Muon Collider Detector Studies in ILCroot

C. Gatto

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Main Detector Challenges

- If we can build a Muon Collider, it will be a precision machine!
- One of the most serious technical issues in the design of a Muon Collider experiment is the background (see all previous talks)
- The major source (from muon decays) is overwelming: for 750 GeV muon beam with $2*10^{12}$ muons/bunch expect ~ $4.3*10^{5}$ decays/m
- Large background is expected in the detector: ~ 10^{8} particles/bunch Xing
- The backgrounds and/or adequate shielding can spoil the physics program
- A Muon Collider Physics&Detector program has been established by Fermilab to address such issues and to guide toward the choice of technology and detector parameters optimization.

MARS and ILCroot Frameworks

MARS – the framework for simulation of particle transport and interactions in accelerator, detector and shielding components.

- New release of MARS15 available since February 2011 at Fermilab (N. Mokhov, S. Striganov, see www-ap.fnal.gov/MARS)
- Among new features:
  – Refined MDI (Machine Detector Interface) with a 10º nozzle
  – Significant reduction of particle statistical weight variation
  – Background is provided at the surface of MDI (10º nozzle + walls)

ILCroot - Software architecture based on ROOT, VMC & Aliroot

- All ROOT tools are available (I/O, graphics, PROOF, data structure, etc)
- Extremely large community of ROOT users/developers

- It is a simulation framework and an offline system:
  - Single framework, from generation to reconstruction and analysis!!
  - Six MDC have proven robustness, reliability and portability
  - VMC allows to select G3, G4 or Fluka at run time (no change of user code)
- Widely adopted within HEP community (Opera, CMB, Panda, 4th Concept, LHeC, T1015)
- It is publicly available at FNAL on ILCSIM since 2006

ILCroot: essential add-ons to Aliroot

1. Interface to external files from Event Generators in various format (STDHEP, text, ***MARS***, etc.)
2. Standalone VTX track fitter
3. Pattern recognition from VTX (for Si central trackers)
4. Track fitters for different trackers technologies (Si Pixels, Si Strips, Drift Chambers, Straw Tubes, TPC's) and a ombination of them
5. Full simulation of ***Dual Readout calorimeters***
6. Parametric beam background (# integrated bunch crossing chosen at run time)

Very important for detector and Physics studies of New Projects

The Virtual Montecarlo (VMC) Concept

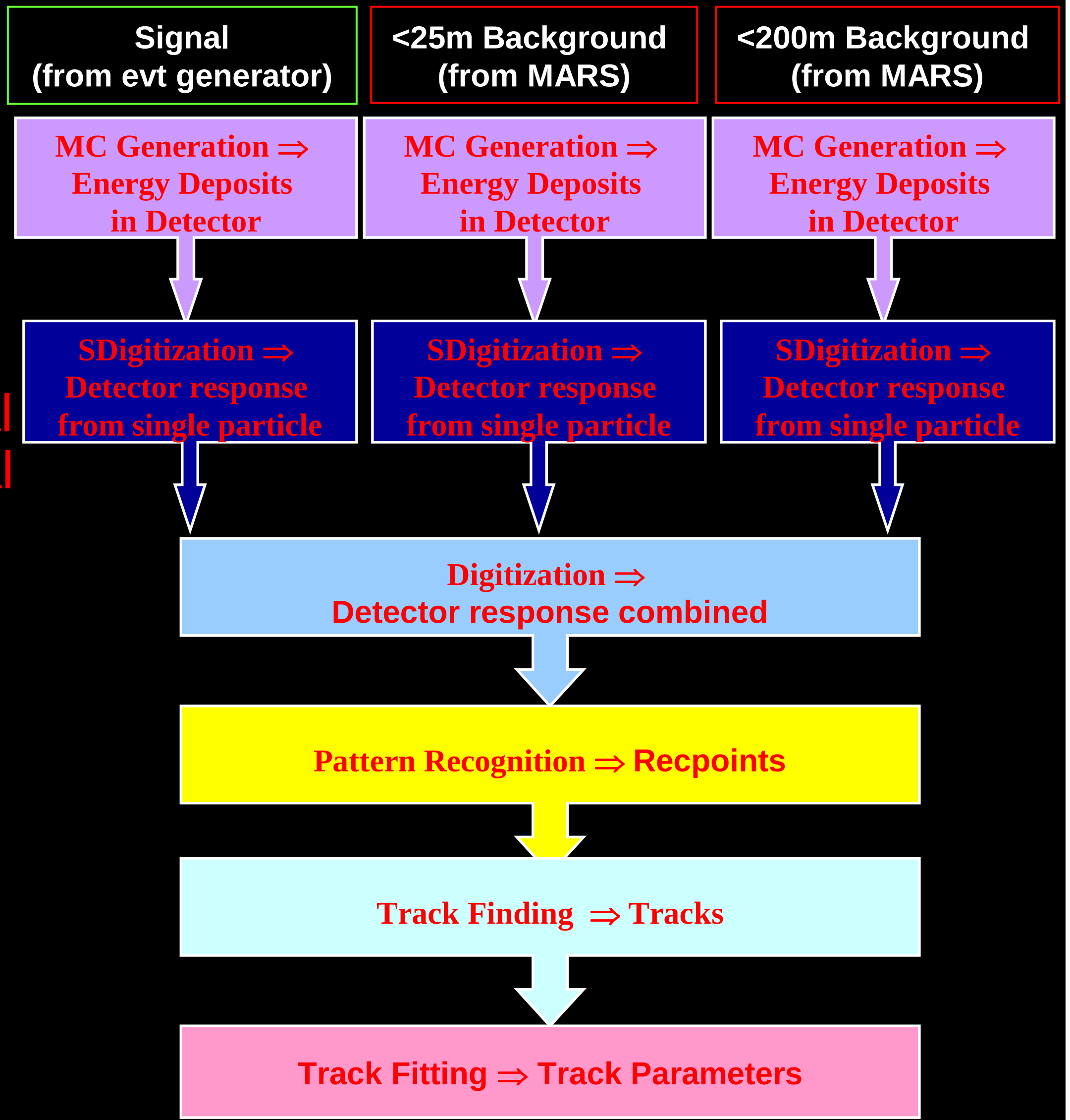
- **Virtual MC provides a virtual interface to Monte Carlo**
- **It allows to run the same user application with all supported Montecarlo's**
- **The real Monte Carlo (Geant3, Geant4, Fluka) is selected and loaded at run time**

Simulating 1 MARS Event @ E_{cm} = 1.5 TeV with $2x10^{12}$ particles

- About $1x10^8$ particles, almost all originating <25m from IP
  - Muon beam decay from beam line components and accelerator tunnel is major source of backround in the detector
  - $4.3x10^5$ decays/m/bunch Xing.
  - Incoherent $3x10^4$ e^+e^- pair production per bunch Xing
- Background is split into two sources:
  - Near (< 25m)
  - Far (25m< < 200m)
- Particle at MDI interface
  - w ~ 20
- Particles from beamline
  - W << 1: need proper statistical treatement
- At large radii also:
  - Bethe-Heitler and beam-halo induced background
- Background with current shielding configuration is reduced by $\mathcal{O}(10^3)$

Processing Flow of Full Simulation: detector hits + digitization + reconstruction

- Hits: produced by MC (G3,G4,Fluka)
- SDigits: simulate detector response for each hit
- Digits: merge digit from several files of SDigits (example Signal + Beam Bkgnd)
- Recpoints: Clusterize nearby Digits
- Pattern recognition + track fit through full Parallel Kalman Filter
- Or Calorimetry shower reco + jet-finder



12 Detectors in ILCroot + 12 from Alice

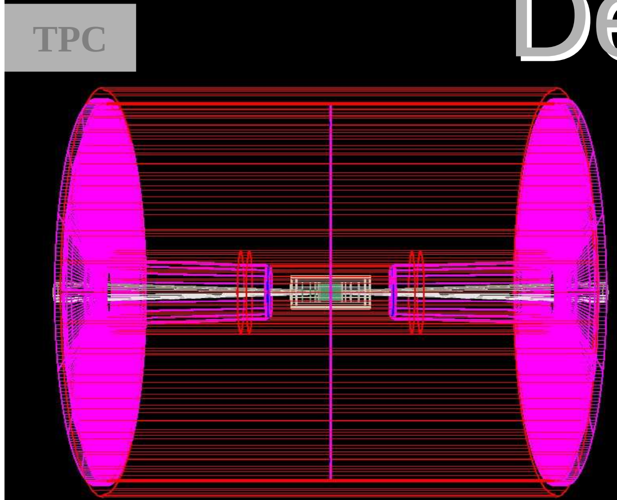
Detector	Layouts	Digit./Cluster.
VXD (SIDMay06)	1 (parametric)	Full
FTD (SiLC)	1	Full
TPC (Hybrid readout)	1	Gauss. Smear.
Si-Tracker (SID01-Polyhedra)	1+1	Full
µCollider/CLIC Tracker	1	Full
Hadron Calorimeter	2	Full
THACAL	1	**Fast**
ADRIANO Calorimeter	1	**Full**
EM Calorimeter	2	Full
Muon Spectrometer (straw tubes)	1	Gauss. Smear.

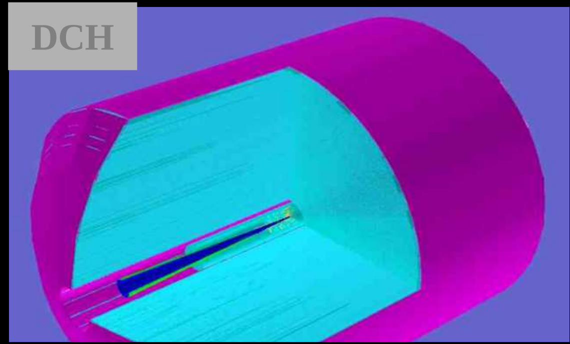
NEW

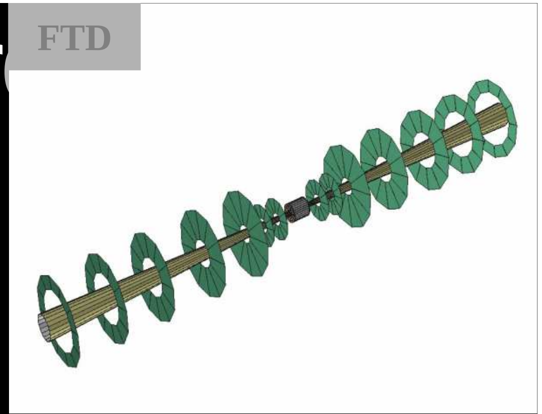
MARS + ILCroot (Dedicated ILCroot framework for MUX Physics and background studies

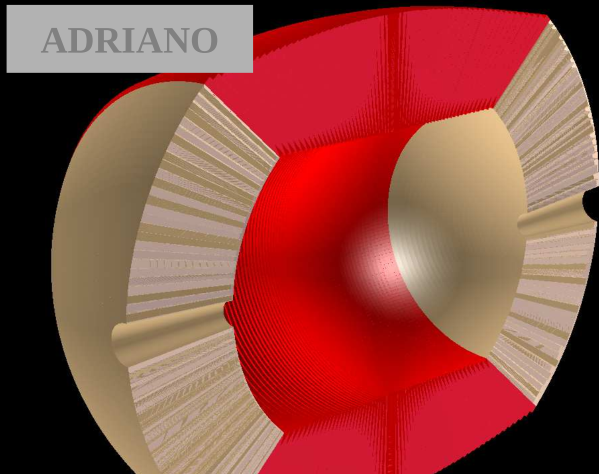
- **The ingredients**:
  - MDI description in MARS & ILCroot
  - Detector description in ILCroot
  - MARS-to-ILCroot interface (Vito Di Benedetto)
- **How it works**
  - The interface (**ILCGenReaderMARS**) is a ***TGenerator*** in ILCroot
  - MARS output is used as a config file
  - **ILCGenReaderMARS** creates a STDHEP file with a list of particles entering the detector area at z = 7.5m
- **ILCGenReaderMARS feeds the Montecarlo with:**
  - 1 particle with corresponding weight
    - OK for calorimetric studies
  - W particles smeared according to ther origin
    - OK for detailed tracking occupancy studies
    - ...but very slow and time consuming
  - A mix of the above
    - OK for most tracking studies

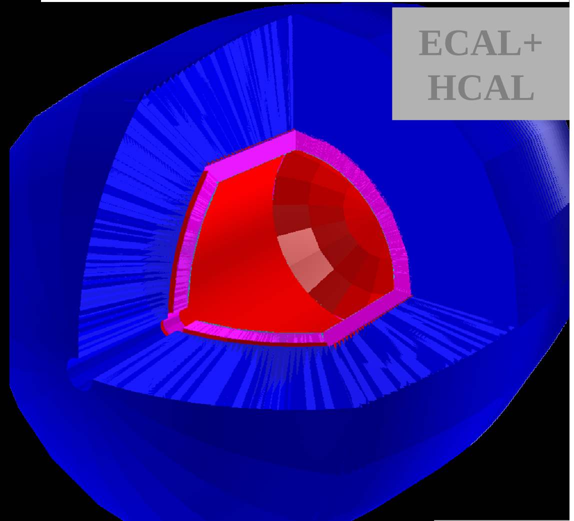
Detectors in ILCr

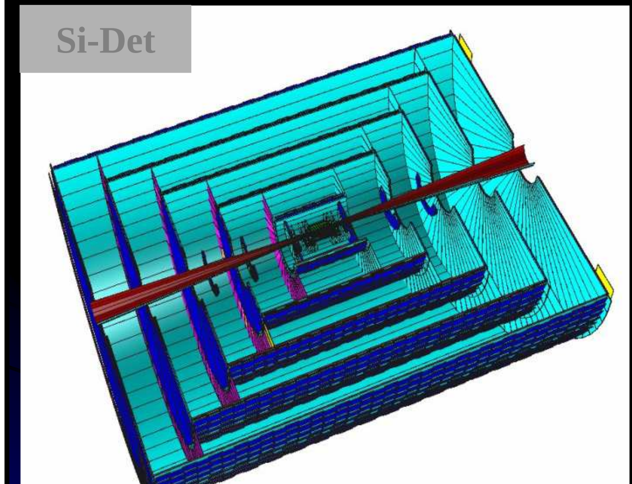


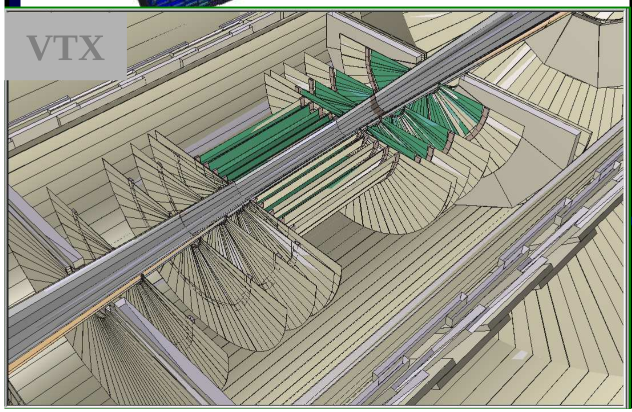


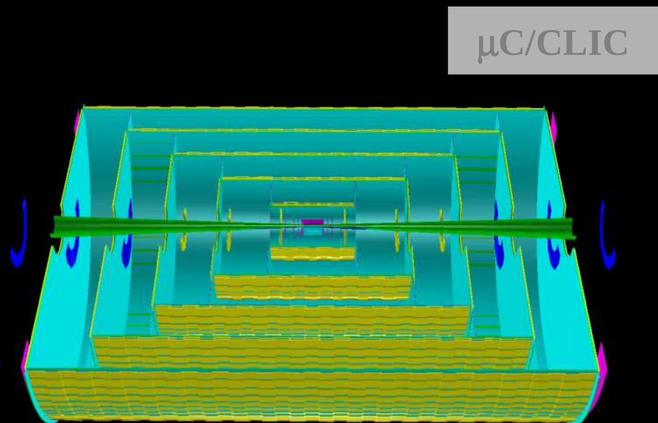


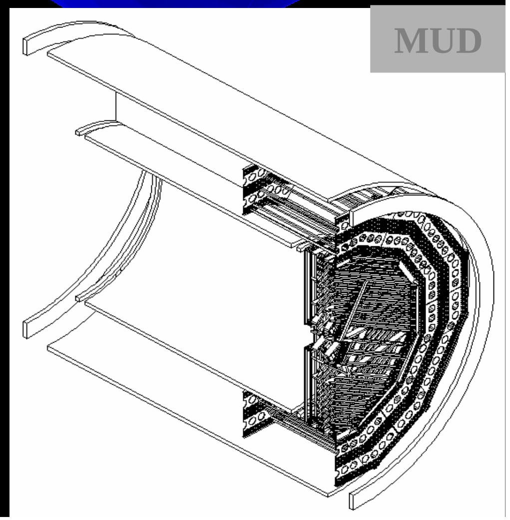




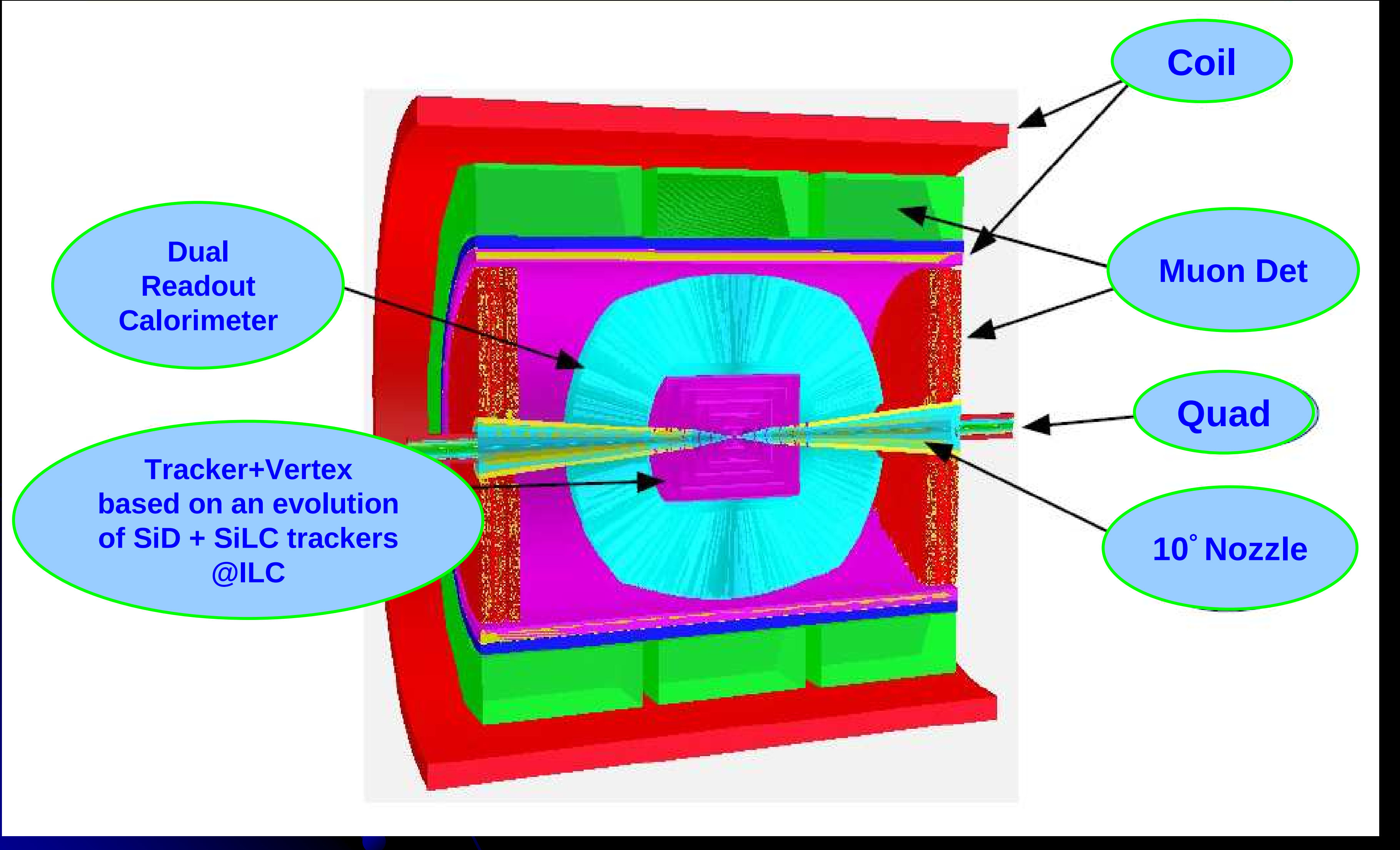








Baseline Detector for Muon Collider Studies

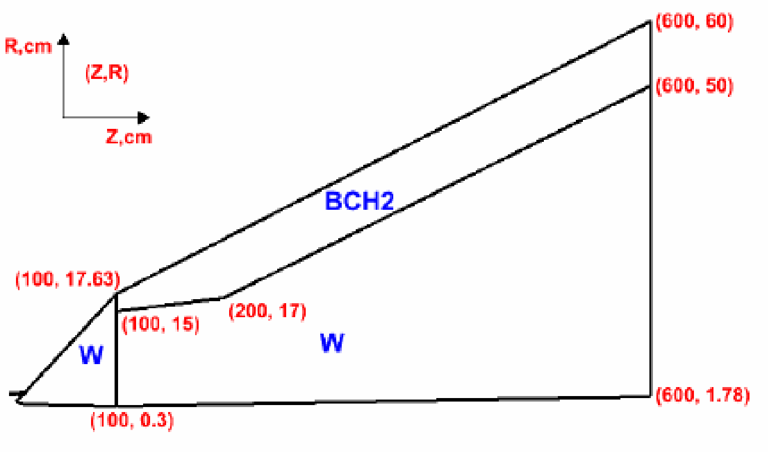


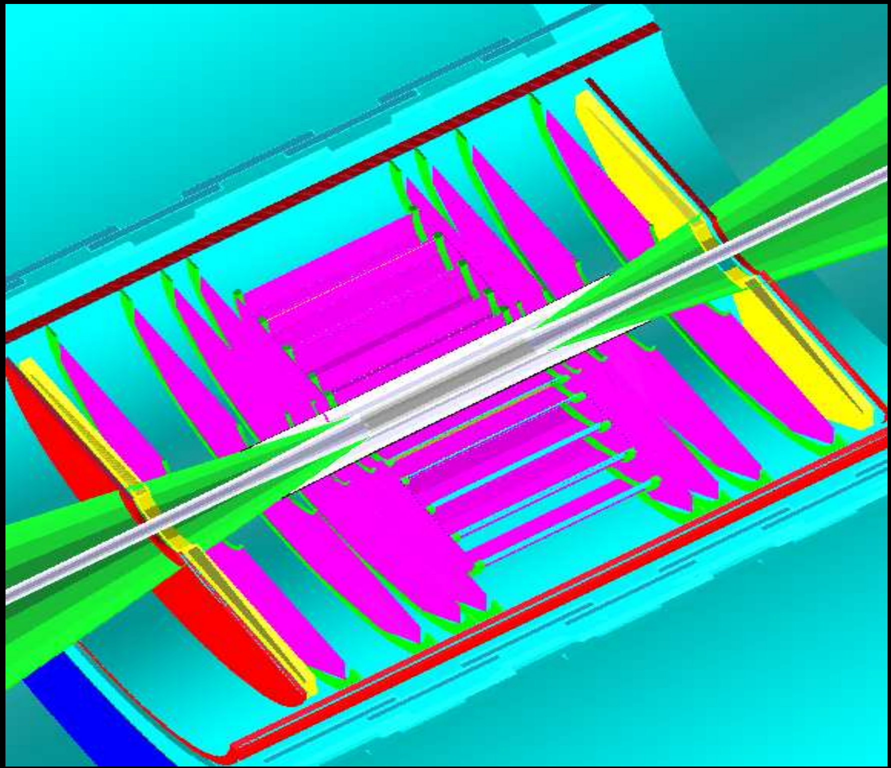
Tracking Studies

Vertex Detector (VXD)
10°Nozzle and Beam Pipe

VXD

- **Modified SiD design**
- 100 μm thick Si layers
- 20 μm x 20 μm Si pixel
- Barrel : 5 layers subdivided in 12-30 ladders
- R_{min}~3 cm R_{max}~13 cm L~13 cm
- Endcap : 4 + 4 disks subdivided in 12 ladders
- Total lenght 42 cm





NOZZLE

- Tungsten core
- Borated Polyethylene (BCH2) jacket

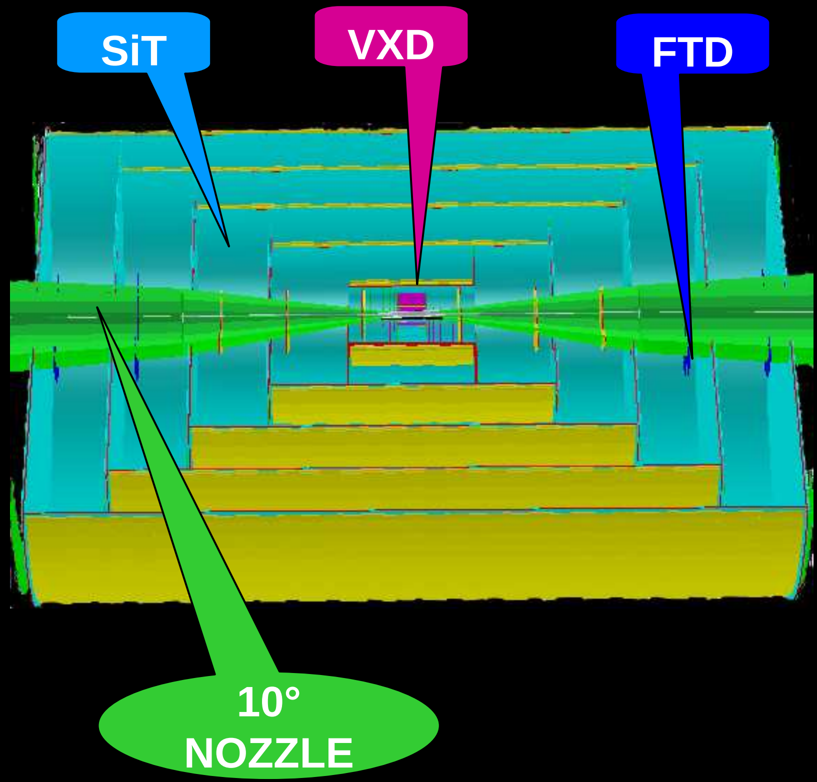
PIPE

- Be – Berylium 400 μm thick
- 12 cm between the nozzles

Silicon Tracker (SiT) and Forward Tracker Detector (FTD)

SiT

- **original SiD design**
- 100 µm thick Si layers
- 50 µm x 50 µm Si pixel (or Si strips or double Si strips available)
- Barrel : 5 layers subdivided in staggered ladders
- Endcap : (4+3) + (4+3) disks subdivided in ladders
- R_{min}~20 cm R_{max}~120 cm L~330 cm



FTD

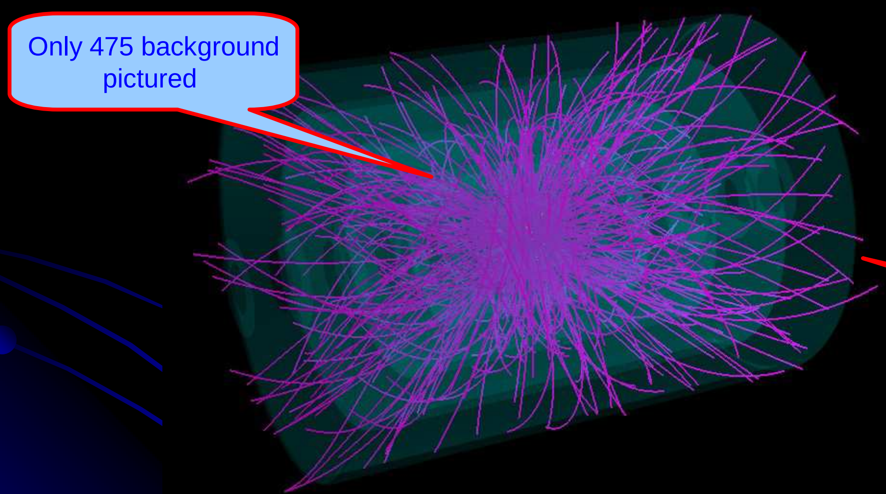
- **from previous collaboration with SiLC/IFIC**
- 20 µm x 20 µm Si pixel
- Endcap : 3 + 3 disks
- Distance of last disk from IP = 190 cm

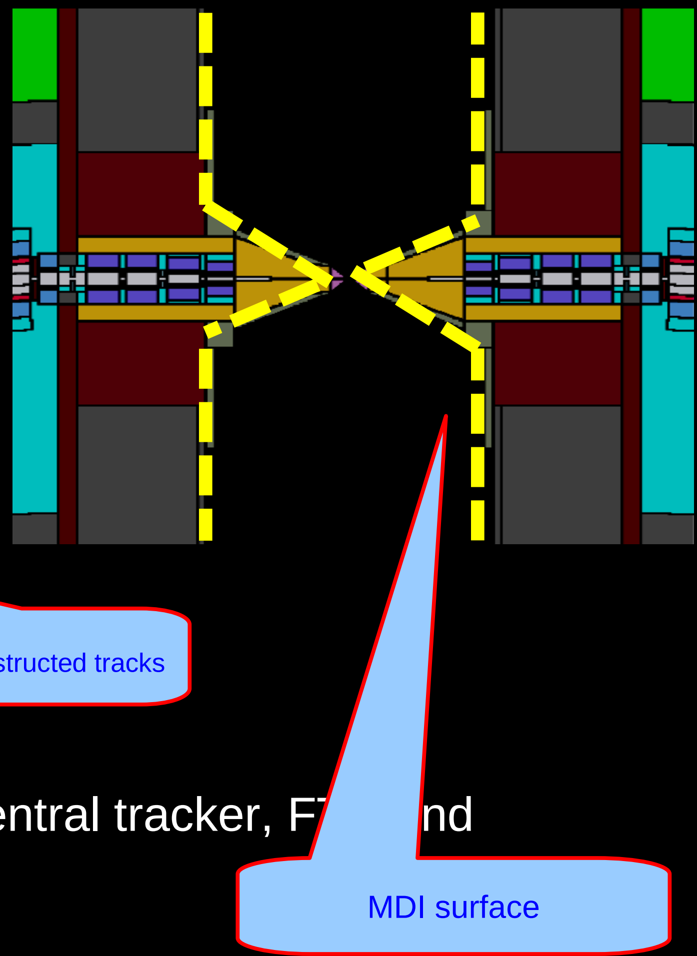
- Silicon pixel for precision tracking amid up to 10^5 hits
- Tungsten nozzle to suppress the background

Ingredients for Tracking & Calorimetry Studies in ILCroot

- MARS background provided at the surface of MDI (10º nozzle + walls)

- GEANT4 /fluka simulated particles in the detector (background + single muons from the I.P.)





