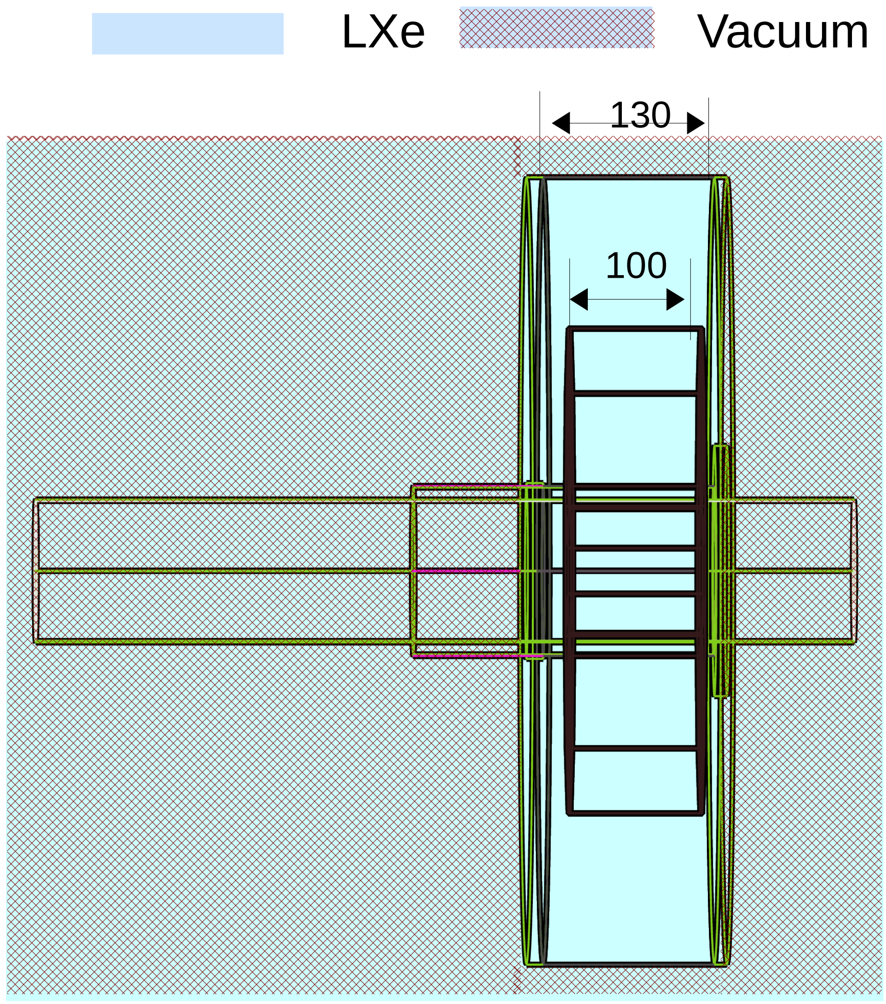
LXe micro-PET performance

Alice Miceli

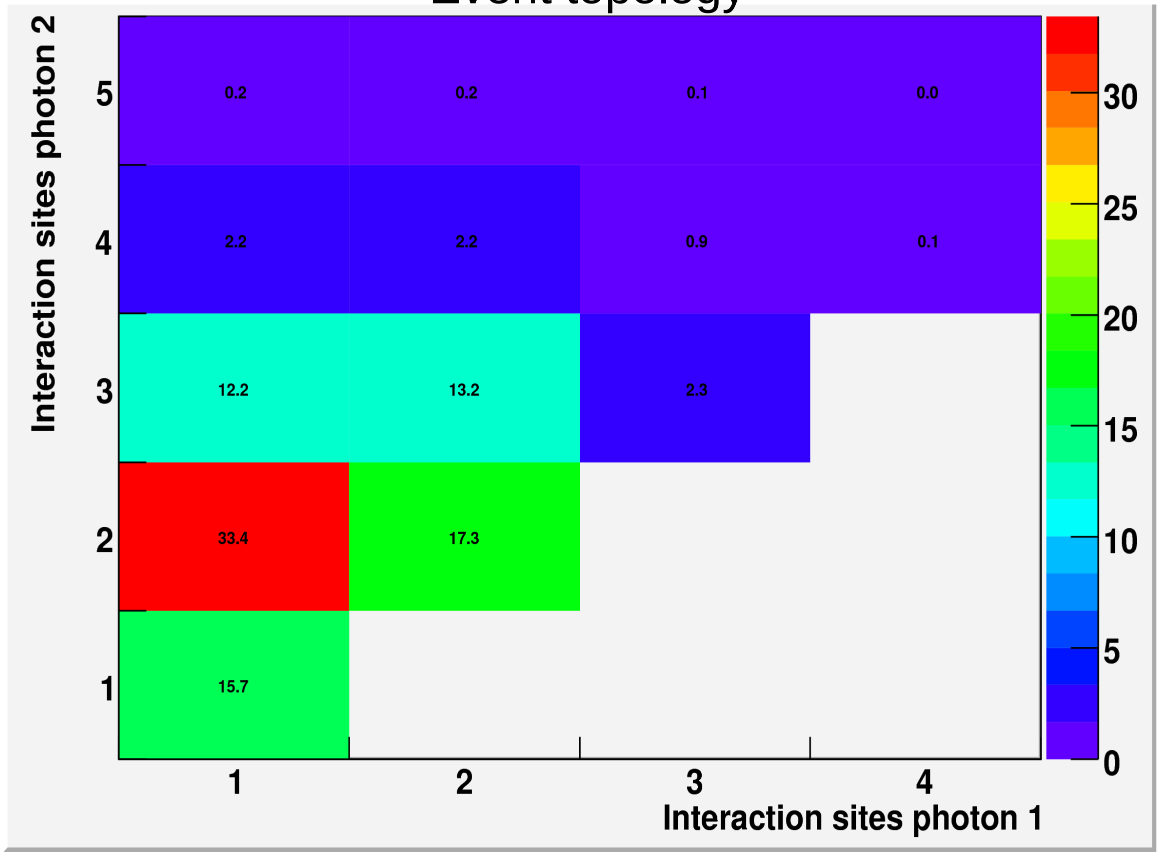
Simulation of LXe micro-PET

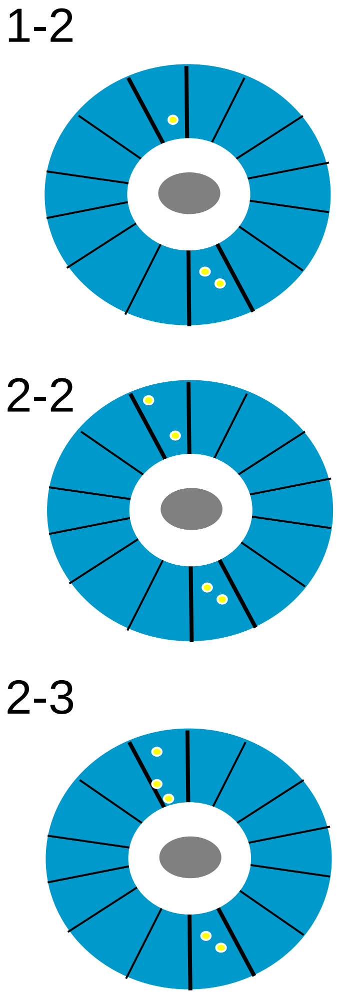
- **Geant4 simulation** of radioactive source, positron decay, annihilation, and photon interactions with LXe detector PET ring
  - Positron range included
  - Non-collinearity included
  - Dead space between sectors included
- **Parameterization of detector response**
  - Info from measurements with test chamber
    - Electron-ion recombination
    - APD: quantum efficiency, electronic noise, fluctuation of APD gain
    - TPC: two hit separation distance, charge detection threshold, electronic noise, position resolution
- **Event selection**
  - Scintillation light photons > 5500
  - Energy window: 450 ~600 keV
- **Event reconstruction**



