Project X and PXIE Design and Beam Physics

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(on behalf of Project X design team)

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Outline

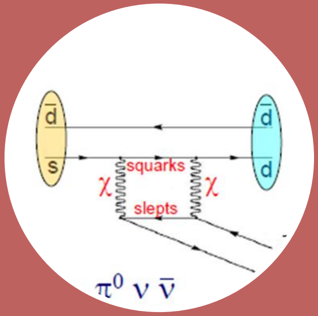
- Introduction
- Project X: Optics and Beam dynamics
- PXIE design
- R&D on critical components:
- Conclusion

Project-X Scientific Mission

Project X is a multi-MW proton facility currently under development by Fermilab with national and international partners. The Project X delivery of high power beams to multiple experiments with differing energy and bunch structure requirements (Intensity Frontier).

Long Baseline Neutrino Experiments

2 MW at 60-120 GeV



Kaon, Muon, Nuclei & Neutron precision experiments

3MW at 3 GeV

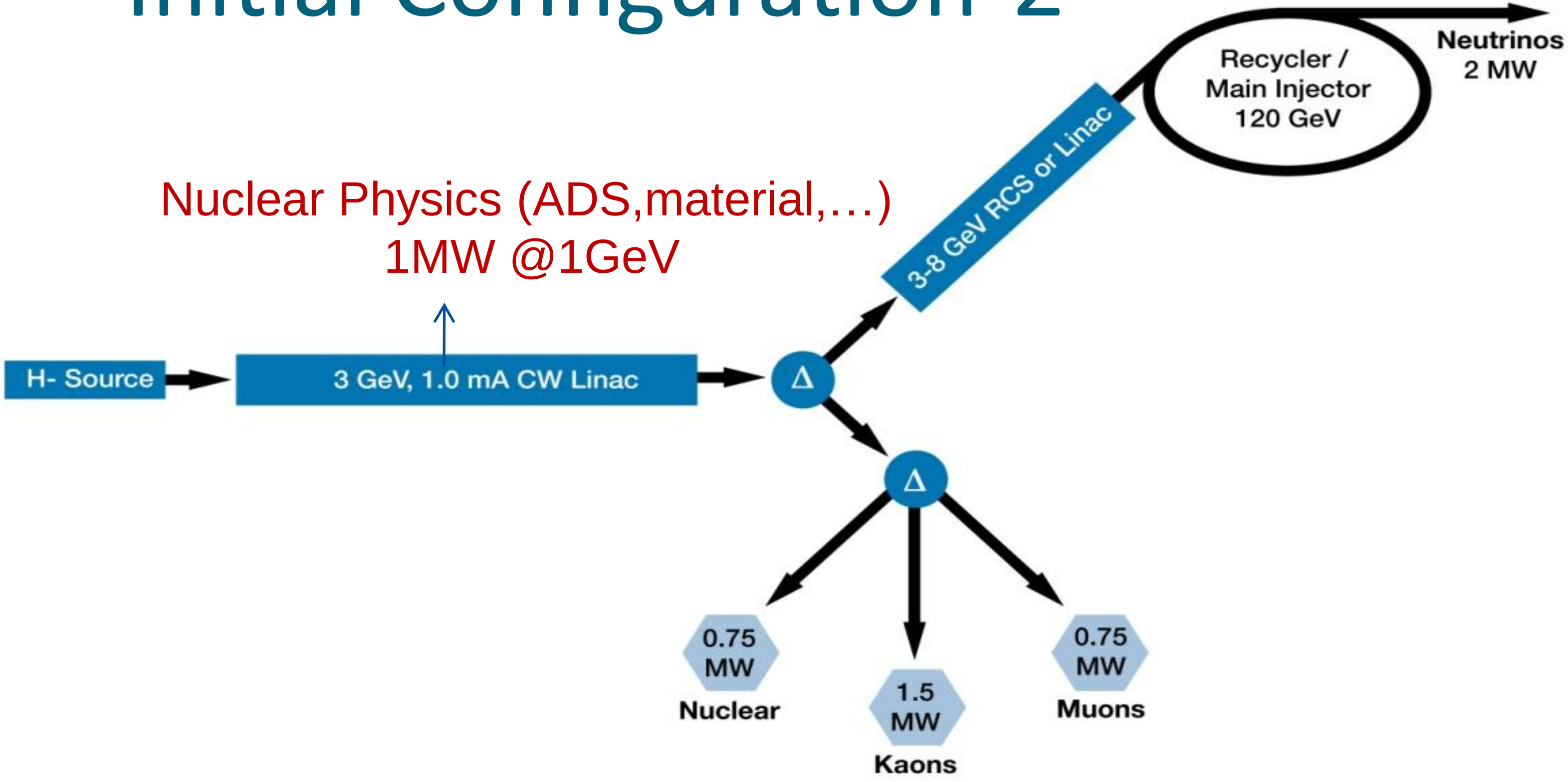
Platform for evolution to a Neutrino Factory and Muon Collider

Future upgrade to 4MW

Energy Applications: materials irradiation and transmutation

1 MW at 1 GeV

Initial Configuration-2



- 3-GeV, 1-mA CW linac provides beam for rare processes program
  - ~3 MW; flexible beam structure supporting multiple users
  - < 5% beam is sent to MI
- 3-8 GeV acceleration: 1.3 GHz pulsed linac based on ILC technology

Power Staging for the Research Program

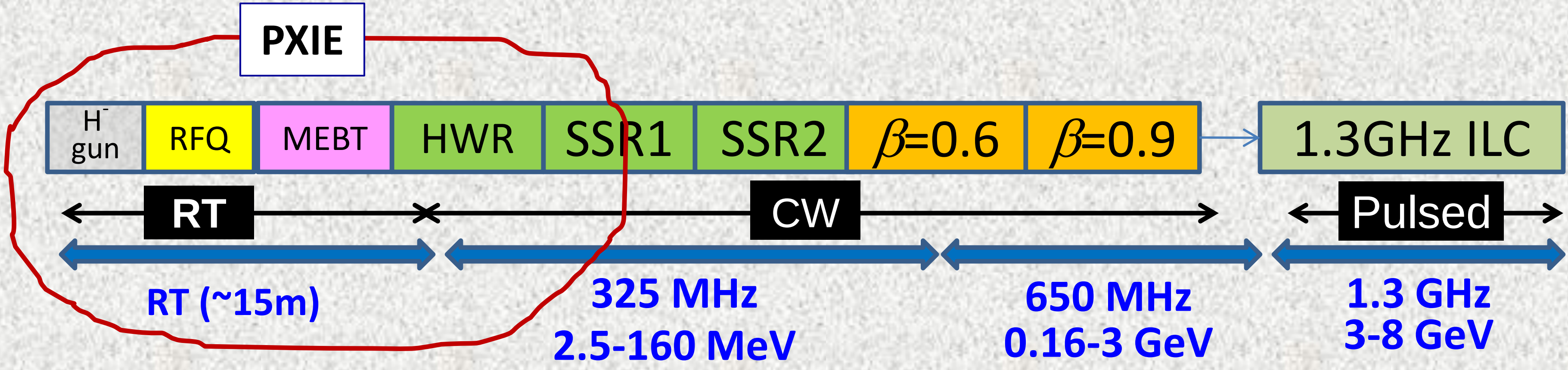
Project X Campaign

Program:	Onset of NOvA operation in 2013	**Stage-1:** 1 GeV CW Linac driving Booster & Muon, EDM programs (MI>80 GeV)	**Stage-2:** Upgrade to 3 GeV CW Linac (MI>80 GeV)	**Stage-3:** Project X RDR (MI>60GeV)	**Stage-4:** Beyond RDR: 8 GeV power upgrade to 4MW
MI neutrinos	470-700 kW**	515-1200 kW**	1200 kW	2300 kW	2300-4000 kW
8 GeV Neutrinos	15 kW + 0-50 kW**	0-40 kW* + 0-90 kW**	0-40 kW*	85 kW	3000 kW
8 GeV Muon program e.g, (g-2), Mu2e-1	20 kW	0-20 kW*	0-20 kW*	85 kW	1000 kW
1-3 GeV Muon program	-----	80 kW	1000 kW	1000 kW	1000 kW
Kaon Program	0-30 kW** (<30% df from MI)	0-75 kW** (<45% df from MI)	1100 kW	1100 kW	1100 kW
Nuclear edm ISOL program	none	0-900 kW	0-900 kW	0-900 kW	0-900 kW
Ultra-cold neutron program	none	0-900 kW	0-900 kW	0-900 kW	0-900 kW
Nuclear technology applications	none	0-900 kW	0-900 kW	0-900 kW	0-900 kW
# Programs:	4	8	8	8	8
Total* power:	585-735 kW	1660-2240 kW	4230 kW	5490 kW	11300kW

*** Operating point in range depends on MI energy for neutrinos.**

**** Operating point in range depends on MI injector slow-spill duty factor (df) for kaon program.**

Concepts of CW 3GeV and Pulsed Linac



PXIE

H⁻ gun | RFQ | MEBT | HWR | SSR1 | SSR2 | β=0.6 | β=0.9 → 1.3GHz ILC

RT | CW | Pulsed

RT (~15m)

325 MHz
2.5-160 MeV

650 MHz
0.16-3 GeV

1.3 GHz
3-8 GeV

Section	**Freq, MHz**	**Energy(MeV)**	**Cav/mag/CM**	**Type**
HWR (β_G=0.11)	162.5	2.1-11	8 /8/1	HWR, solenoid, 5.26m
SSR1 (β_G=0.22)	325	11-38	16 /8/ 2	SSR, solenoid, 4.76m
SSR2 (β_G=0.47)	325	38-177	36 /20/ 4	SSR, solenoid, 7.77m
LB 650 (β_G=0.61)	650	177-520	42 /14*/ 7	5-cell ellip, doublet, 7.1m
HB 650 (β_G=0.9)	650	520-3000	152 / 19**/ 19	5-cell ellipt, doubl, 11.2m
ILC 1.3 (β_G=1.0)	1300	3000-8000	224 / 28/ 28	9-cell ellipt., quad, 12.6m

* 7warm and 7 SC doublets. ** All doublets and correctors are warm

$^+$ Lattice design are now is updated. Main focus to improve performance of front –end (PXIE) and 1GeV

Magnetic Focusing

- In the initial part of the low-energy linac, focusing is provided by superconducting solenoids and triplets in MEBT (round beam).
- Starting with the 650 MHz section, a standard FD-doublet lattice is used.
    - *LE650 - half of quads are warm, half –cold*
    - *HE650 – all quads are warm*
- In the ILC section FODO lattice is used. Cold quads in the middle of CM
- All magnets have built-in dipole correctors and BPM for beam steering.
- Cavities and focusing elements are grouped in cryomodules. For the high energy linac, ILC Type-4 cryomodules is possible to use with minor modifications.

Section	HWR	SSR1	SSR2	LE650	HE650	ILC
Focusing	SR	RSR	SR^2	FDR^3	FDR^8	FR^{8}DR^8

Elements: S – solenoid, R resonator, FD – doublet (F and D – quads).

Optics in SC cryomodules

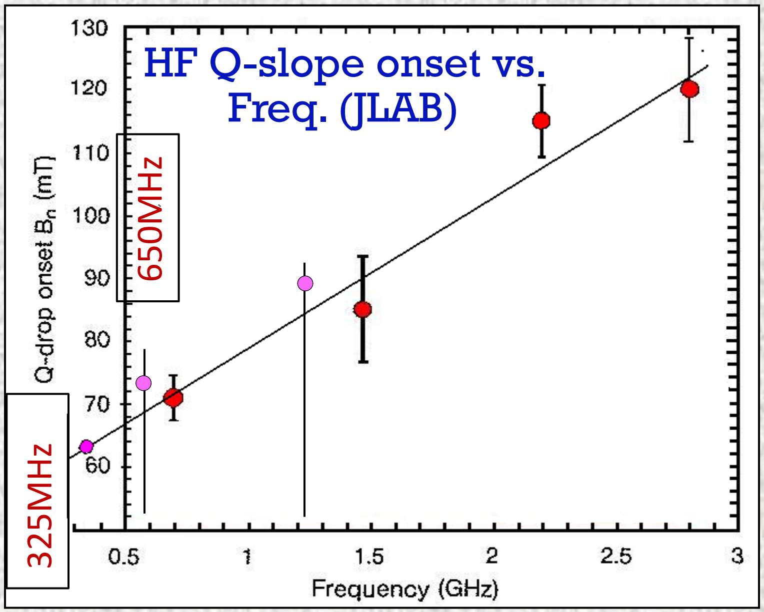
- **Structure of Half-wave cryo-module**
  - *8 cavities, 8 solenoids* **(S C S C S C S C S C S C S C S C)**
  - *Starts with a solenoid to mitigate H_2 influx from MEBT*
- **Structure of SSR1 and SSR2 and 650 MHz Cryo-modules**
  - *SSR1:8 cav/4sol* (**CSC CSC CSC CSC**); *SSR1:9cav/5sol* (**SCC SCC SCC SCC SC**);
  - LE650 : (**CCC FD CCC**); HE650 - 8 cavities
- **Cryomodules have**
  - *X & Y & S BPM near each solenoid*
  - *Transverse (x, y) correctors are located in every solenoid*
  - *Solenoid polarity is changed in each next solenoid (simplifies orbit correction)*
  - *Vacuum valves at each end*
- **Cryomodule interface**
  - *CM-to-CM transition goes through room temperature vacuum chamber*
    - *Good from repair points of view but complicates beam dynamics*
  - *Cryomodules face interface with cavities – improves long. dynamics*
  - *Small space allocated (~20 cm in HWR-SSR1, ~2m at 650 MHz CM's)*
    - *Laser profile monitor, Pumping port*

Choice of cavity gradient

Cavity Gradient Constrains:

- Surface Magnetic field (high field Q-slope onset)

162.5 MHz: $B_{pk} < 60mT$
325 MHz: $B_{pk} < 70\ mT$
650 MHz: $B_{pk} < 70mT$
1300 MHz: $B_{pk} < 80mT$



- Surface Electric Field (Field emission)

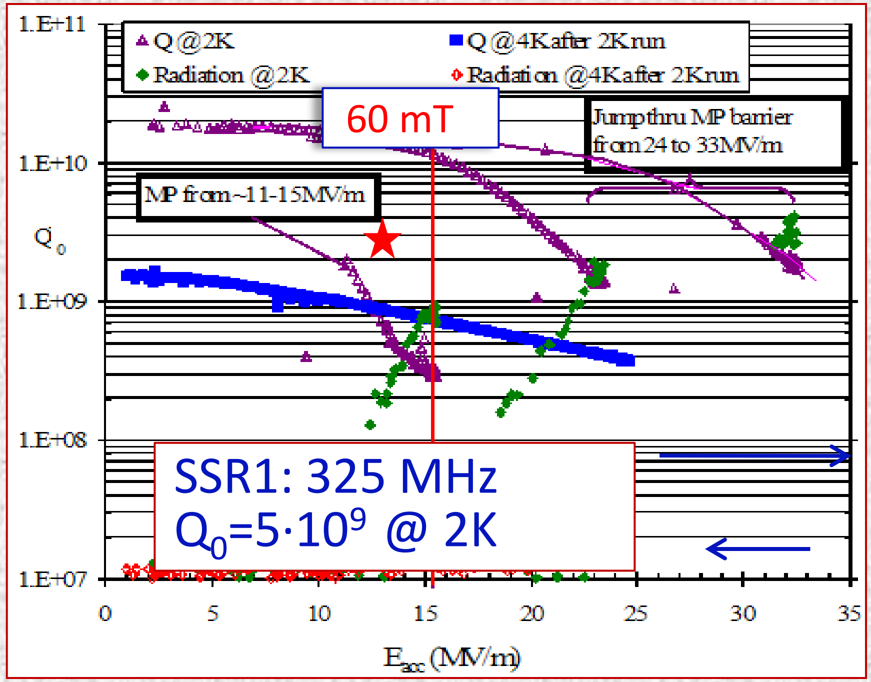
E_{peak} < 40 MV/m

- Limitation of Power dissipation at 2K

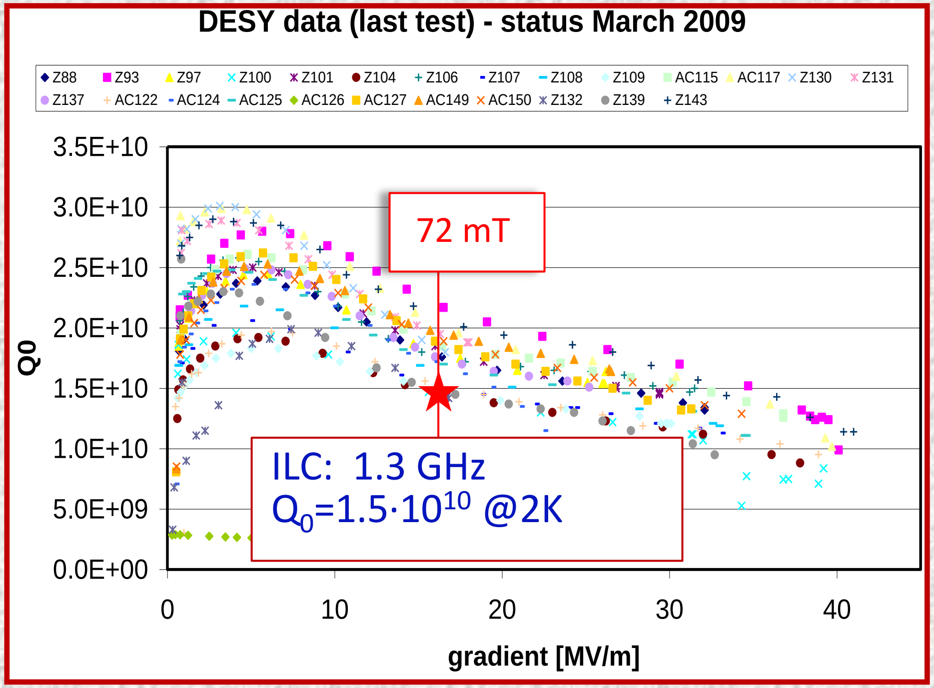
250 W per CM total,
- 25 W per cavity (8 cavities/CM)

Cryo-losses: Assumption

- R_{res} ~ 6 (10) nΩ , frequency independent
- BCS resistance is field dependent (medium field Q-slope). At 2°K we have:
  - *– 325 MHz – resistance is dominated by residual.*
  - *– 650 MHz – BCS and residual gives comparable contribution*
  - *– 1300 MHz – BCS resistance is dominated*
- At ~70 mT medium-field Q-slope gives ~30% of Q-reduction



SSR1: 325 MHz
$Q_0=5\cdot10^9$ @ 2K



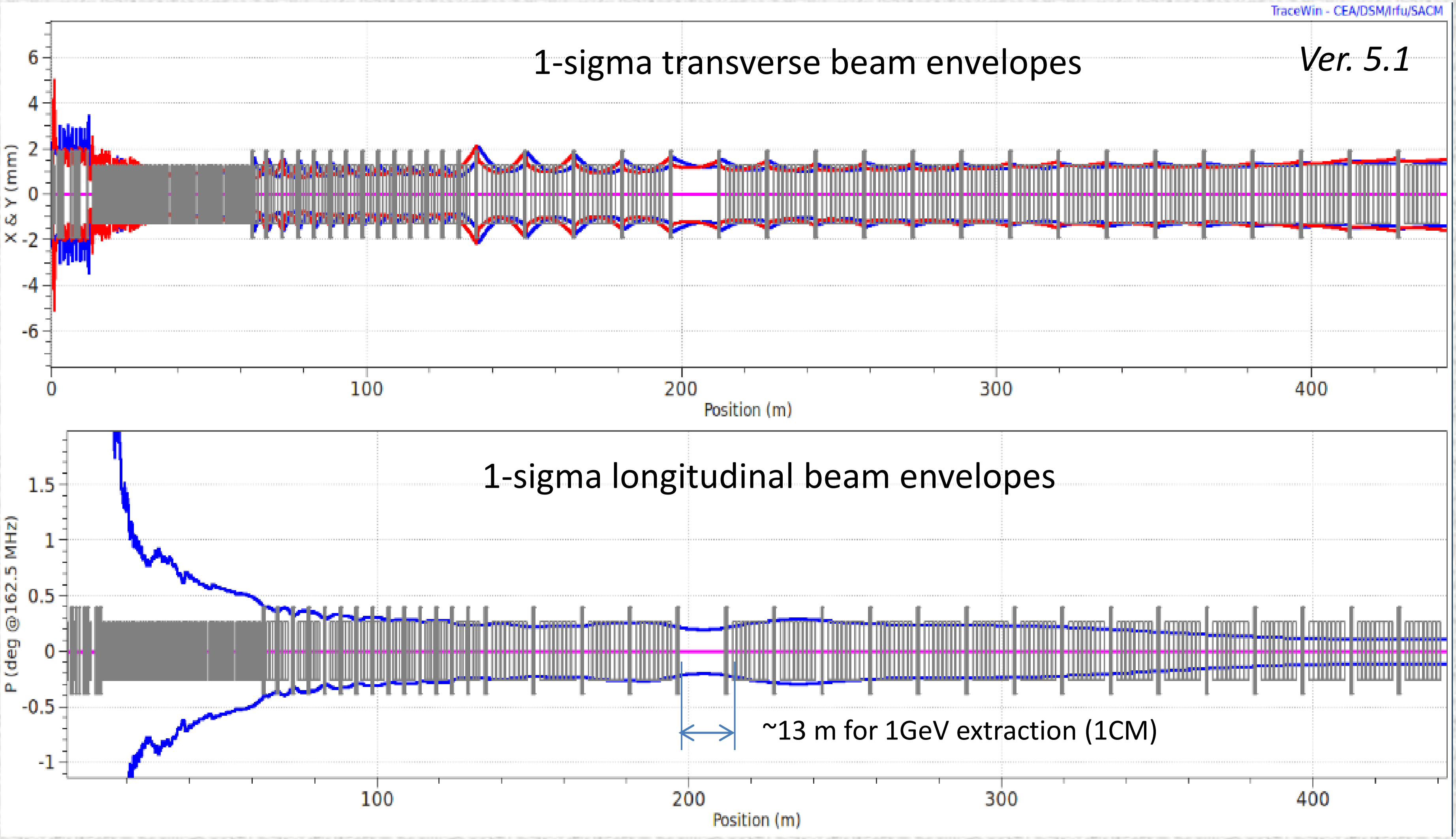
ILC: 1.3 GHz
$Q_0=1.5\cdot10^{10}$ @2K

Lattice design and Beam Physics

Issues:

- Lattice design (Linac and all transport lines)
- Beam dynamics simulatioms
- Emittance and halo growth
- Beam losses (intrabeam stripping, residual gas, field etc.)
- Beam collimation
- Effect of beam mismatch
- Study static/dynamic RF errors and misalignments
- Beam steering algorithm to correct alignment errors
- Failure analysis and optics re-matching to compensate
- Effect of High Order modes

Lattice of CW 3 GeV Linac



1-sigma transverse beam envelopes

Ver. 5.1

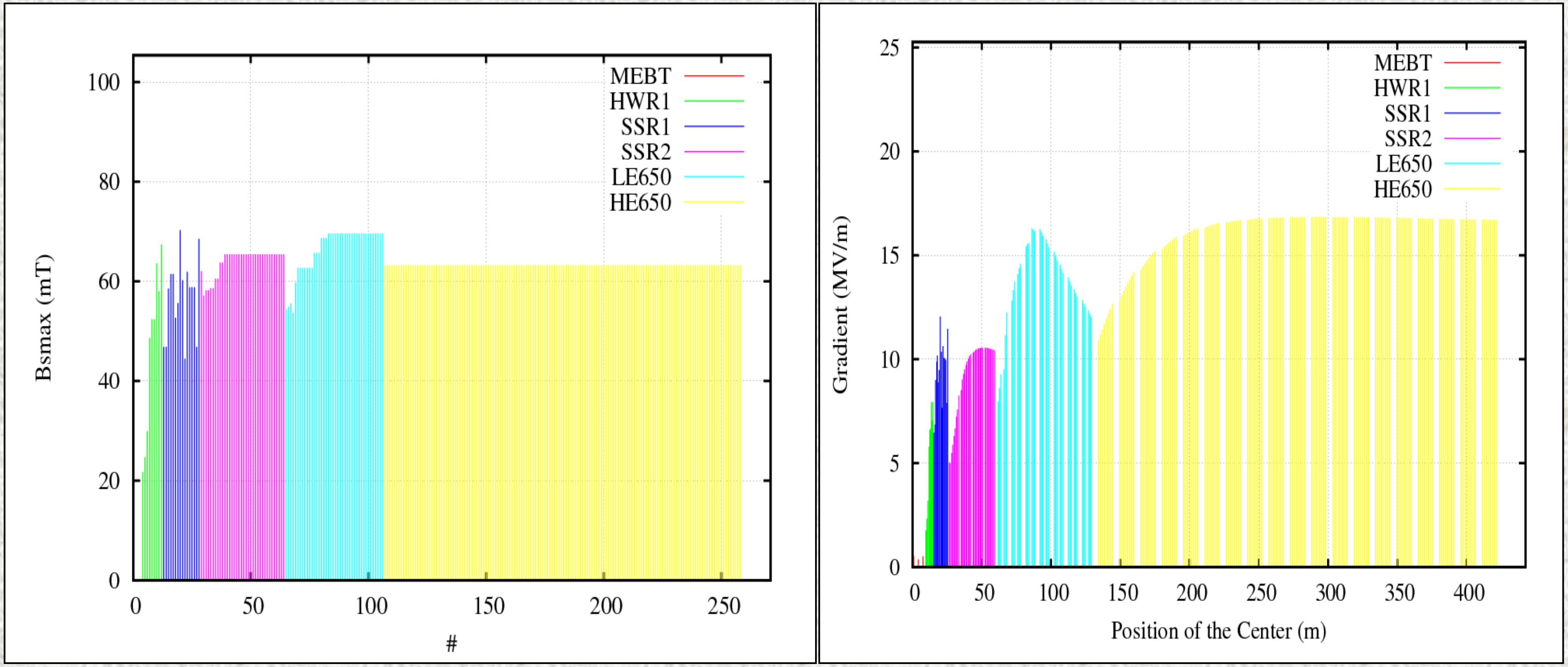
1-sigma longitudinal beam envelopes

~13 m for 1GeV extraction (1CM)

Cavities

Surface magnetic field

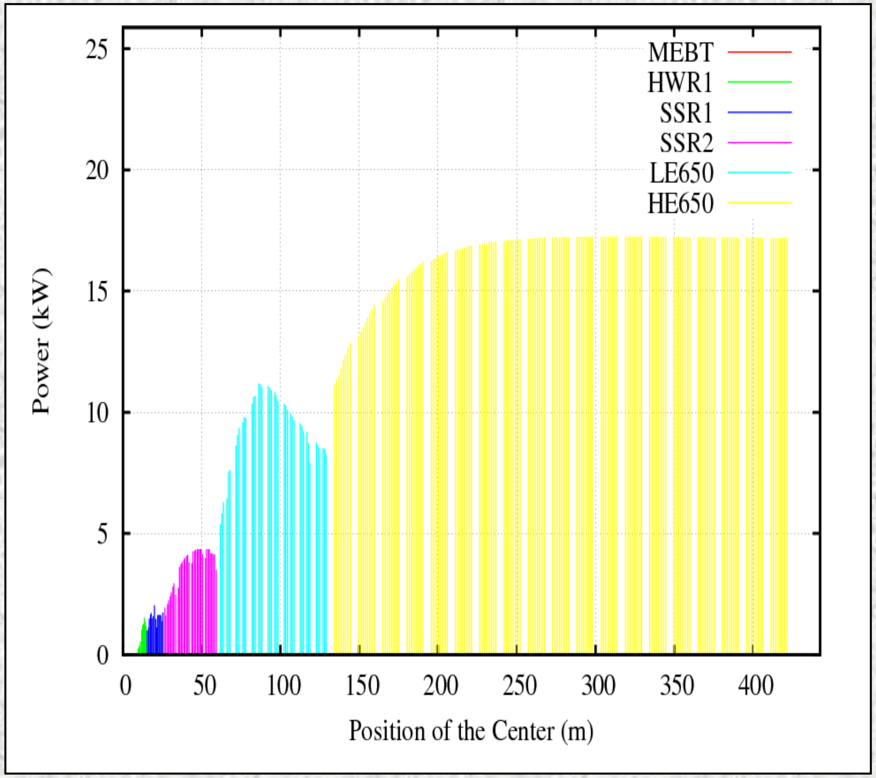
Accelerating Gradient



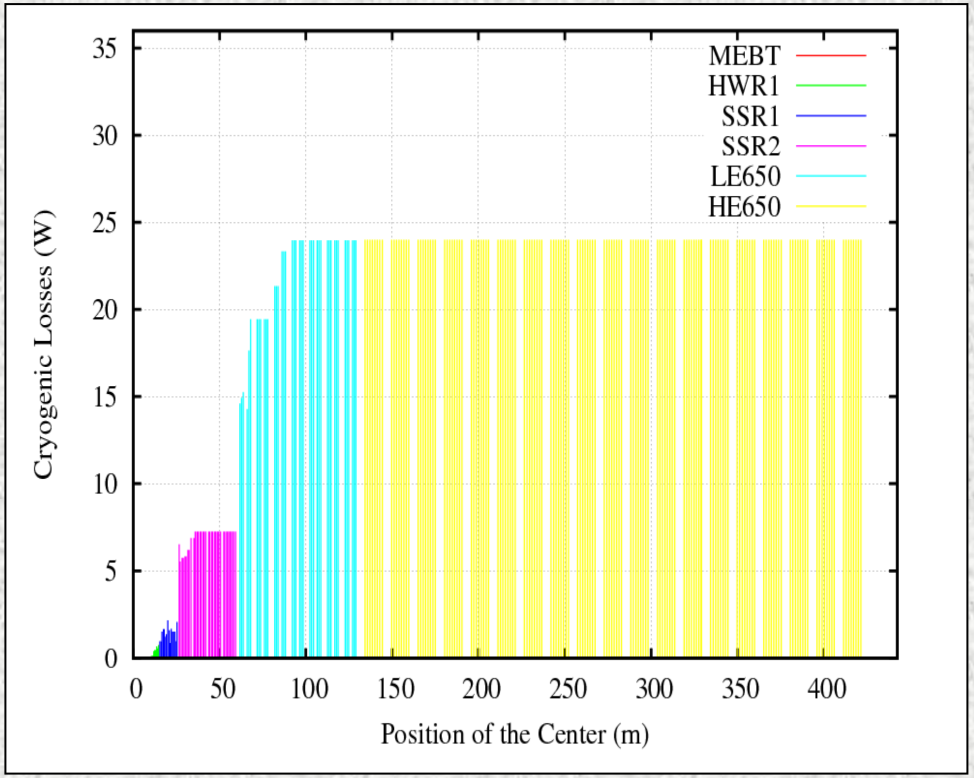
*Recent changes in Front-end design not reflected here

Cavities (2)

Beam Power

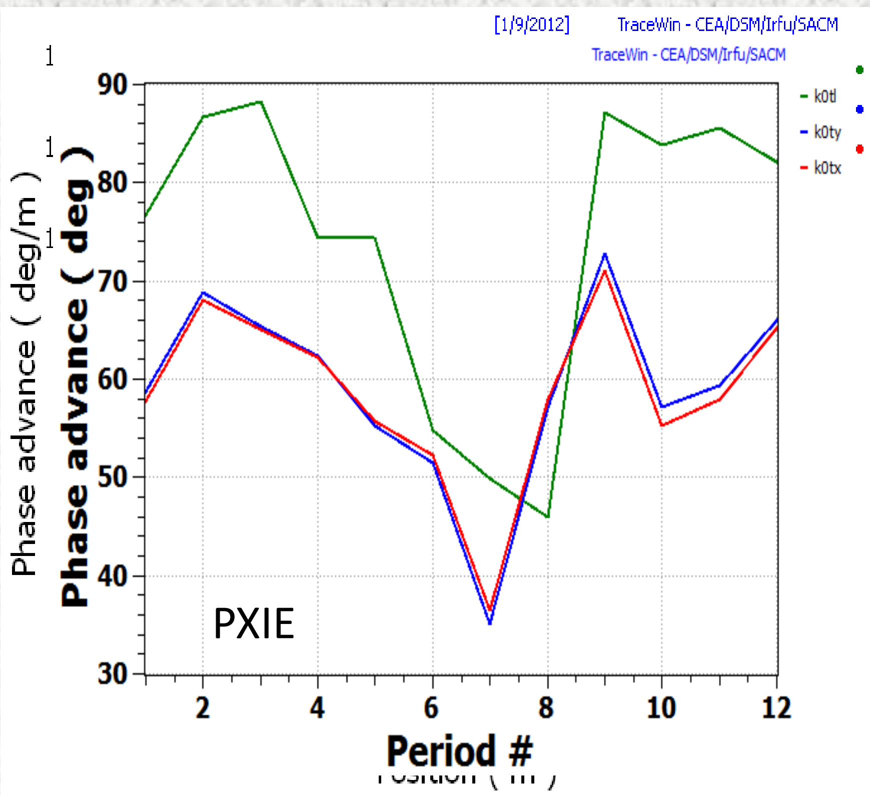


Cryogenic losses

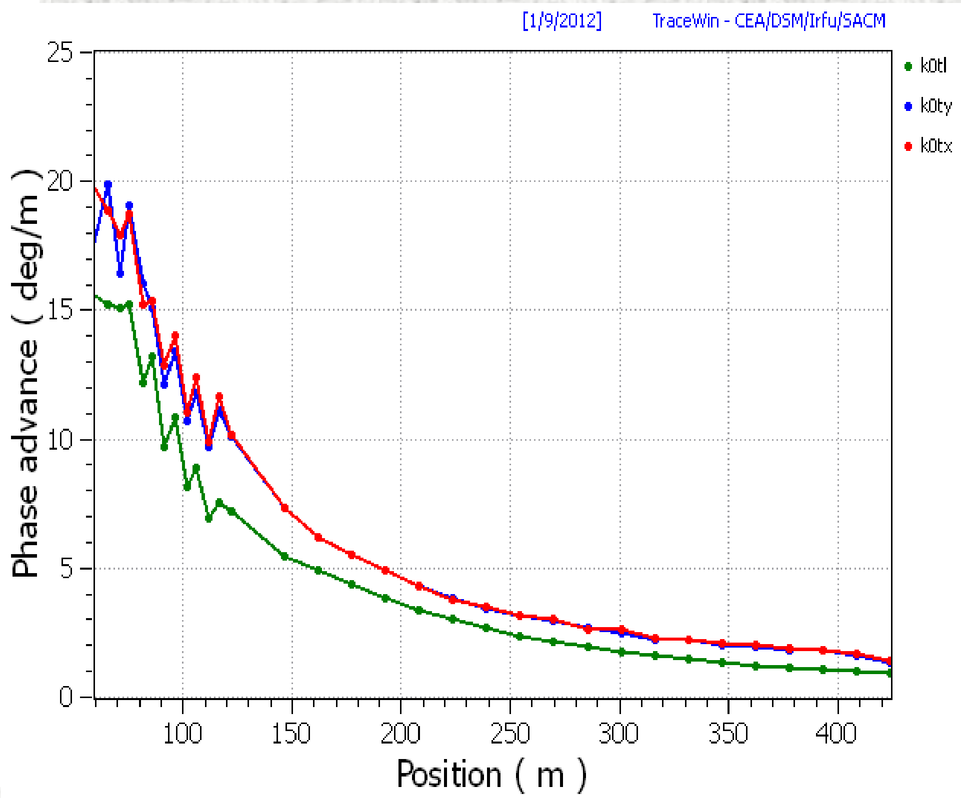


Phase advance

Front End (w/o MEBT)

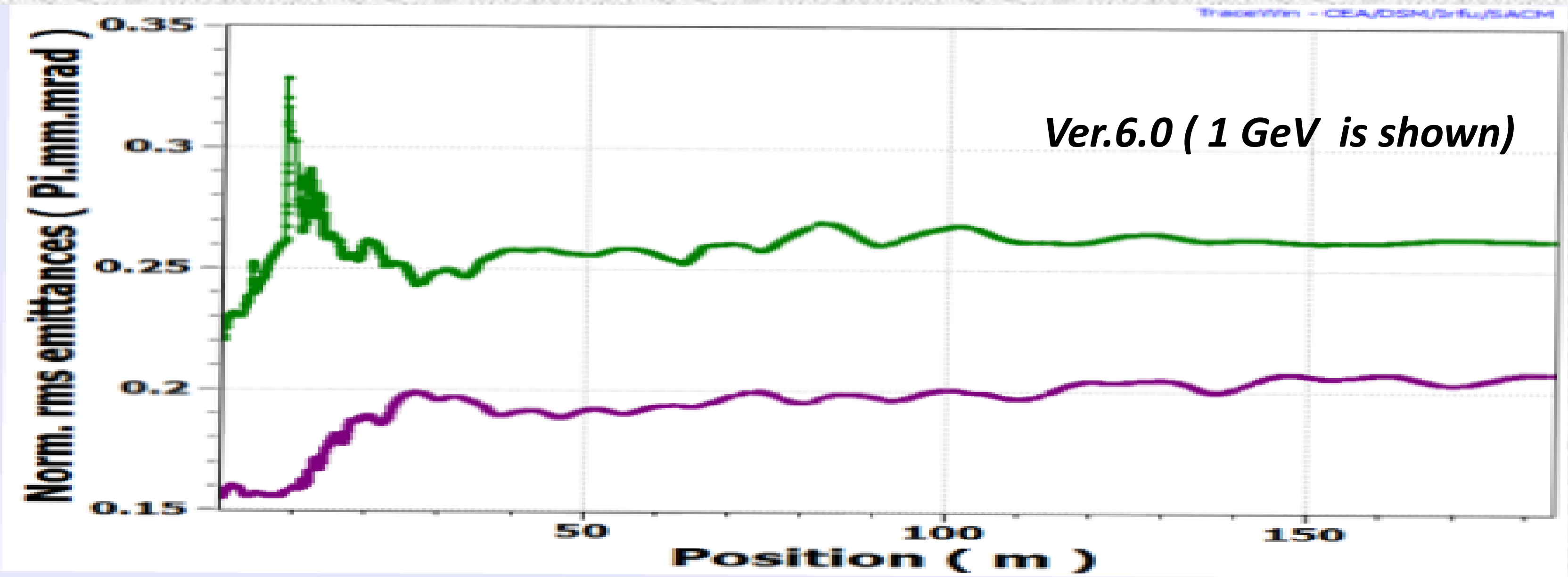


High energy sections

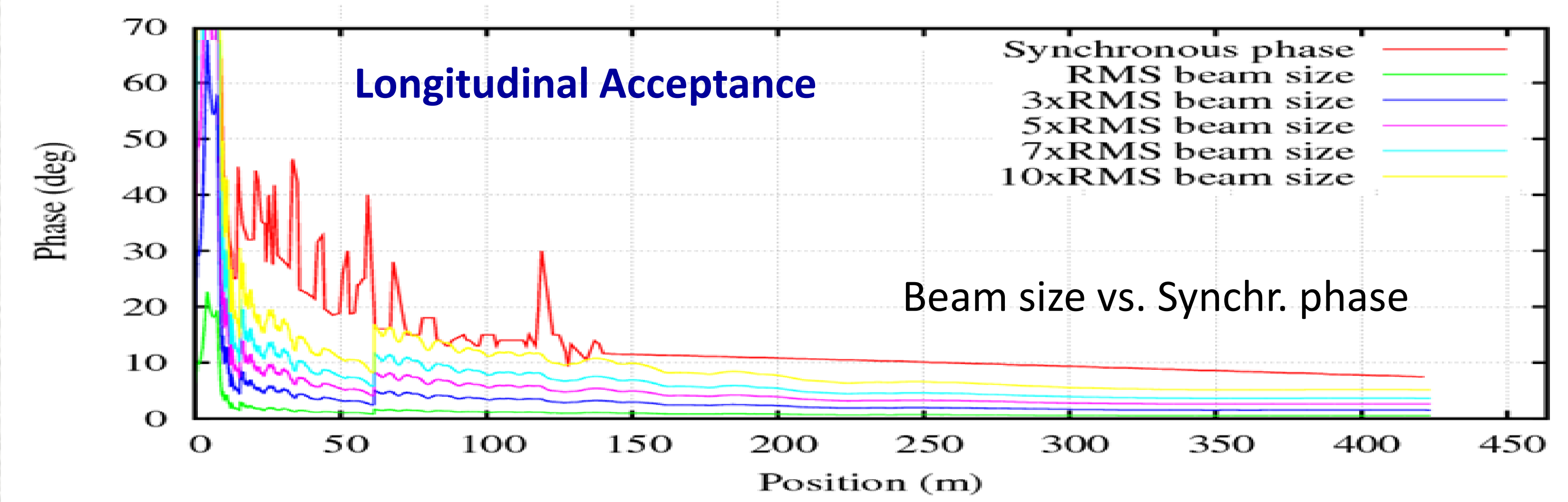


Ver.6.0

Emittances growth



Ver.6.0 (1 GeV is shown)



