Light collection in “shashlik” calorimeters

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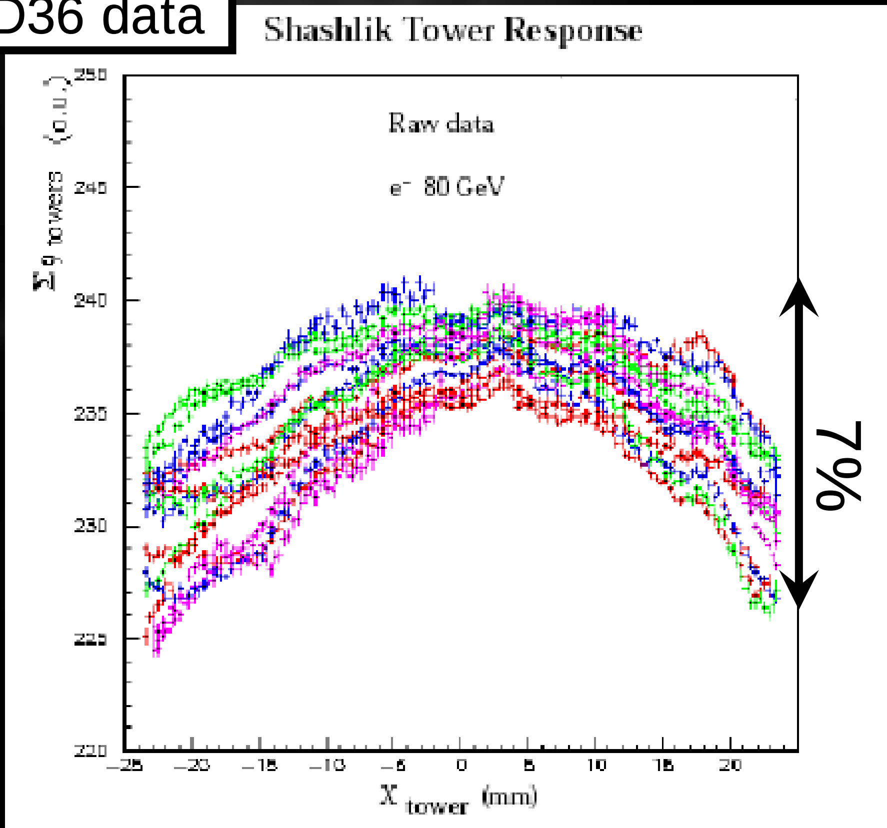
Outline

- Motivation
- Experimental measurements
  - Experimental setup
  - Coordinate determination
  - Results for LHCb and preCBM prototype modules
    - muons and electrons
  - Light yield
- MC modeling
  - Thickness variation
  - Ray tracer
  - GEANT simulation
- Comparison with data
- Simple predictions for current CBM calorimeter

"Shashlik" technology

- Fast
  - 25-30ns trigger signal
  - TOF measurements
    - 120 ps e/γ
    - 300 ps hadrons
- Radiation hardness
  - 2MRad leads to 1.5% constant term increase
- Easy segmentation
  - longitudinal
  - transverse
- Cheap
- Energy resolution
  - typical ~8%/sqrt(E)
  - constant term!

RD36 data

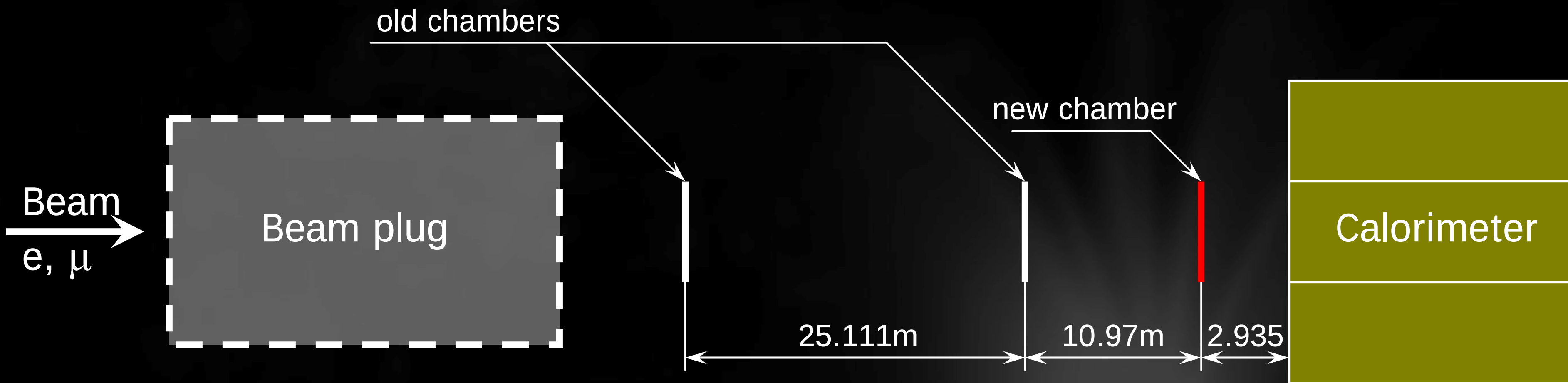


Methods to improve

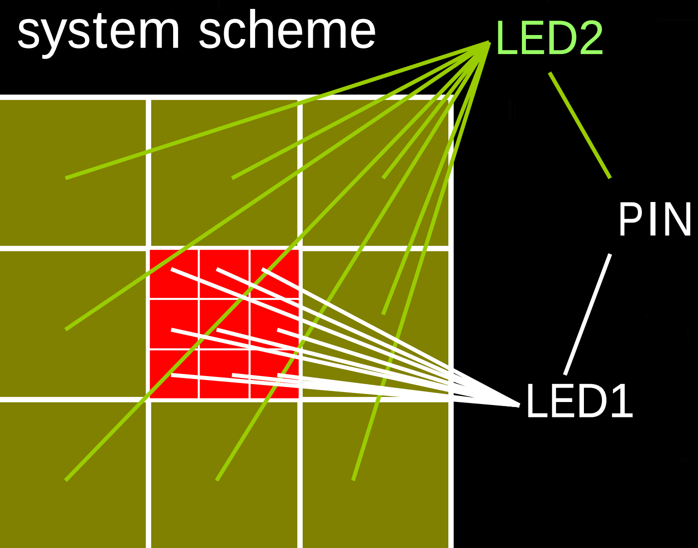
- Sampling term
  - decrease thickness of absorber
    - increase scintillator mass ration
      - increase Moliere radius
        - more shower overlaps
    - decrease scintillator tiles thickness
      - photostatistics
- Constant term
  - increase thickness of scintillator tiles
  - technology
    - die mold price ~7k $
    - model of light collection in calorimeter
- CBM case
  - Large background
  - Minimize Moliere radius
    - less overlapping showers
  - Keep resolution as good as possible
    - better S/B

Studies supported by
INTAS 03-54-6272
INTAS 06-1000012-8914
INTAS 05-111-5257
RosAtom

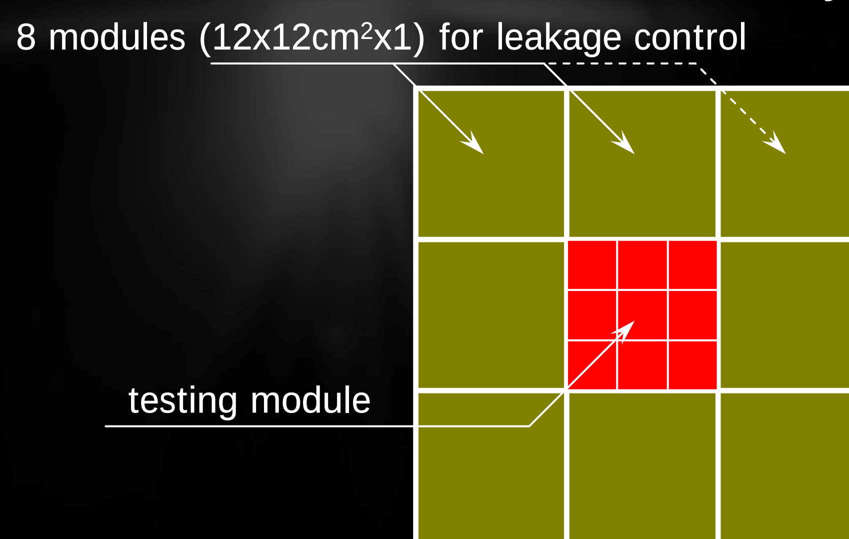
Experimental setup



LED monitoring system scheme

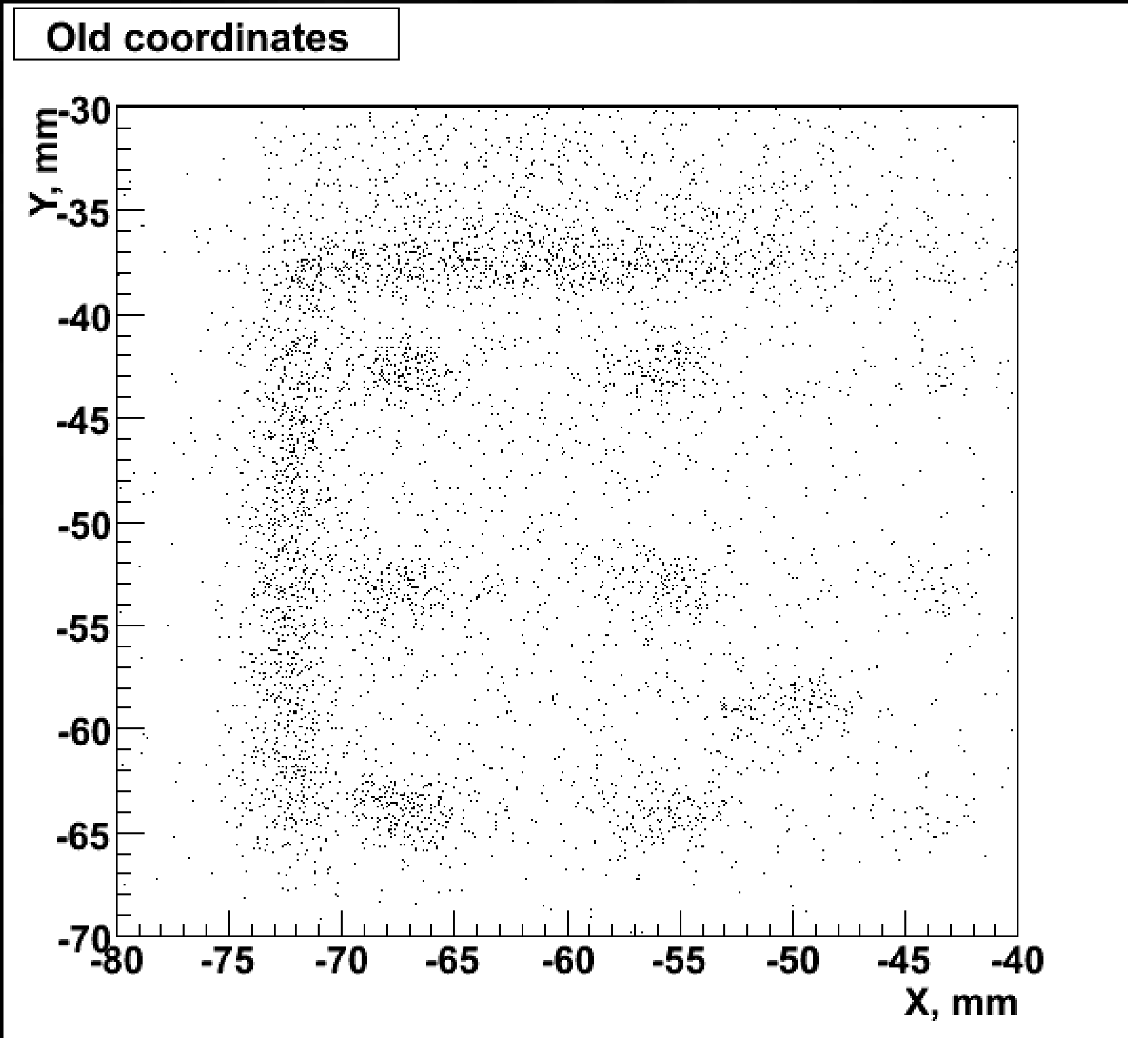


Calorimeter assembly



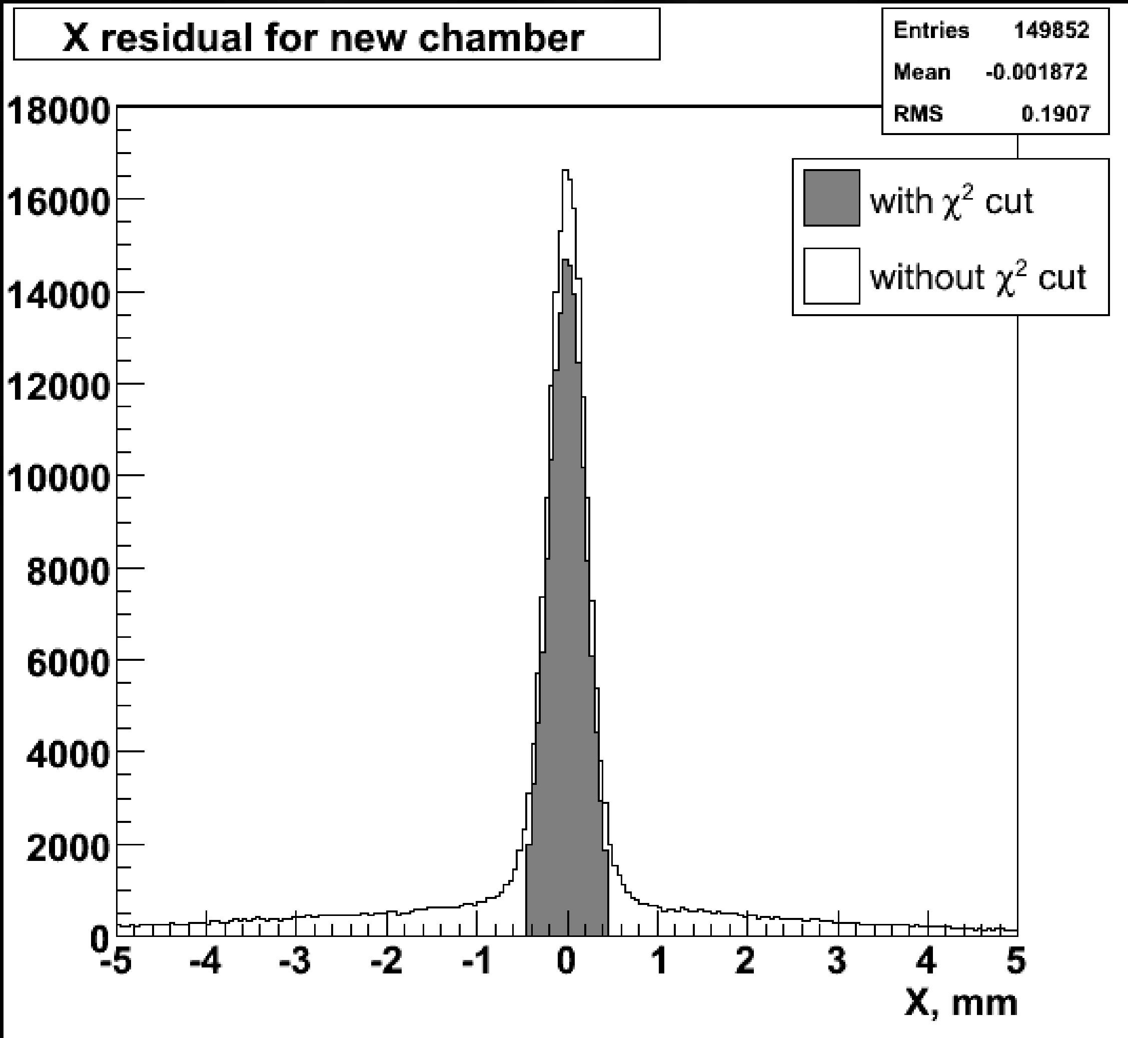
Coordinate determination

- Standard calibration procedure
  - Charge injection in certain points of the chamber
    - Delay wire chambers. A users guide. J.Spanggaard.
  - Shifts and scales can be corrected
  - Quality
- 3-rd chamber
  - track fitting
    - bad track rejecting

