ETH zürich

Small Animal Fast Insert for MRI

CHIPP Winter School 2015

Introduction
Principle of PET

- PET = positron emission tomography
- Positron emitting tracer
  - e.g. F-18 ($T_{1/2} = 109.8\,\mathrm{min}$), O-15 ($T_{1/2} = 122.2\,\mathrm{s}$)
  - electron-positron annihilation
  - Detect 511 keV back-to-back gammas in coincidence
- Wanted: tracer distribution ("Image")

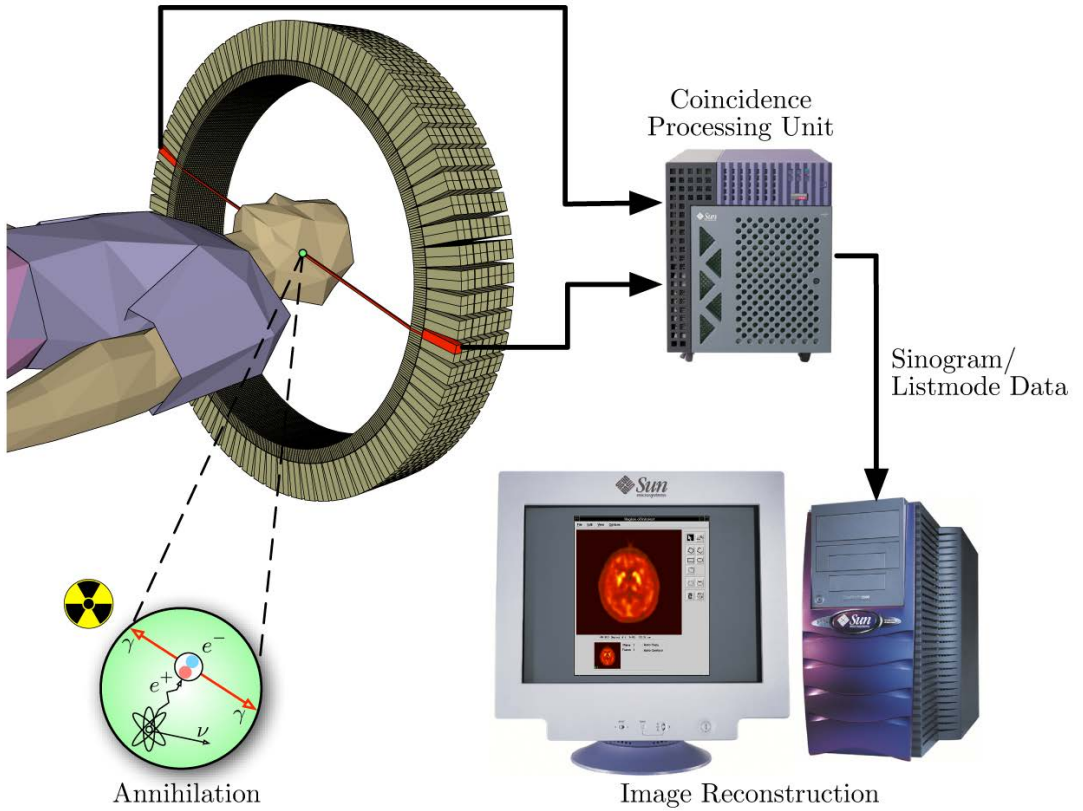
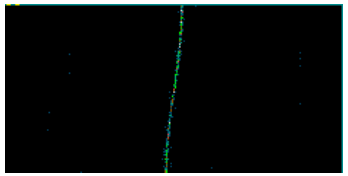
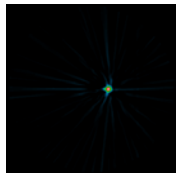


Image by Jens Maus, public domain

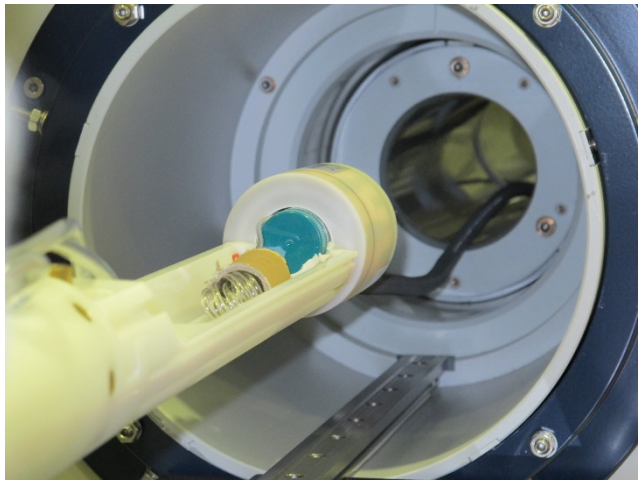




- Noisy Projections → Reconstruction → Image + Noise
- $y_i = P_{ij} \lambda_j + r_i$

