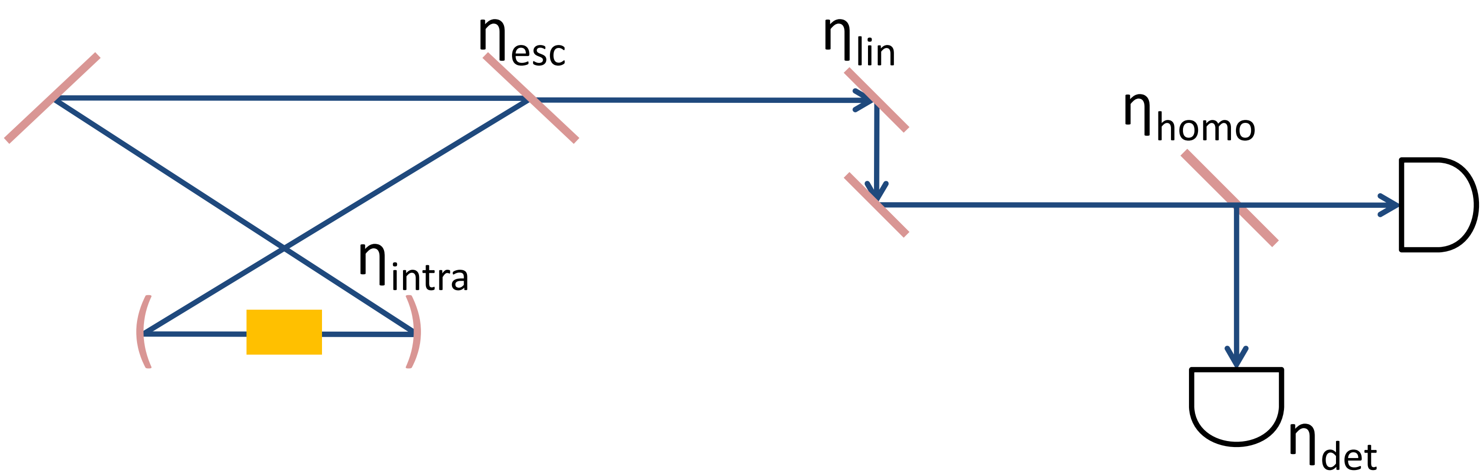
Efficiency of Squeezing

$$\eta_{\mathbf{sqz}} = \eta_{\mathbf{intra}}\eta_{\mathbf{esc}}\eta_{\mathbf{lin}}\eta_{\mathbf{homo}}\eta_{\mathbf{det}}$$



η_{intra} – Intra-cavity Efficiency → Intra-cavity nonlinear process

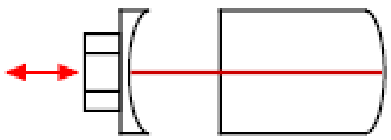
η_{esc} – Escape Efficiency → Ratio between output coupling rate to total cavity decay rate

η_{lin} – Transmission Efficiency → From Cavity to Detection

η_{homo} – Homodyne Efficiency → Square of the Fringe Visibility

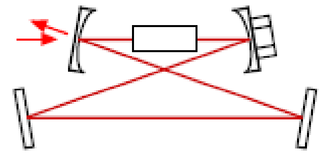
η_{det} – Detector Efficiency → Photodetector Efficiency

OPO Design
Hemilithic vs Bow-tie Configuration



Hemilithic (Standing Wave)

- Fewer reflecting surfaces, thus having lower loss
- Negligible spatial and polarisation distortion through its normal incidence operation.
- Limited number of input ports/ reflected beams from normal incidence operation.
- Single air/crystal interface, but greater difficulty in exchange of crystals
- Squeezer in hemilithic configuration to be installed at GEO600.



Bow-tie (Travelling Wave)

- Inherent isolation to backscattered light
  - Less critical on additional Faraday isolation
- Bowtie configuration minimizes astigmatism.
- Ready access to multiple input ports/ reflected beams, due to their physical separation.
- Ability for easy exchange of crystals.
- The travelling wave characteristic makes the phase matching condition less dependent on temperature.

OPO Design
Doubly Resonant Cavity

Cavity resonant at both fundamental (1064nm) and pump (532nm) wavelengths.

Advantages

- Simplicity of obtaining a cavity length error signal (using the pump 532nm field)
- Assurance of optimum mode matching of the interacting fields.
- Non-matched spatial components of the pump field (to the cavity mode) filtered
- The pump field amplitude is resonantly enhanced, giving a higher nonlinear gain for the same input pump power.
  - Allows possibility of increasing the transmission of the output coupler at 1064nm to increase η_{esc}.
- Less critical to internal cavity losses.
- Provide additional signal for phase-matching locking (if required).

