Measurement of Solar Wind Heavy Ions with CTOF

CELIAS Workshop
27.08.2014

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Christian Albrechts Universität zu Kiel

Outline

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- Motivation: Differential streaming of solar wind heavy ions
- In-flight calibration of CTOF: SSD calibration
- Results: High-time resolved velocity distributions of oxygen and iron ions derived from PHA data
- Outlook: velocity distributions for other

  ions and error estimation

Differential Streaming of Solar Wind Heavy Ions

Differential Streaming between Protons and Alpha-Particles

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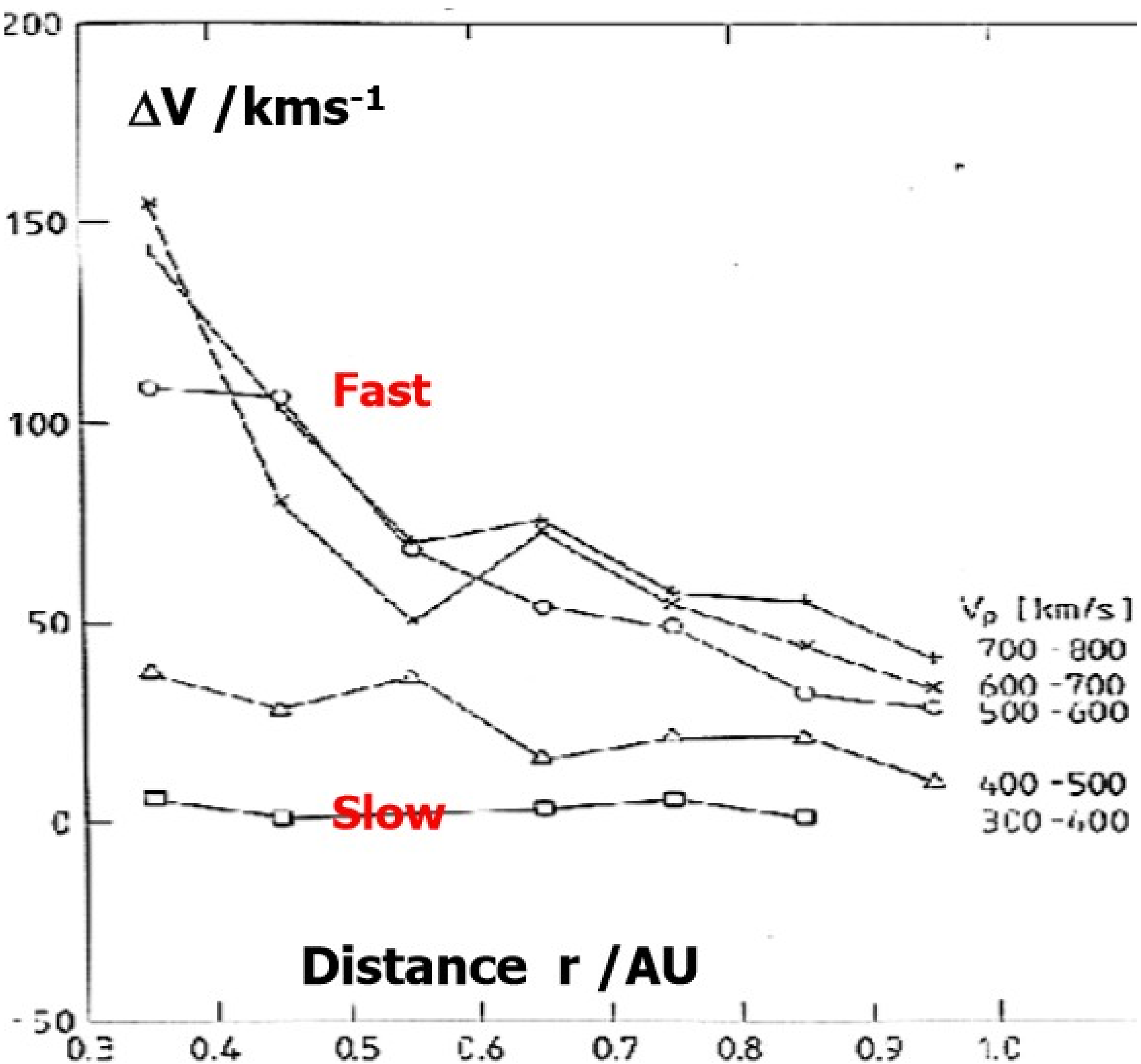

Helios B

Marsch (1987)

Ion cyclotron Resonance: Theory

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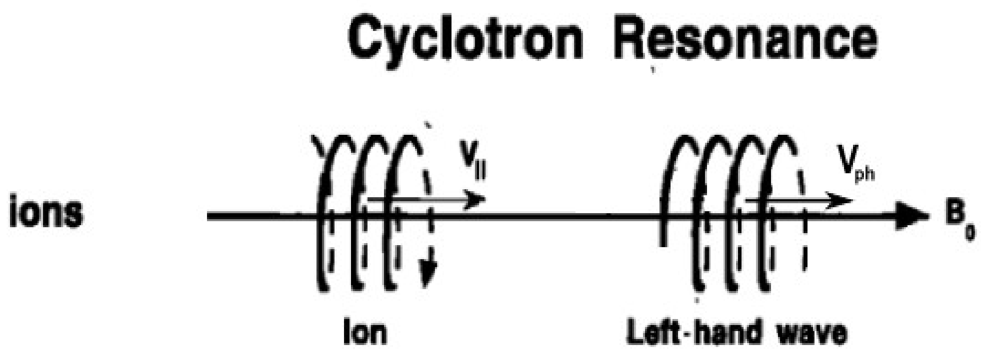
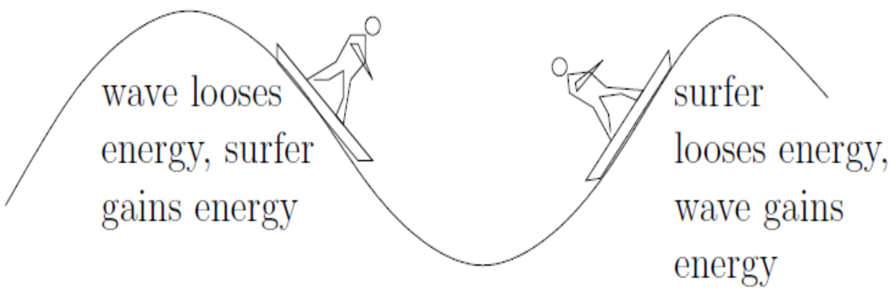


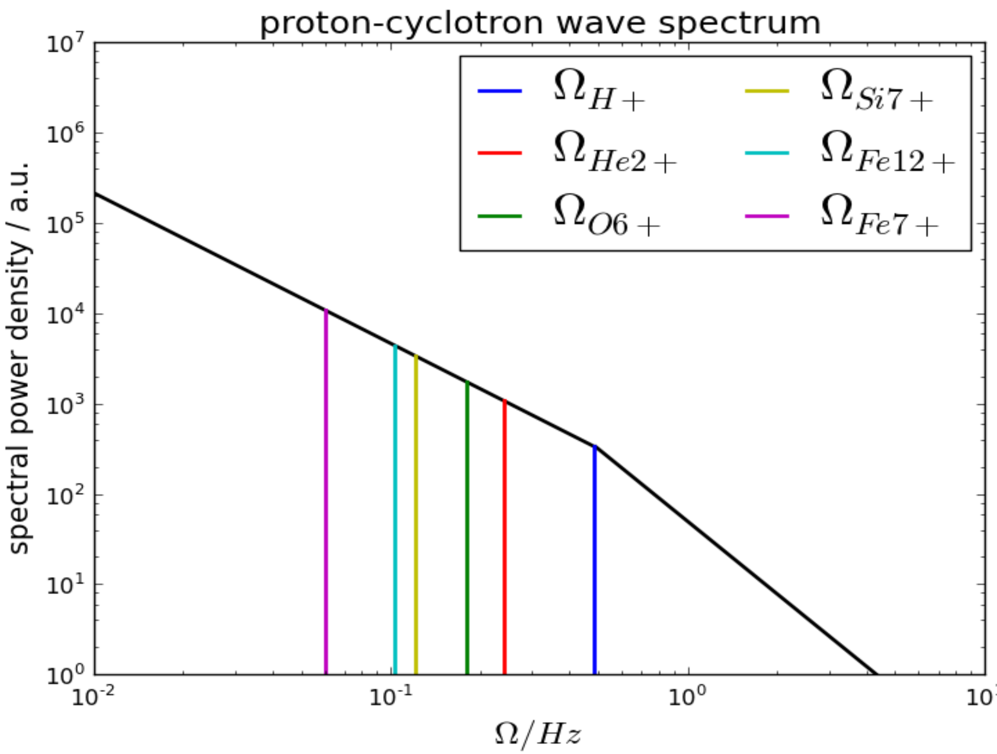
after Tsurutani Review (1997)



Resonance condition:

$$k_{\parallel} v_{\parallel} - \omega = n\Omega$$

$$\Omega_{ion} = \frac{q}{m} \cdot B$$



Differential Streaming Observed with ACE / SWICS

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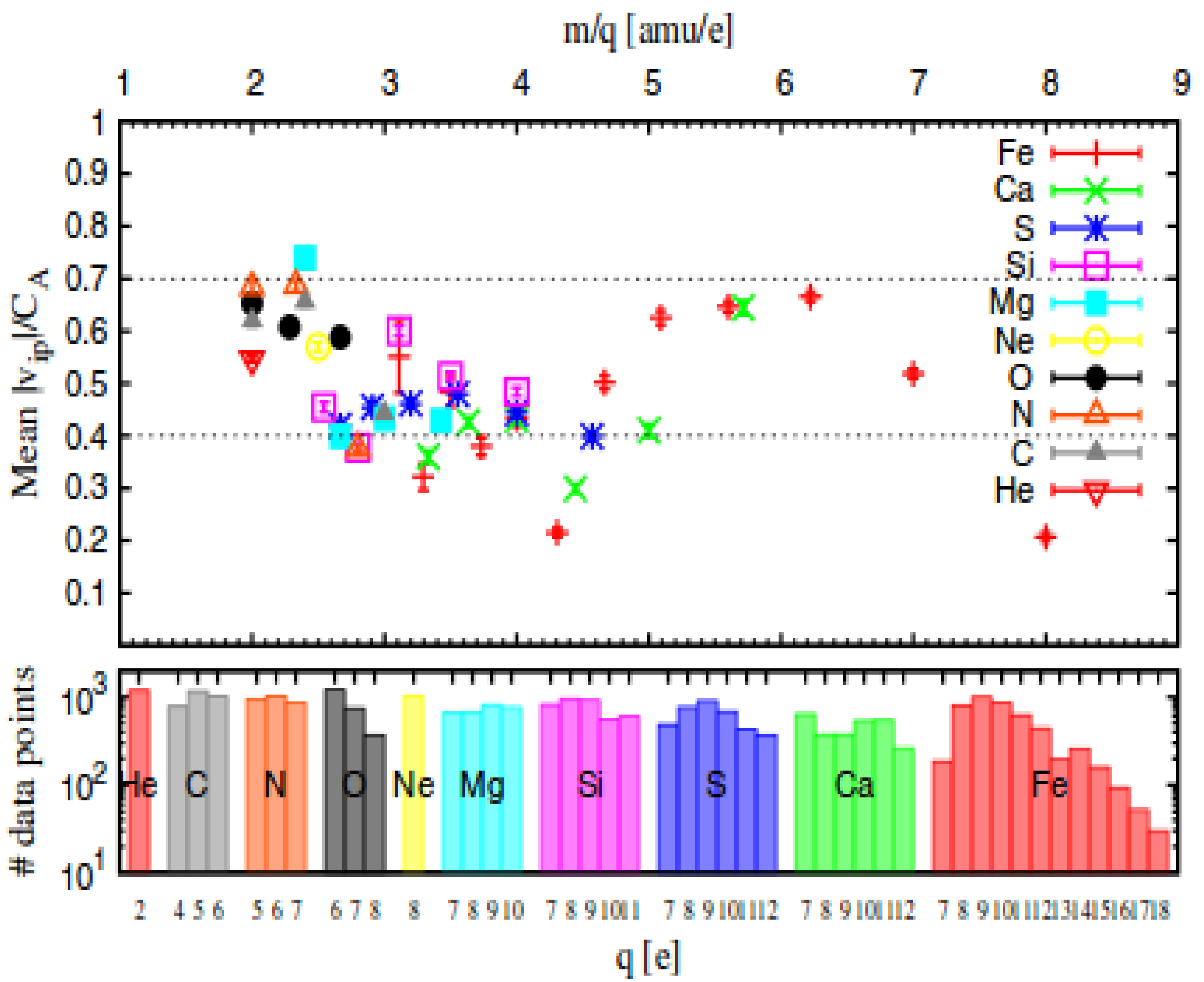
Time Resolution: ~ 12 min



Berger et al. (2011)

Differential Streaming Observed with CELIAS/CTOF

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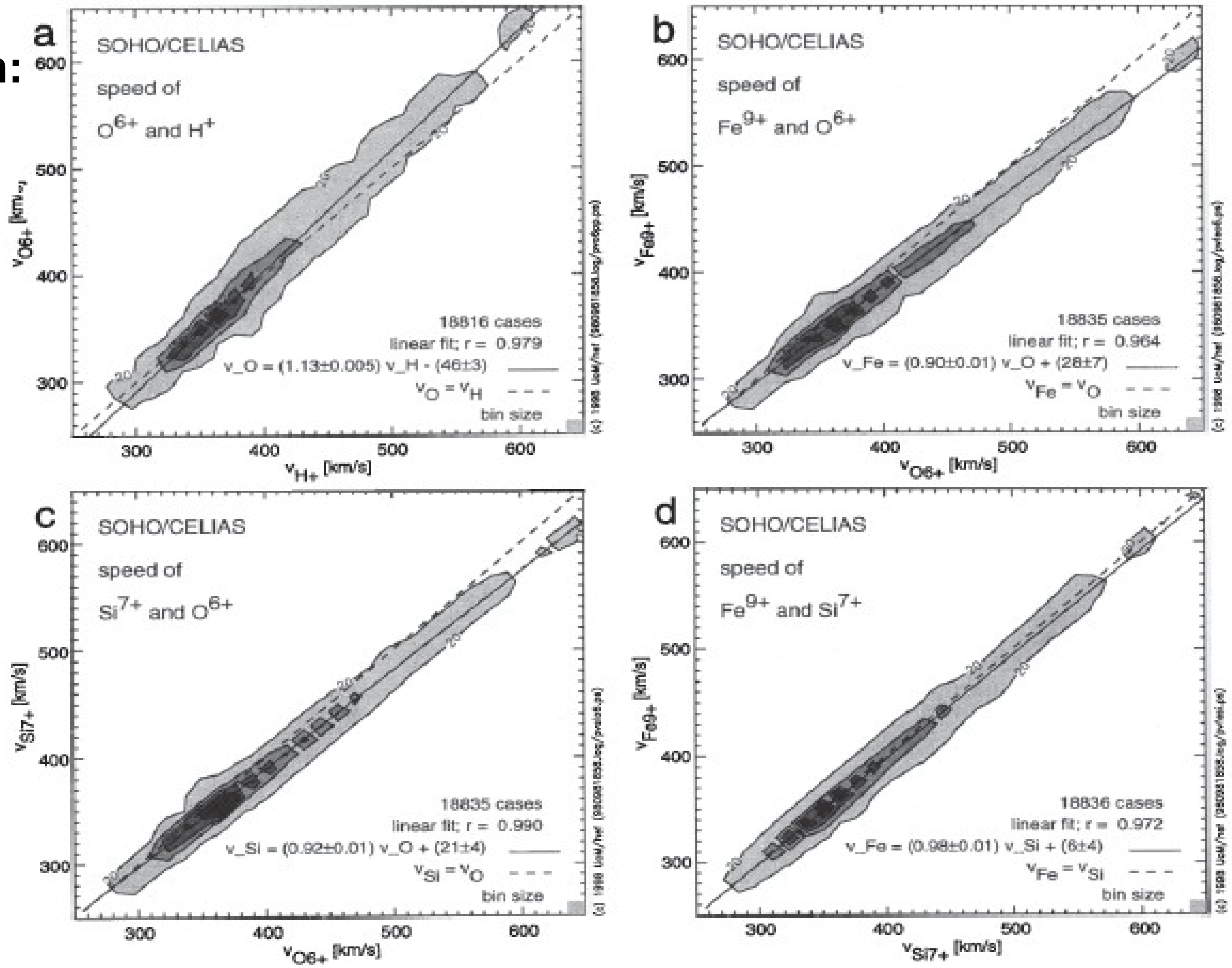
Time Resolution:
~ 10 min
= 2 cycles



Hefti et al. 1998 **CTOF: Measurement Period DOY 1996 90-230**

Differential Streaming Observed with CELIAS/CTOF

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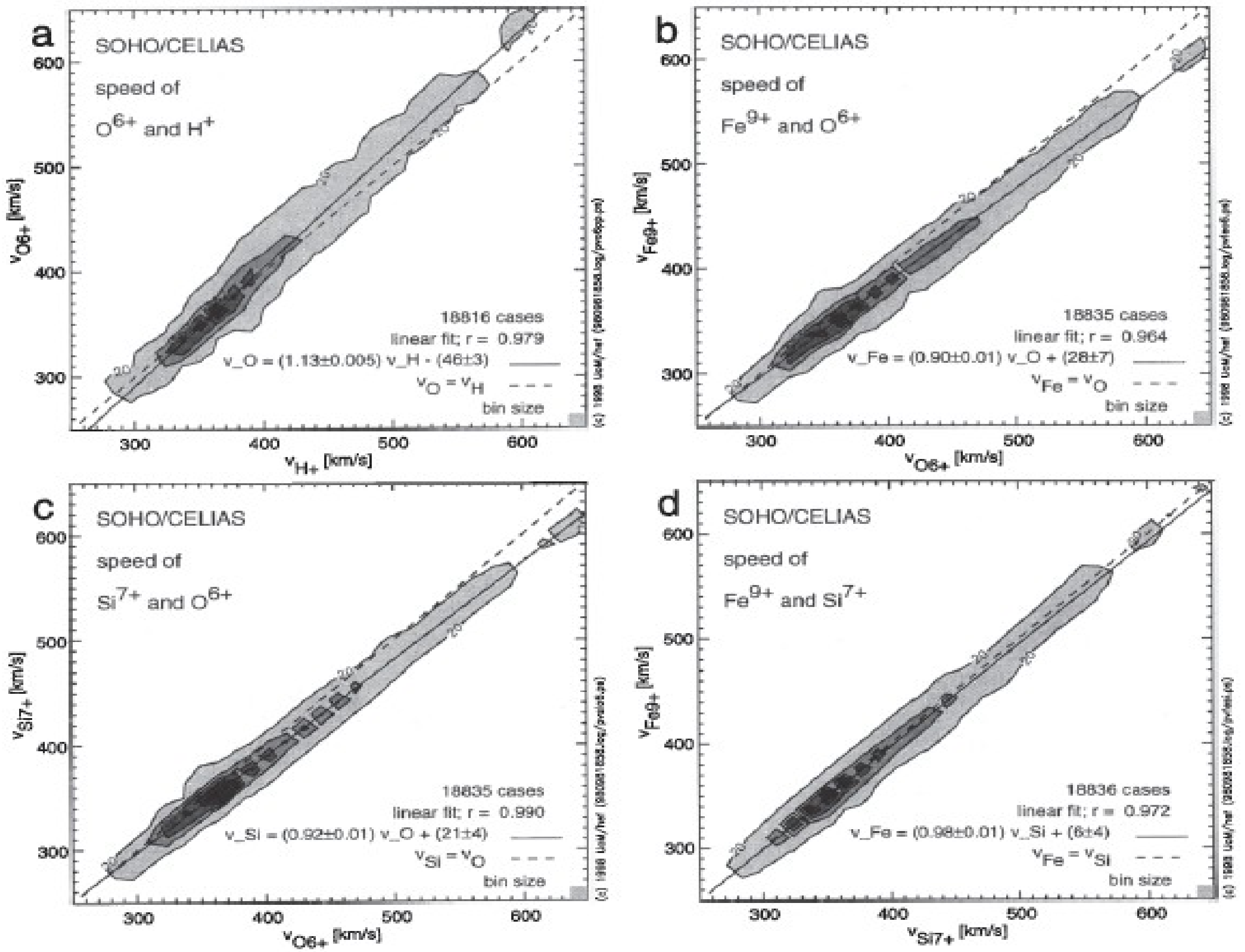

Derived from onboard calculated matrix rates

CTOF: Classification and Data Handling

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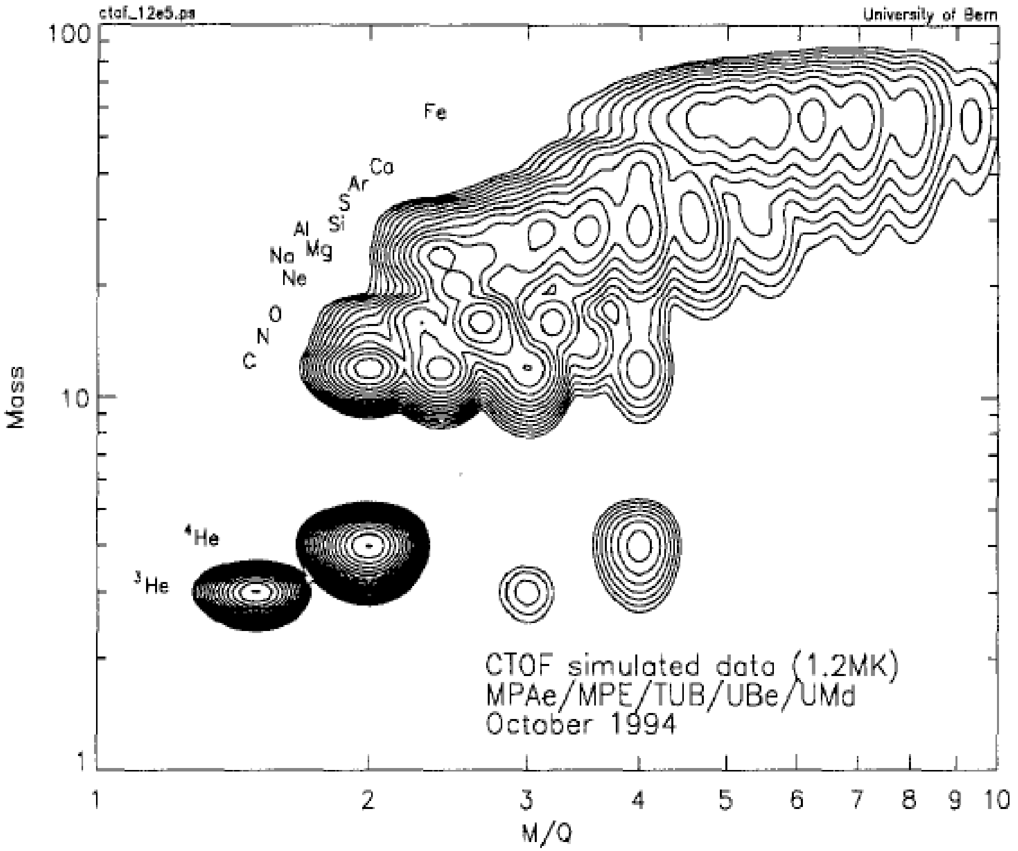

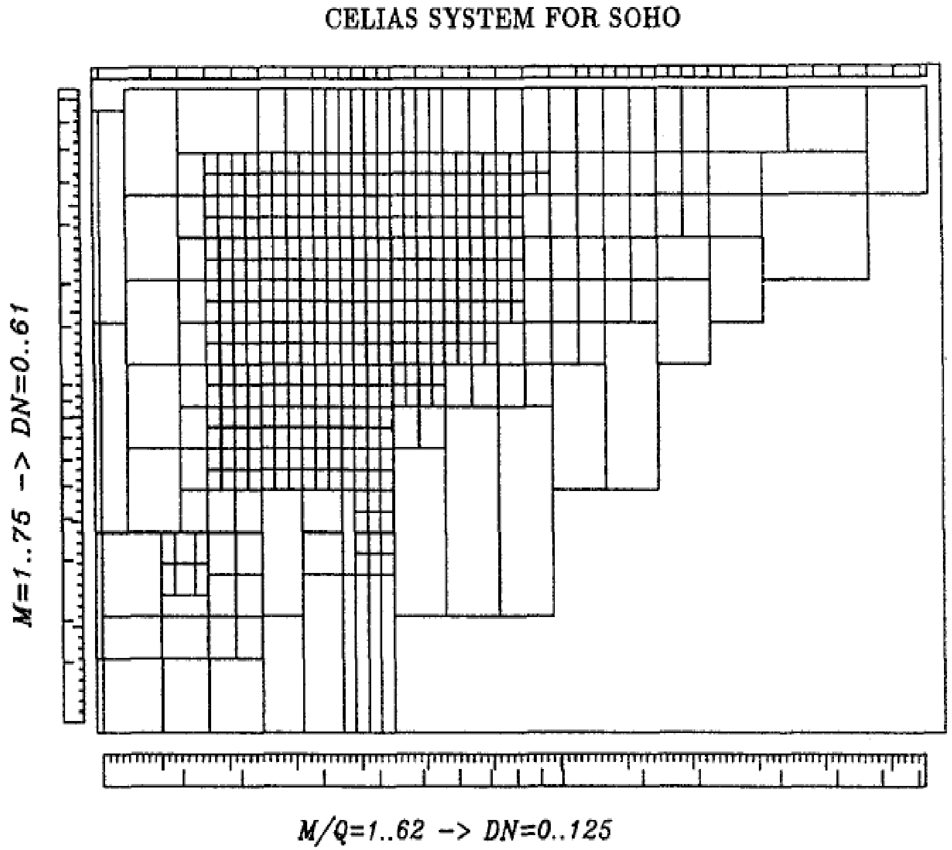

CTOF SMR field definition.

Hovestadt et al (1995)

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In-flight Calibration of CTOF: SSD Calibration

CTOF Sensor: Principle of Operation

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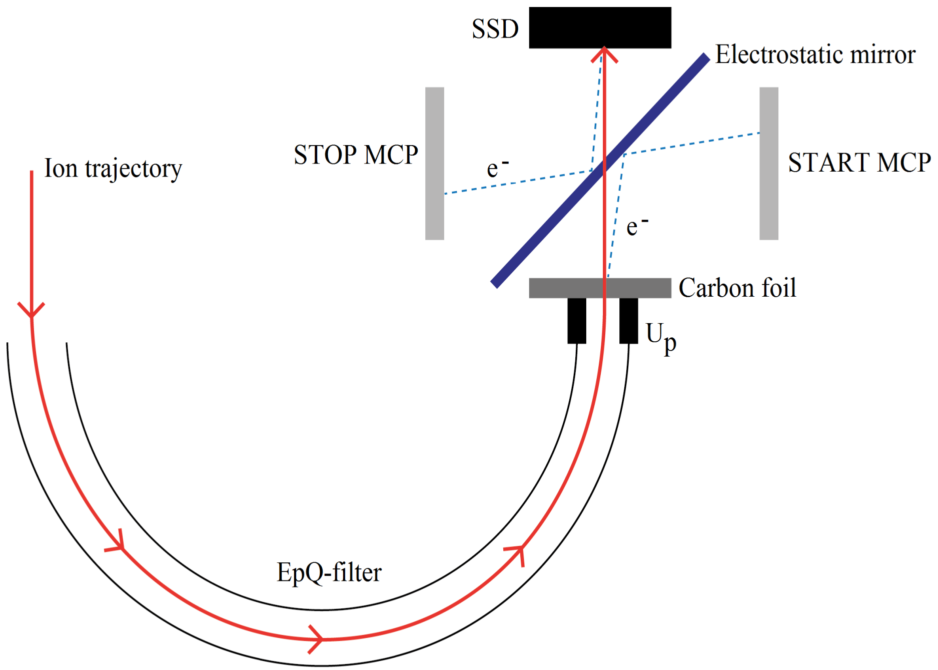

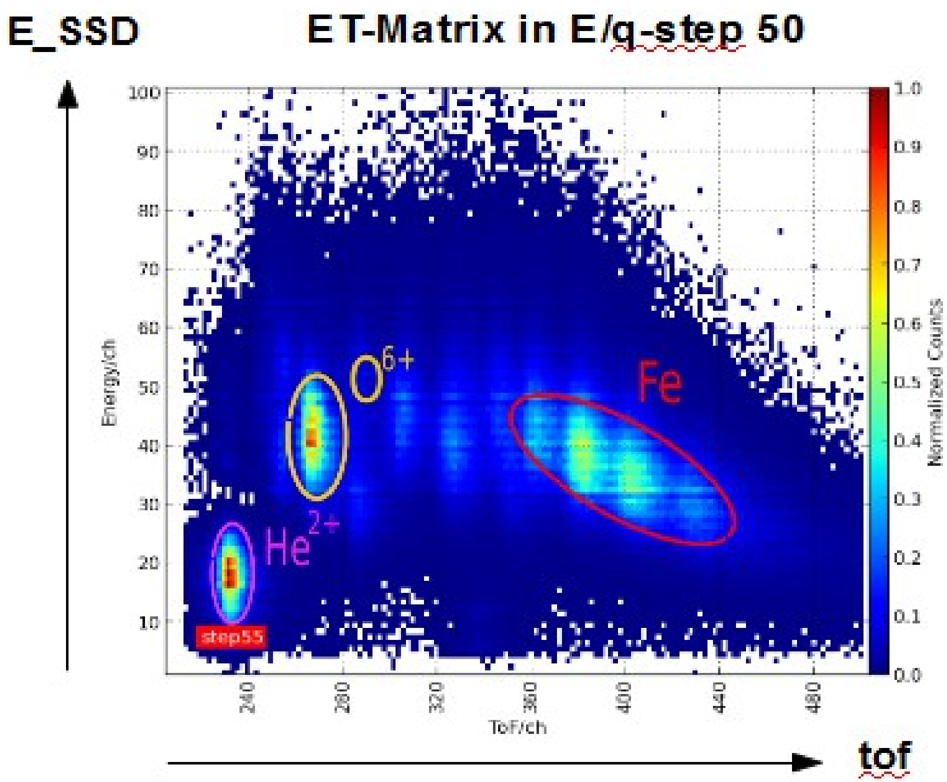

Measuring **E/q, tof** and **E_SSD** gives **m,q,v** of the incident ions.

