ISINN-21
Alushta, Ukraine, May 20 – May 25 2013
21st International Seminar
on Interaction of Neutrons with Nuclei:
«Fundamental Interactions & Neutrons, Nuclear Structure, Ultracold Neutrons, Related Topics»
http://isinn.jinr.ru

Position-Sensitive Coincidence Detection of Two and Three Particle Nuclear Reactions

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Institute of Experimental and Applied Physics
Czech Technical University in Prague

Institute for Nuclear Research KINR
Nat. Ac. of Sciences, Kiev, Ukraine

Research carried out in frame of the Medipix Collaboration

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Basic Research

Astroparticle & non-accelerator physics
- Neutrino physics (NEMO3/SuperNEMO, TGV)
- Cosmic rays (CZELTA)
- Dark matter (PICASSO)

ATLAS at LHC
- SCT detection modules
- Neutron shielding
- Medipix radiation monitoring
- Higgs boson physics

Nuclear spectroscopy
- Fission fragment spectroscopy
- Laser induced nuclear excitation
- Ultra cold neutrons

Applied Research

Radiation imaging
- Medipix pixel detectors: SW, HW
- X-ray radiography and tomography
- Charged particle & neutron imaging
- Biomedical imaging
- Material science and defectoscopy

R&D of semiconductor detectors
- 3D and semi-3D detectors
- Thermal neutron detectors
- Room-temperature detectors
- Instrumentation for detector testing

Applied spectrometry
- Material analysis (CINAA, XRF, Radon)
- Particle tracking and spectroscopy
- Radiation in space (gamma, neutron, micro-sensor)

Fundamental Experiments in the Physics of the Microworld

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IEEE NSS/MIC/RTSD
Seoul
27 Oct - 2 Nov 2013

15th IWORID
Paris
23-27 June 2013

NSS MIC IEEE Conference
29 Oct - 3 Nov 2012

All...

Seminars

28.5.2013
Dr. Alexander V. Podshibyakin
Software for data analysis of experimental results from MASHA+MEDIPIX setup

FLNR, JINR Dubna

2.5 MeV VdG at IEAP CTU in Prague

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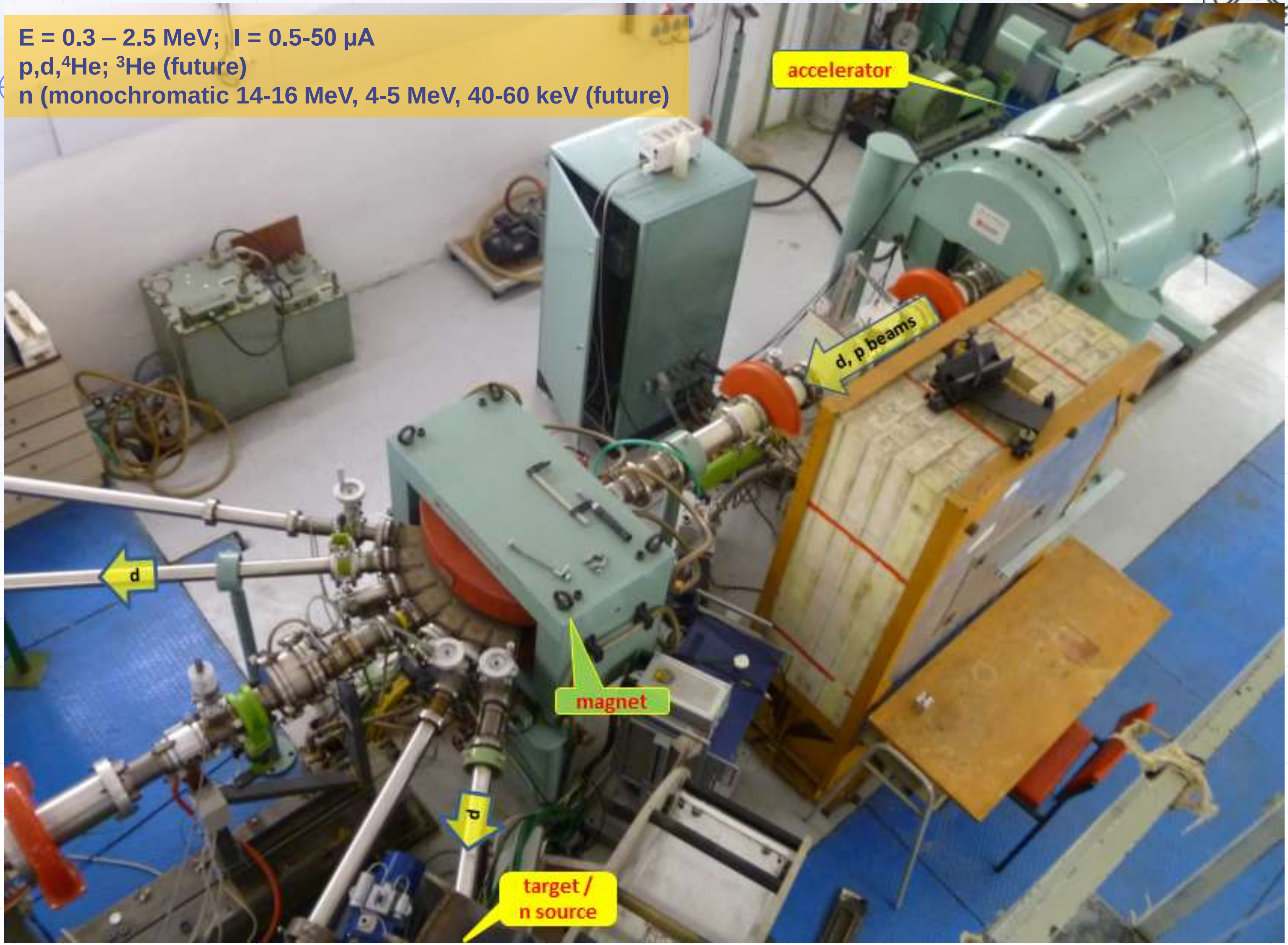
E = 0.3 – 2.5 MeV; I = 0.5-50 μA
p,d,^{4}He; ^{3}He (future)
n (monochromatic 14-16 MeV, 4-5 MeV, 40-60 keV (future)



Outline

- Motivation, studied reactions/channels/resonances
  - Discrepancies in experimental (and theoretical) information of reaction p + ^{11}B
- Instrumentation
  - VdG accelerators
    - Tandem VdG KINR Kiev
    - 0.3 - 2.5 MeV IEAP CTU Prague
  - Hybrid semiconductor pixel detector Timepix
  - Readout electronics,
  - integrated analog signal module
  - coinc/sync unit
- **Position**- and **spectral**-sensitive **coincidence** detection:
  - 2-particle reactions
  - 3-particle reactions
- Tests and studied reactions/sources:
  - p + ^{11}B: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$
  - p + CH_4 : (p,p)
  - ^{226}Ra: α's

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Motivation I: p + ^{11}B: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$

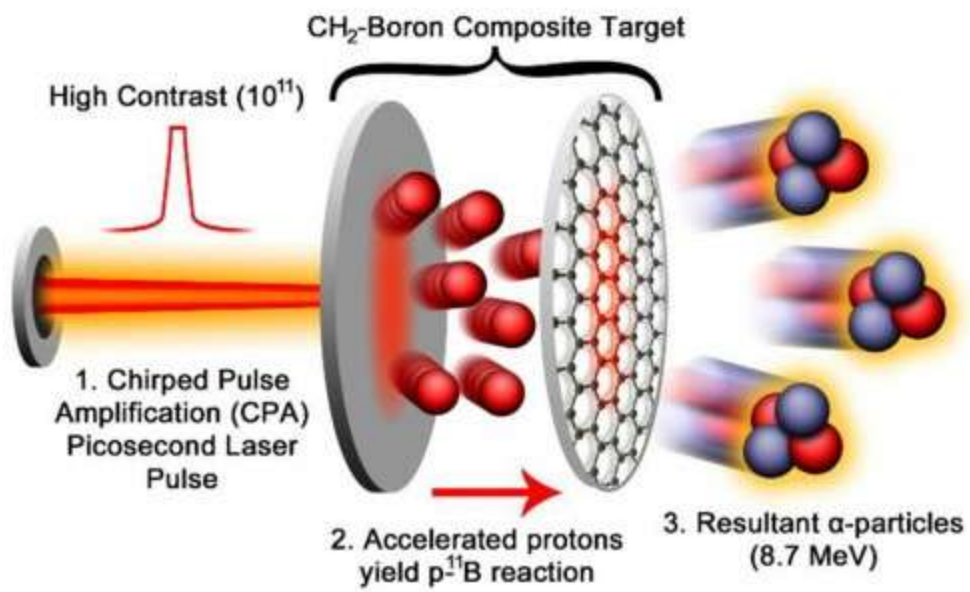
- Astrophysics
- Fusion energy
- Space rocket thrust

Can be studied with new level of accuracy

- Low energy reaction p+11B →
  - charge particle induced **thermonuclear rates**
  - possible **aneutronic fusion reaction** as fuel for
    - space rocket propulsion
    - fusion reactors
- Measurement of angular and energy correlations
  - correct assignments of **reaction/resonance quantum numbers**
- Measurement of angular distributions
  - spectral and angular distribution of reaction products → cross sections, spectroscopic factors, resonance characteristics, etc.,
  - **interference phenomena**, (transition from destructive to constructive phase etc.) → shed light on aspects of reaction mechanism which are hard to be studied with traditional scattering experiments
  - information on yields, **directional information** (! for fusion & rocket purposes)
- Constructed a modular and configurable setup based on the semiconductor pixel detector Timepix and single silicon diode detectors for complete kinematics studies of three-, and four-particle final state reactions
- Experiments @ selected energies (resonances: 0.67 MeV, 2.64 MeV):
  - 5 MeV Tandem VdG, KINR Kiev (2012 tests, 2-3Q 2013 measurements)
  - 300 keV – 2.5 MeV VdG, IEAP CTU Prague (3-4Q, 2013)
  - 100 – 300 keV: … (future)

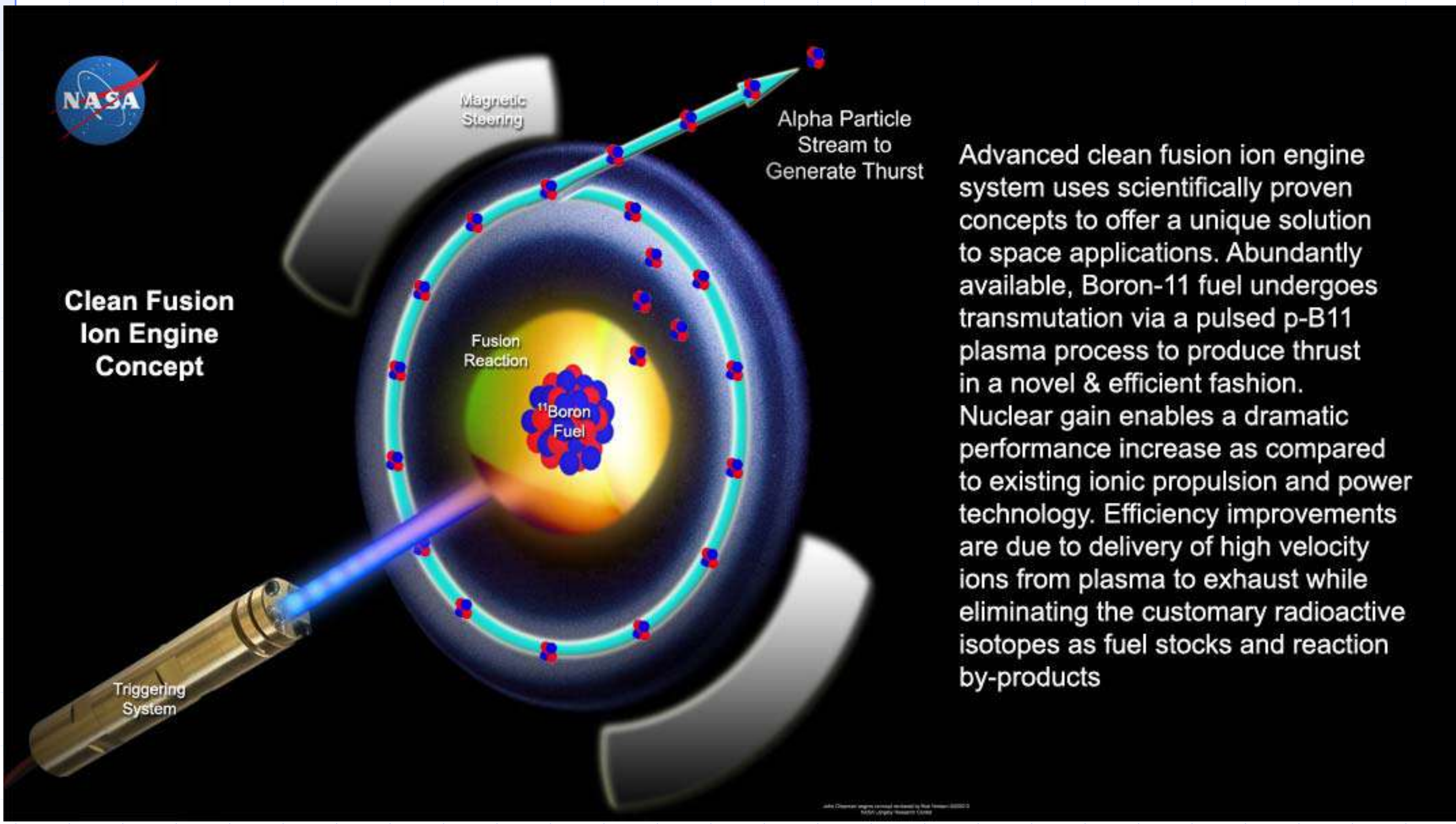
3x α-particle nuclear reaction:
Renewed interest in anuetronic fusion fuel

Suggested at the **IEEE Symposium (2011) on Fusion Engineering** by **John J. Chapman**, a physicist and electronics engineer at **NASA's Langley Research Center** in VA, **aneutronic fusion** could improve space propulsion significantly. The new propulsion method is based on boron fuel rather than deuterium and tritium, the typical fuel for nuclear fusion.



3x α-particle nuclear reaction:
Novel fusion ion rocket propulsion

Advanced Fusion Reactors for Space Propulsion and Power Systems
John J. Chapman, NASA, Langley Research Center



Motivation II: Timepix for true coincident detection for elemental analysis

- This method of detection of two products of two-particle reactions in true coincidences by applying Timepix detectors provides valuable approach for element analysis in thin (nano-, micro-meter scale) foils.
  - e.g. content and spatial distribution with high sensitivity and high spatial resolution of tritium in T samples and T targets
- True coincidence method allows for to enhance separation of rare admixtures by few orders of magnitude in comparison with traditional Rutherford back-scattering method.
- Scanning by micro-beam over the sample under the study one should be able to map the admixture position with a position resolution of the Timepix detector (10-20 μm).

Jine clanky + motivace

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J Fusion Energ (2012) 31:357–367
DOI 10.1007/s10894-011-9473-5

ORIGINAL RESEARCH

The $^{11}B(p,\alpha)^{8}Be \rightarrow \alpha + \alpha$ and the $^{11}B(\alpha,\alpha)^{11}B$ Reactions at Energies Below 5.4 MeV

M. C. Spraker · M. W. Ahmed · M. A. Blackston · N. Brown · R. H. France III · S. S. Henshaw · B. A. Perdue · R. M. Prior · P.-N. Seo · S. Stave · H. R. Weller

Received: 17 August 2011 / Accepted: 1 October 2011 / Published online: 21 October 2011

Abstract Measurements of the absolute cross section and angular distributions for the $^{11}B(p,\alpha)^{8}Be \rightarrow \alpha + \alpha$ and the $^{11}B(\alpha,\alpha)^{11}B$ reactions have been performed from 0.15 to 3.8 MeV for the $^{11}B(p,\alpha)$ study and from 2 to 5.4 MeV for the $^{11}B(\alpha,\alpha)$ reaction. The absolute cross sections are presented in terms of the total number of α-particles detected in order to avoid uncertainties due to ambiguities in the number of alpha particles emitted in the reaction at a particular energy. The angular distributions of the

Keywords Low energy nuclear physics · Aneutronic fusion · Fusion · Triple alpha · Energy production · ^{11}B · Alpha · Proton fusion · Alpha elastic scattering · Cross section · Angular distribution

Introduction

As previously discussed [1], the history of the study of the

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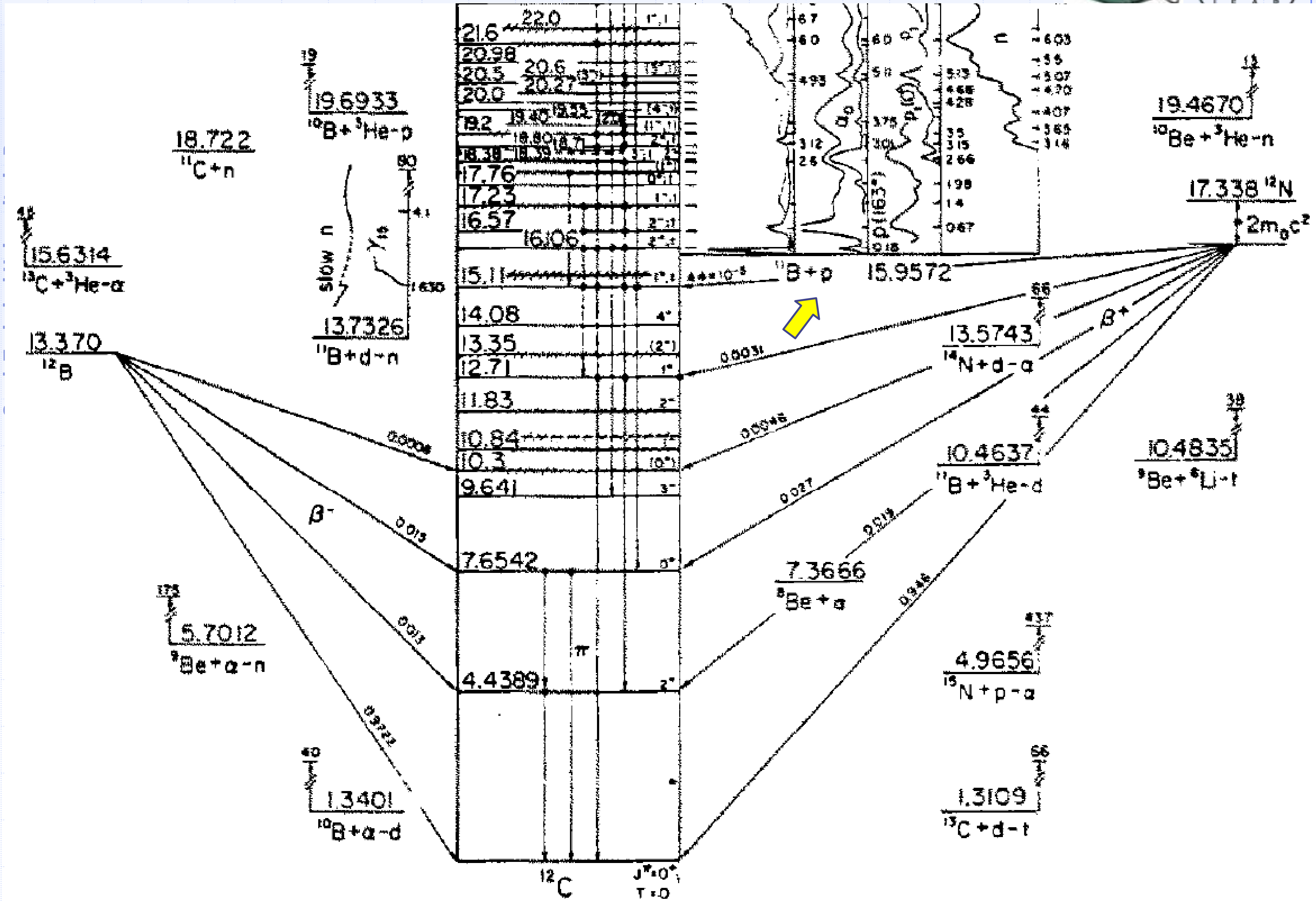
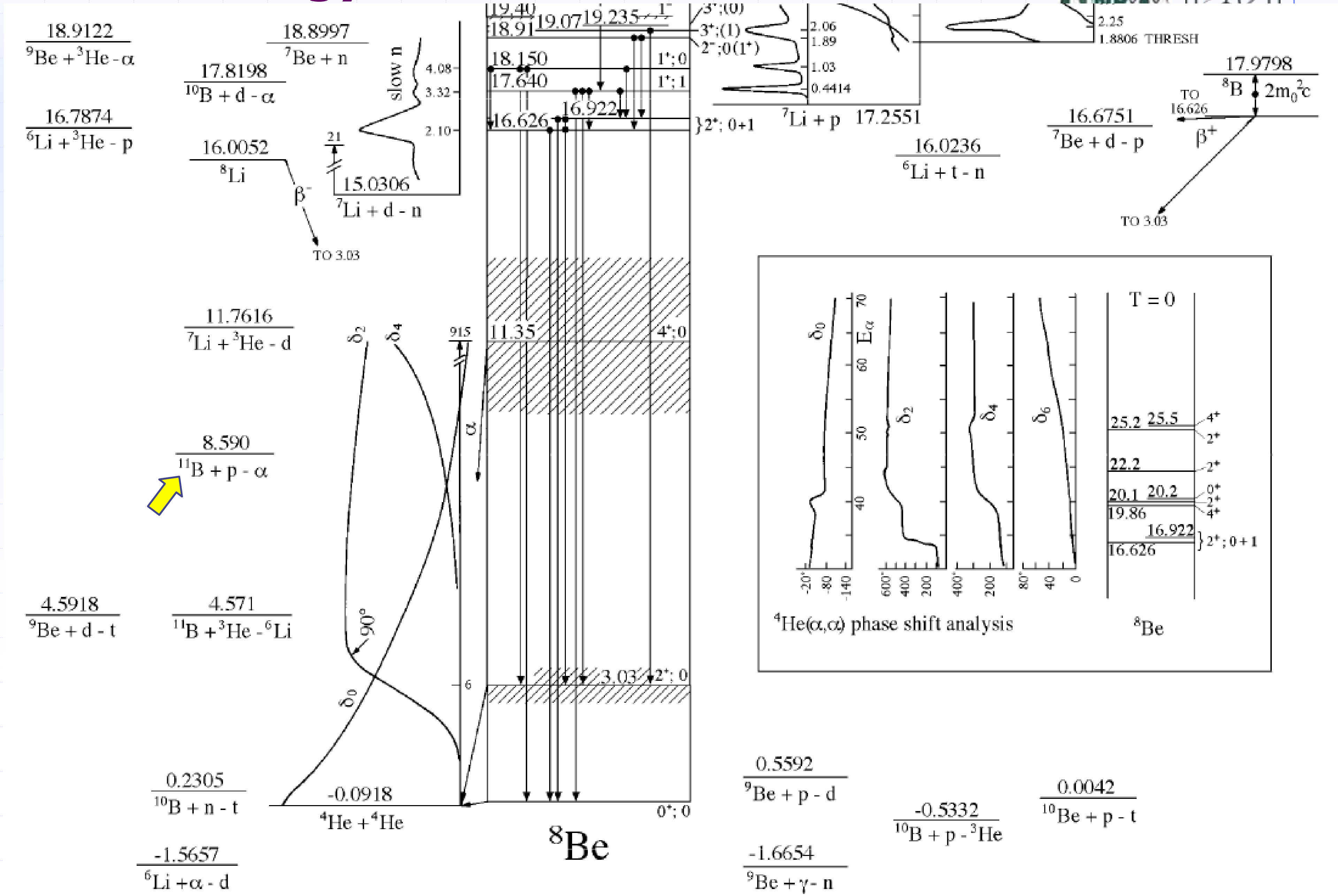
^{12}C: Energy levels



