Recent Results in Analysis of Errors in Fringe Scans by Shintake Monitor (IPBSM)

ATF2 Topical Meeting

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KEK

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Outline

Beam Time Status of 2013 Spring Run

IPBSM Performance & Error studies

- Statistical Fluctuation
- M reduction Factors

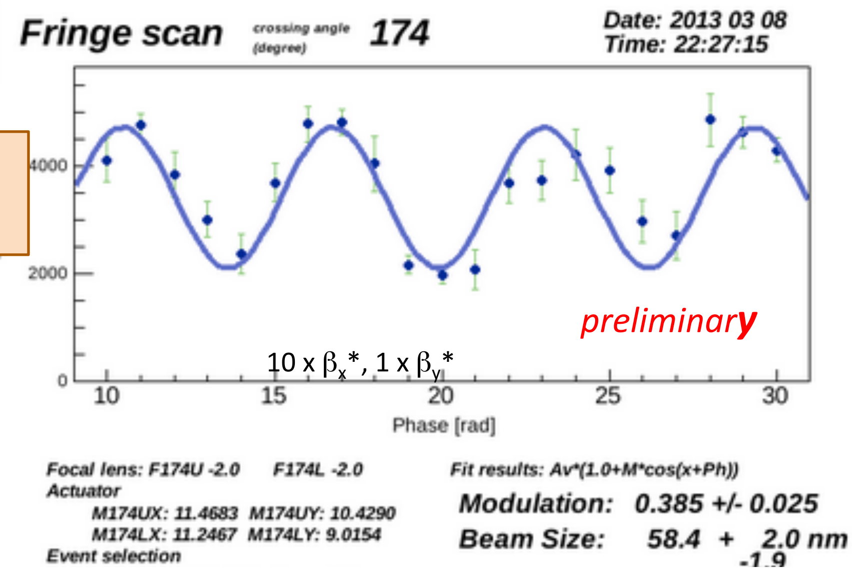
Recent Updates .....

- Relative Position Jitter (Phase Jitter)
- Polarization related issues

Summary & Plans

Recent Beamtime Status (174 deg mode)

Stable IPBSM performance in beam tuning
reiteration of linear /nonlinear knobs in aim of small σy



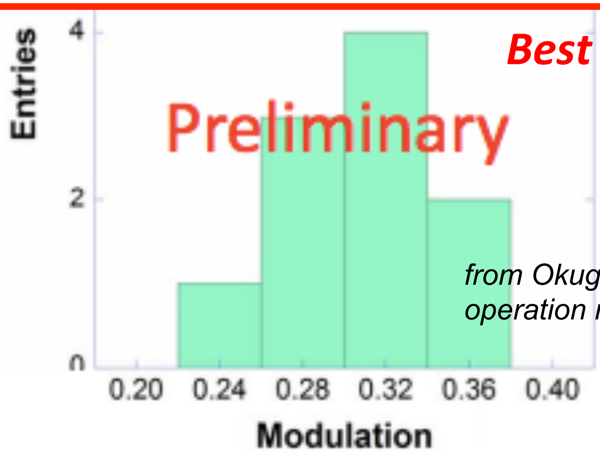
174 ° mode "consistency scan"

2013/03 /14

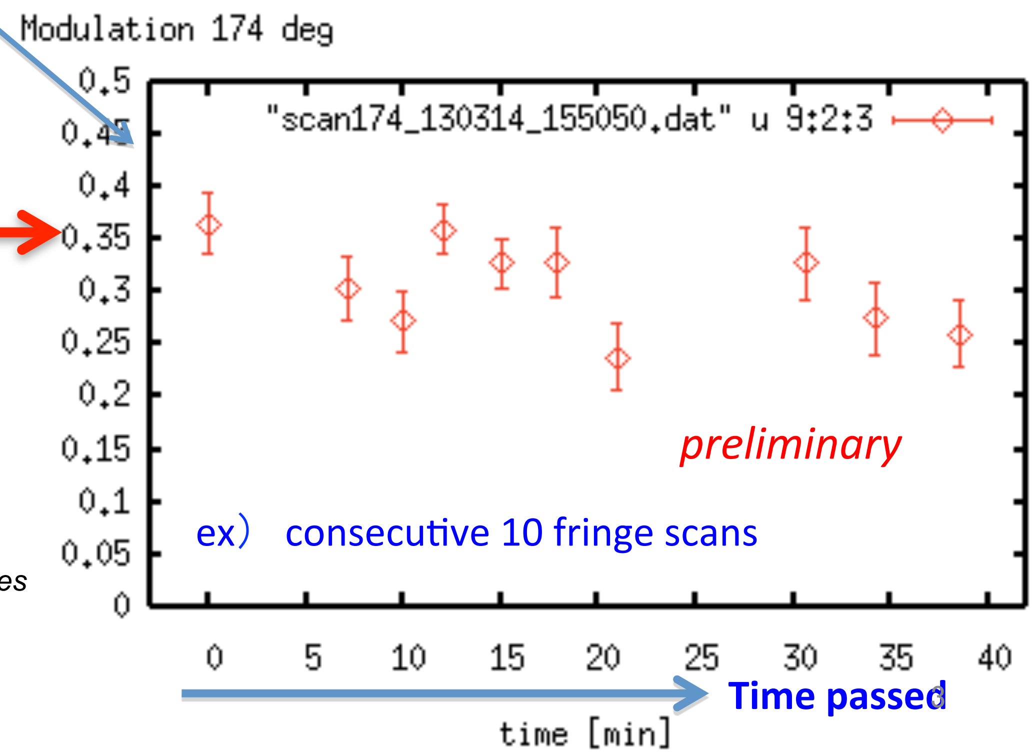
after IP-BSM roll alignment
after IP-BSM pitch alignment

M ～ 0.306 ± 0.043 (RMS)
correspond to σy ～ 65 nm

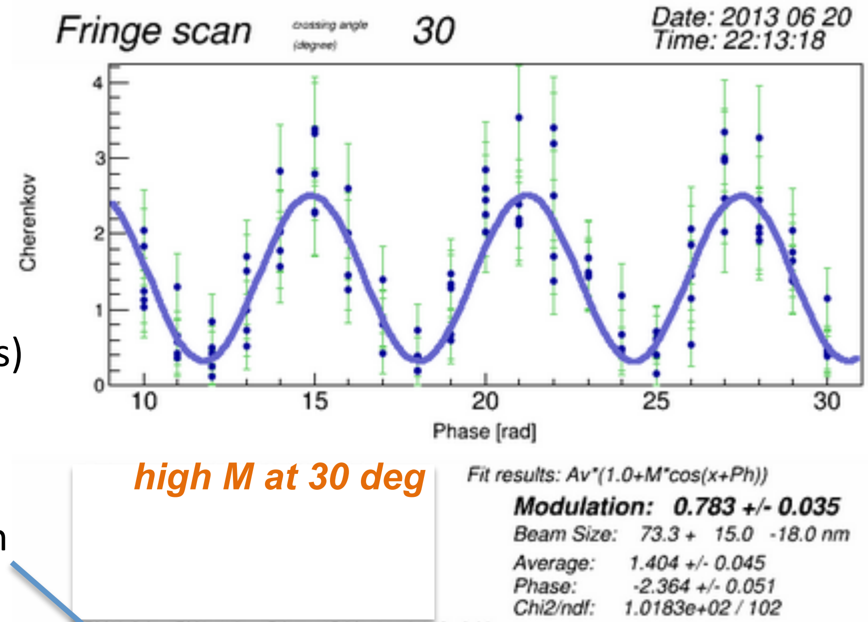
Best record



from Okugi-san's Fri operation meeting slides



Studies@30 deg (2-8 deg) mode



IPBSM phase drift study

Dedicated data for IPBSM error study

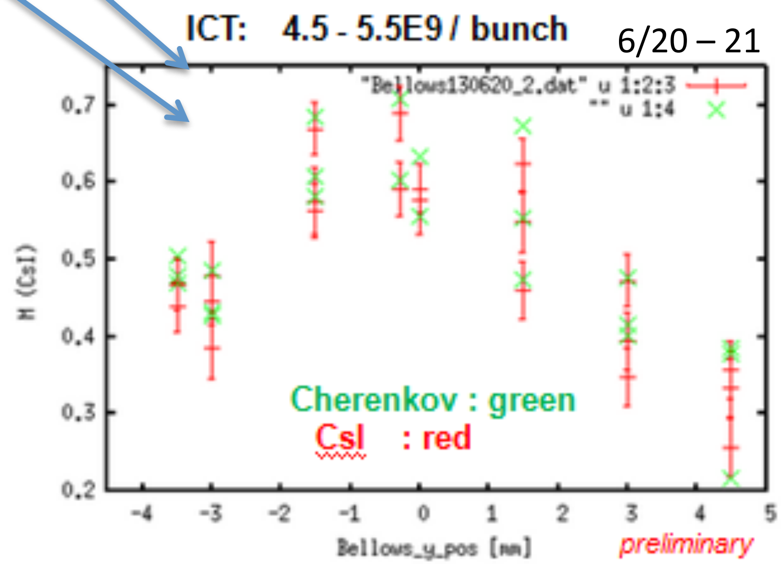
- H and V relative position jitter
- slow drifts (see next page and Okugi-san 's slides)

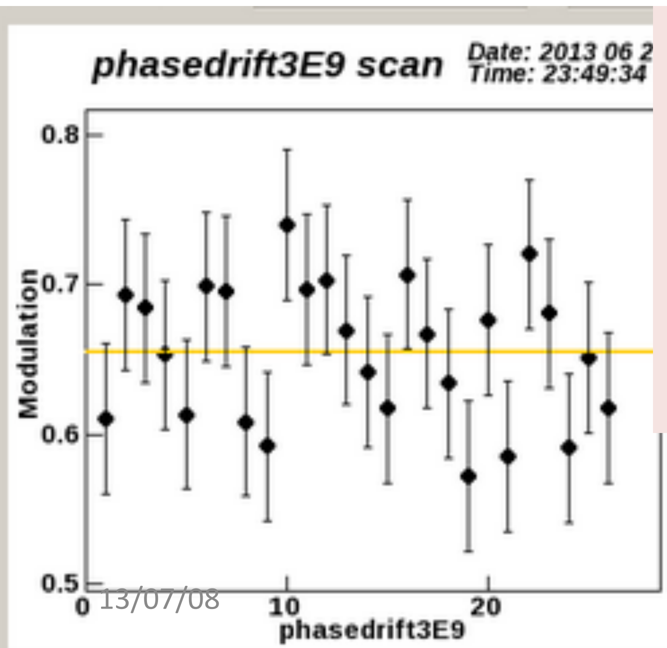
Study of wake-field effects

Ex) intensity dependence /ref cavity & bellows scan

- consistency between Cherenkov and CsI results

Cherenkov S/N ～ 15, CsI S/N ～ 3





Demonstration of Stability:
Consistency scan
(x 26)

fitted M
= 0.655 +/- 0.010
ICT: 2.5 - 3.5E9

preliminary

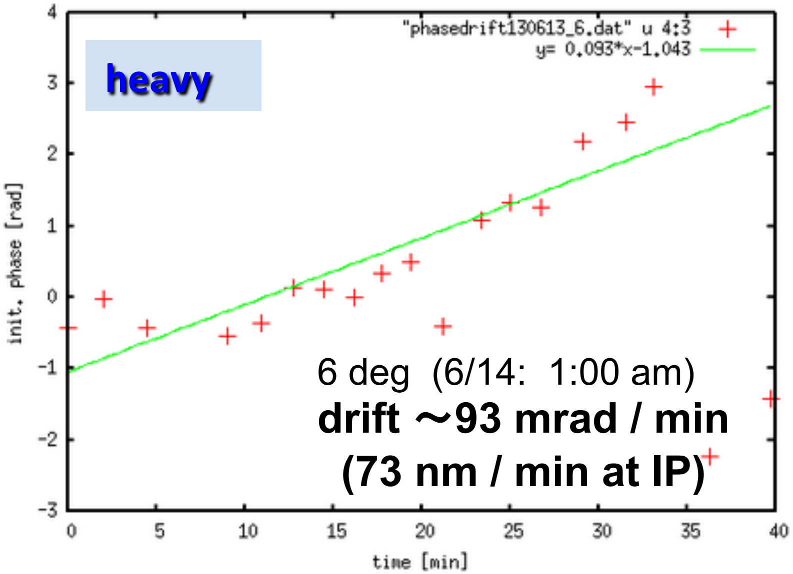
Data file:
phasedrift3E9_fringe_130620_23493