SAFIR
Small Animal Fast Insert for MRI

- Simultaneous acquisition with MRI
  PET insert for preclinical Bruker BioSpin 70/30
- Detect fast biological processes
  Temporal Resolution / Acquisition times ~ seconds
  (Extremly short, usually ~ minutes)
- Increase tracer activity up to 500 MBq (~10 times more than usual) to make up for short acquisition time frames
- e.g. locate increased activity in stimulated mouse cortex ($2 \times 2 \times 2\ \mathrm{mm}^3$)
  Spatial Resolution < 1.5 mm FWHM

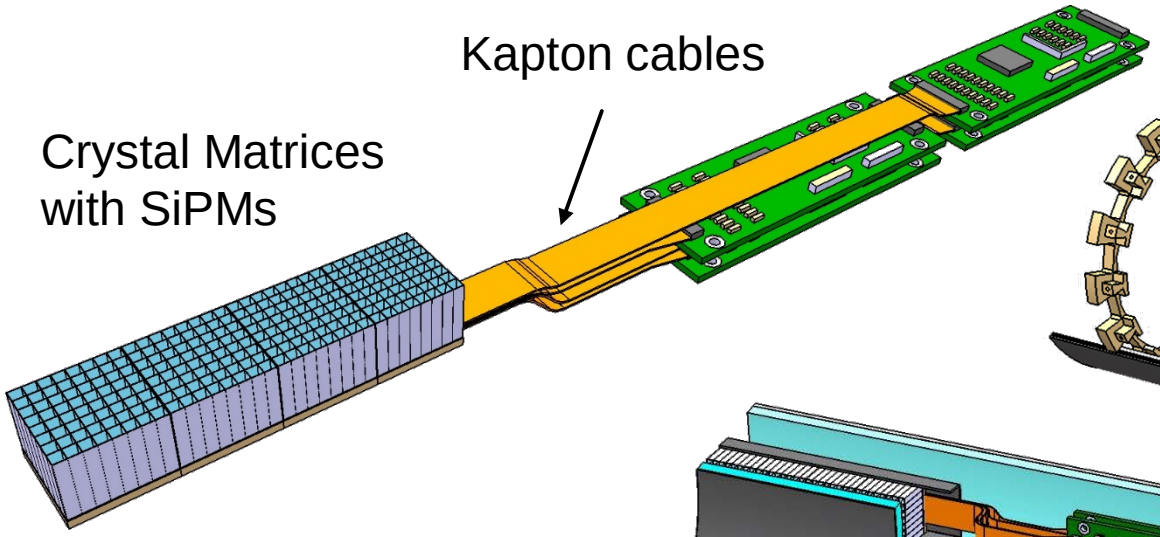


Mechanical Design
Schematic Views

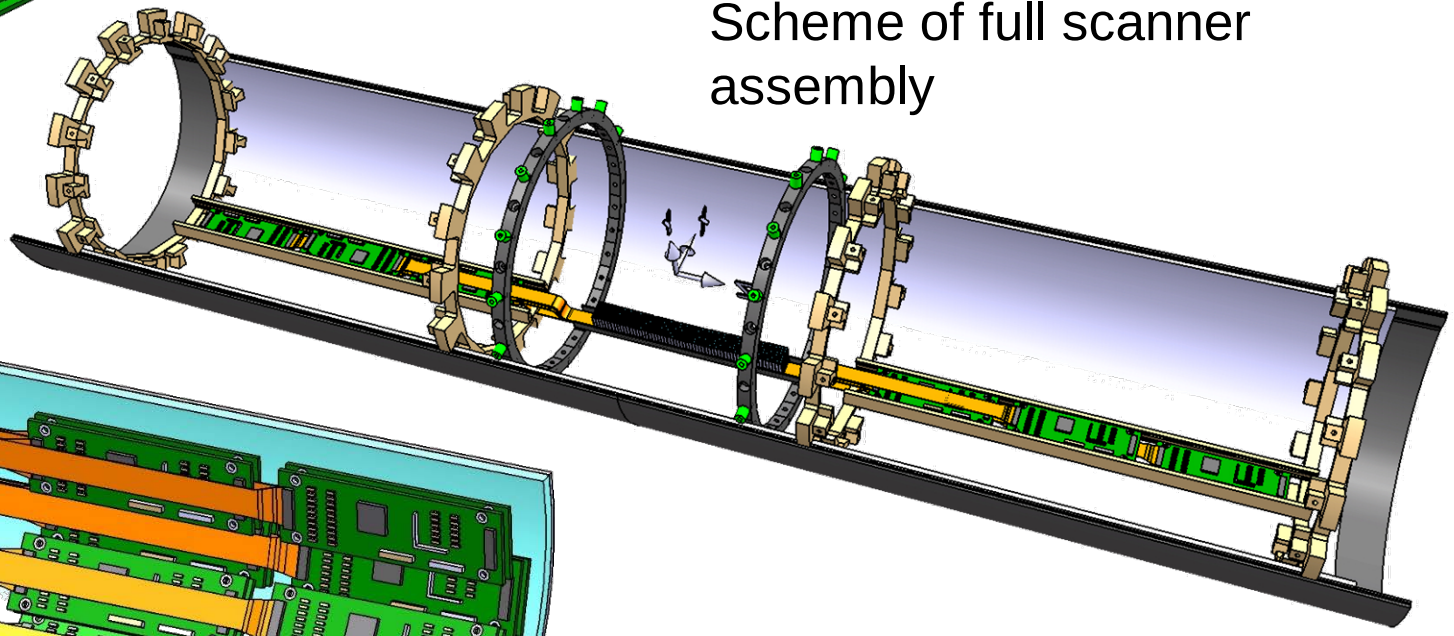
Front-end electronics

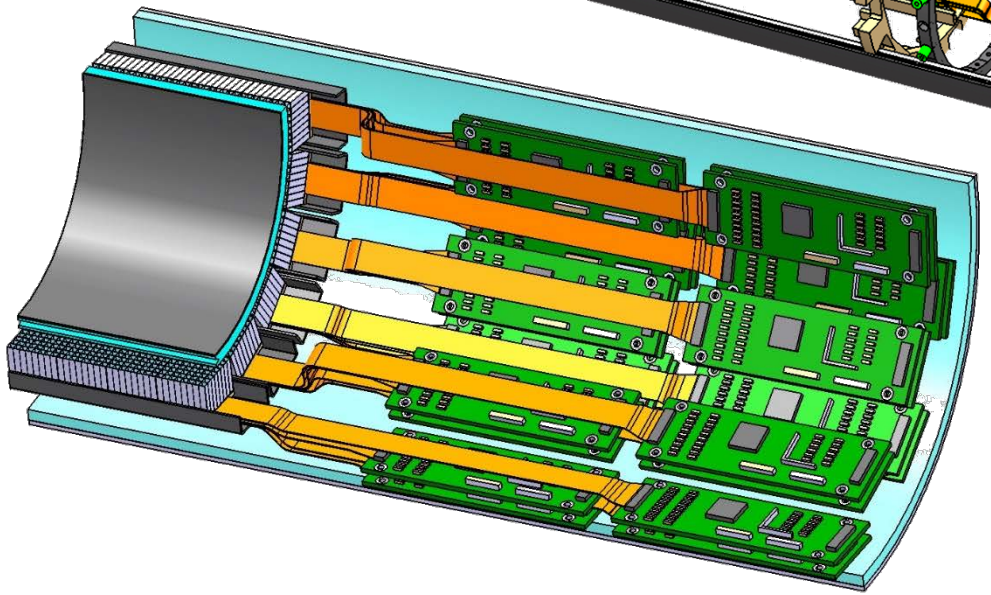
Kapton cables

