TTF HOM measurement analysis with curve fitting method

Shilun Pei

with

Chris Adolphsen, Zenghai Li, Karl L. Bane, et al.

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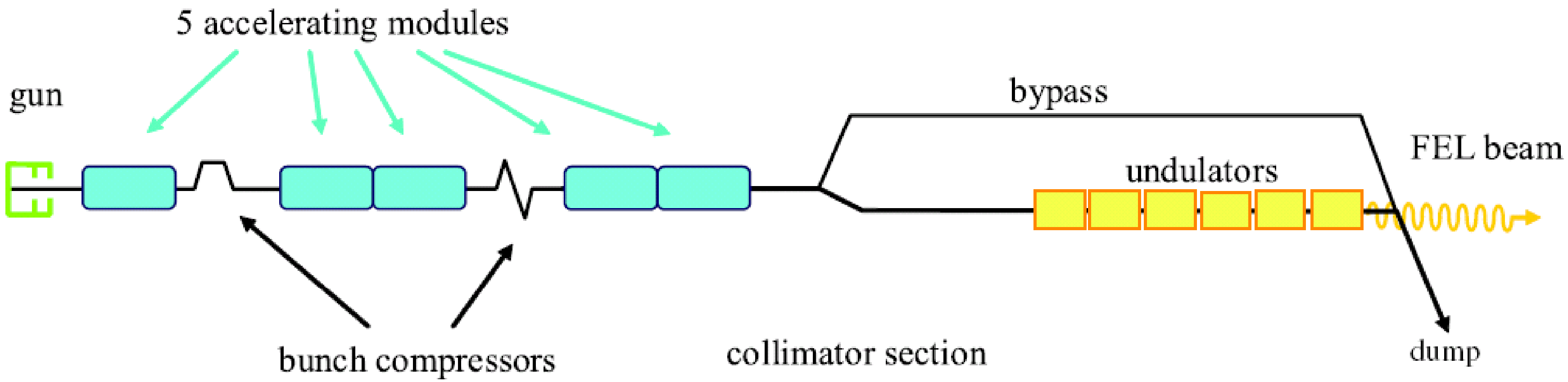
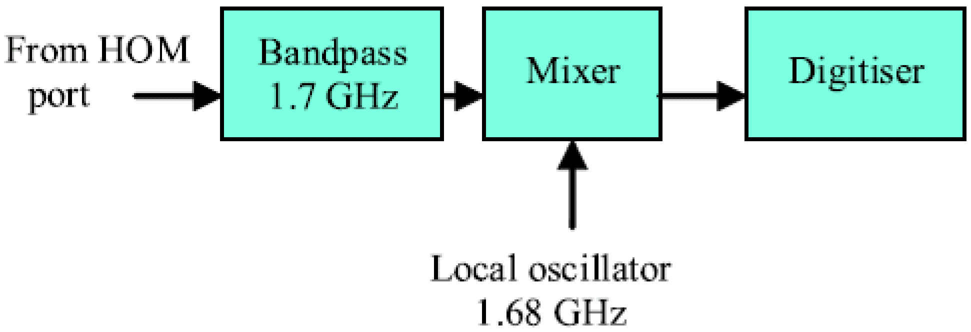
Overview

- Quick review of FLASH facility
- Dipole mode related theory
- Model used and curve fitting method
- Analysis results (mainly focus on narrowband data)
  - **CAV2 in ACC4**
  - **CAV1 in ACC4**
  - **CAV5/CAV6/CAV8 in ACC4**
  - **24 cavities in ACC3/ACC4/ACC5**
  - **Comparison with broadband data**
- Summary

Flash facility

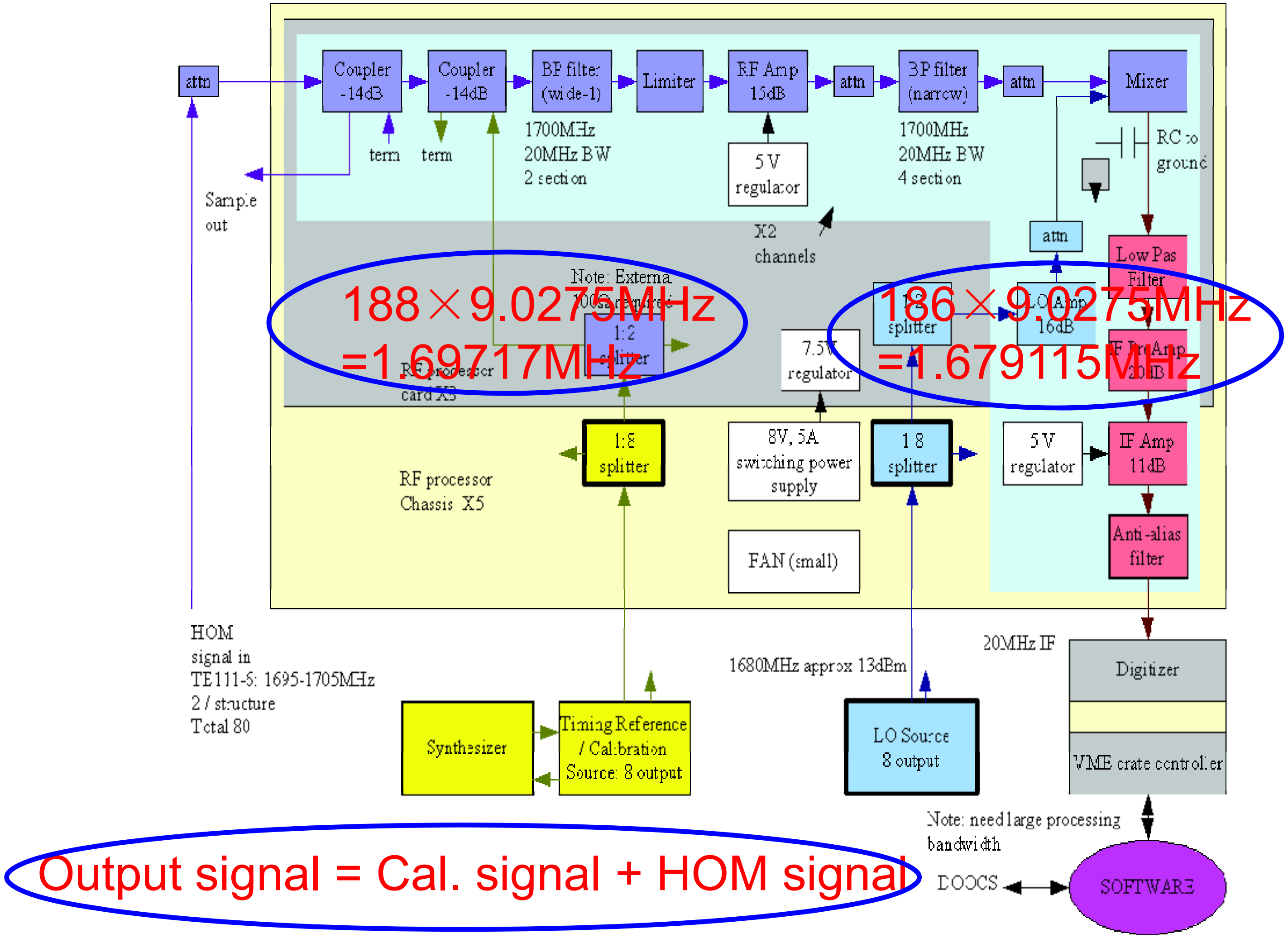


Schematic of Flash facility



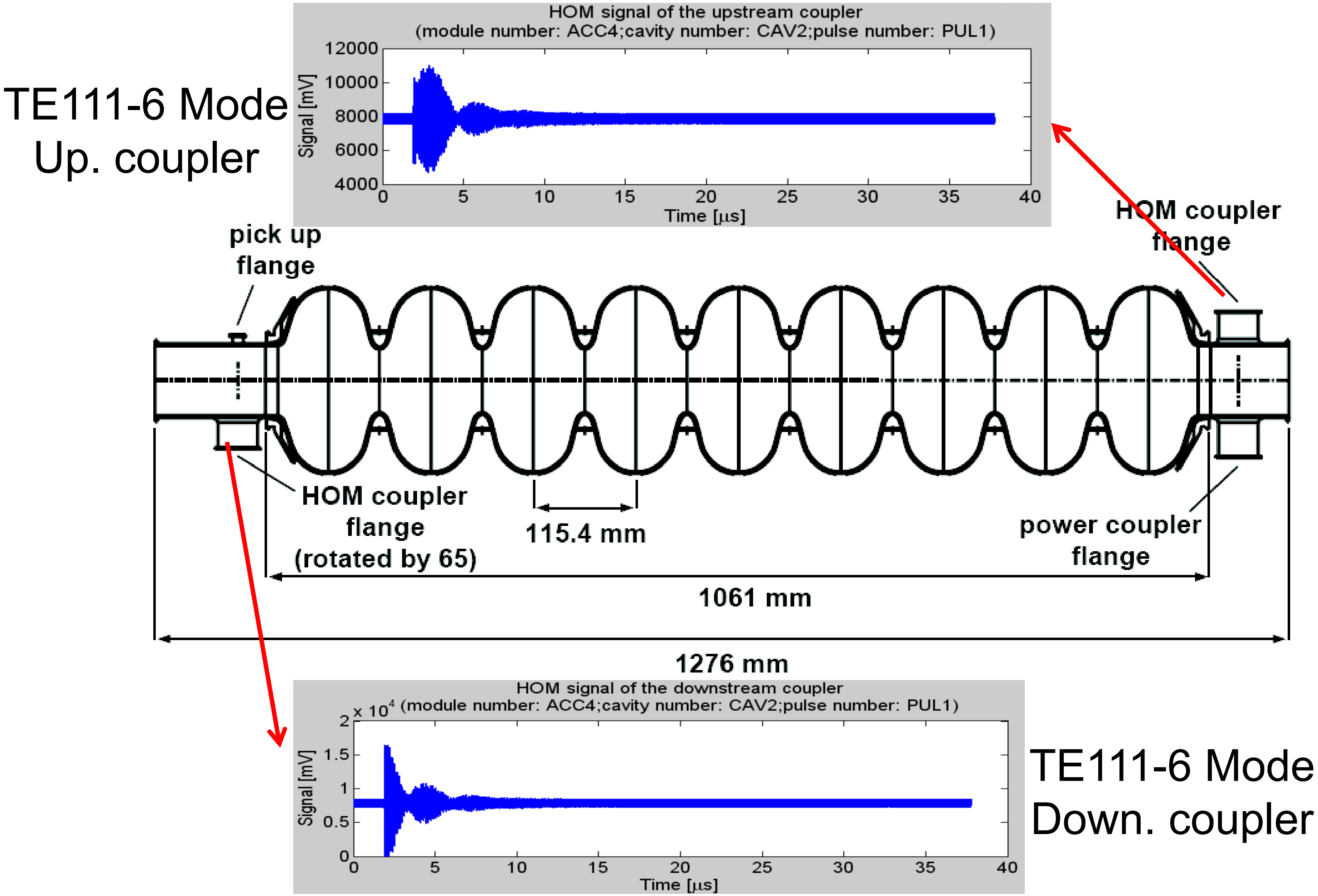
Schematic of the mix-down electronics for measurement of the TE111-6 Mode (S. Molloy et al)

Detailed mix-down electronics



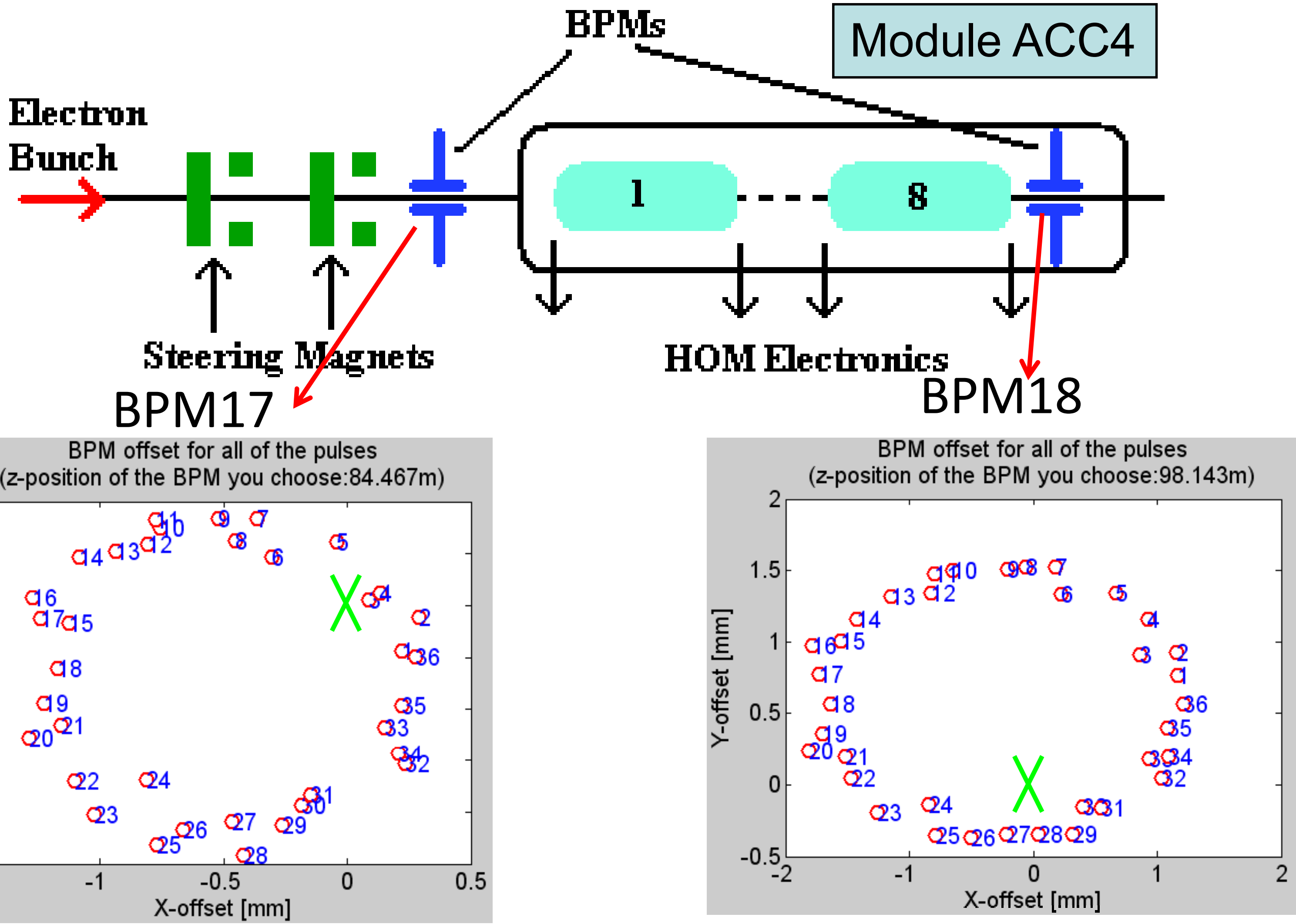
Detailed schematic of the mix-down electronics (S. Molloy et al)

