Electron / Positron Injector Linac

Kazuro Furukawa
for Injector Linac group

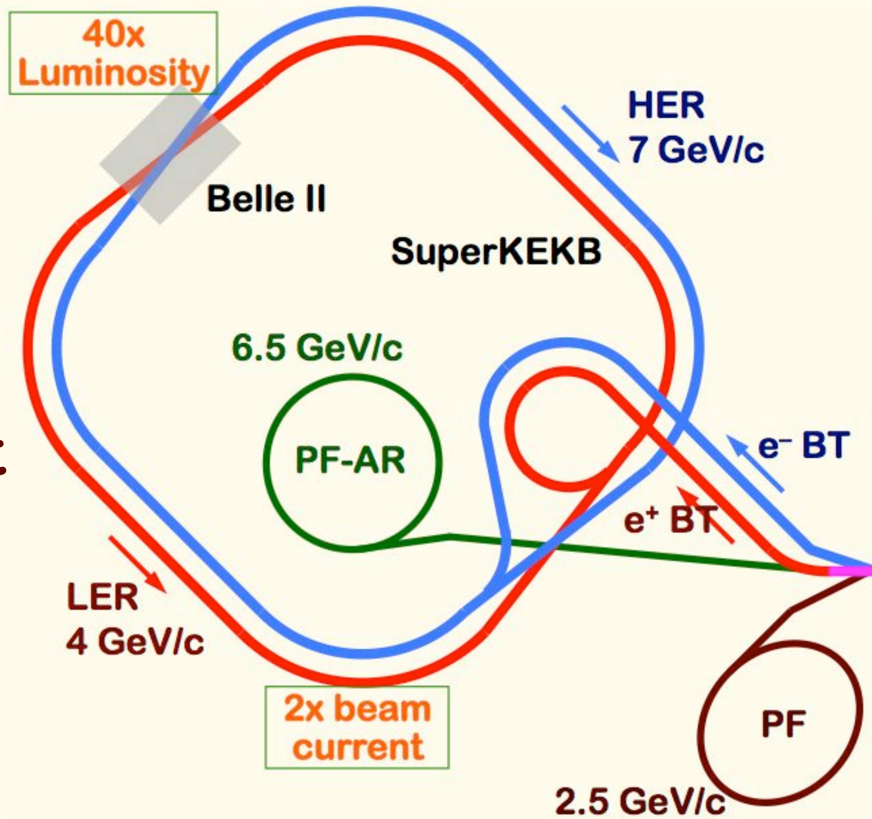
SuperKEKB での Linac の役割

◆ 40-times higher Luminosity

- ❖ Twice larger storage beam → Higher Linac beam current
- ❖ 20-times higher collision rate with nano-beam scheme
  - ⌑ → Low-emittance Linac injection beam
  - ⌑ → Shorter storage lifetime → Higher Linac beam current

◆ Linac challenges

- ❖ Low emittance e-
  - ⌑ High-charge RF-gun
- ❖ Low emittance e+
  - ⌑ Damping ring
- ❖ Higher e+ beam current
  - ⌑ New capture section
- ❖ Beam transport
  - ⌑ Emittance preservation
- ❖ 4+1 ring simul. injection

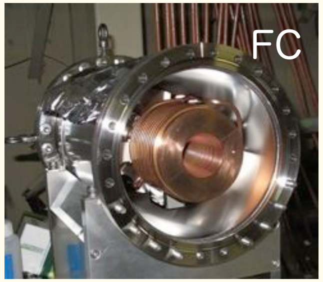


Linac provides:

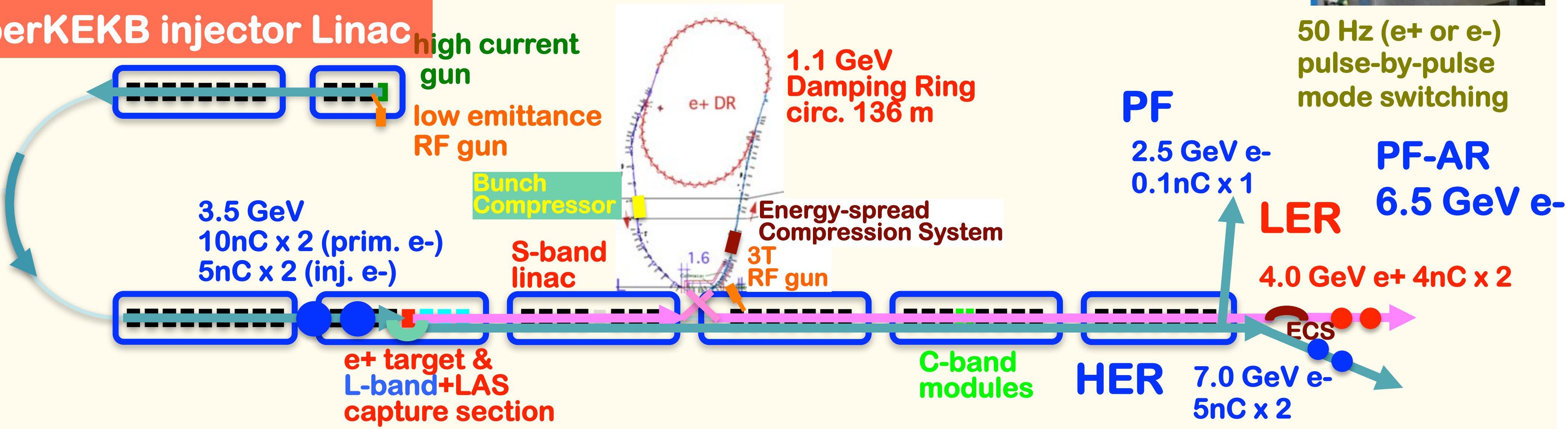
PF:	2.5 GeV e-
PF-AR:	6.5 GeV e-
SuperKEKB:	7 GeV e-
	4 GeV e+

Linac Upgrade for SuperKEKB

- **Higher Injection Beam Current**
  - To Meet the larger stored beam current and shorter beam lifetime in the ring
  - 4~8-times larger bunch current for electron and positron
- **Lower-emittance Injection Beam**
  - To meet nano-beam scheme in the ring
  - Positron with a damping ring, Electron with a photo-cathode RF gun
  - Emittance preservation by alignment and beam instrumentation
- **Quasi-simultaneous injections into 4 storage rings (PPM)**
  - SuperKEKB e⁻/e⁺ rings, and light sources of PF and PF-AR
  - Improvements to beam instrumentation, low-level RF, controls, timing, etc



SuperKEKB injector Linac

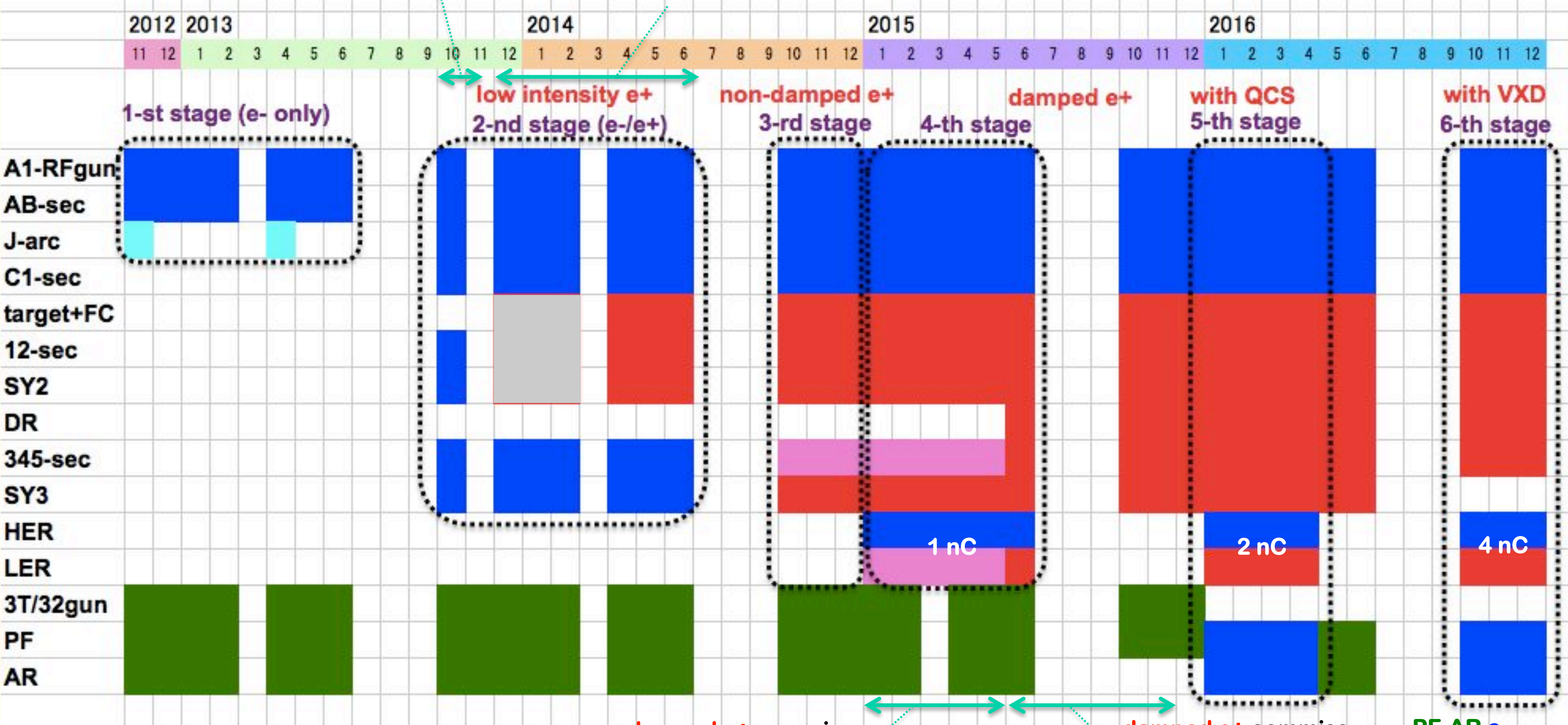


Linac Schedule Overview

RF-Gun e- beam commissioning at A,B-sector Qe- = 5nC

e- commiss. at A,B,J,C,1 Qe- = 5nC

e+ commiss. at 1,2 Qe+ = 0.5nC (FC, DCS, Qe- 50%)
e- commiss. at 1,2,3,4,5 Qe- = 5nC



- : Electron
- : Positron
- : Low current electron

non damped e+ commiss.
at 1,2, 3,4,5 Qe+ = 4nC
e- commiss. pulse-switch
at A→5 Qe- = 5nC

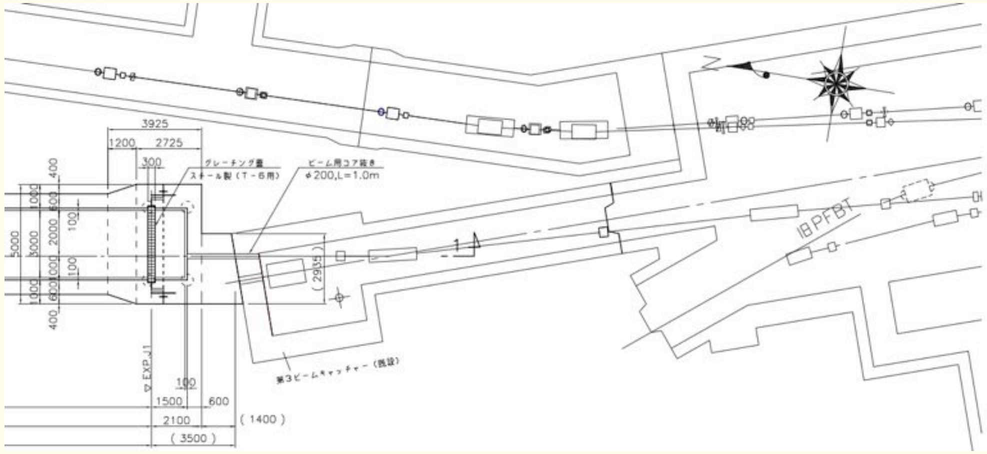
damped e+ commiss.
at 1→5 Qe+ = 4nC
e- commiss.
at A→5 Qe- = 5nC

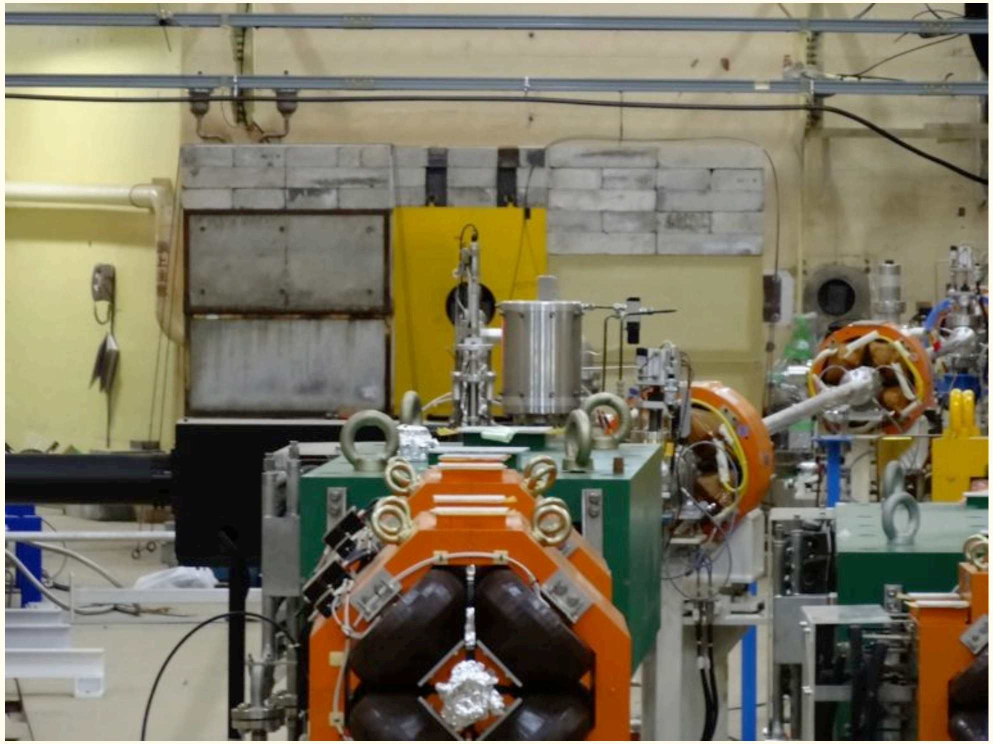
PF-AR e- commiss.