Crystal Matrices
with SiPMs



Scheme of full scanner
assembly



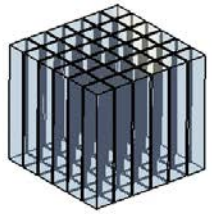


Detector modules with
gradient tube and HF
coils

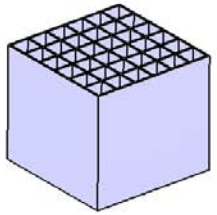
Inner diameter 114 mm
Axially 200 mm of detector modules
10 kHz / mm^2 expected rate

Sensors

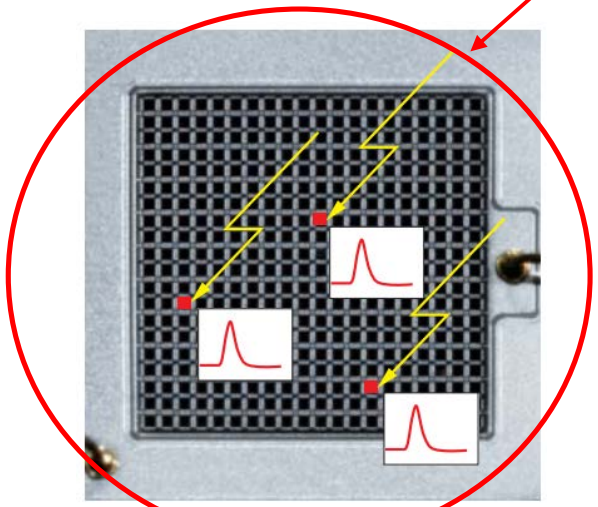
- LYSO crystals (e.g. SG PreLude 420)
  - Light yield: 32000 photons / MeV
  - Peak emission @ 420 nm
  - 41 ns decay time
- SiPMs (e.g. Hamamatsu “MPPC”)
  - Multiple APD cells, operated in Geiger-mode, connected parallely
  - Peak sensitivity @ 450 nm
  - MR-compatible
- Electronics
  - Amplification
  - Shaping
  - Discrimination
  - Digitization



