A Containerized Ion Optical Optimizer for the SECAR Recoil Mass Separator

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2021-22 MSU ICER Cloud Computing Fellow

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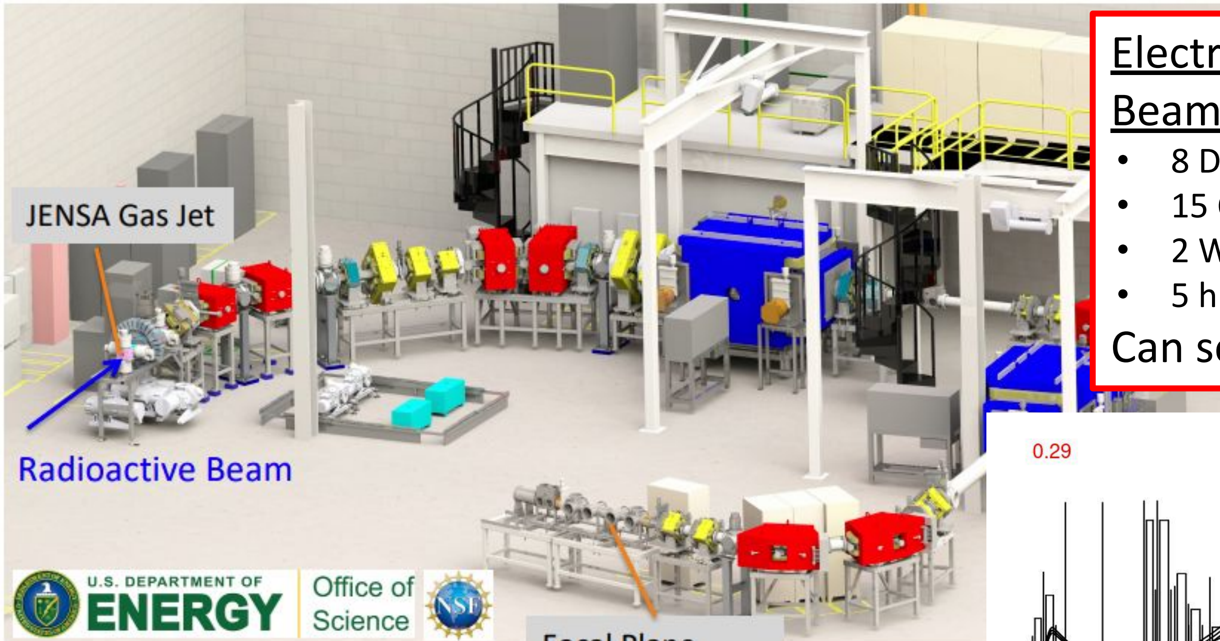
The SECAR Recoil Separator

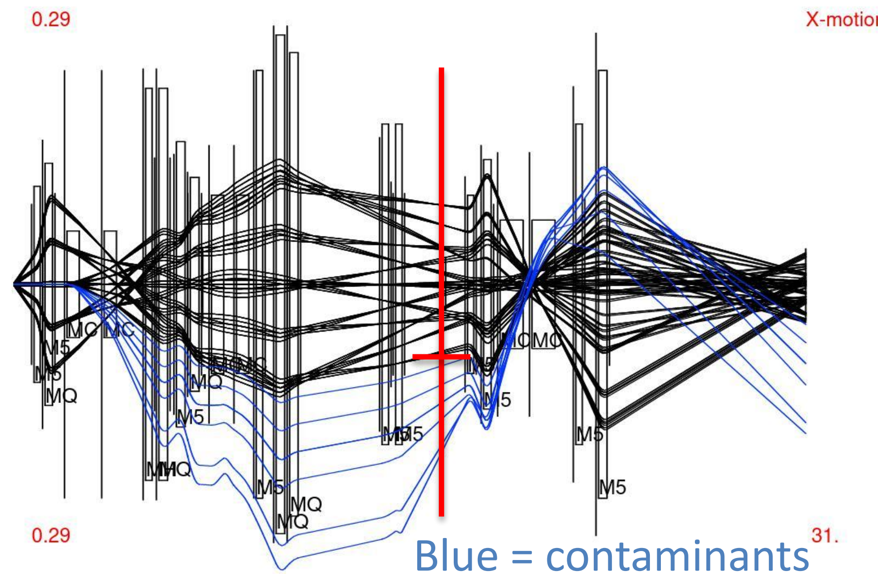


Electromagnetic System to Separate Beam Components

- 8 Dipole Magnets
- 15 Quadrupoles Magnets
- 2 Wein filters (Velocity Filters)
- 5 higher order Multipole Magnets

Can separate 1 part in 10^{13}!!!

- Each experiment has different beam types, and requirements of SECAR
- Python algorithm to find optimal solutions to the specified requirements
- Algorithm runs for a period until we are satisfied with the result (up to 7 days)



Blue = contaminants
Black = target recoils

1. H. Schatz 2020 SECAR Project Update
2. Berg et al. Nuc Inst and Methods, A877 (2018) 87-103

Ideal Situation

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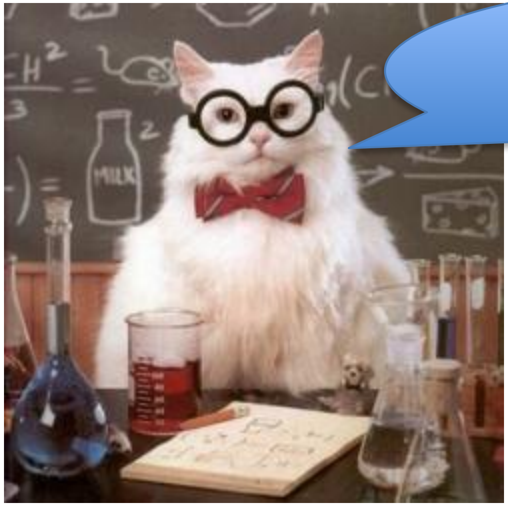

Can I use SECAR to study
X(a,n)Y reaction?

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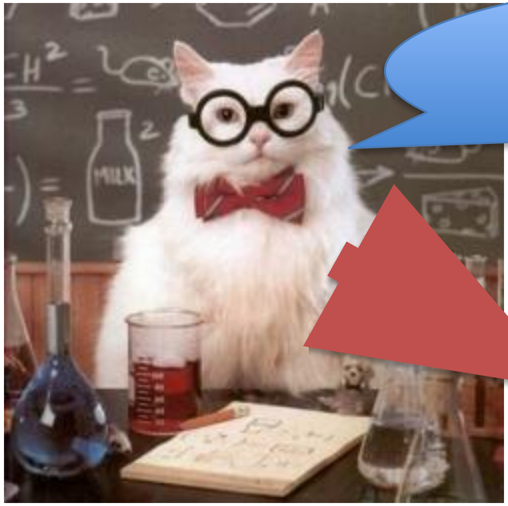

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Goes to collaboration website, runs optimizer

SECAR

http://secar.space/

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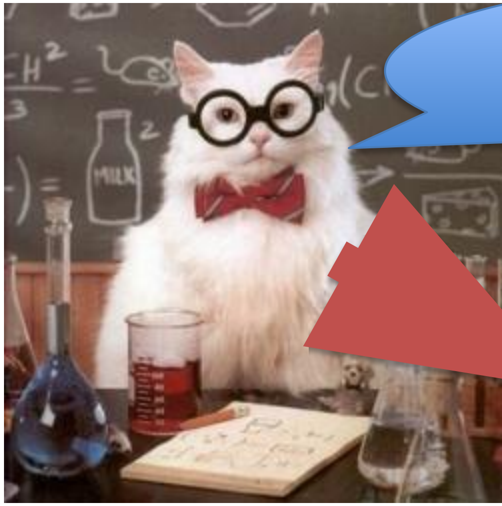

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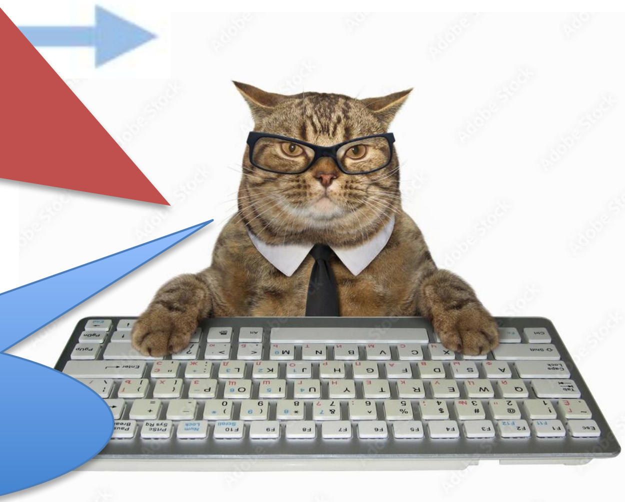


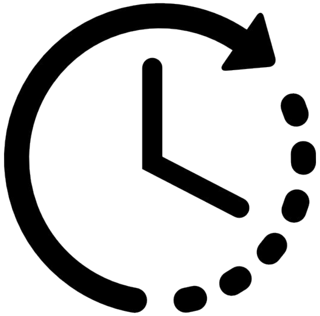
Now I can write my proposal!

