MAX IV linac operation

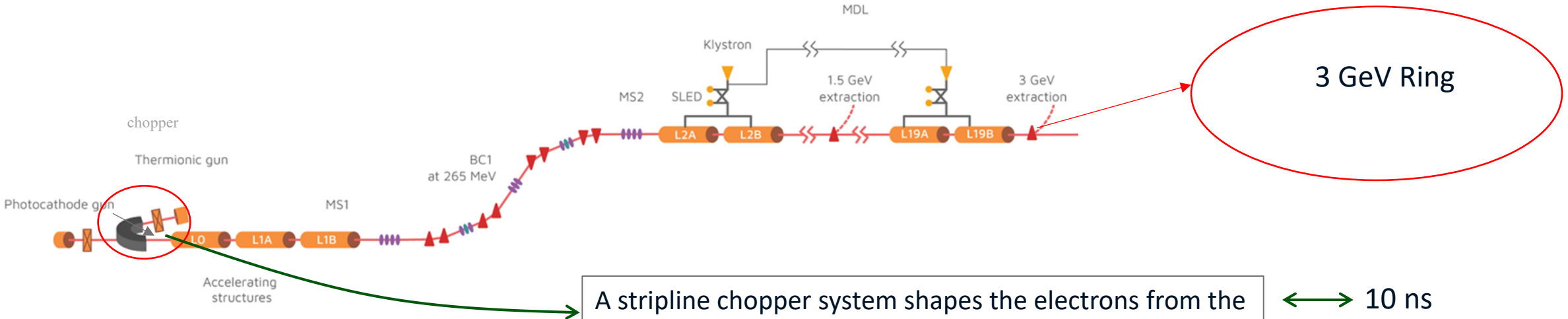
Workshop on full energy injection

Sara Thorin

Outline

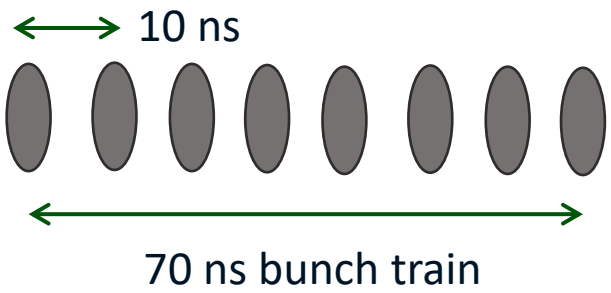
- Injection with a thermionic RF gun
- Injection modes in the storage rings
- New injection capabilities: photo cathode gun
- Day to day operation
- Off phase, on axis injection for MAX4^{U}

Linac as injector: thermionic gun



Full energy injection and top up operation for the two storage rings

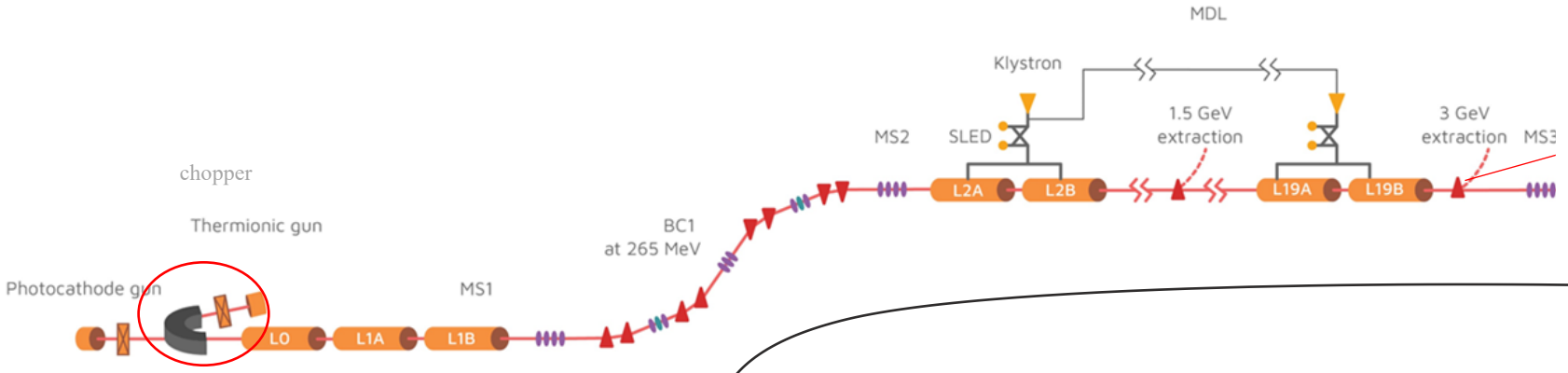
A stripline chopper system shapes the electrons from the thermionic gun in 10-100 ns macro bunches with a separation of 10 ns to match the 100 MHz ring RF frequency.