概略の予定

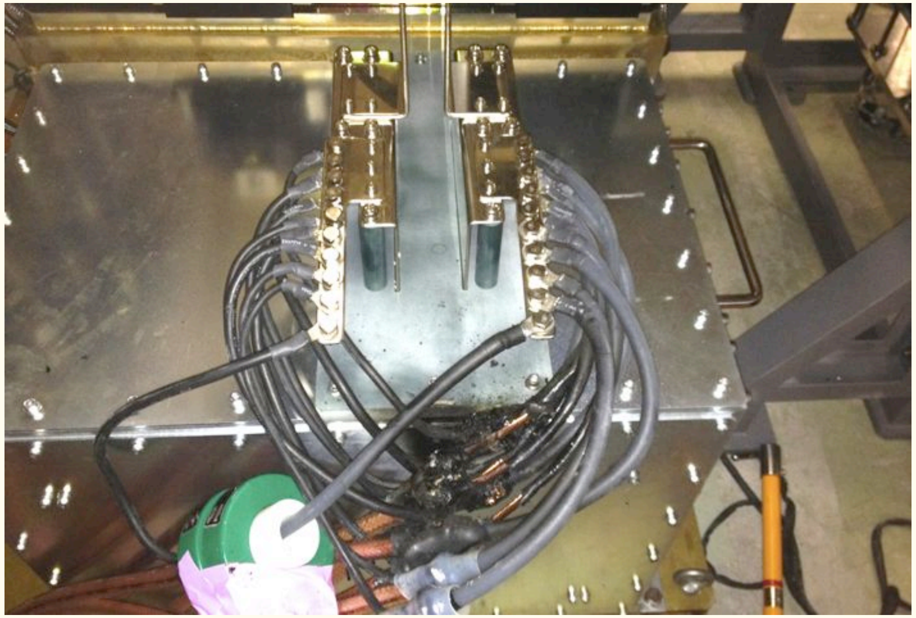
- **2013 夏: 多数の機器の設置**
- **2013 秋: e– commissioning (limited)**
  - 後半部: PF 入射, 前半部 日中準夜: ビームコミッショニング
- **2014 春: Commissioning 継続, 後半部調整, Alignment 等々**
  - 後半部: PF 入射, 前半部 日中: DR 建設, 準夜: ビームコミッショニング
- **2014 夏: 機器の設置, PFAR-BT (部分)**
  - 冷却水・電力増強, Pulsed magnets 設置, 安全系
- **2014 秋: Linac (nearly) full commissioning**
  - PF without daytime top-up? BPM (partially), RF-monitor
- **2015 冬: MR then (春) DR injection commissioning**
  - Normal emittance, 1nC, Non-continuous injection, PF Top-up
- **2016: MR commissioning**
  - Lower emittance, 2nC, Continuous injection

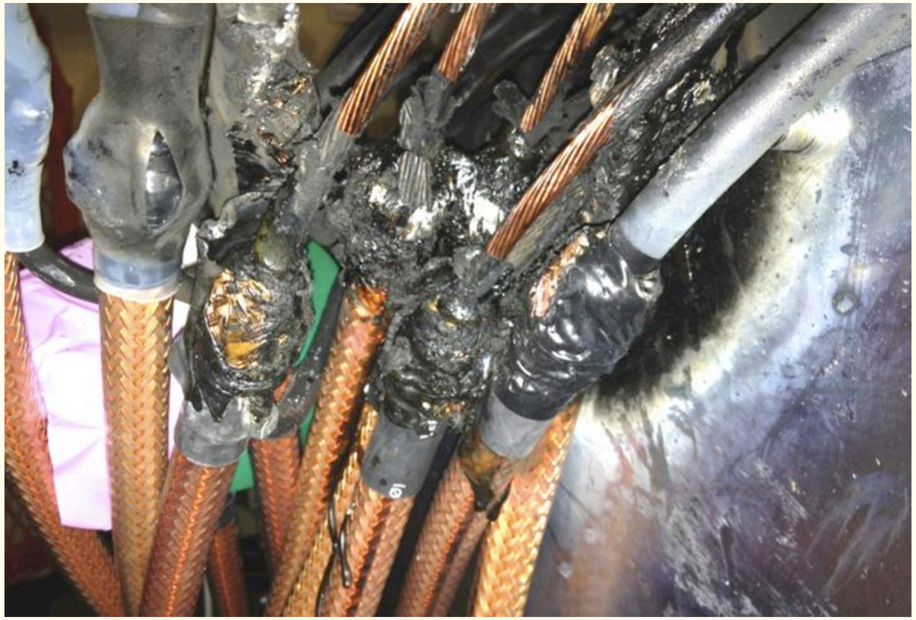
PF-AR 直接入射路工事 追加シールド





FC 開発 3 号機ぼや　Cable 20cm 焼損





SLAC-SuperKEKB Workshop (Injector Linac)

- **Injector commissioning and issues** ***30'***
  - Speaker: Masanori Satoh (KEK)
- **Photo-cathode RF gun** ***20'***
  - Speaker: Takuya Natsui (KEK)
- **Positron source** ***30'***
  - Speaker: Takuya Kamitani (KEK)
- **Timing synchronization** ***20'***
  - Speaker: Hiroshi Kaji (KEK)
- **Linac alignment** ***20'***
  - Speaker: Toshiyasu Higo (KEK)
- **Beam optics design for simultaneous injection** ***20'***
  - Speaker: Takako Miura (KEK)

Questions and Answers

- PEDD dependent on beam repetition?
  - SLAC study was on single-pulse energy density
    - may need further investigation
- Fiber loss monitor blackening around target?
  - Can be replaced routinely
- Diamond loss detector?
  - Is worth comparing in the future
- Orbit stability tolerance against beam size?
  - Pinhole 2mm and beam sigma 0.3mm are possible
    Beam orbit jitter will be studied, as well as for emittance preservation
- Rotating target/spoiler?
  - Should be studied for the beam current larger
- Frequency synchronization btw. linac/ring?
  - All SKEKB frequencies are generated from common freq. with ring circumference compensation
- Beam charge variation pulse-pulse?
  - Can be important
  - Technically possible with different event assignment
  - Means different injection modes with different orbit stabilization for wakefield
- Target quad – pulsed ?
- Beam jitter should be small
- DR extraction angle jitter
  - Offset injection position/angle jitter should be small

BPM 読み出しの技術選択

- **Beam position monitor (BPM)**
  - Emittance preservation に重要となる
  - ~10μm の要求分解能 (現在の装置は 50~100μm)
- **Libera と SLAC の技術を基礎とした新規開発**
  - それぞれ開発・評価中
- **SLAC の Steve Smith 氏と Andrew Young 氏に Review 依頼**
  - SLAC – SuperKEKB の協力の枠組み
  - Filter 設計、Dual-bunch 信号処理、System 設計に関して詳細な Comment をもらう (may.22-27, jun.15-18.2013.)
  - Reviewer は新規開発を選択
- **詳細設計の改善中**
  - 予算の関係で当初からの全数設置は避けるが、現在のところ、新規開発が性能、価格、運用、保守の全般で有利として、開発中

Laser RF 電子銃 Workshop

- **ATF, cERL, Linac** から計 **16** 人参加、**6+** 件の発表
- 機構内でも共通技術の交換の可能性がある
- 低 **Emittance** はほぼ共通目標であるが、**Linac** で重要な大電流 **+** 低エネルギー幅は **Unique** で、そのための技術交換はあまりなかった
- 安定度などについて、今後とも情報交換の予定
- **Web** を準備する予定

LAS 加速管 Processing

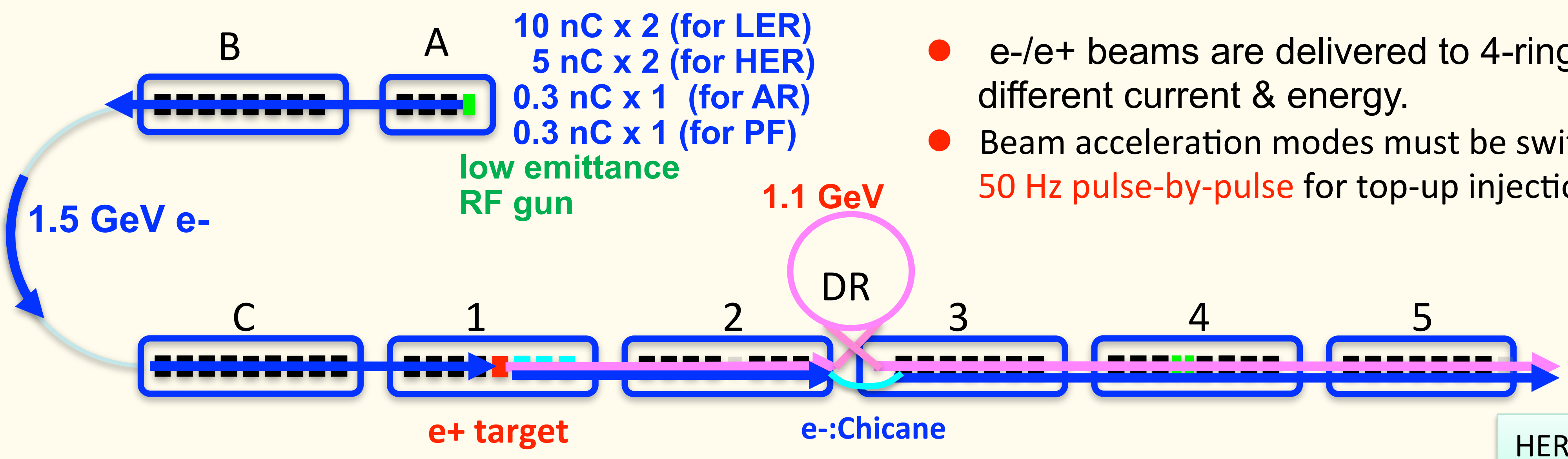
- 陽電子捕獲のための大口径加速管
  - Large aperture S-band structure (LAS)
- Processing に 1 ヶ月以上掛かっていることについて、識者意見を求め、22 人以上の多数の方の参加を得た (Dec.10.2013.)
- 時間が足りないと思われ、当面の試験運転対策、中期の改善対策について、議論が行われた
  - Interlock の改善、Baking は不要・無意味であること、RF monitor 等測定装置が重要であること、等助言を受けた

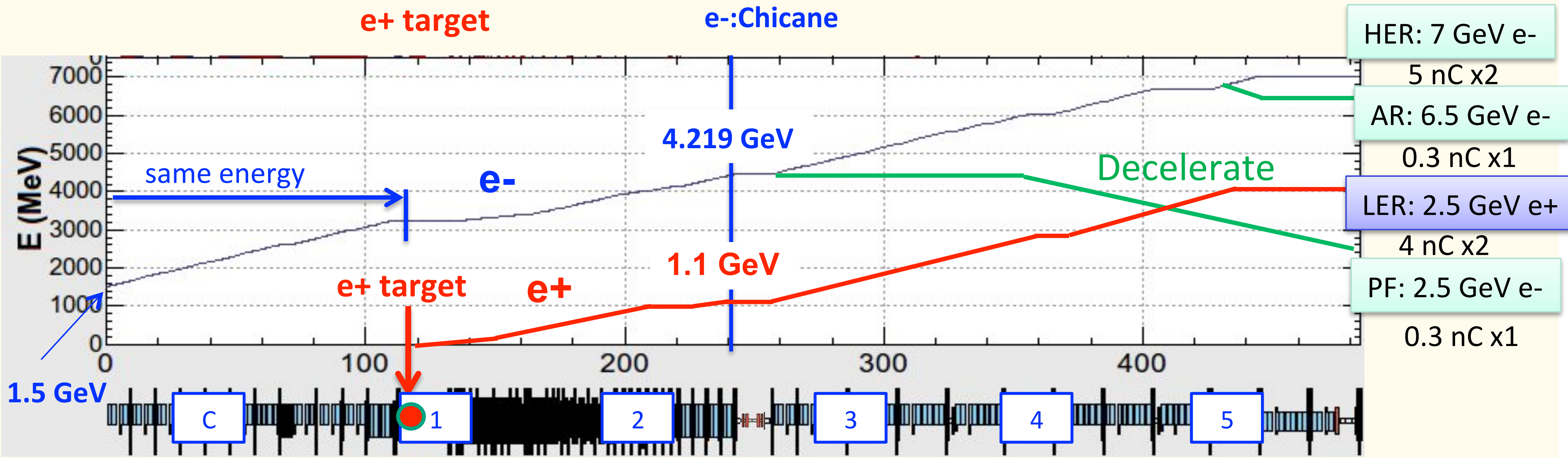
ビーム光学設計

- Pulsed quad の追加　–　同時入射向け
- FODO → Doublet　–　Low emittance
- Orbit correction simulation
- Emittance preservation
- 予算の Optimize…

KEK e-/e+ Injector LINAC

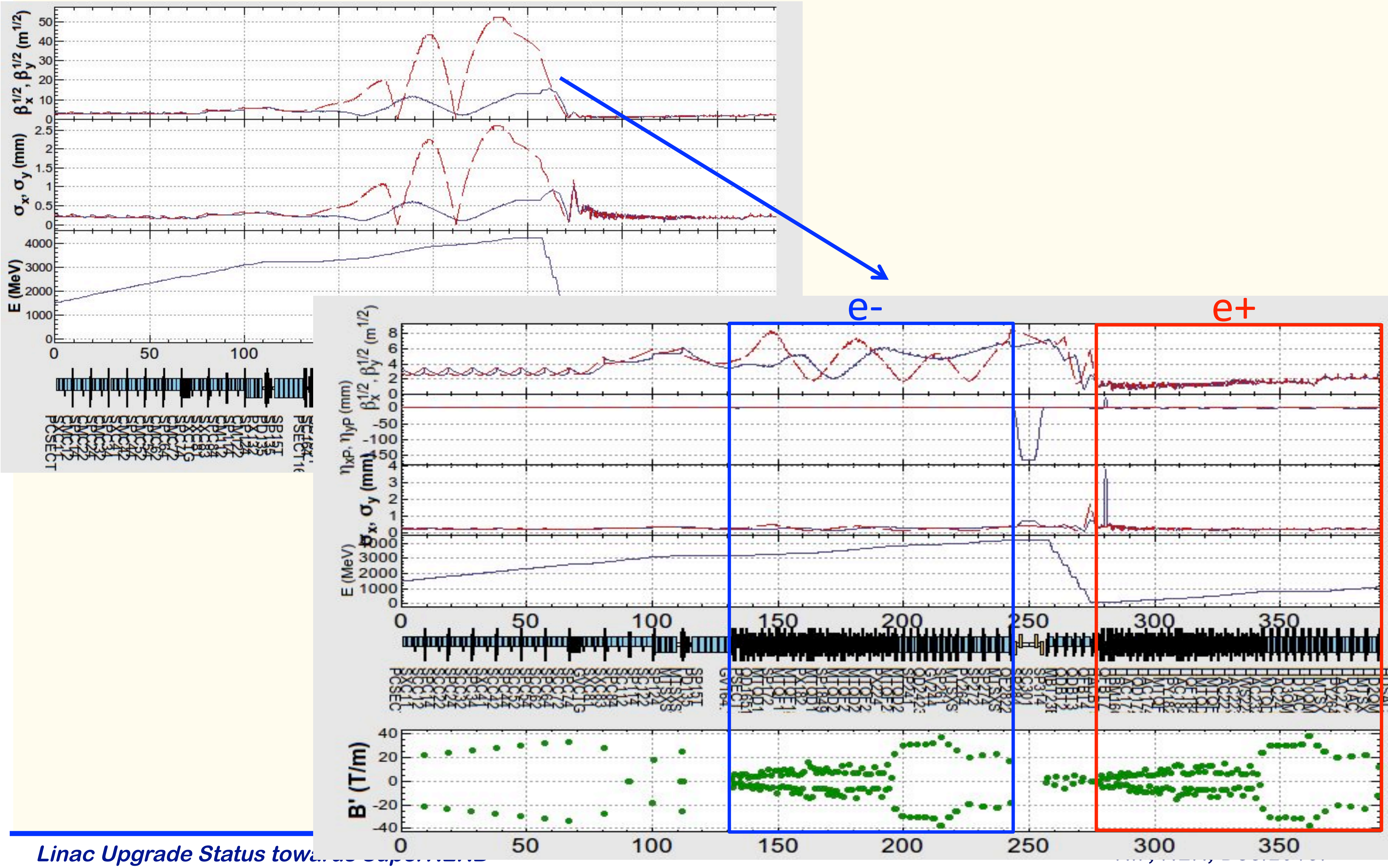
- e-/e+ beams are delivered to 4-rings with different current & energy.
- Beam acceleration modes must be switched by 50 Hz pulse-by-pulse for top-up injection.