Time domain HOM signal



2007-01-22T091106.mat (S. Molloy et al)

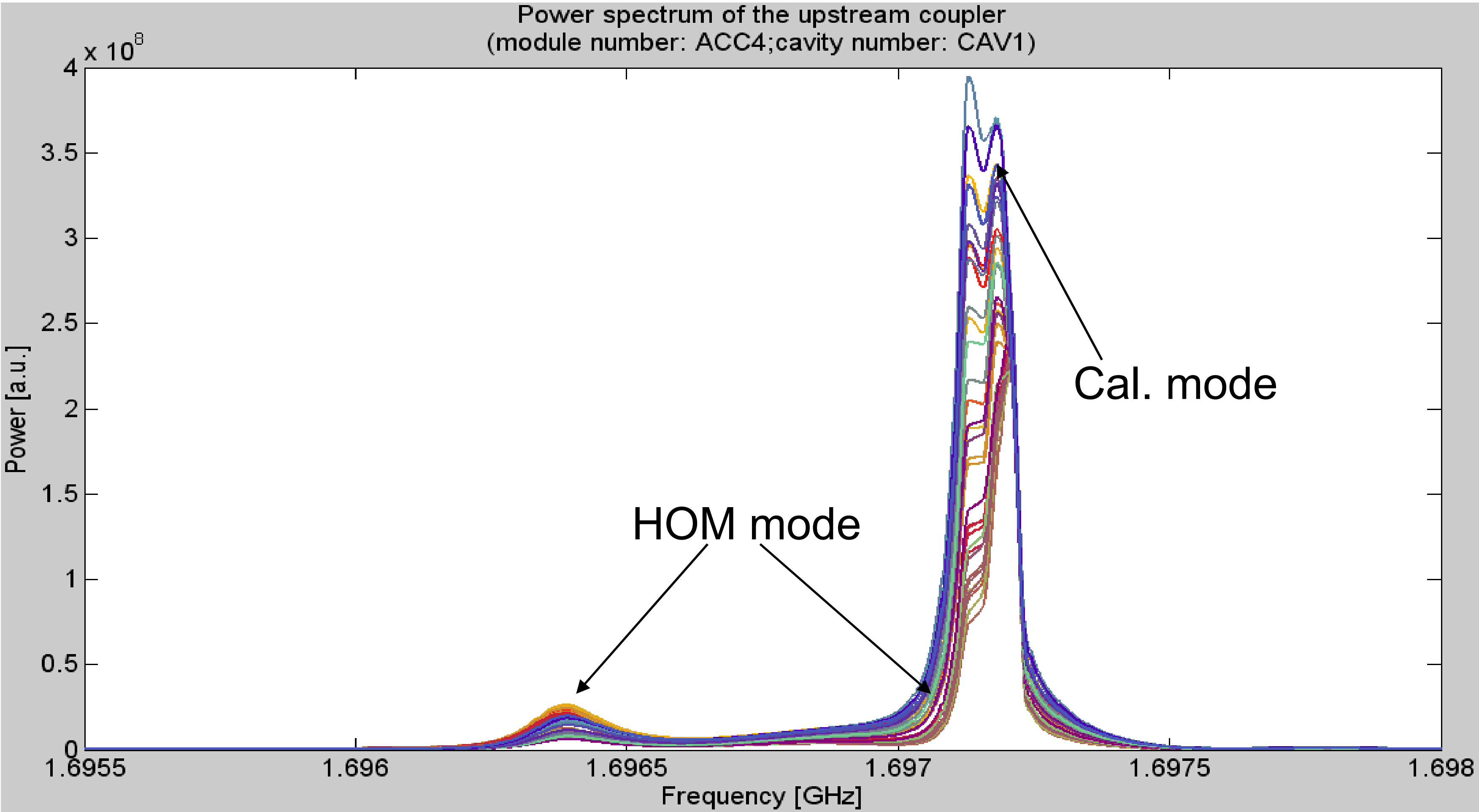
Steering setup for the experiment



2007-01-22T091106.mat (Stephen Molloy et al)

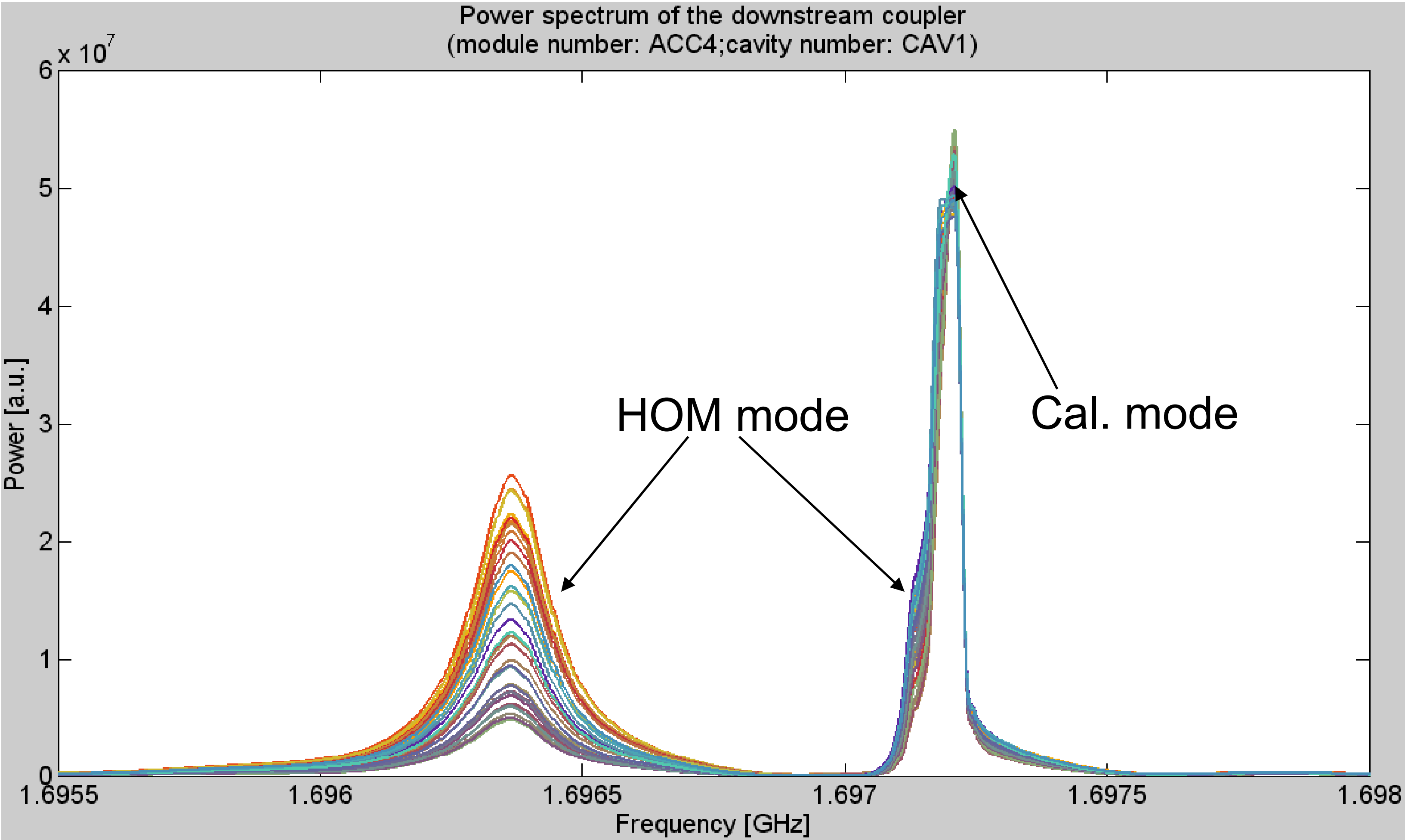
Frequency domain HOM signal (1)

Calibration mode overlaps with the HOM mode
(ACC4, CAV1, Upstream, 2007-01-22T091106.mat)



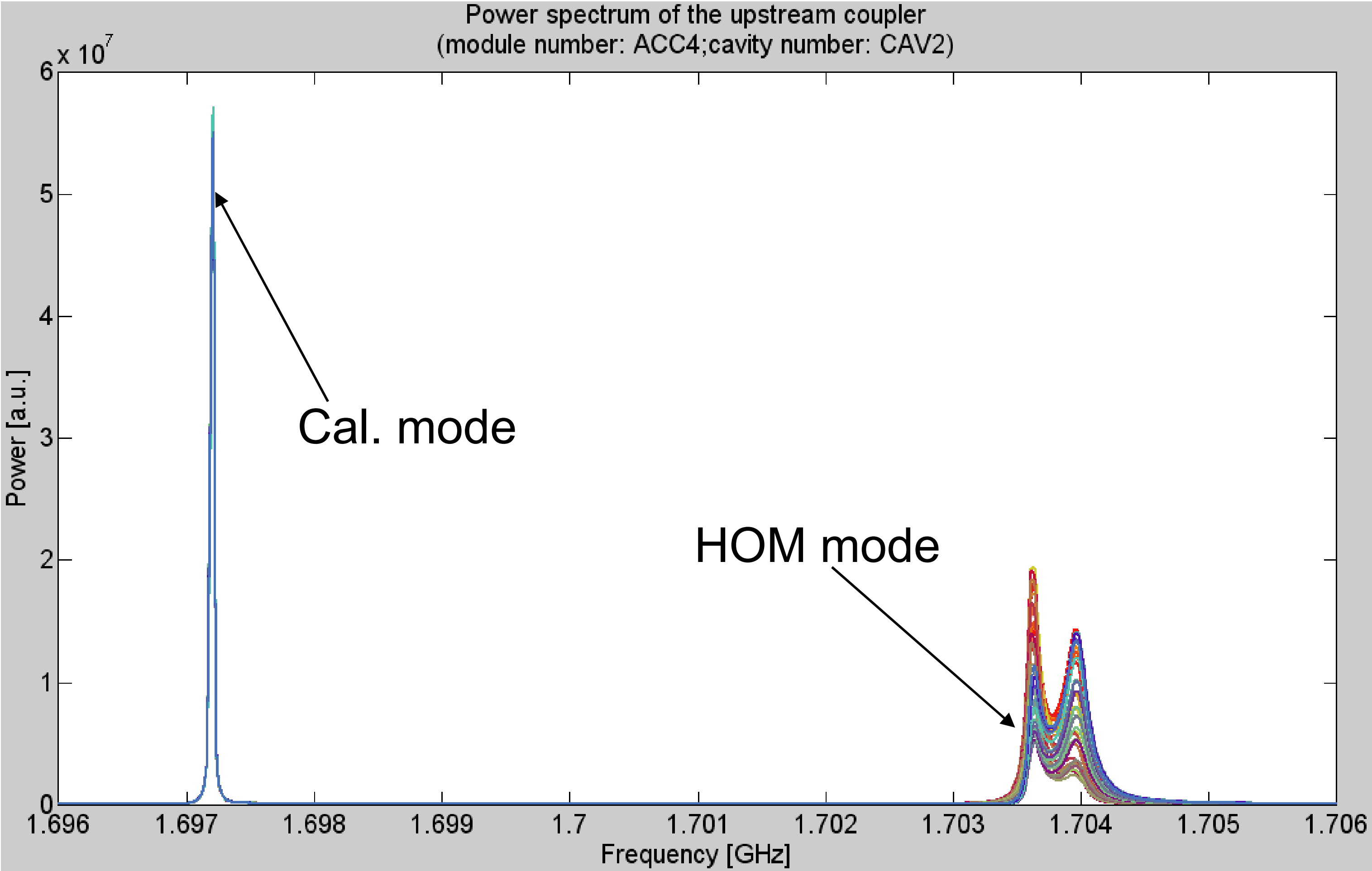
Frequency domain HOM signal (2)

Calibration mode overlaps with the HOM mode
(ACC4, CAV1, Downstream, 2007-01-22T091106.mat)



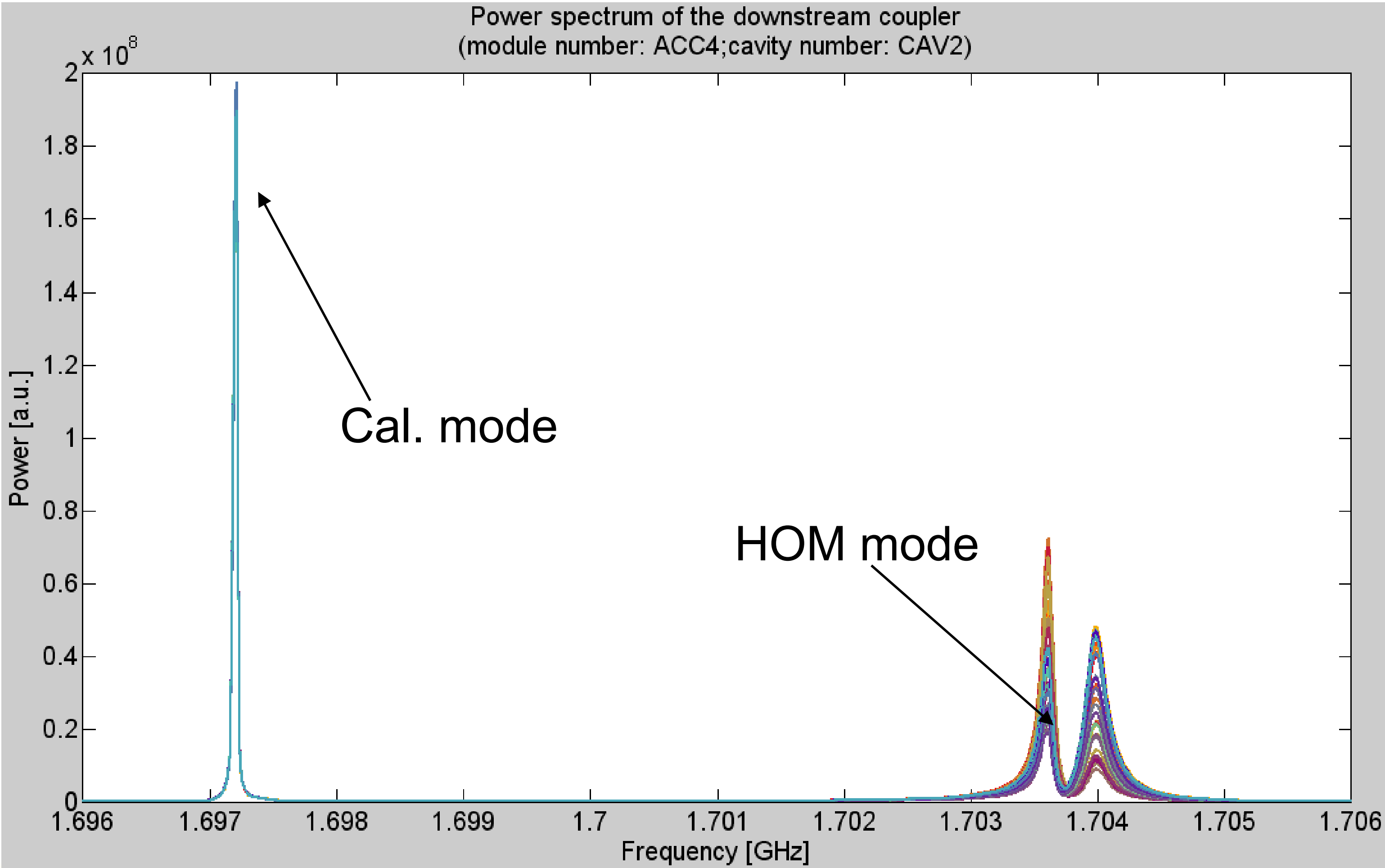
Frequency domain HOM signal (3)

Calibration mode splits with the HOM mode
(ACC4, CAV2, Upstream, 2007-01-22T091106.mat)

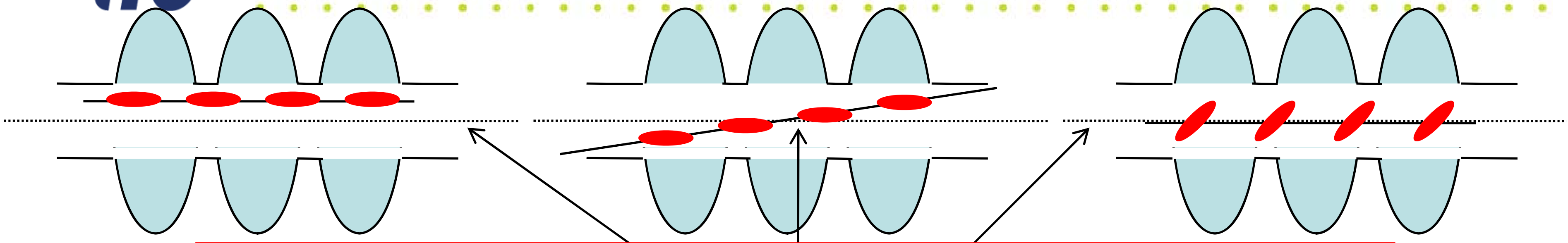


Frequency domain HOM signal (4)

Calibration mode splits with the HOM mode
(ACC4, CAV2, Downstream, 2007-01-22T091106.mat)



Dipole mode response (1)



Mode axis along the cavity, a little different from cavity axis.

