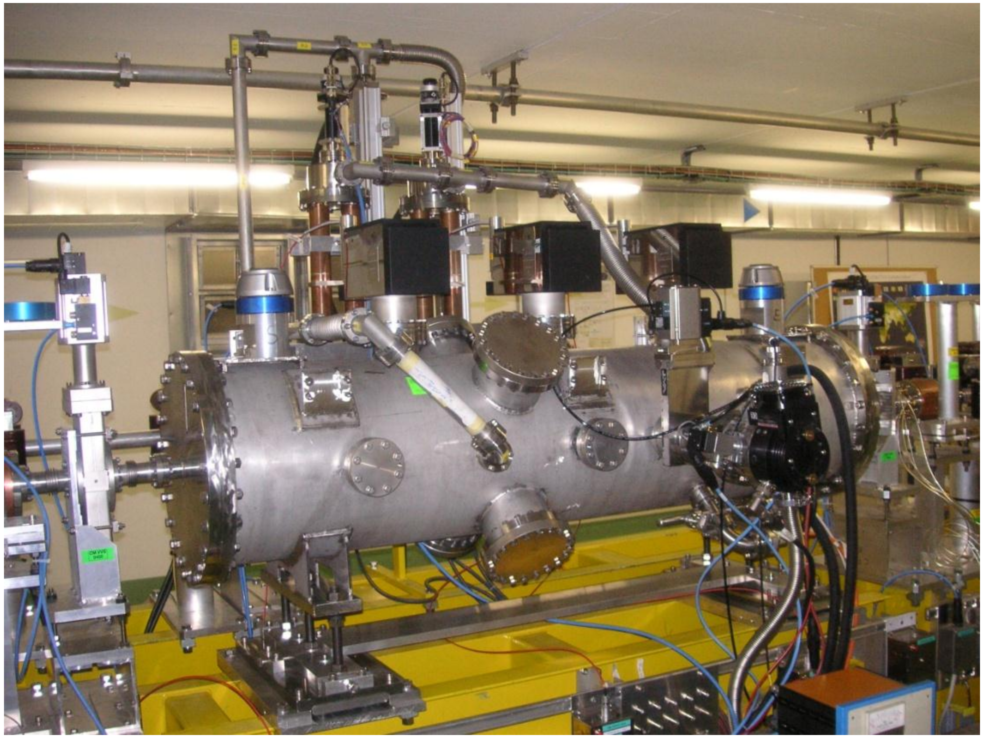
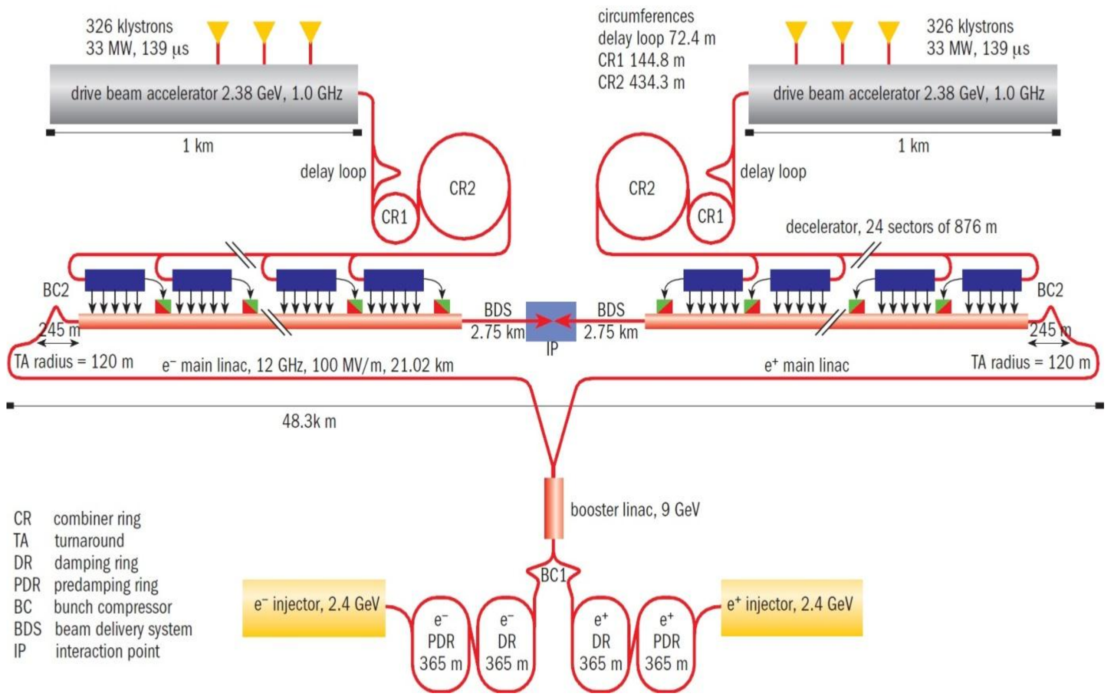
Phase Reconstruction for Drive Beam Recirculation in the CTF3 Two-Beam Test Stand



