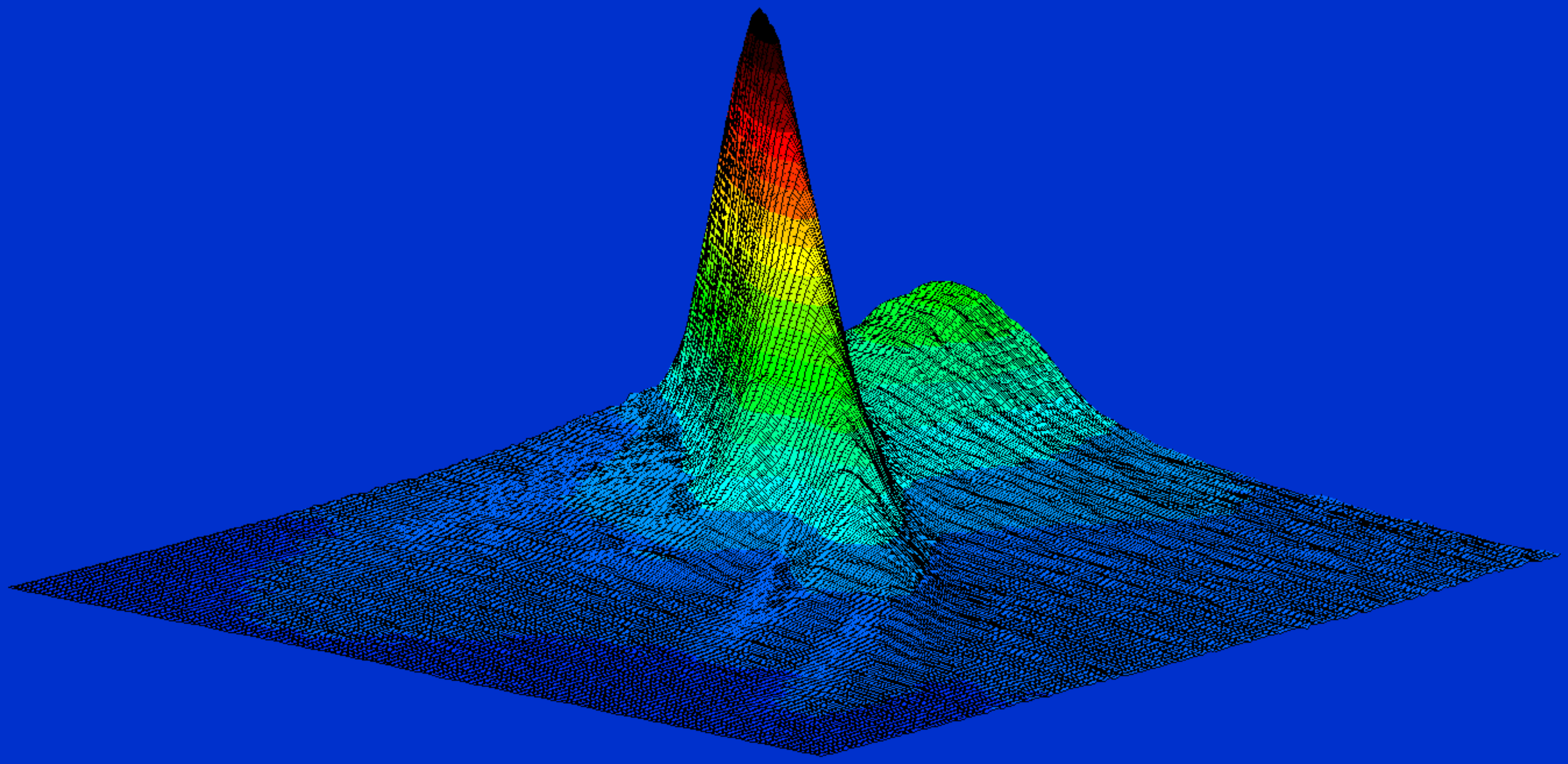
Telescope energy spectra and the Ockham's razor

(on the possibility to identify and calibrate the KRATTA punch through hits)



Busan, 10-13 September 2018

Supported by Polish National Science Center, contract No. UMO-2017/25/B/ST2/02550

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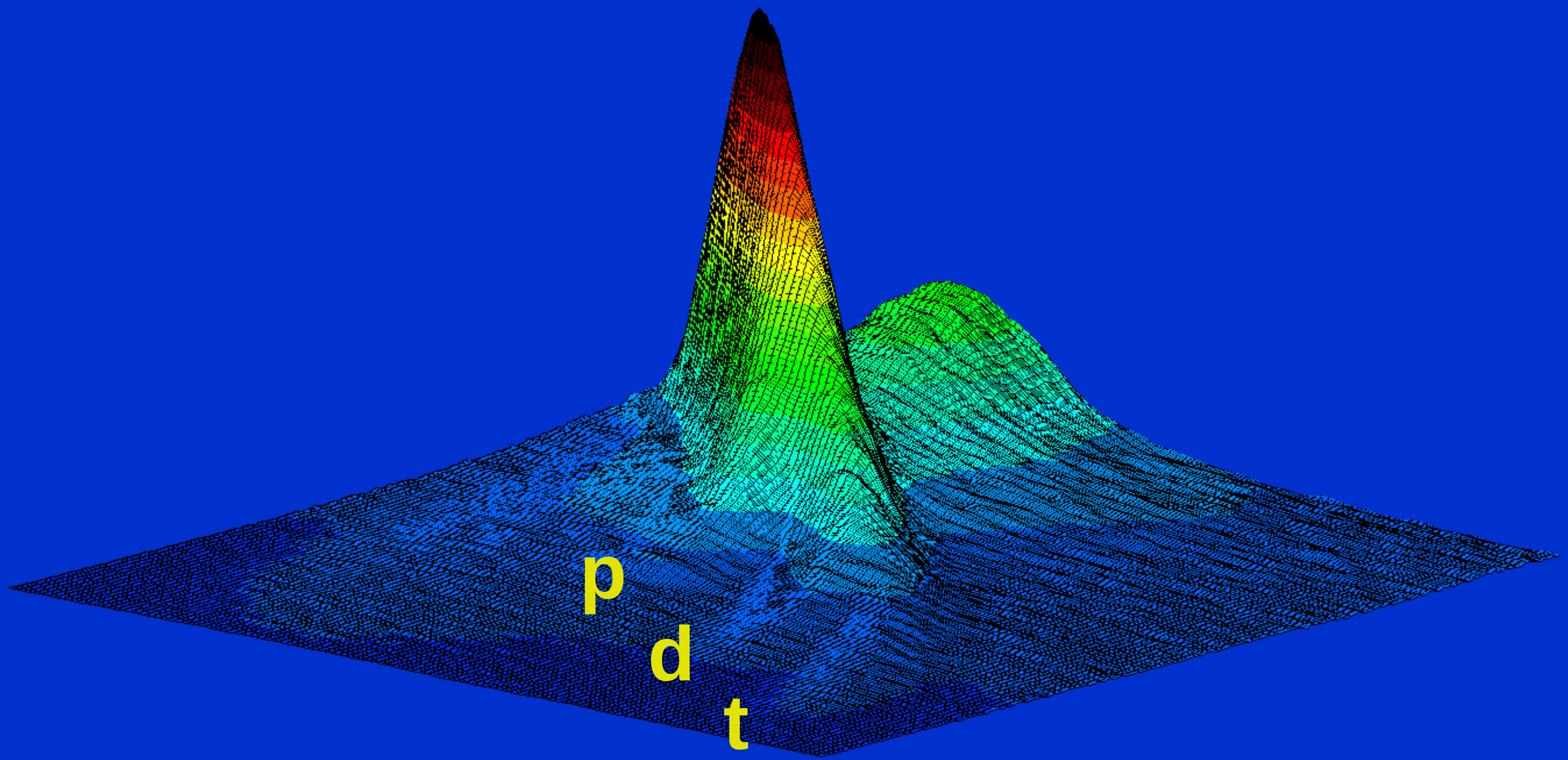

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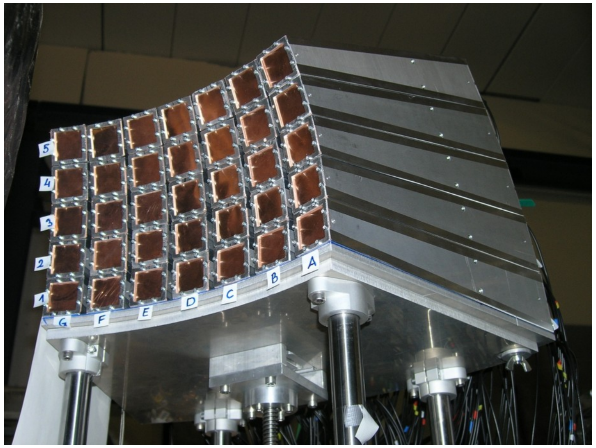
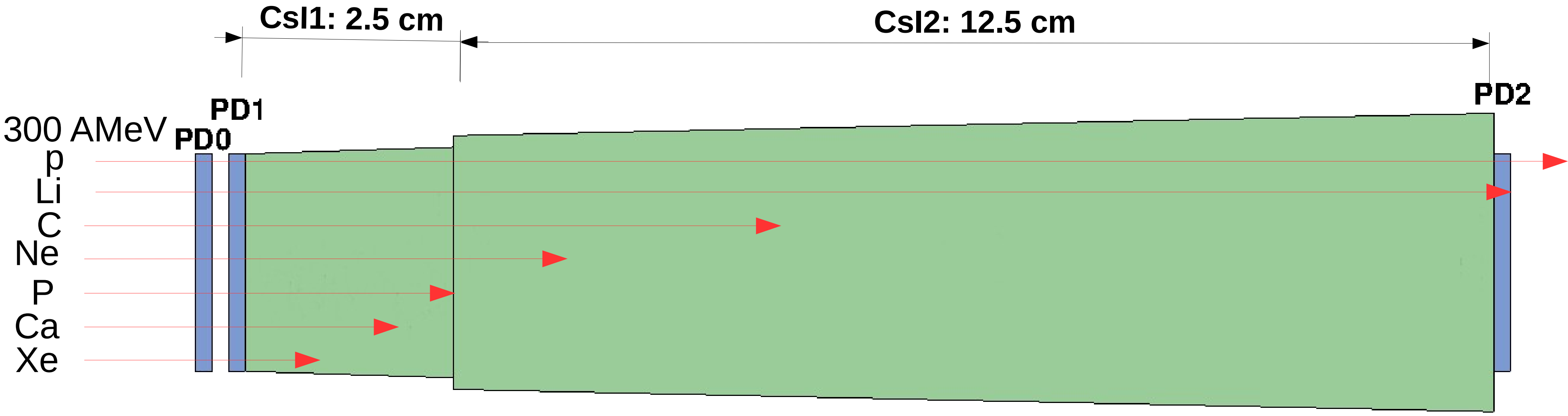
Outline

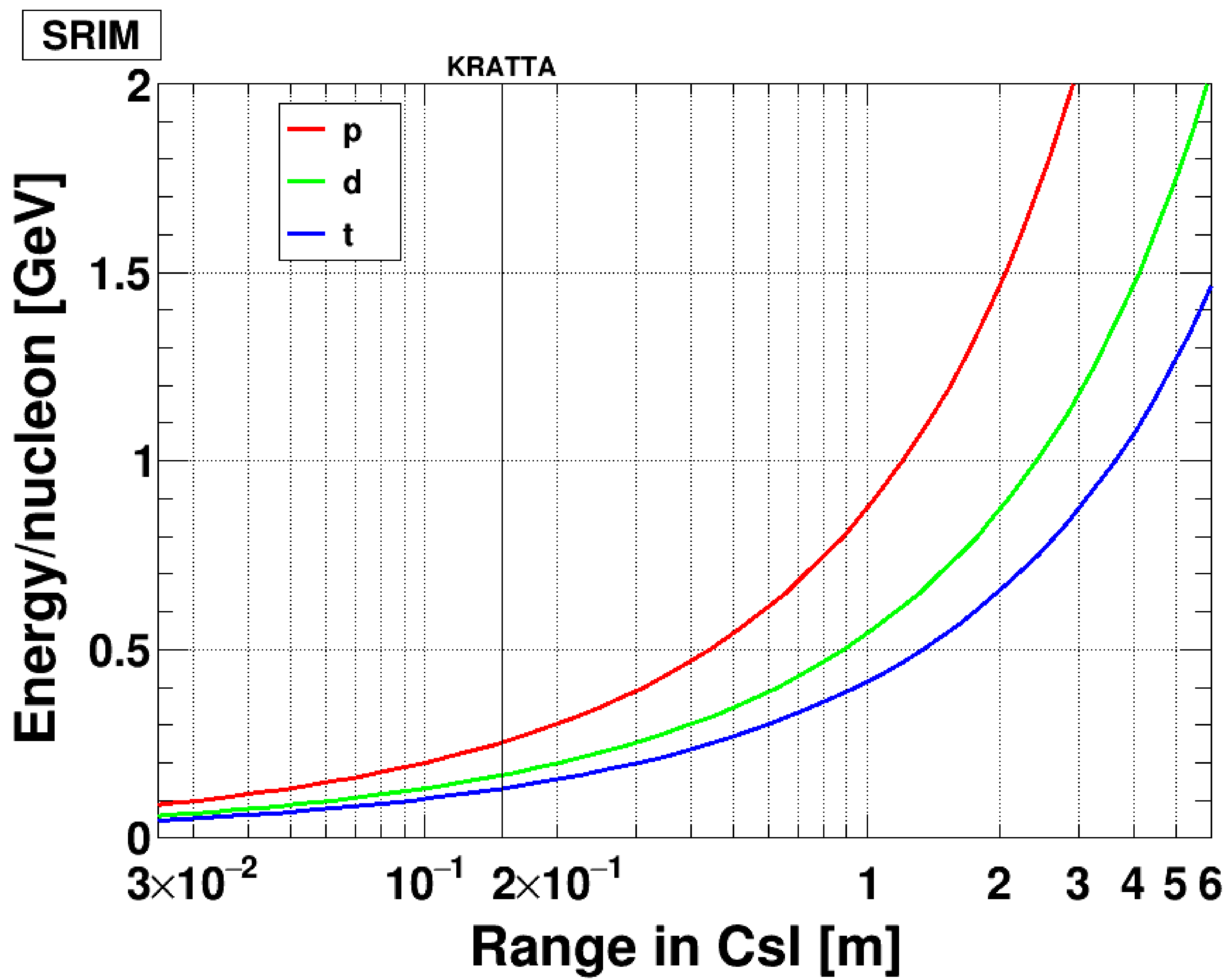
- limitations of the telescope method
- a way to go beyond
- is it worth the effort?



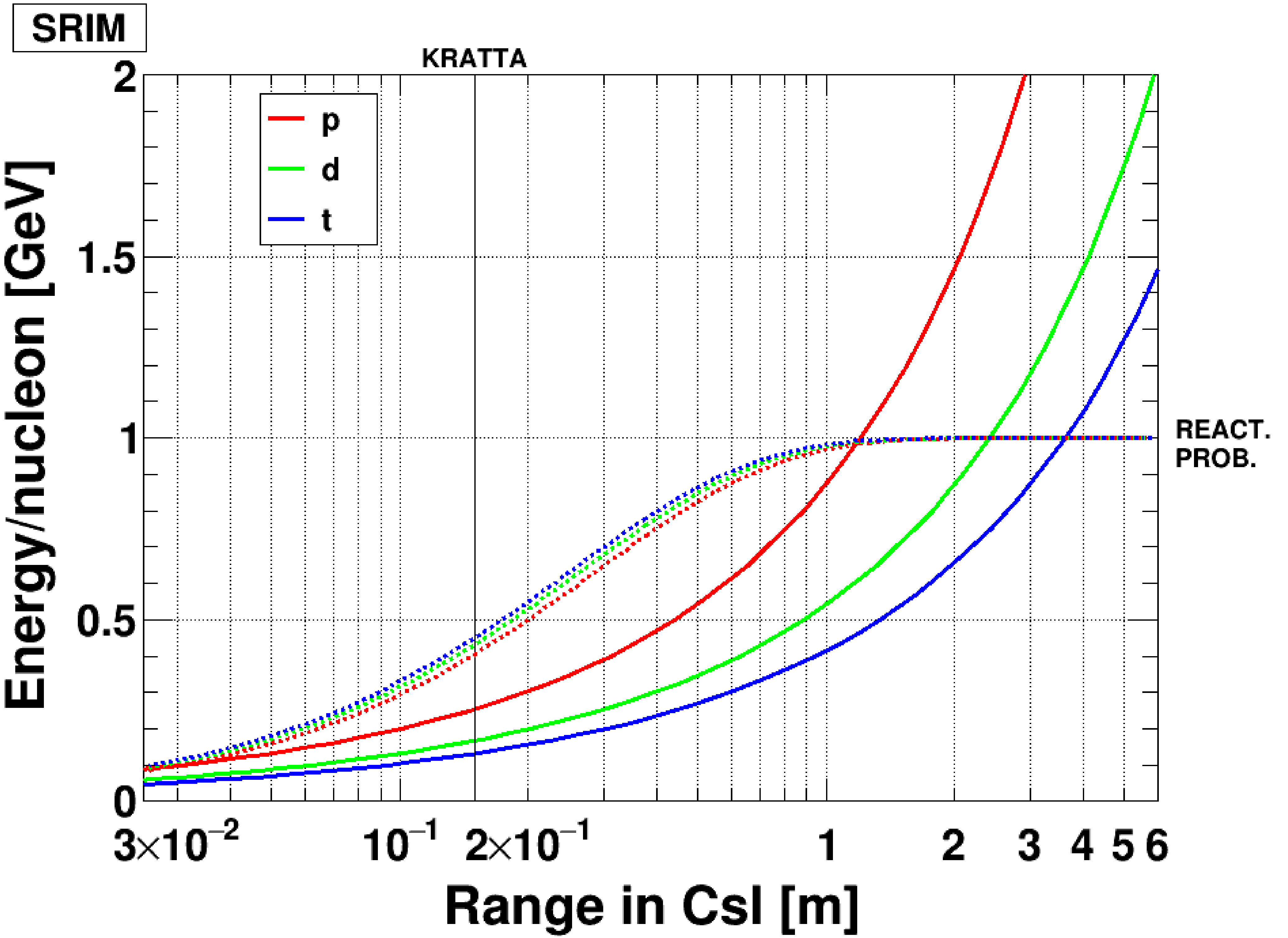
KRATTA module active elements

PD0, PD1, PD2 – HAMAMATSU PIN photodiodes for direct detection, 500 μm thickness
Active area: 28×28 mm^2

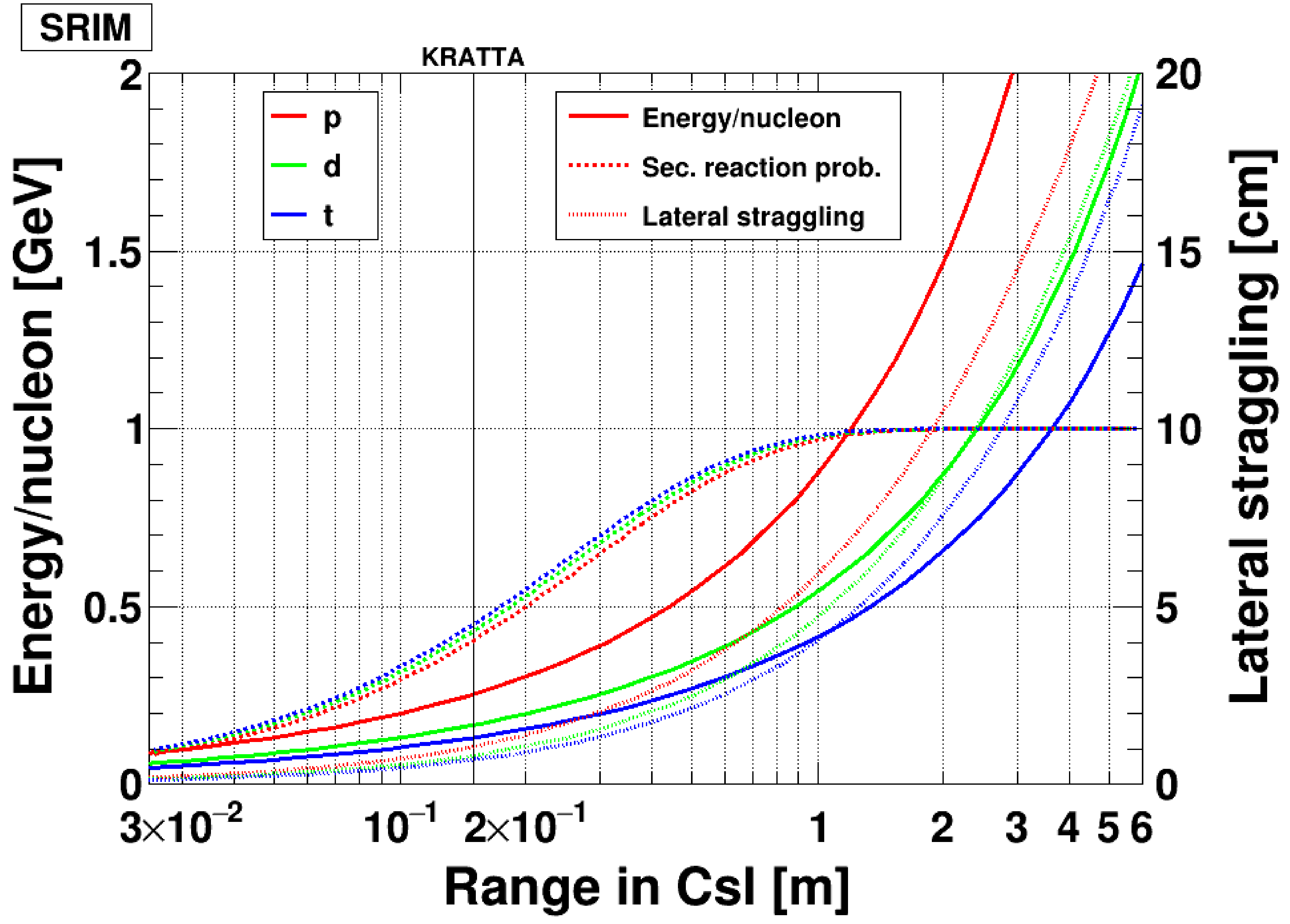




SRIM
KRATTA
p
d
t
Energy/nucleon [GeV]
Range in CsI [m]
0
0.5
1
1.5
2
3×10^{-2}
10^{-1}
2×10^{-1}
1
2
3
4
5
6