Event reconstruction

Event topology





Find the first interaction points to correctly determine the line of response

Event reconstruction

Compton reconstruction algorithm

For each possible interaction sequence

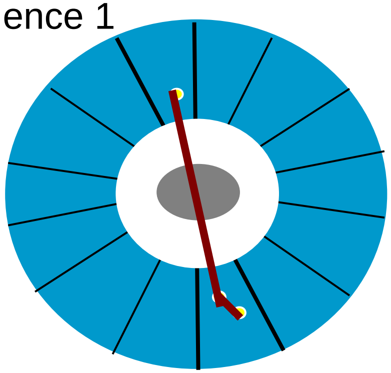
- Check if:
  - the line of response passes through the phantom
  - The sequence is energetically possible

- Calculate the scattering angles at every interaction point
  - From energy
  - From geometry

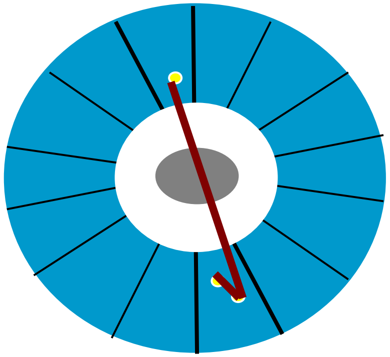
- Sum the differences of the scatter angles quadratically (χ^2)

- Select the sequence with lowest χ^2

Sequence 1



Sequence 2

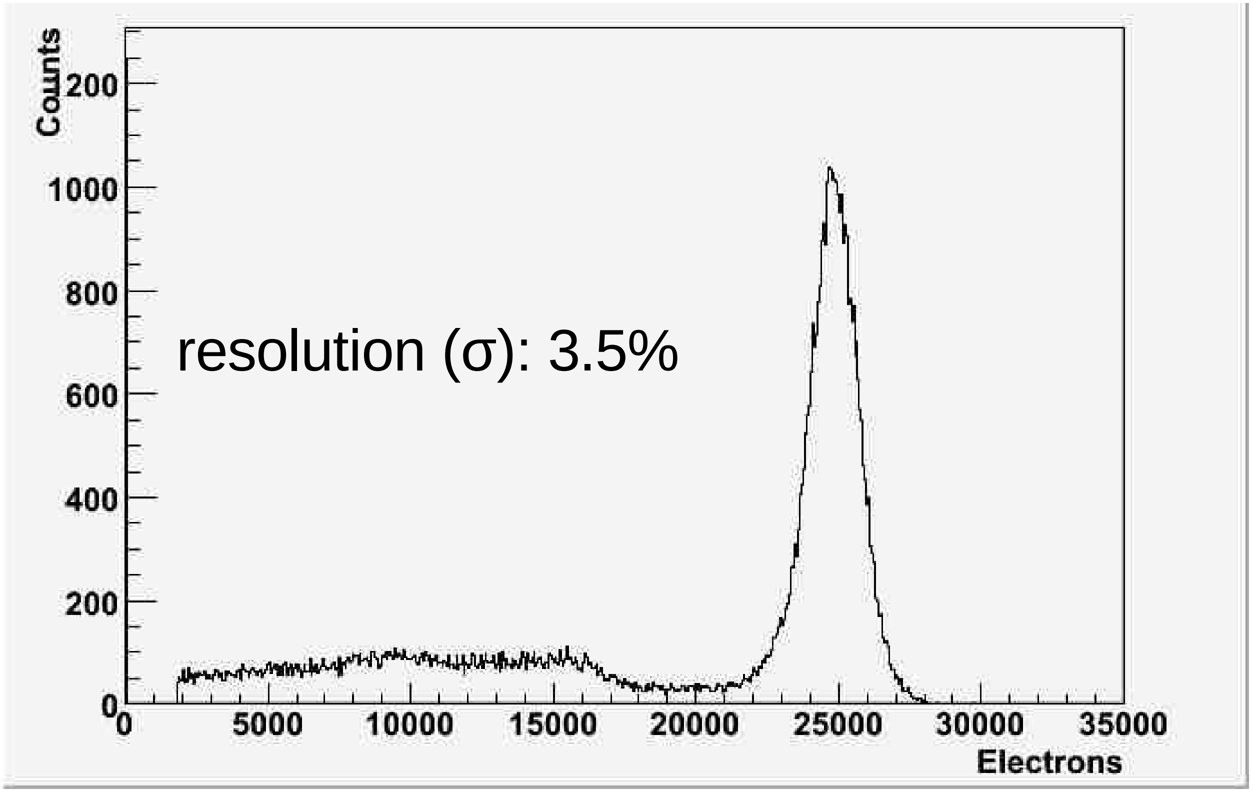


Aprile et al. Nucl.Instrum.Meth.A, 2008

LXe micro-PET performance

- Energy resolution at 511 keV

Energy spectrum (**charge**) of a F18 point source (drift field of 2.66 kV/cm)



