

NEOCLASSICAL COLLISION PHYSICS REGULARIZATION OF 4D FAST-ION DISTRIBUTION RECONSTRUCTIONS IN CONSTANTS OF MOTION SPACE

O. Hyvärinen^{*1}, G. Venezia², M. Rud³, H. Järleblad², A. Snicker⁴, J. Eriksson⁵, M. Nocente⁶, B.C.G. Reman⁷, A. Valentini², D. Moseev⁸, S. Siltanen¹, and M. Salewski²

University of Helsinki¹, Technical University of Denmark², École Polytechnique Fédérale de Lausanne³, VTT Technical Research Center of Finland⁴, Uppsala University⁵, University of Milano-Bicocca⁶, Royal Military Academy⁷, Max-Planck-Institut für Plasmaphysik⁸

^{*} corresponding author, email: otso.hyvarinen@helsinki.fi

Introduction

The reconstruction of 4D(R, z, E, p) fast-ion distribution function is a sparse problem in which the experimental data must be augmented by prior information for physically significant results.

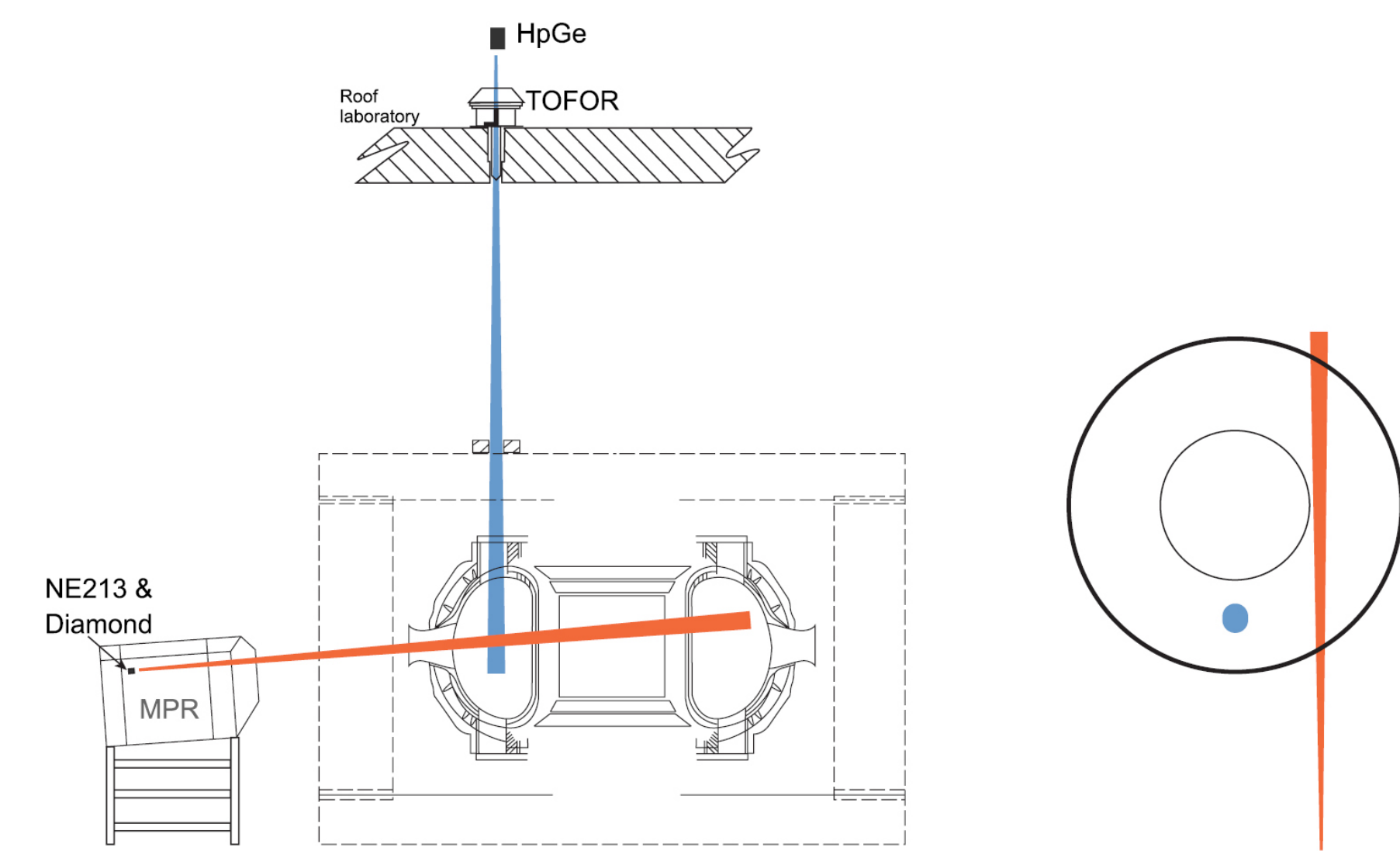


Fig. 1: Fast ion diagnostic view in JET-tokamak.[1]

Orbit following codes, like ASCOT[2,3], can be used to encode collisional physics into these reconstruction problems by solving them in a basis of slowing down distributions[4]. In this work JET DT shot #99971 is investigated with simulated data.

Reconstruction problem

Let fast-ion distribution function, f , be mapped to diagnostic measurements, m , by $m = Af + \epsilon$, where A is the forward operator, and ϵ is noise. We can solve for f in a set of basis functions, given the following optimization problem:

$$\begin{cases} \lambda' = \arg \min_{\lambda} \{ \|A\Psi\lambda - m\|_2^2 + \alpha_0 \|\mathbf{I}\lambda\|_2^2 + \alpha_1 \|\mathbf{L}_1\lambda\|_2^2 \} \\ f' = \Psi\lambda', \end{cases} \quad (1)$$

