

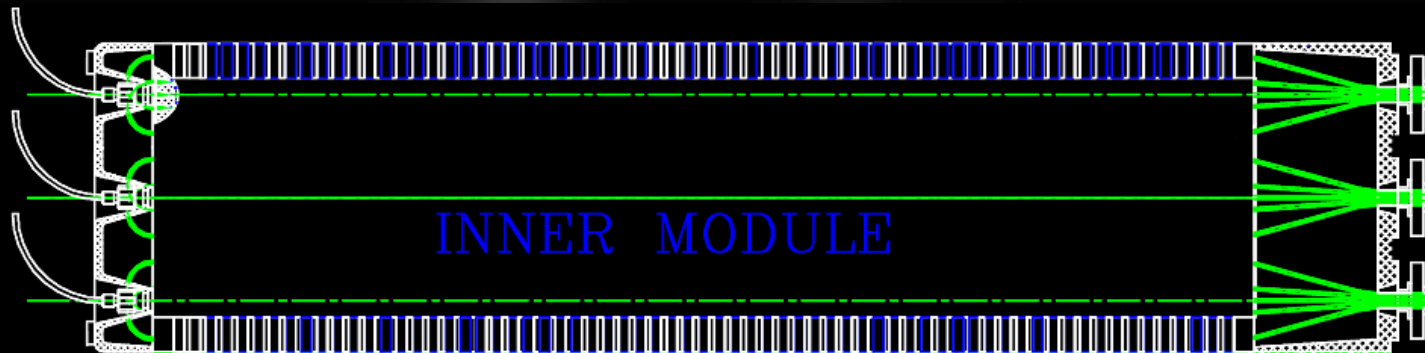
# Fine "shashlik" simulation from tests results



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# Outline

- ▶ Motivation
- ▶ Geometry of LHCb modules
- ▶ Experimental setup
- ▶ Data treating
- ▶ MC modeling
  - ray tracer
  - GEANT simulation
- ▶ Results
  - response (light collection) uniformity
  - light yield
- ▶ Conclusions



# Motivation. "Shashlik" upgrade

## ▶ "Shashlik" technology

- ▶ cheap
- ▶ fast enough for trigger
- ▶ radiation hard
- ▶ easy to segment

## ▶ Resolution

$$\frac{dE}{E} = \frac{a}{\sqrt{E}} \oplus b$$

- a – sampling term  $\sim 8\%/\sqrt{E}$
- b – constant term
  - ▶ light collection nonuniformity
  - ▶ dead material

## ▶ sampling term

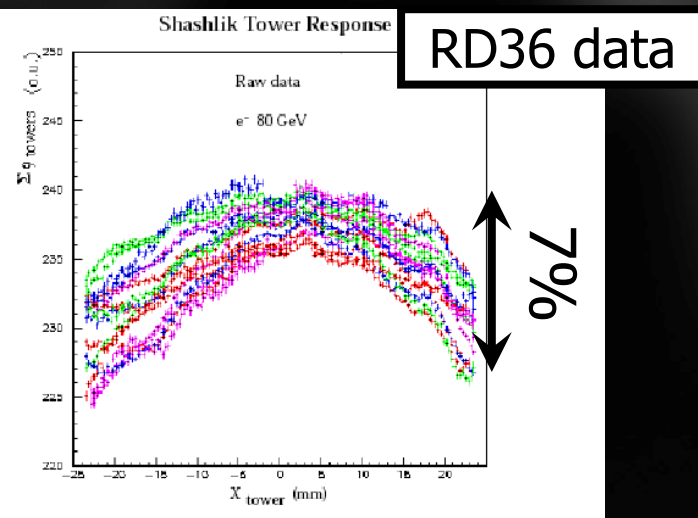
- decrease thickness of absorber

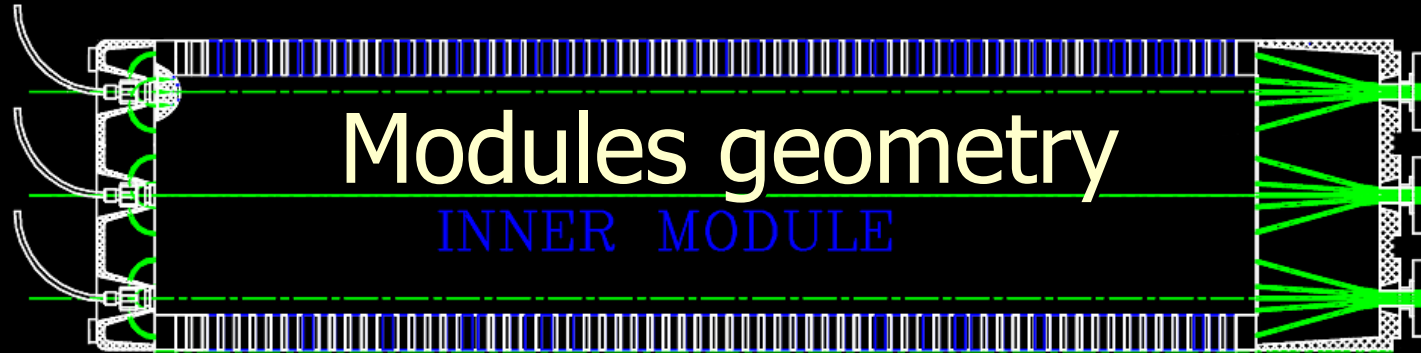
- ▶ increased volume ratio
  - ▶ more shower overlaps
- ▶ keep volume ratio constant
  - ▶ photostatistics!

## ▶ constant term

- increase the volume ratio
- technology

- ▶ measurements for model construction and verification
- ▶ MC model of light propagation in scintillator tile