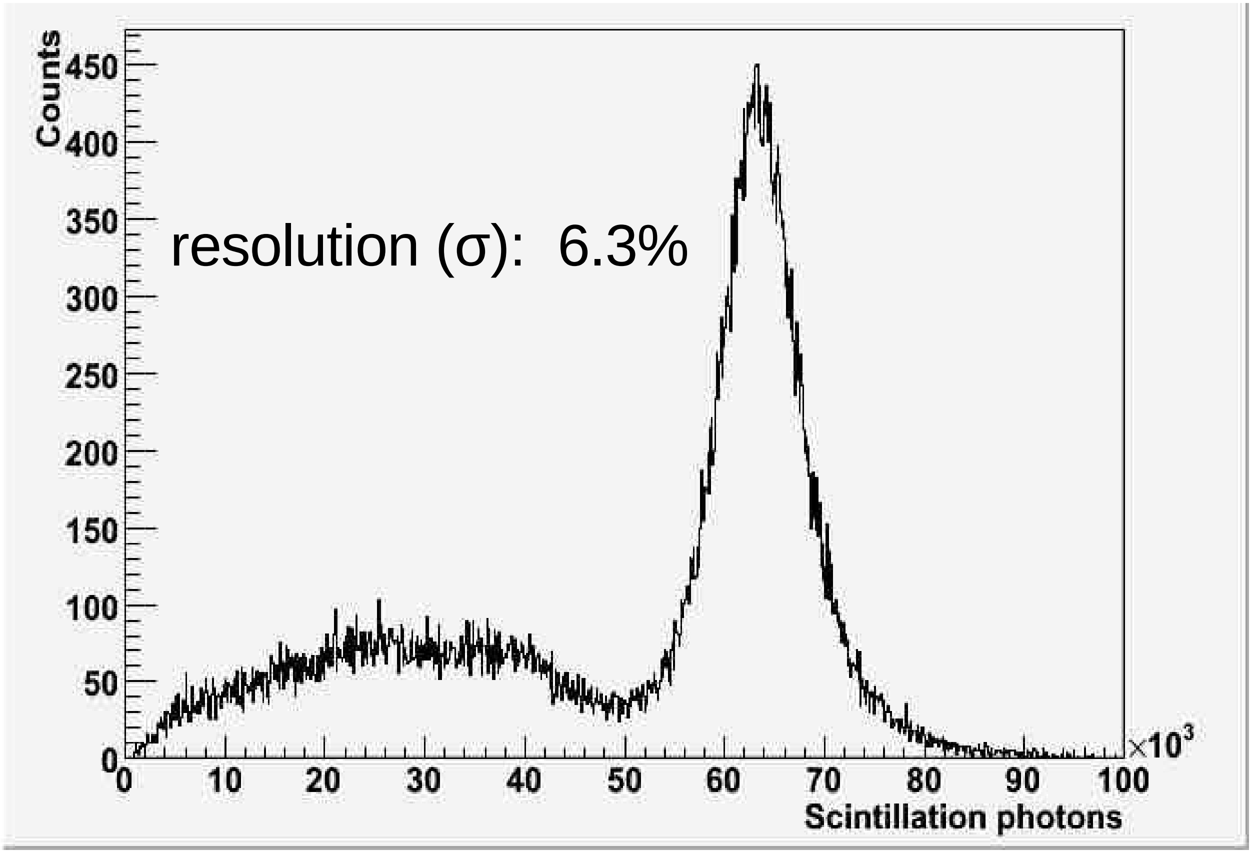
<u>Effects included in the simulation</u>

- Positron range
- Non-colinearity
- Dead space between sectors
- Dead material in cryostat
- Electron-ion recombination
- APD: quantum efficiency, electronic noise, fluctuation of APD gain
- TPC: two hit separation distance, charge detection threshold, electronic noise, position resolution

LXe micro-PET performance

• Energy resolution at 511 keV

Energy spectrum (**light**) of a F18 point source
(drift field of 2.66 kV/cm)



<u>Effects included in the simulation</u>

- Positron range
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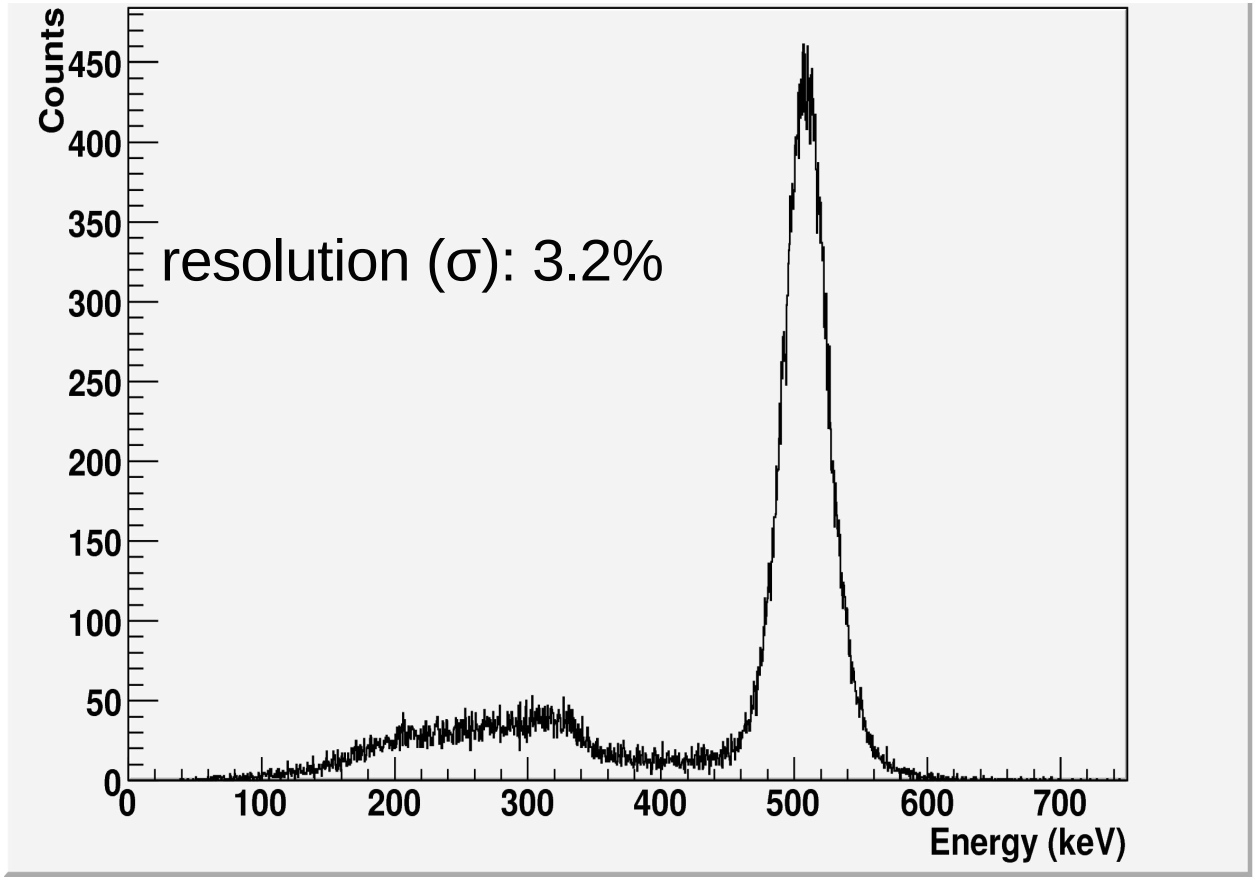
LXe micro-PET performance

- Energy resolution at 511 keV

Energy spectrum (**combined**) of a F18 point source (drift field of 2.66 kV/cm)