Long-Time Data Fits

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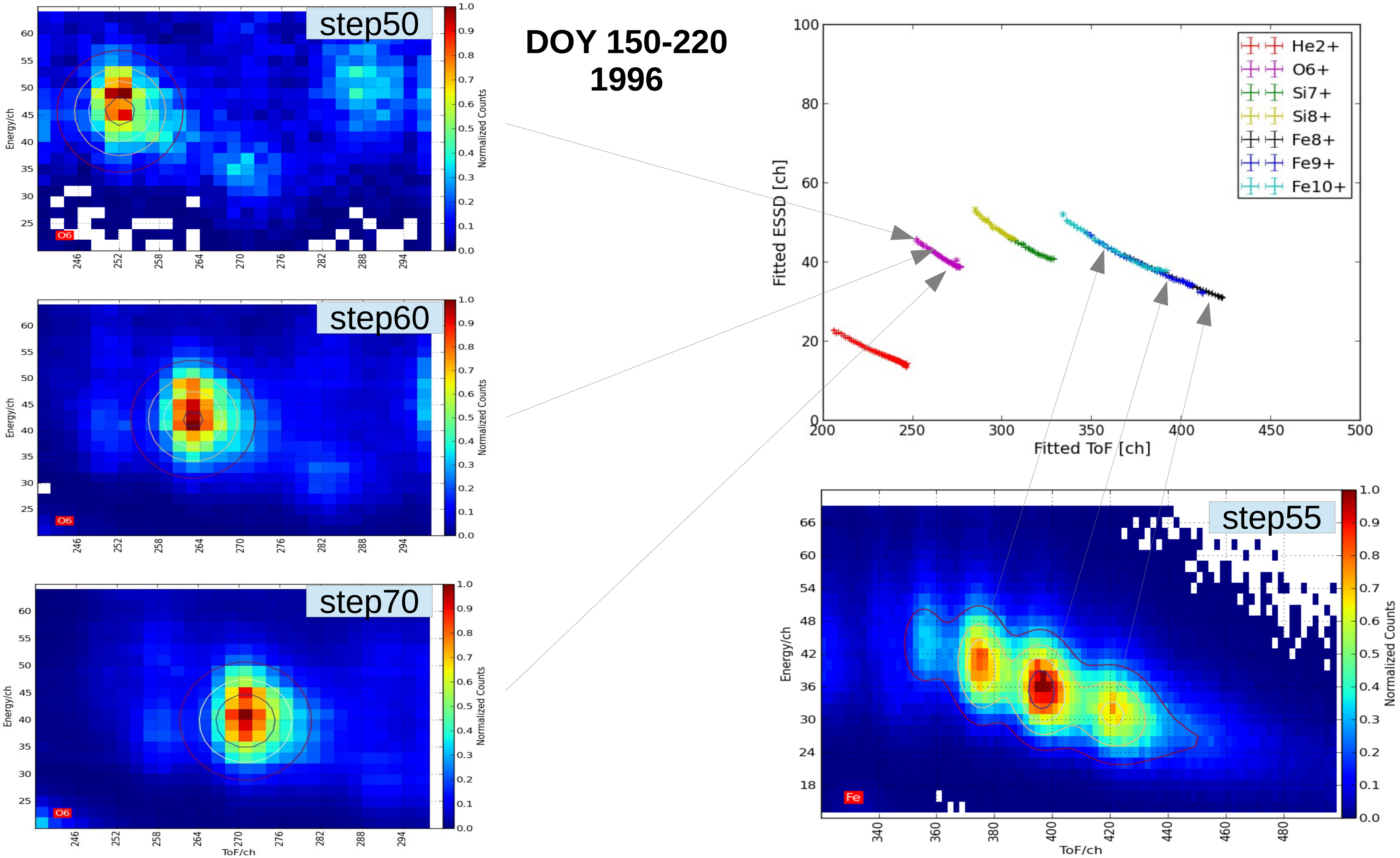

Long-Time Data Fits

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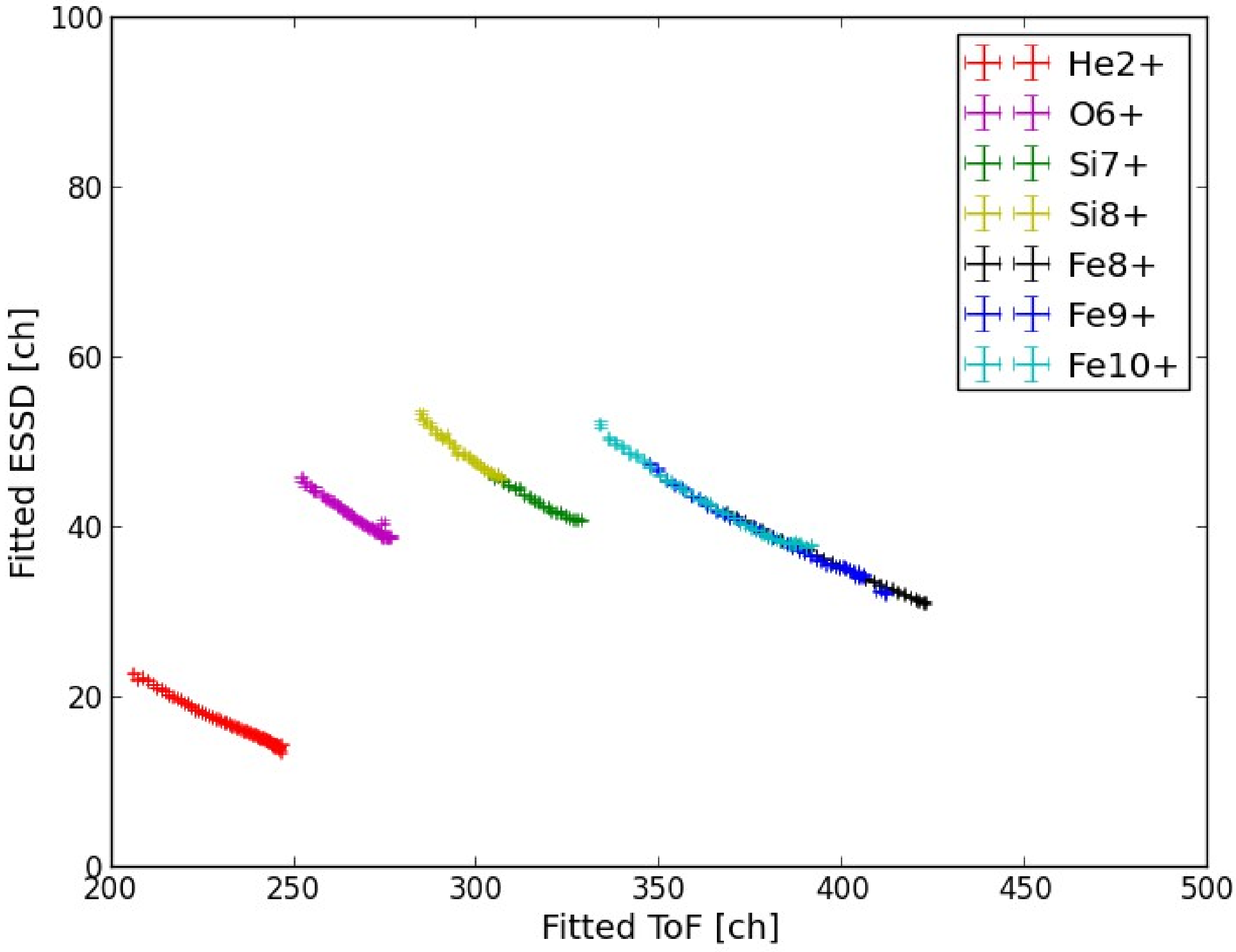

Long-Time Data Fits

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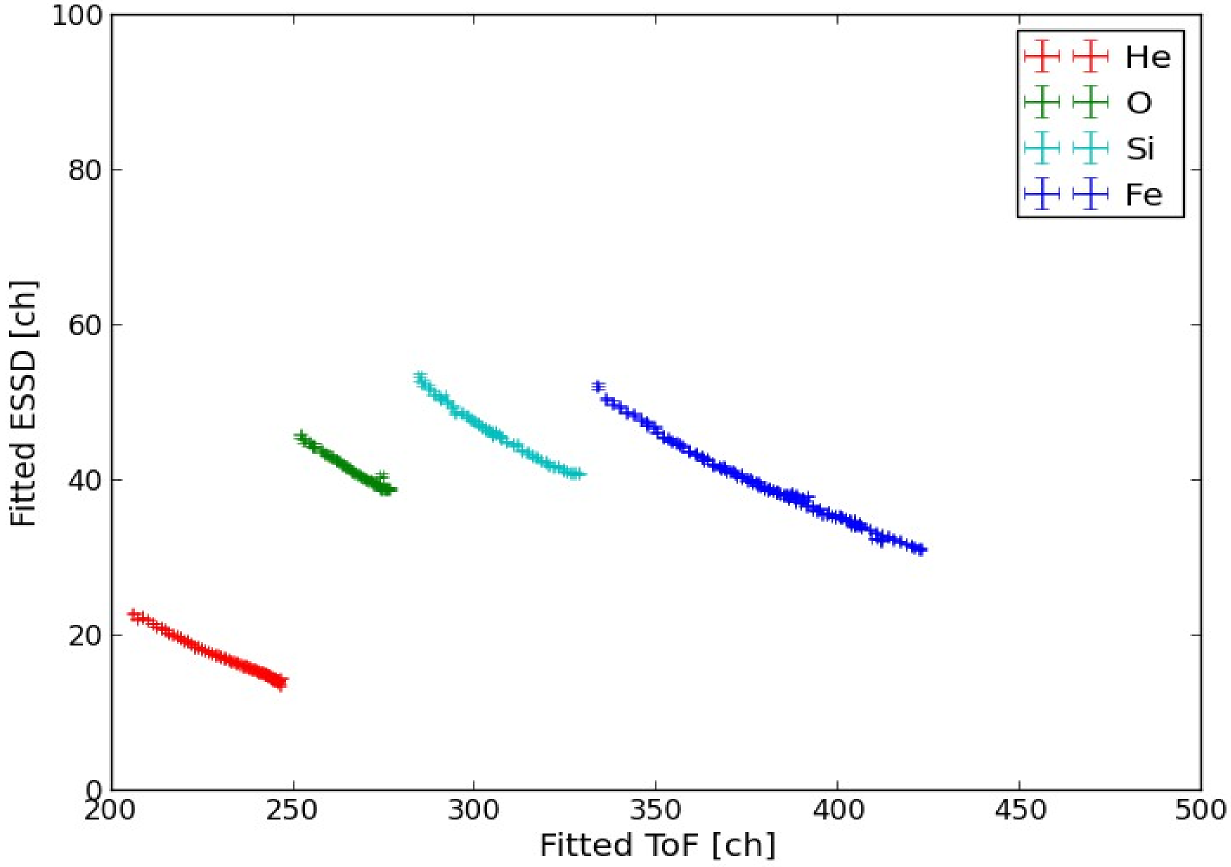

Particles stop in detector: $E_{dep} = E_\tau = \frac{1}{2} \cdot m \cdot L_\tau^2 \cdot \tau^{-2}$

Long-Time Data Fits

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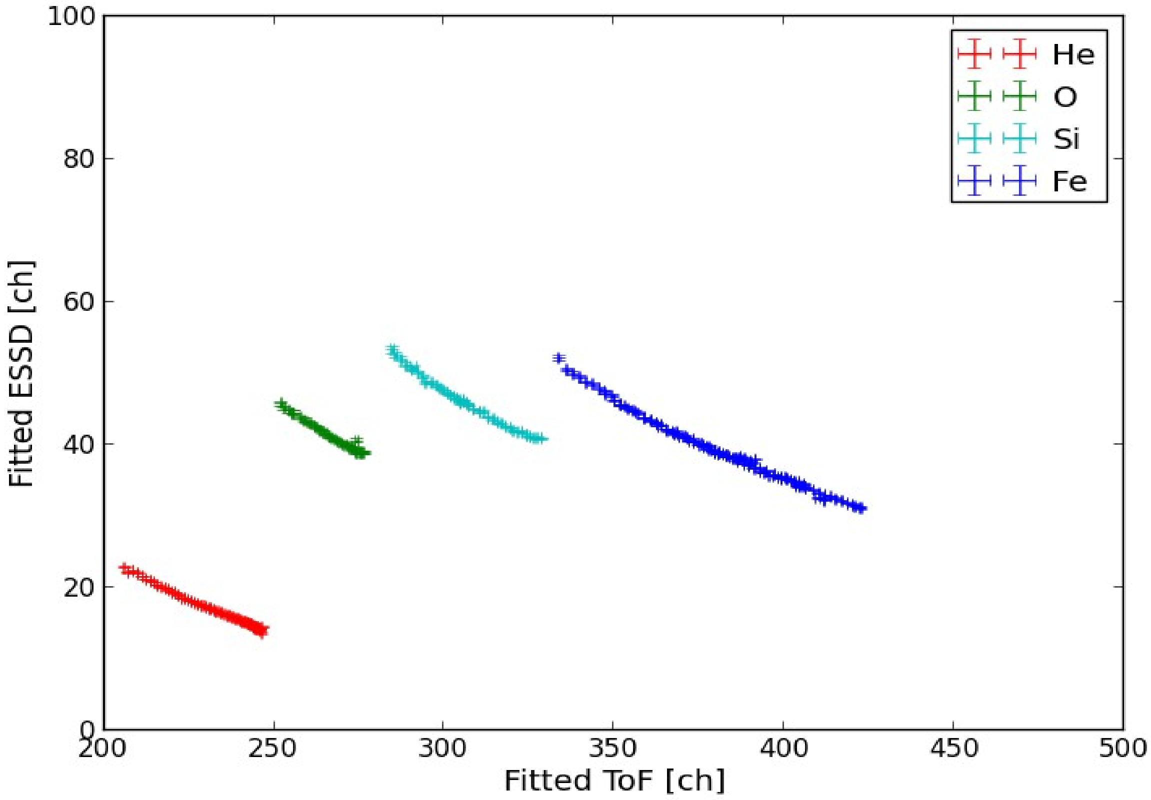

Ideal detector:

$$E_{SSD} = E_{meas} = A_0 \cdot \frac{1}{2} \cdot m \cdot L_\tau^2 \cdot \tau^{-2} + B_0$$

$A_0 :=$ gain, $B_0 :=$ pedestal, valid for all ions

Long-Time Data Fits

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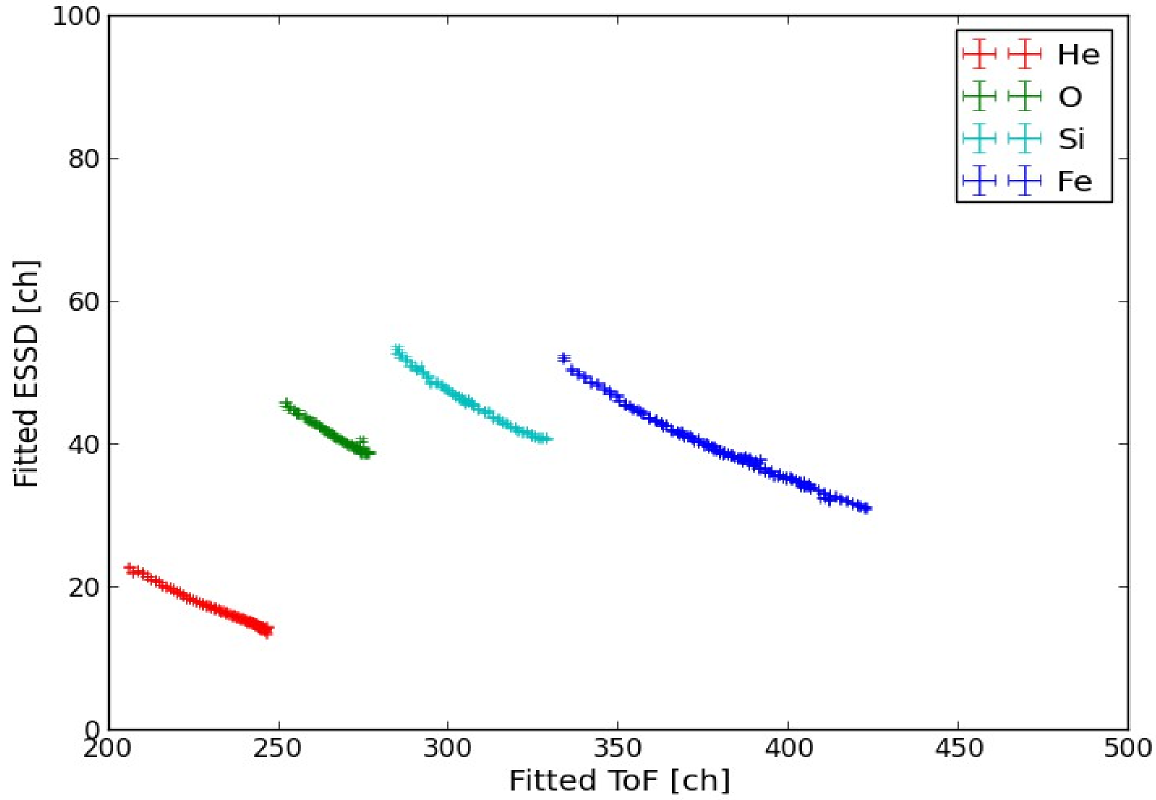

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Long-Time Data Fits

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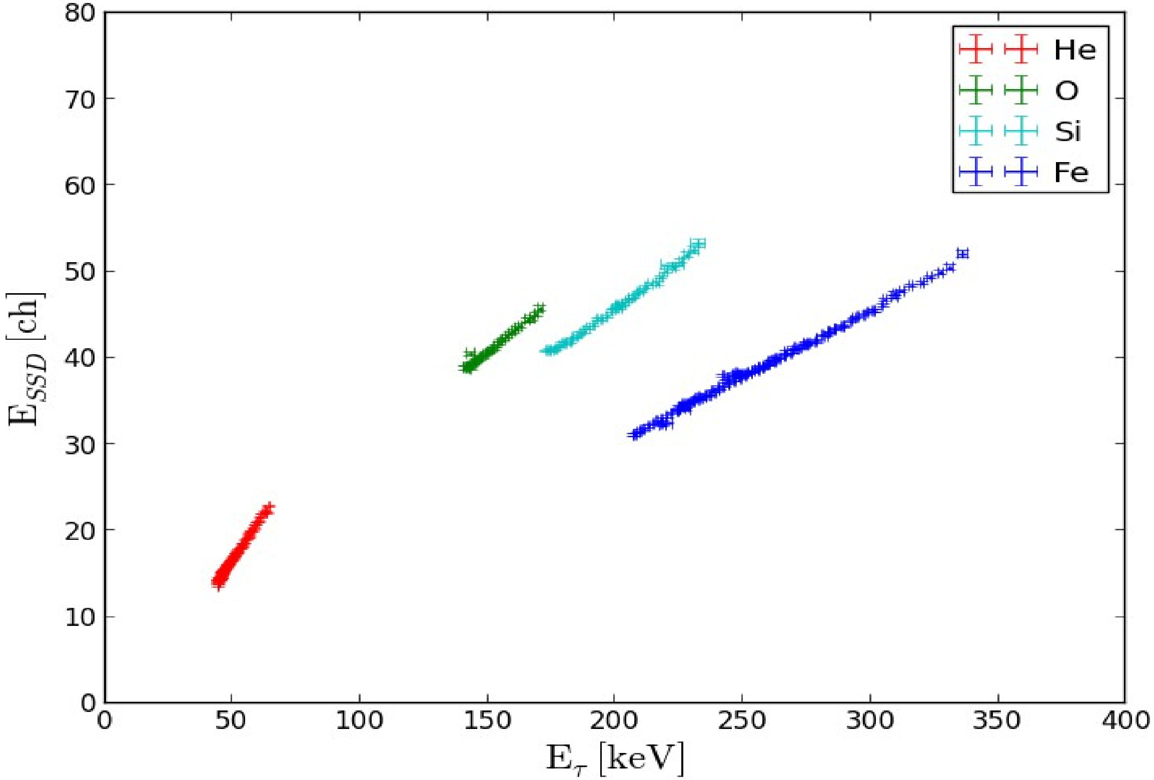

Ideal detector:

$$E_{SSD} = A_0 \cdot E_\tau + B_0$$

$A_0 :=$ gain, $B_0 :=$ pedestal, valid for all ions

CTOF Solid State Detector

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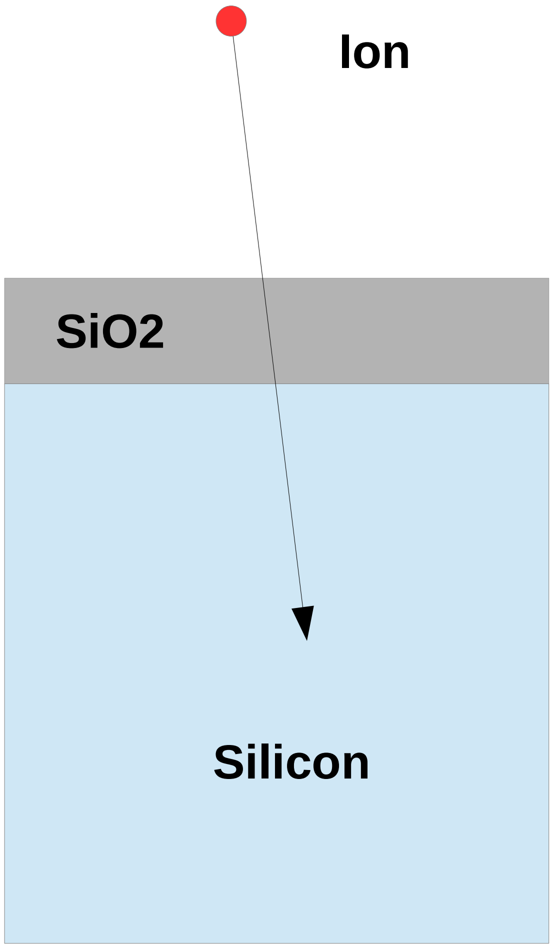
PIPS detector
measurement principle:

- **Ions penetrate through deadlayer and deposit energy in Si-electrons**
- **electron-hole pair creation :**

  3.6 eV per pair
- **Measured charge pulse is converted to energy channel**



CTOF Solid State Detector

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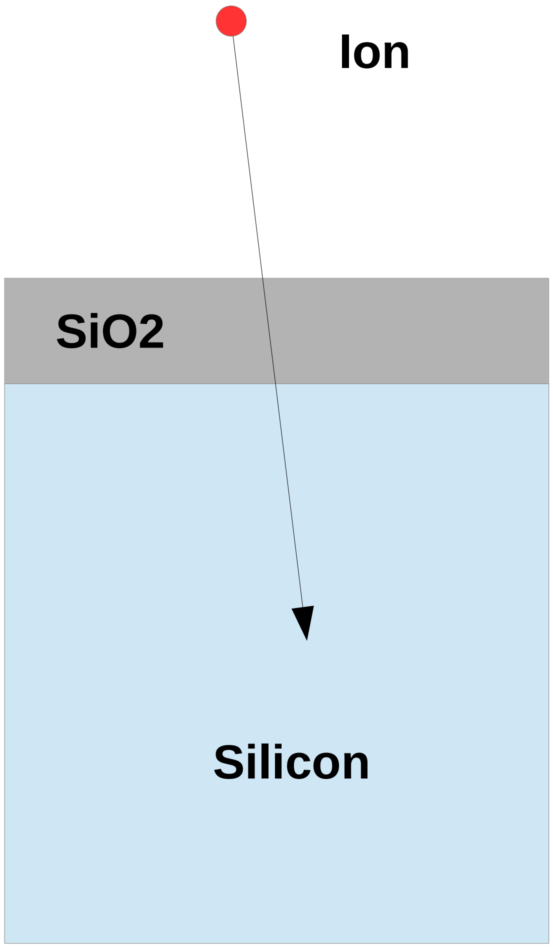
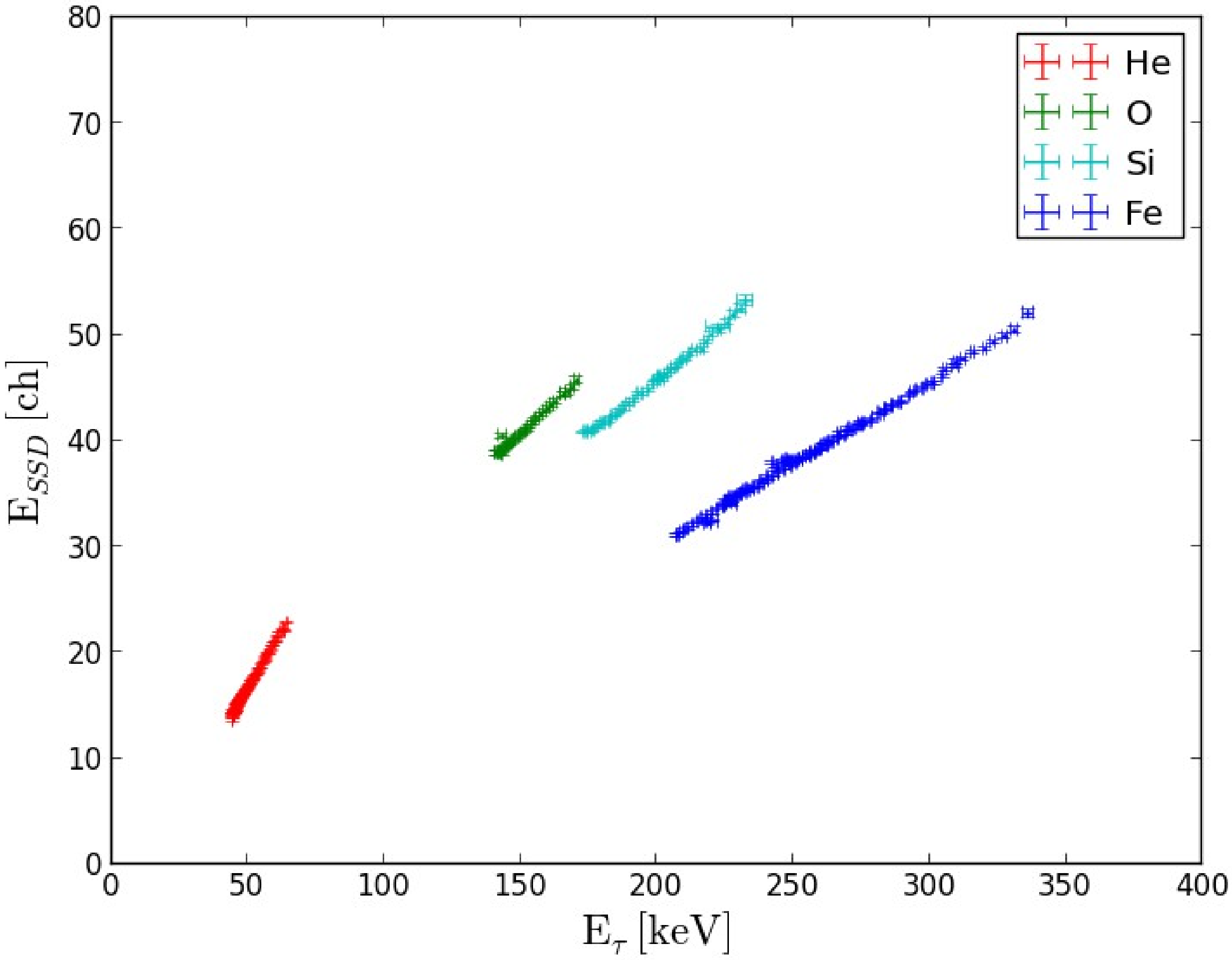
PIPS detector energy loss:

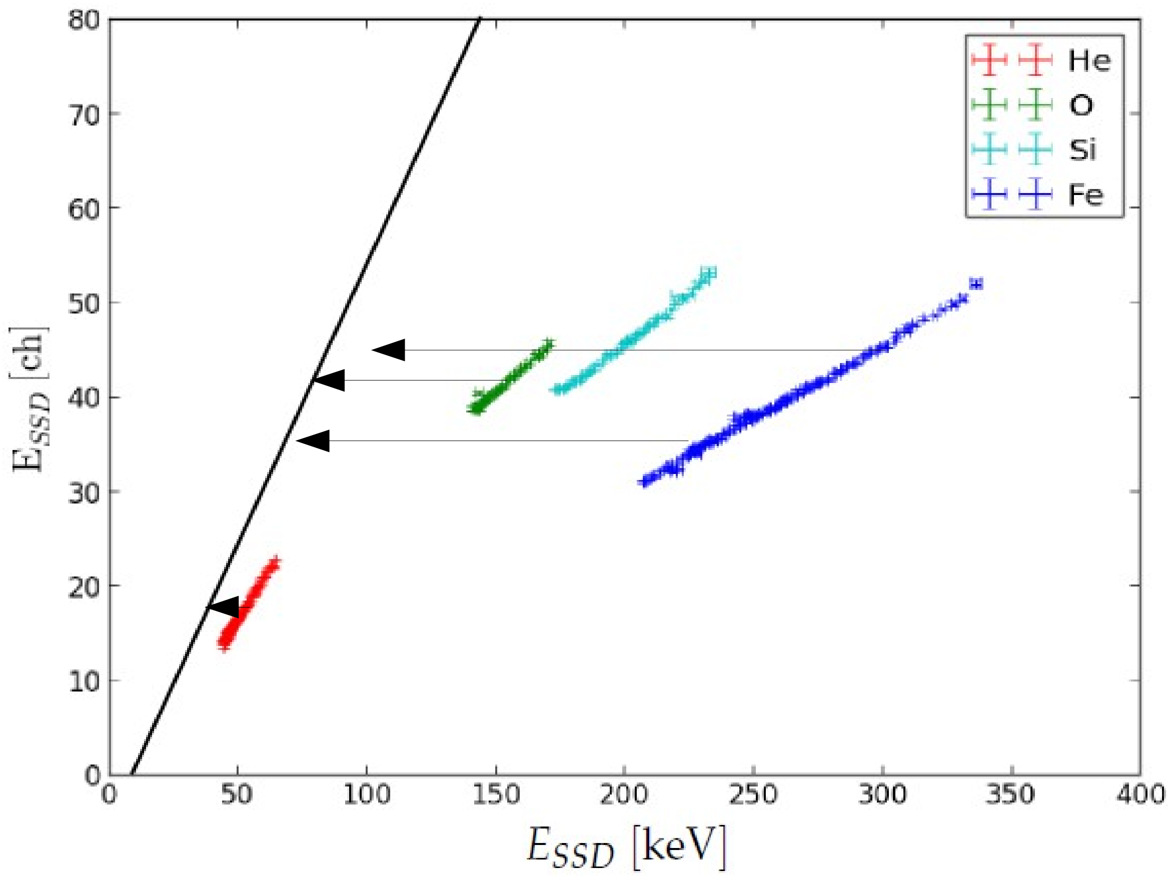
- **Ions already lose energy within the SiO2 deadlayer**
- **Ions lose energy to target atoms, partly going into phonons and target damage**
- **Only a fraction of the incident ion energy is measured (*pulse height defect*)**
- ***pulse height fraction :*** $\frac{E_{meas}}{E_{\tau}} =: \eta(Z, v)$



SSD Pulse Height Defect

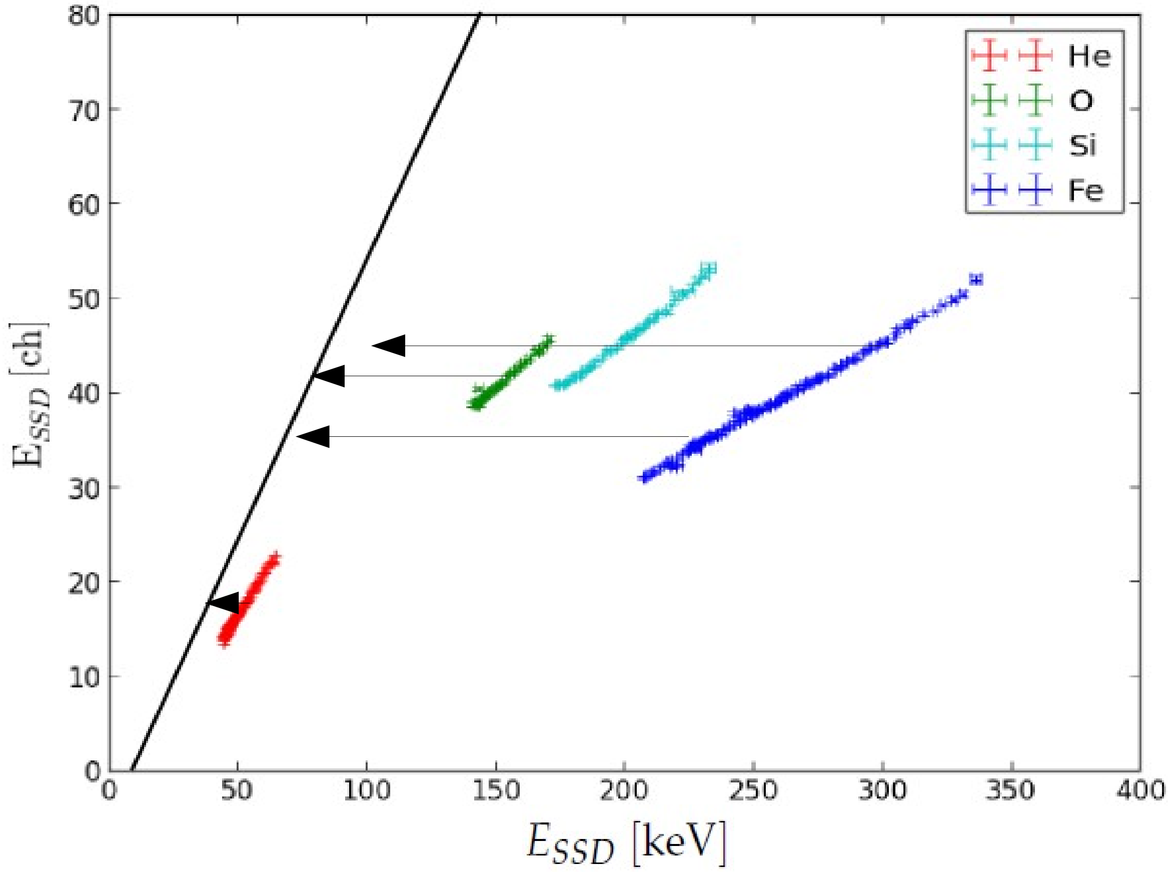


SSD Pulse Height Defect



Real detector: $$E_{SSD,i} = A_0 \cdot \underbrace{\eta(Z_i, v_i) \cdot E_{\tau,i}}_{E_{SSD}\,[\mathrm{keV}]} + B_0$$

SSD Pulse Height Defect

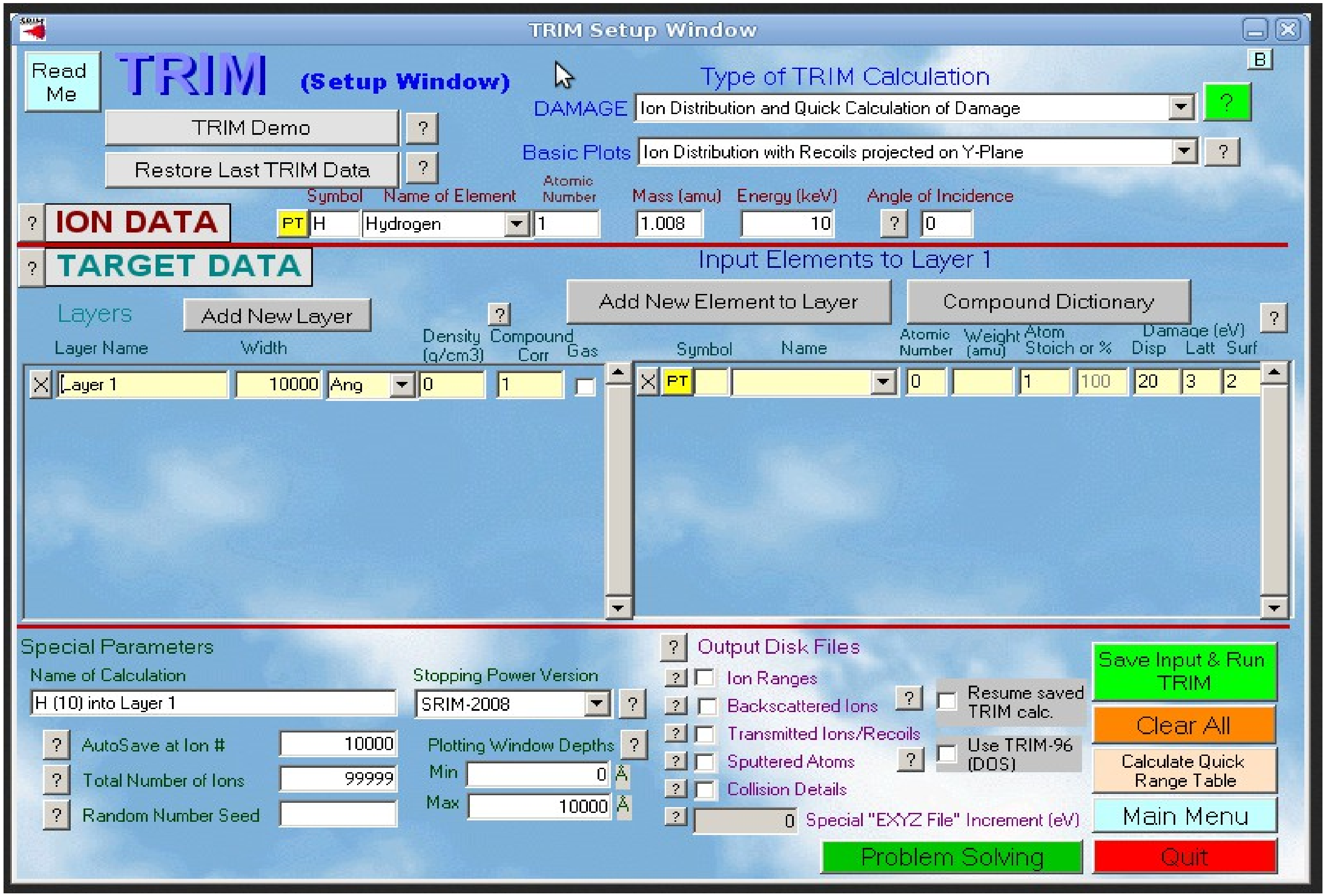


Real detector:

$$E_{SSD,i} = A_0 \cdot \eta(Z_i, v_i) \cdot E_{\tau,i} + B_0$$

n equations for n+2 variables
=> simulation of pulse height defect with TRIM

SRIM / TRIM


TRIM Setup Window
Read Me
TRIM
(Setup Window)
TRIM Demo
Restore Last TRIM Data
Type of TRIM Calculation
DAMAGE
Ion Distribution and Quick Calculation of Damage
Basic Plots
Ion Distribution with Recoils projected on Y-Plane
ION DATA
Symbol
Name of Element
Atomic Number
Mass (amu)
Energy (keV)
Angle of Incidence
PT
H
Hydrogen
1
1.008
10
0
TARGET DATA
Input Elements to Layer 1
Layers
Add New Layer
Add New Element to Layer
Compound Dictionary
Layer Name
Width
Density (g/cm3)
Compound Corr
Gas
Symbol
Name
Atomic Number
Weight (amu)
Atom Stoich or %
Damage (eV)
Disp
Latt
Surf
Layer 1
10000
Ang
0
1
0
1
100
20
3
2
Special Parameters
Name of Calculation
H (10) into Layer 1
Stopping Power Version
SRIM-2008
AutoSave at Ion #
10000
Total Number of Ions
99999
Random Number Seed
Plotting Window Depths
Min
0
Å
Max
10000
Å
Output Disk Files
Ion Ranges
Backscattered Ions
Transmitted Ions/Recoils
Sputtered Atoms
Collision Details
Special "EXYZ File" Increment (eV)
0
Resume saved TRIM calc.
Use TRIM-96 (DOS)
Save Input & Run TRIM
Clear All
Calculate Quick Range Table
Main Menu
Problem Solving
Quit

TRIM Results:
Simulated SSD Response

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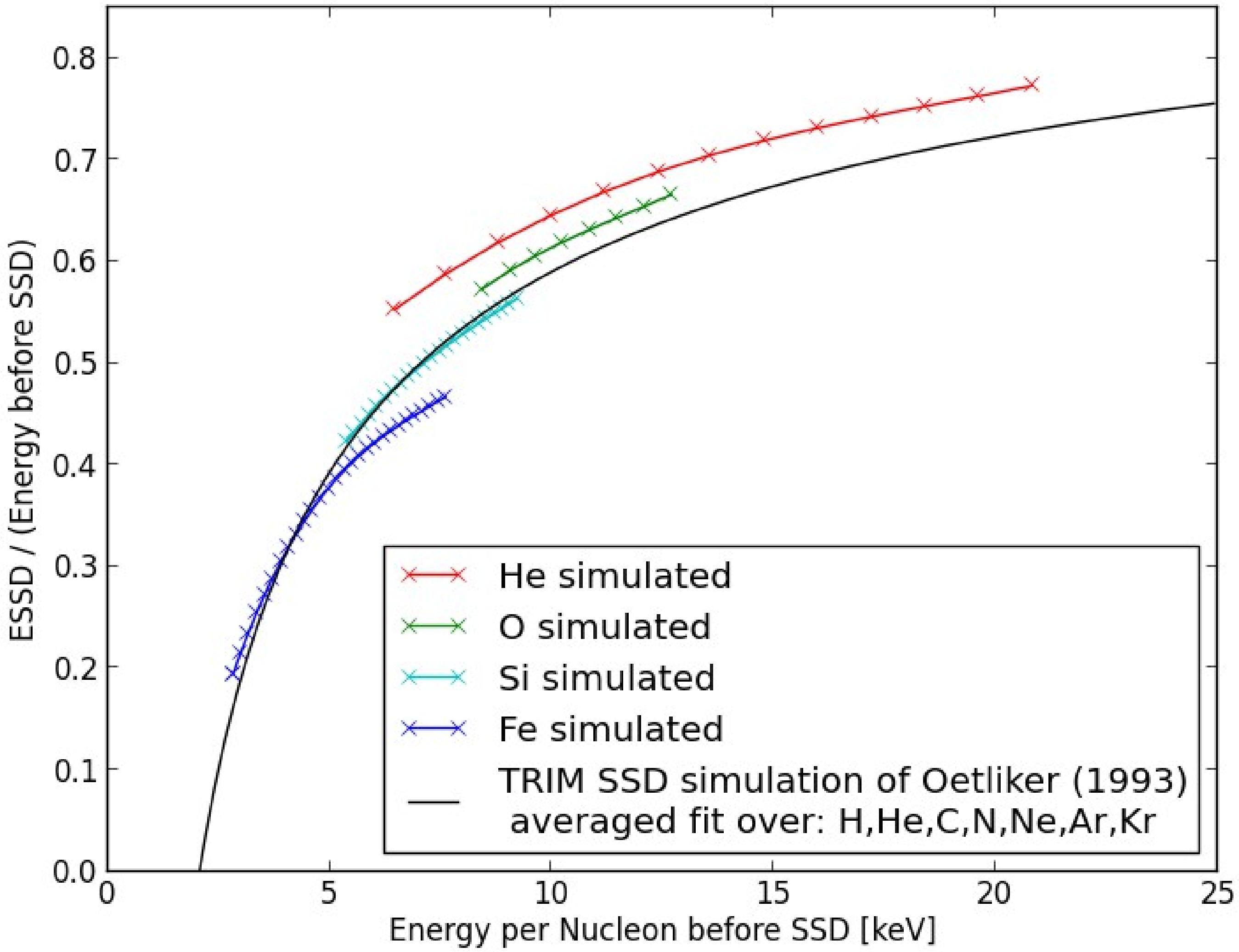

TRIM Results: Simulated SSD Response

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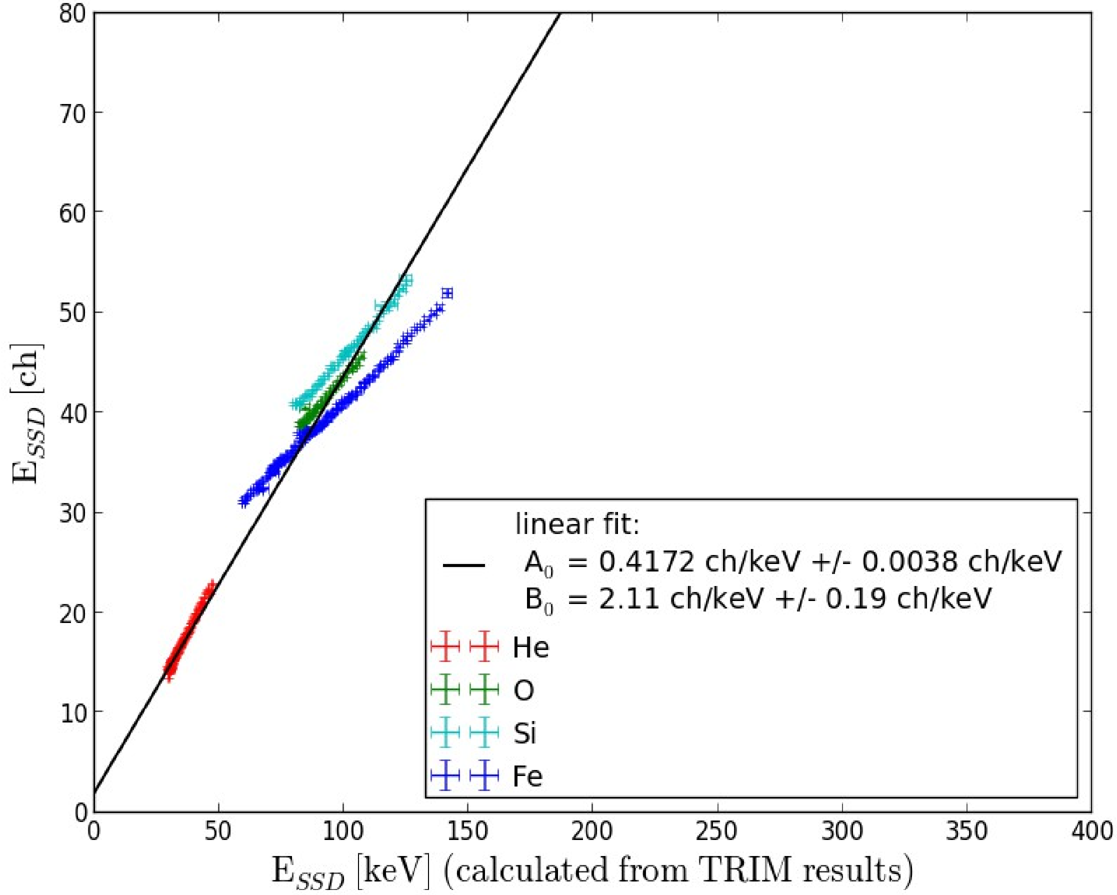

TRIM Results: Simulated SSD Response

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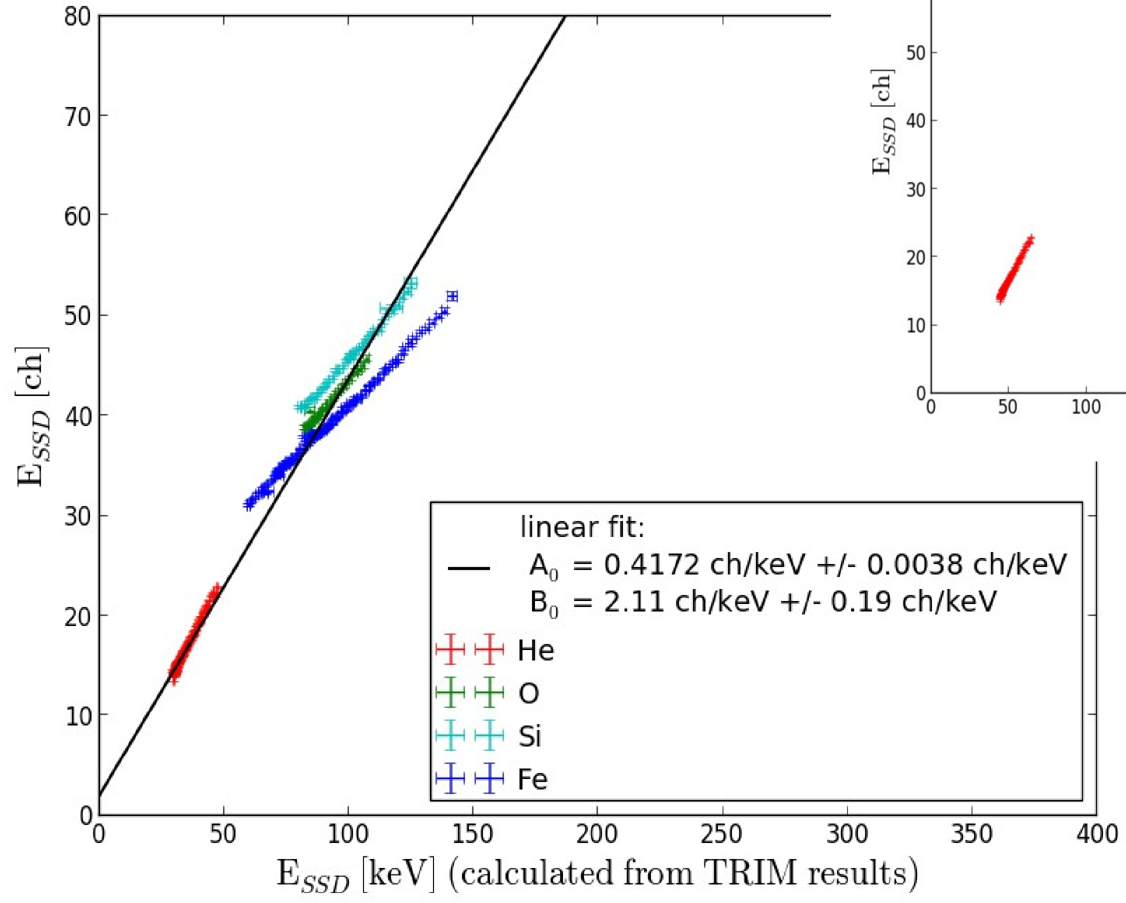

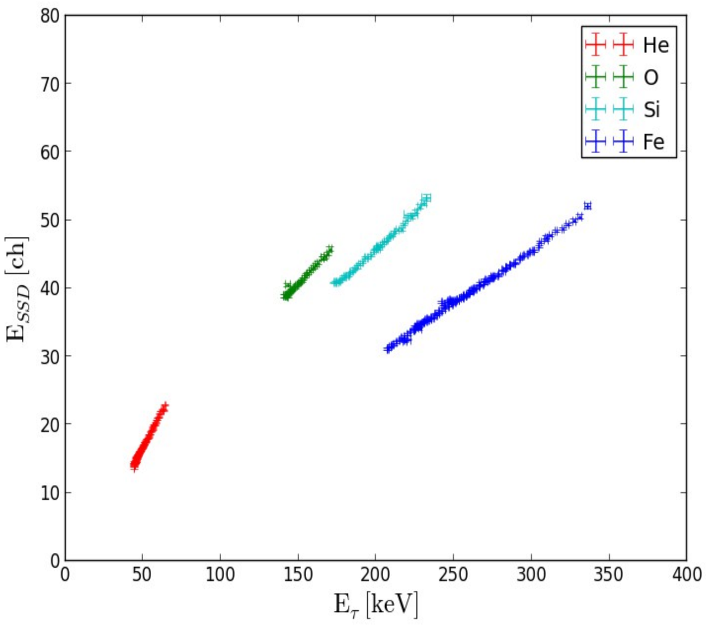

TRIM vs measured SSD signal

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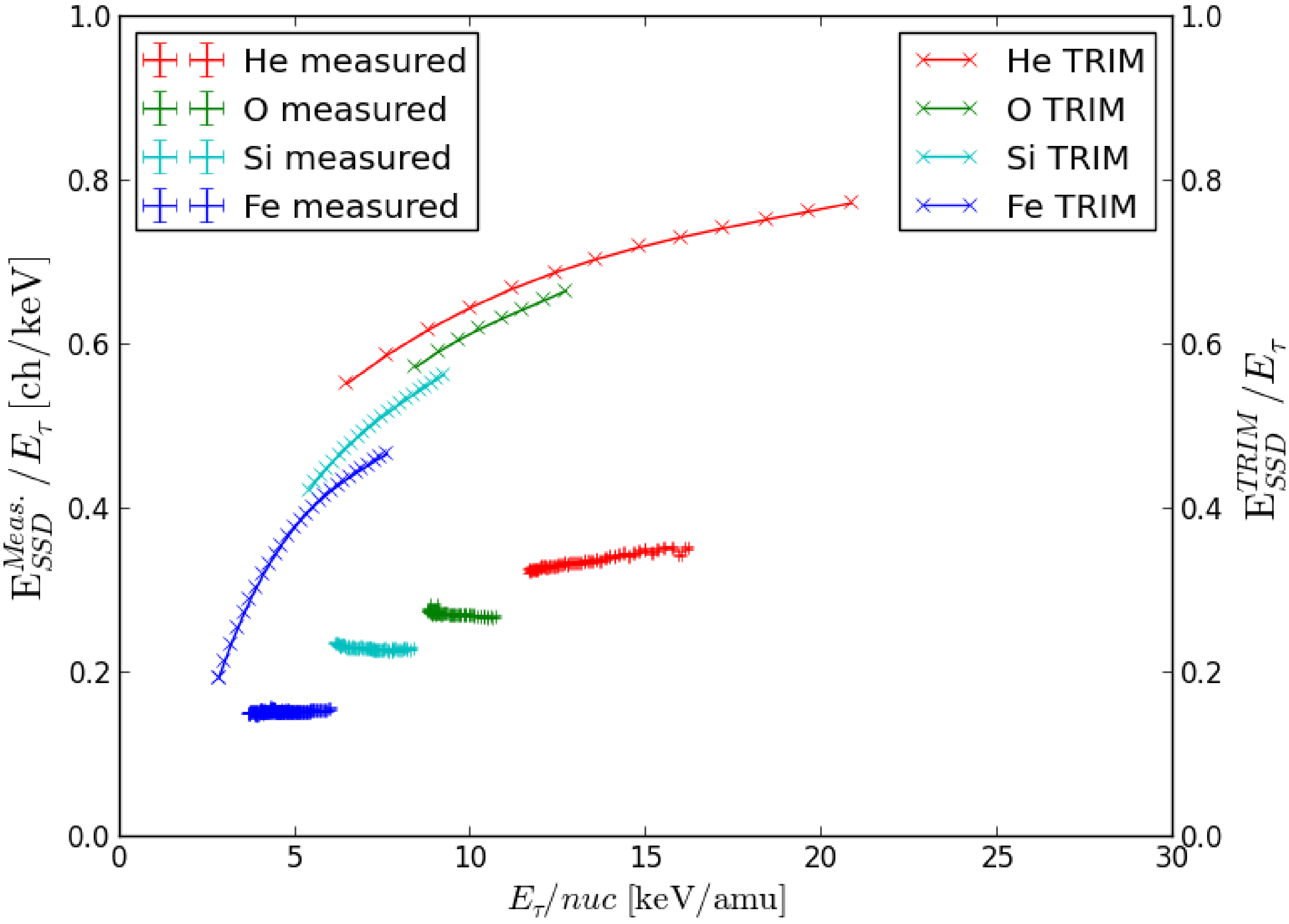