⁸Be: Energy levels



S. Stave, et al, *Understanding the 11B(p,a)2a reaction at the 675 keV reaction*, Phys. Lett. B 696 (2011)

3-particle reaction: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$

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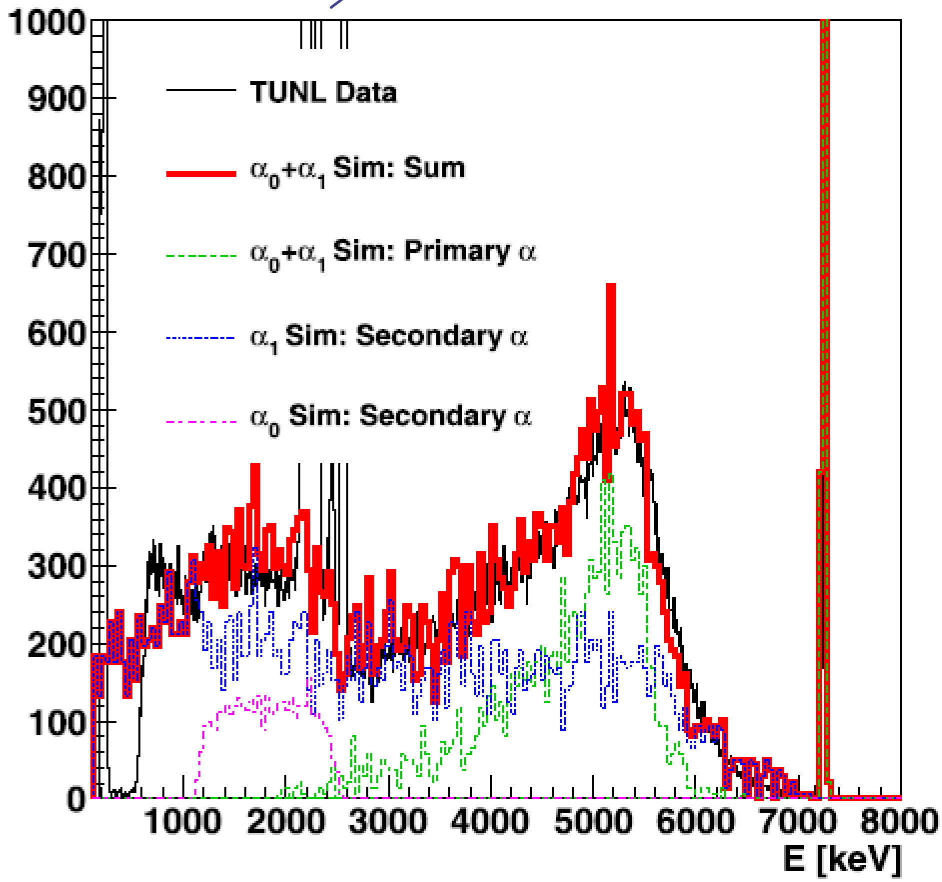
elastic scattered primary p

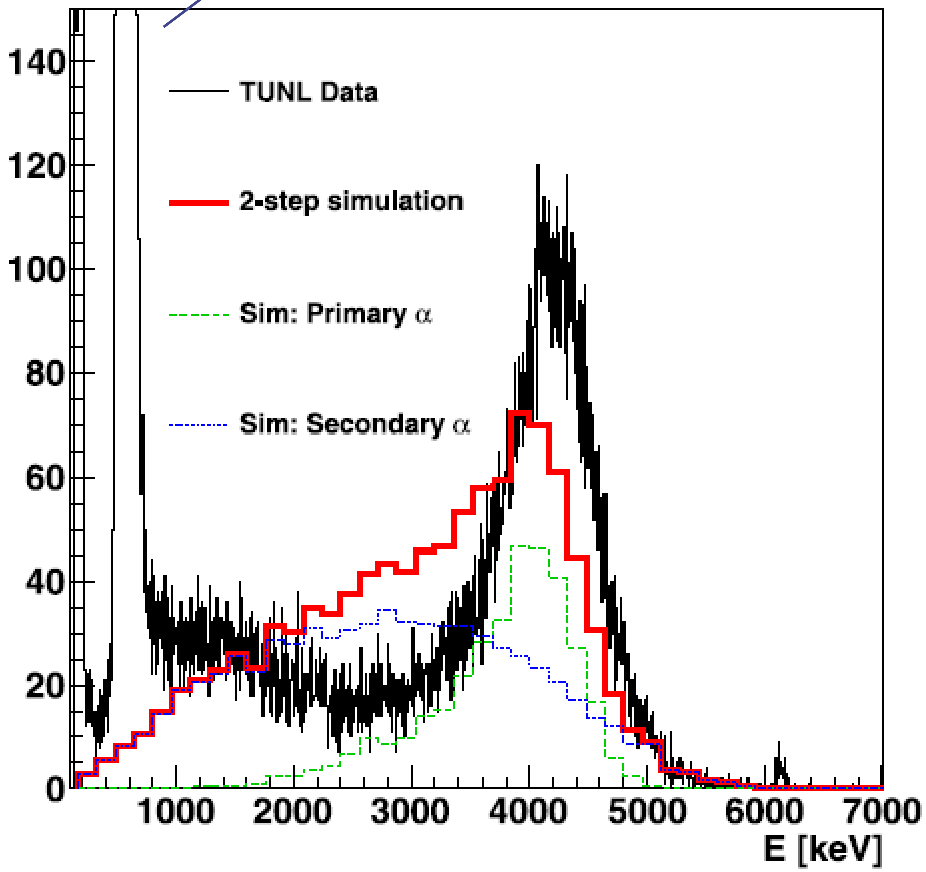


Comparison of the two-step reaction simulation with data at $\theta_{\alpha}^{lab} = 90^{\circ}$ and $E_p = 2.64$ MeV. The sharp peak at 7.26 MeV corresponds to the α_0 channel.

S. Stave, et al, *Understanding the 11B(p,a)2a reaction at the 675 keV reaction*, Phys. Lett. B 696 (2011)

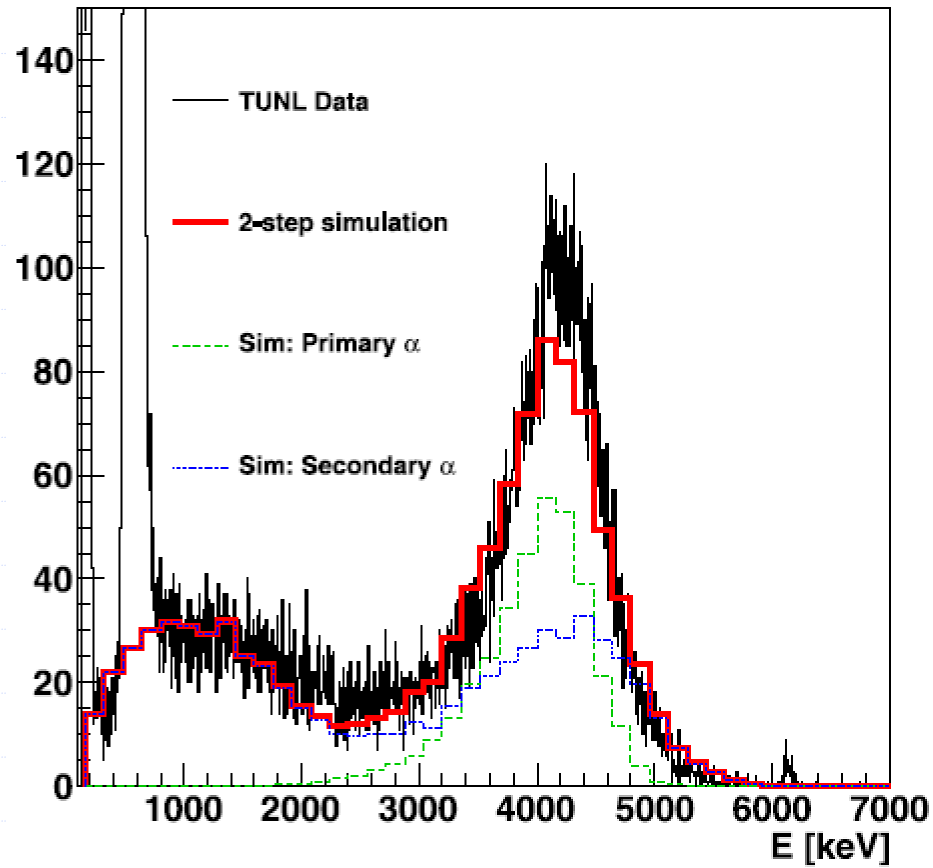
3-particle reaction: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$

elastic scattered primary p



Comparison of the two-step reaction simulation using $\ell = 1$ with data at $\theta_\alpha^{lab} = 90°$ and $E_p = 0.675$ MeV.

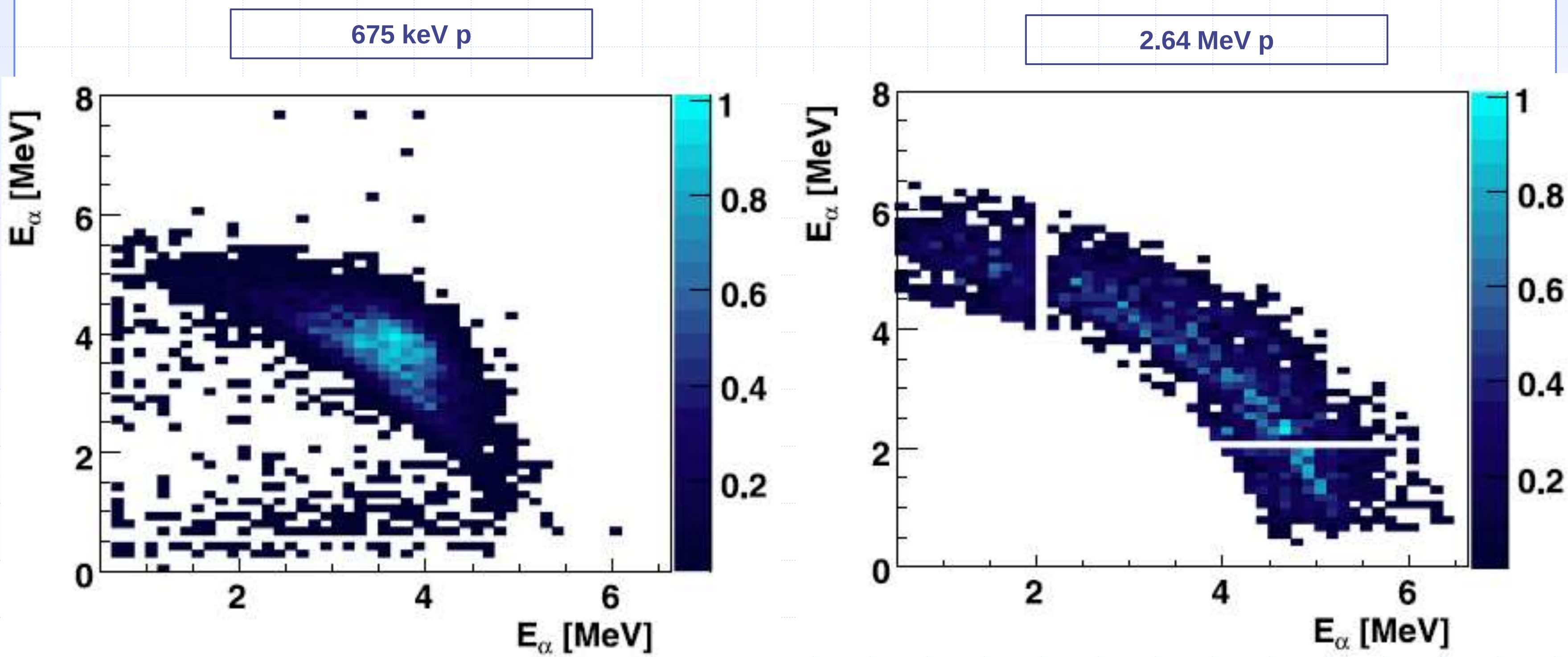
elastic scattered primary p



Comparison of the two-step simulation using $\ell = 3$ with data at $\theta_\alpha^{lab} = 90°$ and $E_p = 0.675$ MeV.

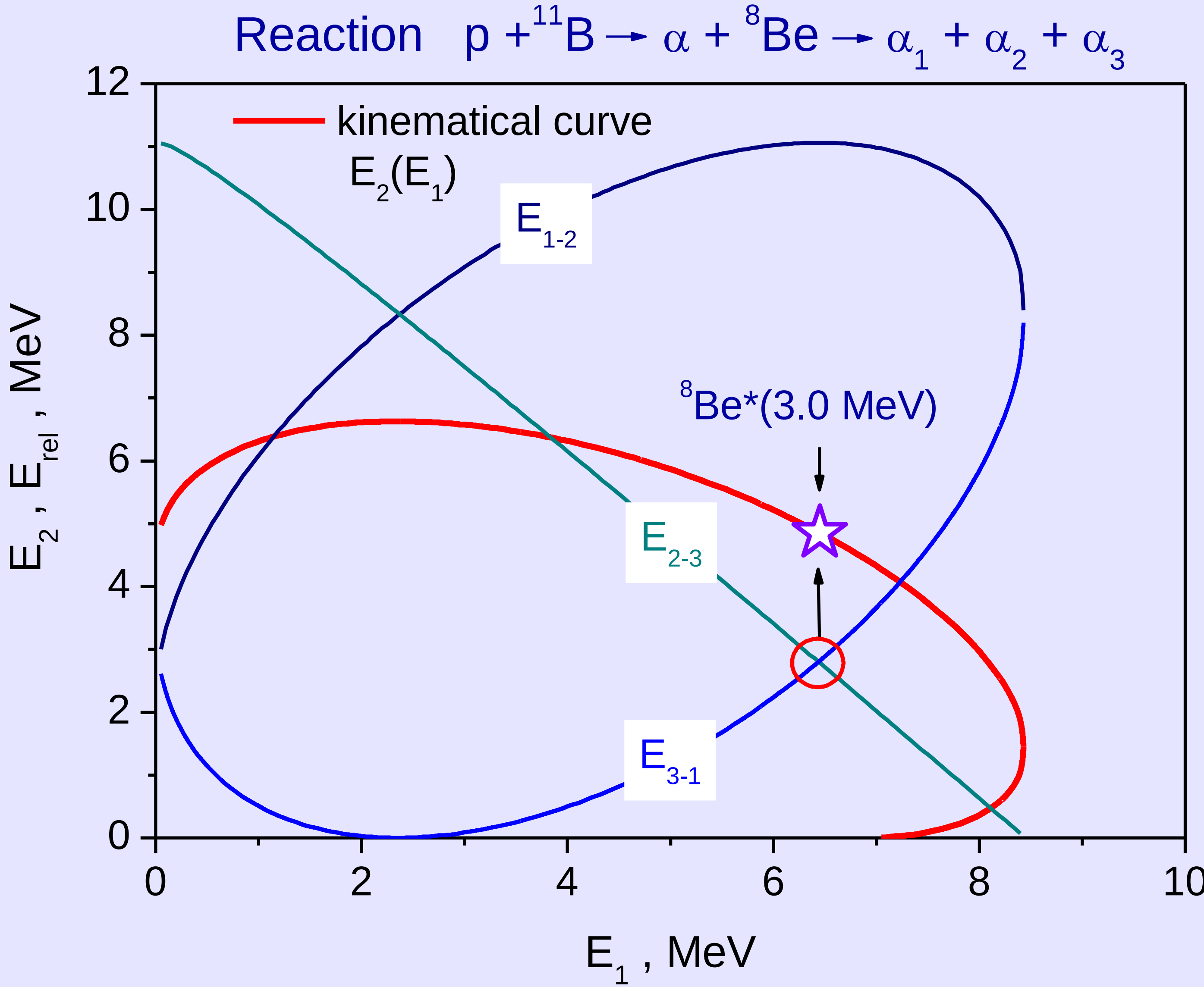
S. Stave, et al, *Understanding the 11B(p,a)2a reaction at the 675 keV reaction*, Phys. Lett. B 696 (2011)

3-particle reaction: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$



Coincidence spectra for $E_p = 0.675$ MeV (top) and 2.64 MeV (bottom) at the same lab α–α opening angle of 150°. The spectra have been normalized so that the maximum in the z direction is 1.0. The vertical and horizontal slices in the lower figure removed the elastic events.