<u>Effects included in the simulation</u>

- Positron range
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- APD: quantum efficiency, electronic noise, fluctuation of APD gain
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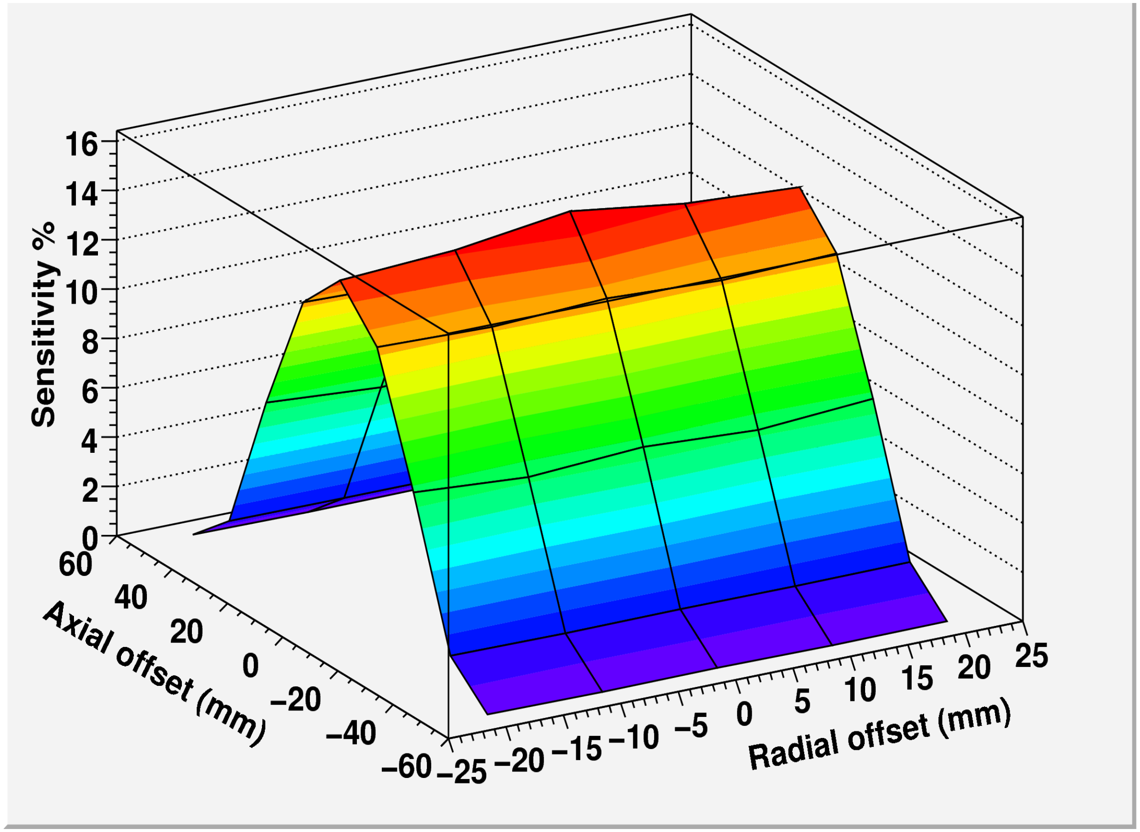
LXe micro-PET performance

- Energy resolution at 511 keV

- Sensitivity

Sensitivity profile simulated using a F18 point source with an energy window of 450~600 keV



Sensitivity at the center of the field of view: 14.9%

Effects included in the simulation

- Positron range
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- Electron-ion recombination
- APD: quantum efficiency, electronic noise, fluctuation of APD gain
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LXe micro-PET performance

- Energy resolution at 511 keV
- Sensitivity
- Image quality (preliminary study)

Effects included in the simulation

- Positron range
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- Dead space between sectors
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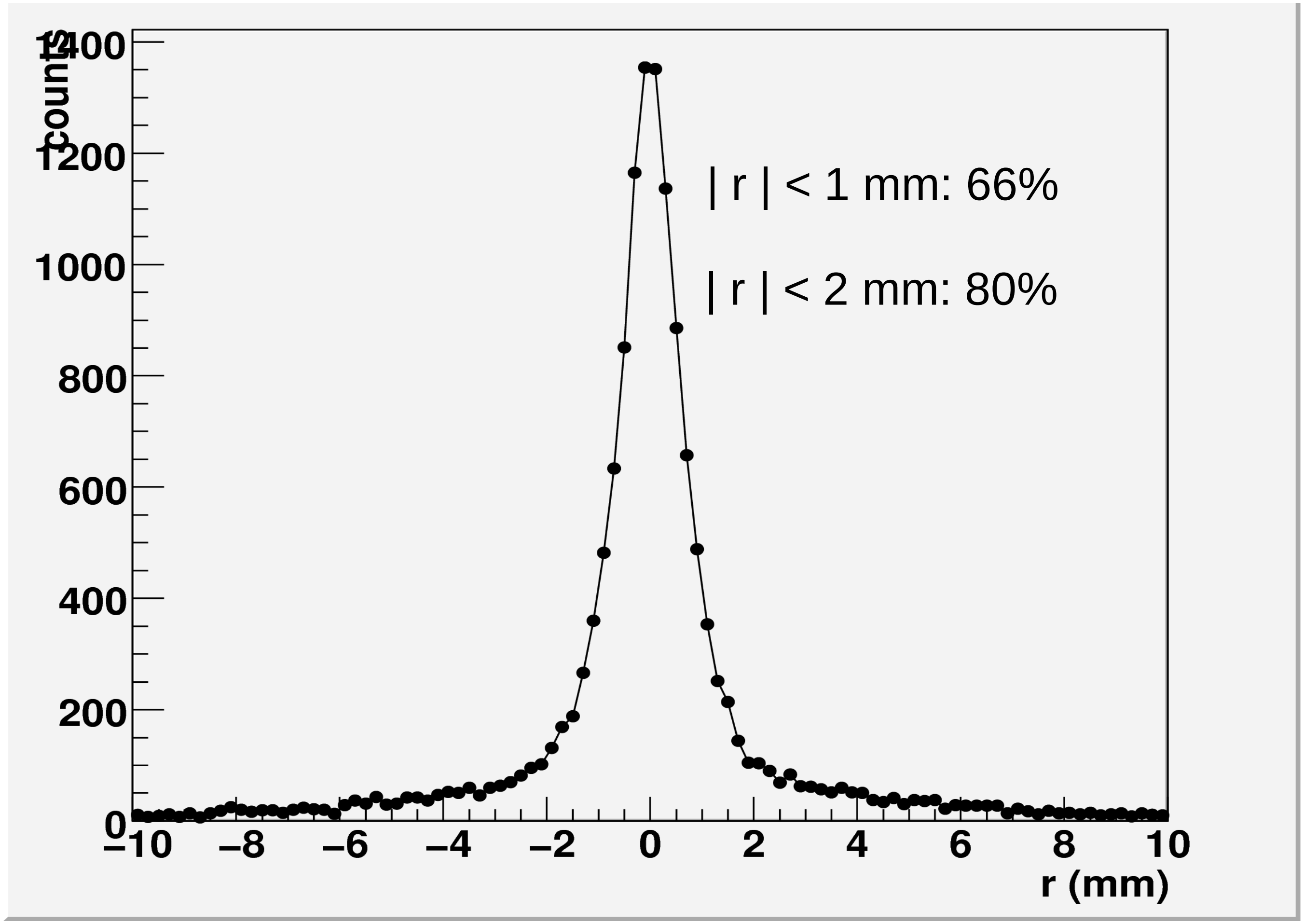
Radial sinogram profile of a F18 point source in the center of the field of view