Beam optics should satisfy the fast beam-mode switching.

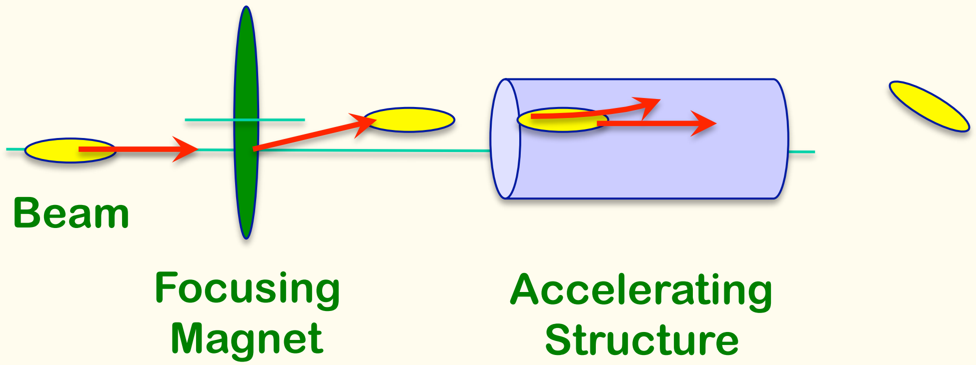
Result of e-p fitting

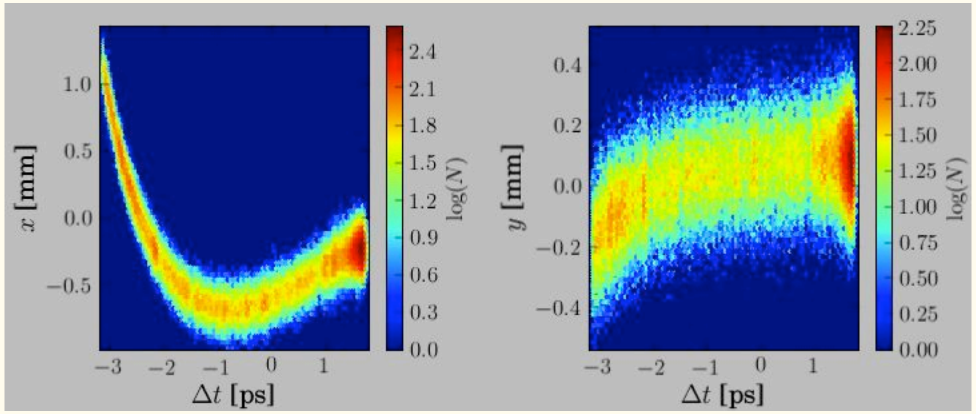


Emittance Preservation

- **If Device is off center of the beam**
  - Focusing magnet (quad) kicks the beam bunch
  - Accelerating structure (cavity) excites wakefield, to bend the tail
- **Distorted bunch in banana shape**
  - Emittance dilution or blow-up
  - Depending on the beam optics and the beam charge
- **Orbit correction is crucial to preserve the emittance**

Sugimoto et al.



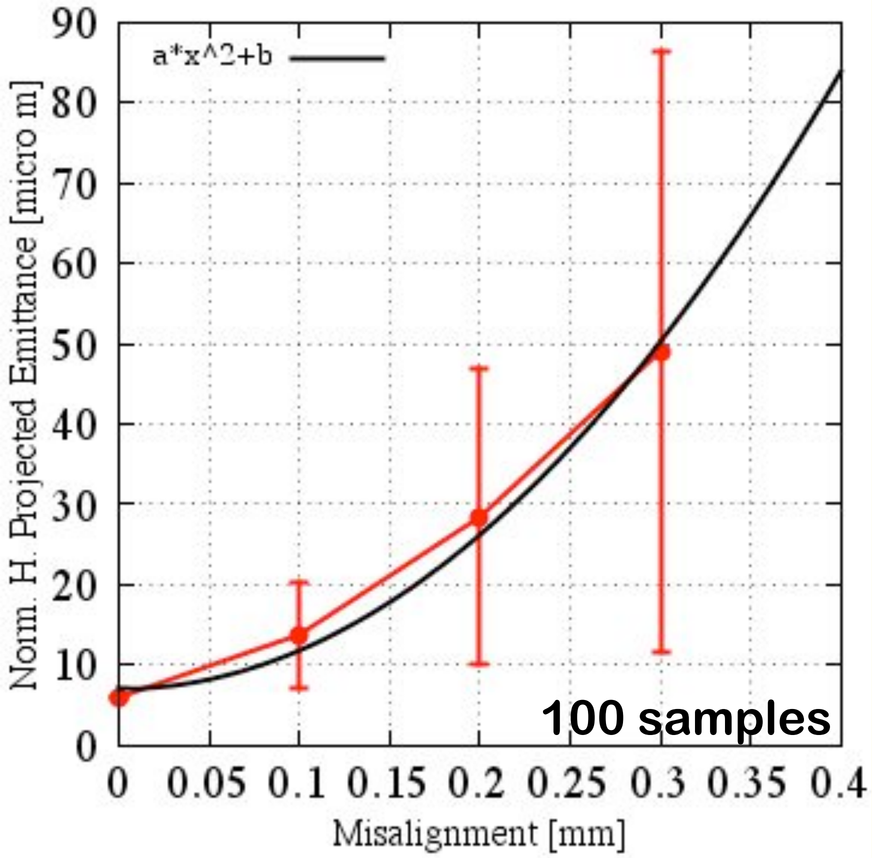


Transverse distribution in time direction

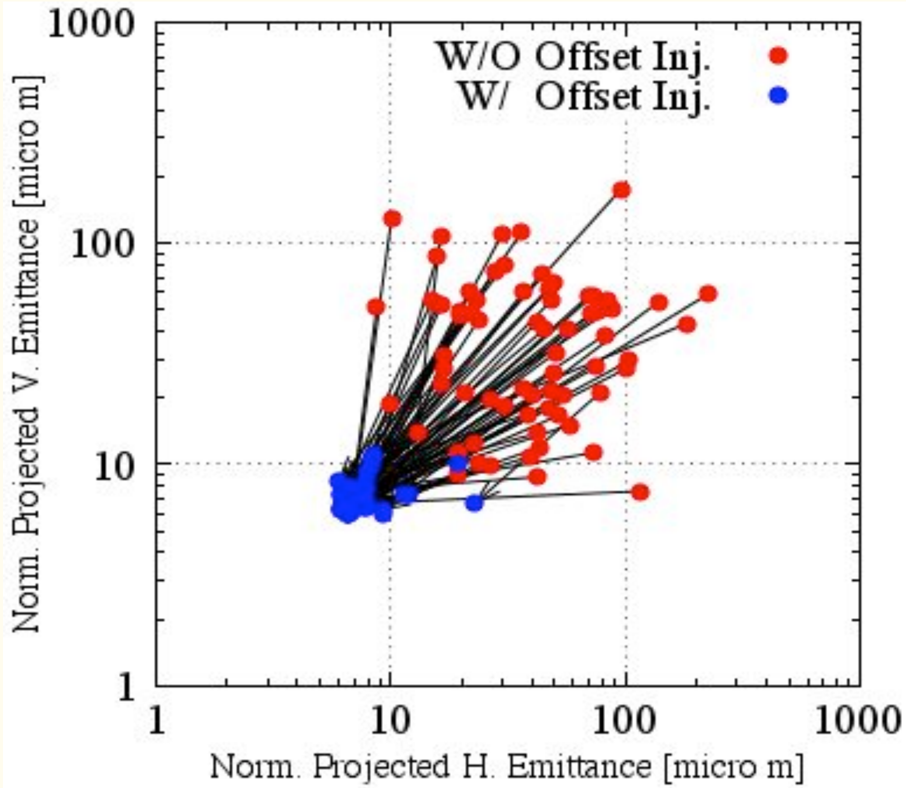
Emittance Dilution

- ◆Offset injection may solve the issue
- ◆Orbit have to be maintained precisely

Mis-alignment leads to Emittance blow-up



Orbit manipulation compensates it



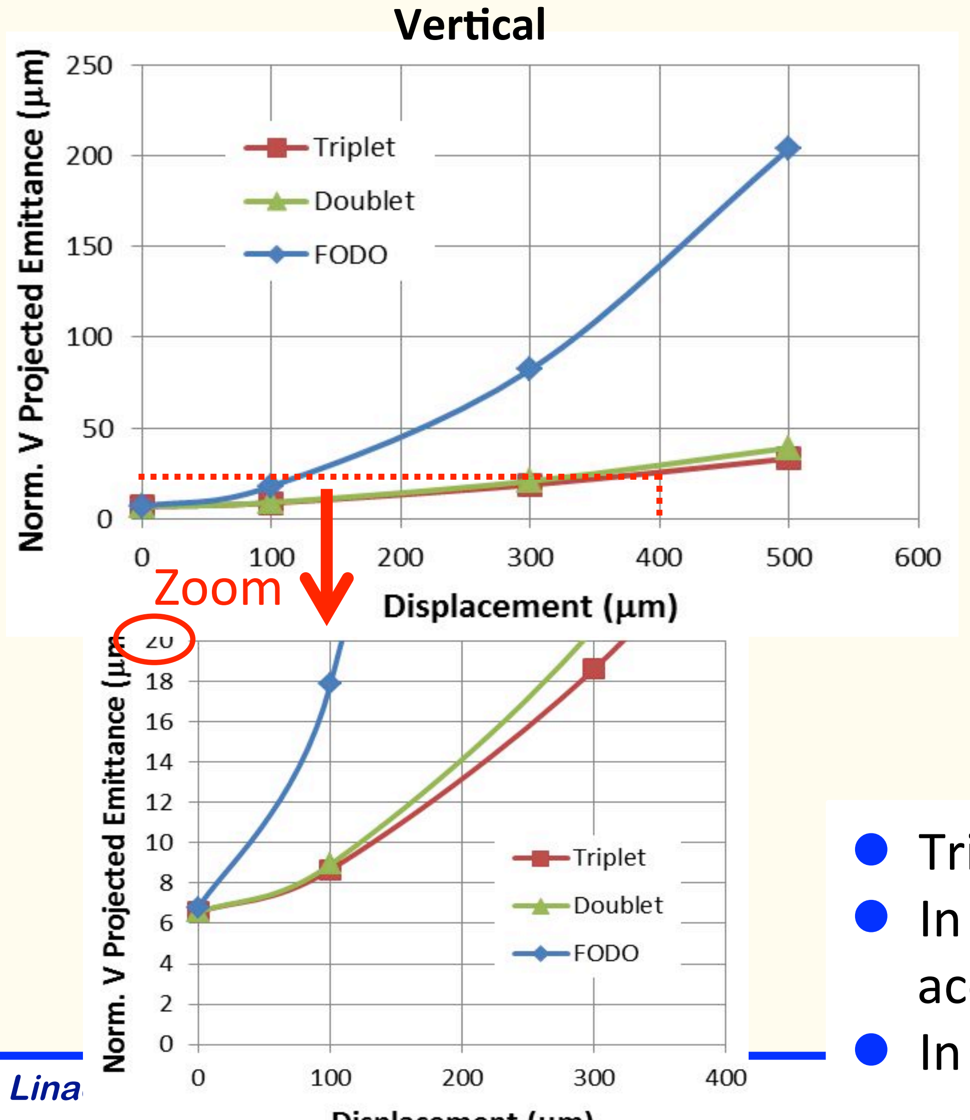
Sugimoto et al.

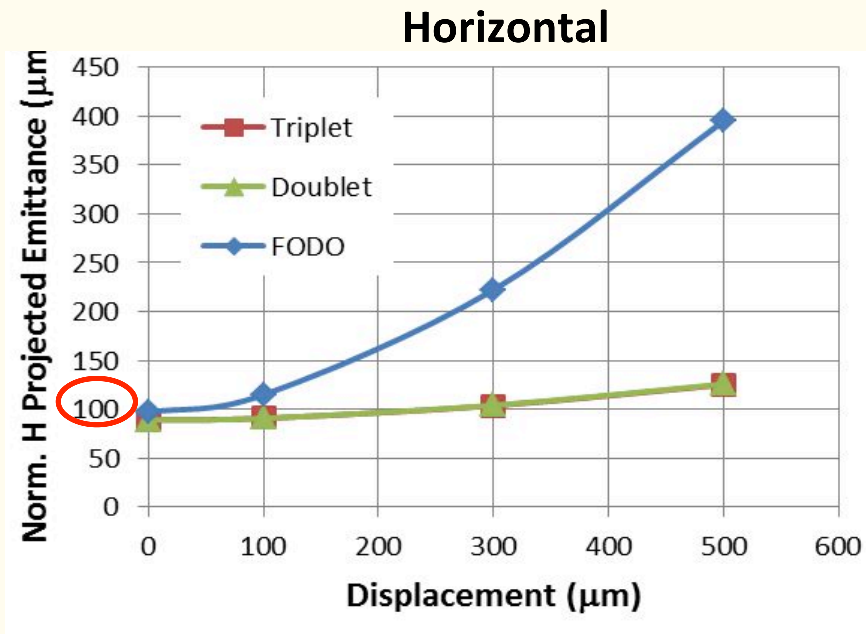
Alignment Error vs. Emittance Growth

<Tracking Condition>

Calculated by H. Sugimoto

- Positron is transported from DR outlet to LINAC end.
- Alignment error is given in quads and cavities.
- The orbit correction is performed by assuming the center of the quads and BPM are exactly the same.
- Initial Emittance@Outlet of DR =6.5 μm / 89 μm (Vertical / Horizontal)





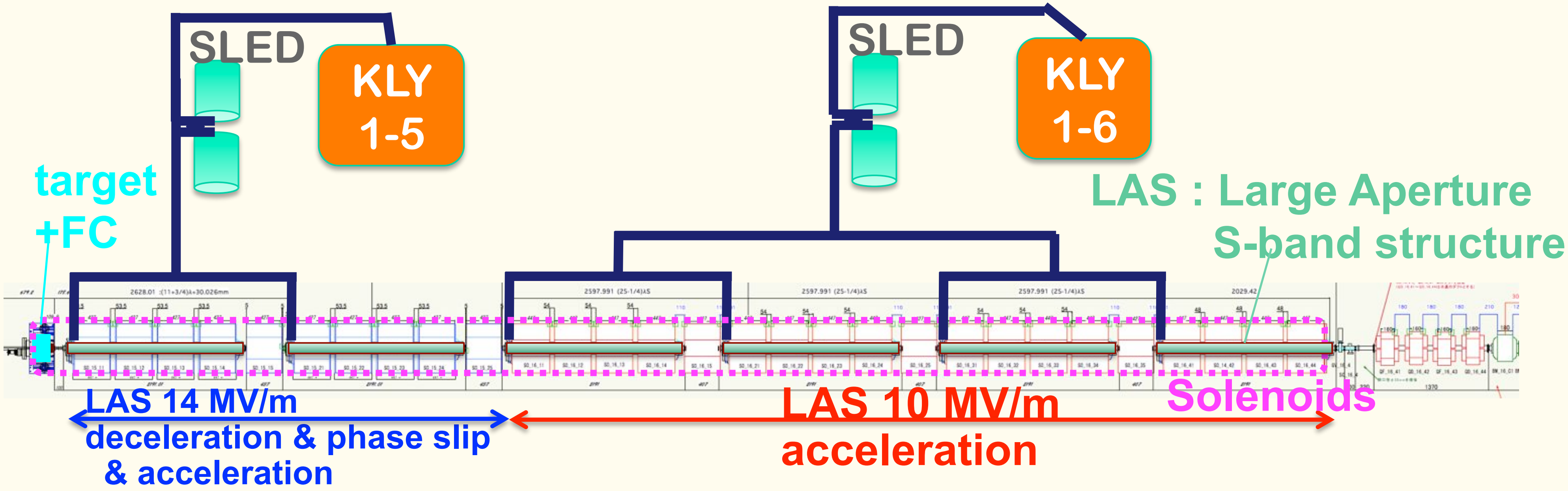
e+ norm. ε at LINAC-end should be less than 20 μm / 100μm (Ver. / Hor.)

