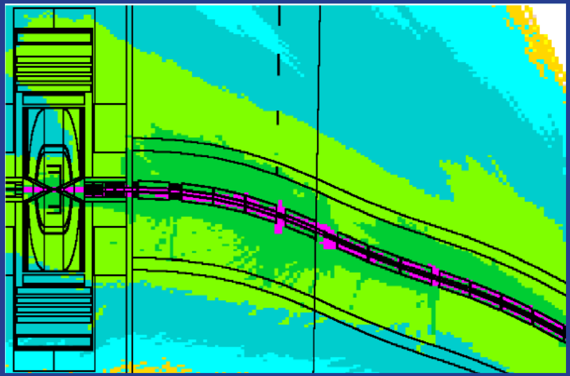
Muon Collider Detector Backgrounds

Nikolai Mokhov
Fermilab

KA12 DOE Review
June 22-23, 2010

Outline

- Muon Collider and Background Issues
- Background Sources
- Earlier Results
- New Wave
- Backgrounds in Detector
- MDI and Detector Simulation Plans



Muon Collider Motivation

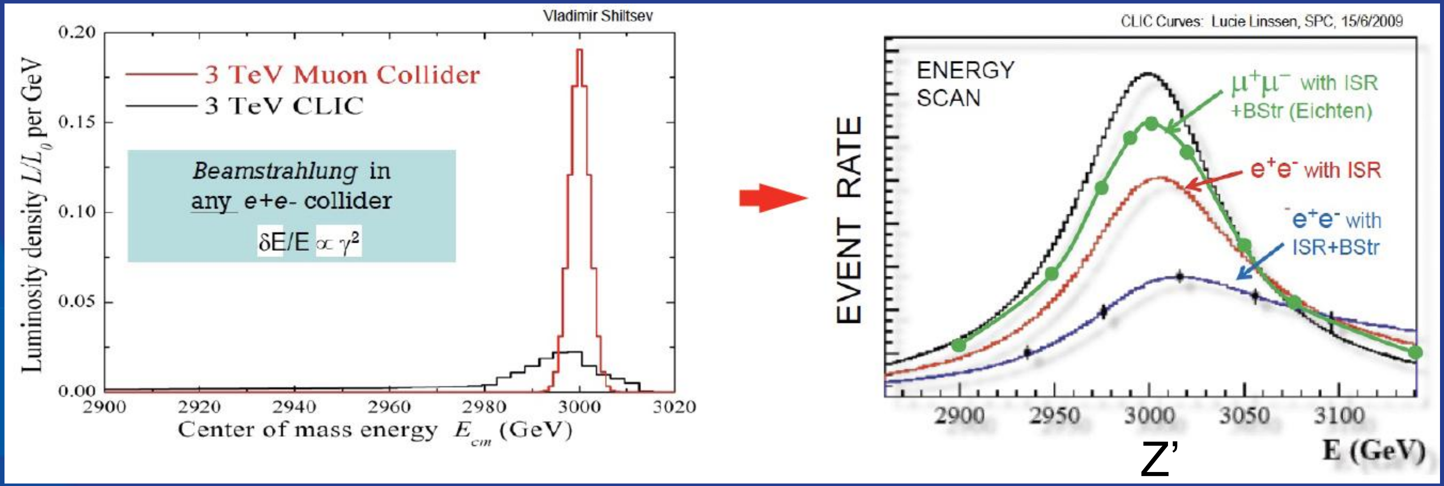
- If we can build a multi-TeV muon collider it's an attractive option because muons don't radiate as readily as electrons (m_m / m_e ~ 207):
  - COMPACT
    - Fits on laboratory site
  - MULTI-PASS ACCELERATION
    - Cost Effective (e.g. 10 passes → factor 10 less linac)
  - MULTIPASS COLLISIONS IN A RING (~1000 turns)
    - Relaxed emittance requirements & hence tolerances
  - NARROW ENERGY SPREAD
    - Precision scans & kinematic constraints
  - TWO DETECTORS (2 IPs)
  - ΔT_{bunch} ~ 10 μs
    - Lots of time for readout; Backgrounds don't pile up
  - $(m_\mu/m_e)^2$ = ~40000
    - Enhanced s-channel rates for Higgs-like particles

COST

PHYSICS

Muon Collider: Physics and Detectors

- The overall physics goals of a future lepton collider are similar for ILC/CLIC/MC.
- A coordinated program of detector research is appropriate. The 5 Labs have proposed this to DOE.
- The MC physics effort is in the early stages. Needs much more work to scope out the potential.
- The physics and backgrounds are significantly different for a 500-GeV ILC and a multi-TeV CLIC/MC. For a MC there are additional backgrounds due to muon decays.



Detector Backgrounds

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

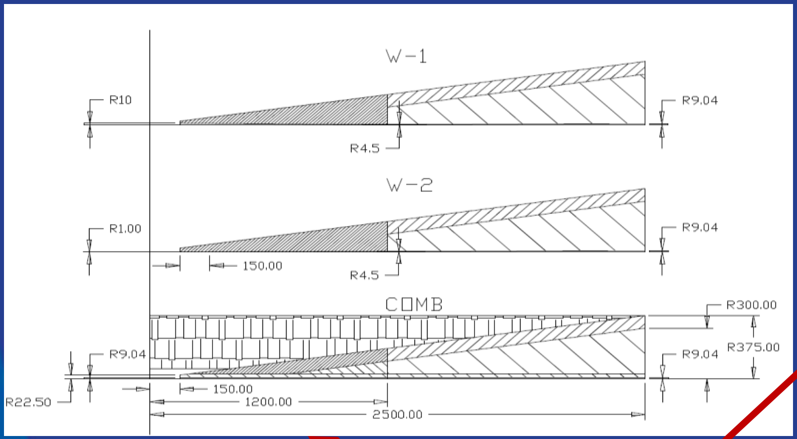
- Deleterious effects of the background and radiation environment produced by muon decays is one of the fundamental issues in the feasibility study of MC ring, Interaction Region (IR) and detector.

