ATF2 Technical Review

Beam Size Measurement using IPBSM Performance Evaluation

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KEK, Japan

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Introduction

Measurement Scheme
Expected Performance
Role in Beam Tuning

Role of IPBSM (Shintake Monitor) at ATF2

ATF2: Linear Collider FFS test facility@KEK

$$L = \frac{n_b N^2 f_{rep}}{4\pi \sigma_x \sigma_y} H_D$$

Ultra-focused vertical beam size at IP !!

Crucial for **high luminosity**

IPBSM is crucial for achieving ATF2 's Goal 1 !!

focus **σ_y to design 37 nm**

➔verify Local Chromaticity Correction

Outline

Introduction

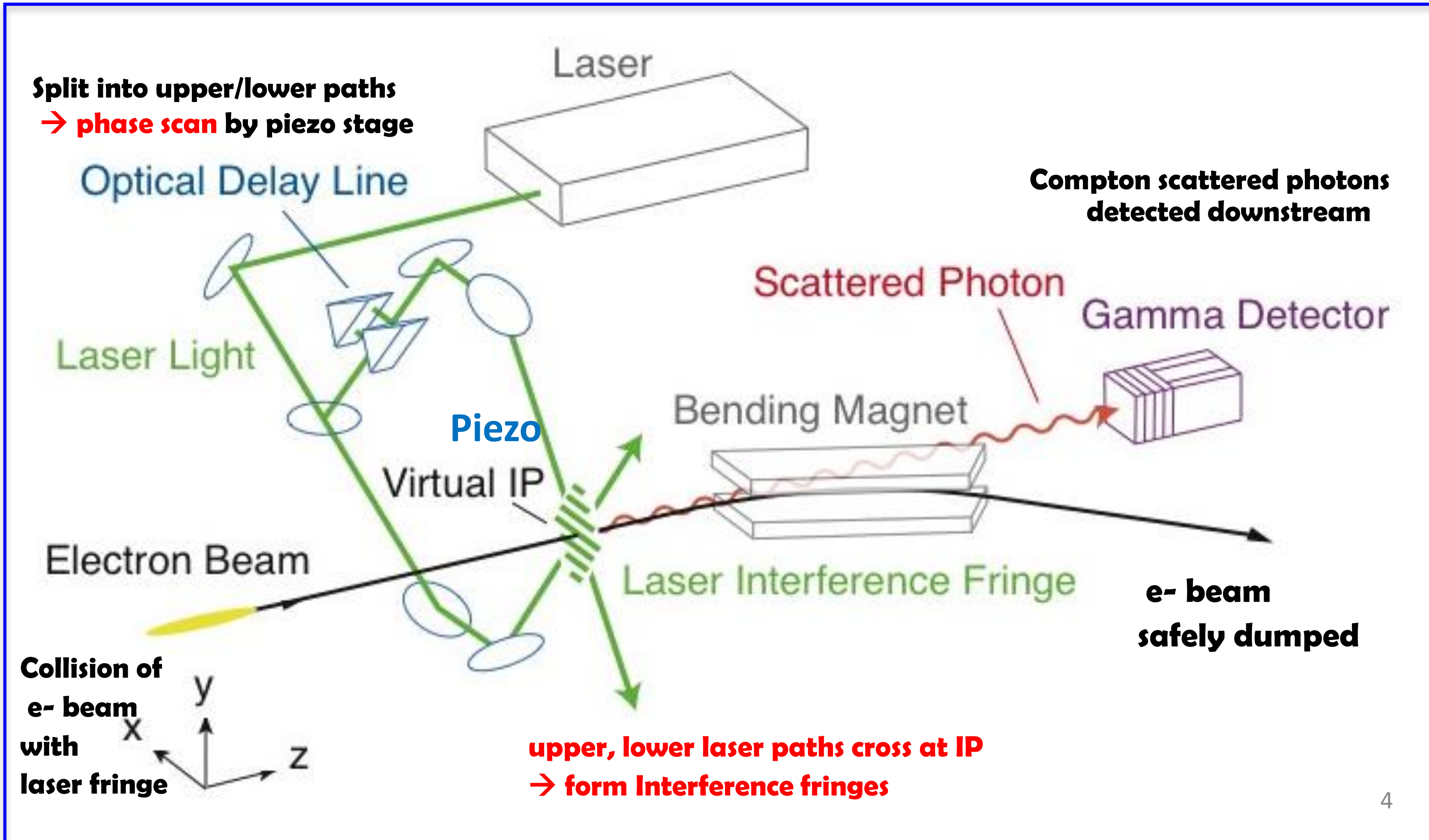
Beam Time Status
- **Dec 2012**
- **Jan– Mar, 2013**

- **IPBSM Performance**
- **Error studies**
- **Hardware Upgrades**

Summary & Goals and Plans

Measurement Scheme

- use **laser interference fringes** as target for e- beam
Only device able to measure σ_y < 100 nm !!
- Crucial for ATF2 beam tuning and realization of ILC



Detector measures

signal **Modulation Depth "M"**

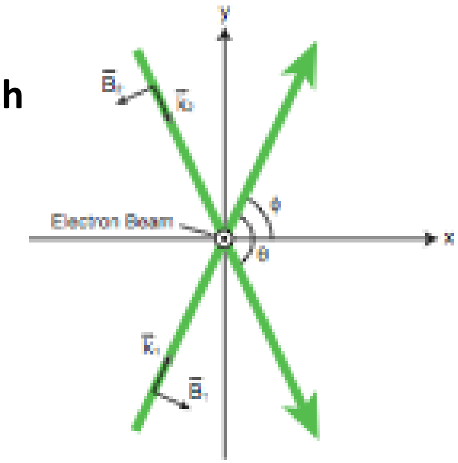
$$\mathbf{M} = \frac{N_+ - N_-}{N_+ + N_-} = \left|\cos(\theta)\exp\left(-2(k_y\sigma_y)^2\right)\right|$$

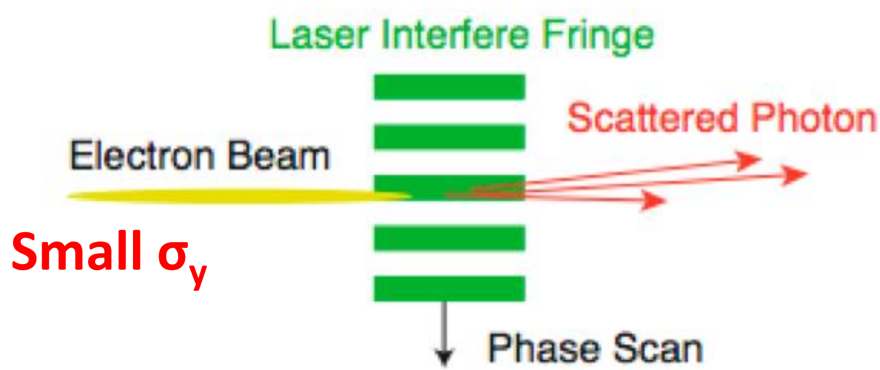
$$\Rightarrow \quad \sigma_y = \frac{d}{2\pi}\sqrt{2\ln\left(\frac{|\cos(\theta)|}{M}\right)}$$

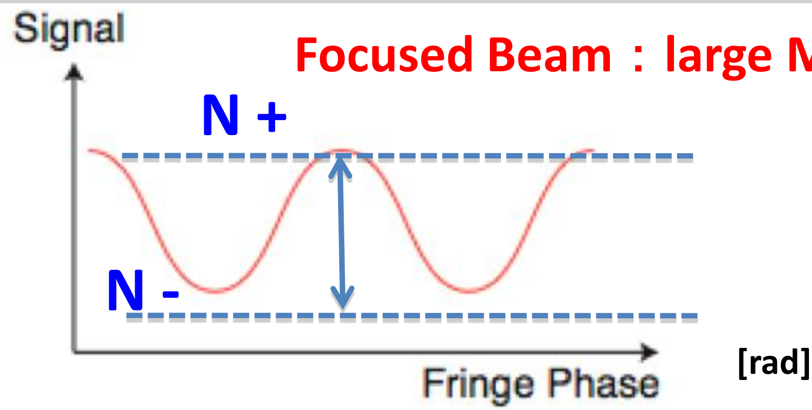
measurable range determined by **fringe pitch**

$$d = \frac{\pi}{k_y} = \frac{\lambda}{2\sin(\theta/2)}$$

depend on crossing angle θ (and λ)

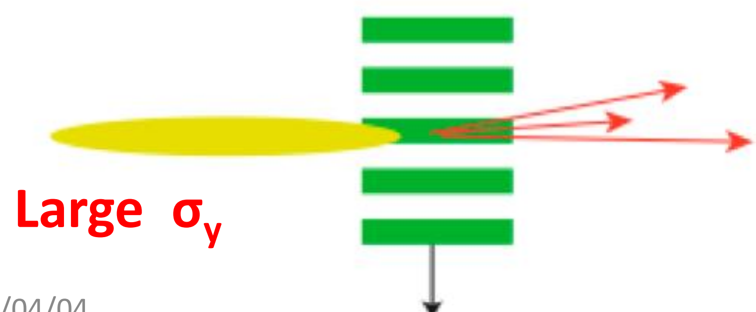


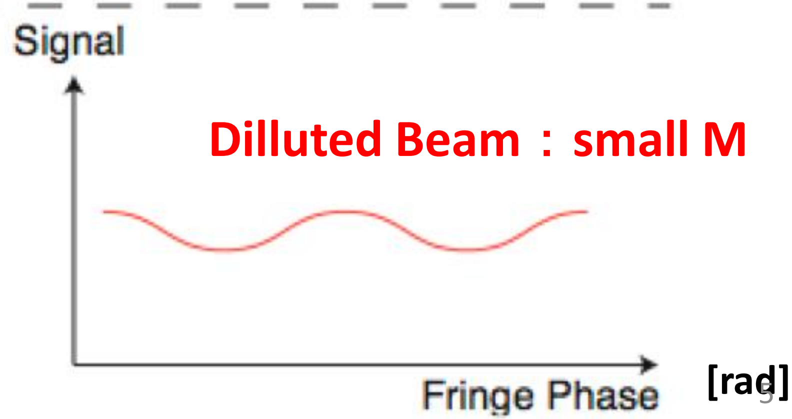




N: no. of Compton photons

Convolution between e- beam profile and fringe intensity





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

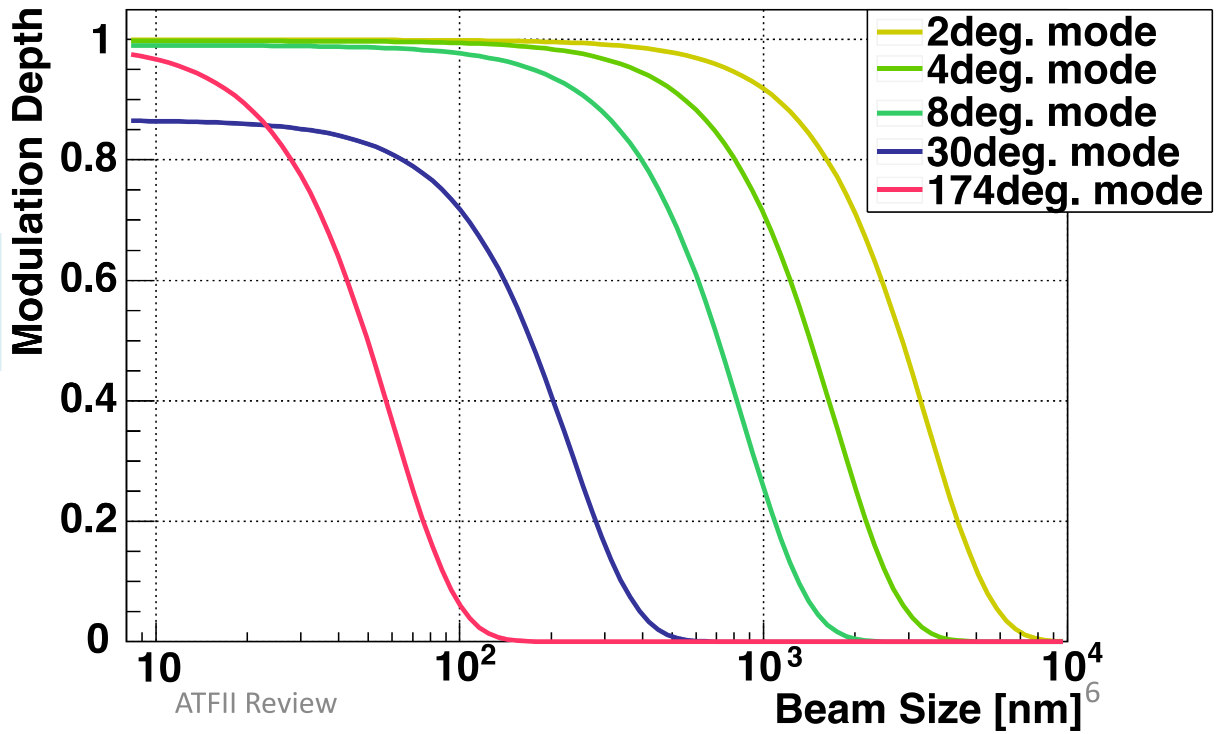
Expected Performance

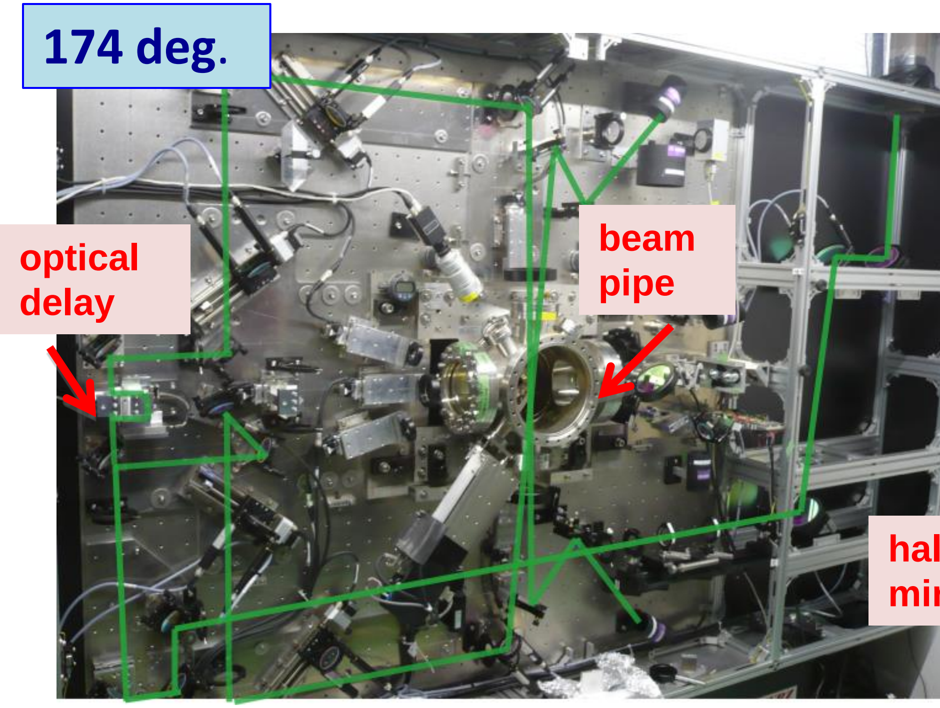
Measures
σy* = 20 nm ∼few μm
with < **10% resolution**

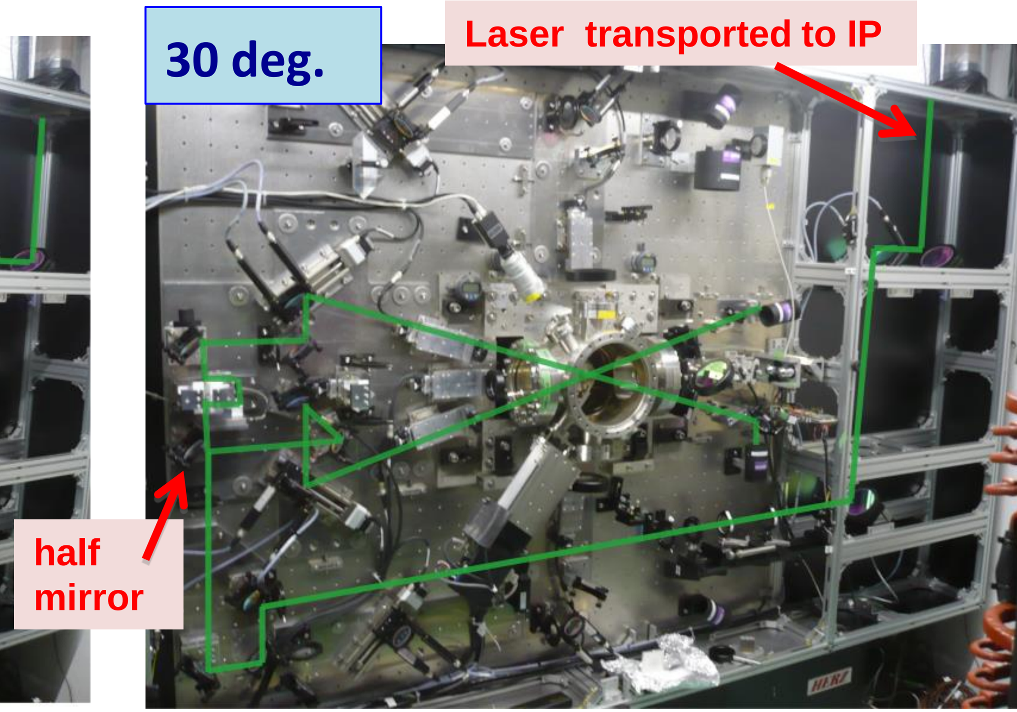
$$\sigma_y = \frac{d}{2\pi}\sqrt{2\ln\left(\frac{|\cos(\theta)|}{M}\right)}$$

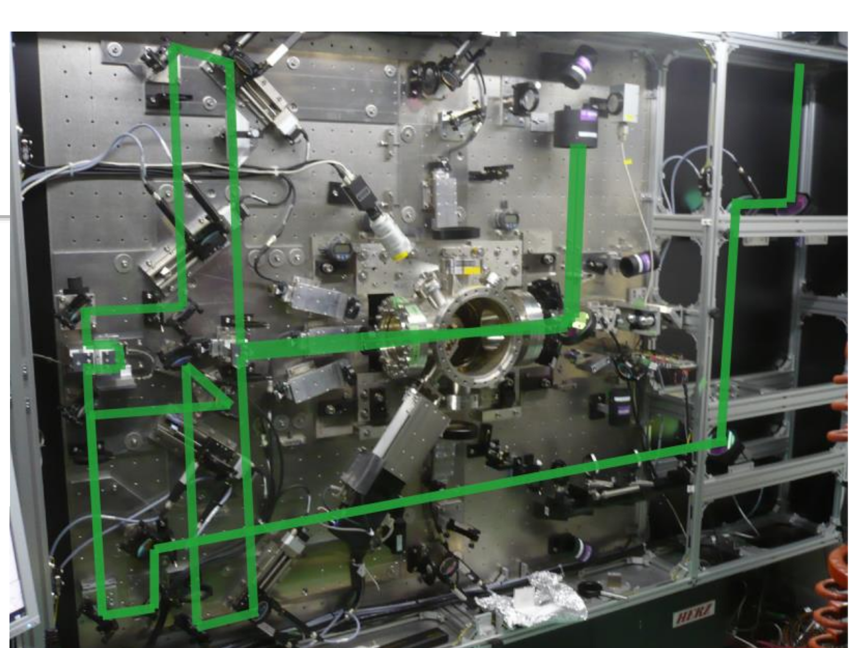
σ_y and M for each θ mode

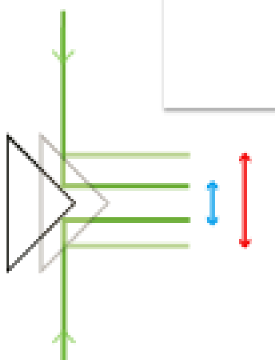
select appropriate mode according to beam focusing











