Digitisation Effects in the ILD Software

Tracker and Calorimeters

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DESY

Digitisation

- Realistic processing of raw Geant4 energy depositions
  - Tracker: hit position (efficiencies, timing, amplitudes?)
  - Calorimeters: hit amplitude (efficiencies, time resolution?)

- Modelling of intrinsic sensor effects
  - Statistics, efficiencies, resolutions, ...
- Modelling of electronics, readout, real world effects
  - Noise, ASIC limitations, miscalibrations, ...

- Ideally input and verification from R&D groups
  - Based on detailed simulation, experience or **testbeam data**

ILD Tracker Digitisation

- Hit position smearing based on resolutions supplied by R&D groups
- Strip tracker hit positions calculated from double layer stereo angle
  - Including correct covariance matrix
- TPC point resolution parametrised by track angles, Z position
  - Effects from diffusion, orientation track↔pad

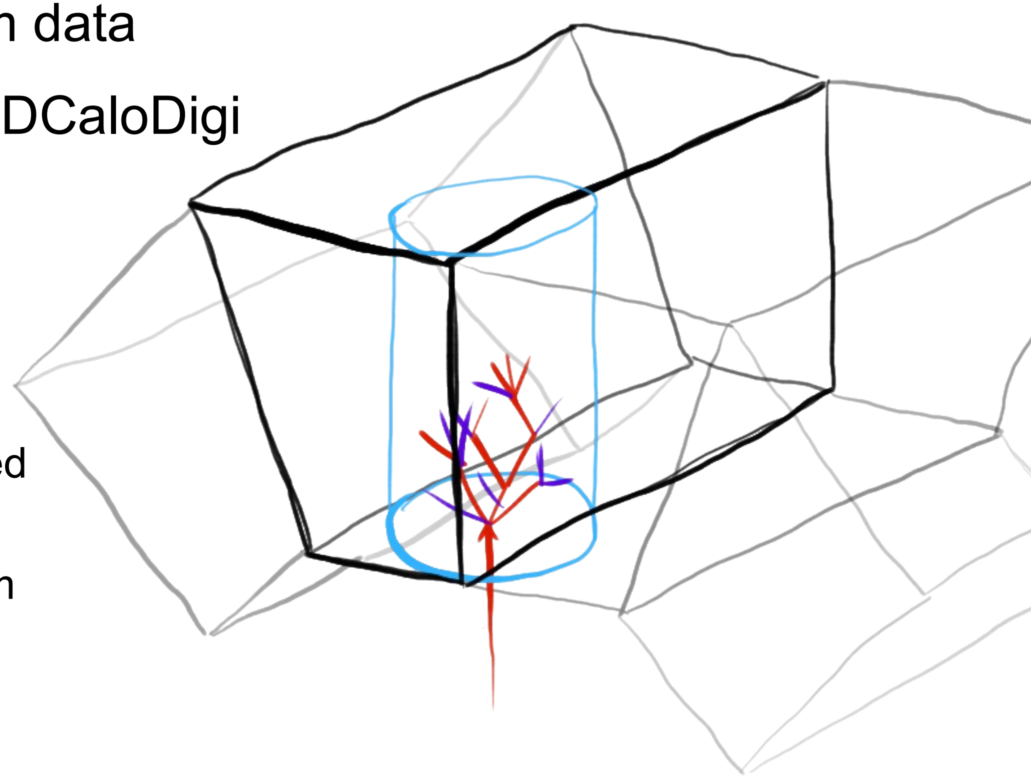
Detector	Point Resolution
VTX	$\sigma_{r\phi,z} = 2.8\mu m$ (layer 1) $\sigma_{r\phi,z} = 6.0\mu m$ (layer 2) $\sigma_{r\phi,z} = 4.0\mu m$ (layers 3-6)
SIT	$\sigma_{\alpha_z} = 7.0\mu m$ $\alpha_z = \pm 7.0^\circ$ (angle with z-axis)
SET	$\sigma_{\alpha_z} = 7.0\mu m$ $\alpha_z = \pm 7.0^\circ$ (angle with z-axis)
FTD *Pixel*	$\sigma_r = 3.0\mu m$ $\sigma_{r_\perp} = 3.0\mu m$
FTD *Strip*	$\sigma_{\alpha_r} = 7.0\mu m$ $\alpha_r = \pm 5.0^\circ$ (angle with radial direction)
TPC	$\sigma^2_{r\phi} = (50^2 + 900^2 \sin^2\phi + ((25^2/22) \times (4T/B)^2 \sin\theta)(z/\text{cm}))\,\mu m^2$ $\sigma^2_z = (400^2 + 80^2 \times (z/\text{cm}))\,\mu m^2$ where ϕ and θ are the azimuthal and polar angle of the track direction

