SPring－8極短バンチモニタ開発テストベンチの大電力RF系

谷 内 努

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第10回高輝度・高周波電子銃研究会
2013.1.10, 11　SPring-8

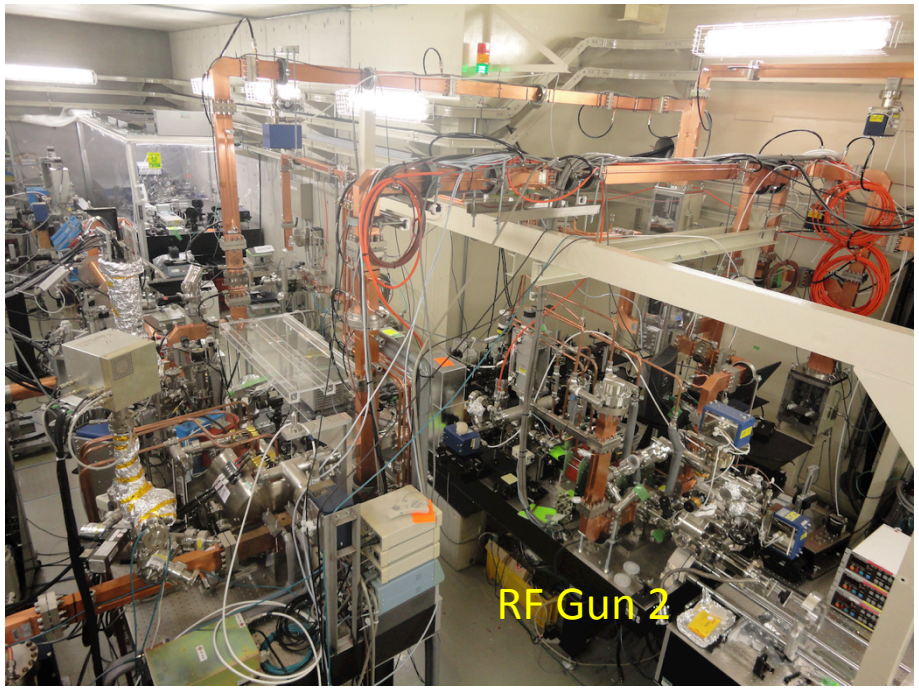
RF電子銃試験装置
SPring-8
線型加速器
マシン実験棟

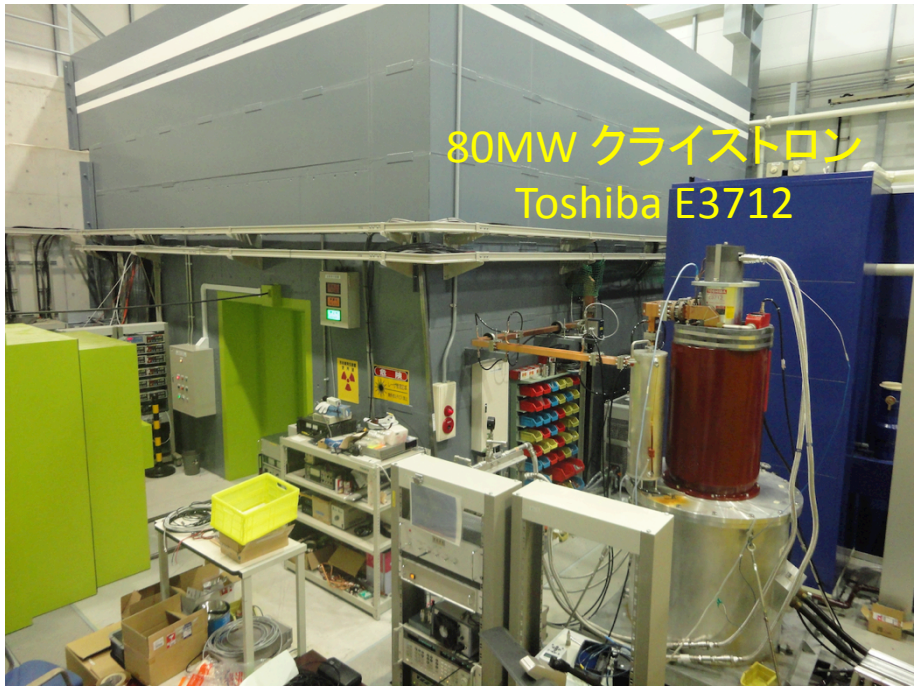
Photocathode RF gun at SPring-8

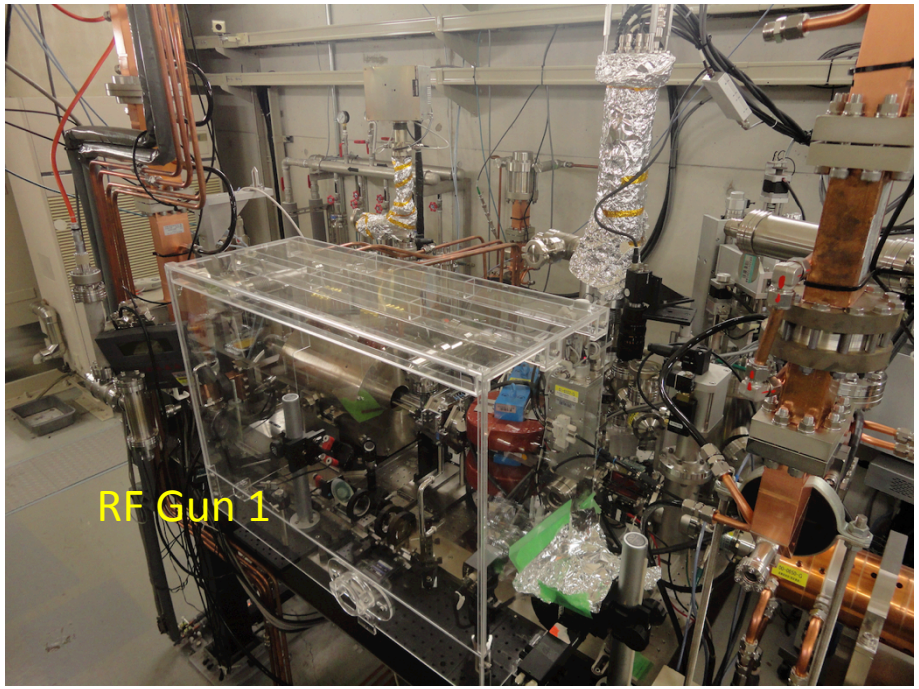
Brief History

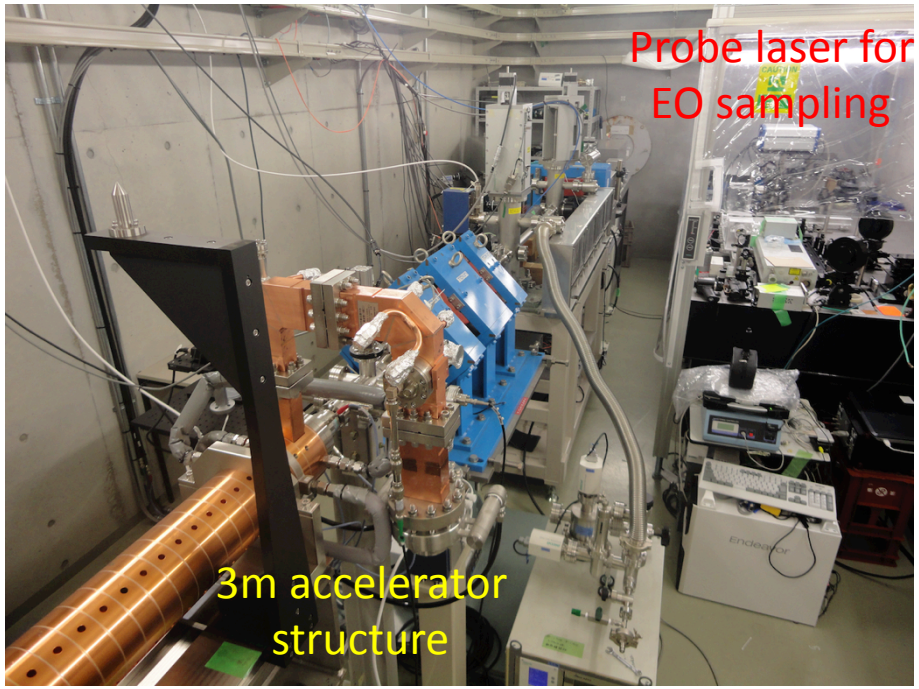
1997	Photcathode RF Gun R&D started.
1999	First beam from Cu cathode.
	Field gradient on cathode 127 MV/m with 35 MW Klystron.
2002	175 MV/m with 80 MW Klystron.
	Cartridge cathode RF gun (Gun2) installed.
2003	3m structure installed. (30 MeV)
2004	190 MV/m achieved after chemical etching adopted.
2012	SLED and bunch compressor will be newly installed and
	RF Gun and Accelerator structure will be replaced.

-> Test bench for femtosecond bunch monitor based on EO-sampling


RF Gun 2


80MW クライストロン
Toshiba E3712


RF Gun 1

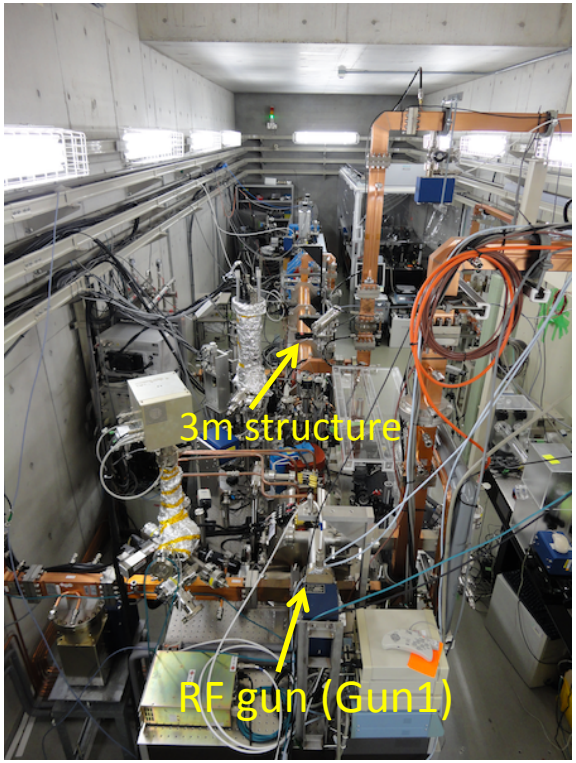

Probe laser for
EO sampling
3m accelerator
structure

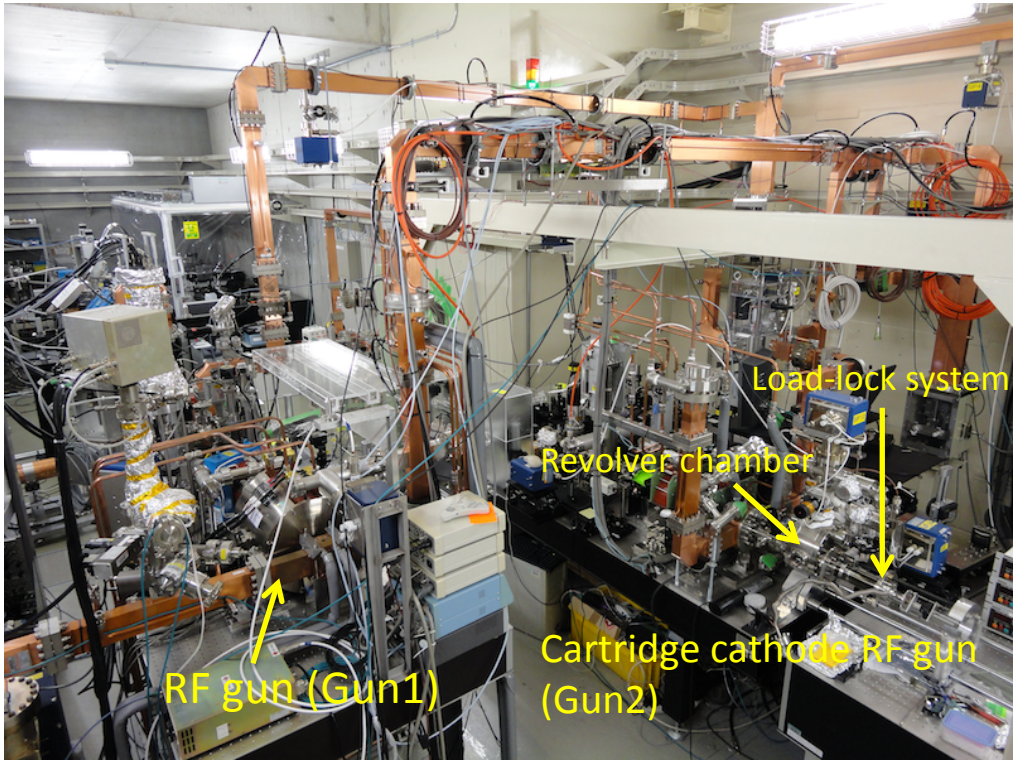
Present status

Operation parameters

Max. $E_{cathode}$	157 MV/m
RF Pulse width	700 ns
Dark current	60 pC/pulse

- Low emittance study (1.4πmmmrad@0.38nC)
- Z-pol laser injection (Gun2)
- Bunch monitor R&D based on EO-sampling