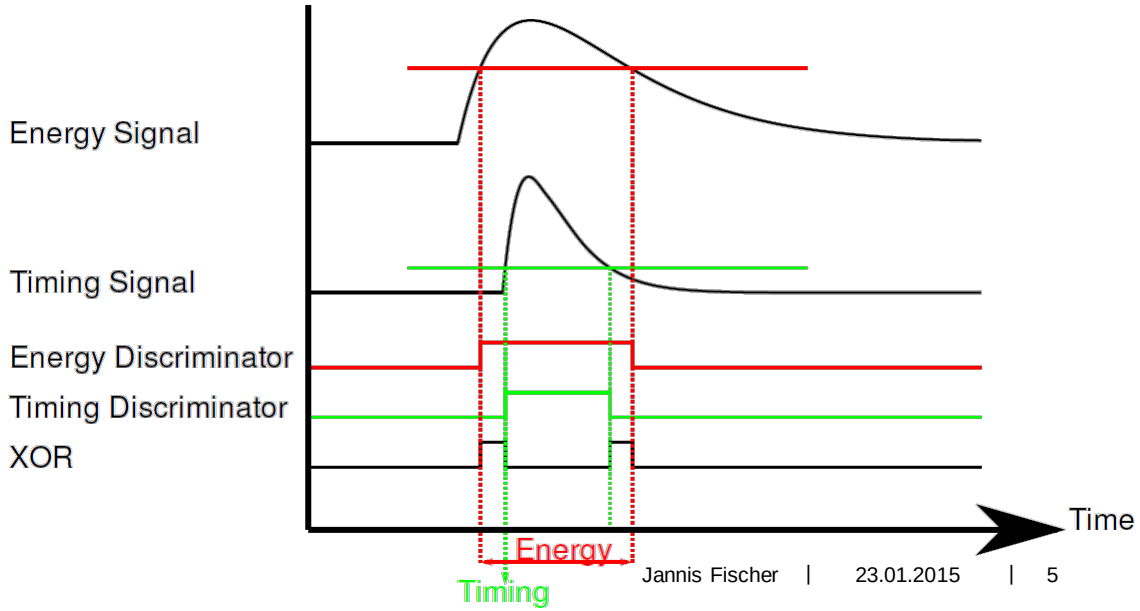
Readout ASIC: TOFPET or STiC
Crystal surface 1.5x1.5 mm^2 → 20k channels



