Muon Collider Detector Backgrounds

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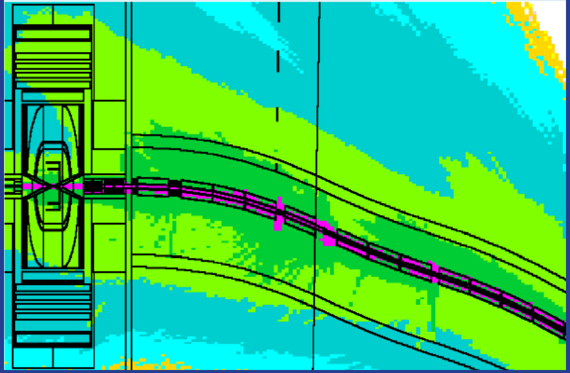
Outline

- Background Sources
- Earlier Results
- New Wave
- Loads in IR and Detector
- R&D on Machine-Detector Interface



Introduction

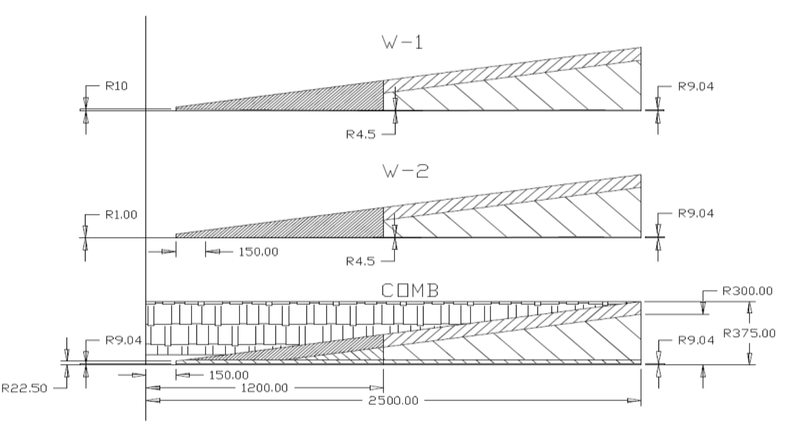
The high physics potential of a Muon Collider (MC) is reached only if a high luminosity of $\mu^+\mu^-$ collisions in the TeV range is achieved (~10^{34} cm^{-2} s^{-1}). The overall detector performance in this domain is strongly dependent on the background particle rates in various sub-detectors. The 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.

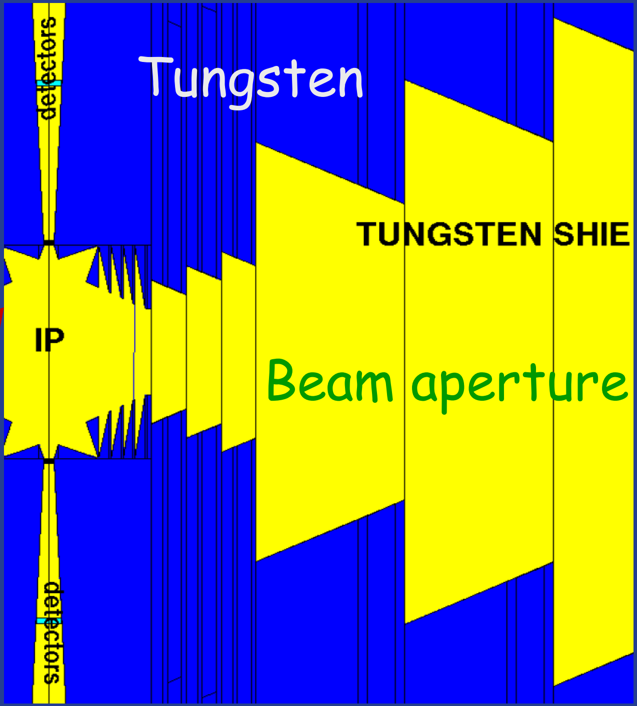
Sources of Background at Muon Colliders

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 2e12, 4.3e5 dec/m per bunch crossing, or 1.3e10 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. Nozzle at IP

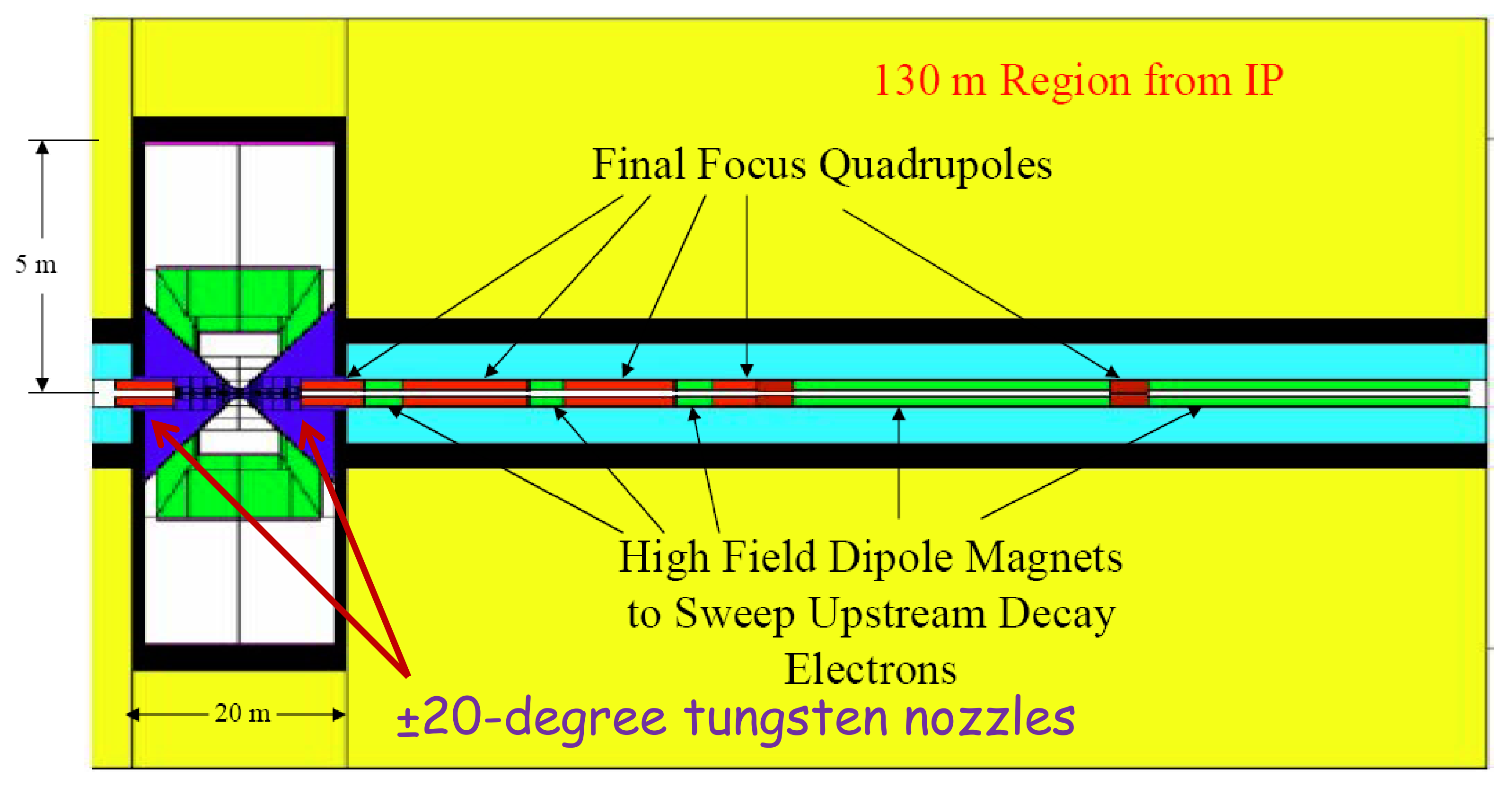
Very first calculations (~1995) have shown that expected particle fluxes and dose in MC detector components are well beyond known technological capabilities. First techniques: collimating nozzles at IP, detector magnetic field assisted.





