Timepix3 Single-layer Compton Camera: Progress Update (November 2020)

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On the menu today

- Reminder of the working principle.

- Results of recent data analysis:
  - ^{192}Ir – a Allpix^2 simulation,
  - ^{192}Ir – measurement, July 2020,
  - ^{57}Co – measurement, October 2020.

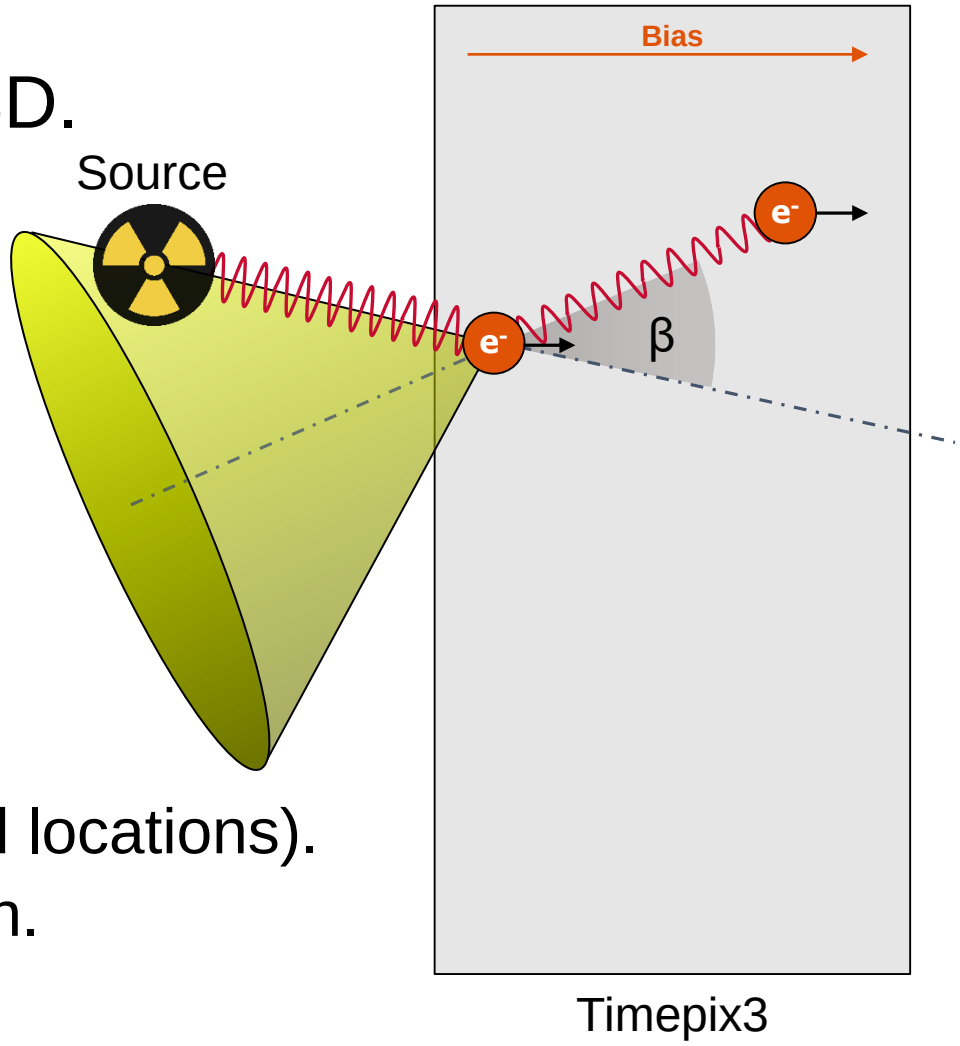
- A small experiment involving various uncertainties.

Working principle

- We want to localize a γ-ray source in 3D.
- Procedure:
  1. Look for coincident cluster pairs (< 4px).
  2. Estimate scattering angle β from E via:

$$\cos\beta = 1 - m_e c^2 \left(\frac{1}{E'_\gamma} - \frac{1}{E_\gamma} \right)$$

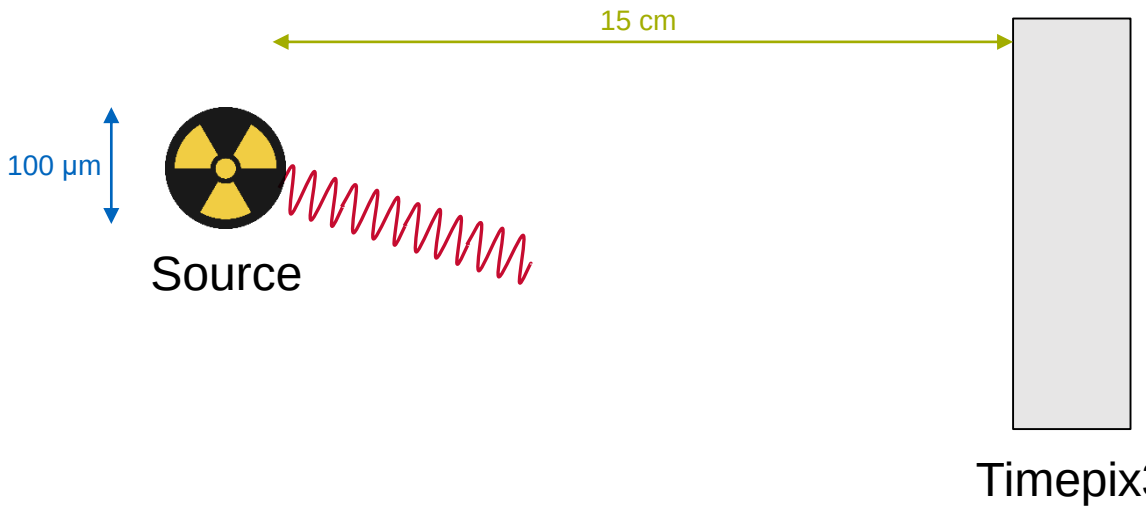
  3. Estimate e^- locations as:
     - [X;Y] from cluster centroids,
     - Z from ΔToA depth reconstruction.
  4. Project multiple cones (defined by β and locations).
  5. Source of γ-rays lies at cone intersection.



^{192}Ir Simulation

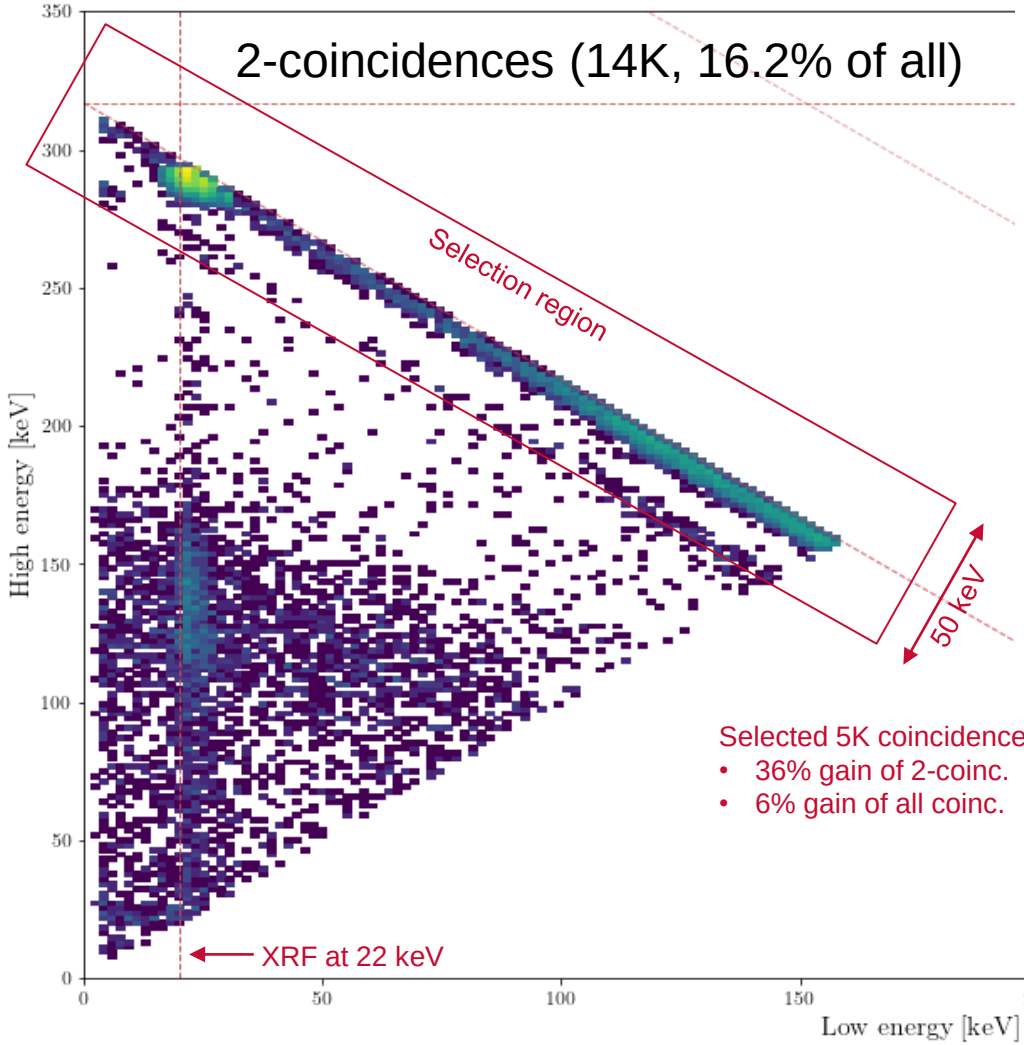
(simulation courtesy of Petr Smolyanskiy)