Advantages of Cloud Deployment

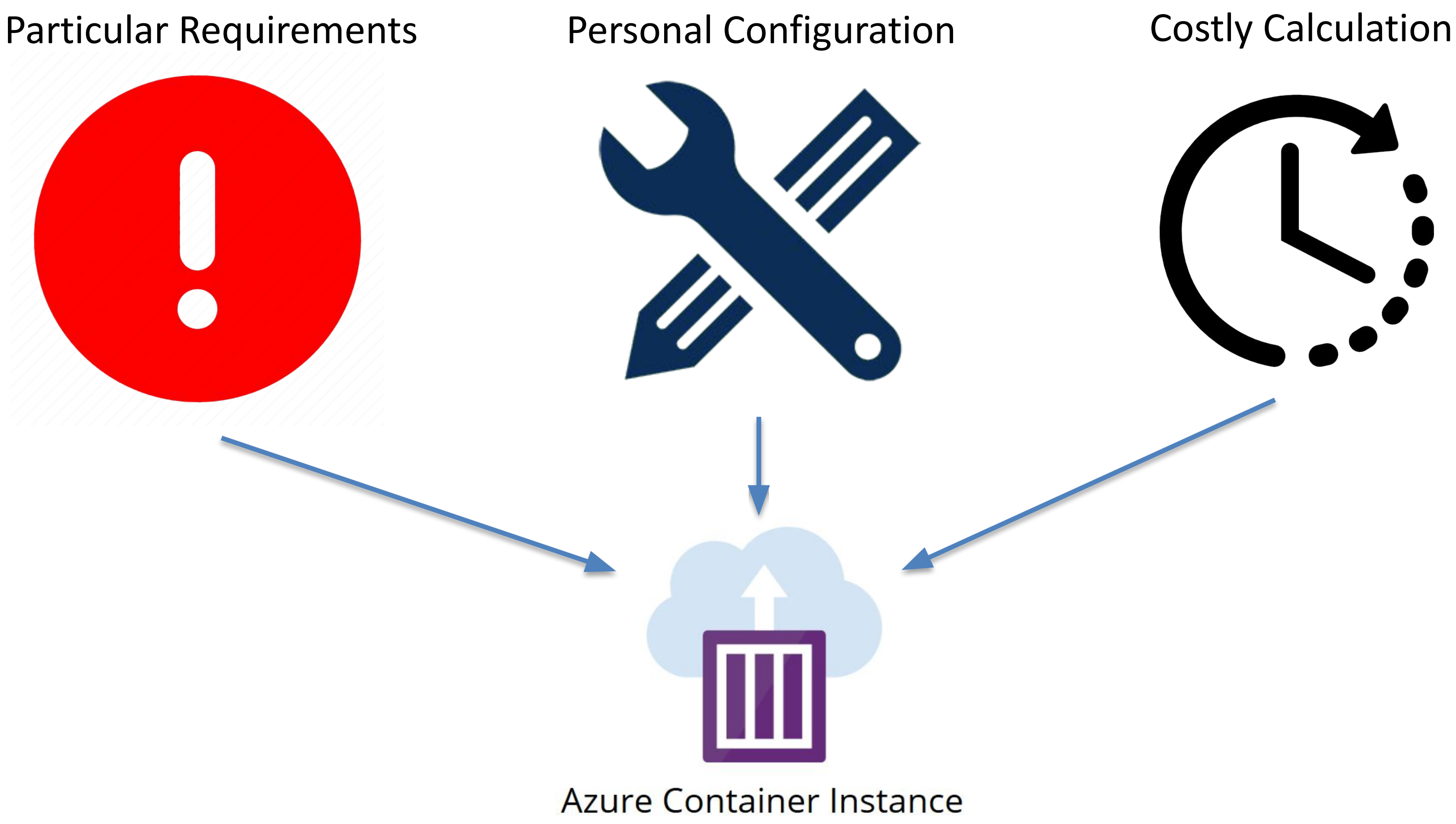
Particular Requirements

Personal Configuration

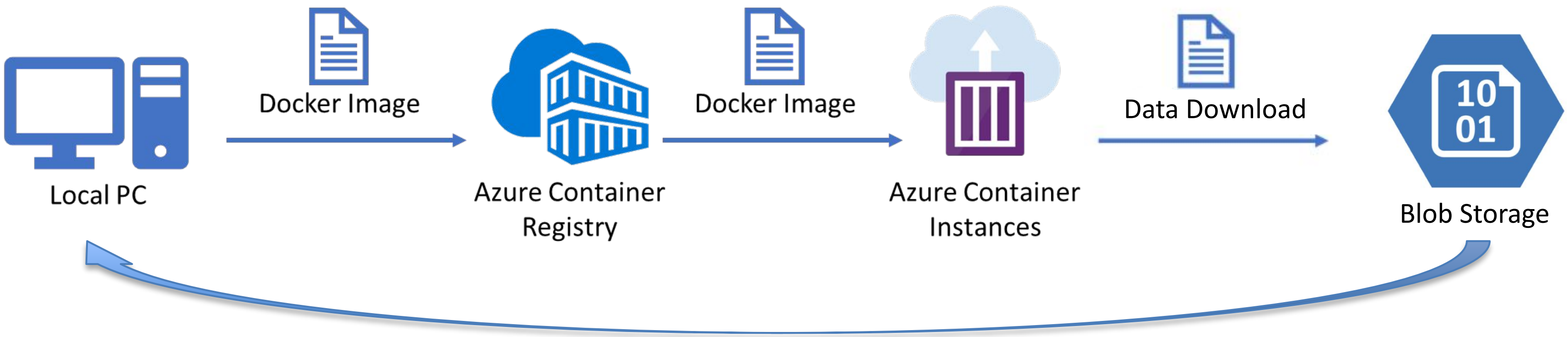
Costly Calculation



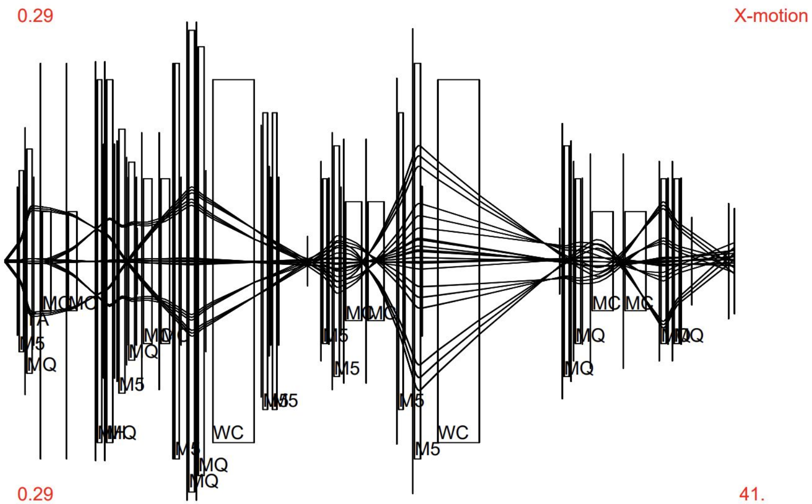
Advantages of Cloud Deployment



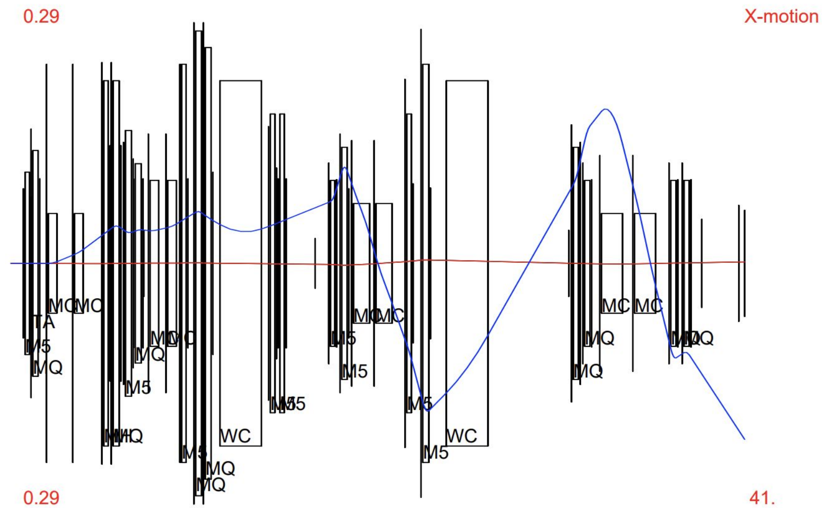
Cloud Implementation



Verified and analyzed locally



X-profile



X-profile separation

Story of the Project

Challenges

- Significant time cost makes direct feedback difficult
- Pipeline is not yet complete or flexible enough to release directly to users

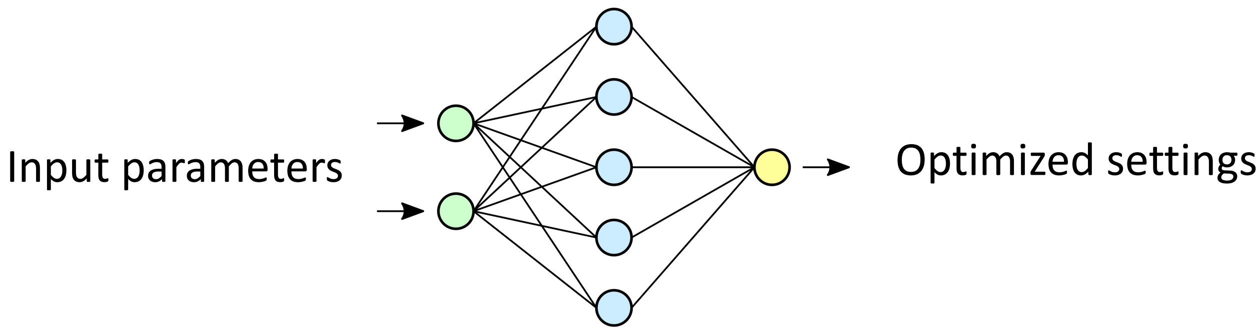
Successes

- Container Instances allow for flexible and repeatable deployment
- Dockerization gives portability