# Modules geometry

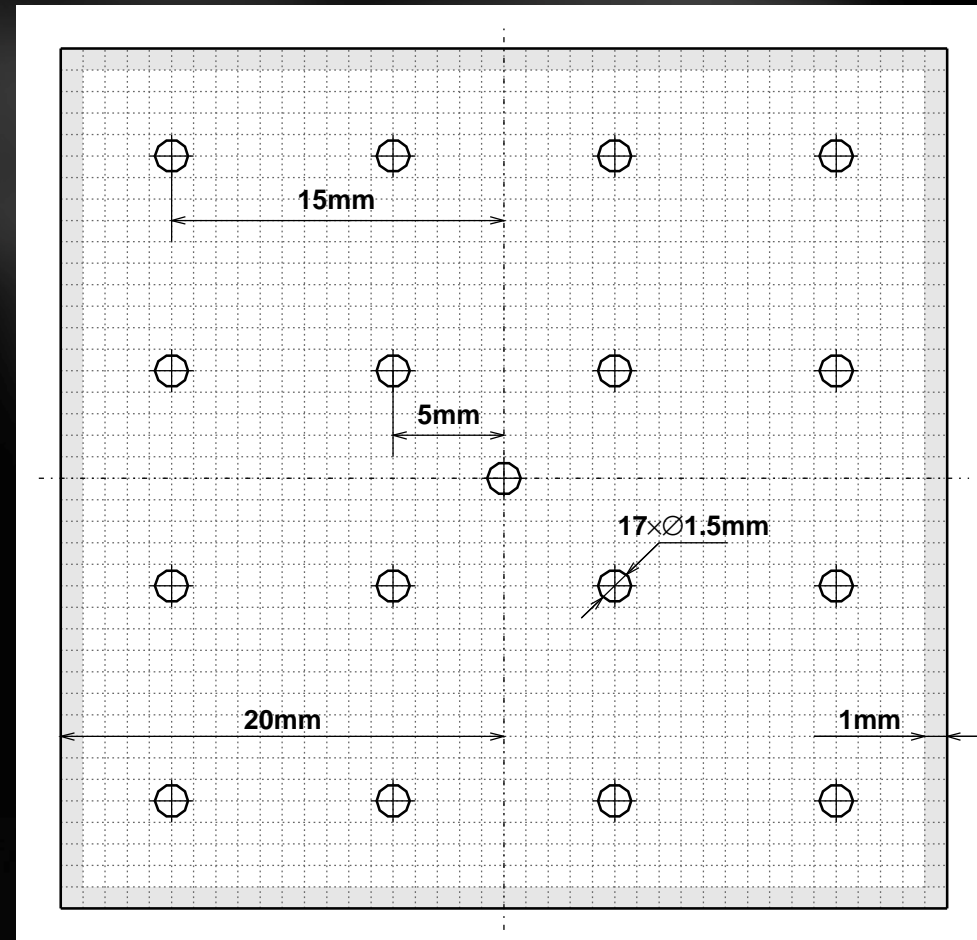
INNER MODULE

## ▶ LHCb

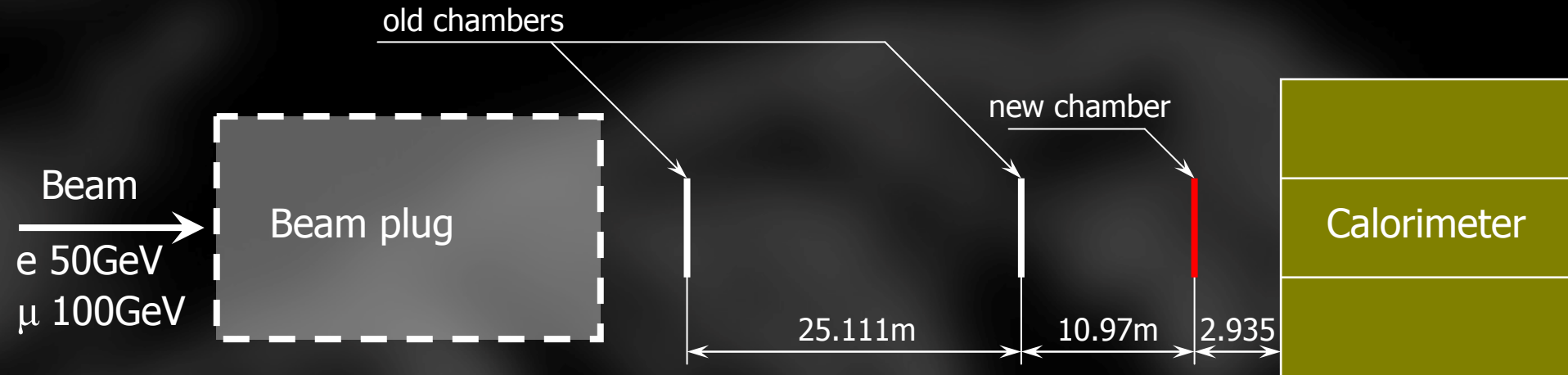
- ▶ inner:  $4 \times 4 \text{cm}^2$  cells
- ▶ middle:  $6 \times 6 \text{cm}^2$  cells
- ▶ outer:  $12 \times 12 \text{cm}^2$  cells
- $67 \times 4 \text{mm}$  layers of scintillator
- $66 \times 2 \text{mm}$  layers of lead

## ▶ Prototype

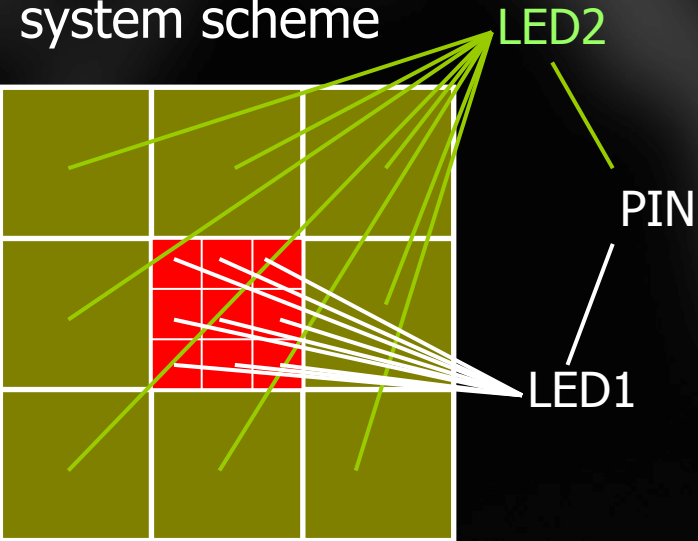
- $4 \times 4 \text{cm}^2$  cells
  - ▶ Like LHCb inner
- $280 \times 0.5 \text{mm}$  layers of scintillator
- $280 \times 0.5 \text{mm}$  layers of lead



# Experimental setup

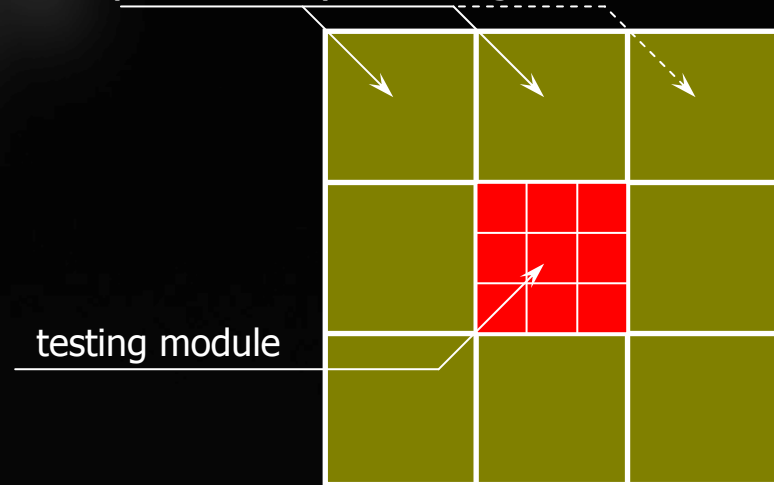


## LED monitoring system scheme



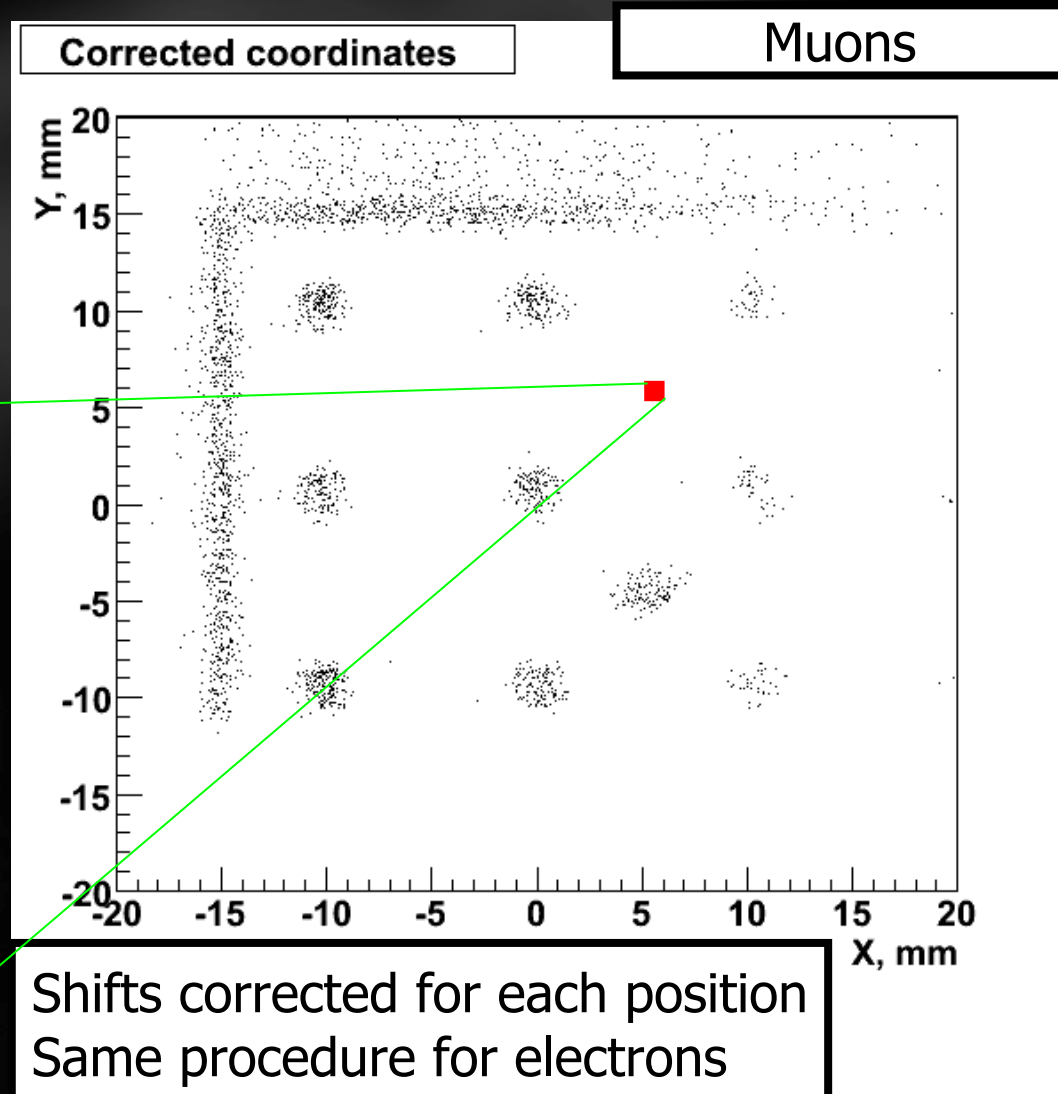
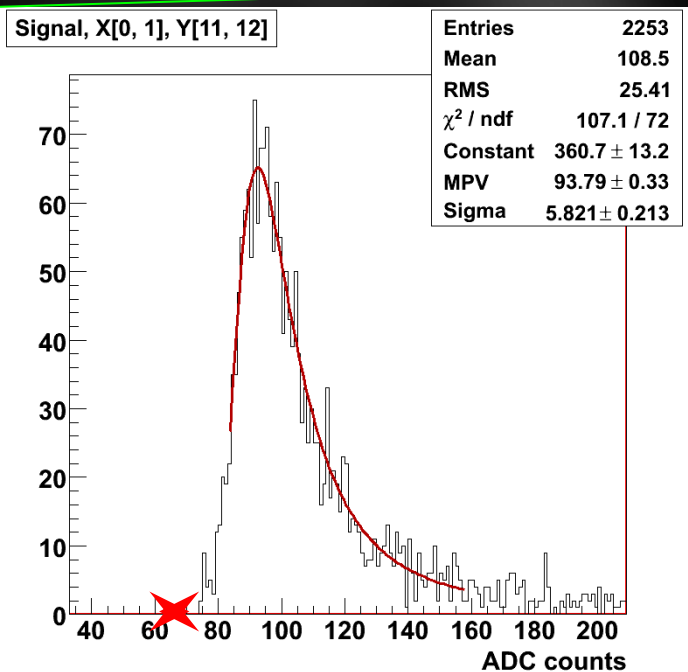
## Calorimeter assembly

