Two-beam Test Stand:
Beams, Structures and Experiments

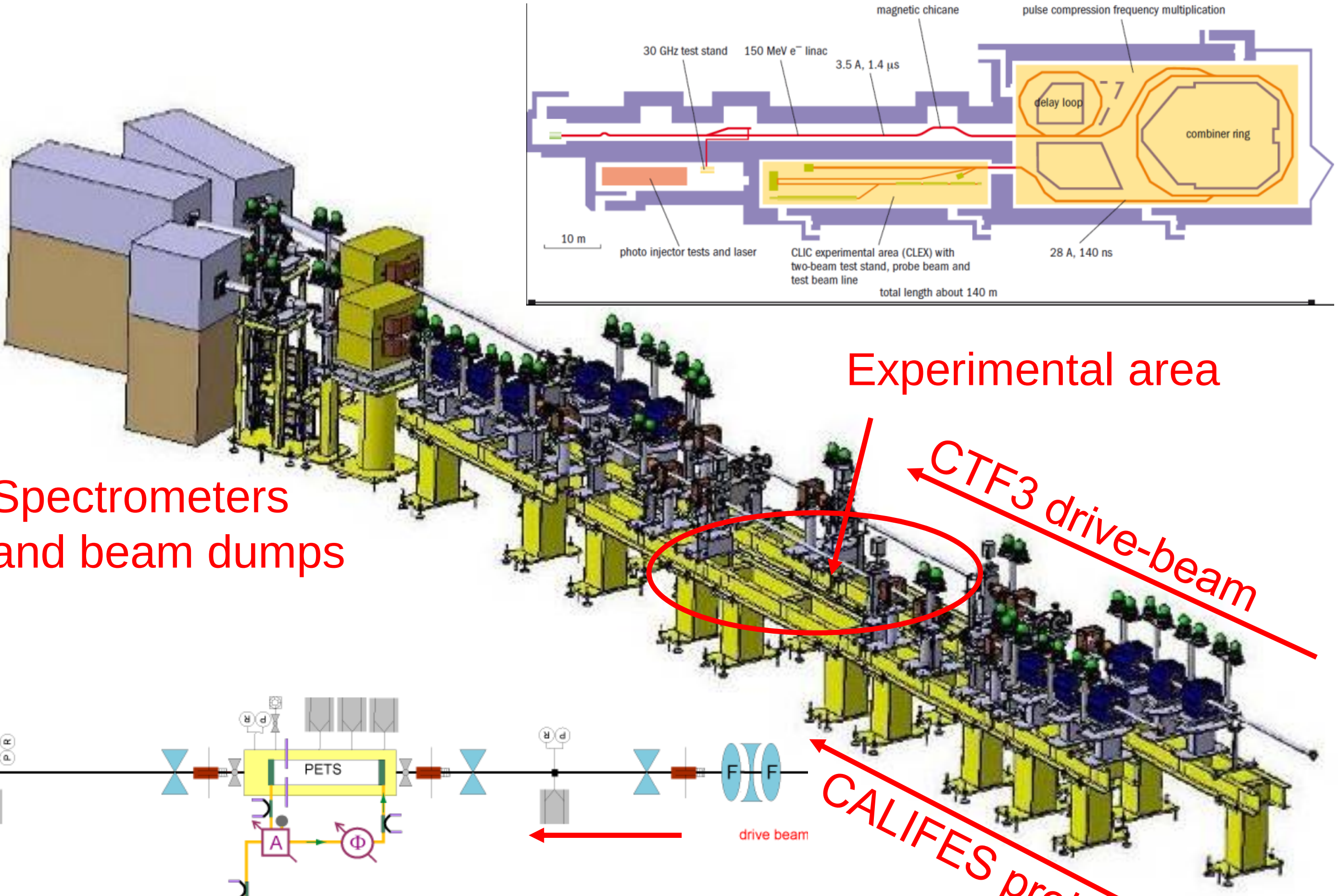
Roger Ruber for the TBTS Team

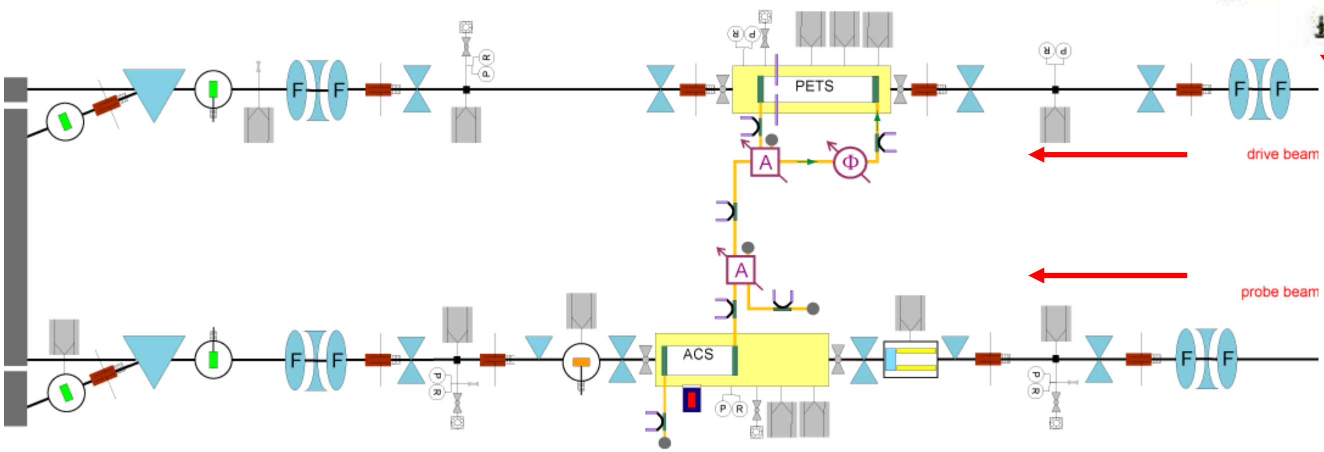
http://cern.ch/ctf3-tbts

CTF3 Collaboration Meeting
5 May 2010

Two-beam Test Stand

Construction supported by the Swedish Research Council and the Knut and Alice Wallenberg Foundation