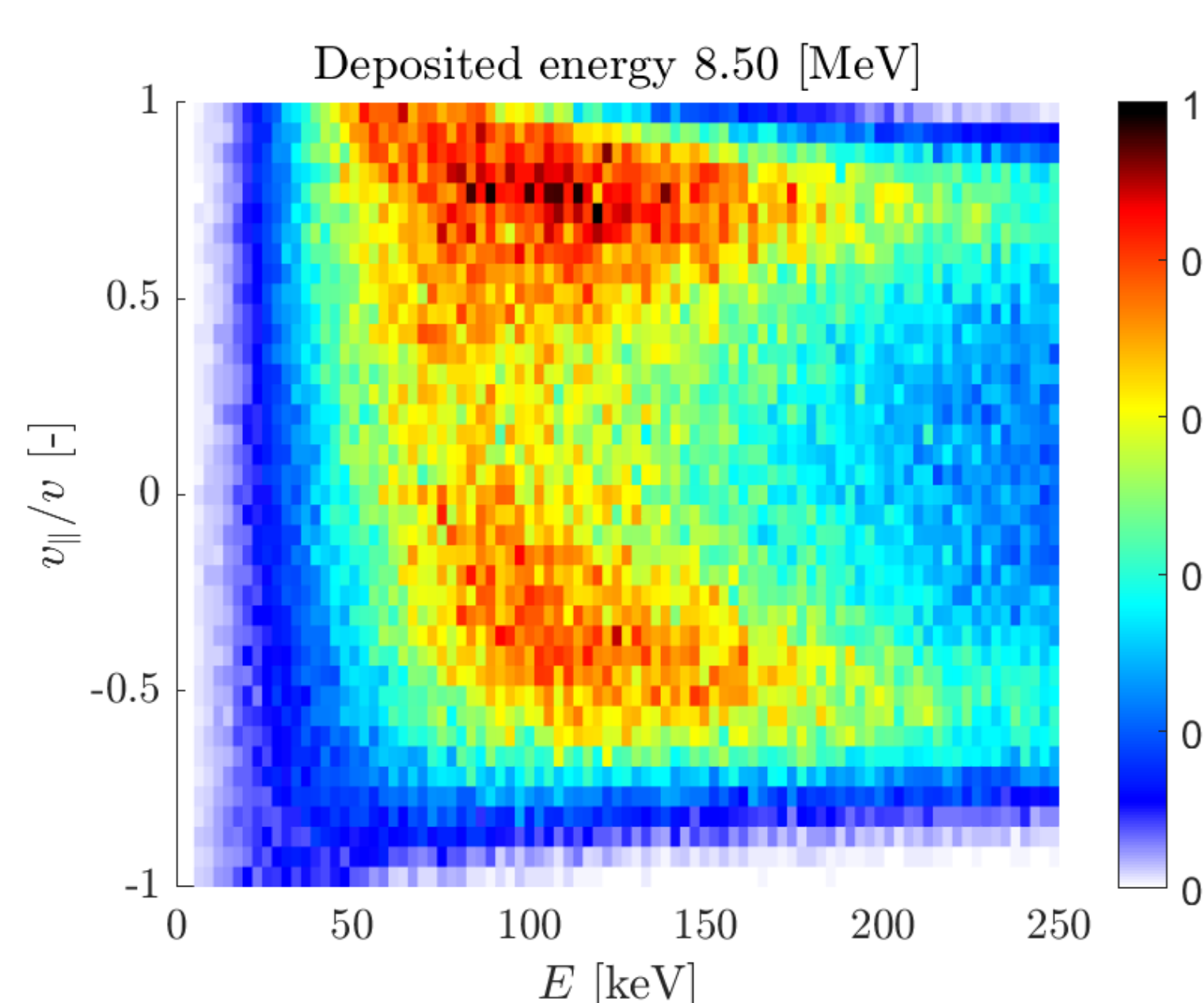


Fig. 2: Sensitivity of KM15 diagnostic in velocity space at point (2.99, 0.3) in (R, z), instrumental response included. Calculated with OWCF code [5].

Construction of the basis

Further developed from previous work with basis functions from the NBI ionization profile[4], we construct a set of basis functions from a grid in the constant of motion(CoM) space (E, P_ϕ, μ).

Taking as basis functions only topologically valid orbits locations, the basis functions are simulated with ASCOT[2] for a fixed amount of time. The simulation time is limited to better capture correlations between neighboring basis functions in the CoM space.