Crossing angle continuously adjustable by prism

Vertical table

1.7 (H) x 1.6 (V) m

- **Interferometer**
- **Phase control (piezo stage)**

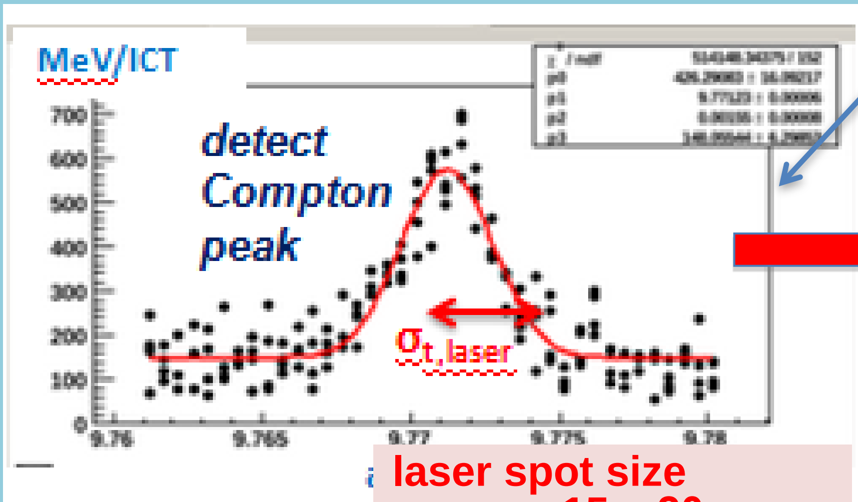
path for each θ mode

（auto-stages + mirror actuators ）

Role of IPBSM in Beam Tuning

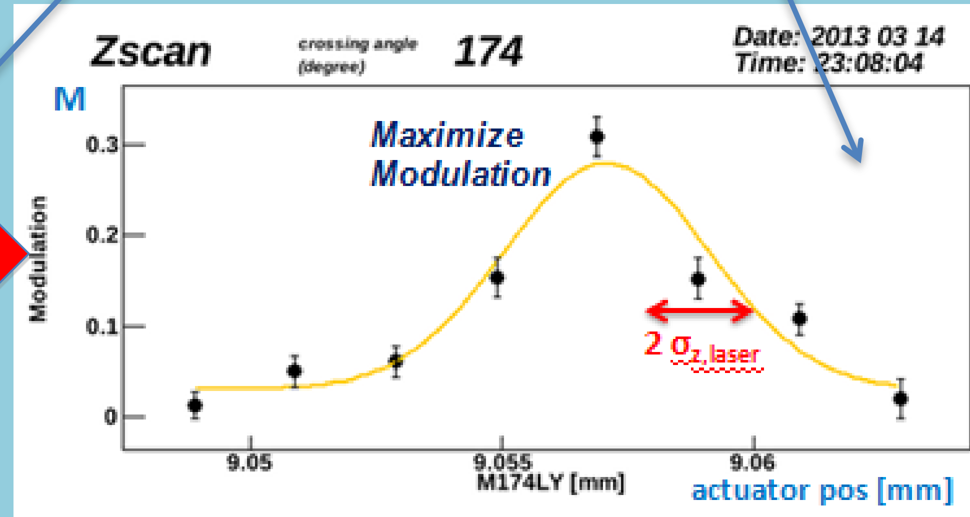
beforehand ….
Construct & confirm laser paths, timing alignment
precise position alignment by remote control

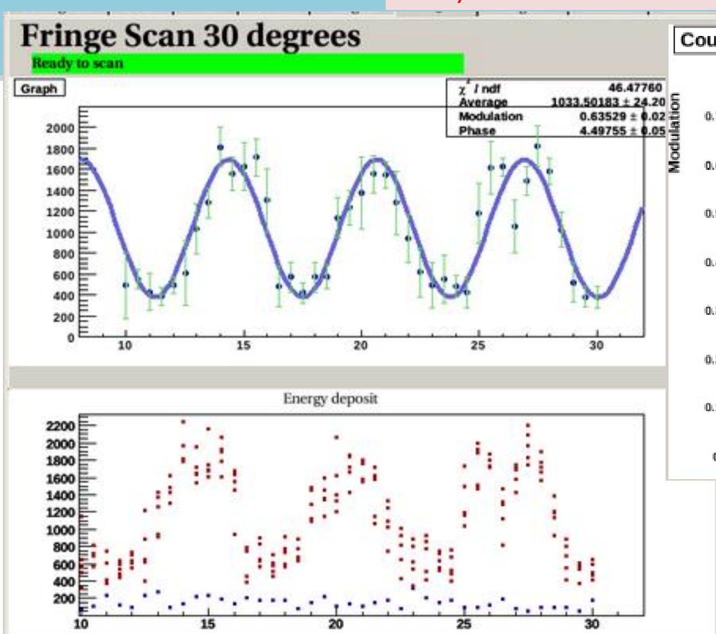
transverse : laser wire scan

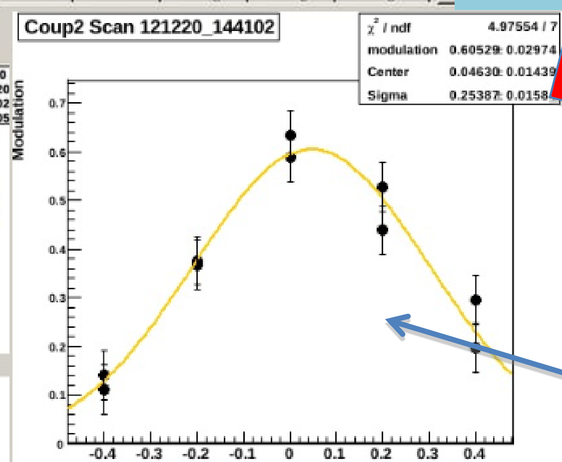


laser spot size
$\sigma_{t,laser}$ = 15 – 20 μm

Longitudinal : z scan







Modulation	0.635	+/-	0.028	
Beam Size	128.8	+/-	6.8	nm
Average	1033.502	+/-	24.206	
Phase	4.498	+/-	0.056	

After all preparations ……….

continuously measure σ_y using fringe scans

→ **Feed back to multi-knob tuning**

Beam Time Status

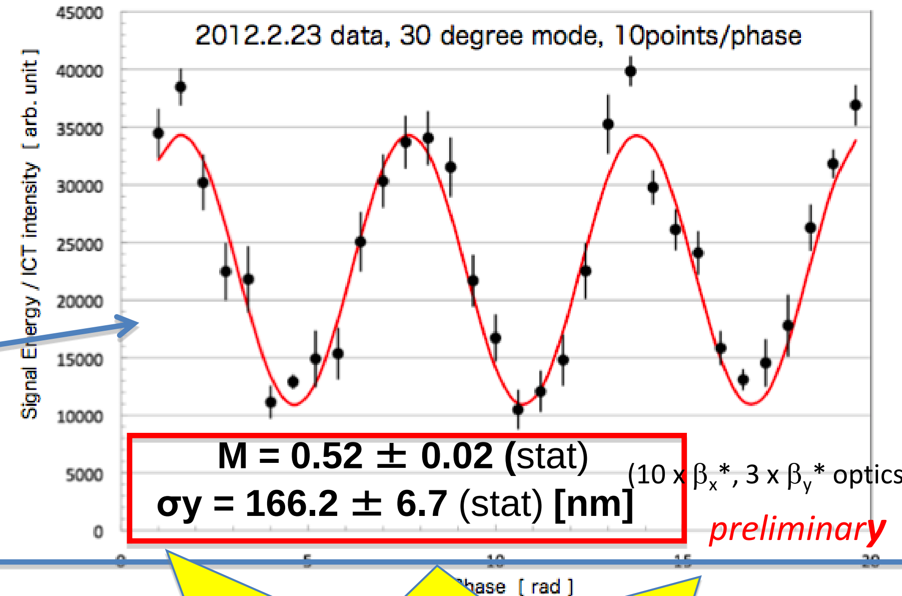
Beam time status in 2012

Spring run

Feb ; 30 deg mode commissioned
(1st M detection on 2/17)

stable measurements of M ∼ 0.55

- 2 - 8 ° mode: clear contrast（Mmeas ∼0.9)
- Prepare 174 deg mode commissioning



M = 0.52 ± 0.02 (stat)
σy = 166.2 ± 6.7 (stat) **[nm]**

(10 x β_x^*, 3 x β_y^* optics)

preliminary

Major optics reform of 2012 summer

By IPBSM group@KEK

- **Suppress systematic errors**
- **Higher laser path stability / reliability**

Winter run

- High M measured at 30 ° mode
- Contribute with **stable operation** to ATF2 continuous run

  (beam focusing / tuning study)

12/20 :
1st success in M detection
at 174 deg mode
10 x βx* , **1 x βy***

Last 2 days in Dec run

preliminary

Measured many times M = 0.15 – 0.25
（correspond to **σy ∼ 70 – 82 nm**）

＊ IPBSM systematic errors uncorrected
** under low e beam intensity (∼ 1E9 e / bunch)

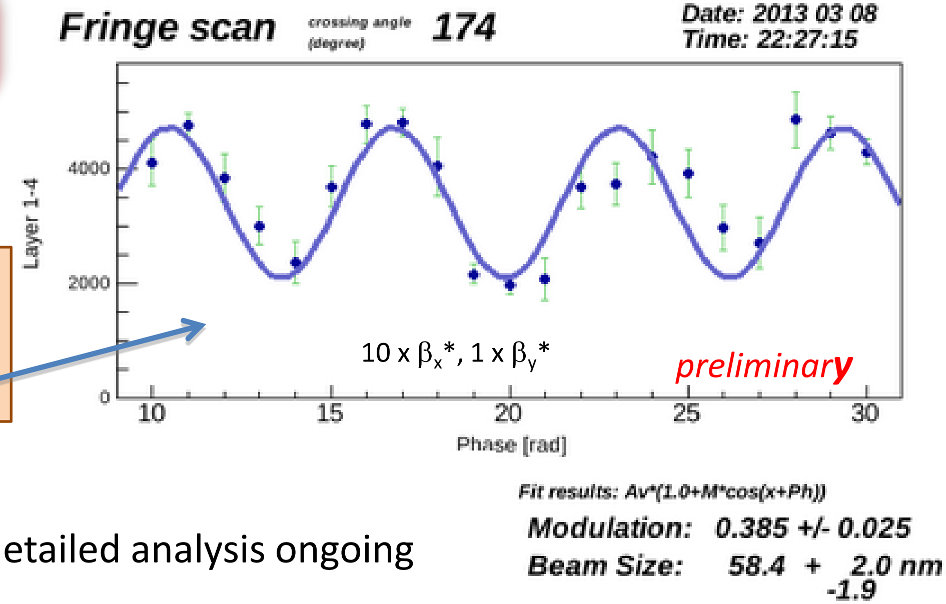
Large step towards achieving ATF2 's goal !!

error studies ongoing aimed at deriving “true beamsize”

Beam time status in 2013 Spring

Stable IPBSM performance
→ play major role in beam tuning

174 ° mode M reconfirmed & stably measured over long periods of continuous **reiteration of linear / nonlinear tuning knobs**



also :

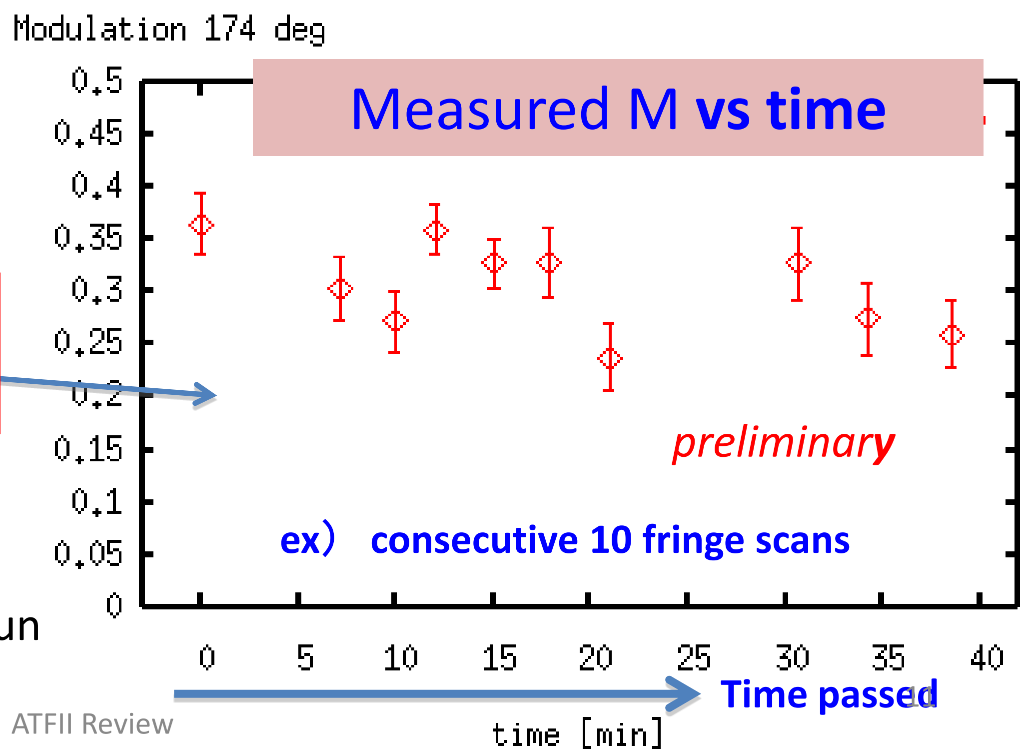
- ➢dedicated data acquired for error studies → detailed analysis ongoing
Reform of laser profile & alignment methods

174 ° mode "consistency scan"

Best record

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

towards goal of σy = 37 nm :
aim at still higher precision and stability for remaining of current run



Optics reform of 2012 summer

By IPBSM group@KEK

Proved greatly effective in 2012 winter run

Aim:

- **Suppress systematic error sources**
- **Higher alignment alignment precision & reproducibility**

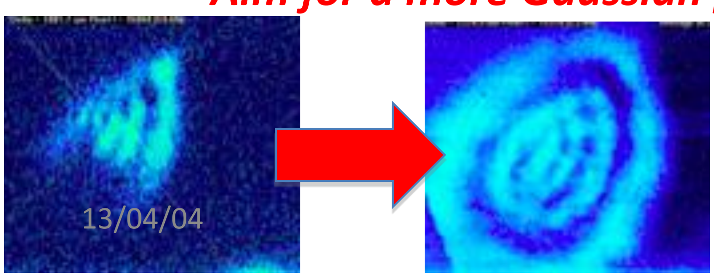
improvements	details
alignment precision ✓match focal point to IP ✓Injection position / angle into lens ✓Re-optimize expander / reducer **consistency , reproducibility** before / after mode switching	• focal point scan for all modes • CW laser + redefined ref. lines on new base plates • **new IP target** (screen monitor) • **θ mode switching tech. :** **{small linear stage + mirror actuators }** now: independent for each mode (before: shared rotating stages)
balanced profiles	suppress difference in path length & focal point

Tuning of main laser

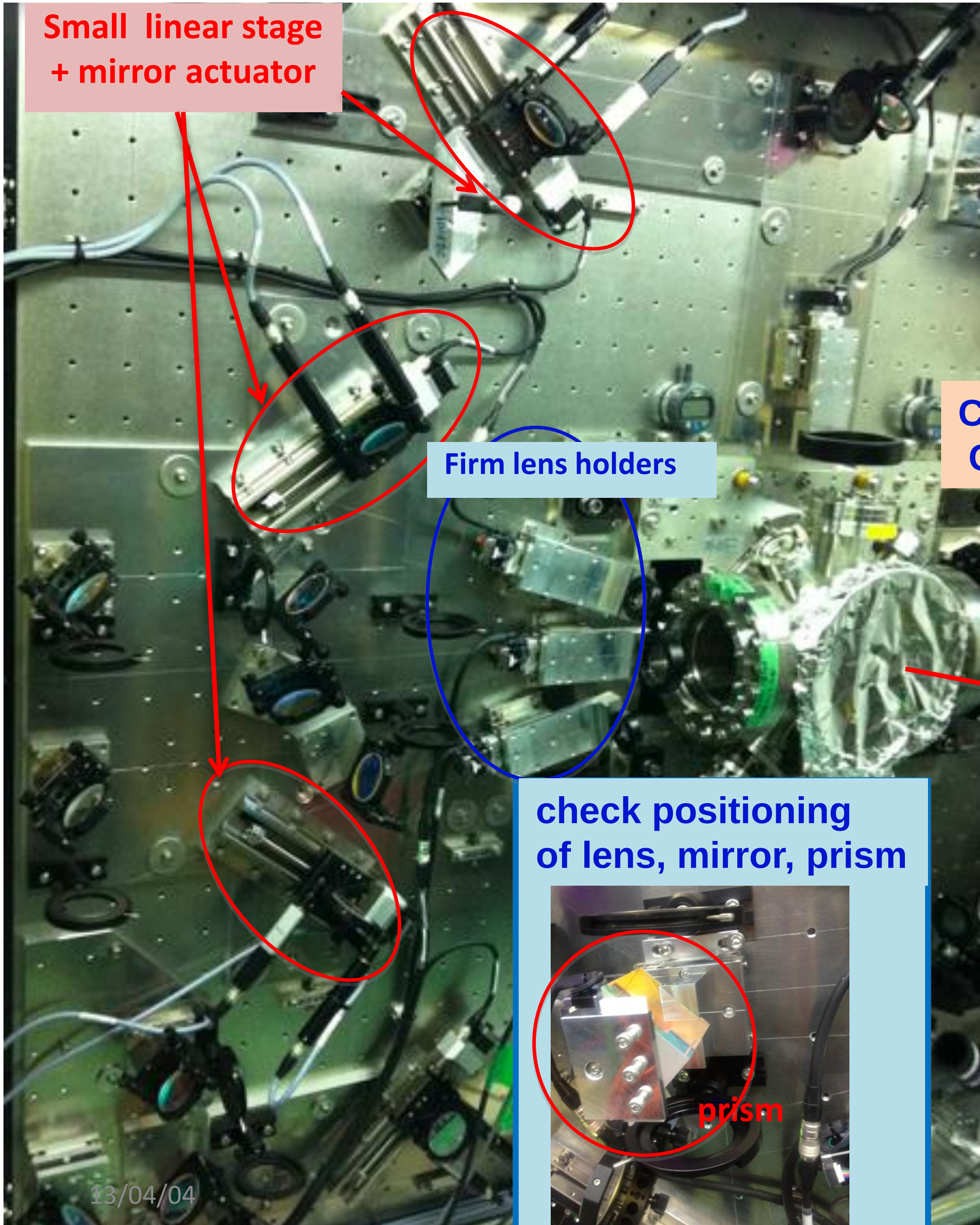
by Spectra Physics

ex: spring 2012 :
Adjust curvature of laser cavity mirrors

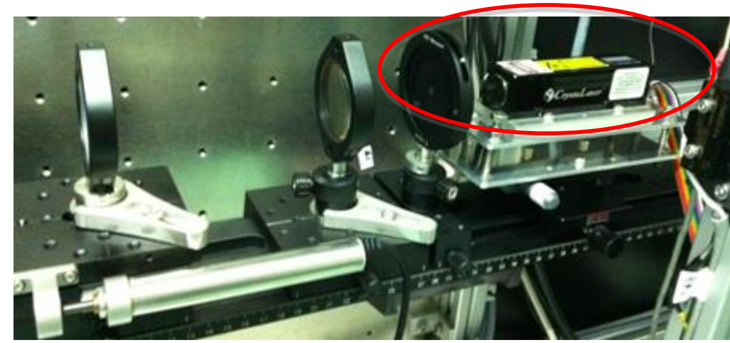
Aim for a more Gaussian profile



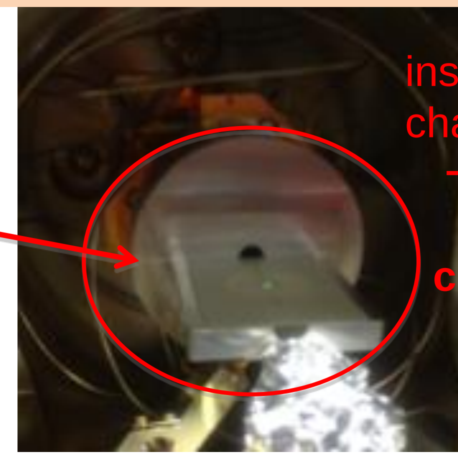
- ❖ Reform laser profile and spatial coherence (adjust YAG rod & cavity mirrors)
- ❖ Exchange flash lamp
- ❖ seeding laser tuning (→ oscillation stability)



just after injection onto vertical table



Confirm fine alignment using CW laser and transparent IP target



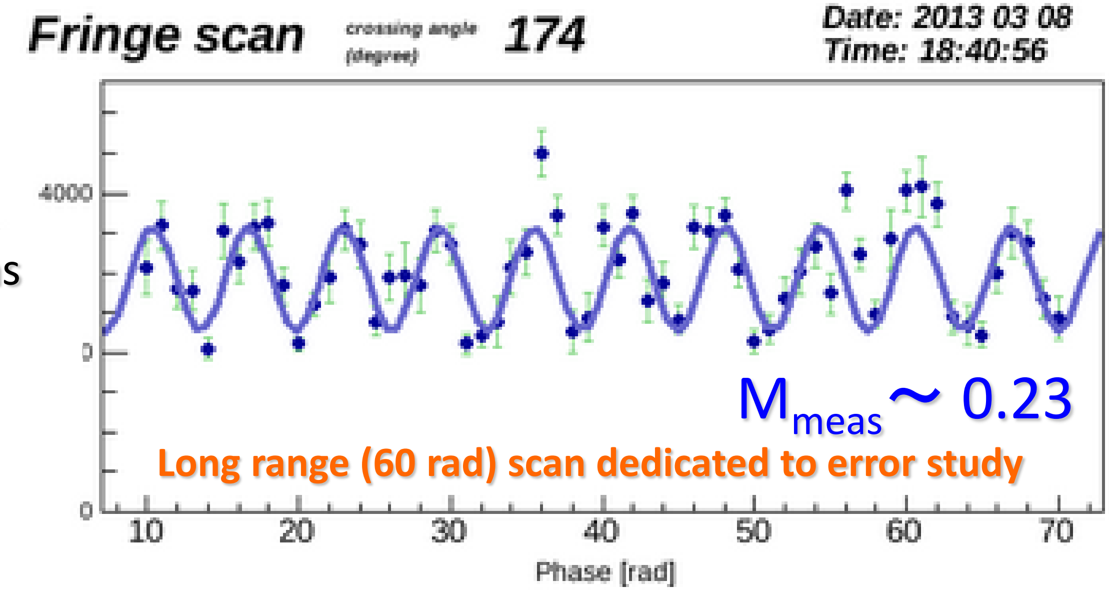
Performance Evaluation #1: Stability

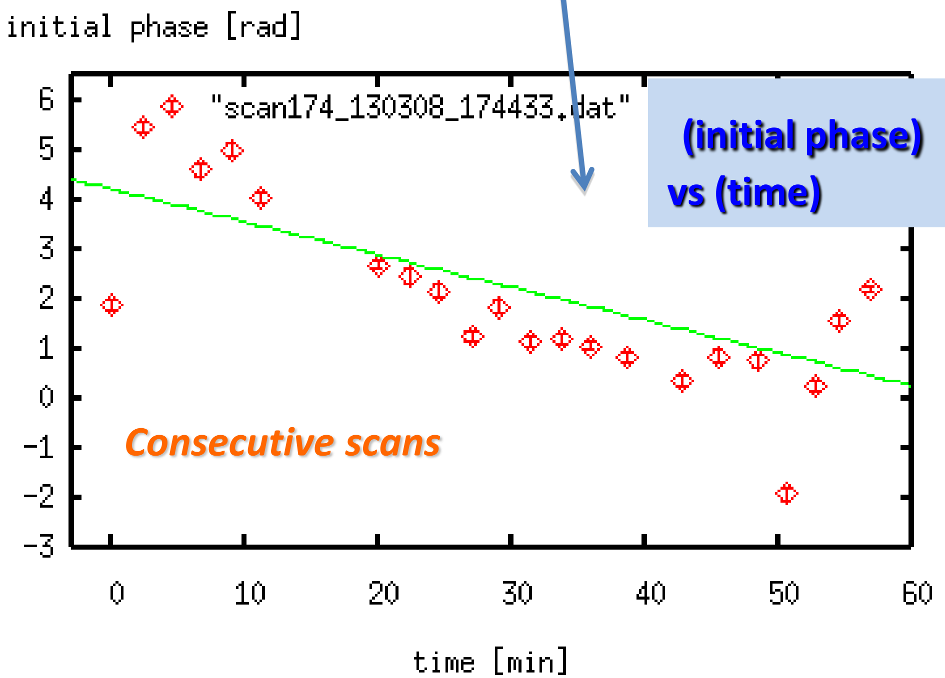
Signal jitter sources
phase drift / jitter
Laser timing & power