$V_o \propto x\, e^{-t/2\tau} \sin(\omega t)$ $\quad V_\theta \propto -\theta\, e^{-t/2\tau} \cos(\omega t)$ $\quad V_\alpha \propto -\alpha\, e^{-t/2\tau} \cos(\omega t)$

For 9-cell cavity, their relation can be roughly estimated as

$$\frac{V_{\alpha amp}}{V_{o amp}} = \left|\frac{\omega\sigma_Z^2 \tan(\alpha)}{xc}\right|$$

$$\frac{V_{\alpha amp}}{V_{\theta amp}} = \left|\frac{\omega\sigma_Z^2 tan(\alpha)\left(\frac{L}{2}+\frac{c\sin\left(\frac{\omega L}{c}\right)}{2\omega}\right)}{c\tan(\theta)\left\{\frac{c^2\cos^2(\theta)}{4\omega^2}\sin\left(\frac{\omega L}{c\cos(\theta)}\right)-\frac{Lc\cos(\theta)}{4\omega}\cos\left(\frac{\omega L}{c\cos(\theta)}\right)\right\}}\right|$$

$$\frac{V_{o amp}}{V_{\theta amp}} = \left|\frac{x\left(\frac{L}{2}+\frac{c\sin\left(\frac{\omega L}{c}\right)}{2\omega}\right)}{\tan(\theta)\left\{\frac{c^2\cos^2(\theta)}{4\omega^2}\sin\left(\frac{\omega L}{c\cos(\theta)}\right)-\frac{Lc\cos(\theta)}{4\omega}\cos\left(\frac{\omega L}{c\cos(\theta)}\right)\right\}}\right|$$

Dipole mode response (2)

- Due to the very short bunch length in TTF, bunch tilt angle caused dipole signal can be ignored. While for dipole signal excited by bunch trajectory obliquity angle, sometimes it can also be ignored, sometimes not (bunch offset relative to the mode axis is not so large).
- The signal at HOM coupler will be

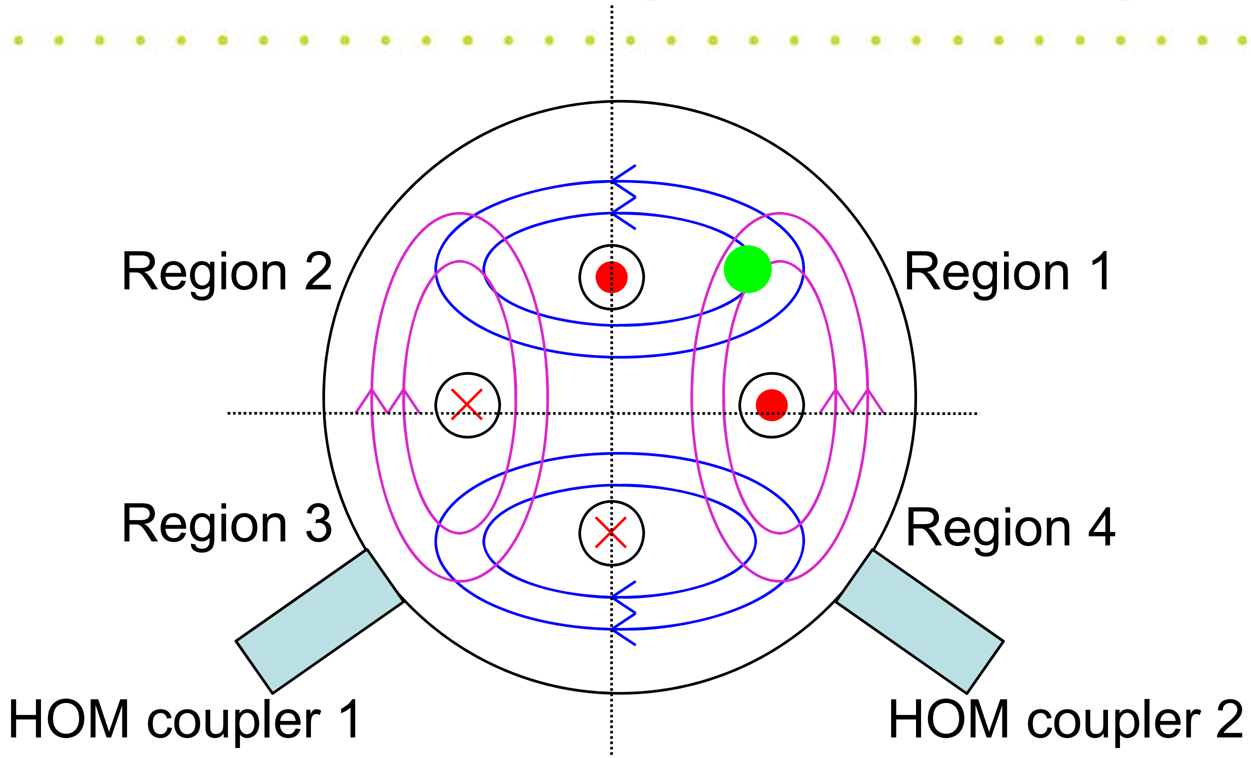
$$V_{HOM}(t) = V_o(t) + V_\theta(t) + V_\alpha(t) \cong V_o(t) + V_\theta(t)$$

$$= \sqrt{\left(V_{oamp}\right)^2 + \left(V_{\theta amp}\right)^2} \cos(\omega t + \varphi)$$

- While if there are many dipole modes, we have

$$V_{HOM}(t) = \sum_{n=1}^{\infty} \mathrm{A_n} \cos(\omega_{0n} \mathrm{t} + \varphi_n)$$

Dipole mode phase



- If HOM signal is excited by beam with constant offset at region 1 (similar for beam at other regions), the phase difference of the two polarization modes will be 0^o at HOM coupler 1 and 180^o at HOM coupler 2. while if the beam trajectory has some angle of obliquity θ, the phase difference of the two polarization modes will deviate from 0^o or 180^o.

Model used

HOM signal in time domain

$$\sum_{n=1}^{\infty} A_n \,\mathrm{Cos}[\omega_{0\,n}\, t + \varphi_n]\, \mathrm{Exp}[-\omega_{0\,n}\, t/2/Q_n]$$

or

$$\sum_{n=1}^{\infty} A_n \,\mathrm{Sin}[\omega_{0\,n}\, t + \varphi_n]\, \mathrm{Exp}[-\omega_{0\,n}\, t/2/Q_n]$$

or

$$\sum_{n=1}^{\infty} A_n \,\mathrm{Exp}[i\,(\omega_{0\,n}\, t + \varphi_n)]\, \mathrm{Exp}[-\omega_{0\,n}\, t/2/Q_n]$$

HOM signal in frequency domain

$$\sum_{n=1}^{\infty} A_n \frac{(2\,Q_n\,(-2\,i\,Q_n\,\omega\,\mathrm{Cos}[\varphi_n] + (-\mathrm{Cos}[\varphi_n] + 2\,Q_n\,\mathrm{Sin}[\varphi_n])\,\omega_{0\,n}))}{(4\,Q_n^2\,\omega^2 - \omega_{0\,n}\,(4\,i\,Q_n\,\omega + (1 + 4\,Q_n^2)\,\omega_{0\,n}))}$$

or

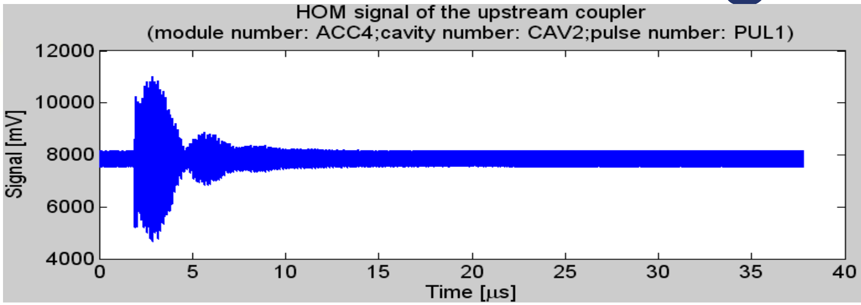
$$\sum_{n=1}^{\infty} A_n \frac{(2\,Q_n\,(-2\,i\,Q_n\,\omega\,\mathrm{Sin}[\varphi_n] - (2\,Q_n\,\mathrm{Cos}[\varphi_n] + \mathrm{Sin}[\varphi_n])\,\omega_{0\,n}))}{(4\,Q_n^2\,\omega^2 - \omega_{0\,n}\,(4\,i\,Q_n\,\omega + (1 + 4\,Q_n^2)\,\omega_{0\,n}))}$$

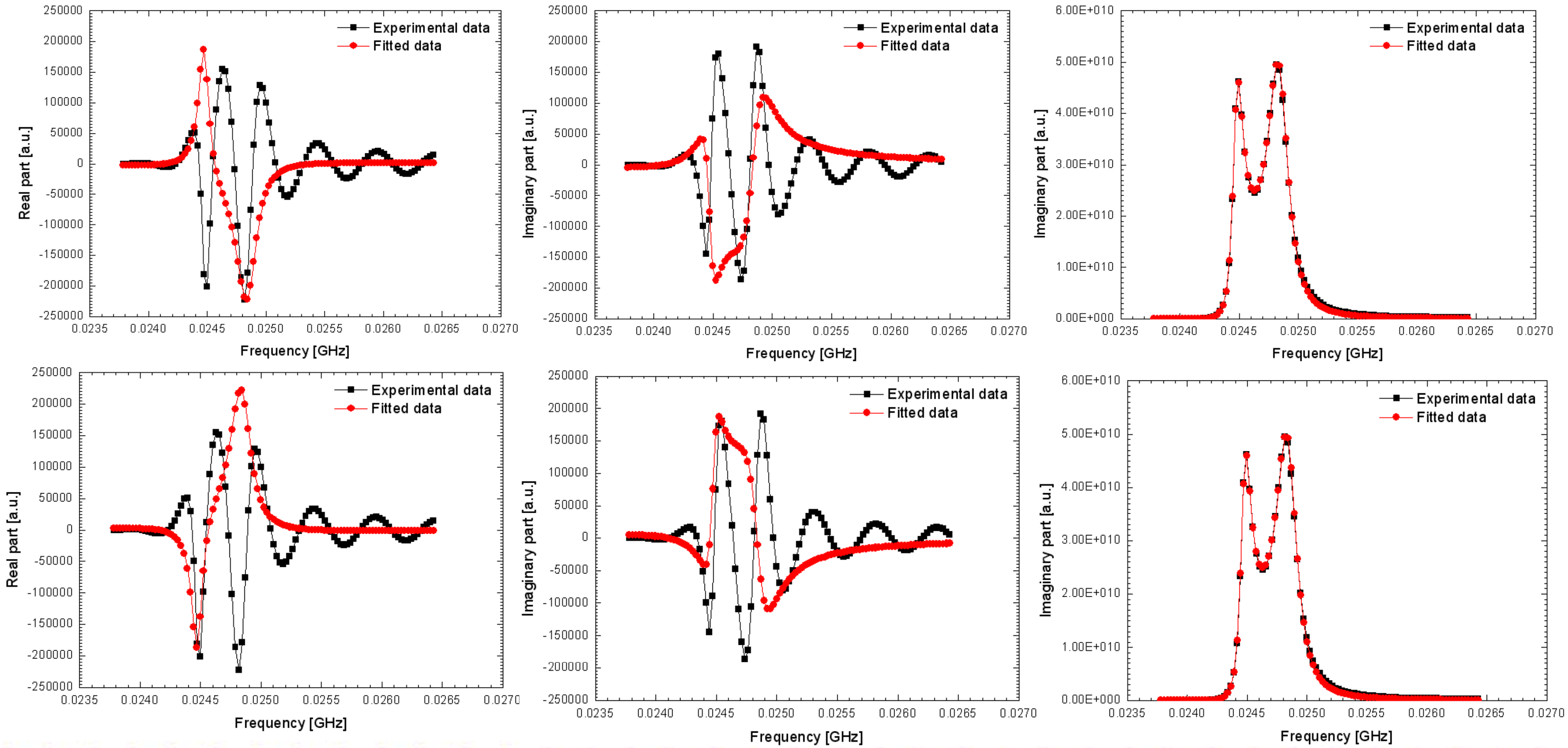
or

$$\sum_{n=1}^{\infty} A_n \frac{2\,i\,e^{i\,\varphi_n}\,Q_n}{-2\,Q_n\,\omega + (i + 2\,Q_n)\,\omega_{0\,n}}$$

