Occupancy Studies for the CLIC_ILD TPC with Pad and Pixel Readout

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On behalf of the CLIC detector and physics study

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* Now with DESY

The CLIC_ILD TPC

Same dimensions as the ILD TPC

- Inner radius 395 mm (active area)
- Outer radius 1.739 mm (active area)
- 1×6 mm^2 pad (default pad size)
- 224 pad rows (default pad size)
- T2K gas ($Ar/CF_4/iC_4H_{10}$ 95/3/2)
- $v_{\text{drift}} = 79$ mm/μs

Voxel size (3D space bucket):

- Pad size $\times$ $t_{\text{sample}} \cdot v_{\text{drift}}$
- $\approx$1 mm $\times$ 6 mm $\times$ 2 mm[†]

[†] With 40 Mhz readout frequency and $v_{\text{drift}} = 79$ mm/μs

Conditions at CLIC (3 TeV)

Beam parameters

	CLIC (3 TeV)	**ILC** (500 GeV)
Bunch spacing	0.5 ns	554 ns
Bunches per train	312	1312
Bunch train length	156 ns	727 μs
Bunch train repetition	50 Hz	5 Hz

Readout time of the TPC $\mathcal{O}(30\ \mu s)$:
TPC integrates a full BT (physics and background)!

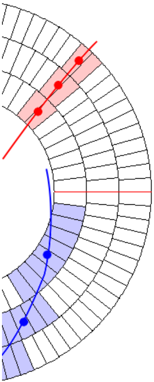
Beam induced backgrounds

- 300,000 incoherent e^+e^- pairs per BX from beamstrahlung
- 3.2 $\gamma\gamma \rightarrow$ hadrons events per BX
- 1 beam halo muon per BX

All occupancies calculated without safety factor!

Simulation and Digitisation

Primary Ionisation with Mokka



Simulation

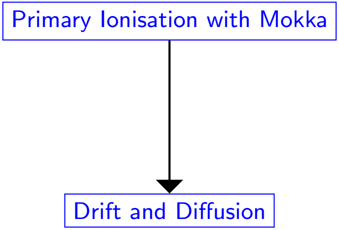
- Default Mokka driver places one hit in the middle of the pad row
    - Pad response not realistic for low angle tracks
    - Delta electrons and micro curlers also occupy voxels:

  ⇒ Need detailed charge depositions

⇒ Run Mokka TPC driver with step length limit of 200 μm

- Realistic ionisation clusters

Simulation and Digitisation



Drift and Diffusion

- Calculate number of electrons from energy in Mokka hit
- Drift each electron separately
- Displace according to diffusion

Why so detailed?

- Most clusters only have few (1, 2, 3) electrons
- Continuous Gaussian smearing is not very realistic

⇒ Displacing individual electrons is a better description of the fluctuations

Simulation and Digitisation

Primary Ionisation with Mokka

↓

Drift and Diffusion

↓

Overlay Voxels in Memory

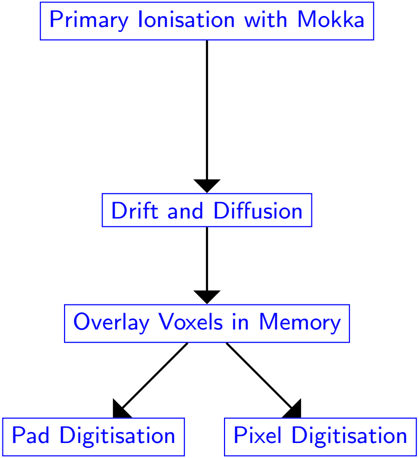
Voxelisation using 3D voxel map

- Smear amplified charge with diffusion in MPGD
  - Triple-GEM for pads
  - Micromegas for pixels (InGrid)
- Calculate fraction on each pad
- Put charge into corresponding voxel

Why so detailed?

