Light charge particle flows in the ASY-EOS experiment measured with the KRATTA detector

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and the ASY-EOS Collaboration

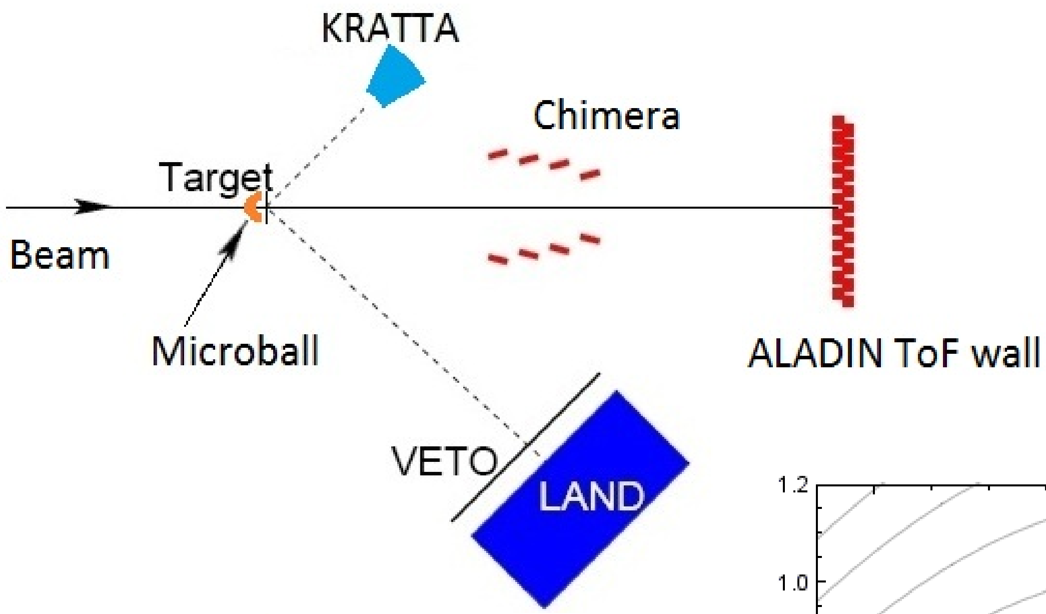
Introduction: The ASY-EOS experiment

KRATTA detector
- **detection technique**
- **methods of data analysis**

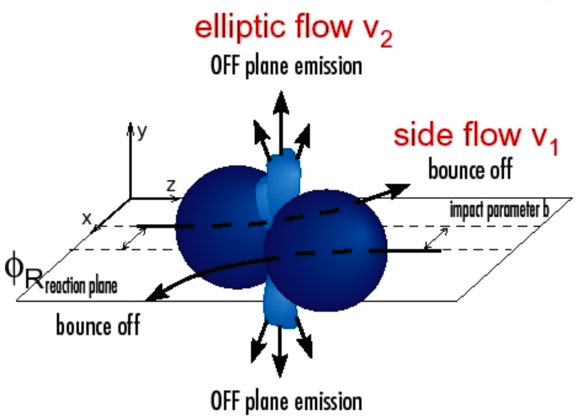
KRATTA data vs UrQMD predictions
- **isotope ratios**
- **flow parameters**

Conclusions

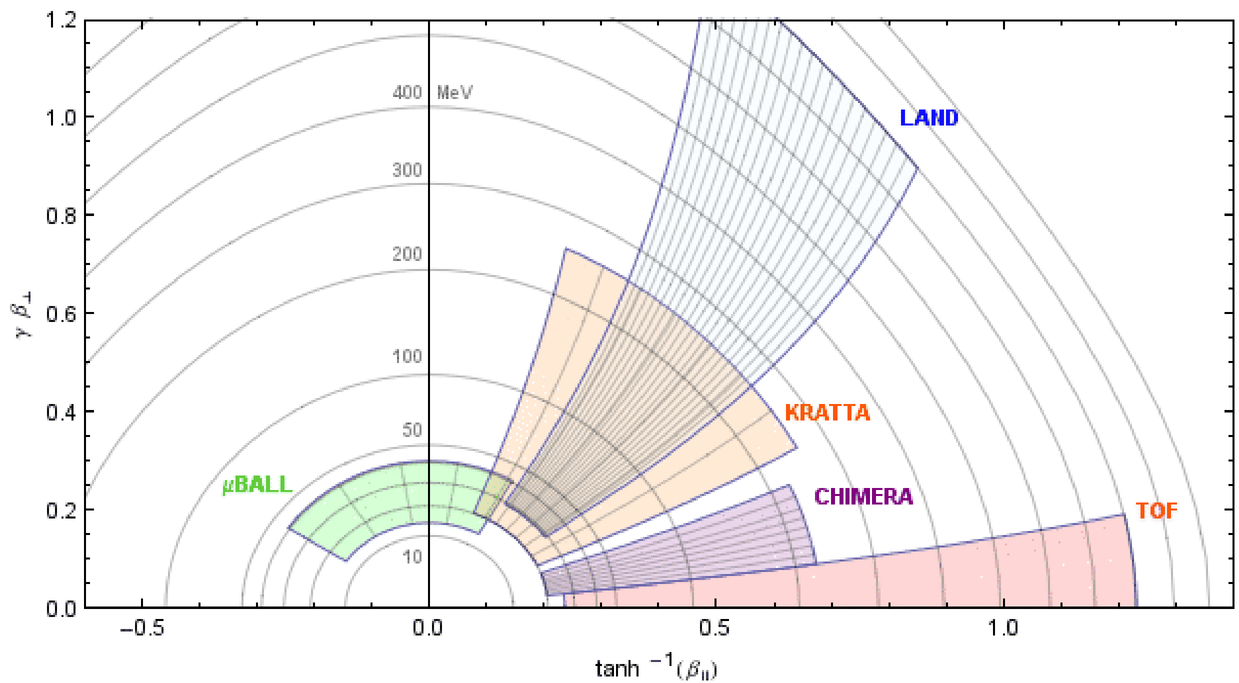
ASY-EOS Experiment (GSI 2011)



$^{197}Au + ^{197}Au$
$^{96}Zr + ^{96}Zr$
$^{96}Ru + ^{96}Ru$
$E_{proj} = 400$ A·MeV



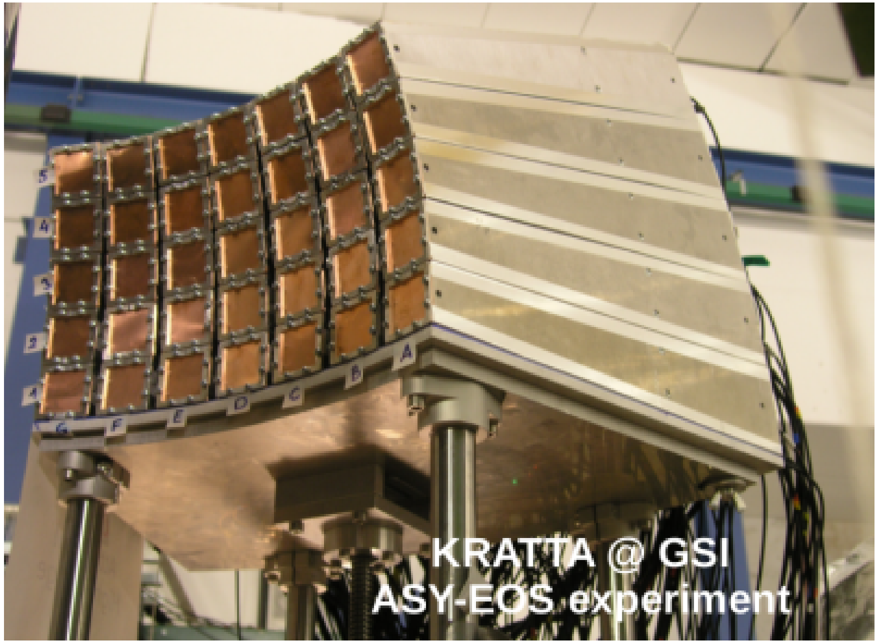
Acceptance of the setup (protons)



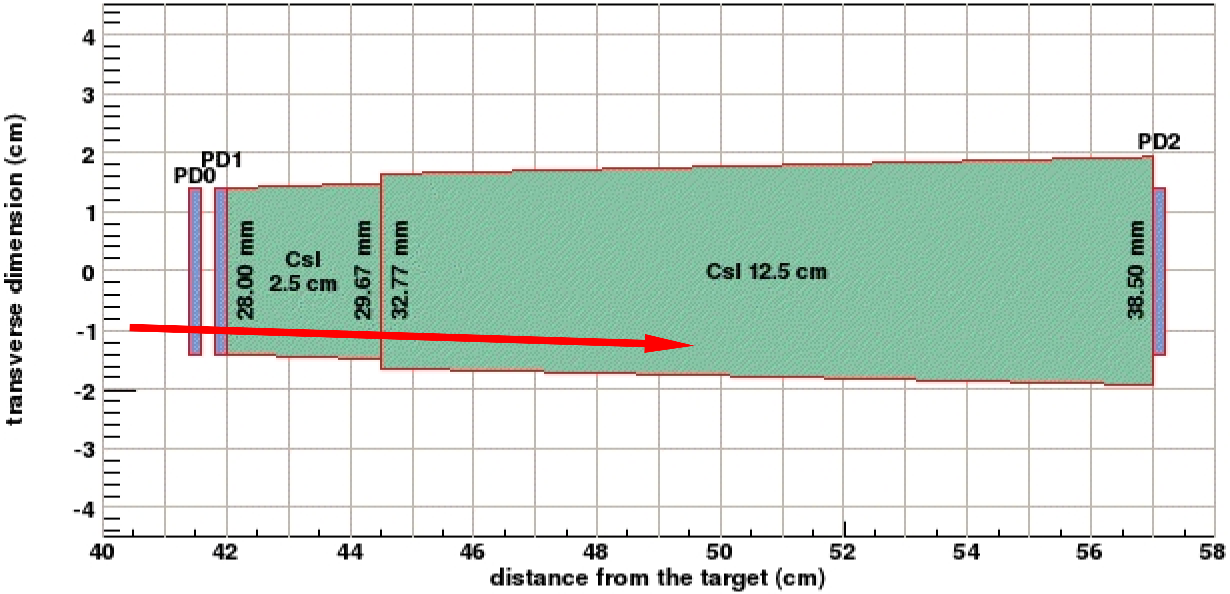
KRATTA

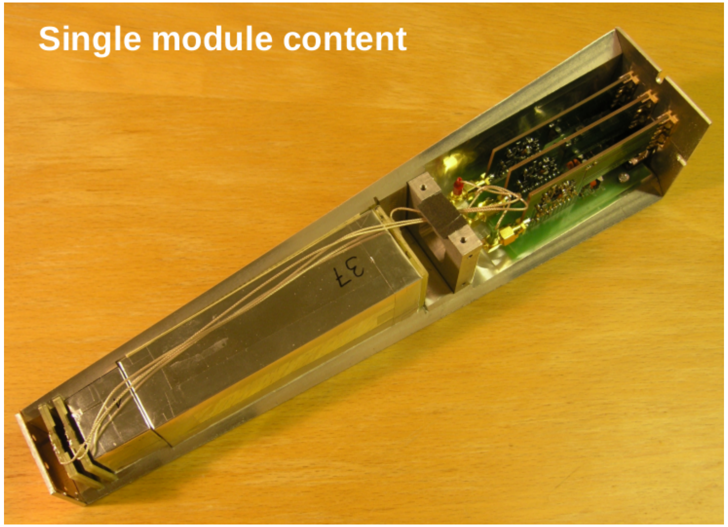
KRAkow Triple Telescope Array

- **Detection of light charged particles with isotopic resolution**
- **35 telescope modules**
- **Broad energy range (2 < E/A < 260 MeV for p, α)**



Active elements of the telescope module





Photodiodes: HAMAMATSU S5377-02

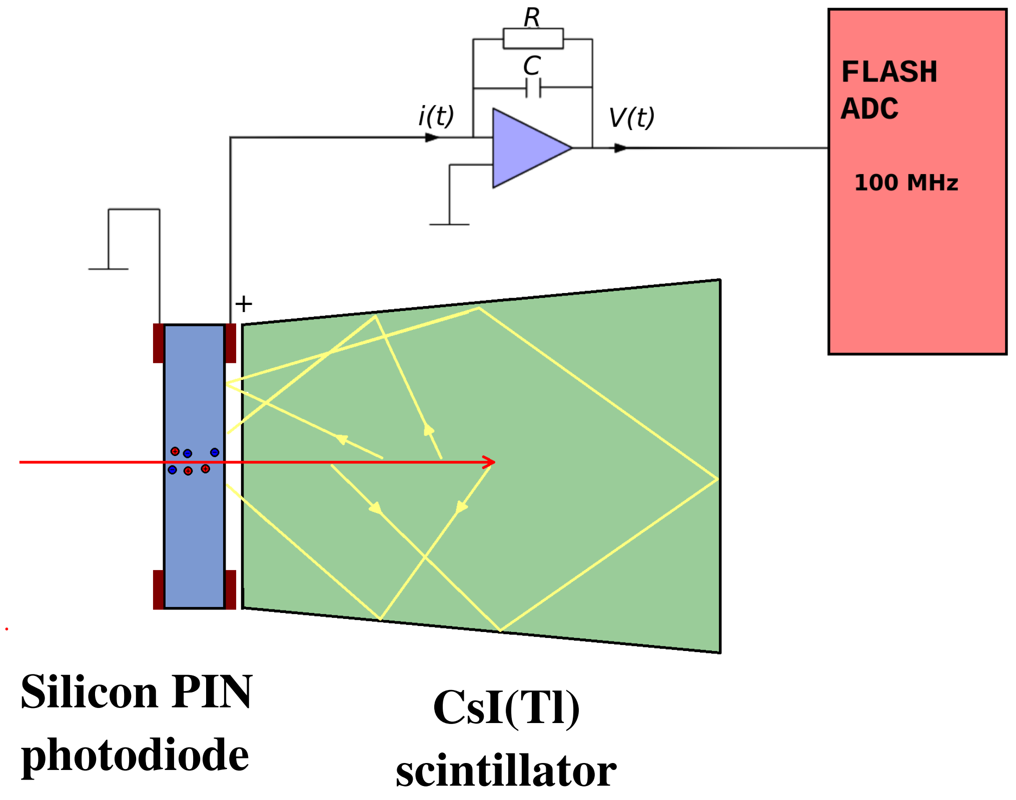
- Active Area: 28x28 mm^2
- Thickness: 500 ± 15 μm
- Orientation: (111)
- Dead Layers: 1.5 μm front, 20 μm rear
- Full Depletion: ~170 V
- Dark Current: 30 nA, (Max. 150 nA)
- Rise Time: 40 ns
- Capacitance: 200 pF