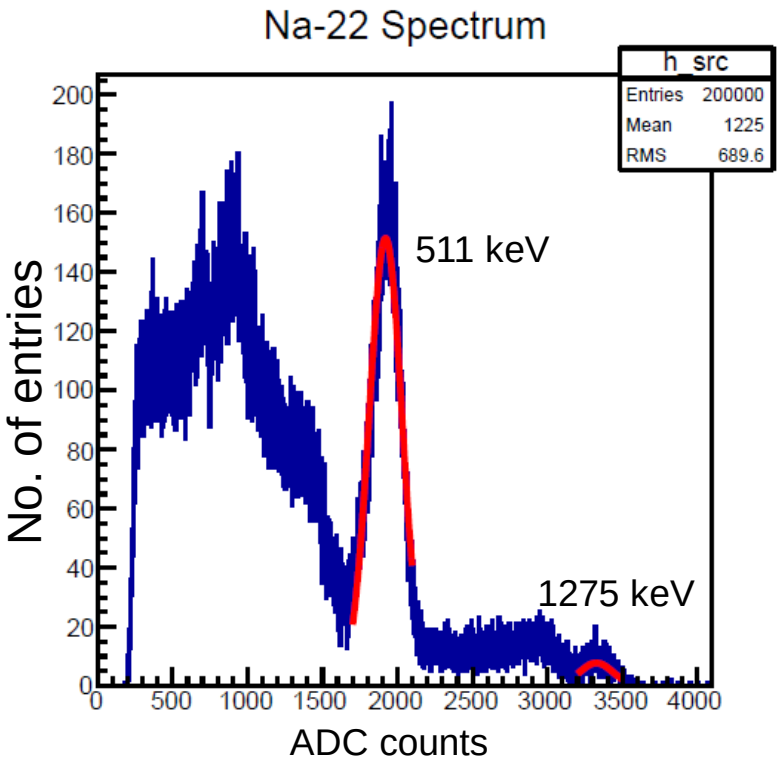
Reflective support

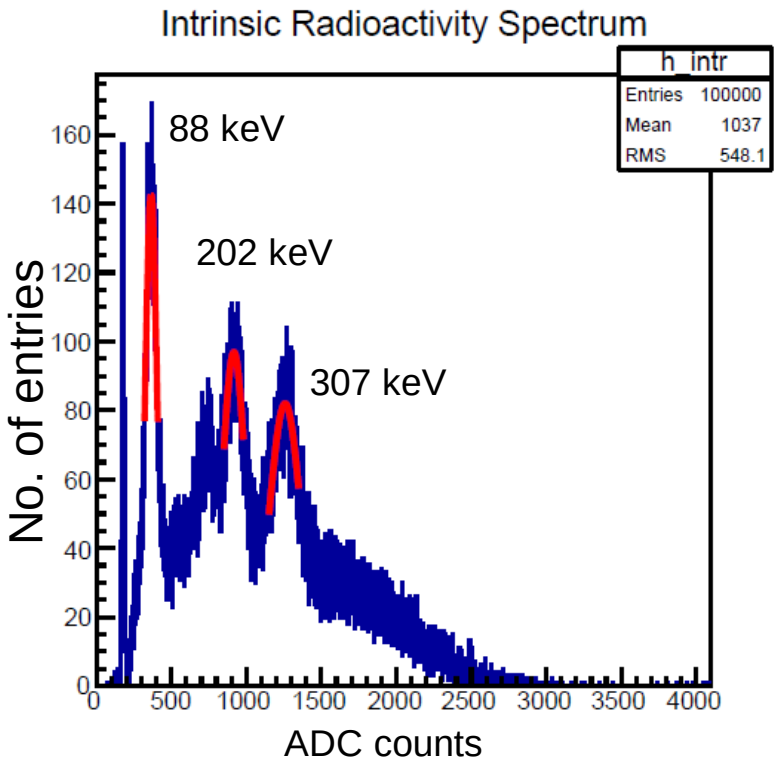


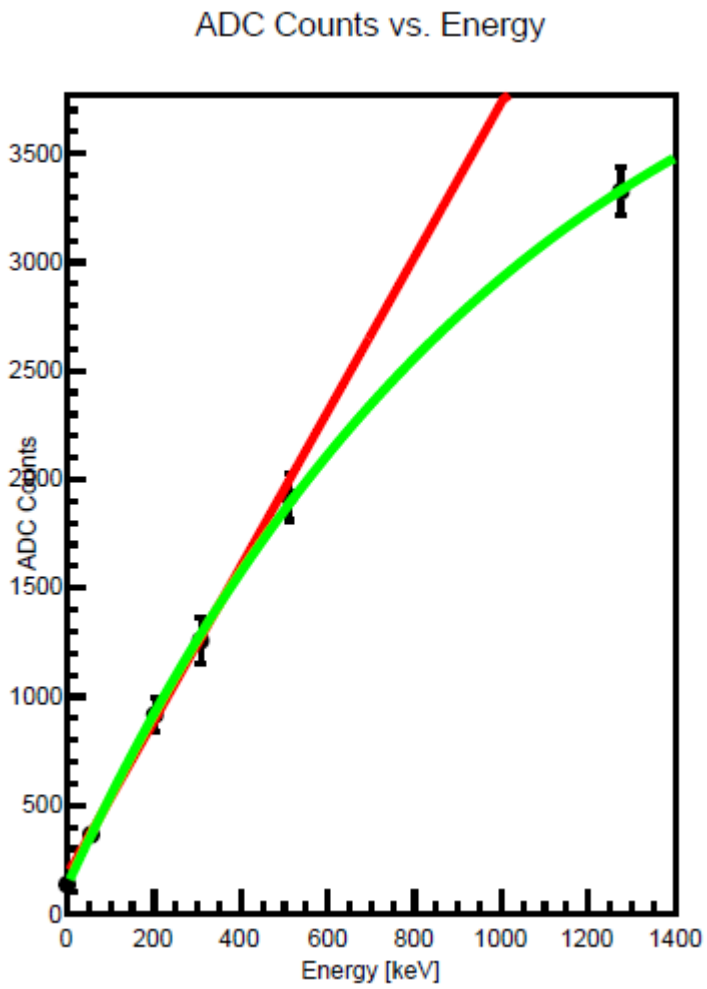
© Hamamatsu



Energy Spectra And Calibration



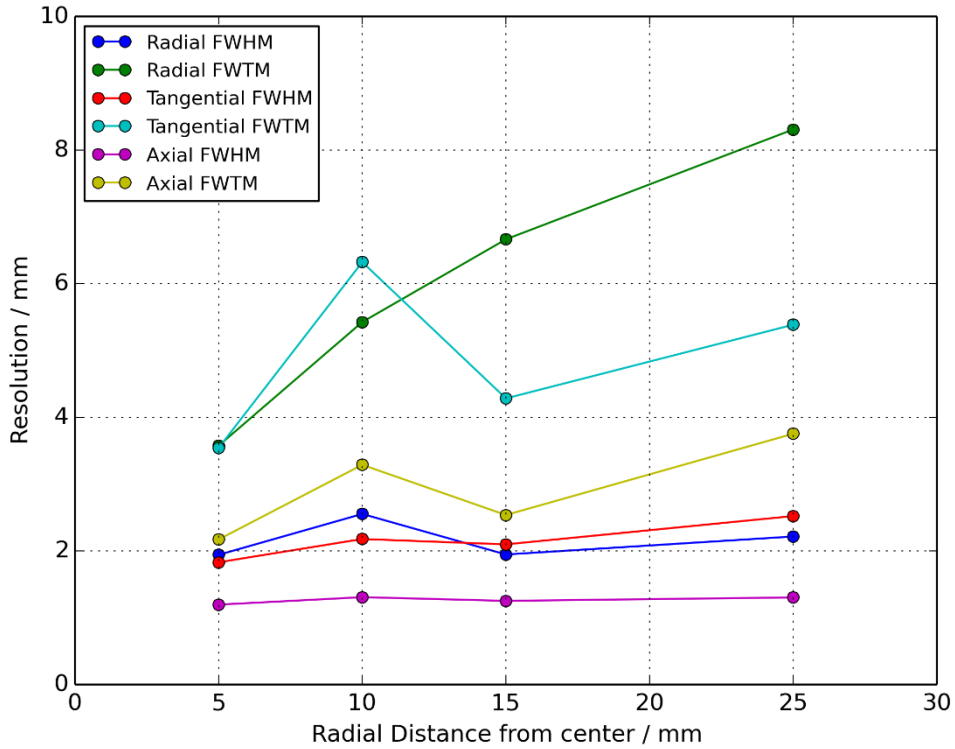




Simulation
Spatial Resolution

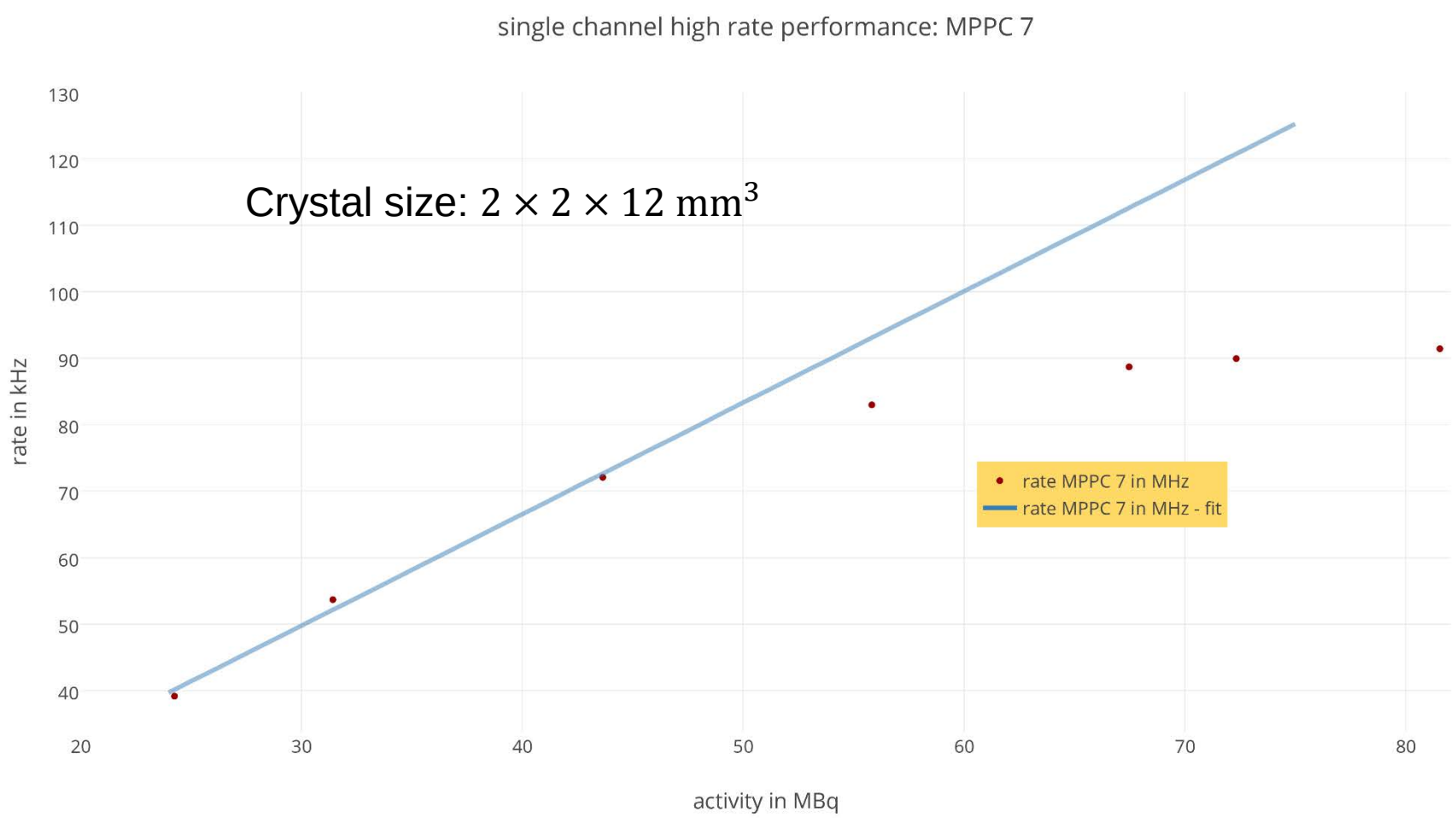
- Evaluation of scanner geometries through simulation
  - Spatial Resolution
  - Sensitivity
  - Scatter fraction
  - Signal-to-noise ratio (a.k.a. NECR)
- e.g. Spatial Resolution
  - Point-like source of Na-22 at different radial distances from center
  - Reconstruction (FBP)
  - FWHM and FWTM around maximum pixel to characterize spatial resolution
  - Along three perpendicular axes (radial, tangential, axial)

Spatial resolution



Crystal size: $2.1 \times 2.1 \times 12\ \mathrm{mm}^3$

High-rate Capability Of Read-Out ASIC e.g. TOFPET



- Syringe with F-18
- Single SiPM connected to TOFPET ASIC (no limitation by output bandwith)
- Random rate measured linear up to ~70 kHz

