Status of ILCroot framework for Muon Collider studies

Corrado Gatto

Outline

- Review of previous results (Nov. 2009 workshop)
- Present status of the framework and newer results
- Proposal for upcoming studies

ILCroot: root Infrastructure for Large Colliders

- **C++ Software architecture based on root, VMC & Aliroot**
  - G3, G4, Fluka + all ROOT tools (I/O, graphics, PROOF, data structure, etc)
  - **Single framework, from generation to reconstruction through simulation and analysis**

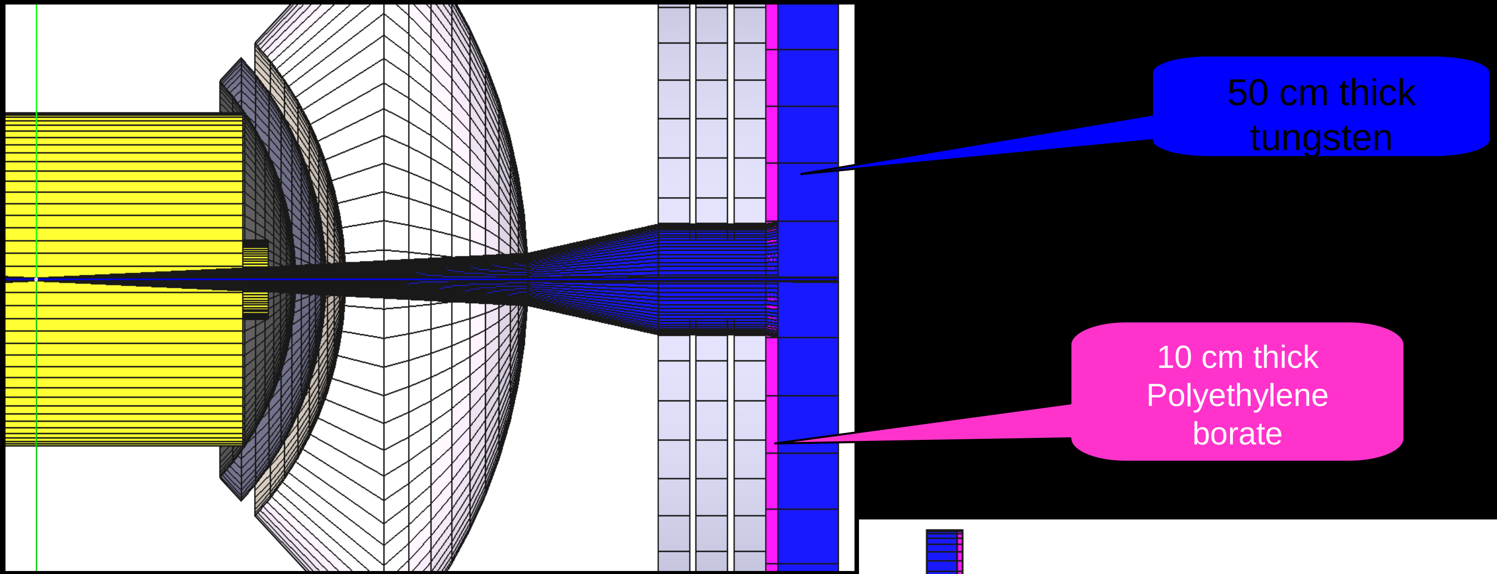
- **Main add-ons Aliroot:**
  1. Interface to external generator files in various format (MARS, STDHEP, txt, etc.)
  2. Standalone VTX track fitter
  3. Pattern recognition from VTX (for silicon central trackers)
  4. Parametric beam background (# integrated bunch crossing chosen at run time)

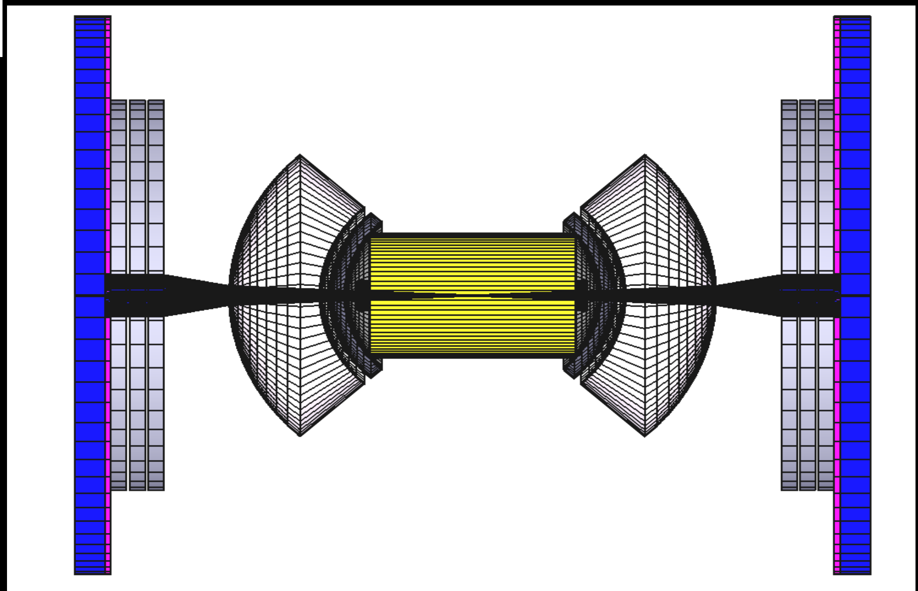
- Growing number of experiments have adopted it: Alice (LHC), Opera (LNGS), (Meg), CMB (GSI), Panda(GSI), 4th Concept, (SiLC ?) and **LHeC**
- ***It is Publicly available at FNAL on ILCSIM since 2006***

Summary of previous studies for a Muon Collider

(FNAL workshop - Nov. 2009)

Detector layout & shielding





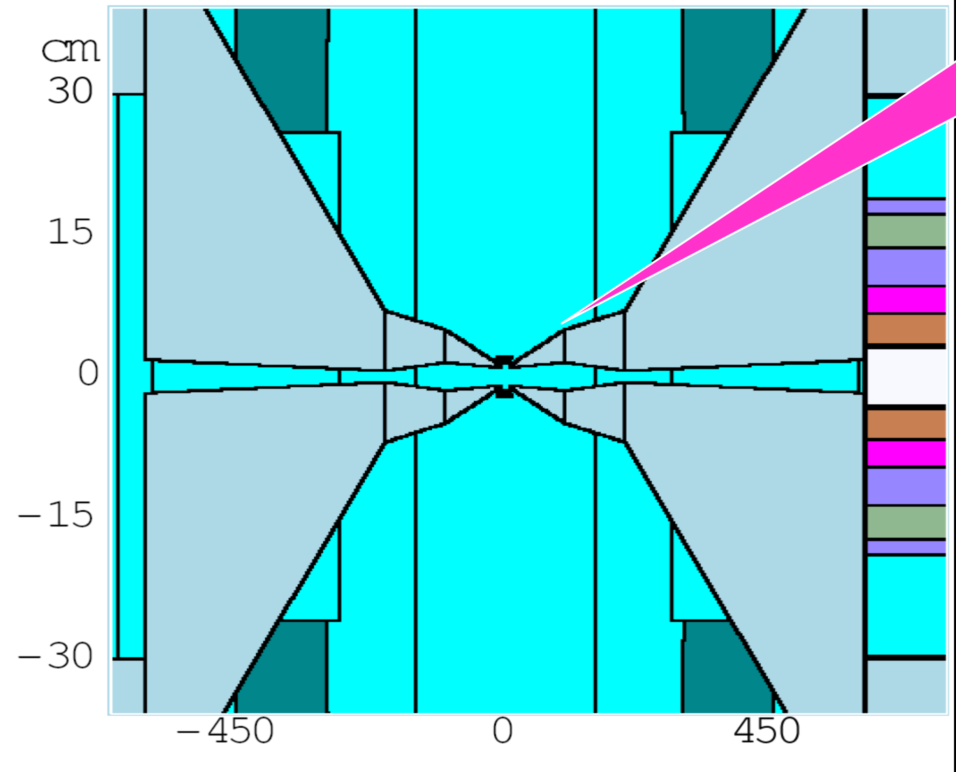
Modification of 4th Concept Detector for 3 TeV Physics + shielding

1. Vertex Detector 20-micron pixels (modifed SiD layout)
2. Silicon Tracker (SiD layout with 50umx50mm pixels)
3. Forward Tracker Disks (SiLC layout)
4. Triple-readout calorimeter
5. Dual-solenoid with Muon Spectrometer
6. 3.5 T magnetic field

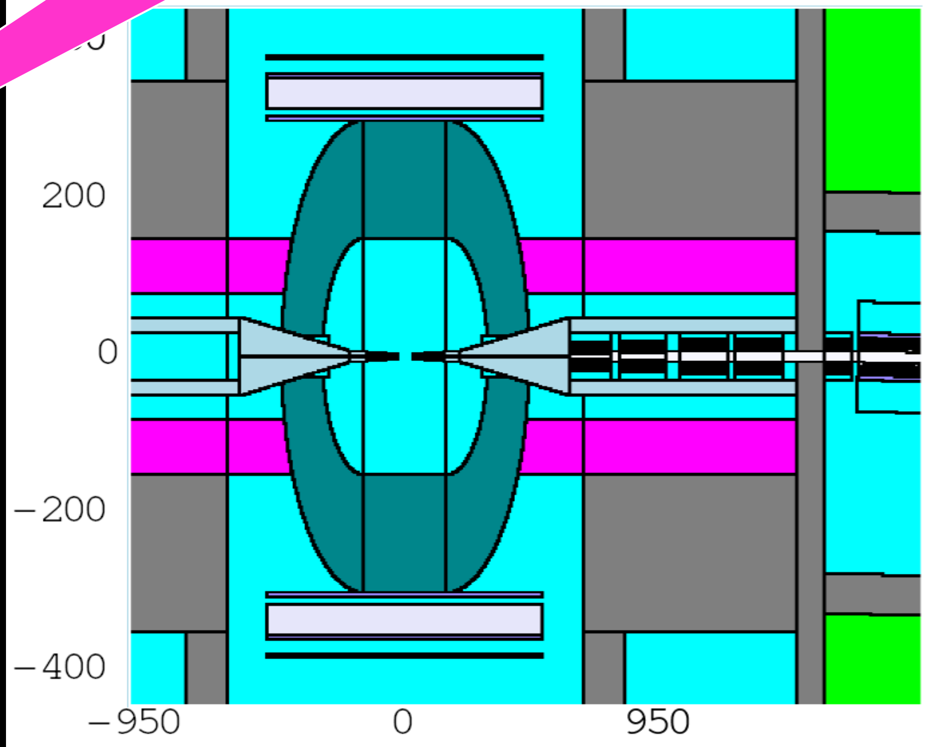
Inner Tungsten Nose

Wrong z position:
Responsible for 30° shading rather than 6°

Fixed in present version



Still useful infos



Detector Studies

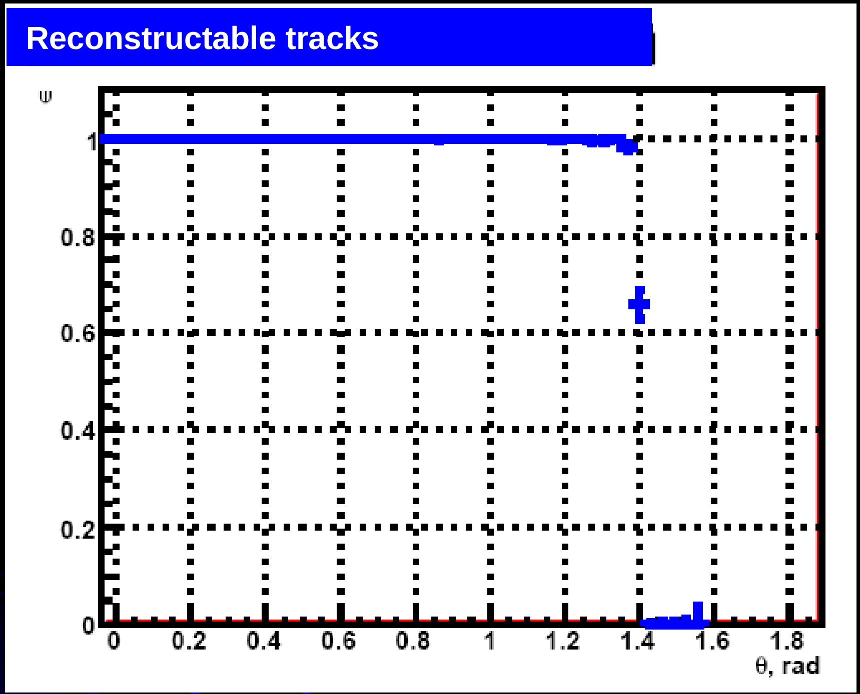
- Ingredients for this study:
  - 4th Concept detector modified for Muon Collider
  - Single muons
  - W,Z -> q$\bar{q}$
  - Geant4
  - Full simulation, patter recognition and reconstruction in ILCroot
- Goals:
  - Understanding effects of shielding on track reconstruction

single muons

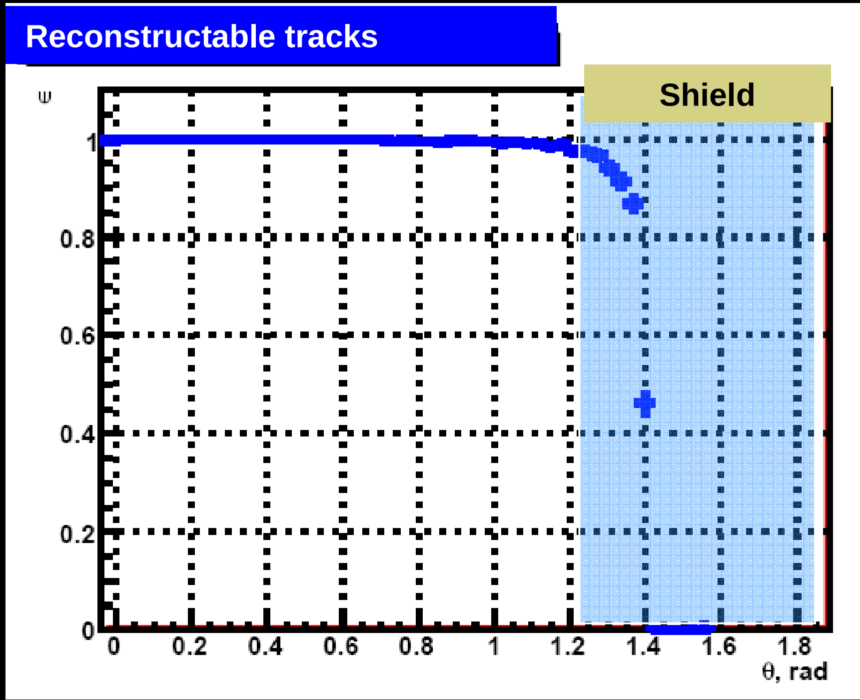
F. Ignatov
M. Peccarisi

Effect of 30° Shielding on Tracking Efficiency

Excluding Shielding



Including Shielding



Definition of a reconstructable track

I. DCA(true) < 3.5 cm

AND

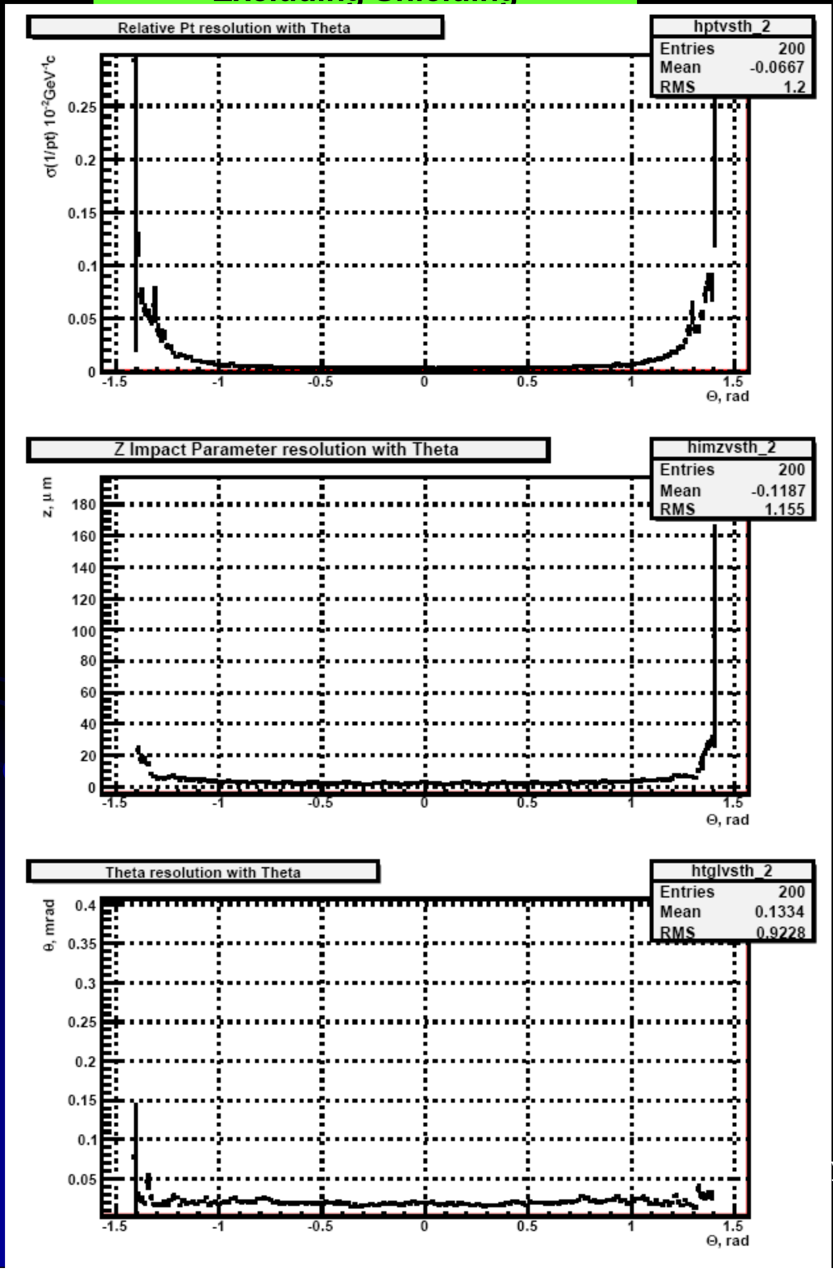
II. At least 4 hits in the detector

- Geometric efficiency is lower
- Kalman Fitting is mostly unaffected for reconstructable tracks

