FJPPL - FKPPL on ATF2 Accelerator R&D

Beam Size Measurement using IPBSM: Newest Results and Performance Evaluation

2013 Feb 11
LAL, Orsay

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Recent Beam Time Status : Dec 2012 – Feb, 2013

Error studies

Hardware Upgrades

Summary & Goals and plans

Recent Beam Time Status : 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

Last 2 days of Dec Beam Operation

conditions

Beam

- Ref cavity set for low BG levels (S/N ~ 4)
- Low beam intensity
- 10 x βx* , **1 x βy***

IPBSM

- Underwent several upgrades in optics, profile

(improved path alignment, syst errors suppressed)

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

σy* = 137.3 ± 18.4 nm
M = 0.607 ±0.056

12/20 evening : switched to 174 deg mode

Modulation detected !! → Set to peak → many times fringe scans : σy 60 – 80 nm

Problems: z scan profile too narrow , peak position not consistent , laser & beam drifts

Temporarily lost 174 deg M during Owl

12/21 morning : → switch back to 30 deg , re-optimize knobs, study wake and intensity dependence

12/ 21 afternoon (last 3 hours) : **recovered 174 deg operation!!**

M detected , stable continuous fringe scans → results（RMS）

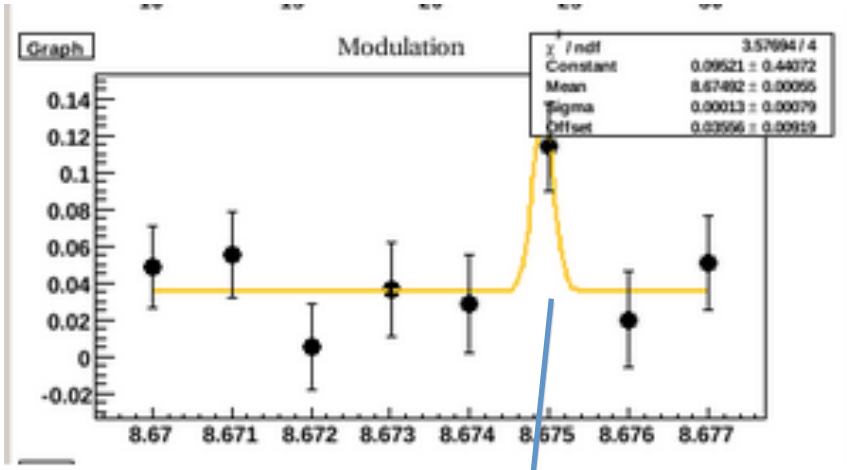
σy* = 73.4 ± 4.6 nm
M = 0.224±0.0420

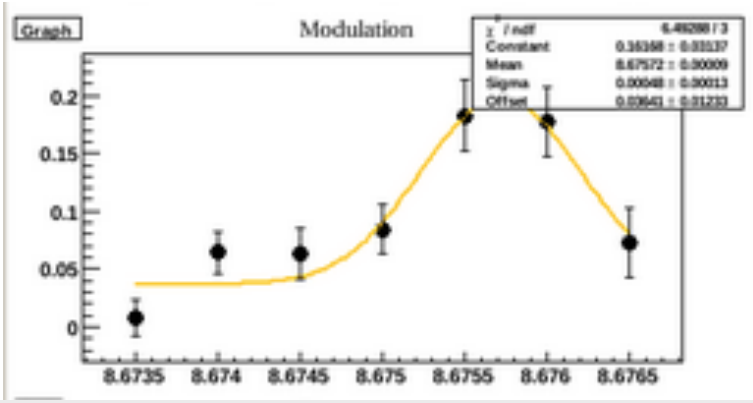
σy* = 73.0 ± 6.8 nm
M = 0.230±0.062

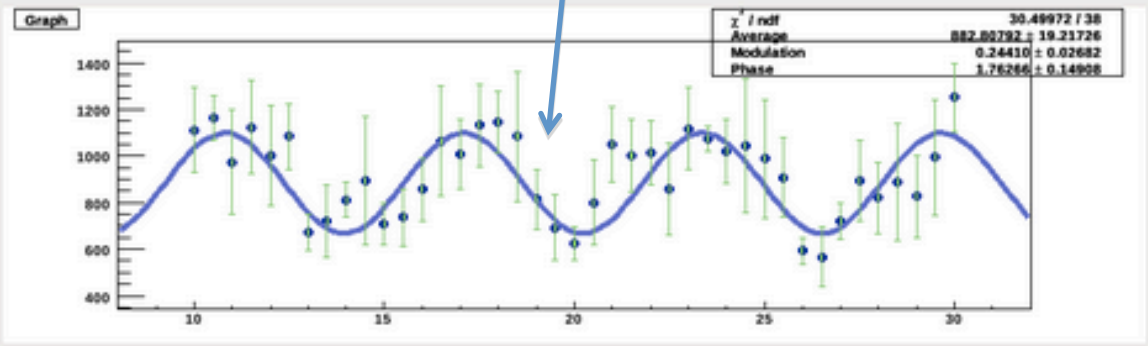
But no M at higher e beam intensity

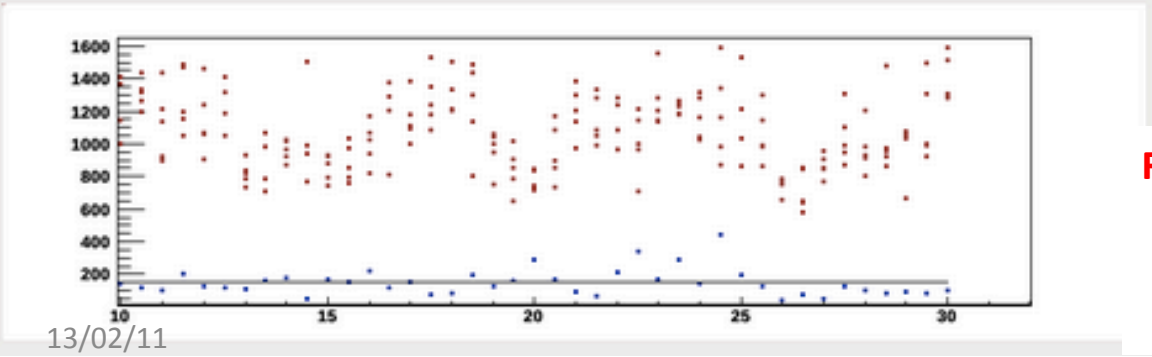
First Detection of 174 deg M : 12/20

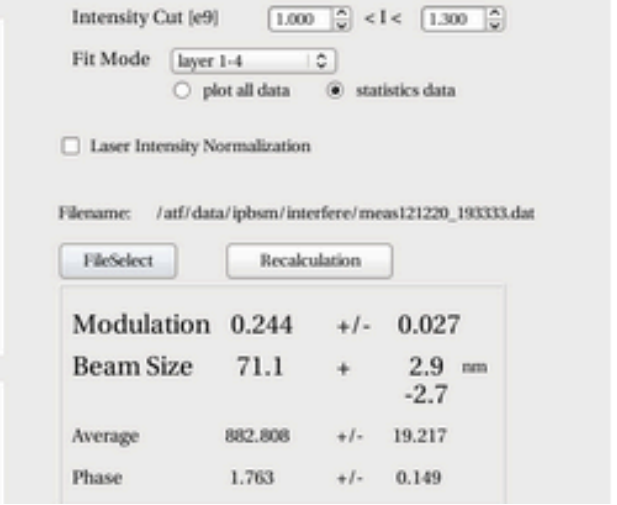
z scan profile too narrow ,
peak position not consistent











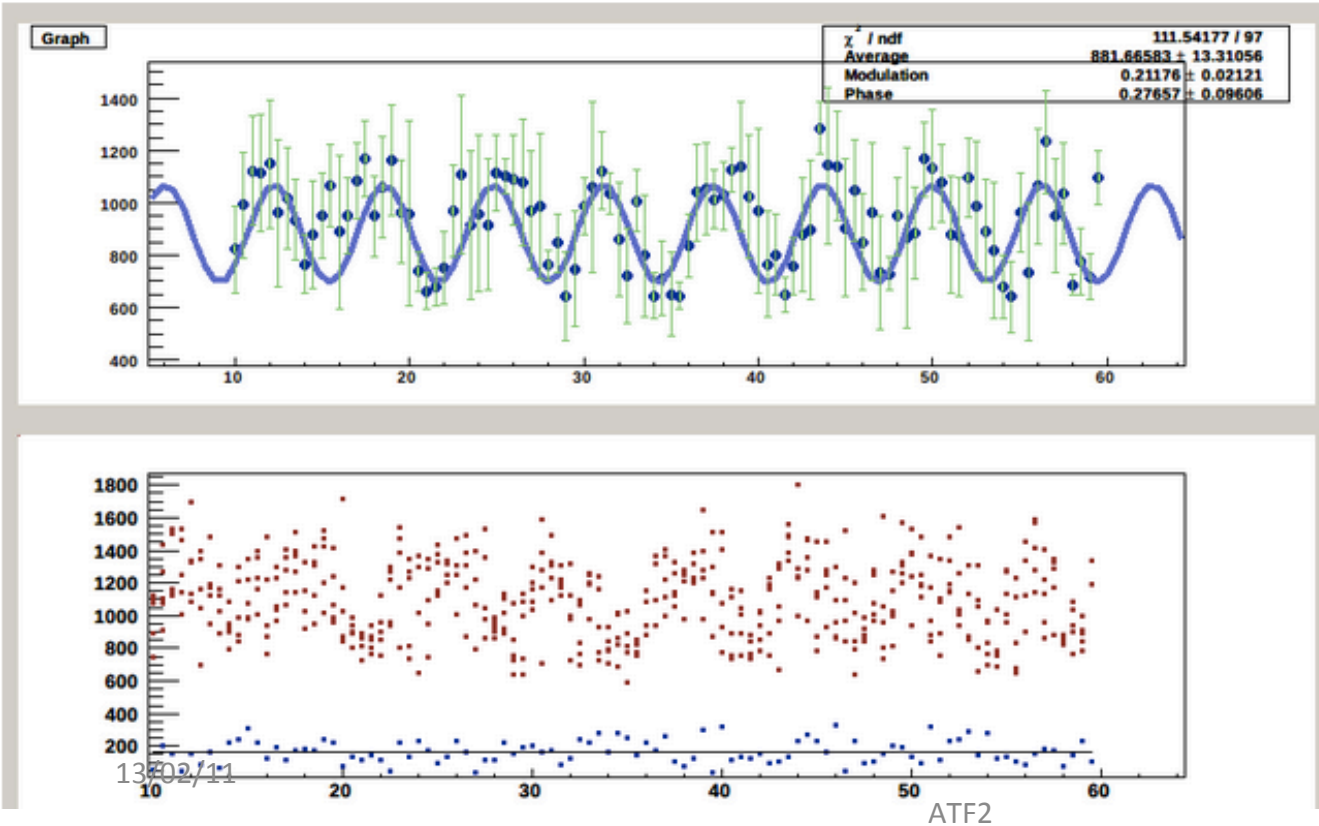
Fringe scans at (temporary)
z scan peak position
→ about 70 nm

