ICFA Workshop on Future Light Sources
March 5-9, 2012
Thomas Jefferson National Accelerator Facility

FLS2012報告

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KEK 加速器研究施設

2012/3/29 第60回ERL検討会

Figure is cited from an opening talk by George Neil.

v2a

Outline

1. ワークショップについて
2. 主要な発表・議論の紹介
    1. Opening
    2. ERL
    3. Storage Ring
    4. FEL
    5. Compact Source
3. その他（議論、聞いた話）
4. まとめ

参加者記念撮影

1. ワークショップについて

ワーキンググループ

- Storage Ring Based Light Source
- ERL Based Light Source
- FEL Based Light Source
- Compact Light Source
- Electron Sources
- Timing and Diagnostics
- Undulators and Insertions

Planary talk では、上記の7分野に加えて、Science, Beamline の話もあった

日本からの参加者

- 東北大: 2名 → 東北放射光計画の発表
- Spring-8/Riken からはなし（Hettel氏のトーク中にSPring-8 IIのスライドあり）

KEK/JAEA からの発表

ワーキンググループで7件の発表をした

ERL WG

- S. Sakanaka, “Status of the ERL Project in Japan”
- S. Sakanaka, “Plans of XFELO in Future ERL Facilities” (Joint)
- M. Shimada, “Lattice and optics design of both compact ERL and 3-GeV ERL projects”
- M. Shimada, “X-RAY LIGHT SOURCE BY INVERSE COMPTON SCATTERING OF CSR”
- T. Miyajima, ”Development of an Injector for the compact ERL”
- H. Sakai, “ERL Cryomodule Development in Japan”

Electron Source WG

- N. Nishimori, “Status of 500-kV DC gun at JAEA”

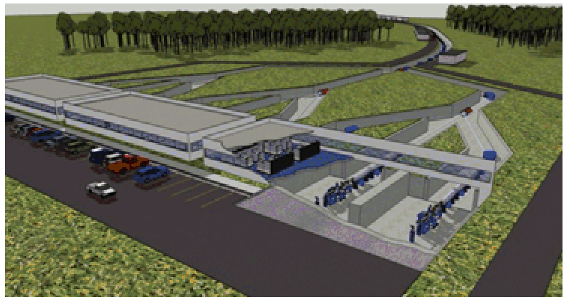
２．主な発表・議論の紹介

Opening のスライドより

(George Neil, JLab)

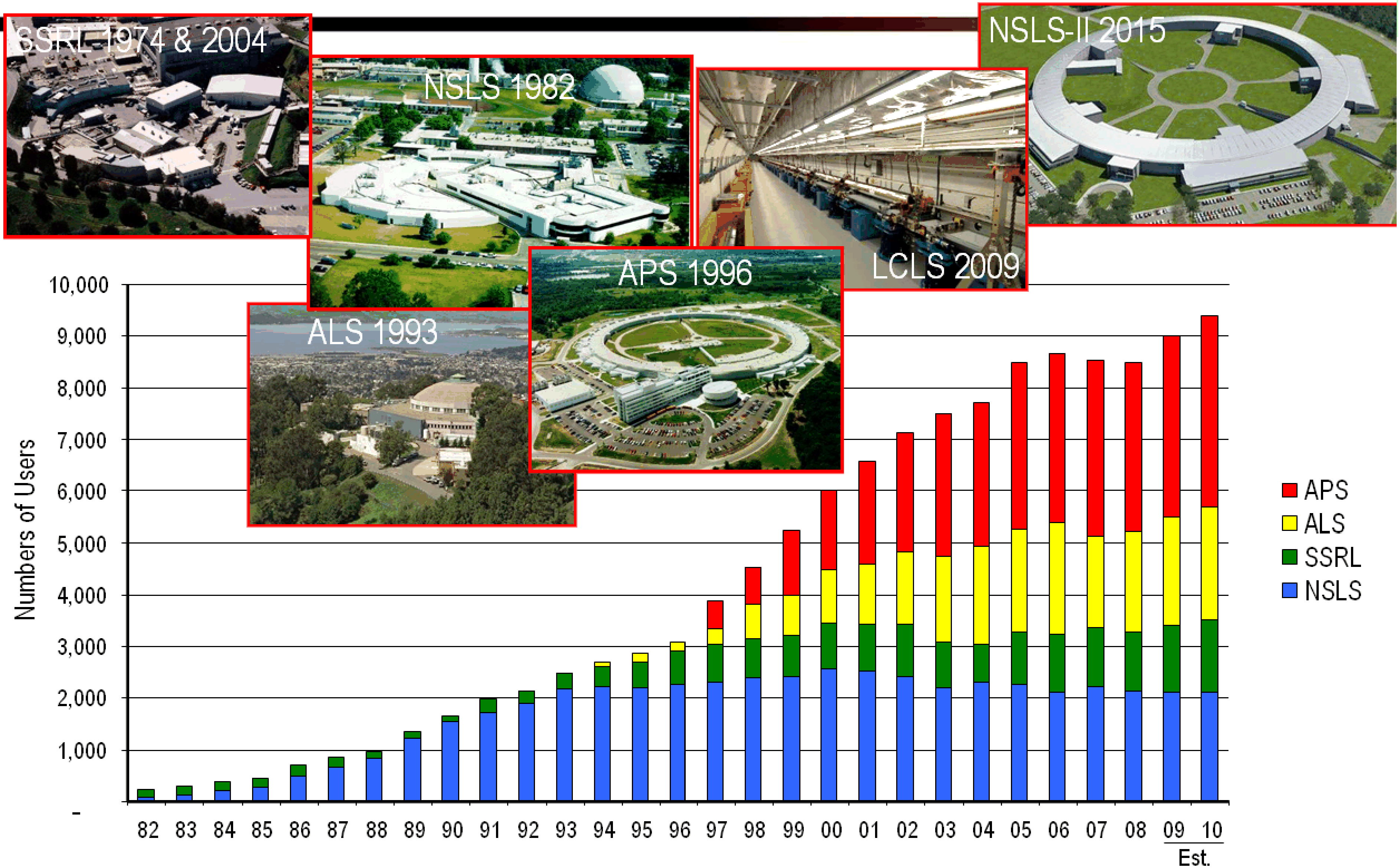
US-DOE Light Sources

Next Generation Light Source



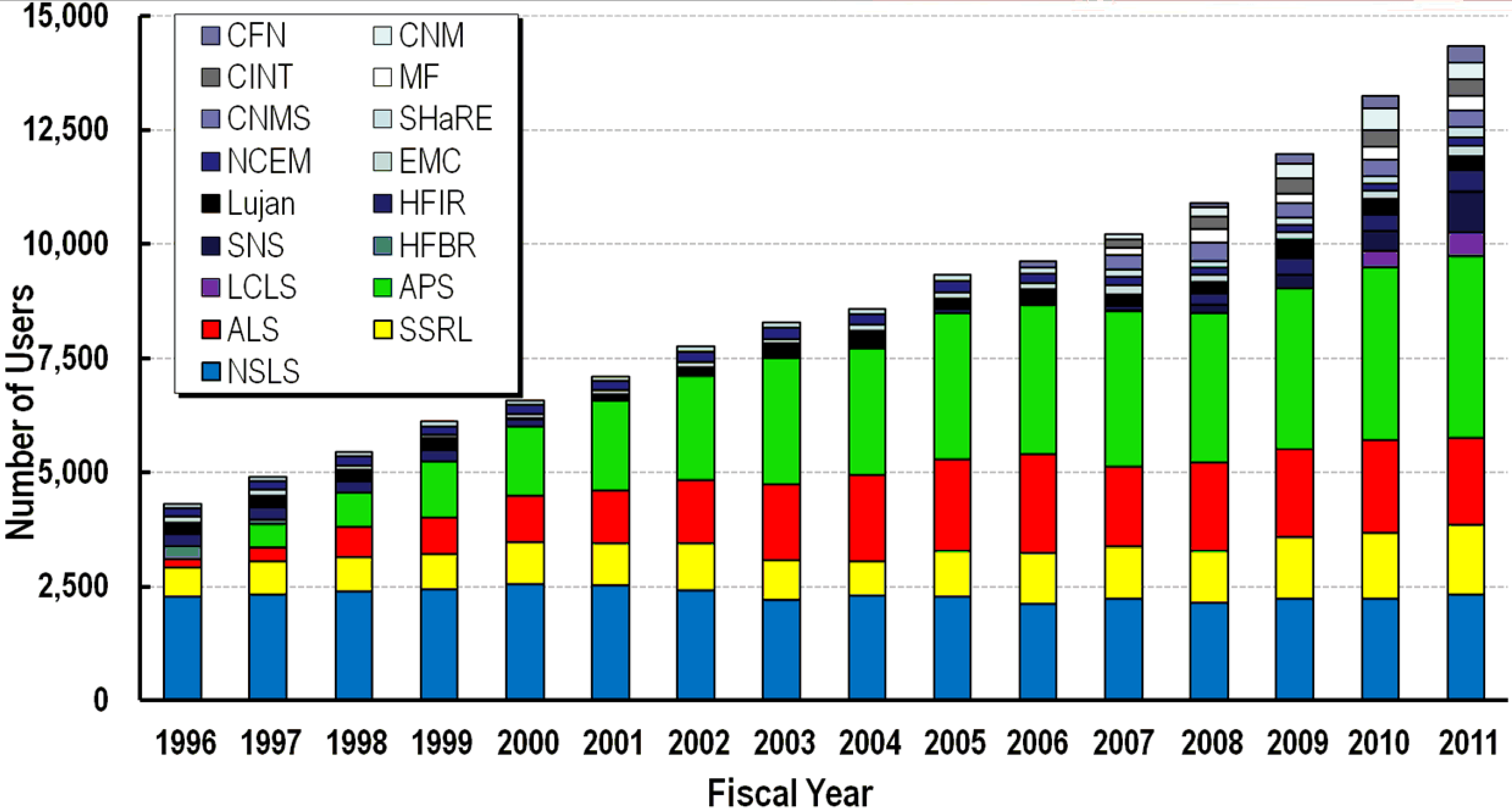
Typically ~$100M/year operations

DOE Synchrotron Light Sources



(Harriet Kung – DOE Basic Energy Sciences)

BES User Facilities Hosted Over 14,000 Users in FY 2011



More than 300 companies from various sectors of the manufacturing, chemical, and pharmaceutical industries conducted research at BES scientific user facilities. Over 30 companies were Fortune 500 companies.

Courtesy: Harriet Kung

ERL WG & Plenary Talk

(Conveners: Susan Smith, Bettina Kuske）

ERL-WGでの主な発表

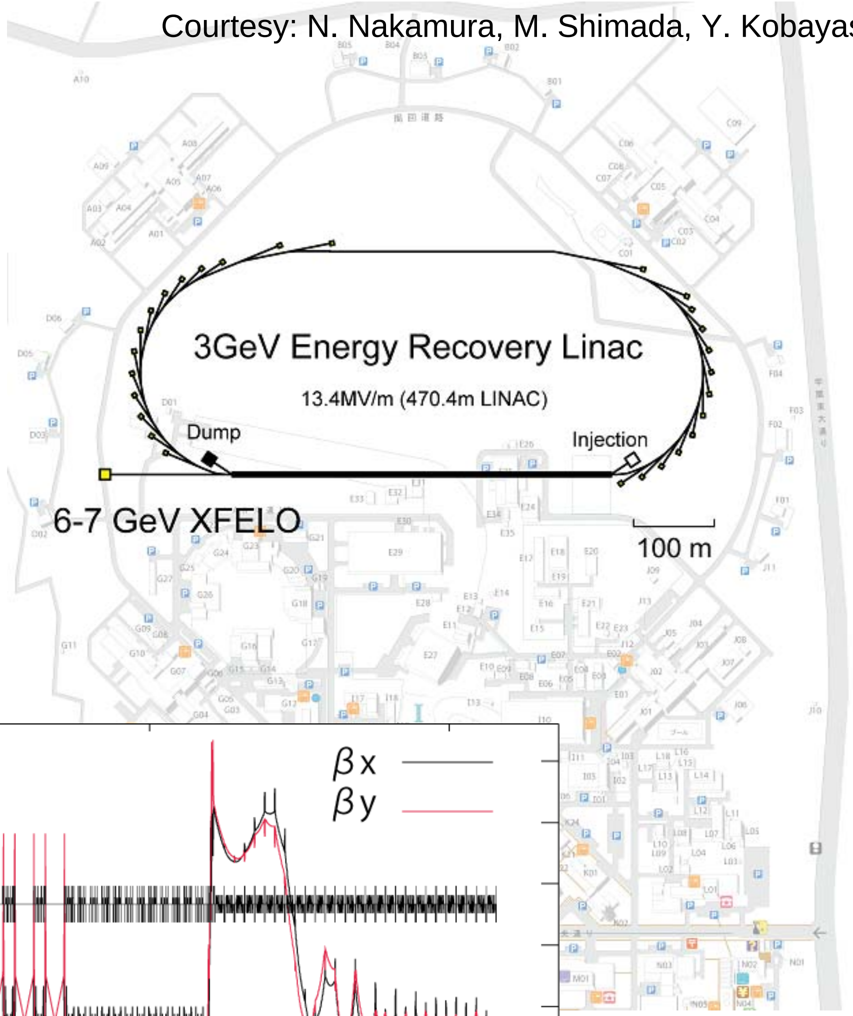
- 日本のERL計画（我々）
- BerlinPro: 50 MeV, 100 mA (Jankowiak, B. Kuske)
- Cornell ERL: Plenary talk のみ（Bazarov）
- ALICE: シミュレーションとビーム運転の比較 (Kalinin, Smith)
- JLab: ERL/FEL Status & Activities (D. Douglas)
- その他
  - Long undulator のERLへの影響（Borland）
  - ERLへのアンジュレータの影響（Jim Clarke）
  - eRHIC での FEL option (30 GeV) 用のバンチ圧縮器の検討 (Yichao Jing)
- Unwanted beam loss (Joint）
  - Problems observed at PITZ (Krasinikov)
  - Unwanted beam observations at ELBE (Teichert)