CERN Summer Student Presentations 2011

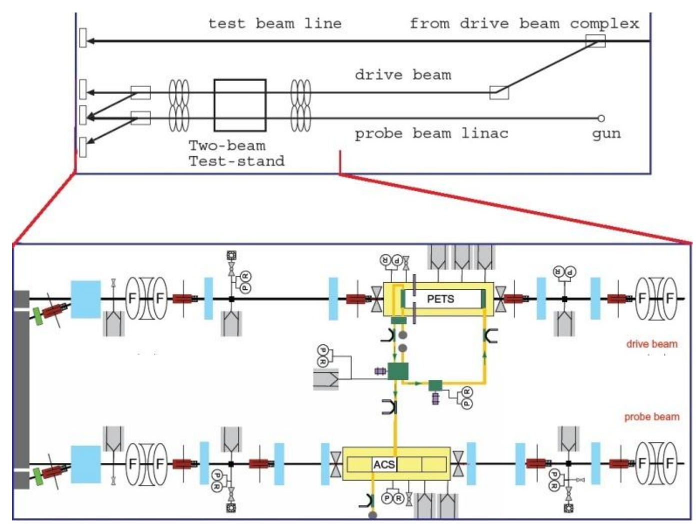
Daniel Xavier Ogburn

CLIC and CTF3

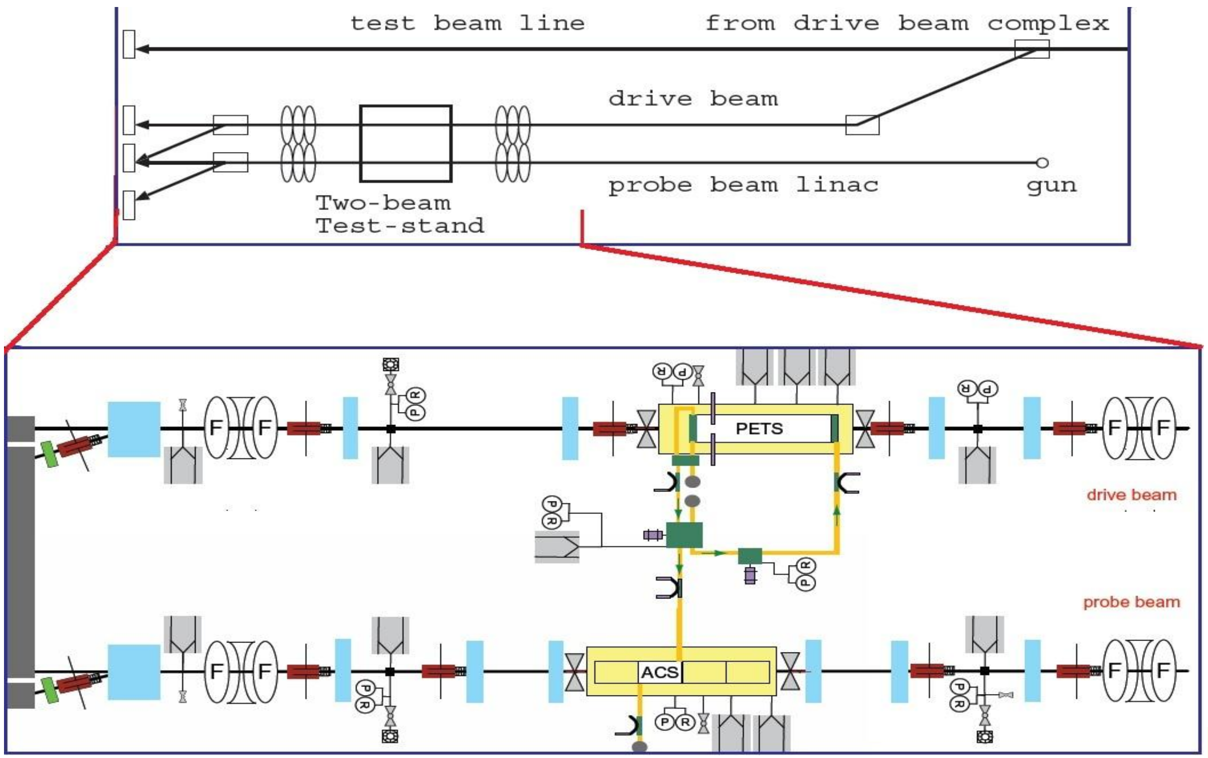


- **CLIC (Compact Linear Collider)**
- Lepton Collider (e+ e-).
- High gradient (100MV/m) linear accelerating structures.
- RF Cavities ~ room temperature (not SC).
- 12GHz beams with target energy 1.5TeV
- Two-beam acceleration .

- **CTF3 (CLIC Test Facility 3)**
- Generation of Drive Beam - thermionic gun, 3GHz linac, combiner rings (*cf. 'lemmings'*) to reach 12GHz.