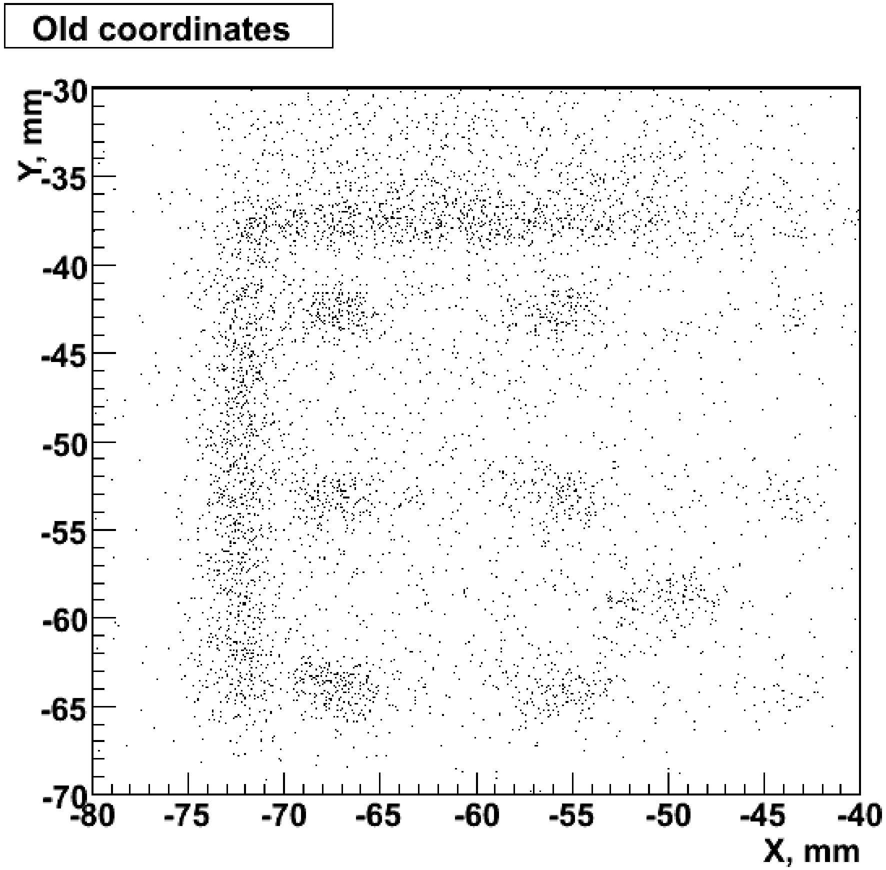


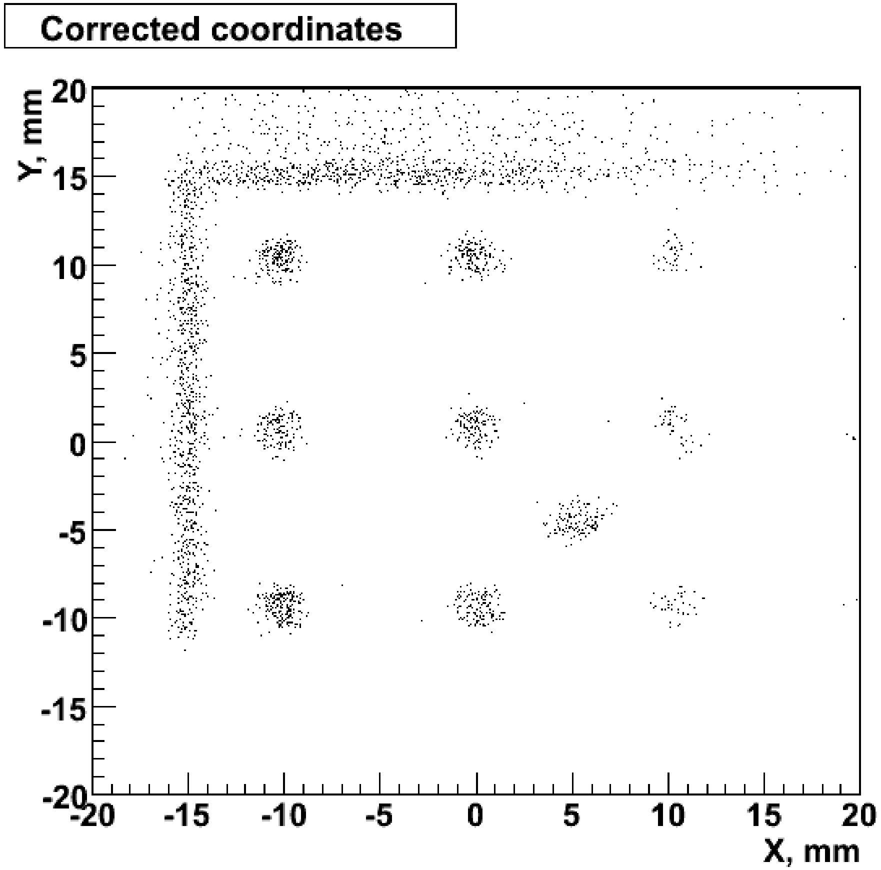
Coordinate determination

- Modify coefficients
  - residuals
    - keep 0 average
    - narrow
- Cut $\chi^2<4$
  - denominator from “Delay wire chambers…” by J.Spanggaard.



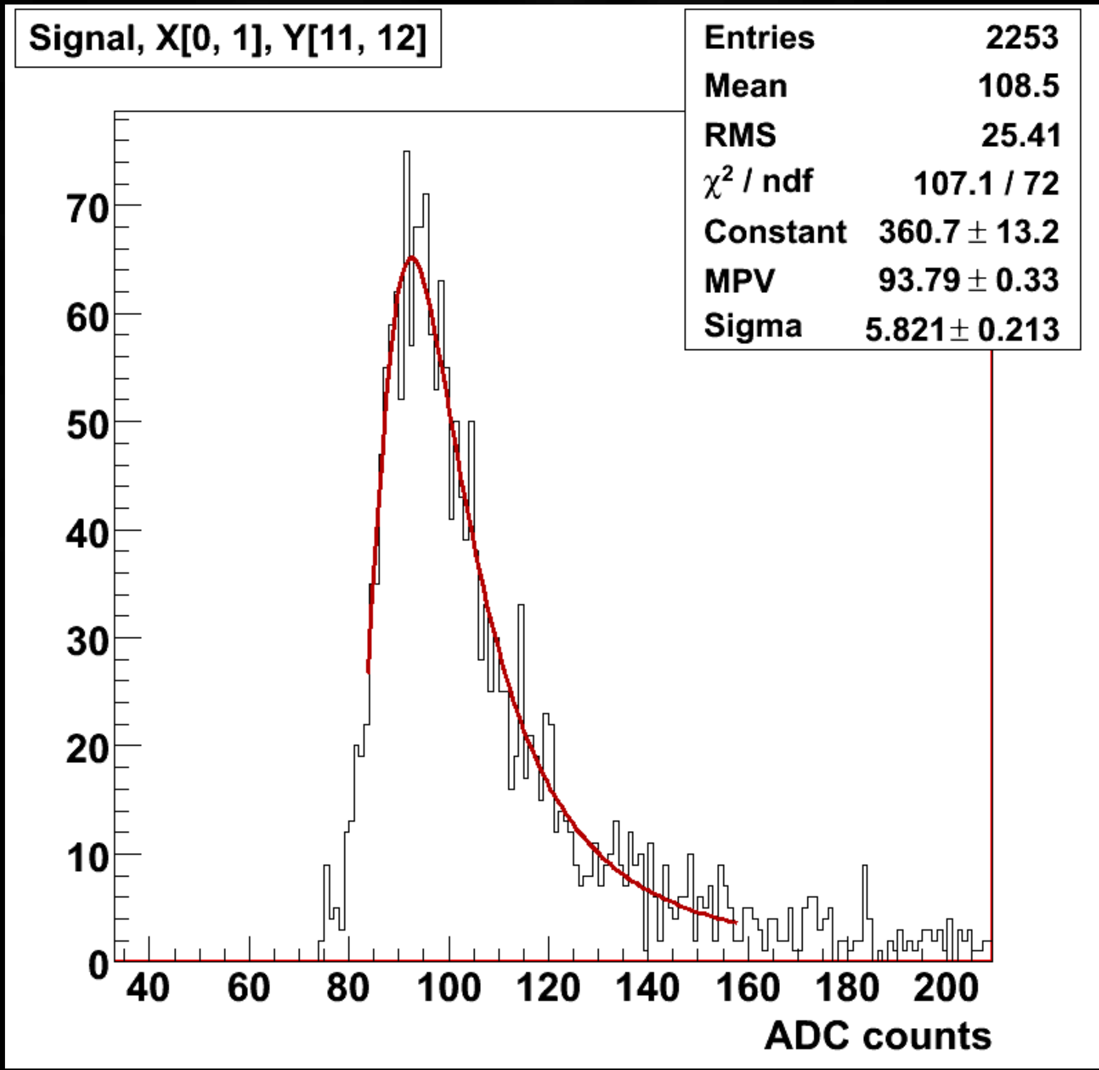
Coordinate determination





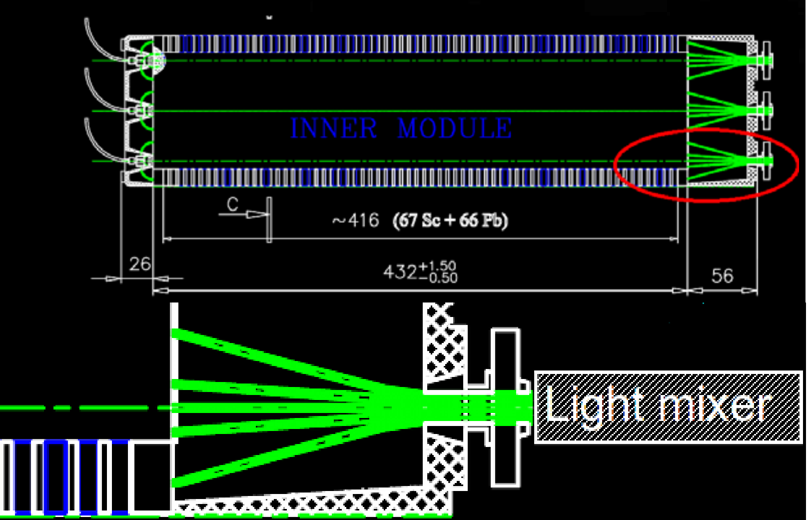
Muons. Procedure

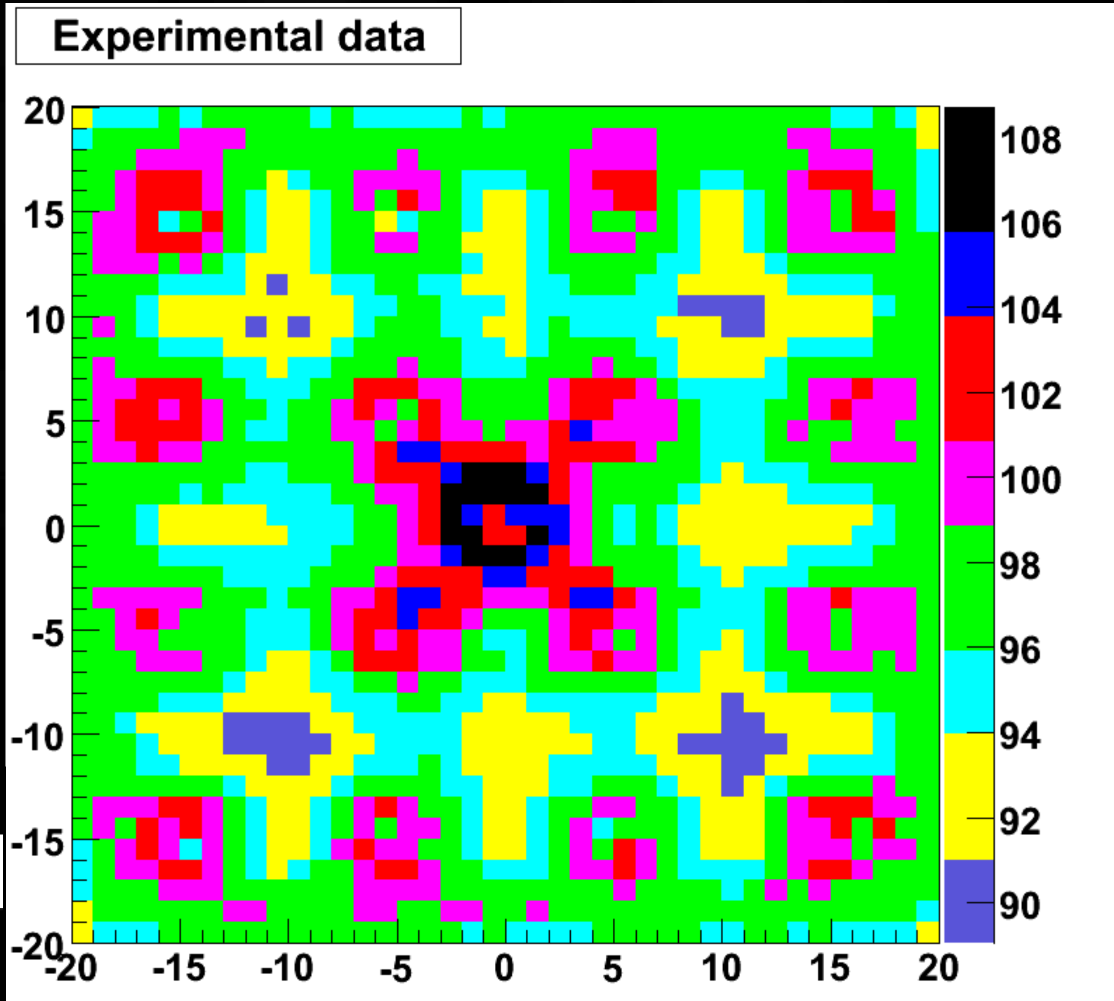
- energy only in central cell
- 1x1 mm^2 regions
- fit with Landau distribution
  - first fit to estimate ranges
  - second fit with
    - $f(x_{start})=0.4*Max$
    - $f(x_{end})=0.05*Max$
  - no Landau Gauss convolution
    - much more statistics