Interference phenomena



E_p = 2.65 MeV

Θ_1 = 45°

Θ_2 = 120°

$\varphi_1 - \varphi_2$ = 0°

$E_x(^8Be) = E_{rel} + E_{th}$

KINR Kiev
5 MeV Tandem VdG

KINR Kiev
Ion beam, chamber, team, setup

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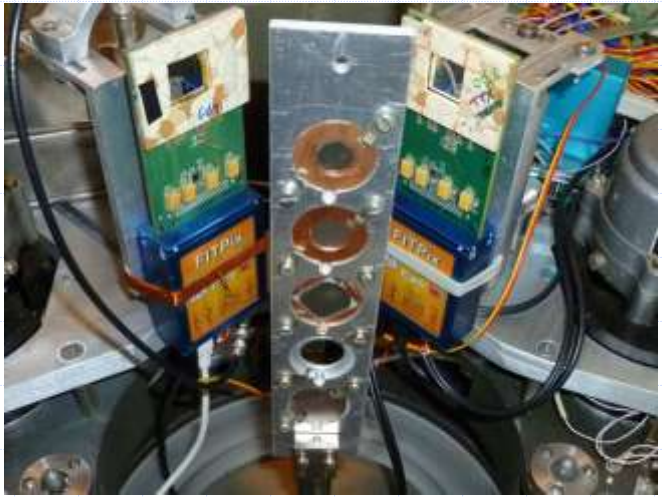

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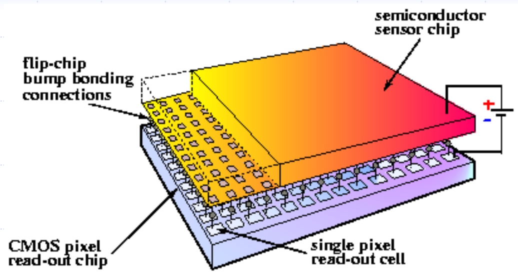
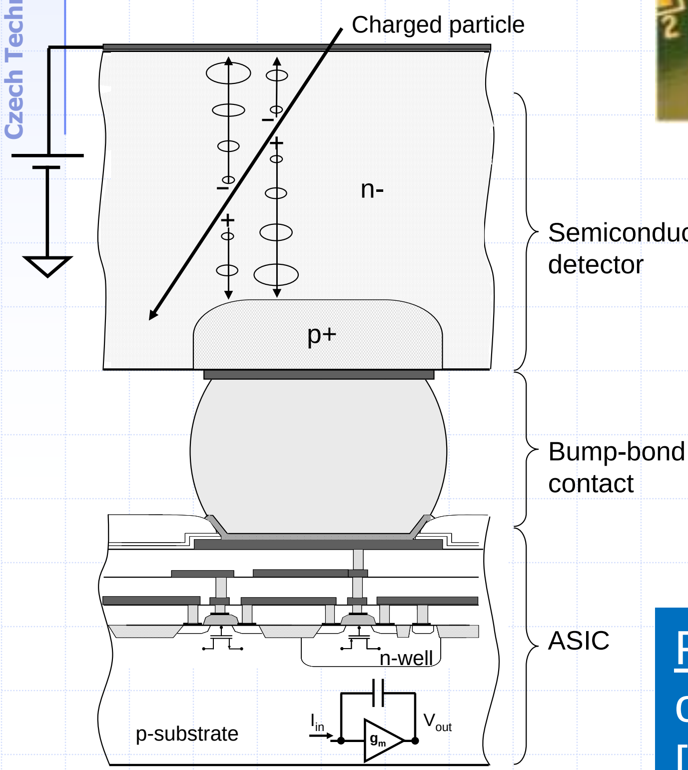
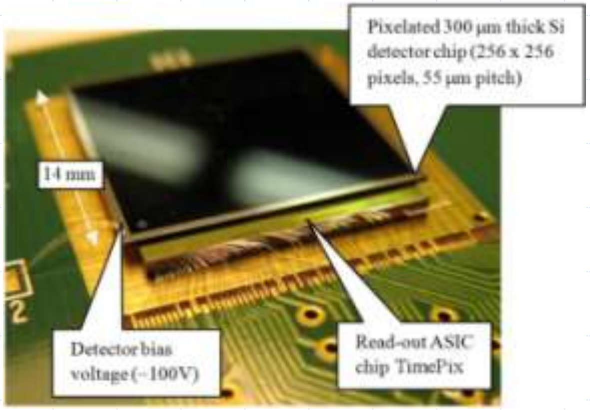
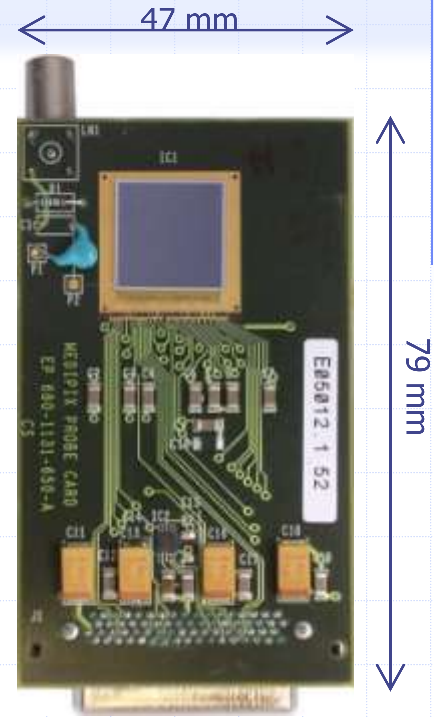
Hybrid semiconductor pixel detector Timepix:
per-pixel E, t sensitivity









- Single particle counting (no dark current)
- Per-pixel energy and time sensitivity
- Hybrid technology allows the use of different semiconductor sensors (e.g, Si, CdTe, GaAs) and sensor thickness.
- Pulse processing electronics provides simultaneously fast and noise free images.
- .Integrated readout interface: online visualization, trigger in/out.

Pixelman SW tool: control & online visualization
[*J. Jakubek, D. Turecek*]

Timepix [TOT] @ focal plane
Position & Energy

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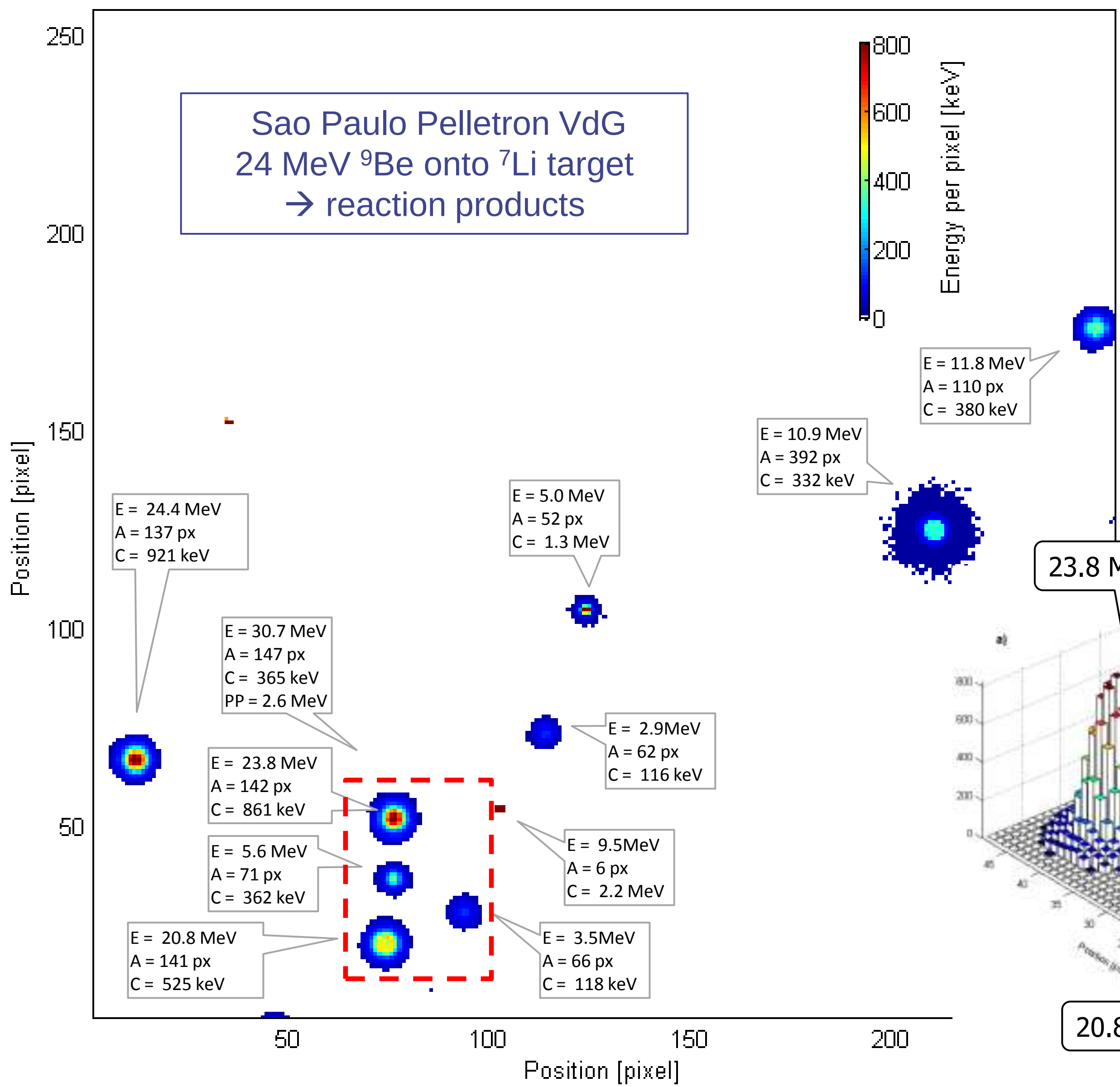

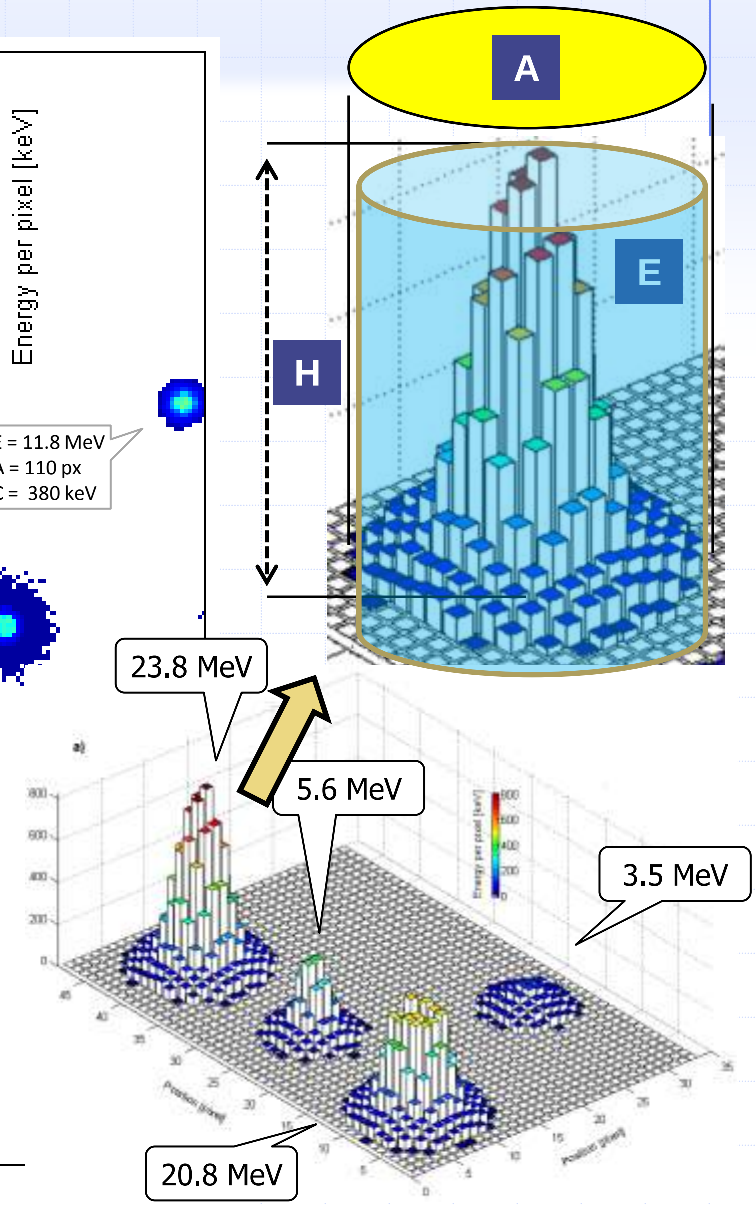

Timepix + KINR VdG Kiev:
2- and 3- particle reactions

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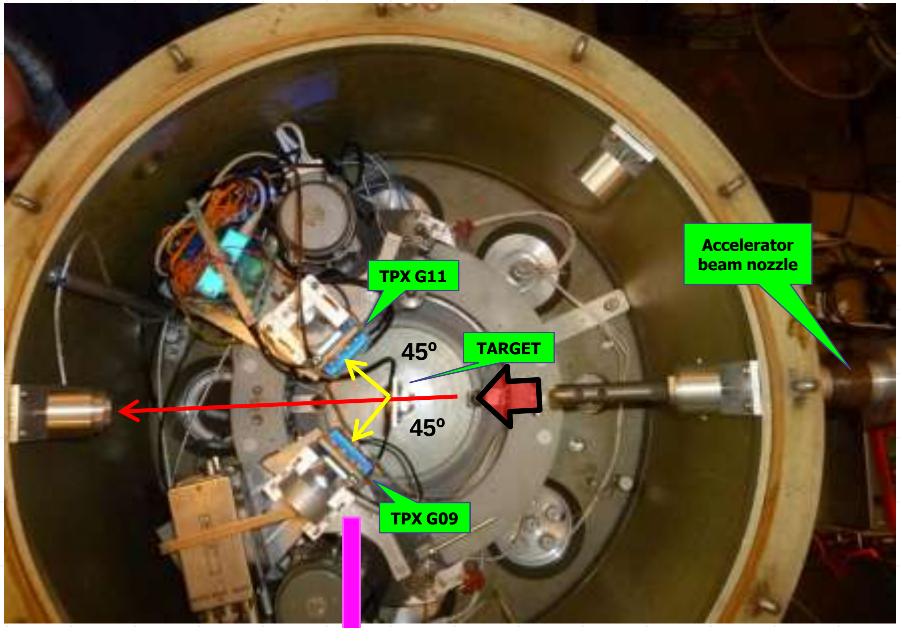
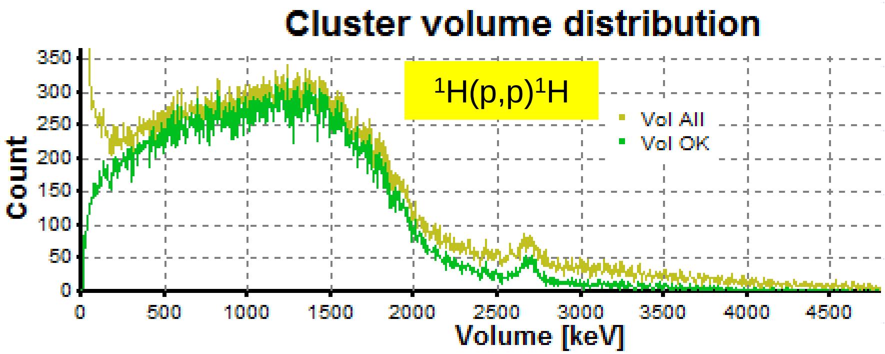
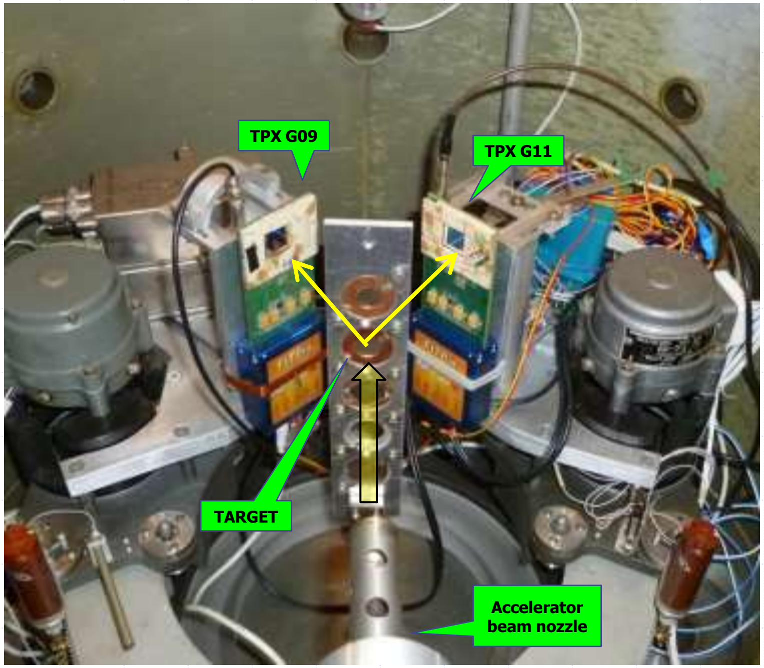
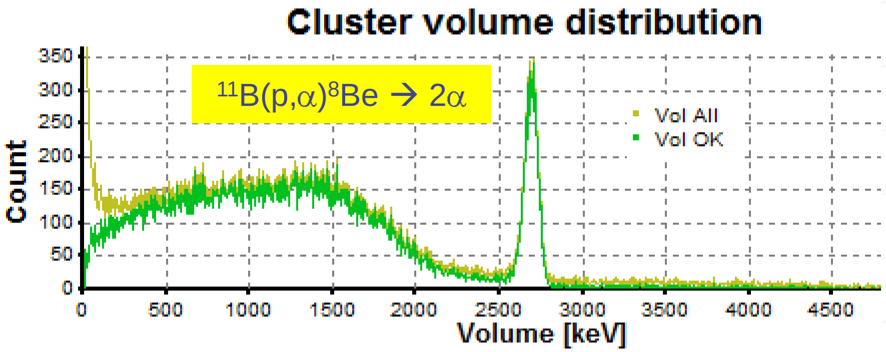
$^{1}H(p,p)^{1}H$ E_p = 2.65 MeV





$^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$ E_p = 2.65 MeV





Timepix + FITPix R/O interface + Pixelman SW:
Position– and energy– sensitive detection

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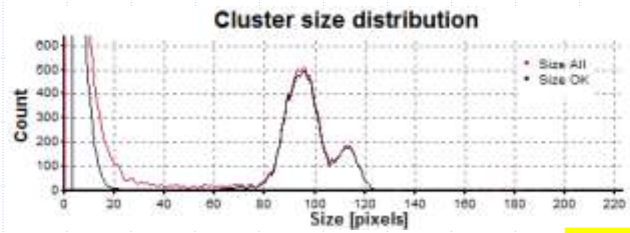
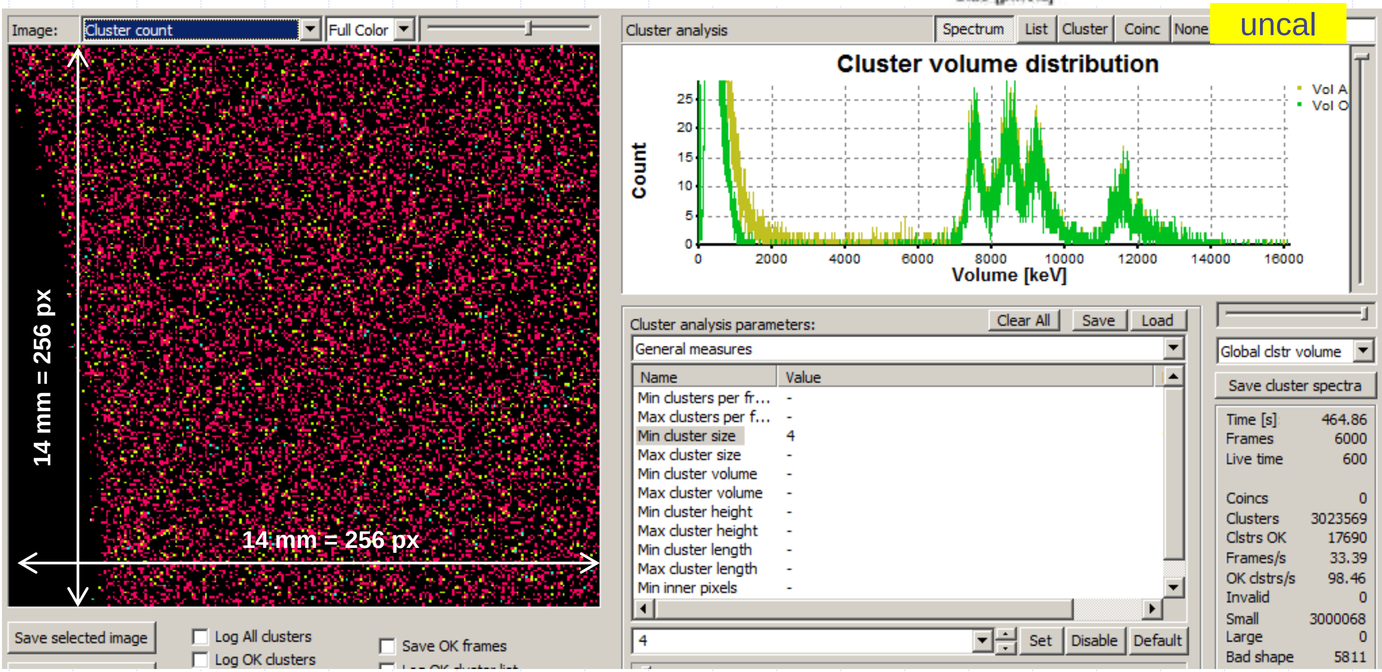
Distribution of signal event size (#'s px)