8 modules ( $12 \times 12 \text{cm}^2 \times 1$ ) for leakage control



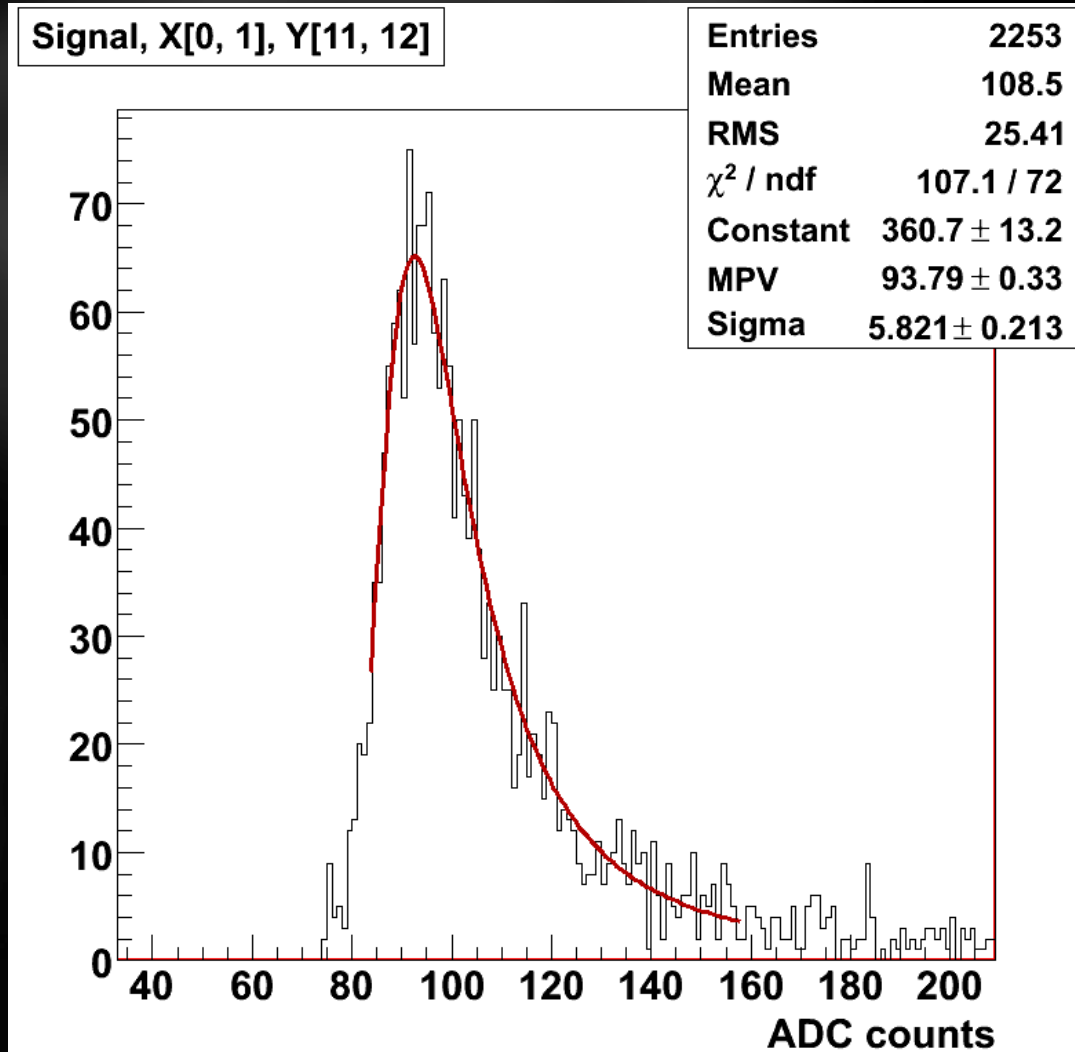
# Coordinate determination

- ▶ Beam size:  $3 \times 3 \text{ cm}^2$
- ▶ Energy cut: 60-65% MPV position
- ▶ Details of calorimeter construction are visible



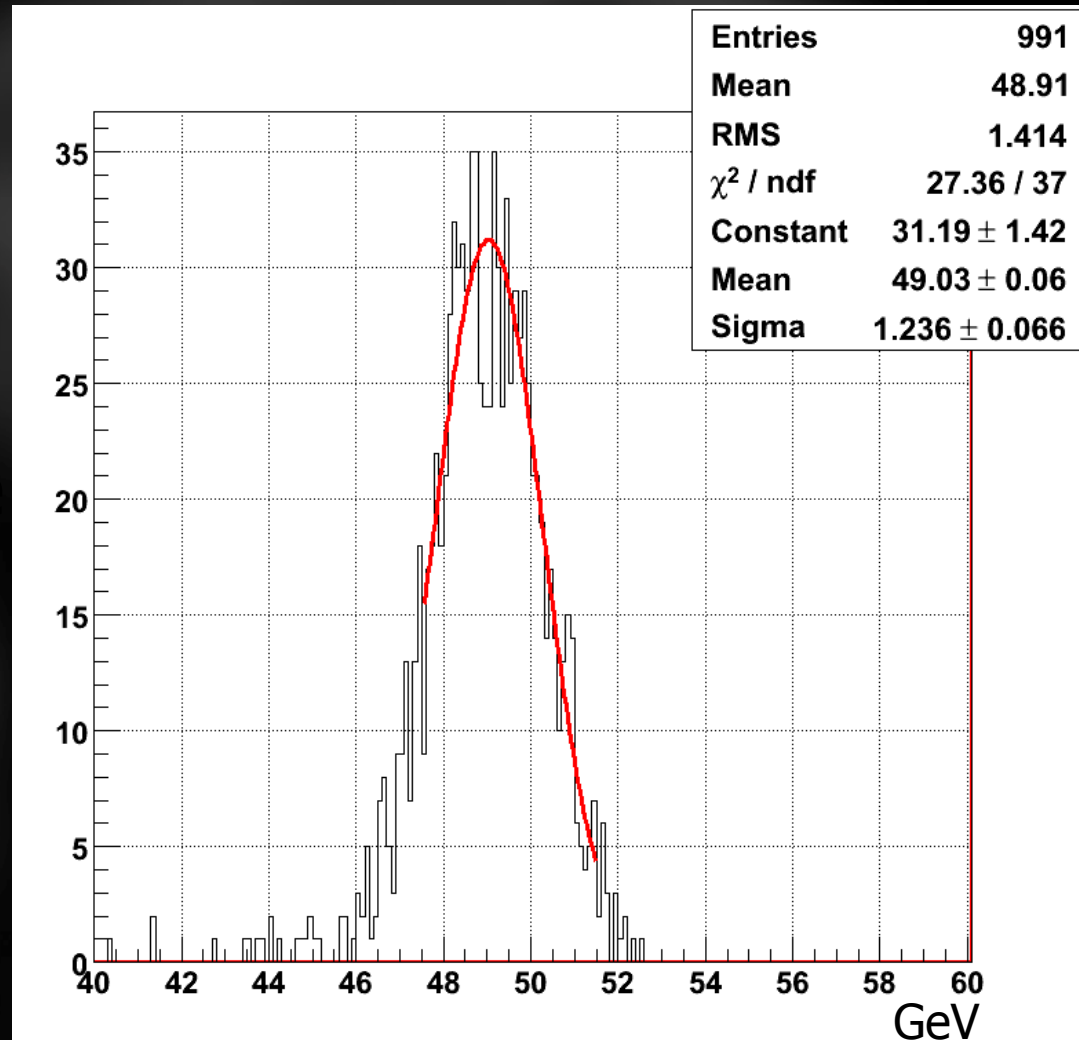
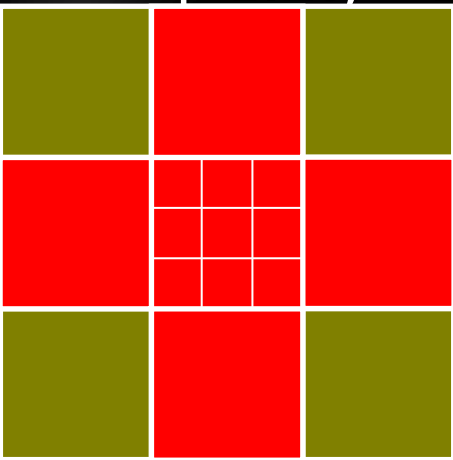
# Muons. Procedure

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



# Electrons. procedure

- ▶ Collect energy in 3x3+4 cells
  - wider signals with if other 4 cells included
- ▶ 1x1 mm<sup>2</sup> regions
- ▶ Iterative fit procedure
  - [-1.2 $\delta$ , +2 $\delta$ ] region