ILD Calorimeter Digitisation

- *ILDCaloDigi* part of MarlinReco
  - Support for silicon & scintillator-SiPM readout
  - Many options to simulate misbehaving detectors
- General effects
  - Timing, amplitude thresholds
  - Electronics noise, dead channels
  - Channel miscalibration (correlated, uncorrelated)
- Silicon specific effects
  - Dominated by Landau fluctuations (included by Geant)
- Scintillator-SiPM specific
  - SiPM statistics model (saturation behaviour etc.)
- ILDCaloDigi included in current calorimeter optimisation studies
  - Reasonable defaults for all parameters

ILD Scintillator HCAL Validation

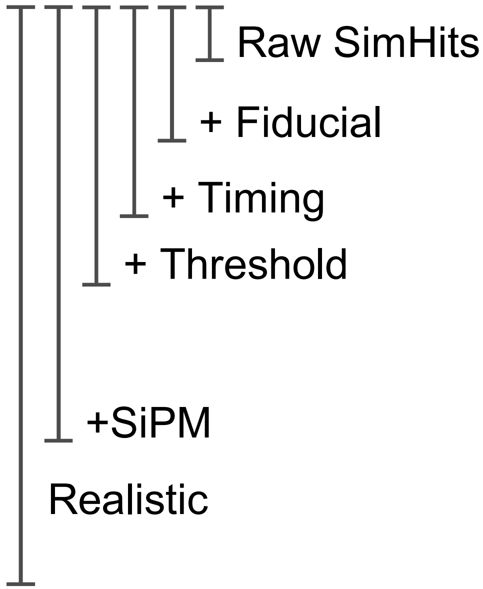
- Validate ILD HCAL with testbeam data
- Using ILD HCAL standalone + ILDCaloDigi



- Testbeam prototype geometry is different to ILD HCAL
  - ILD HCAL sampling structure modified to testbeam prototype sampling
  - Setup particle gun similar to testbeam
  - Limit fiducial volume of ILD HCAL
- Check MIPs, electrons, pions ILD model vs. testbeam

Digitisation Steps

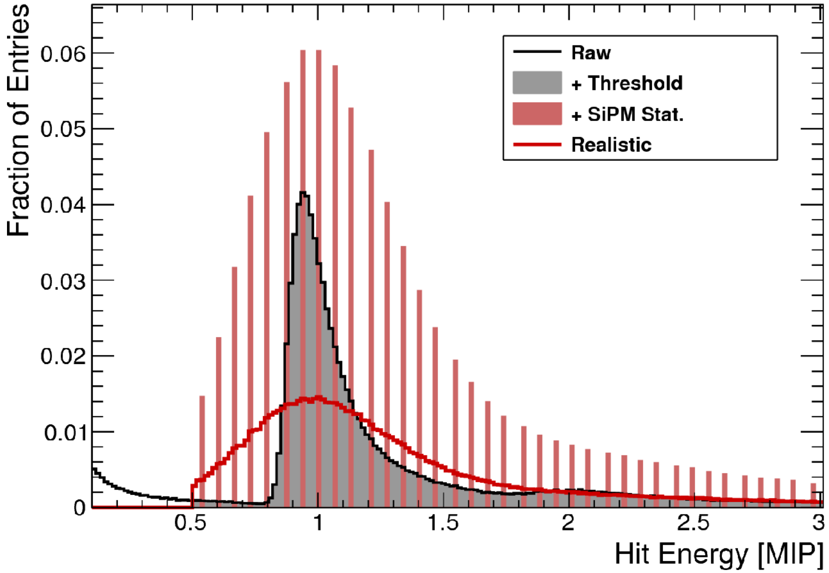
Parameters:	ILD Baseline	Testbeam
Scintillator	3mm	5mm
Absorber	20mm Fe	21mm Fe
Layers	48	64
MIP2GeV:	489.6keV/MIP	817.0keV/MIP
Fiducial cut:	yes	yes
Timing:	-10..150ns	-10..150ns
Threshold:	0.5MIP	0.5MIP
Lightyield:	15px/MIP	13.7px/MIP
SiPM NPixel:	2000px	1156px
Electronic Noise:	0.3px	0.3px
Pixel non-uniformity:	10%	10%