OPO Design
Nonlinear Crystal

Choice between 2 crystals: PPKTP and $MgO:LiNbO_3$

PPKTP

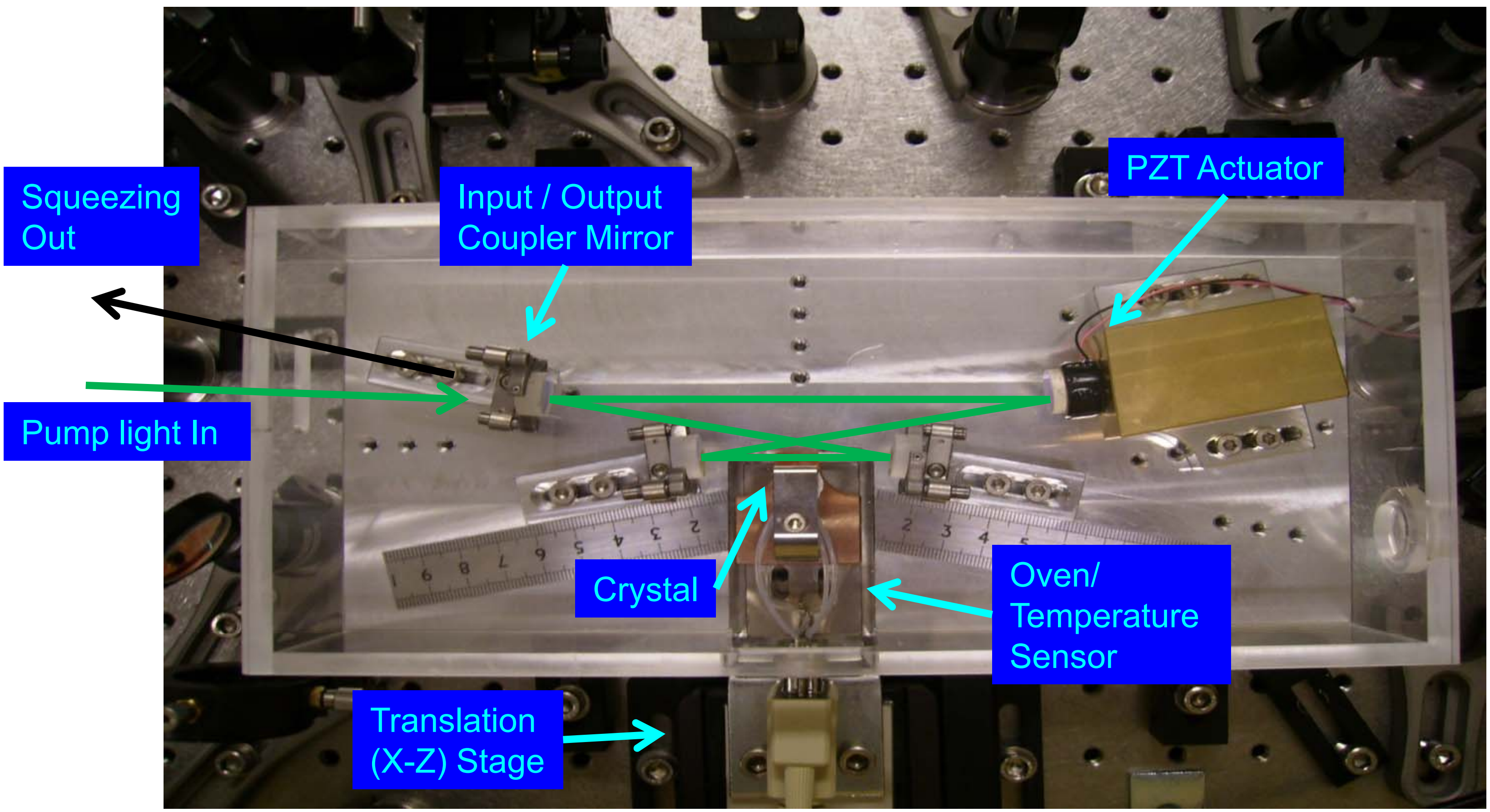
- Very high nonlinearity via the use of the d_{33} of KTP.
- Grey tracking was a known problem when PPKTP is used near the UV wavelength (795/397 nm). To date, we have no data on grey tracking at 1064/532 nm.
- Best result obtained was > 9 dB squeezing (Tokyo University).

$MgO:LiNbO_3$

- Lower nonlinearity compare with PPKTP
- More robust than PPKTP.
- MgO doping is used to increase the photo-refractive damage threshold.
- Larger parasitic photothermal effects.
- Squeezer using $MgO:LiNbO_3$ to be installed at GEO600.
- Best results obtained was > 10 dB of squeezing (AEI Hannover).

OPO Design Summary

- **Configuration:** Doubly Resonant Bow-Tie Cavity
- **Crystal:** PPKTP [Flat-wedge geometry]
- **Finesses** ~ $\mathcal{F}$ = 50 for 1064nm, ~ $\mathcal{F}$ = 100 for 532nm
- **Temperature Control:** Oven and Newport Temperature Controller
- **Optical Path Length:** ~ 700mm
- **Physical Dimensions:** ~ 200 mm x 150mm



OPO Squeezer Control

Dispersion Compensation

• The reflections at mirrors from dielectric coatings will produce a differential phase shift between the pump and fundamental fields. Dispersion compensation is required to co-resonate both fields, obtained through the use of a flat- (1-2 degree) wedge surface geometry of the nonlinear crystal.

Cavity Length Control

• Pound-Drever-Hall locking with cavity error signal derived from the reflected pump (532nm) field.

• Control of cavity length is done via a single PZT with a locking bandwidth of 20 kHz. If needed, a high speed PZT coupled with Molybdenum rod can extend the locking bandwidth to around 200 kHz.

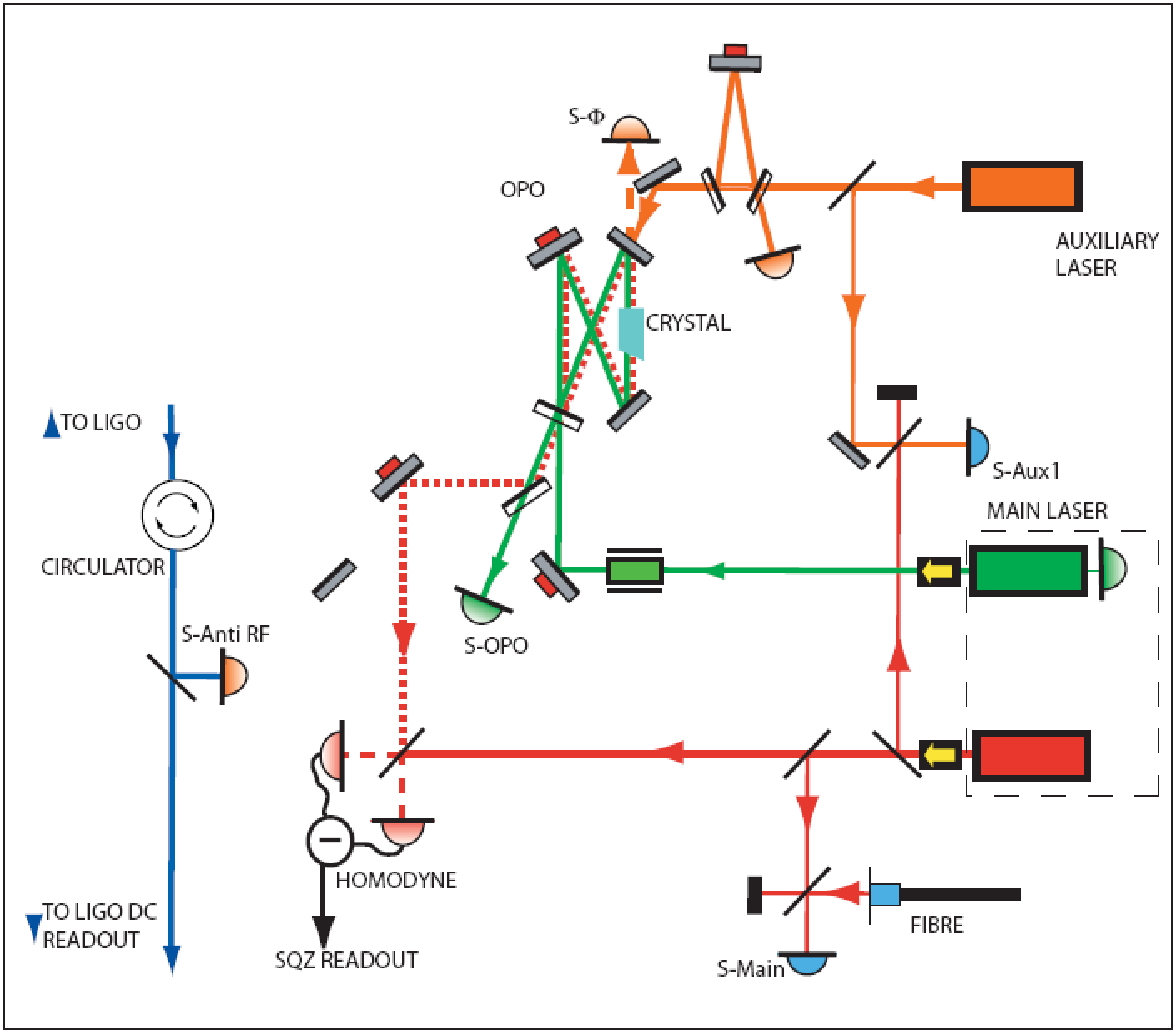
Squeezed Quadrature and Local Oscillator (LO) phase control