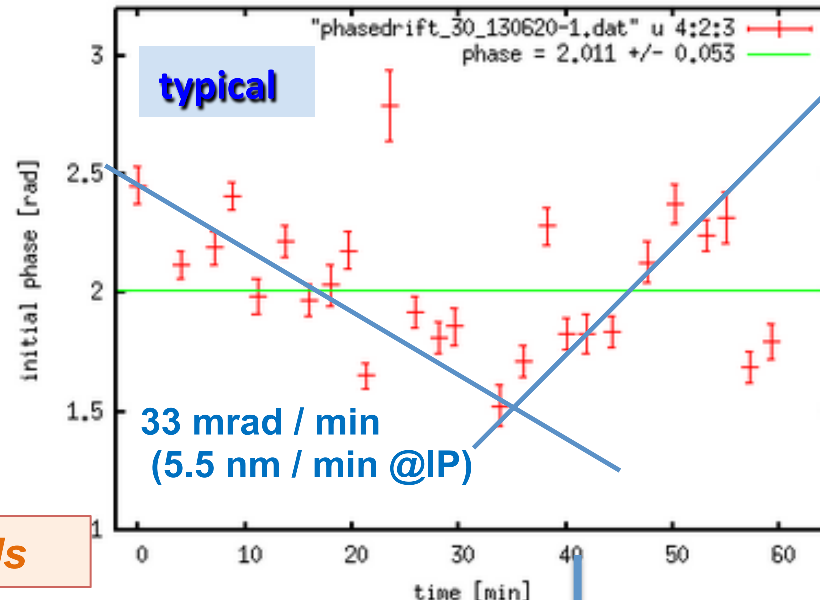
Phase Drift (initial phase vs time)

26 consecutive scans over 1 hr @ 30 deg (6/21)

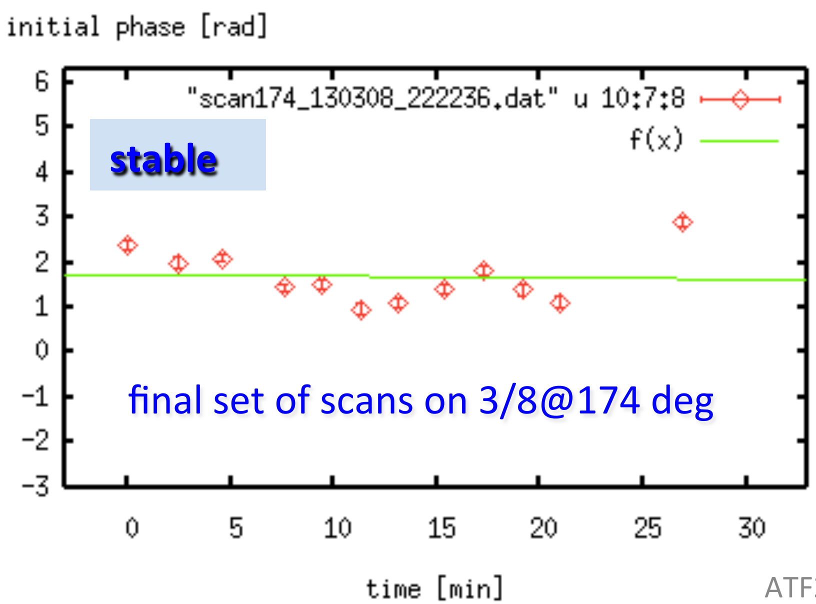
generally stable overall :

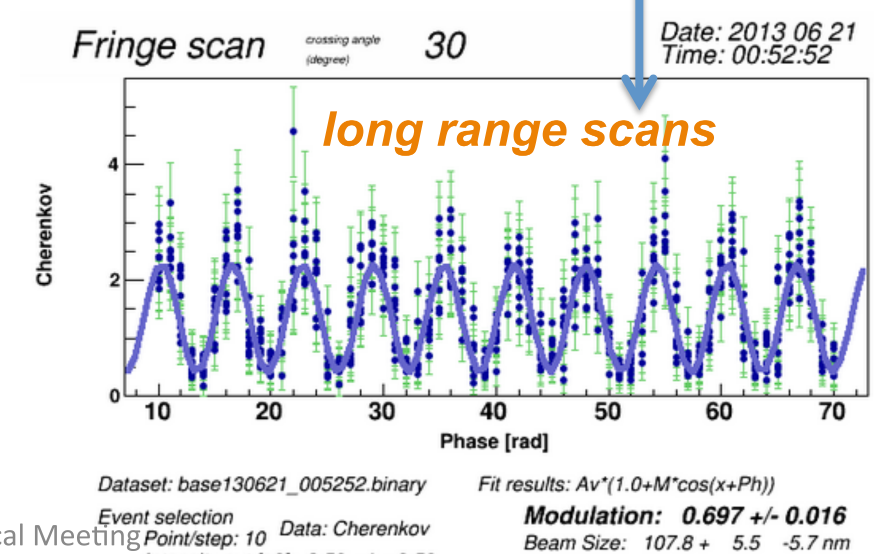
init. phase = 2.01 +/- 0.05 rad (~ 2.5%)





Drift varies for different periods





Signal Fluctuation

Spring, 2013: 174 deg mode

	contribution to Sig Jitter $\Delta E_{sig} / E_{sig,\,avg}$
Laser timing	6 - 7 % (PIN-PD signal)
Laser power	< 1.5 % (photo-diode)
Relative beam –laser position	***under investigation***
BG fluc	< 10%
detector energy resolution	< 1 % * Intrinsic CsI detector energy resolution
Comp γ stat.	~ 3 %
ICT monitor accuracy	< 5 %

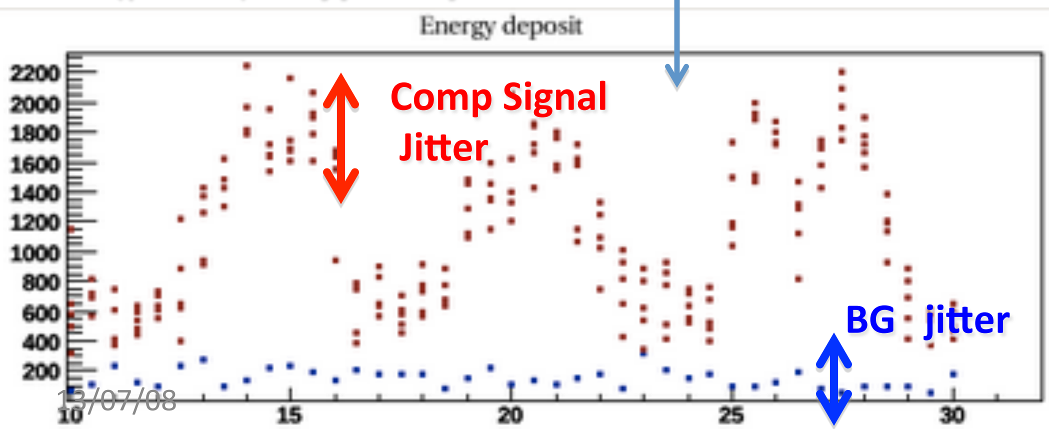
offline veto for timing, power

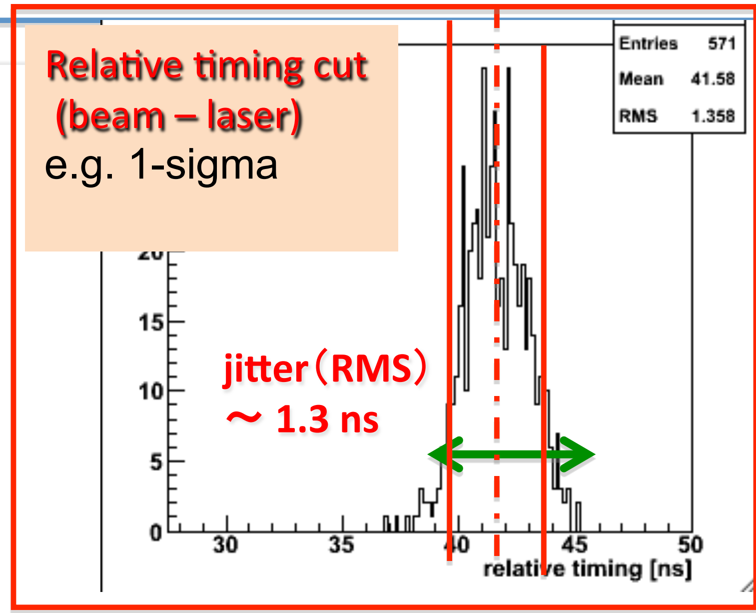
Maybe few % from each of Δy and Δx

varies with beam condition and S/N

measured Comp sig energy normalized by beam intensity

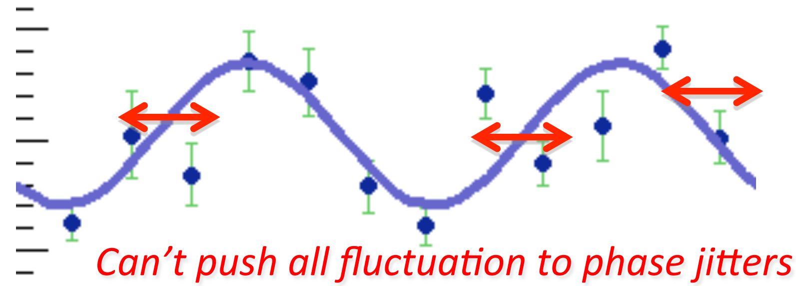
signal jitter derived directly from actual fringe scans (peaks) **: typically ～25%**





Phase Jitter / Relative Position Jitter

- hard to separate from other fluctuation sources (laser pointing jitters, drifts, ect….)
- Vary over time



take high statistics scans (Nav ~ 100) under optimized conditions for dedicated analysis

Issue 1: Δy <-> M reduction

residual M reduction factors must be assessed in order to derive the true beamsize !!!