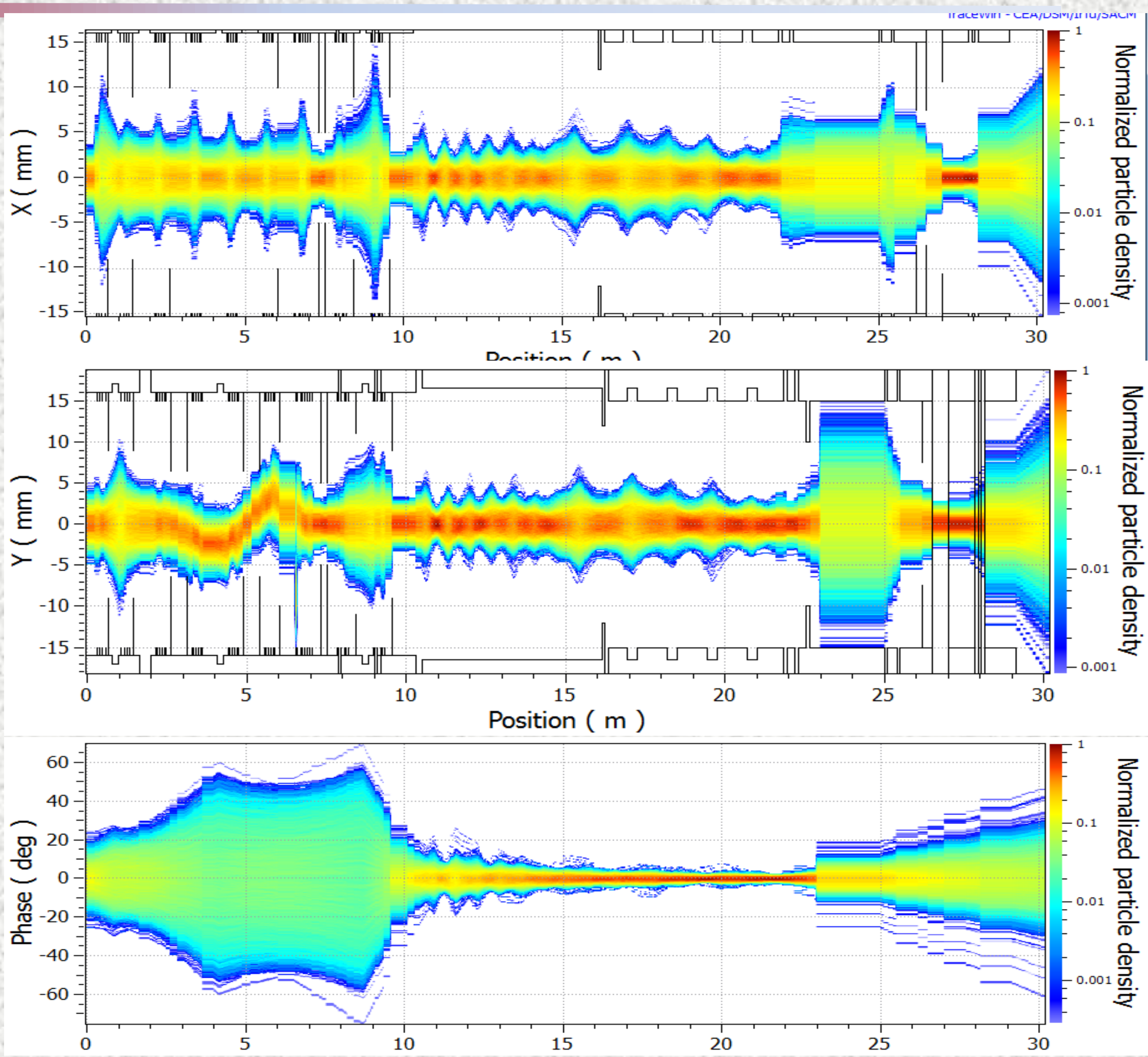
Longitudinal Acceptance

Beam size vs. Synchr. phase

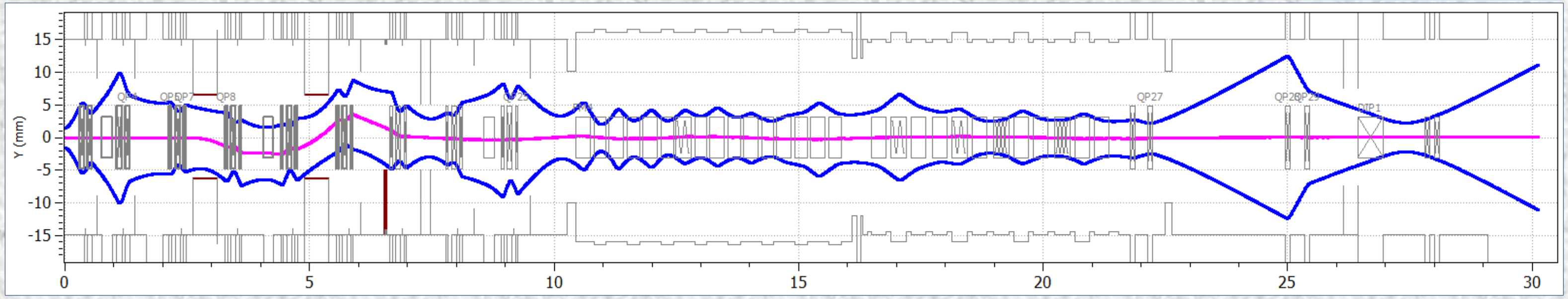
PARTRAN tracking, collimation

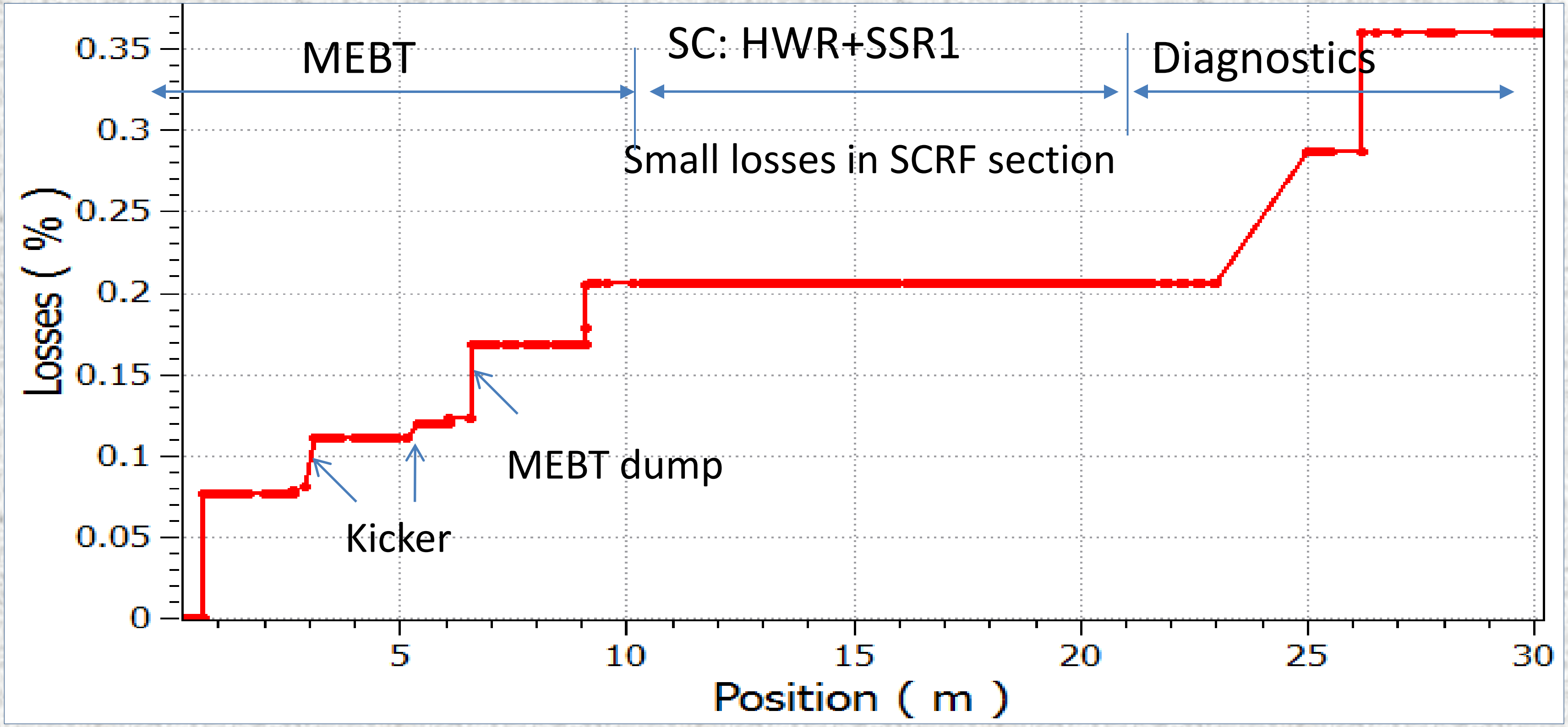
Beam Losses

- Intra-beam stripping < 0.5 W
- Non-Gaussian tail of RFQ longitudinal distribution (after RFQ) is the major source of particle loss, <$3\cdot10^{-4}$ (< 10 W) in SCRF section:
  - *Small fraction of total beam loss will be intercepted by warm interface between CM's*
  - *Major fraction will be lost at 2 K*
- It is still small relative to the RF losses in CM (~50 W)



Beam Losses for passing beam




MEBT

SC: HWR+SSR1

Diagnostics

Small losses in SCRF section

MEBT dump

Kicker

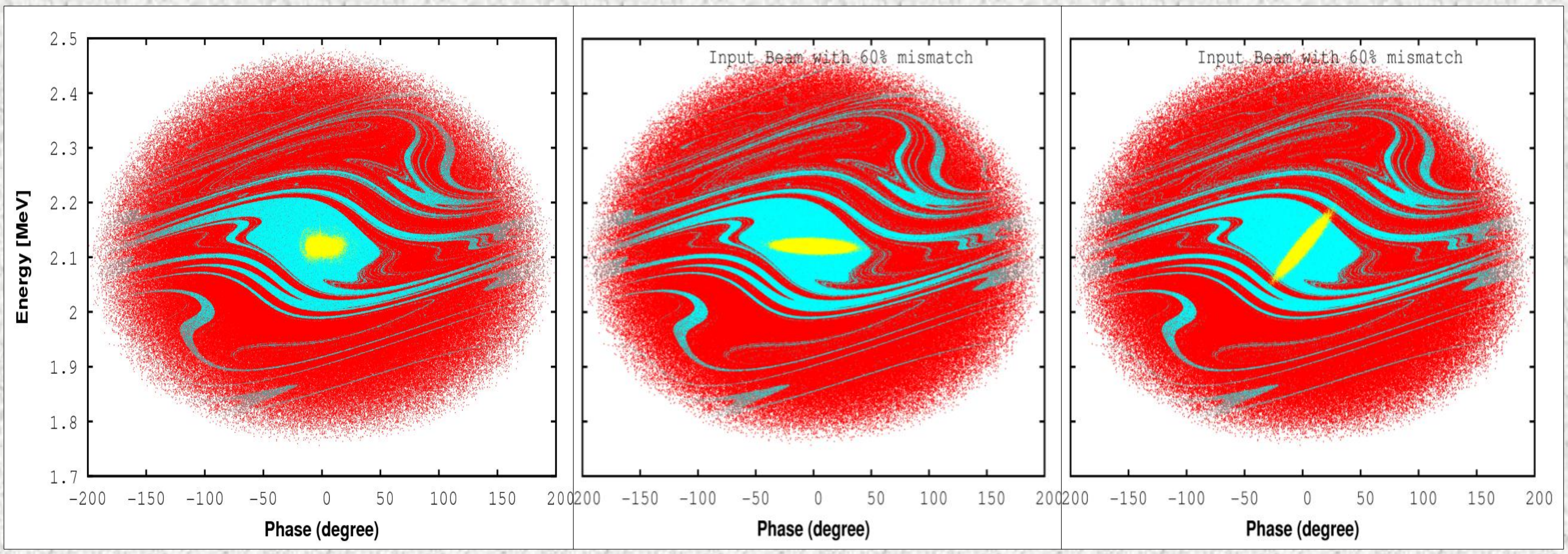
Chopped beam are lost at MEBT dump at level 99.94% (6σ Gaussian)

Longitudinal acceptance @ end of SSR1

🟥 **Initial distribution**

🟦 **Acceptance boundary**

🟨 **6σ Gaussian**

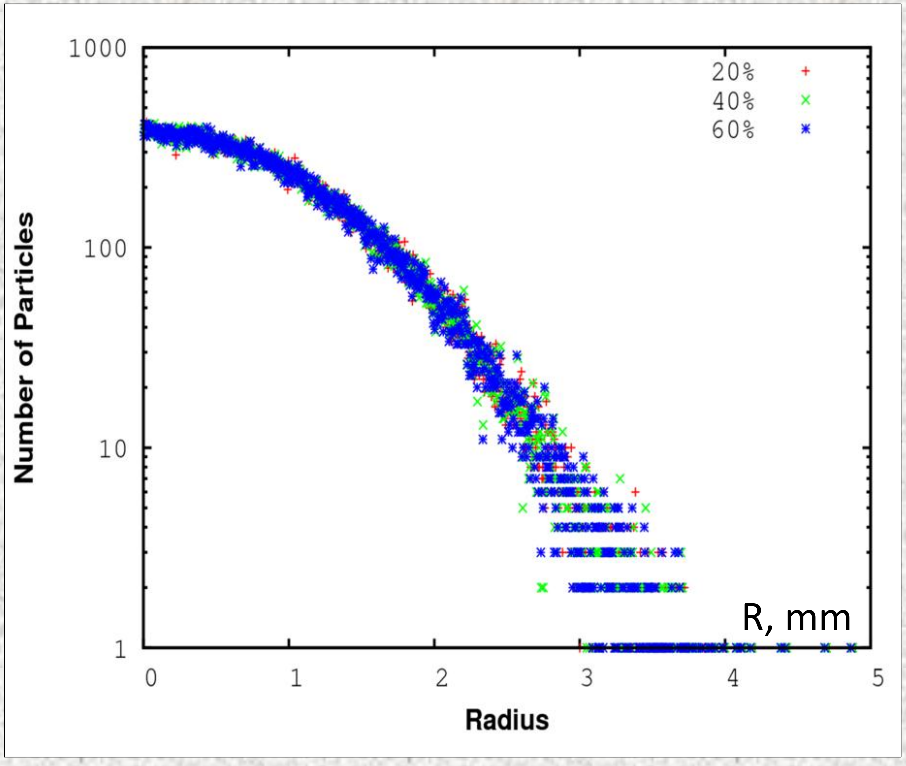


No mismatched

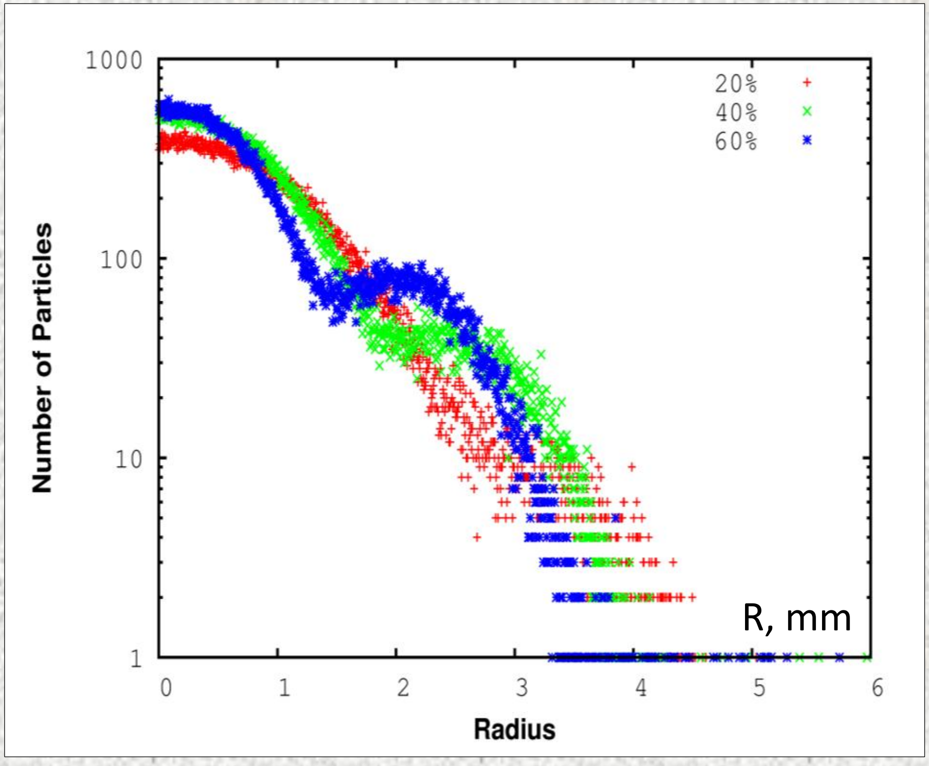
60 % mismatched input beam @ MEBT entrance

60 % mismatched input beam @ HWR entrance

Mismatch effect on Longitudinal profile



Input beam @ MEBT entrance

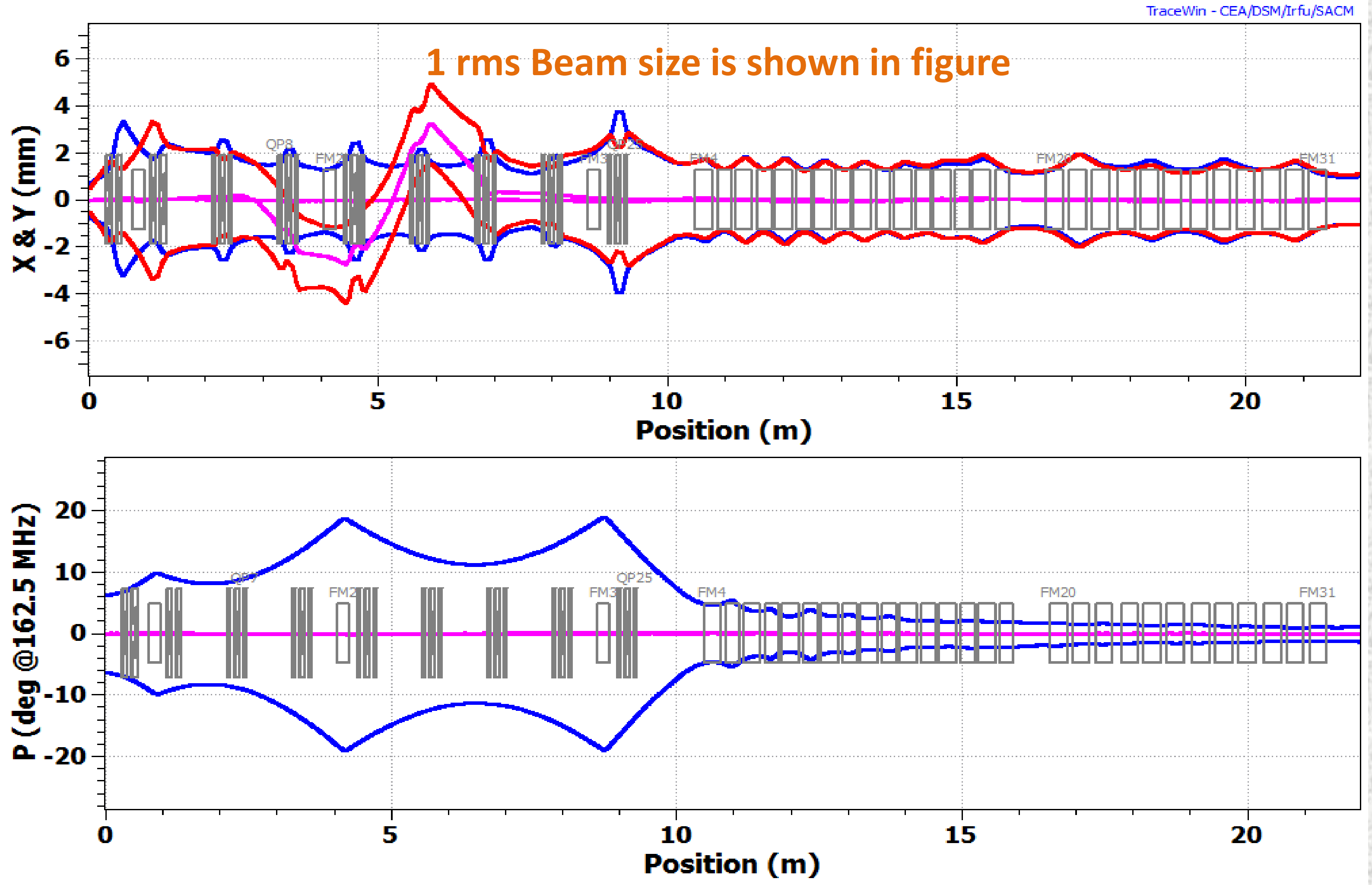


Output beam @end of 1 GeV Linac

Small effect on transverse beam profile

Recent work on PXIE optics optimization

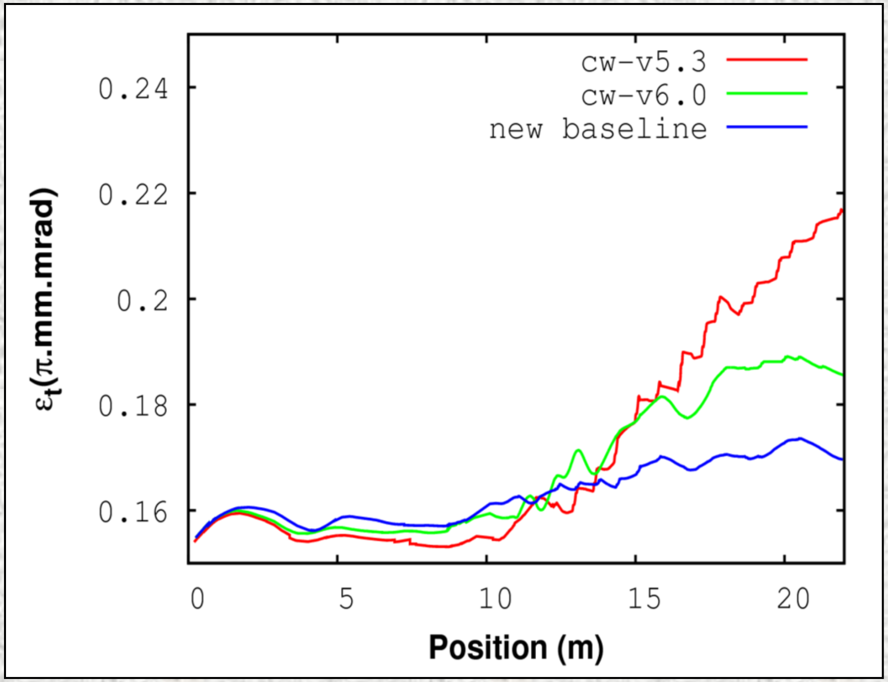
Goal: improve longitudinal dynamics, increase acceptance