- Realistic charge content of each pad and time bin
- Overlay different bunch crossings in memory

Simulation and Digitisation



Digitisation

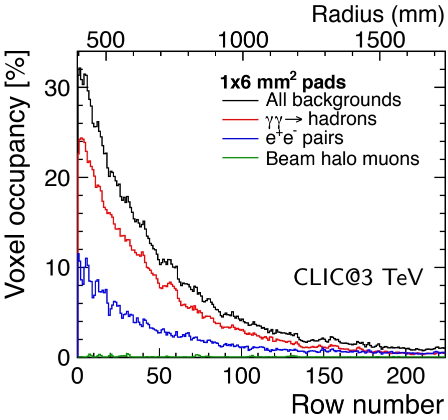
- Apply electronics shaping for each incoming voxel
- Calculate ADC values for each time sample
- Apply electronics thresholds
- Write out pixel or pad raw data

Why so detailed?

- Electronics shaping can affect the z-resolution and occupancy
- ADC dynamic range can affect overall performance

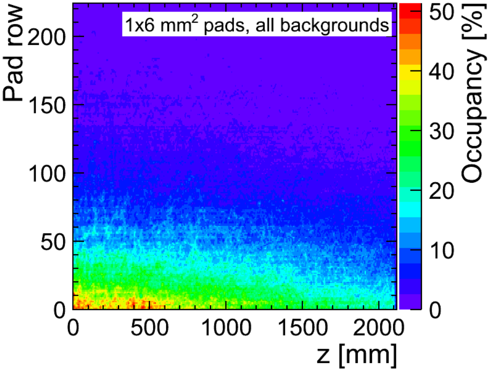
Occupancies are calculated from the digitised raw data

Occupancy for the Different Backgrounds



- Occupancy is up to 30 % for the inner pad rows (averaged over z and φ)
- Largest component is $\gamma\gamma \to$ hadrons (25 %)
- Incoherent e^+e^- pairs cause up to 10 % occupancy
- Beam halo muons are negligible

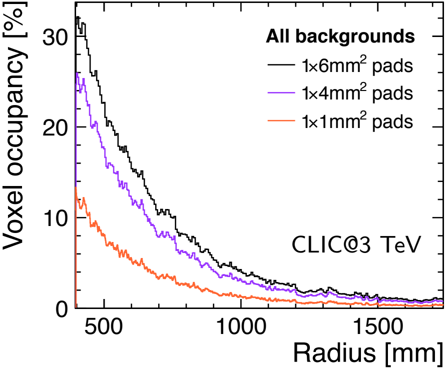
Occupancy in Dependence on z



CLIC@3 TeV

- Occupancy near the IP is up to 50 %
- Near the readout (forward region) occupancy below 20 %

Occupancy for Different Pad Sizes

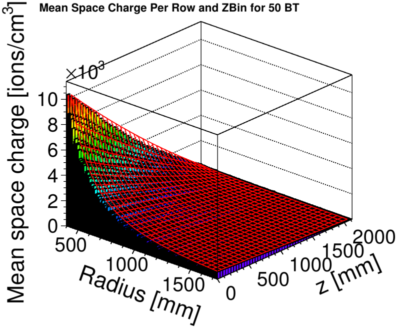


- 1×1 mm^2 reduces the occupancy to a tolerable level
- 1×1 mm^2 cannot be implemented with current technology
  → needs further R&D

Space Charge and E-Field Disortions

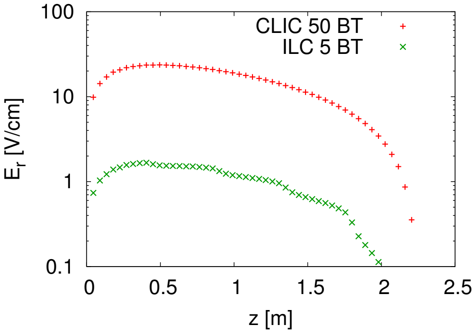
- Ion drift time $\mathcal{O}(1\ s)$
- 50 bunch trains @ CLIC
- 5 bunch trains @ ILC