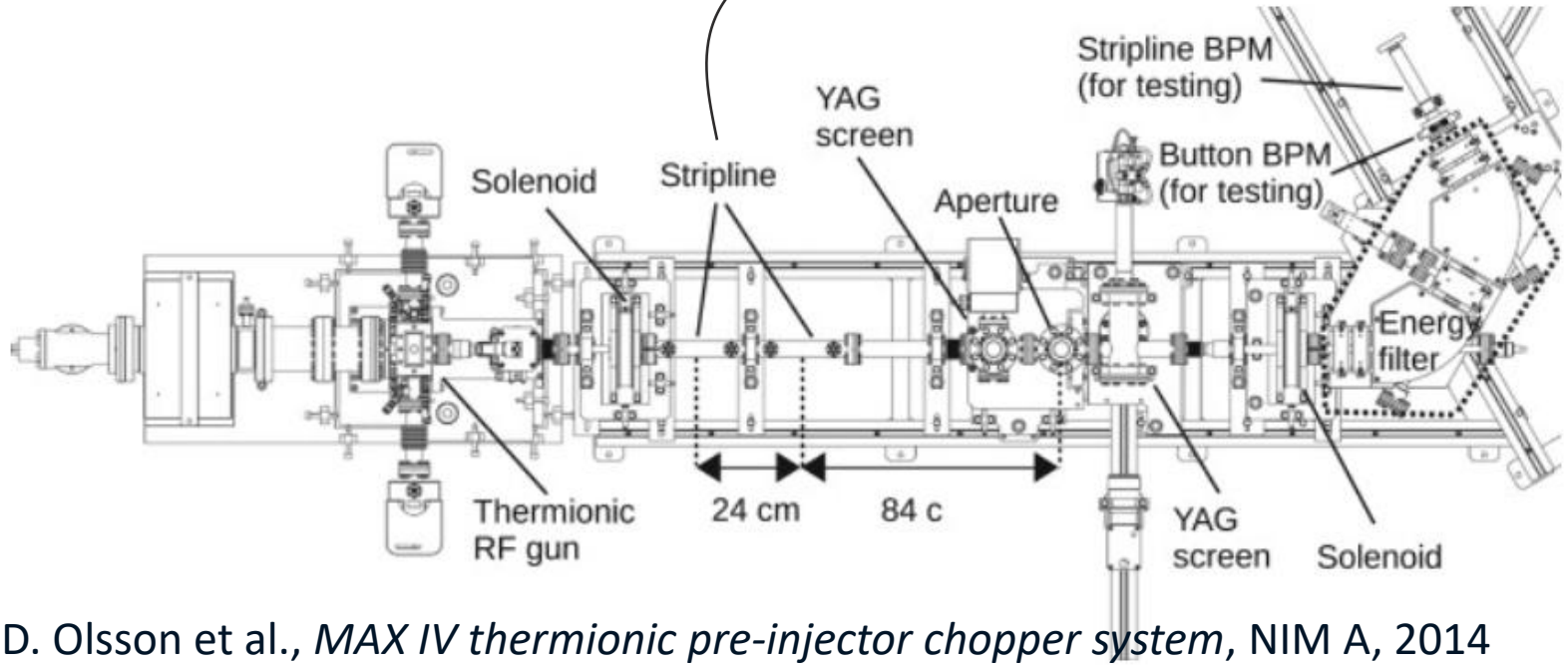


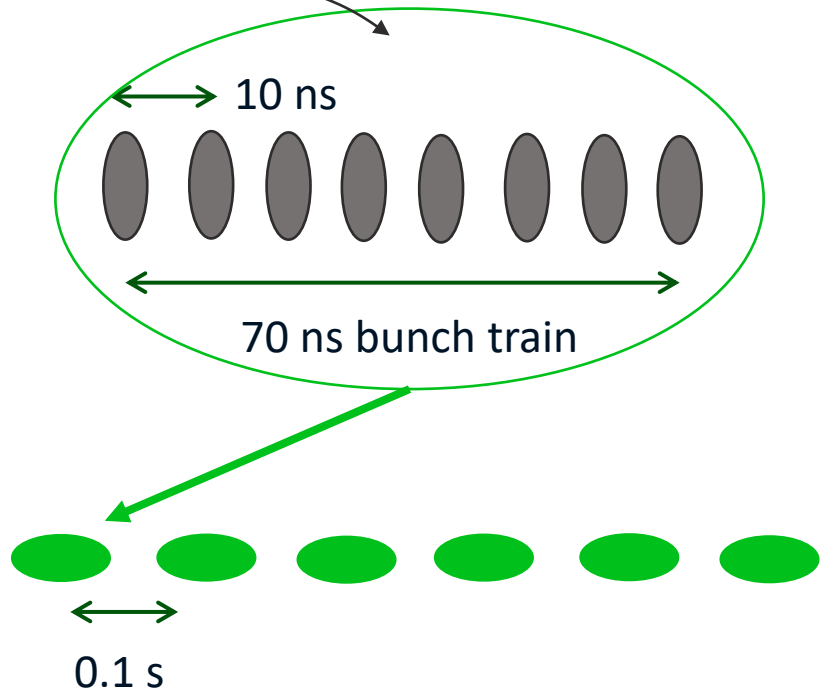
Energy	1.5 GeV/ 3GeV
Repetition rate	10 Hz
Charge	300 pC/shot
Emittance	5 mm mrad
Energy spread	<0.3 %

- High Charge per pulse
- ~8 buckets filled at every shot
- ~ 3 S-band bunches per ring bucket.
- Requires large phase acceptance in the ring
- Larger energy spread over the bunch train
- Allows off-axis, on-energy injection scheme, with high injection rate