# MC modeling

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

# Ray tracer program

## ► Optics

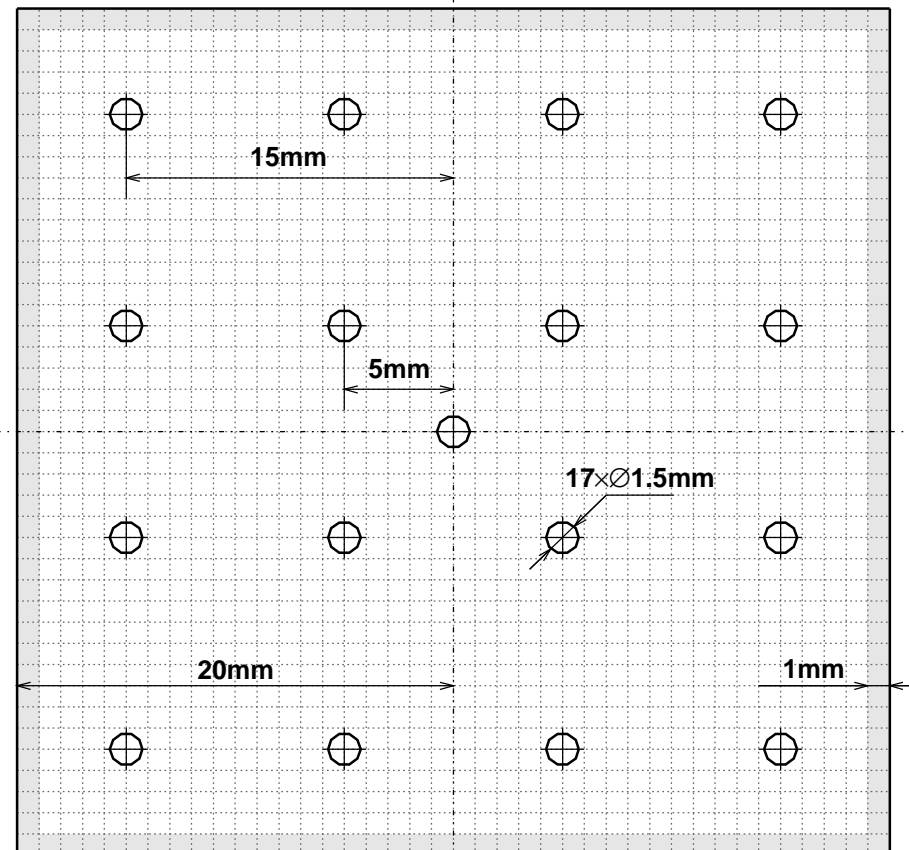
- refraction
  - Fresnel formulas
- reflection
  - mirror
  - diffuse
- attenuation
  - in medium
  - on surface
- all processes could depend on wavelength

## ► Geometry

- geometrical primitives
  - cylinder
  - cuboids
- Boolean operations
- voxelization

## ► Main optical parameters

- quality of scintillator surface
- whiteness of paint
- size of "edging"

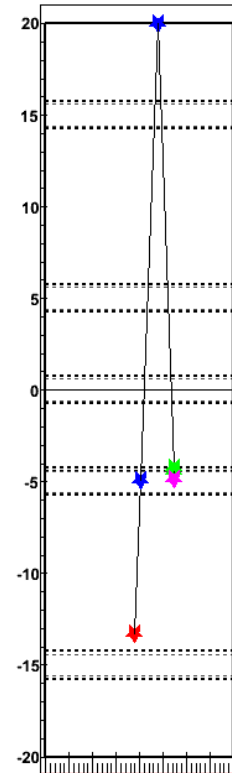
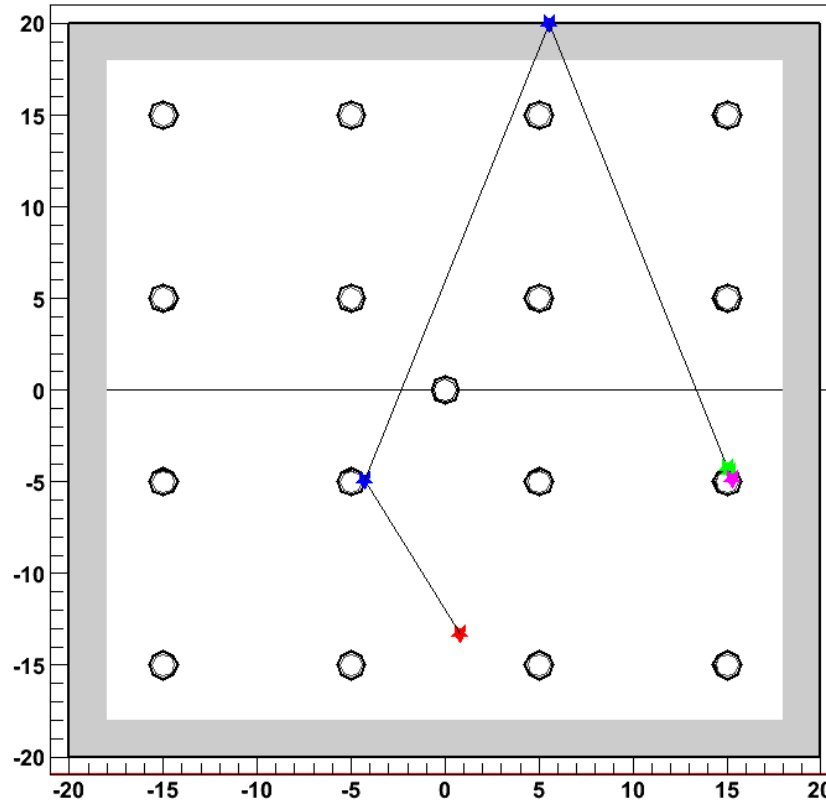
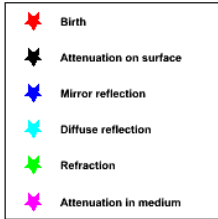
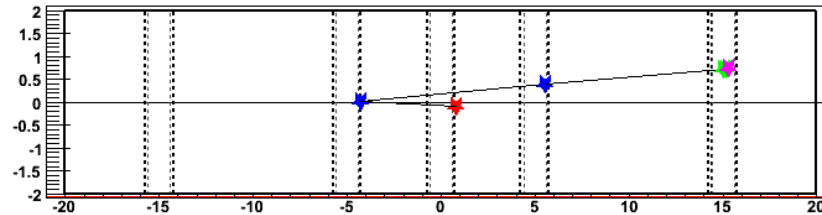