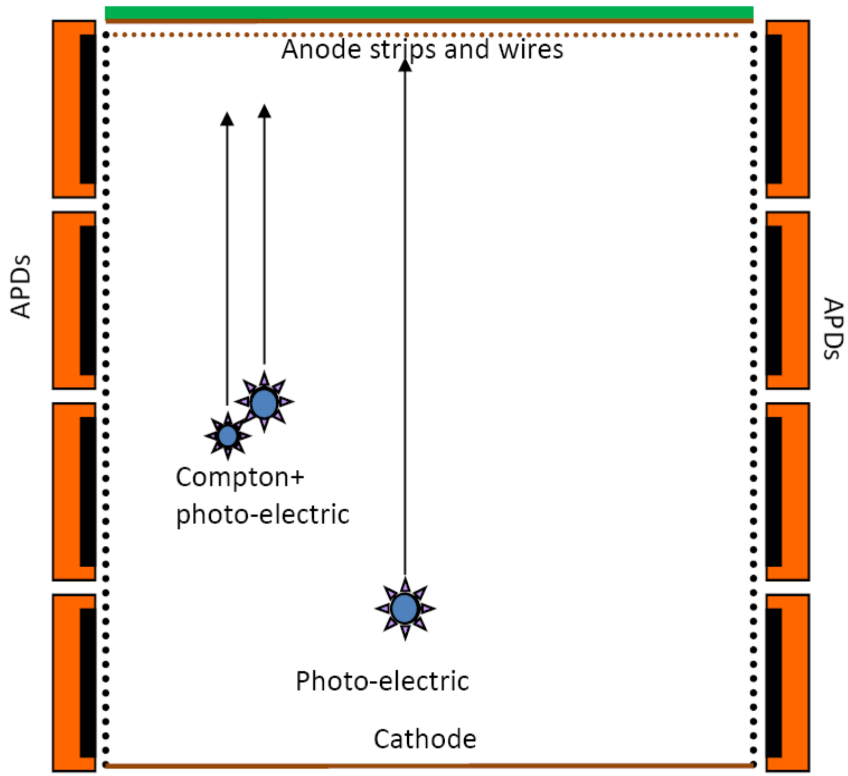
High rate capability

Astrid Muennich

Dealing with high rates

Limit event pile up at high rates:

- Use fast light signal to pinpoint location of energy deposit to define region of interest (goal within 1~ml).
- Match light with corresponding slow charge signal.
- Benefit: Only region of interest is blind to next event occurring while charge from first event is still drifting.



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Neural Networks (NN)

The Challenge

- input: 48 APD signals
- looking for 3D position
- multiple interactions producing light

The Solution

- Neural Network
- 48 inputs, 3 outputs, one hidden layer with 160 neurons
- implemented in ROOT/C++

The Idea

Train NN on solid angle calculation as opposed to realistic Geant4 simulated data
Why?
Much faster (~min.) and better coverage of chamber possible compared to generating Geant4 data (~weeks)

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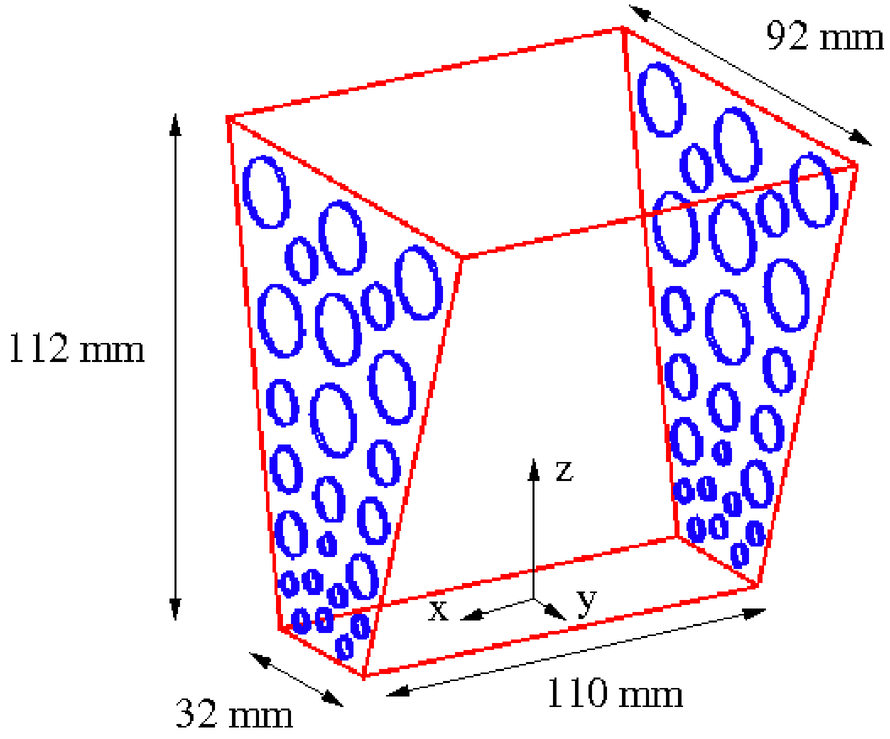
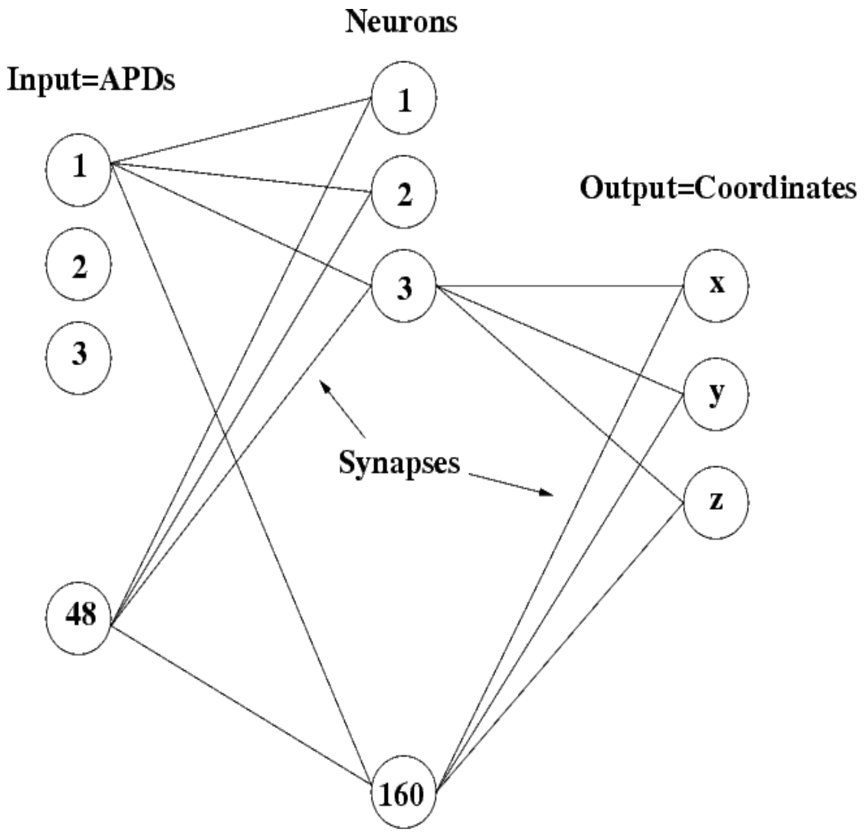
Geometry