- Full digitization of signal and background in VTX, Central tracker, FT nd ADRIANO
- Fast simulation for TAHCAL
- Reconstruct tracks with a parallel Kalman Filter in a 3.5 T B-field
- Reconstruct jets with A. Mazzacane recursive jet finder

Full Simulation of Si Detectors

VXD SDigitization

- Follow the track in steps of 1 µm
- convert the energy deposited into charge
- spreads the charge asymmetrically (B-field) across several pixels:

$$f(x,z) = Errf(x_{step}, z_{step}, \sigma_x, \sigma_z)$$

$$\sigma_x = \sqrt{T \cdot k / e \cdot \Delta l / \Delta V \cdot step}$$

$$\Delta l = Si\,tickness, \quad \Delta V = bias\,voltage, \quad \sigma_x = \sigma_x \cdot fda$$

- Add couplig effect between nearby pixels
- Parameters used:
  - Eccentricity = 0.85 (fda)
  - Bias voltage = 18 V
  - cr = 0% (coupling probability for row)
  - cc = 4.7% (coupling probability for column)
  - T°= 300 °K

Charge pile-up is automatically taken into account

VXD Digitization

- Merge signals belonging to the same channel (pixel)
  - Include non-linearity effects
  - Add threshold
  - Add saturation
- Add electronic noise
- Save Digits over threshold
  - threshold = 3000 electrons
  - electronic noise = 0 electrons

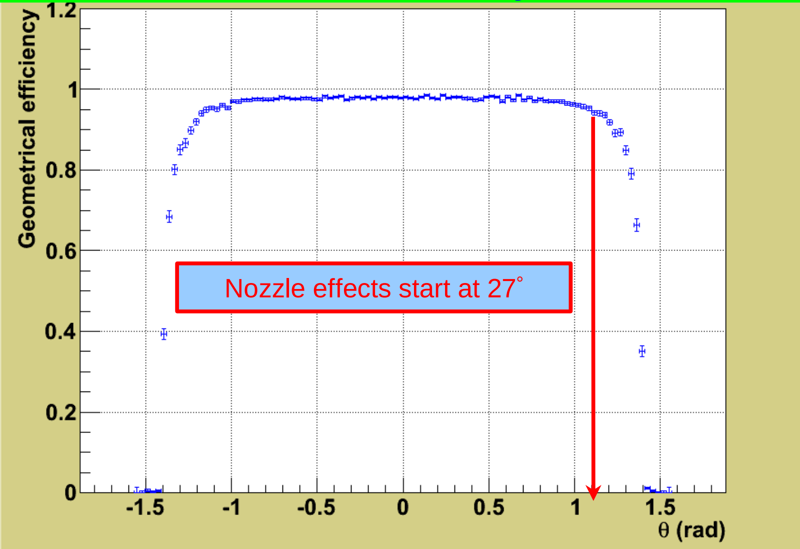
Pattern recognition

- Create a initial cluster from adjacent pixels (no for diagonal)
- Subdivide the previous cluster in smaller NxN clusters
- Get cluster and error matrix from coordinate average of the cluster
- Kalman filter picks up the best Recpoints

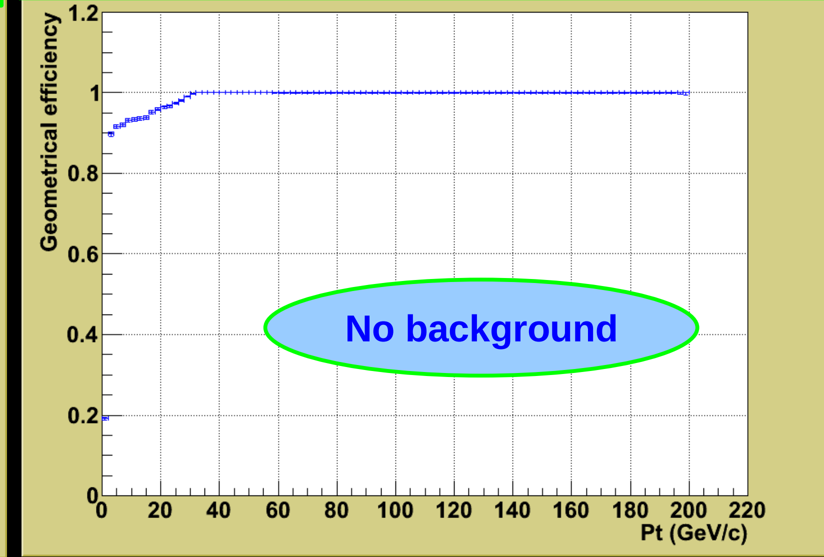
Full simulation of 10 muons – no bkg

Reconstruction Efficieny for Single Muons

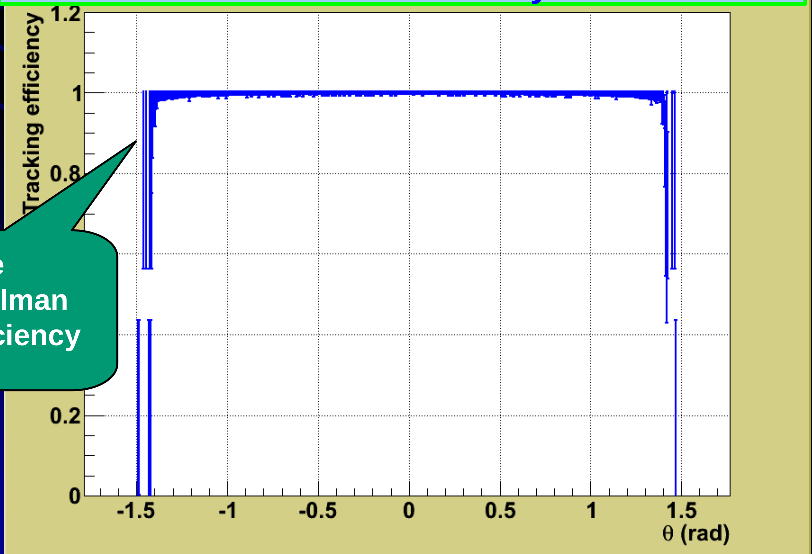
Geometrical Efficiency vs Theta



Geometrical Efficiency vs Pt

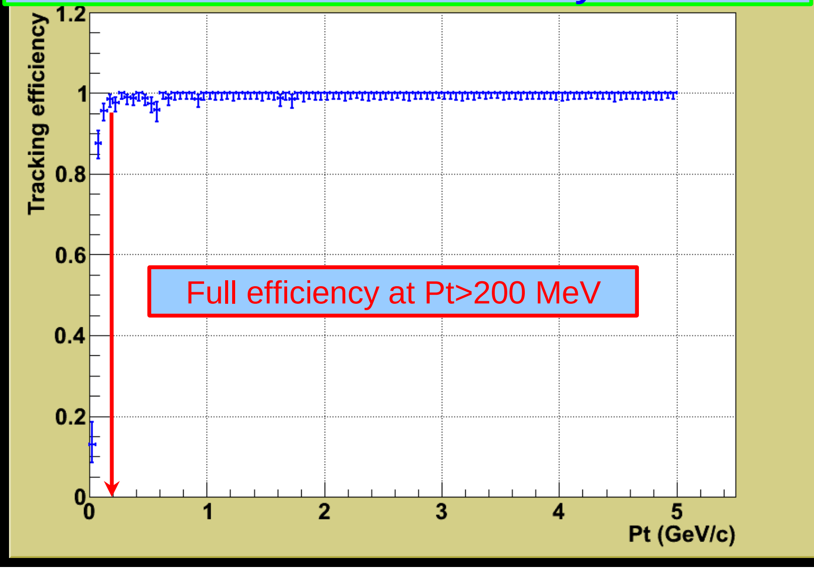


Kalman Filter Efficiency vs Theta

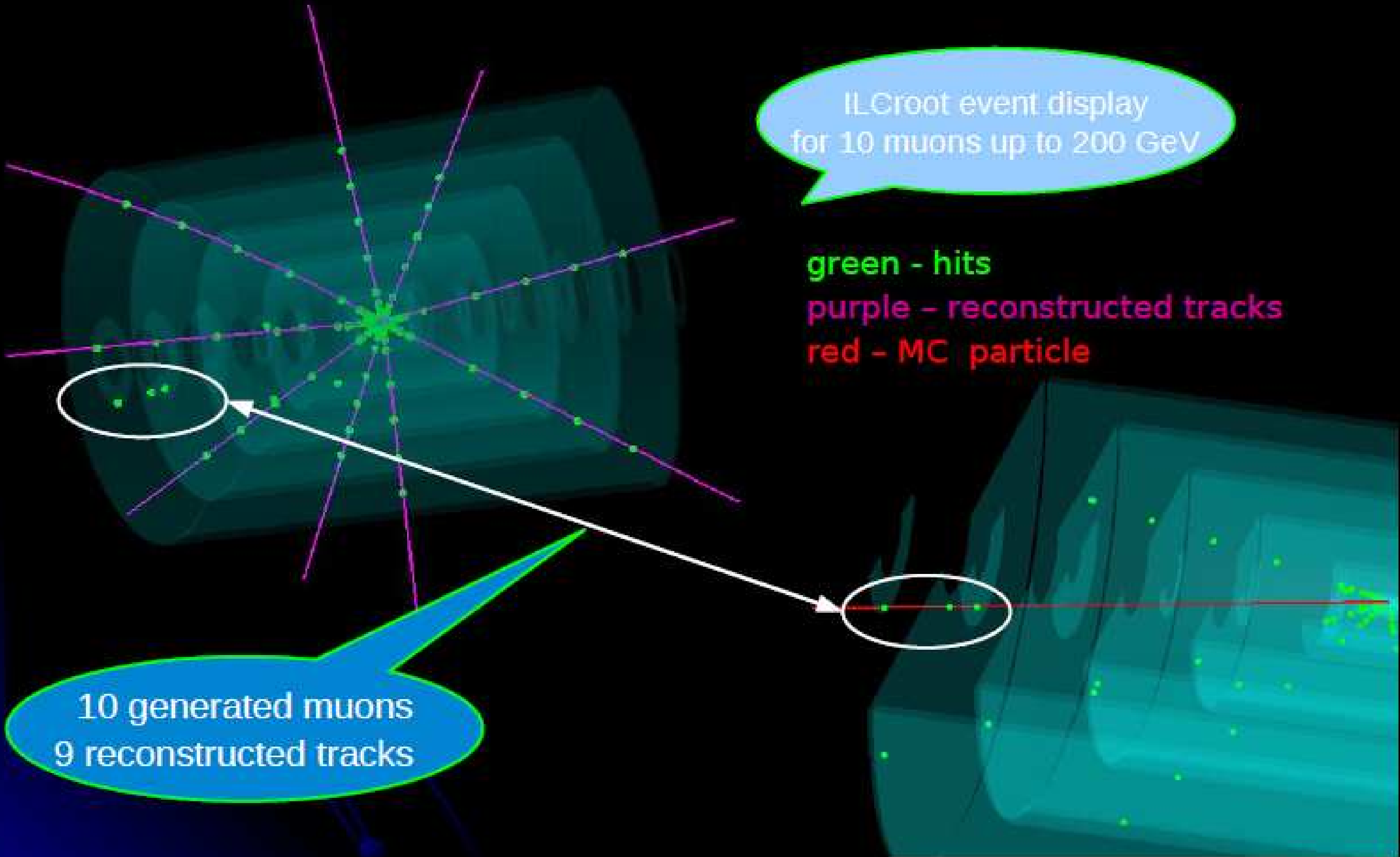


If hits are there, Kalman filter efficiency is ~100%

Kalman Filter Efficiency vs Pt



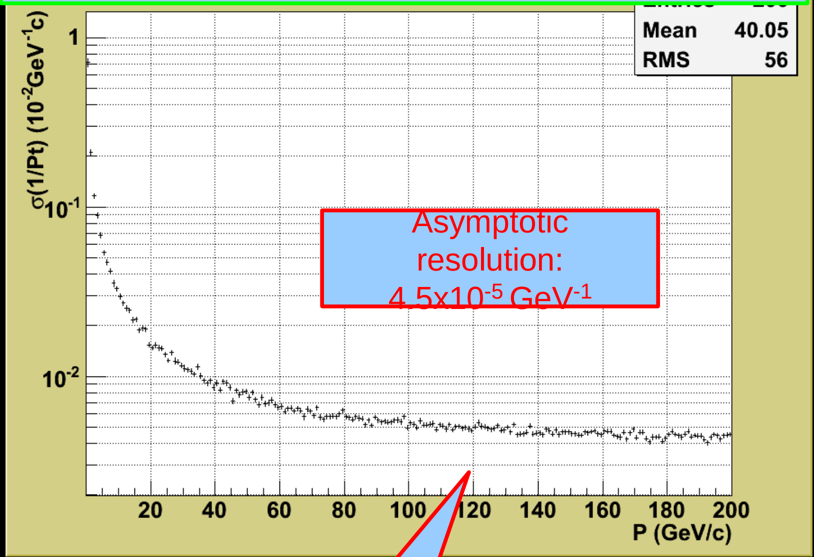
Effect of the 10° nozzle



Full simulation of 10 muons – no bkg

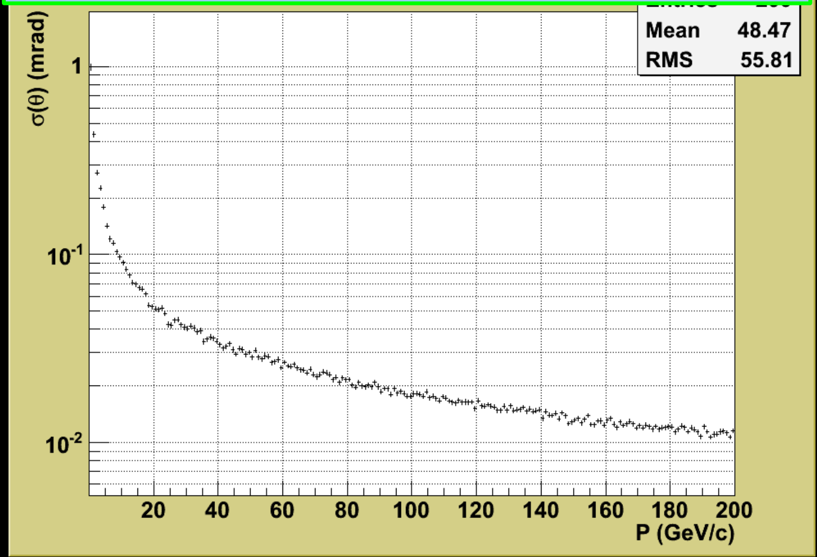
Resolutions for single muons

1/Pt Resolution vs P

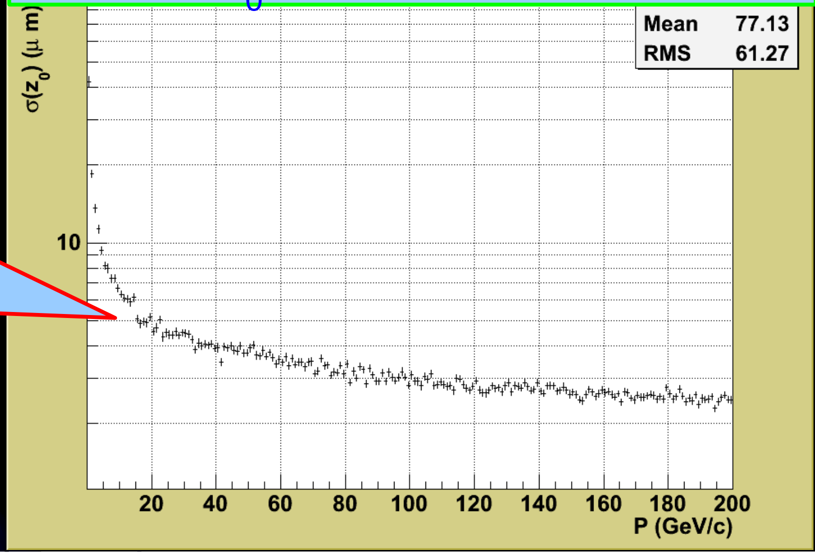


Asymptotic resolution: 4.5×10^{-5} GeV^{-1}

Theta Resolution vs P



Z_0 Resolution vs P



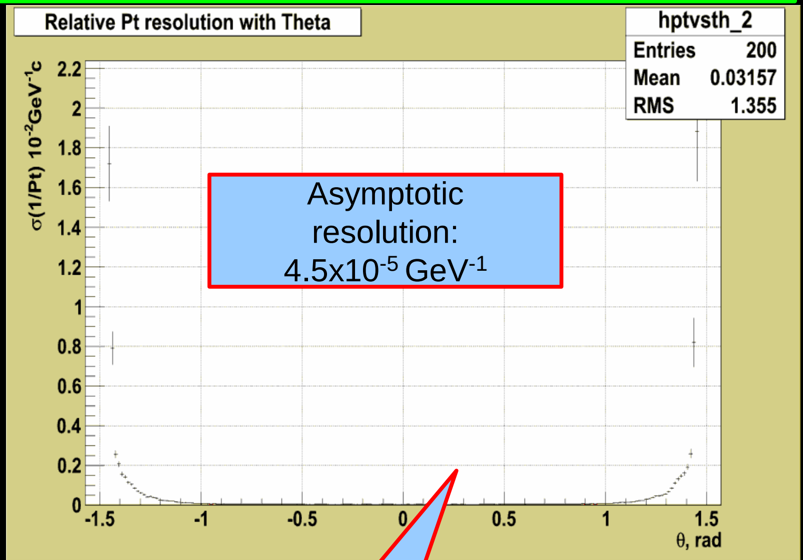
Well within requirements for precision physics

No background

Full simulation of 10 muons – no bkg

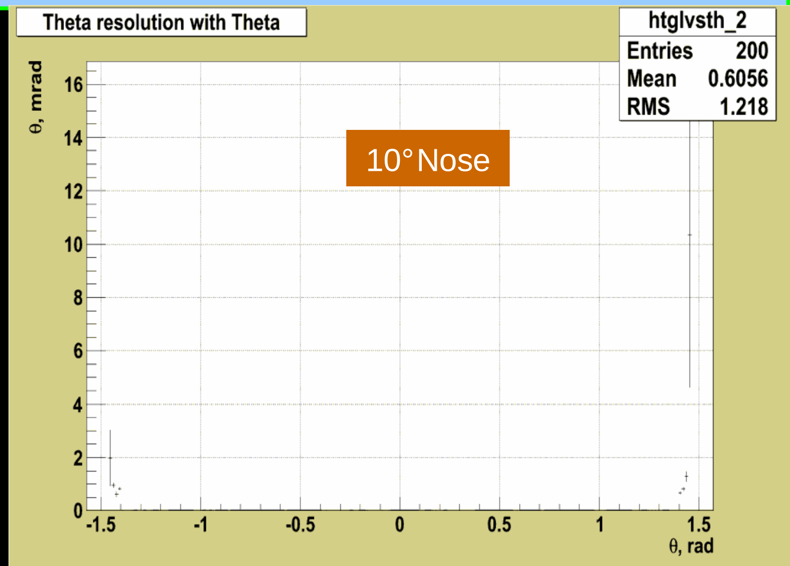
Resolutions vs θ for single tracks

1/Pt Resolution vs θ



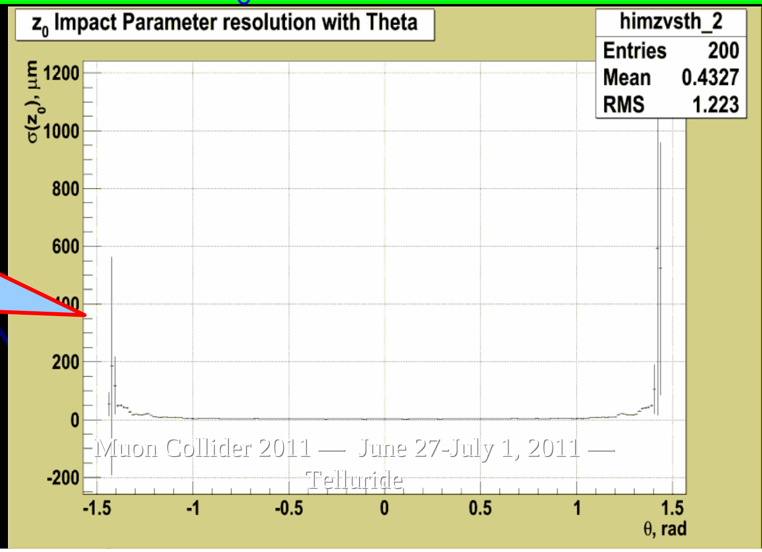
Asymptotic resolution: 4.5×10^{-5} GeV^{-1}

Theta Resolution vs θ



10° Nose

Z_0 Resolution vs θ



Well within requirements for precision physics

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Beam Background Studies

- We simulated in ILCroot 4 detectors with different timing capabilities:
  - Det. A – No time information (integrates all hits)
  - Det. B – Acquires data in a fixed 7 ns time gate (minimal timing capabilities
  - Det. C - Acquires data in a adjustable 3 ns time gate tuned to distance from IP (advanced timing capabilities)
  - Det. D - Acquires data in a 1 ns time gate tuned to pixel distance from IP (extreme timing capabilities)

See N. Terentiev ‘s talk

Full simulation of bkg

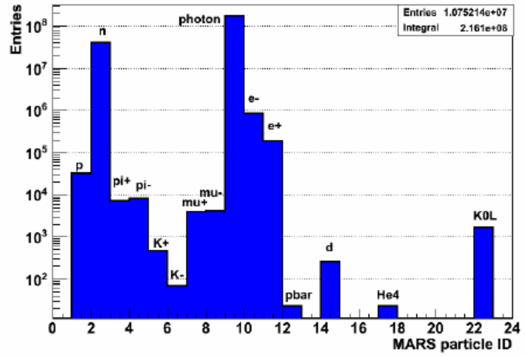
A. Mazzacane
N. Terentiev

Add Beam Background

2x10^5/cm^2 in layer1

Particles Entering the Detector region

- MARS background particle ID's yields for 750 GeV 2*10^{12} muons/bunch

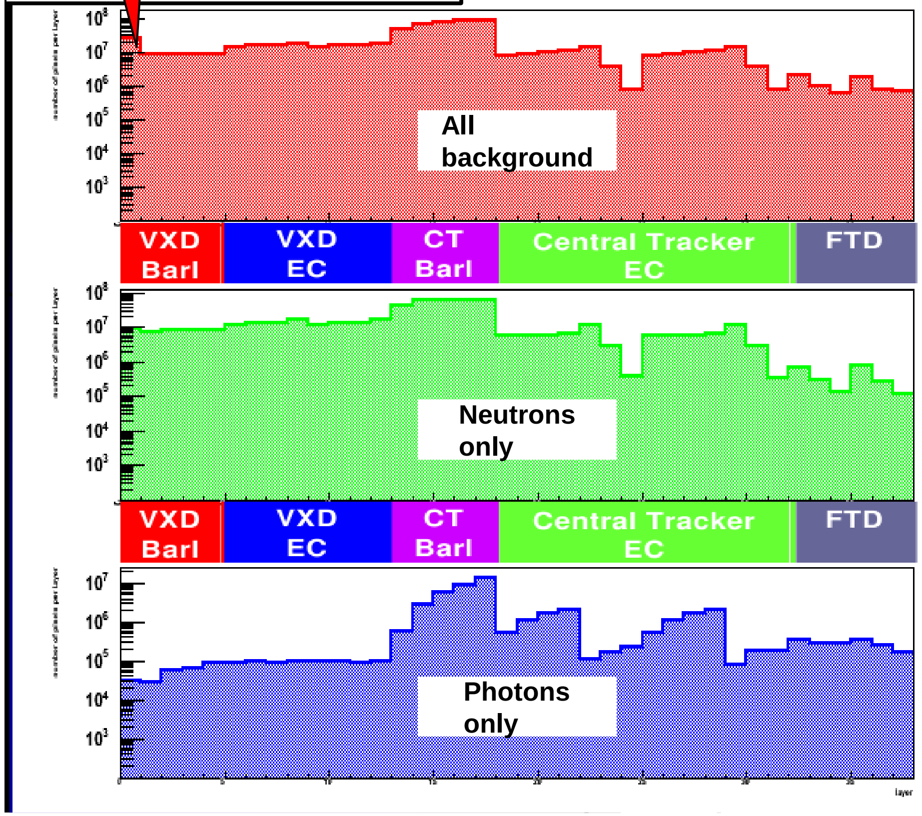


- Background yields/bunch on 10^0 nozzle surface and MARS thresholds

	γ	n	e^{+-}	μ^{+-}
Yield	1.77e+08	0.40e+08	1.03e+06	0.80e+04
Ethr, MeV	0.2	0.1	0.2	1.0

N. Terentiev (CMU/Fermilab) Muon Collider 2011 27 June – 01 July, 2011 7

Pixels per layer



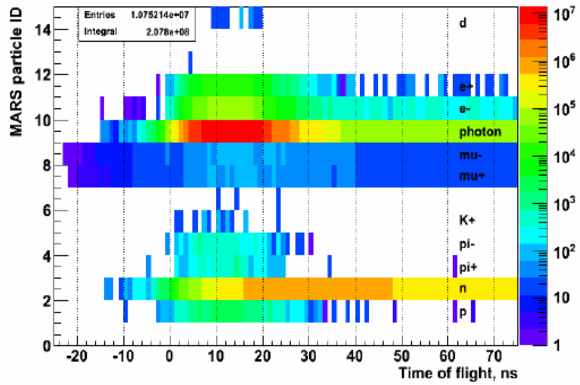
Actual pixels Turned on

Total clusters found: **4x10^7**
Too many for any practical track reconstruction systems!