CsI(Tl): IMP-CAS, Lanzhou, China

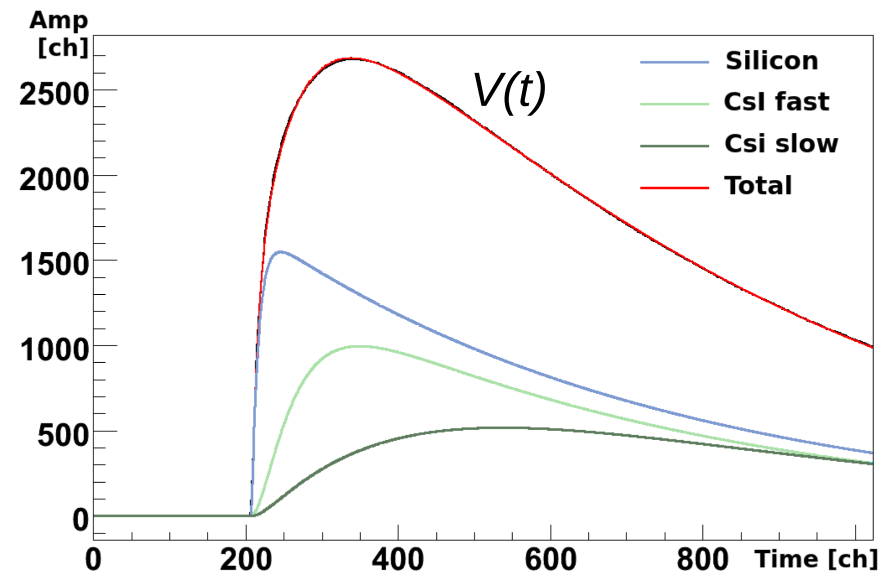
- Tl concentration: 1500 ppm
- LO non-uniformity: <7%
- Shape: Truncated pyramids
- Tolerance: ± 0.1 mm

Wrapping: 3M Vikuiti™ ESR foil

- Reflectance: >98%
- Thickness: 65 μm

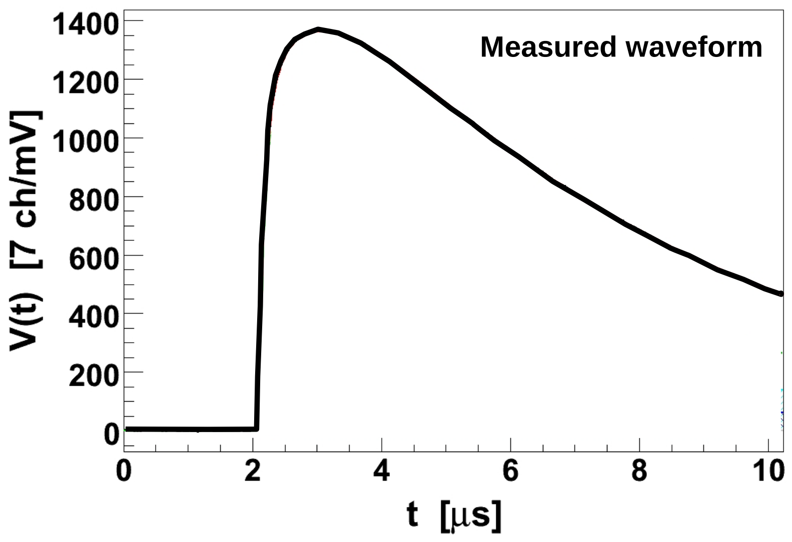


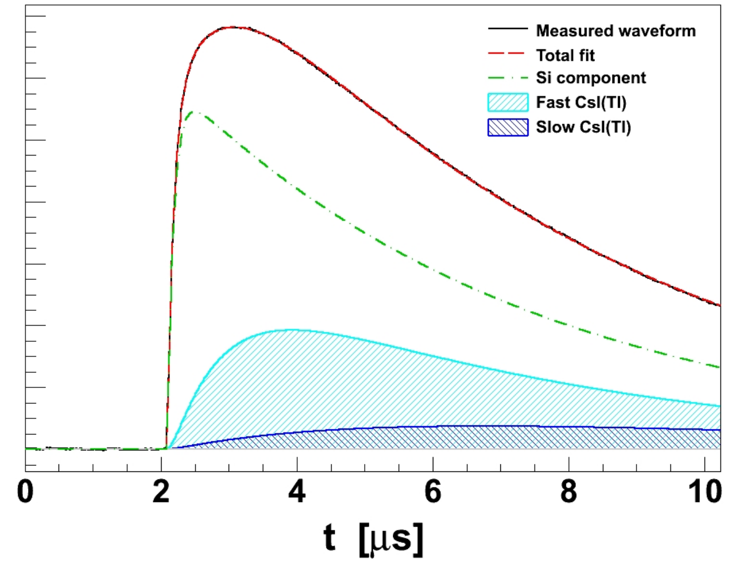
R
C
i(t)
V(t)
FLASH ADC
100 MHz
+
Silicon PIN photodiode
CsI(Tl) scintillator

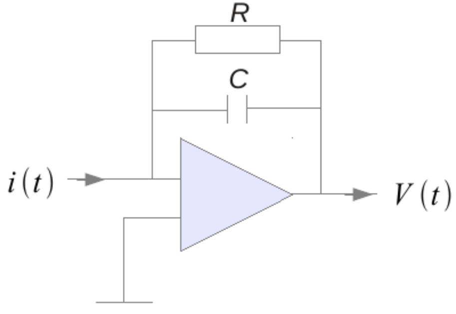


Amp [ch]
V(t)
Silicon
CsI fast
Csi slow
Total
0
500
1000
1500
2000
2500
0
200
400
600
800
Time [ch]

Pulse decomposition analysis



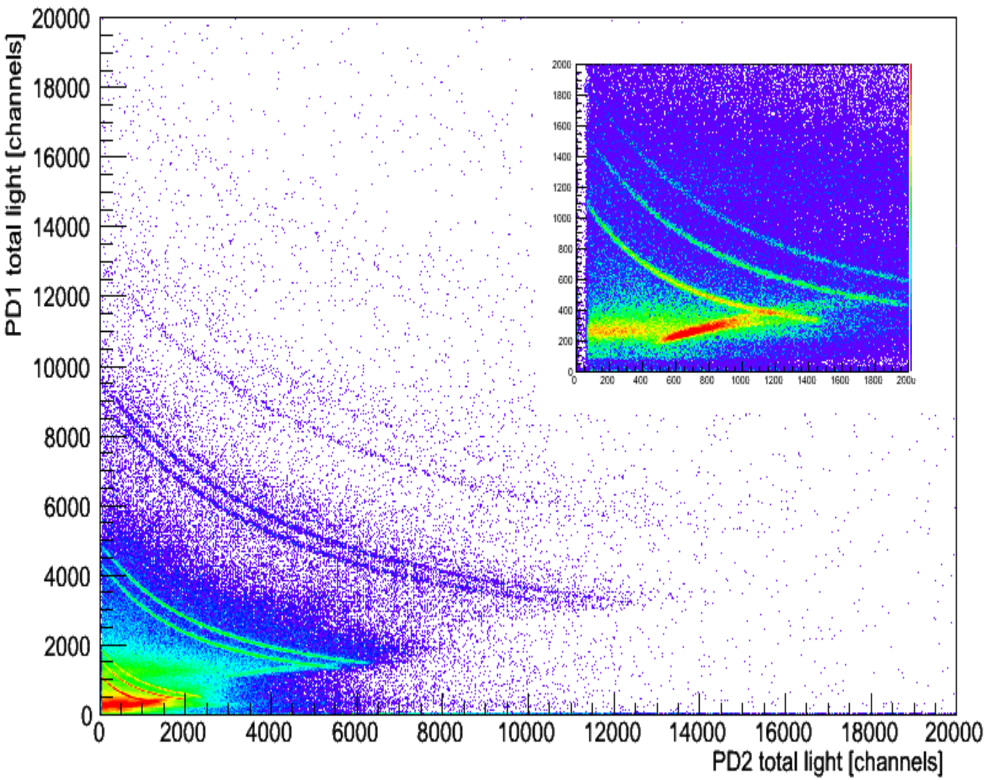


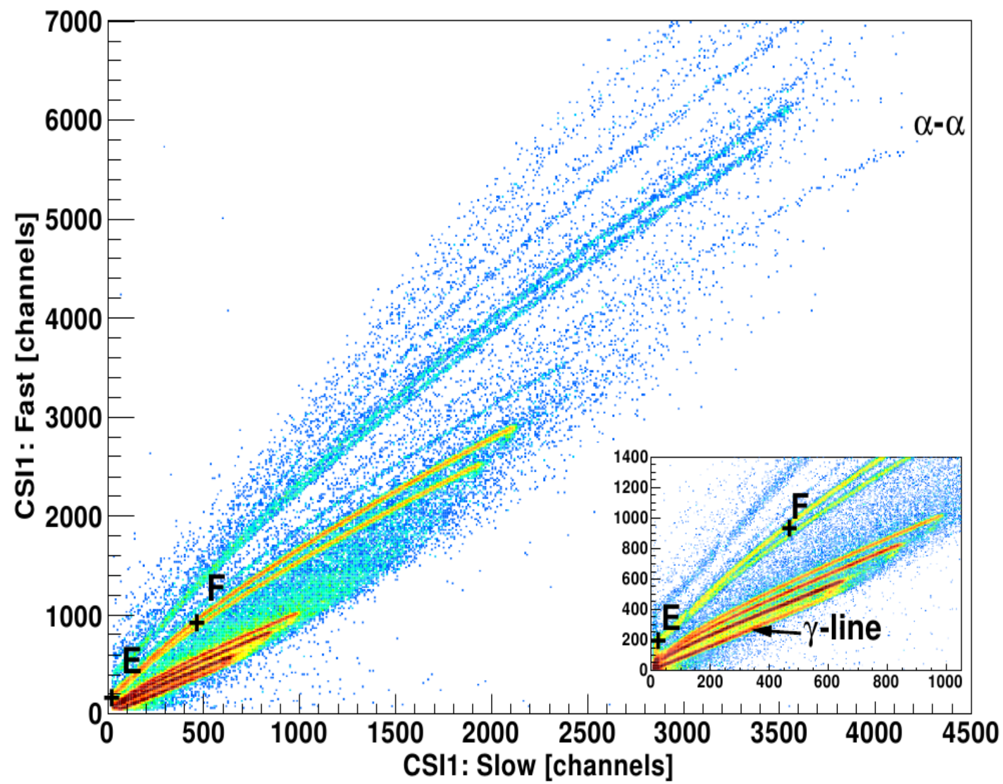


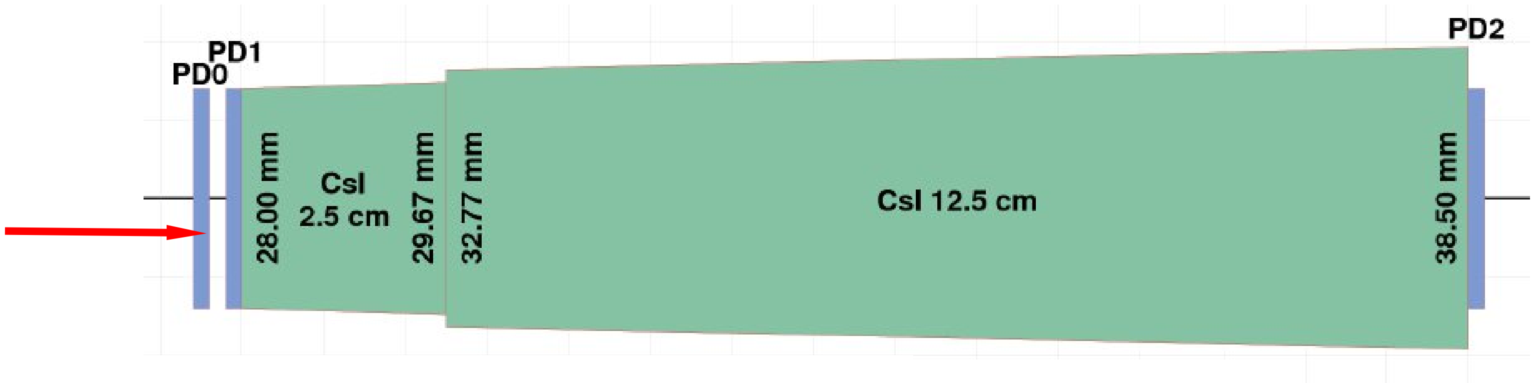
$$\frac{dV(t)}{dt}+\frac{1}{RC}V(t)=\frac{i(t)}{C}$$

