CONTRIBUTION TO "THE HIGH BRIGHTNESS PHOTO-INJECTOR ELECTRON BEAM OF THE APS LINAC" PRESENTED BY YINE SUN AT THE 2018 FUTURE LIGHT SOURCE MEETING

Argonne NATIONAL LABORATORY

THE HIGH BRIGHTNESS PHOTO-INJECTOR ELECTRON BEAM OF THE APS LINAC

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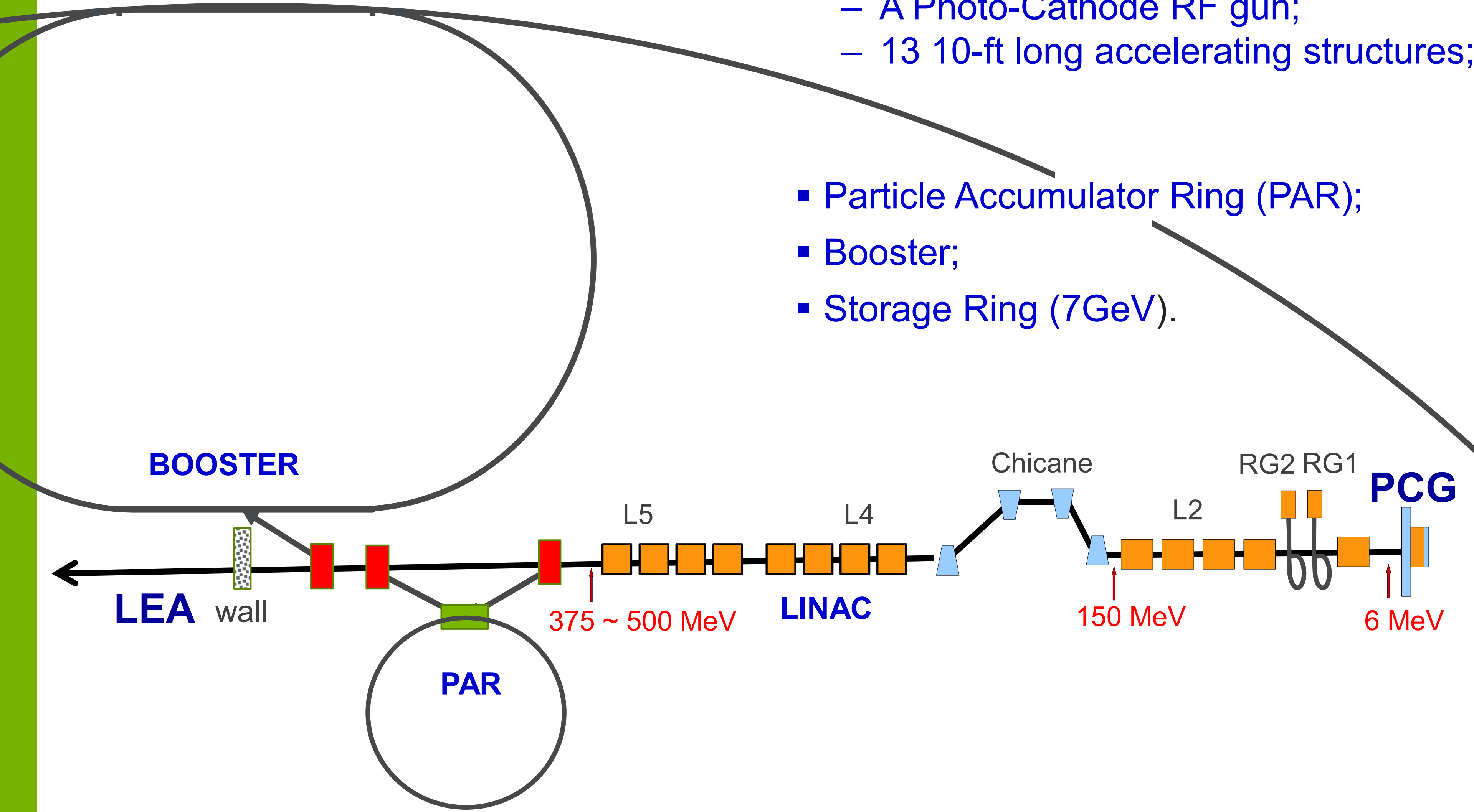
Advanced Photon Source
Argonne National Laboratory

OUTLINE

- ❑APS Accelerator Complex;
- ❑Photo-Injector Linac;
- ❑Linac Extension Area (LEA);
- ❑Interleaving Operation;
- ❑Photo-Injector Beam;
- ❑First Experiment in LEA.

APS ACCELERATOR COMPLEX

- S-band Electron Linac (375 ~ 500 MeV)
  - Two thermionic RF guns;
  - A Photo-Cathode RF gun;
  - 13 10-ft long accelerating structures;
- Particle Accumulator Ring (PAR);
- Booster;
- Storage Ring (7GeV).



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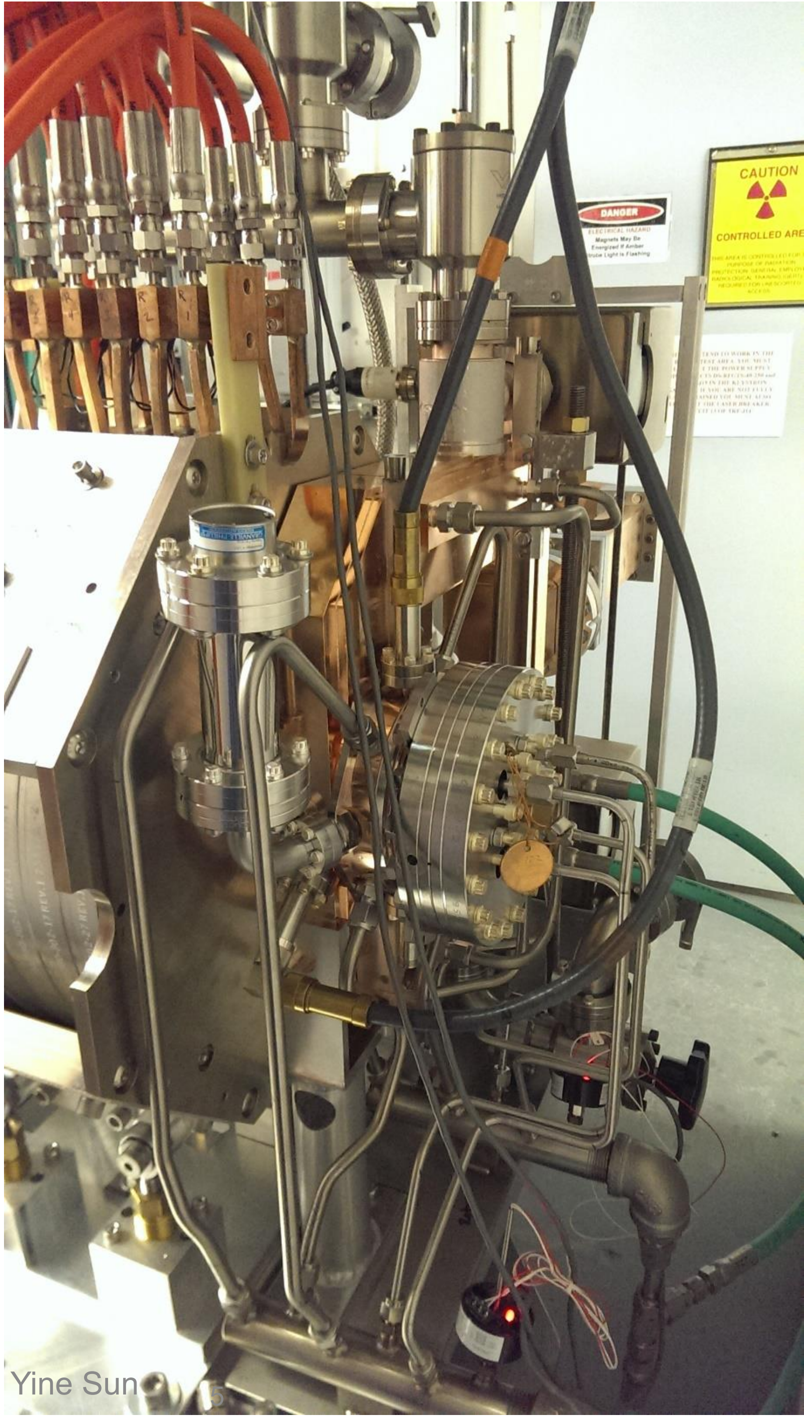
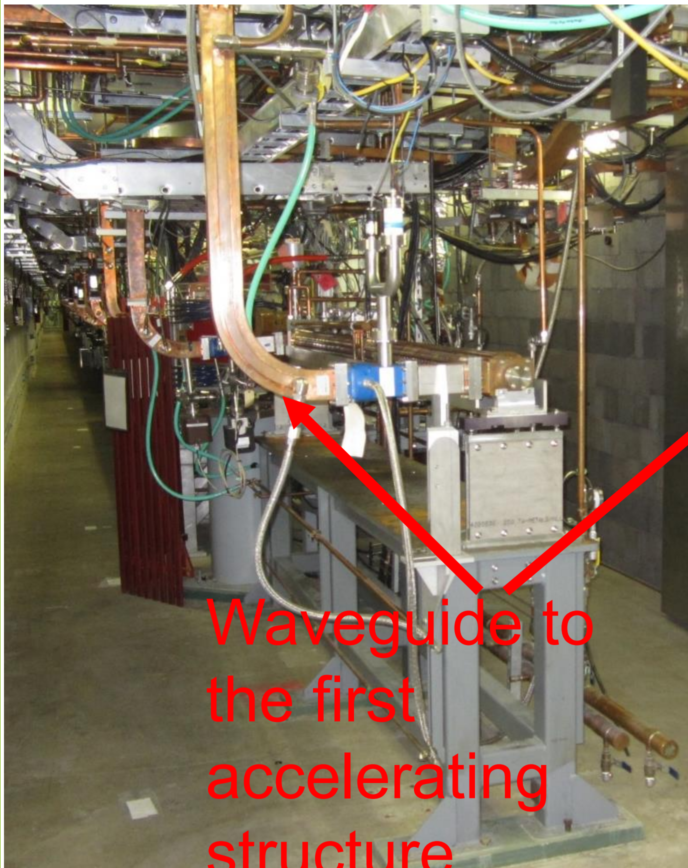
PHOTOCATHODE RF GUN

