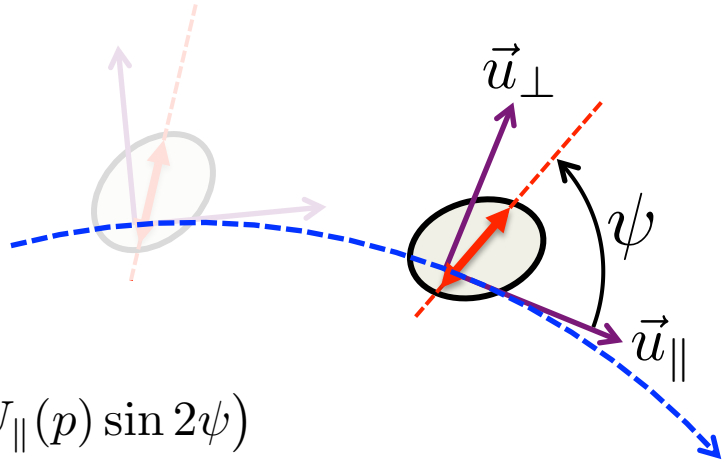
Systematics mitigation for PICO

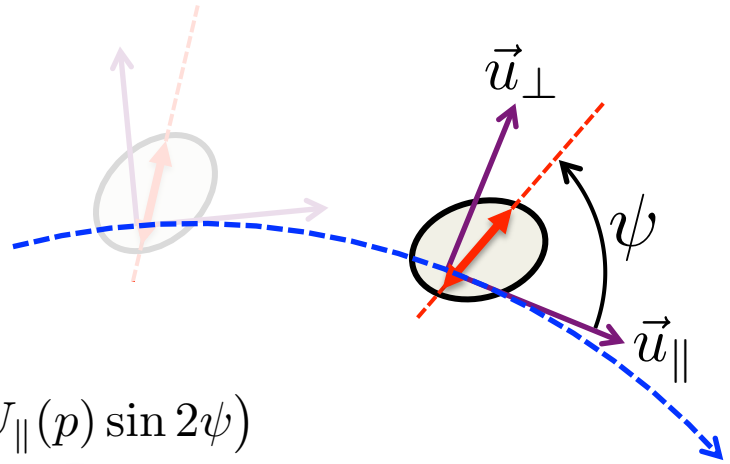
- Building an instrument that is perfect enough for systematics to be negligible is *impossible* in practice (control T to P at the level of 10^{-5}).
- Requirements would be to stringent for this to be
  - doable in a reasonable time
  - cost effective
- *Systematics must be corrected for in the data analysis pipeline.*
- *This requires the exquisite knowledge of an adequate model of the instrument.*
- While some of this knowledge can be obtained through prior calibration, the best knowledge of the instrument will be obtained from the scientific data themselves.
- (Of course, lower systematics are better so instrument design is important)

An (incomplete) model of the measurement



$$
\begin{aligned}
s(t) \simeq\ & I(p) + \eta\left(Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right) \\
& + a_\parallel \nabla_\parallel^2 I(p) + a_\perp \nabla_\perp^2 I(p) + a_\times \nabla_\perp \nabla_\parallel I(p) \\
& + b_\parallel \nabla_\parallel \left[I(p) + \eta\left(Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right)\right] \\
& + b_\perp \nabla_\perp \left[I(p) + \eta\left(Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right)\right] \\
& + 2\delta\,\eta\left[-Q_\parallel(p)\sin 2\psi + U_\parallel(p)\cos 2\psi\right] \\
& + \epsilon I(p) + \xi\left[Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right] \\
& + \sum_{qq'} M_{tqq'} L_q I_{q'} + \sum_c \gamma_c I_c(p) + n(t) + \ldots
\end{aligned}
$$

An (incomplete) model of the measurement



polar efficiency

beam ellipticity

position offset

polar angle

gain error

error on polar efficiency

sidelobe map

bandpass mismatch

noise

$$
\begin{aligned}
s(t) \simeq\ & I(p) + \eta\left(Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right) \\
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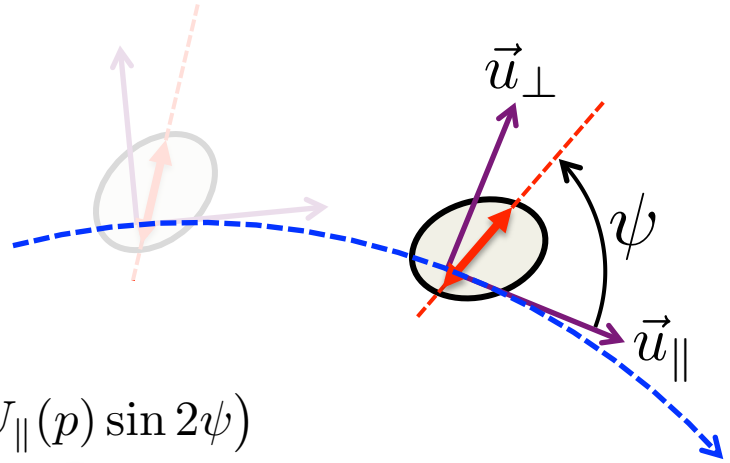
An (incomplete) model of the measurement



