Injector Linac and RF gun

Mission of electron/positron Injector in SuperKEKB

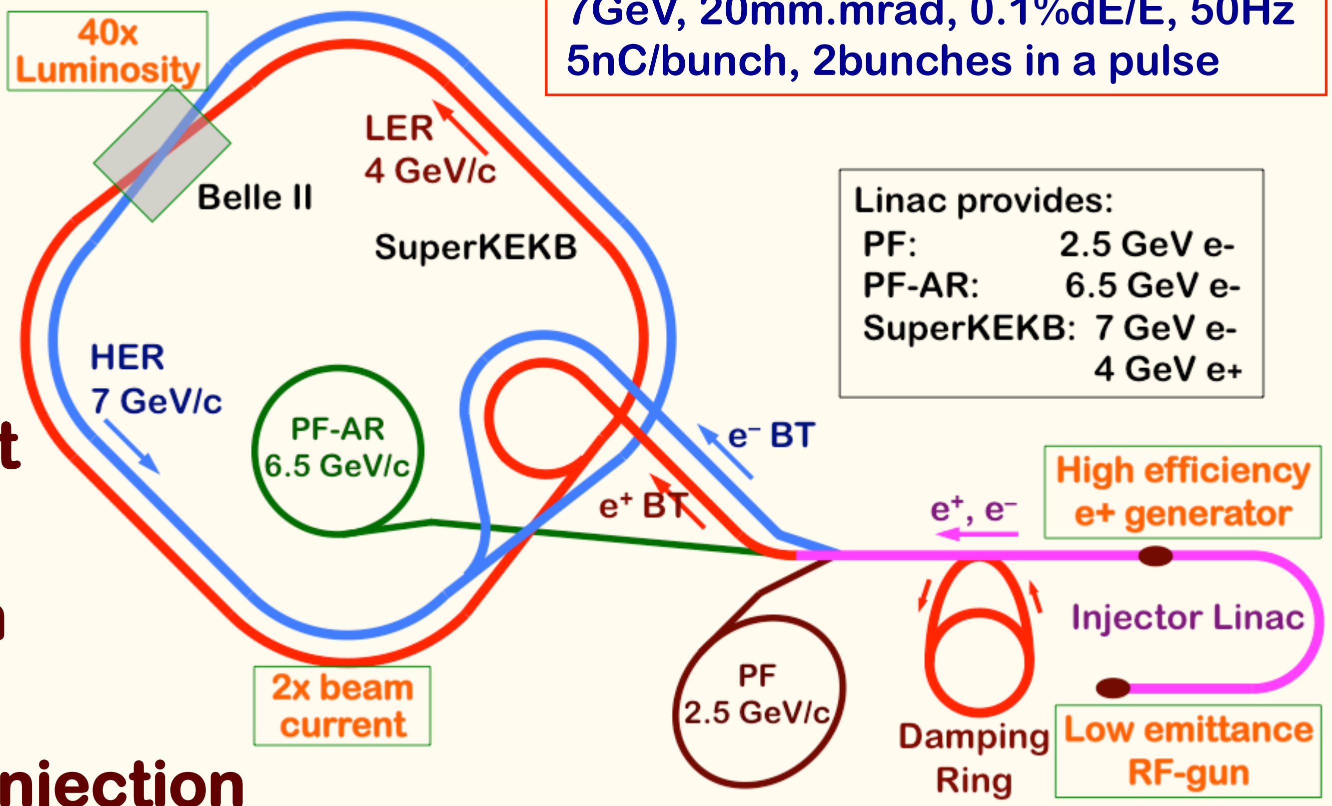
◆ 40-times higher Luminosity

- Twice larger storage beam → **Higher beam current** at Linac
- 20-times higher collision rate with nano-beam scheme
  - → Low-emittance even at first turn → **Low-emittance beam** from Linac
  - → Shorter storage lifetime → Higher Linac beam current

◆ Linac challenges

- Low emittance e-
  - with high-charge RF-gun
- Low emittance e+
  - with damping ring
- Higher e+ beam current
  - with new capture section
- Emittance preservation
  - with precise beam control
- 4+1 ring simultaneous injection

7GeV, 20mm.mrad, 0.1%dE/E, 50Hz
5nC/bunch, 2bunches in a pulse

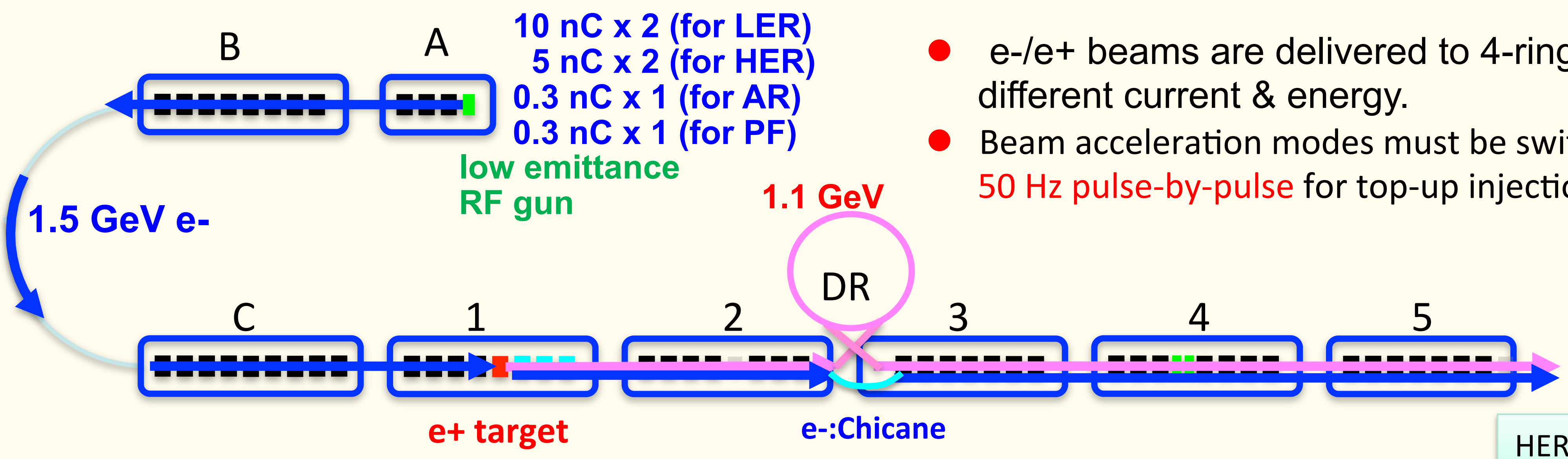


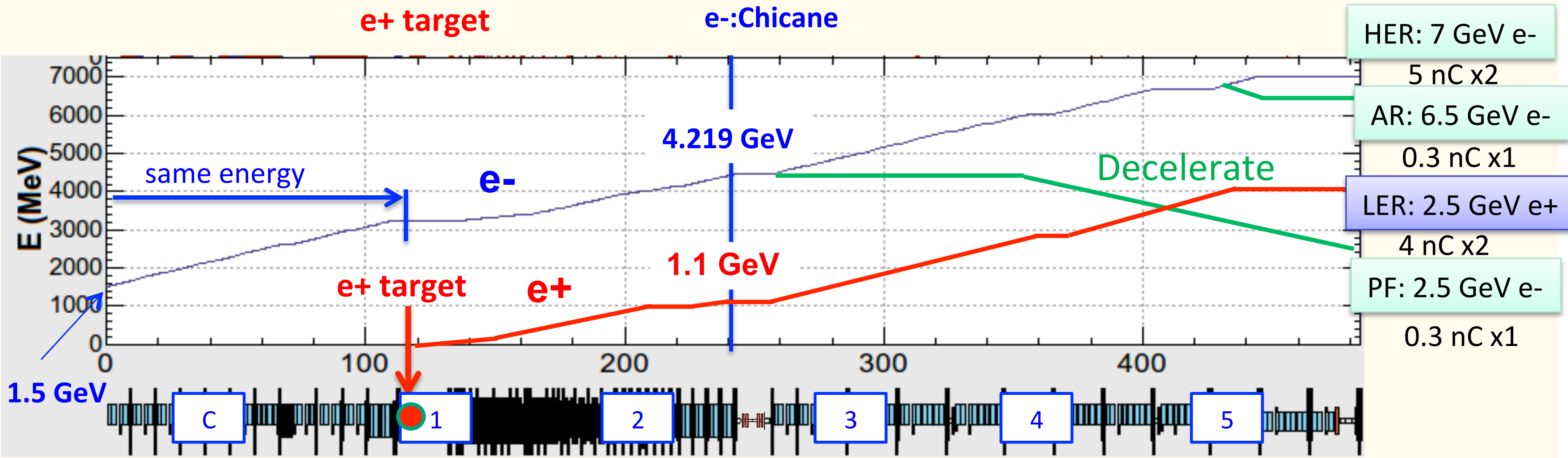
Linac provides:

PF:	2.5 GeV e-
PF-AR:	6.5 GeV e-
SuperKEKB:	7 GeV e-
	4 GeV e+

Energy profiles and beam properties

- e-/e+ beams are delivered to 4-rings with different current & energy.
- Beam acceleration modes must be switched by 50 Hz pulse-by-pulse for top-up injection.