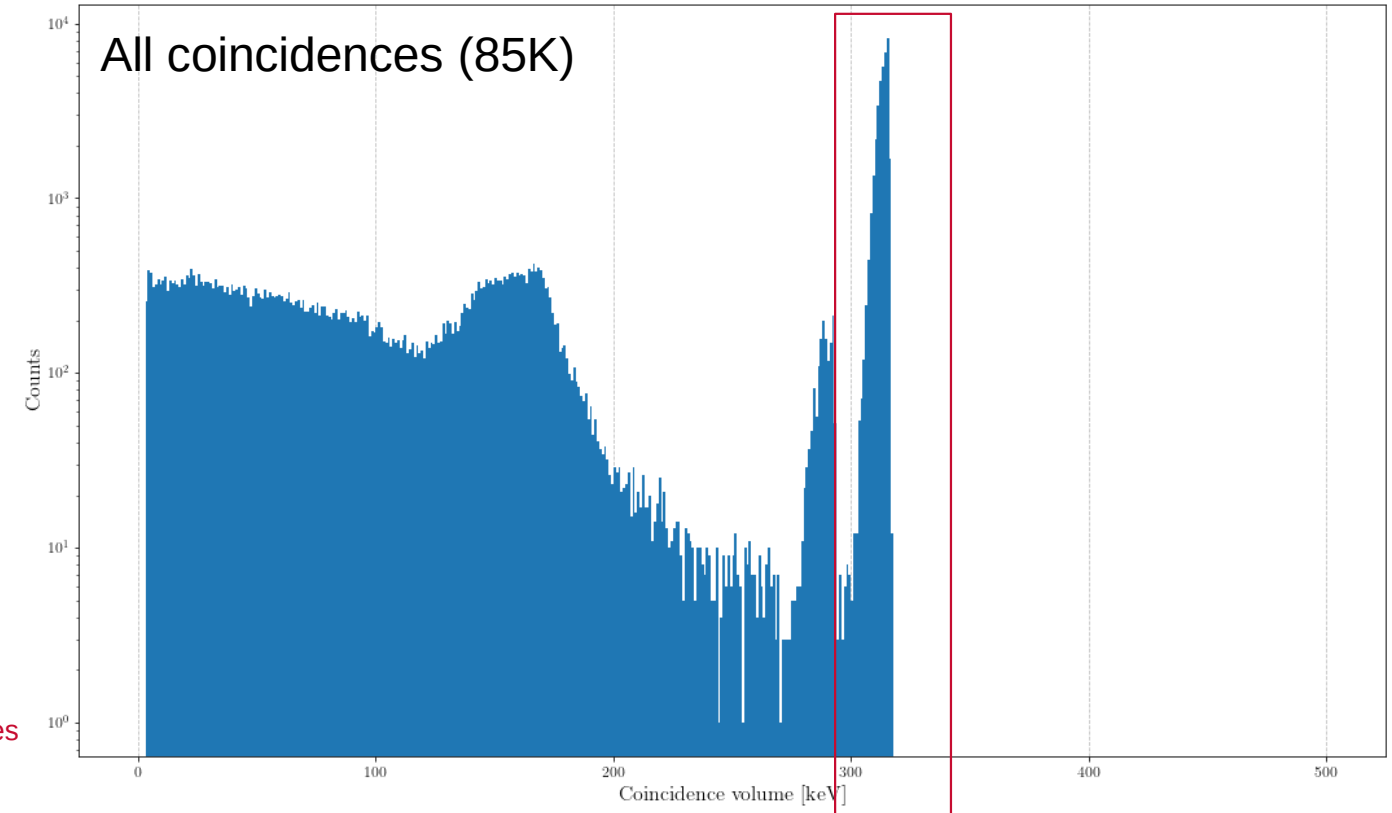
- Simulated 85K events using Allpix^2, Geant4.
- Parameters:
  - Single point source, gaussian profile with 100 µm width.
  - Placed 15 cm in front of Timepix3 (CdTe, 1 mm thick).
  - Not true ^{192}Ir spectrum, only a single line (316 keV).



^{192}Ir Simulation: spectrum

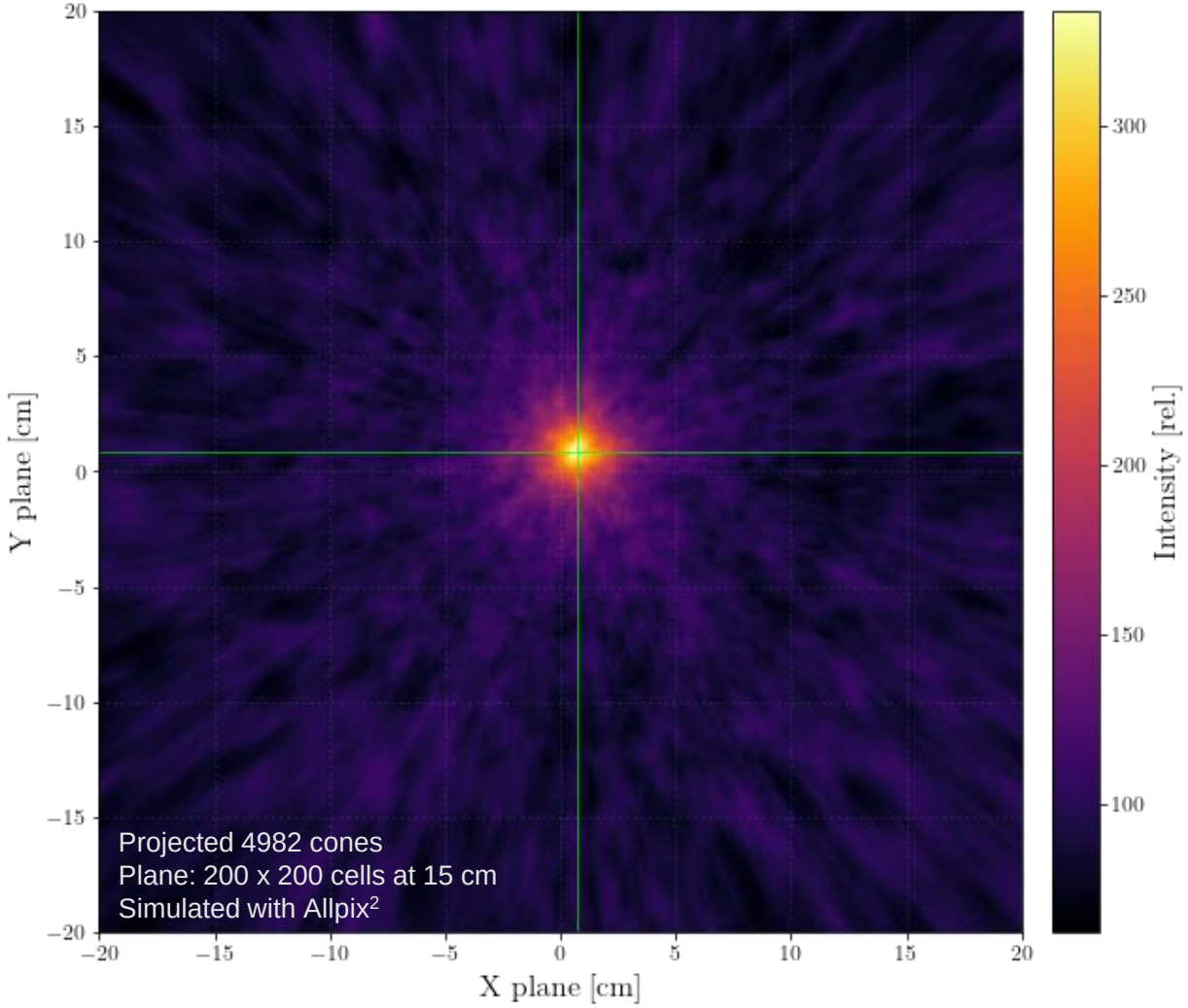
(simulation courtesy of Petr Smolyanskiy)



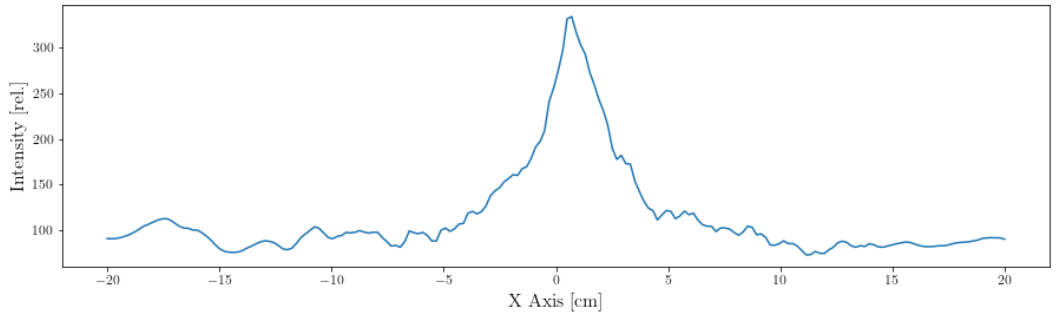


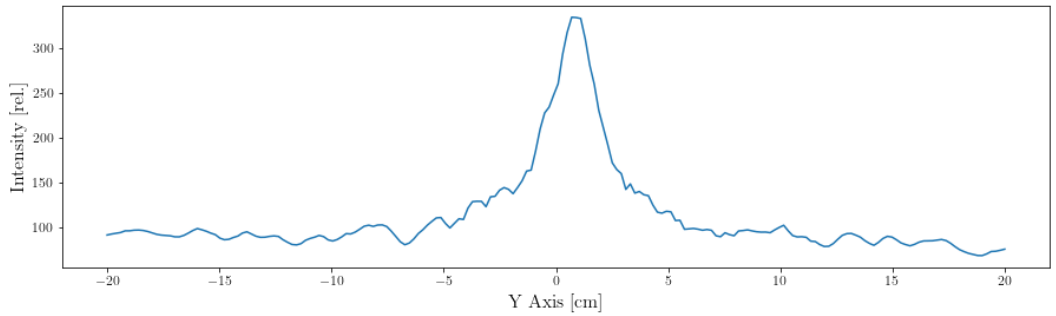
^{192}Ir Simulation: projection

(simulation courtesy of Petr Smolyanskiy)



- Localized response at the expected location.
- SNR ≈ 3:1
- $E_{abs.}$ = [0.55; 1.10] mm (at 15cm)