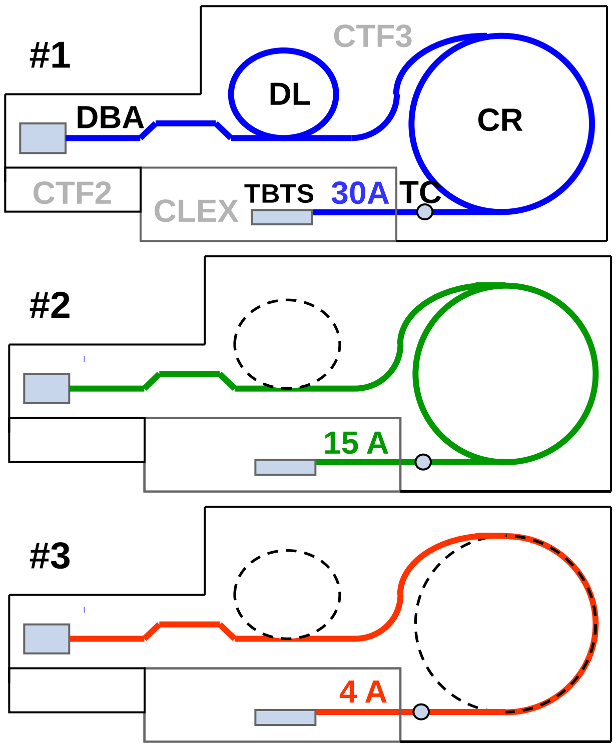


Two-beam Test Stand Prospects

- Unique and versatile facility
  - two-beam operation
    - high power drive-beam [~110 MeV, ~30A]
    - high quality probe-beam [~140 MeV, ~0.5A]
  - excellent beam diagnostics, long lever arms
  - easy access & flexibility for future upgrades
- Excellent test possibilities
  - power production & accelerating structures
    - beam kick
    - beam dynamics effects
  - full CLIC module
    - beam-based alignment

CTF3 Drive Beam

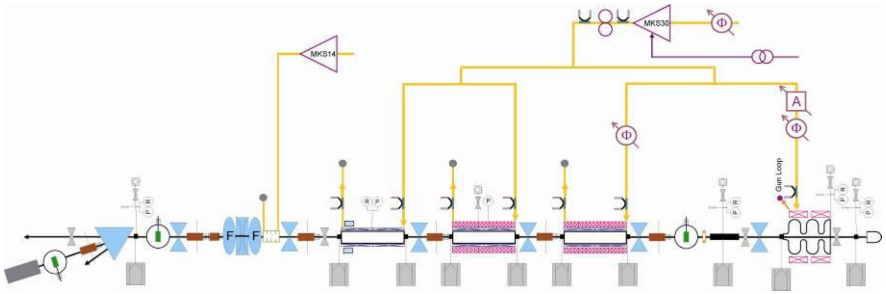
Mode	#1	#2	#3	
Energy	110(*)			[MeV]
Energy spread	2			[%]
Current	30	15	4	[A]
Pulse length	140	240	1100	[ns]
DBA frequency	1.5	3	3	[GHz]
Bunch frequency	12	12	3	[GHz]
Repetition rate	0.8(*)			[Hz]
PETS power	200	61	5	[MW]

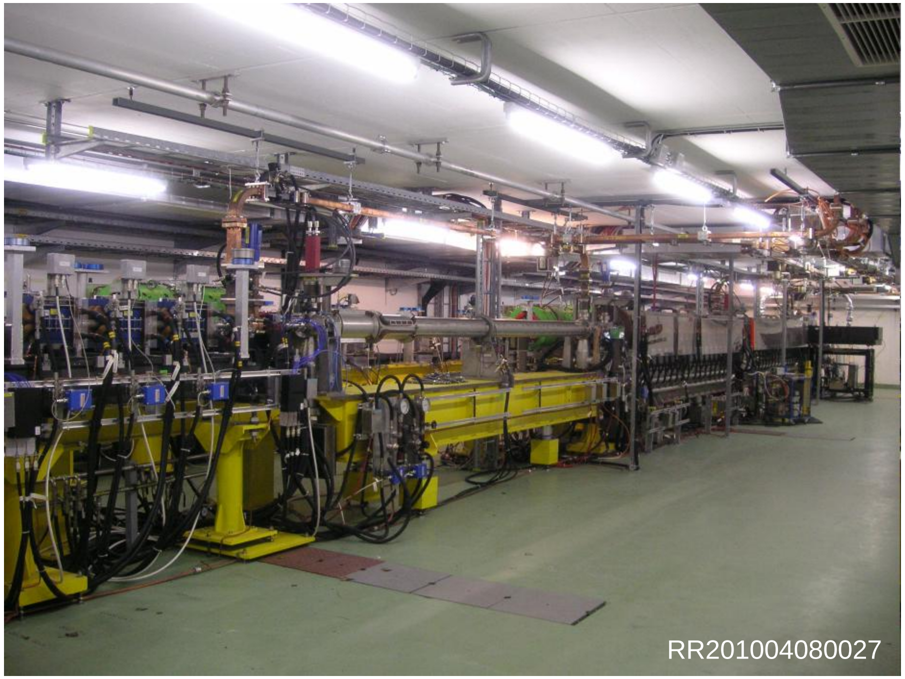


NOTE:
- PETS length 1 m (0.215 m in CLIC)
- To adjust the pulse length,
  a tail clipper (TC) is installed between CR and TBTS.
- Upgrade possible to nominal 150 MeV at 5 Hz repetition rate.

CALIFES Probe Beam

Mode	SP	LP	
Energy	140		[MeV]
Energy spread	2		[%]
Current	1	0.13	[A]
Bunch charge	0.6	0.085	[nC]
Bunch number	32	226	
Pulse length	20	150	[ns]
Bunch frequency	1.5		[GHz]
Repetition rate	5		[Hz]