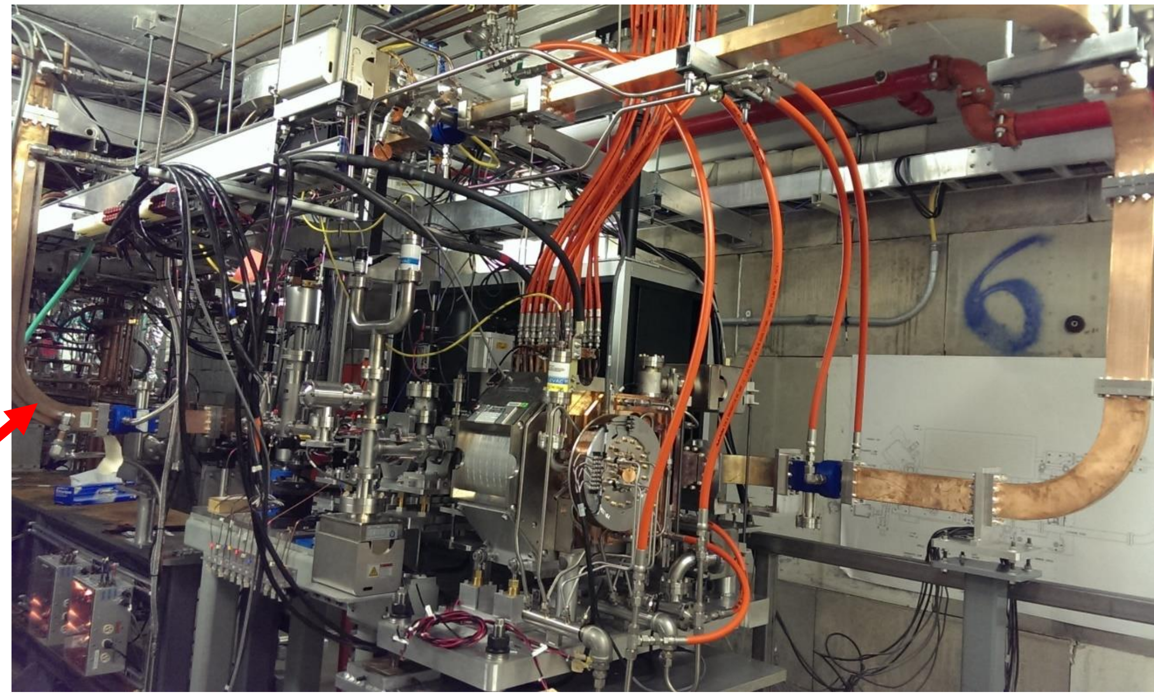
- LCLS-I type 1.6-cell 2856 MHz Gun:
  - Gun conditioned to 12 MW power (>125MV/m on cathode), 2.5 μs RF pulse and up to 30Hz repetition rate;
  - Maximum dark current per RF pulse is ~150 pC.
- Copper back plate serves as cathode:
  - QE: ~[2-4]x10^{-5} at commissioning, currently ~6.5 x10^{-5} (2018/2/5: 320 pC with 23 μJ UV laser power).
- Main/bucking solenoid for emittance compensation.



THE APS LINAC PHOTOCATHODE RF GUN (PCG)

- 09/2014: Installed at the APS linac front end;
- 12/2014: Beam commissioning in the linac;
- 03/2016: PCG beam injection into PAR/Booster/Storage Ring.
- 10/2017: Interleaving demonstrated in supporting of APS storage ring top-up operations.

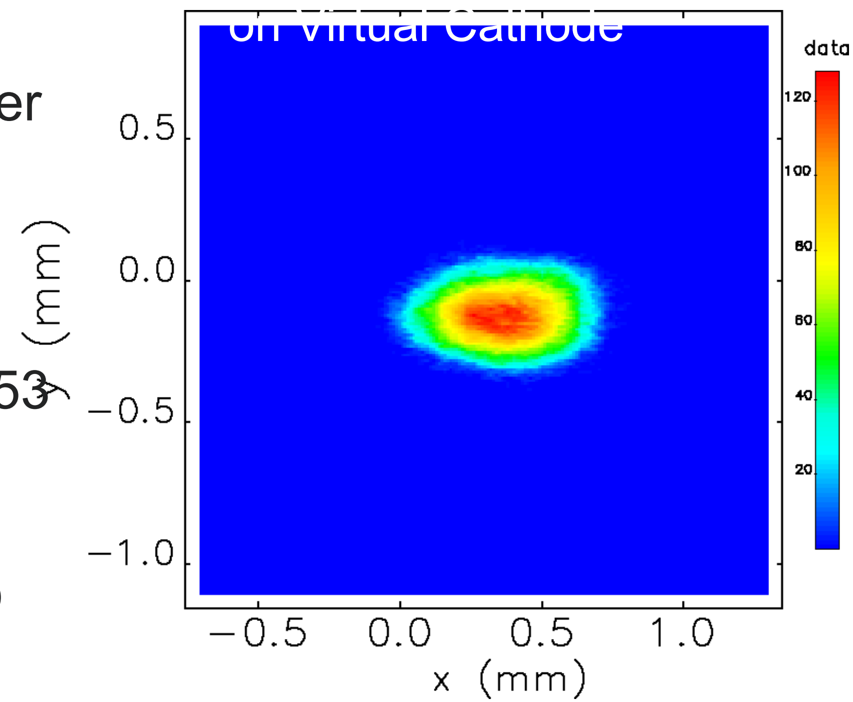




PC Gun Installed upstream of the 1st accelerating structure.

PHOTO-CATHODE DRIVE-LASER

- Nd:Glass Laser composed of both oscillator seed and regenerative amplifier (regen)
- Amplifier pumping using AlGaAs laser diodes (808 nm).
- Typically 3 mJ out of the amplifier at 1053 nm, compressed to 2-3 ps with 50% transmission efficiency
- Twice doubled using 2 1-mm-thick BBO crystals (1053→526.5→263.3 nm); maximum overall conversion efficiency: 12%
- Rep rates: 2-30 Hz
- 3% Nd-doped Brewster-cut rods 4-mm diam., 75-mm length
- TEM_{00} elliptical output



	Center of mass (mm)	rms width (mm)
X	0.3700	0.1645
Y	-0.1093	0.0976

After laser shaping, nominal UV energy on cathode ~25μJ/pulse.

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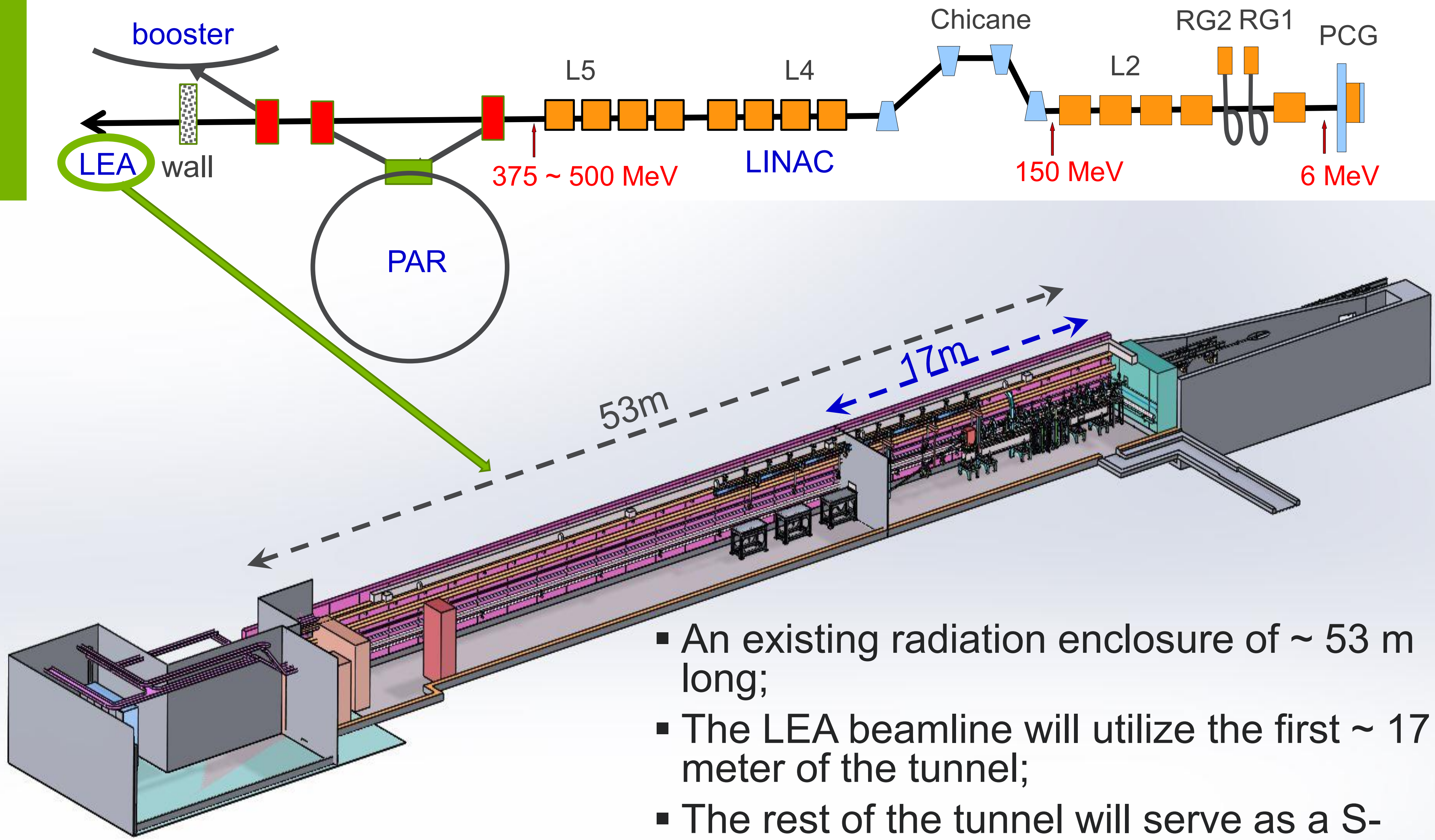
- ❑First Experiment in LEA.