Results. Mouns. LHCb

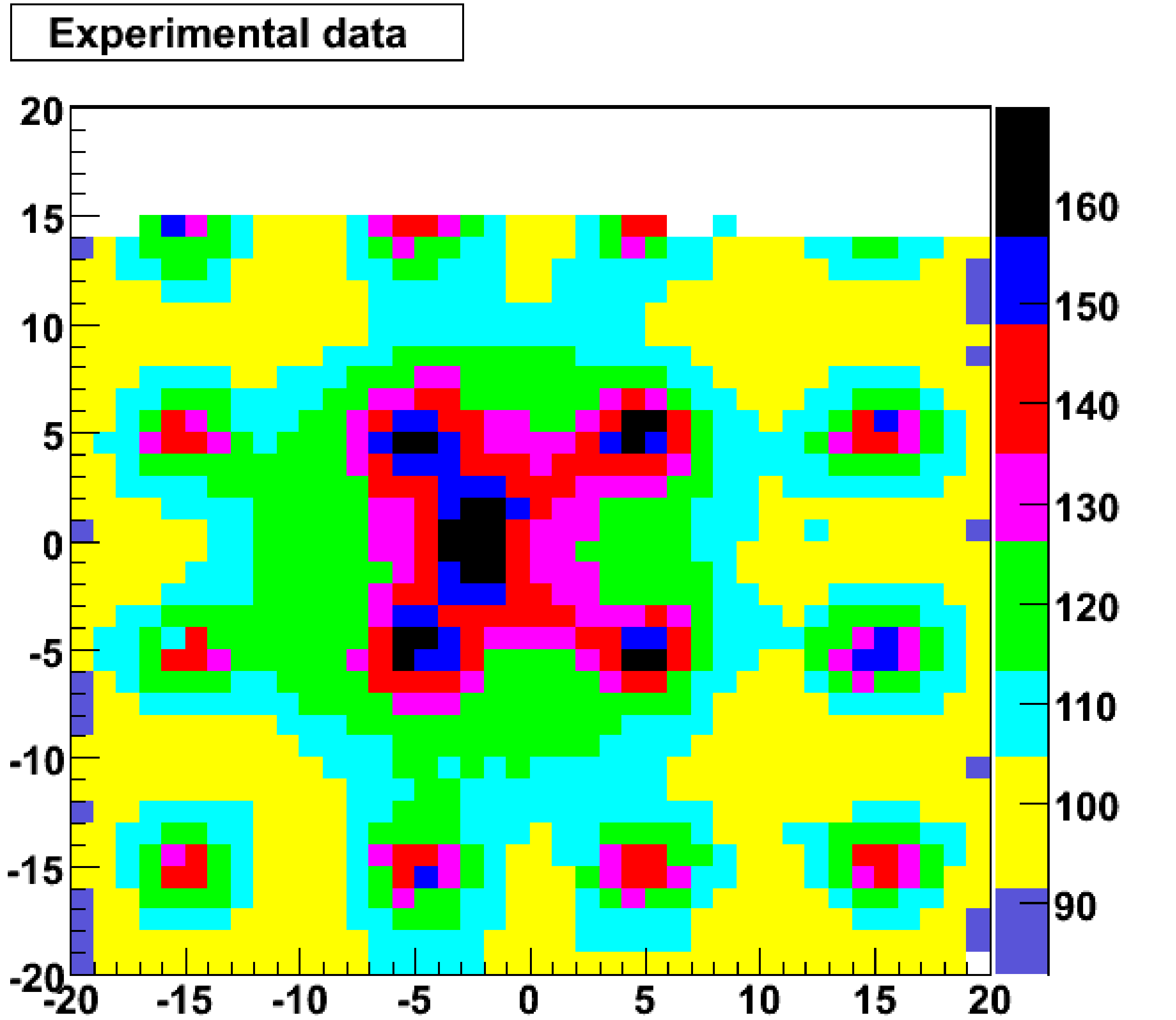
- Geometry:
  - 40x40mm cells
  - 16 fibers
  - 67x4mm scintillator layers
  - 66x2mm lead layers
- Light mixer!





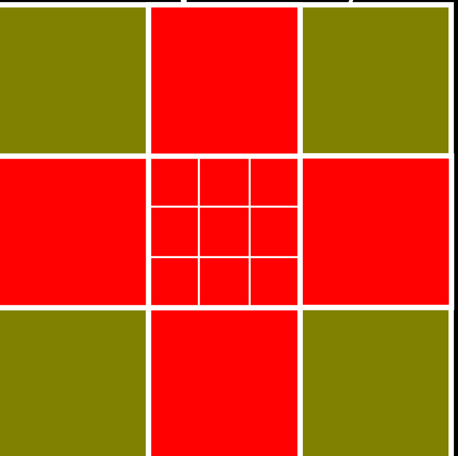
Results. Muons. preCBM

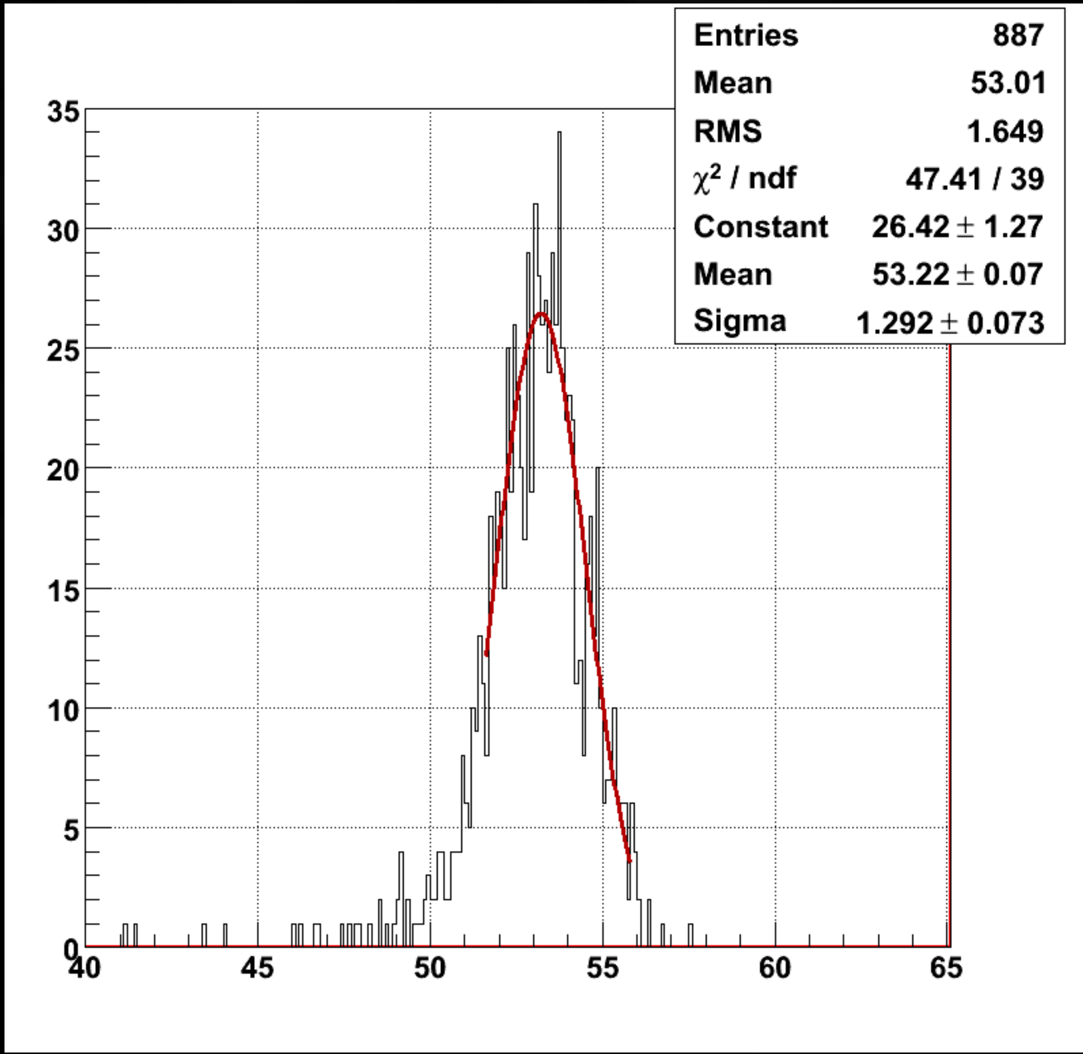
- Geometry:
  - 40x40 mm cells
  - 16 fibers
  - 280x0.5 mm lead layers
  - 280x0.5 mm scintillator layers
    - extreme
    - for MC tuning



Electrons. procedure

- Collect energy in 3x3+4 cells
  - wide signals with if other 4 cells included
- 1x1 mm2 regions
- Iterative fit procedure
  - [-1.2δ, +2δ] region



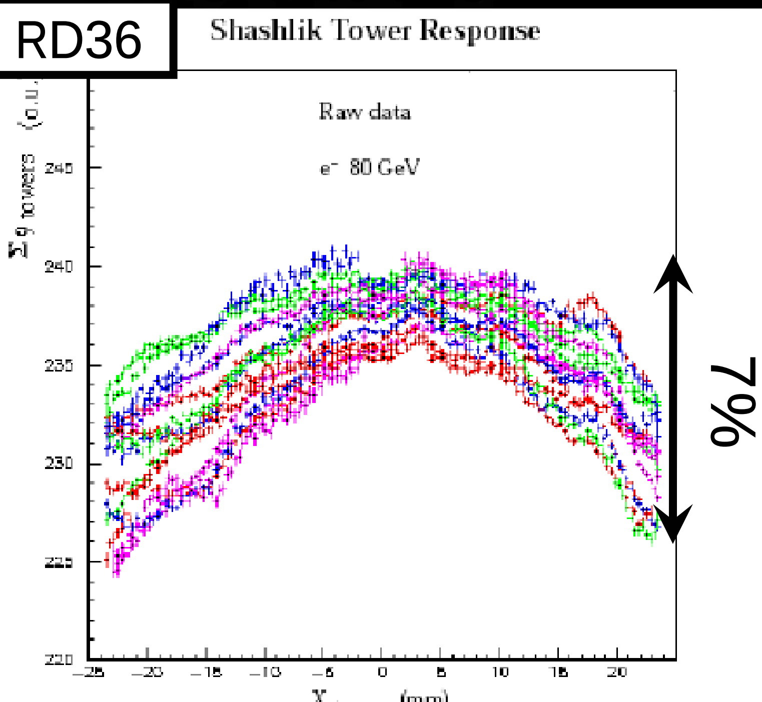


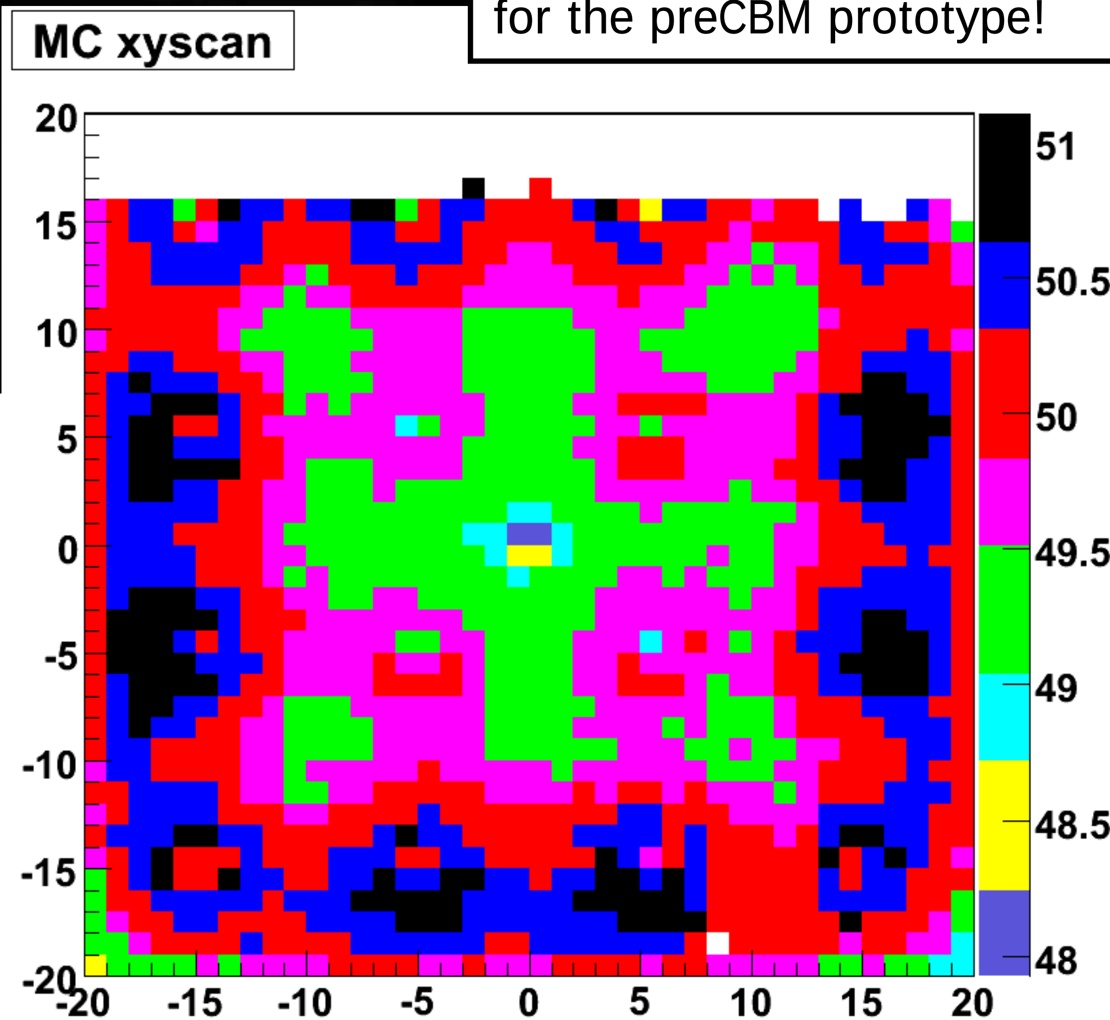
50 GeV electrons. LHCb. Results

- Geometry:
  - 67x4mm scintillator layers
  - 66x2mm lead layers
- Different module!

No electrons measurements for the preCBM prototype!