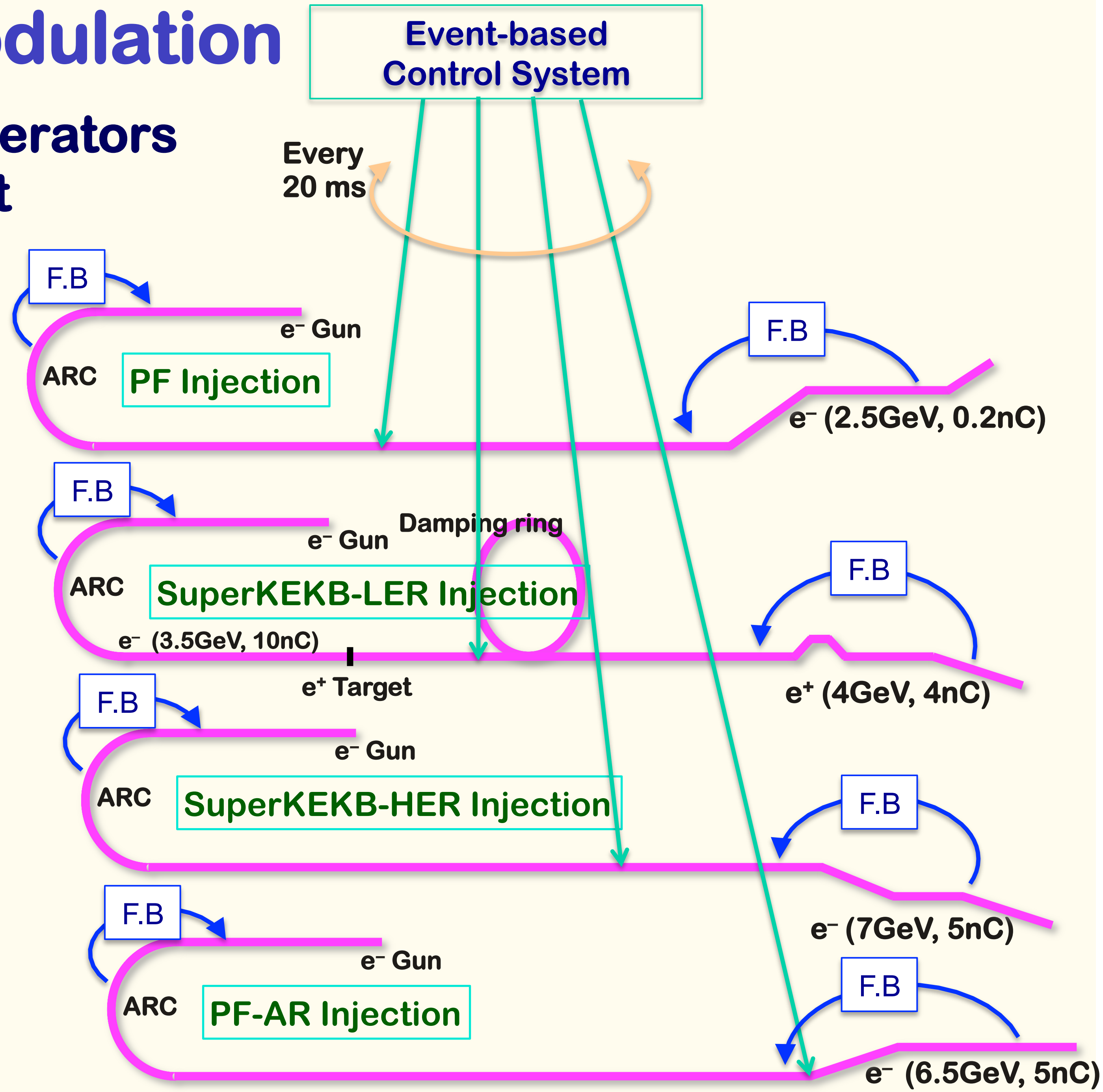
Beam optics should satisfy the fast beam-mode switching.

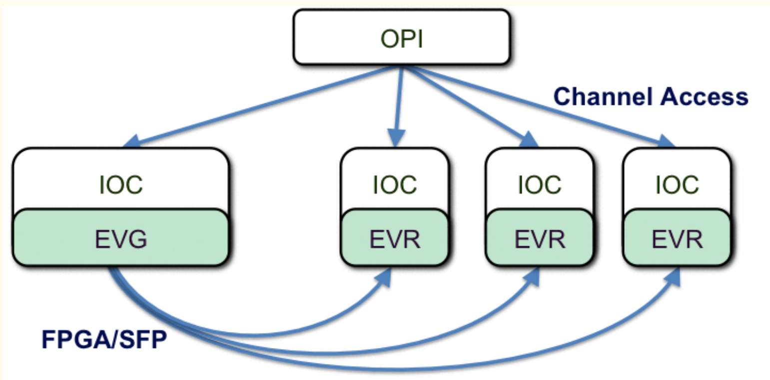
Pulse-to-pulse modulation

- **Four PPM virtual accelerators for SuperKEKB project**

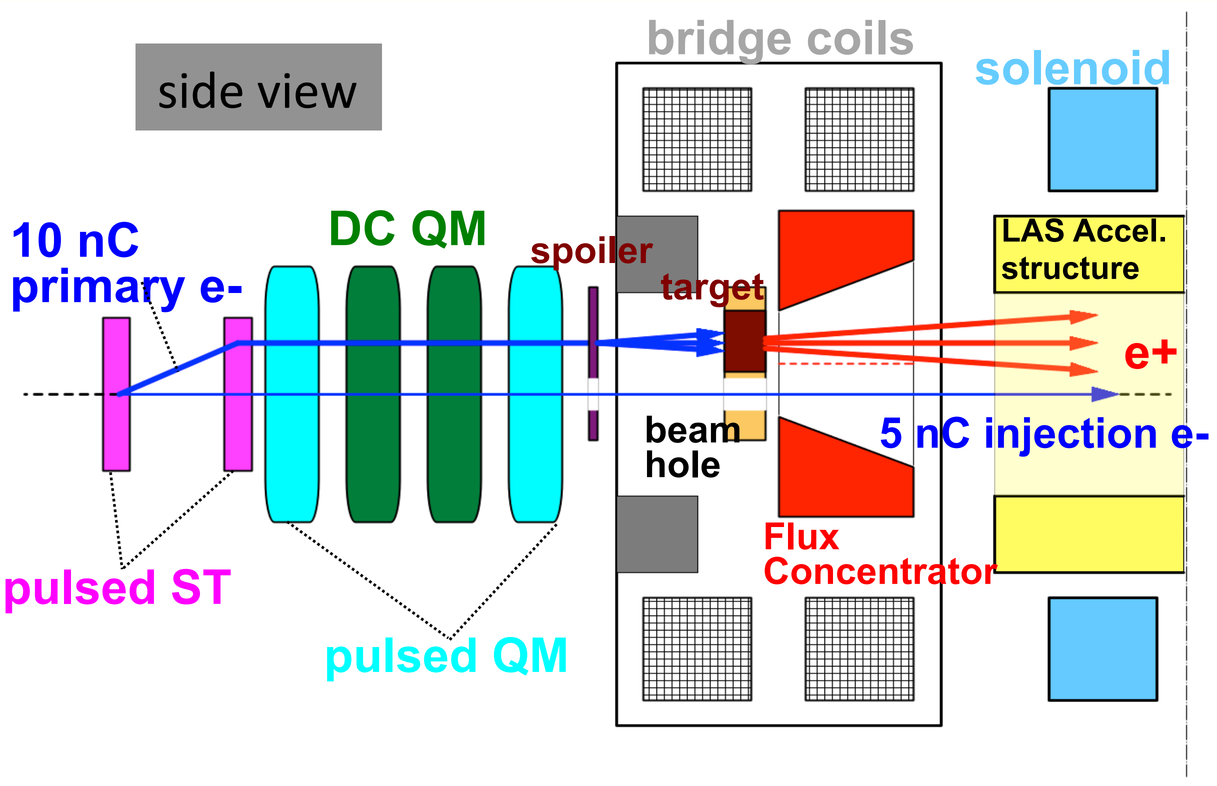
maybe with additional PPM VAs for stealth beam measurements

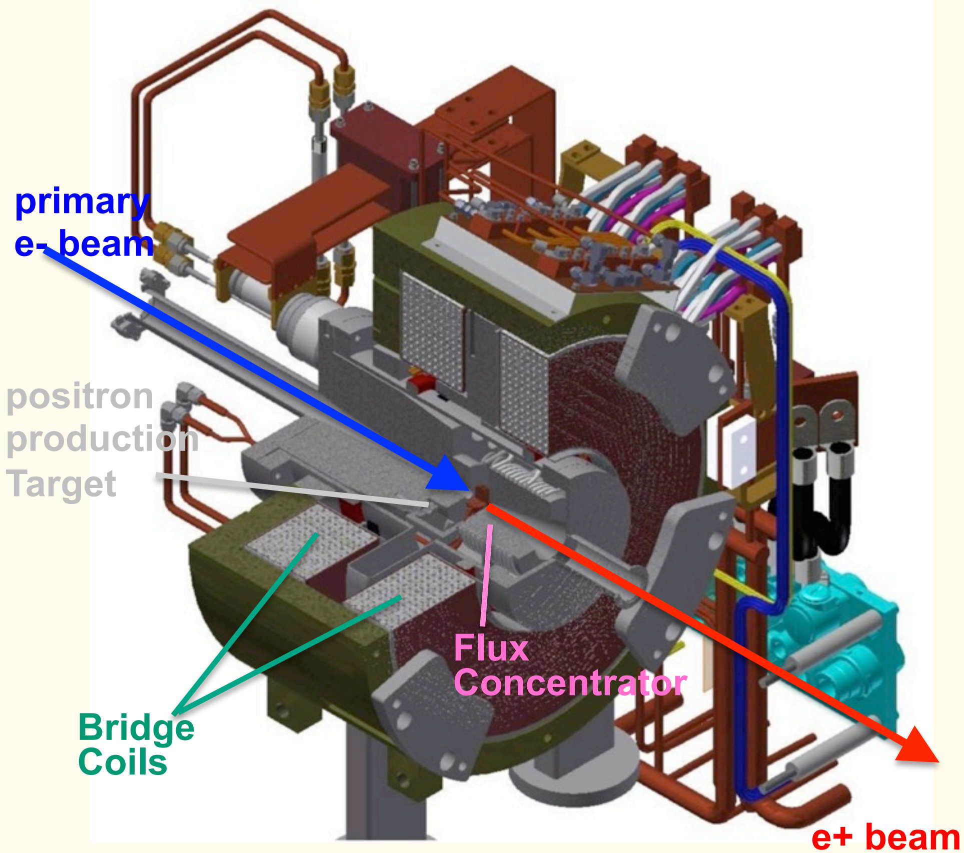
based on Dual-tier controls with EPICS and event-system





Positron generation for SuperKEKB





4-times more positron is required at SuperKEKB than KEKB
New positron capture section after target with
 Flux concentrator (FC) and large-aperture S-band structure (LAS)
Satellite bunch (beam loss) elimination with velocity bunching
Pinhole (2mm) for electrons beside target (3.5mm)
Beam spoiler for target protection

Positron Generation

T.Kamitani

1) **Installation of positron generator for SuperKEKB in April 2014**
   (Beamline construction since summer 2013)
   (positron target, spoiler, Flux Concentrator, bridge coils, LAS structures [x6], DC solenoids [16+13], e+/e- separator, quads [>90])

2) **Commissioning of positron beam, observation of the first positron after reconstruction for SuperKEKB, further improvements expected**