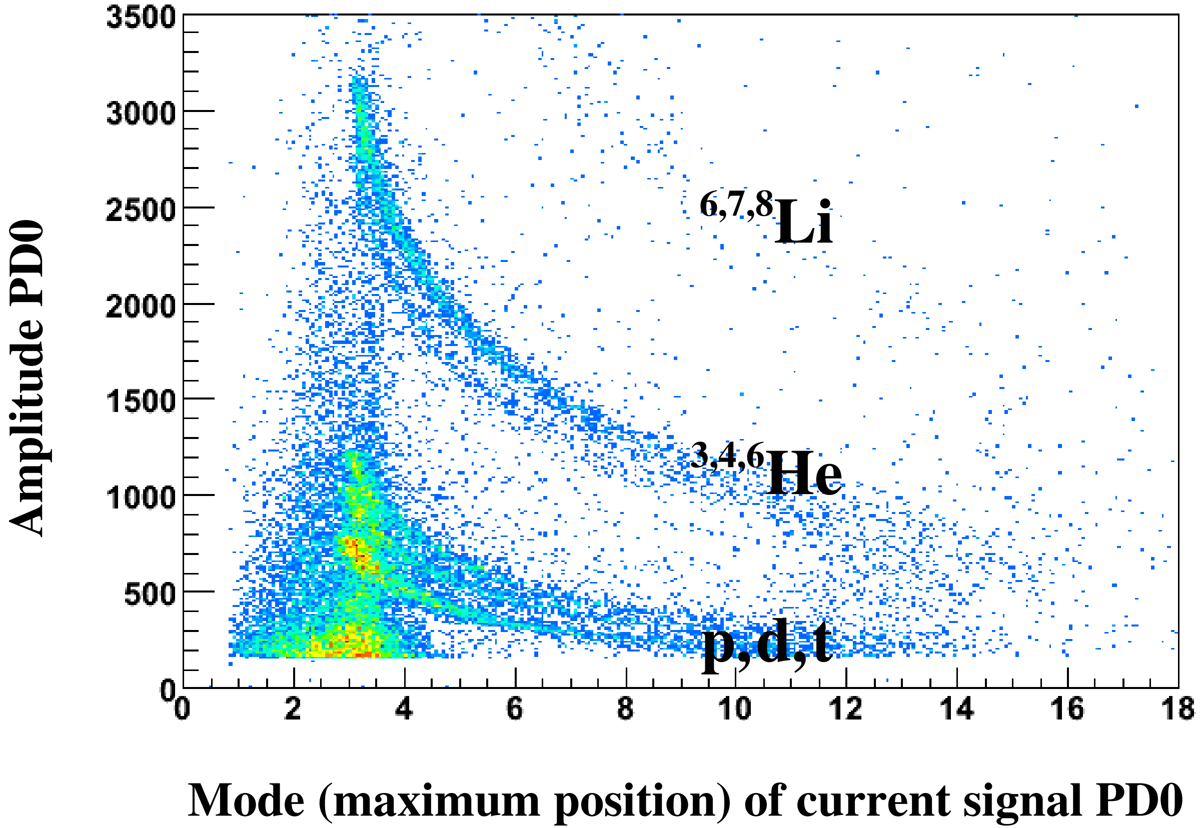
$$\frac{Q_1\left(e^{-t/\tau_1}-e^{-t/\tau_2}\right)}{\tau_1-\tau_2}=i(t) \Rightarrow V(t)=Q_1 RC\left(\frac{e^{-t/RC}RC}{(RC-\tau_1)(RC-\tau_2)}+\frac{e^{-t/\tau_1}\tau_1}{(\tau_1-RC)(\tau_1-\tau_2)}+\frac{e^{-t/\tau_2}\tau_2}{(\tau_2-\tau_1)(\tau_2-RC)}\right)$$

Isotope identification maps



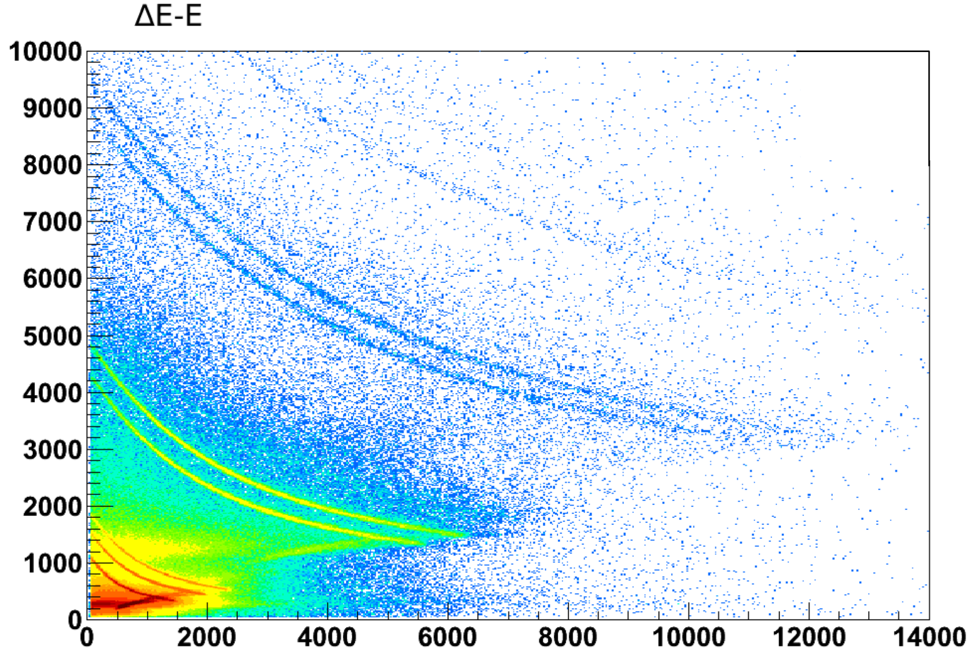




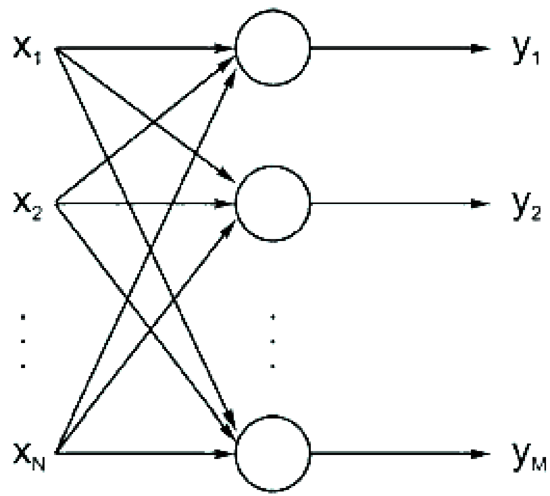


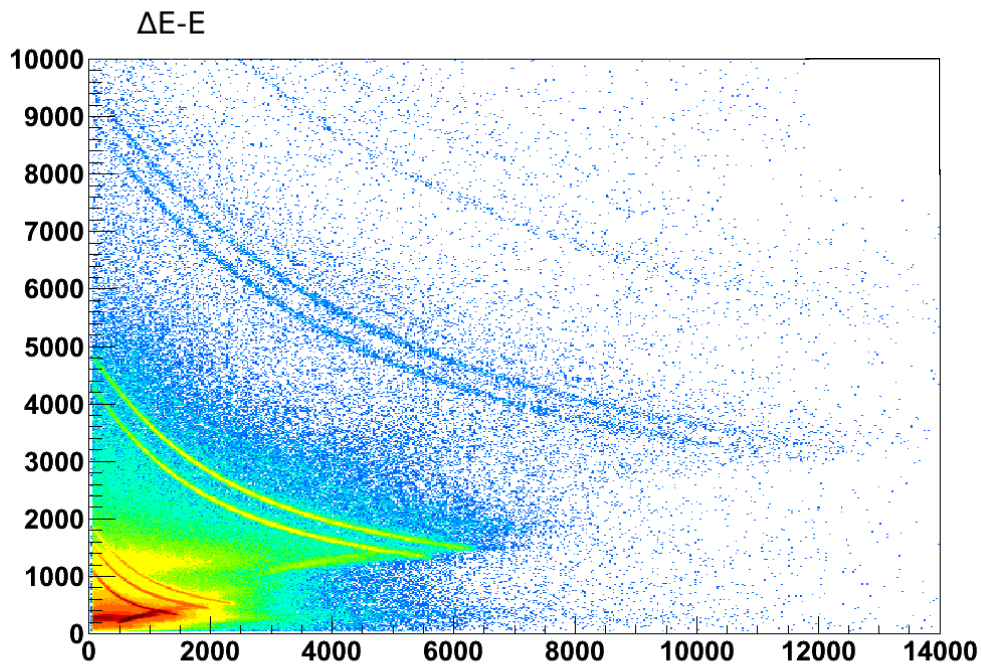
Identification threshold lowered to ~2 MeV/u

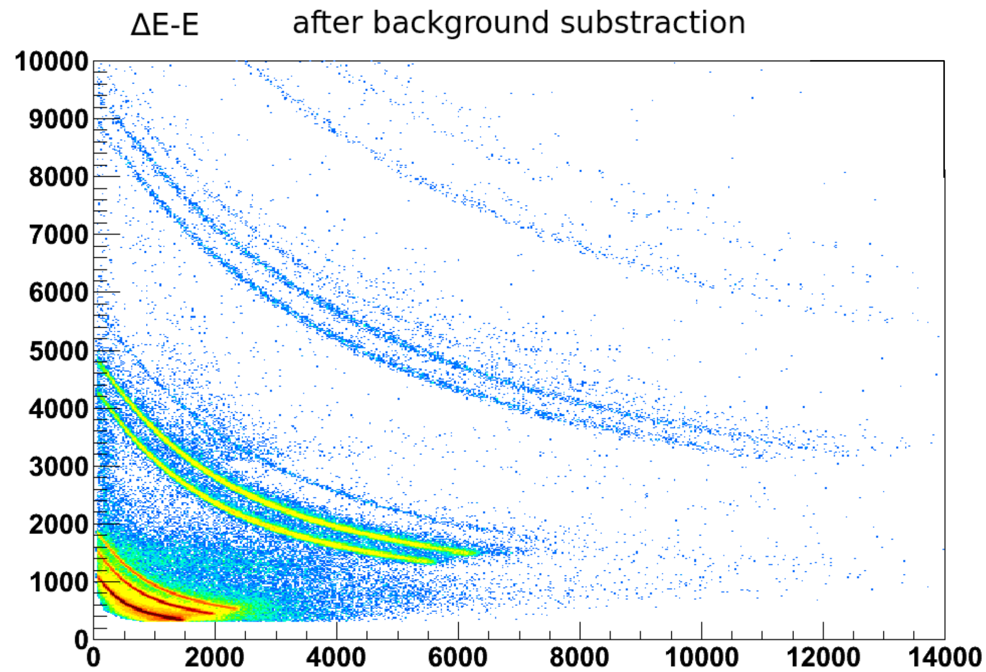
Recognition of background hits

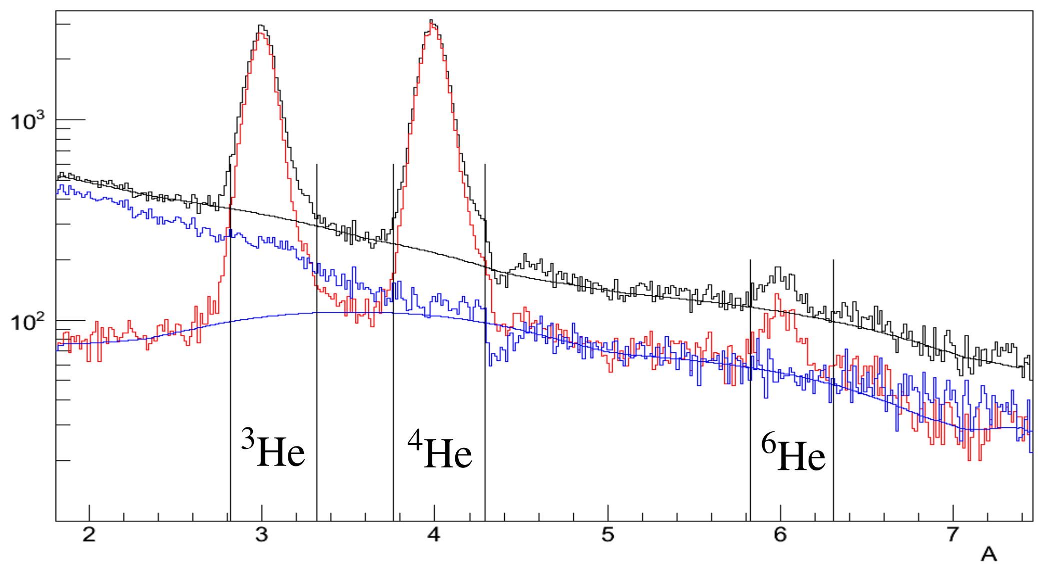


Kohonen self-organized neural network



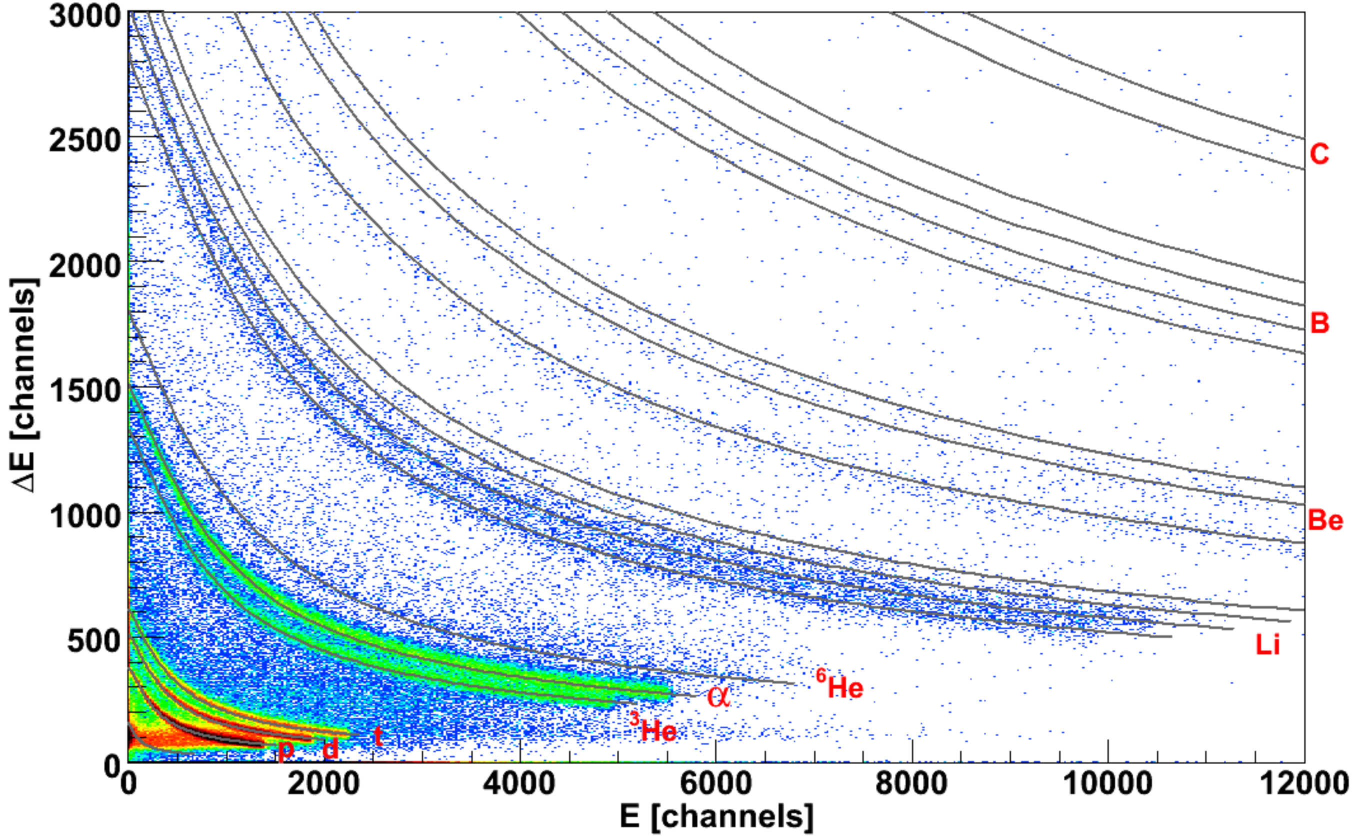

ΔE-E
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
2000
4000
6000
8000
10000
12000
14000


