FUTURE LEA EXPERIMENTS WORKSHOP

APS LINAC INTERLEAVING OPERATION OVERVIEW

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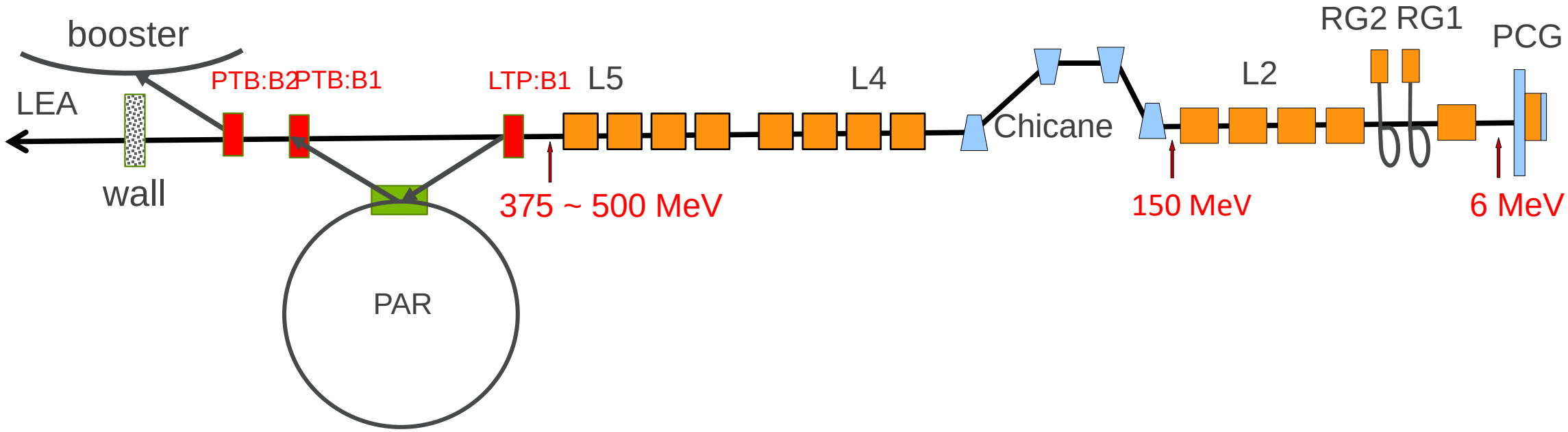
OUTLINE

- Introduction;
- Interleaving of the Linac Sub-systems:
  - ACIS;
  - Magnets and Power Supplies;
  - RF;
  - Controls.
- Physics and Operations:
  - Photo-Cathode Gun Beam Parameter Measurements in the linac.
- Linac Extension Area (LEA) Beamline.

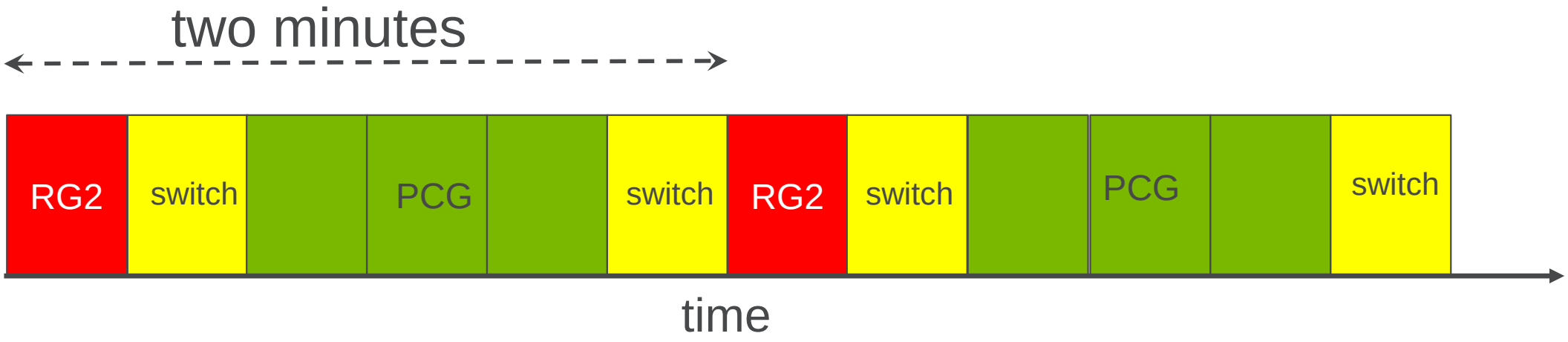
RF GUNS OF THE APS LINAC

- Thermionic cathode RF Gun RG2 (RG1 is a backup for RG2):
  - RG2 provides electron beam for PAR/Booster/Storage Ring.
- Photo-Cathode Gun (PCG):
  - Generates high-brightness electron beams for the Linac Extension Area (LEA).



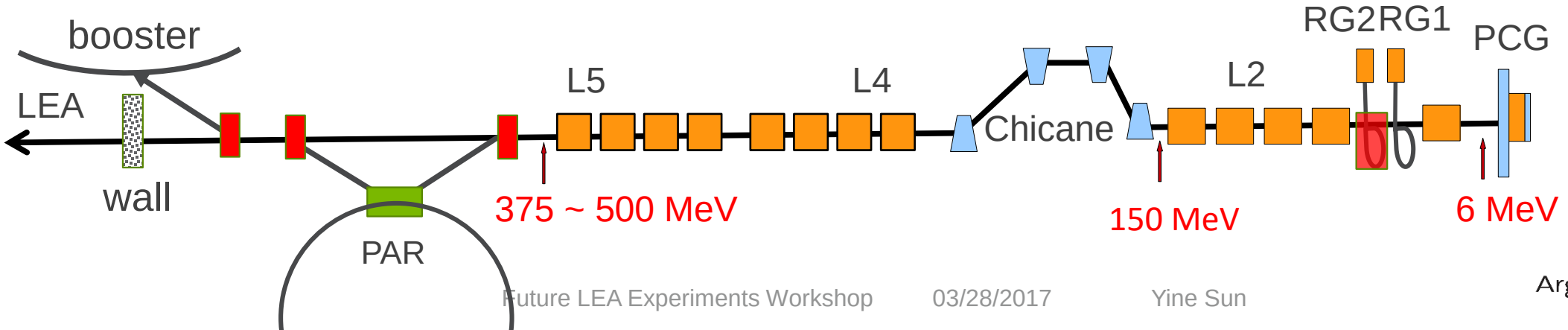
LINAC INTERLEAVING OPERATION

- During the storage ring top-up operation, 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 the rest of the two minutes → PCG beam can be accelerated through the linac 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.