• Coherent (Frequent Shifted Sideband or F.S.S.) locking to implemented.

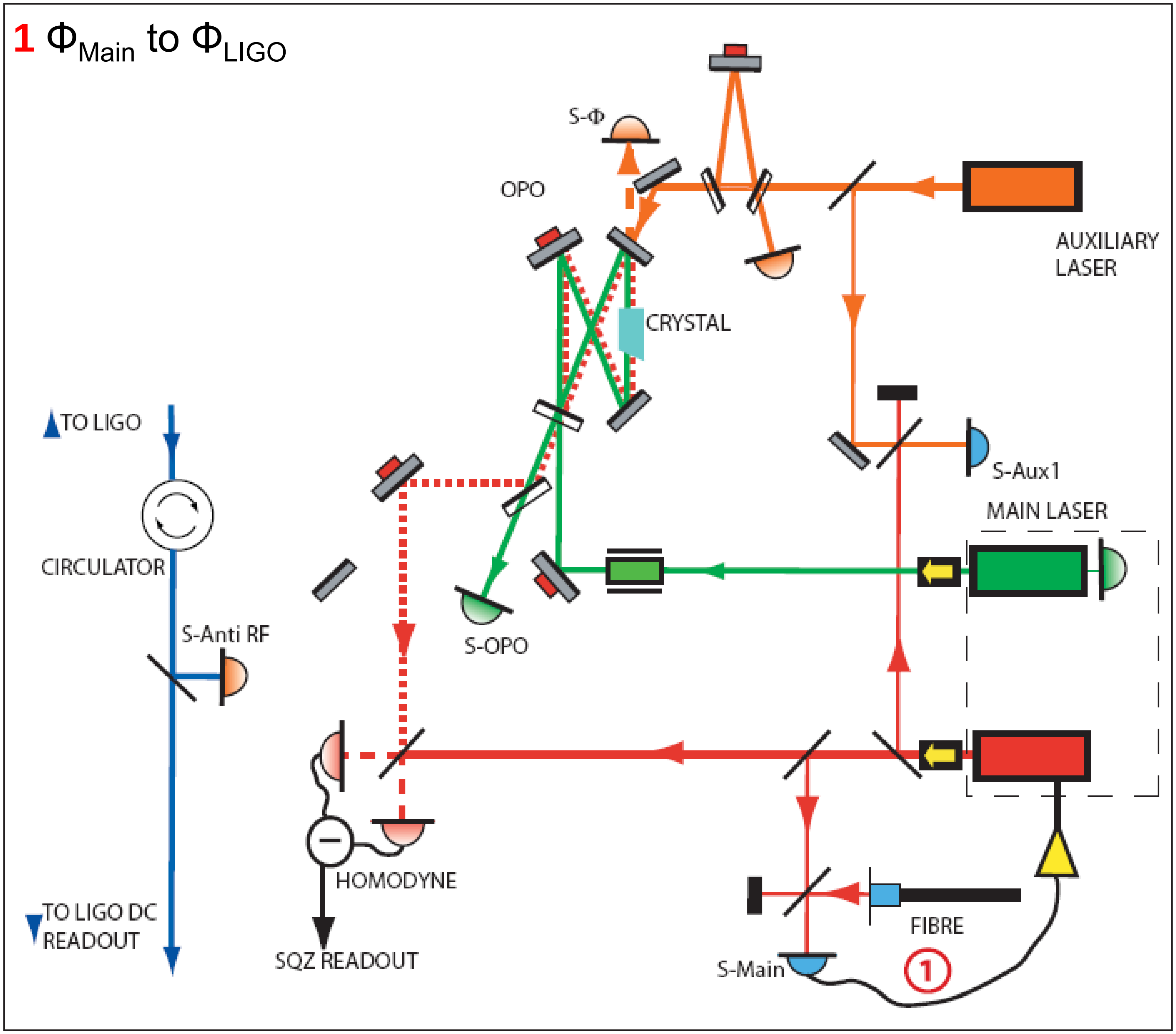
Temperature

• A Newport temperature controller (Series 3040) can be used to control the crystal phase matching temperature accurate to ±1 mK (long term stability).

