JGW-G2617195

February 13, 2026

Power recycling cavity length and power recycling gain measurements

Yuta Michimura

RESCEU, University of Tokyo

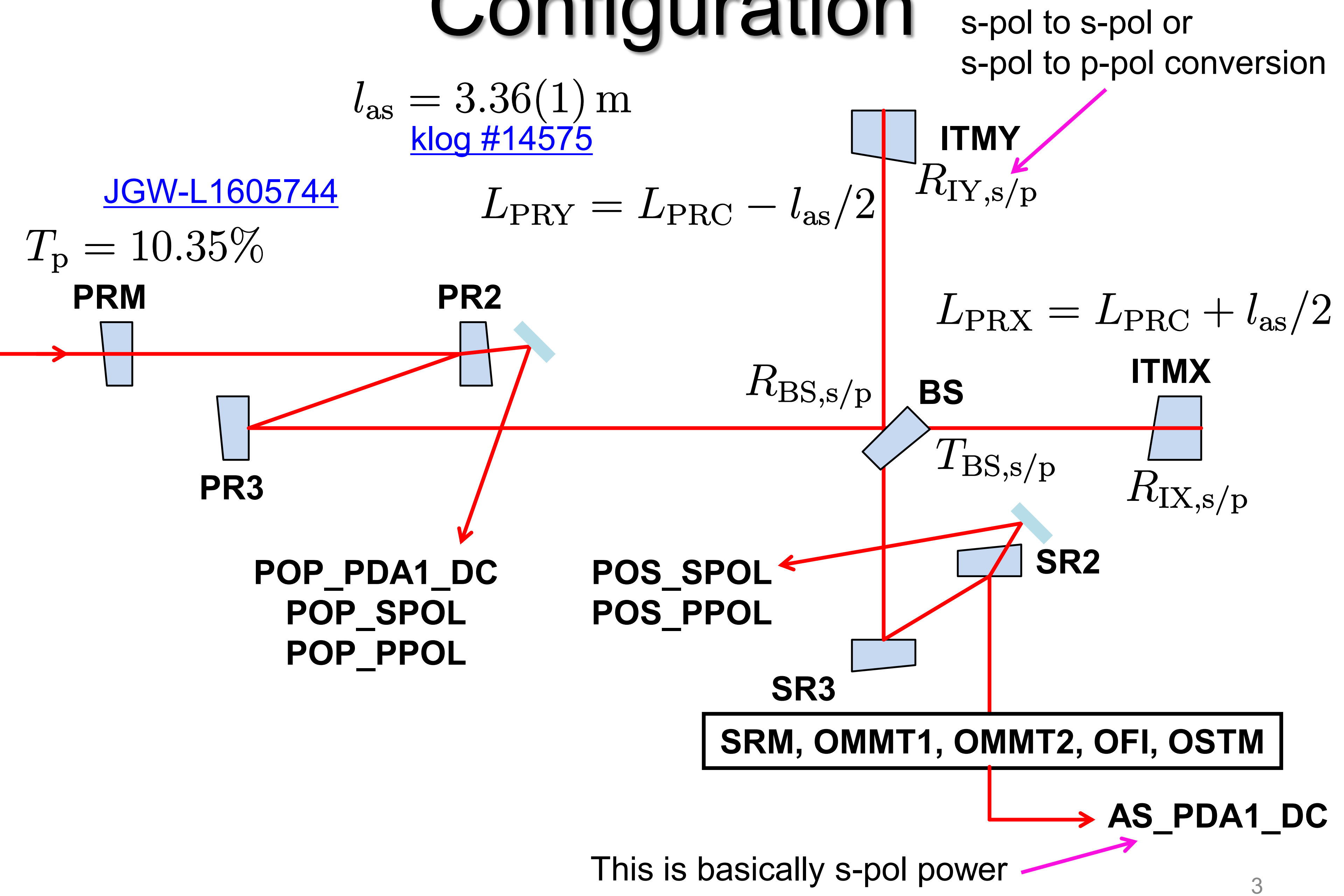
Kavli IPMU, WPI, UTIAS, University of Tokyo

