AHCAL Digitisation

AHCAL ILD vs. Testbeam Simulation Models & Data

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HELMHOLTZ | ASSOCIATION

HORIZON 2020

BERGISCHE UNIVERSITÄT WUPPERTAL

DESY

Outline

> Verification of SiPM digitisation models

> Additions to ILD calorimeter digitisation processor *ILDCaloDigi*

> Digitisation steps and their influence on spectra and resolutions

> Comparison of Resolutions from ILD simulations vs. prototype data

> Summary

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SiPM Sensor Effects

> ## Finite number of pixels

- Quantisation, drives resolution for low amplitudes

- Saturation, drives resolution for very high amplitudes

Raw [px] → Poisson Smearing → MC photon-by-photon
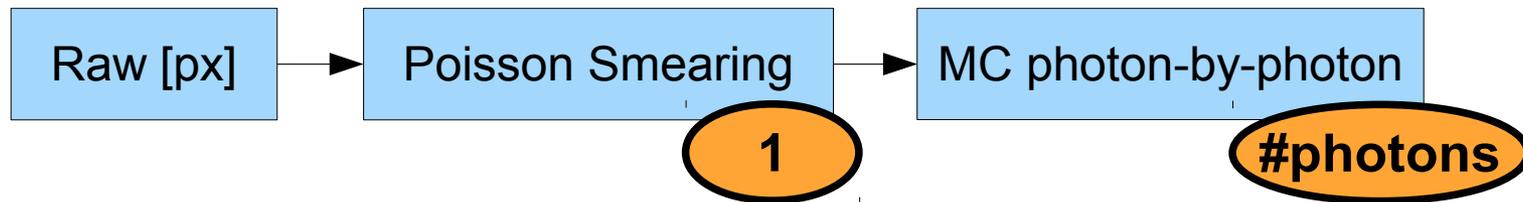
1   **#photons**

> ## Photon-by-photon simulation model

- For each photon: roll hit SiPM pixel, signal is no. of hit pixels

- Simple, correct, but inefficient (n+1 random numbers)

- Analytical resolution calculation (Stoykov et. al., arXiv: 0706.0746):
  Poisson term + saturation term

$$\mathrm{Res}^{Stoykov} = \frac{1}{\sqrt{m}} \sqrt{\frac{1}{\frac{a}{m}} + \left(\frac{1}{\frac{a}{m}} \sqrt{e^{\frac{a}{m}} - 1 - \frac{a}{m}} \right)^2} = \frac{\sqrt{m \left(e^{\frac{a}{m}} - 1 \right)}}{a}$$

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A Better SiPM Model

Raw [px]	→	Saturation	→	Binomial Smearing

1

> ## Testbeam model

- Less intuitive
- Efficient (1 random number)
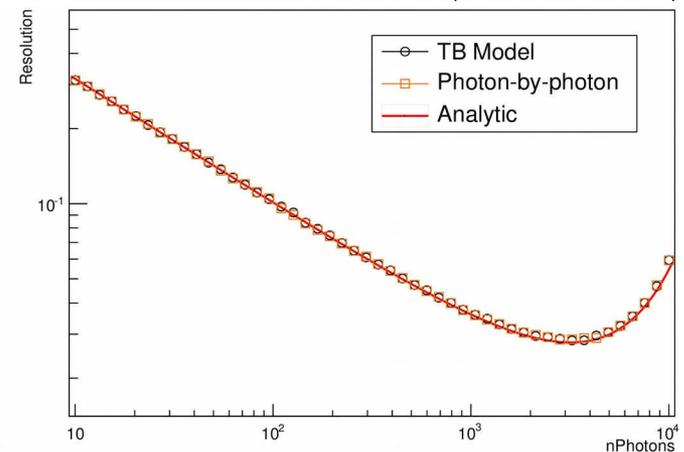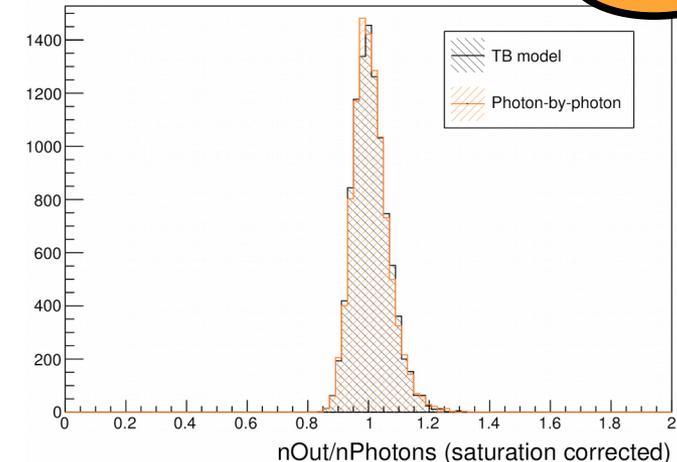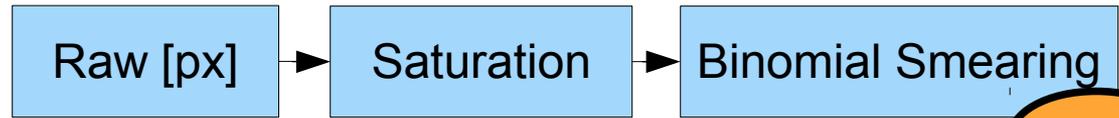- Was always used in AHCAL TB digitisation