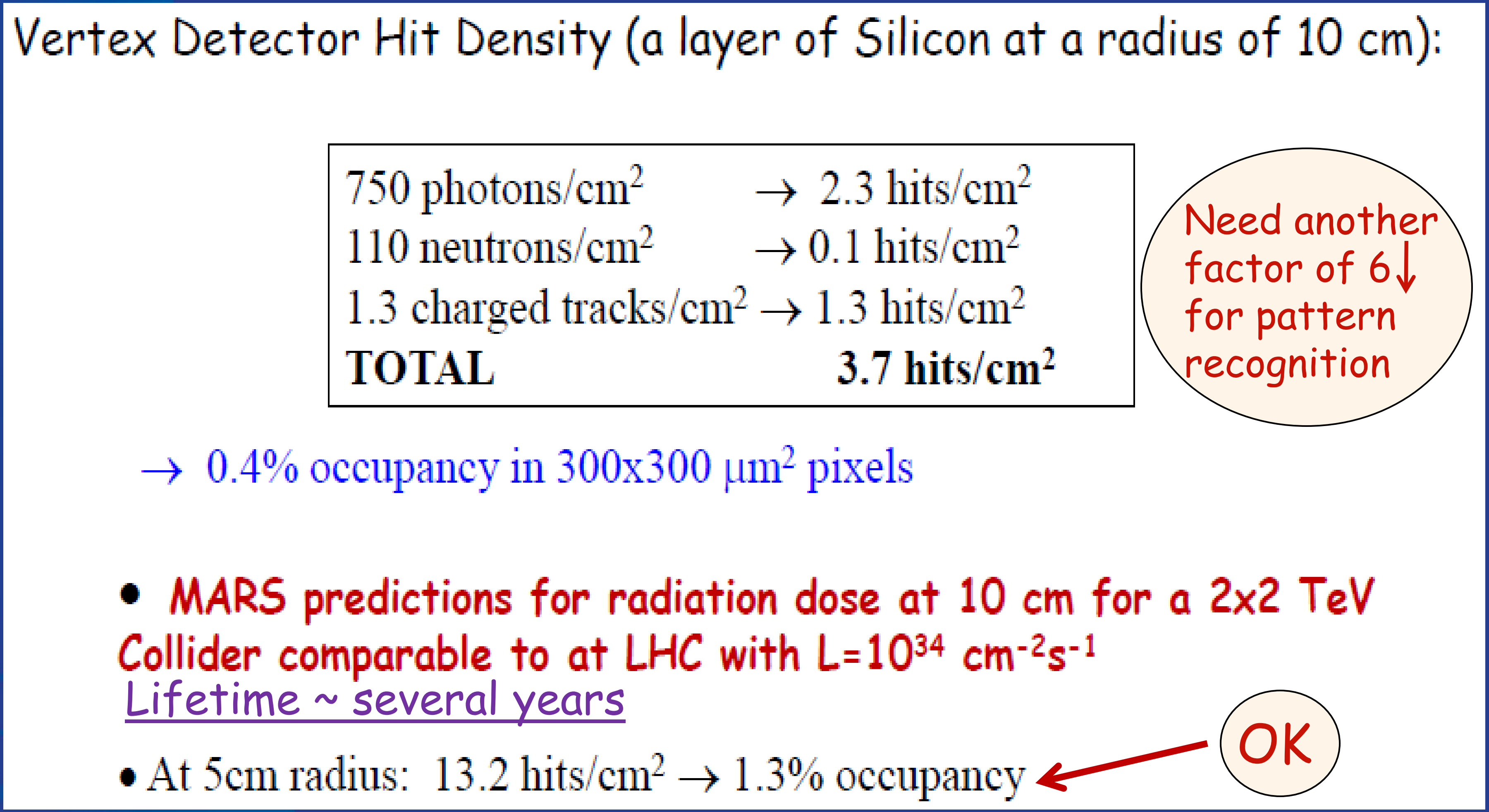
Machine background reduction up to 500 times.
Also can fully confine incoherent pairs if B > 3 T

Suppressing Backgrounds: 2. Dipoles in IR



~10 T dipoles in IR with tungsten masks in between: further substantial reduction in loads on central detectors; also help reduce Bethe-Heitler muon flux at large radii

'96 Studies with 20-deg Nozzles and IR Dipoles



Vertex Detector Hit Density (a layer of Silicon at a radius of 10 cm):

750 photons/cm^2	→ 2.3 hits/cm^2
110 neutrons/cm^2	→ 0.1 hits/cm^2
1.3 charged tracks/cm^2	→ 1.3 hits/cm^2
TOTAL	**3.7 hits/cm^2**

Need another factor of 6↓ for pattern recognition

→ 0.4% occupancy in 300x300 μm^2 pixels

- **MARS predictions for radiation dose at 10 cm for a 2x2 TeV Collider comparable to at LHC with L=10^{34} $cm^{-2}s^{-1}$**

Lifetime ~ several years

- At 5cm radius: 13.2 hits/cm^2 → 1.3% occupancy

OK

SCRAPING MUON BEAM HALO

- For TeV domain, extraction of muon beam halo with electrostatic deflector reduces loss rate in IR by three orders of magnitude.
- Efficiency of an absorber-based system is much lower and can be used only if muon energy is < 50 GeV.