Scope

- This slide explains recent measurements of
  - Power recycling cavity length
  - Power recycling gain
  - Beam Splitter T and R for s-pol and p-pol

  using PRX and PRY (and ITMX/Y single bounce)
- See klog #36249 and klog #36340
- See, also, klog #36283
- See JGW-T2617194 for simulations and how to deal with f2-PRCL mismatch

Configuration



BS ratios from ITM single bounce

- From AS and POS_SPOL, ITM reflectivity of s-pol to s-pol can be measured

Power when ITMX single bounce

ITMY single bounce

$$\frac{P^X_{\mathrm{AS}}}{P^Y_{\mathrm{AS}}} = \frac{P^X_{\mathrm{POS\_SPOL}}}{P^Y_{\mathrm{POS\_SPOL}}} = \boxed{\frac{R_{\mathrm{IX,s}}}{R_{\mathrm{IY,s}}}}$$

- Next, using POP_SPOL, BS T:R for s-pol can be measured

$$\frac{P^X_{\mathrm{POP\_SPOL}}}{P^Y_{\mathrm{POP\_SPOL}}} = \boxed{\frac{T^2_{\mathrm{BS,s}}}{R^2_{\mathrm{BS,s}}}}\frac{R_{\mathrm{IX,s}}}{R_{\mathrm{IY,s}}}$$

- Then, using POP_PPOL and POS_PPOL, BS T:R for p-pol and ITM reflectivity of s-pol to p-pol can be measured

$$\frac{P^X_{\mathrm{POP\_PPOL}}}{P^Y_{\mathrm{POP\_PPOL}}}\frac{P^Y_{\mathrm{POS\_PPOL}}}{P^X_{\mathrm{POS\_PPOL}}} = \frac{T_{\mathrm{BS,s}}R_{\mathrm{IX,p}}T_{\mathrm{BS,p}}}{R_{\mathrm{BS,s}}R_{\mathrm{IY,p}}R_{\mathrm{BS,p}}}\frac{R_{\mathrm{IY,p}}T_{\mathrm{BS,p}}}{R_{\mathrm{IX,p}}R_{\mathrm{BS,p}}} = \frac{T_{\mathrm{BS,s}}}{R_{\mathrm{BS,s}}}\boxed{\frac{T^2_{\mathrm{BS,p}}}{R^2_{\mathrm{BS,p}}}}$$

$$\frac{P^X_{\mathrm{POP\_PPOL}}}{P^Y_{\mathrm{POP\_PPOL}}}\frac{P^X_{\mathrm{POS\_PPOL}}}{P^Y_{\mathrm{POS\_PPOL}}} = \frac{T_{\mathrm{BS,s}}R_{\mathrm{IX,p}}T_{\mathrm{BS,p}}}{R_{\mathrm{BS,s}}R_{\mathrm{IY,p}}R_{\mathrm{BS,p}}}\frac{R_{\mathrm{IX,p}}R_{\mathrm{BS,p}}}{R_{\mathrm{IY,p}}T_{\mathrm{BS,p}}} = \frac{T_{\mathrm{BS,s}}}{R_{\mathrm{BS,s}}}\boxed{\frac{R^2_{\mathrm{IX,p}}}{R^2_{\mathrm{IY,p}}}}$$