Outlook

Generate large dataset via cloud pipeline

Train neural network



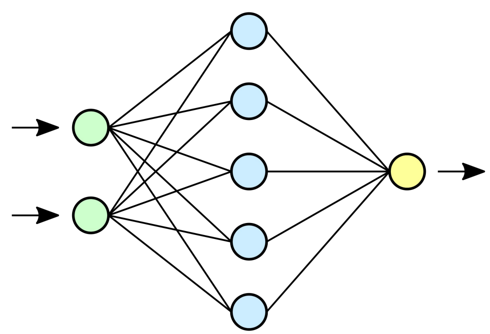
Web app wrapper

Outlook

Generate large dataset via cloud pipeline

Train neural network

Input parameters



Optimized settings

Web app wrapper

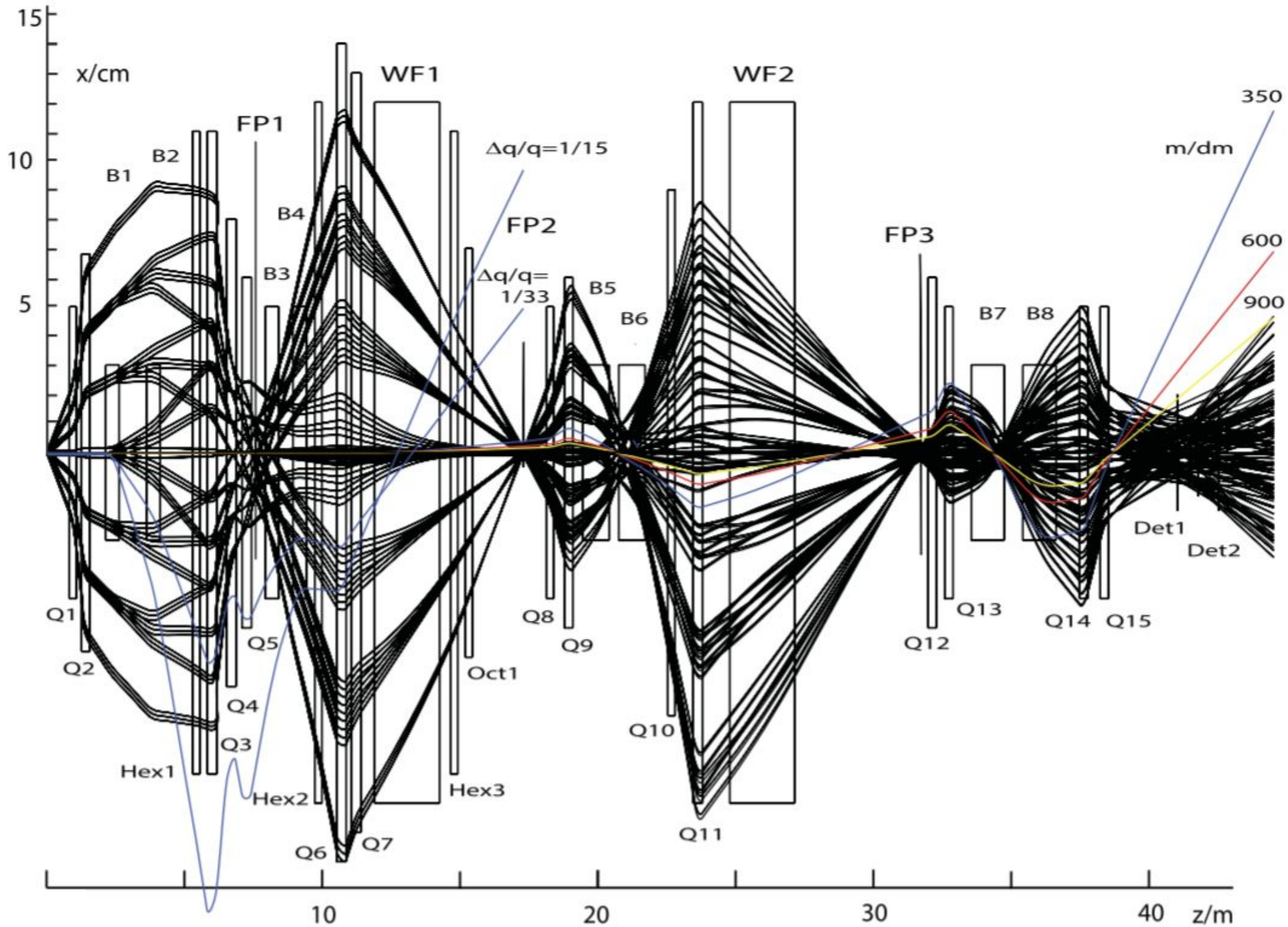
Acknowledgements and Thanks

Particular thanks to Manoel Couder for his assistance with COSY Infinity

Additional thanks to all the members of the SECAR Collaboration for making it all possible!

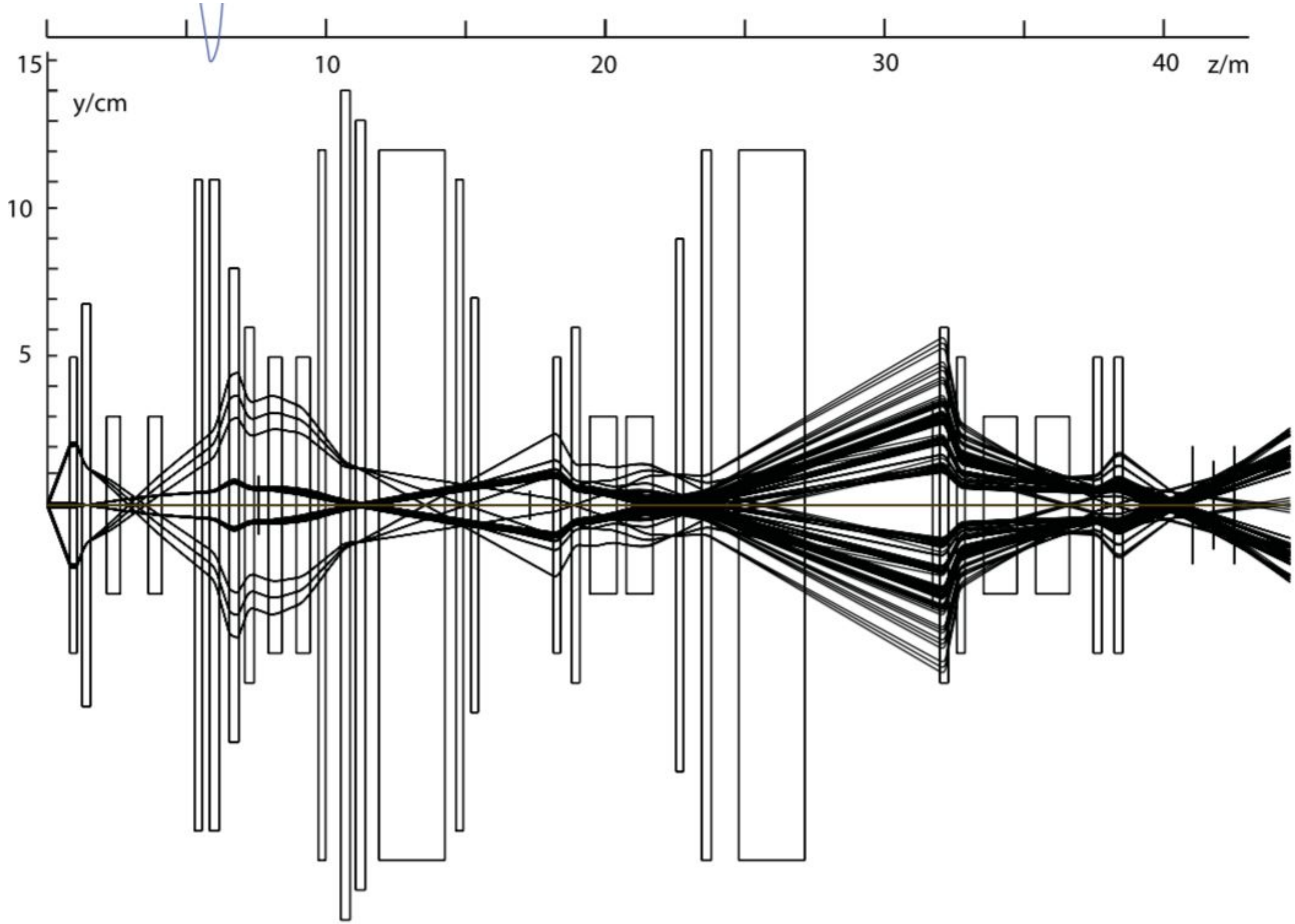
Backup Slides

COSY Infinity Simulations for Modeling Ion Optics



1. Berg et al. Nuc Inst and Methods, A877 (2018) 87-103

COSY Infinity Simulations for Modeling Ion Optics



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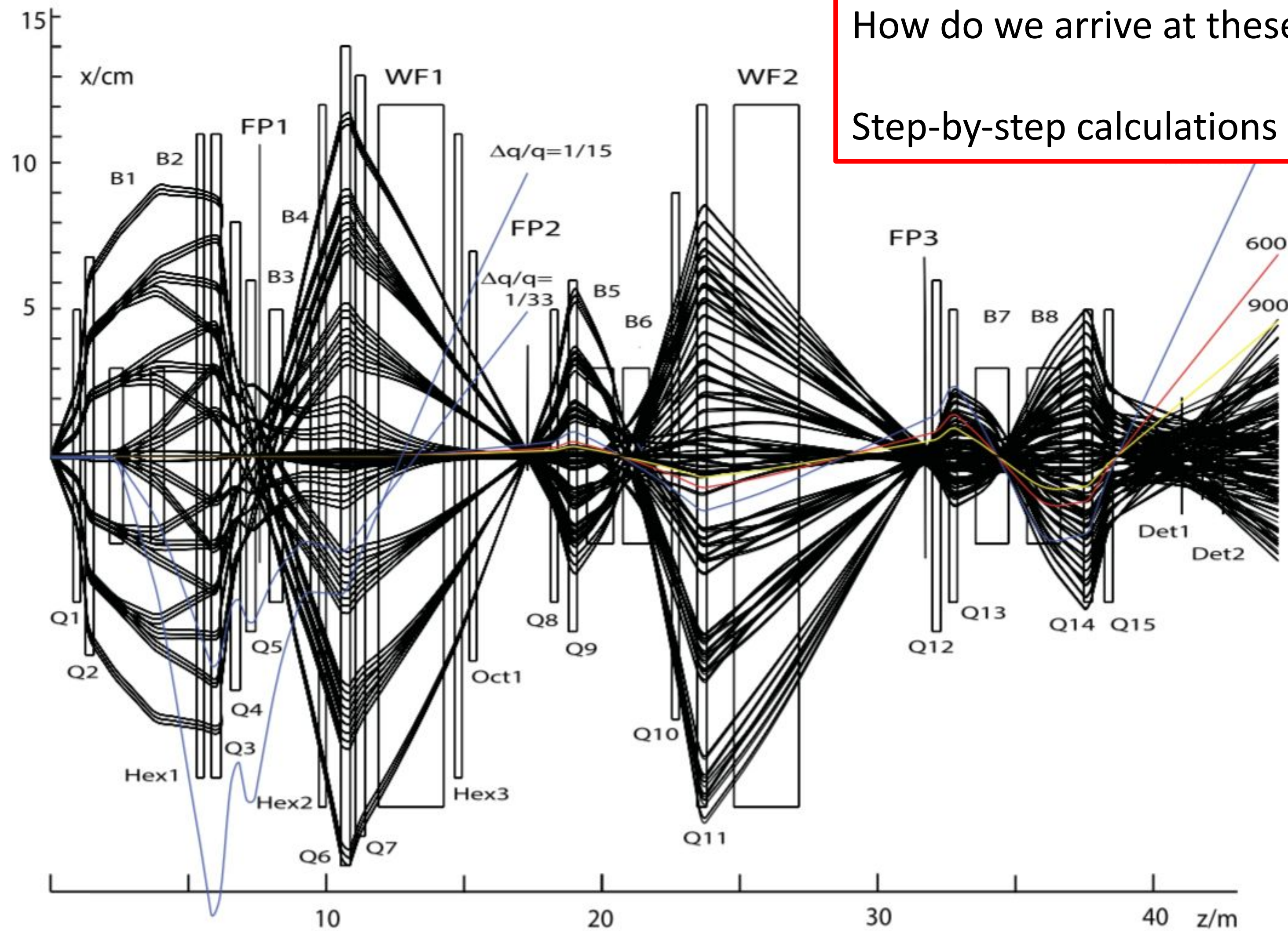
Calculation of Nominal Magnet Values