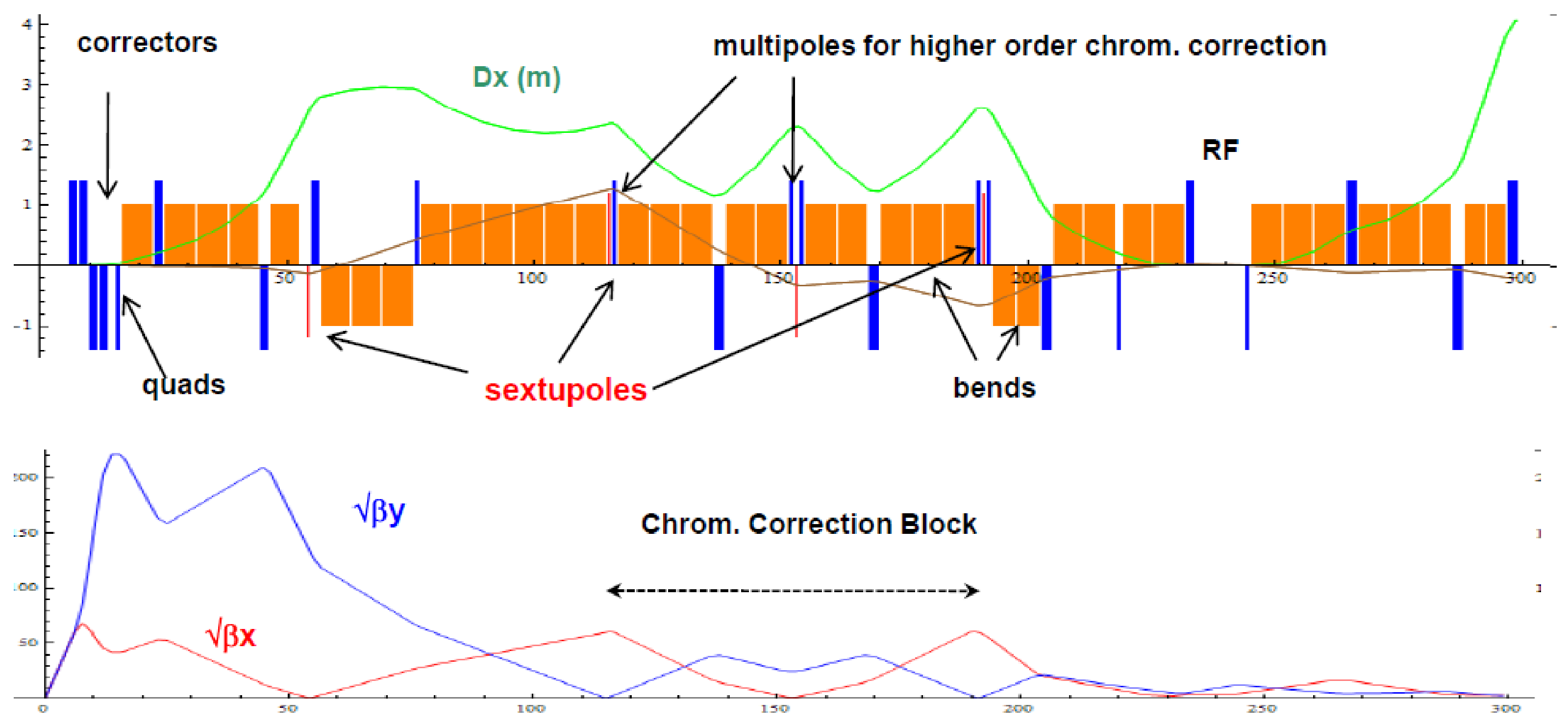
New Wave: 2009-2010

- Compact lattice: C=2.5 km with B=10 T
- Consistent IR design
- Realistic IR magnets
- Full MARS modeling of MDI
- Detector: fast and full simulators

Muon Collider Parameters

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

IR & Chromatic Correction Section



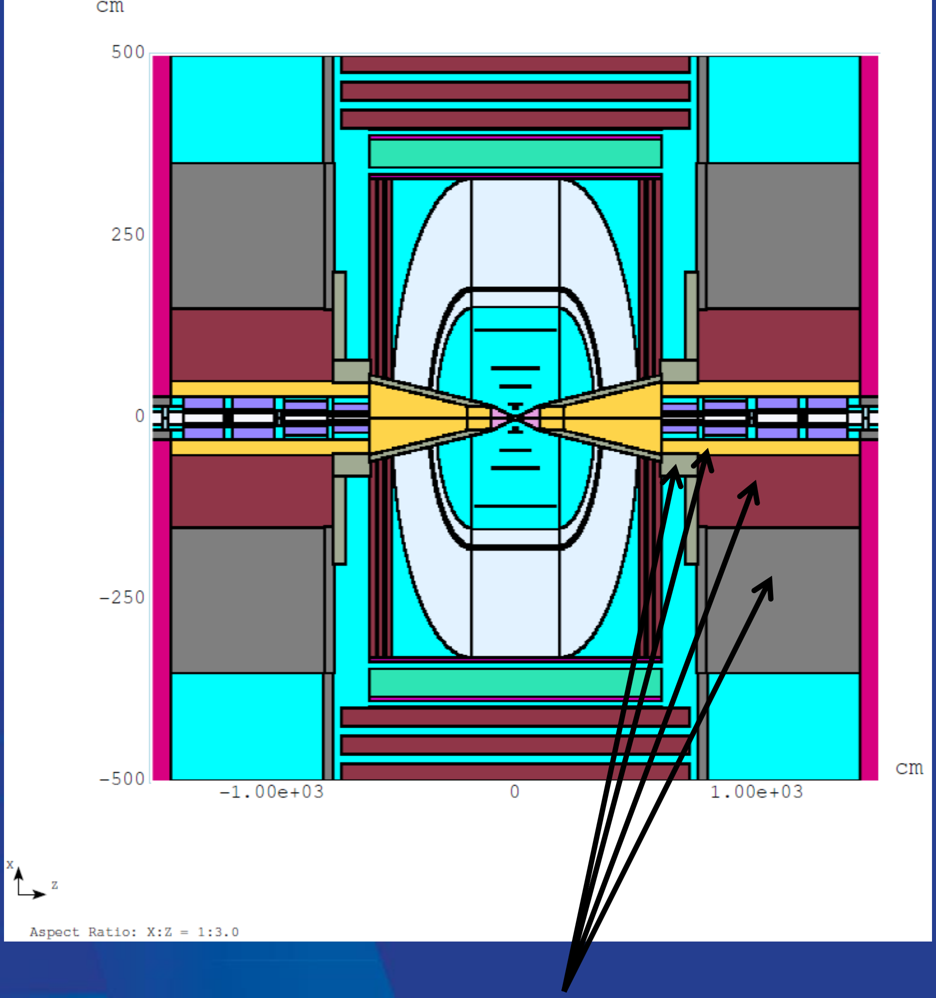
8-T dipoles in IR to generate large D at sextupoles to compensate chromaticity and sweep decay products; momentum acceptance of 1.2%; momentum compaction factor of -1.5e-5; dynamic aperture sufficient for transverse emittance of 50 μm; under engineering constraints.

Iterative studies on lattice and MDI with magnet experts: High-gradient (field) large-aperture short Nb3Sn quads and dipoles.

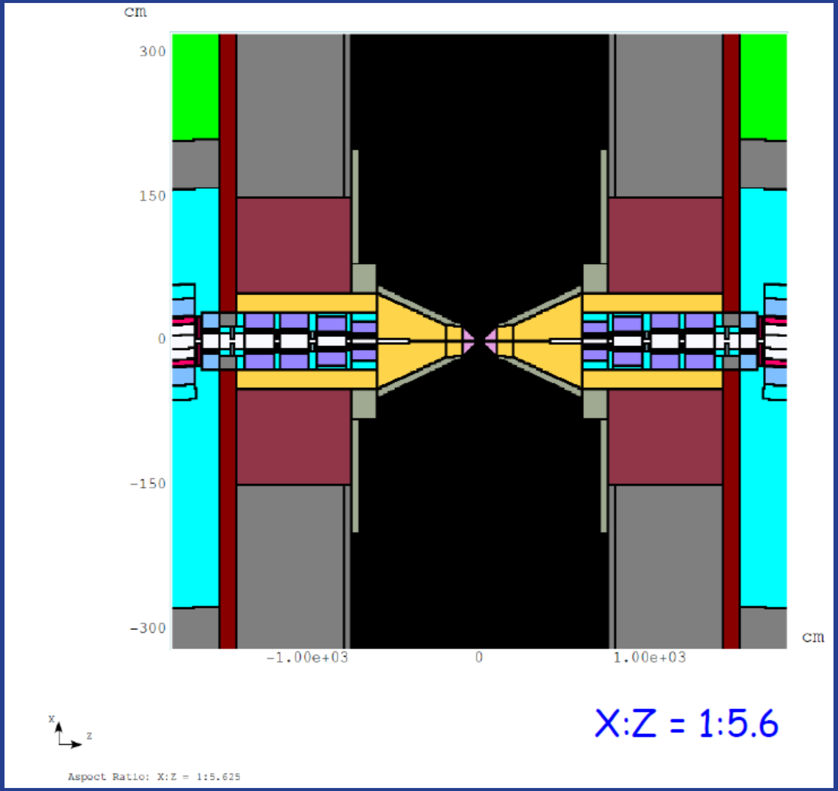
MARS15 Modeling

- 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 ±6cm 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}=75 to 250 m at 4.28×10^5 per meter rate.
- 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