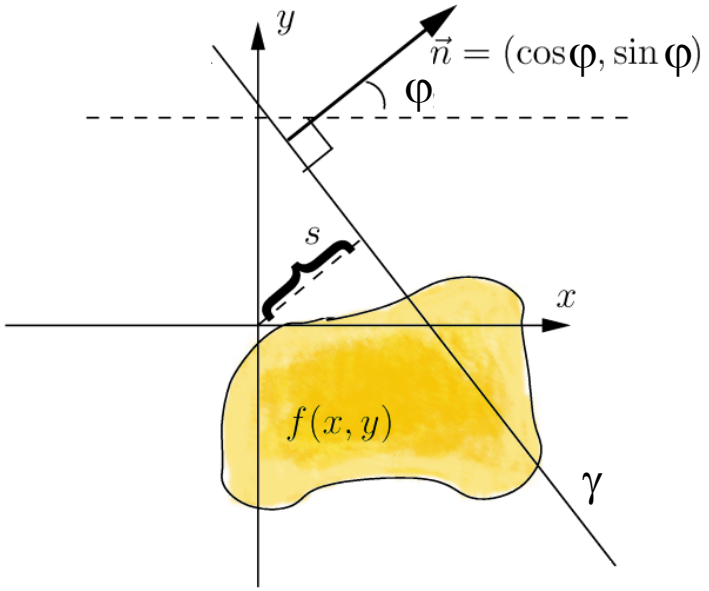
Summary

- Offers unprecedented biomedical research opportunities
- Challenging…
  - Mechanical constraint (insert)
  - Maintain state-of-the-art spatial resolution
  - Fast sensors
  - High-rate capable electronics (tens of kHz / channel)
  - Readout bandwidth
  - DAQ (~GB/s)
- …but feasible

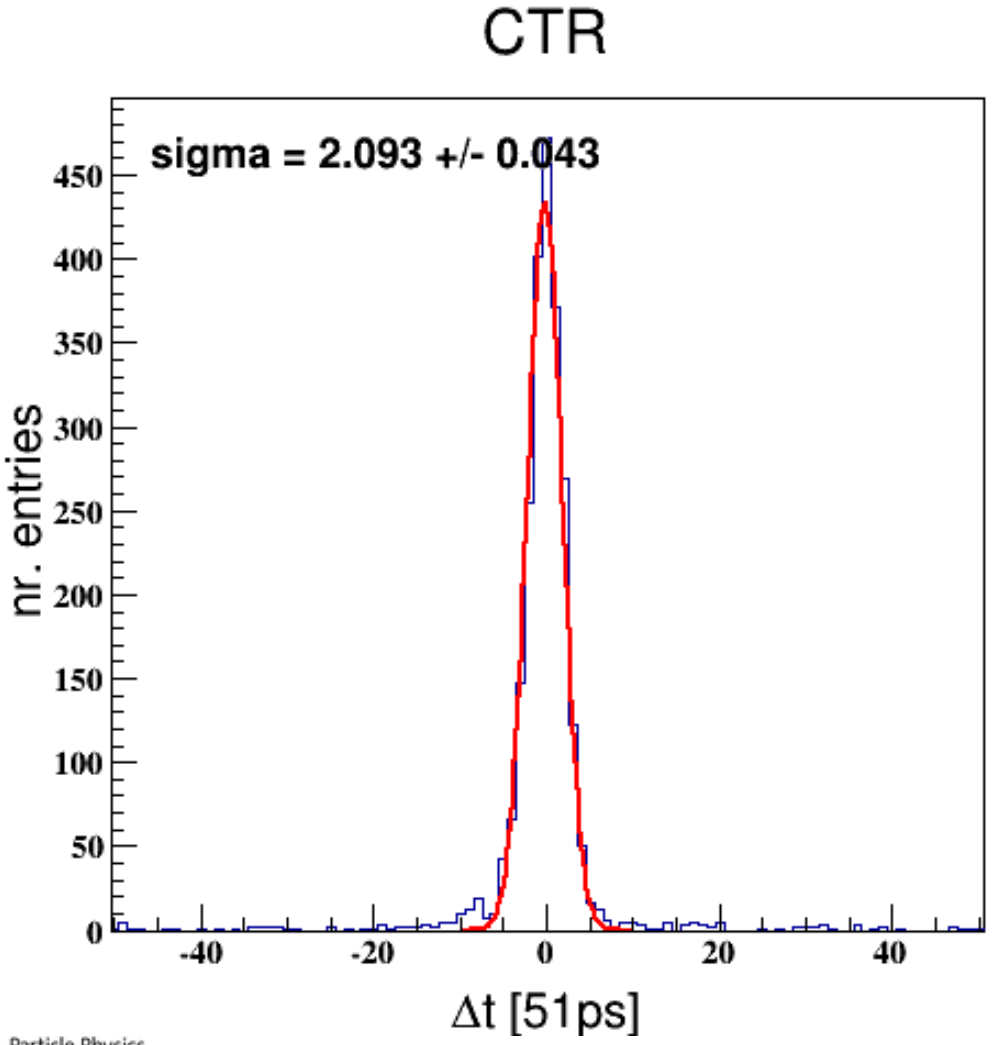
Backup
Image Reconstruction

- Noisy Projections → Reconstruction → Image + Noise
- $y_i = P_{ij} \lambda_j + r_i$
- Analytical (Filtered Back Projection)
  - Tracer distribution in 2D: $f(x, y)$, measure line integrals along γ
  - Ideal Measurement = Radon transform $(Rf)(s, \varphi) = \int_\gamma f(x, y)$
  - Back-project with Central Section Theorem + Fourier transform (CST relates 1D-FT of projection to 2D-FT of distribution)
- Iterative (ML-EM)
  - Maximum-Likelihood Expectation-Maximization
  - Iteratively find image λ_j which would "best" match measurements y_i given a system matrix P_{ij}