RD36

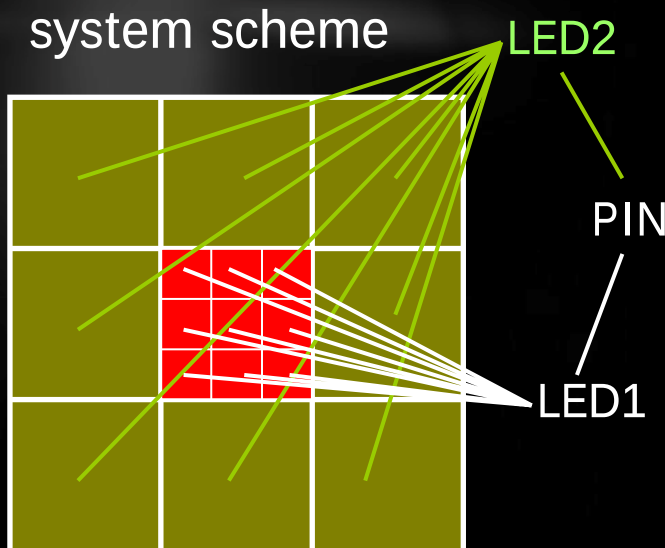




Light yield measurements

- Procedure
  - measure LED signal amplitude and width by PMT
    - monitoring system!
  - Number of photoelectrons $= \text{Amplitude}_{LED} / (\text{Width}_{LED})^2$
    - Poisson statistics
    - Other factors -> wider signal
      - underestimated number of photoelectons
      - width of pedestals subtracted
      - different LED amplitudes
  - Calibration
    - ADC count -> GeV

LED monitoring system scheme



Light yield measurements

	Geometry	Scintillator/Lead volume ratio	Testbeam	Cosmic setup
Small	$40x40x4mm^3$ fiber per $1x1cm^2$	2:1	3000	3100
Middle	$60x60x4mm^3$ fiber per $1x1cm^2$	2:1	4200	3500
Large	$120x120x4mm^3$ fiber per $1.5x1.5cm^2$	2:1	2500	2600
preCBM	$40x40x0.5mm^3$ fiber per $1x1cm^2$	1:1	700	-

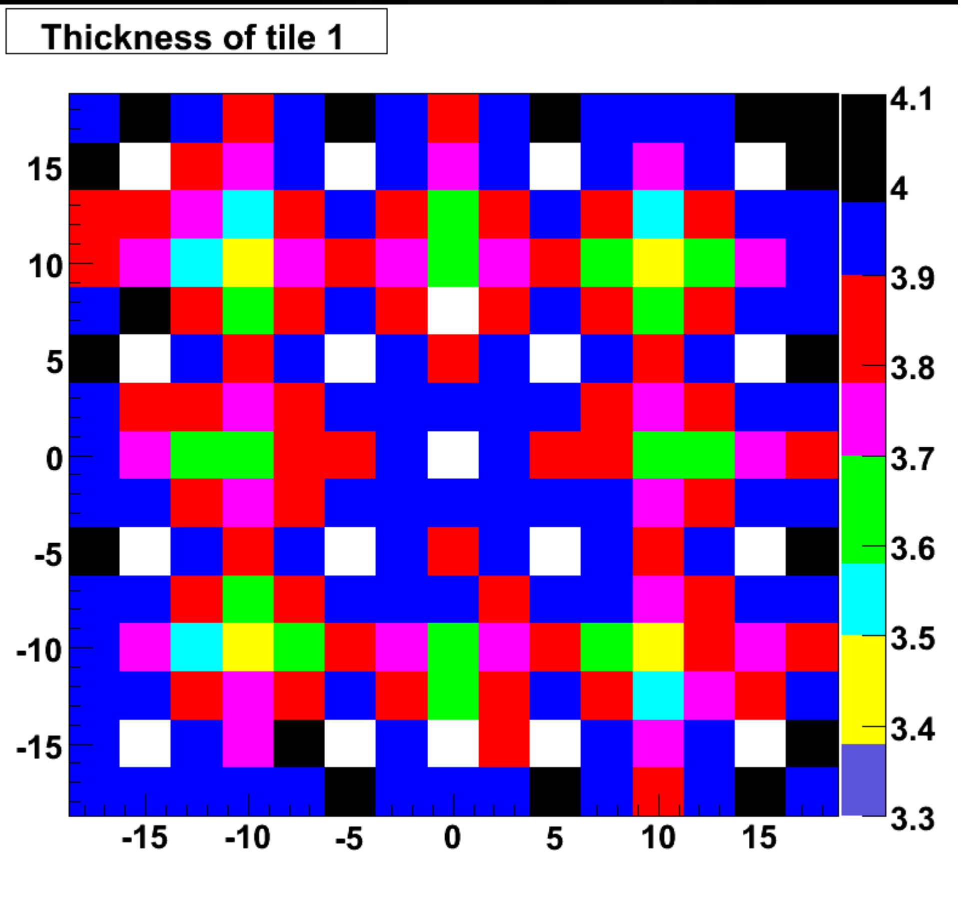
MC modeling

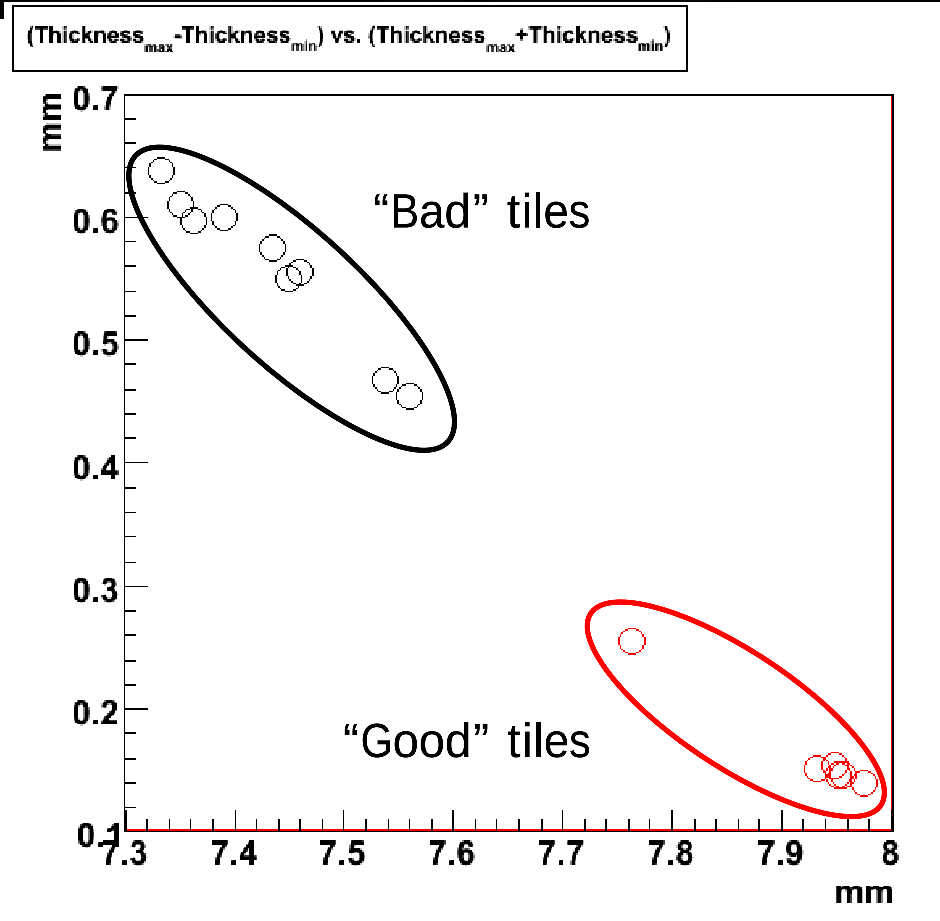
- Signal nonuniformity
  - Scintillator tile thickness variations
    - Measured directly
  - Light collection nonuniformity
    - Special ray tracer program
  - Convolution with particle energy deposition
      - “natural” smearing
      - energy deposition nonuniformity
    - GEANT

Thickness variations

- Direct measurements with micrometer
- ~250 measured points per tile
- Spline extrapolation

Thickness measurements

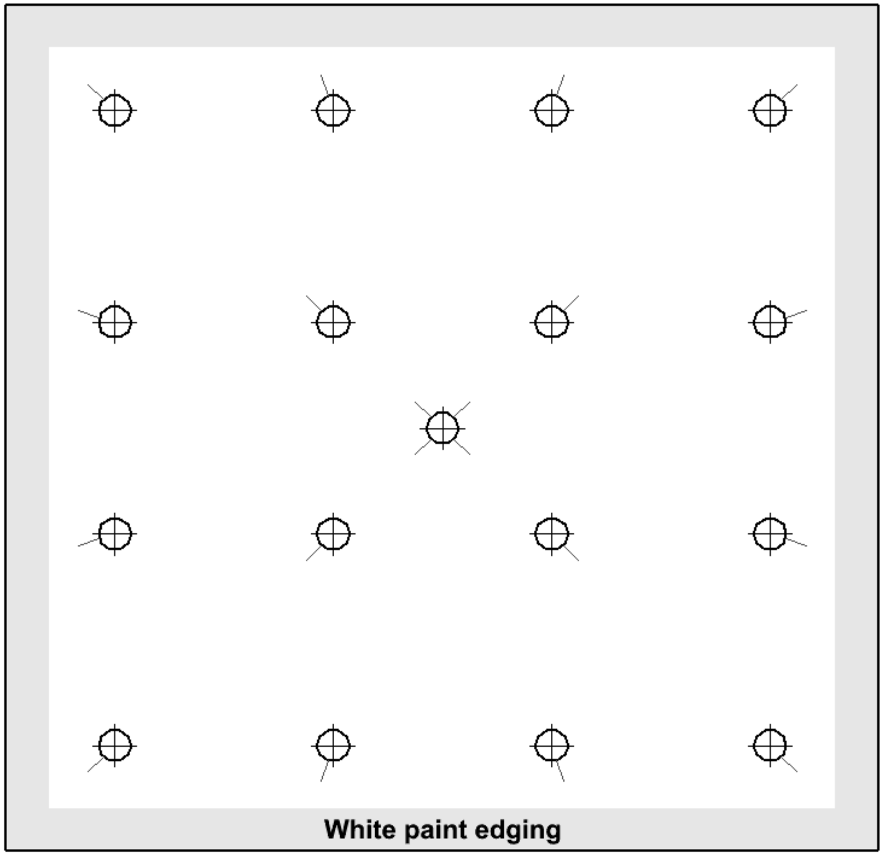


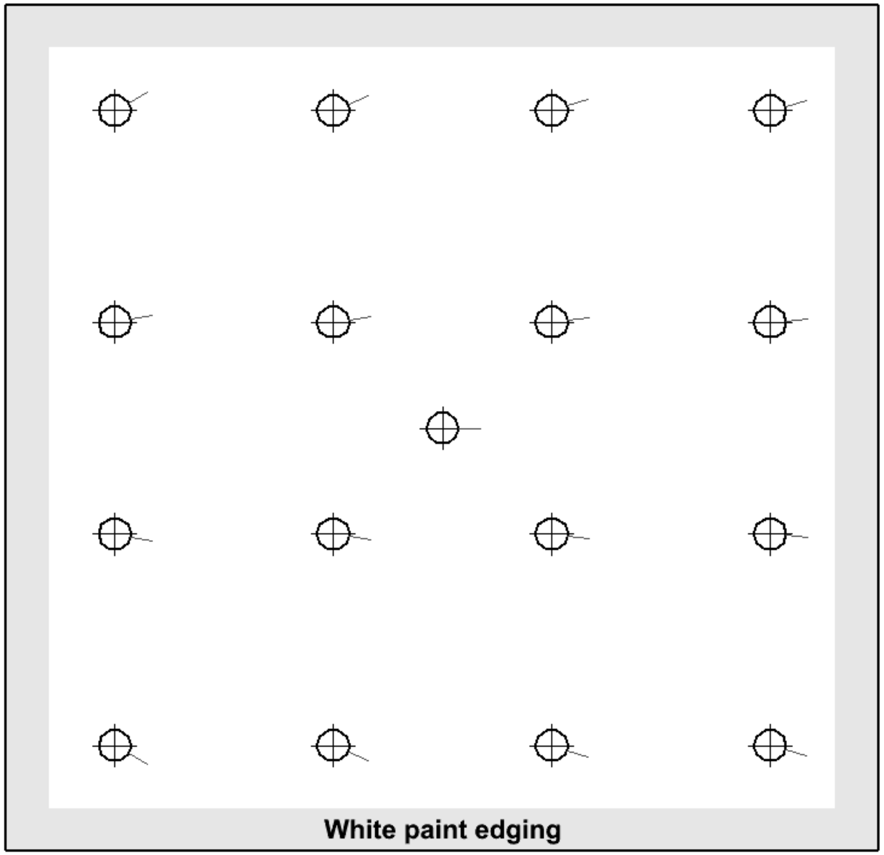


Thickness measurements

“Bad” tile

Example of “good” tile

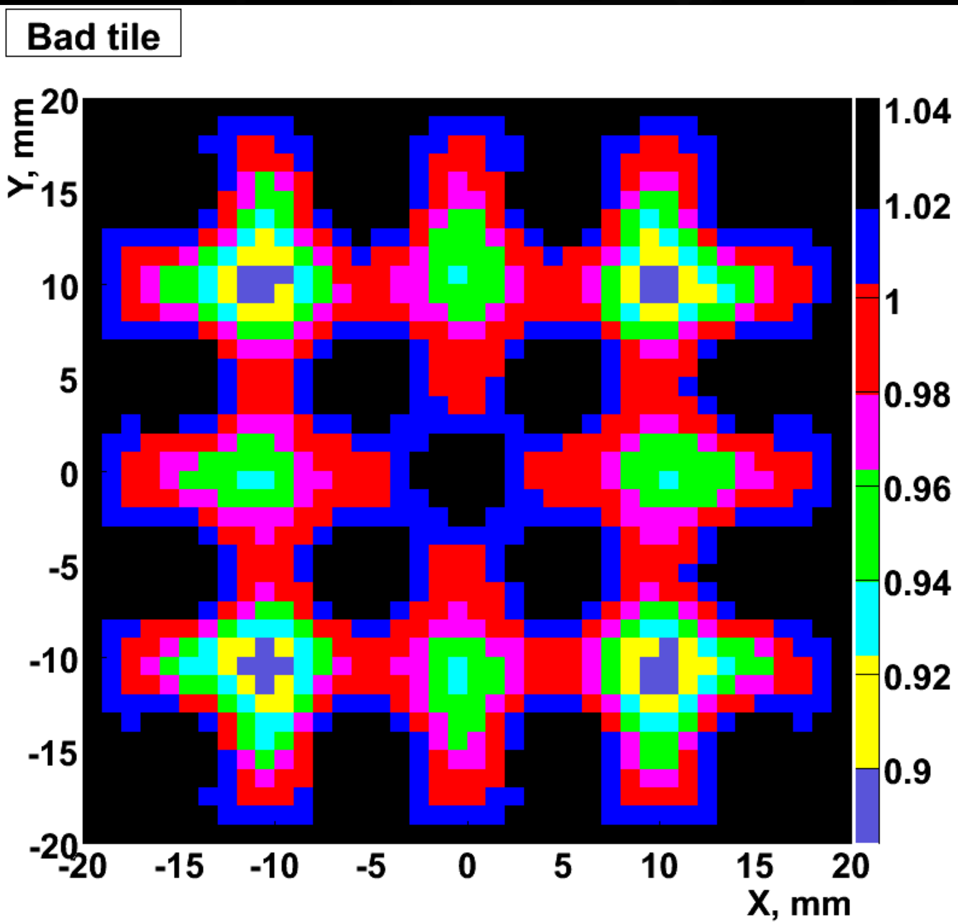


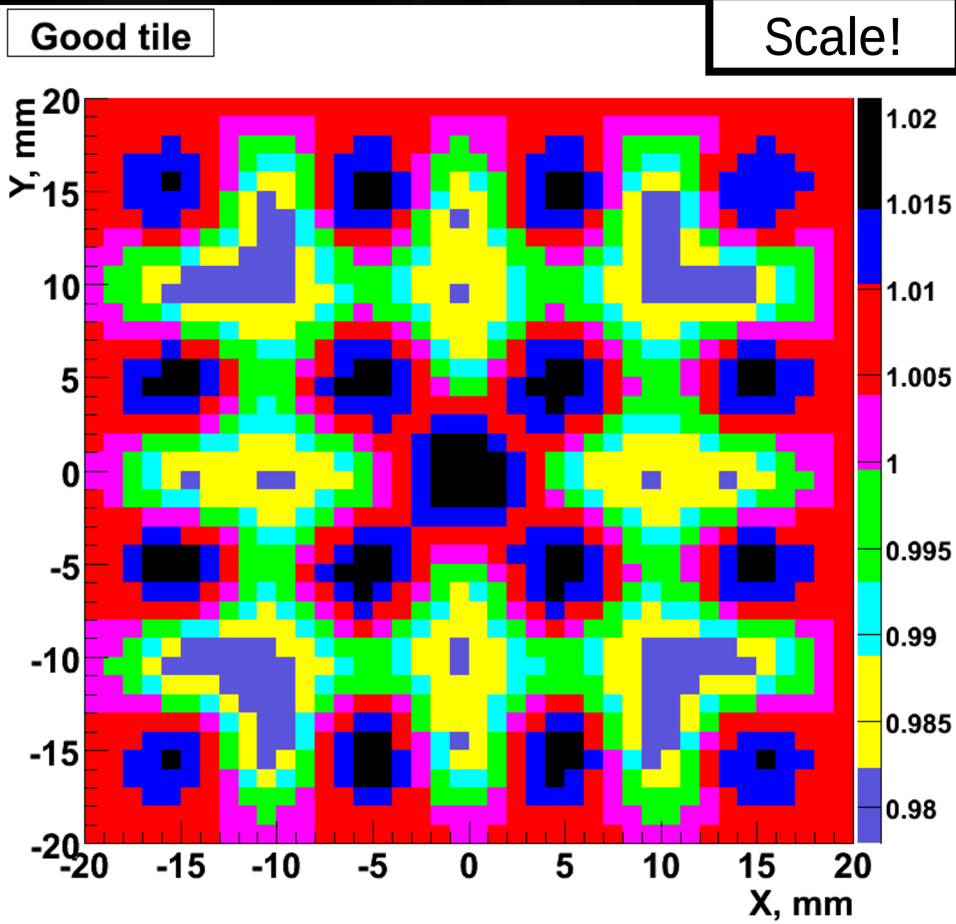


Traces on the surface are different for “good” and “bad” tiles!