Source term at black hole to feed detector simulation groups: INFN, CD, SiD



X:Z = 1:5.6

Sophisticated shielding:
W, iron, concrete & BCH2

Tungsten Nozzle in BCH2 Shell

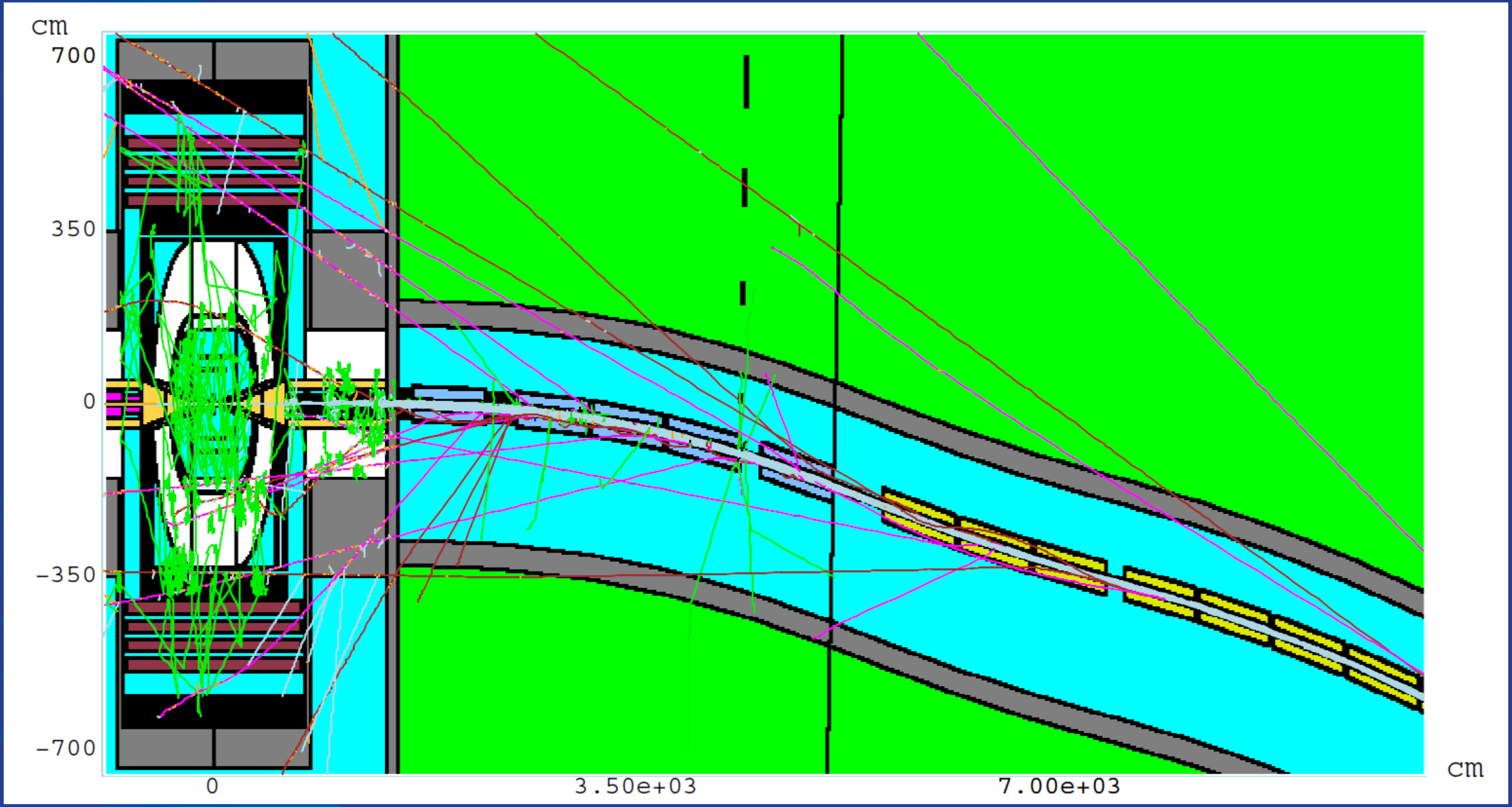
1. **Optimize and minimize it** as much as possible (20^0 to 10^0) because of limitations on possible physics:

- Top production in forward regions as CoM energy goes up
- Asymmetries are more pronounced in forward regions
- Z' => ttbar
- Final states with many fermions (like ordinary 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 integrated luminosity (ΔL/L ~ 10-3)
- Beam-cal at smaller angles for beam diagnostics

Particle Tracks in IR



Load to Detector: Optimizing Nozzle

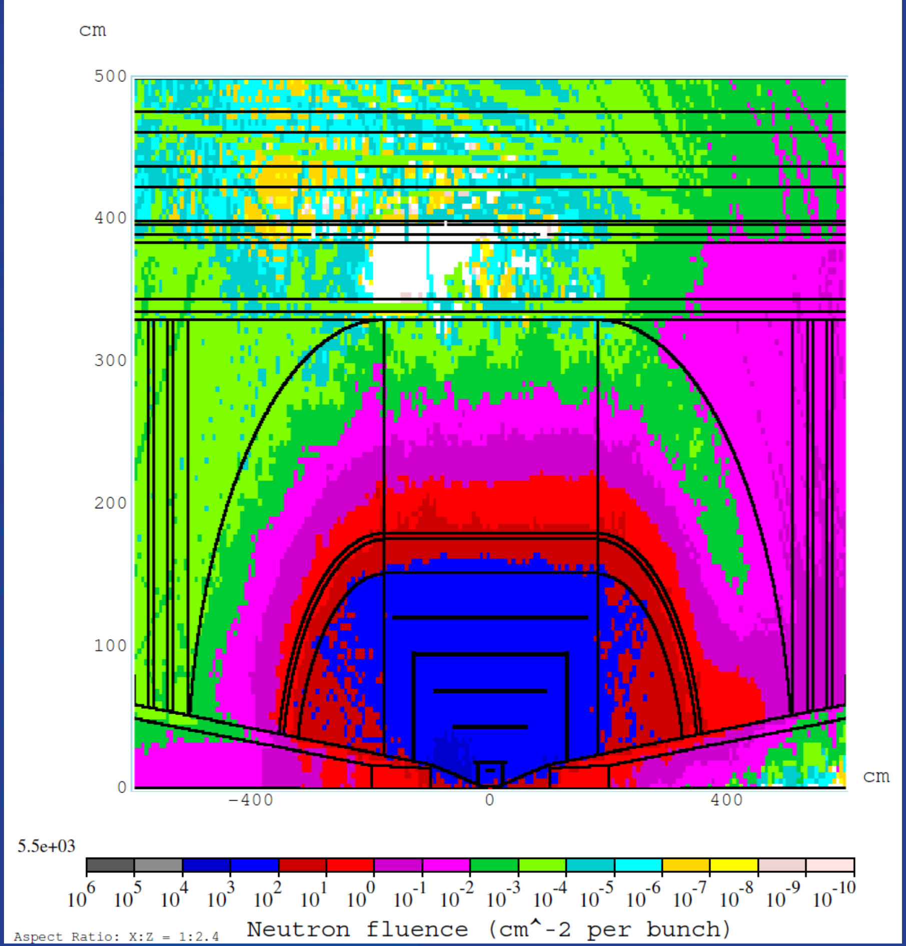
Number of particles per bunch crossing entering detector, starting from MARS source term for S_{max}=75m

