Current status of double bunch generation at FLASH

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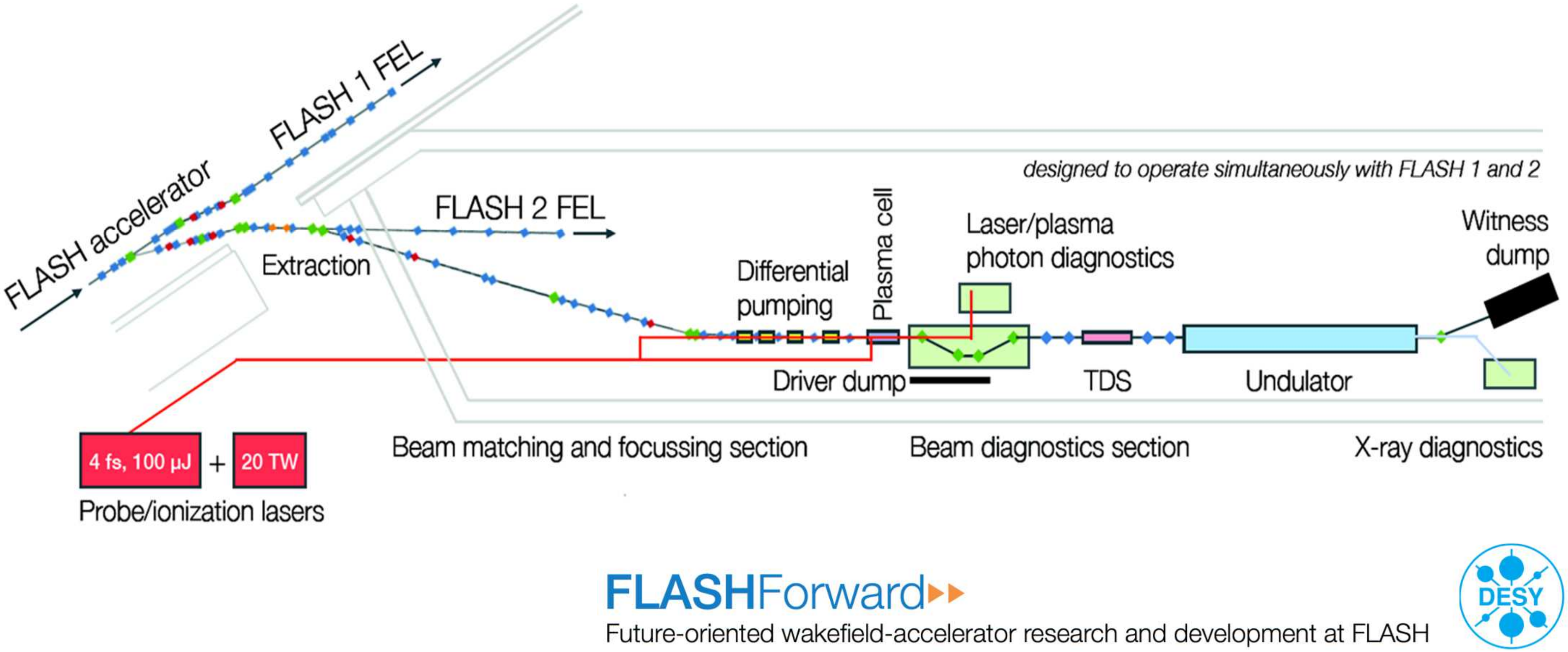
S2E meeting, 12/10/2015

Overview

- Introduction
  - FLASHForward
  - Double bunch
- Experiments
  - Pulse stacker
  - Flash gun
  - Beam transport
  - LOLA
  - Lessons learnt
- Simulations
  - Previous work
  - Gun simulations with ASTRA
  - Analytic model
  - 1D tracking codes
  - Solvers
- Summary

FLASHForward



Double bunch

- Why double bunch?
  - External injection at FLASHForward.
  - Two colour FEL.

- Why pulse stacker to generate double bunches at FLASH?
  - Can tune charge of bunches independently.
  - Can tune initial distance between bunches.

- FLASHForward requirements.
  - Final bunch distance ~100 µm.
  - Witness bunch charge less than driver bunch charge.
  - Witness bunch shorter than driver bunch.

