Fermilab **Accelerator Physics Center**

DETECTOR BACKGROUNDS AT MUON COLLIDERS

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Outline

- Introduction
- Background Sources
- MDI and Background Load Modeling
- Main Characteristics of Backgrounds

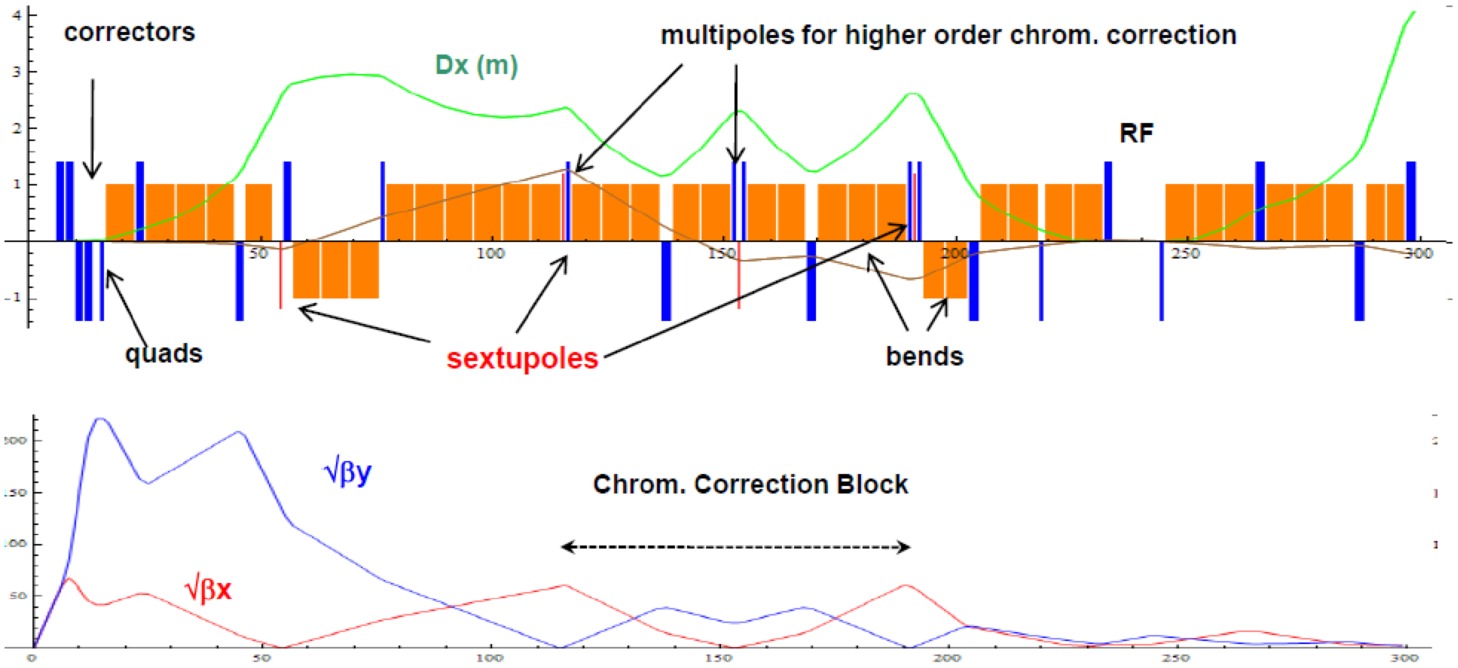
Introduction

Physics goals of a Muon Collider (MC) can only be reached with appropriate design of the ring, interaction region (IR), high-field superconducting magnets, machine-detector interface (MDI) and detector. *All* - under demanding requirements, arising from the short muon lifetime, relatively large values of the transverse emittance and momentum spread, unprecedented dynamic heat loads (0.5-1 kW/m) and background particle rates in collider detector.

Muon Collider Parameters

E_{cms}	TeV	1.5	4
f_{rep}	Hz	15	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%; dynamic aperture sufficient for transverse emittance of 50 μm; under engineering constraints.

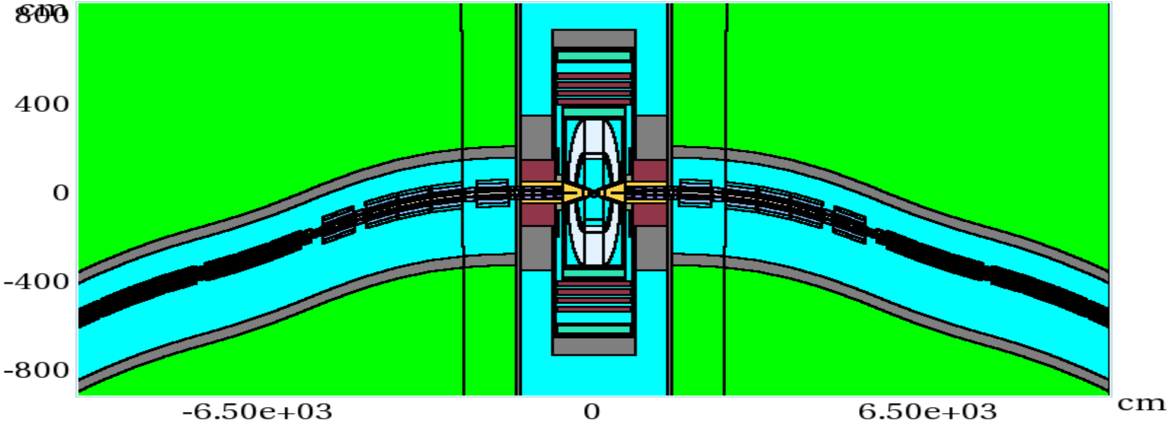
Iterative studies on lattice and MDI with magnet experts:

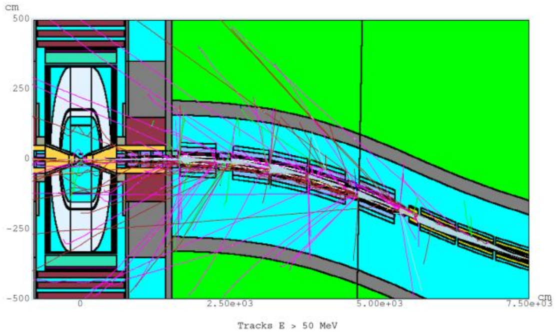
High-gradient (field) large-aperture short Nb_3Sn quads and dipoles.

Sources of Background and Dynamic Heat Load

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 nozzle & detector B)
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 $2\mathrm{x}10^{12}$, $4.28\mathrm{x}10^5$ dec/m per bunch crossing, or $1.28\mathrm{x}10^{10}$ dec/m/s for 2 beams; 0.5 kW/m.
4. **Beam halo:** Beam loss at limiting apertures; severe, can be taken care of by an appropriate collimation system far upstream of IP.