    SC-RF gun からの暗電流（field emission）の問題などを報告
    常伝導RF電子銃（LBNL）でも同様に暗電流が大きいとのこと
  - DC/SC-RF/N-RF のどの電子銃でもカソード表面電場は～10 MV/m 程度で同程度とのこと。空間電荷によるエミッタンス増大は表面電場でかなり決まるので、どれも同程度ではないかとの話あり。

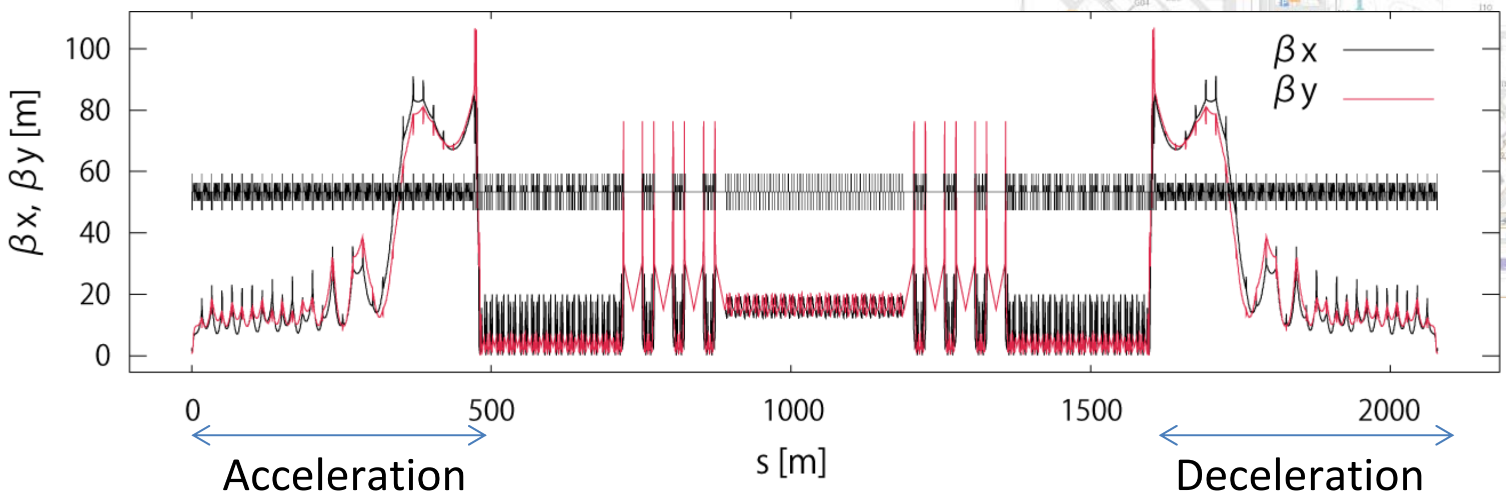
Tentative Layout of 3-GeV ERL at KEK

Courtesy: N. Nakamura, M. Shimada, Y. Kobayashi

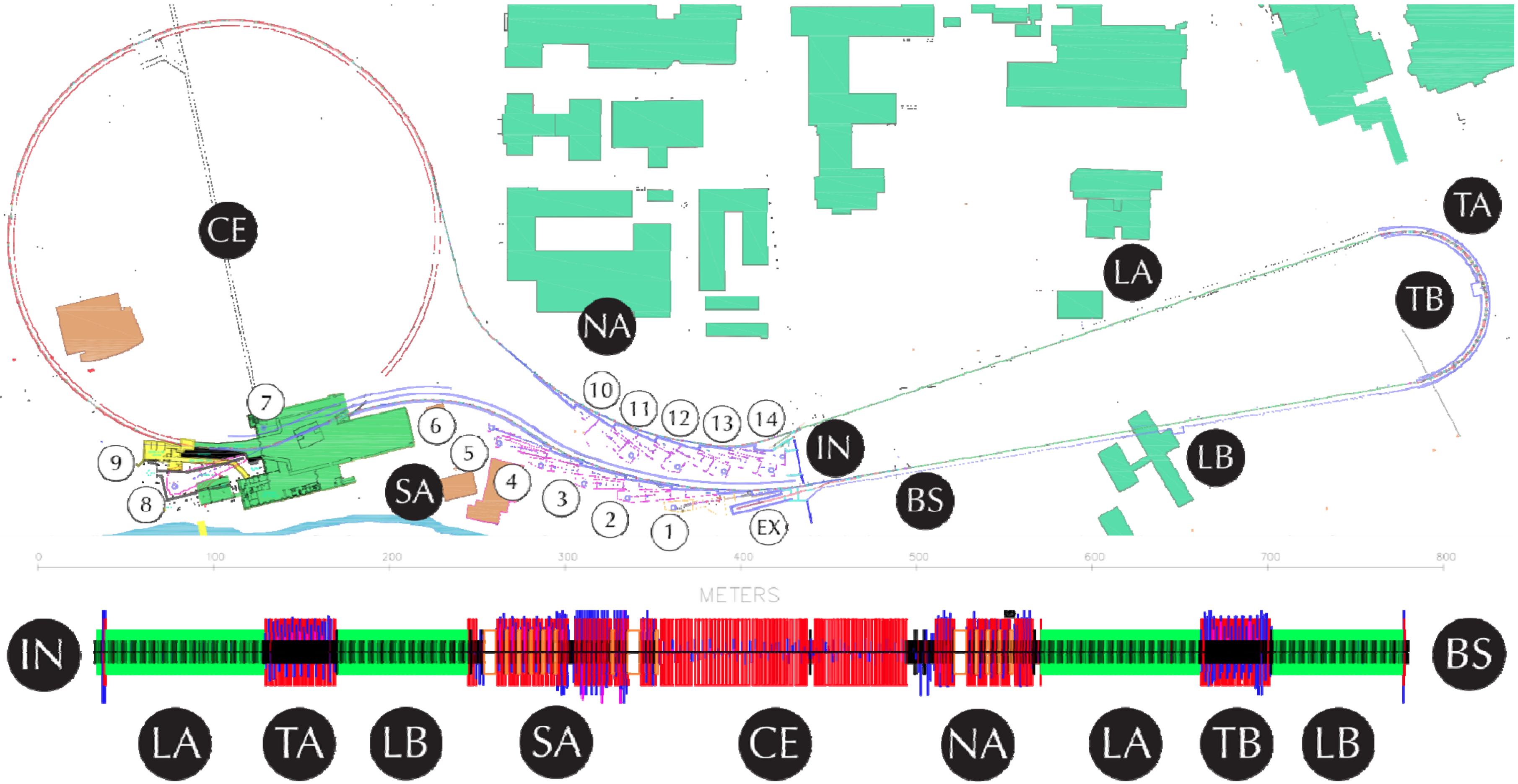
- Beam energy
  - Full energy: 3 GeV
  - Injection and dump :10 MeV
- Geometry
  - From the injection merger to the dump line : ~ 2000 m
  - Linac length : 470 m
- Straight sections for ID's
  - 22 x 6 m short straight
  - 6 x 30 m long straight



Overall beam optics (merger → dump)



Cornell ERL Layout



The 15MeV injector **IN** sends electrons into a 2.8GeV Linac **LA** to be turned around by **TA** into a 2.2GeV Linac **LB**. After X-ray production in the south arc **SA**, return through **CE**sr and X-rays in the north arc **NA**, the beam energy is recovered in the Linacs before being stopped at DU.

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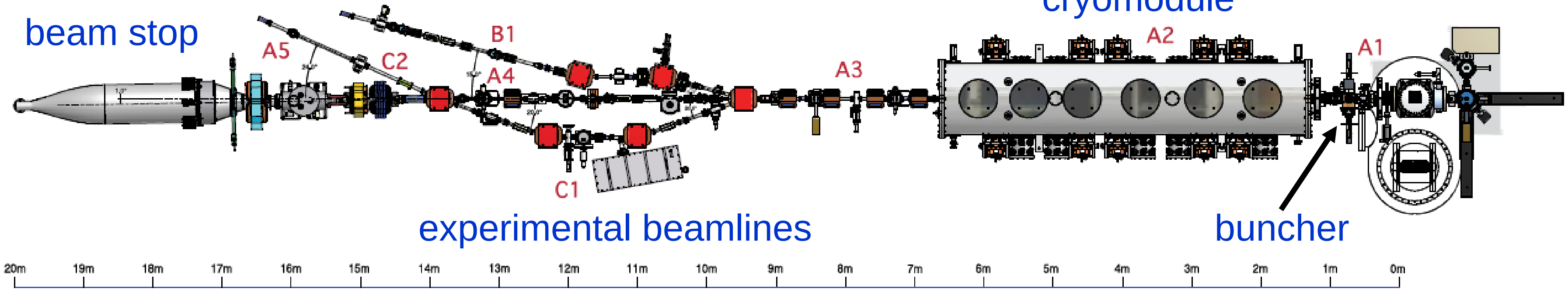
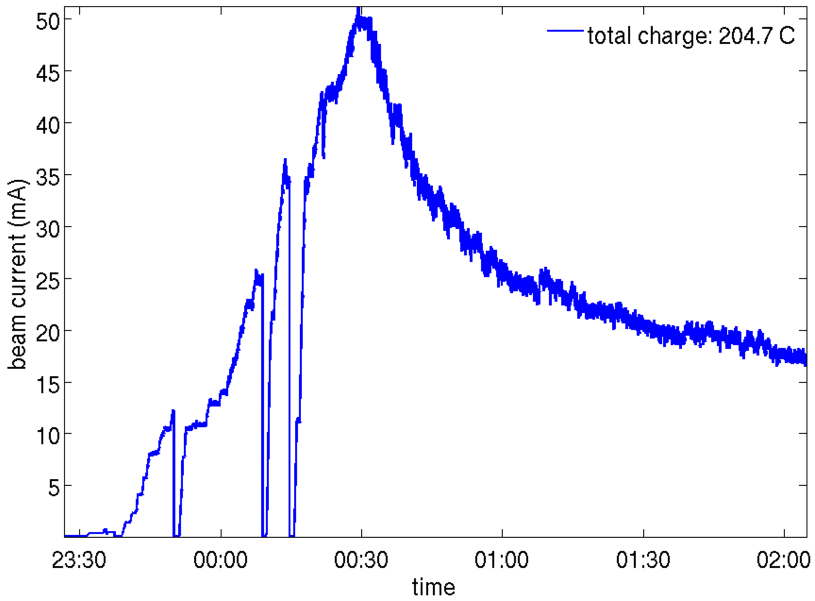
Existing Prototype Injector





Cornell currently operates a prototype ERL injector. The team has measured core emittances (the central 2/3 of the bunch) of 0.3 mm-mrad for 80 pC bunches and 0.15 mm-mrad for 20 pC bunches, and expect these numbers to improve as the gun voltage is increased.

In February 2002, Cornell's prototype injector delivered a continuous-duty current of 50 mA. This is the world record for any laser-driven photocathode electron gun.

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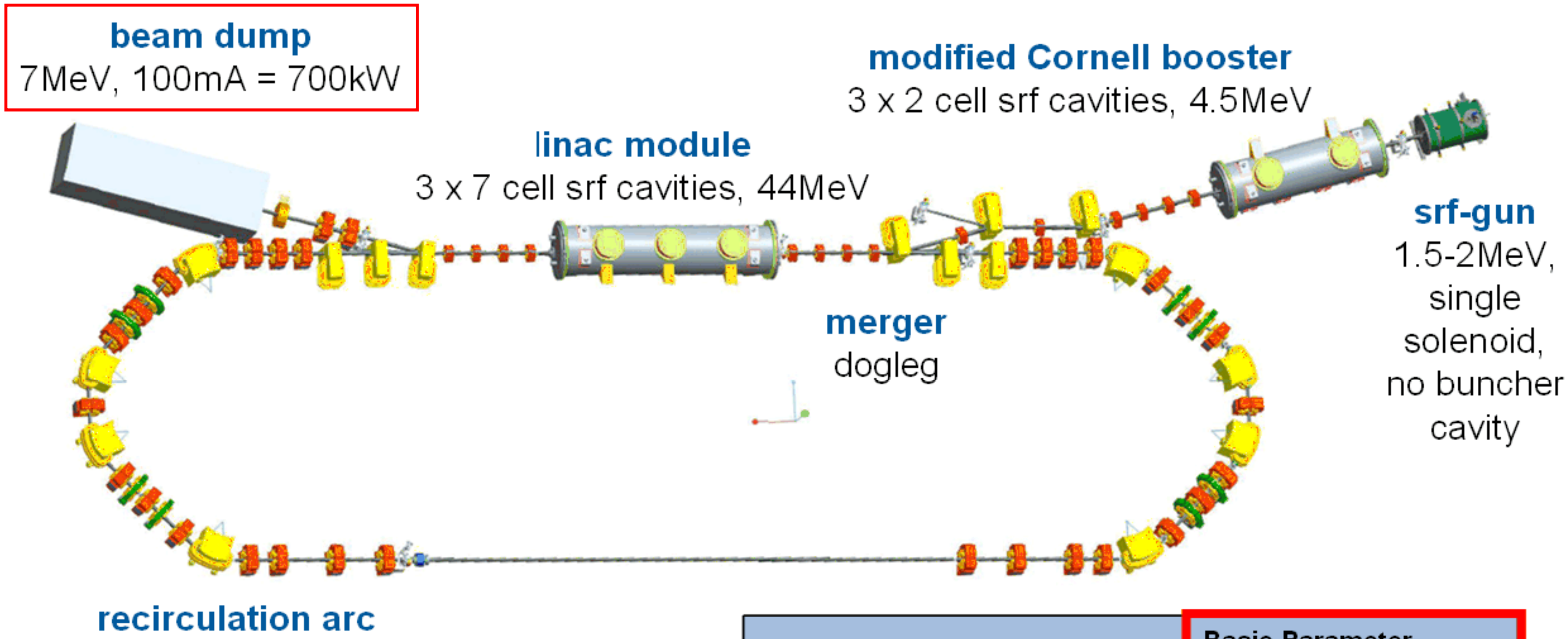
BERLinPro – Machine layout / parameters