ΔE-E
after background substraction
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
2000
4000
6000
8000
10000
12000
14000

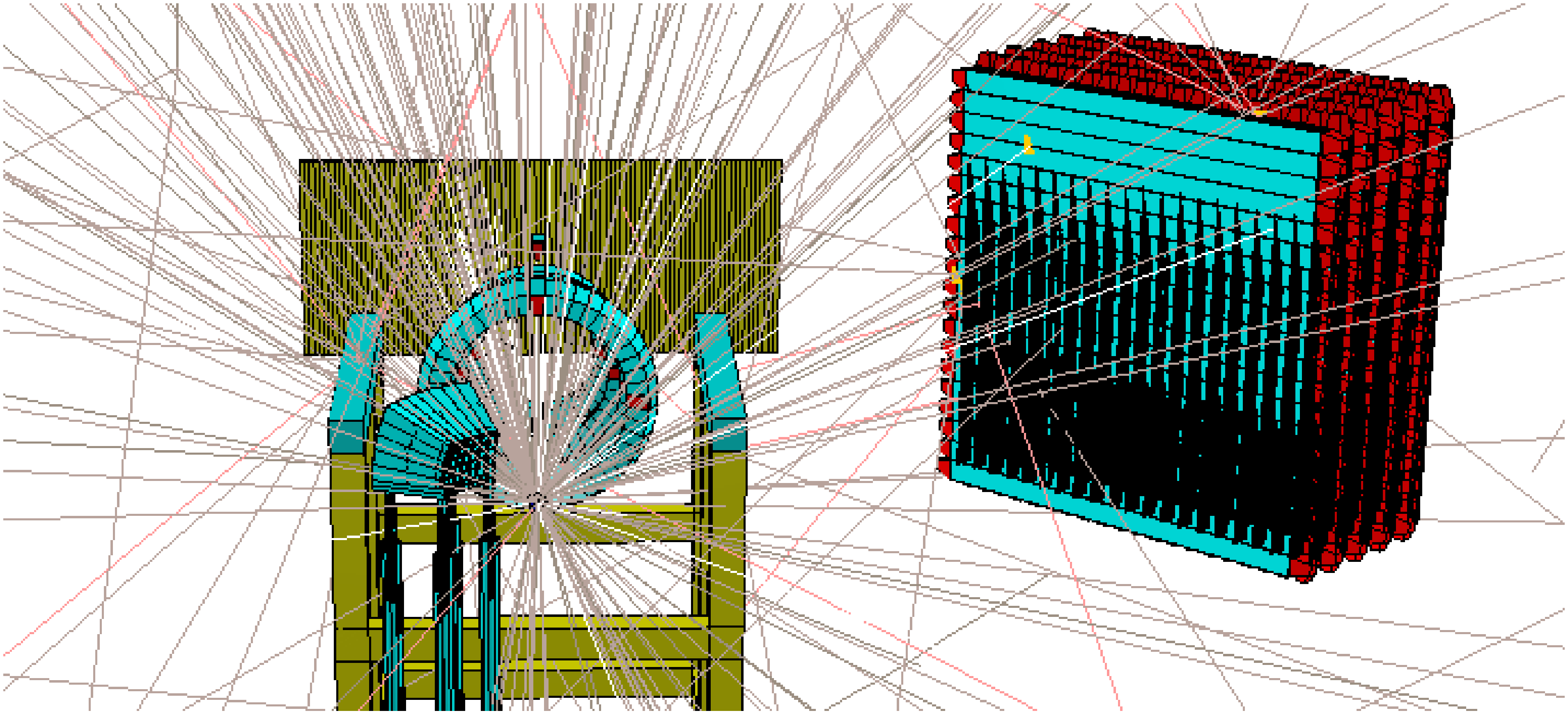

10^3
10^2
^{3}He
^{4}He
^{6}He
2
3
4
5
6
7
A

Energy calibration

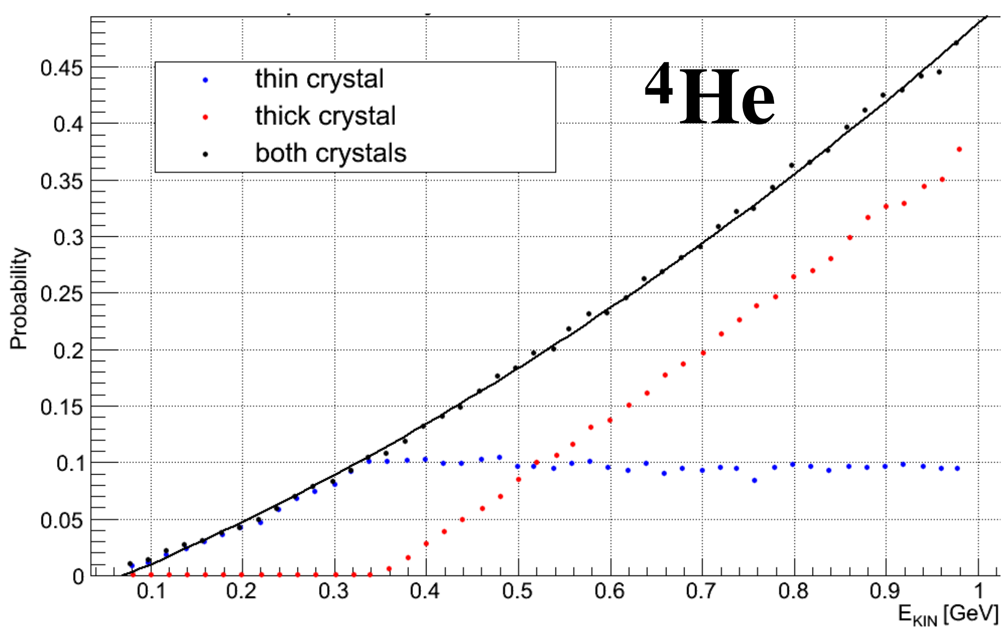
(lines from the ATIMA range-energy tables)

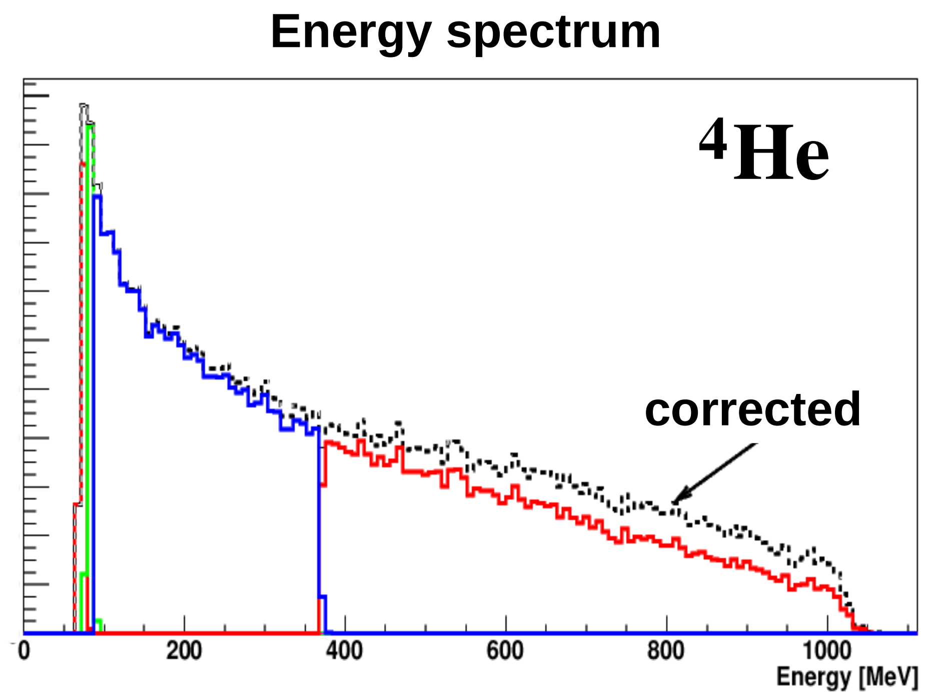


Scattering and secondary reactions in the detector material: Simulations with GEANT 4

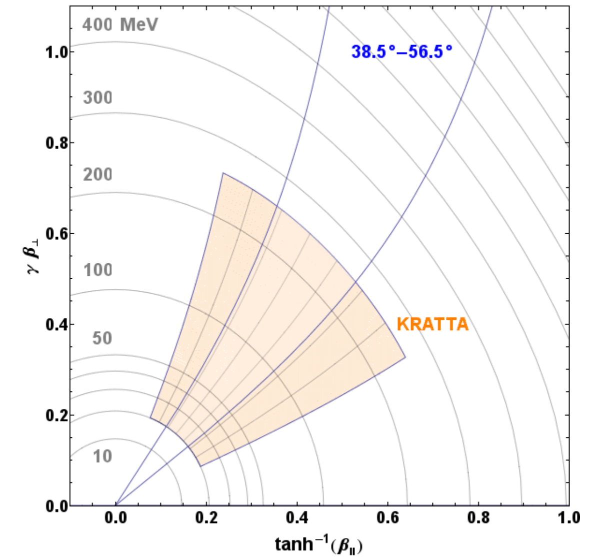


Reaction probability in the CsI crystals





Flows of light charged particles in Au (400 MeV/u) + Au reactions:
KRATTA vs FOPI results

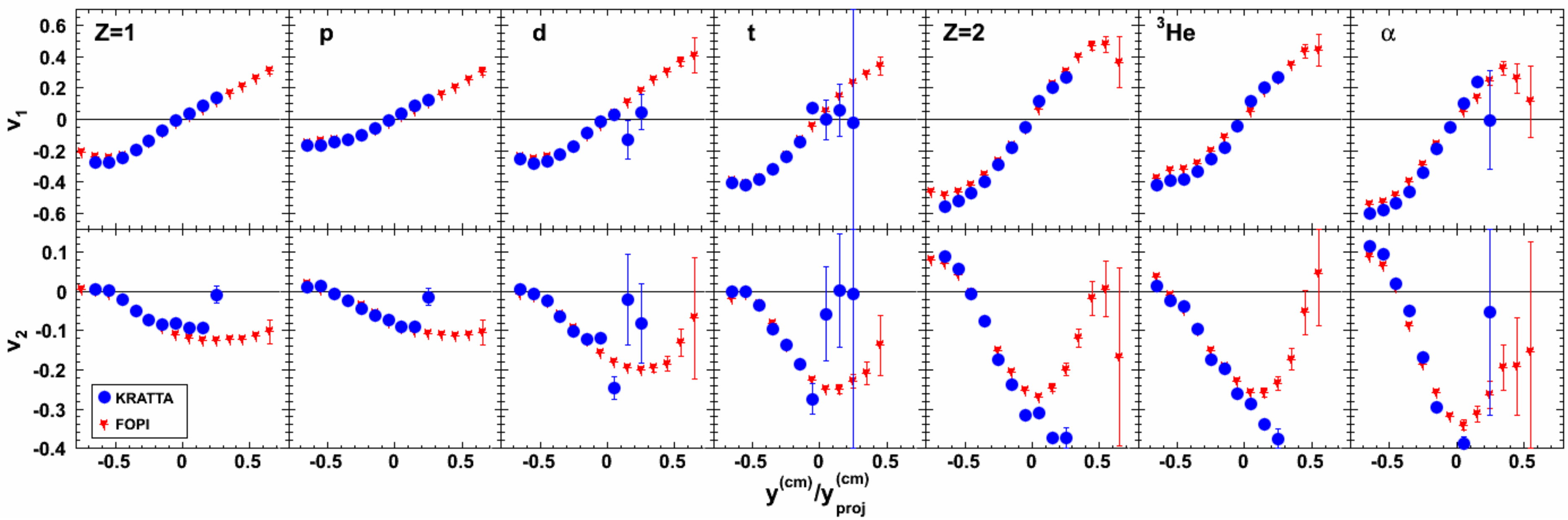


Fourier decomposition of the azimuthal distributions with respect to the reaction plane (ϕ_R) :

$$\frac{dN}{d(\phi-\phi_R)} = \frac{N_0}{2\pi}\left(1 + 2\sum_{n\geq 1} v_n \cos n(\phi-\phi_R)\right)$$