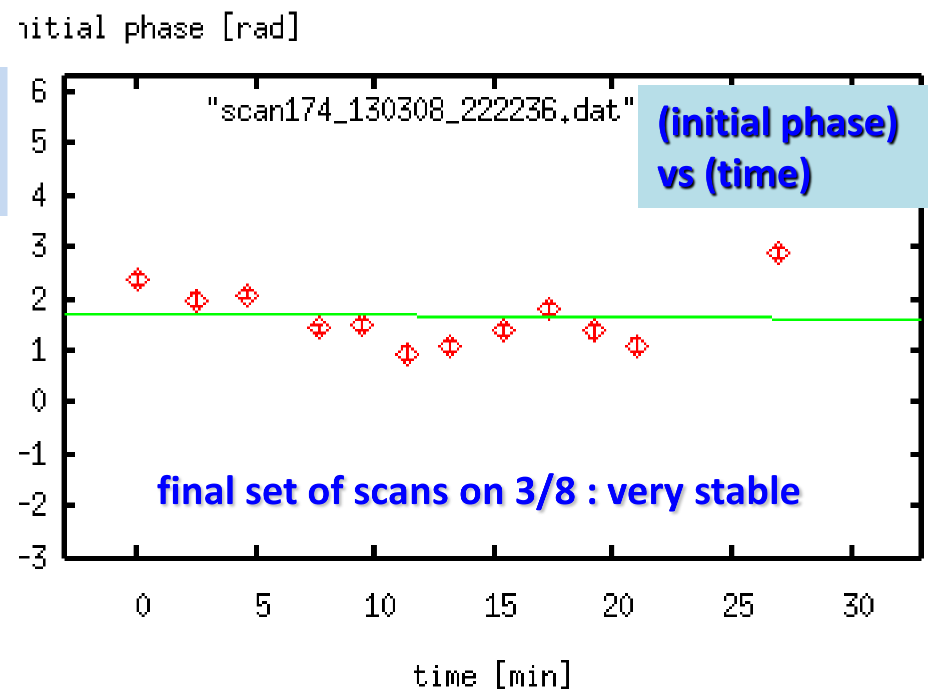
Phase Drift

Observed in consecutive fringe scans

drift < 70 mrad / min
(→ negligible)







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Demonstration of stability in IPBSM operation : signal Jitter

long term stable performance is maintained under various scan conditions ➔ considered as "standard"

Long range scans dedicated to error studies compared to (20 rad) scans immediately before / after

→ jitter is not increased for longer range scans or finer scans, just as stable

(beam & IPBSM conditions, analysis method kept consistent)

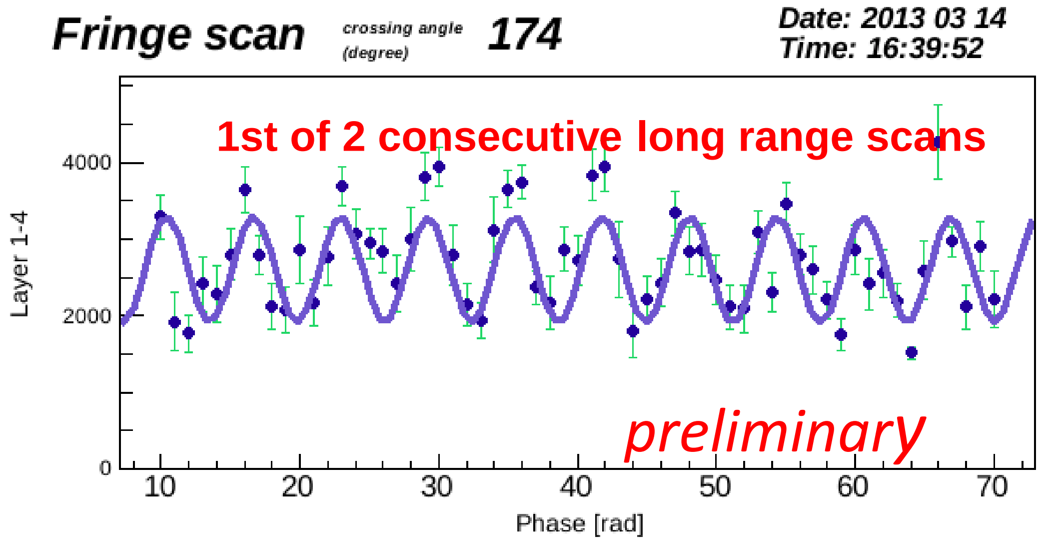
Comp Sig. jitter is quite consistent at generally 20 – 25 % (@peak of fringe scans)

data	range	Comp sig jitter (@peak of fringe scans)
130314_155758	20 rad Nav = 10	21.1 %
130314_165737	20 rad Nav = 10	25.2 %
130314_163420	20 rad **Nav = 20**	24.3%
130314_163952	**60 rad** Nav = 10	25.4 %
130314_164840	**60 rad** Nav = 10	26.3 %

Long scans from other periods show similar stability

Fine scan
Nav = 20 events
at each phase step

Long range scans
60 rad
(usually 20 rad)



Stability is maintained for long range scans as well

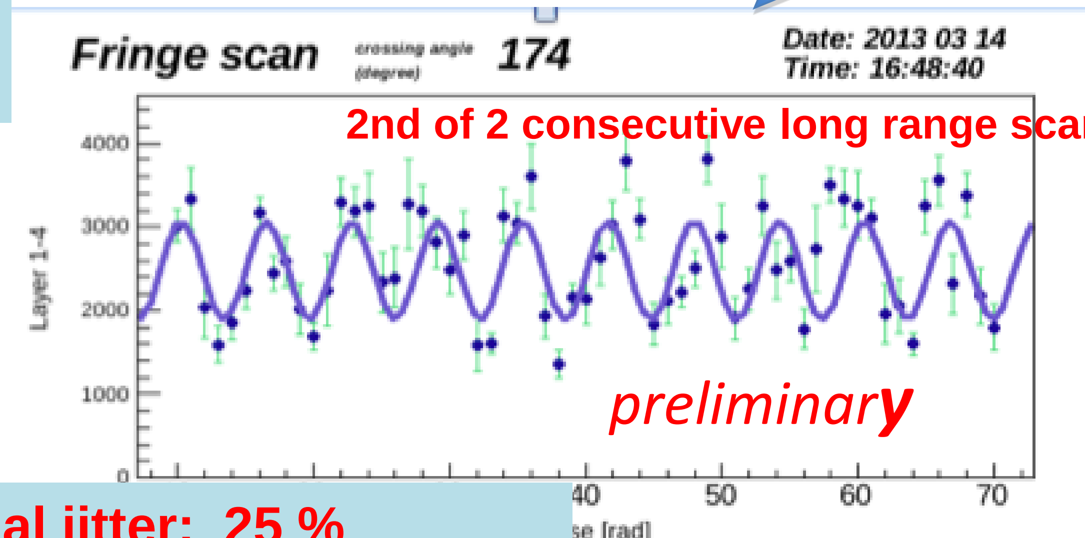
Other fluctuation sources also as stable as typical
(BG, timing, power, ect…)

Signal jitter: 24.3 %
(at fringe scan peaks)
S/N = 5.8

Fit results: Av(1.0+M*cos(x+Ph))*

Modulation: 0.265 +/- 0.017

Beam Size: 69.0 + 1.7 -1.7 nm



Signal jitter: 25 %
(at fringe scan peaks)
S/N = 5.8

Fit results: Av(1.0+M*cos(x+Ph))*

Modulation: 0.237 +/- 0.017

Beam Size: 71.8 + 1.9 -1.8 nm

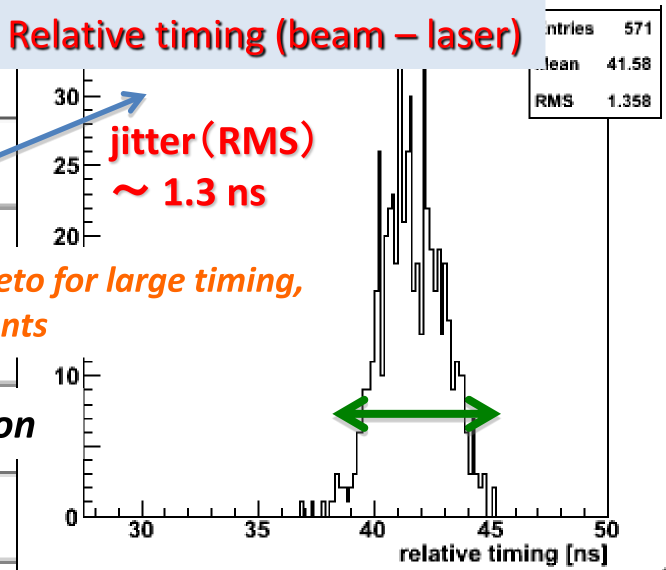
Signal Fluctuation Sources

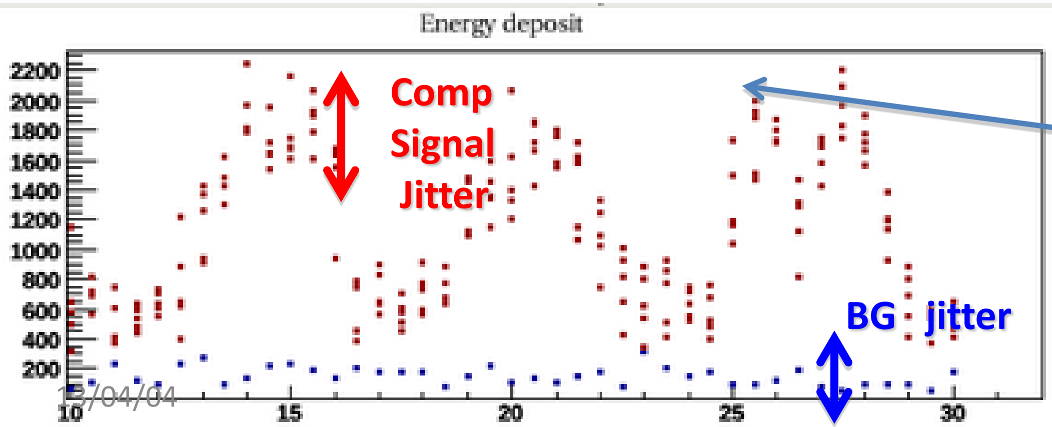
2013, 174 deg mode

Fluctuation sources	Contribution to ΔS_{stat}	
Laser timing	~ 7 %	
Laser power	0.5 %	
Relative beam –laser position	unknown, ***under investigation***	
BG fluc	3 -8 %	*scaled by S/N
detector energy resolution	0.4 %	* Intrinsic CsI detector energy resolution GEANT4 sim. (not including Comp Signal angular jitter)
Comp γ stat.	3 %	
ICT monitor accuracy	< 5 %	*measured Comp sig energy normalized by beam intensity*

Prepared offline veto for large timing, power jittered events

Relative timing (beam – laser)





signal jitter derived directly from actual fringe scans (peaks) : 20 – 25%

Phase Jitter / Relative Position Jitter

Could be dominant fluctuation source

Currently testing new evaluation method

Compare signal jitter between fringe scan peak & mid & bottom points

affected differently by rel. pos. jitter

aim to derive M reduction

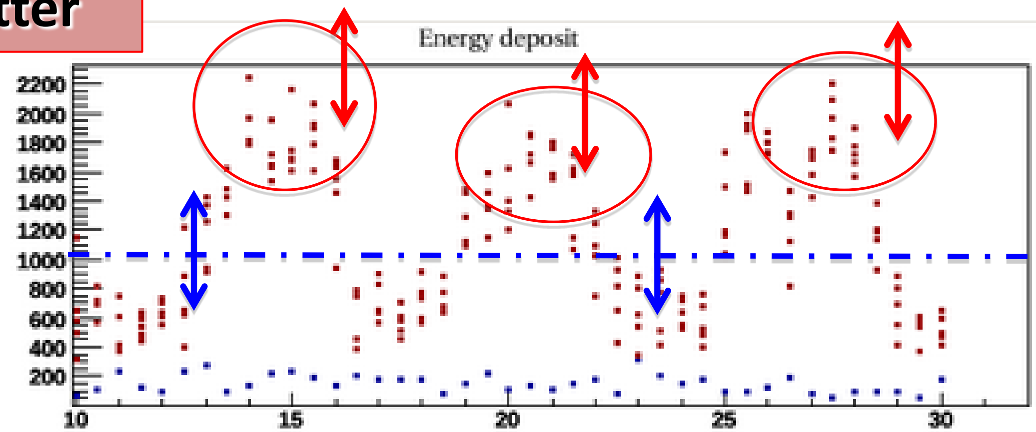
$$y \to y + \Delta y$$

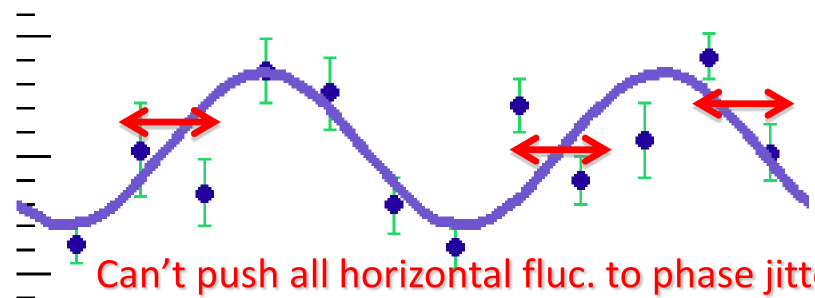
$$\sigma_y^2 \to \sigma_y^2 + (\Delta y)^2$$

if **Δy < 0.3 * σy**

Cδy > 90 % for σy = 65 nm

$$C_{\Delta y} = \exp\left(-2\left(k_y \Delta y\right)^2\right) \qquad k_y = \frac{2\pi}{\lambda}\sin\left(\frac{\theta}{2}\right)$$



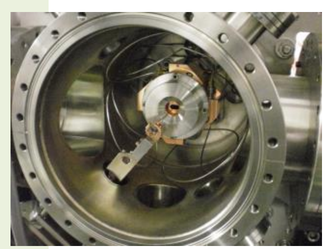


Can't push all horizontal fluc. to phase jitter

Issues:
- hard to separate beam position jitter from other fluctuation sources (laser pointing jitters, drifts, ect….)
- jitters can vary greatly over time

Plans:
- improve analysis precision with **more statistics** (longer range & finer step s) → **April beam time**
- Consider alternative methods

- Anticipate O(nm) res. measurement of beam position jitter at IP by **IPBPMs** (under commissioning)



Performance Evaluation #2:
Study of Modulation Reduction Factors

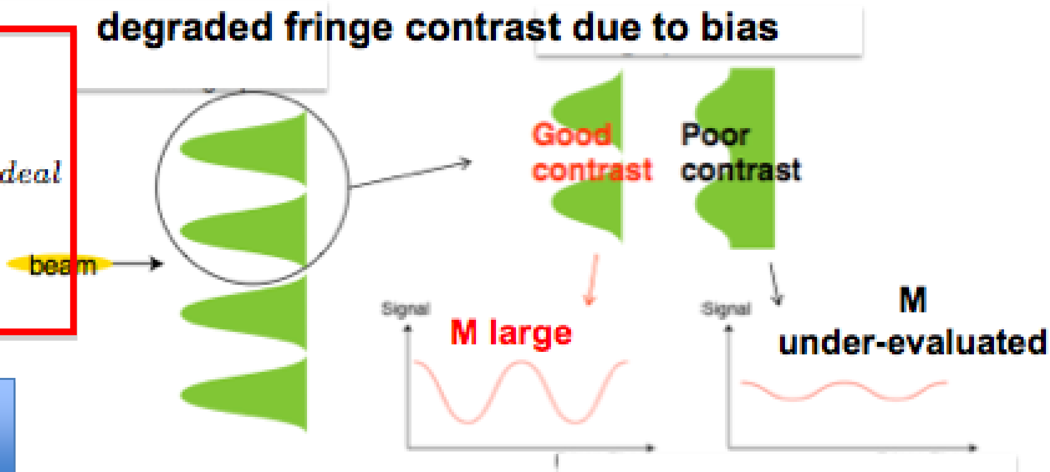
Study of M reduction

Under-evaluate M, over-evaluate σ_y

Modulation Reduction Factor

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

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



How to evaluate M reduction?

（1） "Direct Method"

consecutive mode switching , under same beam condition (e.g. : 2° → 7° → 30°)

use a σy that yields very high M at low θ mode → observe upper limit on Mmeas

Note) **apply to a particular dedicated data sample**

（2） "Indirect Method"

Evaluate each individual factor offline and "sum up"

Note) **represents the typical conditions of a particular period**

however …… **hard to derive overall M reduction**

(e.g. factors vary over time, lack quantitative evaluation, only can get "worst limit", ect …..)