α's from ^{226}Ra in vacuum, KINR Kiev
VdG - 7.5.2013



Spatial distribution of event position

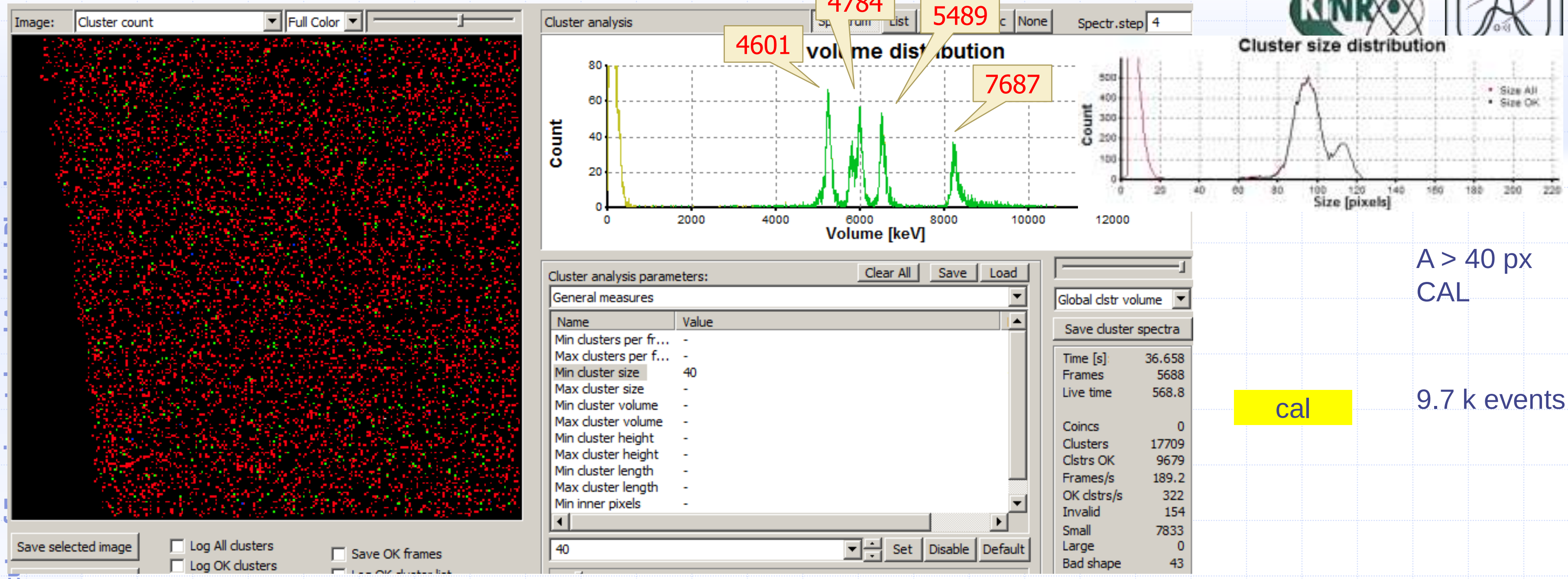


Energy (uncalibrated) spectrum

17.7 k events

1st frame: Fri May 17 18:29:22
Last frame: Fri May 17 18:43:03
Total # of frames acquired in 14 min total measuring time = 6 k. Total 17.7 k events with single filter condition (cluster area < 4 px). Acquisition time in the px detector (shutter time) = 0.1 s.

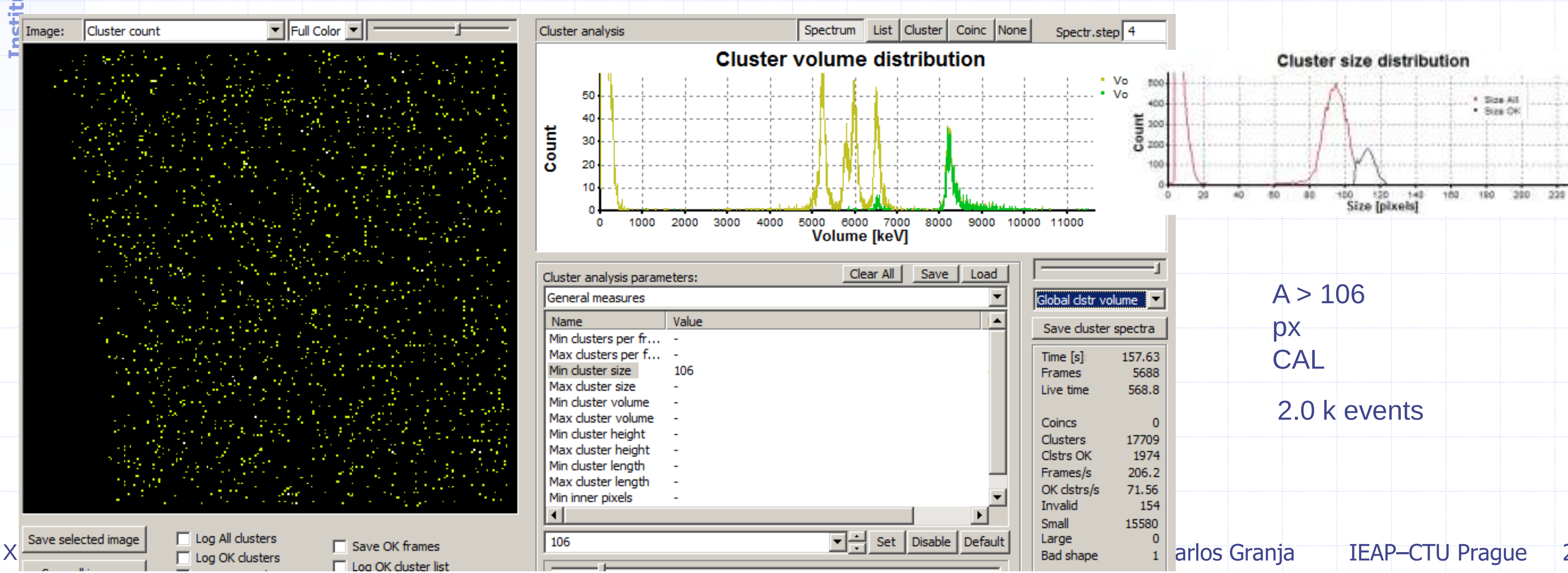
Partial distributions – according to energy range (as indicated by green curve)



A > 40 px
CAL

cal

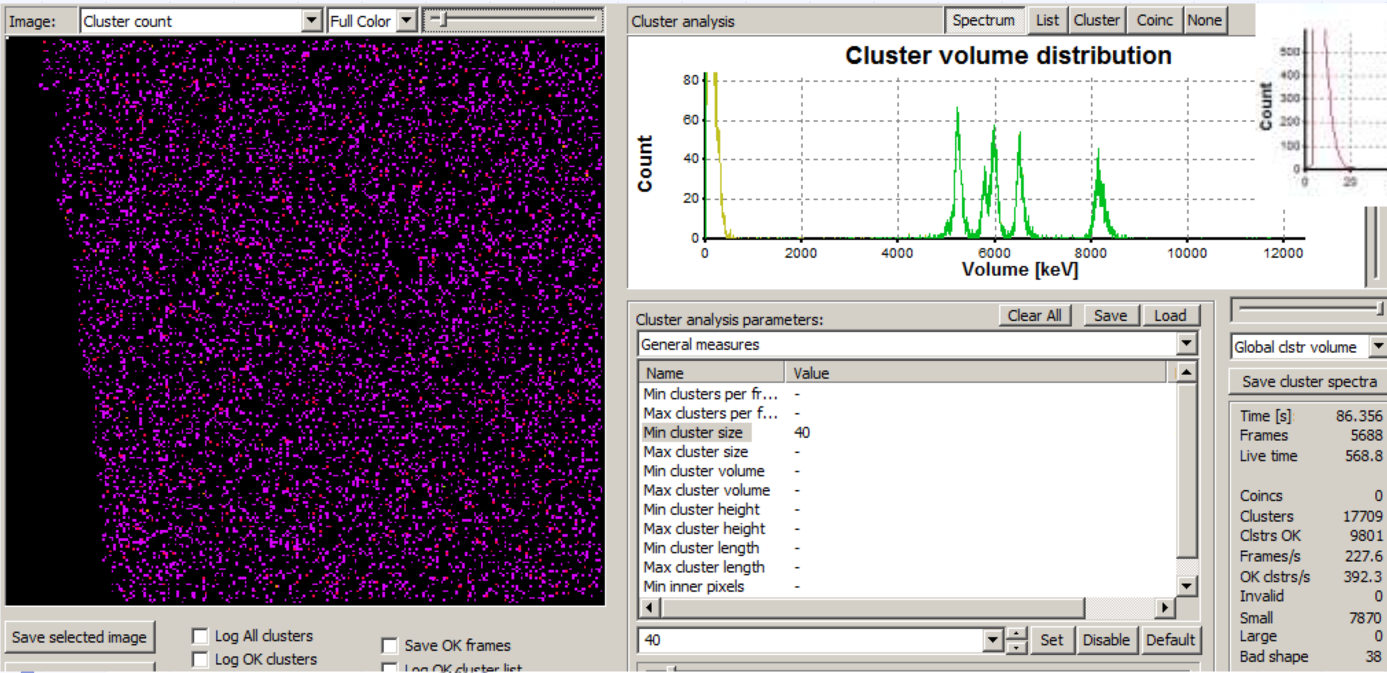
9.7 k events

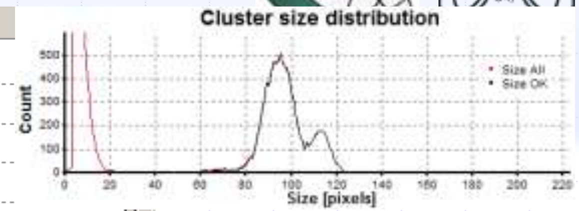


A > 106
px
CAL

2.0 k events

Partial distributions – according to energy range (as indicated by green curve)





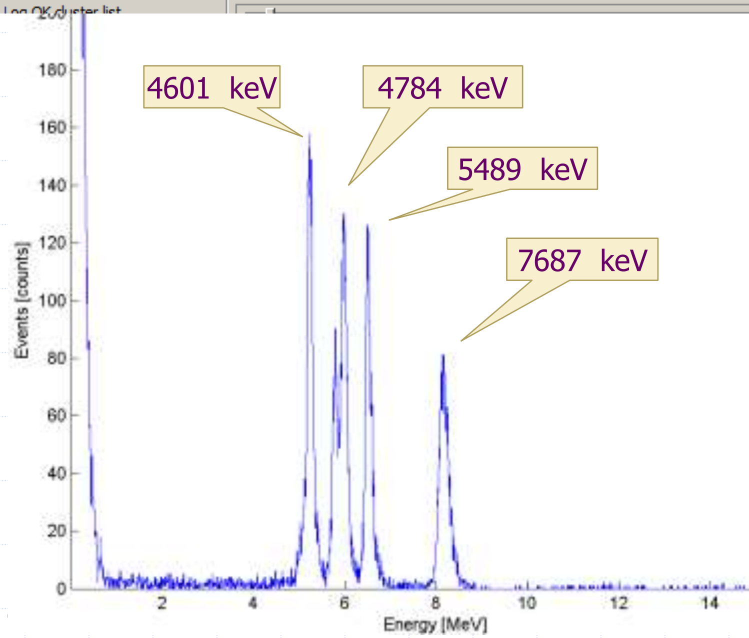
A > 40 px
CAL

cal

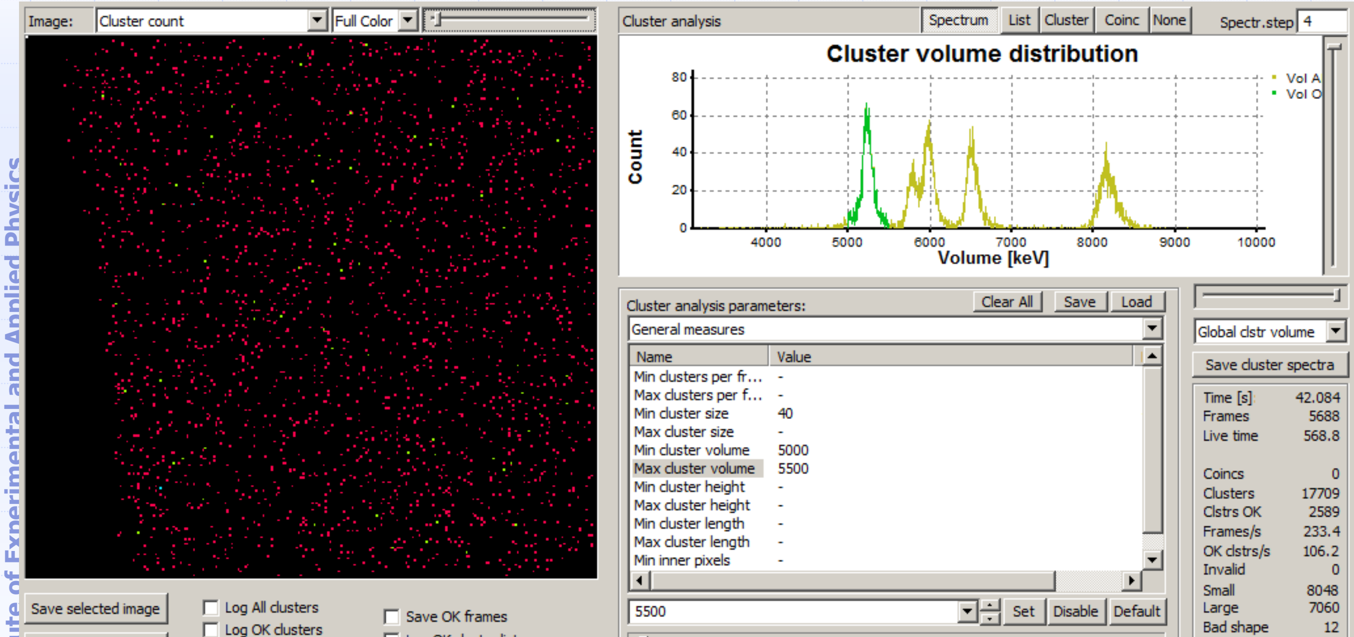
9.7 k events

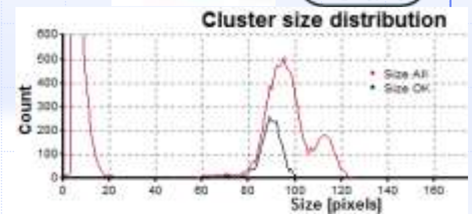
Corrected for per-pixel
ToT saturation/distortion

In



Partial distributions – according to energy range (as indicated by green curve)

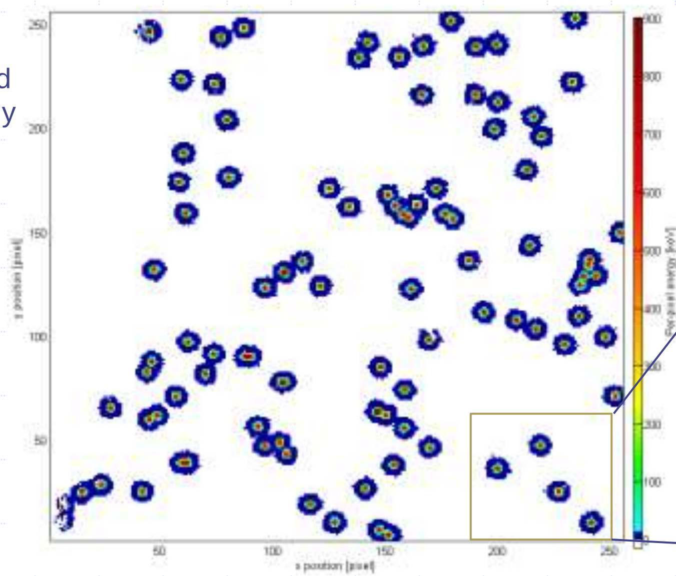


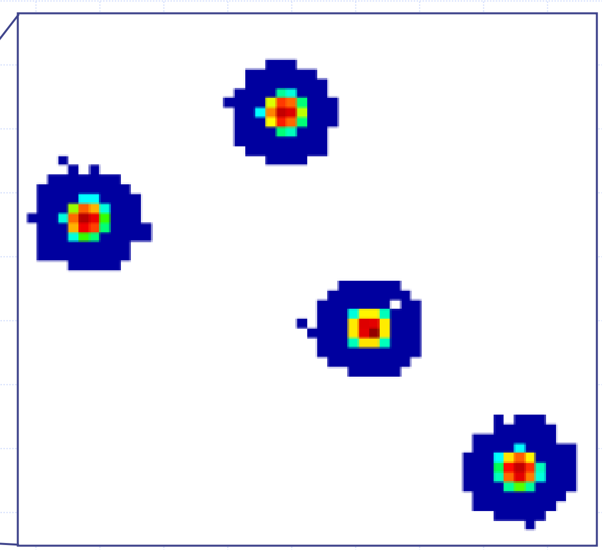


5.0 MeV < E < 5.5 MeV
CAL

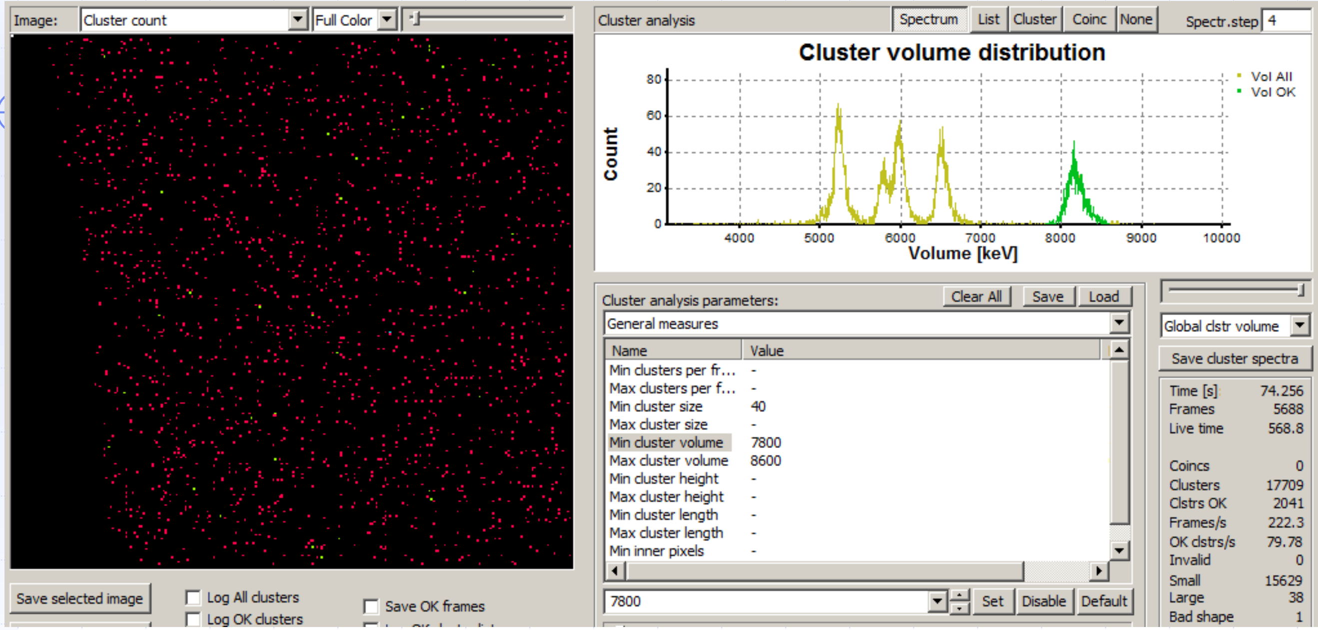
2.6 k events

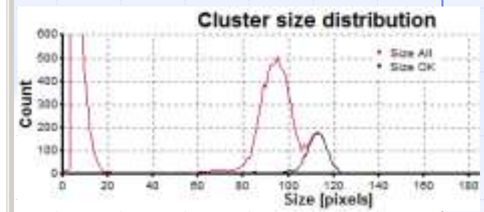
Integrated over many frames





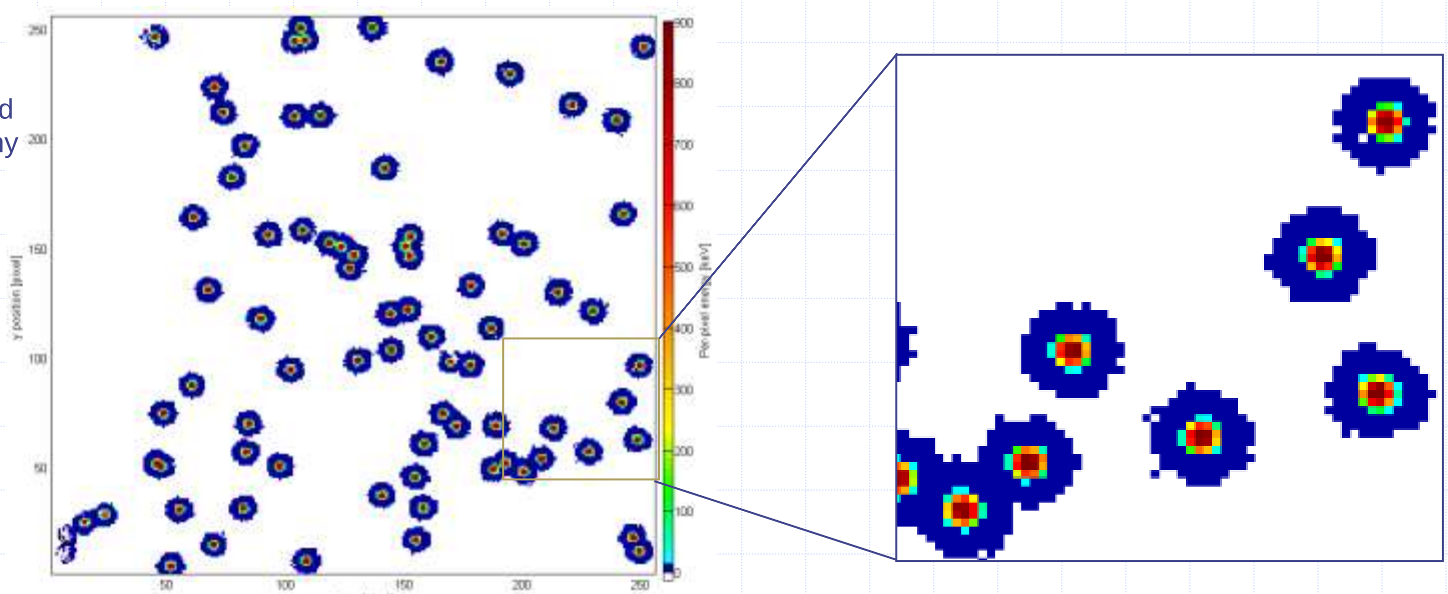
Partial distributions – according to energy range (as indicated by green curve)