A. Mazzacane
N. Terentiev

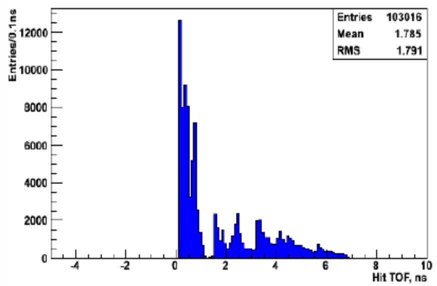
but.. Background is off time

- **MARS particle TOF and their ID (see in backup Ekin, Pt and Z)**
  - Time of flight (TOF) wrt. bunch crossing time, on a surface of the 10^0 nozzle
  - In window 0 <= TOF <= 25 ns:
    ~21% of neutrons, ~36% of muons, >94% of other particles
  - TOF < 0 corresponds to the particles making straight path to detector



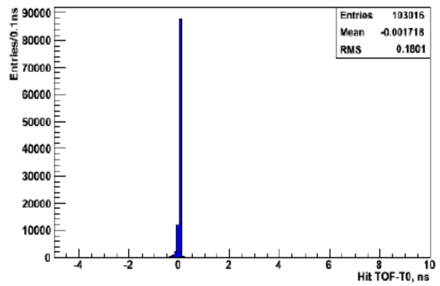
- **Vertex and tracker timing for IP muons**

TOF



RMS ~ 1.8 ns

TOF – T0



RMS ~ 0.18 ns

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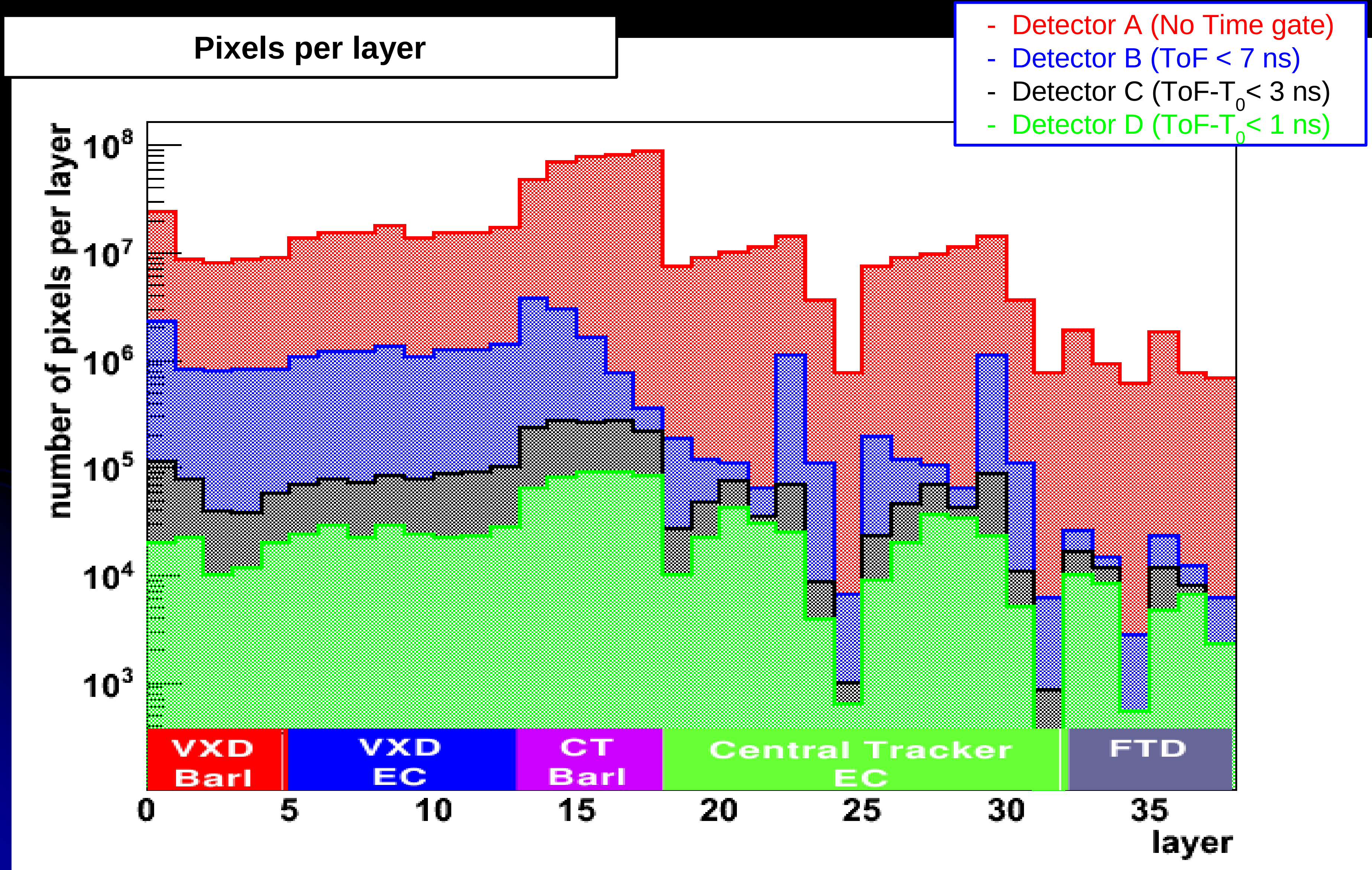
  - Det. D - Acquires data in a 1 ns time gate tuned to pixel distance from IP (extreme timing capabilities)

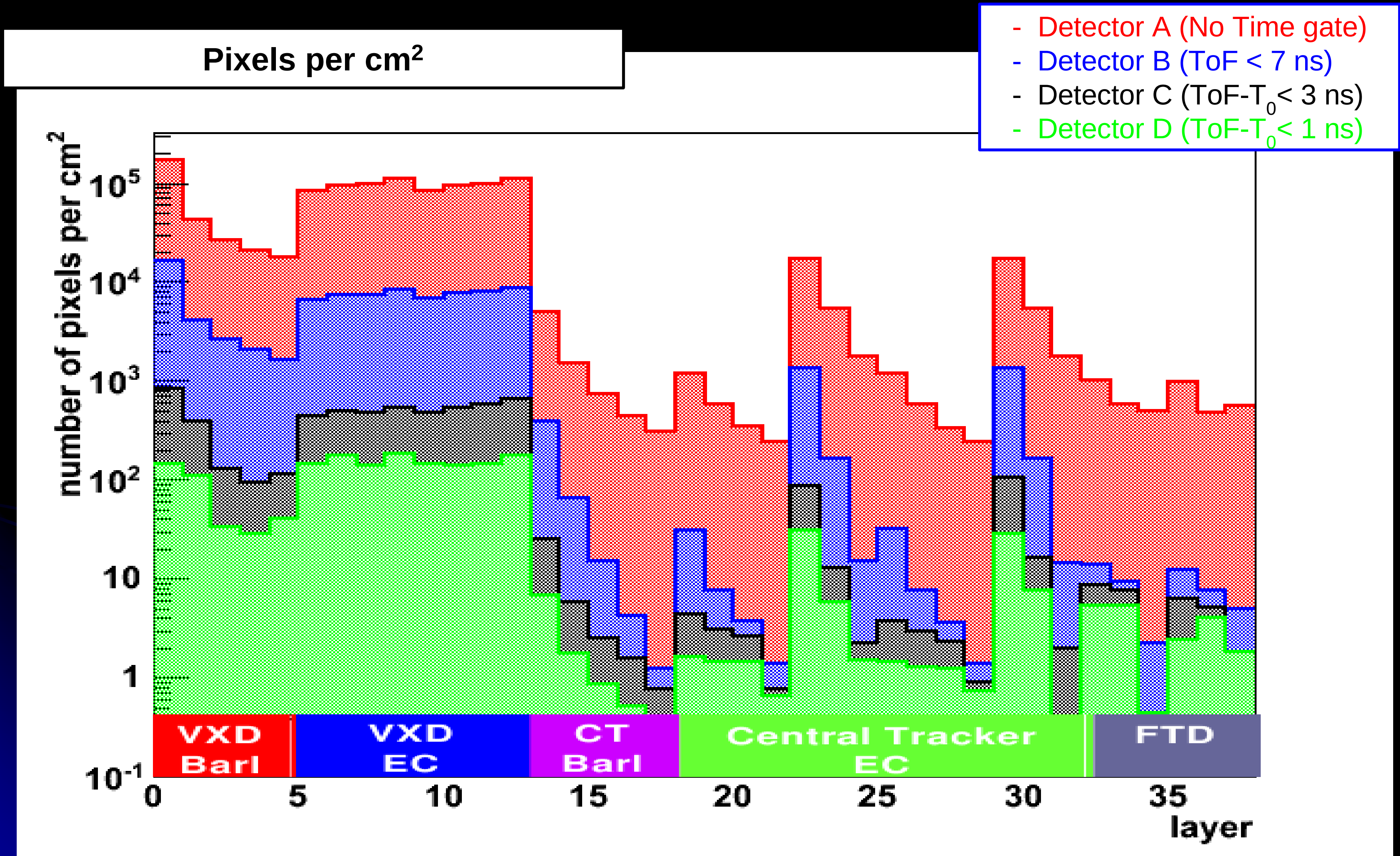
Full simulation of bkg

Total Pixels vs Layer for 4 detectors

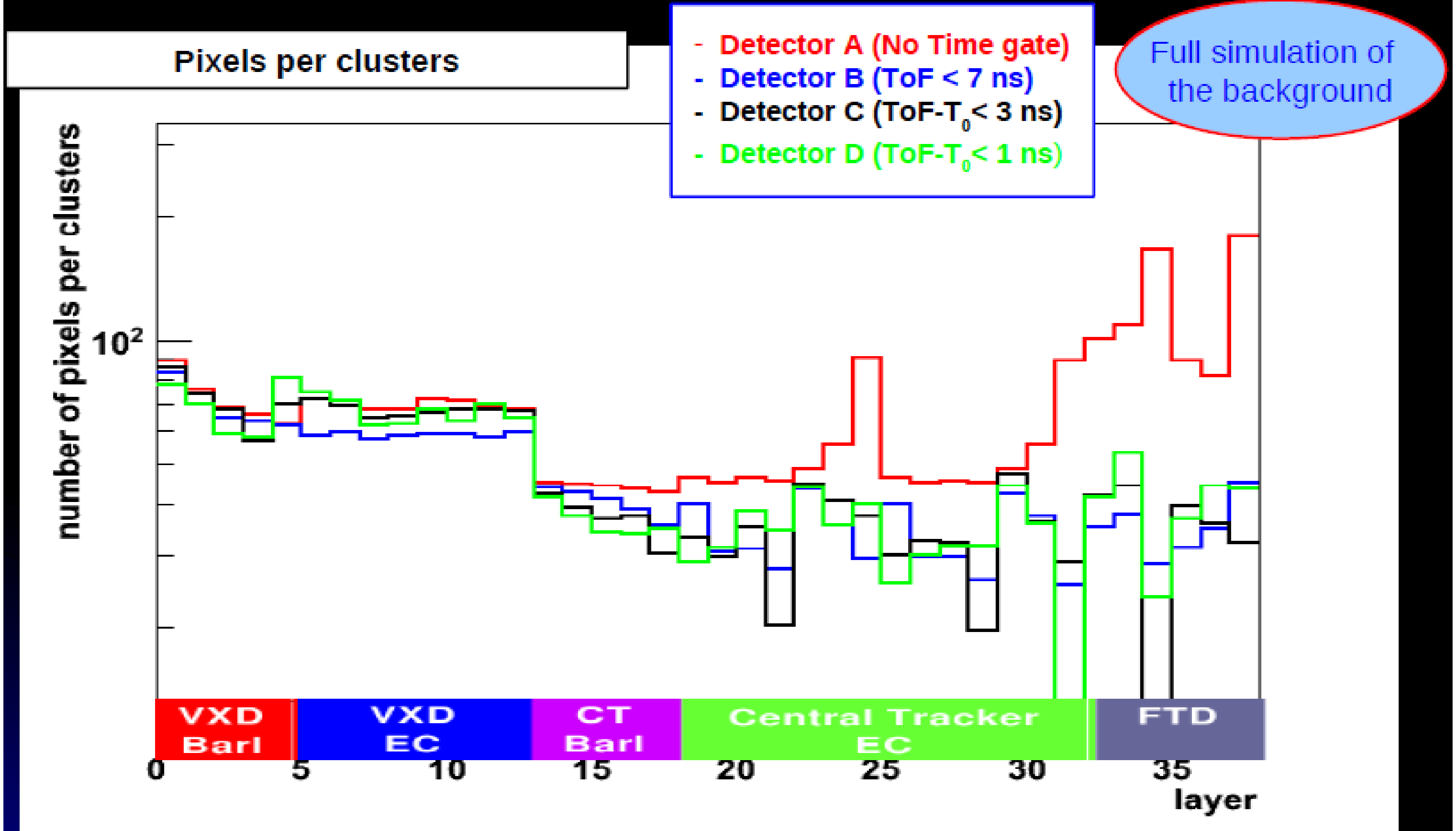


Full simulation of bkg

Pixels occupancy vs Layer for 4 detectors



Pixels Occupancy for 4 detectors



Reconstructed Background Tracks (from Kalman filter)

Detector type	Reconstructed Tracks (full simu)	Reconstructed Tracks (fast simu)
Det. A (no timing)	Cannot calculate	Cannot calculate
Det. B (7 ns fixed gate)	75309	64319
Det. C (3 ns adjusteble gate)	6544	4639
Det. D (1 ns adjusteble gate)	1459	881

Full reconstruction is paramount when combinatorics is relevant

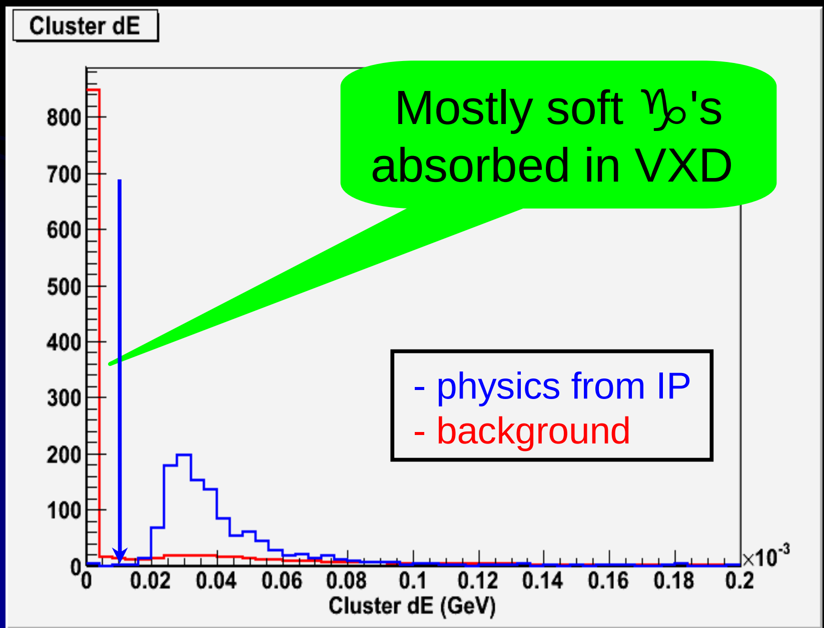
Reconstructed Background Tracks (from Kalman filter)

Detector type	Reconstructed Tracks (full simu)	Reconstructed Tracks (fast simu)
Det. A (no timing)	Cannot calculate	Cannot calculate
Det. B (7 ns fixed gate)	75309	64319
Det. C (3 ns adjusteble gate)	6544	4639
Det. D (1 ns adjusteble gate)	1459	881

STILL TOO MANY RECONSTRUCTED TRACKS FROM BACKGROUND

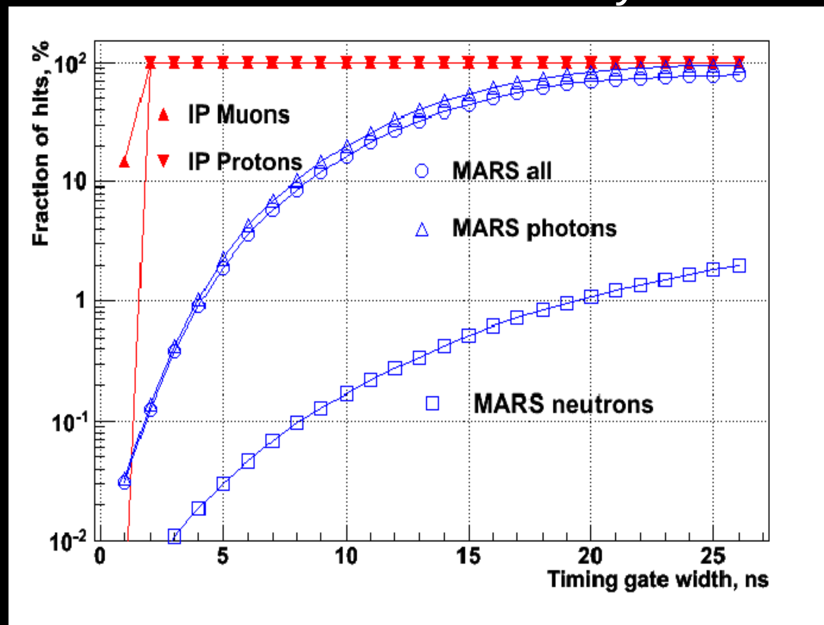
Compare dE/dx and timing for signal vs background

	Kalman Reconstruction	Clusters
Physics: 100 μ (0.2–200)GeV/c	92 (include geom. eff.)	1166
Machine Background	-	4 x 10^7



Choose ΔE threshold 10 KeV (2400 e-)

N. Terentiev's study

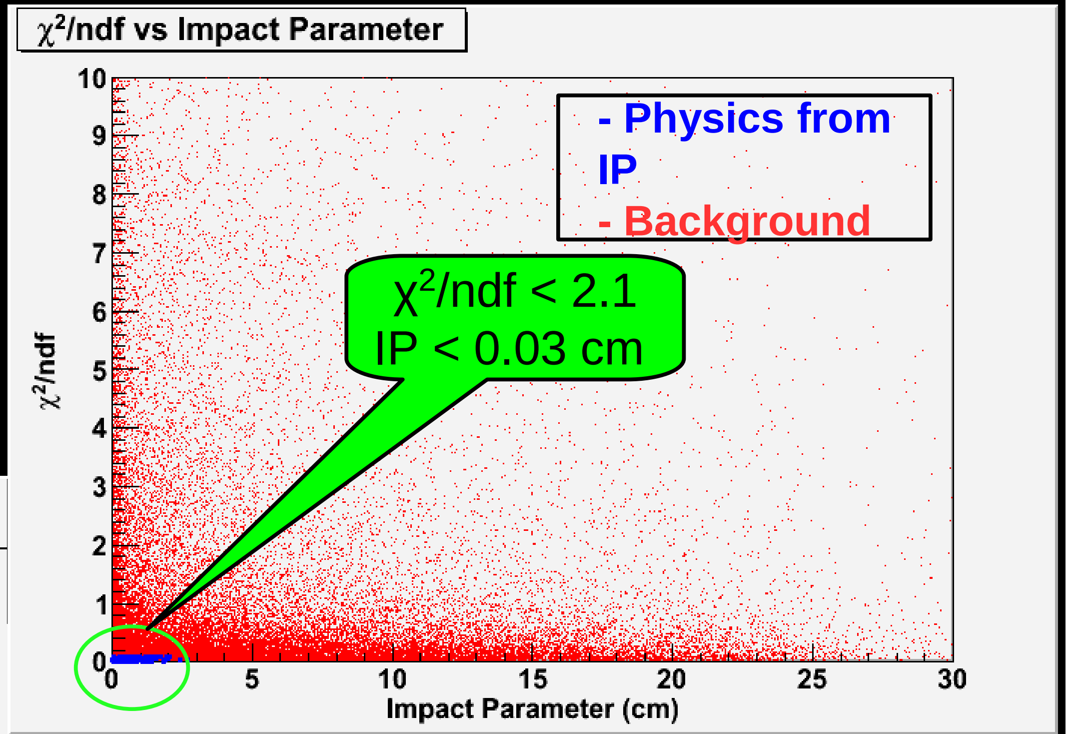


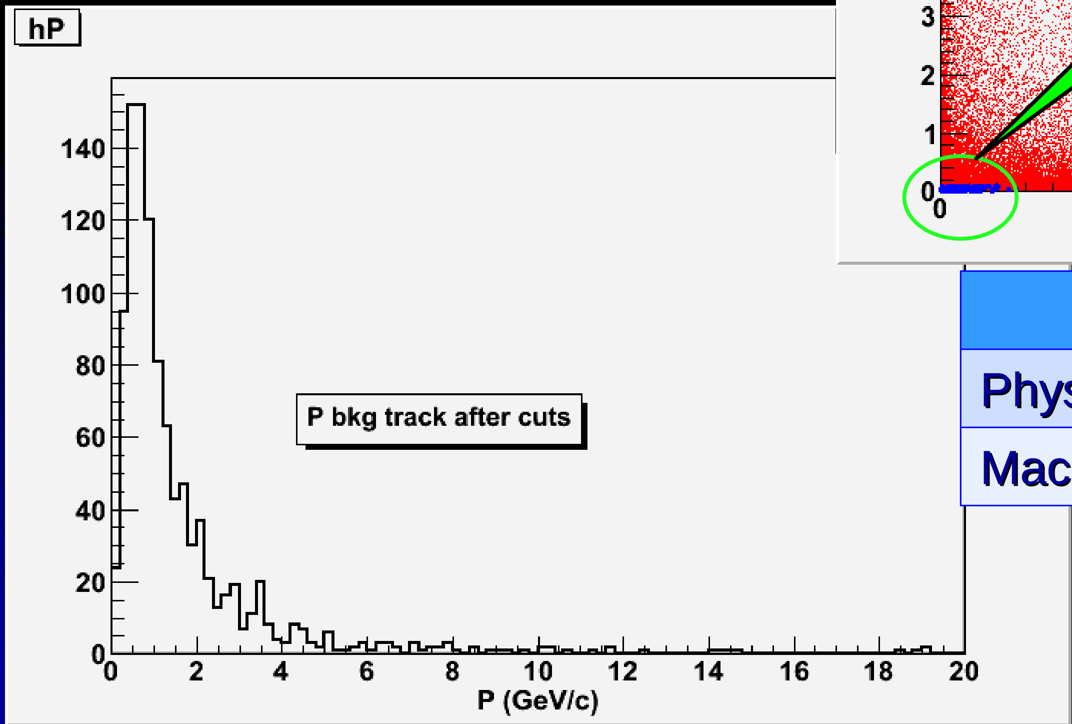
Choose Time Gate Width

Physics vs Background:

a strategy to disantangle reconstructed tracks from IP

Studies based on half background



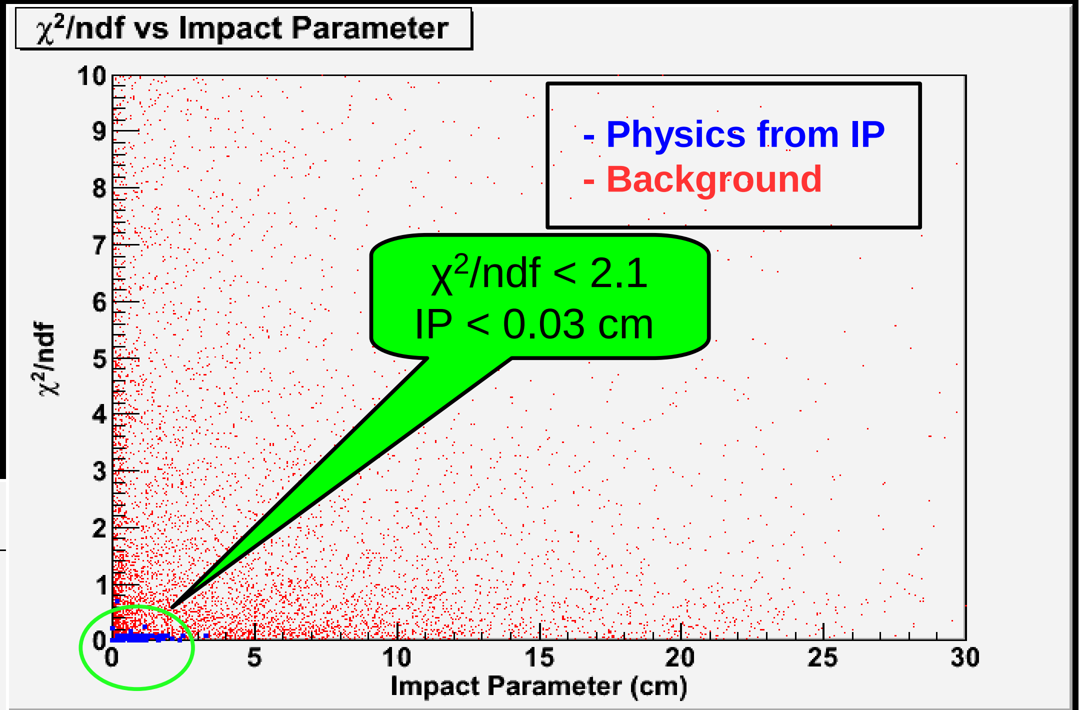


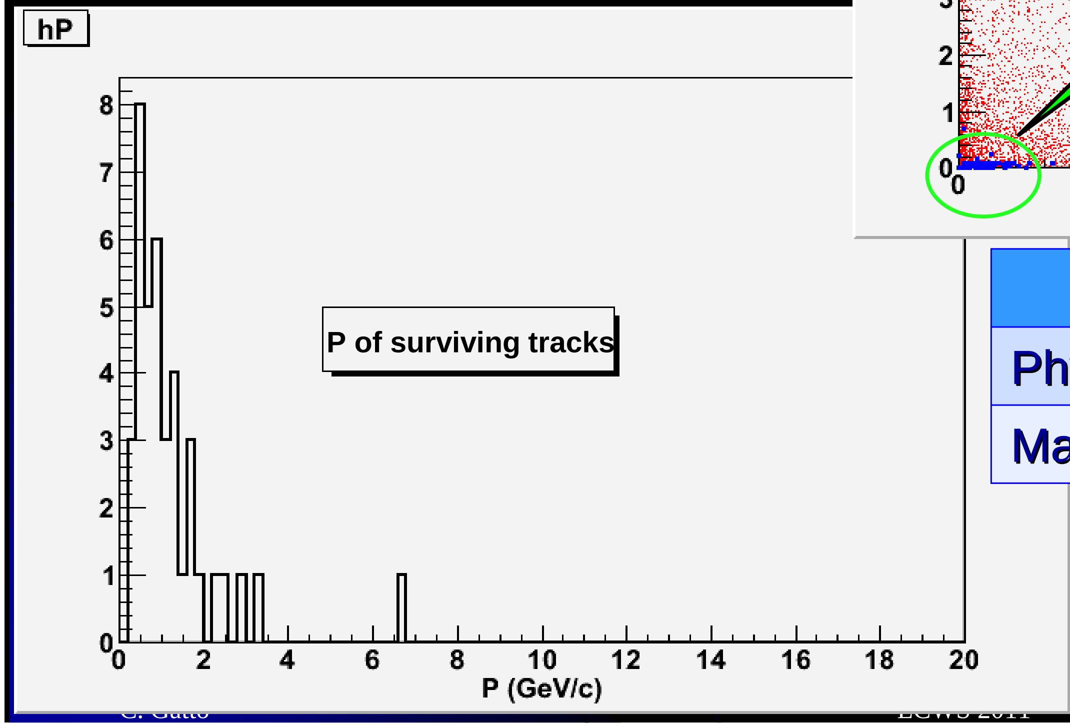
	Surviving tracks
Physics: 100 μ	89
Machine background	2110