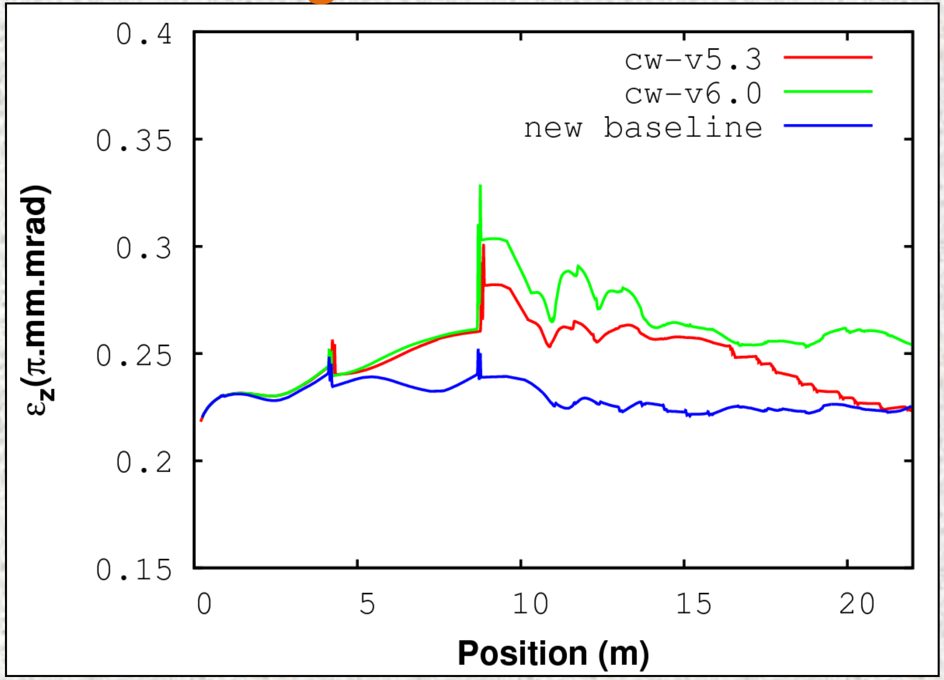
1 rms Beam size is shown in figure

Emittance comparison with earlier version

Transverse emittance



Longitudinal emittance



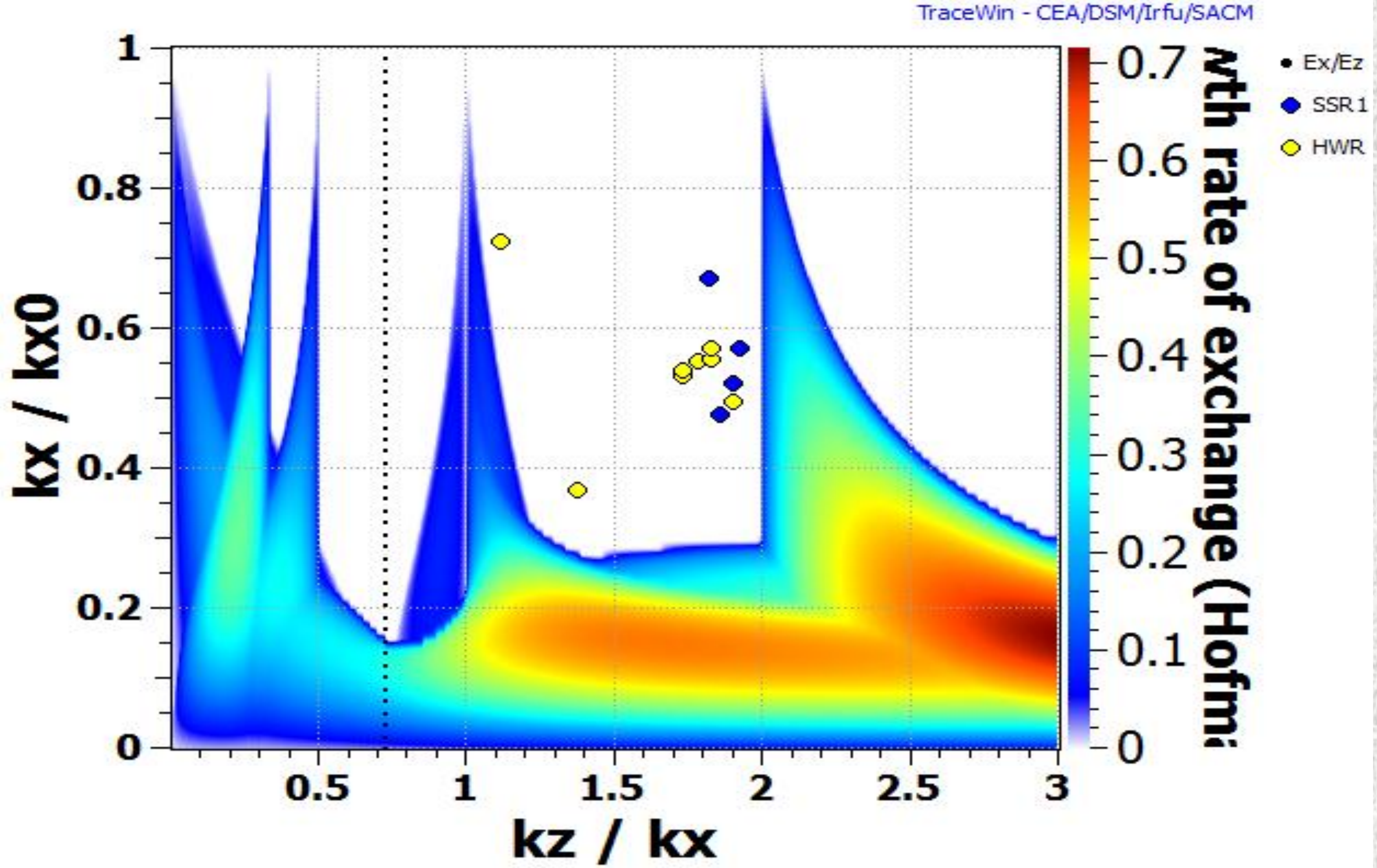
Parameters	CW-v5.3	CW-v6.0	New Lattice
Energy (Mev)	23.72	23.23	18.48
ε_t (π.mm.mrad)	0.2165	0.186	0.1696
ε_z (π.mm.mrad)	0.224	0.254	0.225

Goal to have two types of lattices

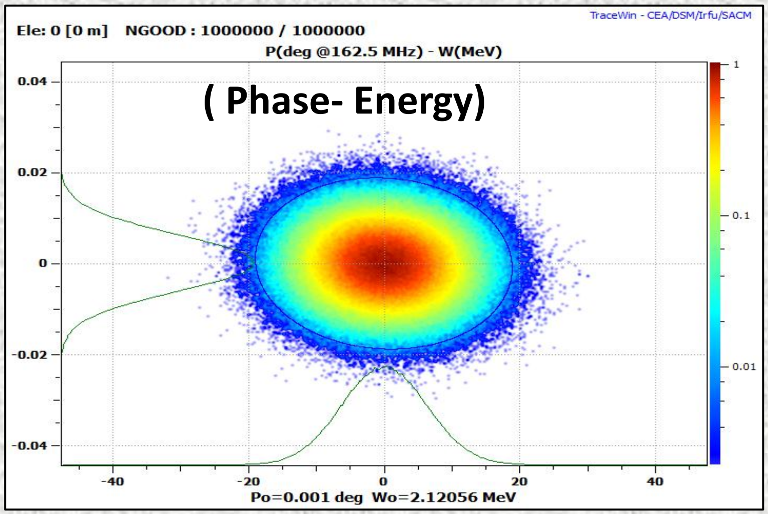
- High Energy optics
- Low emittance/halo growth

A.Saini

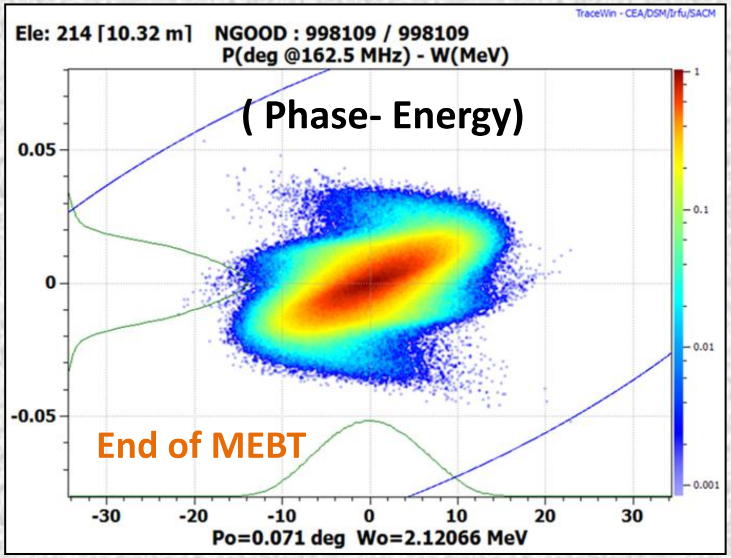
Hoffmann’s Stability Diagram



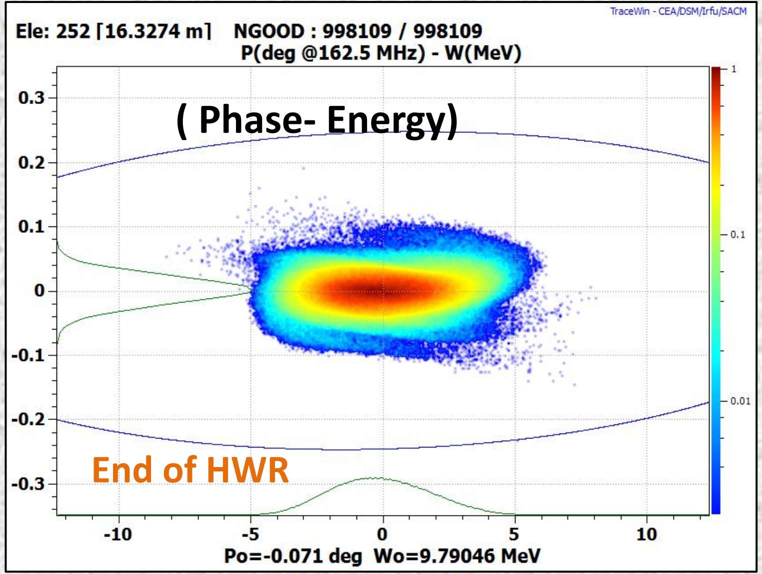
Evolution of Longitudinal phase-space



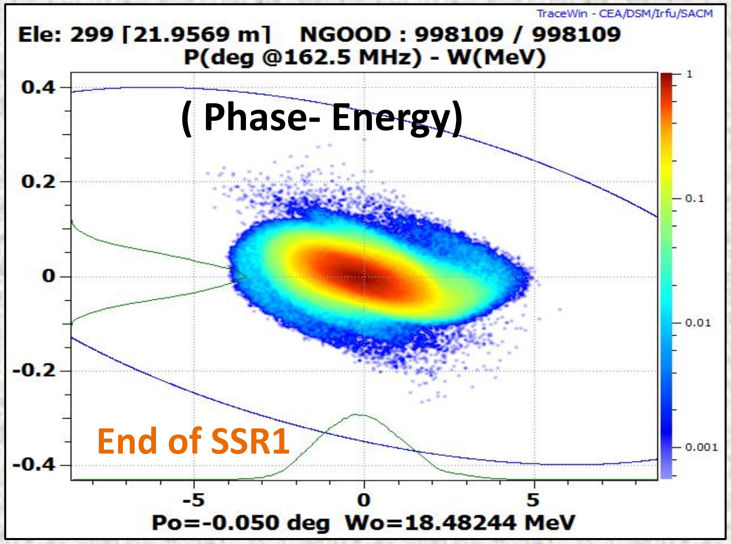
Input longitudinal beam distribution



End of MEBT



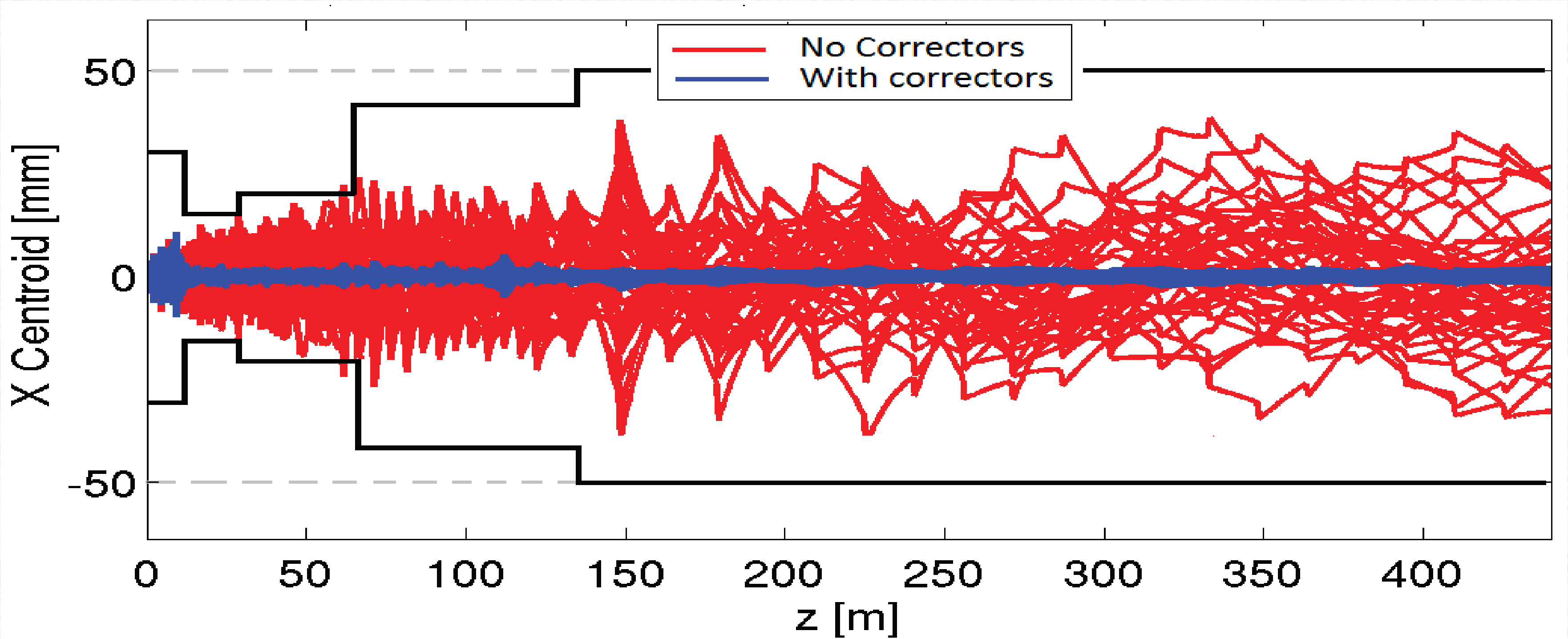
End of HWR



End of SSR1

Errors and misalignments

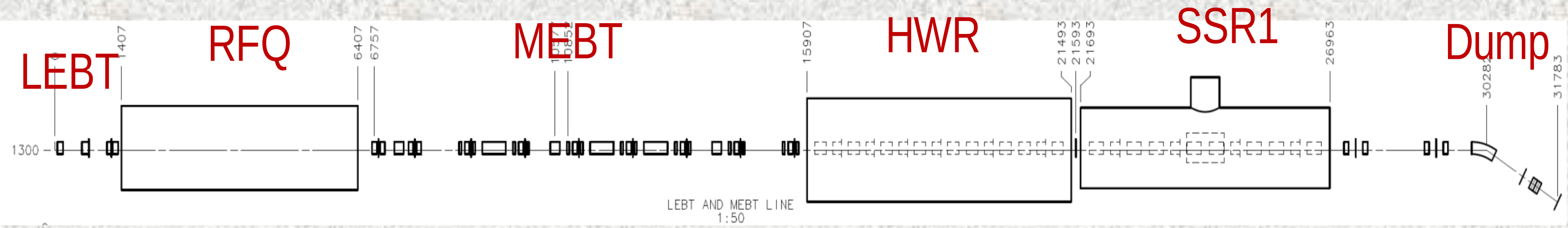
Misalignment of components and RF jitter Studies



TRACK simulations (400 machines) of corrected/uncorrected beam centroid motion along the linac for the set of errors δ_{xy} =1mm for solenoids & cavities, δ_{xy} =0.5mm for quadrupoles, dynamic RF jitter of 0.5^0 + 0.5% and quad roll of 5 mrad around the z-axis. One corrector and one monitor are used per solenoid and per quadrupole dublet. BPM resolution 30μm. Big losses (> 1W/m) if no correction ; No losses after alignment correction

PXIE - Project X Injector Experiment

- PXIE – Front-End of the Project X CW linac
- PXIE should deliver 1 mA CW beam to ~25 MeV energy
  - Arbitrary bunch pattern (5 mA from Ion Source-> 1 mA at the beam dump)
- PXIE includes:
  - *5 mA ion source*
  - *LEBT with pre-chopper*
  - *2.1 MeV 162.5 MHz RFQ*
  - *MEBT with bunch-by-bunch chopper and 11 kW beam dump*
  - *Two SC cryo-modules: HW -162.5 MHz & SSR1 – 325 MHz*
  - *Diagnostics Section and 50 kW beam Dump*



PXIE schematic layout. The total facility length is about 40 m.

PXIE Goals and challenges

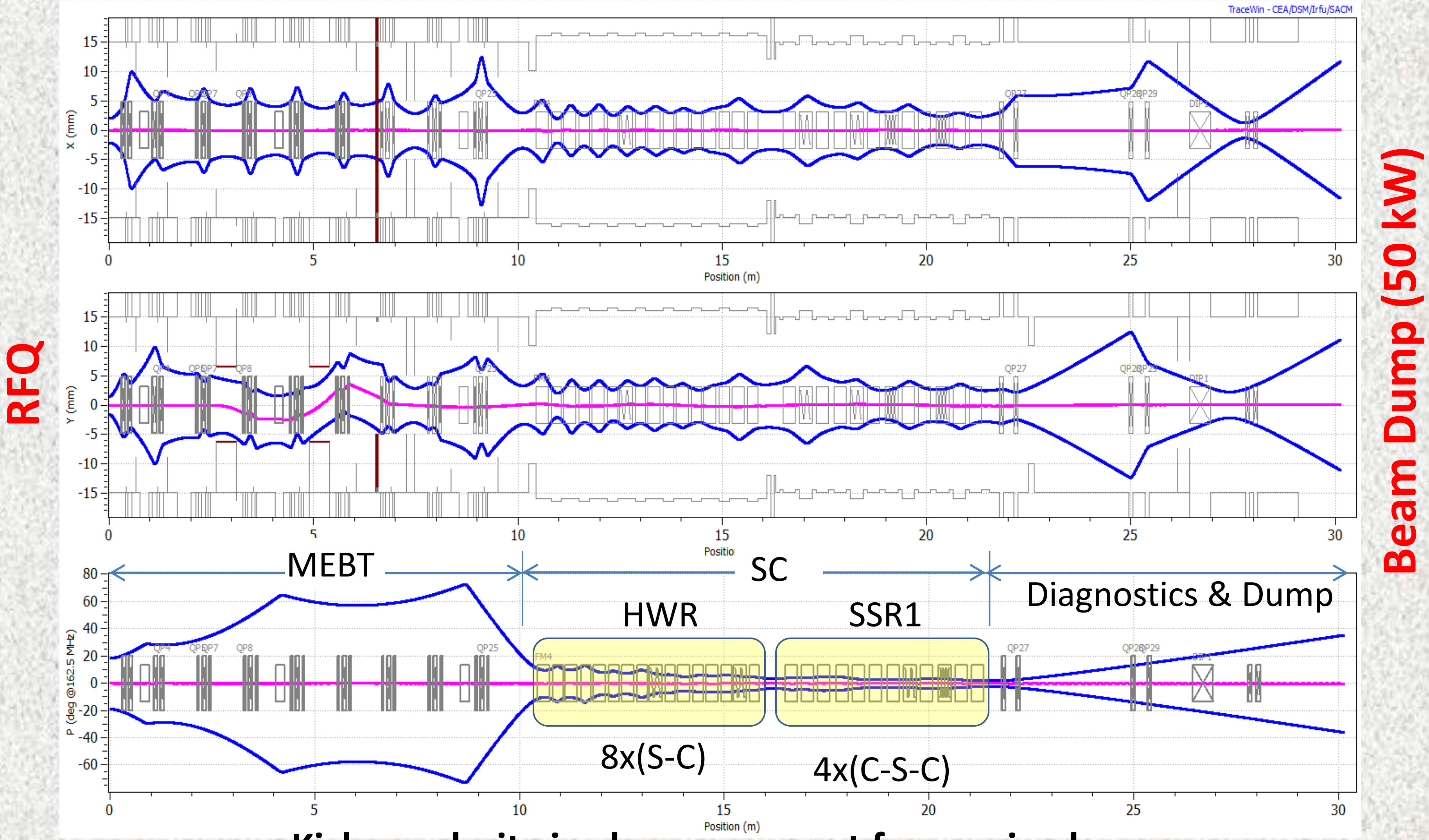
- Specific technical PXIE program goals are to demonstrate (challenges):
    - ***reliable operation of a CW 2.1 MeV RFQ accelerator,***
    - ***a bunch-by-bunch chopper,***
    - ***low-β acceleration in SRF cryomodules***
    - ***sufficiently small emittance growth during initial acceleration and***
    - ***good particle extinction for the removed bunches (10^{-4} – PXIE specs)***

- PXIE has to operate at full Project X design parameters delivering up to 1 mA average current while accommodating up to 100% chopping of 5 mA RFQ beam.

- The beam current upgradability requirement (to 2 mA CW) is determined by possible staging of the Project X and its future upgrades (~20mA peak current at 325 MHz).

- The PXIE design and construction is being carried out by collaboration between Fermilab, ANL, LBNL, SLAC and Indian institutions. It is planned to have PXIE operational (at least 15 MeV, 1 mA CW, 5 mA peak, arbitrary bunch chopping) by the end of 2016.