Linac as injector: thermionic gun

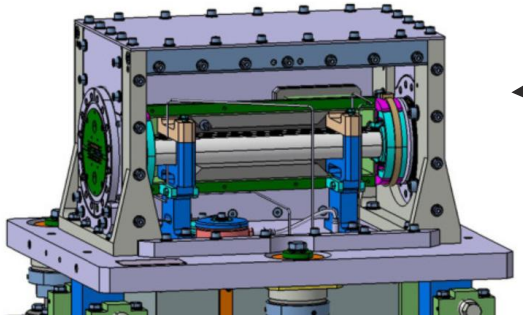


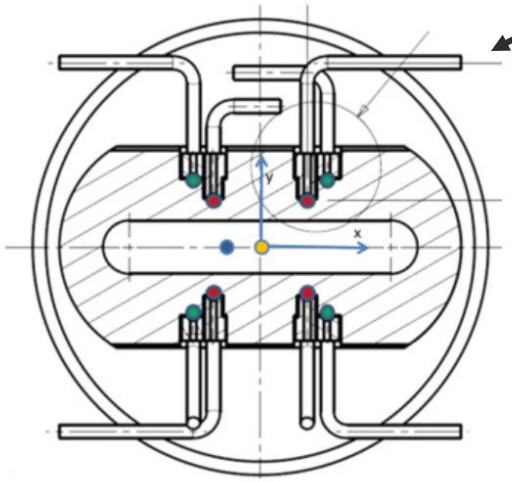




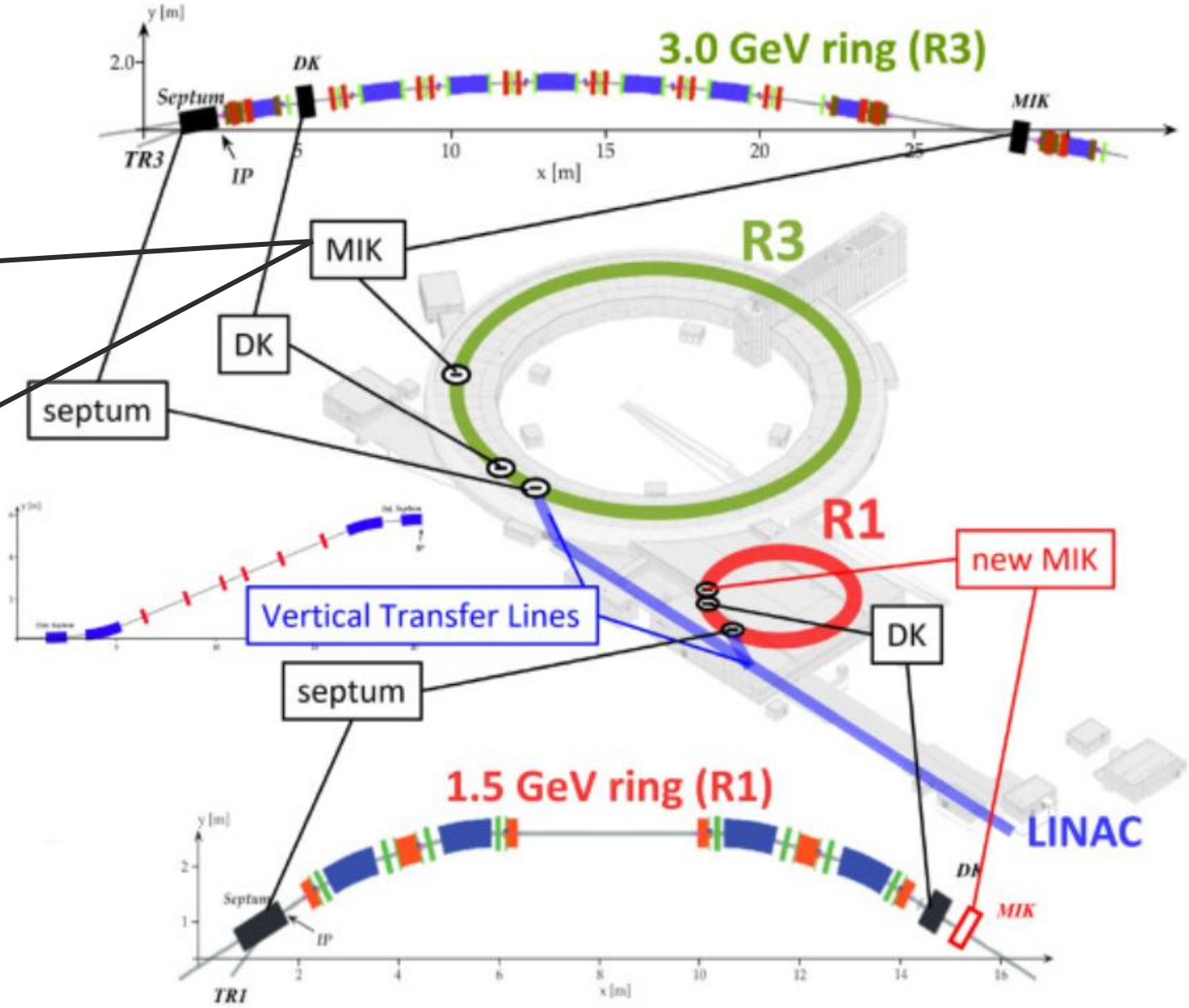
D. Olsson et al., *MAX IV thermionic pre-injector chopper system*, NIM A, 2014

Injection





P. Alexandre, *et al.*
Transparent top-up injection into a fourth-generation storage ring
Nucl. Inst. Methods Phys. Res. A, 986 (2021)



