

LhARA Stage 1 Energy Selection

Slides to be shown at LhARA Fortnightly (06/10/26)

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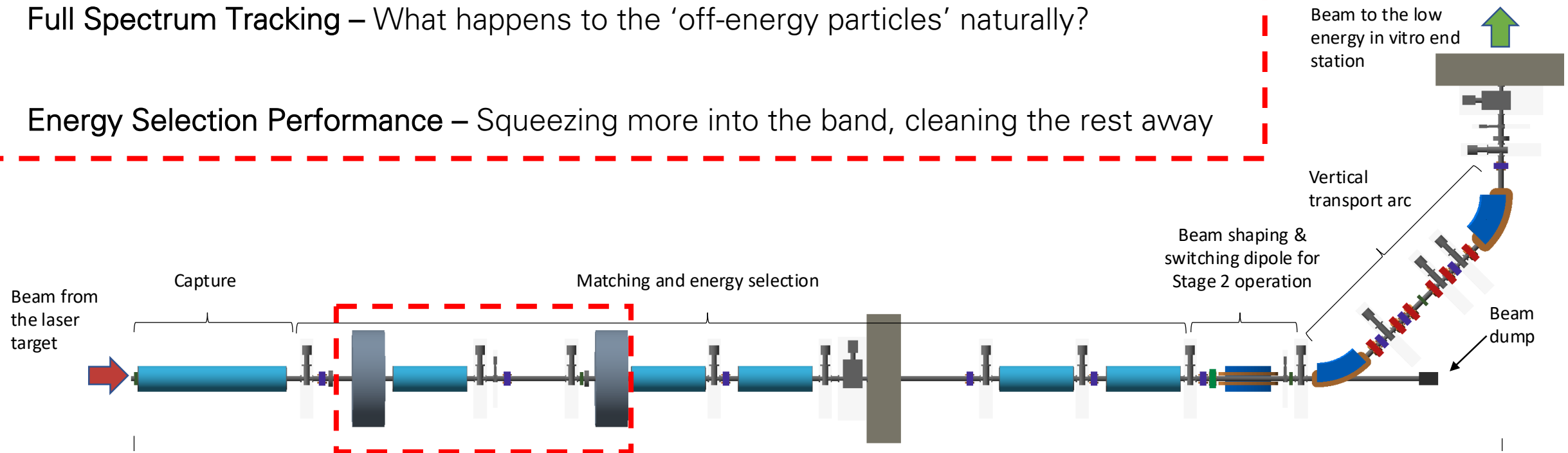
LhARA Stage 1 Start-to-End Tracking

Stage 1 Tracking So Far

- Parametrised Source Beam – Representing the laser-driven beam in simulation
- Source-Nozzle Tracking Workflow – Coupling the target room vacuum to the S1 beamline
- Gabor Lens Optics Matching – Transporting the nominal energy band to the S1 End Station

Next Step – Energy Selection

- Full Spectrum Tracking – What happens to the 'off-energy particles' naturally?
- Energy Selection Performance – Squeezing more into the band, cleaning the rest away