BS ratios from ITM single bounce

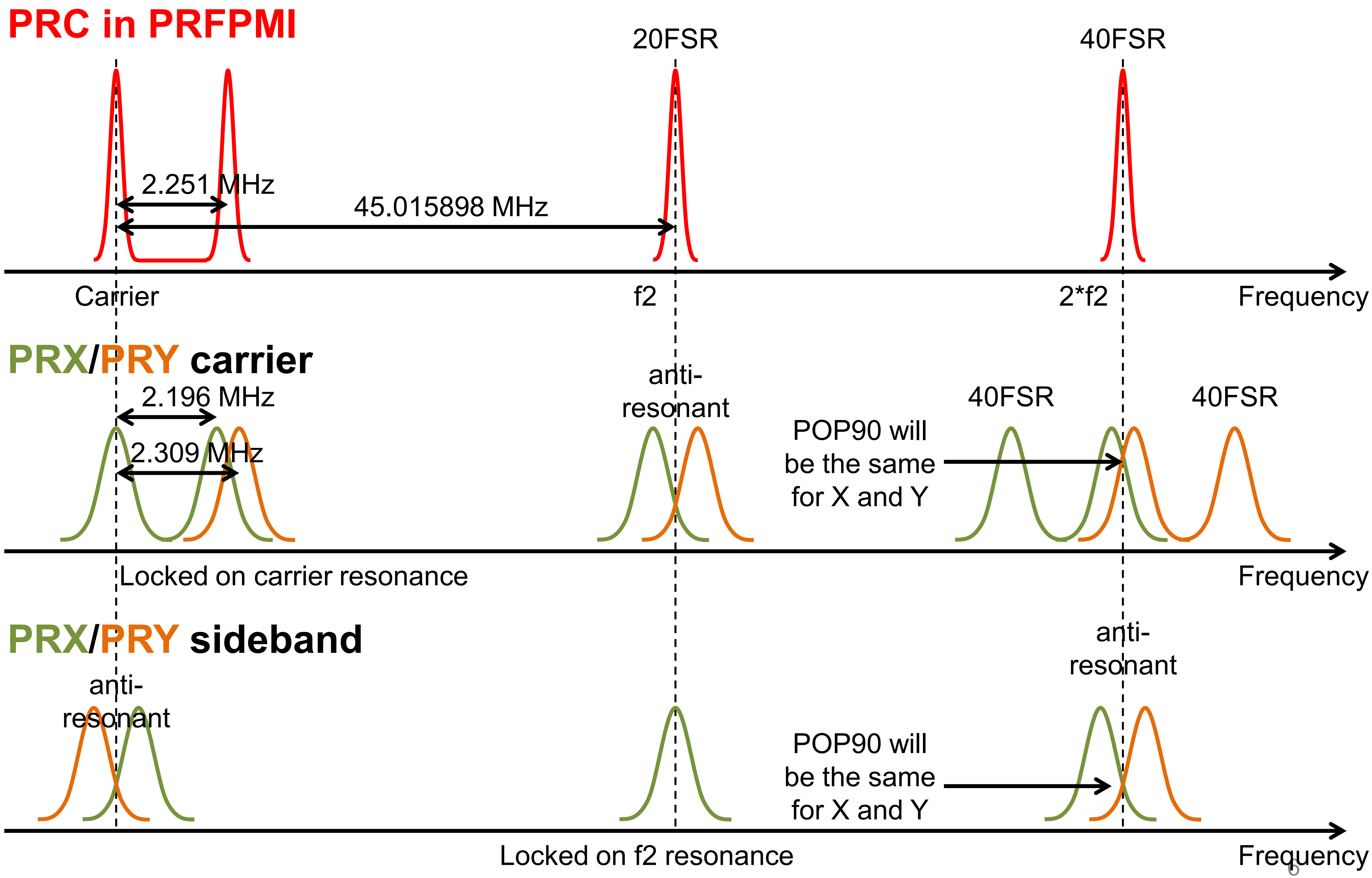
klog #36249

- Results are the following (no significant loss in BS assumed):