> ## Analytical calculation

$$\text{Res}^{TB} = \frac{\sqrt{m\left(e^{\frac{a}{m}} - 1\right)}}{a}$$

- Identical to photon-by-photon model
- Higher moments hard to access

> ## Shape in very good agreement

- Analytic resolution matches simulations

> ## Models are identical

- Use binomial (testbeam) model for all SiPM digitisation!

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ILDCaloDigi

> New features in ILDCaloDigi Processor (Daniel Jeans, OH)

> Sensor modelling (SiPM & Silicon)

  - Binomial SiPM model, SiPM pixel charge non-uniformity

  - Electronics noise (rudimentary)

> Timing cut

  - New default parameter: `SimpleTimingCut = true`. Simple box timing cut. Previous implementation has possible unintentional effects

  - Caveat: `/Mokka/init/lcioDetailedShowerMode true` mandatory!

> Calorimeter imperfections

  - Dead channel fraction (random per event, fixed per run)

  - Scintillator strip response non-uniformities

  - Miscalibrations (response, saturation scale, … correlated and uncorrelated)

> Available in SVN: marlin_reco_trunk.

  - Includes documentation

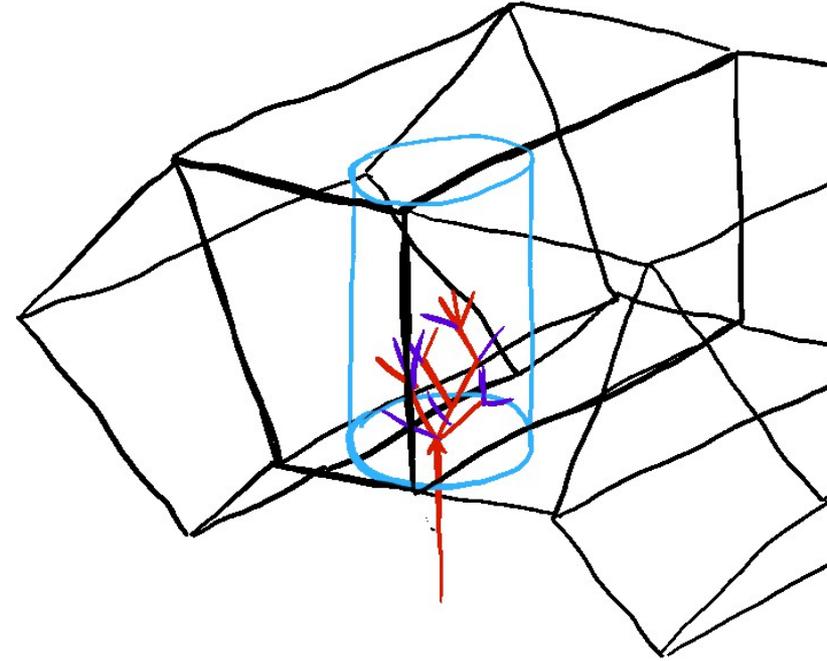BERGISCHE
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Digitisation Steps

> Setup: ILD HCAL standalone + ILDС

  ▪ Both ILD and AHCAL prototype sampling
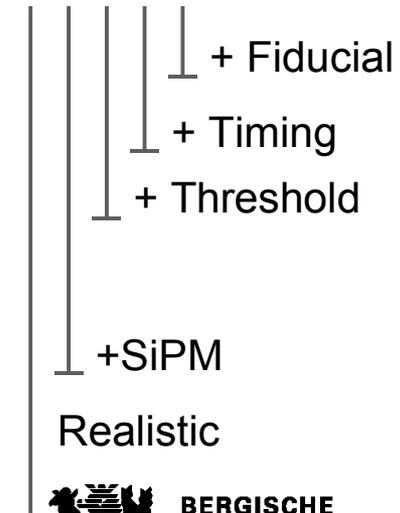
  ▪ Particle gun similar to testbeam setups

> Parameters: **ILD**

	ILD	
Scintillator	3mm	
Absorber	20mm Fe	
Layers	48	
MIP2GeV:	489.6keV/MIP	
Fiducial cut:	yes	yes
Timing:	-10..150ns	-10..150ns
Threshold:	0.5MIP	0.5MIP
Lightyield:	15px/MIP	13.7px/MIP
SiPM NPixel:	2000px	1156px
Electronic Noise:	0.3px	0.3px
Pixel non-uniformity:	10%	10%