Primary charge from 50 BT at CLIC@3 TeV



- Very high charge near the cathode
- Charge up to 10,000 ions/cm^3

Electric field near the inner field cage

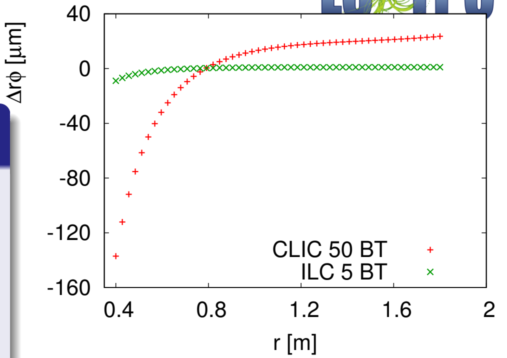


- E_r for 50 BT at CLIC is up to 25 V/cm
- E_z component will not be negligible
- Effects on drift velocity and diffusion
- Simulations have to be adapted to include these effects!

Drift Distortions Near the Inner Field Cage

Calculations Based on Keisuke Fujii's *ioneffects* programme

- Parameterised ion density $(p_0 + p_1 z + p_2 z^2)/(r - p_3)^2$
- No φ dependence
- Calculate E_r by solving Green's function (see Keisuke's talk at the LCTPC collaboration meeting 2012)
- "Track" electrons along z for $r = const$
- Calculate $\Delta(r\varphi)$ for fix E_z, B and $\omega\tau$



Drift over the full TPC drift length

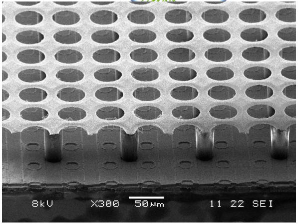
- Distortions for ILC are small (9 μm for 5 BT)
- Distortions for 50 BT CLIC not negligible: 137 μm need to be corrected for
- Changes in E_z, drift velocity and diffusion are not included

Pixel Readout for a TPC

InGrid-like “TPCPix” readout

Simulate the “ideal” readout chip

- Integrated micro mesh ✓
- Time and charge per pixel ✓
- Fast shaping time (ADC per pixel) ✓
- Unlimited multi-hit capability ✓
- Polya-like gas gain fluctuations (not impl. yet)
- Adjustable cross-talk (not impl. yet)



Timepix chip with integrated micro mesh

Detect every primary electron

- Ultimate spatial resolution
- Best possible track separation (only limited by diffusion)
- Reject delta electrons ⇒ improve dE/dx and momentum resolution

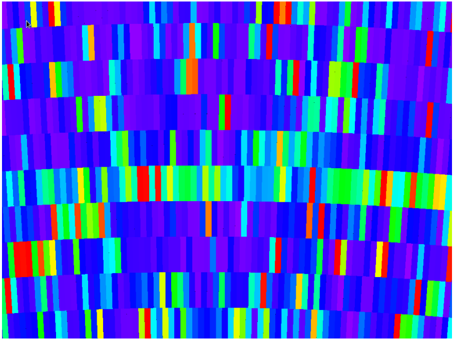
Studies:

- Occupancy at CLIC (full bunch train of beam background)
- Momentum resolution
- dE/dx (planned)
- Tracking efficiency (requires full reconstruction)