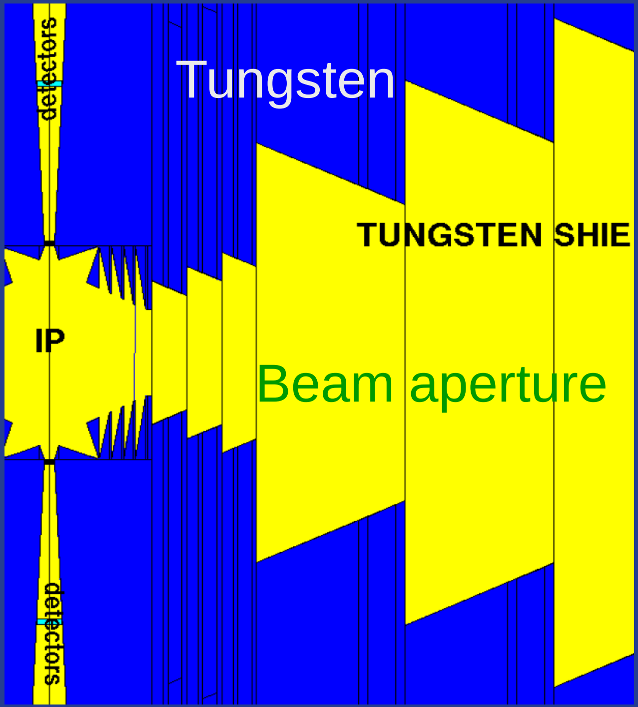
Sources of Background at Muon Colliders

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. Nozzle at IP

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

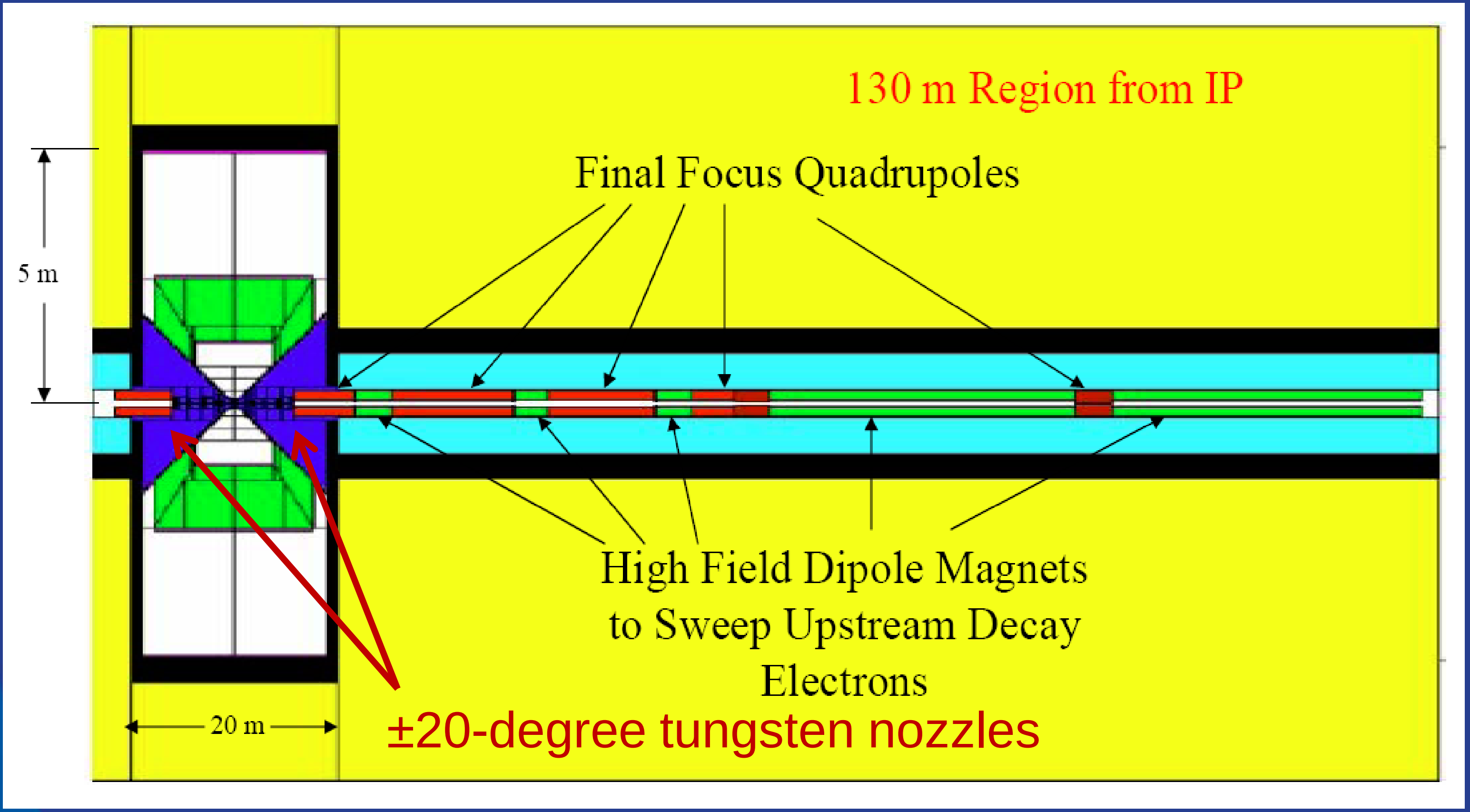




Machine background reduction up to 500 times. Also can fully confine incoherent pairs if B > 3 T

Fermilab

Suppressing Backgrounds: 2. Dipoles in IR



~10T 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

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)

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.