+ Fiducial

+ Timing

+ Threshold

+SiPM

Realistic

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MIPs

> Notable effect of SiPM modelling on MIP spectrum

- Electronics noise smears out quantisation

> Good agreement in MIPs for every prototype

- Including 3mm ILD-like tiles from 2nd AHCAL prototype

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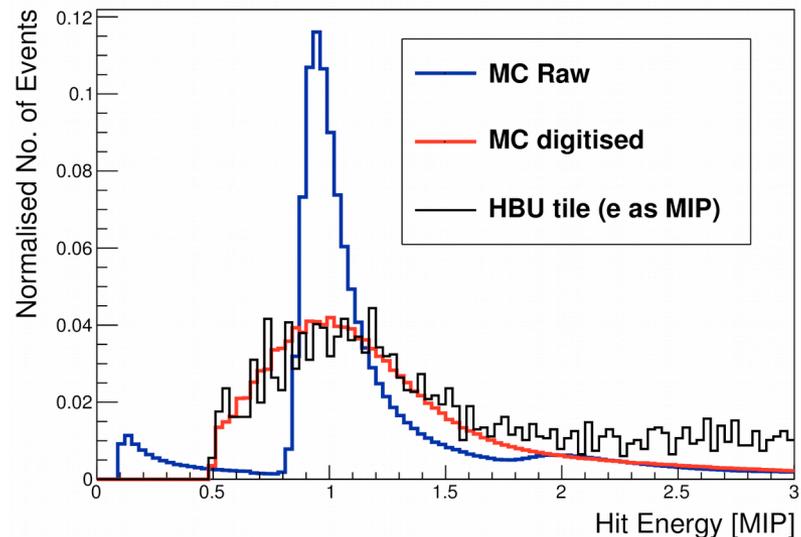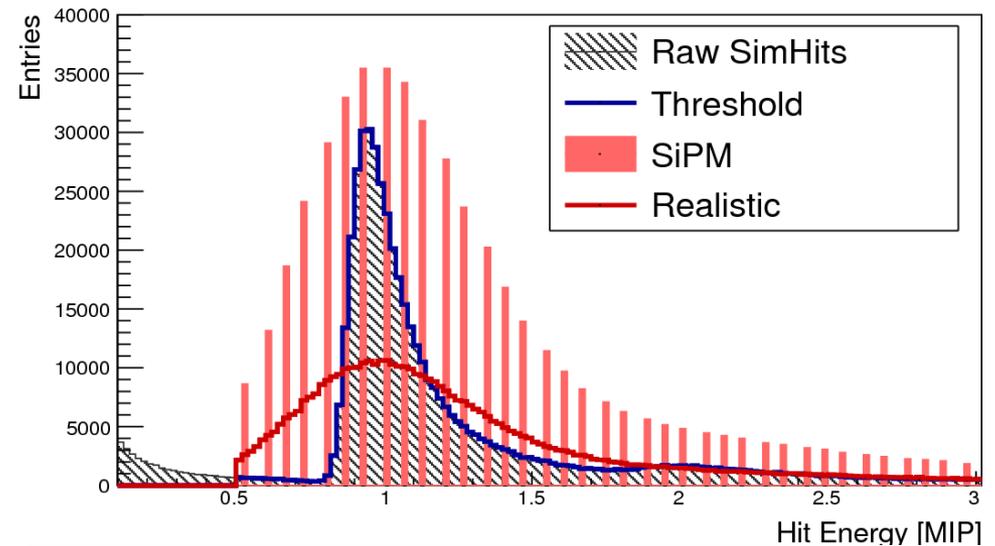
Resolution Breakdown Electrons

> 30 GeV electrons

> ~10% impact on resolution

  ▪ No effect from fiducial cut, timing

  ▪ 5% effect from threshold

  ▪ 5% from SiPM (saturation)

  ▪ Small effect from noise
    (affects fully saturated cells)