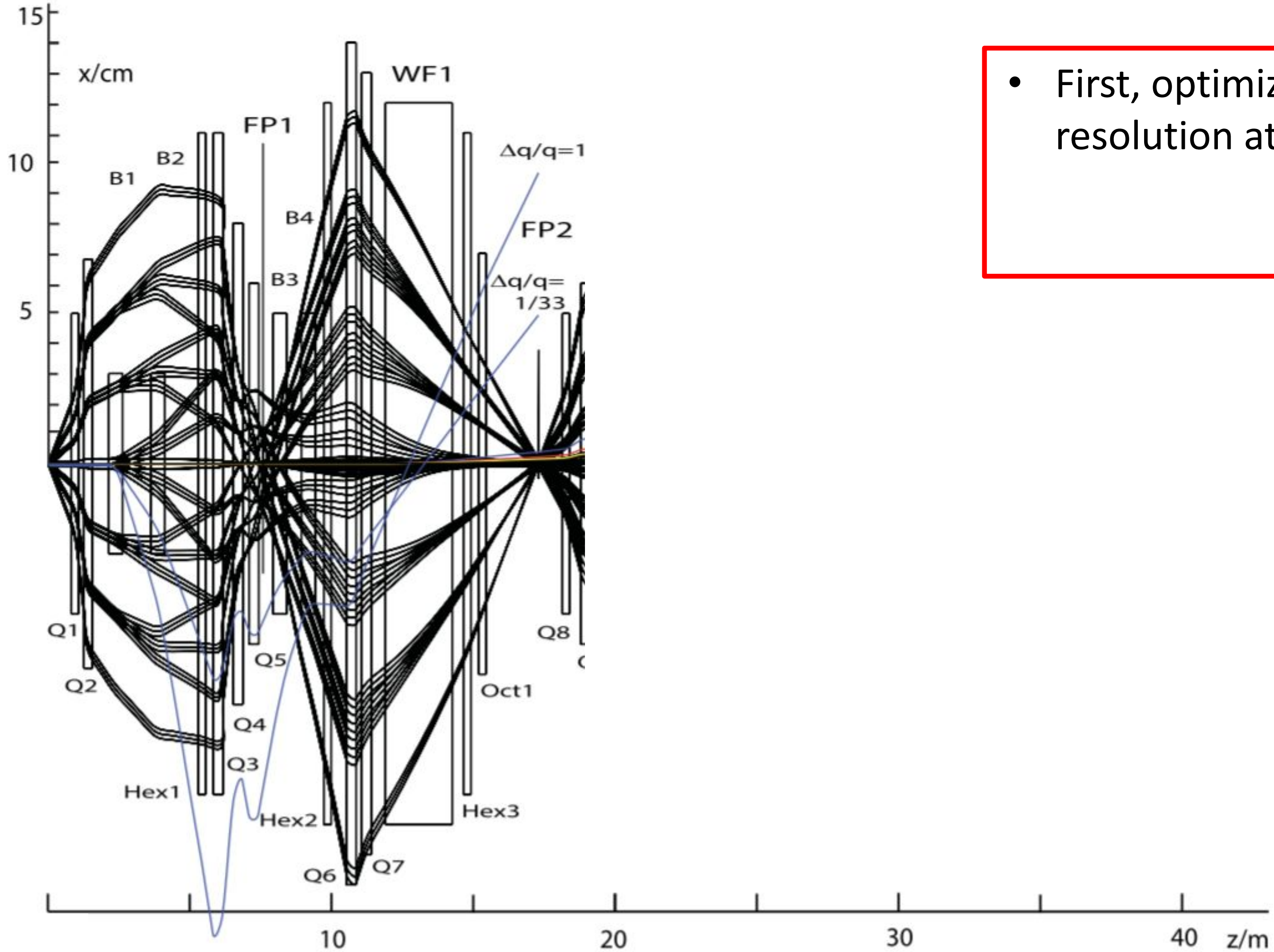


How do we arrive at these values?

Step-by-step calculations by hand…

1. Berg et al. Nuc Inst and Methods, A877 (2018) 87-103

Calculation of Nominal Magnet Values



- First, optimize the mass resolution at FP2

1. Berg et al. Nuc Inst and Methods, A877 (2018) 87-103

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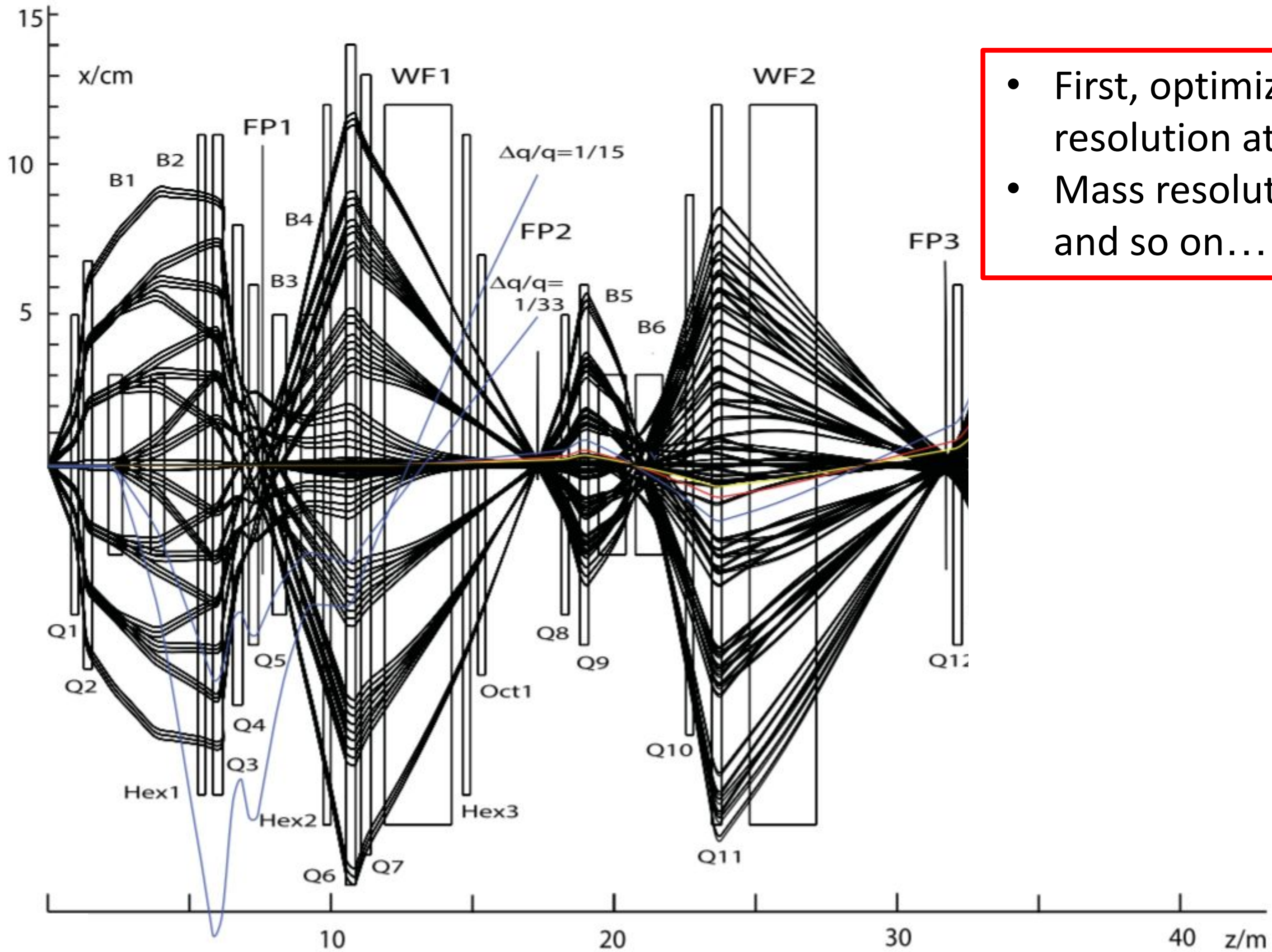

- First, optimize the mass resolution at FP2
- Mass resolution at FP3, and so on…

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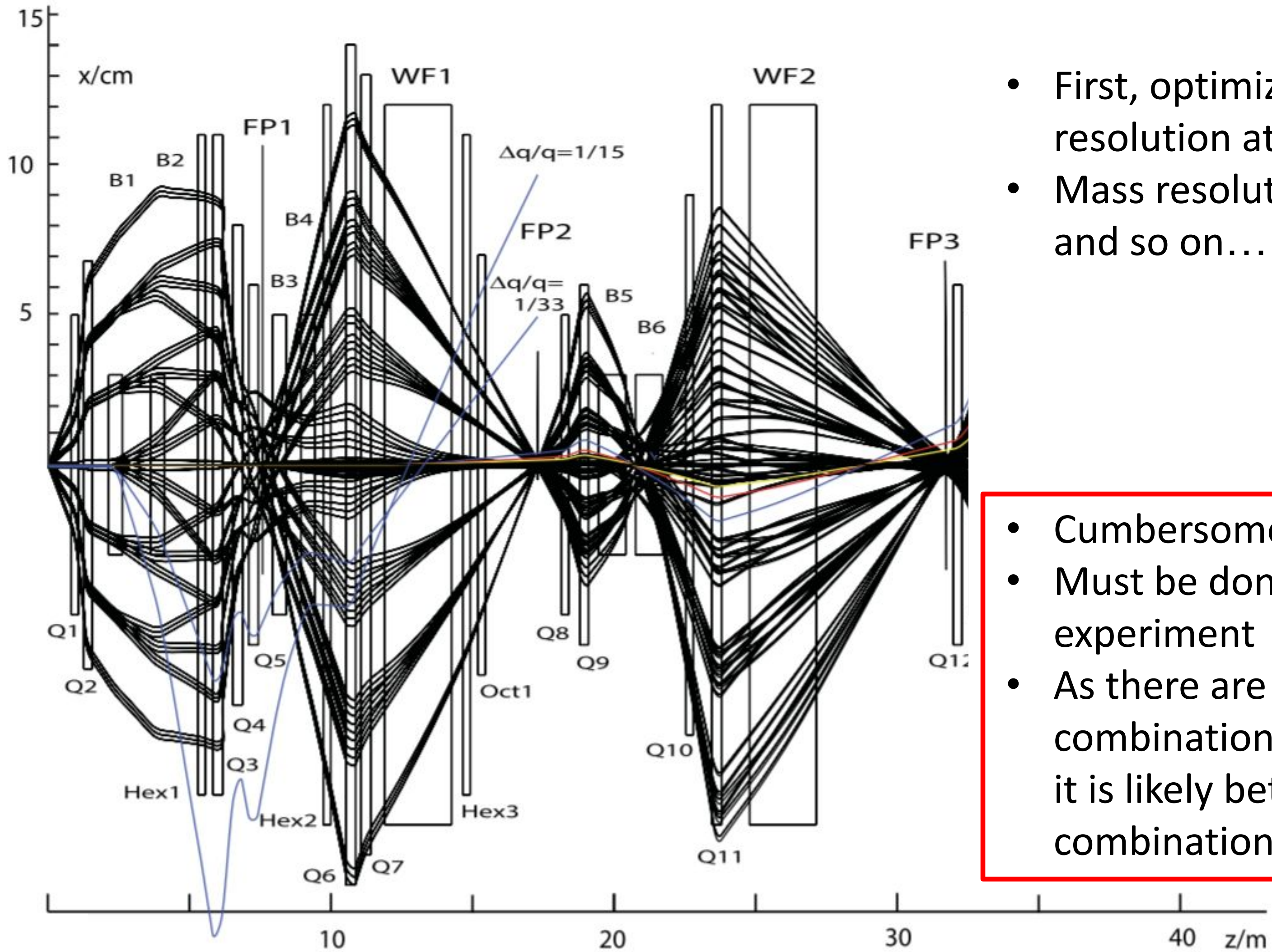
Drawbacks of the Current Method