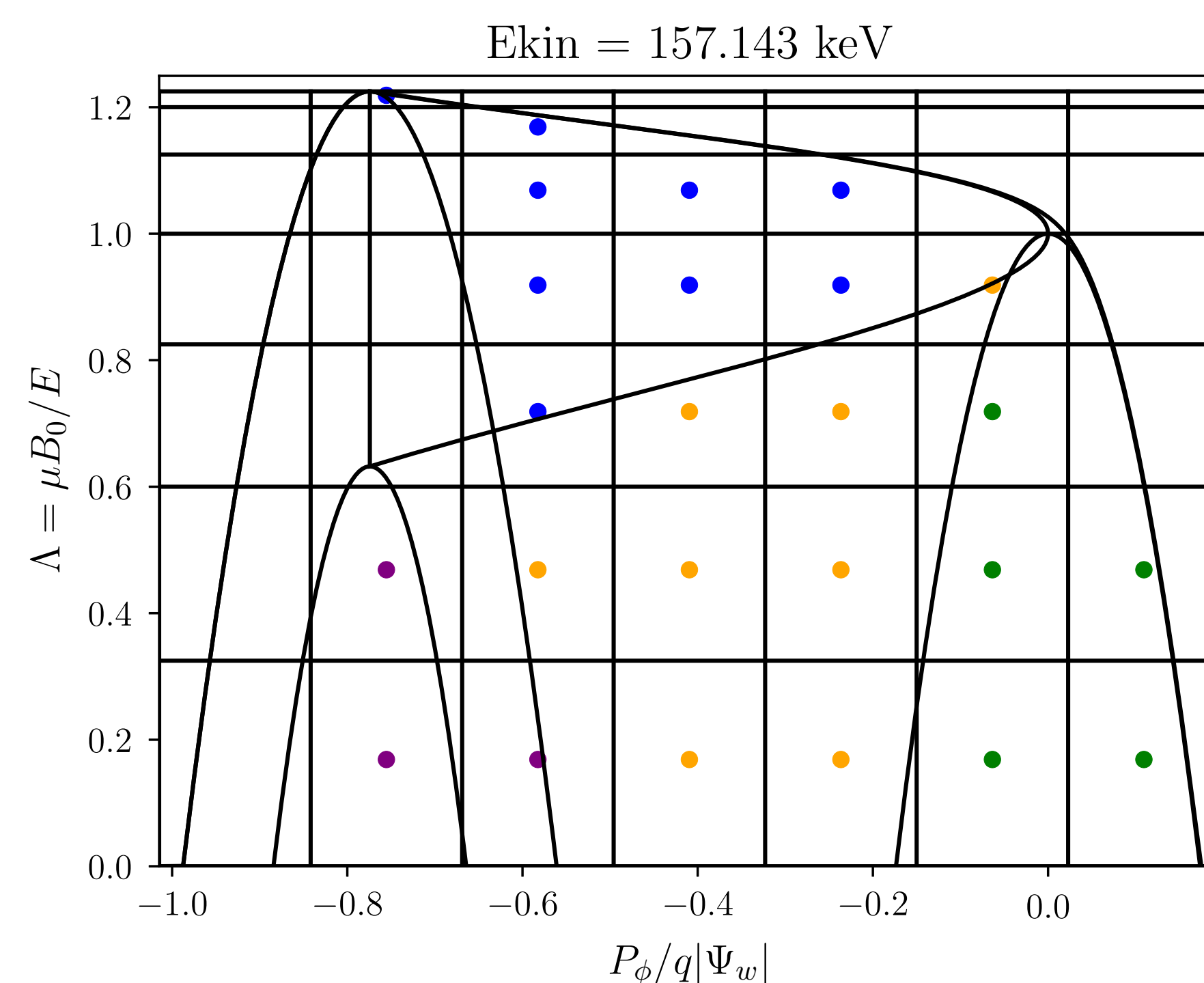


Fig. 3: Energy slice from 7x7x7 pitch uniform distribution, that shows all valid basis functions.