$$y \to y + \Delta y$$

$$\sigma_y^2 \to \sigma_y^2 + (\Delta y)^2$$

$$C_{\Delta y} = \exp\left(-2\left(k_y \Delta y\right)^2\right)$$

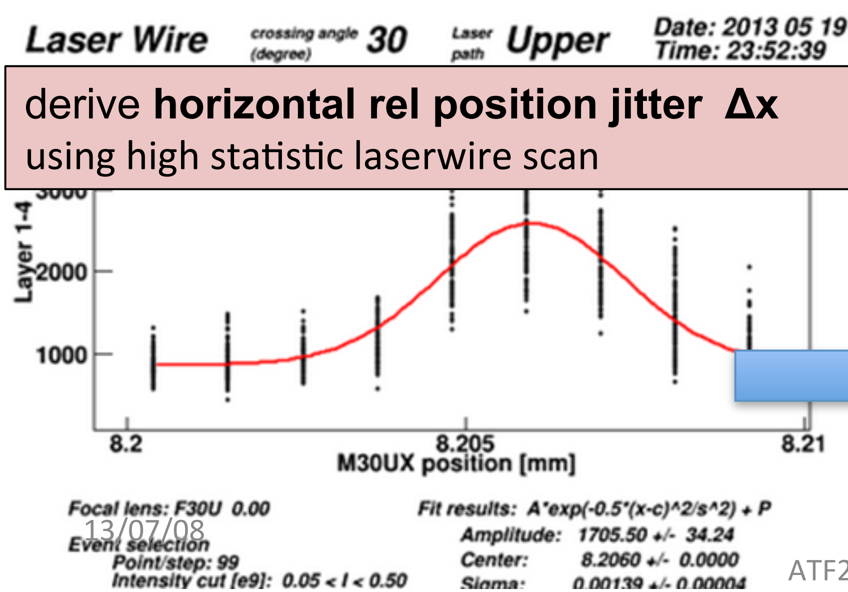
if **Δy < 0.3 * σy**
(ATF2 beamline design)
CΔy > 90 % for σy* = 65 nm

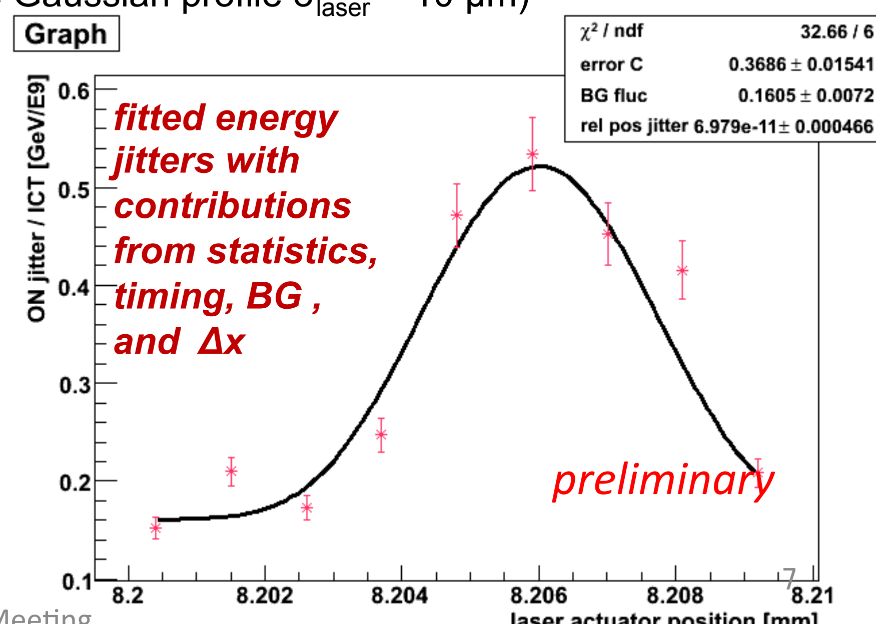
$$k_y = \frac{2\pi}{\lambda} \sin\left(\frac{\theta}{2}\right)$$

Issue 2 : fluctuation source during fringe scan

If **Δx ∼2.5 μm** cause ∼ 4 % signal jitters (assume Gaussian profile σ_{laser} = 10 μm)

derive **horizontal rel position jitter Δx**
using high statistic laserwire scan



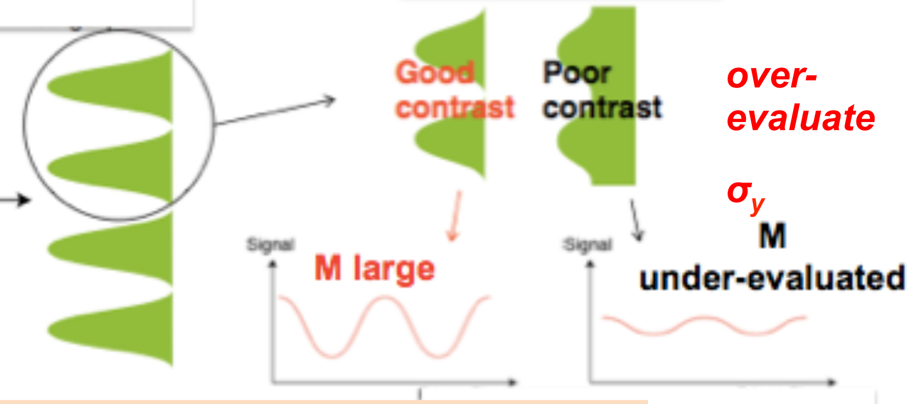


How to evaluate M reduction?

degraded fringe contrast due to bias

$$M_{meas} = C_1 C_2 ....M_{ideal} = \left(\prod_i C_i\right) M_{ideal}$$

$$\sigma^2_{y,ideal} + \frac{1}{2k_y^2}\left|\sum lnC_i\right|$$



priorities

1st : suppress M reduction → aim for Ctotal ~ 1

2nd: precisely evaluate any residual errors → derive the "true beam size"

（1） **"Direct Method"** compare M measured at different modes under same beam conditions

→ observe upper limit on M_{meas}

Goals:

1) Obtain "overall" M reduction *only apply to a particular data*

(2) investigate a certain "unknown factor" : (e.g. rel pos jitter, spatial coherence)

however ,we must first ....

- ✓ *clear up all other factors !!*
- ✓ *Prove these factors are ϑ mode independent*

（2） **"Indirect Method"** : evaluate each individual factor offline and "sum up"

represents the typical conditions of a particular period

however …… hard to derive overall M reduction (only "worst limit ") ??

Individual M Reduction Factors

typical conditions of a particular period

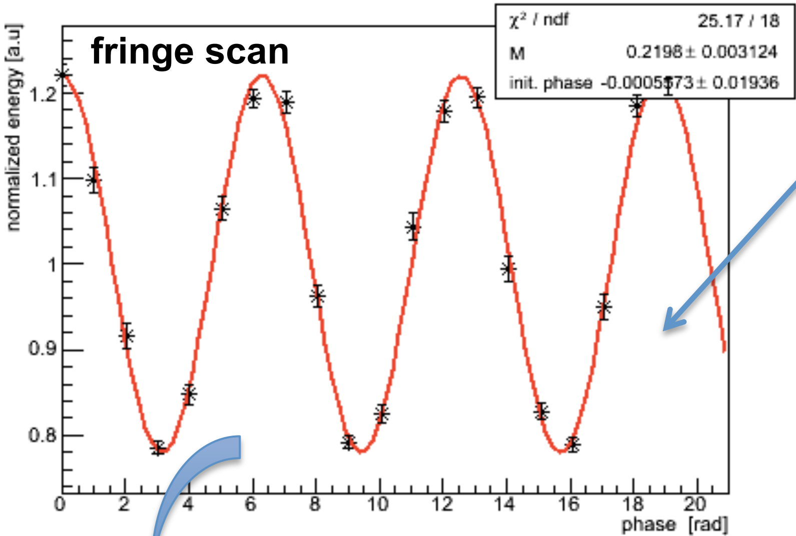
Error source	M reduction factor	Spring 2013, 174 deg
Fringe tilt (z, t)	Beamtime→ optimization by **"tilt scan"** **alignment precision is important**	Major bias if unattended to
Laser polarization	Optimized to **"S state"** using λ / 2 plate	Cleared up through measurements of laser polarization and **half mirror reflective properties**
Still quantitatively uncertain	**Could be major bias**	
Relative position jitter	**main theme of today's talk !!**	
Phase drift	under investigation	drift : **typically 30 - 70 mrad / min**
Spatial coherence	under investigation , monitor by CCD (??)	

Minor factors

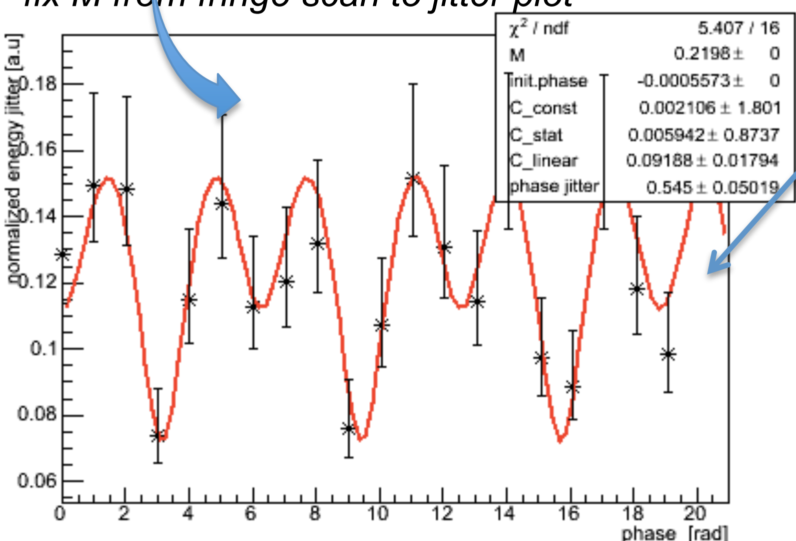
- ✓ **profile imbalance :** negligible after focal lens scanned well
- ✓ **power imbalance:** power measured directly for each path
- ✓ **Laser path alignment :** Resolution of mirror actuators aligning laser to beam

Deriving Relative Position Jitter Δy (phase Jitter Δϕ)

Test validity of method using simulation



fix M from fringe scan to jitter plot



Plot signal jitter vs phase

(1) generate fringe scan

Aim for "**realistic**" **ATF-like assumptions**

e.g. nominal σ_y = 70 nm, 174 deg

S/N = 5, BG fluc = 20%, ICT = 1E9/bunch

timing jitter, power jitter , ect…..

$$E = E_{avg} \cdot \{1 + M \cdot \cos(2k_y y + \varphi_0)\}$$

$$y \rightarrow y \pm \Delta y$$

$$E_{avg} \cdot \{1 + M \cdot \cos(2k_y(y + (Random->Gaus(0,\Delta y)) + \varphi_0)\}$$

(2) obtain Δy from fitting

Model

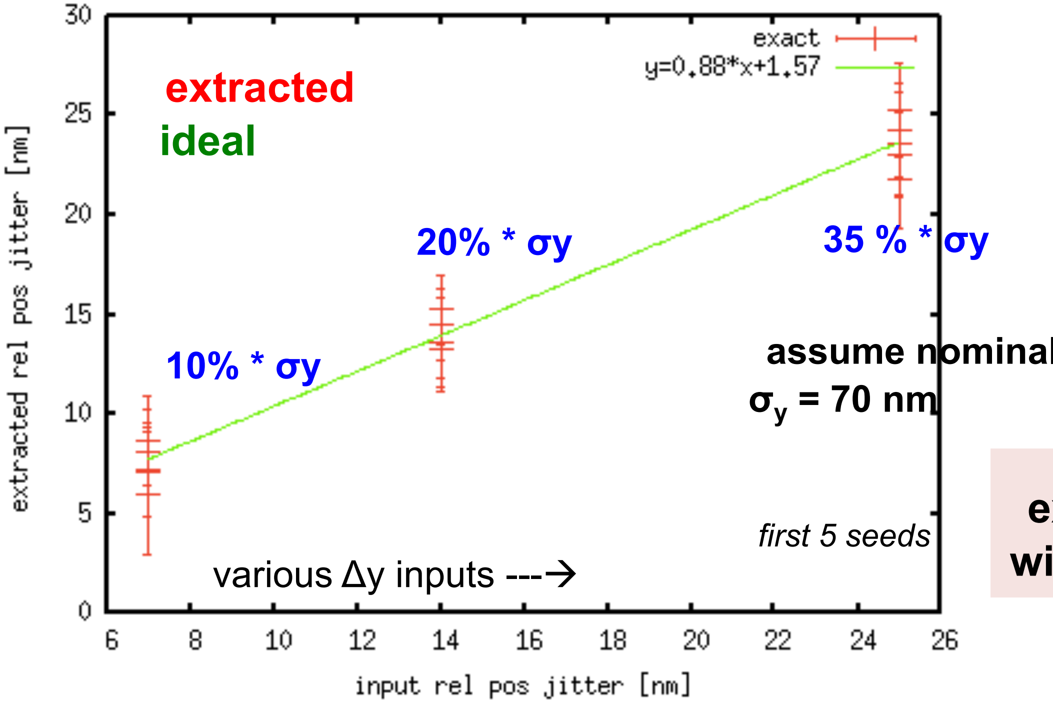
$$\Delta E \equiv \sigma_{tot} = \sqrt{\sigma_V^2 + \sigma_{pos}^2}$$

