15th ATF Project Meeting

IPBSM:

Beam Size Measurement and Performance Evaluation

2013 Jan 23 – 25,
KEK, Tsukuba, Japan

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Recent Beam Time Status : Oct ~ Dec, 2012

Optics upgrade of Summer, 2012

Issues , Error studies

goals and plans

Summary

Recent Beam Time Status : Oct ~ Dec, 2012

- **Best Status and dedicated studies at 30 deg mode**
- **First M detection of 174 deg mode**
- **174 deg operation during last 3 hours of 2012 beam time**

Progress during Last 2 days of Beam Operation

- set to Ref cavity for low and stable BG levels, Low beam intensity
- 10 x βx^* , **1 x βy^* ,** S/N ~ 4

12/ 20 Day: study at 30 deg mode : 13 continuous scans

12/20 evening shift , switched to 174 deg mode
Modulation detected !! → Set to peak → many times fringe scans : σy 60 – 80 nm
but z scan profile too narrow , peak position not consistent
Conditions (laser, e- beam) drifts → needed frequent lwscan realignment
Eventually 174 deg M drifted off during Owl shift

12/21 morning : → switch back to 30 deg mode
re-optimize knobs at 30 deg mode , take data for wakefield and intensity dependence

12/ 21 afternoon (last 3 hours) : **switch to 174 deg mode again**
more stable M measurement than the previous night
M detected , sets of stable continuous fringe scans → results (RMS)
show response to multiknob tuning

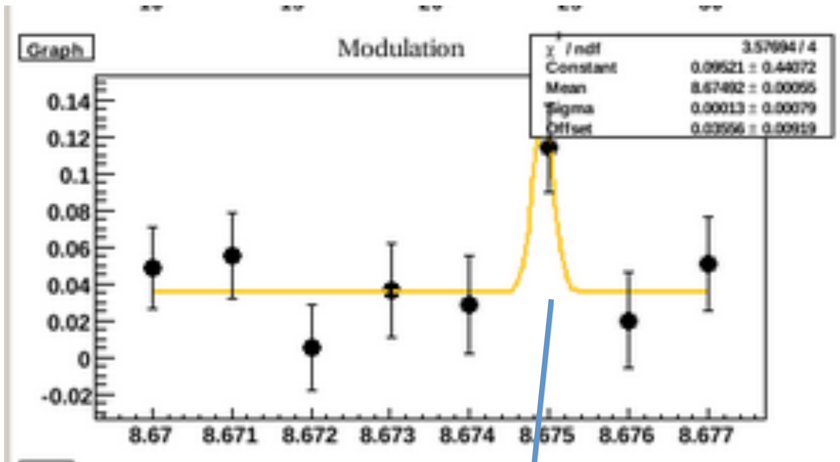
$\sigma y^* = 73.4 \pm 4.6$ nm
M = 0.224 ± 0.0420

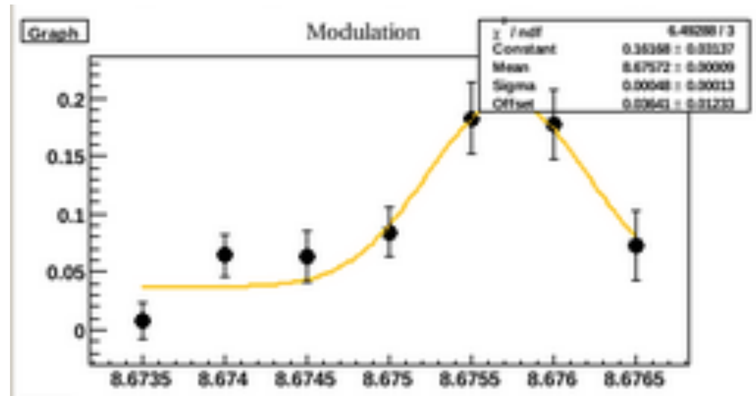
But no M at higher e beam intensity

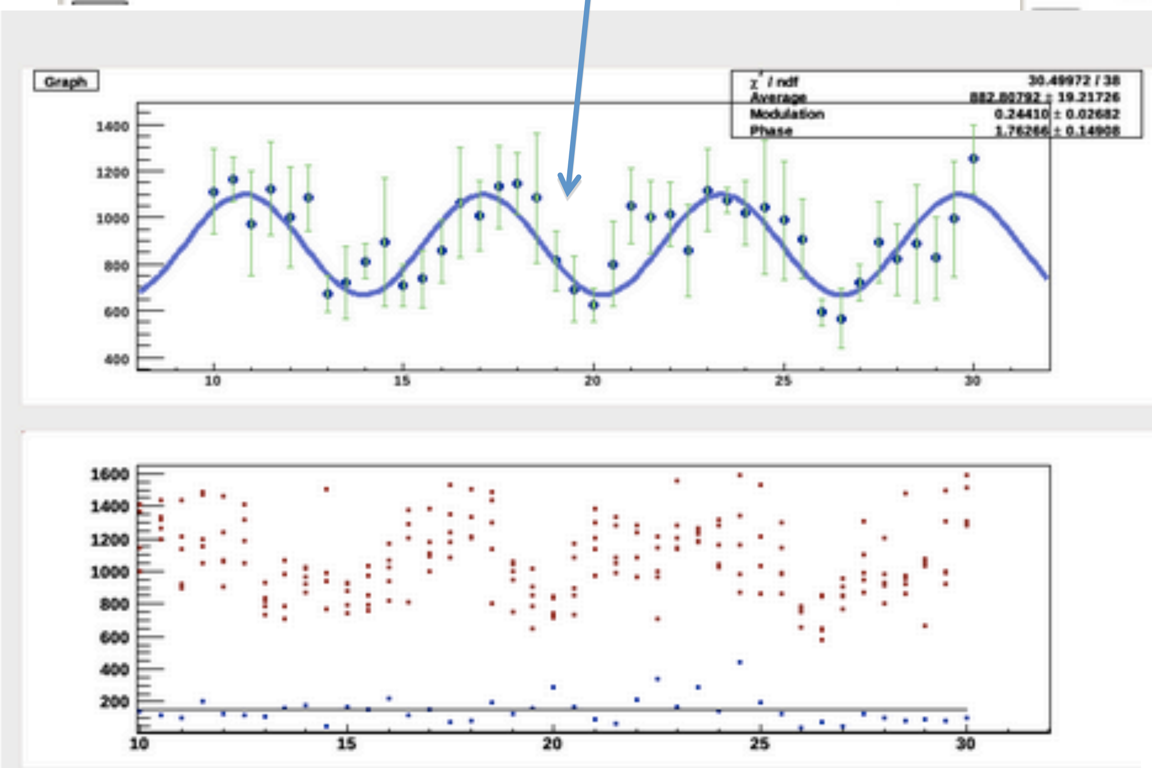
$\sigma y^* = 73.0 \pm 6.8$ nm
M = 0.230 ± 0.062

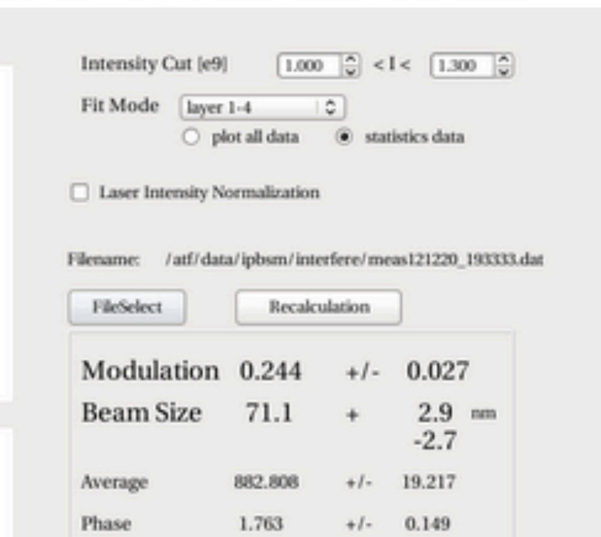
First Detection of 174 deg M : 12/20

z scan profile too narrow ,
peak position not consistent









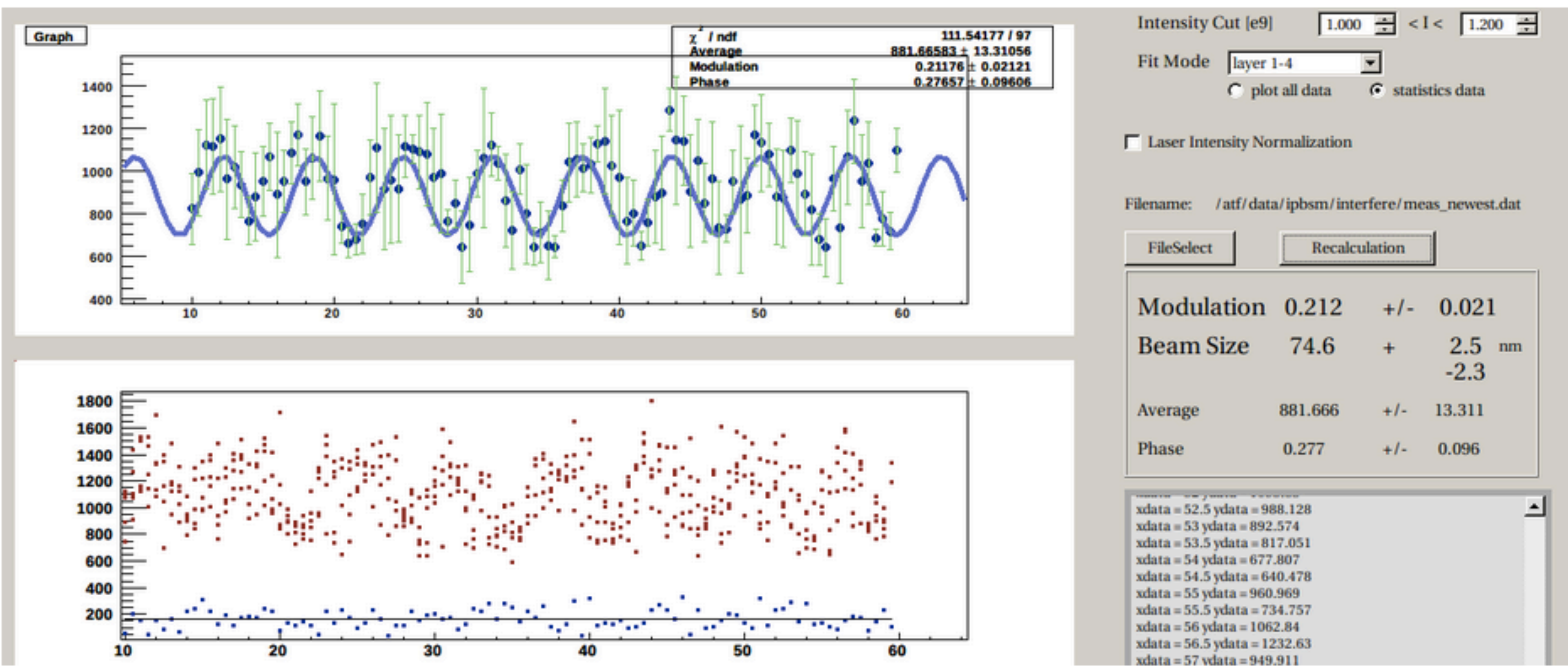
Fringe scans at (temporary)
z scan peak position
→ about 70 nm

Long Range Scans

12/ 20 174 deg mode

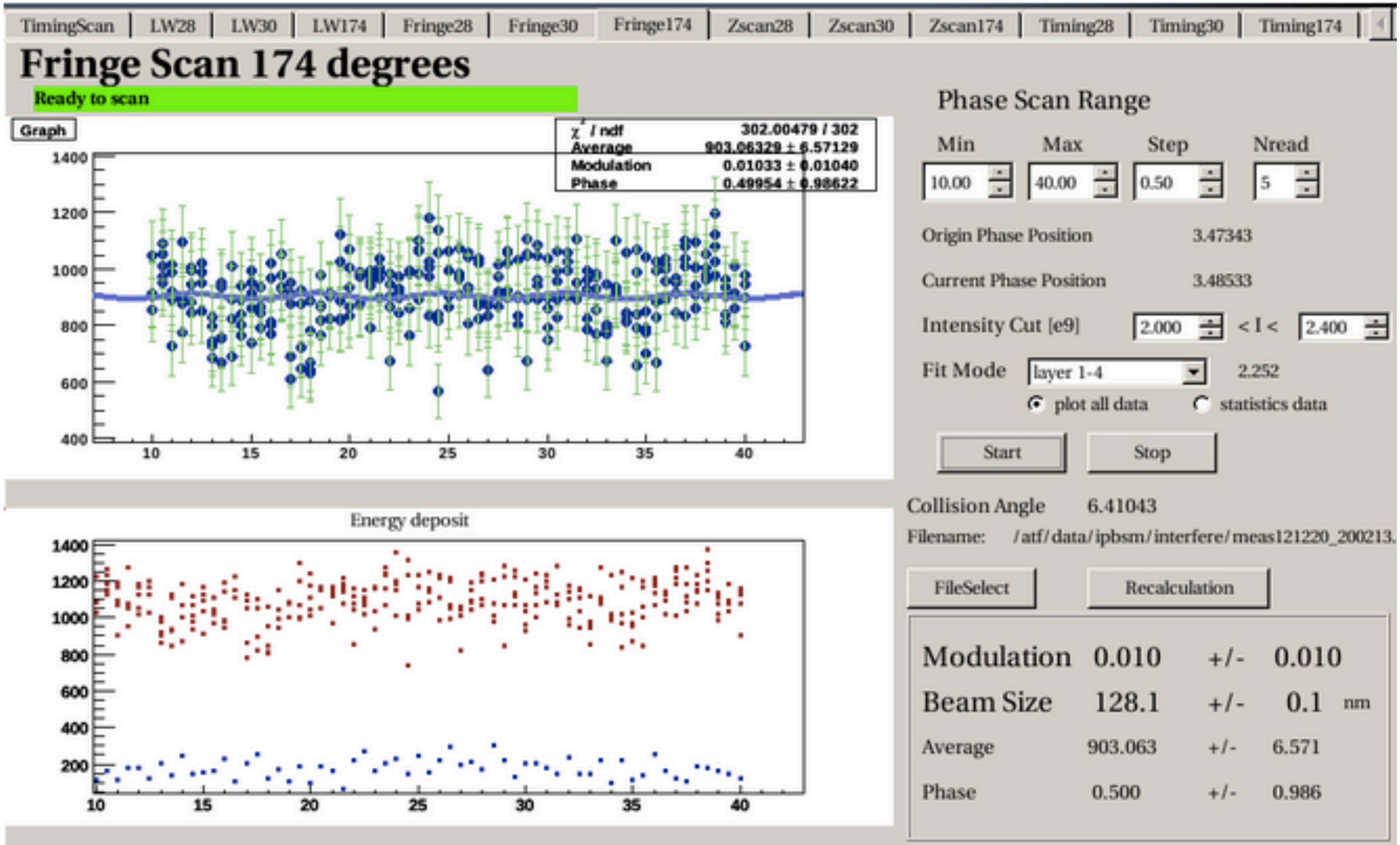
conditions remained stable enough for some long range (50-60 rad) scans

75 nm even for 50 – 60 rad scan



Confirmed 174 M cannot detect at high intensity (~ 0.4)

high intensity cannot see significant M

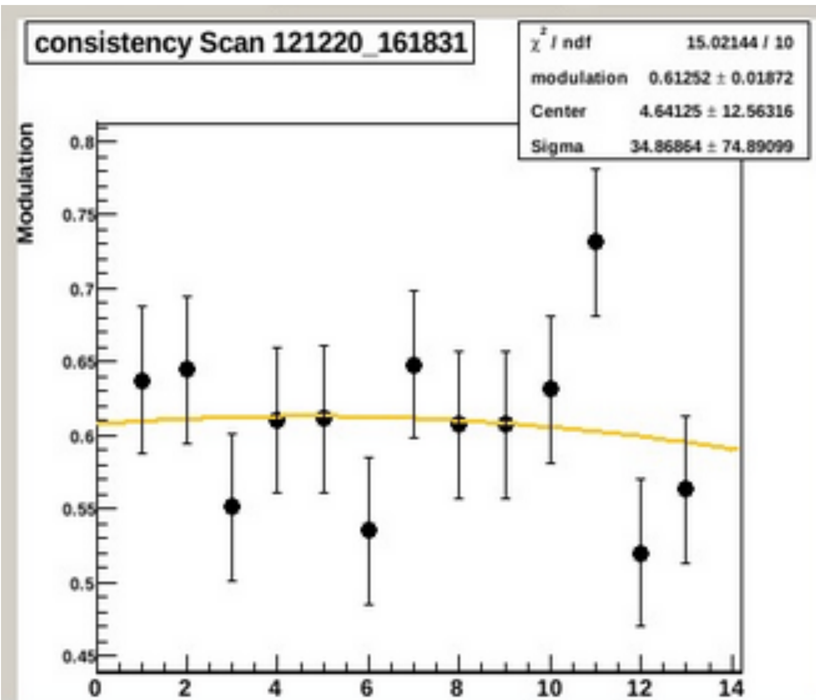


30 deg mode operation

Dec 20

Best ever 13 consistent scans at 30 deg

(after linear & nonlinear knob tuning,
ref cavity optimized)



σy* = 137.3 ± 18.4 nm

M = 0.607 ±0.056

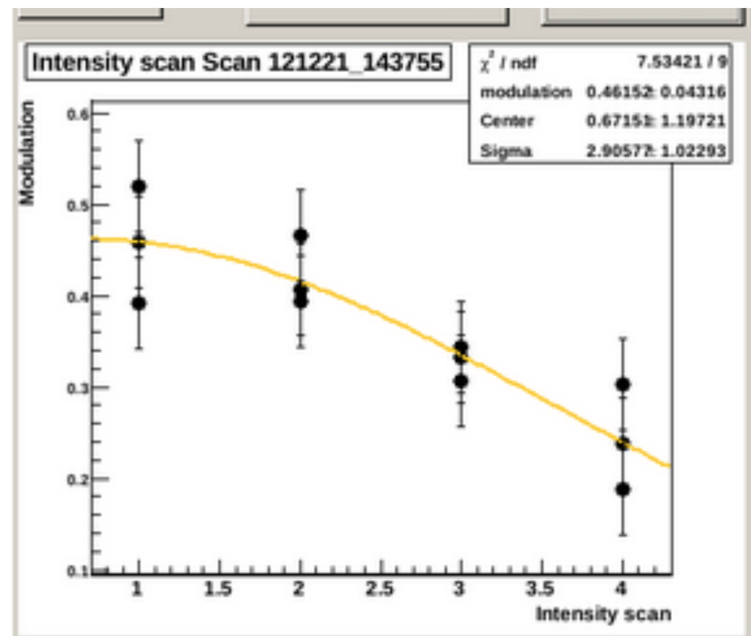
Dec 21, morning

switch back to 30 deg mode

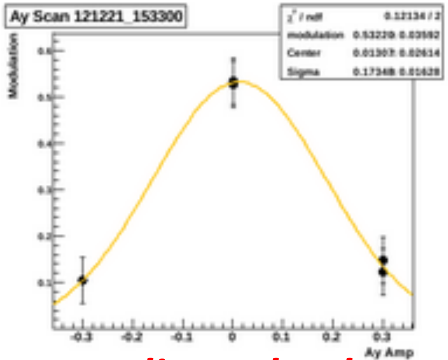
Goal*

- re-optimize (nonlinear, linear) knob tuning
- Take **BPM data to study wakefield dependence**
- Take data on **intensity dependence**

Best M ∼ 0.55 reached
during knob scans



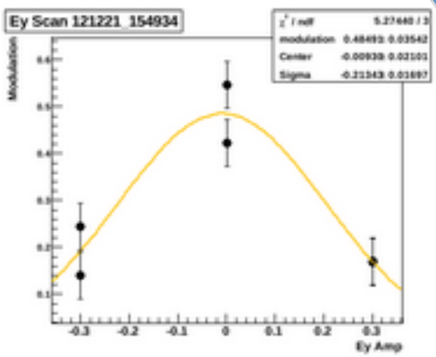
Ay scan, set to 0.01, almost no change



linear knobs

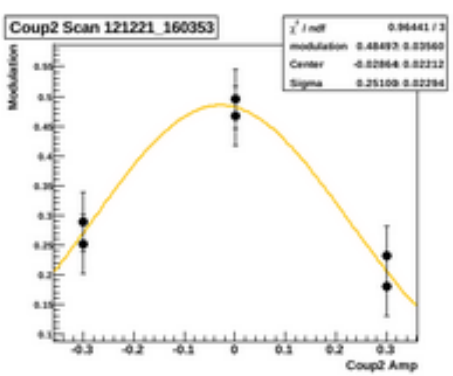
Ey scan

leave at 0, no change, M about 0.55 at peak



Coup2 scan

set to 0.02



[1] higher intensity

(ICT: 0.3 – 0.4)