> Small influence from SiPM effects

  ▪ Smaller for lower energy electrons

  ▪ High energy electrons very rare in AHCAL
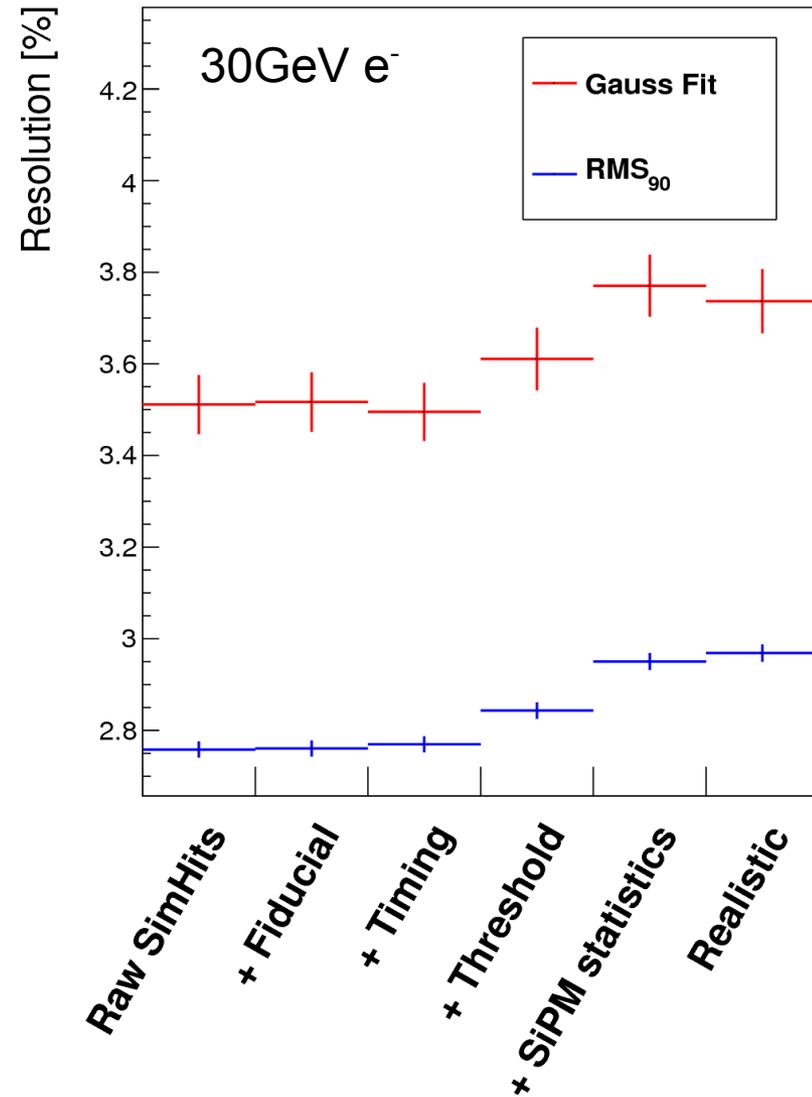
Resolution Breakdown Pions

> 30 GeV pions

> ~40% influence on resolution

> Important effects: Fiducial cut, timing, threshold

  ▪ Have been implemented in ILD simulations since long time

> Hadron resolution not influenced by SiPM effects

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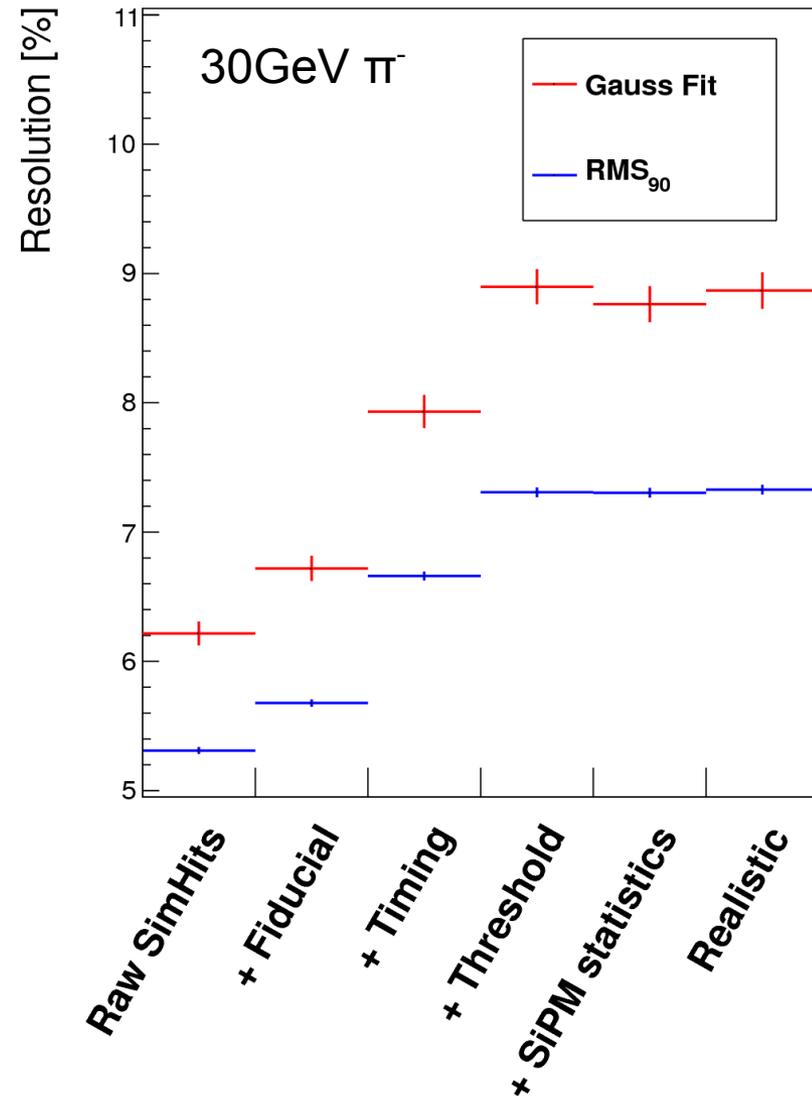
Resolution Electrons