Thickness measurements. Results

Scale!





Ray tracer program. Requirements

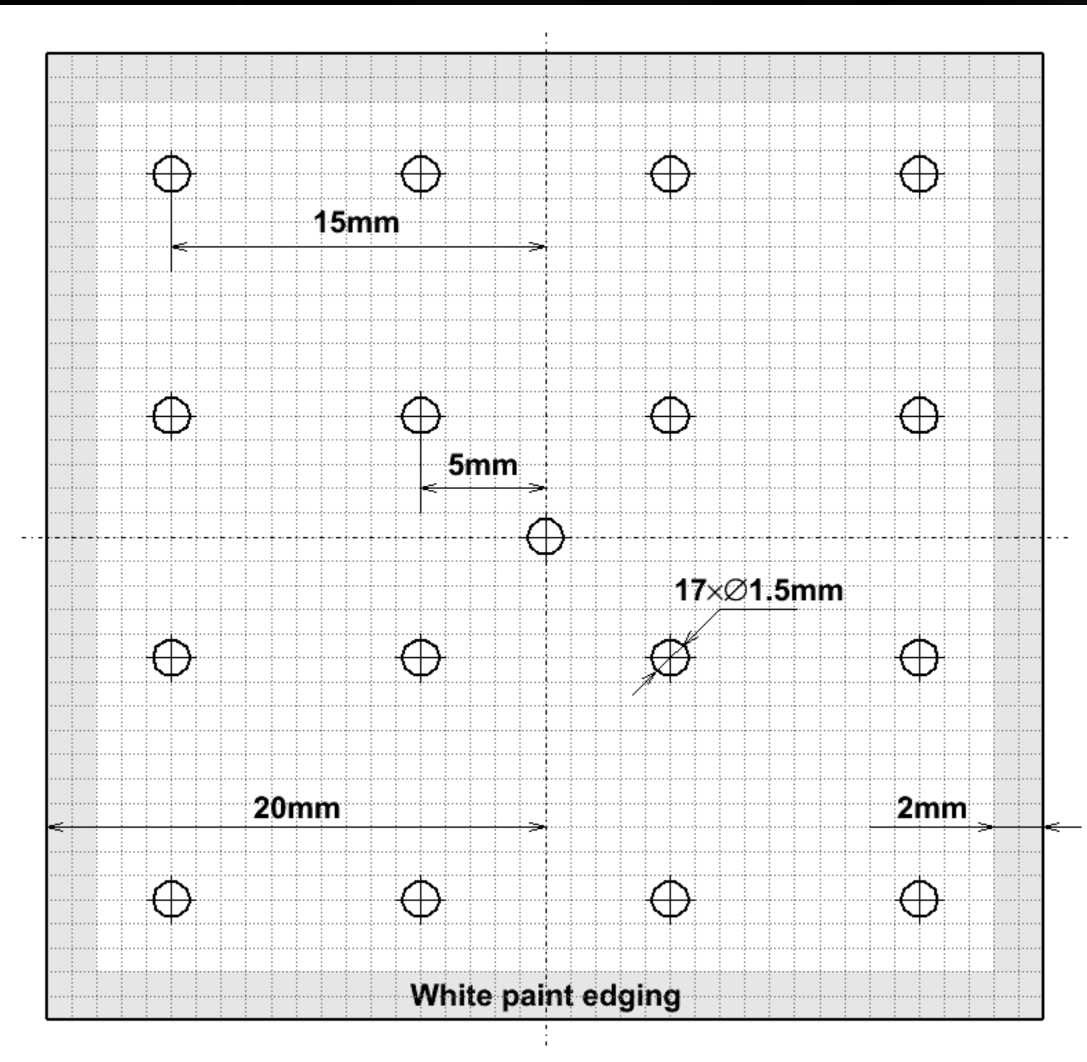
- Quite complex geometry
  - Boolean shapes
- Large statistics
  - 10^7 photons per measurement
    - 1% precision
    - ~3% light collection and transport efficiency
      - 200eV for scintillator photon
      - 10% of energy deposition visible
      - 20% photon to electron conversion probability in PMT
        - 10^5 photons per GeV without light transport and collection
      - ~3000/GeV photoelectrons in PMT

CPU:
ITEP batch farm
GSI batch farm
GRID
$5x10^4$hx2.4 GHz spent
$1x10^4$ jobs

Ray tracer program

- Optics
  - refraction
    - Fresnel formulas
  - reflection
    - mirror
    - diffuse
  - attenuation
    - in medium
    - on surface
  - all processes could depend on wavelength
- Geometry
  - Geometrical primitives
    - cylinder
    - box
  - Boolean operations
  - Voxelizaliton
    - for speedup

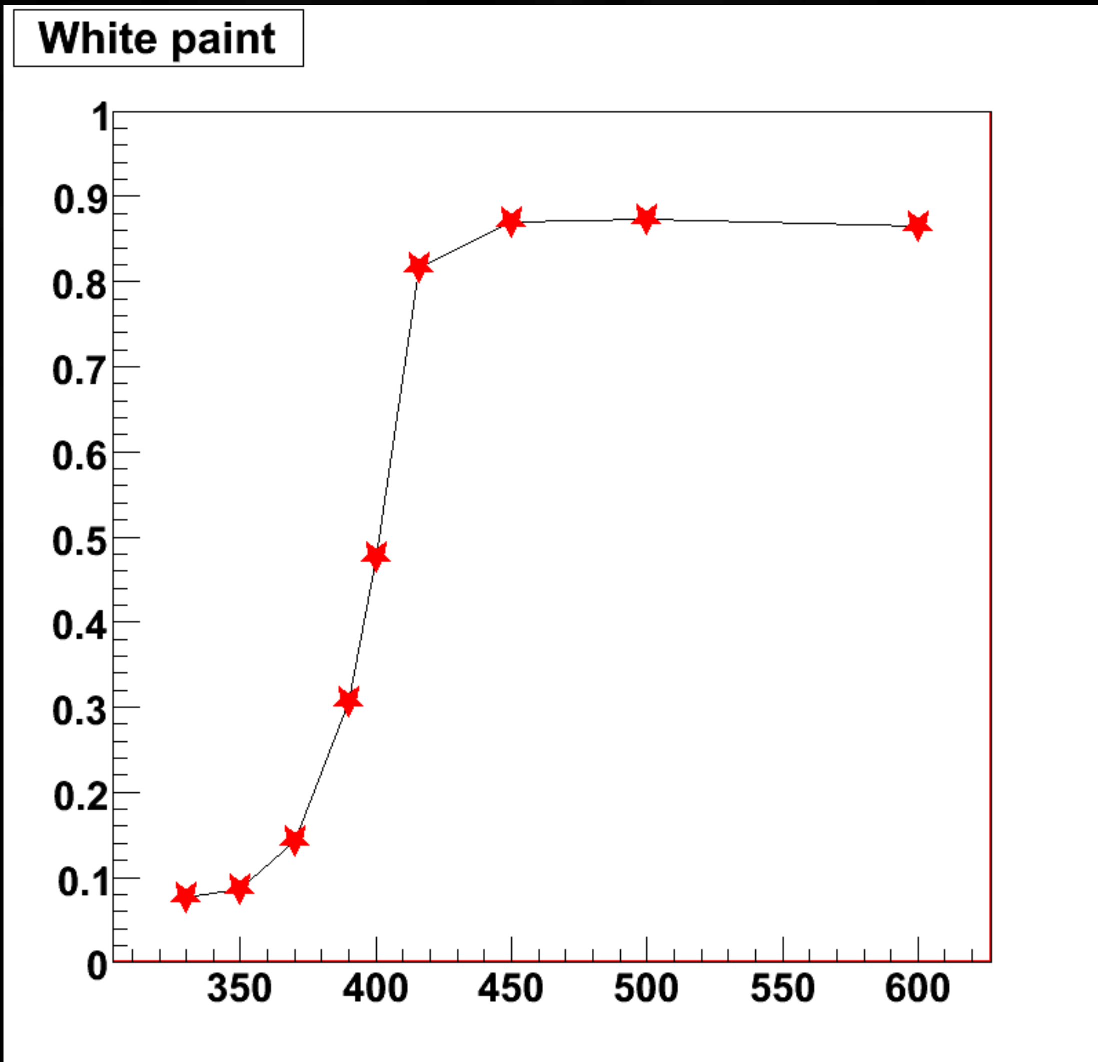
Voxelization. Surface quality



- Idea: small regions ($0.5x0.5mm^2$)
  - list of excluded objects
  - sorted by distance list of objects
    - remove objects with distance larger then found
  - classical trade CPU/memory
- 2 materials
  - plastic
    - fully transparent
  - tyvek
    - 40% diffuse reflection
    - 60% black
  - tyvek(surface quality)+plastic(1-surface quality)

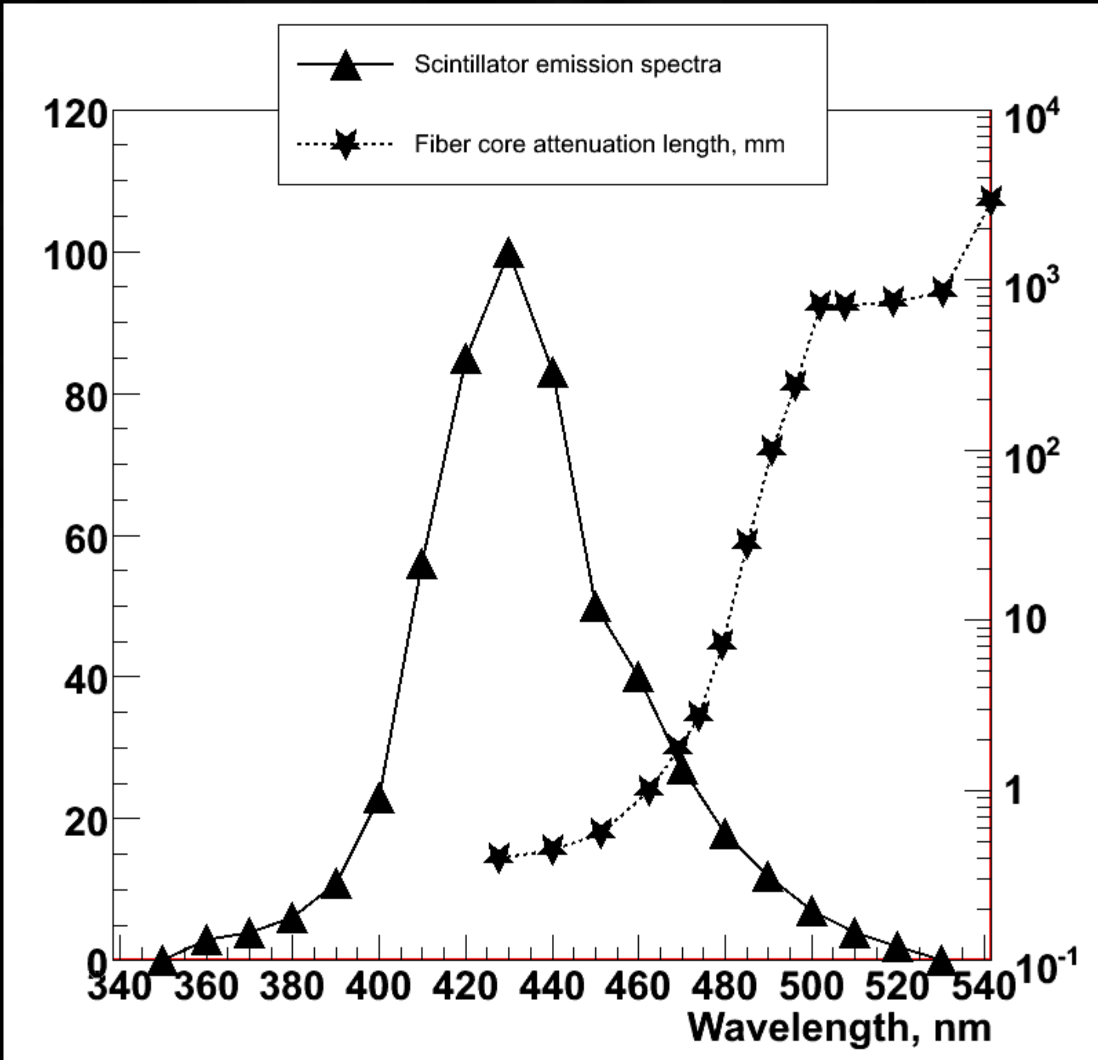
White paint

- Edges and edging
  - edging width require fine tuning
  - no mirror reflection or transparency
  - scaling coefficient introduced
    - one of the main parameters