MARS15 Modeling

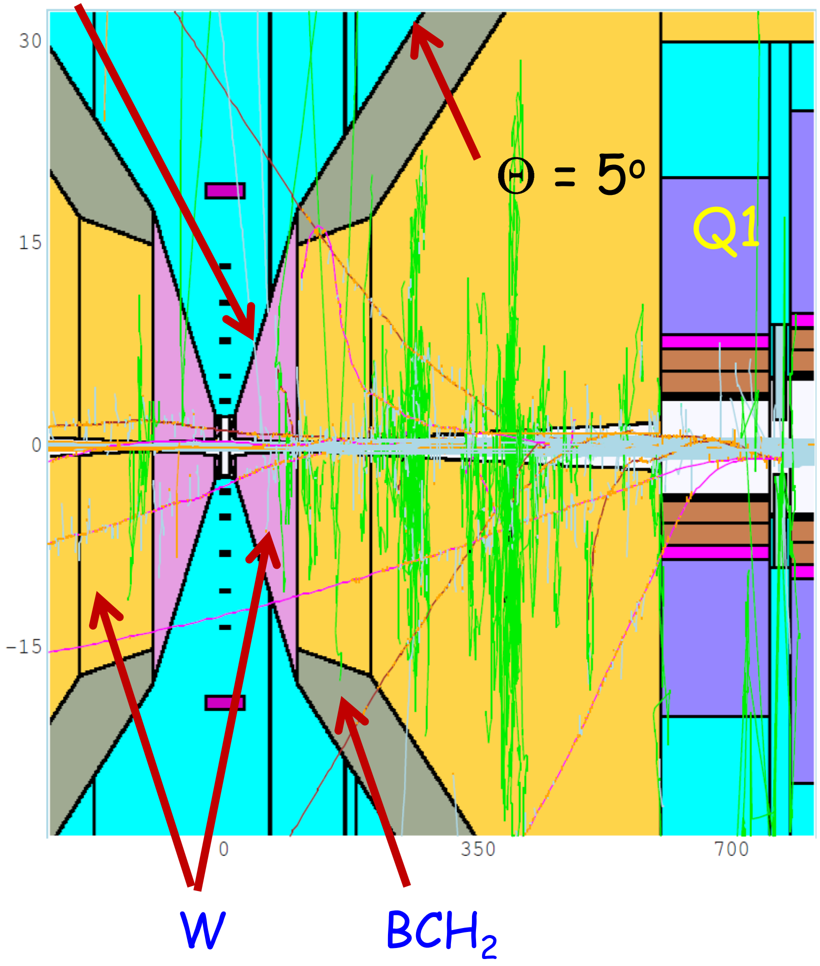


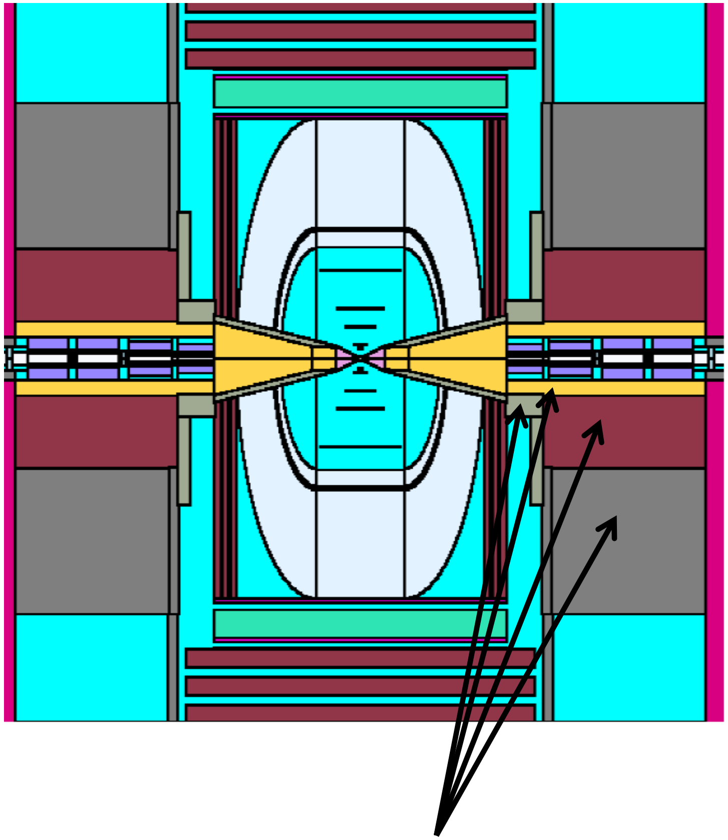


- Detailed magnet geometry, materials, magnetic fields maps, tunnel, soil outside and a simplified experimental hall plugged with a concrete wall.
- Detector model with $B_z = 3.5$ T and tungsten nozzle in a BCH_2 shell, starting at ±6 cm from IP with R = 1 cm at this z.
- 750-GeV bunches of 2×10^{12} μ^- and μ^+ approaching IP are forced to decay at $|S| < S_{max}$, where S_{max} up to 250 m at 4.28×10^5 / m rate, 1000 turns.
- Cutoff energies optimized for materials & particle types, varying from 2 GeV at ≥100 m to 0.025 eV (n) and 0.2 MeV (others) in the detector.

Machine-Detector Interface

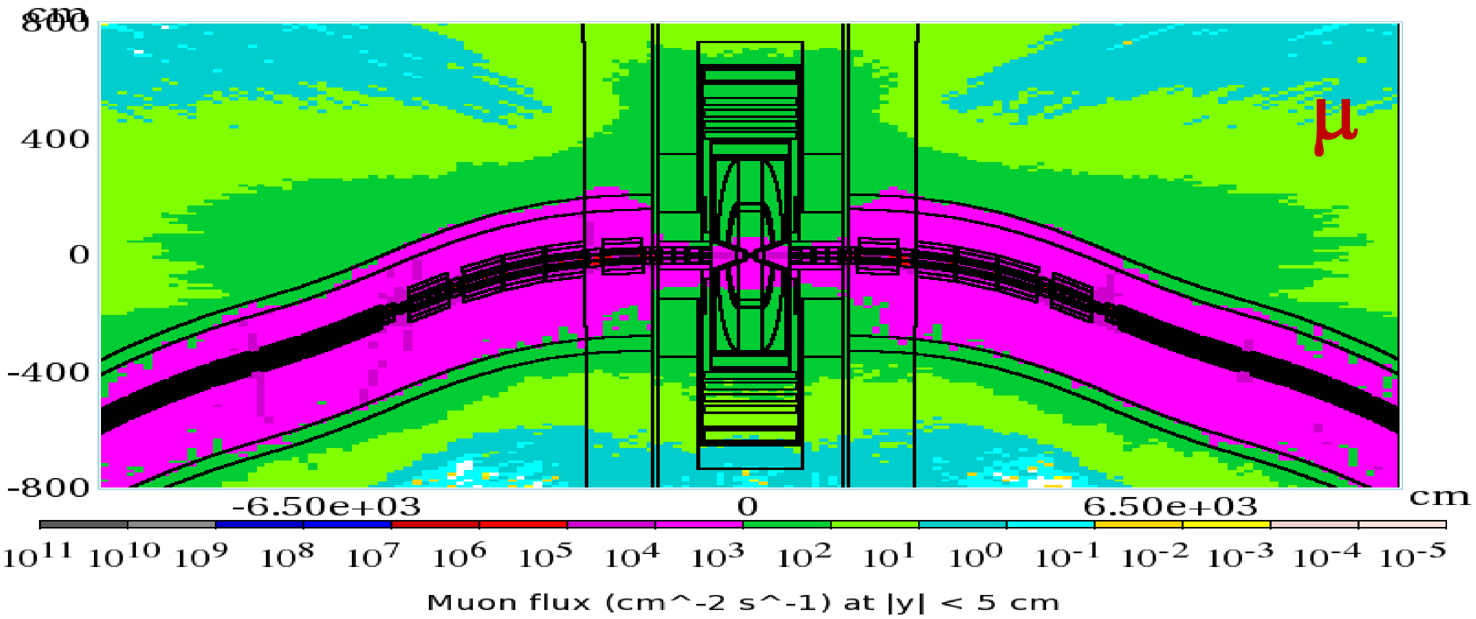
$\Theta = 10^o$ $6 < z < 600$ cm   x:z = 1:17





Sophisticated shielding:
W, iron, concrete & BCH_2

Background Suppression



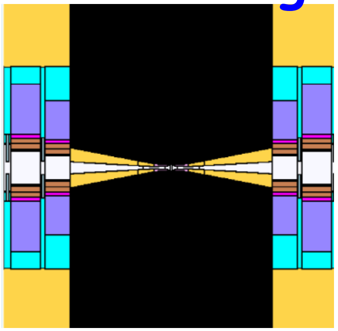
Dipoles close to the IP and tungsten masks in each interconnect region help reduce background particle fluxes in the detector by a substantial factor. The tungsten nozzles, assisted by the detector solenoid field, trap most of the decay electrons created close to the IP as well as most of incoherent e^+e^- pairs generated in the IP. With additional MDI shielding, total reduction of background loads by more than three orders of magnitude is obtained.