Individual M Reduction Factors :

Mar 2013, 174 deg

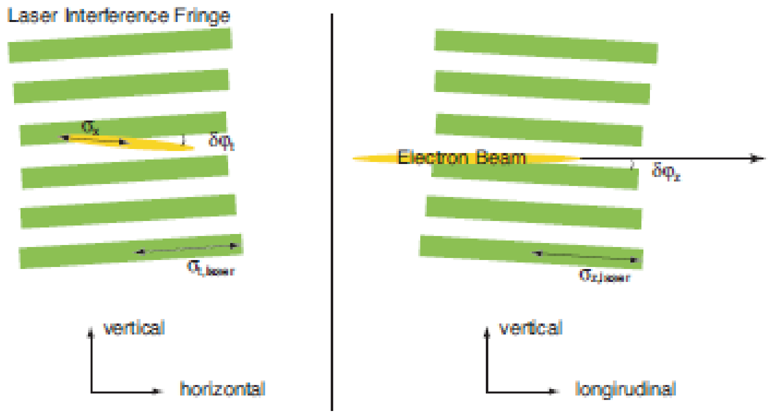
Represent typical condition of a particular period

Error source	M reduction factor
Fringe tilt (z, t) Limited by alignment precision	During beamtime: final optimization by **"tilt scan"** Major bias if unattended to
profile imbalance	Uncertain for now **Adjustment of transport pipe** *projected laser profile (spot size) of laserwire scan not strictly Gaussian* **→ aim for improvement and precise evaluation of profile balance**
power imbalance	Cpow > 99.1 % **Measured directly for each path**
polarization	Optimized to **S polarization state** using λ / 2 plate **Measured laser polarization and half mirror reflective properties**
Phase drift	Not a major issue for now **Drift : < 70 mrad / min** during consecutive fringe scans
Laser path alignment	Ct,pos : ~ 99 %, Cz,pos : > 98 % **Resolution of mirror actuators aligning laser to beam**

Still uncertain for quantitative evaluation:

- **relative position jitter (phase jitter)**
- **Spatial coherence**

Could be major bias



transverse   longitudinal

evaluation of Fringe Tilt

Mismatch in axis between fringe and beam

past method:

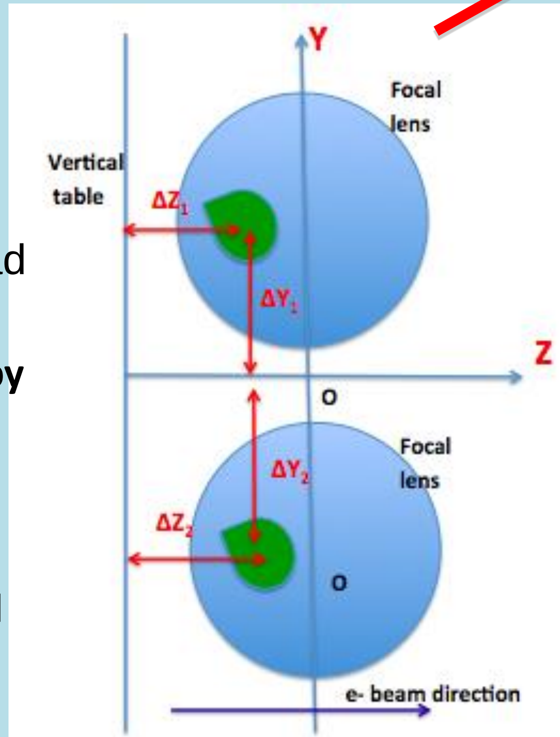
observe laser paths

Problems:

- **Precision** limit
  Δ = 0.5 mm ←→ few mrad

- **Position may have drifted by the time of fringe scans**

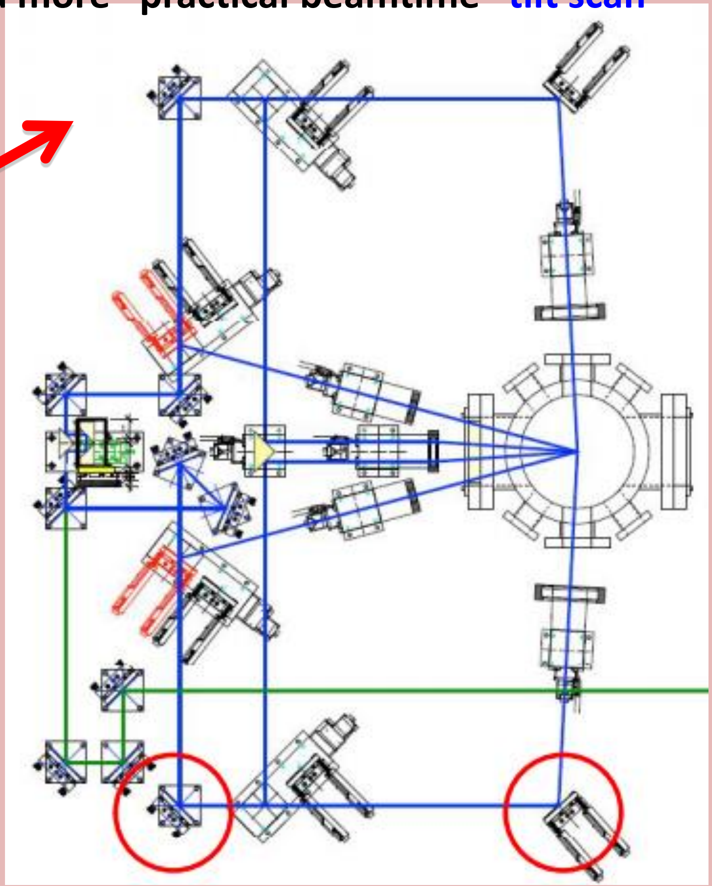
- For transverse tilt:
  beam may also be rotated



what is reference for tilt adjustment??

Current method :

a more practical beamtime "tilt scan"



change M174L and injection mirrors

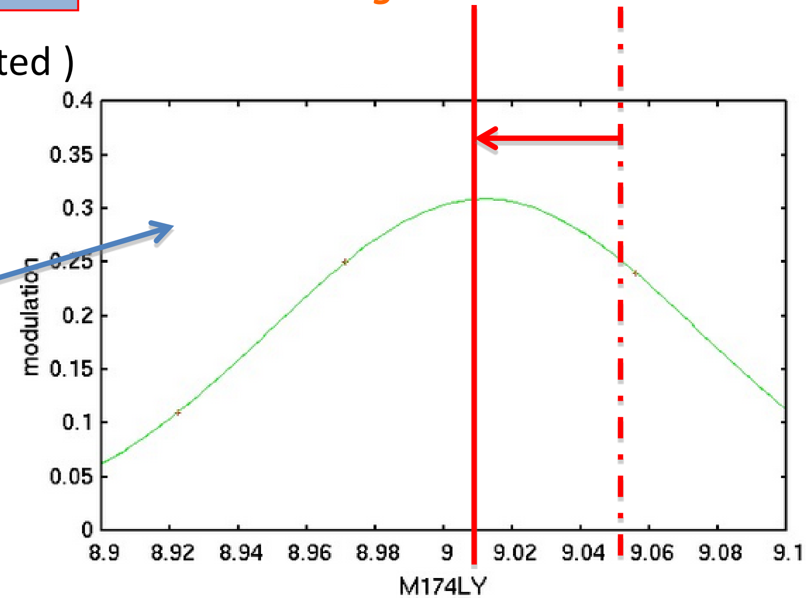
→Maximize M

(details on next page)

Fringe Tilt : practical application of **"tilt scan**

important adjustment in aim of eliminating M reduction

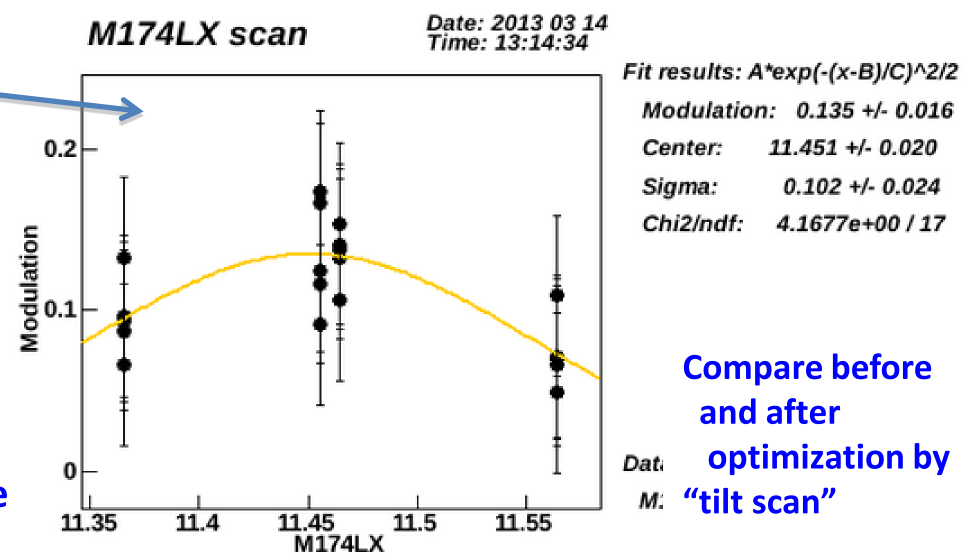
Can observe M reduction Ctilt (70 - 80% if left uncorrected)
directly from change in M wrt e beam
(regardless of beam tilt)



Ex#1 3/8 : fringe pitch adjustment:
changed M174L Y (8.9 mm → 9.014 mm)
Max. M increased as 0.07 → 0.32

(study of fringe tilt by Okugi-san)

EX#2: 3/14 : fringe roll adjustment :
(**M174XL changed** > 0.1 mm)
Max M increased as 0.1 → 0.14



Each time change mirror,
accessed to IP to align path
→ **make necessary mirrors remote controllable**

Compare before and after optimization by "tilt scan"

Plan for assessment of M reduction factors

priorities

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

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

For "uncertain" individual factors: (e.g. Relative position jitter, spatial coherence, ect ……)

Do we really have large bias ? how much ? → ***how to find out ??***

test using "direct method"

At a low θ mode : measure a large M (near resolution limit) using a sufficiently small σy

compare results with higher θ modes

example:

if we measure M corresponding to σy = 350 nm at 7 deg mode

then expect **M = 0.98 at 2.75 deg mode** *(try to keep within 2-8 deg)*

what if we get only 0.95 ??? (averaged over many scans) → **Ctotal ∼ 0.97**

this means **no individual bias factor worse than 0.97** (at least not for this particular period)

Note:

- conditions may vary greatly over time → confirm with repeated measurements
- need prove whether these factors depend on Θ mode ??

Summary

Shintake Monitor (IPBSM):

beamsize monitor using laser interference

- Only existing device capable of measuring σy < 100 nm
- Indispensible for achieving ATF2 goals and realizing ILC

< Status >

- **contribute with stable operation to continuous beam size tuning**
- **Consistent measurement of M > 0.3** （174° mode) *at low beam intensity*
  correspond to σy ~ 65 nm (assuming no M reduction)
- Application of various linear / non-linear multi- knobs
- dedicated studies of e beam and IPBSM errors

<towards performance improvement>

Performance significantly improved by laser optics reforms

suppressed error sources, improved laser path reliability & reproducibility

Goals

Towards confirming σ_y = 37 nm

- **Maintain / improve beamtime performance :**e.g. stability, precision
- **Assessment of residual systematic errors** → derive the "true beam size"
- **stable measurements of σy* < 50 nm within this run**

Backup

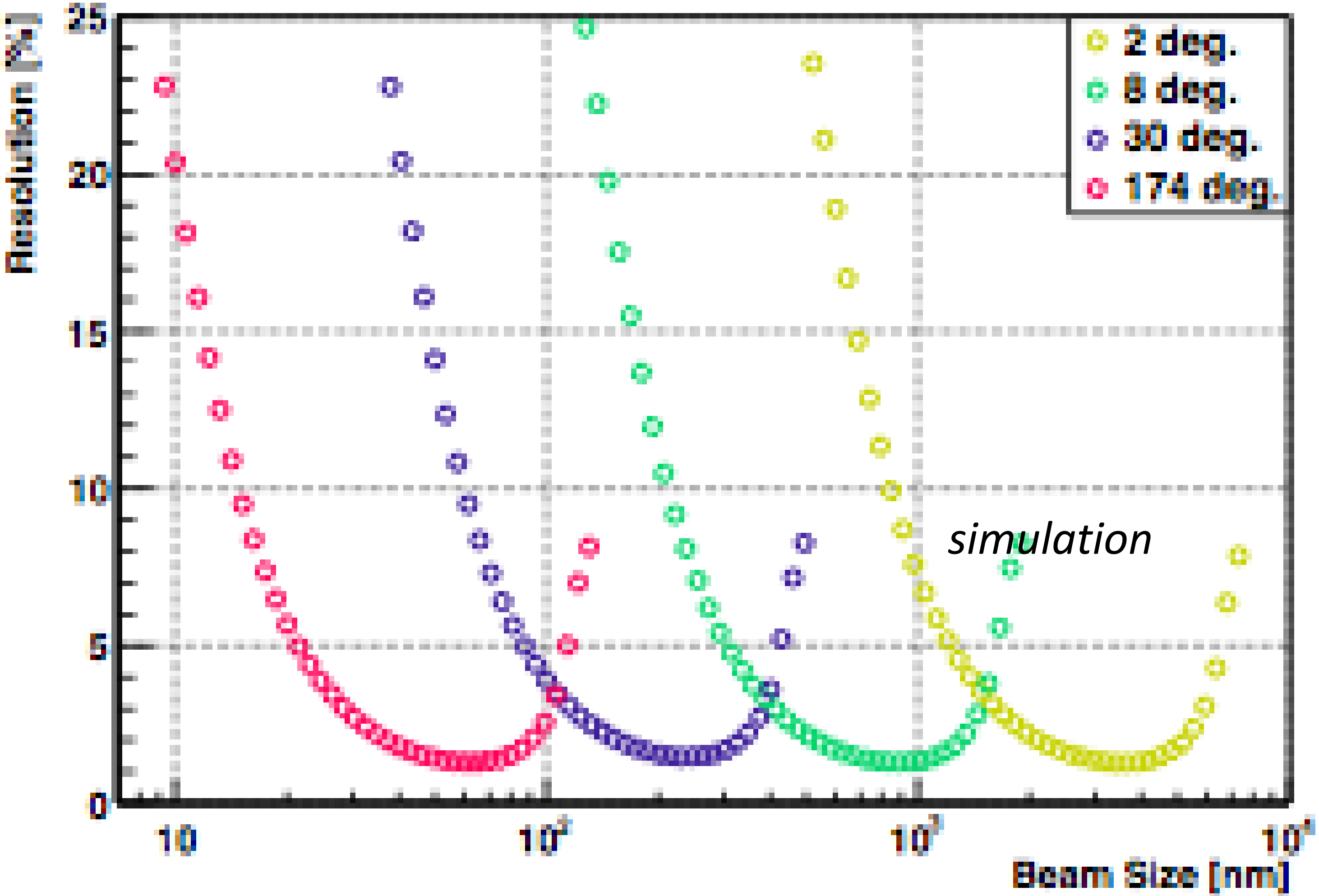
Expected Performance

$$37 \pm 2\,(\text{stat.})\ ^{-0}_{+4}\,(\text{syst.})\quad \text{nm}$$

must select appropriate mode according to beam focusing

Resolution for each θ mode

Measures
σy* = 25 nm ~few μm
with < **10% resolution**

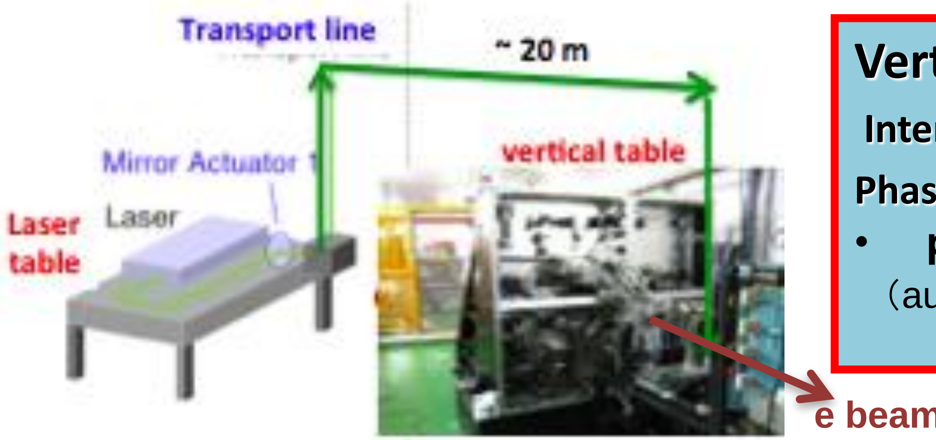


Laser Optics

Laser table

Source , SHG

Diagnostic devices



Vertical table

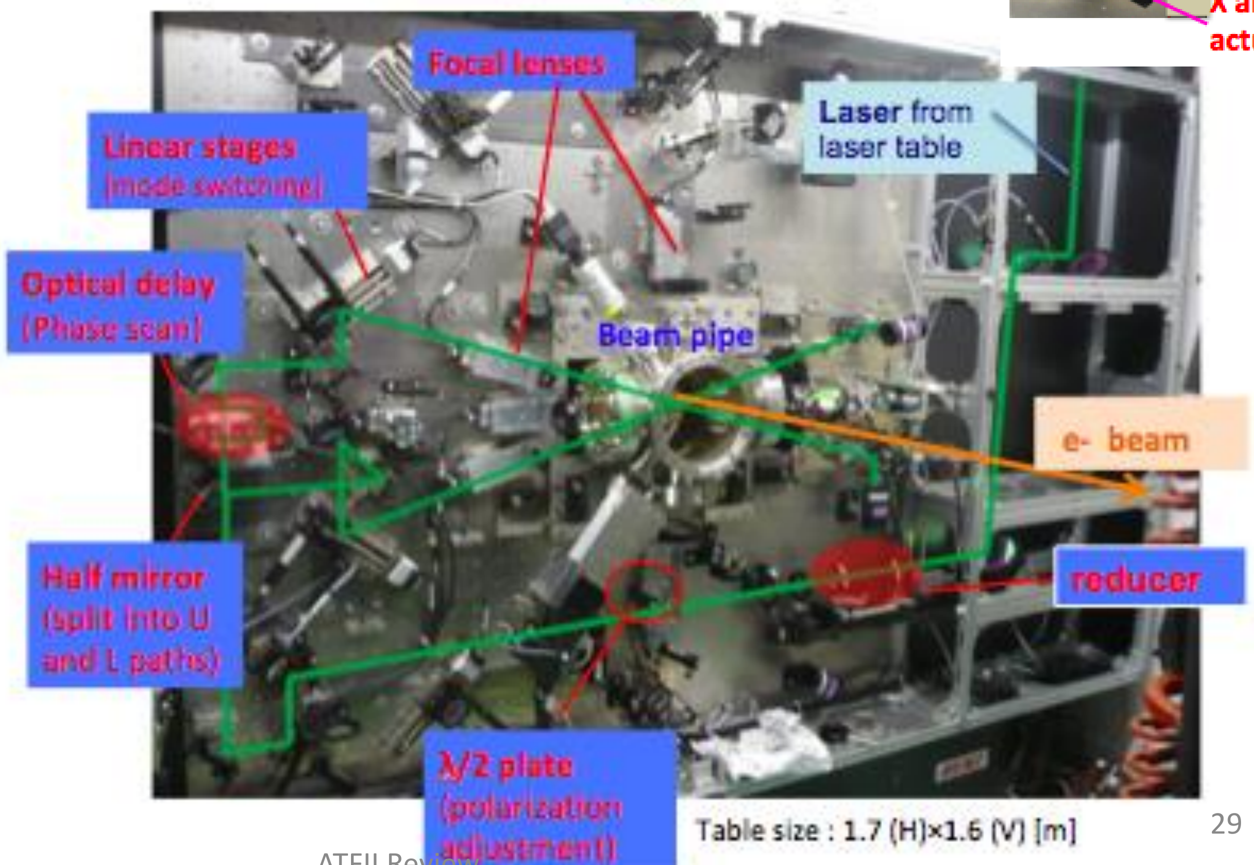
Interferometer

Phase control (piezo stage)

- **path for each θ mode**

（auto-stages + mirror actuators ）

Layout of Vertical table (ex: 30 deg mode path)

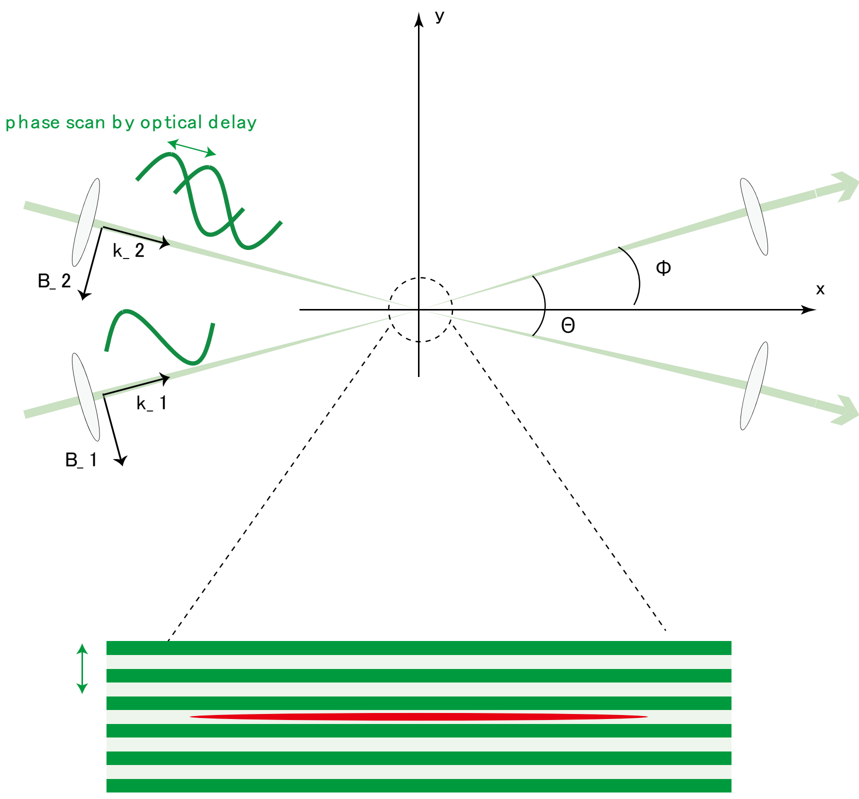


Nd :YAG Q-Switch laser

PRO350 Spectra Physics

Wavelength	532 nm (SHG)
Pulse Energy	1.4 J
Peak power	164 MW
Pulse Width	8 ns (FWHM)
f_{rep}	6.25 Hz
Line Width	$< 0.003\ cm^{-1}$
Timing Stability	< 0.5 ns
Energy Stability	± 3%