M. Apollonio et al., *Commissioning of the Multipole Injection Kicker in the MAX IV 1.5 GeV ring*, NIM A, 2025.

Linac as injector: photogun

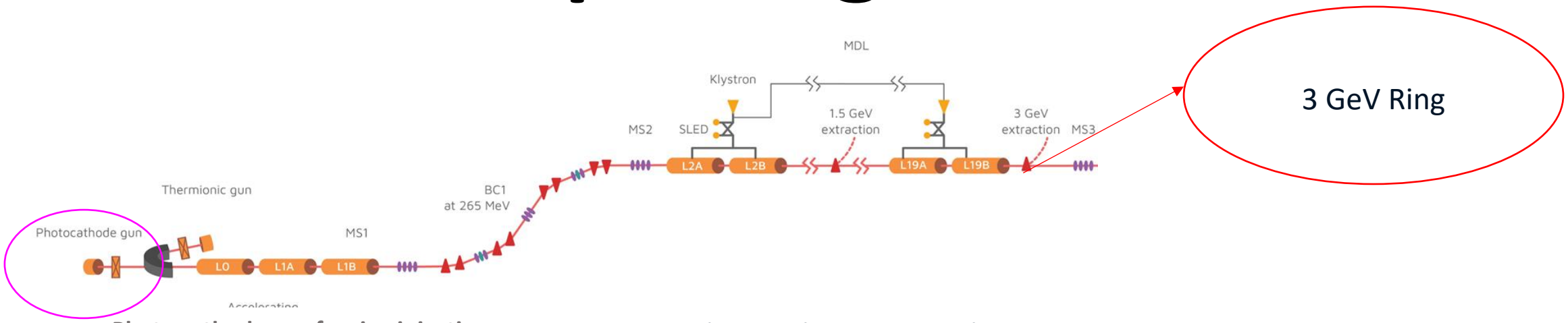


Photo cathode gun for ring injection

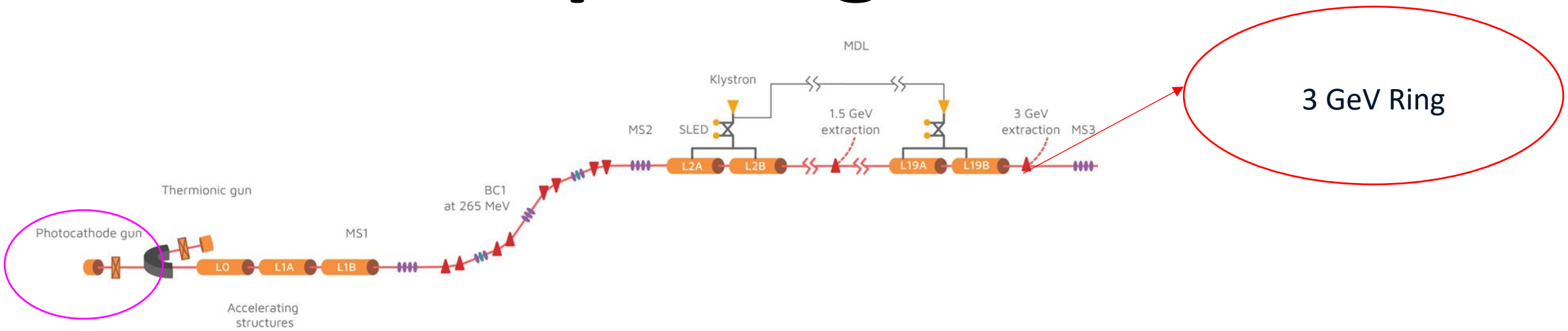
Energy	3 GeV
Repetition rate	10 Hz
Charge	200 pC
Bunch length (rms)	~5 ps
Emittance	2-3 mm mrad
Energy spread (rms)	<0.05%

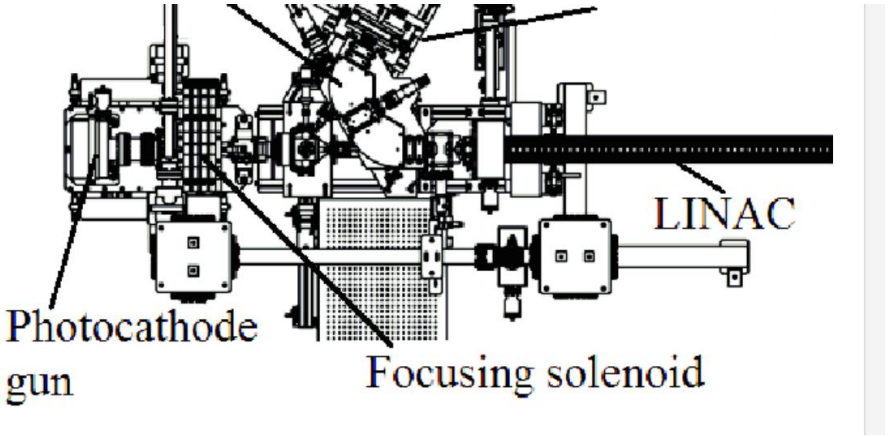
- lower charge per pulse
- 1 bucket filled at every shot
- 1 S-band bunch per ring bucket.
- Small phase extension, small bunch length and energy spread