- Triplet and doublet give almost same results.
- In triplet and doublet, misalignment of 300μm is acceptable.
- In FODO lattice, significant emittance growth is seen.

Positron Source

- High current positron is required
- Positron capturing with flux concentrator (FC) and large aperture s-band structure (LAS)
- Deceleration field to reduce satellite bunches
- Pinhole beside target for electron beam
- Protection system with beam spoilers

陽電子ビームライン建設　–　捕獲部分



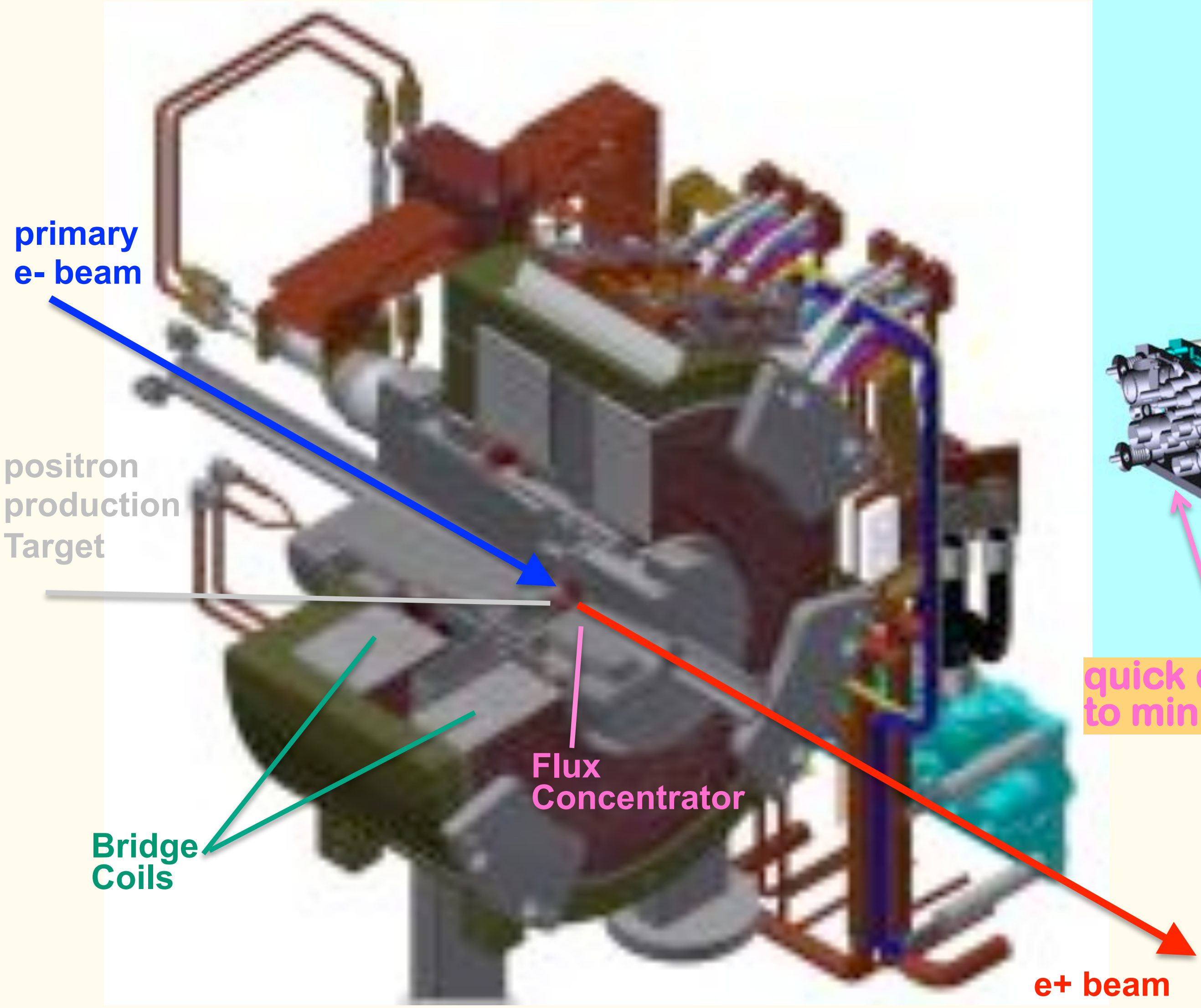
- primary e- 3.2 GeV, 10 nC x 2 bunch, 50 Hz
- tungsten target
- AMD system (5.0 T x 200mm Flux Concentrator + 0.4 T x 15m DC solenoids)
- KLY1 2m LAS x 2 (14 MV/m), aperture 2a = 32 -> 30 mm (typical S-band ~20 mm)
- KLY2 2m LAS x 4 (10 MV/m), aperture 2a = 32 -> 30 mm

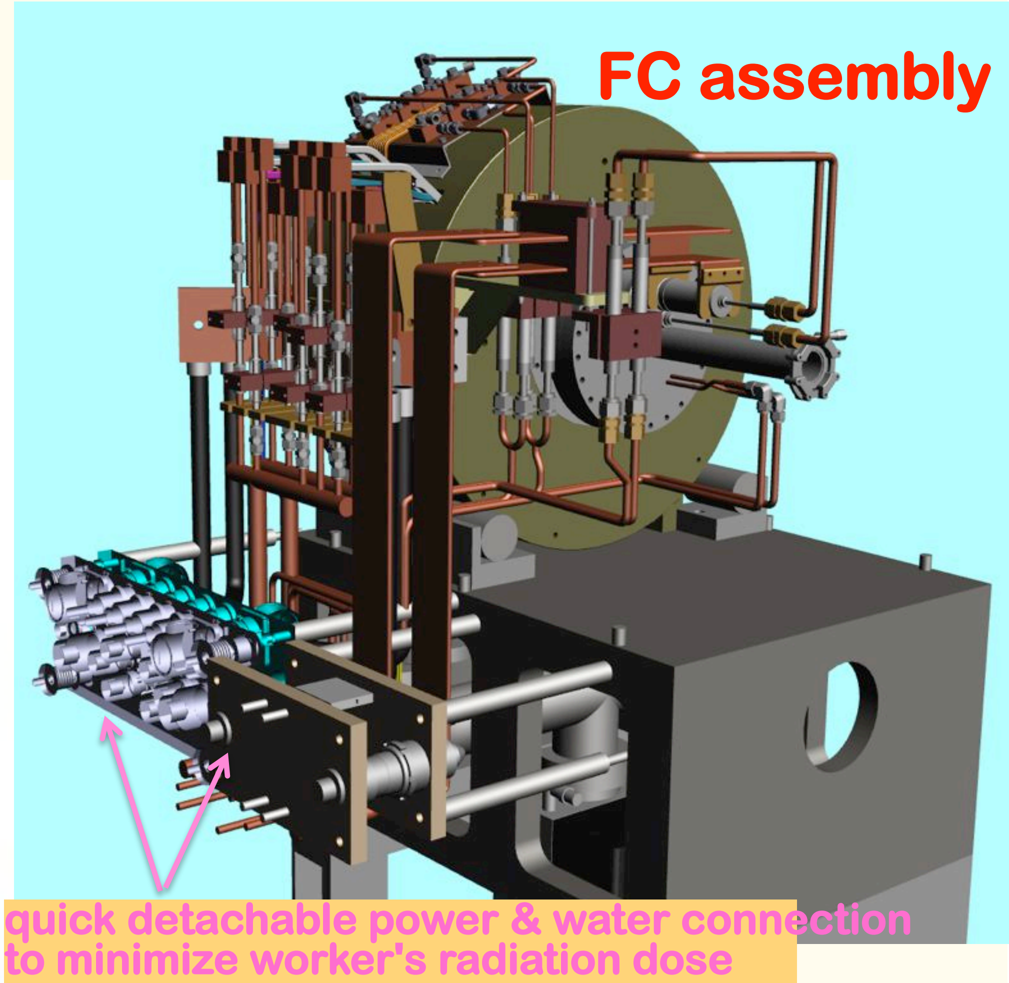
Deceleration capture

- e+ beam energy at capture section exit : 110 MeV

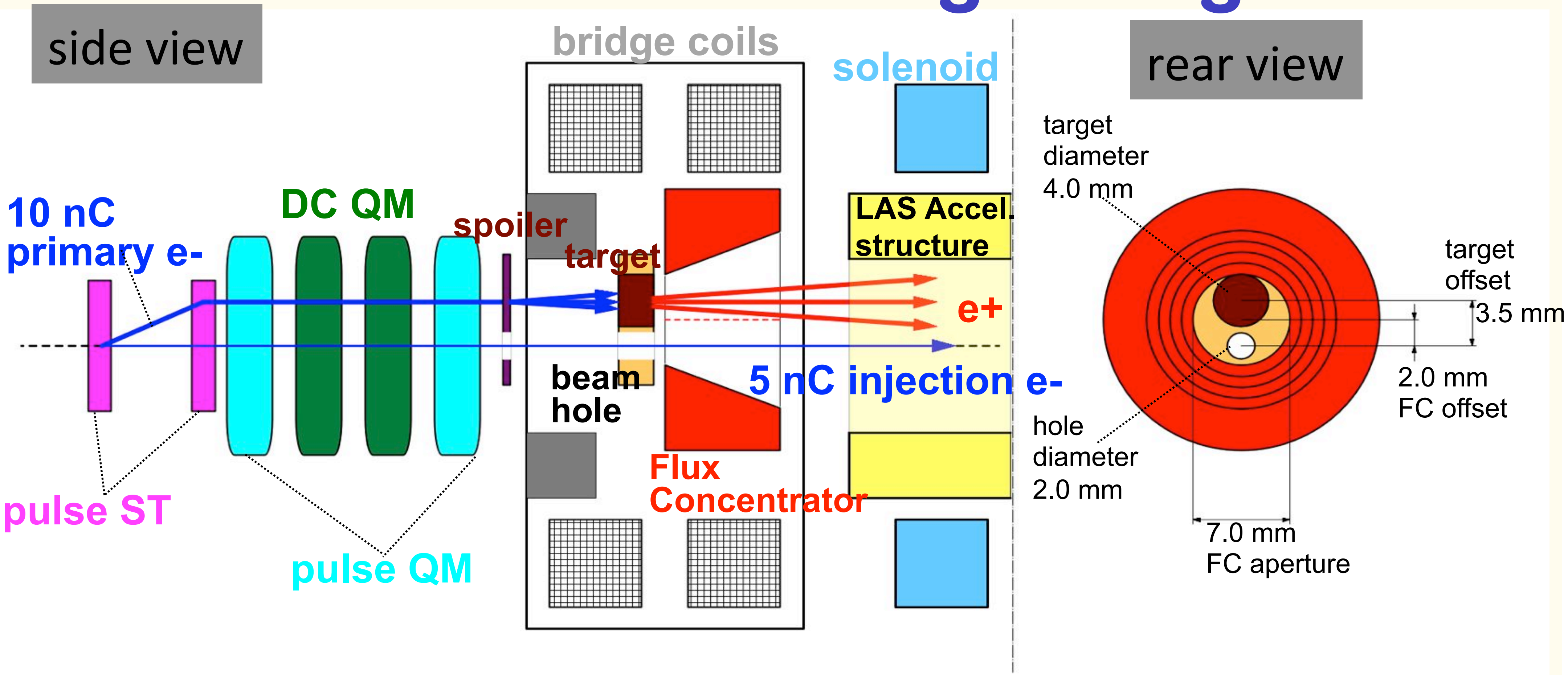
e+ yield: N(e+)/N(e-) = 49 % at 1.1 GeV DR

Flux Concentrator Assembly





e+/e- beam switching at target



Two possible schemes of beam switching by orbit bump

1) e+ on-axis, e- offset
   -> e- emittance growth by solenoid kick induced orbit
2) e- on-axis, e+ offset
   -> e+ yield degradation (50% -> 10%)