7.8 MeV < E < 8.6 MeV
CAL
2.0 k events

Integrated over many frames



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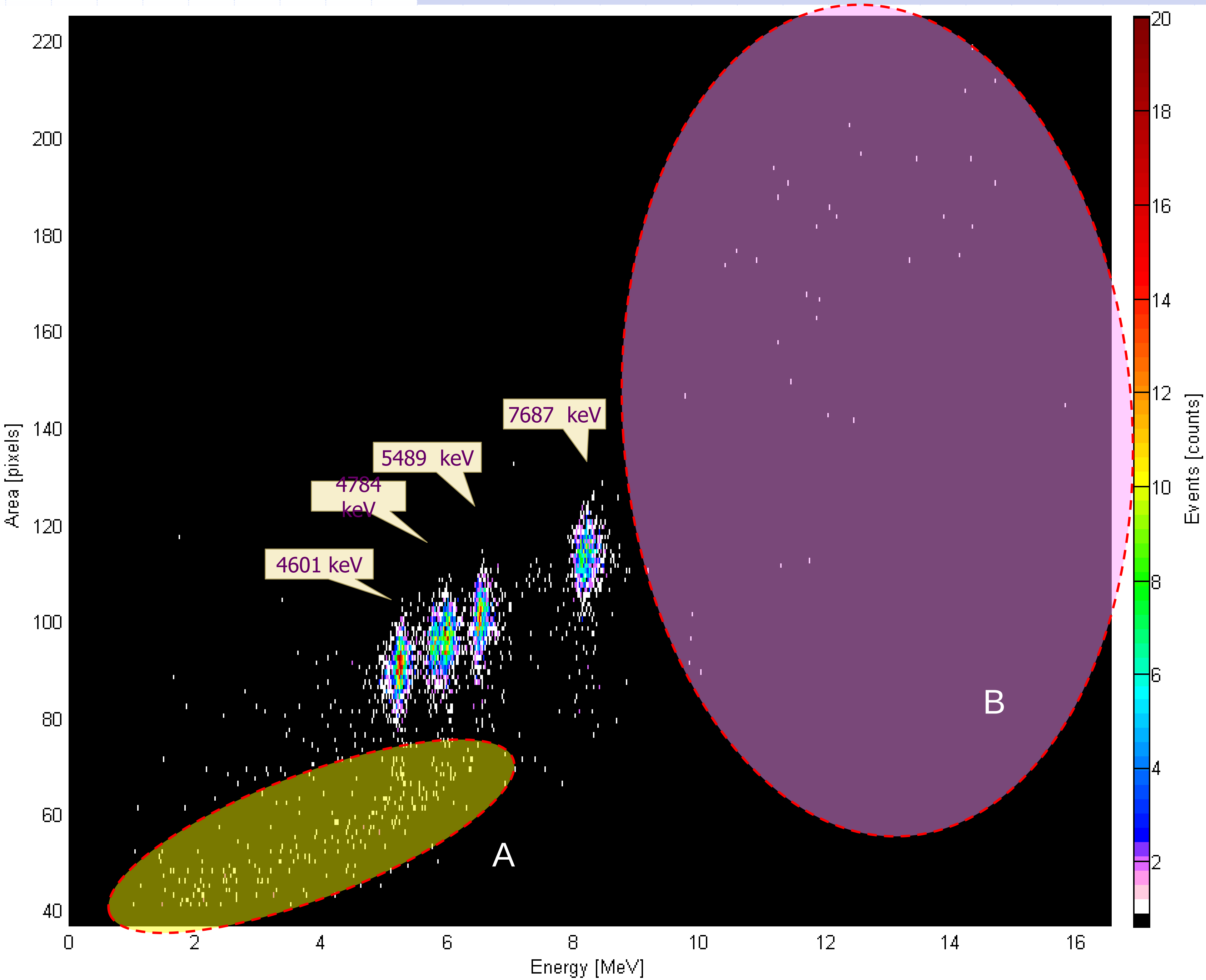


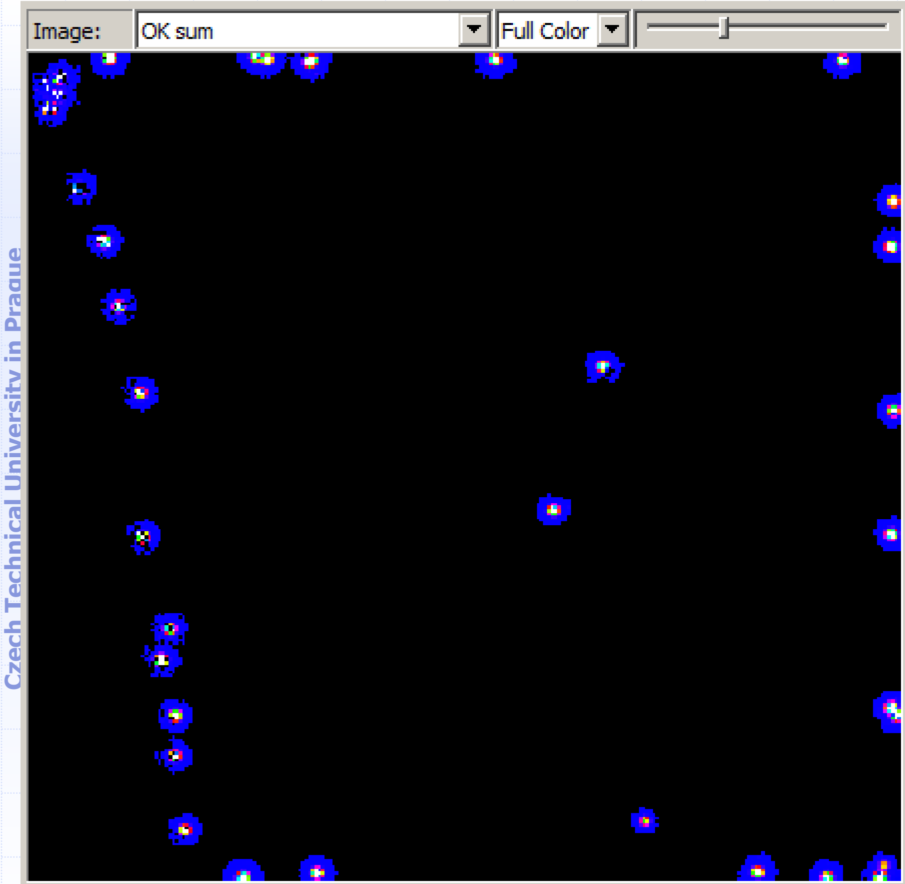
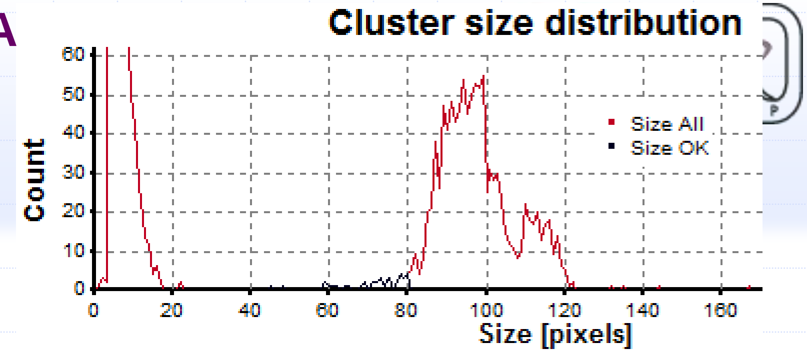
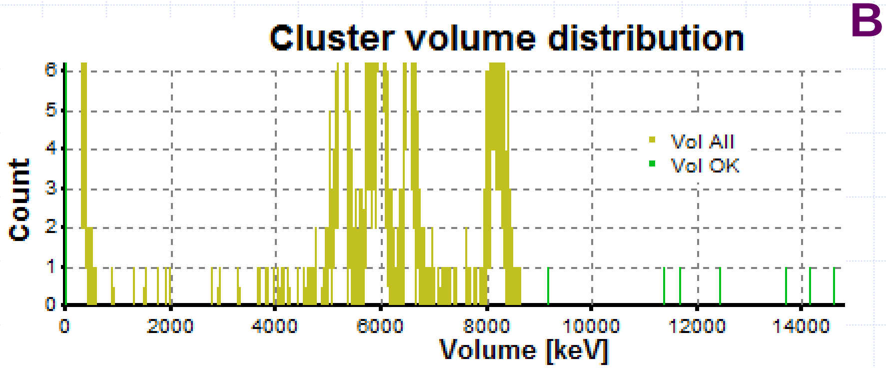


Image:
OK sum
Full Color

A


Cluster size distribution
Count
Size [pixels]
Size All
Size OK
0
10
20
30
40
50
60
0
20
40
60
80
100
120
140
160

B


Cluster volume distribution
Count
Volume [keV]
Vol All
Vol OK
0
1
2
3
4
5
6
0
2000
4000
6000
8000
10000
12000
14000

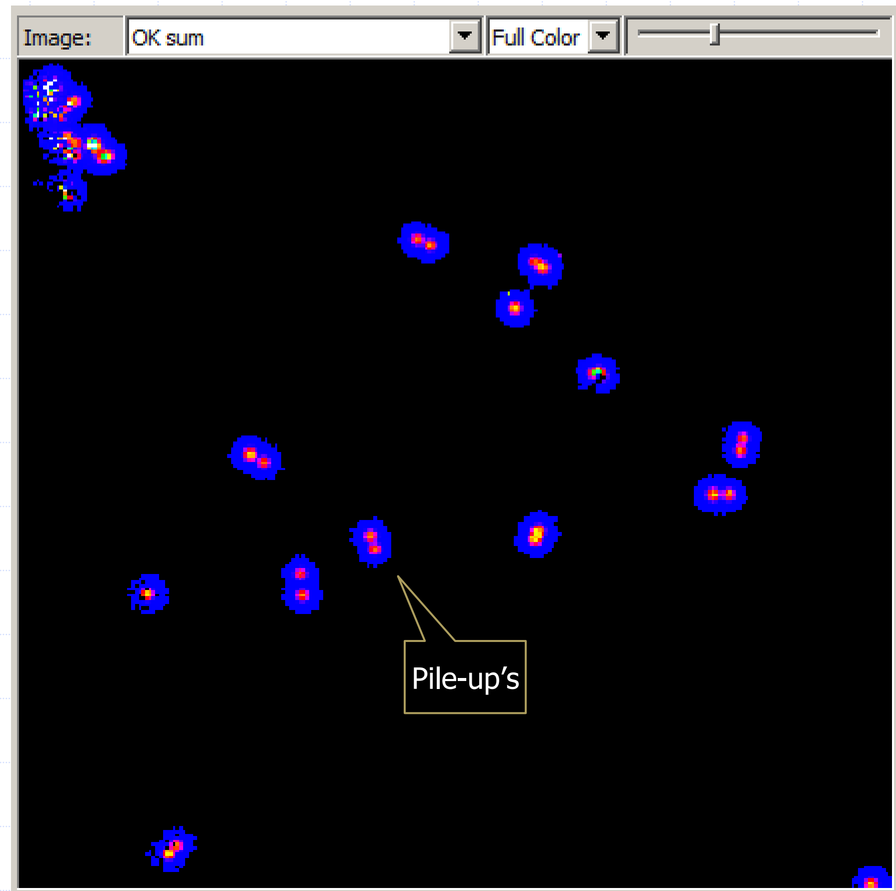


Image:
OK sum
Full Color
Pile-up's

2.65 MeV p + CH_4: p + p elastic scattering

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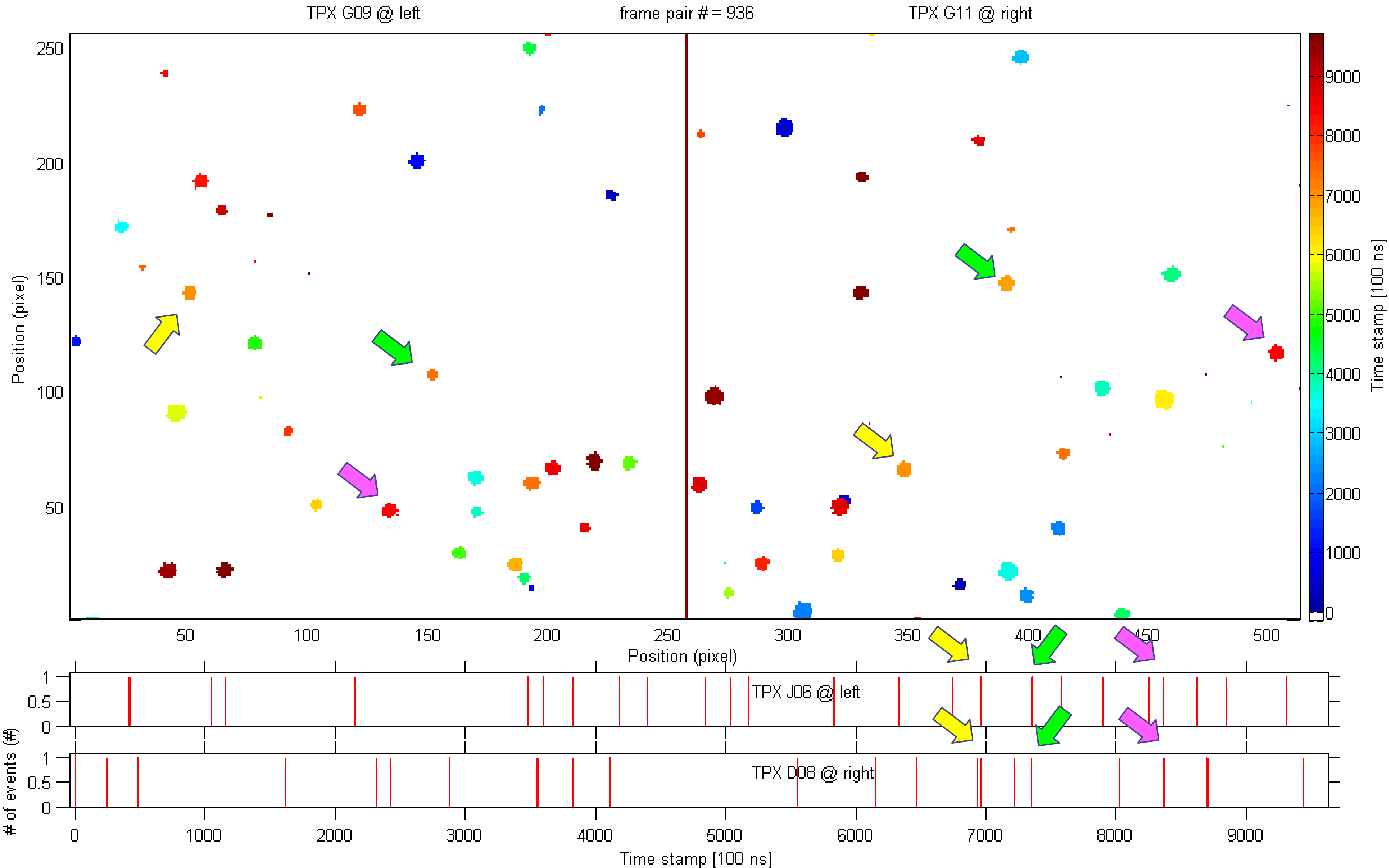
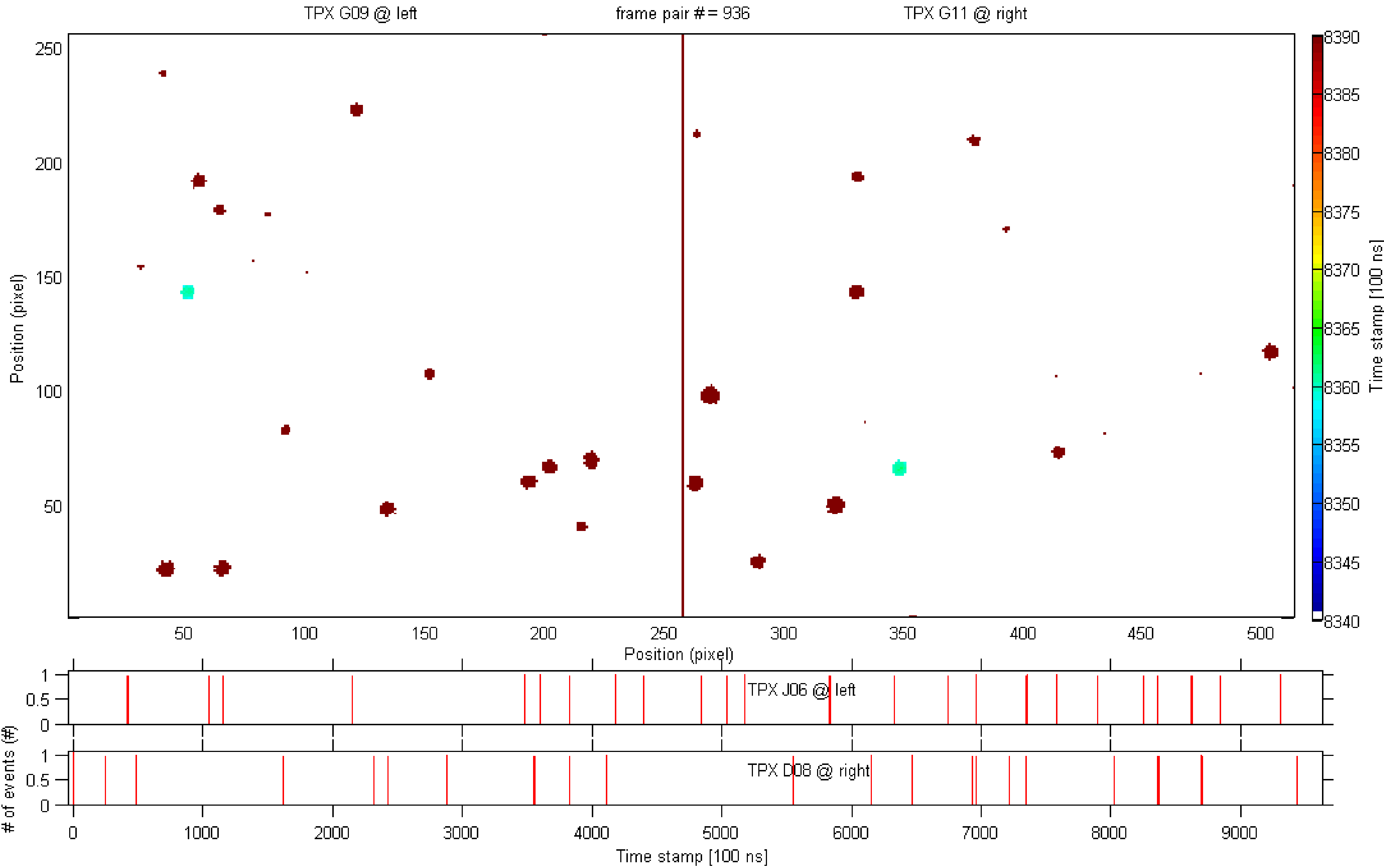
- Si diode (trigger) + 1x Timepix — tests, long data taken
- 2x Timepix in coincidence, sync DAQ — tests, more data
- 3x Timepix in coincidence, sync DAQ — future