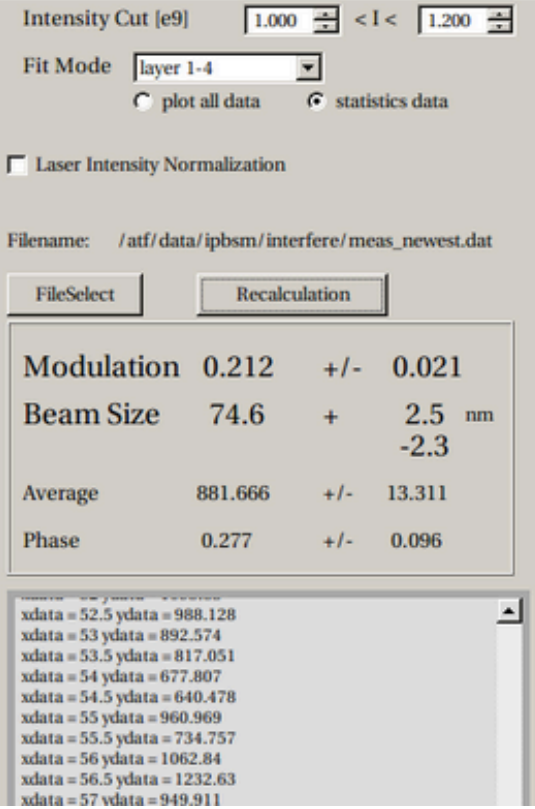
Long Range Scans

12/ 20 174 deg mode

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

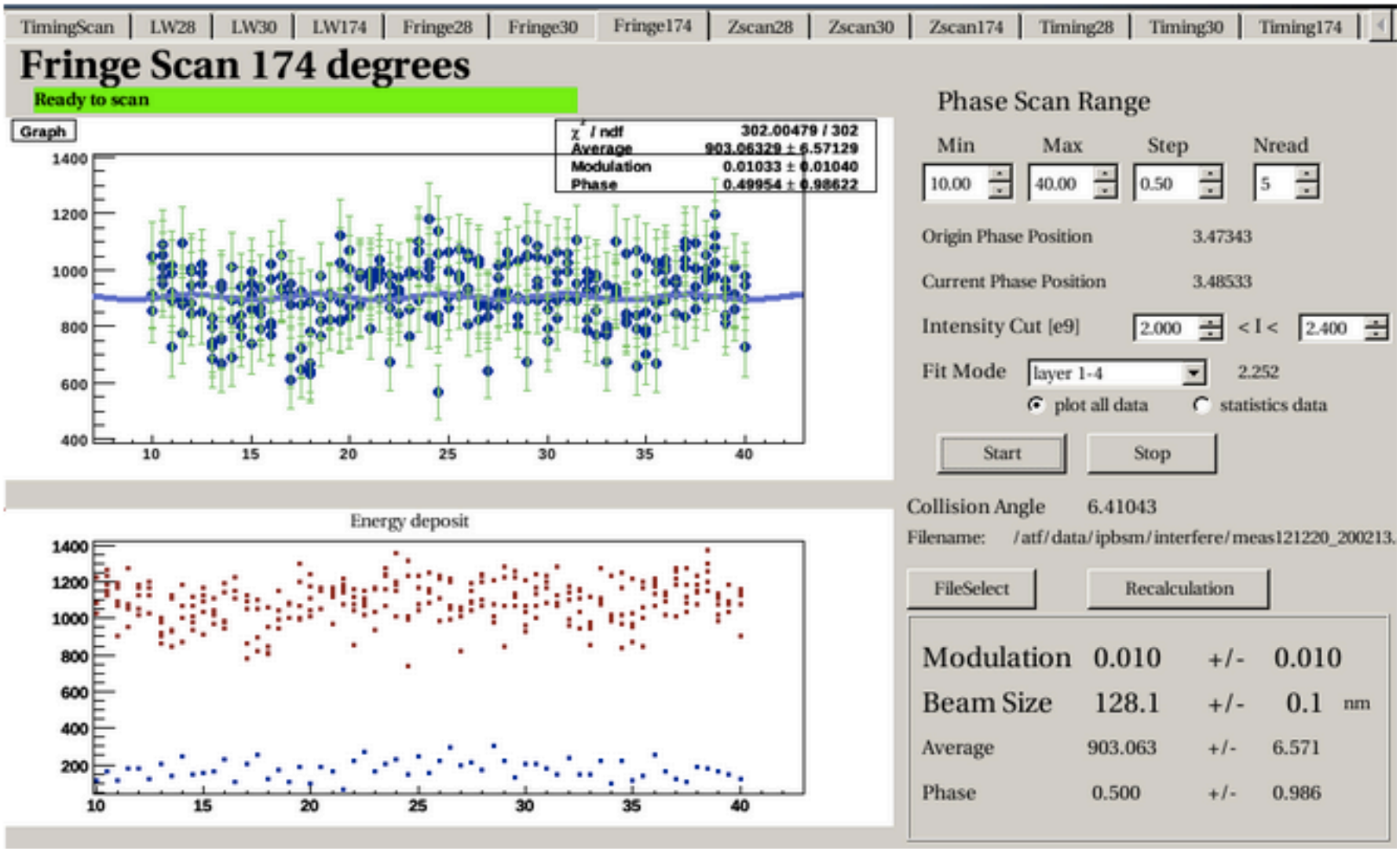
75 nm even for 50 – 60 rad scan





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

high intensity cannot see significant M

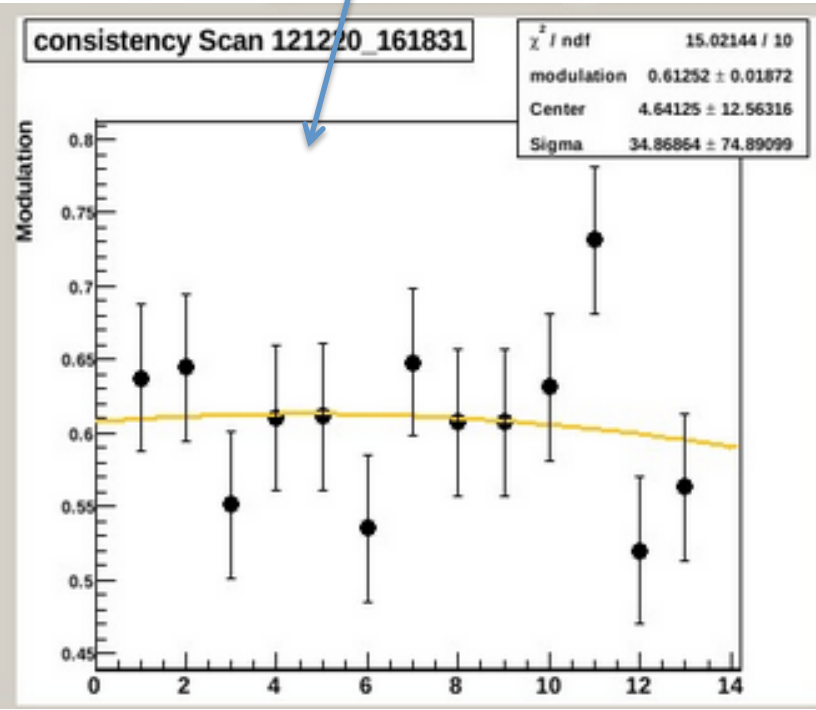


30 deg mode operation

Dec 20

Best ever 13 consistent scans at 30 deg

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



σy* = 137.3 ± 18.4 nm

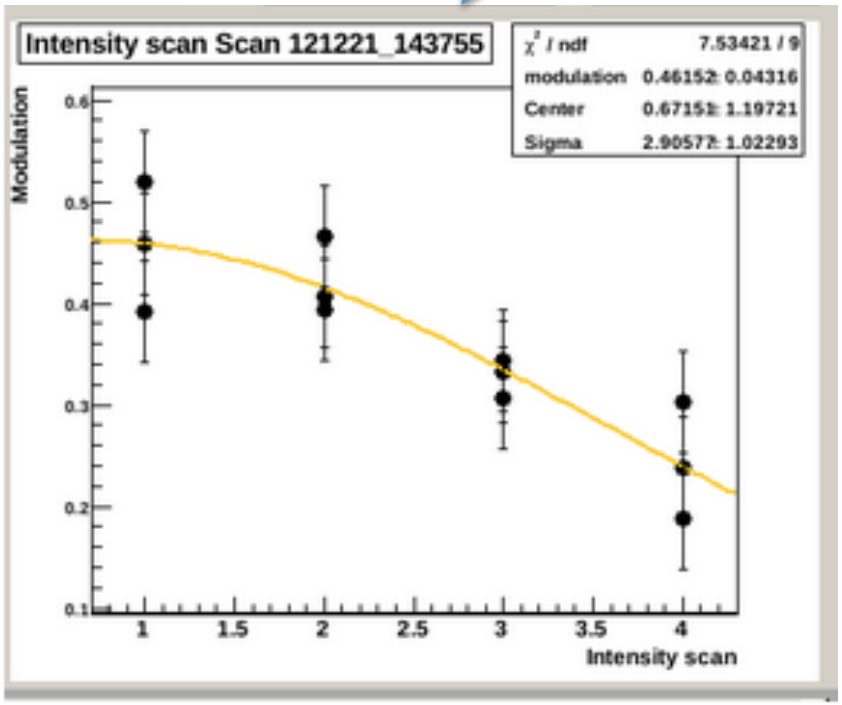
M = 0.607 ±0.056

Dec 21, morning

switch back to 30 deg mode

Goal*

- re-optimize (nonlinear, linear) knob tuning
  → reached **M ~ 0.55**
- **wakefield and beam intensity studies**



Last 3 hours: 174 deg mode operation

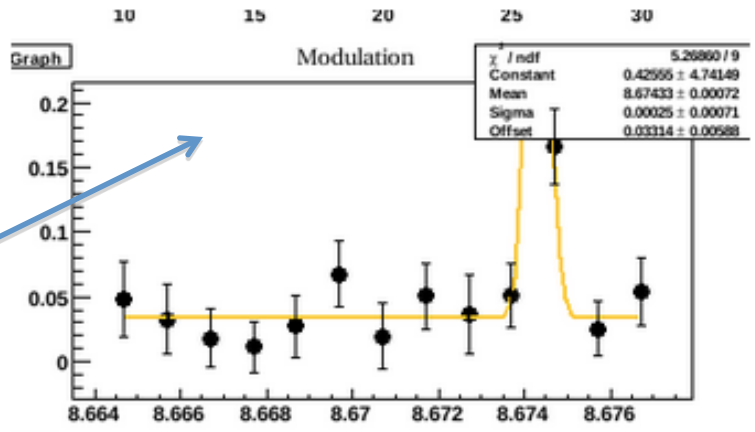
turned ATF2orbit feedback OFF

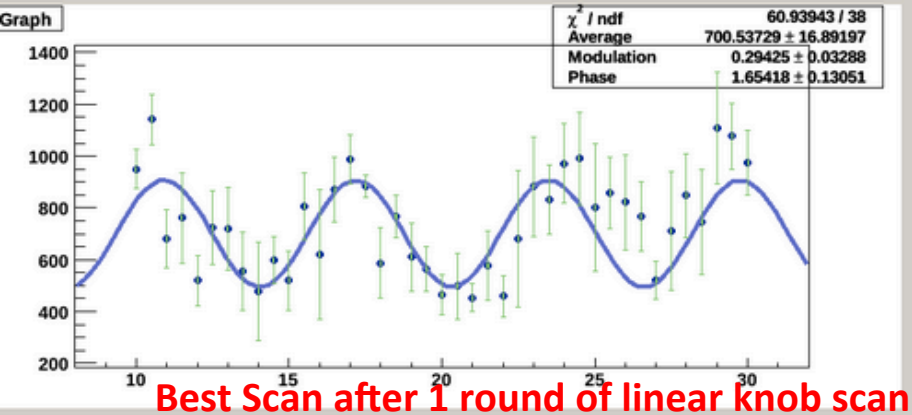
Strict ICT cut window: [0.8 – 1.2]