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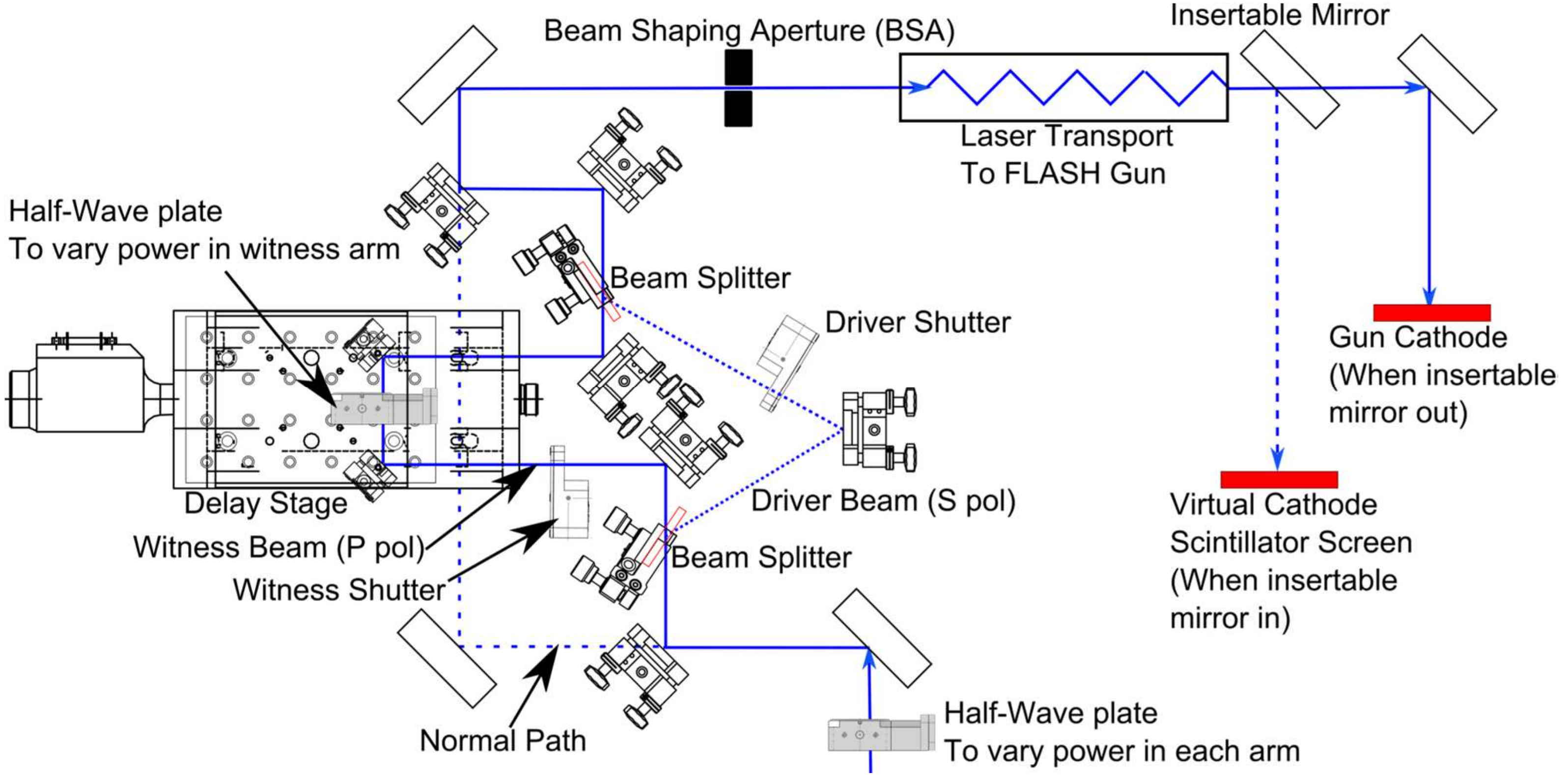
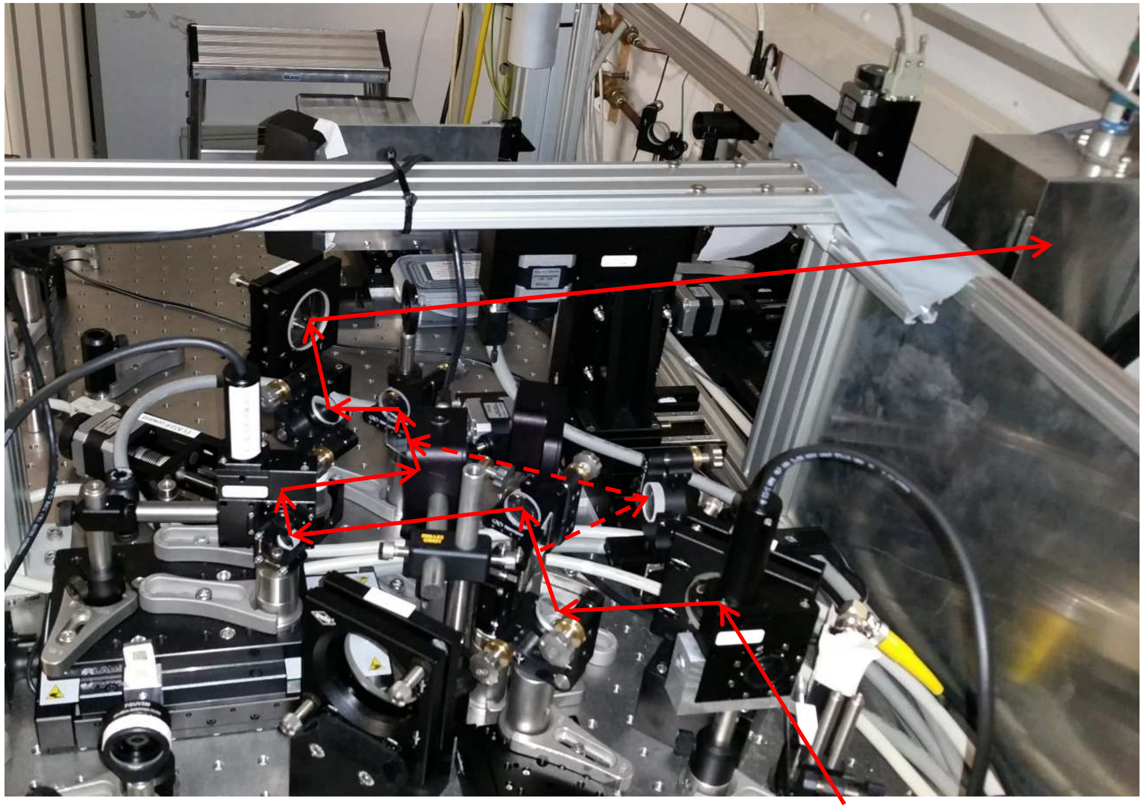
Pulse stacker