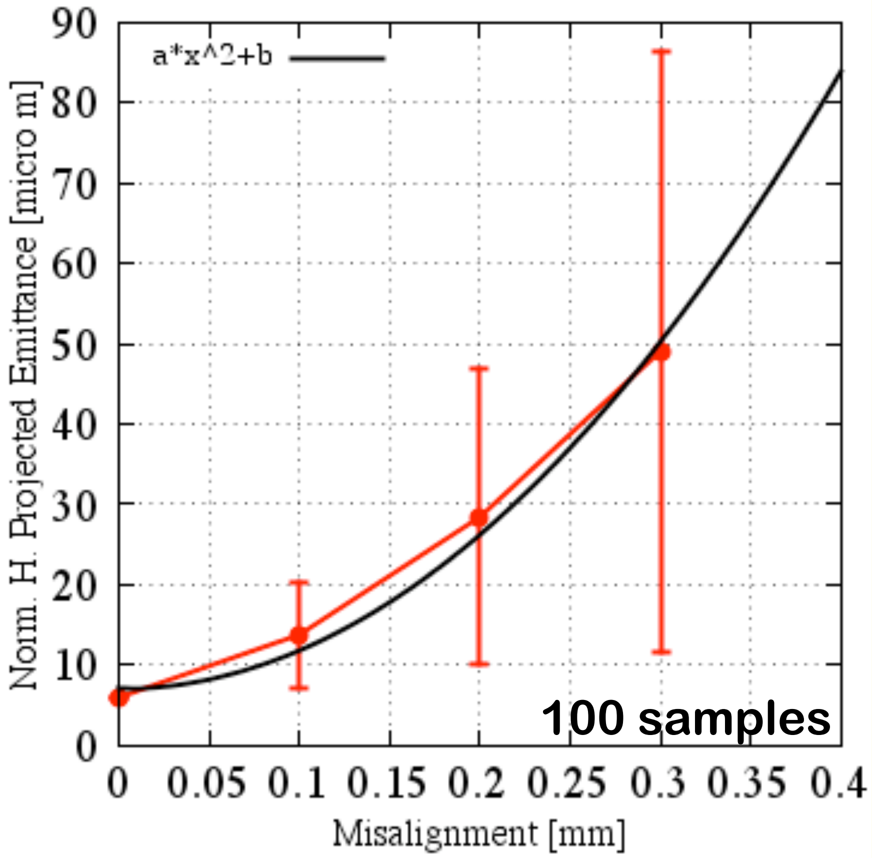
	Primary e- [nC]	Positron [nC]	Efficiency	Parameters
June 2014	0.6	0.12	20%	FC 6.4kA, Solenoids 370A, LAS capture field 10 MV/m
	x17	x42	x2.5	
Specification (at SY2)	10.0	5.0	50%	FC 12kA, Solenoids 650A, LAS capture field 14 MV/m
DR injection (2016?)		4.0	40%	Energy spread acceptance 0.5%

3) Oct.~Dec.2014 : Linac commissioning
   Jan.~Mar.2015 : Construction
   Apr.~Jun. : Linac commissioning
   Jul.~Sep.2015 : Construction
   Oct. : LER injection

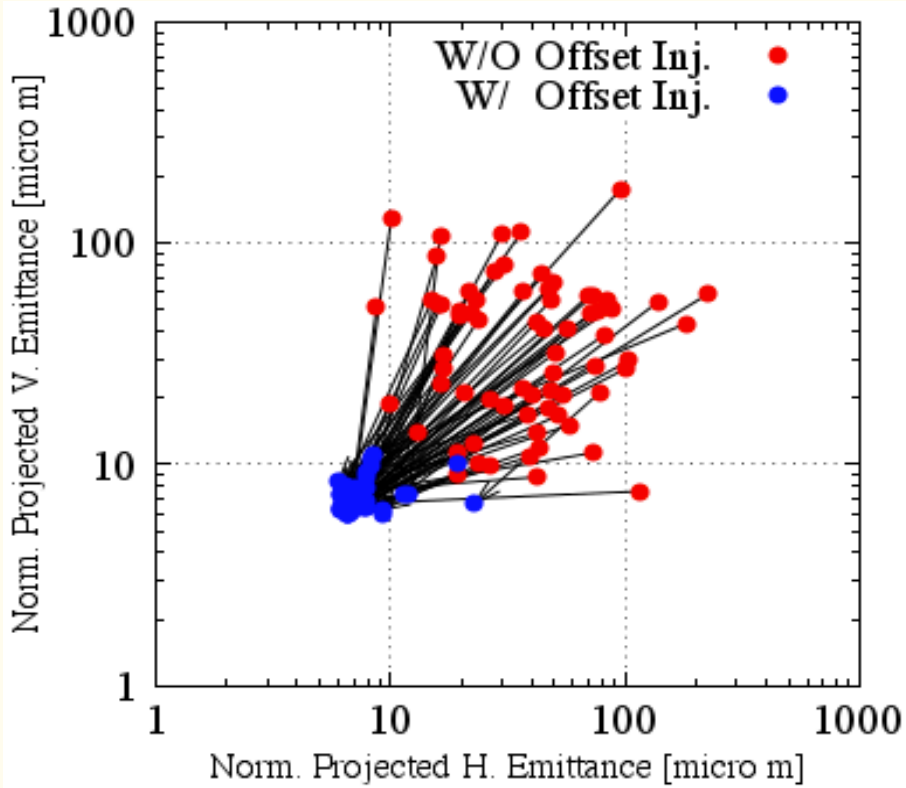
Emittance Preservation

- Offset injection is required to preserve emittance
- Orbit have to be maintained precisely
- Mis-alignment should be <0.1mm locally, <0.3mm globally

Mis-alignment leads to Emittance blow-up



Orbit manipulation compensates it



Sugimoto et al.

Alignment work during summer 2014

Higo et al.

- For the first time after earthquake at downstream sectors
- Several measurements during summer
- Measurement reproducibility was confirmed up to ~0.2 mm
- While there existed several conflicting measurements, consistent scheme has been established
- Movement of tunnel by several 10's of micrometer was observed (→ mover)
- Further work necessary in 2015, for alignment and girder replacement

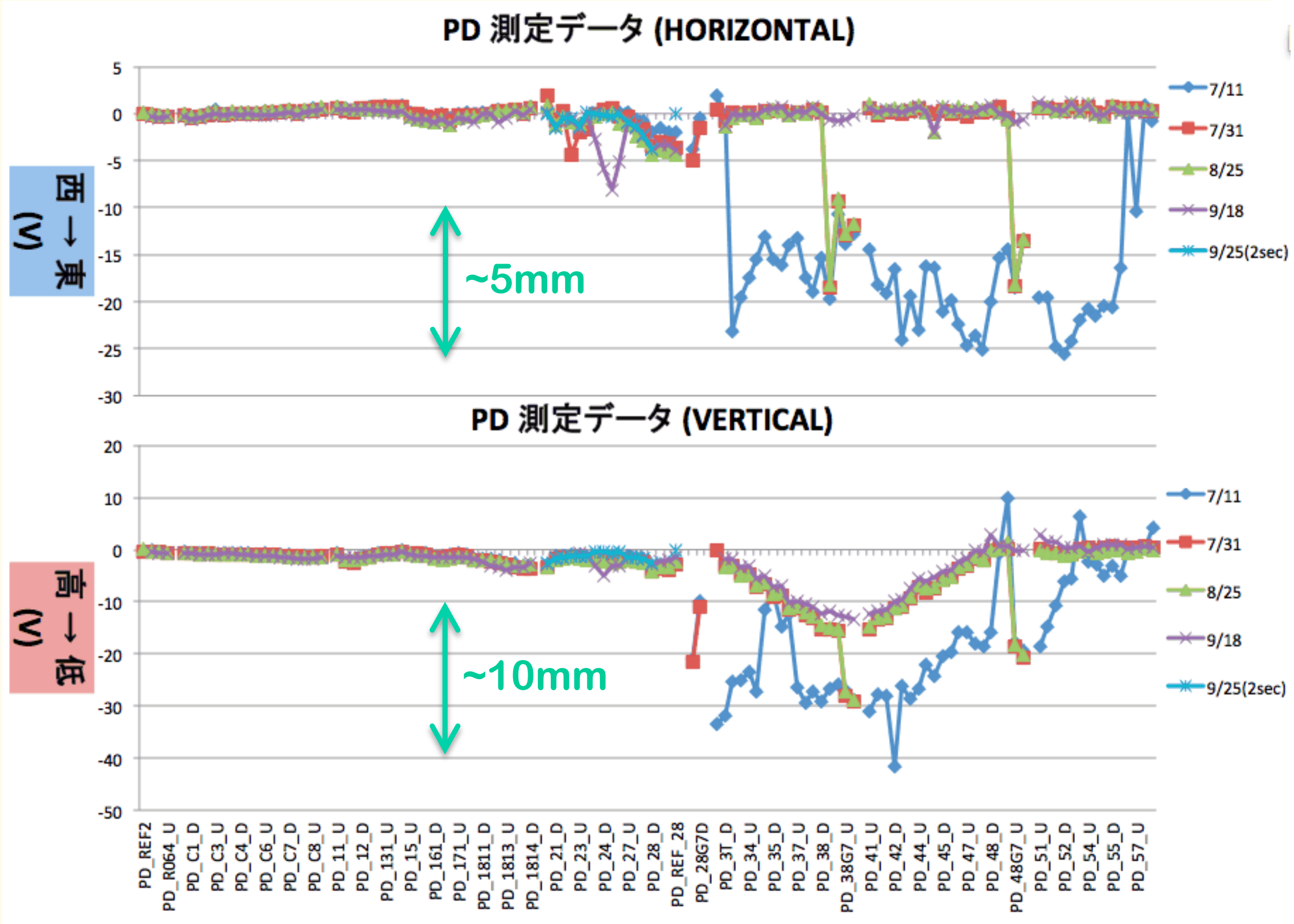
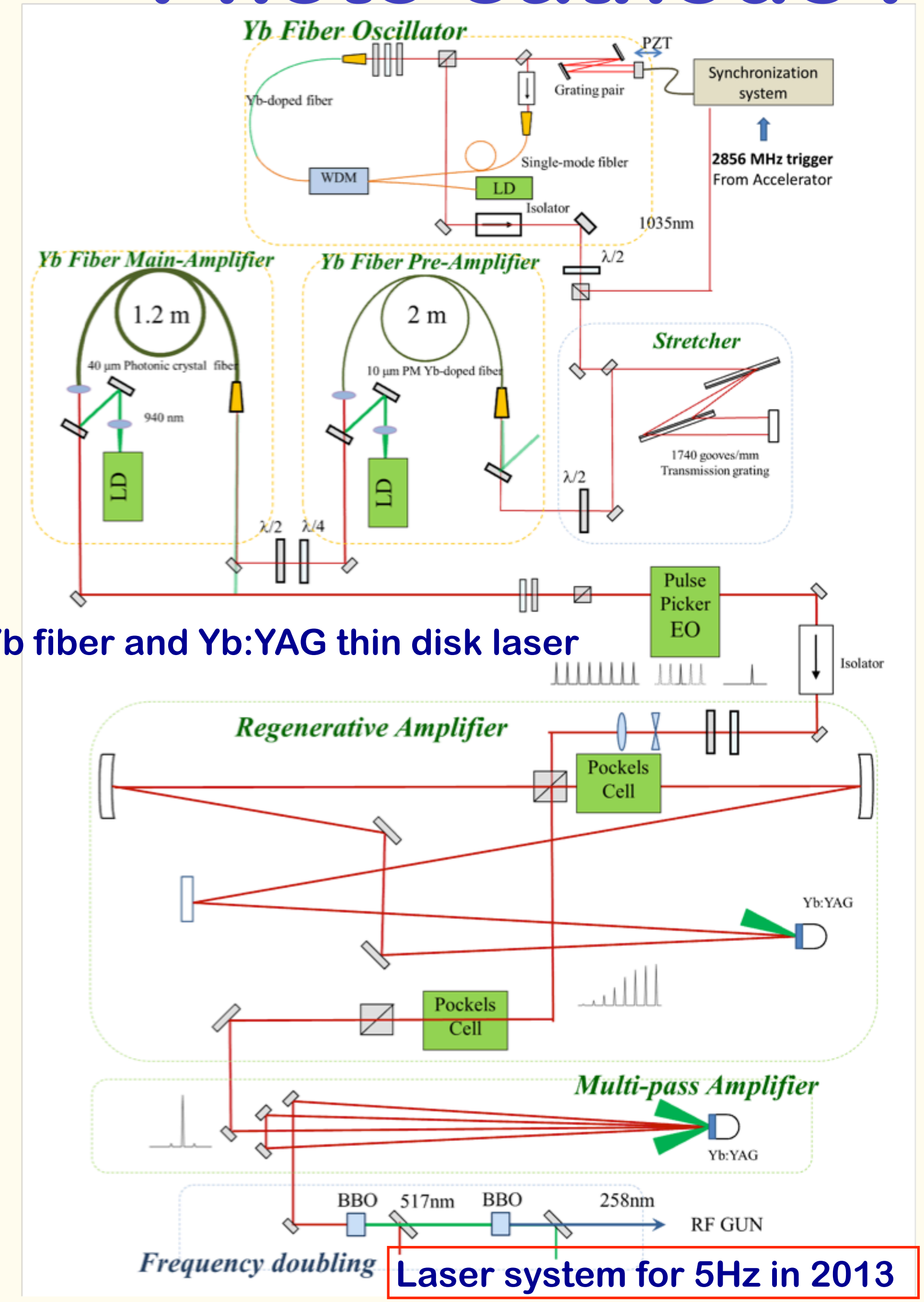