APD Setup



Neural Network Structure



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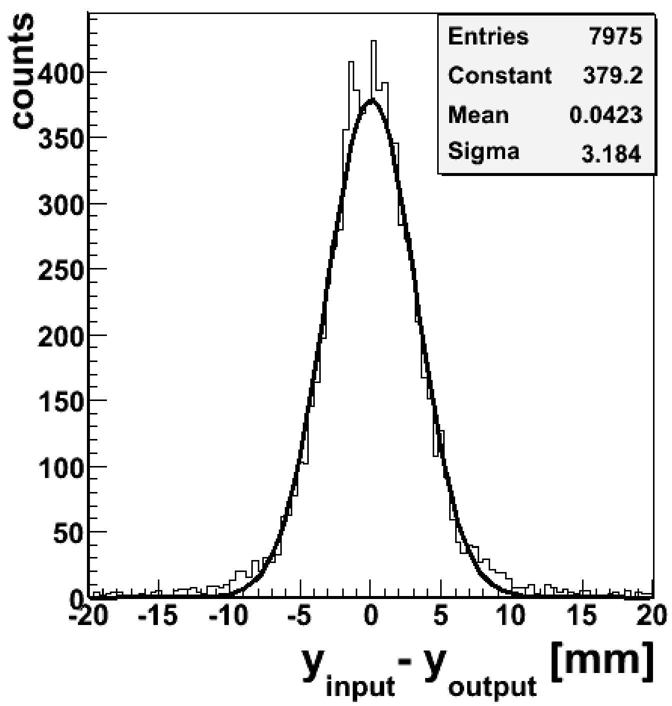
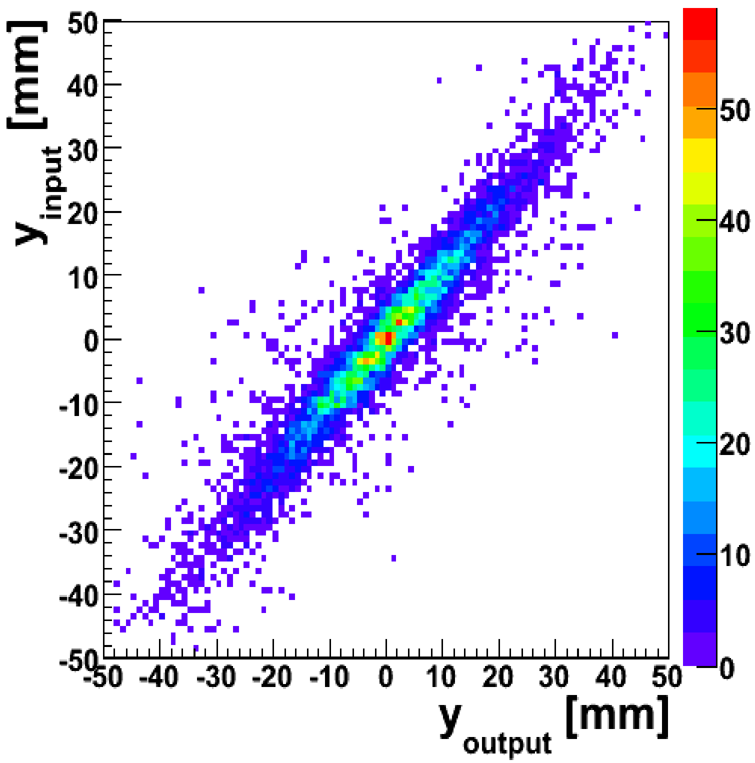
Performance of Neural Network

Although training data for NN does not include any fluctuations or multiple interactions the capability to reconstruct the center of gravity for the light emission works surprisingly well





Volume in which interaction can be found: ~1ml depending on noise

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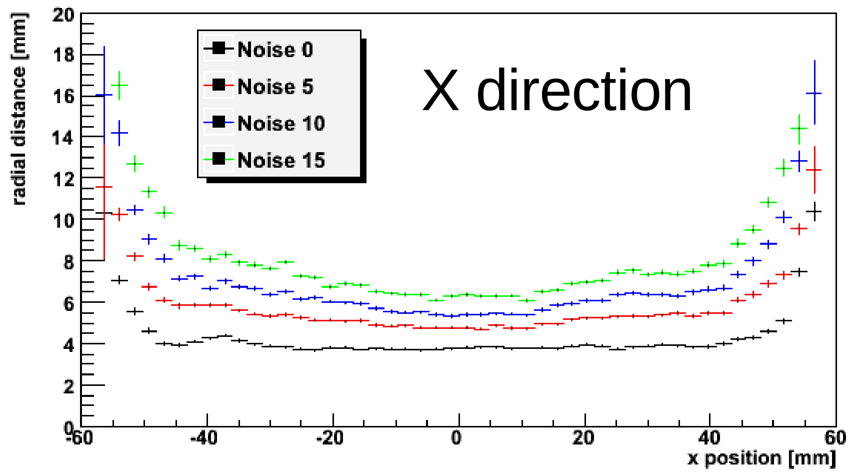
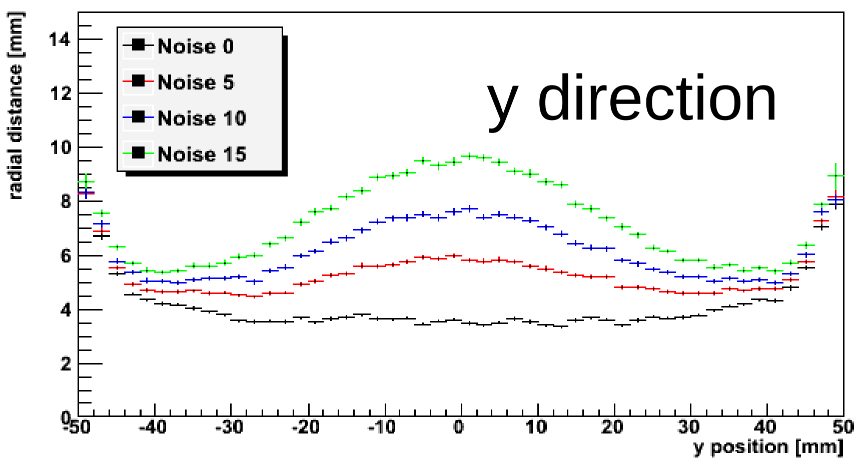
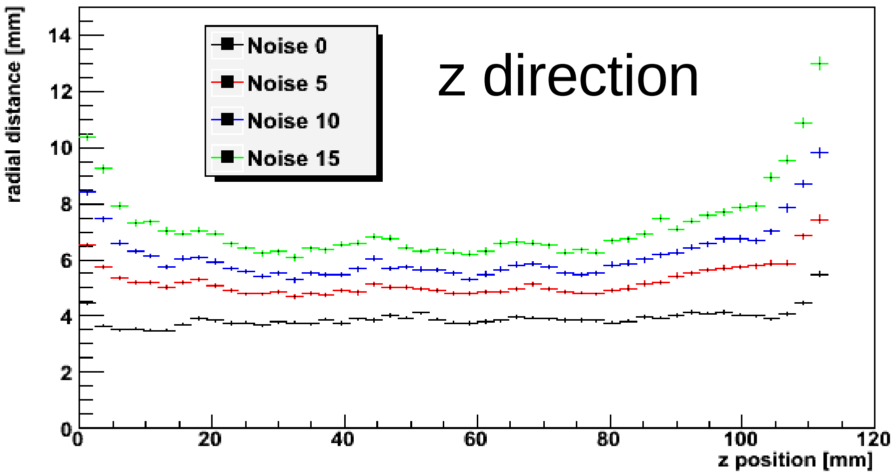
Noise Effect on NN