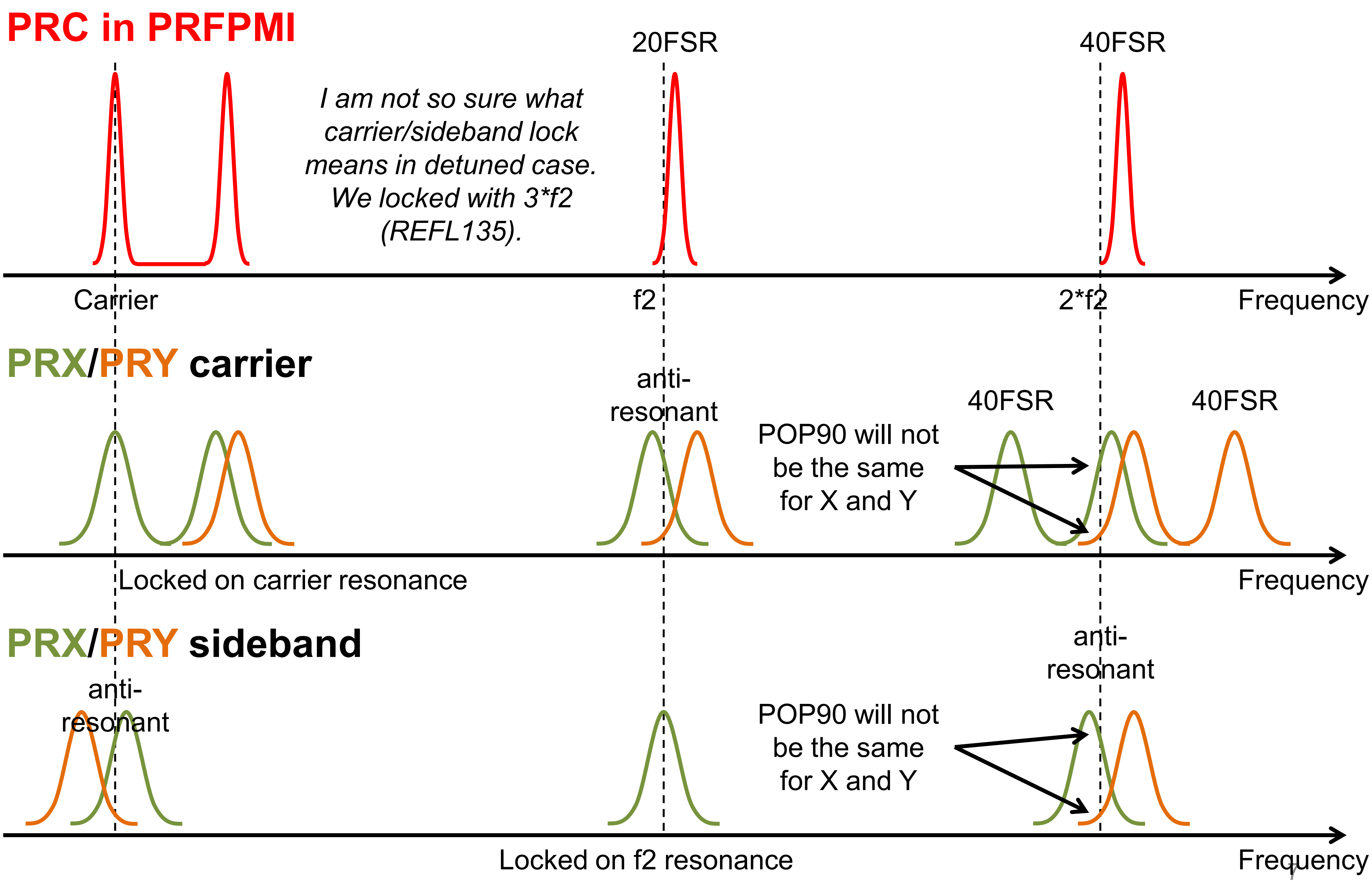
ITM reflectivity ratio X/Y for s-pol	**1.039+/-0.005**
BS T/R ratio for s-pol	**0.998+/-0.012**
BS T for s-pol	**0.4995+/-0.0030**
BS R for s-pol	**0.5005+/-0.0030**
BS T/R ratio for p-pol	**4.025+/-0.031**
BS T for p-pol	**0.8010+/-0.0012**
BS R for p-pol	**0.1990+/-0.0012**
ITM p-pol conversion ratio X/Y	**0.663+/-0.005**