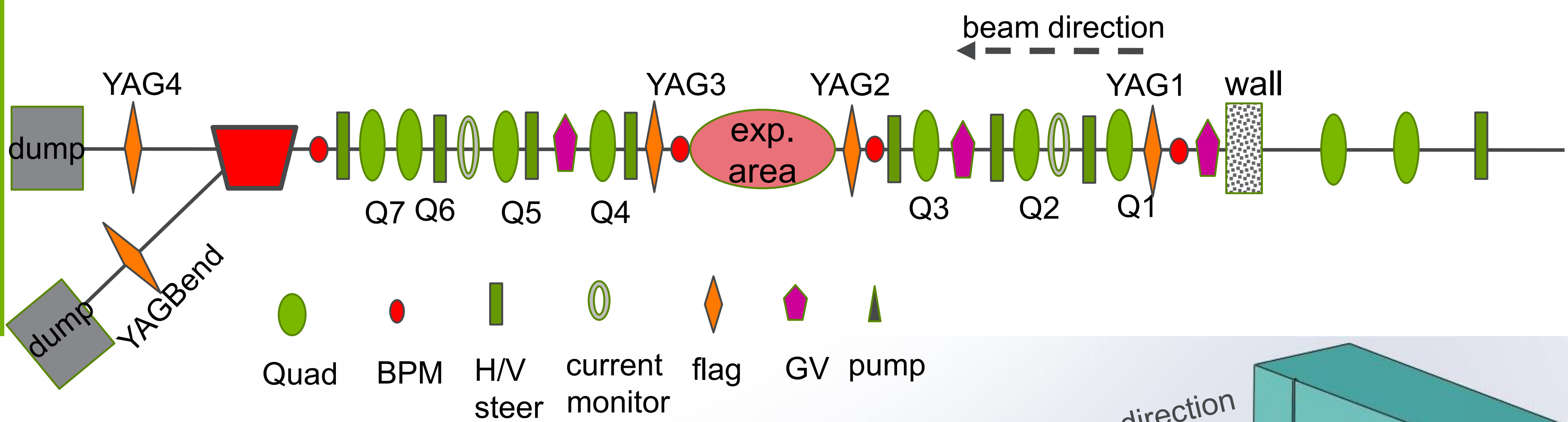
LEA: LINAC EXTENSION AREA

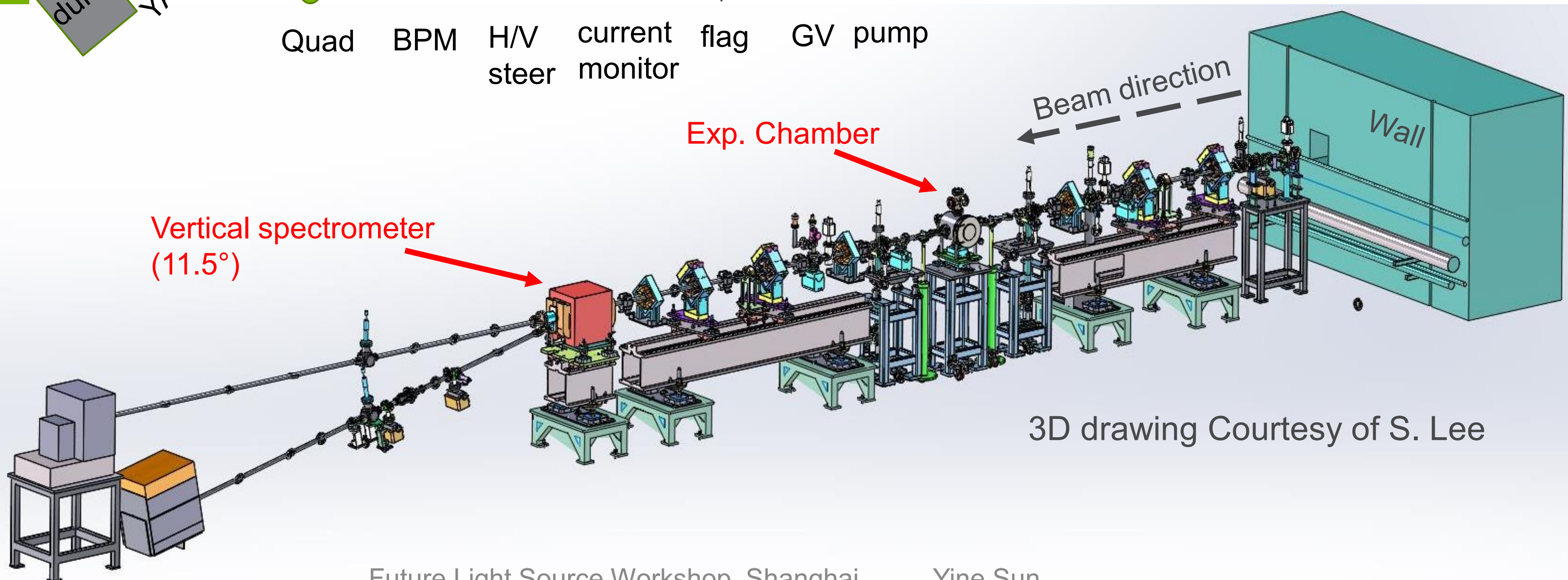


- An existing radiation enclosure of ~ 53 m long;
- The LEA beamline will utilize the first ~ 17 meter of the tunnel;
- The rest of the tunnel will serve as a S-band RF test stand.

LEA BEAMLINE

- A new beamline utilizes the high brightness photo-injector beam for advanced R&D for accelerator technology and beam physics;
- An experimental area is incorporated into the beamline.





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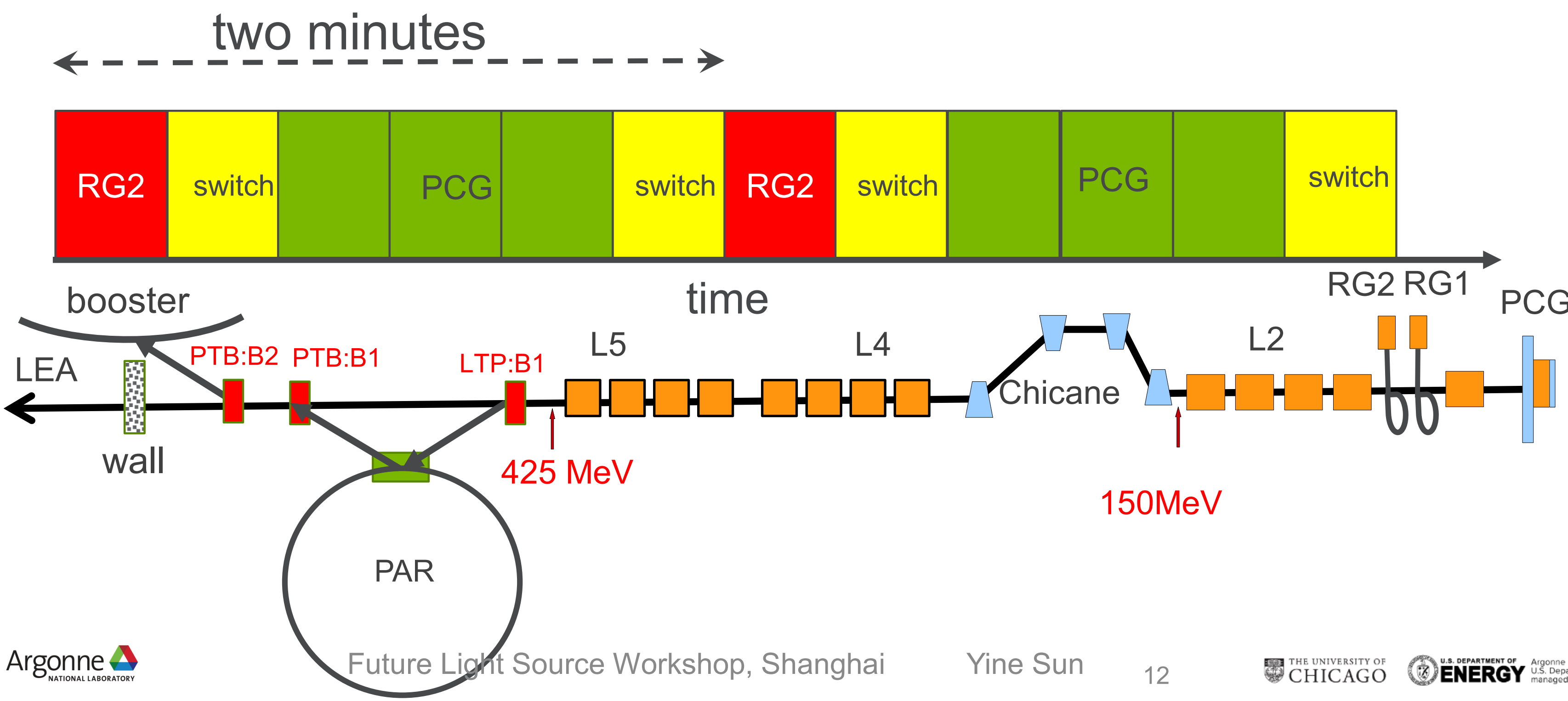
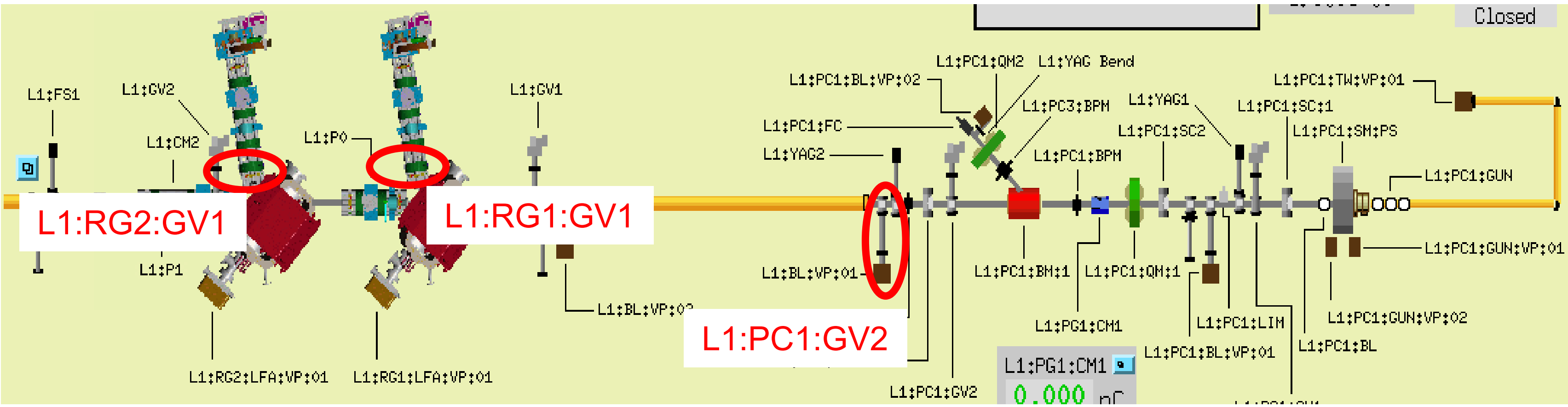
LINAC INTERLEAVING OPERATION

- During storage ring top-up operation, most of the time the Linac is needed for ~20 seconds every two minutes to inject the RG2 beam into PAR;
- There is no beam in the linac during rest of the two minutes → PCG beam can be accelerated through and transported to LEA;
- **Interleaving Operation** of the RG2 and PCG beams in the APS linac.
  - If RG1 is providing beam to the LINAC, there will be no interleaving.