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

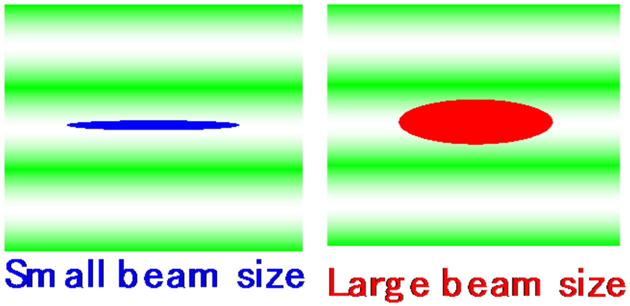
Laser magnetic field

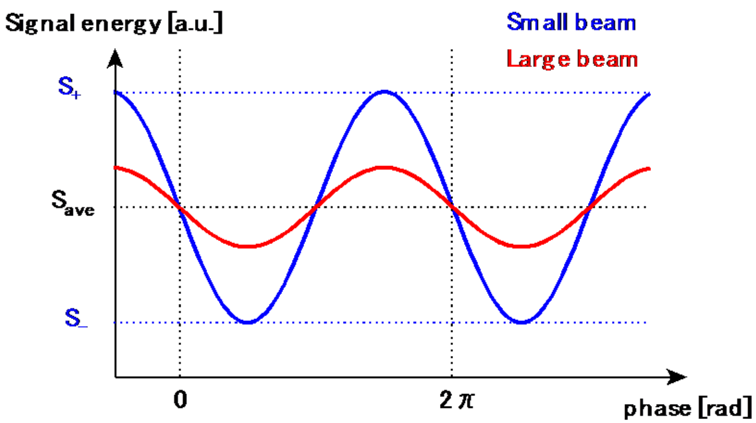
Electron Beam profile with beam size σ_y along y-direction

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

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

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





$S_\pm$: 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

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

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

Laser timing stability

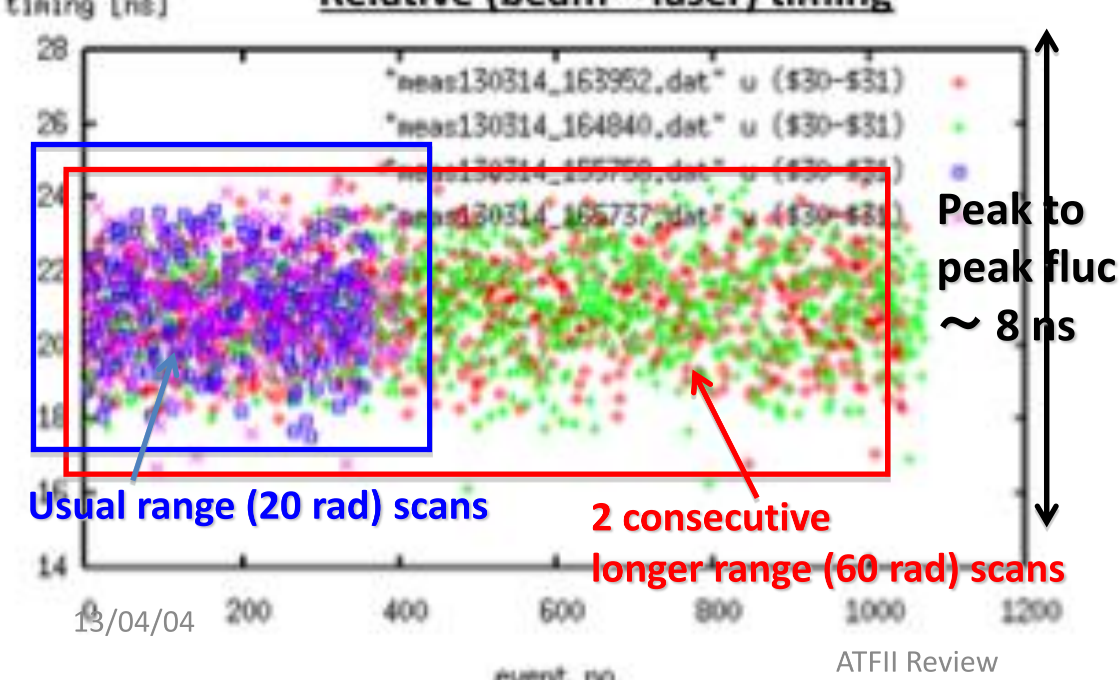
- beam time: **"timing scans"**
- relative timing matched by TD2s to optimize collision
  - ➢beam : BPM signal → TDC
  - ➢laser : PIN-PD signal → TDC

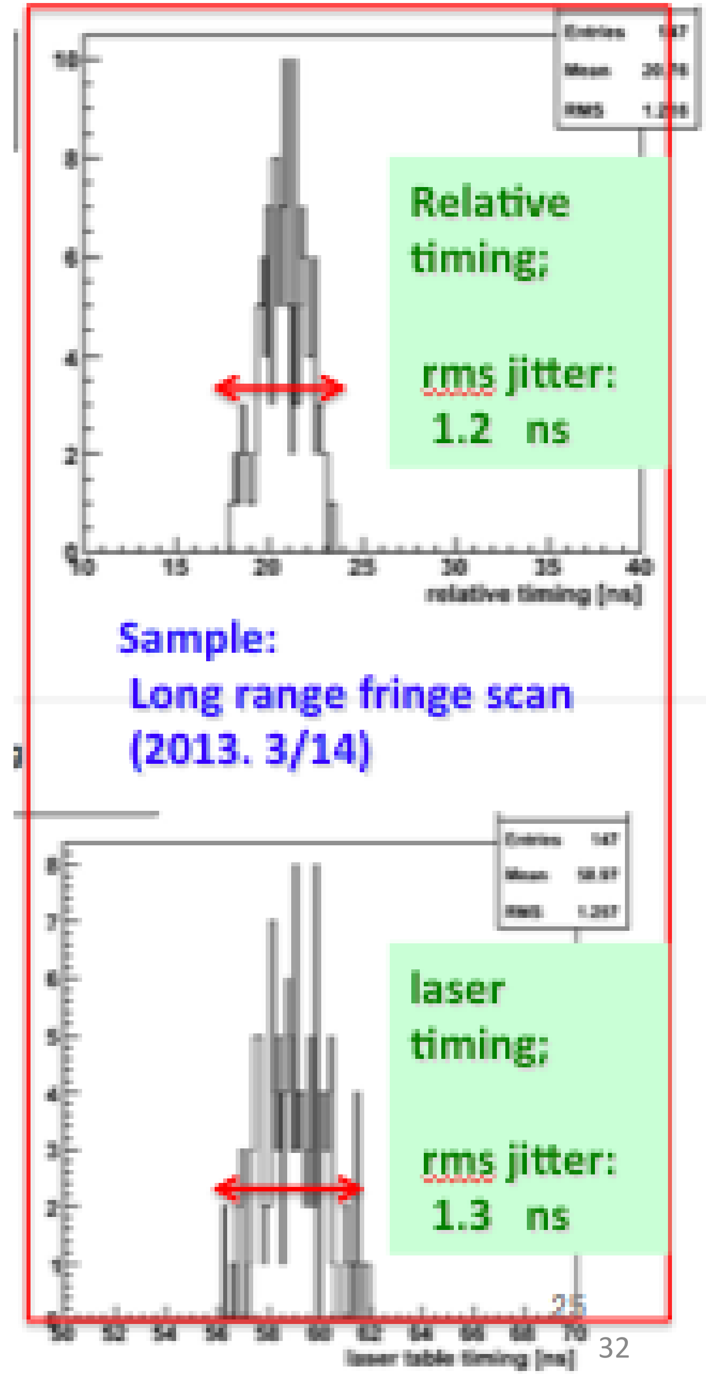
- **PIN-PD waveform jitter** (due to external trigger?)
  (peak-to-peak) ∼ few ns (on oscilloscope)
  (rms) ∼ 1.3 ns

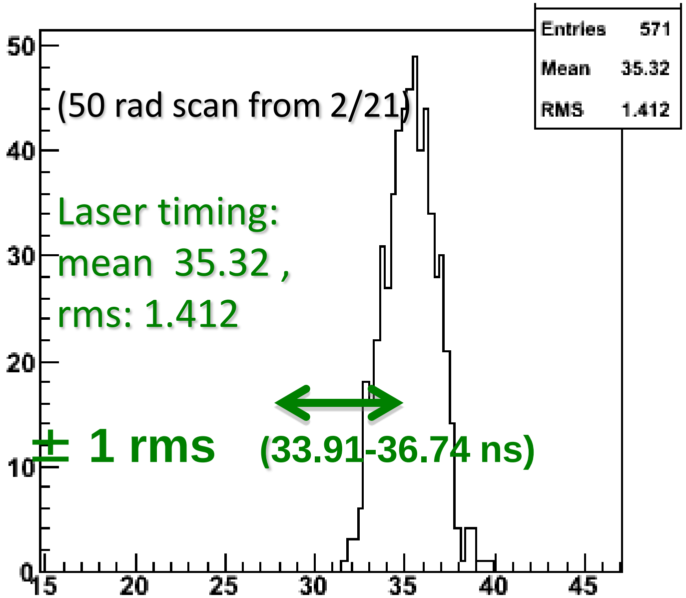
→ contribute **a few % to Comp. signal jitters**

$$\Delta S_{timing} \approx \frac{1}{2}\left(\frac{\Delta t}{\sigma_{t,laser}}\right)^2$$

Relative (beam – laser) timing







Offline laser timing cut

Try different cut ranges: small improvement in Signal Jitter

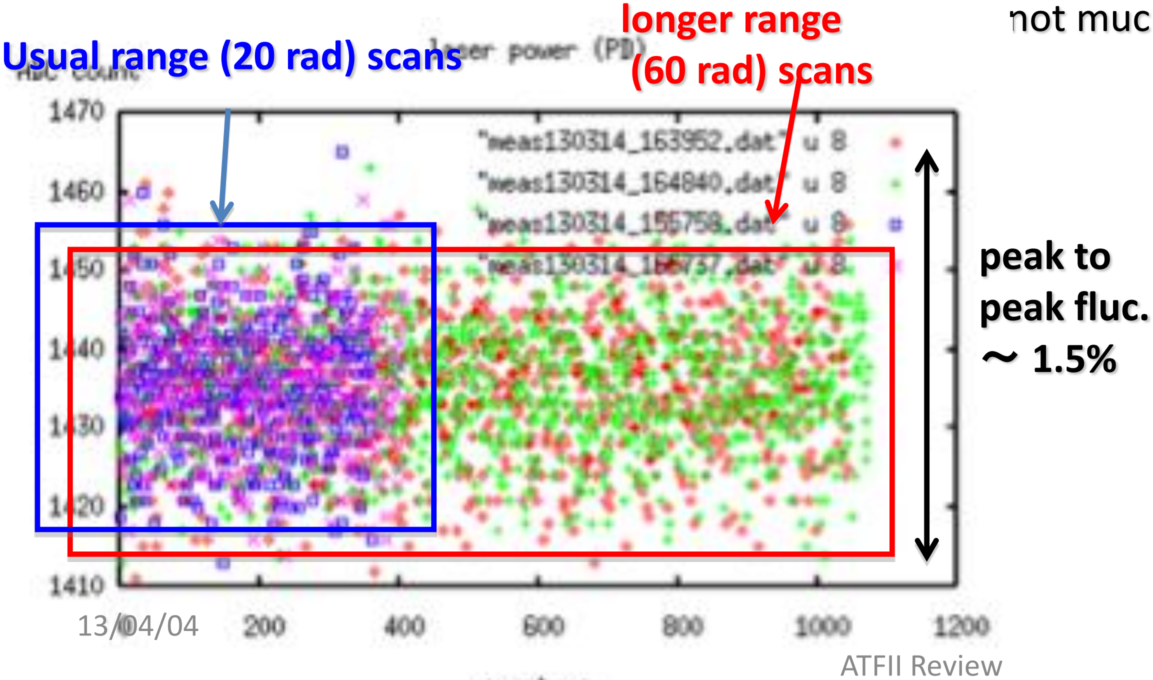
❖**cut: ± 1 rms : Sig jitter : 18.8 %**

❖**No cut: Sig jitter : 21.4 %**

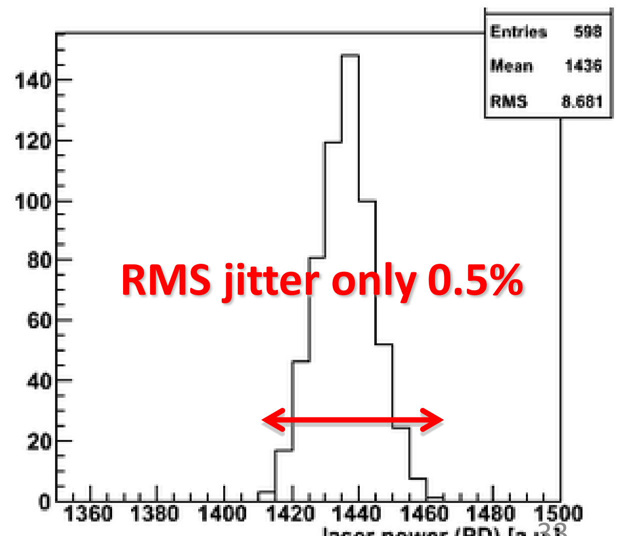
•significant improvement is not always observed
timing not seriously jittered in the first place //

Plan: keep veto method in practice
apply when necessary to larger timing jittered scans
Also **tried relative (beam – laser) timing cut**
Beware of accuracy of measured timing of low current beam

Laser power stability



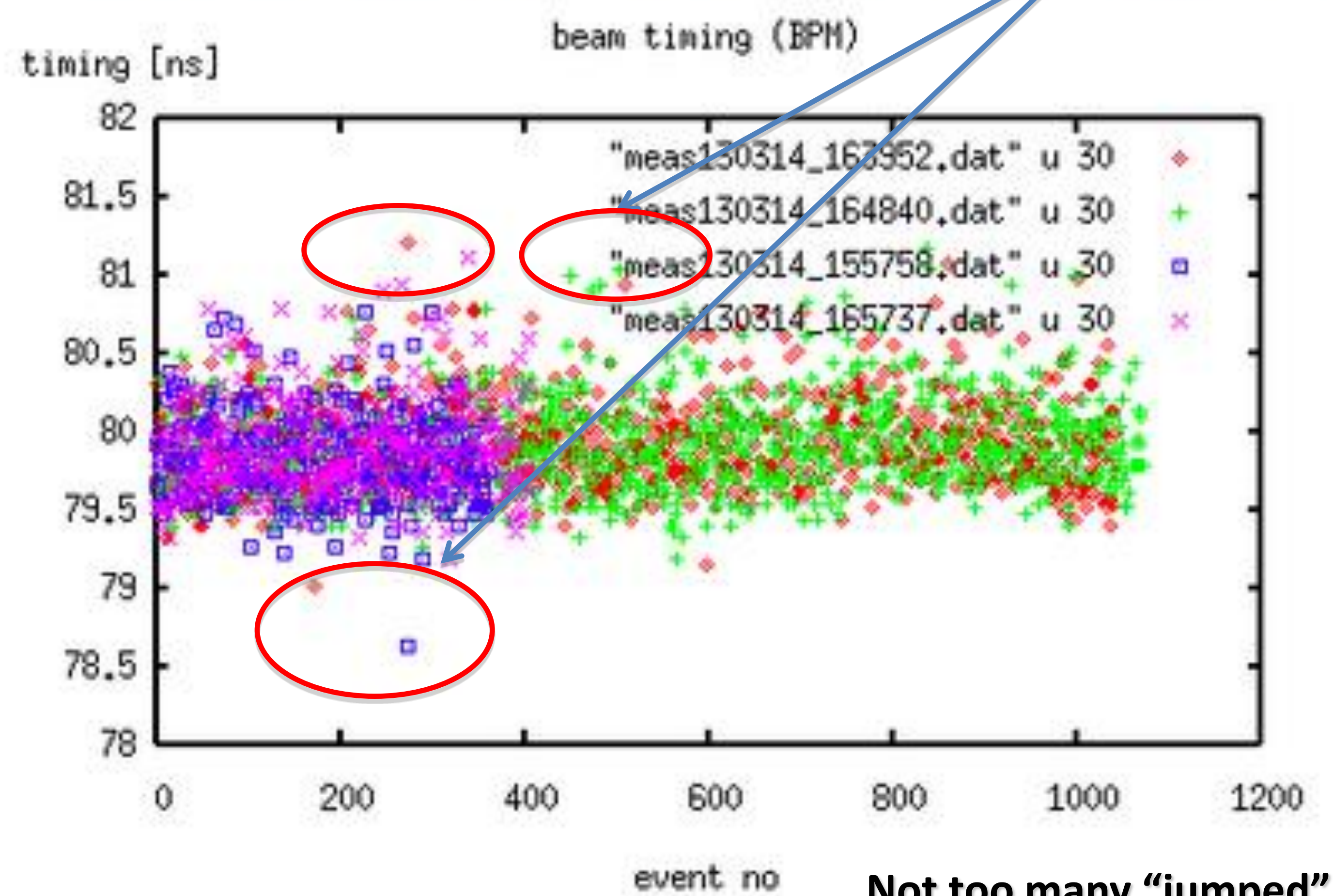
•Laser power constantly very stable
•monitored by photodiode (on laser table)
not much drift nor jitters, regardless of scan range



Beam timing status

Example: 3/14

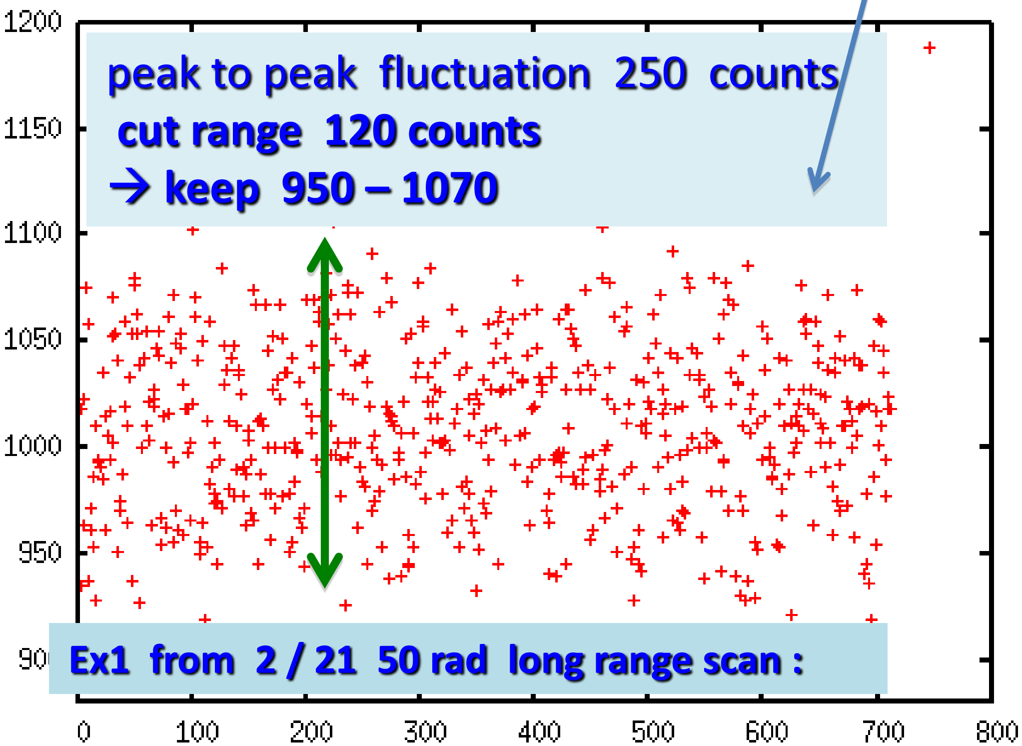
beam timing : seem like teher is half clock jump, about 1.4 ns (not 1 clock 2.8 ns)



Not too many "jumped" events currently , will keep watch

offline TDC cut → then compare signal jitter / phase jitter

- apply to **TDC cut selection** on panel
- first look at TDC raw value in data to decide cut range



•no significant improvement seen yet
• may be effective for offline / online use when timing jitter is more serious

Change in fitted M
Before : M=0.219 +- 0.013
After: M=0.233 +- 0.012

change in Chi^2
(→ small improvement ?)
Before : kai: 3.00E2/98
After: kai: 2.73E2/98

Demonstration of stability in IPBSM operation : signal Jitter

long term stable performance is maintained under various scan conditions ➔ considered as "standard"

Long range scans dedicated to error studies compared to (20 rad) scans immediately before / after

→ jitter is not increased for longer range scans or finer scans, just as stable

(beam & IPBSM conditions, analysis method kept consistent)

Comp Sig. jitter is quite consistent at generally 20 – 25 % (@peak of fringe scans)

data	range	Comp sig jitter (@peak of fringe scans)	S/N	BG jitter (scaled by S/N)
130314_155758	20 rad Nav = 10	21.1 %	6.4	4.5 %
130314_165737	20 rad Nav = 10	25.2 %	6.2	2.7 %
130314_163420	20 rad **Nav = 20**	24.3%	5.8	4.0 %
130314_163952	**60 rad** Nav = 10	25.4 %	5.8	4.1 %
130314_164840	**60 rad** Nav = 10	26.3 %	5.3	6.0 %

Long scans from other periods show similar stability

Fine scan
Nav = 20 events
at each phase step

Long range scans
60 rad
(usually 20 rad)

Individual M Reduction Factors : Dec 2012, 30 deg

Represent typical condition of a particular period

Error source	M reduction factor
Fringe tilt (z, t) Major bias Limited by alignment precision	Ct,tilt ・ Cz,tilt > 0.85% tilt ～ few mrad ?? not sure since e beam may be rotated in transv plane
profile imbalance U path vs L path	Maybe 5 : 6 (←→ Ct,pro ～ 98 %) However: projected laser profile (spot size) of laserwire scan not strictly Gaussian
power imbalance	Cpow > 98.5 % Measured directly for each path
polarization	Cpol = 96.5 ± 1.3 % (after optimization of λ/2 plate) Measured laser polarization and half mirror reflective properties
Phase drift	Cphase > 99.6 % **Drift : < 70 mrad / min** during consecutive fringe scans
Laser path alignment	Ct,pos : ~ 99 % Cz,pos : > 98 % Resolution of mirror actuators aligning laser to beam