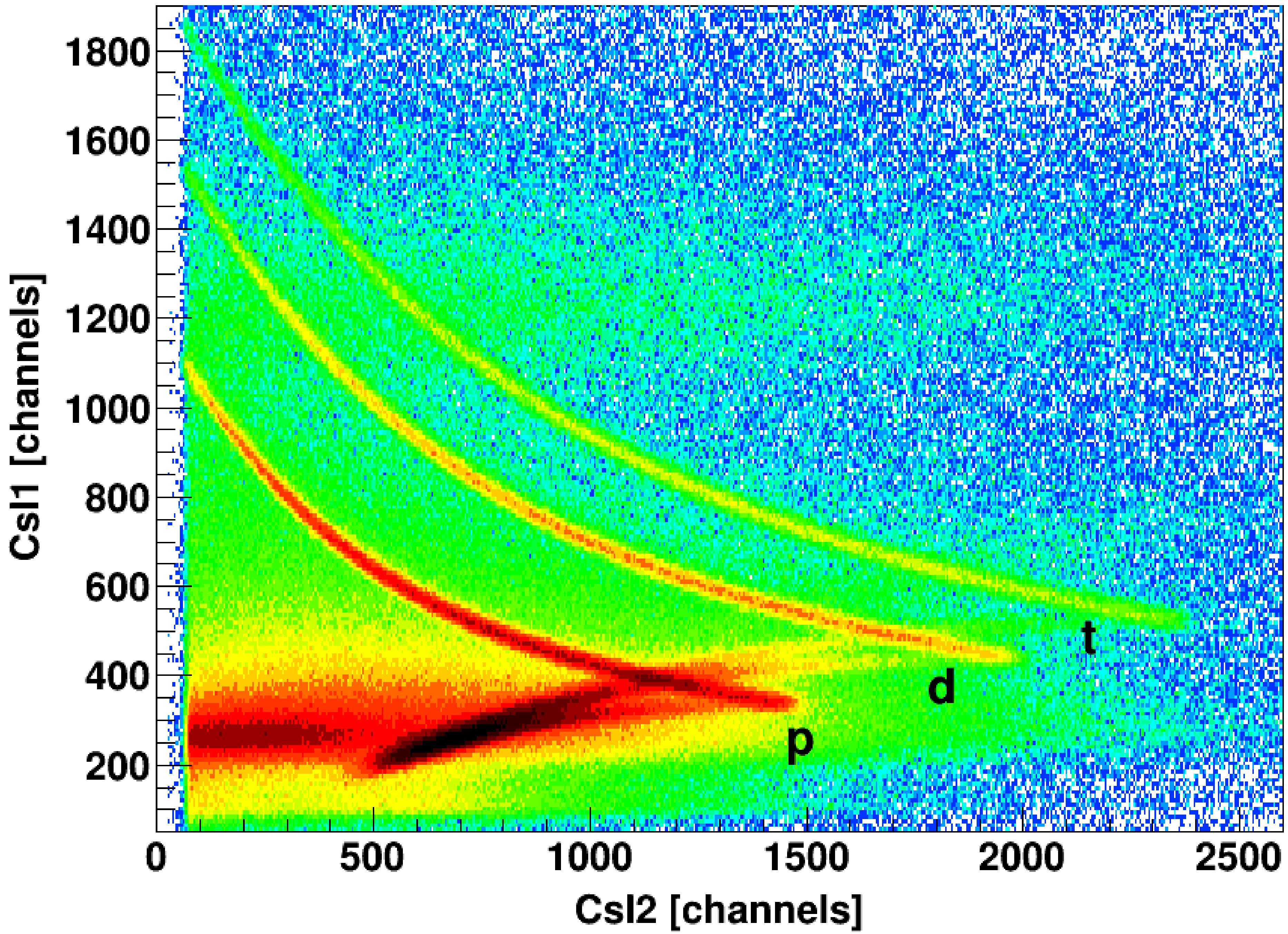
SRIM
KRATTA
p
d
t
REACT.
PROB.
Energy/nucleon [GeV]
Range in CsI [m]
0
0.5
1
1.5
2
3×10⁻²
10⁻¹
2×10⁻¹
1
2
3
4
5
6


SRIM
KRATTA
p
d
t
Energy/nucleon
Sec. reaction prob.
Lateral straggling
Energy/nucleon [GeV]
Lateral straggling [cm]
Range in CsI [m]
0
0.5
1
1.5
2
0
5
10
15
20
3×10^{-2}
10^{-1}
2×10^{-1}
1
2
3
4
5
6

Au+Au @ 400 MeV/nucleon

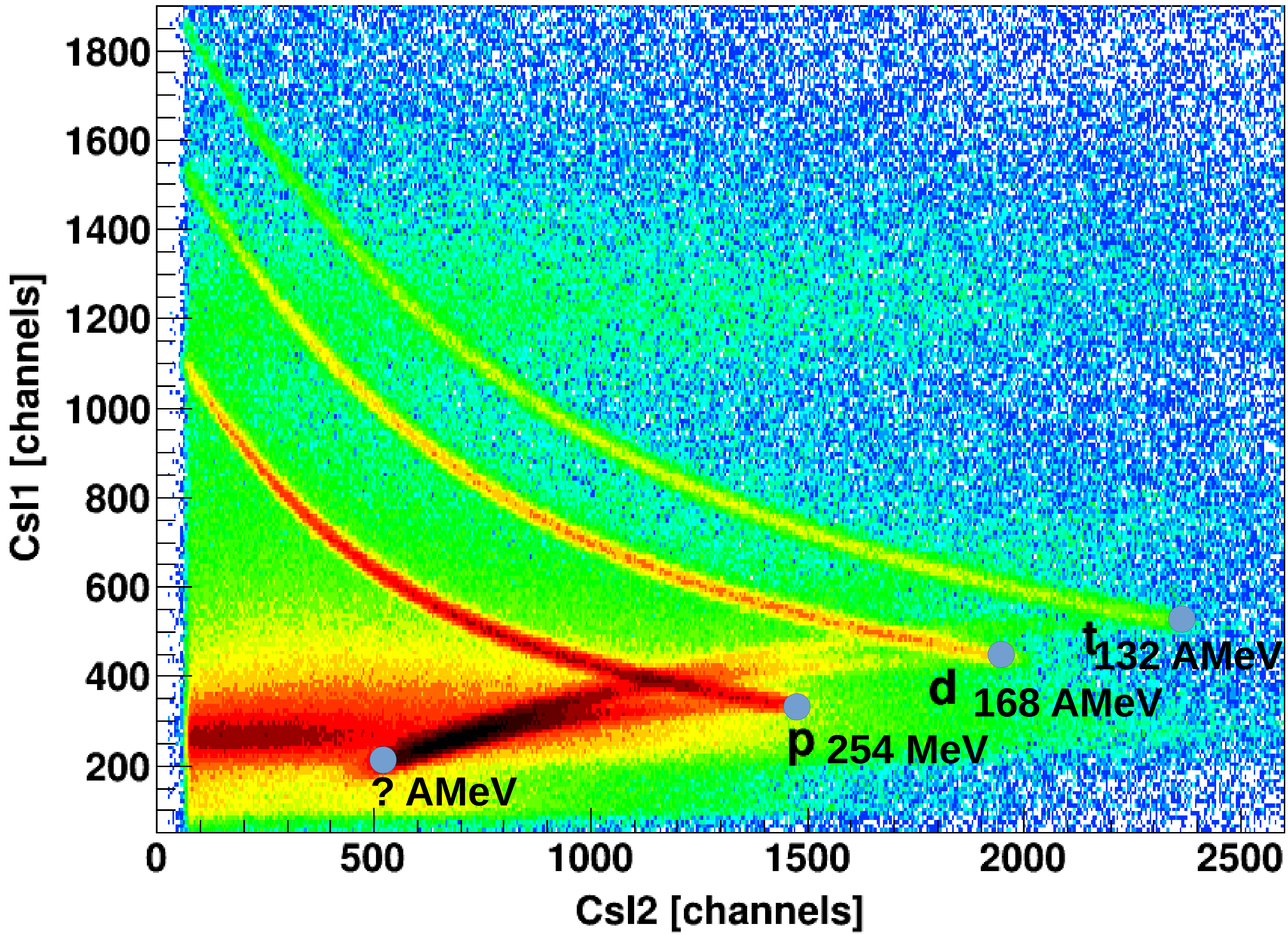
(data and simulations
single telescope placed at 26º)

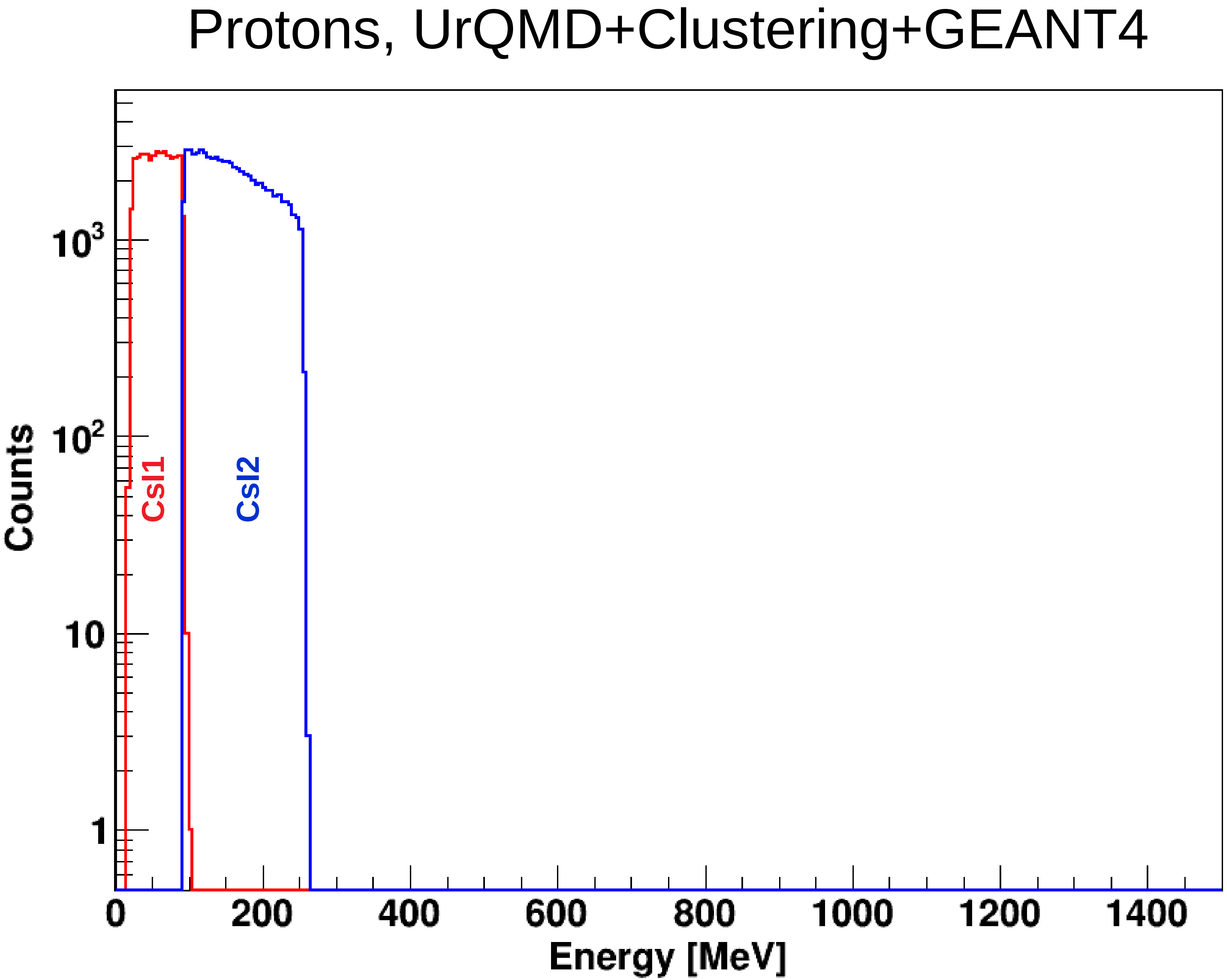
ΔE-E (raw exp) $\Delta E \sim \frac{A Z^2}{E}$



ΔE-E (raw exp)

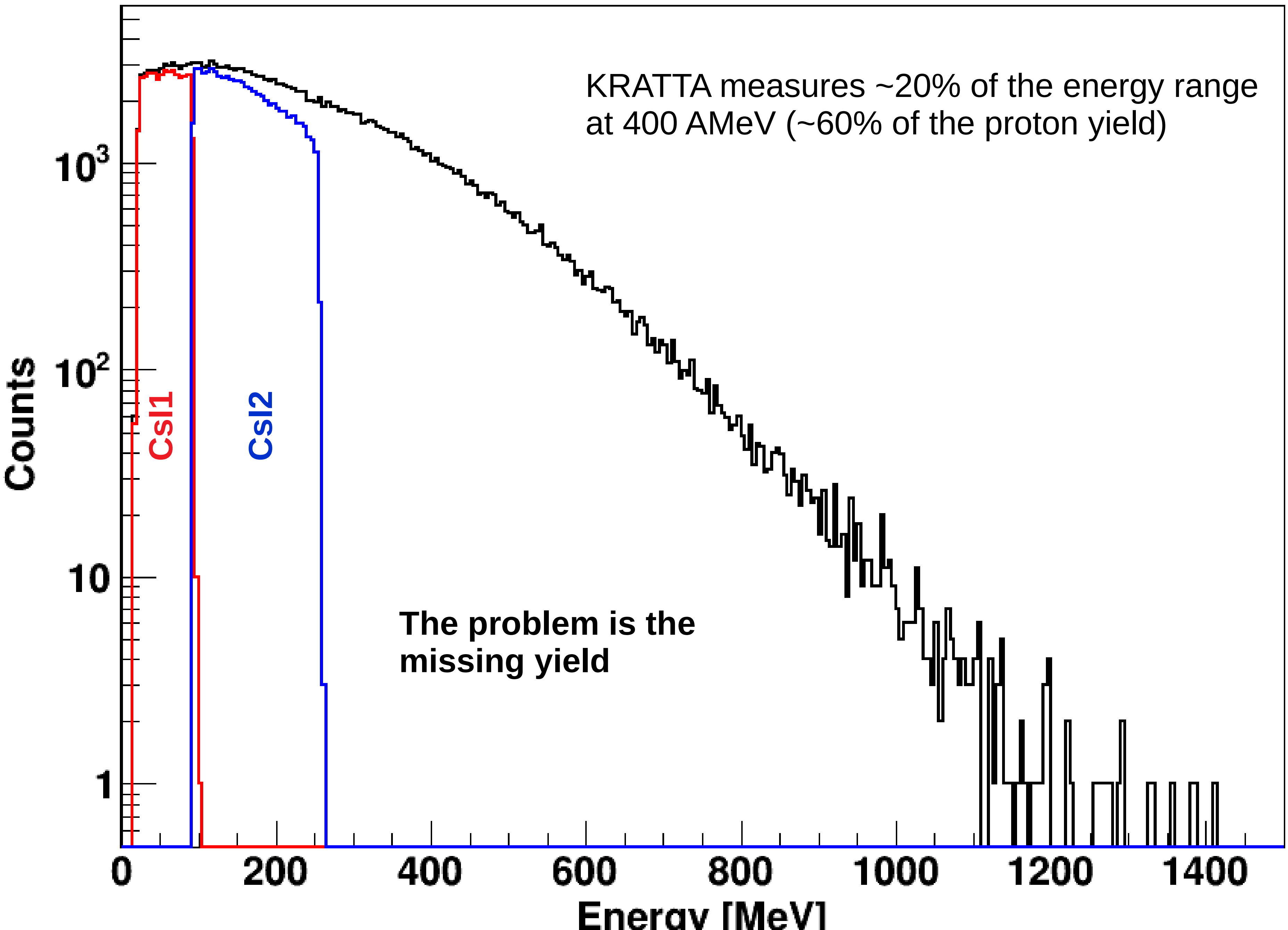
$$\Delta E \sim \frac{A Z^2}{E}$$



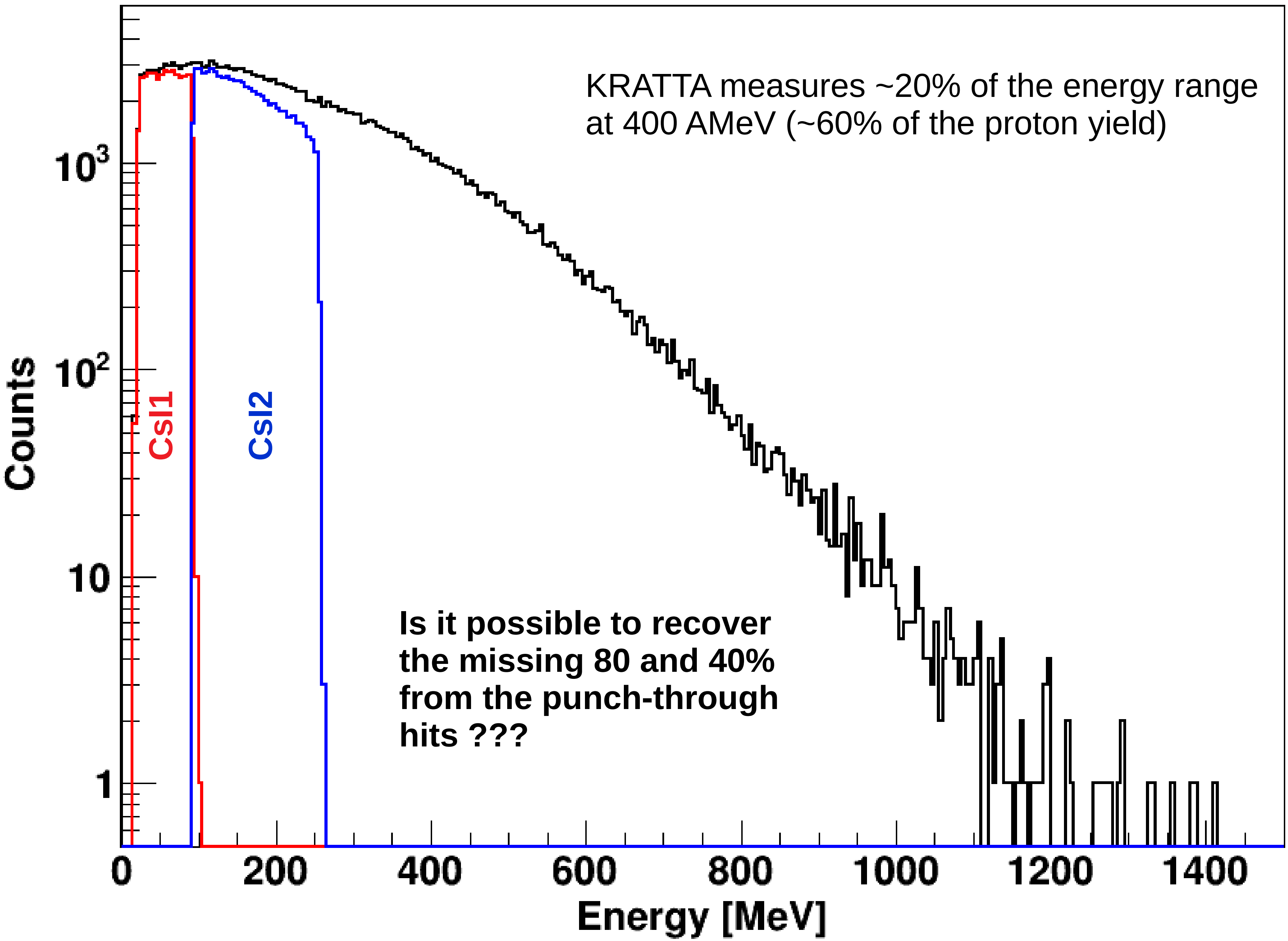


Protons, UrQMD+Clustering+GEANT4
Counts
10^3
10^2
10
1
CsI1
CsI2
0
200
400
600
800
1000
1200
1400
Energy [MeV]