M detected → 2 sets of consecutive good scans :

σy * = 65 – 80 nm

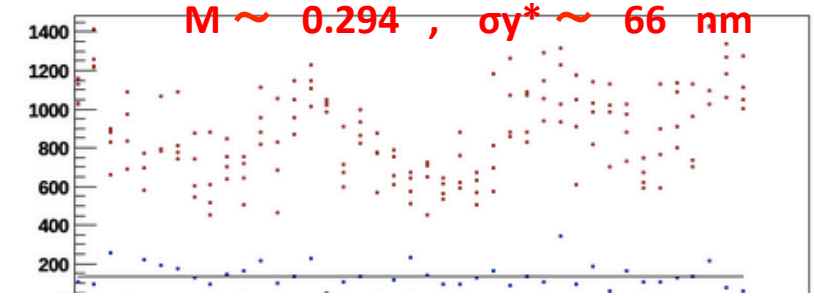
Detailed analysis, error studies are ongoing

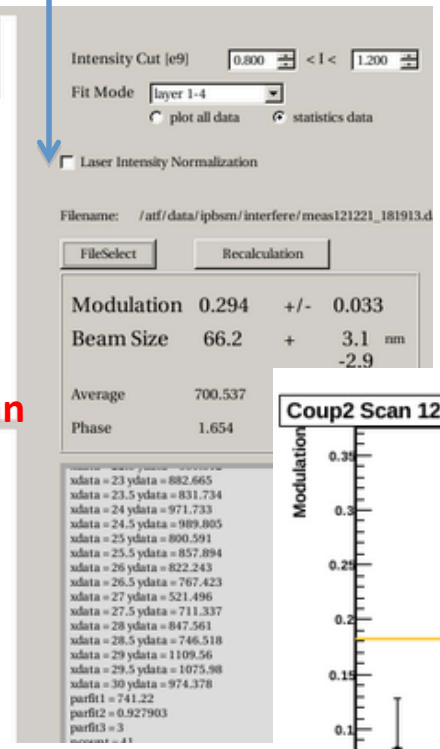




Best Scan after 1 round of linear knob scan

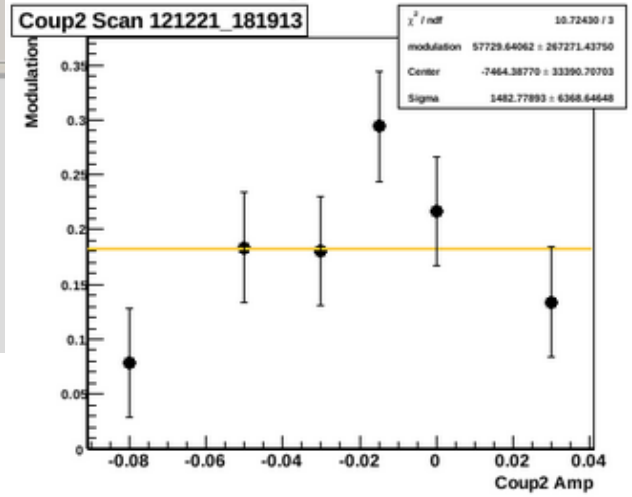
M ~ 0.294 , σy* ~ 66 nm





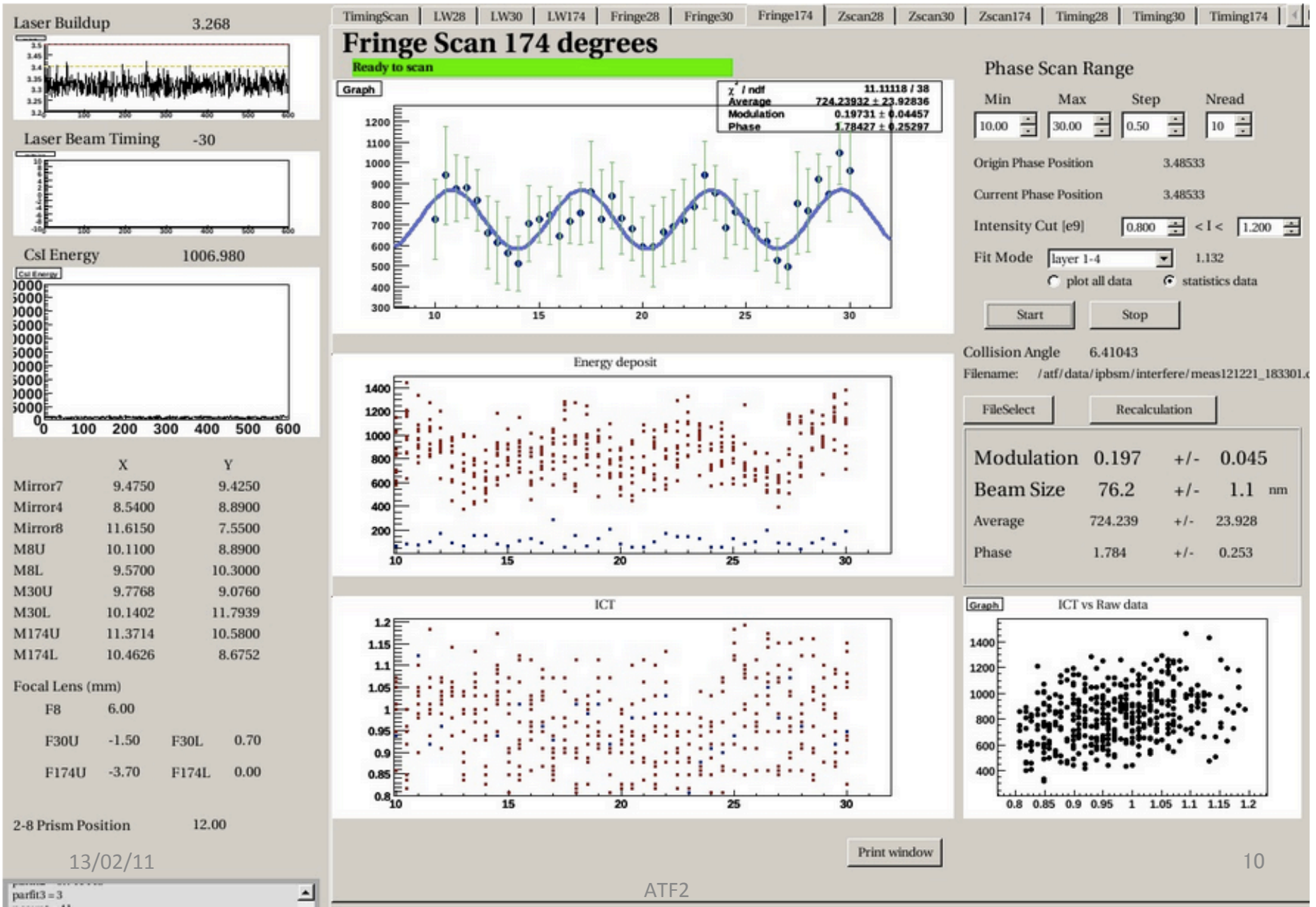
Show response to all 3 types of linear knobs

consistent at each peak



Nav – 10 fine scan

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



Some IPBSM related Issues from Dec run

(1) Inconsistency in M when mode switching 30 deg → 174 deg mode

measured σy = 80 nm at 174 deg mode

- expect M = 0.77 at 30 deg mode, but only get 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 (30 deg mode)

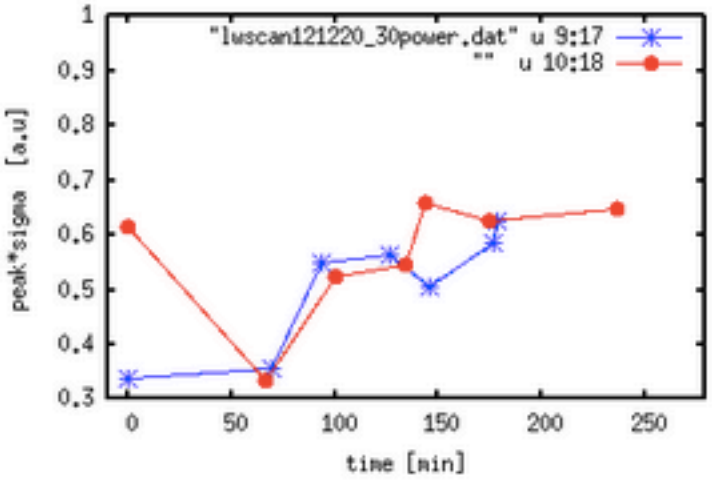
(3) Effect of polarization on M → "half lambda plate scan"

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

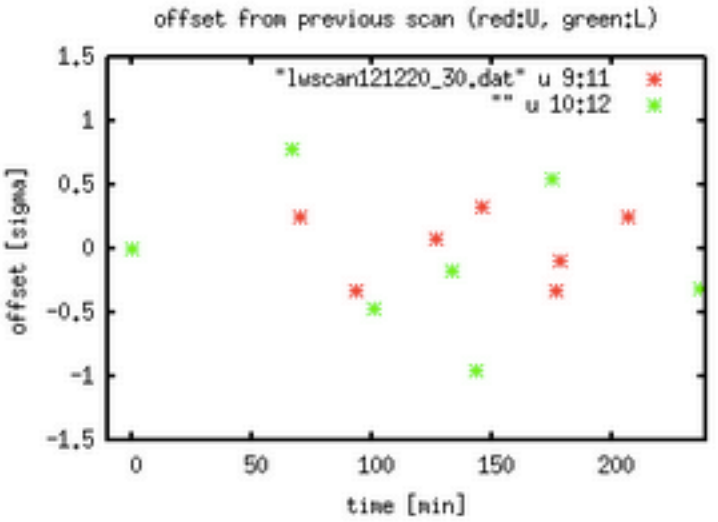
Significant change in power and peak position for both U and L paths

- 12/20 Day 30 deg mode

Total power (sigma * peak)



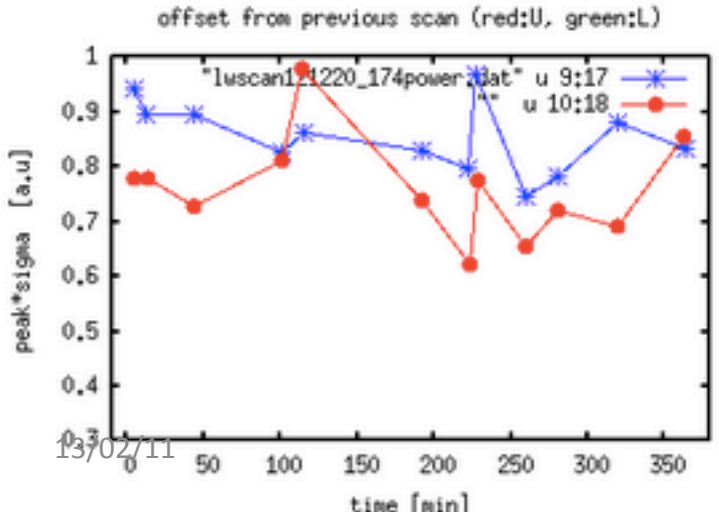
drift in peak position (from previous scan)



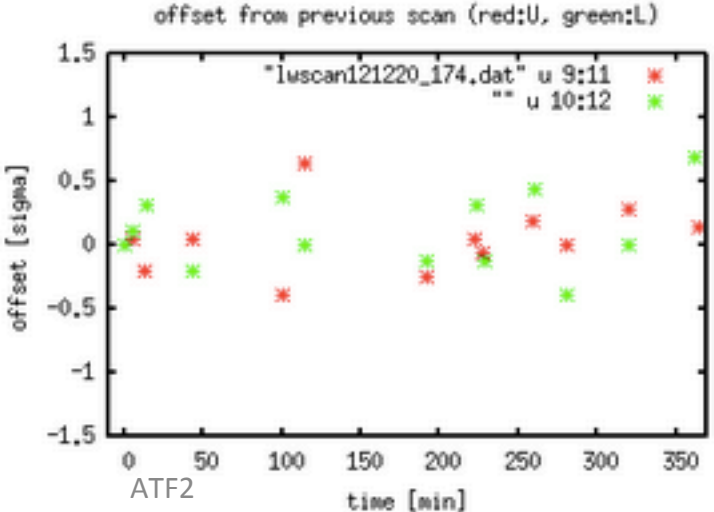
Drift
±1 sigma

- 12/20 Swing, 174 deg mode

Total power (sigma * peak)



drift in peak position (from previous scan)



Drift
±0.5 sigma

Recent Beam Time Status

Jan - Feb, 2013

Week of 1/28 – 2/1

IPBSM start up at 6 deg mode

could not find M at 30 deg by end of week

- Most likely **e beam size not focused small enough**
- But also suspect **IPBSM systematics**

one issue: experiment expanding σlaser from 10-20 micron to 80 - 90 micron

however **zscan sigma remained narrow ??**?