BERLinPro = Berlin Energy Recovery Linac Project

100mA / low emittance technology demonstrator (covering key aspects of large scale ERL)



	Basic Parameter
max. beam energy	50MeV
max. current	100mA (77pC/bunch)
normalized emittance	1 π mm mrad
bunch length (straight)	2 ps or smaller
rep. rate	1.3GHz
losses	< 10^{-5}

Challenges (i)

- electron source with cathode and laser system
  staged approach for development of srf photo electron source

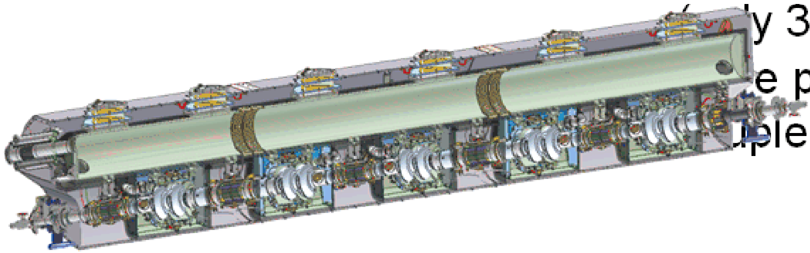
Gun_0 → Gun_1 → Gun_2

already started, fully sc (Pb cathode film), first beam 21.04.11
demonstrator, beam dynamic

nc cathode, CsK_2Sb cathode
m dynamic, emittance, cathode performance

lessons learned / high power

- generate high power beam in booster
  modified Cornell booster design , adapt to our needs



y 3 cavities,
e power per
pler – KEK design)

Challenges (iii)

- high “virtual” beam power, very high loss rates possible

BESSY II:	200μC / a @ 1.7GeV	typical
BERLinPro:	some 100μC / 1s @ 50 MeV	possible
		(30kW linac RF-power)

new regime of operation (compared to storage ring)
→ radiation protection issues favor an underground bunker

BERLinPro – Project timeline + budget

2008 | 10/2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017

Application

Approval
(25.8M€ over 5a)

CDR TDR

Building

first recirculation

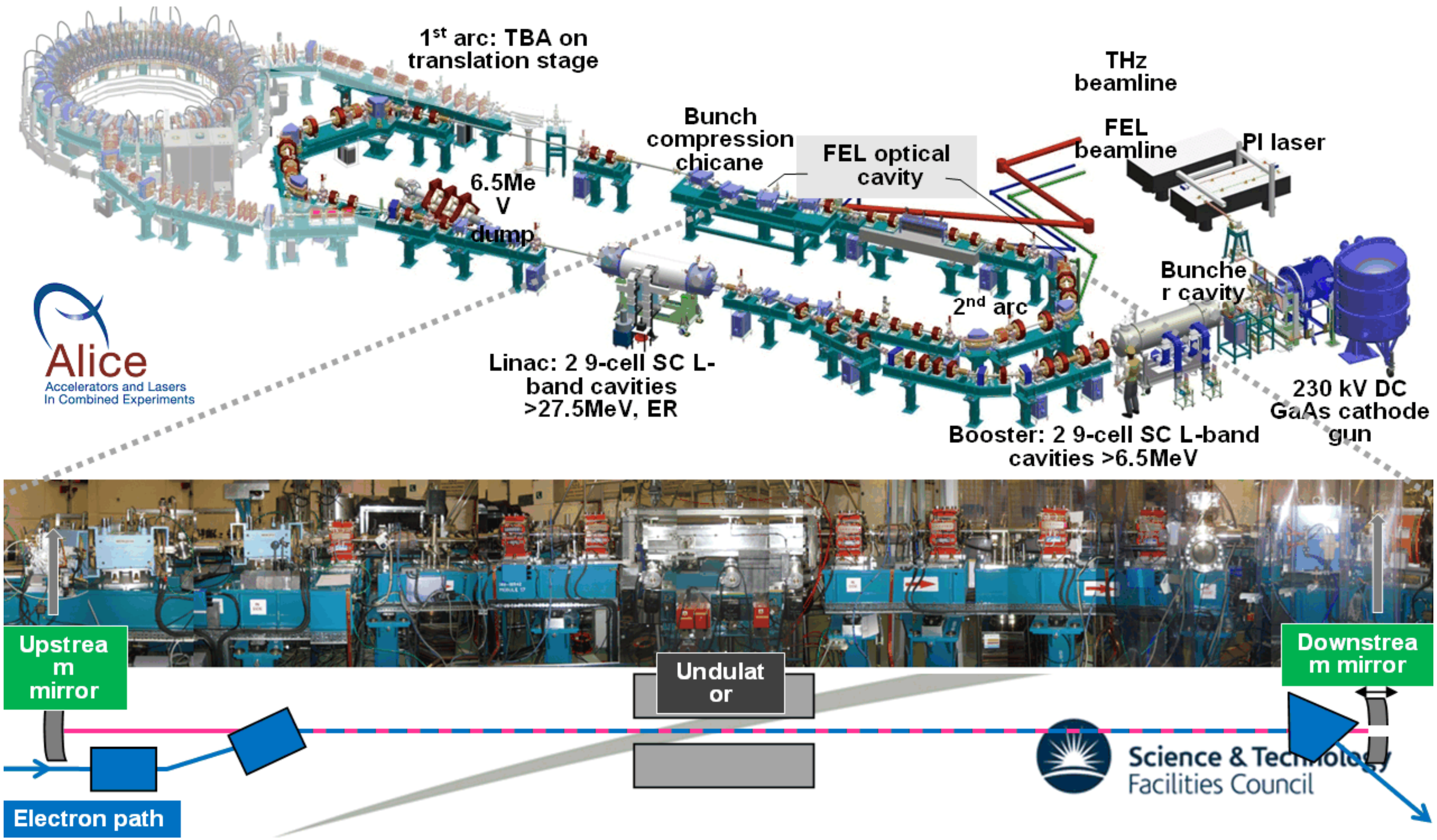
Project start

- first MAC 05/2011
- re-scoping of the project
  (100MeV = 50M€
  → 50MeV
  following BERLinPro Mac recommendation)
- detailed time planning
- detailed costing
  (50MeV = 36.2Mio€, need to stretch timeline)

still hiring additional personnel

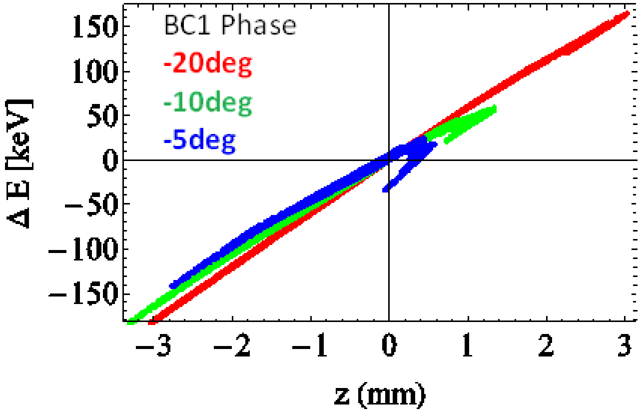
ALICE accelerator

Accelerators and Lasers In Combined Experiments

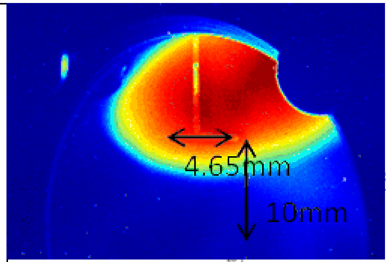


ALICE Beam Simulations

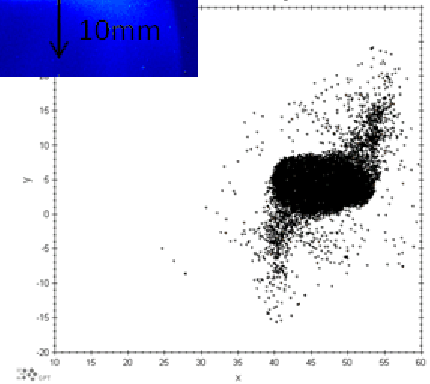
Deepa Angal-Kalinin



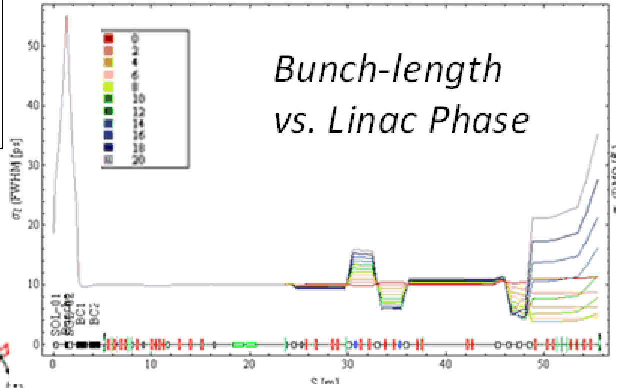
Injector dynamics complicated by reduced gun energy (230 KeV), long multi-cell booster cavity and long transfer line.

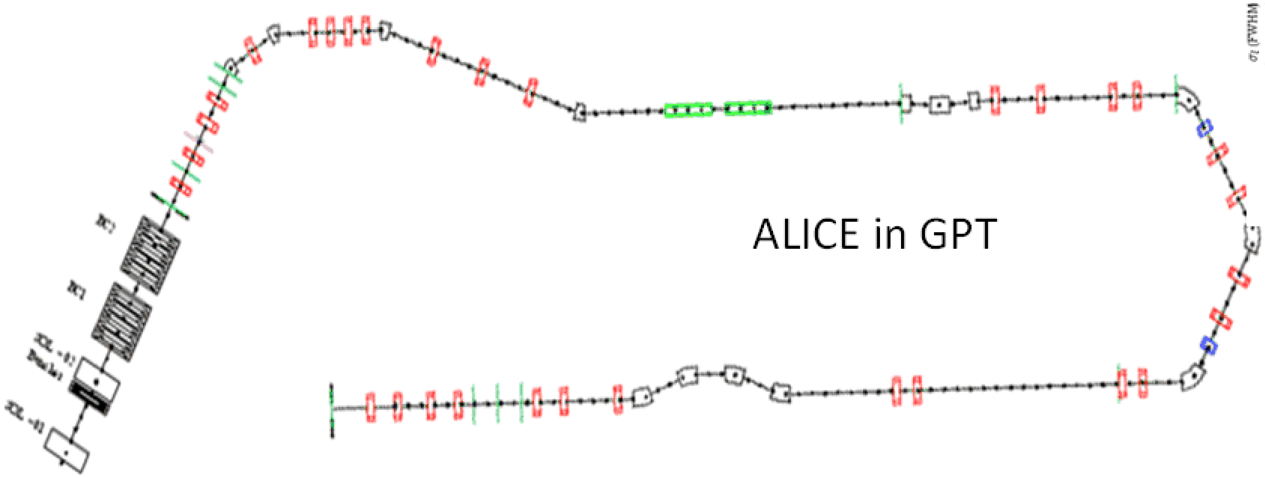


Elliptical beam – effect of stray fields?



Using ASTRA and GPT to go around the machine to understand longitudinal dynamics. Non trivial to use dipoles. GPT (Space charge off) and MAD matching quite good, small differences in vertical focussing.





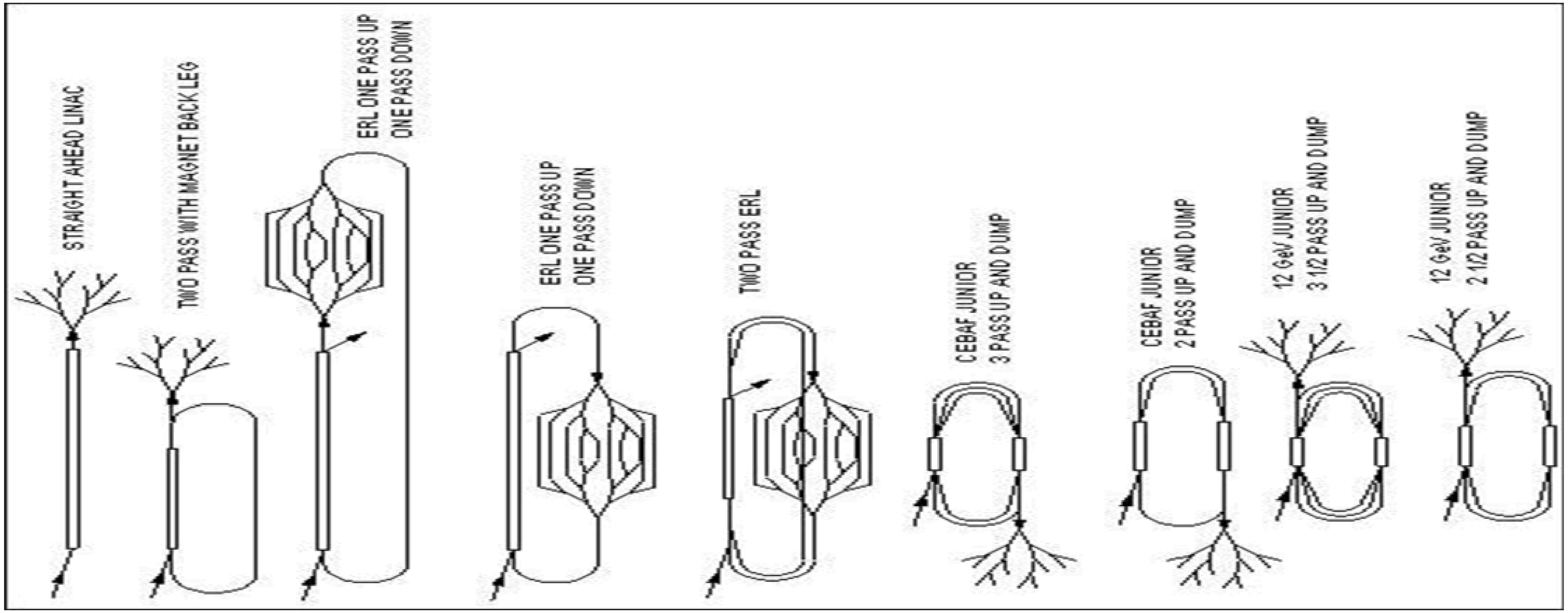
Plan to validate 6D machine model to understand different machine set ups with additional diagnostics .