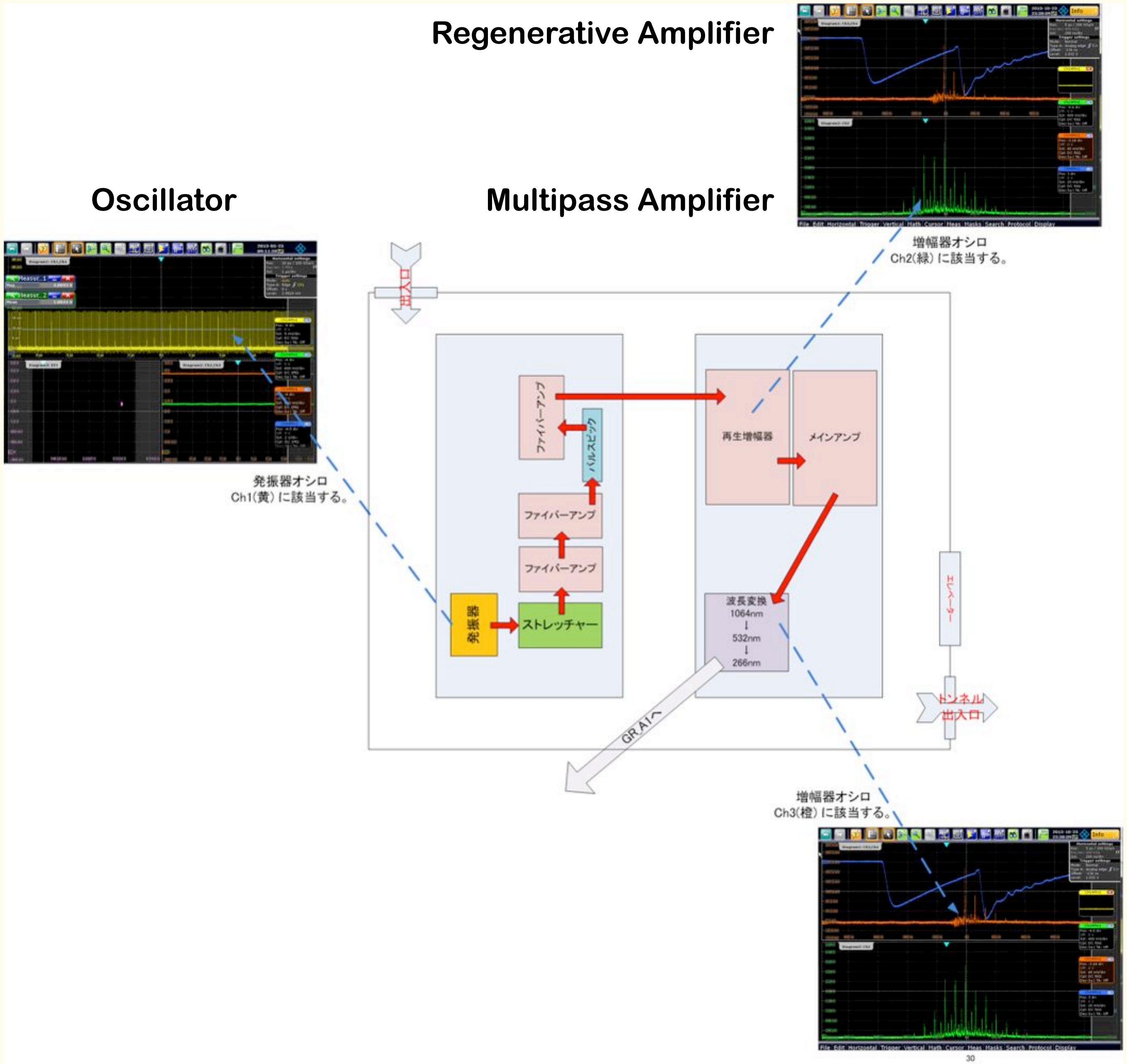
we take this scheme.

T.Kamitani

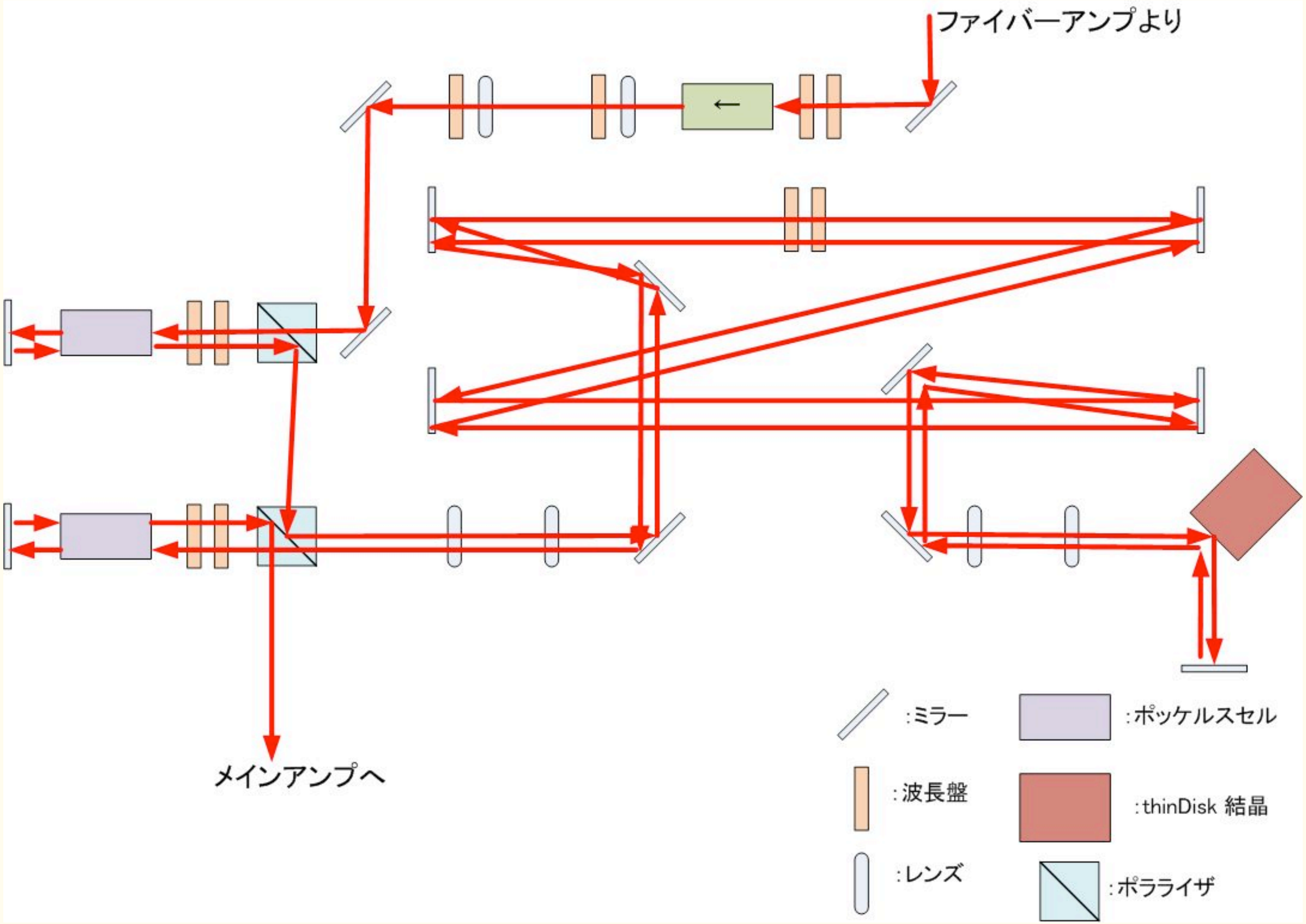
RF 電子銃開発

- **A1 電子銃 (GR_A1) の試験が進行中**
  - 擬似進行波型空洞や **Ir2Ce** 陰極、**Yb Fiber laser** など、今年度の大きな進展
  - **Energy** 幅・安定度制御のための **Laser** 光時間構造制御を行う必要がある
  - その前に **Beam** 開発用の **Beam** 供給とその安定化が重要
  - 陽電子生成用の一次電子も当面 **RF** 電子銃で生成するが、熱電子銃も捨てず、得失をよく検討する
  - 新規開発の **Component** が多いので、経験の積み重ねが重要と思われる