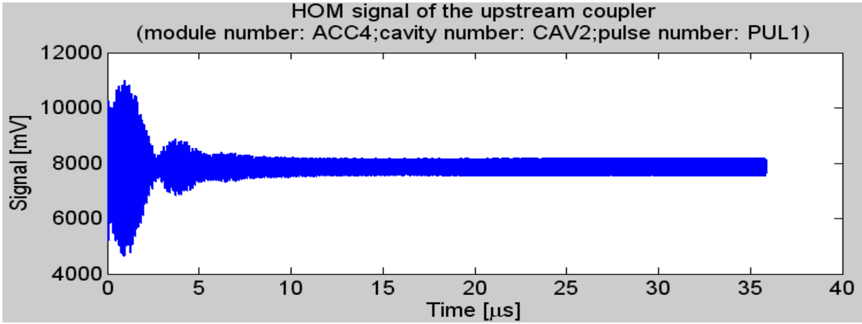
Complex Lorentzian $\displaystyle\sum_{n=1}^{\infty} \frac{A_n}{\omega - \omega_{0\,n} + \Gamma i}$

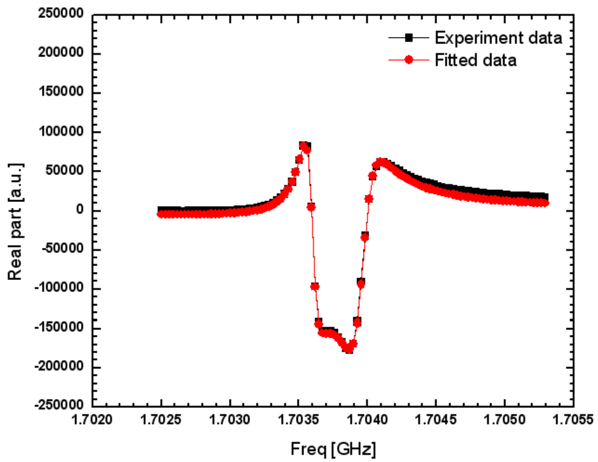
Fitting method (1)

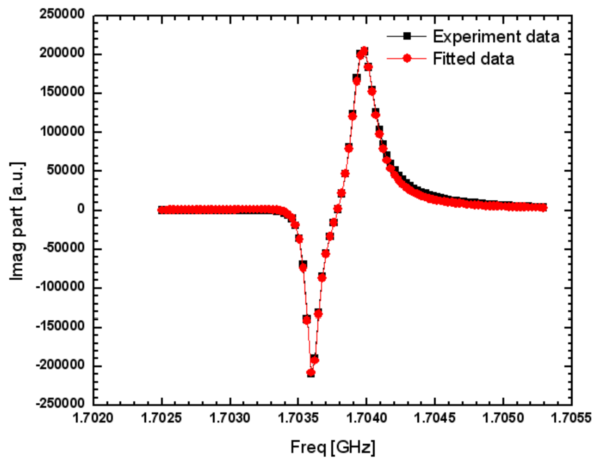


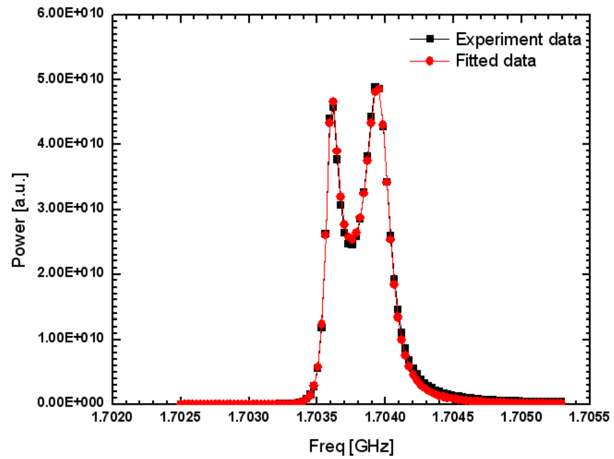


Fitting method (2)



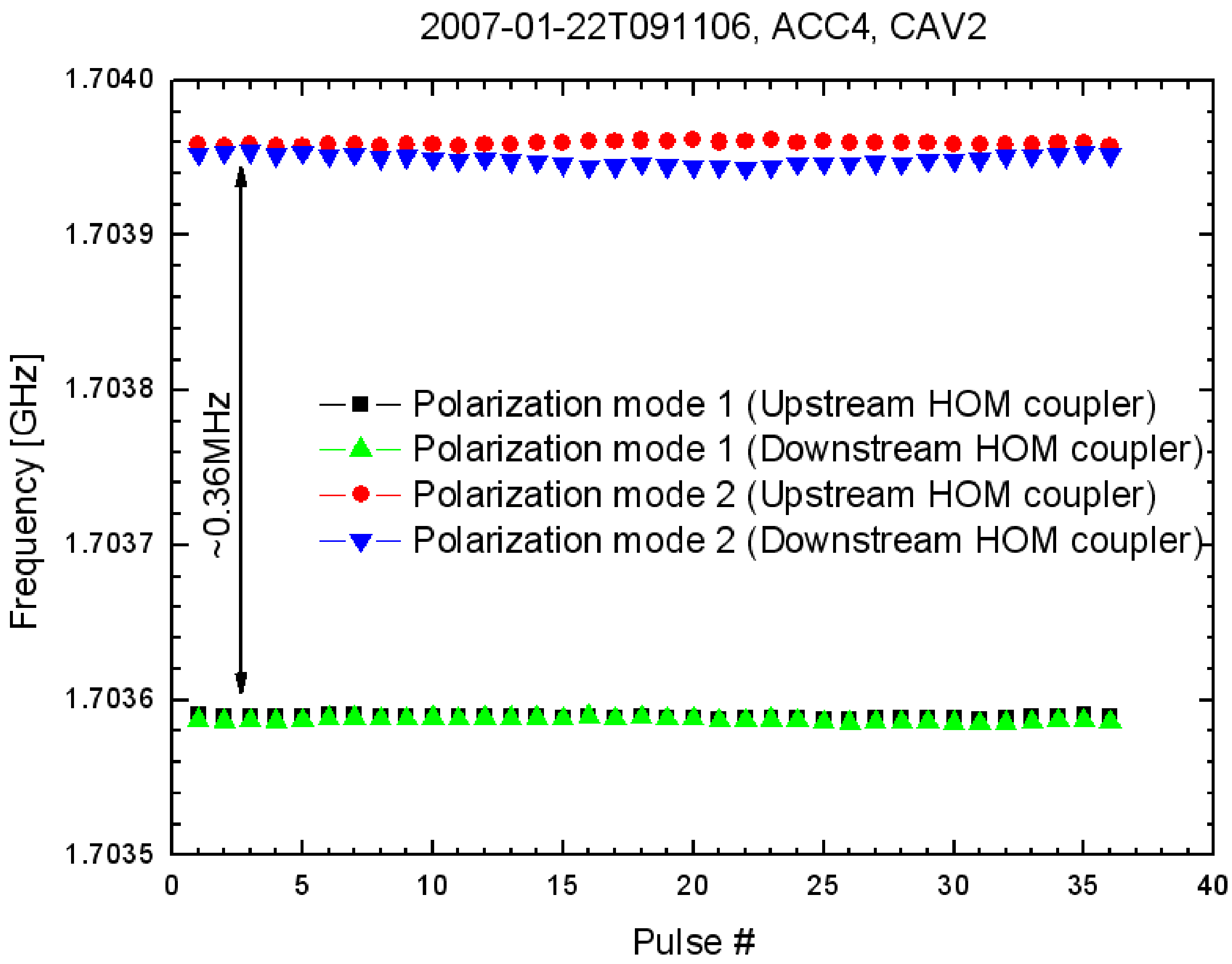






For later analysis, we will use this method.
With VBA (Visual Basic for Application) language, we wrote some macros to do the fitting automatically.

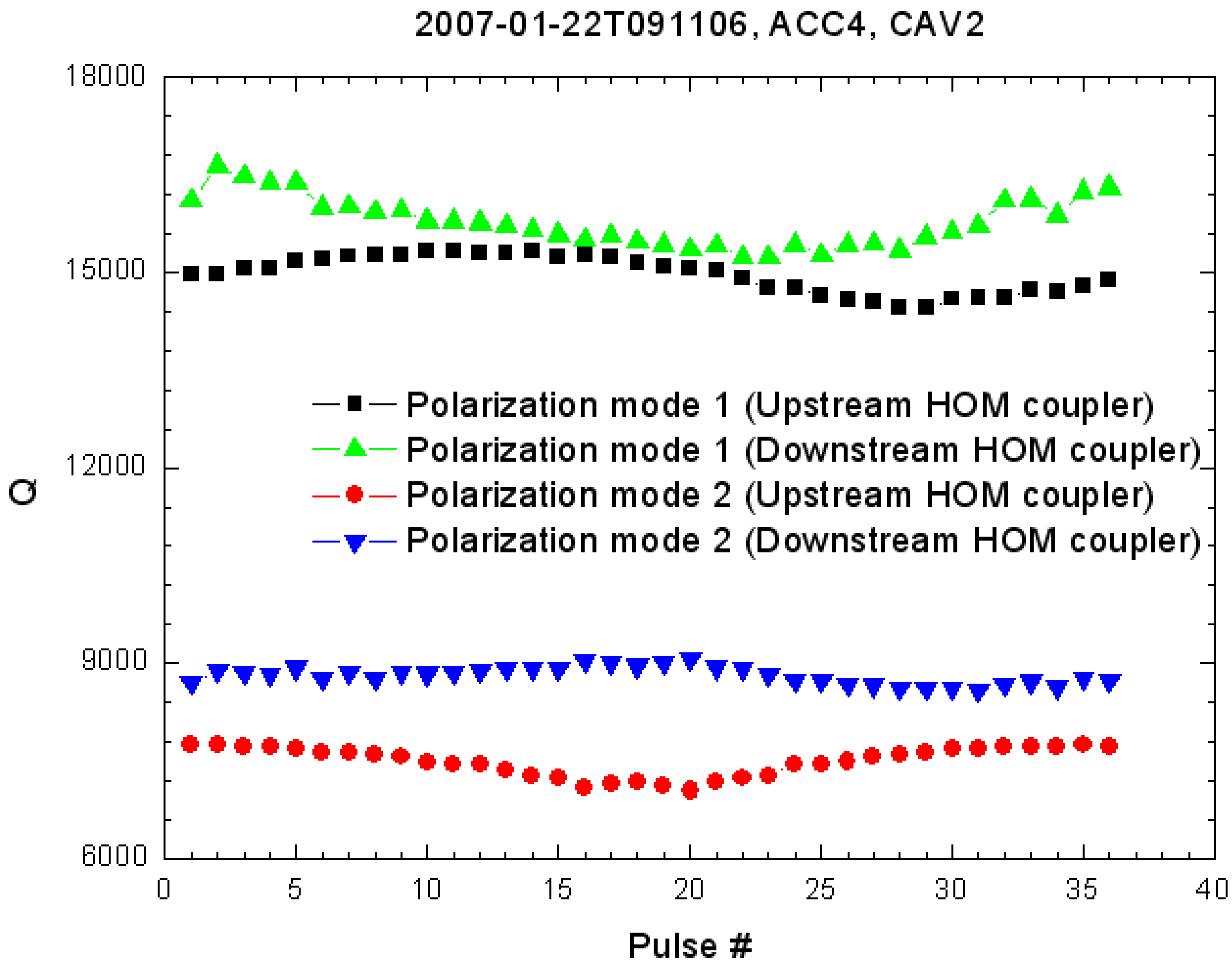
Dipole mode frequency



Up Mode 1:
1703.5892±0.0009MHz
Down Mode 1:
1703.5873±0.0011MHz
Up Mode 2:
1703.9593±0.0013MHz
Down Mode 2:
1703.9488±0.0032MHz

Fitting error of the frequency is about several kHz.

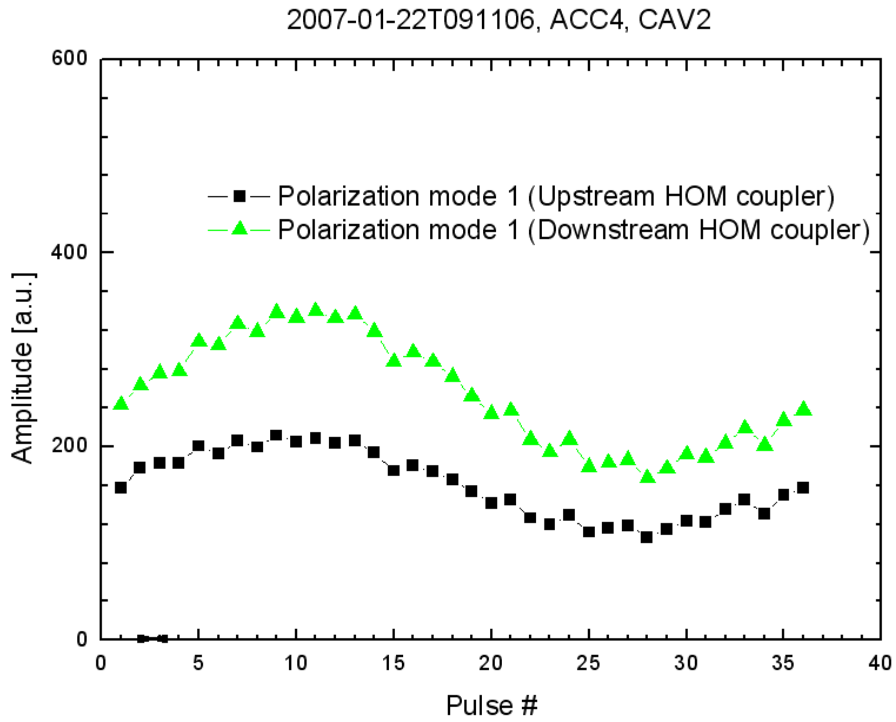
Dipole mode Q

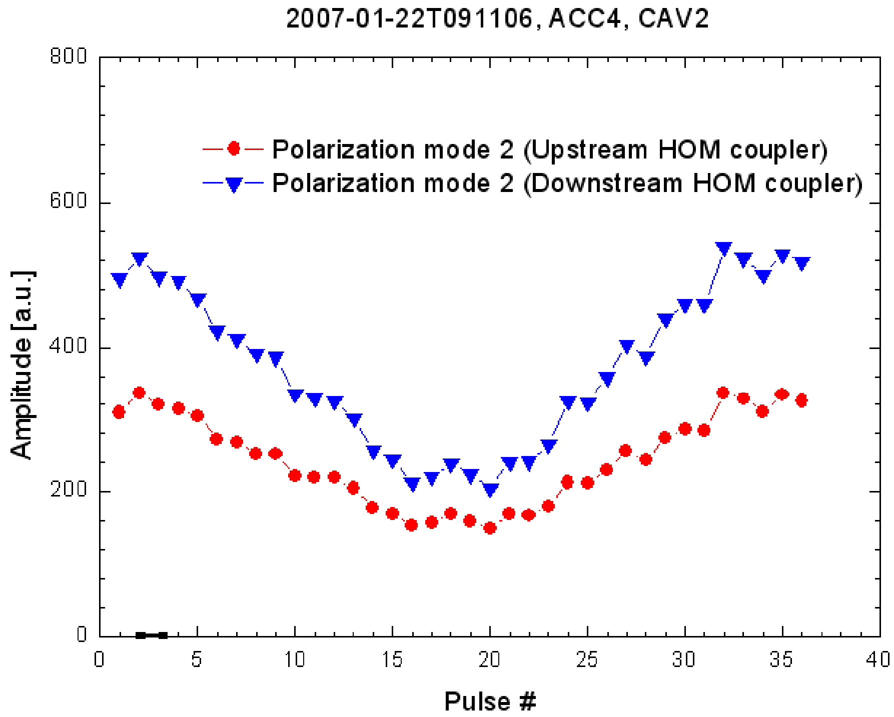


Up Mode 1:
14972±289
Down Mode 1:
15779±381
Up Mode 2:
7502±227
Down Mode 2:
8817±131