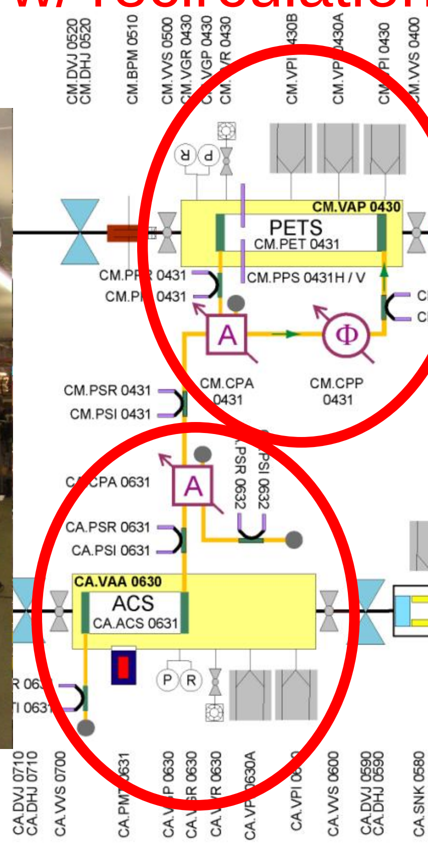


NOTE:
- Beam waist 0.1mm on OTR screen

TBTS Test Area

CERN EDMS Id. 894313 (version 6.3)
Roger Ruber, 2010/03/03

1x PETS
w/ recirculation

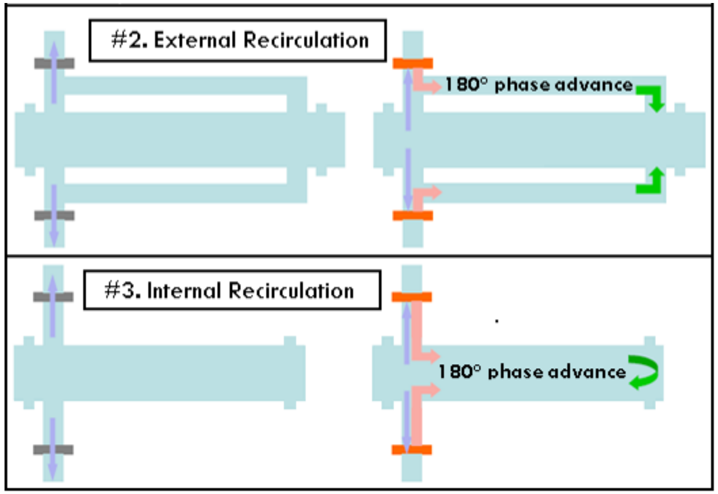


1x accelerating
structure

Future upgrades:
G. Riddone, Th. 06-May 15:00

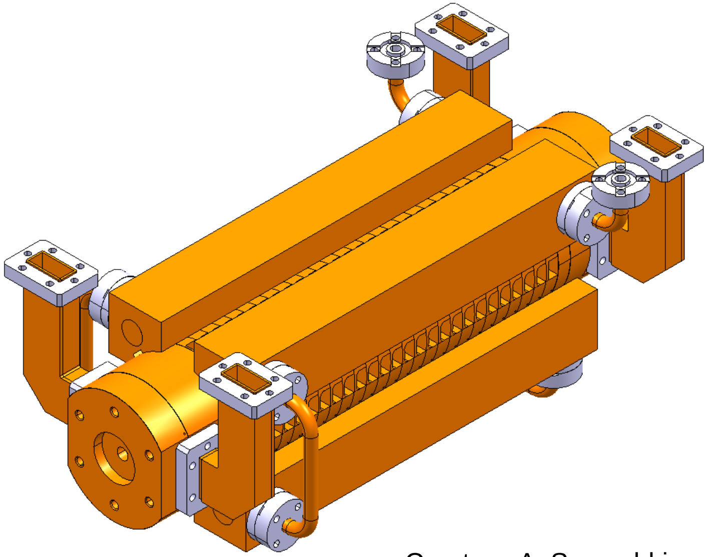
Structures Test Program

- Drive Beam Area
  - Installed:
    - TBTS PETS, 1m long
    - external RF power recirculation
  - Next test foreseen:
    - PETS On/Off option (active reflector)
      A. Cappelletti (04-May-2010)
      4th X-band Workshop
      http://indico.cern.ch/event/75374



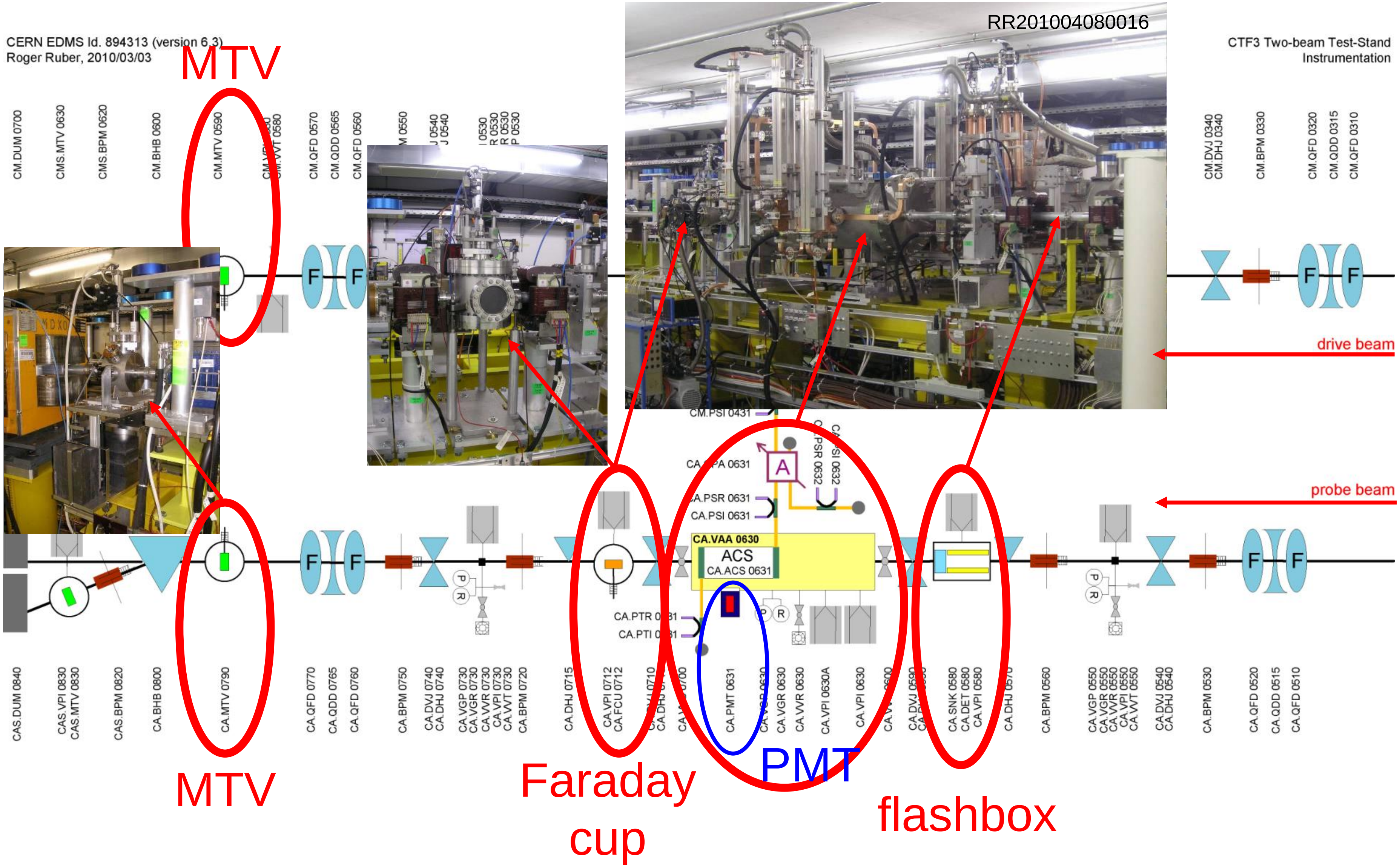
Courtesy A. Cappelletti

- Probe Beam Area
  - Installed:
    - TD24 = disks, tapered, damped, 24 cells
      A. Samoshkin (07-Apr-2010)
      CLIC RF struct. dev. meeting
      http://indico.cern.ch/event/72089
  - Next test foreseen:
    - TD24 with wakefield monitor



