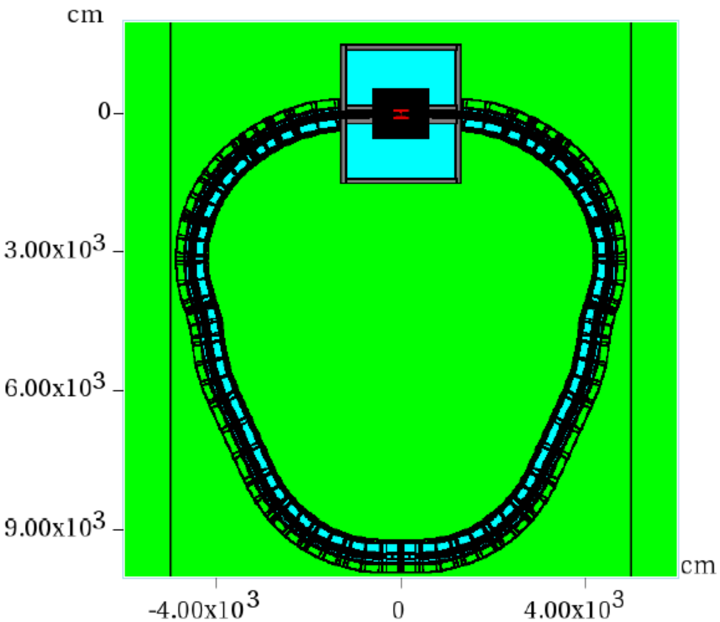
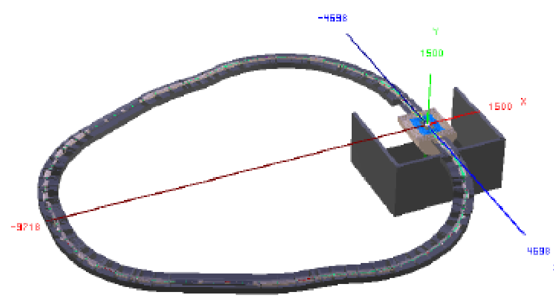
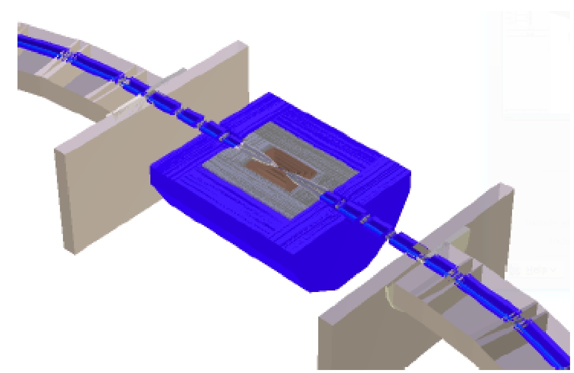
125-GeV Higgs Factory MARS15 Model



HF Muon Collider with IR, MDI and SID-like detector with SVD and tracker model based on that of the CMS detector upgrade. The circumference is about 300 m. Simplified tunnel and detector hall geometry.

The decay length for a 62.5 GeV muon is $3.9 \cdot 10^5$ m. With $2 \cdot 10^{12}$ muons per bunch, these result in 10^7 decays per meter in a single pass. The HF ring is designed for 1000 to 2000 turns per a store with 30 stores per sec. This provides the average luminosity of 8×10^{31} cm^{-2} s^{-1} compared to ~4×10^{33} cm^{-2} s^{-1} at 1.5TeV MC.