Particle	**Minimal "6-deg"**	**Optimal "10-deg"**
Photon	1.5e11	1.8e8
Electron	1.4e9	1.2e6
Muon	1.2e4	3.0e3
Neutron	5.8e8	4.3e7
Charge hadr	1.1e6	2.4e4

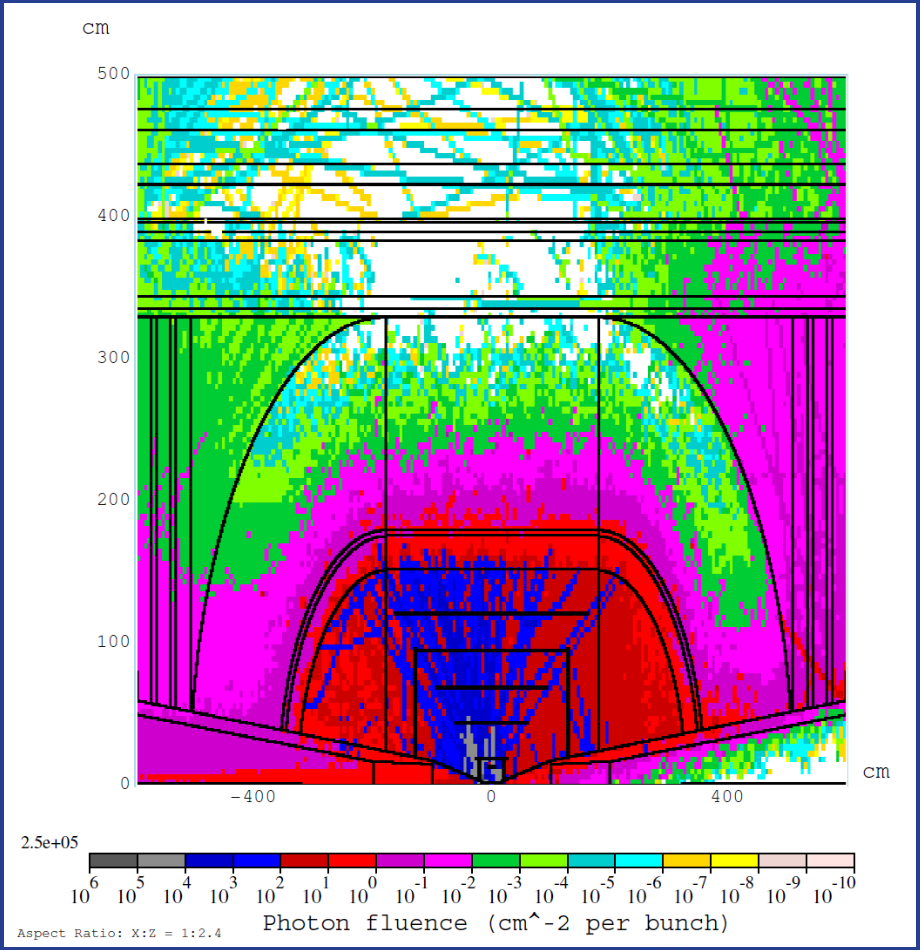
Neutron and Photon Fluence

Fluence per bunch entering right-hand side of detector, starting from MARS source term for S_{max} = 75 m

Peak: 1/10 x best 20-deg '96



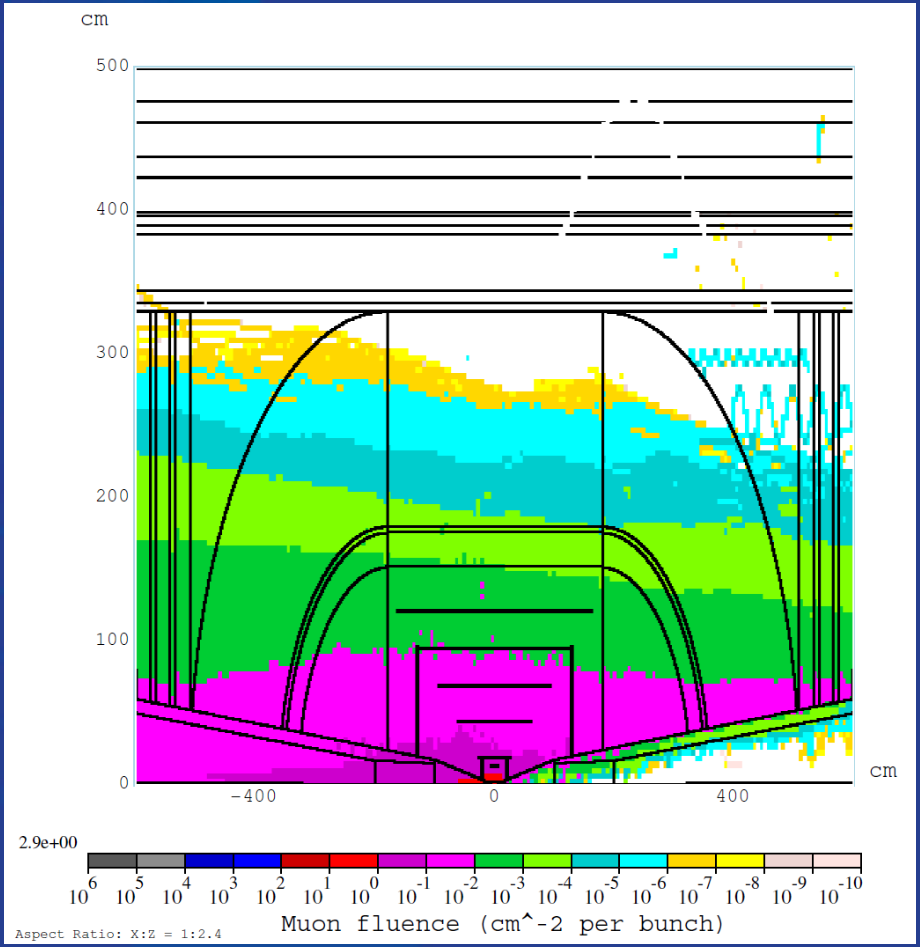
Peak: 5 x best 20-deg '96



Muon Fluence and Dose (vs LHC)

Fluence per bunch entering right-hand side of detector, starting from MARS source term for S_{max} = 75 m