Integration with LIGO

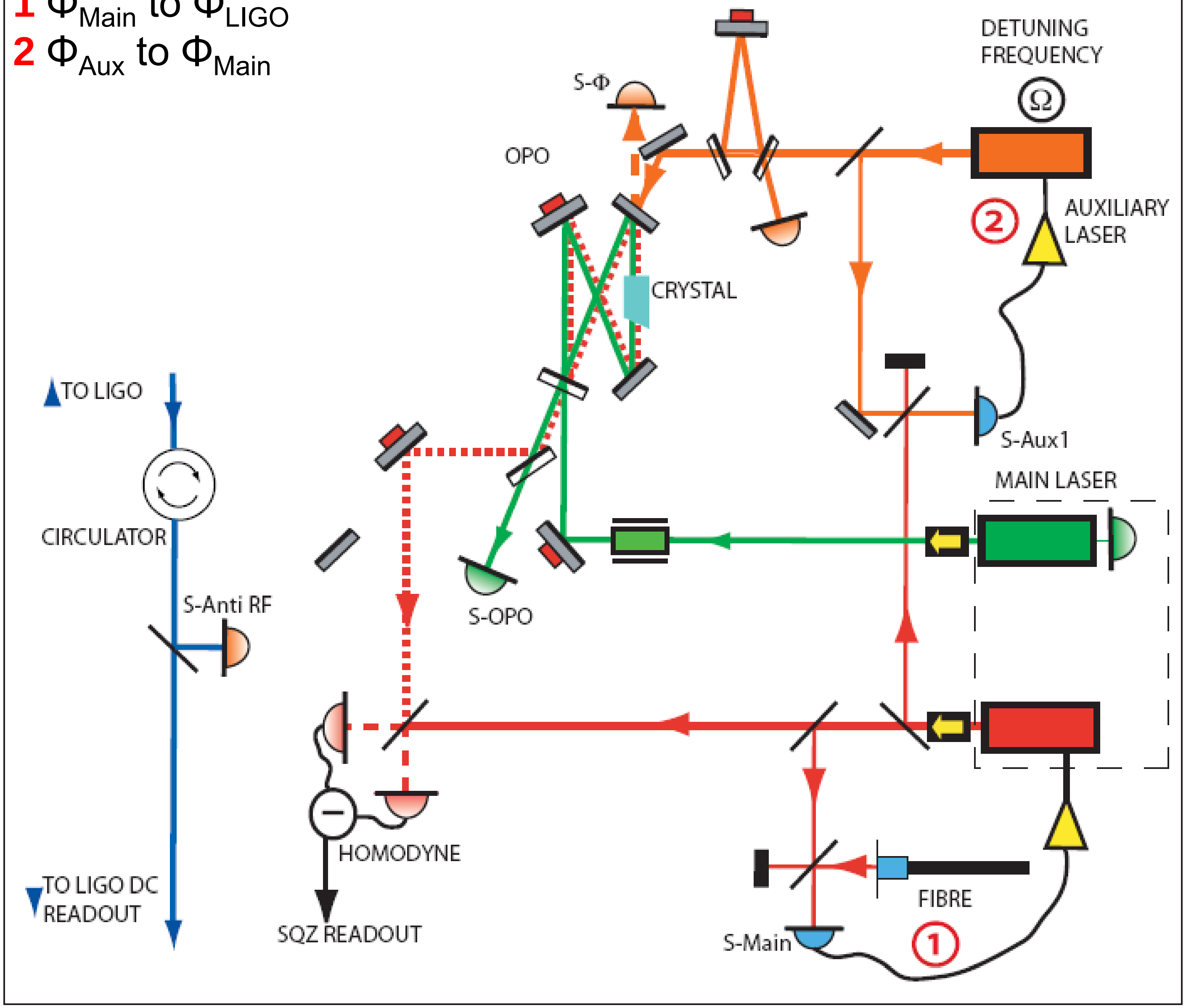


Integration with LIGO



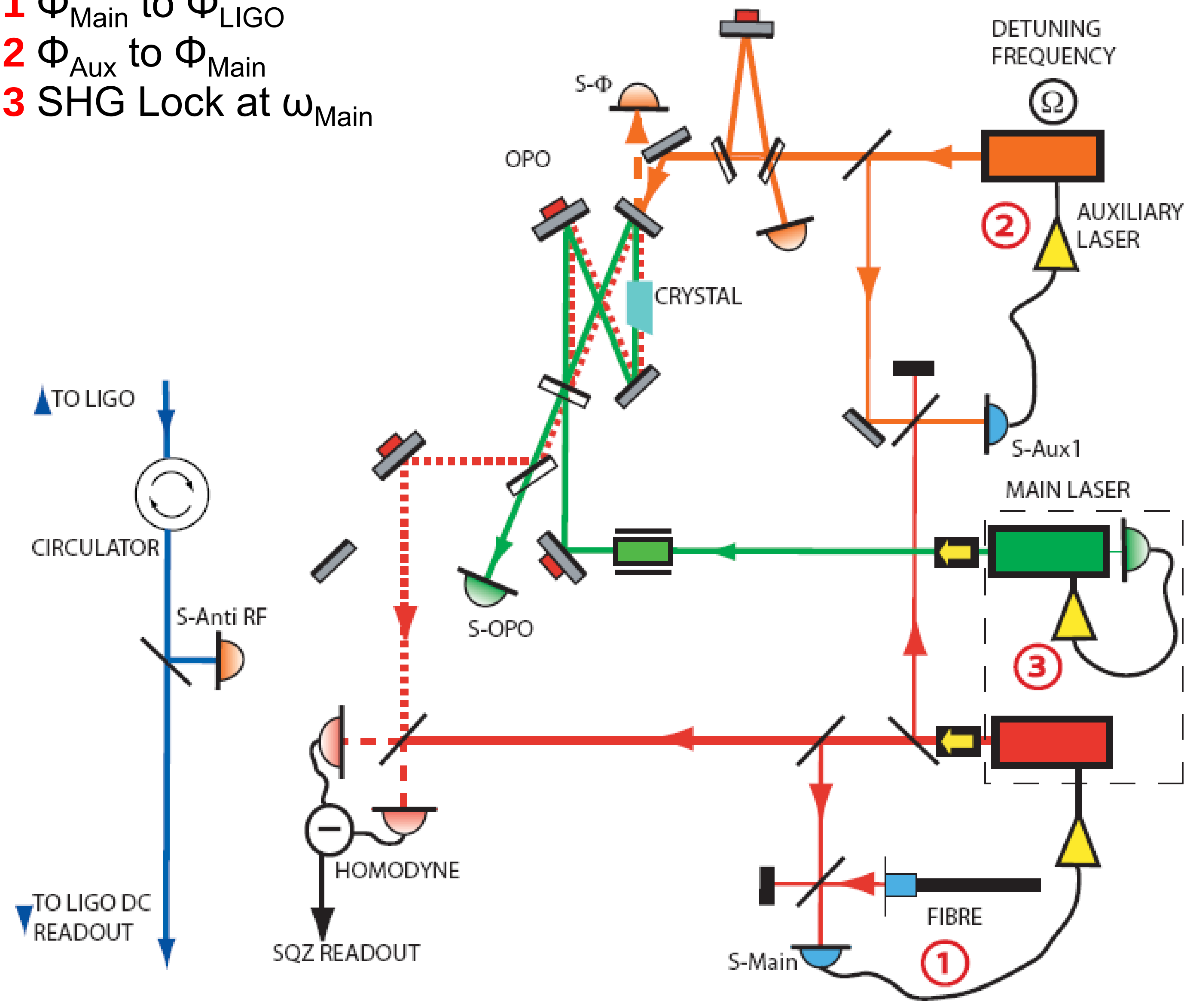
Integration with LIGO

1 Φ_{Main} to Φ_{LIGO}
2 Φ_{Aux} to Φ_{Main}