TRIM vs measured SSD signal

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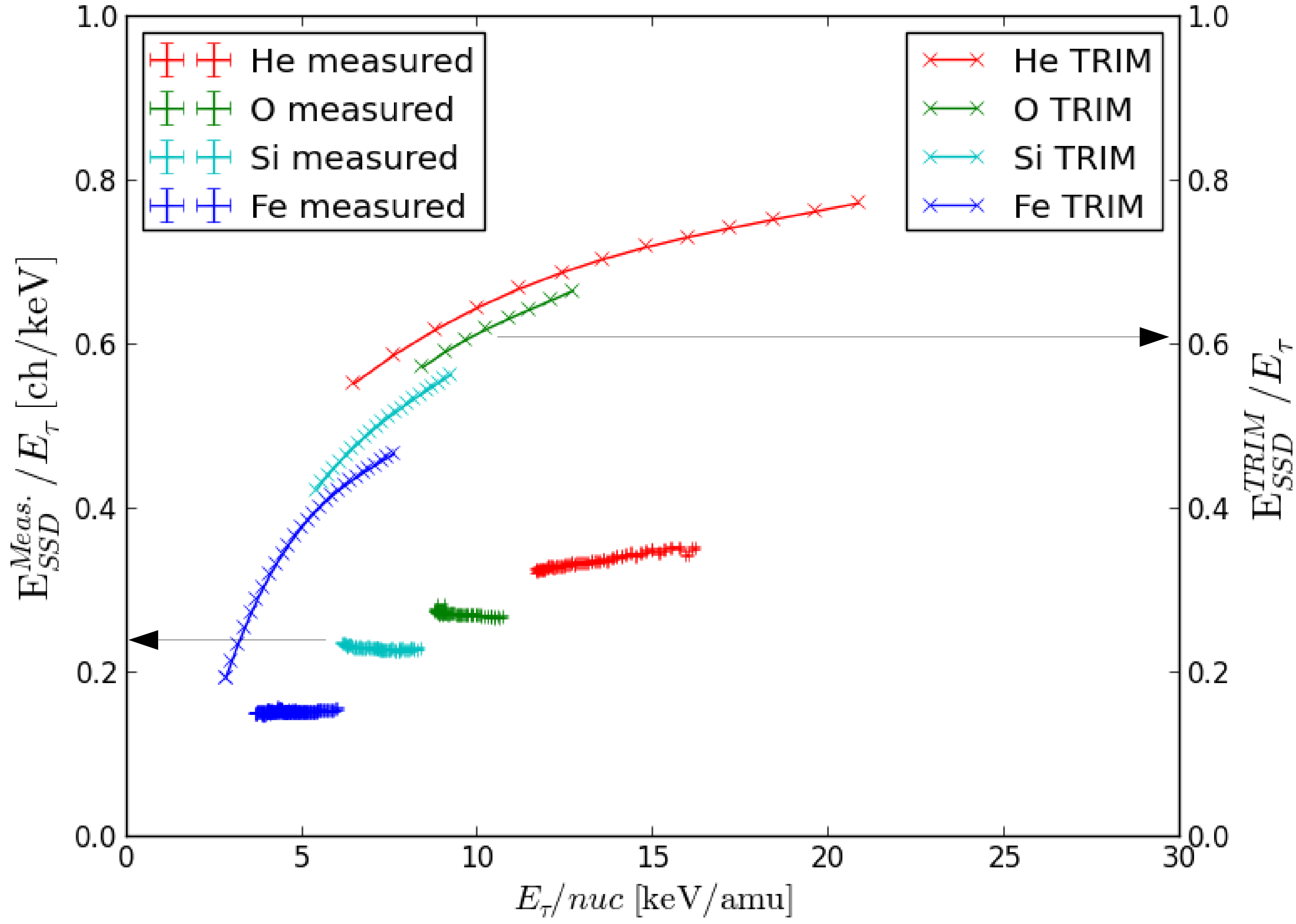

TRIM vs measured SSD signal

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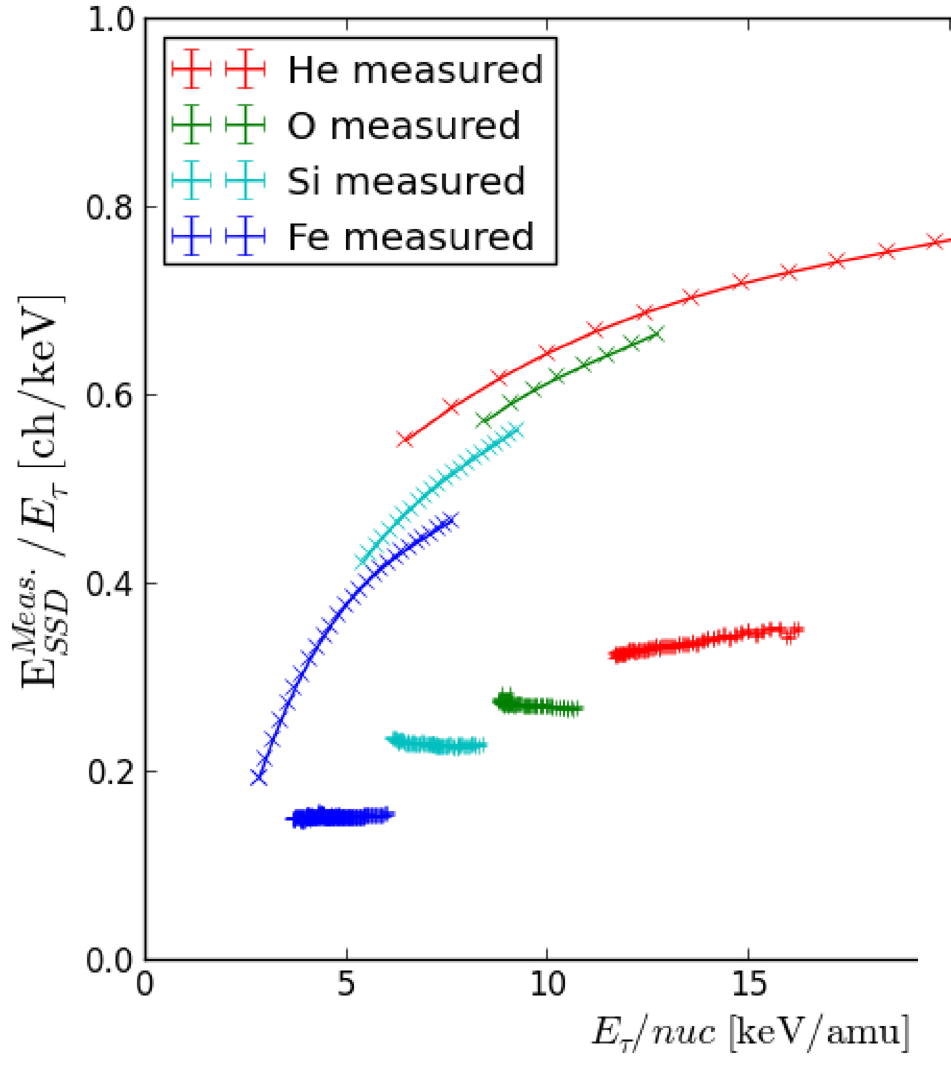

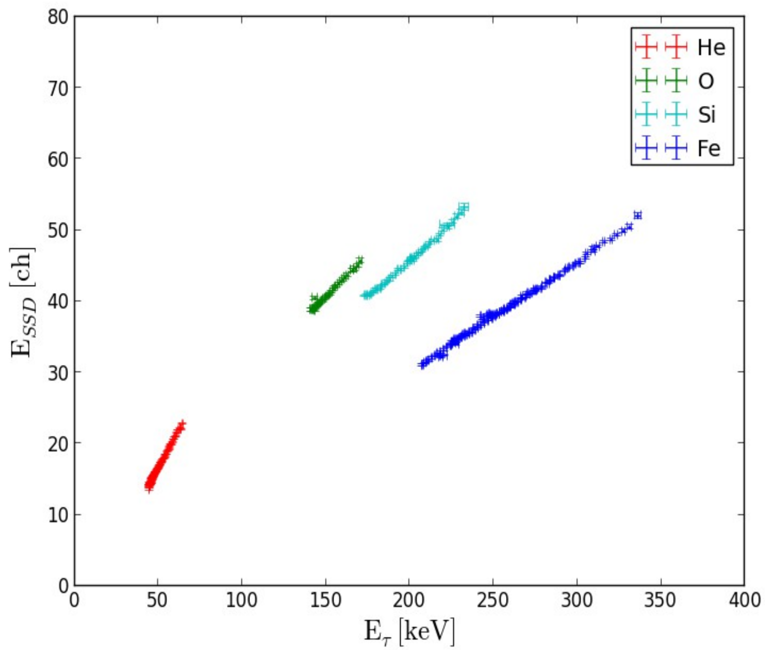

TRIM vs measured SSD signal

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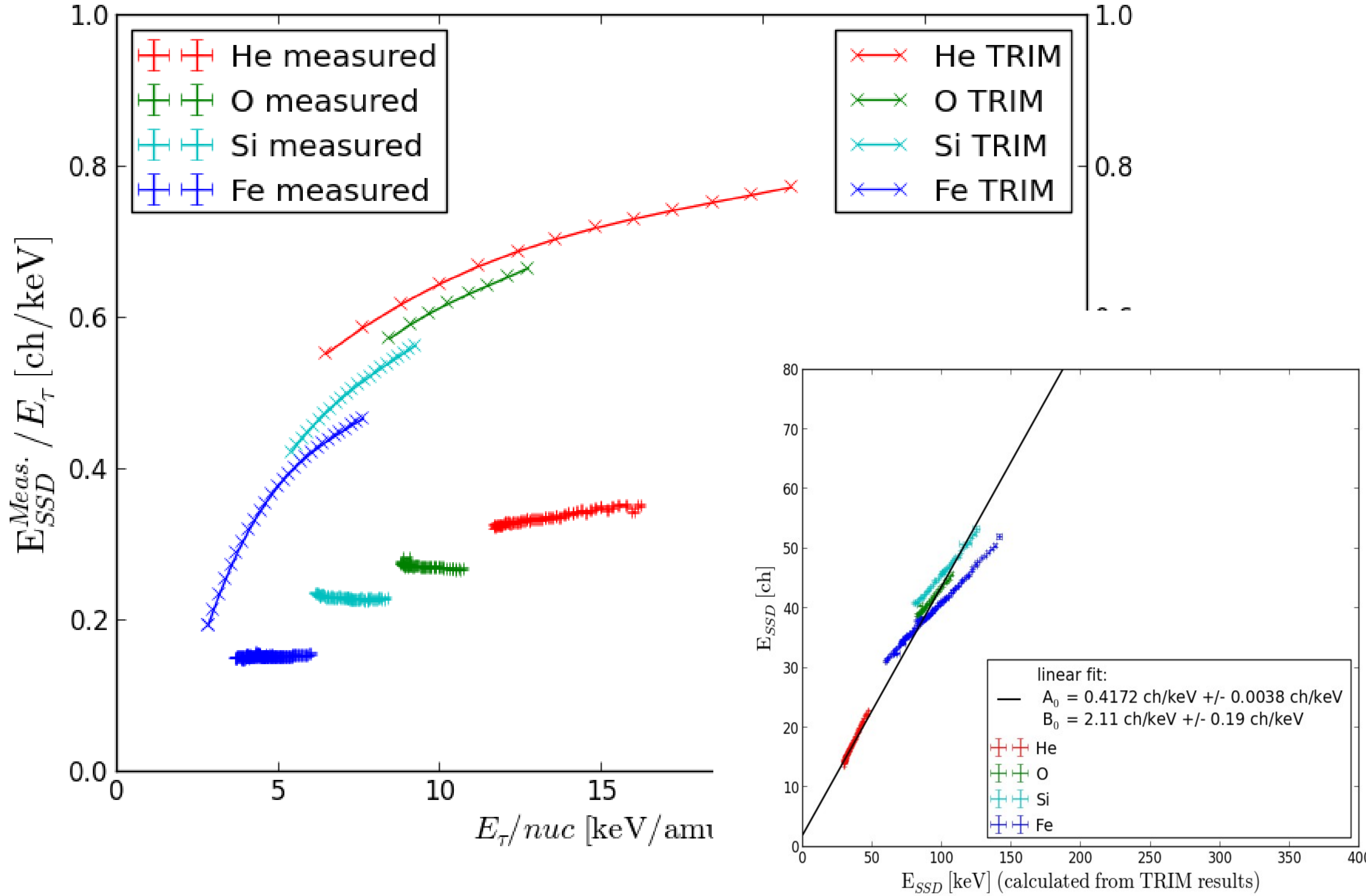

TRIM vs measured SSD signal

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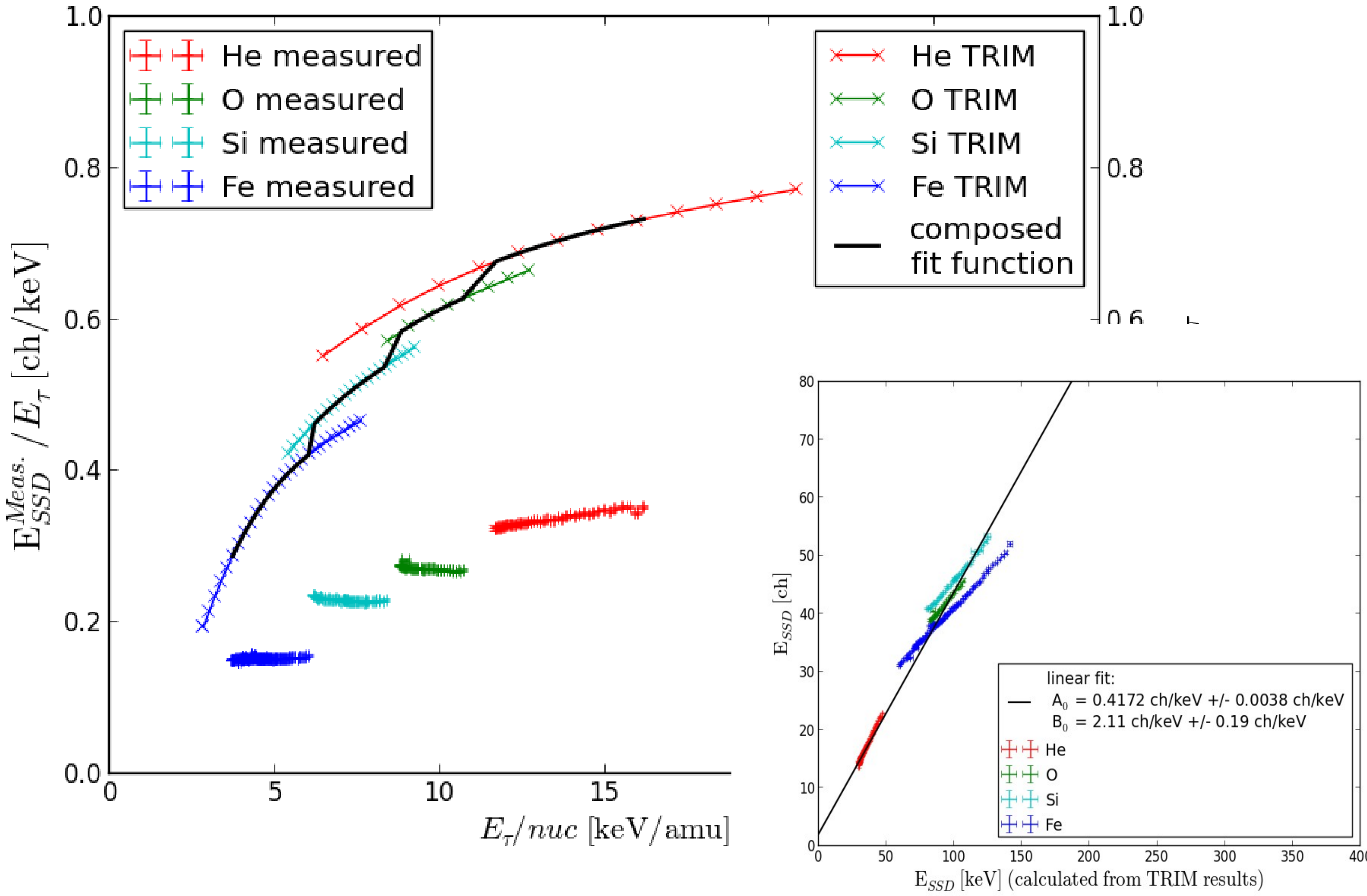
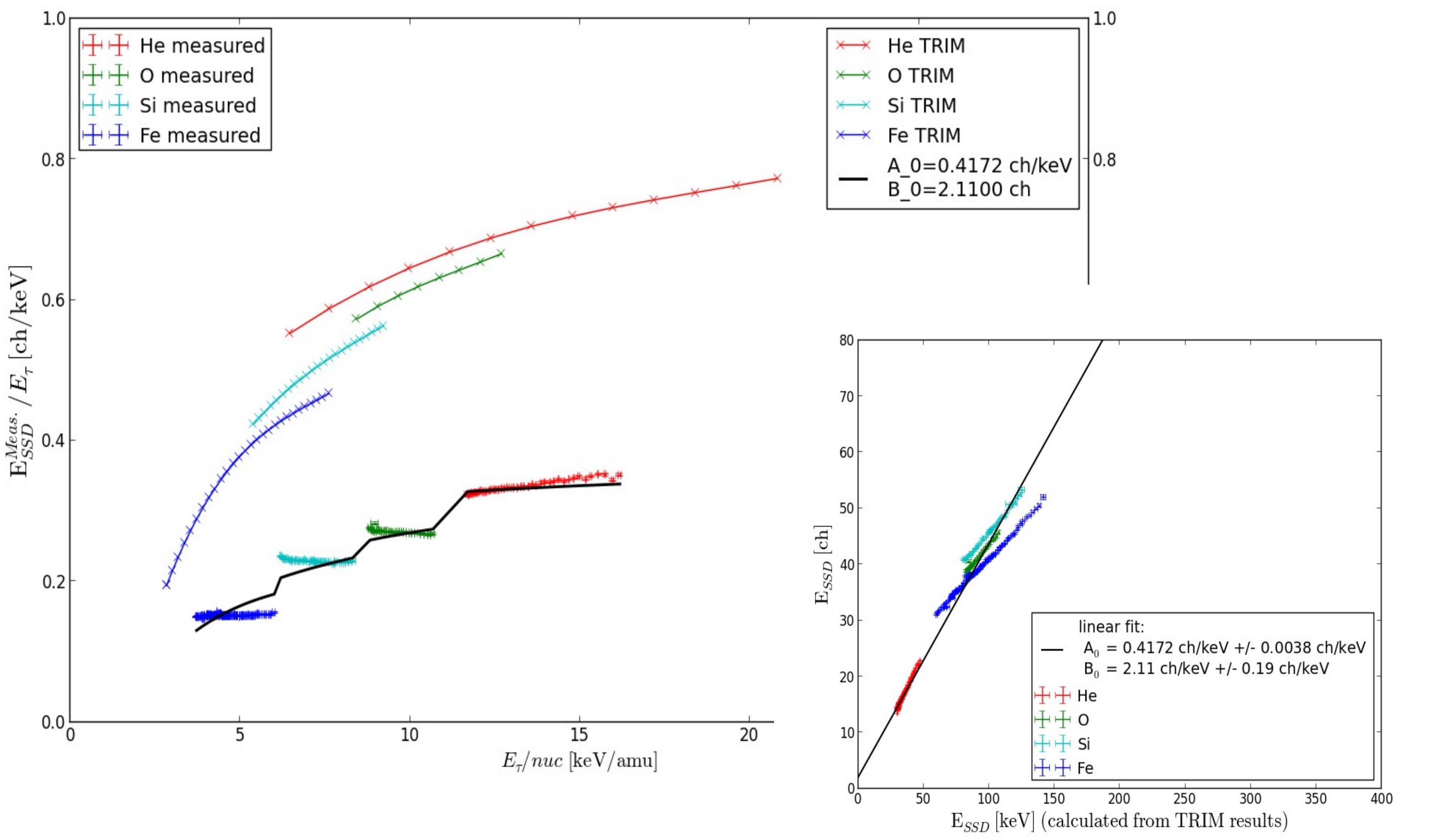
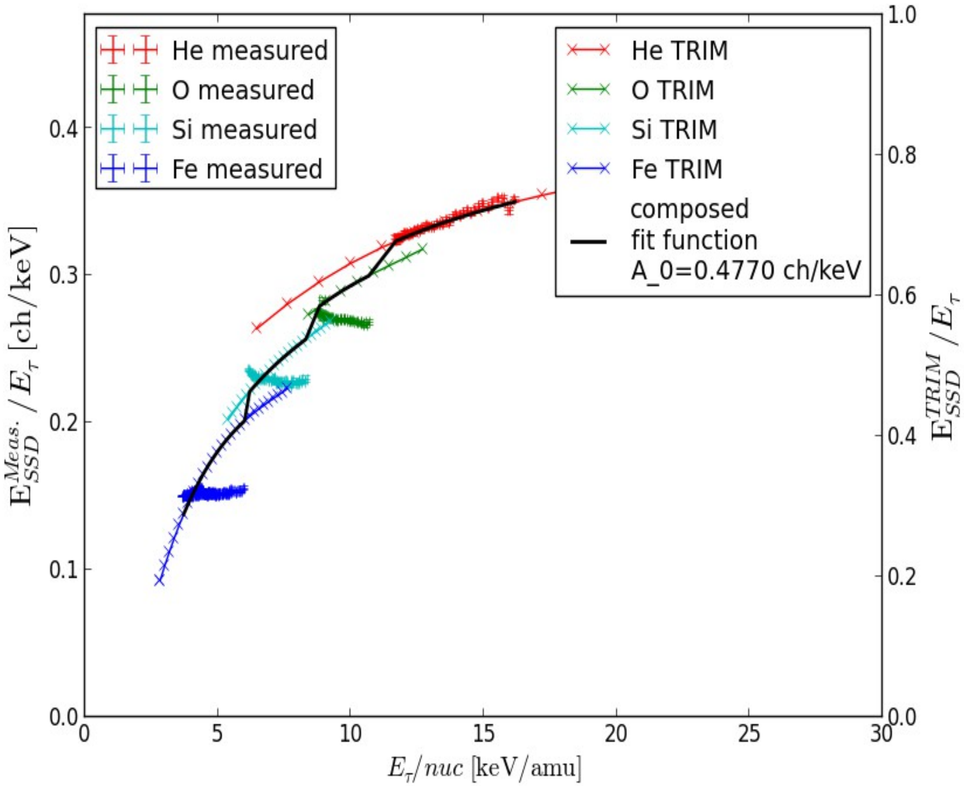
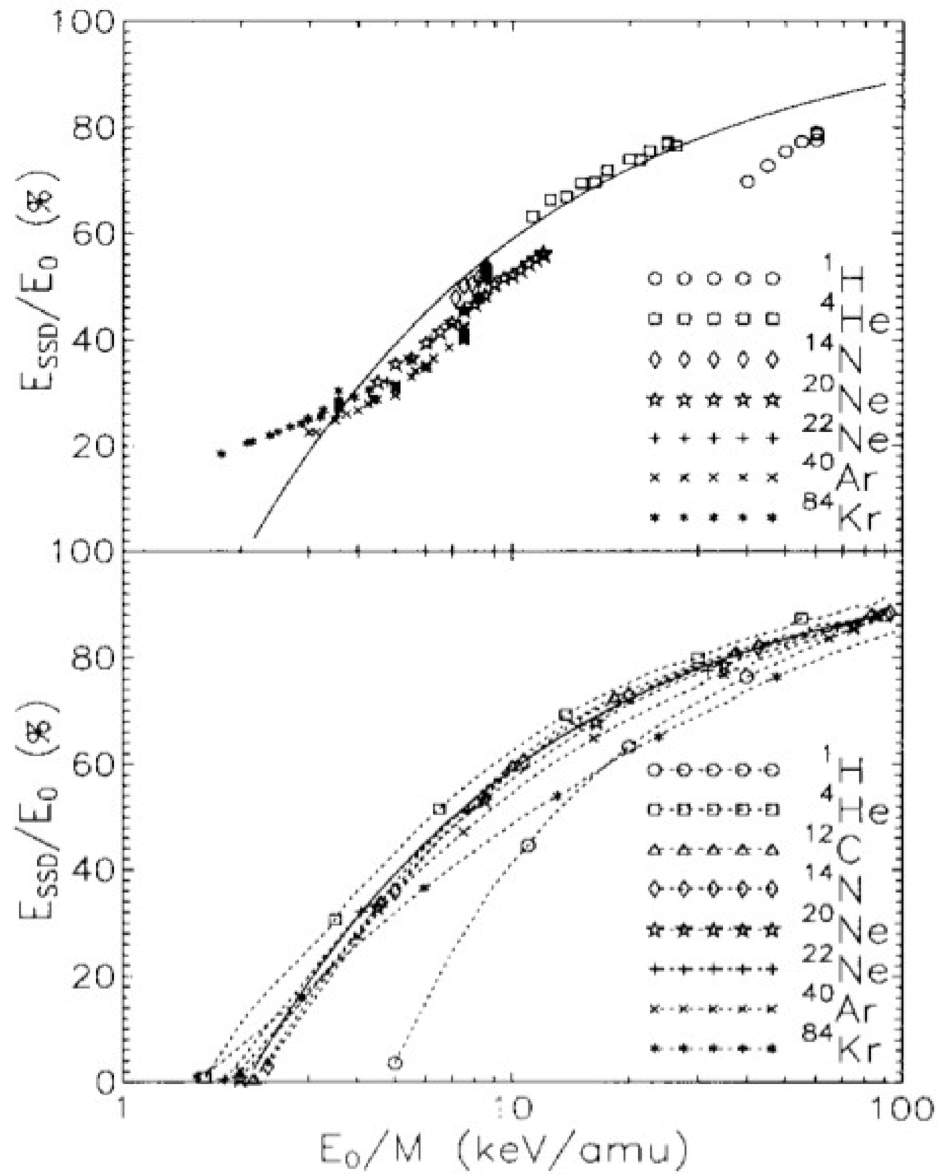


TRIM vs measured SSD signal



Comparison with SSD Preflight Calibration





Solution: Calculate Detector Gain from Calculated He PHD

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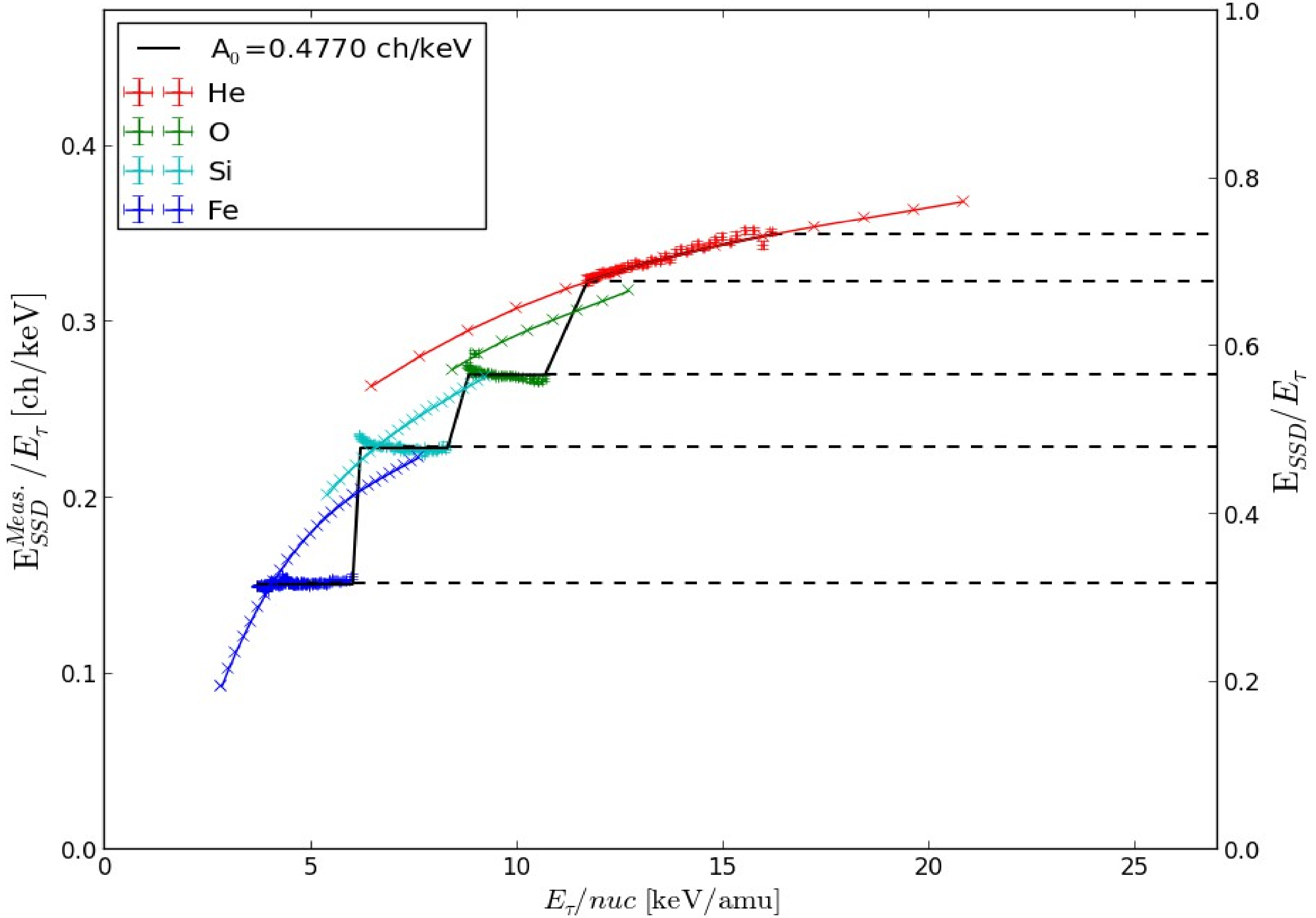