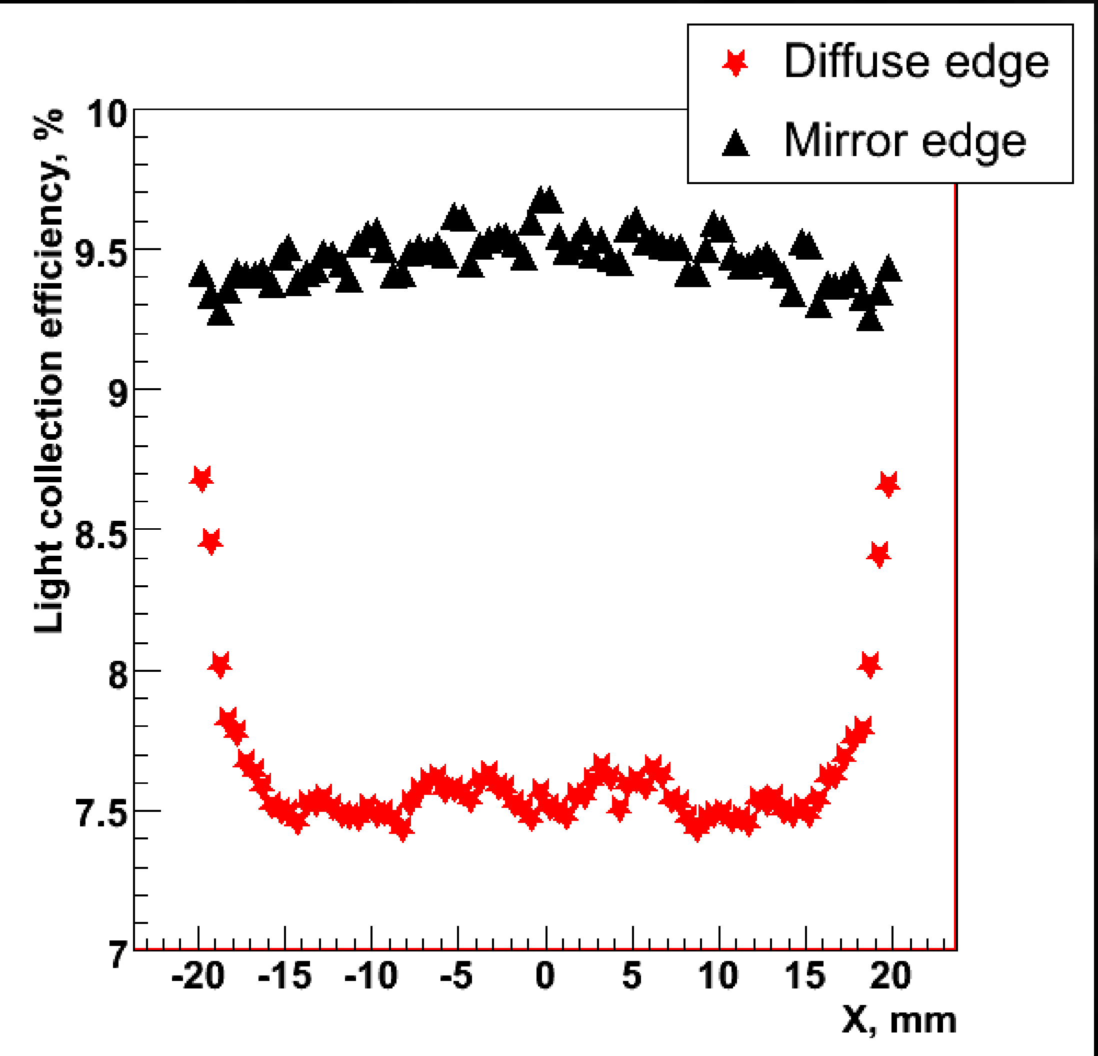


Procedure

- 0.5x0.5mm^2 regions
- Photons generated uniformly
  - also on Z axis
  - isotropic
- Transported till photon absorption
- Reemission in fiber
  - isotropic
  - check angles (transport to PMT)



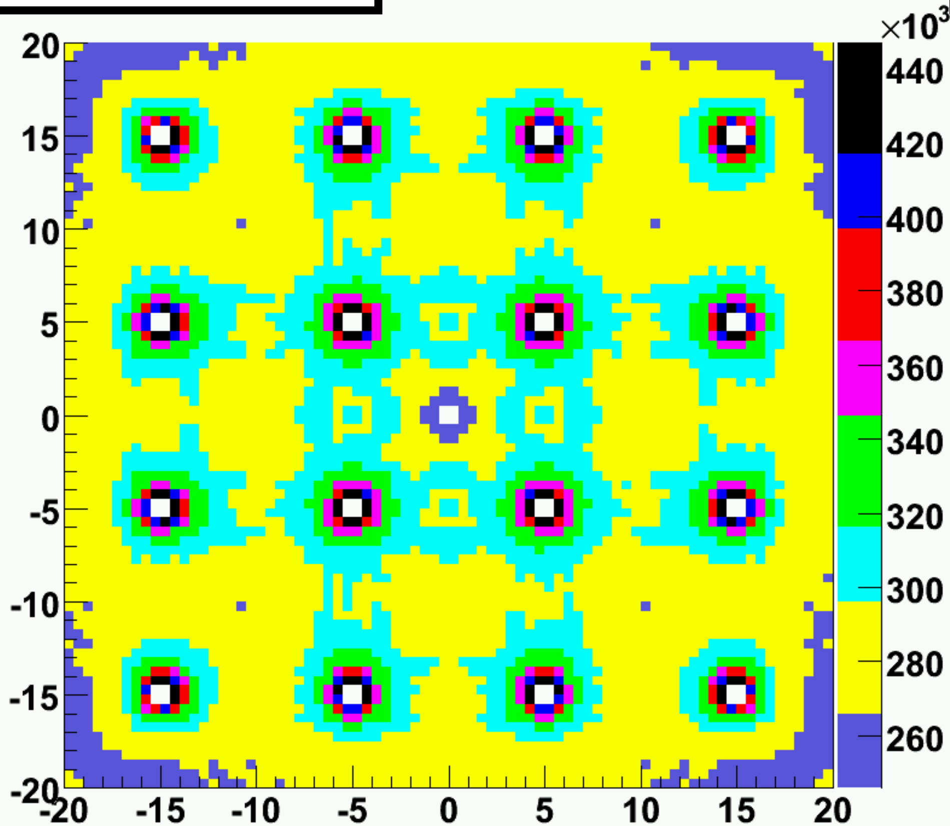
Example of ray tracer test



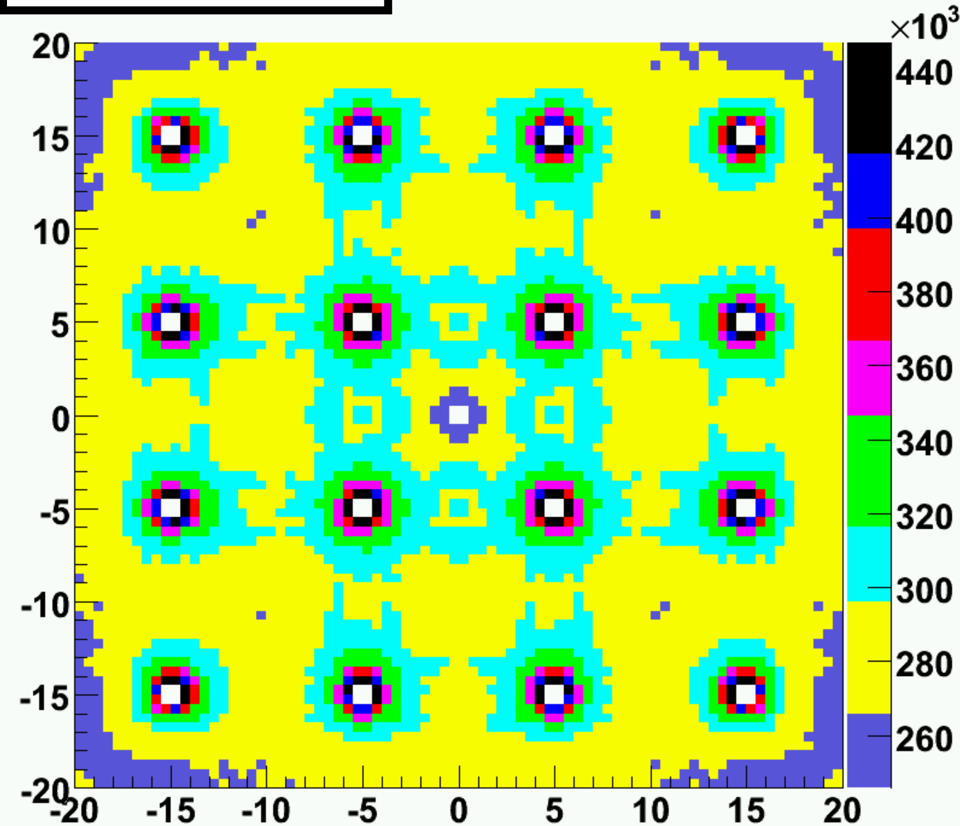
- Edge effect in light collection
  - dead material between tiles
  - not trivial
  - LHCb technology

Ray tracing. Results

Whiteness 1.02



Whiteness 1.08



preCBM prototype: 0.5mm thickness, no edging, surface quality 0.06

Ray tracing. Comparison with light yield

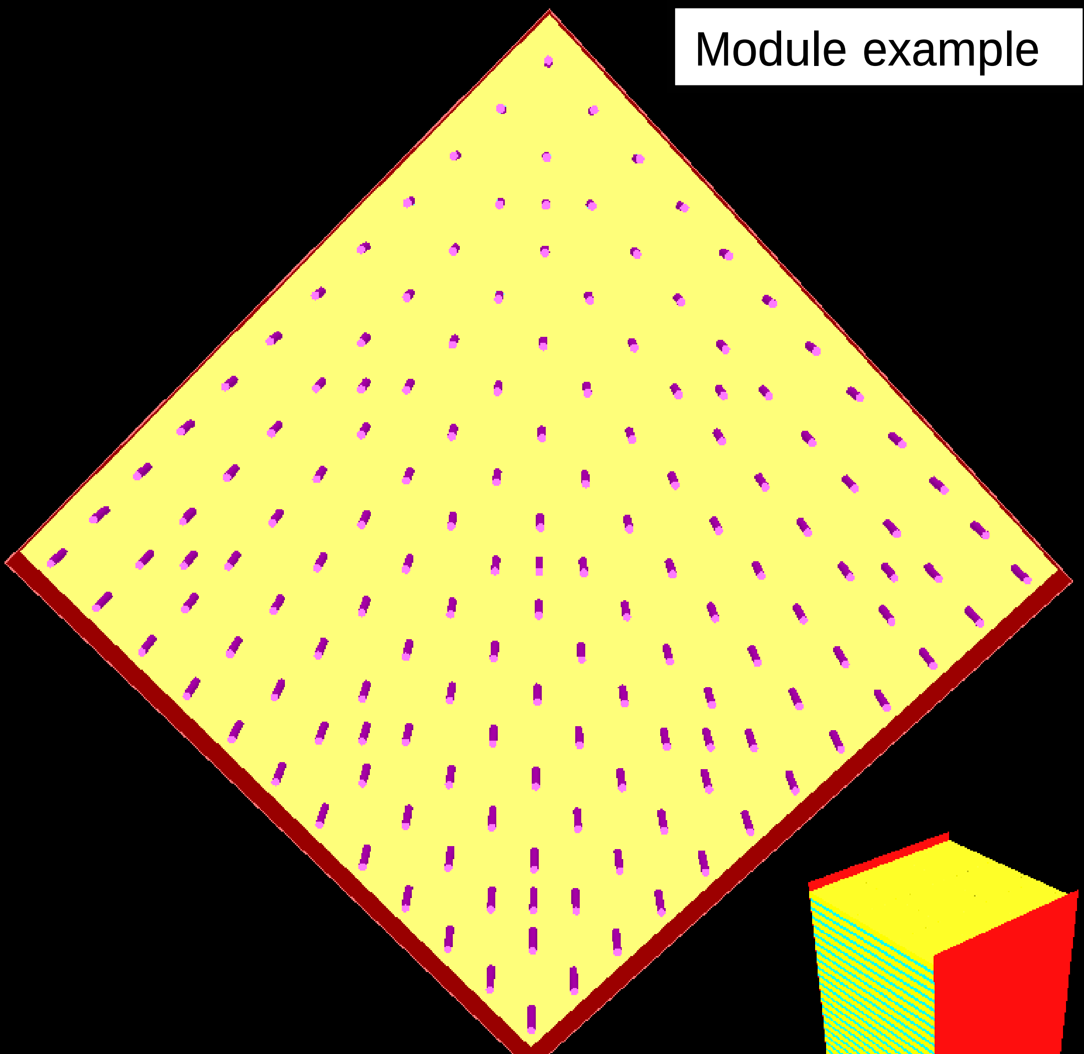
- Generate photons uniformly inside tile volume
- Take small LHCb tiles for normalization

	Testbeam	Cosmic setup	MC
Small	3000	3100	3000
Middle	4200	3500	3600
Large	2500	2600	2570
preCBM	700	-	600

Excellent middle module at testbeam?

GEANT model

- Tile model with holes and fibers
  - same as for ray-tracing
- Assemble the module
  - steel tapes
- Assemble the calorimeter wall
- Gorynych framework
  - for FLINT experiment
  - similar to FAIRROOT
    - code can easily used for modeling CBM calorimeter