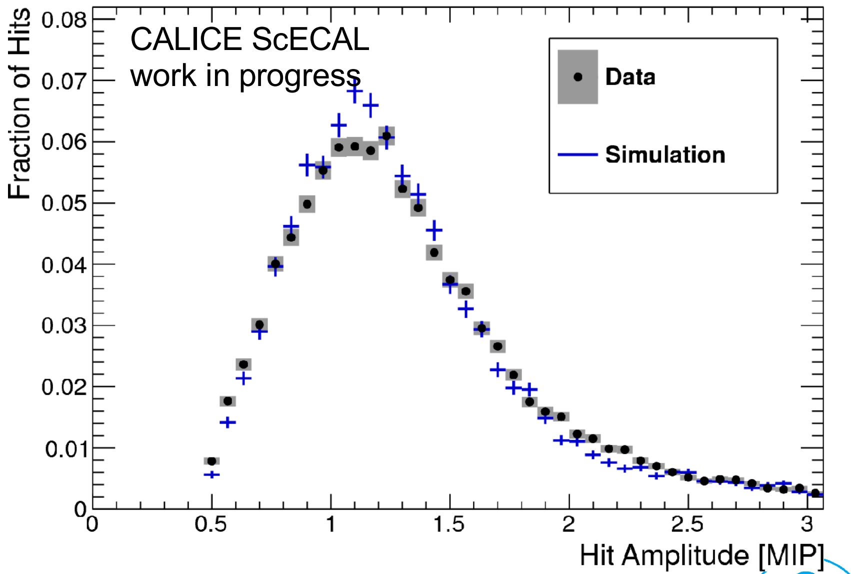


- Inspect digitisation procedure step-by-step

MIPs

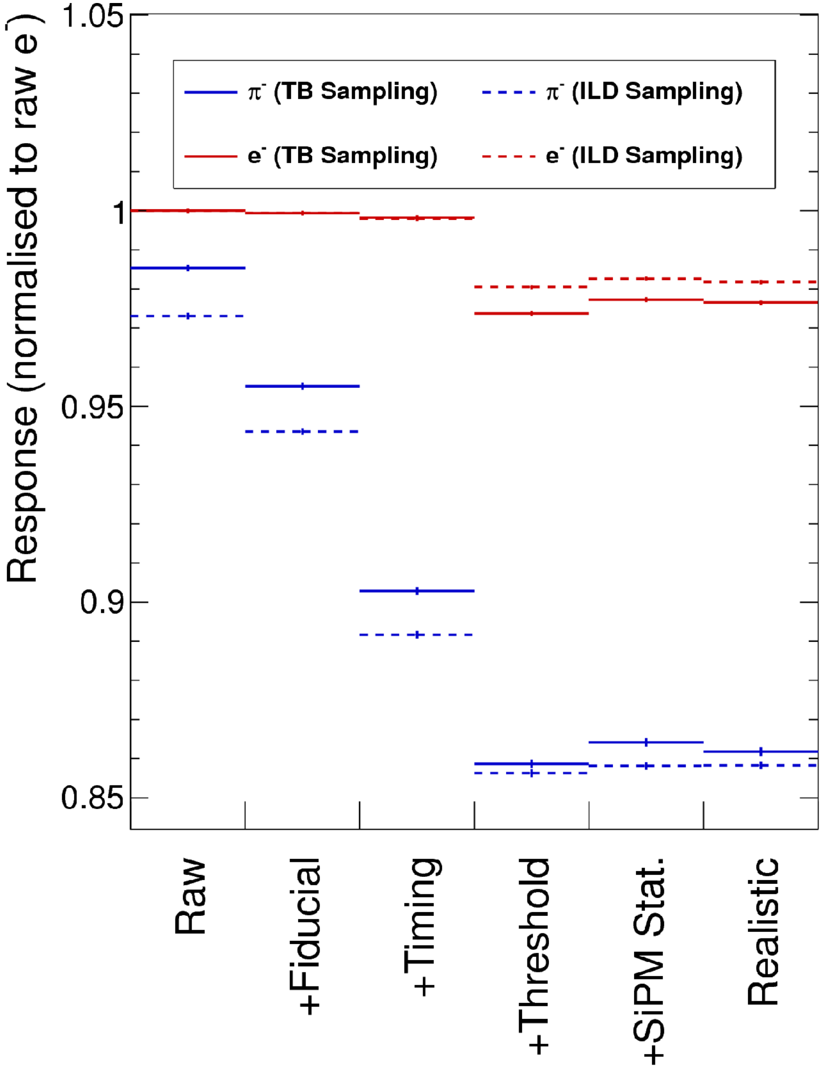
- Notable effect of SiPM modelling on MIP spectrum
  - Electronics noise smears out quantisation
- Good agreement with data