- BS T:R=50:50 for s-pol and 80:20 for p-pol consistent with Hirose-san's characterizations and coating design (JGW-T1503347)
- ITM p-pol conversion is 6-7% for X and 9-10% for Y (klog #36283). This asymmetry explains ITM reflectivity asymmetry for s-pol as well.

PRC resonant conditions: Design



PRC resonant conditions: Detuned



PRGs for PRX and PRY

- From power ratio at POP_DC and AS_DC when ITM single bounce and PRX/PRY, carrier PRG for carrier lock can be estimated:

[klog #36249]

Carrier PRG for PRX 0.341+/-0.006
Carrier PRG for PRY 0.330+/-0.009

- f2 PRG is given by

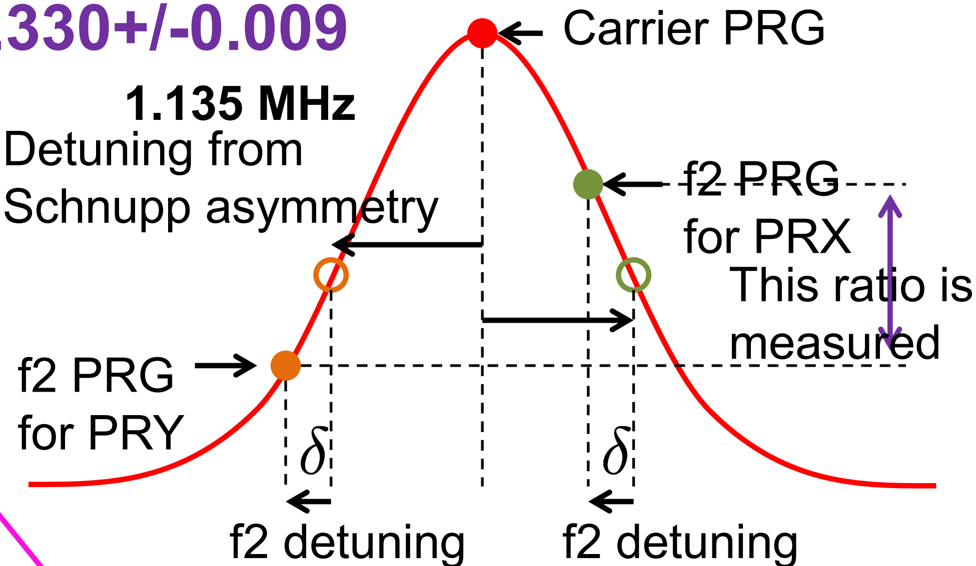
$$G_{\mathrm{pr,sb}} = \frac{G_{\mathrm{pr,cr}}}{1 + \left(\frac{2\mathcal{F}_{\mathrm{pr}}\Delta}{\nu_{\mathrm{PRC}}}\right)^2}$$

FSR of PRC

Finesse of PRC
3.71(14) with optical loss of 13(5)%

$$\mathcal{F}_{\mathrm{pr}} = \frac{\pi\sqrt{r_{\mathrm{p}} t_{\mathrm{BS}}^2 r_{\mathrm{loss}}}}{1 - r_{\mathrm{p}} t_{\mathrm{BS}}^2 r_{\mathrm{loss}}}$$

(HWHM is therefore ~0.303 MHz)