- Nonlinear knob Y22, Y44
- Linear knob scans

Best M ∼ 0.55 reached

during knob scans

[2] lower intensity

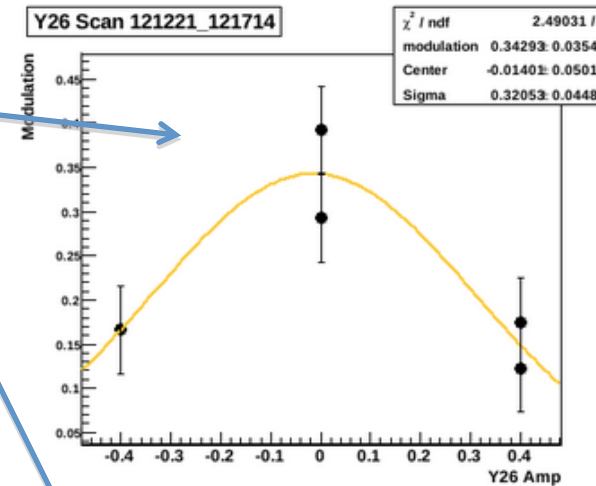
(set at 0.8 < ICT < 1.2)

check linear knob again

This time at low intensity

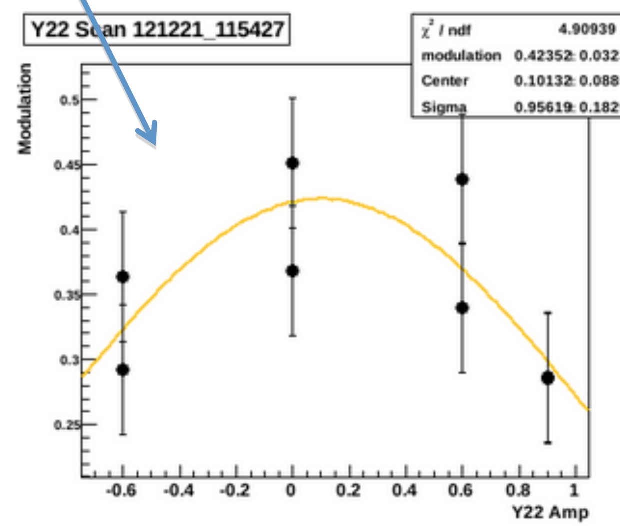
almost no offset at all

Y26 leave at 0



non-linear knobs

Y22: set to 0.1



Last 3 hours: 174 deg mode operation

turned ATF2orbit feedback OFF

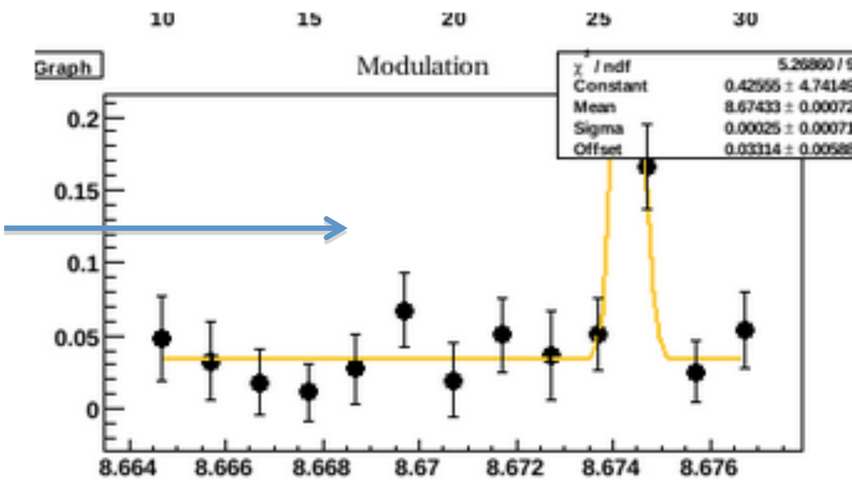
Continuously tune beam to fit within **Strict ICT cut window: [0.8 – 1.2]**

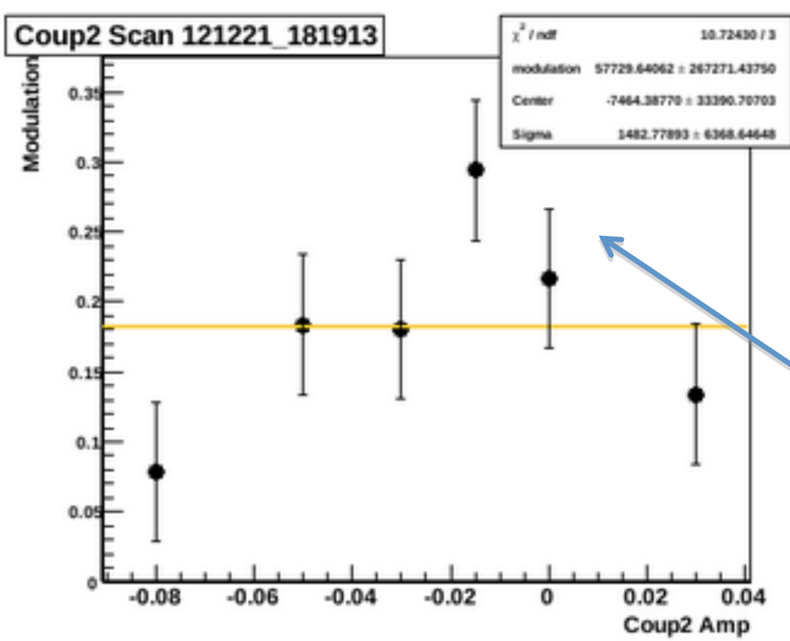
→2 sets of consecutive good scans

σy * = 65 – 80 nm

Detailed analysis, error studies are ongoing

Set mirror at zscan rise-up point (still too narrow)





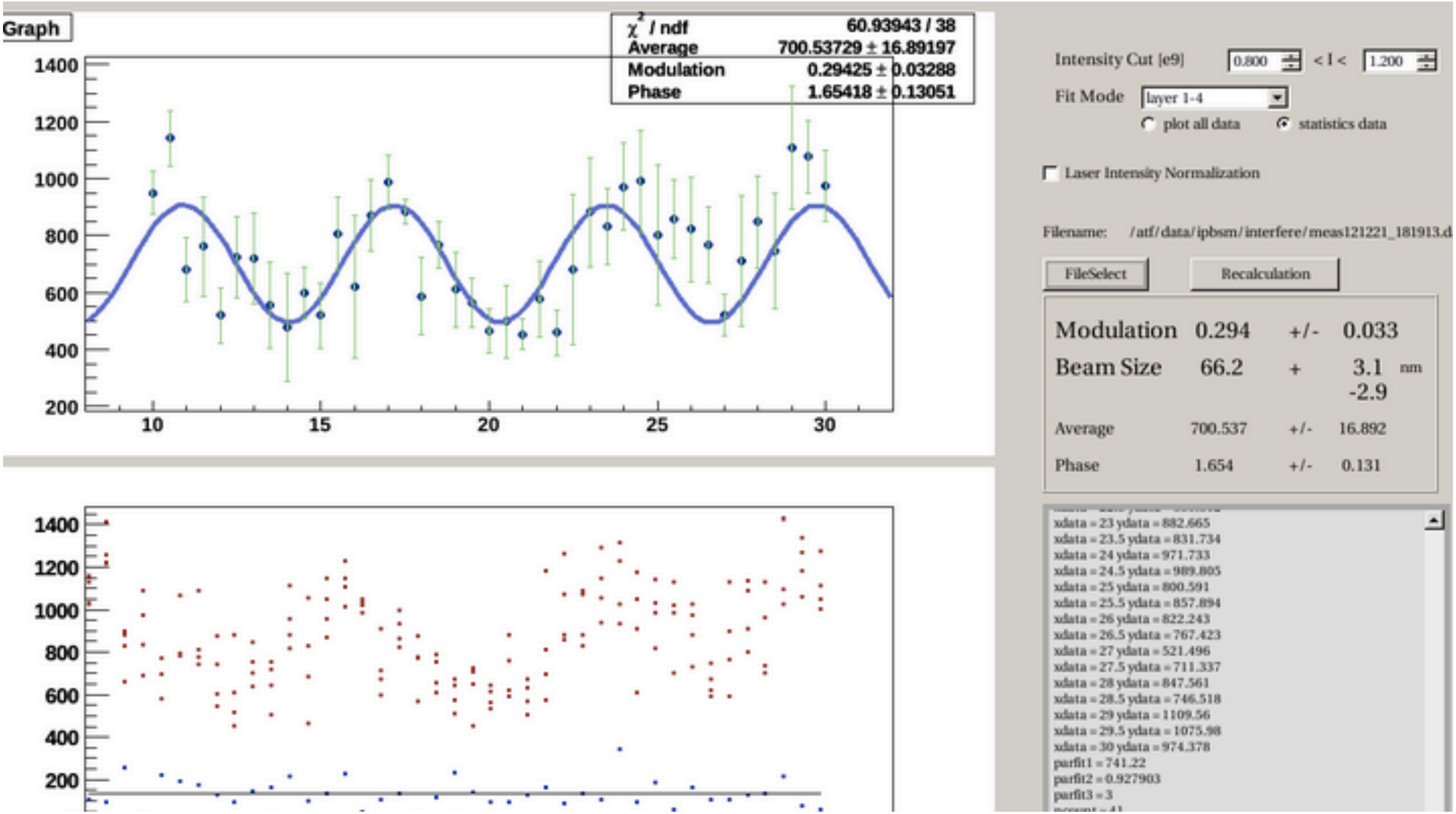
Clear dependence seen for

all 3 types of linear knobs

Quite good consistency at each peak

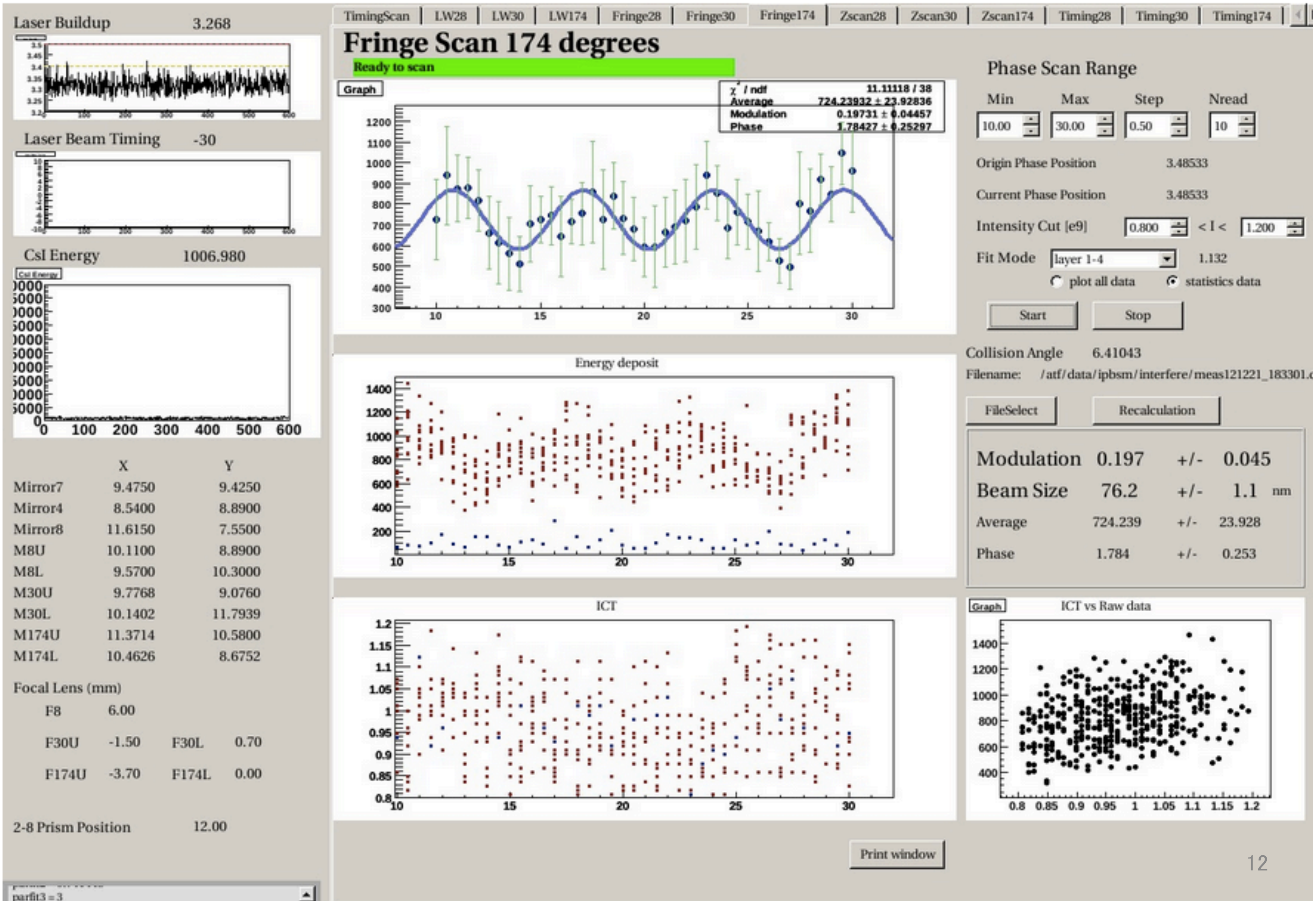
Best Scan after 1 round of linear knob scan

M ~ 0.294 , σy* ~ 66 nm



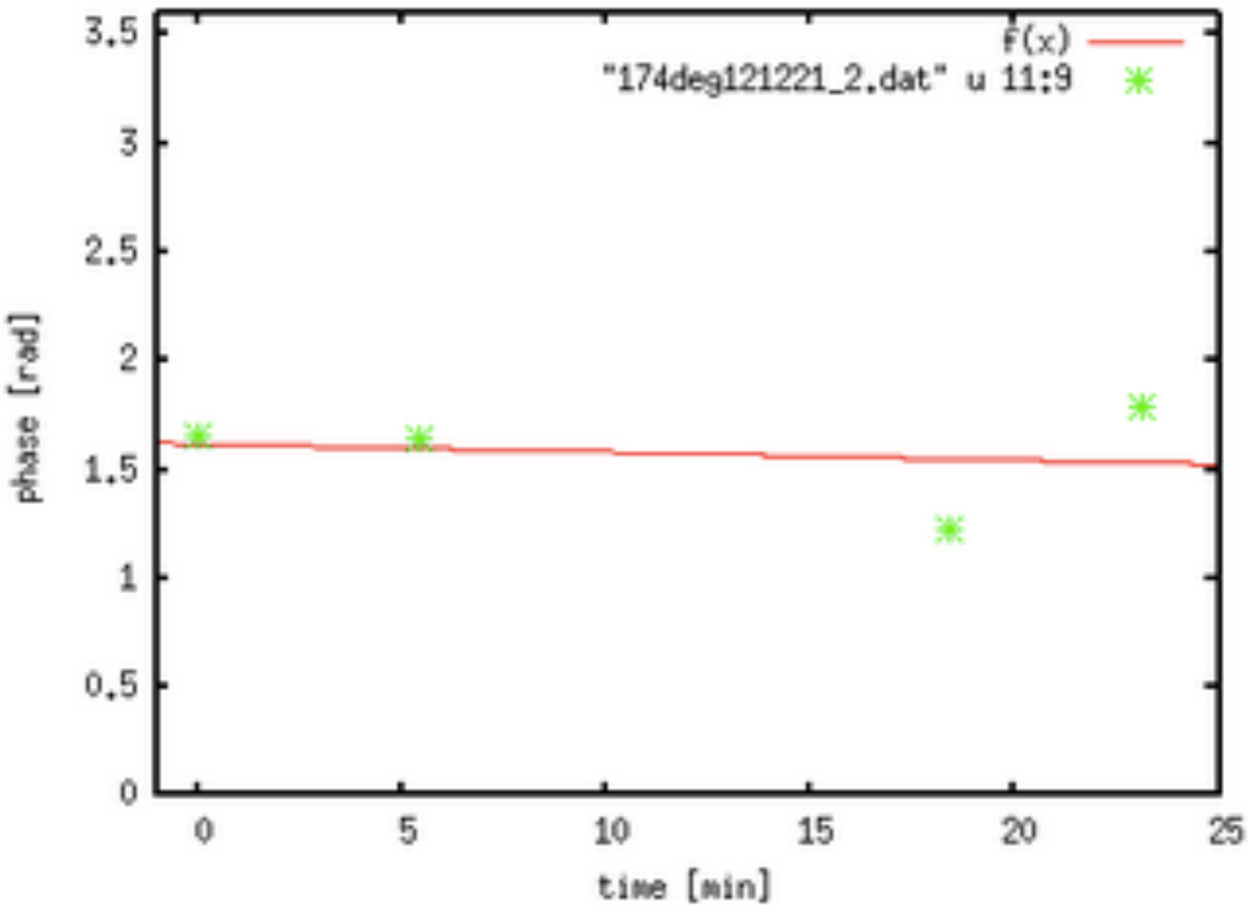
Nav – 10 fine scan

harder to counter drift for long scan,   But even so, achieved M ∼ 0.2 , σy* ∼ 76 nm



beam and laser *happened to* remain quite stable within last few consecutive scans

But not always so….



Issues

(1) Inconsistency in M (compared to expectation)

when switching from 30 deg to 174 deg mode

- measured σy = 80 nm at 174 deg mode
- expect M = 0.77 at 30 deg mode, but only go up to about M = < 0.65

→ ***worse than 85% total M reduction (??)***

Large systematic errors intrinsic to 30 deg mode ?

(2) Drift in laser wire scan peak and laser power

(3) Effect of laser profile on M

(4) Why M change drastically with half lambda plate setting?

(5) Why were we able to measure M = 0.55 at 30 deg mode in Feb , 2012, at higher intensity?