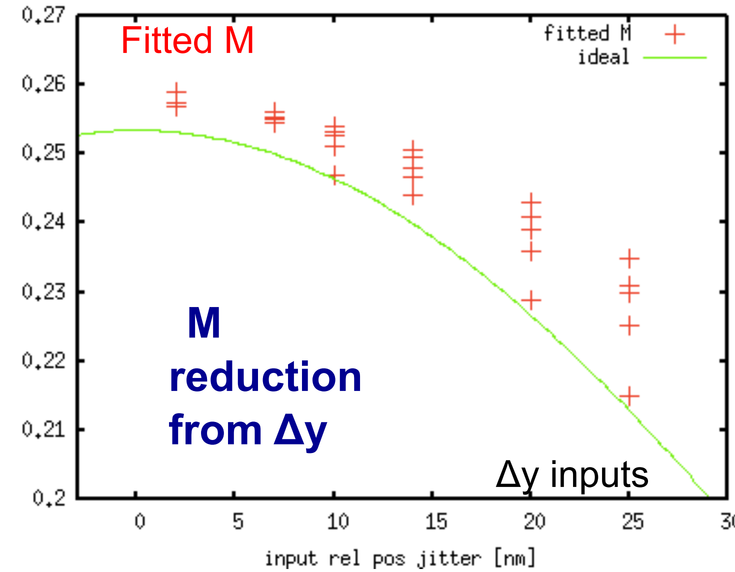
vertical jitter

σ_{pos}: horizontal jitter from Δy (Δφ)

$$\sigma_V = C_{const} \oplus C_{stat}\sqrt{E} \oplus C_{linear} \cdot E$$

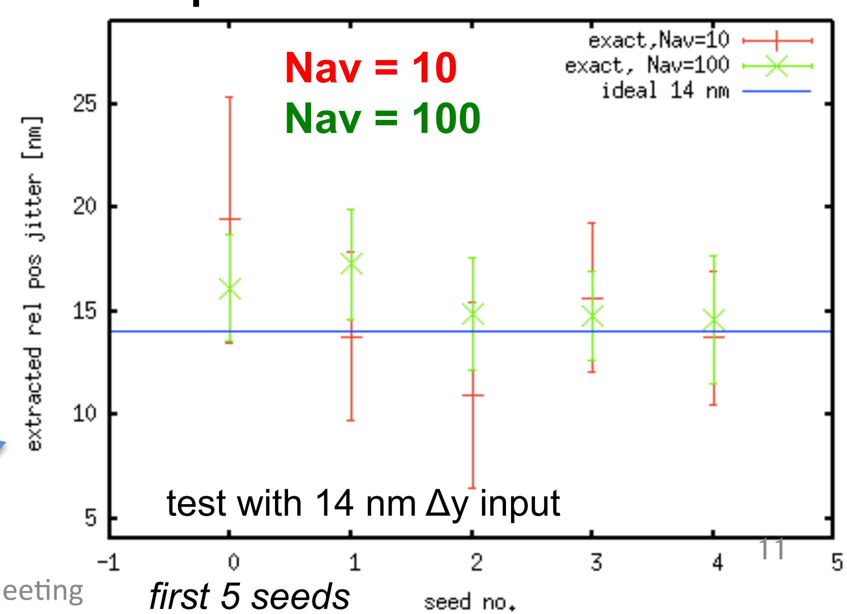
Deriving Δy (Δϕ) : Test of Method using Simulation





extracted Δy agree with input within errors

Compare Nav = 100 and Nav = 10



also observed effect of input vertical jitters

- ➢ light jitter (∼10%), S/N = 5
- ➢ heavy jitter (∼ 20%) , S/N = 2

signal jitters disturb precision in Δy extraction (i.e. large errors)

less vulnerable for large statistics (e.g. Nav = 100)

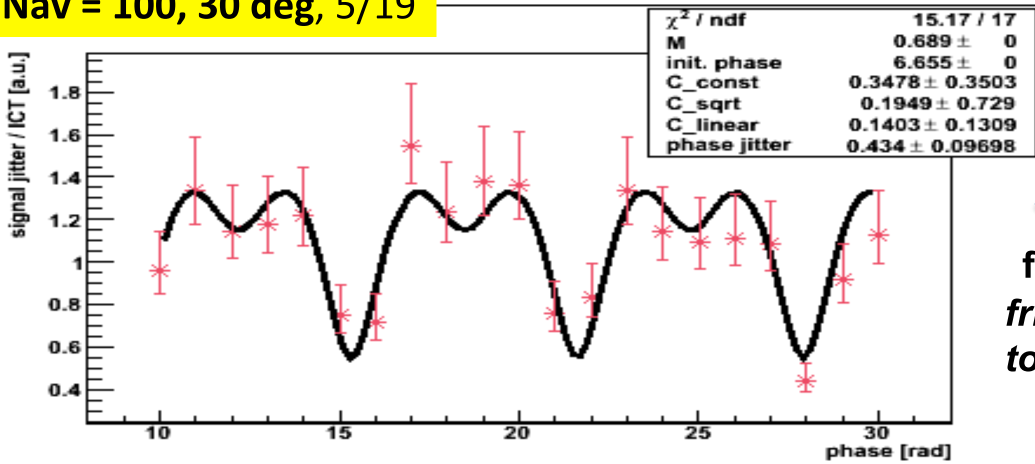
Deriving Δy (Δϕ) : apply to actual data

very preliminary attempts !!

Note:

- errors are only from fitting (we may have other systematic effects
- Not enough (large Nav) data yet for drawing any conclusions

Nav = 100, 30 deg, 5/19

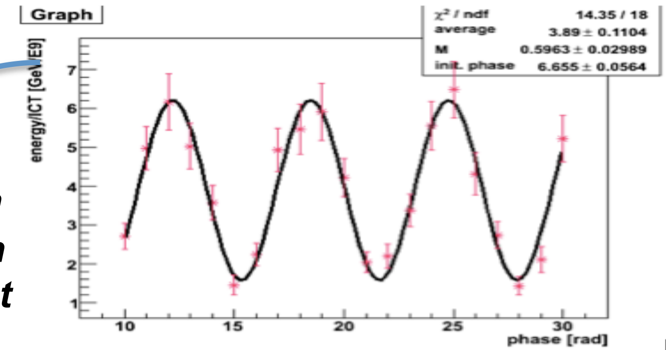


preliminary

Δy = 71.0 +/- 15.9 nm

Δφ = 434 .0 +/- 97.0 mrad

fix M from fringe scan to jitter plot



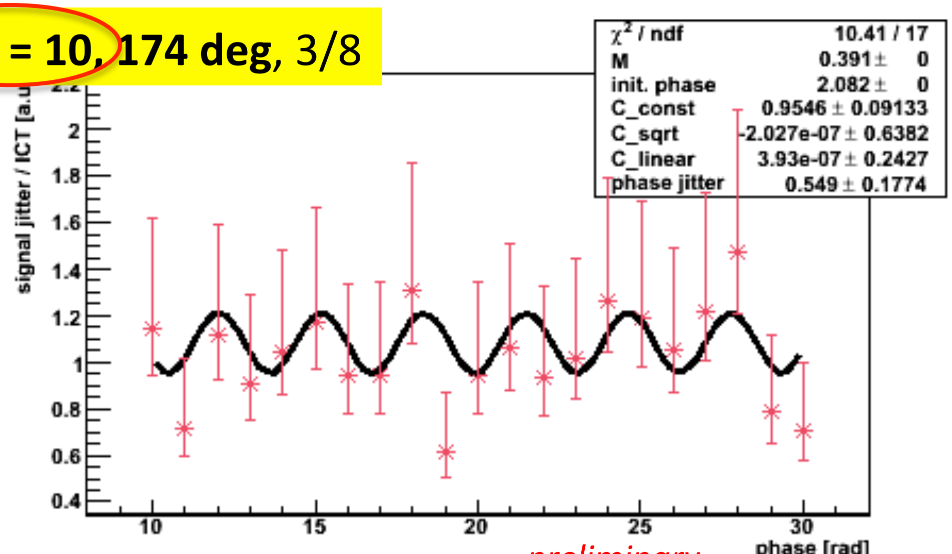
Fitted σ_y : 141.3 $^{+8.9}_{-9.0}$ nm

Corrected σ_y : 122.2 $^{+10.2}_{-10.1}$ nm

M reduction due to Δy about 85 – 95% (?)

Nav = 10, 174 deg, 3/8

no Nav = 100 data available for 174 deg



Fitted σ_y : 64.9 $^{+2.7}_{-2.5}$ nm

Corrected σ_y : 60.6 $^{+2.8}_{-2.7}$ nm

Δy = 23.2 +/- 9.6 nm

Δφ = 549.0 +/- 177.4 mrad

Deriving Δy (Δϕ) : Current Status

possibly valid model for deriving Δy (Δϕ) (???)

BUT !!!!! be aware of limitations on reliability

When applied to actual data.......

- Slow drifts, other large jitters,
- conditions always changing
- how realistic were assumptions in test simulation ??

Proposal / Plan

how to apply this method reliably ??