Peak: 1/10 x best 20-deg '96



Absorbed dose in Si

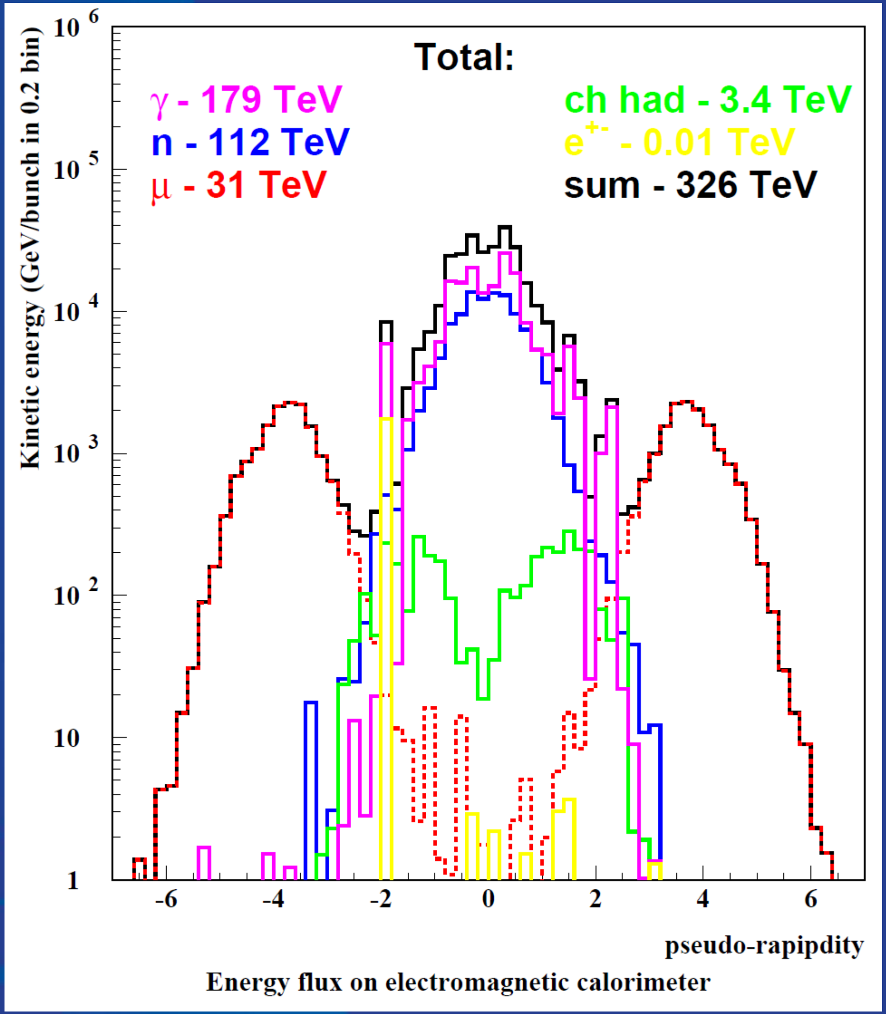
for bilateral irradiation

Peak at r=4 cm:

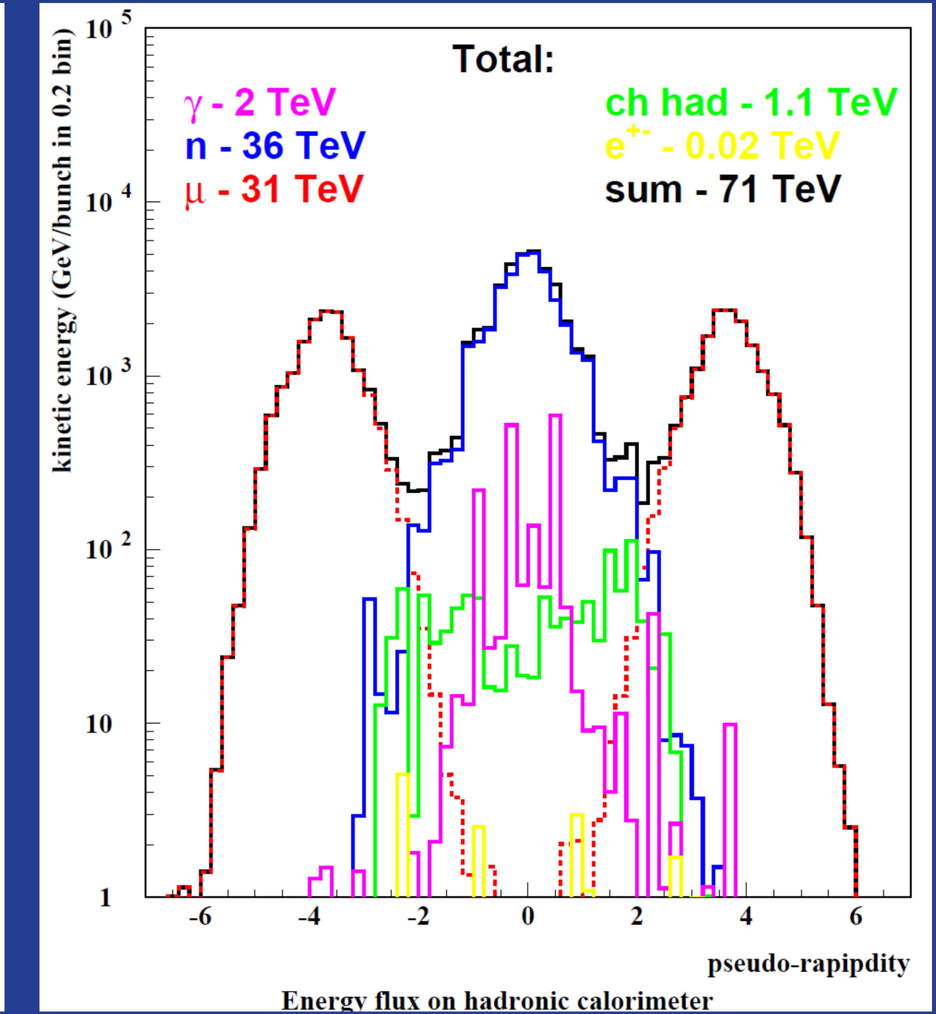
MC: 0.1 MGy/yr

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

Energy Flux into Ecal and Hcal vs Rapidity

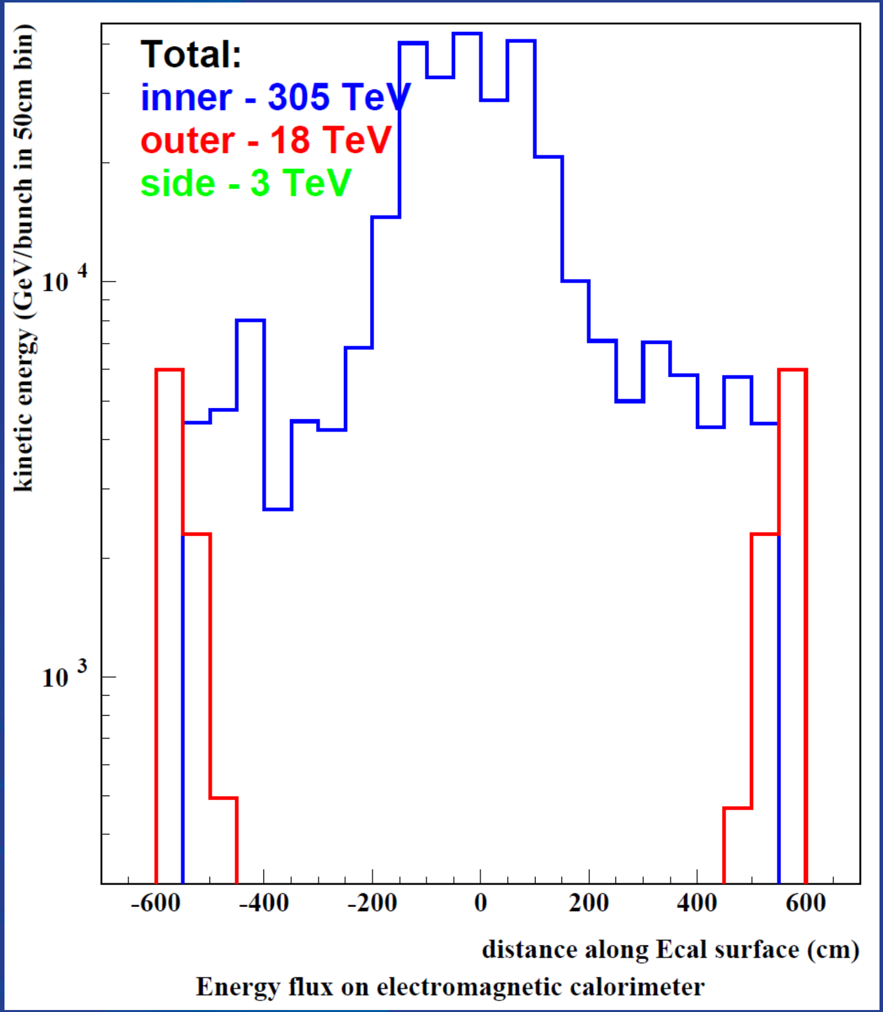


Energy flux on electromagnetic calorimeter

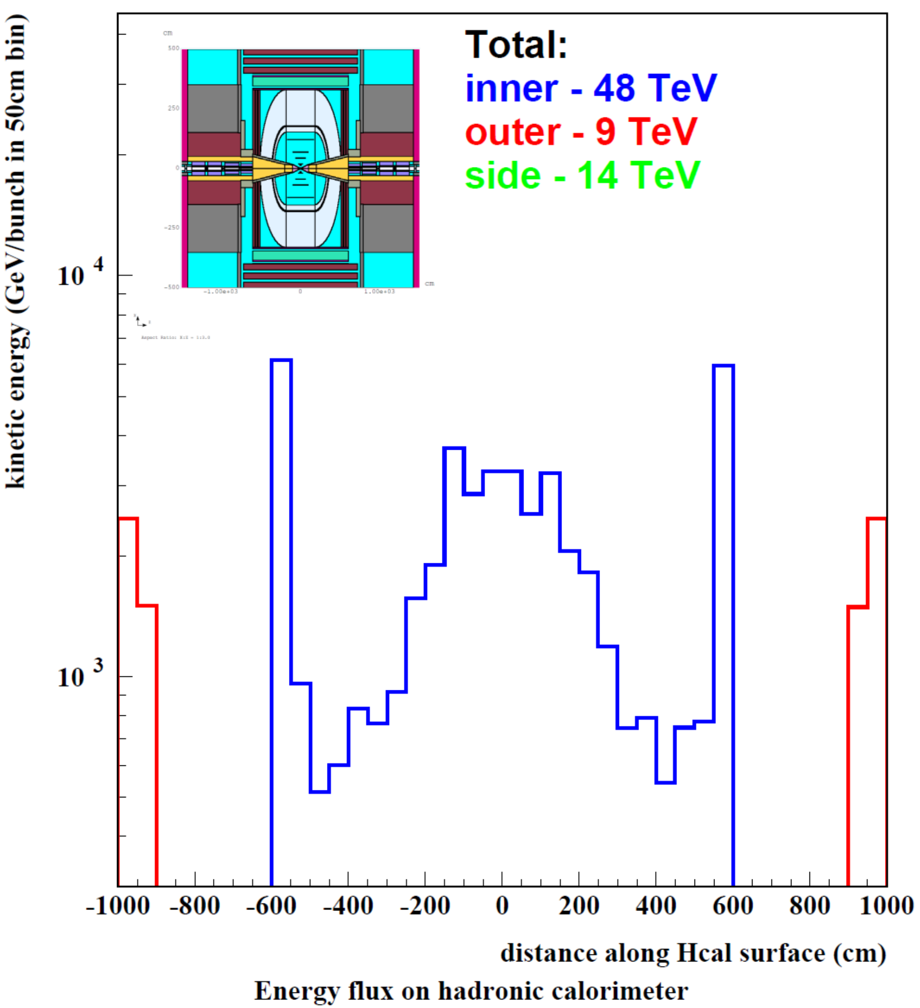


Energy flux on hadronic calorimeter

Energy Flux into Ecal and Hcal along Surface



Energy flux on electromagnetic calorimeter

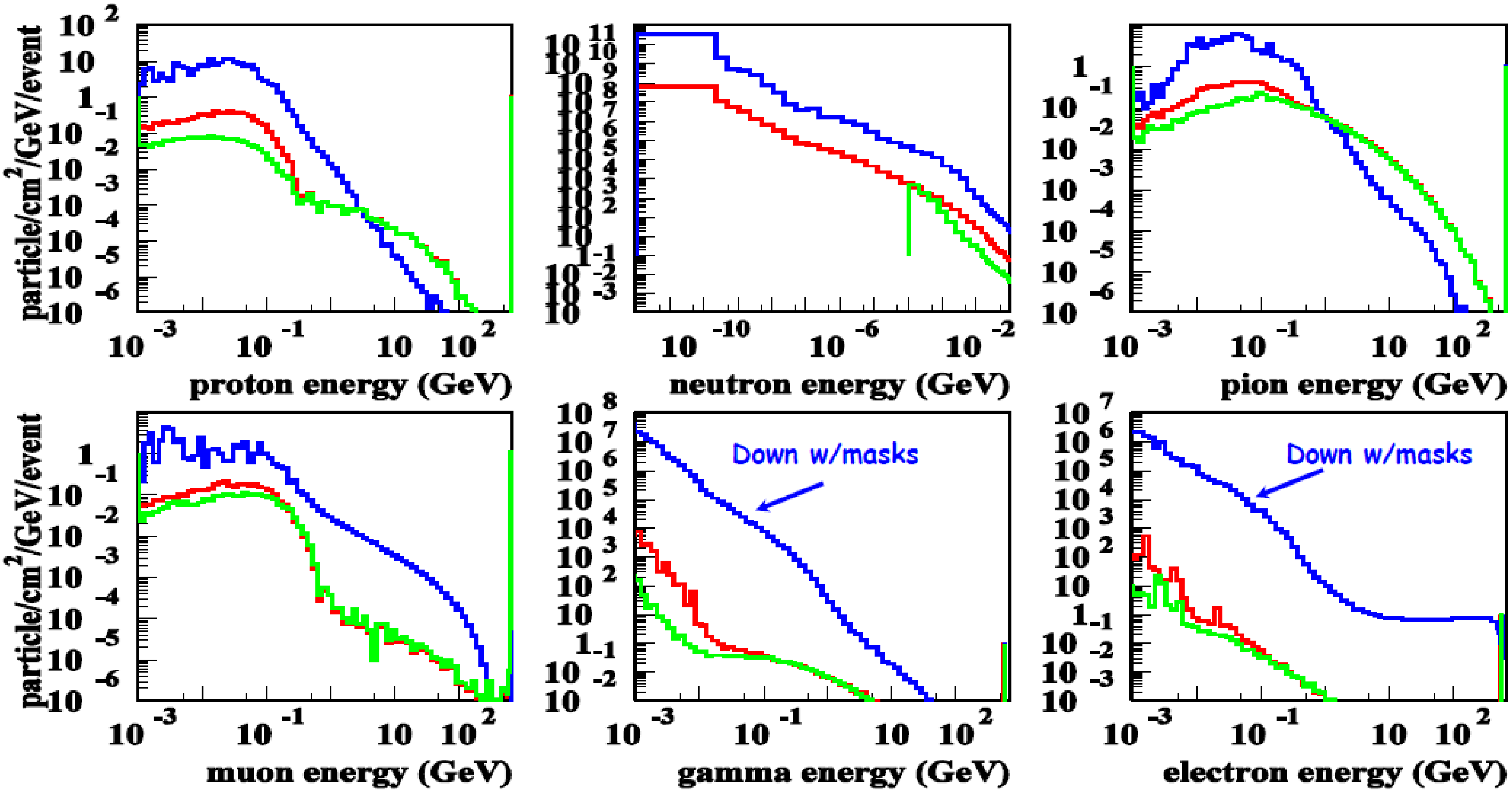


Energy flux on hadronic calorimeter

Machine vs IP Backgrounds in Tracker

Energy spectra in tracker (+-46x46x5cm)