Load to Detector: Two Nozzles

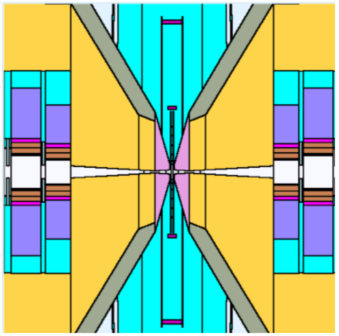
Number of particles per bunch crossing entering detector, starting from MARS source term for S_{max}=75m

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

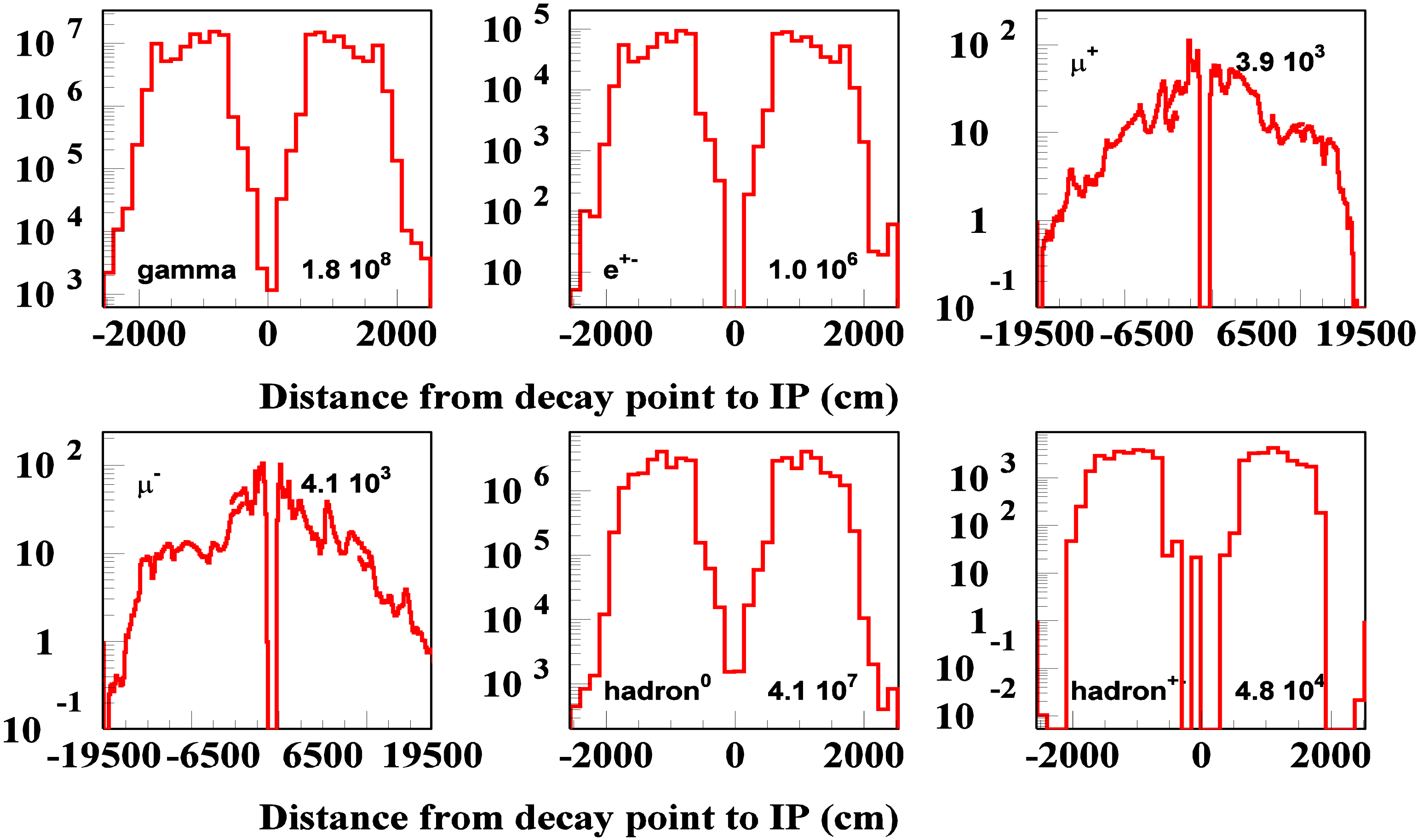


10-deg

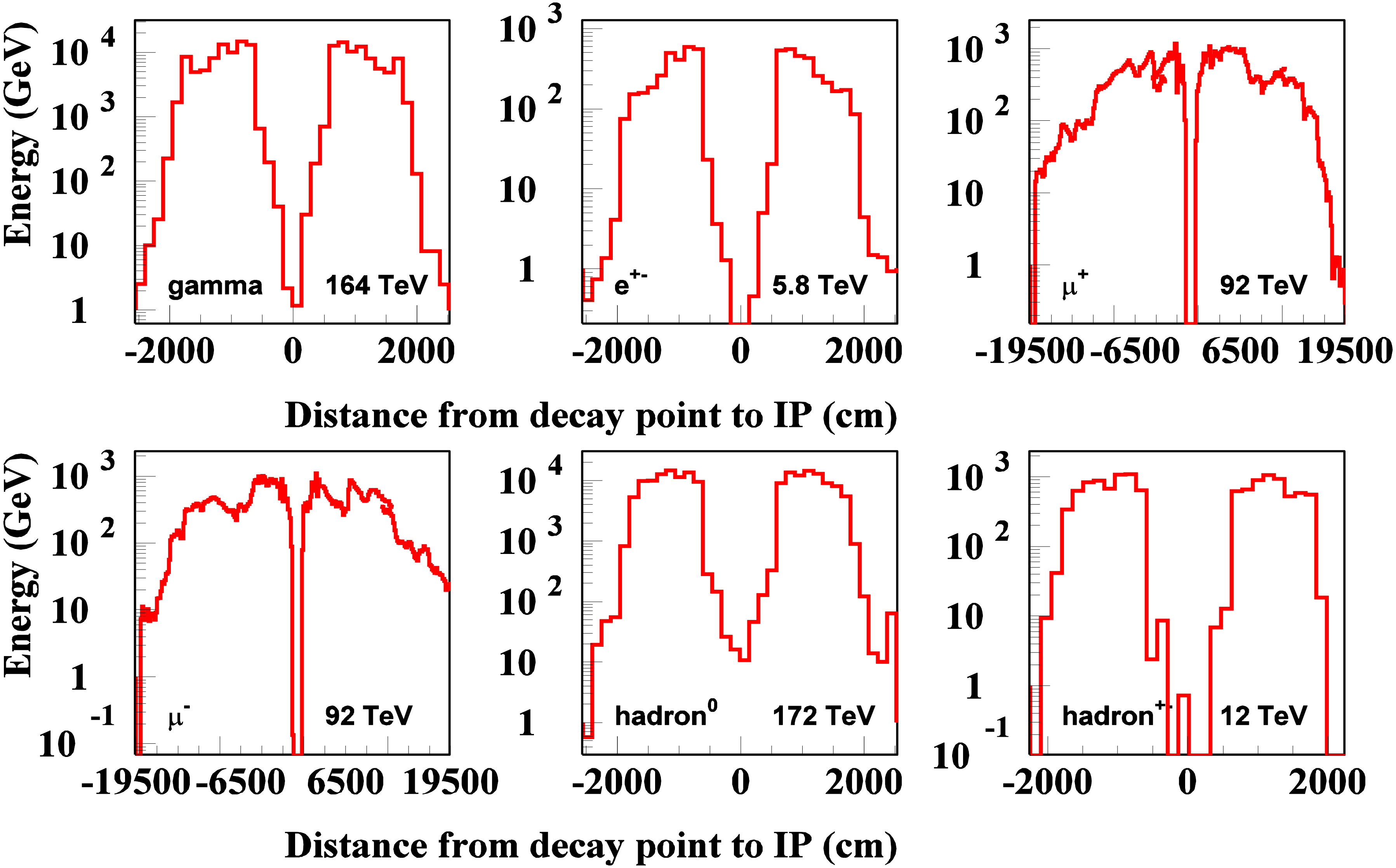