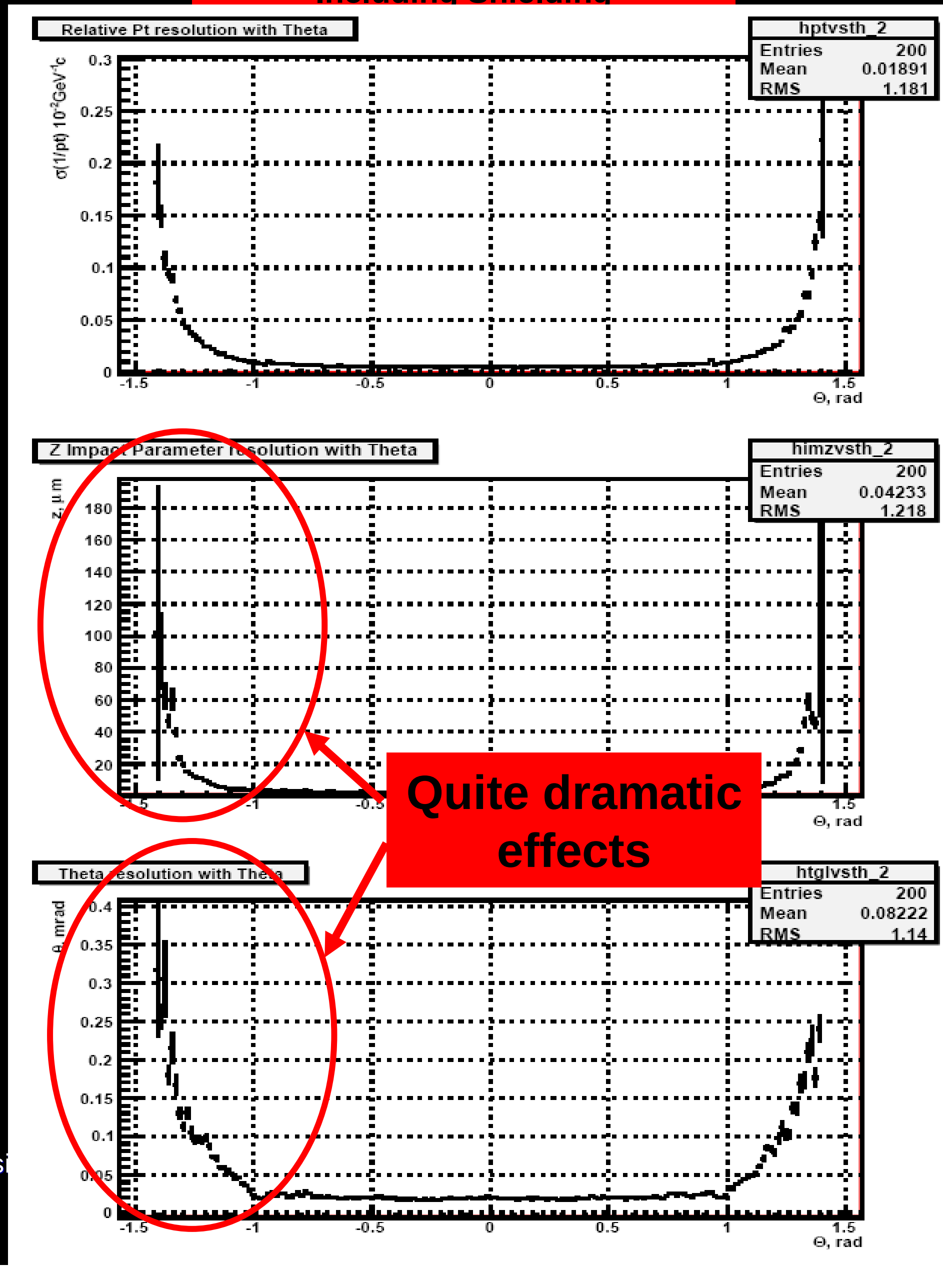
single muons

Effect of 30° Shielding on Track Reconstruction

Excluding Shielding



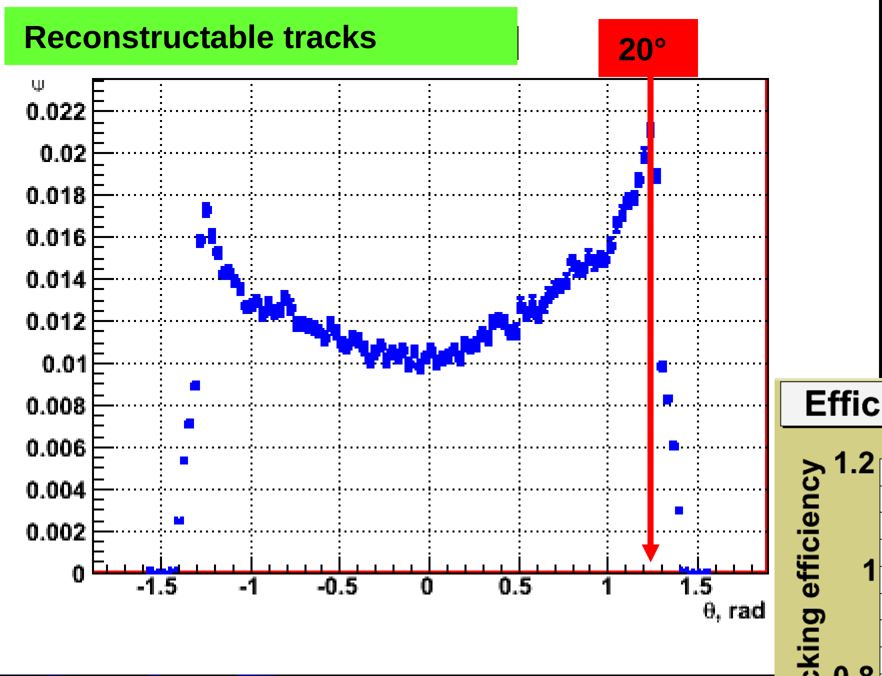
Including Shielding



Quite dramatic effects

F. Ignatov

Effect of 30° Shielding on Physics: WWνν



Definition of a reconstructable track

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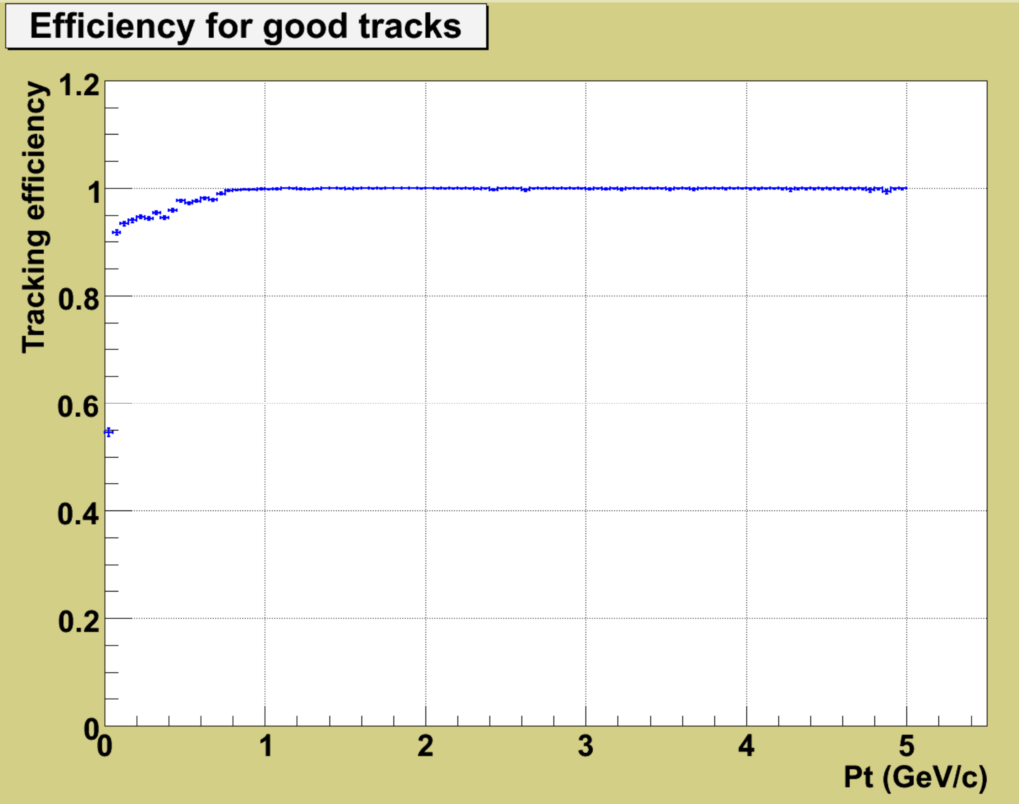
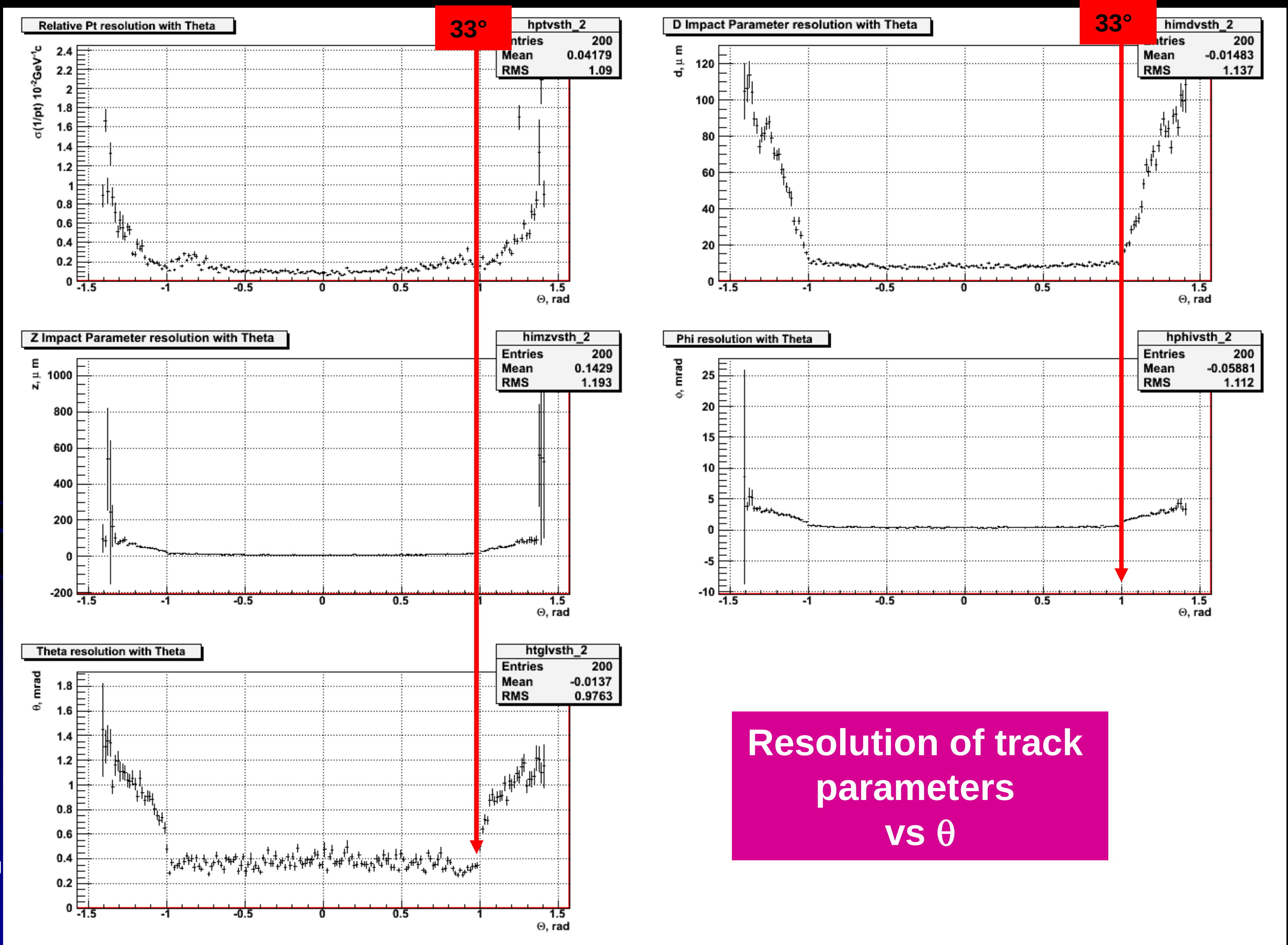


F. Ignatov

Effect of 30° Shielding on Physics: WWνν



Resolution of track parameters vs θ

Background Studies

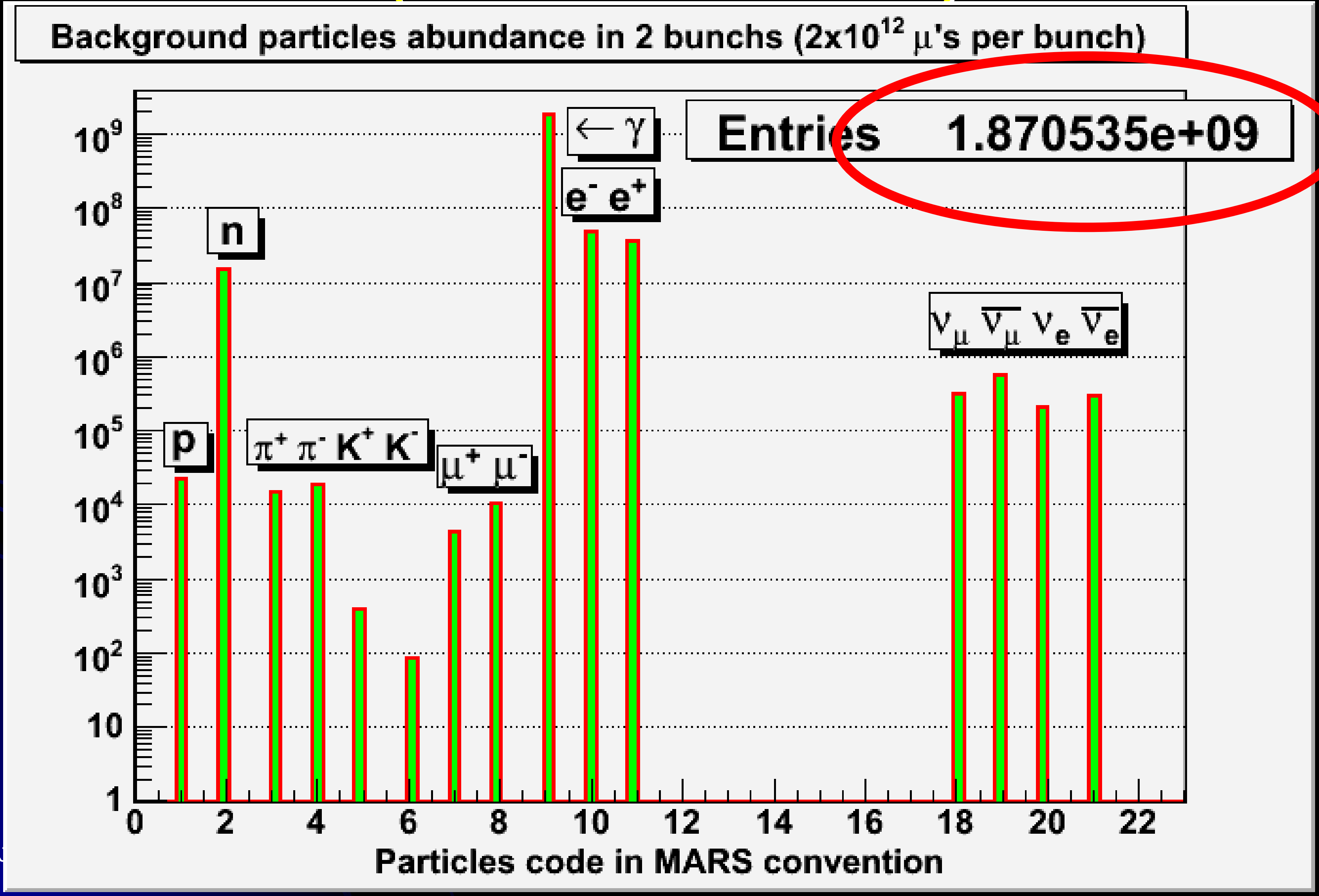
- Ingredients for this study:
  - Final Focus description as in MARS (Vadim Alexakhin)
  - Detector description in ILCroot
  - MARS-to-ILCroot interface (Vito Di Benedetto)

Description was not optimized for μCollider studies:

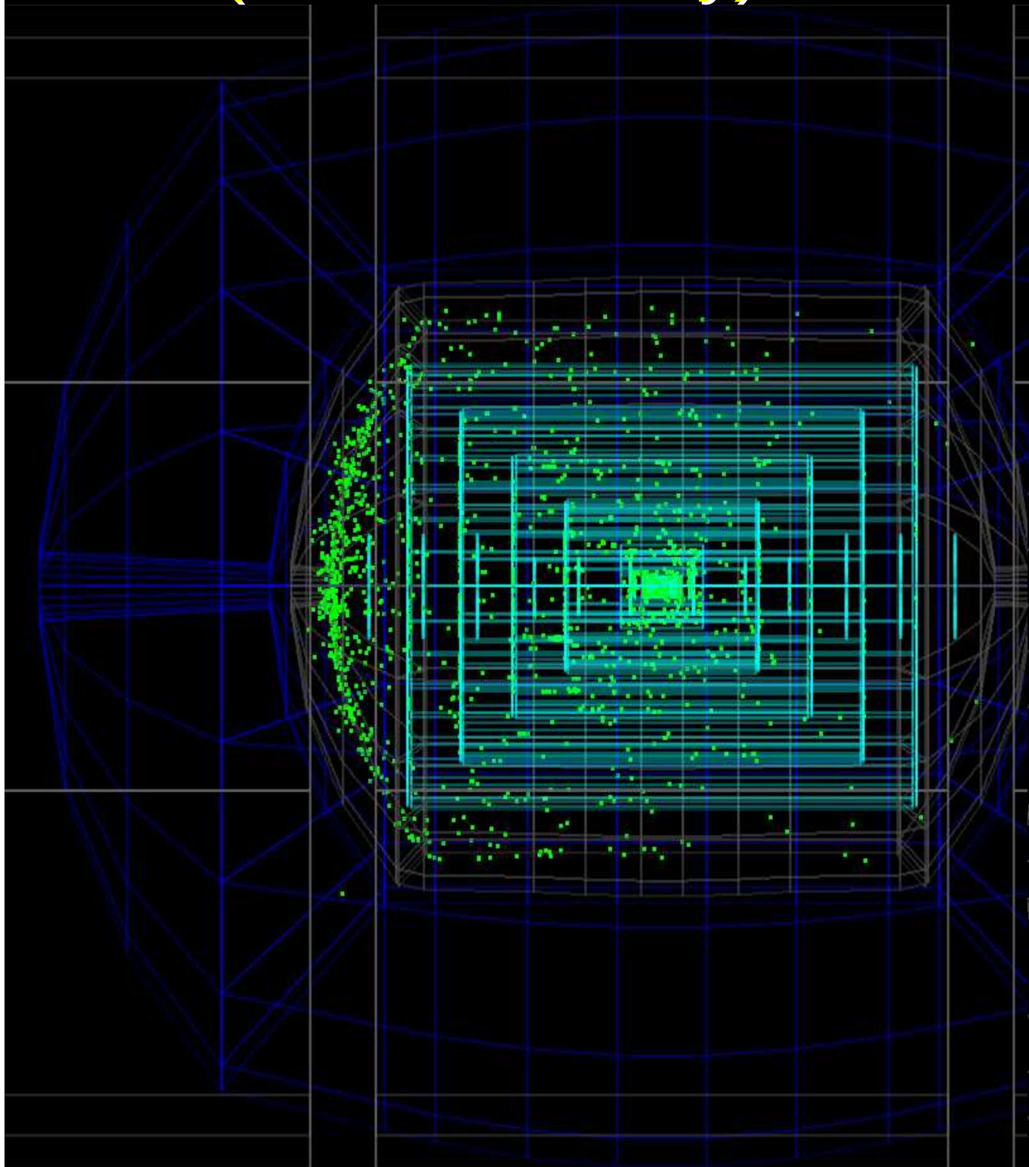
Extreme details -> very slow

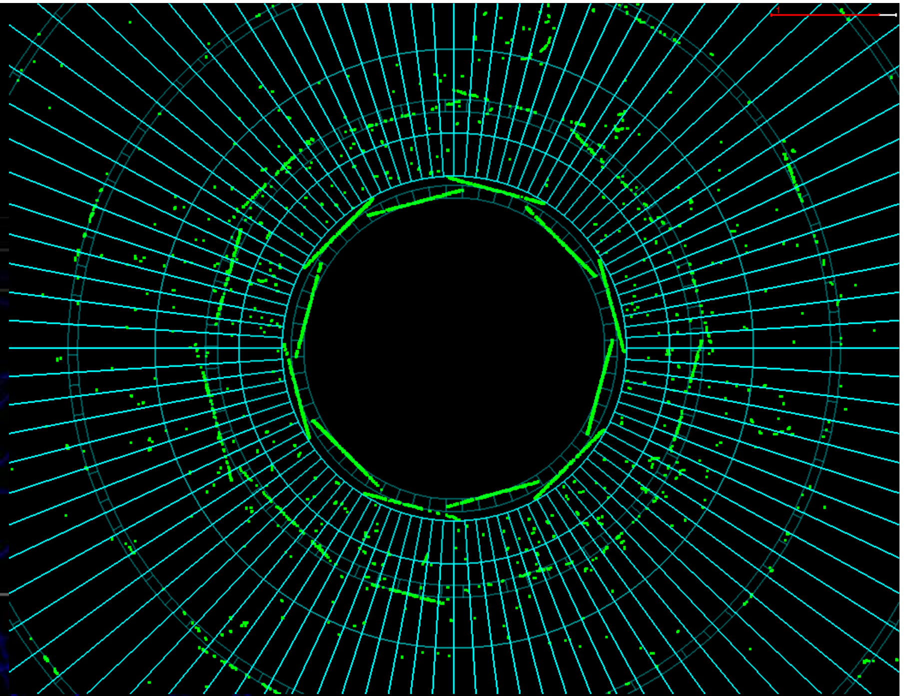
- How it works
  - The interface (ILCGenReaderMARS) is a ***TGenerator*** in ILCroot
  - MARS output is used as a config file
  - ILCGenReaderMARS create a STDHEP file with a list of particles entering the detector area at z = 6m
  - MARS weights are used to generate the particle multiplicity for G4
  - Threshold cuts are specified in Config.C to limit the particle list fed to G4
  - Geant4 takes over at 6m
  - Events are finally passed through the usual simulation (G4)-> digitization->reconstruction machinery

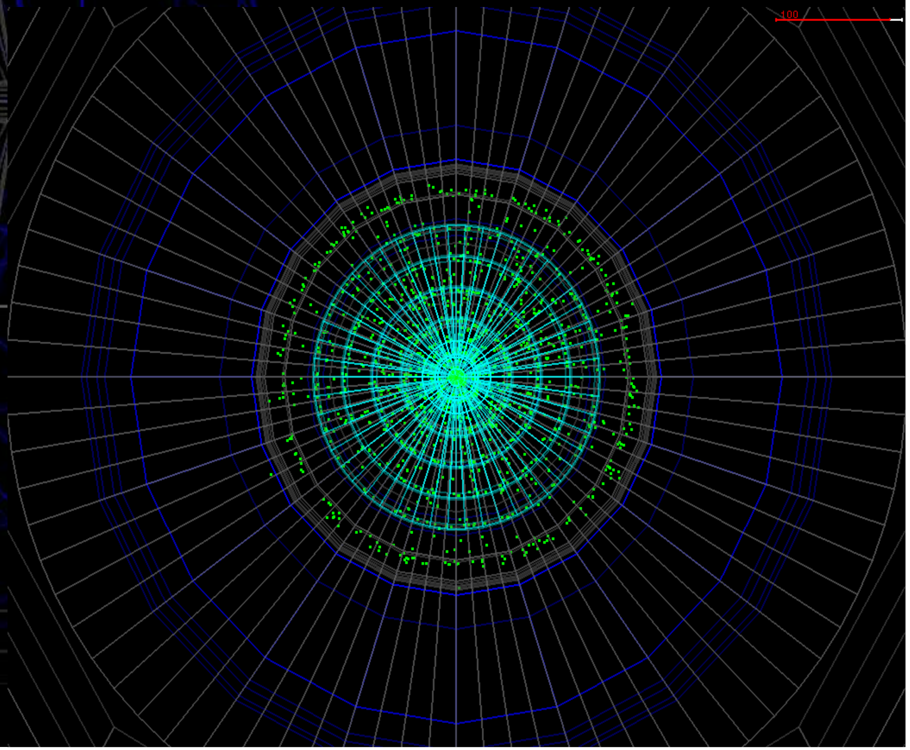
Expected Bkg in the Detector at MDI plane (no shield included)



e^- Induced Background (one beam only)

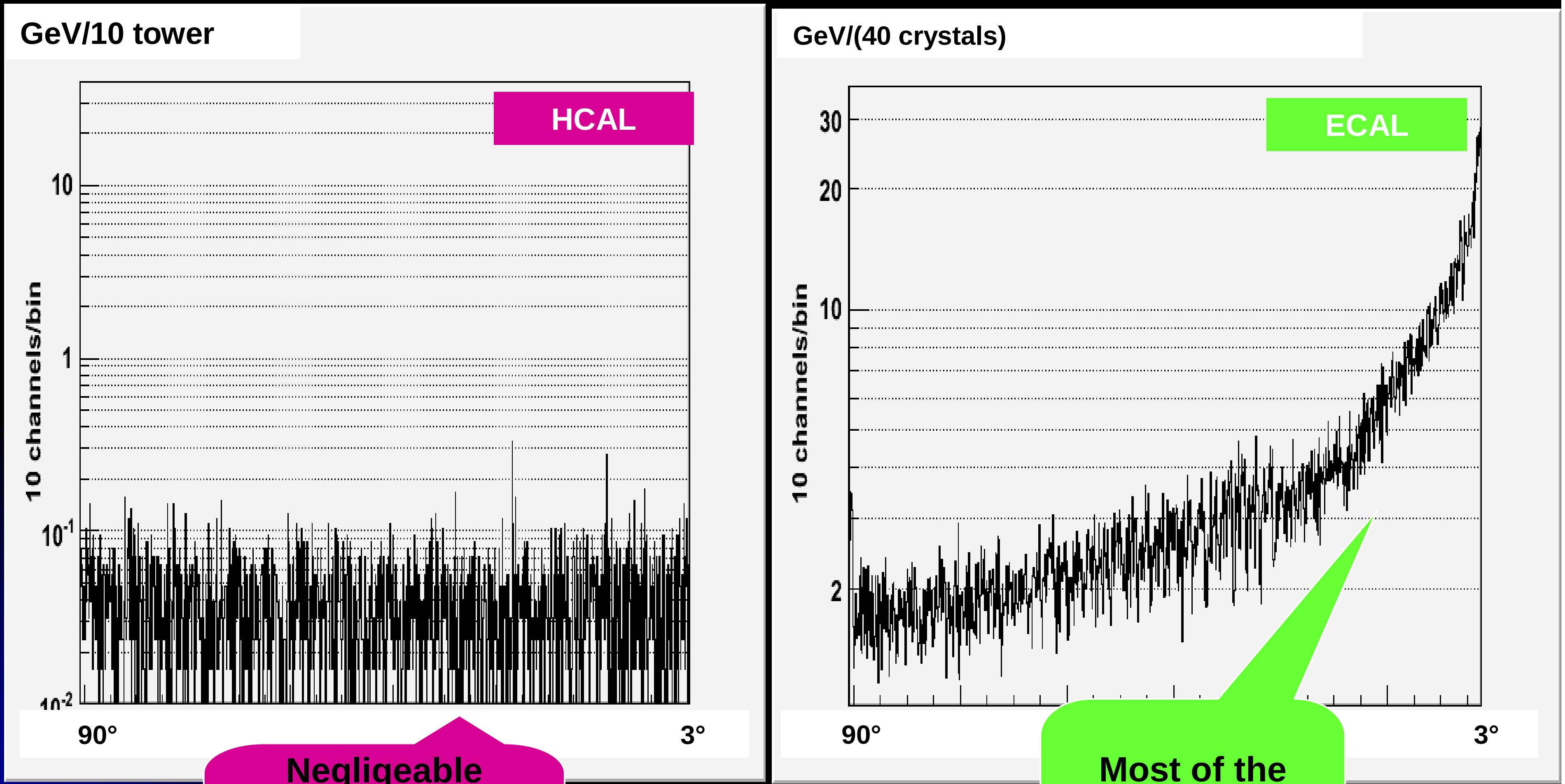






Beam Background in EM and HAD Calorimeter

Alexakhin
Di Benedetto



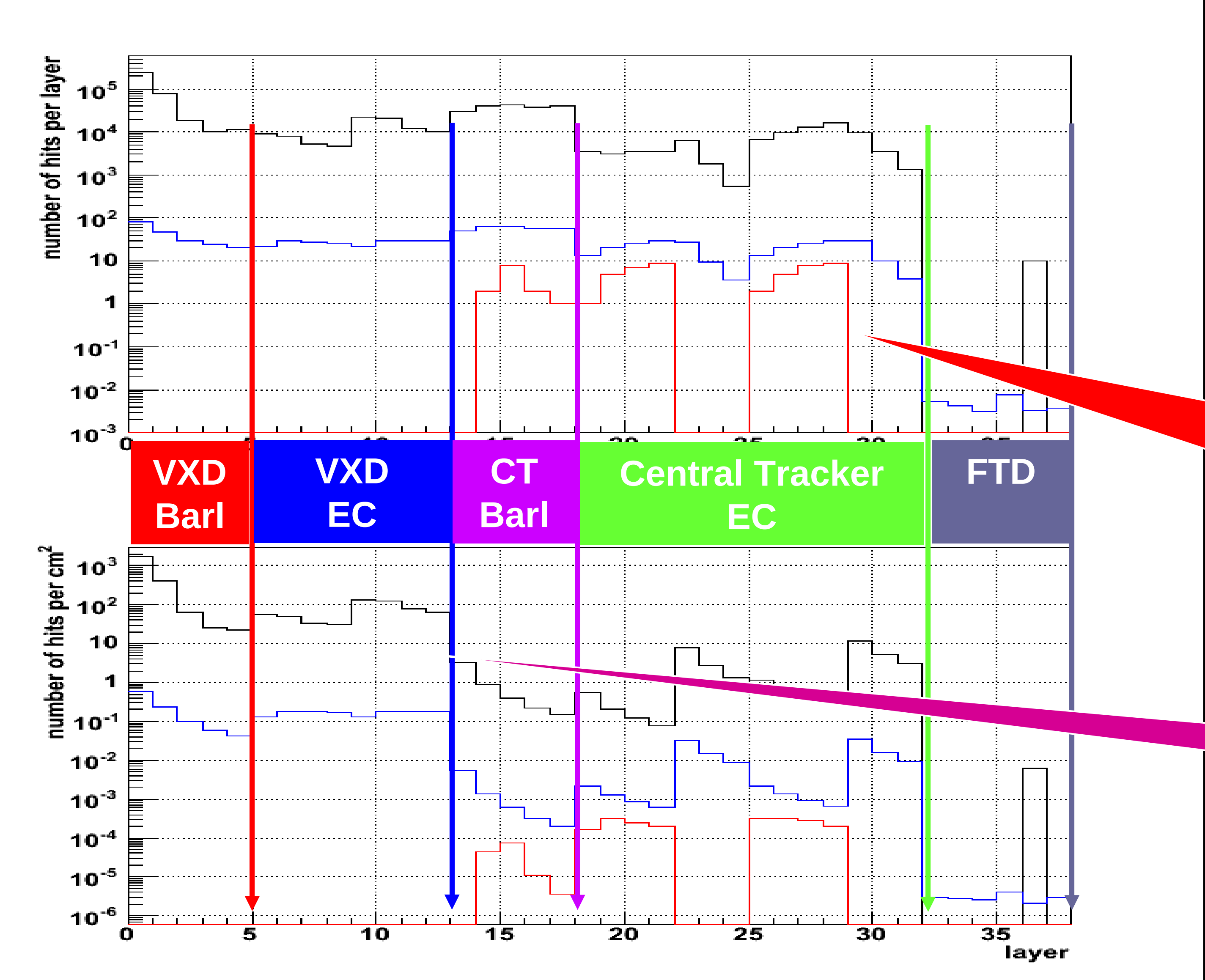
Negligeable hadronic background (mostly muons)

Most of the background is from e^-

F. Ignatov

Occupancy in the Tracking Systems

Preliminary



Legenda

- **-WWnunu**
- **-Beam bkg except muons**
- **-muons**

About 10 muons per BX (rejected easily by μ spectrometer)

5 hits/cm² at R=20 cm

Few considerations on Nov. 2009 framework and studies

- Pro
  - Machinery for background and Physics studies is in place
- Con
  - Nose design was wrong (impacting Physics more than necessary)
  - Still provides interesting informations
  - Detector description too detailed
  - Simulation too slow (10^6 particles passing pre-cuts need about 1 week to simulate/reconstruct)
  - **Harsh** pre-cuts to limit particles fed into Geant4
  - Weights in MARS not optimized for tracking studies

New framework for Physics and background studies (in collaboration with N. Mokhov group) released on Feb. 2010

- Addresses the following issues
  - "Nose" design
  - Detector Simulation speed
  - Weigth definition in MARS
  - We provided an easy detector configuration for initial Physics & Detector studies by non-experts

Still not the final version for detector studies
OK for Physics studies

Updated MARS & MARS interface

- New nose (minimal design, with correction of old mistakes)
- New definition of weights (N. Mokhov)
- Fine tuning of weight definition by separating muon decay from EM interactions (N. Mo
- ILCGenReaderMARS with double option:
  - List of individual particles with unitary weight
  - List of weighted particles
- New background events by Vadim