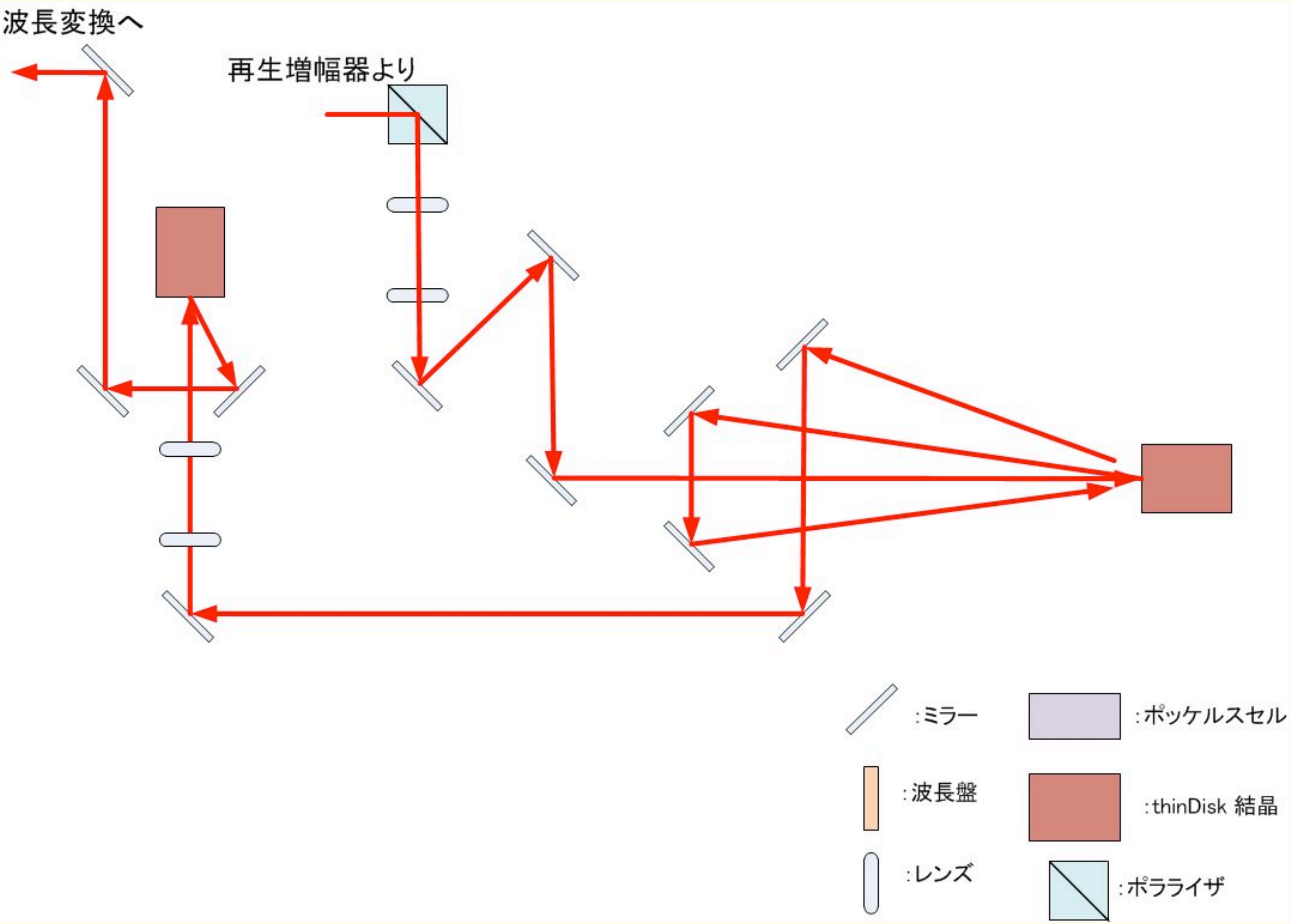
RF Gun GR_A1 Overall Structure



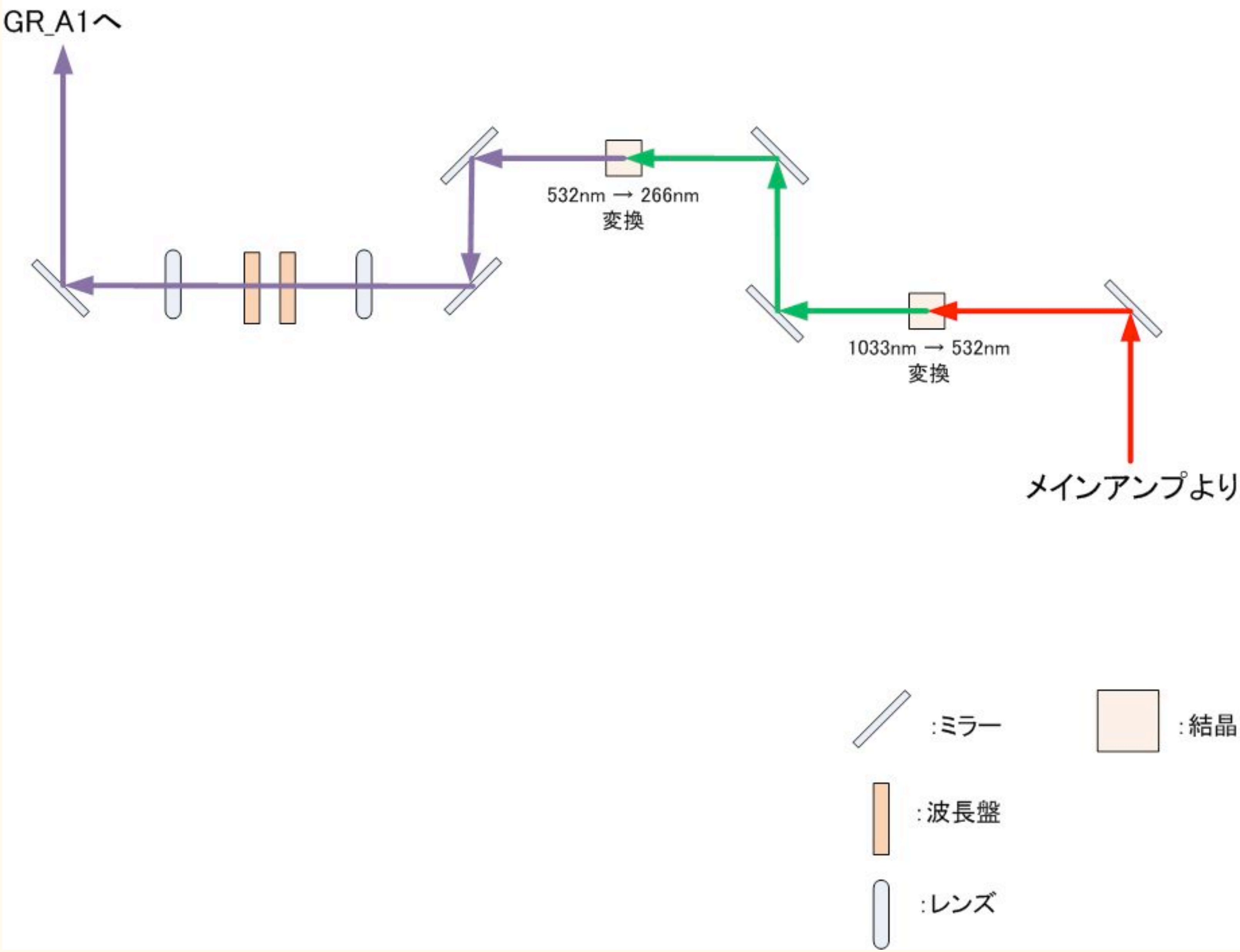
Regenerative Amplifier

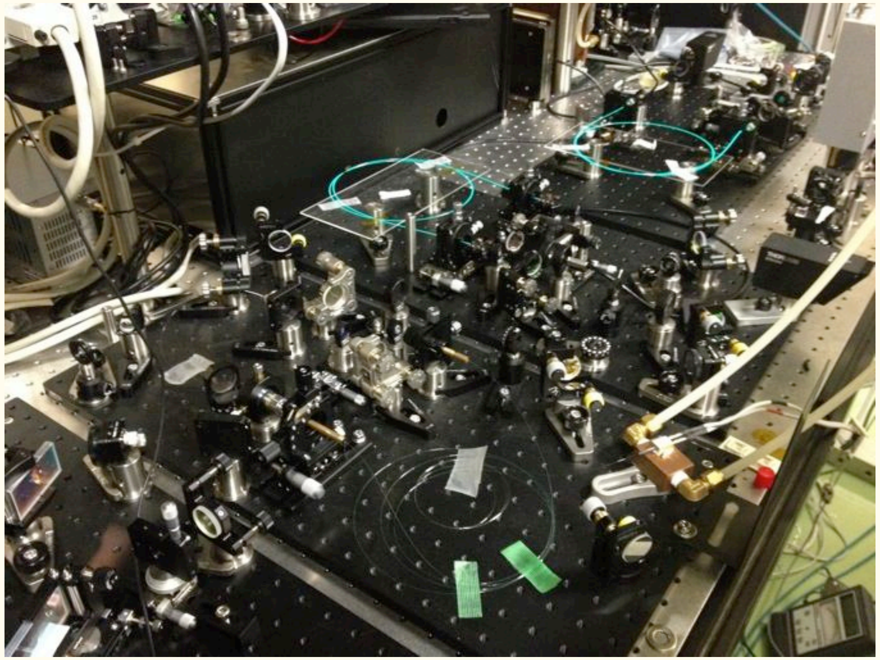


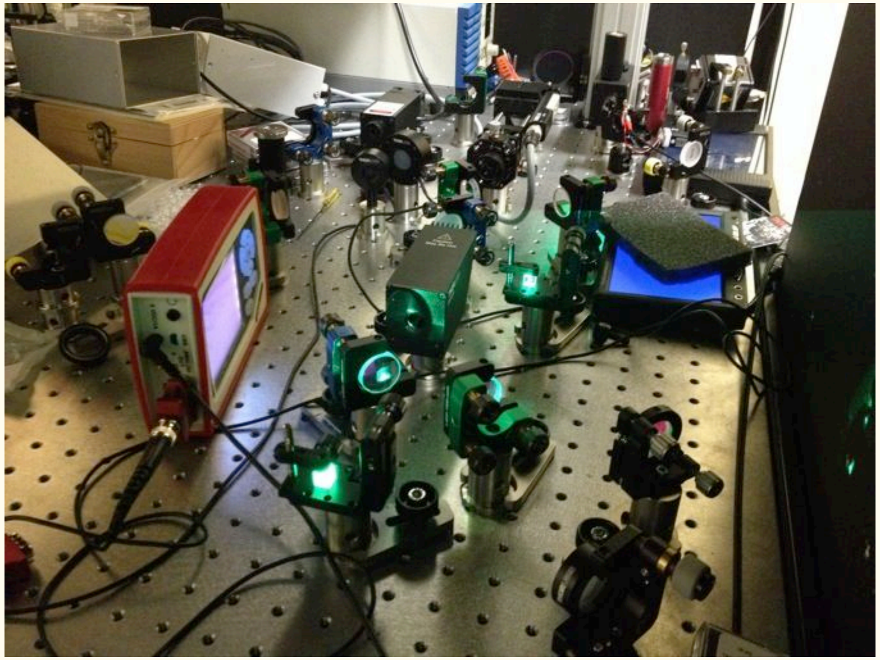
Multipass Amplifier

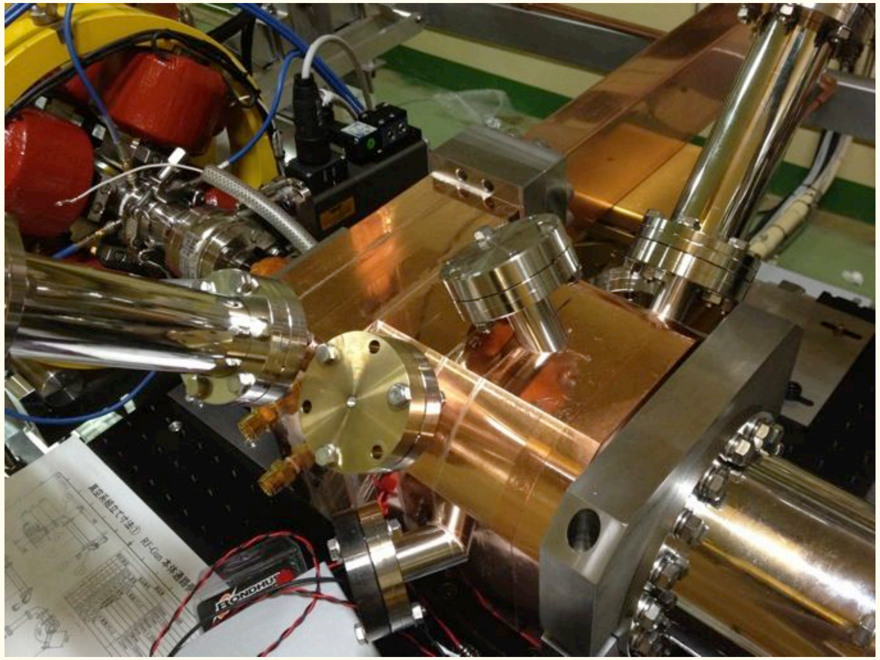


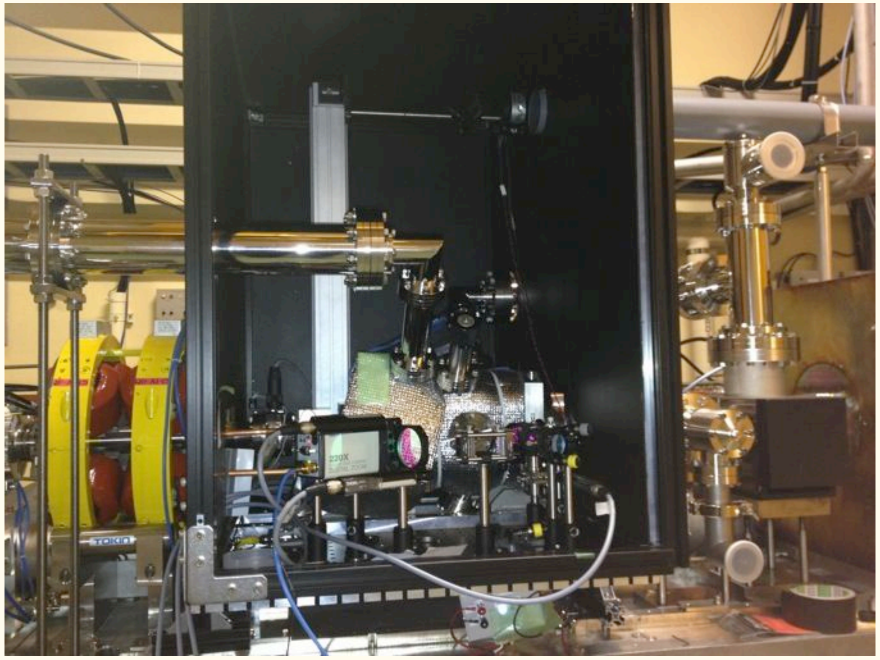
Quadruple Frequency



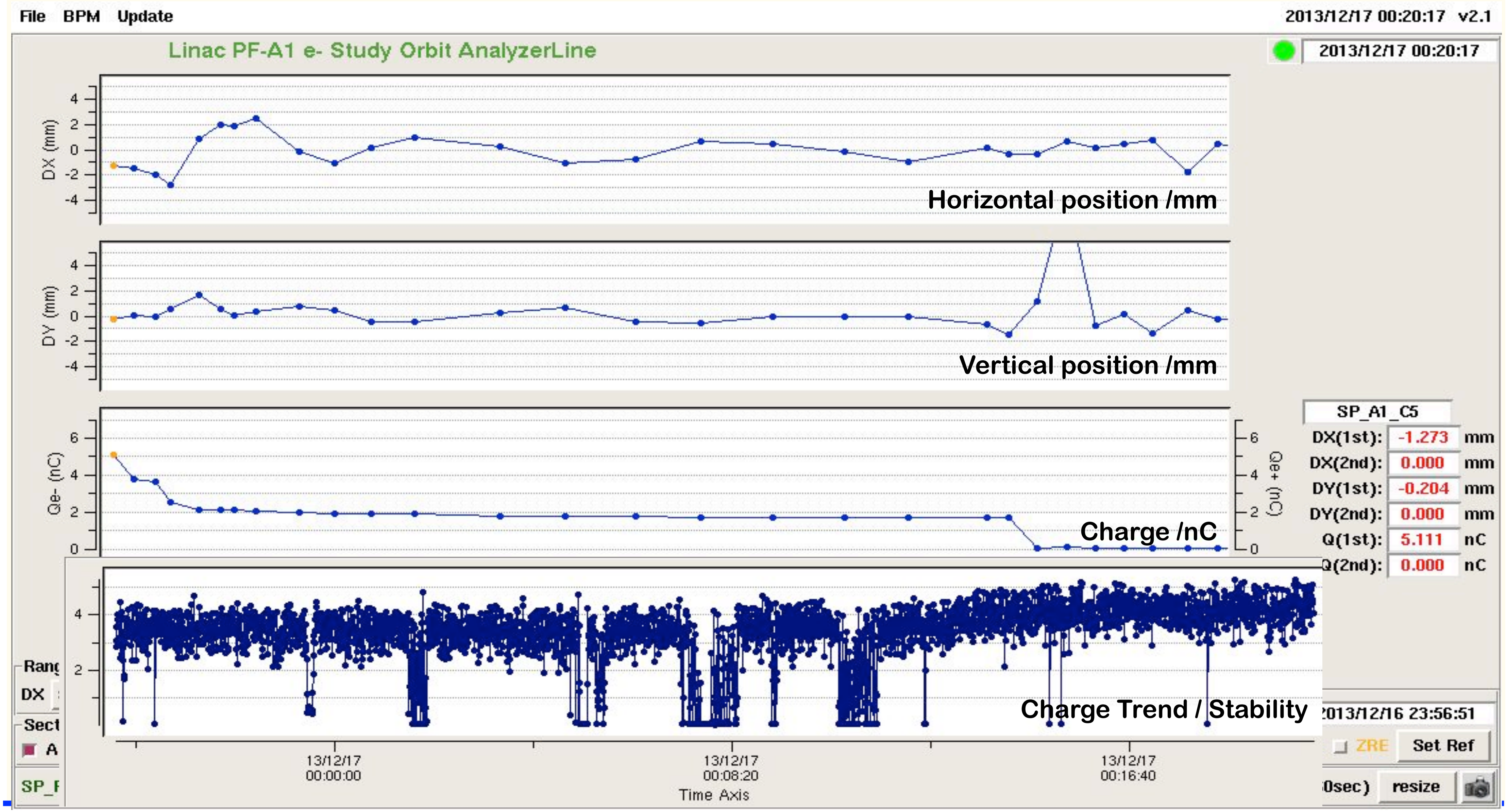




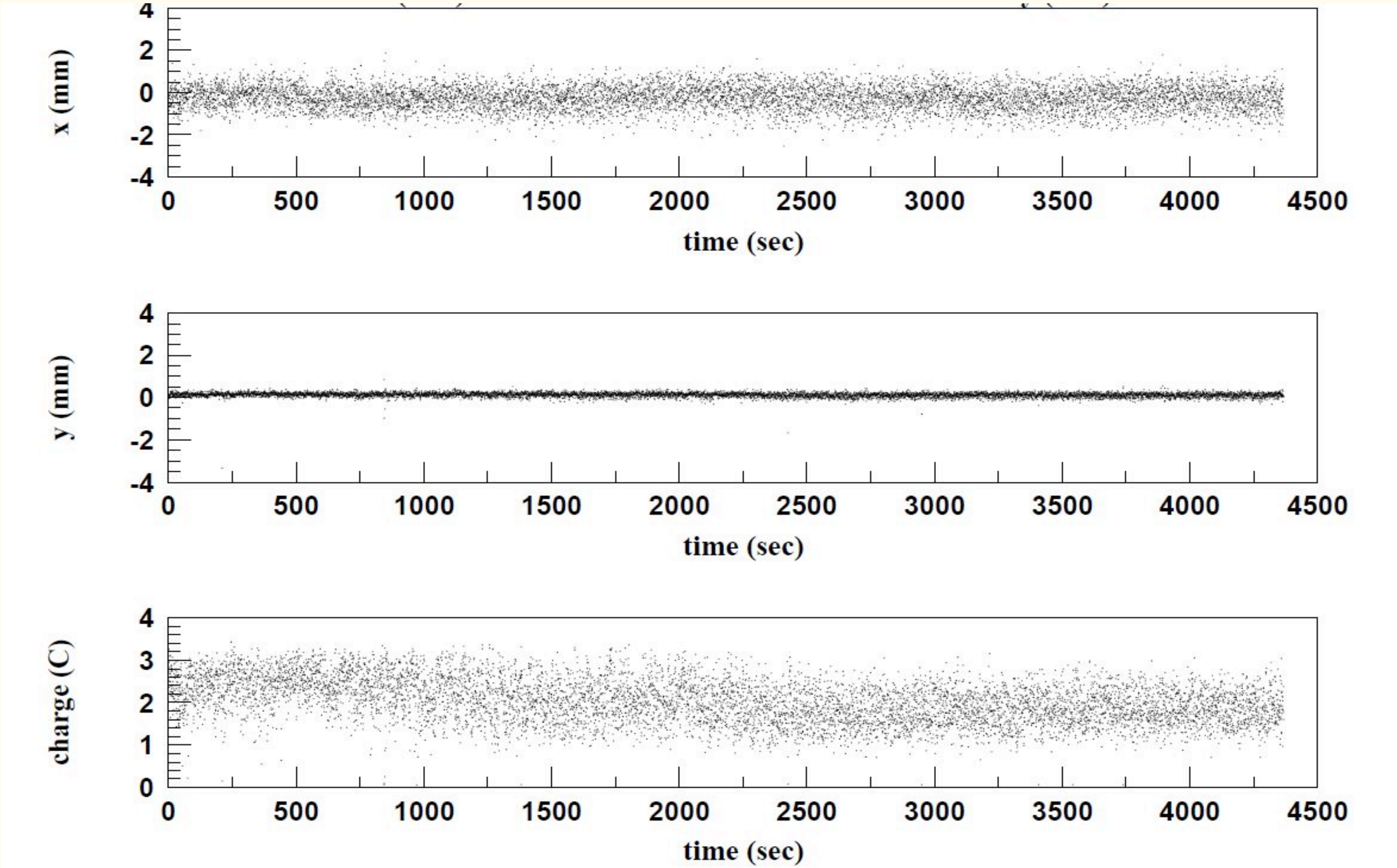




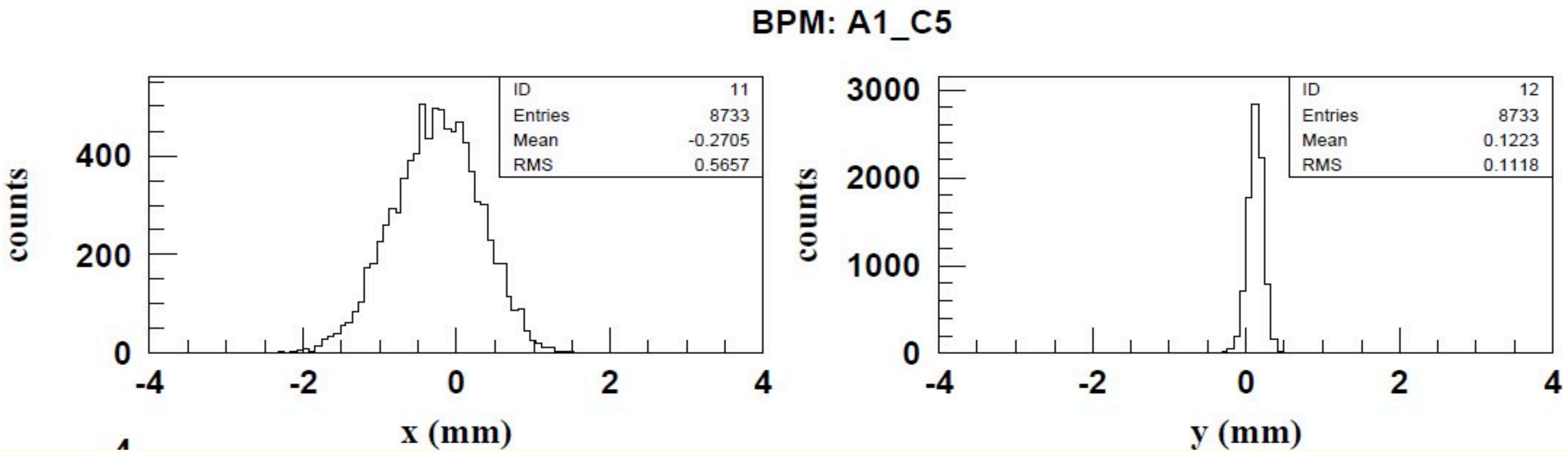