Event Displays

1 bunch train of background for CLIC@3 TeV

1×6 mm^2 pads

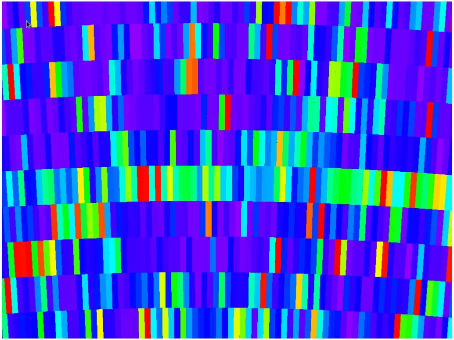


$\approx 75 \times 60$ mm^2 at a central radius of 550 mm

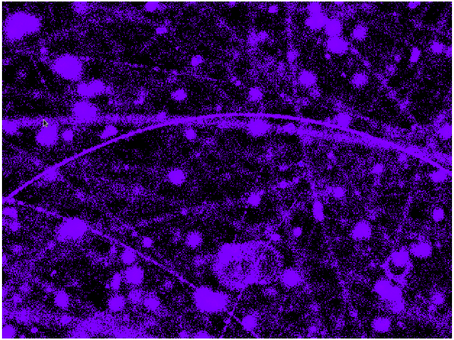
Event Displays

1 bunch train of background for CLIC@3 TeV

1×6 mm^2 pads

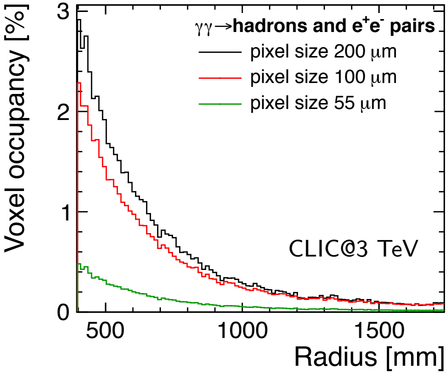


100×100 μm^2 pixels



$\approx 75 \times 60$ mm^2 at a central radius of 550 mm

Occupancy for Different Pixel Sizes



- Factor 4 in voxel occupancy between 55 μm and 100 μm pixels
  $\Rightarrow$ Each voxel is only occupied by one electron / cluster
  $\Rightarrow$ 55 μm and 100 μm pixels can resolve individual electrons
- Factor 1.3 between 100 μm and 200 μm pixels
  $\Rightarrow$ More than one electron / cluster per voxel for 200 μm pixels

Consistent with expectations (primary cluster distance, diffusion)

Momentum Resolution with Pixel Readout

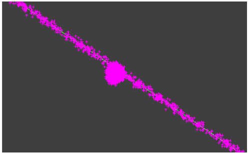
"Reconstruction":

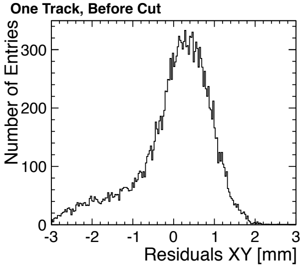
No pattern recognition for pixels available

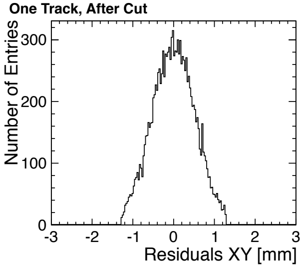
- Current Kalman filters work layer (pad row) based
- Hough-transform does not work (too many pixels)

Current solution for single tracks without background and noise

- Fit a helix to all recorded pixels
- Treat all pixels equally (digital readout, charge information not used)
- Perform outlier rejection (delta electrons) $\rightarrow$ cut at 2.5 RMS of residual distribution
- Iterate