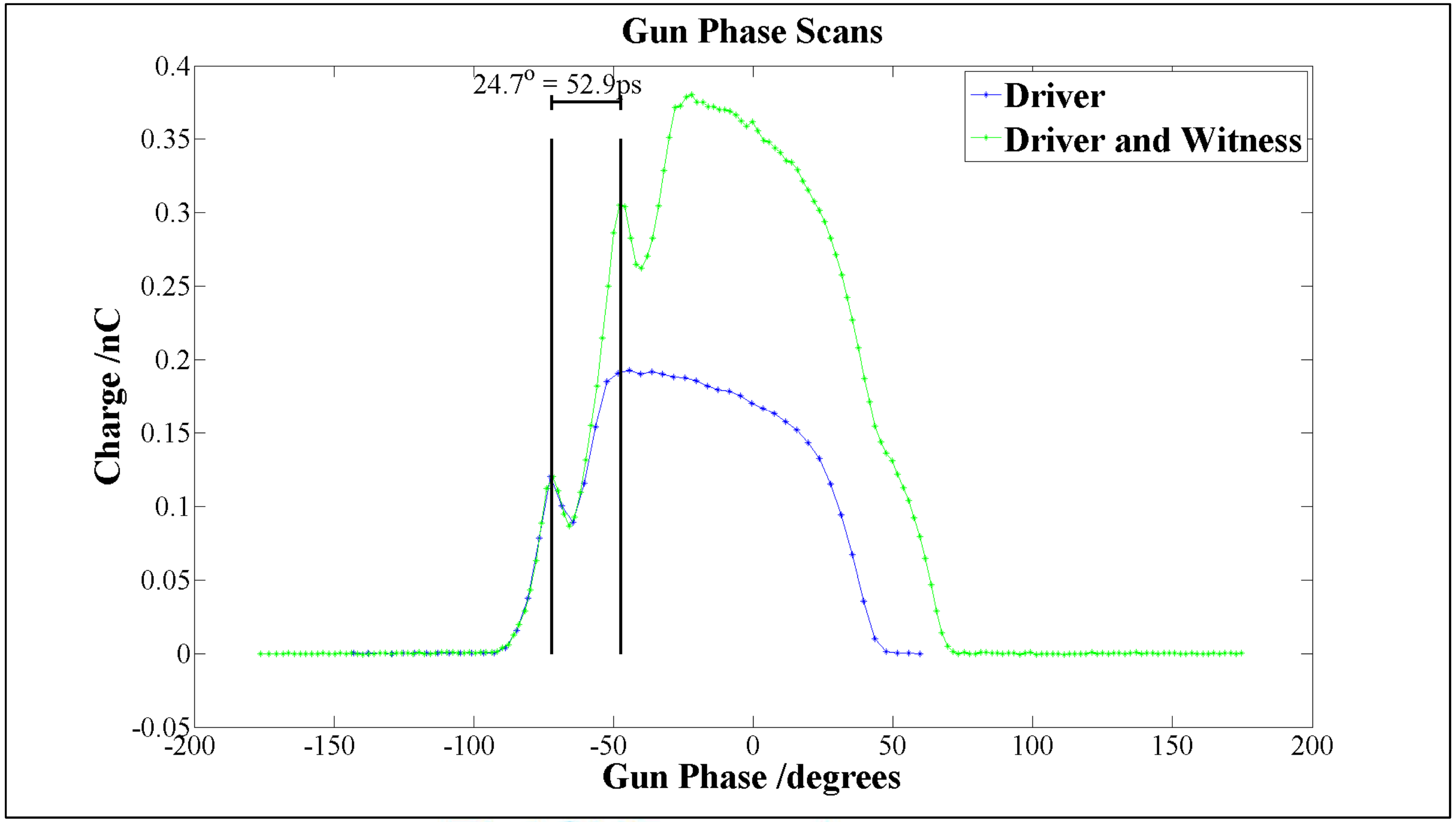
Pulse stacker



FLASH gun

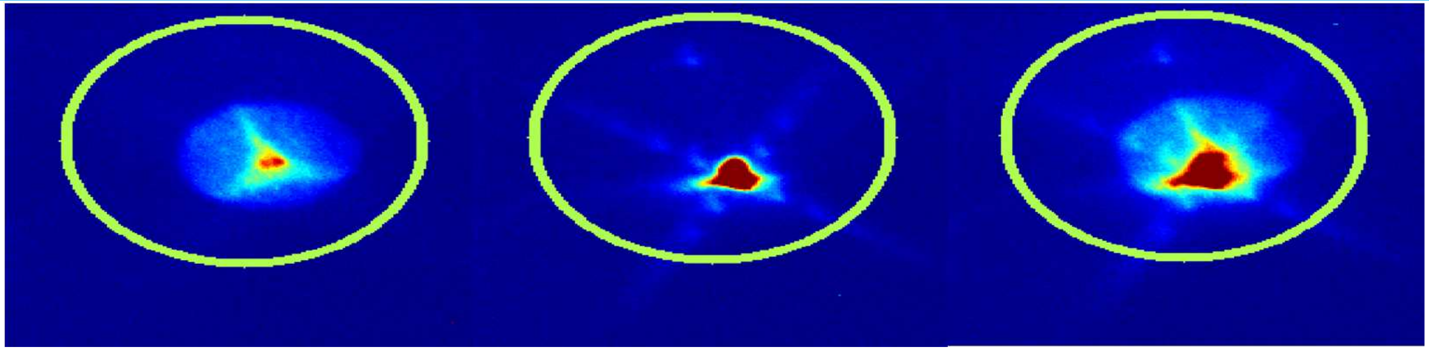
- Images of laser pulses on the virtual cathode.
- Brightness difference due to different number of electron bunches

FLASH gun


Gun Phase Scans
24.7° = 52.9ps
Driver
Driver and Witness
Charge /nC
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-200
-150
-100
-50
0
50
100
150
200
Gun Phase /degrees