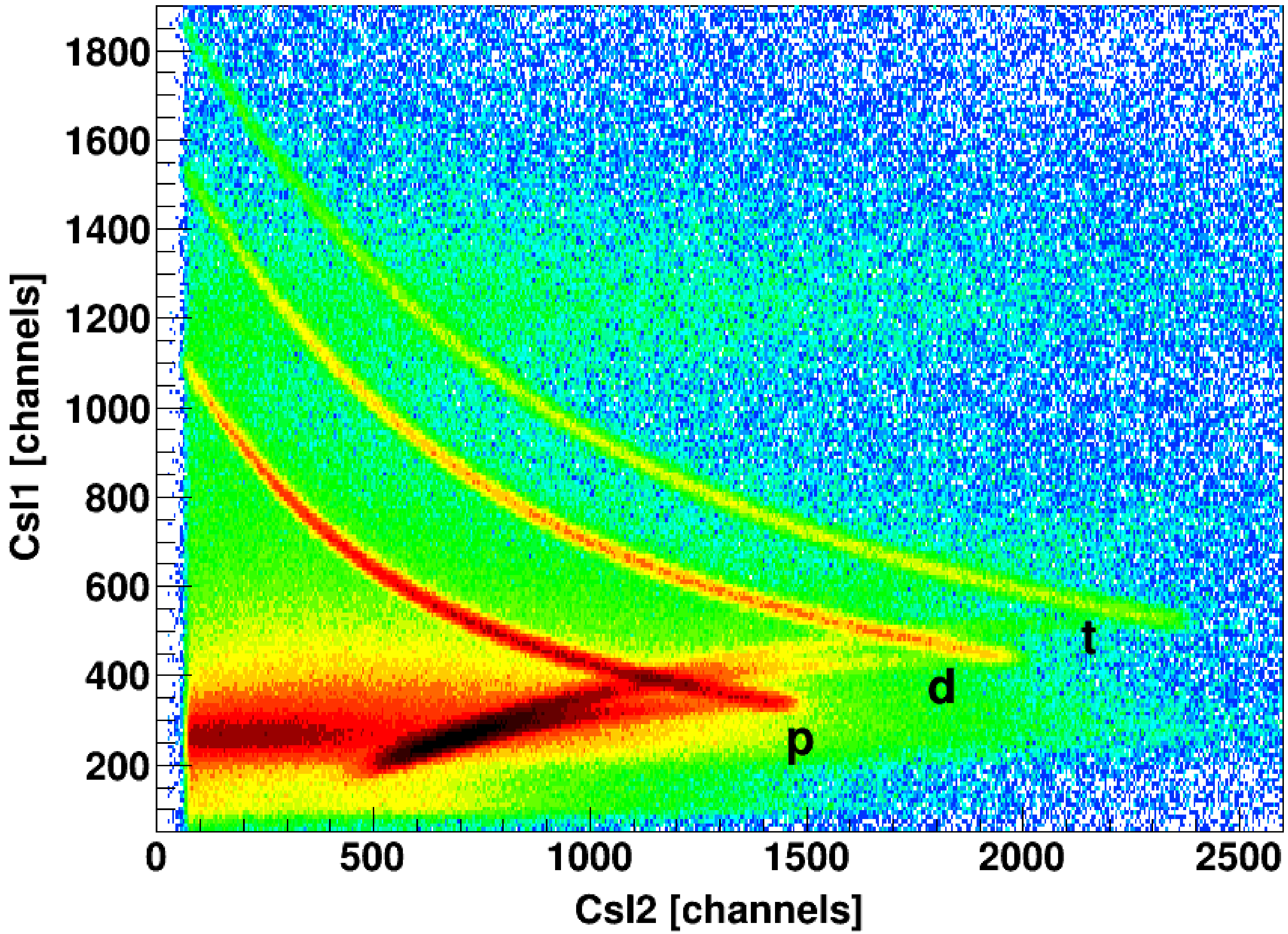
Protons, UrQMD+Clustering+GEANT4



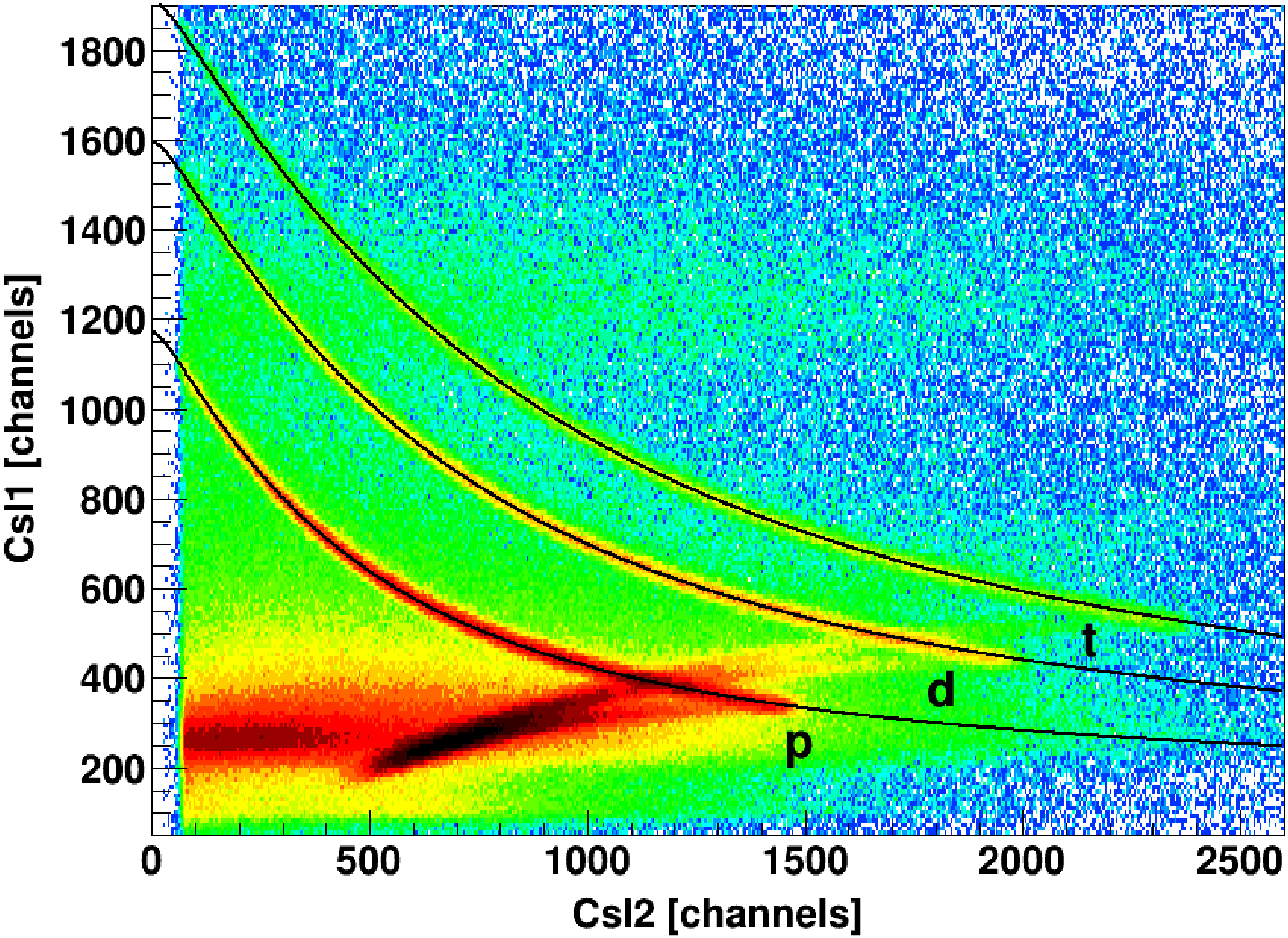
Protons, UrQMD+Clustering+GEANT4



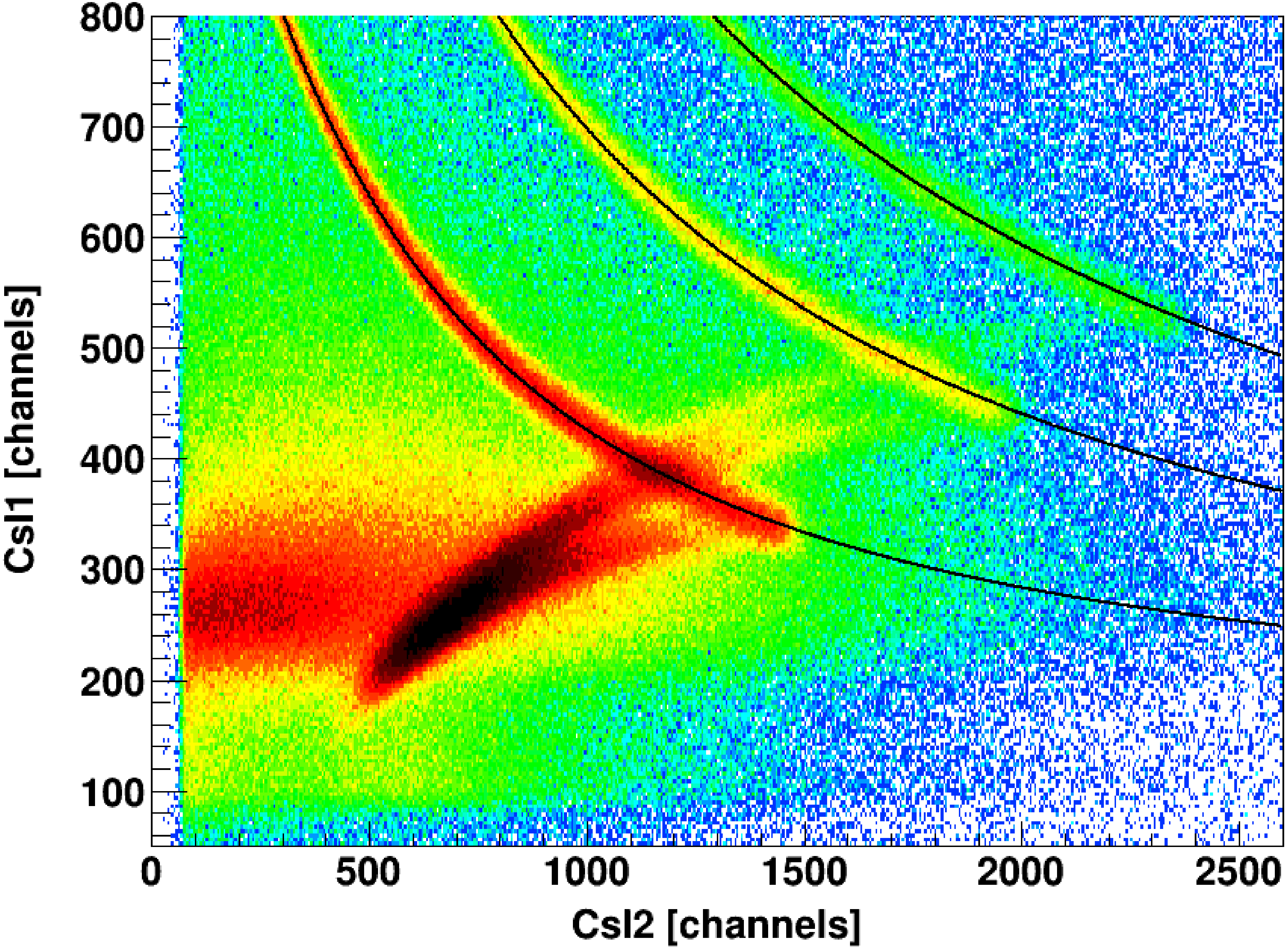
ΔE-E (raw exp)


1800
1600
1400
1200
1000
800
600
400
200
CsI1 [channels]
0
500
1000
1500
2000
2500
CsI2 [channels]
p
d
t

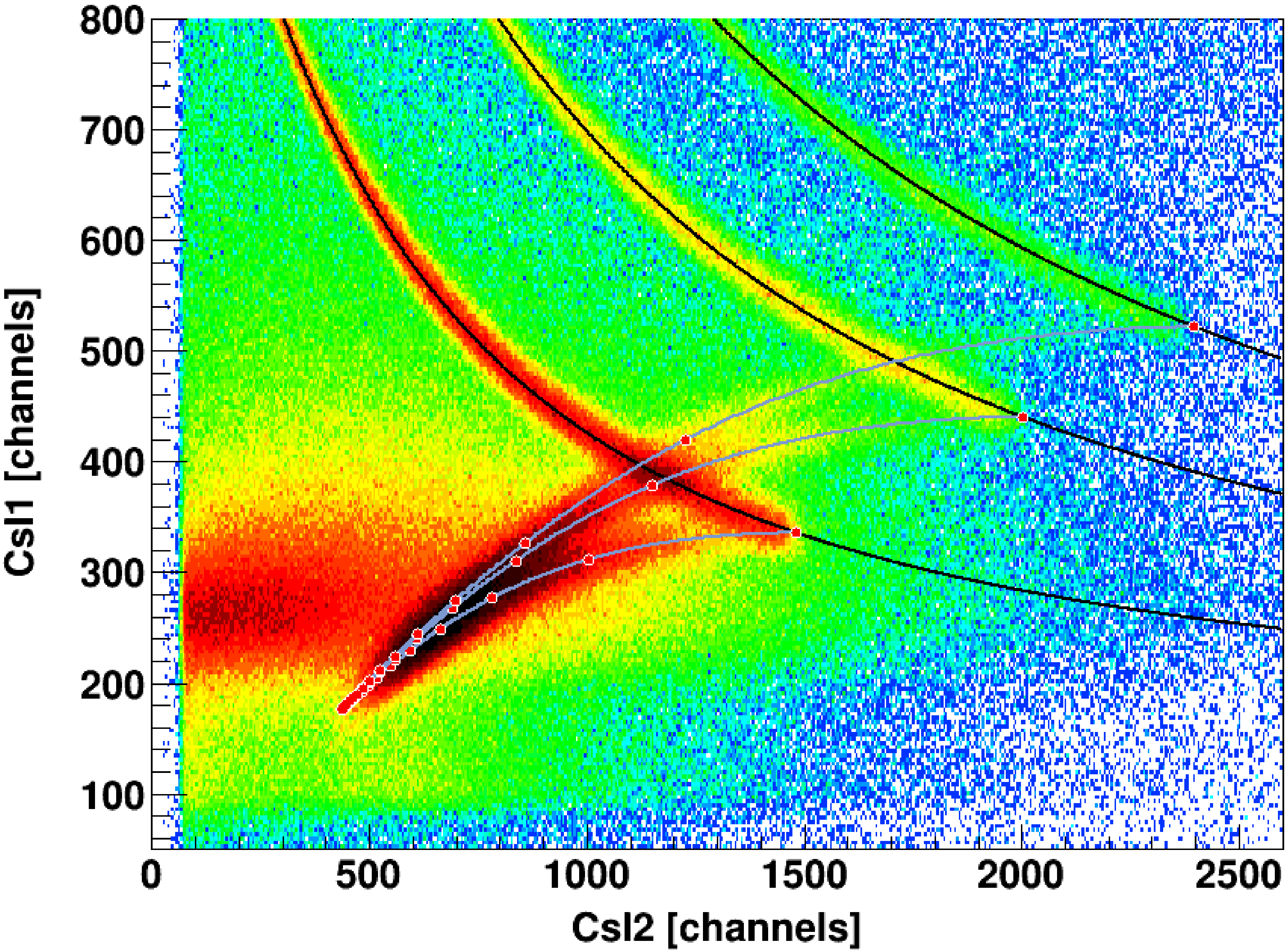
ΔE-E (calibration lines → ATIMA+Light(E))



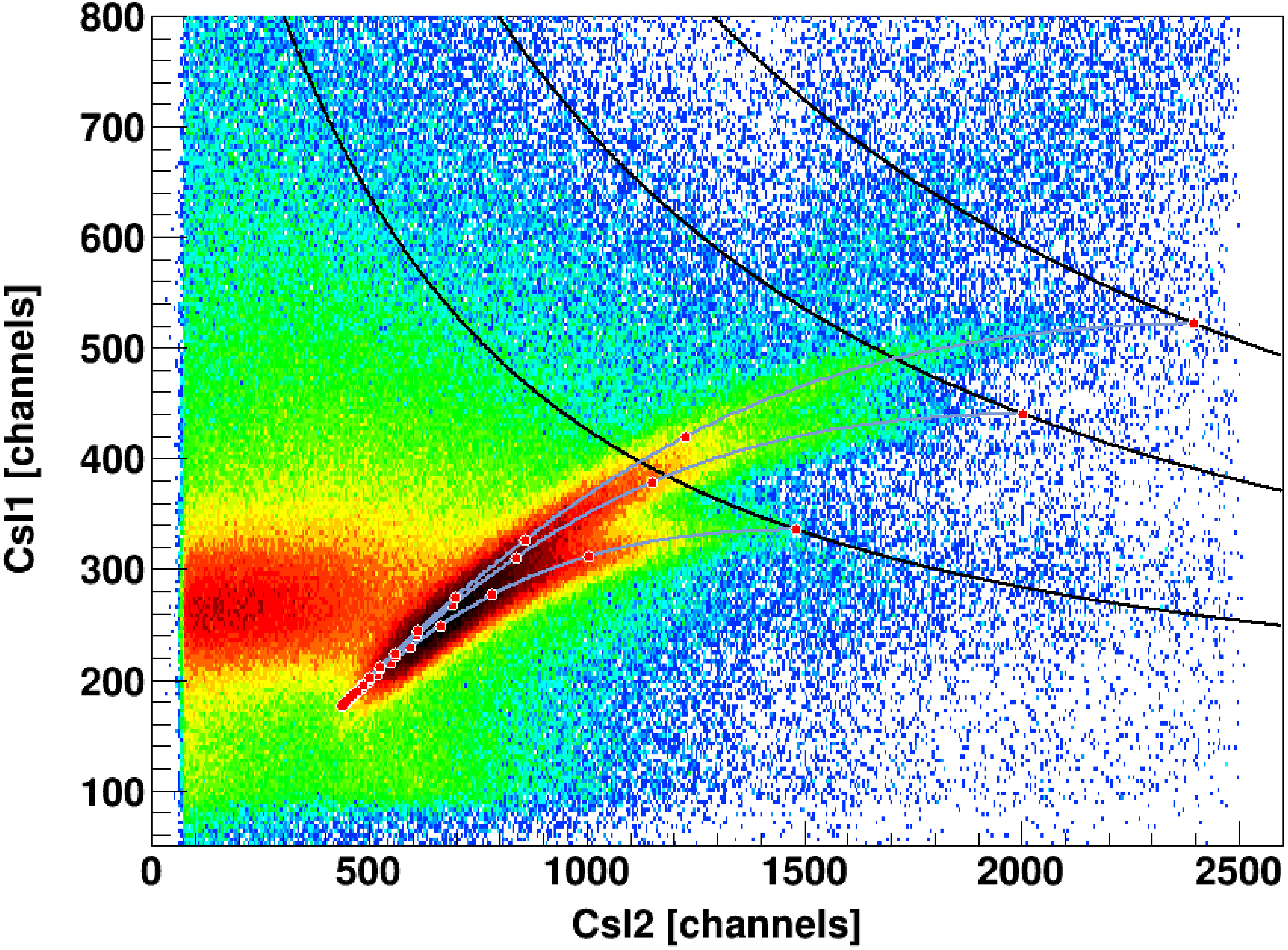
ΔE-E (more detailed)



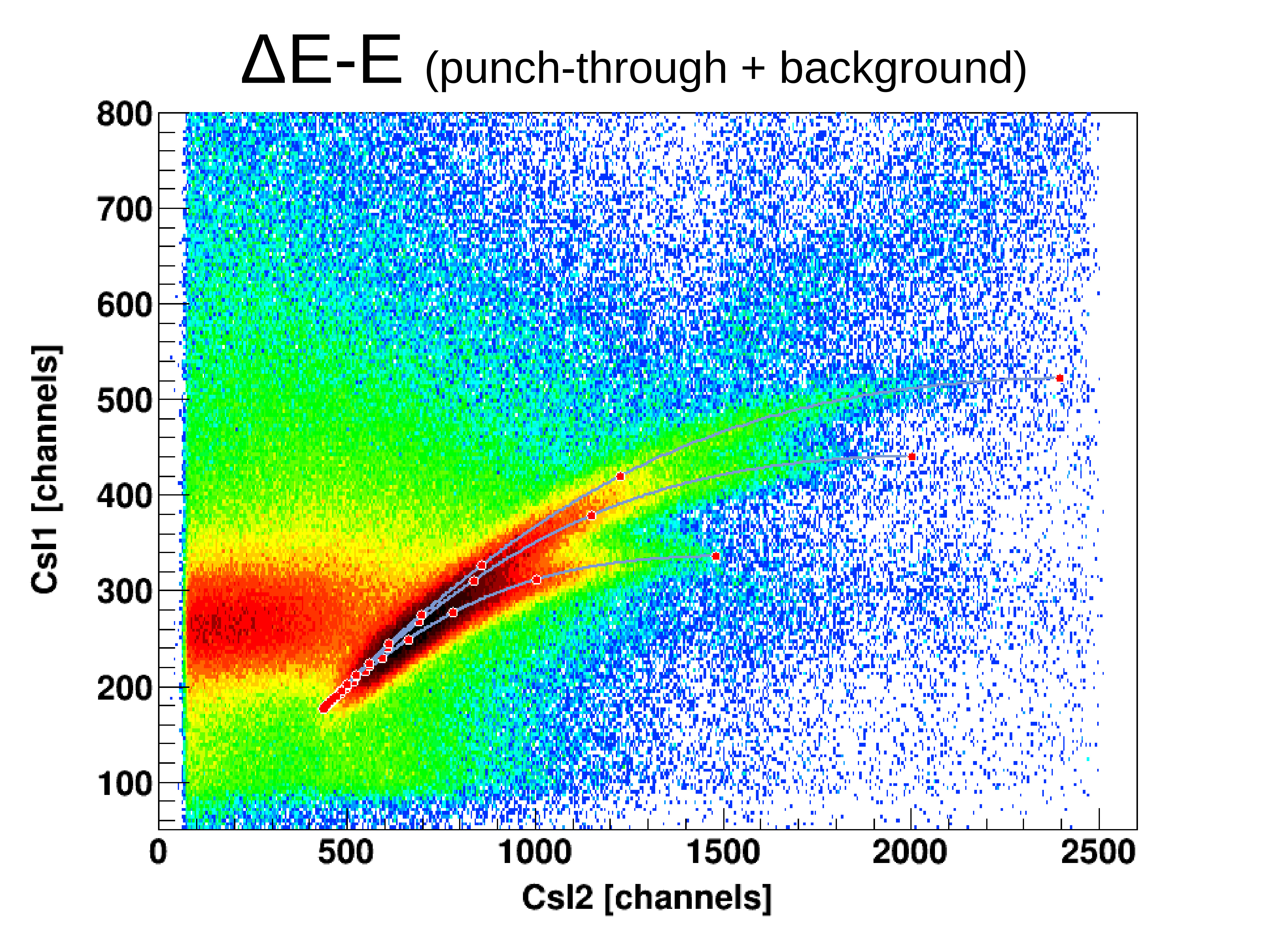
ΔE-E (punch-through calibration lines → **dots every 100 AMeV**)



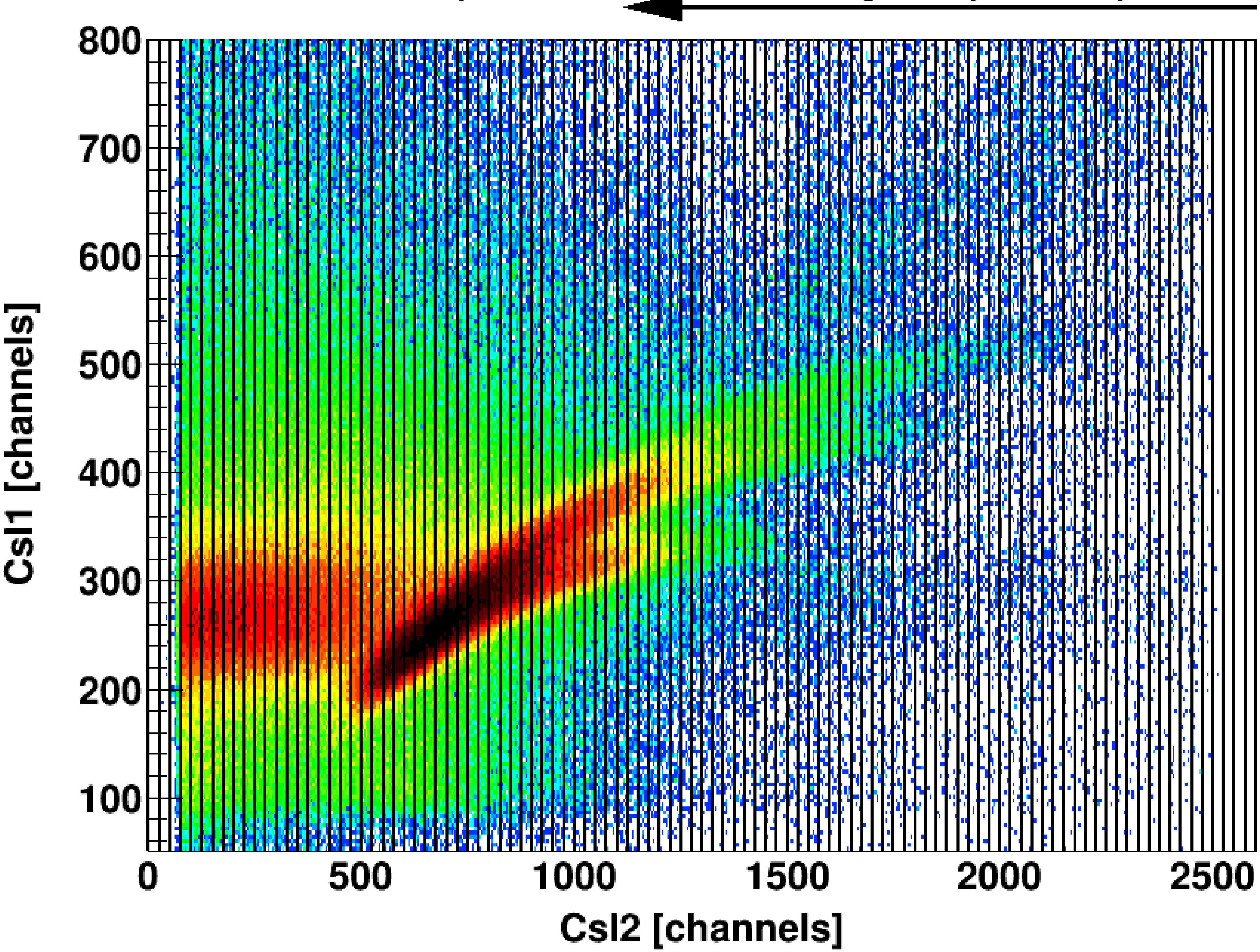
ΔE-E (punch-through + background)