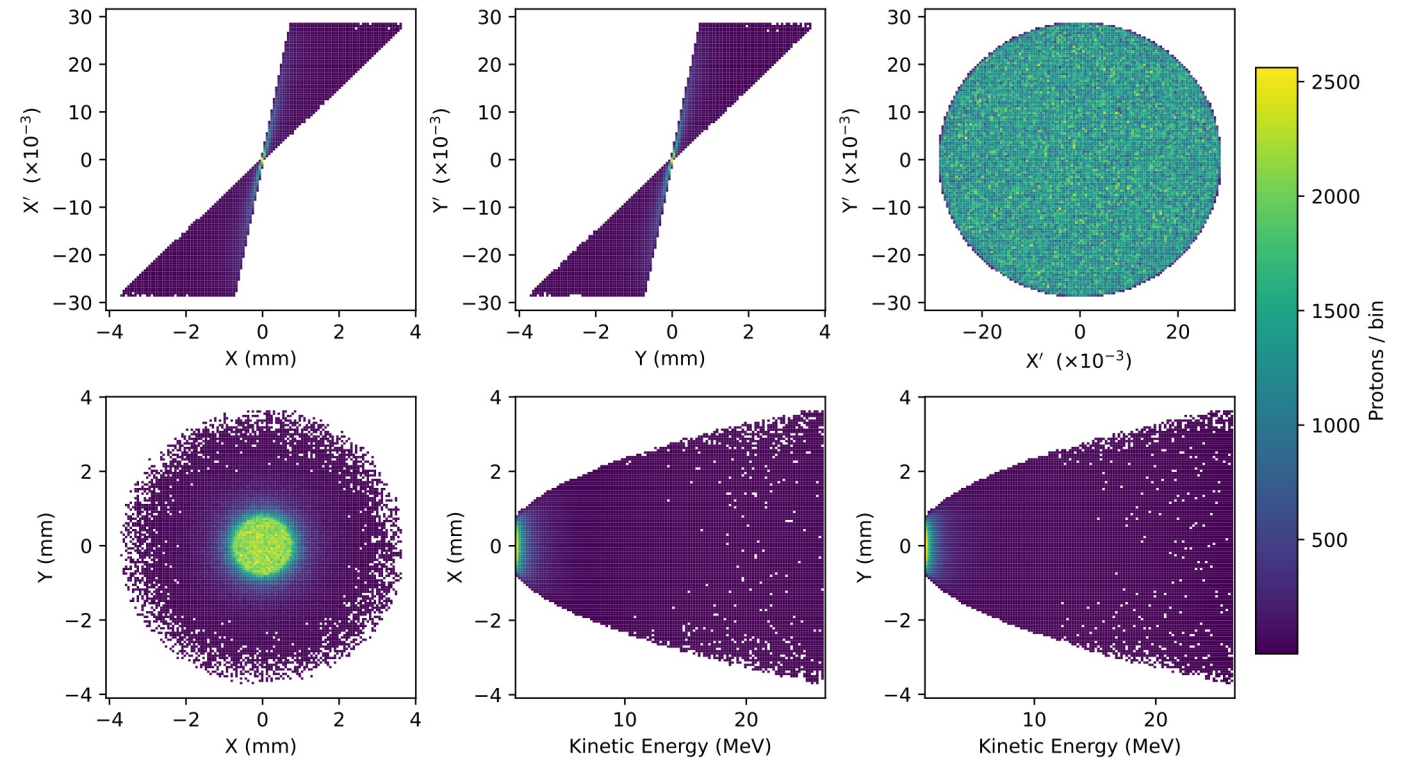
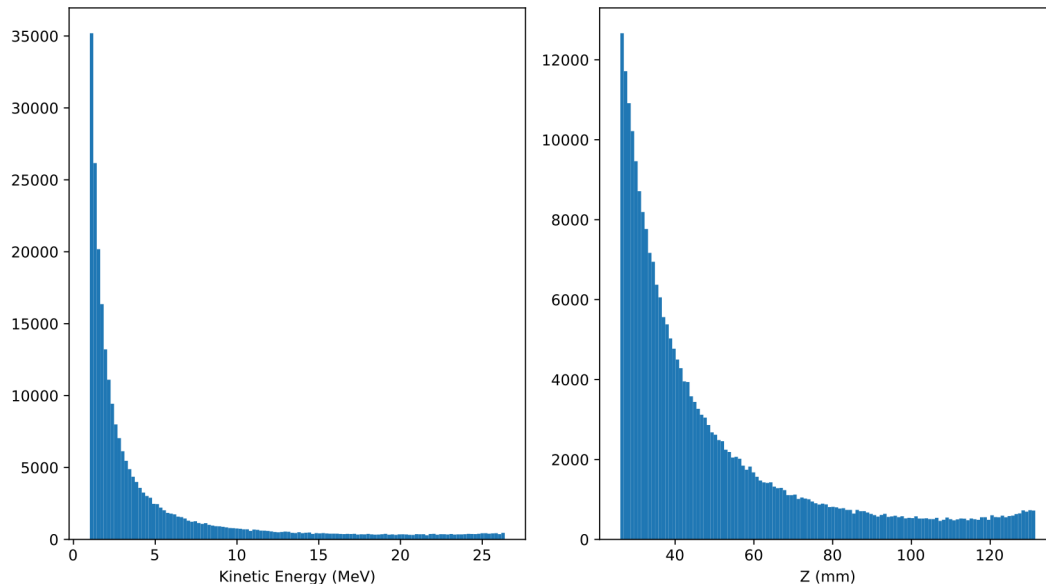


Stage 1 Full Spectrum Beam

Source parameters taken from LhARA CDR for LhARA Linear Optics TNSA beam generation.

Source-Nozzle region simulated in RF Track with space charge.