Damaged laser transport mirror

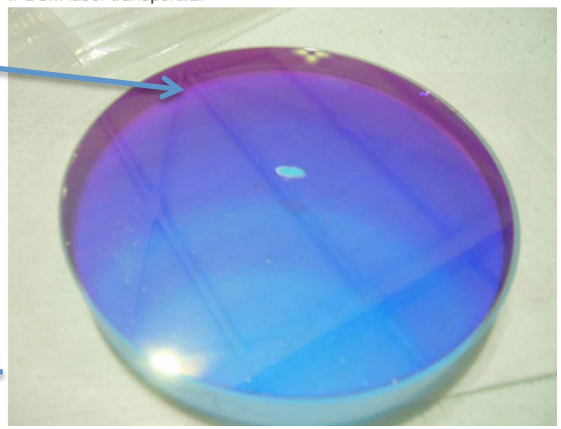
Maybe unexpected focusing somewhere during transport

Burnt spots on lenses and viewport window (→ exchanged)

need to carefully control laser power and focusing

S/N about 4 now → no need for higher intensity

IPBSM laser transport#2:



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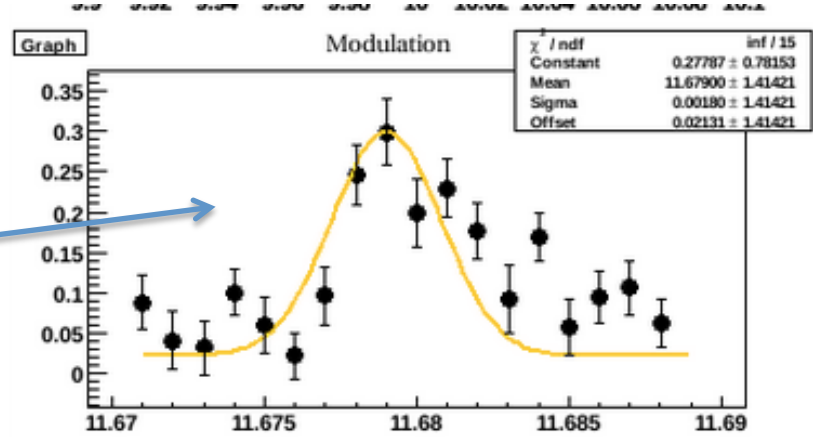
other changes important to beam size measurements by IPBSM

Benefits from effective SD4FF - SF5FF swap:

- BG levels in IPBSM reduced from Dec
- No σy* blowup (linear optics preserved) when FF sexts turned on & set to BBA offsets

QDF1FF strength adjustment → σx* reduced to 10 um finally → Less effect from fringe tiltt ??

Week of 2/4 - 7



Start out at 4 deg → 6.9 deg → 30 deg M detected

z scan sigma still a little too narrow :

usually σz < 1.5 times of laserwire scan spot size

- Linear / non-linear knob scans, focal lens optimization
- Checked ref cavity MRF3FF, half lambda plate, intensity lowered from 3E9 to 1E9

High M reached at 30 deg → Switch to 174 deg

seem to have found M > 0.2 , but soon vanished ,

Accessed in the middle to check and fix laser path

reason not yet known : 174 deg laser path alignment, or beam size focusing itself ??

2/4 ~ some hardware changes:

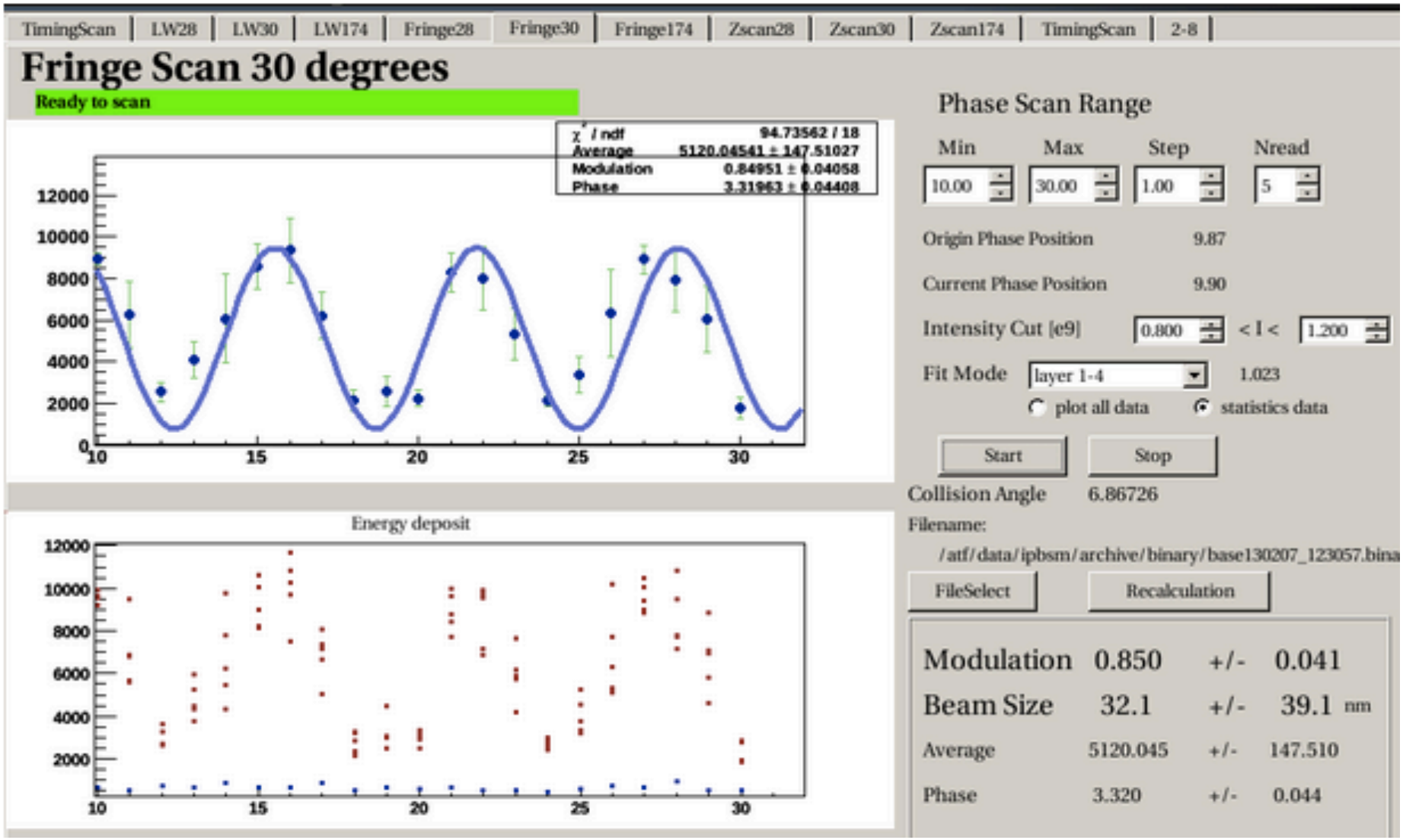
❖ Temporarily tried lowering laser power , using 50% beamsplitter on laser table

But next day restored power → didn 't want to risk alignment precision

❖ Renewed timing trigger system → aim for less timing jitters

2/7 M reached high at 30 deg mode (same condition as dec 2012)