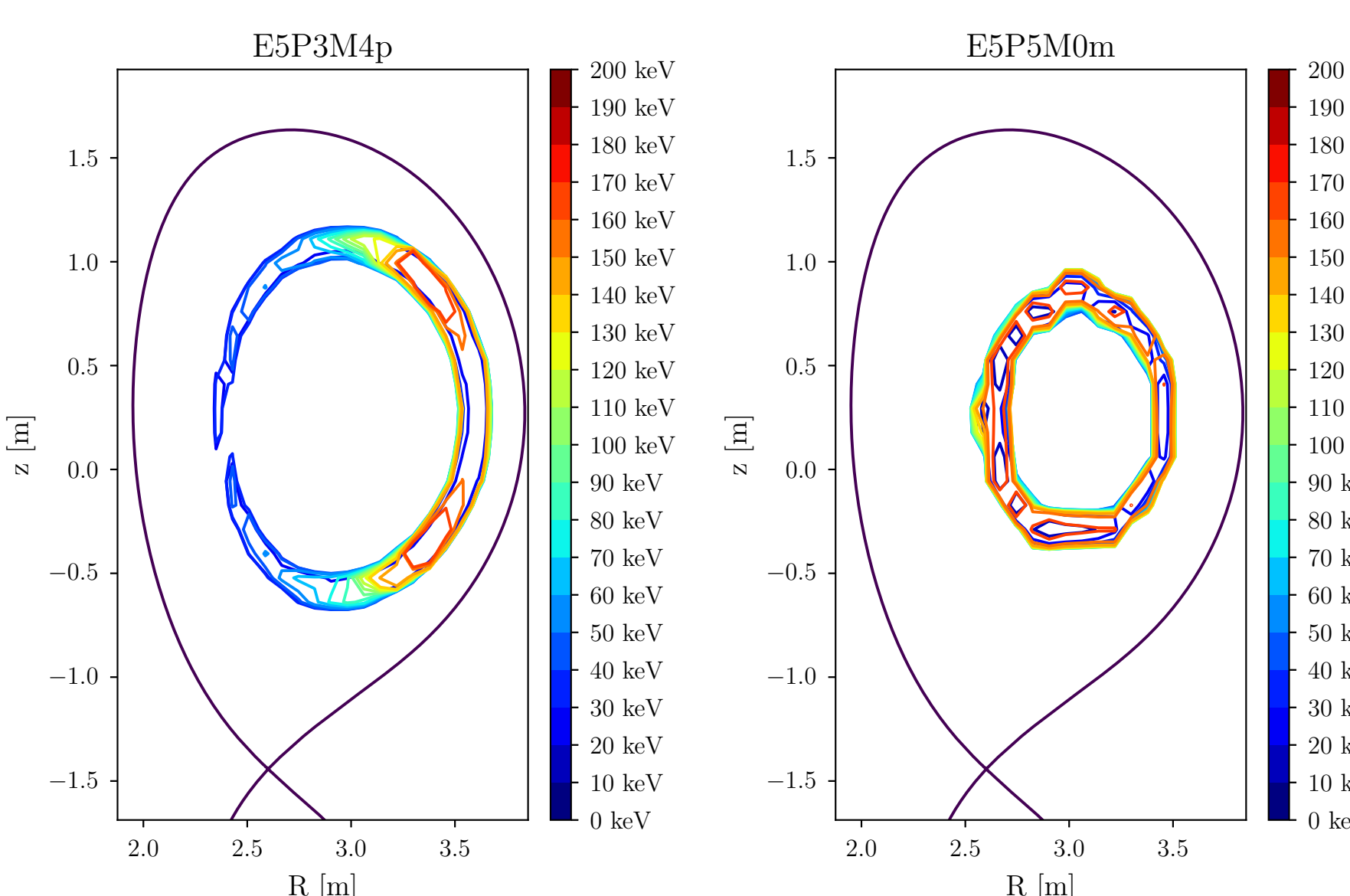


Fig. 4: Two basis functions from 7x7x7 pitch uniform basis shown as energy contours in (R, z)

Inversion

Inversion was performed for different basis configurations to find better configurations:

Basis set	# of basis functions	Discrepancy	Error
5x5x5 0.04s	125	72.7%	75.2%
5x5x5 0.08s	125	64.4%	68.1%
5x5x5 p 0.08s	87	64.5%	67.7%
5x5x5 p 0.16s	87	54.8%	60.3%
7x7x7 p 0.16s	235	38.8%	47.1%