Particle coordinates at the nozzle exit as input to BDSIM tracking of the Stage 1 lattice
(Shown on this slide)



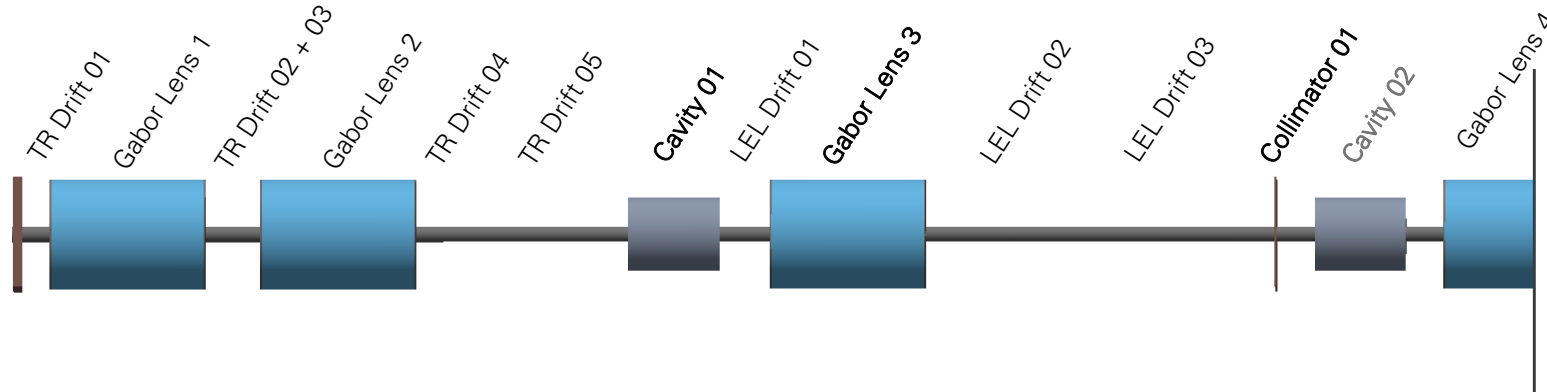
3M protons at source generation

~29,000 protons in $15 \pm 2\%$ MeV band (~1% of total pop.)

250k protons survive the nozzle

~1220 protons in $15 \pm 2\%$ MeV band (~0.5% of total pop.)

Stage 1 Energy Selection



Cavity 1 – Increase the population of the nominal energy band at Collimator 1

Gabor Lens 3 – Focus the nominal energy band to a hard focus at Collimator 1

Collimator 1 – Energy Cleaning at a hard focus

Cavity 2 – Longitudinal Phase Space rotation for bunch length compression

Full Spectrum Tracking at the Collimator

BDSIM Tracking

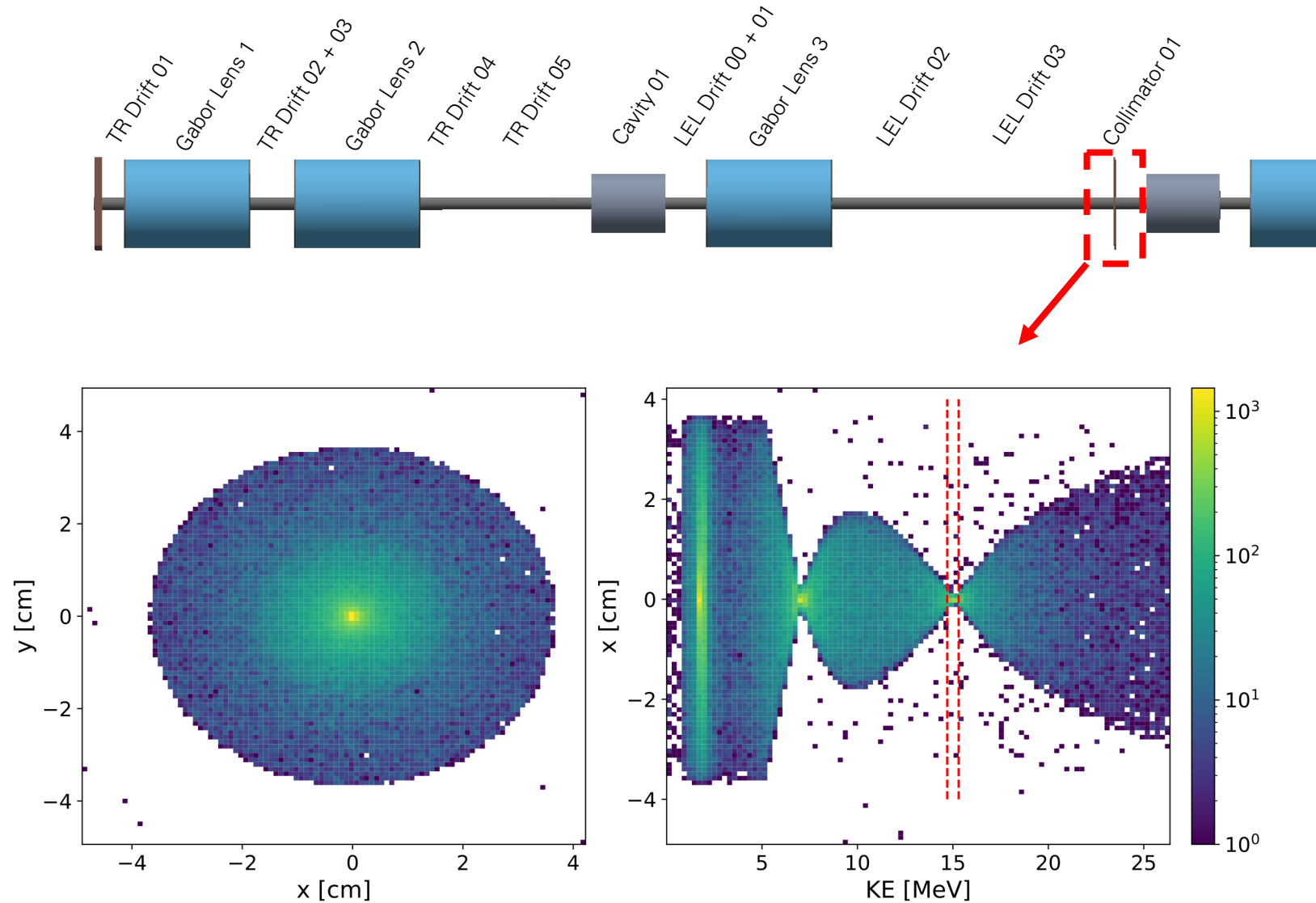
- Physical aperture of 3.65cm
- No RF or Collimation simulated