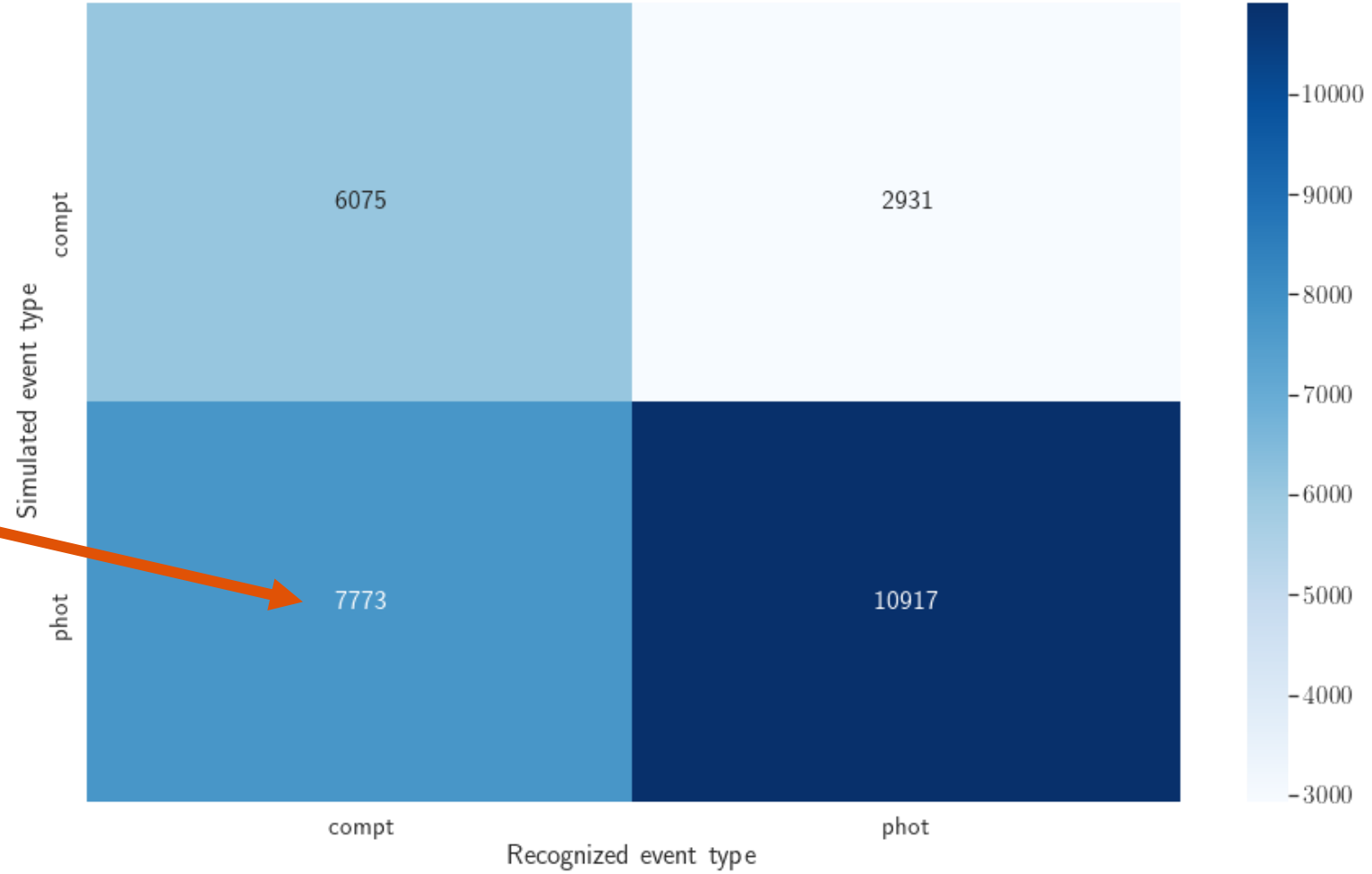




^{192}Ir Simulation: improvement?

(simulation courtesy of Petr Smolyanskiy)

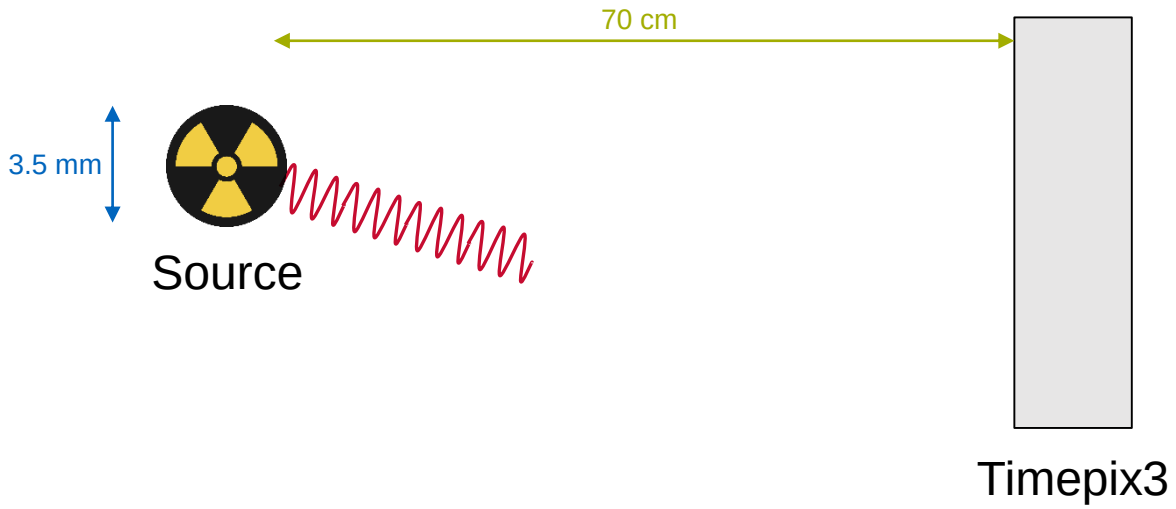
Absorption clusters falsely labeled as scattering clusters.



^{192}Ir Measurement

(performed in collaboration with Petr Smolyanskiy, Anna Odložilíková, MOU)

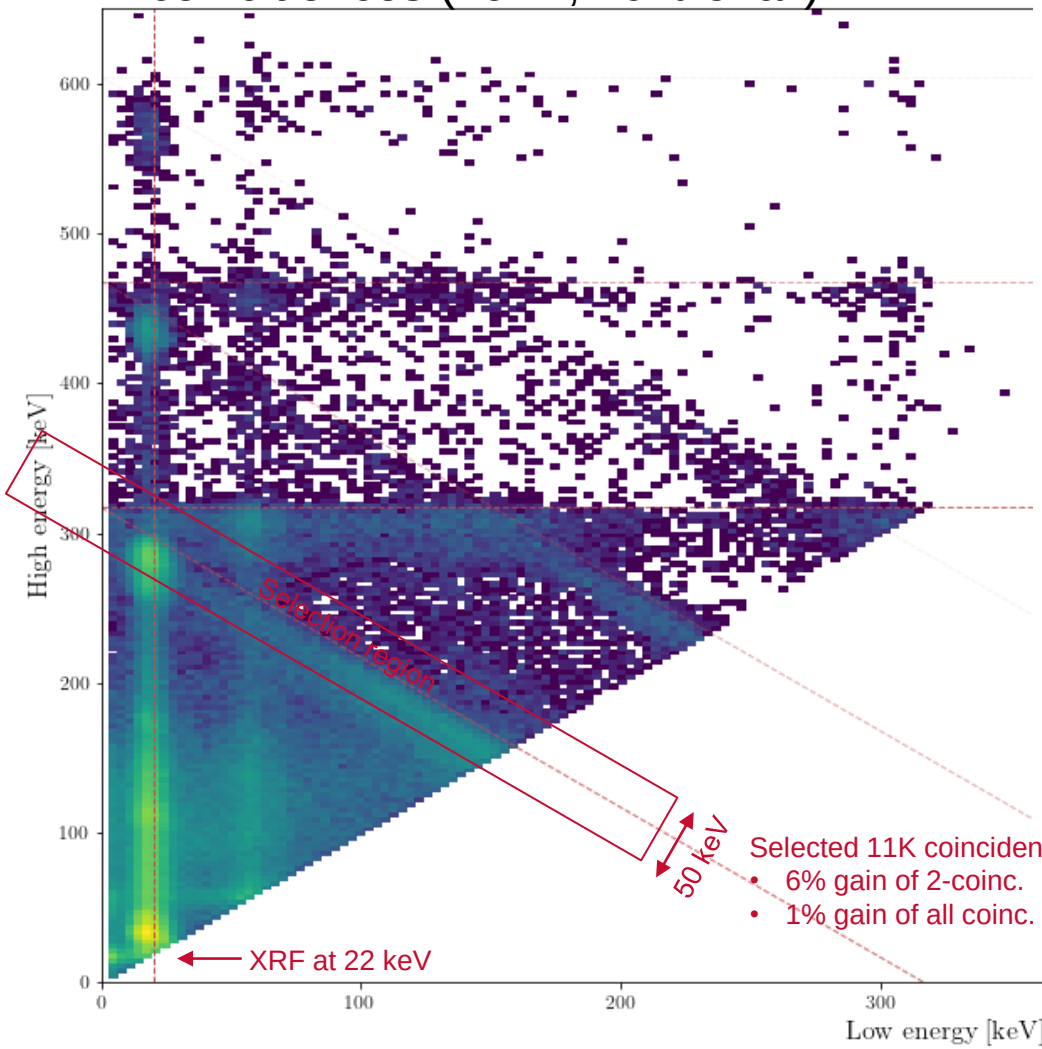
- Processed 1M events measured at BRT (Brno) in July 2020.
- Parameters:
  - Single point source, activity 140 GBq, pellet with 3.5 mm width.
  - Placed 70 cm in front of Timepix3 (CdTe, 1 mm thick).
  - Only a selected subset of data, have more files available.



^{192}Ir Measurement: spectrum

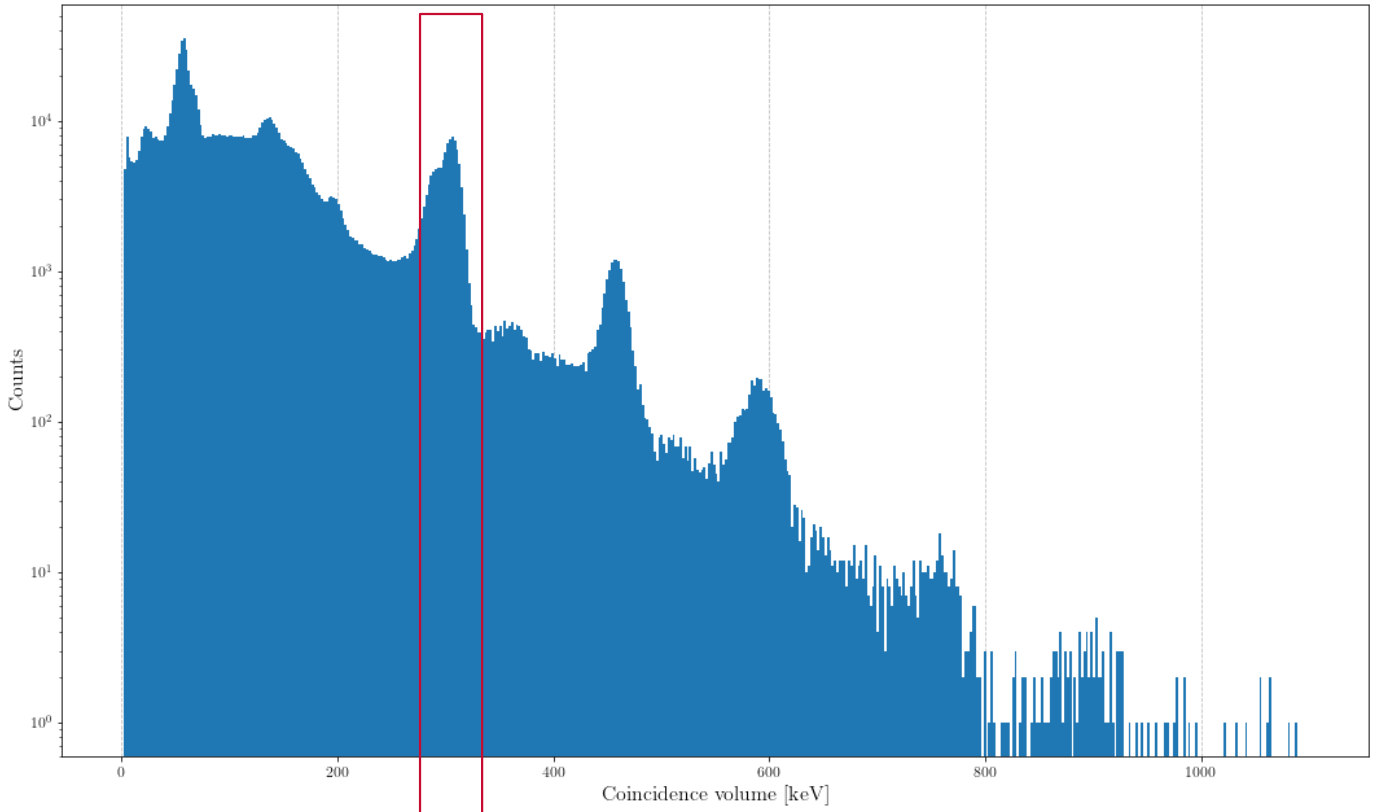
(performed in collaboration with Petr Smolyanskiy, Anna Odložilíková, MOU)