2012 summer: **major upgrade of laser optics**
Goal: **alignment precision & reproducibility**

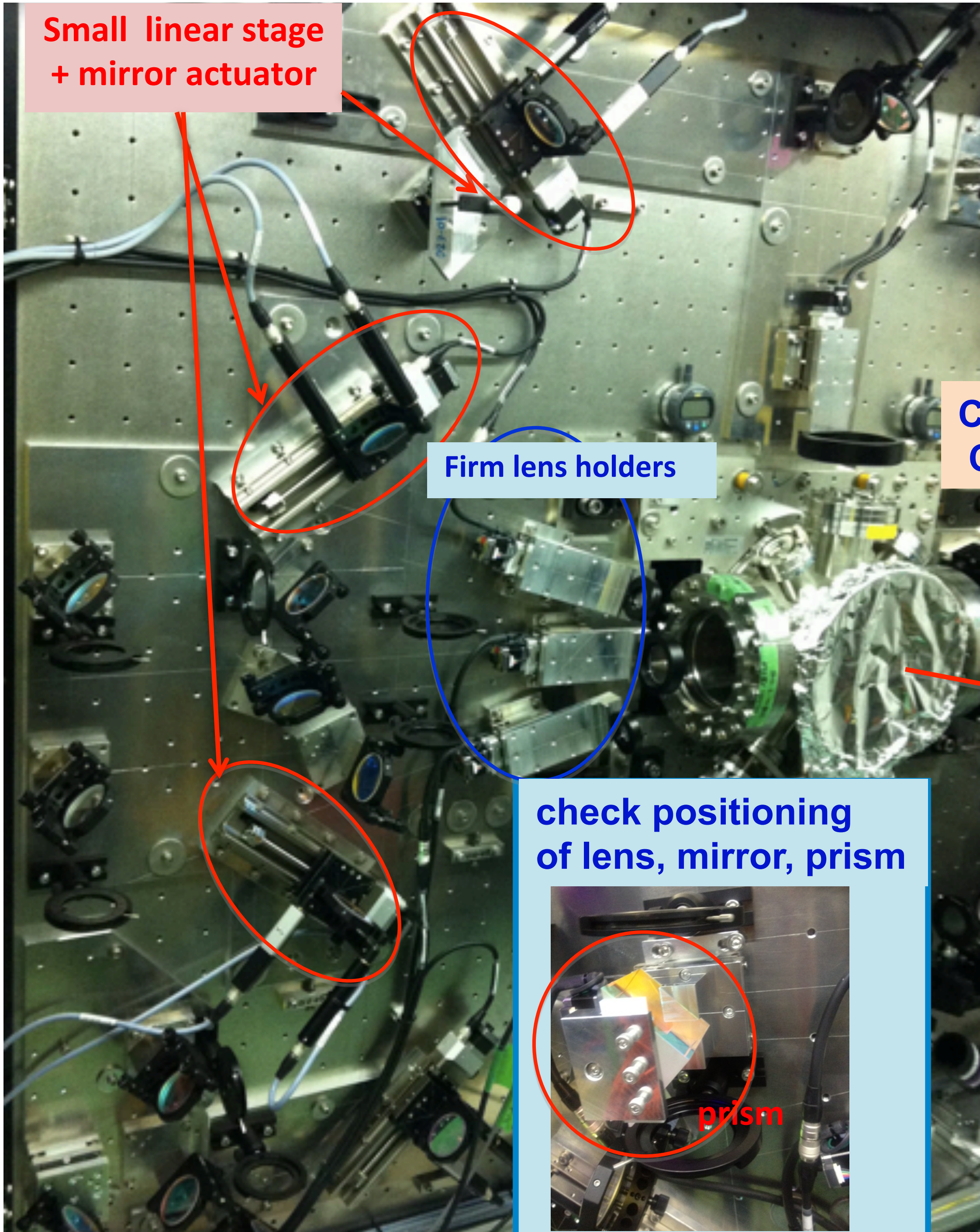
- suppress syst. errors
- effective small **σy*** tuning

Major factor in achieving
BEAM TIME GOAL for winter run:

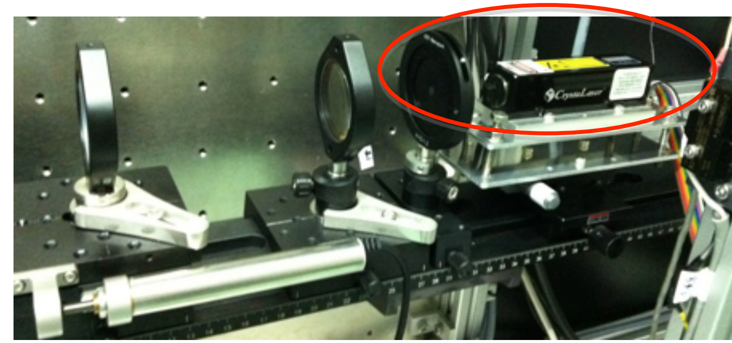
commissioning of 174° mode
→ stably measure σy* < 100 nm

major examples of improvements	details
easier alignment match focal point to IP Injection position / angle into lens **consistency , reproducibility** esp. before / after mode switching	• focal point scan for all modes • redefine clear reference lines on new base plates • **new θ switching method** **{small linear stage + mirror actuators }** independent for each mode (instead of shared rotating stages)
profile imbalance focal point difference between upper/lower paths	• suppress path length difference in new design

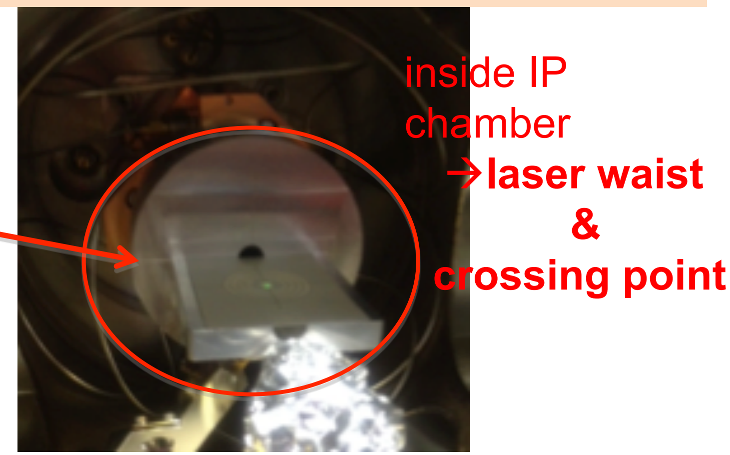
(re) commission various monitors : (CCD, timing system, **PSDs)**

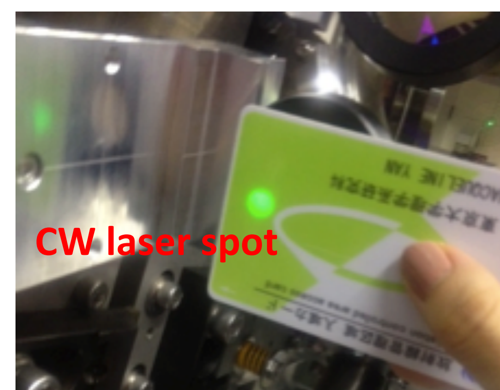


just after injection onto vertical table



Confirm fine alignment using CW laser and transparent IP target





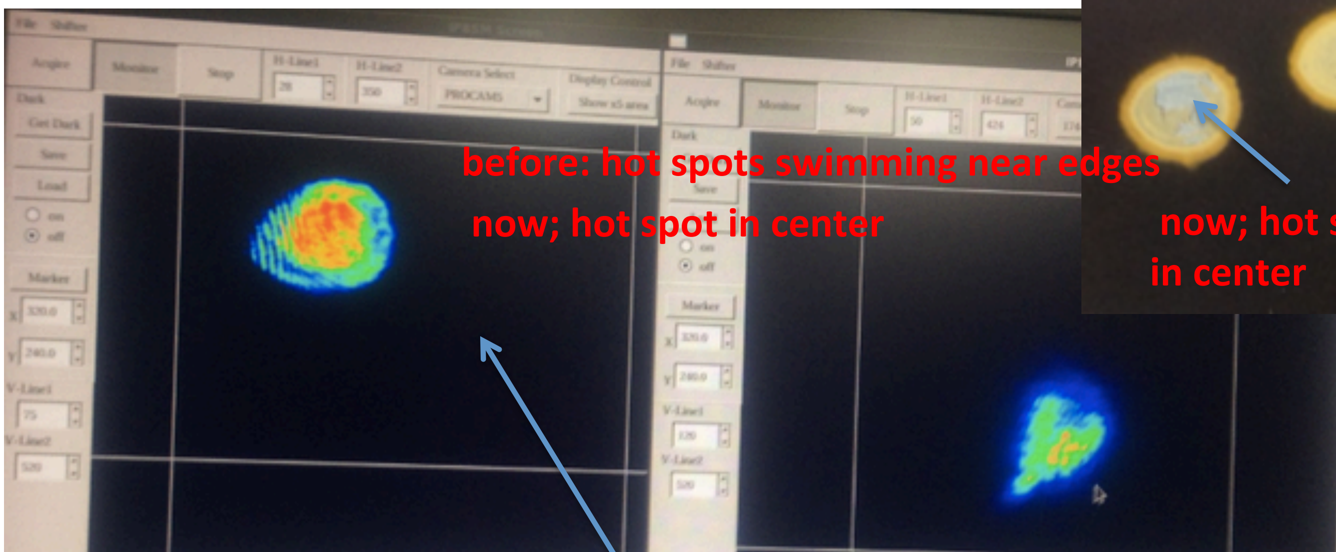
Optics reform in autumn:
Change in Profile after Adjustment by Spectra Physics

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

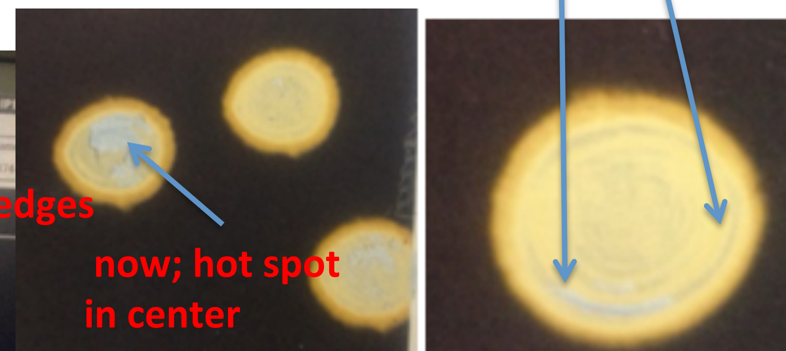
→ (maybe) resolve "two peak" structure in laserwire scan profile

•exchanged rear mirror to curvature is now 2 levels tighter

- Lowered oscillator voltage to prevent intensity damage



before: hot spots swimming near edges



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)

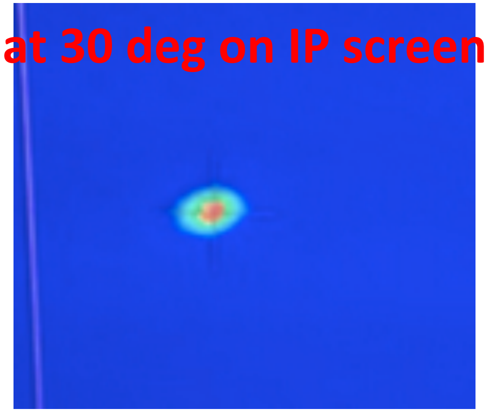
Also adjusted seeding laser seeding

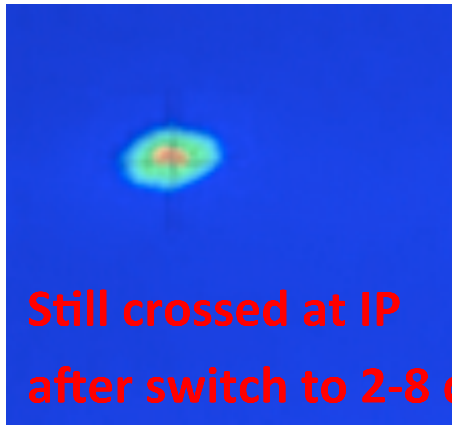
→ Afterwards: continuous efforts to stabilize timing jitters

New IP target: Nov 21

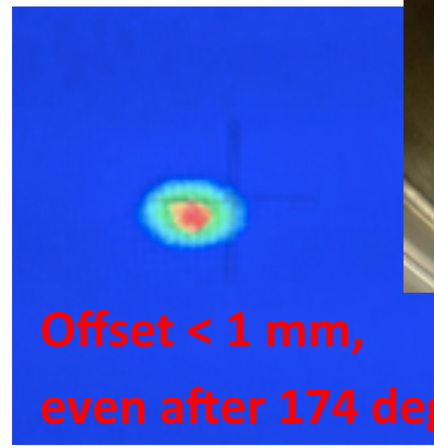
- More reliability and effectiveness during mode switching, and realignment

2 laser spots crossed at 30 deg on IP screen





Still crossed at IP after switch to 2-8 deg



Offset < 1 mm, even after 174 deg mode

Re-optimize expander / reducer : Nov 21

Optimize expander lens (angle)

→ Try to widen spot size before transport, aim for more stable profile

before: overall M = 1

- expander lens: f = -200, 350 mm, reducer lens : f = 350 , - 200 mm

After: overall M = 1.33

- Expander; f = -150, 350 mm M = 2.33, Reducer; f = 350, - 200 mm M = 0.57

laser spot size after reducer: 15 mm x 10 mm

Optics reform in Jan, 2013

Laser table

Previously: offset after ejection from main laser is transmitted all the way downstream

Now: **Setup changed from upstream mirrors**

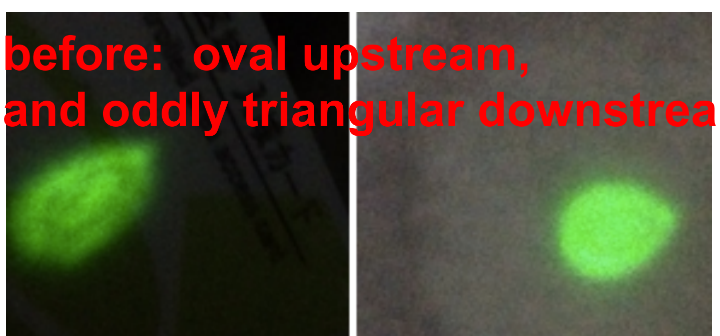
•More freedom to align a good path into expander (irises) and absorb offset from upstream

expander, reducer : lens distance, angle, holders

Vertical table: Injection mirrors

Result : **Laser profile on vertical table is greatly improved !!!** (see next page)

look forward to what is effect on IPBSM beamtime measurements



- **Much rounder now**, from upstream to final lens
- **Spot size is larger than before**
  → should have bigger 30 deg lenses ??

Issue #1: Drift in laser wire scan peak and laser power

Drift in lwscan peak and power (peak*sigma)

- both U and L paths, esp significant for 30 deg mode
- took lots of time for frequent realignment by lwscan, to maintain Compton sig. avg

Investigated series of laserwire scans 12/20 – 21 (30 deg, 174 deg)

see http://atf.kek.jp/twiki/bin/view/IPBSM/Laser_stability

<u>Possible causes and solutions:</u>

(1) Laser position drift , misalignment from injection → hit edge of lens holder

change to larger (60 mm) 30 deg lenses ?? maybe when time allows

- expect improvement after recent reform of laser table , expander / reducer setup

→Higher precision and freedom in injection alignment

(2) Effects from laser transport line

Deformation in base support , temperature effects (??)

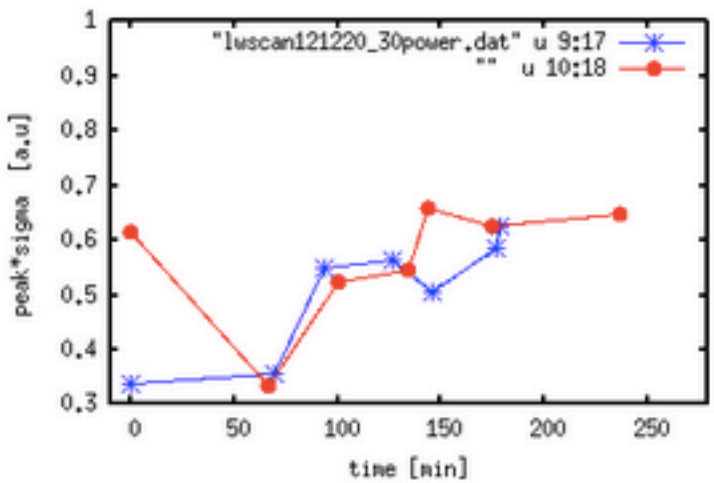
Note) laserwire scan profile is convolution between laser and e beam.

➔ Not totally sure always laser moving

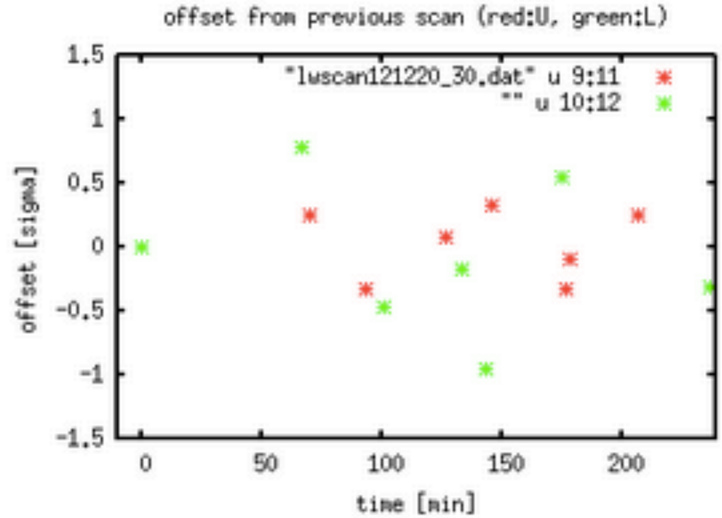
Significant change in power and peak position for both U and L paths

- 12/20 Day 30 deg mode

Total power (sigma * peak)



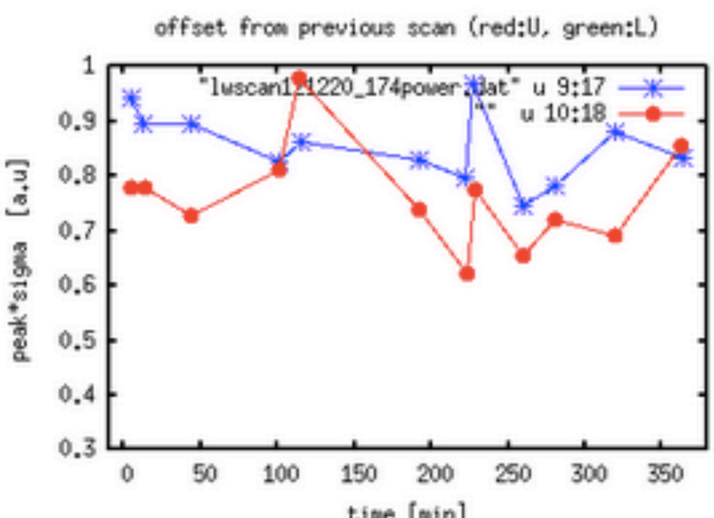
drift in peak position (from previous scan)



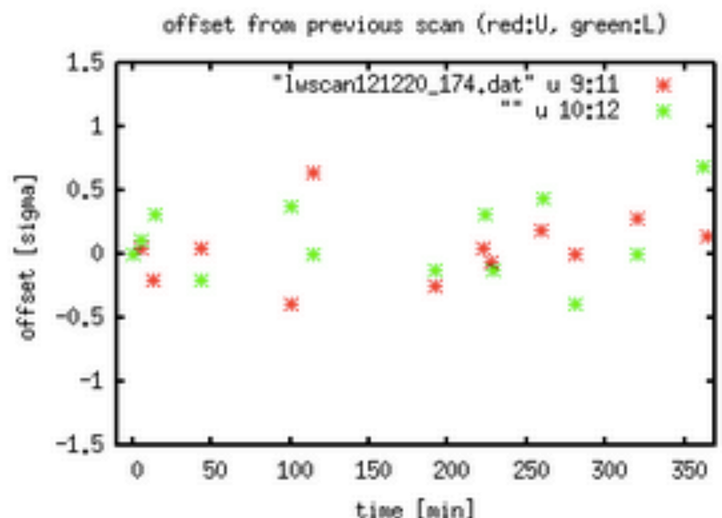
Drift ±1 sigma

- 12/20 Swing, 174 deg mode

Total power (sigma * peak)



drift in peak position (from previous scan)

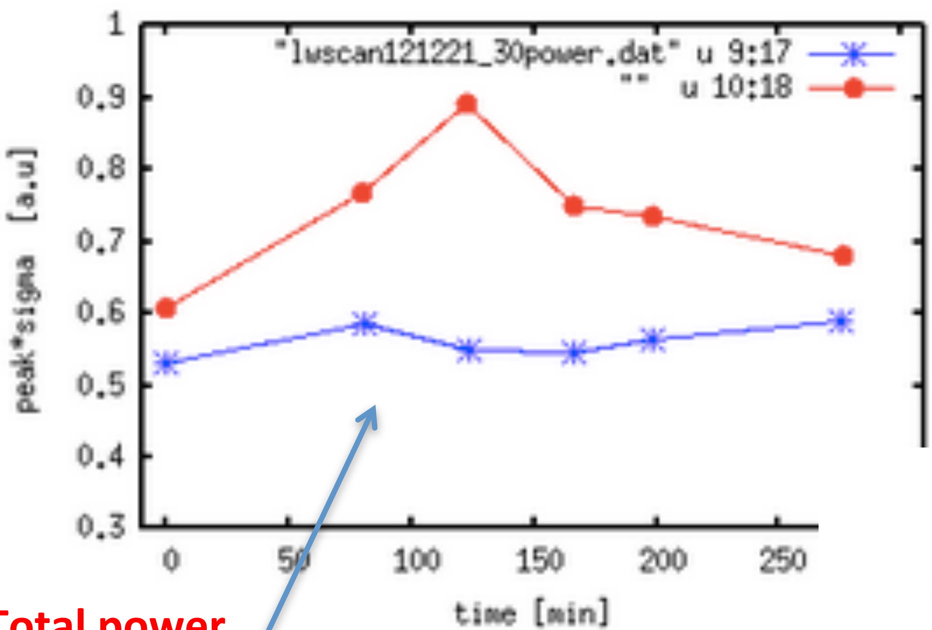


Drift ±0.5 sigma

- **12/21 Day, 30 deg mode**

relatively stable power

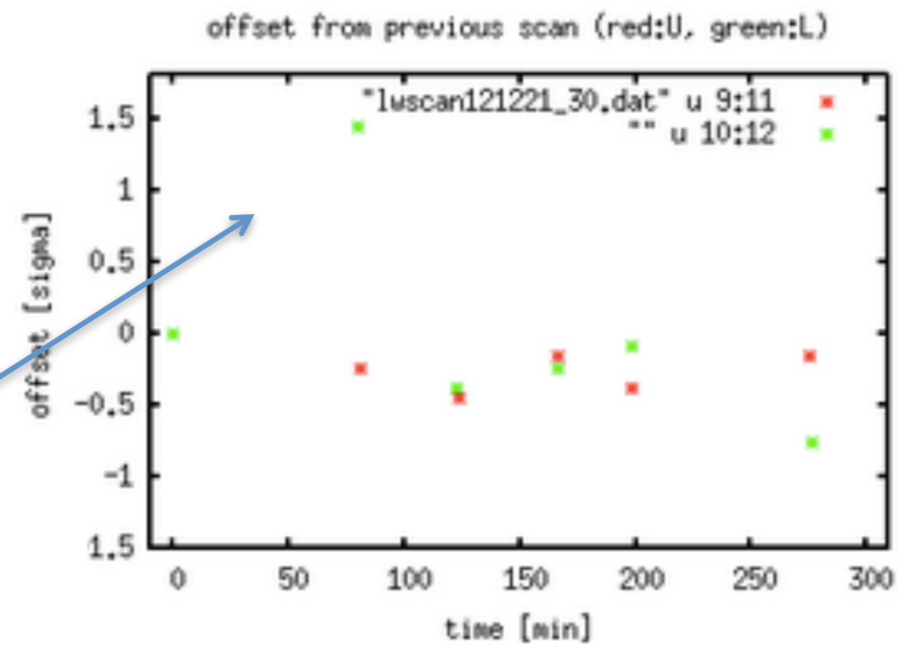
Note: ICT was raised for first part of 30 deg operation and for intensity scan, later lowered



Drift seem lighter on 12/21 (30 deg mode)

maybe laser / e beam became more stable overnight ??