> ## ILD simulation very similar to published results

- Dependence on dead channel fraction (+ exact positions of dead channels)
- Strong resolution dependence on dead channel fraction >5%

> ## Small effect of digitisation

- Mostly threshold

> ## ILD sampling: Slightly worse resolution
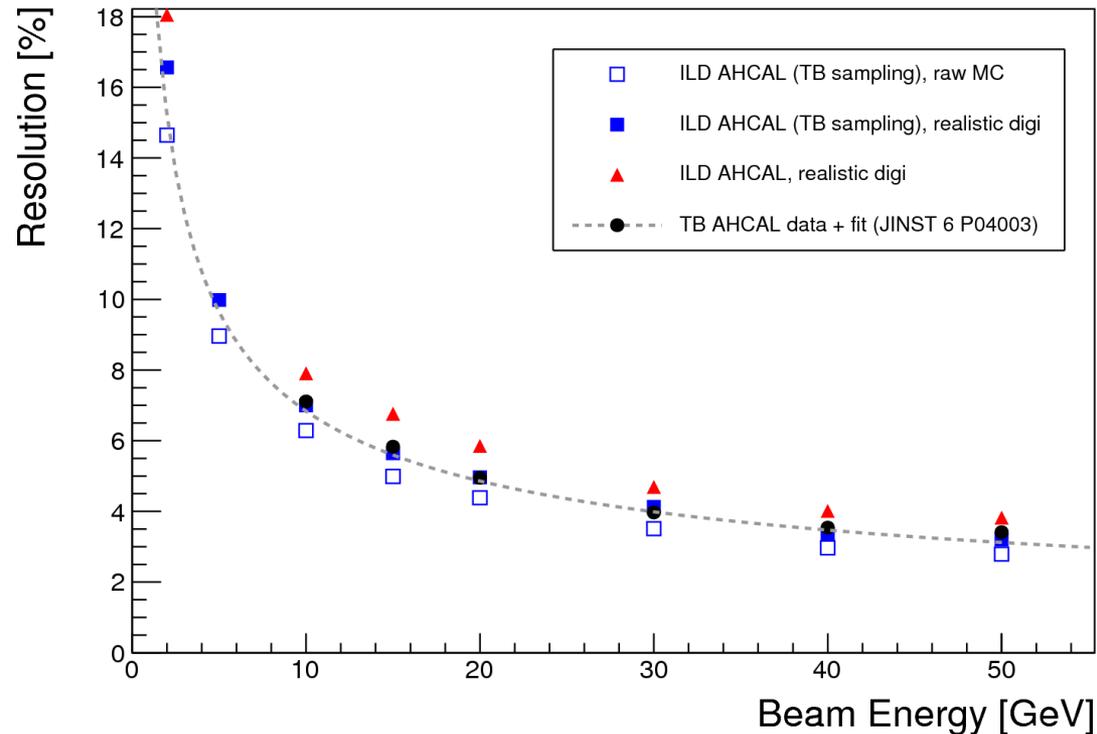
> ## ILD simulation very similar to published results

  - Simplified geometry, missing channelwise calibration etc.

  - Dependence on dead channel fraction (5-7% in prototype)

> ## Large effect of digitisation on resolution

  - Fiducial cut (clustering),
    timing, threshold.