Three regions of transverse focusing due to the broadband nature of the beam through three chromatic lenses

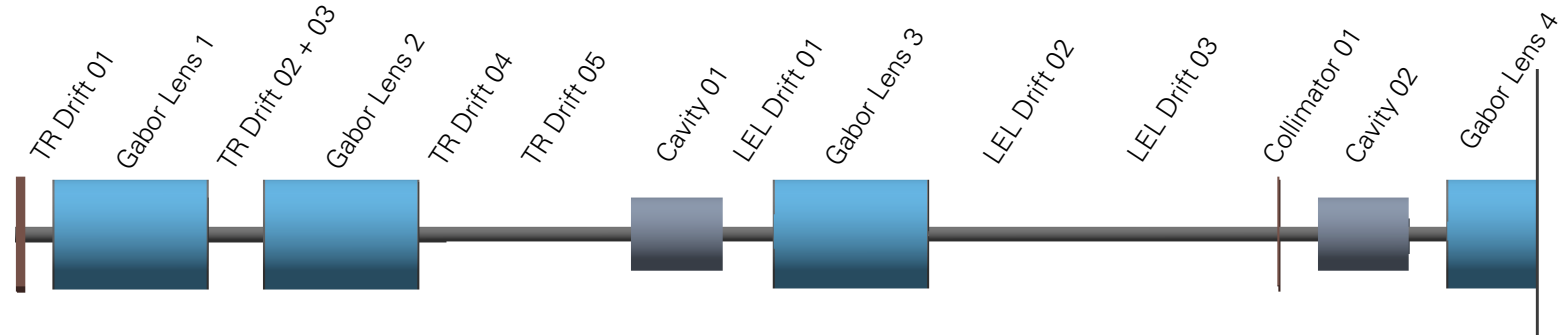
94k protons at the collimator

~1220 protons in $15 \pm 2\%$ MeV band

~63% total beam loss but in-band population is maintained from nozzle to collimator



Stage 1 Energy Selection



Fixed Parameters

Cavity 1

- Frequency - 50 MHz
- Length – 0.26 m

Gabor Lens 3

- Length – 0.857 m

Collimator 1

- Length – 1 cm
- Material - Iron

Free Parameters

Cavity 1

- Voltage [MV]

Gabor Lens 3

- Field Strength [T equiv.]