Dipole mode amplitude

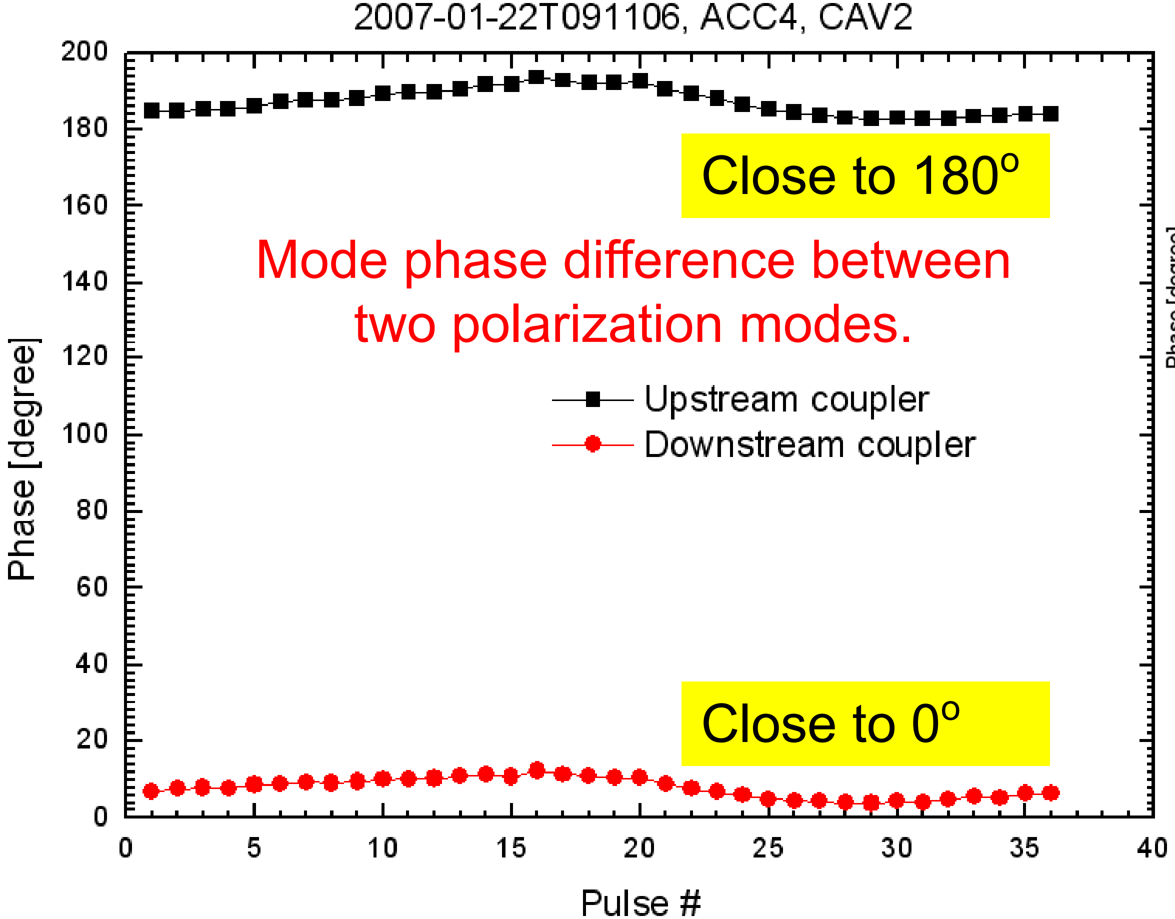
In order to reduce the systematic error, we do the fitting with same dipole mode frequency and Q, while different initial phase and amplitude for the 36 pulses. So there will be 36×4+2+2=148 parameters need to be fit at the same time.

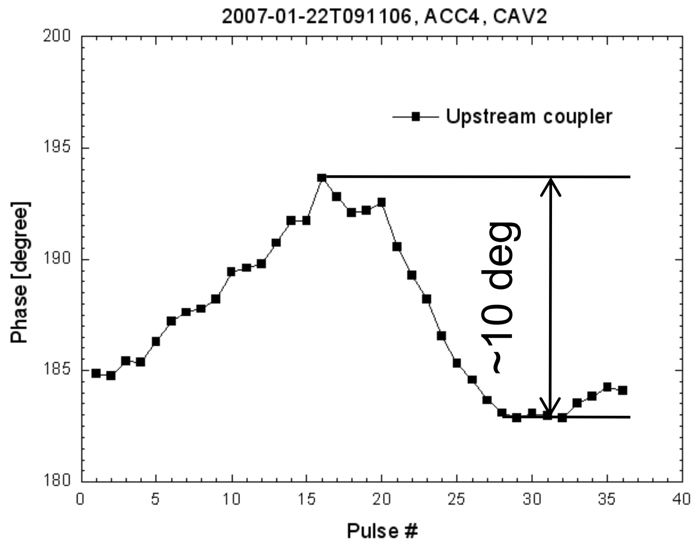




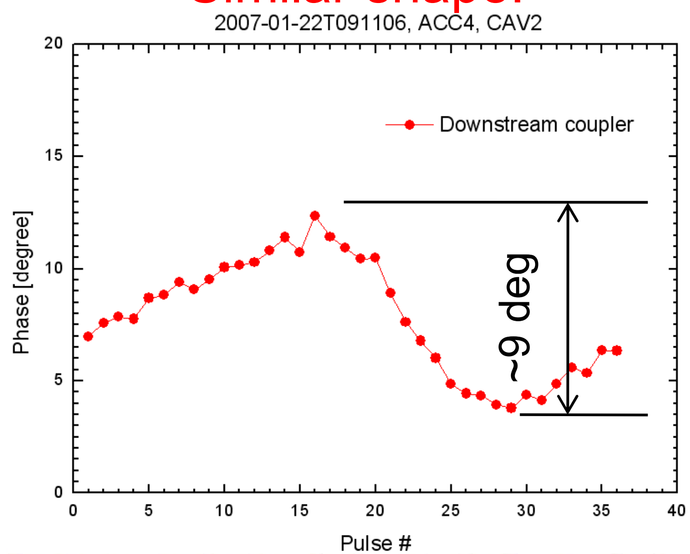
At both upstream and downstream coupler, the amplitude of the two polarization modes have similar shape.

Dipole mode phase difference



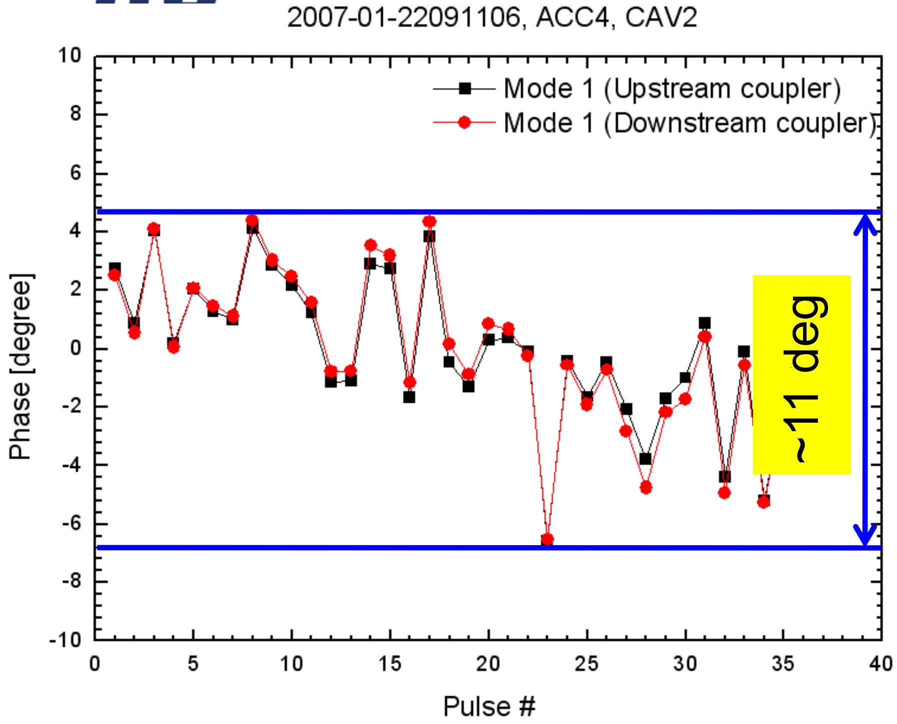


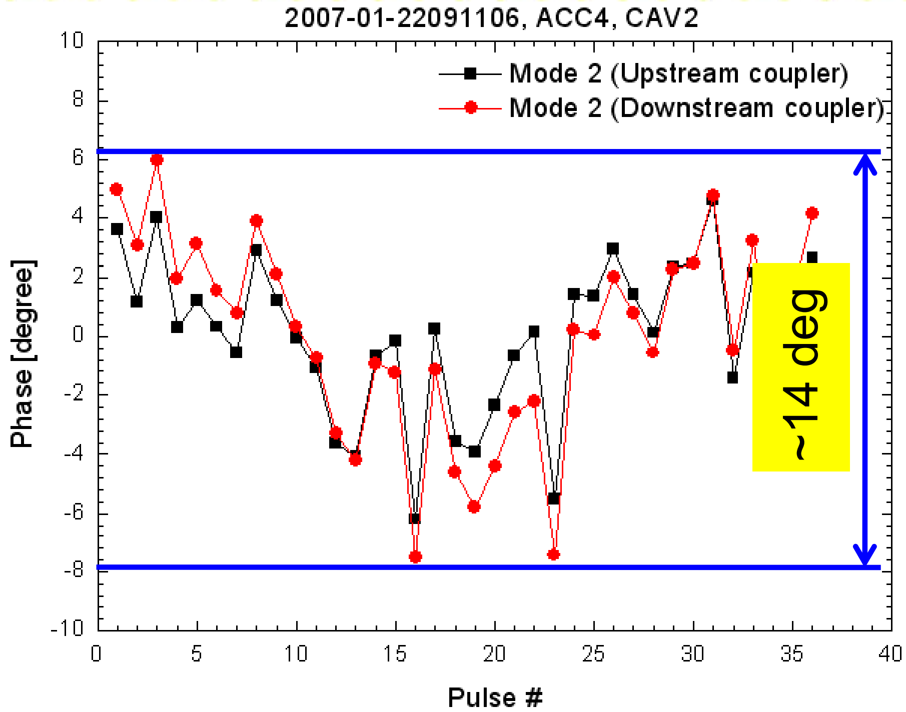
Similar shape!



Variation is mostly caused by nonzero beam trajectory obliquity angle relative to mode axis along cavity.

Dipole mode initial phase variation

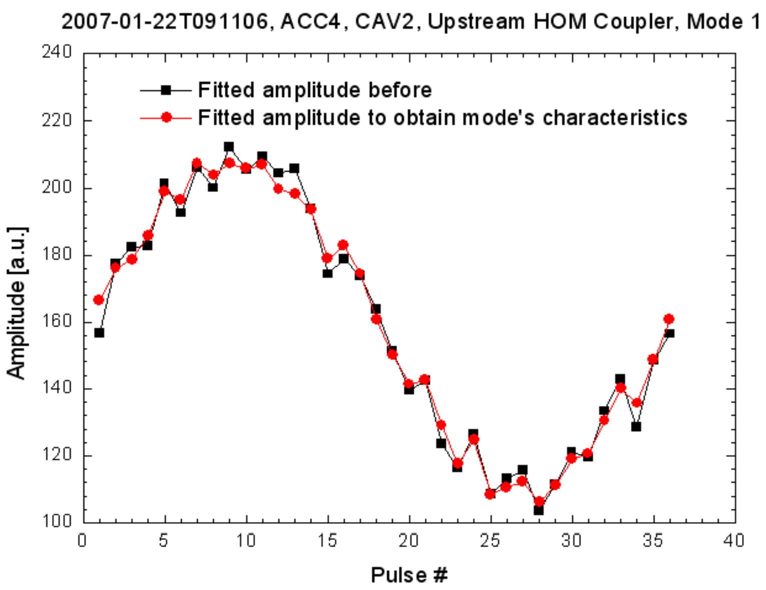


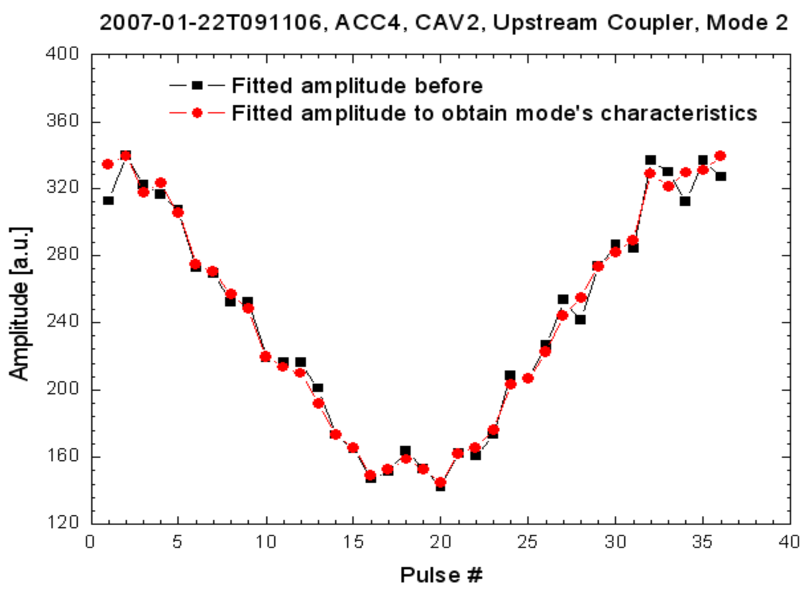


- Initial phase variation means that we cut off the from part of the raw data, fit the dipole mode and cal. mode phase at the cut off point, then got the mode initial phase variation relative to the cal. mode (the phase of the cal. mode for the 36 pulses is almost constant).
- The initial phase variations at both couplers for each mode are similar, and not so large, which means the HOM signal excited by nonzero beam trajectory obliquity angle is relatively small and can be ignored.

Dipole mode characteristics (1)

- For CAV2 in ACC4, with data set 2007-01-22T091106, if we ignore the HOM signal excited by beam trajectory angle (not always true, which will be shown later), the dipole mode center and polarization axis can be roughly determined by further fitting the fitted HOM signal's amplitude.