  - SiPM effects negligible

> ## ILD sampling:
  worse for higher energies

  - Less layers → leakage
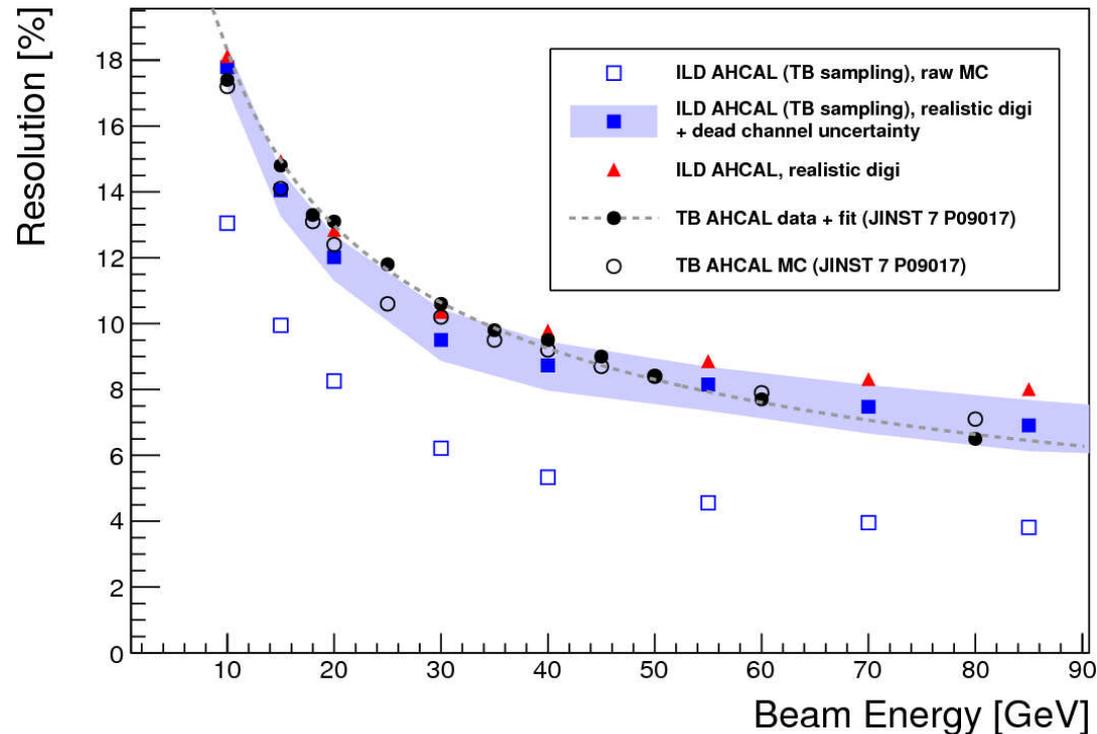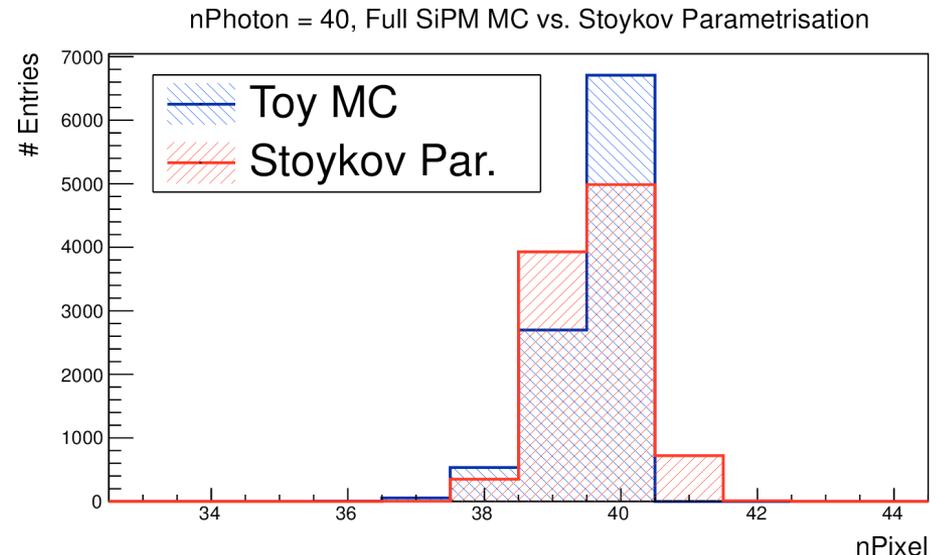
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Summary

> Validated "Testbeam model" as fast and correct SiPM modelling

  - Implemented in updated ILDCaloDigi + other new features

> SiPM effects on AHCAL single particle energy resolution are small

  - Visible for electrons >20GeV (rare in HCAL)

  - Irrelevant for hadrons (driven by clustering, timing, threshold)