Collimator 1

- Aperture Radius [mm]

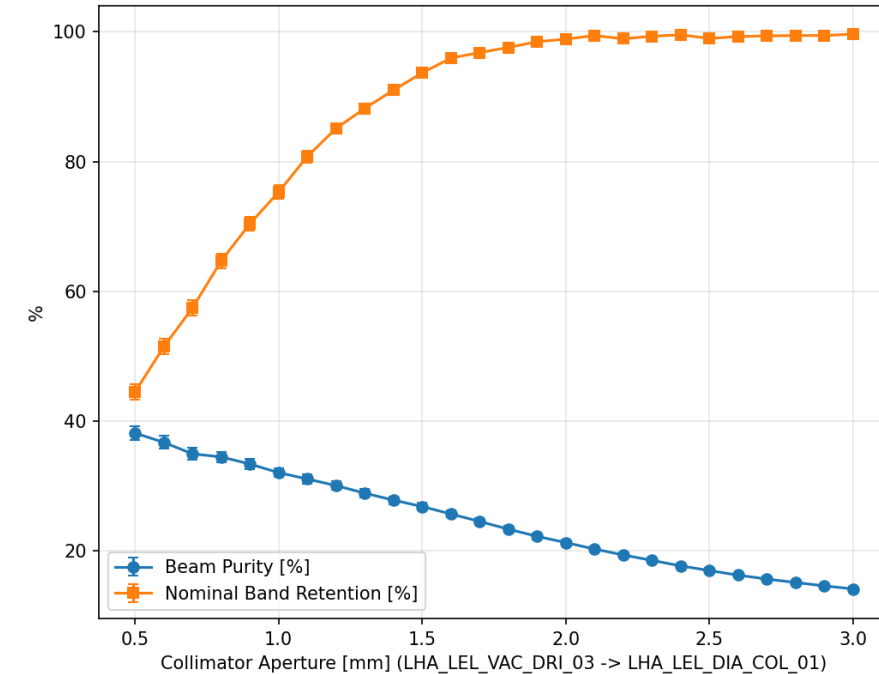
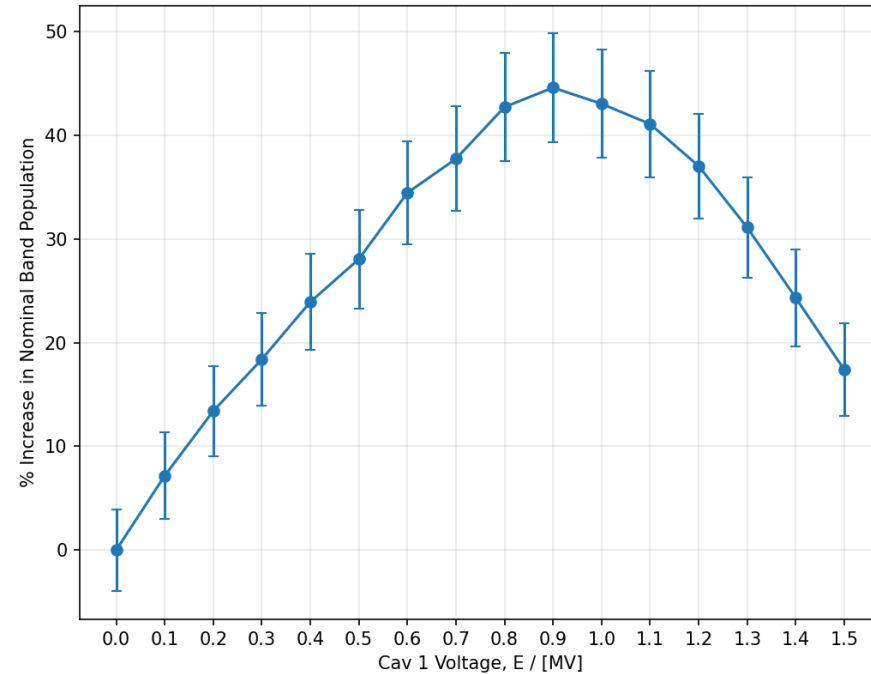
Objectives

1. Increase the population of the nominal band (yield)
2. Clean away particles outside of the band (purity)

Sequential Grid Scans

Optimising one parameter at a time:

- Cavity 1 voltage -> Gabor Lens 3 field strength -> Collimator 1 radial aperture



Achieved a 37% increase in the nominal band population with a beam purity of 21% (Sampled after Cavity 2)

- Cavity Voltage – 0.9 MV, GL3 Field – 0.84 T equivalent, Collimator Aperture – 2.0 mm radius

Gap – Sequential scans do not see interaction effects between parameters

Rather than scanning for optima element-by-element, Multi Objective Bayesian Optimisation (MOBO)

Free Parameters – {Bounds}

- RF Voltage – {0.5, 1.5} MV
- Gabor Lens 3 Field Strength – {0.1, 1.4} T Equivalent
- Collimator Aperture – {0.5, 3.0} mm

Initial bounds are the same as the sequential scans for comparisons of runtime and convergence.