Total power (sigma * peak)

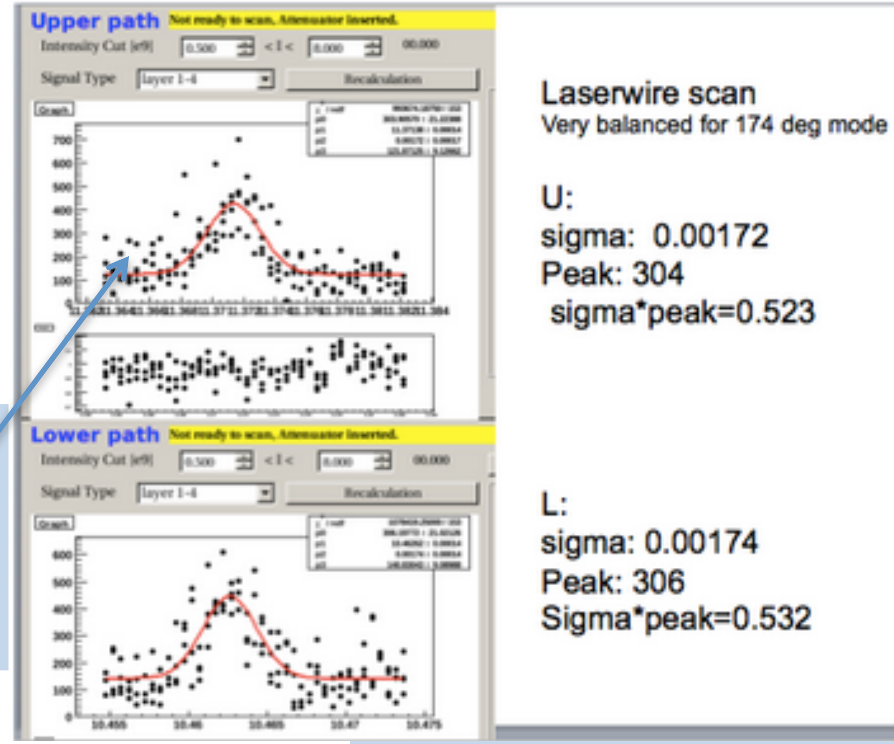


drift in peak position (from previous scan)

Profile (sigma and peak) relatively balanced on 12/21

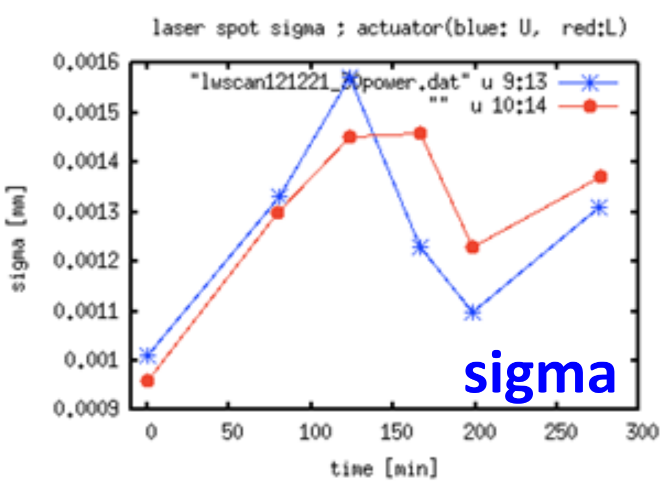
(compared to e.g. 12/20)

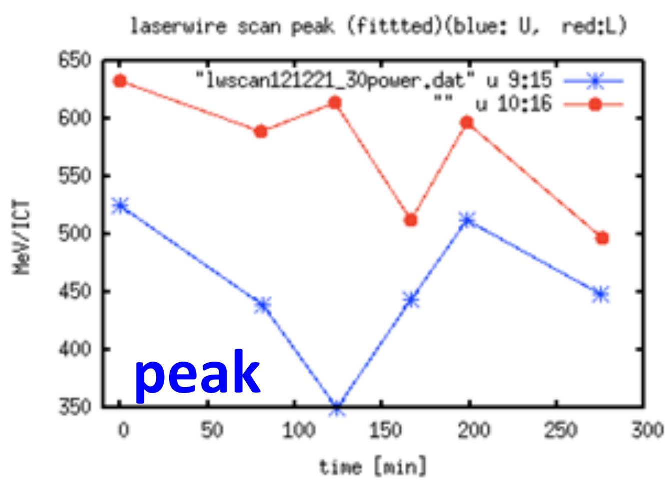
Profile and power very balanced for final 174 deg mode (12/21)



worst limits for syst error:

- **profile imbalance (frm sigma): C,t < 99.7% , C,z < 99.4%** : (6:7)
- power imbalance : C < 98..8 (11:15)





Issue#2: Power & Polarization

Motives:

- **Confirm validity of λ/2 plate setting** before/ during last beam run
  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

Results:

Balanced power ~ 0.75 W each → same as Nov adjustment

this doesn't necessarily give highest M !!

→Plan to reconfirm using λ/2 plate scan during beamtime

power balance at Dec's λ/2 setting :

U : 0.660 W, L : 0.925 W (±0.005) **2 : 3 power imbalance**

→ C = 98.6% M reduction (??) → negligible compared to polarization errors

measure half mirror's reflective property

Ideally, R is 50% for only pure S polarized state

pass CW laser through half mirror → Measure ratio of reflected / transmitted light :

For S polarized (CW laser) : R: T = 4:5 (10% precision)

→ need reconfirmation, maybe change to new half mirror

- **dependence of M on half-lambda plate setting : *greater than expected***

M reduction due to polarization related errors

Dec 5 :

M at 7 deg limited to < 0.5

moved half lambda plate setting significantly (controller set values from 350000 to 180000)

→ **M reached > 0.8**

confirmed many times , at 7 deg and 3 deg , at different ref cavity settings

Before beamtime, 11/26: set half lambda plate to 350000

because it gave U and L balanced power

measured **at 30 deg lenses : (U , L) = (0.721 W, 0.771 W)**

Why this didn't give highest M ???

(1) balanced power doesn't necessarily guarantee pure S state and highest M

→ syst errors related to polarization

(2) Conditions changed after passing through **mirrors with different R for S and P**

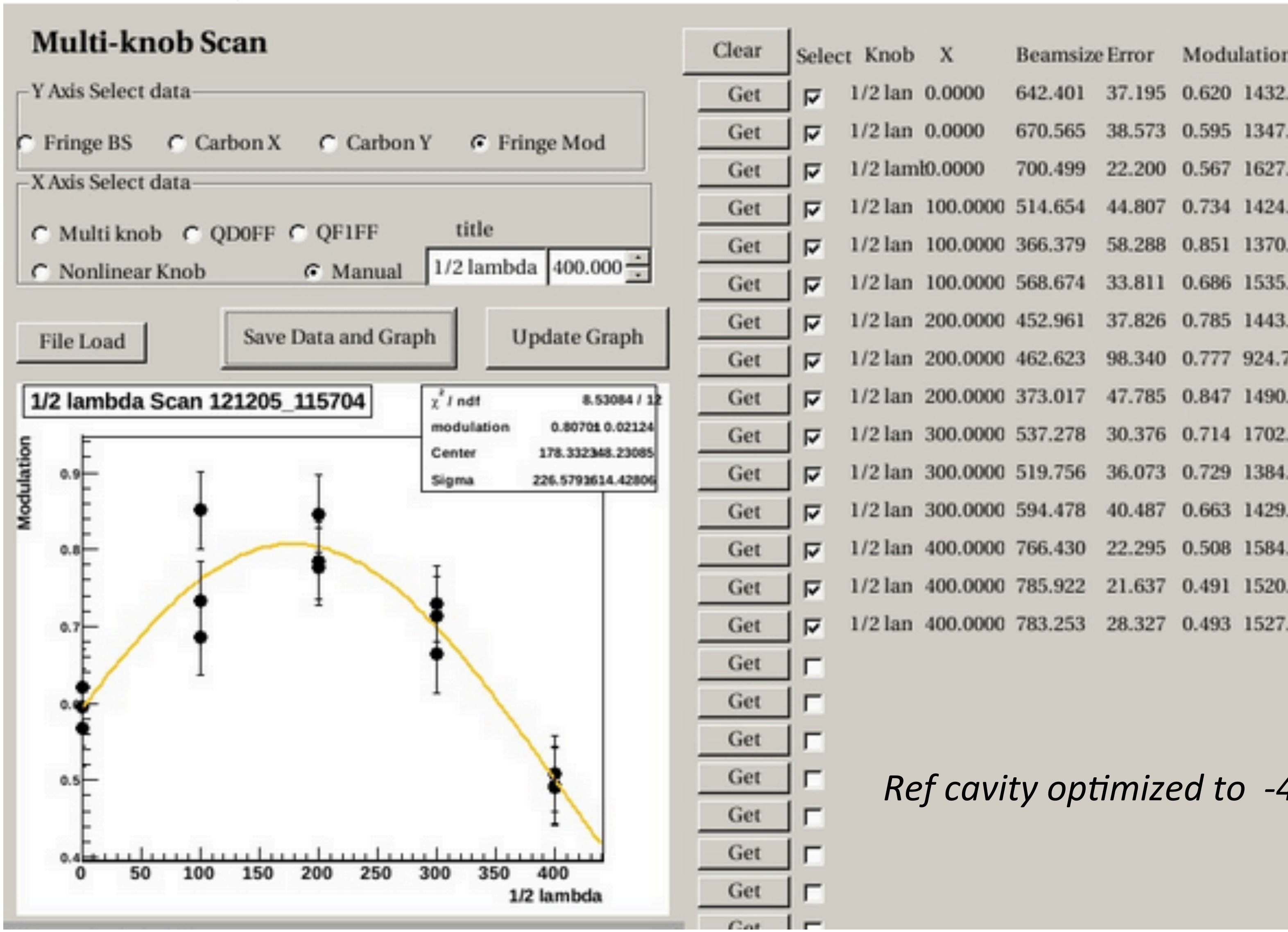
350000 maybe best in terms of power balance, but not highest M

→ **Measure polarization to confirm**

7 deg mode : half lambda scan

λ/2 = 400000 (original) : M = 0.55 ➔ λ/2 = 180000 (after) M = 0.8

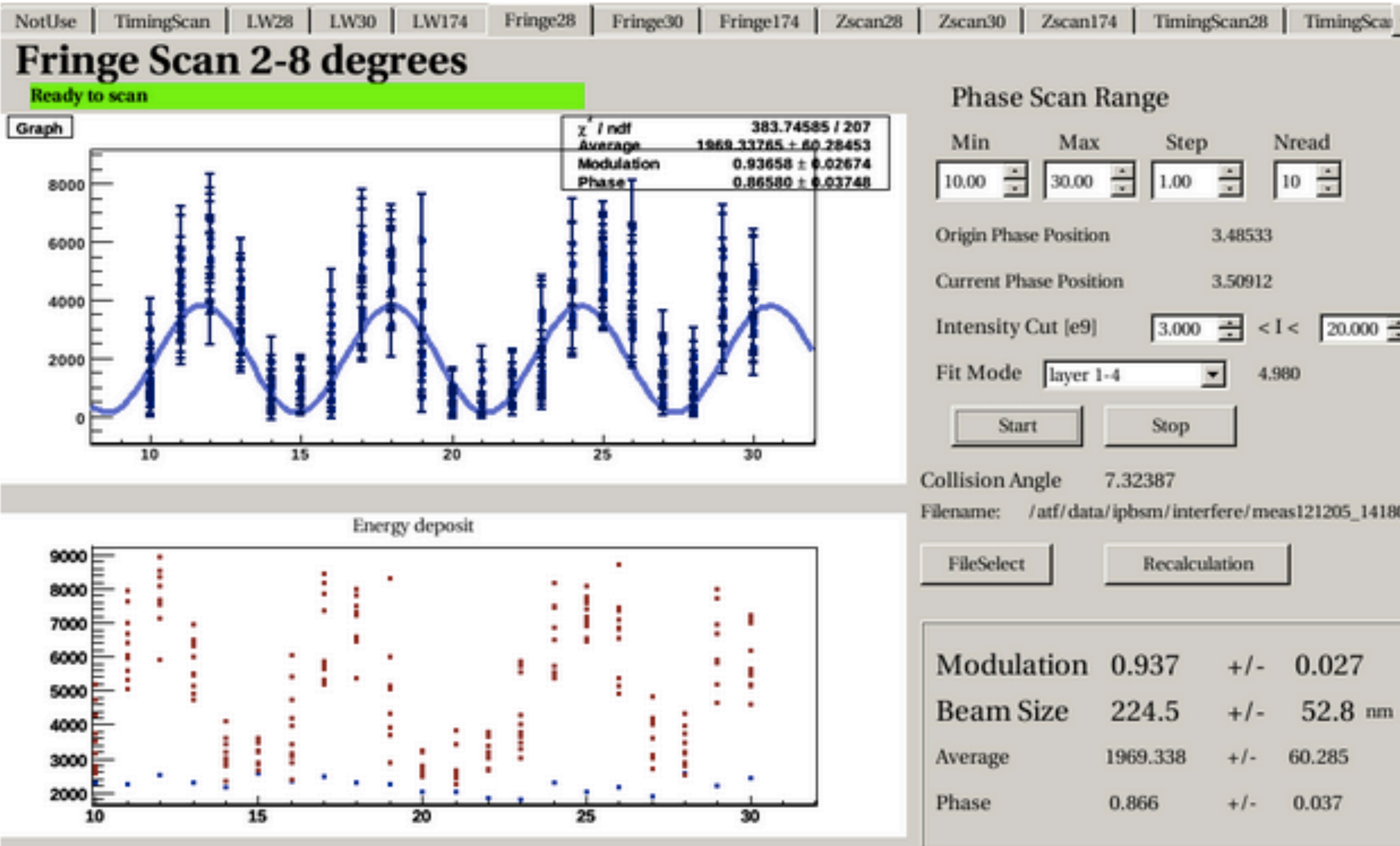
consistent with a few other similar scans



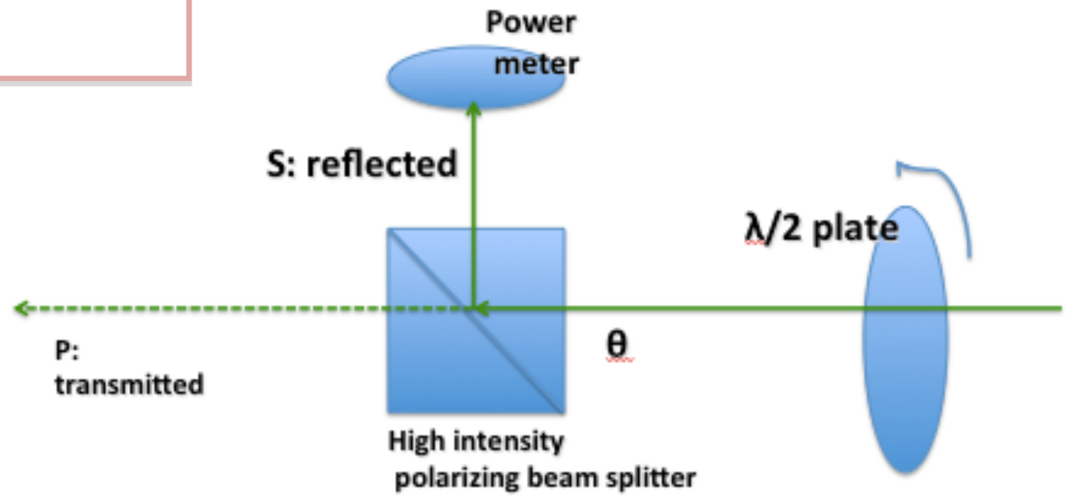
Ref cavity optimized to -4.6 mm

After optimization : M climbed very high to 0.94 (@ 7 deg)

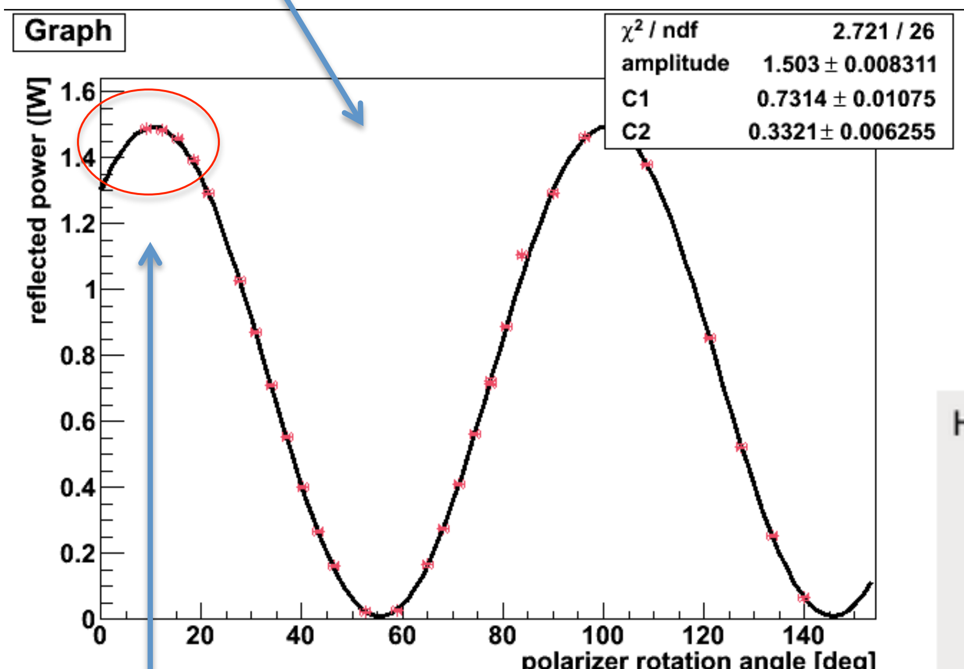
M = 0.937 , beam size fitted to 225 nm



polarization measurement
Jan 18, 2013



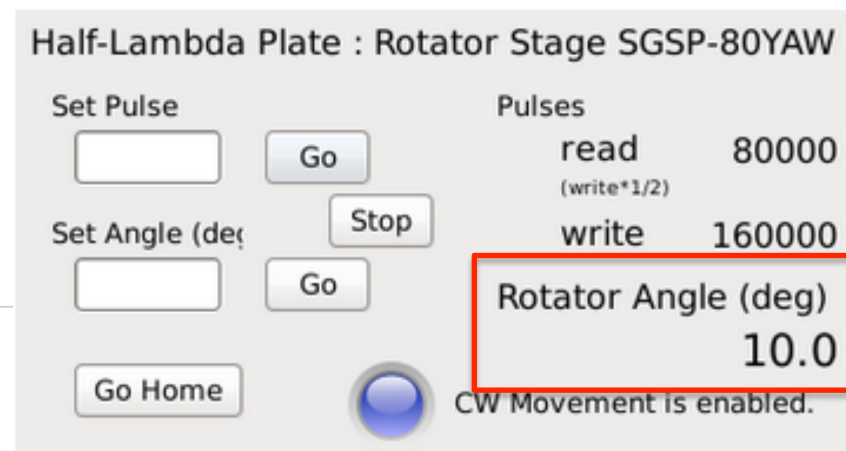
Clear modulation for polarizer angle vs S polarized laser intensity
(reflected from beamsplitter)