- Demonstrate two beam acceleration (RF power production in PETS, high gradient acceleration with low breakdown rate).
- Study beam stability and dynamics.
- Understand physics of RF breakdown (limitations, diagnostics and prevention).



CTF3 and the Two-Beam Test Stand



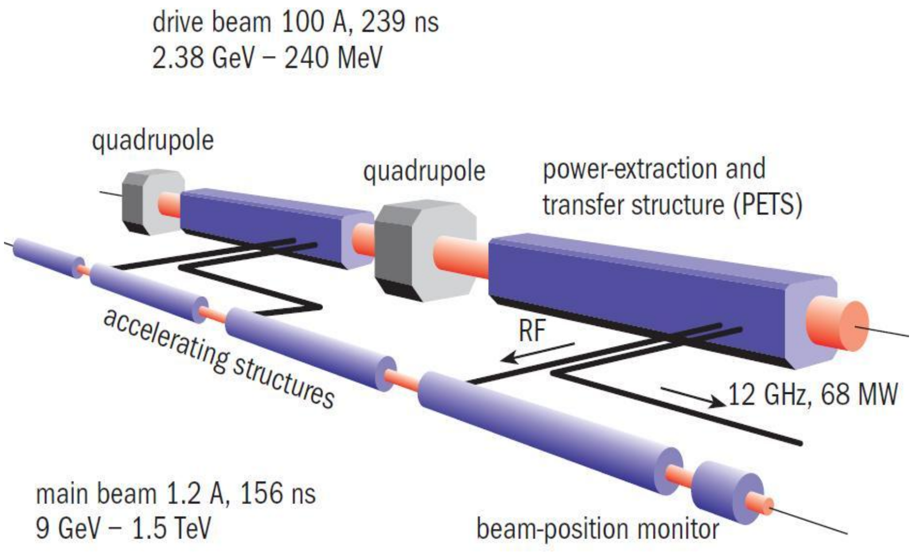
- **Beam generation**
- The CTF3 complex produces a high power, high current (≈32A) drive beam.
- Main ('probe') beam (≈ 0.9A) is generated by the CALIFES linac. Electron source = photocathode + electric field.
- System acts like a giant transformer (*cf. Megatron*).