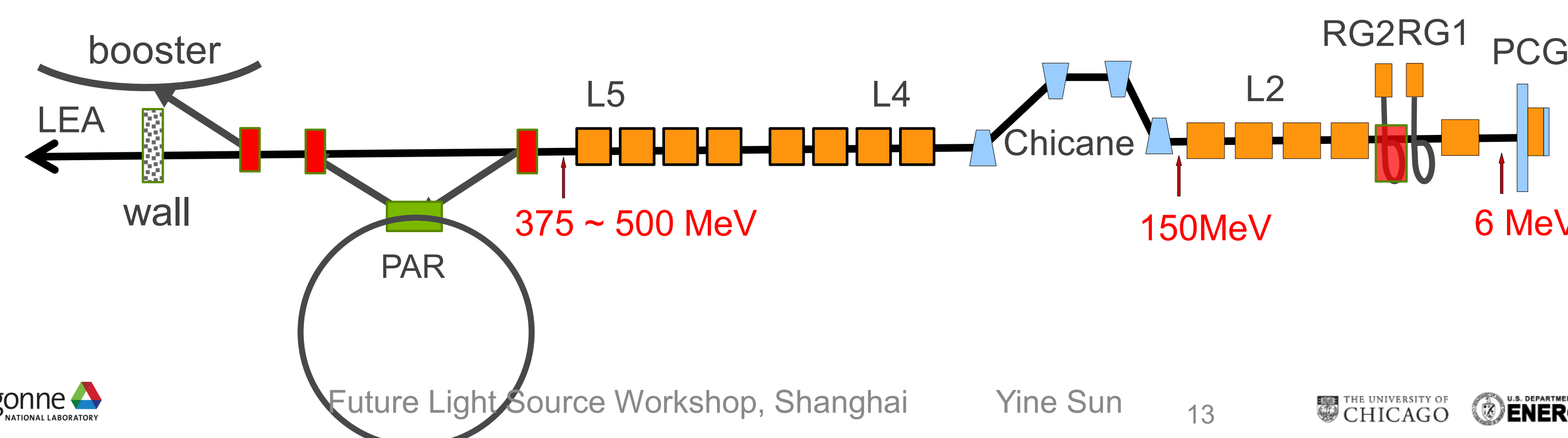


LINAC MODIFICATIONS FOR INTERLEAVING

- Gate valves for PCG and RG2 beams need to remain open simultaneously.
  - Radiation Safety/Controls systems are modified to allow interleaving operations.

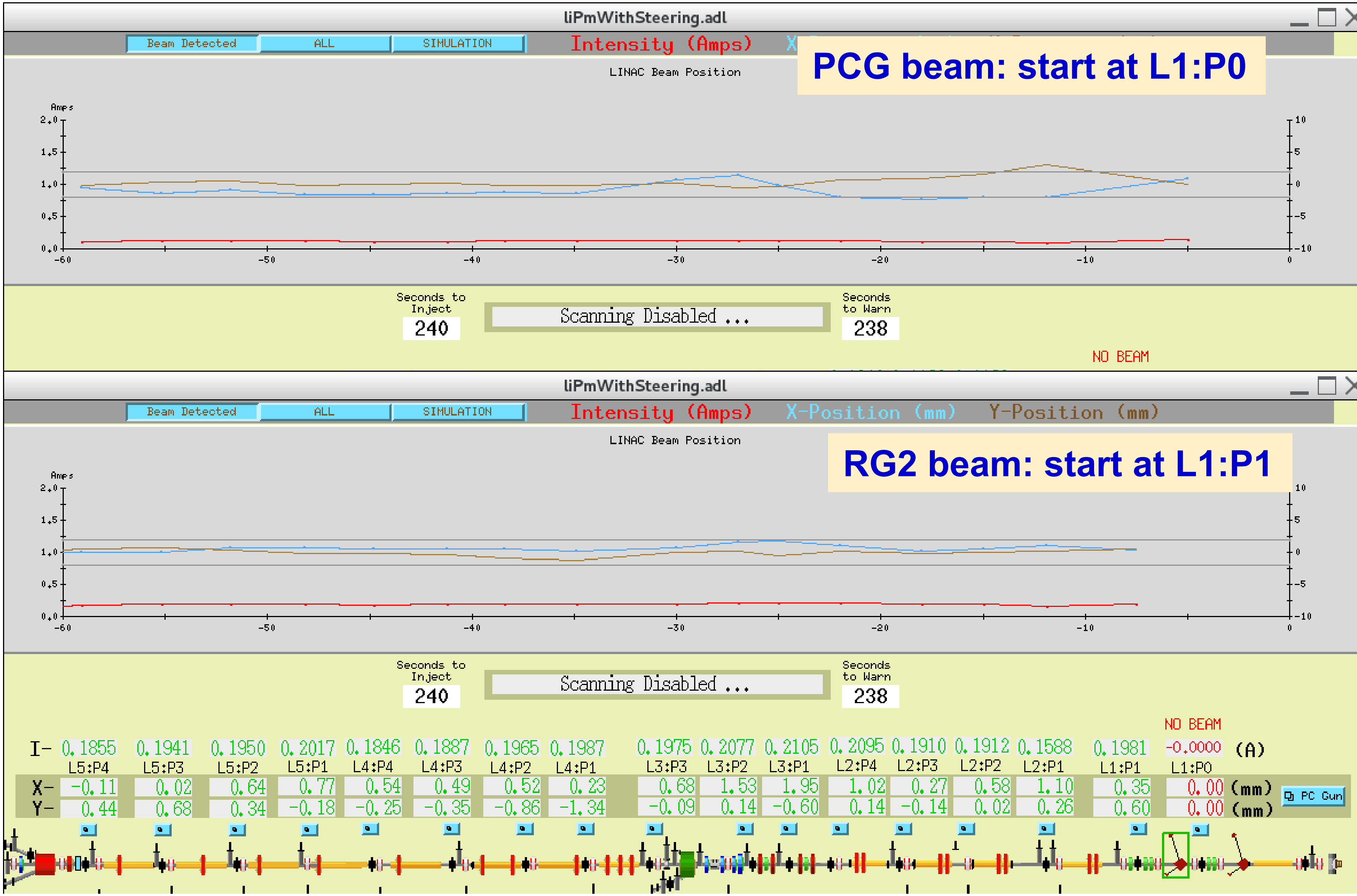


- Beam Trajectory Control: Interleaving operation of four trajectory switching magnets.
- Interleaving RF timing, phase, and amplitude.

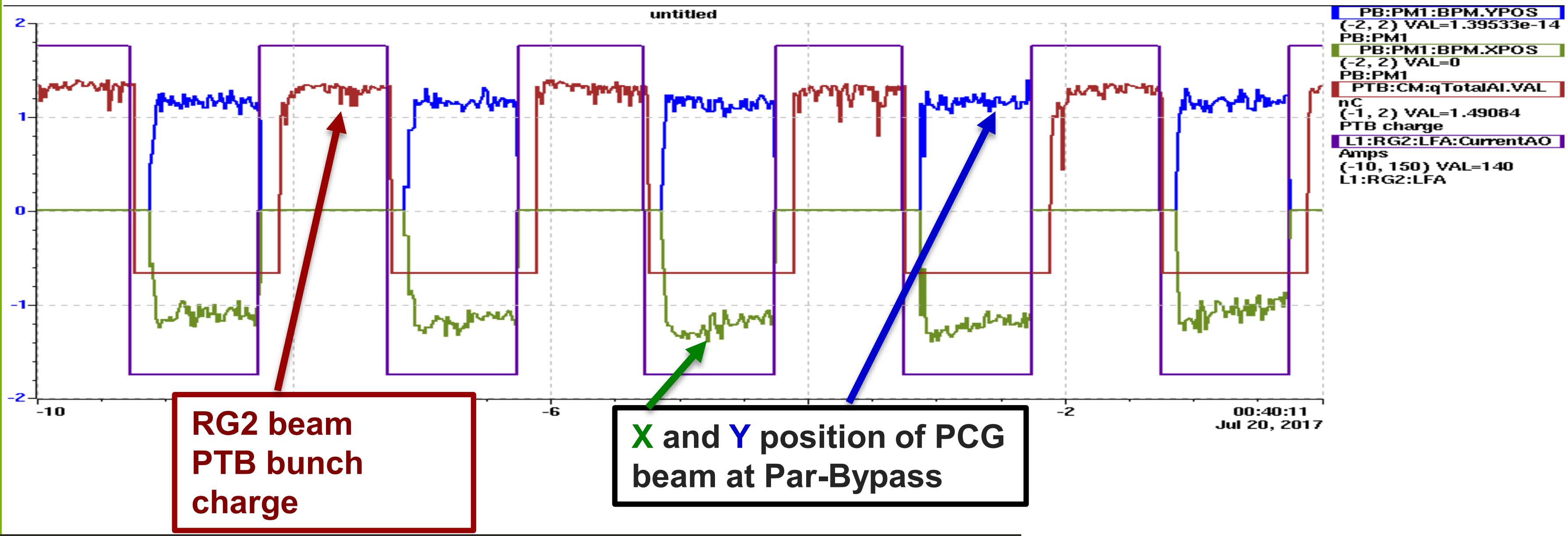


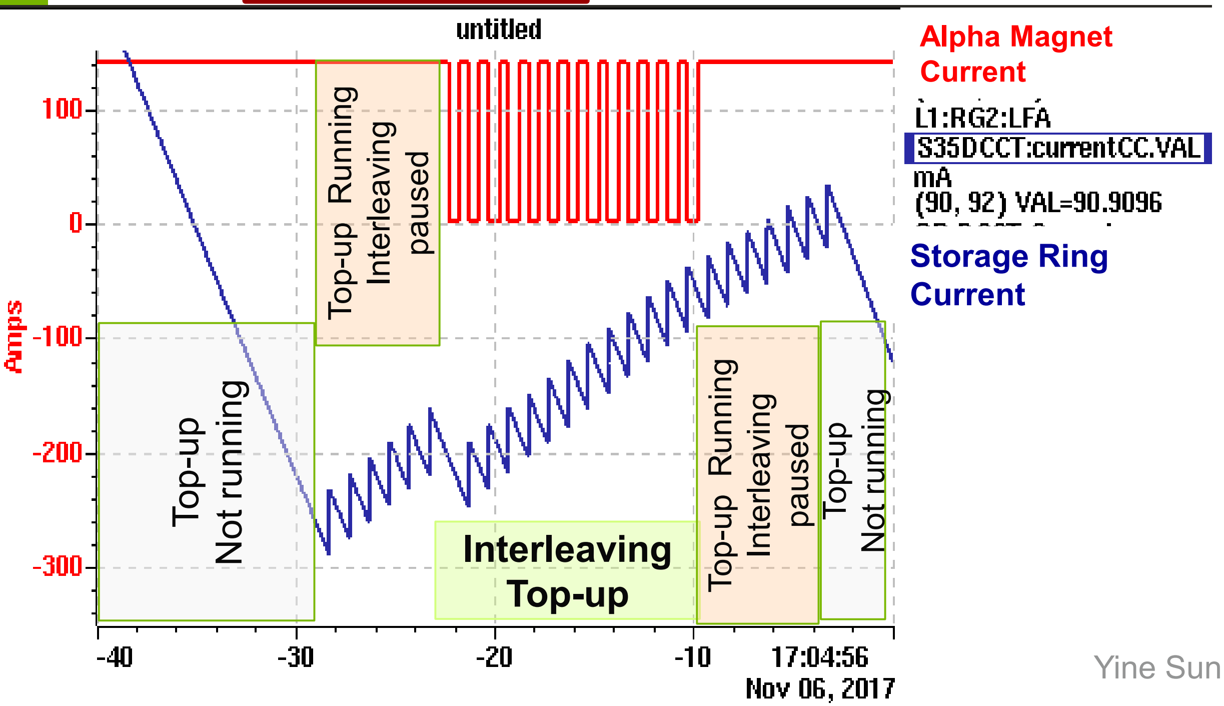
RG2 AND PCG BEAM TRAJECTORY THROUGH THE LINAC

Same settings for linac quadrupole and steering magnets.