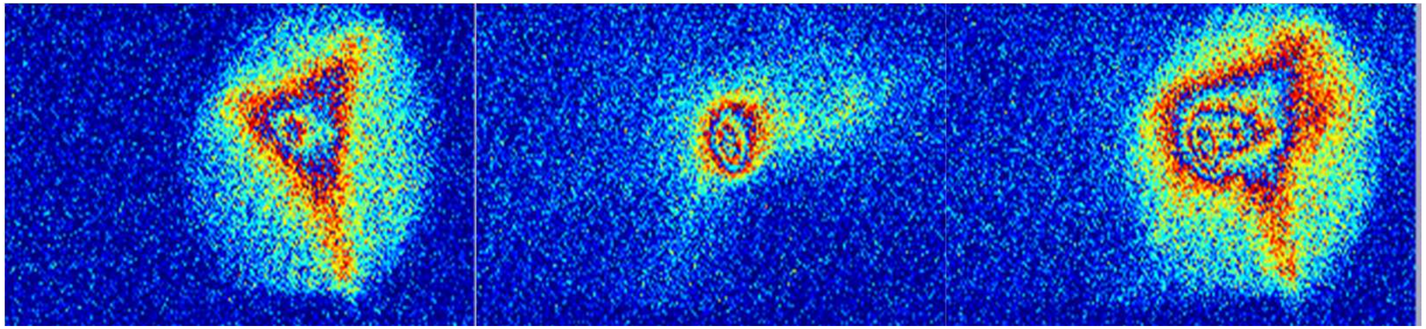
Beam transport

Screen
Gun 3



Driver | Witness | Both

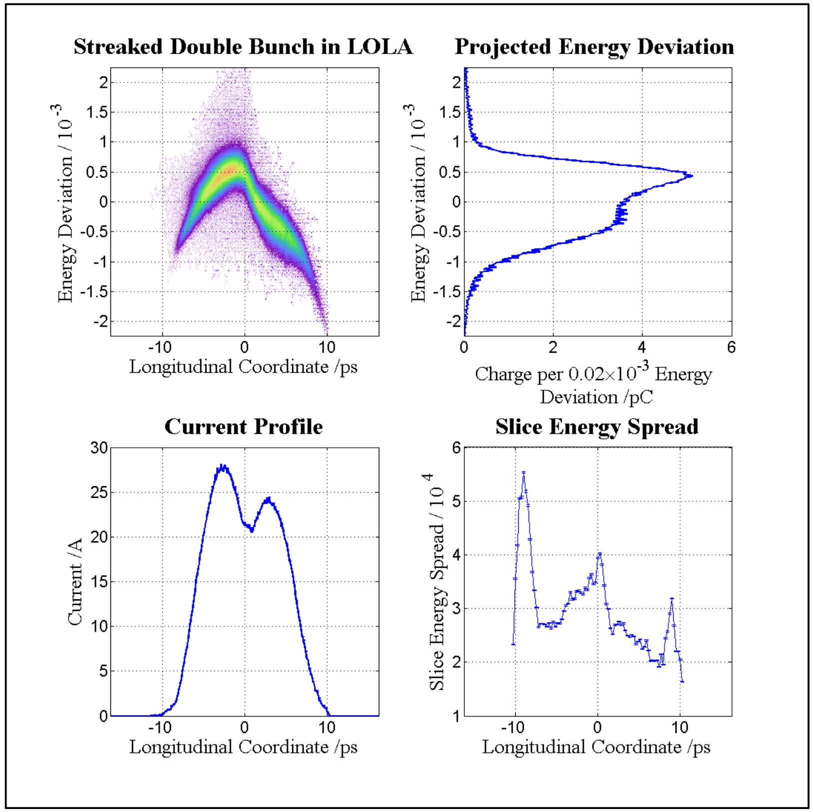
Screen
10DBC2

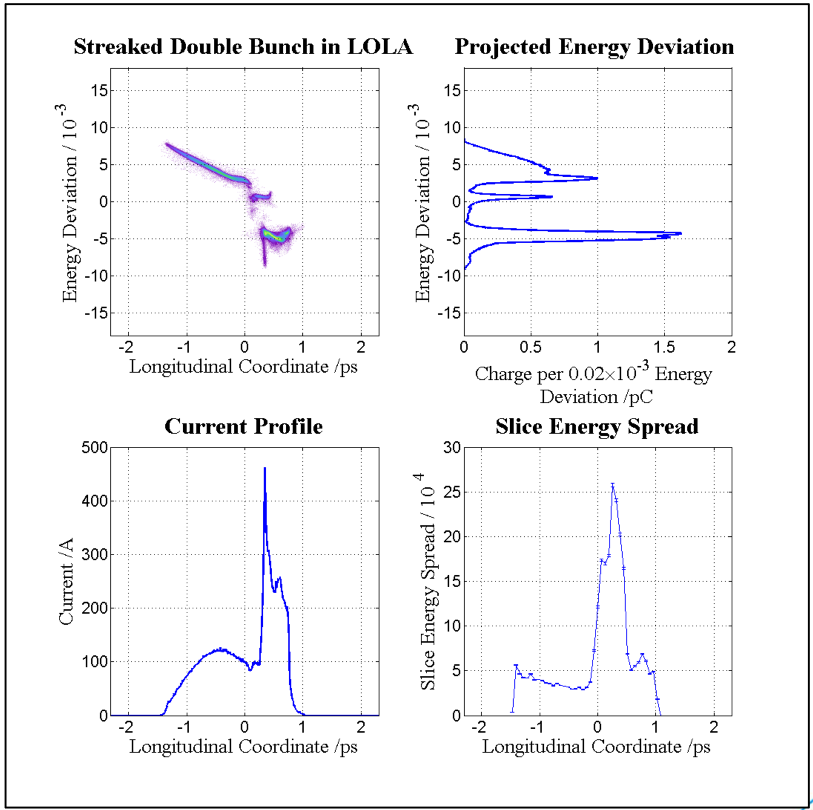


FLASHForward
Future-oriented wakefield-accelerator research and development at FLASH

DESY

LOLA measurements





Experimental lessons learnt

- Pulse stacker needs to be upgraded.
  - Currently not very stable over long periods of time.
- Beam losses due to energy in BC2.
  - Possible due to too high an energy in BC2.
- Can perform delay measurements with gun scans.
- Need to determine working points in machine compatible parameters.
- More time requested for next year.
- Simulations are on going.

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Previous work

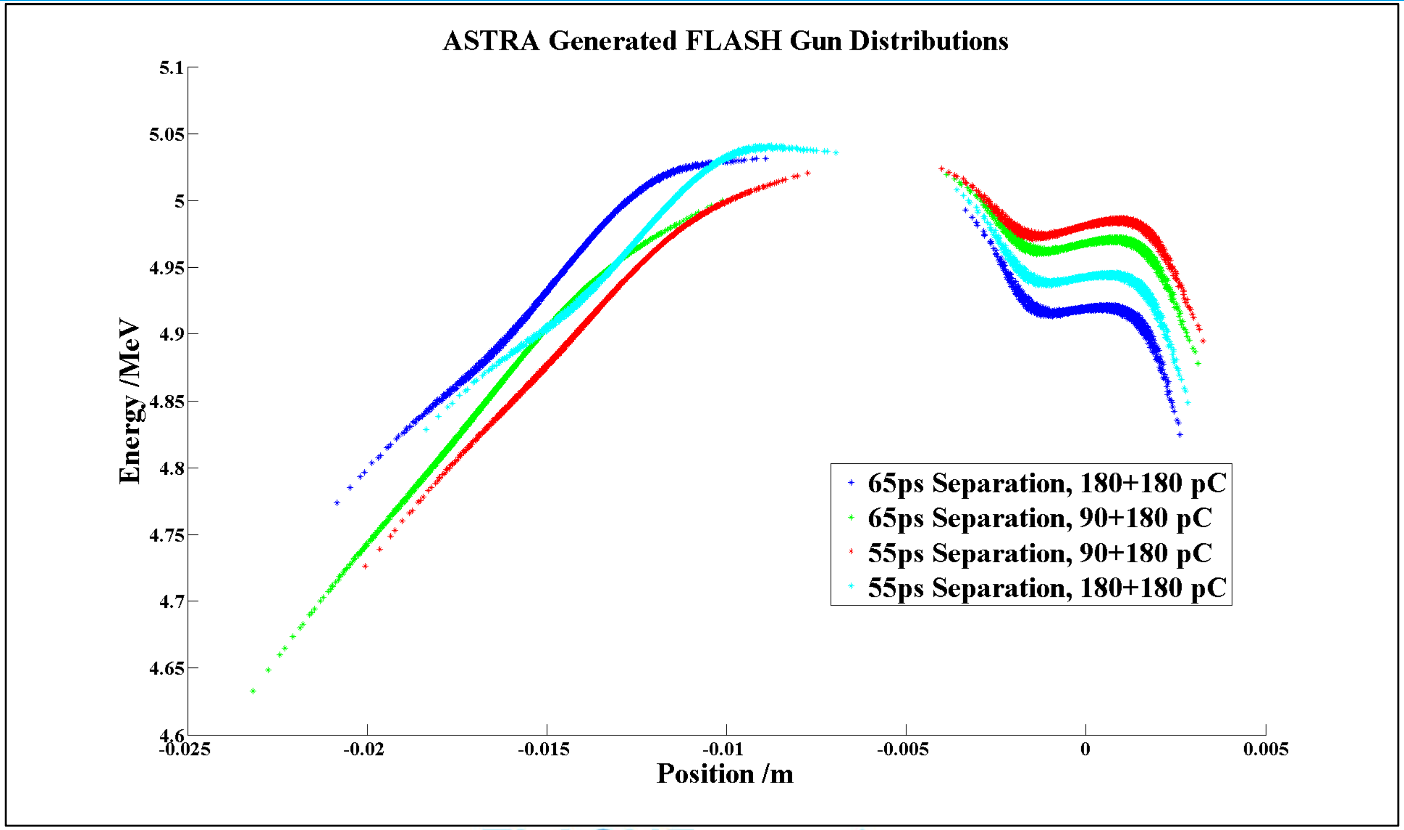
- Initial double bunch simulations performed by Carlos Entrena Utrilla (former masters student) [1] supervised by Steffen Wunderlich.

- Gun simulated with ASTRA[7] (3D) with collective effects.
  - Can set different charges for the bunches.
  - Can adjust the delay between the bunches.
  - Can adjust the phase in the gun.

- Semi-analytical model with RFTweak (1D tracker) to determine compression and RF parameters [1].

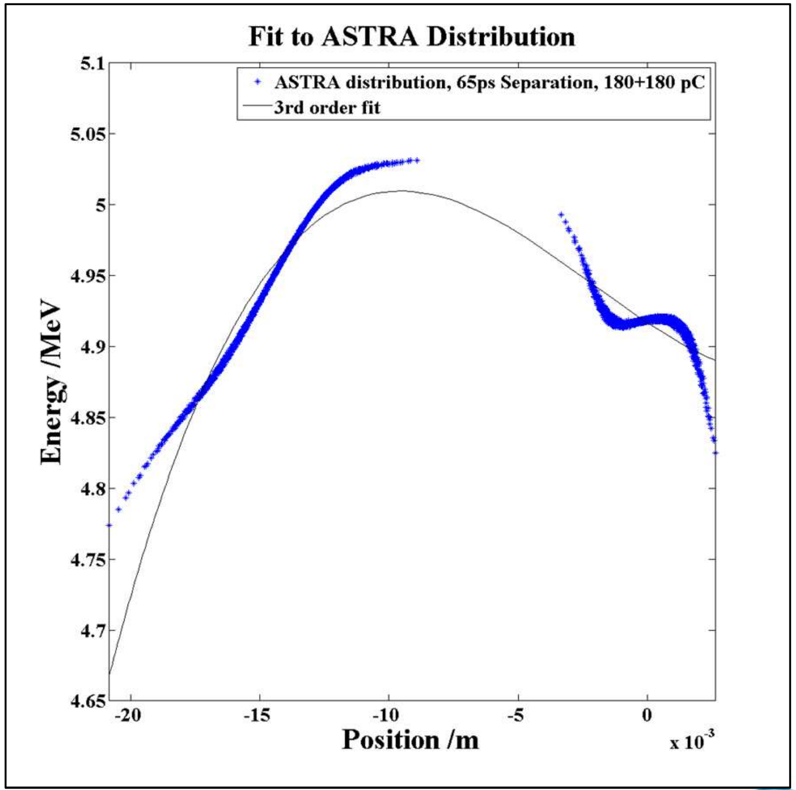
- Defined centre (zero phase) as weight between both bunches
  - Definition of zero phase not easily realisable in FLASH.
  - Now changed to centre of drive (first) bunch.