Solution: Determine Absolute Pulse Height Fractions Relative to Helium

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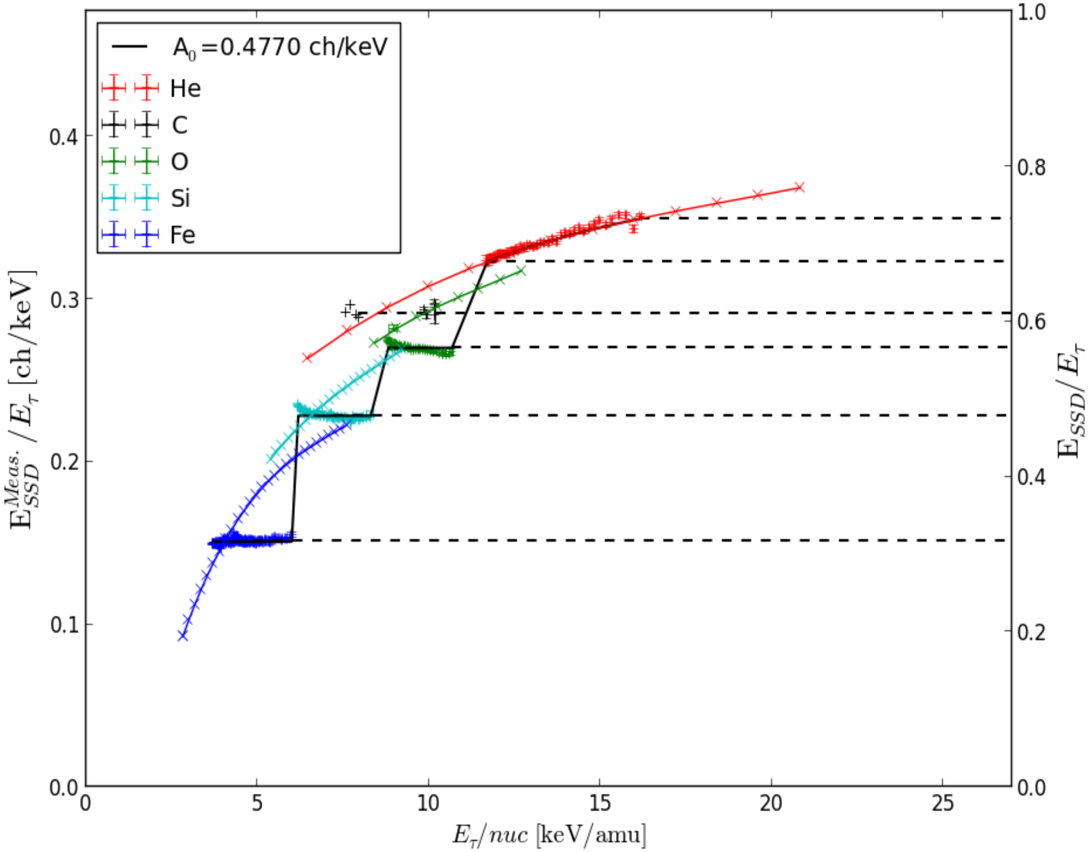

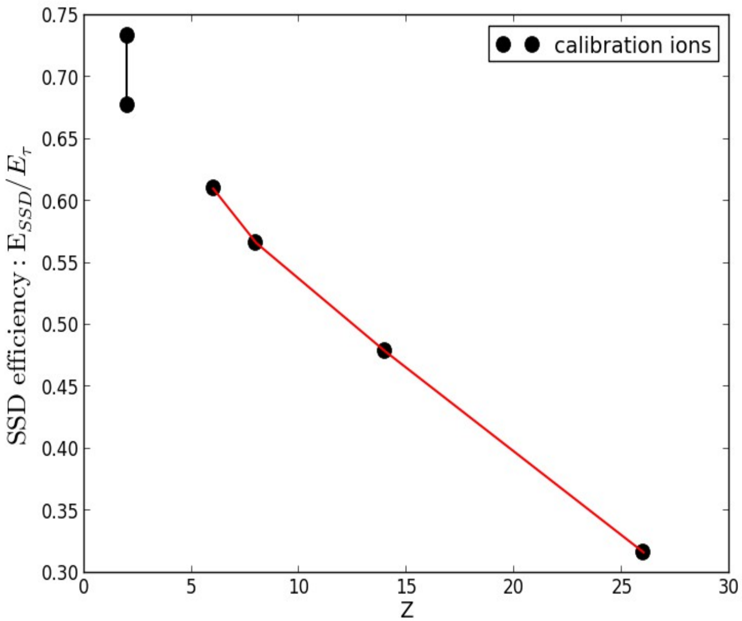

SSD Pulse height fraction:
Z dependence

Calibrated Ion Positions in in the ET-matrix

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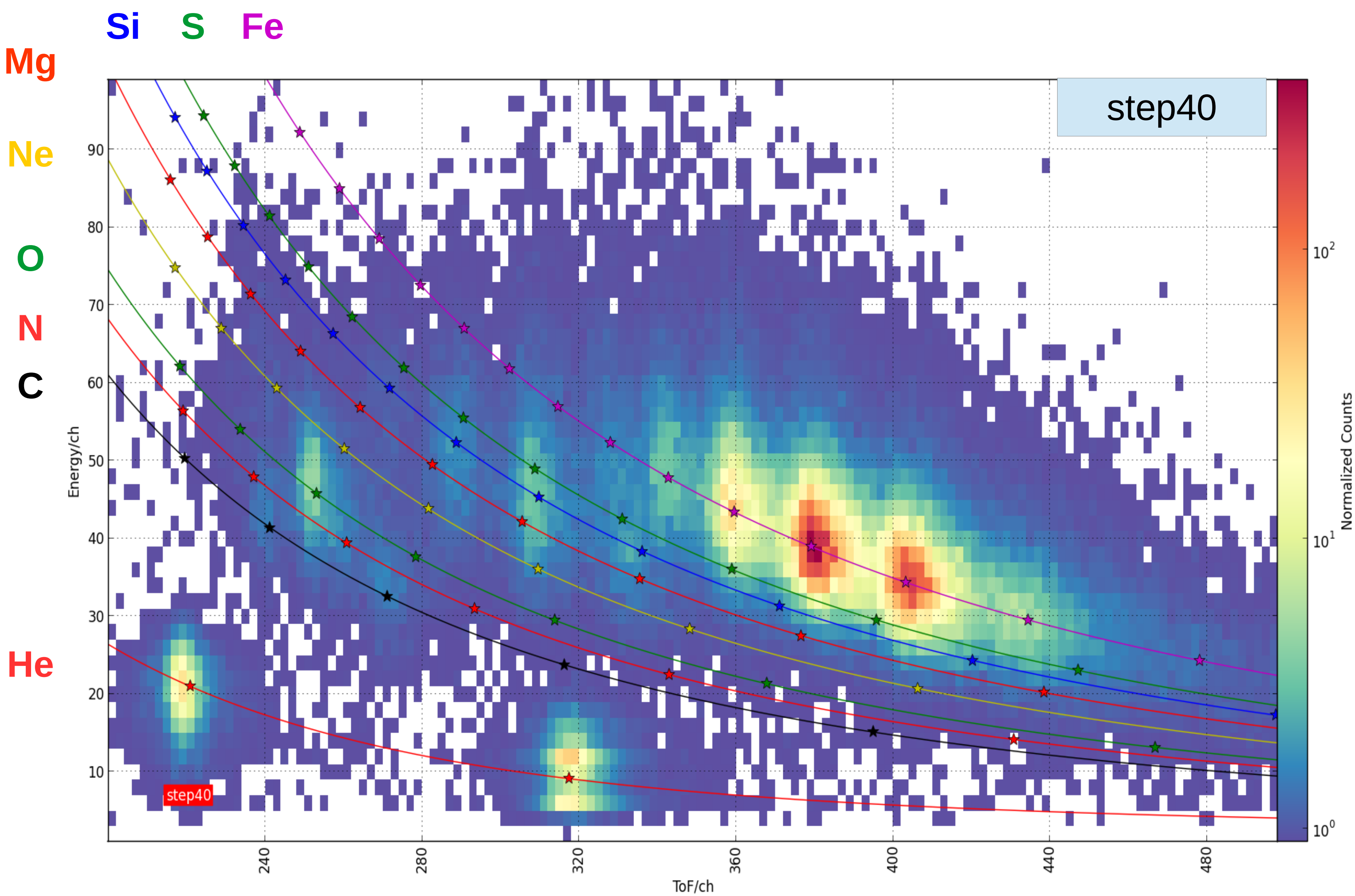

Calibrated Ion Positions
in in the ET-matrix

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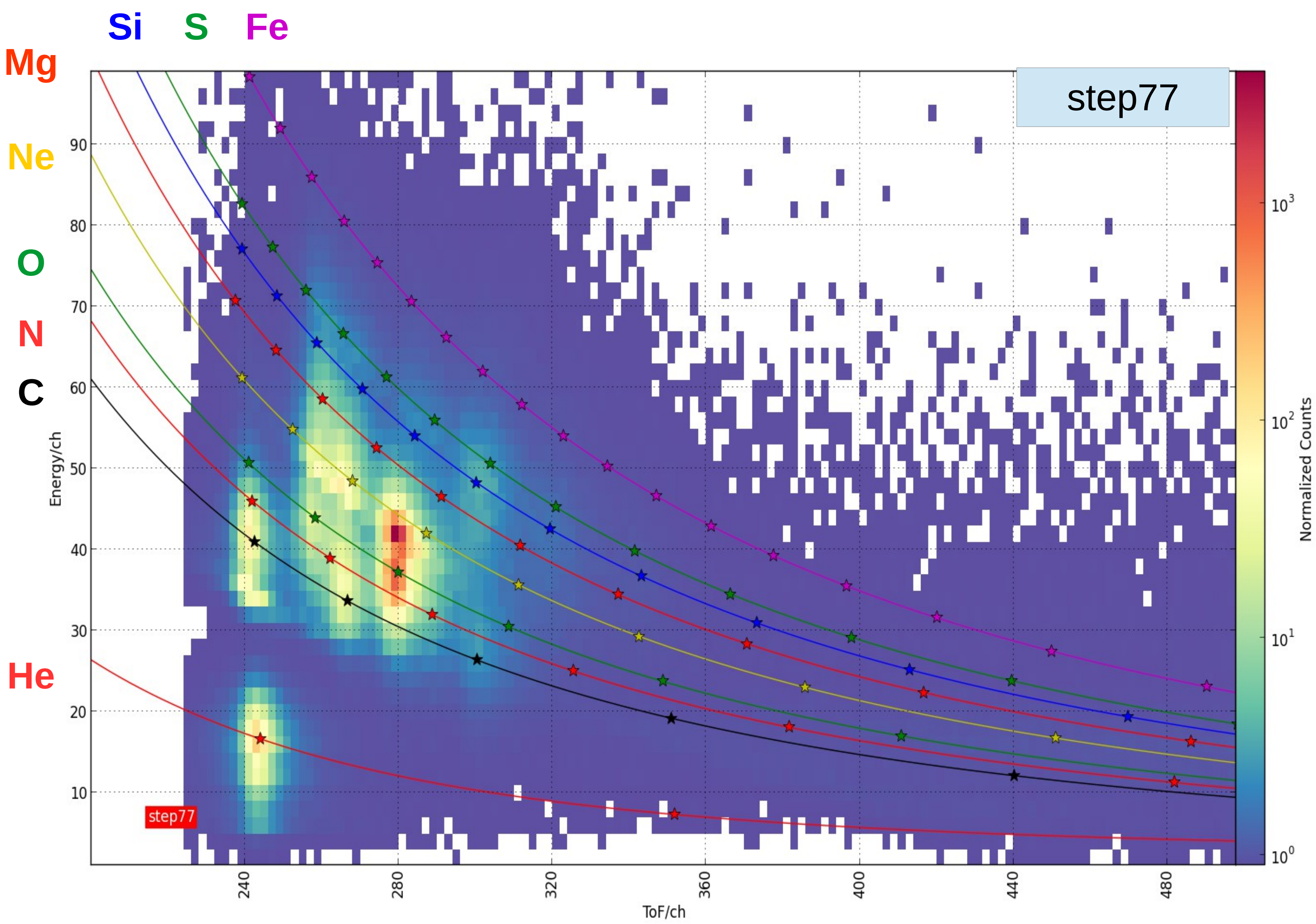

Calibrated Ion Positions within in the ET-matrix

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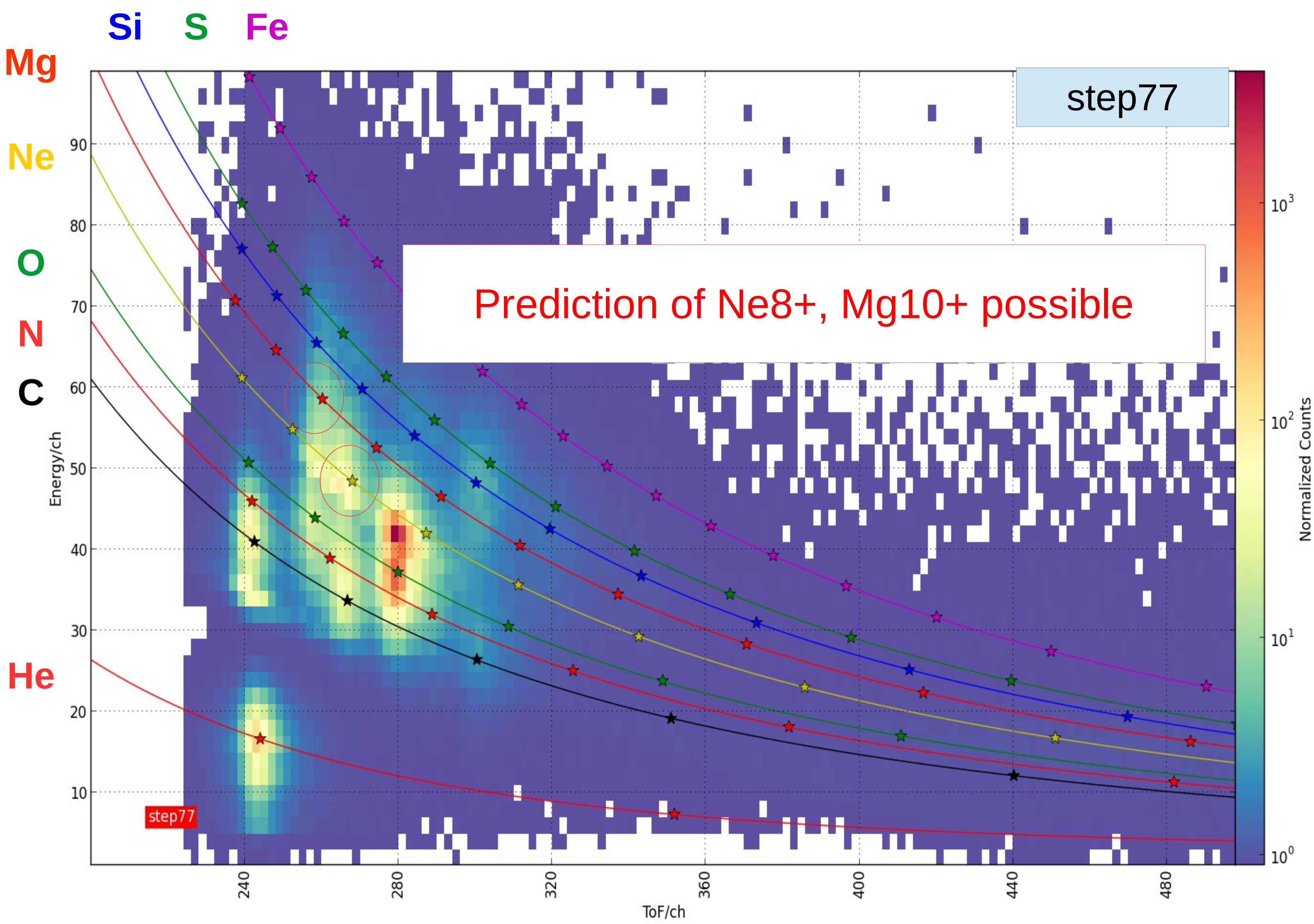
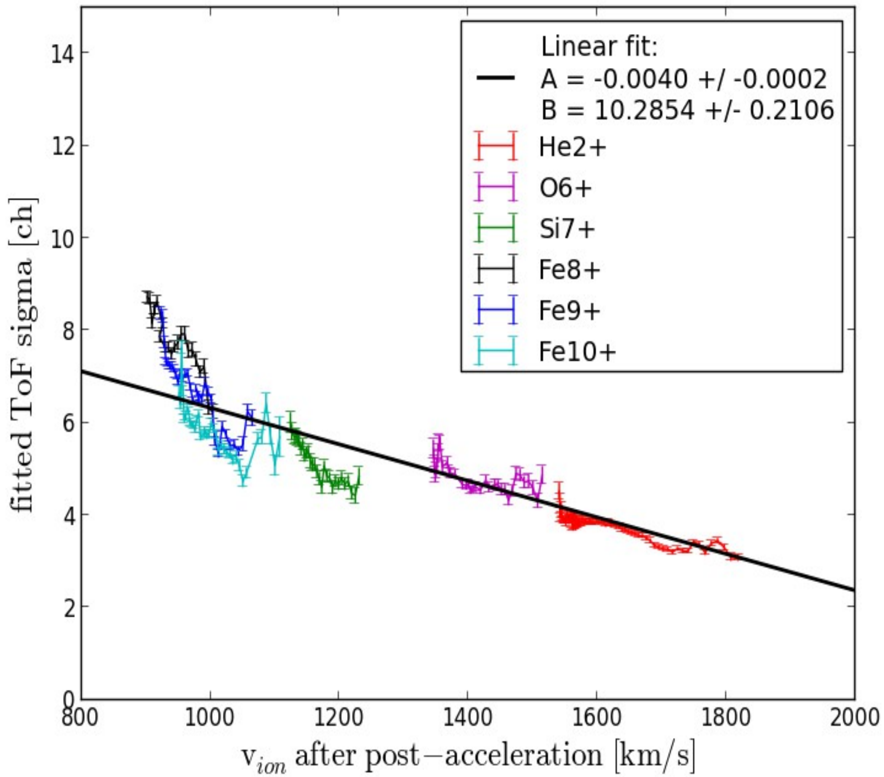
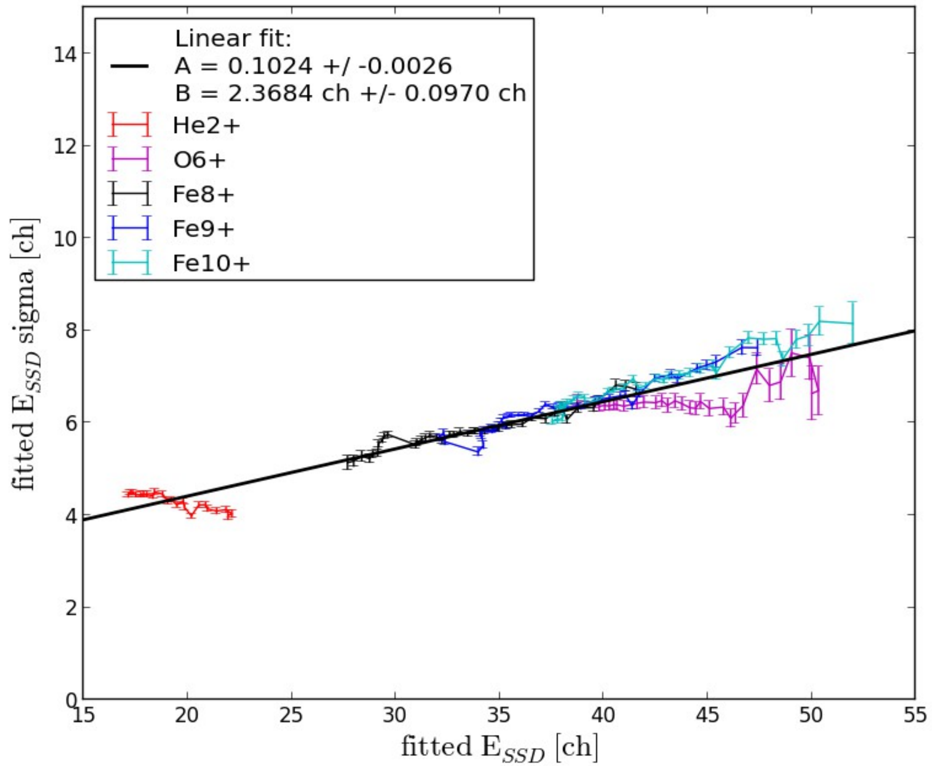
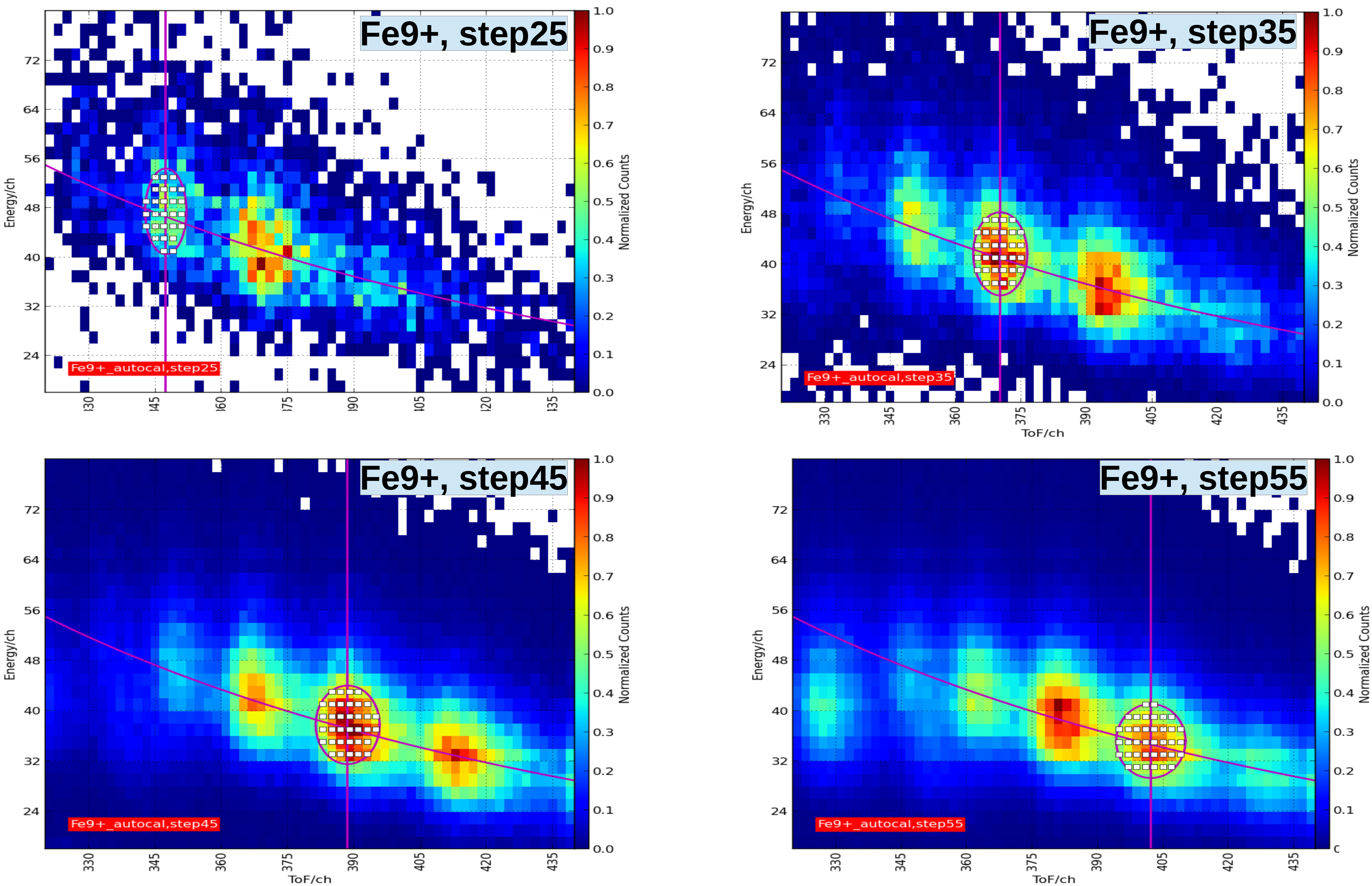


Fitted ToF and ESSD widths





Calibration Check with Long-Time Data



Obtaining Velocity Distributions from CTOF Short-Time Data

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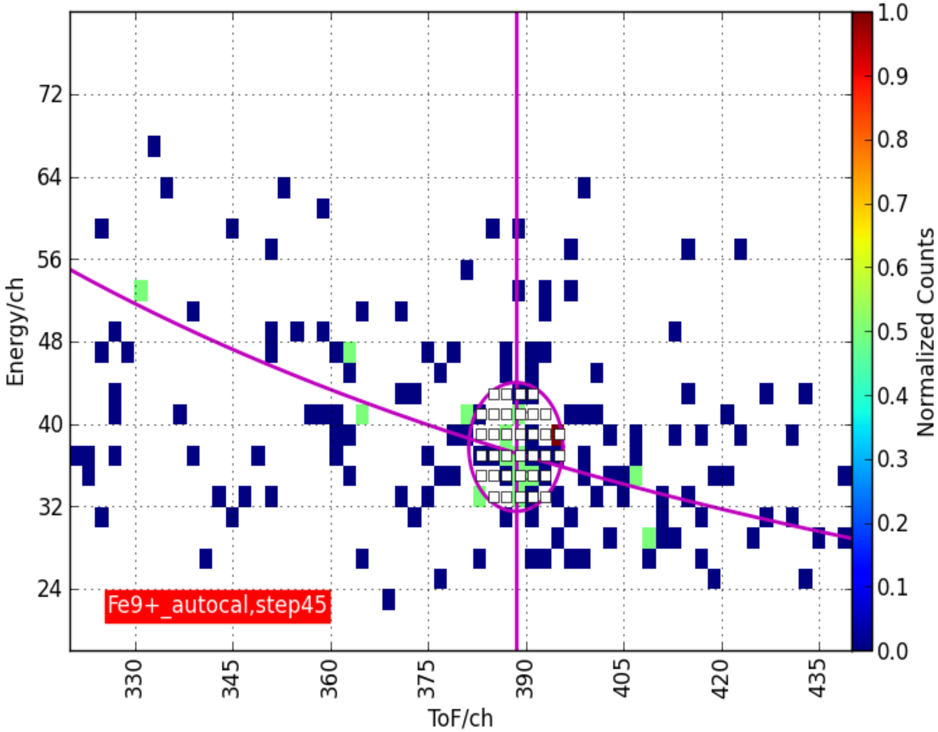
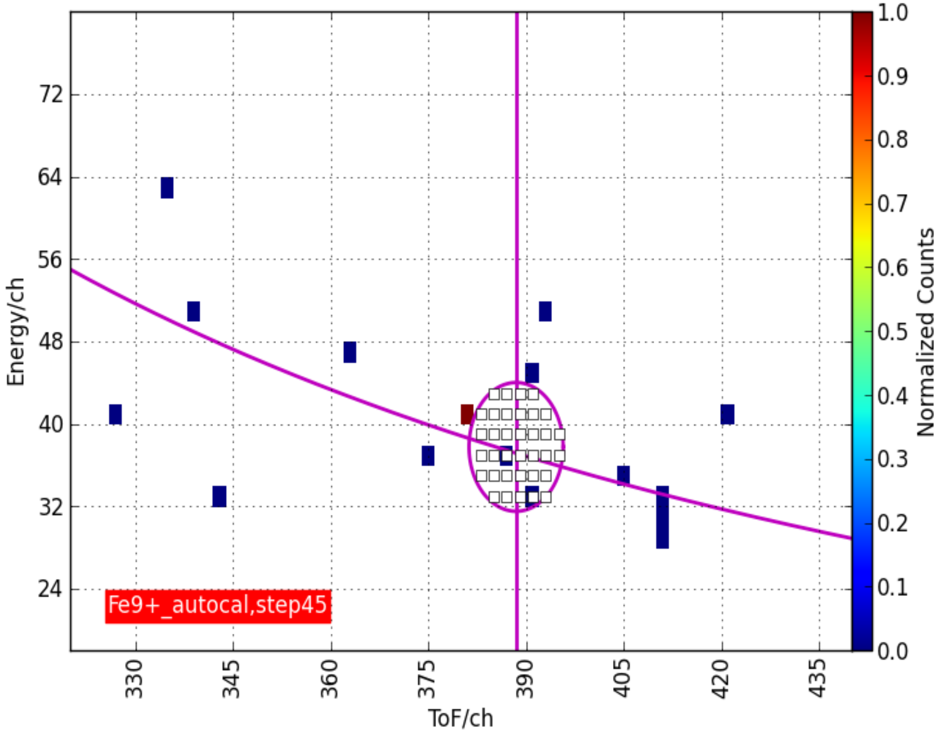
(DOY 213 1996, min 144-204)