Still uncertain for quantitative evaluation:

- **relative position jitter (phase jitter)**
- **Spatial coherence**

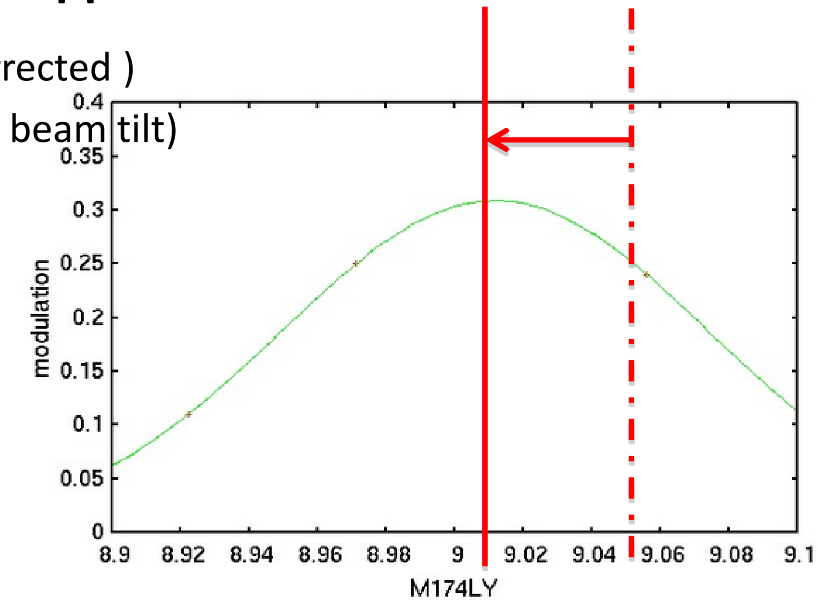
Could be major bias

evaluation of Fringe Tilt

practical application of **beamtime "tilt scan"**

Can observeo M reduction Ctilt (70 - 80% if left uncorrected)

directly from change in M wrt e beam (regardless of beam tilt)



(study of fringe tilt by Okugi-san)

Ex#1 3/8 : fringe pitch adjustment:

(**M174L Y changed** 9.056 mm → 9.014 mm)

Max. **M changed as 0.25 → 0.32**

M reduction before optimization bt "tilt scan"

Cz,tilt= 0.78 ←→ longitudinal tilt ~ 1.5 mrad

(assume σ_zlaser = 20 micron)

EX#2: 3/14 : fringe roll adjustment :

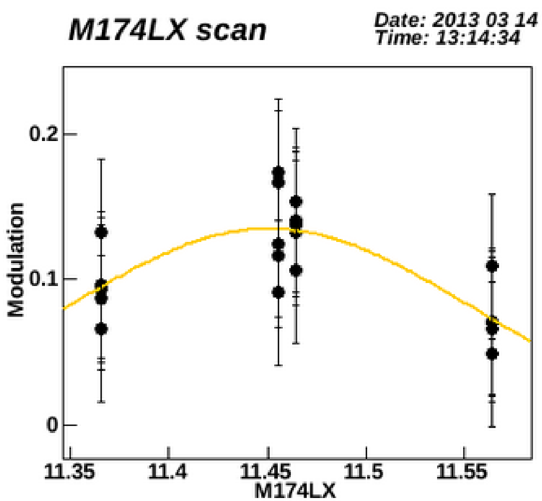
(**M174XL changed** 11.35 mm → 11.45 mm)

Max M changed as 0.1 → 0.14

M reduction before optimization bt "tilt scan"

Ct,tilt = 0.71 ←→ tranv tilt ~ 4.4 mrad

(assume σ_x = 8 micron)

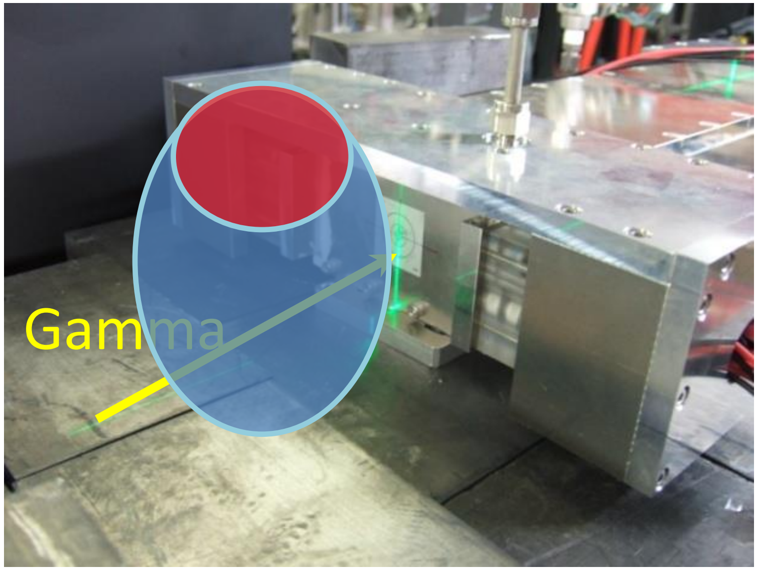


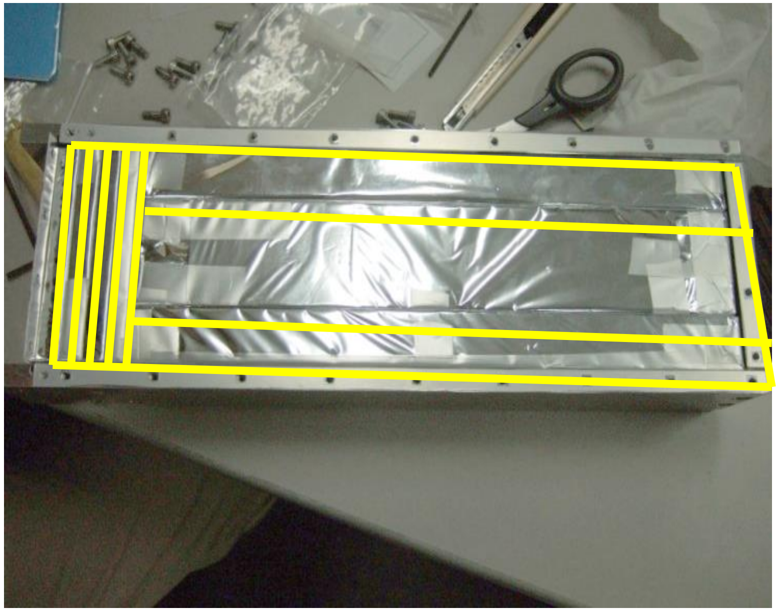
Compare before and after optimization by "tilt scan"

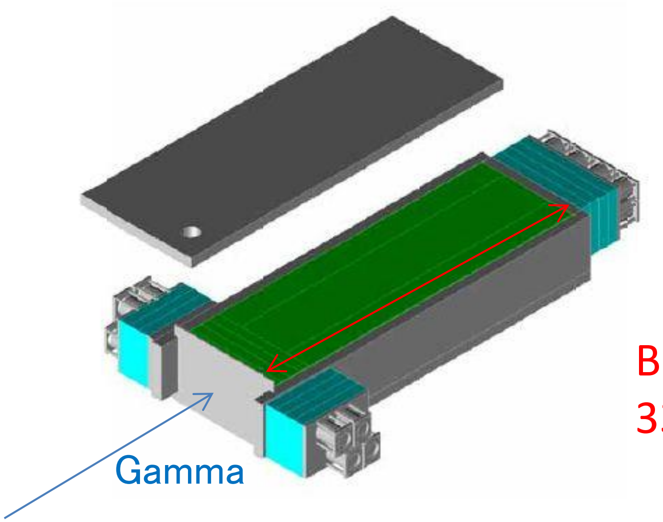
Each time change mirror, access to IP to align path

→ Will make necessary mirrors remote controllable

Gamma detector







Calorimeter like gamma detector

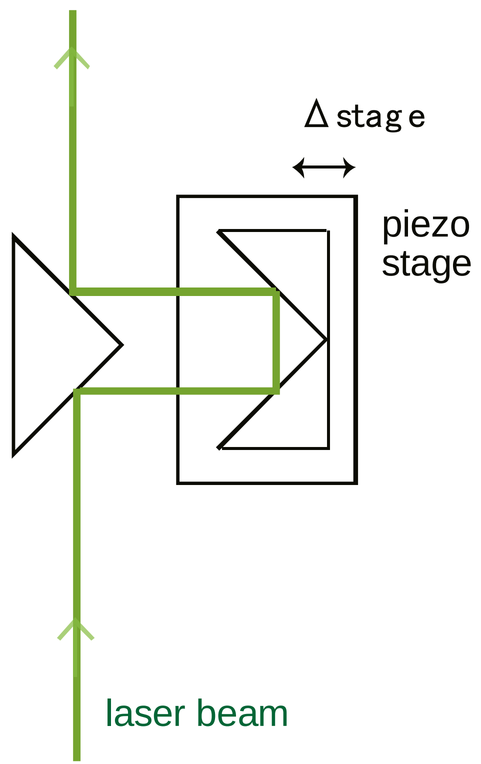
- Multi layered CsI(Tl) scintillator
- PMT R7400U (Hamamatsu Photonics)

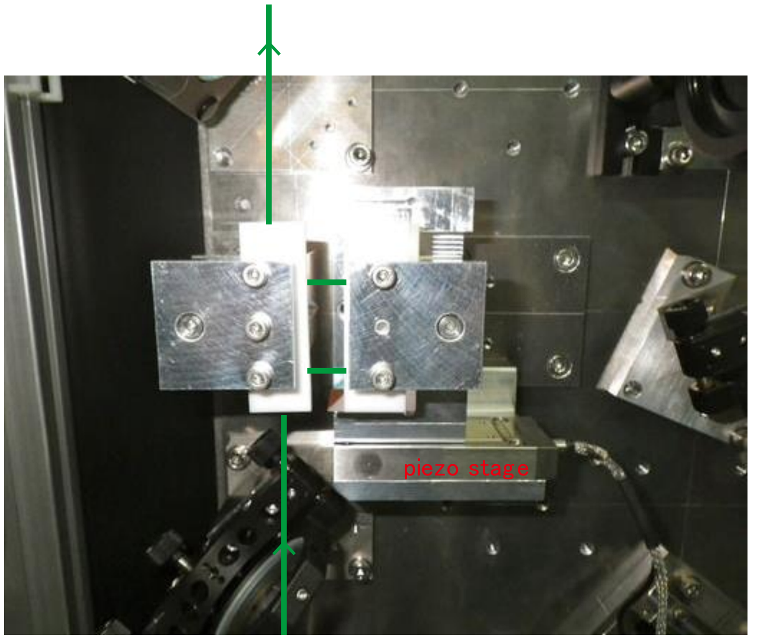
Beam longitudinal direction:
33cm (17.7radiation length)

Width : 10 cm
Height : 5 cm

Phase control by optical delay line

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



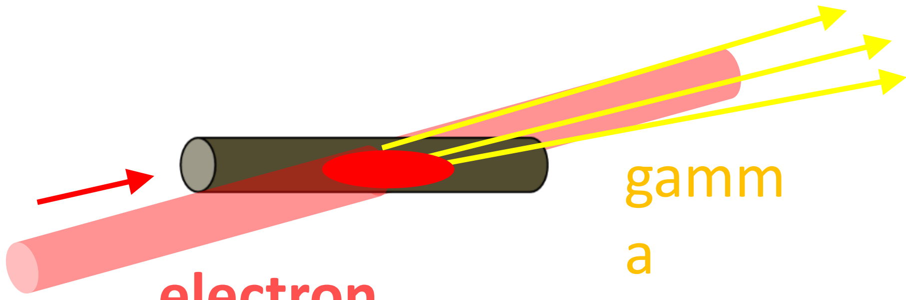


Movement by piezo stage : Δ_{stage} ➡ Phase shift

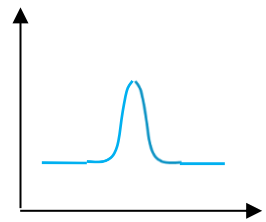
$$\Delta\alpha = 2\pi\frac{\Delta_{stage}}{\lambda}$$

measurement scheme

wire scanner, laser wire



Total energy of gamma ray

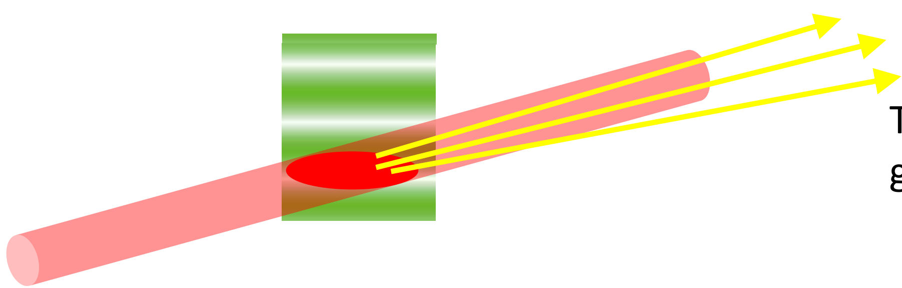


wire position

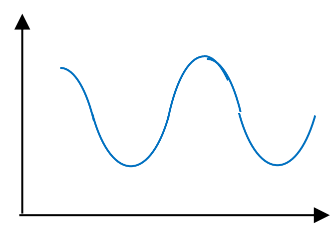
Calculate beam size from Gaussian sigma

measurable beamsize ~ 1μm

Shintake monitor



Total energy of gamma ray

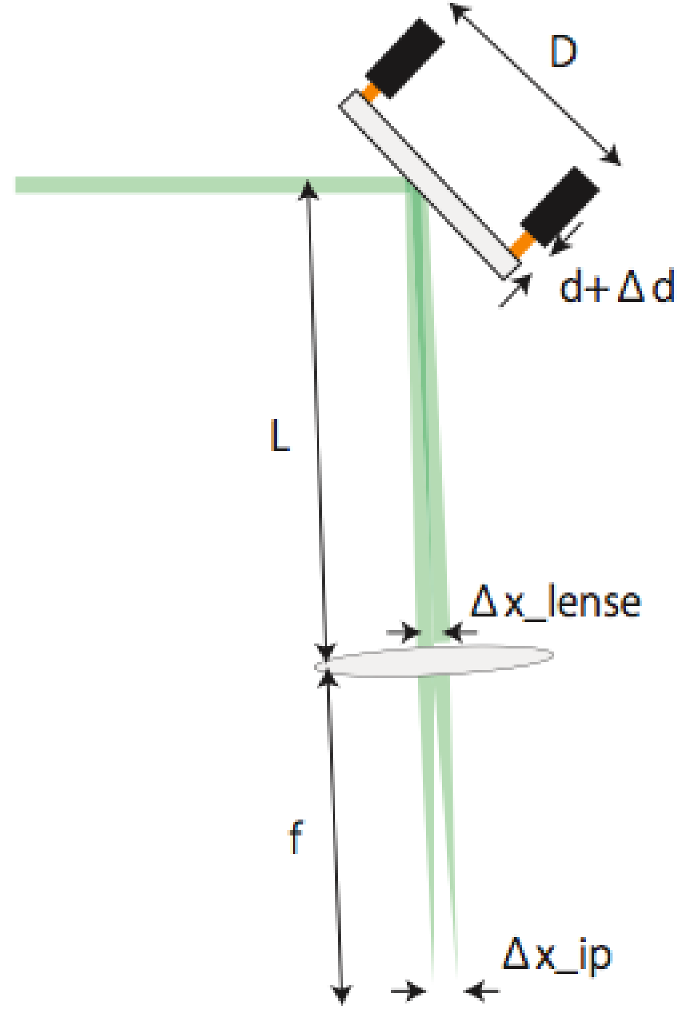


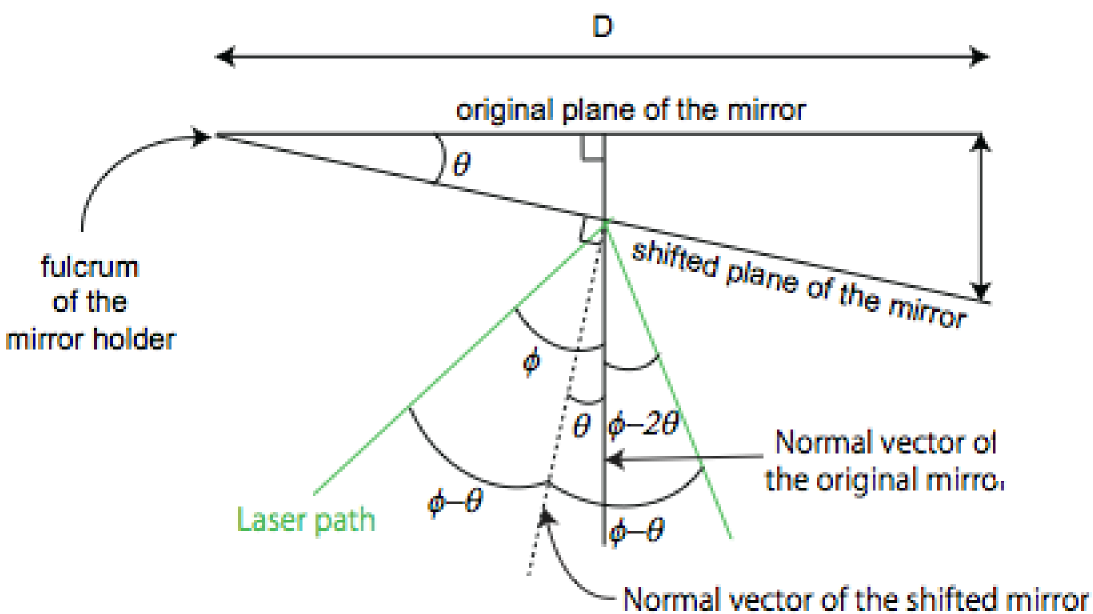
Phase of laser fringe

Calculate beam size from contrast of sine curve

measurable beamsize < 100nm

mode	D [mm]	L [mm]	f [mm]	$2\frac{L}{D}$
2 to 8 deg	61.9	900	250	29.0
30 deg	61.9	400	300	12.9
174 deg	61.9	350	250	11.3





$$\Delta x_{IP} = 2f \tan\frac{\Delta d}{D}$$
$$\simeq 2\frac{f}{D}\Delta d$$

M reduction Factor method#1

How large M can we measure at low θ mode ?
Observe consistency with higher modes

Note) this is a demonstration of "method #1" using a particular data sample
Conditions vary over time
error bars simply taken from fitting panel → very preliminary values

Data from 2012 / 12/5

M (measured) | M (expected from higher modes) | reduction

θ [deg]	M_{meas}	Mideal expected from7 deg	Mideal expected from 30 deg	C_{total} $= M_{meas} / M_{ideal}$
2.75	$0.944^{+0.056}_{-0.066}$	0.981 ± 0.013	0.987 ± 0.002	$0.962^{+0.038}_{-0.059}$
7	0.882 ± 0.071	-----	0.917 ± 0.01	$0.962^{+0.038}_{-0.078}$
30	0.214 ± 0.040	-----	-----	

M max

mode switching

2.8 deg, 7 deg

Similar results for 2-8° mode (within error bar range)

Data from 2012 / 12/20

M (measured) | M (expected from higher modes) | reduction

θ [deg]	M_{meas}	M_{ideal} expected from174 deg	C_{total}
30	0.732 ± 0.034	0.790 ± 0.006	0.926 ± 0.044
174	0.246 ± 0.027	-----	------

M max

mode switching

30 deg

There is some M reduction here

Inconsistency in $\sigma_{y,\, meas}$: IPBSM systematics vs e beam factors

- **Apparent discrepancy when switching to higher deg modes**

Ex1: measured σy+ about 70 nm at 174 deg mode

if this is "real" → **expect M = 0.79** at 30 deg , however stable **Mmax = 0.65** ←→ 125 nm

Ex2: sometimes consistent : 2-8 → 30 deg mode → ***under what circumstances ??***

Dec 5: M = 0.94 measured at 7 deg consistent with M = 0.3 at 30 deg

However not always so

- **show inconsistency , larger M than expected when go to higher θ → Kubo-san's studies**

Ex 3 2/6 Swing shift

- 6.9 deg Mmax about 0.8 --> 460 nm
- after switch to 30 deg mode: M = 0.3 --> 240 nm