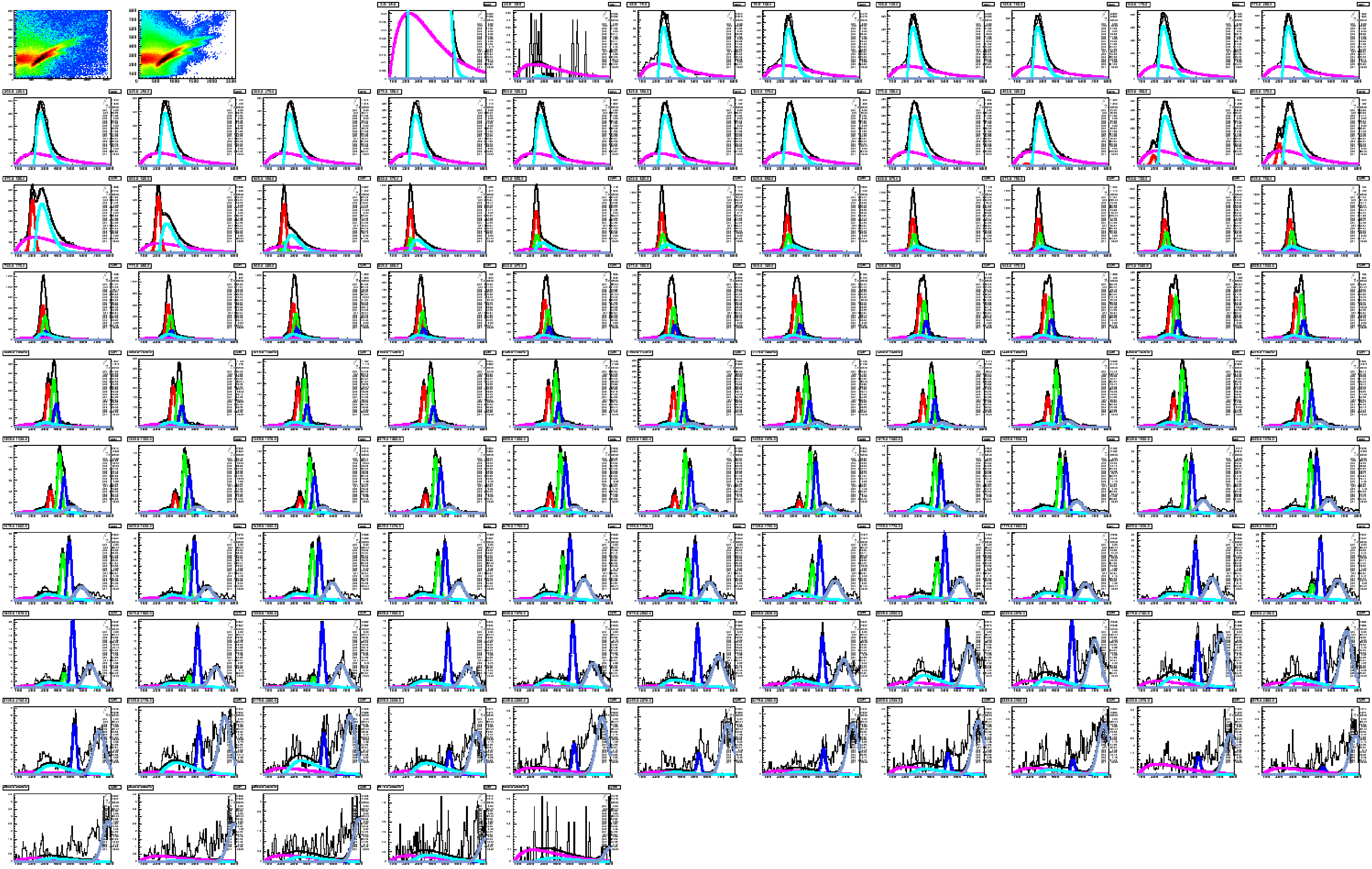
J. Łukasik et al., EPJ Web of Conf. 88, 01017 (2015)


ΔE-E (punch-through + background)
800
700
600
500
400
300
200
100
CsI1 [channels]
0
500
1000
1500
2000
2500
CsI2 [channels]

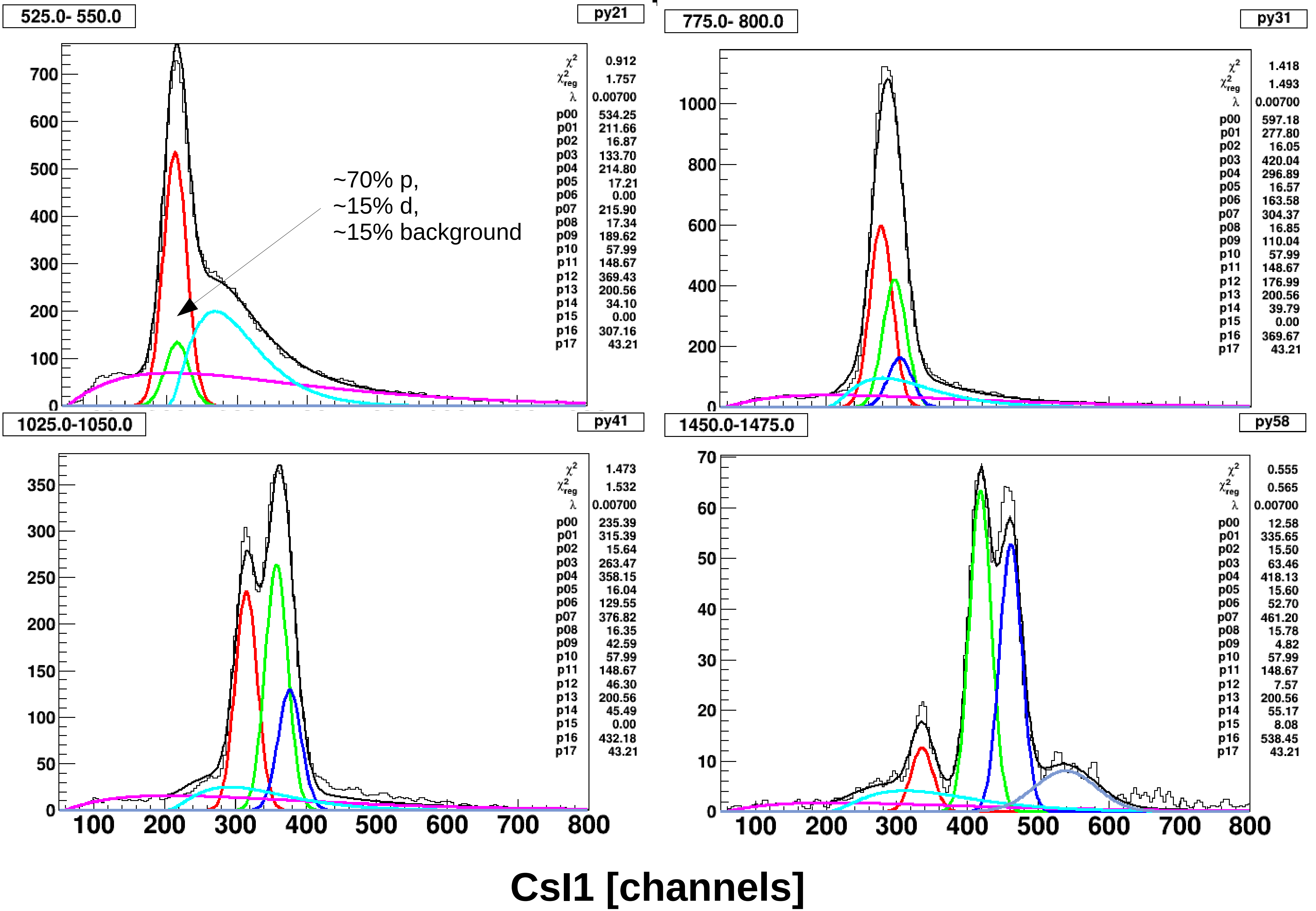
ΔE-E (slices + fitting sequence)



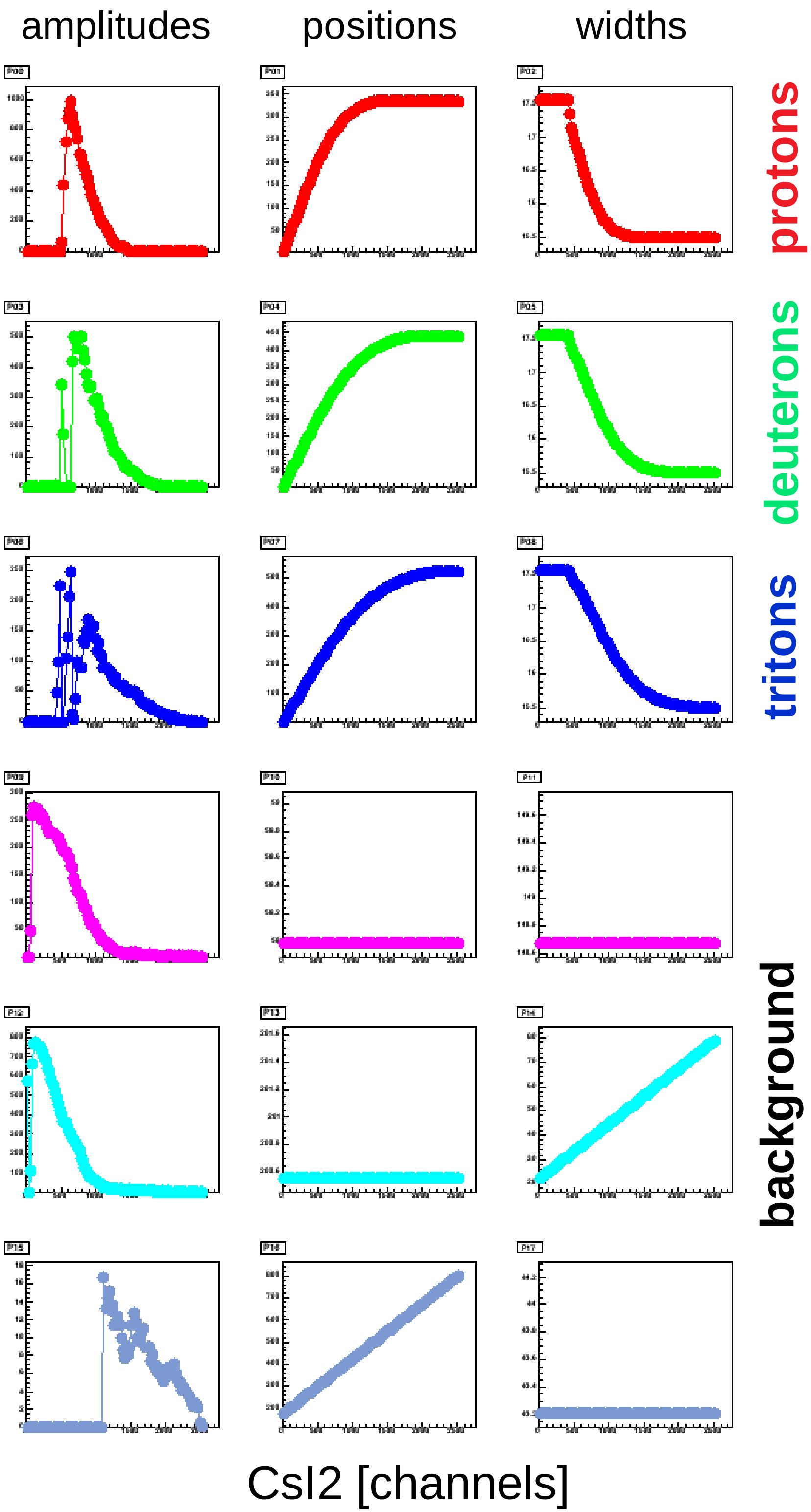
Decomposition into protons deuterons tritons background for 104 slices

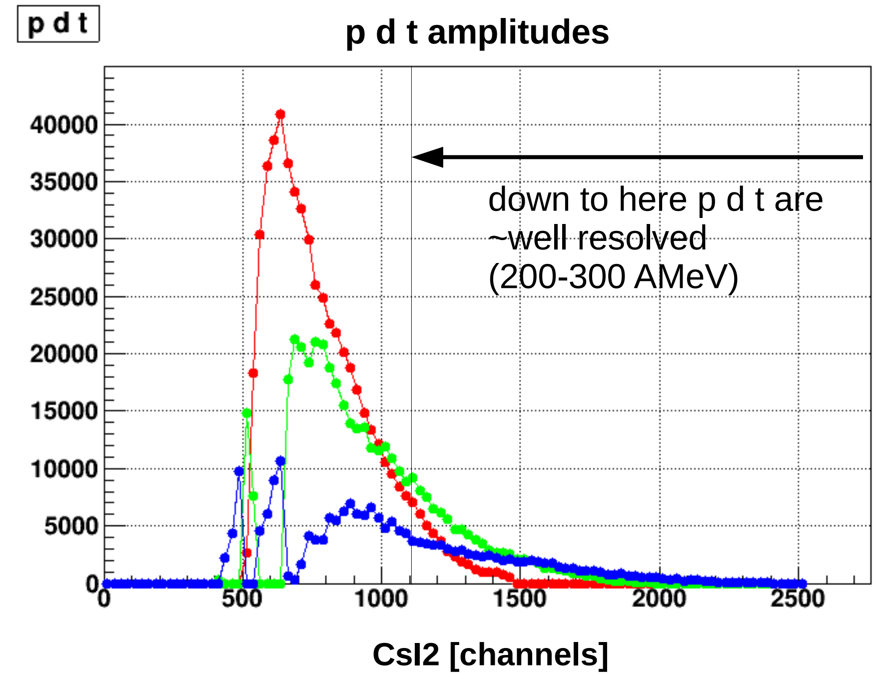


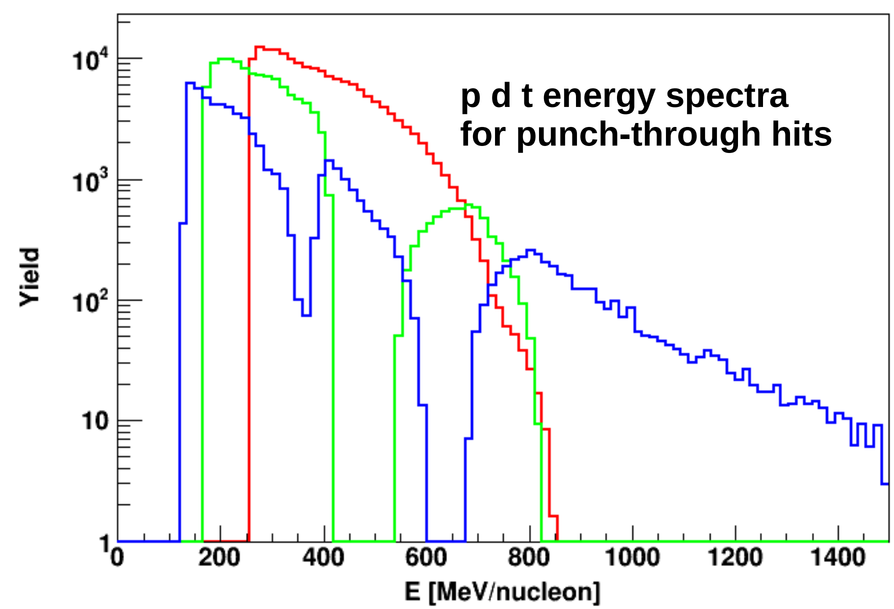
Example fits



18 parameters (12 fixed), χ^2 **alone**







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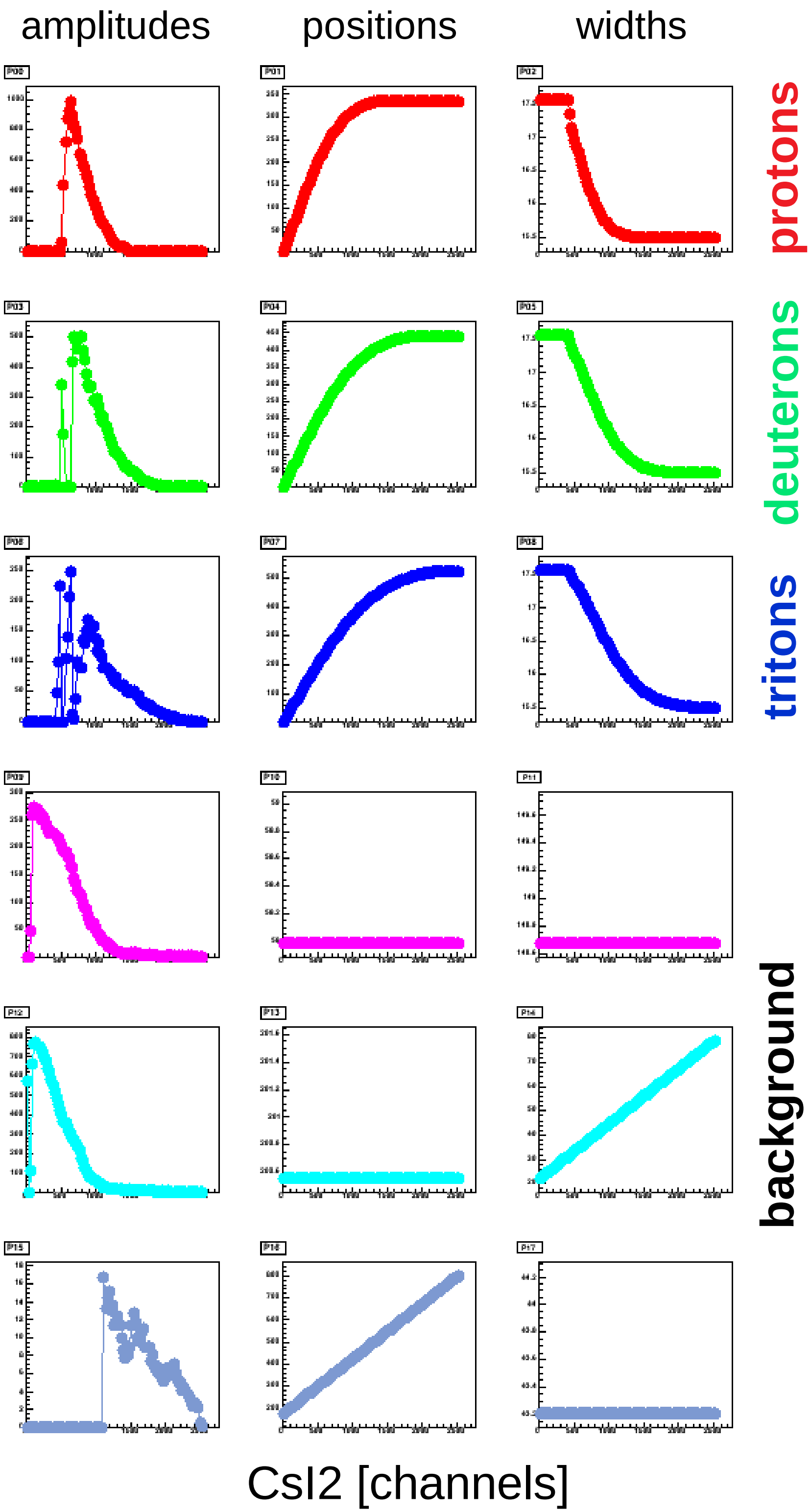
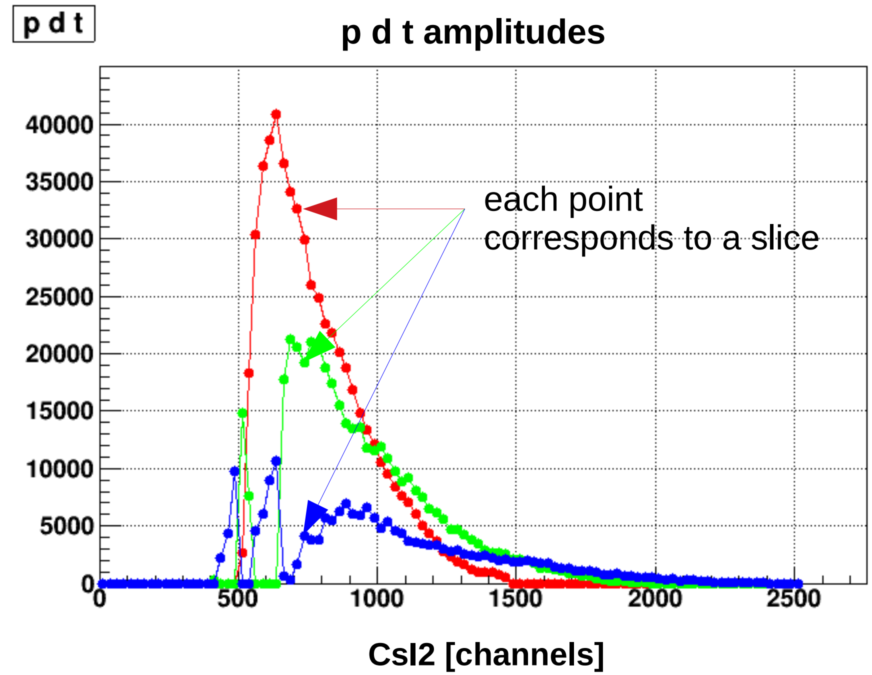
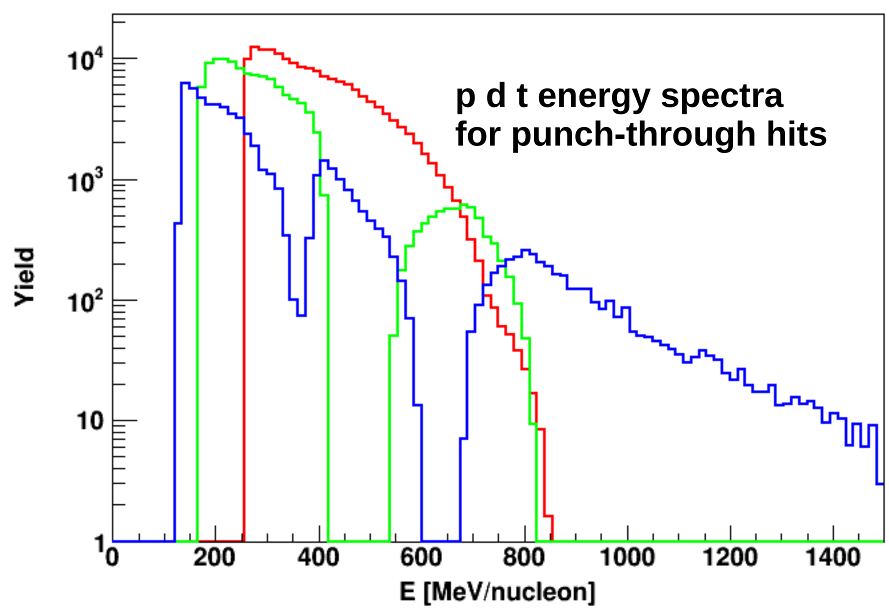
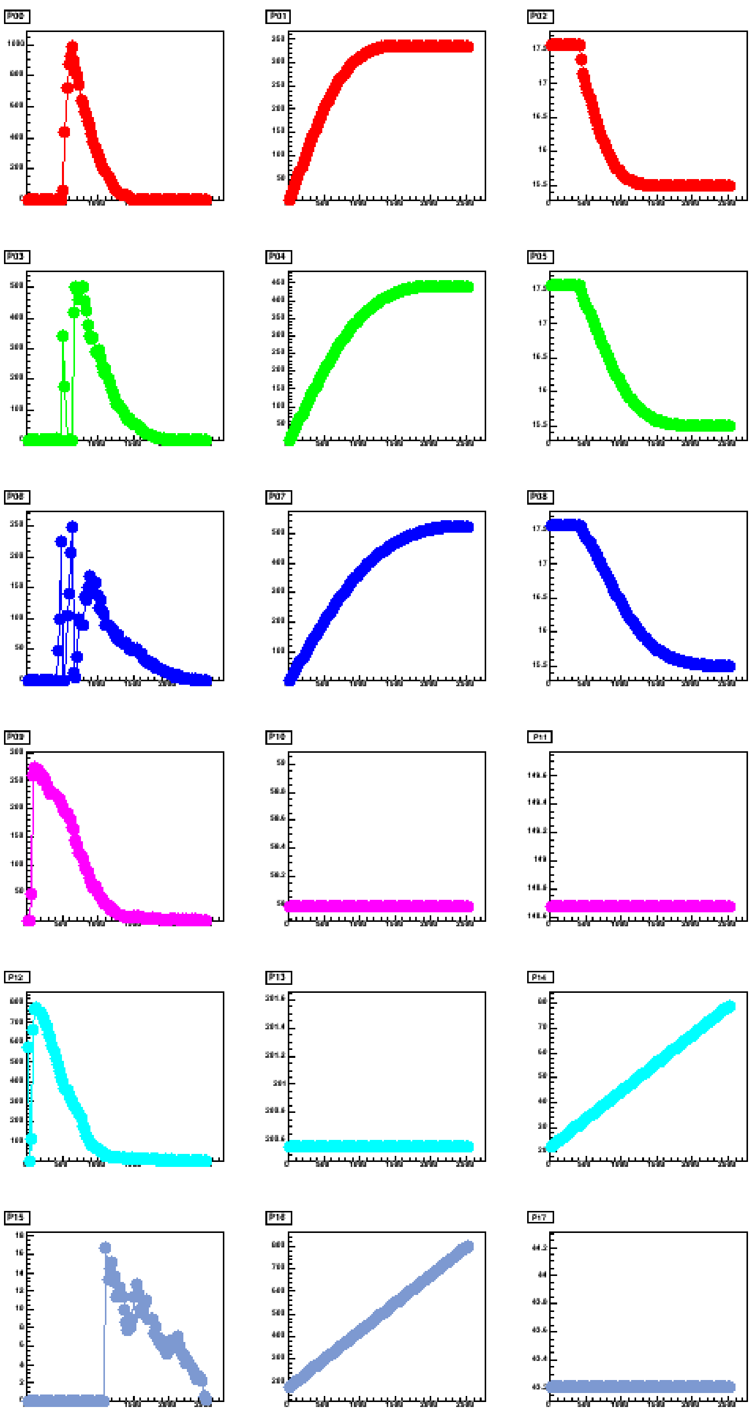