E/q-step45 (=>v_Fe9+=419 km/s)

1h-data

(DOY 213 1996, min 149-154)



E/q-step45 (=>v_Fe9+=419 km/s),

5min-data

CTOF: 1h, 15min, 5min Velocity Distributions for Fe9+

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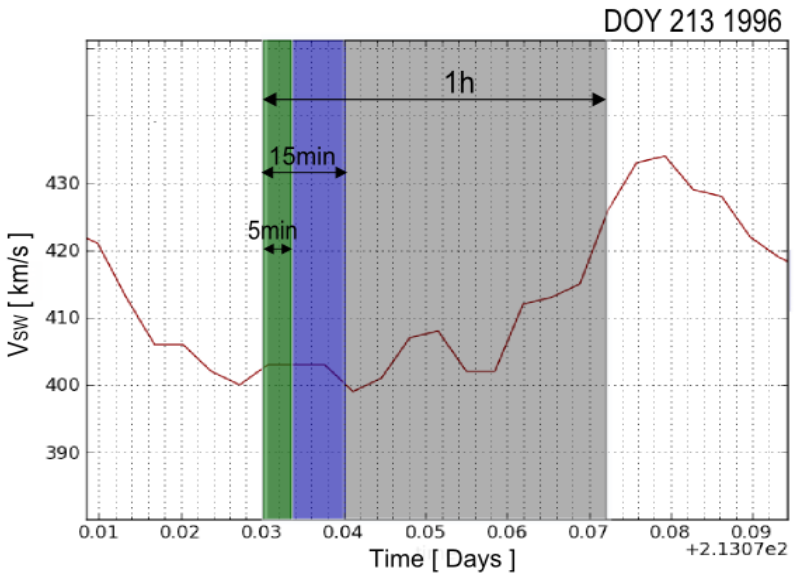

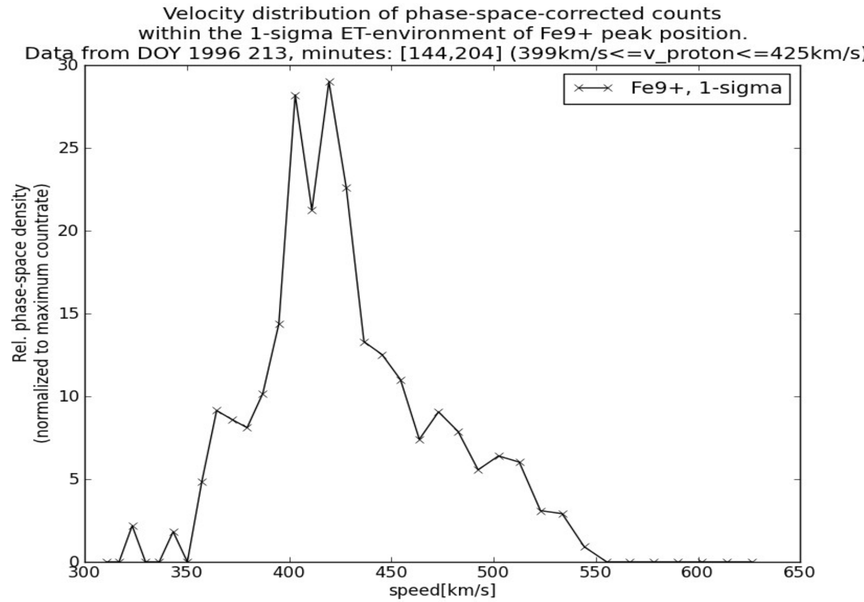

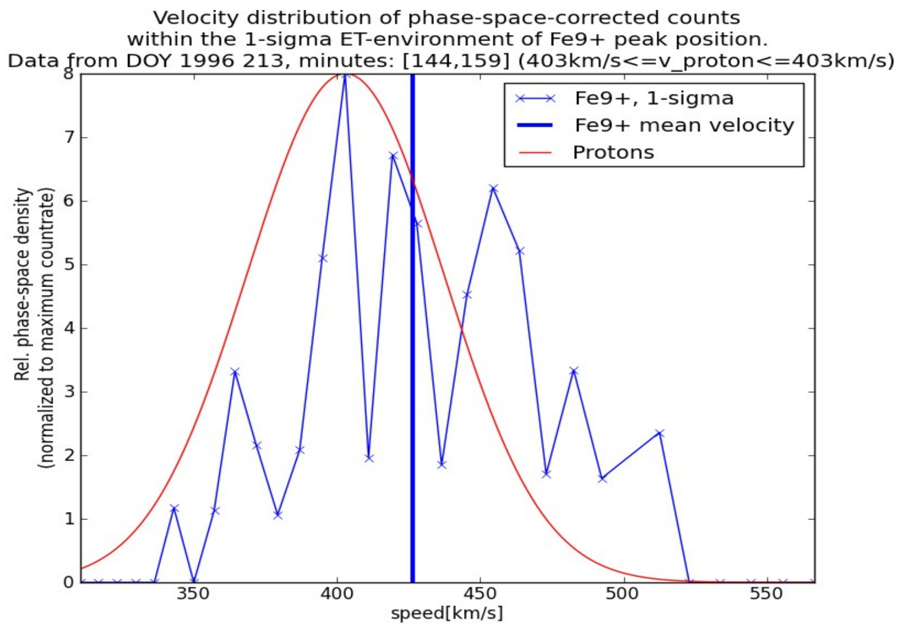

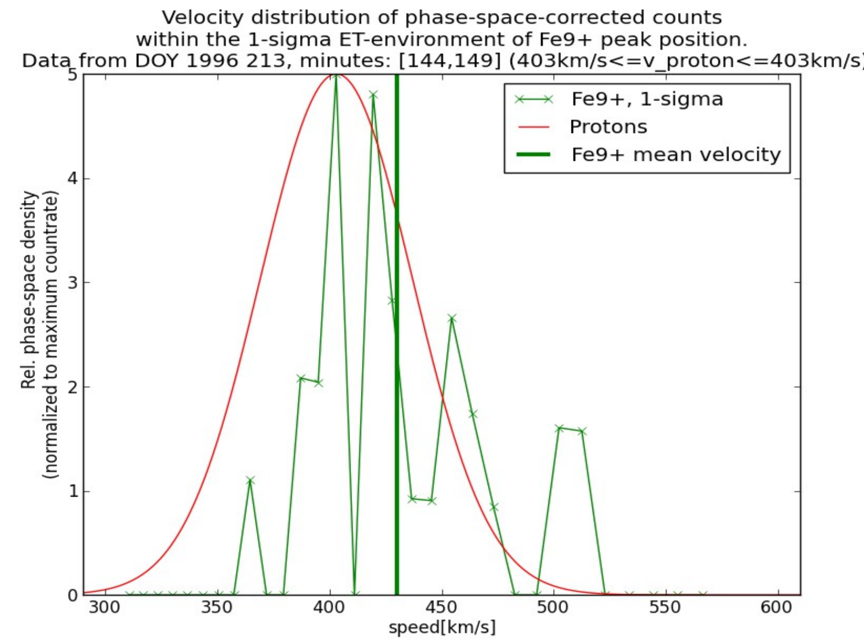

Results: 5-Minute Resolved Velocity Distributions for Oxygen and Iron Ions Derived from Box Rates

Differential Streaming Obtained from Box Rates

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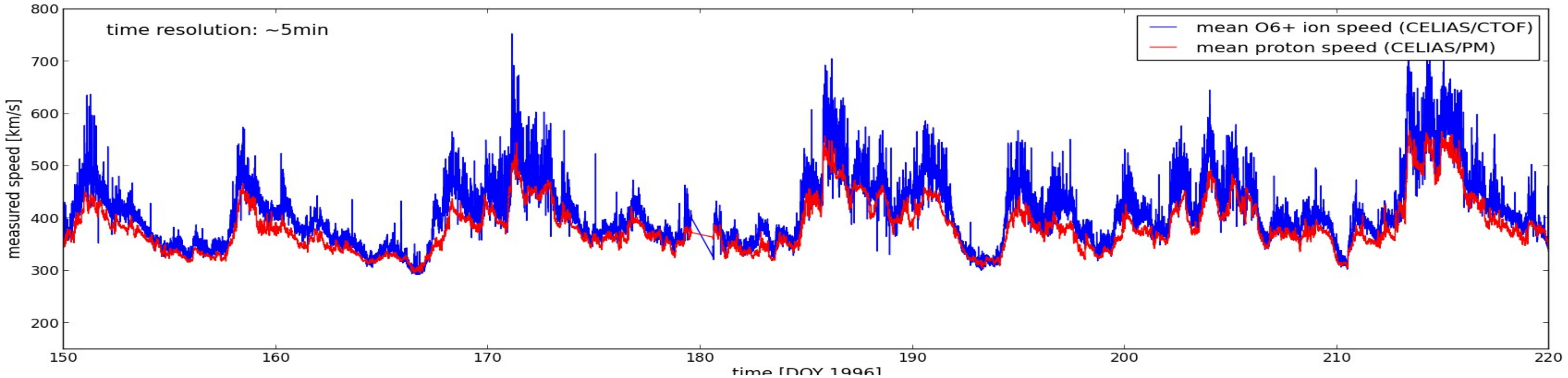
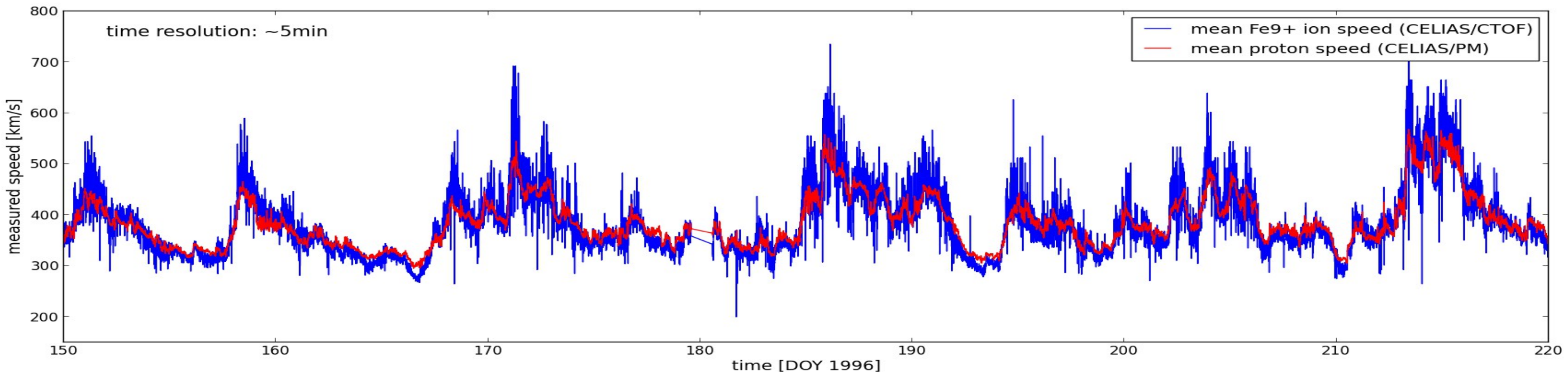
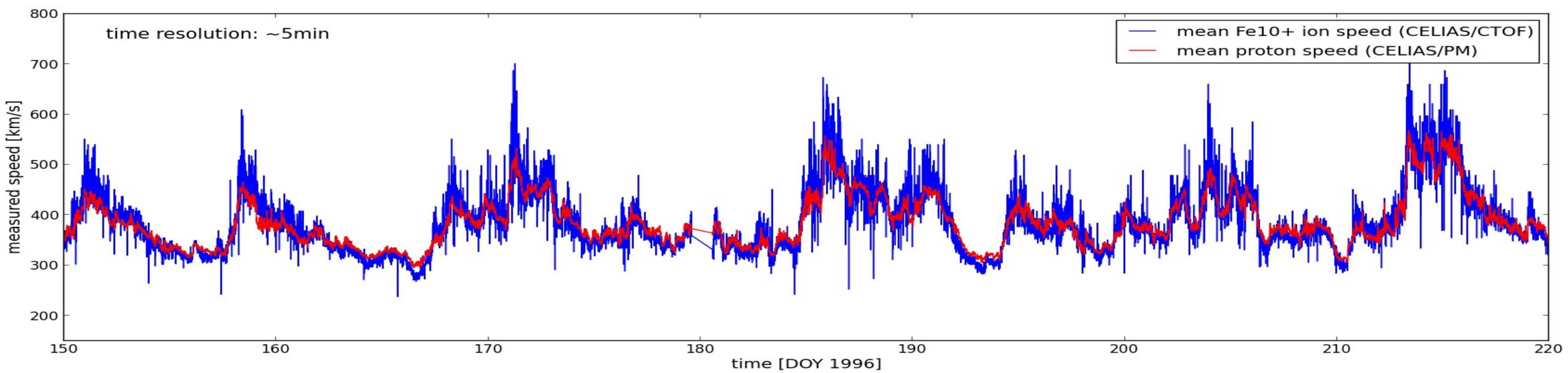
O6+



Fe9+



Fe10+



Differential Streaming Obtained from Box Rates

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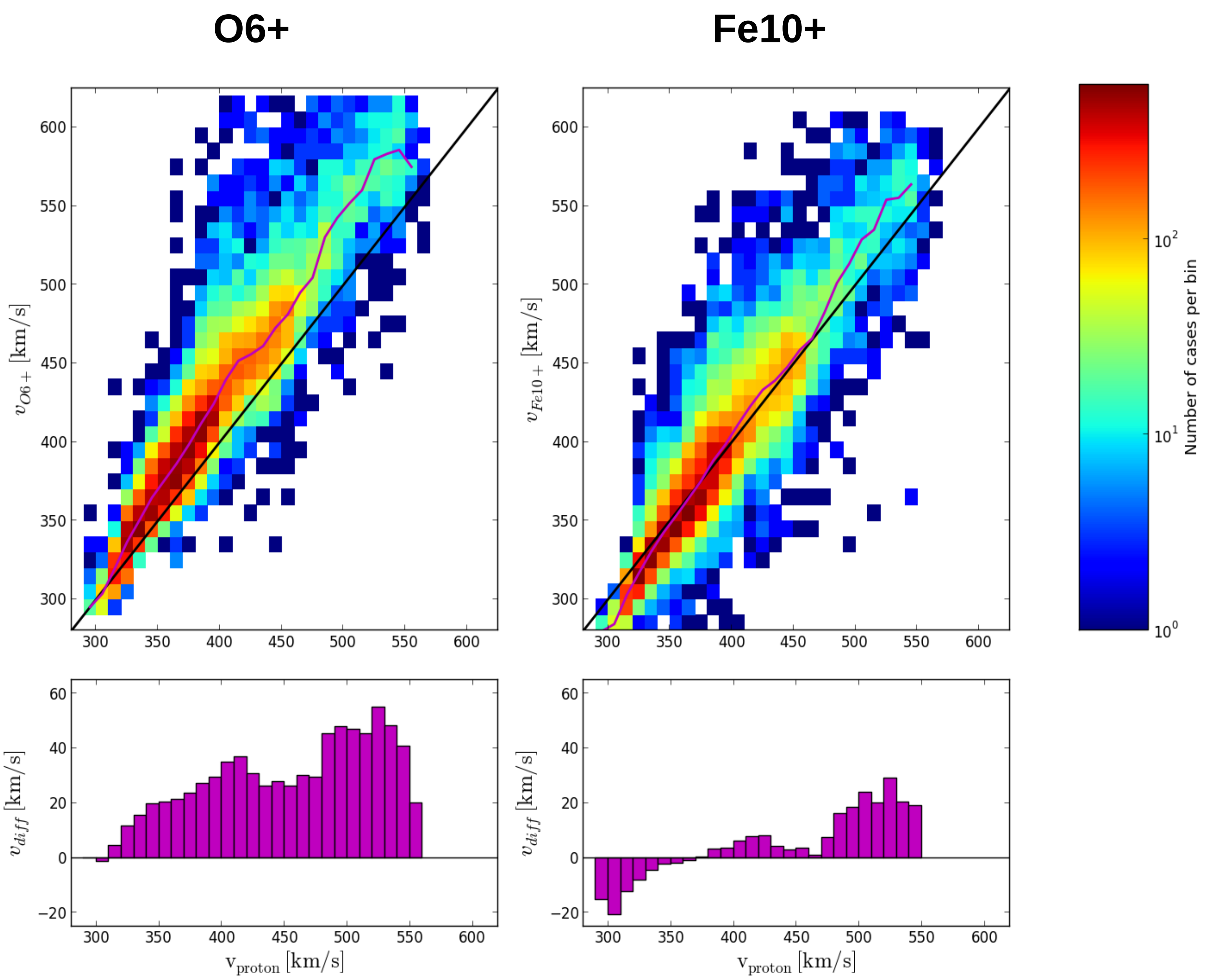
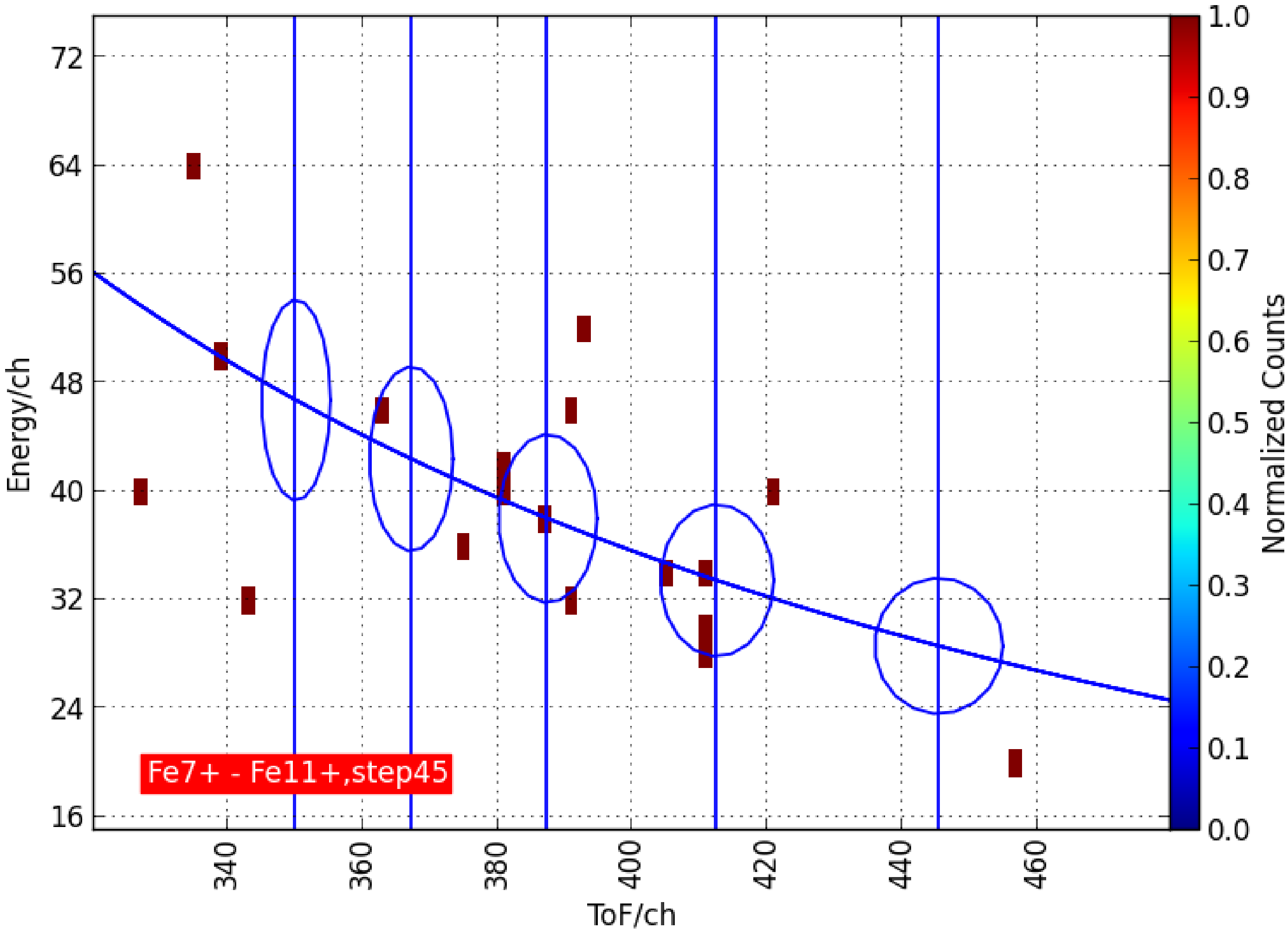
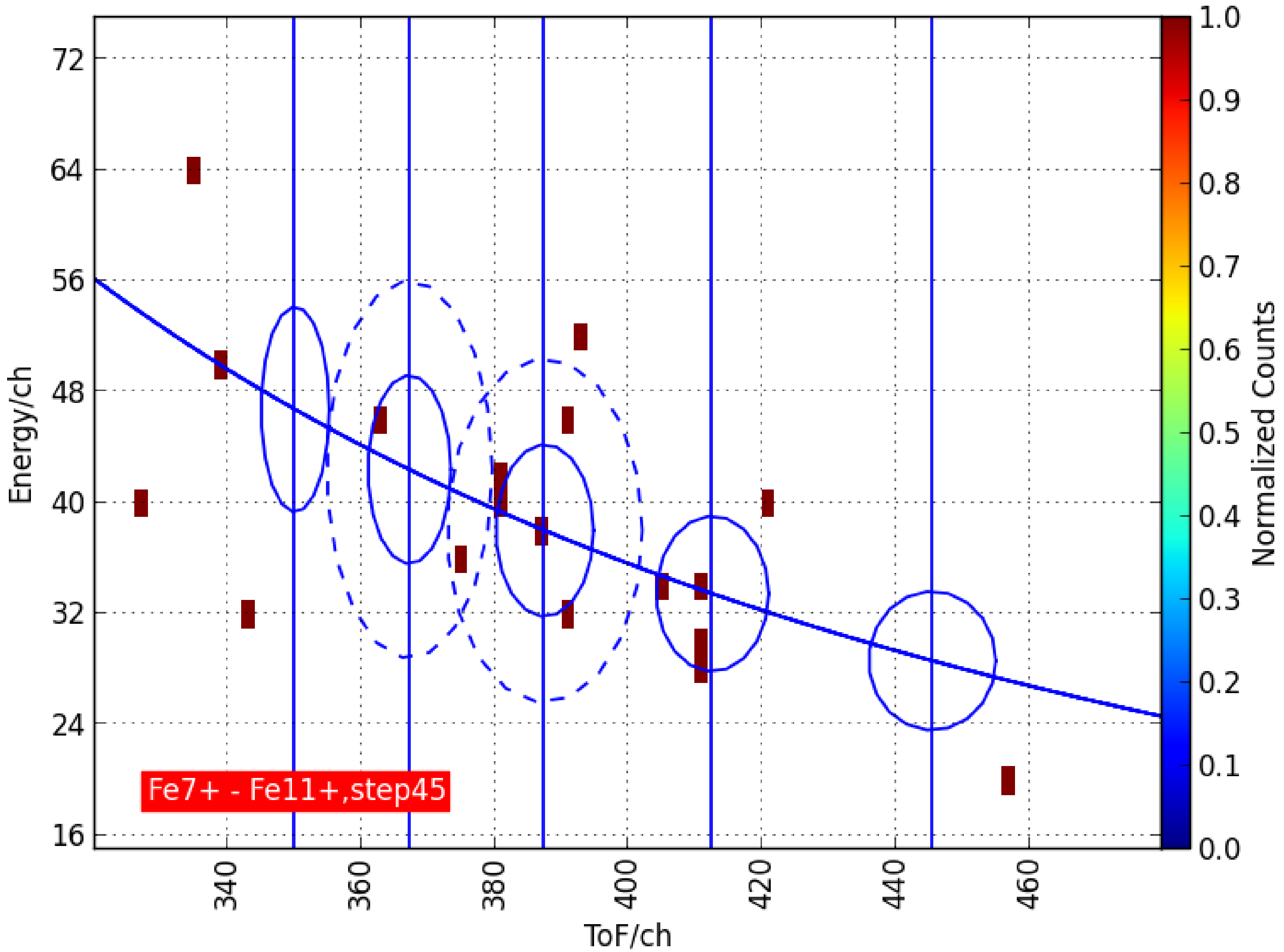


Assignment Problems with Box Rates



Assignment Problems with Box Rates



Assignment Problems with Box Rates

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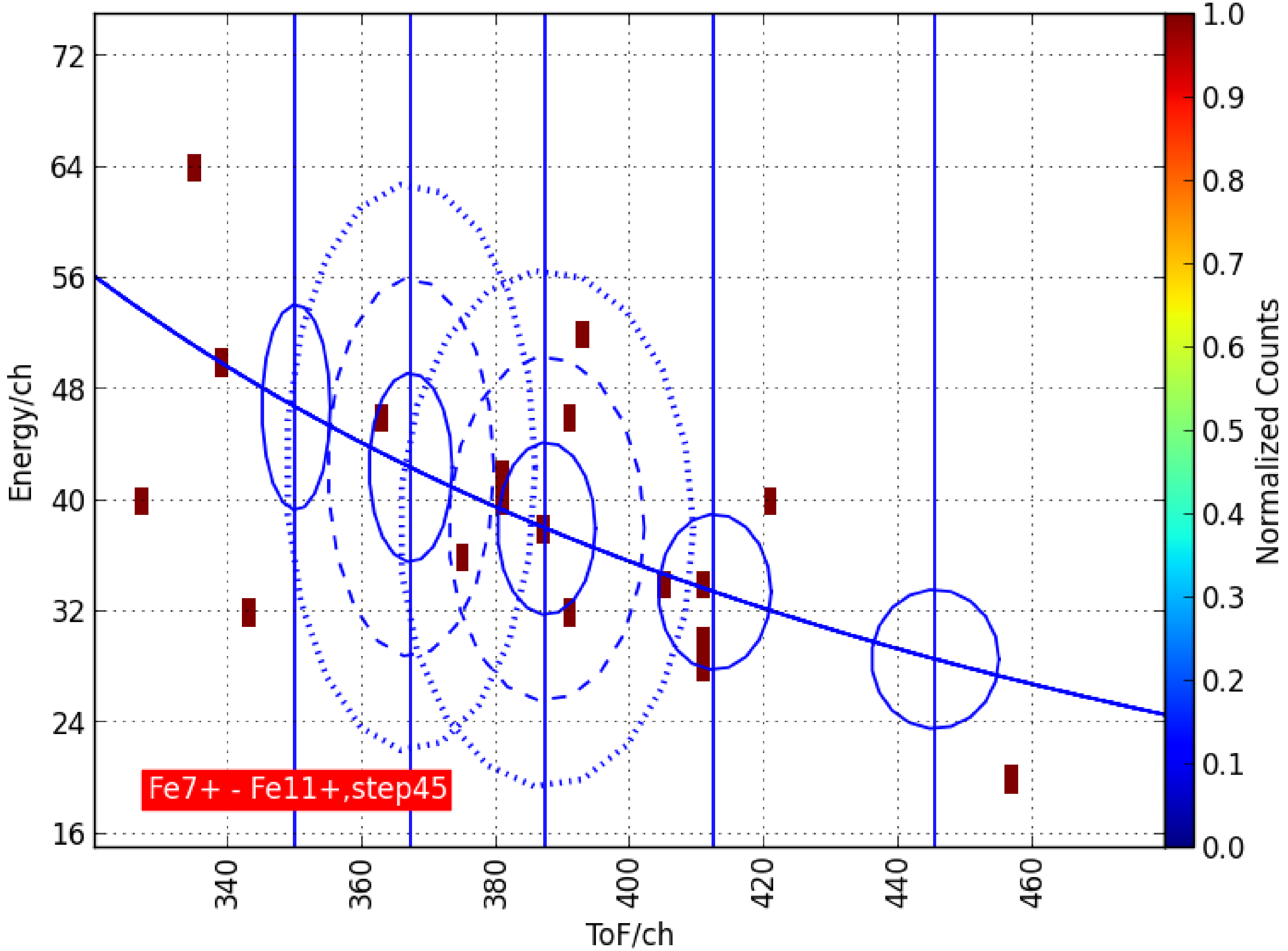
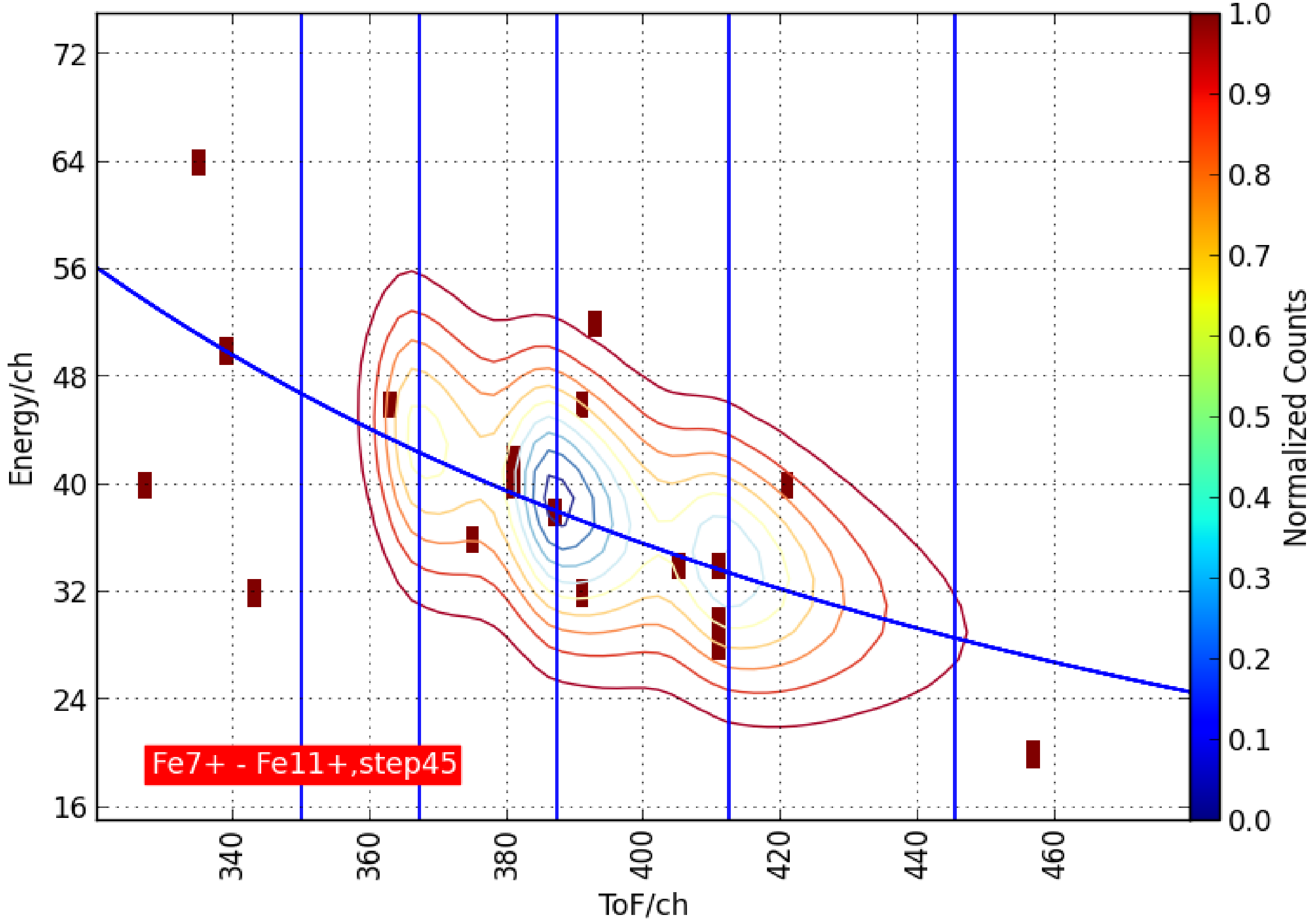