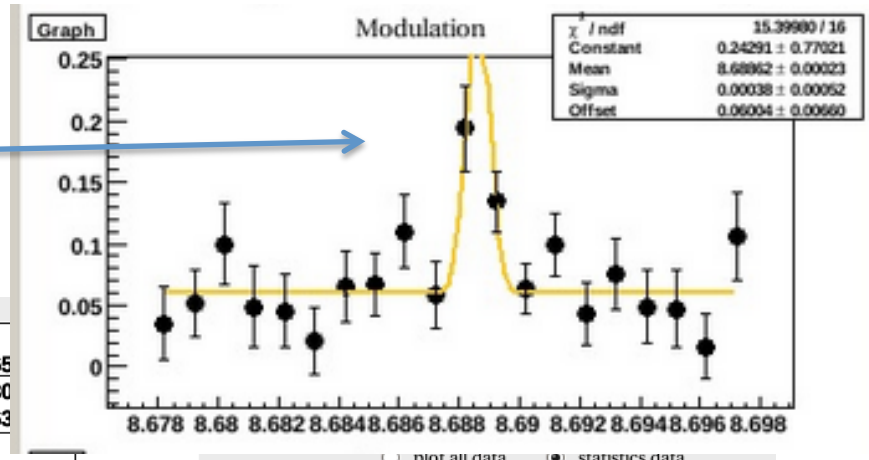
prepared to switch to 174 deg mode



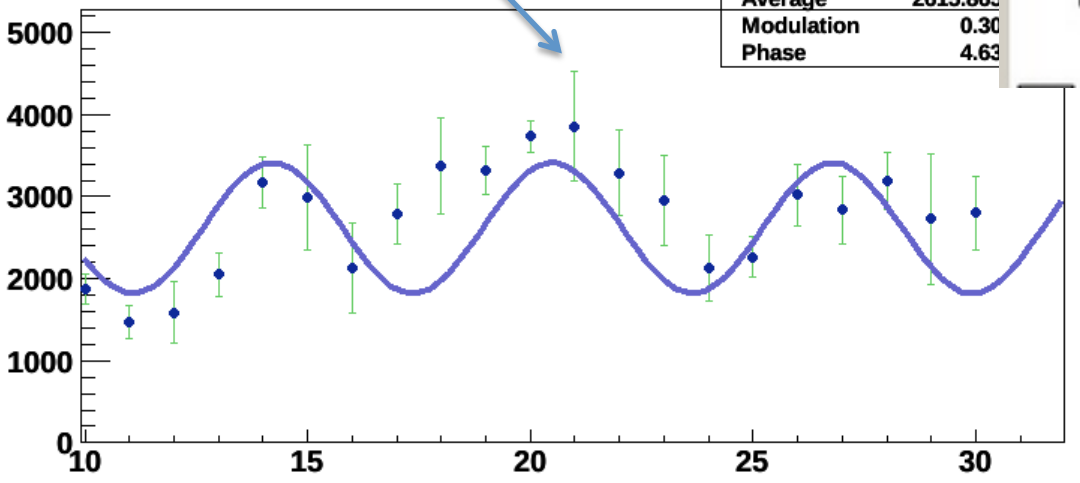
ATF2orbit feedback OFF

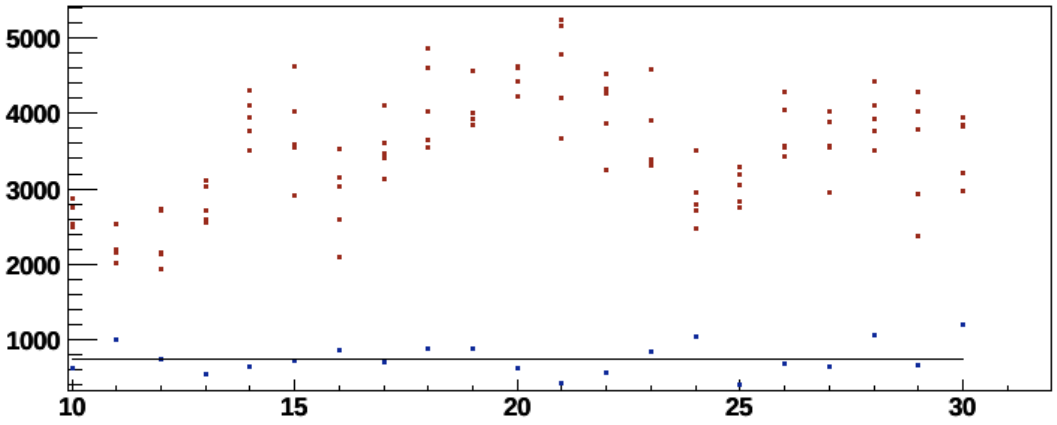
Strict ICT cut window: [0.8 – 1.2]

Seemed to have found zscan peak (too narrow!!)



One of highest M on 2/7, at z scan peak





plot all data statistics data

Laser Intensity Normalization

Filename: base130207_144122.binary

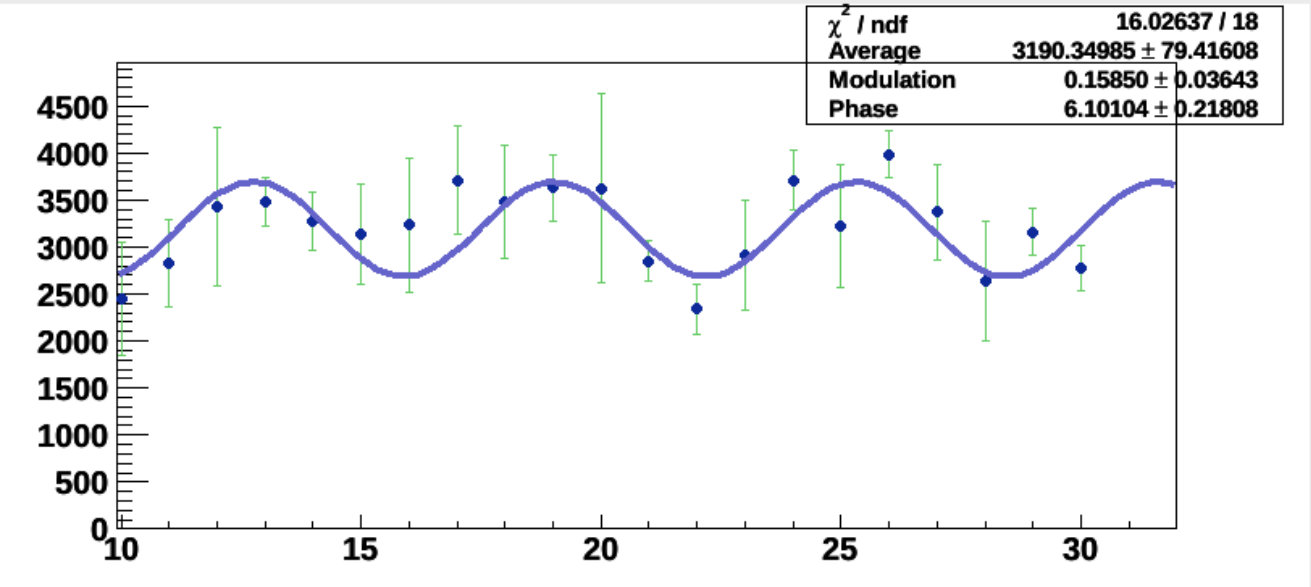
FileSelect | Prev | Next | Recalculation

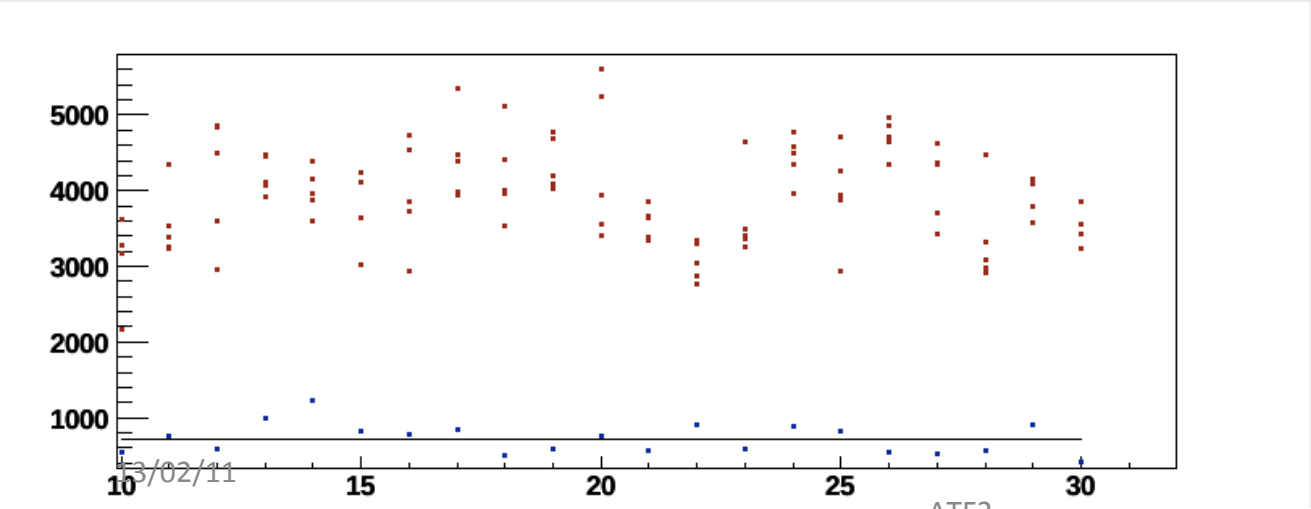
Modulation	0.304	+/-	0.039
Beam Size	65.3	+	3.7 nm
			-3.4
Average	2615.865	+/-	71.894
Phase	4.633	+/-	0.133

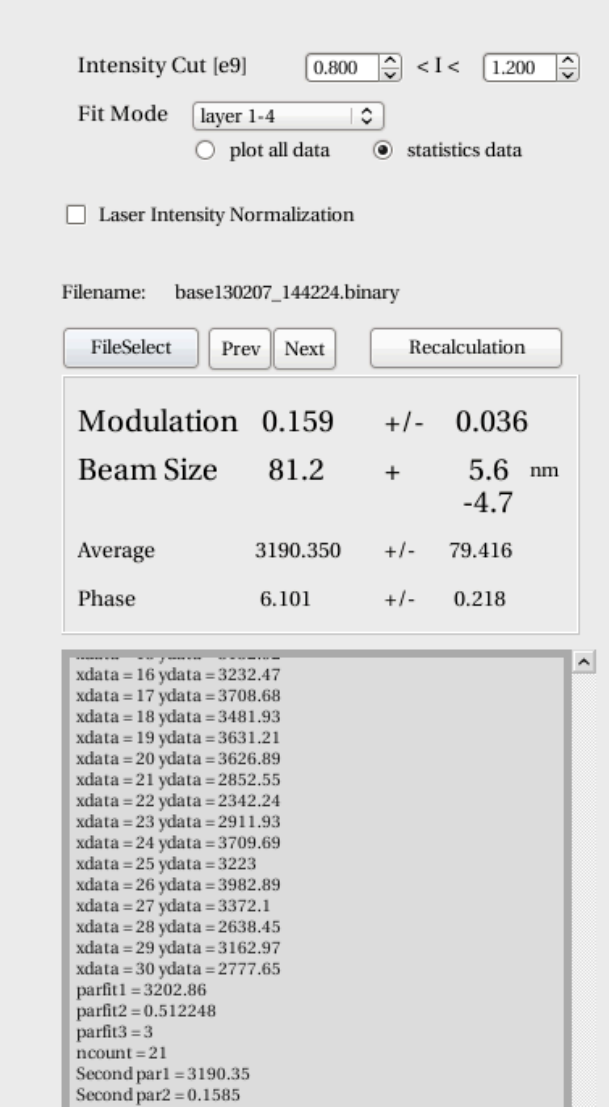
xdata = 16 ydata = 2129.09
xdata = 17 ydata = 2794.43
xdata = 18 ydata = 3377.92
xdata = 19 ydata = 3314.43
xdata = 20 ydata = 3738.03
xdata = 21 ydata = 3852.64
xdata = 22 ydata = 3290.23
xdata = 23 ydata = 2953.22
xdata = 24 ydata = 2131.38
xdata = 25 ydata = 2267.08
xdata = 26 ydata = 3020.32
xdata = 27 ydata = 2840.53
xdata = 28 ydata = 3189.54
xdata = 29 ydata = 2726.11
xdata = 30 ydata = 2803.61
parfit1 = 2740.84
parfit2 = 0.871472
parfit3 = 3
ncount = 21
Second par1 = 2615.87
Second par2 = 0.303706