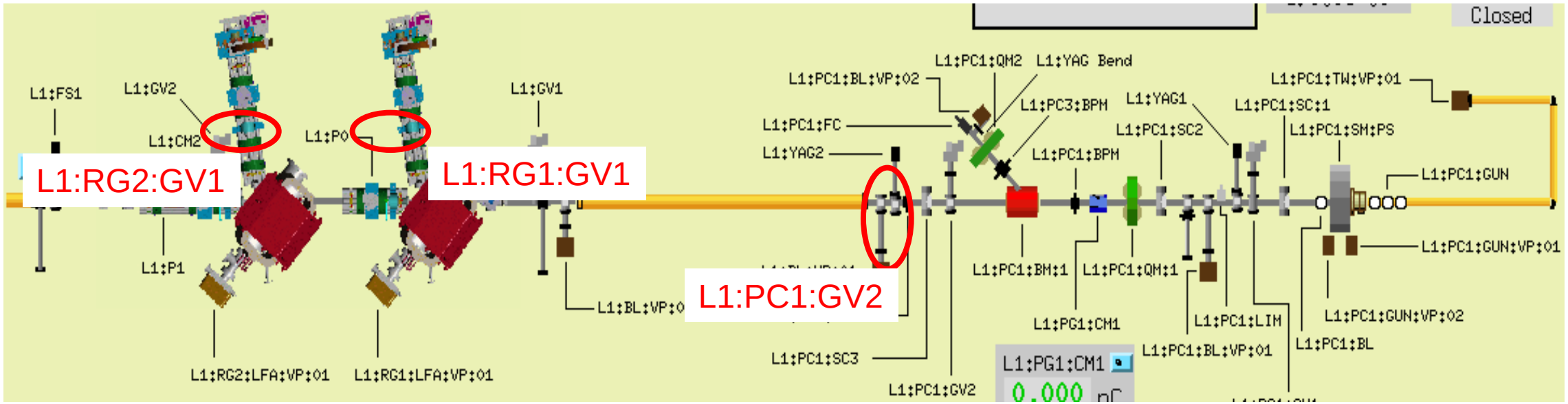


REQUIRED LINAC MODIFICATIONS FOR INTERLEAVING

- Gate valves for PCG and RG2 beams need to remain open simultaneously.
- Beam Trajectory Control: Interleaving operation of four magnets and the corresponding power supplies:
  - RG2 alpha magnet;
  - Linac to PAR, PAR to Booster trajectory switching dipole magnets: LTP:B1, PTB:B1 and PTB:B2.
- RF LLRF start time, gate width, rf phase and amplitude:
  - L1 LLRF gate start and gate width;
  - L2 rf amplitude;
  - L3 RF enable/disable switches;
  - All Linac sections rf phases.



GUN GATE VALVES



Currently:

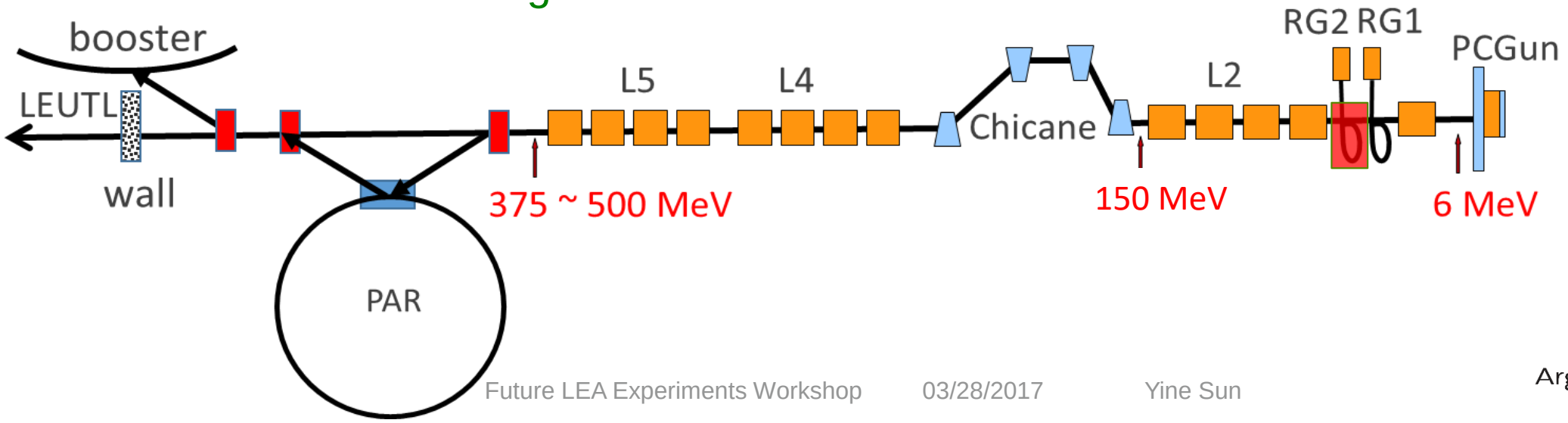
PCG gate valve L1:PC1:GV2 is closed when one of the thermionic gun gate valve is open;

Interleaving:

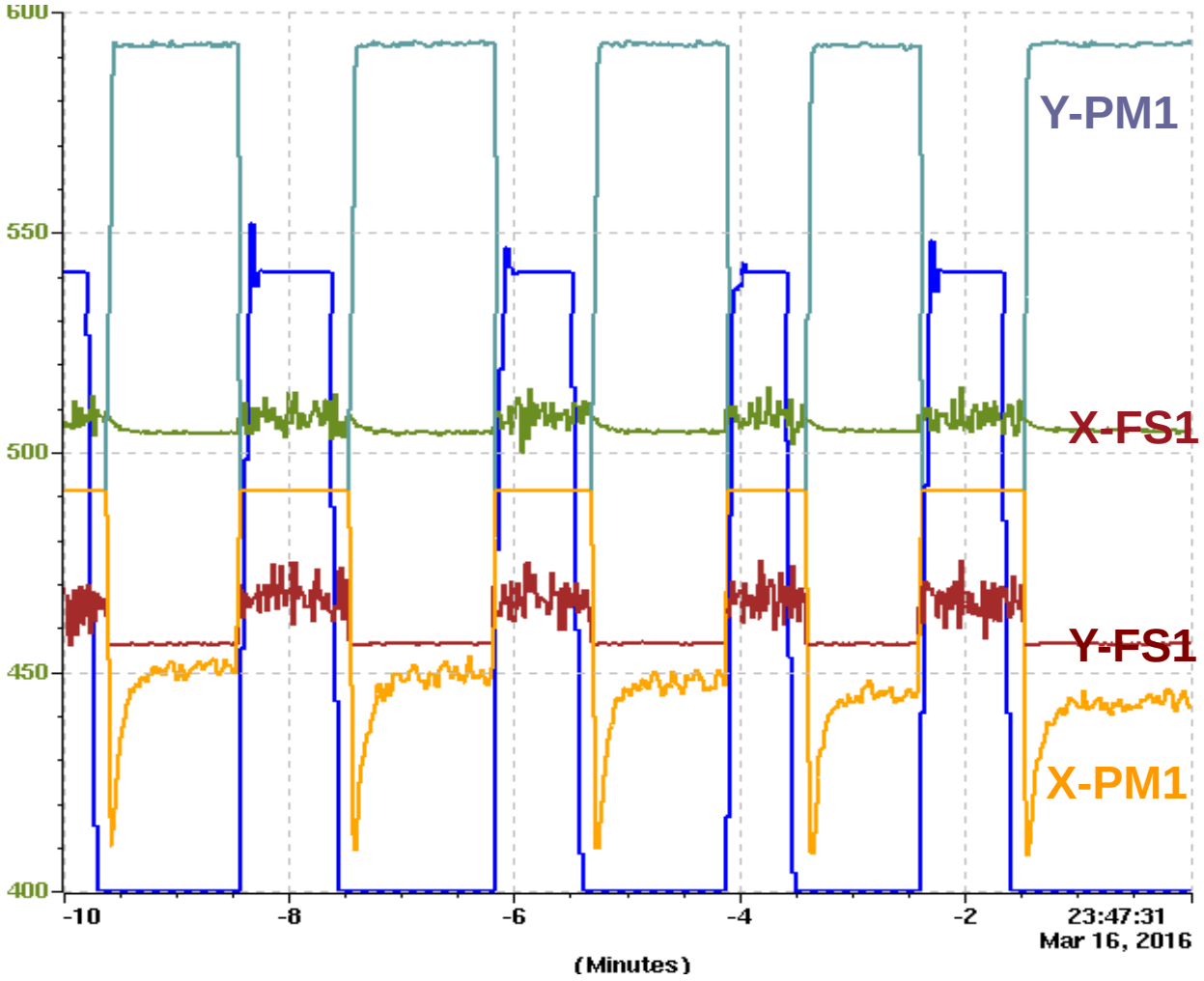
L1:PC1:GV2 + L1:RG2:GV1 open.