DEMONSTRATION OF LINAC INTERLEAVING OPERATION WITH STORAGE RING IN TOP-UP MODE





- With linac running in interleaving mode, RG2 beam is injected into the PAR/Booster and storage ring as usual;
- PCG beam is delivered in the straight line by-passing PAR and booster.

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- ❑**Photo-Injector Beam;**
- ❑First Experiment in LEA.

PHOTO-INJECTOR DESIGN

- Energy: Up to 500 MeV;
  - Nominal energy 425 MeV;
- Energy Spread: 250 – 500 keV
- Charge: 50 – 500 pC
- Rep rate: up to 30Hz

- Optimization of the APS photo-injector for high-brightness electron beams:

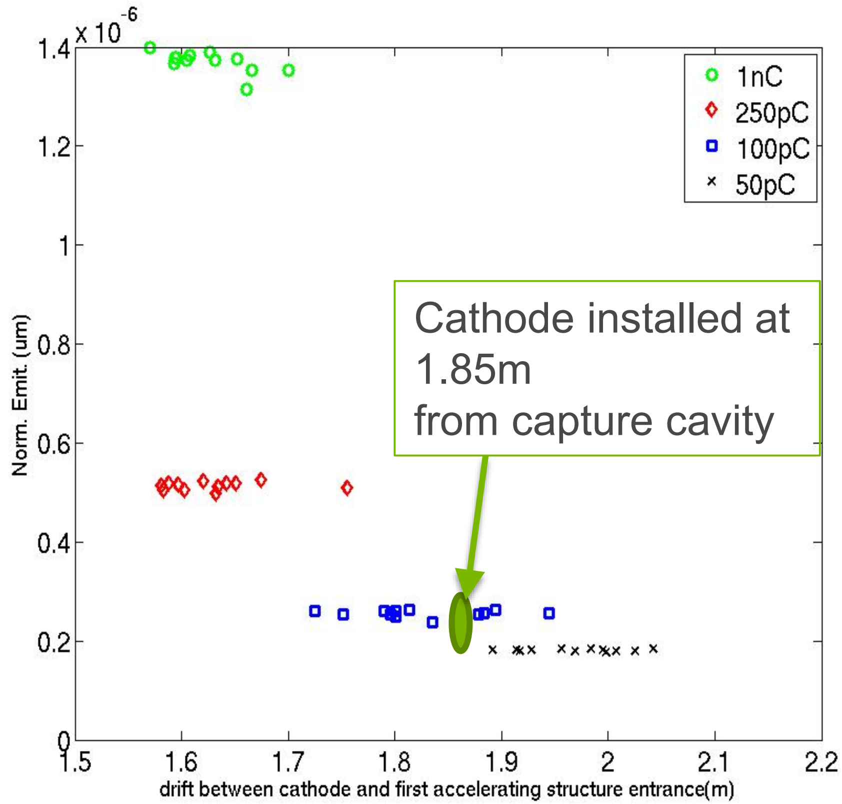
- Variables include:

variable	range	unit
Gun gradient	[110 ~ 130]	MV/m
Solenoid peak field	[0.2 ~ 0.315]	Tesla
Cathode and solenoid center separation	[0.183 ~ 0.202]	m
Bunch charge	[50, 100, 250, 1000]	pC
Drive laser pulse	[2 ~ 5]	ps
Drive laser size	[0.1 ~ 0.8]	mm
Cathode and first accelerating structure distance	[1.12 ~ 2.12]	m
Energy gain in the first acc. structure	[11 ~ 33]	MeV
Energy gain in the next four acc. stuctures	[27 ~ 33]	MeV

PHOTO-INJECTOR DESIGN

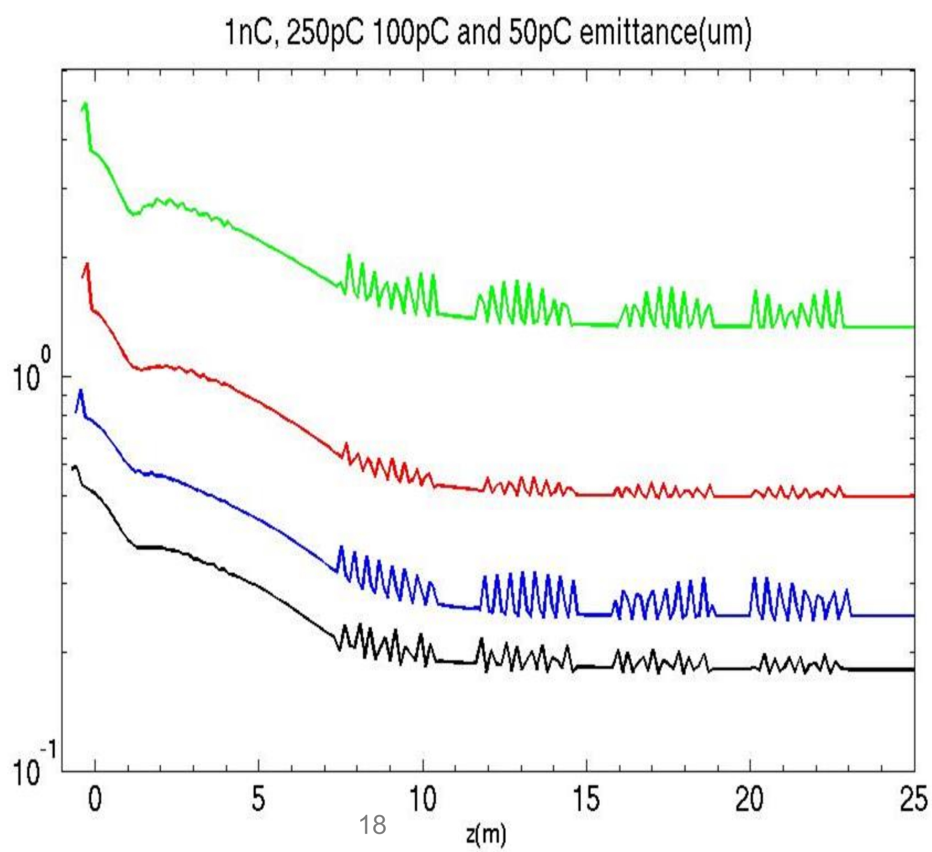
CAPTURE CAVITY LOCATION

- Distance between the cathode and the first accelerating structure optimized for best emittance.



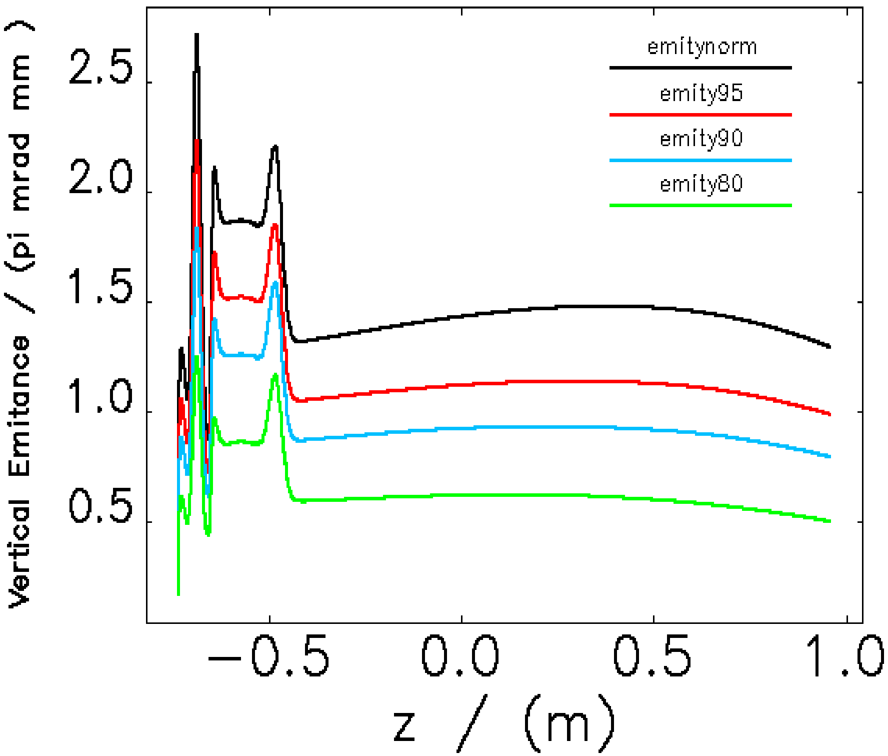
EMITTANCE OPTIMIZATION

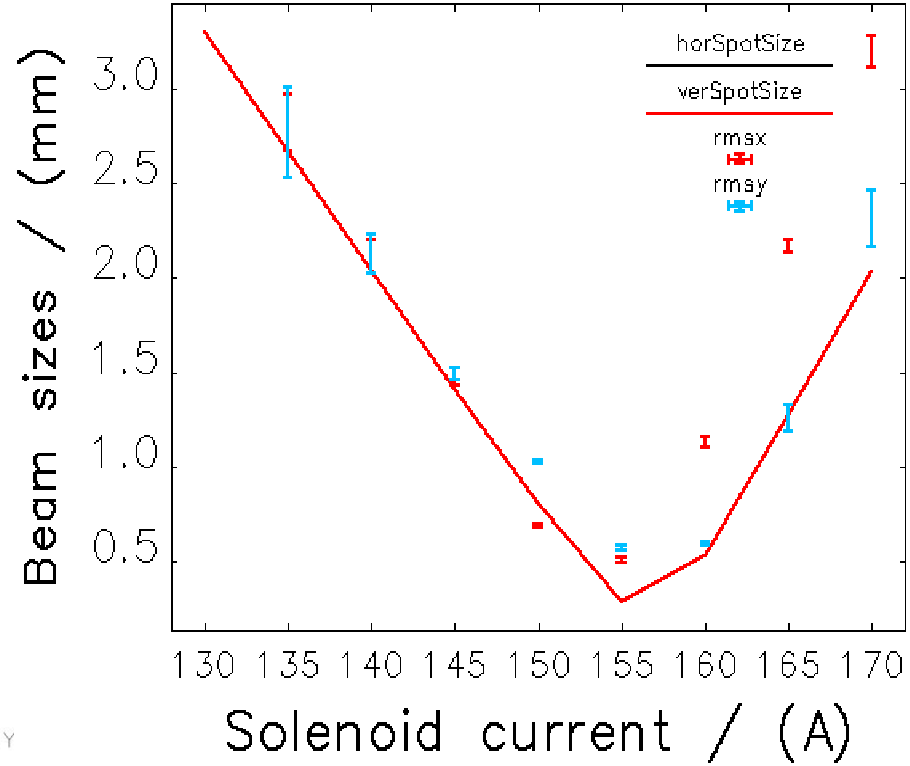
- Machine parameters optimized for best emittance at bunch charge [50 –1000] pC; normalized emittance [0.2-1.1] μm.