For tracking studies

For calorimetric studies

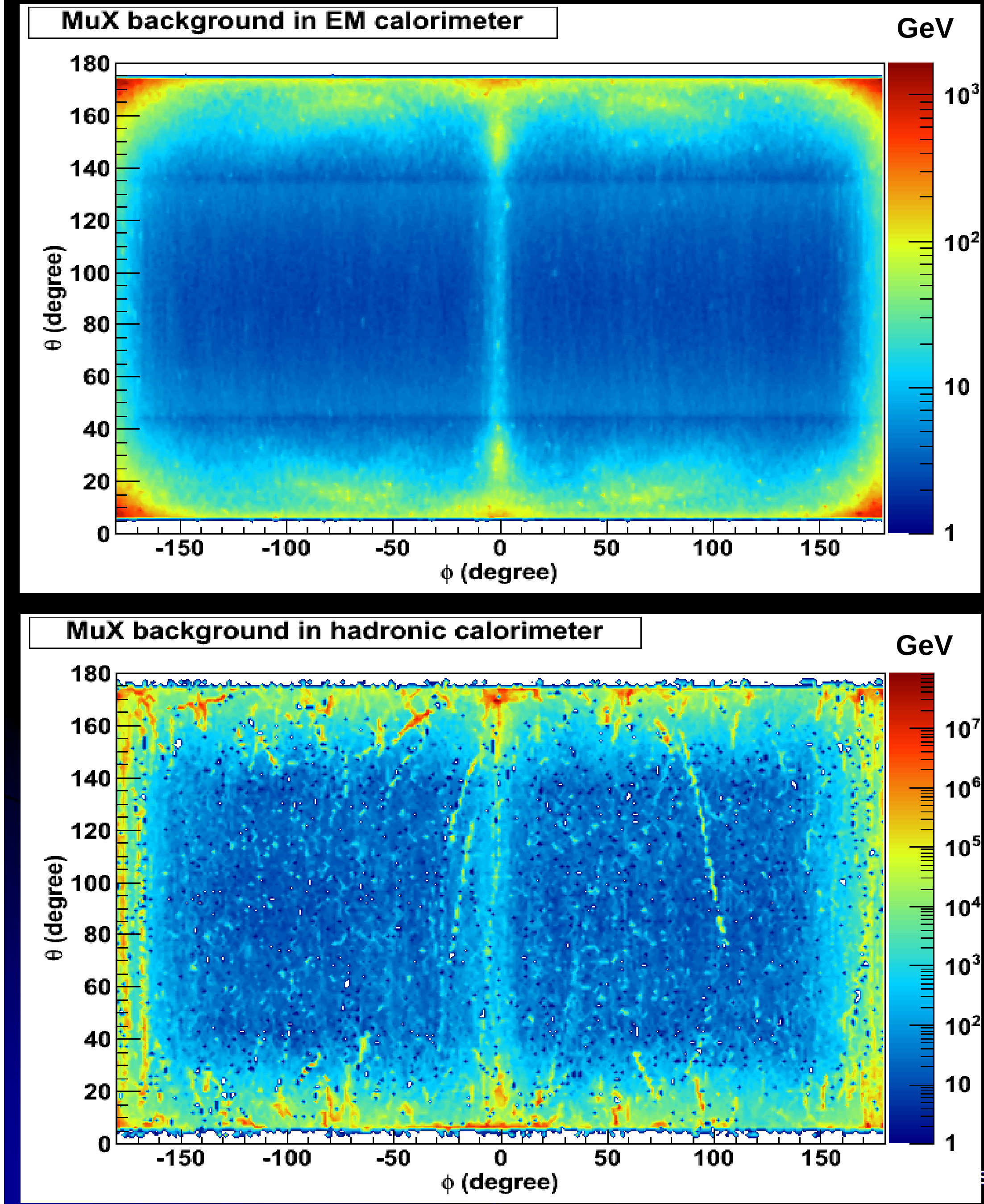
Updated ILCroot

- Replaced EM and HAD calorimeters with homogeneous lauout mimicing dual-readout calorimeters

$$\sigma_{EM}/E = 2.8\%/\sqrt{E} \oplus 0.2\%/ \quad \sigma_{HAD}/E = 30\%/\sqrt{E} \oplus 1.7\%/$$

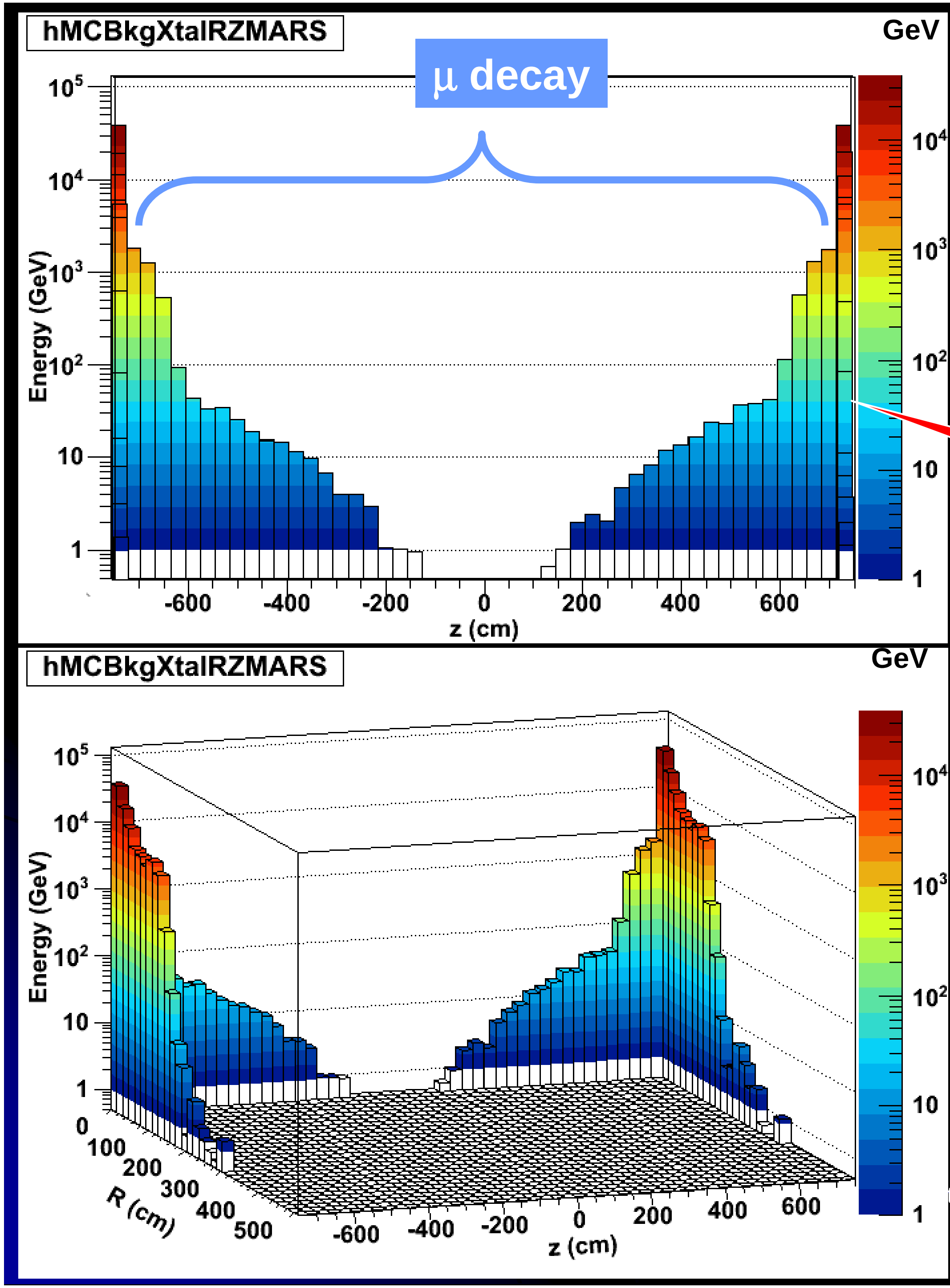
- Parametrized VXD description for tracking studies (unfinished)
- Insert quadrupoles for final focus (as MDI plane =7.5m)
- B-field = solenoid + quadrupole
- Faster simulation/reconstruction
- Tutorials for installation/running

New results



Integrated background in EM and Hadron calorimeters:

- Backround source from 1 collision (MARS - Dec. 2009)
- E_{CM} = 1.5 TeV
- Calorimeter coverage 6°<θ<174°
- Weighted particles method
- MDI separation plane: 7.5 m from I.P.
- No pre-cuts
- Full G4 simulation
- 1 bin = 4x4 cm² cell



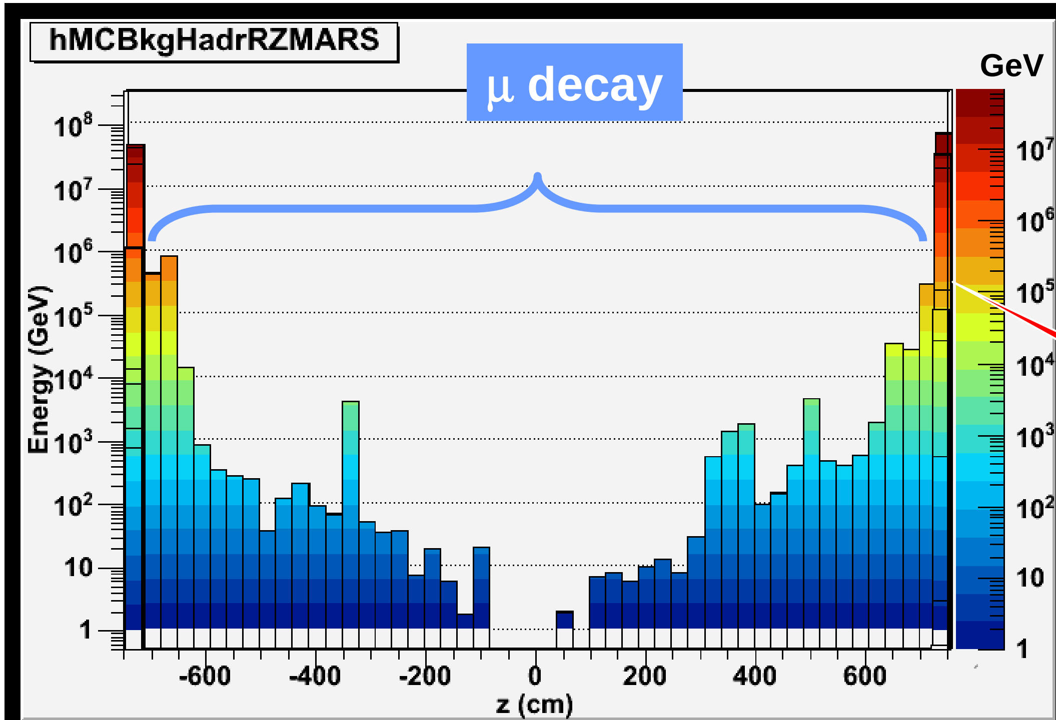
Integrated background from MARS in EM calorimeter vs origin of particle

Entering detector area at 7.5 m

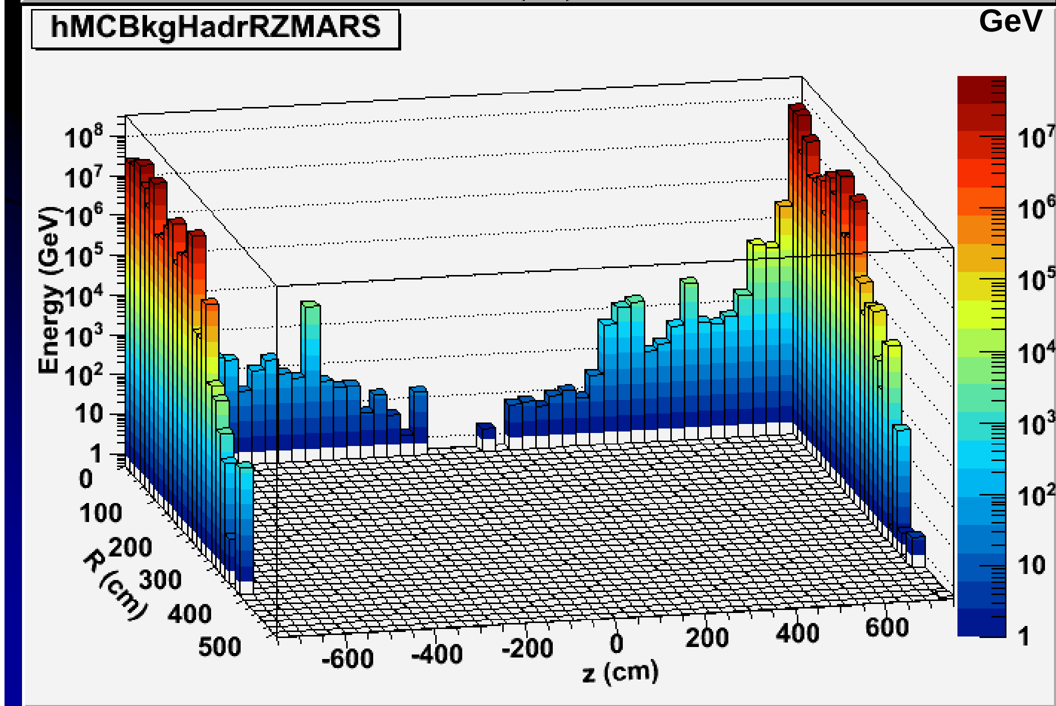
R = r_{xy} of particle origin (1bin= 30cm)

Z=7.5 means that the particle originated outside the MDI separation plane (1bin=16cm)

Integrated background from MARS in HAD calorimeter vs origin of particle



Entering detector area at 7.5 m



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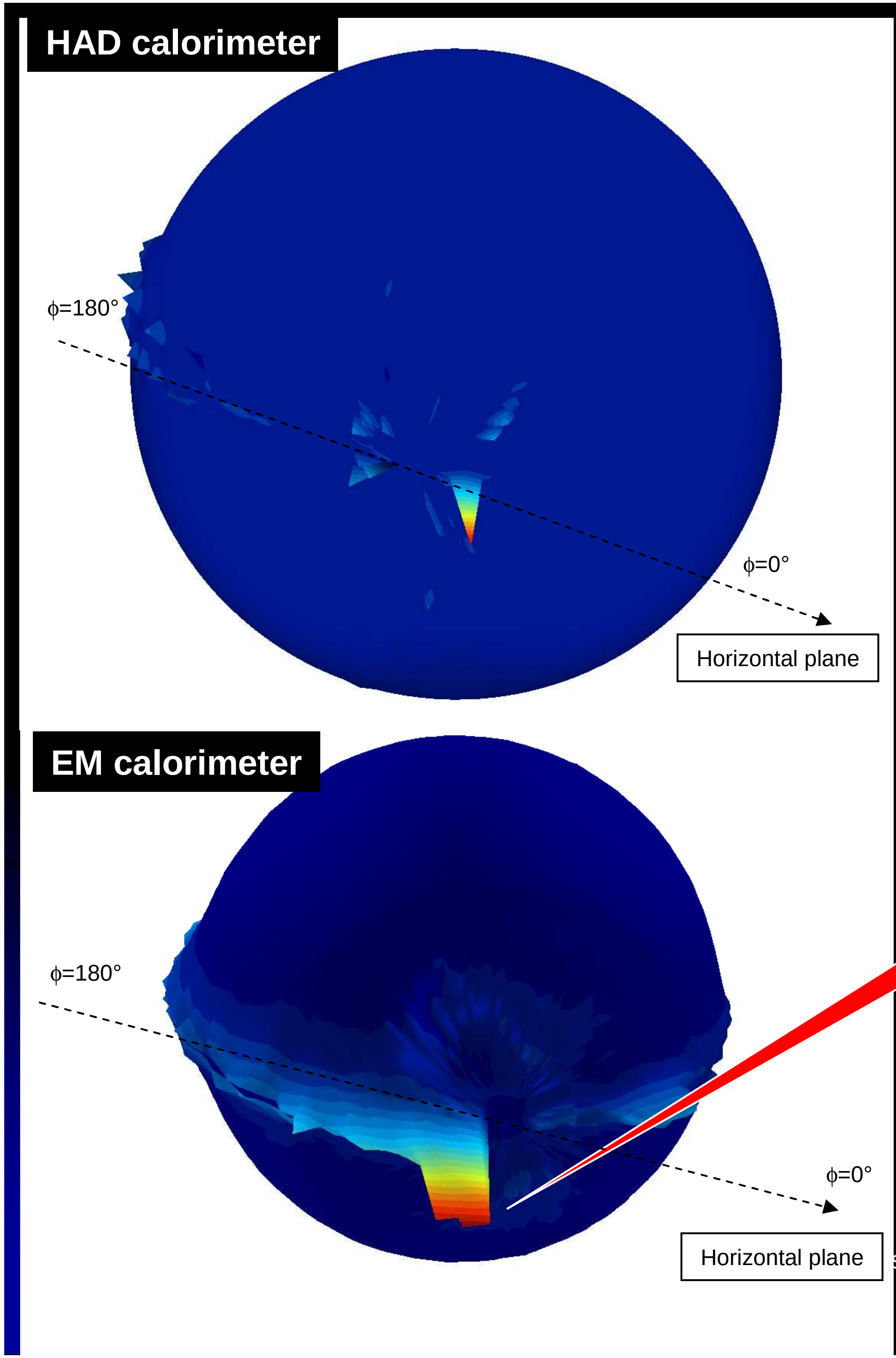
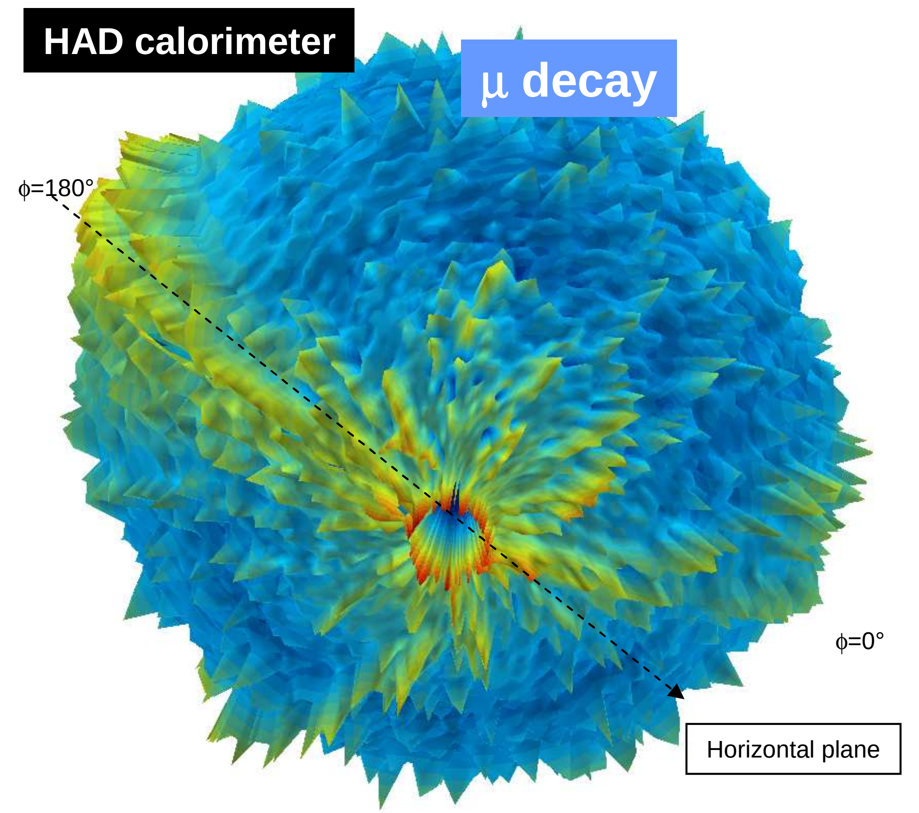