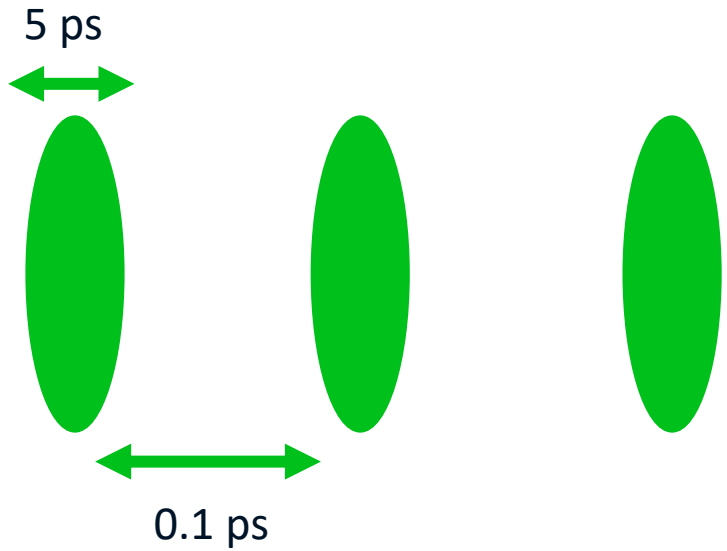
Current Injection parameters

- Pulse duration ≃ 5 ps (0.18°)
- Phase jitter ≃ 150 ps rms (4°)
- Energy spread < 5 10^{-4}
- Energy jitter < 5 10^{-4}
- Charge ≤ 150 pC