LINAC INTERLEAVING: MAGNETS AND POWER SUPPLIES

- For ACIS: Design, install and test high/low current value threshold sensors for the RG2 alpha magnet, and provide the signals to ACIS;
- Magnets to switch beam trajectories (1): Thermionic RF gun alpha-magnets (completed):
  - Main alpha magnets ramp up for RG2 beam, and ramp down for PCG beam;
  - Alpha magnet trim can be used to zero alpha magnet the residual field and stay at this DC level, and can be used as a steering magnet;
  - Magnet current ramp up/down time and residual field measured;
  - Successfully tested the manual ramping (AOP-TN-2016-045) – Ramping will be automated for interleaving.

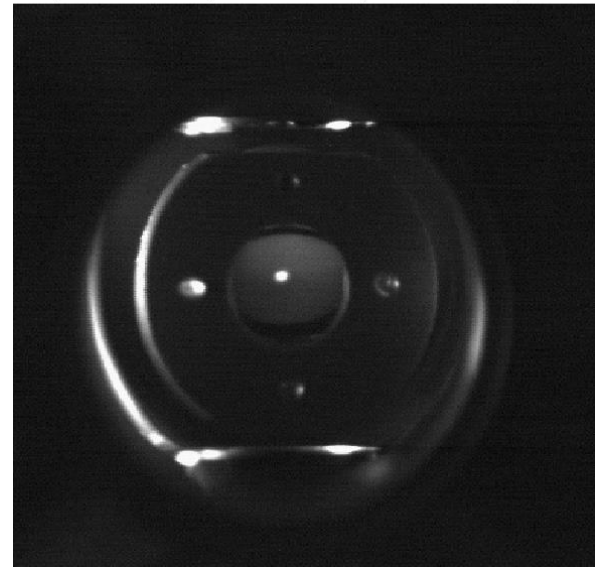


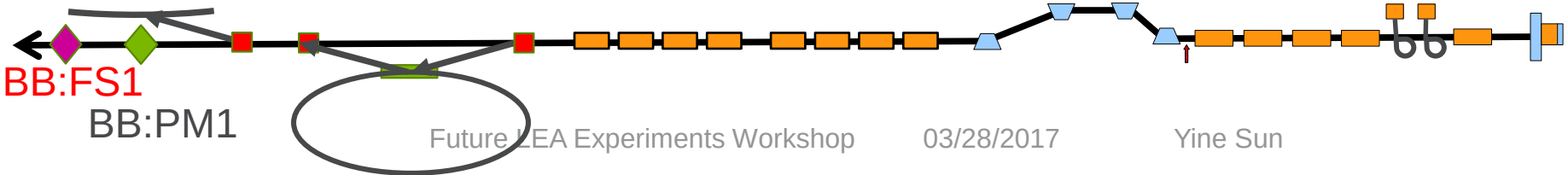
GUN ALPHA MAGNET INTERLEAVING TEST



Beam Position at Booster Bypass BB:PM1 and last accessible flag BB:FS1 recovers in ~30s as the alpha magnet current ramps up/down.

Image from BB:FS1





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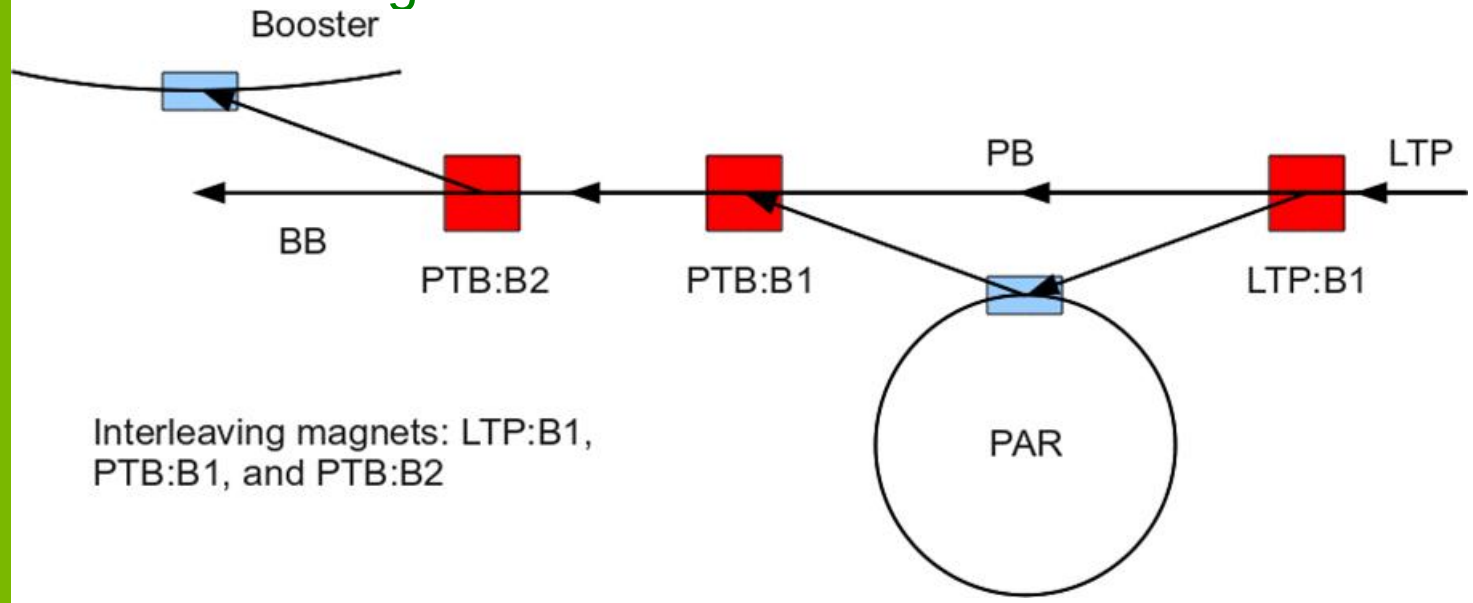
INTERLEAVING MAGNETS CONT'D