polar efficiency ✗

$$s(t) \simeq I(p) + \eta\left(Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right)$$

beam ellipticity ✓

$$+ a_\parallel \nabla^2_\parallel I(p) + a_\perp \nabla^2_\perp I(p) + a_\times \nabla_\perp \nabla_\parallel I(p)$$

position offset ✓

$$+ b_\parallel \nabla_\parallel \left[I(p) + \eta\left(Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right)\right]$$

$$+ b_\perp \nabla_\perp \left[I(p) + \eta\left(Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right)\right]$$

polar angle ✓

$$+ 2\delta\eta\left[-Q_\parallel(p)\sin 2\psi + U_\parallel(p)\cos 2\psi\right]$$

gain error ✓

$$+ \epsilon I(p) + \xi\left[Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right]$$

error on polar efficiency ✗

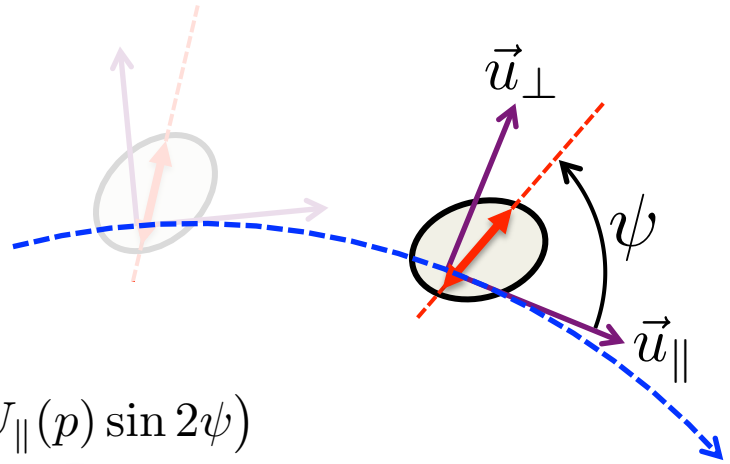
$$+ \sum_{qq'} M_{tqq'} L_g I_{q'} + \sum_c \gamma_c I_c(p) + n(t) + \ldots$$

sidelobe map !

bandpass mismatch ✓

noise ✓

An (incomplete) model of the measurement



polar efficiency ✗

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\begin{aligned}
s(t) \simeq\ & I(p) + \eta \left(Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right) \\
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& + b_\perp \nabla_\perp \left[I(p) + \eta \left(Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right)\right] \\
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& + \sum_{qq'} M_{tqq'} L_g I_{q'} + \sum_c \gamma_c I_c(p) + n(t) + \ldots
\end{aligned}
$$

beam ellipticity ✓

position offset ✓

polar angle ✓

gain error ✓

error on polar efficiency ✗

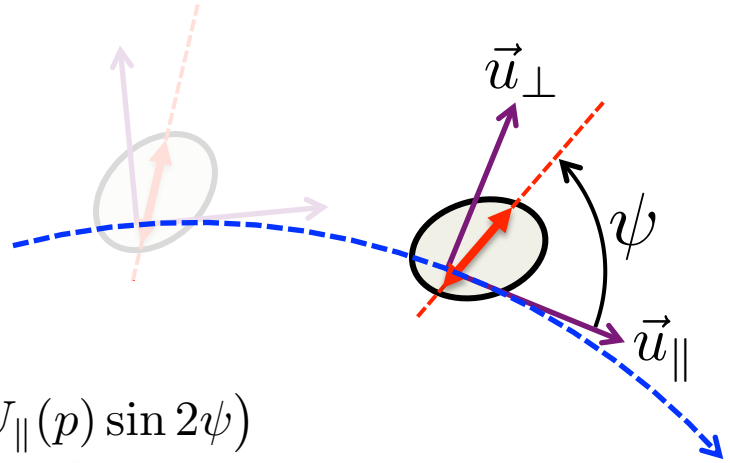
sidelobe map !

bandpass mismatch ✓

noise ✓

all together ✗
time variations ✗

An (incomplete) model of the measurement



polar efficiency ✗

$$s(t) \simeq I(p) + \eta\left(Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right)$$

beam ellipticity ✓

$$+ a_\parallel \nabla^2_\parallel I(p) + a_\perp \nabla^2_\perp I(p) + a_\times \nabla_\perp \nabla_\parallel I(p)$$

position offset ✓

$$+ b_\parallel \nabla_\parallel \left[I(p) + \eta\left(Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right)\right]$$

$$+ b_\perp \nabla_\perp \left[I(p) + \eta\left(Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right)\right]$$

polar angle ✓

$$+ 2\delta\eta\left[-Q_\parallel(p)\sin 2\psi + U_\parallel(p)\cos 2\psi\right]$$

gain error ✓

$$+ \epsilon I(p) + \xi\left[Q_\parallel(p)\cos 2\psi + U_\parallel(p)\sin 2\psi\right]$$

error on polar efficiency ✗

$$+ \sum_{qq'} M_{tqq'} L_g I_{q'} + \sum_c \gamma_c I_c(p) + n(t) + \ldots$$

sidelobe map !

bandpass mismatch ✓

noise ✓

No HWP please!