Courtesy A. Samoshkin

TBTS New Instrumentation



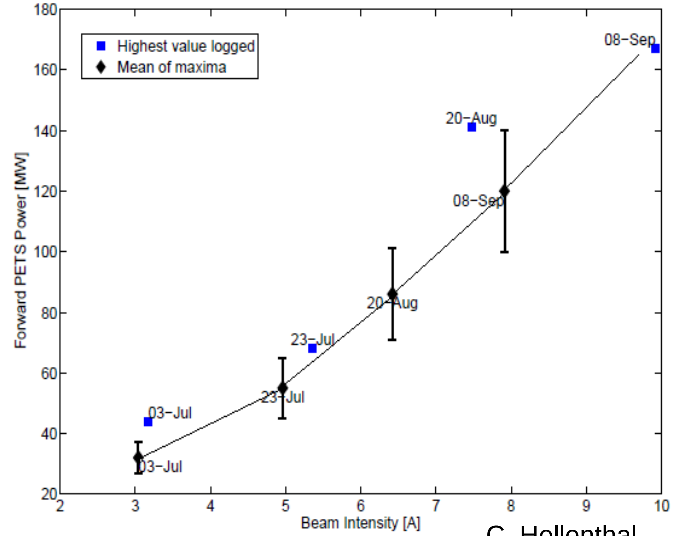
TBTS New Instrumentation

Overview Experimental Program

- 2010 Run Schedule
  - mid June to end July
    - CTF3 restart, initial TBTS beam
  - August
    - PETS conditioning to nominal power/pulse length
  - September
    - accelerating structure conditioning
    - two-beam acceleration tests
  - October to December
    - (PETS) breakdown rate measurements?
    - breakdown kick measurements
    - beam loading compensation?
- 2011 Run Schedule
    - effect beam loading on breakdown rate?
    - test PETS on/off scheme

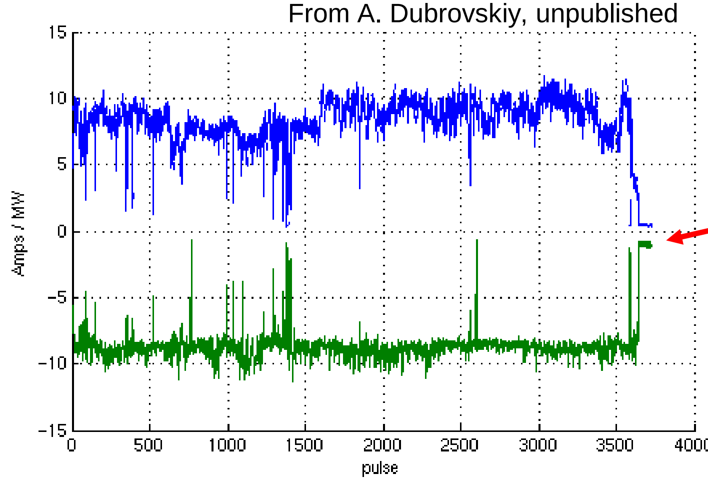
PETS Conditioning

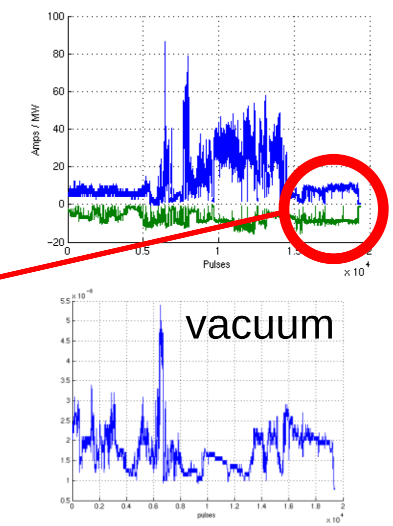
- July/Sept 2009
  – with recirculation
  – limited by recirculation loop
  – P_{max}= 167 MW
  – I_{max}= -9.9 A
- Nov/Dec 2009
  – w/o recirculation
  – $<P_{peak}>$= 8.4 MW
  – $<I_{peak}>$= -8.7 A
  – 250 ns pulse
- see talk A. Cappelletti today, 16:00