2-coincidences (197K, 20% of all)



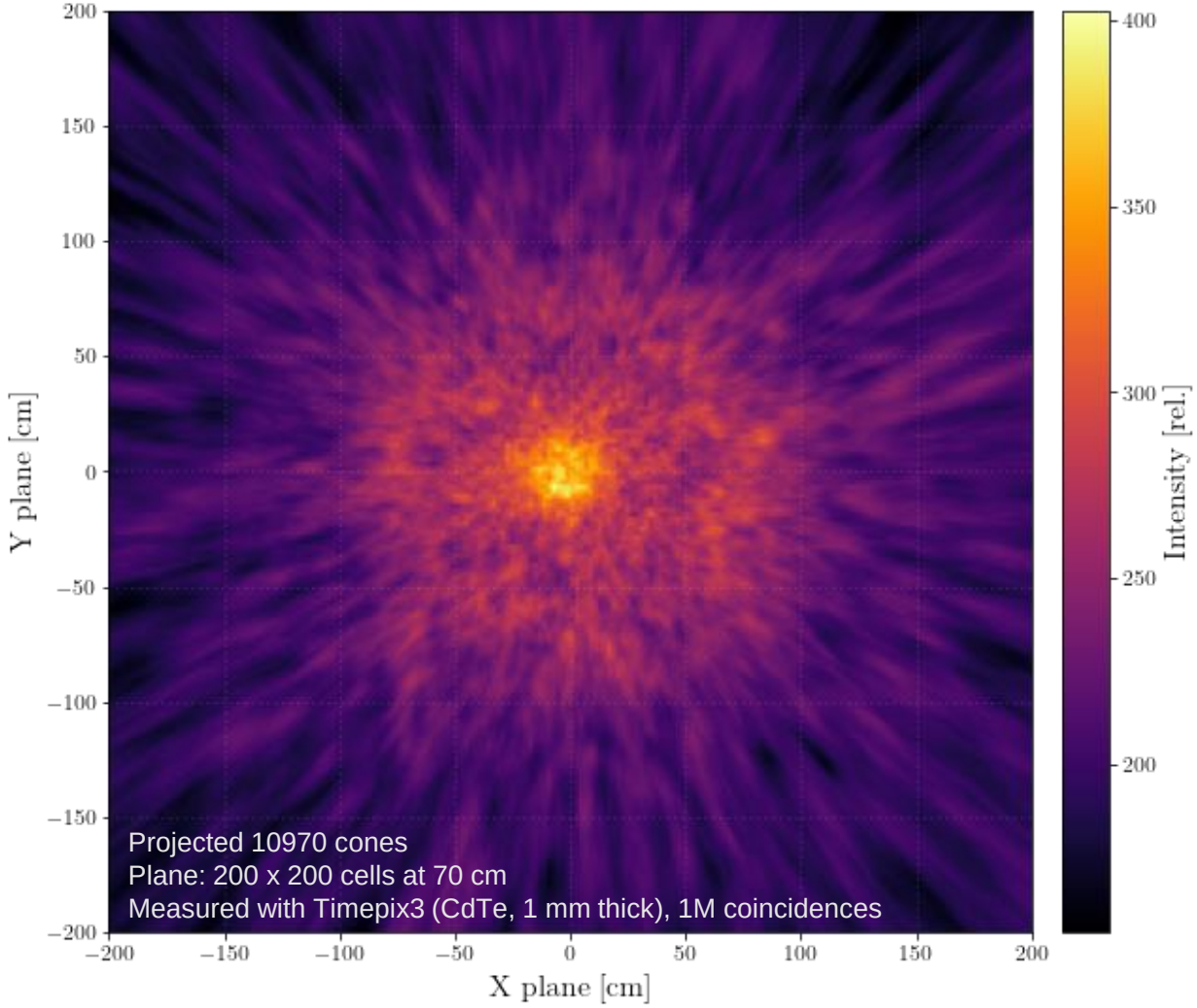
Selected 11K coincidences
- 6% gain of 2-coinc.
- 1% gain of all coinc.

All coincidences (1M)

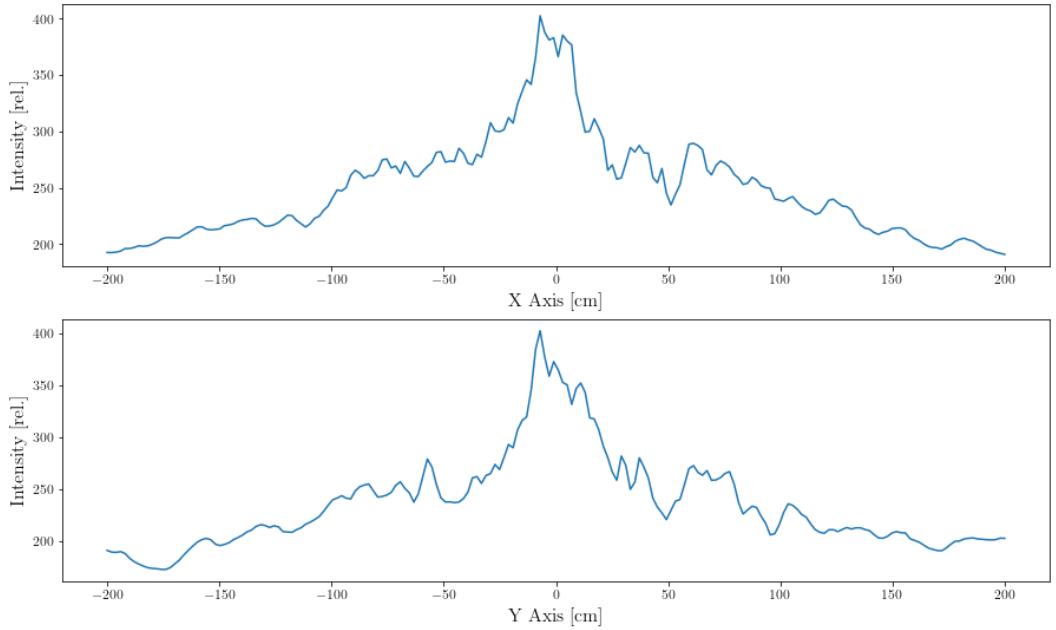


^{192}Ir Measurement: projection

(performed in collaboration with Petr Smolyanskiy, Anna Odložilíková, MOU)



- (Less) localized response around the origin, lower contrast.
- SNR ≈ 2:1

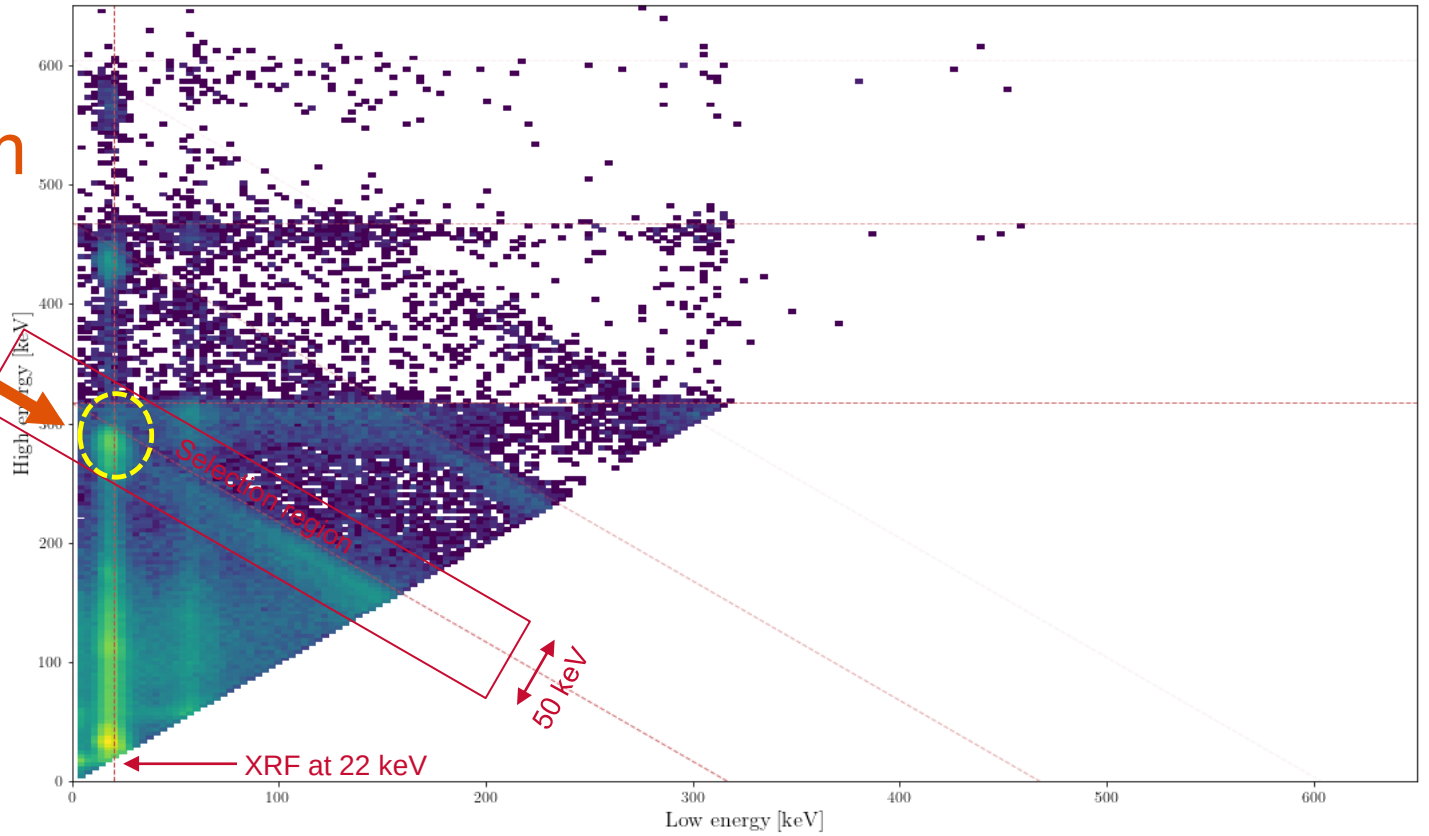


^{192}Ir Measurement: projection

(performed in collaboration with Petr Smolyanskiy, Anna Odložilíková, MOU)