D. Angal-Kalinin

Tom Powers Cost Calculator

gradient	1.80E+07	current (A)	1.00E-01	RF PWR margin	1.3	Cryo margin	1.5	Machine Energy	2	Linac packing factor	1.25	Microphonics	10

Inputs



Total	$3,464M	$3,436M	$1,212M	$1,181M	$693M	$3,558M	$3,433M	$3,554M	$3,424M
Relative capit	1.00	0.99	0.35	0.34	0.20	1.03	0.99	1.03	0.99
10 year Opera	$36M	$24M	$34M	$34M	$20M	$21M	$23M	$19M	$20M
Total cost 10	$3,500M	$3,460M	$1,246M	$1,215M	$713M	$3,579M	$3,456M	$3,573M	$3,444M
Relative Cost	1.00	0.99	0.36	0.35	0.20	1.02	0.99	1.02	0.98

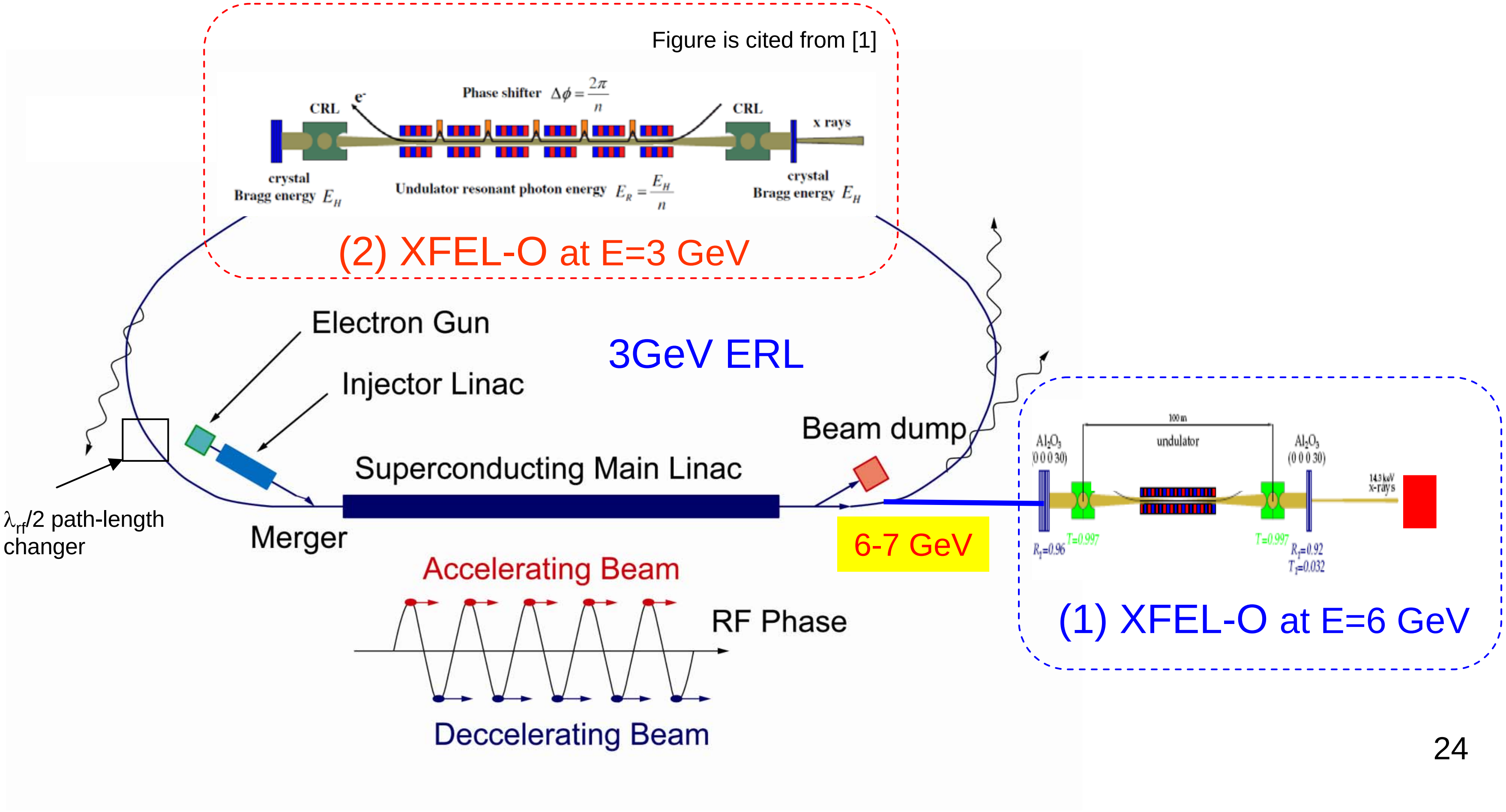
Joint session

FEL & ERL (XFEL-O)

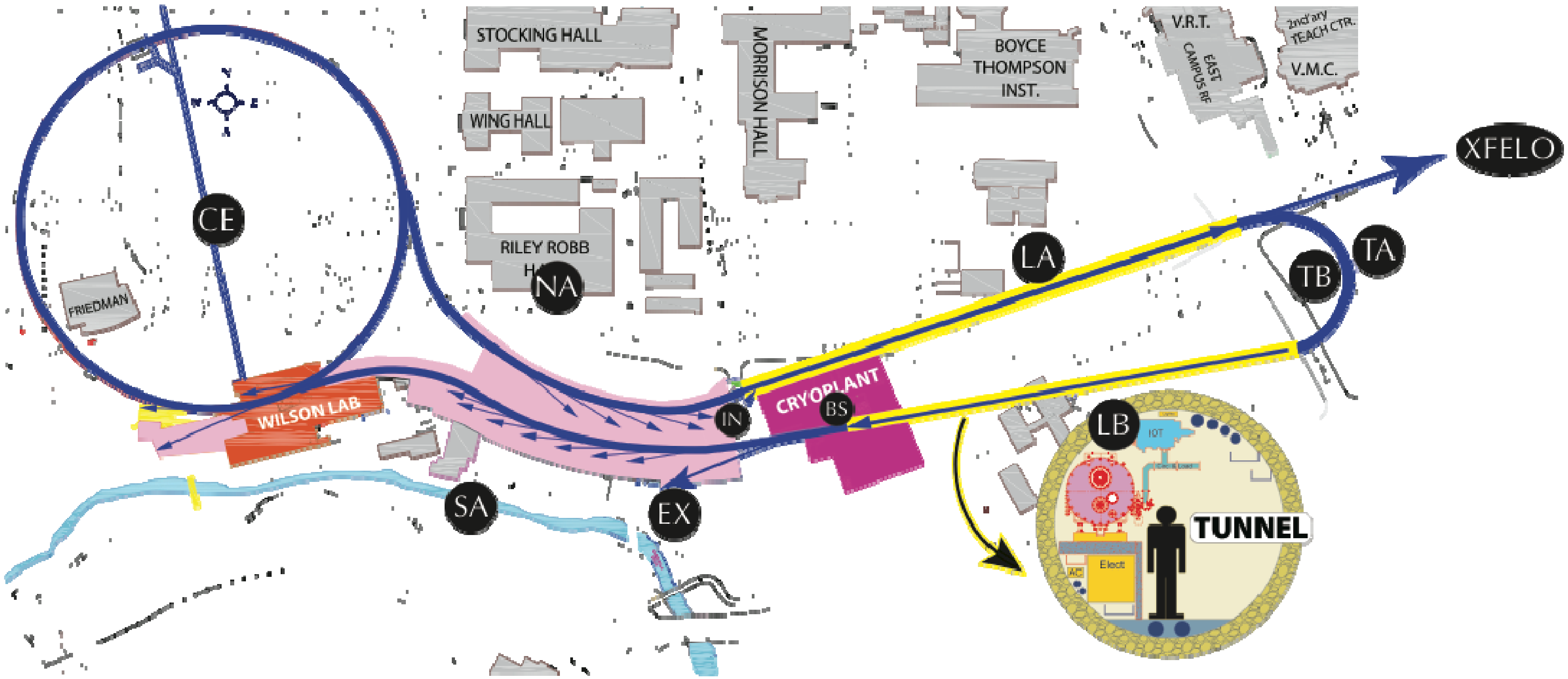
Plan of XFELO in KEK-ERL

We expect the possibilities of:
- driving XFELO at 6 GeV, or
- harmonic lasing scheme at 3 - 3.5 GeV [2].

[2] J. Dai, H. Deng, Z. Dai, Phys. Rev. Lett. **108**, 034802 (2012).



XFELO Option in the Cornell ERL



The Cornell ERL normally injects electron bunches at 15 MeV, accelerates them to 2.8 GeV in Linac A (LA), and another 2.2 GeV in Linac B (LB) to yield 5 GeV in the user region, followed by deceleration. By taking an extra acceleration turn through LA, an XFELO could be operated at 7.8 GeV.

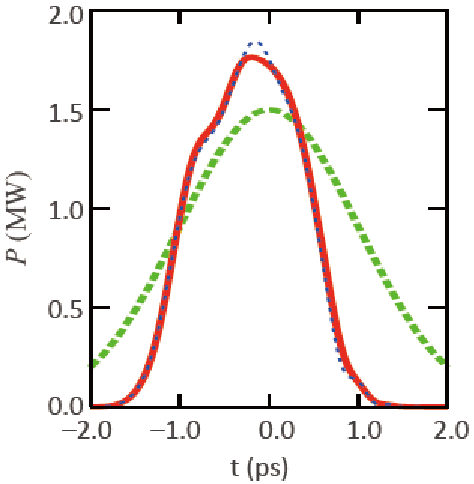
[Cornell ERL PDDR 2011]

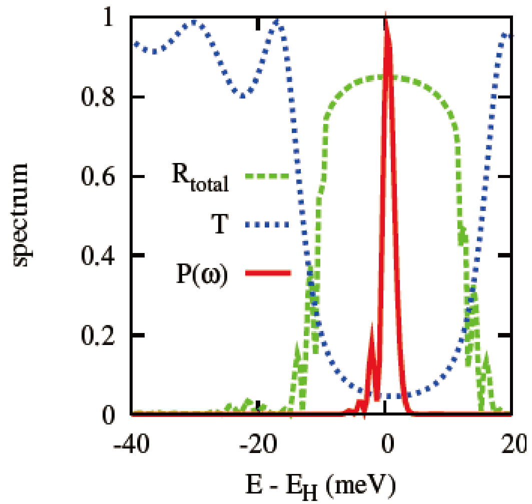
"Canonical" Parameters and performance

γmc^2	7 GeV
Q	25 pC
I_{peak}	10 A
$\varepsilon_{x,n}$	0.2 mm-mrad
$\Delta\gamma mc^2$	1.4 MeV
L_{und}	52 m
G	0.36
R_{tot}	0.85
crystal	C(4 4 4)

P_{out}	1.7 MW
Photons/ pulse	1.1×10^9
ΔE_{FWHM}	1.95 meV
Δt_{FWHH}	1.58 ps

Compress the beam further to increase current and FEL gain





R.R. Lindberg, K-J. Kim, Yu. Shvyd'ko, and W.M. Fawley, *Phys. Rev. ST-AB.* **14,** 010701 (2011)

Joint session

Unwanted Beam Loss

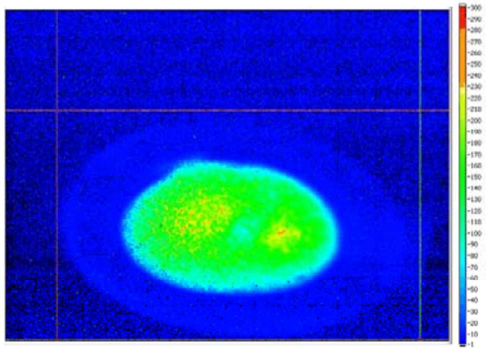
Diagnostics Related to the Unwanted Beam

Pavel Evtushenko (JLab)

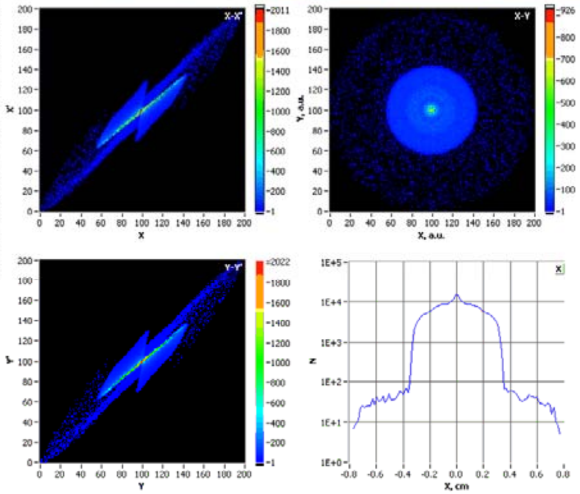
4種類のunwanted beam

- Beam dynamics によるハロー形成
- レーザーのゴーストパルス
- レーザーの散乱、反射、レーザーのタイミングずれ
- Field emission（電子銃、空洞）