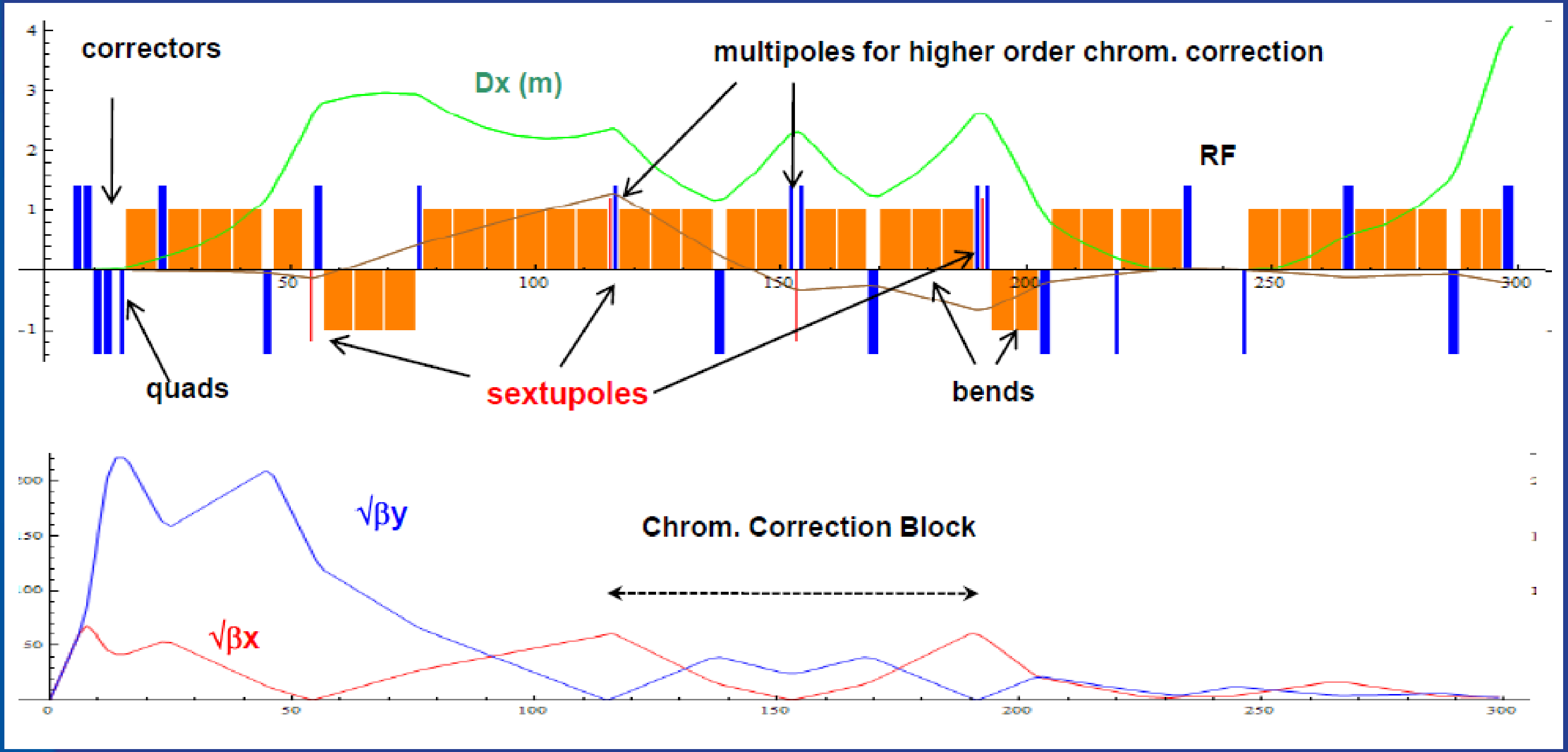
New Wave: 2009-2010

- 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
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 -1.5×10^{-5}; dynamic aperture sufficient for transverse emittance of 50 μm; under engineering constraints.

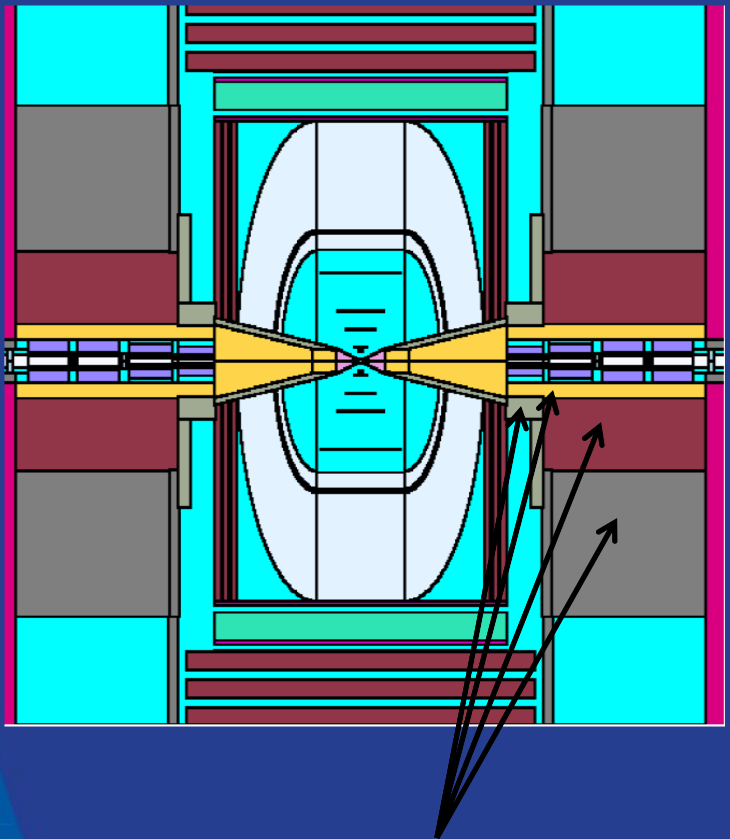
Iterative studies on lattice and MDI with magnet experts:

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

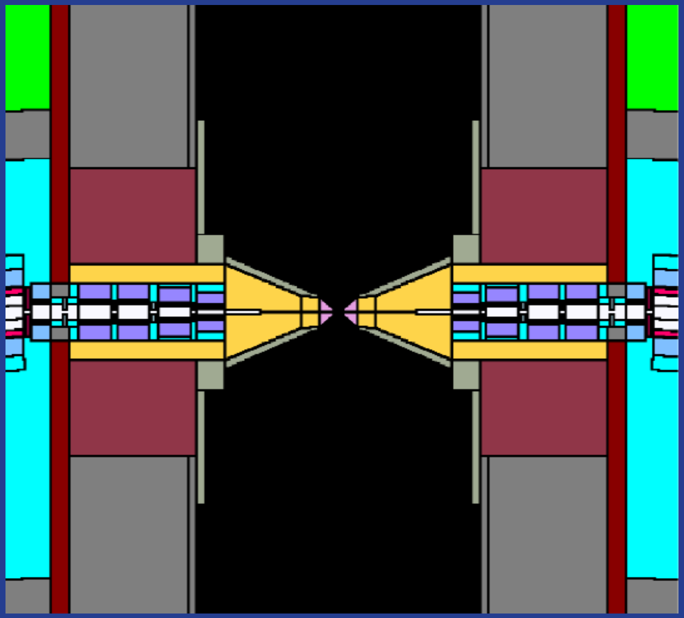
MARS15 Modeling

- 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 $S_{max} = 75$ to 250 m at 4.28×10^5 / m 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



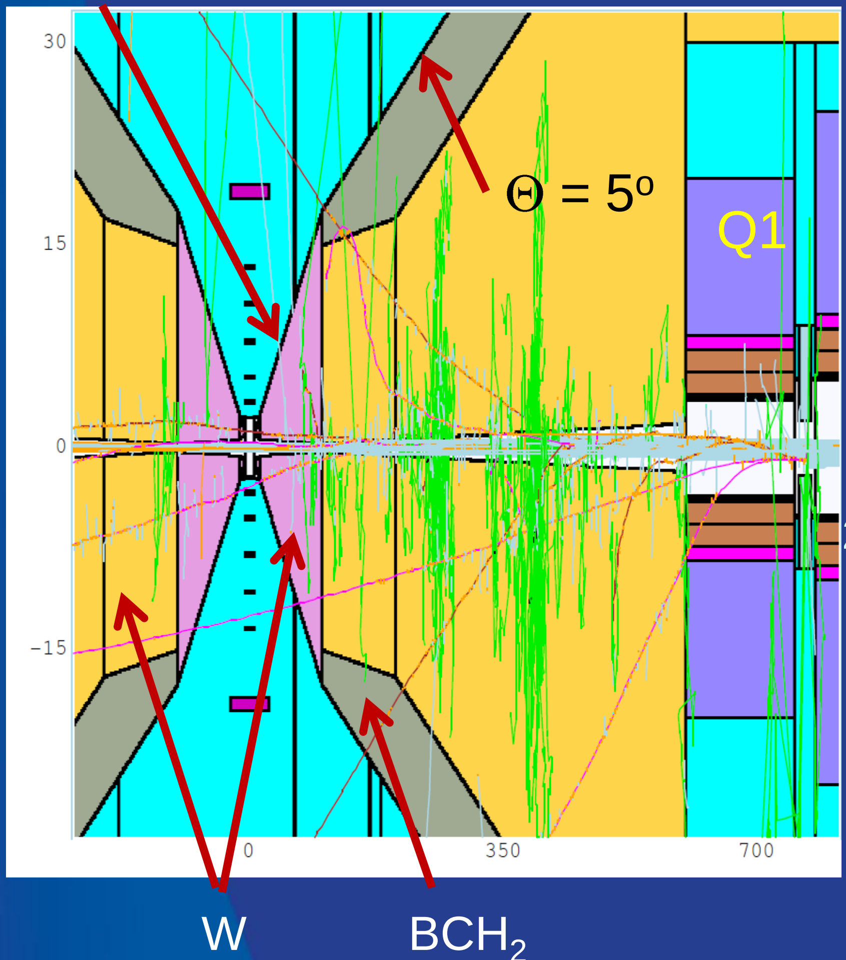
Sophisticated shielding:
W, iron, concrete & BCH_2