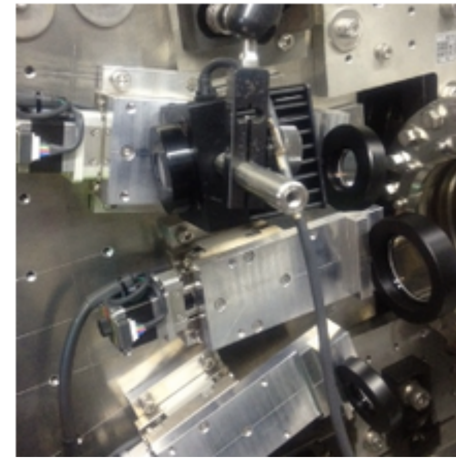
Polarizer (λ/2) angle setting for pure S polarization
(90 deg period)

Recalibration of controller "Shot204" vs λ/2 plate rotation angle

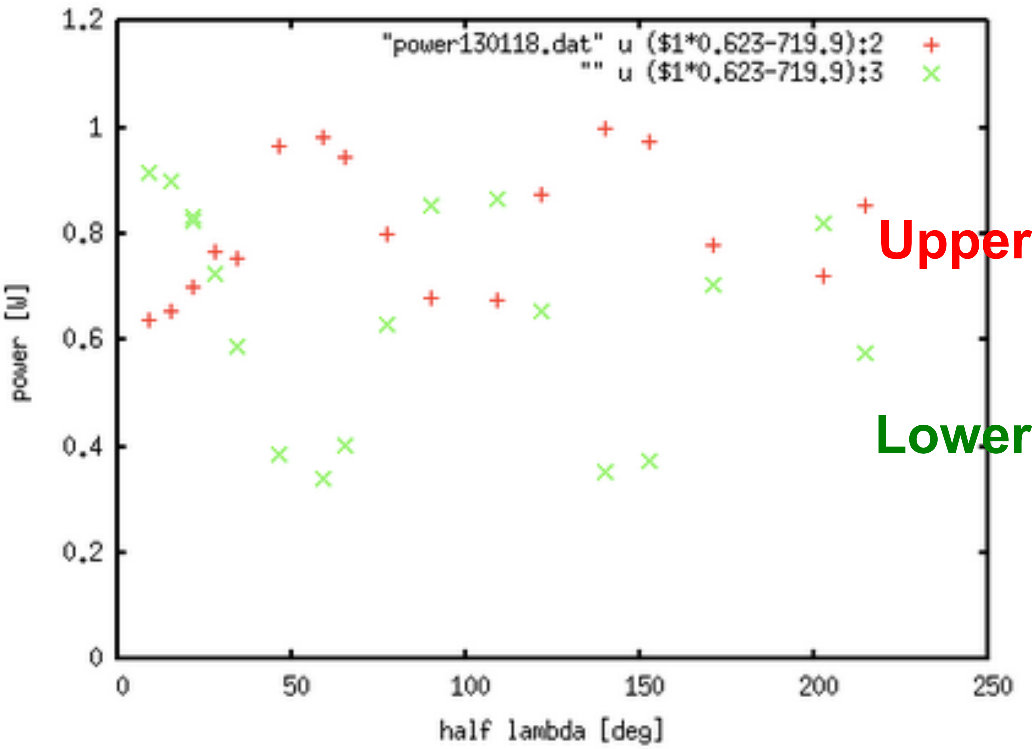
Renewed control software → establish reference from polarization measurement



Compare with power measurement (U, L path) vs λ/2 plate setting



Clear periodic dependence on polarizer rotation



Polarizer (λ/2) angle setting for pure S polarization is about 20 deg away from setting for balanced power

<u>Preliminary Conclusions:</u>
M rose suddenly because λ/2 plate was rotated to nearly pure S state
(originally large P contamination??)

Total power imbalance is negligible compared to polarization related errors

For now, set to λ/2 = 10 deg for best S state, then confirm with M measurement during beam time

Systematic Errors

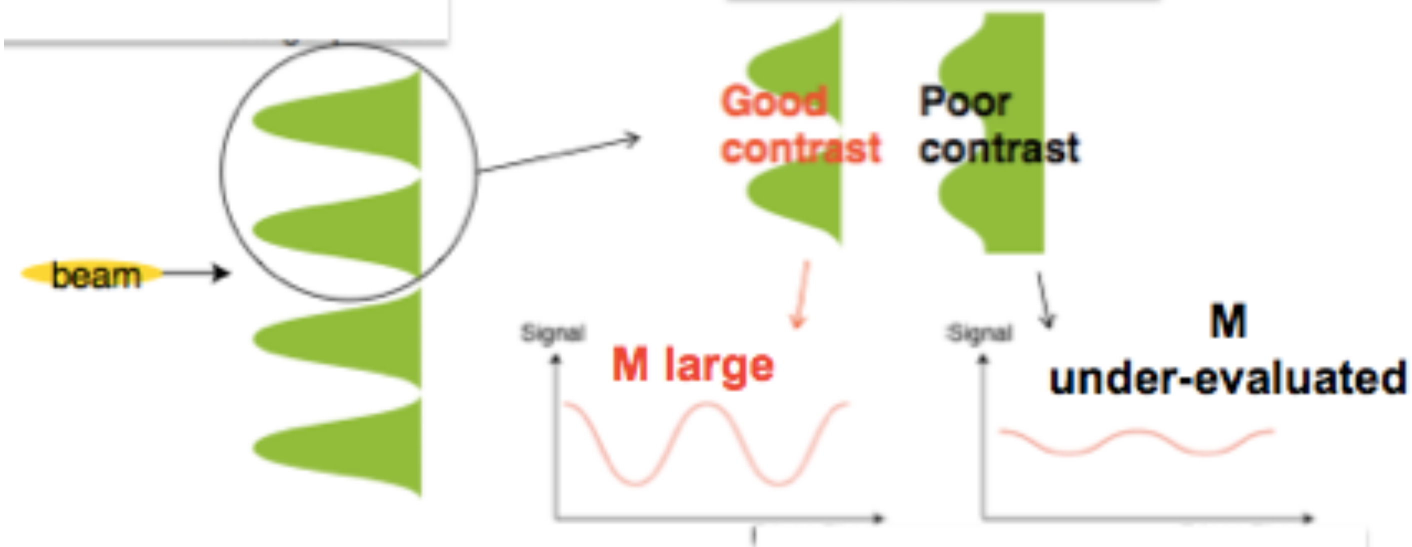
Modulation Reduction Factor

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

over-evaluate σy*

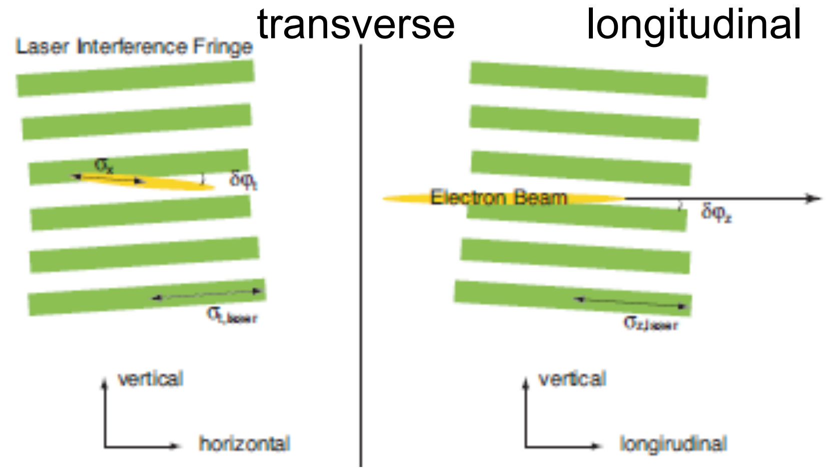
$$\sigma^2_{y,ideal} + \frac{1}{2k_y^2}\left|\sum lnC_i\right|$$

degraded fringe contrast due to bias



Major **"known syst errors"** mostly based on data from 12/20 – 21	**30 deg** **(σy* = 150 nm)** **Mideal ～ 0.55**	**174 deg** **(σy* ～75nm)** **Mideal ～ 0.2**
Profile imbalance (t,z)	**C > 99%**	C > 97%
Laserwire scan sigma, peak : **much improved after summer optics upgrade**		
Power imbalance *sigma,* peak*	**U: L = 2:3 : C > 98.5 %** in general	
Fringe tilt	**U , L paths offset Δ= 1 ~ 3 mm** off from lens center in z, in same direction **C > 95% (?) (if Δ = 1 mrad)**	**2 laser paths tilt symmetrical in longitudinal** ***did not hinder 174 deg M detection***
	Transverse tilt : not a significant issue	
Position alignment (t, z)	**C > 99%**	
Phase drift	24 mrad / min > 99.7%	Very little drift for final scans in general O(10) mrad / min

Fringe Tilt



←→ Laser fringes not completely perpendicular to beam axis

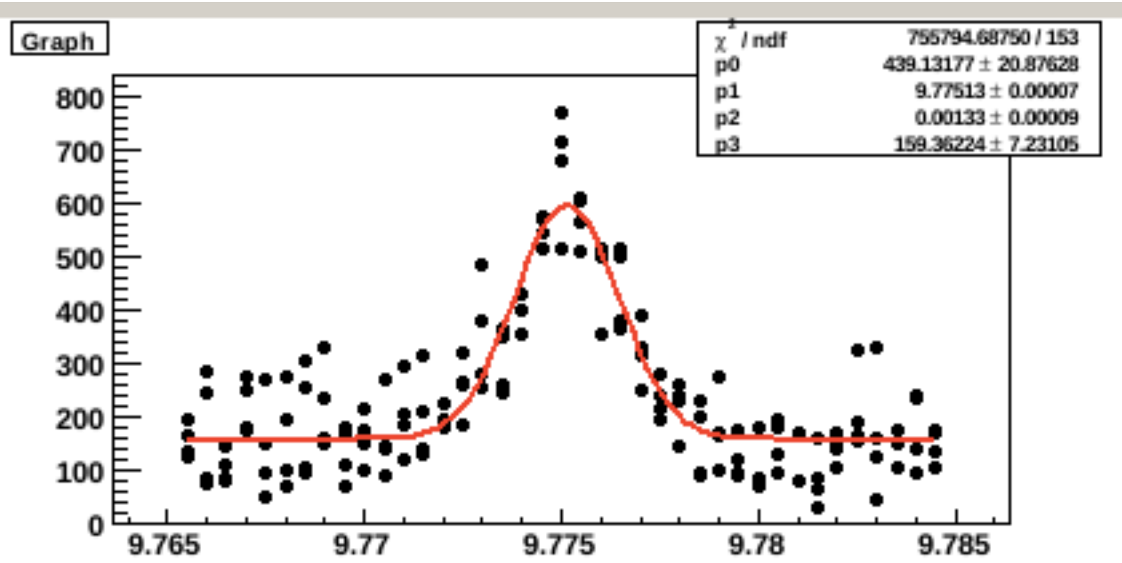
174 deg mode:
Longitudinal :
2 laser paths symmetrically tilt about 10 – 20 mrad (to vertical table)
→ Peak M reduction about cos2θ (??)
not dominate enough to hinder M detection at 174 deg mode

transverse : can tune e beam by rotating → not an issue

Anticipate improved alignment precision after Jan, 2013 optics reform

Example

30 deg Laserwire scan

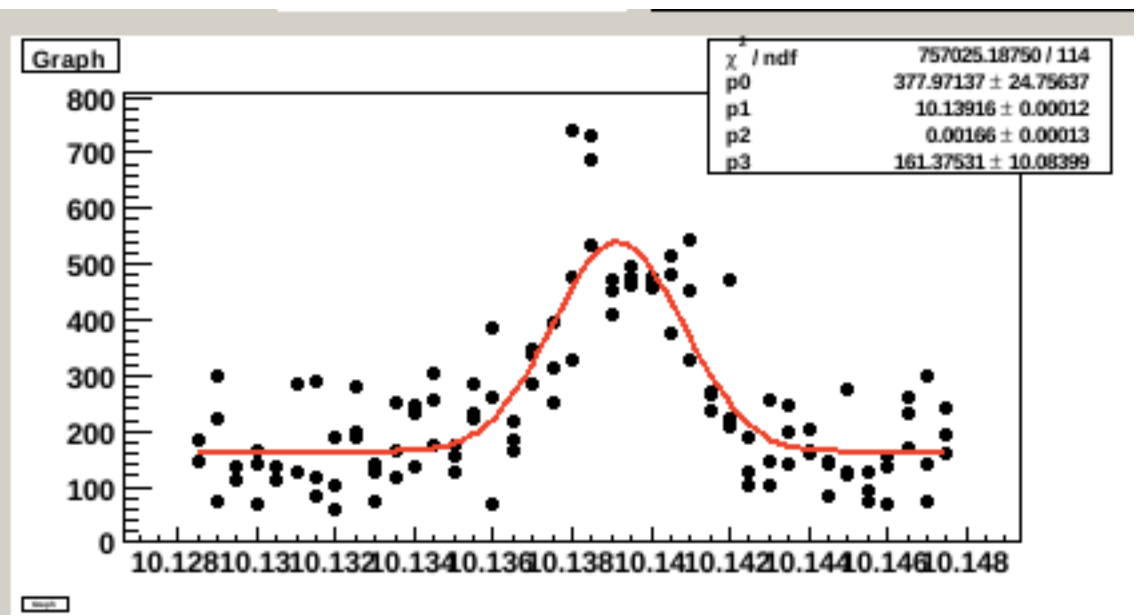


U:

sigma: 0.00133

peak:439

sigma*peak=0.584



L:

sigma: 0.00166

Peak: 378

Sigma*peak=0.627

Uncertain / negligible systematic errors	**30 deg (σ_y^* = 150 nm) Mideal = 0.5**	**174 deg (σ_y^* = 70 nm) Mideal = 0.2**
Phase jitter (relative beam position)	undergoing analysis	
Polarization **From Jan 2013 polarization measurement: may have had significant offset in polarizer setting (~ 10 deg) away from pure S state**		
Change in σ_y^* within fringes **•Spatial coherence** **•Spherical wavefronts**	====================	> 99.7%

Statistical fluctuation sources:

- **BG fluctuation: > 30 %**
- **beam intensity : 10 % in general** (however fringe scans are ICT-corrected)
- **Timing, laser power : few % each**

Need for Error studies

In general, measured M still lacks consistency

12/20 Day: 13 cosecutive scans at 30 deg mode
(just before switching to 174 deg mode)
avg σy* ~ 140 nm (best ~ 100 nm)

after this switched to 174 deg : best σy* ~ 70 nm
→ must have large syst error at 30 deg mode
assuming real σy was at least as small as 70 nm

Proposal for Error Studies

- **polarization: rotate λ/2 plate**
  → observe change in M while comparing with measured power spectrum

- **phase (rel. position) jitter: increase statistics** (Nav = 10 / 60 rad range)

- **Fringe tilt:** intentionally change tilt → observe response in M

SUMMARY #1 : Status and Performance

IPBSM ("Shintake Monitor")

174 deg mode:
consecutive measurements of modulation corresponding to σy <〜 70 nm

- However , only at very low intensity
- Detailed error studies undergoing

At 30 (7) deg modes:
Demonstrated stability during continuous ATF2 beam tuning
contributed to meaningful study on wakefield, beam intensity, ect……

significant reform after laser optics reform
→ suppress jitters & bias factors
→ reliability & reproducibility in laser optics alignment

SUMMARY #2 : Goals Towards beamtime in 2013

❖ **Pre- beam time preparation:**

- **Laser optics reform** (see earlier slides), ***improved profile!!***
- **adjust laser paths → more stable alignment**
- reset various monitors (for timing, intensity, ect….)
- **Polarization optimization**

➔ **Anticipate improvement in IPBSM performance**

❖ **Maintain stable performance of IPBSM for usage in ATF2 studies**

e.g. Wakefield effects, beam intensity dependence, emittance, ect ….

↓

❖ **Improve stability to realize measurement of σy < 50 nm**

- **Dedicated study on potential errors sources**
  (Fringe tilt, phase jitters, ect…….)
- **resolve timing jitters**

Backup

Links to detailed analysis (ATF Twiki)

Profile imbalance and total power:

http://atf.kek.jp/twiki/bin/view/IPBSM/Laser_stability

Phase stability (relative position) :

http://atf.kek.jp/twiki/pub/ATFlogbook/Log20121221d/FringePhase___IPBSM___TWiki.pdf

Timing, laser power

All above , and others: BG fluctuation, beam intensity, ect…

http://atf.kek.jp/twiki/bin/exit.cgi?url=http%3A%2F%2Fatf.kek.jp%2Ftwiki%2Fpub%2FIPBSM%2FAnalysis%2F174degFringe_.xls

Consistent fringe scans at 174 deg mode #1

6 continuous measurements		2012/12/21	174 deg	10x1 beta		20 rad	0.5 rad step			
				consecutive scans #1		after M detection				
data	M	M_err	beamsize	beamsize_err	avg	1/err^2size	size/err^2size		phase	Nav
171524	0.292	0.027	66.3	0.7	811.94	2.040816327	135.3061224		1.197	4
171837	0.212	0.022	74.5	0.5	894.819	4	298		2.027	4
172145	0.232	0.026	72.3	0.7	847.3	全画面表示を閉じる	147.5510204		2.944	4
172344	0.168	0.025	79.9	0.6	878.9	[illegible]	221.9444444		2.434	4
172631	0.24	0.024	71.4	0.6	810.712	2.166	198.3333333		2.166	4
172905	0.2	0.029	75.9	0.7	812.814	3.125	154.8979592		3.125	4
analyzed		σy* = 73.4 ± 4.6 nm				analyzed	σy* = 71.6 ± 0.2 nm			
result (RMS)		M = 0.224±0.0420				result	M = 0.224			