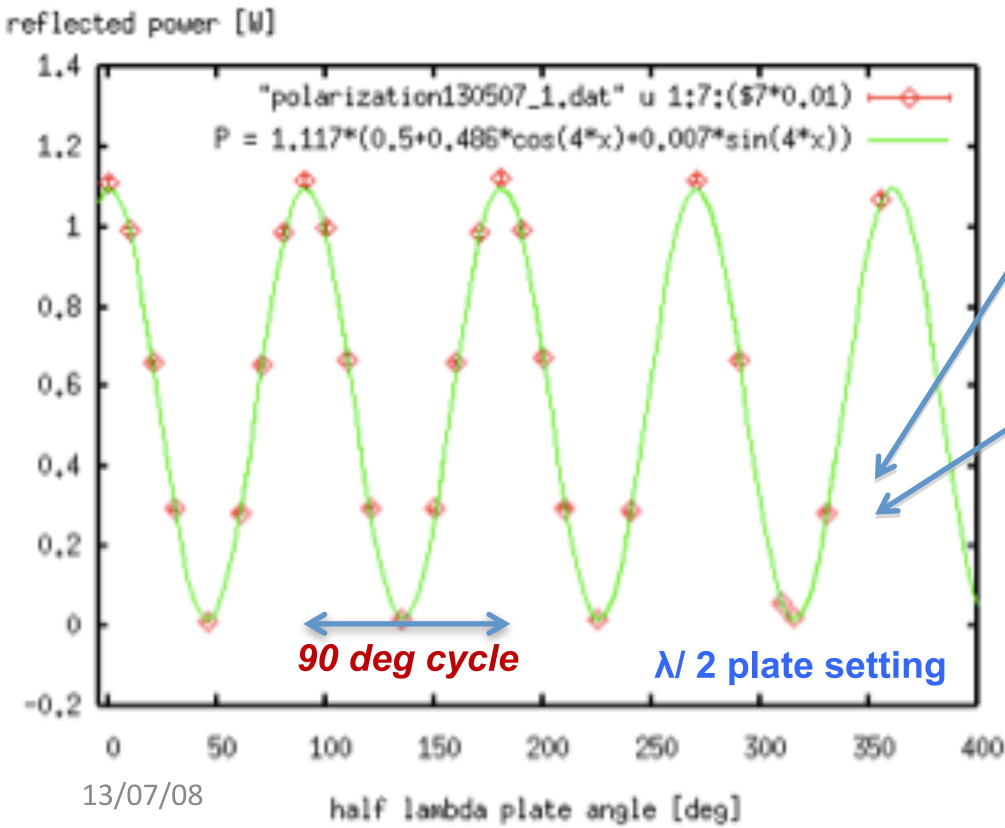
resolve slow drifts (laser & e beam) and large jitters

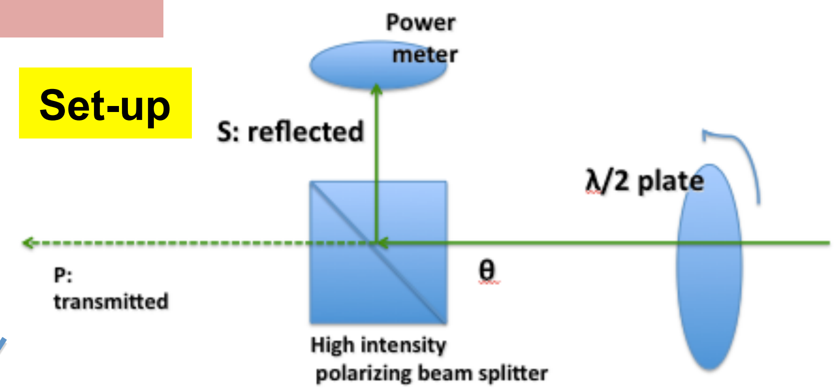
take large Nav data occasionally under appropriate conditions

- further development of method
- optimize data taking scheme

laser polarization related issue are cleared up

IPBSM laser optics is designed for pure linear S polarization





polarization measurement

Just after injection onto vertical table

- **very close to linearly S polarization**
- very little polarization related M reduction

"P contamination": $\mathbf{P_p/P_s = (1.46 \pm 0.06)\ \%}$

power ratio

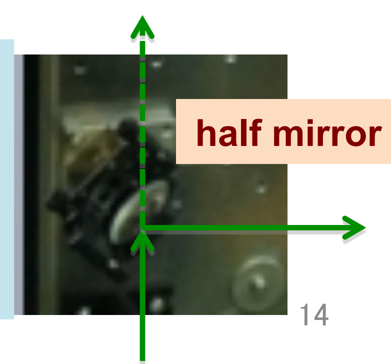
even more precise evaluation planned in autumn (hardware prepared)

individual measurements for upper and lower paths near IP

also measured **reflective properties of "half mirror"**

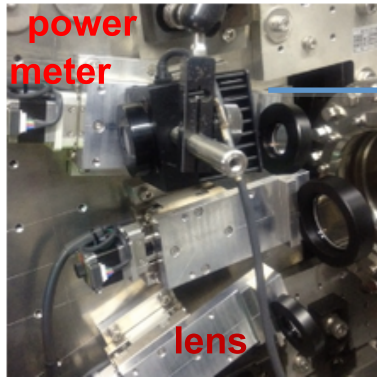
Rs = 50.3 %, Rp = 20.1 %

Match catalog specifications !!

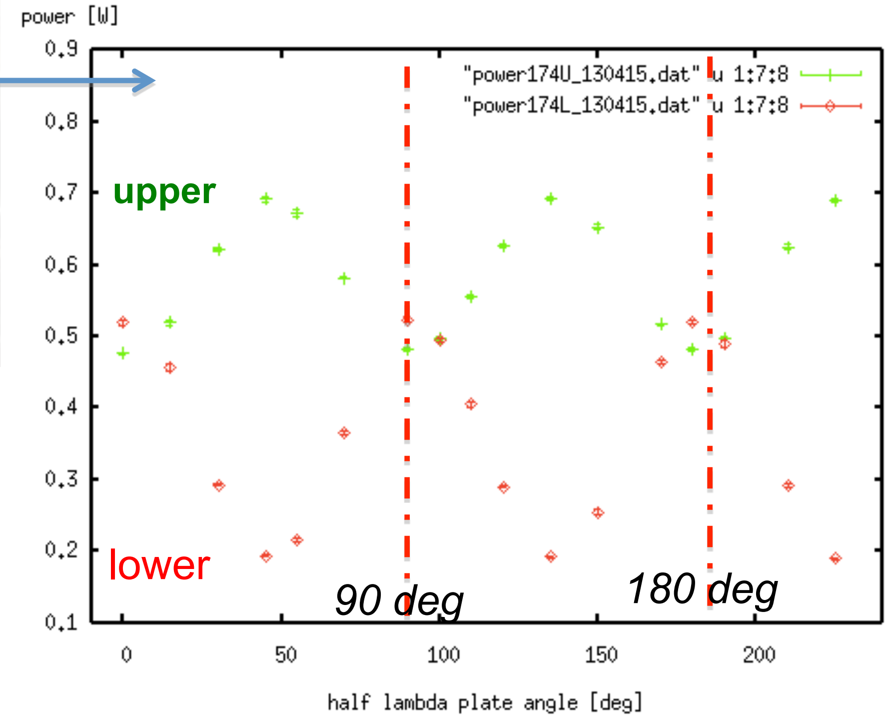


laser polarization and power balance

Rotate λ/2 plate and measure high power Immediately in front of final focus lenses

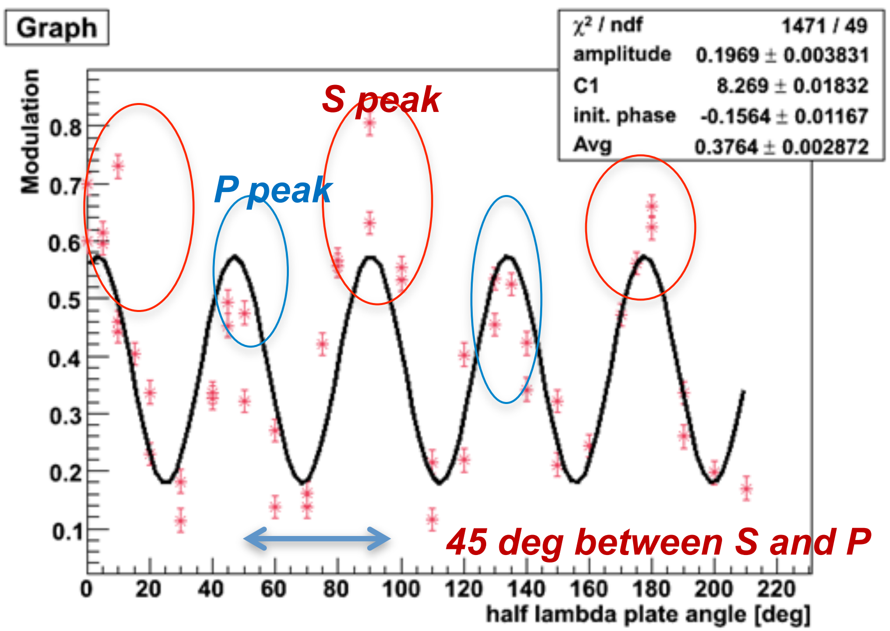


investigate power balance: U vs L path



During Beamtime

"λ/2 plate scan " to maximize M



Rotate λ/2 plate angle

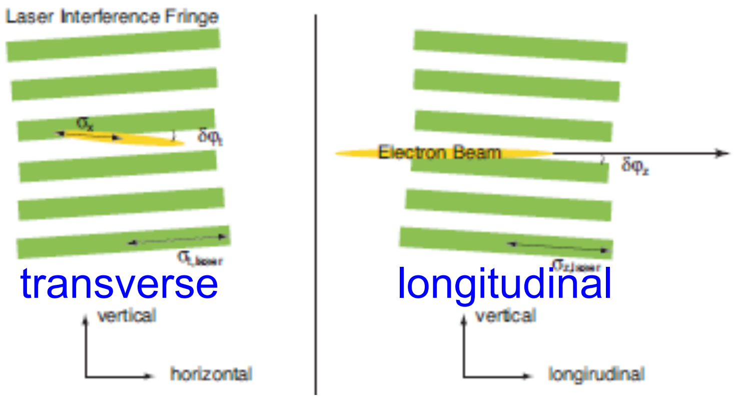
"S peaks" (maximum M)
also yield best power balance
→ Minimize M reduction

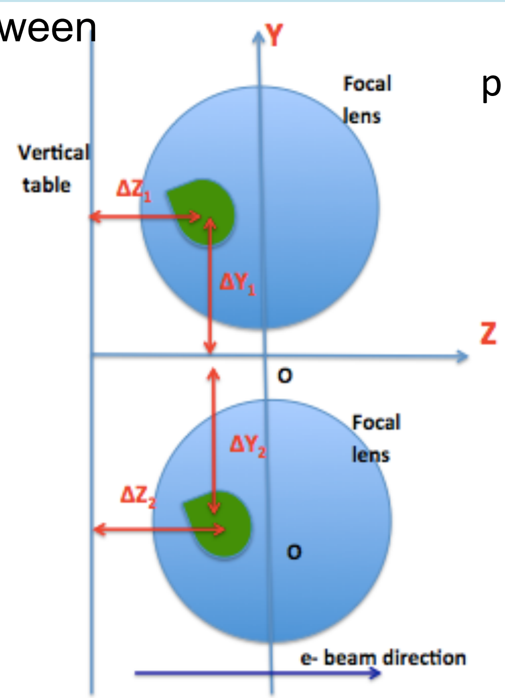
$$C_{pow} = \frac{2\sqrt{P_U / P_L}}{1 + P_U / P_L}$$

M reduction factor due to power imbalance

Fringe Tilt

Mismatch in axis between fringe and beam





laser path observed on lens: precision ~ 0.5 mm (few mrad)

issues:

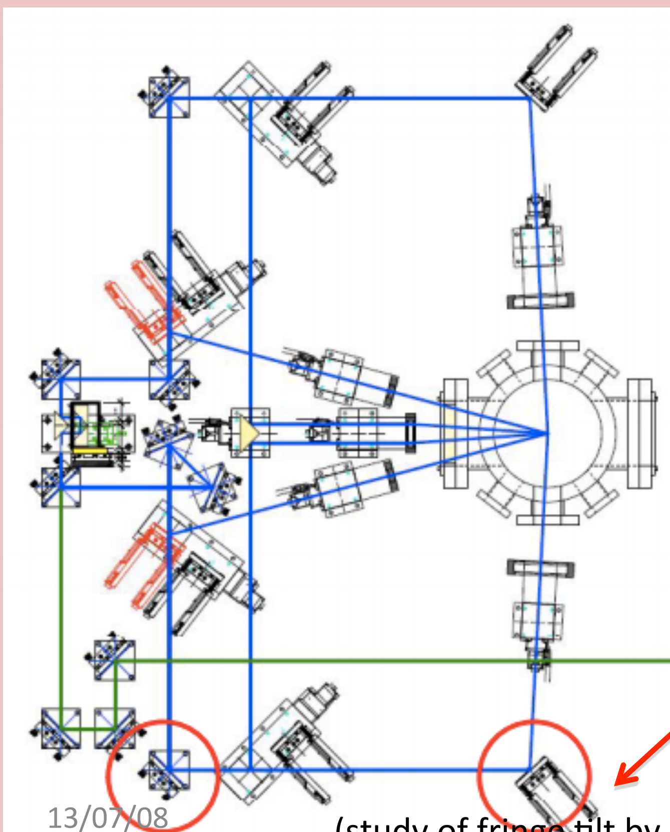
- Position drifts
- e beam rotation in transv

Current method : “tilt scan”

fringe pitch / roll adjustment:

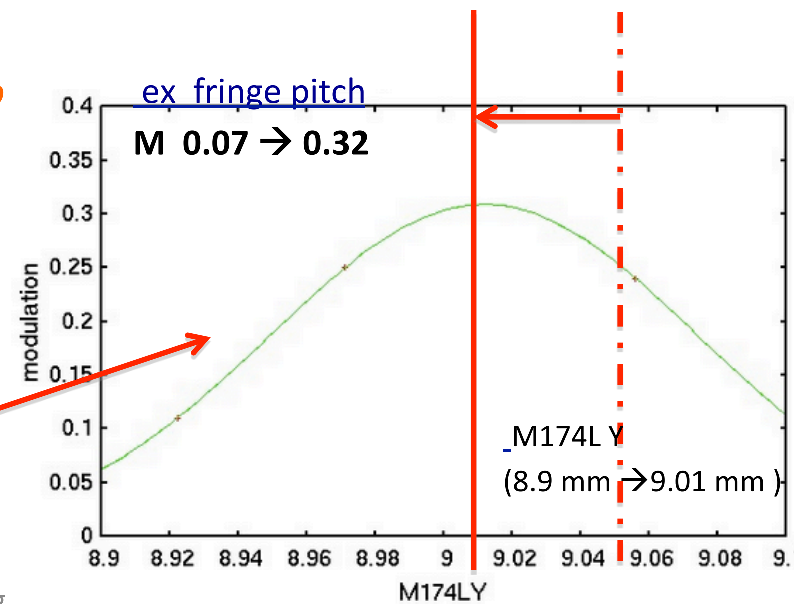
C_{tilt} : 70 - 80% if uncorrected

directly use e beam as reference for tilt adjustment



important adjustment to eliminate M reduction

Mirrors for adjusting tilt



(study of fringe tilt by Okugi-san)

Summary

Shintake Monitor (IPBSM)

as an indispensible device for achieving ATF2 's Goals

< Status >

- contribute with **stable operation to continuous beam size tuning**
- Consistent measurement of **M ∼ 0.3** （174 ° mode) *at low beam intensity*
  correspond to σ_y ~ 65 nm (assuming no M reduction)
  after correction for relative position jitter : maybe ∼ 60 nm ??

< dedicated studies of e beam and IPBSM errors >

- Clearing up of residual M reduction factors
- First attempts at **evaluation of relative position jitter**
  the most unknown and possibly most dominant error source ??

Goals

Towards confirming σ_y = 37 nm

- Maintain / improve **beamtime performance :** e.g. stability, precision
- continue to assess **residual systematic errors.** Especially focus on Δy
  → **derive the "true beam size"**
- **aim for stable measurements of σy < 50 nm** within this run

Backup

Deriving Δy (Δϕ) : apply to actual data

very preliminary examples

M reduction due to Δy about 85 – 95%

Data	Δ ϕ [mrad] / Δ y [nm]	C_Δ y
130519_233909 30 deg, Nav = 99	434.0 ±97.0 / 71.0±15.9	(91±9) %
130621_001022 30 deg, Nav = 5	409.2±109.0 / 66.9 ±17.8	(92±6) %
130308_222715 174 deg, Nav = 10	549.0±177.4 / 23.2 ±9.6	(86±14) %
130314_155050 174 deg, Nav = 10	267.8 ±345.5 / 11.3 ±15.0	82 – 100 %

Current Status:

possibly valid model for deriving Δy (Δϕ) (???)

BUT !!!!! be aware of limitations on reliability

When applied to actual data…….

- Slow drifts, other large jitters,
- conditions always changing
- how realistic were assumptions in test simulation ??

Proposal / Plan

how to apply this method reliably ??

resolve slow drifts (laser & e beam) and large jitters

take large Nav data occasionally under appropriate conditions

- further development of method
- optimize data taking scheme

Crossing angle θ	174°	30°	8°	2°
Fringe pitch $d = \frac{\pi}{k_y} = \frac{\lambda}{2\sin(\theta/2)}$	266 nm	1.03 μm	3.81 μm	15.2 μm
Lower limit	20 nm	80 nm	350 nm	1.2 μm
Upper limit	110 nm	400 nm	1.4 μm	6 μm

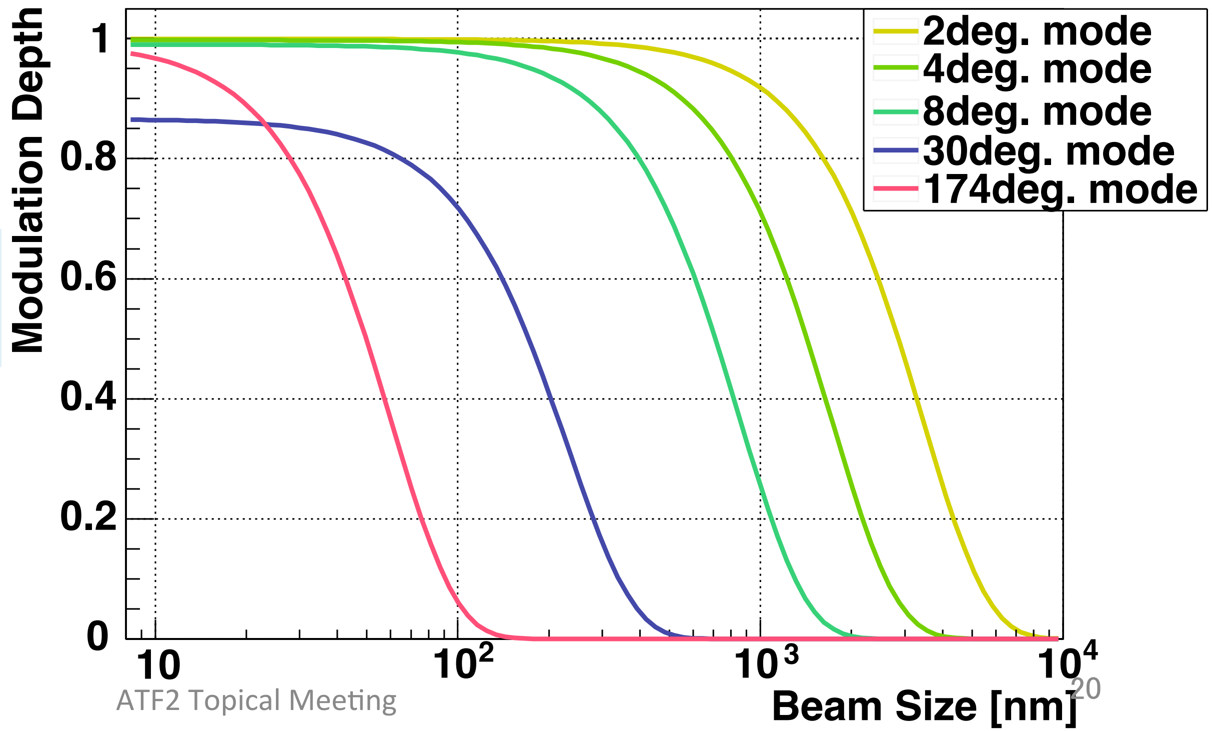
Expected Performance

Measures
σy* = 20 nm ~few μm
with < **10% resolution**

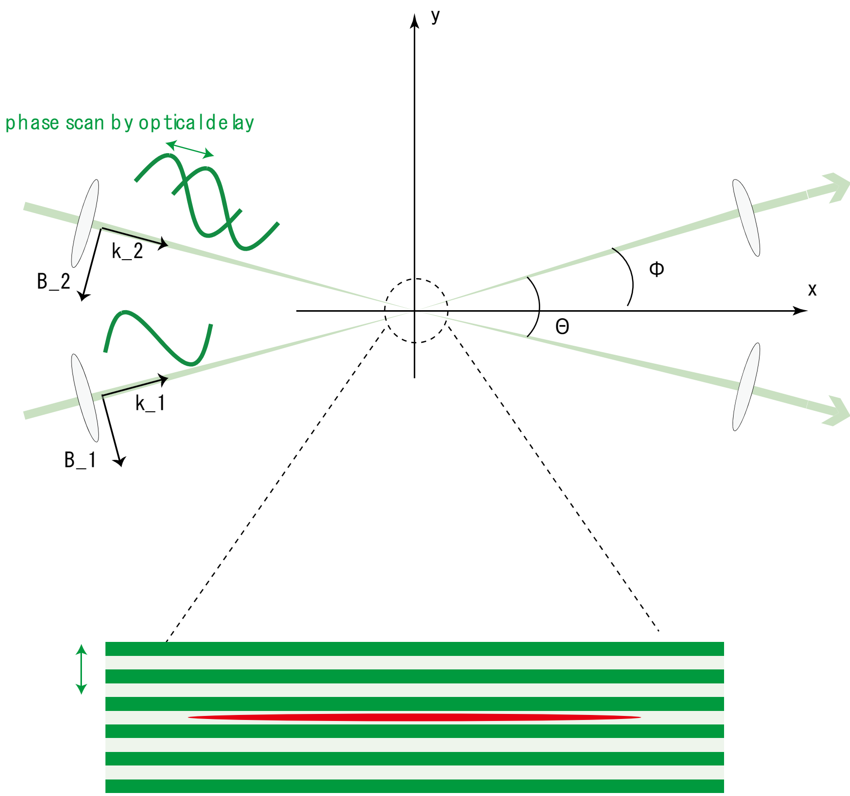
$$\sigma_y = \frac{d}{2\pi}\sqrt{2\ln\left(\frac{|\cos(\theta)|}{M}\right)}$$

σ_y and M for each θ mode

select appropriate mode according to beam focusing



Laser interference scheme



Wave number vector of two laser paths

$$\vec{k_1} = (k\cos\phi, k\sin\phi, 0) \equiv (k_x, k_y, 0)$$

$$\vec{k_2} = (k\cos\phi, -k\sin\phi, 0)$$

S-polarized laser

$$\vec{B_1} = B(\sin\phi, -\cos\phi, 0)\cos(\omega t - \vec{k_1}\cdot\vec{x} - \frac{\alpha}{2})$$

$$\vec{B_2} = B(-\sin\phi, -\cos\phi, 0)\cos(\omega t - \vec{k_2}\cdot\vec{x} + \frac{\alpha}{2})$$

$$\vec{B} = \vec{B_1} + \vec{B_2}$$

$$= 2B\begin{pmatrix} \sin\phi\sin(\omega t - k_x x)\sin(k_y y + \frac{\alpha}{2}) \\ -\cos\phi\cos(\omega t - k_x x)\cos(k_y y + \frac{\alpha}{2}) \\ 0 \end{pmatrix}$$