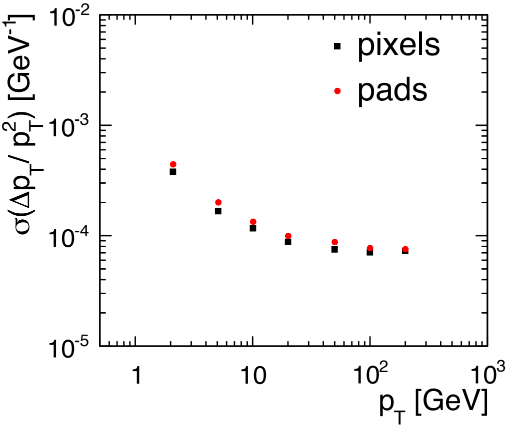






Momentum Resolution with Pixels and Pads

1000 muons from the IP per energy



- Pixel momentum resolution@200 GeV $\sigma(\Delta p_\mathrm{T}/p_\mathrm{T}^2) = 7.3 \cdot 10^{-5}$
  (100×100 μm^2 pixels, simple helix fit)
- Slightly better than resolution for pads($\sigma(\Delta p_\mathrm{T}/p_\mathrm{T}^2) = 7.5 \cdot 10^{-5}$@200 GeV)
  1×6 mm^2 pads, Mokka driver in default mode + MarlinReco / LEPTracking (Kalman Filter)

Summary

Difficult TPC conditions at CLIC

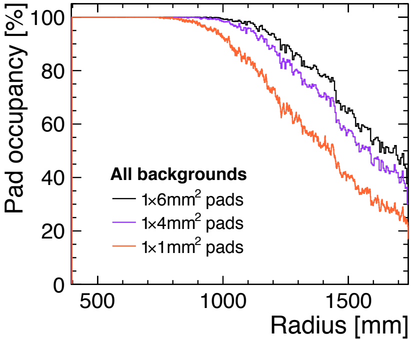
- Occupancy with default pad readout (1×6 mm^2) is up to 30 % in the inner pad rows at 3 TeV (ALICE TPC is designed to work up to 40 %)
- Mainly $\gamma\gamma \rightarrow$ hadrons, also micro-curlers from incoherent e^+e^- pairs
- Space charge causes field distortions up to 10 %, has to be corrected for
- TPC pixel readout is a promising option
  - Occupancy below 3 %
  - Momentum resolution comparable or better than for pad readout
  - dE/dx to be studied
  - Pattern recognition and amount of data have to be addressed

