Power recycling cavity length and power recycling gain measurements

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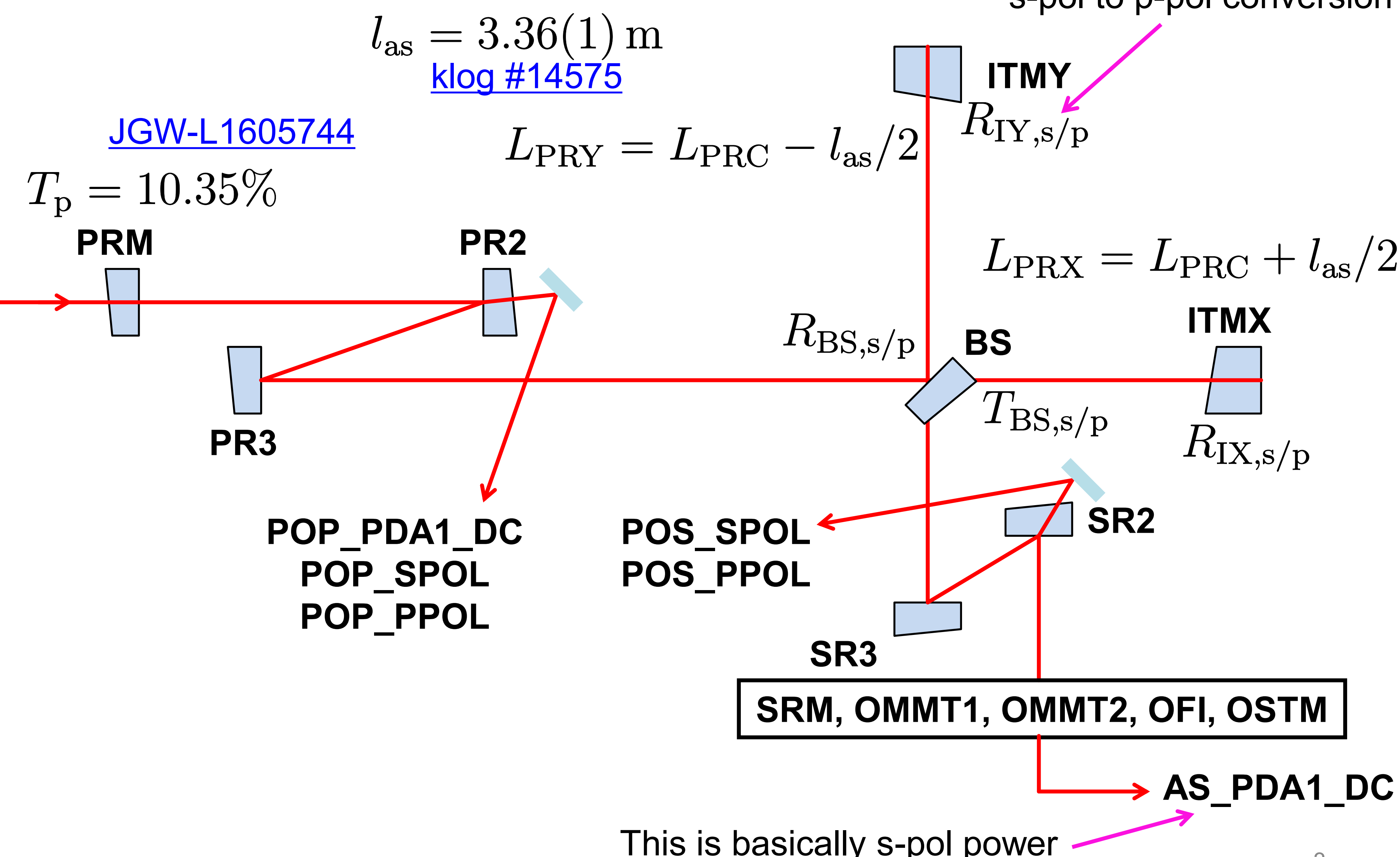
Scope