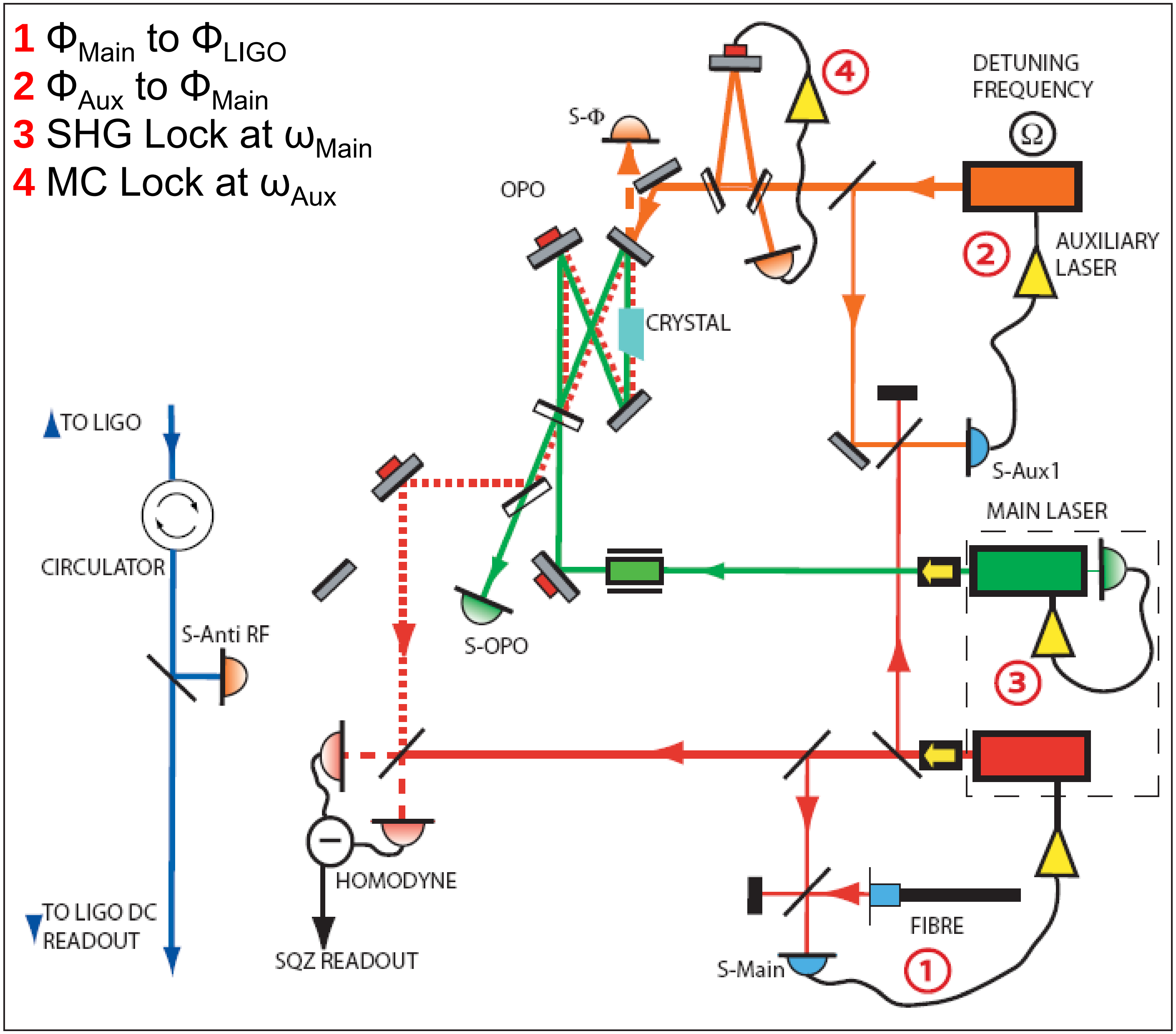


Integration with LIGO

1 Φ_{Main} to Φ_{LIGO}
2 Φ_{Aux} to Φ_{Main}
3 SHG Lock at ω_{Main}

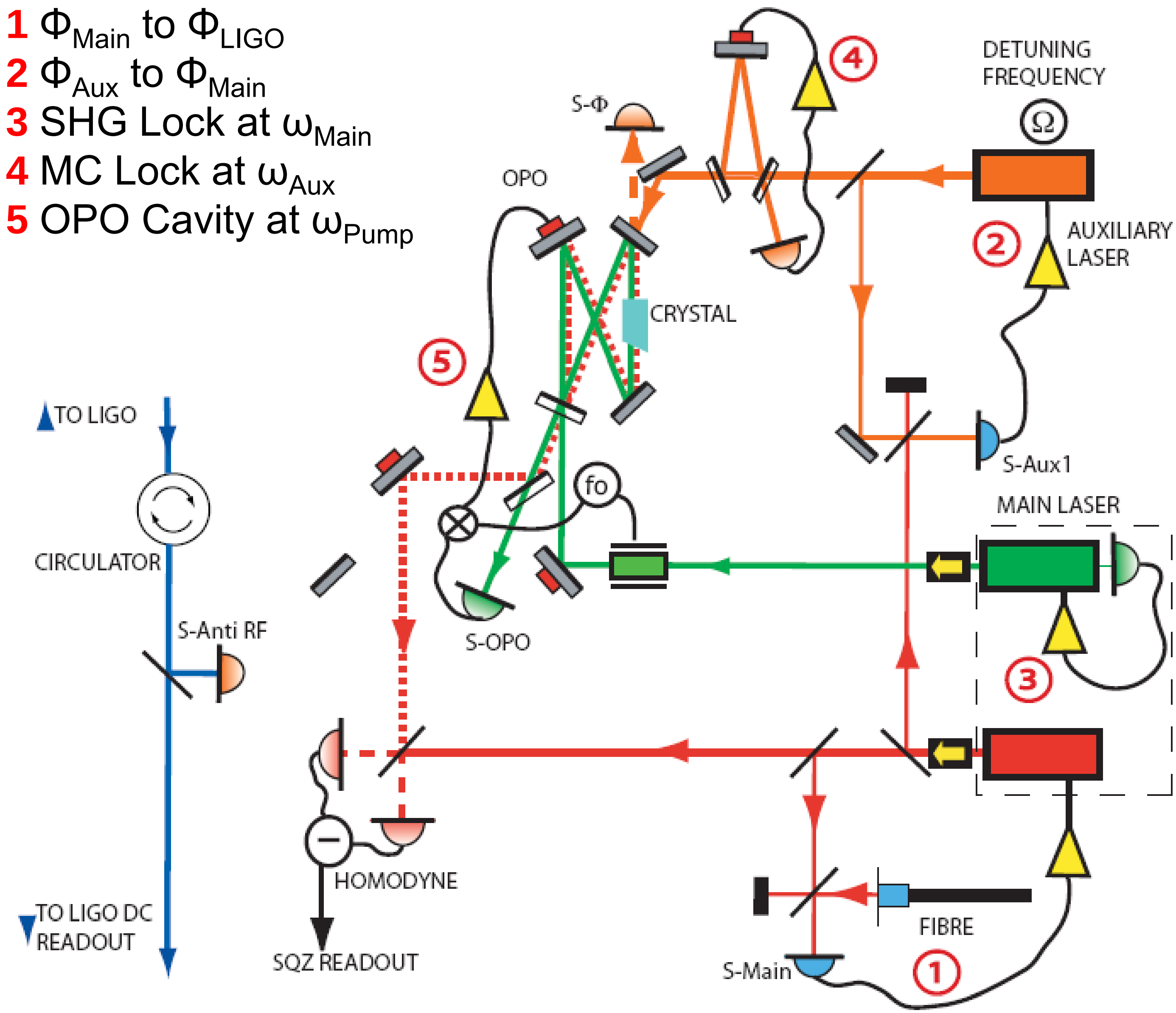