Time averages magnetic field causes inverse Compton scattering

$$< B_x^2 + B_y^2 >= B^2(1 + \cos\theta\cos(2k_y y + \alpha))$$

- phase shift at IP ←→ α
- wave number component along y-axis $2k_y = 2k\sin\phi$
- modulation depends on cosθ

Fringe pitch

$$d = \frac{\pi}{k_y} = \frac{\lambda}{2\sin\phi}$$

Calculation of beam size

Total signal energy measured by γ-detector

Convolution of
- Laser magnetic field : Sine curve
- Electron beam profile : Gaussian

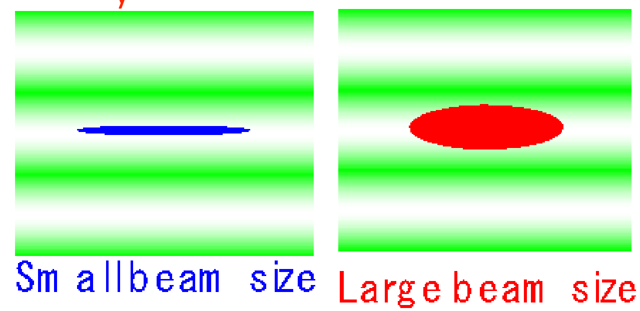
Laser magnetic field

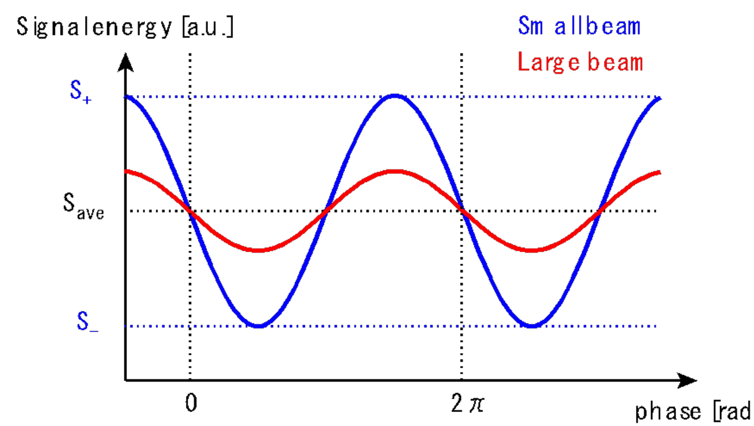
Electron Beam profile with beam size σ_y along y-direction

$$S \propto \int dy' < B_x^2 + B_y^2 > \frac{1}{\sqrt{2\pi\sigma_y^2}} \exp\left(\frac{-y'^2}{2\sigma_y^2}\right)$$

$$= \int dy' B^2 (1 + \cos\theta \cos(2k_y y + \alpha)) \frac{1}{\sqrt{2\pi\sigma_y^2}} \exp\left(\frac{-y'^2}{2\sigma_y^2}\right)$$

$$S = S_{ave}(1 + \cos((2k_y y) + \alpha)\cos\theta \exp(-2(k_y\sigma_y)^2))$$





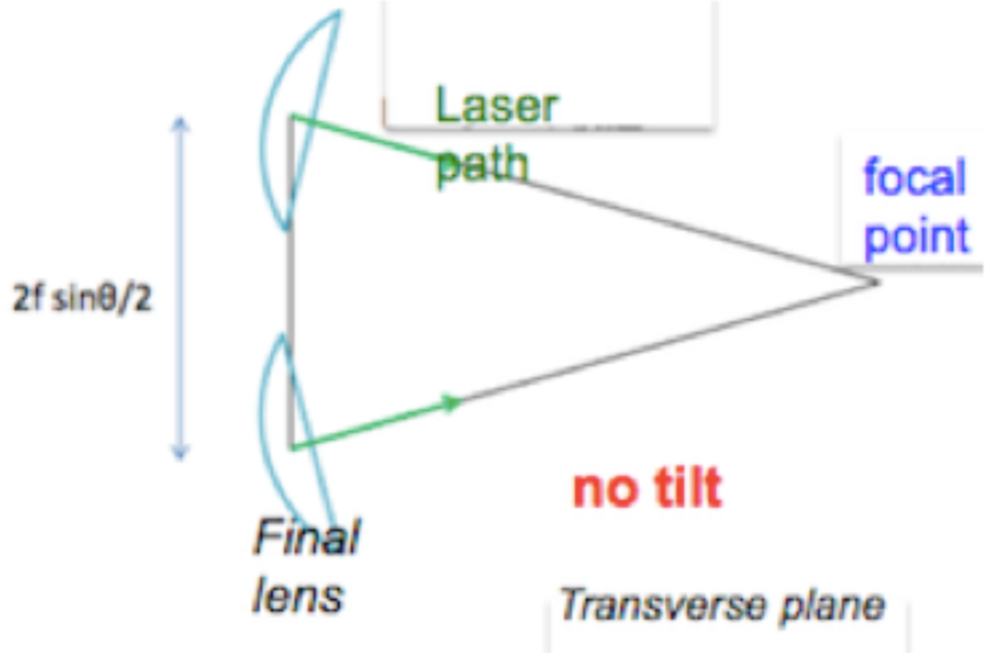
$S_\pm$: Max / Min of Signal energy

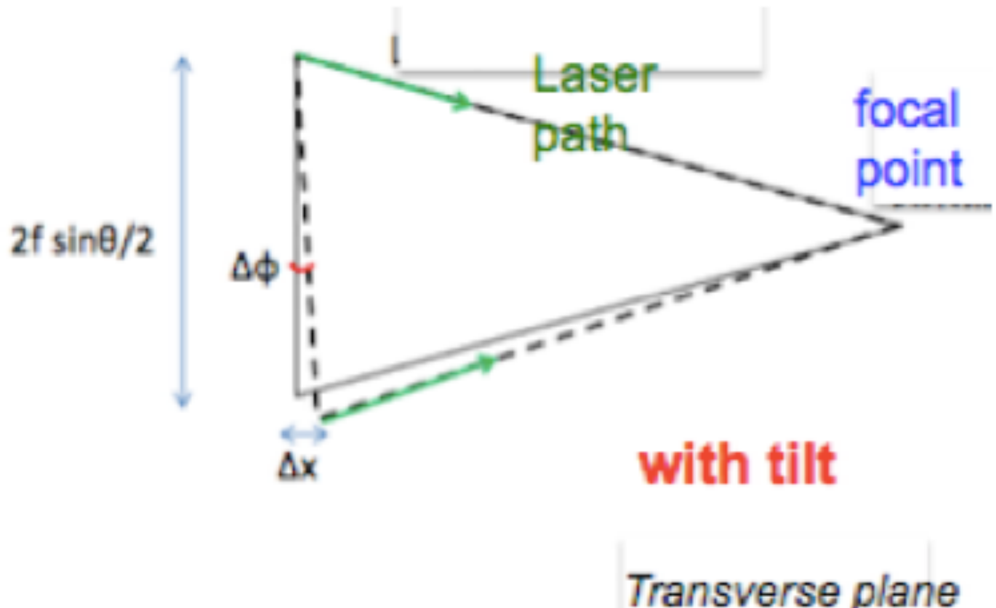
$$S_+ = S_{ave}(1 + |\cos\theta| \exp(-2(k_y\sigma_y)^2))$$
$$S_- = S_{ave}(1 - |\cos\theta| \exp(-2(k_y\sigma_y)^2))$$