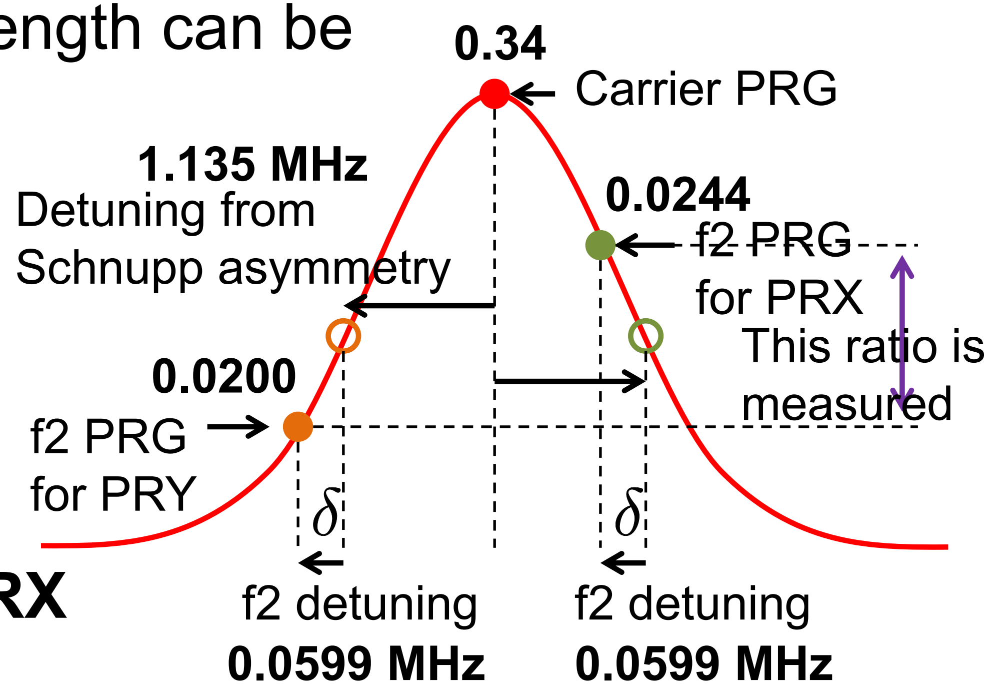
Detuning

$$\Delta = -20\nu_{\mathrm{PRC}} \frac{l_{\mathrm{as}}}{2L_{\mathrm{PRC}}} \pm \delta$$

Optical loss estimated from carrier PRG for PRX/Y

PRGs for PRX and PRY

- From POP90 $\sqrt{(I^2+Q^2)}$ ratios in PRX and PRY sideband locks, f2 detuning δ can be estimated: [klog #36340]
  Estimated f2 detuning of PRC 0.0599+/-0.0033 MHz
- From this detuning PRC length can be estimated:
  Average PRC length
  66.540+/-0.005 m
- Using carrier PRG,
  f2 PRG can be estimated:
  f2 sideband PRG for PRX
  0.0244+/-0.0017
  f2 sideband PRG for PRY
  0.0200+/-0.0014



* HWHM is ~0.303 MHz

This measurement possible due to large Schnupp asymmetry

* These values do not mean that f2 power is enhanced by these amounts

f2 PRG in PRFPMI

- Using the estimated f2 sideband PRG for PRX and PRY, calibration factor for POP90 $\sqrt{I^2 + Q^2}/P_{\mathrm{IMC}}$ can be estimated to be **1.88(9)**.