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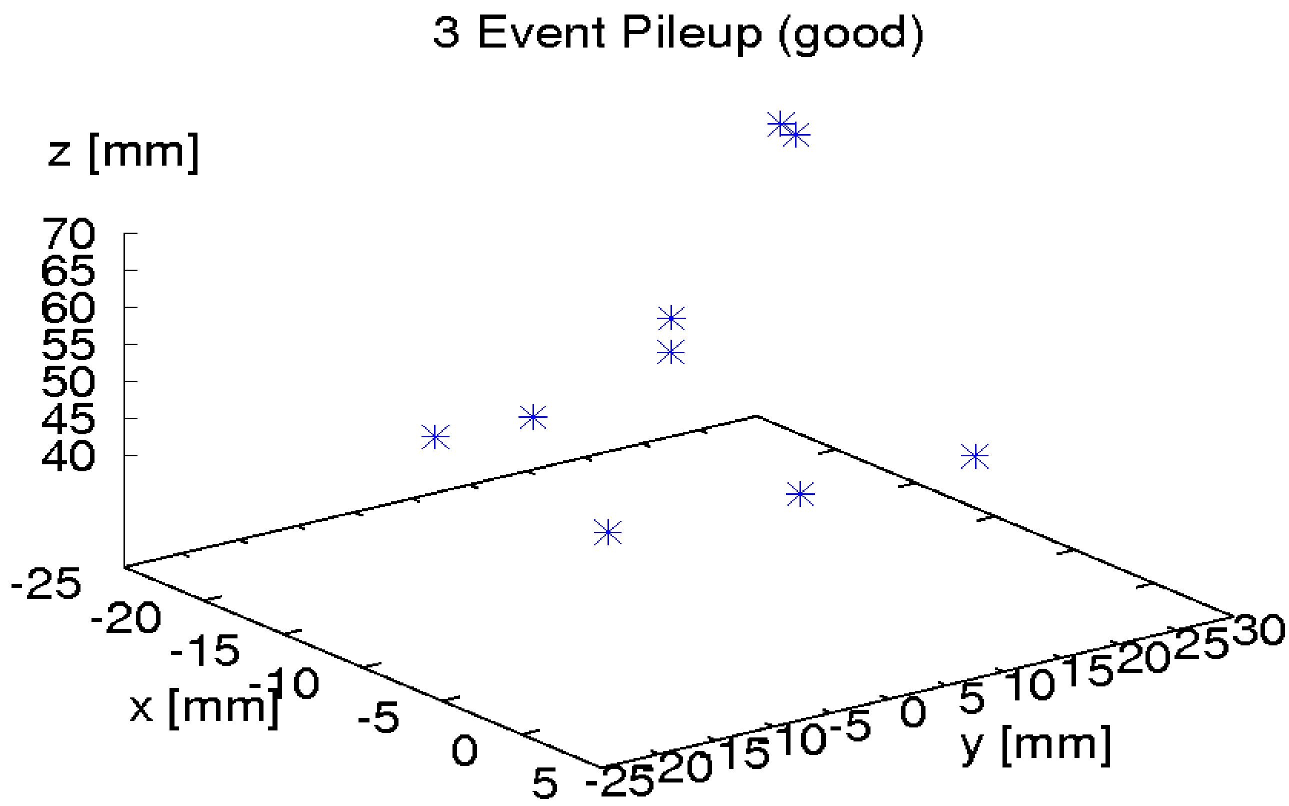
Using NN to entangle Pileup Events

Light-charge matching at high rate



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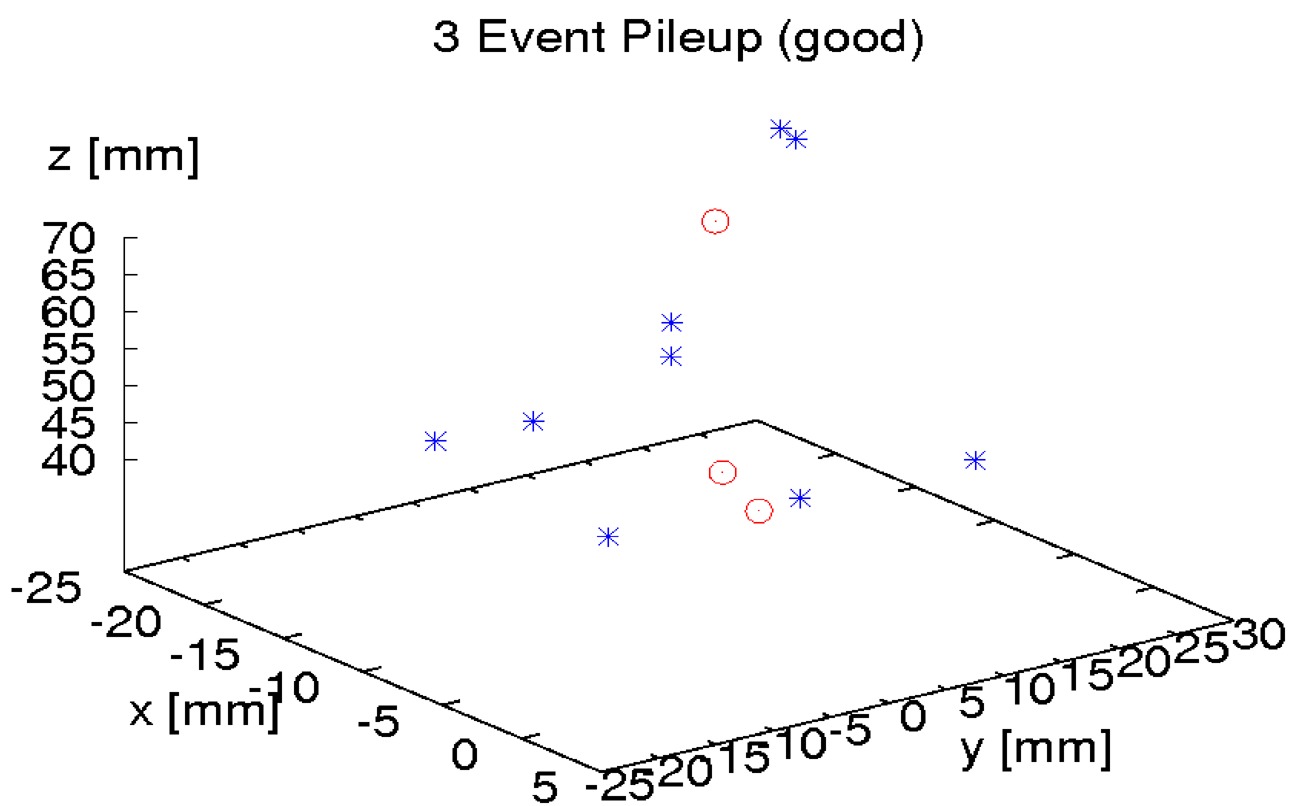
Using NN to entangle Pileup Events