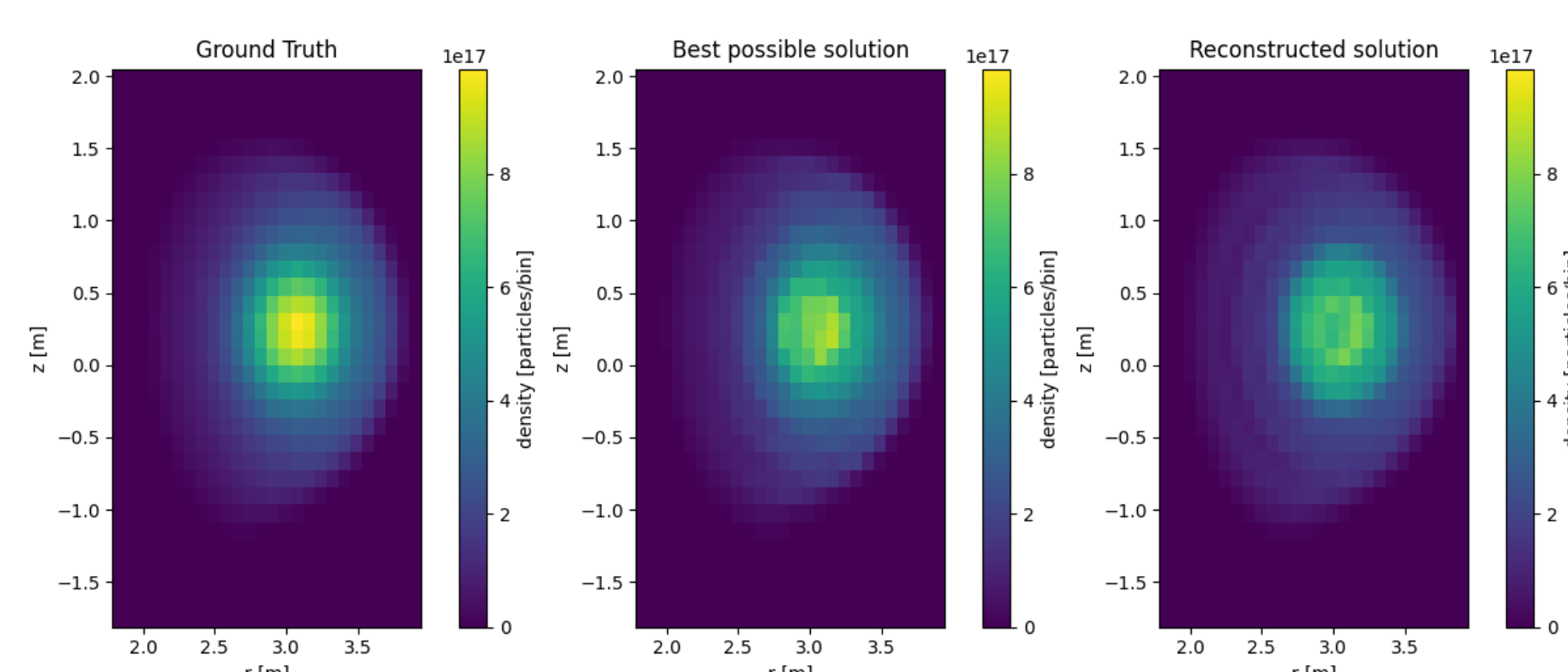


Fig. 5: Inversion results for 7x7x7 p uniform basis in (R, z)