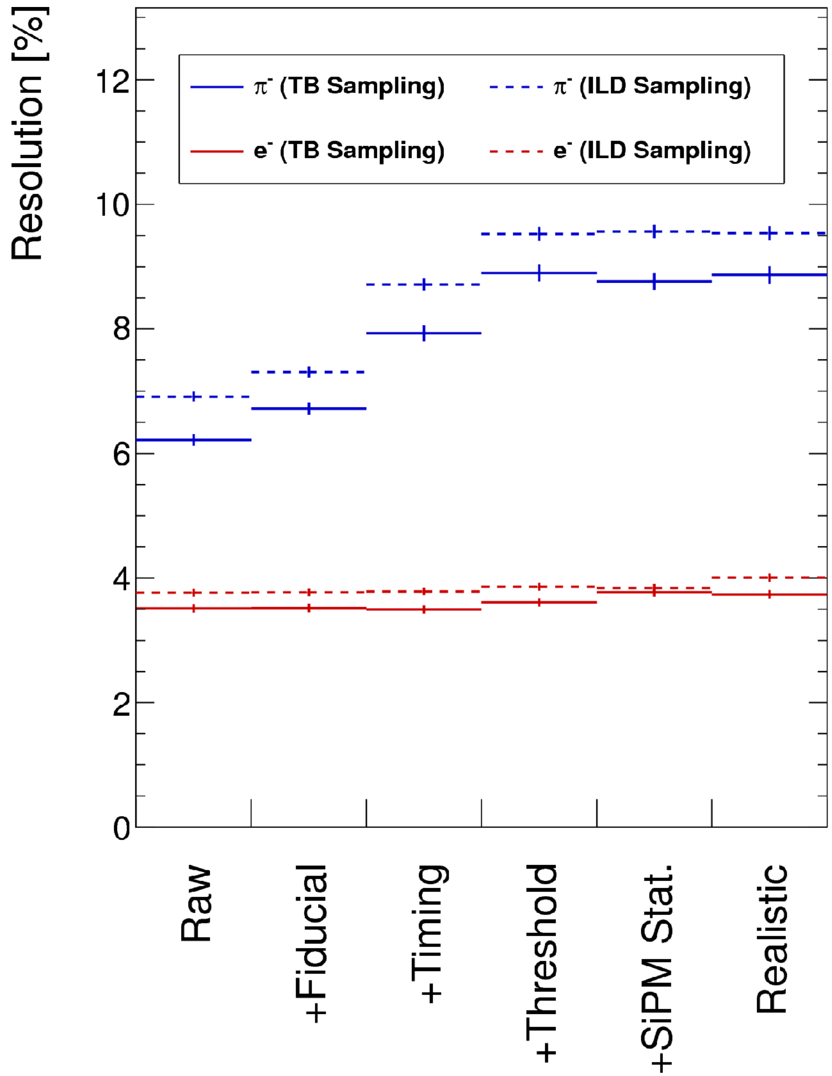
Response and Digitisation @30GeV

- Small loss of response in electrons from hit energy threshold
  - Less in ILD sampling as higher tile lightyield assumed
- 15% loss of response in pions
  - Equal parts fiducial cut, timing, threshold
- N.b.: Testbeam sampling HCAL almost compensating in raw simulations