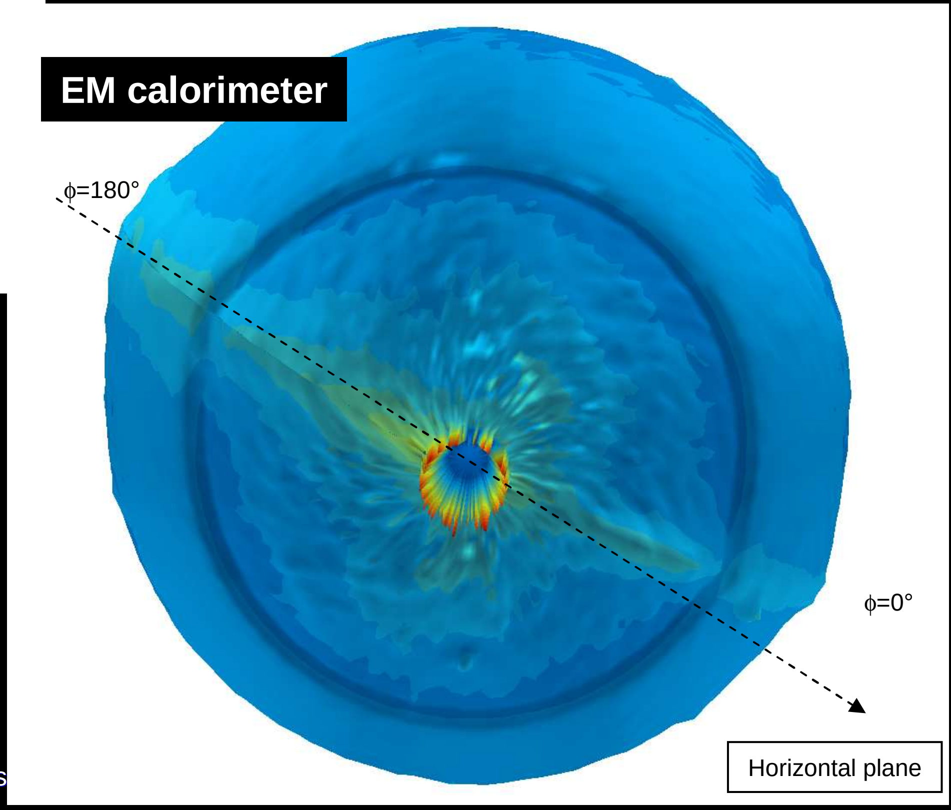
Integrated background from in EM & HAD calorimeters in spherical coordinates

8 orders of magnitued between blue and red area)

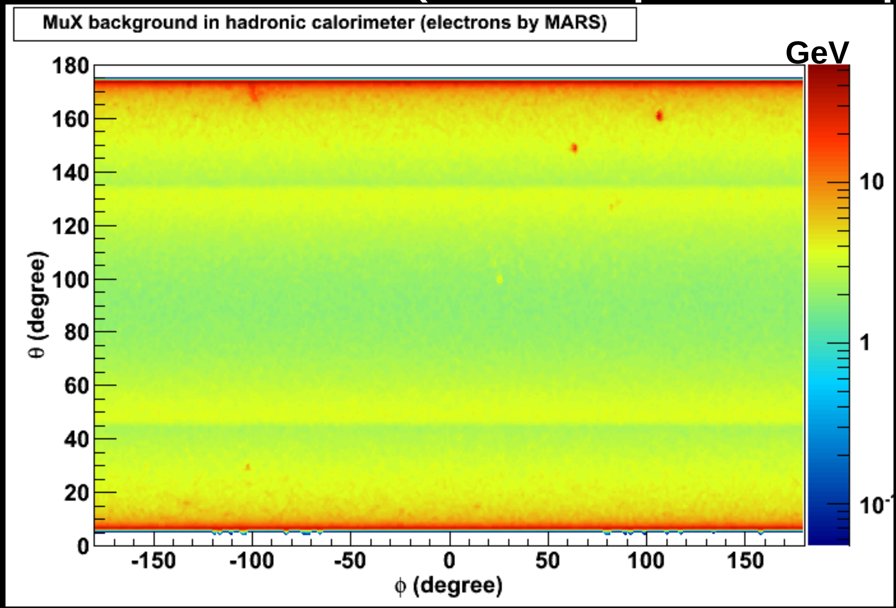
Most of background source is located in well delimited regions

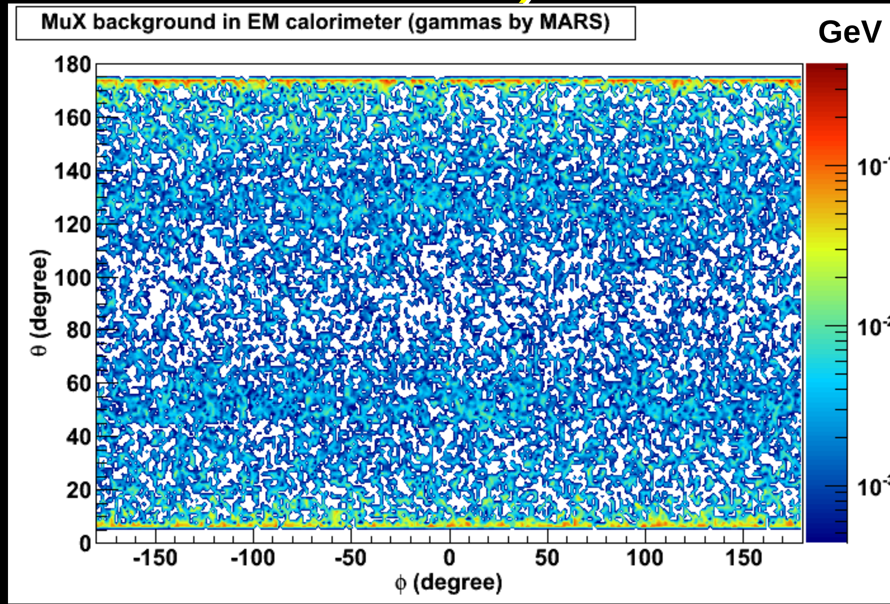


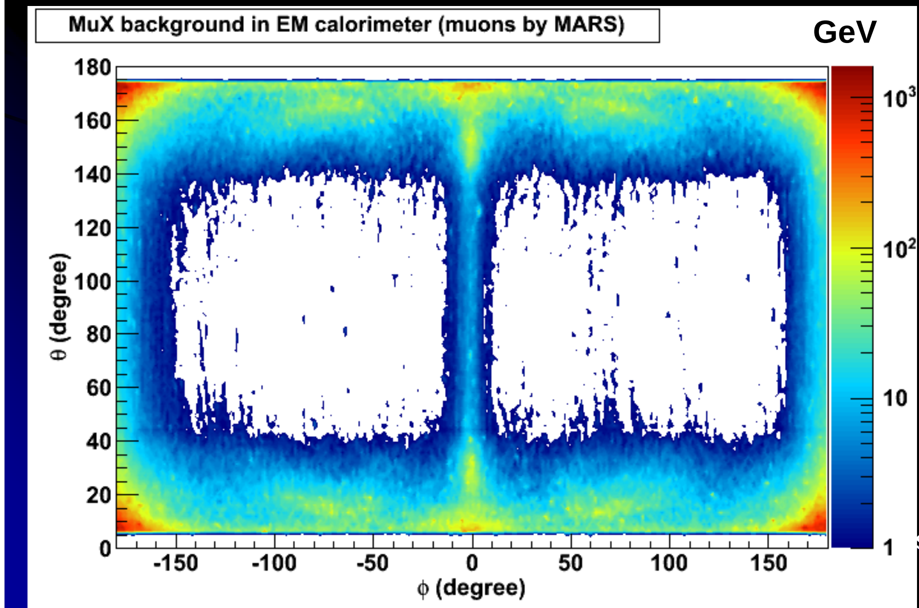
Same plots, in log scale

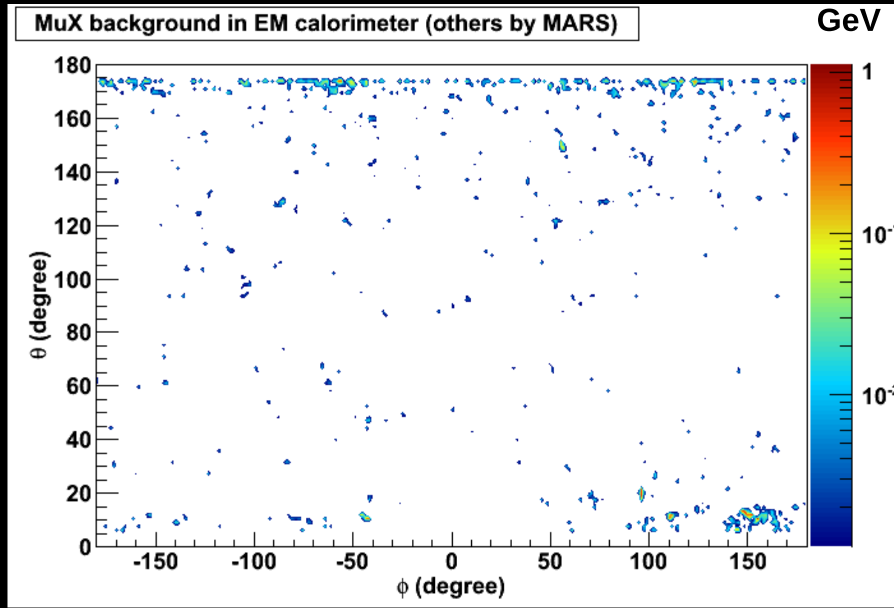


EM Energy/4x4cm^2 vs MARS particle species
(MDI separation plane=7.5 m from IP)



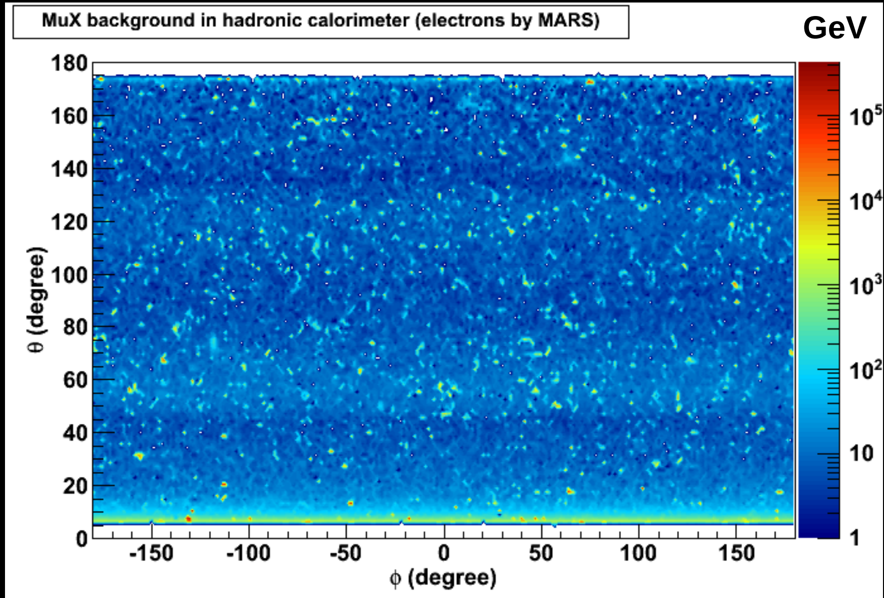


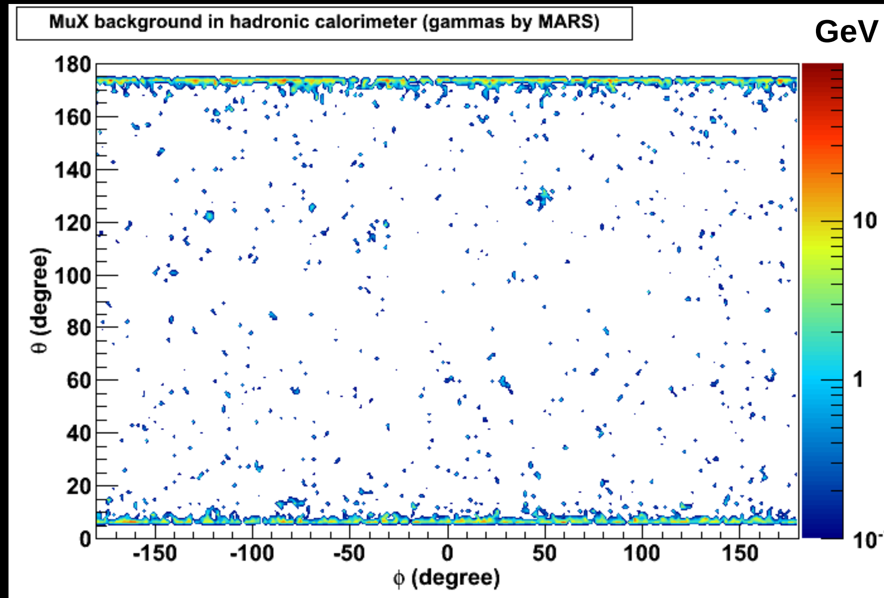


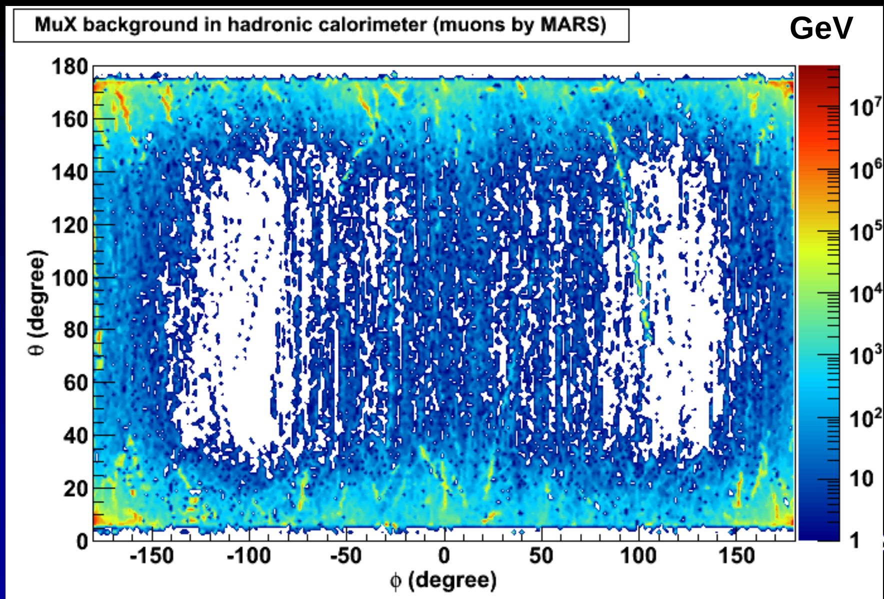


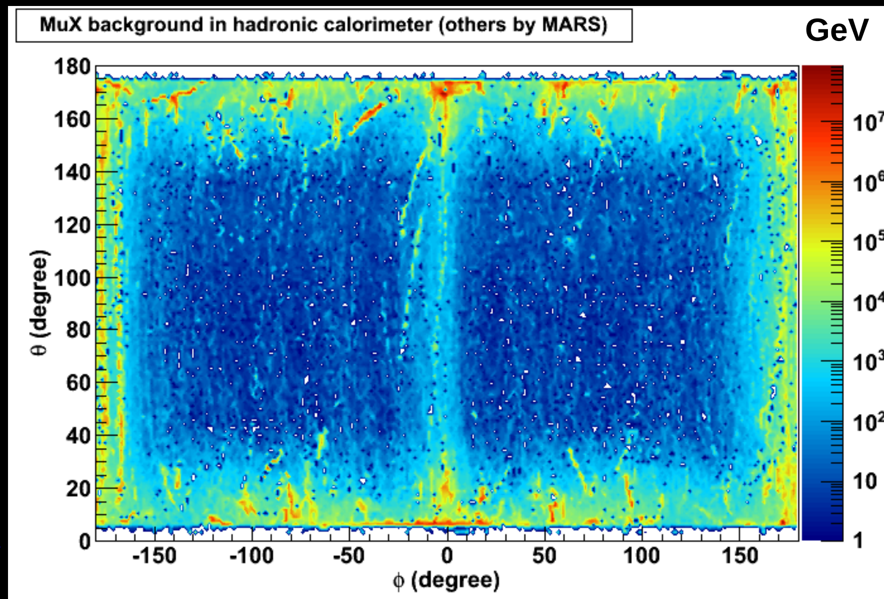
sics

HAD Energy/4x4cm^2 vs MARS particle species (MDI separation plane=7.5 m from IP)