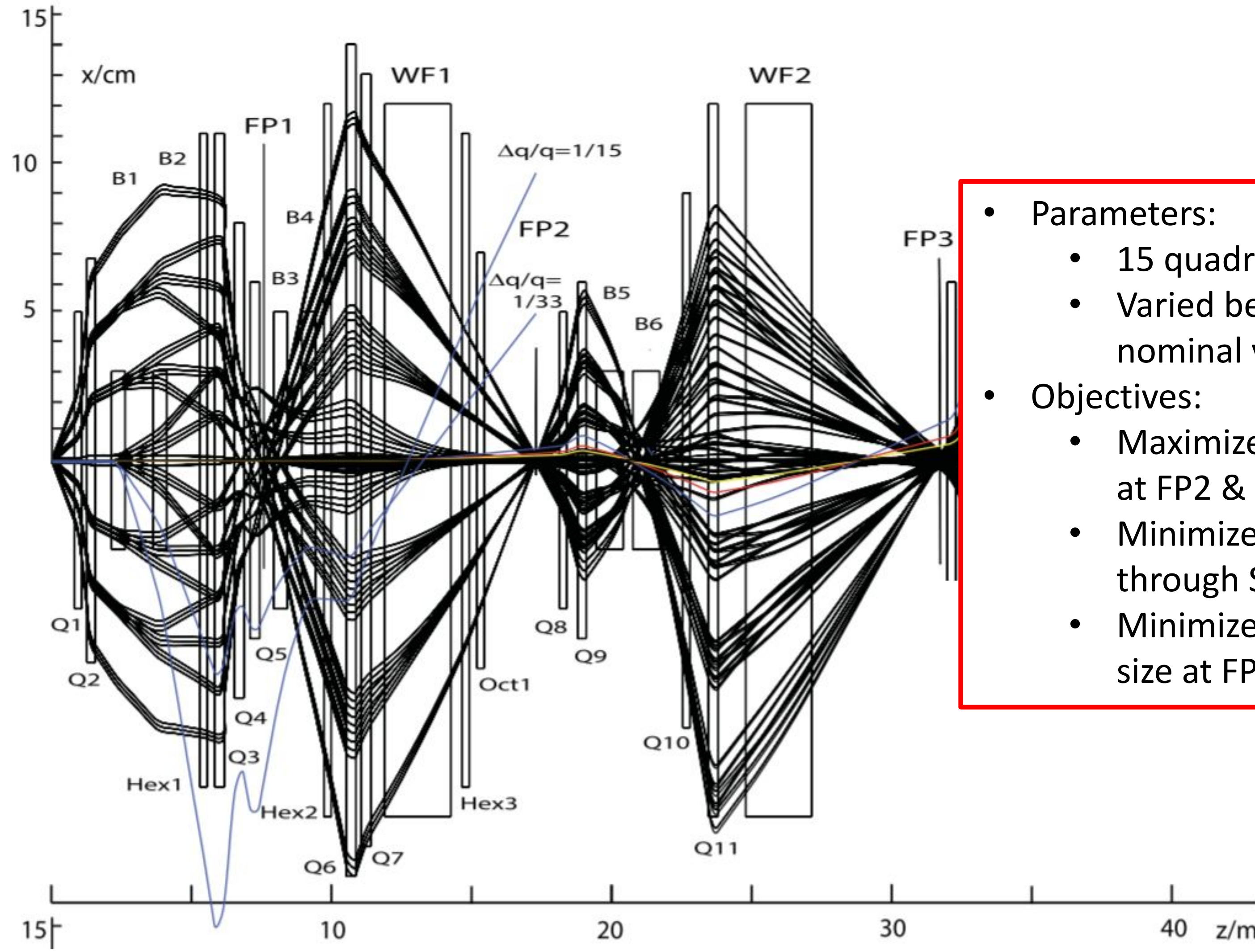


- First, optimize the mass resolution at FP2
- Mass resolution at FP3, and so on…

- Cumbersome to calculate
- Must be done for each experiment
- As there are infinite combinations of magnets, it is likely better combinations exist

1. Berg et al. Nuc Inst and Methods, A877 (2018) 87-103

Construct a Multi-Objective Problem (MOP)



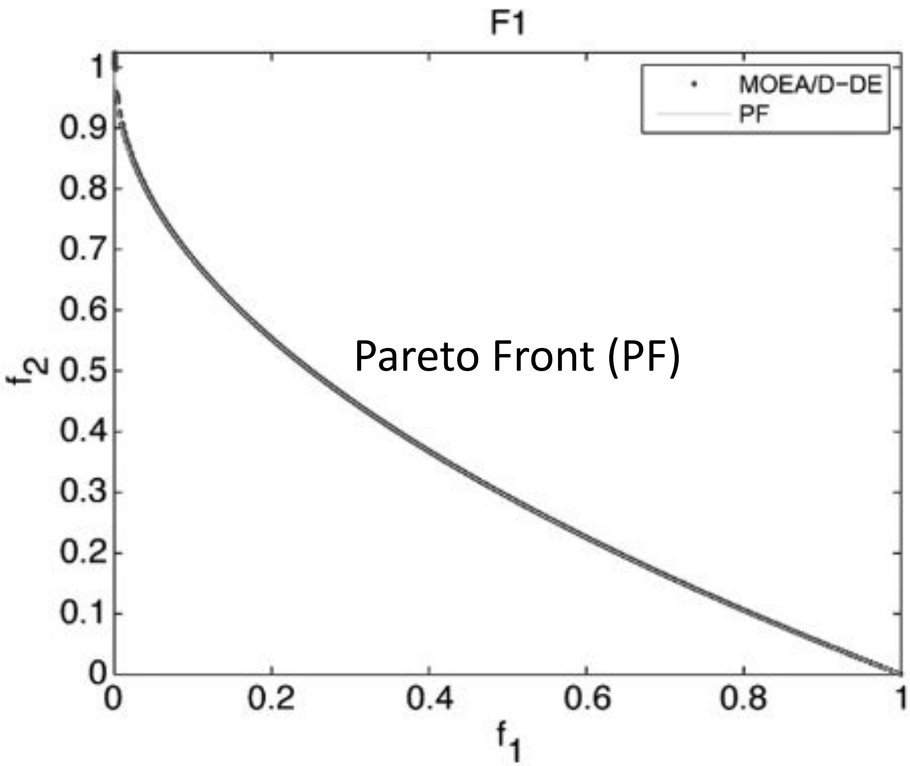
- Parameters:
  - 15 quadrupole magnets
  - Varied between 0.5-2x the nominal values
- Objectives:
  - Maximize mass resolution at FP2 & FP3
  - Minimize the beam spread through SECAR
  - Minimize the beam spot size at FP4 (detectors)

1. Berg et al. Nuc Inst and Methods, A877 (2018) 87-103

Apply an Algorithm to Optimize the MOP

MultiObjective Evolutionary Algorithm based on Decomposition with a Differential Evolution operator (MOEA/D-DE)

- Decomposes a MOP into its subproblems and optimizes these individually via differential evolution
- The resulting points are "Pareto-optimal", meaning an improvement in one objective must lead to a deterioration in another objective
- Implemented in Python using pygmo
  - 800 generations
  - Population size of 84
  - =67200 total simulations (~5sec/sim)



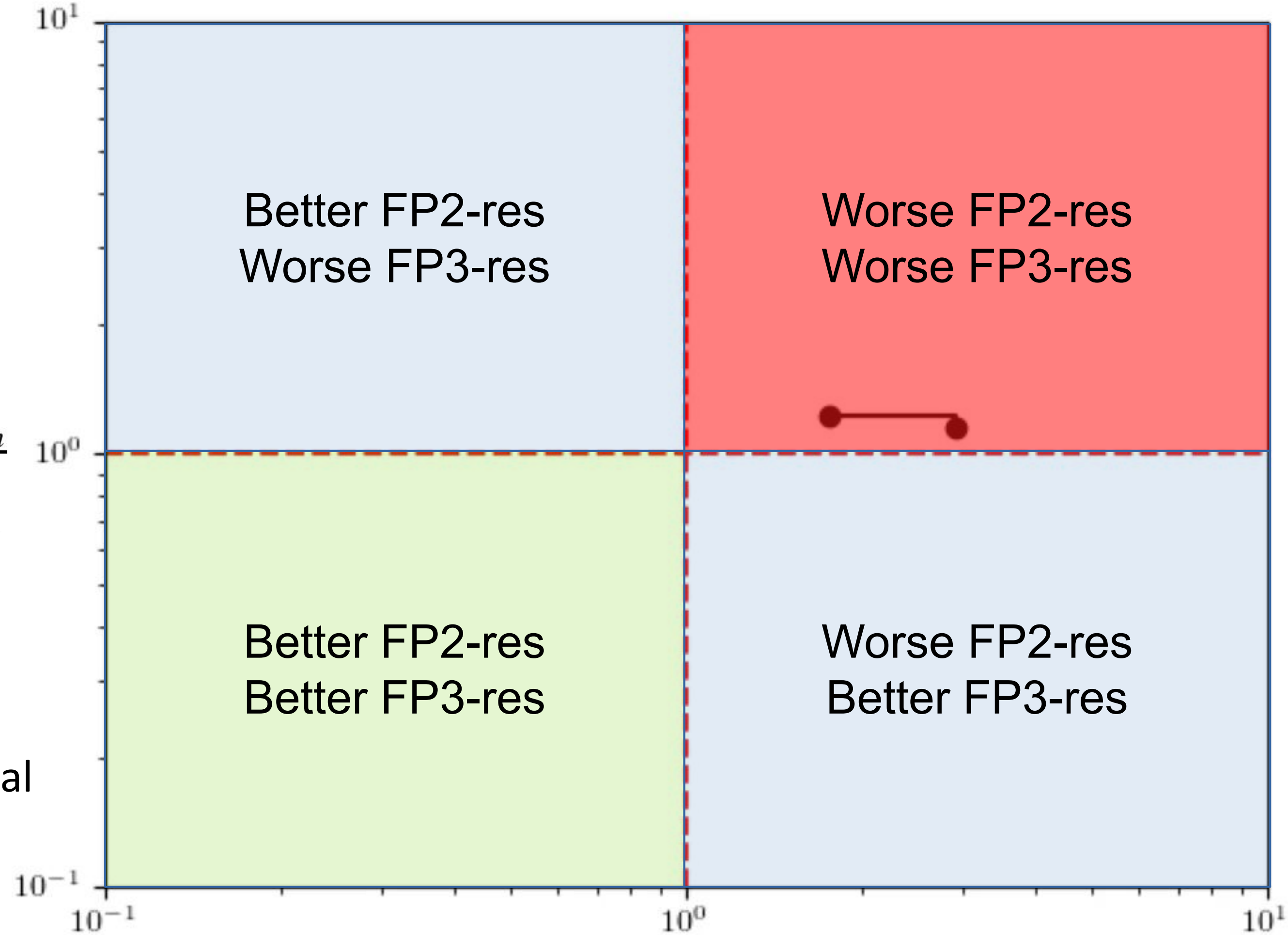
1. Li and Q. Zhang, IEEE Trans. Evol. Comput.,vol. 13, no. 2, pp. 284–302, Apr. 2009.
2. Biscani et al., (2020). Journal of Open Source Software, 5(5), 2338