Can account for detection efficiencies, scanner geometry, attenuation,…

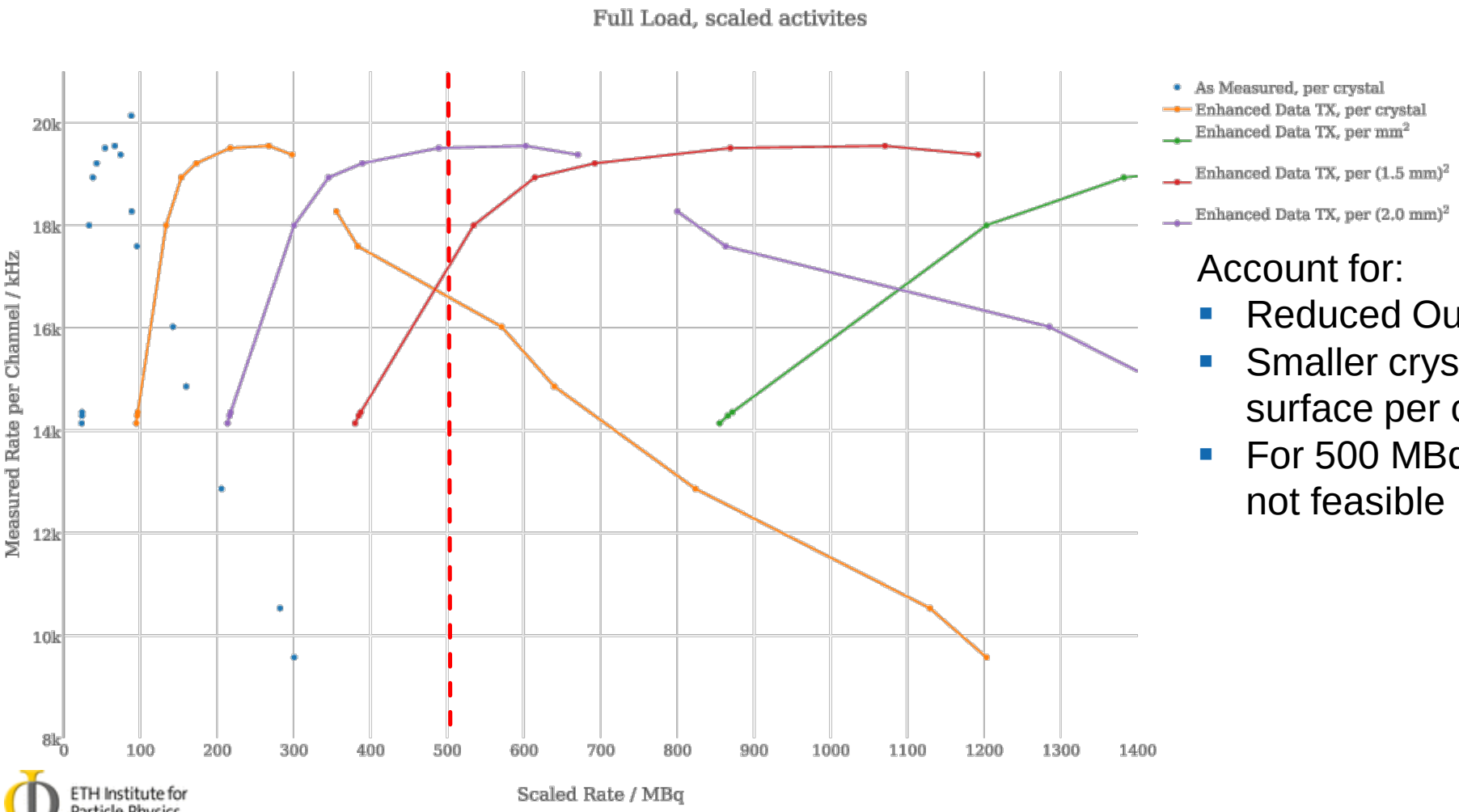


Backup
Timing with STiCv2



- Two LYSO crystals $1.5 \times 1.5 \times 12\ \mathrm{mm}^3$
- Two Hamamatsu SiPM ($3 \times 3\ \mathrm{mm}^2$)
- Connected to STiCv2 ASIC
- Time difference between respective channels with events at photopeak
- CTR(σ) = 2.093 * 51 ps = 106.7 ps
- CTR(FWHM) = 256.0 ps

Backup
TOFPET: Prospective Rate Capability Improved Output Bandwith



Account for:

- Reduced Output Bandwidth (factor 4)
- Smaller crystal size (scales with surface per channel)
- For 500 MBq, larger than $(1.5mm)^2$ not feasible