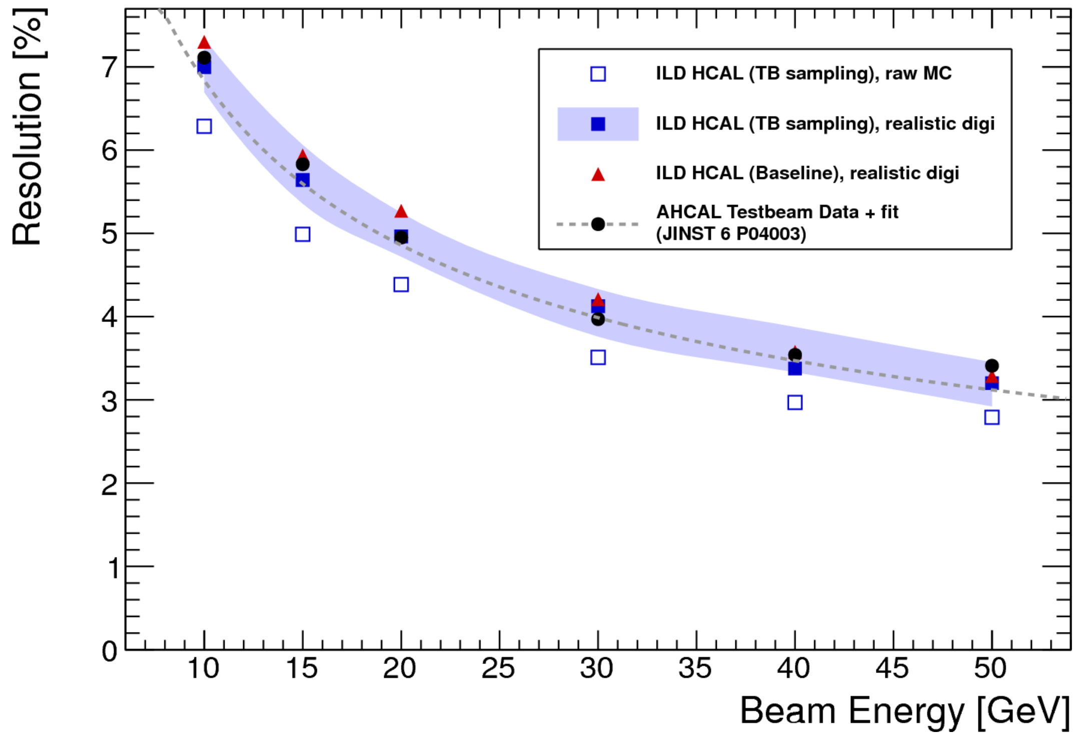
Resolution and Digitisation @30GeV

- Electron resolution barely influenced by digitisation
  - Small effect from noise↔saturation interplay for very high energy electrons in the HCAL
- Pion resolution strongly (~50%!) influenced by digitisation steps
  - Equal parts fiducial cut, timing, threshold
  - No effect from SiPM/electronics effects



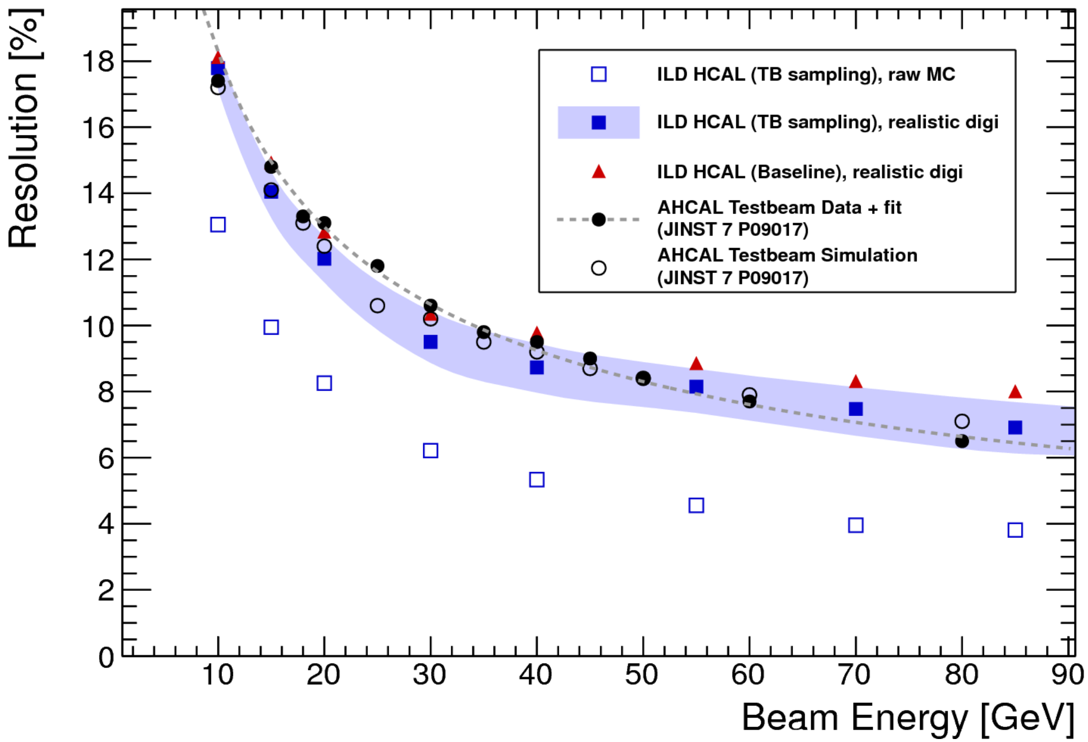
Resolution Electrons

- ILD simulation very similar to published AHCAL testbeam results
  - Systematic uncertainty from dead channel fraction in testbeam
- Small effect of digitisation on resolution
  - Mostly threshold
- ILD sampling:
  Slightly worse resolution



Resolution Pions

- ILD simulation very similar to published AHCAL testbeam results
  - Systematic uncertainty from dead channel fraction in testbeam
- Large effect of digitisation on resolution
  - Fiducial cut (clustering), timing, threshold.
- SiPM effects negligible
- ILD sampling:
  Slightly worse resolution



Summary & Outlook

Summary

- ILD simulation digitisation procedures exist for tracking, Silicon/Scintillator-SiPM calorimeter
- Scintillator-SiPM Digitisation validated vs. AHCAL testbeam data
  - No serious effects on full ILD performance, physics samples stay valid
- ILDCaloDigi in use for HCAL optimisation studies