Consistent fringe scans at 174 deg mode #2

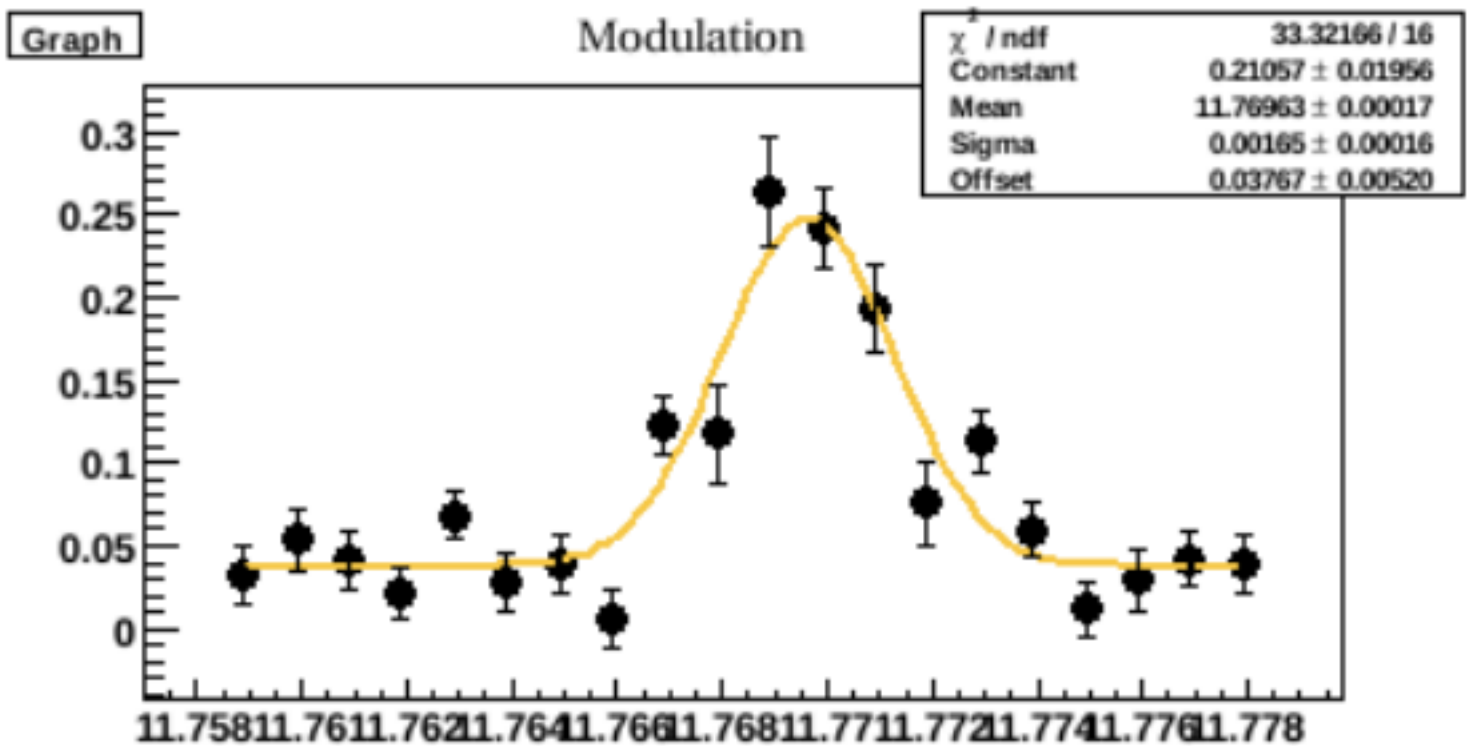
4 continuous measurements		2012/12/21	174 deg	10x1 beta		20 rad	0.5 rad step			
				consecutive scans #2		after 1 round of linear knob scans				
data	M		beamsize	beamsize_err	avg	1/err^2size	size/err^2size		phase	Nav
181913	0.294	0.033	66.2	3.1	700.537	0.104058273	6.888657648		1.654	4
182240	0.16	0.042	81	0.9	685.066	1.234567901	100		1.639	10
183019	0.269	0.042	68.5	1.1	634.6[illegible]	[illegible]	56.61157025		1.22	5
183301	0.197	0.045	76.2	1.1	724.2[illegible]	[illegible]	62.97520661		1.784	10

全画面表示を閉じる

analyzed result (RMS)
$\sigma y^* = 73.0 \pm 6.8$ nm
$M = 0.230 \pm 0.062$

Some issues in z scan profile

Example 30 deg mode   12/15



Some issues in z scan profile

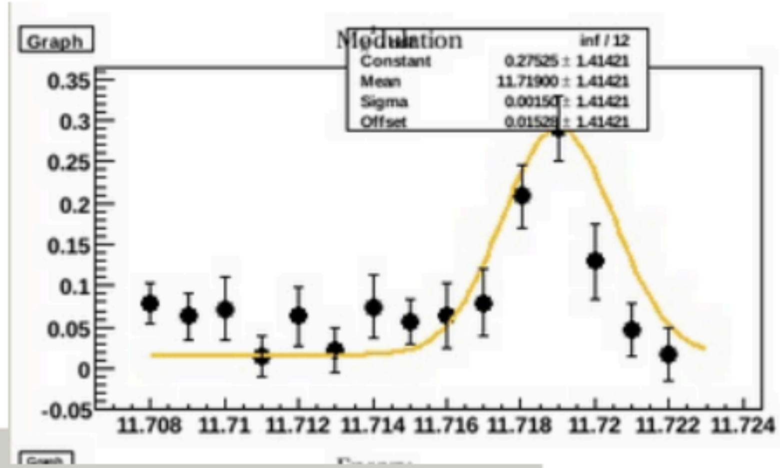
Example 30 deg mode

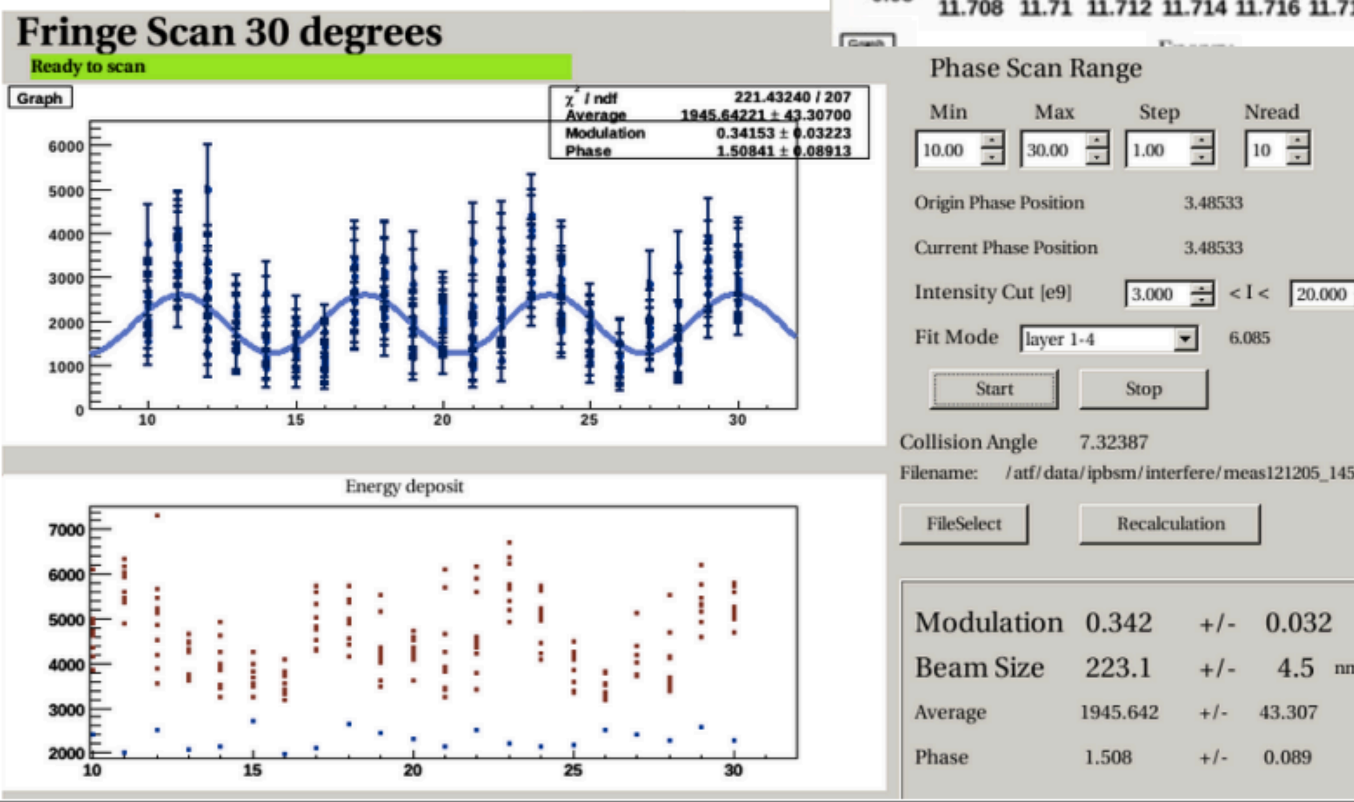
	121215 Swing	121215 Day	121205 Day
σ,laser*[μm] (U,L)	(12.1, 13.9)	(12.1, 9.5)	(16.0, 15.3)
σ,z (zscan sigma) [μm]	16	18.3	14.5
σz / σ,laser_avg	1.2	1.7	0.93
M	0.27	0.3	0.29
Focal lens (U,L) [mm]	(-1.5, 0.7)	(-1.5,0.7)	(-0.4, 0.16)
S/N	2.2	1.7	<= 1
λ/2 plate	180000	180000	180000
MLY	11.769	11.769	11.719

Example : 1st detection of 30 deg mode

30 deg mode z scan
121205 Day
1st detection since Feb, 2012

- many consistent fringe scans after zscan
- Max M = 0.34
- U and L laserwire profiles were well balanced





What is the best laser profile?

Effect of laser profile on M

Need to optimize for most stable measurement

Seem to have less signal jitters when laser spot is not focused too narrow

sigma of zscans

Ideally zscan sigma (σ,z ~2*σz,laser) should be wider than σ,laser

e.g. 12/5*zscan*profile*seems*to*narrow*

Better methods for zscan:

- **For real zscan profile: be careful to rescan in fine steps surrounding peak**

- **Otherwise may miss best mirror setting**
- **Should at least have 33-4 points within 20% of peak**

Well balanced focal point scan is a must

“known syst errors” 174 deg mode	174 deg (σy* = 70 nm) Mideal = 0.25	30 deg (σy* = 150 nm) Mideal = 0.56
Profile imbalance (t,z)	**(99.4%, 98.8%)** Almost no power imbalance U: sigma*peak=0.523 L: Sigma*peak=0.532	Laserwire scan U: (sigma, peak) = (0.00172, 304) L: (sigma, peak) = (0.00174, 306)
Fringe tilt	**84% (if Δ = 1 mrad)** **50% (if Δ = 3 mrad)**	**Observed on screen after beam measurements ~ 1 mm in transv (x, y)**
Position alignment (t, z)	**(99.9%, 98.9%)**	same
Phase drift	Set#1: 63 mrad : > 98.2% set#2: 3.8 mrad: > 99.9%	See http://atf.kek.jp/twiki/pub/ATFlogbook/Log20121221d/FringePhase___IPBSM___TWiki.pdf
[illegible]	[illegible]	[illegible]

Example:
effect of syst error on measured beam size

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

	174 deg (σy* = 70 nm)	30 deg (σy* = 150 nm)	7 deg (σy* = 500 nm)
Ctotal *(assume 1 mrad fringe tilt)*	**71%** **MIdeal = 0.25**	**93%** **MIdeal = 0.56**	**94%** **MIdeal = 0.77**
	→ Mmeas = 0.18 → σmeas = 78 nm	→ Mmeas = 0.52 → σmeas = 163 nm	→ Mmeas = 0.72 → σmeas = 556 nm

Maybe about 10% correction needed for σy ~ < 100 nm @ 30, 174 deg mode !!

Profile imbalance

Much improved after summer upgrade

(status of recent weeks)
when focal lens is optimized,
balance is better than 4:5
(e.g. Actuator sigma 0.0012 vs 0.0015)

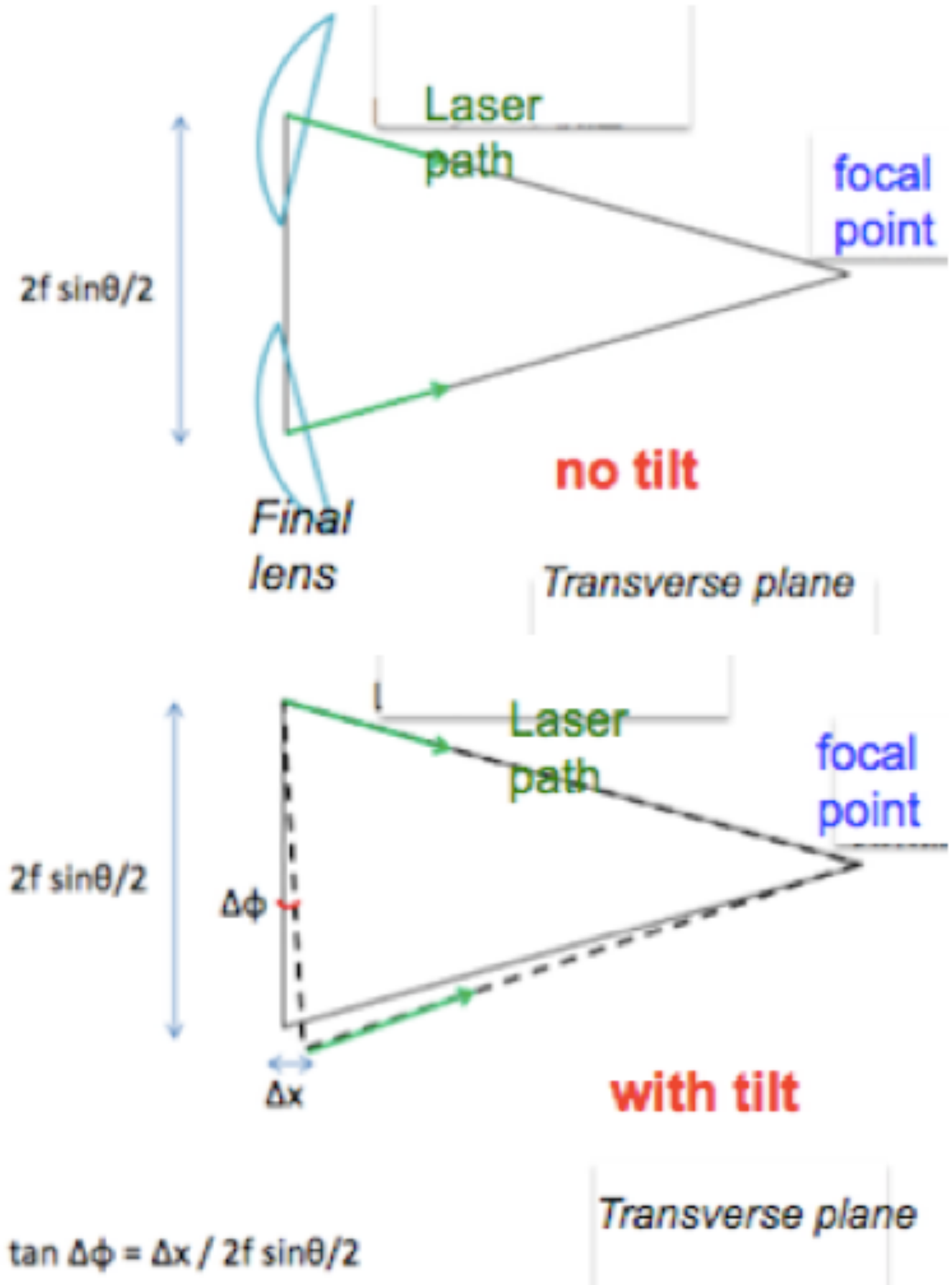
longitudinal : $$C_{z,profile} = \sqrt{\frac{2\sigma_{1z,laser}\sigma_{2z,laser}}{\sigma^2_{1z,laser} + \sigma^2_{2z,laser}}}$$

transverse : $$C_{t,profile} = 2\frac{\sqrt{\sigma_{1t,laser}\sigma_{2t,laser}}}{\sigma_{1t,laser} + \sigma_{2t,laser}}$$

Assume similar balance for transv and longitudinal profile:

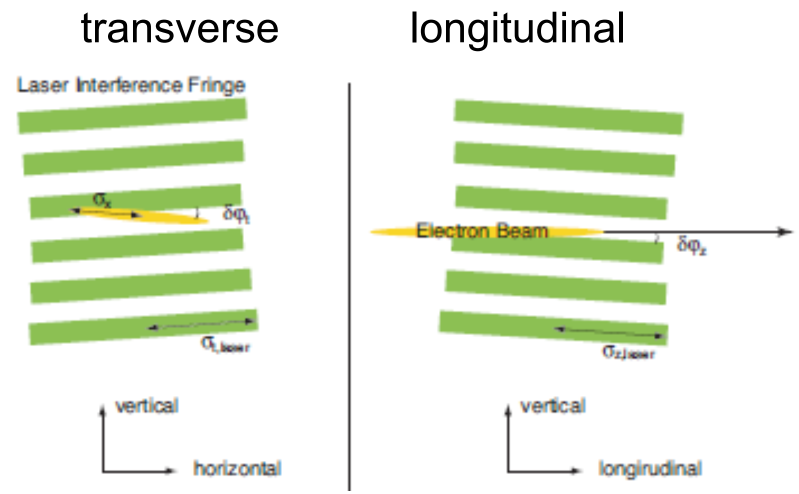
- **C,t,profile ～ 98.8%**
- **C,z,profile ～ 99.4%**
-

sometimes worse state for 7 deg mode → 3:4 balance


Laser path
focal point
2f sinθ/2
Final lens
no tilt
Transverse plane
Laser path
focal point
2f sinθ/2
Δϕ
Δx
with tilt
Transverse plane
tan Δϕ = Δx / 2f sinθ/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 :

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

Fringe Tilt

Relative offset between 2 laser spots

$\Delta_{t,z}$ ∼ 1 mm

(after earthquake 12/7, maybe 1 ~ 3 mm ??)

See records in **http://atf.kek.jp/twiki/bin/view/IPBSM/2012Nov21**

assume $\sigma_{z,laser}$∼ 5 μm. σ_x^* ∼ 5μm

If Δ∼1 mm

$\delta\varphi_{t,z}$ ∼ 5 mrad

- **174 deg: $C_{t,z}$ > 84 %**
- **30 deg: $C_{t,z}$ > 98.3 %**
- **7 deg: $C_{t,z}$ > 99.9 %**

If Δ∼3 mm

$\delta\varphi_{t,z}$ ∼ 10 mrad

- **174 deg: $C_{t,z}$ > 50 %**
- **30 deg: $C_{t,z}$ > 95.3 %**
- **7 deg: $C_{t,z}$ > 99.7 %**

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

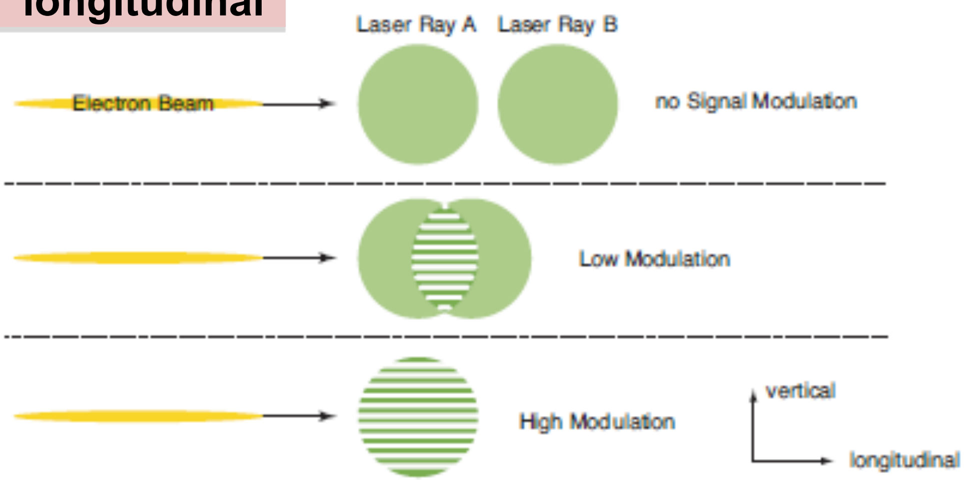
longitudinal **Cz- pos > 98.9 %**

transverse **Ct-pos ~ 99.9 %**

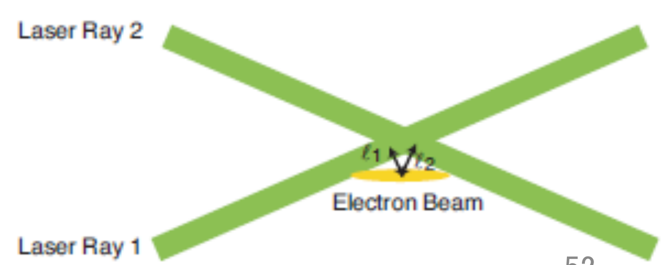
$$\text{longitudinal}: \quad C_{z,pos} = exp\left(-\frac{z_0^2}{2\sigma_{z,laser}^2}\right)$$

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

longitudinal



transverse

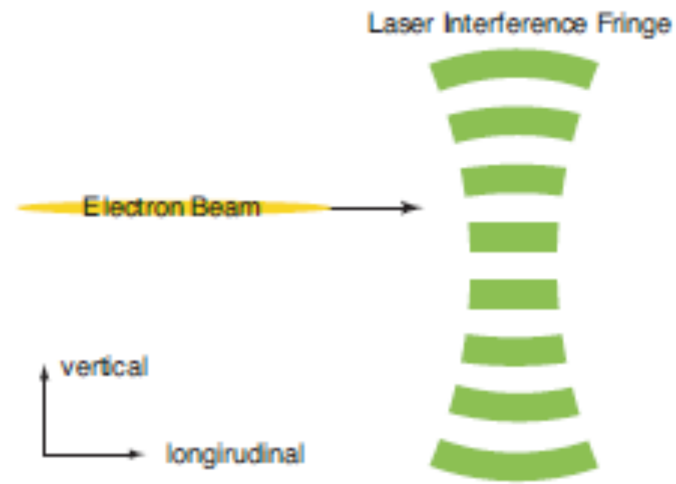


Spherical Wavefront

offset between beam and laser waist

→ e beam feels deformed fringes

$$C_{sphere} = (1+\Delta y^2)^{-1/4}\left[1+\frac{\Delta y^2}{\left(1+z_R\frac{1+\Delta y^2}{2k\sigma_z^2}\right)^2}\right]^{-1/4}$$



focal lens scanner

resolution ～100 μm

rayleigh length > 1 mm

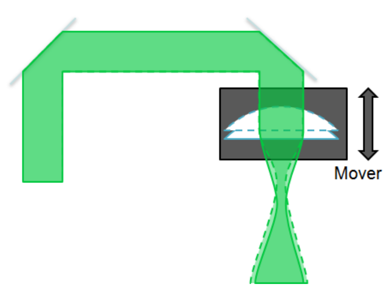
(about 1.5 mm from focal point scan results)