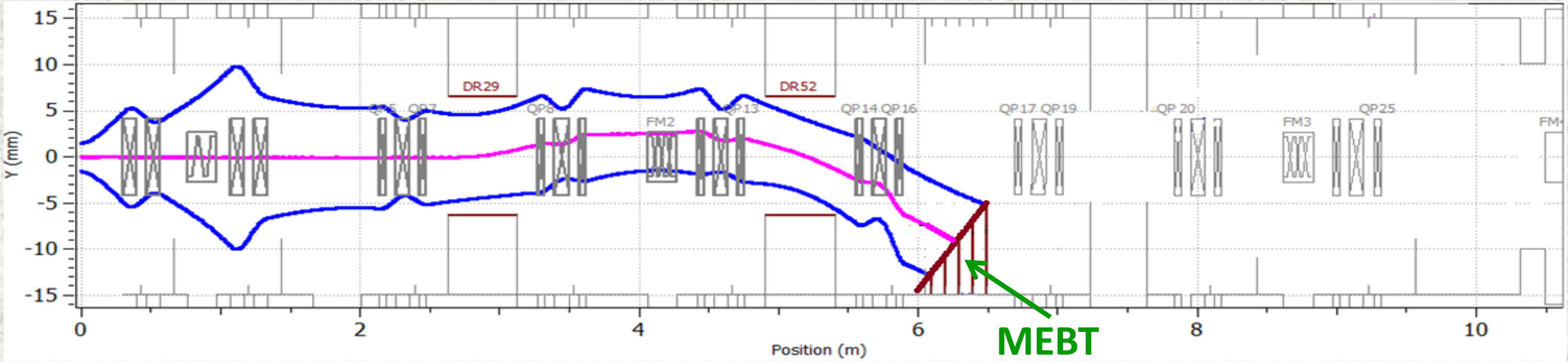
PXIE optics (3-σ envelope)



Kicker polarity in chopper are set for passing beam

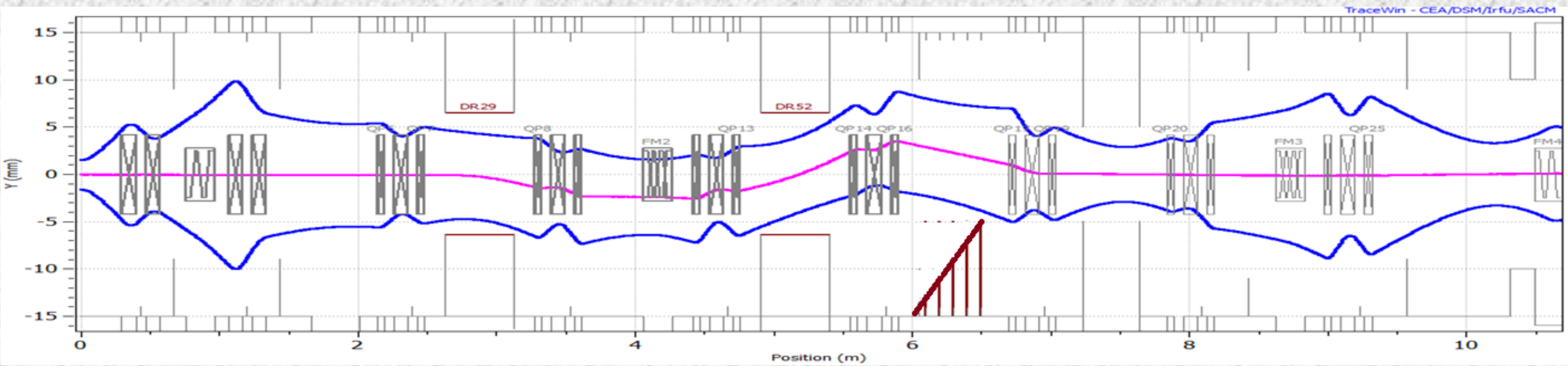
MEBT chopping

Chopped beam



MEBT dump

Passing beam

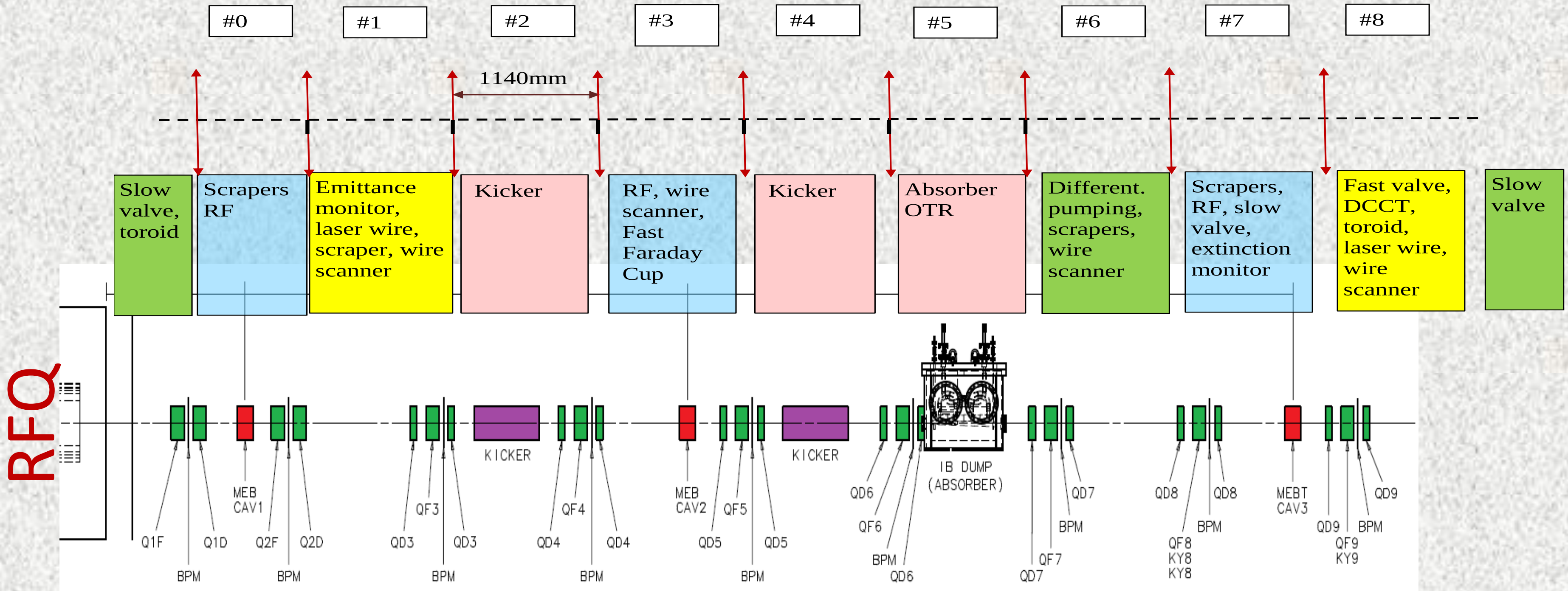


Use of 2 kickers with 180 deg. phase advance reduces kicker voltage

⇒ *±250 V effective voltage on the kicker, 16 mm gap between plates*

DC correctors minimize vertical displacement for passing beam

MEBT diagnostics



Slow valve, toroid

Scrapers RF

Emittance monitor, laser wire, scraper, wire scanner

Kicker

RF, wire scanner, Fast Faraday Cup

Kicker

Absorber OTR

Different. pumping, scrapers, wire scanner

Scrapers, RF, slow valve, extinction monitor

Fast valve, DCCT, toroid, laser wire, wire scanner

Slow valve

Violet - chopping system: 2 kickers (180° tr. phase adv. and absorber (90°from last kicker).

Blue - bunching cavities. + other equipment (scarpers and diagnostics).

Yellow – **mainly diagnostics** to measure beam coming out of RFQ (#1) and to SRF linac (#8)

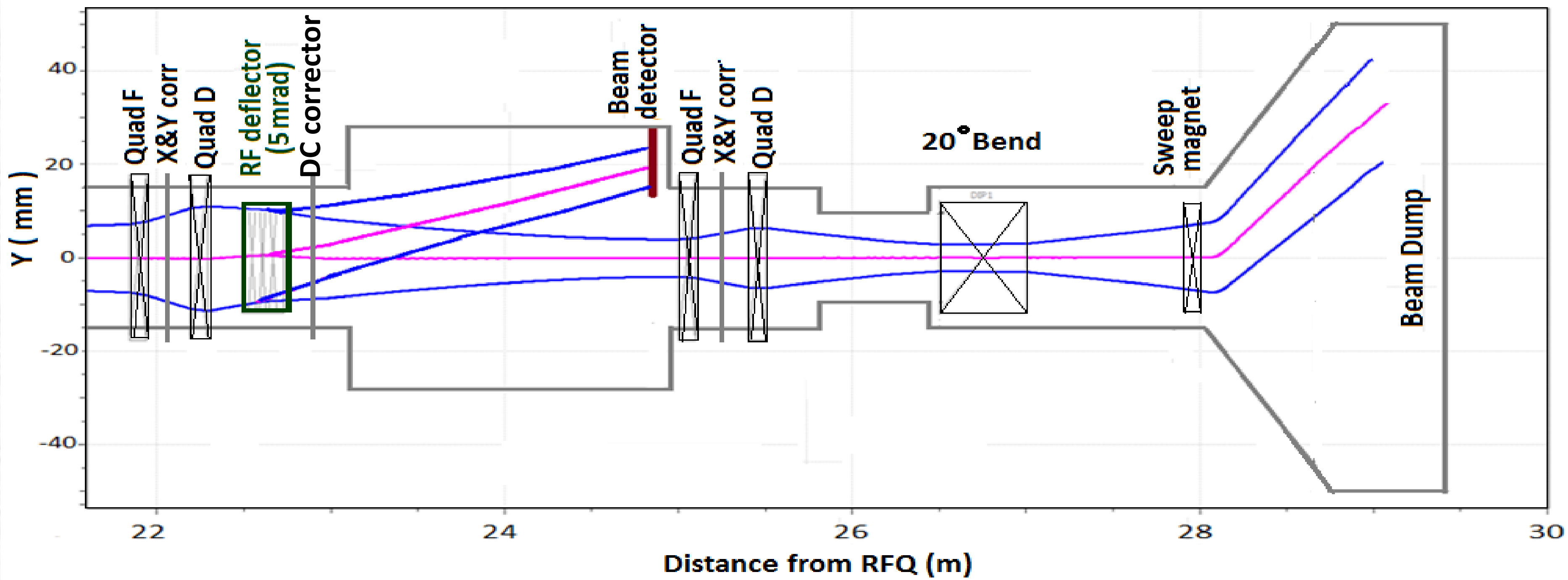
Green - vacuum pumps and **diagnostics**. Start/end– interfaces with the RFQ (left) and HWR

Vacuum:

- ~ 10^{-6} Torr in #5 where a large gas flow from the absorber.
- ~10^{-9} Torr in the last sections of MEBT from the absorber section (after #6):
- Vacuum separation insertion ∅10 mm L=200 mm

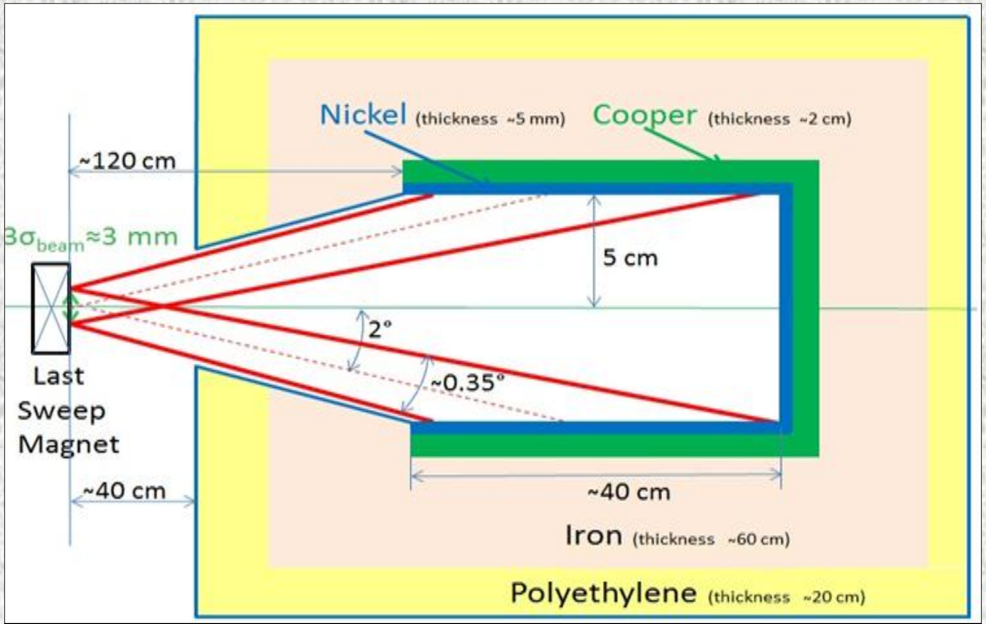
Beam Extinction

Project X will provide beams for different HEP experiments. Some of them (for example mu2e) have a strict requirement ($<10^{-9}$) for beam extinction for removed bunches. An extinction level better than 10^{-4} is specified for the MEBT. This number is mainly determined by available in MEBT diagnostics.

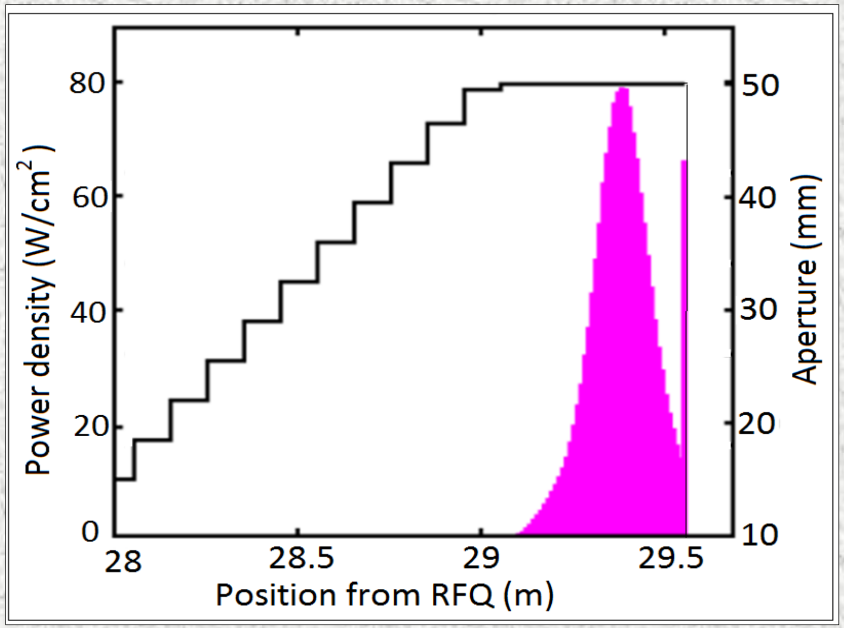


Schematic of extinction measurement experiment, 3-sigma envelope for passing and deflecting beams are shown in blue.

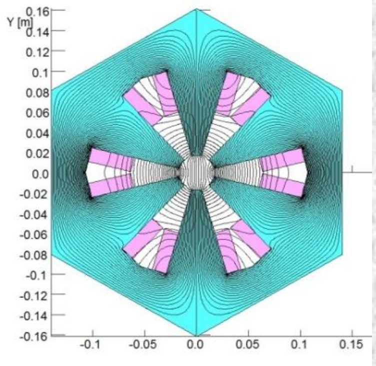
Beam Dump (50 kW)



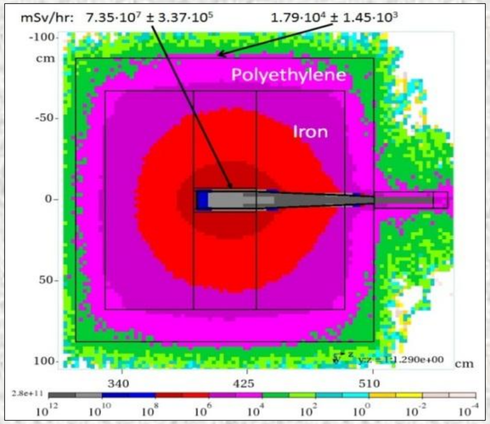
Beam dump, incl. local radiation shielding
Red lines - sweeping beam



Power distribution in absorber



Magnet aperture	34 mm
Length	200 mm
Dipole field, pk	0.2 T
Integ. field	0.04 T-m
Current(pk/av)	250/177 A
Power	810 W



- <u>Local shielding</u> (60 cm iron+20cm polyethylene)
- Attenuation of radiation ~4000 times (~12 W)

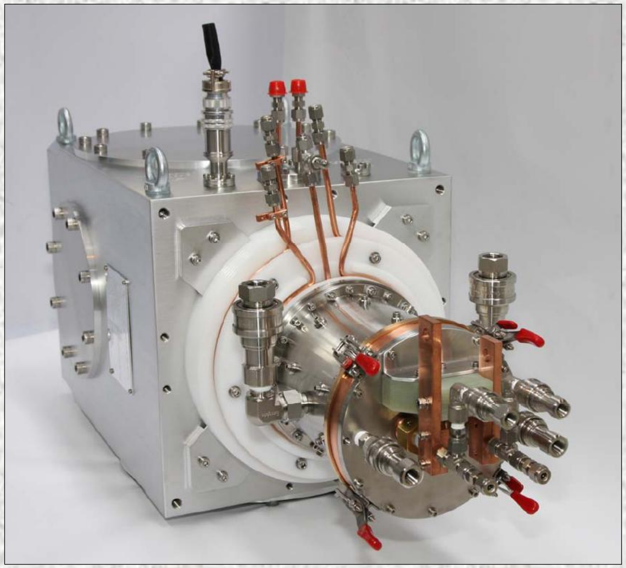
Status of R&D work on critical components for Project X beamline

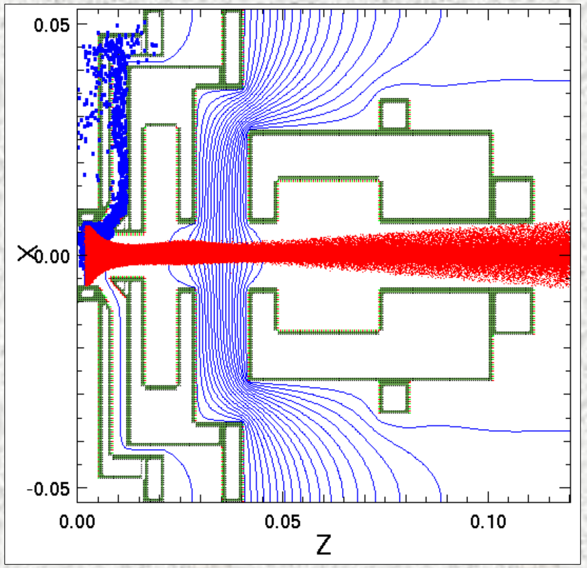
Ion Source

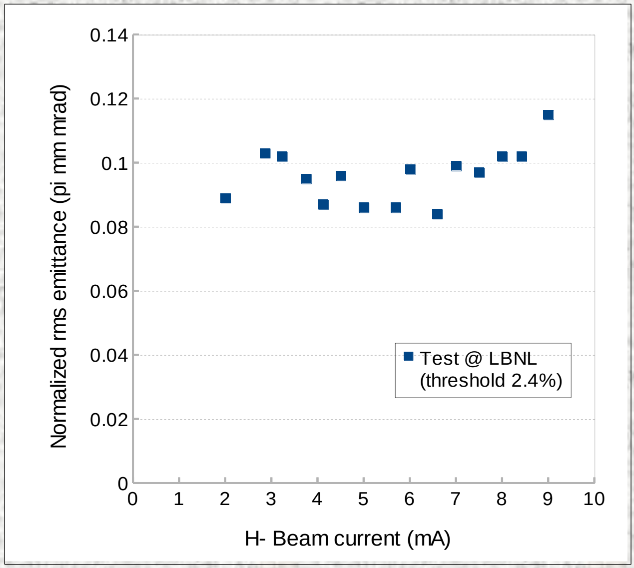
- The Linac beam starts from an H- ion source operating at a constant current, set for a given timeline:
  - The nominal ion source beam current used in Linac design is 5 mA
  - IS is capable of 15 mA; RFQ and MEBT are designed to 10 mA
  - If MI/Recycler is running/NOT running, the min IS current is 1.7 / 1mA

Regardless of the ion source current, the average linac beam current is 1 (2) mA

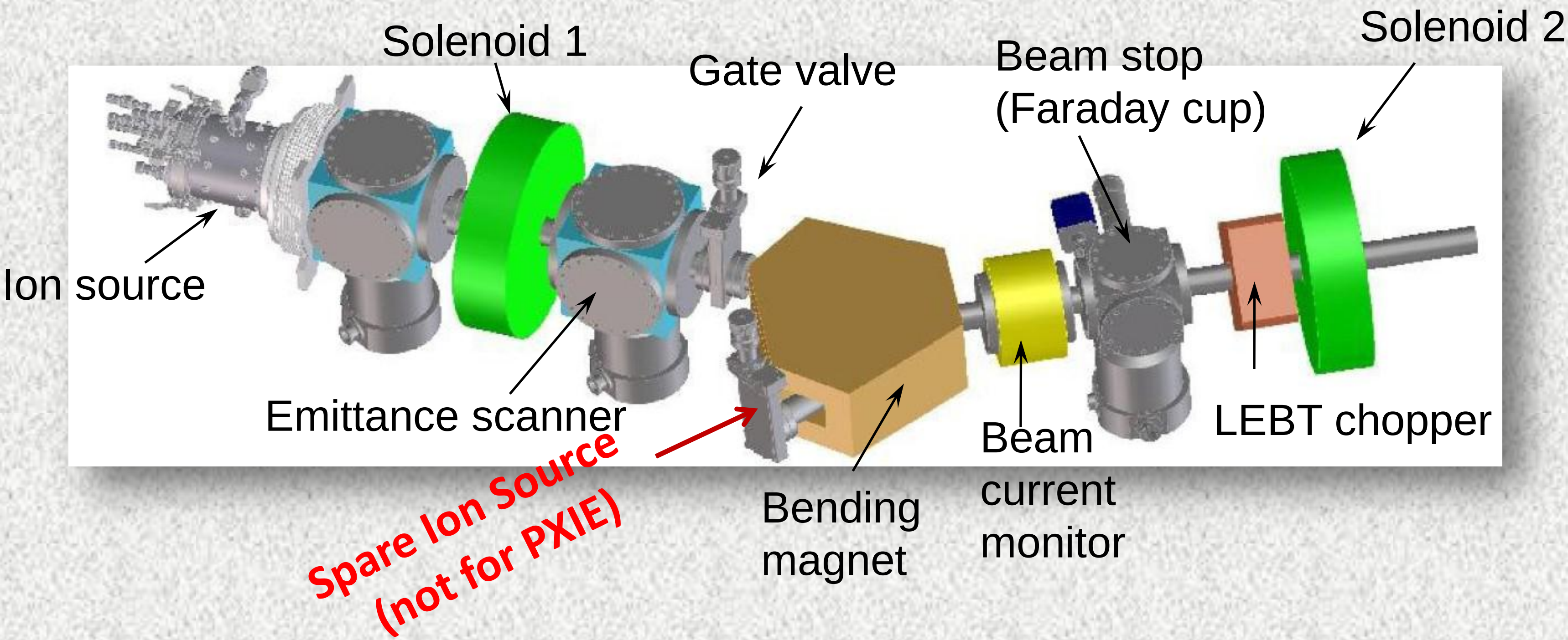
- this is achieved by a LEBT and MEBT choppers