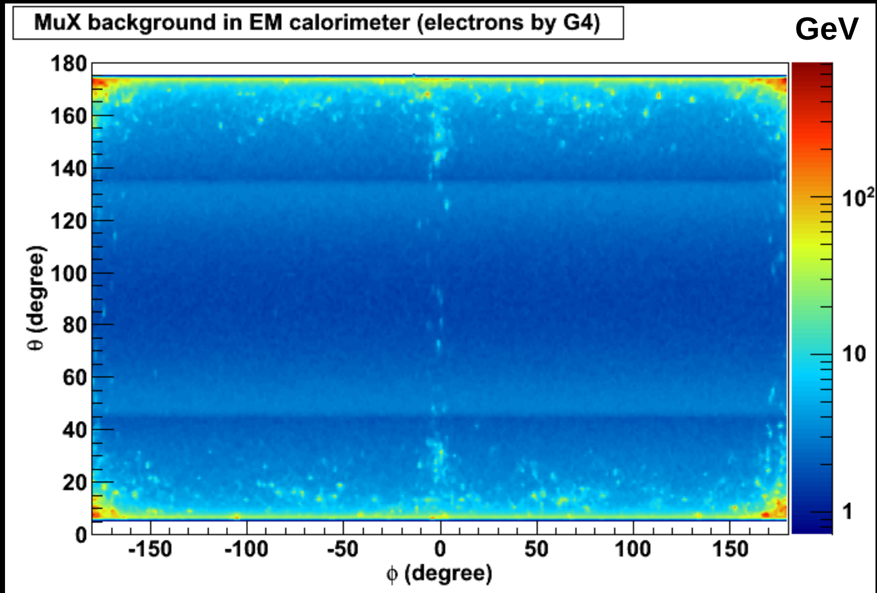


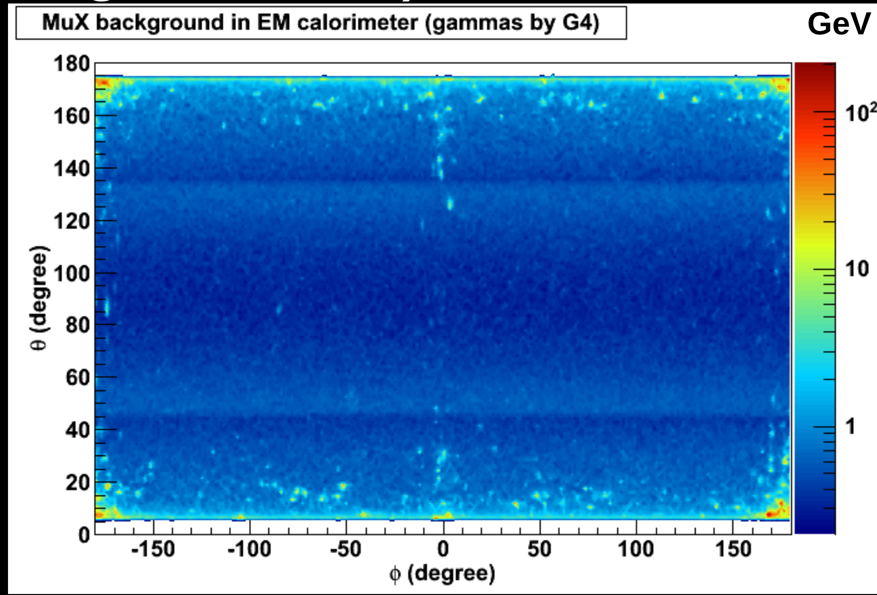


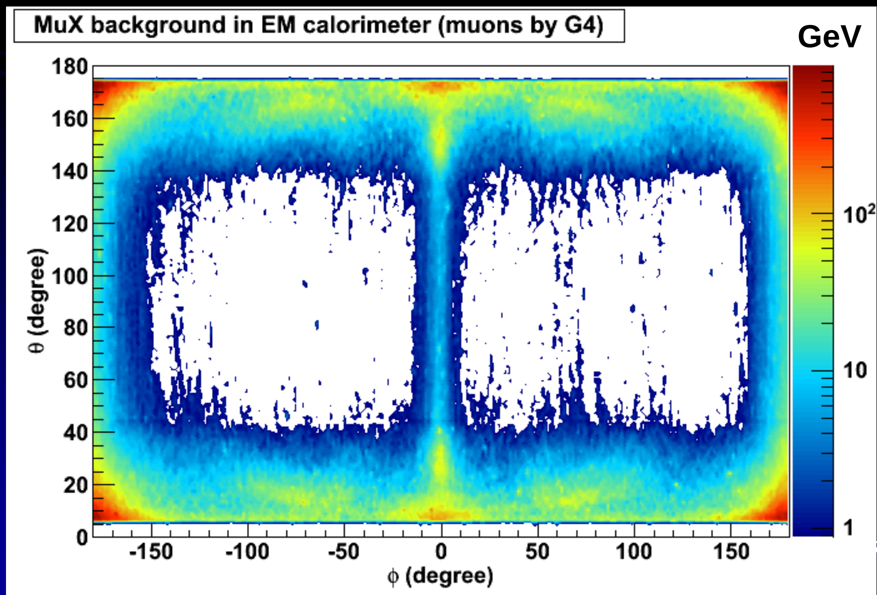


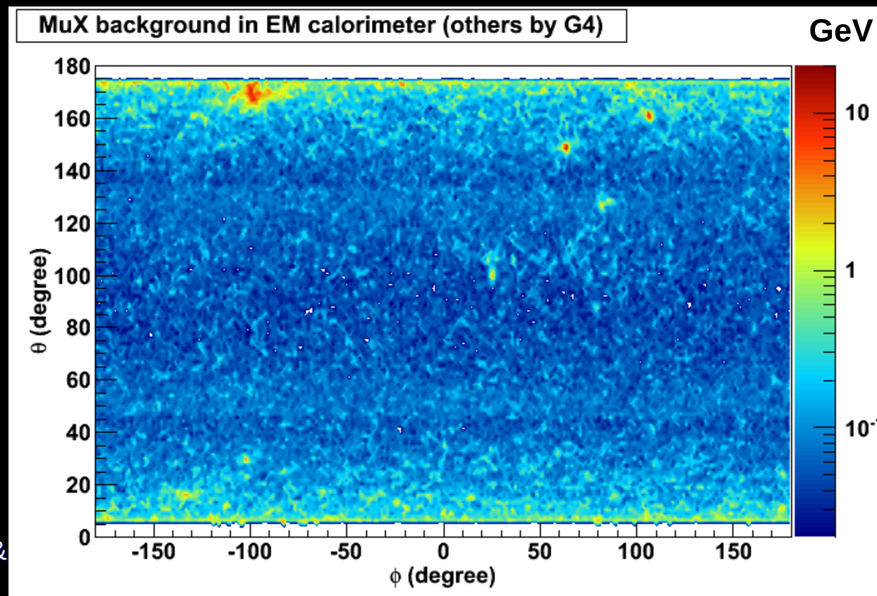


Energy/4x4cm^2 vs particles entering the EM calorimeter (G4 generator)

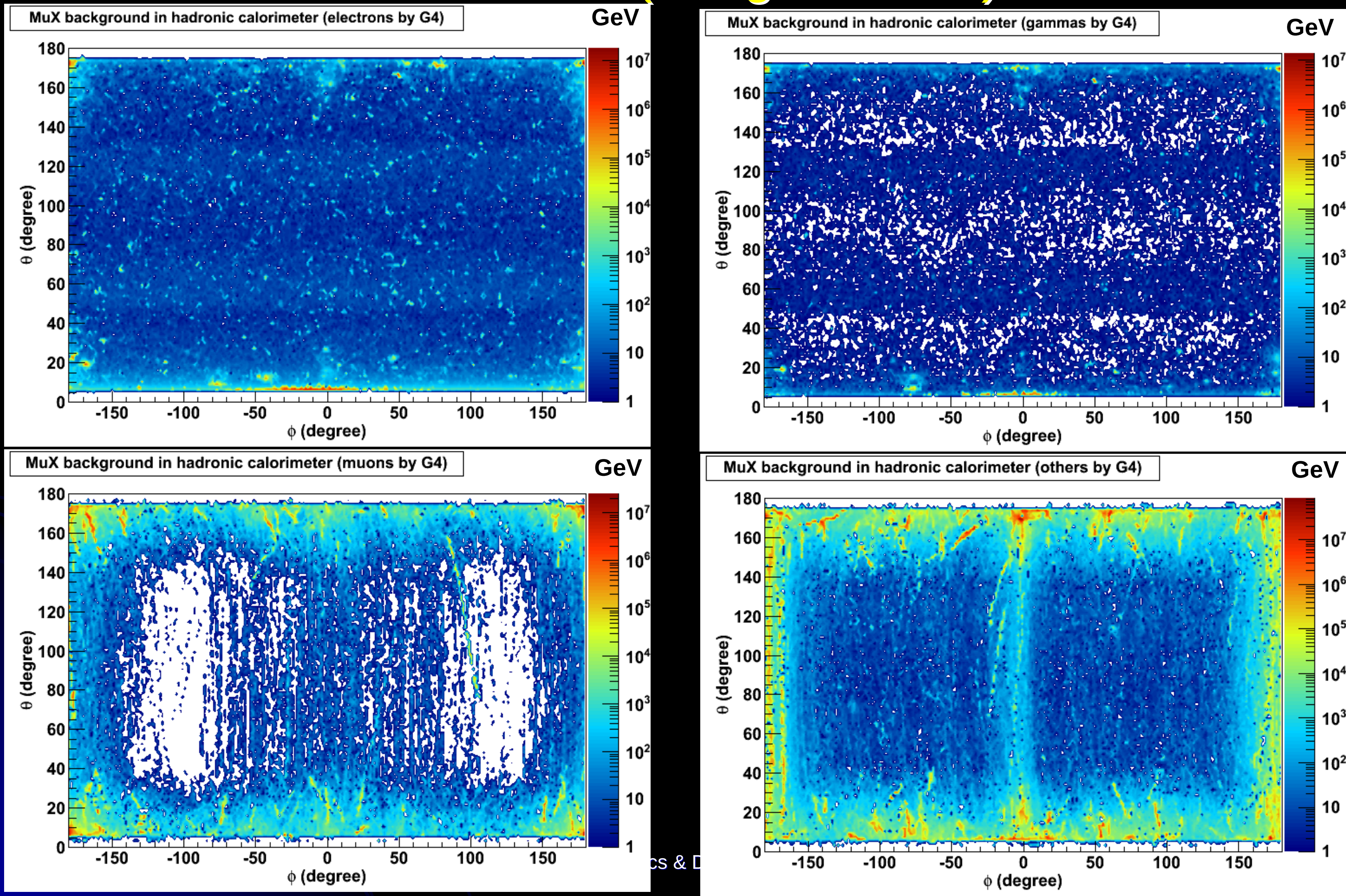




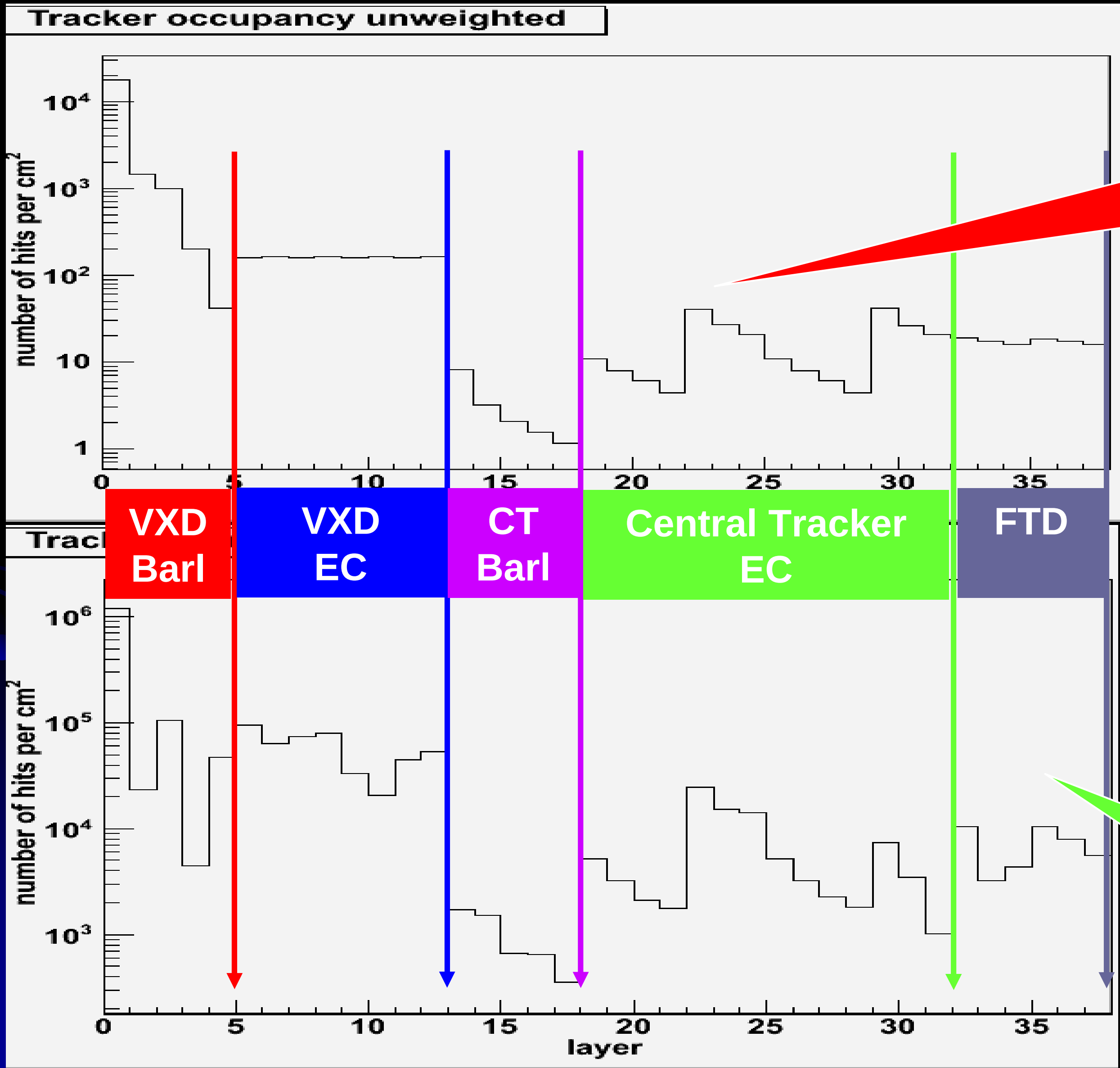




Energy/4x4cm^2 vs particles entering the HAD calorimeter (G4 generator)



Occupancy in the Tracking Systems (from MARS+G4)



Unweighted:
MARS output sent to G4 disregarding the weights

None of the two plots is fully correct

Dedicated approach is required (see later)

Correct occupancy is in the middle

Weighted:
MARS output sent to G4 multiplying by its weight

Performance of new framework

- Consider: μColl background at E_{CM}=1.5 TeV and $2x10^{12}$ μ/bunch (no cut-offs)

- $4.5x10^9$ background particles/event (unweighted)
- $4.6x10^6$ background particles/event with <weight> ≈ $9.8x10^2$
- Processing time with 200 CPU on fermiGrid: 22 hrs/ evt with $4.6x10^6$ weighted or unweighted particles (no pre-cuts)

Few considerations on the updated framework

- Speed improvement is *O(10)* vs Nov. 2009
- Allows for 10^6-10^7/day background particles fully simulated and reconstructed with G4 in a real detector with 200 CPU
- Sufficient for calorimetric studies (which can digest weighted particles), but not for tracking studies
- At least *O(10)* too many particles

Next step:

PROPOSAL
FOR A TASK FORCE WORKING GROUP
ON SIMULATION STUDIES
FOR THE FEASIBILITY OF A
HIGH ENERGY PHYSICS EXPERIMENT
AT A MUON COLLIDER

Contributions by

Y. Alexahin
Y.C. Chen
M. Demarteau
E. Eichten
C. Gatto
S. Geer
E. Gianfelice
J. Yoh
R. Lipton
N. Mokhov
S. Mrenna

- Based on:
  - Tools already existing
  - A time frame of 1.5-2 years
  - The time necessary for the accelerator group and the detector group to implement new configurations in the simulation (about 1 week)
  - The goal of preparing a "Yellow Report"-like document
  - The people who have expressed their interest in such project
  - Write-up distributed on Jan. 2010

- However:
  - It should be re-discussed in case of an enlarged community

Phase I: Tools preparation (on going)

- Physics
  - Preparation of a list of few benchmark processes for their implementation in the Physics event generators
- Accelerator:
  - A machine lattice configuration optimized in MARS15 for 0.75 and 1.5 TeV muon beams, at the machine-detector interface plane (z=7.5) to
  - Preliminary design of forward shielding ("cone") inside the detector in proximity of the IP.
- Detector:
  - Implementation in ILCroot of detector models to be used for various studies to be performed in Phase II and Phase III (see later).
  - Determination of the threshold parameters ("pre-cuts") in MARS15 simulation in order to reduce the contributions to the background only to the sources effectively affecting detector performance.

Goal is to have a stable lattice configuration and three detector configurations for Phase II

Phase II: Optimization of detector and machine lattice wrt background. Initial Physics studies - 9 months

- Physics
  - Preliminary plots of observables for the analysis of few Physics Benchmark processes, using a simplified detector simulation (Det-V0, already distributed)
- Accelerator:
  - A consistent design of the Interaction Region (IR), based on superconducting magnets capable of handling 0.5 kW/m loss rate, verified thorough MARS15 calculations, with inner liners, masks and shielding against Bethe-Heitler muons for 1.5-TeV muon beams.
  - A source term, calculated with MARS15 for 1.5-TeV muon beams, at the machine detector interface plane for the optimal IR and shielding configuration.
- Detector:
  - Optimization of detector wrt background for various lattice configurations (see later)

Goal is to freeze a lattice configuration and a detector layout for Phase III

Phase III: Optimization of detector and forward shielding wrt Physics. Full Physics studies - 12 months

- Physics, Accelerator, Detector:
  - Perform the Physics analysis of the benchmark channels
  - All analysis will be performed for few different forward shielding ("nose").