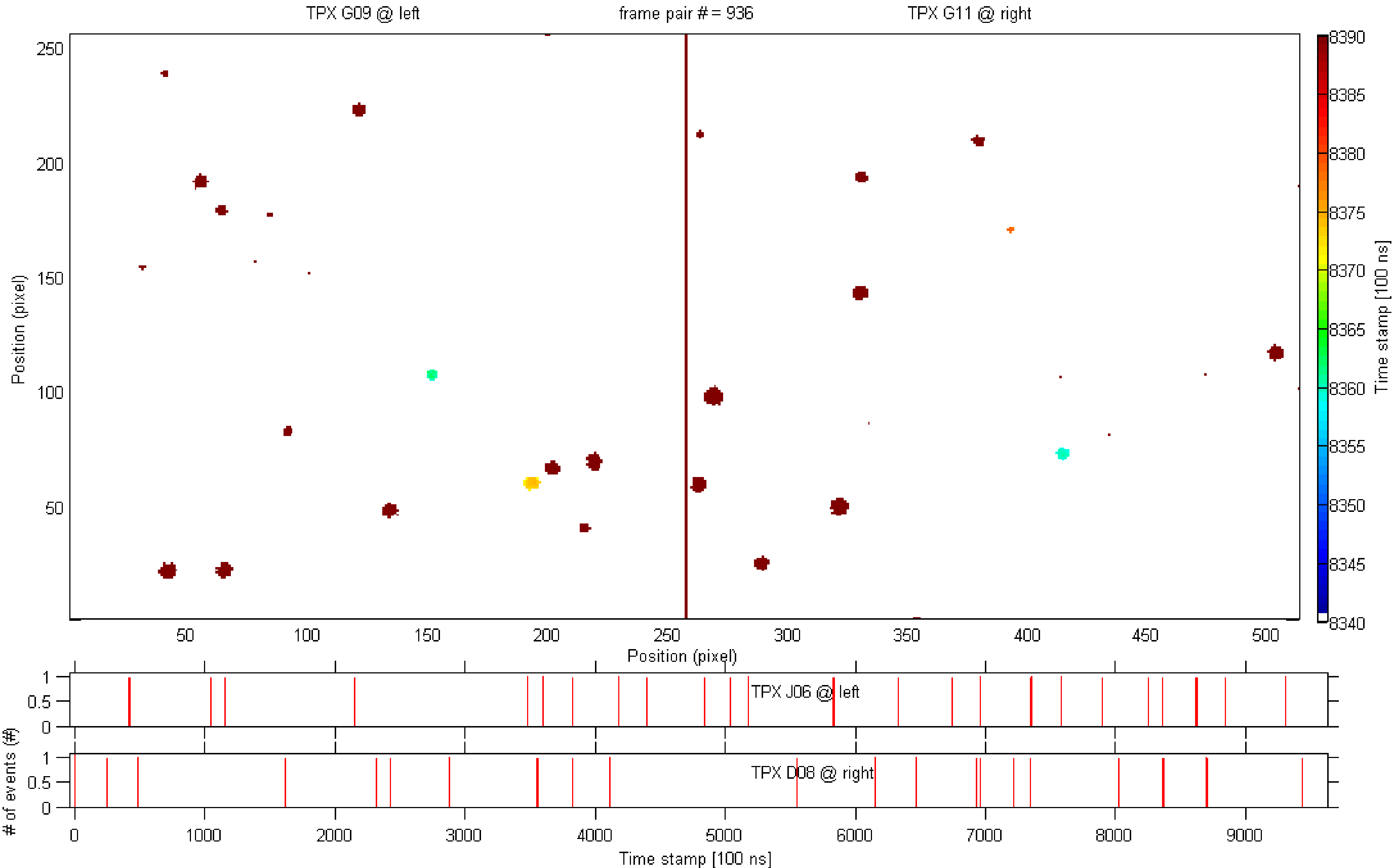
2.65 MeV p + CH_4: p + p elastic scattering



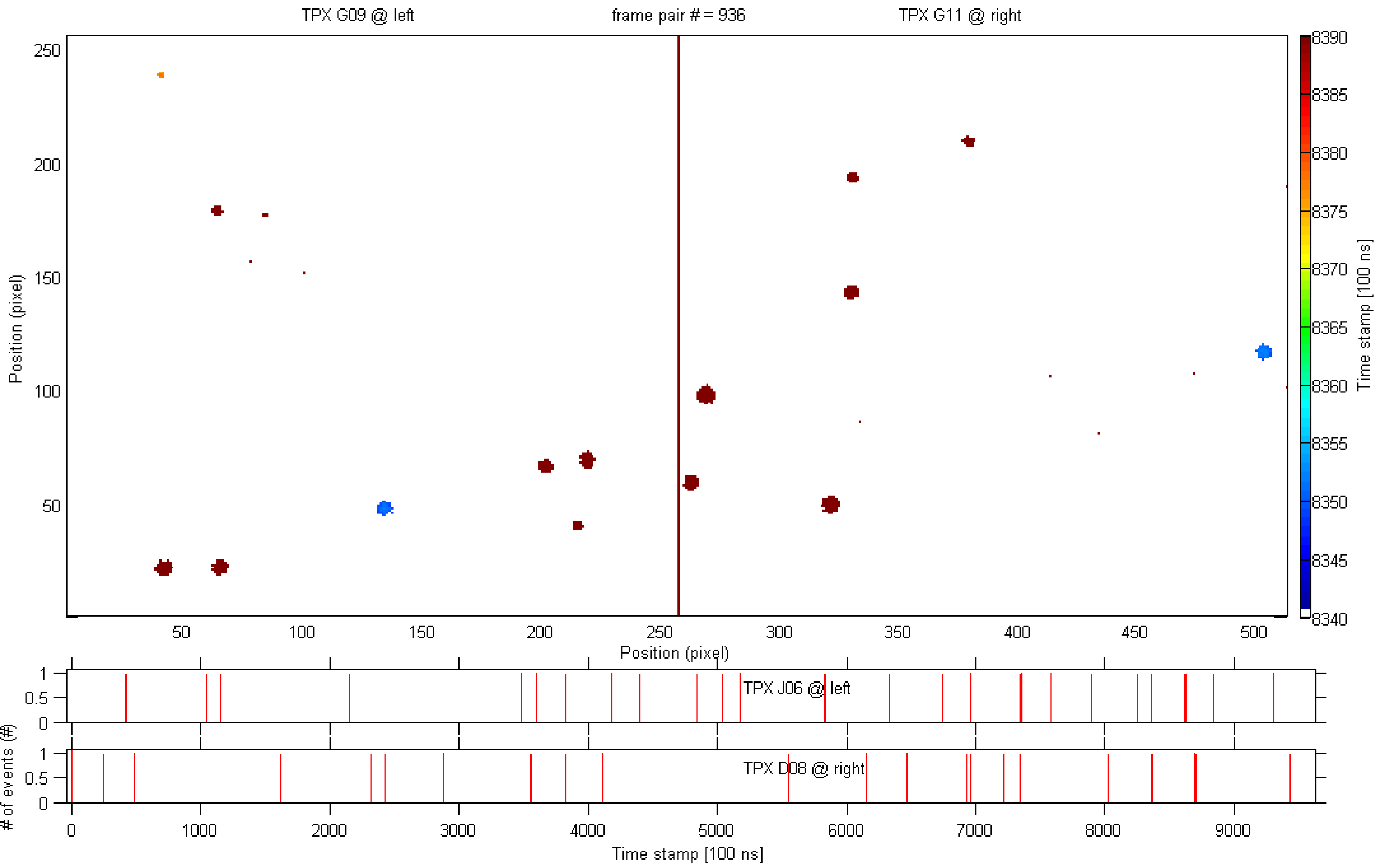
2.65 MeV p + CH_4: p + p elastic scattering



2.65 MeV p + CH_4: p + p elastic scattering

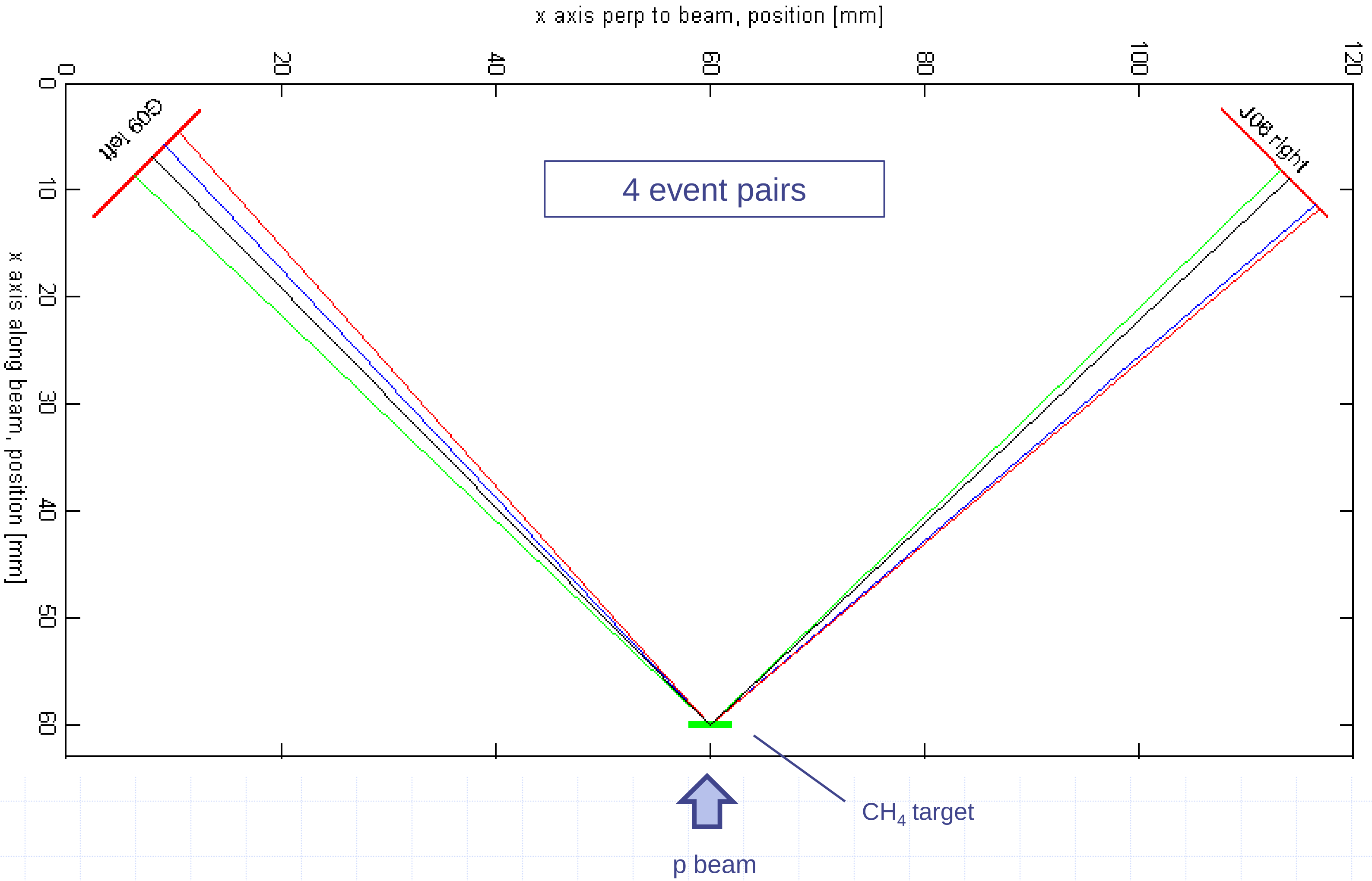


2.65 MeV p + CH_4: p + p elastic scattering



2.65 MeV p + CH_4: p + p elastic scattering

Geometry & vertex reconstruction: plane of the event pair



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2.65 MeV p + CH_4: p + p elastic scattering

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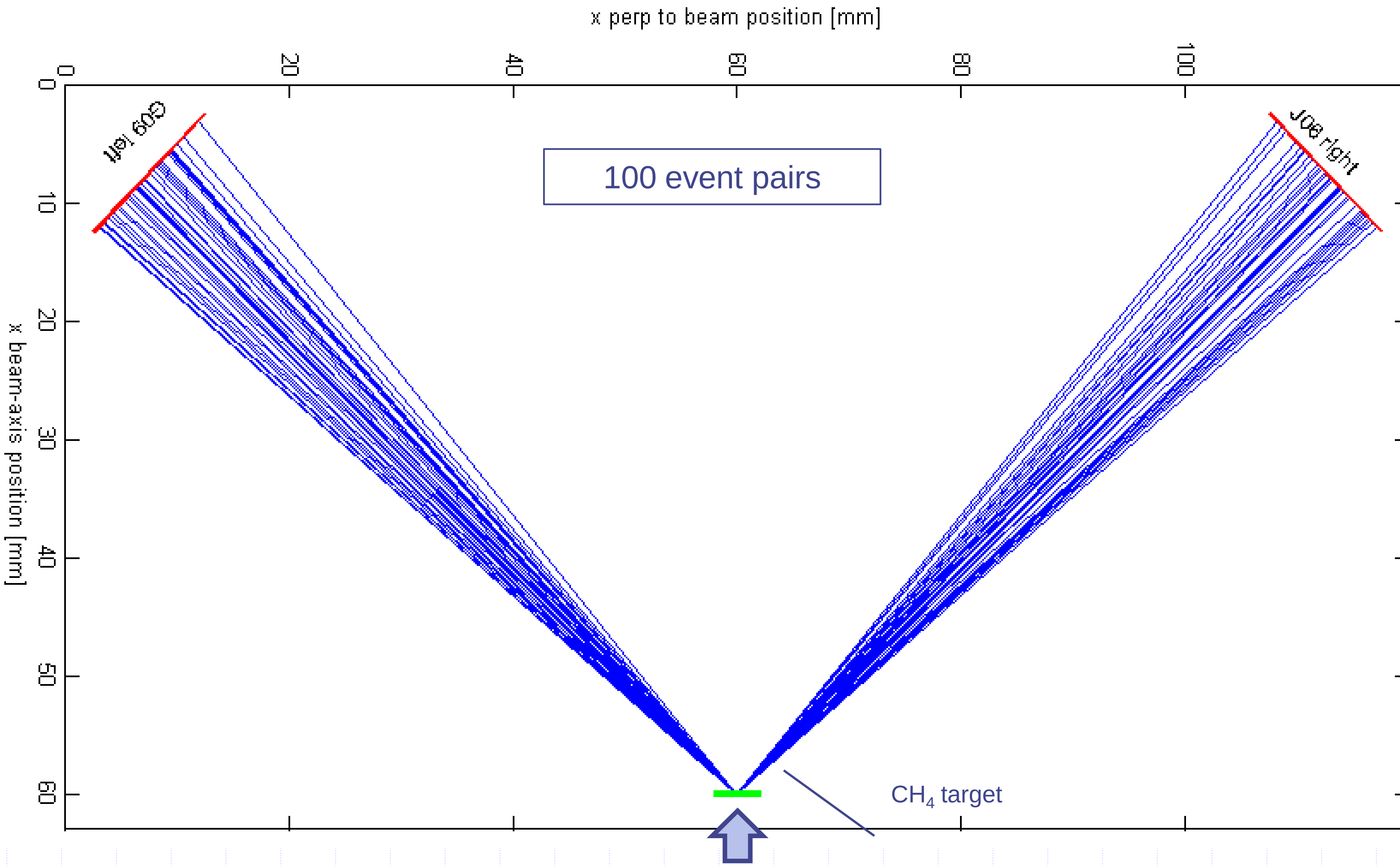
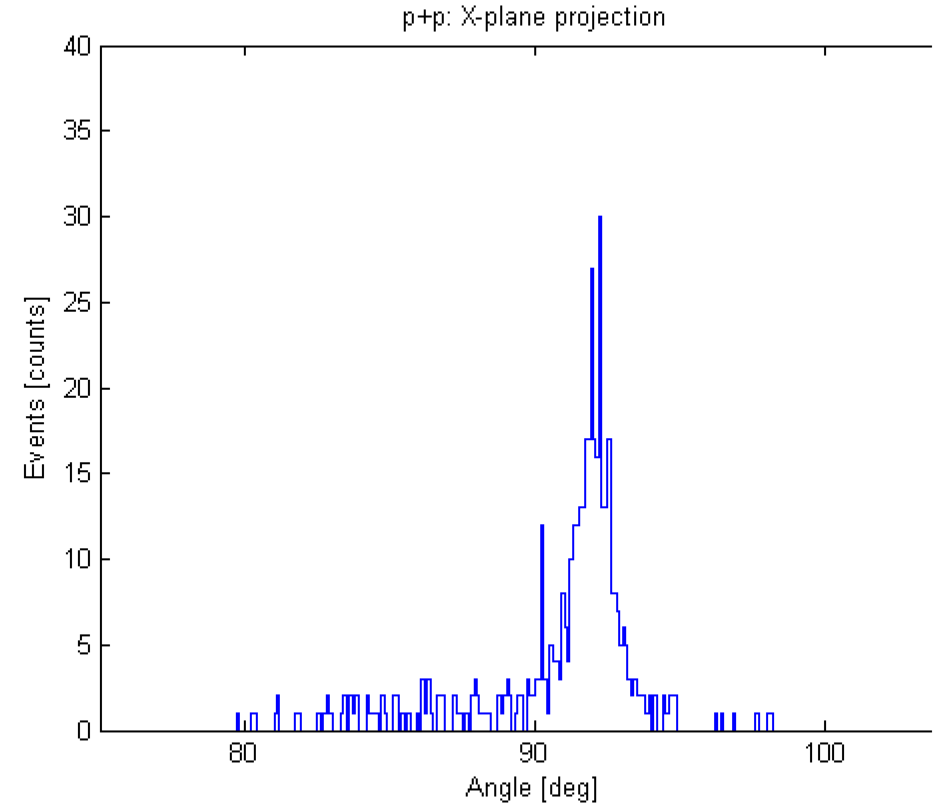
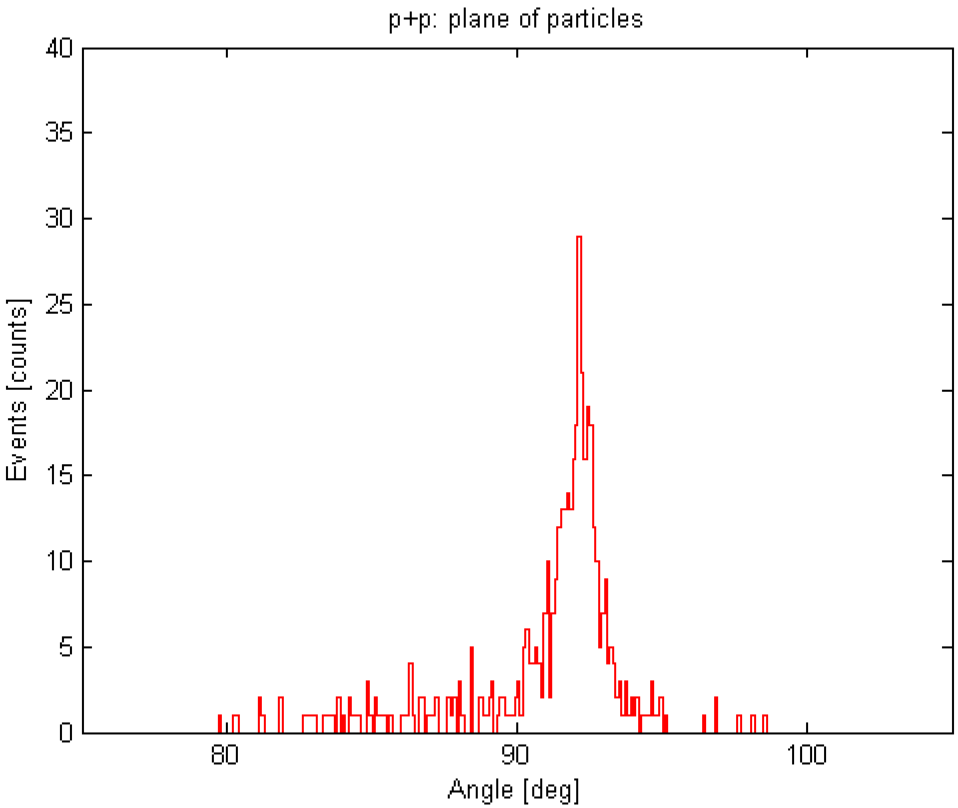
Geometry & vertex reconstruction: plane of the event pair