Gun simulation with ASTRA



1D FLASH analytical model

- Simple equations [1,3]
  - No tracking
  - No Collective effects.
- Fit to the initial distribution
  - 3rd order polynomial $(E_{0,\Delta s_0} = A + B\Delta s_0 + C\Delta s_0{}^2 + D\Delta s_0{}^3)$
- RF module equations:
  - $\Delta E_{ACC1,\Delta s_0} = V_{ACC1} \times \cos(\varphi_{ACC1} + k\Delta s_0)$
  - $\Delta E_{ACC39,\Delta s_0} = V_{ACC39} \times \cos(\varphi_{ACC39} + 3k\Delta s_0)$
  - $\Delta E_{ACC23,\Delta s_2} = V_{ACC23} \times \cos(\varphi_{ACC23} + k\Delta s_2)$
- Compressor equations:
  - $\Delta s_2 = \Delta s_0 - \left(R_{56,2}\delta_{39,\Delta s_0} + T_{566,2}\delta_{39,\Delta s_0}{}^2 + U_{5666,2}\delta_{39,\Delta s_0}{}^3\right)$
  - $\Delta s_3 = \Delta s_2 - \left(R_{56,3}\delta_{23,\Delta s_2} + T_{566,3}\delta_{23,\Delta s_2}{}^2 + U_{5666,3}\delta_{23,\Delta s_2}{}^3\right)$
  - $\delta_{n,\Delta s_c} = \left(E_{n,\Delta s_c} - E_{n,0}\right)/E_{n,0}$
- Derive functions for energy and position at different locations.



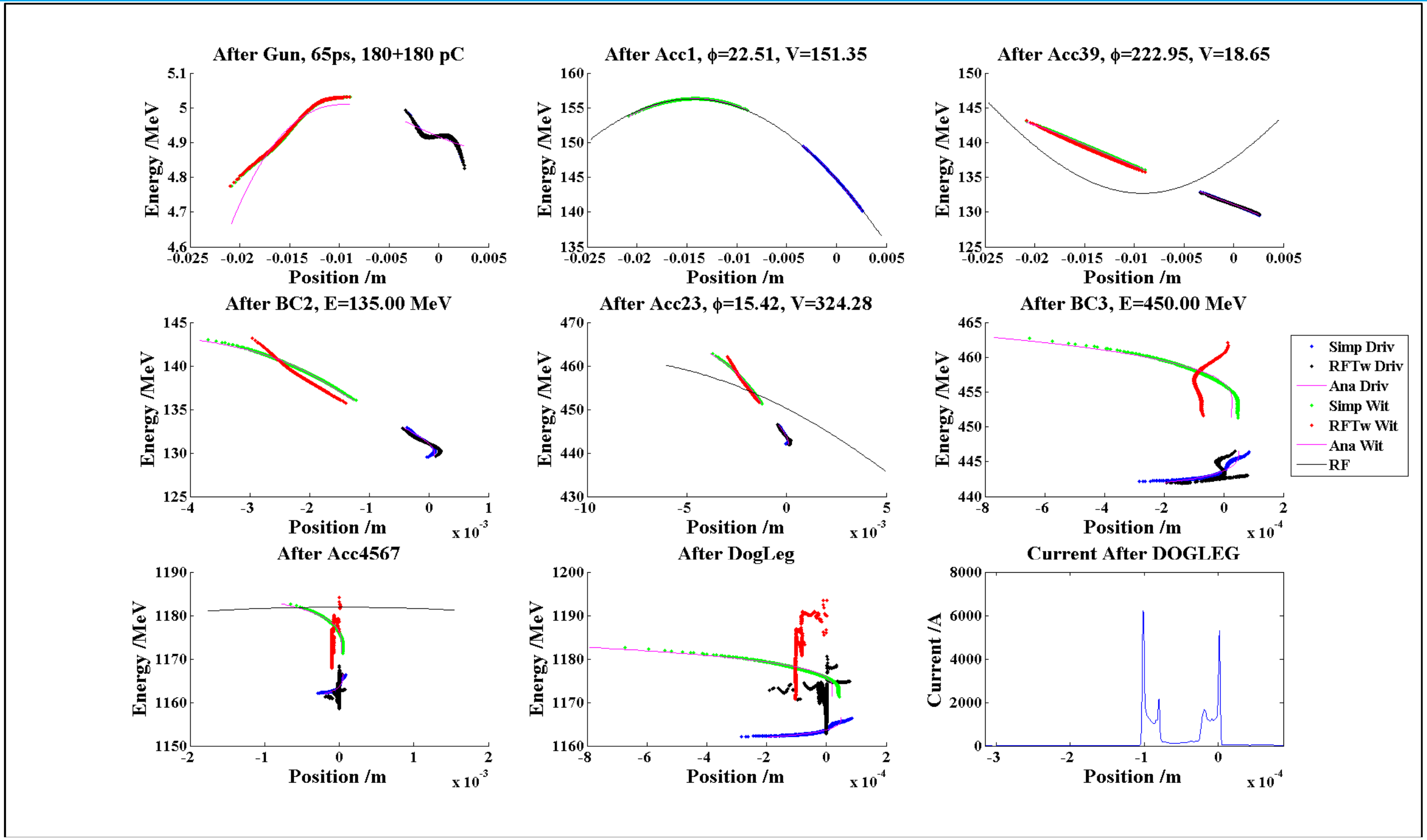
1D FLASH particle tracking codes

- 1D simple tracker.
  - Application of 1D equations to input distribution.
  - ASTRA input.
  - No collective effects.

- RFTweak[2].
  - 1D.
  - ASTRA input.
  - Collective effects:
    - Wakefields
    - Space charge
    - CSR

- Both take the RF and compressor parameters to track the particles.

Comparisons



Compression scenario

- To tune RF parameters to achieve desired compression scenario

- 6 RF parameters, need min 6 compression parameters[1]
  - Compressor energy $E_{ACC39,\Delta S_{0,mid}} = 135\ MeV$
  - Compressor energy $E_{ACC23,\Delta S_{2,mid}} = 450\ MeV.$
  - Inverse compression after BC2, $Z_2 = \left.\frac{\partial \Delta S_2}{\partial \Delta S_0}\right|_{\Delta S_{2,mid}} = \frac{1}{6}$
  - Total inverse compression. $Z_3 = \left.\frac{\partial \Delta S_3}{\partial \Delta S_0}\right|_{\Delta S_{3,mid}} = \frac{1}{160}$
  - 1st order compression shape factor. $Z_3'|_{\Delta S_{3,mid}} = 0.0$
  - 2nd order compression shape factor. $Z_3''|_{\Delta S_{3,mid}} = \frac{2\left({}^{1}/_{C_d} - Z_3\right)}{\Delta S_{3,mid}{}^2}, C_d = 100\ \mu m$

- Can derive equations for compression scenario from 1D analytic equations.
  - Very long and not shown here.