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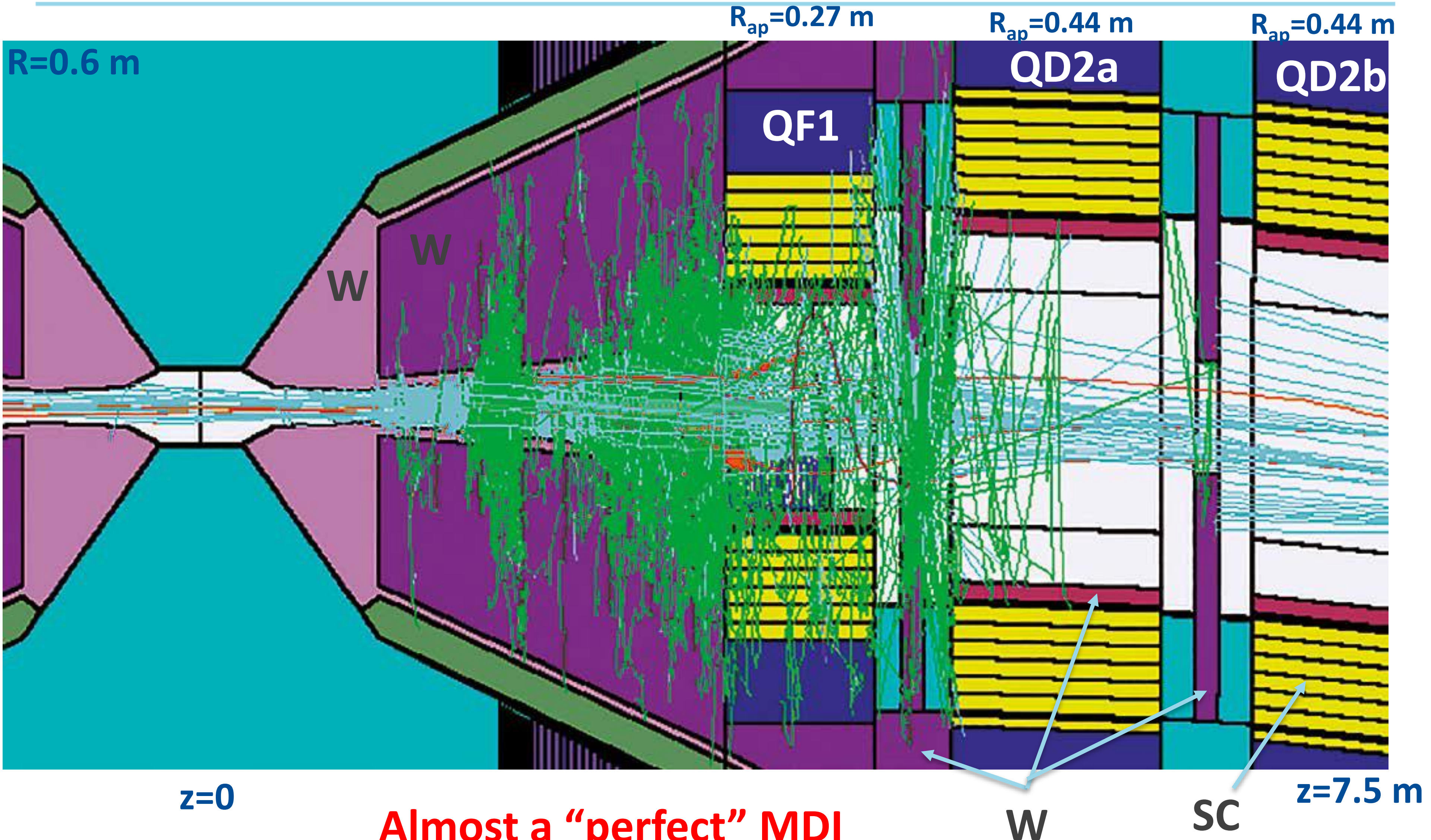
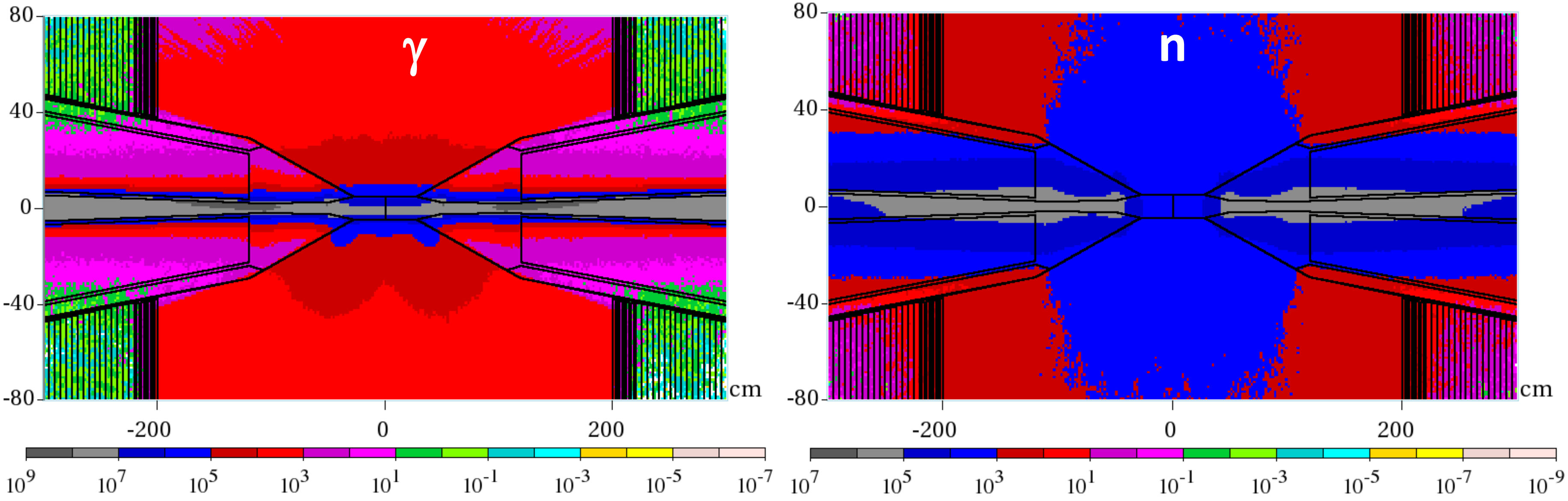
125-GeV Higgs Factory Thoroughly Optimized MDI