Evolve the Algorithm

Red dashed lines give nominal values
i.e. X=1, Y=1

$$Y = \frac{\text{FP3-res}_{nom}}{\text{FP3-res}_i}$$

Better/worse are comparisons to nominal



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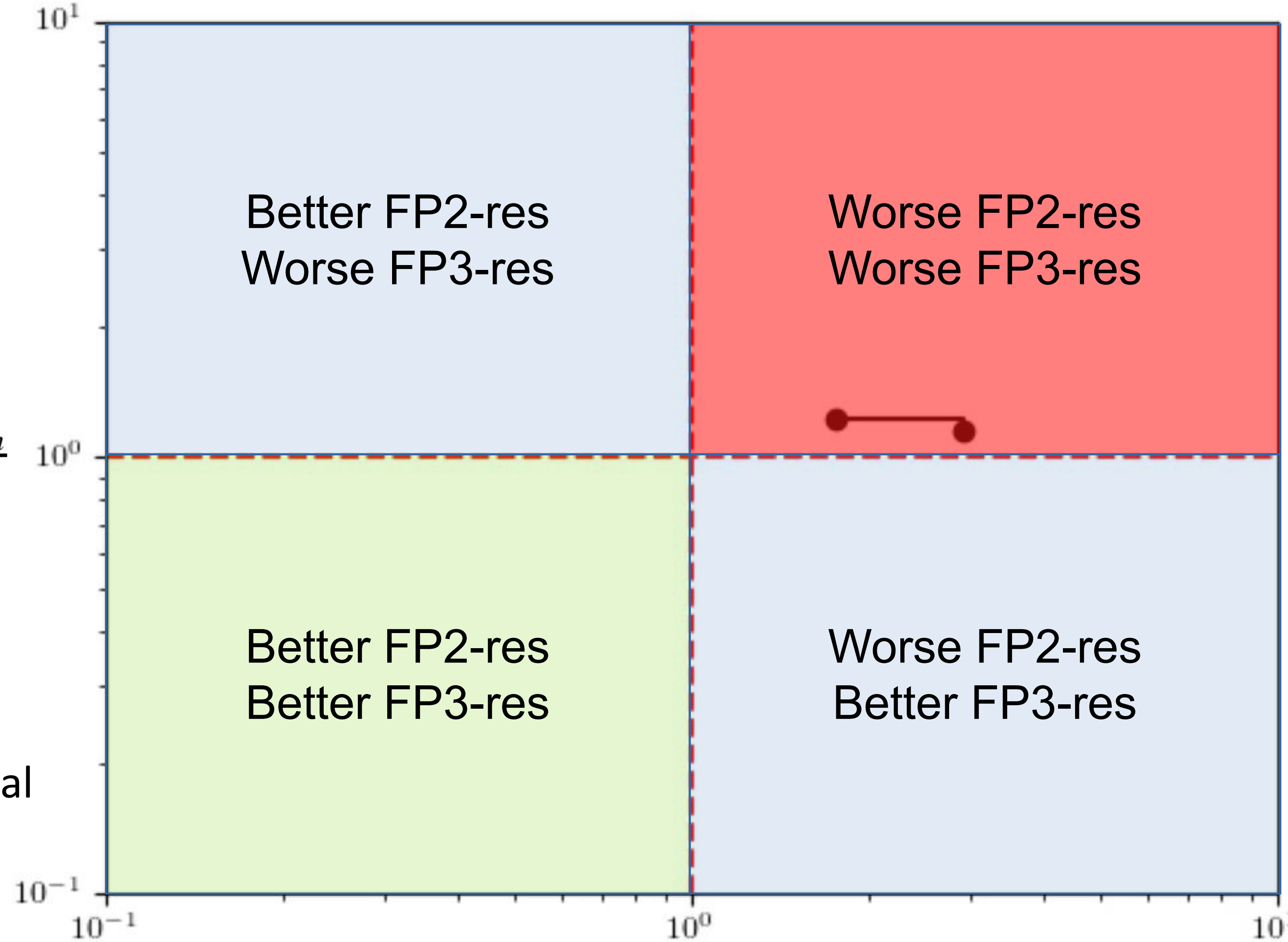
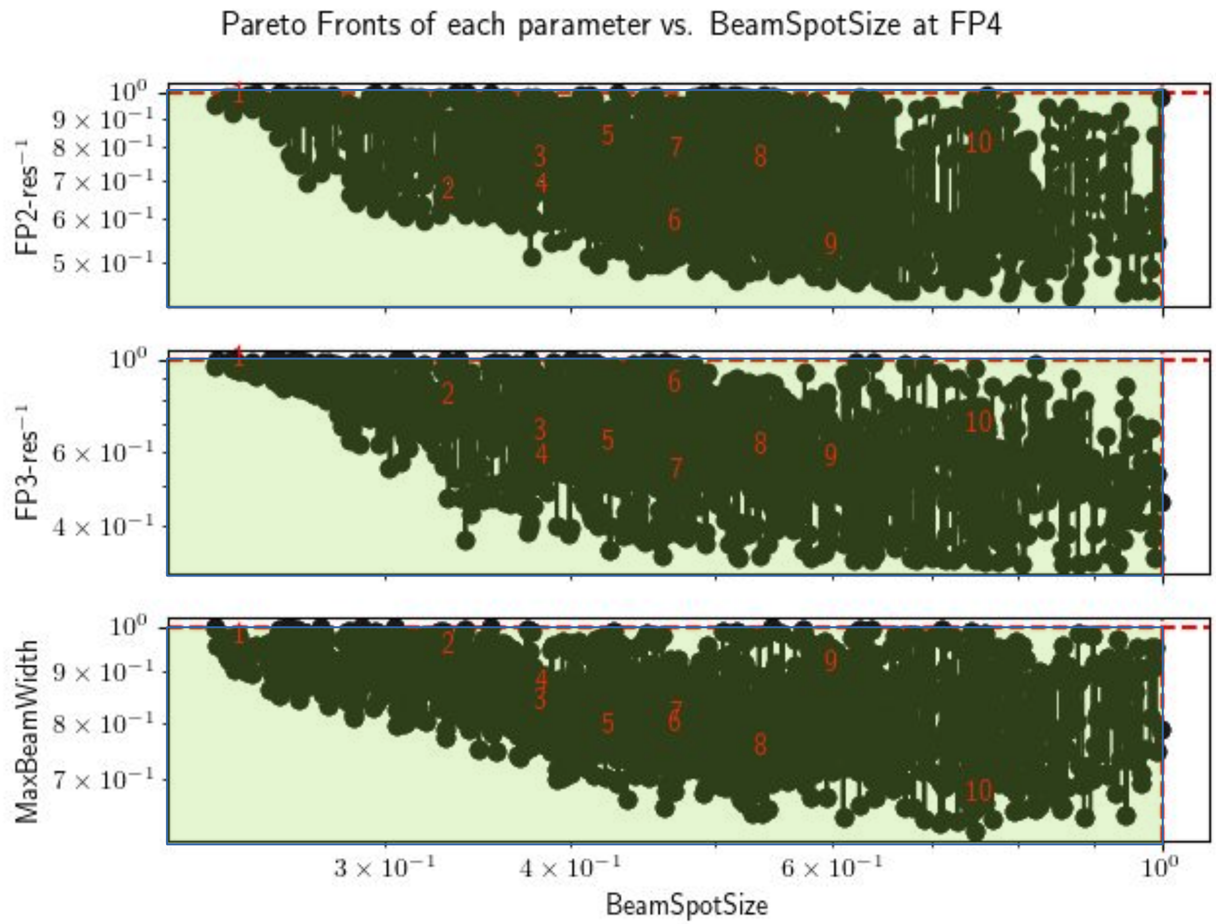
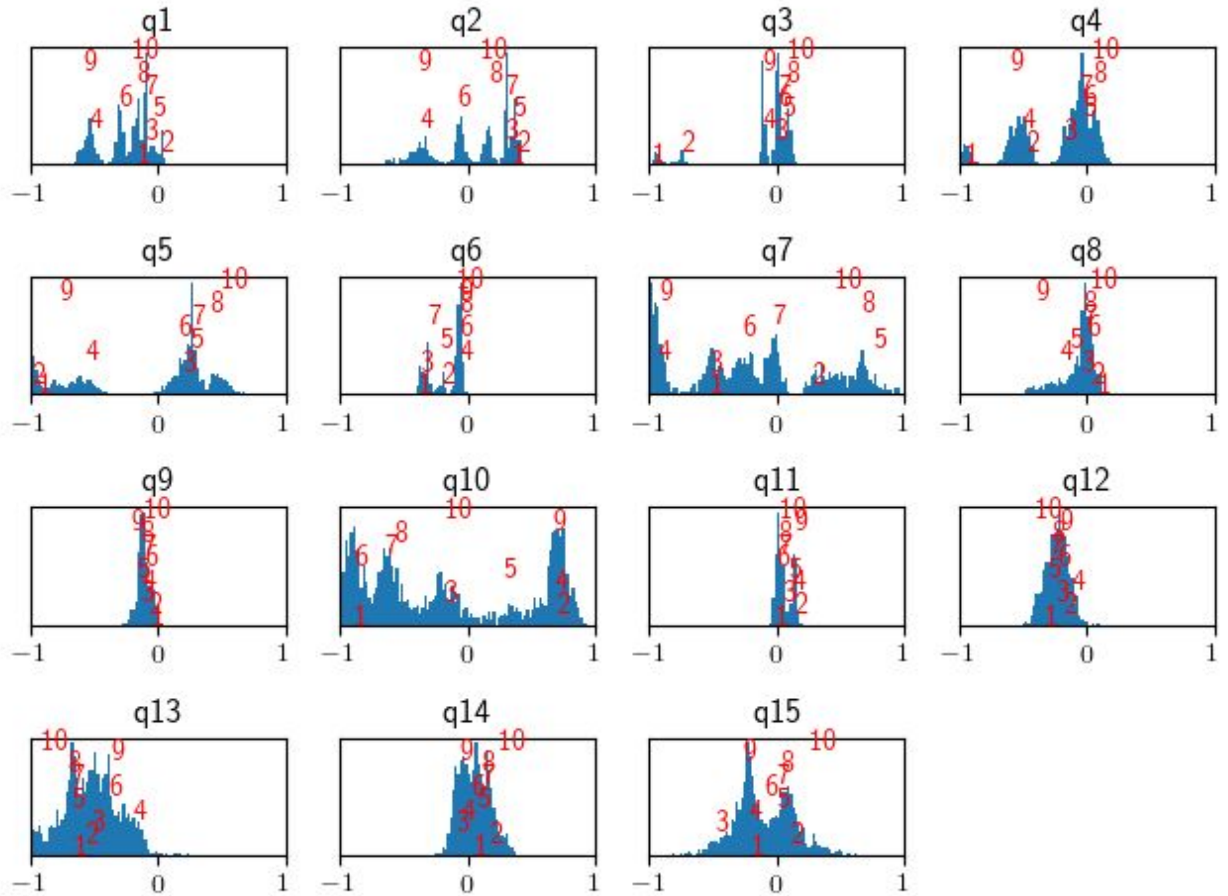


$$X = \frac{\text{FP2-res}_{nom}}{\text{FP2-res}_i}$$

4-Dimensional Pareto Fronts

- As before all objectives are taken as ratios to nominal, and smaller is better, with the red dashed lines indicating the nominal obj values
- For clarity, only the front for points which are strictly better than nominal (all obj < 1.0) are plotted