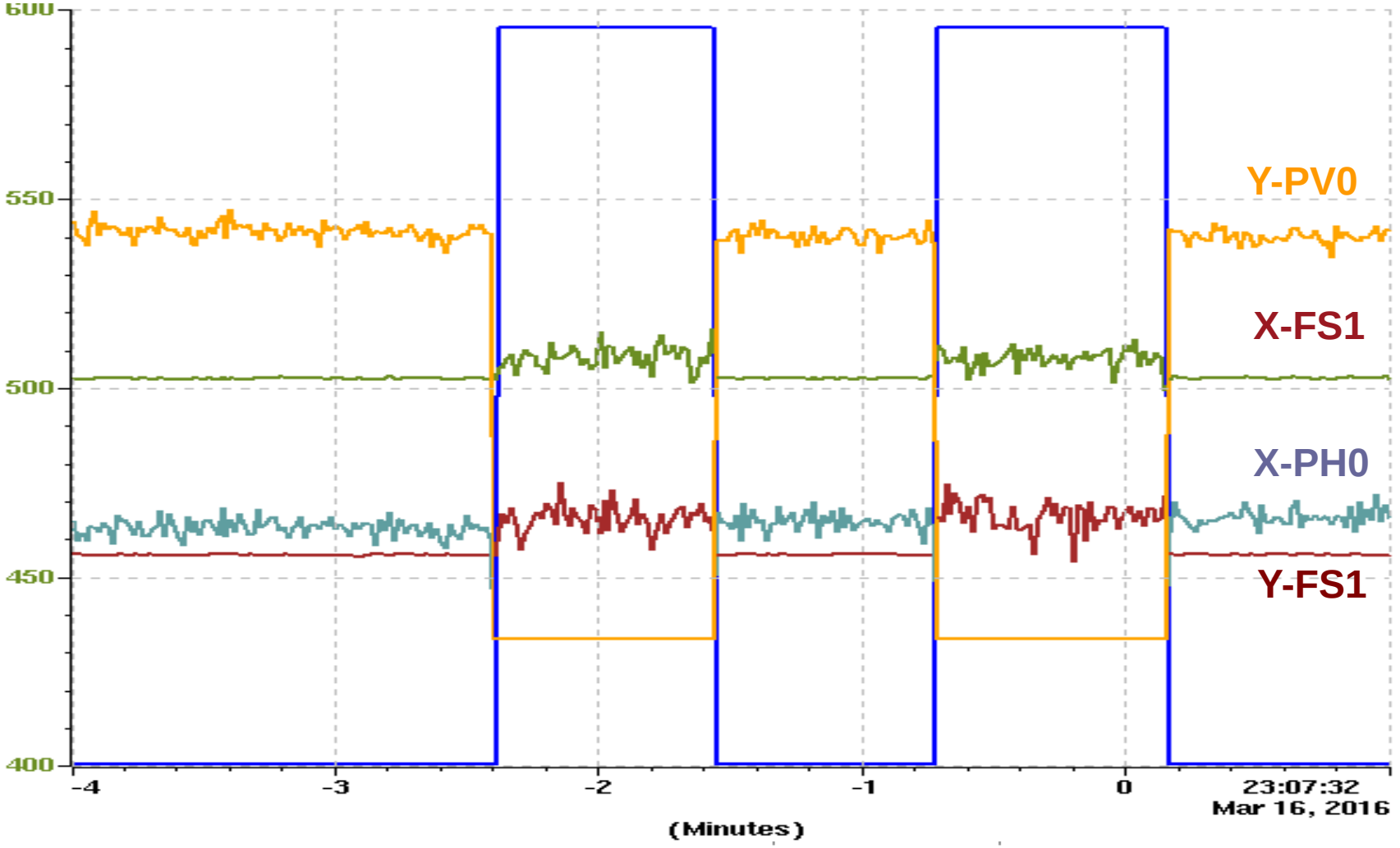
- Magnets to switch beam trajectories (2) interleaving magnets:
  - LTP:B1, PTB:B1 and PTB:B2 to send beam either to PAR/Booster or leave beam undisturbed and straight to LEUTL.
    - Bucking coils installed and commissioned;
    - Zero residual fields are measured with the bucking coil current set at 2.3A.



Interleaving magnets: LTP:B1, PTB:B1, and PTB:B2

LTP:B1, PTB:B1 AND PTB:B2 INTERLEAVING OPERATION TESTING

Alternating between Standby/On: It takes a couple of seconds for the beam position to recover on BB:FS1, and position monitor PH0 and PV0 in PTB line.



An Example of LTP:B2 Interleaving Ops. Test

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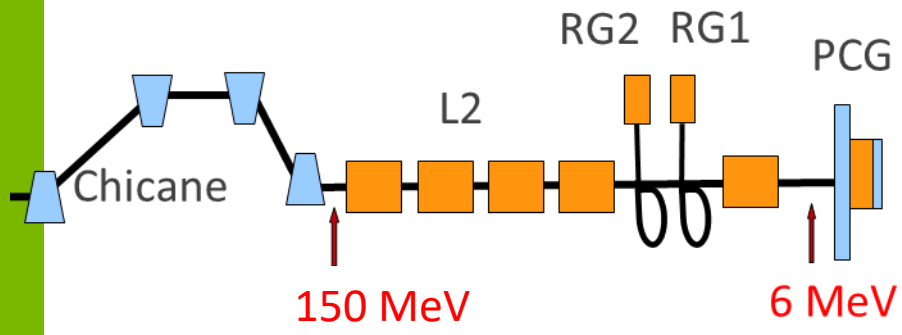
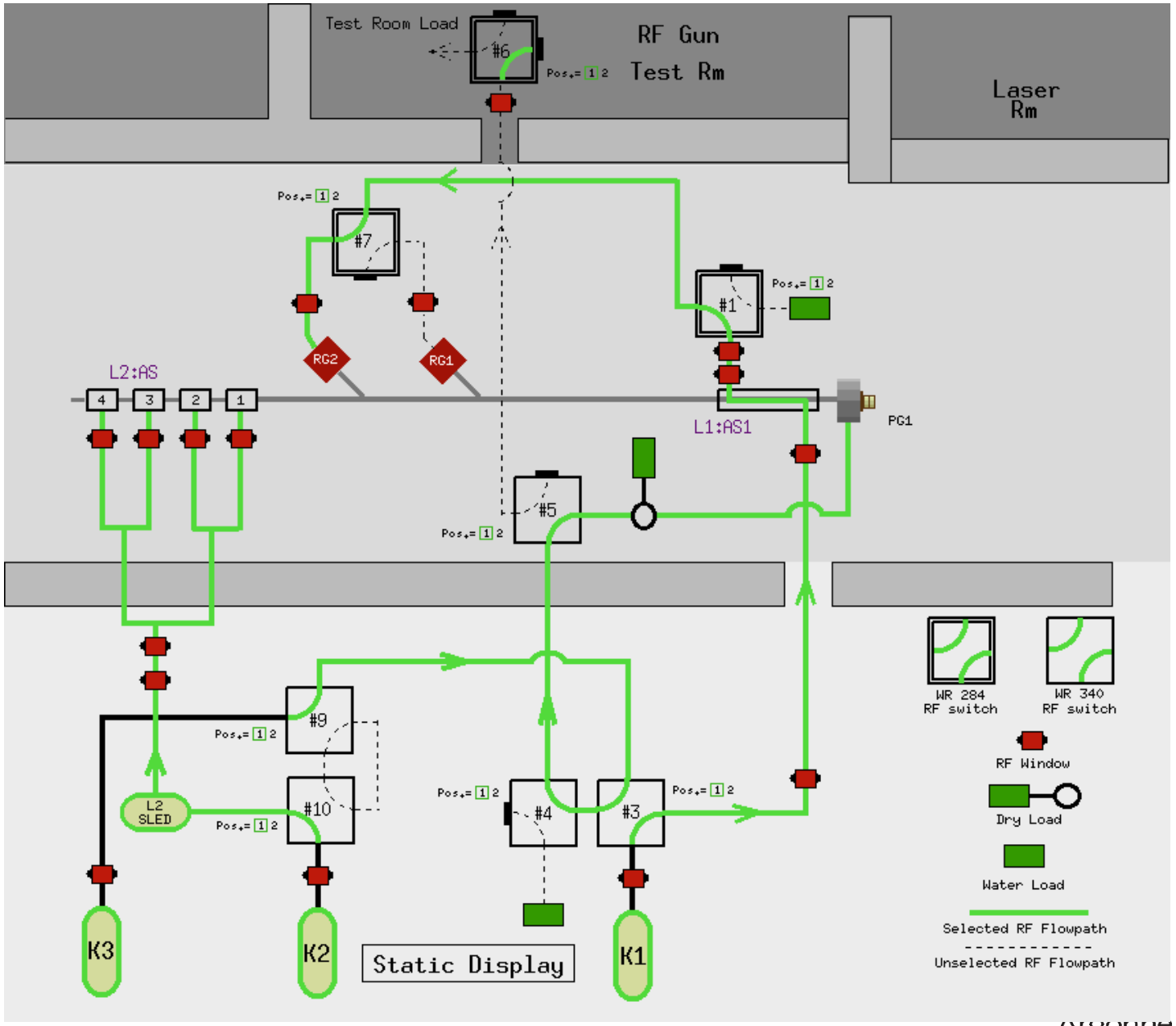
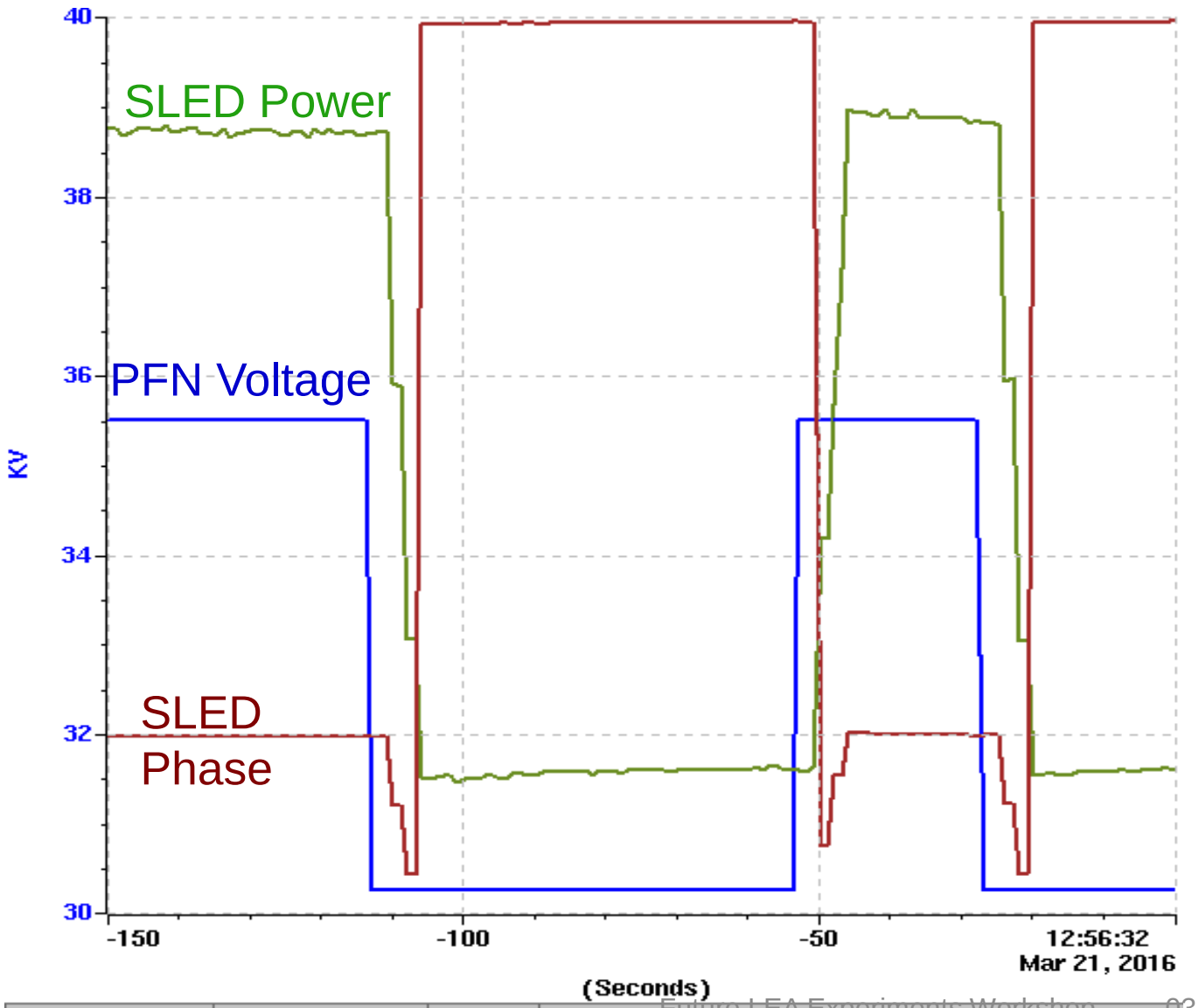
LINAC INTERLEAVING: RF