No time cut applied, can help substantially
All results below are presented for 10-deg nozzle

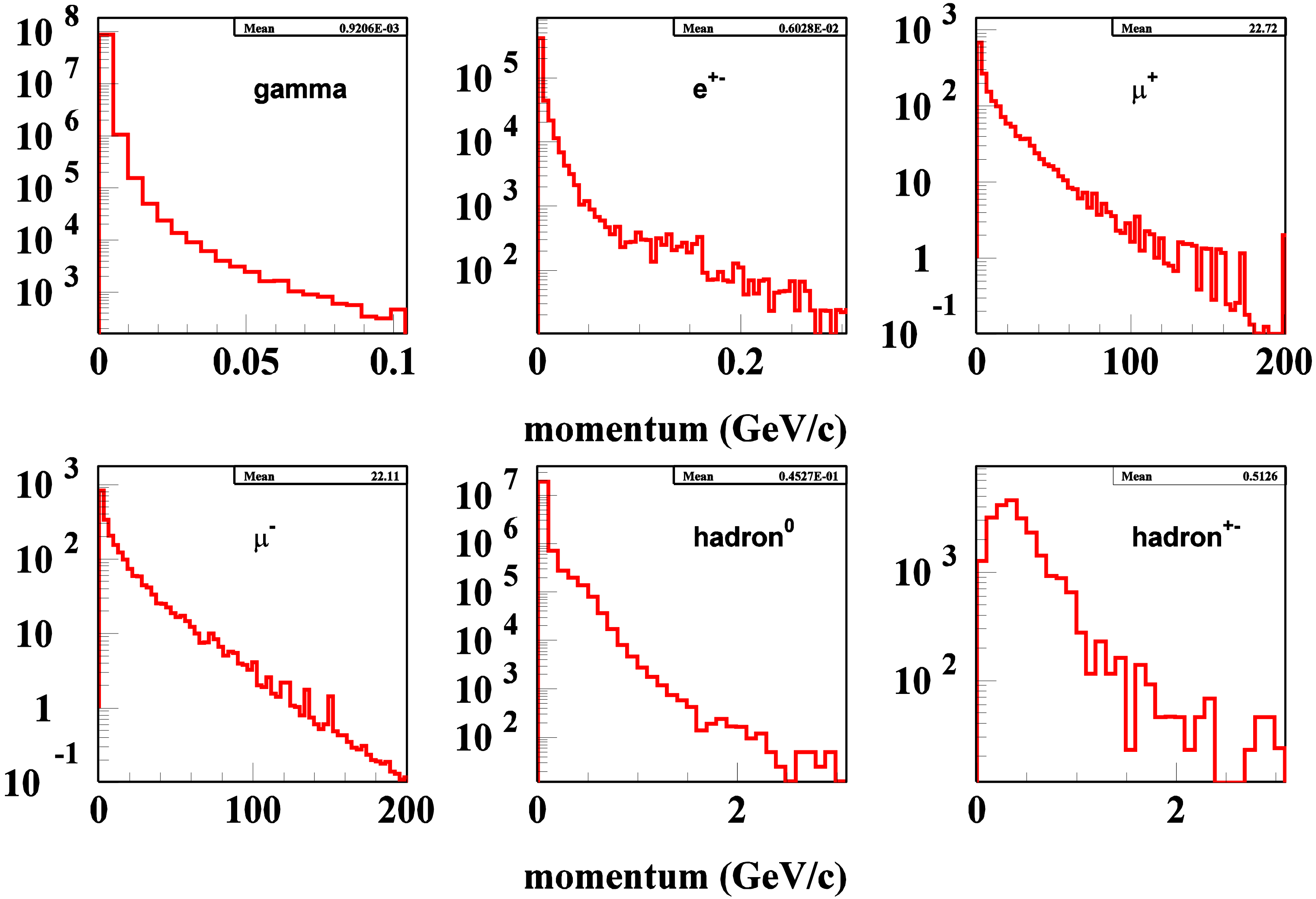
Where is Background Produced?
Number of Particles Entering Detector



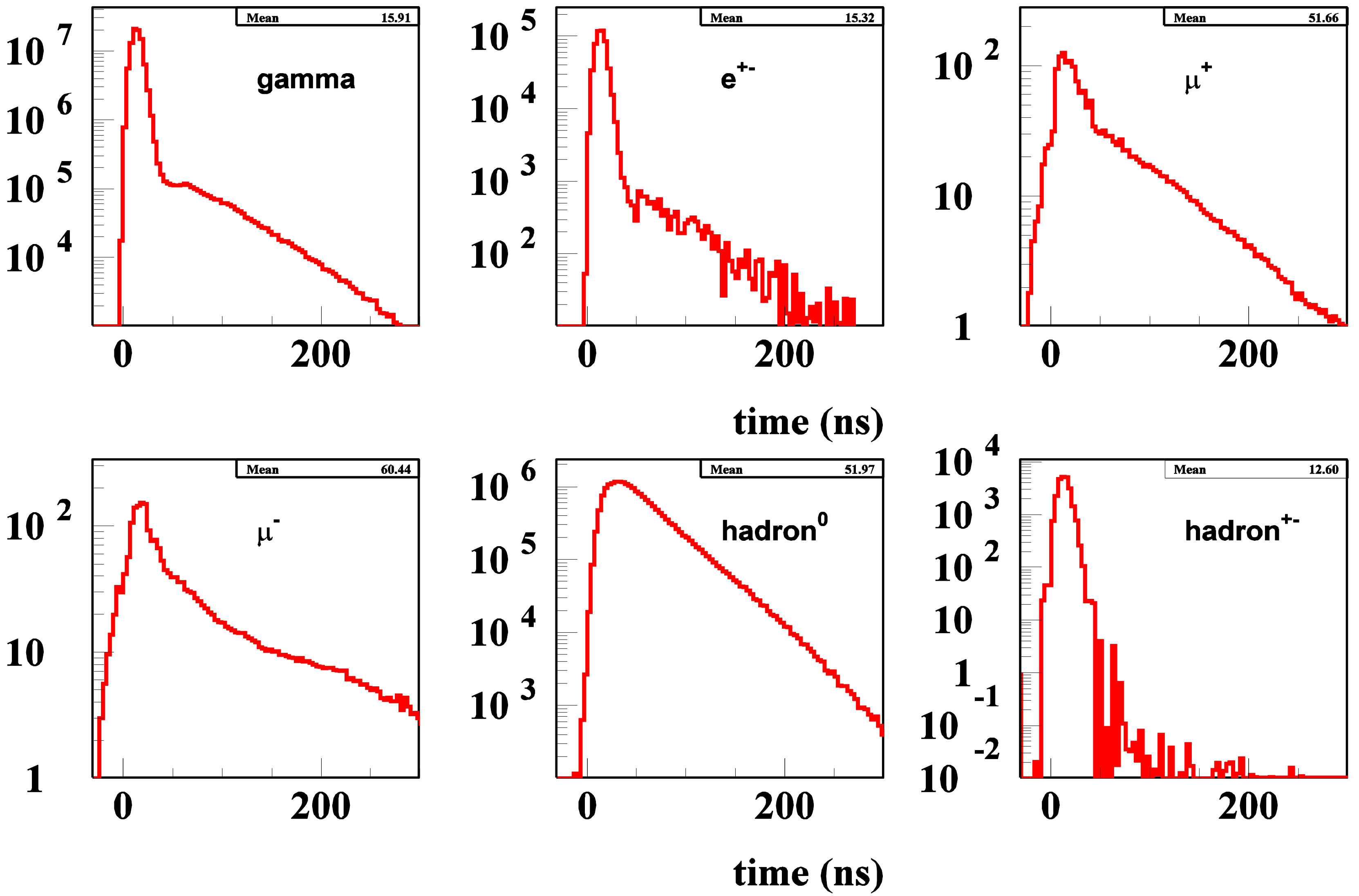
Where is Background Produced? Energy Flow Entering Detector