RF電子銃試験装置アップグレード

SACLAの極短バンチビーム（~30fs）の測定 (XFEL, SPring-8 II)

→ EOサンプリング方式によるバンチモニタ（H. Tomizawa）

平成２４年度SPring-8高度化開発予算

極短バンチモニタ開発テストベンチとして整備

エネルギー増強　30→50MeV（SLED, 加速管）
バンチ圧縮（磁気バンチ圧縮、変調管）
マルチセルRF電子銃

Measurement (Decoding) methods of EO Sampling :

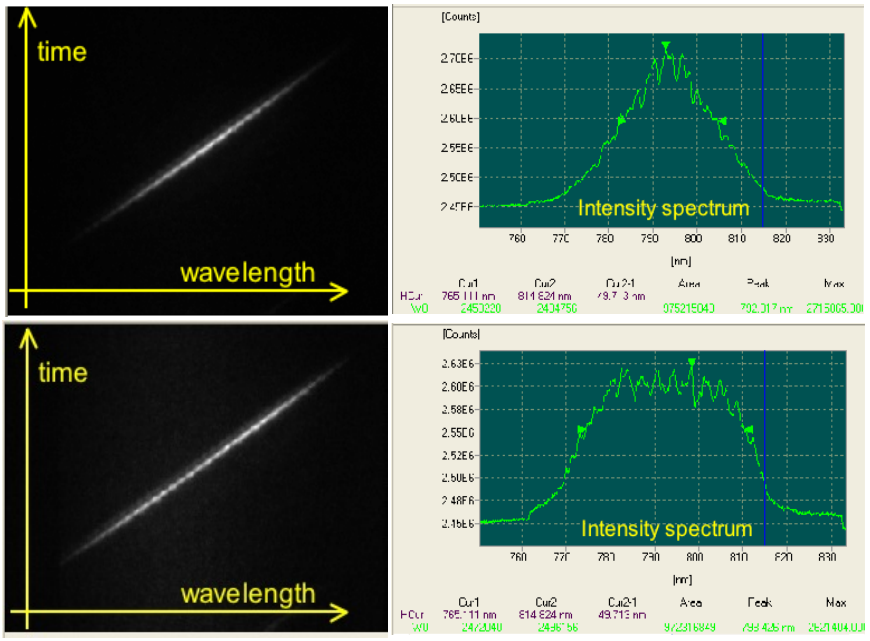
非破壊モニタ

(a) Temporal Decoding

(b) Spectral Decoding

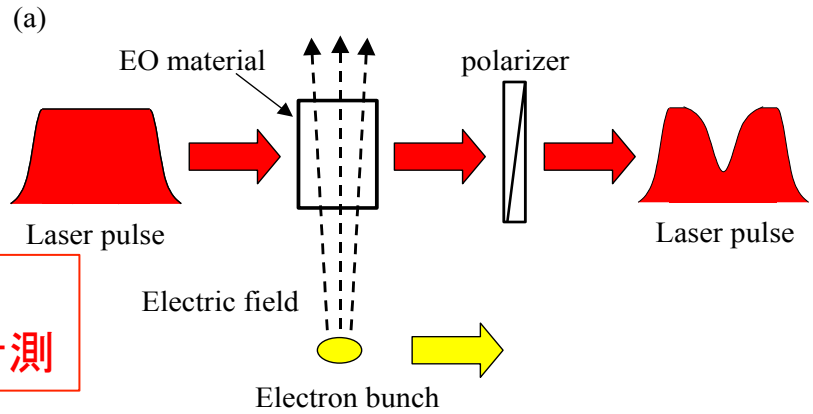
時間・空間
シングルショット計測

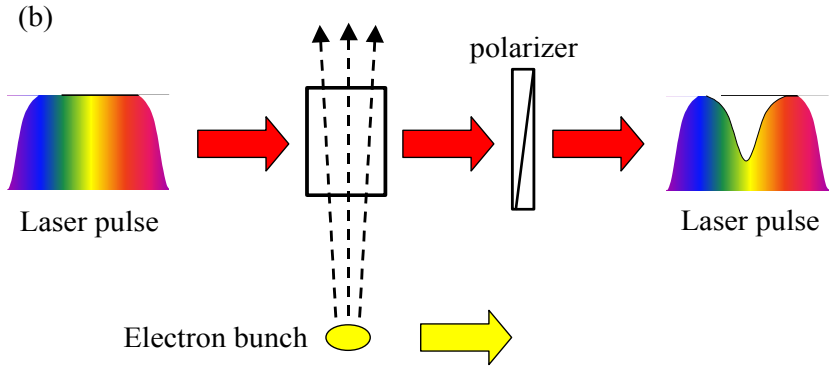
(c) Spatial Decoding

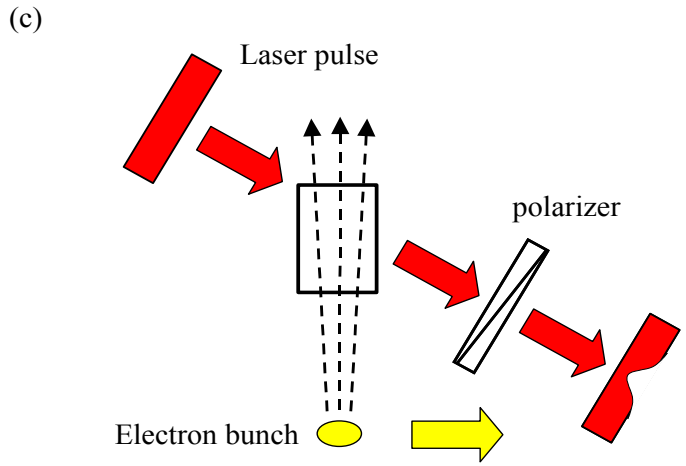


Measurements of linear-chirped laser probe pulse with Spectrograph Streak camera:

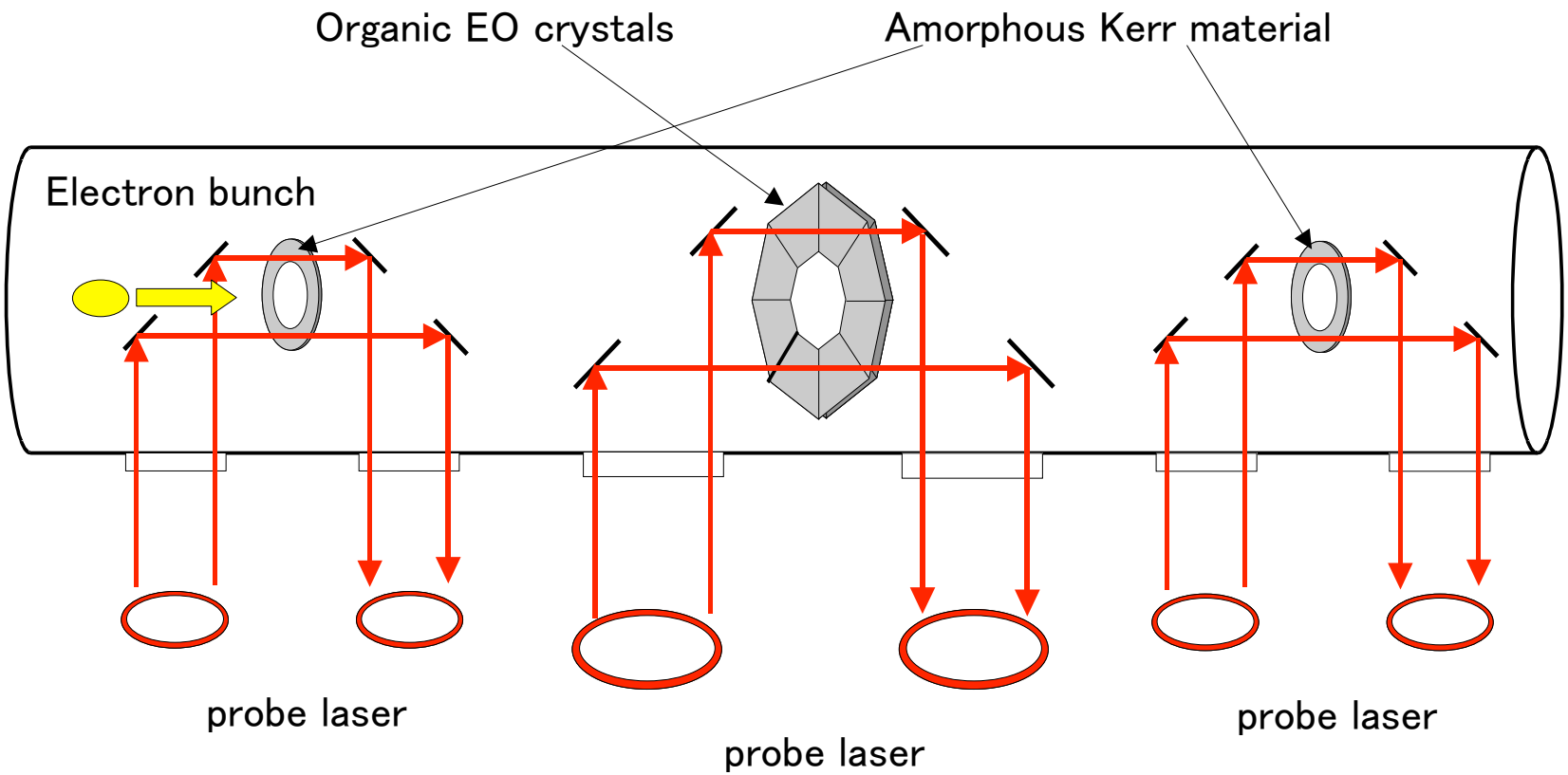
The upper is an original laser probe pulse (constant chirp rate). The lower is squarely shaped spectral intensity distribution by DAZZLER AO-modulator.







Schematic drawing of 3D-BCD Monitor [1,2]

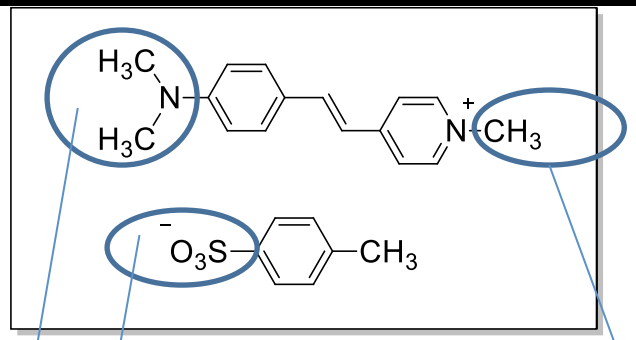


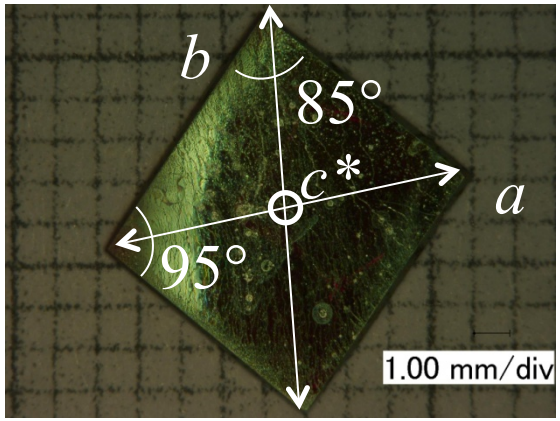
A schematic drawing of 3D-BCD Monitor: (Not that other combination is also possible!)

An amorphous Kerr material is placed on both as BPM functions and an collective EO detector with organic DAST crystals is at the center for 3D-charge distribution measurements of the electron bunch.