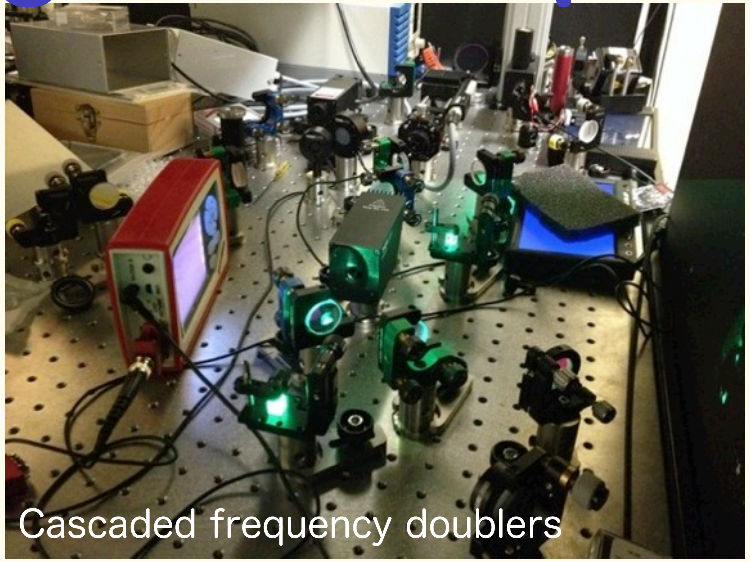
Photo cathode RF gun development

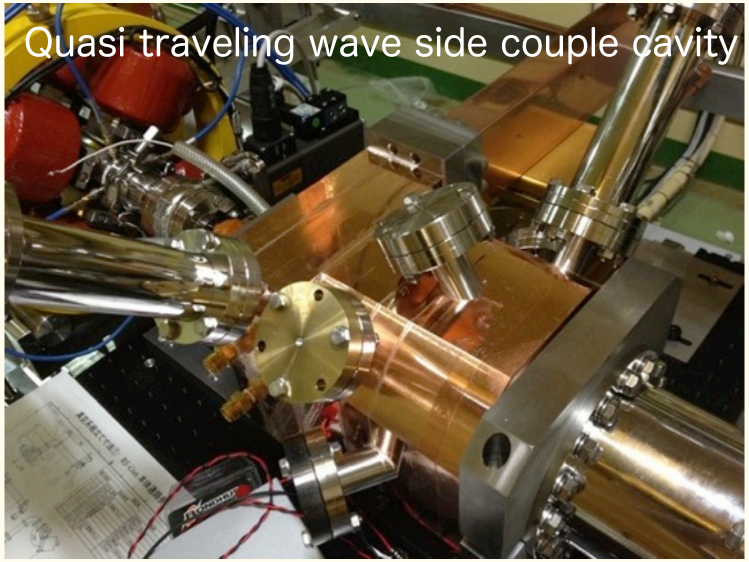
Yoshida et al.



Yb fiber and Yb:YAG thin disk laser

Laser system for 5Hz in 2013


Cascaded frequency doublers

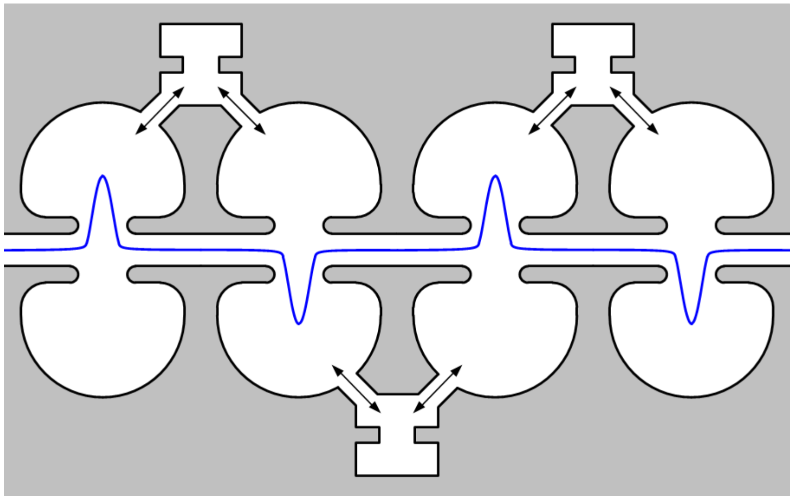

Quasi traveling wave side couple cavity


Ir_5Ce Cathode

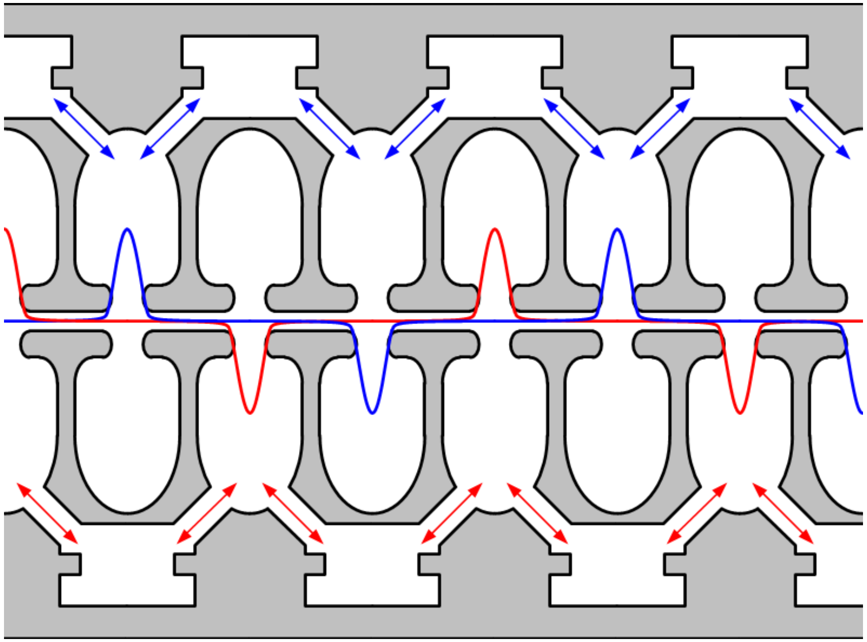
- **5.6 nC / bunch was confirmed**
- **Next step: 50-Hz beam generation with heat dissipation**

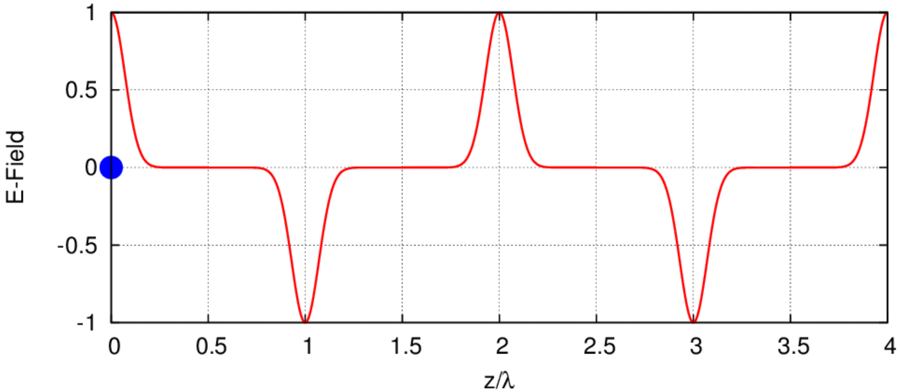
Design of a quasi traveling wave side couple RF gun