Energy Spectra Entering Detector



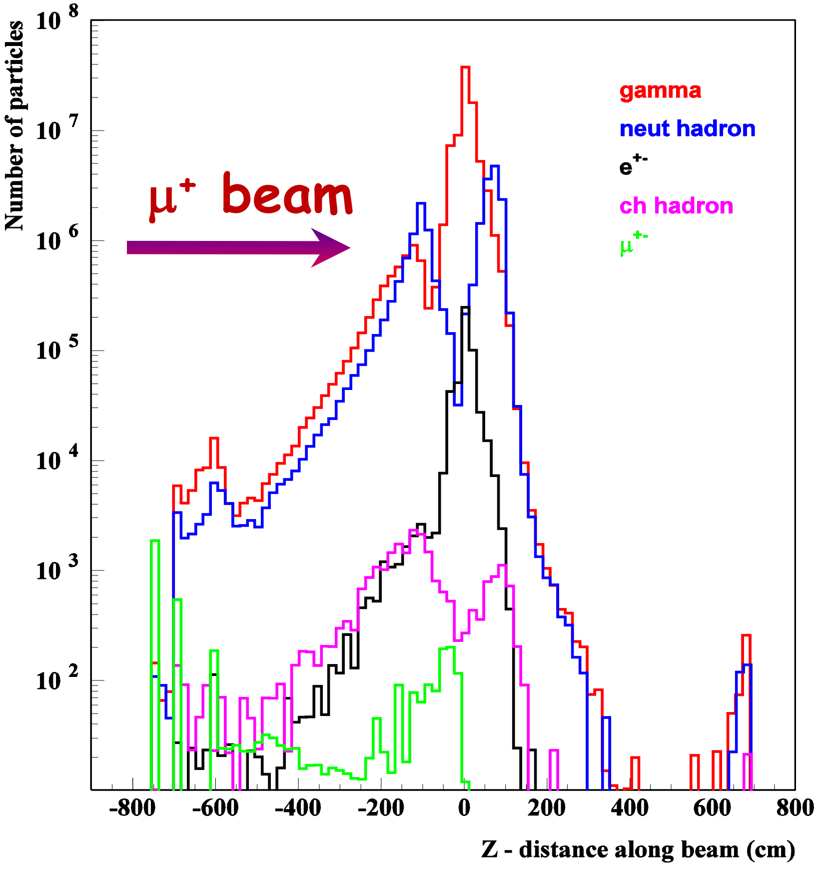
Time Distribution wrt Bunch crossing at Detector Entrance



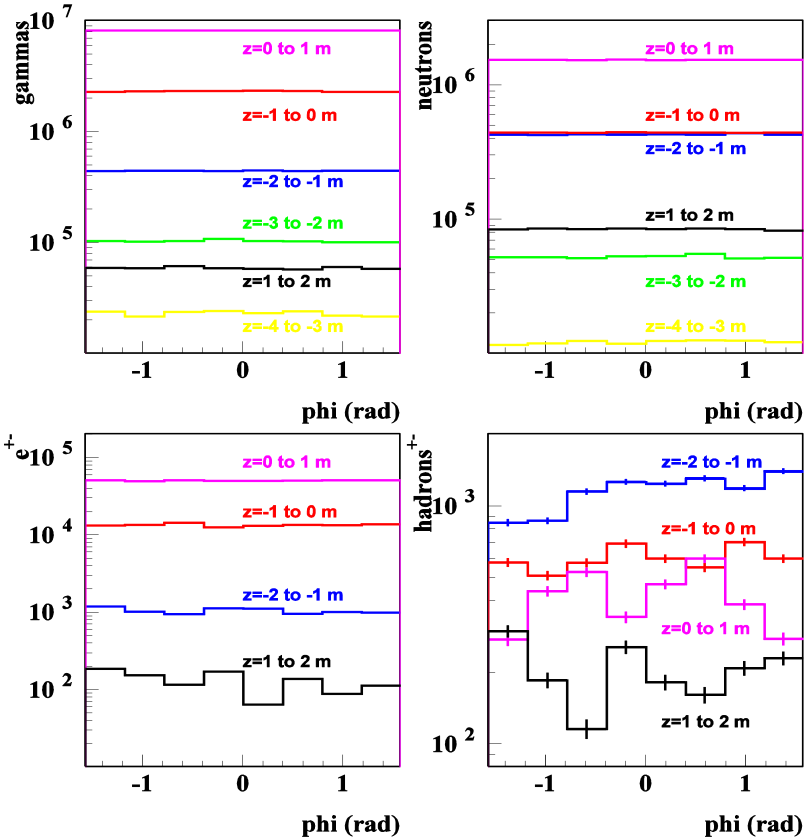
Spatial Distribution at Detector Entrance

Most of particles come to detector through nozzle surface; for muons this fraction is 30%