3 lost

Physics vs Background in Det. B:
a strategy to disantangle reconstructed tracks from IP

Full simulation of physics + bkg



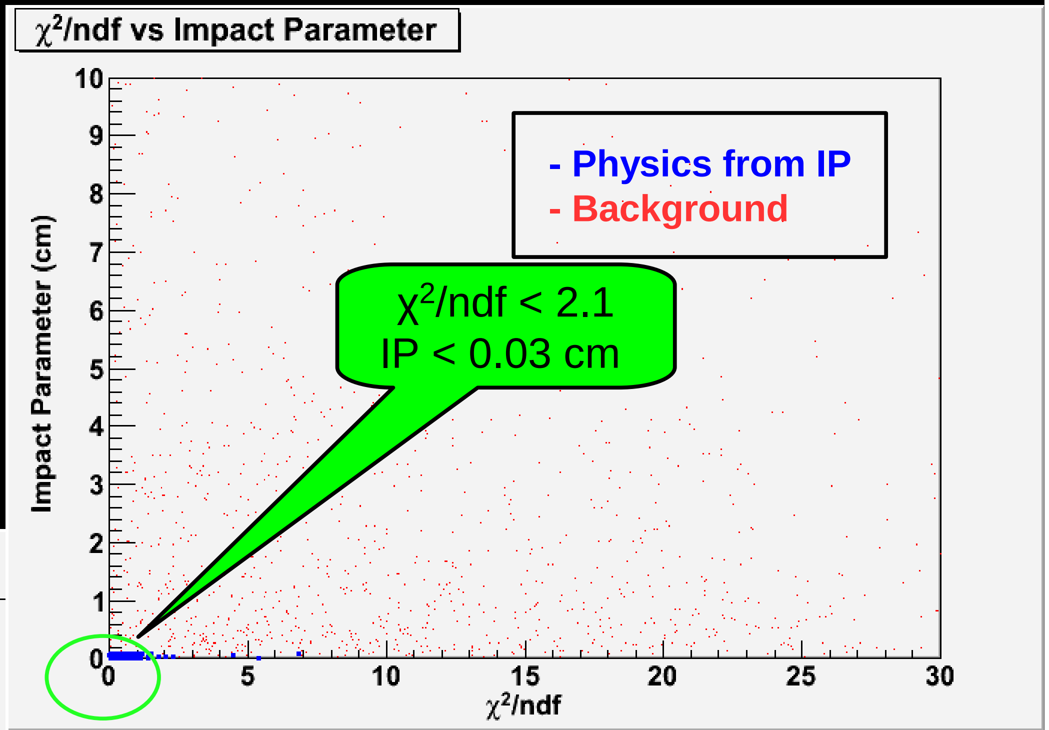


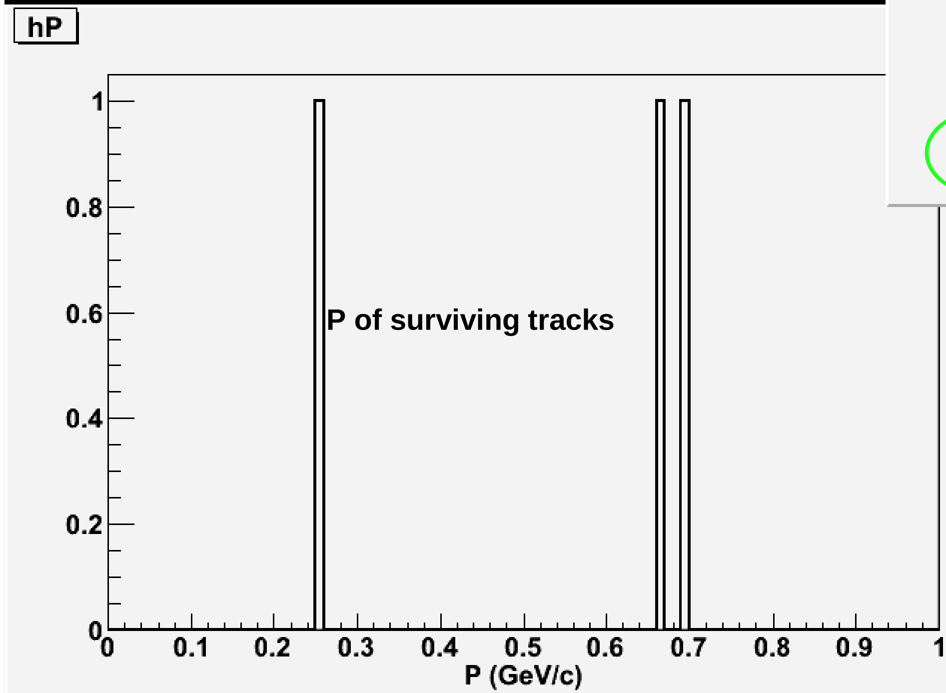
	Surviving tracks
Physics: 100 μ	92
Machine background	41

no lost

Physics vs Background in Det. D:
a strategy to disantangle reconstructed tracks from IP

Full simulation of physics + bkg





	Surviving tracks
Physics: 100 μ	92
Machine background	3

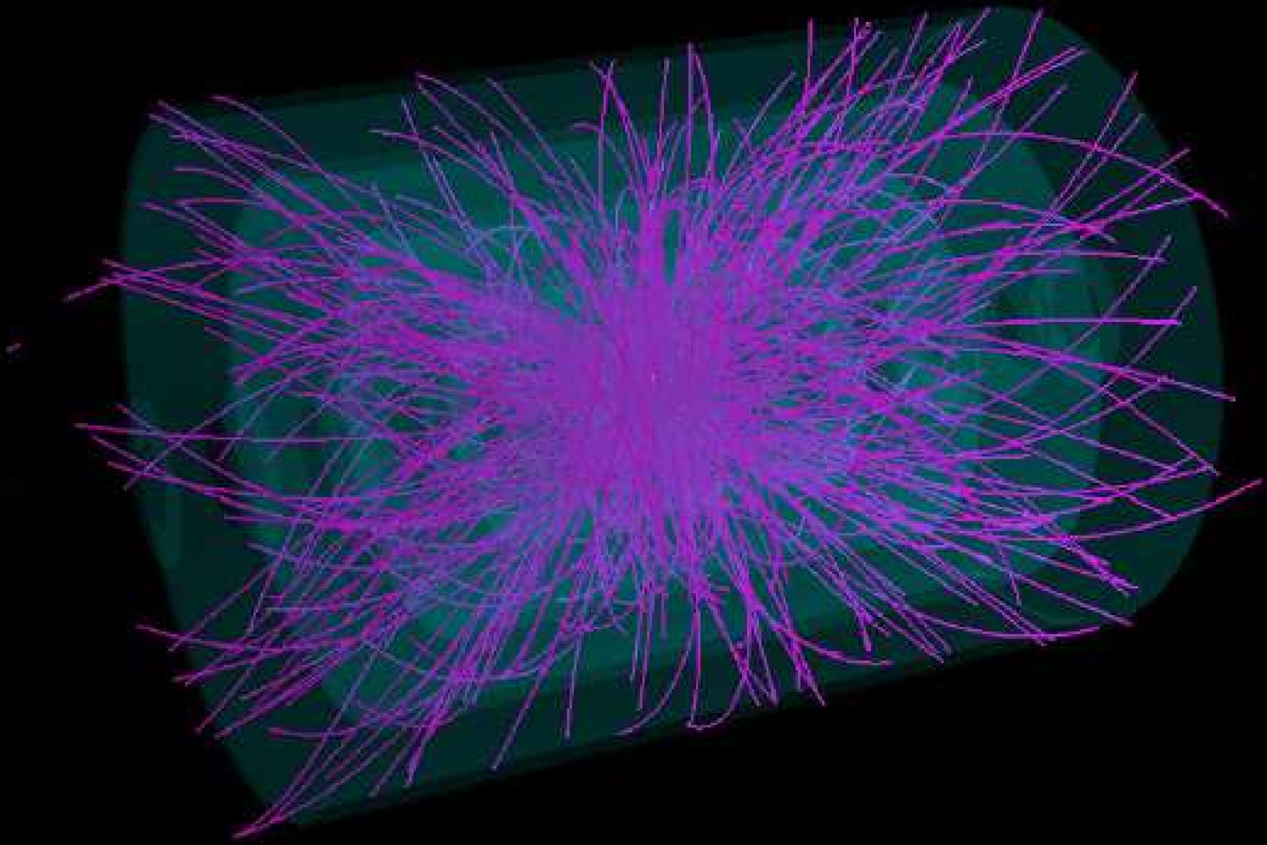
no lost

Reconstructed Background Tracks (from Kalman filter) after χ^2 and Impact Point cuts

Detector type	Reconstructed Tracks (full simu)	Reconstructed Tracks (fast simu)
Det. A (no timing)	Cannot calculate	Cannot calculate
Det. B (7 ns fixed gate)	475	405
Det. C (3 ns adjusteble gate)	11	8
Det. D (1 ns adjusteble gate)	3	1

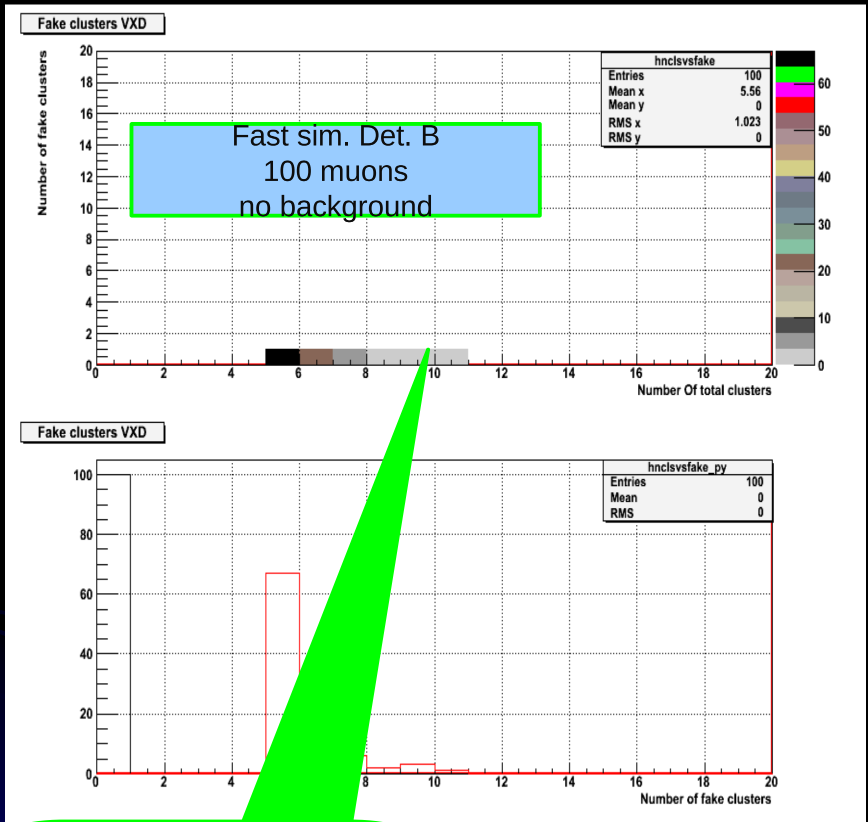
Full reconstruction is paramount when combinatorics is relevant

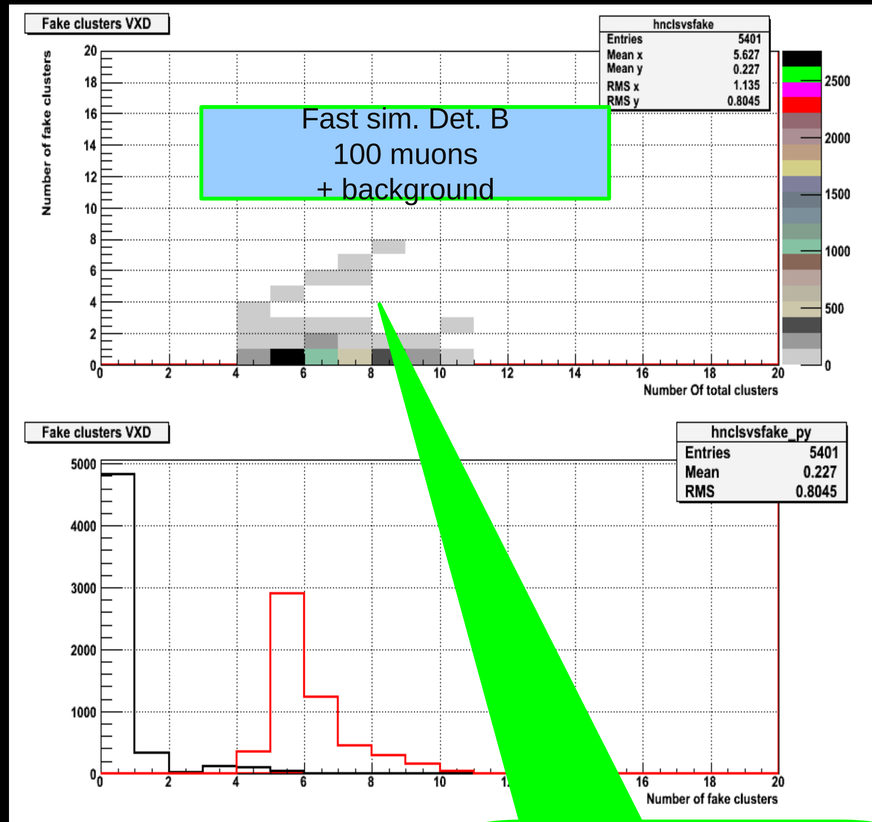
Event Display of Surviving Background tracks



Fast simulation of Det. B

Effects of background Hits on Physics





no fake cluster

physics event = 100 muons

< 5% of tracks have > 1 fake cluster

Effects on track parameter resolution are unaffected by background

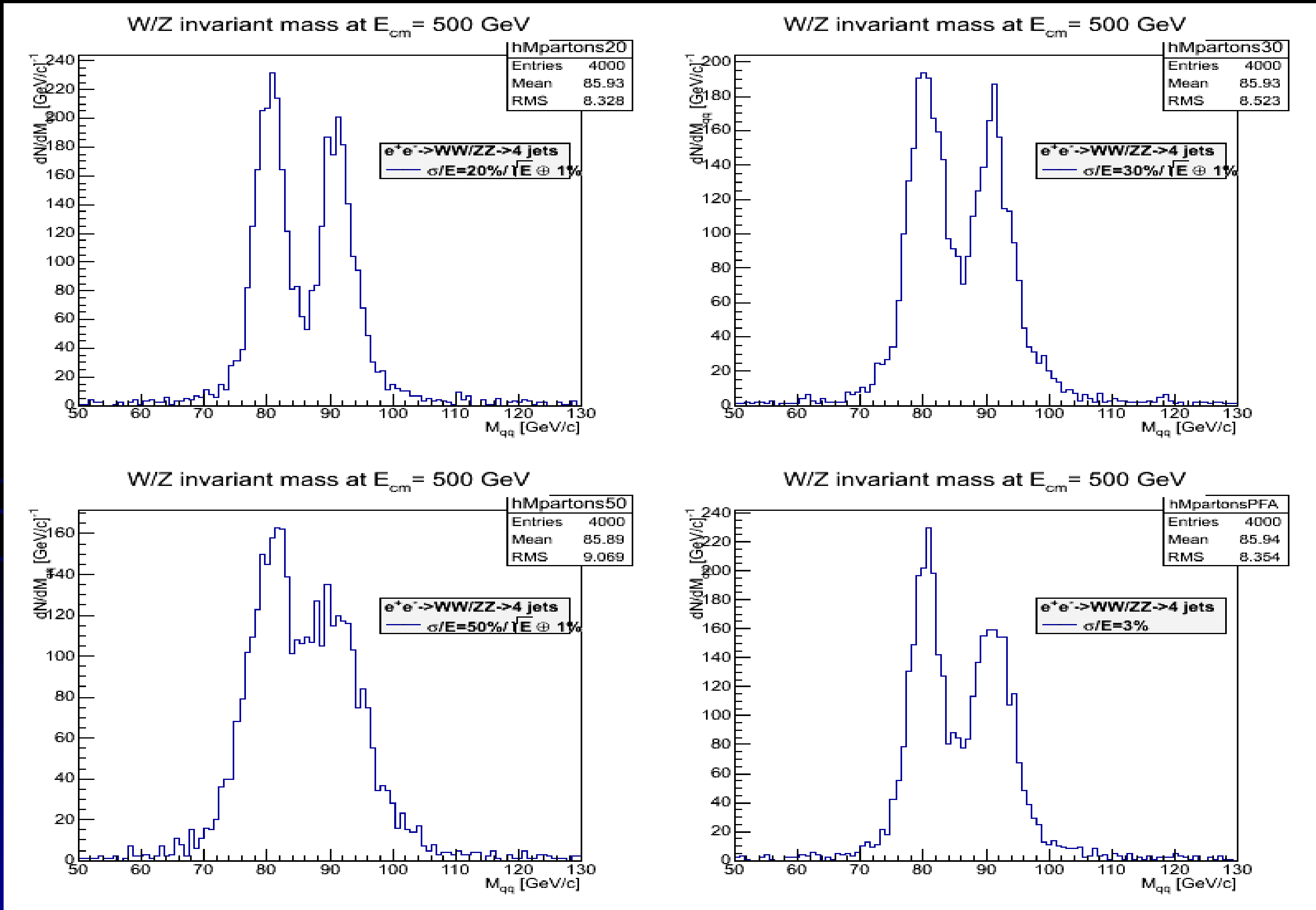
Calorimetry Studies

Fundamental issues at a μCollider

1. Resolution: how good for W/Z separation?
   – Run a Toy Montecarlo with several σ(E) models
   – Assume 10 mrad jet-axis resolution and perfect pattern recognition
2. Longitudinal segmentation
3. Timing
   – Need a full study including instrumentation effects

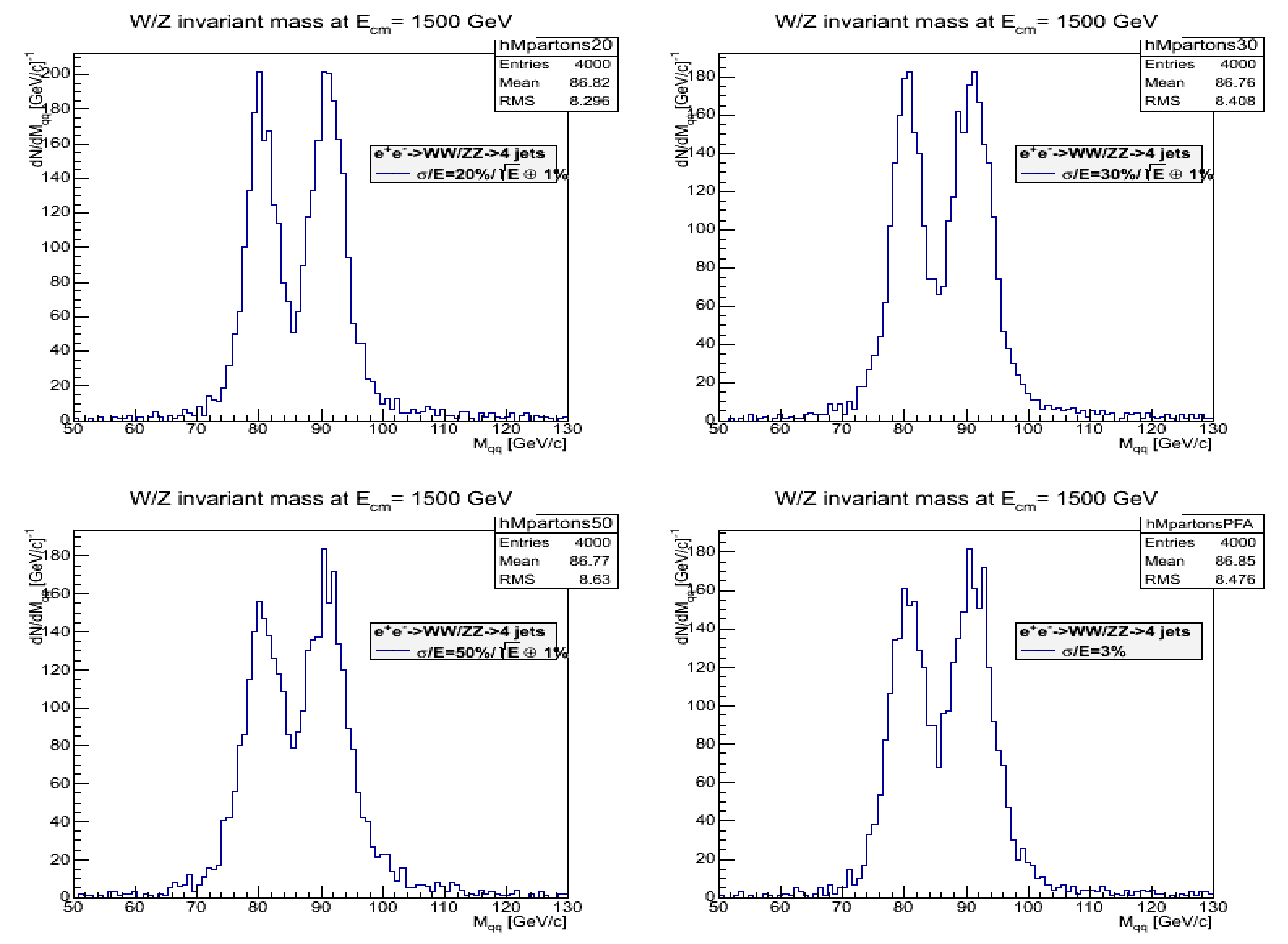
W/Z separation at ILC

Toy Montecarlo



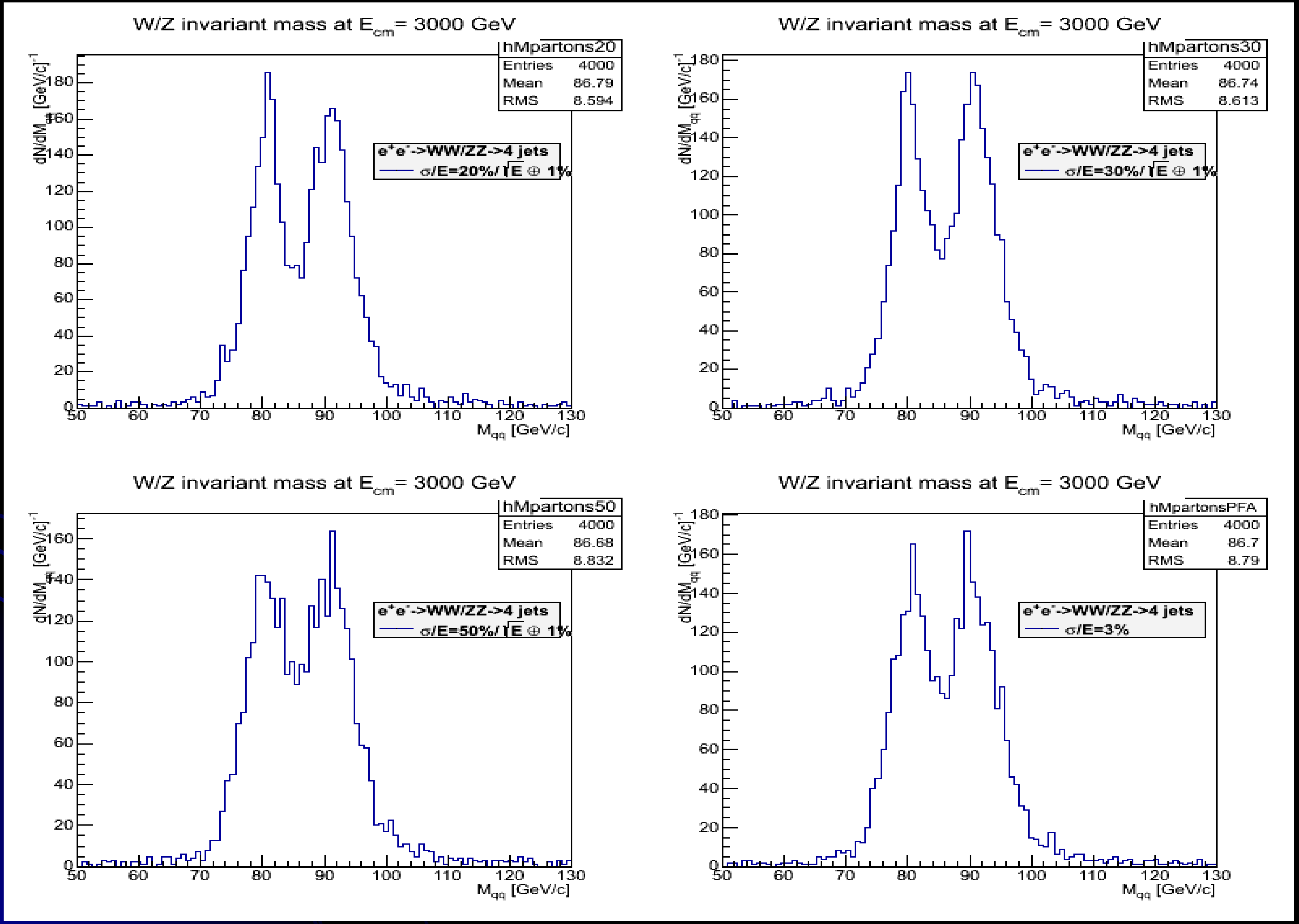
W/Z separation at CLIC/µColl

Toy Montecarlo



W/Z separation at CLIC/μColl

Toy Montecarlo

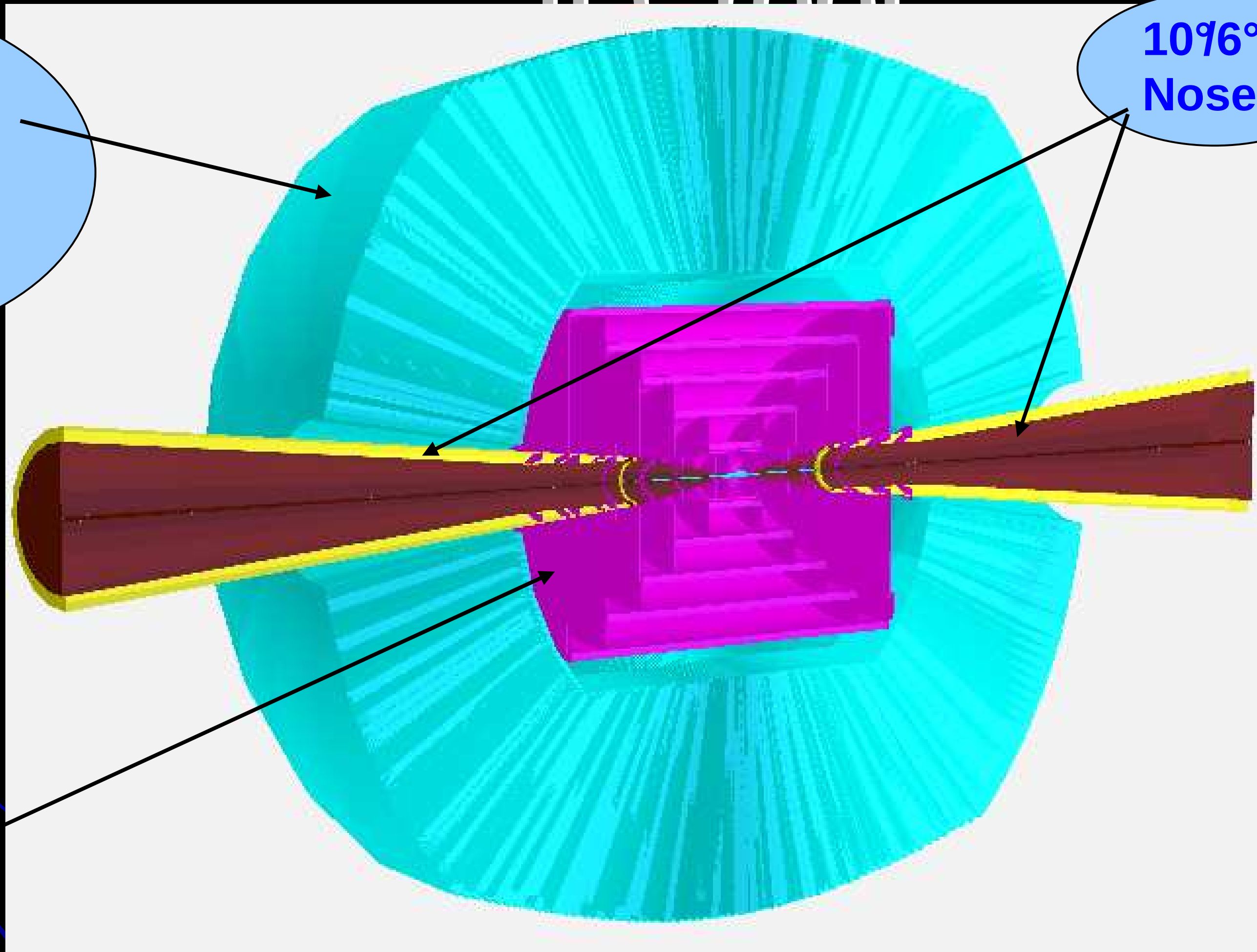


Calorimeter Geometry in ILCroot

Dual Readout

1) ADRIANO (full simulation)
2) TAHCAL (fast simulation)