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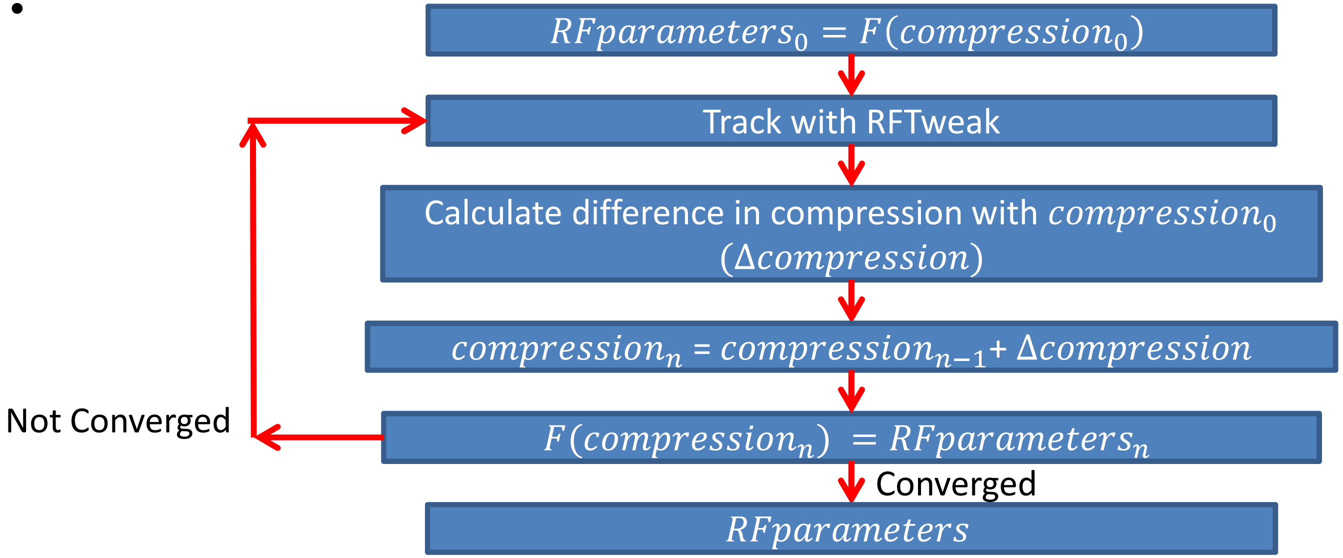
DESY

Semi-analytical solver

- Derive function for RF values from compression scenario [3].
  - $F(compression) = RFparameters$
- 

- Difficulties
  - If skip first point and give optimal RF values, would iterate to non optimal solution and then iterate back.
  - With double bunch RFTweak can fall over when in a very non optimal solution.

Gauss Markov solver

- Definitions[4]:
  - X is vector or variables.
    - RF parameters.
  - L is vector or measurements/desired parameters.
    - Compression scenario.
  - $F(X)$ is vector or calculated/simulated/measured parameters.
    - From RF parameters determines compression parameters
    - Analytic equations, 1D simple tracker or RFTweak.
  - P is the weight matrix (inverse error matrix)
    - Importance of the different compression scenario parameters

Gauss Markov Solver

- $W = F(X) - L$, want to minimize this value.
- $\hat{X} = -(A^T P A)^{-1} A^T P W$
  - $A = \frac{\partial F(X)}{\partial X}|_X$
  - A is calculated using the analytic formulas.
  - No longer dependant on full form of equations, only the first derivatives.
  - Still requires all parameters (R56 etc).
- $X = X - \hat{X}$
- Use damped Gauss Newton line search with RFTweak[5,6].
- Can use the solver with all three methods.