Linac as injector: photogun

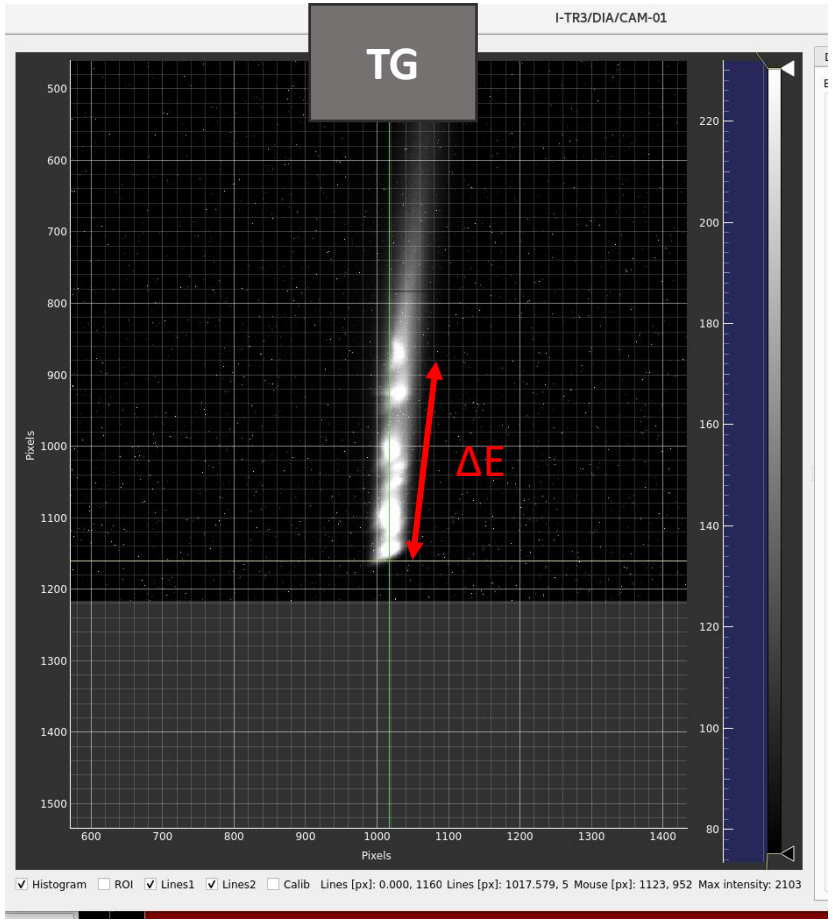


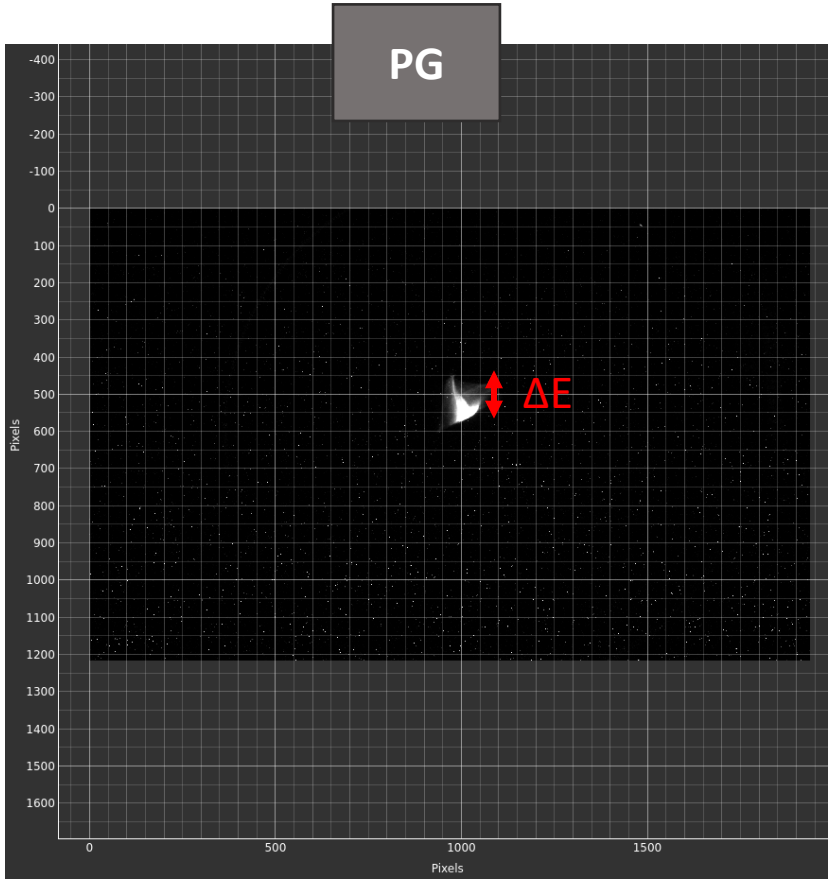




J. Andersson et al., *Beam performance of the photocathode gun for the MAX IV LINAC*, FEL 2014.

Beam difference On screen1 in TR3





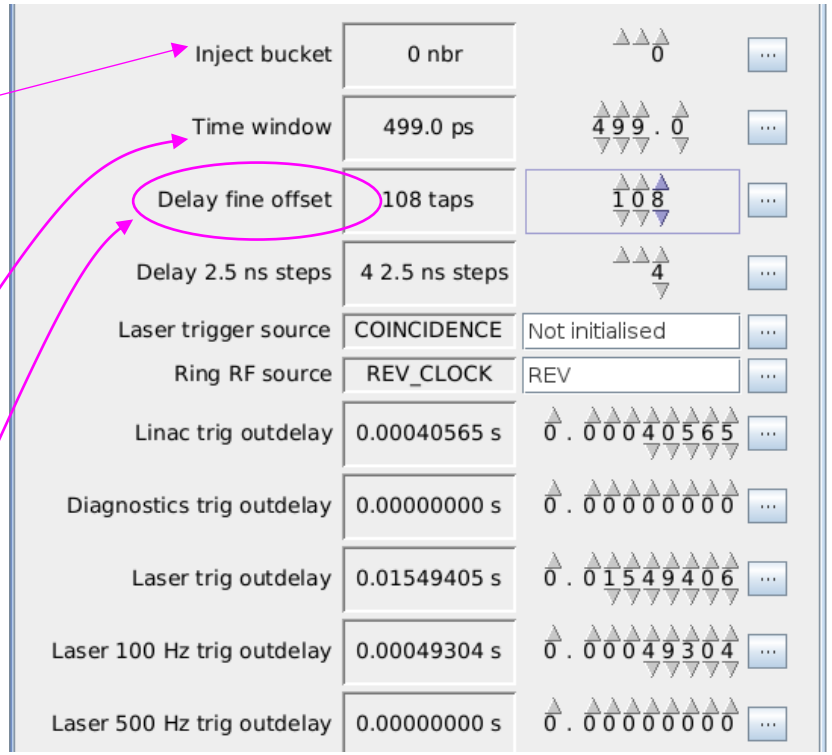
Coincidence system for injection timing

- linac rf frequency is not a multiple of the ring frequency.
- This is not an issue when using the thermionic gun given the long macropulse and the use of a chopper that imparts the ring time-structure onto the LINAC S-band pulse train
- A coincidence detector gives a trig when a ring bucket and a possible shot from the photo cathode gun overlap in time. The linac is then triggered to produce an injection shot.
- Rep rate 2-10 Hz (require coincidence system intervention to change)

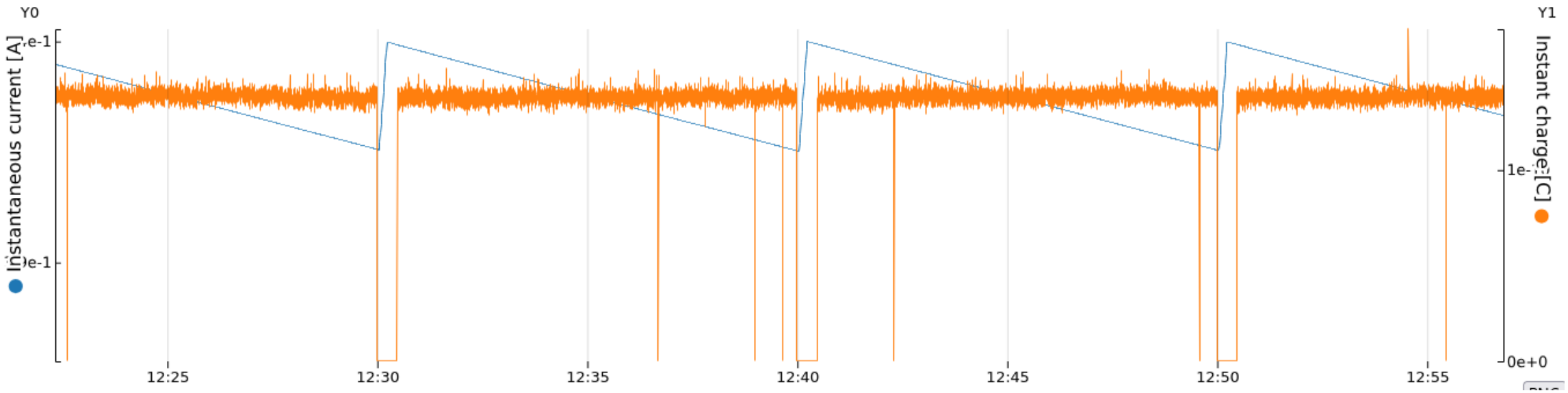
Choose which ring bucket to inject into

Choose time window for coincidence.
- This sets the phase precision jitter. Smaller window means less phase jitter, but also fewer coincidences.