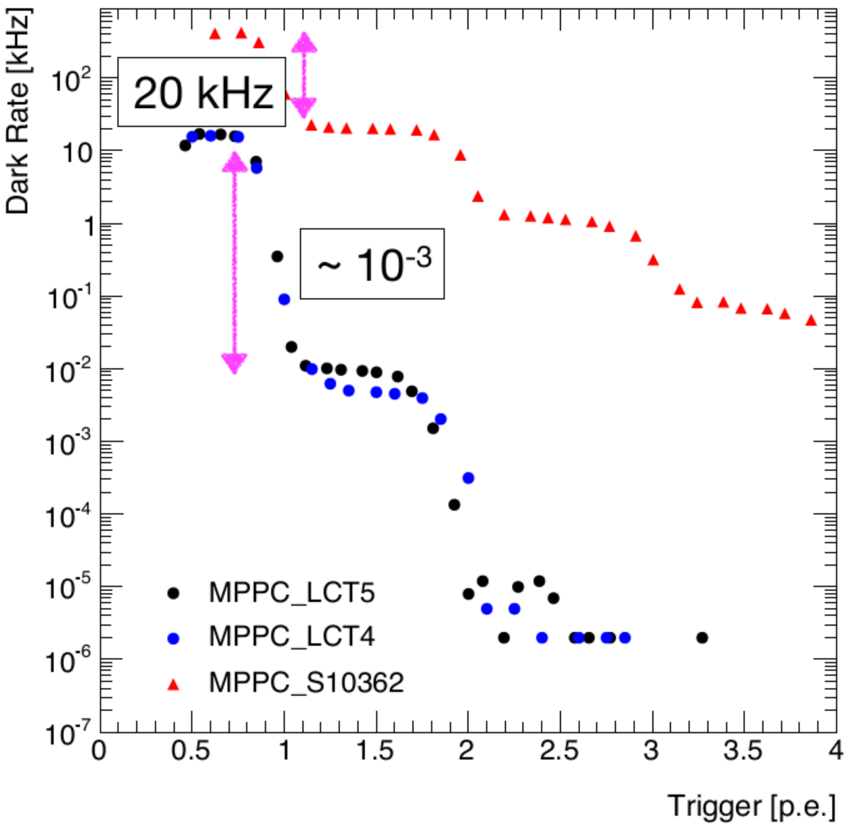
Outlook

- Tracker: More sophisticated parametrisations needed?
- Gaseous calorimeters: Recent breakthrough in RPC simulation
  - Currently needs specific G4 physics lists, implementation in digitisation possible?
- Separate calorimeter digitisation and energy reconstructions?
  - Run digi processor once for each calo (currently lots of code duplication)