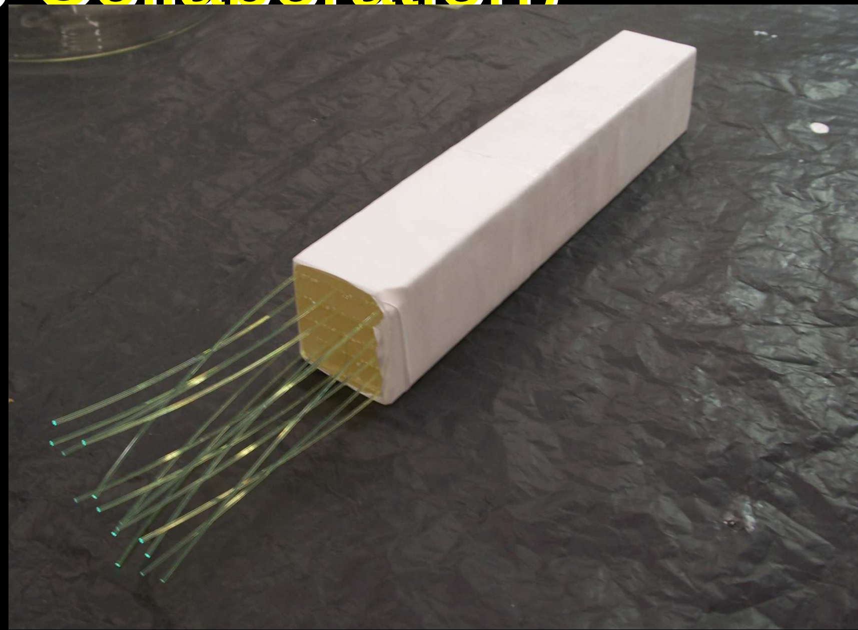
10°/6° Nose



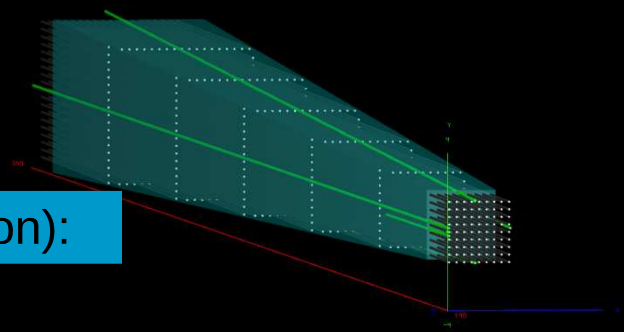
Tracker

ADRIANO Calorimeter (FNAL-INFN Collaboration) is used for the studies presented here

A Dual Readout Integrally Active Non-segmented Option (T1015 Collaboration)



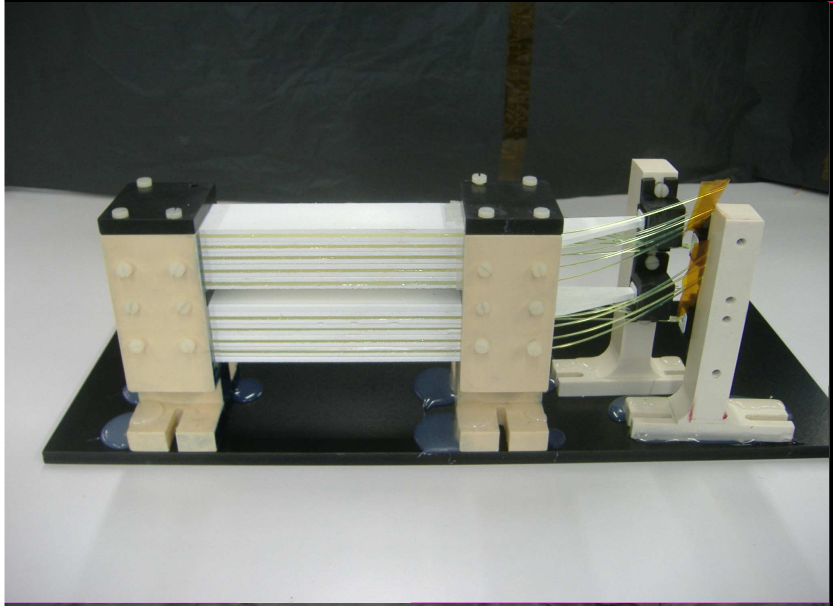
- Lead glass + scintillating fibers
- ~1.4° tower aperture angle
- 180 cm depth
- ~ 7.5 λ_{int} depth
- >100 X_0 depth
- Fully projective geometry
- Azimuth coverage
- down to ~8.4° (Nozzle)
- Barrel: 16384 towers
- Endcaps: 7222 towers



Expected resolution (see my talk at calorimetry session):

$$\sigma_E / E = 30\% / \sqrt{E}$$

ADRIANO Simulation Details



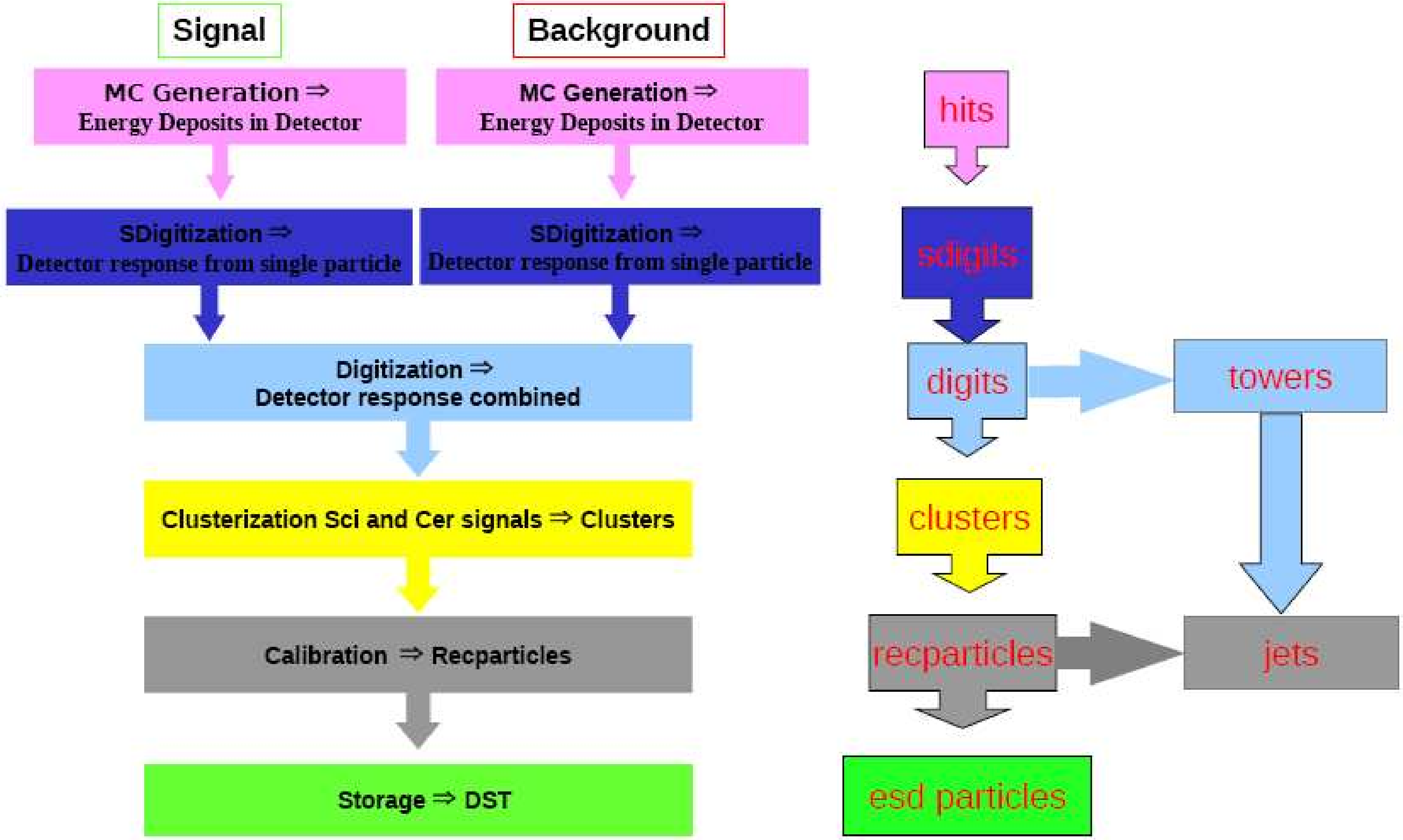
- WLS's collect Cerenkov photons from lead glass (front and back readout)
- Generate and transport scintillating photons (front and back readout for fibers in the core of the tower; only back readout for WLS and Q20)

Simulations include:

- τ_{scifi} = 2.4 nsec (Kuraray SCSF81)
- τ_{WLS} = 2.7 nsec (Bicron BCF92)
- SiPM with ENF=1.016
- Fiber non-uniformity response = 0.8% (scaled from CHORUS)
- Threshold = 3 p.e. (SiPM dark current< 50 kHz)
- ADC with 14 bits
- Gaussian noise with σ= 1 p.e.

Already underwent two test-beams at FNAL

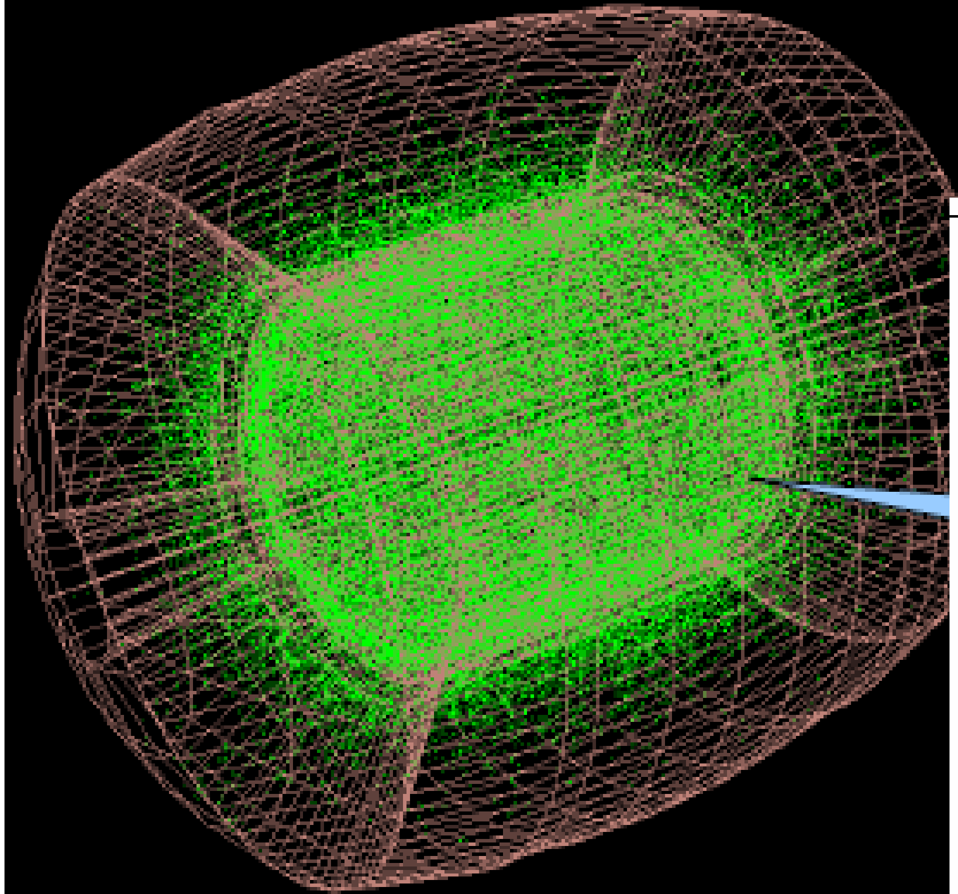
LCroot: for Full Calorimetry

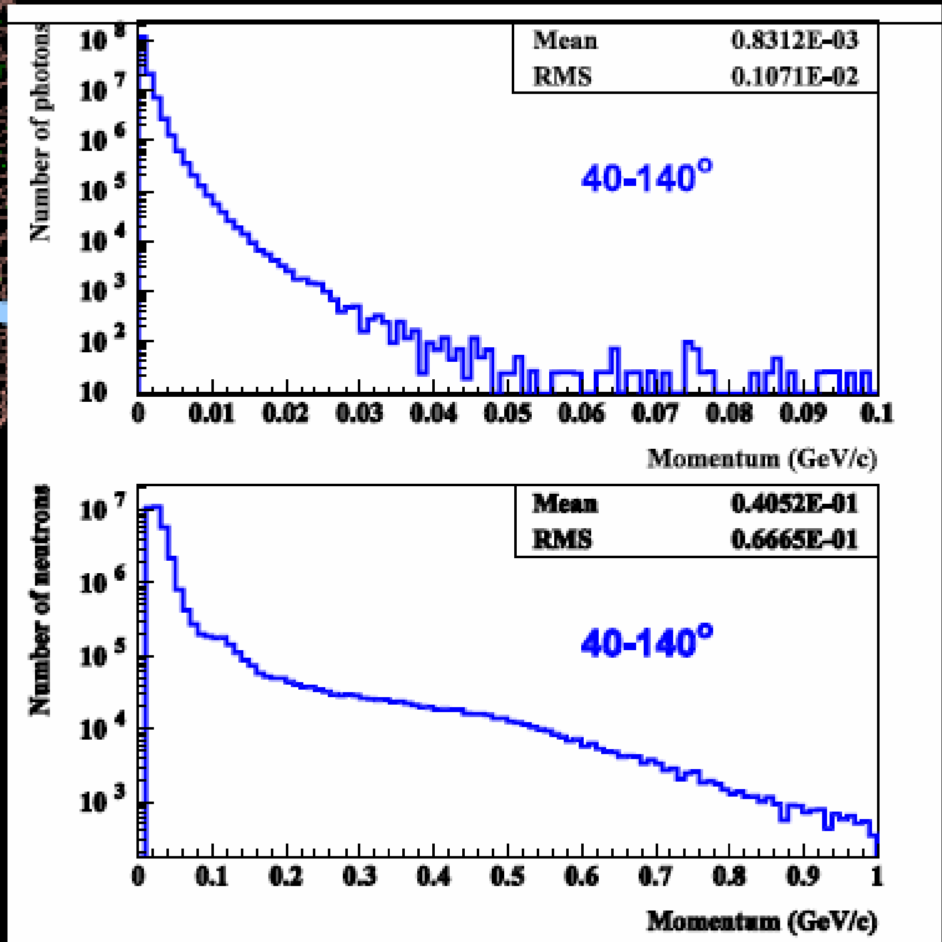


S. Striganov
V. Di Benedetto

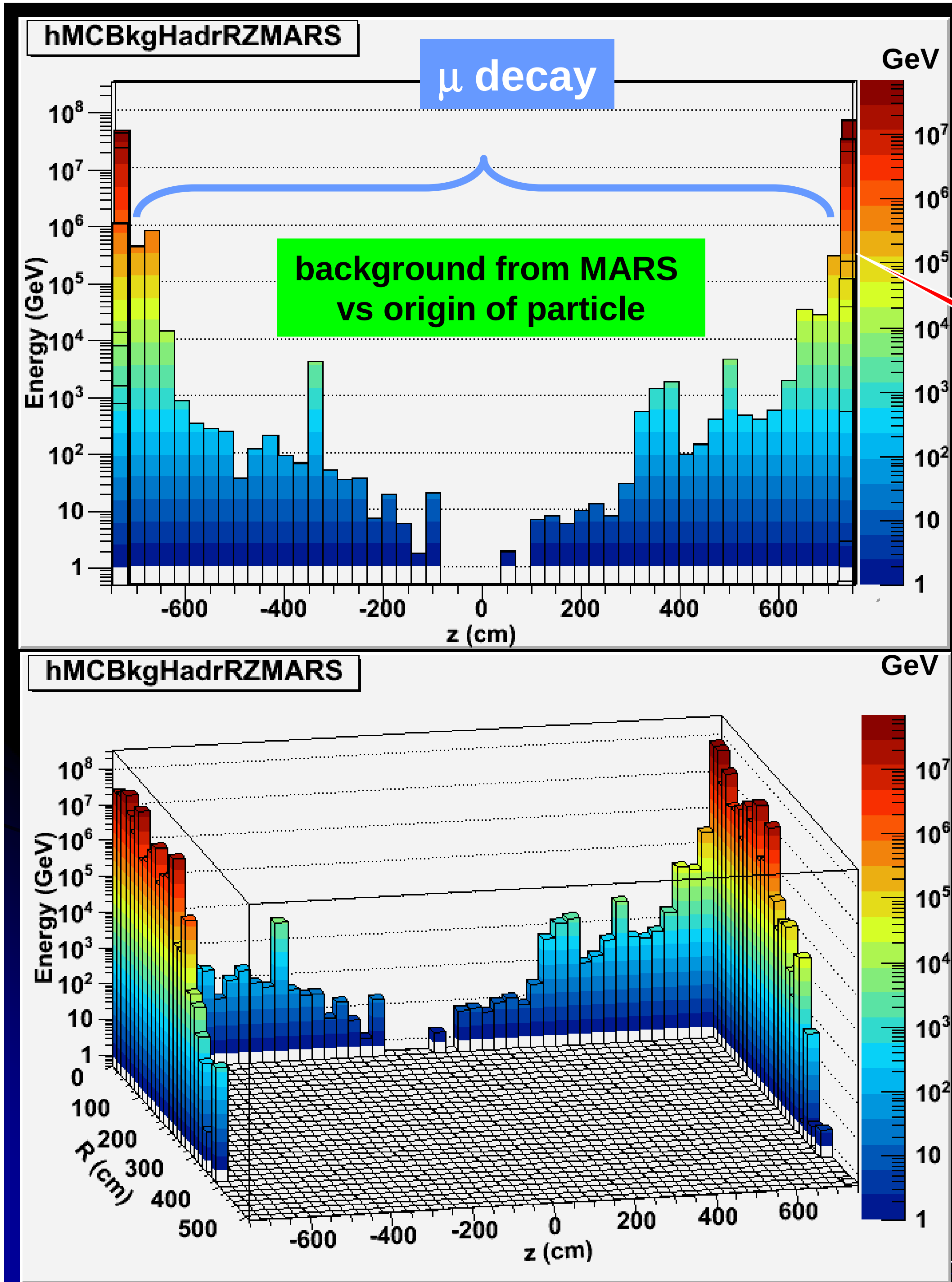
Background Entering the Calorimeter

γ and neutrons entering the calorimeter





4% of a background event depicted



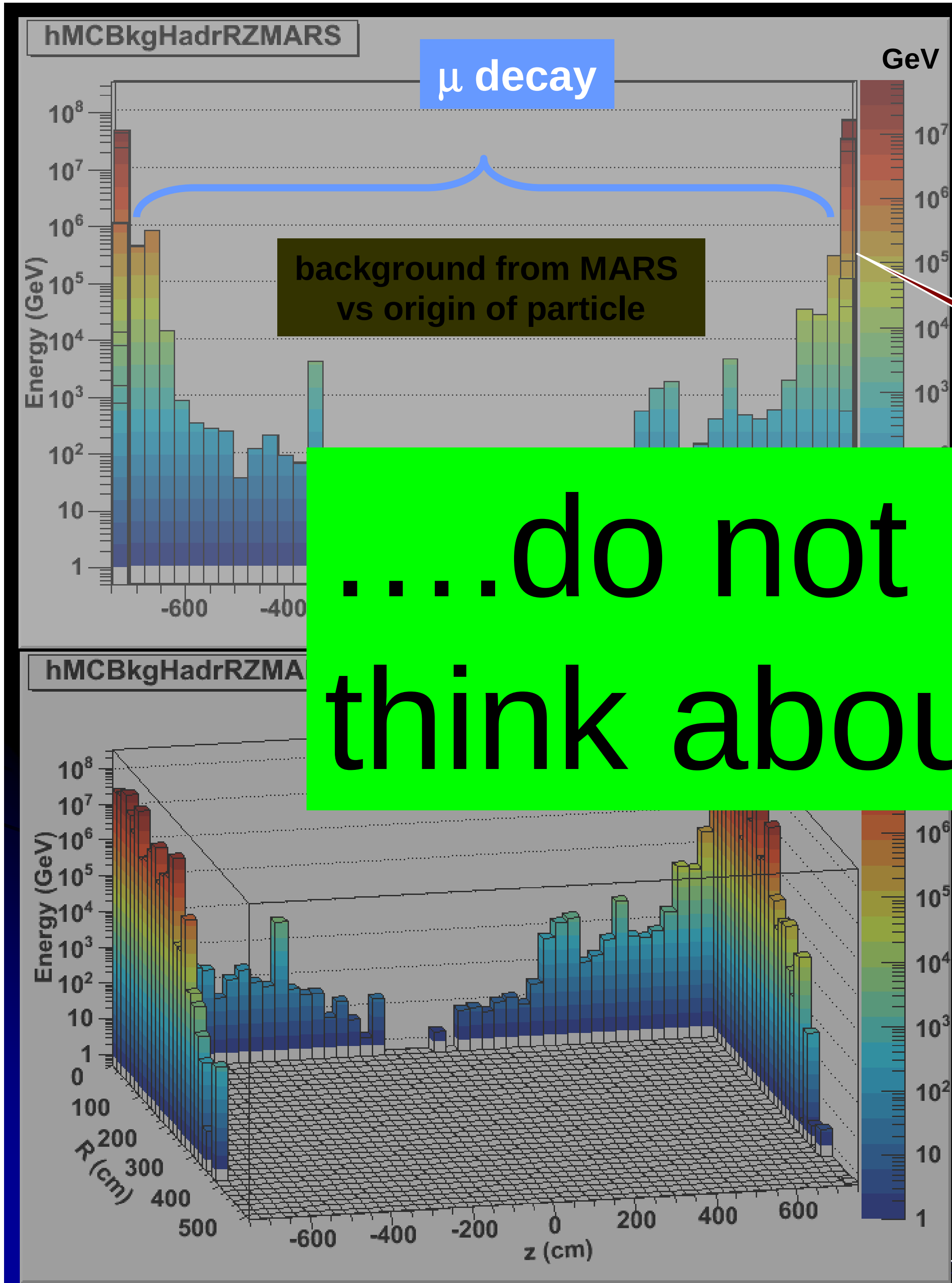
Start with a plain vanilla calorimeter (non segmented & no timing)

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)

6° Nose



Start with a plain vanilla calorimeter (non segmented & no timing)

Entering detector area at 7.5 m

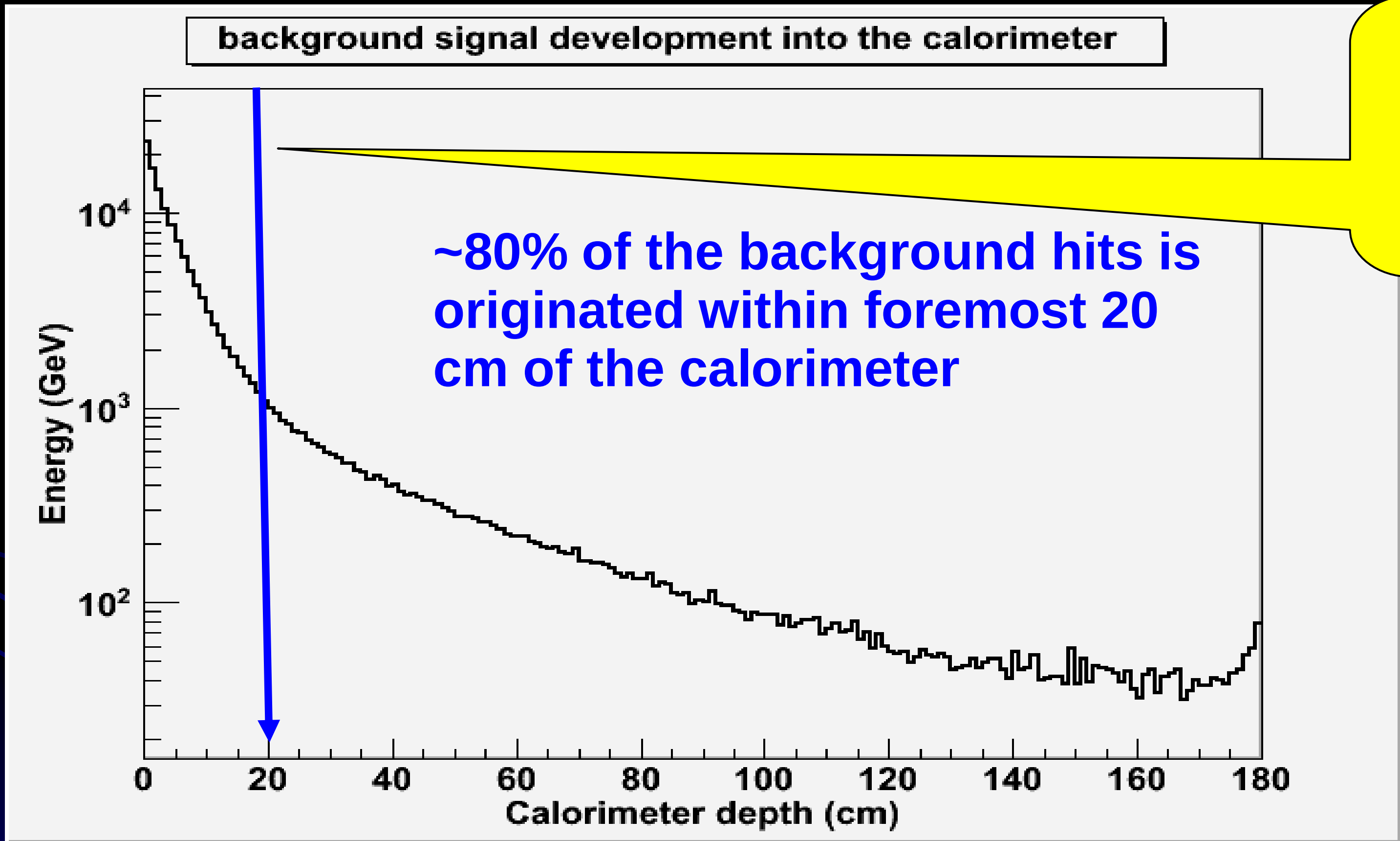
….do not even think about….