Objectives – [Bounds]

- Yield - Total particles in the nominal energy band (normalised to primary population) – [0, 1]
- Purity – Band Population / Beam Population – [0, 1]

All optimisation runs begin with 24 quasi-randomly sampled points (SOBOL)

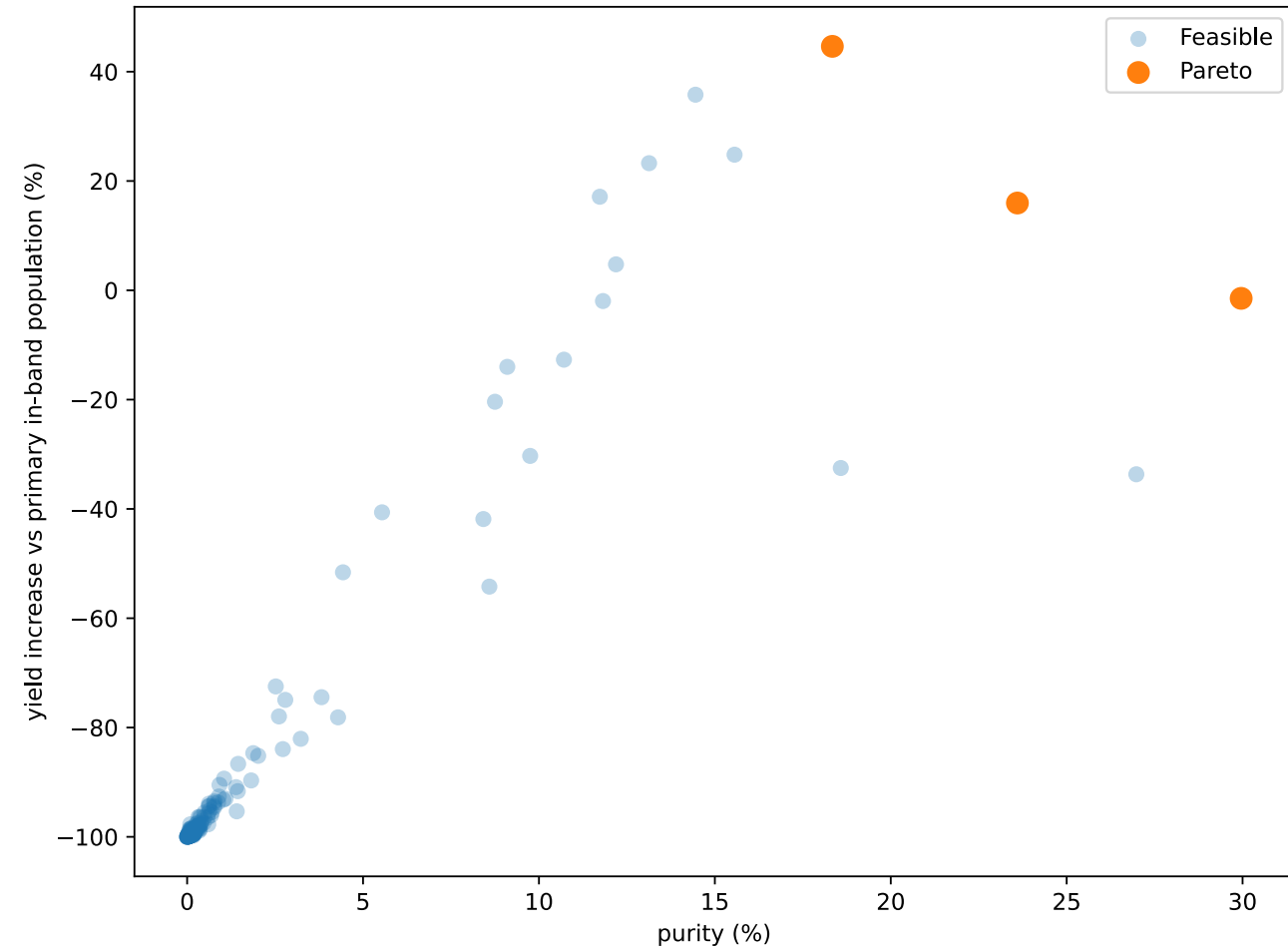
First search follows the random samples with 15 batches of 12 points.