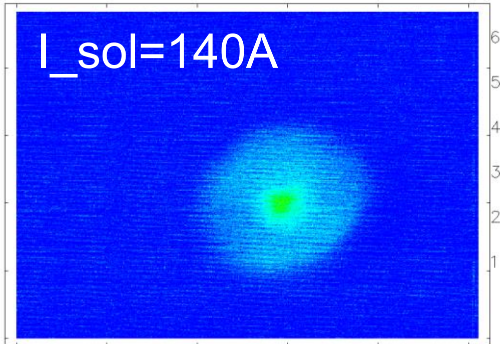
SOLENOID SCAN: MEASUREMENT AND SIMULATION

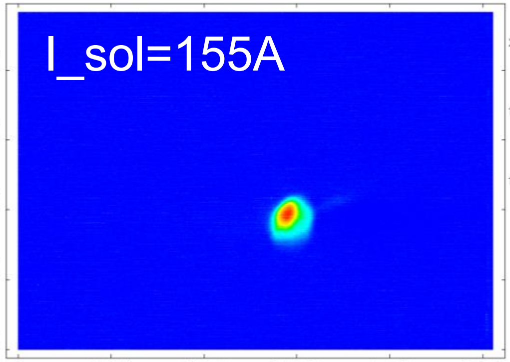
Drive laser: σ=0.1mm, σ_t=2.5ps, bunch charge Q=93pC, beam energy ~ 5.5MeV



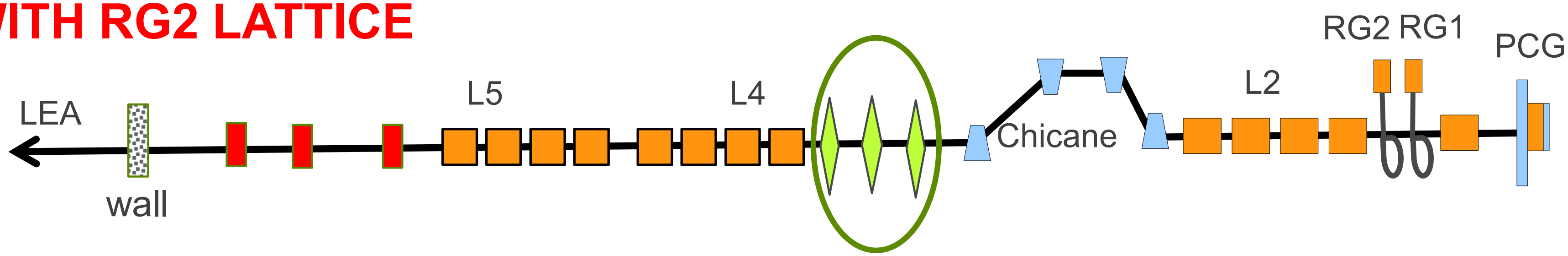


Norm. x-emittance at YAG2 1.0 µm for 95% of the beam (solenoid at 155A).





3-SCREEN MEASUREMENTS AFTER CHICANE (150MEV, 350PC)
WITH RG2 LATTICE

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Analysis of experiment /home/helios/LINAC/daily/2016/04/26/2/PCGun/emit/emit360pC-012 using Raw values
IdealAlpha =          1.732051e+00  IdealBeta (m) =     2.224452e+00
xCalibrations = 92.0 92.0 92.0 pixel/mm
yCalibrations = 116.0 116.0 116.0 pixel/mm
xResolutions =  8.6999999999999993 8.6999999999999993 8.6999999999999993 um
yResolutions =    8.0 8.0 8.0 um
xSigmaErrors =    0.0 0.0 0.0 um
ySigmaErrors =    0.0 0.0 0.0 um
ExcludedFlag1 =
ExcludedFlag2 =
ExcludedFlag3 =
beamEnergy (MeV) =  1.500000e+02