C. Hellenthal, CLIC Note 811 (2009)

From A. Dubrovskiy, unpublished

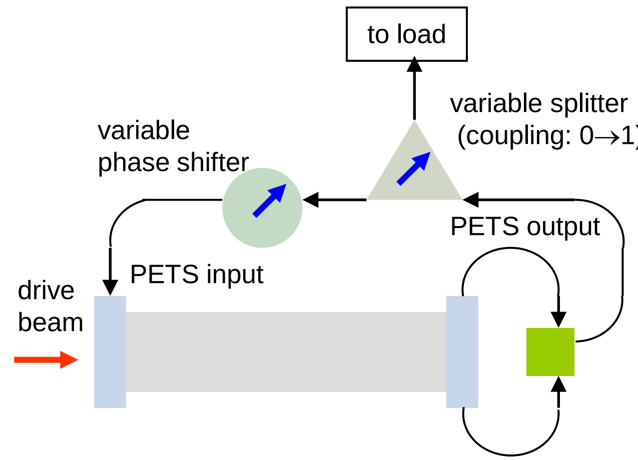


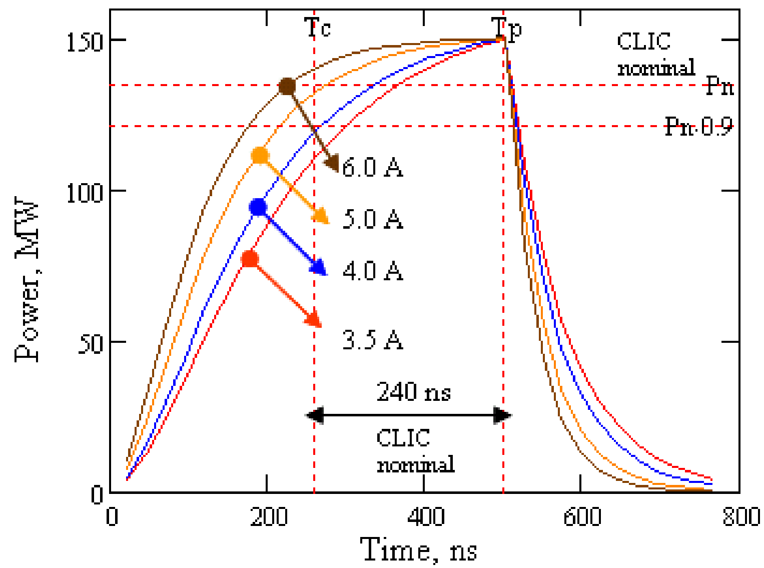


PETS Power Recirculation

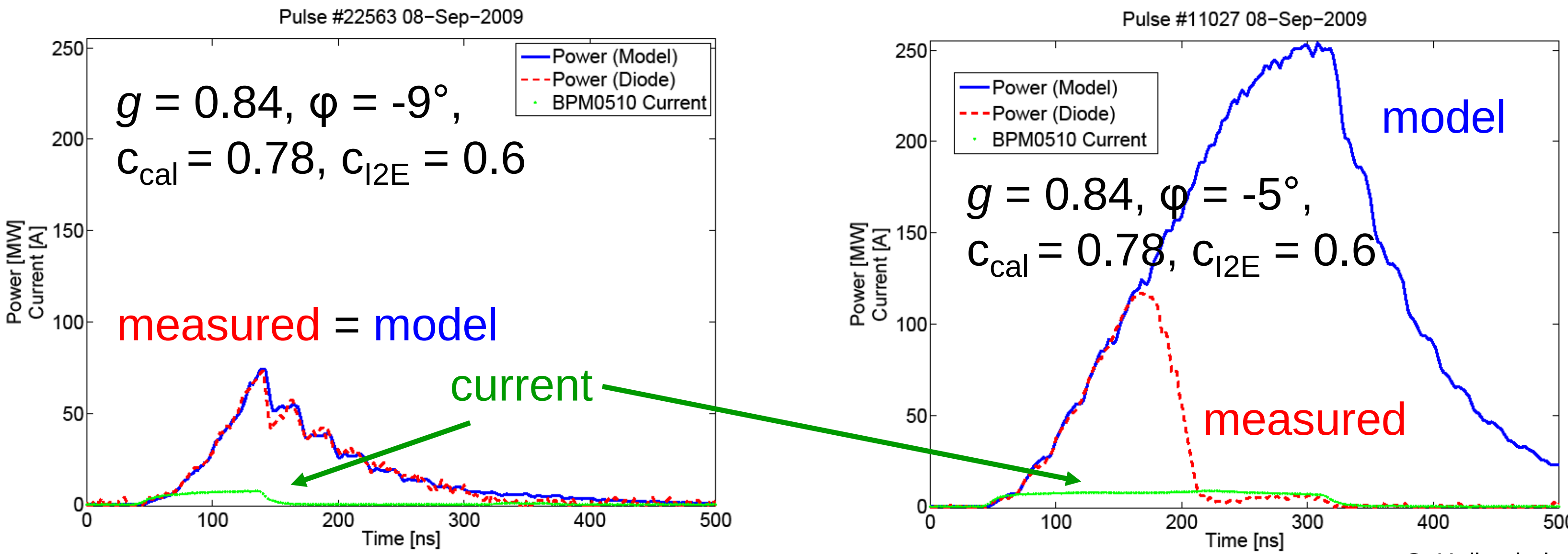
- PETS length 1m, to compensate for lower beam current compared to CLIC
- External recirculation loop
  – increase PETS power in long pulse, low current mode #3
- power recirculation through external feedback loop:
  – electron bunch generates field burst
  – field burst returns after roundtrip time t_r = 26ns

  PETS operates as amplifier (LASER like)
- phase shifter to adjust phase error in the loop





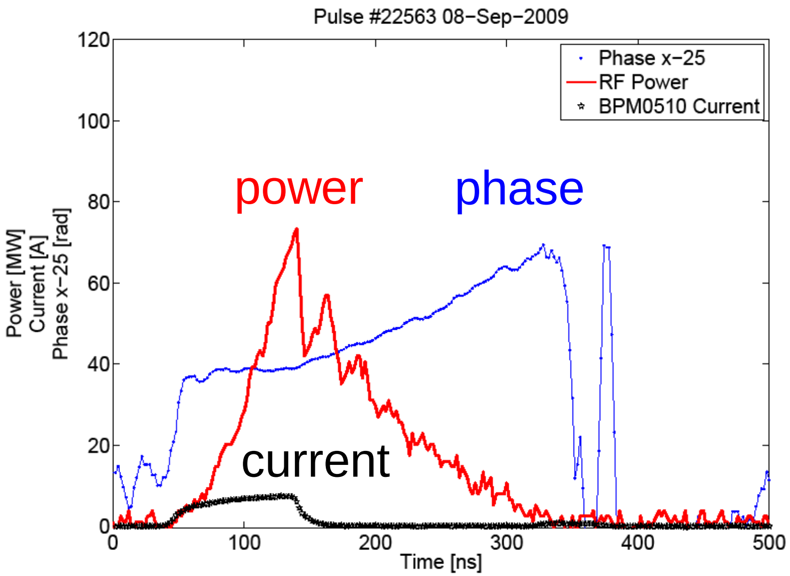
Power Reconstruction with Recirculation

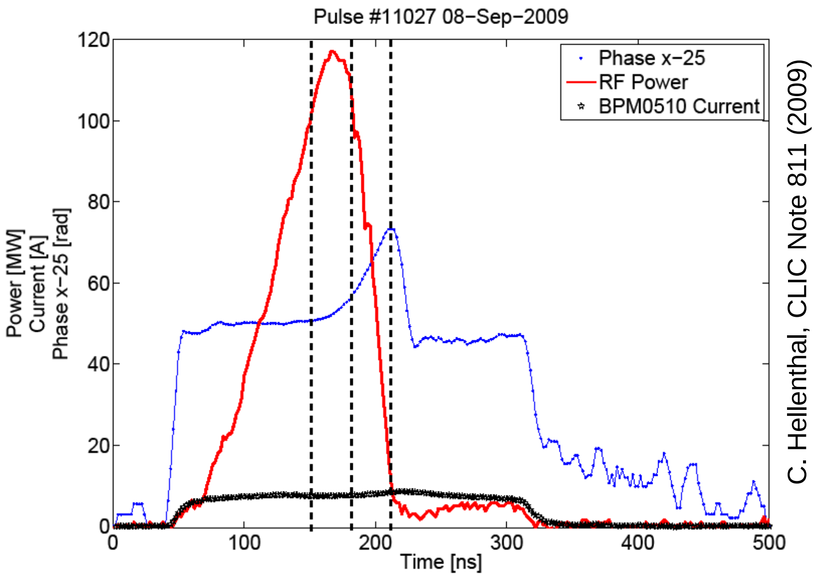


C. Hellenthal, CLIC Note 811 (2009)

- Parameters constant during normal operation
  → predicts PETS output power (CTF3 Note 092, 094, 096)
- Accurate parameter fit rising slope
  → gives recirculation loop loss factor and phase shift
- Energy difference (ε) measurement and model indicates ”pulse shortening” → breakdown indicator

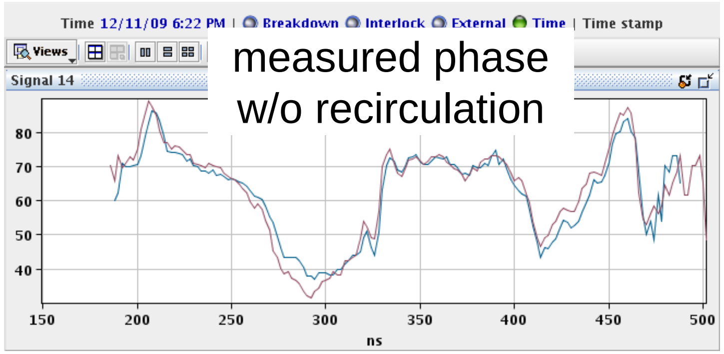
Phase Reconstruction with Recirculation





- Strong phase change around point of ”pulse shortening”
- Effect visible in all pulses with ”shortening”
  → useful for breakdown detection (CLIC Note 811)
- Initial phase variation incoming drive beam
  → interpretation of recirculation phase (CTF3 Note 094) incomplete
  → have to improve the algorithm…