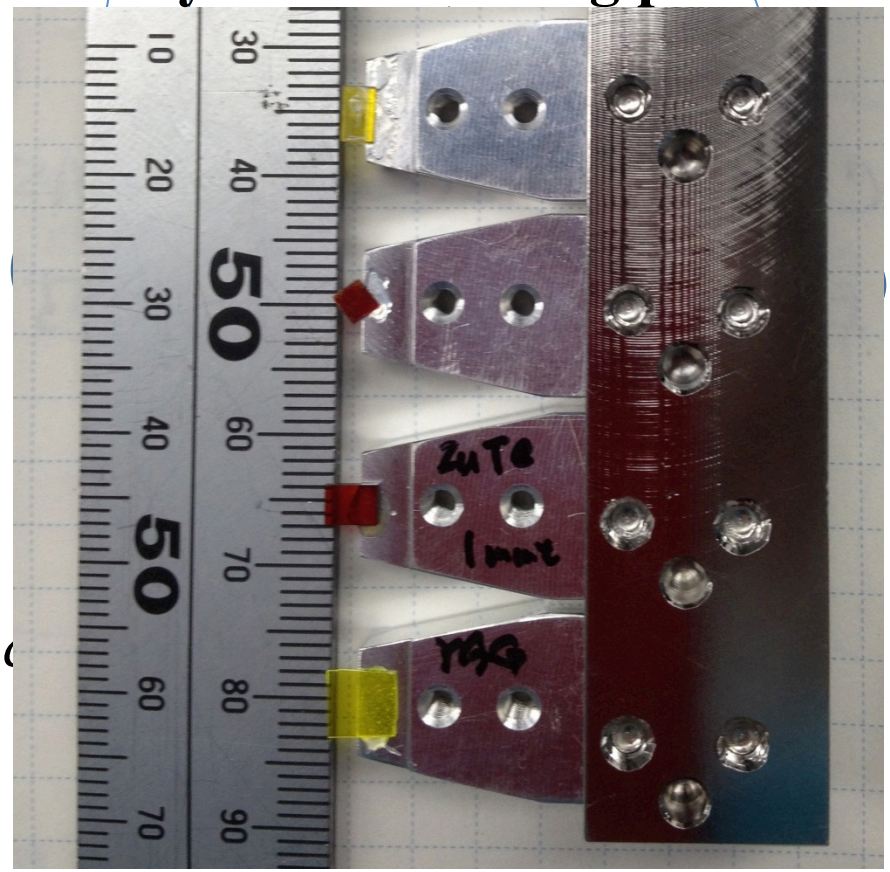
[1] H. Tomizawa, et al., Proc. of FEL 07, Novosibirsk, Russia (2007) 472.
[2] H. Tomizawa et al., Proc. of FEL 10, Malmo, Sweden (2010) 445.

Developments of DAST EO-detector *towards to Res. 30fs!!*

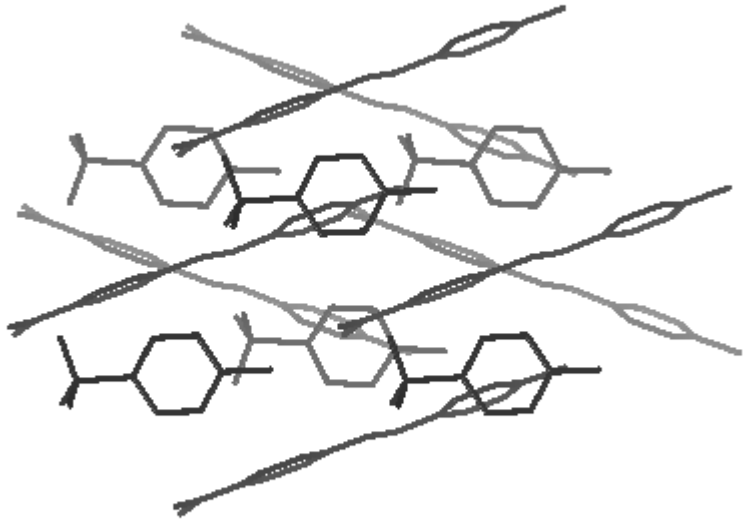


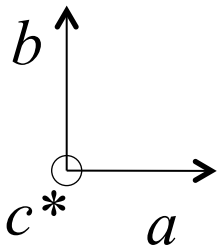


- **Mission for real-time monitoring bunch-by-bunch seeding pulse at Soft-XFEL**



a-*b* plane

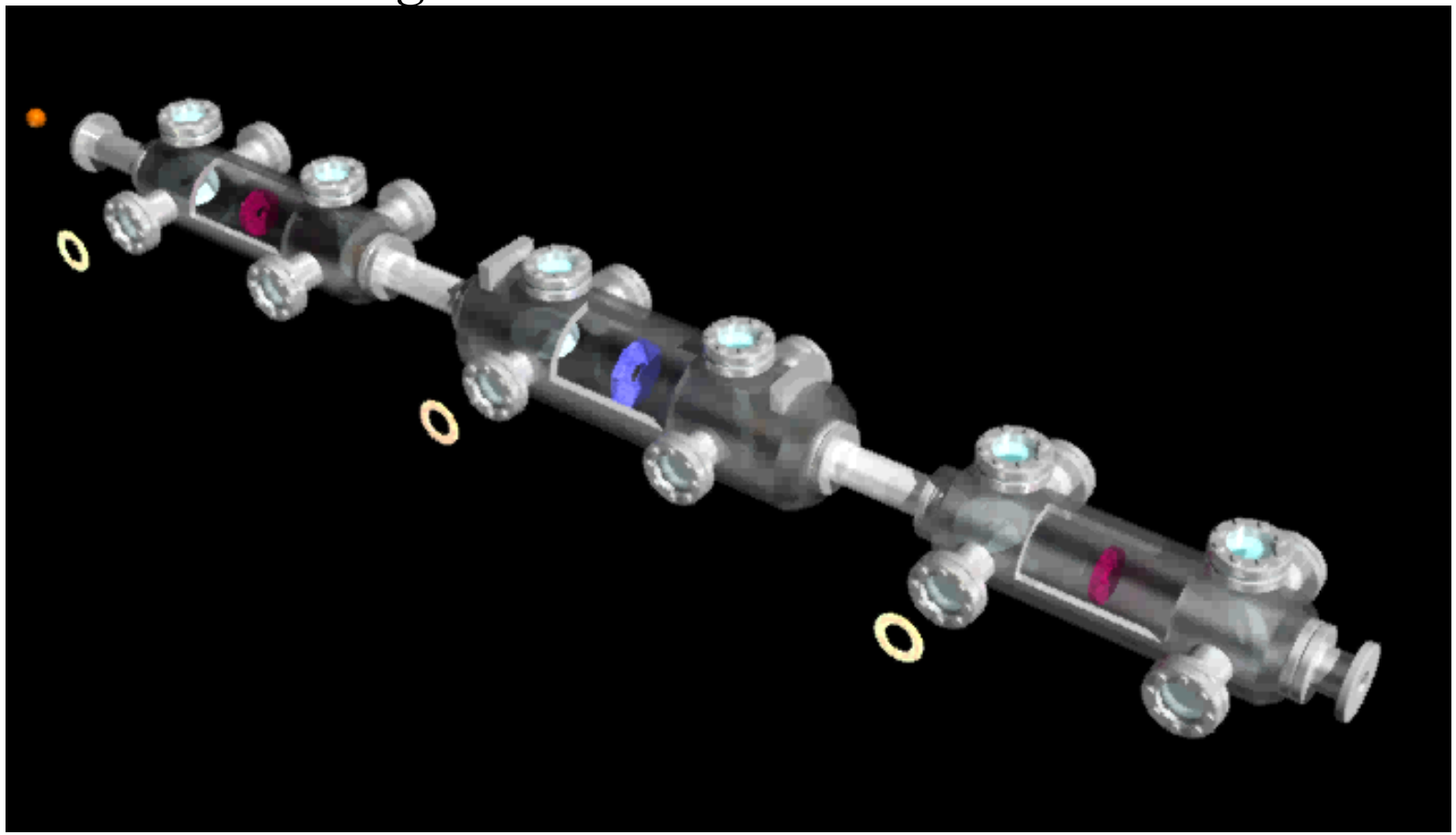


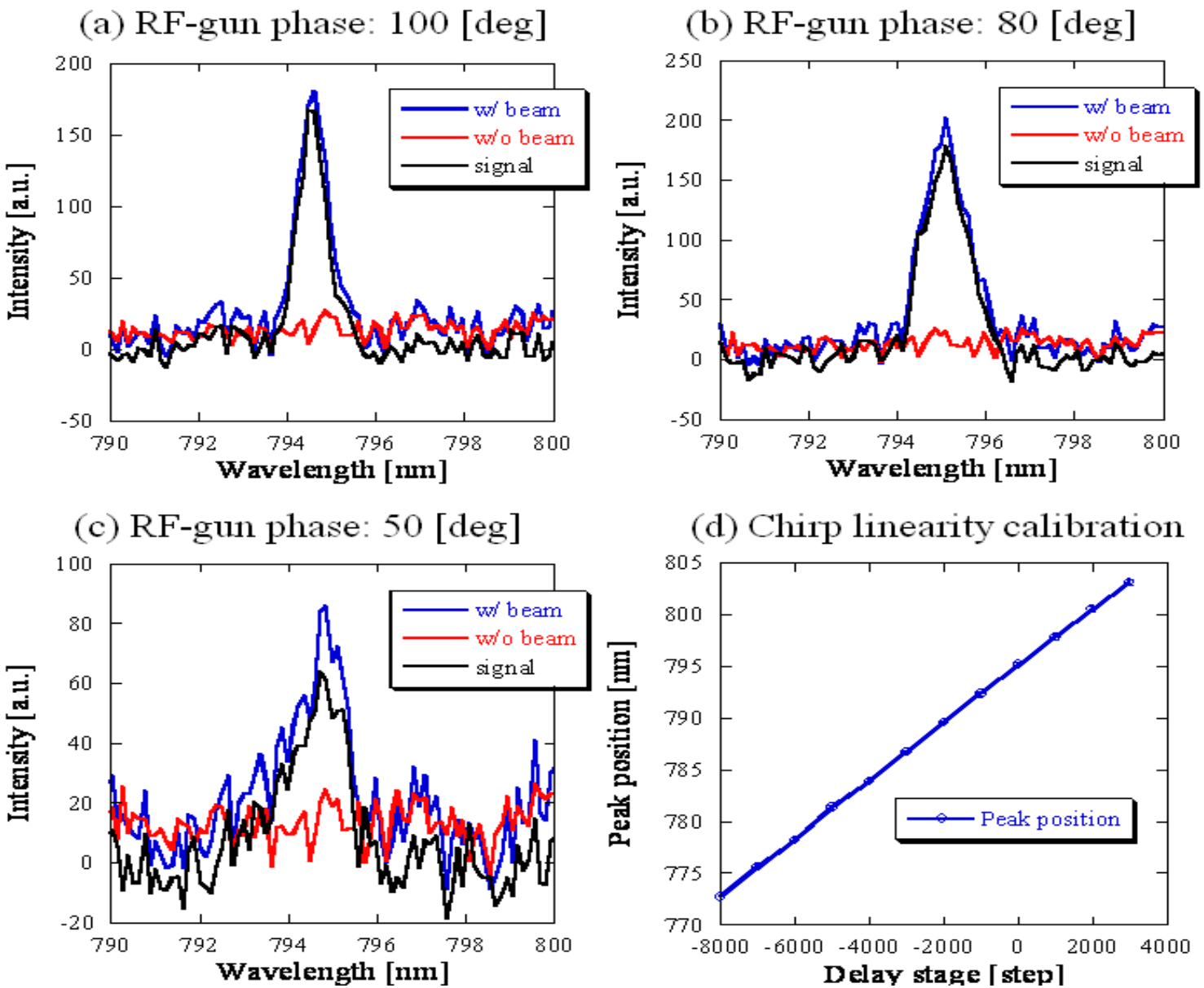


3D bunch shape monitor (BCD: Bunch Charge Distribution)

Three sets of 3D-BCD elements: de/en-coding to de/o- multiplexing

Non-destructive, Shot-by-shot Real-time Monitor to measure 3D-Bunch Charge Distribution





Experimental results of EO signals at the different absolute RF phases of laser incidence at the photocathode and chirp linearity of the probe laser (One of the EO-crystals probed with a hollow laser); Measured electron bunches' width (FWHM) calibrated with (d) 9.58 ps/nm: (a) 6.13 ps, (b) 10.8 ps (c) 11.5 ps

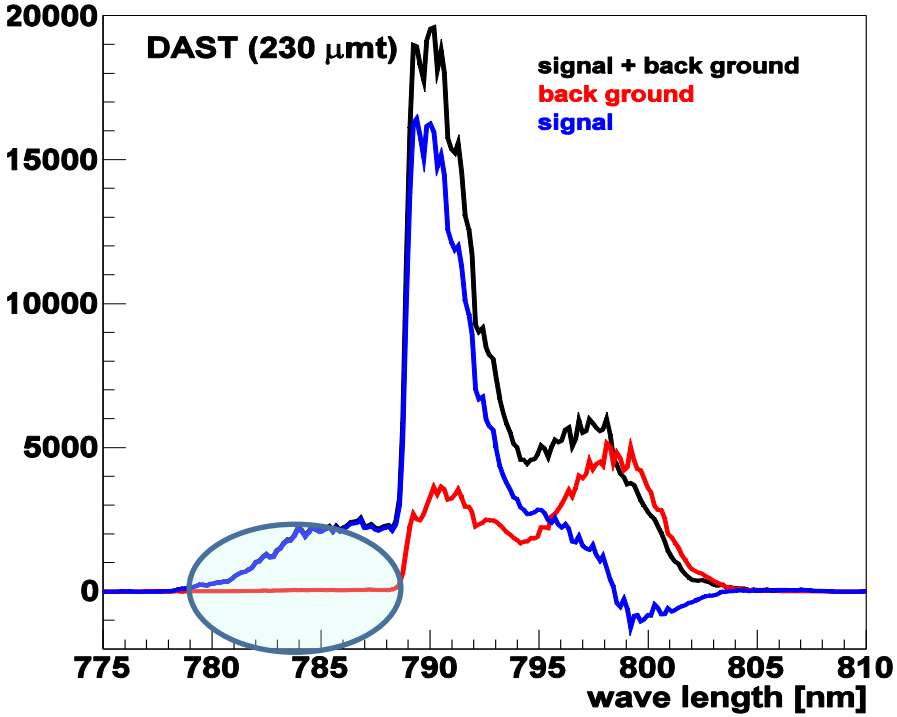
Estimation: temporal response of DAST EO ~30 fs [FWHM]!!