18 parameters (12 fixed), χ^2 **alone**

amplitudes | positions | widths



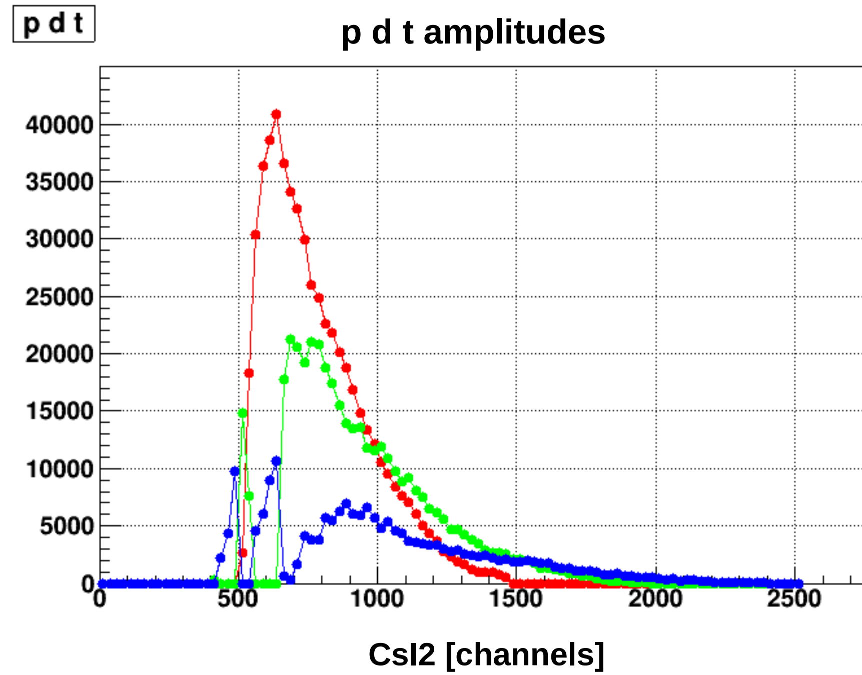
protons

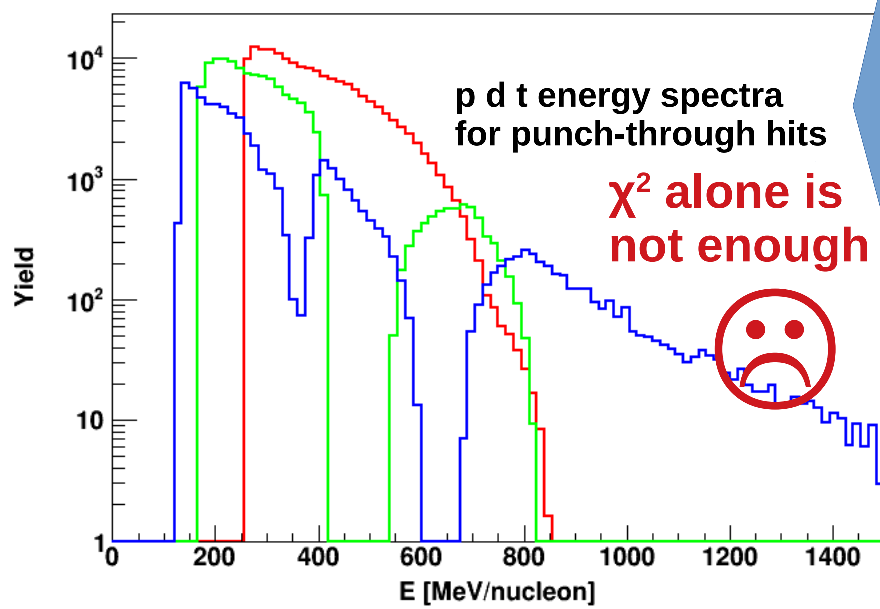
deuterons

tritons

background

CsI2 [channels]





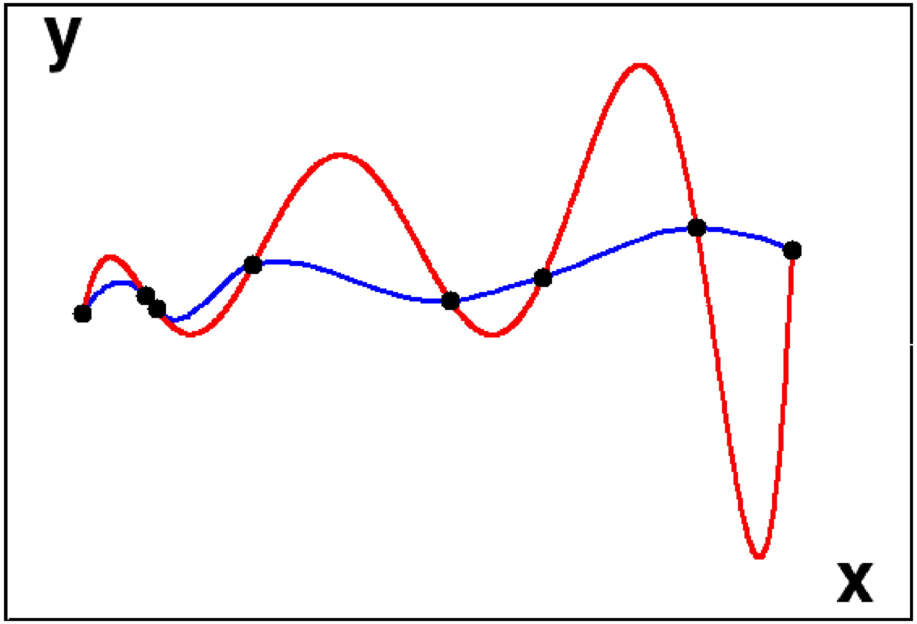
χ^2 alone is not enough ☹

energy spectra constructed using **weights** from amplitude fits and energy **calibration**

REGULARIZATION
comes at a rescue

Regularization is a process of introducing additional information in order to solve an ill-posed problem or to prevent over-fitting.
It attempts to impose **Ockham's razor** on the solution to get the **simplest** one.
(Wikipedia)

$$\min_{\vec{p}} \left\{ \underbrace{\sum_{i=0}^{N} \frac{\left(f\left(x_i; \vec{p}\right) - y_i\right)^2}{\sigma_i^2}}_{\chi^2} + \lambda \cdot Cons\left(\vec{p}\right) \right\}$$



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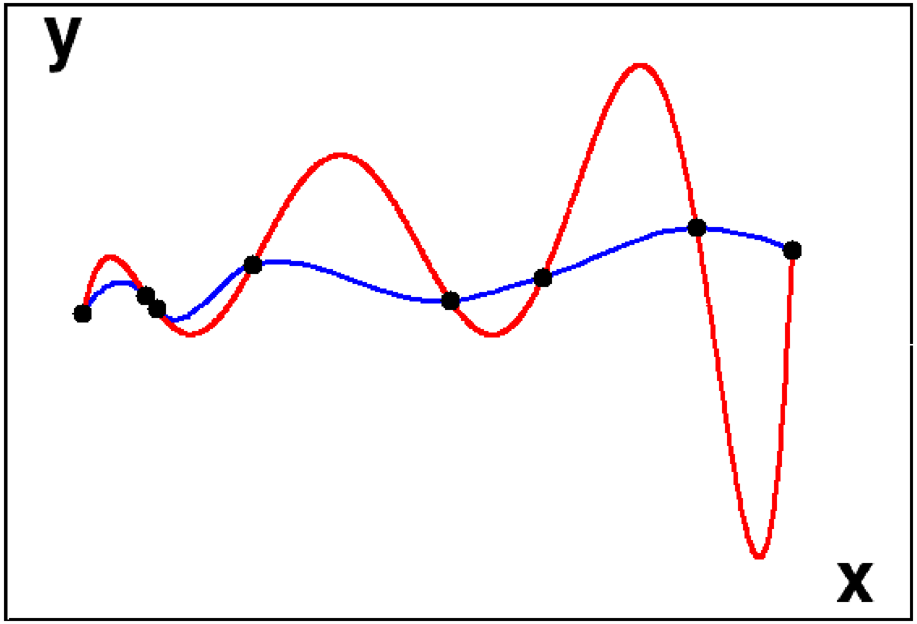
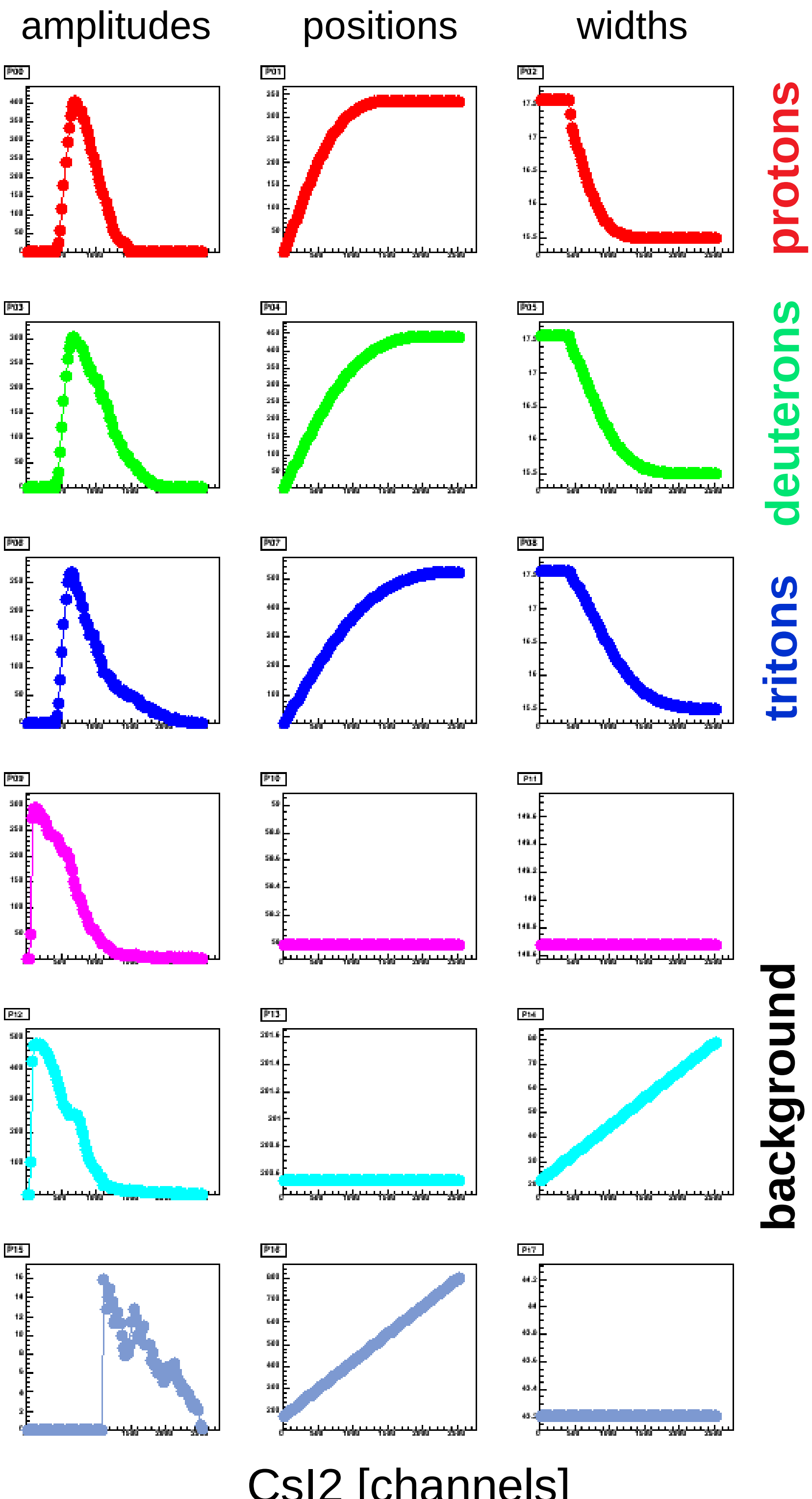


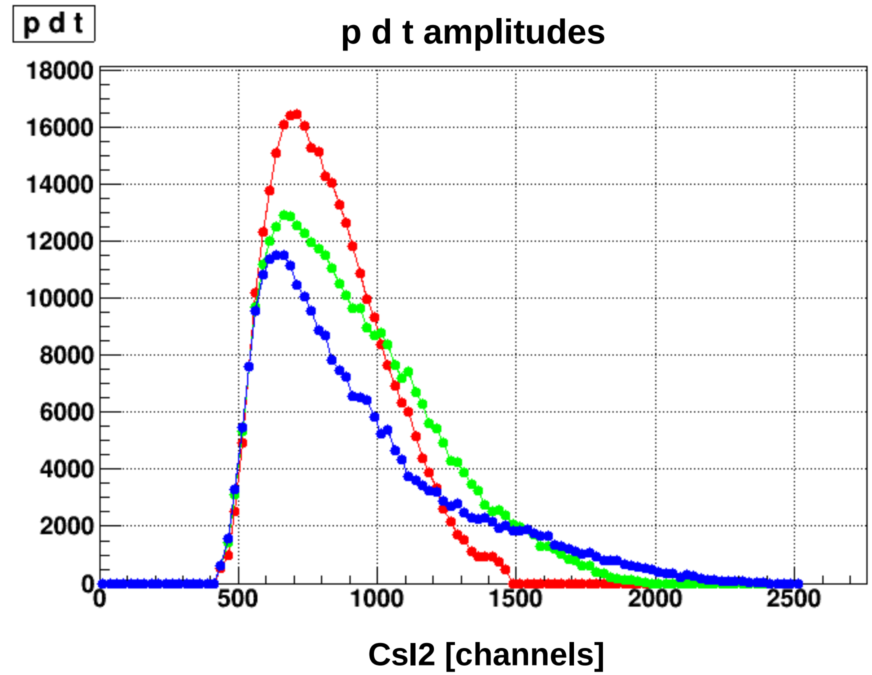
Tikhonov → the simplest regularization:

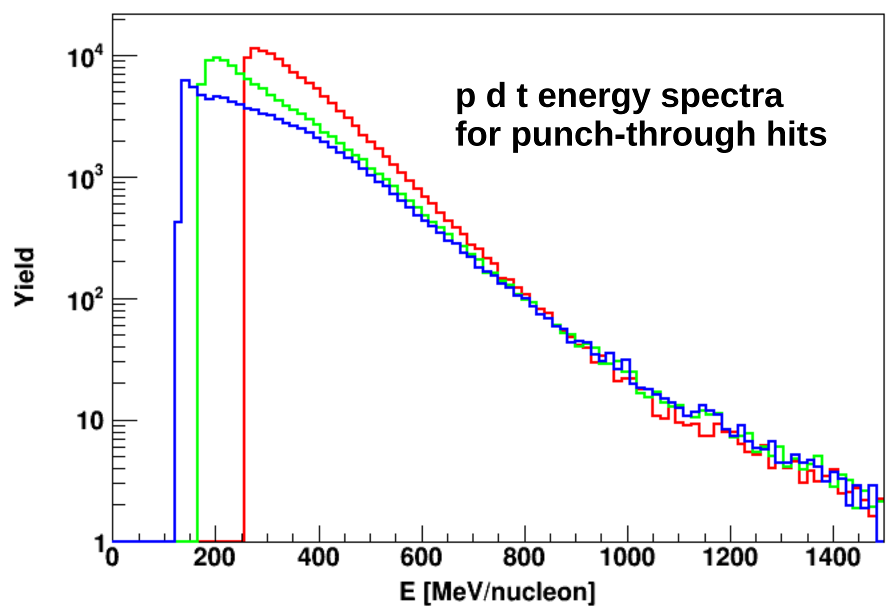
$$Cons\left(\vec{p}\right) = |\vec{p}|^2$$

minimize, in addition to χ^2, the length of the parameter vector.