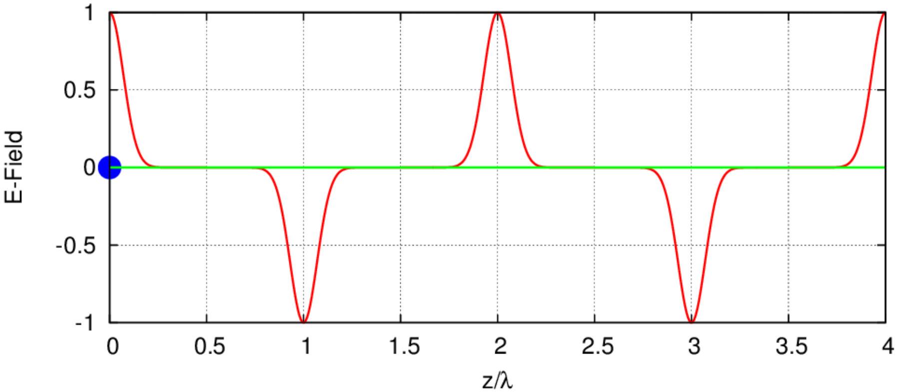
Normal side couple structure



Quasi traveling wave sidecouple structure

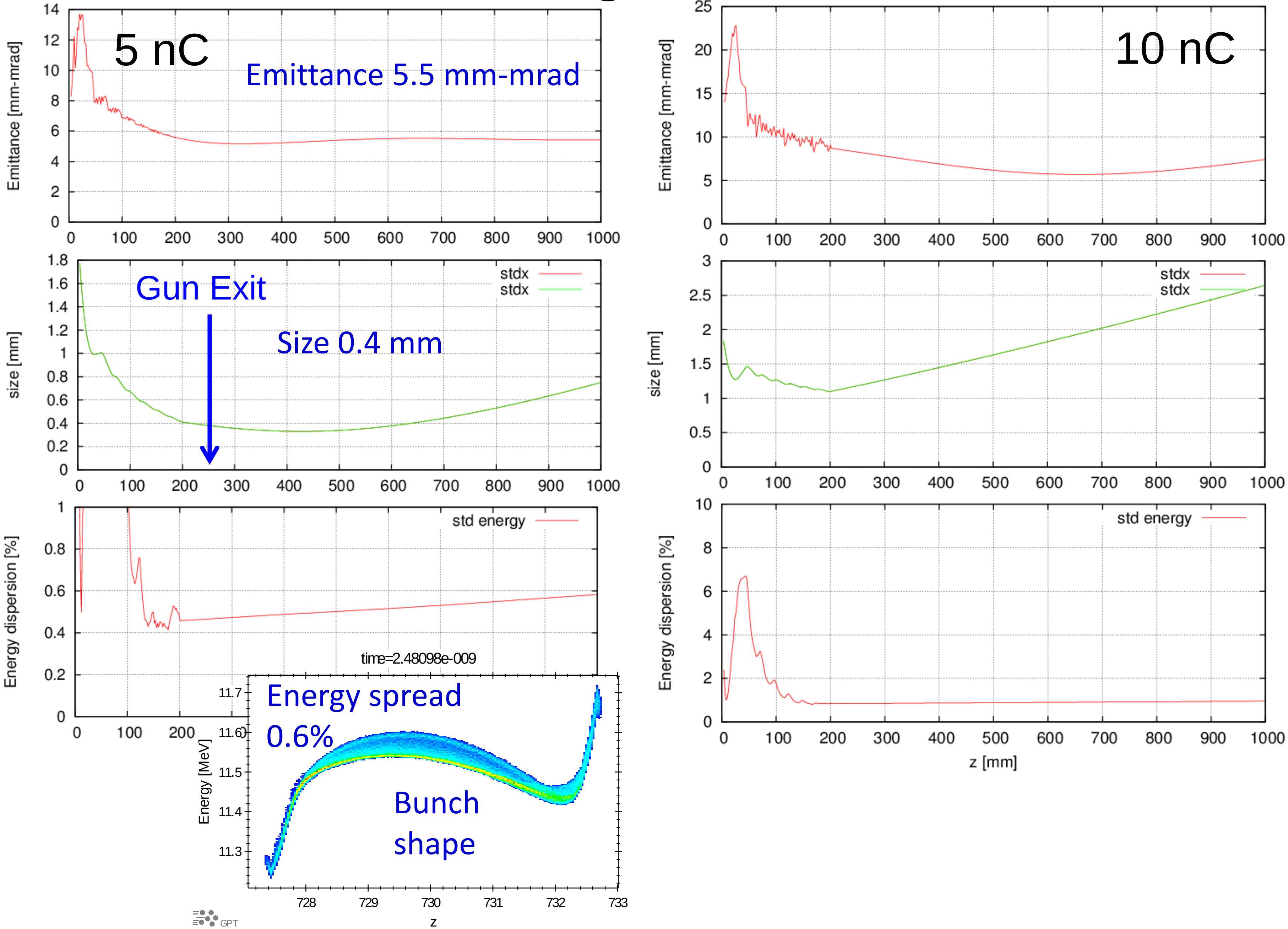




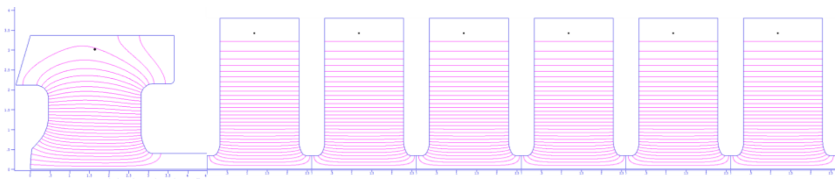


Quasi traveling wave side couple has stronger focusing field

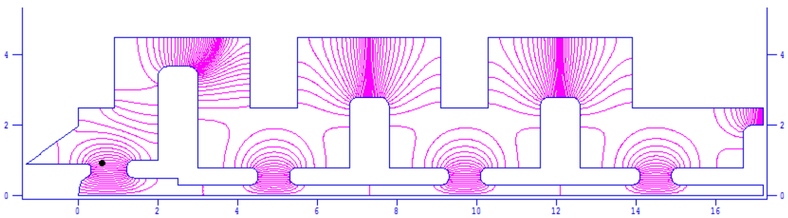
Beam tracking simulation result



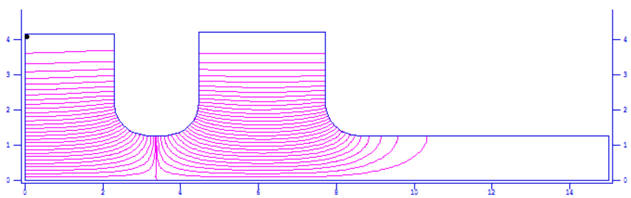
RF-Gun comparison



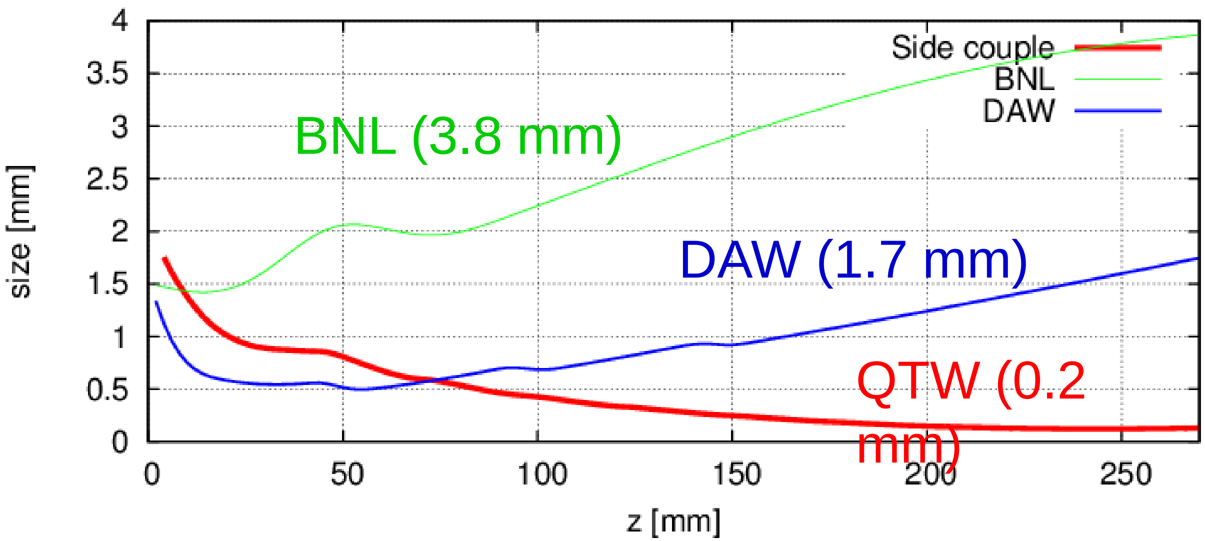
Quasi traveling wave side couple RF gun
(100 MV/m, 6mm-mrad, 13.5 MeV)



DAW-type RF gun
(90 MV/m, 5 mm-mrad, 3.2 MeV)