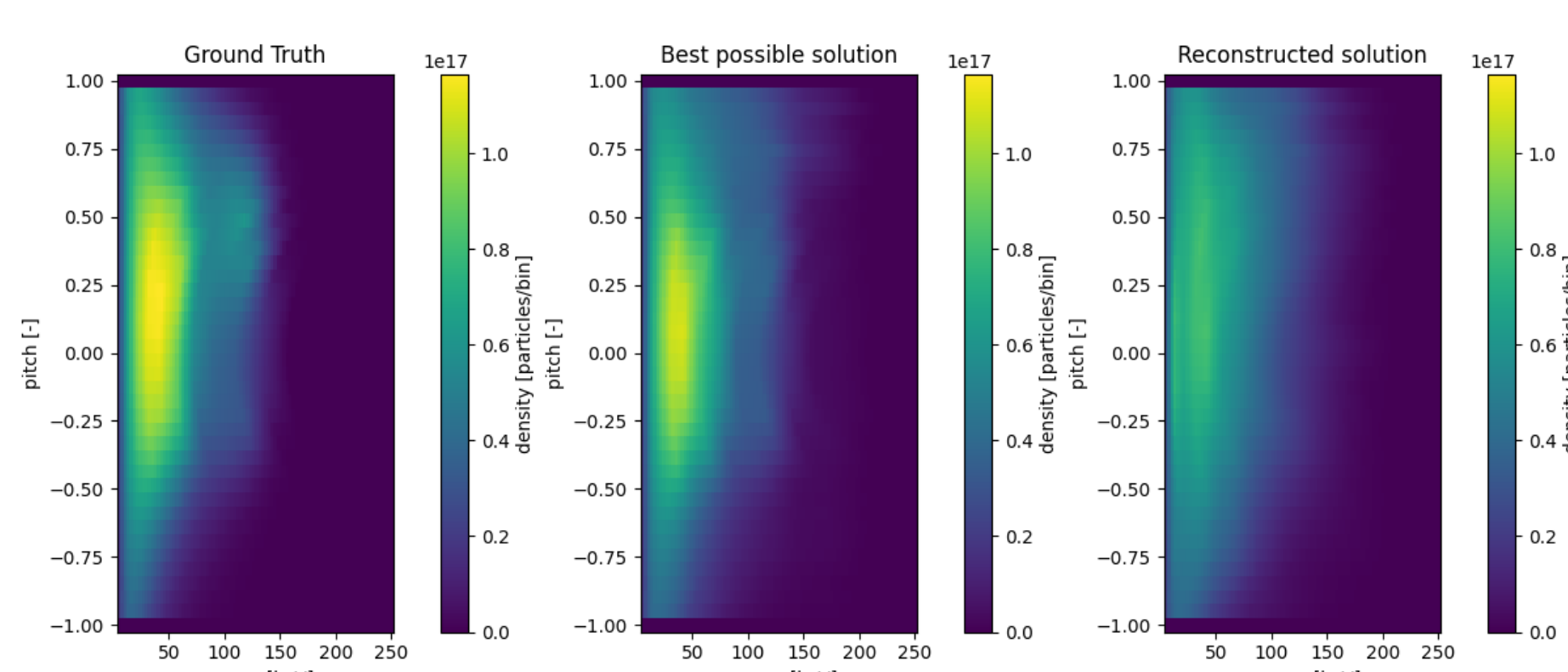


Fig. 6: Inversion results for 7x7x7 p uniform basis in (E, p).