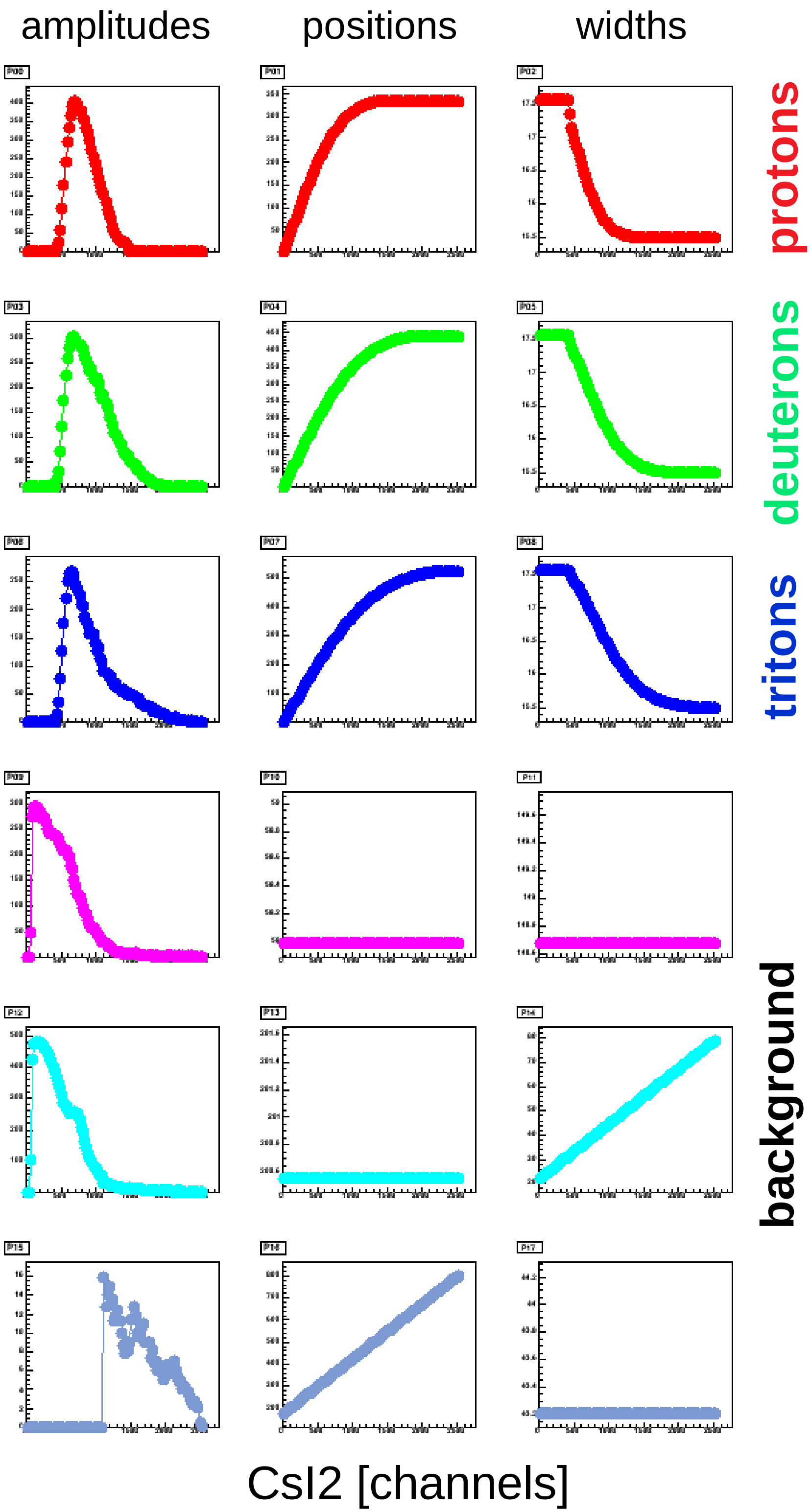
χ² + Tikhonov regularization

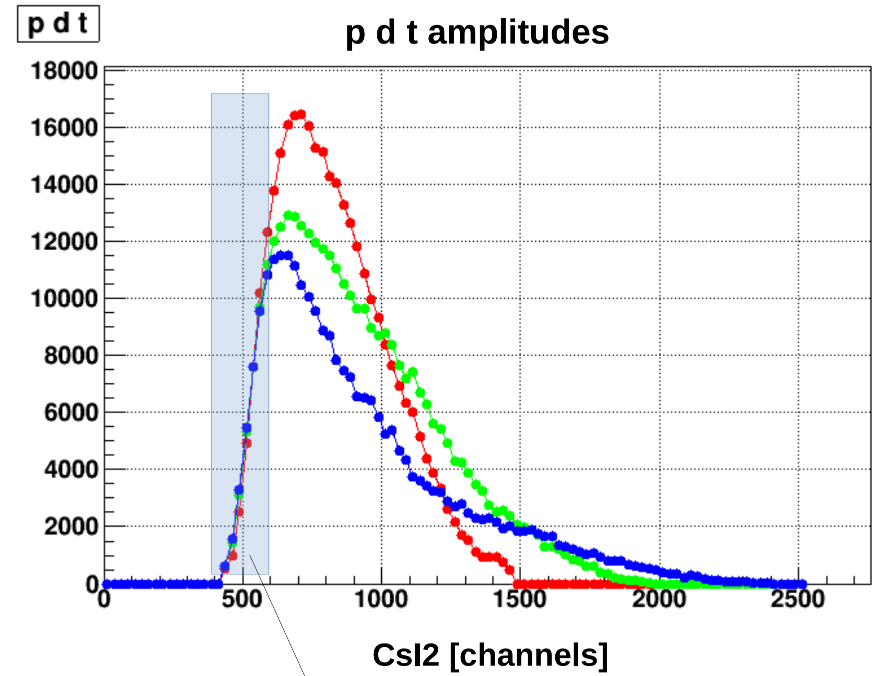


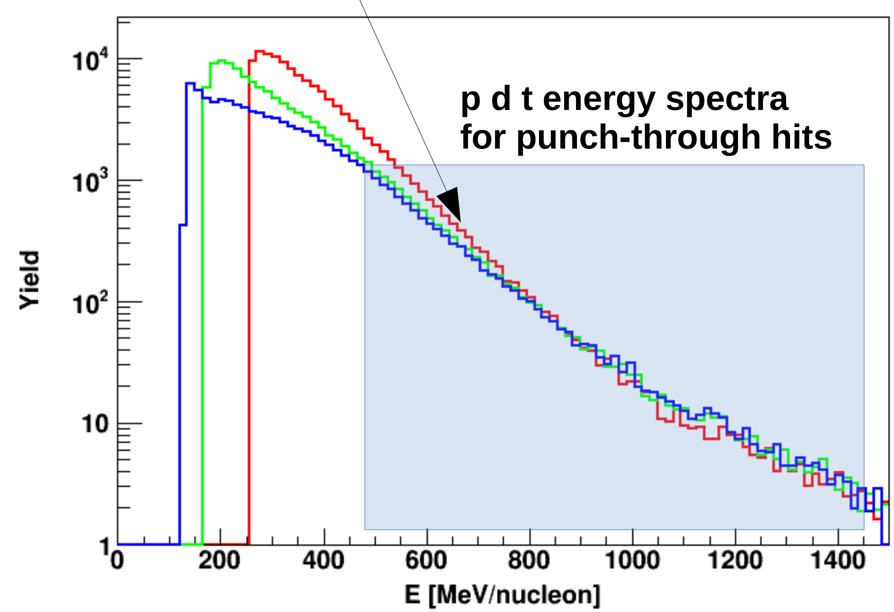




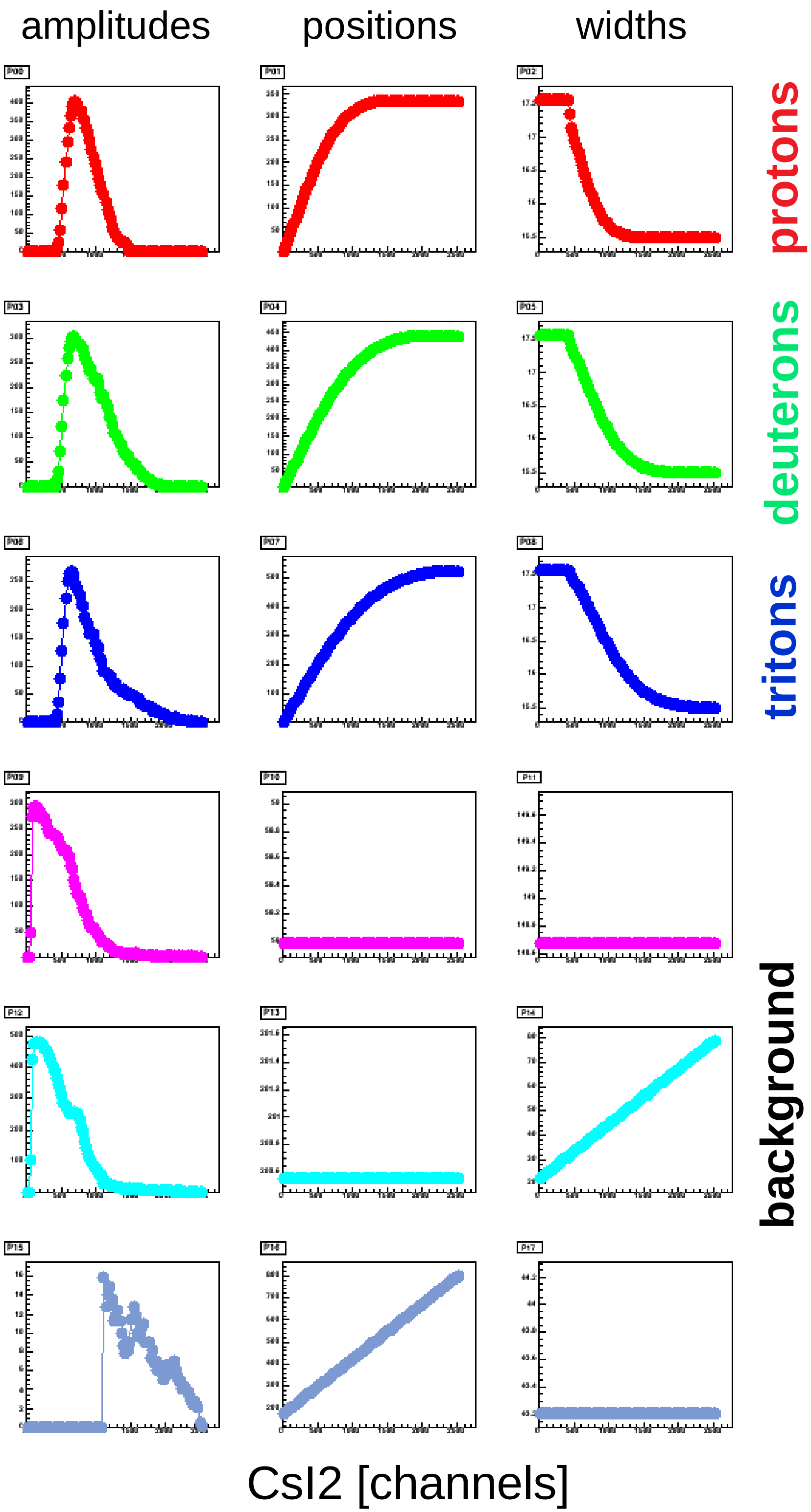
χ^2 + Tikhonov regularization

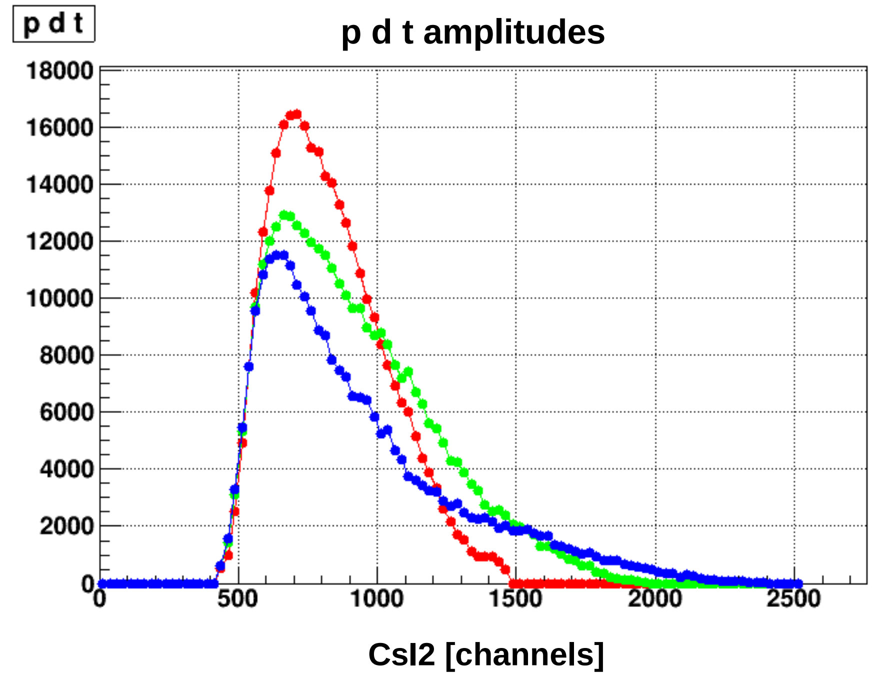


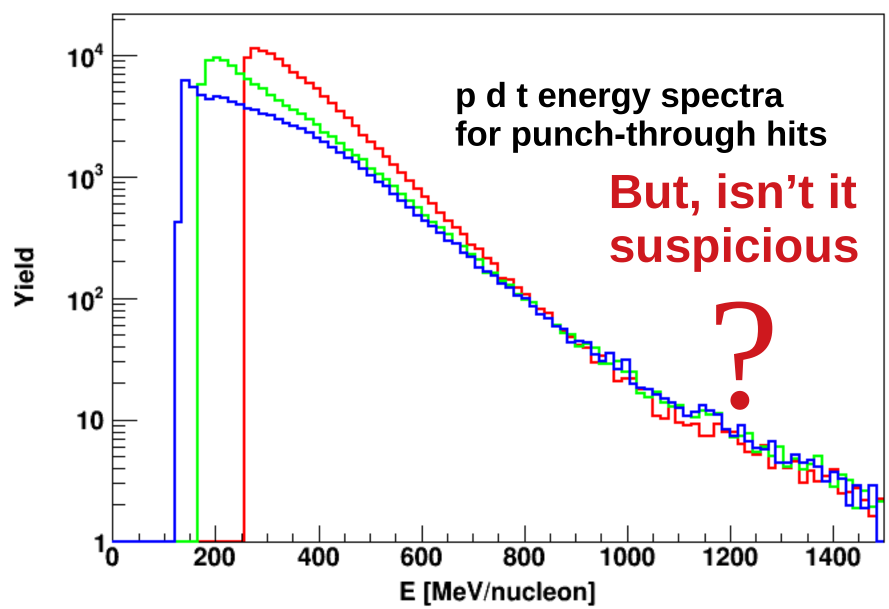




χ^2 + Tikhonov regularization







The razor cuts again

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(Wikipedia)

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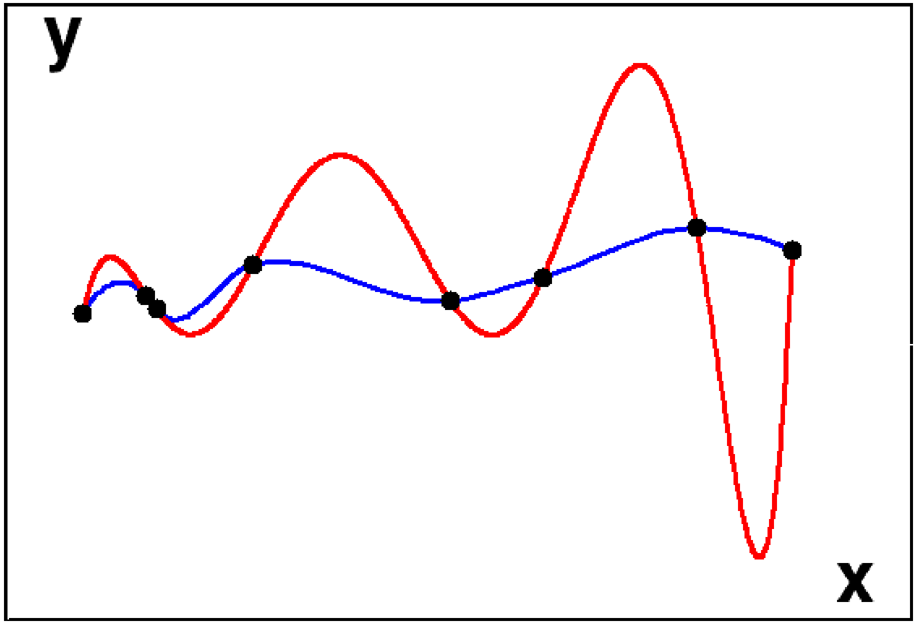


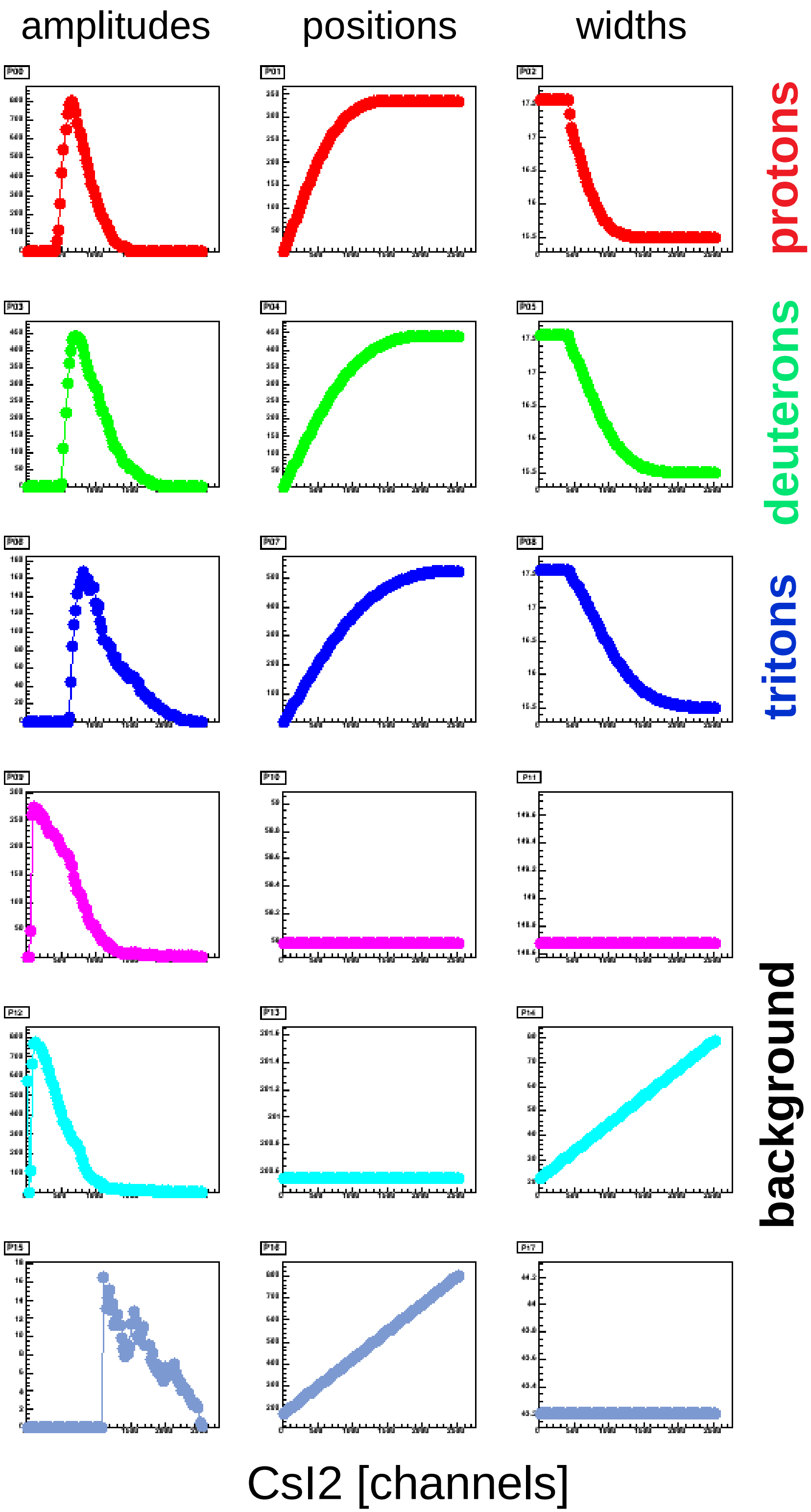
Another try:

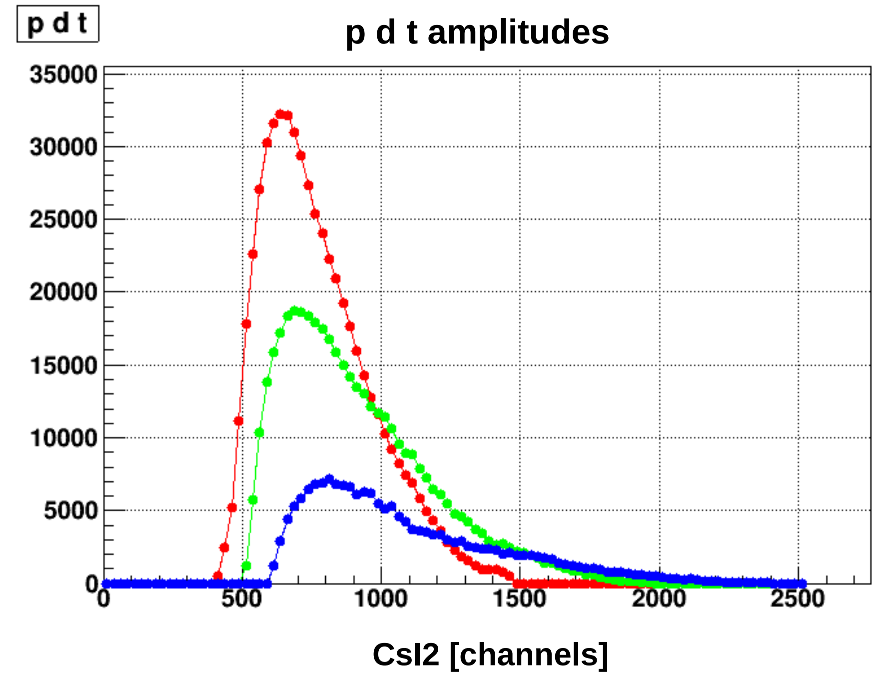
$$Cons\left(\vec{p}\right) = \left|\vec{p}_{slice} - \vec{p}_{slice-1}\right|^2$$

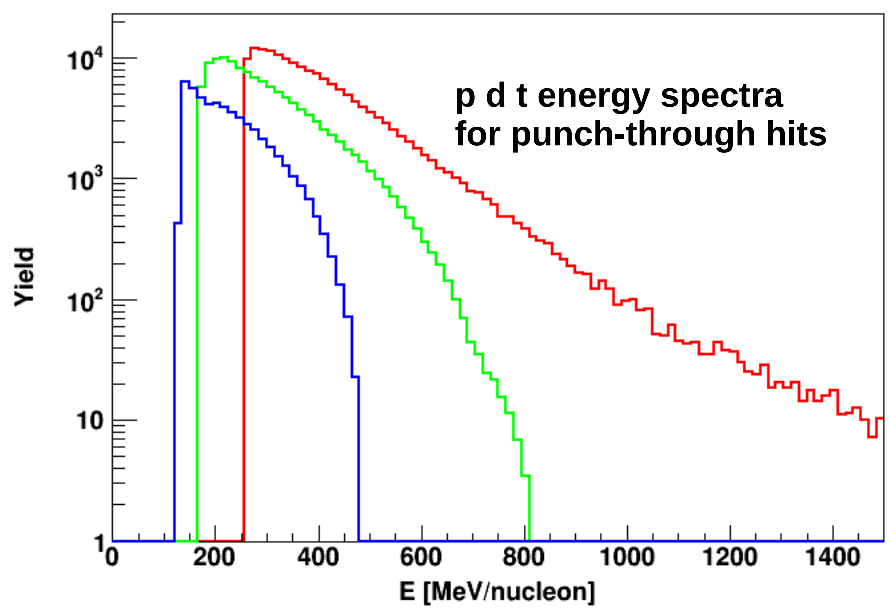
request that the parameters vary slowly from slice to slice, starting from the slice with well resolved peaks. A kind of a Markov-chain.

It makes sense, since we are interested in regular behavior in “orthogonal” direction → **between slices**.