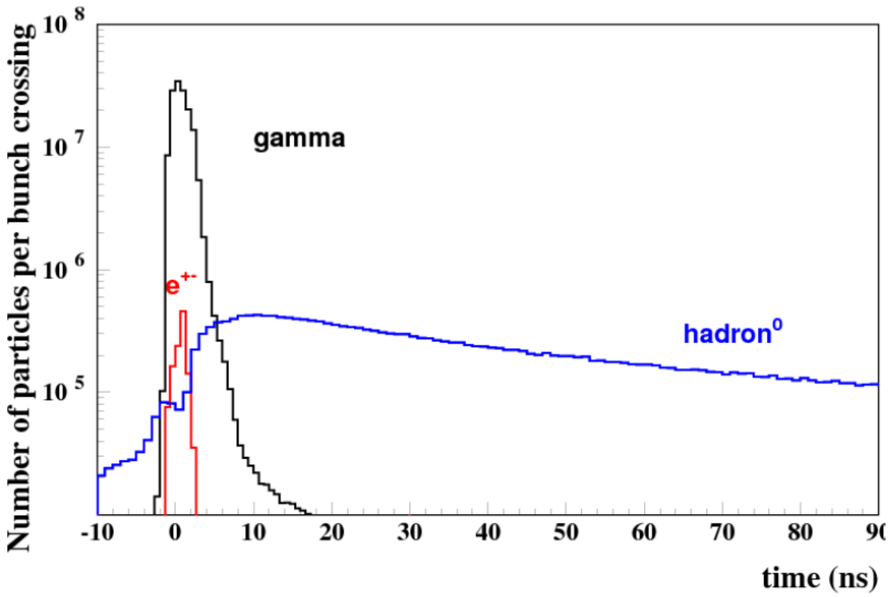
Almost a "perfect" MDI

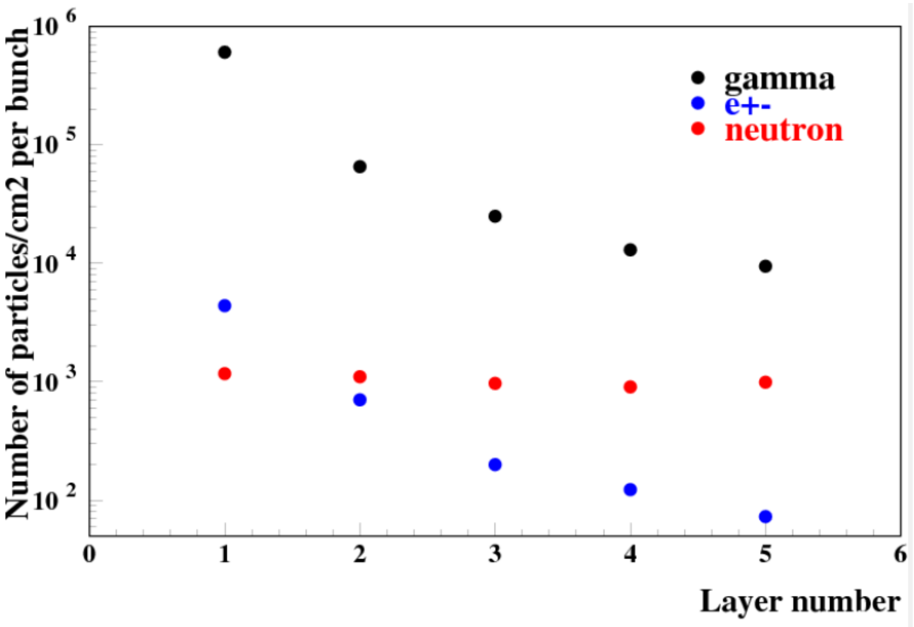
HF MC: Photon and Neutron Fluences (cm^{-2} per BX)



In central detector, the photon fluence is noticeably larger than in the LHC detectors while for neutrons it is much lower

HF MC: TOF and BIB in VXD





BIB TOF wrt bunch xing.
Used for further rejection of BIB

BIB particle fluxes in VXD.
Used to estimate hit rates and occupancy in VXD pixels as about 1%

Path Forward: 3-TeV and 6-TeV MC

- **3 TeV**: preliminary lattice and magnet parameters were designed under protection constraints. In principle, ready for the optimization of the MDI design and BIB simulations.

- **6 TeV**: several LOIs were submitted to Snowmass, a kind of a pre-feasibility study to address design of a lattice for the average luminosity of 10^{35} $cm^{-2}s^{-1}$ with β^*=3 mm, high-field / high-gradient superconducting magnets with the coil apertures as large as 24 cm in IR and 15 cm in the arcs, hybrid multilayer coils made of HTS and LTS with the stress management, optimized MDI with tungsten liners, masks, nozzles etc, detector BIB mitigation techniques as well as appropriate measures to mitigate neutrino hazard.

- All of the above is a subject to support from the community, Fermilab management, budget and the team members availability.