- K1 powers:
  - RG2;
  - L1:AS1;
- K2 for L2:
  - 27 MW (RG2)
  - 18 MW (PCG)
- K3:
  - Powers PCG;
  - RF Enable/Disable.





LINAC INTERLEAVING: RF
L2 PFN AND SLED POWER



The PFN voltage is adjusted to alternate L2 klystron output power.

~10 seconds for the SLED power to switch between 113 MW ↔ 70 MW via PFN changes between 35.5 kV ↔ 30.25 kV (klystron drive at 24.37).

LINAC INTERLEAVING: RF SUMMARY

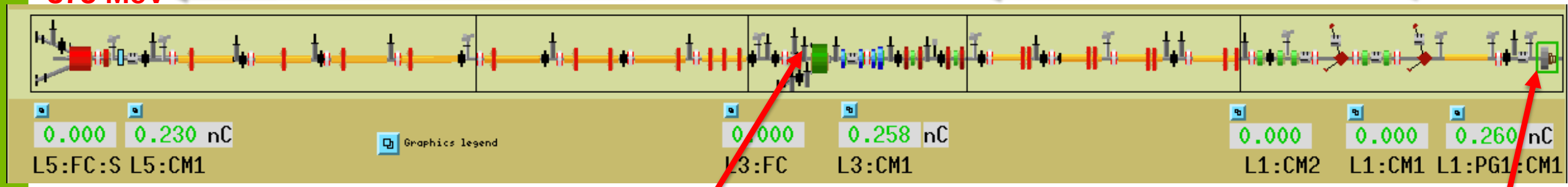
- All RF (except L3) need to have phase interleaving between two values.
  - Tested L2 Phase Interleaving using the existing “Phase Adjustment” Takes less than 3 seconds to settle.
- L1 LLRF window gate start will interleave between -2.03 μs ↔ -1.05 μs, while the gate width and RF power level will remain unchanged.
- L2 PFN voltage will interleave between two values (transition time < 10 seconds).
- L3 RF will interleave between enable/disable to eliminate PCG beam during RG2 beam time:
  - Test to enable/disable the L3 modulator PFN trigger;
  - Test to enable/disable L3 drive amplifier gate.

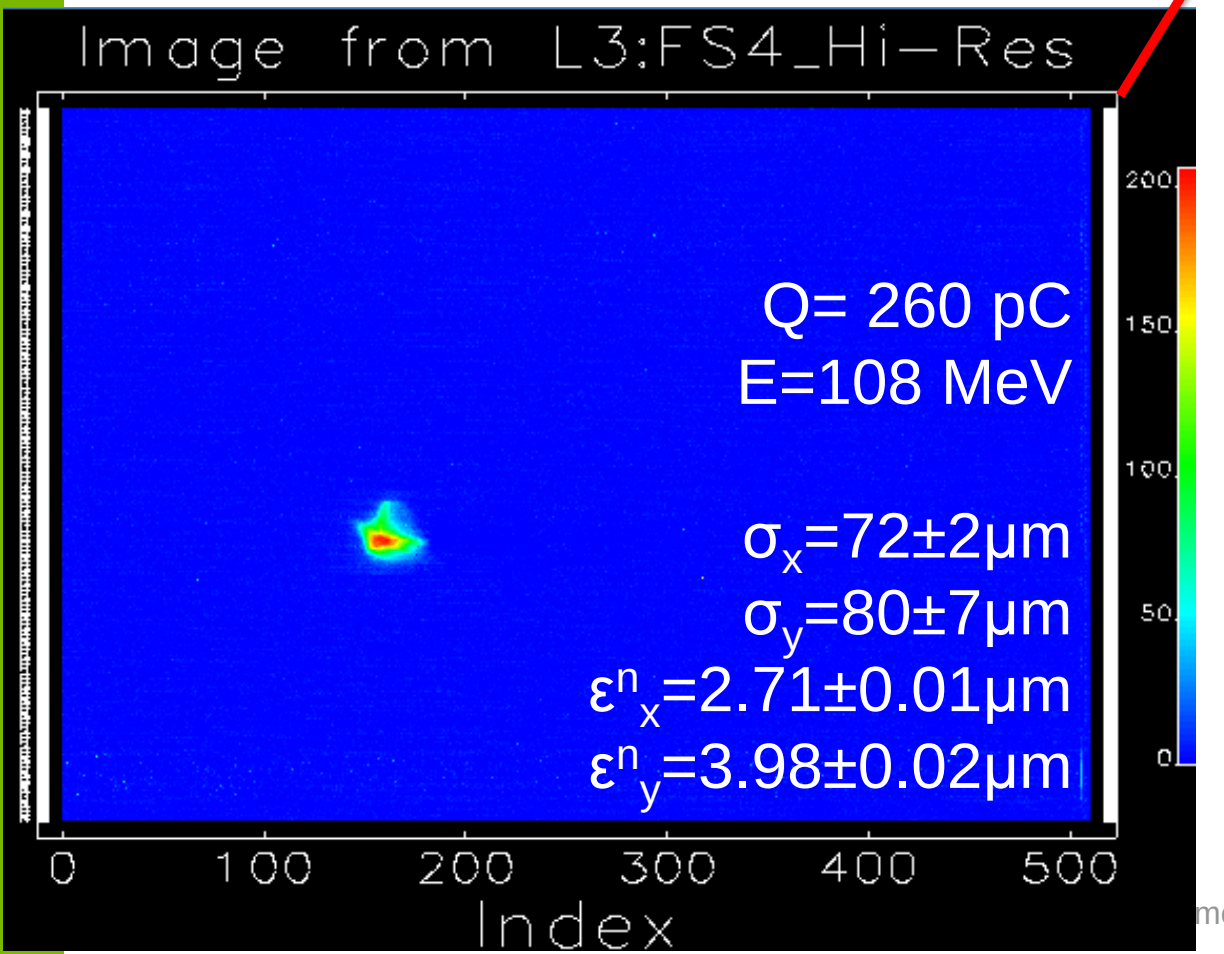
LINAC INTERLEAVING: OPERATIONS AND PHYSICS (AOP)