44-minute Run – 12 Core Machine

3 Point Pareto Front

RF Voltage (MV)	GL3 Field (T Equiv.)	COL Aper. (mm)		Purity (%)	Yield (%)
0.934	0.831	0.969		30%	-1.4%
0.787	0.852	1.44		24%	+16%
0.912	0.849	2.30		18%	+45%

We can see the Yield vs Purity trade-off



MOB0 – Finer Search

Tighter Bounds

- RF Voltage – {0.65, 1.05} MV
- GL3B – {0.75, 0.92}
- COL Aper. – {0.3, 4} mm

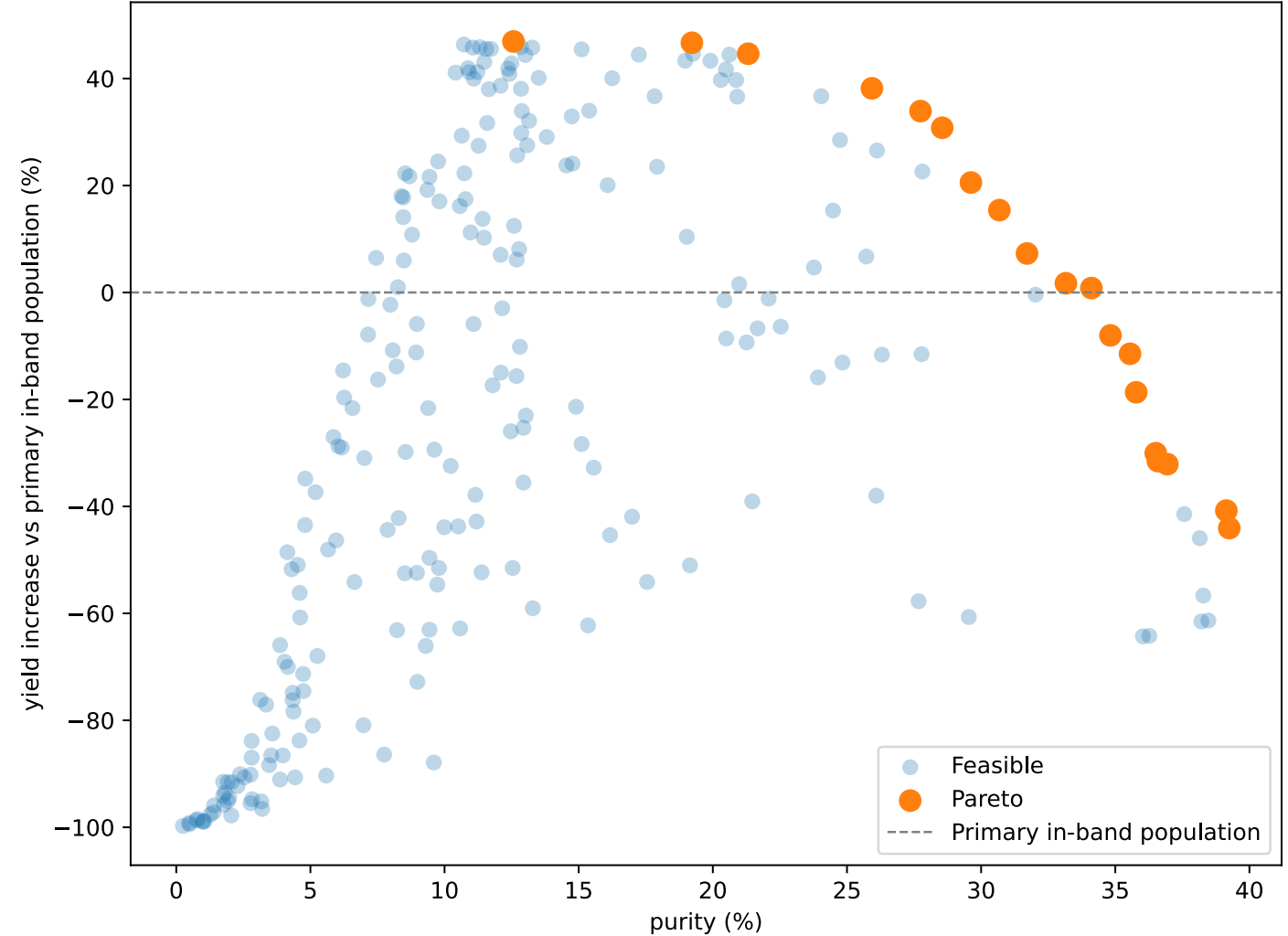
1 hr 44 min – 12 Core Machine

19 Point Pareto Front

- Prominent trade-off curve

Needed Constraint

- Any point with an in-band yield lower than the primary beam should be discarded.