GR_A1 : 5.1 nC / bunch



Beam Trend / Stability

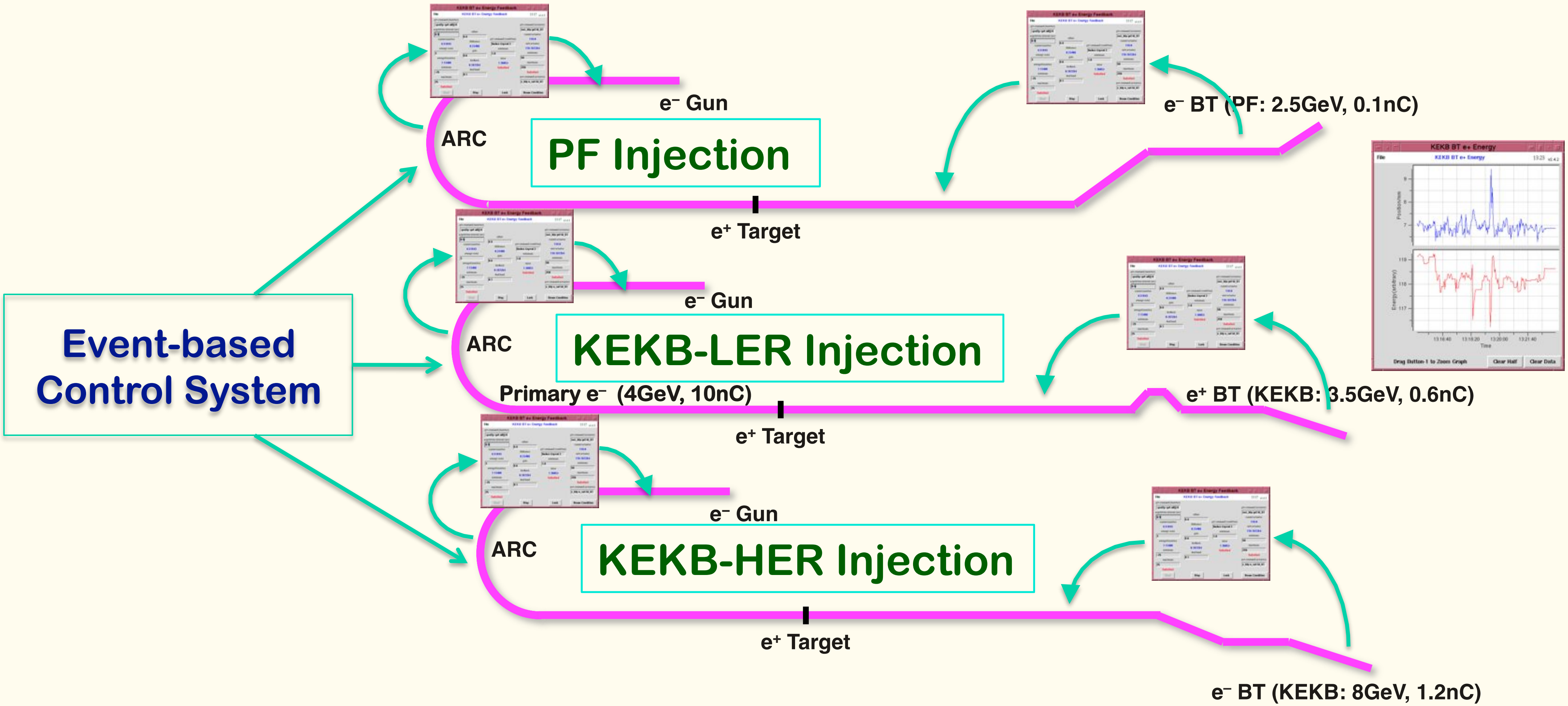


Horizontal / Vertical stability



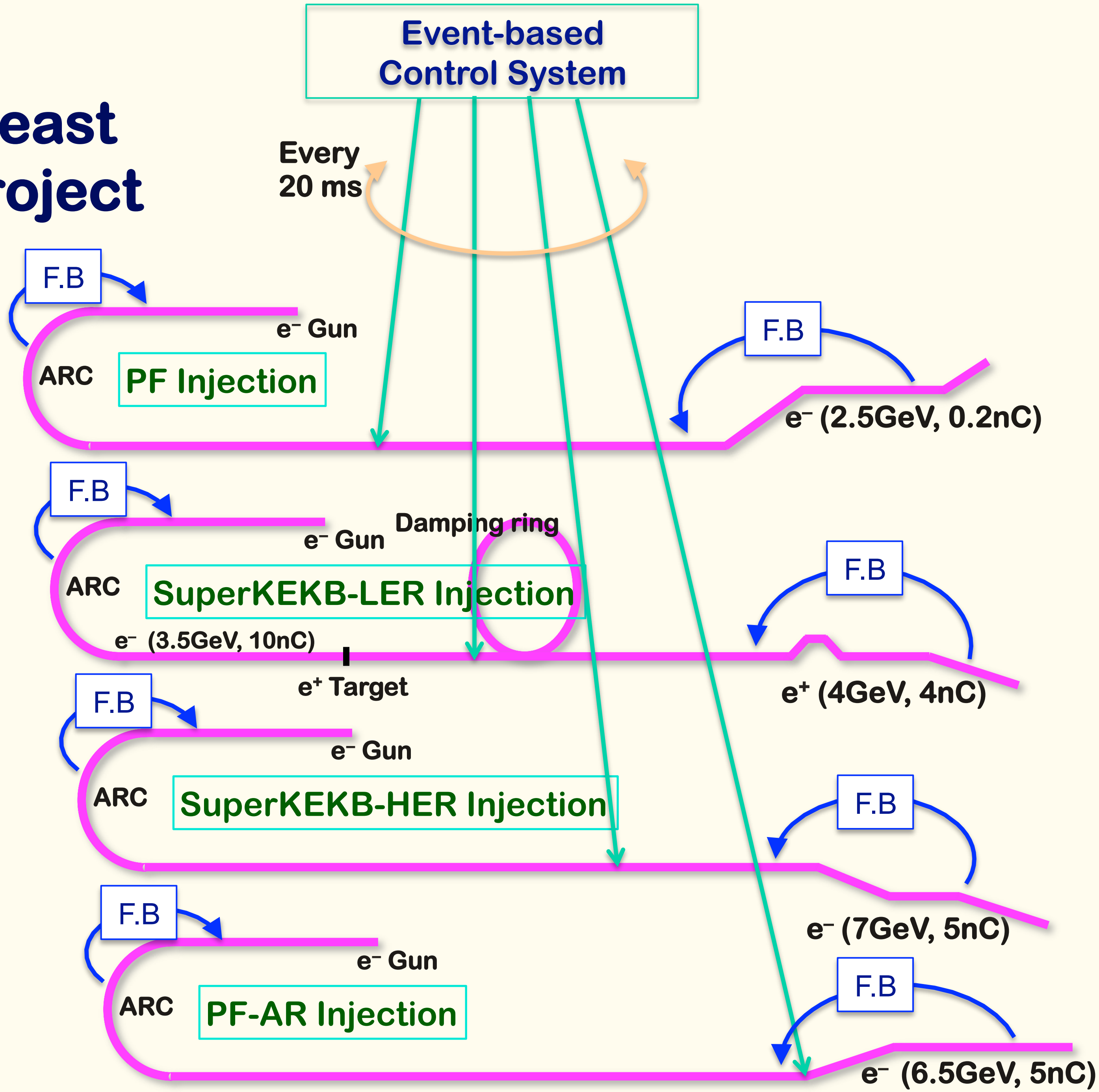
Virtual Accelerator-based Controls

- **Multiple closed loops were installed on each PPM VA independently**
  - **Tested at KEKB**

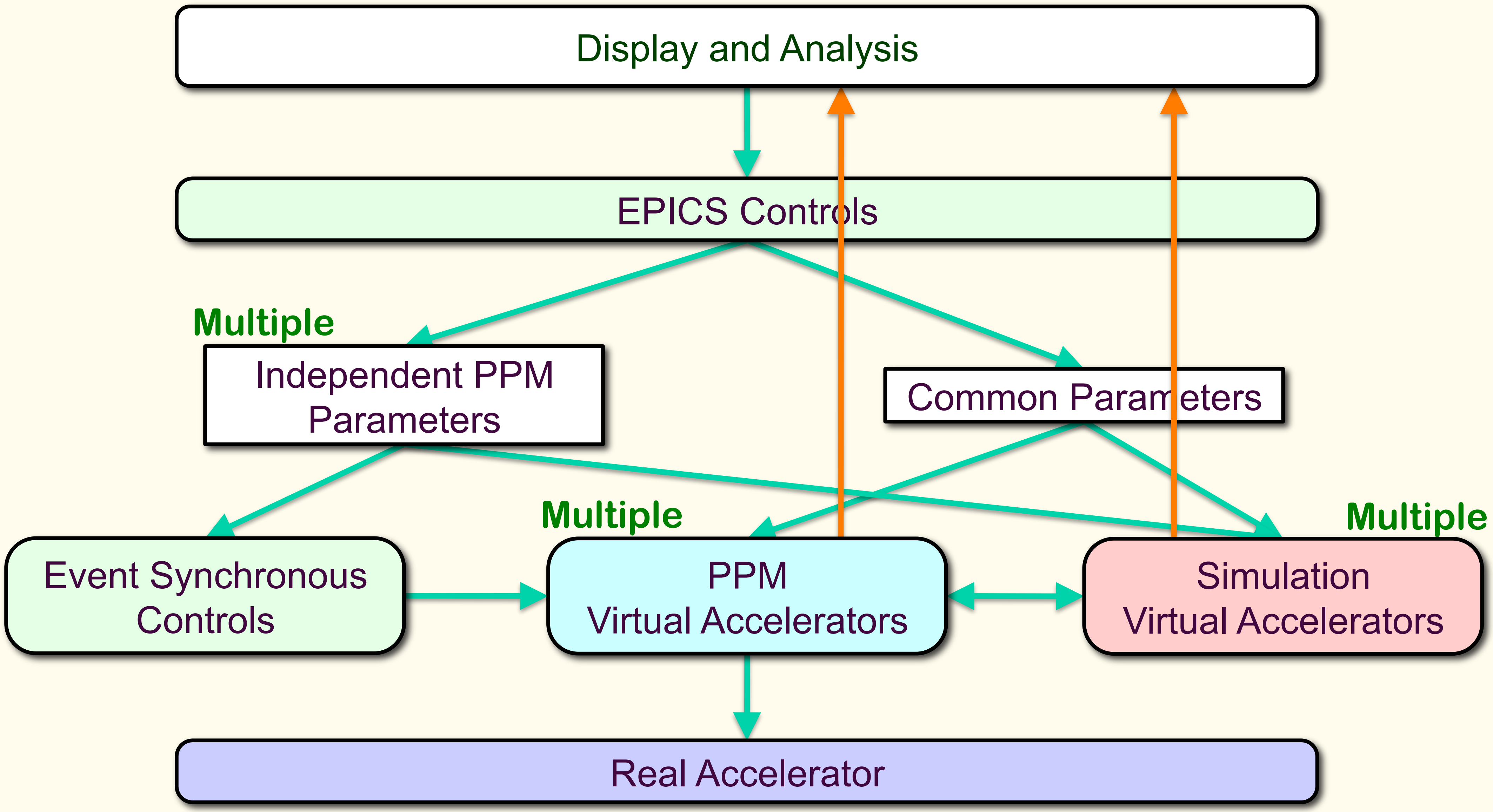


- **Four PPM VAs at least for SuperKEKB project**

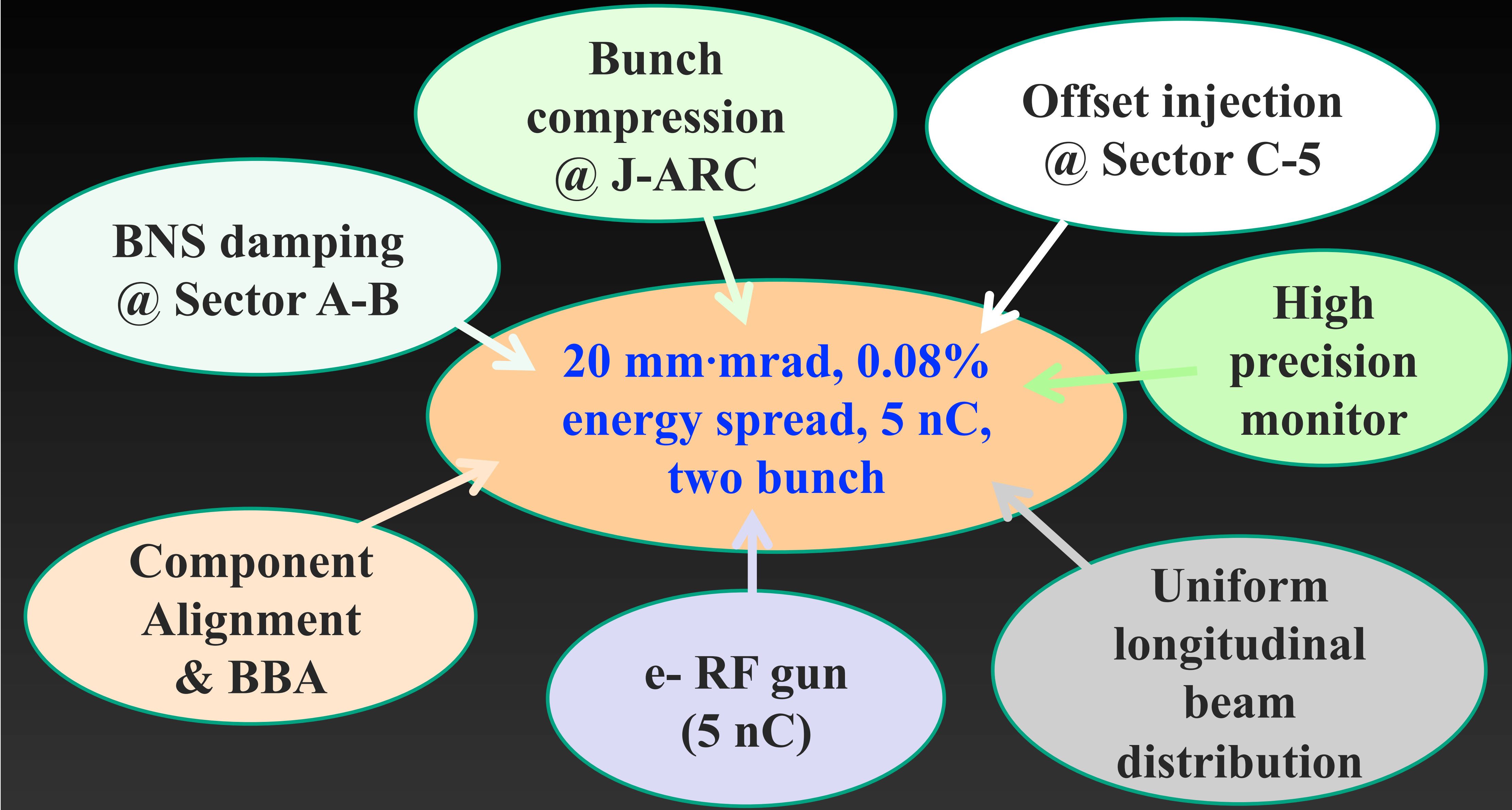
(maybe with additional PPM VA for stealth beam)