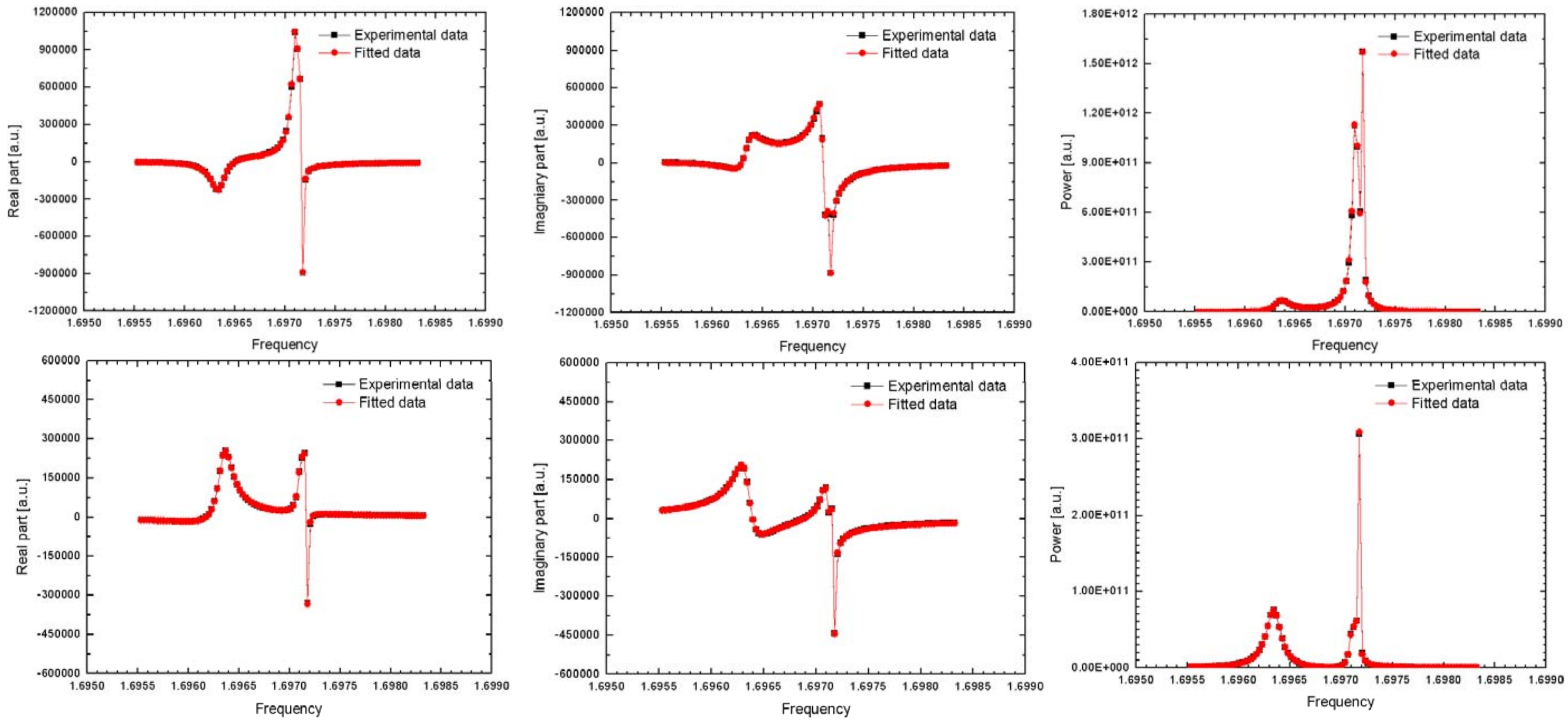


Dipole mode characteristics(2)

- From the fitted mode amplitude at upstream coupler, the dipole mode center can be determined to be (-2.888mm,-2.364mm), the polarization angles of mode 1 and 2 are 90.945^o and 3.189^o.
- Similar, from the fitted mode amplitude at downstream coupler, these values are (-2.906mm, -2.460mm), 93.960^o and -0.206^o.
- To determine the mode center and polarization angle precisely, and also determine the mode axis along cavity, timing information need to be considered to separate the HOM signals excited by beam offset and trajectory obliquity angle (More measurement need to be done).

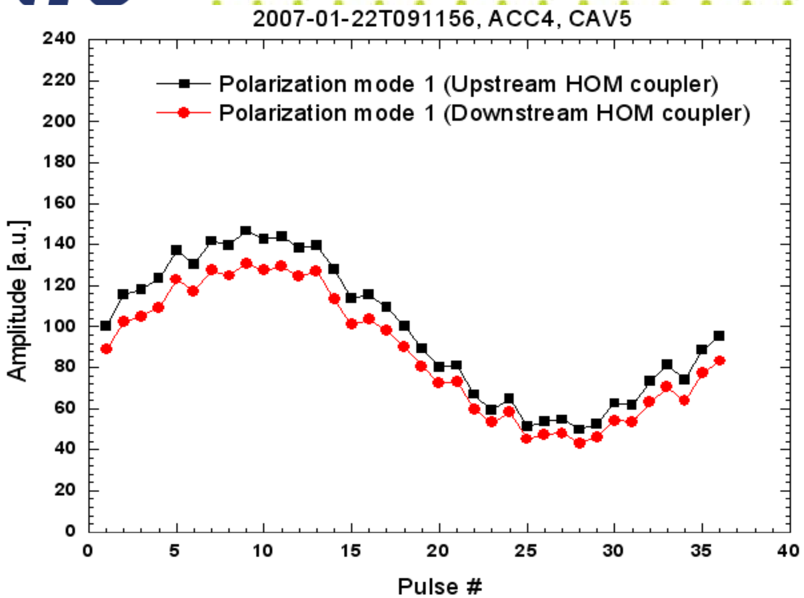
Analysis on CAV1 in ACC4

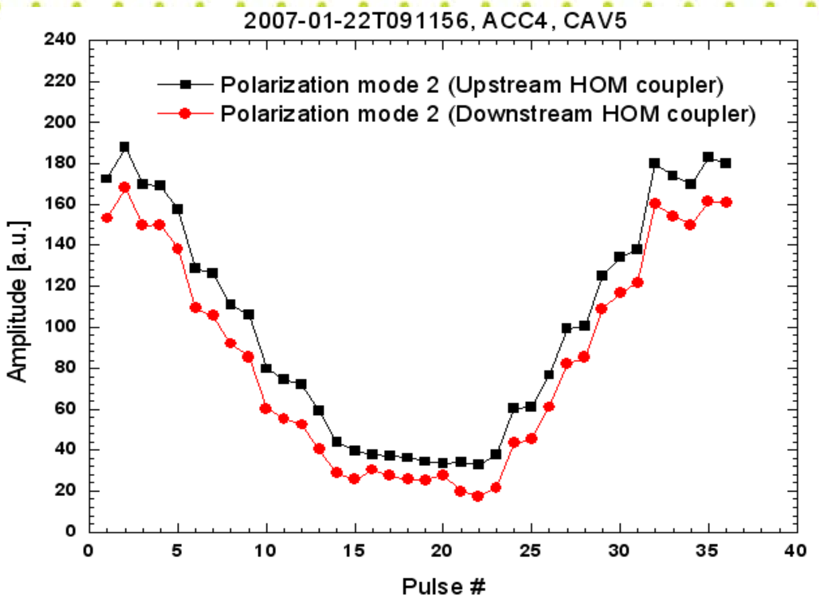
36×6+3+3=222 parameters need to be fit at the same time.

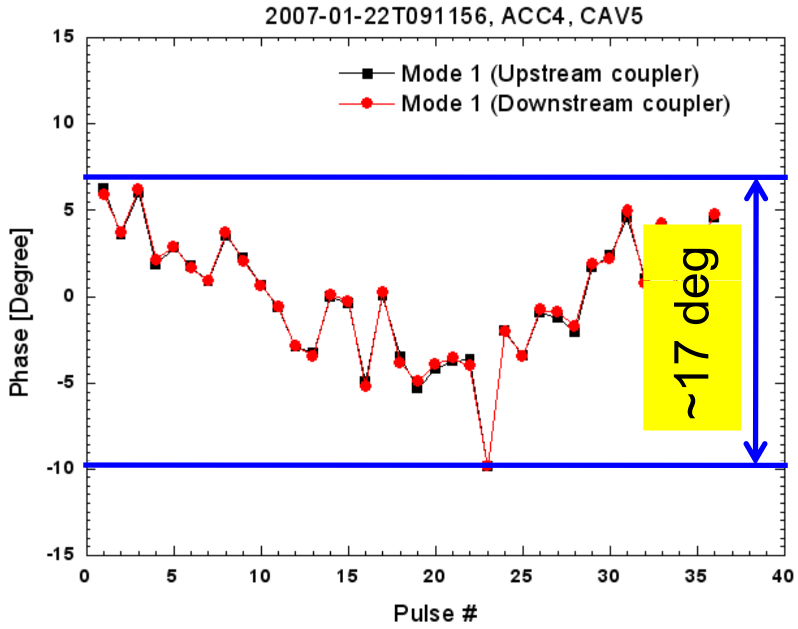


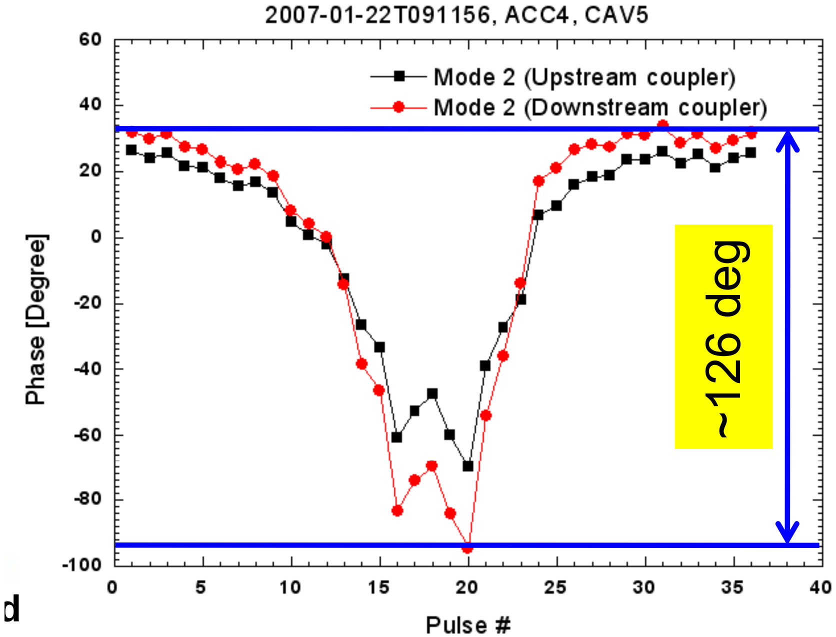
	Mode 1		Mode 2		Cal. Mode
	Freq	Q	Freq	Q	Freq
Up. Coupler	1696.3496±0.0003	9603±158	1697.1077±0.0012	22908±159	1697.1727±0.0001
Down. Coupler	1696.3444±0.0039	9602± 79	1697.1082±0.0028	23217±948	1697.1729±0.0002

Analysis on CAV5 in ACC4 (1)