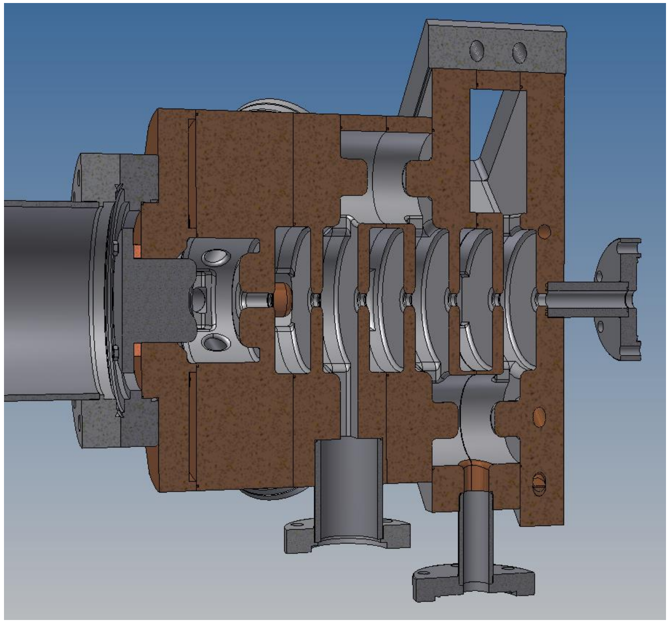


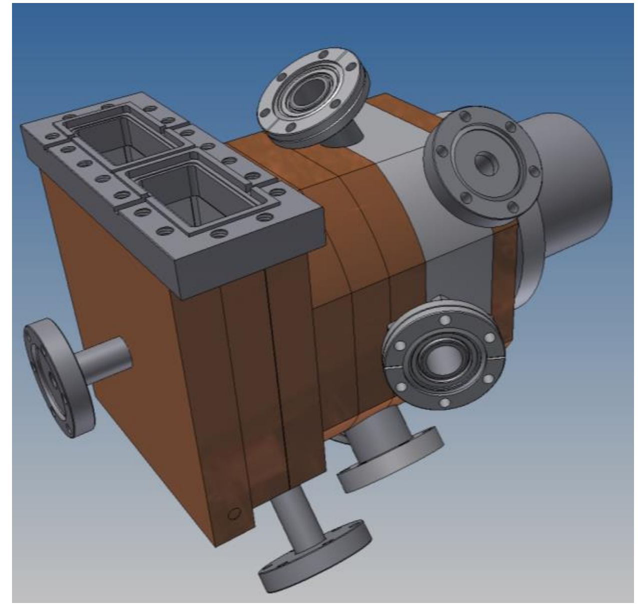
BNL-type RF gun
(120 MV/m, 11.0 mm-mrad, 5.5 MeV)

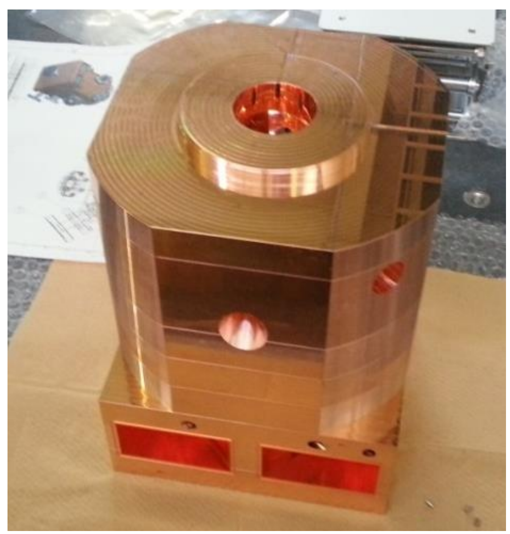


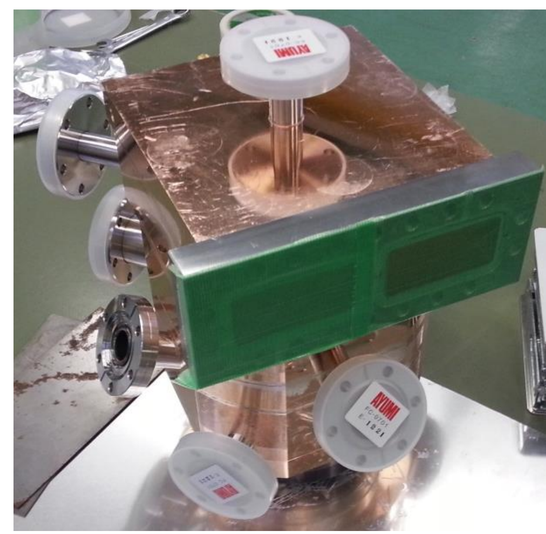
Beam Size

Mechanical design and manufacturing



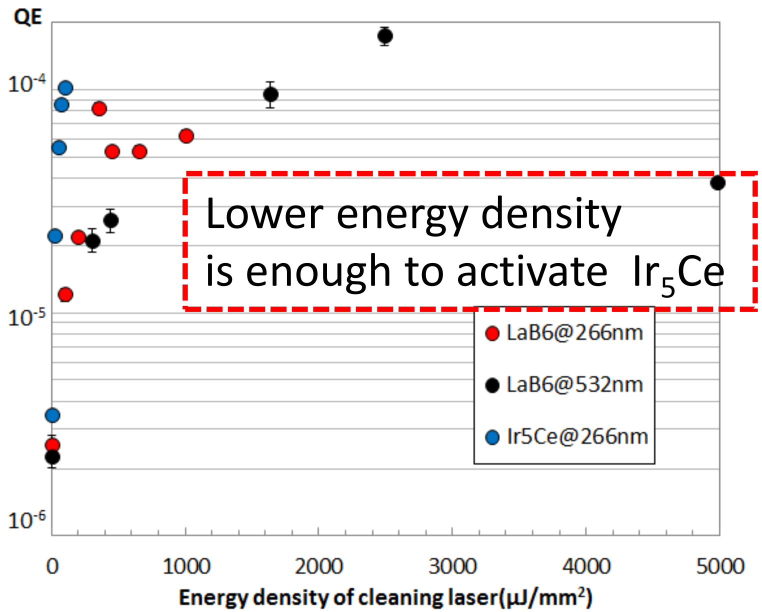


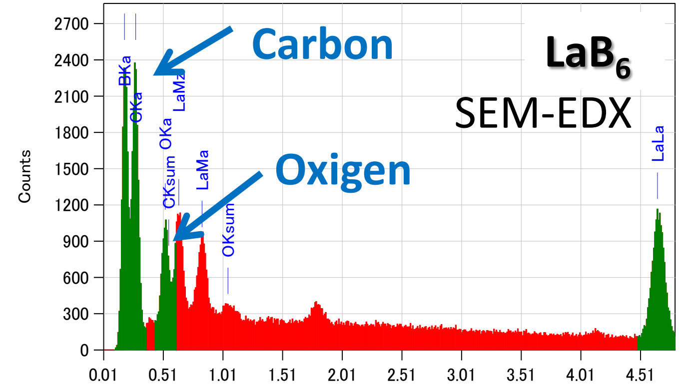


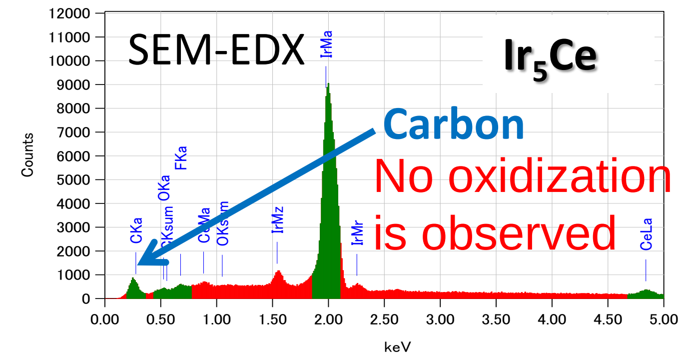


Ir_5Ce Cathode

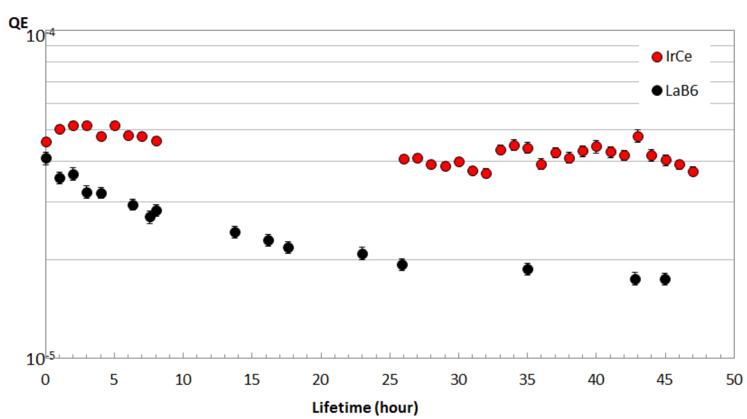
Quantum efficiency improvement by Laser cleaning