Goals are:

1) to freeze a forward shielding configuration
and a detector layout/technology

2) perform final physiscs studies with such configuration

Some optimization issues: background

- Split Background event from MARS into two components:
  1. Source term from 150m to 30m: mostly muons. Unlikely to be changed during the optimization phase of the beam delivery systems.
  2. Source term from 30m to MDI layer (7.5m)

- The two components are merged in ILCroot at run time (pretend they are incorrelated background sources)

Some optimization issues: background

- Need to reduce the event multiclicity by 90%. Two possible alternatives:
  1. Set cut-off values and use particles with weight = 1
     - from external fast-simulation (ex. S. Mrenna)
     - from ILCroot/G4 and force energy deposition within few steps
  2. Use no cut-off and use particles with weight *O(10)*

Some optimization issues: detectors

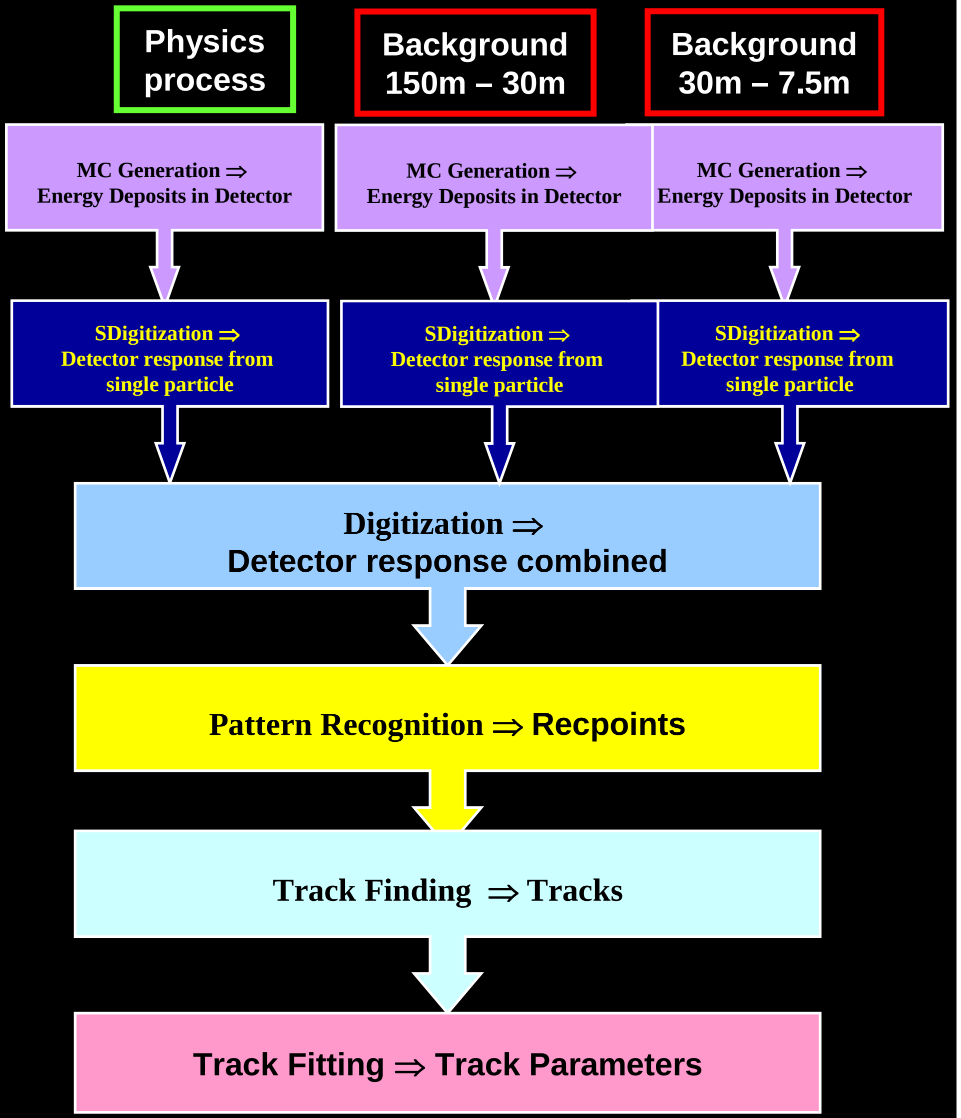
- Phase II would work better with two detector models:
  - Det-V1 for calorimetric studies: uses weighted particles from MARS (already implemented)
  - Det-V2 for tracking studies (occupancy, track separation, resolution, etc.): requires split of MARS weigthed particle into a list of unweighted particles
  - A compromise would be to reduce in ILCGenReaderMARS the weight and increase the particle multiplicity
  - Ex: a particle with weight 200 could be fed to G4 as:
    - 1 particle with weight 200
    - 200 particles, each with weight 1
    - 20 particles, each with weight 10

Already implemented (1 particle with weight 200; 200 particles, each with weight 1)

Not implemented (20 particles, each with weight 10)

Simulation + full digitization + reconstruction

1) Merge background with physics events or with jets
2) Reconstruct tracks with proper pattern recognition + Kalman Filter
3) Reconstruct Calorimetric Clusters
4) Study the effect on detector performance and measuremnts of Physics quantity



What's missing in ILCroot

- Complete parametrc description of VXD geometry (M. Peccarisi had to quit)
- Add variable weigth in ILCGenReaderMARS

About 3 weeks

- Implement VXD with two different technologies with fully depleted silicon (and an optional variant):
  1. 10 µm active for MAPS on 50 micron inactive base
  2. 50 µm for 3D - all active
  3. Variant with double layers separated by D mm (D=100µm, 1 mm) (optional)
- Define a final calorimeter for Phase III (Det-V3)

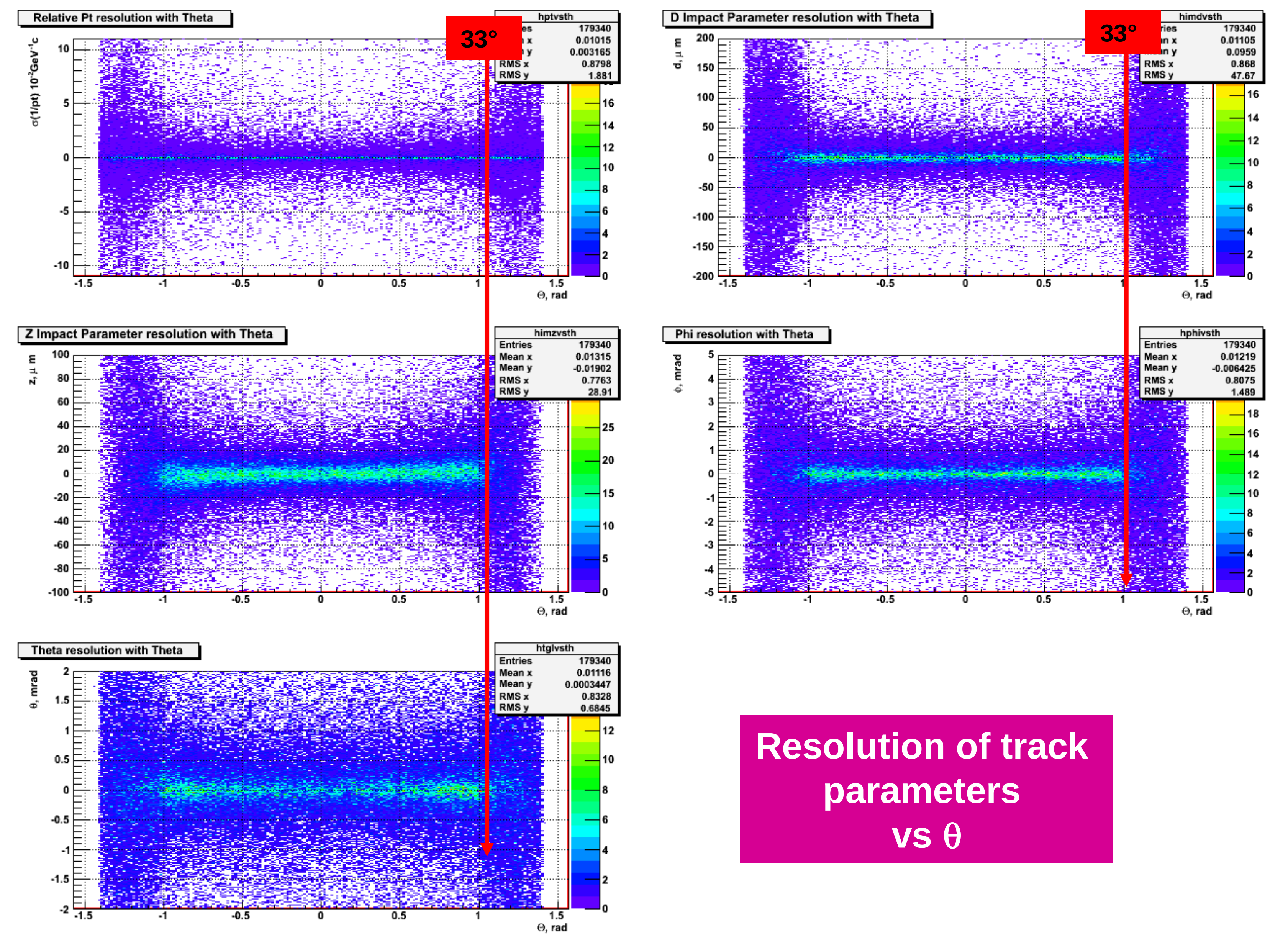
Major effort (~2 months)

Conclusions

- Work on ILCroot suspend for the moment
- Need to establish an official activity for TFSG on Muon collider
- Detector-wise, needs about 2 months to complete Phase I
- Nonetheless, status of ILCroot for Muon Collider studies is very advanced
- About 8-10 non-Fermilab people interested in joining the studies (Italy, Russia, etc.)
- Large effort by Giorgio Bellettini to get INFN officially involved

Backup slides

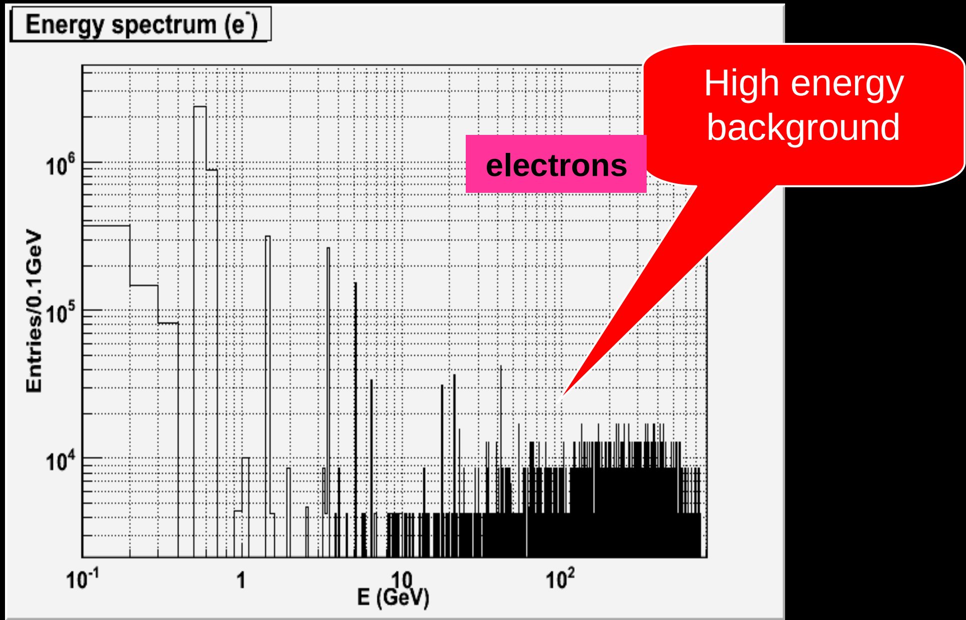
Effect of Shielding on Physics: WWνν

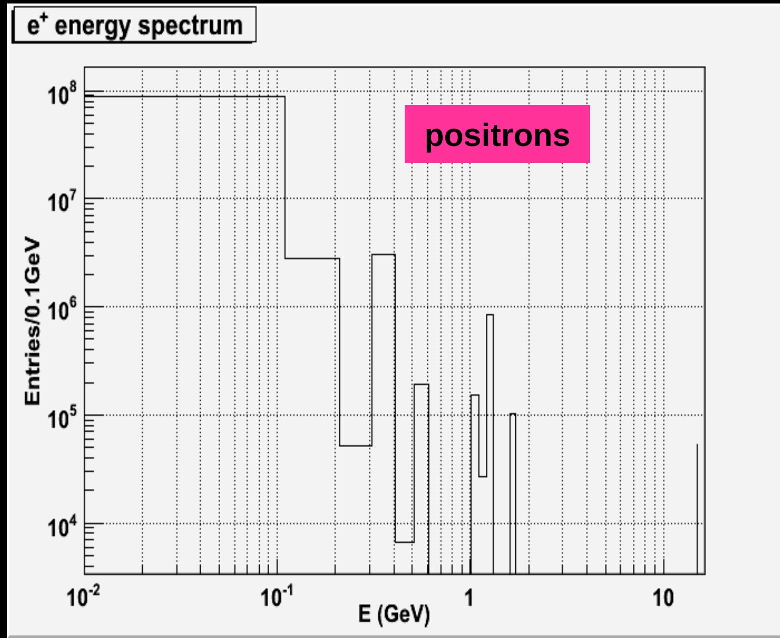


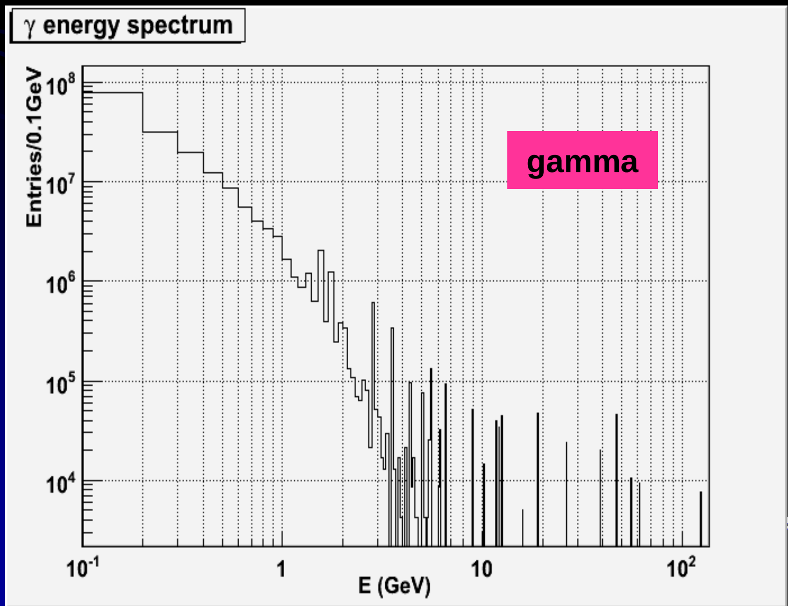
Resolution of track parameters vs θ

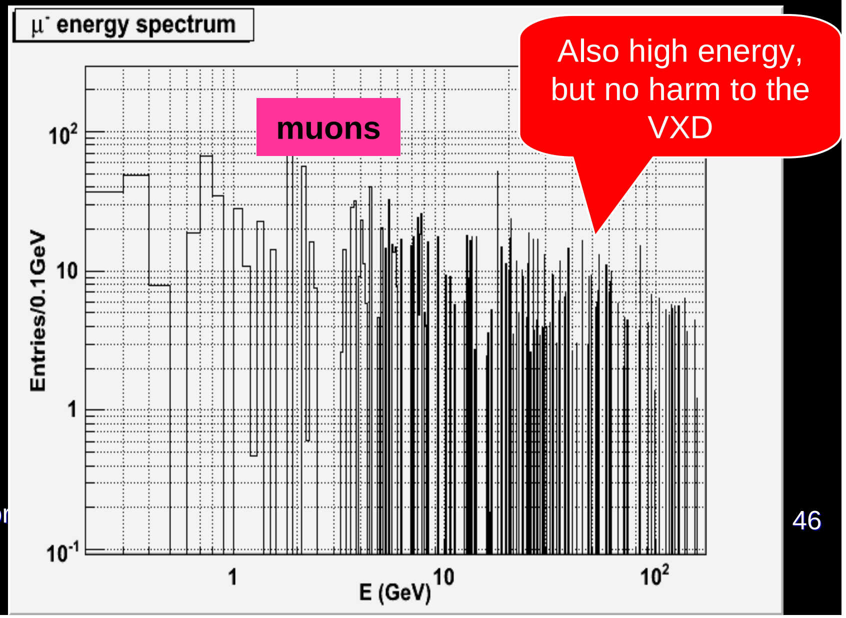
Alexakhin
Di Benedetto

Beam Background Spectrum in MARS (before shield)