→ **Δ < 0.1**

C.sphere > 99.9%

(assume σx* ～ 5 μm)

Align laser waist to IP



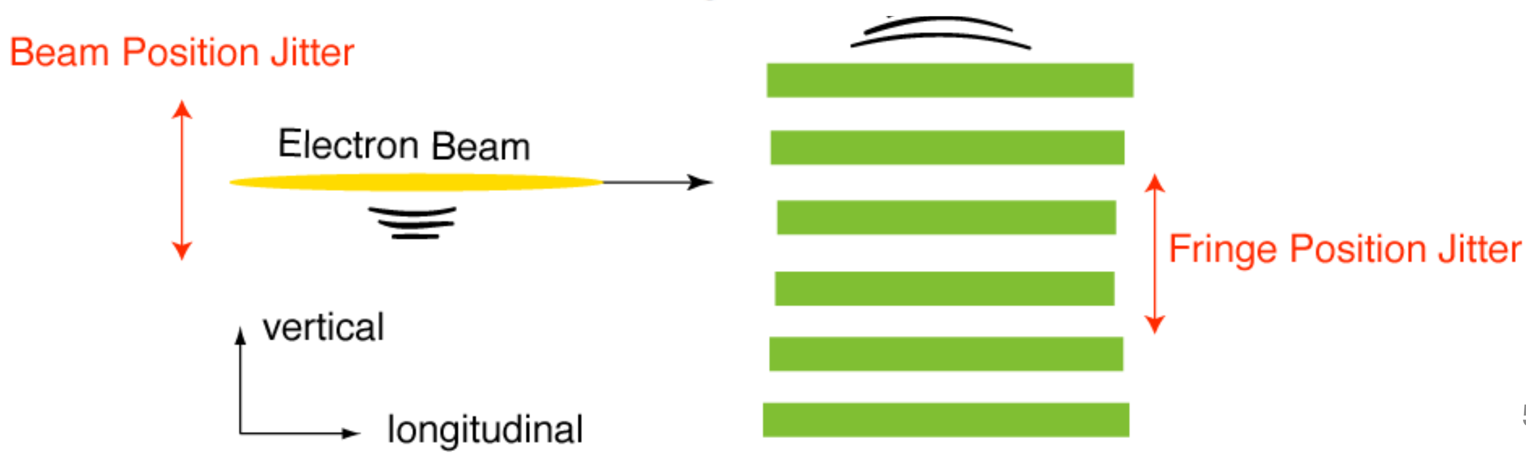
Not certain#2: Phase (relative position) jitter

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 % (????)

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

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



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

Phase jitter $\quad$ **beam pos jitter** $\quad$ **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

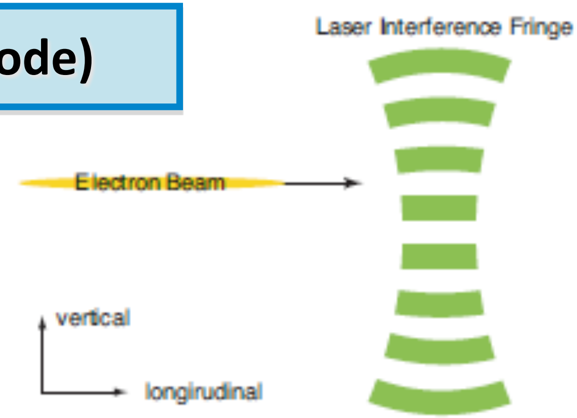
Correlation between phase jitter and beam pos jitter

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)

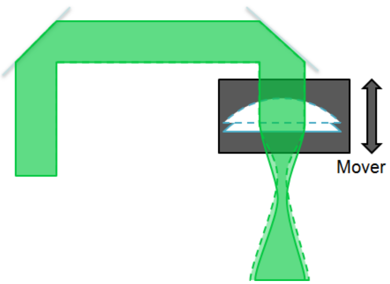


Spherical wavefronts

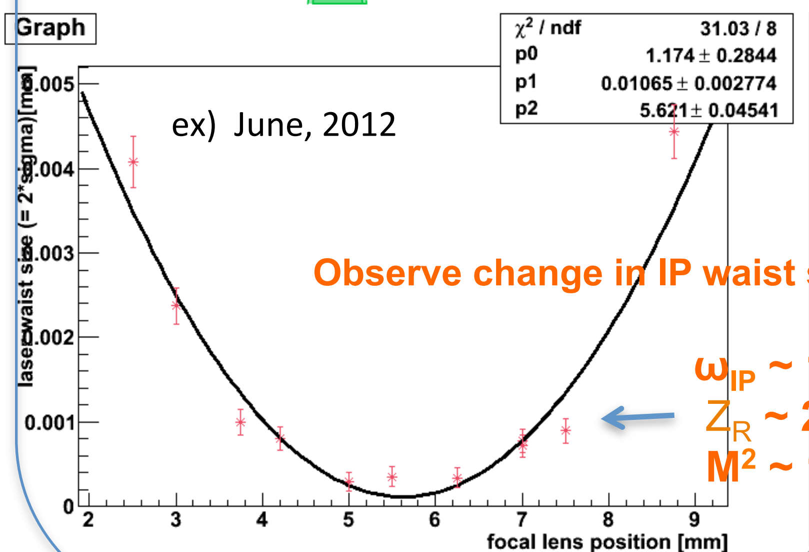
Offset of ultra-focused e- beam vs laser waist → distorted fringes

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

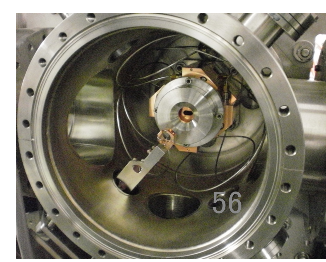
due to strong focusing,

Cgrowth ~ 99.7%

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

IPBPM (O(nm) design resolution)
under commissioning

- beam pos. monitoring
- feedback correction



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

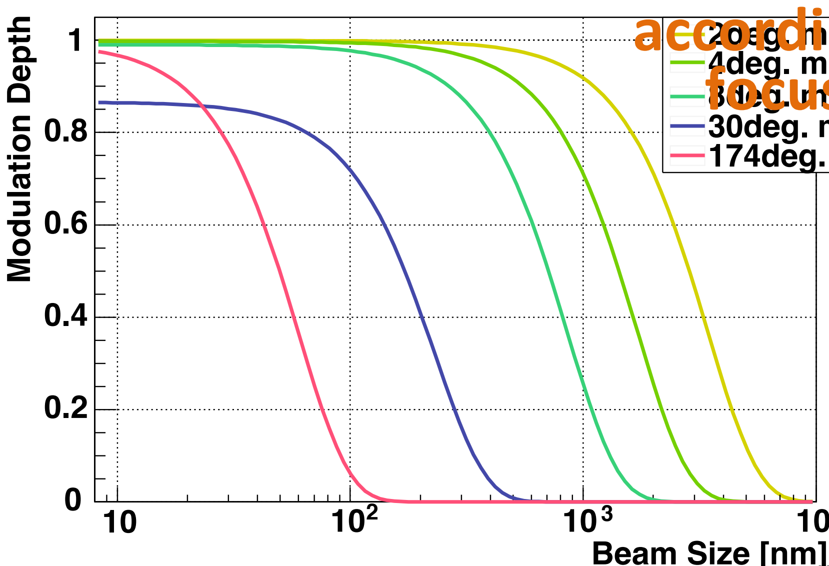
$$37 \pm 2\,(\text{stat.})\ ^{-0}_{+4}\,(\text{syst.})\ \ \text{nm}$$

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

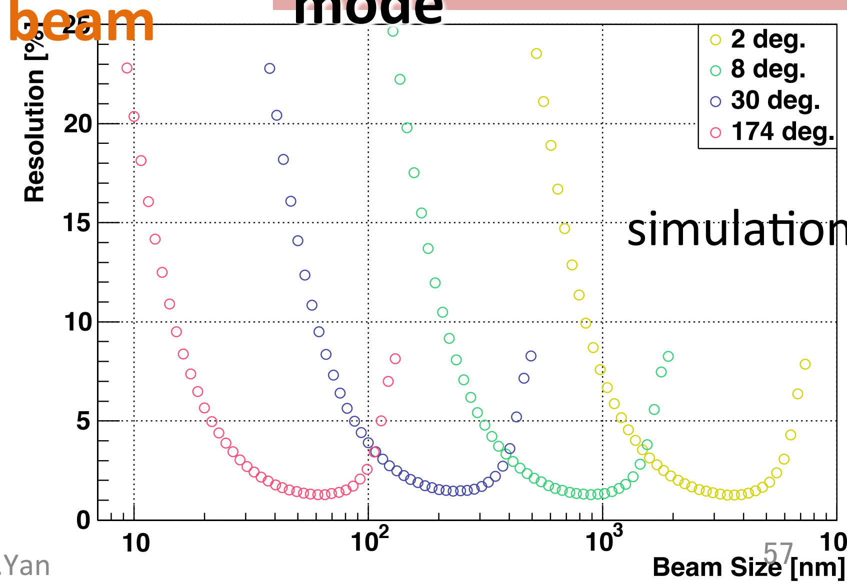
$$\sigma_y = \frac{d}{2\pi}\sqrt{2\ln\left(\frac{|\cos(\theta)|}{M}\right)}$$

σy*and M for each θ mode

must select appropriate mode according to beam focusing



Resolution for each θ mode



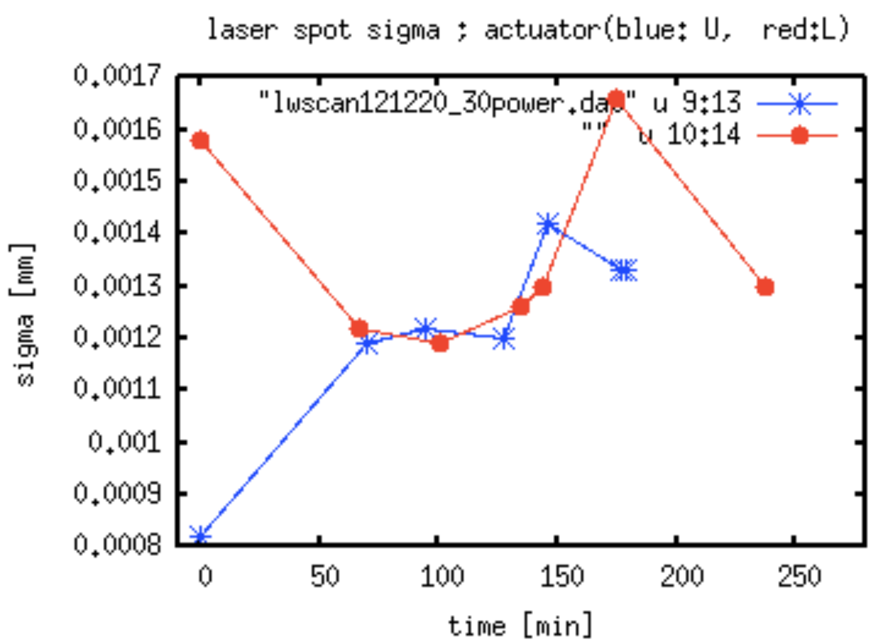
simulation

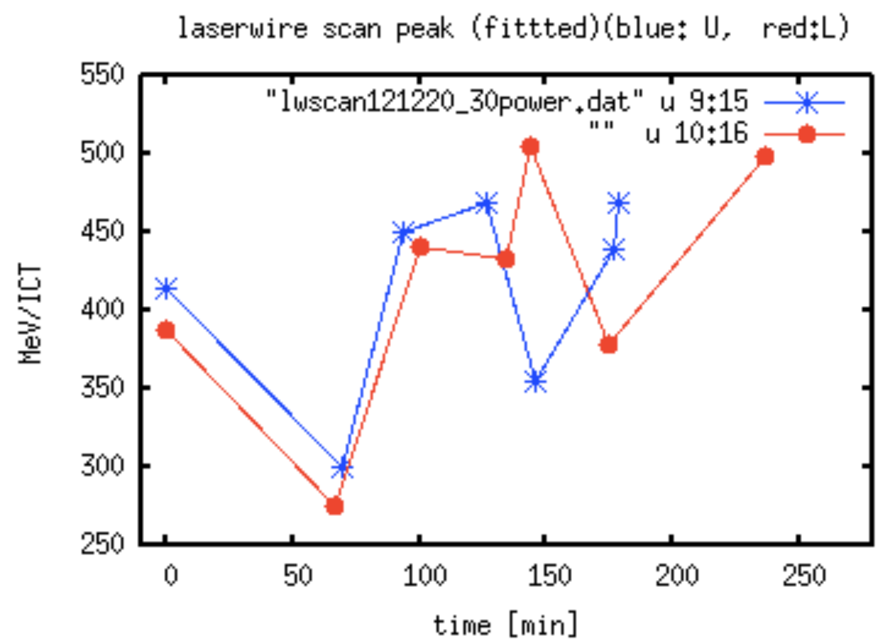
12/20 Day 30 deg mode

profile stayed balanced for about 2 hours, but then drifted (esp L path)

worst limits for syst error:

- **profile imbalance (frm sigma): C,t < 99.5% , C,z < 98.9%** : (13:16) , both longitudinal and transverse (?)
- power imbalance : C < 98.6 (5:7)

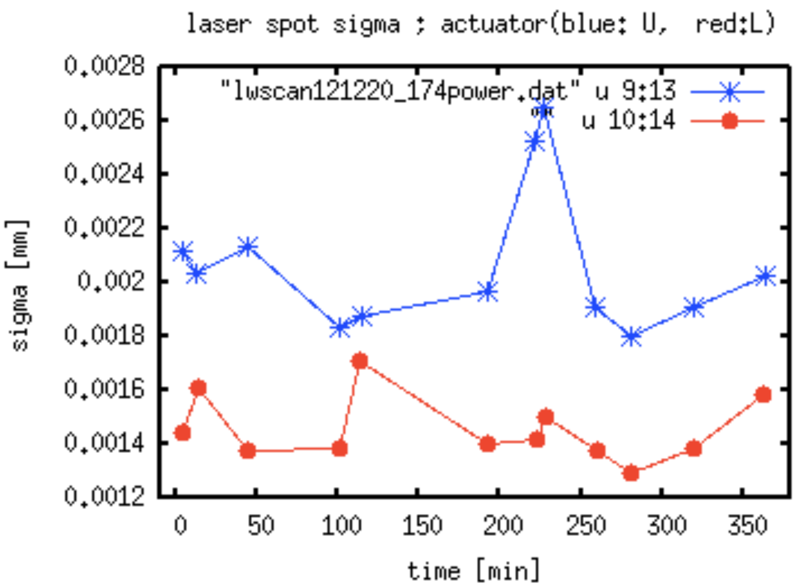


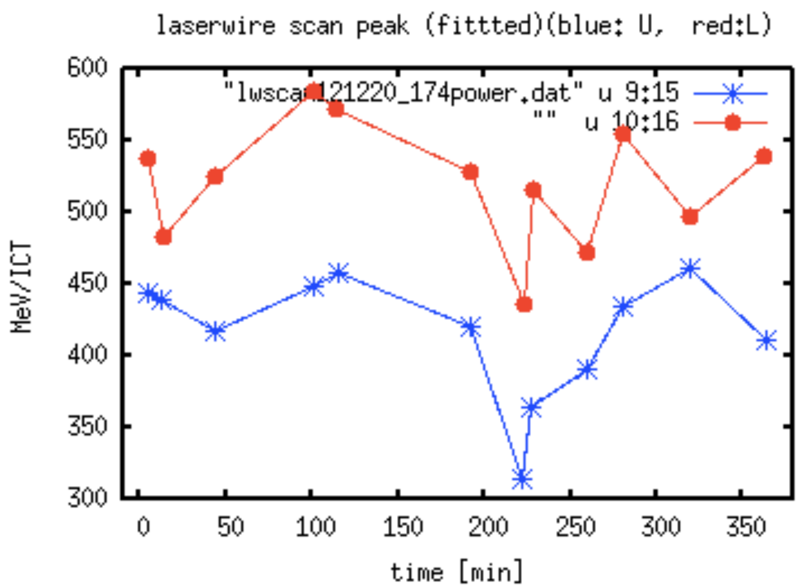


12/20 Day 174 deg mode

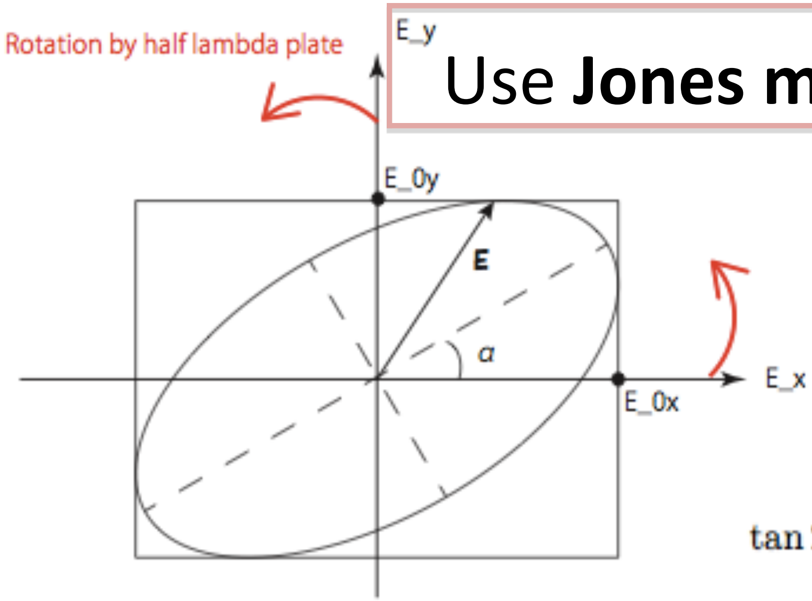
worst limits for syst error:

- **profile imbalance (frm sigma): C,t < 97.5% , C,z < 95.2%** : (11:7), ignore large jump , both longitudinal and transverse (?)
- power imbalance : C < 99.2 (9:7)





Use **Jones matrix** to calculate effect of rotation:



Get **ellipticity** and

phase difference φ = φy − φx
from scanning θ (rotating half lambda plate)

$$\tan 2\alpha = \frac{2E_{0x}E_{0y}\cos(\phi_y - \phi_x)}{E_{0x}^2 - E_{0y}^2}$$

$$\begin{pmatrix} E'_x(t) \\ E'_y(t) \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \begin{pmatrix} \cos 2\theta & \sin 2\theta \\ \sin 2\theta & -\cos 2\theta \end{pmatrix} \begin{pmatrix} E_x(t) \\ E_y(t) \end{pmatrix}$$

$$= \begin{pmatrix} E_x(t)\cos 2\theta + E_y(t)\sin 2\theta \\ 0 \end{pmatrix}$$

$$= \exp\{i(kz - \omega t + \phi_x)\} \begin{pmatrix} E_{0x}\cos 2\theta + E_{0y}\exp\{i(\phi_y - \phi_x)\}\sin 2\theta \\ 0 \end{pmatrix}$$

$$\int \left(|E'_x(t)|^2 + |E'_y(t)|^2\right) dt = E_{0x}^2 \cos^2 2\theta + E_{0y}^2 \sin^2(\phi_y - \phi_x)\sin^2 2\theta + 2E_{0x}E_{0y}\cos(\phi_y - \phi_x)\sin 2\theta$$

linearly polarized → modulation = 100%
Totally circularly polarized → no modulation.
Elliptical components → in between