2/7: 174 deg mode operation

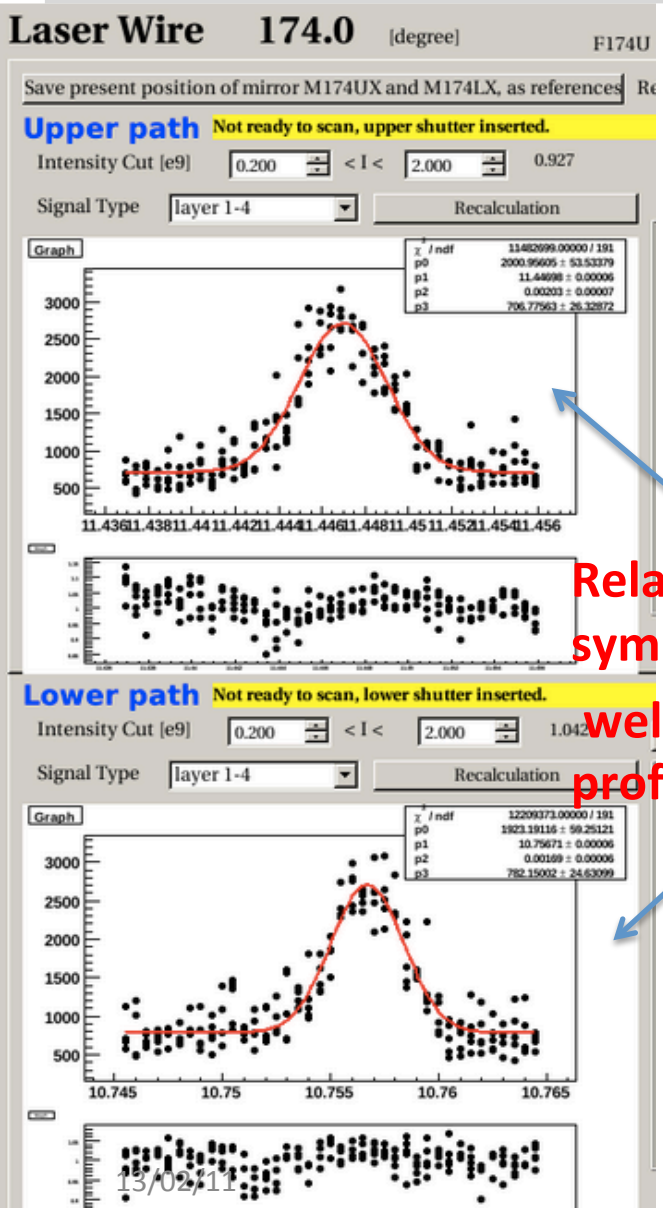
Some smaller M surrounding peak



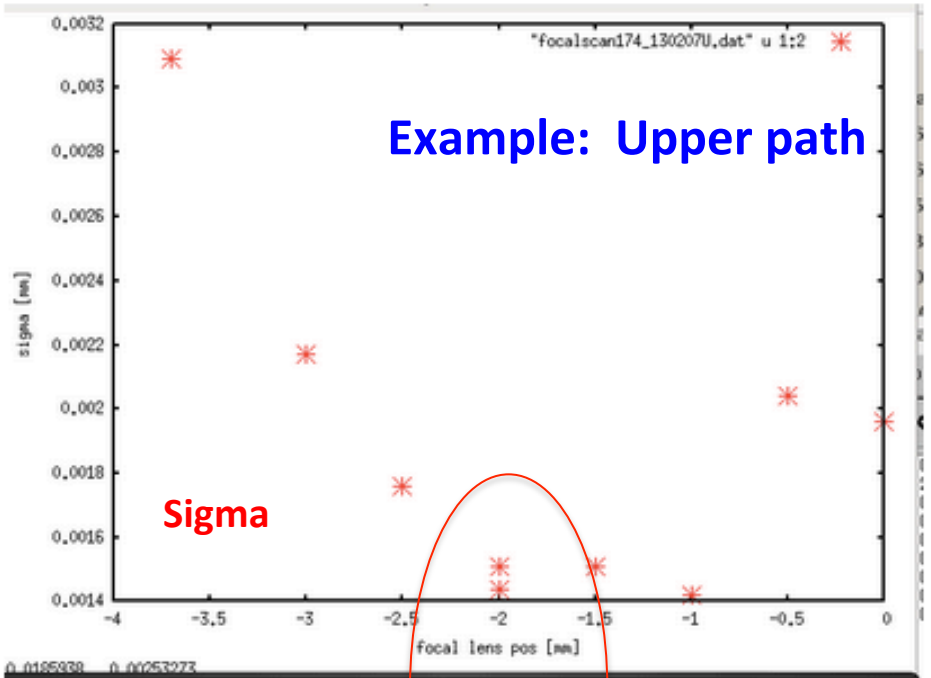


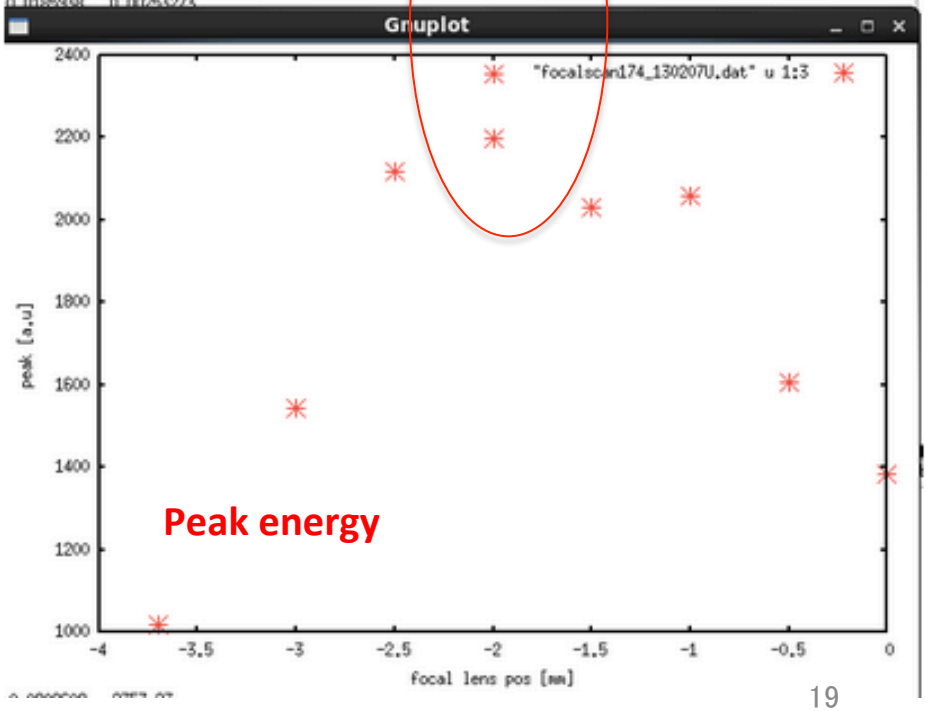


2/7: 174 deg mode operation
Focal lens scan



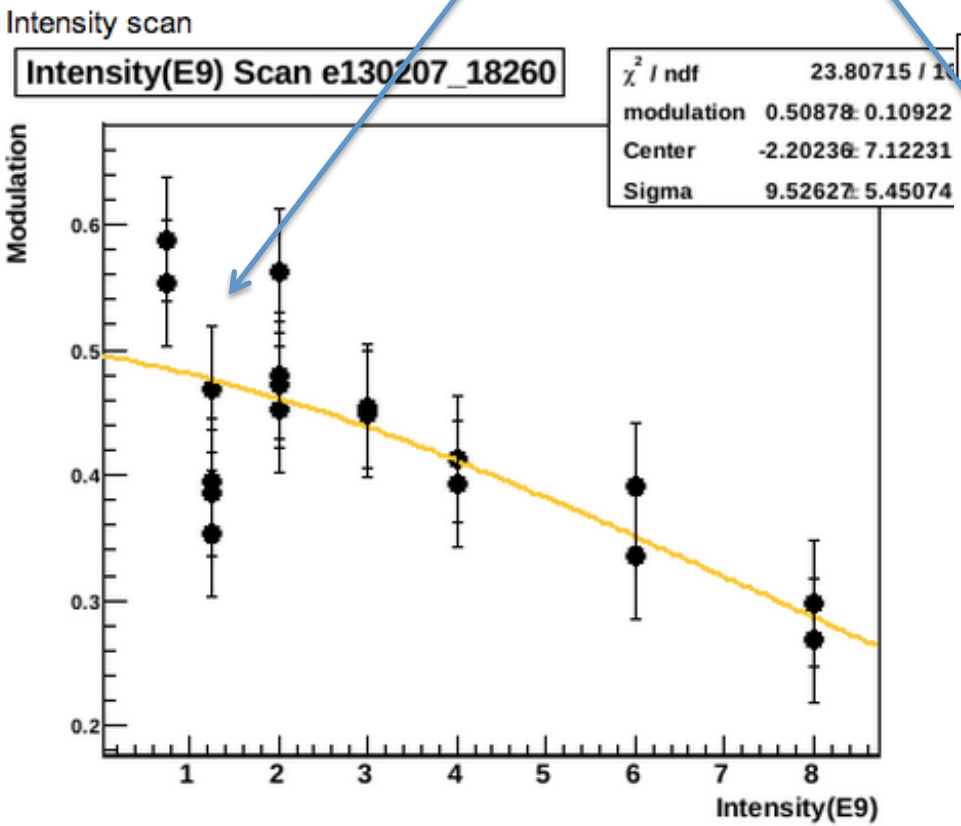
Relatively symmetrical well balanced profiles

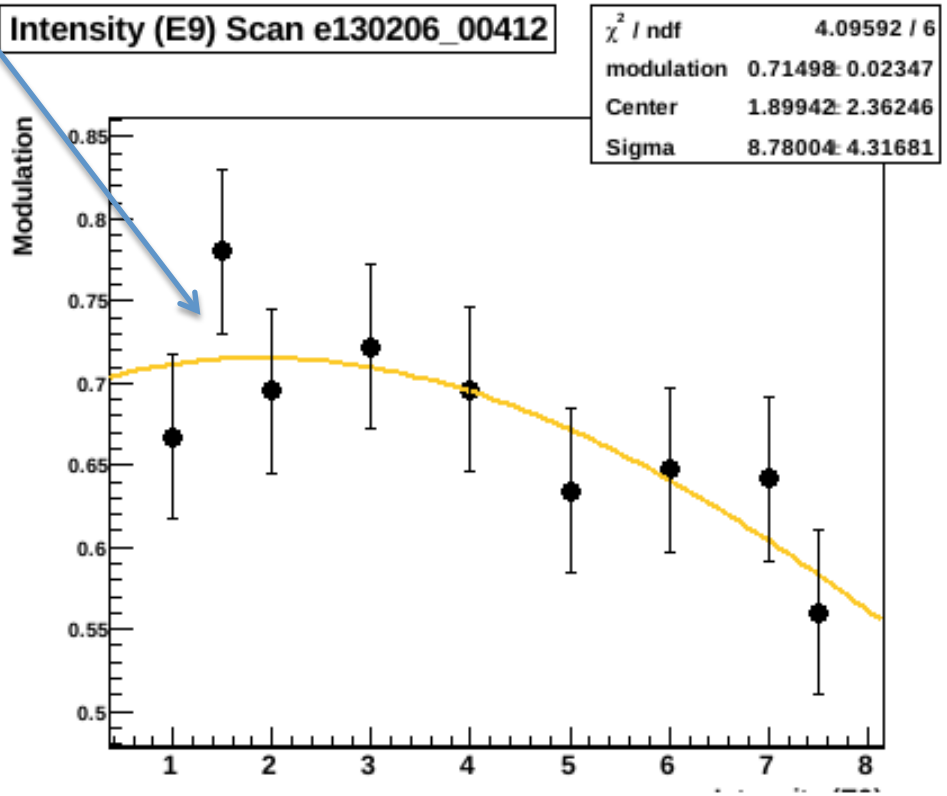




Intensity cut at first set to 3 x 10^9, then later **lowered to 1 x 10^9** (as in Dec)

intensity scan doesn't show very clear response in low intensity regions
(fluctuations during measurements , monitor, module-related issues)





Study of systemtic errors
and
hardware issues

Assessment of Polarization related systematic errors

Motives:

Quantitative evaluation of polarization / power related systematic errors

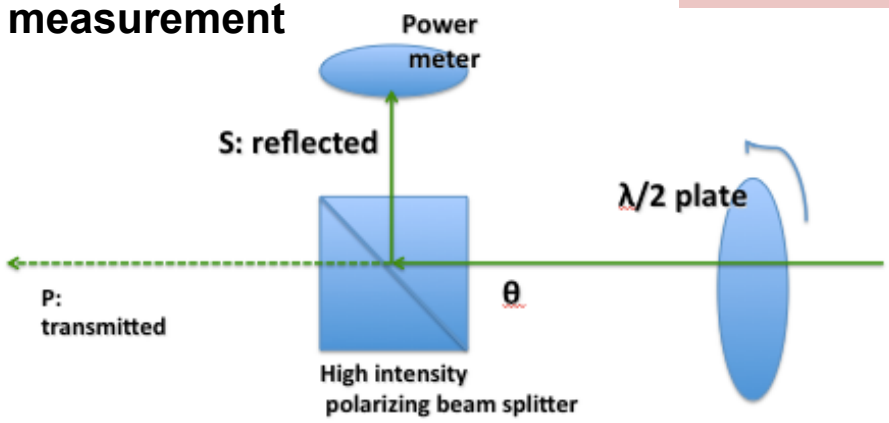
- **Confirm validity of λ/2 plate setting** during past / present beam time
- why M changed so much ????　(0.5 --> 0.93 @ 7 deg) with λ/2 plate

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

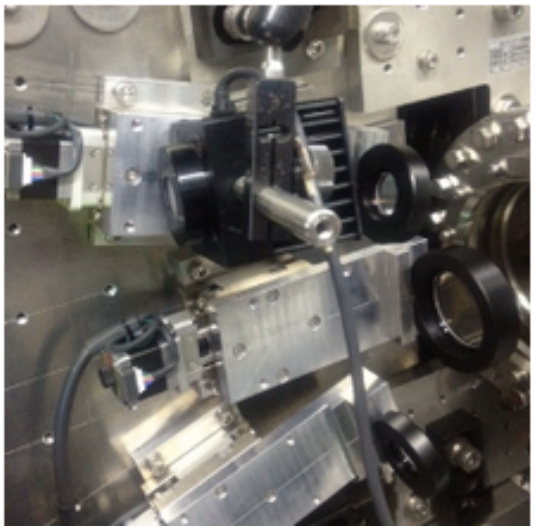
Measure high power at usual place Immediately in front of 30 deg lenses

setup

Polarization measurement



Power measurement



Assessment of Polarization related systematic errors

Results and interpretations:

Balanced power (～ 0.75 W each) doesn't necessarily give highest M !!

Compromise with 2:3 power imbalance (e.g. Dec: U:0.660 W, L : 0.925 W (±0.005)
C = 98.6% M reduction → **negligible compared to polarization errors**

1/18: polarization measured (Powp / Pows = 1.7% , ϕ = 91.3 deg , eccentricity 0.18)

- **Found half lambda plate angle that yields nearly pure S polarization and maximize M**
  → Repeatedly verified during beamtime
- In Dec , sudden M due to λ/2 plate rotated to pure S state (initially large P contamination)

2/4 : measured half mirror reflective properties

measured power ratio of reflected / transmitted S / P light of real pulsed laser

Rs = 53% (Rp = 21%) → within design specifications !!

Now achieved all parameters for syst error evaluation

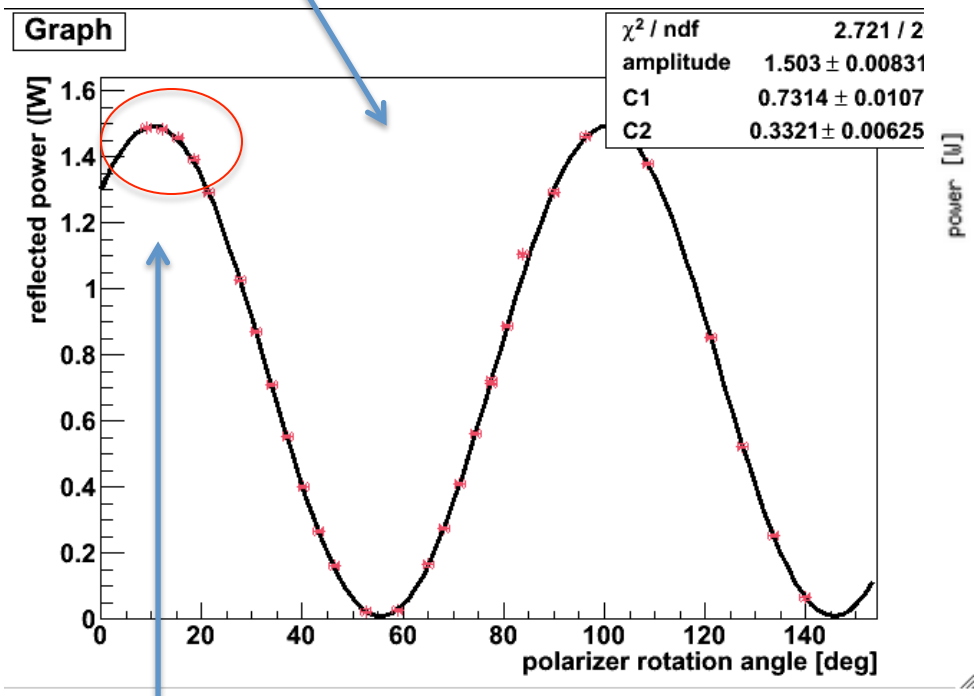
result: **C > 99% for all modes (if half lambda plate optimized)**

now one of the best understood IPBSM systematic errors

polarization measurement

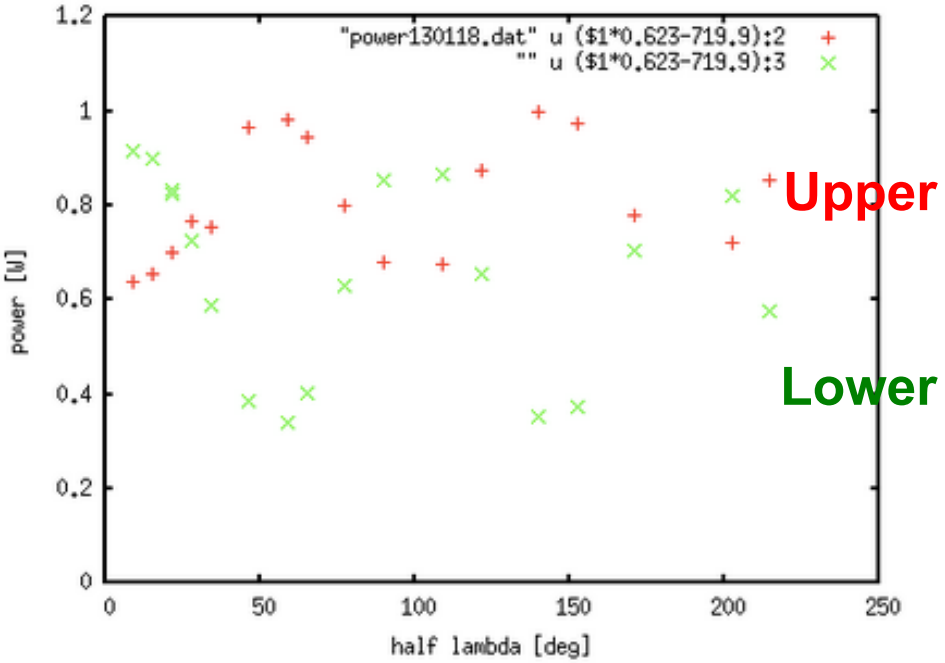
power measurement (U, L path) vs λ/2 plate setting

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)

Clear periodic dependence on polarizer rotation
(λ/2) angle setting for pure S polarization is about 20 deg away from setting for balanced power



Half mirror and Laser power

2/4 **measured half mirror's reflective property**

Rs = 53% (Rp = 21%) (**Ideally, R_S = 50 ± 3 %** for pure S polarized state)

then **changed to new new half mirror** (AR coated, radiation protected)

Same measurement as previous → ***Rs = 60 % ??***

suspected insufficient alignment but **seemed to be confirmed during laserwire scans**

Apparent power imbalance : L > U

Udata	Upeak	Usigma	Upower	Lpeak	Lsigma	Lpower	deg	Rs
30205_222743	180	0.00084	0.1512	197	0.00118	0.23246	6.87	60.6%
30206_003040	221	0.00083	0.18343	175	0.00112	0.196	6.87	51.7%
30207_?	959	0.00087	0.83433	1020	0.00117	1.1934	30	58.9%
owl	917	0.0009	0.8253	922	0.00118	1.08796	30	56.9%
day	2098	0.0009	1.8882	3592	0.00065	2.3348	30	55.3%

regardless of 7 or 30 deg mode

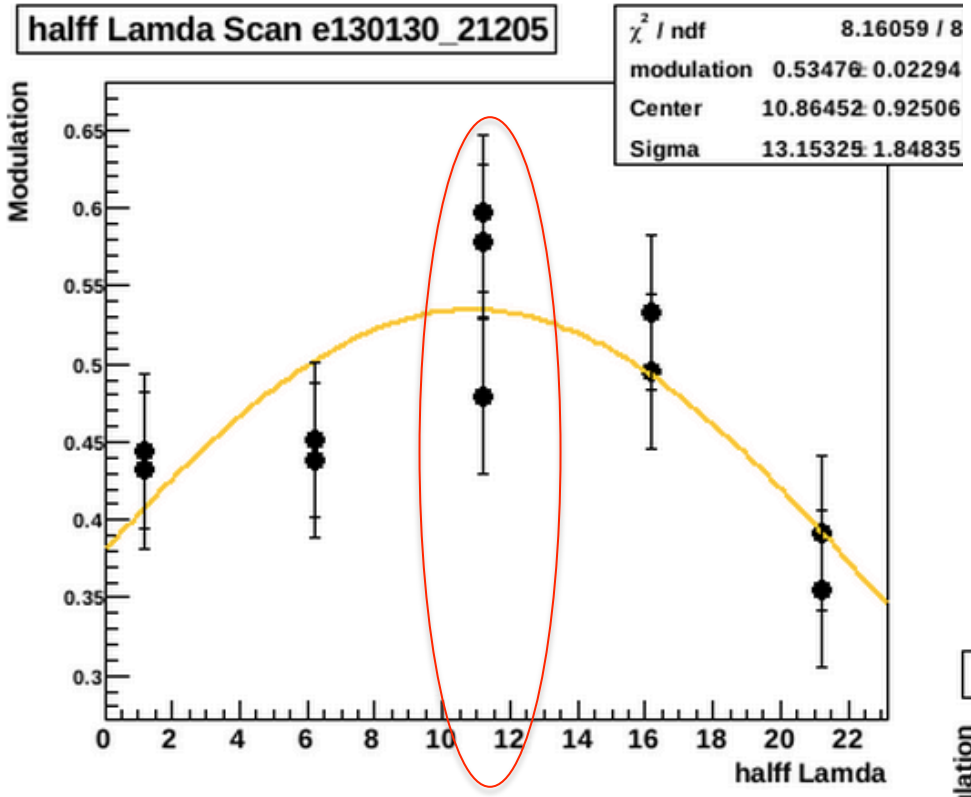
consistent with Rs = 60% (L path)

maybe total power imbalance is not a problem (2:3 → Only 98.5% M reduction)