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

Tungsten Nozzle in BCH_2 Shell

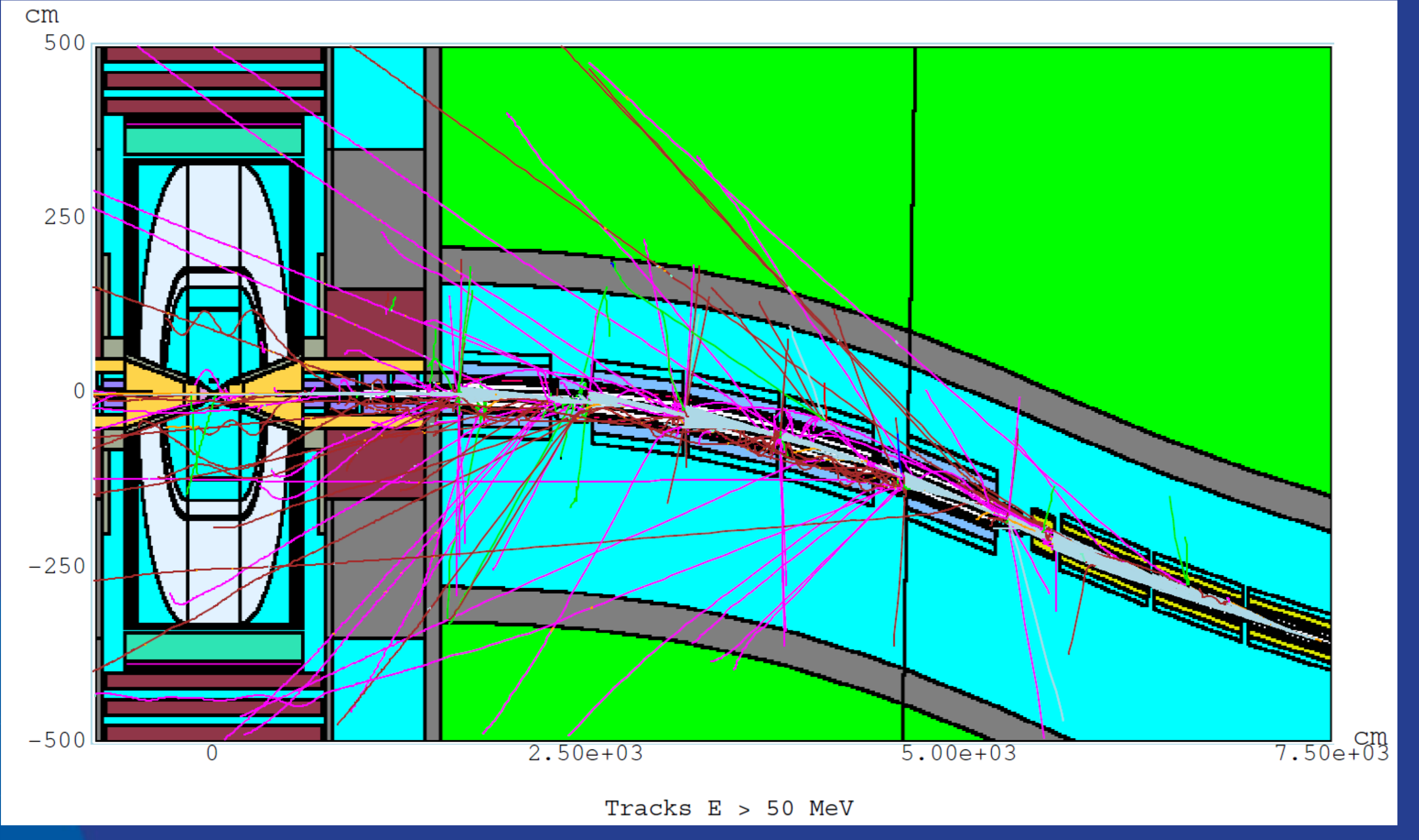
$\Theta = 10^o$ 6 < z < 600 cm x:z = 1:17



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

Fermilab

Particle Tracks in IR

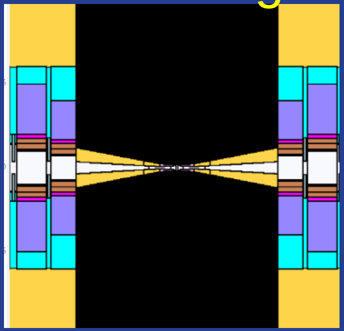


Load to Detector: Optimizing Nozzle

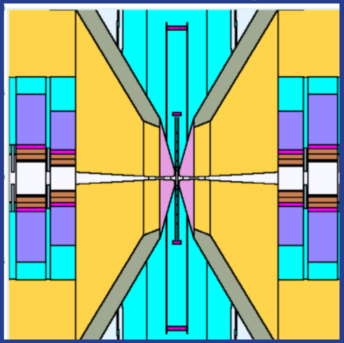
Number of particles per bunch crossing entering detector, starting from MARS source term for S_{max}=75m