# Ray tracer testing

## ► Visualize trajectories

- individual photons
- using ROOT for drawing

## ► Simple...



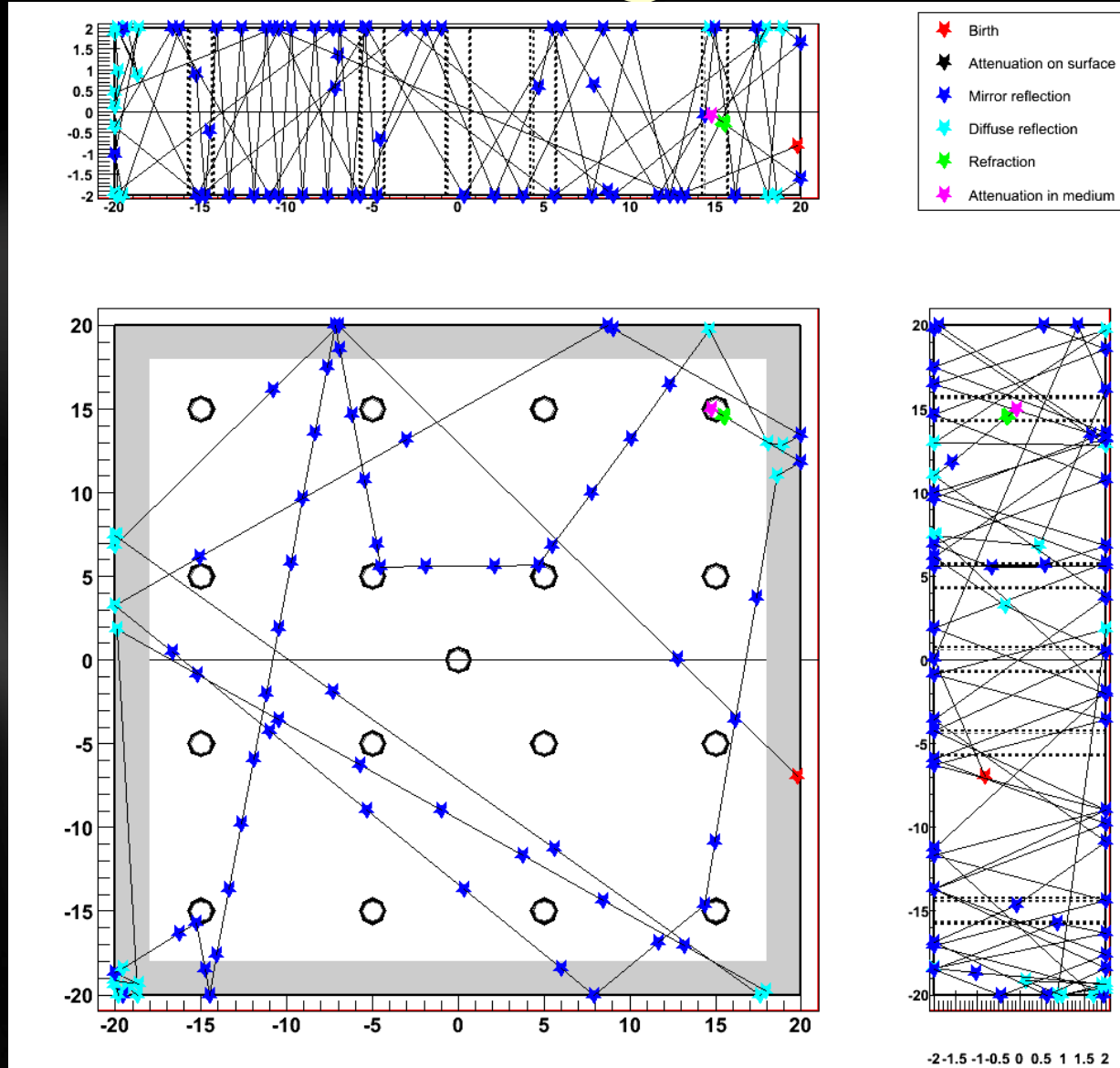
-2 -1.5 -1 -0.5 0 0.5 1 1.5 2

# Ray tracer testing

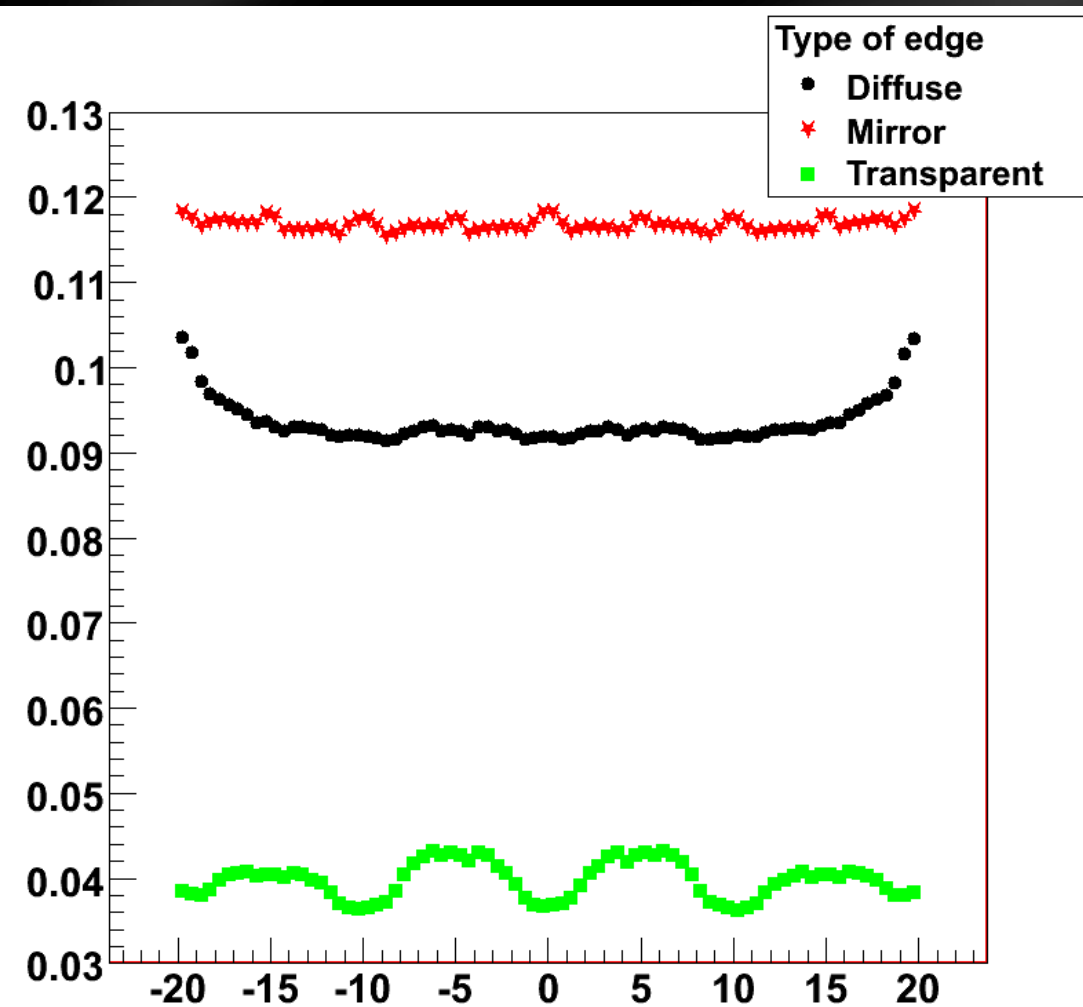
## ► Visualize trajectories

- individual photons
- using ROOT for drawing

## ► A bit more complicated...



# Example of ray tracer test



## ► Edging effect in light collection

- compensate dead material between tiles
- not trivial
- LHCb innovation



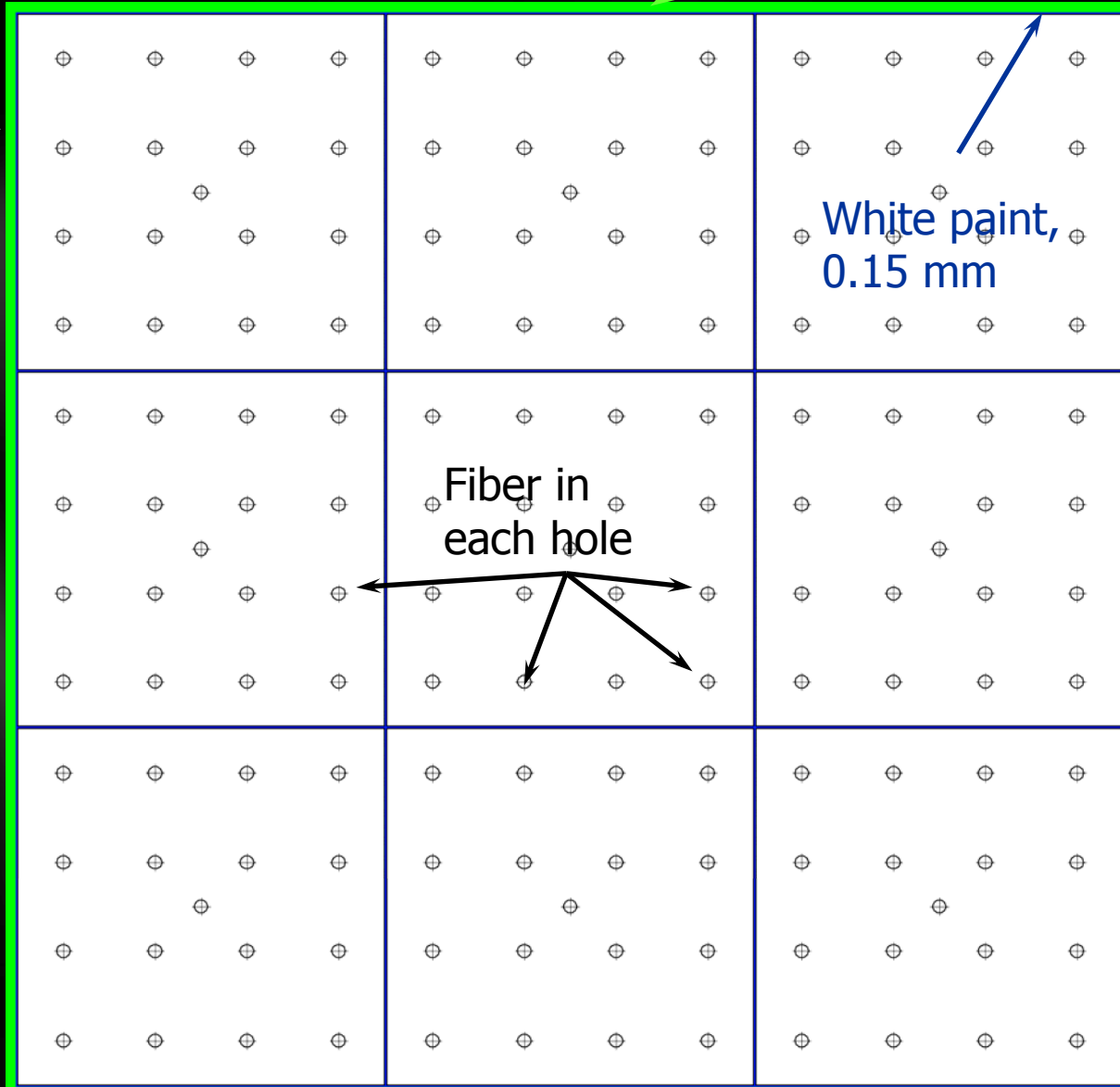
# Geant model

Steel tape, 0.2 mm

White paint,  
0.15 mm

Fiber in  
each hole

- ▶ GEANT3
  - Geant4 for crosscheck
- ▶ Gorynych framework
  - for ITEP FLINT experiment
- ▶ Tile model with holes and fibers
  - same as for ray-tracing
- ▶ 67x4mm scintillator layers
  - 66x2mm layers of lead
- ▶ Dead material
  - steel tape, 0.2mm thick
  - white paint, 0.15mm at edge of each tile



# Comparison with data

- ▶ Light collection efficiencies maps
  - $0.5 \times 0.5 \text{mm}^2$  segmentation
- ▶ Calorimeter response with GEANT
  - 30KeV GEANT3 cuts
  - $1.0 \times 1.0 \text{mm}^2$  segmentation
  - converge with
    - ▶ light collection maps
    - ▶ tile thickness maps
- ▶ Most important optical parameters
  - quality of scintillator surface
  - “whiteness” of paint
  - width of “edging”

Independent fit of each of available experimental data sets gives single set of optical parameter values.