- 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

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

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

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

- 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

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

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

BS ratios from ITM single bounce

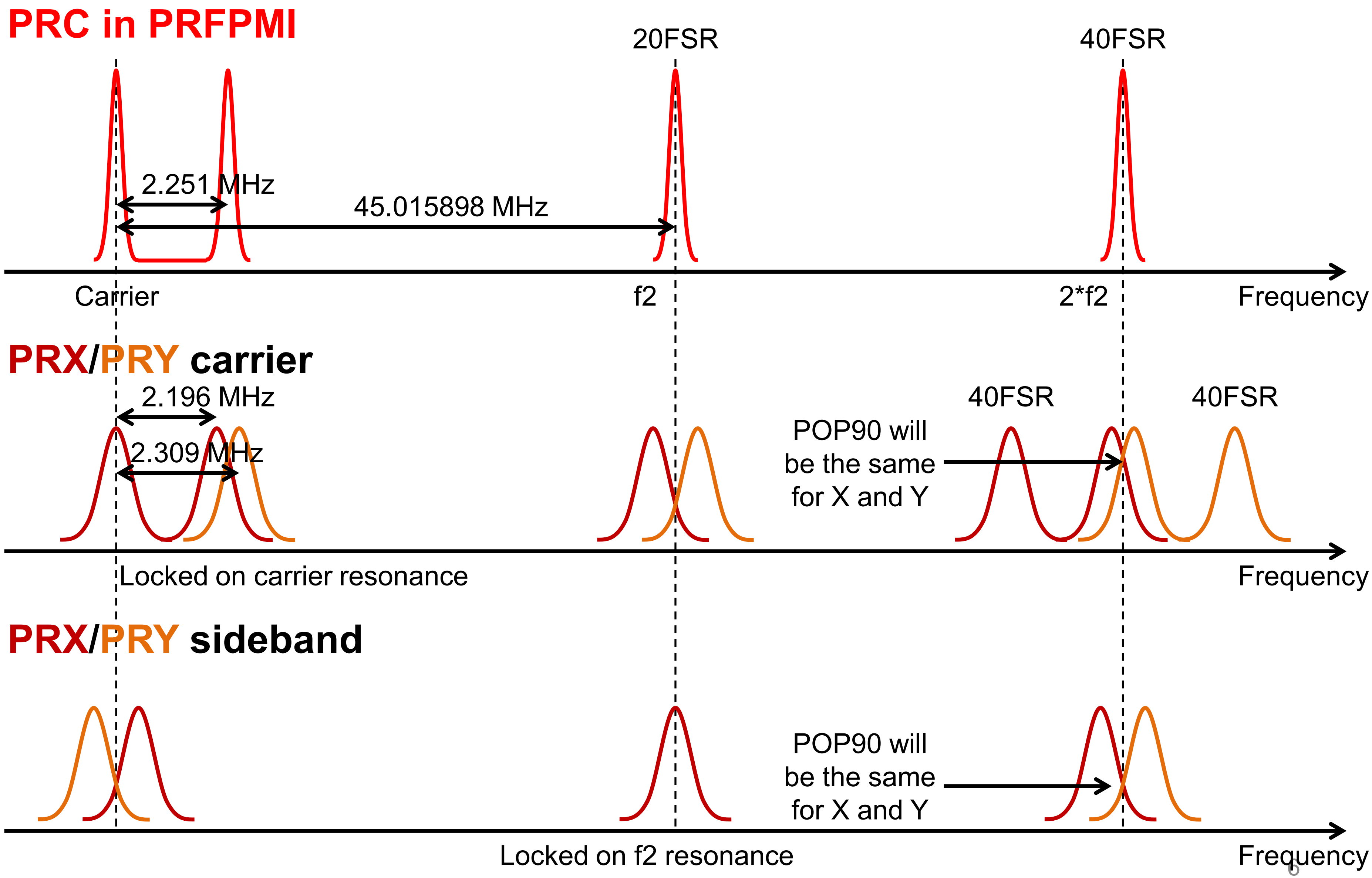