Measurements vs. Modeling at the level ~10^3

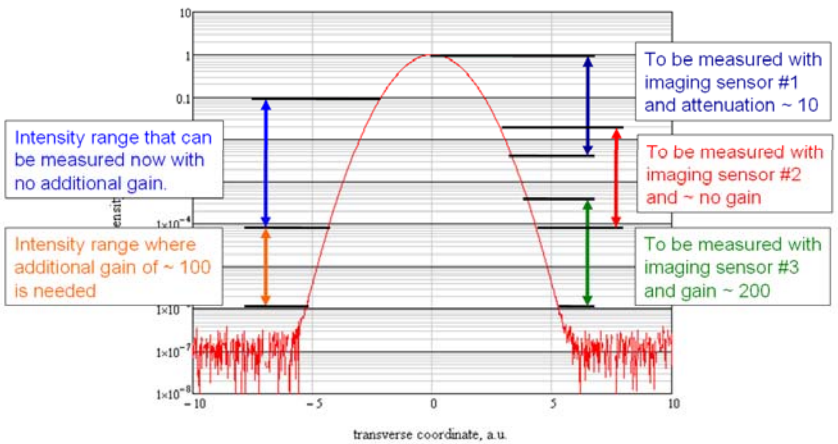


Measured in JLab FEL injector, local intensity difference of the core and "halo" is about 300. (500 would measure as well) 10-bit frame grabber & a CCD with 57 dB dynamic range



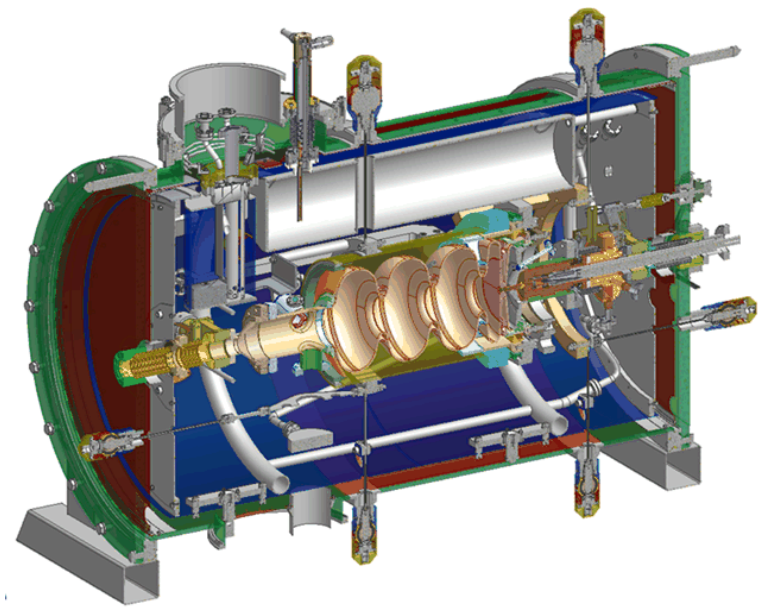
PARMELA simulations of the same setup with 3E5 particles: X and Y phase spaces, beam profile and its projection show the halo around the core of about 3E-3.
Even in idealized system (simulation) non-linear beam dynamics can lead to formation of halo.

Large Dynamic Range imaging (3)



Unwanted Beam Observations at ELBE

J. Teichert (HZDR)



Design

medium average current:
1 - 2 mA (< 10 mA)

high rep-rate:
500 kHz, 13 MHz and higher

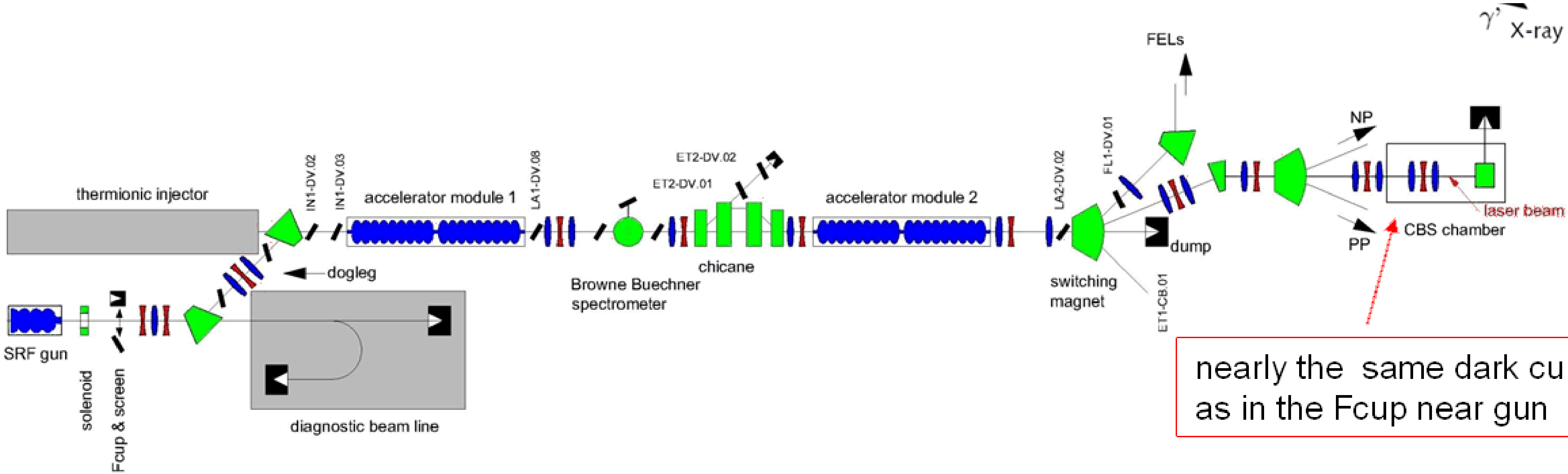
low and high bunch charge:
80 pC - 1 nC

low transverse emittance:
1 - 3 mm mrad

high energy:
≤ 9 MeV, 3½ cells (stand alone)

highly compatible with ELBE cryomodule (LLRF, high power RF, RF couplers, etc.)

LN2-cooled, exchangeable high-QE photo cathode



nearly the same dark current as in the Fcup near gun

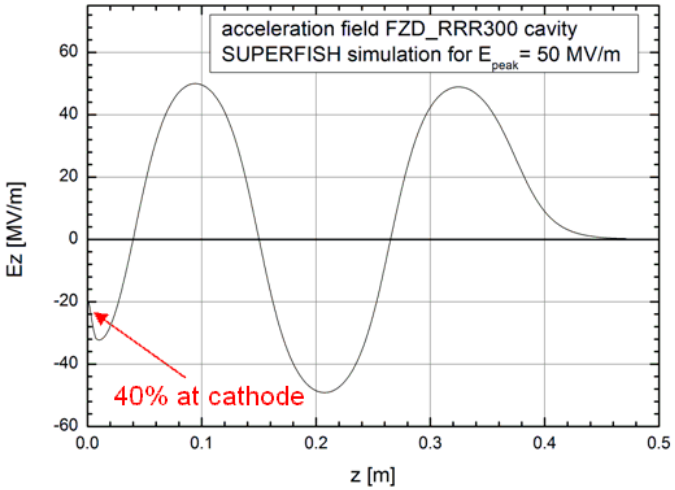
Unwanted Beam Observations at ELBE

J. Teichert (HZDR)

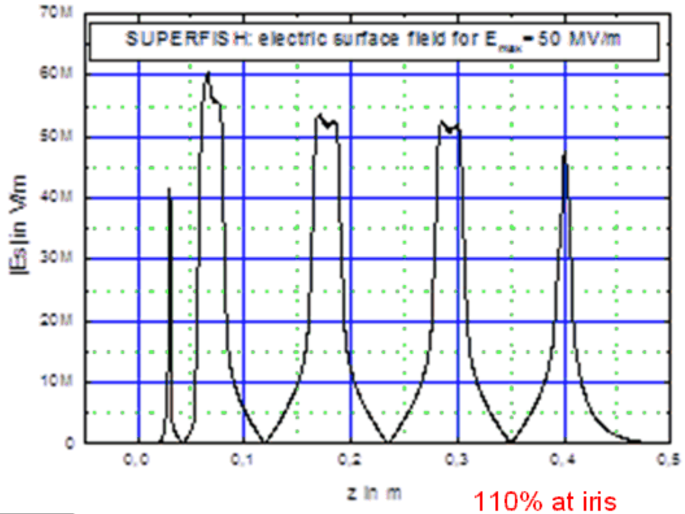
DARK CURRENT – Cavity field

HZDR

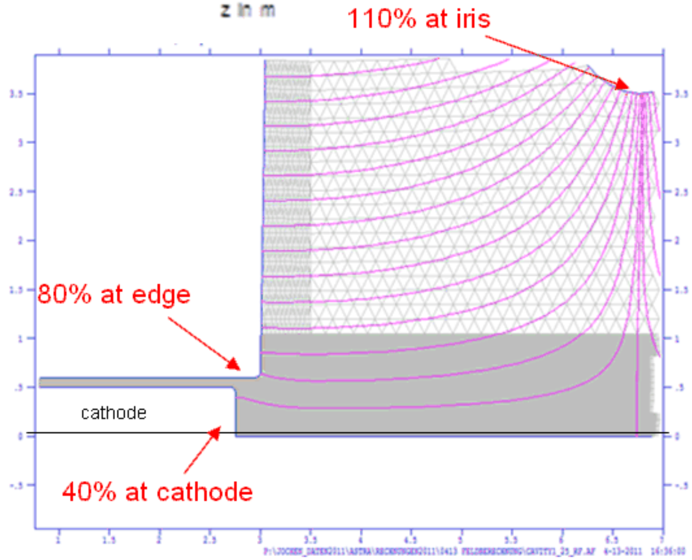
field profile on axis



surface electric field



gun operation mode	CW	pulsed RF
acceleration gradient	6.0 MV/m	8 MV/m
electron kinetic energy	3 MeV	4 MeV
peak field on axis	16.5 MV/m	21.5 MV/m
peak field at cathode (2.5 mm retracted)	6.5 MV/m	8.4 MV/m
cathode field at launch phase (10°)	1.1 MV/m	1.5 MV/m
cathode field at 10° and -5 kV bias	2.2 MV/m	2.6 MV/m
cathode field at 90° and -5 kV bias	7.6 MV/m	9.5 MV/m



Important for emitted dark current:

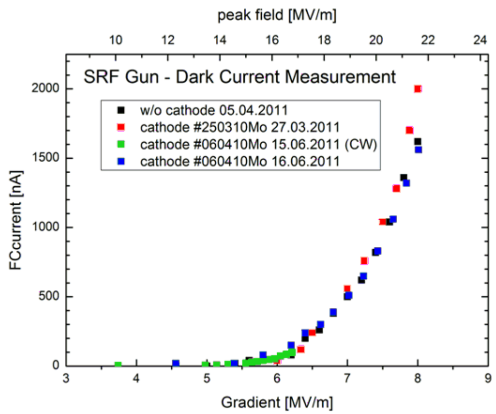
- cathode surface field is ~ 40 % of peak field
- field at cathode hole edge is ~ 80 % of peak field
  without field enhancement (scratch in our cavity)

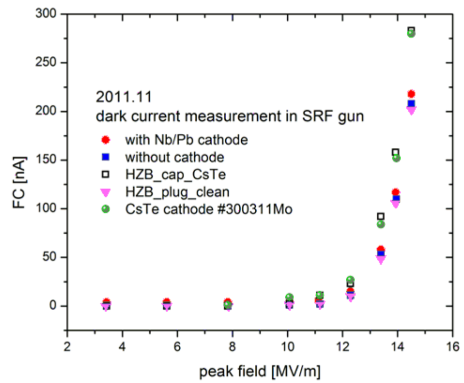
Unwanted Beam Observations at ELBE

J. Teichert (HZDR)

DARK CURRENT – Measurement

Dark current in Faraday cup (~1.5 m from cathode) versus gradient for different cathodes





- about 20 % dark current from cathode, 80% from cavity (scratch)
- only cathodes with CsTe layer have dark current, exception: #060410Mo, but without direct comparison

Dark current

- 20%はカソードより発生
- 80%はcavityより発生
  （カソードあり/なしで測定）
- エネルギーをspectrometerで測定

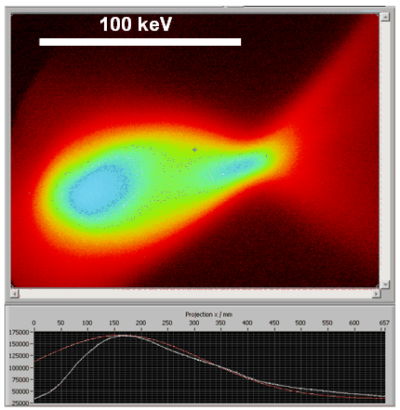
- 常伝導RF電子銃（LBNLなど）でも、同様のDark Currentの発生があるとの事 （超伝導電子銃だから悪い訳ではない）

DARK CURRENT – Properties

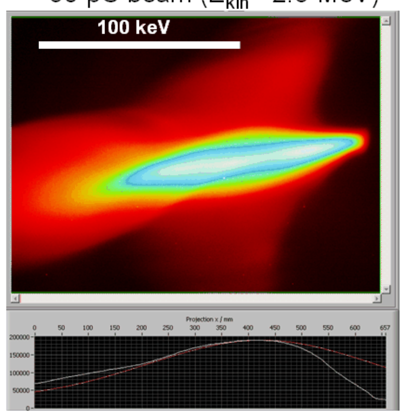
Measurement of kinetic energy and energy width of dark current and comparison with low-bunch-charge beam – 180° bending magnet in diagnostic beamline