$v_1 \equiv \langle \cos(\phi-\phi_R)\rangle$ directed flow

$v_2 \equiv \langle \cos 2(\phi-\phi_R)\rangle$ elliptic flow

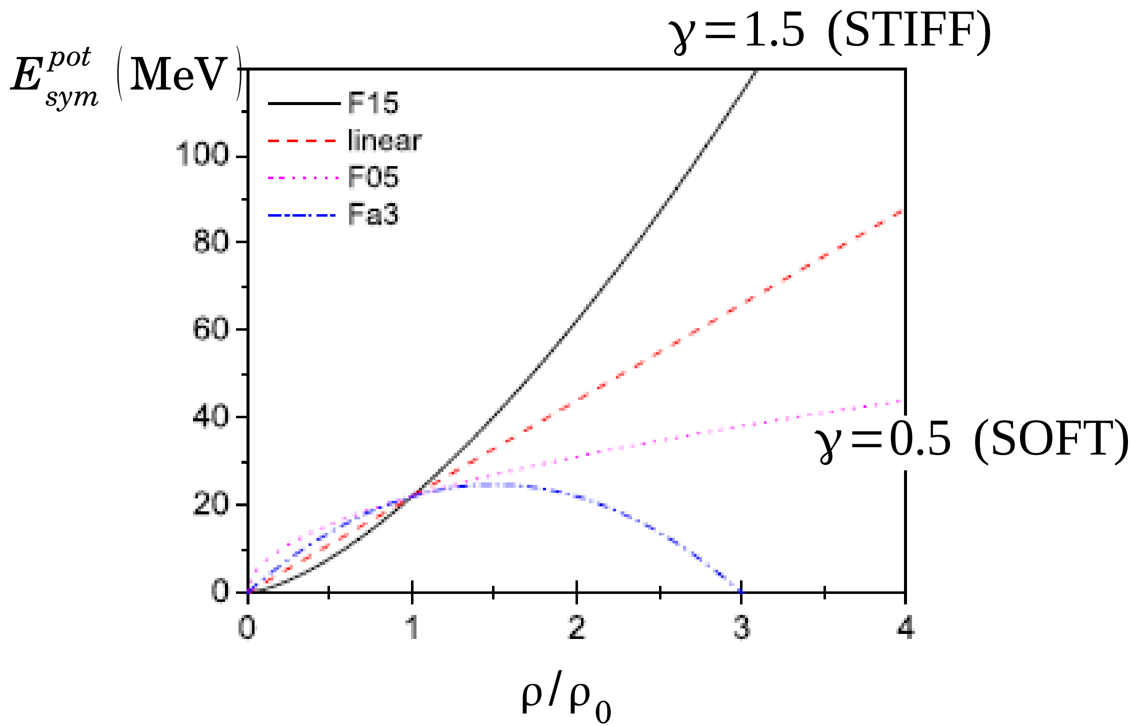


Model simulations

UrQMD Q. Li, J.Phys. G 31(2005)1359

„Fermi-gas" parametrization of the symmetry term:

$$E_{sym} = E_{sym}^{pot} + E_{sym}^{kin} = 22\ \text{MeV} \left(\frac{\rho}{\rho_o}\right)^{\gamma} + 12\ \text{MeV} \left(\frac{\rho}{\rho_o}\right)^{2/3}$$



Stopping time = 150 fm/c

Nucleons $\rightarrow \{\vec{r}_i, \vec{p}_i\}$

Clustering procedure

$(\Delta r = 2.5\ \text{fm},\ \Delta p = 290\ \text{MeV/c})$

$(\Delta r = 3\ \text{fm},\ \Delta p = 100\ \text{MeV/c})$

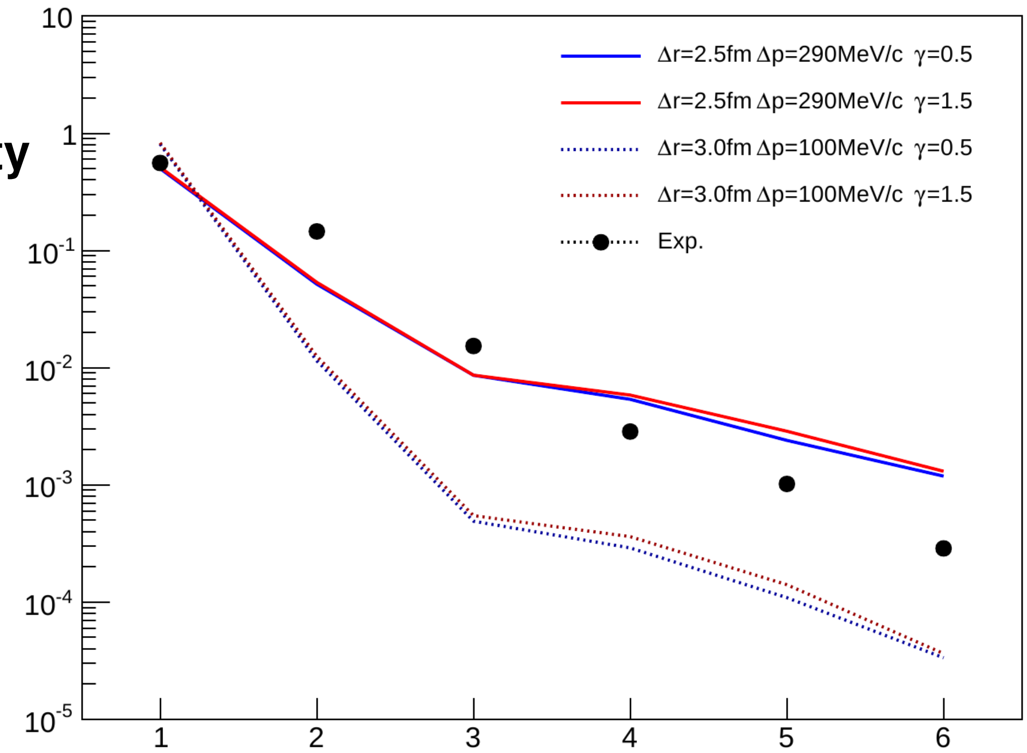
$\vdots$

KRATTA data ⟷ UrQMD predictions

ASY - SOFT

ASY - STIFF

Mean multiplicity



Z

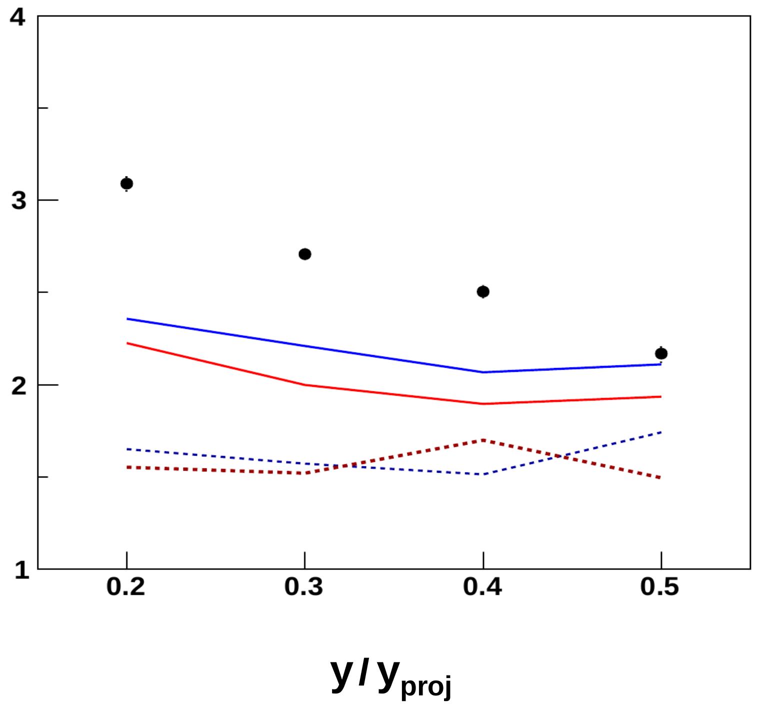
Au (400 MeV/u) + Au

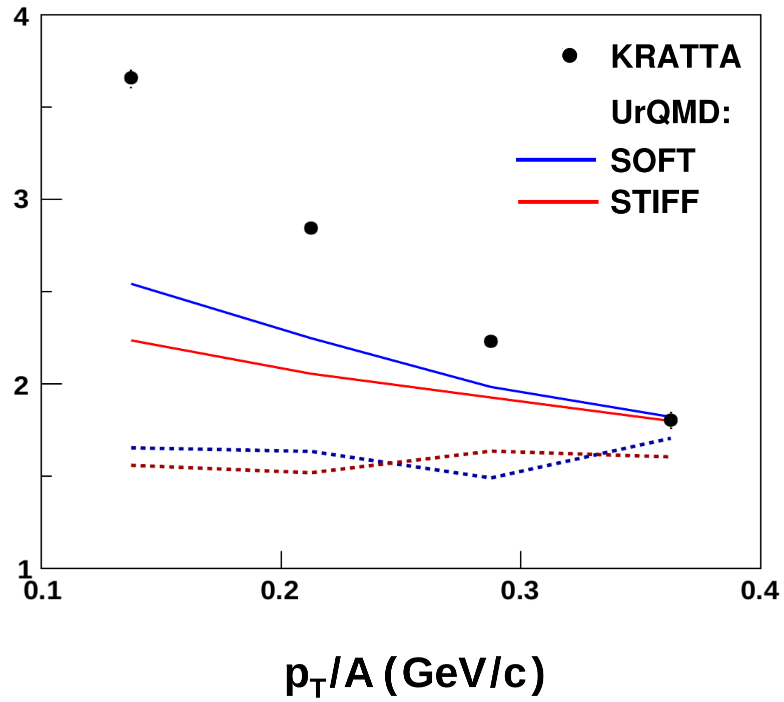
5.5 < b < 7.5 fm

$24^\circ < \Theta_{LAB} < 62^\circ$

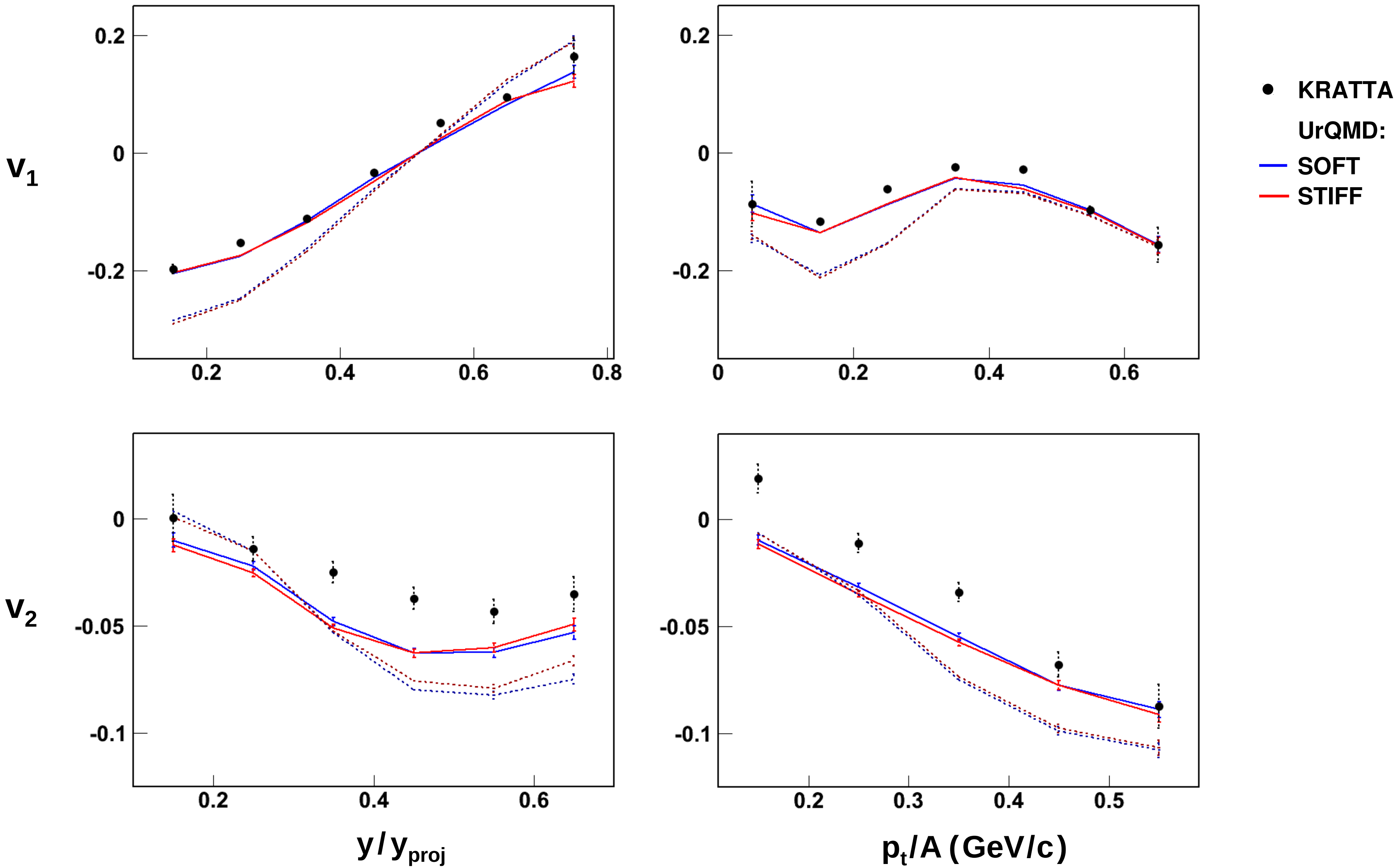
$20 < E_{KIN}/A < 133$ MeV

t / ^{3}He isotope ratios (20 < E_{kin}/A < 133 MeV)