Backup

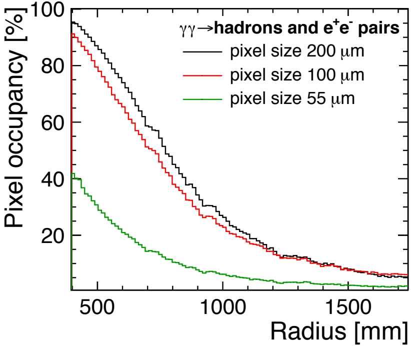
Pad / Pixel Occupancies

Fraction of pads / pixels which see signal within a bunch train

Pads

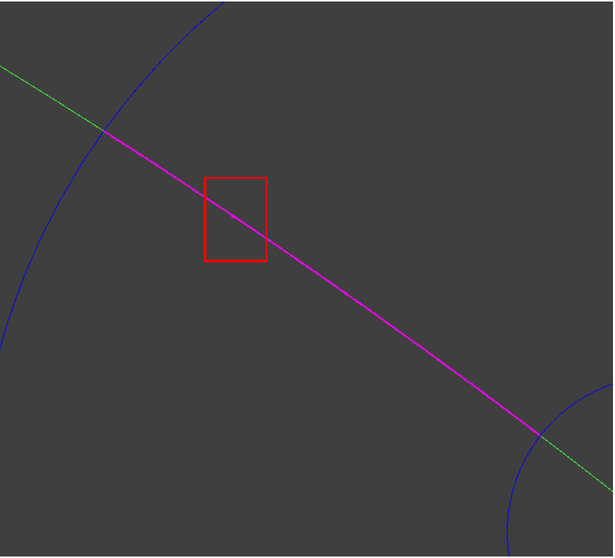


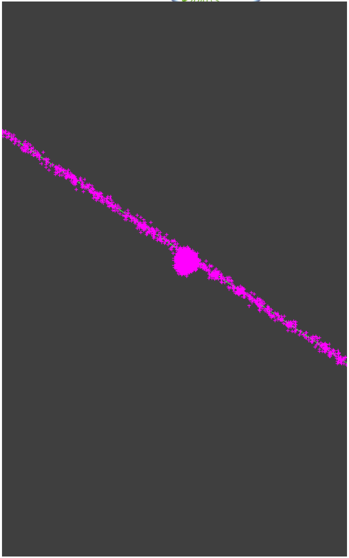
Pixels



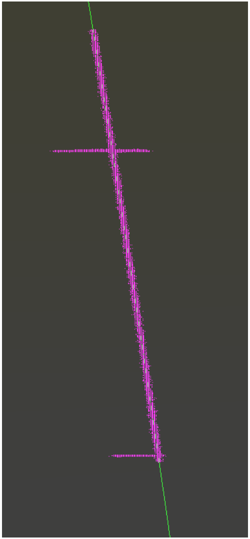
Event Displays

xy Projection

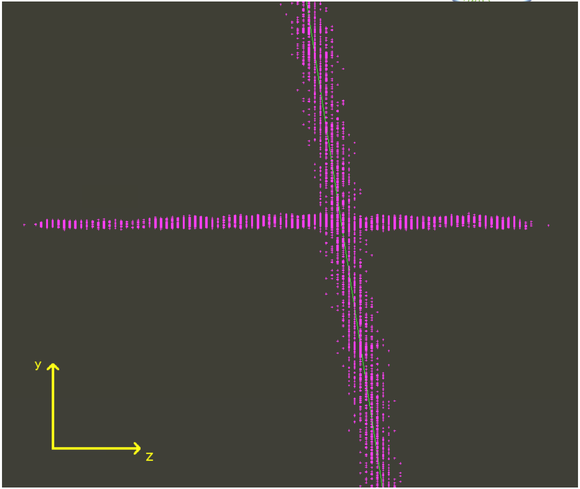




Event Displays



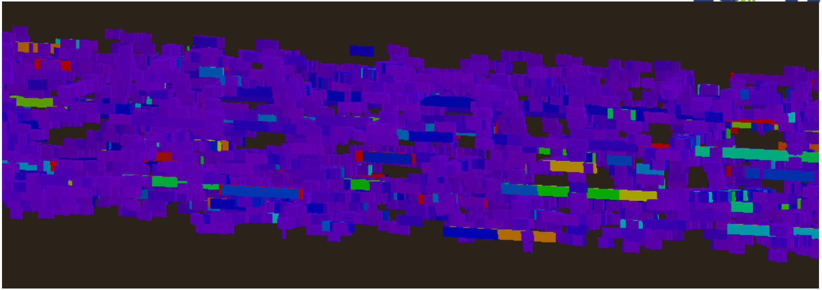
yz Projection



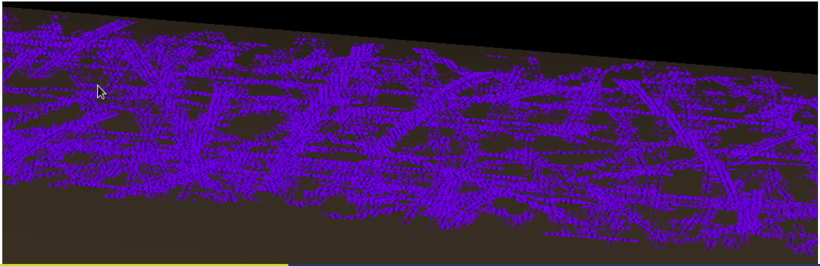
Binning in z due to 40 MHz readout frequency $\hat{=}$ 2 mm drift distance