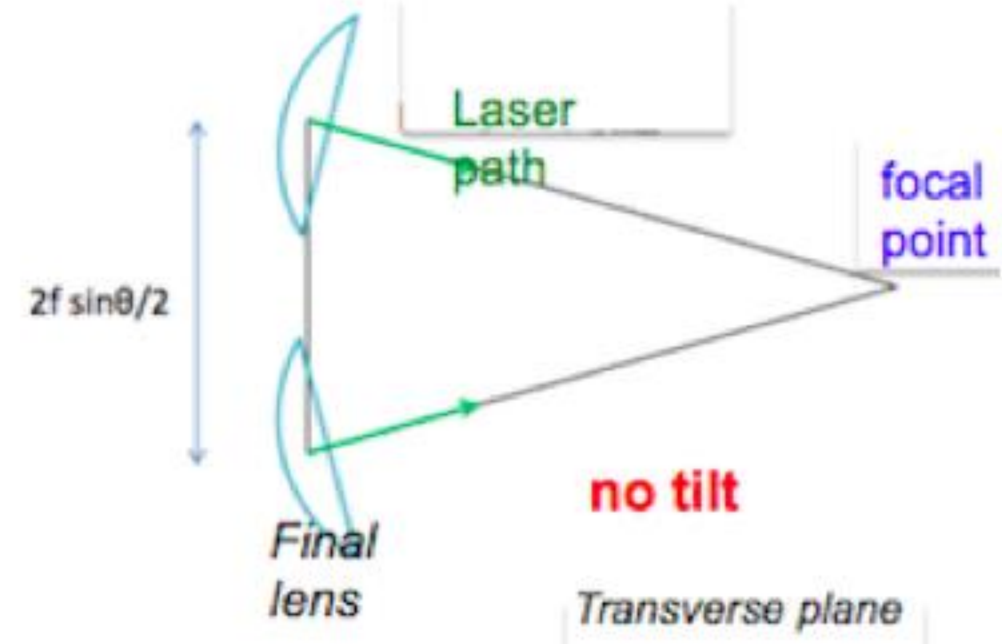
- **seem to do better when switching between 2-8 deg modes (???)**

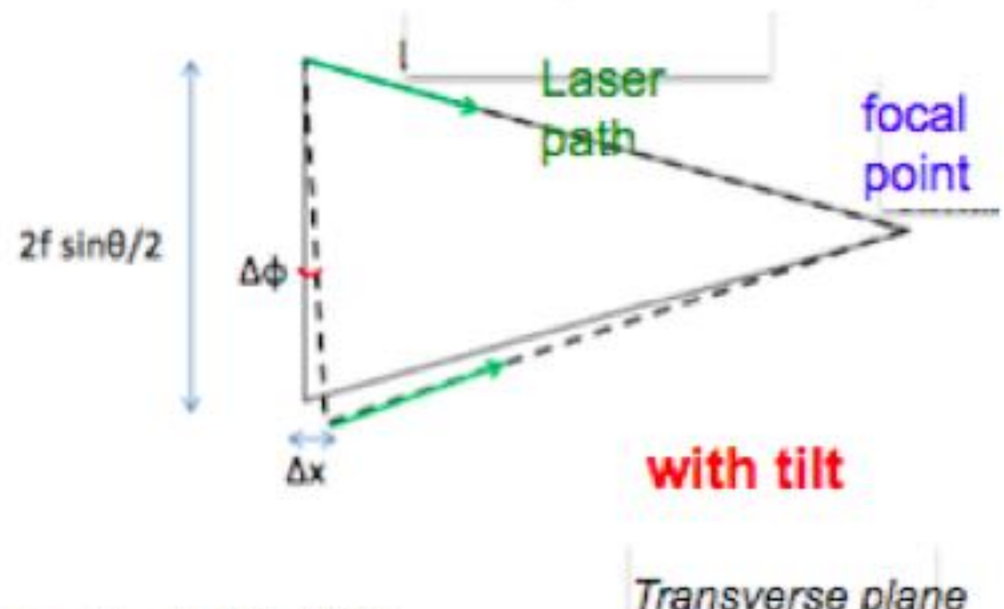
Ex 4: 2/5 Swing:

- 4.12 deg mode : M = 0.8 --> 782 nm
- go to 6.87 deg mode : M = 0.55 --> 768 nm consistent

- **When good consistency** (e.g. 12/5 7 deg → 30 deg) :

is it due to very little IPBSM errors, or something changed in e beam condition??

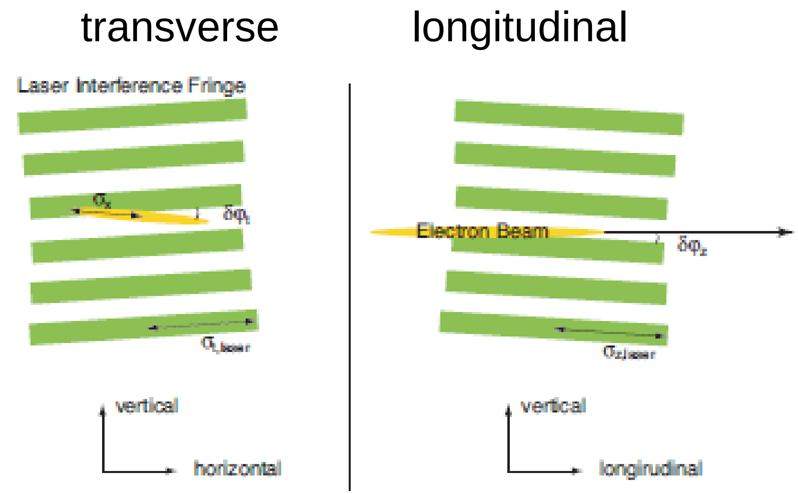




$\tan \Delta\phi = \Delta x / 2f \sin\theta/2$

Fringe Tilt

←→ Laser fringes not completely perpendicular to beam axis
10 - 20 m rad



$$C_{z,tilt} = exp\left(-2k_y^2 \sigma_{z,laser}^2 \delta\varphi_z^2\right)$$

$$\sigma_y^2 \to \frac{\sigma_y^2}{cos^2 \delta\varphi_z} + \sigma_{z,laser}^2 sin^2 \delta\varphi_z \simeq \sigma_y^2 + \sigma_{z,laser}^2 \delta\varphi_z^2$$

$$C_{t,tilt} = exp\left(-2k_y^2 \frac{\sigma_x^2 \delta\varphi_t^2}{1 + \left(\sigma_x / \sigma_{t,laser}\right)^2 sin^2\phi}\right) \simeq exp\left(-2k_y^2 \sigma_x^2 \delta\varphi_t^2\right)$$

causes σ_y^* to be over-evaluated as :

$$\sigma_y^2 \to \sigma_y^2 cos^2 \delta\varphi_t + \frac{\sigma_x^2 sin^2 \delta\varphi_t}{1 + \left(\sigma_x / \sigma_{t,laser}\right)^2 sin^2\phi} \simeq \sigma_y^2 + \sigma_x^2 \delta\varphi_t^2$$

Assessment of Polarization related systematic errors

<u>Motives:</u>
Quantitative evaluation of polarization / power related systematic errors

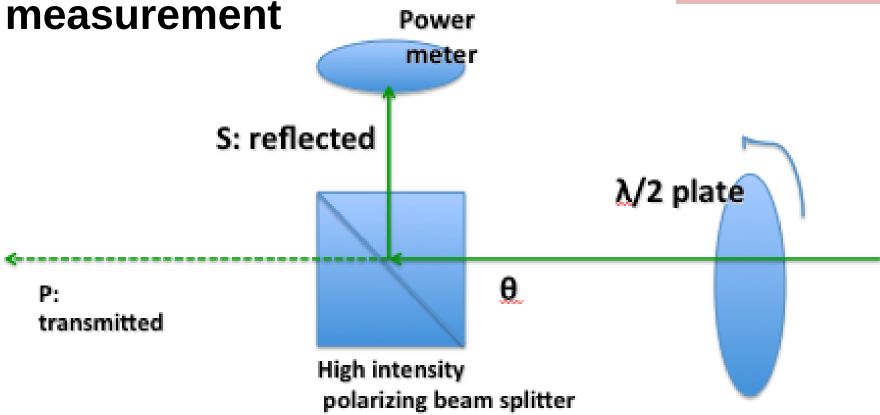
- **Confirm validity of λ/2 plate setting** during past / present beam time
- why M changed so much ???? (0.5 --> 0.93 @ 7 deg) with λ/2 plate

- **Find out power balance U vs L path** for Dec 's measurements

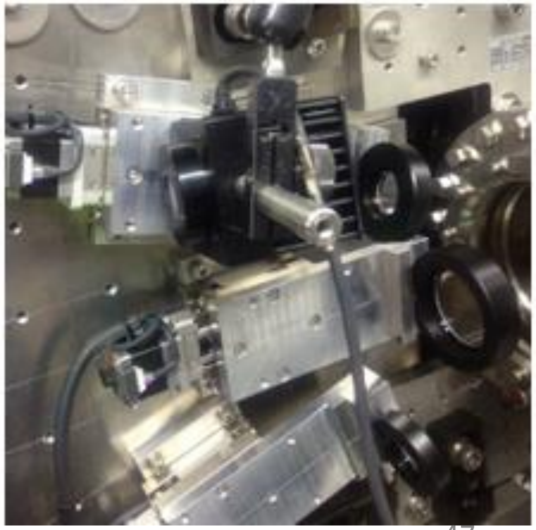
Measure high power at usual place Immediately in front of 30 deg lenses

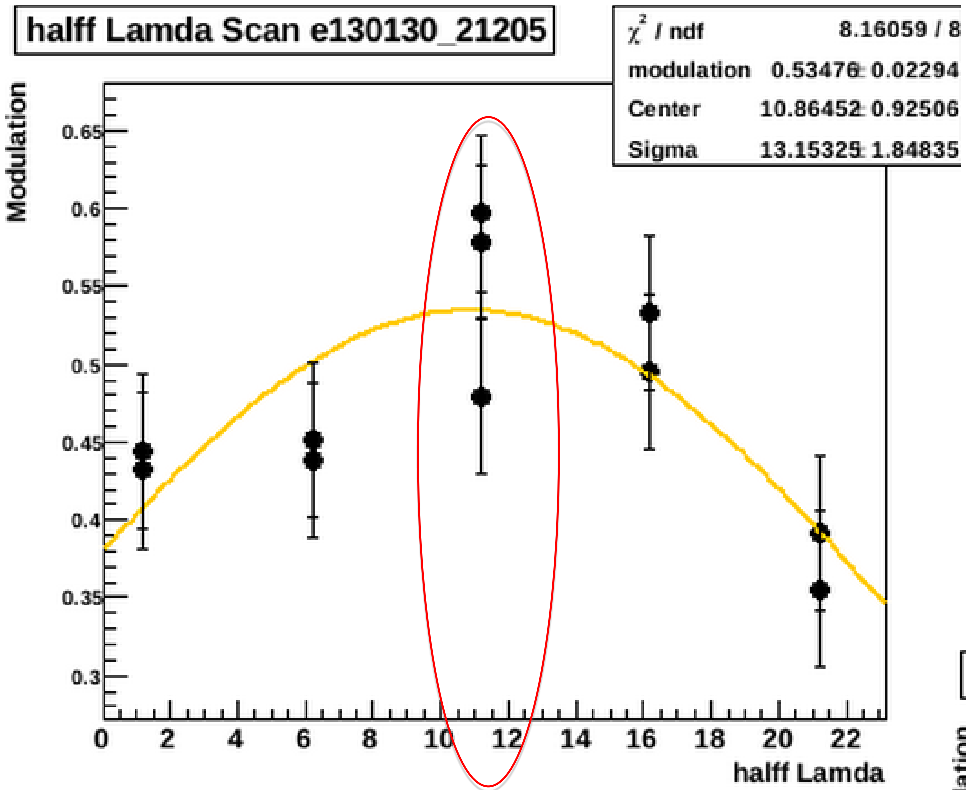
setup

Polarization measurement

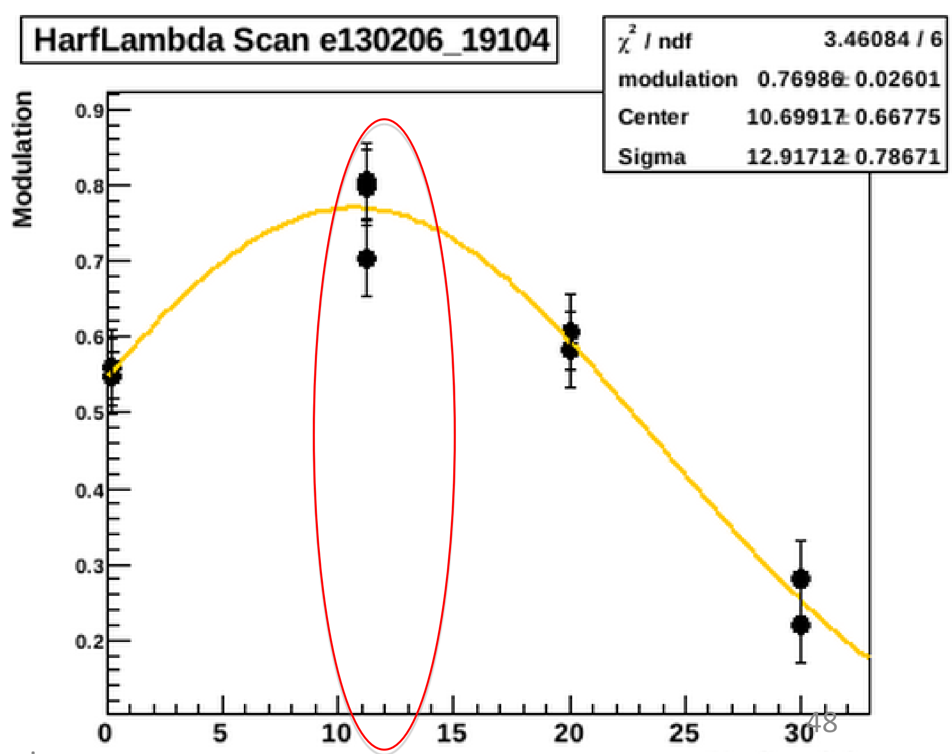


Power measurement





Polarization measurement results confirmed during actual beamtime



Half lambda plate 11.2 deg for pure S → highest M

laser path misalignment

precision of alignmnet by mirror actuator

- Δz, about 15-20% of σz,laser (from zscan)
- Δt about 5-10% of σt, laser * (from laserwire scan)

σz,laser about half of σt,laser

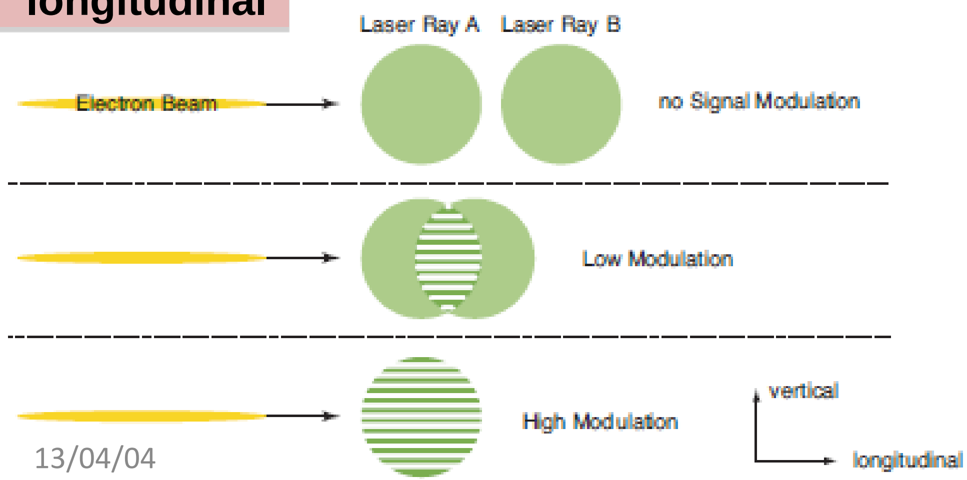
$$\text{longitudinal}: \quad C_{z,pos} = exp\left(-\frac{z_0^2}{2\sigma_{z,laser}^2}\right)$$

$$\text{transverse}: \quad C_{t,pos} = \frac{1}{cosh\left(-\frac{l_1^2}{4\sigma_{t,laser}^2}\right)}$$

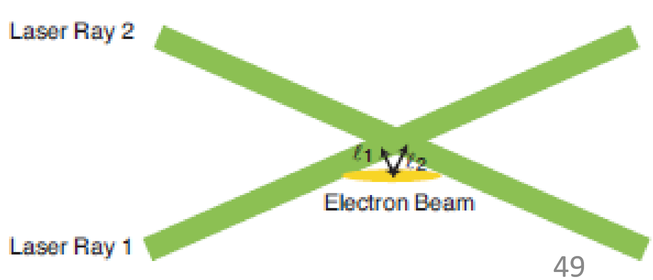
longitudinal Cz- pos > 98.9 %

transverse Ct-pos ~ 99.9 %

longitudinal



transverse



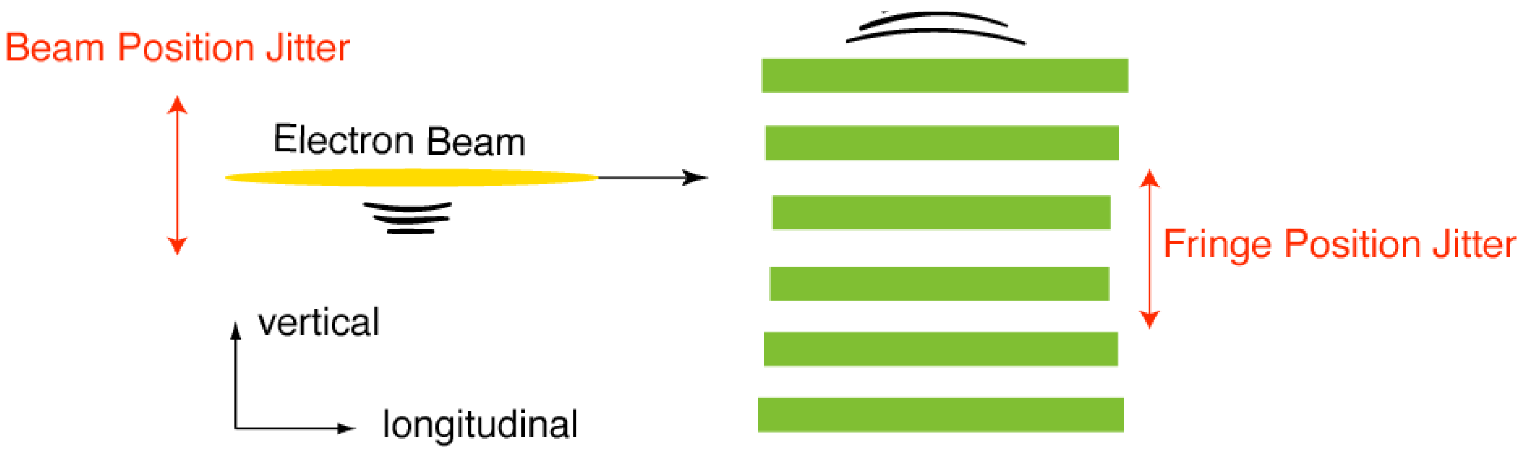
Not certain#2: Phase (relative position) jitter

From beam: if Δy ~ 0.3 σy
  C ~ 88.4% for 70 nm @ 174 deg
C~ 96.2% for 150 nm@30 deg mode
C~97.7% for 500 nm@7 deg mode

phase jitter observed from fringe scan: about 200 mrad ??
→ C ~ 98 % (????)

$$C_{phase} = exp\left(-\frac{(\Delta\alpha)^2}{2}\right) \Longleftrightarrow C_{\Delta y} = exp\left(-2\left(k_y \Delta y\right)^2\right) \qquad \left(k_y = \frac{2\pi}{\lambda} sin\left(\frac{\theta}{2}\right)\right)$$

$$\Longrightarrow \quad \Delta y = \frac{\Delta\alpha}{2k_y} = \frac{\lambda\Delta\alpha}{4\pi sin\left(\theta/2\right)}$$



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

Phase jitter **beam pos jitter** **beam size**

$$C_{phase} = \exp\left(-\frac{(\Delta\alpha)^2}{2}\right)$$

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

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

$$\Delta y \Leftrightarrow \frac{\Delta\alpha}{2k_y} = \frac{\lambda\Delta\alpha}{4\pi\sin(\theta/2)}$$

Δα [mrad]	C_{phase}	Δy [nm] @2°	Δy [nm] @8°	Δy [nm] @30°	Δy [nm] @174°
200	0.98	**485**	**121**	**33**	**8.5**
300	0.96	**728**	**182**	**49**	**13**
400	0.92	970	243	65	17
500	0.88	1212	303	82	21

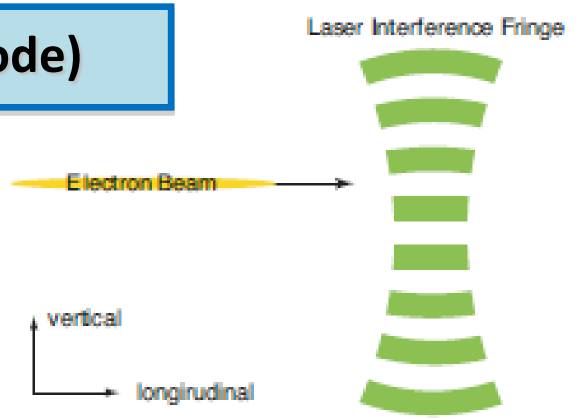
Correlation between phase jitter and beam pos jitter

Typical requirement Δy < 0.3 σy*

	2 deg	8 deg	30 deg	174 deg
Beam pos. jitter (Δy ~ 0.3*σy)	**0.3 x 1 μm = 300 nm**	**0.3 x 500 nm = 150 nm**	**0.3 x 100 nm = 30 nm**	**0.3 x 40 nm =12 nm**
IPBPM res. (< 1/3 *Δy)	< 100 nm	< 50 nm	< 10 nm	< 4 nm

➔ Phase jitter Δα tolerance : 200 – 300 [mrad]

Syst. Errors specific to very small σ_y^* (174 deg mode)

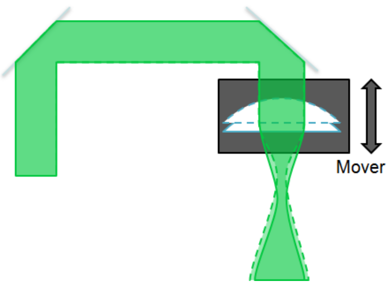


Spherical wavefronts

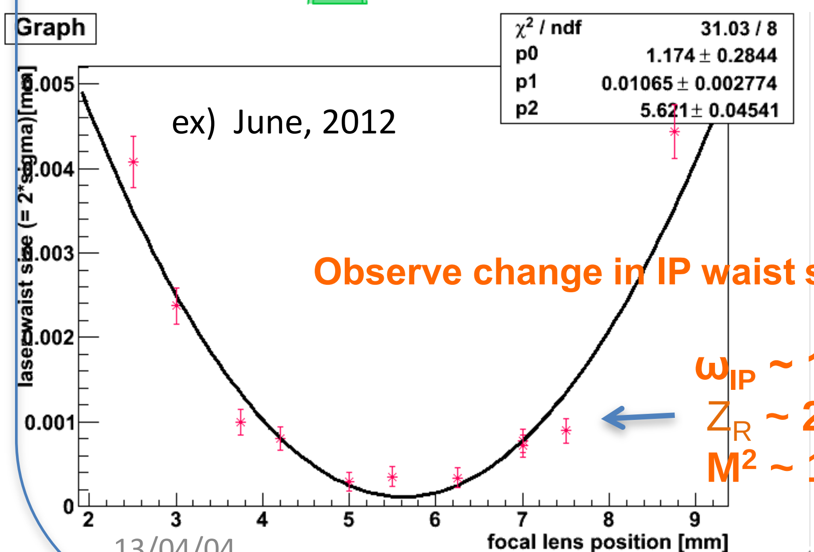
Offset of ultra-focused e- beam vs laser waist → distorted fringes

Csphere > 99.7 %

Solution is **focal point scan**



attach mover to lens
→ **align focal point to IP within < 100 μm**
(~0.1*Raylegh length Z_R)

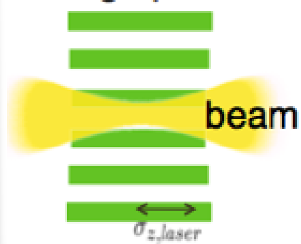


ex) June, 2012

Observe change in IP waist size ω_{IP}

ω_{IP} ~ 10 μm
Z_R ~ 2.2 mm
M^2 ~ 1.2

Change of σy* within fringes



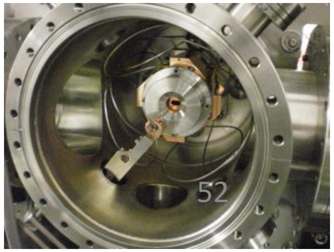
due to strong focusing,

Cgrowth ~ 99.7%

Tiny σy* is very sensitive to **relative position jitter** ! !