Background (except muons) on nozzle surface weakly depends on azimuthal angle



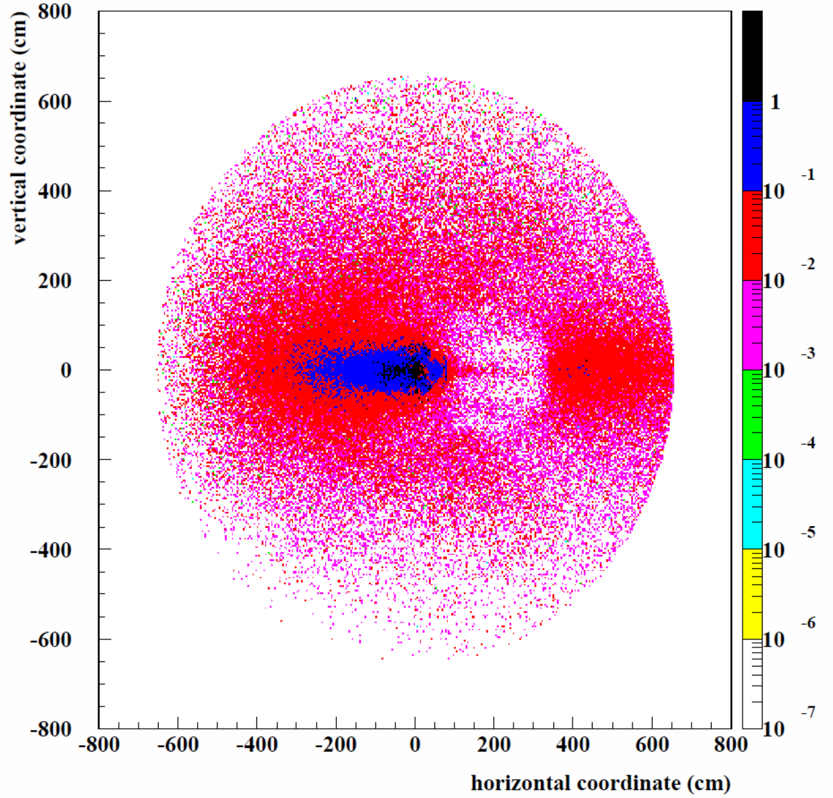
Particles at interface surface (one bunch)



Azimuthal distribution at interface surface (one bunch)

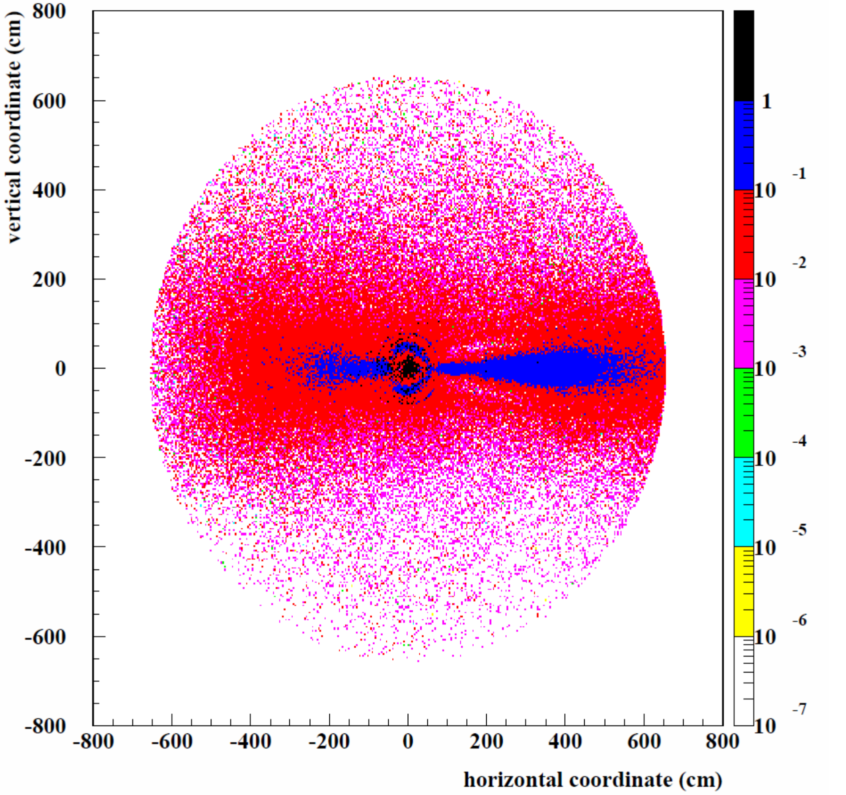
Muon Lateral Distribution at Detector Entrance

Positive muons deflected by beam-line magnetic field to negative direction



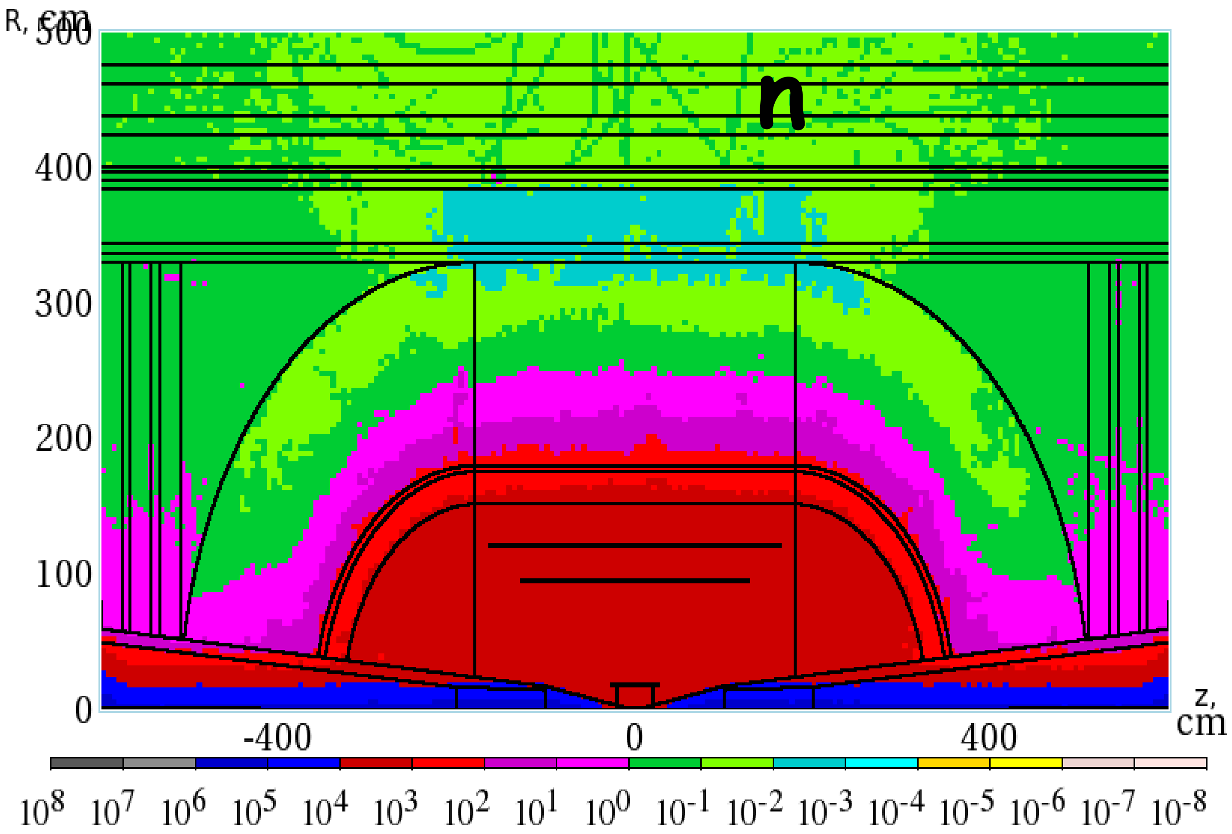
μ^+ distribution at shielding exit (μ^+ bunch)

Negative muons deflected by beam-line magnetic field to positive direction



μ^- distribution at shielding exit (μ^+ bunch)

