PSB longitudinal studies in 2017:
Experience with Finemet cavities, large longitudinal emittance beams

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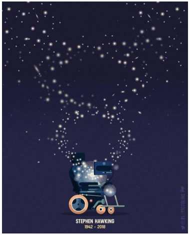

1. **FINEMET RELIABILITY RUN**
   - ISOLDE
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2. **RELATIVE PHASE ALIGNMENT**
3. **TRIPLE HARMONIC CAPTURE**
4. **LONGITUDINAL EMITTANCE BLOW-UP**
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   - Phase noise
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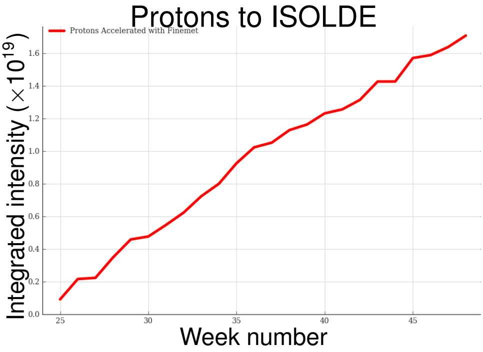
FINEMET RELIABILITY RUN

- Finemet used for ISOLDE beams from week 25 (21-June-2017) $\rightarrow$ week 49 (6-December-2017)
- $\approx 1.7 \times 10^{19}$ protons delivered using Finemet (much higher including MDs)
- Amplifiers specified for 700V per cell (10 cells in current cavity), 800V regularly supplied
- No faults during 5.5 months, hardware was not treated gently!



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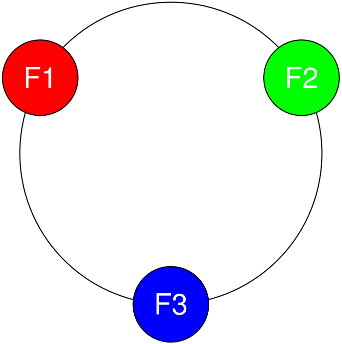
RELATIVE PHASE ALIGNMENT

Context



- Three Finemet cavities after LS2
- Baseline is “distributed cavity” operation
- Beam must see the same phase in each cavity
- Azimuthal positions, time of flight, cables etc cause phase difference
- Time delay and azimuth offset for frequency dependent and fixed phase difference

Measurement

- Define a “master” and “slave” cavity, define master as having 0 phase offset
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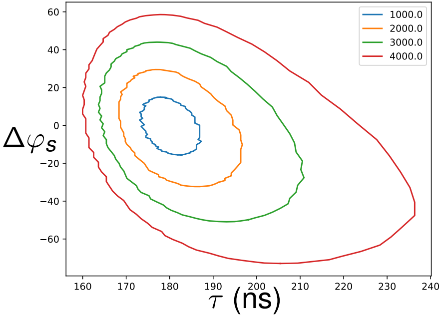
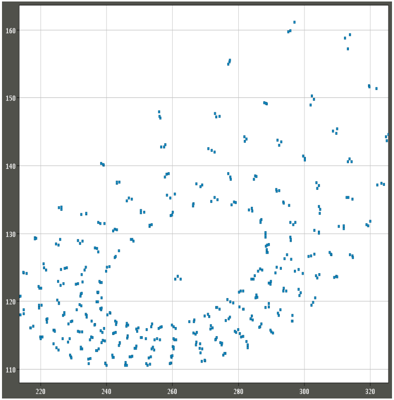
Simulated:

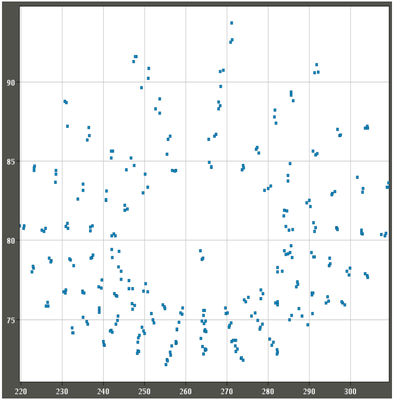


- Phase rotation of the slave cavity creates an ellipse in φ_s, τ space
- Size of the ellipse determined by voltage ratio between maser and slave
- Position on the ellipse determined by phase difference (as seen by the beam) between master and slave

Measured C575 (1)