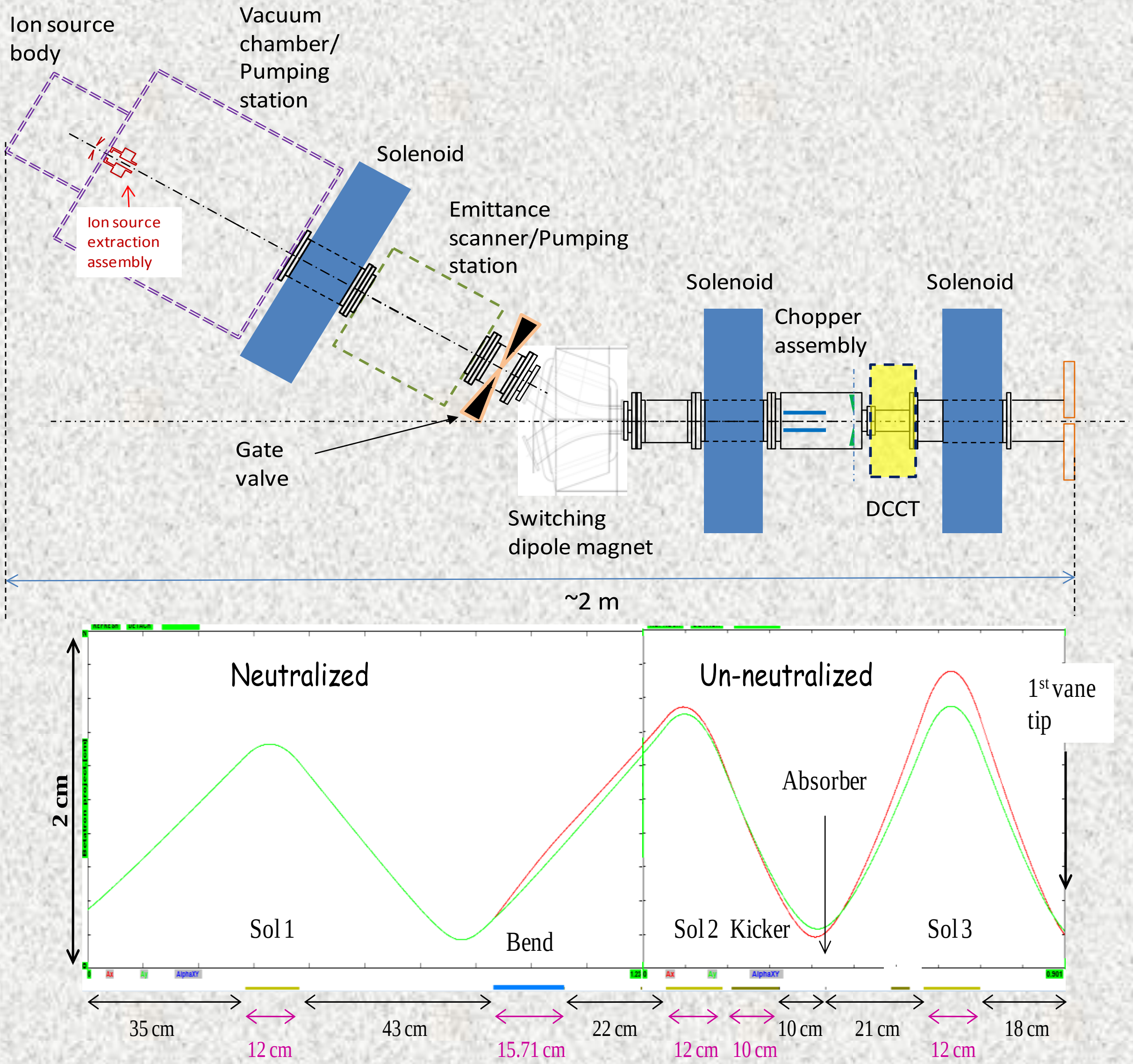


Low Energy Beam Transport



- Provides 30-keV beam transport from the Ion Source to the RFQ
  - two ion sources (not running concurrently); Dipole switch
  - Chopper (pulsed beam operation during commissioning)
  - Diagnostics and machine protection

LEBT (continue)



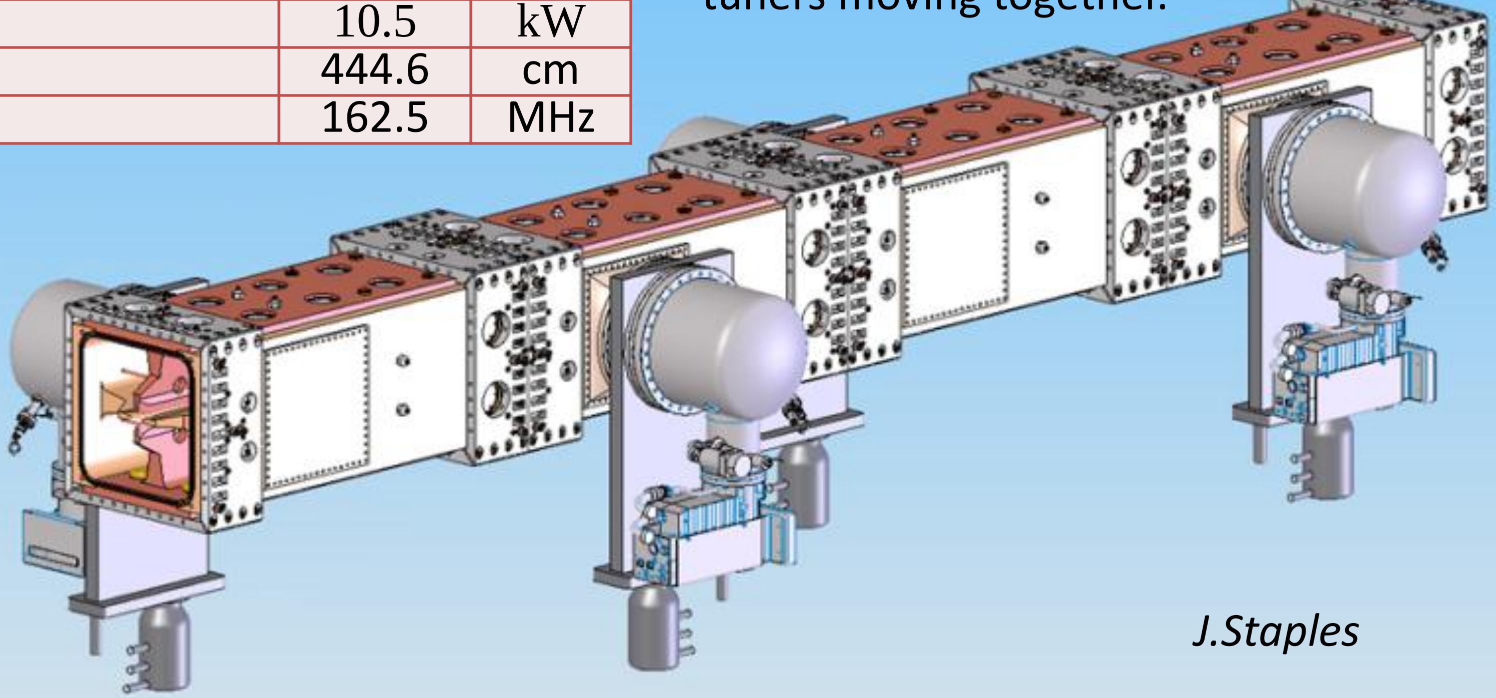
Longer LEBT option (3 solenoids):

- implementation of several diagnostics, in particular after the chopper.
- avoid re-neutralization (and transition effects)
- Beam optics in LEBT.

RFQ design (LBNL)

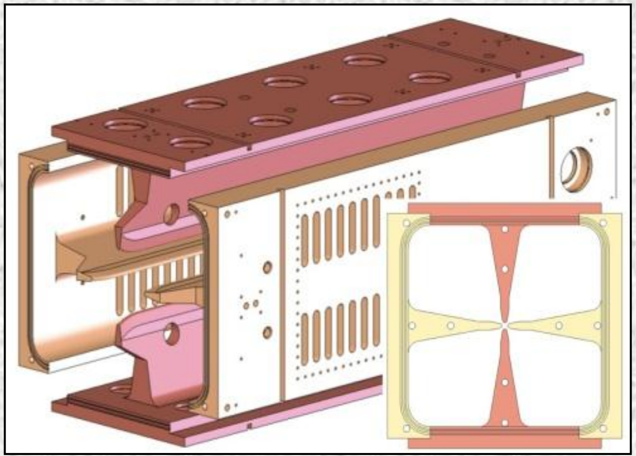
Parameter	Value	Units
Ion type	H-	
Beam current (nom/range)	5 (1-10)	mA
Trans. emitt. (rms, norm)	<0.25	µm
Long. emitt. (rms)	0.8-1.0	keV-ns
Input energy	30	keV
Output energy	2.1	MeV
Vane-vane voltage	60	kV
RF power	100	kW
Beam Power	10.5	kW
Length	444.6	cm
Frequency	162.5	MHz

- **32 pi-mode stabilizers**, 4 pairs in each module separate the dipole frequency to 17 MHz above the 162.5 MHz quadrupole frequency
- **80 tuners**, 20 in each quadrant have a diameter of 6 cm, a nominal insertion of 2 cm, and a tuner sensitivity of 170 kHz/cm, all tuners moving together.

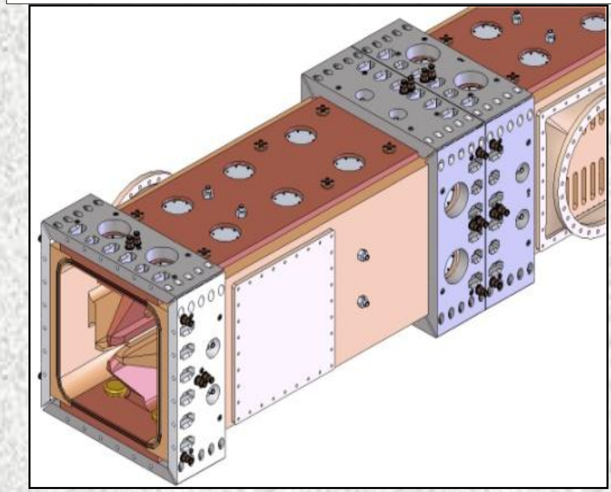


J.Staples

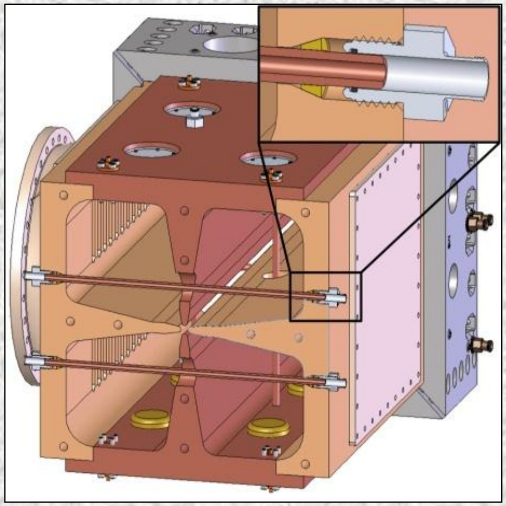
RFQ mechanical design



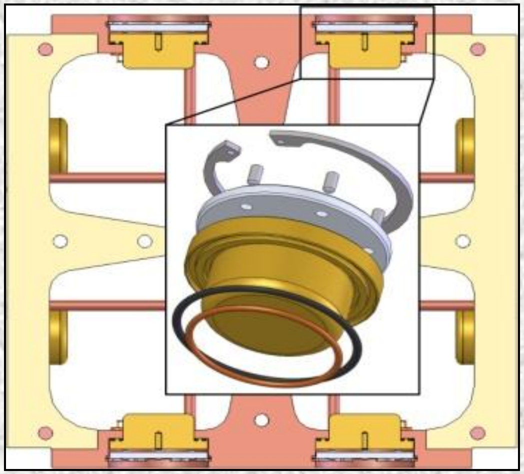
Exploded (1/4) 4-vane module



RFQ modules connected by joint plate method

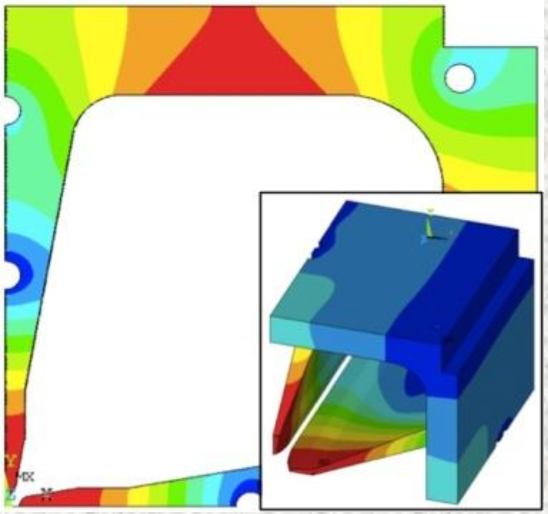


Pi-mode rod
shifts dipole mode
+17 MHz up



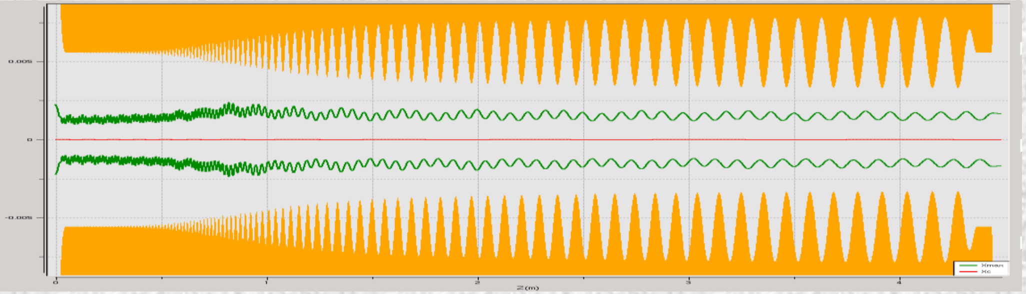
Fixed slug tuner

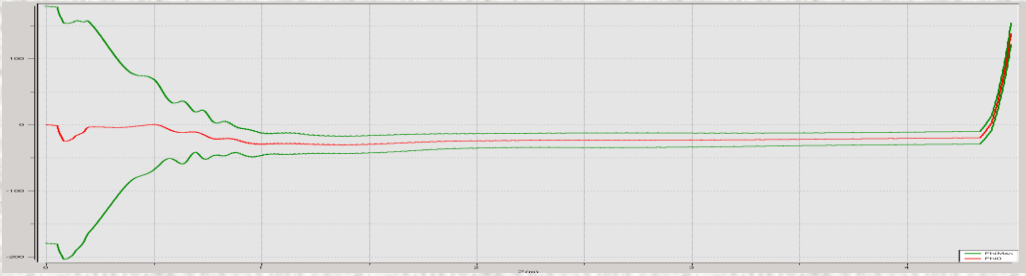
Linear power density =137 W/cm
Peak heat flux = 0.7 W/cm^2.
Tmax = 25°C

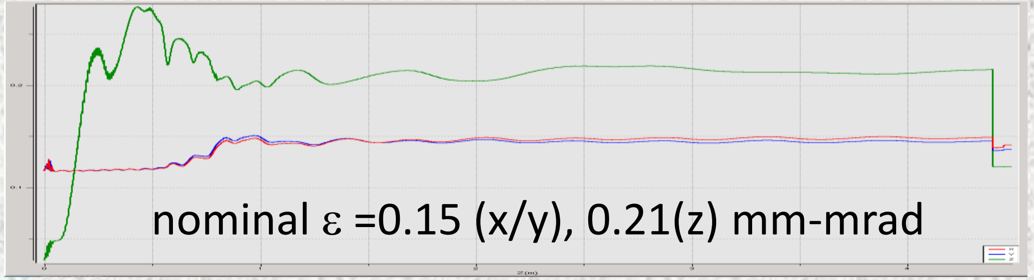


RFQ beam dynamics

- Design done in PARMTEQ (J.Staples)
- Cross-check: TRACK (3D field-map) and Toutatis
- Errors and mismatch studies (PARMTEQ and Toutatis)

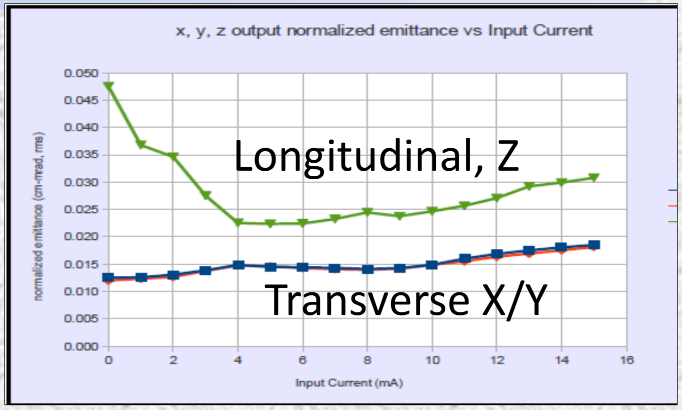


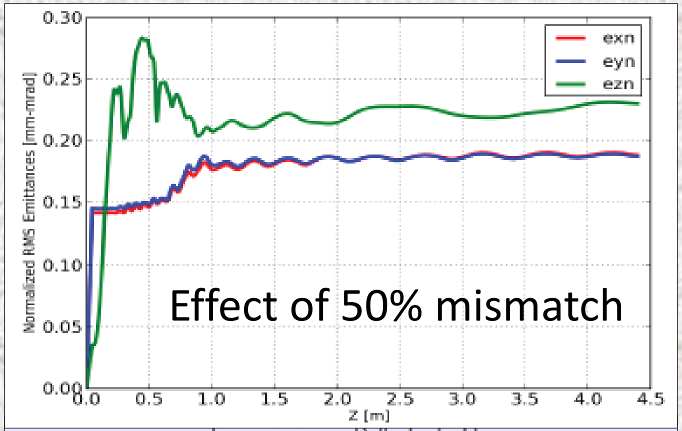




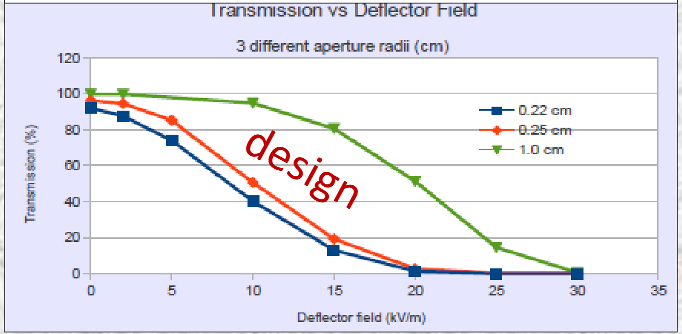
nominal ε =0.15 (x/y), 0.21(z) mm-mrad

Partially chopped beam





Effect of 50% mismatch



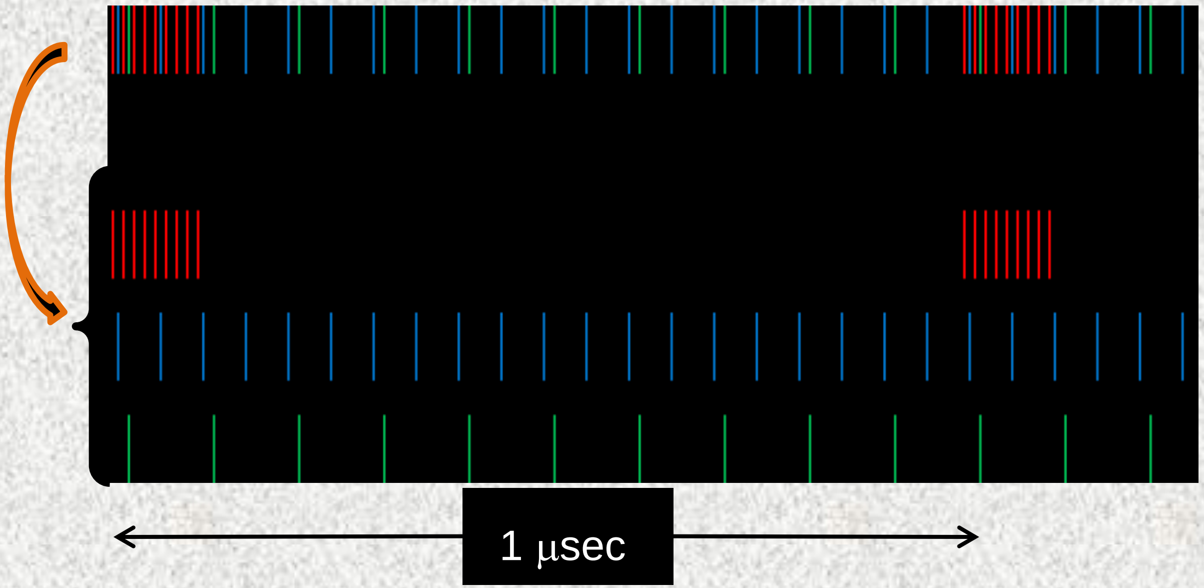
Operating Scenario for 3 GeV CW Linac

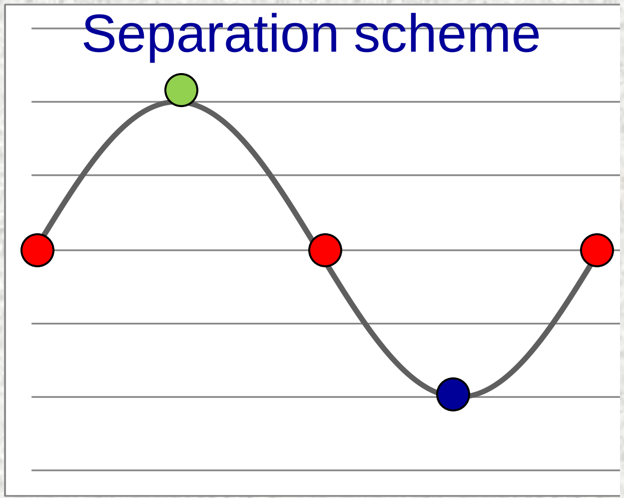
Ion source and RFQ operate at 4.4 mA

77% of bunches are chopped @ 2.1 MeV ⇒ maintain 1 mA over 1 μsec

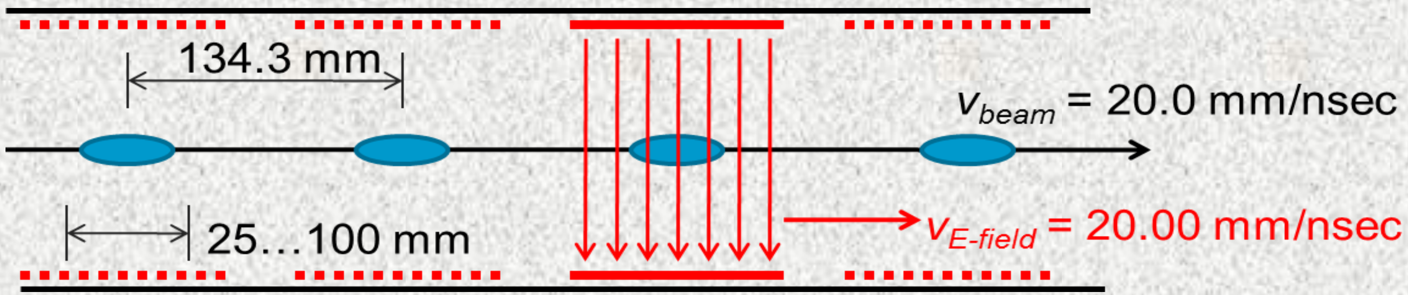
1 μsec period at 3 GeV

Kaon pulses (17e7) 20 MHz	1540 kW
Nuclear pulses (17e7) 10 MHz	770 kW
Muon pulses (17e7) 80 MHz, 100 nsec burst @ 1 MHz	700 kW