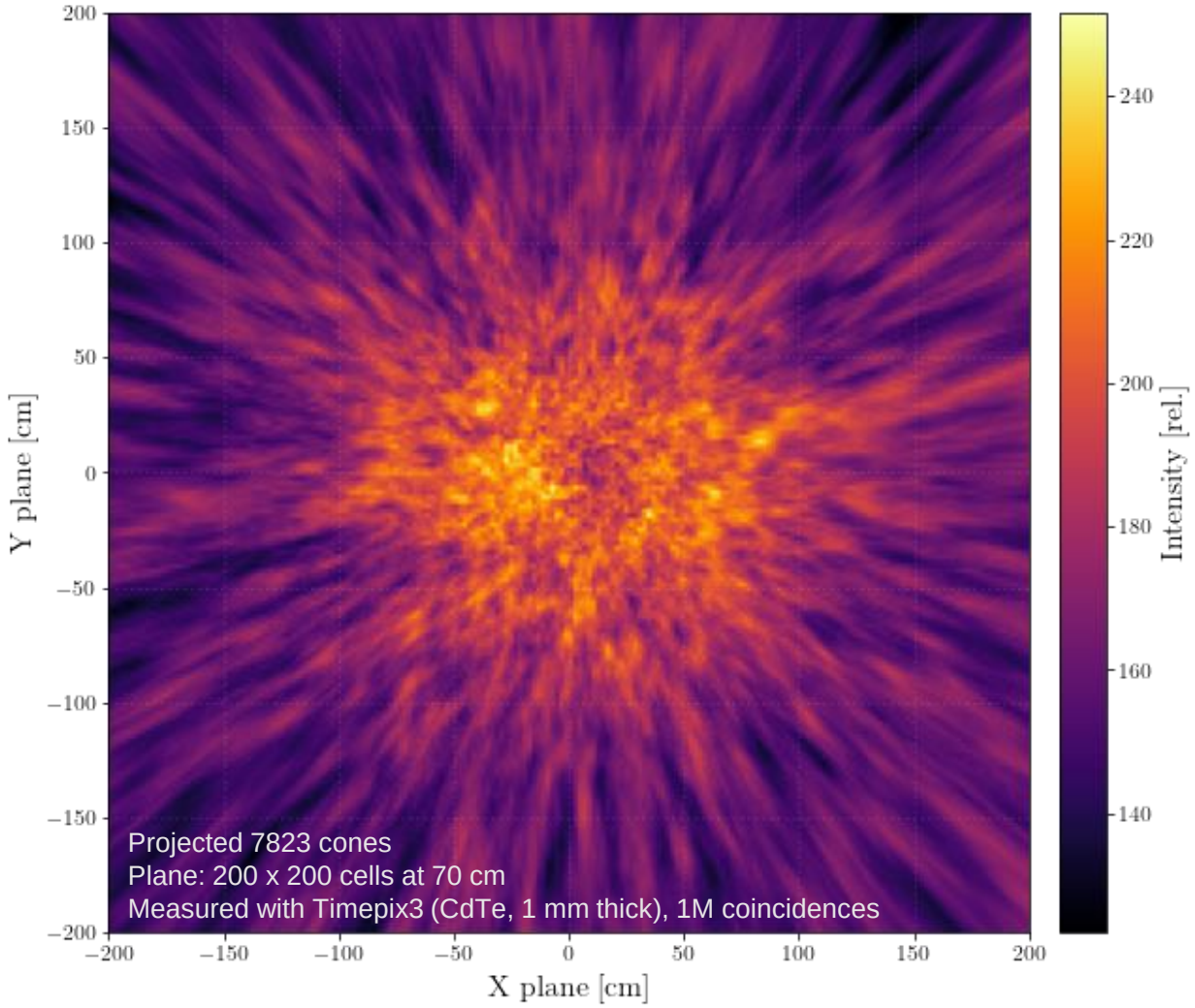
…but if we examine cones that contribute to the desirable (central) part of the response, we discover a problem:

- Low β cones come from this region:
- XRF (22 keV) overlaps with scattering events and causes fake coincidences.

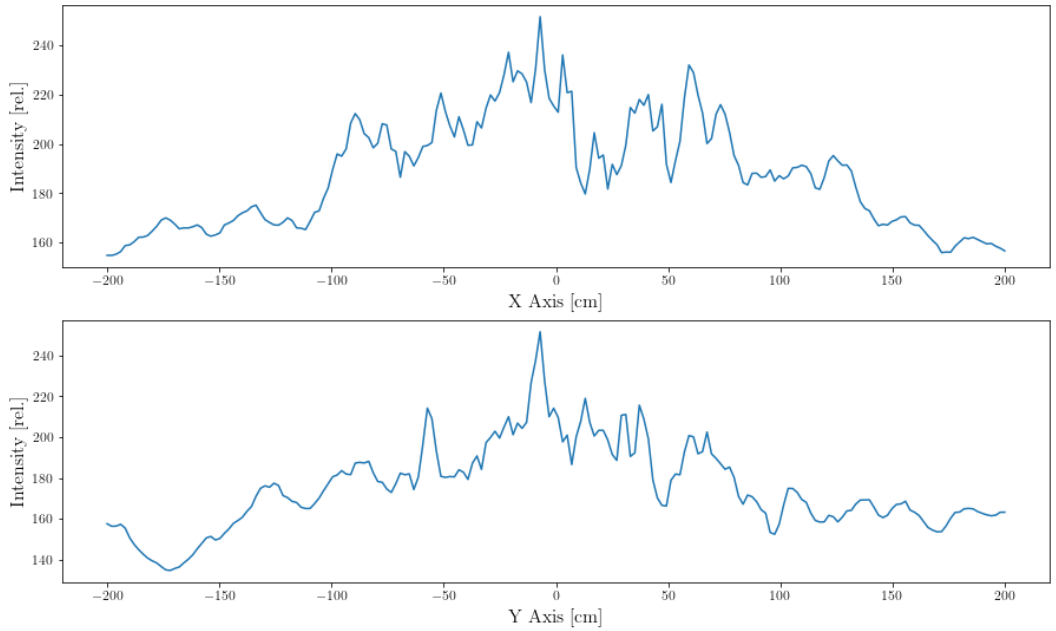


^{192}Ir Measurement: projection

(performed in collaboration with Petr Smolyanskiy, Anna Odložilíková, MOU)



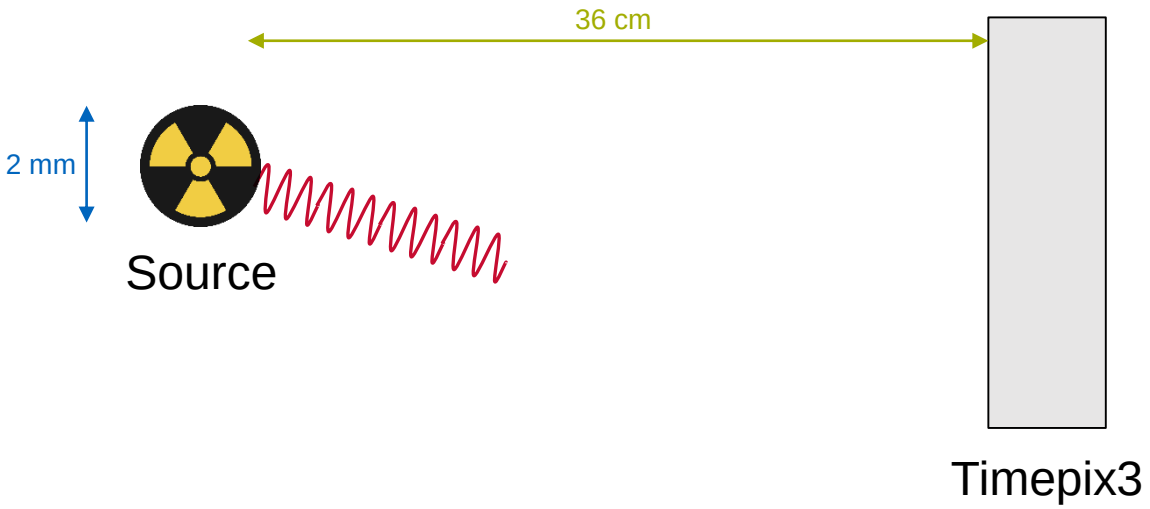
- Exclude XRF by requiring that scattering angle β > 35°.
- Contrast sharply drops.

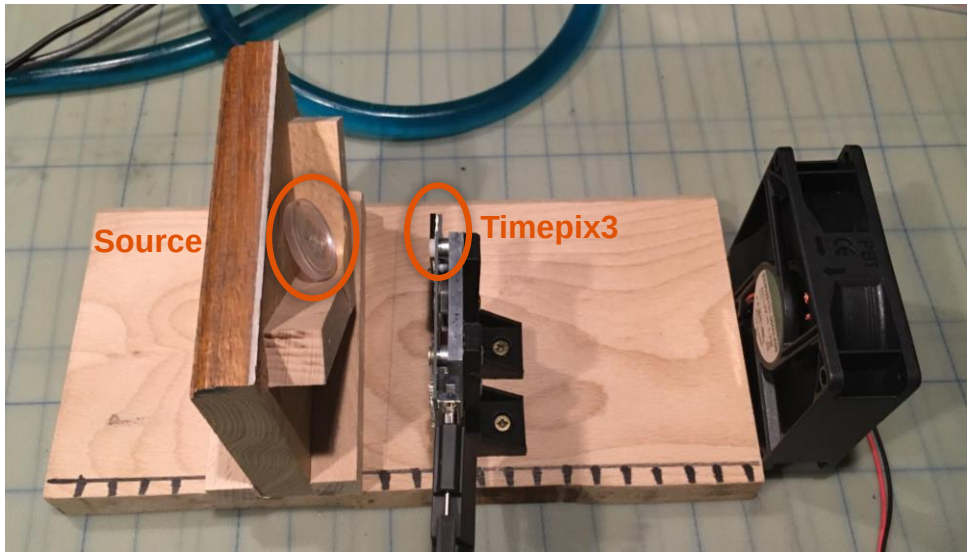


^{57}Co Measurement

(performed in collaboration with Petr Smolyanskiy, Jiří Zajíček)

- Processed 1M events measured at IEAP in October 2020.
- Parameters:
  - Single point source, activity 145 kBq, pellet with 2 mm width.
  - Placed 36 mm in front of Timepix3 (CdTe, 1 mm thick).
  - Only a selected subset of data, have more files available.