klog #36249

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

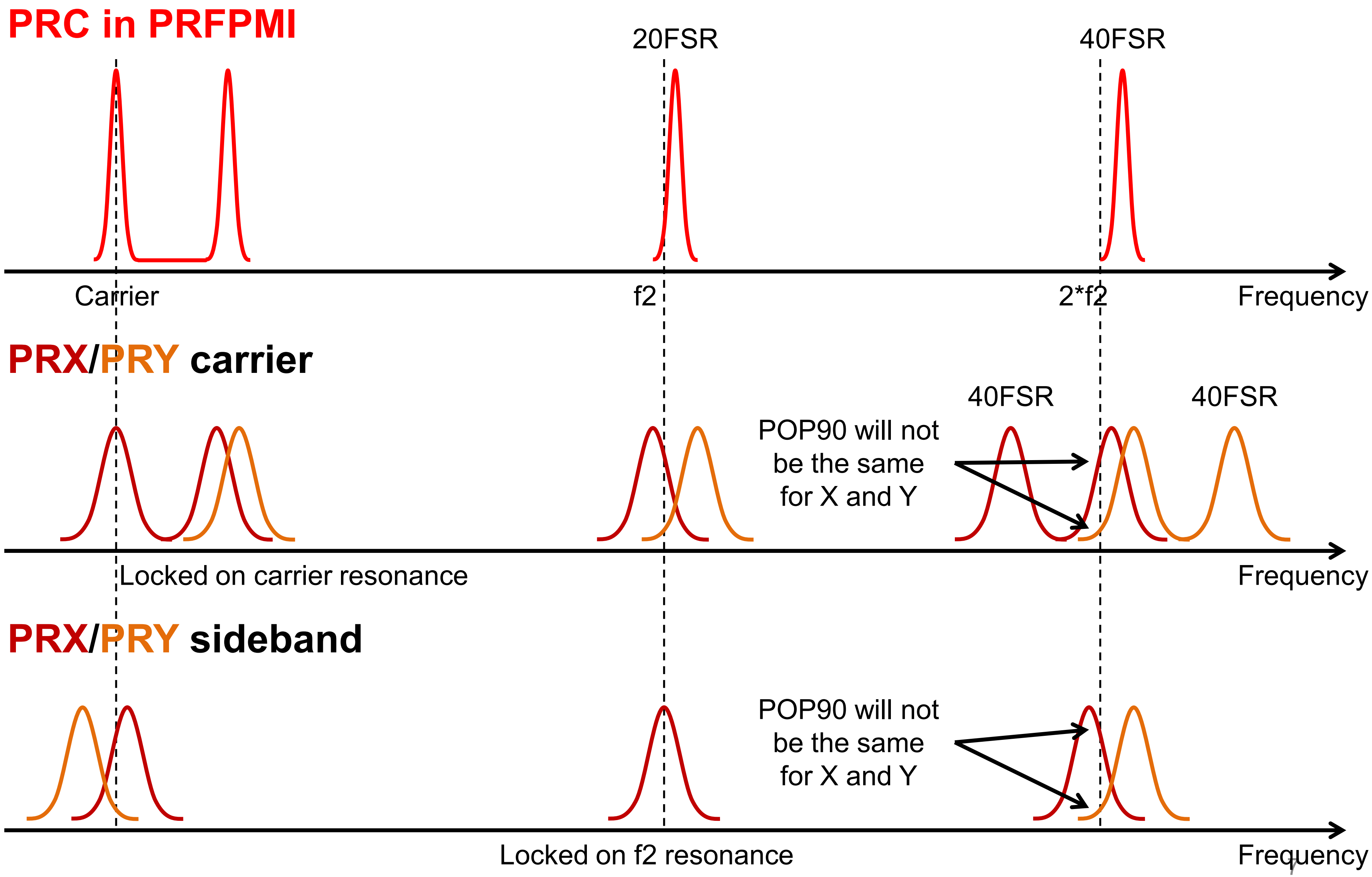
ITM reflectivity ratio X/Y for s-pol	**1.039+/-0.005**
BS T/R ratio for s-pol	**0.998+/-0.012**
BS T for s-pol	**0.4995+/-0.0030**
BS R for s-pol	**0.5005+/-0.0030**
BS T/R ratio for p-pol	**4.025+/-0.031**
BS T for p-pol	**0.8010+/-0.0012**
BS R for p-pol	**0.1990+/-0.0012**
ITM p-pol conversion ratio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