- largest fraction has nearly beam energy (emission from backplane near cathode)
- small fraction with lower energy (other high-field iris regions in cavity)

dark current



30 pC beam (E_{kin}= 2.8 MeV)



parameters:
6 MV/m CW, 5 kV DC bias
120 nA dark current,
1.5 μA @ 50 kHz beam

$$\Delta E = \bar{E}_{DC} - E_{kin} \approx 60\ keV$$

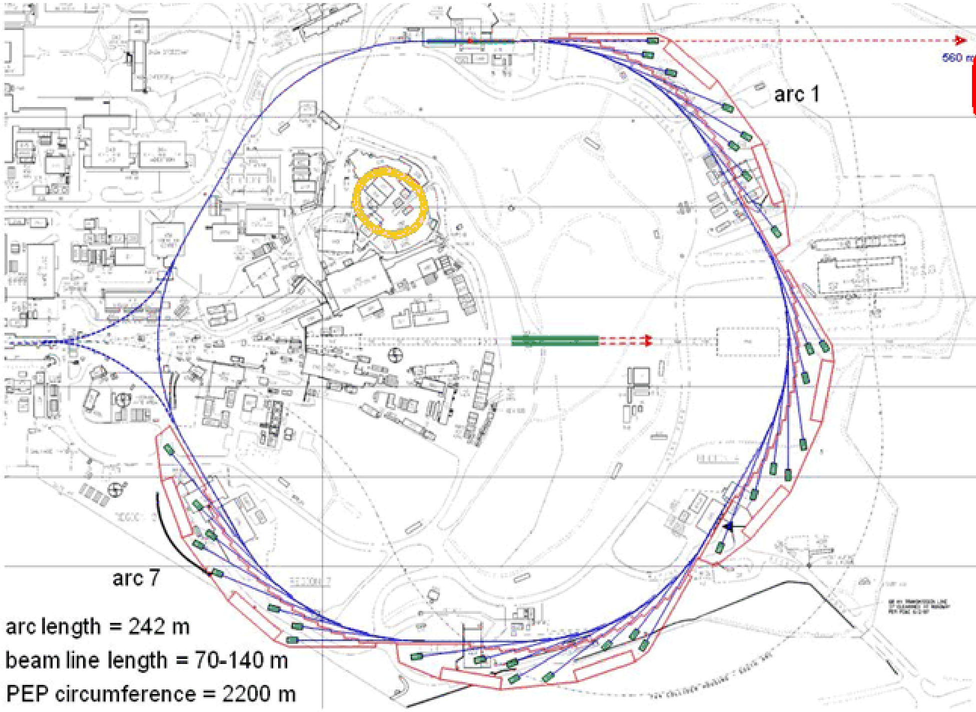
$$\frac{\Delta E}{E_{kin}} \approx 2\ \%$$

Storage Ring

WG & Plenary Talk

PEP-X: Diffraction-Limited Storage Ring at SLAC

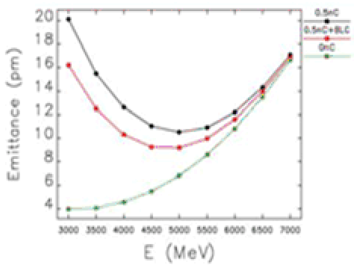
Bob Hettel (SLAC)



Energy	4.5-5 GeV
Current	200 mA
Emittance (x/y)	11/11 pm
Bunch size (x/y, ID)	7.4/7.4 μm rms†
Bunch length	4 mm rms*
Lifetime	>2 h*
Damping wigglers	~90 m
ID length (arc)	~4 m
ID length (straight)	<100 m
Beta at ID center, (x/y)	4.92/0.8-5 m
Circumference	2199.32 m
Harmonic number	3492

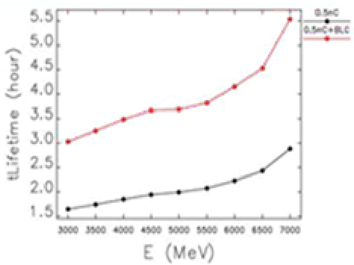
† Vertical beam size can be reduced towards 1 μm

* Harmonic cavity system would increase bunch length to ~8 mm and double the lifetime

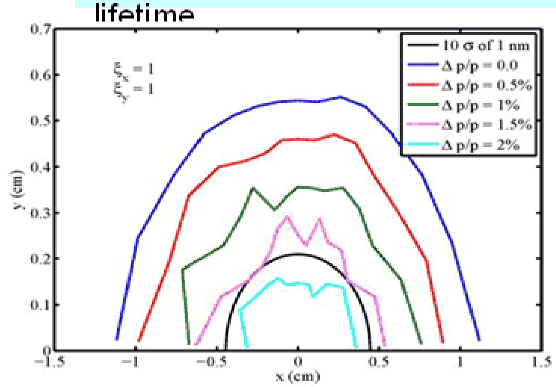


Emittance with 200 mA (0.5 nC/bunch, 100% coupling) is minimized with a bunch-lengthening cavity at 4-5.5 GeV.

courtesy M. Borland



Lifetime at 200 mA (0.5 nC/bunch, 100% coupling) is doubled with a bunch-lengthening cavity.



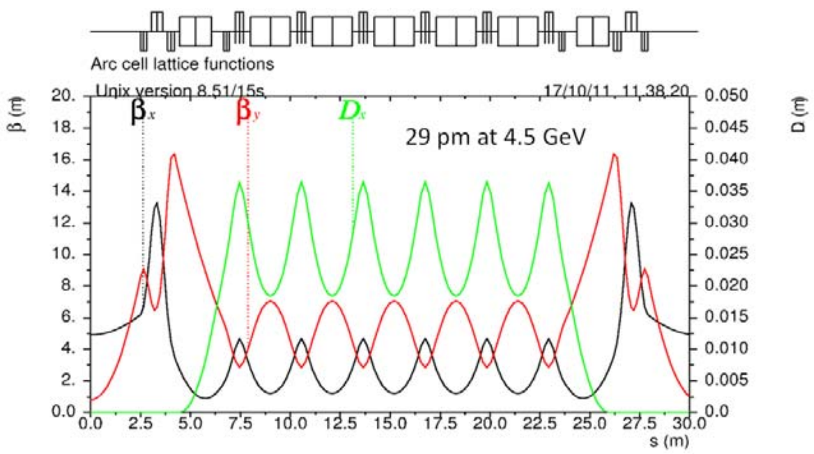
sufficient dynap for off-axis injection

NATIONAL ACCELERATOR LABORATORY

PEP-X における Dynamic Apaerture の改善

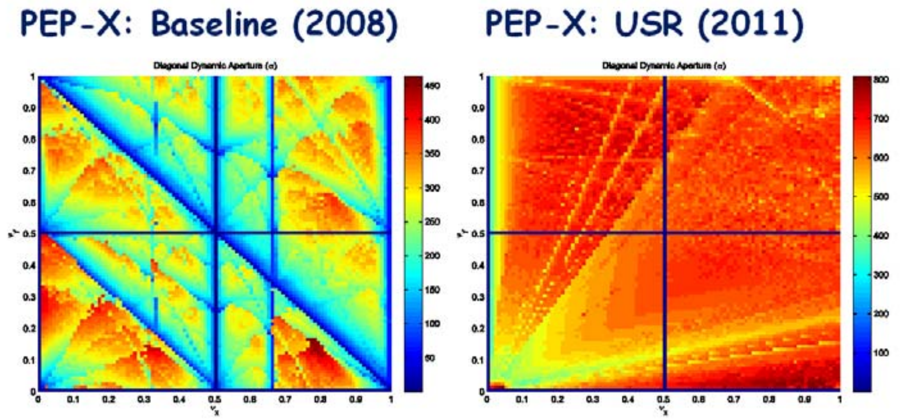
Yunhai Cai (SLAC)

PEP-X 7 Bend Achromat



Cell phase advances: μ_x=(2+1/8) x 360^0, μ_y=(1+1/8) x 360^0.

Tune Scan of Dynamic Aperture

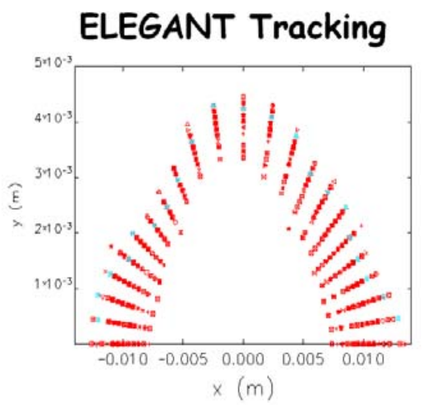


The dynamic aperture is in unit of sigma of the equilibrium beam size. The USR design is built with 4th-order geometric achromats and therefore no 3rd and 4th order resonances driven by the sextupoles seen in the scan.

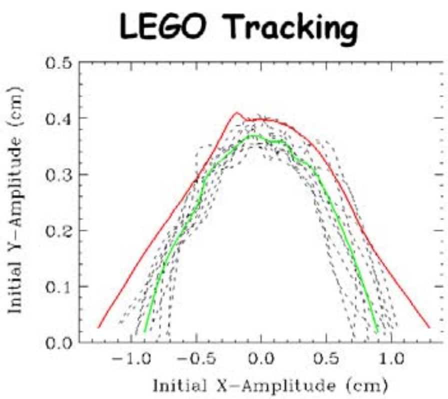
Resonances のキャンセル方法

- Cancellation of All Geometric 3rd and 4th Resonances Driven by Strong Sextupoles except $2\nu_x-2\nu_y$
- Harmonic Sextupoles For Tune Shifts and $2\nu_x-2\nu_y$ Resonance
- 4th Order Geometric Achromat

Dynamic Aperture with Machine Errors



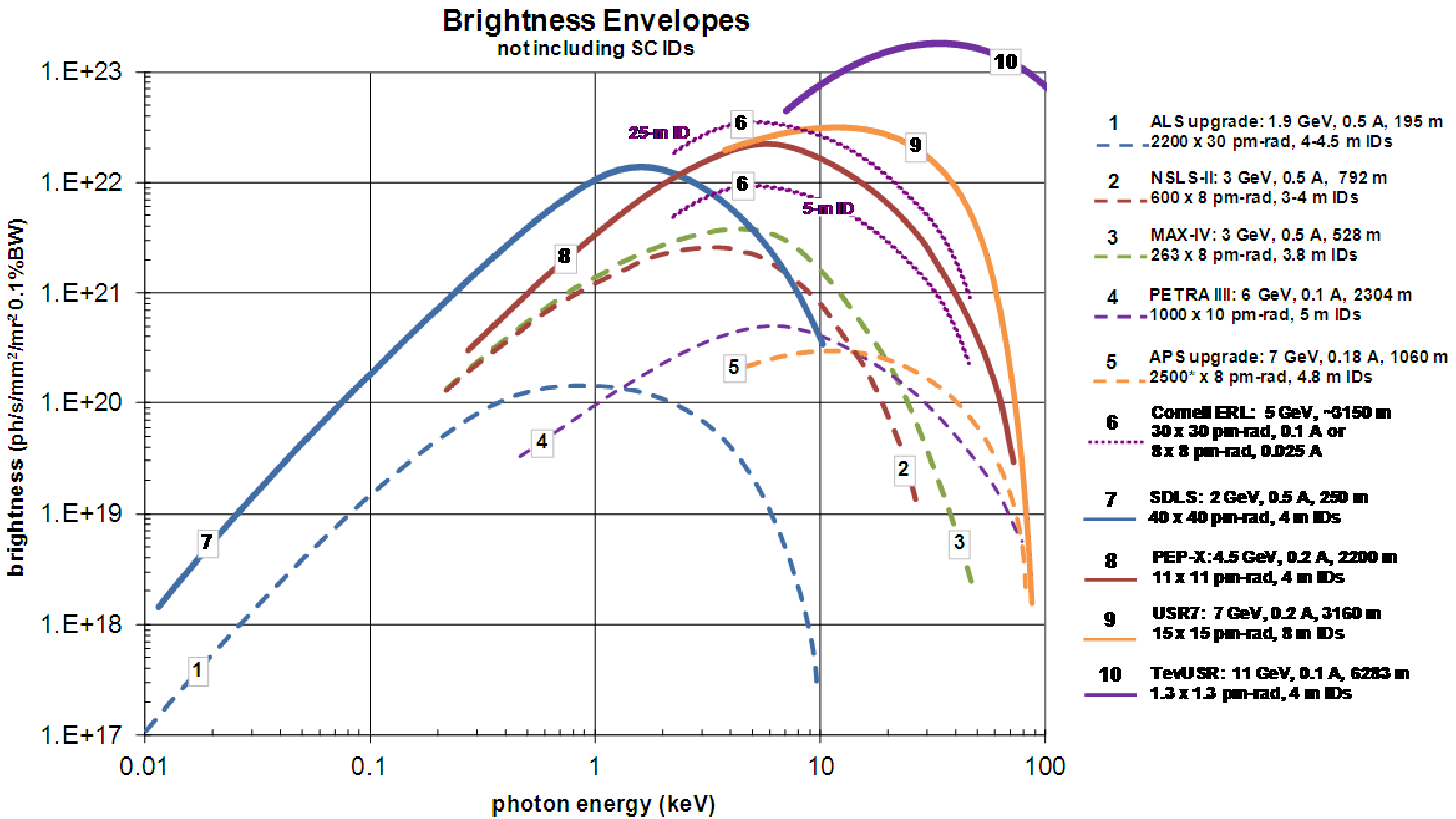
1% coupling & 1% beta beating



Misalignments 20 microns in x.