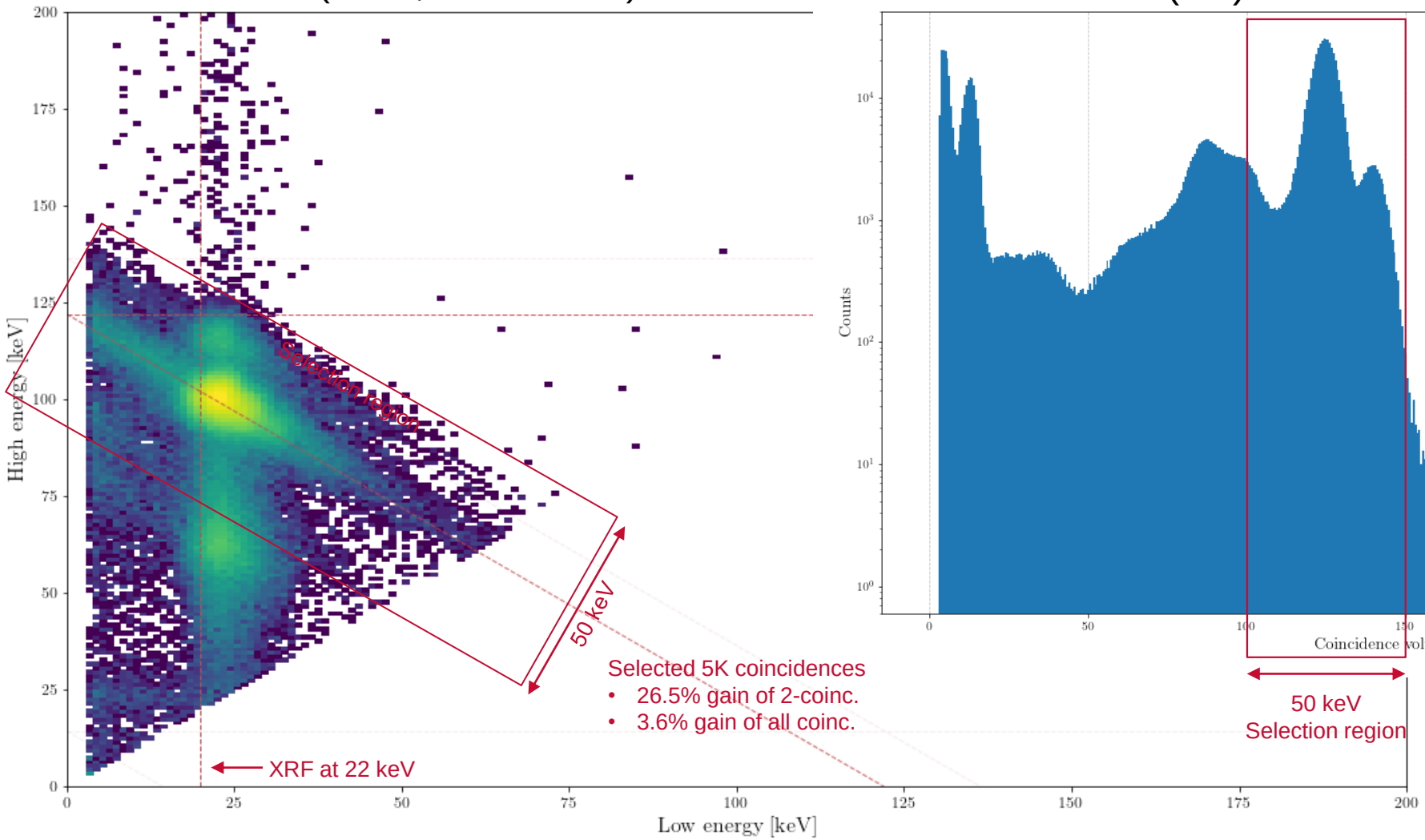




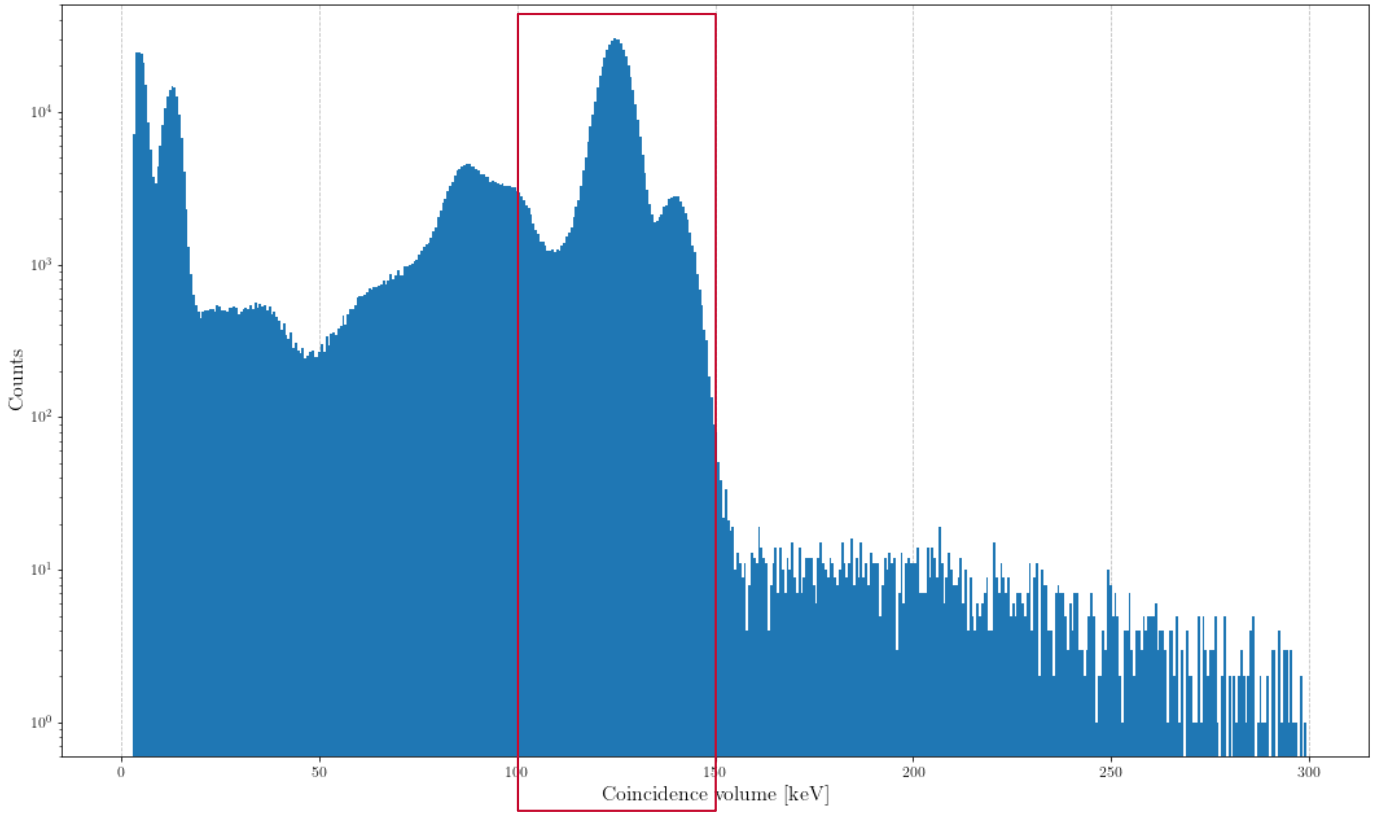
^{57}Co Measurement: spectrum

(performed in collaboration with Petr Smolyanskiy, Jiří Zajíček)

2-coincidences (137K, 13.7% of all)

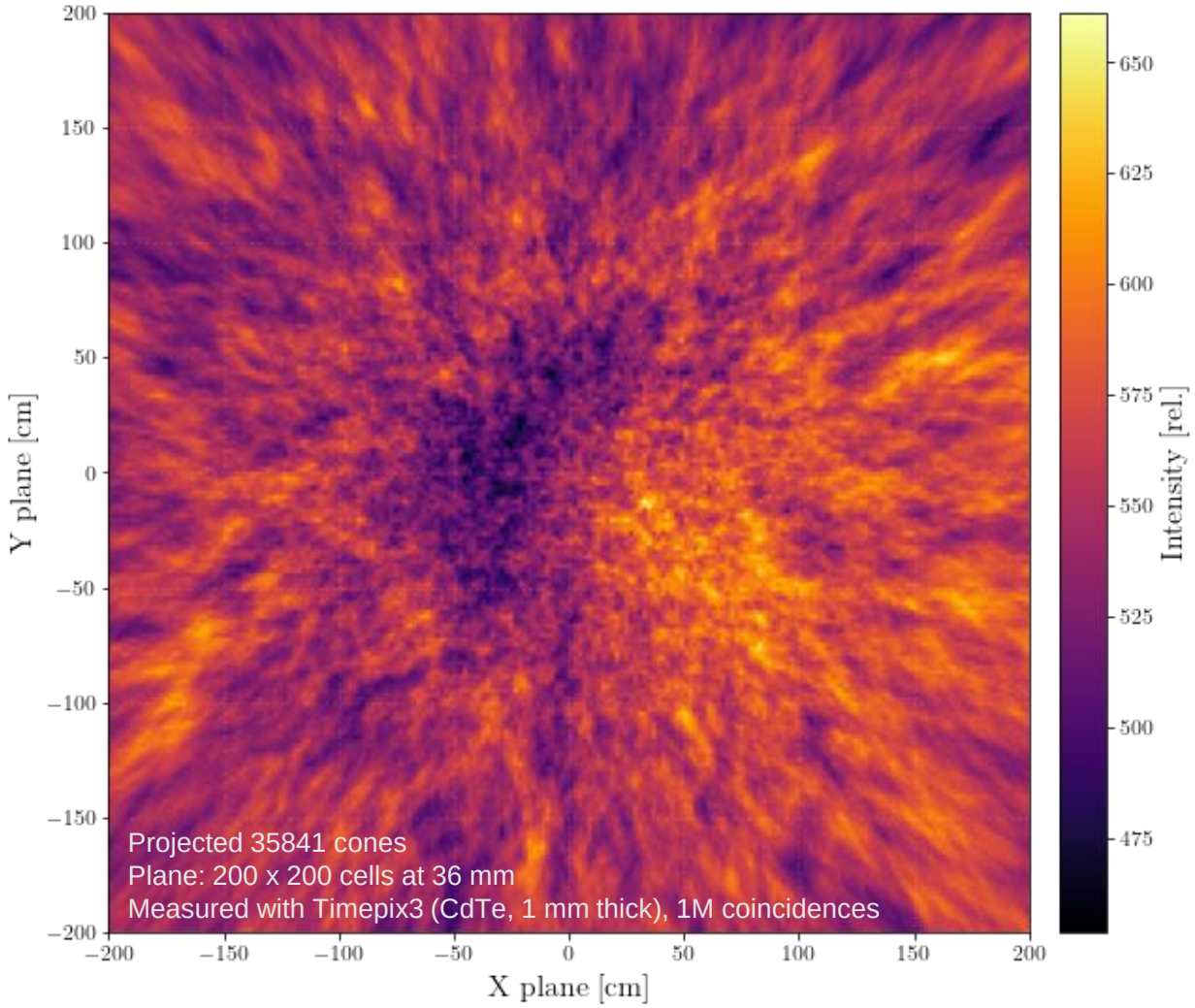


All coincidences (1M)