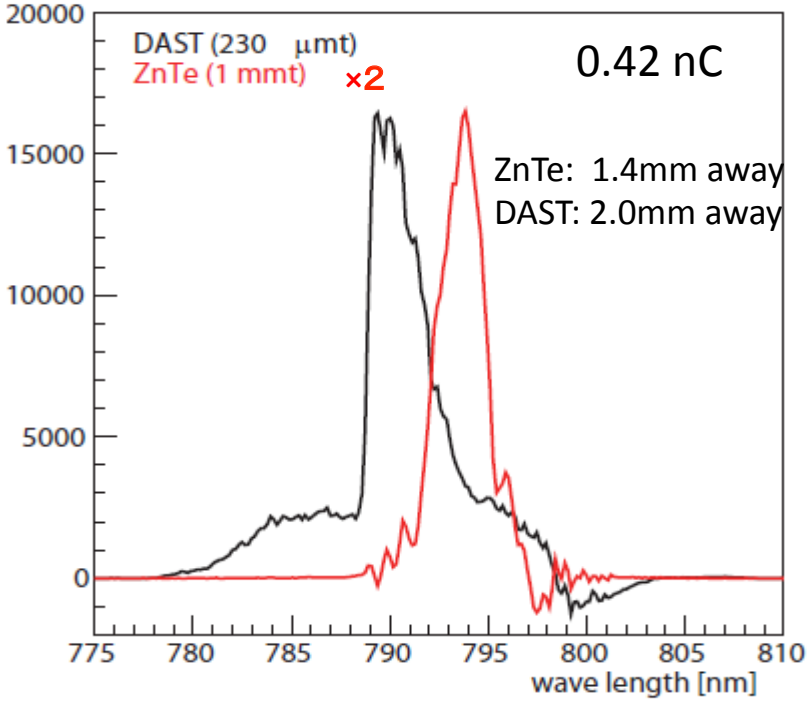
ZnTe and GaP has phonon absorption at 6 THz and 11 THz, respectively.
⇒THz pulse shape is distorted by the dispersion at THz region.

For 30-fs resolution, *EO crystal is required which is transparent for 0 -30THz*.

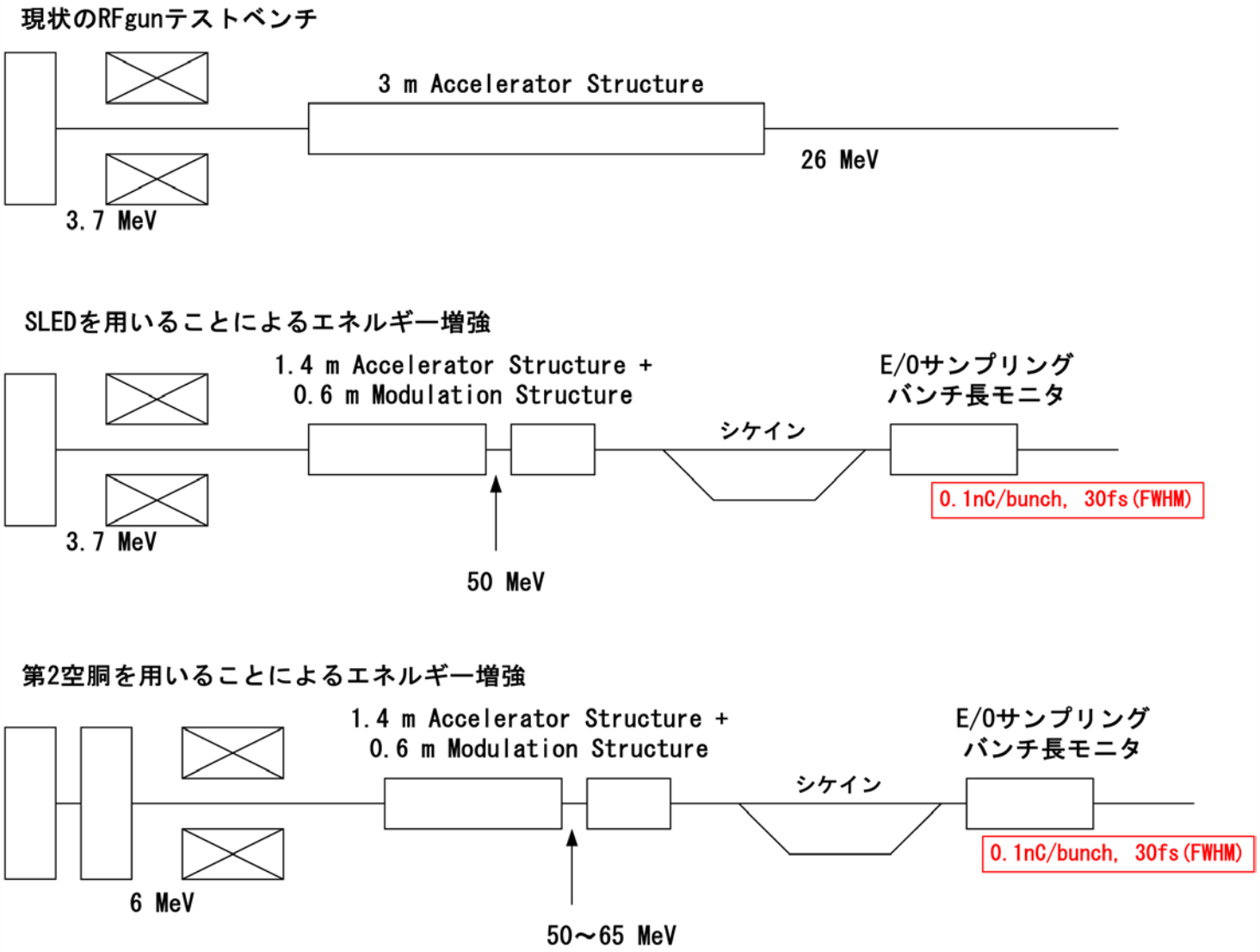
DAST : n1=2.4, n2=1.68, n3=1.62, r11=77pm/V, r21=42pm/V, r13=15pm/V @800nm

In 2011, we measured electron bunches via EO-Sampling with DAST at VUV-FEL (SCSS). It was the first EOS-measurements in the world (***We observed a spectral broadening. It indicates that DAST is higher response than ZnTe < 50fs [FWHM]***).