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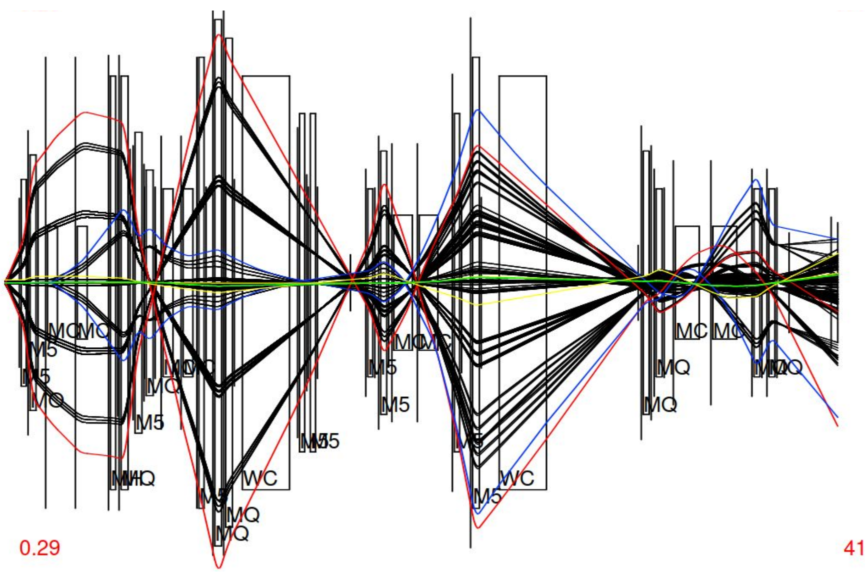
1

Examining Candidate Solutions

- Improvement in FP4 Beam Spot Size and Max Beam Width is clear

X-profile for Nominal Magnet Settings



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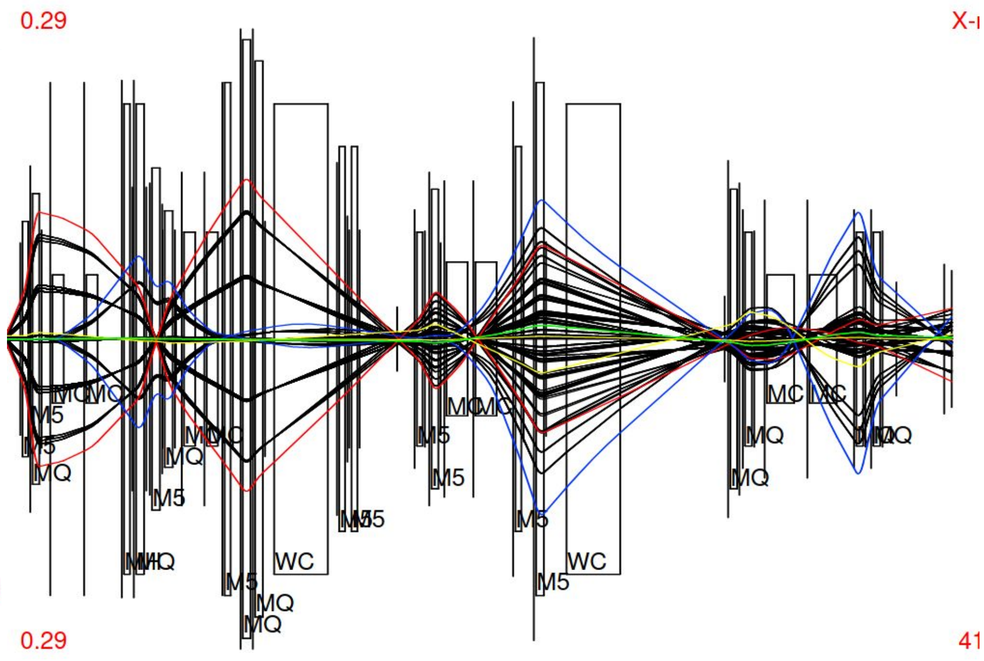

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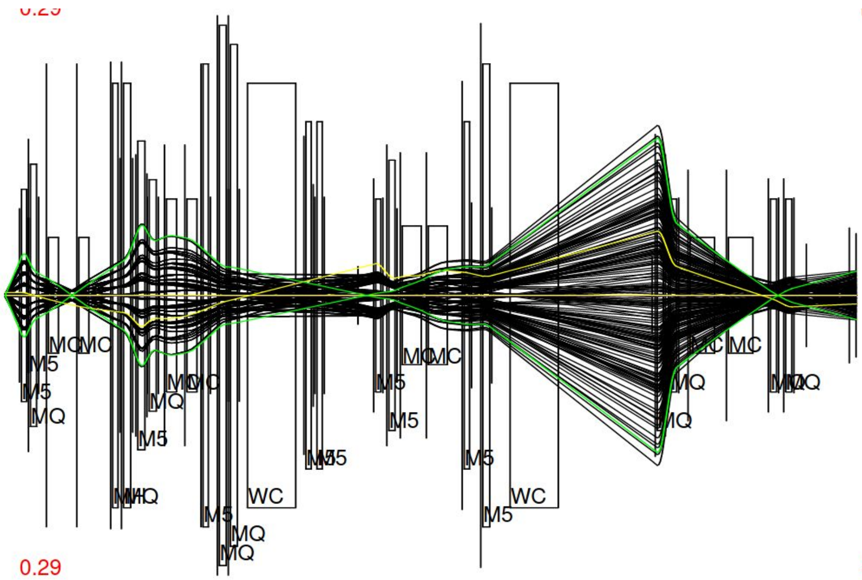
Y-profile for Nominal Magnet Settings



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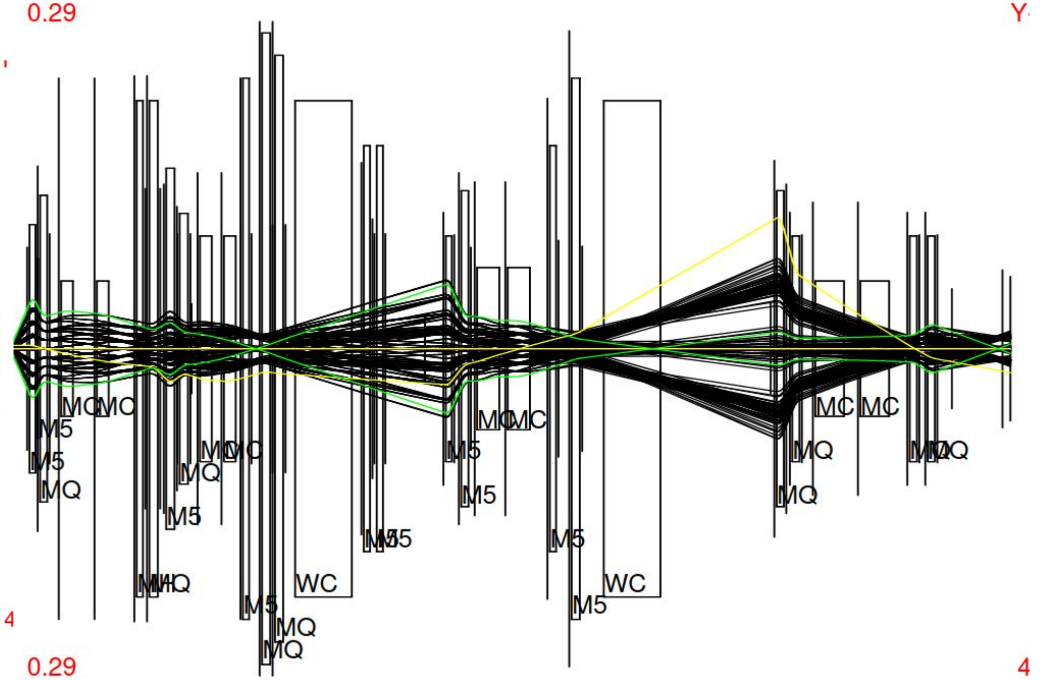

Examining Candidate Solutions

- Improvement in FP4 Beam Spot Size and Max Beam Width is clear
- Fixing Q12-Q15 has a clear impact on the behavior past FP3

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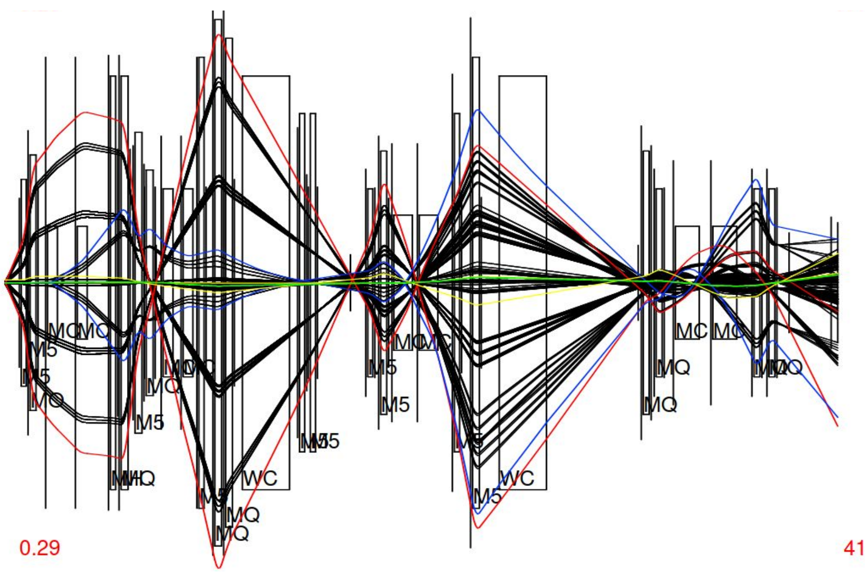

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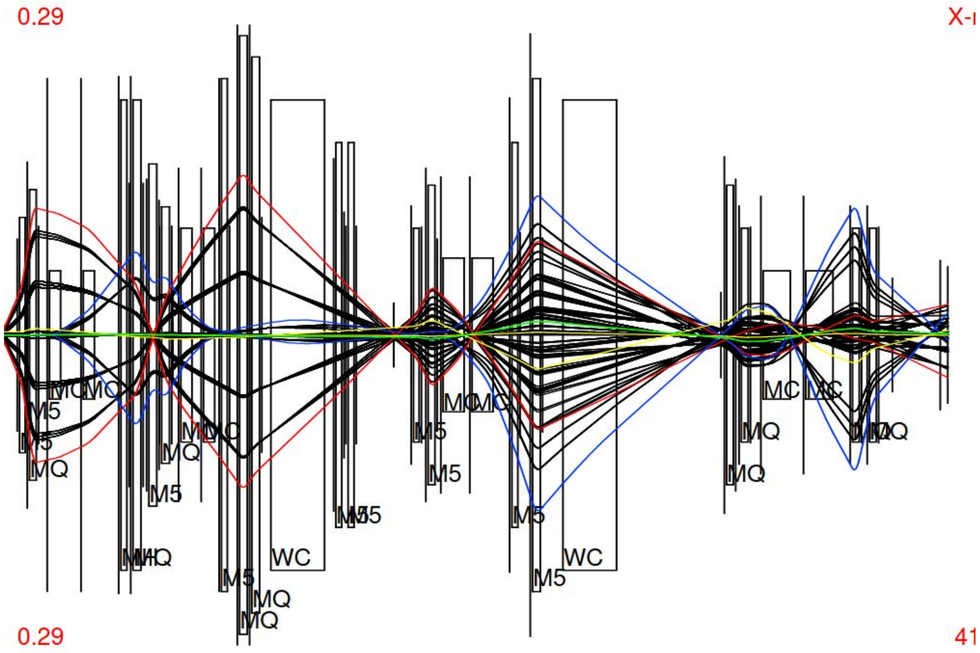