From A. Dubrovskiy, unpublished

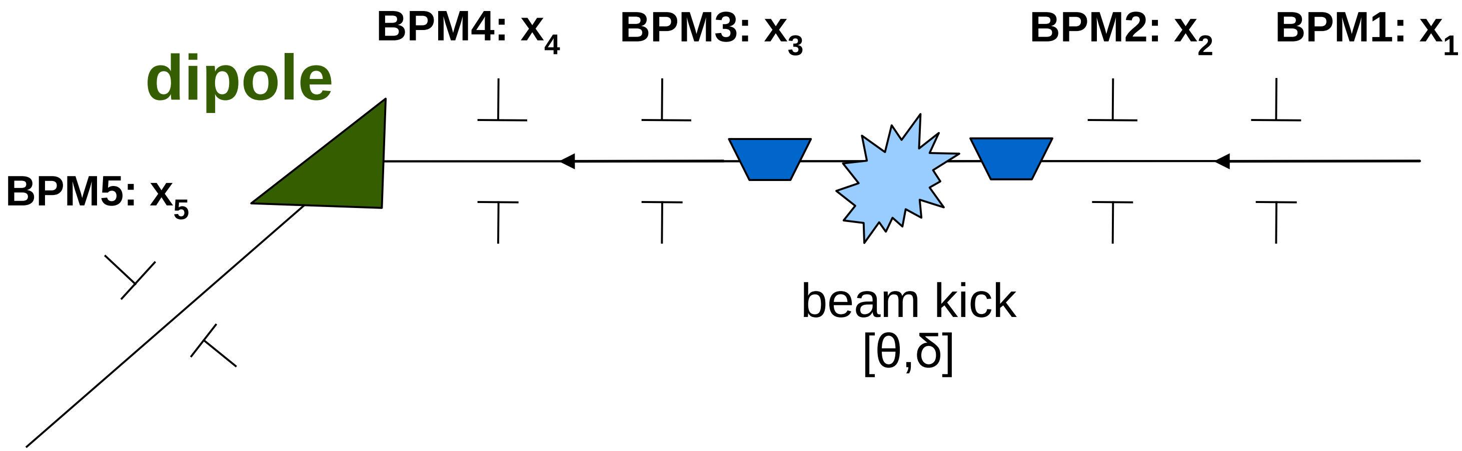


Two-beam Acceleration

- Coarse timing drive and probe beam (ns adjustment)
  - assure signals on BPM and RF channels to overlap
- Calibration of RF system
  - characterize losses in waveguides
    PETS output RF pulse (shape) == ACS output if no probe beam
- Demonstrate acceleration by energy gain probe beam
  - scan along PETS 12GHz RF phase
    (sub-ps timing adjustment, $1^{o} = 0.23$ps):
    modify laser phase to adjust bunches to PETS phase
    → monitor energy gain
  - **Note:** acceleration by 15% → adjust downstream optics!

Beam Kick Measurements

M. Johnson, CLIC Note 710



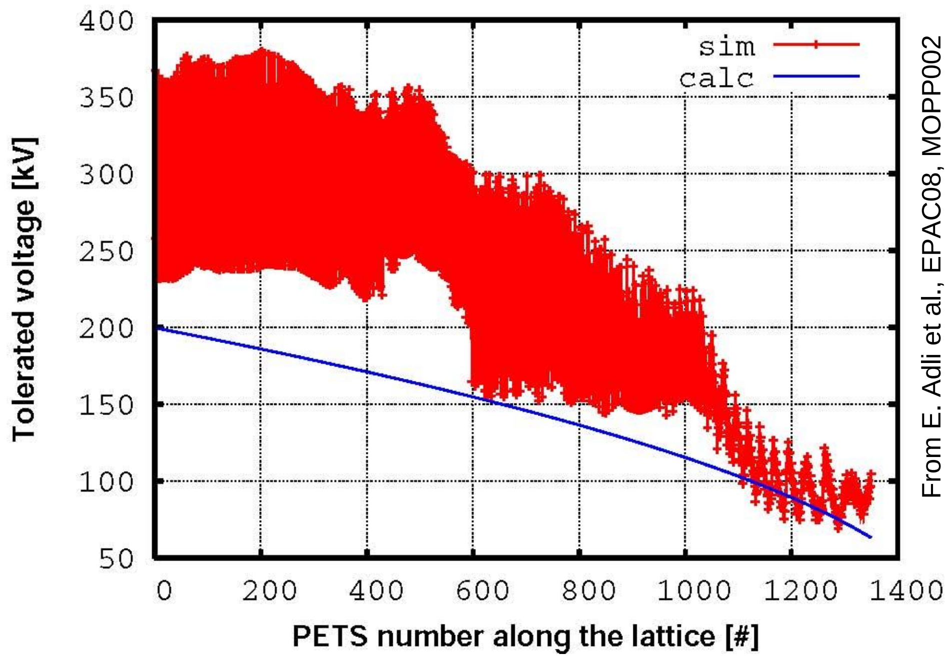
- 5 BPMs: incoming angle & offset, kick angle
- dipole + BPM5 for energy measurement

$$\vec{x} = A\vec{\theta}$$

$$\vec{\theta} = (A^t A)^{-1} A^t \vec{x}$$

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ R_{11}^{12} & R_{12}^{12} & 0 & 0 \\ R_{11}^{13} & R_{12}^{13} & R_{12}^{c3} & 0 \\ R_{11}^{14} & R_{12}^{14} & R_{12}^{c4} & 0 \\ R_{11}^{15} & R_{12}^{15} & R_{12}^{c5} & D^5 \end{pmatrix} \begin{pmatrix} x_1 \\ x_1' \\ \theta \\ dp/p \end{pmatrix}$$