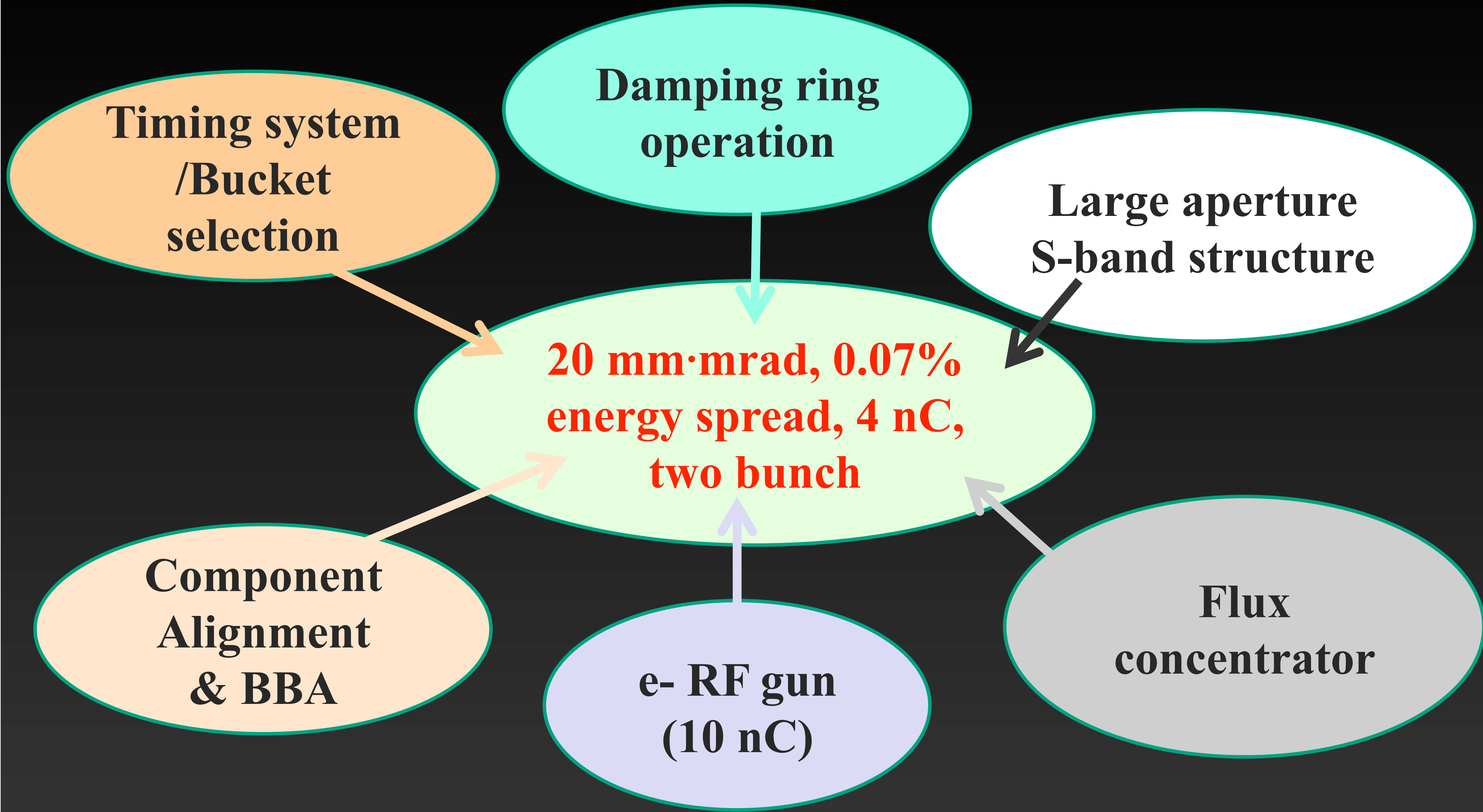
System Construction



e- beam

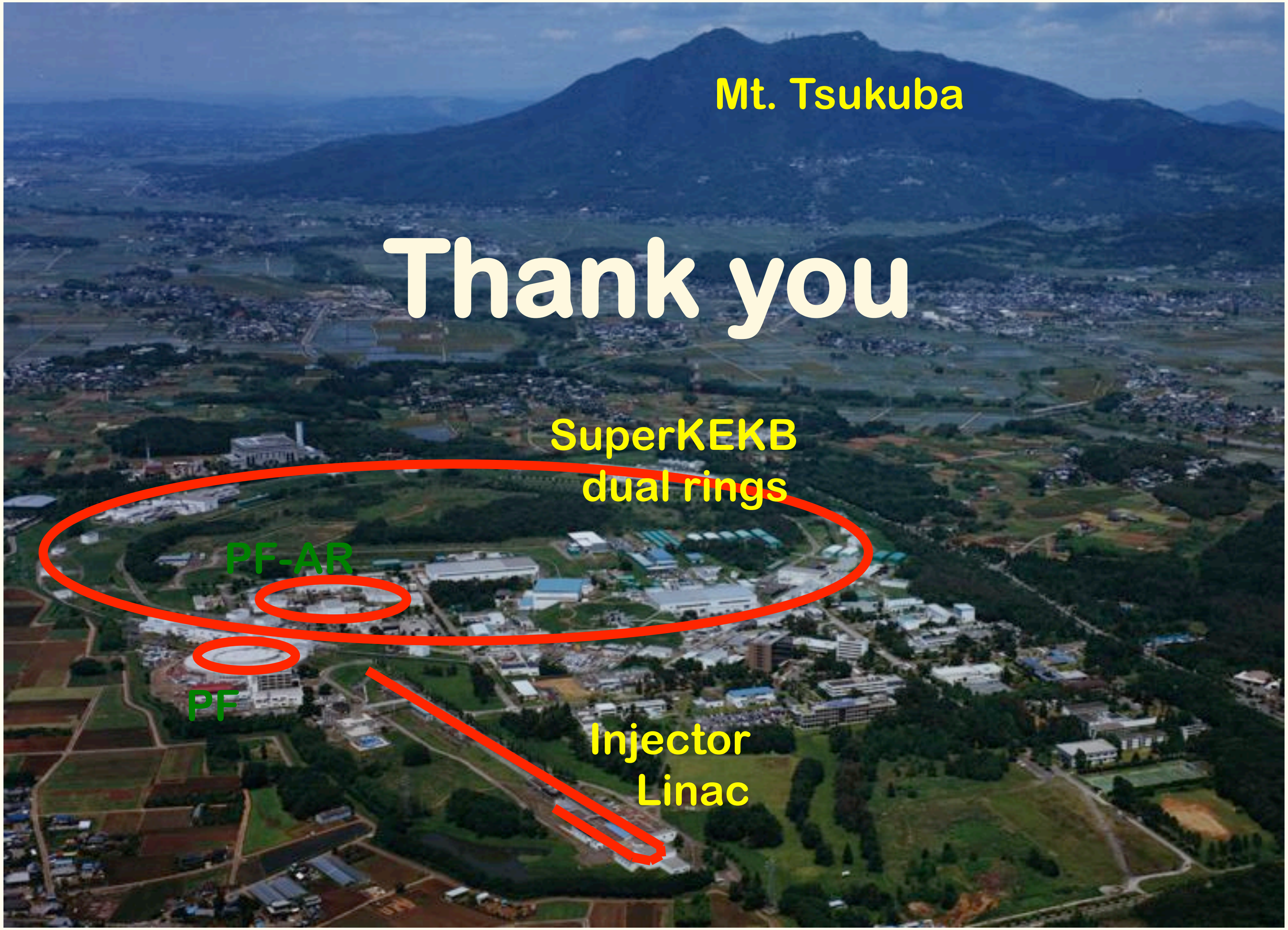

Bunch compression @ J-ARC
Offset injection @ Sector C-5
BNS damping @ Sector A-B
20 mm·mrad, 0.08% energy spread, 5 nC, two bunch
High precision monitor
Component Alignment & BBA
e- RF gun (5 nC)
Uniform longitudinal beam distribution

e+ beam


Timing system /Bucket selection
Damping ring operation
Large aperture S-band structure
20 mm·mrad, 0.07% energy spread, 4 nC, two bunch
Component Alignment & BBA
e- RF gun (10 nC)
Flux concentrator

まとめ

- (2015年に目標を達成する) 建設計画からは一部遅れている部分があるが、現在のところ概ね期待どおり
- 震災復旧も順調 (ただし作業負荷は高くなっている)
- 昨年は小さな障害が多かったが、今年は少し大きめの障害が少数
- 最終的に達成すべき目標 **Beam quality** 達成と、**2015** 年から運用する当面の **Beam** の供給を、**Balance** よく計画する
- 資源が厳しいので、**2015** 年までの開発に固執せず、安全に配慮し、最適な選択肢を選び、ひとつずつ開発項目をこなしていく

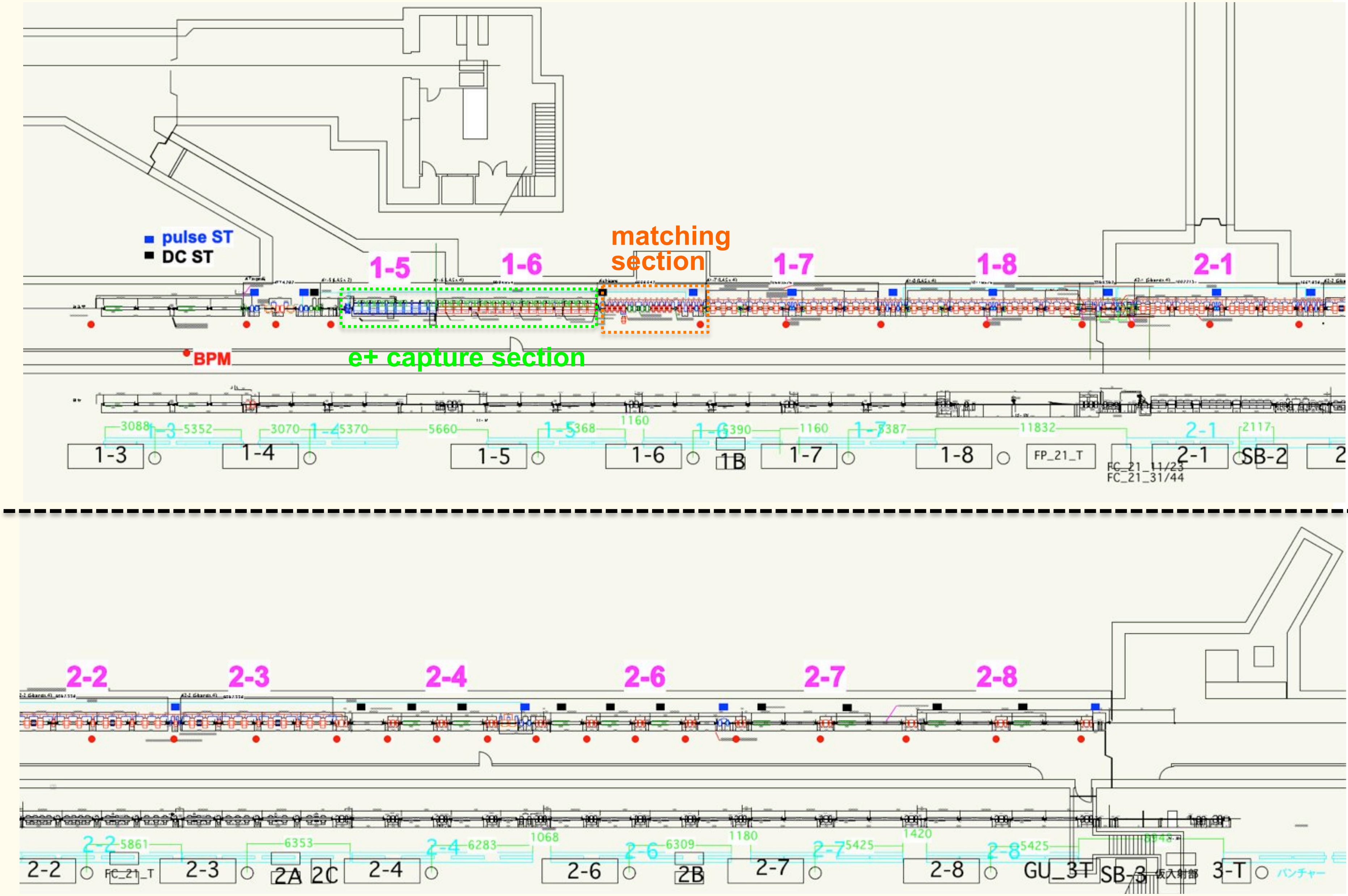

Mt. Tsukuba
Thank you
SuperKEKB
dual rings
PF-AR
PF
Injector
Linac

ビームライン詳細

陽電子ターゲットからLTRまで

地下と地上の摺合わせ

各機器の最終調整と発注



まとめ

- 2 年後の MR 入射コミッショニングに向け、ひとつの Milestone は越えた
- 震災の影響の懸念をある程度払拭した
- SuperKEKB のビーム仕様を満たすための試験の準備が整ってきた
- まずは T=0 の 1nC ビームのエミッタンスとエネルギー幅を満足し、さらに大電流ビームのビーム特性達成を目指す
  - そのために、機器の安定度向上、ビーム・マイクロ波・タイミング測定、大電流加速、ビーム安定化機構、特にエミッタンス・エネルギー幅制御の確立、などをひとつずつ段階を踏んで進めて行く