IPBPM **(O(nm) design resolution)** under commissioning

- beam pos. monitoring
- feedback correction



$$S(y) = S_{avg}\left(1 + M\cos\left(2k_y y + \alpha\right)\right)$$

estimate relative position jitter

from the amount of signal jitter it caused (inferred from fringe scans)

if $y \rightarrow y + \Delta y$ — relative position jitter Δy

$$S(y+\Delta y) = S_{avg}\left(1 + M\cos\left(2k_y (y+\Delta y) + \alpha\right)\right)$$

S: measured Compt signal energy

y : relative position

$2k_y y$: fringe scan phase

α: initial phase

$$\Delta S = \left|S(y+\Delta y) - S(y)\right|$$
$$= S_{avg} M \left|\cos\left(2k_y (y+\Delta y) + \alpha\right) - \cos\left(2k_y y + \alpha\right)\right|$$

Corresponding signal jitter (%)

is $(2k_y \Delta y)$ small enough to use approximation ?? ← **depend on θ mode**

174 deg mode is most sensitive !!

---

for 30 deg mode $\left(k_y = \frac{\pi}{1028\ \text{nm}}\right)$ $2k_y \Delta y \ll 1$

$$\therefore \quad \frac{\Delta S}{S} = \frac{S_{avg} M \sin\left(2k_y y + \alpha\right)\cdot\left(2k_y \Delta y\right)}{S_{avg}\left(1 + M\cos\left(2k_y y + \alpha\right)\right)}$$

can use approximation for 30 deg mode ??

at fringe scan mid point: $\cos\left(2k_y y + \alpha\right) = 0 \quad (S \approx S_{av})$

$$\therefore \quad \frac{\Delta S}{S} = M\cdot\left(2k_y \Delta y\right)$$

$$\Delta y = \frac{(\Delta S/S)[\%]}{2M\left(\frac{\pi}{1028\ [\text{nm}]}\right)}$$

Sig jitter due to rel pos jitter was observed at mid point if Δy is about O(10 nm)

$(2k_y \Delta y)$ is not small for 174 deg mode $\left(k_y = \dfrac{\pi}{266\ \text{nm}}\right)$

if $y \rightarrow y+\Delta y$

$$\sigma_y^2 \rightarrow \sigma_y^2 + \Delta y^2$$

$$\therefore \quad \frac{\Delta S}{S} = \frac{S_{avg} M \left|\cos\left(2k_y(y+\Delta y)+\alpha\right) - \cos\left(2k_y y+\alpha\right)\right|}{S_{avg}\left(1+M\cos\left(2k_y y+\alpha\right)\right)}$$

Corresponding signal jitter (%)

[1] at fringe scan peak: $\cos\left(2k_y y+\alpha\right)=1 \qquad \left(2k_y y = 2m\pi \qquad m=1,2,\ldots\ldots\ldots\right)$

$$\therefore \quad \left.\frac{\Delta S}{S}\right|_{peak} = \frac{M\left(1-\cos\left(2k_y \Delta y\right)\right)}{1+M}$$

$$\Delta y = \frac{\cos^{-1}\left(1-\dfrac{(\Delta S/S)[\%](1+M)}{M}\right)}{\left(\dfrac{2\pi}{266\ [\text{nm}]}\right)}$$

ΔS / S = 0 from relative pos jitter is not zero at peak

[2] at fringe scan mid point: $\cos\left(2k_y y+\alpha\right)=0 \qquad \left(S \approx S_{av}\right)$

$$\therefore \quad \left.\frac{\Delta S}{S}\right|_{mid} = M \cdot \sin\left(2k_y \Delta y\right)$$

Sig jitter due to rel pos jitter was observed at mid point

$$\Delta y = \frac{\sin^{-1}\left(\dfrac{(\Delta S/S)[\%]}{M}\right)}{\left(\dfrac{2\pi}{266\ [\text{nm}]}\right)}$$

depend on θ mode

174 deg mode is most sensitive !!

(pitch d = π/k_y is most narrow)

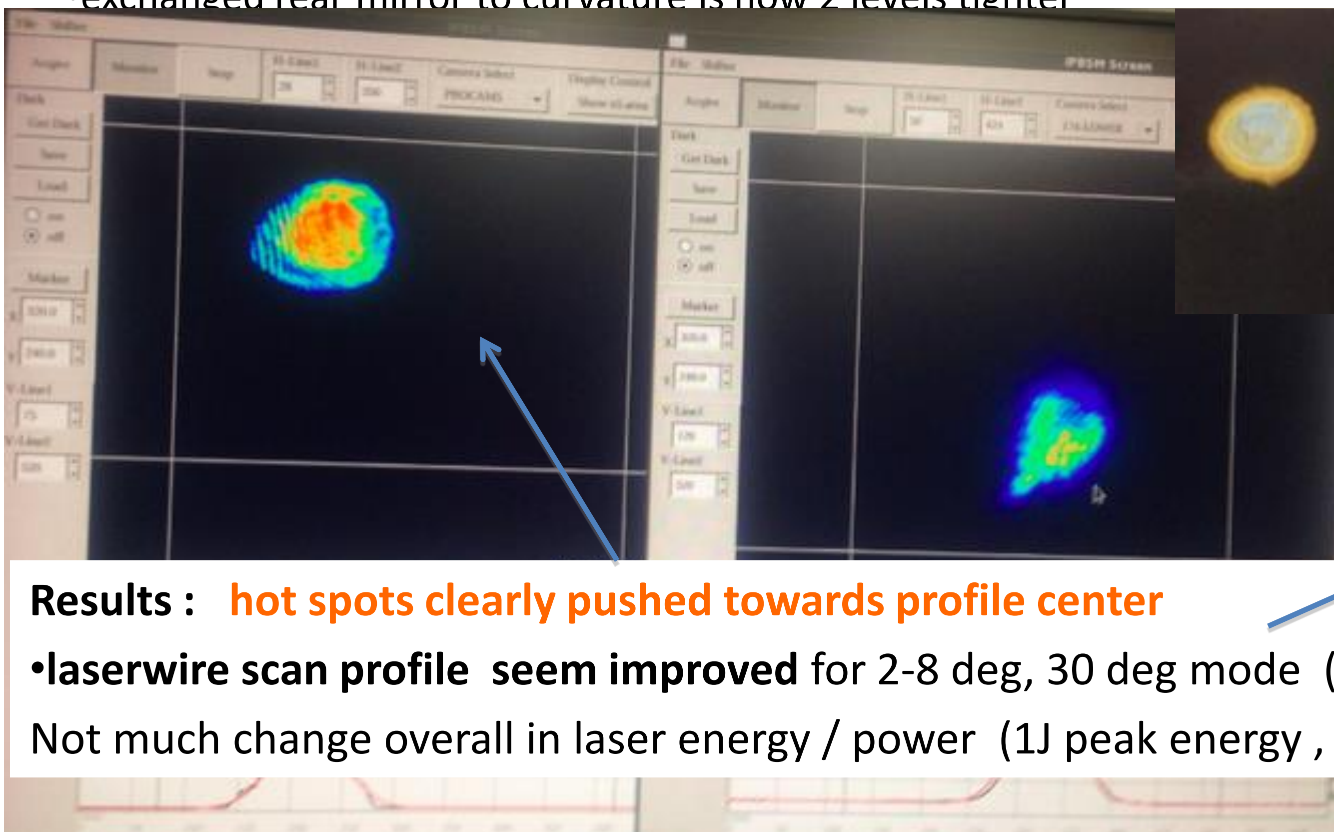
Optics reform in autumn:
Change in Profile after Adjustment by Spectra Physics

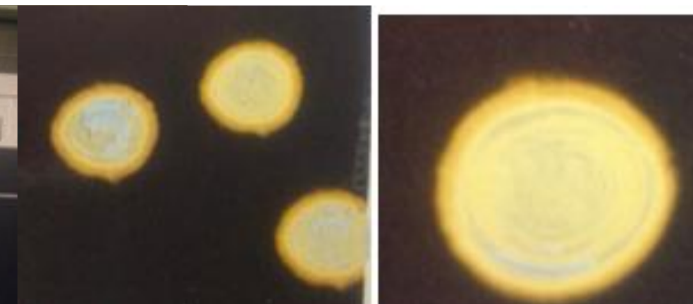
Re-optimize expander / reducer : Nov 21

Goal: Push intensity "hot spots" to center of profile

→ (maybe) resolve "two peak" structure in laserwire scan profile

•exchanged rear mirror to curvature is now 2 levels tighter





Also visible from burn pattern

Results : **hot spots clearly pushed towards profile center**

•**laserwire scan profile seem improved** for 2-8 deg, 30 deg mode (not totally consistent)

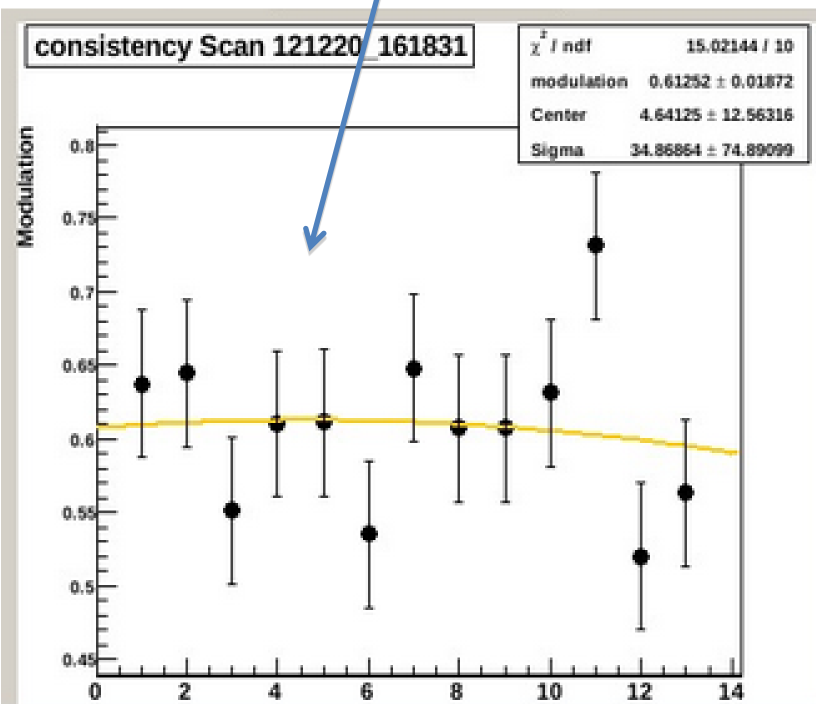
Not much change overall in laser energy / power (1J peak energy , 6.3 W)

Studies at 30 deg mode operation

Dec 20

13 consistent scans at 30 deg

Under optimized conditions



$\sigma y^* = 137.3 \pm 18.4$ nm

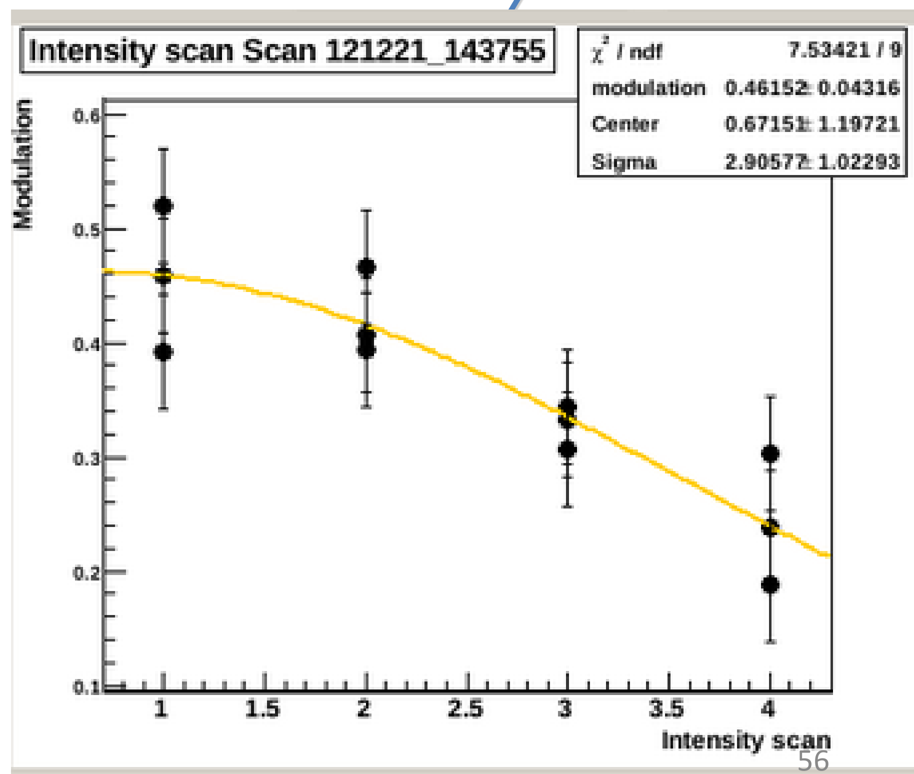
$M = 0.607 \pm 0.056$

wakefield and beam intensity **studies**

Checking of linear / nonlinear knobs

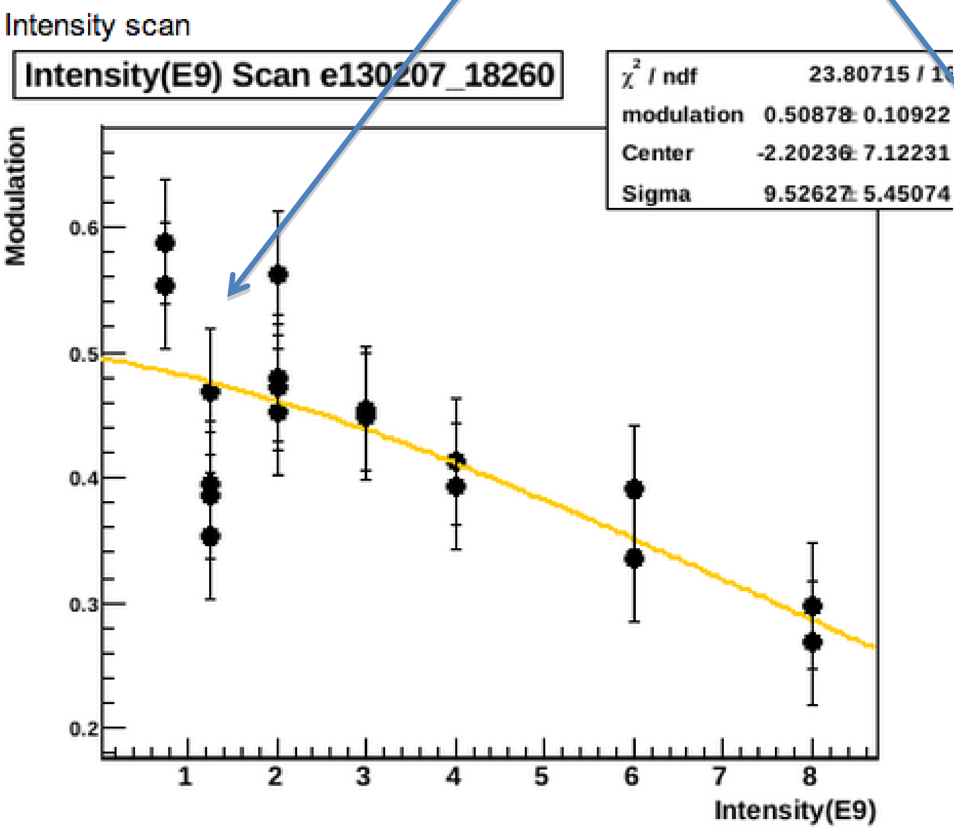
Tests of effects of IPBSM systematic error sources

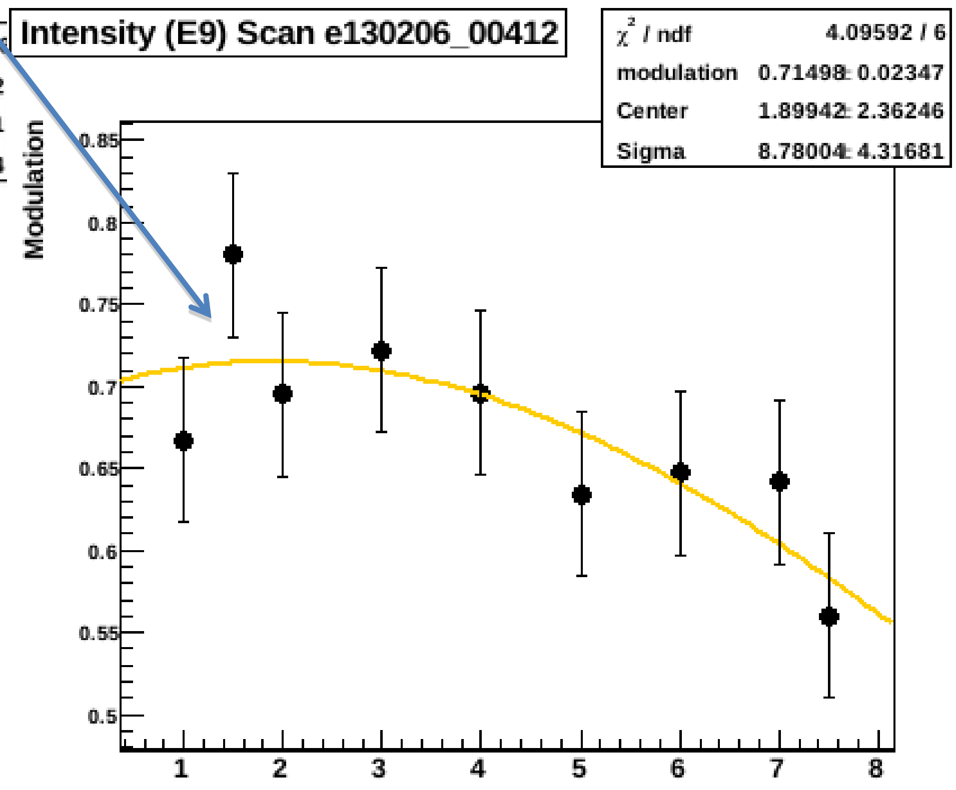
intensity scan



Intensity cut at first set to 3 x 10^9,   then later **lowered to 1 x 10^9** (as in Dec)

intensity scans in 2013





Detection of M at 174 deg mode still limited by intensity
ex: Dec 2012

high intensity cannot see significant M