Importance of the Drive Beam Kick



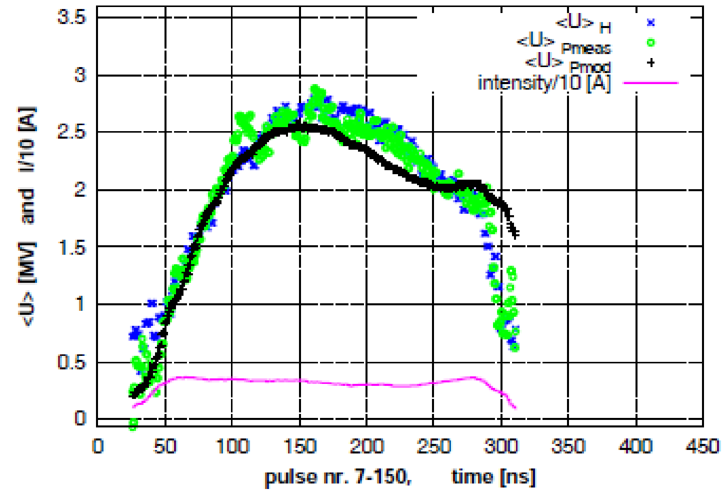
- Maximum accepted PETS break down voltage in CLIC
  - transverse voltage required for 1mm offset in drive beam
  - as function of PETS (position) along linac
- PETS beam kick estimate: (point like bunch, 15GHz)

$$\theta / x_P = 2 \frac{L_{\text{PETS}}}{E_{tot}} e \frac{I}{f_{\text{bunch}}} k'_T = 27 \mu\text{rad/mm}$$

From E. Adli, Thesis (2009)

Drive Beam Energy Loss in PETS

- Energy loss (CTF3 Note 097)
  - spectrometer line (blue)
  - PETS power + BPM intensity (green)
  - BPM intensity (black)

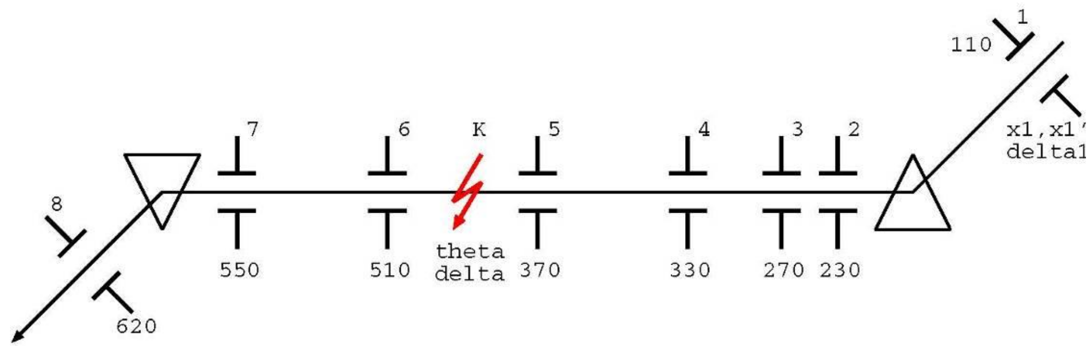


From E. Adli et al., DIPAC09 MOPD29

- Include initial energy variation
  → improves kick measurement (CTF3 Note 098)

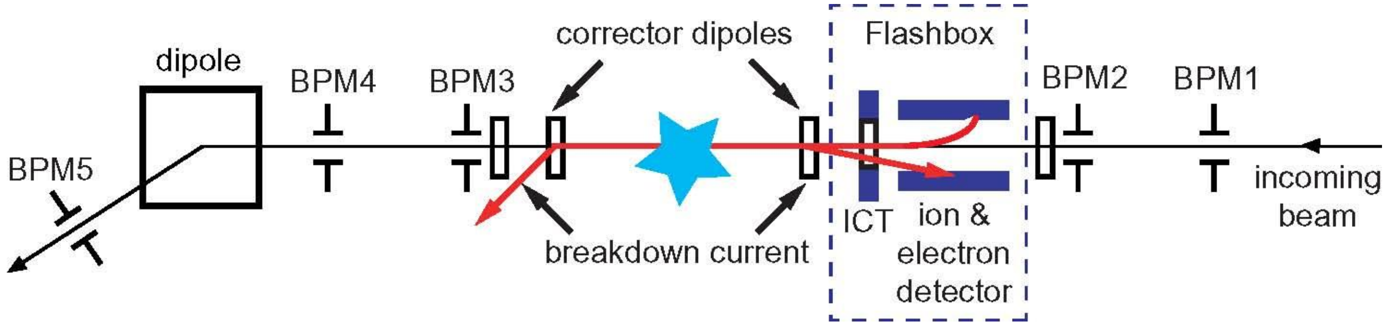
$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ R_{11}^{21} & R_{12}^{21} & R_{16}^{21} & 0 & 0 \\ R_{11}^{31} & R_{12}^{31} & R_{16}^{31} & 0 & 0 \\ R_{11}^{41} & R_{12}^{41} & R_{16}^{41} & 0 & 0 \\ R_{11}^{51} & R_{12}^{51} & R_{16}^{51} & 0 & 0 \\ R_{11}^{61} & R_{12}^{61} & R_{16}^{61} & R_{12}^{6K} & 0 \\ R_{11}^{71} & R_{12}^{71} & R_{16}^{71} & R_{12}^{7K} & 0 \\ R_{11}^{81} & R_{12}^{81} & R_{16}^{81} & R_{12}^{8K} & R_{16}^{8K} \end{pmatrix} \begin{pmatrix} x_1 \\ x_1' \\ \delta_1 \\ \theta \\ \delta \end{pmatrix}$$

$$\begin{pmatrix} x_1 \\ x_1' \\ \delta_1 \\ \theta \\ \delta \end{pmatrix} = (A^T A)^{-1} A^T \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \end{pmatrix}$$