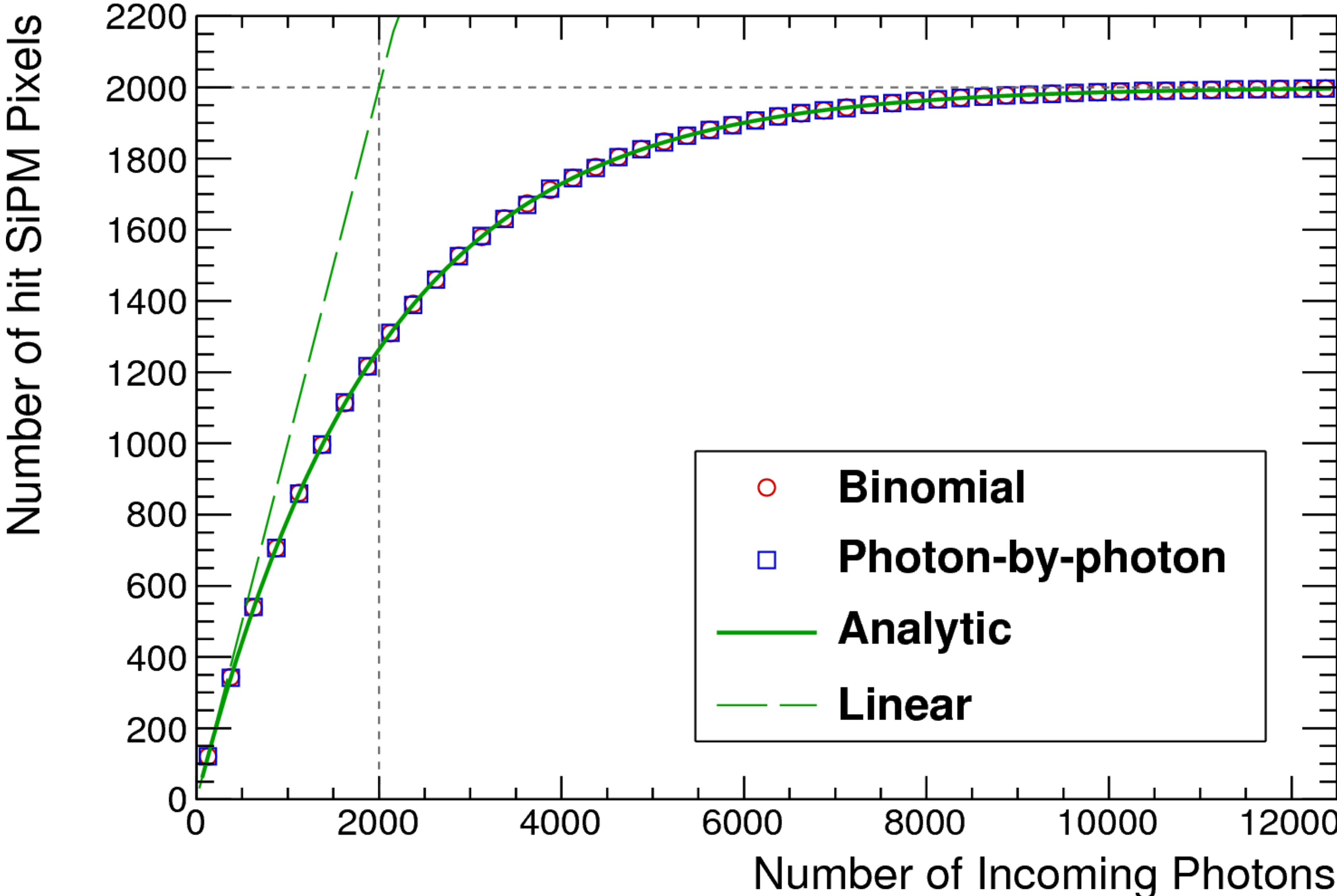
Backup

Noise Level with state-of-the-Art SiPMs

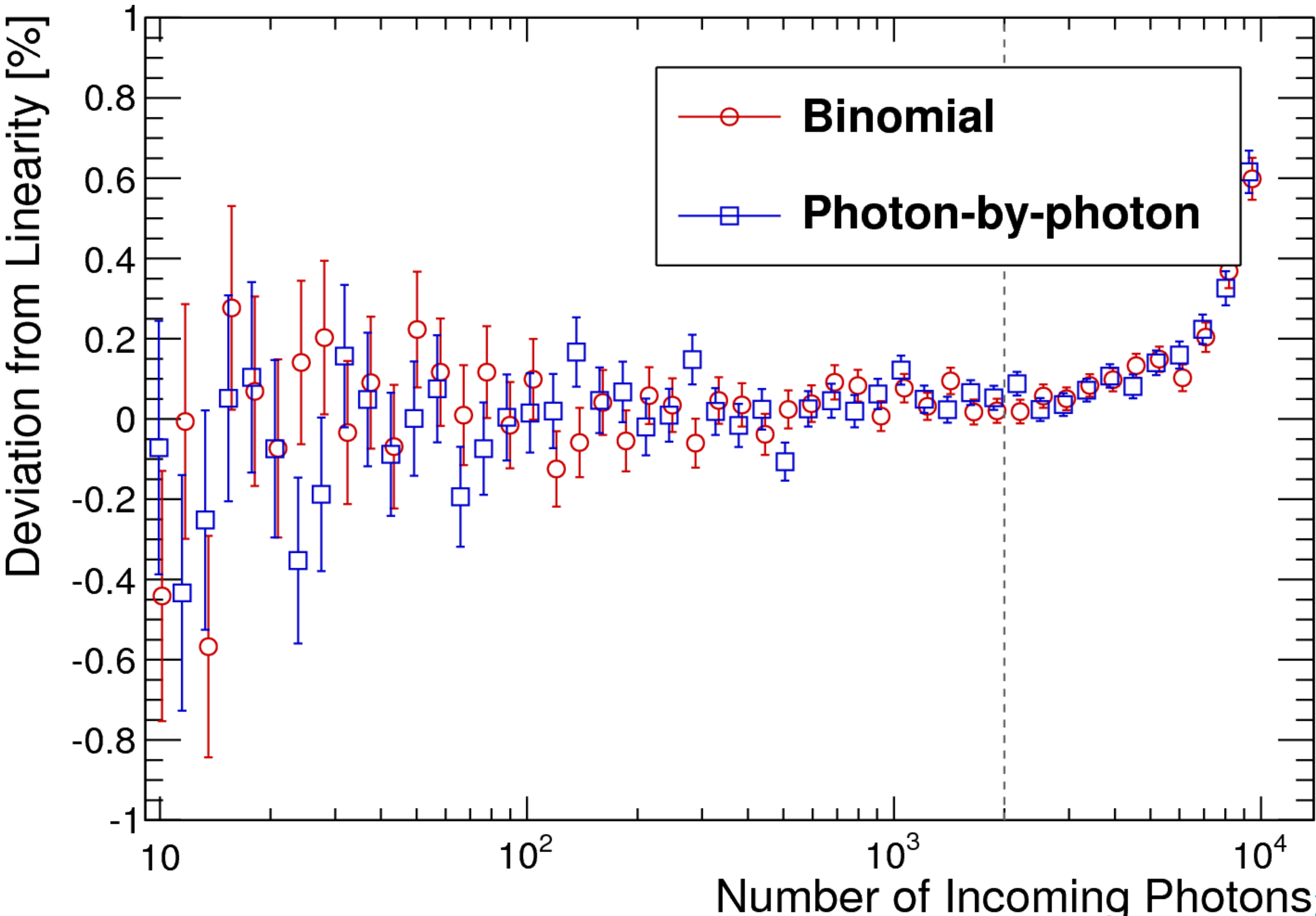
- Expected Noise at 0.3 MIP:
  - light yield: 15 p.e. / MIP
    -> Noise cut at 4.5 p.e.
  - 1 p.e. noise level: < ~ 20 kHz
  - cross talk: 10^{-3} - 10^{-2} (conservative)
  - Rate at 5 p.e. : 20 kHz x $(10^{-2})^4$
    = 2 x 10^{-4} Hz
  - Rate in full AHCAL(10^7 channels):
    2 kHz = 2 / bunch train