Particle	Minimal 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



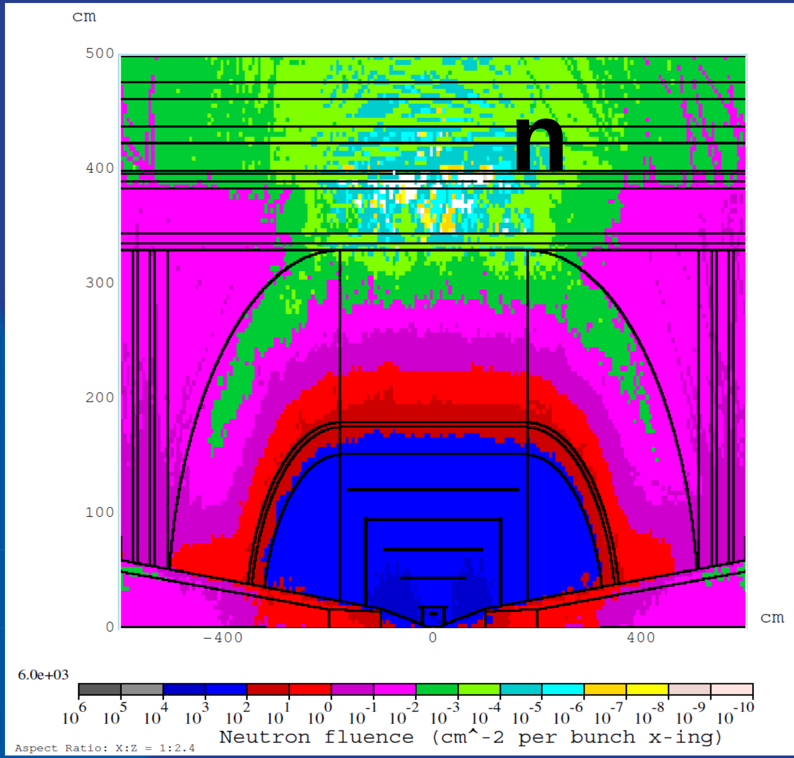
X:Z=1:20

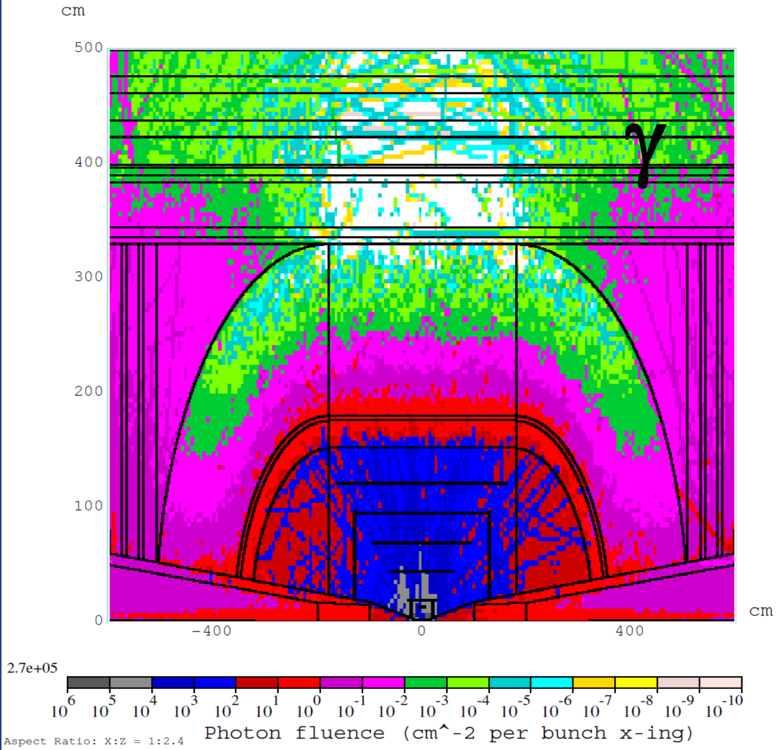
No time cut applied, can help substantially

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}





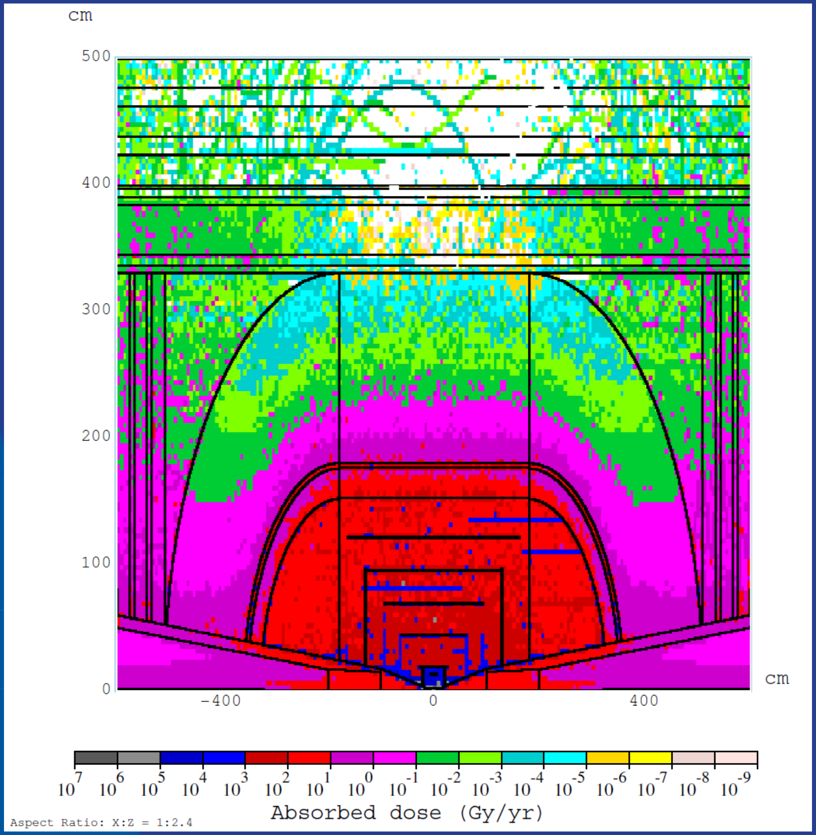
Absorbed Dose (vs LHC)

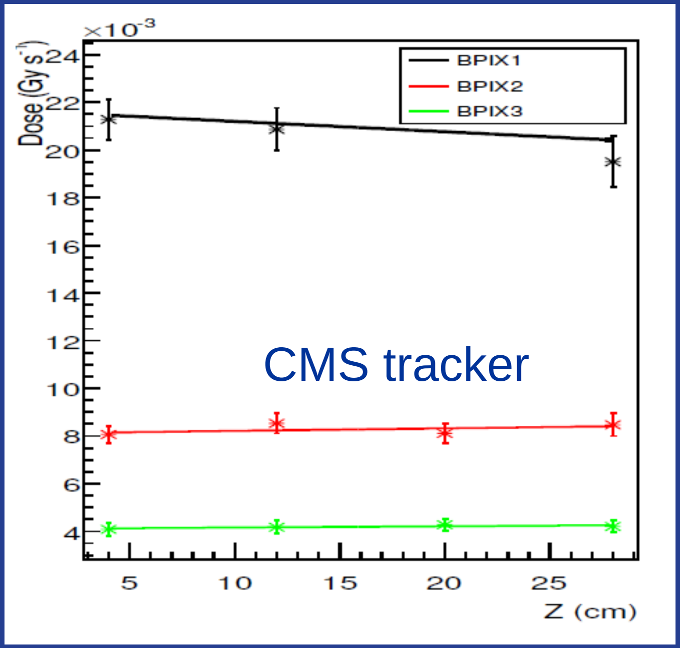
Total absorbed dose in Si

Peak at r=4 cm:

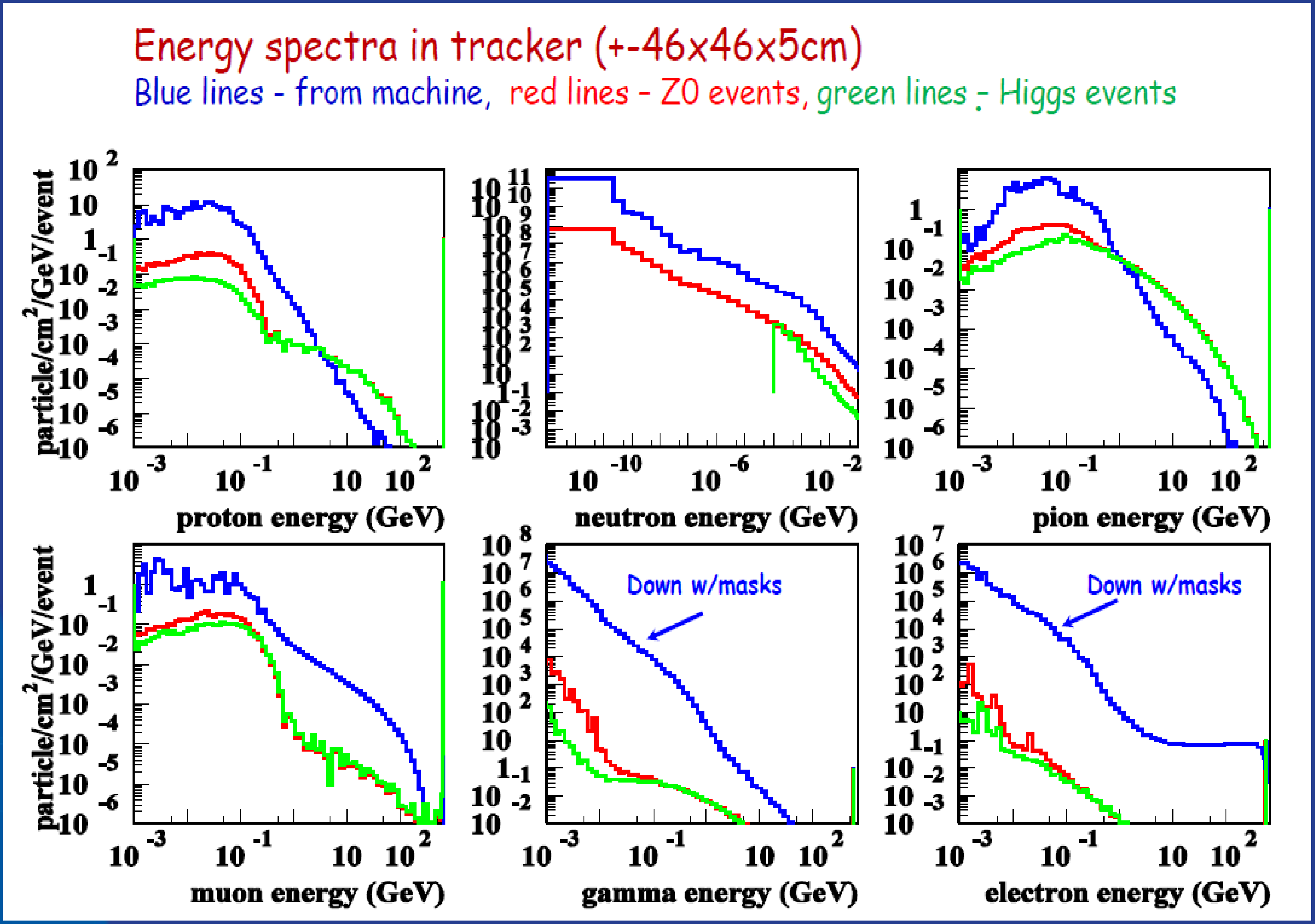
MC: 0.1 MGy/yr

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

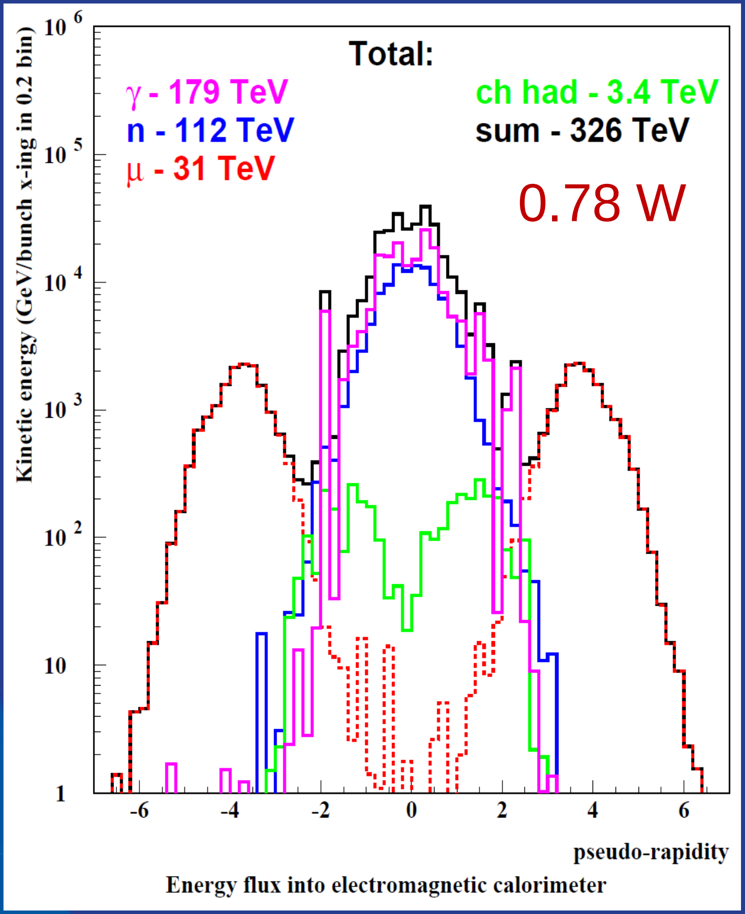


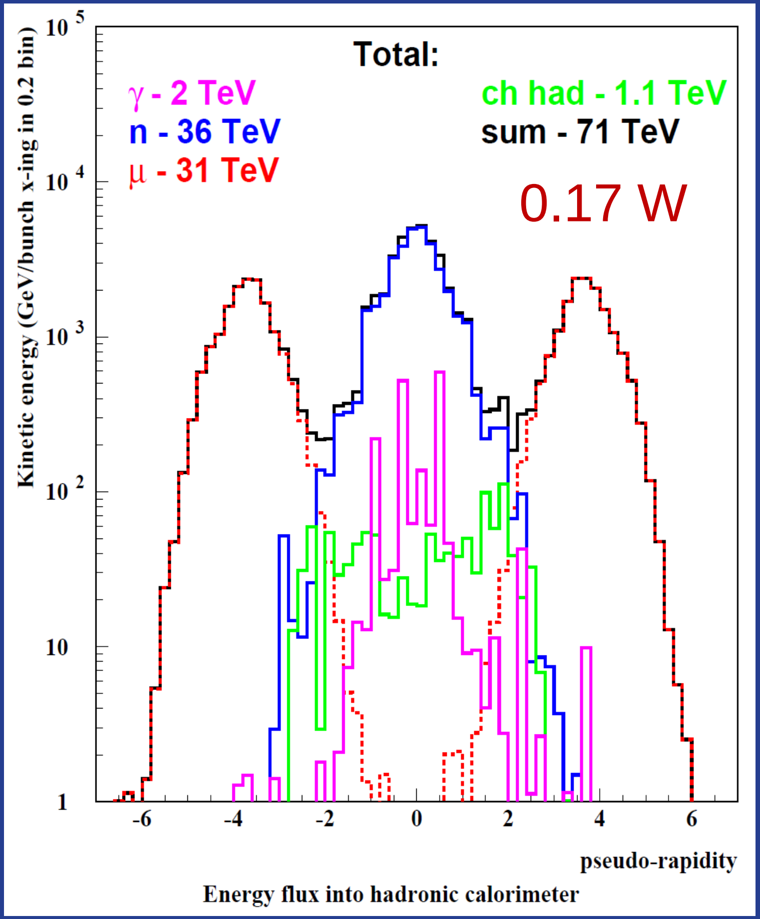


Machine vs IP Backgrounds in Tracker



Energy Flux into Ecal and Hcal vs Rapidity





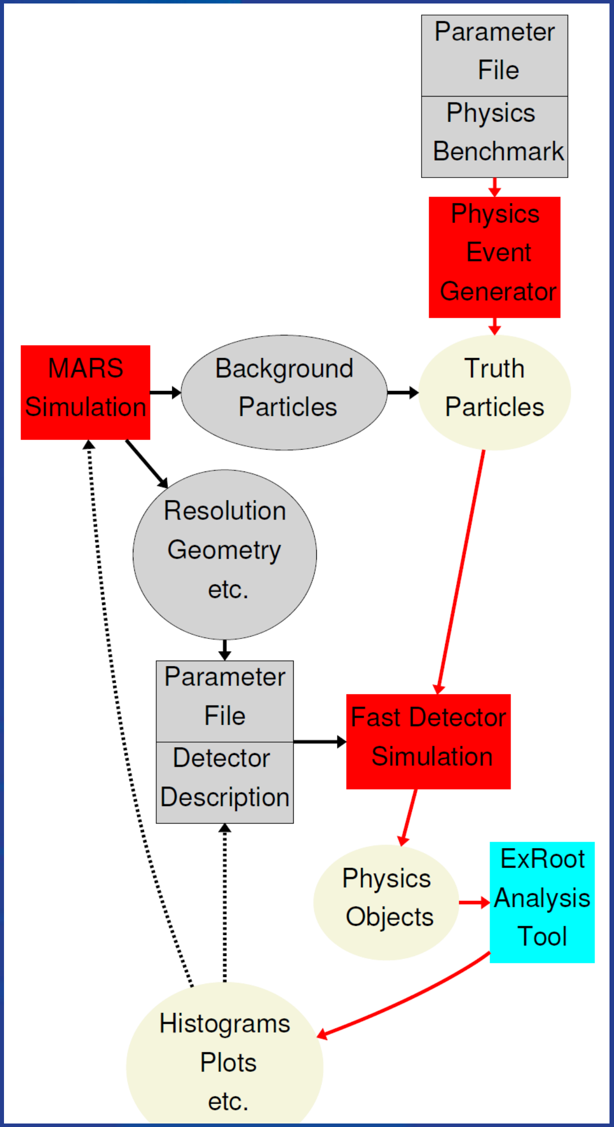
Peak: ~1 GeV / 2x2 cm^2 cell with σ_E ~ 30 MeV

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

Detector Fast Simulation

- MARS generated MDI files will be used to drive a fast simulation tool to demonstrate that physics can be extracted from the challenging background environment. This tool must have an accessible and straightforward user interface in order to engage the theoretical community.
  - Calorimetry: use MARS energy flow, straightforward.
  - Tracker & vertex: occupancy & hit density, more challenging (statistical weight spread).
- 2-3 FTE of computing and scientific effort over the next year will be necessary to incorporate event generators and detector parameterization into a fast simulation tool that will guide MDI optimization in a timely way.
- Detector parameterization and MDI optimization studies will also serve to guide and focus detector technology R&D.
- Associated physics benchmarking at 0.5 FTE level.

Detector MC: Flow Chart & Plans



- Develop an initial physics and detector report by the end of 2011. Allows input to the design parameters of the MAP study:
  - Set requirements on luminosity, energy, acceptable background rates and suggest feasible methods of attaining these levels.
  - Evaluate the impact of 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, lcsim) do detailed simulations to identify further needs for detector development.

Related MDI Critical R&D Directions

(in framework of the Muon Accelerator Program)

1. Thorough optimization of the nozzle & shielding at the machine-detector interface, for 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 3.5T field – interlaced with Detector & Physics R&D (KA12).

2. Design and optimization of masks in 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).

3. Radiation and heat loads to IR components.

4. Iterate with lattice and magnet designers.

5. Conceptual design of beam collimation system.