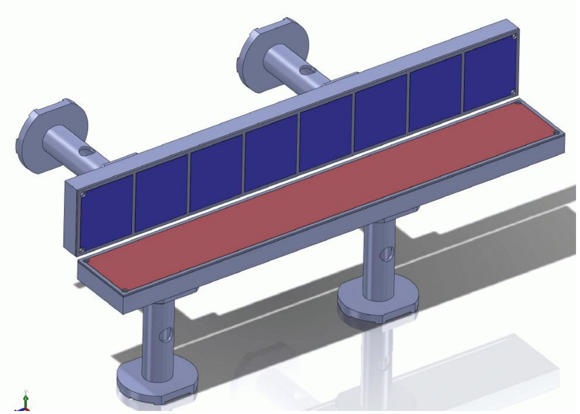


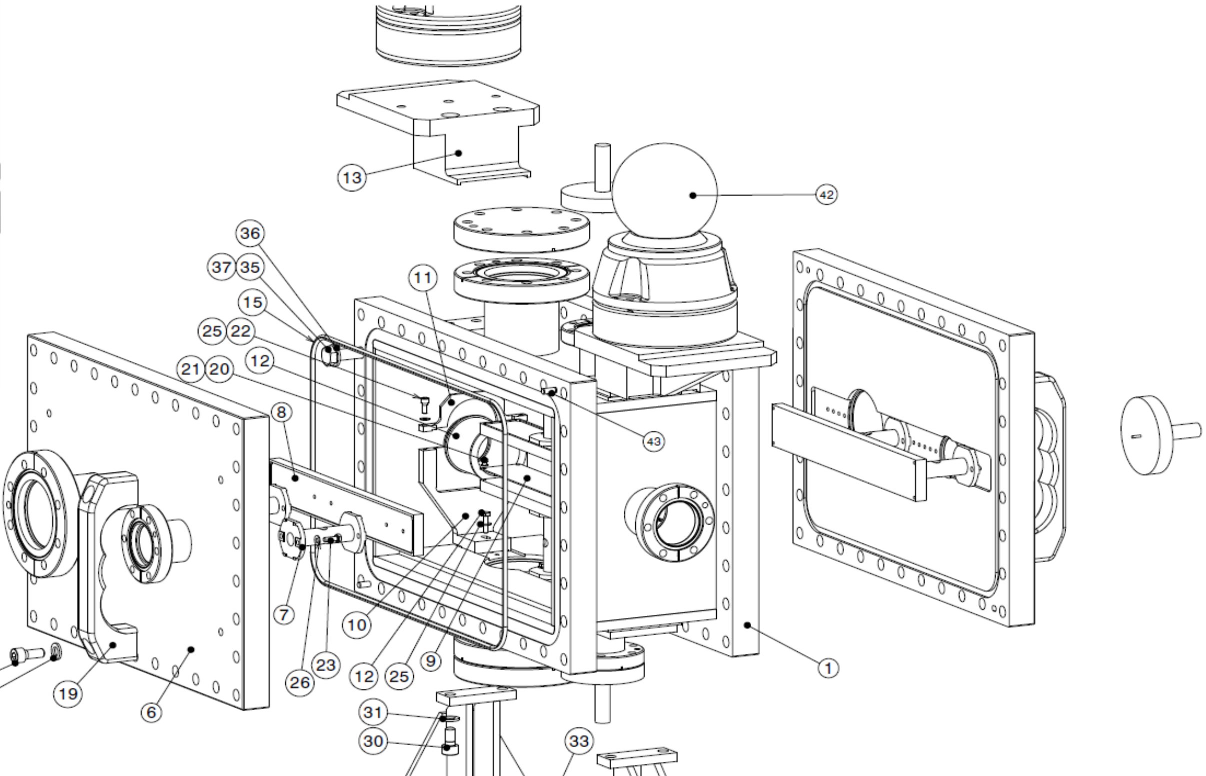
Electron and Ion Detection

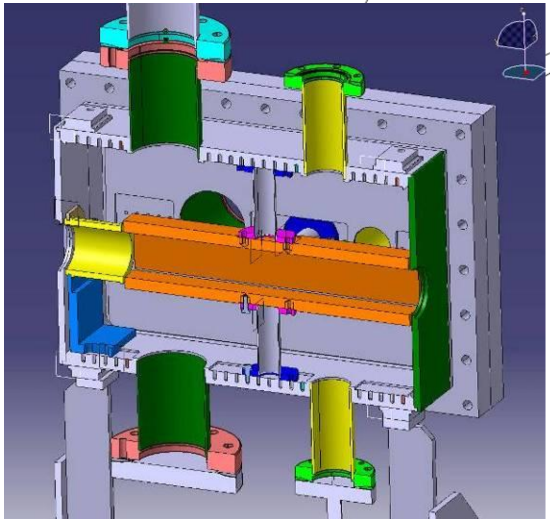
- Downstream: moveable Faraday cup, if CALIFES off
- Upstream: Flashbox in-line detector for dark current and electrons/ions emitted during RF breakdown
  - magnetic chicane for electron deflection
  - DC field for ion deflection
  - fast electron signal as breakdown trigger, CALIFES off/on
  - segmented detector plates → longitudinal ion profile proportional to velocity distribution → plasma parameters of breakdown from Coulomb explosion model

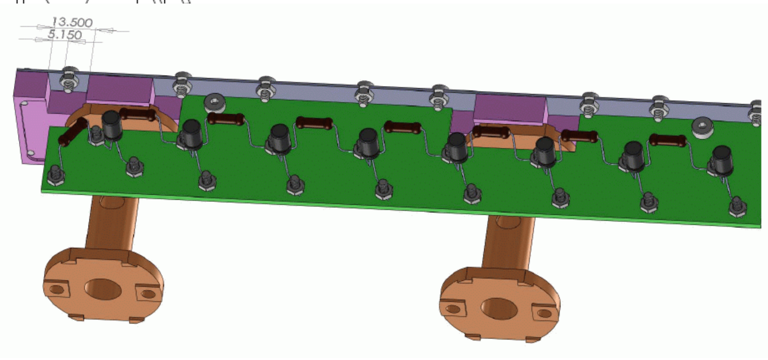


Flashbox for Electron and Ion Detection



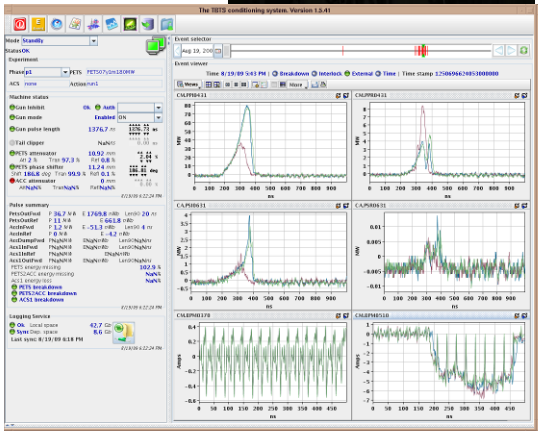


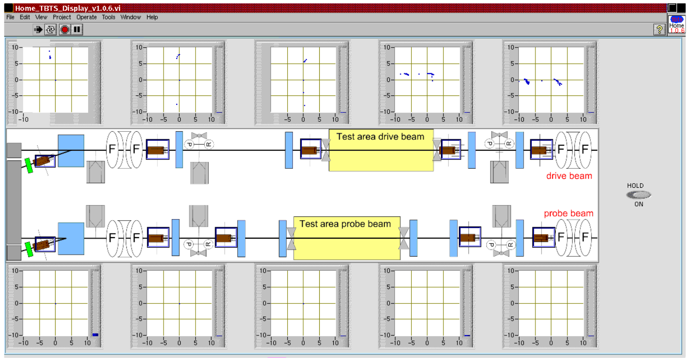




Data Acquisition and Controls

- Electronics
  - 16x 12GHz diode channels
  - 8x I&Q demodulator channels
  - 4x variable signal attenuators
  - 32x 1 GS/s 250 MHz Acqiris ADCs
- Software
  - data acquisition and monitoring
    - adding drive beam upstream energy measurement
    - adding conditioning control ACS
  - GUI control & monitoring TBTS, CALIFES, TL2'





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Summary

- TBTS provides us with a versatile & unique facility for exciting physics!

- Related talks:
  - Status of CTF3
    F. Tecker, today 14:30
  - Results of Beam Based RF Power Production in CTF3
    A. Cappelletti, today 16:00
  - CALIFES Status
    W. Farabolini, tomorrow 09:30
  - CLIC Modules Program in CTF3
    G. Riddone, tomorrow 15:00