First Improvement: Distribution Fits



Only free prameters: distribution heights

First Improvement: Poisson Fits

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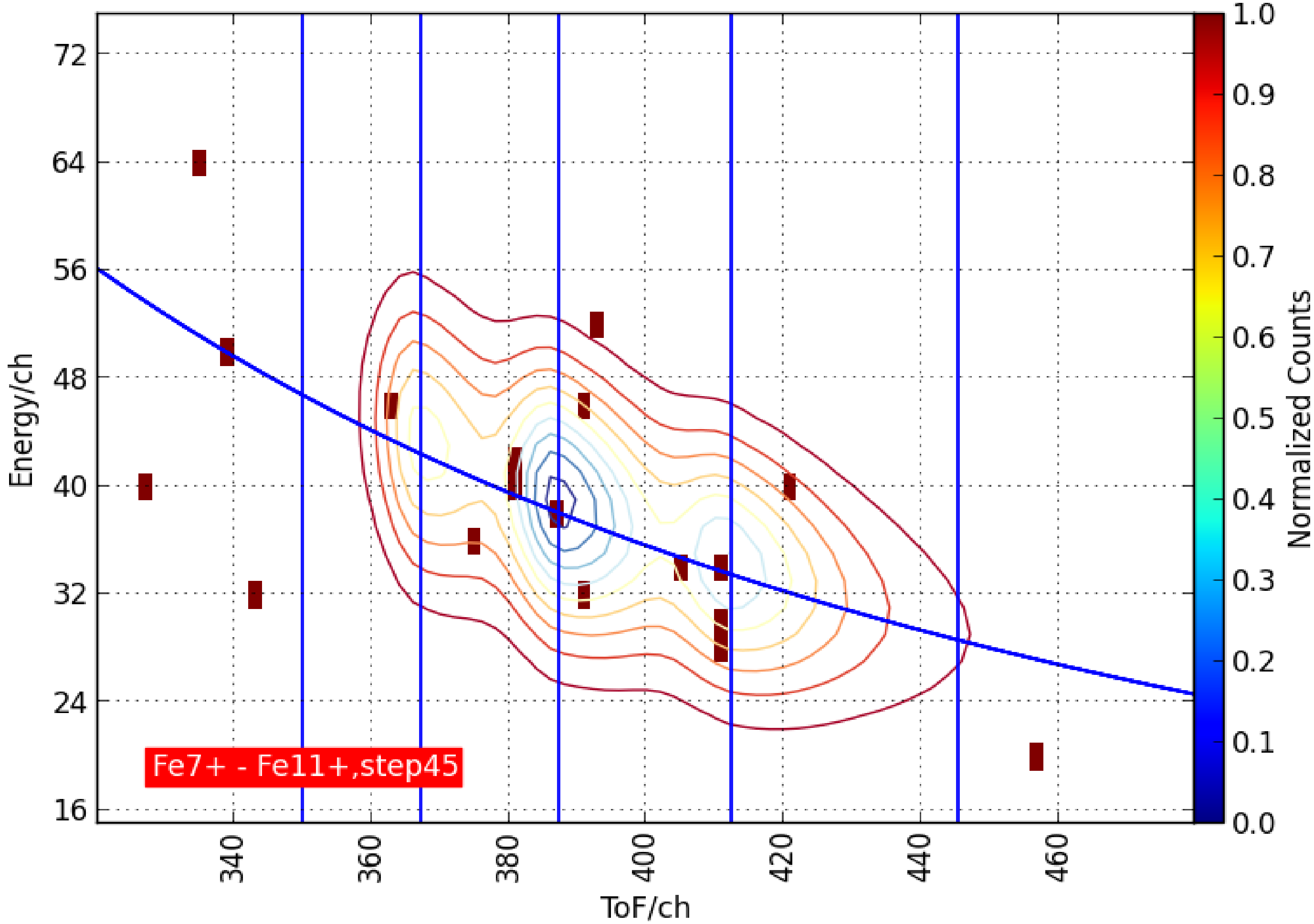

$$\chi_P^2 = \sum_{i=1}^{N} \left[2(f(x_i,\vec{\alpha}) - n_i) + (2n_i+1)log\left(\frac{2n_i+1}{2f(x_i,\vec{\alpha})+1}\right)\right]$$

Almeida Jr. and Barbi (2005)

Second Improvement: Asymmetric Ion distributions

C A U
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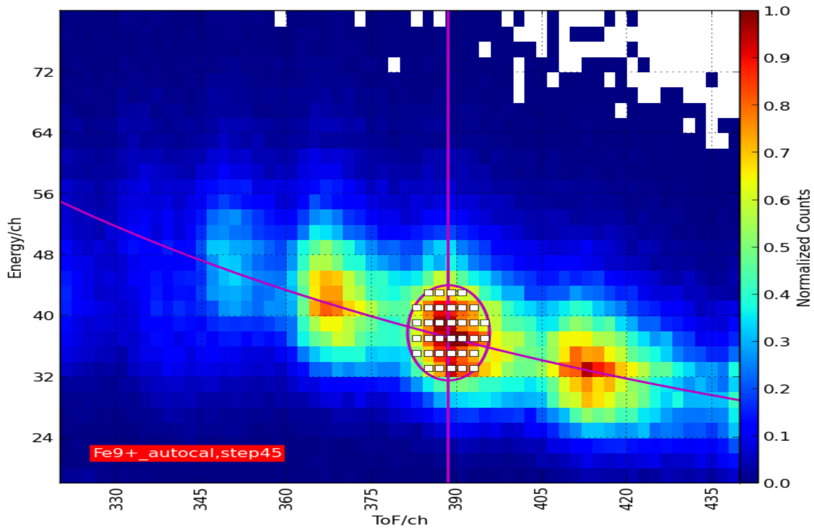
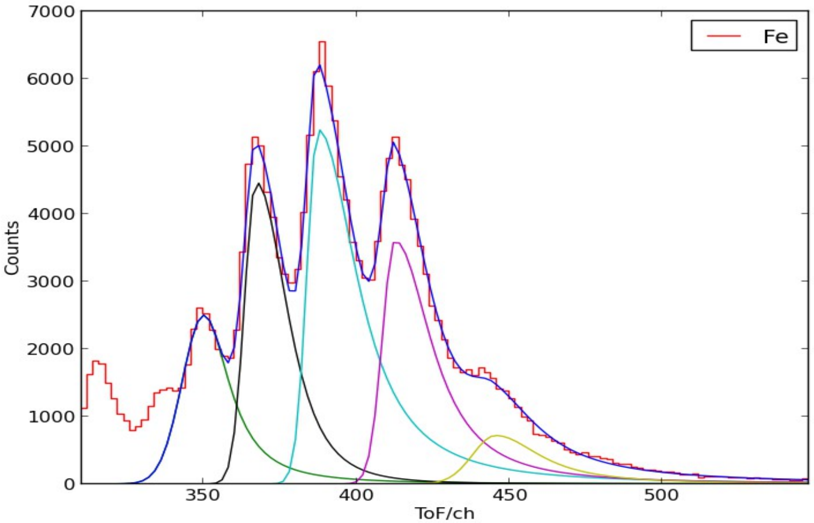
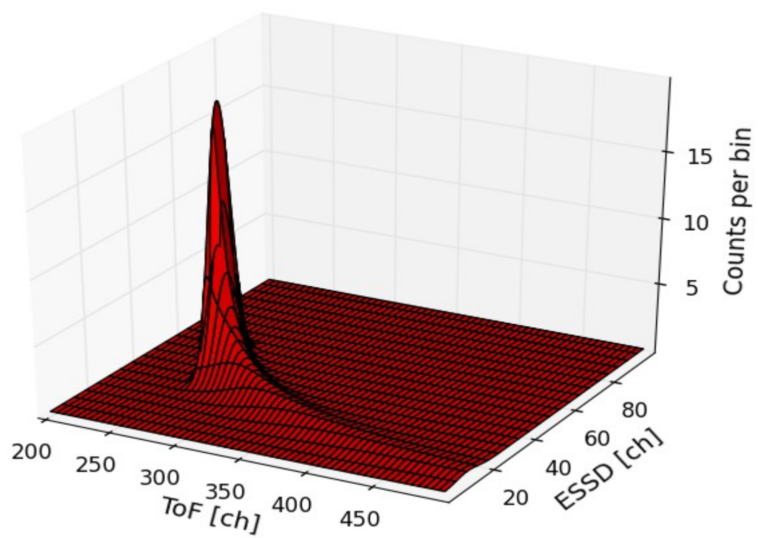
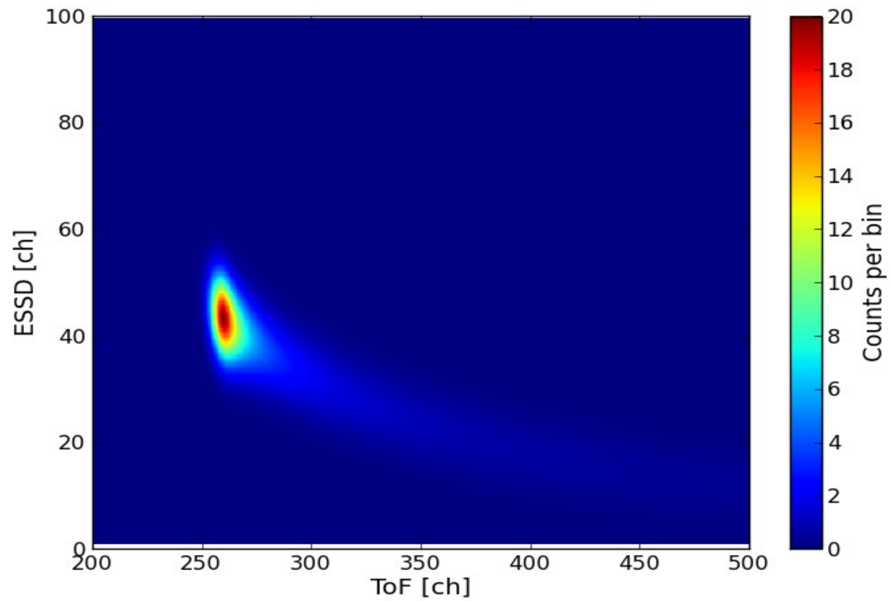
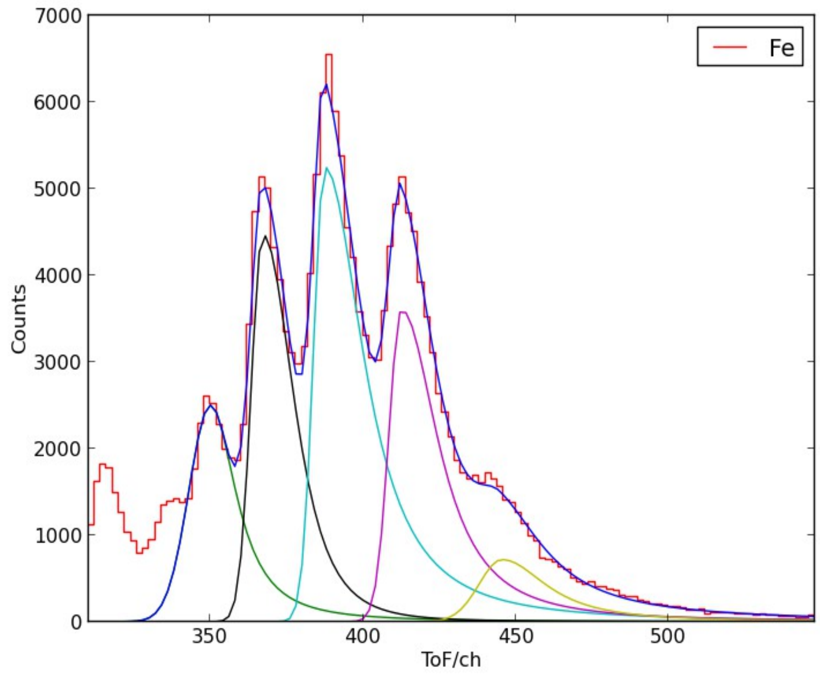
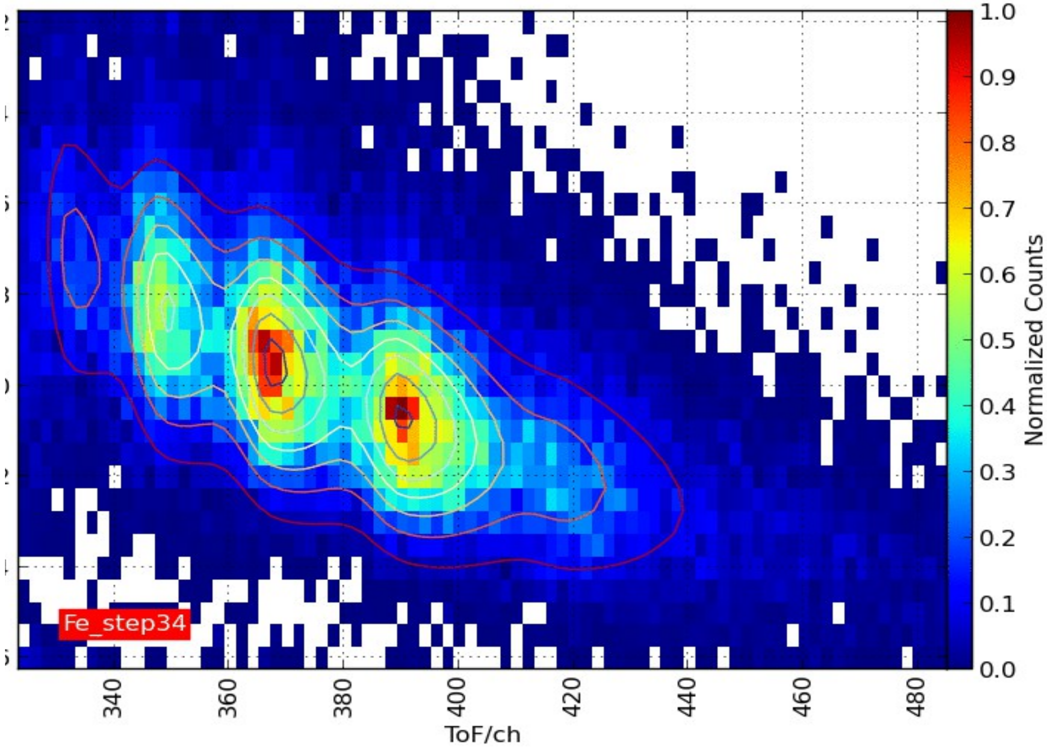








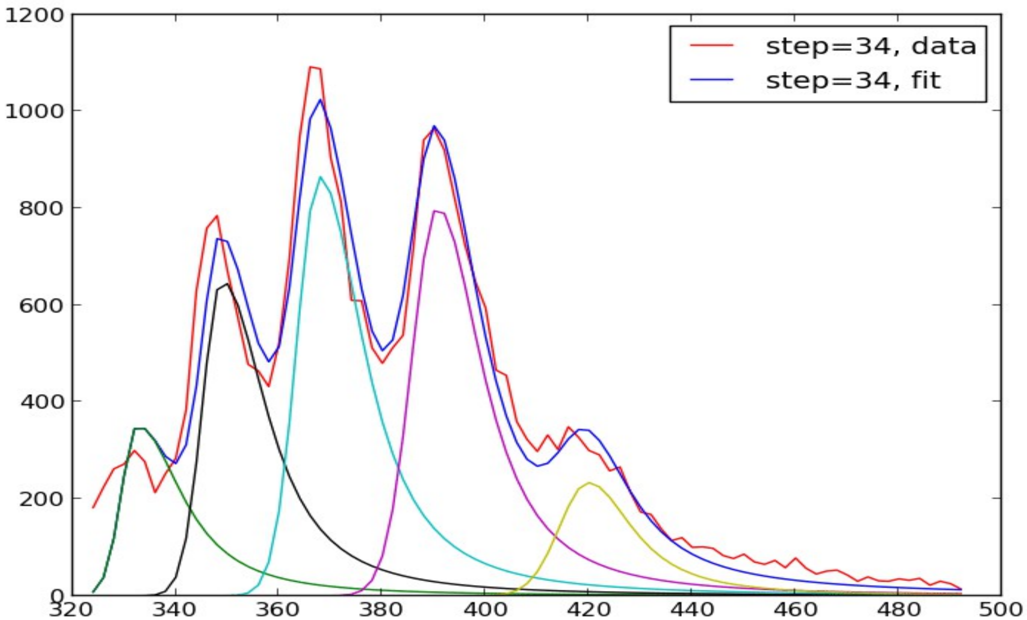




Fit parametrization:

Peakwidths tied to calibrated peak position.

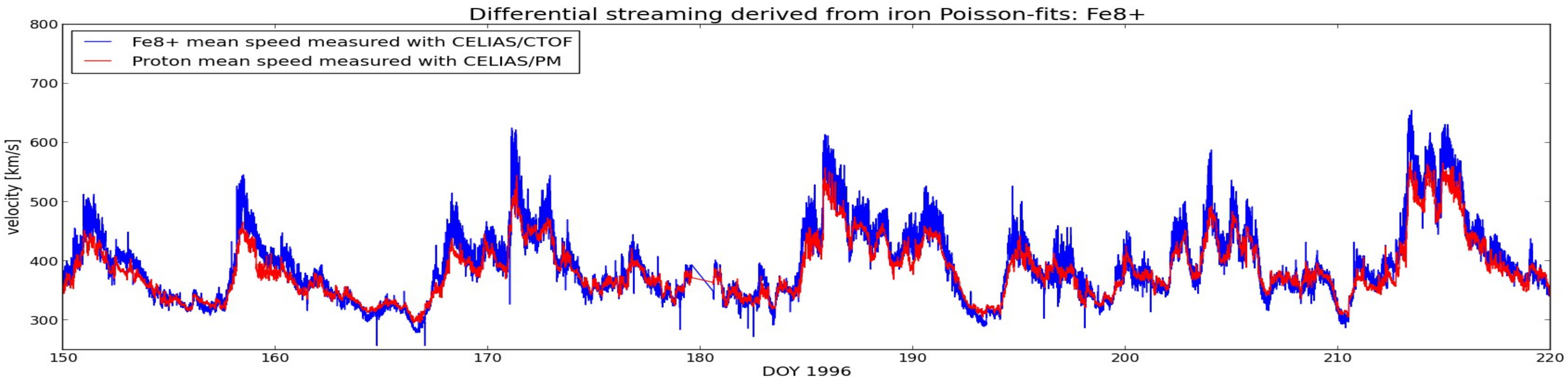
→ peak widths do not arbitrarily expand on each others cost



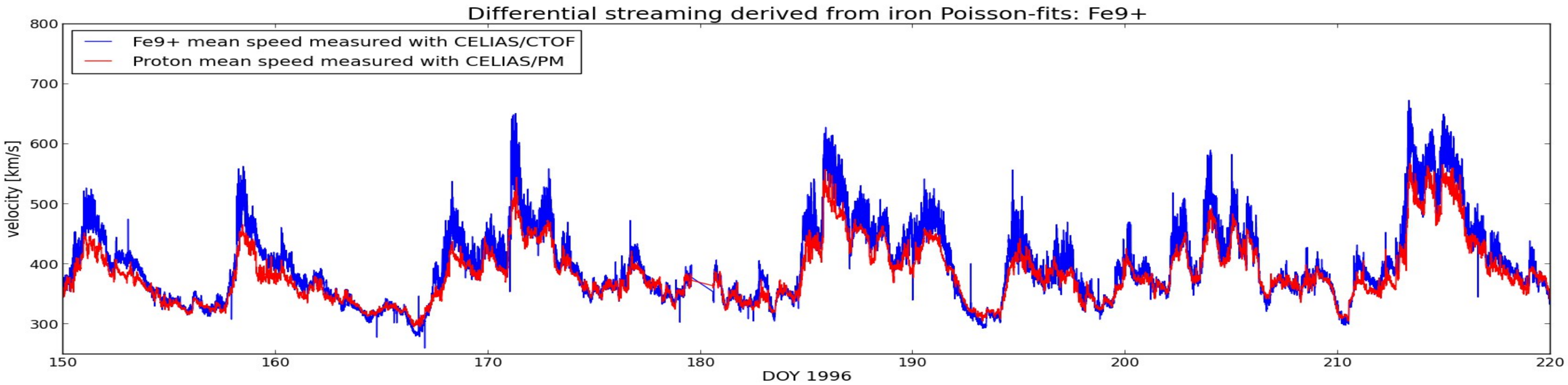
Final Results: 5-Minute Resolved Velocity Distributions for Oxygen and Iron Ions Derived from Poisson Fits

Results from Poisson Fits

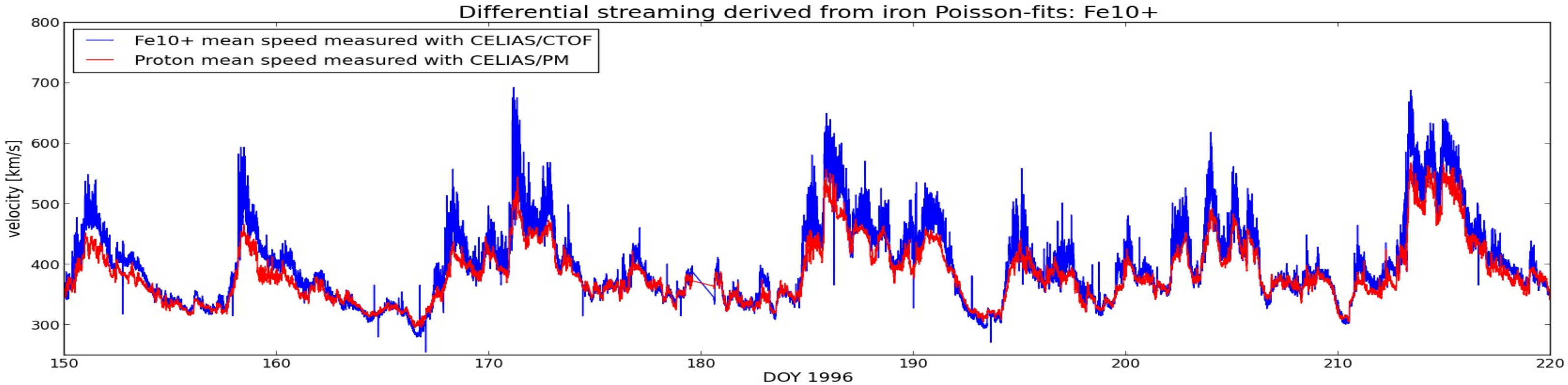
Fe8+

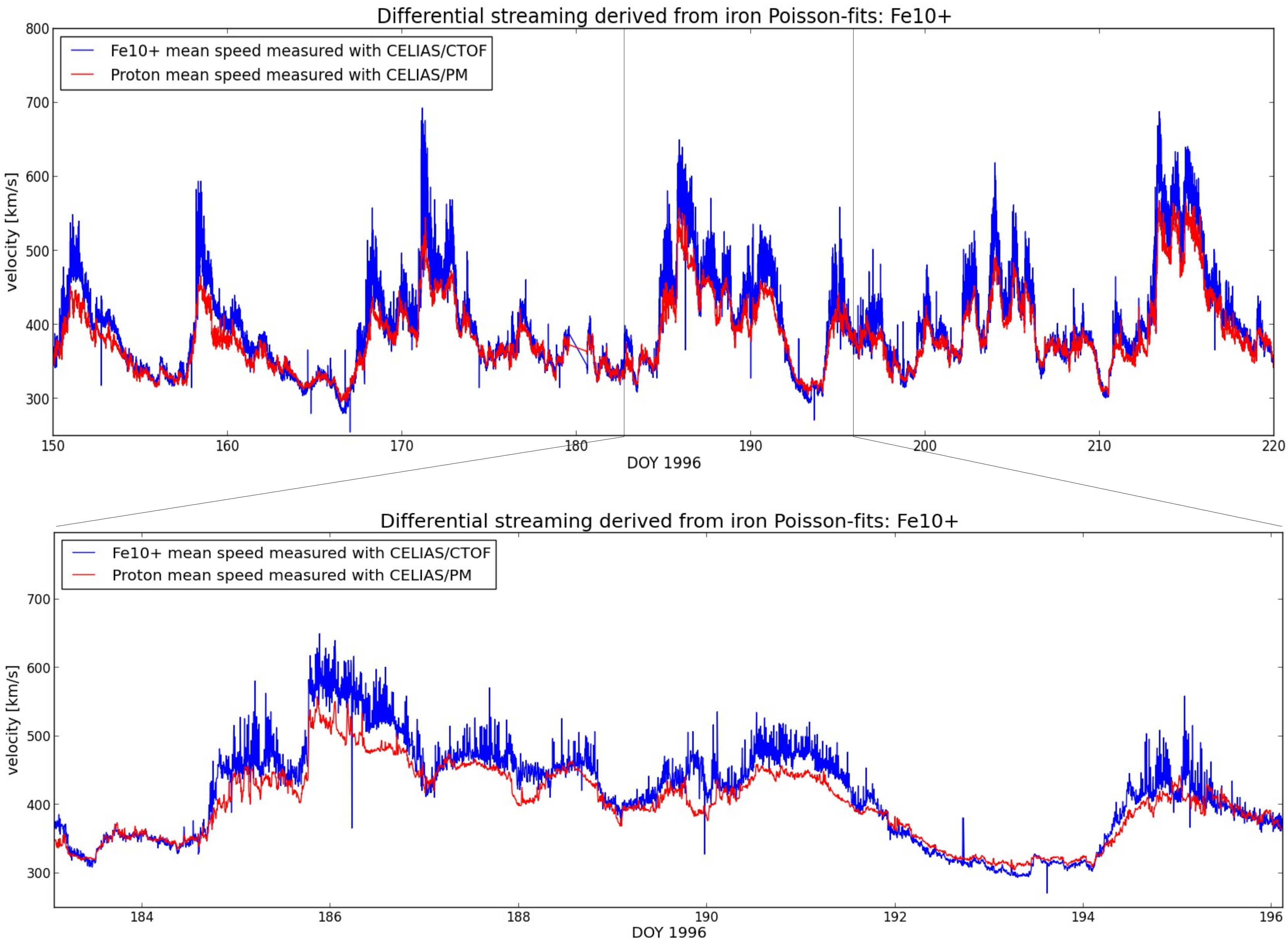


Fe9+



Fe10+





Differential streaming derived from iron Poisson-fits: Fe10+
Fe10+ mean speed measured with CELIAS/CTOF
Proton mean speed measured with CELIAS/PM
velocity [km/s]
800
700
600
500
400
300
150
160
170
180
190
200
210
220
DOY 1996
Differential streaming derived from iron Poisson-fits: Fe10+
Fe10+ mean speed measured with CELIAS/CTOF
Proton mean speed measured with CELIAS/PM
velocity [km/s]
700
600
500
400
300
184
186
188
190
192
194
196
DOY 1996