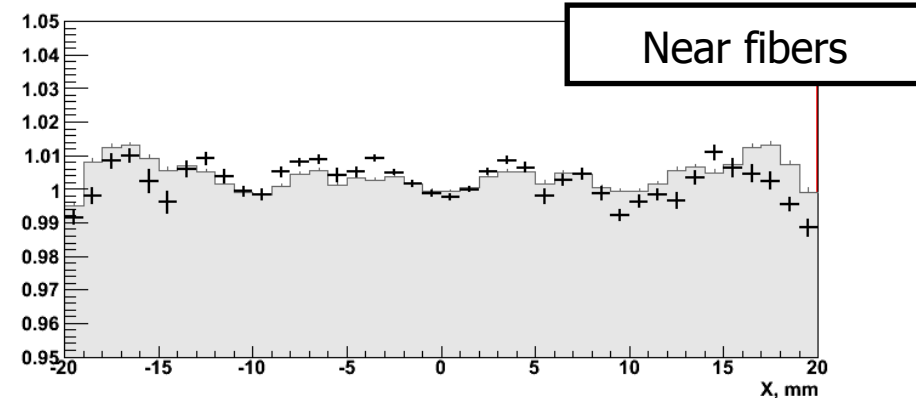
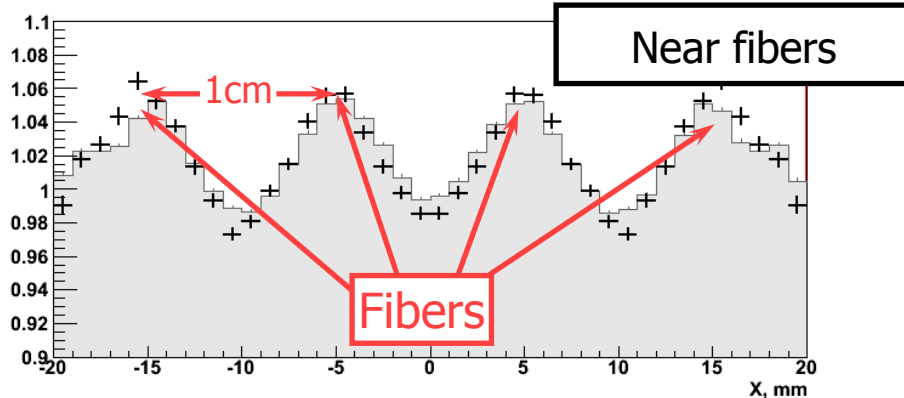
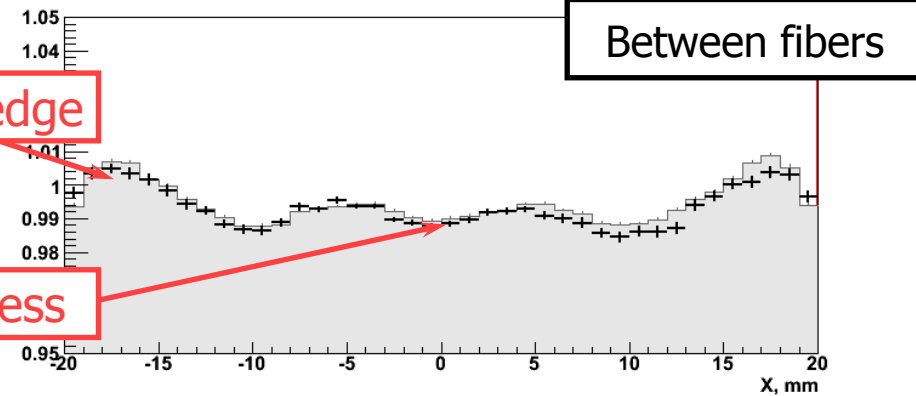
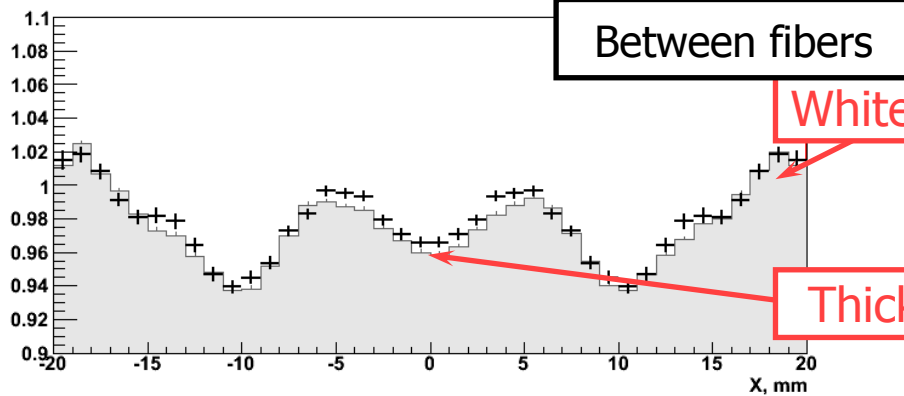
$\chi^2$  minimization



# LHCb inner module.

Muons

Electrons

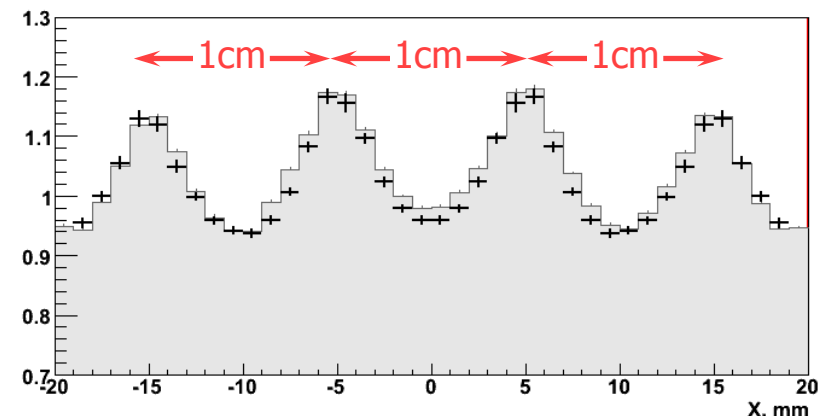
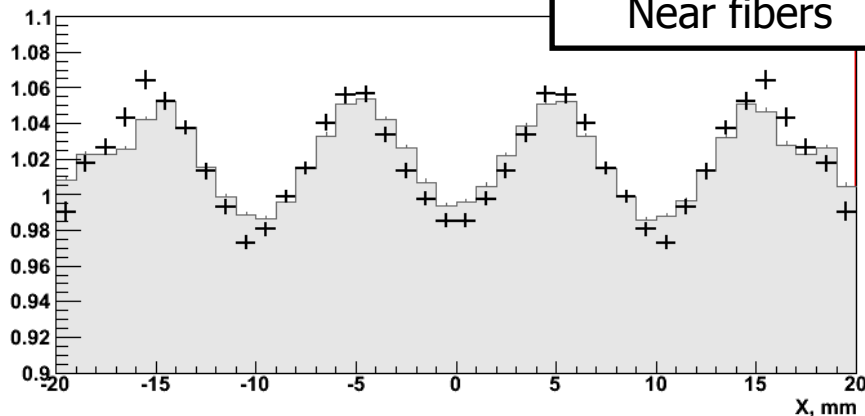
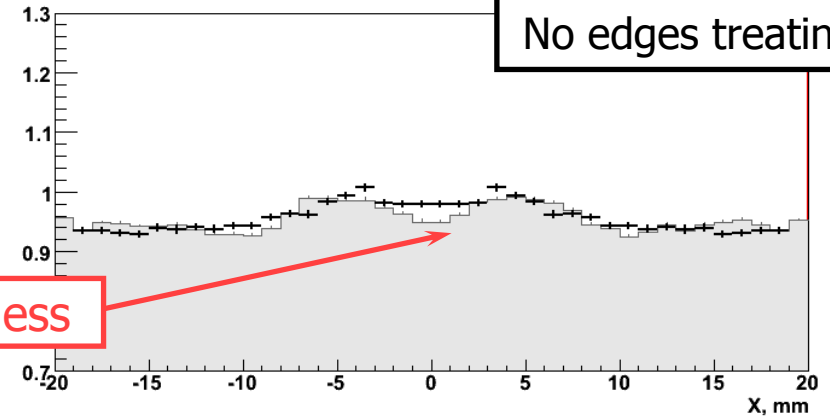
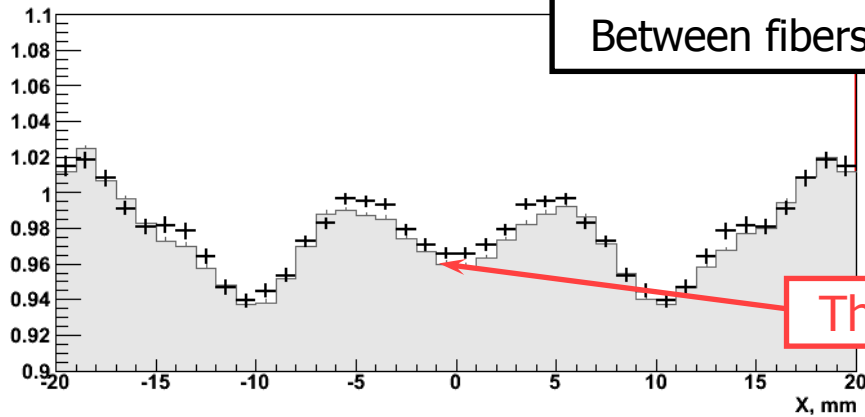