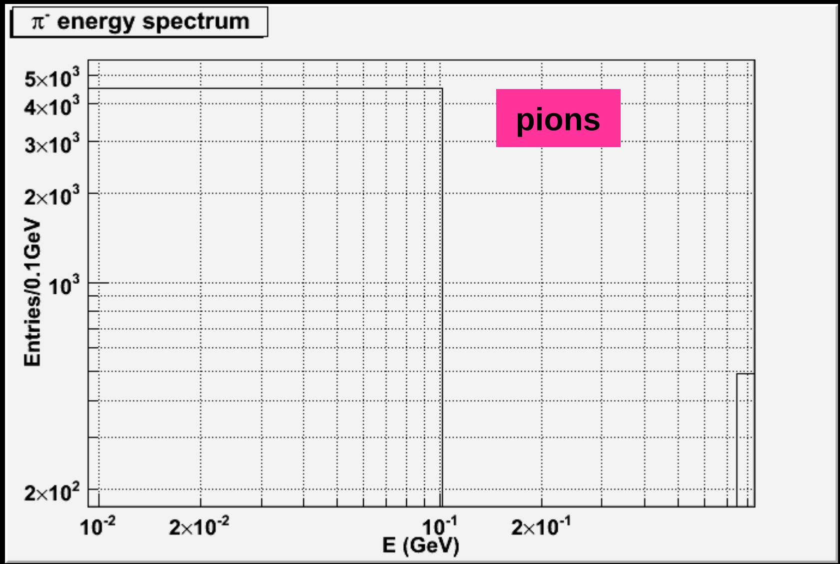


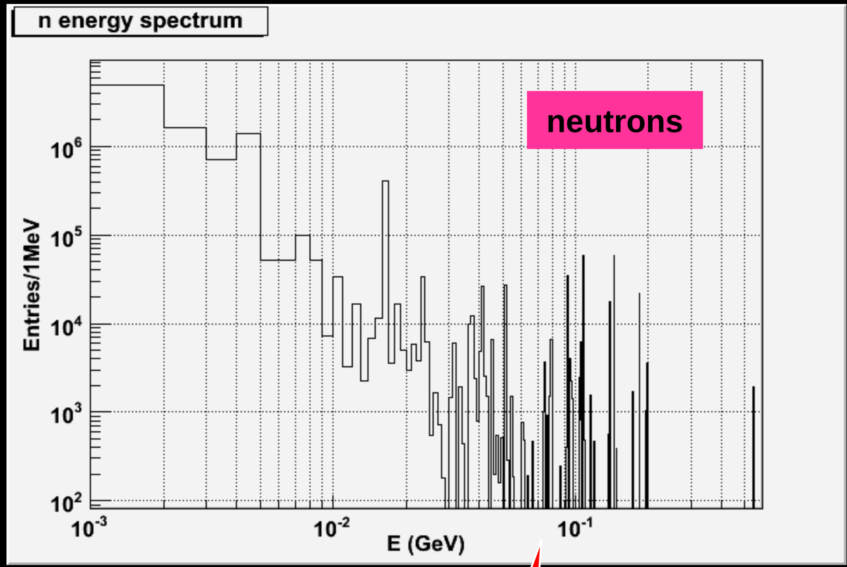


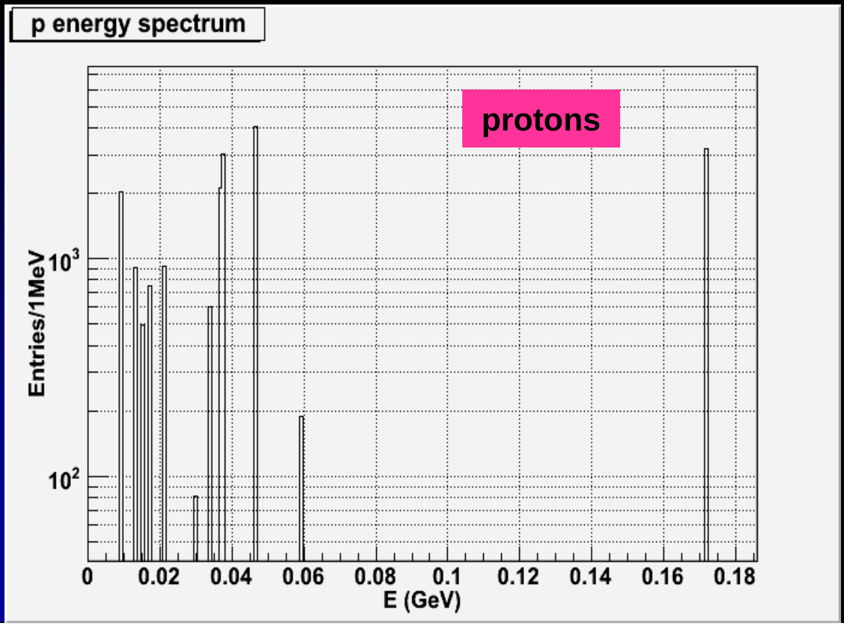


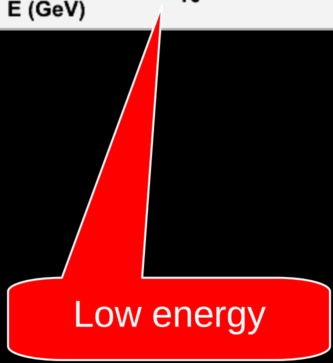
Beam Background Spectrum in MARS (before shield)

Alexakhin
Di Benedetto



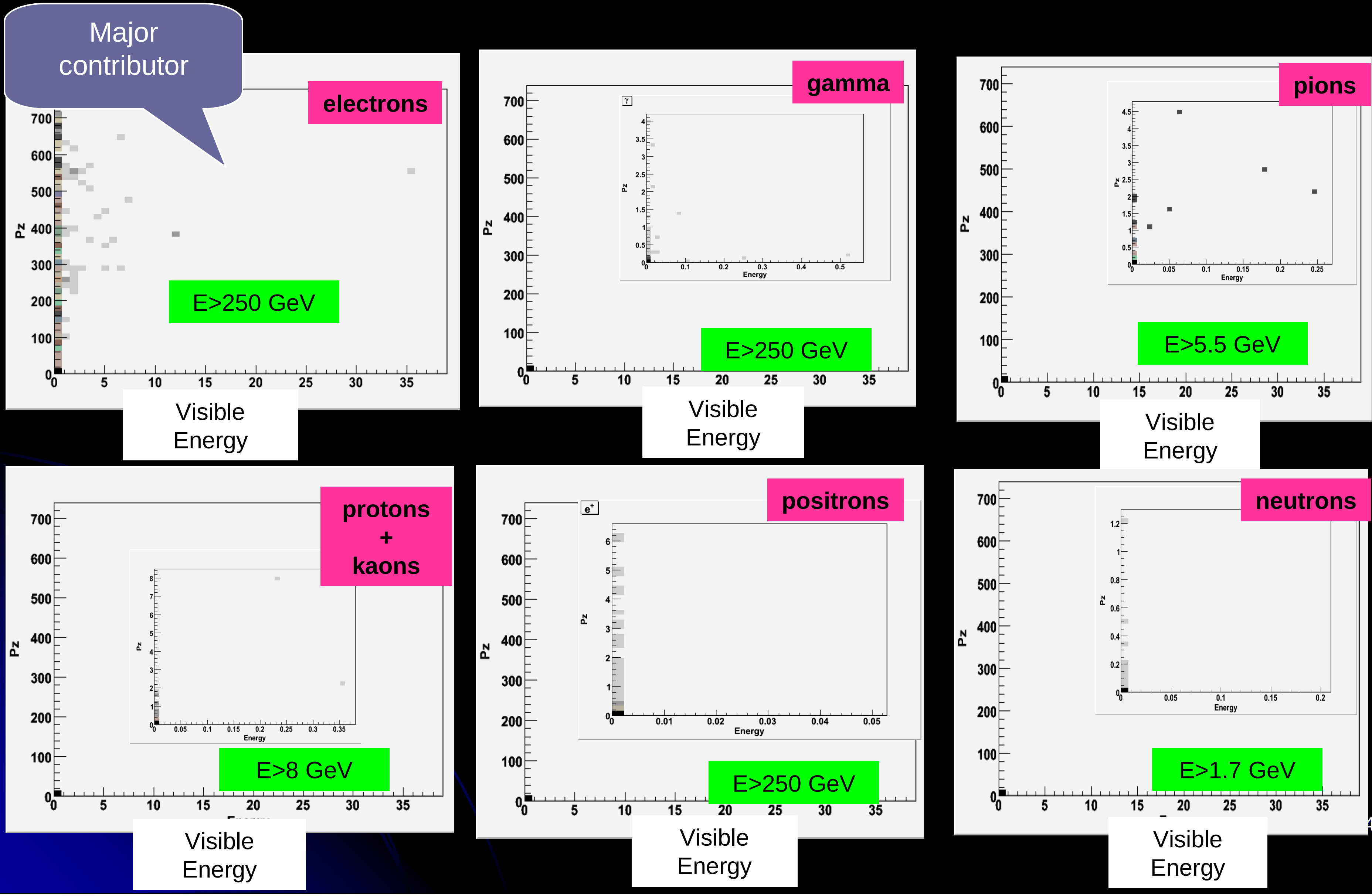






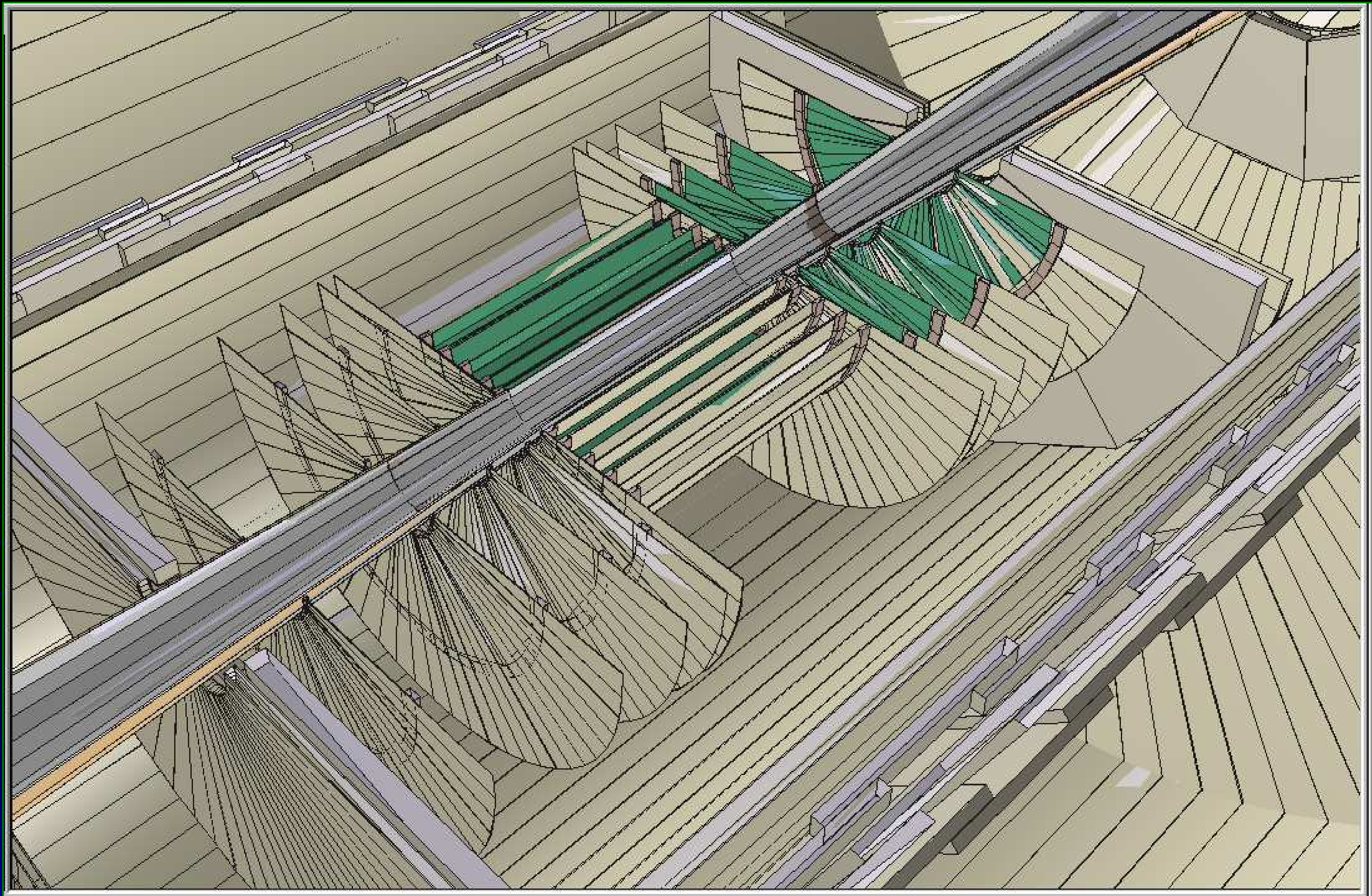
Pre-cuts in ILCGenReaderMARS
Visible Energy vs E_{bkg} (1.9×10^9 -> 4.3×10^6)

Alexakhin
Di Benedetto



D. Barbareschi
M. Rucco

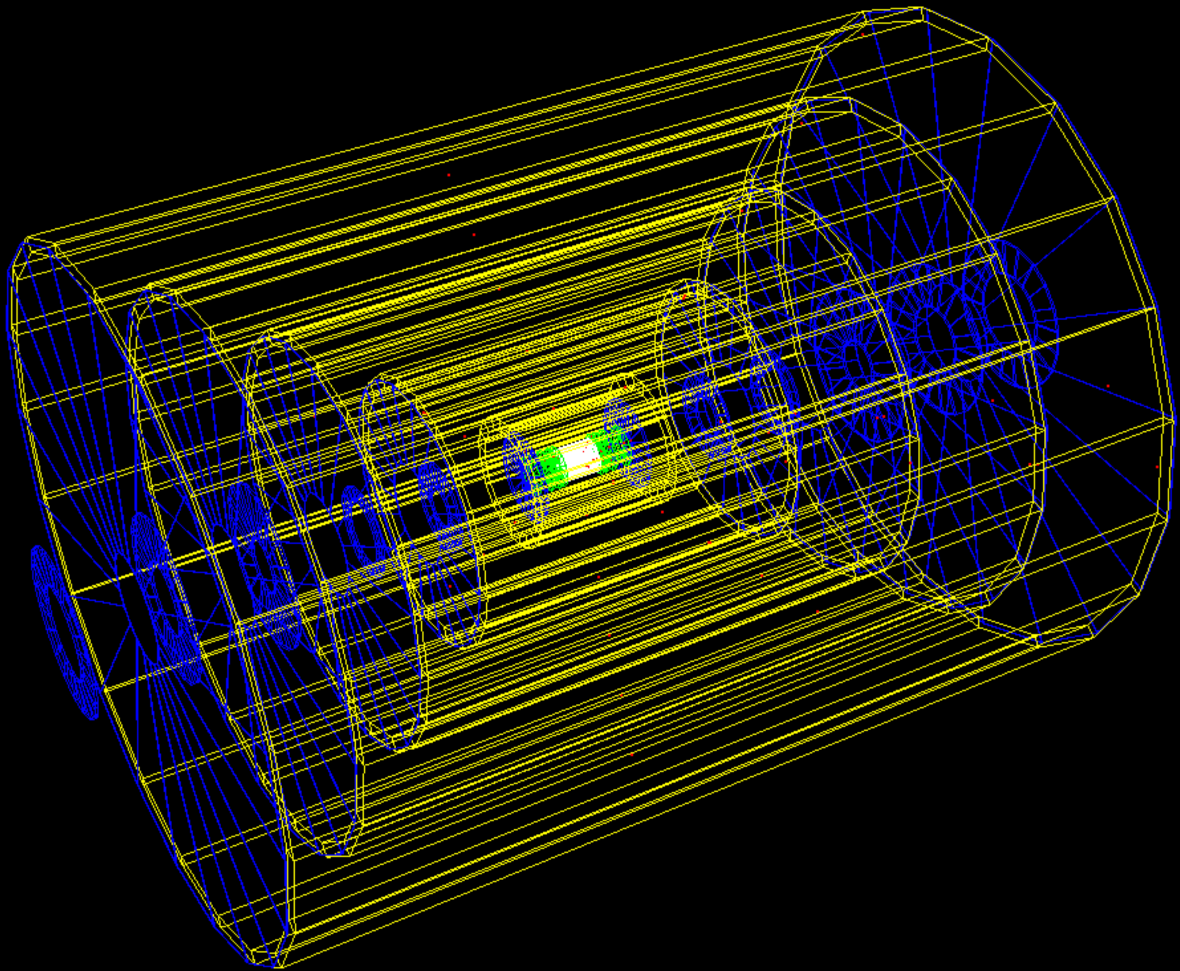
Beam Pipe and VXD layout



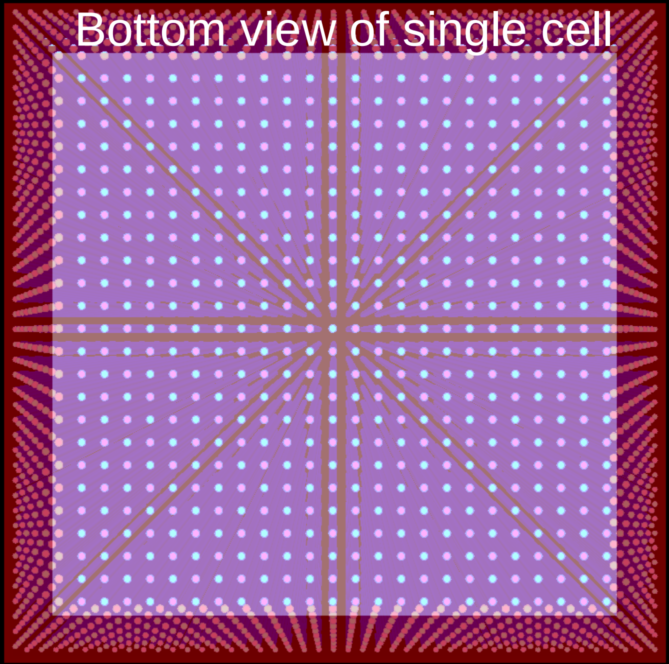
ILCRoot simulation

Event Display in ILCroot Tracking Systems

e^+e^- -> 10 muons
E_{CM} = 3 TeV
in Tracking System

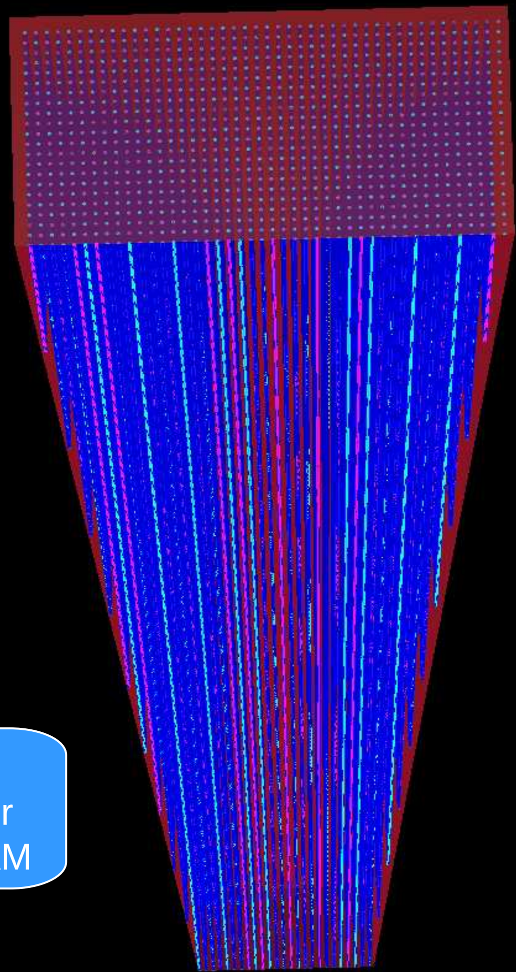


Hadronic Calorimeter Cells



Prospective view of clipped cell

Top cell size:~ 8.1 × 8.1 cm^2



Bottom cell size: ~ 4.4 × 4.4 cm^2

1 mm diameter

Plastic/Quartz fibers

Aperture Number=0.50

(C fibers)

Same absorber/fiber ratio as DREAM

Number of fibers inside each cell: ~1600 equally subdivided between Scintillating and Cerenkov

Fiber stepping ~2 mm

Cell length: 150 cm

Each tower works as two independent towers in the same volume