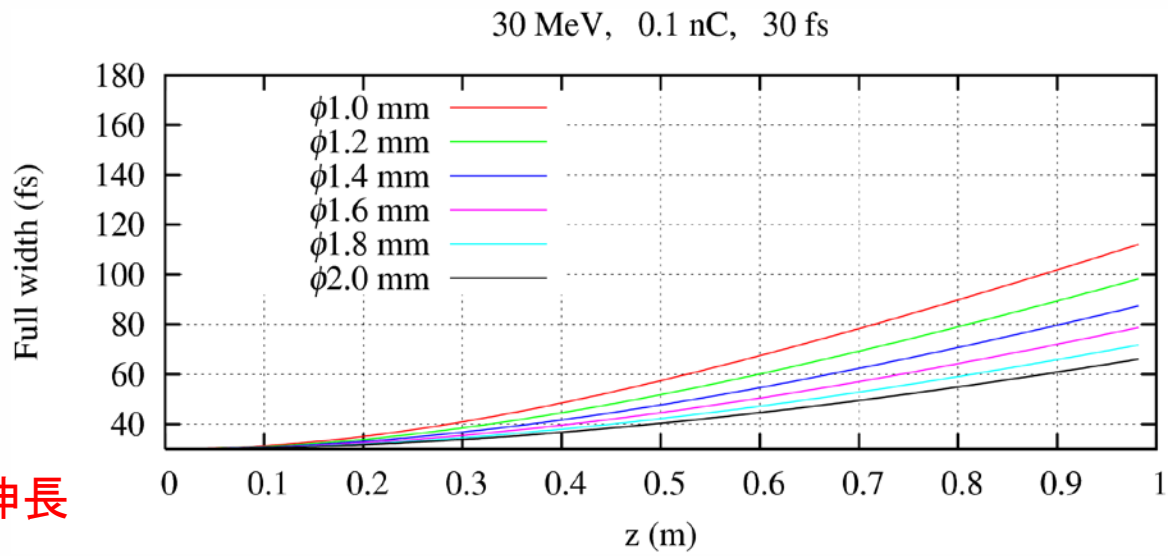




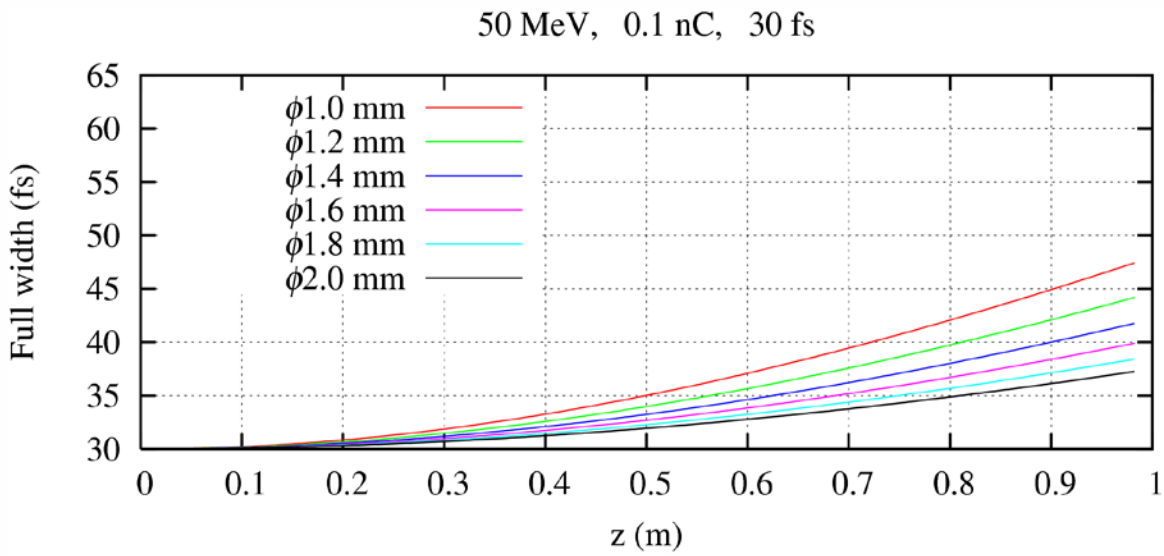
RF電子銃テストベンチの改造計画



エネルギー増強（50MeV～）の理由

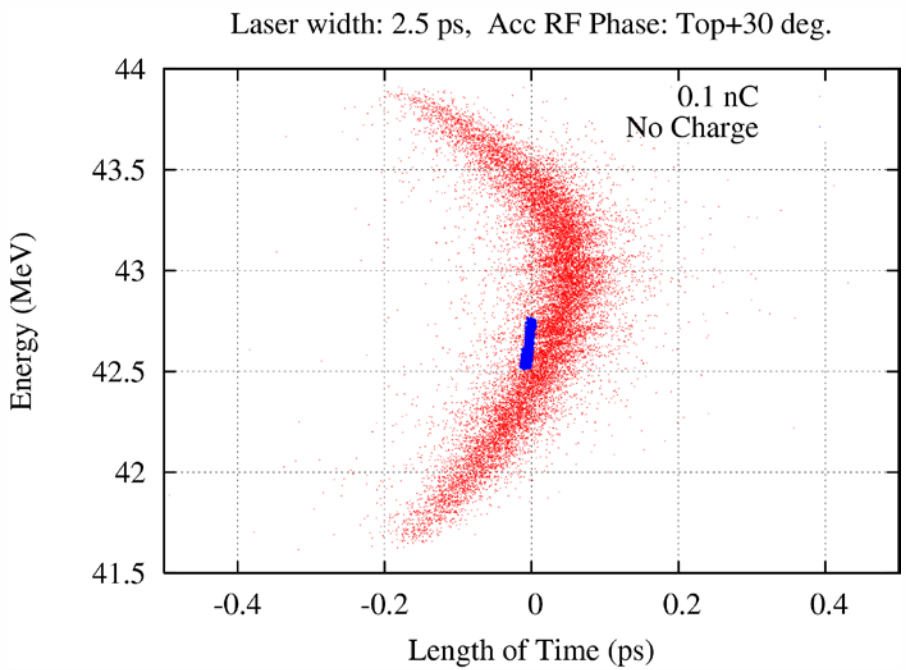


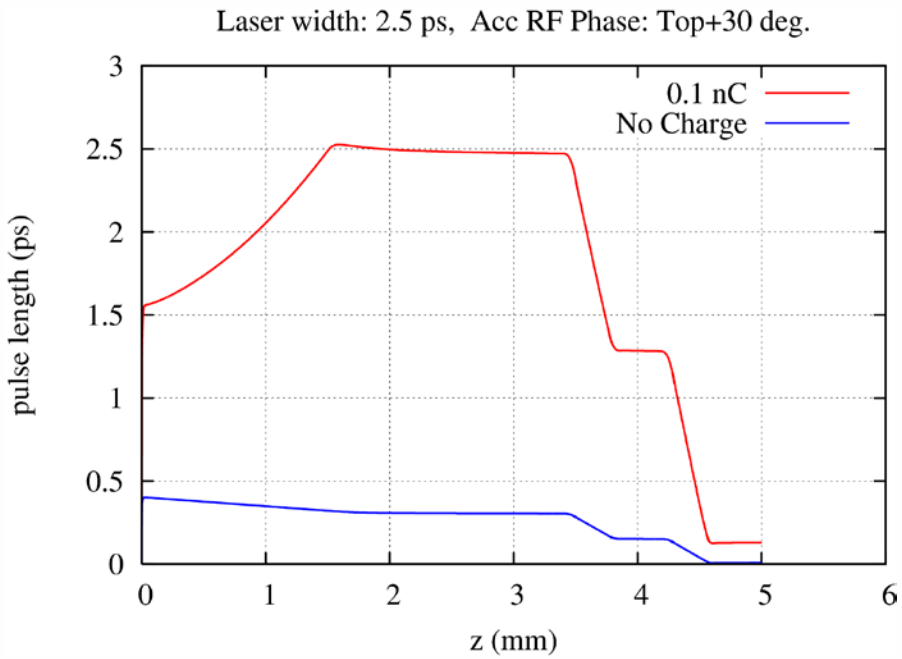
圧縮後のバンチ伸長
↓
測定エリアの確保



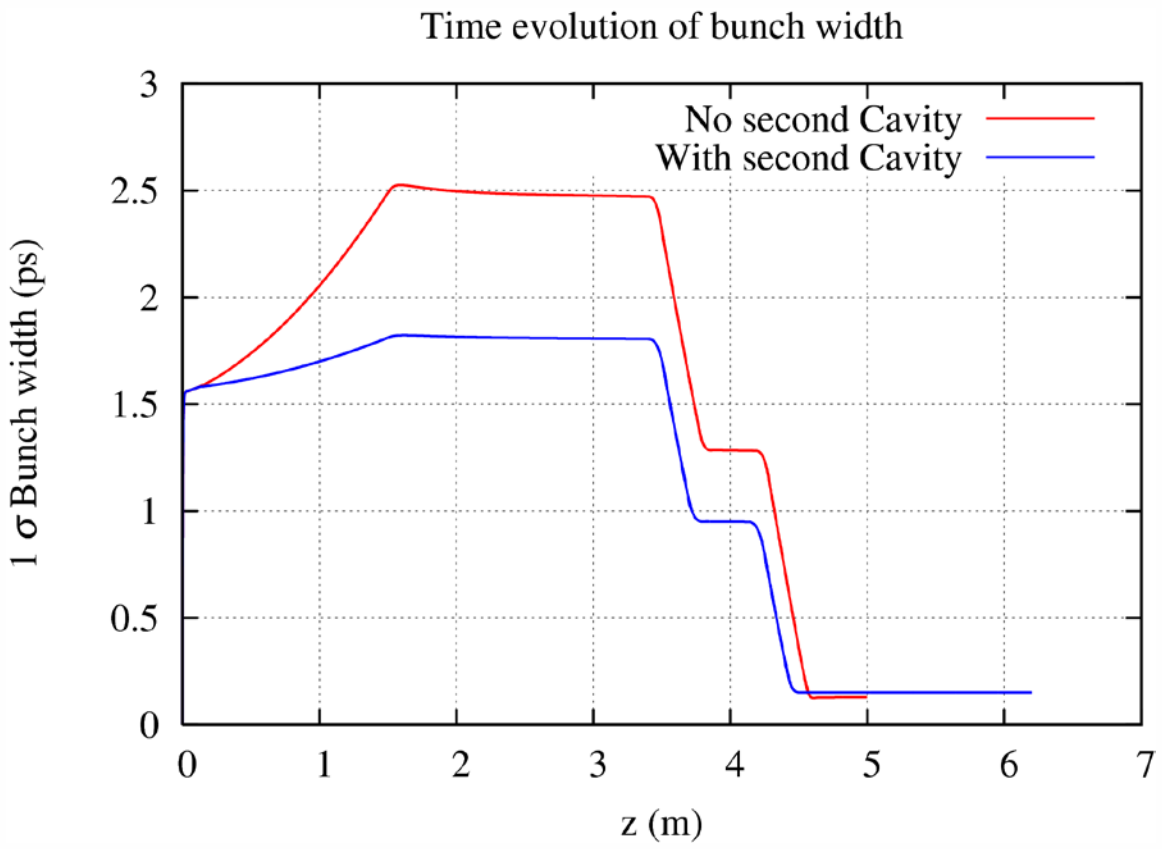
バンチ圧縮の障害　RFのカーブによる非線形性

レーザーパルス幅　：　通常　10ps～20ps　⇒　2.5　ps

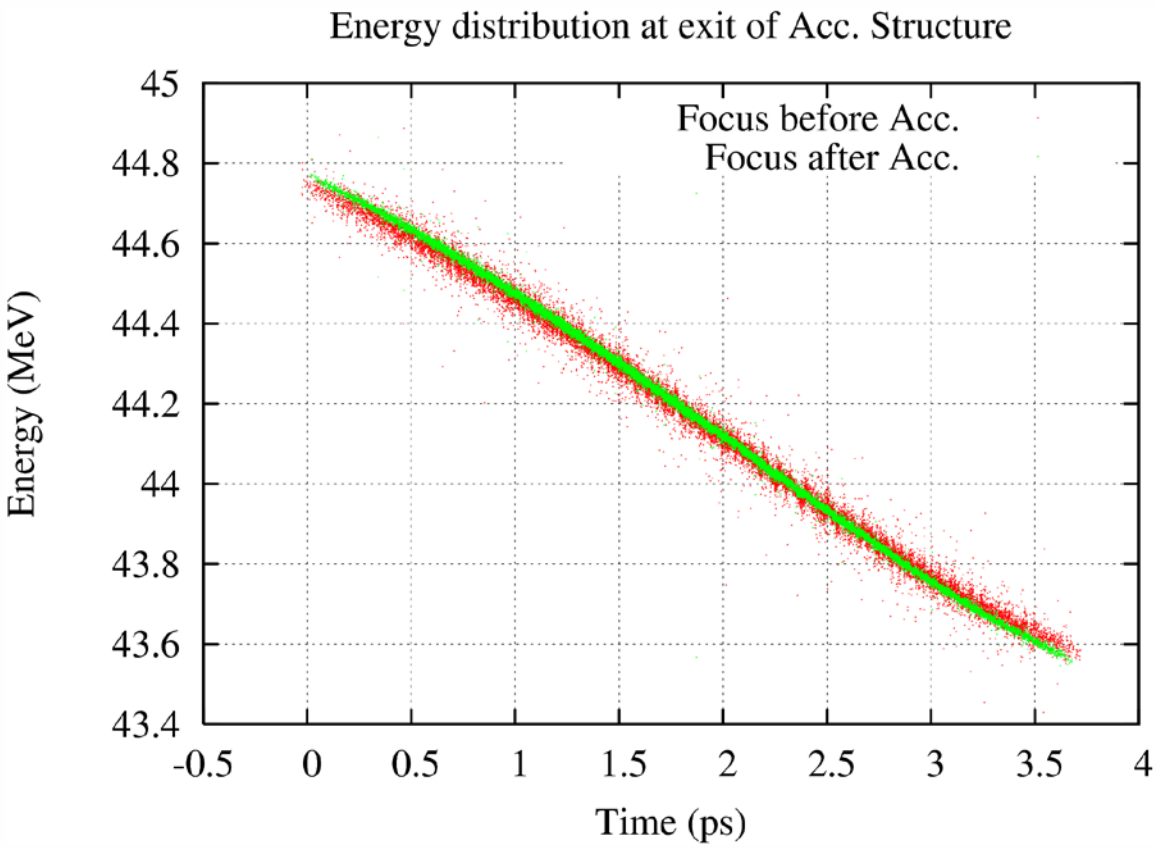




第2空胴を用いることによってRF電子銃空胴出口でのエネルギーを6MeVまで増強

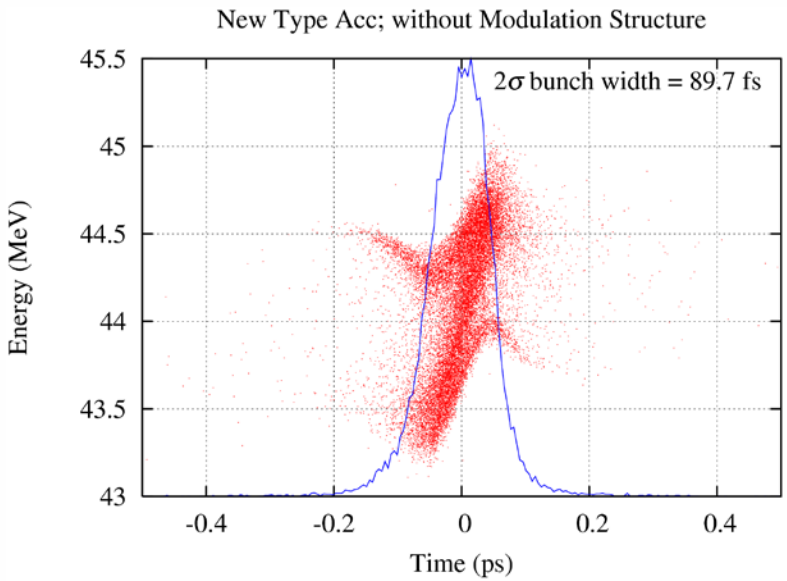


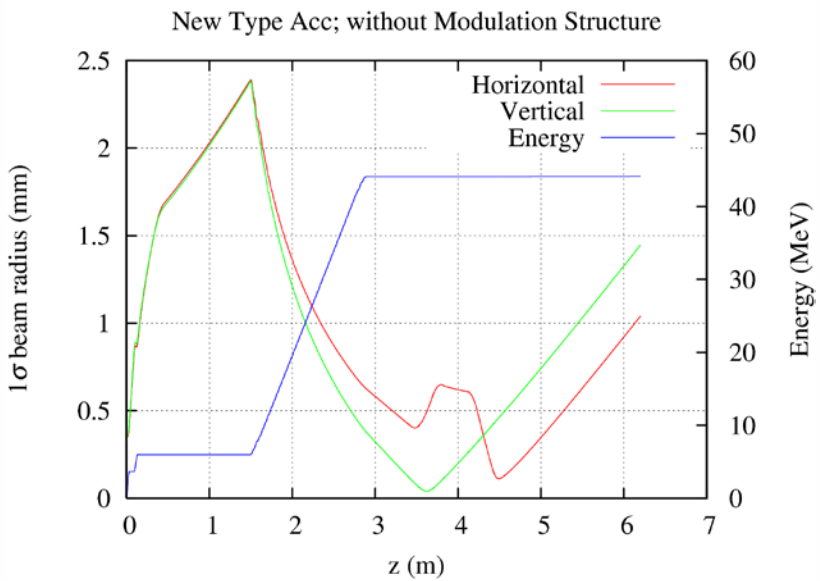