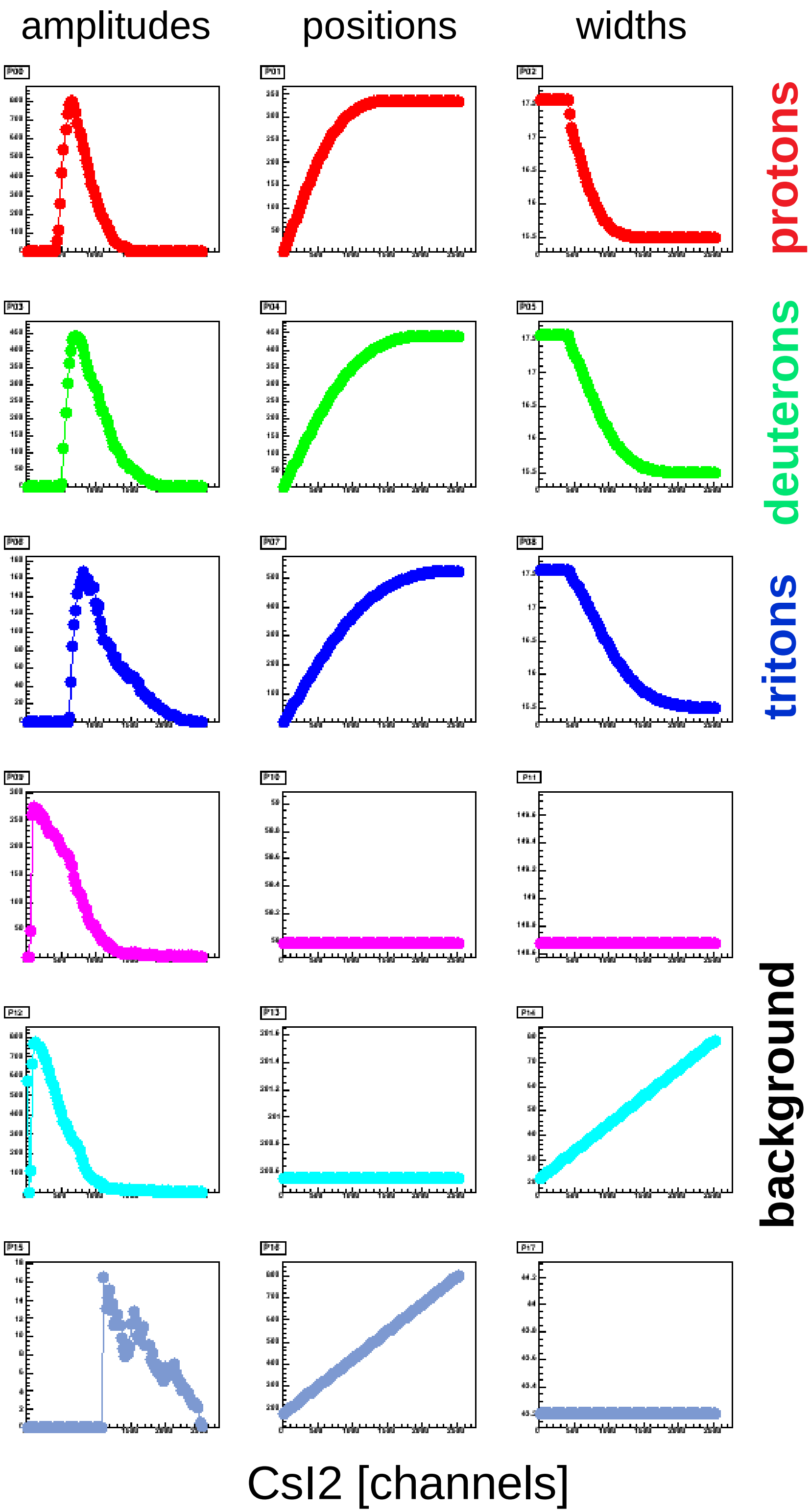
χ^2 + smooth variation

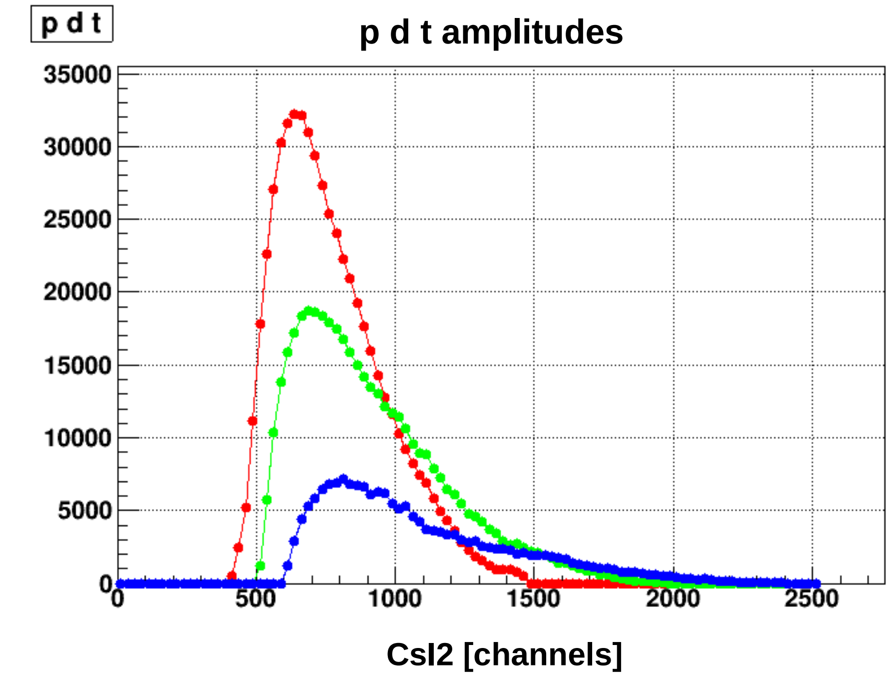


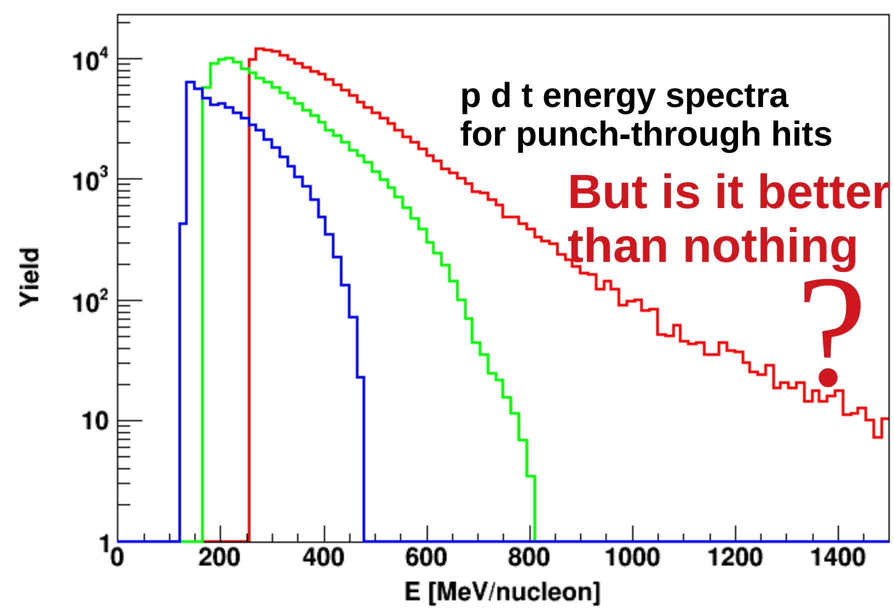




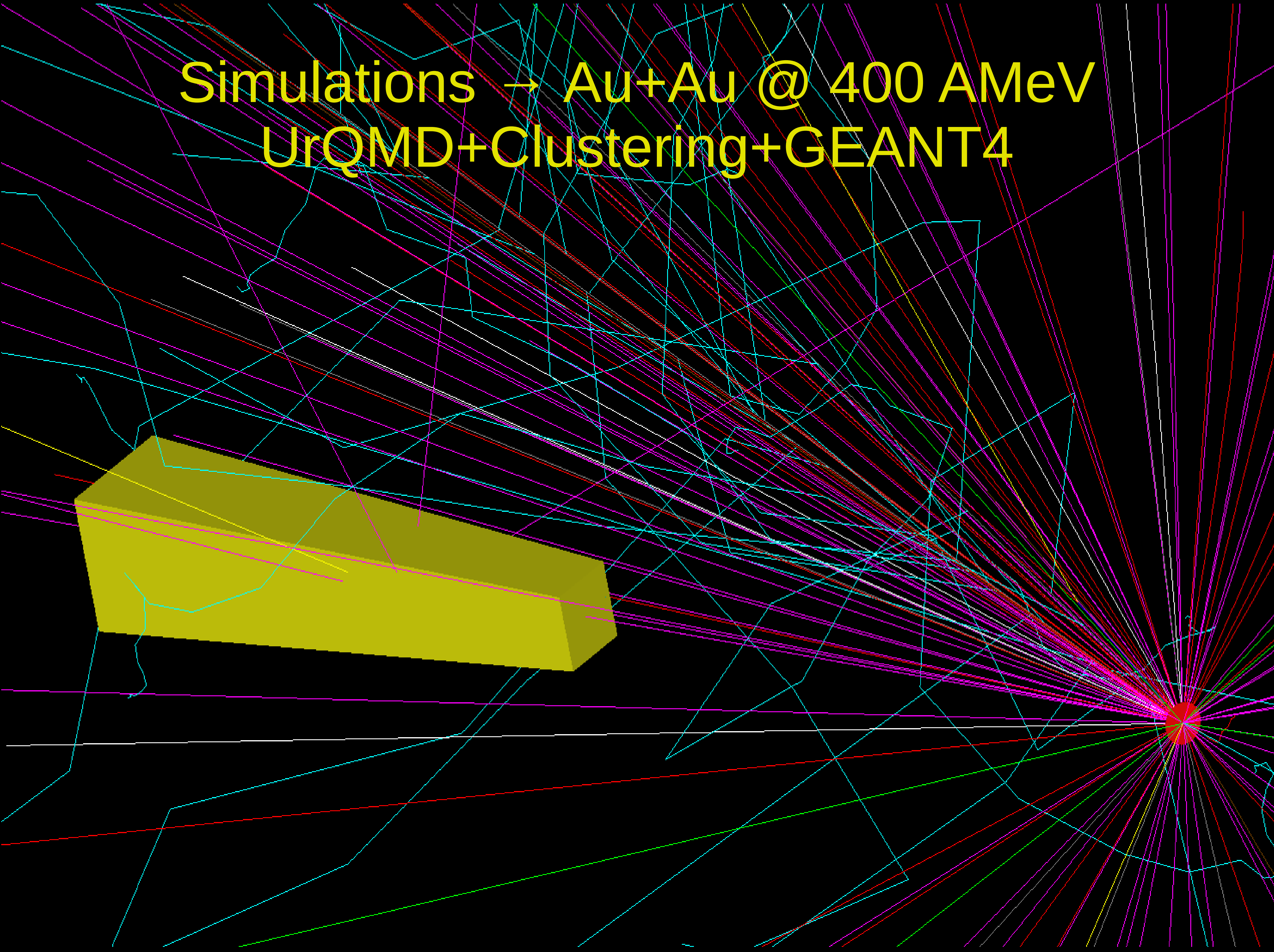
χ² + smooth variation





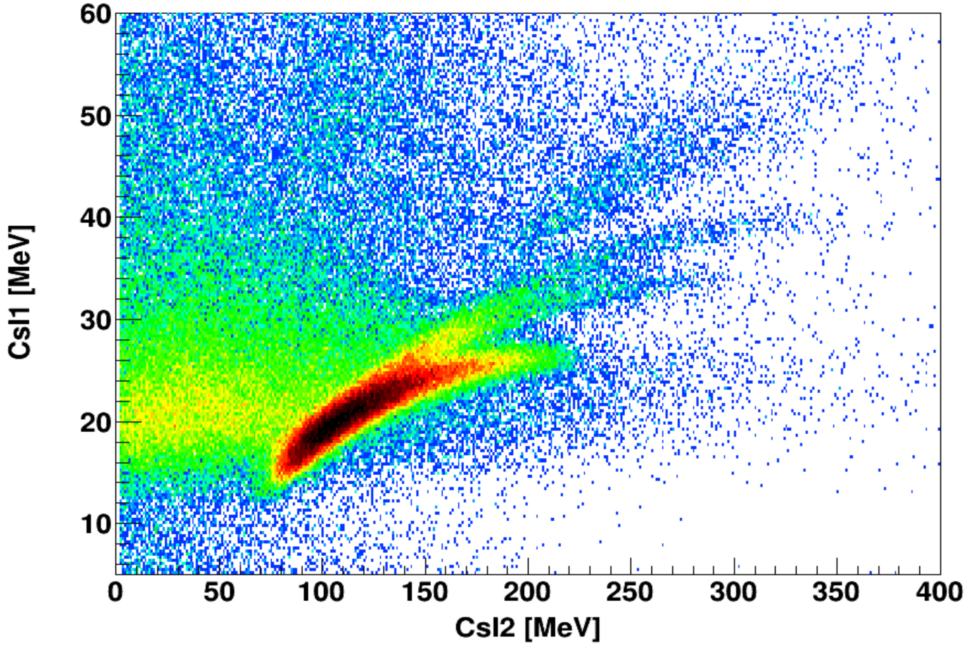


Simulations → Au+Au @ 400 AMeV
UrQMD+Clustering+GEANT4

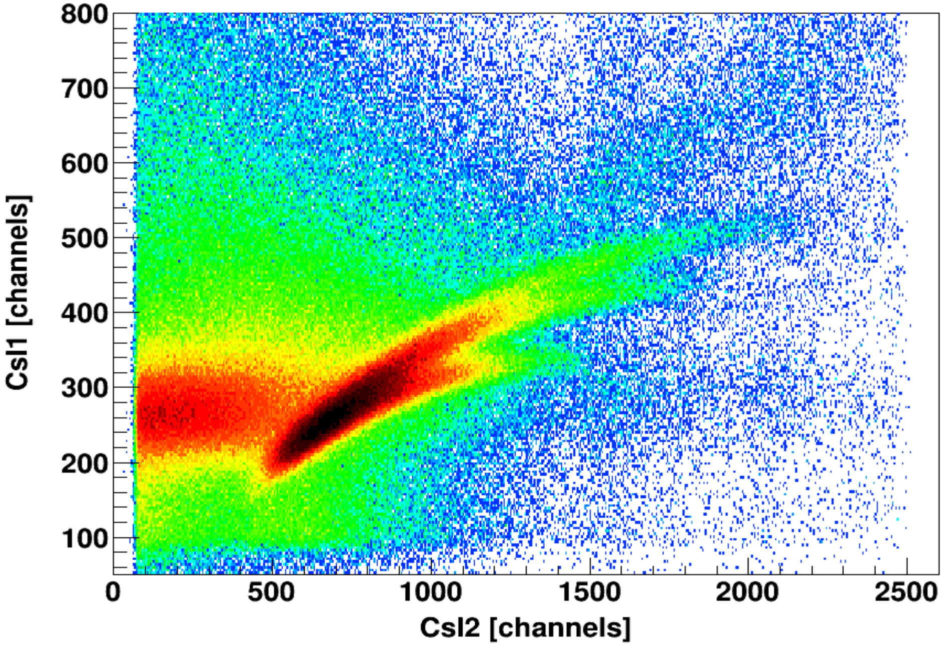


ΔE-E: punch-through + background

UrQMD+GEANT4



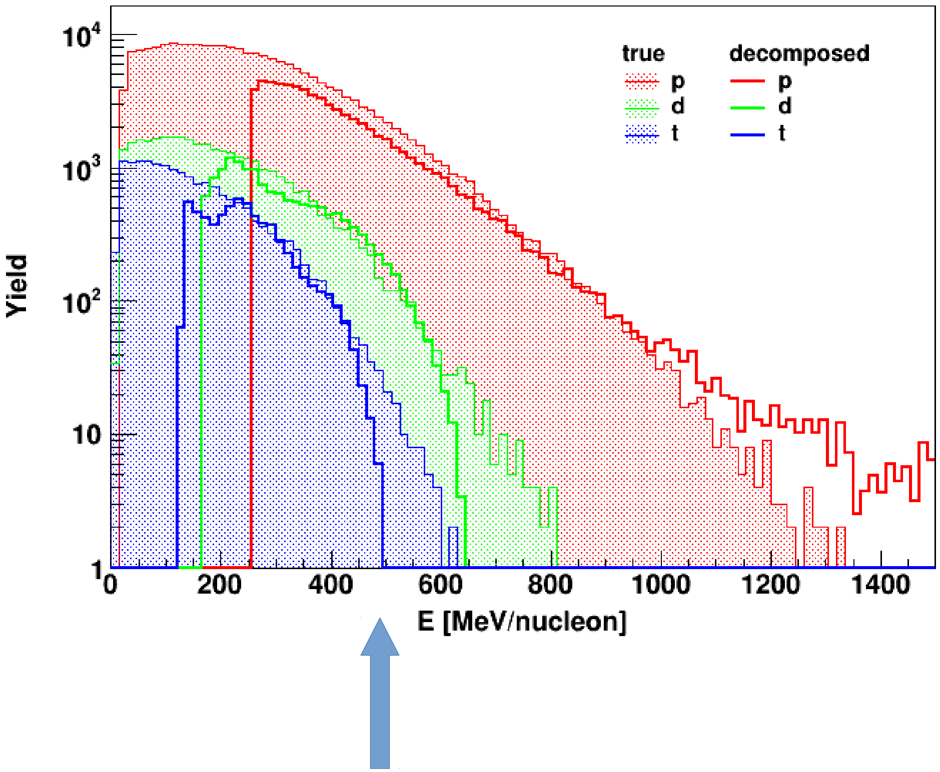
Experiment



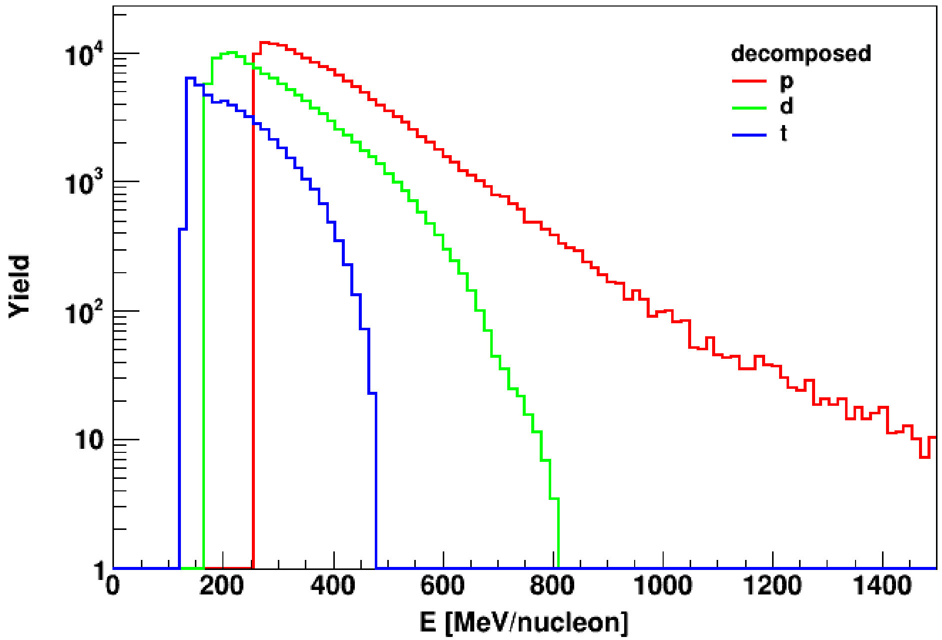
Note different background intensities
in simulation and in the experiment
(also more double-protons in UrQMD)

Precision of decomposition

UrQMD+GEANT4



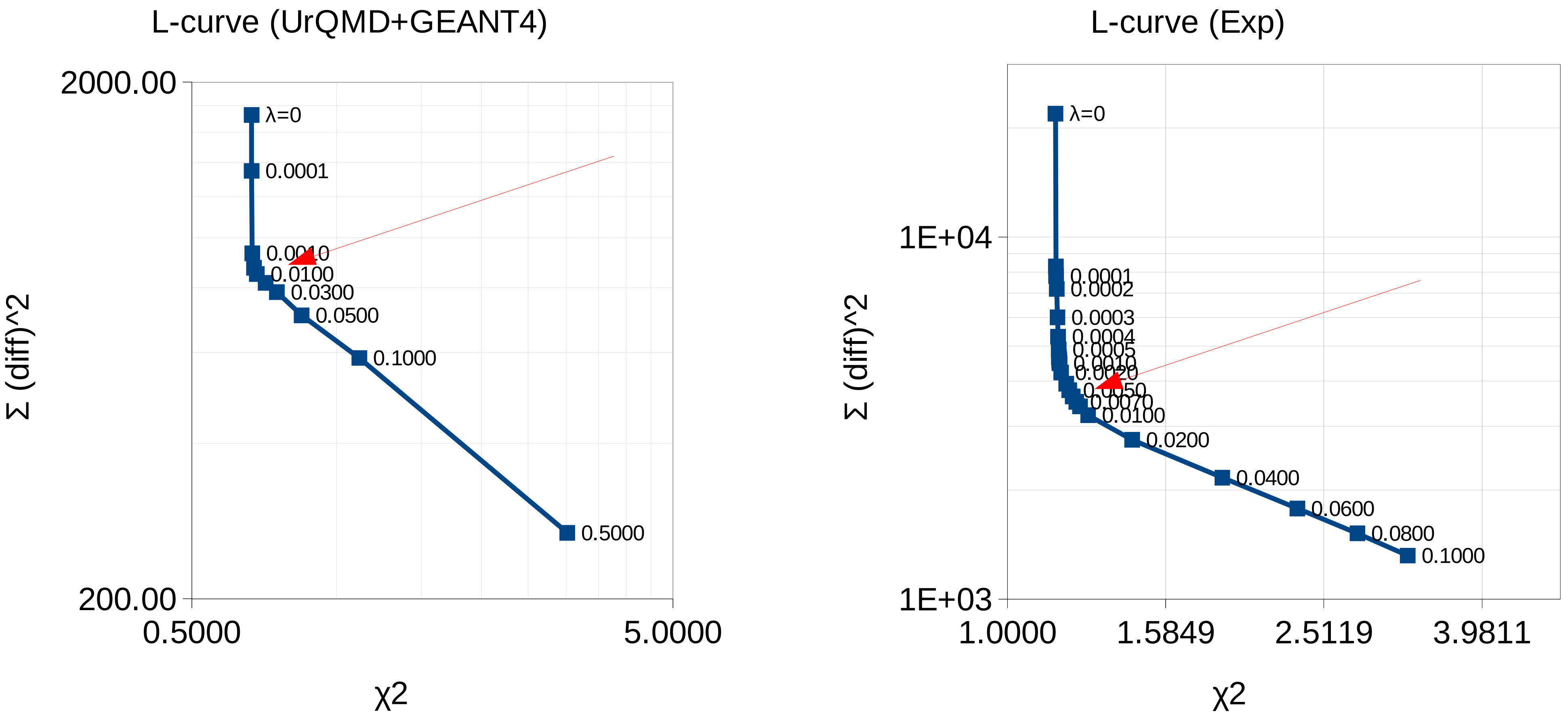
Experiment



Reasonable decomposition up to ~500 AMeV

Note different proportions of p d t in simulation and in the experiment

How to select λ? → L-curves



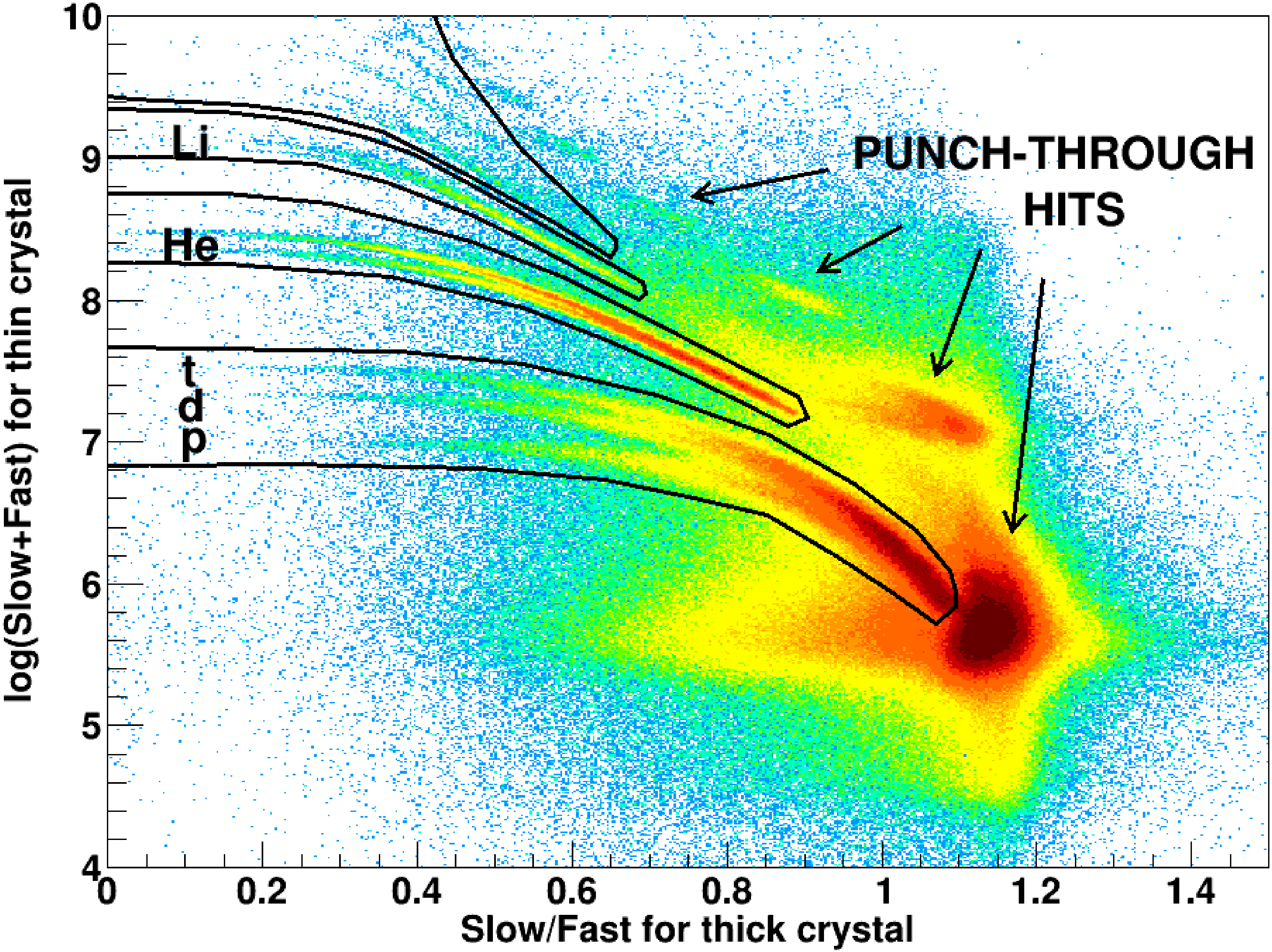
Optimal value of λ ≈ 0.01 for simulations and λ ≈ 0.007 for the experiment

Key points of the work flow

1) separate the well identified particles from the background (secondary reactions, escapes, punch-through, multi-hits) → graphical cuts
2) perform precise energy calibration using the Energy→Light conversion formula and the Range-Energy tables for the well identified particles and using the punch-through points
3) extrapolate of identification lines and the energy calibration for the punch-through particles
4) parametrize the background and the signals
5) fix/restrict as many parameters as possible (at least positions and widths)
6) perform decomposition based on χ^2 minimization and regularization for 1D slices
7) find the optimal value of the regularization parameter λ
8) derive the ID-weights from the fitted amplitudes
9) construct the energy spectra using the ID-weights and energy calibration