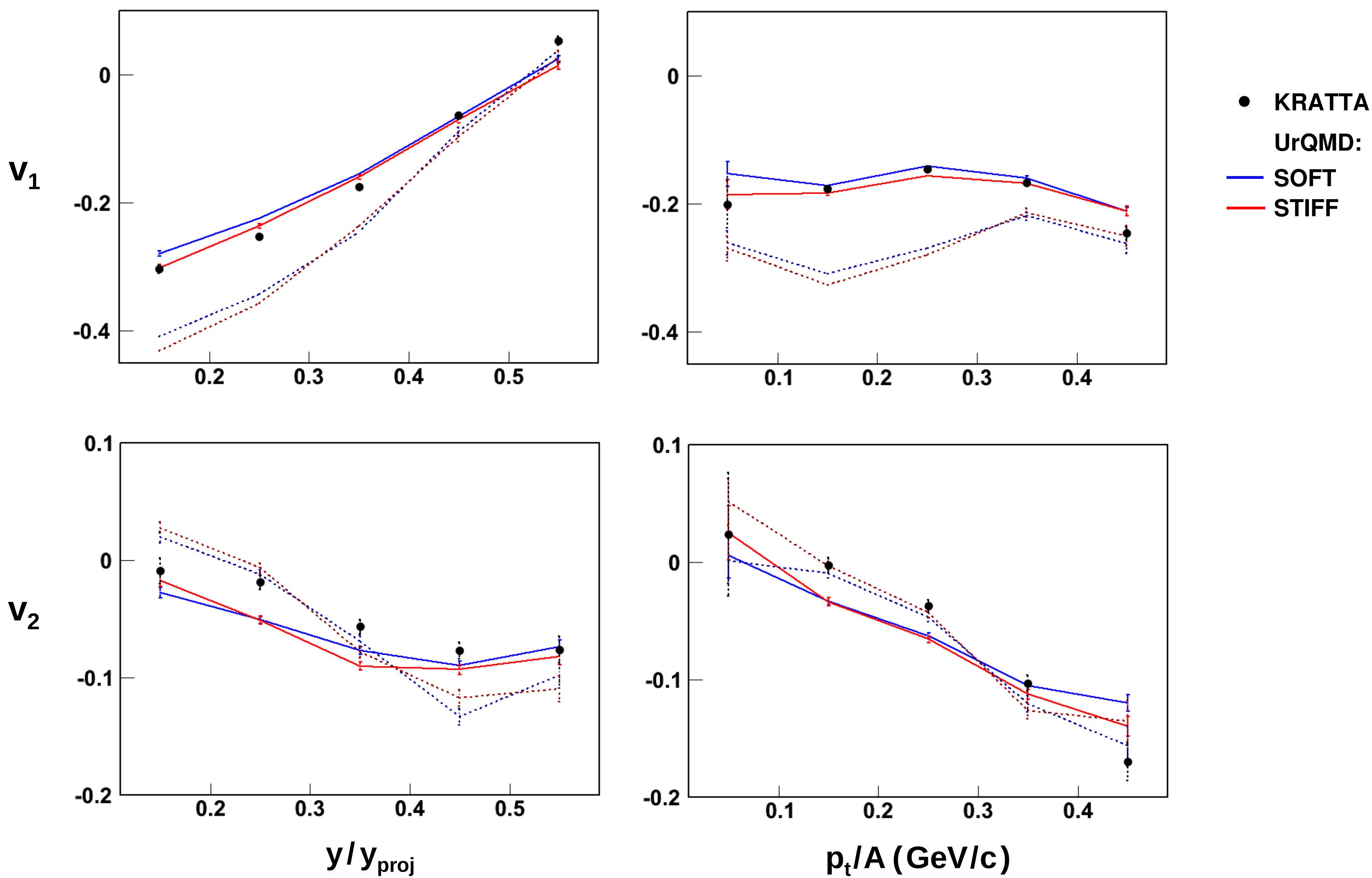




Proton flow (20 < E_{kin} < 250 MeV)



Deuteron flow (20 < E_{kin}/A < 160 MeV)



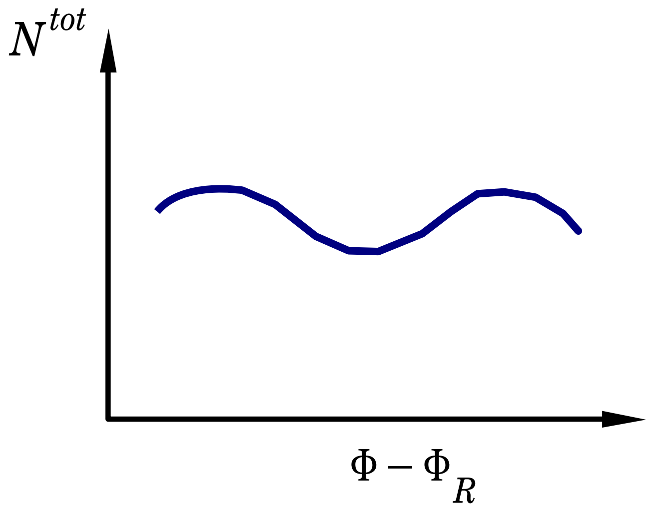
Counting the total number of protons/neutrons:

$$N_p^{tot} = N_p + N_d + N_t + 2N_{^3He} + 2N_\alpha + \ldots$$

$$N_n^{tot} = N_n + N_d + 2N_t + N_{^3He} + 2N_\alpha + \ldots$$

KRATTA data

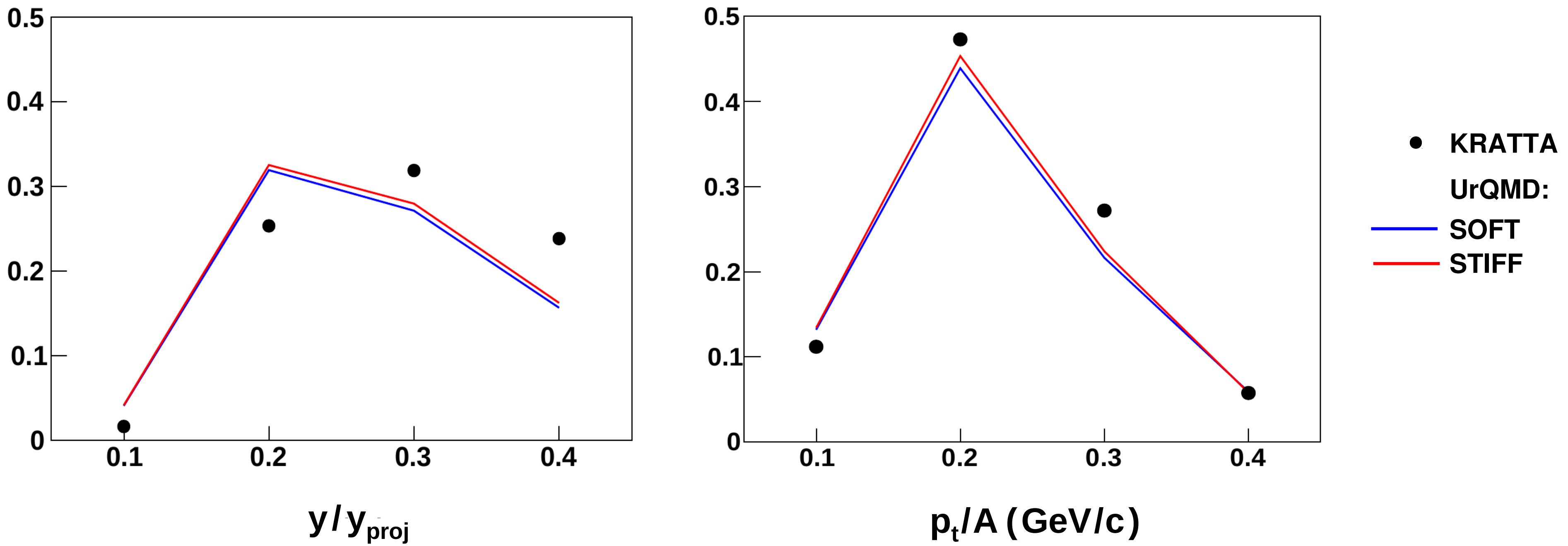
20 < E_{kin}/A < 133 MeV



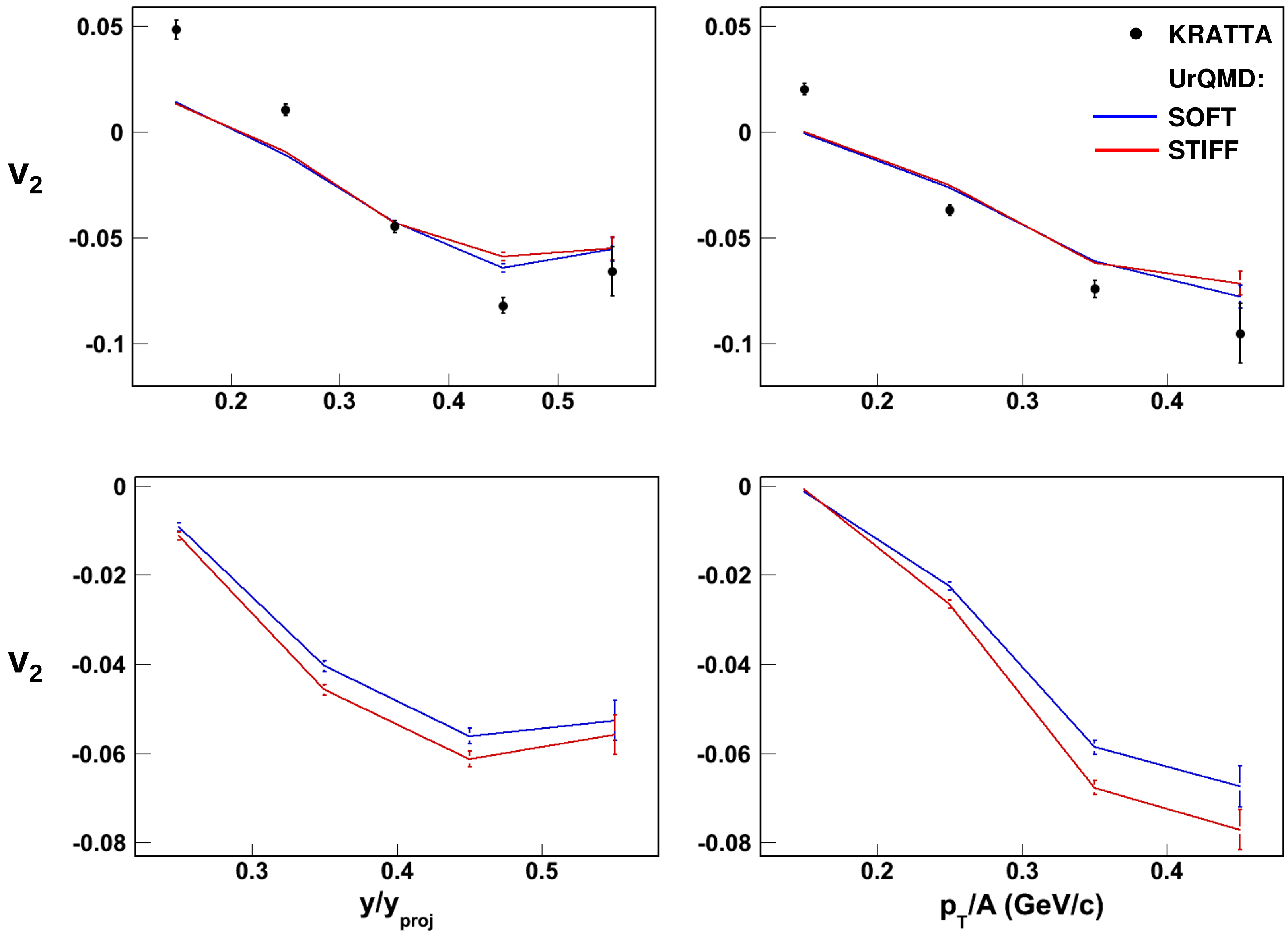
$\Rightarrow v_1, v_2$

Mean multiplicity of all protons (free and bound)

$20 < E_{kin}/A < 133$ MeV



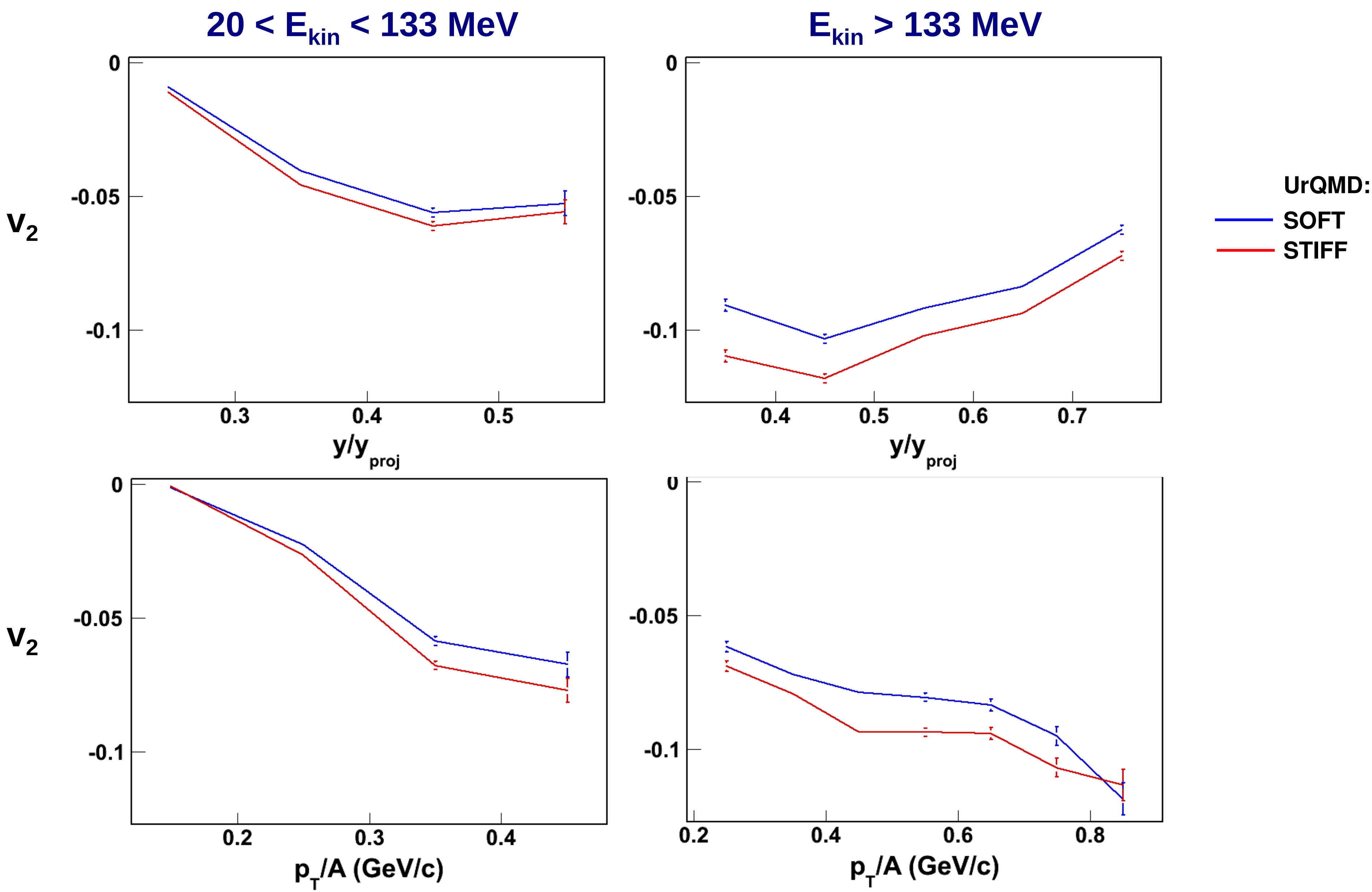
Elliptic flow $(20 < E_{kin}/A < 133\ \mathrm{MeV})$



all protons

all neutrons

Elliptic flow of all neutrons



Conclusions

KRATTA

- **good detector performance**
- **usefulness of photodiodes operating in the double mode**