Integration with LIGO



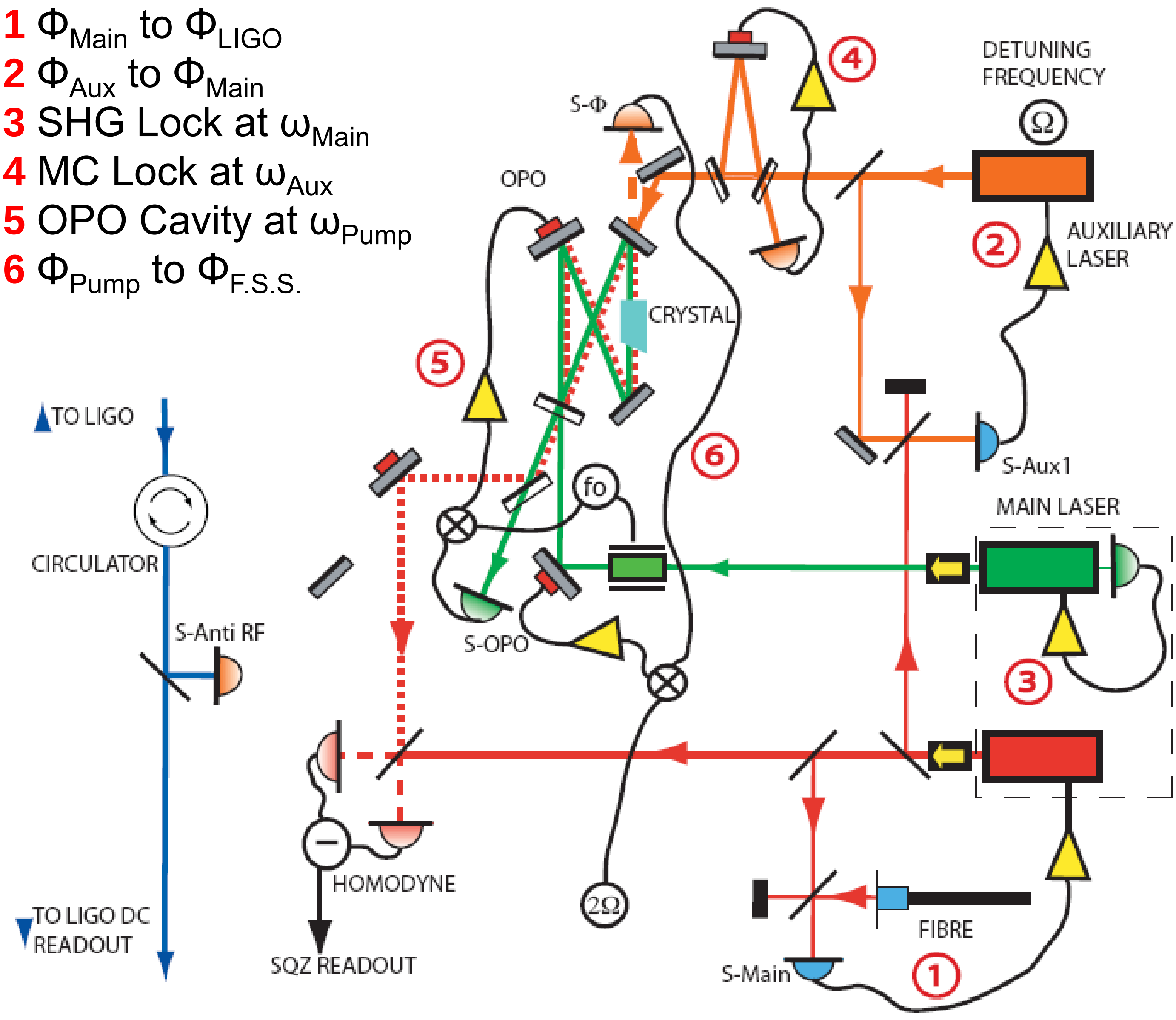
Integration with LIGO

1 Φ_{Main} to Φ_{LIGO}
2 Φ_{Aux} to Φ_{Main}
3 SHG Lock at ω_{Main}
4 MC Lock at ω_{Aux}
5 OPO Cavity at ω_{Pump}