    → All relevant effects have been included since LOI

> Can reproduce published AHCAL results in ILD model

  - From MIP-spectra to hadron resolutions

  - Using prototype-like sampling & reasonable dead channel fractions

> ILD sampling: Slighty worse resolutions

  - Expected from lower sampling fraction

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Very special thanks to Daniel and all of Uni Tokyo Komamiya group for weeks of hospitality and collaboration
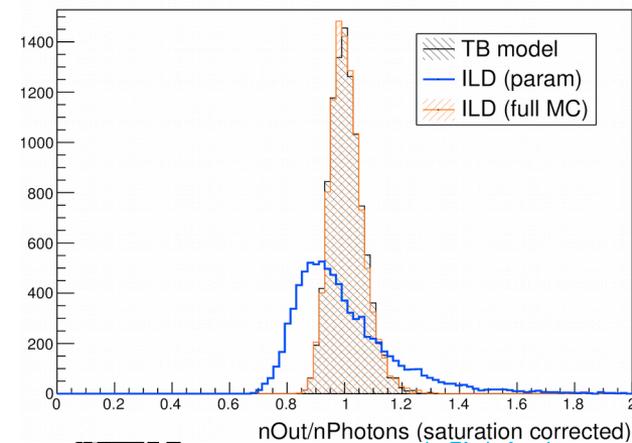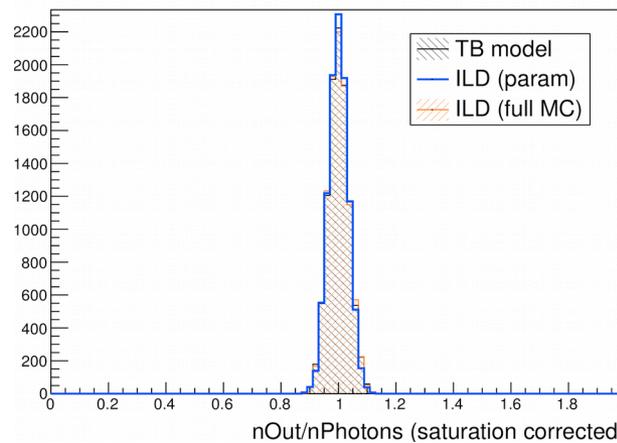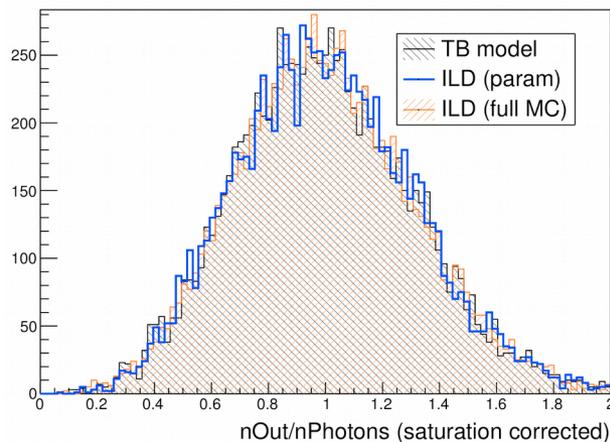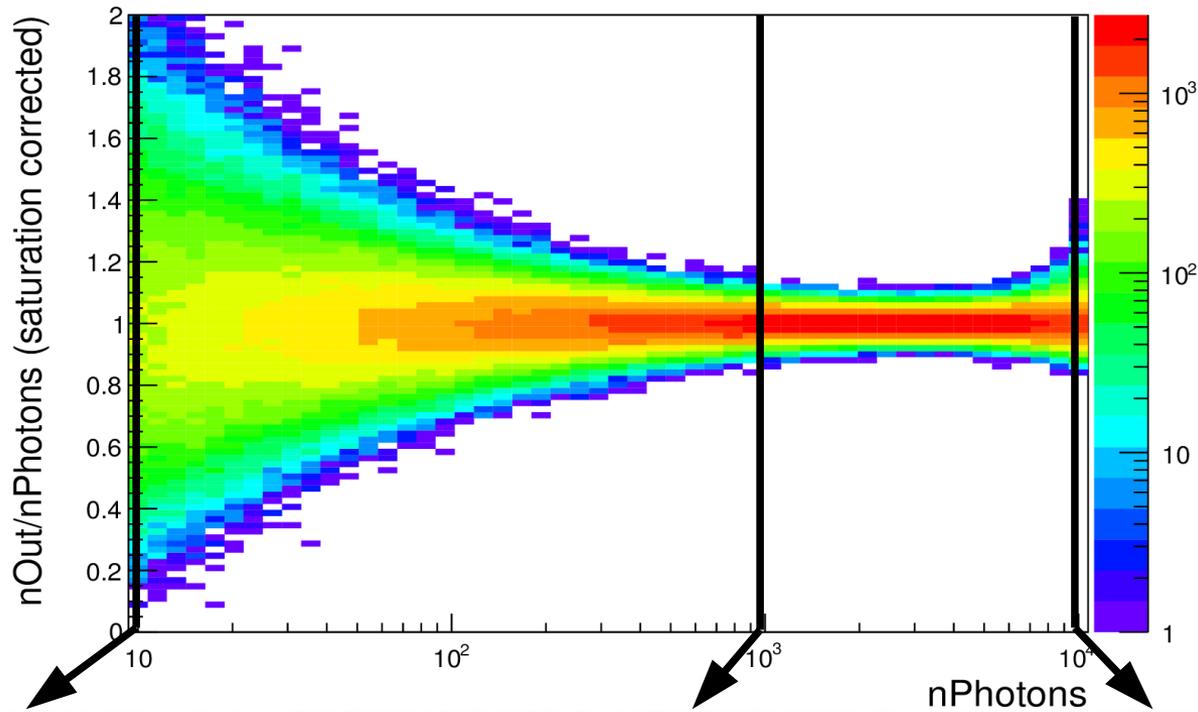
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Backup