Gaussian blob

Introducing an artificial Gaussian blob that removes particles (8.1%) from the phase space, near $p = 1$, with the inclusion of beamline bases in [4].

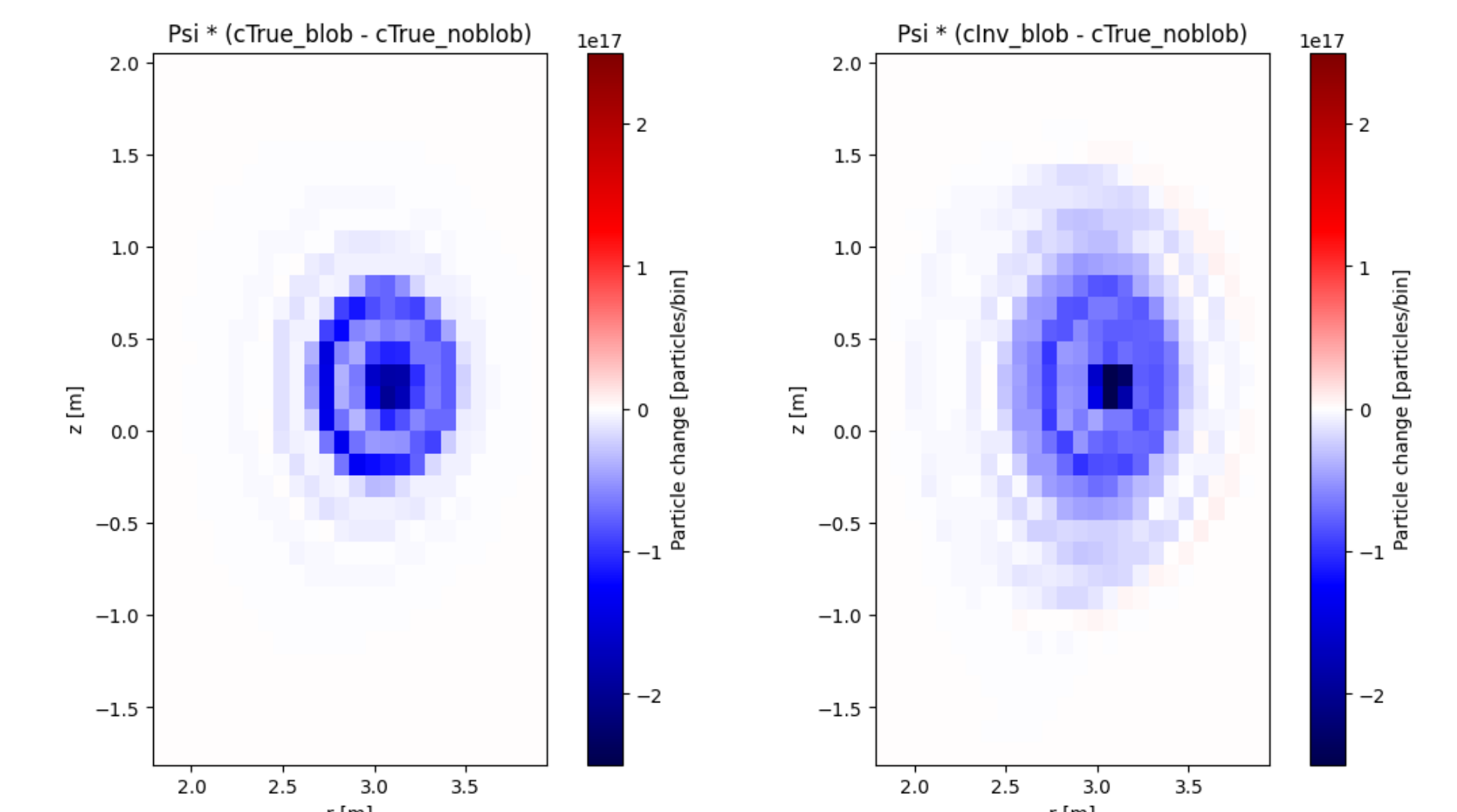


Fig. 7: Reconstructed Gaussian blob shape in (R, z)