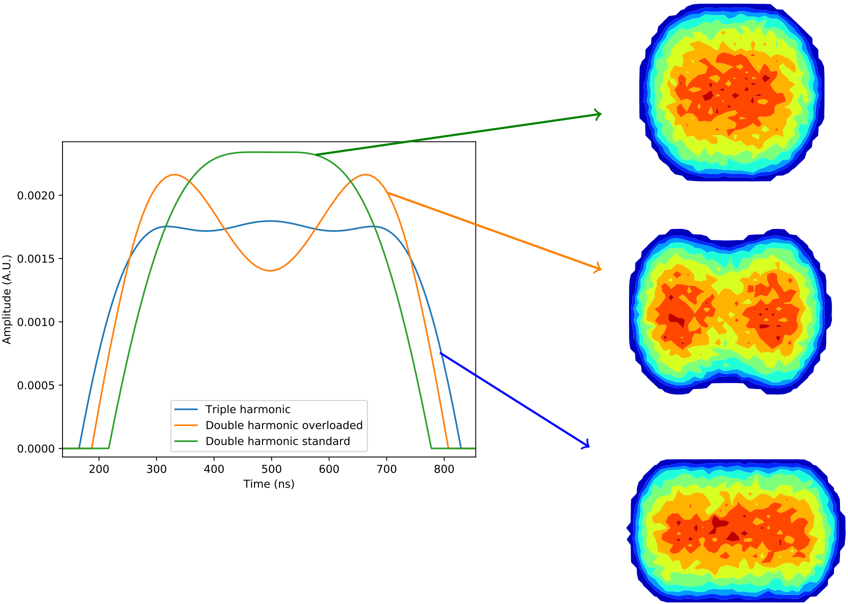


Measured C750 (2)

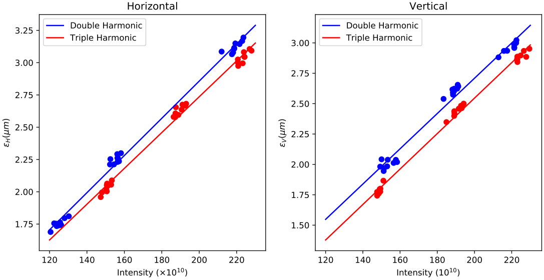


- $\varphi_{2,1} = D\omega_{RF,1} + \varphi_A, \qquad \varphi_{2,2} = D\omega_{RF,2} + \varphi_A$
- $\omega_{RF,1}dt + \Delta\varphi = -\varphi_{2,1}, \qquad \omega_{RF,2}dt + \Delta\varphi = -\varphi_{2,2}$

Triple Harmonic Capture


0.0020
0.0015
0.0010
0.0005
0.0000
Amplitude (A.U.)
200
300
400
500
600
700
800
Time (ns)
Triple harmonic
Double harmonic overloaded
Double harmonic standard

LHC25 Brightness ($\frac{I}{\varepsilon_H \varepsilon_V}$) 10% higher at extraction



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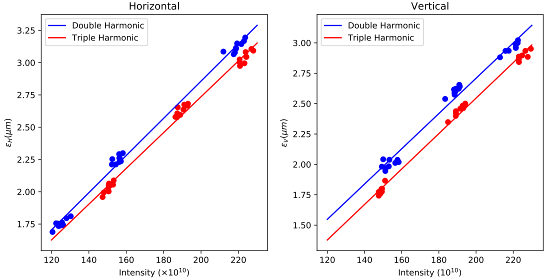
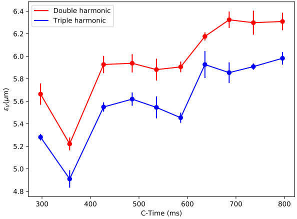


MTE ε_V lower by 0.5μm through complete ramp (Measurement of A. Santamaria-Garcia)



Longitudinal Emittance Blow-up

Two approaches are available:

- Phase noise - “random” phase modulations of the main harmonic
- High harmonic - Single frequency sinusoidal modulation of a high harmonic cavity (currently used in operation)

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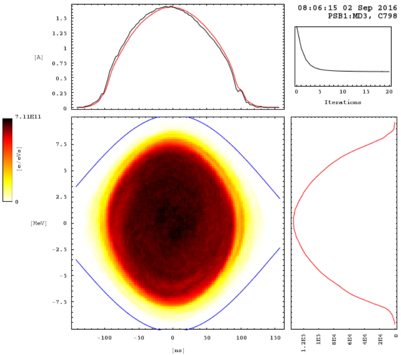
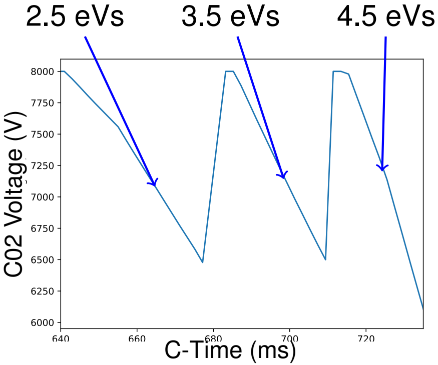
PHASE NOISE

- No high harmonic RF system
- Smaller parameter space
- Able to target specific synchrotron amplitudes
- Slower
- More difficult to compensate for changing synchrotron frequency