Gray – MC. Black – data. **Scale!**

# Prototype module and inner LHCb module

LHCb inner. 4mm

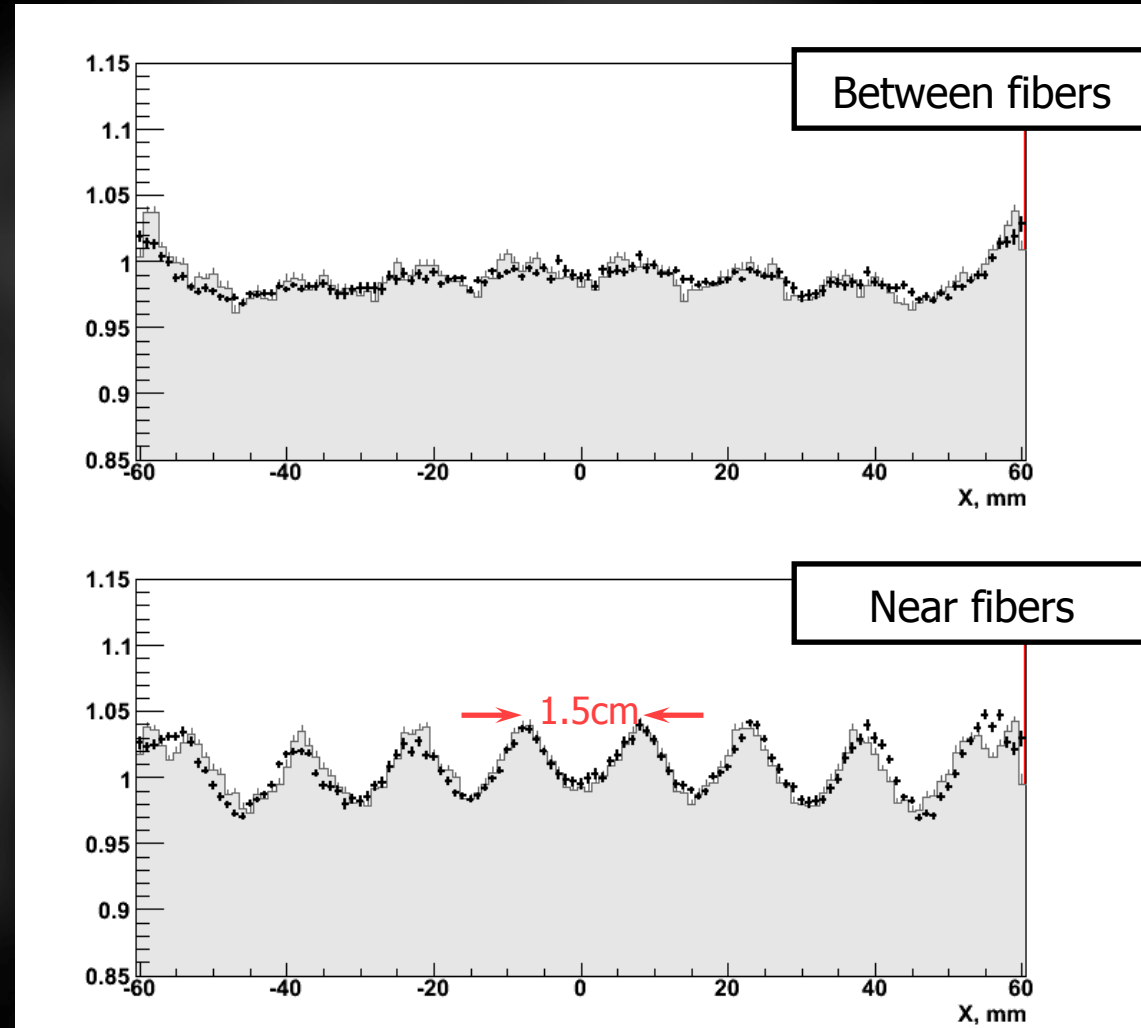
Prototype. 0.5 mm



Gray – MC. Black – data. **Scale!**

# LHCb outer module

- ▶  $12 \times 12 \text{ cm}^2$
- ▶ Distance between fibers 15mm
  - 10mm in inner and prototype modules
- ▶ Only 2 delay wire chambers
  - worse position resolution



Gray – MC. Black – data.

# Light yield

- ▶ PhE/GeV  
Experiment
- ▶ Use monitoring system
  - MIP position for calibration for cosmics
  - Test beam/GEANT:
    - ▶ MIP  $\approx 0.33\text{GeV}$
- MC
- ▶ Generate photons uniformly inside tile volume
- ▶ Inner module for normalization

|           | Beam tests | Cosmic setup | MC   |
|-----------|------------|--------------|------|
| inner     | 3000       | 3100         | 3000 |
| middle    | 3600       | 3500         | 3600 |
| outer     | 2500       | 2600         | 2570 |
| prototype | 700        | -            | 600  |

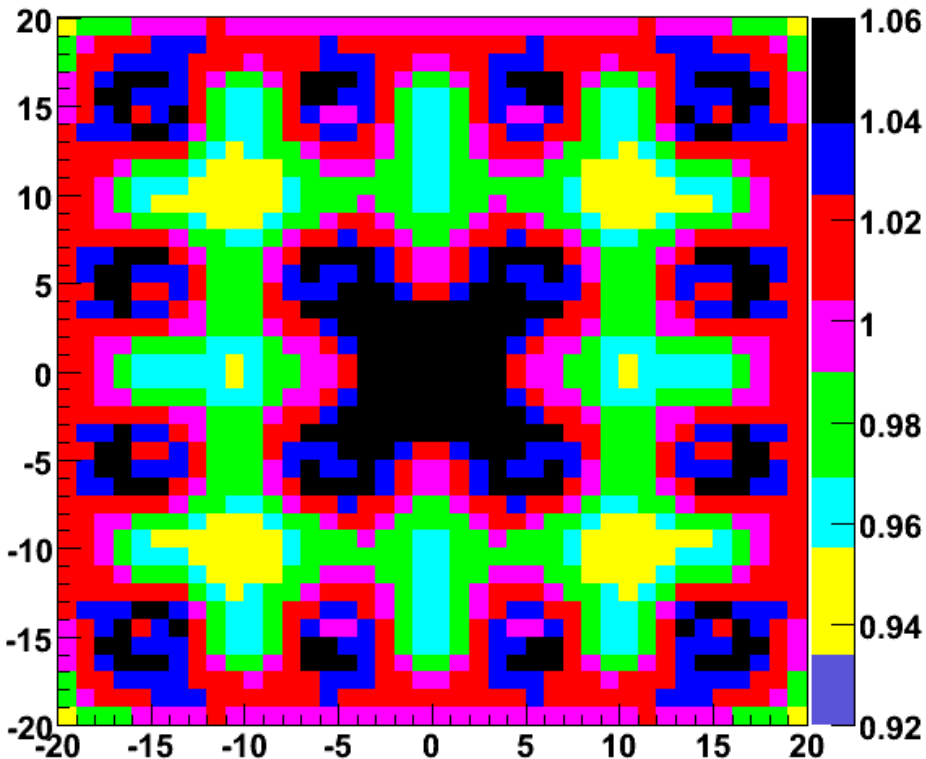
# Conclusions

- ▶ Measurements of “shashlik” modules response uniformity done
  - spatial resolution  $1 \times 1 \text{mm}^2$
  - different probes: electrons and muons
  - different geometries
    - ▶ including module with scintillator thickness 0.5mm
- ▶ Calorimeter response uniformity modeled
  - ray tracer and optical model of the tile
    - ▶ single set of optical parameters to describe all data
  - high precision GEANT model
    - ▶ don't forget tile thickness variations