Example of results from Yamaguchi-san 's measurement : 2010

s と p 偏光の位相差 φ	91 ± 7 degree
レーザー楕円率 $\tan\chi$	0.132 ± 0.002
$\frac{Pow_p}{Pow_s}$	$(1.72 \pm 0.02) \times 10^{-2}$
ハーフミラー s 偏光反射率	$53.4 \pm 0.5\,\%$
ハーフミラー p 偏光反射率	$21.3 \pm 0.5\,\%$

$$C_{total\ power} = \left\{ \left(2\frac{\sqrt{R_s(1-R_s)}Pow_s + \sqrt{R_p(1-R_p)}Pow_p}{Pow} - 2\cos\varphi\tan\theta\left(\sqrt{R_s(1-R_p)} - \sqrt{R_p(1-R_s)}\right)\frac{\sqrt{Pow_s Pow_p}}{Pow} \right)^2 + \left(2\sin\varphi\tan\theta\left(\sqrt{R_s(1-R_p)} + \sqrt{R_p(1-R_s)}\right)\frac{\sqrt{Pow_s Pow_p}}{Pow} \right)^2 \right\}^{\frac{1}{2}}$$

Estimated systematic error (Yamaguchi-M thesis)

C ～ 97% (considering Goos-Hänchen shift)

This is not consistent with large effect on M during beamtime

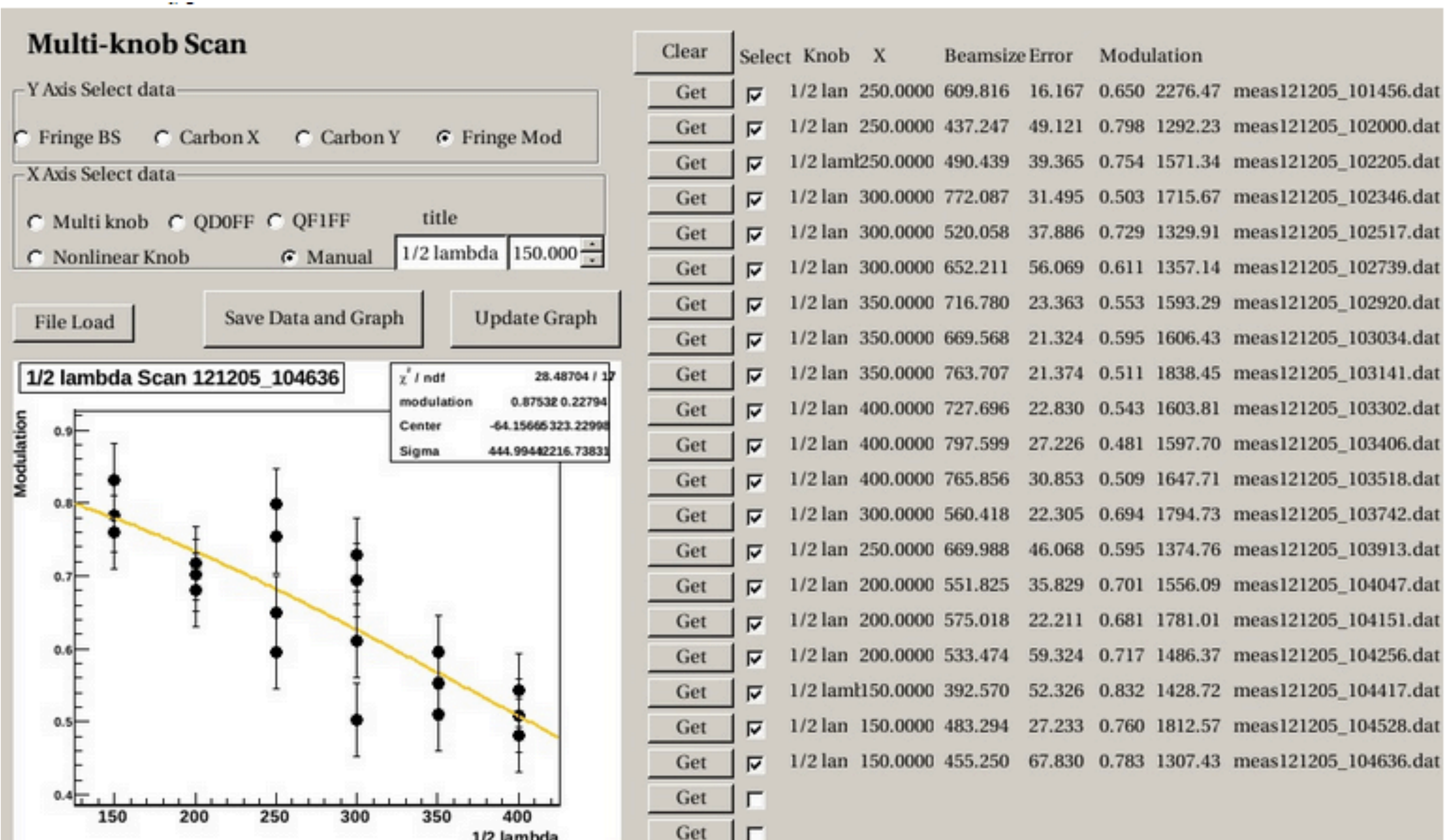
Expect C = 99% if we can make a precisely linear S polarized light !!

→try to adjust polarization this time with high intensity beamsplitter

M found to change greatly with half lambda plate setting: (at 7 deg mode)

Scan #1 : M change from 0.5 (λ/2 = 400) to 0.8 (λ/2 = 150)

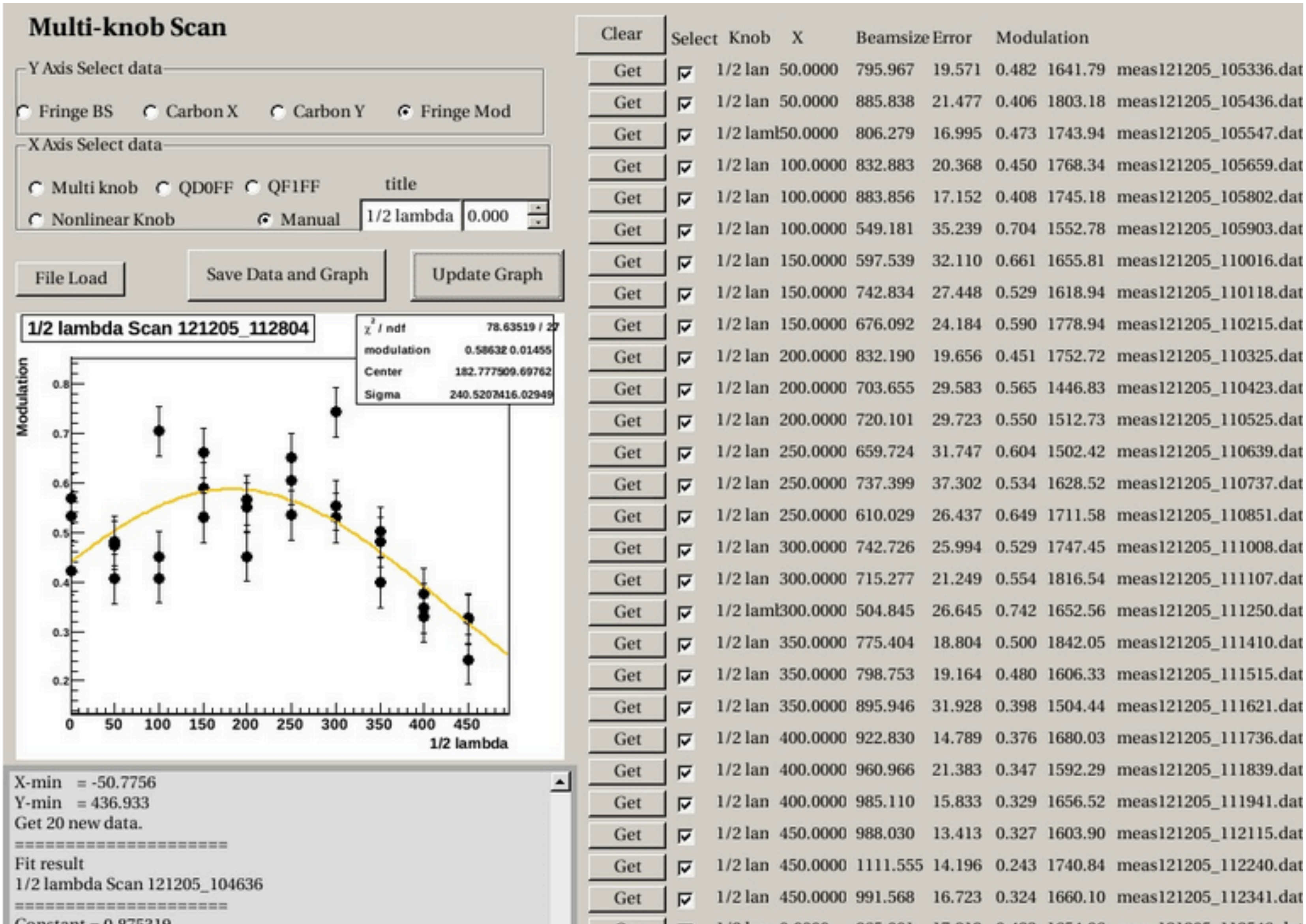
ref cavity at – 4.6 mm



Select	Knob	X	Beamsize	Error	Modulation		
☑	1/2 lan	250.0000	609.816	16.167	0.650	2276.47	meas121205_101456.dat
☑	1/2 lan	250.0000	437.247	49.121	0.798	1292.23	meas121205_102000.dat
☑	1/2 laml	250.0000	490.439	39.365	0.754	1571.34	meas121205_102205.dat
☑	1/2 lan	300.0000	772.087	31.495	0.503	1715.67	meas121205_102346.dat
☑	1/2 lan	300.0000	520.058	37.886	0.729	1329.91	meas121205_102517.dat
☑	1/2 lan	300.0000	652.211	56.069	0.611	1357.14	meas121205_102739.dat
☑	1/2 lan	350.0000	716.780	23.363	0.553	1593.29	meas121205_102920.dat
☑	1/2 lan	350.0000	669.568	21.324	0.595	1606.43	meas121205_103034.dat
☑	1/2 lan	350.0000	763.707	21.374	0.511	1838.45	meas121205_103141.dat
☑	1/2 lan	400.0000	727.696	22.830	0.543	1603.81	meas121205_103302.dat
☑	1/2 lan	400.0000	797.599	27.226	0.481	1597.70	meas121205_103406.dat
☑	1/2 lan	400.0000	765.856	30.853	0.509	1647.71	meas121205_103518.dat
☑	1/2 lan	300.0000	560.418	22.305	0.694	1794.73	meas121205_103742.dat
☑	1/2 lan	250.0000	669.988	46.068	0.595	1374.76	meas121205_103913.dat
☑	1/2 lan	200.0000	551.825	35.829	0.701	1556.09	meas121205_104047.dat
☑	1/2 lan	200.0000	575.018	22.211	0.681	1781.01	meas121205_104151.dat
☑	1/2 lan	200.0000	533.474	59.324	0.717	1486.37	meas121205_104256.dat
☑	1/2 laml	150.0000	392.570	52.326	0.832	1428.72	meas121205_104417.dat
☑	1/2 lan	150.0000	483.294	27.233	0.760	1812.57	meas121205_104528.dat
☑	1/2 lan	150.0000	455.250	67.830	0.783	1307.43	meas121205_104636.dat
☐							
☐							

Scan #2 :   M change from 0.35   (400000) to 0.65 (150000)

M is lower because ref cavity was changed   to 0 mm



Select	Knob	X	Beamsize	Error	Modulation		
Get	1/2 lan	50.0000	795.967	19.571	0.482	1641.79	meas121205_105336.dat
Get	1/2 lan	50.0000	885.838	21.477	0.406	1803.18	meas121205_105436.dat
Get	1/2 lam	50.0000	806.279	16.995	0.473	1743.94	meas121205_105547.dat
Get	1/2 lan	100.0000	832.883	20.368	0.450	1768.34	meas121205_105659.dat
Get	1/2 lan	100.0000	883.856	17.152	0.408	1745.18	meas121205_105802.dat
Get	1/2 lan	100.0000	549.181	35.239	0.704	1552.78	meas121205_105903.dat
Get	1/2 lan	150.0000	597.539	32.110	0.661	1655.81	meas121205_110016.dat
Get	1/2 lan	150.0000	742.834	27.448	0.529	1618.94	meas121205_110118.dat
Get	1/2 lan	150.0000	676.092	24.184	0.590	1778.94	meas121205_110215.dat
Get	1/2 lan	200.0000	832.190	19.656	0.451	1752.72	meas121205_110325.dat
Get	1/2 lan	200.0000	703.655	29.583	0.565	1446.83	meas121205_110423.dat
Get	1/2 lan	200.0000	720.101	29.723	0.550	1512.73	meas121205_110525.dat
Get	1/2 lan	250.0000	659.724	31.747	0.604	1502.42	meas121205_110639.dat
Get	1/2 lan	250.0000	737.399	37.302	0.534	1628.52	meas121205_110737.dat
Get	1/2 lan	250.0000	610.029	26.437	0.649	1711.58	meas121205_110851.dat
Get	1/2 lan	300.0000	742.726	25.994	0.529	1747.45	meas121205_111008.dat
Get	1/2 lan	300.0000	715.277	21.249	0.554	1816.54	meas121205_111107.dat
Get	1/2 lam	300.0000	504.845	26.645	0.742	1652.56	meas121205_111250.dat
Get	1/2 lan	350.0000	775.404	18.804	0.500	1842.05	meas121205_111410.dat
Get	1/2 lan	350.0000	798.753	19.164	0.480	1606.33	meas121205_111515.dat
Get	1/2 lan	350.0000	895.946	31.928	0.398	1504.44	meas121205_111621.dat
Get	1/2 lan	400.0000	922.830	14.789	0.376	1680.03	meas121205_111736.dat
Get	1/2 lan	400.0000	960.966	21.383	0.347	1592.29	meas121205_111839.dat
Get	1/2 lan	400.0000	985.110	15.833	0.329	1656.52	meas121205_111941.dat
Get	1/2 lan	450.0000	988.030	13.413	0.327	1603.90	meas121205_112115.dat
Get	1/2 lan	450.0000	1111.555	14.196	0.243	1740.84	meas121205_112240.dat
Get	1/2 lan	450.0000	991.568	16.723	0.324	1660.10	meas121205_112341.dat

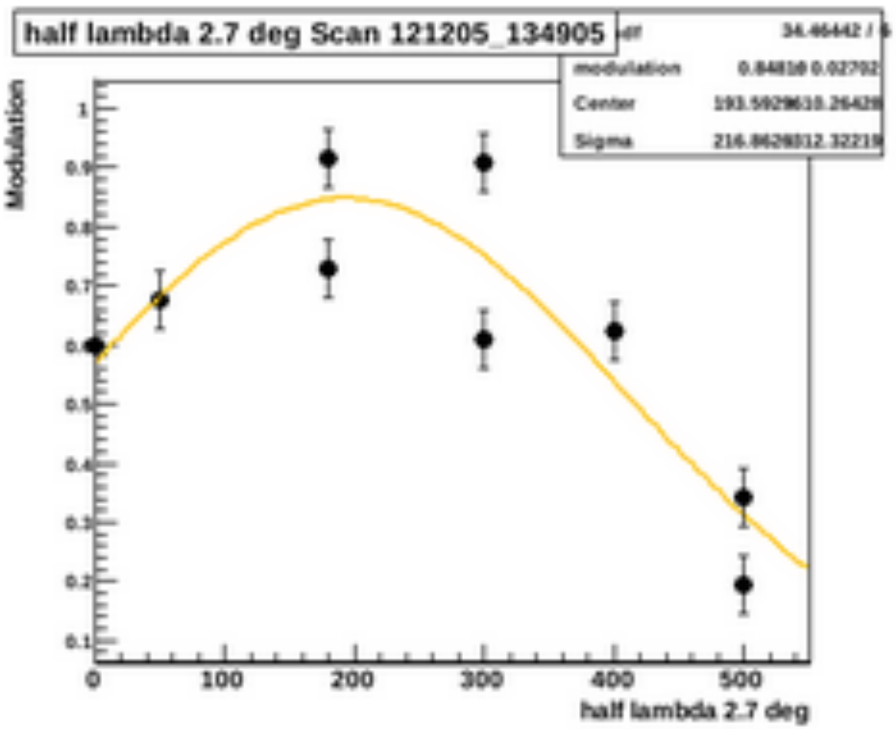
M REACHED 0.8

CHECK WITH ONE MORE TIME HALF LAMBDA PLATE SCAN

original is previous optimum setting 180

maximum M > 0.9 during scan

set to best position 180000 (consistent with 7 deg mode)

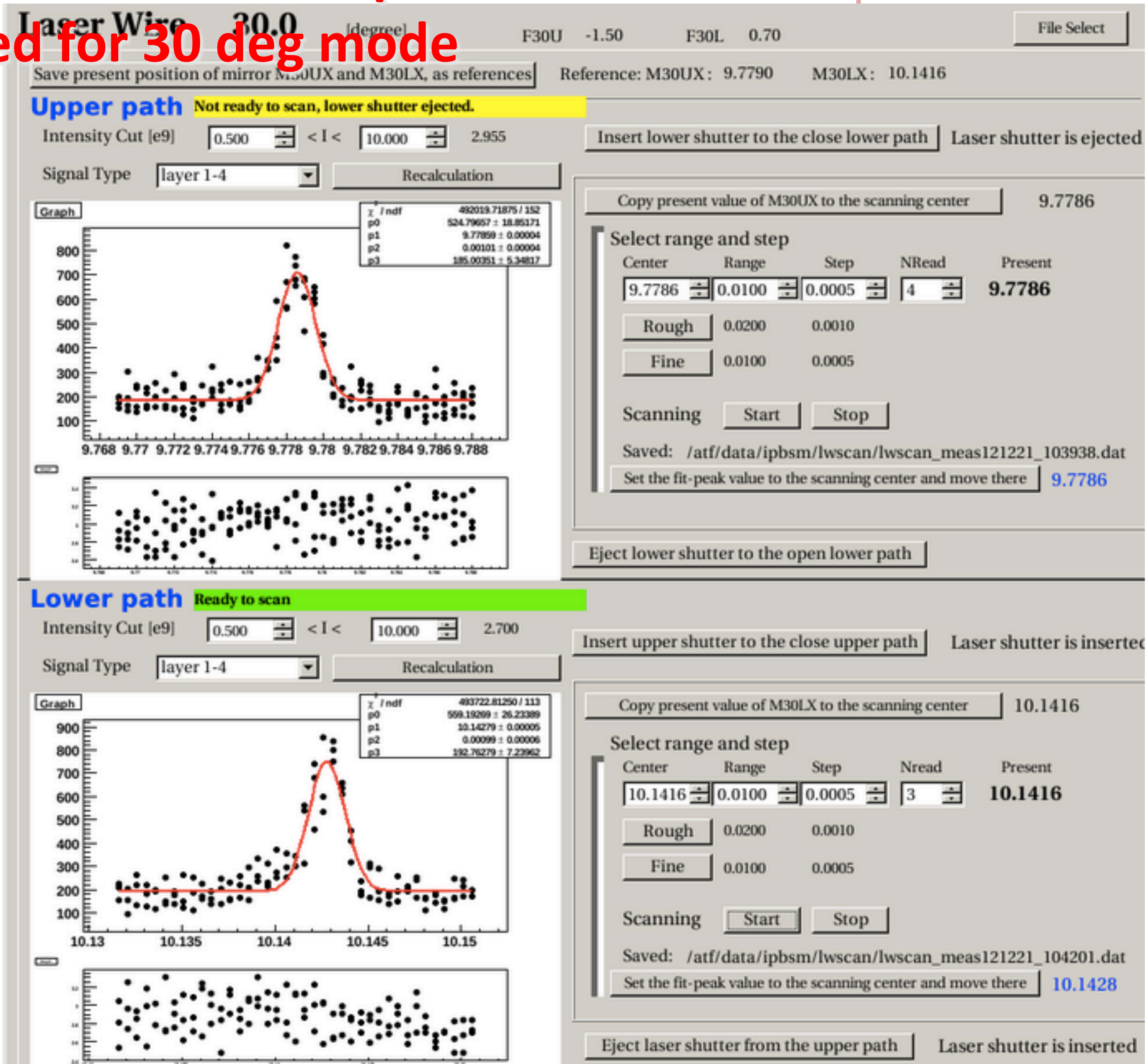


Scan #4: Confirm with 3 deg mode

(in case 7 deg mode was chipped off)

Best setting is consistent

Very clear laserwire scan profile maintained for 30 deg mode



Last of all pull out 174 deg screen

Confirmed U and L laser spots
not off from e beam   (marker)