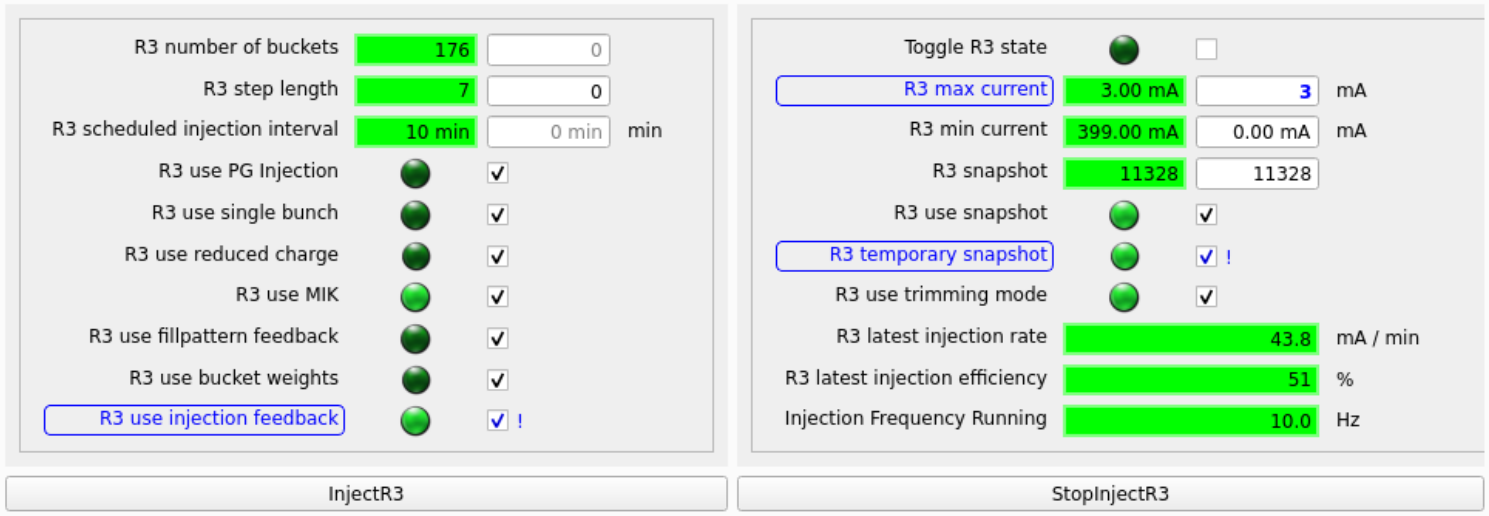
Delay of the injection shot.
- This sets where in the ring phase the injection occurs. Precision of 40 ps (1.5 °)



Day to day operation



- Top up in R3 and R1 every 10 minutes
- SPF delivery at all other times
- Switching time a few seconds, top up time a few seconds – total ~30s
- Controlled by the State Machine (more info in Filips's talk)



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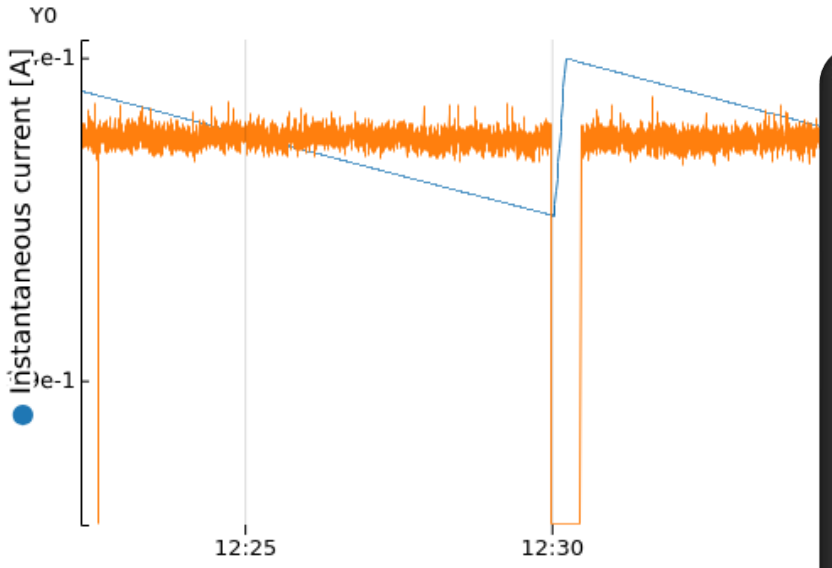

2025 Accelerator Operations Statistics

Accelerator	Planned delivery [hours]	Uptime	MTTR [hours]	MTBF [days]
3 GeV Ring	4968	97.0%	2.7	3.8
1.5 GeV Ring	4968	99.1%	1.6	8.0
SPF	4536	97.4%	0.77	0.4