- **TBTS (Two-Beam Test Stand)**
- Drive beam deceleration and power transfer to Probe beam (via PETS).
- RF signals detected by diodes (amplitude) & IQ demodulators (phase info).
- BPM signals detected with 8 electrode inductive pick up. Faraday cups measure (H/V) position.

MAIN PARAMETERS

	Drive beam	Probe beam
Incoming beam		
Energy	150 MeV	170 MeV
Bunch frequency	1.5--15 GHz	1.5 GHz
Pulse length		
- nominal	140 ns	21 ns
- long pulse	1.5 µs	150 ns
Intensity		
- nominal	32 A	0.9 A
- long pulse	5 A	0.09 A
Repitition rate	5 Hz	5 Hz
Test area		
Available length	1.8 m	2.0 m
Beam height to floor	1.35 m	1.36 m
Distance between beams	0.75 m	

Drive Beam and PETS

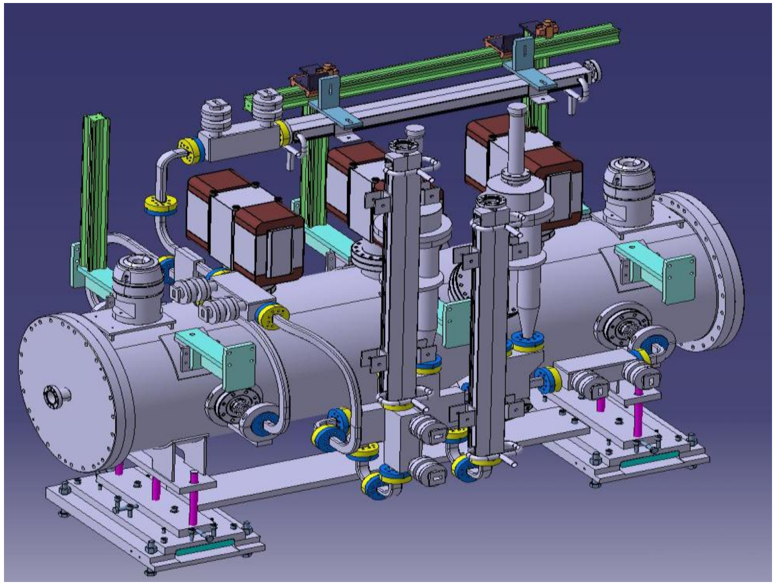


- **Power Extraction Transfer Structure**
- Drive beam enters the PETS recirculation loop. This excites resonant frequencies in the RF cavity which resonates @ beam freq (rel. to e^- bunch spacing).
- RF waves are launched and extracted from the cavity via waveguides.
- Power extracted from Drive beam is transferred to Probe beam. Drive beam decelerated by a few MeV = this generates ~ MW of power.

- **PETS Recirculaton**
  - As drive beam recirculates through PETS we get a power build up like laser pumping if beam is in phase.
  Lose power if out of phase.

  - RF and Beam temporal alignment is a big issue (constructive/destructive interfence).

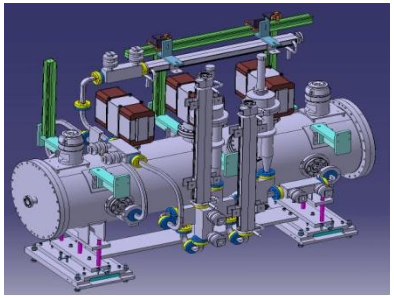
  - Power gain is currently ≈ 0.8 to 0.9.