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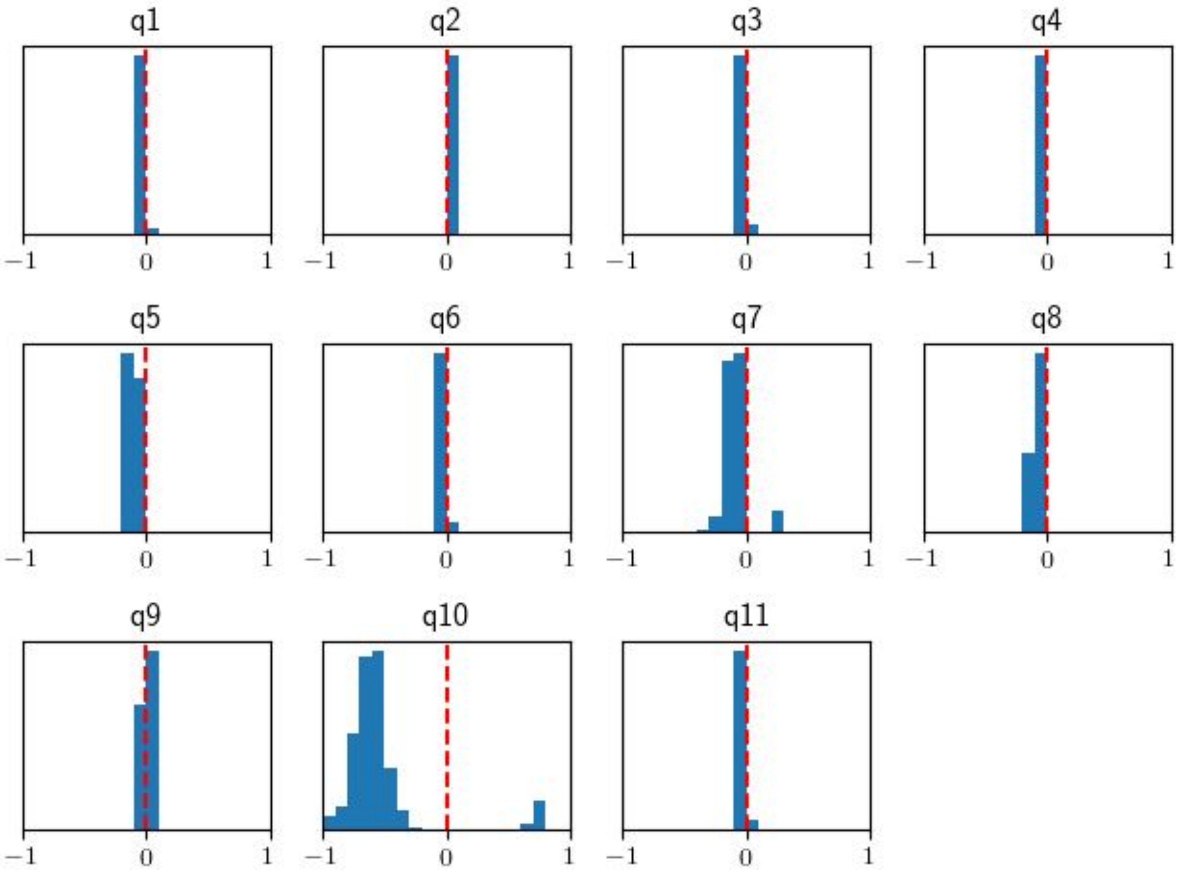
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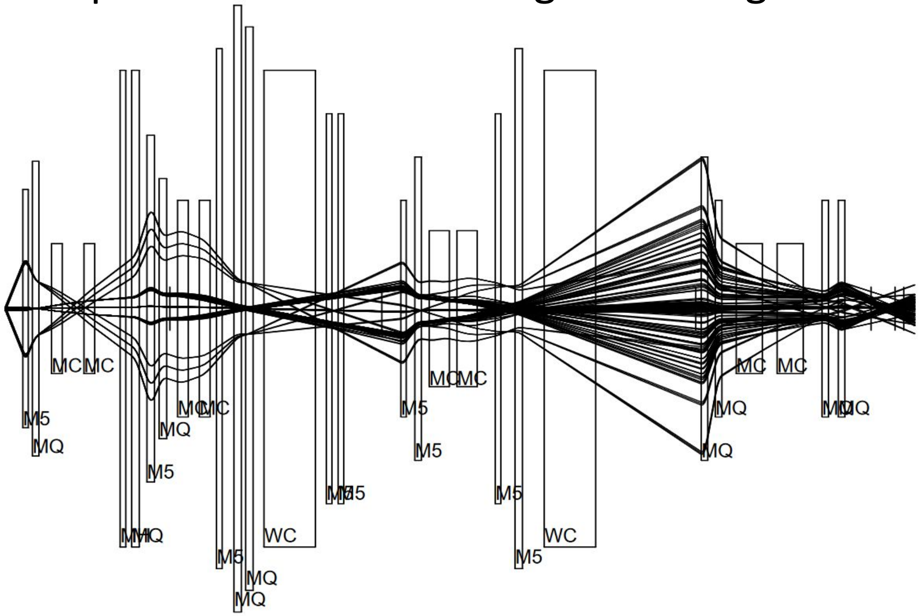

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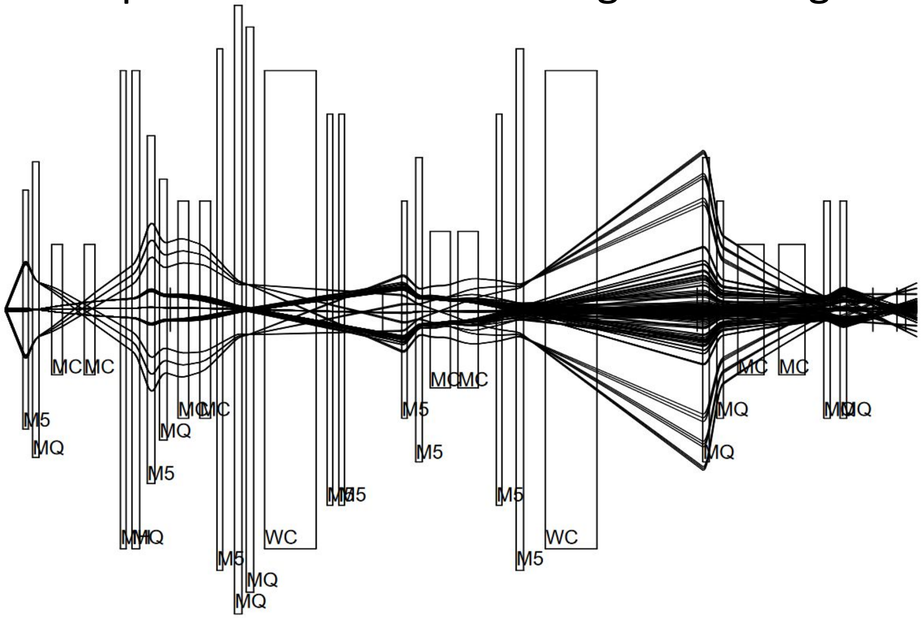

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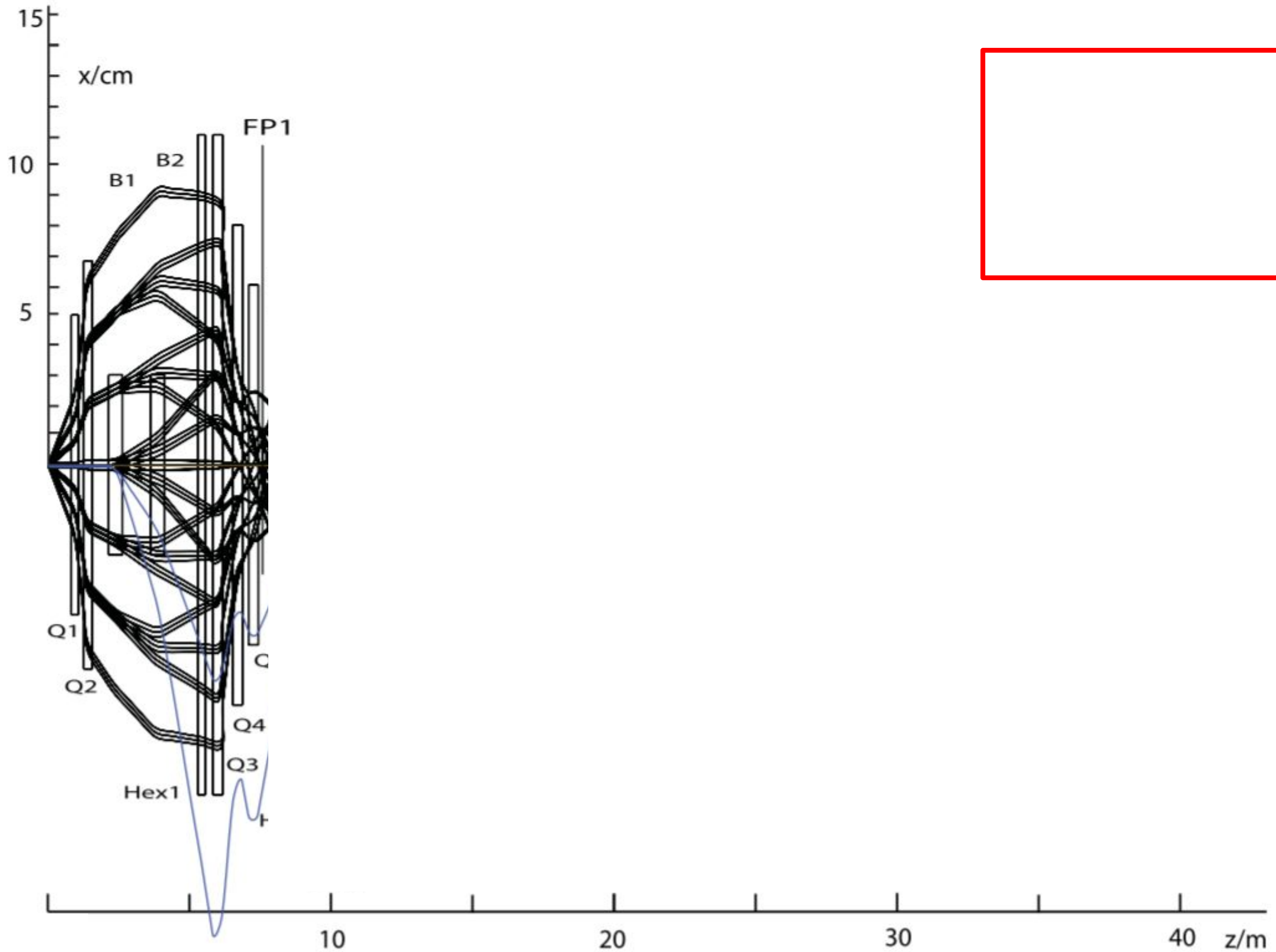

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