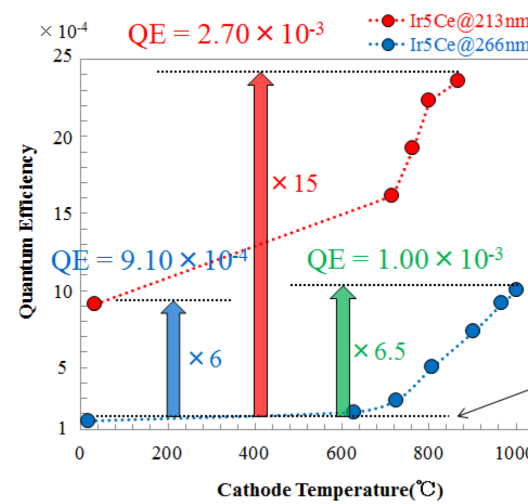




QE lifetime

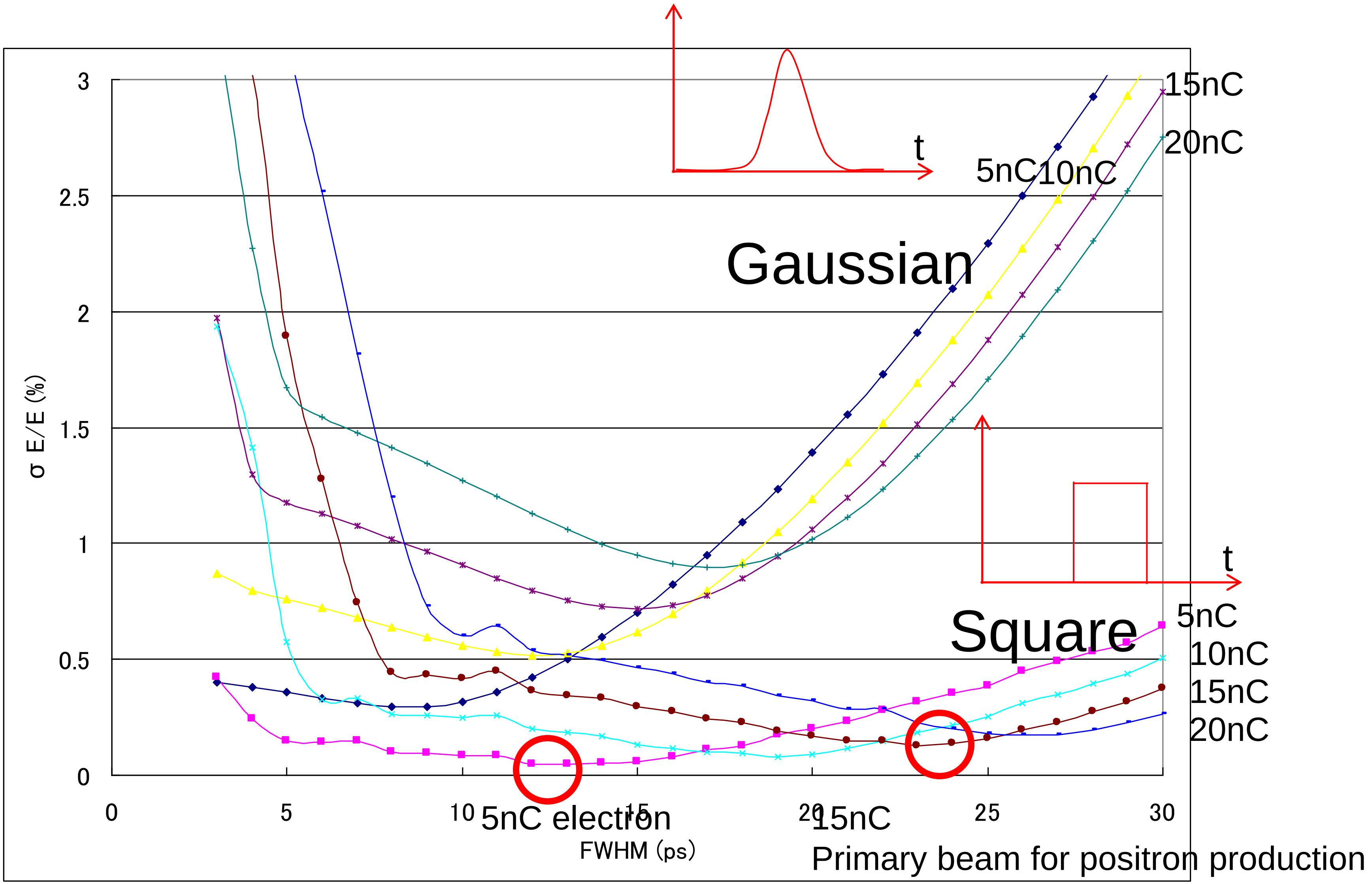


QE Enhancement of IrCe cathode



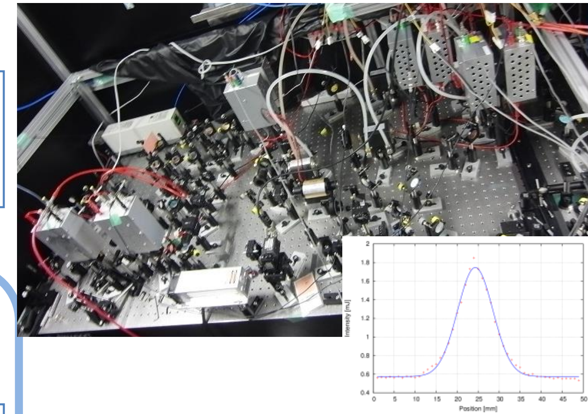
Energy spread reduction using temporal manipulation

Energy spread of 0.1% is required for SuperKEKB synchrotron injection.



Properties of laser medium

Nd laser system for 3-2 RF-Gun



Nd-doped

- ○ 4-state laser is easy to operate.
- ○ High power pump LD is available.
- ○ Large crystal is available
- × Pulse width is determined by SESAM. (Gaussian)

τ～200μs, 40%

LD Pump (808nm) → 808nm → Nd:YVO4 / Nd:YAG → 1064nm → SHG(532nm) 40% / FHG(266nm) 20% / 5HG(213nm) 3%

Yb-doped

- ○ Wide bandwidth => pulse shaping
- ○ Long fluorescent time => High power
- ○ Fiber laser oscillator => Stable
- ○ Small state difference
- × ASE
- × Absorption

τ～900μs, 40%

LD Pump (941/976nm) → 941/976nm → Yb-glass / Yb:YAG / Yb:BOYS → 1040nm → SHG(520nm) 40% / FHG(260nm) 20% / 5HG(208nm) 3%

→ Best for RF-Gun

Ti-doped

Pump: τ=200μs, 40%; 40%

Pump (808nm) → 808nm → Nd:YAG → 1064nm → SHG → 532nm → Ti:Sapphire → 800nm → SHG(400nm) 40% / THG(266nm) 20% / FHG(200nm) 10%

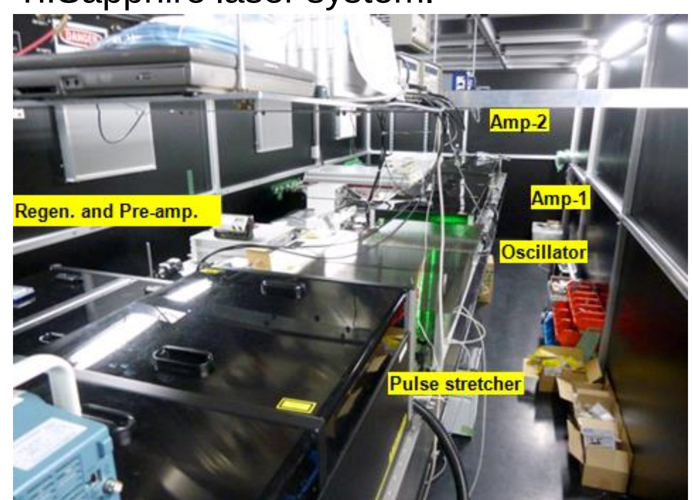
τ～3μs, 40%

- ○ Very wide bandwidth
- ○ High breakdown threshold
- × Low cross section
- × Short fluorescent time => Q-switched laser is required for pumping

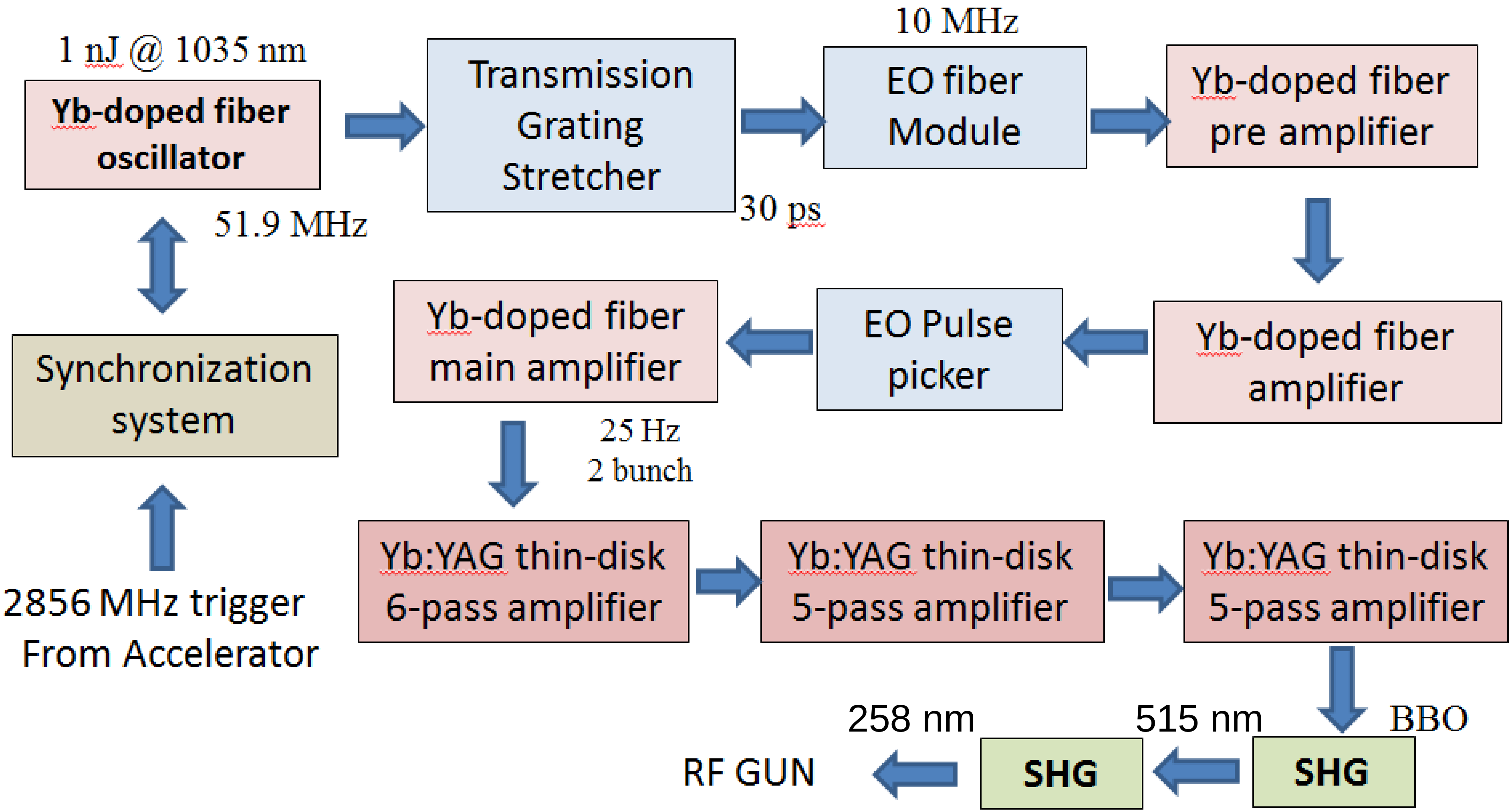
(High breakdown threshold, Low cross section) } TW laser is based on Ti-Sapphire

	Material	Nd:YAG	Yb:YAG	Ti:Sapphire
Fluorescence	Wavelength	1064nm	1030nm	660−1100nm
	Fluorescent time	230μs	960μs	3.2μs
	Spectral width	0.67nm	9.5nm	440nm
	Fourier minimum Pulse width	2.48ps	165fs	2.59fs
Absorption	Wavelength	807.5nm	941nm	488nm
	Spectral width	1.5nm	21nm	200nm
	Quantum efficiency	76%	91%	55%

Ti:Sapphire laser system.