MOB0 – Finer Search – Constrained

Same Tight Bounds

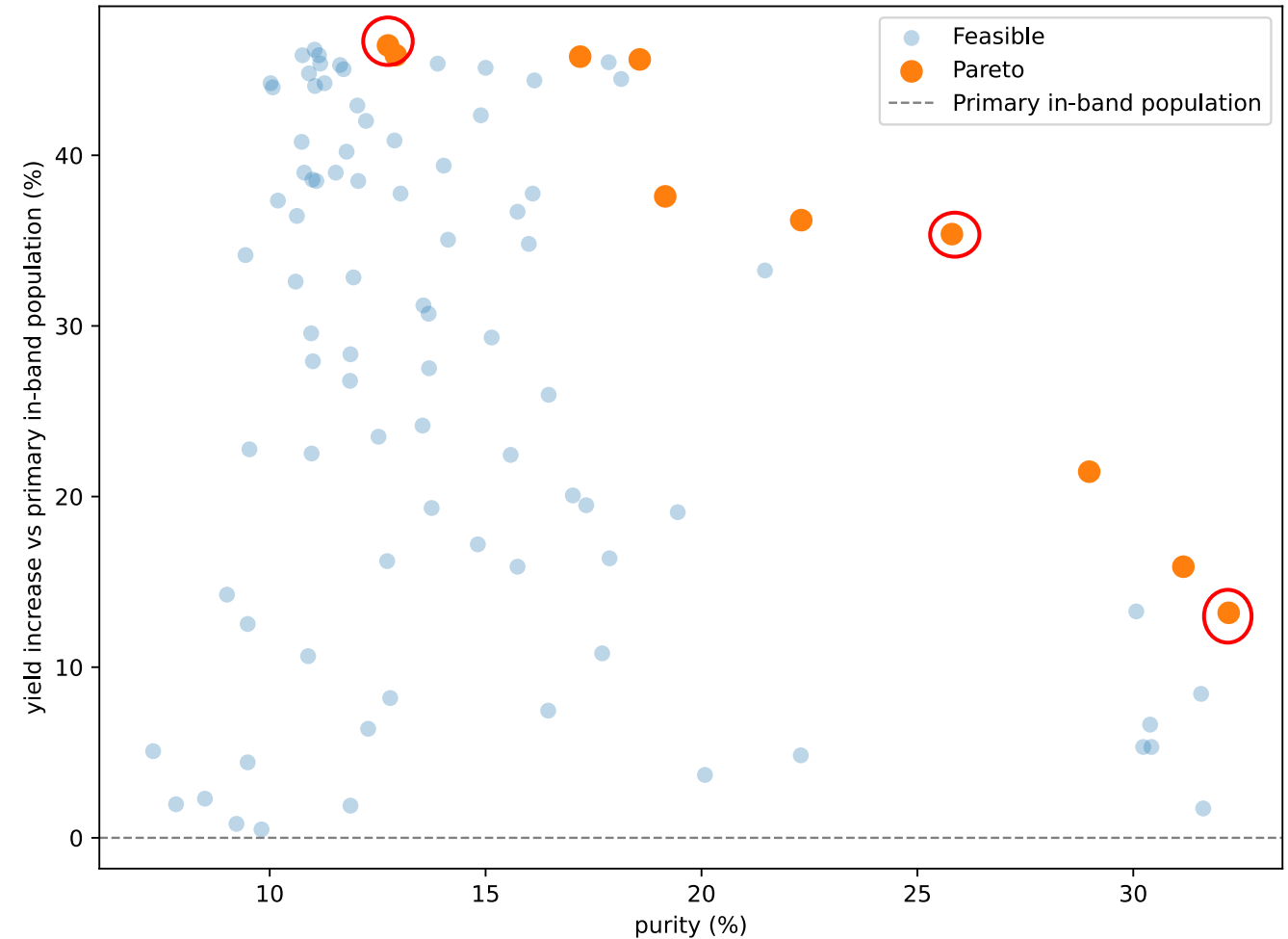
- RF Voltage – {0.65, 1.05} MV
- GL3B – {0.75, 0.92}
- COL Aper. – {0.3, 4} mm

10 Point Front - 3 Highlights

- Purity Favoured (**bottom-right**)
 - 32% purity, 12% yield increase
 - 0.978 MV, 0.8420 T, 1.02 mm
- Balanced (**middle-right**)
 - 26% purity, 35% yield increase
 - 0.70 MV, 0.835 T, 1.57 mm
- Yield Favoured (**upper-left**)
 - 13% purity, 45% yield increase
 - 0.975 MV, 0.853 T, 3.3 mm

GL3 Field converges to 0.83 – 0.86 T equiv.
across all pareto points.

Much tighter than other parameters.



Summary

- Carried out holistic optimisation of S1 energy selection
- Characterised the trade-off between in-band population and overall beam purity

Next Steps

- Sensitivity scans around the pareto points
- Introducing Cavity 2 for bunch length compression
- Study of momentum selection collimation in the vertical arc

Thank You

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