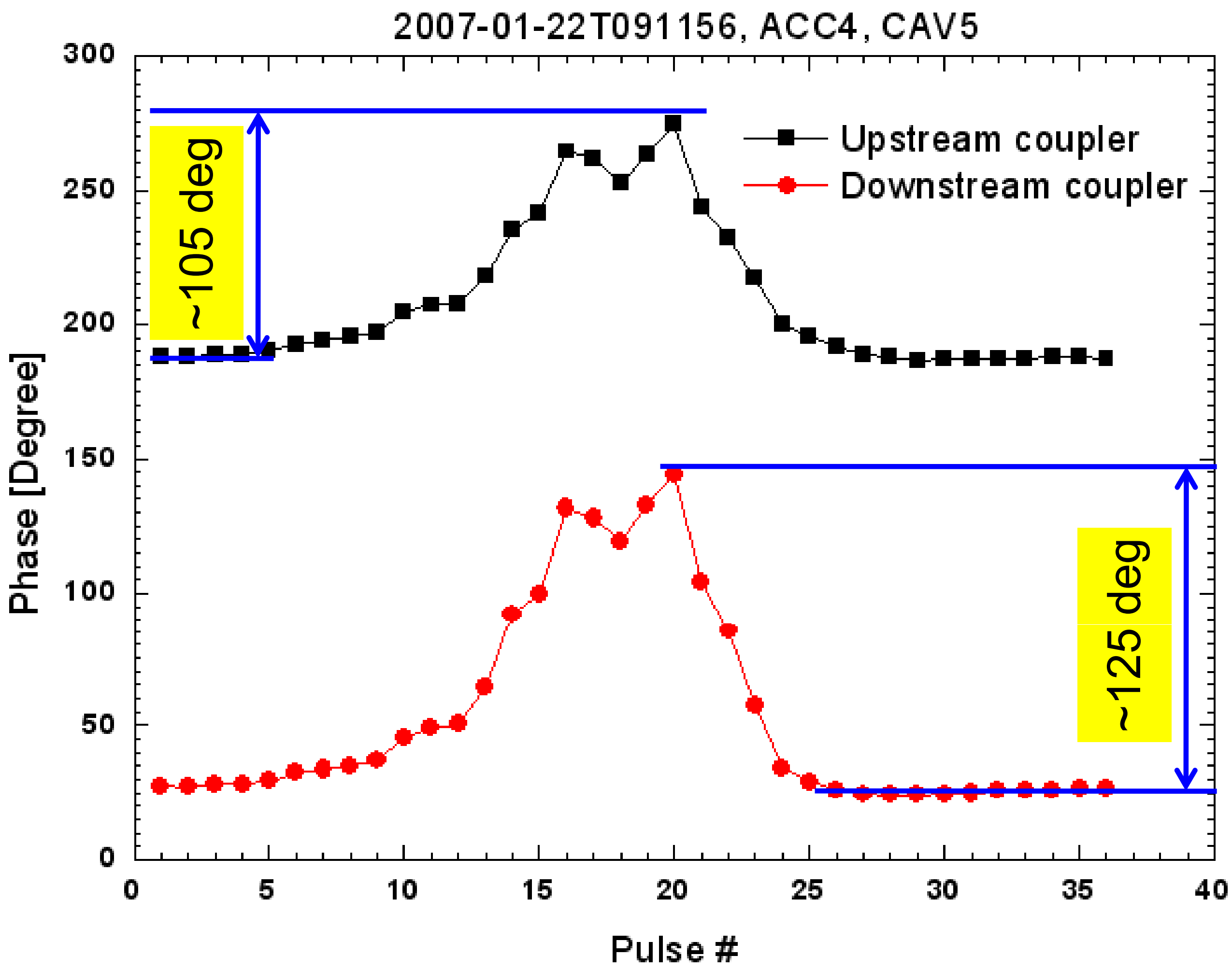




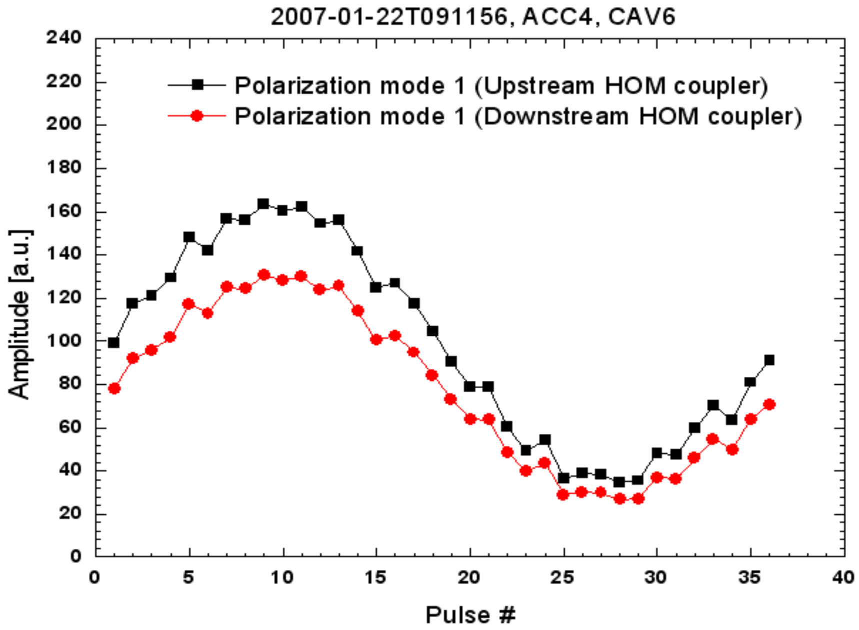


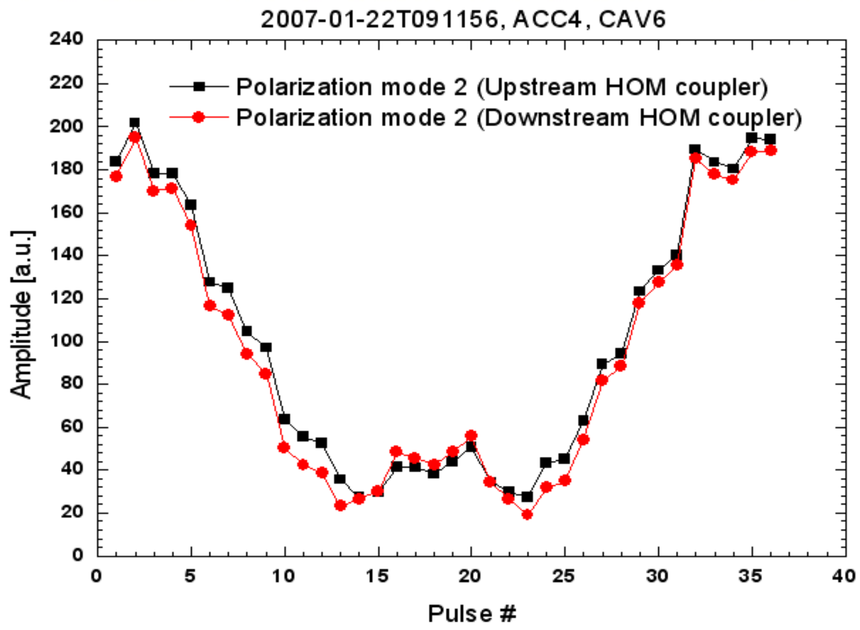


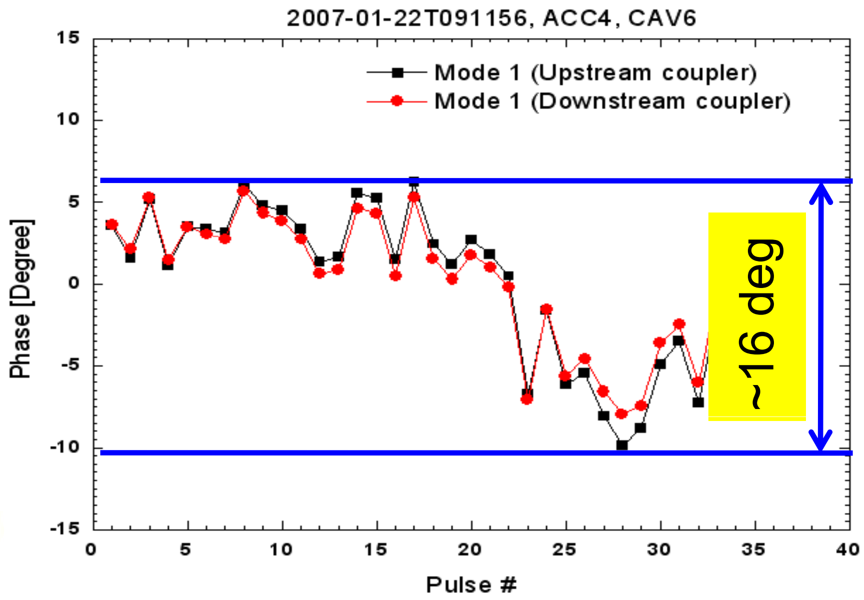
Analysis on CAV5 in ACC4(2)

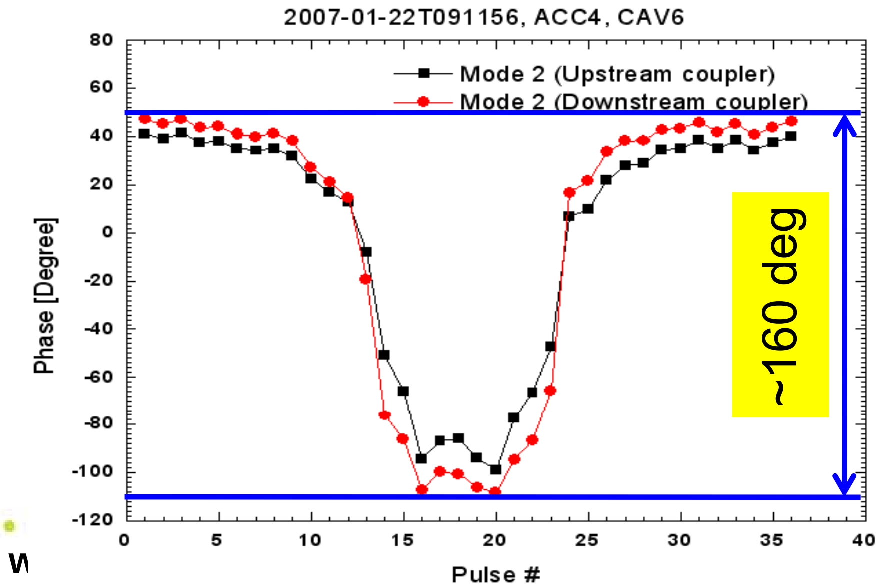


Analysis on CAV6 in ACC4 (1)

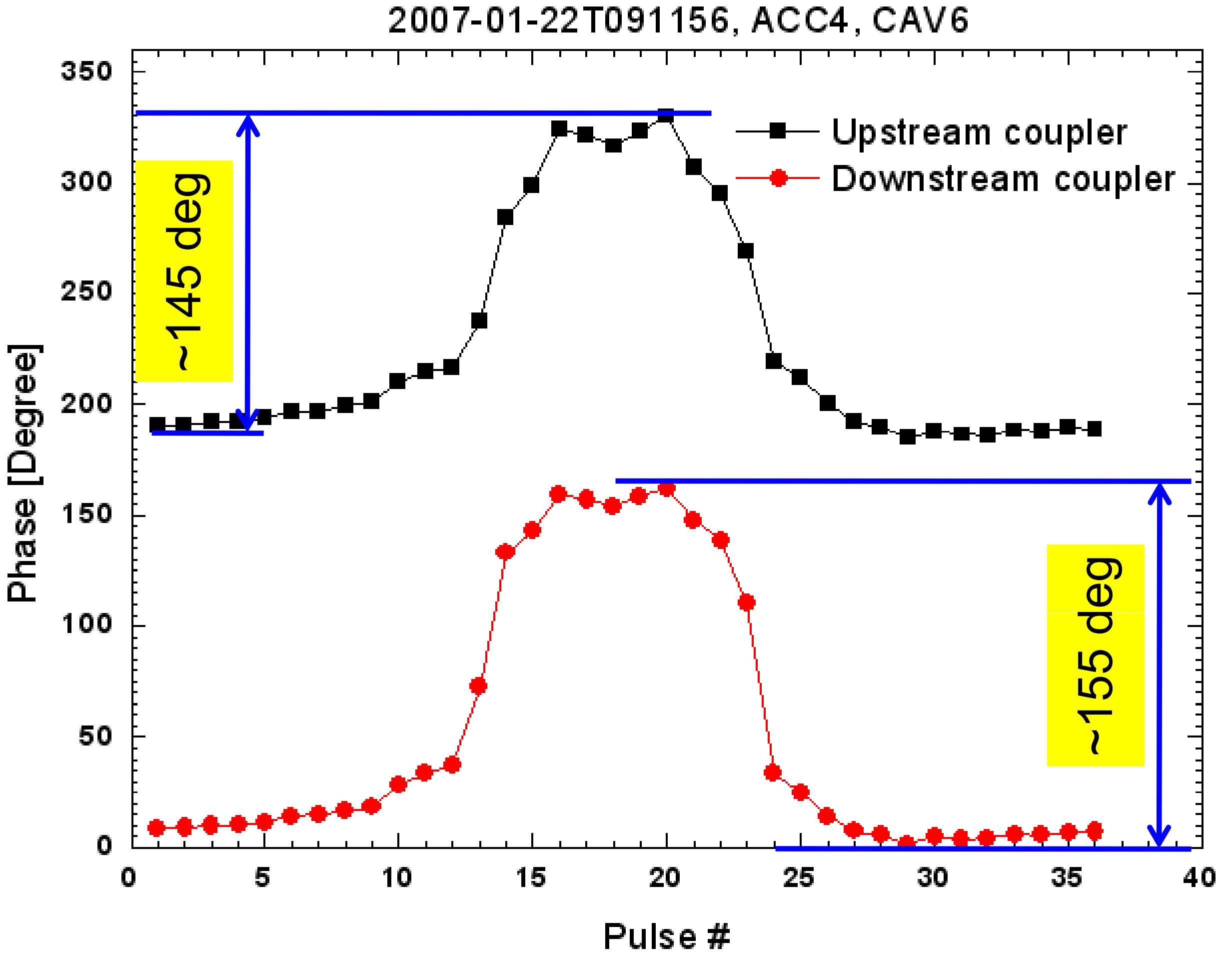




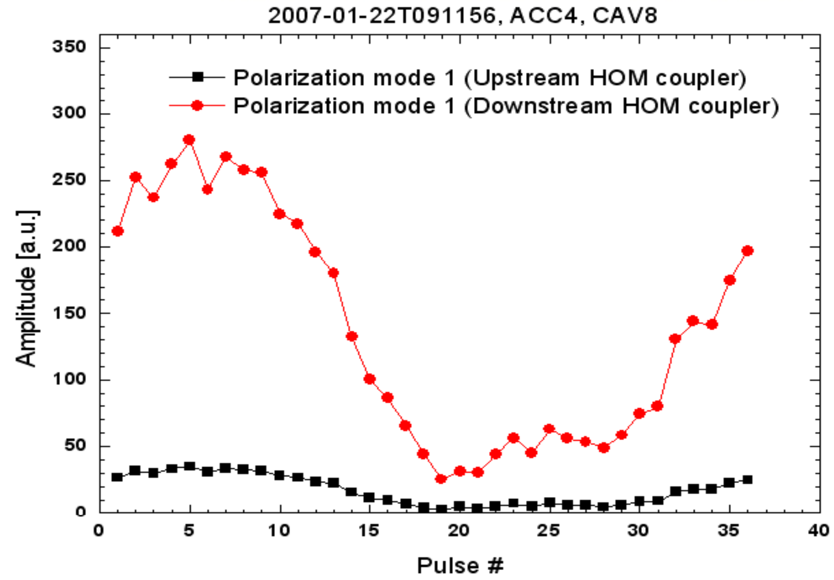


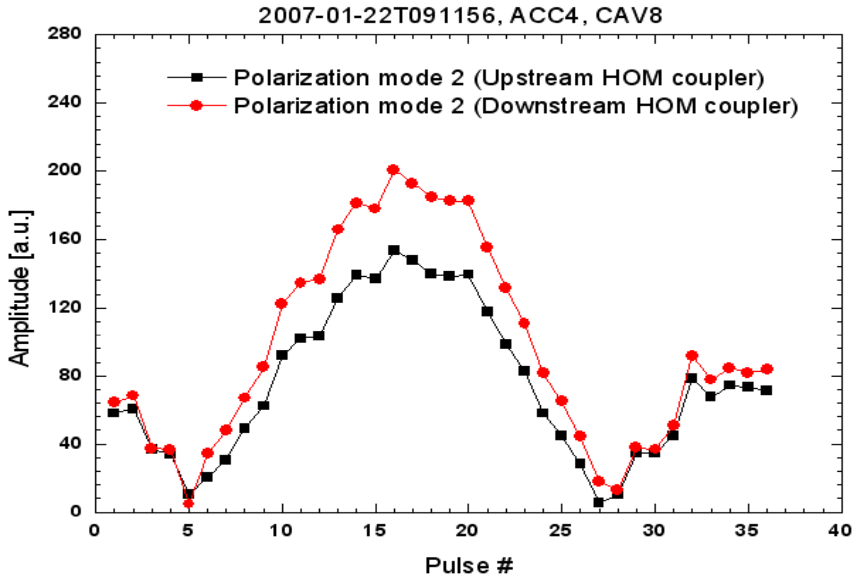


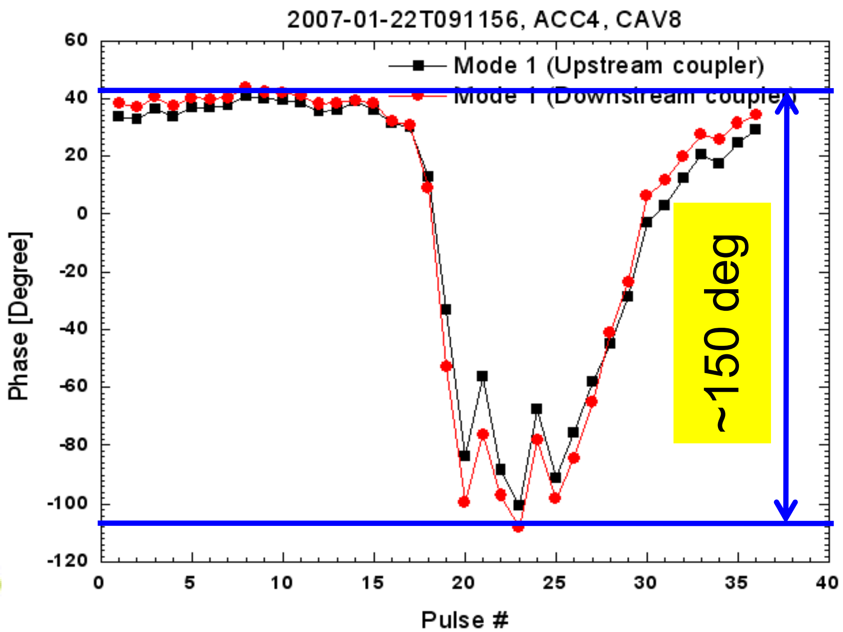
Analysis on CAV6 in ACC4 (2)