Digital pulse shape analysis

- **possibility of pulse decomposition**
- **efficient recognition of background hits**

Results from the ASY-EOS measurements

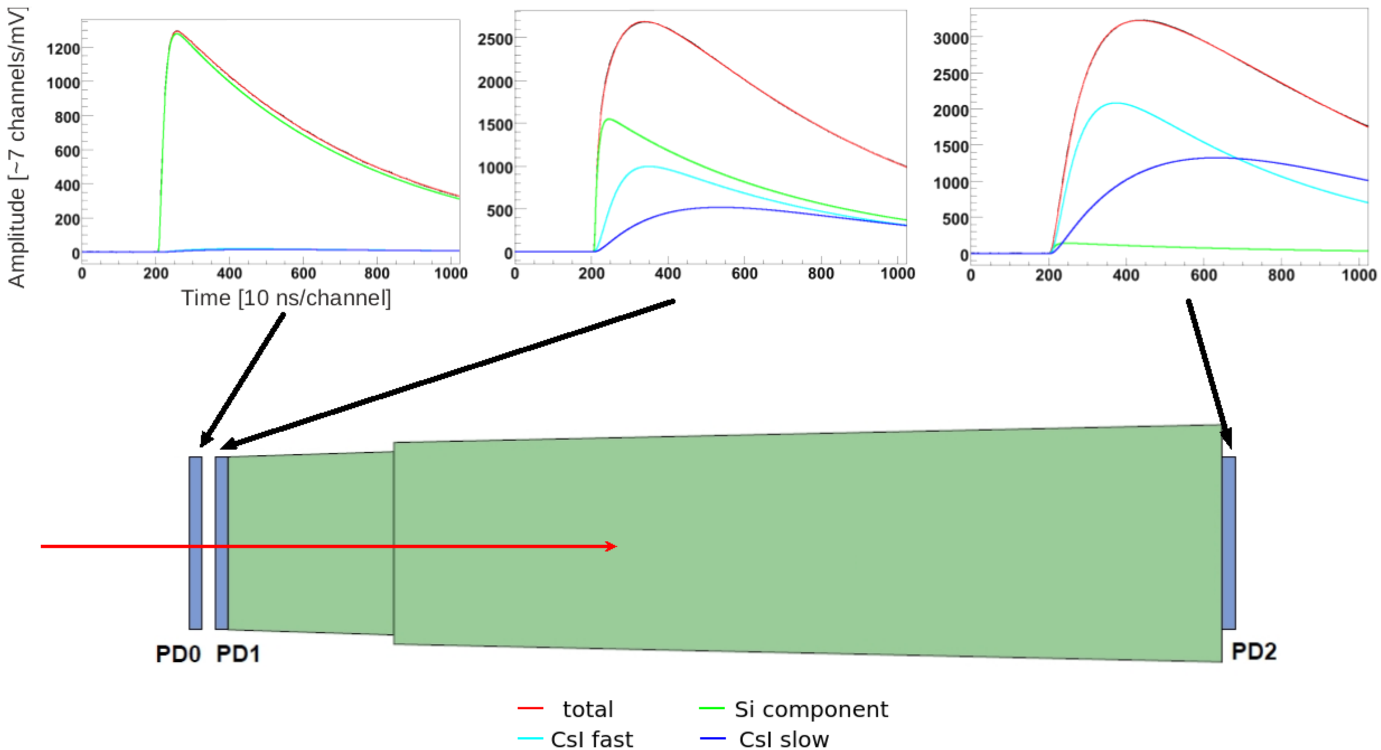
- **flow parameters consistent with FOPI data**
- **UrQMD (+ clustering) fails in reproducing isotope ratios**
- **the need for realistic description of cluster formation**
- **possibility of examining all protons / neutrons**

The ASY-EOS Collaboration

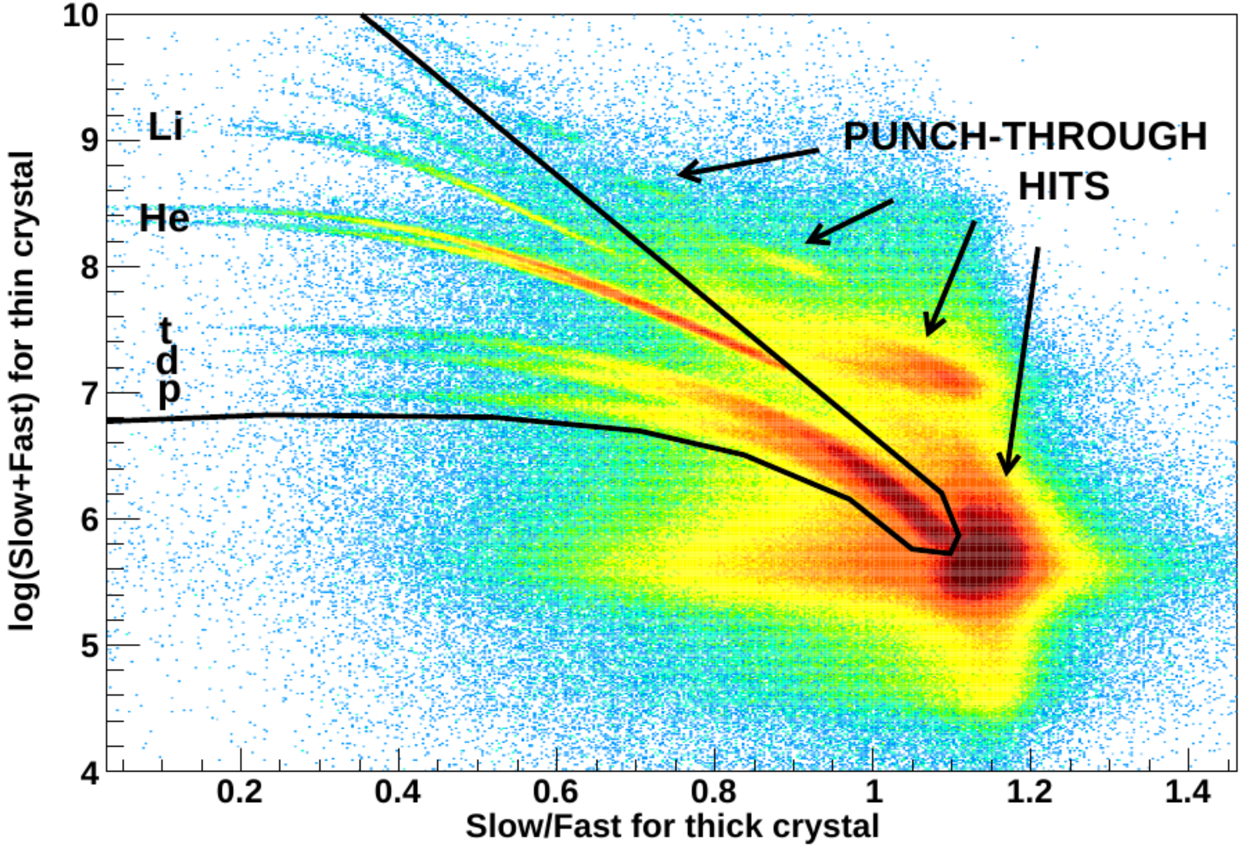
Co-Spokespersons: R.C. Lemmon[1] and P. Russotto[2]

Collaboration

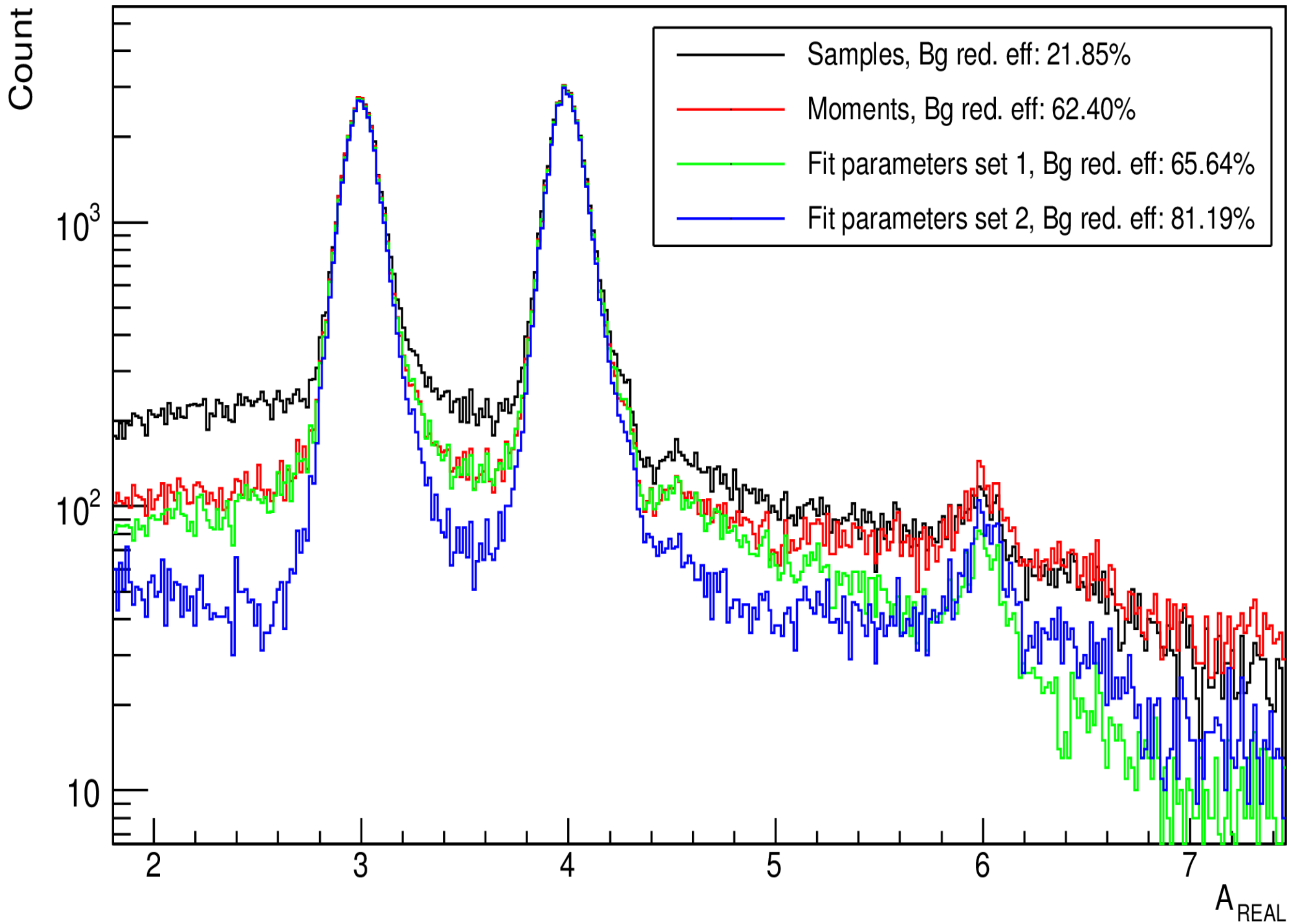
F. Amorini[2], A. Anzalone[17], T. Aumann[3], V. Avdeichikov[12], V. Baran[23], Z. Basrak[4], J. Benlliure[13], I. Berceanu[11], A. Bickley[14], E. Bonnet[6], K. Boretzky[3], R. Bougault[30], J. Brzychczyk[8], B. Bubak[22], G. Cardella[7], S. Cavallaro[2], J. Cederkall[12], M. Chartier[5], M.B. Chatterjee[16], A. Chbihi[6], M. Colonna[17], D. Cozma[11], B. Czech[10], E. De Filippo[7], K. Fissum[12], D. Di Julio[12], M. Di Toro[2], M. Famiano[27], J.D. Frankland[6], E. Galichet[18], I. Gasparic[4], E. Geraci[15], V. Giordano[2], P. Golubev[12], L. Grassi[15], A. Grzeszczuk[22], P. Guazzoni[21], M. Heil[3], J. Helgesson[31], L. Isaksson[12], B. Jacobsson[12], A. Kelic[3], M. Kis[4], S. Kowalski[22], E. La Guidara[20], G. Lanzalone[29], N. Le Neindre[30], Y. Leifels[3], Q. Li[9], I. Lombardo[2], O. Lopez[30], J. Lukasik[10], W. Lynch[14], P. Napolitani[30], N.G. Nicolis[24], A. Pagano[7], M. Papa[7], M. Parlog[30], P. Pawlowski[10], M. Petrovici[11], S. Pirrone[7], G. Politi[15], A. Pop[11], F. Porto[2], R. Reifarth[3], W. Reisdorf[3], E. Rosato[19], M.V. Ricciardi[3], F. Rizzo[2], W.U. Schroder[28], H. Simon[3], K. Siwek-Wilczynska[26], I. Skwira-Chalot[26], I. Skwirczynska[10], W. Trautmann[3], M.B. Tsang[14], G. Verde[7], E. Vient[30], M. Vigilante[19], J.P. Wieleczko[6], J. Wilczynski[25], P.Z. Wu[5], L.Zetta[21], W. Zipper[22]