USRs - Spectral Brightness

Bob Hettel (SLAC)



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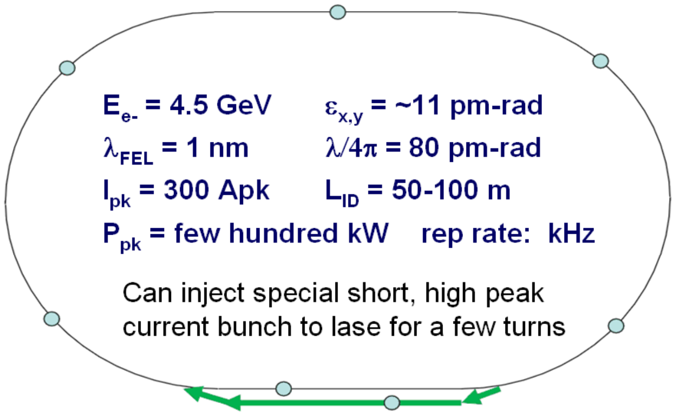
PEP-X のオプション？

Bob Hettel (SLAC)

PEP-X Soft X-ray FEL in switched bypass



Nuclear Instruments and Methods in Physics Research A318 (1992) 730–735
North-Holland

40 Å FEL designs for the PEP storage ring

Alan S. Fisher and Juan C. Gallardo
*Brookhaven National Laboratory *, Building 510D, Upton, NY 11973, USA*

Heinz-Dieter Nuhn, Roman Tatchyn and Herman Winick
*Stanford Synchrotron Radiation Laboratory **, SLAC, Bin 69, P.O. Box 4349, Stanford, CA 94309-021*

Claudio Pellegrini
Department of Physics, University of California, Los Angeles, CA 90024-1547, USA

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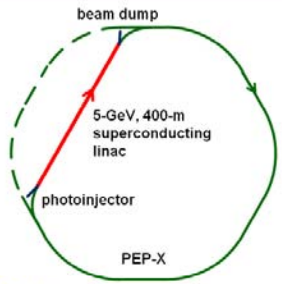
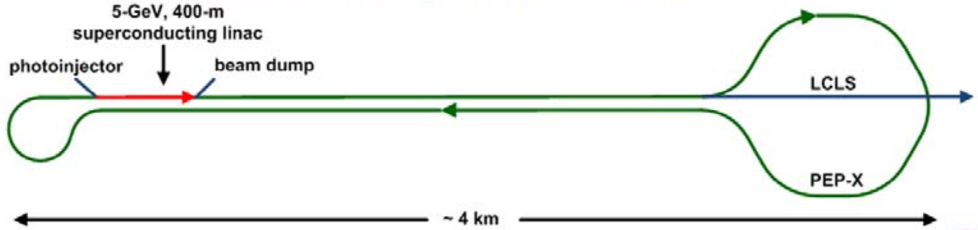
PEP-X ERL – some options



Option: 2-pass with 2.5-GeV linac

- SCRF = 1.3 GHz
- "bunch stealing" @ ~ 1 MHz could drive FELs



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SPring-8 II

T. Watanabe
（Bob Hettel が代理発表）

	SPring-8	SP-8 II (planned)
Electron energy	8 GeV	6 GeV
Current	100 mA	~300 mA
Emitance	3.4 nm.rad	67→10 pm.rad
Energy spread	0.0011	~0.001
Coupling	0.2 %	~2 %
Bunch length (rms)	13 ps	>20 ps
Circumference	1436 m	1436 m
# beamlines	62 max.	62+ max.

* Parameters for SP8-II may be changed.

SPring-8 II – at-energy linac injector

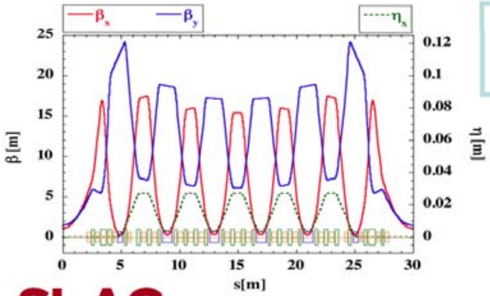
A high-quality injection beam is needed.
At SPring-8 we have XFEL Linac, which will be used as a full-energy injector to the storage ring.

Linac Parameters: (typical)

- Energy: 8 GeV (max.)
- Emittance: 40 pm.rad
- Energy Spread: 0.01 %
- Bunch Length: 30 fs (rms)
- Electron Charge: 300 pC – 1 nC

SPring-8 II – 6-bend achromat lattice

$$\text{Emittance} = K \frac{(\text{Electron energy})^2}{(\#\ \text{bends})^3} \times D$$

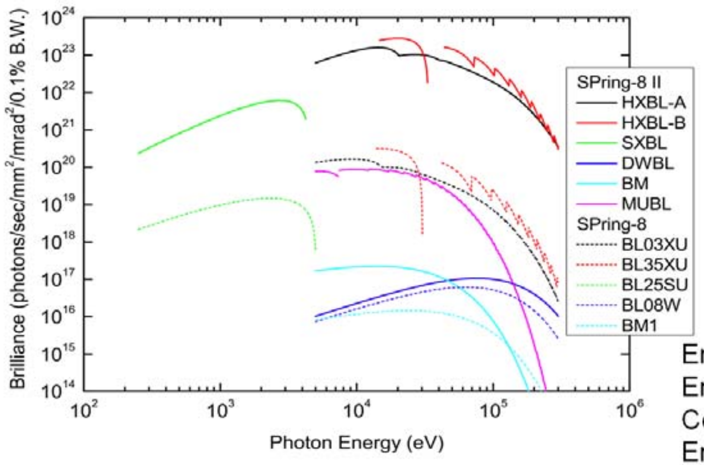


Natural emittance = 67 pm.rad

+

Damping by ID's
Damping wiggler
Damping partition control
Coupling control
etc...

Brilliance: SPring- 8 vs. SPring-8 II



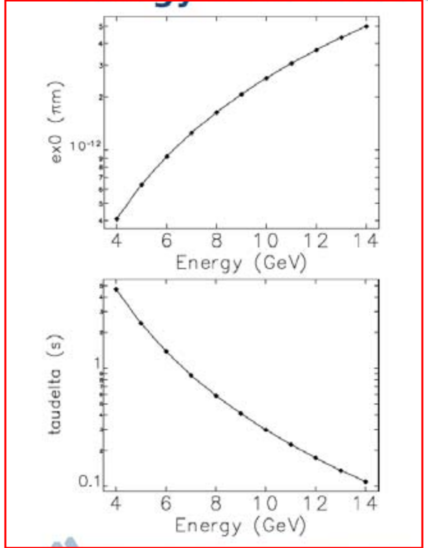
X 1000

Energy : 6 GeV
Emittance: 35 pm.rad
Coupling: 2 %
Energy spread: 0.1%
Current: 300 mA

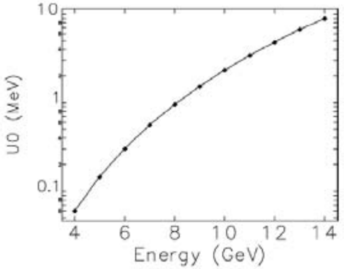
Tevatron-Size USR の検討

Michael Borland (ANL)

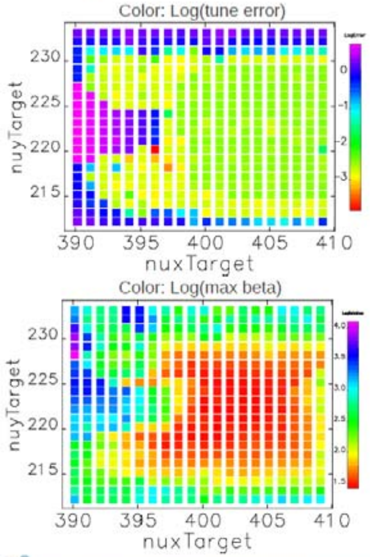
Energy Scan with no DUs



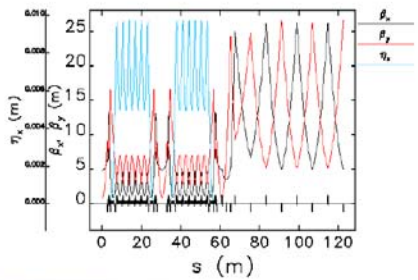
- Longitudinal damping time is very long
- <100ms is "desirable"
  - Means we need damping wigglers plus relatively high energy
- For 11 GeV electron beam, APS U55 can reach below 4 keV x-ray energy



Integer Tune Scan with Matching/FODO Quads



- Fairly wide region within which tune can be varied with matching and FODO quads only
- Start with ν_x=403.1, ν_y=222.2



Lattice w/o Damping Undulators (DUs)

Betatron Tunes		
Horizontal	403.098	
Vertical	222.198	
Natural Chromaticities		
Horizontal	-580.114	
Vertical	-468.581	
Lattice functions		
Maximum β_x	26.341	m
Maximum β_y	29.000	m
Maximum η_x	0.009	m
Average β_x	5.199	m
Average β_y	7.112	m
Average η_x	0.006	m
Radiation-integral-related quantities at 11 GeV		
Natural emittance	3.092	pm
Energy spread	0.089	%
Horizontal damping time	55.241	ms
Vertical damping time	133.097	ms
Longitudinal damping time	225.349	ms
Energy loss per turn	3.425	MeV
Straight Sections		
Effective emittance	0.003	nm
β_x	4.922	m
η_x	-0.000	m
β_y	0.778	m
Miscellaneous parameters		
Momentum compaction	4.468×10^{-6}	
Damping partition J_x	2.409	
Damping partition J_y	1.000	
Damping partition J_δ	0.591	

Conclusion

- Storage ring light sources are among the most successful scientific facilities in existence
- Reports that rings had reached the end of the road were premature
  - NSLS-II and MAX-IV under construction
  - MBA lattice design with genetic algorithms
  - New injection ideas: 100% coupling and swap-out
- Studies continue in Japan, US, Europe
  - Interest in a possible international collaboration on a large ultimate light source
- A Tevatron-sized USR is very intriguing, but much work needed
  - collective instabilities
  - magnet design
  - error studies and nonlinear dynamics optimization
  - cost reduction
  - science case

Light Source in East Japan – Hiroyuki Hama, Tohuku University

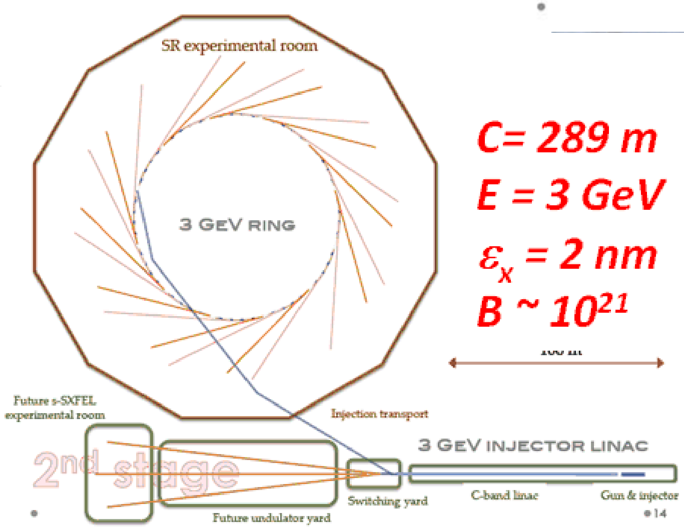
(LSEJ)

- Need another mid-E high brightness source in Japan
- Project would stimulate investment and economy in NE Japan
- Supported by 7 national universities
- 3-GeV C-band linac injector (could be soft-XFEL driver)
- Want simple lattice – want construction and commissioning to be quick
- 12-cell, 4BA as baseline (are 10 IDs OK?)
- Alba is closest design – 4 nm, 16 cells
- Needs at least 250 M$-- will abandon proposal if funding not approved in 2 years (before KEK ERL, SPring-8 funding)

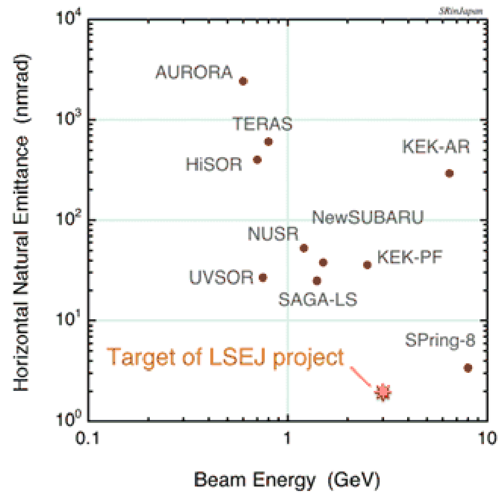
Major machine parameters

Energy	E	2.997 GeV ($B\rho$ = 10)
Circumference	C	289.2 m
Betatron tune	(ν_x, ν_y)	(22.10, 5.27)
Natural chromaticity	(ξ_x, ξ_y)	(- 56.99, - 33.58)
Natural horizontal emittance*)	ε_x	1.862 nmrad
Momentum compaction factor	α	0.00076
Damping time*)	$(\tau_x, \tau_y, \tau_\varepsilon)$	(6.32, 8.88, 5.56) ms
Natural energy spread*)	σ_E/E	8.69×10^{-4}
Synchrotron energy loss*)	ΔE	0.652 MeV/turn
Min. and max. horizontal beta function	$(\beta_x^{min}, \beta_x^{max})$	(0.28, 14.71) m
Min. and max. vertical beta function	$(\beta_y^{min}, \beta_y^{max})$	(4.00, 26.80) m
Min. and max. dispersion function	$(\eta_x^{min}, \eta_x^{max})$	(0.02, 0.21) m
Length (number) of straight section	L_{ss}	5 m (12)
Lattice functions at straight section	$(\beta_x, \beta_y, \eta_x)$	(13, 4, 0.07) m

*)Only dipoles are taken into account



C= 289 m
E = 3 GeV
ε_x *= 2 nm*
B ~ 10[21]