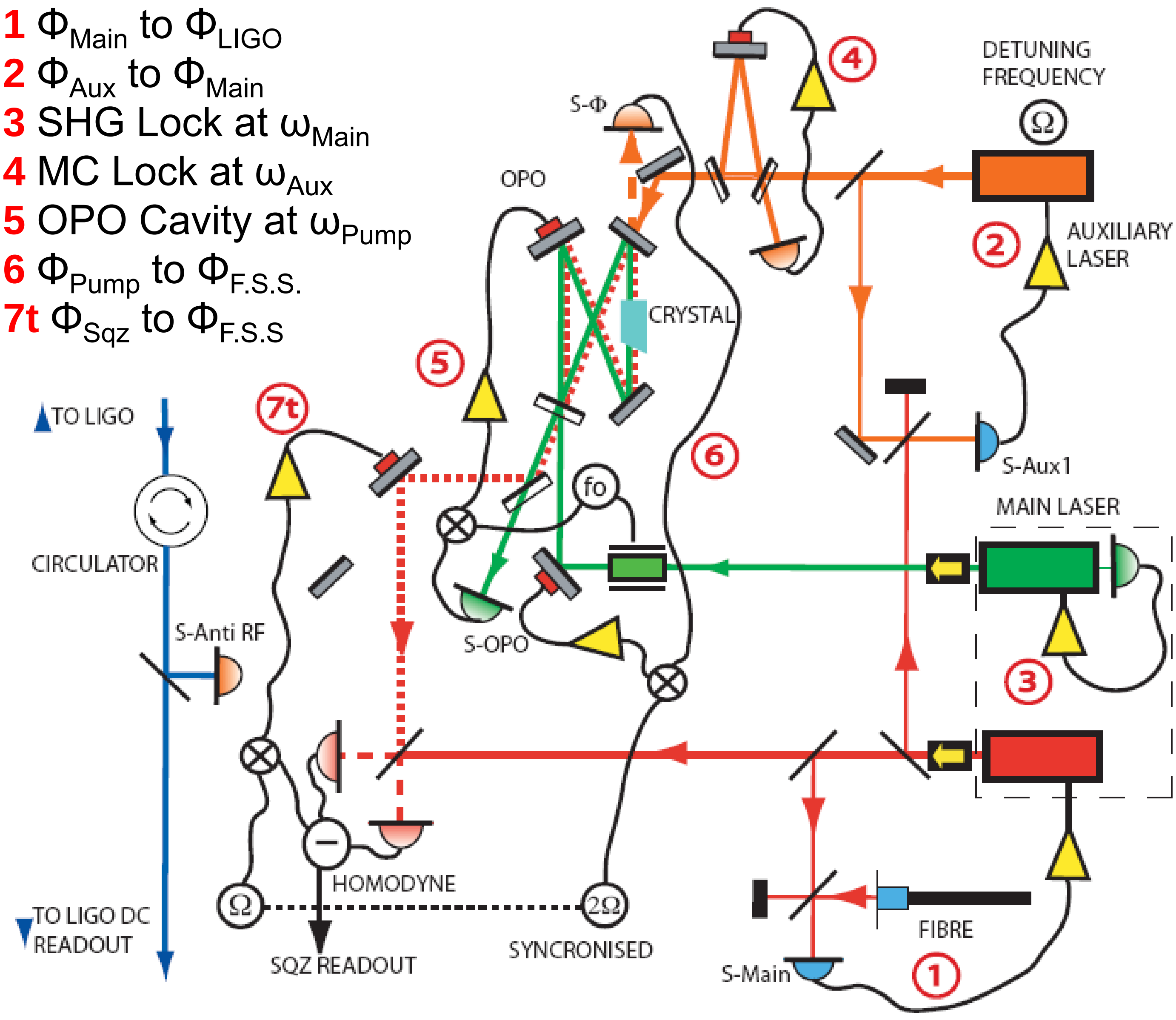
Integration with LIGO

1. Φ_{Main} to Φ_{LIGO}
2. Φ_{Aux} to Φ_{Main}
3. SHG Lock at ω_{Main}
4. MC Lock at ω_{Aux}
5. OPO Cavity at ω_{Pump}
6. Φ_{Pump} to $\Phi_{F.S.S.}$