2.65 MeV p + CH_4: p + p elastic scattering

Distribution of angles

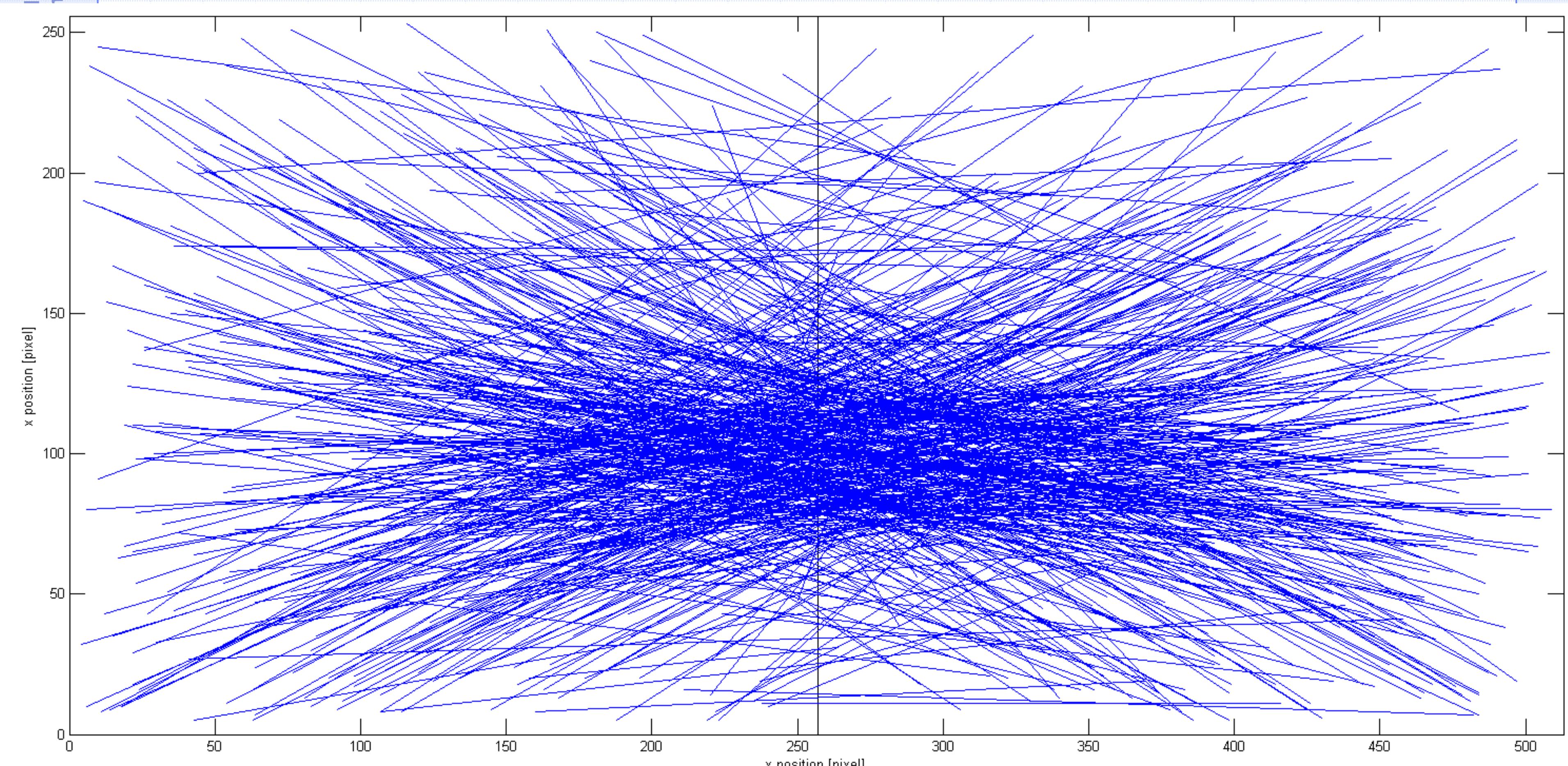




100 event pairs

2.65 MeV p + CH_4: p + p elastic scattering

Geometry & vertex reconstruction: plane of the detectors



left detector

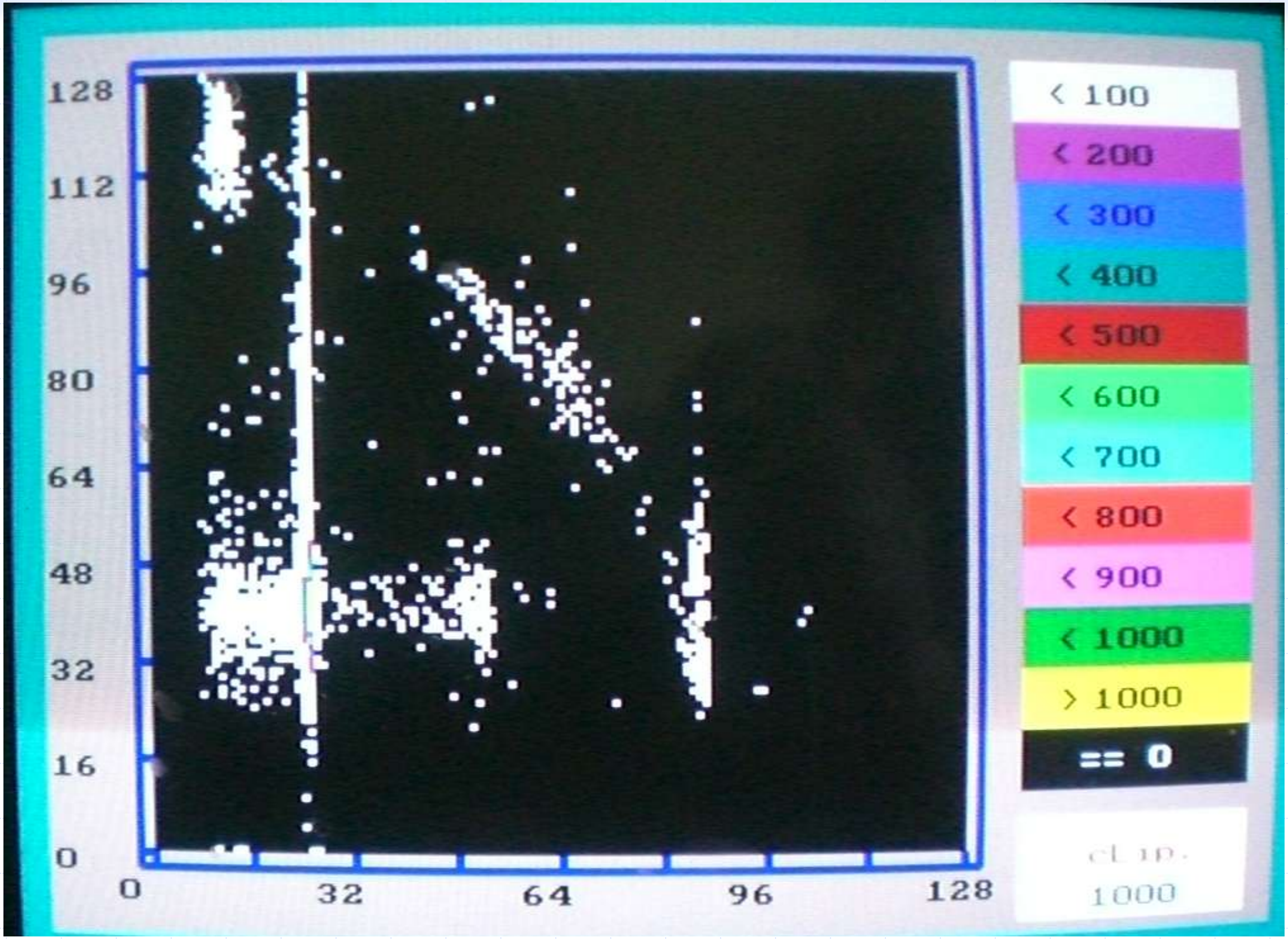
right detector

2.65 MeV p + ^{11}B: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$

Si diode + Timepix: setups

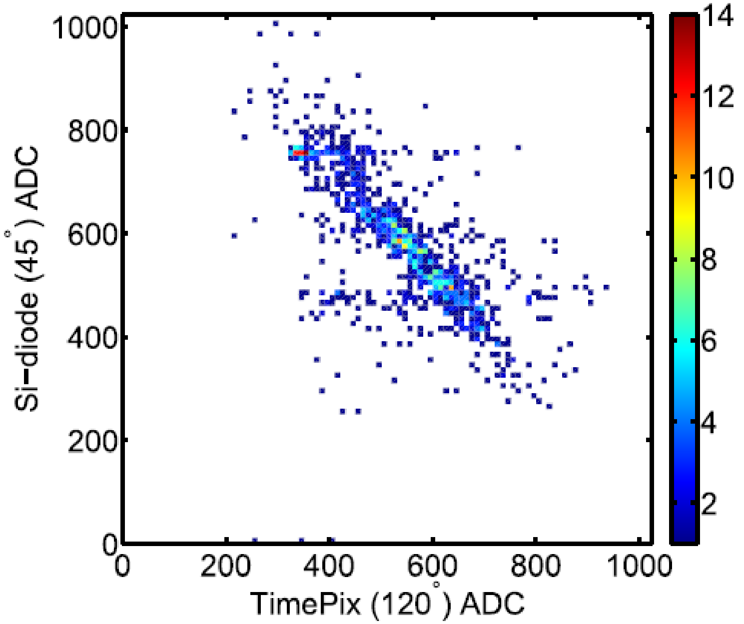
❑ Si diode (trigger) + 1x Timepix	tests, long data taken
❑ 2x Timepix in coincidence, sync DAQ	tests, more data
❑ 3x Timepix in coincidence, sync DAQ	future

Correlation: on-line
Si diode & Timepix analog signal



Correlation: off-line
Si diode & Timepix pixelated signal

Coincidence between Si-diode (45°) and TimePix (120°) in $^{11}B + p \rightarrow 3\alpha$ reaction.
Processed files: D00.028-D00.034



2.65 MeV p + ^{11}B: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$

Si diode (trigger) + Timepix

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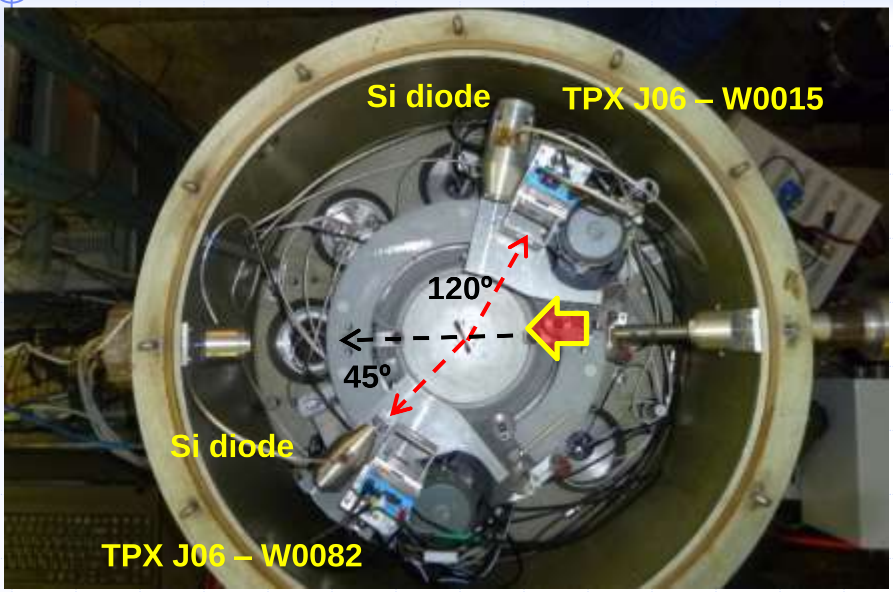
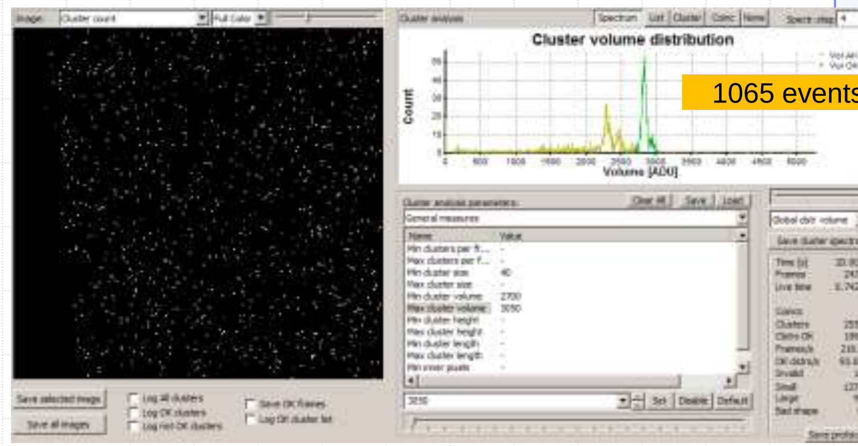
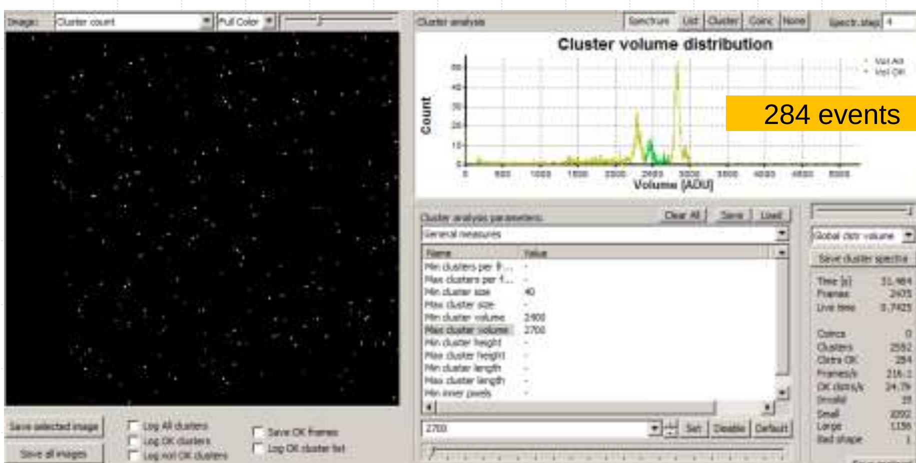
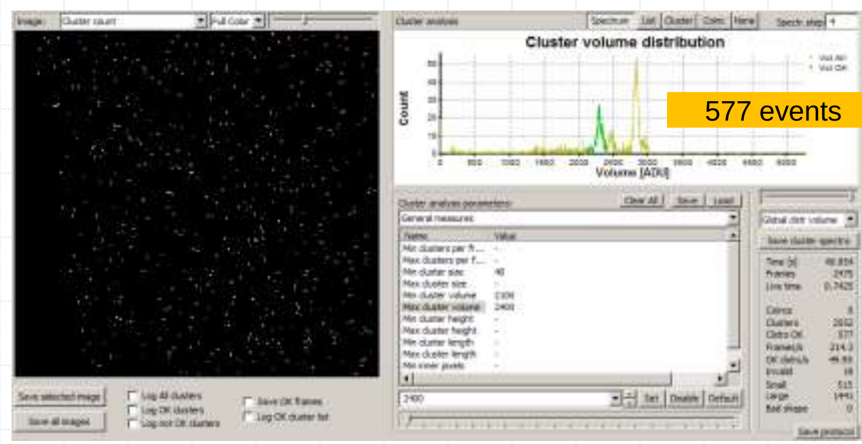