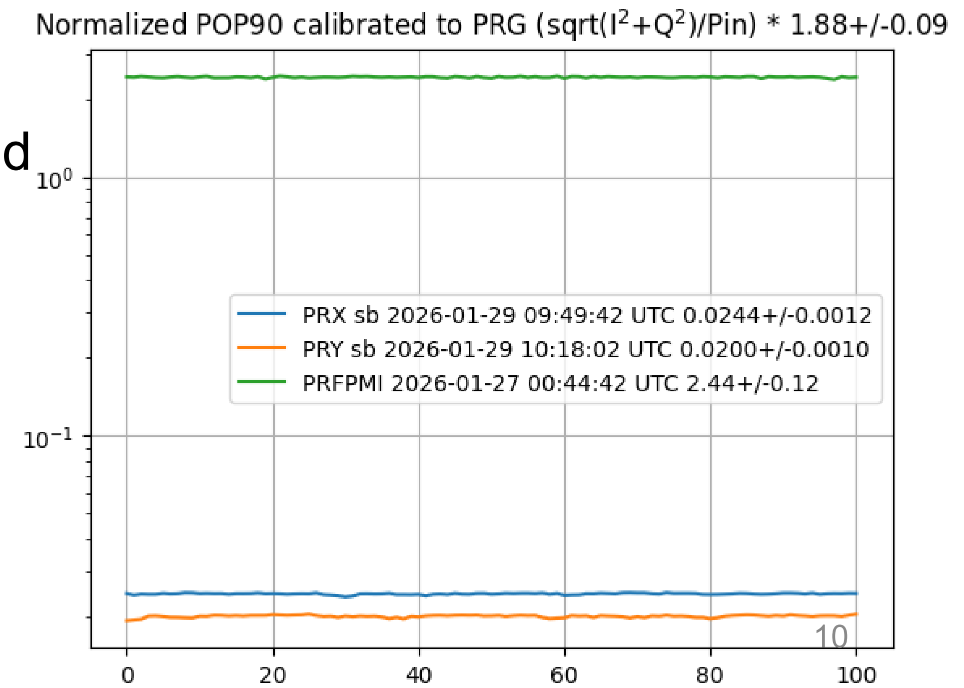
[klog #36340](#)

K1:LSC-POP_PDA2_RF90_I_ERR_DQ
K1:LSC-POP_PDA2_RF90_Q_ERR_DQ

K1:LAS-POW_IMC_DC_INMON

- Using this calibration factor, f2 PRG in PRFPMI is estimated to be
  f2 sideband PRG for PRFPMI 2.44+/-0.12

- This is quite low compared with carrier PRG in PRFPMI estimated from TRX and TRY (~13 now)
- This is probably mostly due to f2 detuning (see next page)



Losses in PRC for PRFPMI

- Schnupp asymmetry of $l_{\mathrm{as}} = 3.36(1)\,\mathrm{m}$ (klog #14575) gives loss-less Michelson reflectivity for f2 of
$$r_{\mathrm{mi}}^2 = \cos\left(f_2 l_{\mathrm{as}}/(\pi c)\right) = 0.97455(15)$$
klog #36340
- This gives f2 PRG of $G_{\mathrm{pr,tuned}}$ = **36.62(4)**, if PRC length is perfectly matched with f2.
- The finesse for loss-less PRC is $\mathcal{F}_{\mathrm{pr}} = \dfrac{\pi\sqrt{r_{\mathrm{p}} r_{\mathrm{mi}}}}{1 - r_{\mathrm{p}} r_{\mathrm{mi}}} = 24.25(6)$
- The FSR for PRC using the measured value 66.540(5) m is ν_{PRC} = **2.25272(17) MHz.**
- Using the measured f2 detuning δ, PRG for detune f2 is
$$G_{\mathrm{pr,detuned}} = \frac{G_{\mathrm{pr,tuned}}}{1 + (2\mathcal{F}_{\mathrm{pr}}\delta/\nu_{\mathrm{PRC}})^2} = 3.41(32)$$
* HWHM is ~0.0242 MHz
- To explain measured f2 PRG in PRFPMI of **2.44(12)**, **additional 12.6-16.1% loss** is necessary. This is consistent with loss measurements in PRX and PRY.

Next

- It would be nice to have an independent method to measure PRC length
  - Inject auxiliary beam to do cavity scan?
  - Kick PRM during PRMI lock to do cavity scan?

- I first thought carrier PRG and sideband PRG in PRFPMI and arm cavity finesse would give independent measurements of arm losses, PRC losses and ITM reflectivity, but distinguishing these losses seems tricky in current detuned case