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

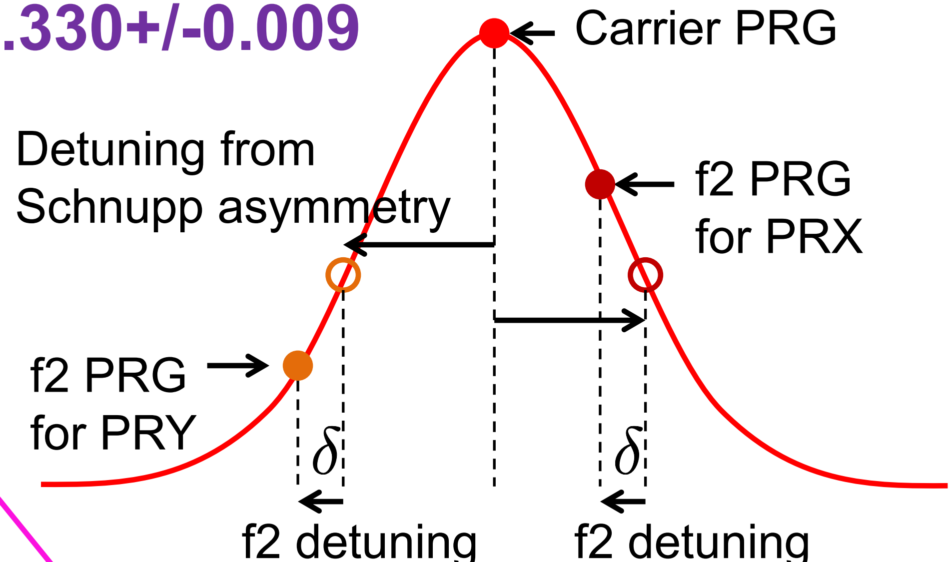
FSR of PRC

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, f2 detuning δ can be estimated: klog #36340

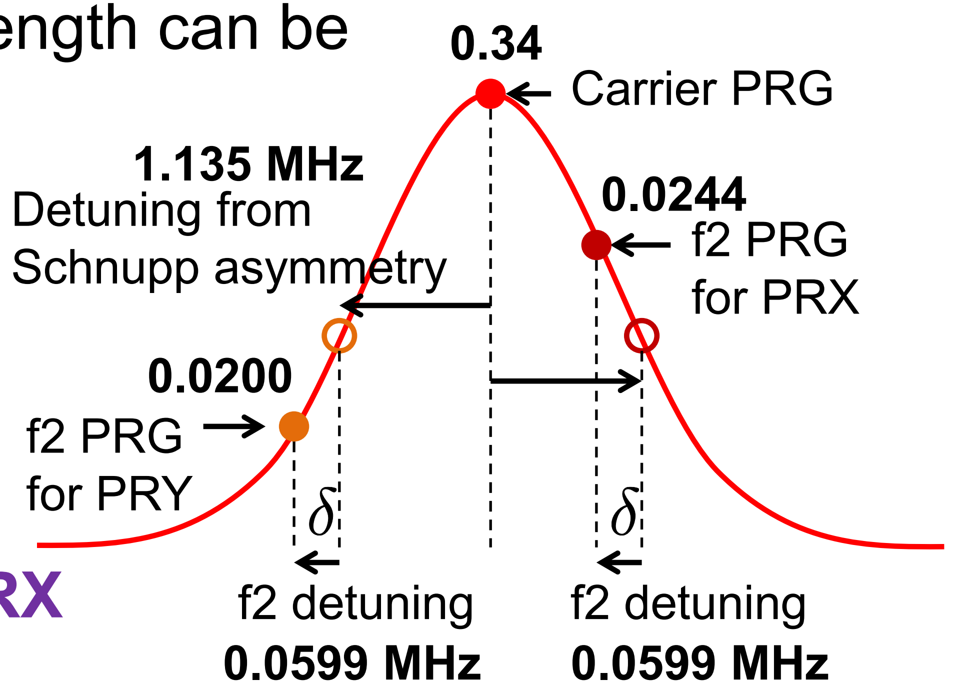
  Estimated f2 detuning of PRC 0.0599+/-0.0033 MHz

- 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

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

Losses in PRC for PRFPMI

- Schnupp asymmetry of $l_{\rm as} = 3.36(1)\,\mathrm{m}$ (klog #14575) gives loss-less Michelson reflectivity for f2 of klog #36340
  $$r_{\rm mi}^2 = \cos\left(f_2 l_{\rm as}/(\pi c)\right) = 0.97455(15)$$
- This gives f2 PRG of $G_{\rm pr,tuned}$ = **36.62(4)**, if PRC length is perfectly matched with f2.
- The finesse for loss-less PRC is $\mathcal{F}_{\rm pr} = \dfrac{\pi\sqrt{r_{\rm p} r_{\rm mi}}}{1 - r_{\rm p} r_{\rm mi}} = 24.25(6)$
- 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
  $$G_{\rm pr,detuned} = \frac{G_{\rm pr,tuned}}{1 + (2\mathcal{F}_{\rm pr}\delta/\nu_{\rm PRC})^2} = 3.41(32)$$
- 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.