… of particle (1bin= 30cm)

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

6° Nose

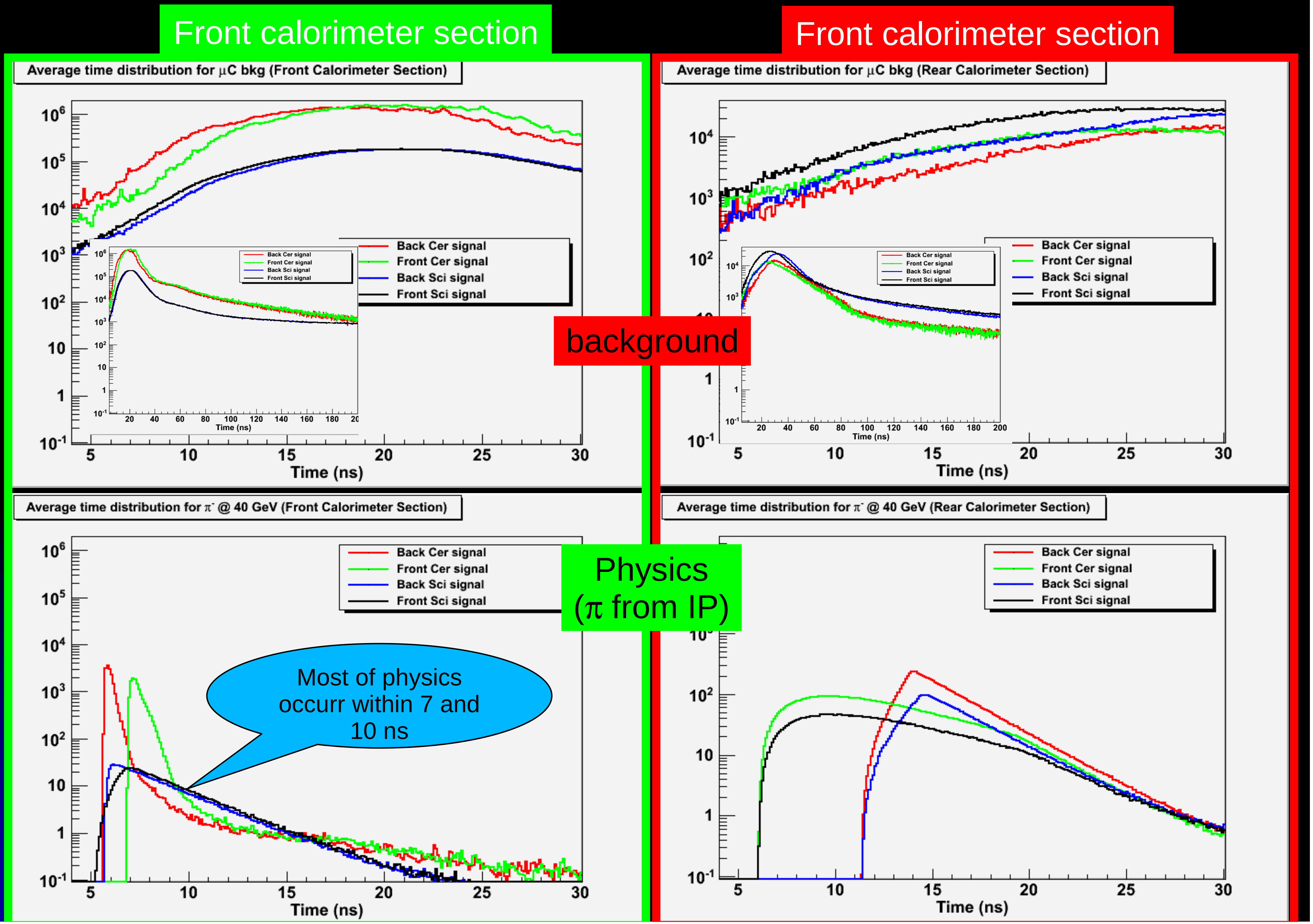
First step: look at the longitudinal energy deposition in the calorimeter produced by 1 background event



Longitudinal segmentation of the calorimeter is mandatory

Minimal segmentation at μCollider requires a 20cm front section to stop the overwelming EM background

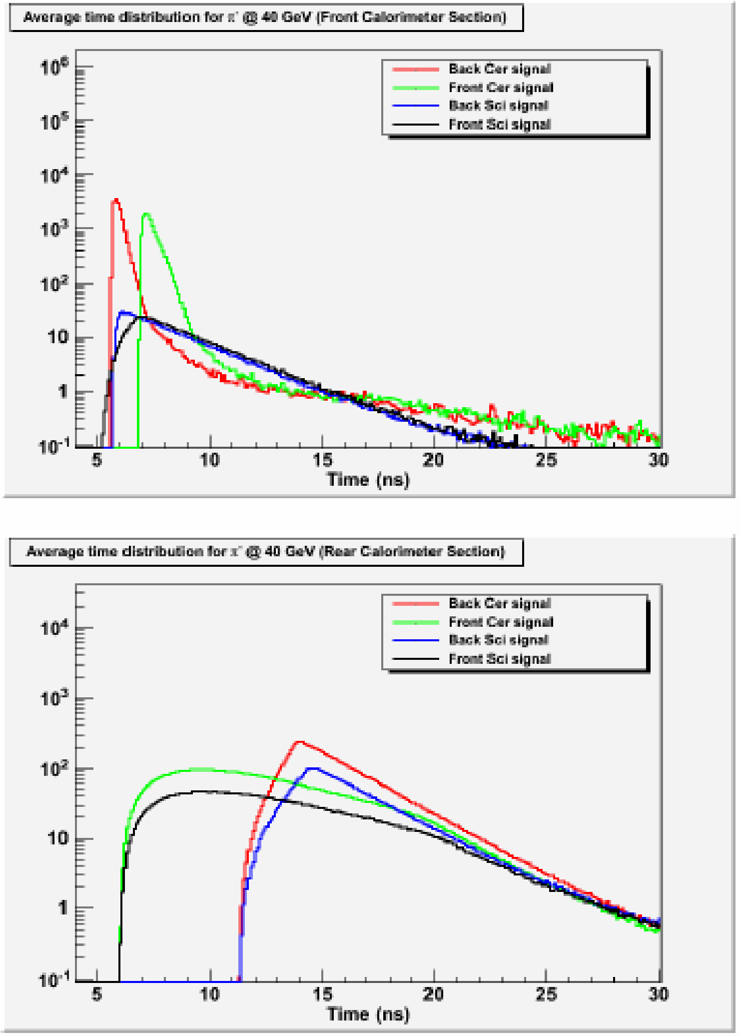
Next step: Time distribution of signal vs background



Three Detector Configurations under Study

Front Section

Rear Section

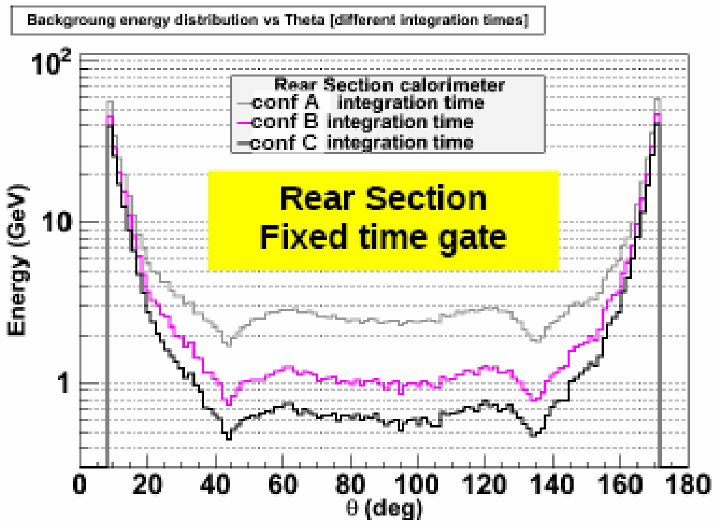


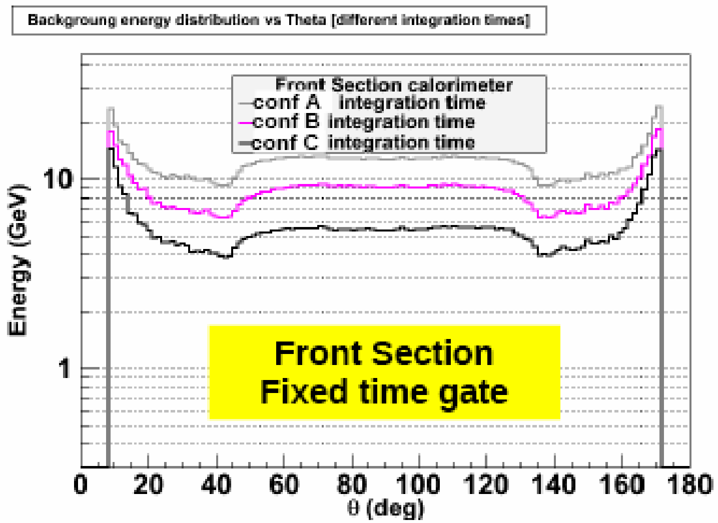
Integration time gate for each section				
	Front Section		Rear Section	
	Scint	Cer	Scint	Cer
conf A	100 ns	100 ns	100 ns	100 ns
conf B	20 ns	15 ns	25 ns	25 ns
conf C	15 ns	6 ns	22 ns	22 ns

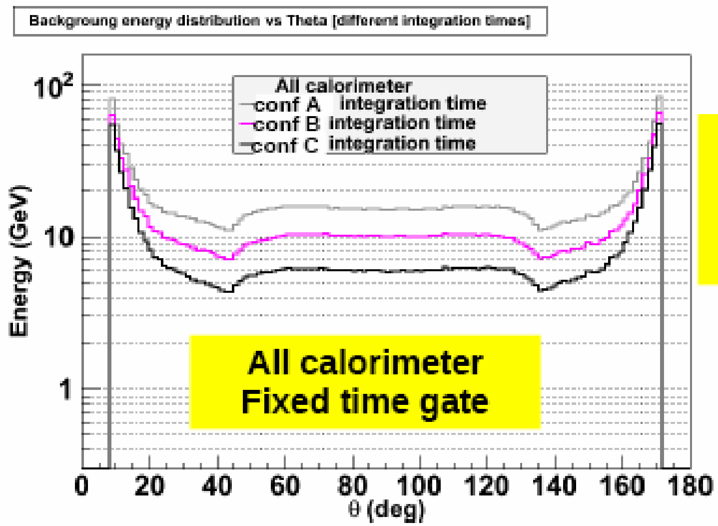
- **In conf B 95% of the signal is integrated**
- **In conf C 90% of the signal is integrated**

Angular distribution of background for fixed integration times

1 entry = <1 tower>

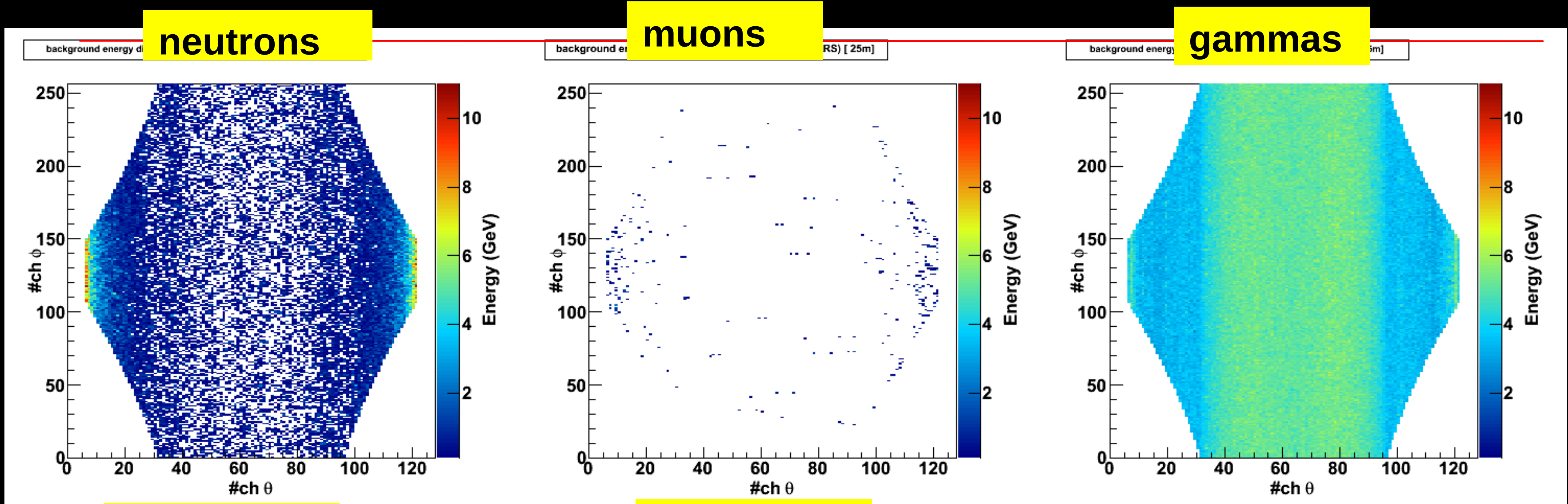


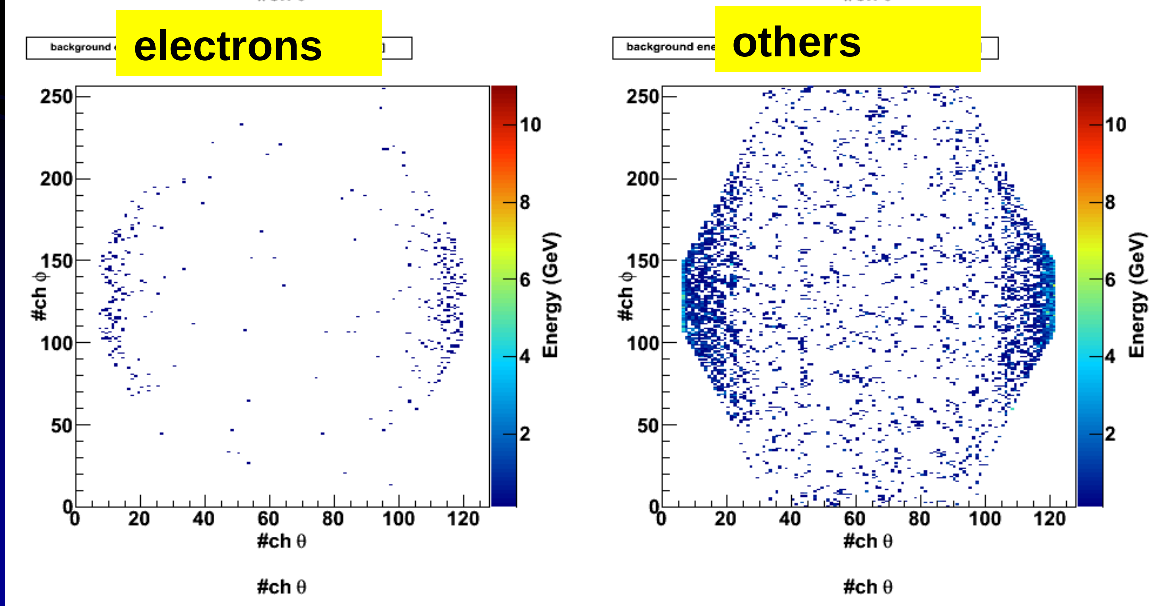




The background reduction is higher going from 25 to 15 ns than going from 100 to 25 ns
Note: the background energy peak is between 20 – 35 ns

Energy distribution per tower. Calorimeter Front Section Integration time gate 15 ns.



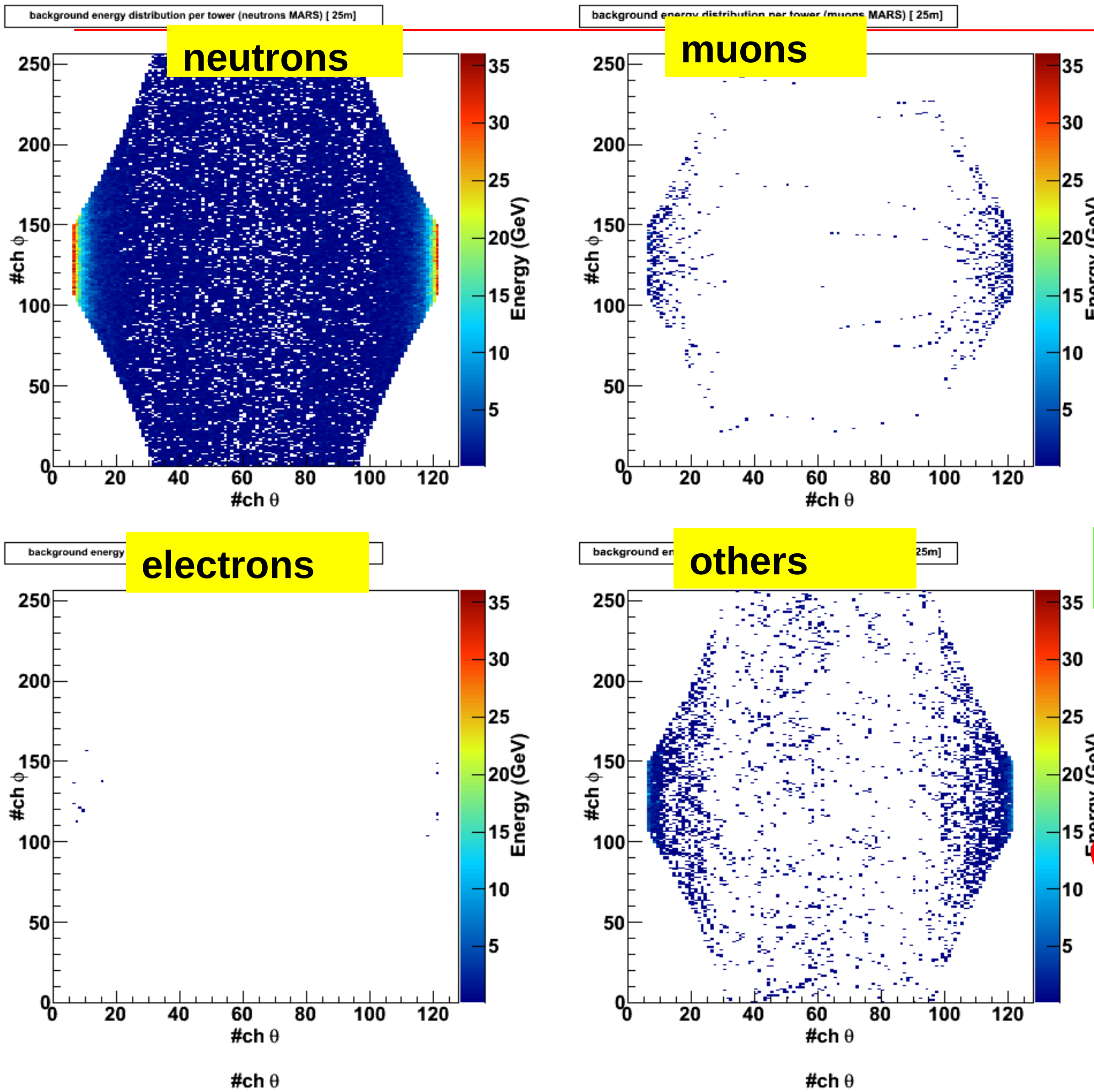


1 entry = energy of 1 tower

Most of the energy is in the endcaps originated by Neutrons and in the barrel originated by gammas

With shorter integration ti gate background is reduce

Energy distribution per tower. Calorimeter Rear Section Integration time gate 15 ns.

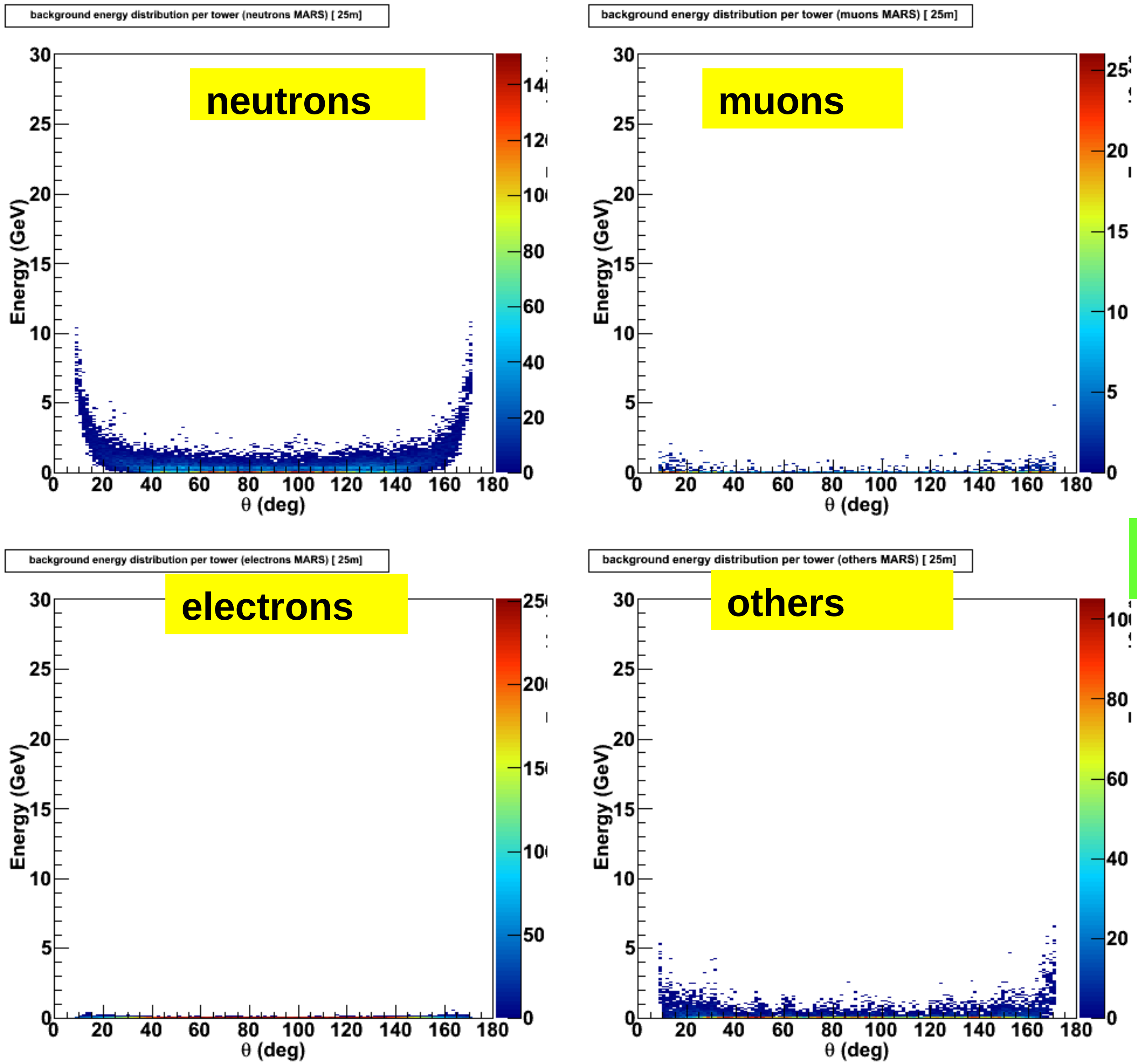


1 entry = energy of 1 tower

Most of the energy is in the endcaps originated by neutrons

some muons hotspot

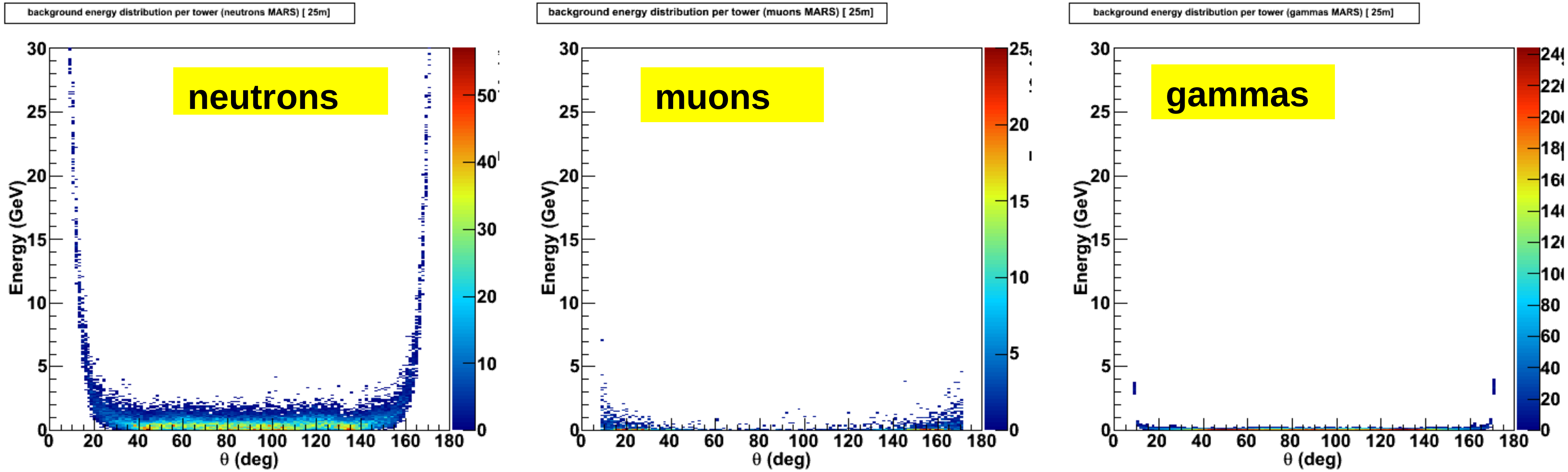
Energy distribution per tower vs theta.
Calorimeter Front Section; Integration time gate 15 ns