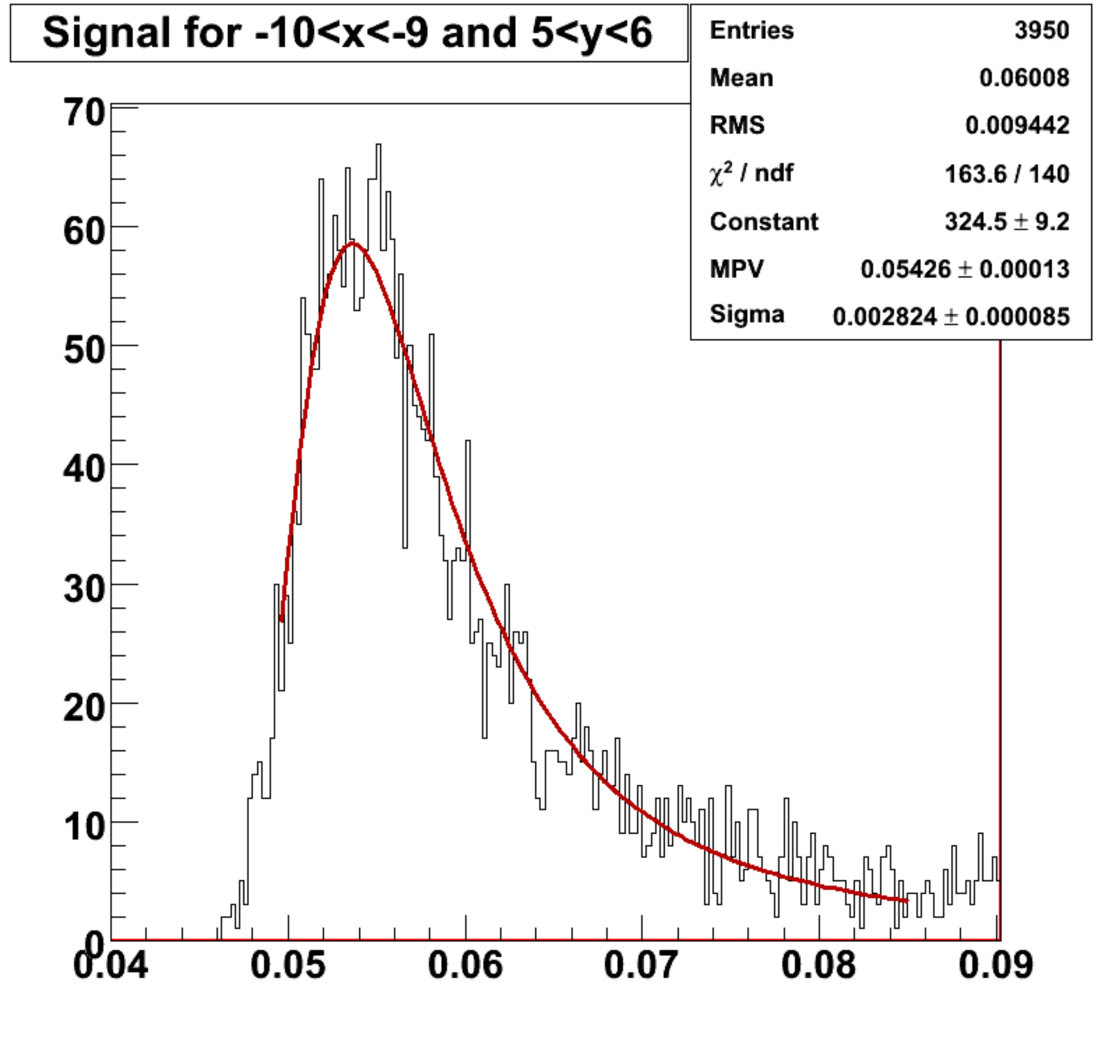


Comparison with data

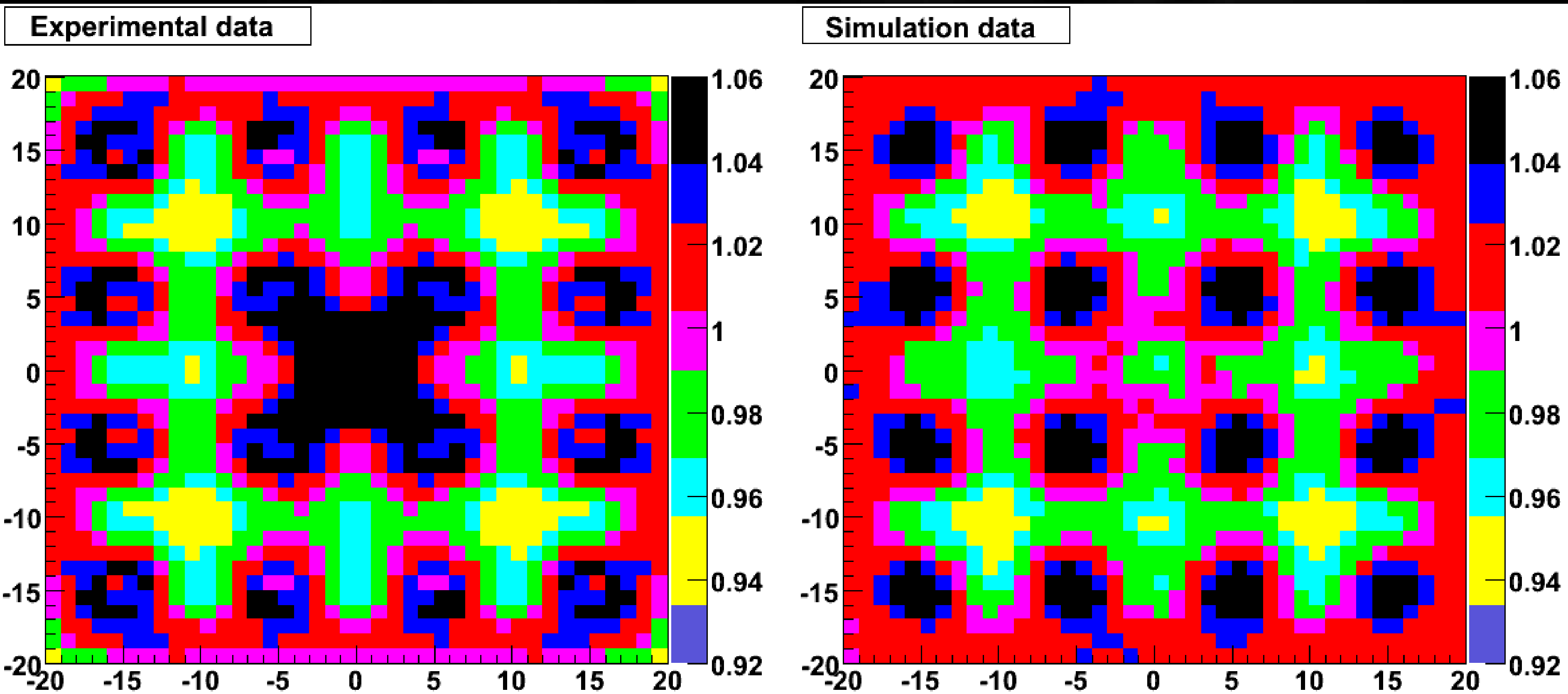
- Light collection efficiencies maps
  - 0.5x0.5mm^2 segmentation
- Calorimeter response with GEANT
  - 30KeV Geant3 cuts
  - 1.0x1.0mm^2 segmentation
  - converge with
    - light collection maps
    - thickness maps
- Free parameters
  - fraction of “bad” tiles in calorimeter
  - light collection
    - for LHCb
      - whiteness of edges and edging
      - size of edging
    - for preCBM prototype
      - surface quality of the tile

Muons. Fitting

- Fit with Landau distribution
  - first fit to estimate ranges
  - second fit with
    - $f(x_{start})=0.4*Max$
    - $f(x_{end})=0.05*Max$
- $1x1mm^2$ regions



LHCb inner module

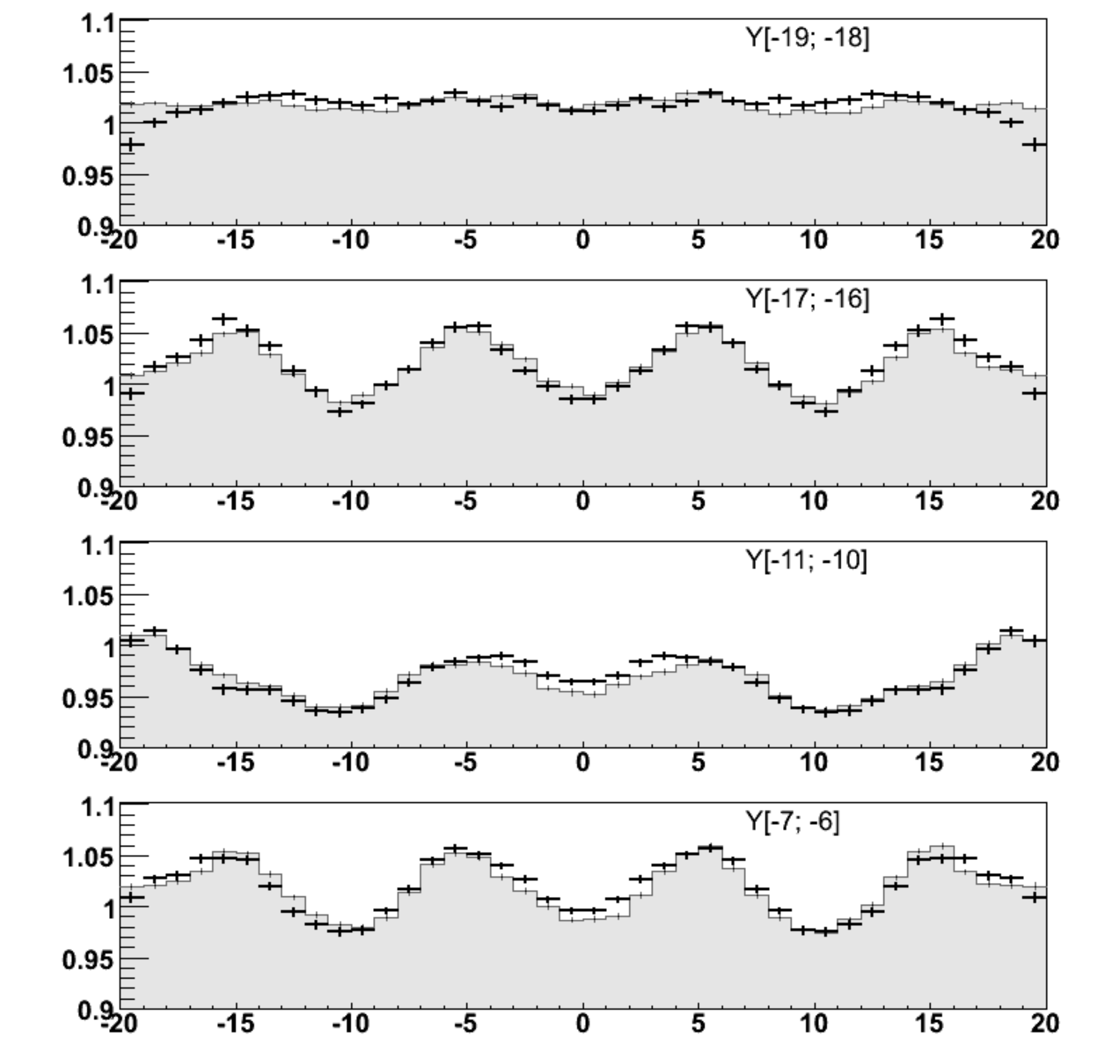


No light mixer in MC because of no Cherenkov light treating.

LHCb inner module

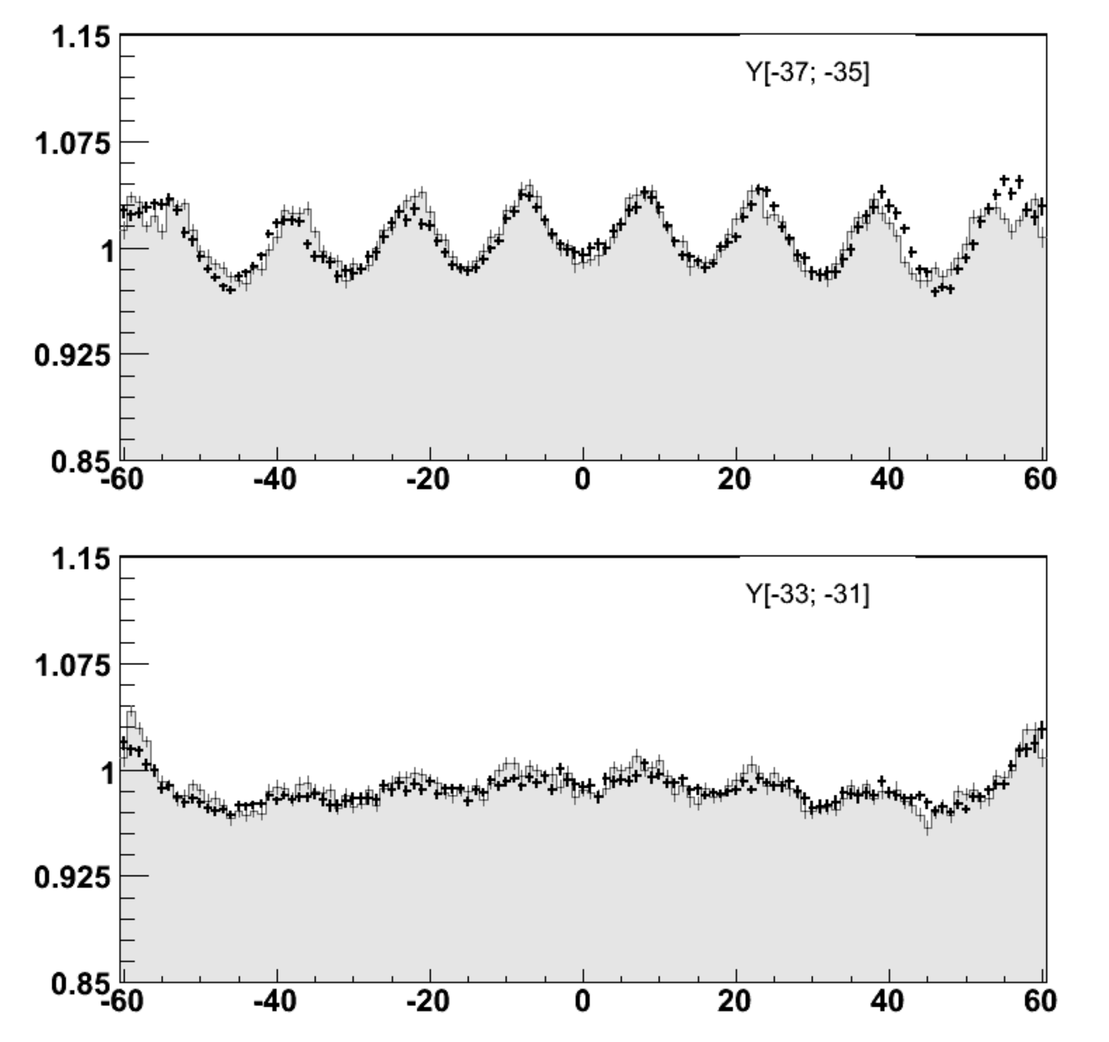
- Idea:
  - exclude central region
    - no light mixer
  - fit experiment with MC
    - normalization is only parameter
    - errors taken from fits
- Extracted parameters
  - Fraction of bad tiles 0.3
  - Whiteness of edge 1.13
  - Edging size 1.0mm
  - Surface quality n/r

Gray – MC, Black – data



LHCb outer module

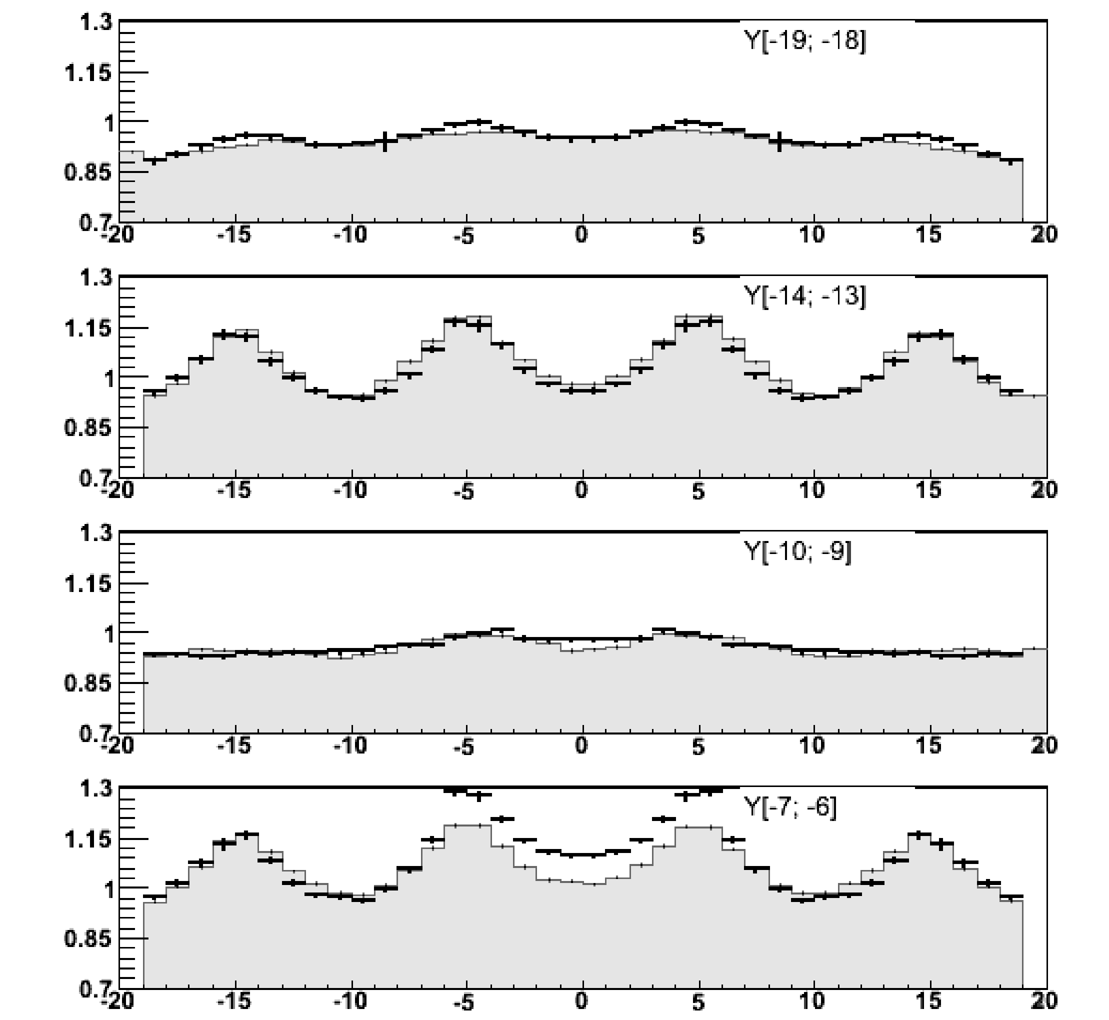
- No thickness map
  - generated to be “alike” inner module
- Available experimental data scaled on one axis
- 1x2mm^2 regions
- Extracted parameters
  - Fraction of “bad” tiles 0.2
  - Whiteness of the edge 1.11
  - Thickness on edging 1.0mm
  - Surface quality n/r