Gauss Markov Solver

Define Initial RF parameters, Phases, 0,180,0, Voltages 160,21,350 MeV

↓

Define compression scenario

↓

Gauss Markov with analytic equations, with initial RF parameters

↓

Gauss Markov with 1D simple tracker, with analytic RF parameters

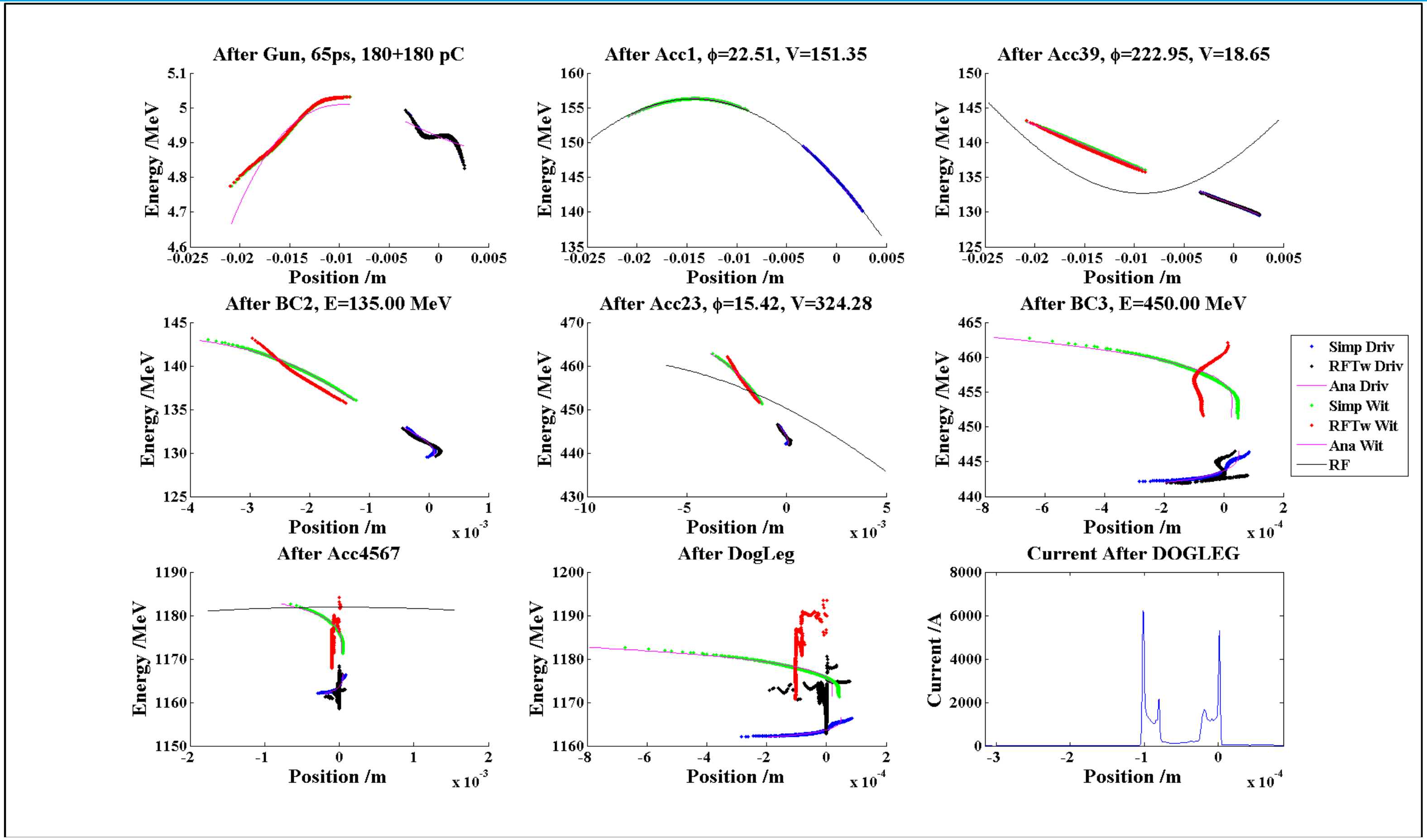
↓

Gauss Markov with RFTweak, with 1D simple tracker parameters

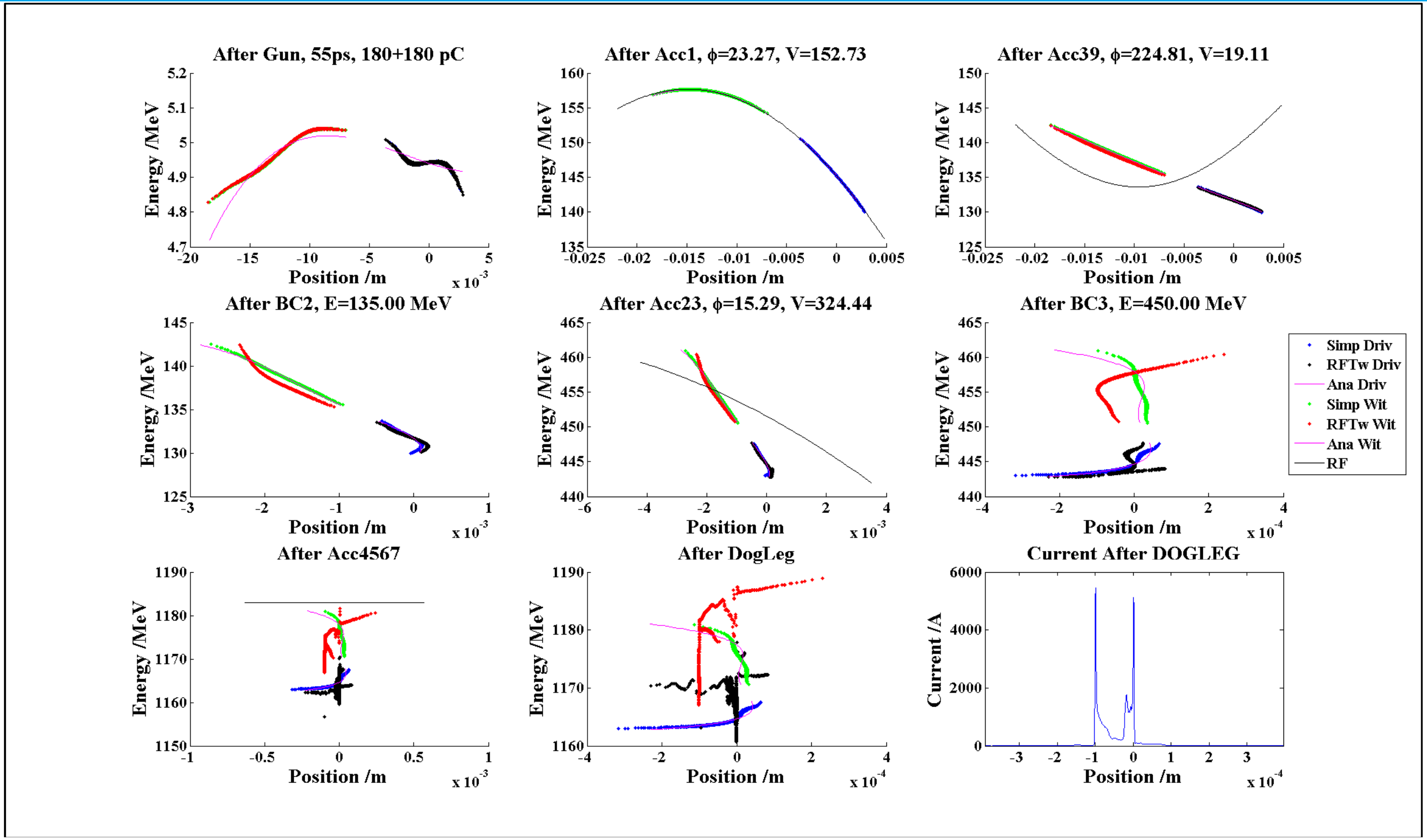
↓

Final RF parameters

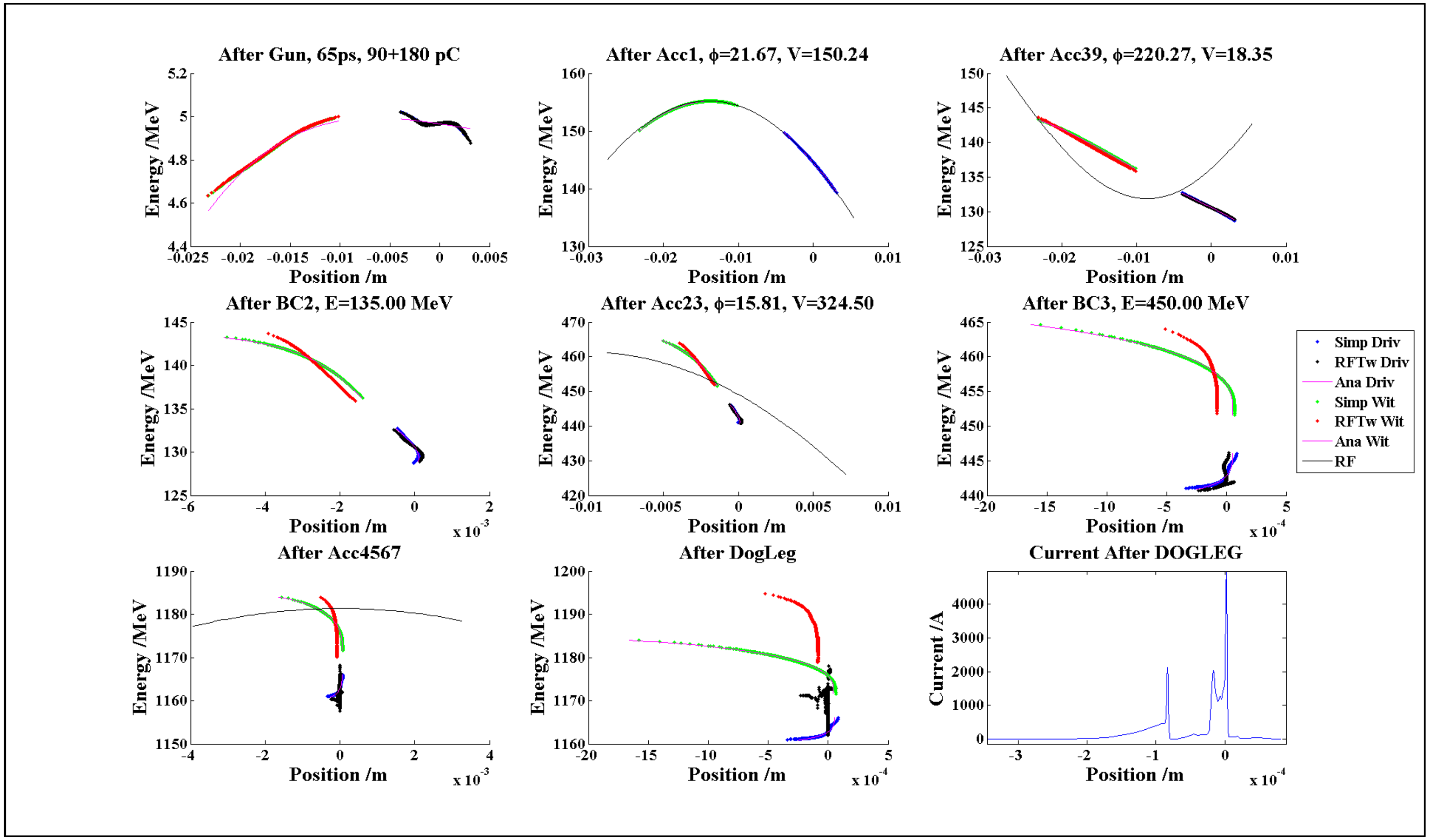
180pC, 180pC, 65ps



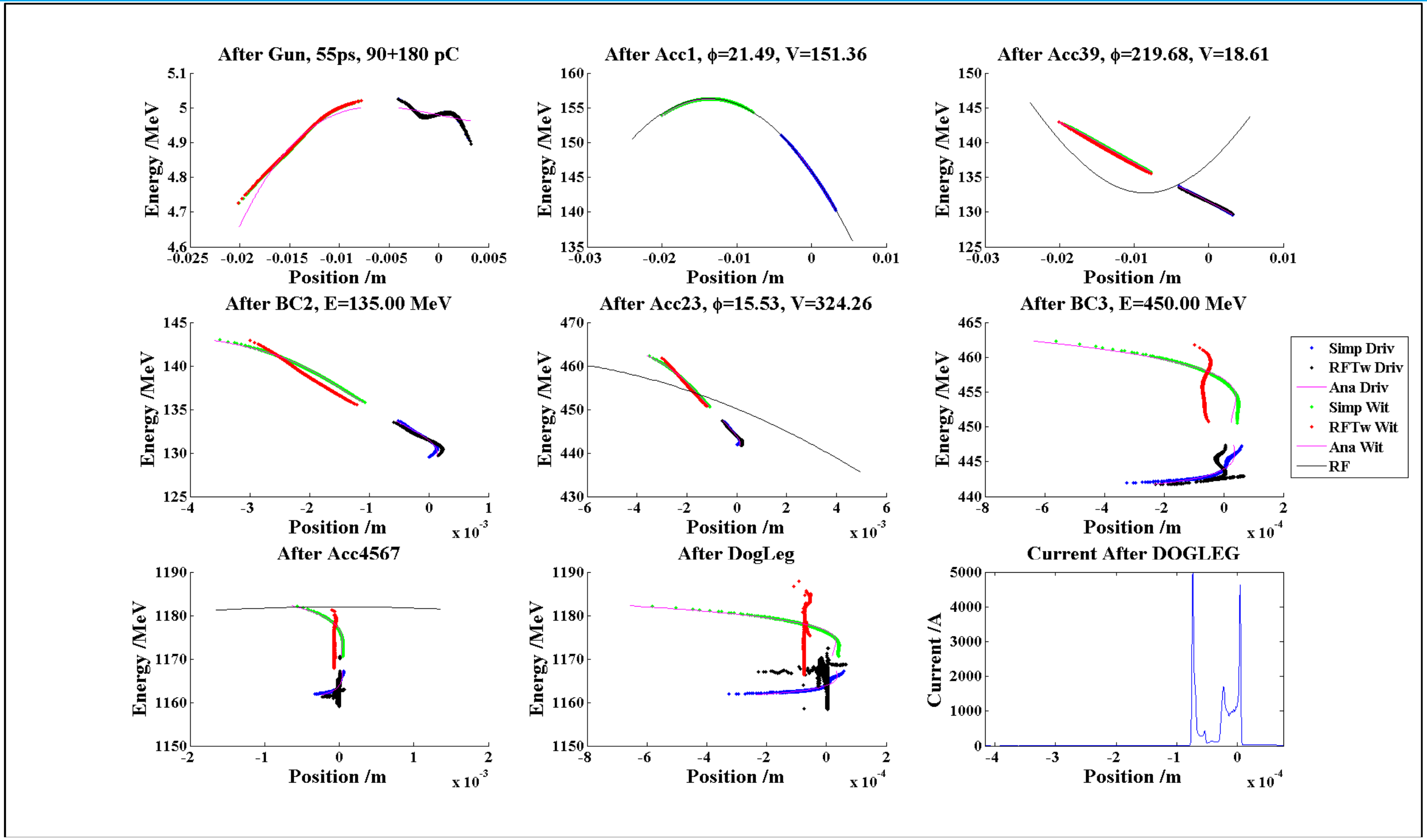
180pC, 180pC, 55ps



180pC, 90pC, 65ps



180pC, 90pC, 55ps



Future work

- Comparison of semi-analytical and Gauss Markov solver
  - Number of iterations.
  - Difference in results.

- More work on new solver
  - Can it be made faster?
  - Weighting the compression scenario.
  - 3D simulations.
  - Understand uncertainties and errors (different parameters in analytical and simulation).
  - Can add more equations.

- Determine range of working points for different.
  - Gun phases.
  - Charges.
  - Initial delays.
  - Compression scenarios.
  - Change in definition.

- Can Gauss Markov solver be applied to FLASH?
  - Can equations be derived for the machine measurements?
  - Can the model be used to steer operations?
  - Kalman filter equations?

Summary

- First experiments conducted
  - Double bunches transported through FLASH
  - Delay can be varied
  - Charge can be varied
  - Pulse stacker needs improvement (alignment)
  - Working points need determining

- New solver developed
  - Uses iterative steps
  - Faster (2-3 iterations) and more reliable for double bunch
  - Calls RF tweak less times
  - Need to explore simulations further.
  - 3D simulations.
  - Explore FLASH usage

- More beam time requested for 2016.

My Questions

- Can the analytical model be improved to be more realistic?
- Are there any improvements?
- Suggested studies for the simulations?
- Other compression scenarios?
- Single bunch simulations.
- XFEL simulations
- Use with FLASH?

References

- [1] C.M.E. Utrilla, Desy-thesis-2014-034, DESY
- [2] M. Dohlus et al, xfel-wiki.desy.de/RF_tweak_GUI
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- [5] Jorge Nocedal and Stephen J. Wright. *Numerical optimization*. Springer, 1999.
- [6] A. Perelmuter. *Adjustment of free networks*. Journal of Geodesy, 53(4):291–295, December 1979.
- [7] K. Floettmann, www.desy.de/~mpyflo/