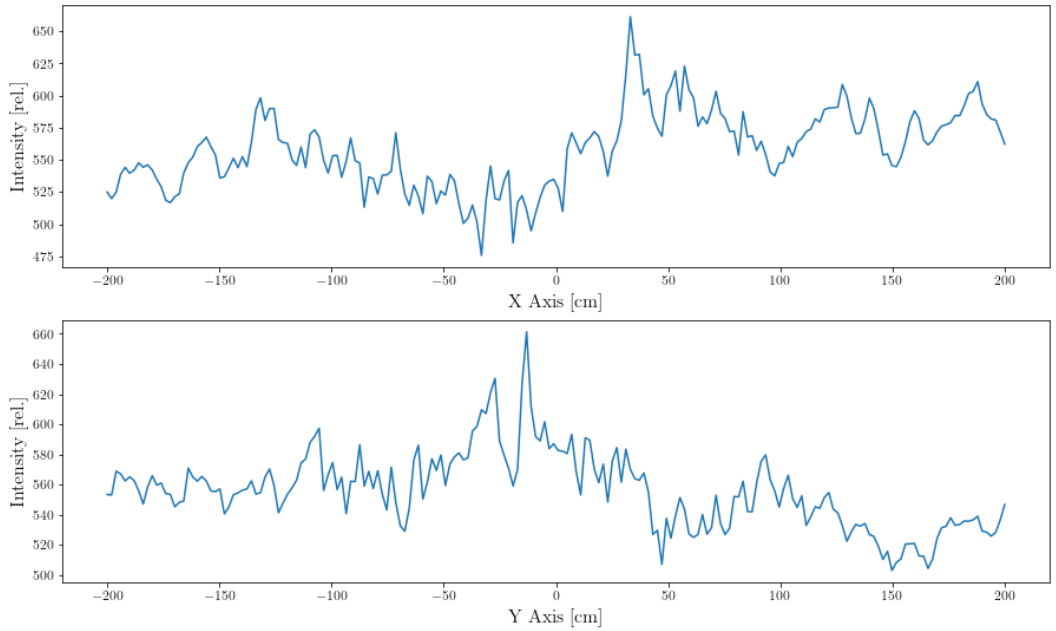


^{57}Co Measurement: projection

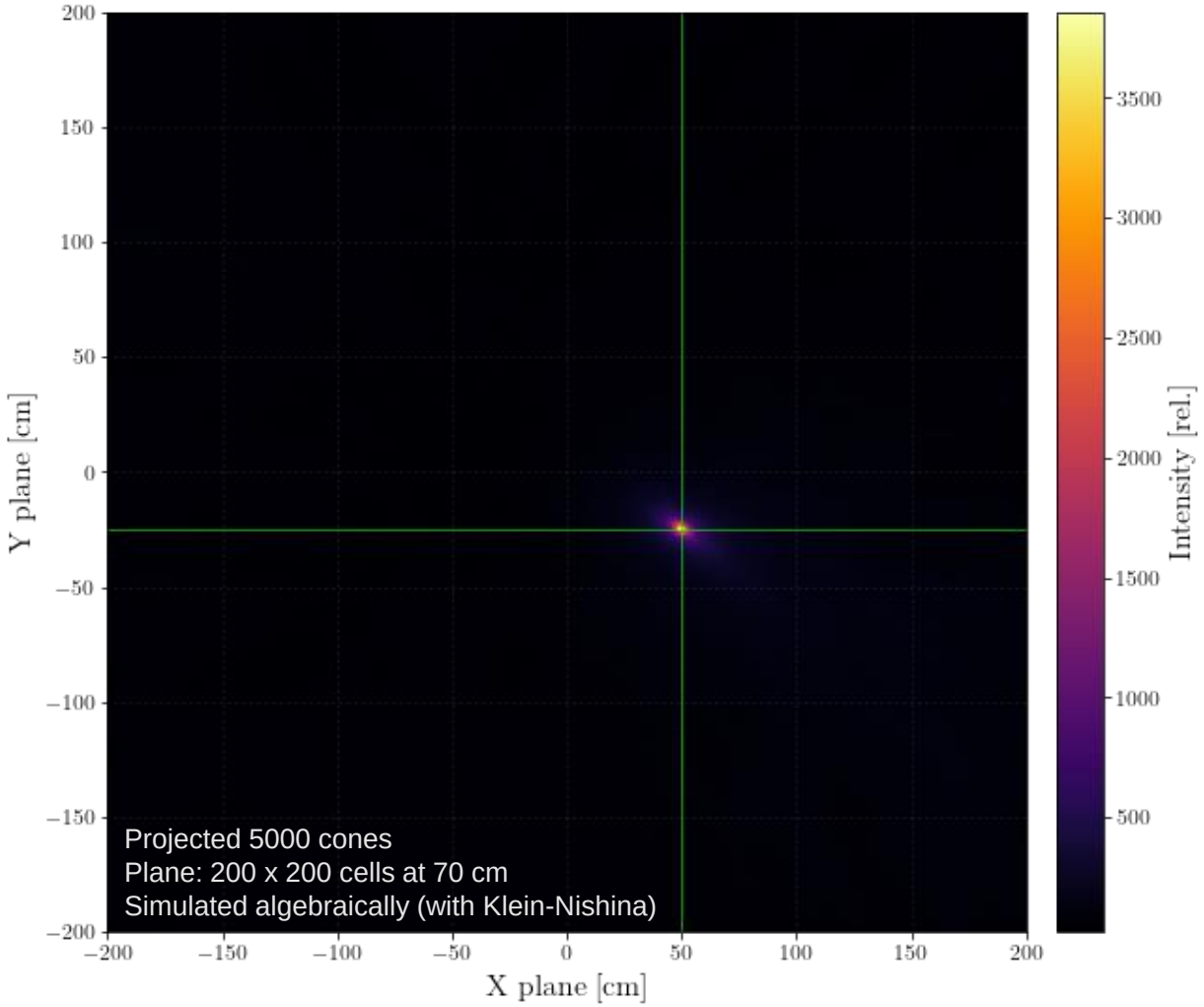
(performed in collaboration with Petr Smolyanskiy, Jiří Zajíček)



- Response not localized at all.
- Narrowing the selection region has no significant effect.



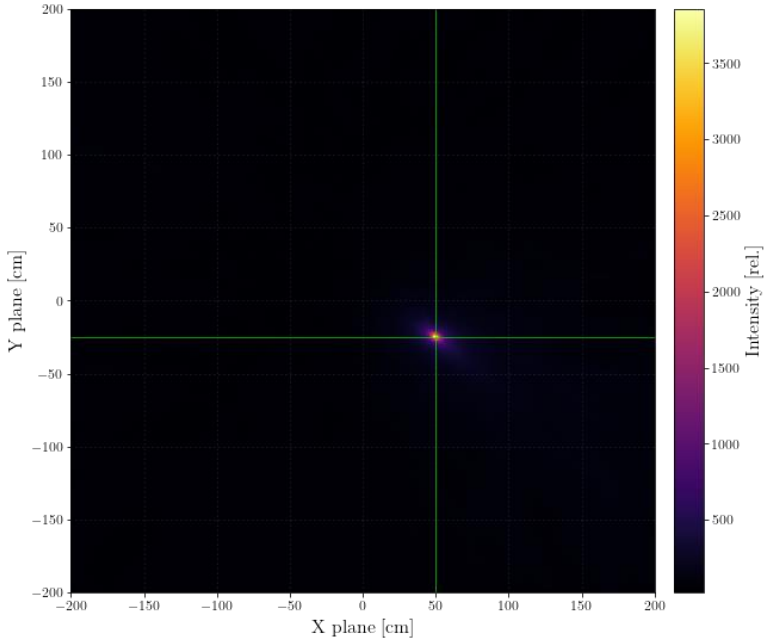
Playing with uncertainties



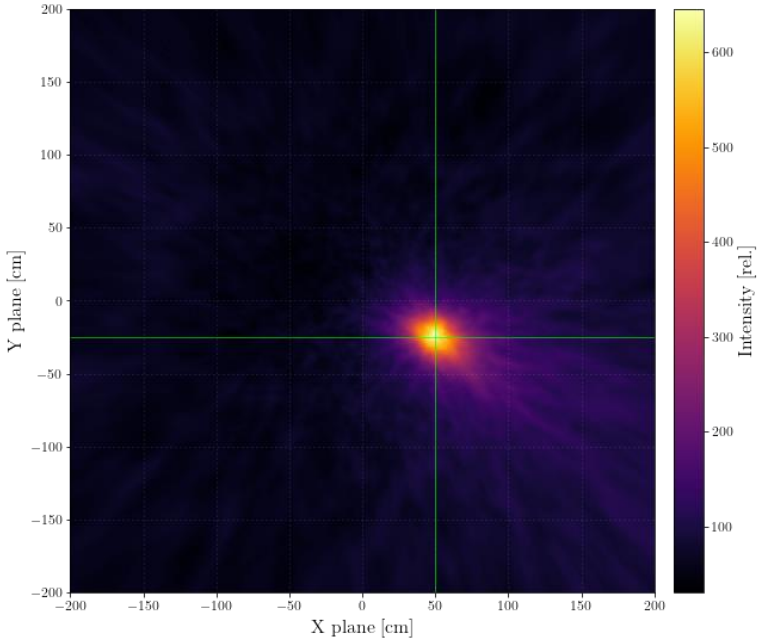
- Wanted to see influence of uncertainties on projection.
- Fast algebraic simulation:
  - Correct distribution of β.
  - Perfect coincidence assignment.
  - No material effects.
  - No detector response.
- Confirmed projection accuracy.
- Started introducing various uncertainties.