   betax    betaxSig     alphx    alphxSig    exNorm    exNormSig  xMismatch  xMismatchSig
   betay    betaySig     alphy    alphySig    eyNorm    eyNormSig  yMismatch  yMismatchSig
     m         m                                um         um                       um
     m         m                                um         um                       um
--------------------------------------------------------------------------------------
     2.14       0.01       1.74       0.00       5.46       0.06       1.00         0.00
     2.34       0.00       1.86       0.00       4.64       0.02       1.00         0.00
```

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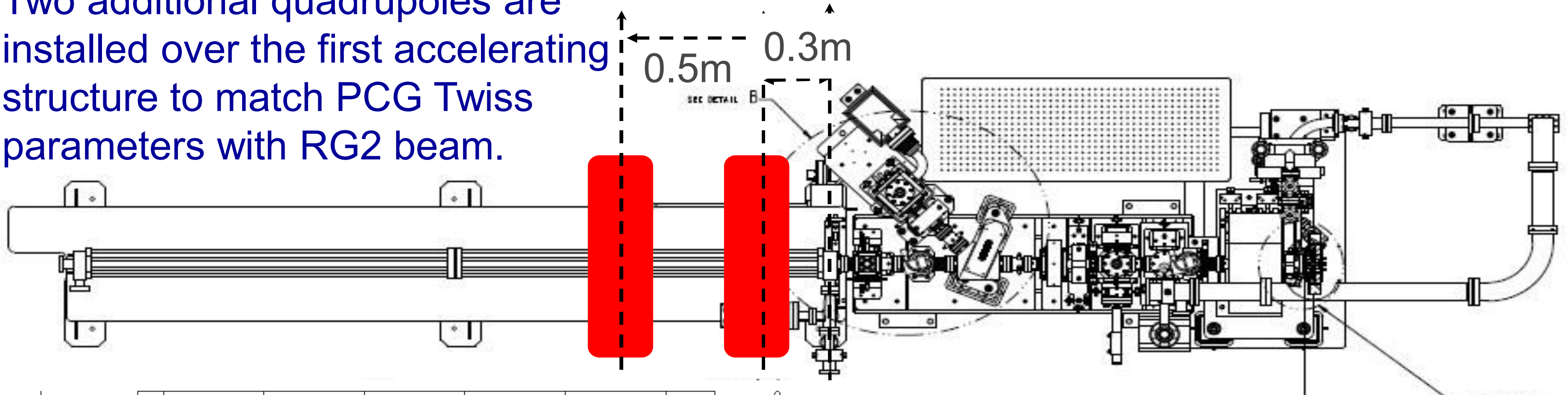
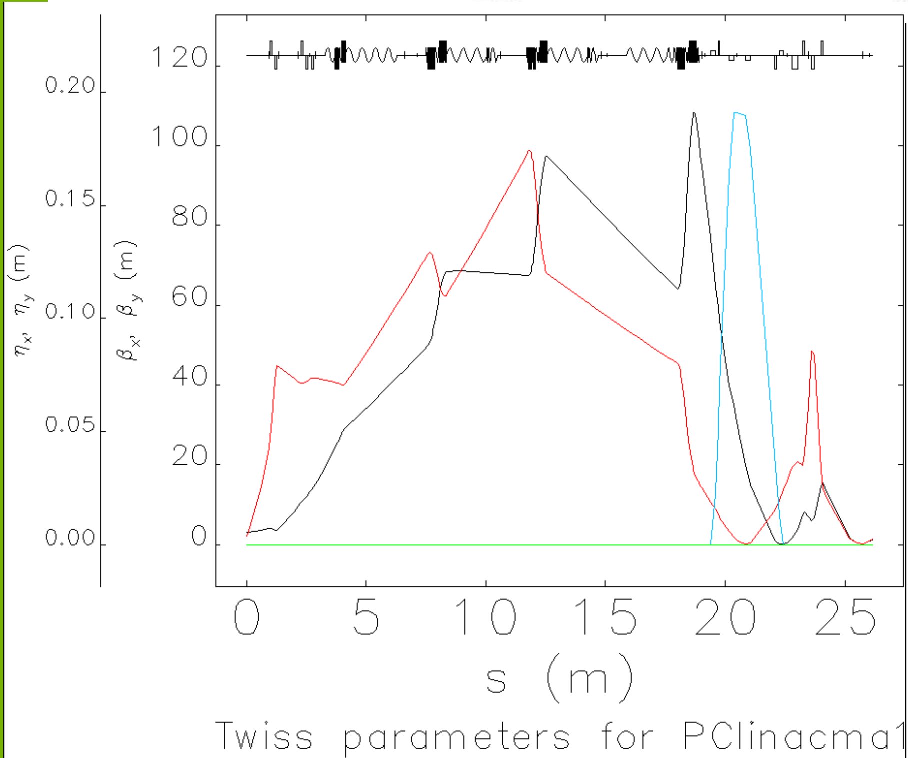
CURRENT EFFORTS

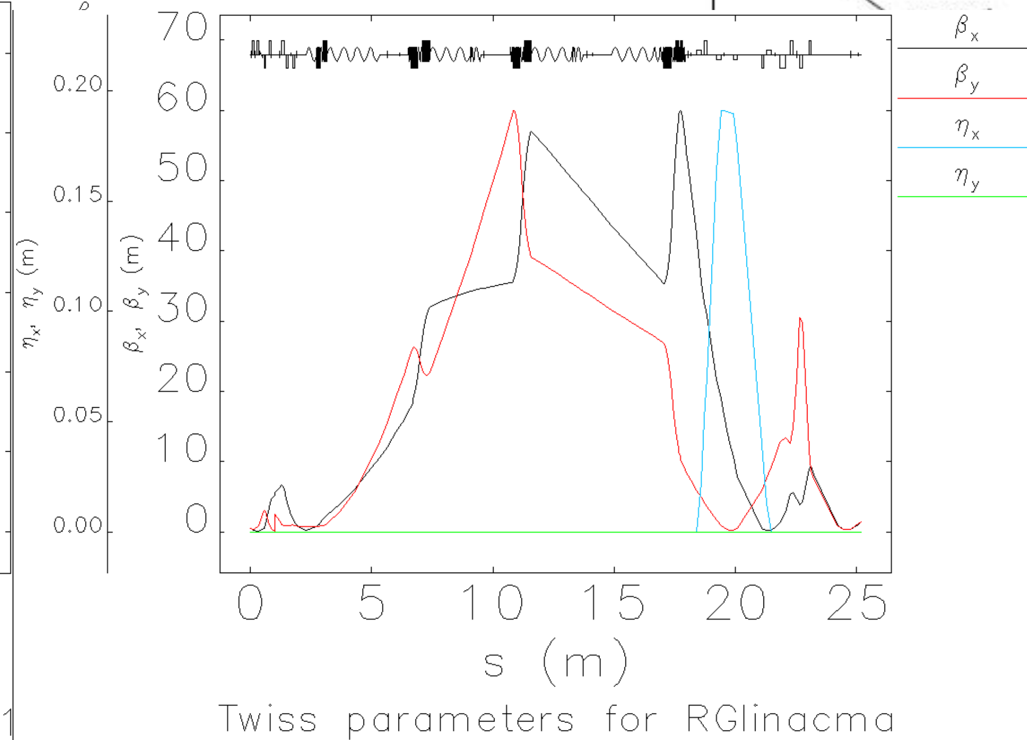
INTERLEAVING LATTICE OPTIMIZATION:
Installed two new additional quadrupoles to bring the PCG Twiss parameters to match with the RG2 beam.
TAILOR THE SIZE OF THE PHOTO-CATHODE DRIVE LASER FOR DIFFERENT BUNCH CHARGES:
Currently the laser is asymmetric and adjusting the laser beam size requires replacing focusing lens.
REDUCTION OF THE TRANSVERSE WAKE FIELD BY REPLACING THE SAGGED LINAC ACCELERATING STRUCTURES:
Work in progress.
IMPROVING BEAM STABILITY BY REDUCING LASER AND RF JITTER.

INTERLEAVING LATTICE DESIGN

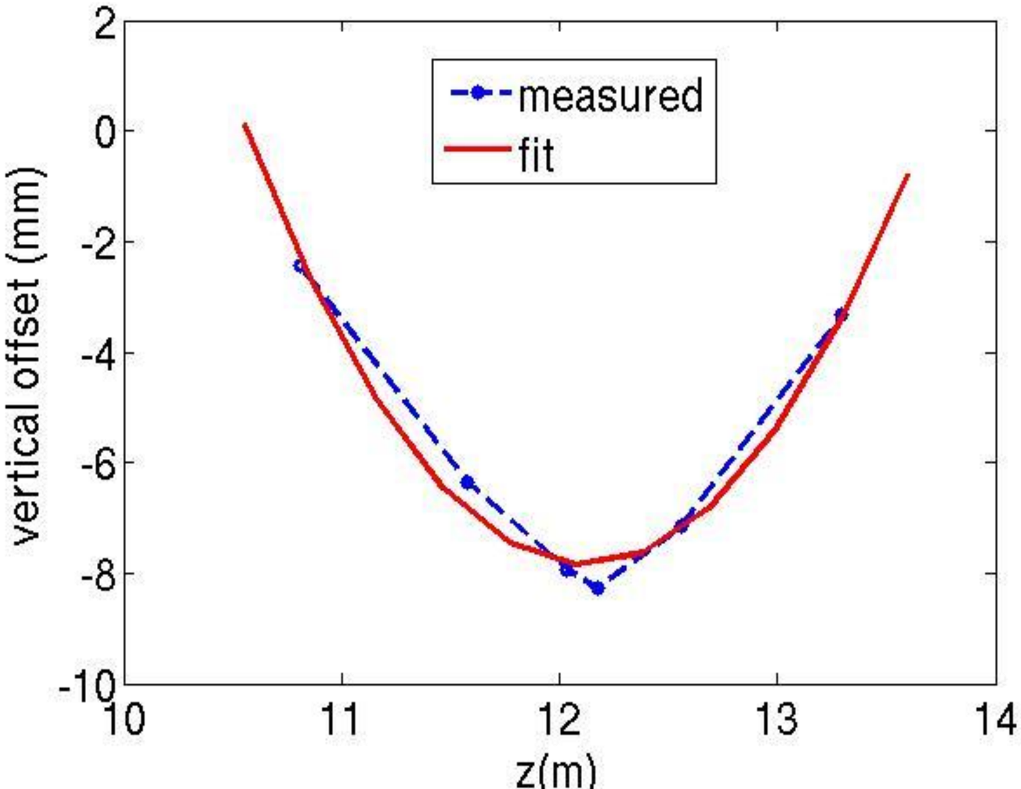
Two additional quadrupoles are installed over the first accelerating structure to match PCG Twiss parameters with RG2 beam.







WAKEFIELD EFFECTS FROM THE LINAC STRUCTURES

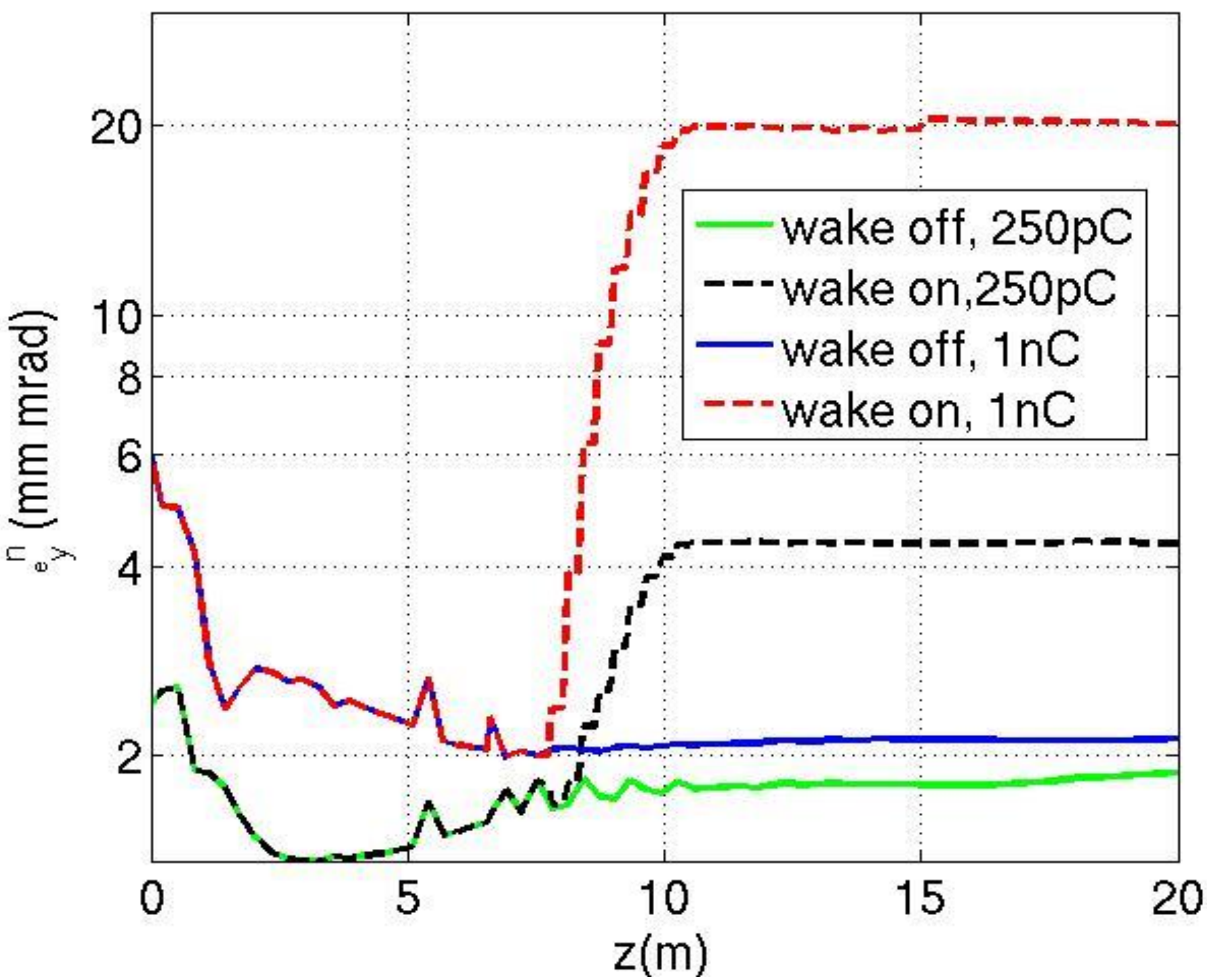


Survey data of linac accelerating structure L2:AS1.

Implementation in ASTRA

- Divide the 10-ft structure into 10 sections;
- Assign each section a y-offset using the fitted curve;
- Scale the wake field strength by a factor of 0.1 from the whole structure wake field map.