PETS Recirculation Model

- **AIM**: Use phase information from PETS recirculation to optimize beamline parameters in realtime.
- **Objective**: Determine phase shift of drive beam as it circulates through PETS.
- **Method:** Least squares reconstruction using I,Q demodulated RF signals and Beam intensity (current) signals.
- We can relate the E-field E_m at a given time 'm' to the E-field E_{m-n} in the previous loop ('m-n') and the beam intensity I_m at time 'm'. The recirculation time is given by 'n'.

$$\bar{E}_m = q\bar{E}_{m-n} + c\, e^{i(\alpha_m+\psi)} I_m$$
$$= q\bar{E}_{m-n} + r_m I_m \;.$$



- Here $q = g\, e^{i\phi}$ gives the round trip gain **g** & phase shift from the PETS loop.
- Coupling between cavity and the beam is represented by $R_m = ce^{i(\alpha_m + \Psi)}$ where $e^{i(\alpha_m)}$ the arrival phase variation of the beam and c is a beam-cavity coupling constant.

Implementation of Model

- Reconstruct the E-field by recording the I,Q demodulated signals coming out of PETS with 250MHz sample rate. Result is complex E-field.
- Measure the current (beam intensity) using BPM channels upstream from PETS. These have 192MHz sample rate.

$$\bar{E}_m = q\bar{E}_{m-n} + r_m I_m \ .$$

- We have a linear system of equations: $\begin{pmatrix} \vdots \\ \bar{E}_m \\ \vdots \end{pmatrix} = \begin{pmatrix} \vdots & \vdots \\ \bar{E}_{m-n} & I_m \\ \vdots & \vdots \end{pmatrix} \begin{pmatrix} q \\ \bar{r} \end{pmatrix}$
- Rewrite this in the general least squares form (derived from Variational Inequality and Best Approximation property of a Hilbert Space):

$$\begin{pmatrix} q \\ \bar{r} \end{pmatrix} = (A^* A)^{-1} A^* \begin{pmatrix} \vdots \\ \bar{E}_m \\ \vdots \end{pmatrix}$$

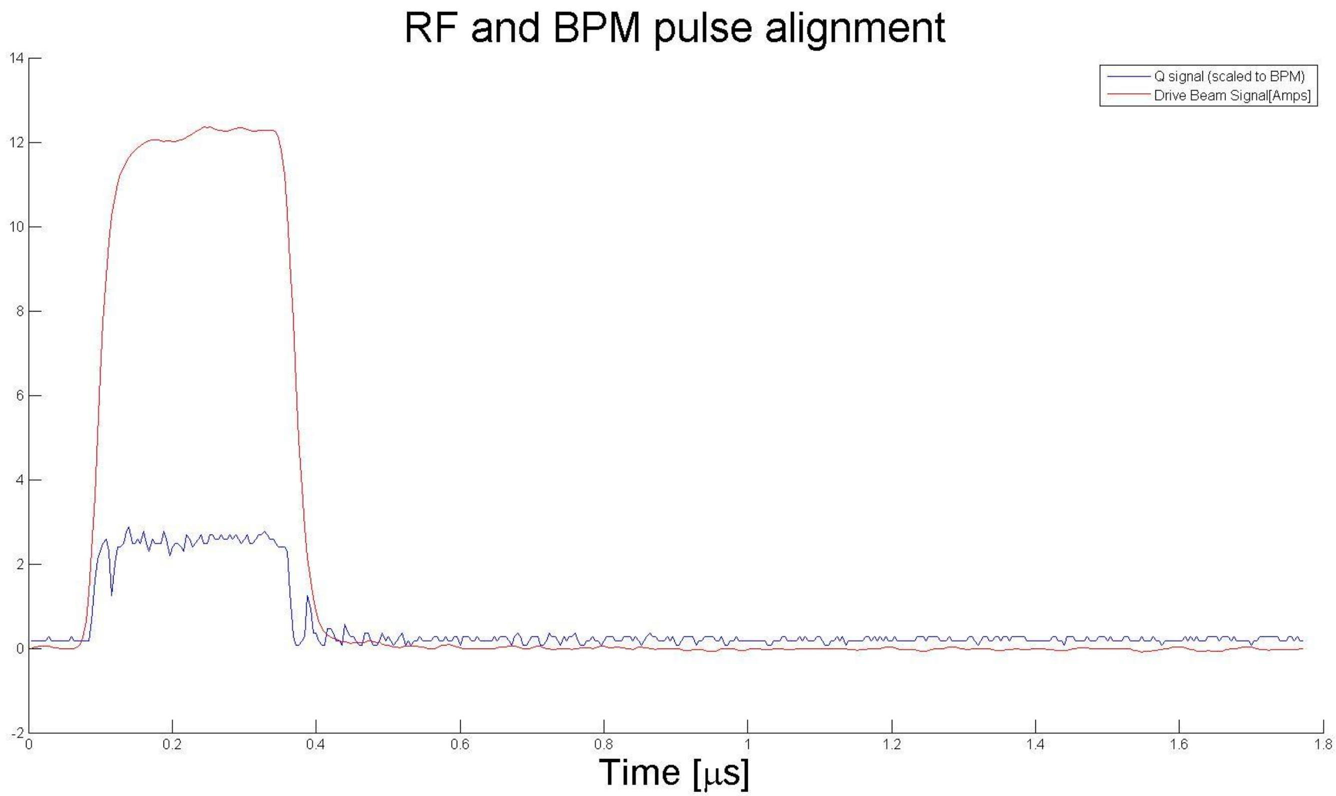
- Solve for q and r (assuming r is constant) via LS algorithm (Matlab).
- Solve for r_m using the LS estimate for q:

$$r_m = \frac{\bar{E}_m - q\bar{E}_{m-n}}{I_m}$$

Preliminary Issues – Data Acquisition and Processing

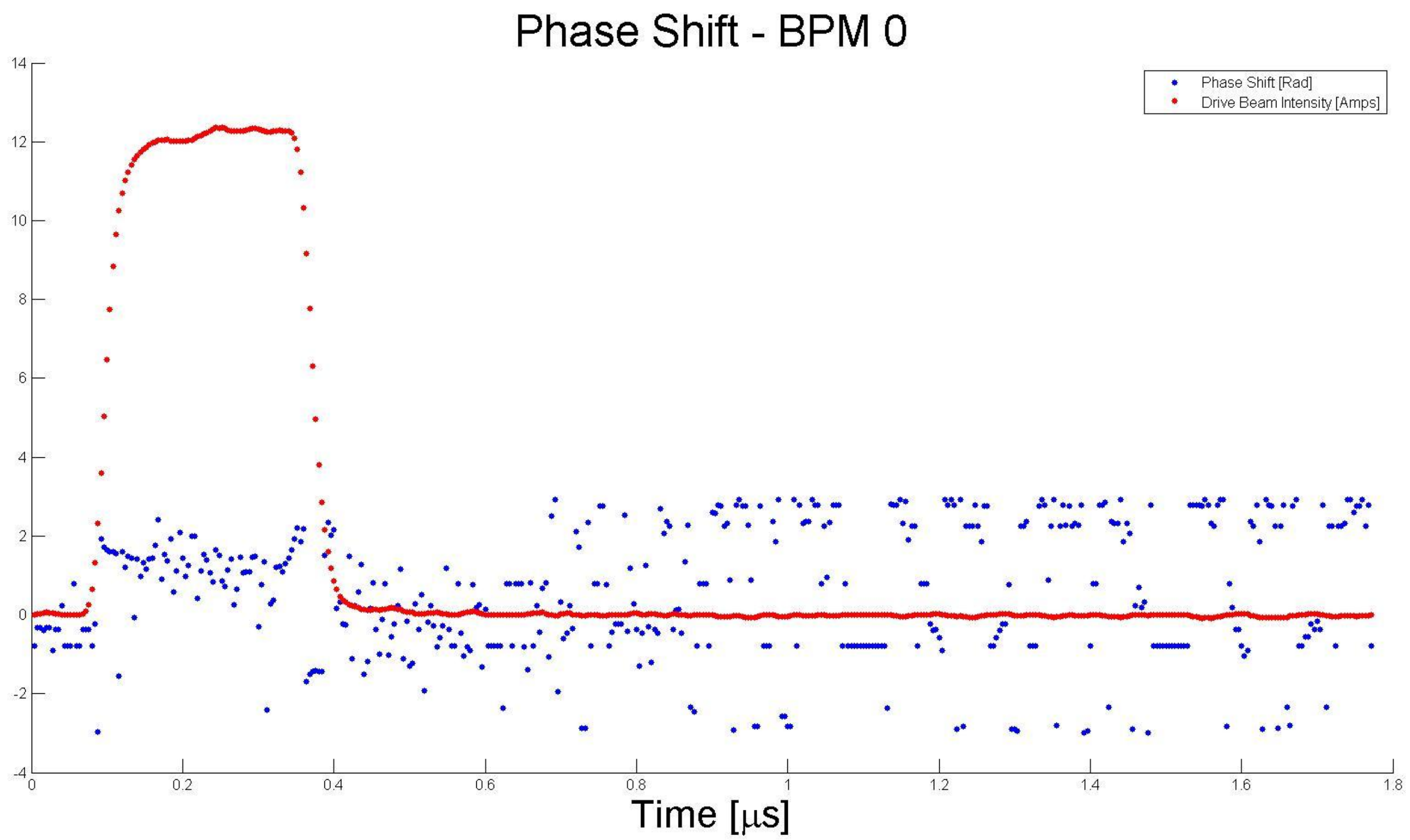
- BPM and RF pulse acquisition is triggered when breakdown occurs in the RF cavity. Three beam and three RF pulses are recorded (breakdown + two prior pulses).
- **Synchronization** problem. Timestamps have approximately 1 pulse delay between RF and BPM traces (delay varies). *Need to put RF and BPM events into 1-1 correspondence.*
- Issue with timestamp acquisition in control software.
- RF is sampled at 250MHz, BPM @ 192MHz.
- Have to upsample BPM signals via interpolation routine. Add zeroes to RF sample, align with BPM and then trim (select pulse only).
- To temporally align RF and BPM pulses, had to write rising edge selection algorithm.
- Noise and missing signals – have to sort through several datasets …

Results (1) – RF and BPM pulse alignment



- The I and Q RF signals are approximately aligned with the three drive beam traces (only Q and BPM0 shown here).
- Need to try and refine alignment code – use Volker's Chi-Squared fitting, or try and filter noise out of BPM and RF signals (cleaner data). Maybe numerical integration or 'data smoothing' (~ low pass filter) will help.

Results (2) – Phase Reconstruction



- For the drive beam pulse duration (0.1 to 0.4 microseconds) the phase appears to decay from ~ 2 radians to 0 radians (with noise and outliers).
- Need to analyze a lot more events (which are clean). This means automating the algorithm once we are confident it is doing what it should be.

Forward Strategy and Conclusion

- Break down events produce plasma (Cu ions and e^-). The plasma interacts with the beam resulting in beam kick, reflections and noise (non-resonant frequencies travelling in beamline).
- Do phase reconstruction on good **clean data** that is relatively free of breakdown.
- **Sense and Sensibility:** Control software needs to be rewritten so that each signal has a designated name as opposed to random assignment + lookup function. Saves hassle and is computationally more efficient.
- Real-time phase reconstruction and feedback into control software (to optimize drive beam power gain in the PETS recirculation loop) seems possible if the beam is operating under relatively stable conditions.
- Harry is a Cylon.

Acknowledgements

- My project supervisors from Uppsala University – Volker Ziemann, Roger Ruber and Andrea Palaia.
- The CERN Summer Student Organizers.
- The CERN Summer Students.