シケイン直前でのバンチ内エネルギーチャープの様子



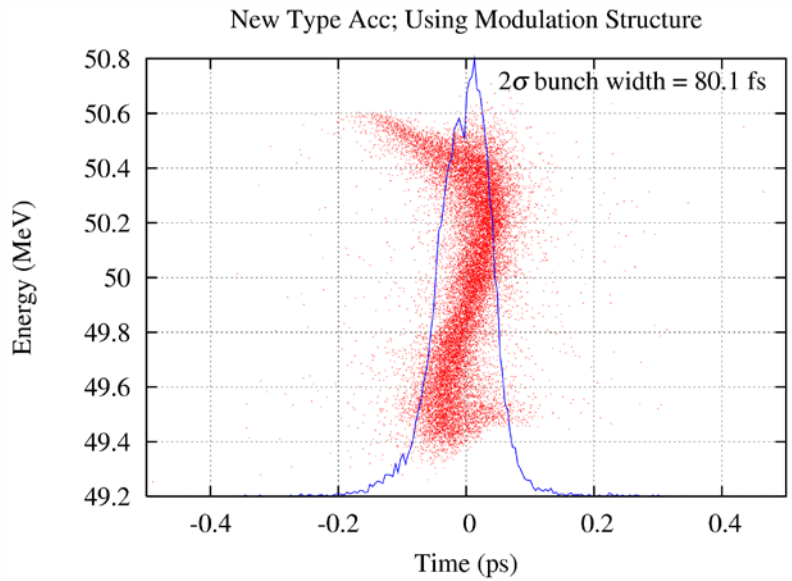
新規設計の導波管型カップラーを用いたDouble Feed 加速管

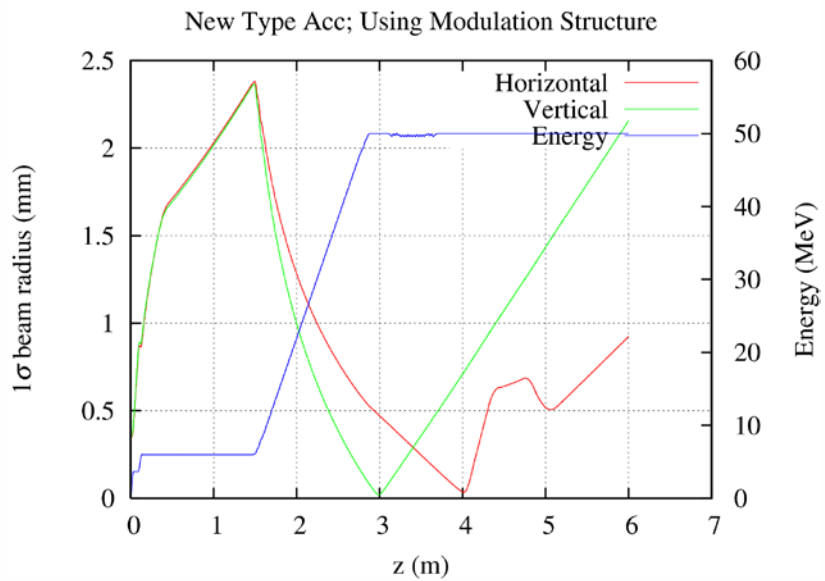
変調管無し



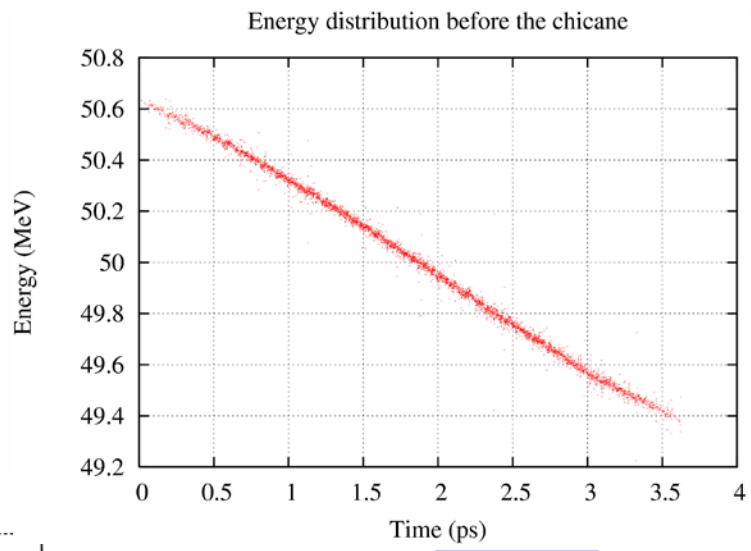


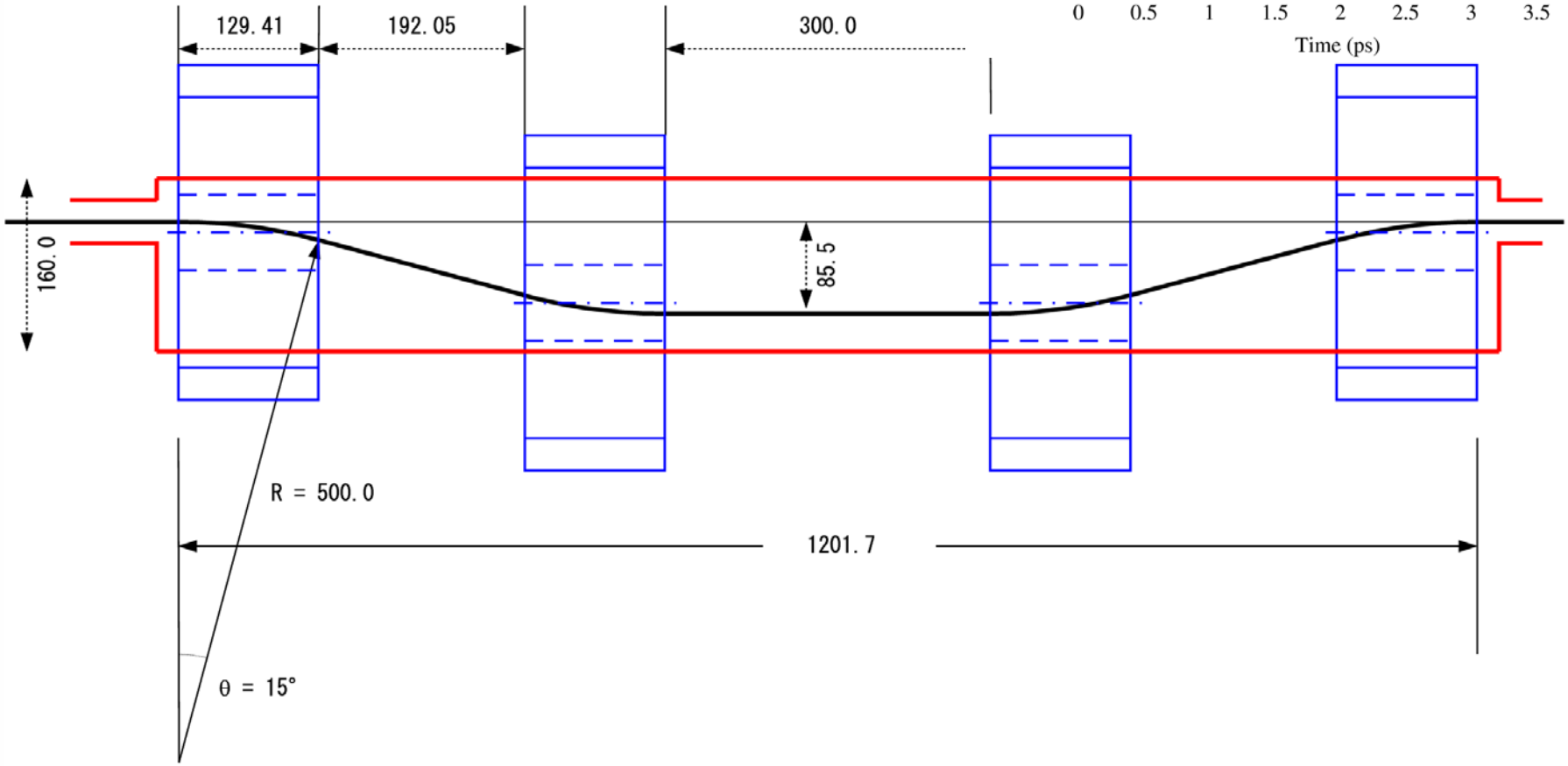
変調管有り



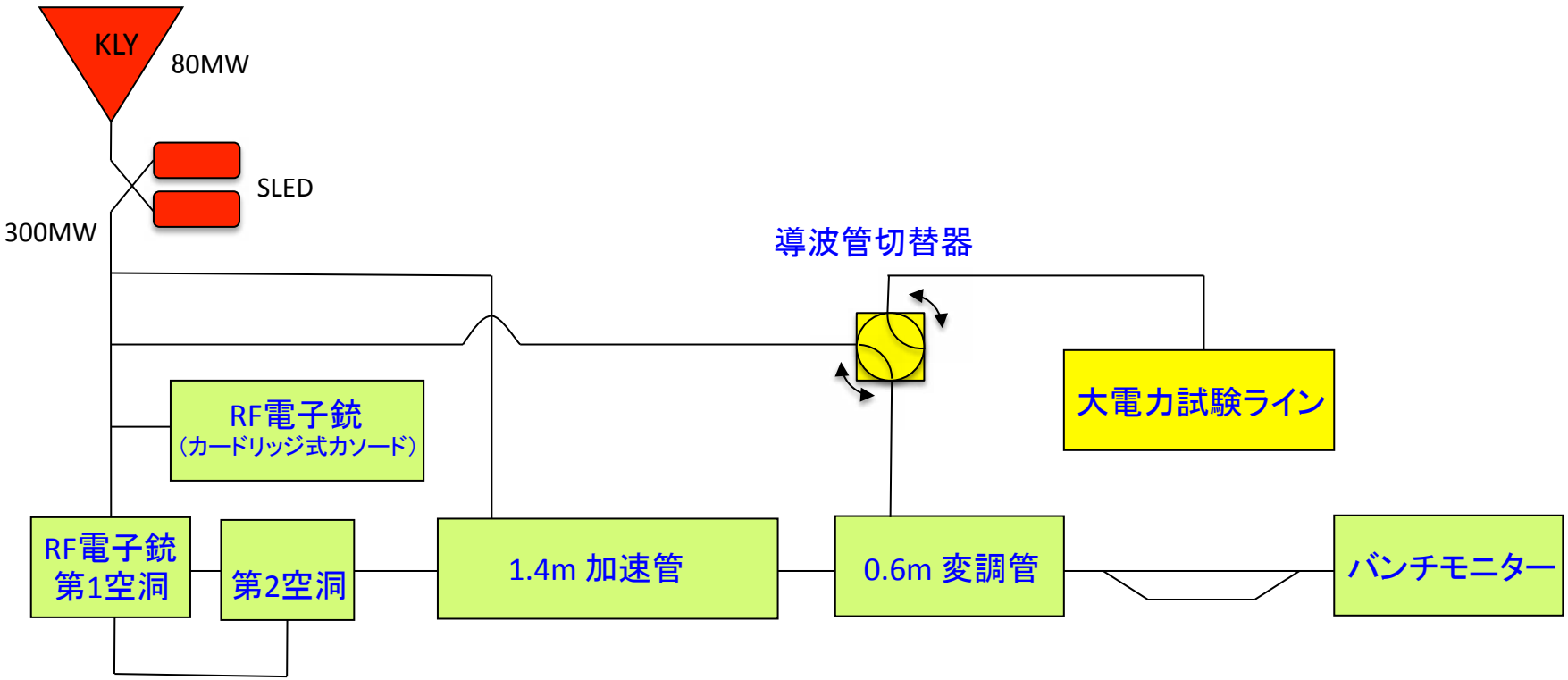


シケインのデザイン

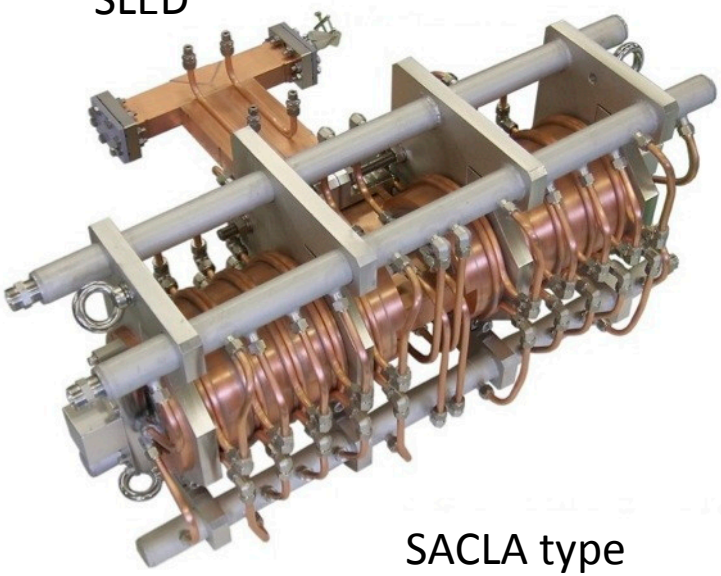

Energy distribution before the chicane
Energy (MeV)
Time (ps)
50.8
50.6
50.4
50.2
50
49.8
49.6
49.4
49.2
0
0.5
1
1.5
2
2.5
3
3.5
4