Effect on Vertical Emittance from L2:AS1 Transverse Wake



Vertical Emittance:

1nC: 2.1mm mrad
==>20.0 mm mrad

250pC: 1.9 mm mrad
==>4.4 mm mrad

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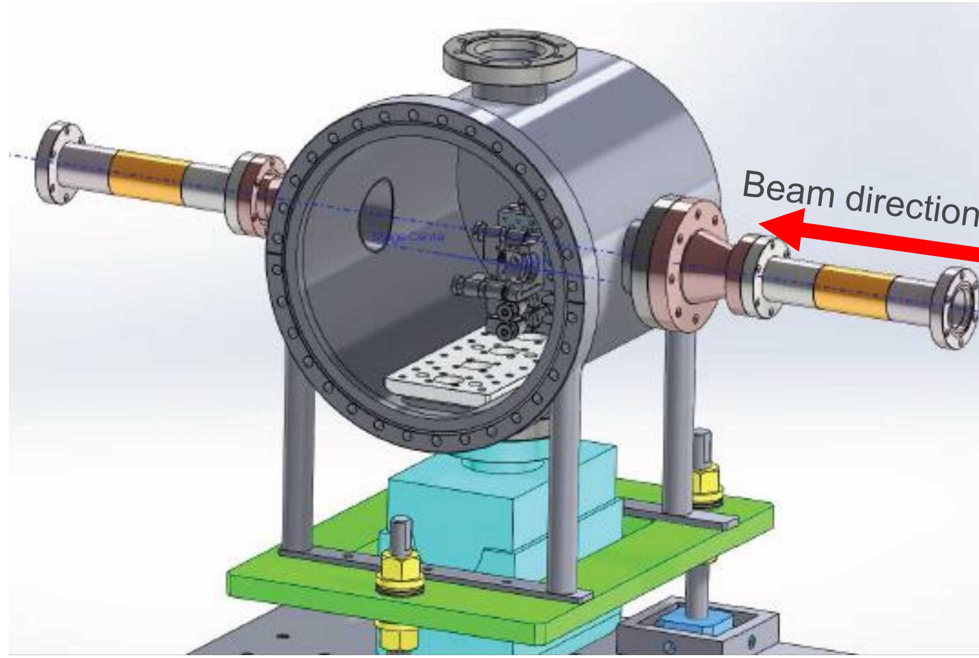
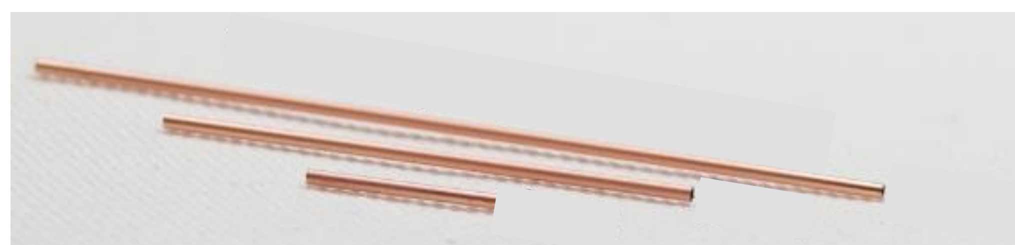
FIRST EXPERIMENT IN LEA
IN COLLABORATION WITH EUCLID TECHLABS

- experimental chamber 9.75” along beam path;
- Chamber internal setup design, fabrication and installation are done in collaboration with Euclid;
- The first experiment will be the testing of dielectric wakefield tubes provided by Euclid:
  - Main goal is to commission the LEA beam line and characterizing the PCG beam.

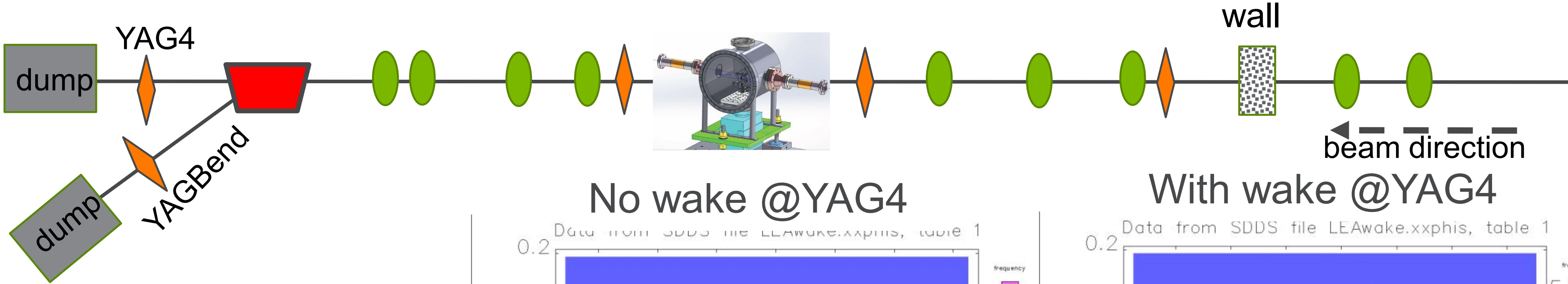


	Type I	Type II
Mode	Single	Multi
Inner diameter (mm)	0.8	0.5
Outer diameter (mm)	1.0	1.5
dielectric	3.8	3.8
length (cm)	12	6

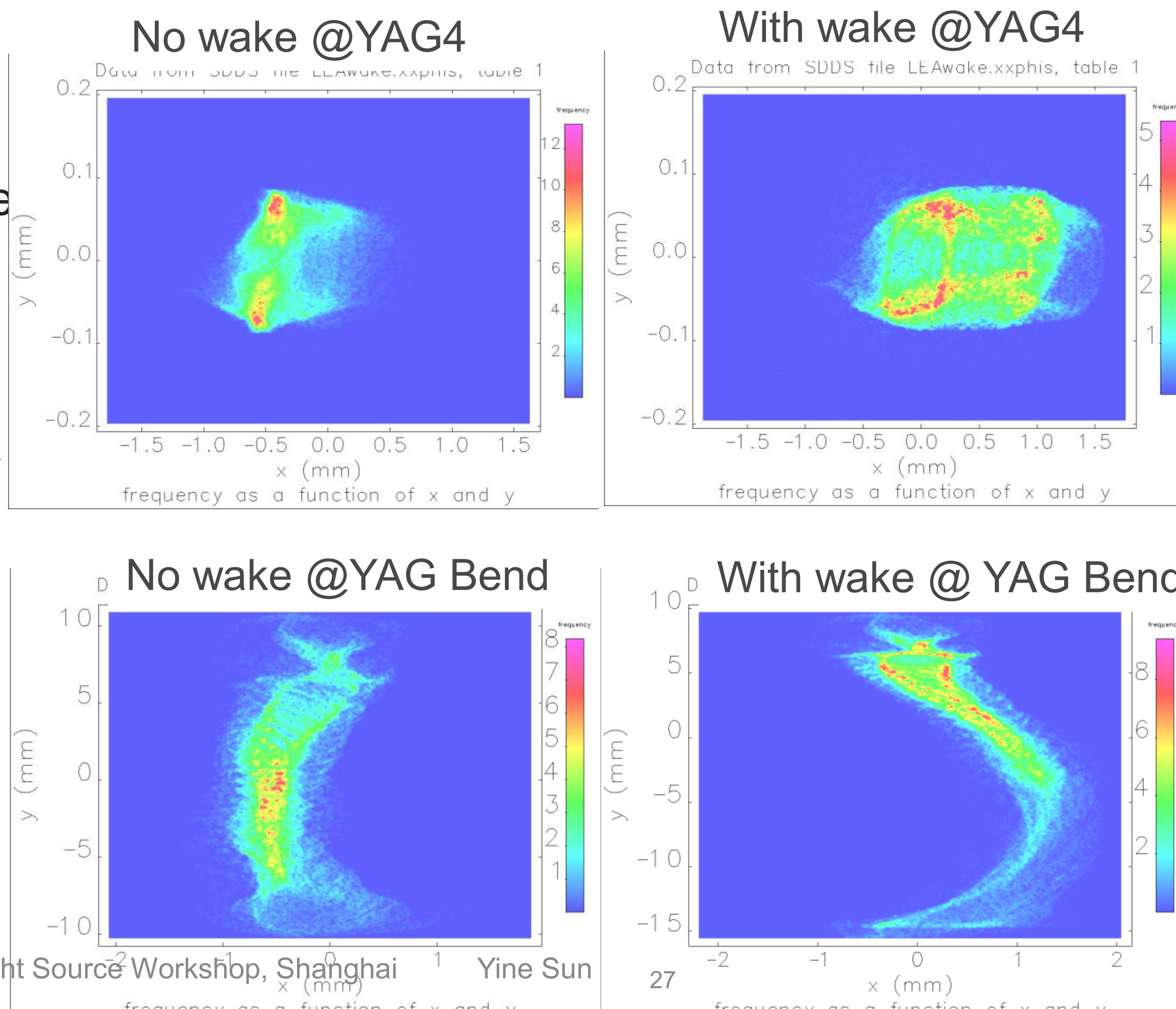
Quartz tubes
S. Antipov, Euclid TechLabs.



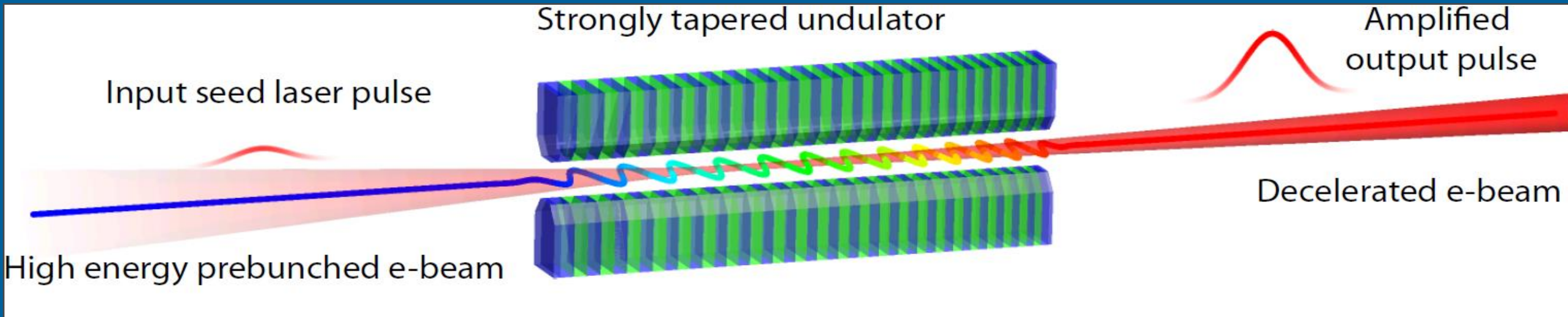
START-TO-END SIMULATION (ASTRA+ELEGANT)



- From PCG to chicane (150 MeV) using ASTRA with space charge effects;
- From chicane to LEA using ELEGANT with CSR included;
- LEA experimental chamber area with type I dielectric wake field tubes inserted, 10 cm long, 100µm offset.



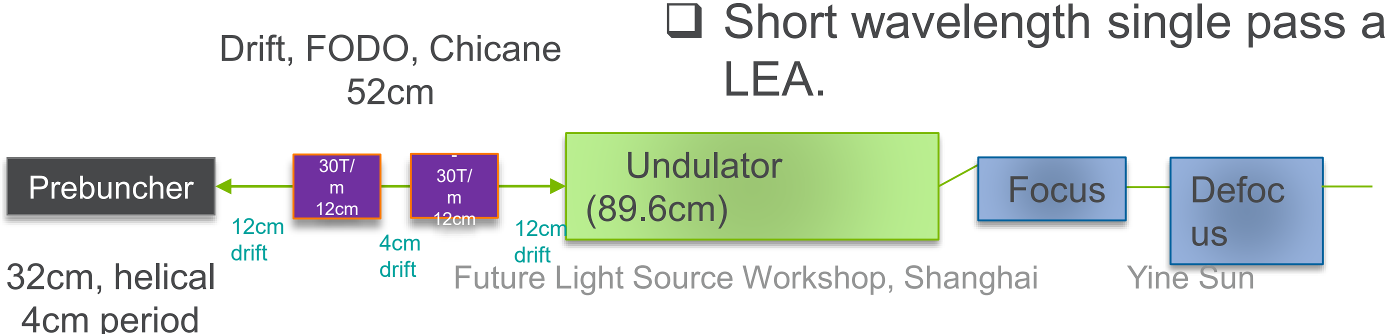
FUTURE LEA EXPERIMENT: TESSA-266



PIETRO MUSUMECI
University of California
at Los Angeles

LEA programmatic review
November 10, 2017

- ❑ Tapering Enhanced Stimulated Superradiant Amplification:
  - <u>Reversing the laser-acceleration process</u>, extract a large fraction of the energy from an electron beam provided:
    - ✓ A high current, microbunched input e-beam: 300 MeV 1000 A;
    - ✓ An intense input seed;
    - ✓ Gradient matching to exploit the growing radiation field.
- ❑ Short wavelength single pass amplification demo at LEA.



THANK YOU FOR YOUR ATTENTION!