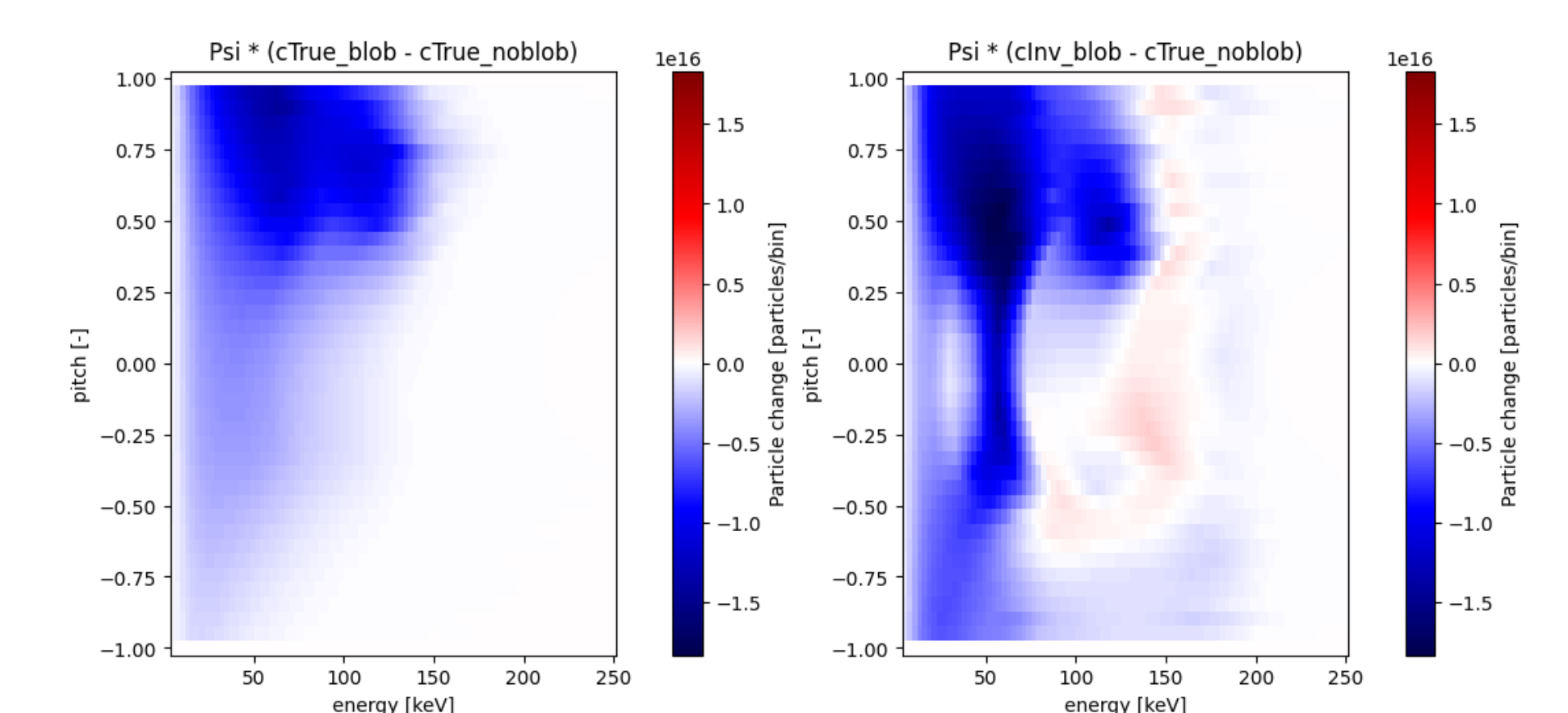


Fig. 8: Reconstructed Gaussian blob shape in (E, p)

The shape of the Gaussian blob in (R, z) can be recovered very well, although broadening is observed. In (E, p) significant transfer to lower pitch values is observed. In total, the inversion overestimates the effect of particle loss to 11%.

Conclusions and discussion

- CoM basis provides a framework to construct all physically possible distributions in axisymmetric tokamaks.
- General basis form provides means to observe/detect anomalies, like Gaussian blobs.
- Future: Inversion for JET shot #99971 real data
- Future: Inversions for different JET shots and different machines
- Further development of the CoMm grid scheme, simulation until marker(test particle) escapes CoM grid cell

References

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