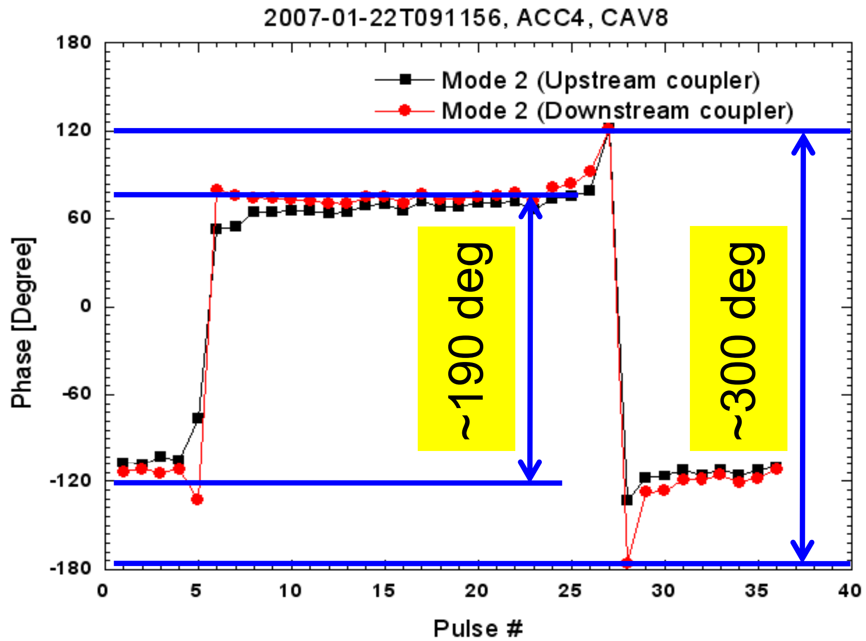


Analysis on CAV8 in ACC4 (1)

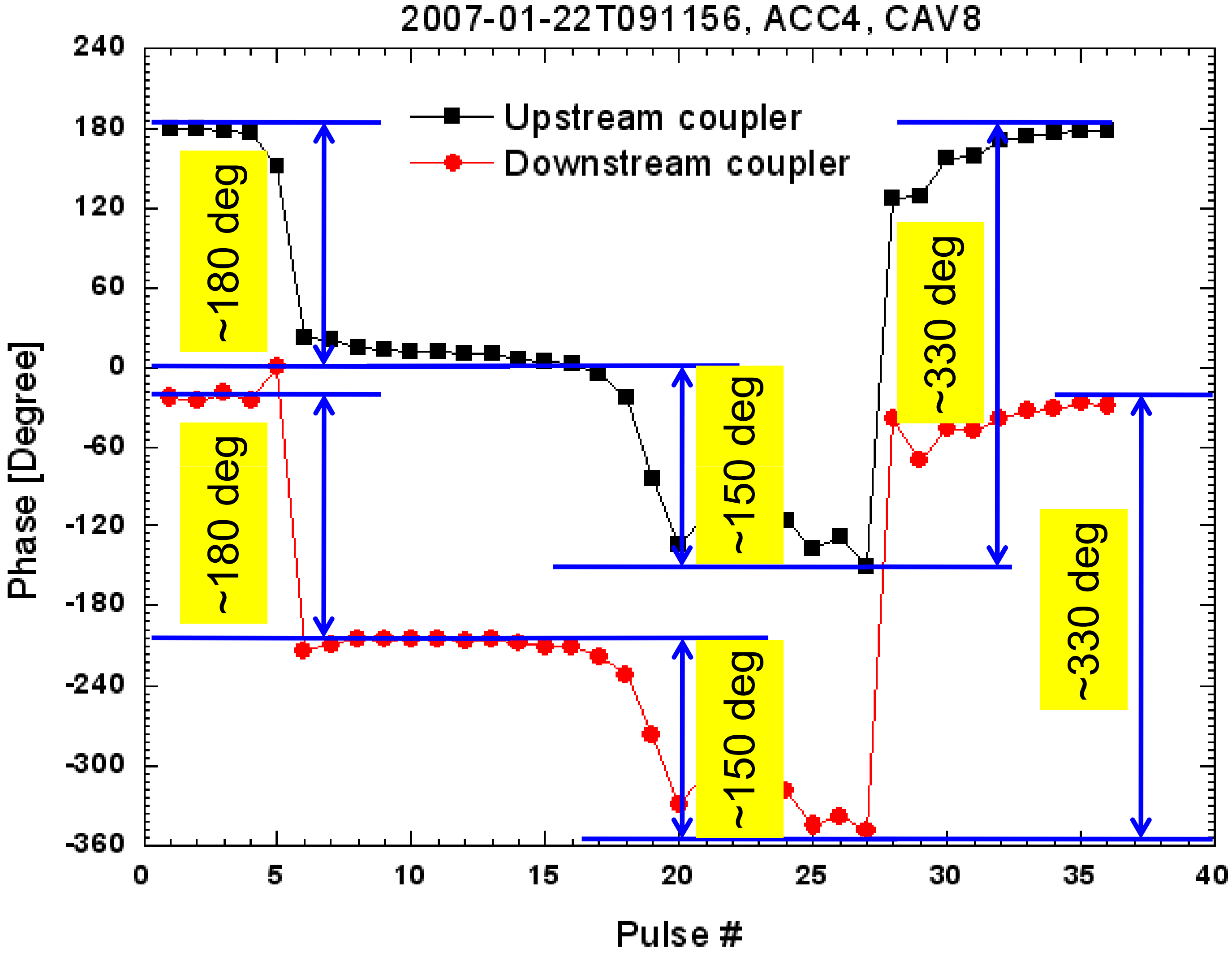




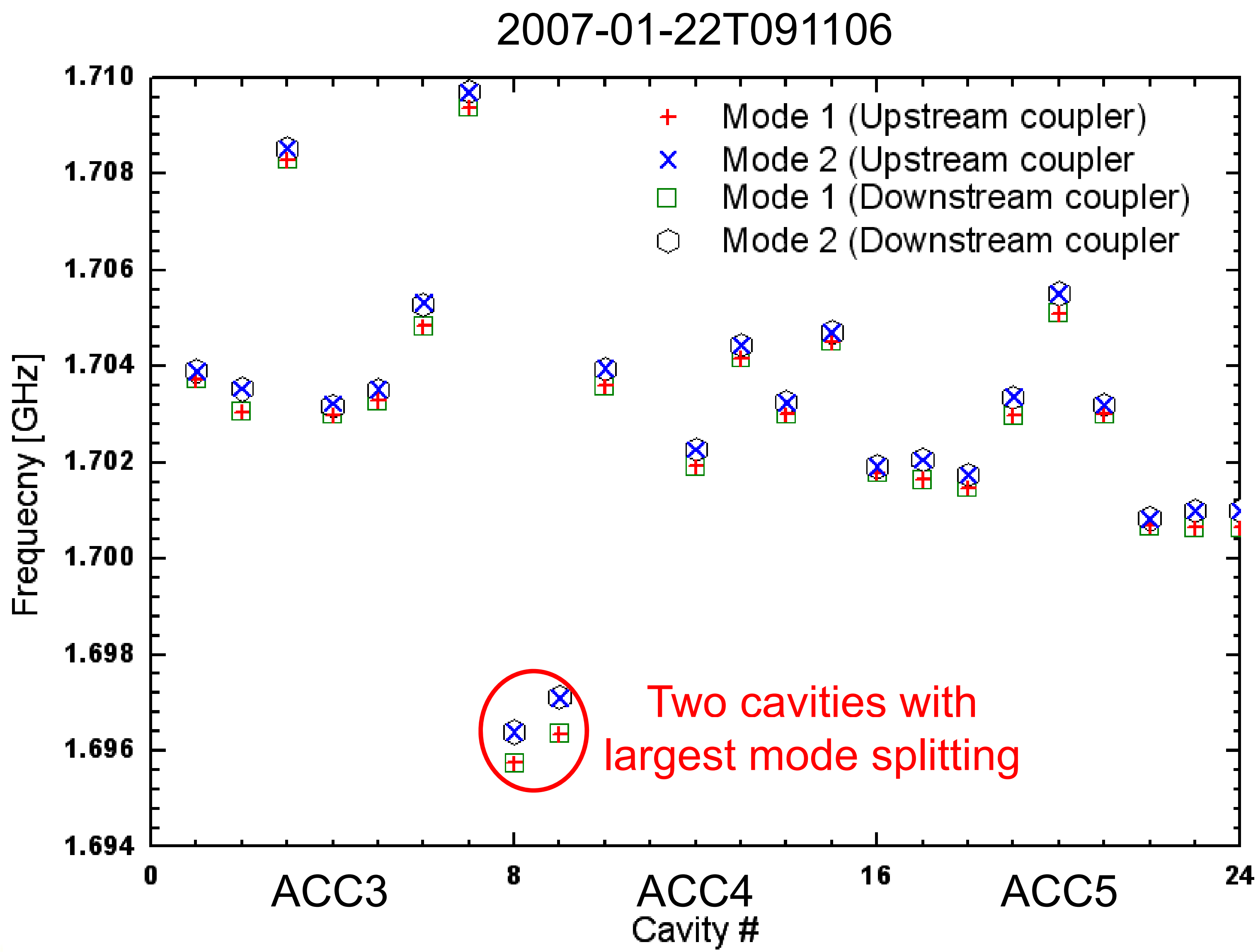




Analysis on CAV8 in ACC4 (2)

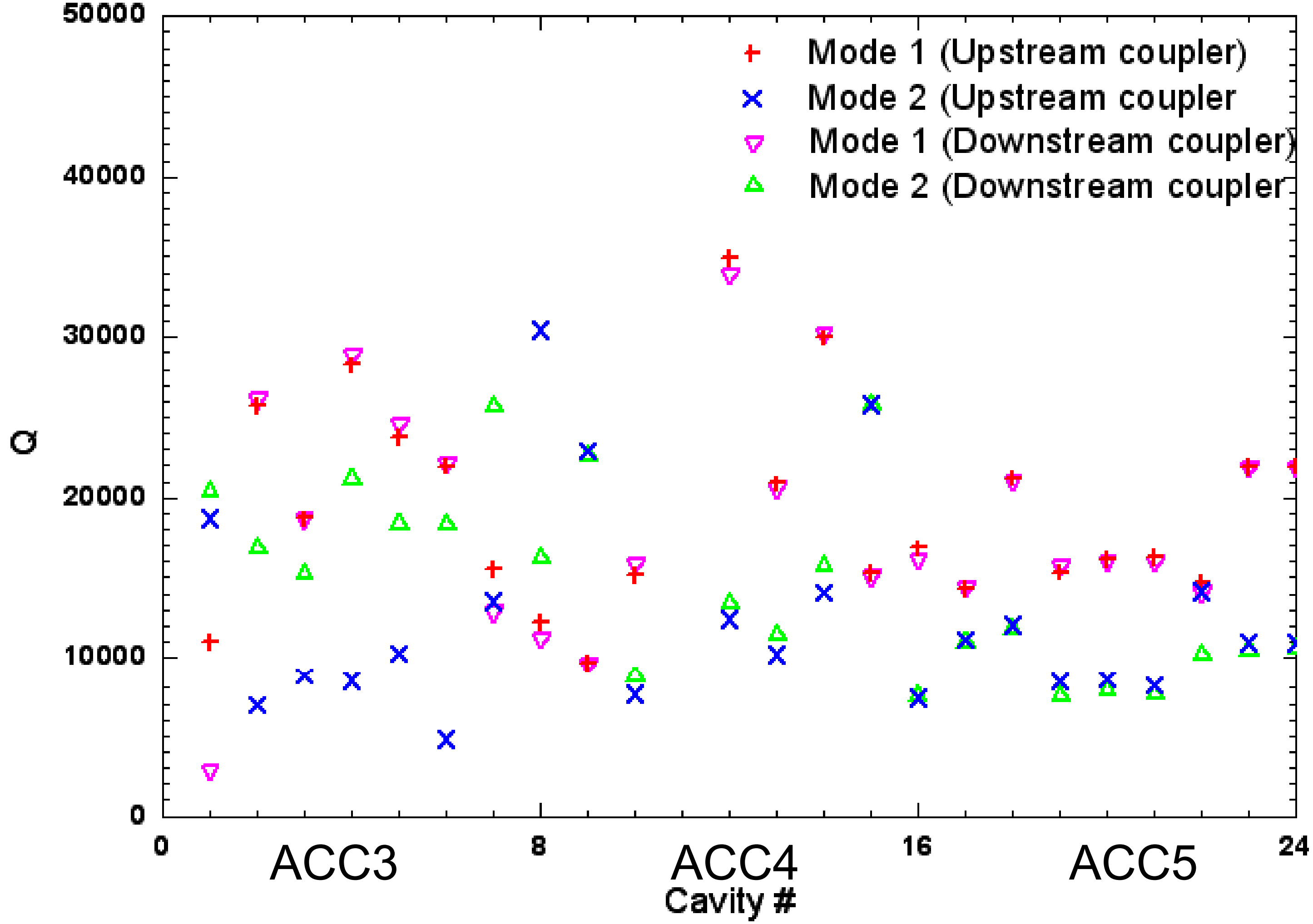


Cavities in ACC3/ACC4/ACC5 (1)



Cavities in ACC3/ACC4/ACC5 (2)

2007-01-22T091106



Comparison with broadband data

2007-01-22T091106, ACC4, CAV1

		Narrow band	Broad band
Upstream coupler	Mode 1 Freq.	1696.346	1696.335
	Mode 2 Freq.	1697.107	1697.092
Downstream coupler	Mode 1 Freq.	1696.345	1696.329
	Mode 2 Freq.	1697.108	1697.092
Upstream coupler	Mode 1 Q	9672	9672
	Mode 2 Q	22931	22773
Downstream coupler	Mode 1 Q	9620	9602
	Mode 2 Q	22592	21770

- NB data and BB data have almost the same Q.
- NB data and BB data have some difference on frequency, which is because of the frequency resolution difference(~0.03MHz for NB, 0.05MHz for BB).
- BB data is more irregular than NB data due to much noise and many spurious modes existence.

Summary(1)

- We have investigated one new method to analyze the HOM signal data, and some results have been obtained.
- The new method can be used to extract the HOM mode frequency, Q and relative phase from the HOM signal data. On the other hand, this method can also be used to find the HOM mode center, polarization axis, mode axis along the cavity, while careful handling of beam timing information need to be considered both in measurement and analysis.
- Comparing with SVD, this method is more physical, and can also be used in the beam diagnostic data analysis to obtain the beam position and beam trajectory obliquity.

Summary(2)

- More measurements need to be done to get better understanding of HOM mode characteristics.
  - **Sampling time or sampling frequency need to be increased to increase frequency resolution.**
  - **Do the measurements when the beam travel through the cavity along a circle with pure beam offset or the beam travel through the cavity along different beam trajectory with different obliquity angle while the initial beam position is fixed.**
  - **Try to get the absolute initial angle of the HOM signal in the measurements to separate the HOM signal caused by different sources.**
  - **……**