Background Loads in Detector



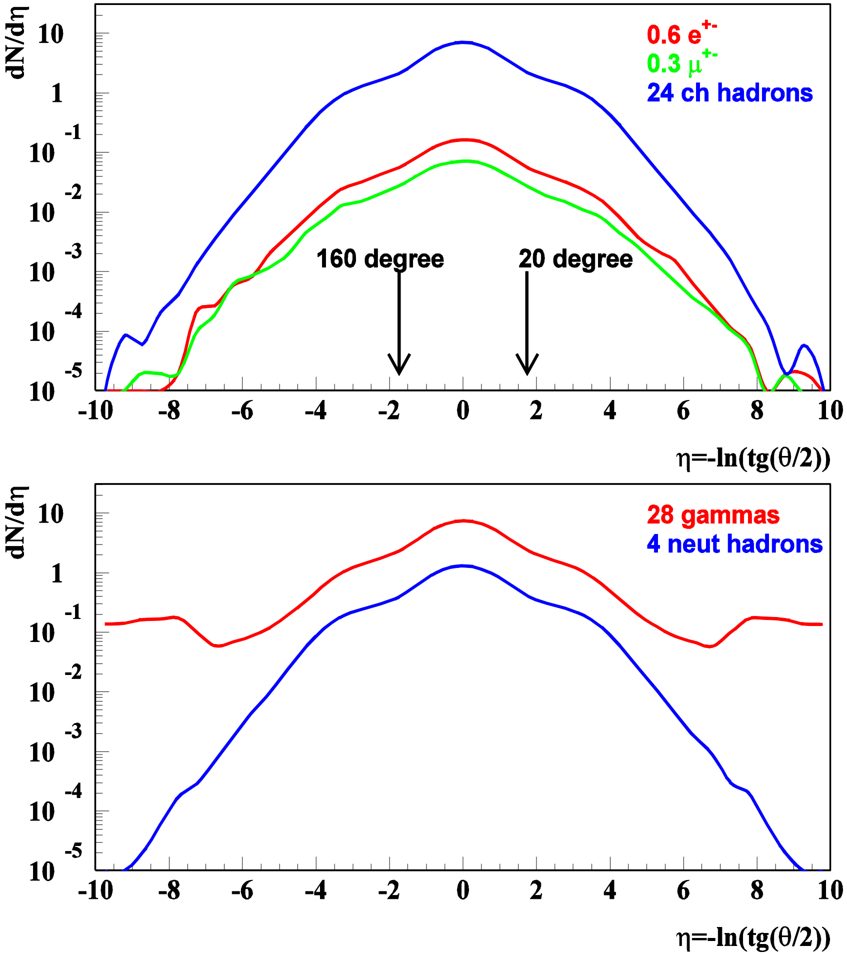
Neutron fluence (cm^-2 per bunch x-ing)

Maximum neutron fluence and absorbed dose in the innermost layer of the silicon tracker for a one-year operation are at a 10% level of that in the LHC detectors at the luminosity of 10^{34} cm^{-2}s^{-1}

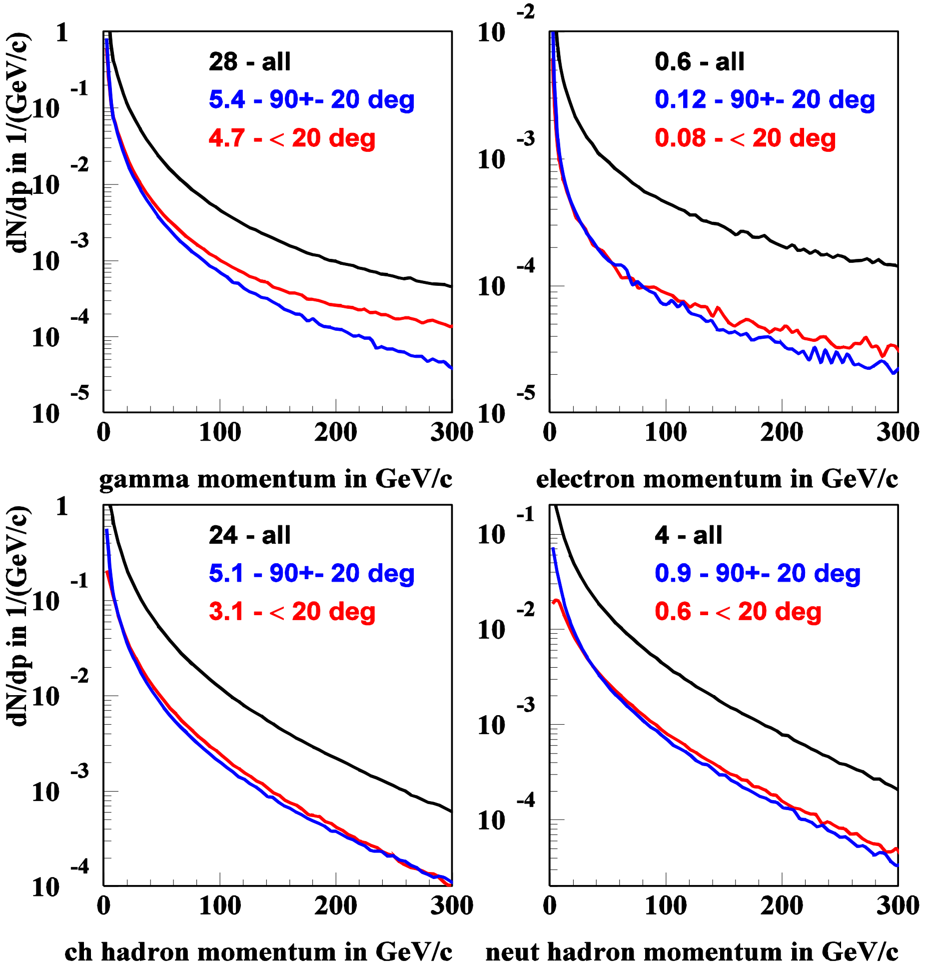
Summary

- A consistent IR lattice, which satisfies all the requirements from the beam dynamics point of view, has been designed for a 1.5-TeV muon collider with luminosity of 10^{34} cm^{-2}s^{-1}.
- Detector background simulations are advancing well, MDI optimization is underway, files are available to the community.
- Main features of background loads on the detector have been studied and are well understood.
- Detector physics modeling in presence of the machine backgrounds has been started and progressing very well.