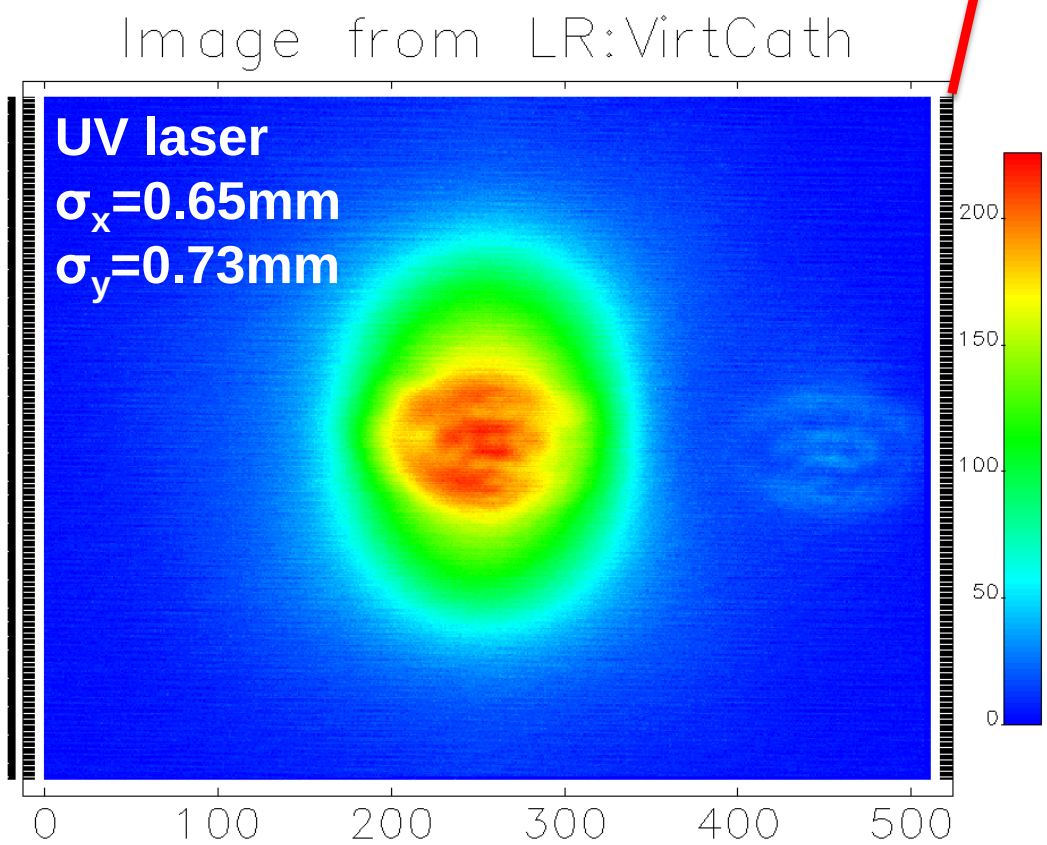
- Test alpha magnets and RF interleaving operations;
- Design and bench test of the bucking coils for interleaving dipole magnets;
- Test beam trajectory recovery for interleaving of the two gun beams;
- Design and test of the interleaving lattice for RG2 and PCG beams;
- Design and test of the Interleaving scripts;
  - Requires the permit of interleaving ACIS.
- Interleaving operation commissioning.

PCG BEAM MEASUREMENTS USING INTERLEAVING LATTICE

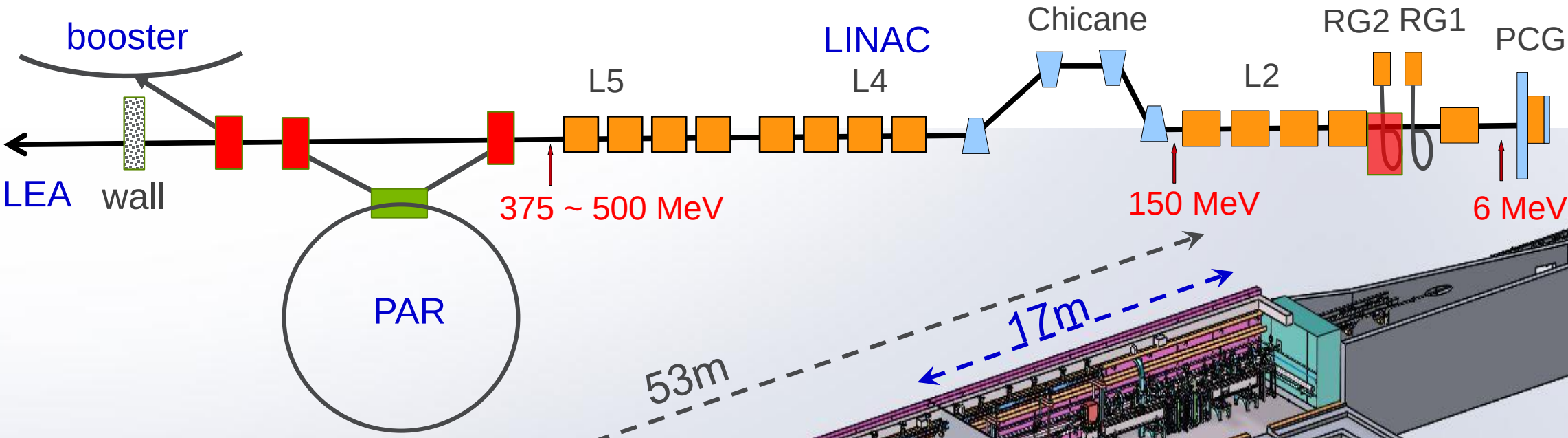
375 MeV ← 100 ~ 150 MeV ← 43 MeV ← 6.5 MeV