Amplitude [~7 channels/mV]
Time [10 ns/channel]
PD0
PD1
PD2
total
Si component
CsI fast
CsI slow

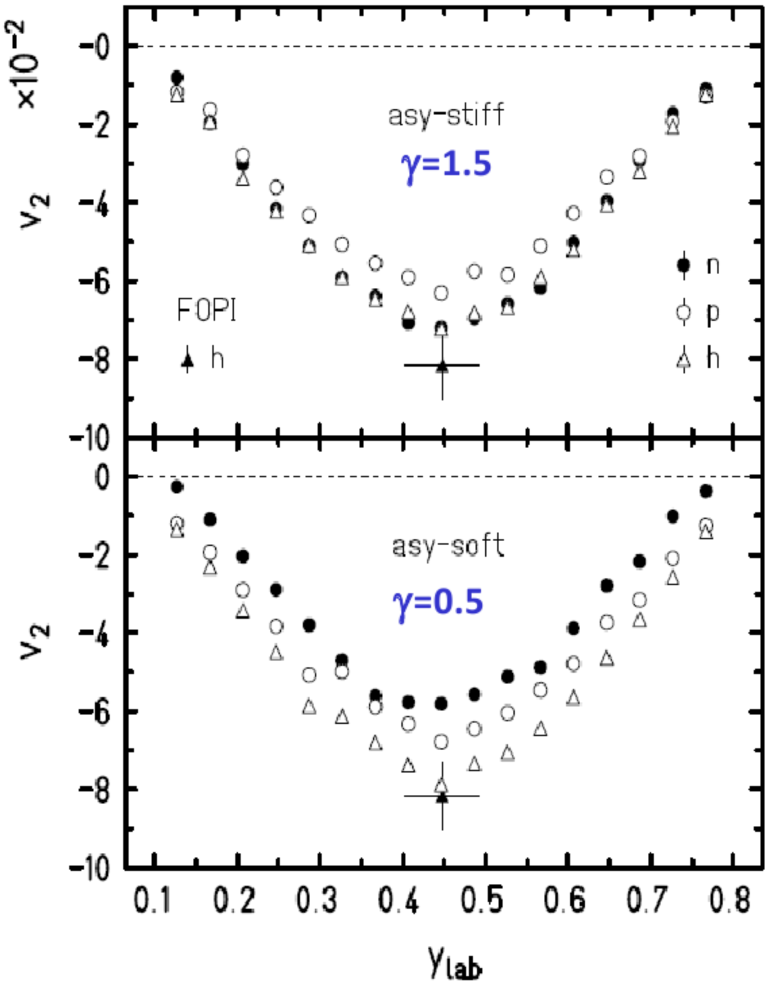


PUNCH-THROUGH
HITS
Li
He
t
d
p
log(Slow+Fast) for thin crystal
Slow/Fast for thick crystal
10
9
8
7
6
5
4
0.2
0.4
0.6
0.8
1
1.2
1.4

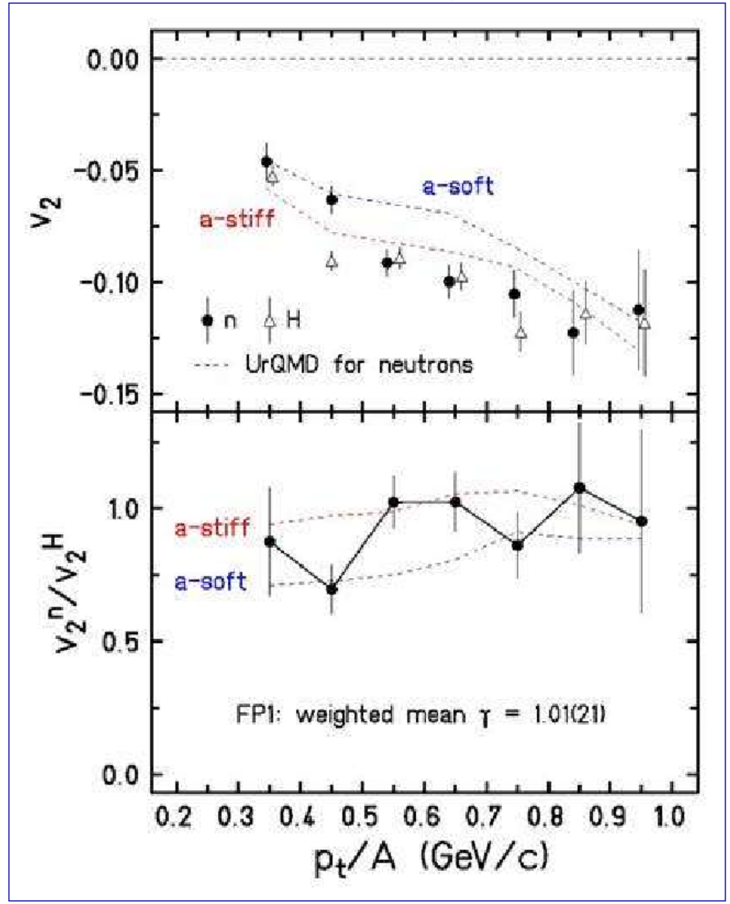


Count
10^3
10^2
10
2
3
4
5
6
7
A_{REAL}
Samples, Bg red. eff: 21.85%
Moments, Bg red. eff: 62.40%
Fit parameters set 1, Bg red. eff: 65.64%
Fit parameters set 2, Bg red. eff: 81.19%

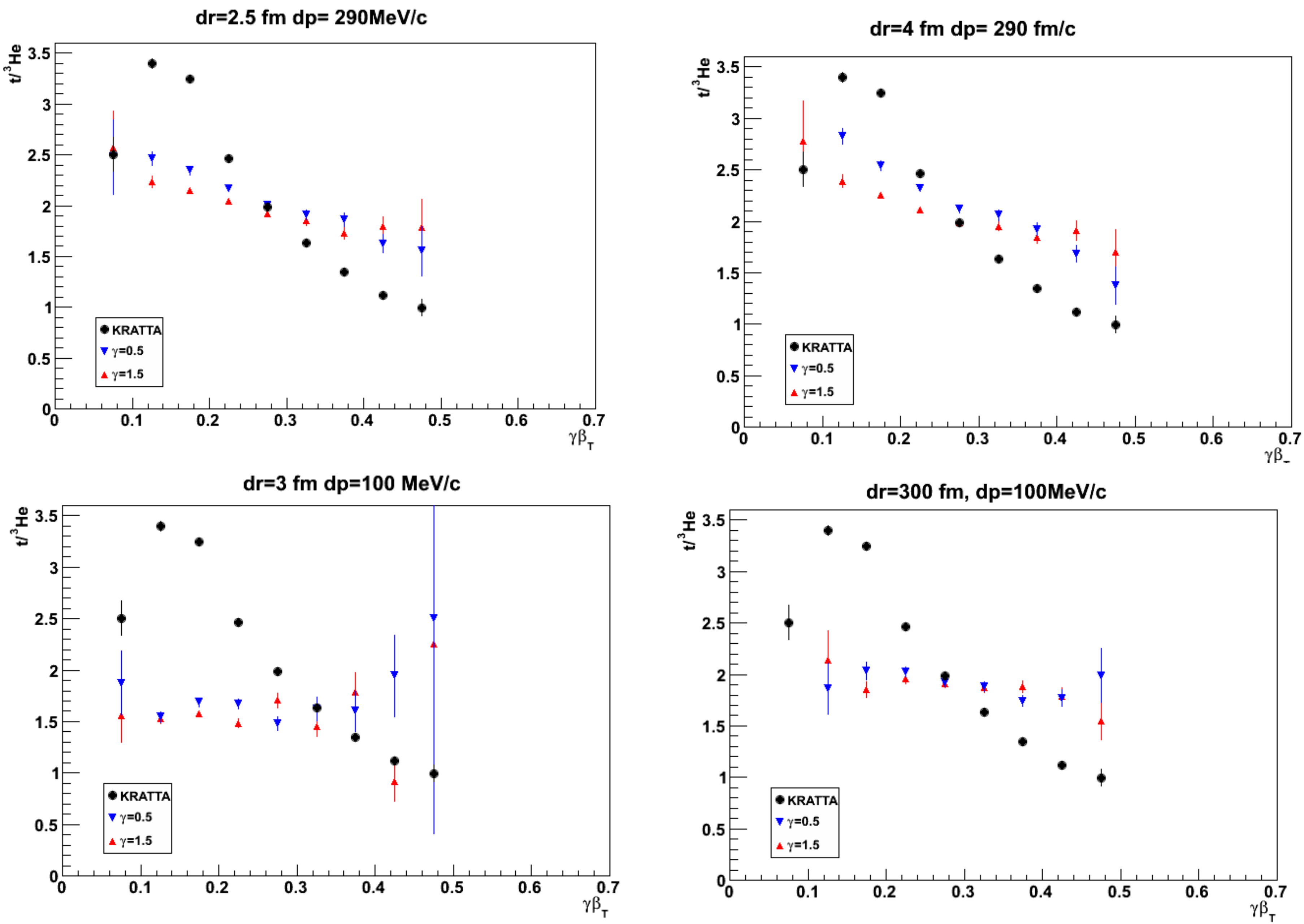
UrQMD :Au+Au @ 400 AMeV
5.5<b<7.5 fm

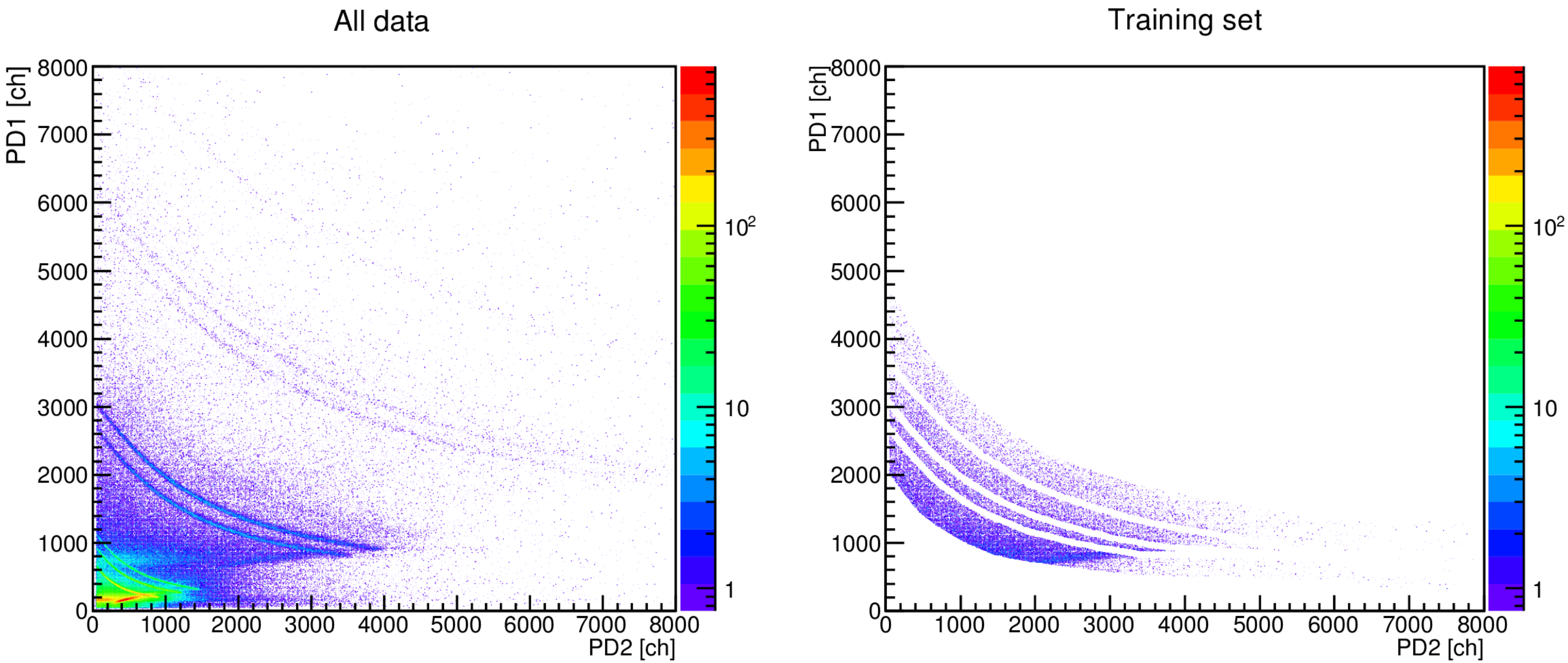


Au+Au 400 A MeV
b< 7.5 fm



Y. Leifels et al., PRL 71, 963 (1993)
P.Russotto et al., PLB 697 (2011)


dr=2.5 fm dp= 290MeV/c
dr=4 fm dp= 290 fm/c
dr=3 fm dp=100 MeV/c
dr=300 fm, dp=100MeV/c
t/³He
γβ_T
KRATTA
γ=0.5
γ=1.5


All data
PD1 [ch]
PD2 [ch]
Training set
PD1 [ch]
PD2 [ch]