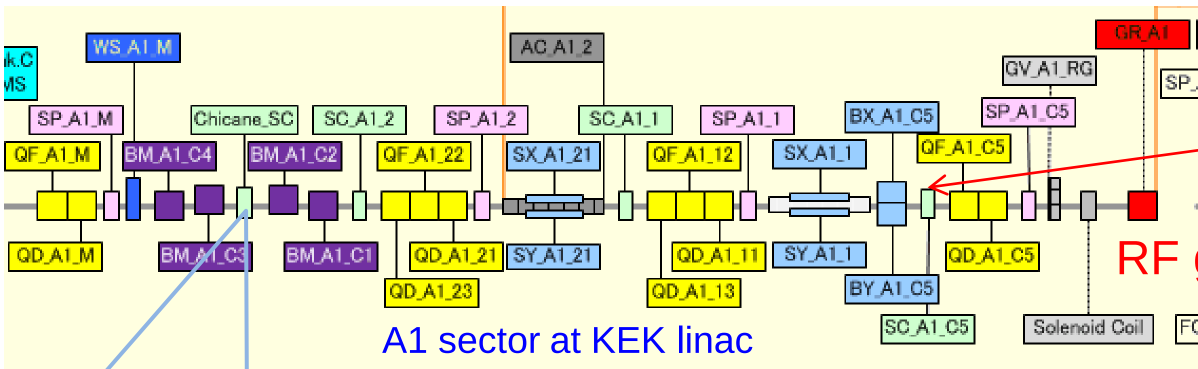


Yb fiber & thin disk hybrid laser system

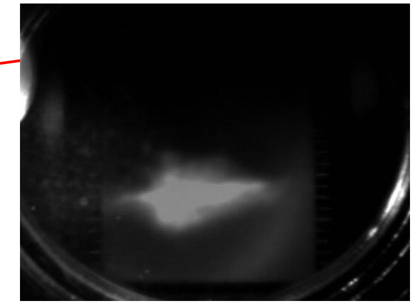


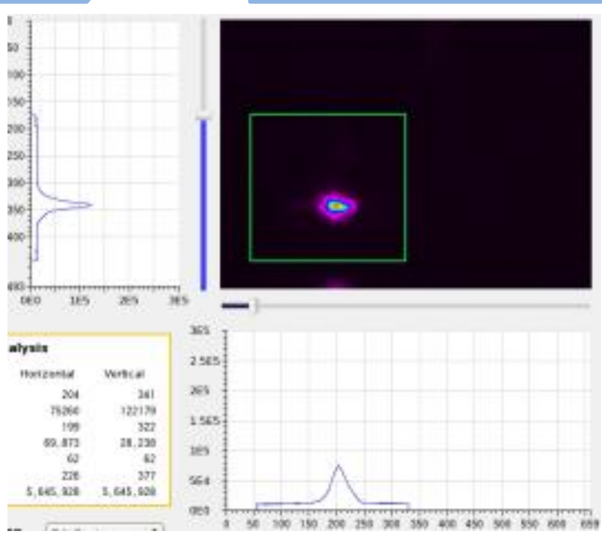
QE = 10^{-4} ➡ A few mJ @ 258nm, 50Hz is required.

A-1 RF gun results

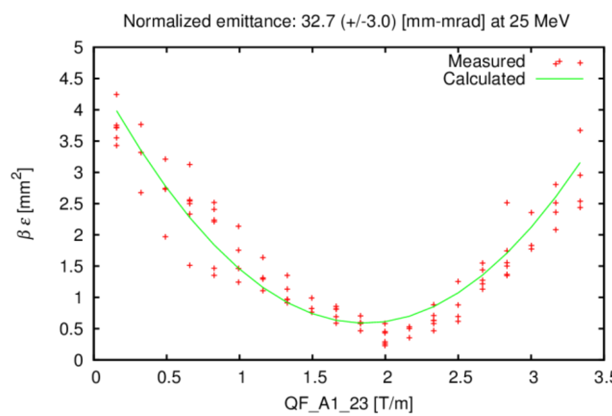


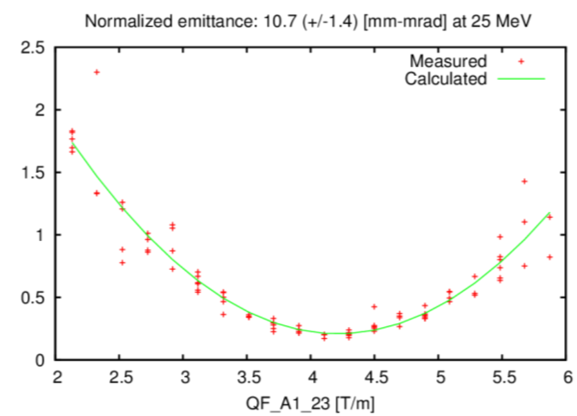
5.6 nC bunch charge was observed.





beam size measurement for Q-scan





Q-scan emittance measurement

x	y
32.7 ±3.1 mm-mrad	10.7 ±1.4 mm-mrad

Photo cathode RF gun improvement

- Crucial for high-current low-emmittance beam
- New Ir5Ce cathode and new cavity QTWSC were successful
- Basic features were confirmed at 5 Hz
- Cavity: DAW (disk and washer) → QTWSC (high space charge)
- Cathode: LaB6 → Ir5Ce (long life, medium q.e. >10^{-4})
- Laser: Nd:YAG → Yb:YAG thin disk and fiber
  Regenerative amp. → Multi-pass amp. w/ cooling
  - Yb-fiber-oscillator – stretcher – fiber-amp – fiber-amp – pulse-picker – Yb:YAG-thin-disk-multipass-amps (6-pass, 5, 5, 2, 1) – SHG – SHG
- Staged laser system improvements with beam measurements
  - 5-nC low-emittance stable beam for electron injection
  - 10-nC beam for positron generation
  - 50Hz generation with heat dissipation (several possible plans)
  - Stability improvement, with precise synchronization (commercial oscillator)
  - Temporal manipulation for lower energy spread

Schedule Summary (Typical)

- **October 2015 (Phase-1, earliest)**
  - MR normal emittance injection for vacuum scrubbing
  - 2bunch in a pulse, 50Hz, 1nC electron, 10nC primary electron for positron generation
- **February 2017 (Phase-2, earliest?)**
  - MR low emittance injection for collision tuning
  - 20 mm.mrad (linac end), 2nC, 2bunch, 0.1%dE/E, 50Hz
  - Normal emittance, 5nC, 2bunch, 50Hz for positron
- **October 2017 (Phase-3, earliest?)**
  - MR low emittance injection for collision physics experiment
  - 20 mm.mrad, 4nC (→5nC), 2bunch, 0.1%dE/E, 50Hz
  - Normal emittance, 10nC, 2bunch, 50Hz for positron

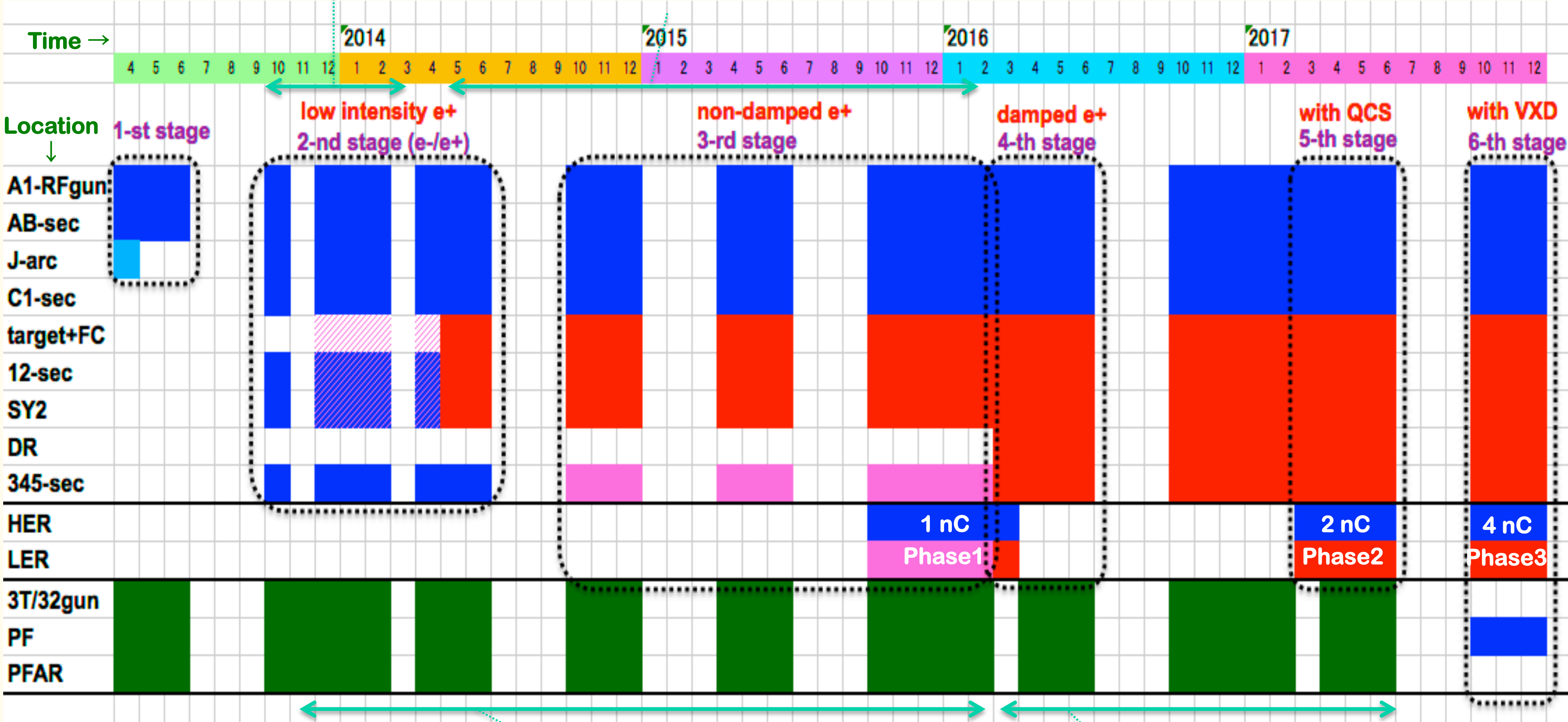
Linac Schedule Overview (autumn 2014)

RF-Gun e- beam commissioning at A,B-sector

e- commiss. at A,B,J,C,1

e+ commiss. at 1,2 sector (FC, DCS, Qe- 50%)
e- commiss. at 1,2,3,4,5 sector

Phase1: high emittance beam for vacuum scrub
Phase2,3: low emittance beam for collision



non damped e+ commiss.
at 1,2, 3,4,5 sectors
e- commiss. at A→5 sectors

damped e+ commiss.
at 1→5 Qe+ = 1~4nC
e- commiss.
at A→5 Qe- = 1~5nC

PF-AR e- commiss.

- : Electron
- : Positron
- : Low current electron