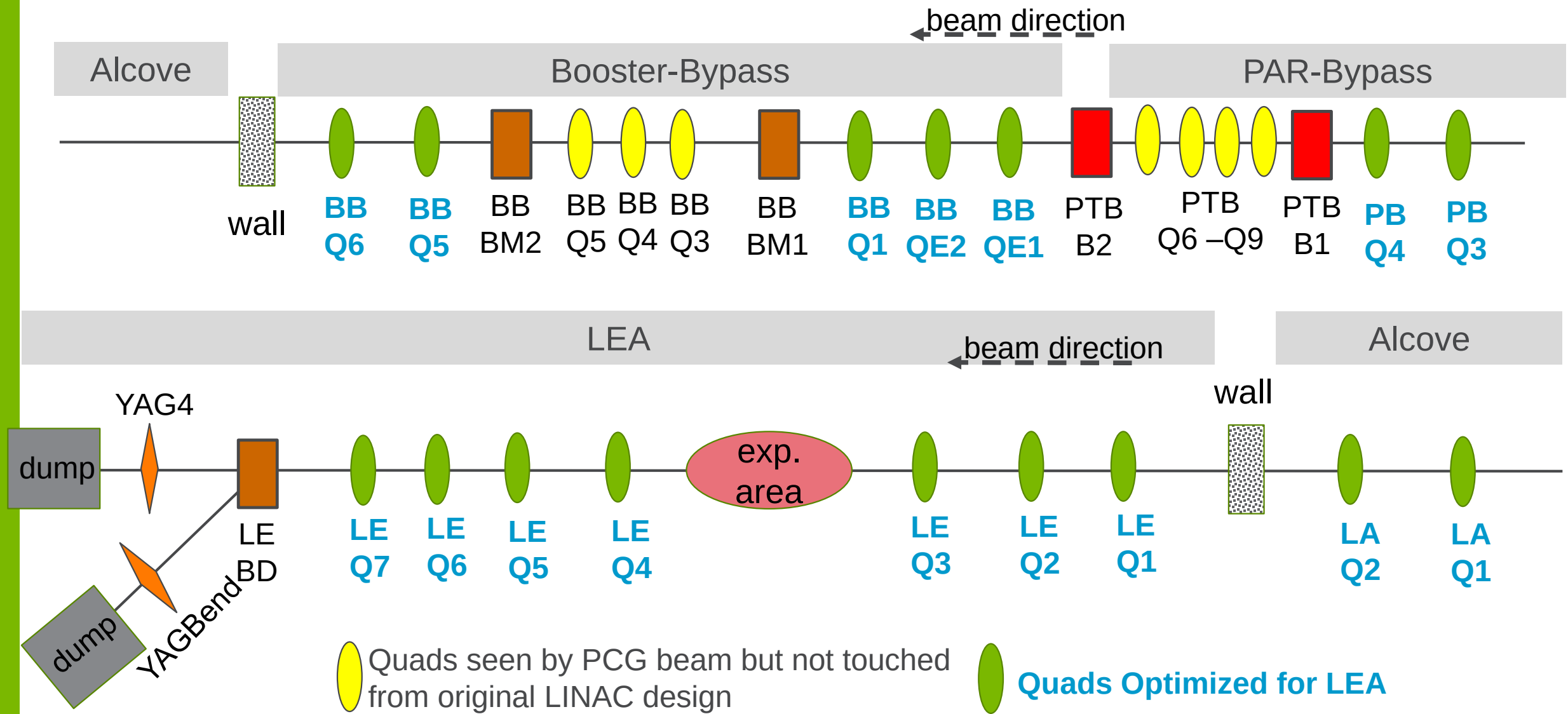
LEA: LINAC EXTENSION AREA



3D tunnel drawing: S. Lee
Dimensions: W. Berg

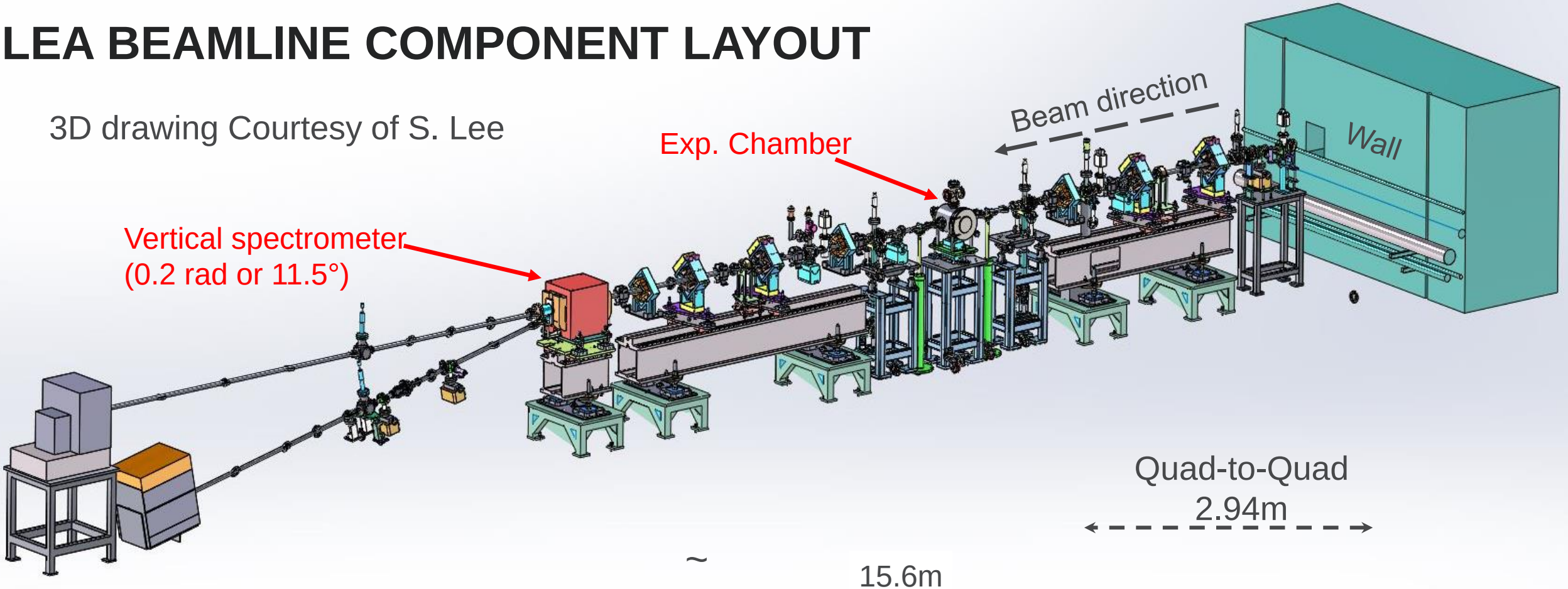
- Phase-I beamline will utilize the first ~ 17 mete of the tunnel;
- The tunnel enclosure is rated for 1000W
- Maximum PCG beam power < 65 W:
  - Max copper cathode quantum efficiency: 2e-4
  - Max UV drive laser power: 3mW
  - Max beam energy from linac: 500MeV