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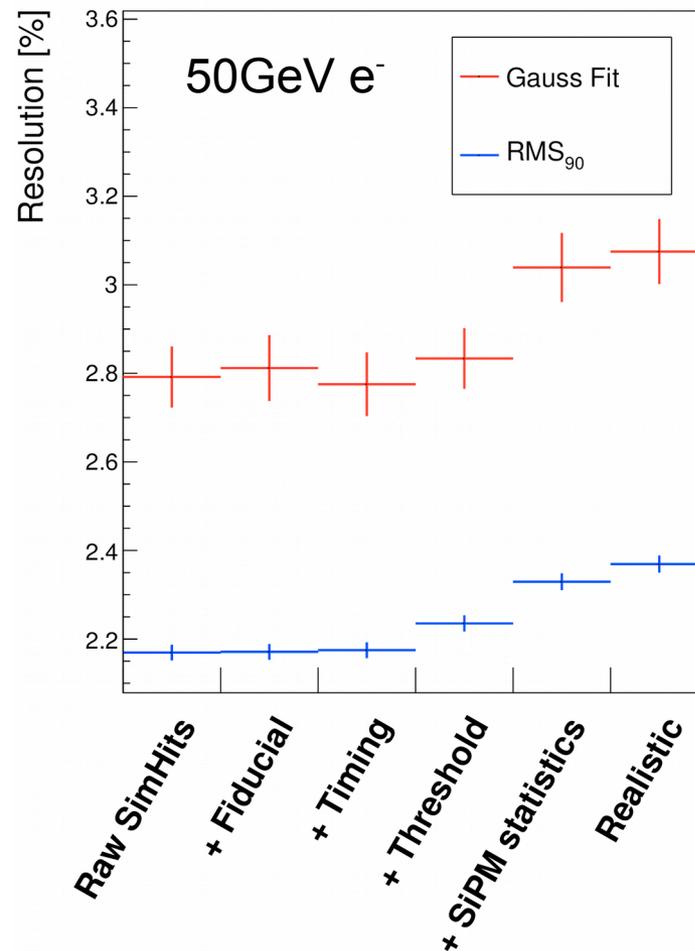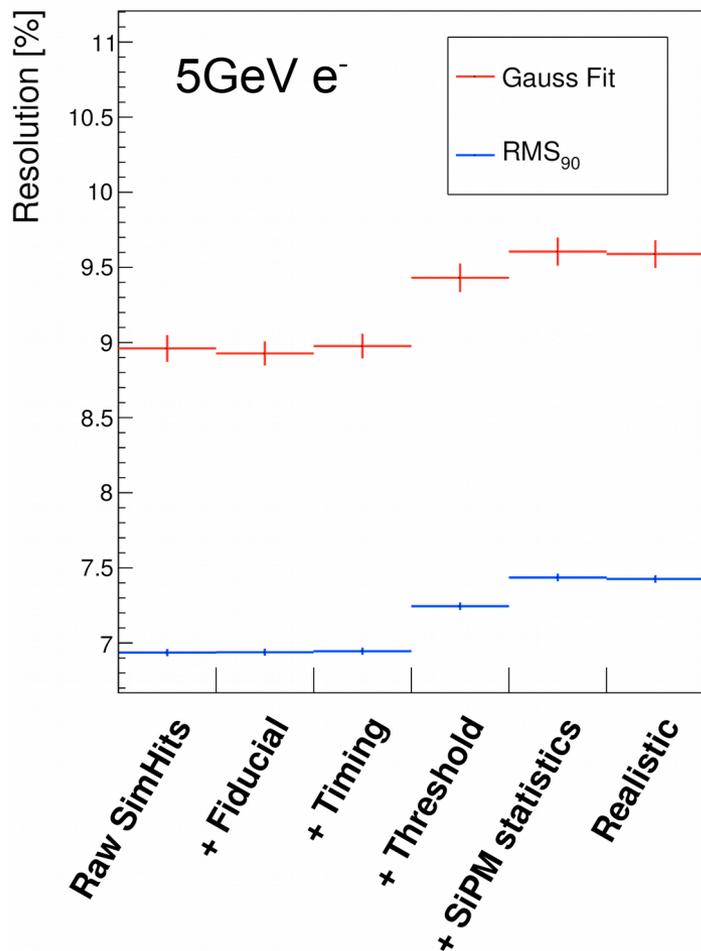UNIVERSITÄT
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Saturation Smearing

> Finite no. of pixels: Chance to hit same pixel twice

- Saturation
- Reponse widening

> Reponse widening: "Stoykov Parametrisation"

- RMS as function of amplitude
- Shape unknown → Gaussian
- Need to apply saturation separately

> Toy MC

- Roll dice for each incoming photon
- Only count first photon per pixel
- Solves saturation and response

nPhoton = 40, Full SiPM MC vs. Stoykov Parametrisation

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Digitisation Resolution Breakdown Electrons

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Digitisation Resolution Breakdown Pions