M : Modulation depth

$$M = \frac{S_+ - S_-}{S_+ + S_-} = |\cos\theta| exp(-2(k_y\sigma_y)^2)$$

$$\sigma_y = \frac{1}{2k_y}\sqrt{2\ln\left(\frac{|\cos\theta|}{M^2}\right)}$$

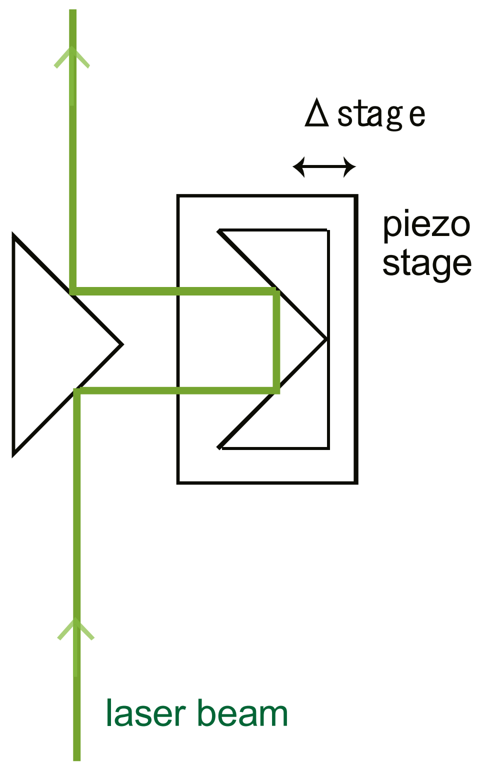


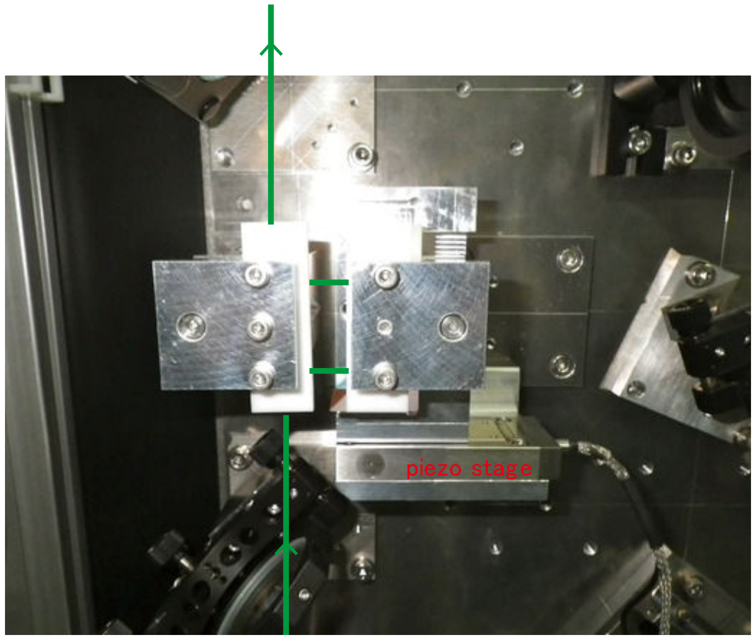


$\tan \Delta\phi = \Delta x / 2f \sin\theta/2$

Phase control by optical delay line

Optical delay line (~10 cm)
Controlled by piezo stage



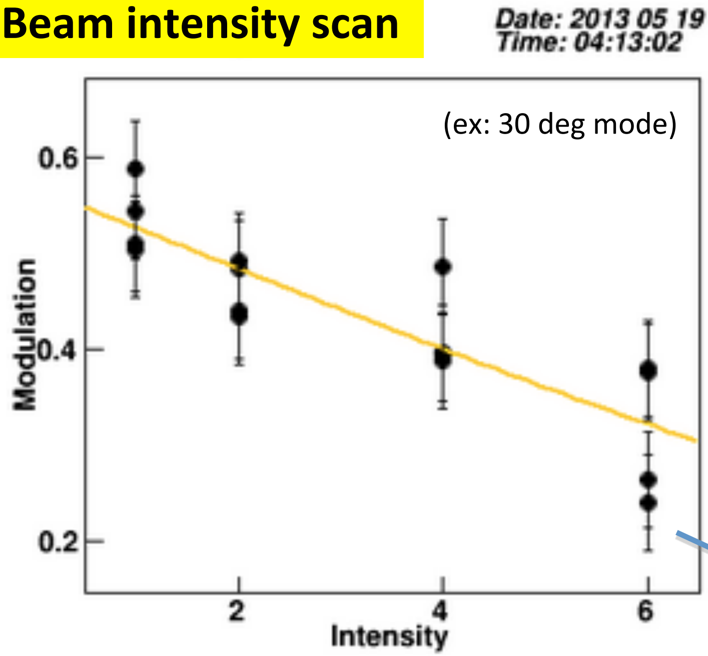


Movement by piezo stage : Δ_{stage} → Phase shift

$$\Delta\alpha = 2\pi\frac{\Delta_{stage}}{\lambda}$$

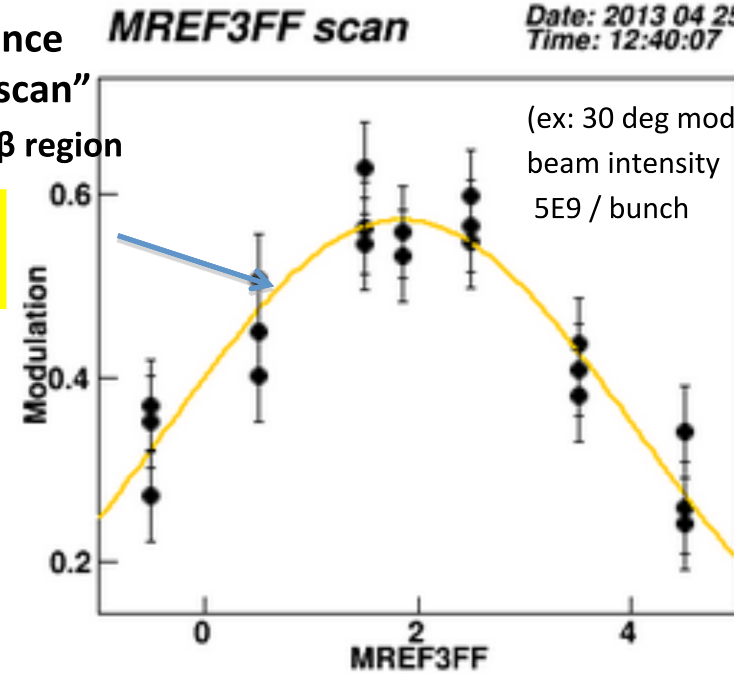
Other studies using IPBSM

Beam intensity scan



"Reference Cavity scan" in high β region

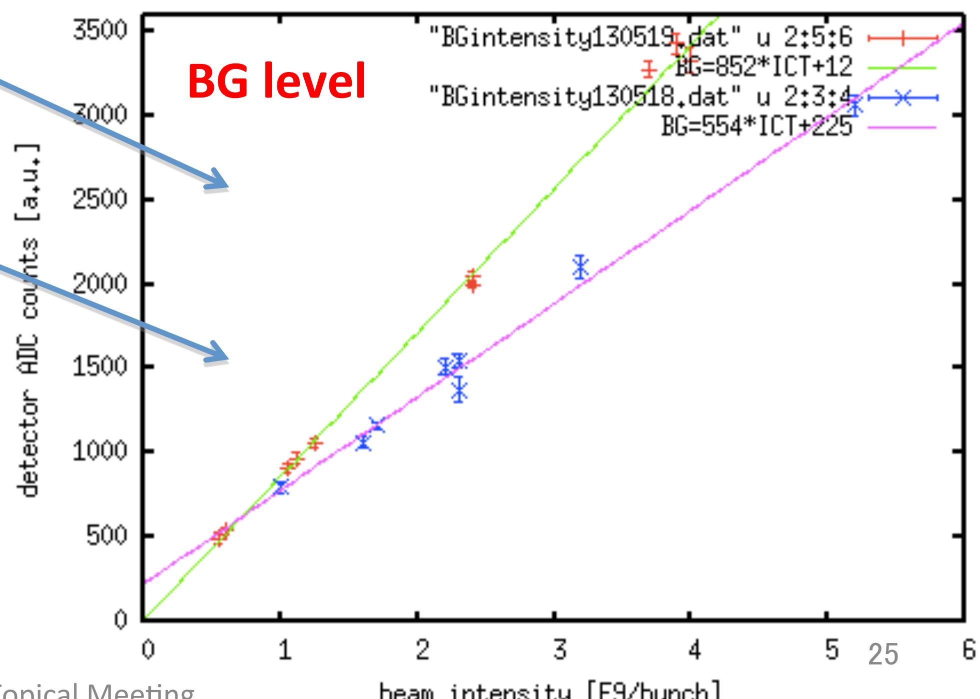
wakefield studies



Check linearity of BG levels in IPBSM detector

→Observe **"steepness" of intensity dependence**

compare with other periods to test effects of orbit tuning and / or hardware improvement for wake suppression



others:

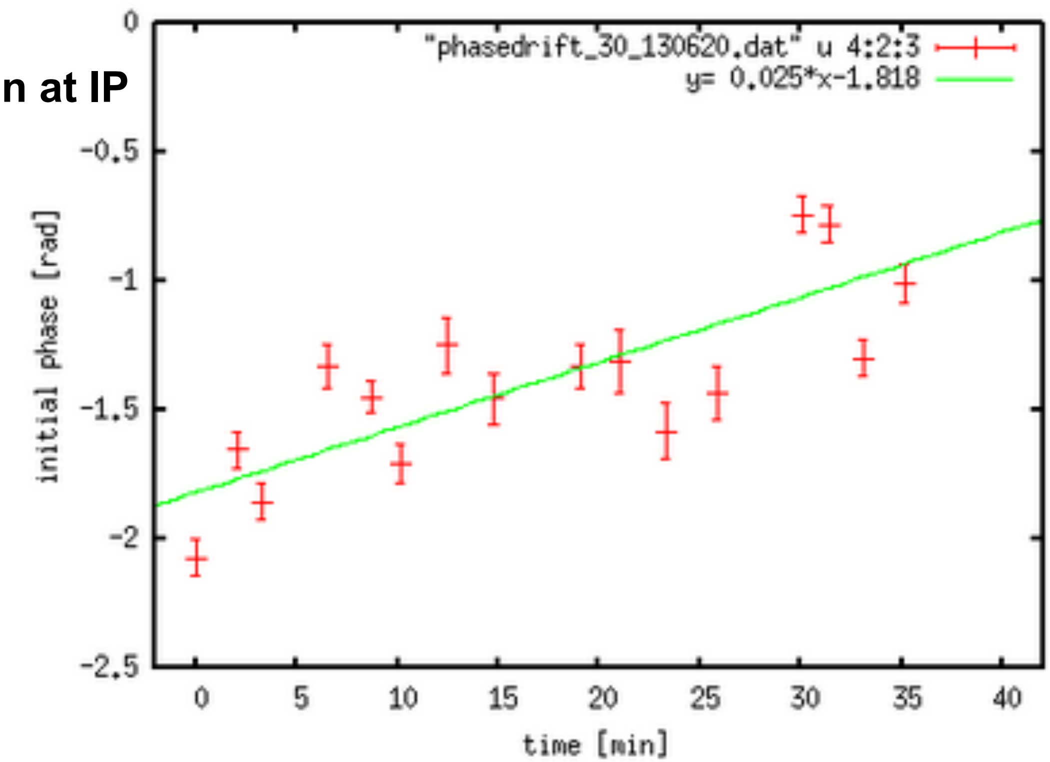
- Test various linear / nonlinear tuning knobs
- IPBSM systematic error studies

IPBSM phase drift study

6/20-21

by plotting initial phase of the last Bellows y pos scan
(ICT : 1.5-2.5E9/bunch)

slight drift about 25 +/- 5 mrad
→ convert to 3.3 – 5.0 nm / min at IP



$$E(\varphi,\Delta\varphi) = E_{avg}\left(1 + M\cos(\varphi + \Delta\varphi + \varphi_0)\right)$$

$$P(\Delta\varphi) = \frac{1}{\sqrt{2\pi}\sigma_\varphi}\exp\left(-\frac{\Delta\varphi^2}{2\sigma_\varphi^2}\right)$$

$$\overline{E(\varphi)} = \int E(\varphi,\Delta\varphi)\ \cdot P(\Delta\varphi)\,d\Delta\varphi$$

$$= \frac{1}{\sqrt{2\pi}\sigma_\varphi}E_{avg}\int \exp\left(-\frac{\Delta\varphi^2}{2\sigma_\varphi^2}\right)\left(1 + M\cos(\varphi + \Delta\varphi + \varphi_0)\right)d\Delta\varphi = E_{avg}\left(1 + M\cos(\varphi + \varphi_0)\exp\left(-\frac{\sigma_\varphi^2}{2}\right)\right)$$

$$\overline{E(\varphi)^2} = \int E(\varphi,\Delta\varphi)^2 \cdot P(\Delta\varphi)\,d\Delta\varphi$$

$$= E_{avg}^2\left(1 + 2M\cos(\varphi + \varphi_0)\exp\left(-\frac{\sigma_\varphi^2}{2}\right) + \frac{1}{2}M^2\left[1 + \cos(2\varphi)\exp\left(-2\sigma_\varphi^2\right)\right]\right)$$

$$\sigma_{pos}(\varphi) = \sqrt{\overline{E(\varphi)^2} - \left(\overline{E(\varphi)}\right)^2}$$

$$= E_{avg}M\sqrt{\frac{1}{2}\left[1 - 2\cos^2\varphi \cdot \exp\left(-\sigma_\varphi^2\right) + \cos(2\varphi)\exp\left(-2\sigma_\varphi^2\right)\right]}$$

if σ_φ is small:

$$\sigma_{pos}(\varphi) \approx E_{avg}M\sqrt{\sigma_\varphi^2\sin^2\varphi + \sigma_\varphi^4\left(\frac{3}{2}\cos^2\varphi - 1\right)\text{..........}}$$

$$\left(\frac{\Delta E}{E}\right)_{timing} = 1 - \frac{\int dt \frac{1}{\sqrt{2\pi\sigma_{\Delta t}^2}} \exp\left(-\frac{t^2}{2\sigma_{\Delta t}^2}\right) P_{laser}(t)}{\int dt \delta(t) P_{laser}(t)} = 1 - \sqrt{\frac{\sigma_t^2}{\sigma_t^2 + \sigma_{\Delta t}^2}} \approx \frac{1}{2}\left(\frac{\sigma_{\Delta t}}{\sigma_t}\right)^2$$

relative timing: $t \equiv t_{beam} - t_{laser}$

laser temporal profile: $P_{laser}(t) = P_0 \exp\left(-\frac{t^2}{2\sigma_t^2}\right)$ (laser pulse width: $\sigma_t = 3.4$ ns)

$$\left\langle P(\Delta t) \right\rangle \approx P_0 \left\{ 1 - \frac{1}{2}\frac{\sigma_{\Delta t}^2}{\sigma_t^2} + \frac{3}{2}\left(\frac{\sigma_{\Delta t}^2}{\sigma_t^2}\right)^2 - \ldots\ldots \right\}$$

$$\frac{\Delta P(\Delta t)}{P_0} \approx \frac{\sigma_{\Delta t}^2}{\sqrt{2} \cdot \sigma_t^2} \sqrt{1 - 3\frac{\sigma_{\Delta t}^2}{\sigma_t^2} + \ldots\ldots}$$