129.41
192.05
300.0
160.0
85.5
R = 500.0
1201.7
θ = 15°

大電力RF系の構成

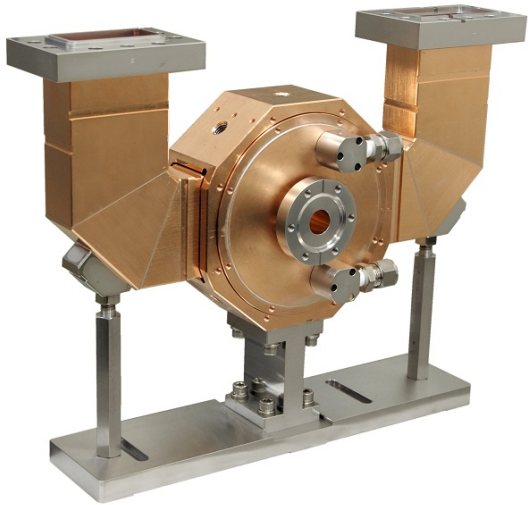

KLY
80MW
SLED
300MW
導波管切替器
RF電子銃
（カードリッジ式カソード）
大電力試験ライン
RF電子銃
第1空洞
第2空洞
1.4m 加速管
0.6m 変調管
バンチモニター

SLED

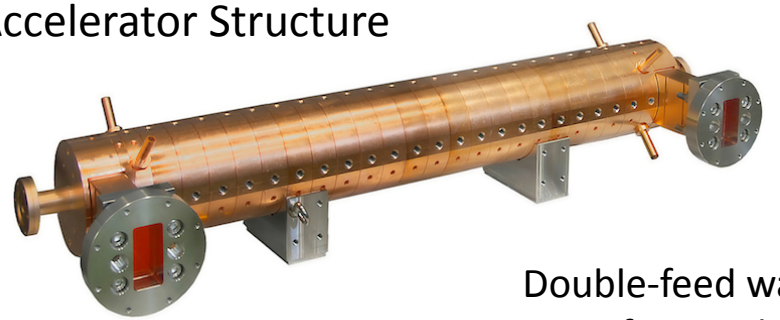


SACLA type

RF Gun 2nd cavity



Accelerator Structure



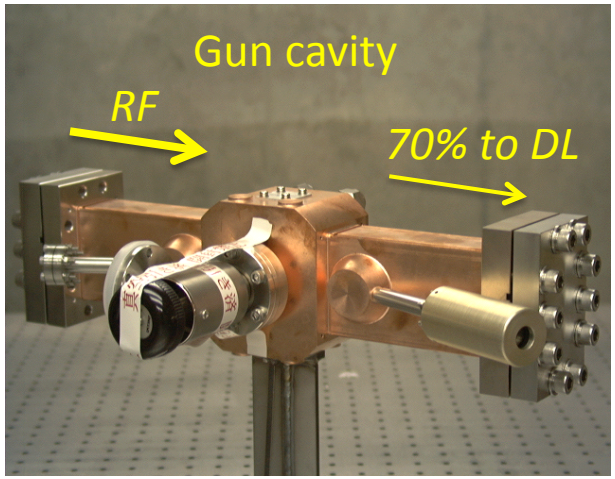
Double-feed waveguide coupler
1.4m for acceleration
0.6m for energy modulation

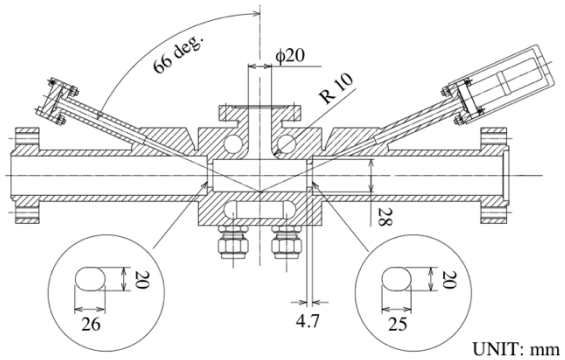
RF Gun cavity

Single cell with output RF port for low Q

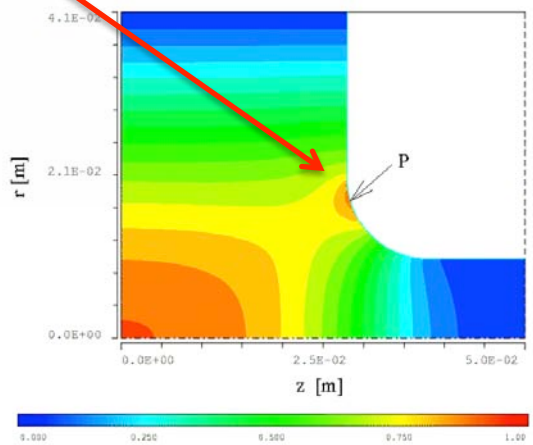
enables short RF pulse operation

stability in high gradient field



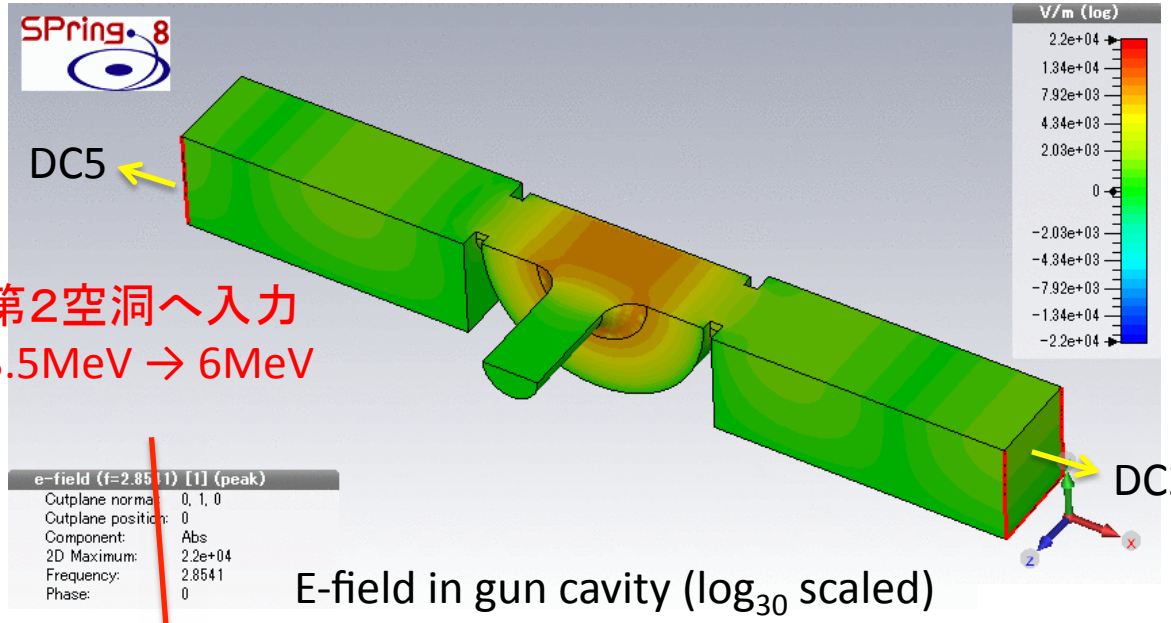


Frequency		2856 [MHz]
Loaded Q value		1414
Coupling		1.02
Filling time	0.31	[μsec]
$E_{max} / E_{cathode}$		1.09



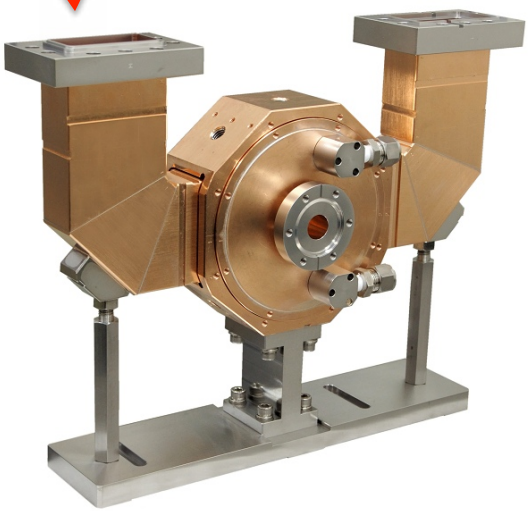
平成24年度内

第2空洞を追加

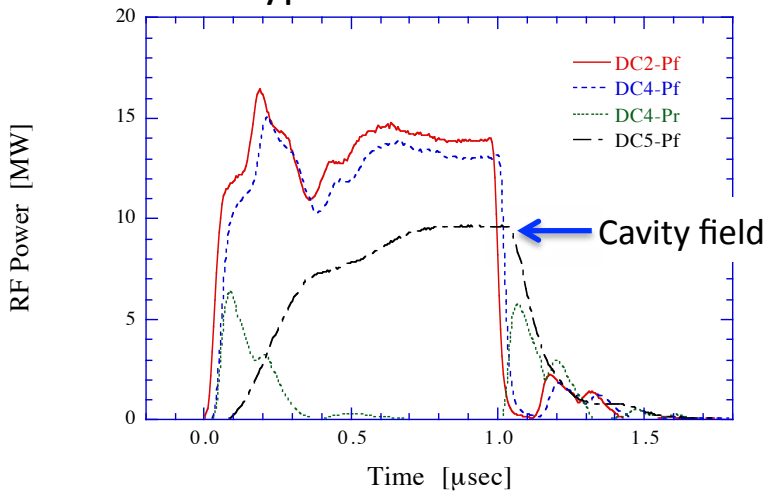


第2空洞へ入力
3.5MeV → 6MeV

E-field in gun cavity ($\log_{30}$ scaled)

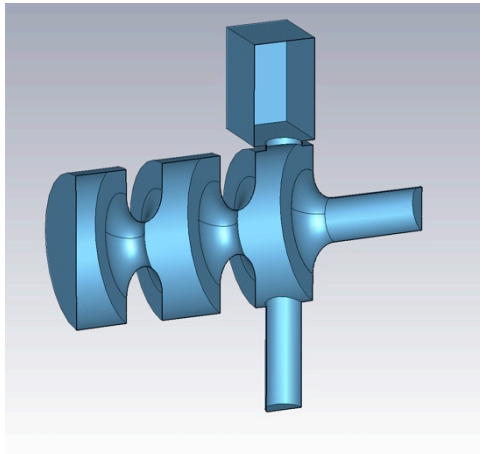


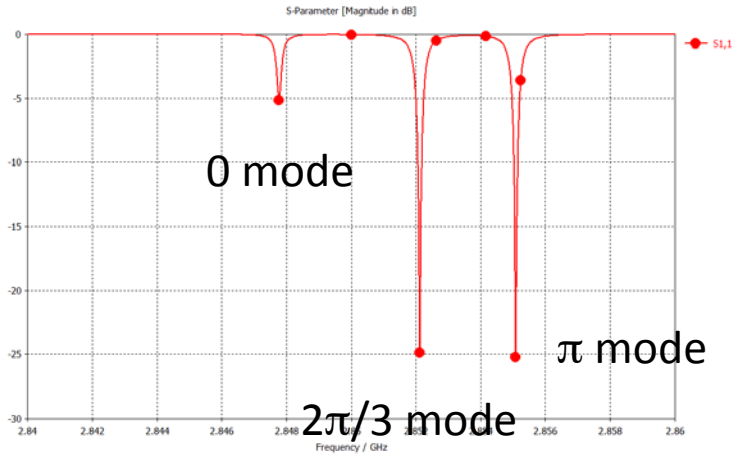
Typical RF waveforms



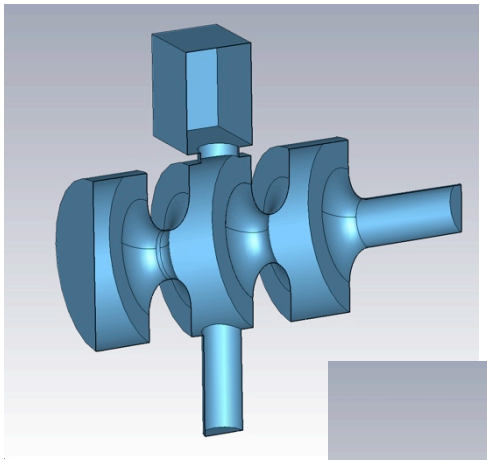
2.7セル空洞の開発　ビームエネルギー　6MeV → 10MeV（平成25年度）