LEA LATTICE

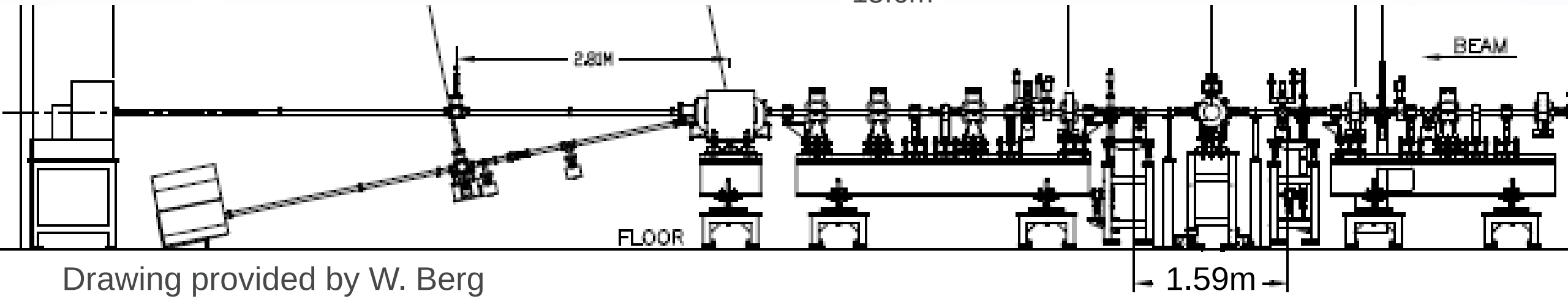


LEA BEAMLINE COMPONENT LAYOUT

3D drawing Courtesy of S. Lee



~ 15.6m



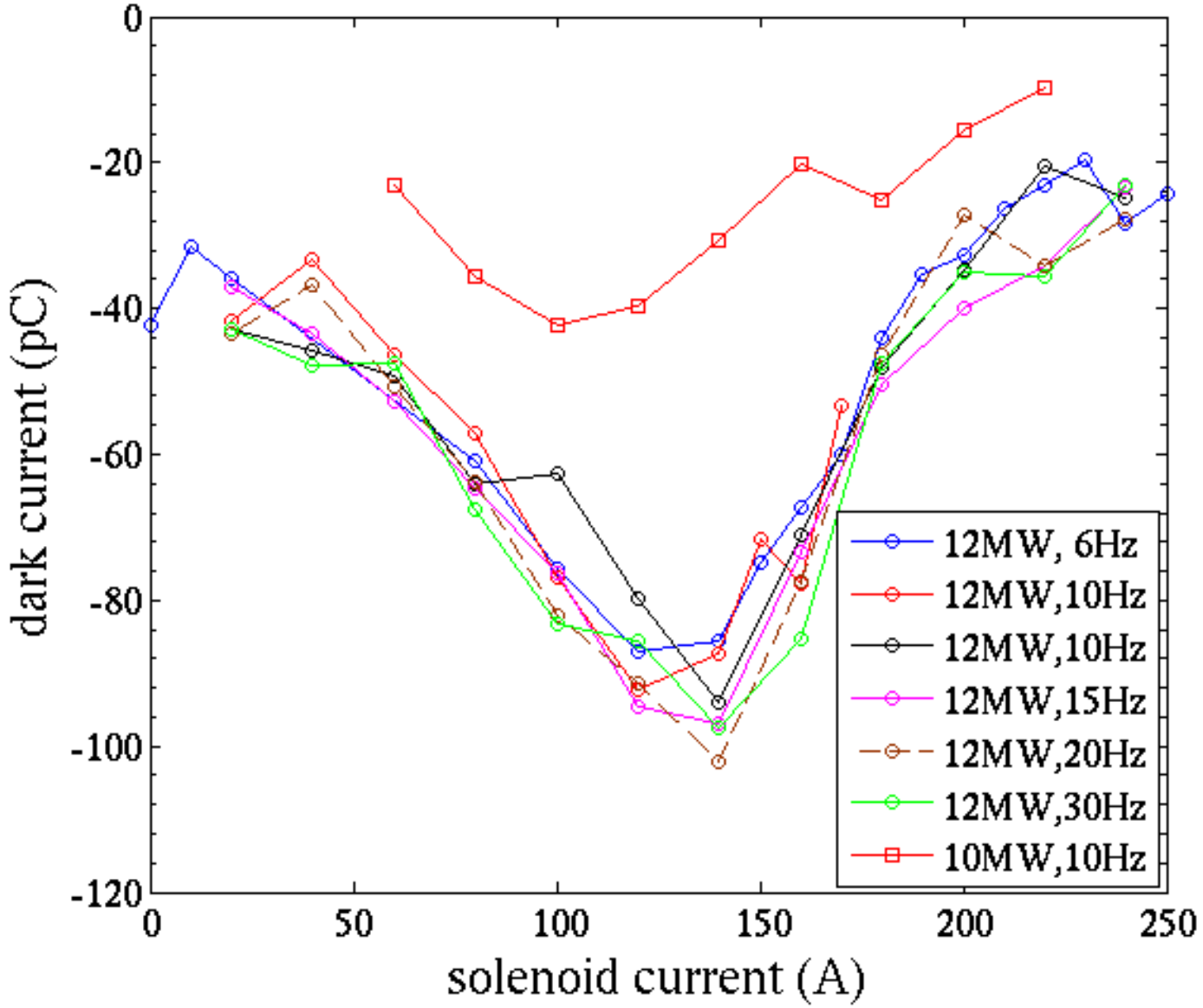
Drawing provided by W. Berg

Thanks for your interest!

PC GUN DARK CURRENT

- The maximum dark current per RF pulse observed during the RF conditioning is <150 pC.

- The corresponding maximum power of the PC Gun dark current at the exit of the linac is 150pC*30Hz*550MV=2.5 mW

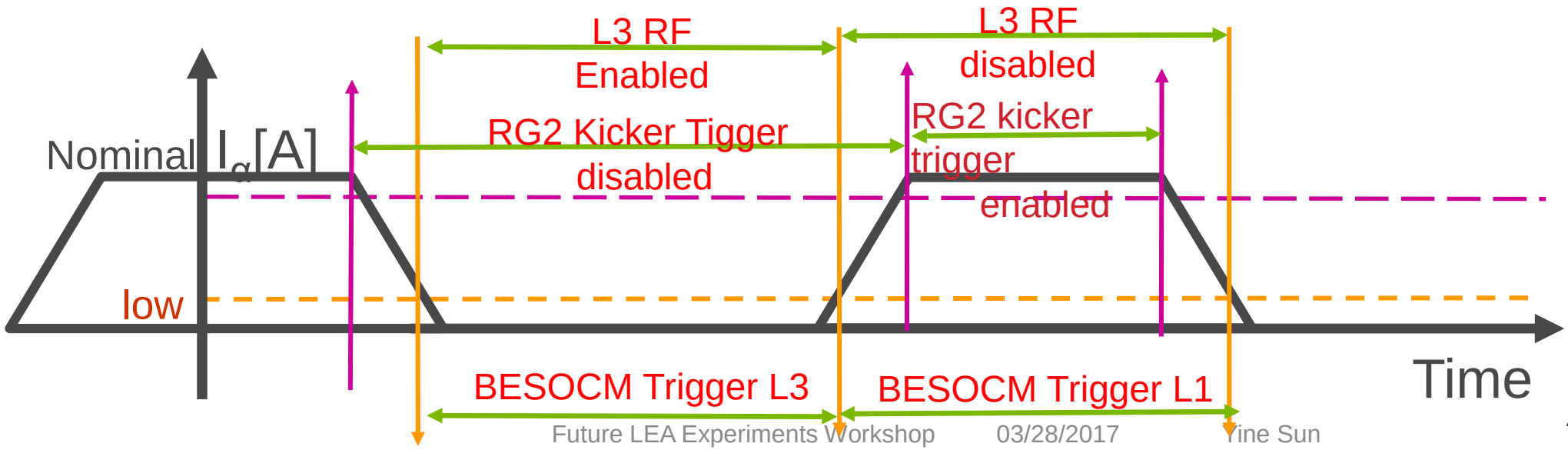


Measured PCG Dark Current

INTERLEAVING SEQUENCE DESIGN

- -30 second (I_α=0A)
  - set $I_\alpha = I_0$;
- I_α>low value threshold
  - disable L3 RF;
  - Set L1 LLRF gate start for RG2;
  - Set L2 PFN for RG2;
  - Set LTP:B1,PTB:B1 and PTB:B2 for RG2;
- I_α>high value threshold
  - Enable gun kicker;
  - Inject;
  - Check storage current to meet top up requirement;

- Storage Ring current OK:
  - set I_α =0A;
- I_α<high value threshold
  - Disable gun kicker;
  - Set L1 LLRF gate start for PCG;
  - Set L2 PFN for PCG;
  - Set LTP:B1,PTB:B1 and PTB:B2 for PCG
- I_α<low value threshold
  - Enable L3 RF.
- Repeat; -30 second(I_α=0A)…



INTERLEAVING LATTICE DESIGN AND TESTING

- Same linac lattice for RG2 and PCG beams;
- Same Beam energy ~150MeV at L3;
- Good injection efficiency for RG2 beam;
- Preserve PCG beam emittance and meet the design goal at the LEA experimental area.
- Experimental test the interleaving lattice.