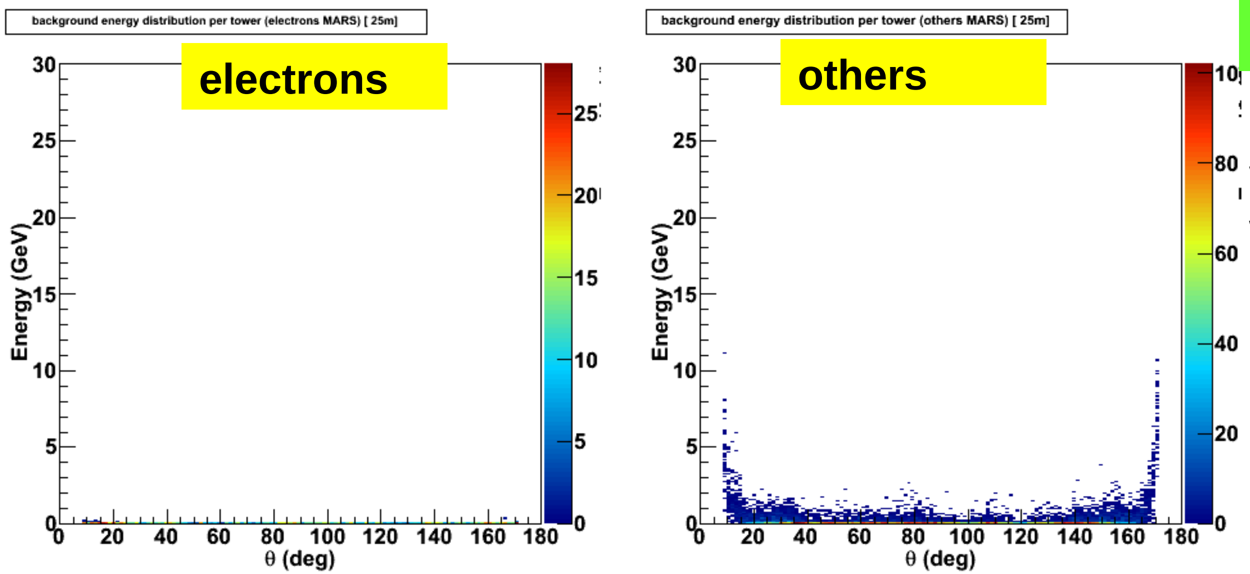
1 entry = energy of 1 tower averaged over φ

With background particles within 25 m mostly neutrons and gammas contribute to energy into the calorimeter

Energy distribution per tower vs theta.
Calorimeter Rear Section; Integration time gate 15 ns

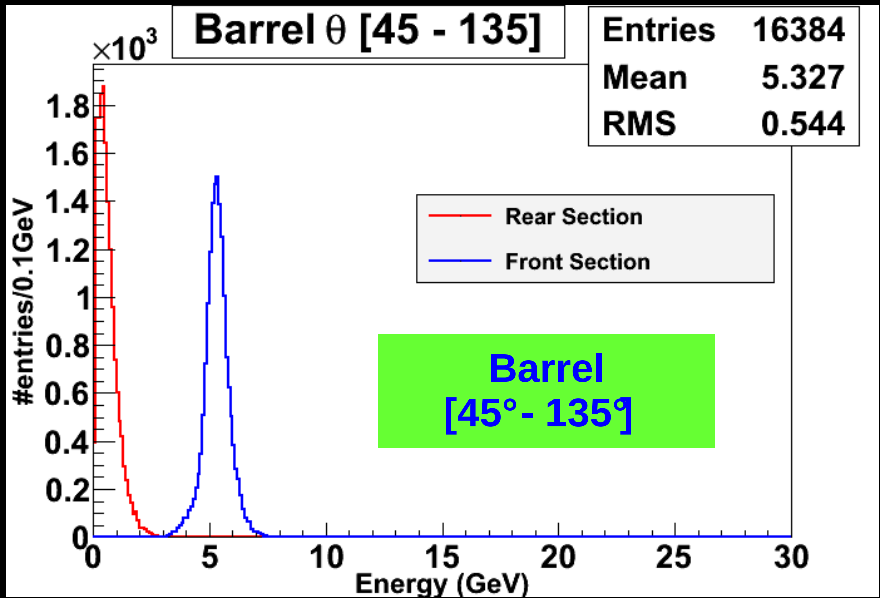


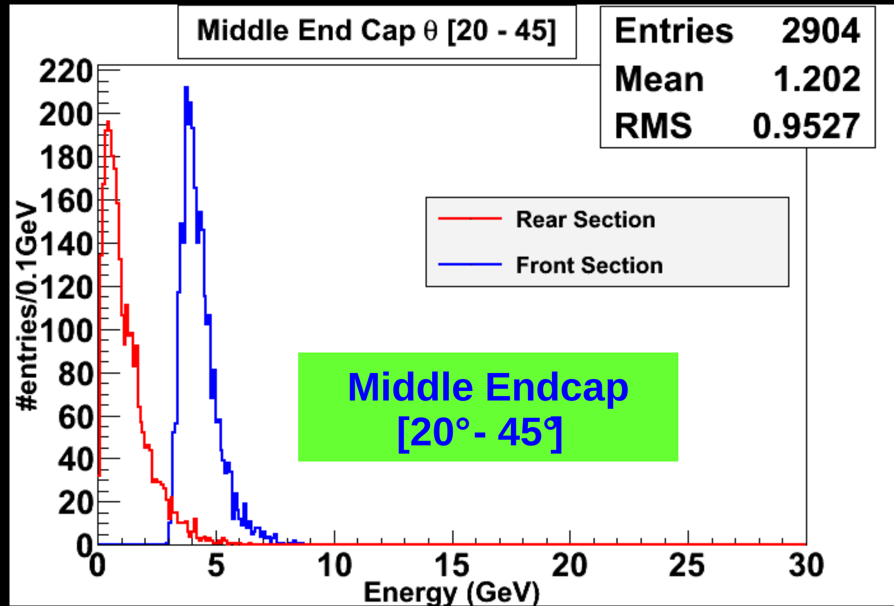
1 entry = energy of 1 tower
Averaged over φ

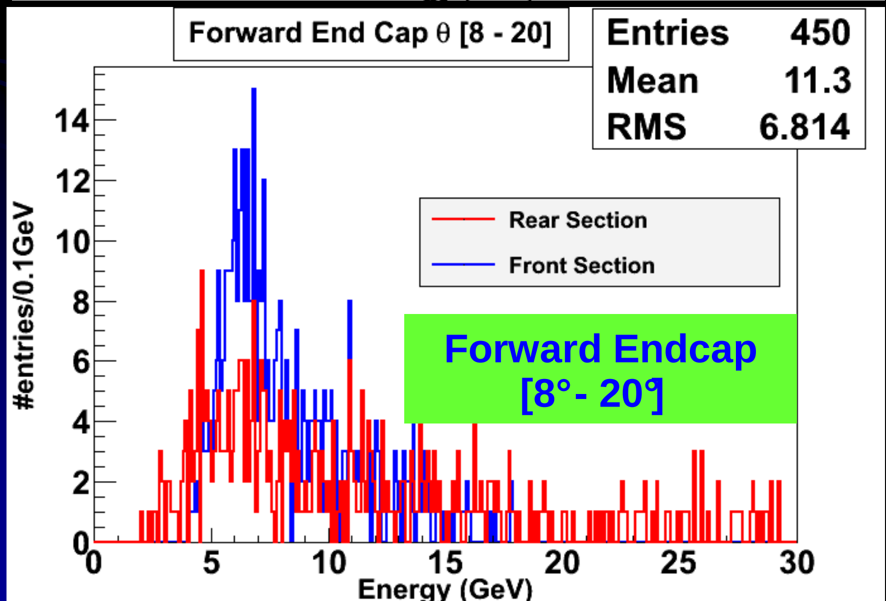


With background particles within 25 m mostly neutrons contribute to energy into the calorimeter

SUMMARY: Energy per tower in Front and Rear Section
Integration time 15 ns







In the front section most of contribution is from gammas and neutrons

Background energy fluctuation		
Energy (GeV)	Front	Rear
Barrel	5.33±0.54	0.63±0.43
Mid ECap	4.33±0.79	1.20±0.95
Forward ECap	8.31±2.94	11.3±6.8

Effect on a typical 150 GeV jet

Assume 16-25 towers interested

	RMS(E)	Contribution to resolution
Barrel [45° - 135°]	2.5-3 GeV	12%/√E
Middle Endcap [20° - 45°]	5-6 GeV	25%/√E
Fwd Endcap [8° - 20°]	20-25 GeV	100%/√E

Some Considerations on Calorimetry for a Muon Collider

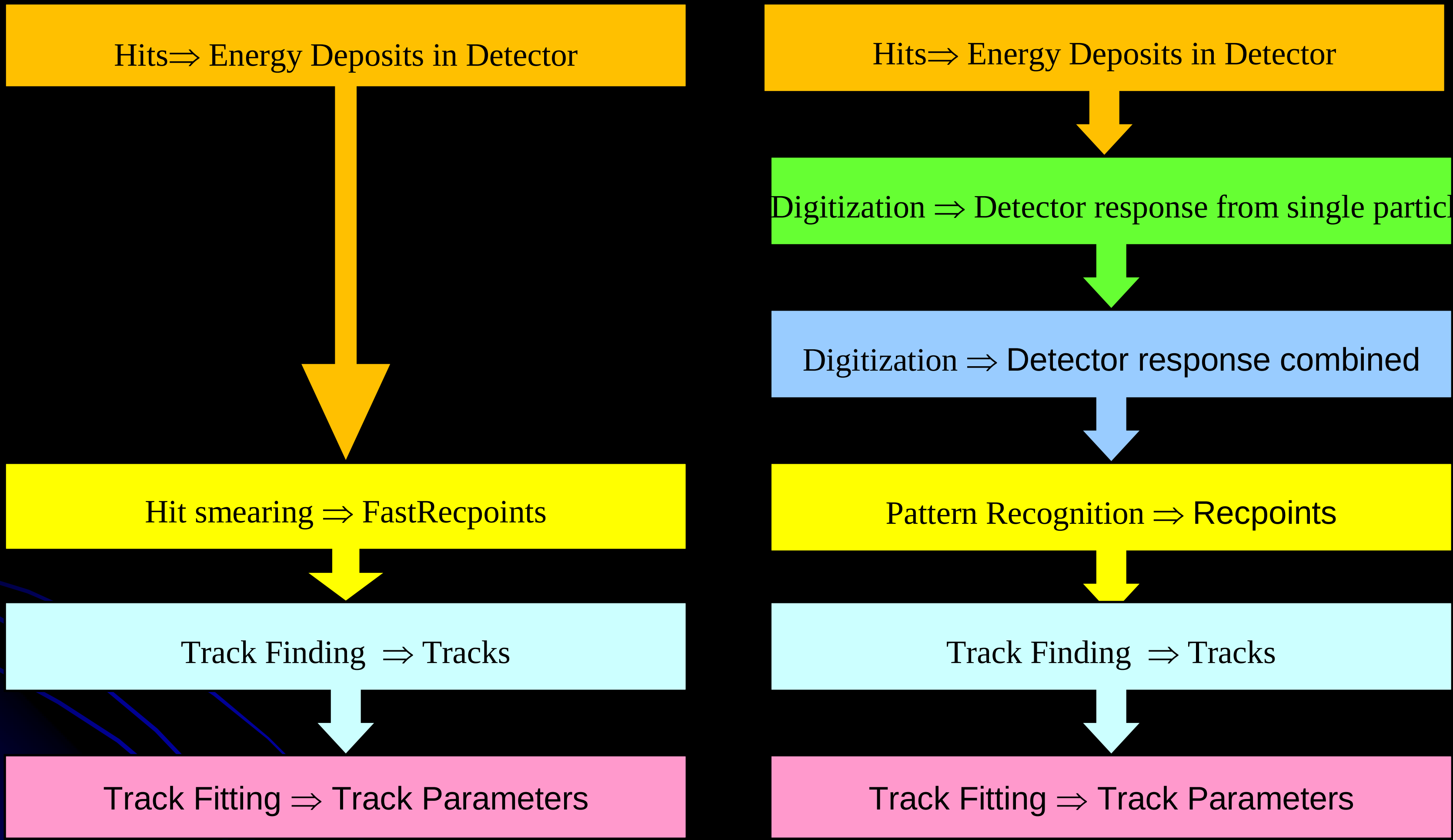
- A 30%/√E calorimeter (stochastic) or RMS90 = 3% detector (non stochastic) have adequate energy resolution for a lepton collider with E_{cm} = 500 GeV or above
- However, the higher E_{cm} the more important jet axis angular resolution becomes over energy resolution -> high granularity
- Two-sections ADRIANO calorimeter is adequate for physics and resilient to background at θ>20°. But:
  - Must use fast (3 nsec) fibers
  - Must have short (15 nsec) integration times and sophisticated time gate
- Below θ=20° the present solution should be improved (more segmentation ?).
- The very problem are fluctuations in $E_{background}$
- T1004 nd T1015 at Fermilab are also looking for total active tecnique with crystals and heavy scintillating glasses.
- However, both such materials are intrinsecally slow (t > 30 nsec) and probably inadequate at a muon collider.

Conclusions

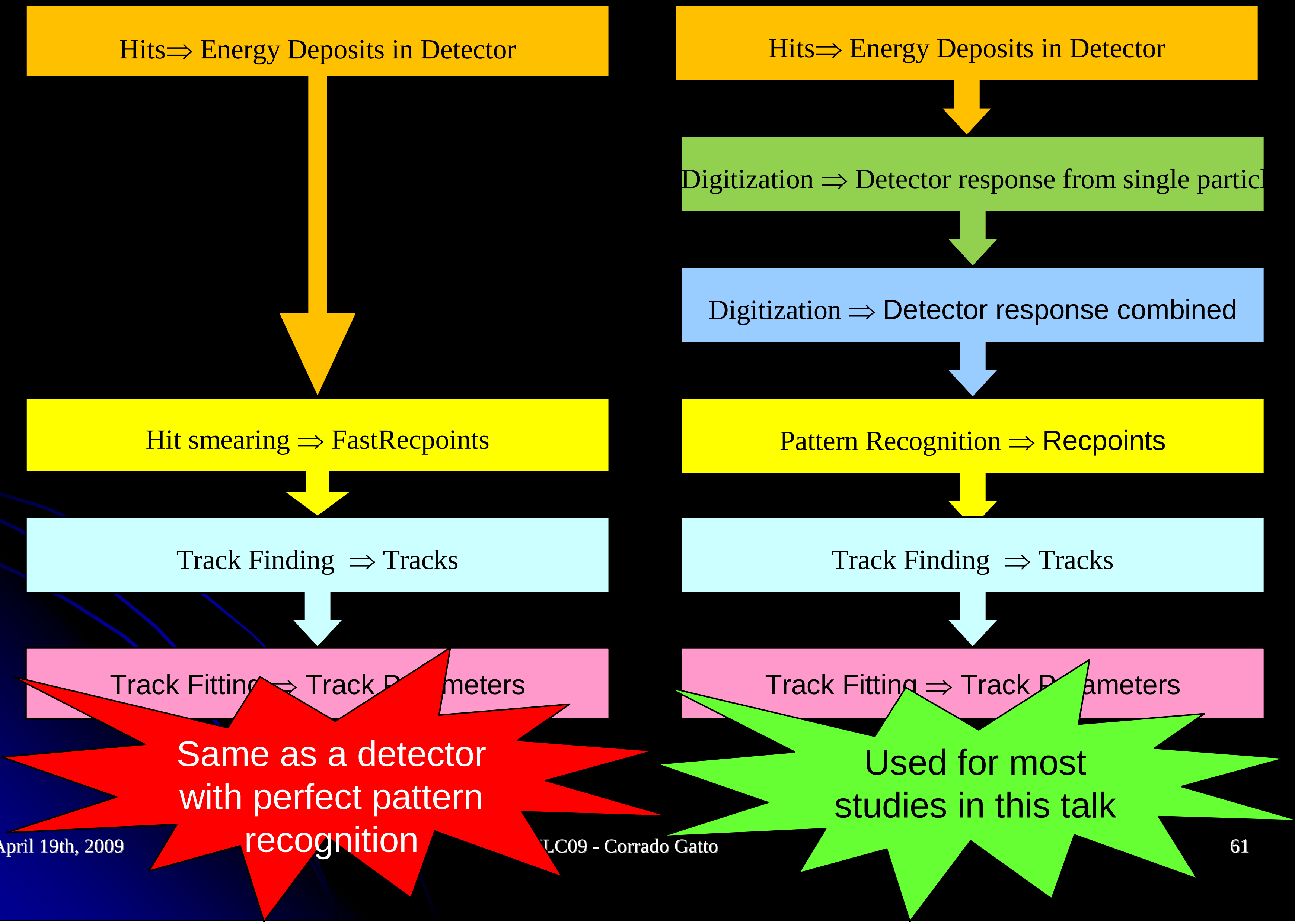
- A ILCroot-based simulation effort is ongoing at Fermilab: the goal is understanding the Physics capabilities and optimal technology choises
- Background is very nasty even with 10° tungsten nozzle, but fully understood
- Tracking systems requires very fast tecnologies (sub nsec) to reject out of time background
- Several solutions for tracking are being considered:
  - 3-D Si-tracker with precision timing
  - 4-D Kalman filter
- Calorimetry (being an integrating device) is far more subject to background.
- What really matters are fluctuations aound a pedestal.
  - A two-section calorimeter with appropriate time gate has been considered
  - It works fine down to 20 degrees
  - More effort is needed to fight background at smaller angles

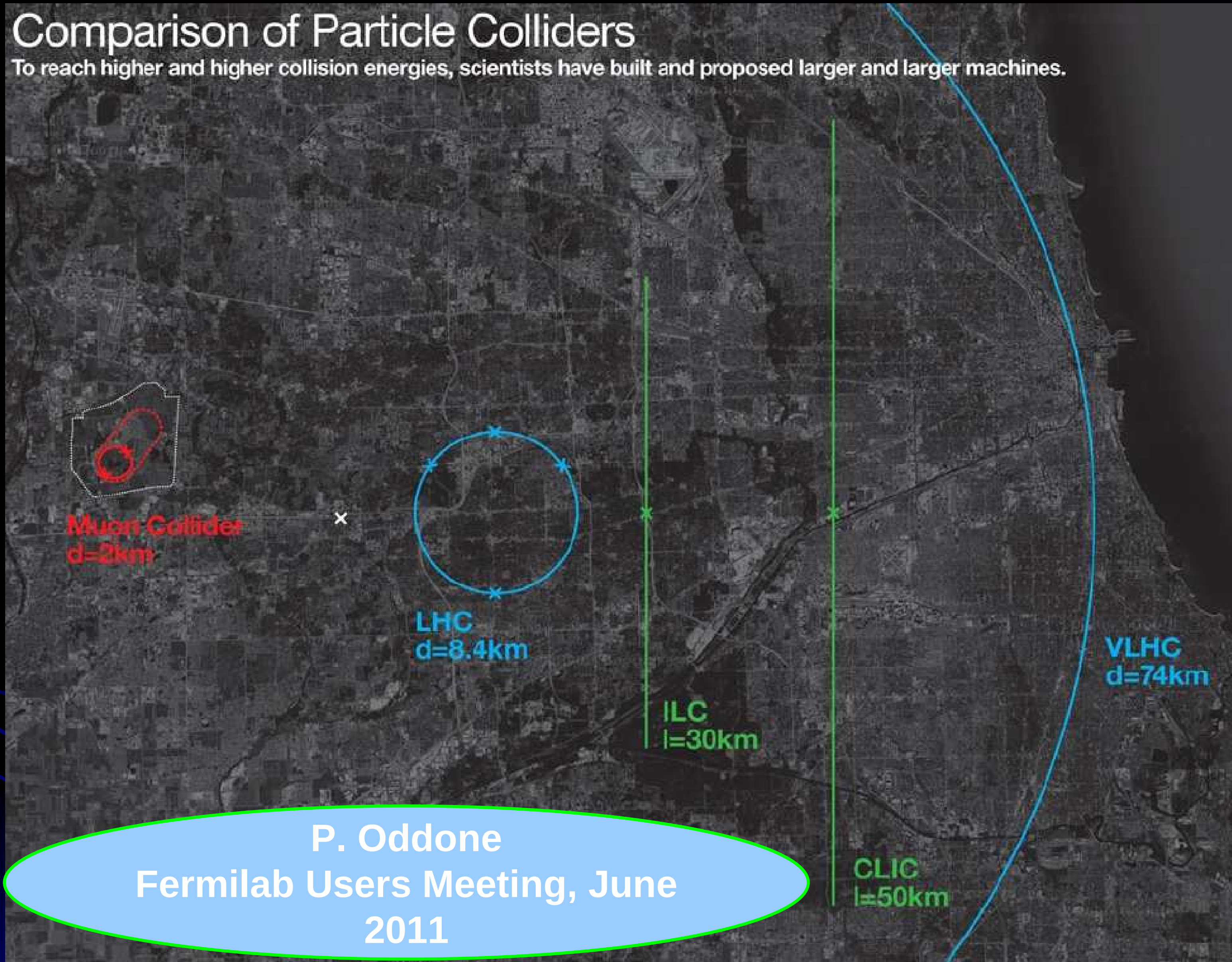
Backup slides

Fast vs Full Simulation



Fast vs Full Simulation




Comparison of Particle Colliders
To reach higher and higher collision energies, scientists have built and proposed larger and larger machines.
Muon Collider
d=2km
LHC
d=8.4km
ILC
l=30km
CLIC
l=50km
VLHC
d=74km
P. Oddone
Fermilab Users Meeting, June 2011

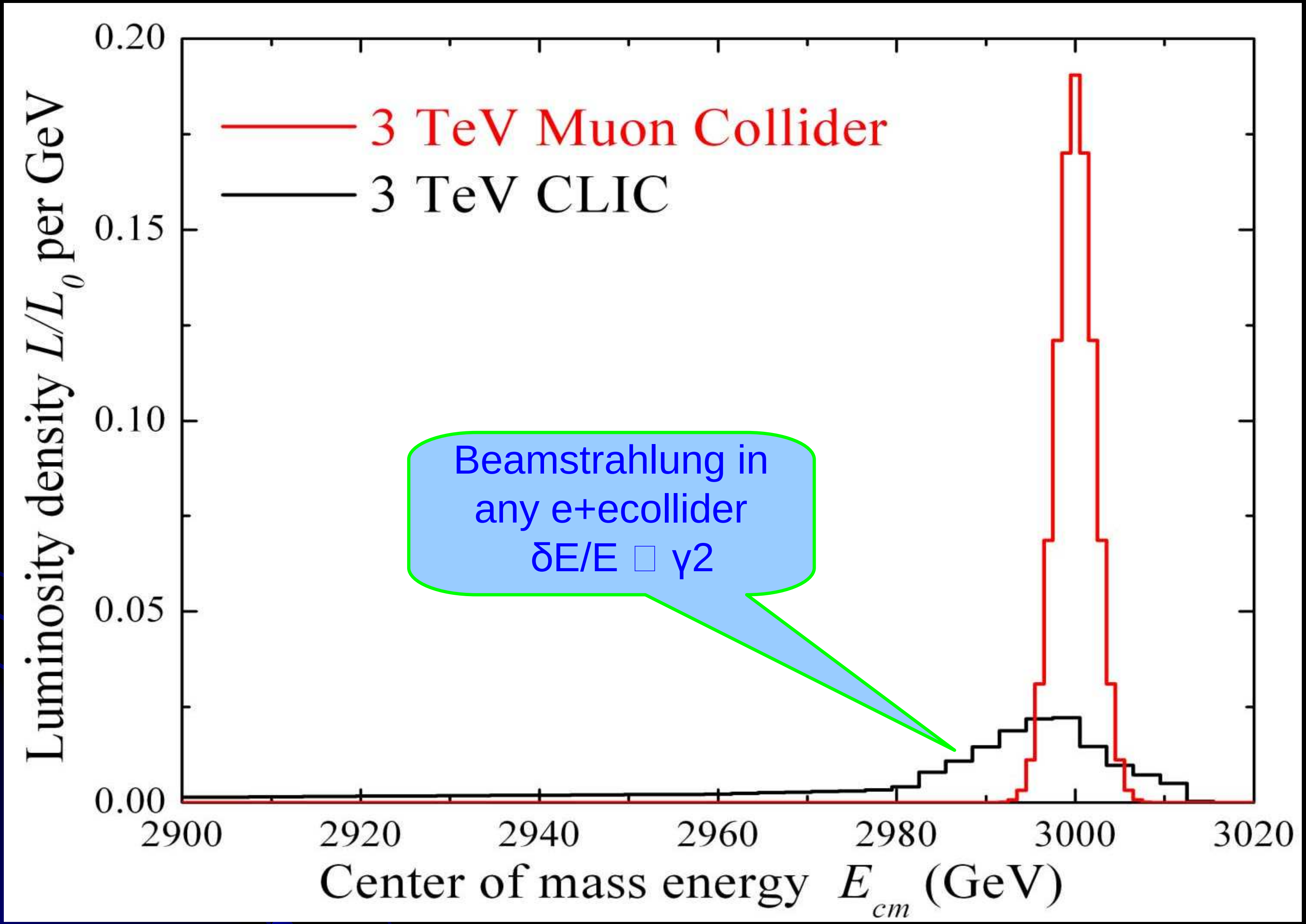
MUON COLLIDER MOTIVATION

If we can build a muon collider, it is an attractive multi-TeV lepton collider option because muons don't radiate as readily as electrons ($m\mu$ / me ~ 207):

S. Geer- Accelerator Seminar SLAC 2011

- COMPACT
  Fits on laboratory site
- MULTI-PASS ACC
  Cost Effective operation & construction
- MULTIPASS COLLISIONS IN A RING (~1000 turns)
  Relaxed emittance requirements & hence relaxed tolerances
- NARROW ENERGY SPREAD
  Precision scans, kinematic constraints
- TWO DETECTORS (2 IPs)
- ΔTbunch ~ 10 μs … (e.g. 4 TeV collider)
  Lots of time for readout
  Backgrounds don't pile up
- $(m\mu/me)^2$ = ~40000
  Enhanced s-channel rates for Higgs-like particles

Energy Spread



Challenges

- Muons are produced as tertiary particles.

To make enough of them we must start with a MW scale proton source & target facility.

- Muons decay

Everything must be done fast and we must deal with the decay electrons (& neutrinos for CM energies above ~3 TeV).

- Muons are born within a large 6D phase-space.

For a MC we must cool them by O(106) before they decay □ New cooling technique (ionization cooling) must be demonstrated, and it requires components with demanding performance (NCRF in magnetic channel, high field solenoids.)

- After cooling, beams still have relatively large emittance.

S. Geer- Accelerator Seminar SLAC 2011

Fast simulation and/or fast digitization also available in ILCroot for tracking system

- Fast Simulation = hit smearing
- Fast Digitization = full digitization with fast algorithms
- Do we need fast simulation in tracking studies?

  Yes!

  – Calorimetry related studies do not need full simulation/digitization for tracking
  – Faster computation for quick answer to response of several detector layouts/shielding
- Do we need full simulation in tracking studies?

  Yes!

  – Fancy detector and reconstruction needed to be able to separate hits from signal and background

Technologies Implemented

- 3 detector species:
  - Silicon pixels
  - Silicon Strips
  - Silicon Drift

Used for VXD SiT and FTD in present studies

- Pixel can have non constant size in different layers
- Strips can also be stereo and on both sides
- Dead regions are taken into account
- Algorithms are parametric: almost all available technologies are easily accomodated (MAPS, 3D, DEPFET, etc.)