Summary and conclusion

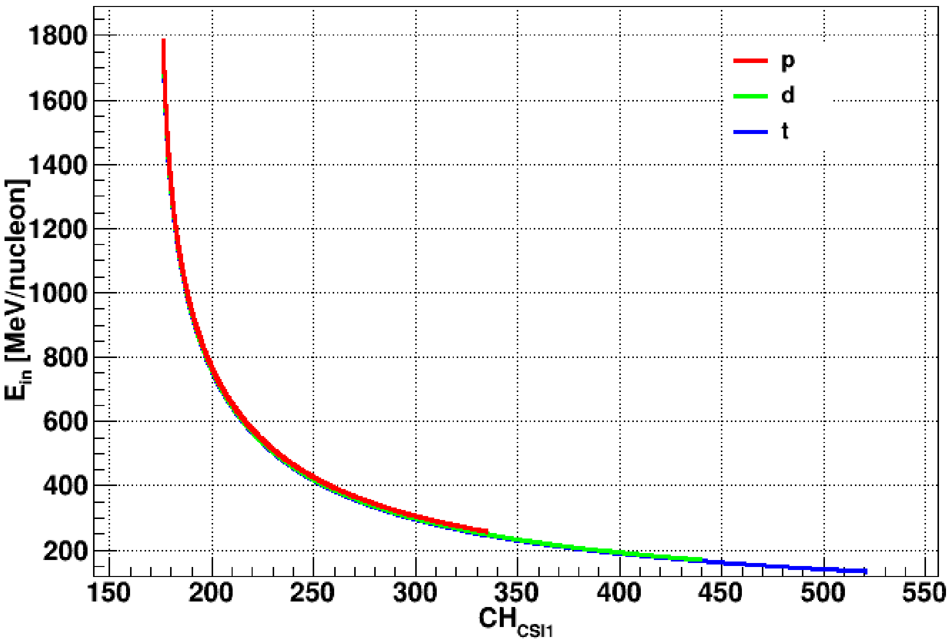
- **decomposition** method with **regularization** has been applied to punch through p d t measured with a telescope method
- it allowed to **extend**, with a moderate precision, the identification and energy calibration **from ~130 to at least ~500 MeV/nucleon** (for the **KRATTA** module)



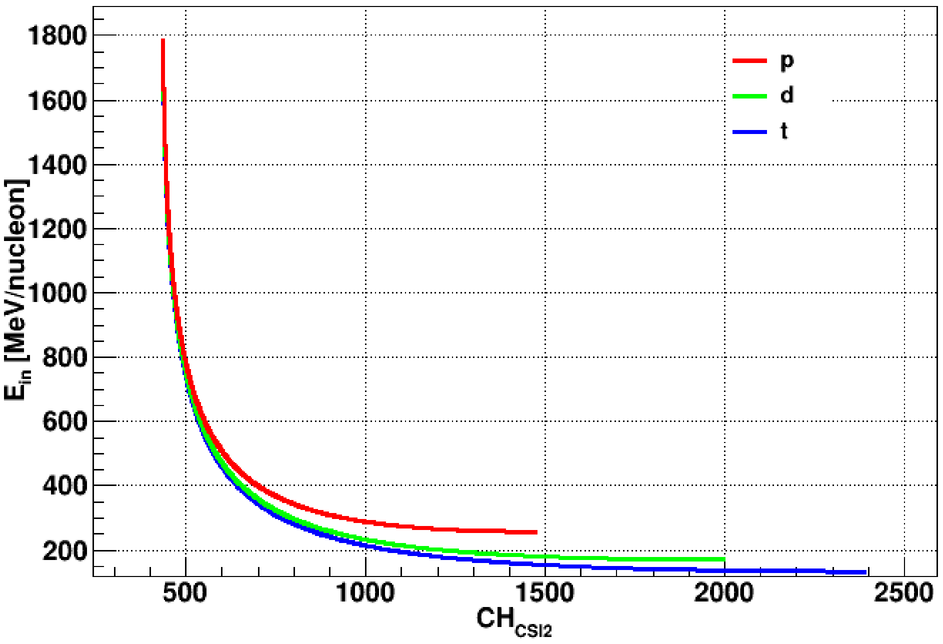
J. Łukasik et al., EPJ Web of Conf. 88, 01017 (2015)

Energy/nucleon calibration curves for punching-through p d t

25 mm CsI



125 mm CsI

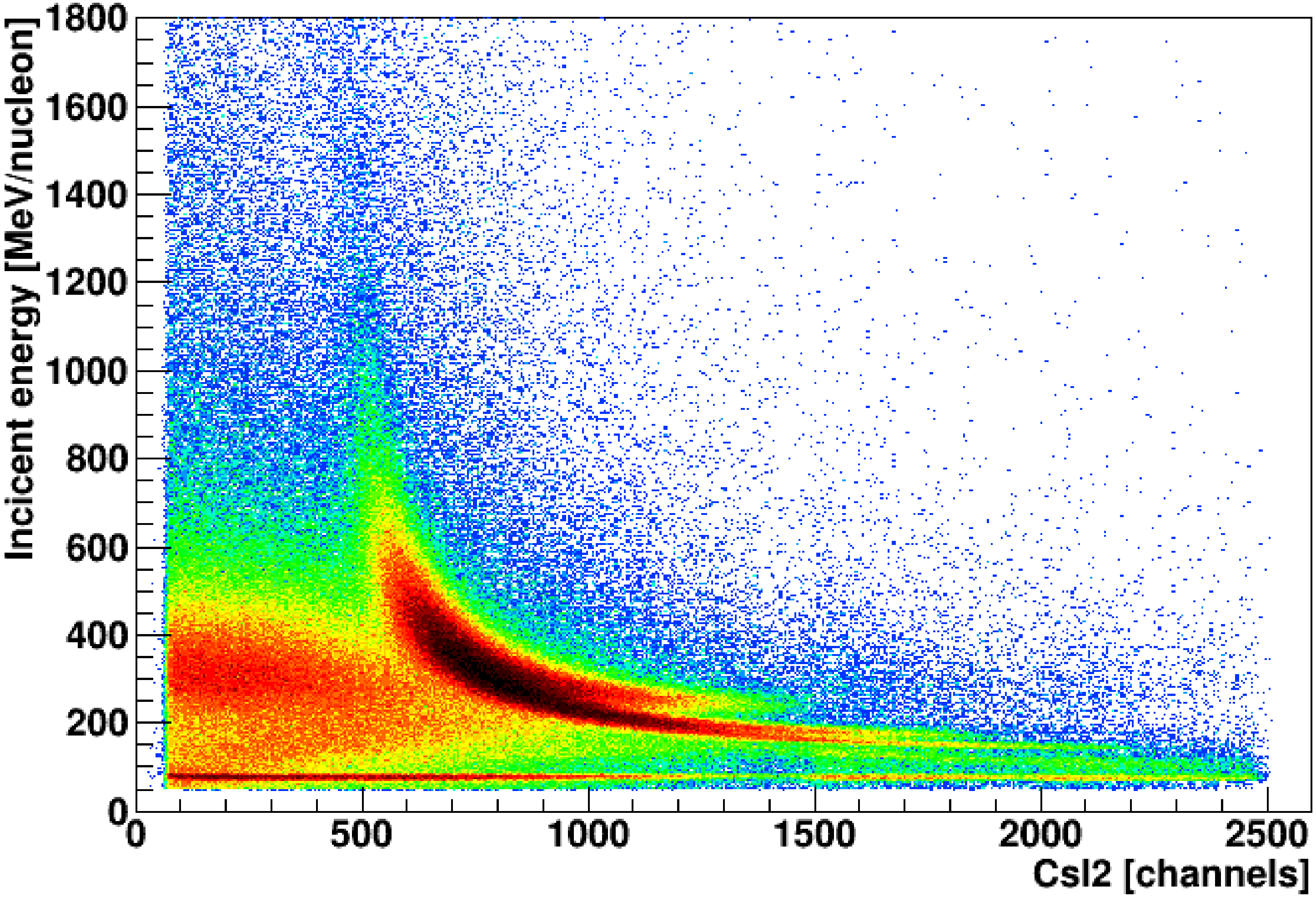


$$\frac{E}{A} \sim \frac{Z^2}{\Delta E}$$

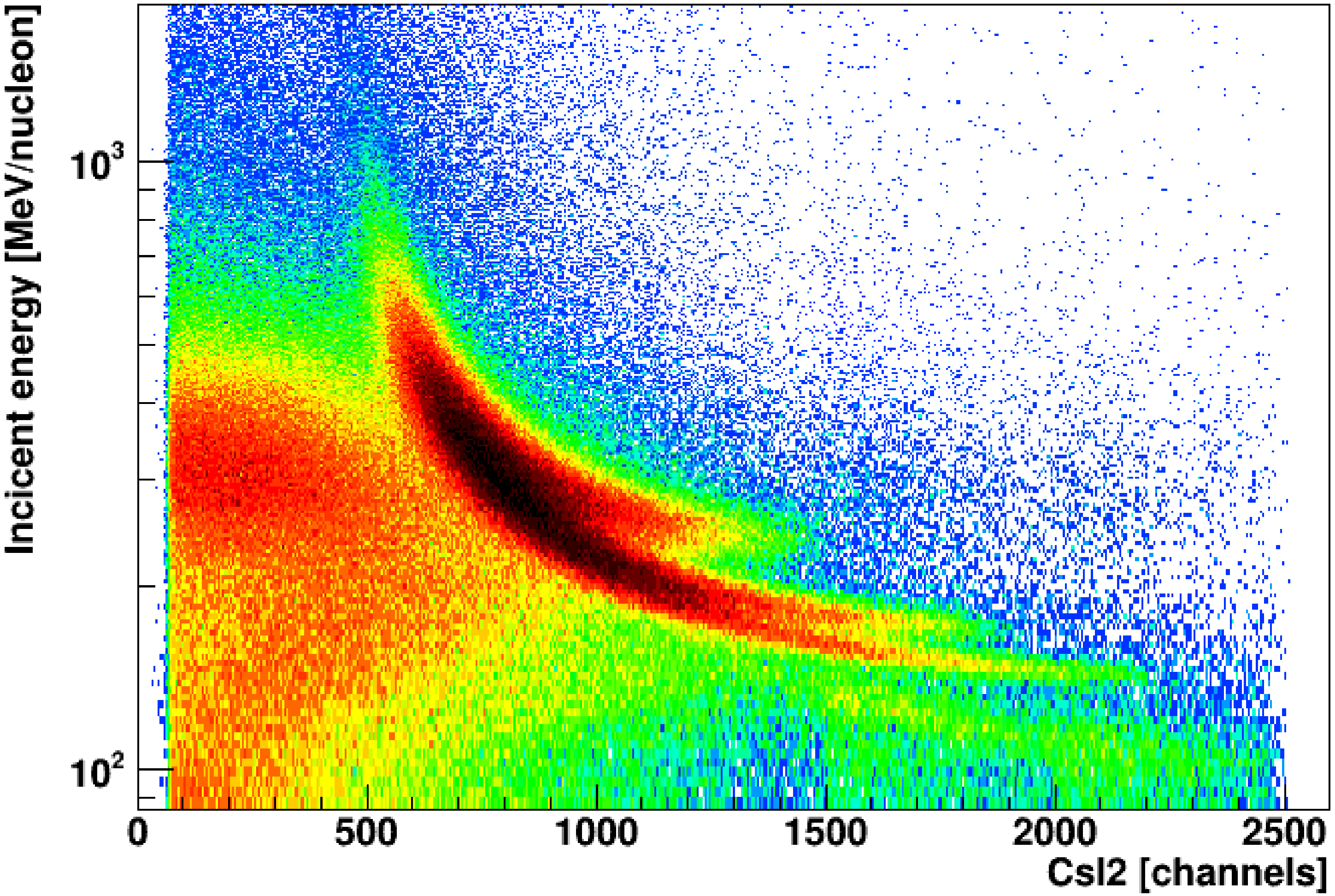
for sufficiently thin ΔE detector
almost no dependence on A (~2%)

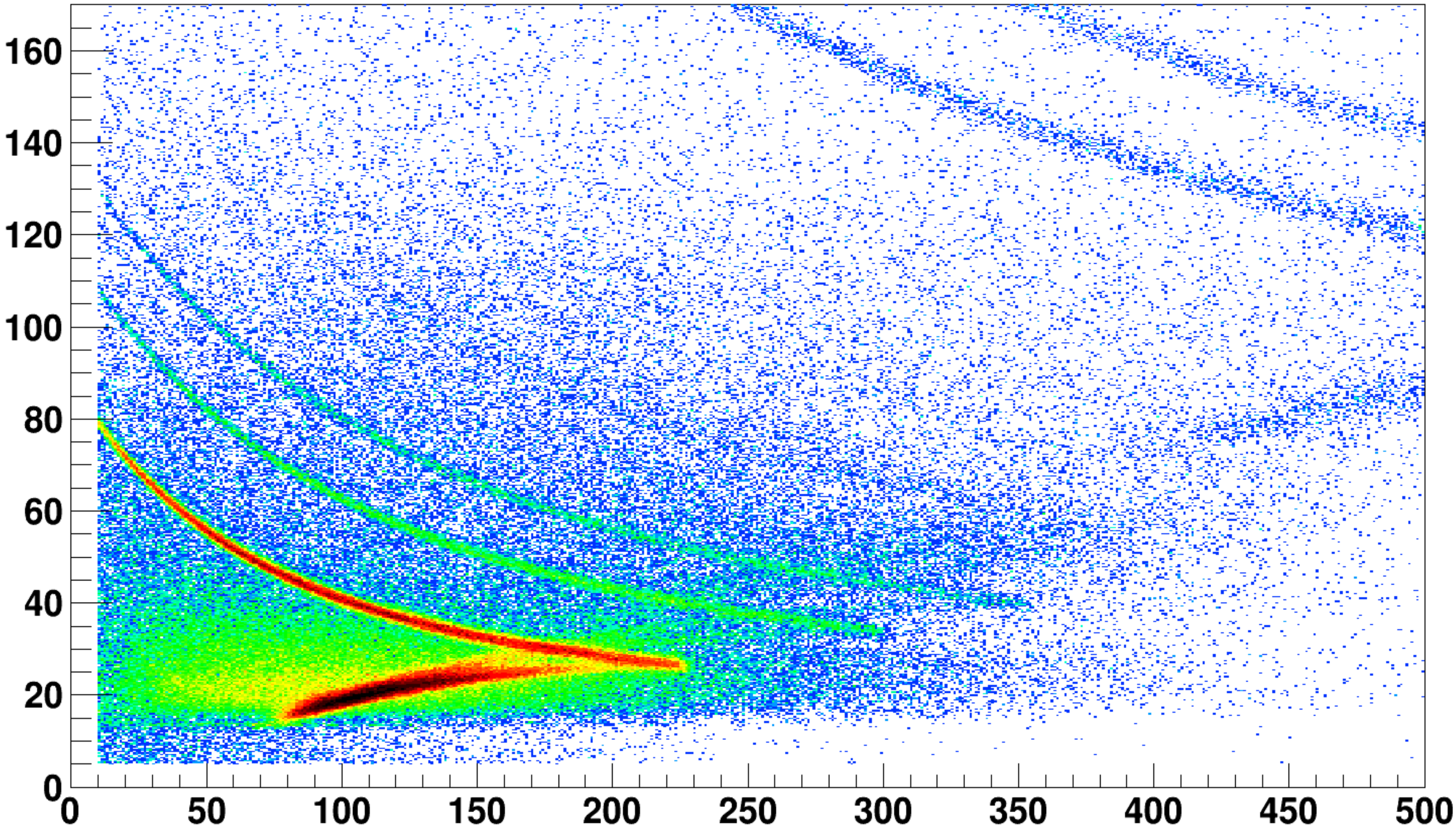
it is possible to calibrate Z=1 (in MeV/nucleon)
without identification → limited utility → can we go beyond?

Energy/nucleon calibration from ΔE in CsI1



Energy/nucleon calibration from ΔE in CsI1

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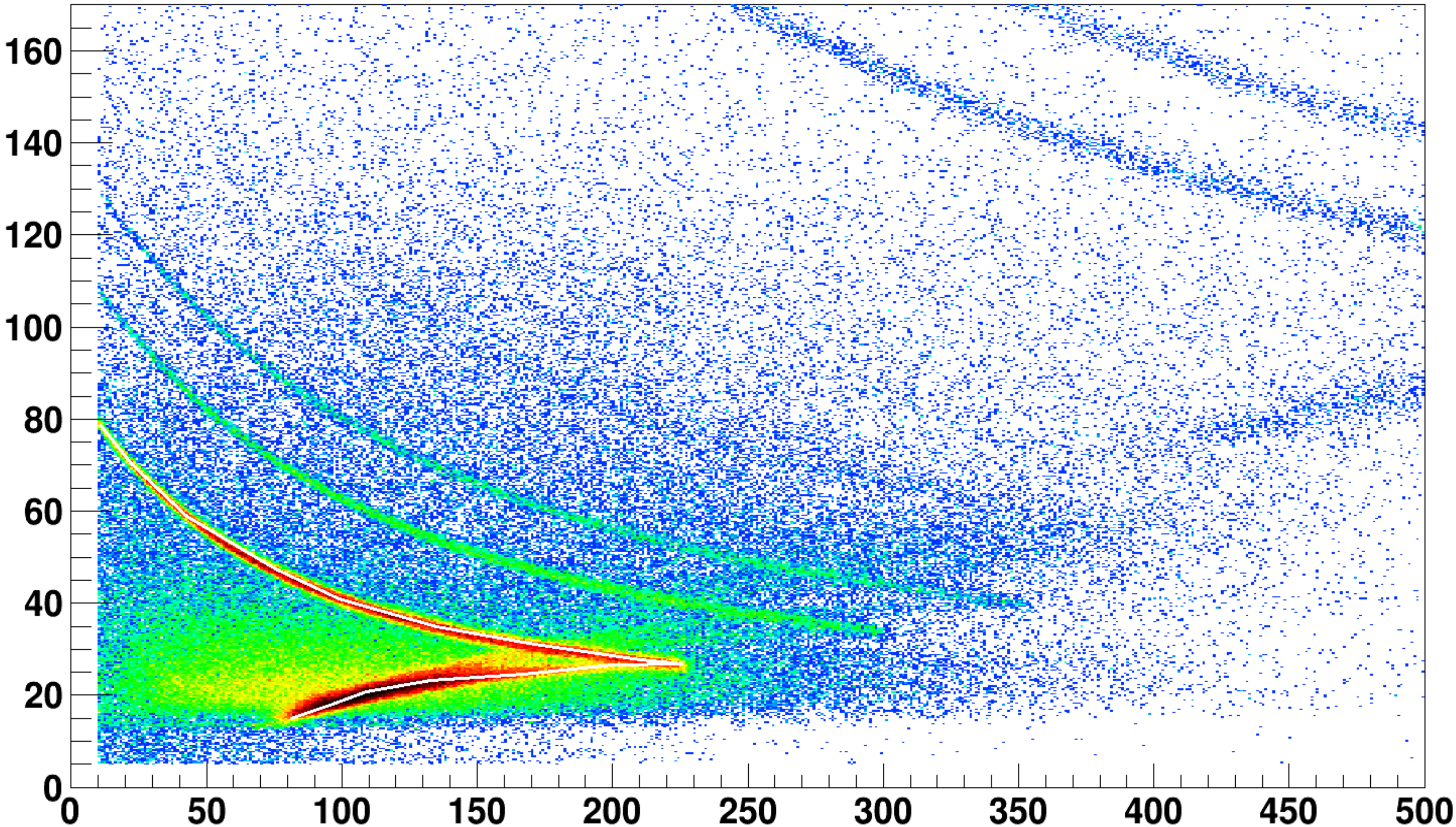
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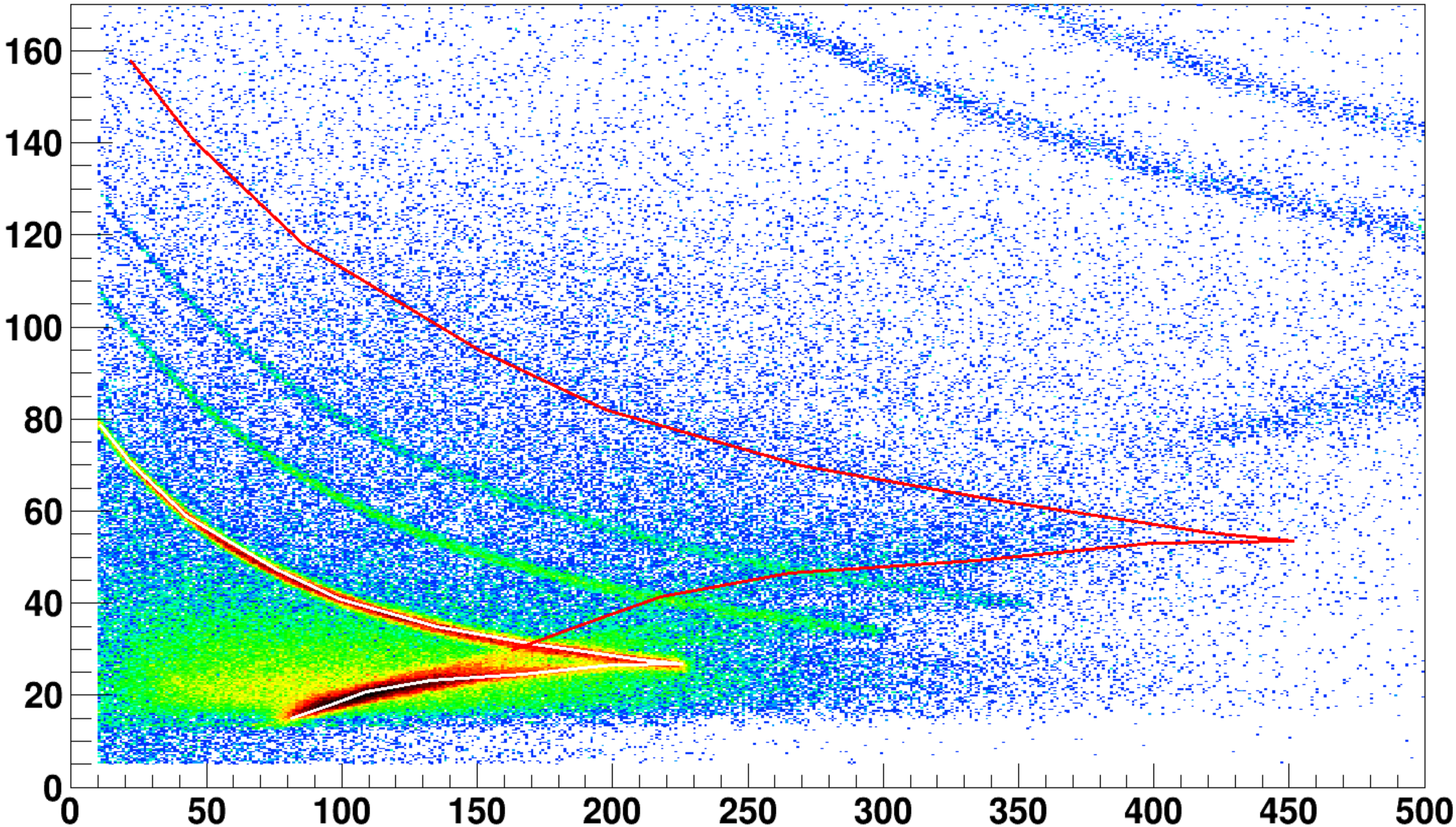
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