Gray – MC, Black – data

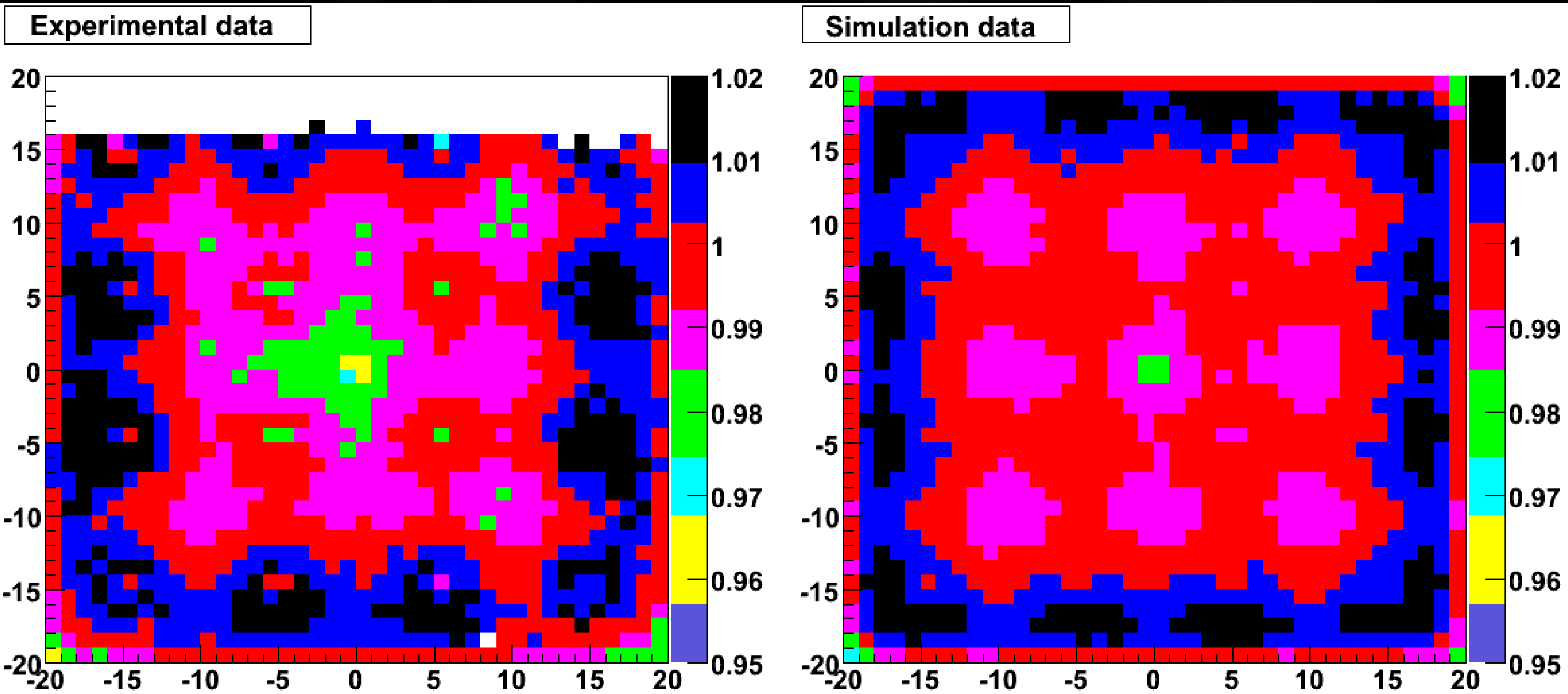
preCBM prototype

- Extracted parameters
  - Fraction of bad tiles 0.2
  - Edge whiteness n/r
  - Size of edging 0.0mm
  - Surface quality 0.06



Gray – MC, Black – data

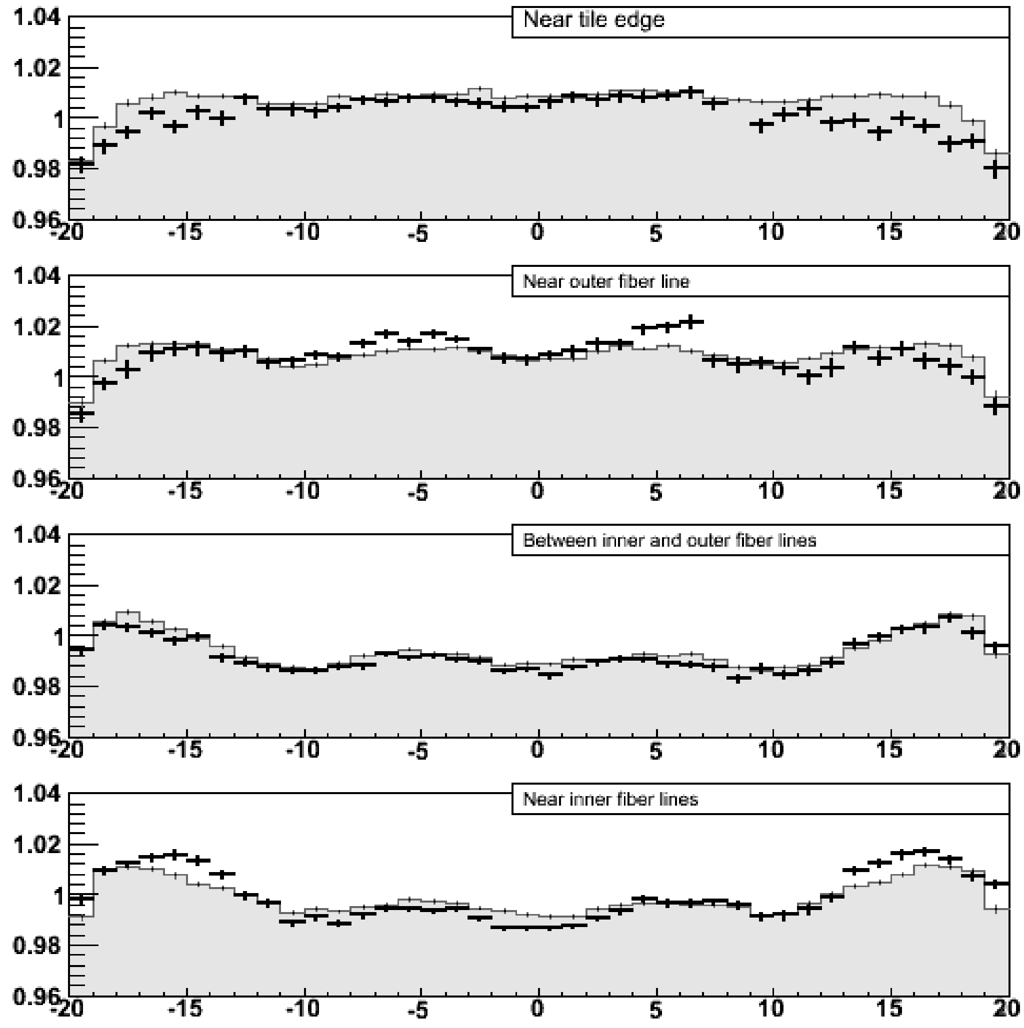
Electrons. LHCb inner module



Iterative fit with Gaussian in [-1.2δ,+2δ] for signals

Electrons. LHCb inner module

- Extracted parameters
  - Fraction of “bad” tiles 0.3
  - Edge whiteness 1.13
  - Size of edging 2.0mm
  - Surface quality n/r



Gray – MC, Black – data

Summary

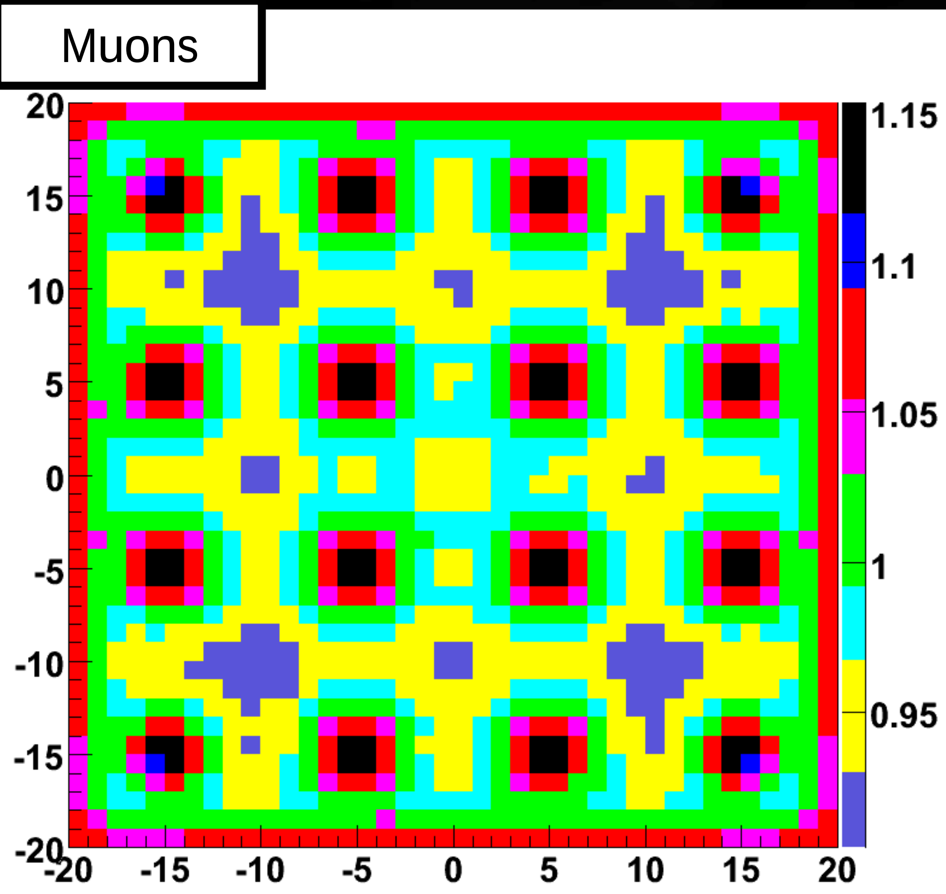
	LHCb muons	LHCb electrons	preCBM	LHCb large
Fraction of “bad” tiles	0.3	0.3	0.2	0.2
Edge whiteness	1.12	1.13	n/r	1.11
Size of edging	1.0mm	2.0mm	0.0mm	1.0mm
Surface quality	n/r	n/r	0.06	n/r

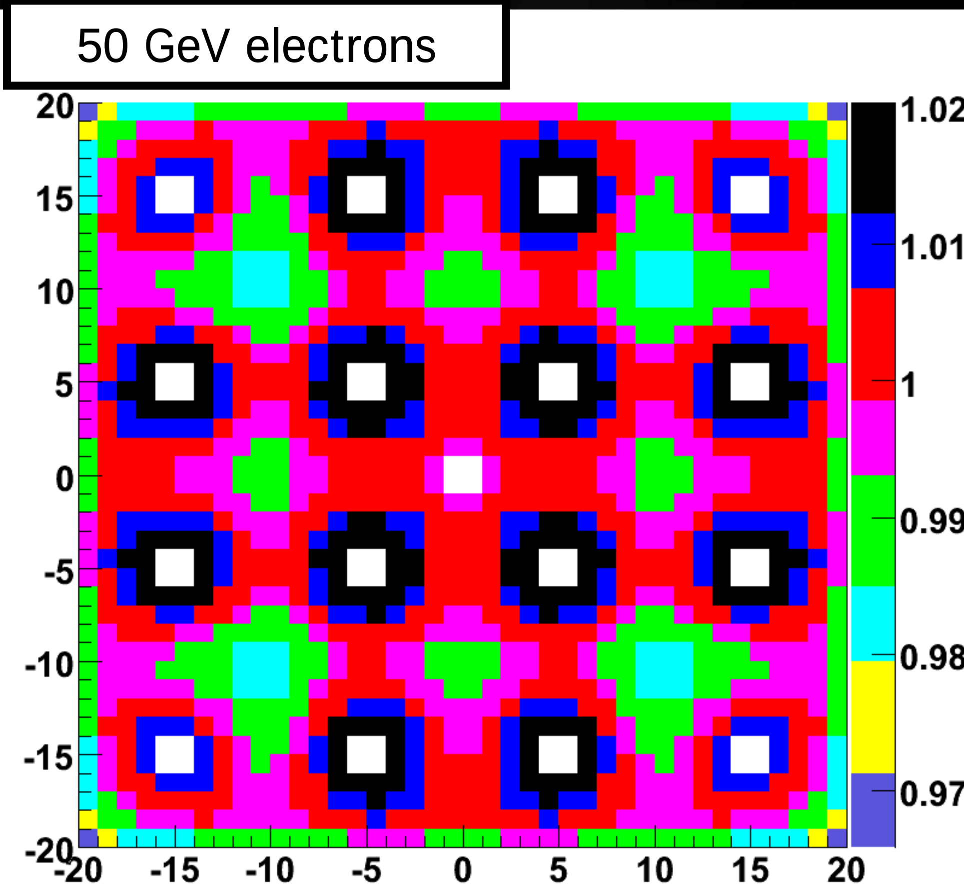
n/r means not relevant

CBM module (simple prediction)

- Geometry
  - 4x4cm^2 cells
    - all information available
  - 140 layers
    - 1mm scintillator
    - 1mm lead
- Take parameters from LHCb and preCBM modules
    - current technology
  - fraction of “bad” tiles 0.7
  - edge whiteness 1.12
  - size of edging 1.0mm
  - surface quality 0.06
- Thickness measurements from LHCb tiles
- Procedure described above

CBM module (simple prediction)





Nonuniformities

- Measured
  - LHCb
    - different geometry
    - different probes
  - preCBM prototype
- Modeled
  - light collection
    - ray-tracer code
  - GEANT
- Model crosschecked
  - same parameters
  - different geometries
  - different probes

- Results are consistent
- Non uniformities prediction
  - current technology
  - 15% nonuniformity with muons
  - 2% with 50GeV electrons
- Technology upgrade
  - surface quality
  - remove “bad” tiles
    - technology of tiles manufacturing!
  - adjust edge whiteness
    - can be controlled during production stage
  - light masking, die mold shape …

Light yield measurements

- Idea: Relative width of LED signal in PMT only number of photoelectrons
  - Poisson statistics
  - Calibration for ADC counts -> GeV
  - Other factors: wide signal -> less photoelectrons
    - subtract width of pedestals
- Results
  - small ($40x40mm^2$ fiber per $1x1cm^2$) cells
    - 3000 (3100)
  - middle ($60x60mm^2$, fiber per $1x1cm^2$) cells
    - 4200 (3500)
  - outer ($120x120mm^2$, fiber per $1.5x1.5cm^2$) cells
    - 2500 (2600)
  - preCBM ($40x40mm^2$, fiber per $1x1 cm^2$)
    - 700