$\mu^+\mu^- \to \gamma^*/Z^0$ events
“detectable” energy - 1300 GeV

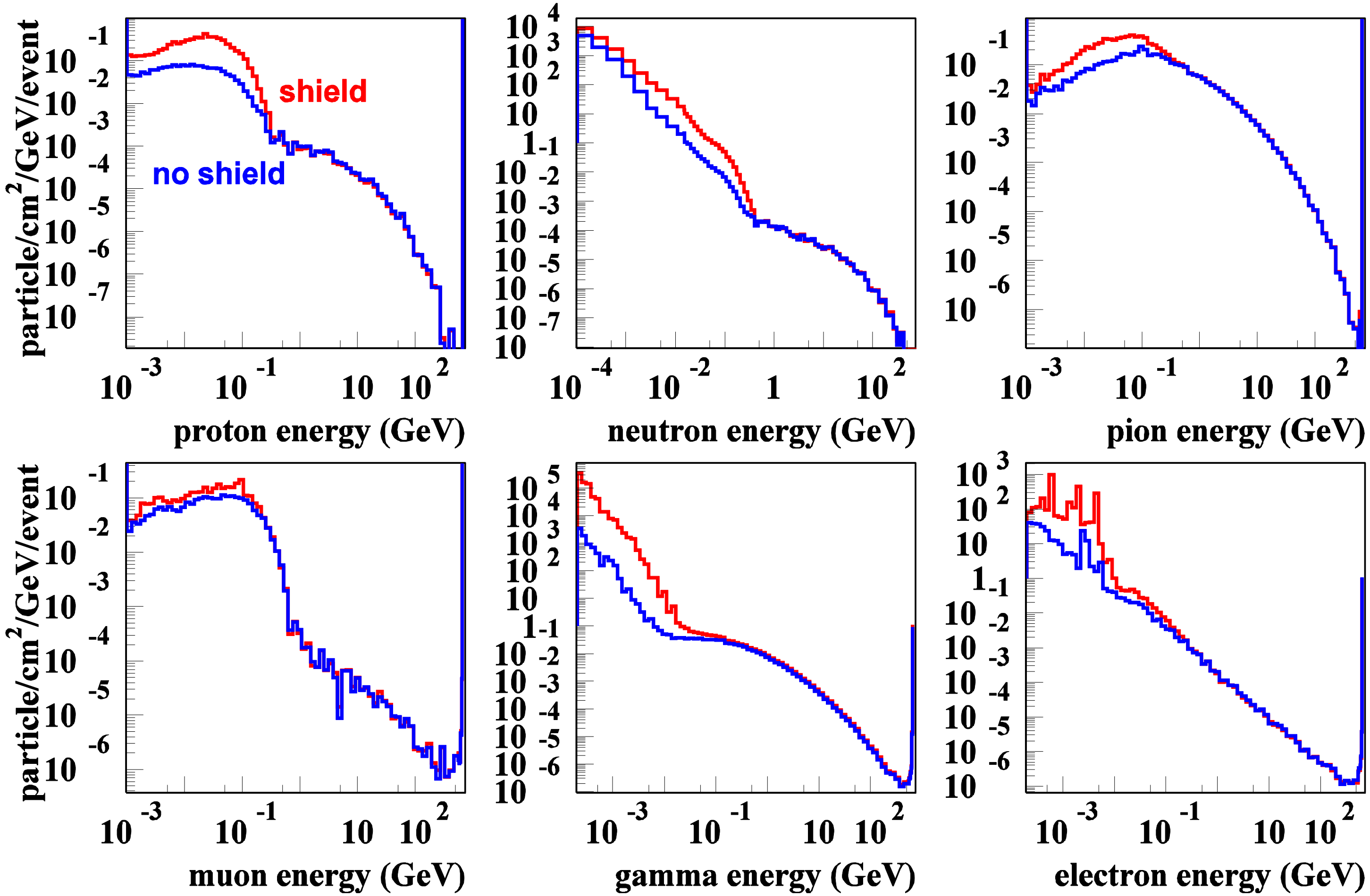


$\mu^+\mu^- \to \gamma^*/Z^0$ at 1500 GeV (1.34 pb)



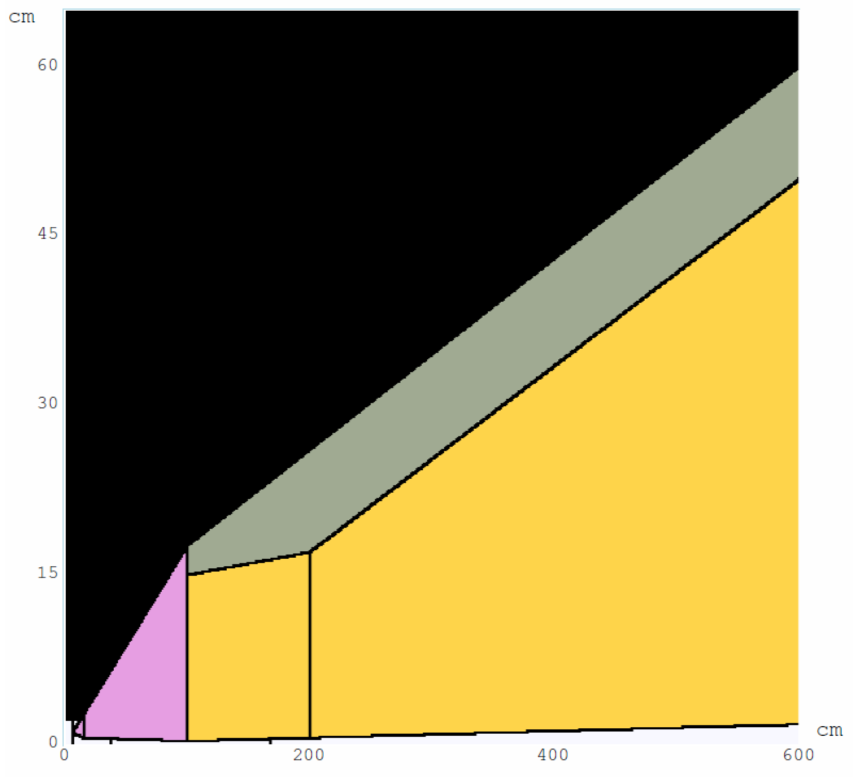
$\mu^+\mu^- \to \gamma^*/Z^0$ at 1500 GeV (1.34 pb)

Energy spectra in tracker (+-46x46x5cm) with and without tungsten shielding

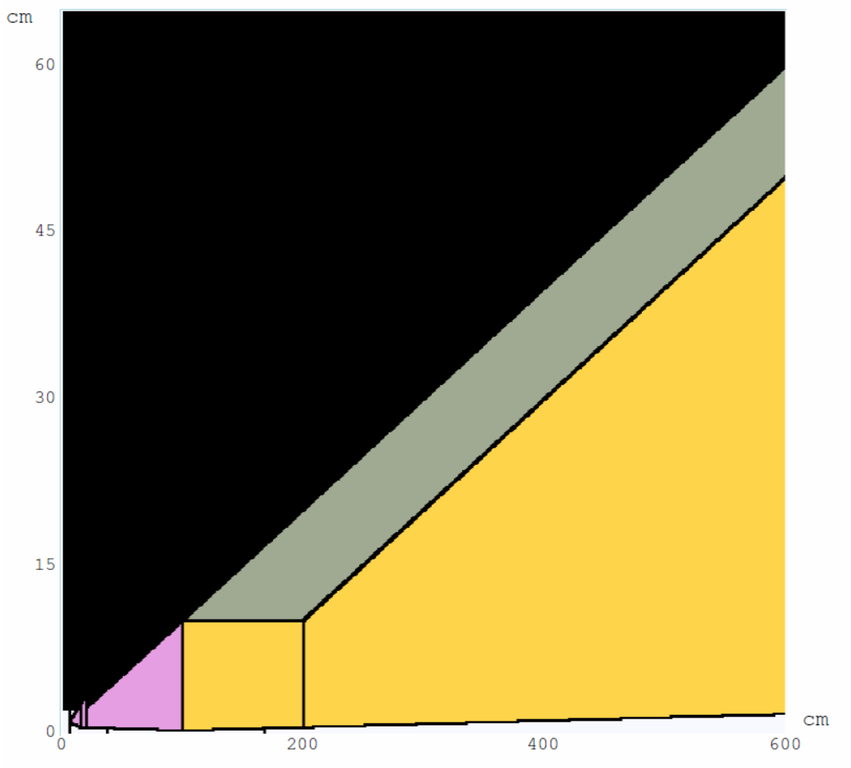


Nozzle geometry in MARS

Standard 10 degree nozzle



New nozzle



Comparison new and old shielding

Tungsten radiation length – 0.35 cm

Tungsten nuclear interaction length – 10 cm.

10 cm tungsten -29 gamma/electron interactions.

10 cm tungsten – 1 proton/neutron interaction.

Ratio new/old shielding

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	number	energy
Gamma	26	28
Positron	14	8
Electron	26	15
Muon	38	3.5
Neutron	3.2	2.2
Ch hadron	2.5	2.8