Light-charge matching at high rate



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Using NN to entangle Pileup Events

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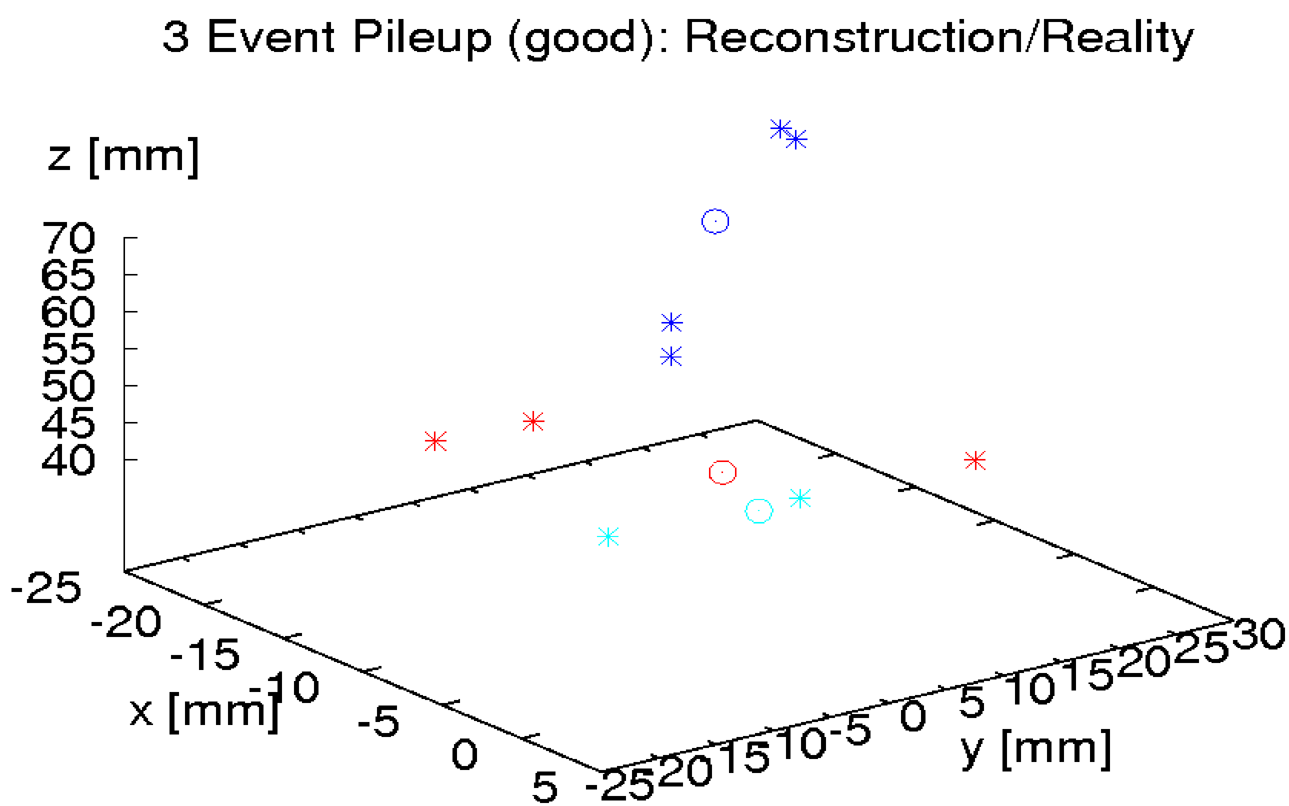

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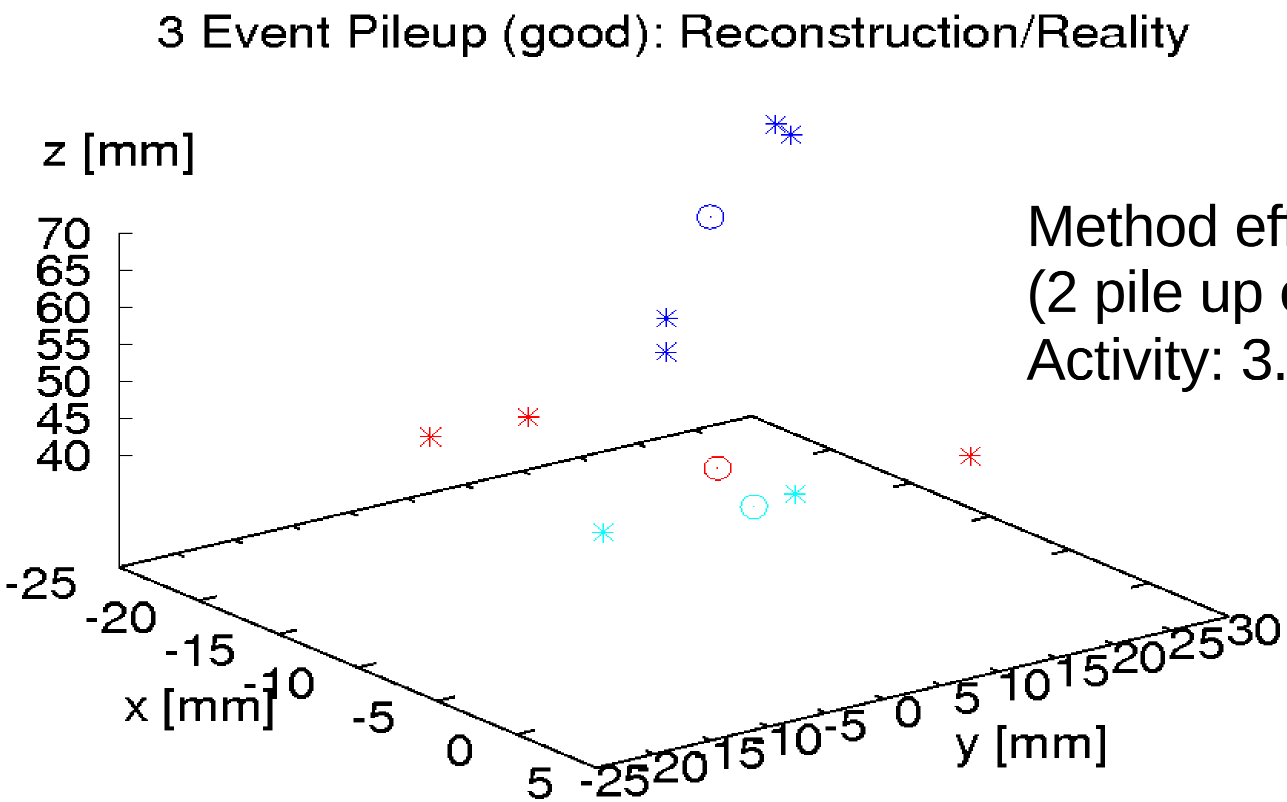
Using NN to entangle Pileup Events

Light-charge matching at high rate



Method efficiency = 99%
(2 pile up events,
Activity: $3.7*10^7$ Bq)

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Conclusions

- Compton scattering reconstruction: first interaction points
- LXe micro-PET simulated performance:
  energy resolution 3.2%, sensitivity 14.9%
- Neural networks handle noise signals
- Neural networks as a solution to match light with corresponding charge signal at high rate