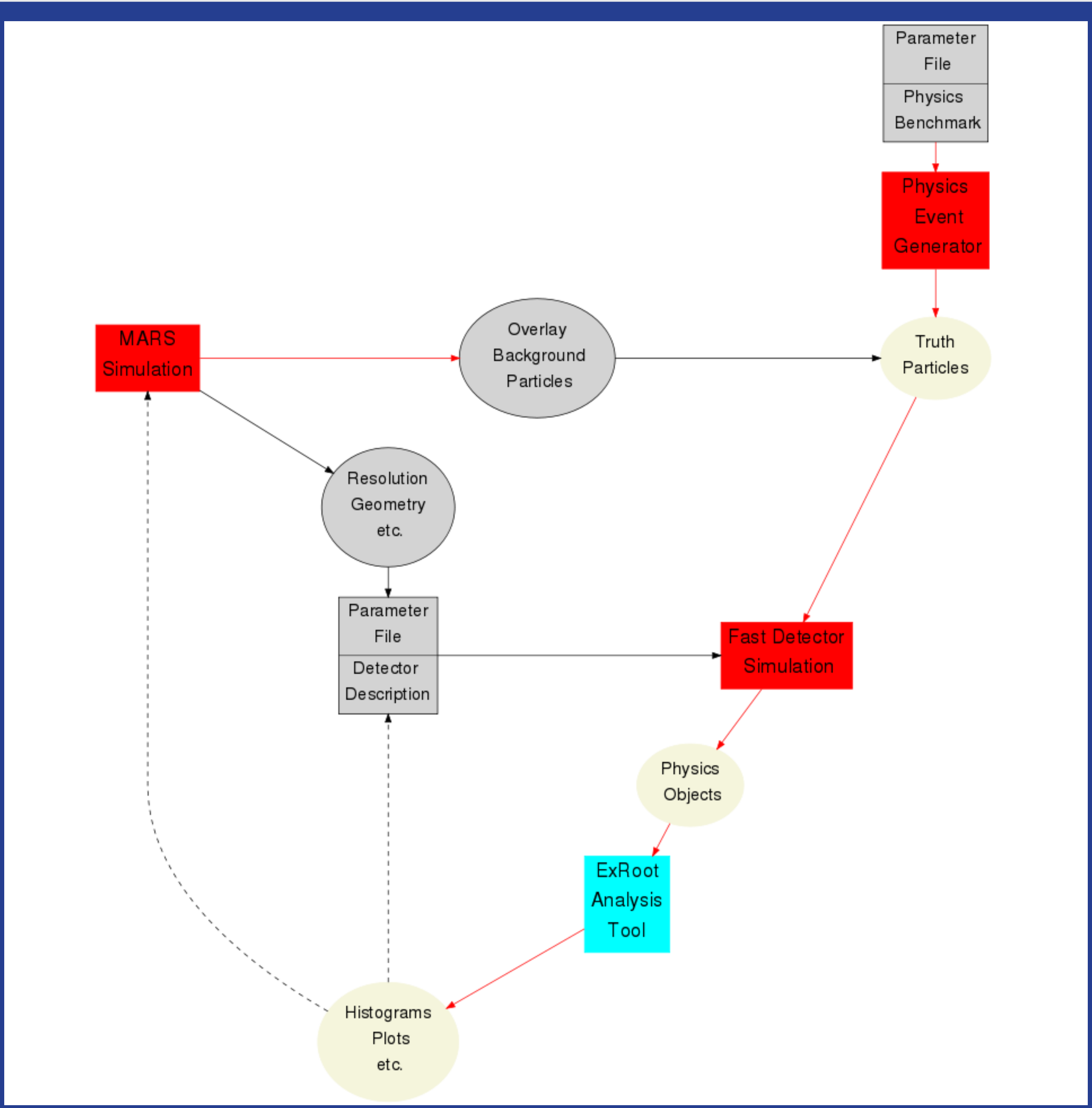
Blue lines - from machine, red lines - Z0 events, green lines - Higgs events



Detector Simulation

- Using as a source term MARS files at MDI, fast parameterized Monte-Carlo to demonstrate that physics can be extracted in the presence of a fierce beam-related backgrounds, engaging the theoretical community.
- Calorimetry: use MARS energy flow, straightforward
- Tracker & vertex: occupancy & hit density, more challenging (statistical weight spread)
- Identify issues to optimize MDI and help set the focus for detector component research.
- 1 FTE of computing+scientist development effort for 3 years to built and use in MDI optimization a tool that incorporates an event generator and beam backgrounds to deliver parameterized detector response and analysis object.

Detector MC Development Flow Chart



Detector Simulation Plan for 2011-2013

- Complete a fast Monte Carlo for physics simulations.

- Develop an initial physics and detector report by the end of 2011. Allows input to the design parameters of the MAP study:

  - ➢ This study should set requirements on luminosity, energy, acceptable background event rates and suggest feasible methods of attaining these levels.

  - ➢ Evaluate the impact of the polarized beams, energy spread, and detector fiducial volume.

  - ➢ Compare physics opportunities to CLIC and take account of the substantial running of LHC after luminosity upgrade.

  - ➢ Possible synergy with the ILC/CLIC and LHC detector R&D.

- Using existing framework (ILCRoot, SiD) do detailed simulations to identify further needs for detector development.

MDI Critical R&D Directions

1. Thorough optimization of the nozzle and shielding at the machine-detector interface, for both 1.5 and 4 TeV, balancing advantages of a smaller nozzle angle vs effects of the greater background if it has a smaller angle, not sacrificing physics; consider its instrumentation (Lumical etc.). Optimization also includes the nozzle efficiency to confine incoherent pairs with the detector 3.5-T field.

2. Model detector response to physics signal in presence of IP and machine backgrounds. To first order, the backgrounds will drive critical parameters of the MC detector design, not the physics.

3. Design and optimization of the masks in the IR magnet interconnect regions and liners inside the magnets to mitigate effect of 0.5-1 kW/m loss rate on detector backgrounds and magnet performance (dynamic heat load, quench stability and lifetime).

4. Iterate with lattice and magnet designers to improve IR and MDI system performance.

MDI Design & Simulation Tasks to Complete Design & Feasibility Study

1. Design & optimization of detector shielding (50 pm)
2. Background simulations for 1.5 & 4 TeV com (45 pm)
3. Detector performance via fast Monte-Carlo (24 pm)
4. Radiation & heat load calculations (30 pm)
5. Beam halo collimation (12 pm)
6. Auxilary systems (12 pm)
7. Launch full detector simulations, ILCRoot & SiD (12 pm)

Related: IR lattice (20 pm) and IR Magnets (30 pm)

Efforts in person-months (pm)