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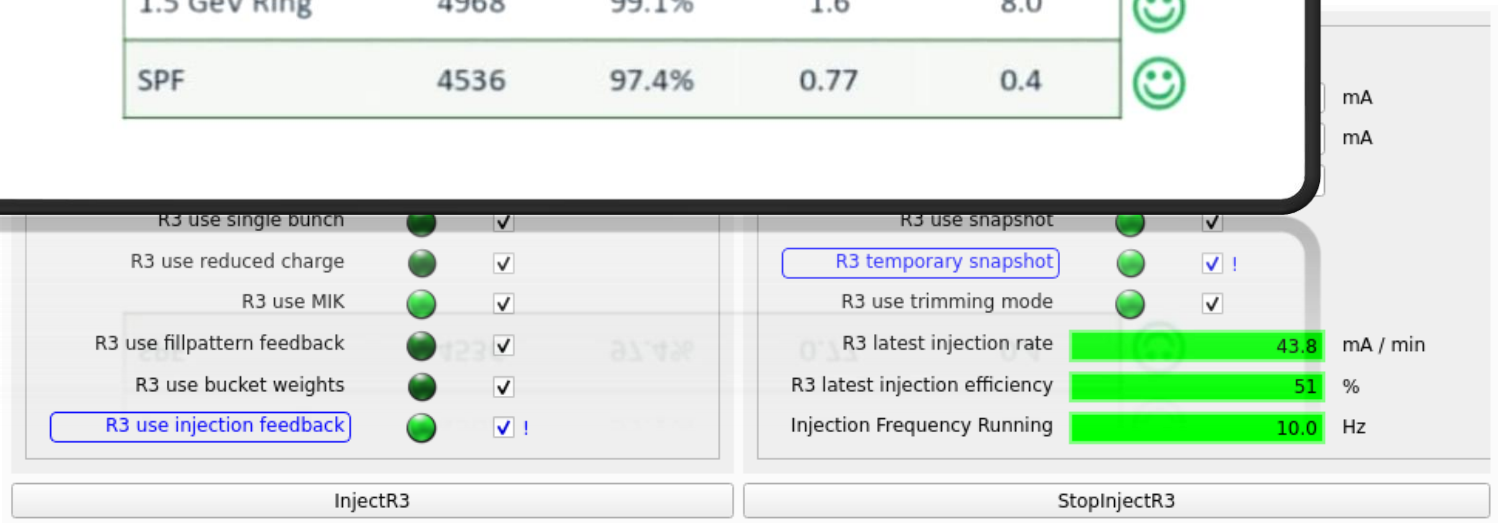
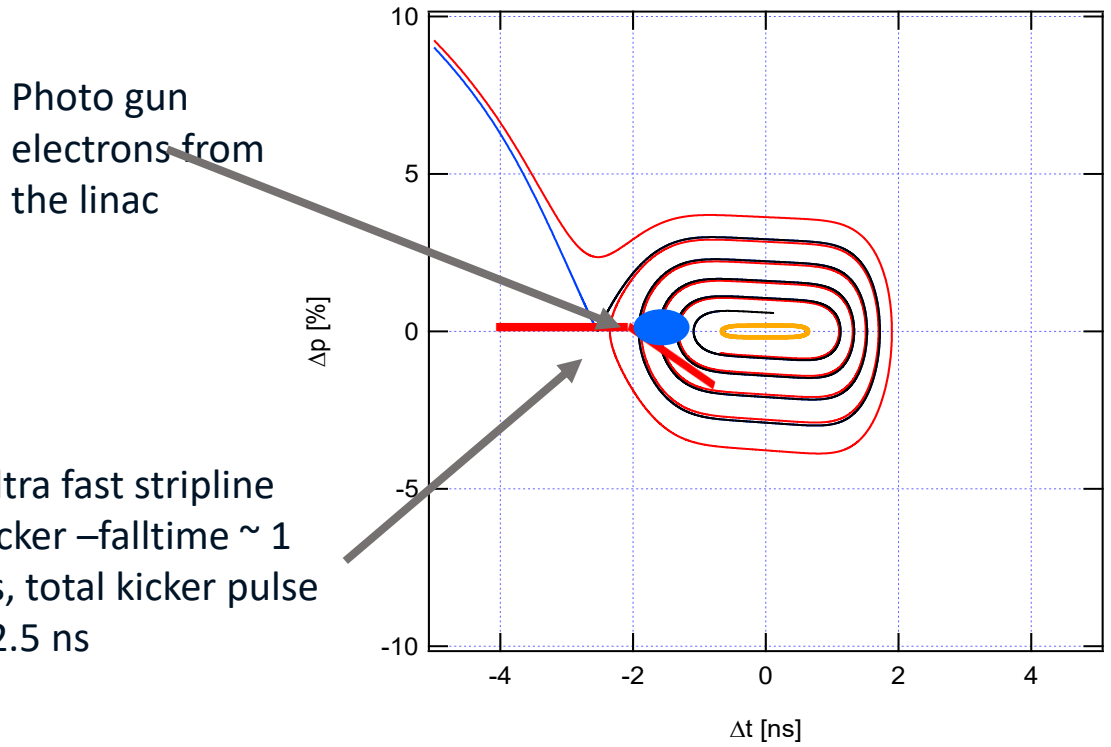


Off-phase, on-axis injection Scheme MAX4^{U}

Current Injection parameters
- Pulse duration ≃ 5 ps (0.18°)
- Phase jitter ≃ 150 ps rms (4°)
- Energy spread < 5 10^{-4}
- Energy jitter < 5 10^{-4}
- Charge ≤ 150 pC

- Our injector (full-energy linac) and low (100 MHz) ring RF frequency puts us in a privileged position to implement these schemes

- This approach
  - Allows advanced IDs with small horizontal gap.
  - Improves top-up transparency.
  - Eases accumulation into lattices with small dynamic aperture.



- Electron bunch injected on-axis, off phase in the ring RF bucket
- Fast kicker with minimal interference to the stored bunch

Summary

- MAX IV uses a full-energy LINAC injector for storage ring injection.
- Thermionic gun injection enables high charge and efficient multi-bucket filling using a chopper system.
- Photocathode gun injection provides lower charge per pulse but better beam quality and timing control.
- A coincidence timing system synchronizes LINAC shots with storage ring buckets.
- Routine operation includes top-up injection in R1 and R3 every ~10 minutes with fast switching to deliver to the SPF.
- Off phase, on axis injection considered for MAX4^{U}