Compact Source

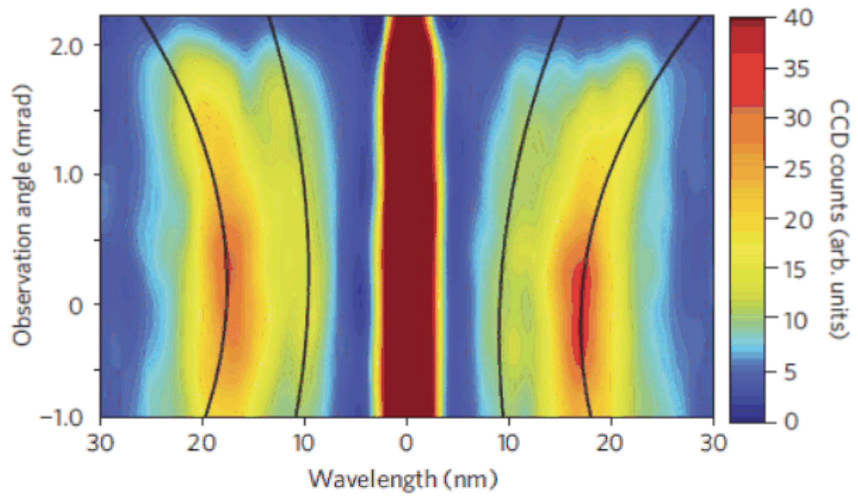
WG & Plenary Talk

Experimental measurement of undulator radiation at MPQ

M. Fuchs et al., Nature Physics (2009)

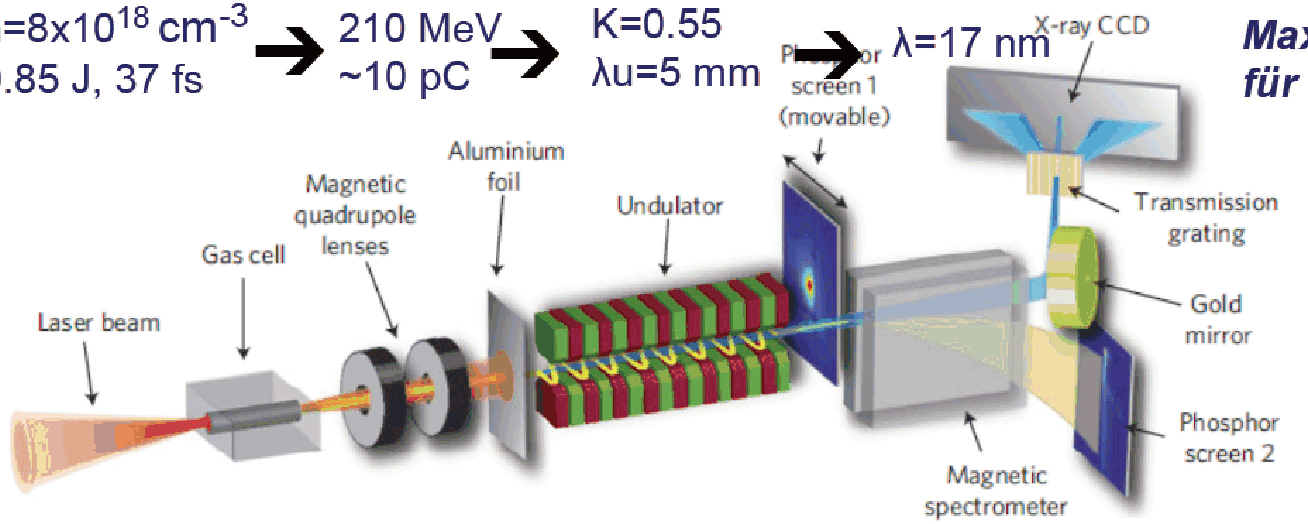
- Measured 1st and 2nd harmonic:

$$\lambda = \frac{\lambda_u}{2n\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right)$$



n=8x10^{18} cm^{-3} 0.85 J, 37 fs → 210 MeV ~10 pC → K=0.55 λu=5 mm → λ=17 nm

Max-Plank-Institut für Quantenoptik



Intense Super-radiant X-rays from a Compact Source

W.S. Graves (MIT)

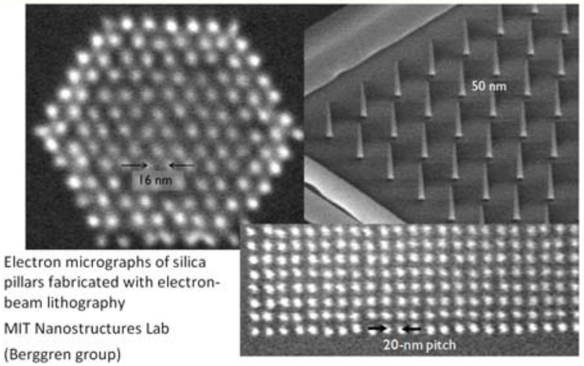
アイディア

- 横方向に濃淡のあるビームを出す
- Emittance exchangeにより、縦方向にバンチしたビームを作る
- Super-radiant X-ray を発生

コメント

- Super-radiant を発生させるためには横方法emittanceも小さくないといけないのでは？(Zholents氏)
- 空間電荷効果の影響は受けないか？

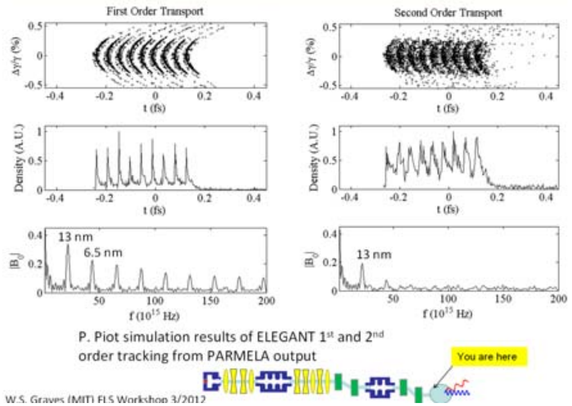
Nano-Fabrication of Field Emission Tips



Electron micrographs of silica pillars fabricated with electron-beam lithography

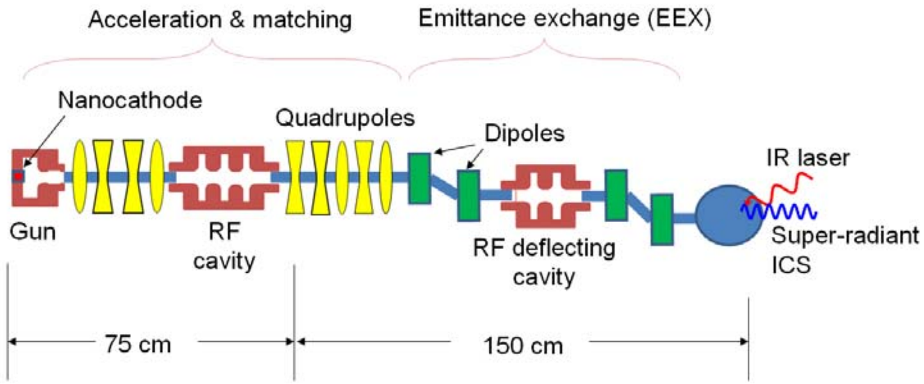
MIT Nanostructures Lab (Berggren group)

9X9 Array Bunching after EEX



Super-radiant ICS Example at 13 nm

FEA ⇨ gun ⇨ focus & matching ⇨ emittance-exchange ⇨ ICS



Super-radiant X-rays via ICS

ICS (or undulator) emission is not a coherent process, scales as N

Super-radiant emission is in-phase spontaneous emission, scales as N^2

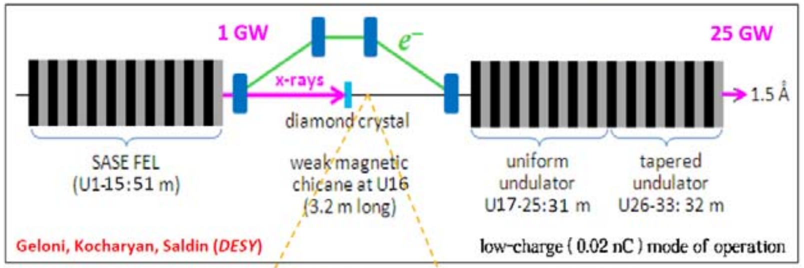
FEL

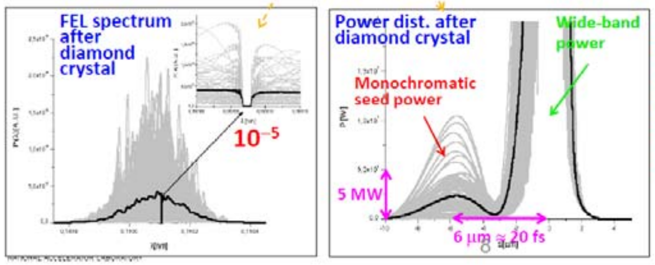
Plenary Talk

Some R&D Toward Brighter X-ray FEL

Zhirong Huang (SLAC)

Hard x-ray self-seeding

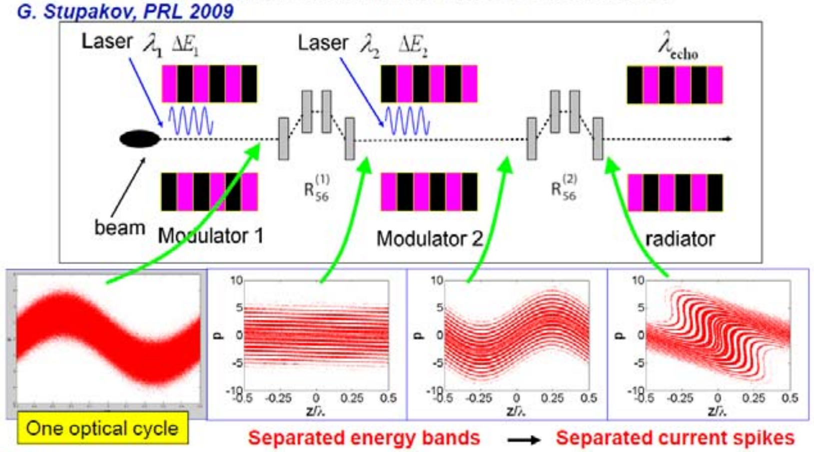




Self-seeding of 1-µm e^- pulse at 1.5 Å yields 10^{-4} BW with low charge mode

Echo-Enabled Harmonic Generation

G. Stupakov, PRL 2009

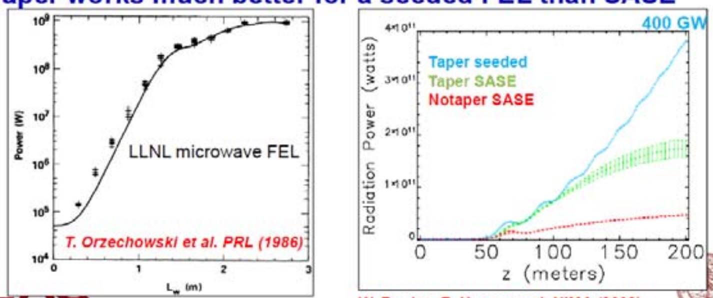


- Very high harmonic bunching may be produced from external laser
- Demonstration experiments at SLAC and SINAP look promising
- High harmonic bunching may seed a soft x-ray FELs (a few nm wavelength)

Taper to enhance FEL efficiency

- FEL saturates due to significant E-loss
- Tapered undulator keeps FEL resonance and increase power

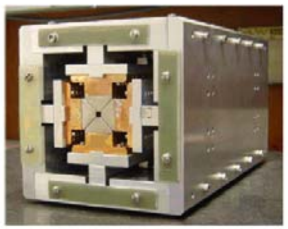
- **Taper works much better for a seeded FEL than SASE**



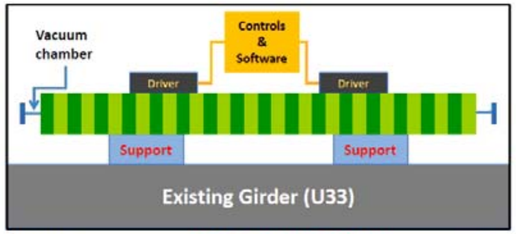
W. Fawley, Z. Huang et al. NIMA (2002)

DELTA undulator

- Delta undulator is a novel, compact design that fits to existing LCLS girder
- LCLS plans to build and test a 3.2-m Delta @ U33 in two years
- Degree of circular polarization for 1 DELTA ~70% at soft x-rays.
- Adding 1 or 2 more DELTA in future provides >90% polarization



Cornell Delta undulator (A. Temnykh)



H.-D. Nuhn, E. Kraft

3. その他

（ERL WG での議論や

Coffee Break の時に聞いた話など）

その他（超伝導空洞まわり）

空洞横のゲートバルブのシール

- シール材としてvitonが良く、metal はダメとの主張あり（Tom Powers）
- SNS, ALICEはviton、Cornell injector, cERL はmetal とのこと
- 後でBob Rimmerに聞いたところ、シール材がmetalでダメという話はない。内部をクリーンにする事が大切で、ゲートバルブは分解、cleaningして使っている。RFシールド付きは分解が難しいのでcleaningしていない。
- JLabではRFシールド付きを使用しているはず（Rimmer）

Fast Closing Valve (FCV)は必要か？

- JLab-FELでは、主リニアックの両端に設置。役に立つ（Dave Douglas）
- 主に、FEL/THzビームラインからのガス突入を警戒

CEBAFでの話 (Rimmer）

- CEBAFの超伝導空洞は、年に1～2%の数の空洞で、field emission が増加してしまう現象がある。全く真空を開けていなくても。原因は不明だが、ビームでのdust trappingによりゴミが運ばれてくる可能性もあるのではないか？

その他（超伝導空洞まわり）

入射器用カップラー

- KEKの設計では内導体を水冷しているが、冷却水が止まった時に凍結してリークする事はないのか？どういう対策を取るのか？ （TRIUMFでの議論で）

その他（THz trap、ビーム調整）

THz trap

- テラヘルツ光を吸収するために、銅チェンバーの内側に溝を付けたTHz trap というものをJLabでは設置している。→ これが必要との主張あり
- George Neil によると、FEL用共振器ミラー（液体ヘリウム冷却）をTHz光による発熱から守るものだとの事。

ビーム調整になぜビーム電流300nAが必要か？

- FEL用optical cavityのチューニングのためには、ある程度の電流が必要という事ではないか？（Dave Douglas）。ビーム輸送の調整だけならもっとlow currentでもできるのではないかと思われる。

4. まとめ

まとめ

ERL

- Cornell, KEK などでのR&Dが着実に進んでいるとの印象
- KEK/Cornell でのXFEL-O については、FELの専門家からの期待感を感じた。

Storage Ring

- PEP-X で dynamic aperture を大幅に改善した計算結果が報告され、参加者は注目しているようだった
- Tevatron-sized USRについても関心を呼んでいた。スタディすべきことは多い模様。

FEL

- Hard X-ray用のseeding、tapered undulatorによるFEL効率改善、EEHGの実証実験、Delta Undulator などが話題の中心だった。
- 参加者は約35人とやや少なく、やや一段落していている印象
- LCLS FEL光の利用実験・方法なども関心を集めていた

Compact Source

- レーザー・プラズマ加速器によるコンパクトX線FELが意外に有望そうな印象を与えていた