2016 Result

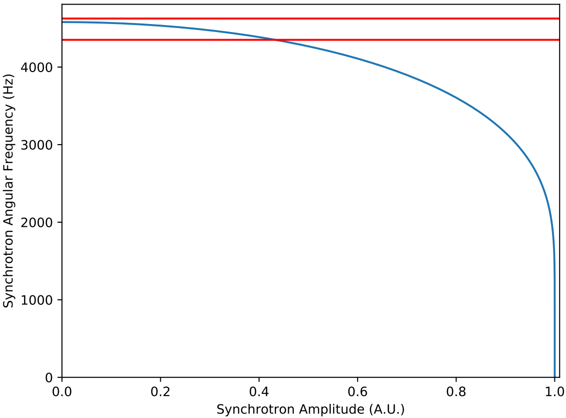




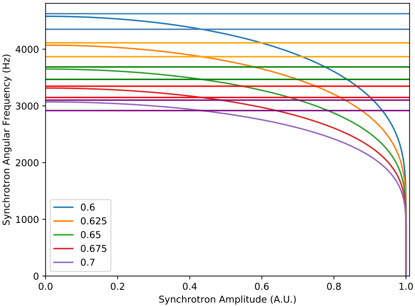
$\varepsilon_{matched} = 2.86$ eVs, $\tau = 224$ ns

High harmonic blow-up with a series of constant bucket area sections (not required after LS2) demonstrated 2.8 eVs LIU baseline with LHC25 style beams for the first time. Same technique has been used to produce 1.5 eVs BCMS in 2017.

- Main harmonic phase modulated with band limited noise
- Particles within noise band excited to higher synchrotron amplitudes



- During acceleration synchrotron frequency varies significantly in the PSB - blow-up from C600 to C700
- Three options available:
  1. Updating noise band regularly



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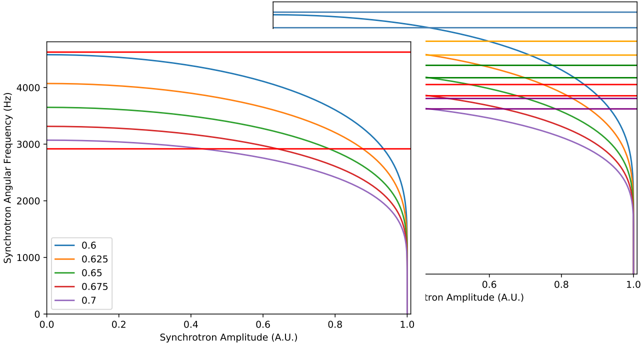

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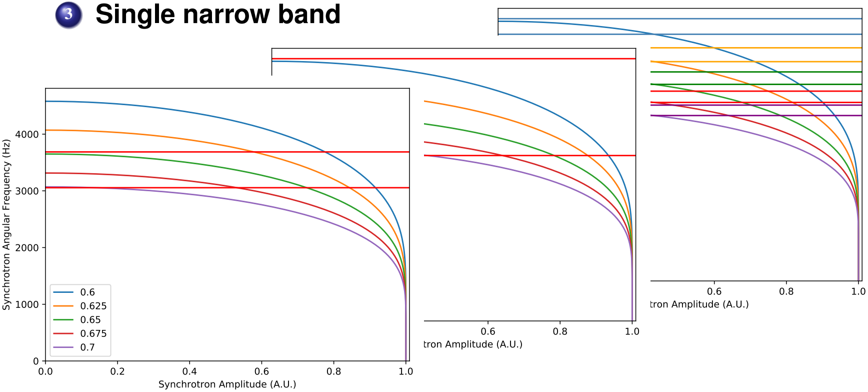
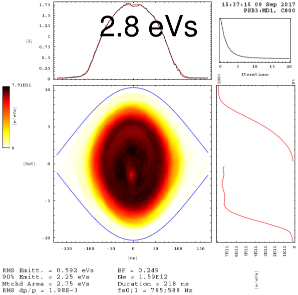
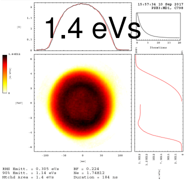
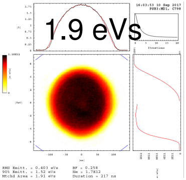


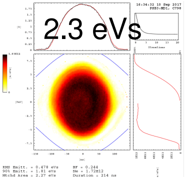
Results

Using option 3 a variety of matched areas have been produced









CONCLUSION & PLANS FOR 2018

Plans for 2018

- New LLRF features needed for 2018 work
- Using 8 harmonics in Finemet LLRF
- Longitudinal blow-up and shaving with high harmonic supplied by Finemet
- Finalising injection synchronisation
- Relative phase alignment
- Finemet reliability run
- Phase noise reliability run
- WR B-train reliability run

Conclusion

- Very successful Finemet reliability run during 2017, 6 months with no faults
- Variety of operatinal style beams set up with Finemet as h=1 or h=2, including splitting
- Proof-of-principle beam based method of relative phase alignment tested
- Triple harmonic capture shown to improve brightness of LHC25 and reduce ε_V for MTE
- High harmonic blow-up revived from 2016 and applied to BCMS successfully
- Phase noise blow-up demonstrated successfully
- Busy MD schedule (like everyone else) for 2018
- More details at LIU-PSB Beam Dynamics WG: `https://indico.cern.ch/event/680904/contributions/2790003/attachments/1565346/2466448/PSBBDWG.pdf`