Results from Poisson Fits

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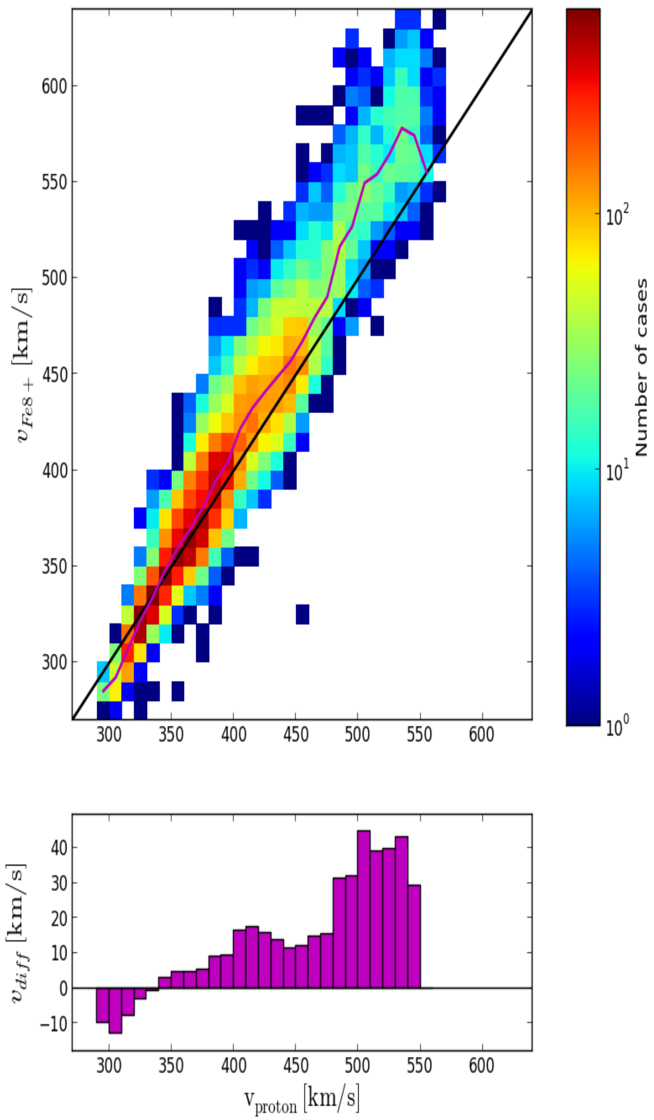
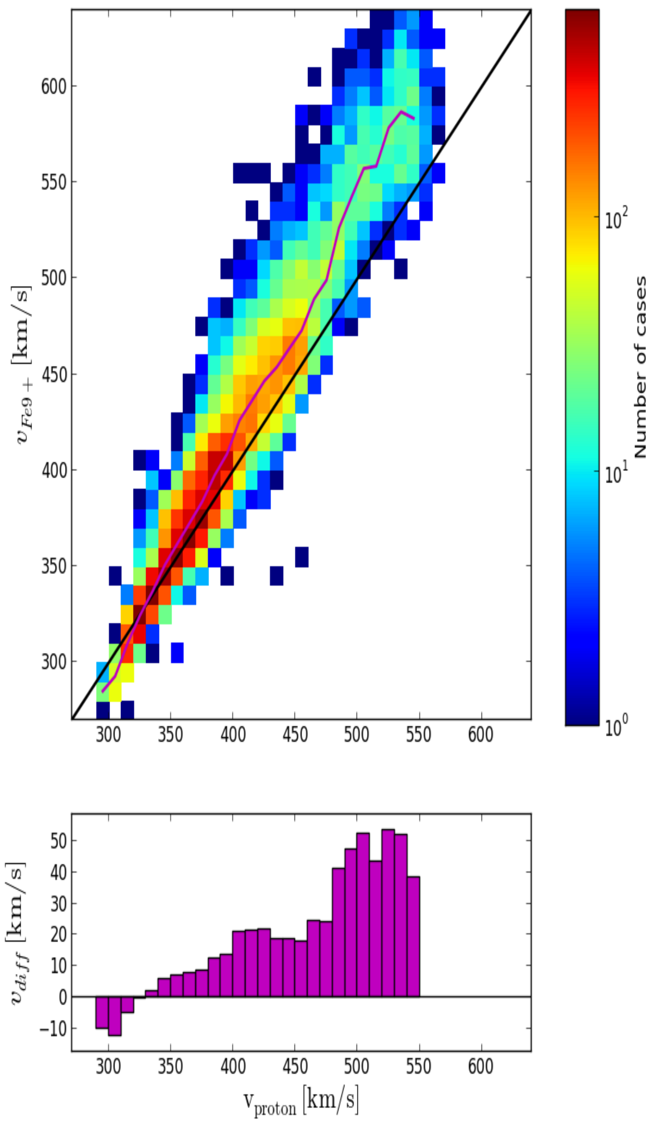
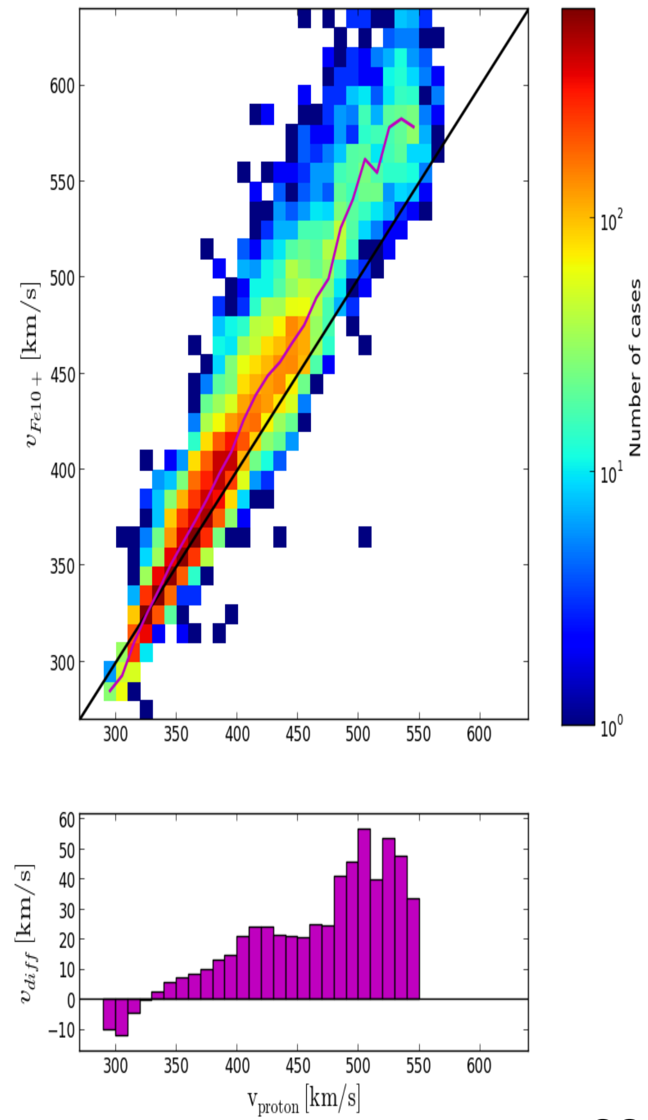
Fe8+



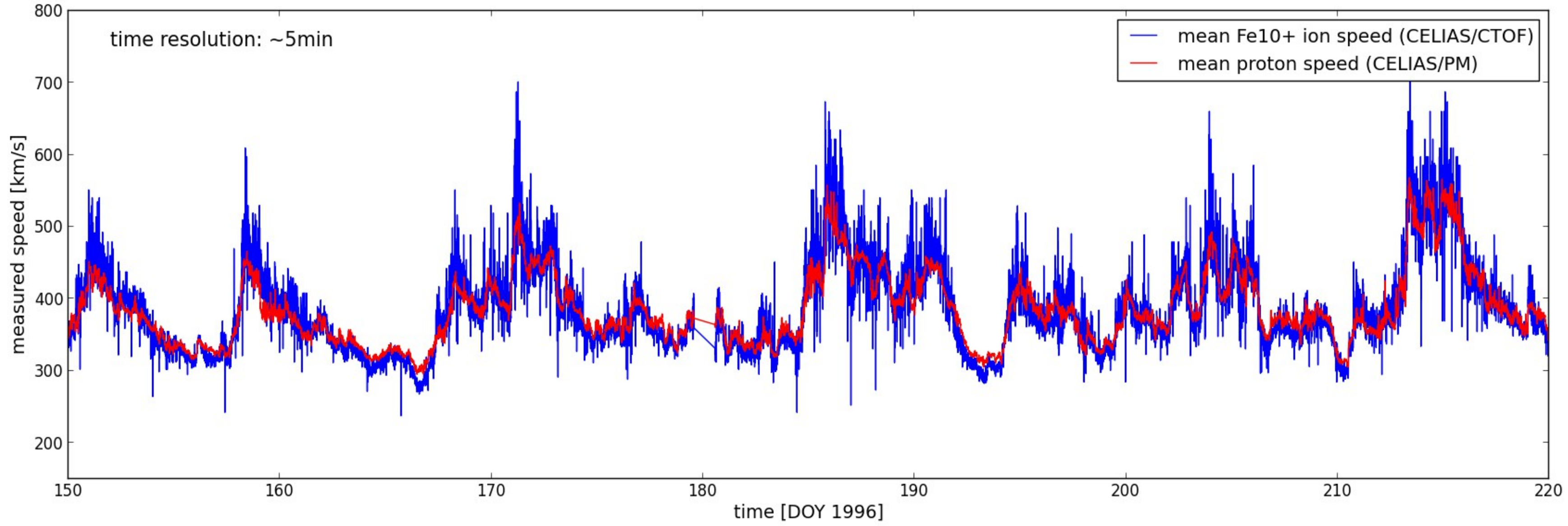
Fe9+

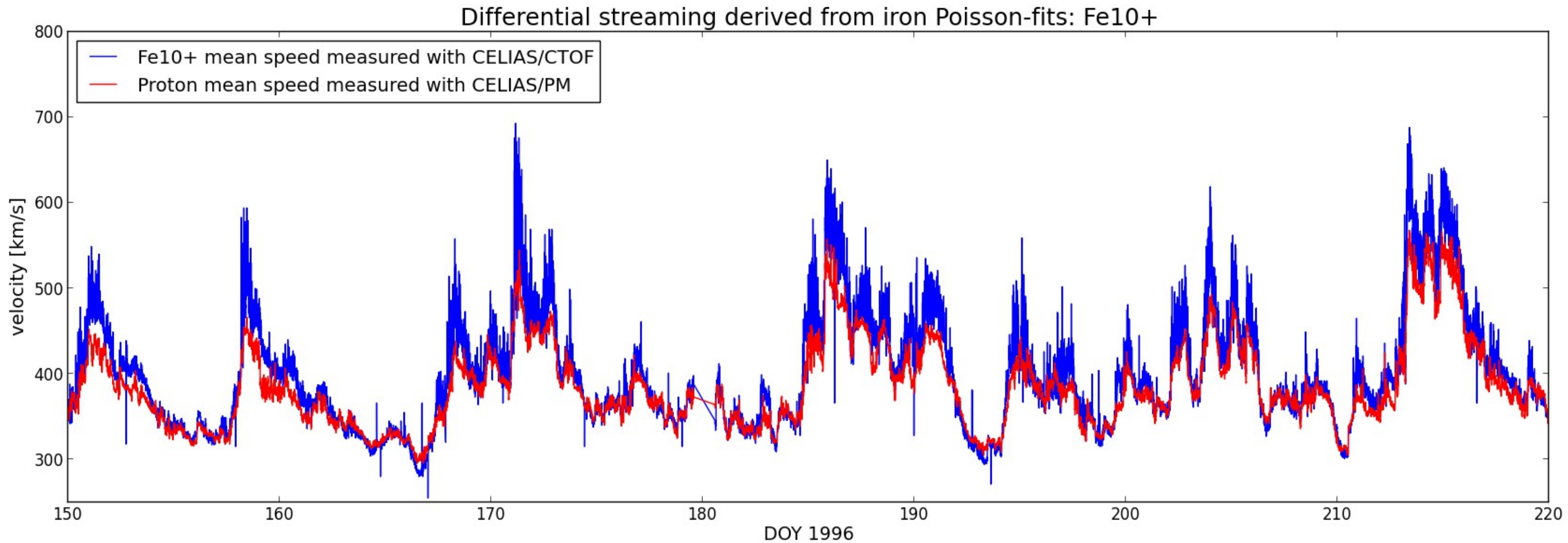


Fe10+

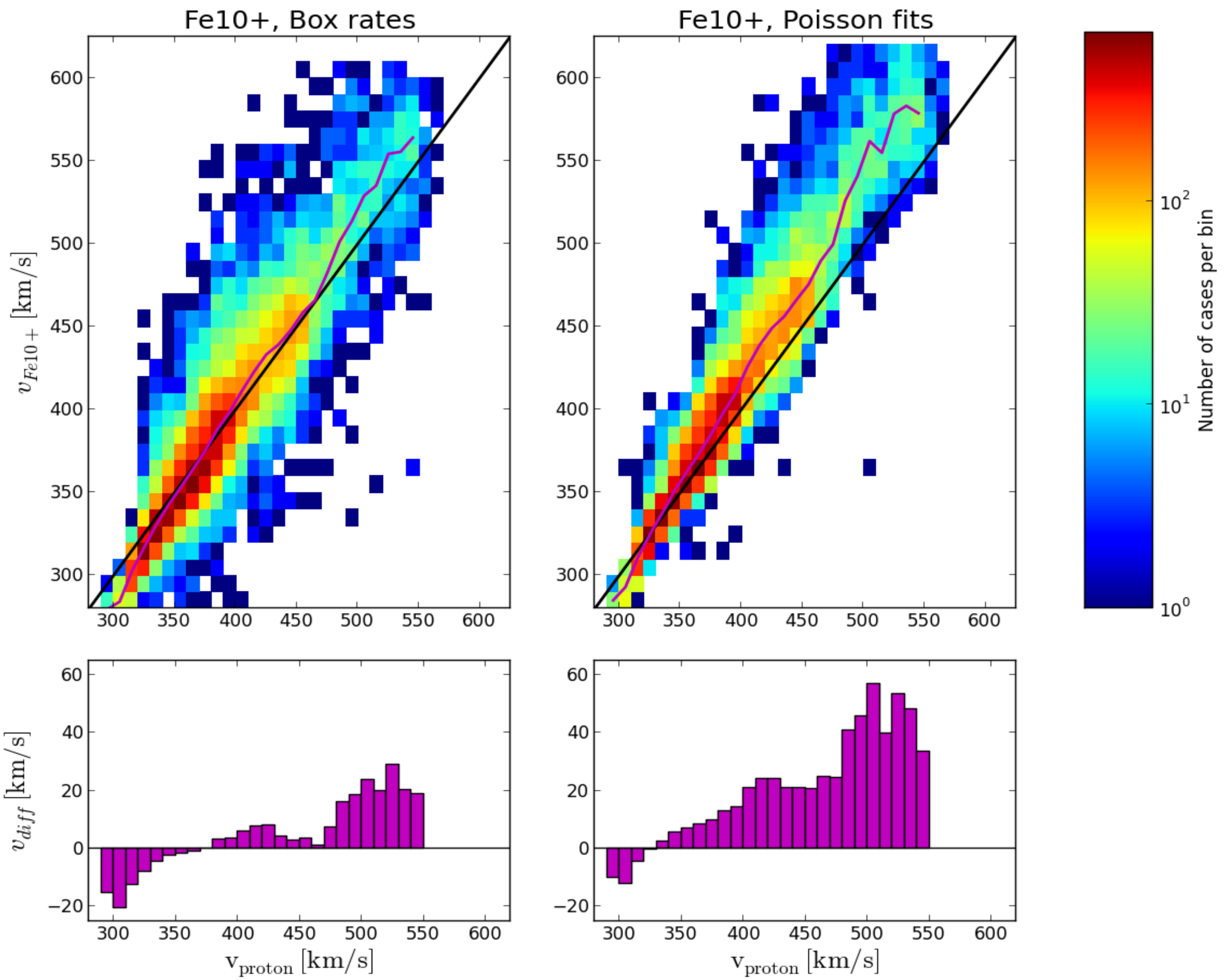


Box Rates vs Poisson Fits





Box Rates vs Poisson Fits



Summary

- Performed in-flight calibration with long-time data. The calibration is able to predict the ion's positions in the ET-matrix.

- 5-minute resolved velocity spectra derived from boxrates show significant differential streaming for O6+ but much lower differential streaming for iron ions Fe9+, Fe10+. At low proton velocities even a slight negative differential streaming is observed.

- 5-minute resolved velocity spectra derived from Poisson fits show significant differential streaming also for iron ions Fe8+, Fe9+, Fe10+.

  The negative differential streaming at low proton velocities has been reduced, but did not vanish completely.

Outlook

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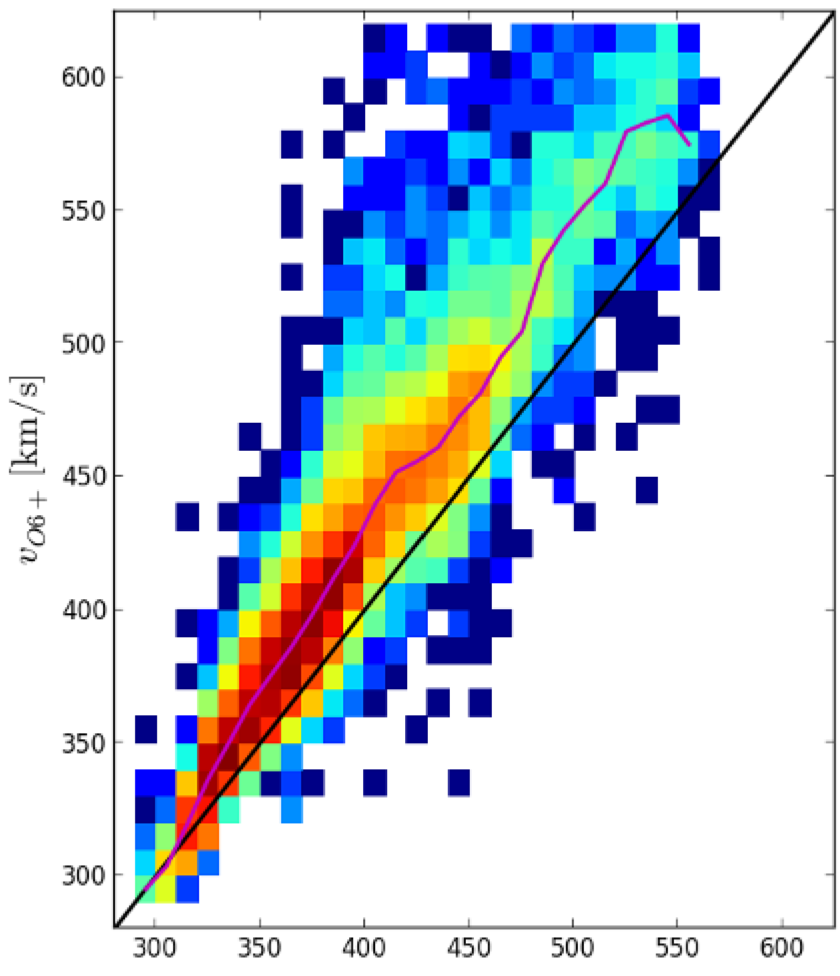
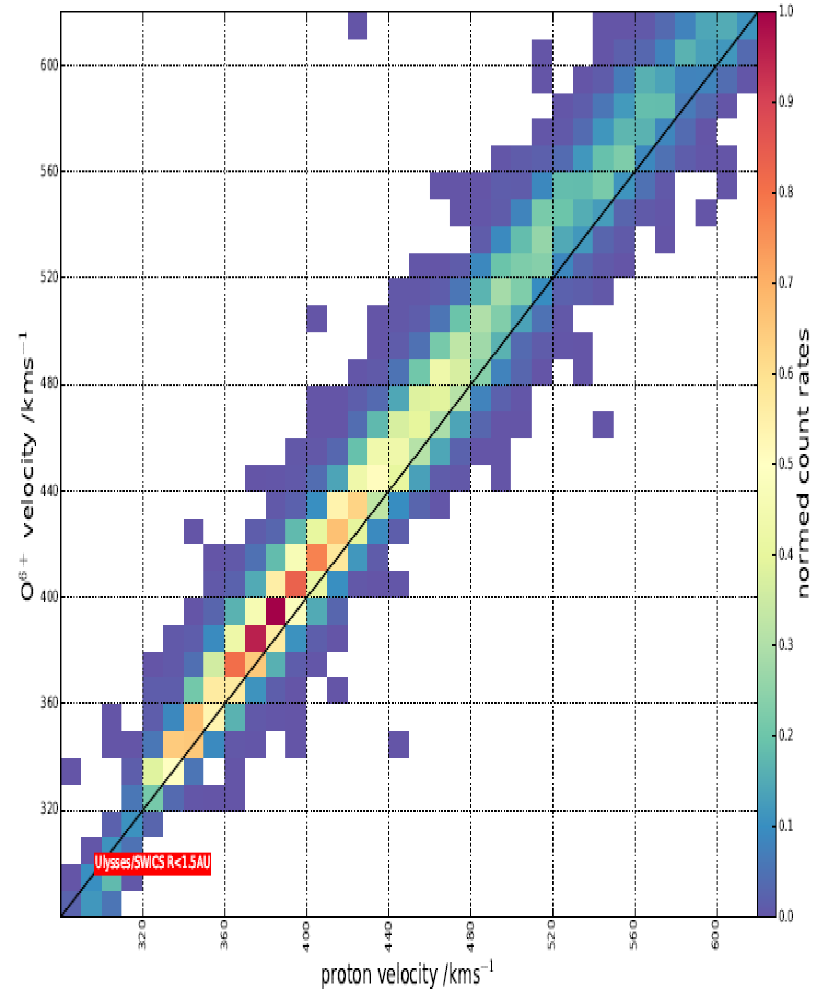
- Application of the Poisson fit method to further ions (e.g. C, Si, Ne ions etc.)
  → uniform fit of the complete ET-matrix

- Estimation of the count rate errors via a Monte Carlo bootstrap procedure
  → Error propagation to the obtained differential streaming

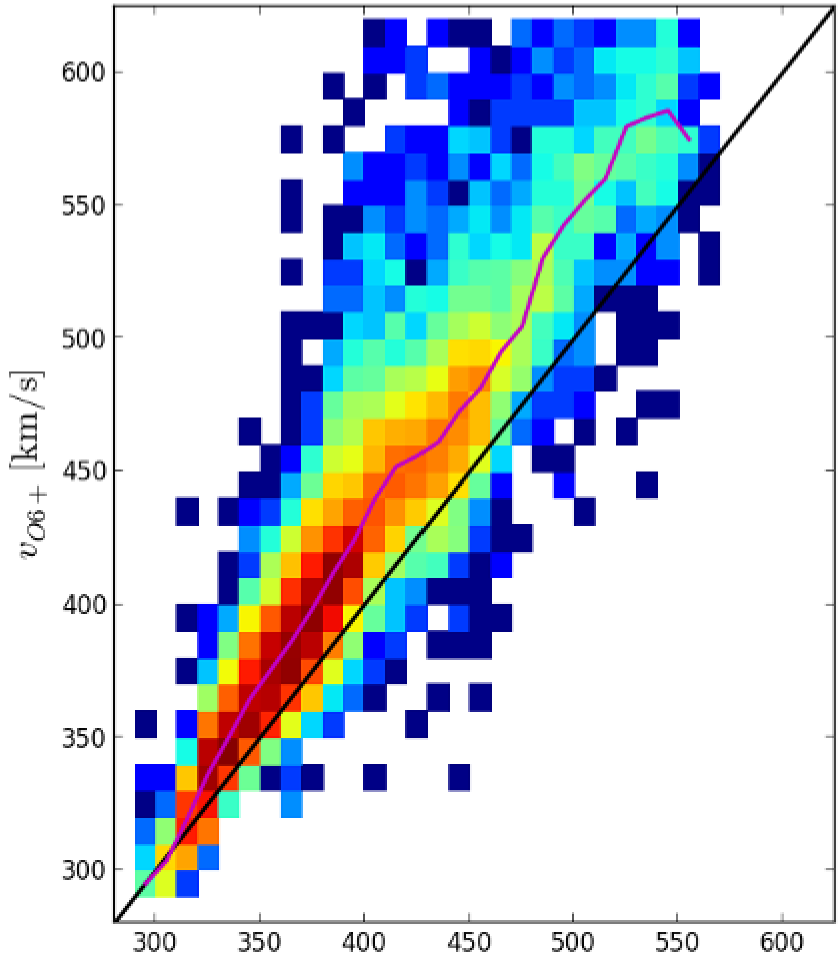
Backup slides



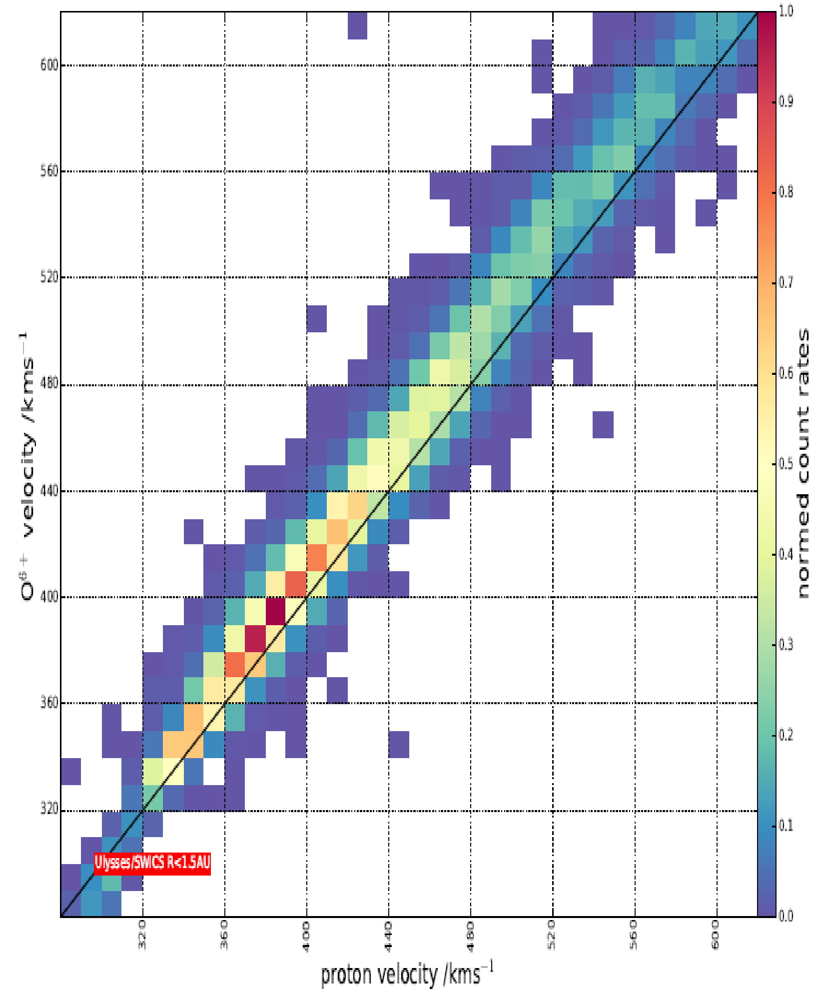
CTOF



Ulysses / SWICS



CTOF



Ulysses / SWICS <1.5 AU