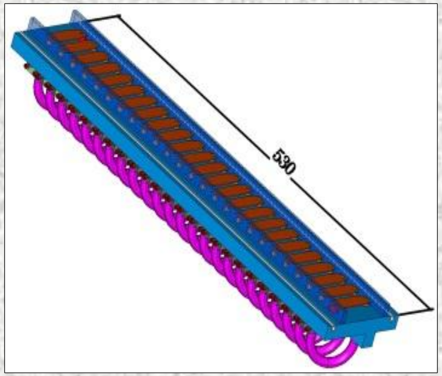
Chopper R&D

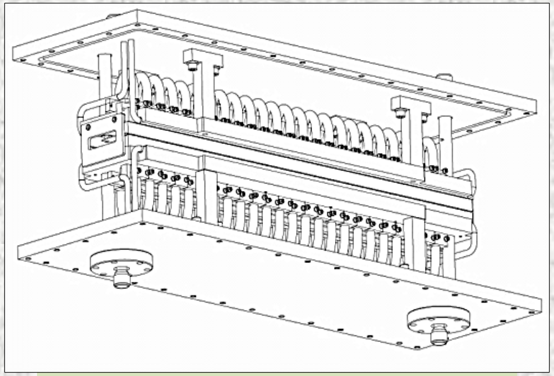


- Kicker
  - Two versions are being pursued: 50 and 200 Ohm
  - Each version must fit into a 65-cm drift: 2 pairs 25-cm long, 16 mm gap
- Kicker driver
  - Broad-band, 500 V, ~2 ns rise/fall time, 30 MHz average pulse rate
  - AC-coupled rf amplifier (50-Ohm) or DC-coupled pulser (200-Ohm)
- Beam absorber
  - 20 kW max. dissipated beam power
  - Issues: high power density, sputtering, high gas load

Wide-band Kicker designs

50 Ω planar electrodes, connected in vacuum by coaxial cables with the length providing necessary delays



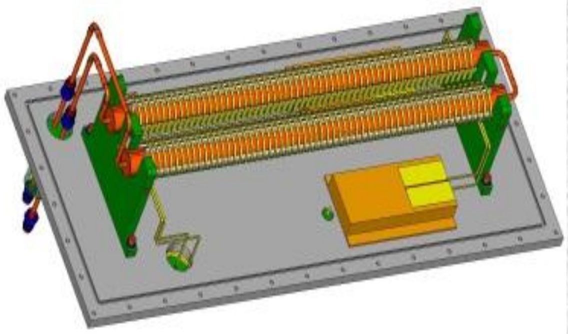


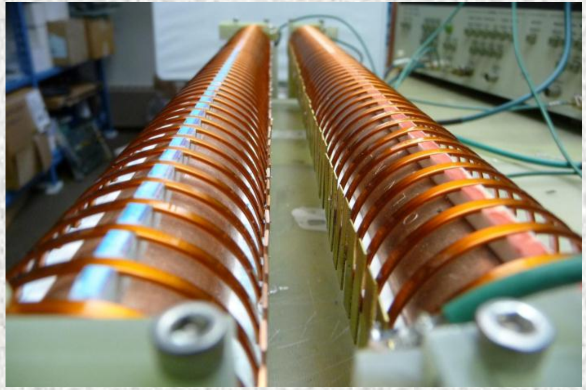
Mechanical schematic of a 50-Ohm kicker

Objectives

- Two +/- 250 Volts kicker plates
- DC coupled drive to the kicker
- Pulse: ~2 ns rise time, ~1.5 ns wide flattop
- Handle power dissipation for high duty factor (140 W)
- Support variable high duty factor waveforms
- Handle rep. rates, ~30 MHz

200 Ω helixes



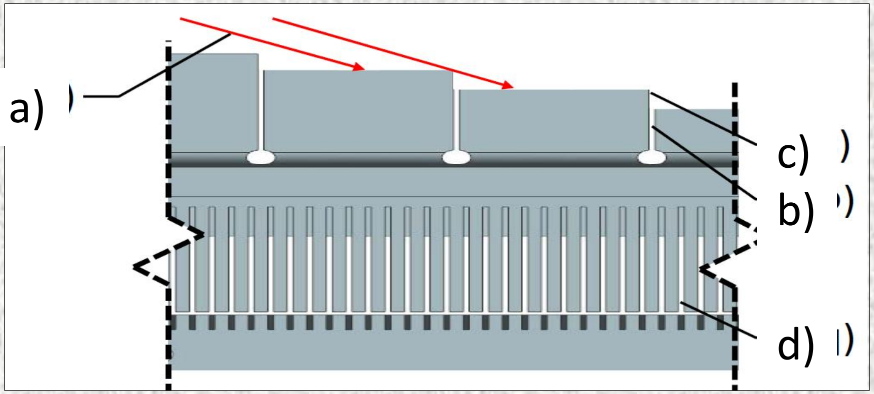


Two helixes

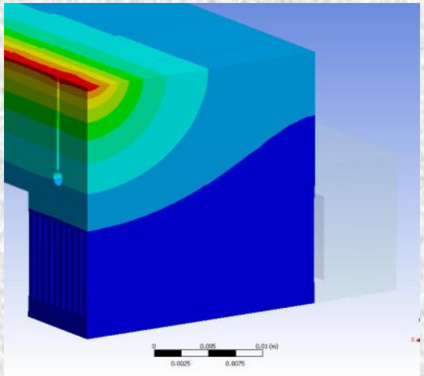
Each helix is a flat wire wound with the 8.5mm helix pitch around a 28.6 mm OD copper grounded tube.

MEBT Absorber

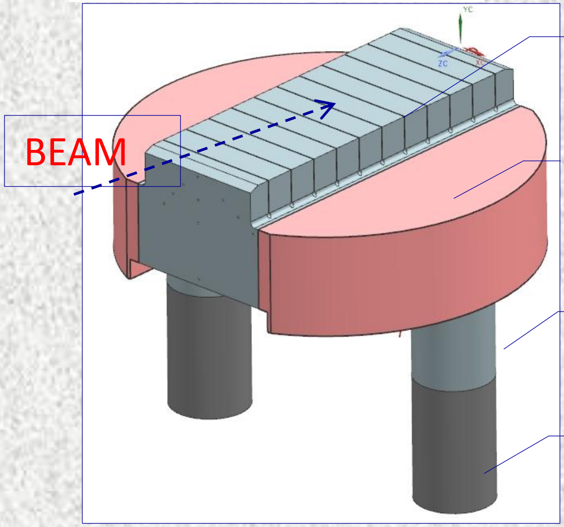
(a) beam incident on surface 29mrad,
(b) axial stress relief slits,
(c) shadowing step increment (not in scale)
(d) 0.3x1 mm^2 pitch water cooling channels.



Conceptual design of the MEBT absorber.
Length = 40 cm



Max temp 1056°C on the beam absorbing surface

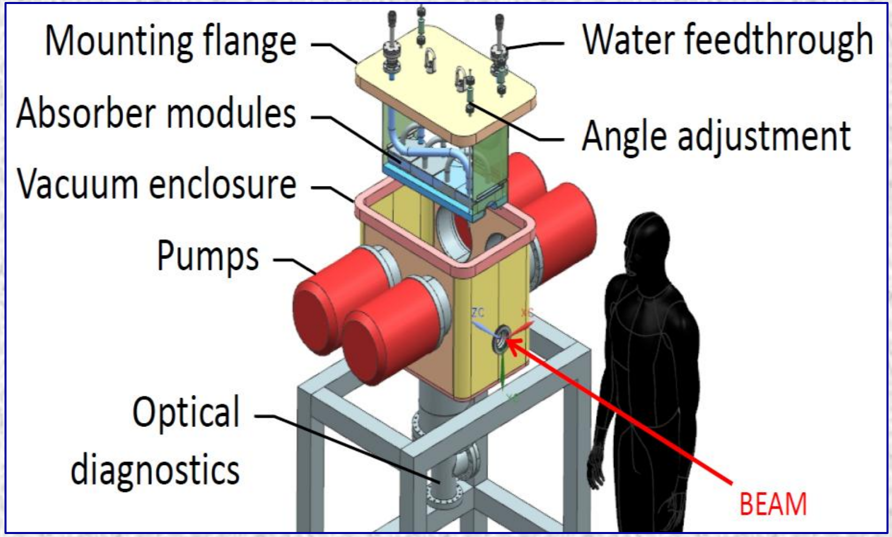


Absorber Surface (Mo TZM)

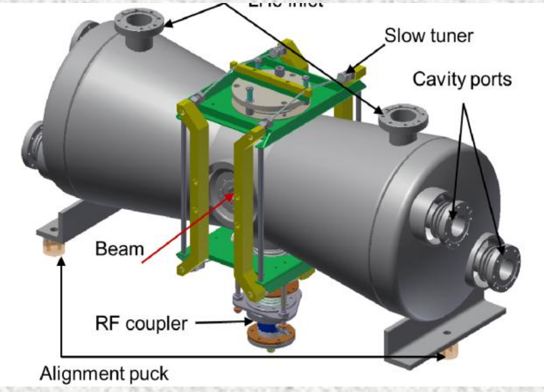
Manifold/Mounting Surface (Mo TZM)

Inboard Water tube (Mo TZM)

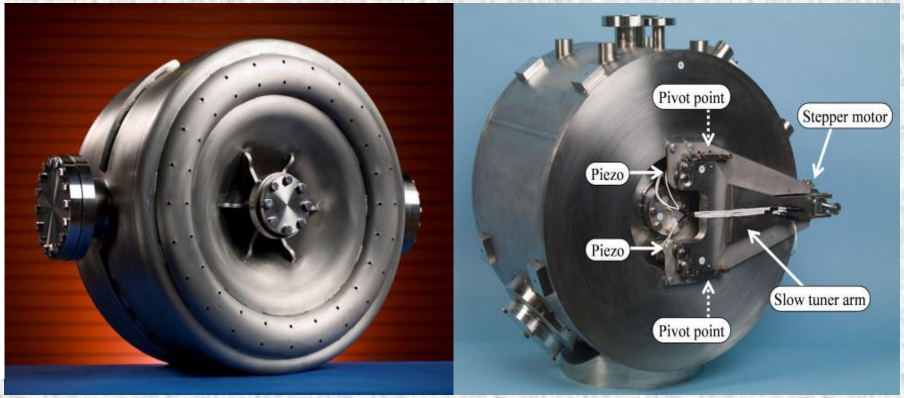
Outboard Tube (Titanium)



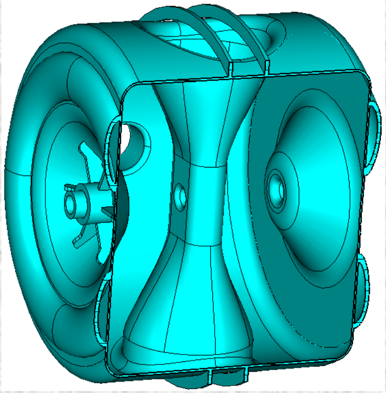
RF Cavities of the Project-X Front-end



HWR model, 162.5 MHz (ANL)



SSR1 prototypes and tests, 325 MHz (FNAL)

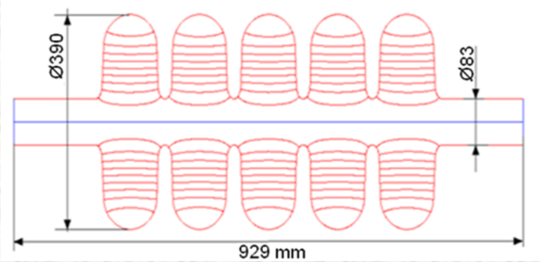


SSR2 model, 325 MHz (FNAL)

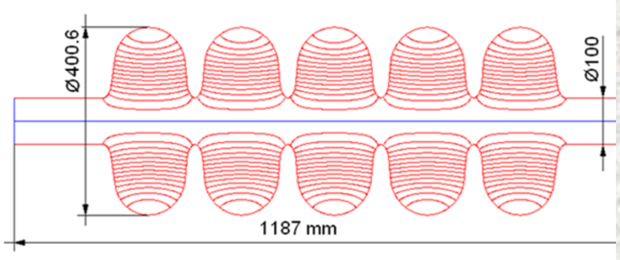
cavity type	β_{geom}	Freq, MHz	Beam pipe ø, mm	E_{acc}, MV/m	$V_{acc,\ max}$ MeV	E_{pk} MV/m	B_{pk} mT	R/Q, Ω	G, Ω	Q_0, $\times 10^{10}$	Power losses W
HWR*	β=0.112	162.5	33	8.2	1.7	38	41	272	47.7	0.5	2.1
SSR1**	β=0.215	325	30	12	2.4	46	70	242	84	0.8	3
SSR2#	β=0.47	325	40	11.4	5	40	70	290	113	1	8.5

- *P.Ostroumovet al., WEPPC039,IPAC12, **T.N. Khabiboulline et.al, WEPPC035, IPAC12; #P.Berrutti, SSR2 report
- Assumption for RF power losses at 2K: $R = R_{res} + R_{BCS} = 10\ n\Omega$

650 MHz and ILC cavities



650 MHz: β=0.61



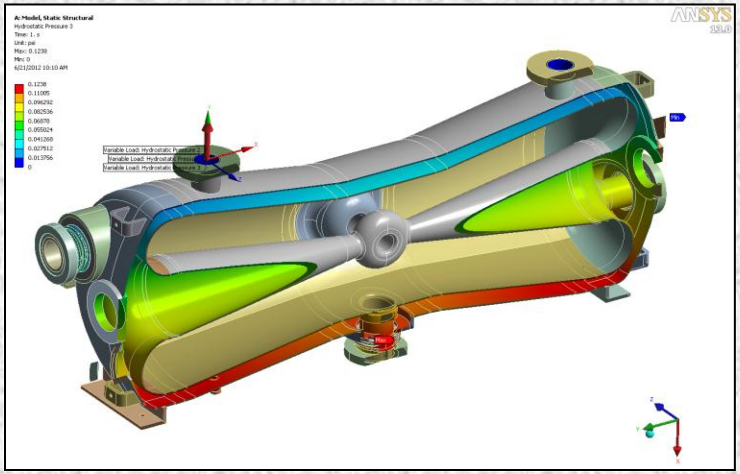
650 MHz: β=0.9

1.3 GHz ILC

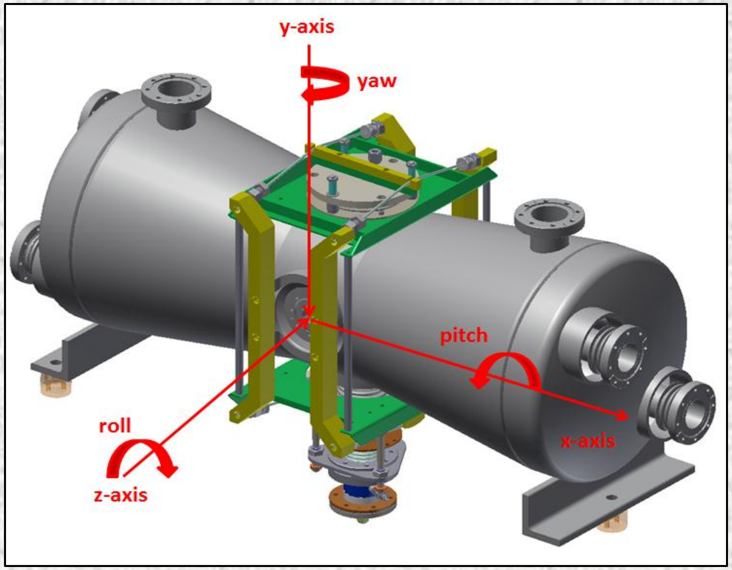
Parameter		**LE650**	**HE650**	**ILC**
β_geom		0.61	0.9	1
Cavity Length = $n_{cell} \cdot \beta_{geom} \lambda/2$	mm	703	1038	1038
R/Q	Ohm	378	638	1036
G-factor	Ohm	191	255	270
Max. Gain/cavity (on crest)	MeV	11.7	17.7	17.2
Acc. Gradient	MV/m	16.6	17	16.9
Max surf. electric field	MV/m	37.5	34	34
Max surf. magnetic field,	mT	70	61.5	72
Q_0 @ 2° K	$\times 10^{10}$	1.5	2.0	1.5
P_{2K} max	[W]	24	24	20

Table 1: HWR main parameters

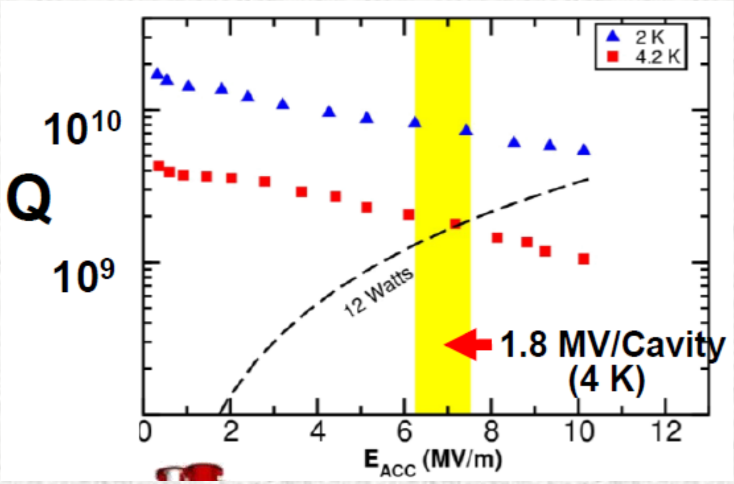
HWR design (ANL)



Donut shape geometry reduce effect of asymmetry in transverse beam dynamics



Parameter	PXIE
Frequency, MHz	162.5
Operating temperature, K	2
Optimal beta, β_{OPT}	0.11
$L_{EEF}= \beta_{OPT}\lambda$, cm	20.7
Aperture, mm	33
Accelerating voltage, MV	1.7
E_{PEAK}/E_{ACC}	4.7
B_{PEAK}/E_{ACC}, mT/(MV/m)	5.0
$G = Q_0R_S$, Ω	48
R/Q_0, Ω	272