Track Fitting in ILCRoot

- Track finding and fitting is a global tasks: individual detector collaborate
- It is performed after each detector has completed its local tasks (simulation, digitization, clusterization)
- It occurs in three phases:
  - Seeding in SiT and fitting in VXD+SiT+MUD
  - Standalone seeding and fitting in VXD
  - Standalone seeding and fitting in MUD
- Two different seedings:
  - Primary seeding with vertex constraint
  - Secondary seeding without vertex constraint

Not yet implemented

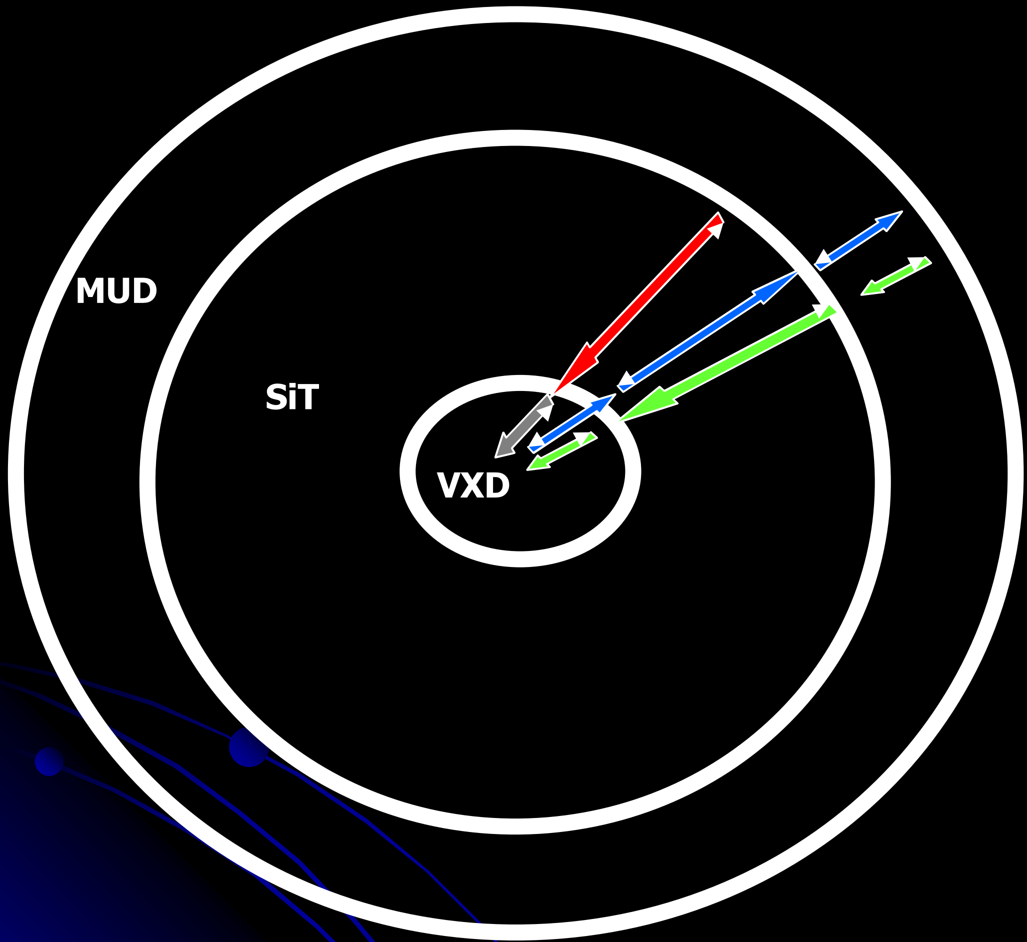
Kalman Filter (classic)

- Recursive least-squares estimation.
- Equivalent to global least-squares method including all correlations between measurements due to multiple scattering.
- Suitable for combined track finding and fitting
- Provides a natural way:
  - to take into account multiple scattering, magnetic field inhomogeneity
  - possibility to take into account mean energy losses
  - to extrapolate tracks from one sub-detector to another

Parallel Kalman Filter

- Seedings with constraint + seedings without constraint at different radii (necessary for kinks and V0) from outer to inner
- Tracking
  - Find for each track the prolongation to the next layer
  - Estimate the errors
  - Update track according current cluster parameters
  - (Possible refine clusters parameters with current track)
- Track several track-hypothesis in parallel
  - Allow cluster sharing between different track
- Remove-Overlap
- **Kinks and V0** fitted during the Kalman filtering

Tracking Strategy – Primary Tracks



- Iterative process
  - Seeding in SiT
  - Forward propagation towards to the vertex

    SiT → VXD
  - Back propagation towards to the MUD

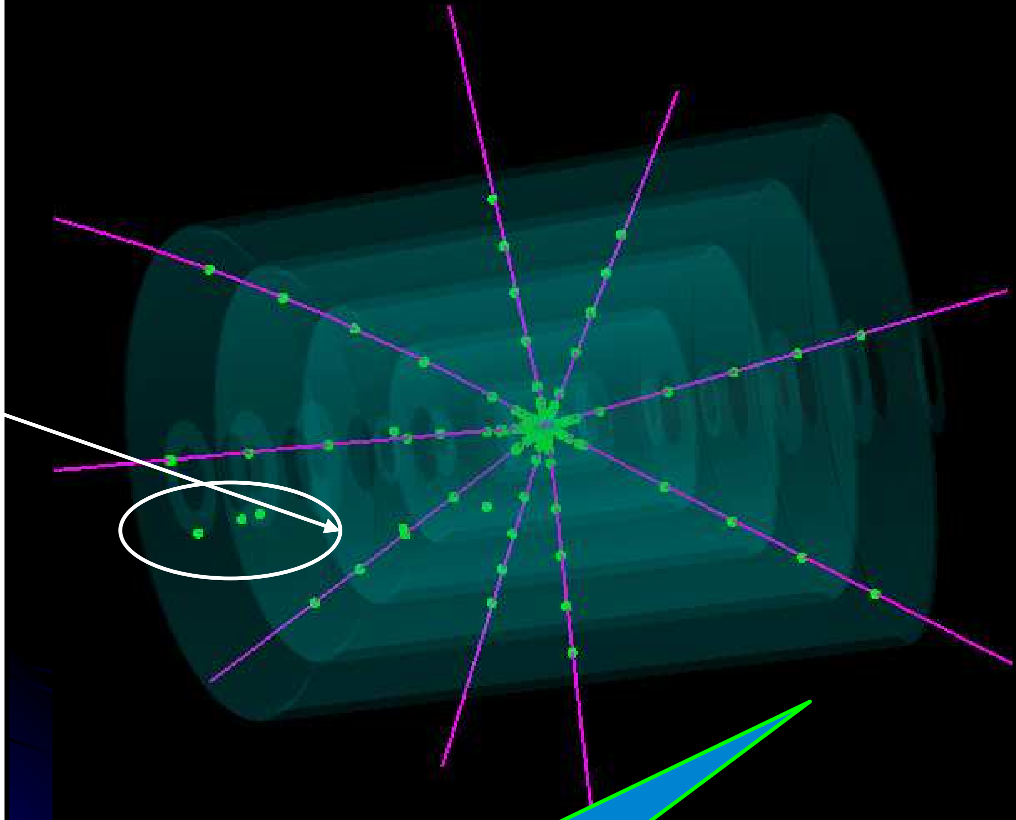
    VXD → SiT → MUD
  - Refit inward

    MUD → SiT → VXD
- Continuous seeding –track segment finding in all detectors

VXD Standalone Tracking

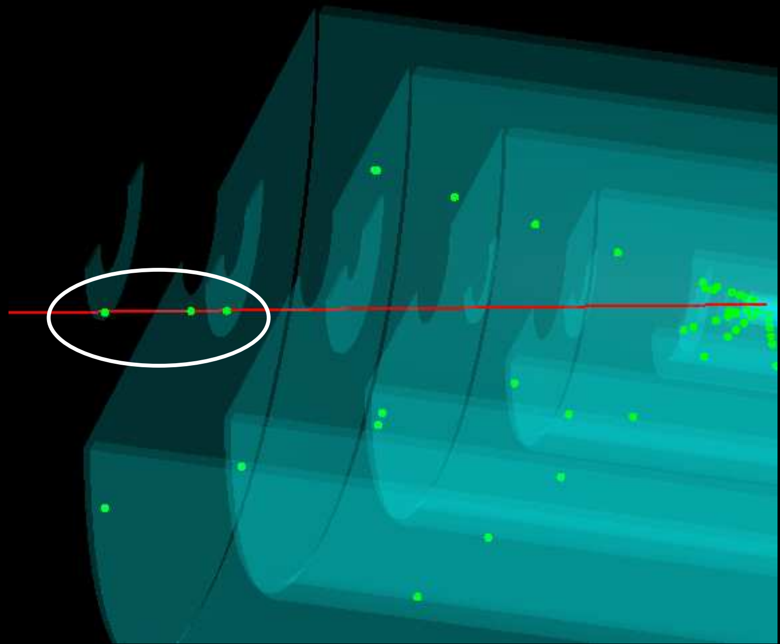
- Uses Clusters leftover in the VXD by Parallel Kalman Filter
- **Requires at least 4 hits to build a track**
- Seeding in VXD in two steps
  - Step 1: look for 3 Clusters in a narrow row or 2 Clusters + IP constraint
  - Step 2: prolongate to next layers each helix constructed from a seed
- After finding Clusters, all different combination of clusters are refitted with the Kalman Filter and the tracks with lowest χ^2 are selected
- Finally, the process is repeated attempting to find tracks on an enlarged row constructed looping on the first point on different layers and all the subsequent layers
- In 3.5 Tesla B-field P_t > 20 MeV tracks reconstructable

Event Display



ILCroot event display
for 10 muons up to 200 GeV

green - hits
purple – reconstructed tracks
red – MC particle



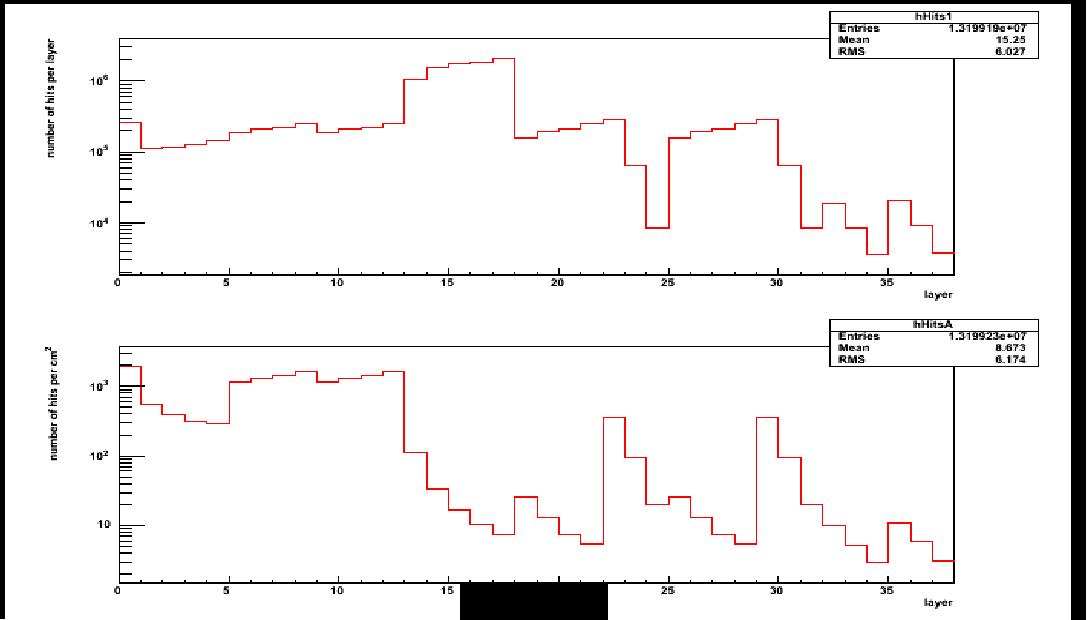
10 generated muons
9 reconstructed tracks

- Effects on Track Resolution
- Background in the calorimeter for different particle species originating within 25 m from IP
- Background in the calorimeter for different particle species originating in [25-200] m from IP
- Future Prospects
- Conclusions
- Backup slides

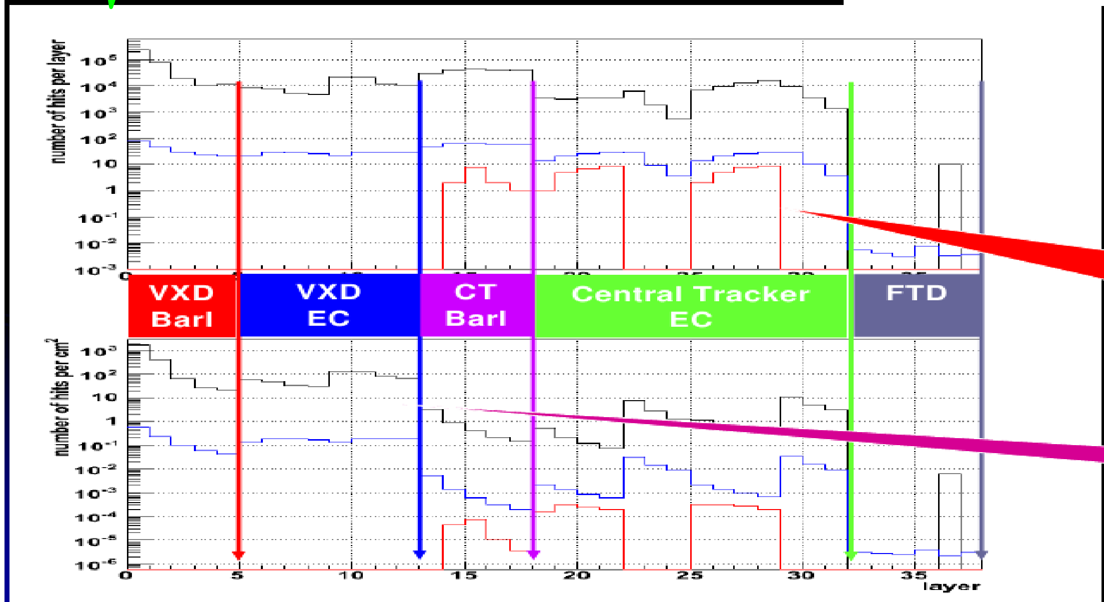
Occupancy in the Tracking System

NEW

Nozzle 10°



Nozzle 6°



Legenda

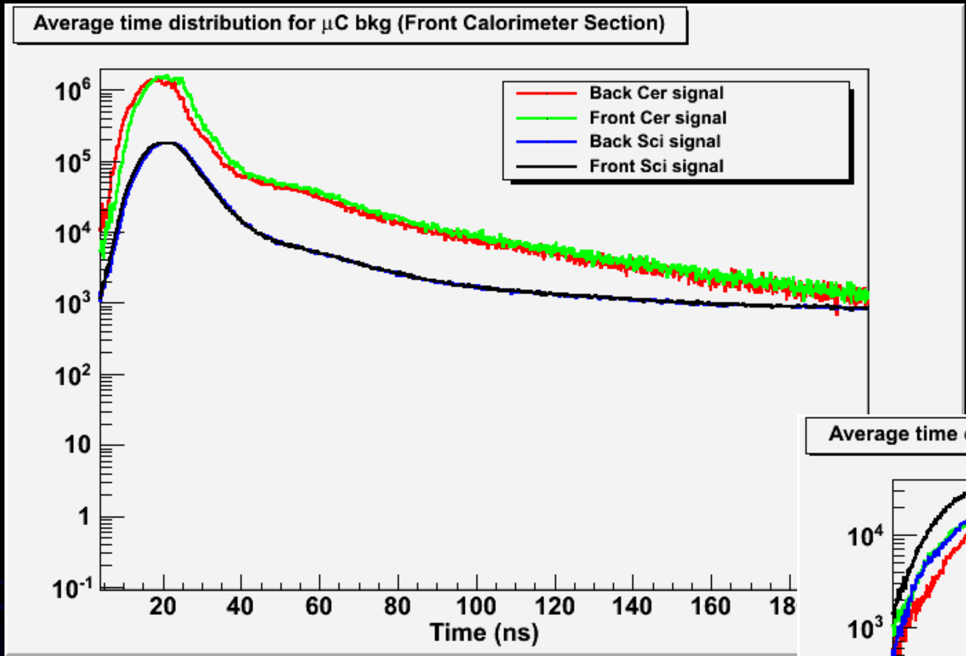
-WWnunu
-Beam bkg except muons
-muons

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

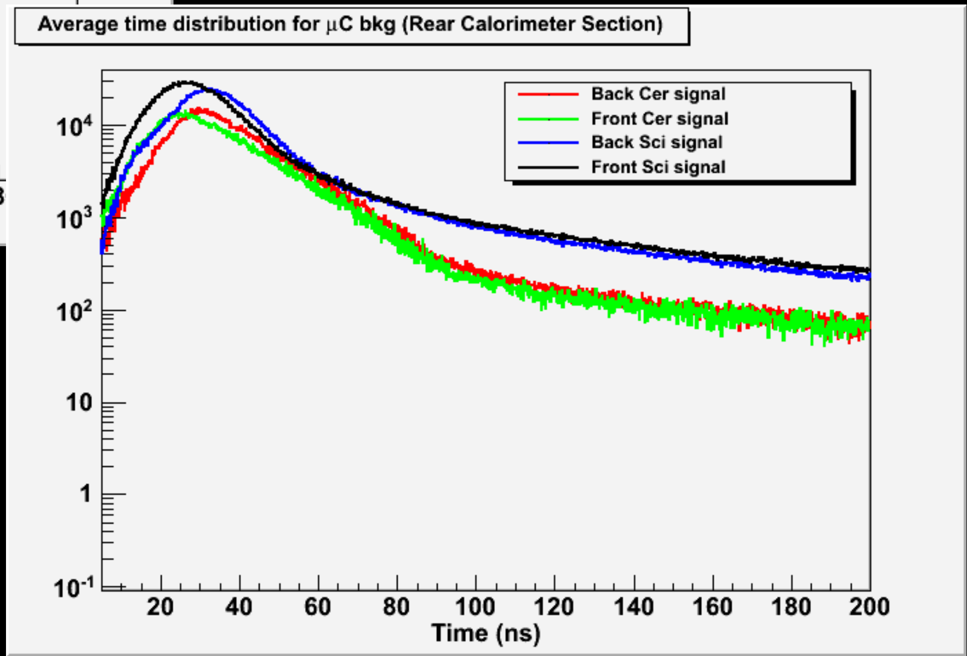
5 hits/cm² at R=20 cm

36

Next step: look at the time distribution of the background



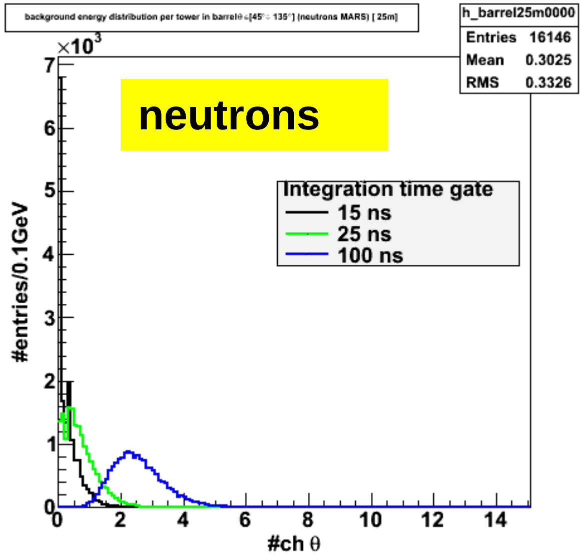
Calorimeter is now split in a forward (20cm) and rear (160 cm) section

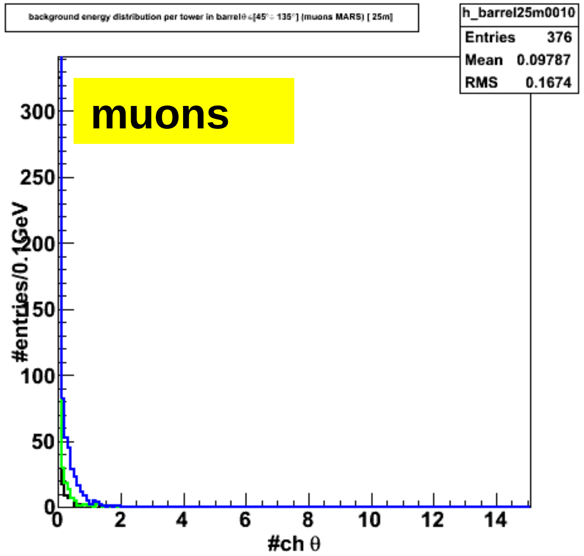


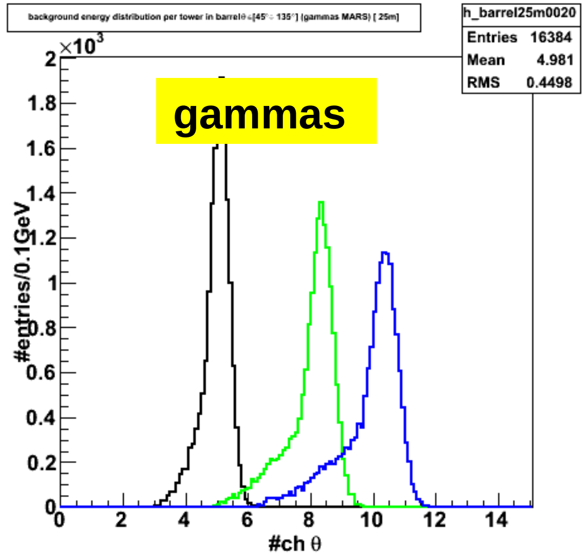
Light propagation in fibers and lead glass is implemented in ILCroot

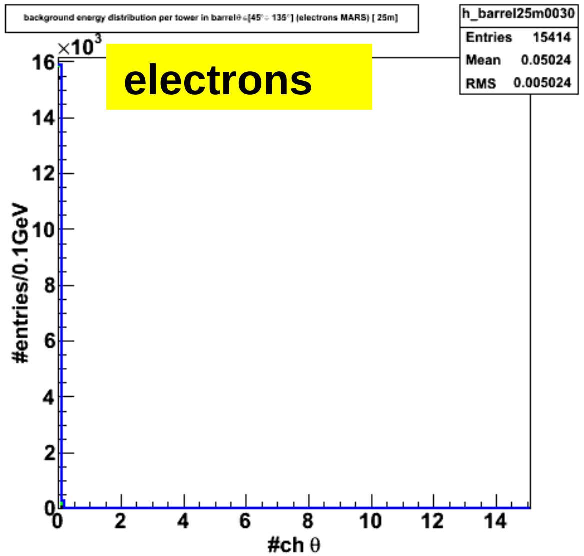
Energy distribution of the background per tower in barrel section for different species using different time gate

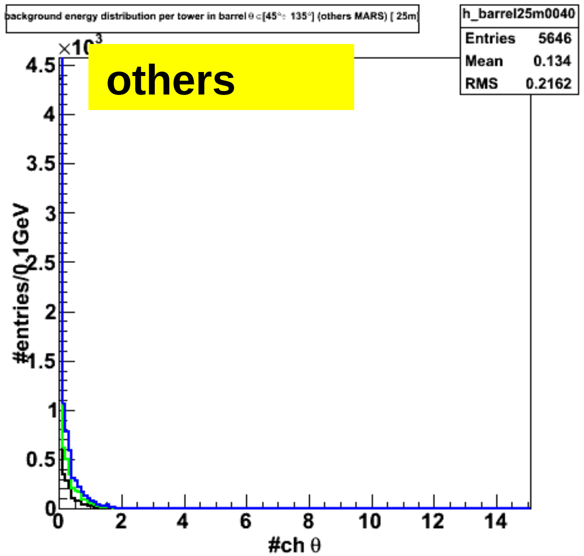
Energy distribution per tower in barrel Calorimeter Front Section for different species







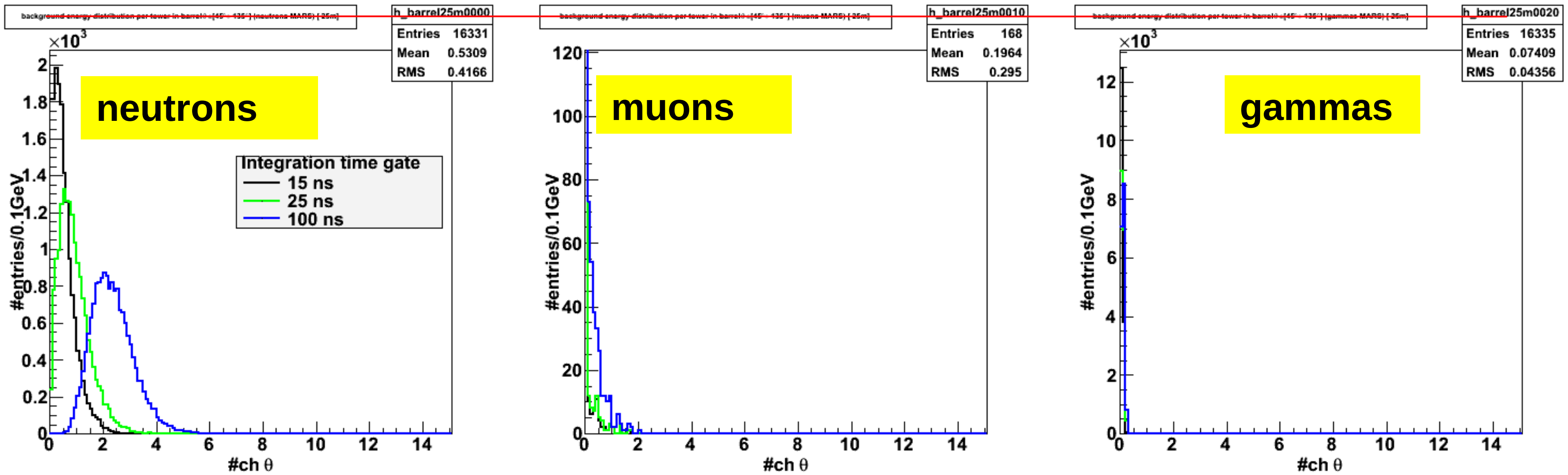


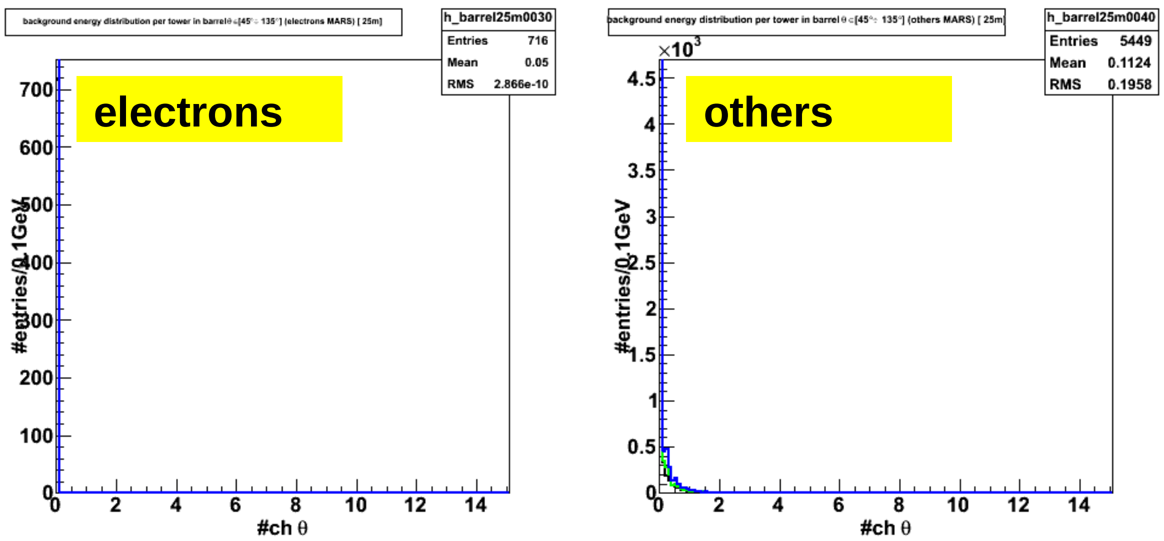


With background particles within 25 m mostly neutrons and gammas contribute to energy into the calorimeter

Substantial background Reduction is obtained with Short time gates

Energy distribution per tower in barrel Calorimeter Rear Section for different species





Rear calorimeter section is Mostly affected by neutrons