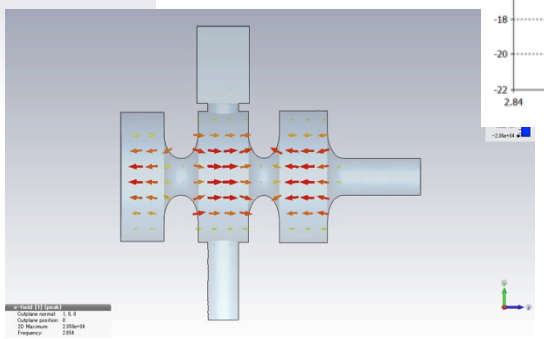
楕円アイリス

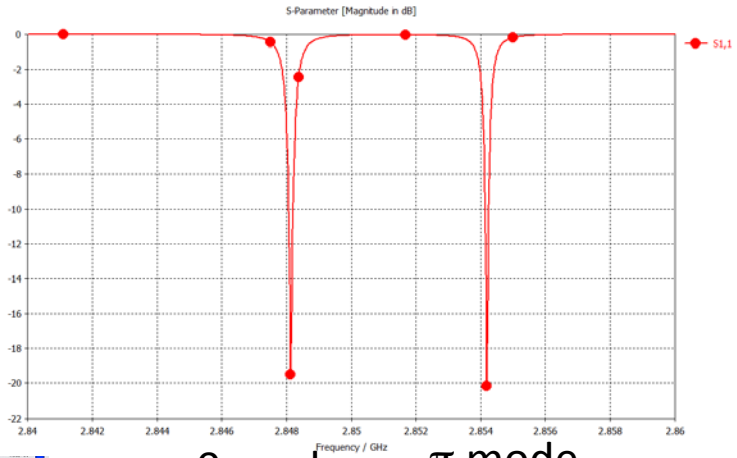




カプラーを第2セルへ



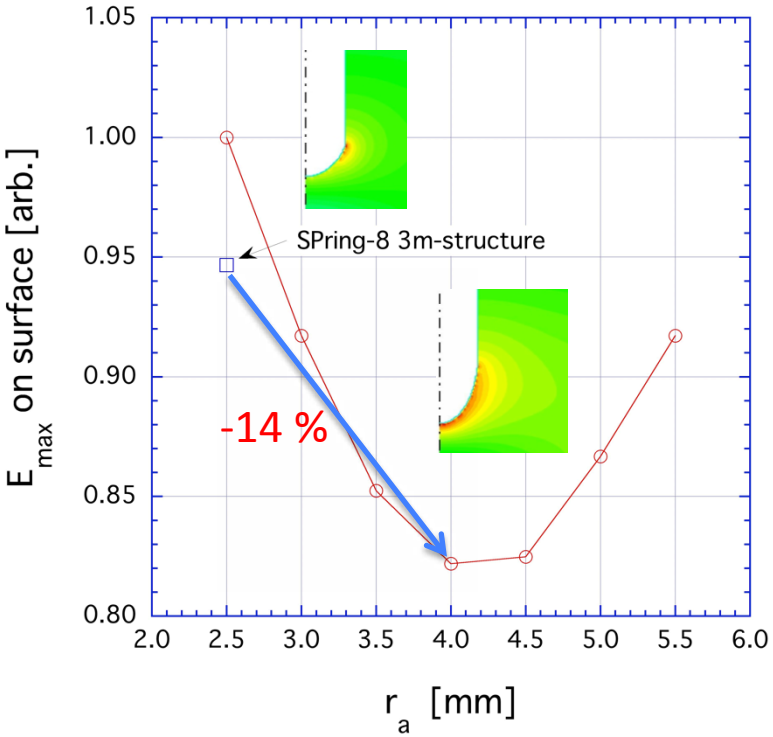




Low Q にする?
RF パワー?

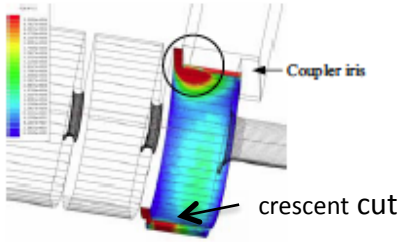
Accelerator Structure for Dark Current Reduction

Modification of disk iris
ellipse cross-section

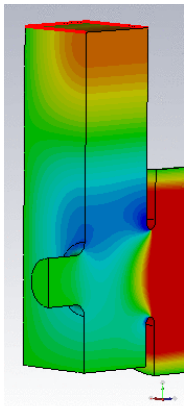


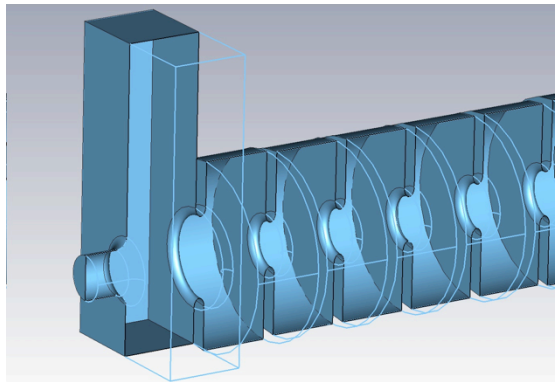
今回のアップグレード
ダブルフィード
1.4m管＋0.6m変調管

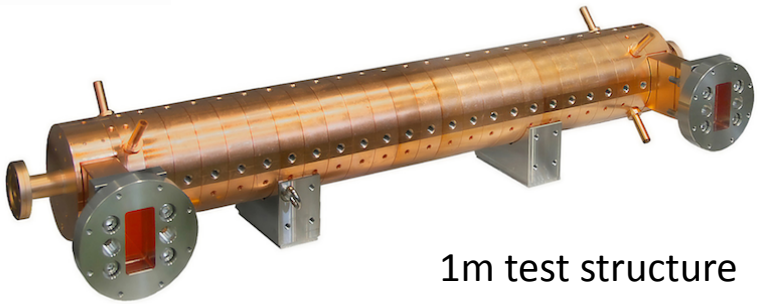
Waveguide coupler (single feed)



Avoiding pulse heating around coupler hole



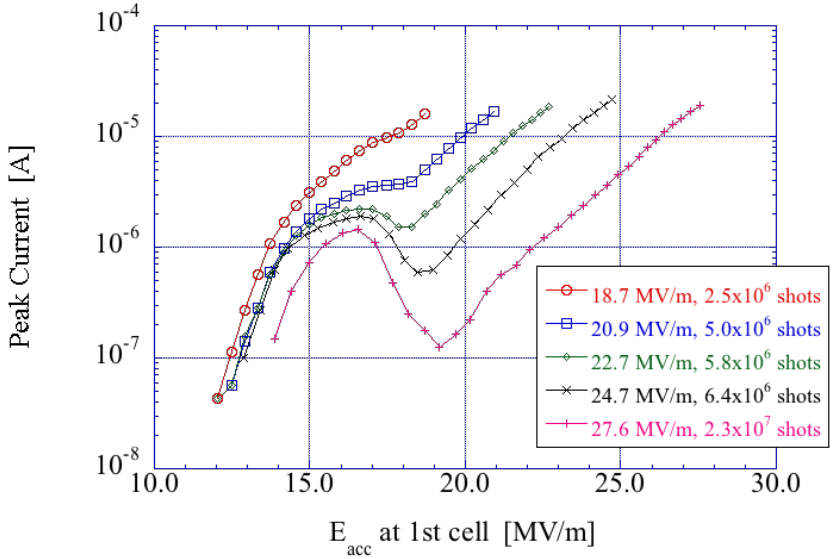


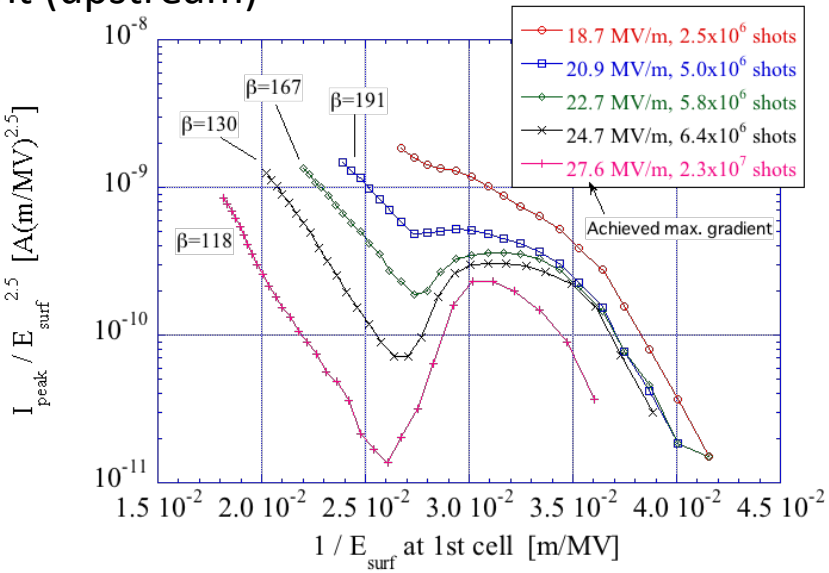


1m test structure

RF Conditioning (ongoing)

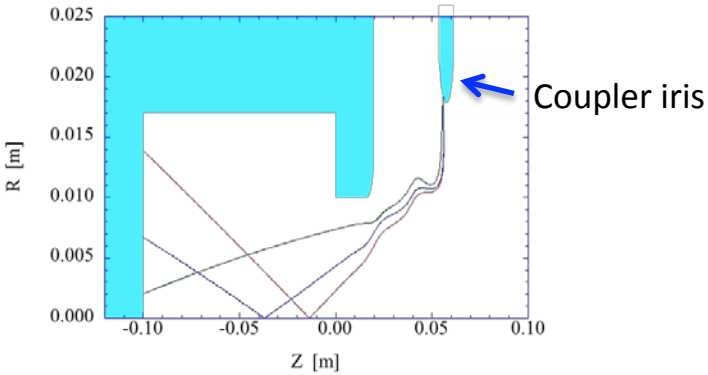
Dark current (upstream)

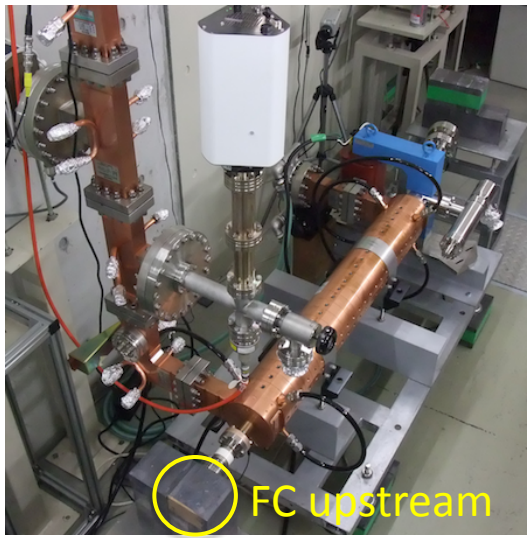




- Max. 27.6 MV/m (max. Klystron output)
- Bump around 16 MV/m

  Electrons emitted from upstream side of coupler iris, focused on Faraday cup by waveguide field.





RF電力分配と加速エネルギー

	RF入力	加速電界	E利得	到達エネルギー
RF Gun 第1空洞	29 MW	138 MV/m	3.2 MeV	3.2 MeV
RF Gun 第2空洞	21 MW	122 MV/m	2.7 MeV	5.9 MeV
1.4m加速管	106 MW	32 MV/m	45 MeV	50.9 MeV
0.6m変調管	55 MW	23 MV/m	14 MeV	（64.9 MeV）

Summary

・ SPring-8 RF電子銃試験装置は今年度より、SACLA, SPring-8 II の30fs極短バンチビーム測定を目指したEOモニタの開発テストベンチとしてアップグレードを進めている。

・RFパルス圧縮器（SLED）、高加速電界加速管、エネルギー変調管及びシケイン電磁石からなるバンチ圧縮器を３月末までに設置し、ビームエネルギーを30MeVから50MeVへ増強予定。

・加えて、RF電子銃空洞のビームエネルギーを3.5MeVから6MeVへ上げるため、第２空洞を設置する。さらに、10MeVビームを発生可能な2.7セル空洞の開発に着手。来年度、大電力試験を経て本体へ導入予定。