Playing with uncertainties

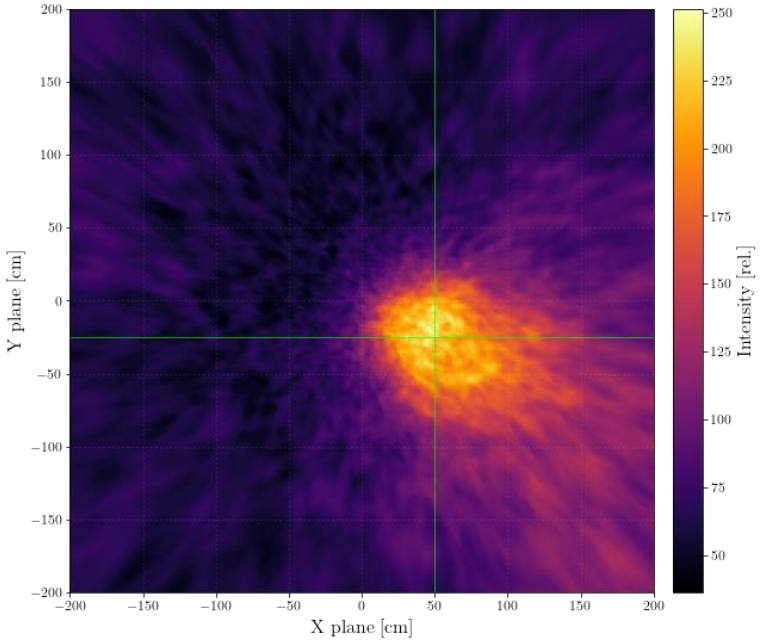
Optimal conditions



β ± 5°



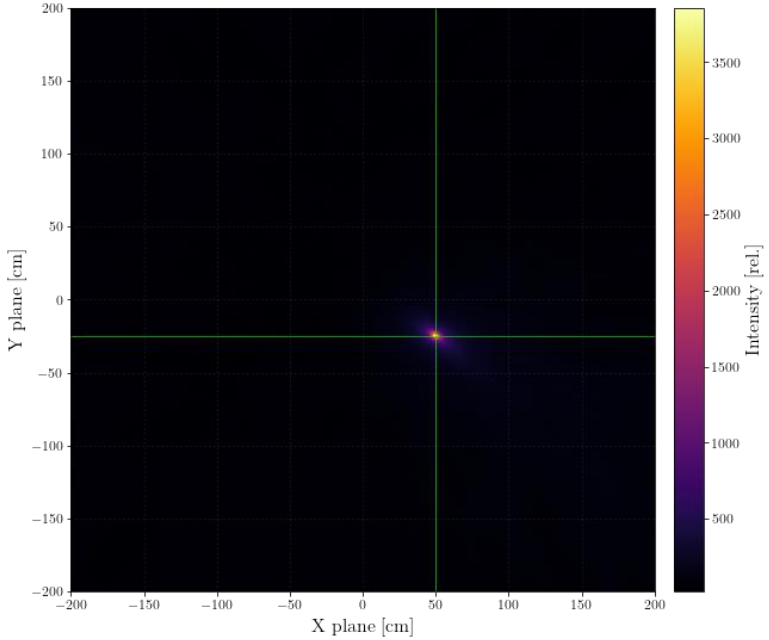
β ± 15°



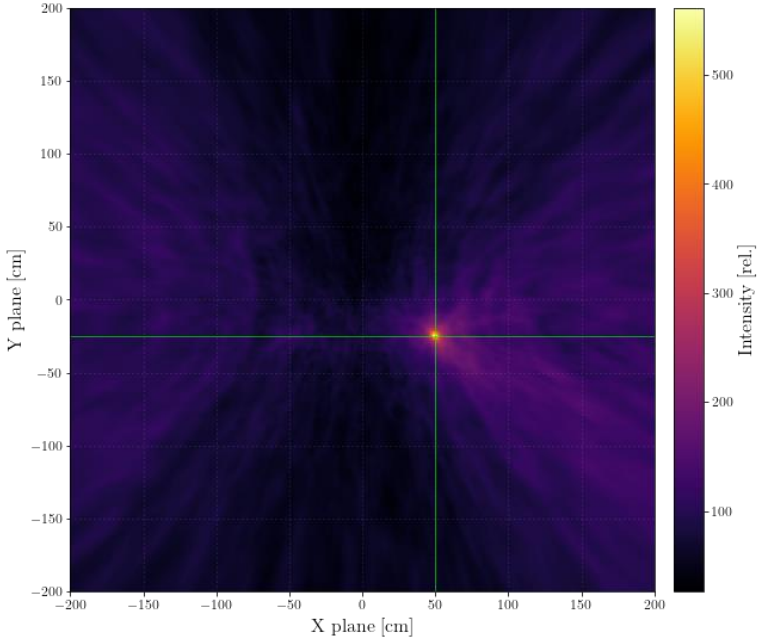
Projected 5000 cones
Plane: 200 x 200 cells at 70 cm
Simulated algebraically (with Klein-Nishina)

Playing with uncertainties

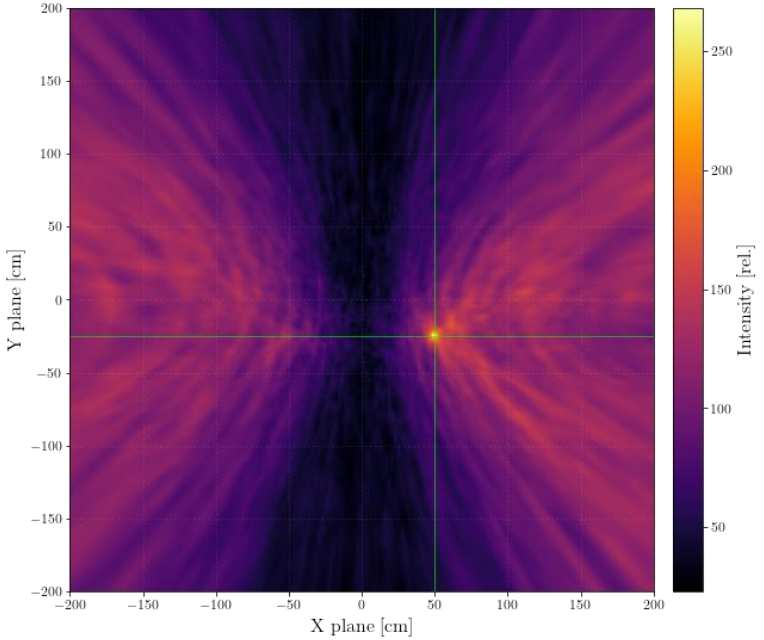
Optimal conditions



$X_{scatter}$ ± 10 px



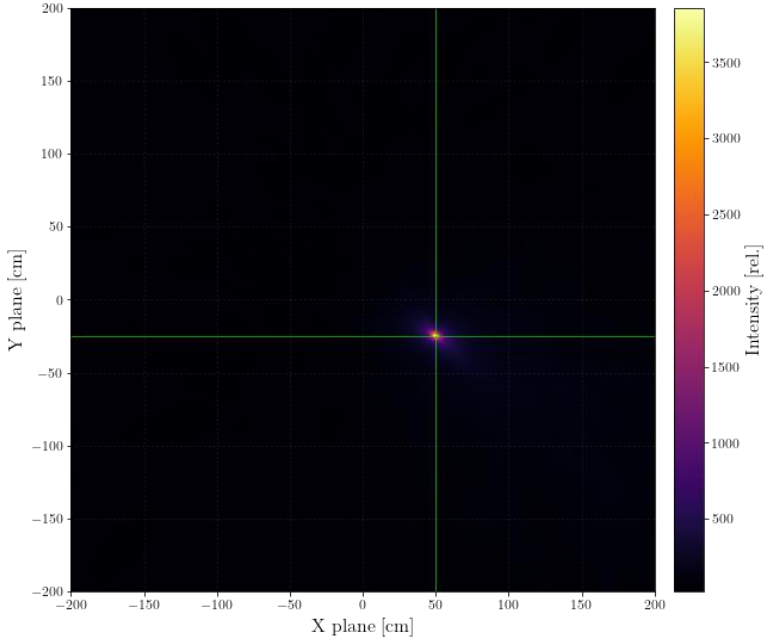
$X_{scatter}$ ± 30 px



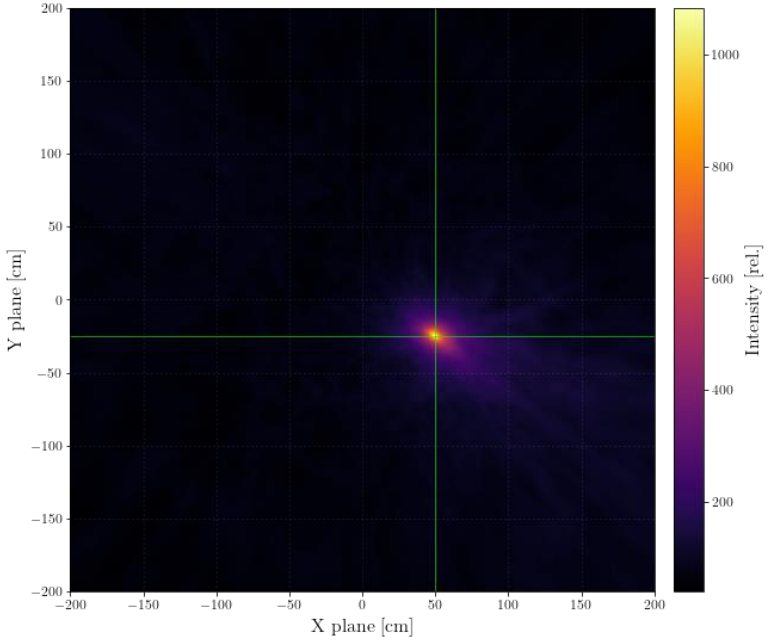
Projected 5000 cones
Plane: 200 x 200 cells at 70 cm
Simulated algebraically (with Klein-Nishina)

Playing with uncertainties

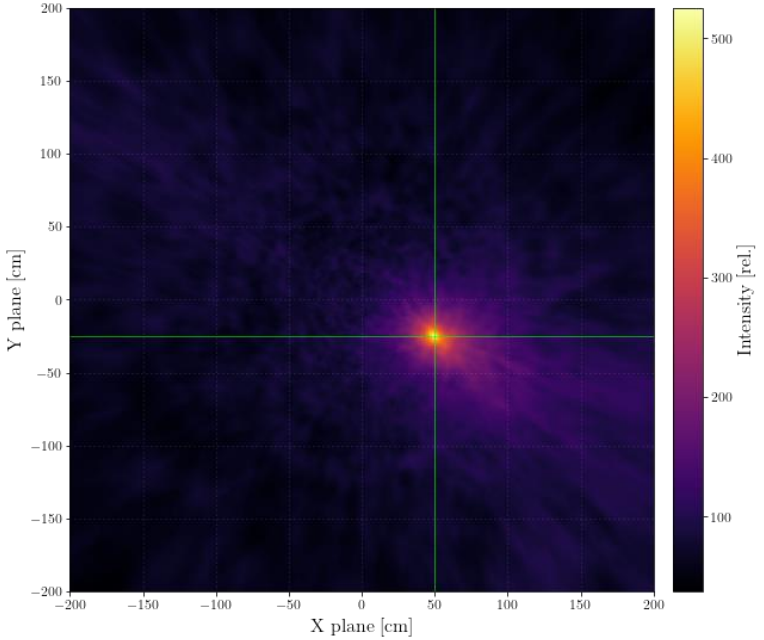
Optimal conditions



$Z_{scatter}$ ± 60 μm



$Z_{scatter}$ ± 180 μm



Projected 5000 cones
Plane: 200 x 200 cells at 70 cm
Simulated algebraically (with Klein-Nishina)

Conclusion

- Simulation:
  - We can fully reconstruct point sources with ≈ 1 mm error at 15 cm.
  - Gain can be increased by improving S/A cluster assignment.
- Measurements:
  - XRFs appear to be the largest background.
  - Even with XRFs suppressed, we do *not* see localized response.
- Spoiler effect in measurements that we are not simulating?
- Next steps: identify and include the missing phenomenon in simulations, re-evaluate, devise compensation strategy.

Thank you for listening!

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Find these slides online: https://bit.ly/pm_cc_nov2020