Event Displays

$1{\times}6\ mm^2$ pads



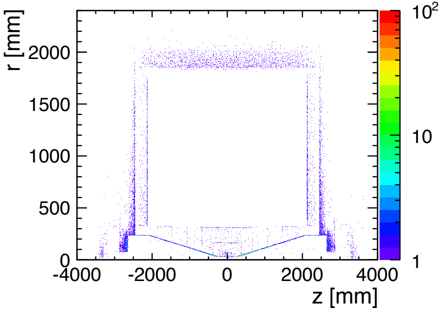
$100{\times}100\ \mu m^2$ pixels



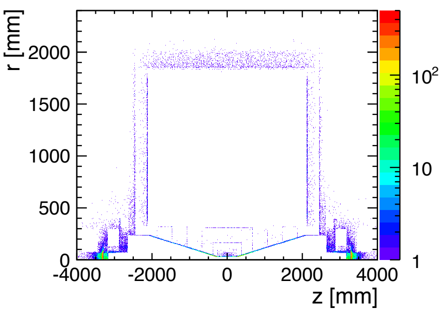
Where do the Particles Come From?

Origins of the MC particles leaving a signal in the TPC

$\gamma\gamma \rightarrow$ hadrons



Incoherent e^+e^- pairs

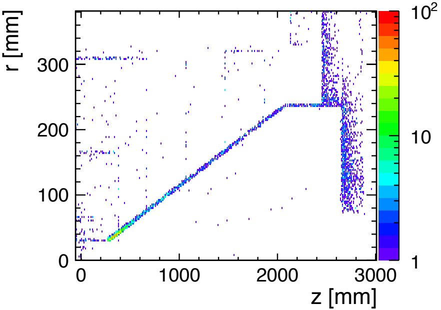


Backscattered particles from all over the detector

Where do the Particles Come From? (zoomed)

Origins of the MC particles leaving a signal in the TPC

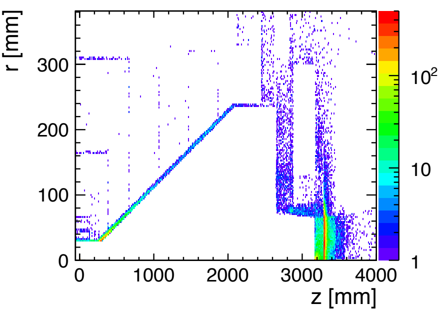
$\gamma\gamma \to$ hadrons



Hot regions:

- Inner region of the pointing beam pipe
- ~25 % directly from the IP (one pixel in the plot)

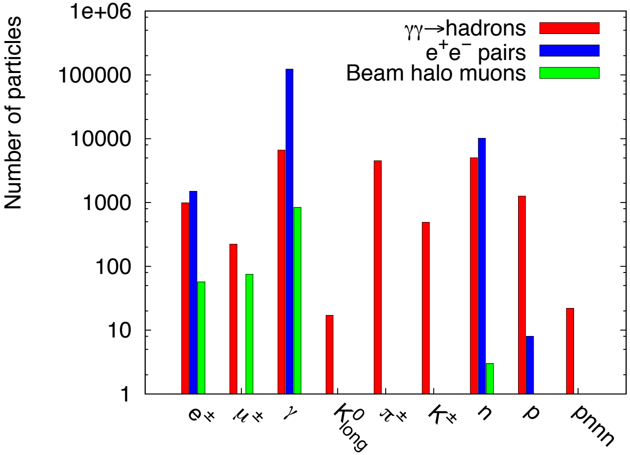
Incoherent e^+e^- pairs



Hot regions:

- BeamCal (low energetic photons) Can this be optimised with a different design?
- Inner region of the pointing beam pipe

Particles Entering the TPC



Direct and Scattered Particles

	From source‡		Total	
Background	Count	E_{dep} [GeV]	Count	E_{dep} [GeV]
$\gamma\gamma \to$ hadrons	4770	4.06	19154	11.0
incoherent e^+e^- pairs	176	0.0717	134908	15.9
beam halo muons	75	0.107	973	0.304

‡IP or beam halo muons scoring plane

Backscattering Particles from the BeamCal

Origins of the MC particles leaving a signal in the TPC