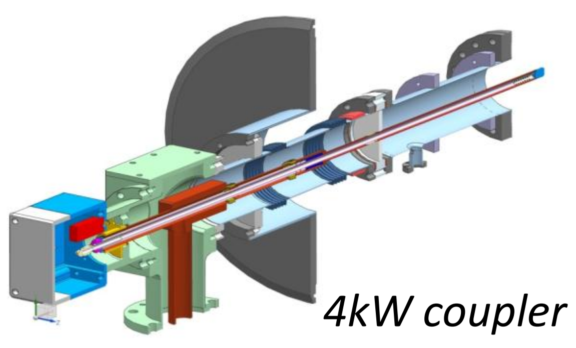


E_{acc}=8.2 MV/m
E_{pk} = 38 MV/m
H_{pk} = 41 mT

Test of 172.5 MHz HWR

SSR1 design and test

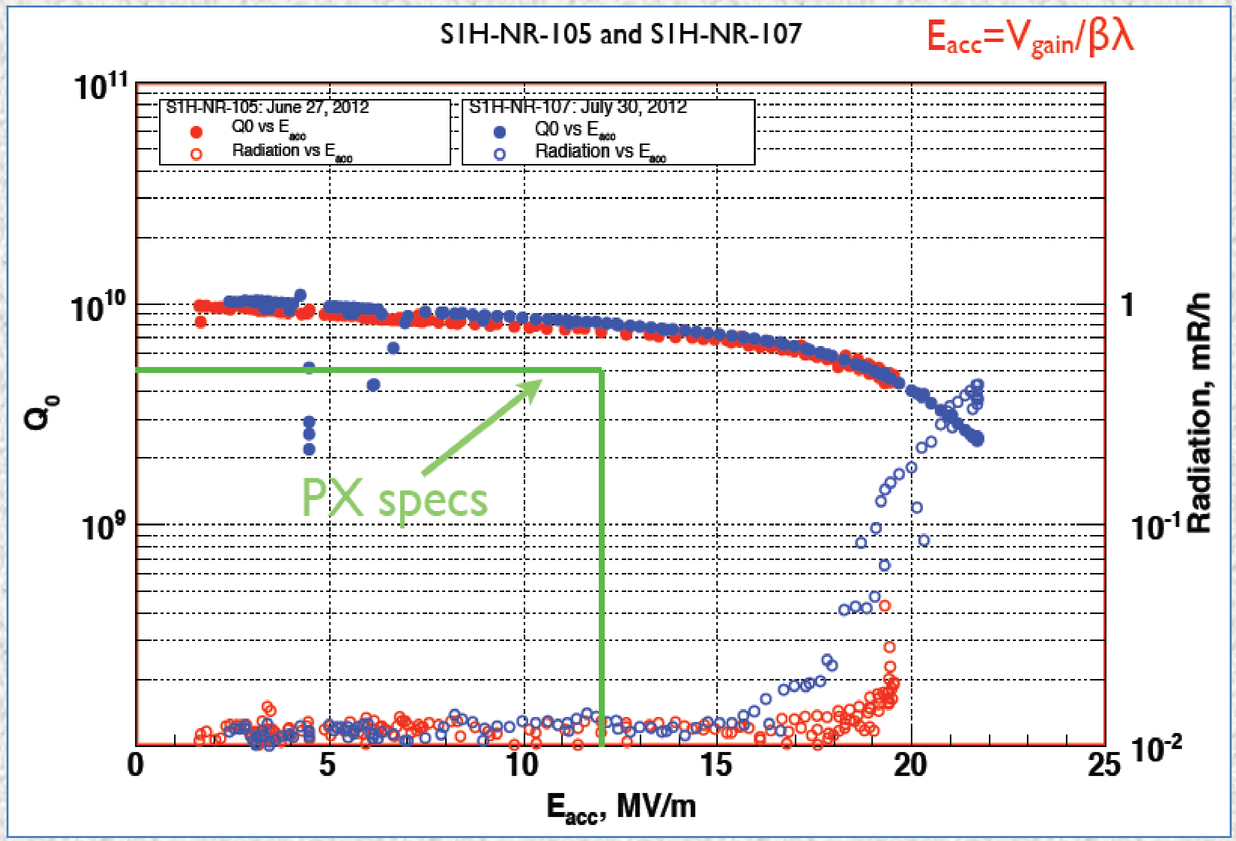
SSR1 cavity



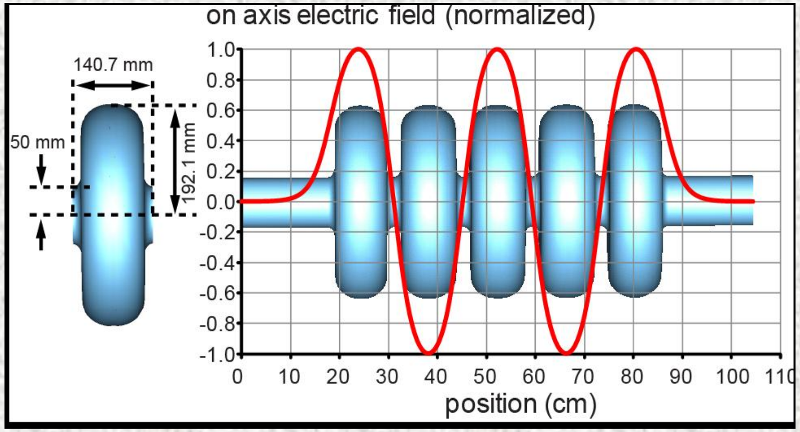
4kW coupler

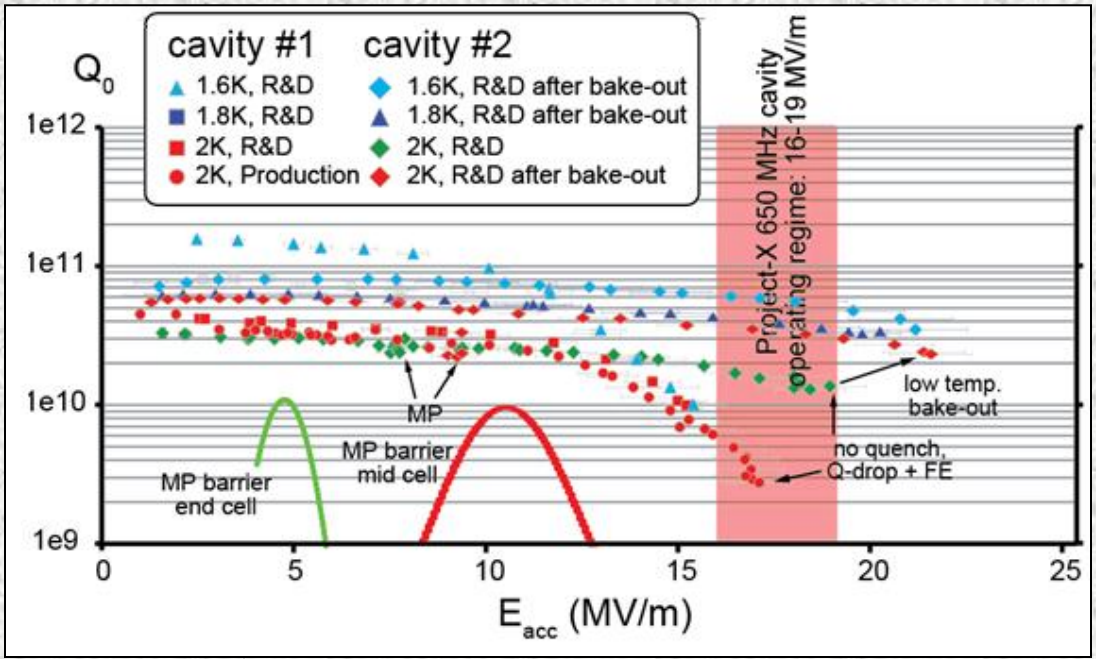
R.Kephart, TH03B03

- **10 ordered (Roark), 6 received, 2-tested**
- **Both cavities passed Project X requirements:**
  - **$E_{acc} = 12$ MV/m; $Q_0 > 5e9$**
- **Soft multipactor at 2-7 MV/m, gone after processing**



JLAB version of the 650 MHz, beta=0.61 cavity for the Project X





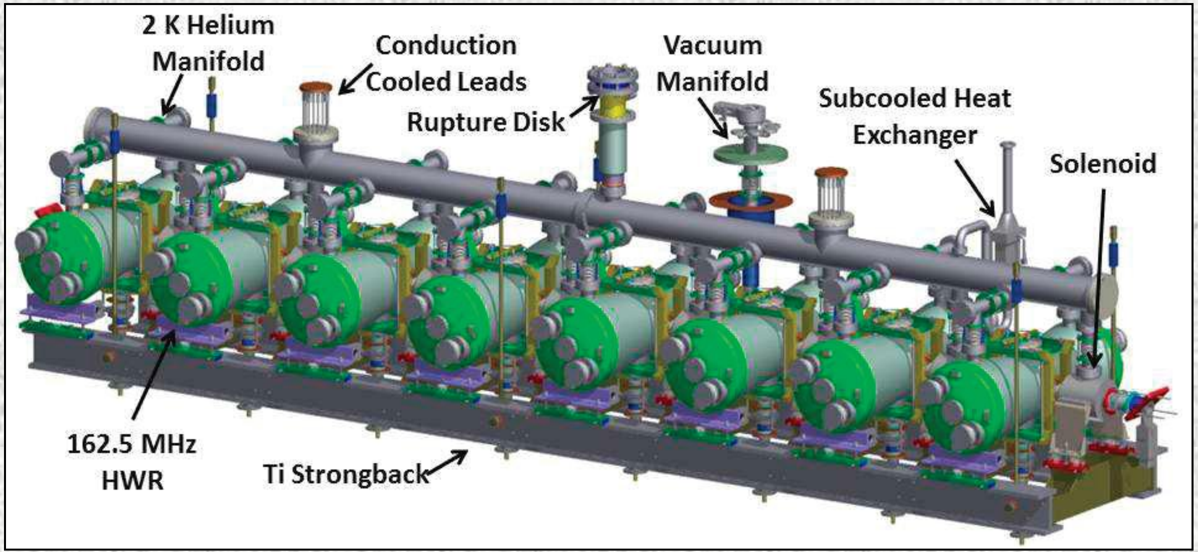
**F. Marhauser, et al, IPAC 2011*

For single-cell cavity #2:

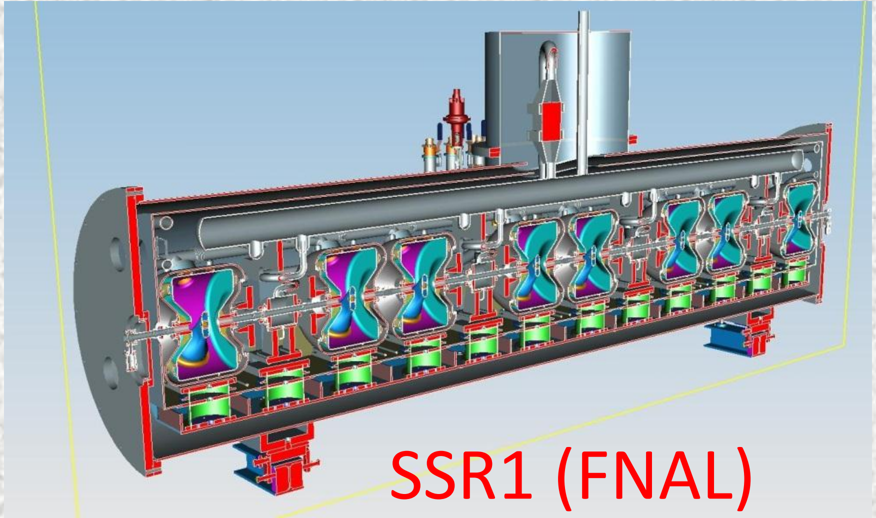
Q_0 >2e10 @17MeV/m

Need more tests and statistics

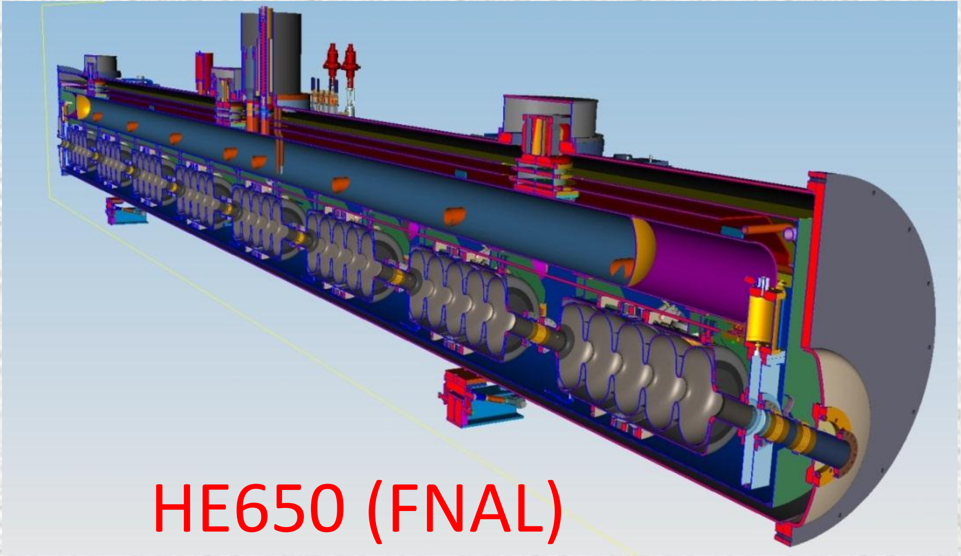
CM designs for Project X CW linac



HWR (ANL)

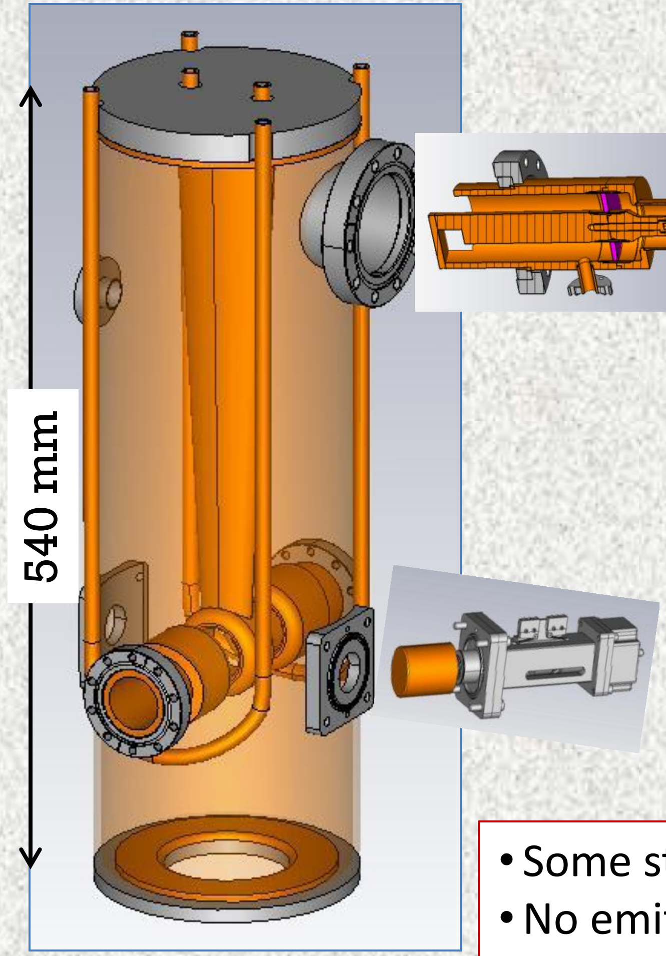


SSR1 (FNAL)
similar design for SSR2



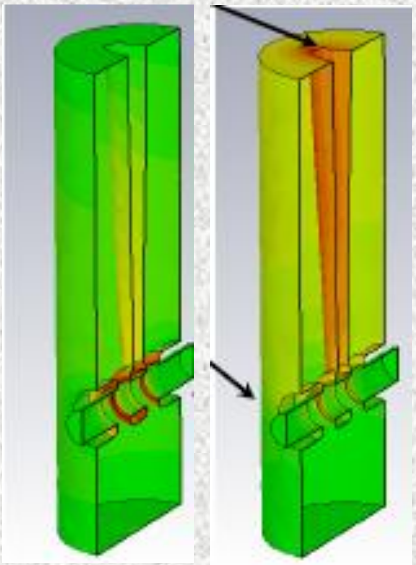
HE650 (FNAL)

QWR Bunching Cavity

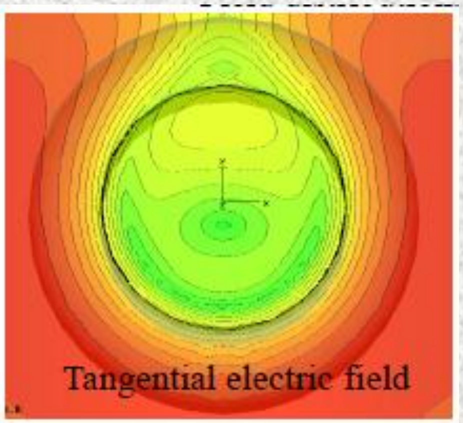


340 mm
(flange-to-flange)

Parameter	Value
Frequency, MHz	162.5
Q factor	10530
Aperture radius, mm	20
Gap, mm	2x23
Particle energy, MeV	2.1
Effect. shunt impedance, Ohm	5.3e6
R_eff/Q	503
Effective voltage, kV	70
Power loss in copper, kW	0.92
Max. elec. surface field, MV/m	4.2

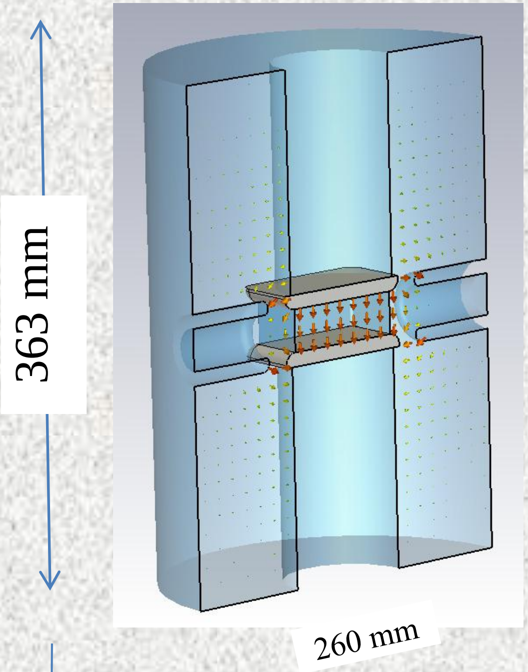

E-field H-field

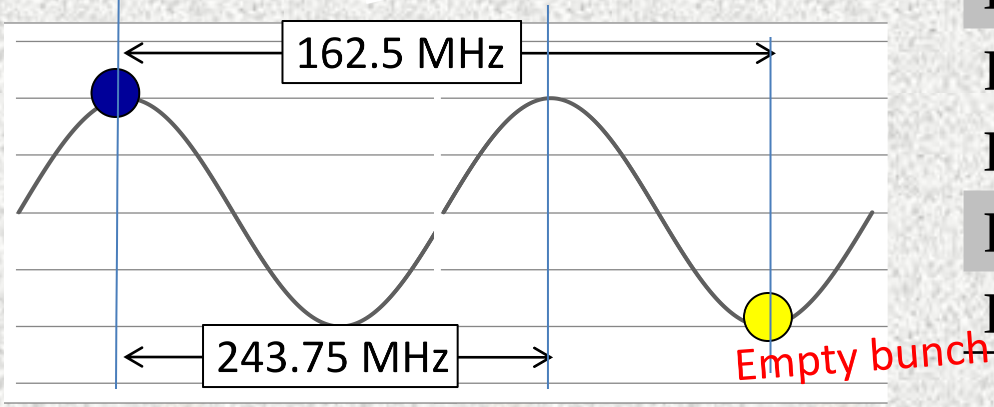
- Some steering effect from field asymmetry.
- No emittance growth is observed.
- Beam deflection is compensated if cavity is shifted down by 0.6mm.



E-field asymmetry

Normal Conducting RF separator





Parameter	Baseline
Frequency, MHz	**243.75**
Inner height, mm	363
Inner diameter, mm	260
Flange-to-flange, mm	350
Gap, mm	30
E_surf_max, MV/m	5.2
E_y_max, MV/m	3.04
Power losses, kW	**2.9**
Kick voltage, MV	1.07
Proton β (23.5 MeV)	0.22
Deflecting angle, mrad	5.0

PXIE RF system

- The PXIE RF systems will include all CW amplifiers that are intended for reuse in the Project X front end.
- The complete PXIE RF system consists of three frequencies at power levels ranging from 4 to 150 kW (total of 21 RF systems)
- At PXIE frequencies and power levels, solid-state amplifiers have been chosen for the RF power sources (compact, reliable).

RF Sources for PXIE (CW)

162.5 MHz

- ***1 RFQ 162.5 MHz – 2 x 75 kW***
- ***3 copper bunchers – 4 kW***
- ***8 SC HWR – 4 kW***

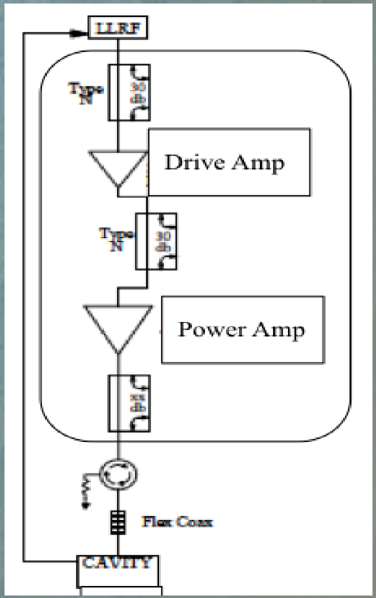
325 MHz

- ***8 SC SSR1 – 4 kW***

243.75 MHz

- ***1 copper RF separator – 7 kW***

BRUKER



Conclusions

- We have good understanding of the Project X lattice and beam dynamics.

- PXIE concept is in good shape, now highest priority.
  - *No obvious showstoppers*
  - *Design work on critical components (RFQ, Chopper, HWR and SSR1 cryomodules) is proceeding well.*

- Plan to have PXIE working at design parameters at the end of 2016.

Thank you for your attention !