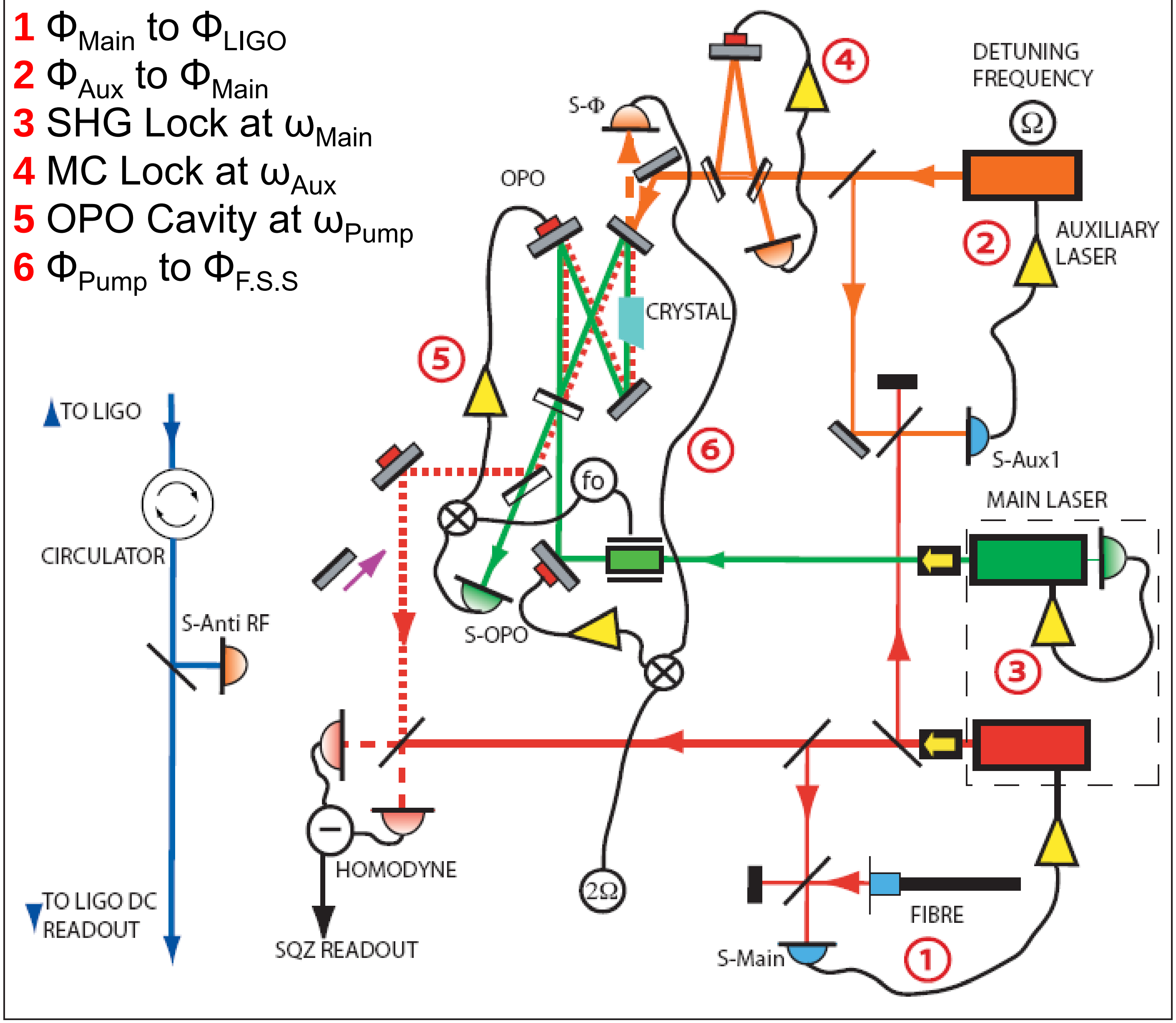
Integration with LIGO

1 Φ_{Main} to Φ_{LIGO}
2 Φ_{Aux} to Φ_{Main}
3 SHG Lock at ω_{Main}
4 MC Lock at ω_{Aux}
5 OPO Cavity at ω_{Pump}
6 Φ_{Pump} to $\Phi_{F.S.S.}$
7t Φ_{Sqz} to $\Phi_{F.S.S}$



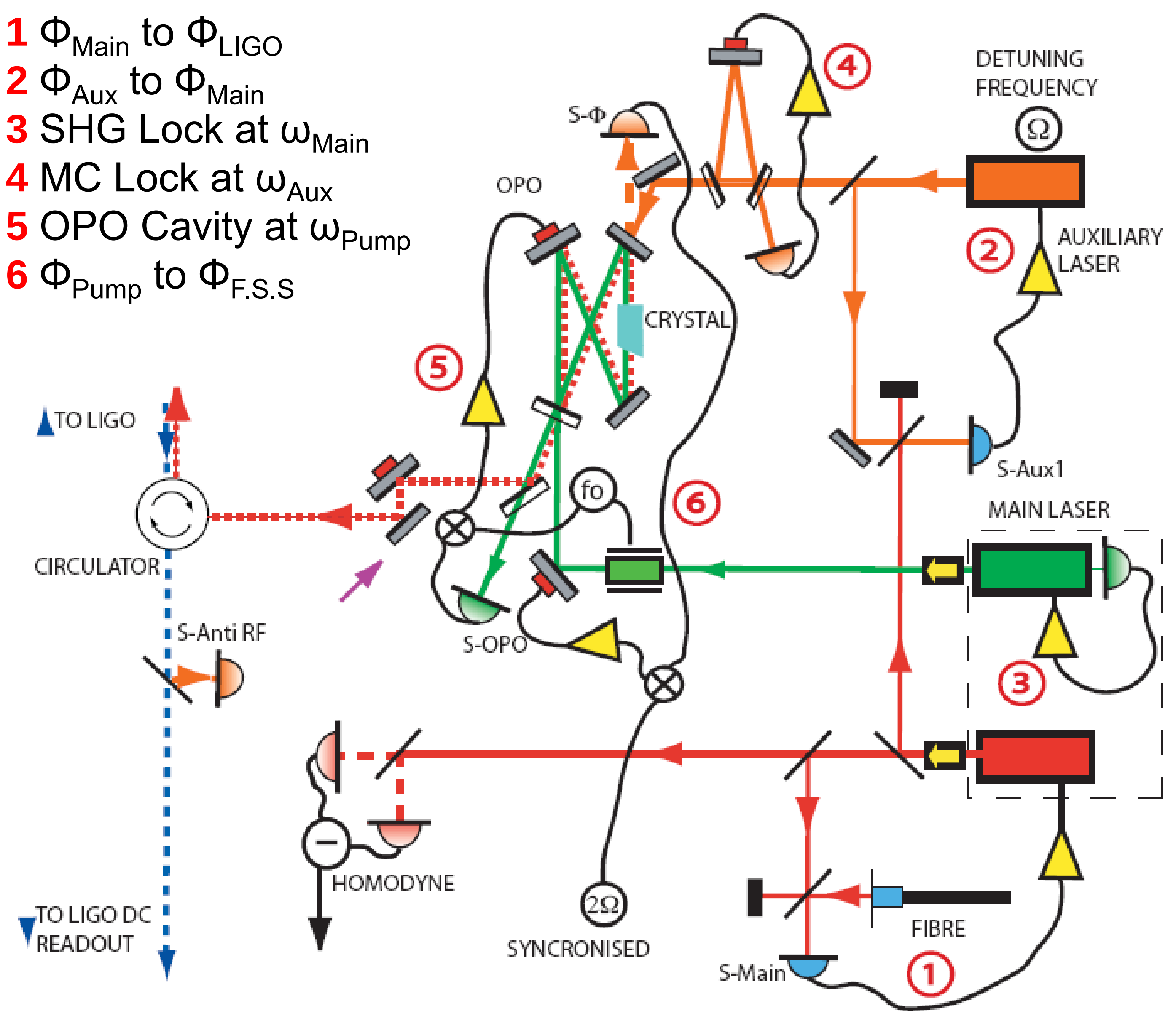
Integration with LIGO

1 Φ_{Main} to Φ_{LIGO}
2 Φ_{Aux} to Φ_{Main}
3 SHG Lock at ω_{Main}
4 MC Lock at ω_{Aux}
5 OPO Cavity at ω_{Pump}
6 Φ_{Pump} to $\Phi_{F.S.S}$



Integration with LIGO

1 Φ_{Main} to Φ_{LIGO}
2 Φ_{Aux} to Φ_{Main}
3 SHG Lock at ω_{Main}
4 MC Lock at ω_{Aux}
5 OPO Cavity at ω_{Pump}
6 Φ_{Pump} to $\Phi_{F.S.S}$



Integration with LIGO

1 Φ_{Main} to Φ_{LIGO}
2 Φ_{Aux} to Φ_{Main}
3 SHG Lock at ω_{Main}
4 MC Lock at ω_{Aux}
5 OPO Cavity at ω_{Pump}
6 Φ_{Pump} to $\Phi_{F.S.S.}$
7L $\Phi_{LIGO\ LO}$ to $\Phi_{F.S.S}$