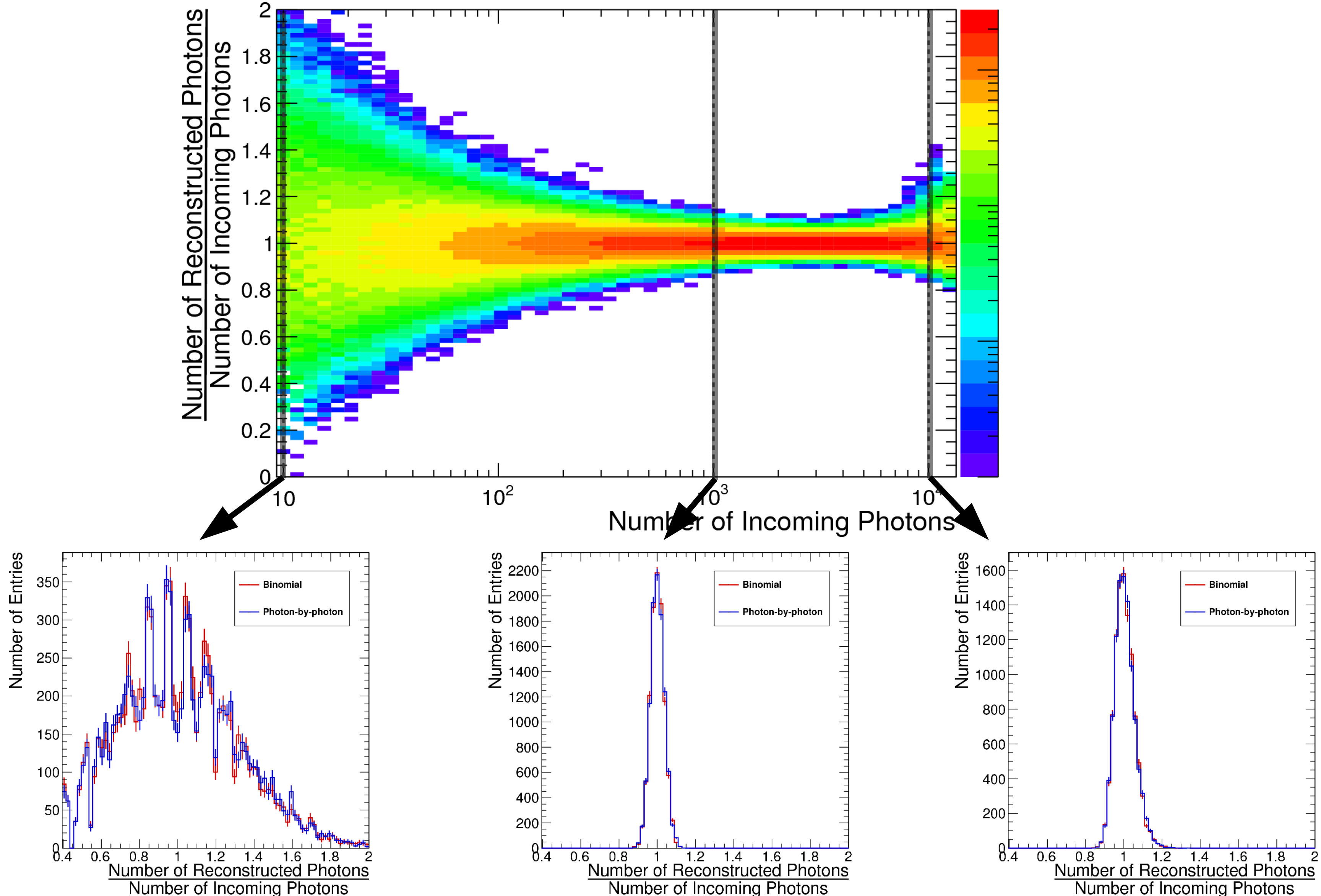
SiPM Saturation



SiPM Saturation



Transfer Function Slices



SiPM Saturation