Spatial distribution

Energy spectra

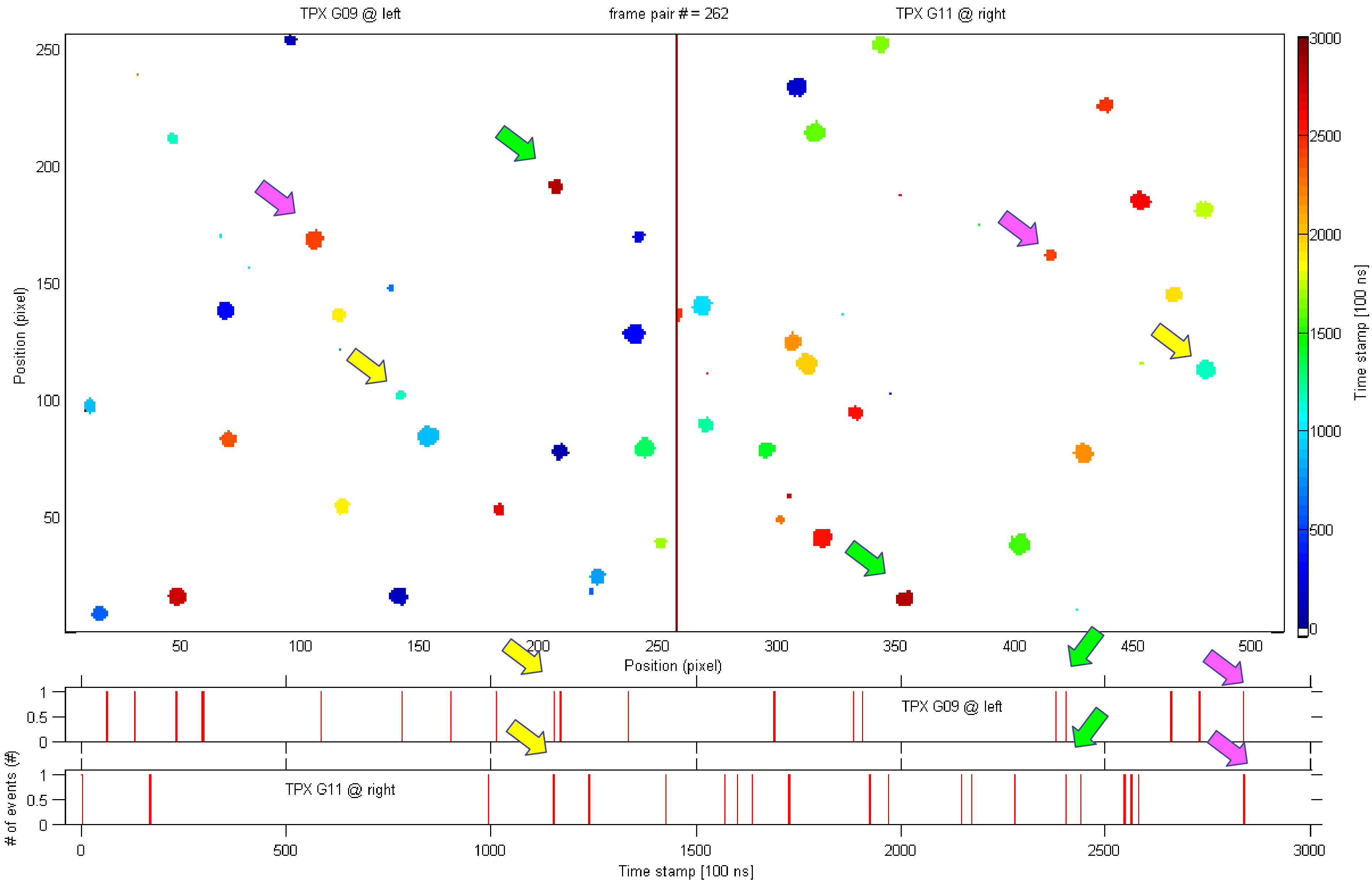




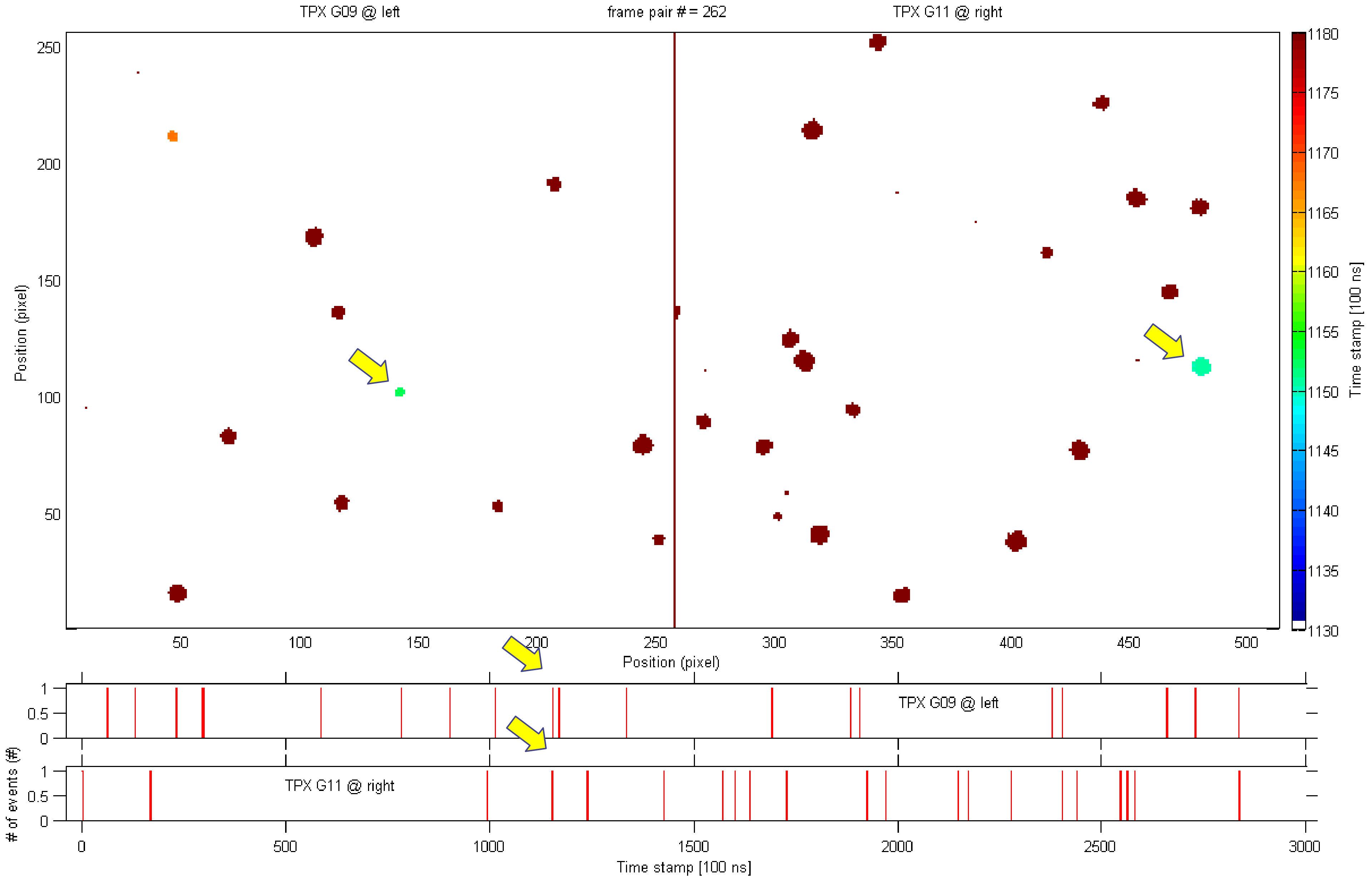


2.65 MeV p + ^{11}B: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$

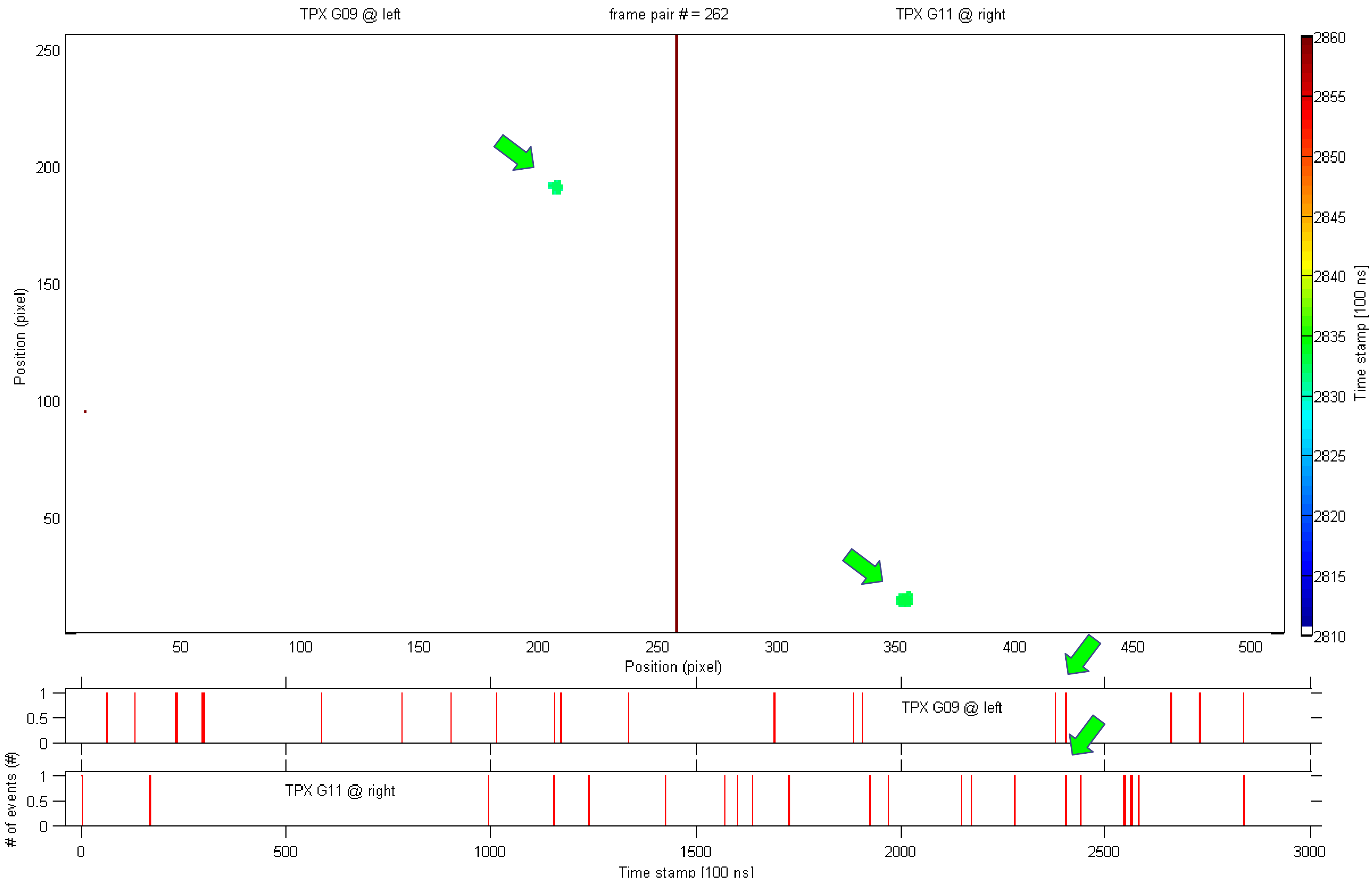
2x Timepix in sync



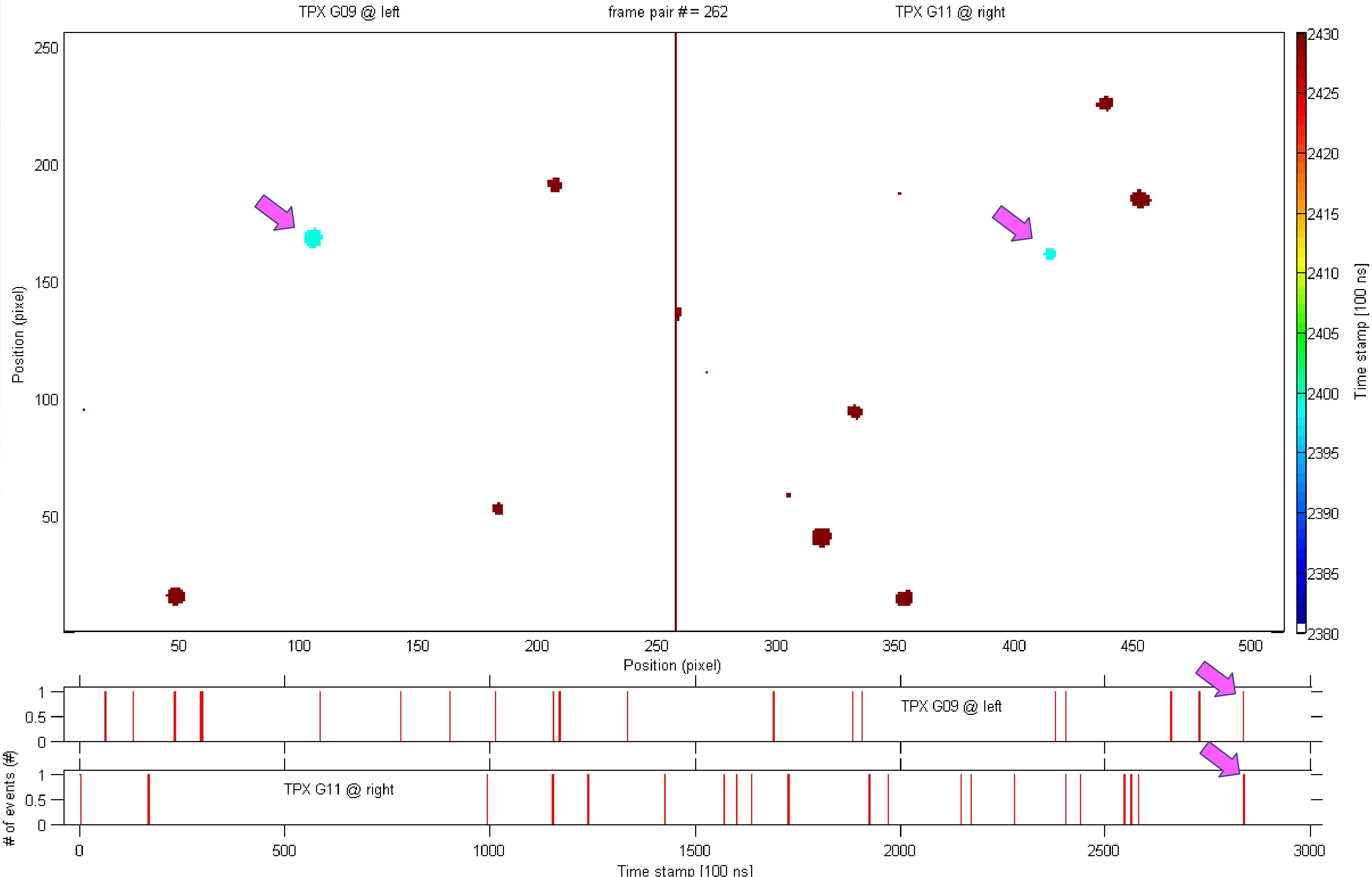
2.65 MeV p + ^{11}B: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$
2x Timepix in sync



2.65 MeV p + ^{11}B: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$
2x Timepix in sync



2.65 MeV p + ^{11}B: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$
2x Timepix in sync



2.65 MeV p + ^{11}B: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$

Si diode (trigger) + Timepix

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In 1 k f's, each 0.3 ms → total measuring t = 300 ms, found 393 pairs.

Lister - [E:\data\...

File Edit Options Encoding Help 31 %

218	2635
226	1691
226	1691
228	450
230	699
231	530
232	951
242	572
245	1822
245	2126
248	560
250	1371
250	748
252	179
256	672
259	1194
262	2399
262	2832
262	1152
263	1690
265	2849
265	120
267	320
268	384
286	1631
289	2299
295	1696
297	1127

2.65 MeV p + ^{11}B: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$

2x Timepix in sync

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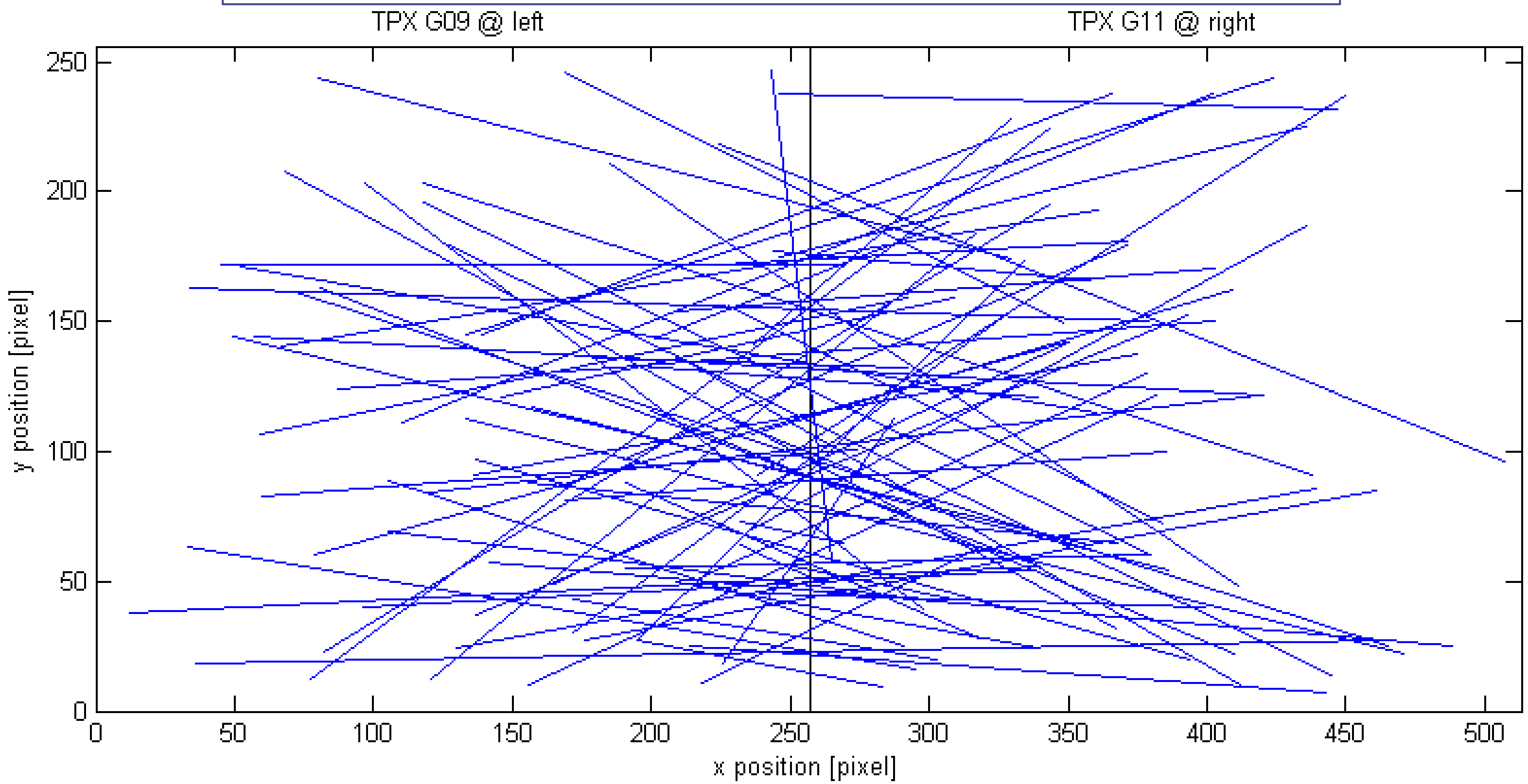
Geometry & vertex reconstruction: plane of the detectors



80 pairs

2.65 MeV p + ^{11}B: $^{11}B(p,\alpha)^{8}Be \rightarrow 2\alpha$
2x Timepix in sync

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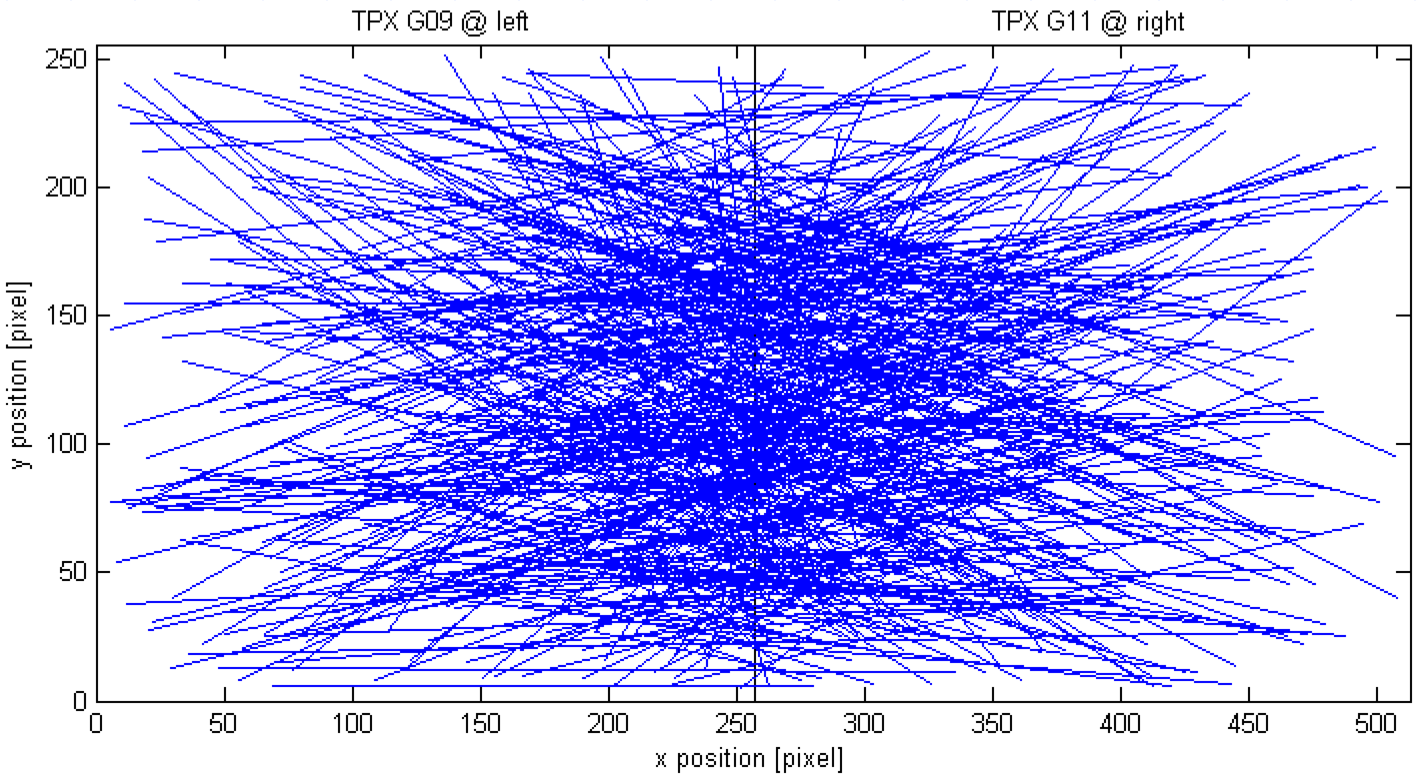
Geometry & vertex reconstruction: plane of the detectors



390 pairs

Further analysis and work in progress

Conclusions

- The granularity and per-pixel energy/time sensitivity of Timepix allows performing spatial- and time-correlated detection of reaction products with high spatial and time resolution and enhanced signal-to-noise resolving power
- Constructed a modular and configurable setup based on the semiconductor pixel detector Timepix and single silicon diode detectors for complete kinematics studies of three-, and four-particle final state reactions
- Instrumentation
  - Developed, configured, calibrated
  - Tested, demonstration of proof-of-principle
- Tests & experiments
  - Tests and proof-of-principle measurements done
  - Long measurements started
- Extension at
  - other resonances
  - Lower p energies (100 keV – 300 keV)

Acknowlegments:

- This work is direct application of instrumentation and know-how developed in frame of fission project together with the FLNP JINR Dubna group (Y. Kopatch, S.A. Telezhnikov, G. Ahmedov)
- We thank Volodymyr Ostashko, and Yurij Pavlenko (KINR NASU, Kiev).
- Research carried out in frame of the Medipix Collaboration
- We thank the XXI ISINN organizers