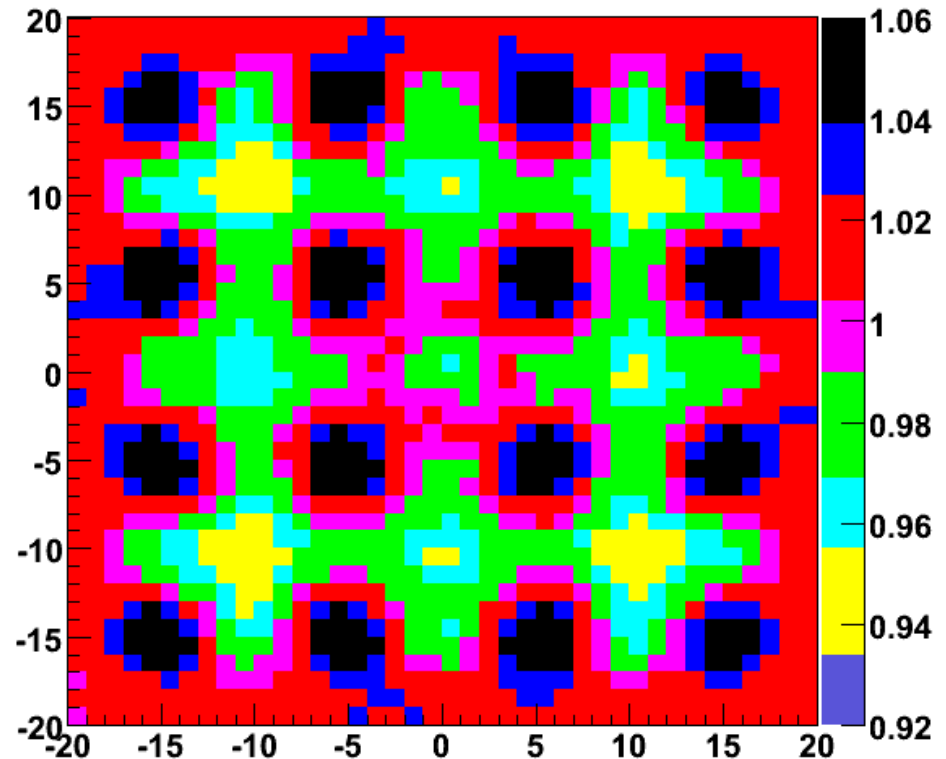


# Inner module

Experimental data



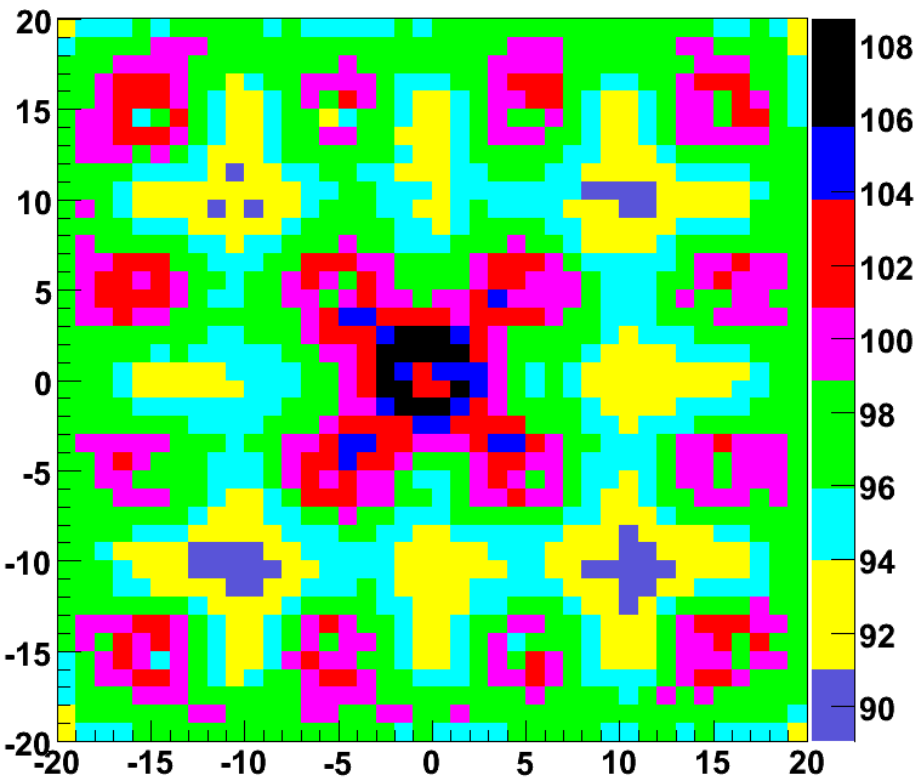
Simulation data



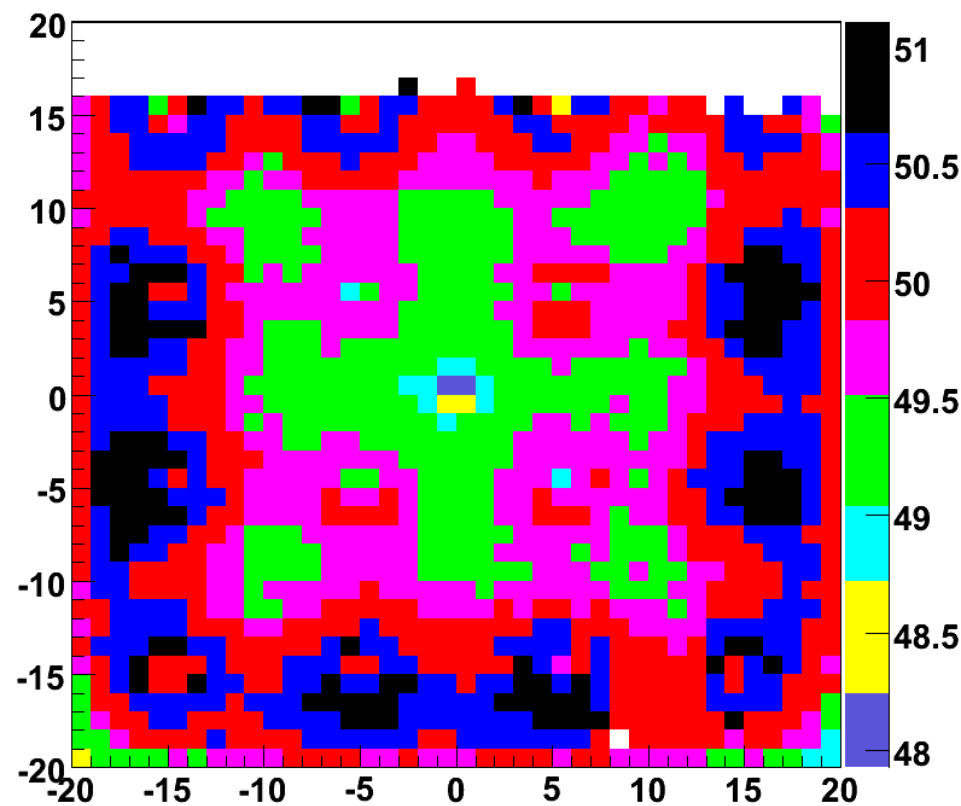
No light mixer in MC because of no Cherenkov light treating.

# LHCb inner module

Muons



Electrons

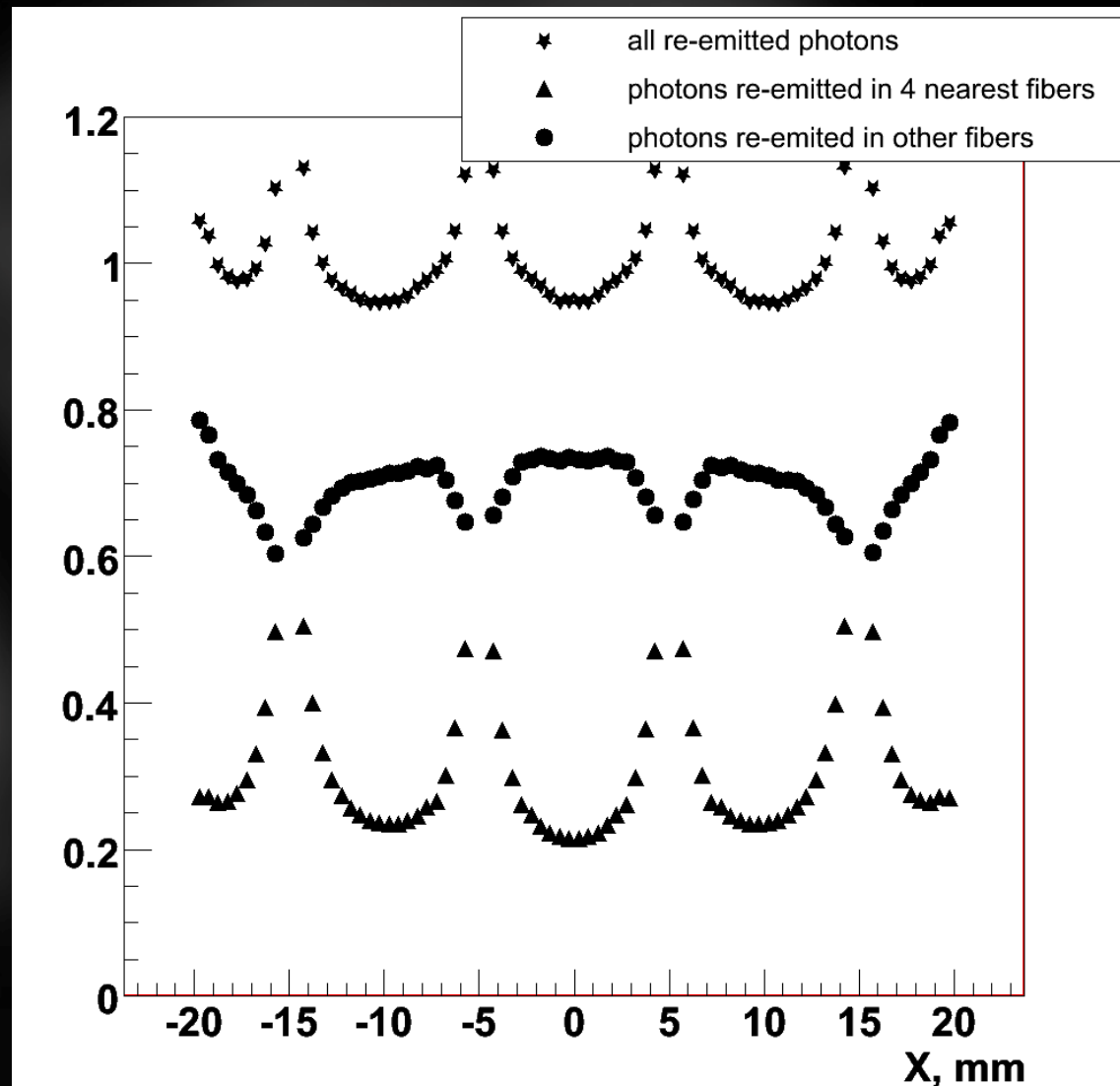


Scale!



# Nature of nonuniformities

- ▶ Direct:
  - 4 nearest to photon birth point fibers
  - Less than 20cm of fly length
- ▶ Local nonuniformity:
  - variations of nearest fibers visual angle
- ▶ Ratio direct/indirect:
  - thickness



# Thickness variations



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