however : 174 deg U and L power balanced

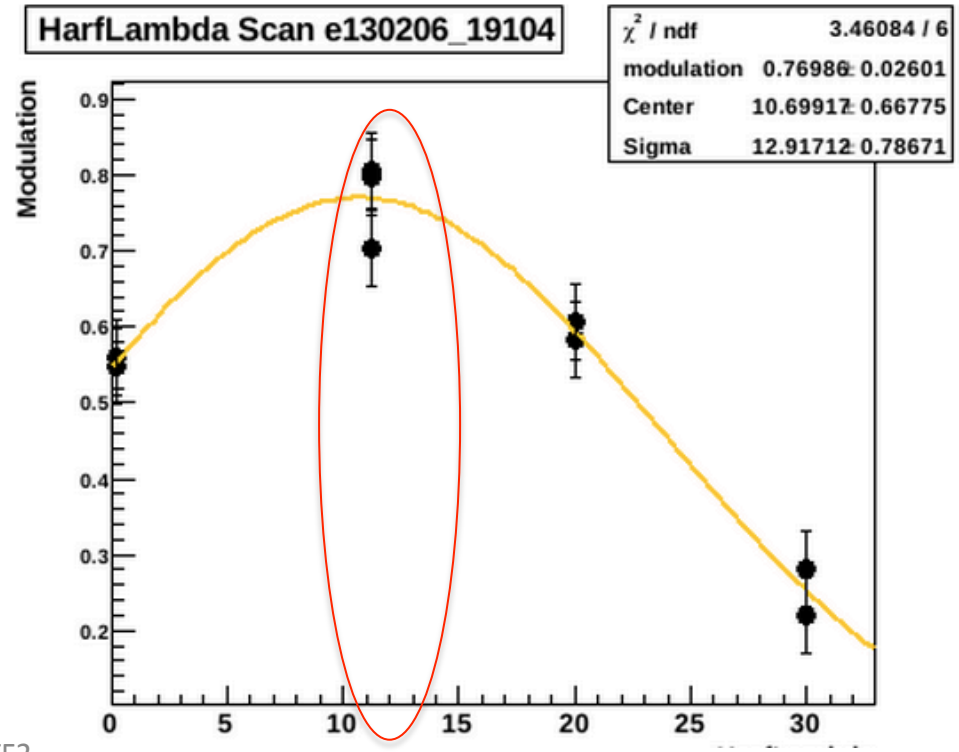
Really half mirror ?? Or something wrong with laser paths { 7 deg, 30 deg} vs { 174 deg}

Plan: re-measure under same setup during later part of beam -off week



Polarization measurement results confirmed during actual beamtime

Half lambda plate 11.2 deg for pure S → highest M

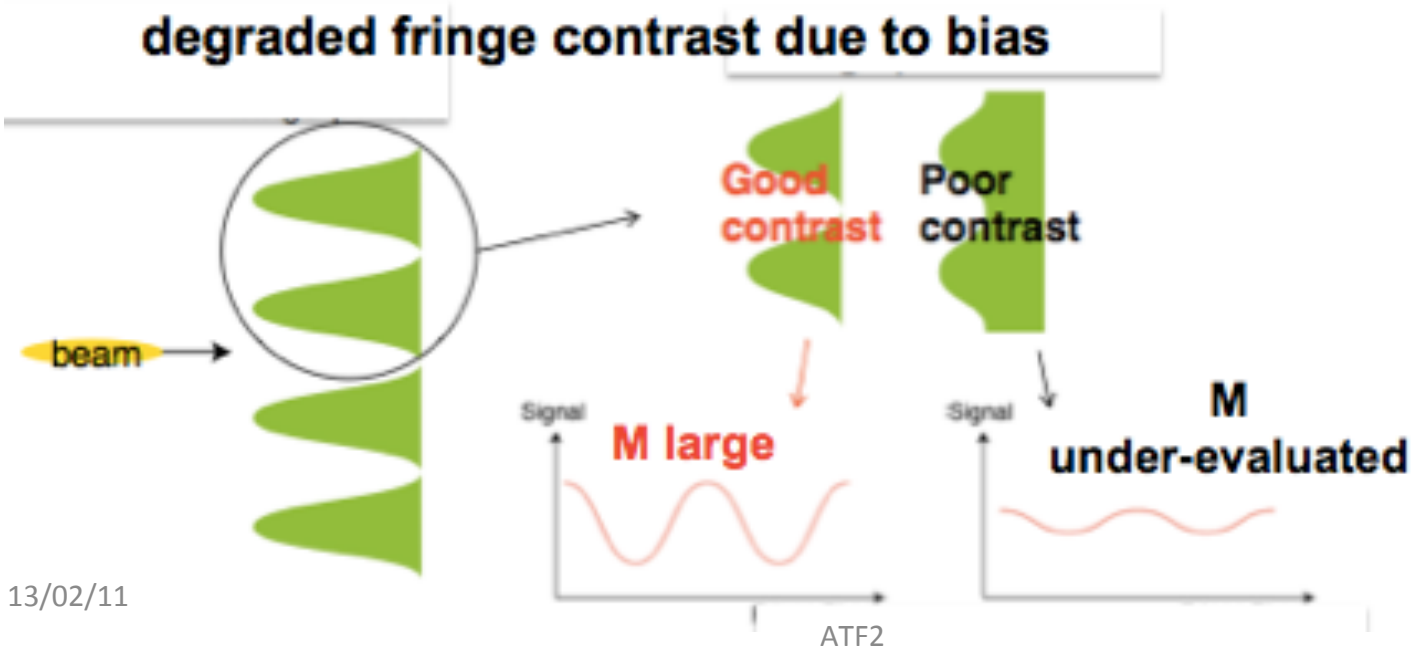


Modulation Reduction Factor

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

over-evaluate σy*

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



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

◆ **Apparent discreptancy 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??

Issues on systemtic errors:

If IPBSM intrinsic factors:

what make up the **M reduction C = 0.85 M at 30 deg mode → over-evaluate σy ??**

sum up the "(sort of) known" bias factors (see next slide) → **only C ∼ 0.92**

(e.g. Polarization, total power imbalance , Profile imbalance , phase drift , ect…)

the rest come from still "unclear" ones (???)

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

  suspect to be large, but hard to evaluate, many factors could affect horizontal jitters

Can only give **"worst limit" : for** 174 deg mode: about 600 - 800 mrad ?? → C > 84%

- **Fringe tilt**

  depend on alignment conditions at the time, no quantitative evaluation yet

Plan to use simulation to grasp effects of yet unknown errors

Other issues:

- **Laser timing jitter : if 1 ns RMS → contribute bout 4% in signal jitters**

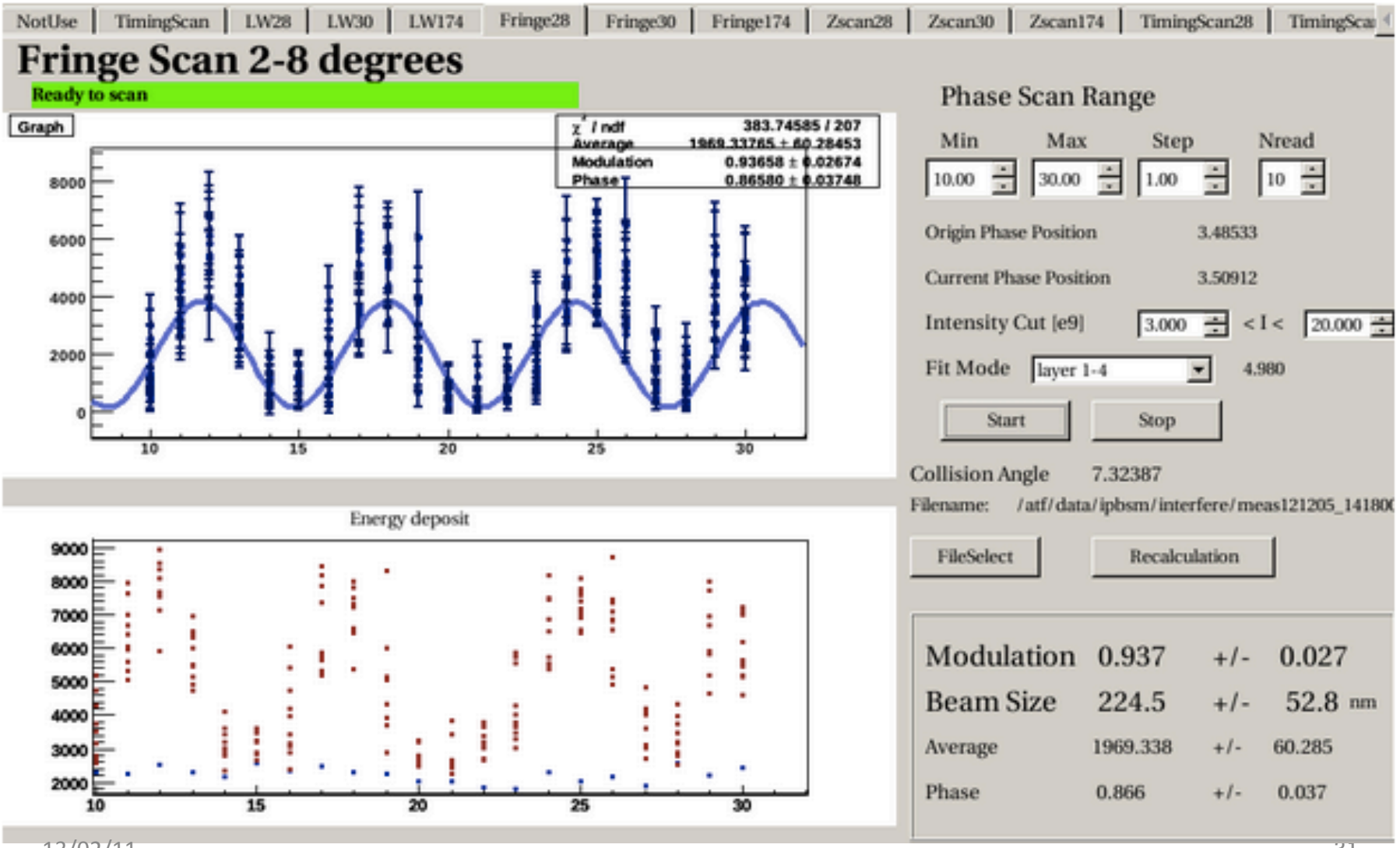
  still under investigation

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	**U: L = 2:3 : C > 98.5 %** in general	
	sigma,* peak	
Polarization ***new !!***	~ 100%	> 99.5%
	After optimize half lambda plate, not a problem at all	
Fringe tilt	**U , L paths Δ= 1 ~ 3 mm** offset from lens center in z, isame direction **C > 95% (?) (if Δ = 1 mrad)**	**maybe slight tilt in longitudinal, 2 laser paths symmetrical** ***did not hinder 174 deg M detection***
	Transverse tilt : not a significant issue	
Pos. alignment (t, z)	**C > 99%**	
Phase drift	24 mrad / min : C> 99.7%	in general O(10) mrad / min

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

Depending on conditions, best M reduction could be as light as 0.95

M = 0.937 , beam size fitted to 225 nm



IPBSM Optics Reforms

(details shown in Backup, and previous project meeting(s))

❖ **Major upgrade of summer. 2012**

Improved alignment precision & reproducibility

New mechanisms for mode switching, focal lens scans

→ Suppressed many syst errors and more effective small σy tuning

Major factor in achieving BEAM TIME GOAL in Dec (stably measure σy < 100 nm)*

❖ **New IP target** : Now can see laser spots crossed at IP on same screen for all modes

❖ **Laser table reform (Jan, 2013)**

Previously: Now: **Setup reformed from upstream mirrors**

- freedom to align a good path into expander (irises) and prevent offset after ejection from main laser from being transmitted all the way downstream
- **Re-optimize expander / reducer setup** : lens distance, angle, holders
- realign vertical table Injection mirrors

❖ **Profile reforms**

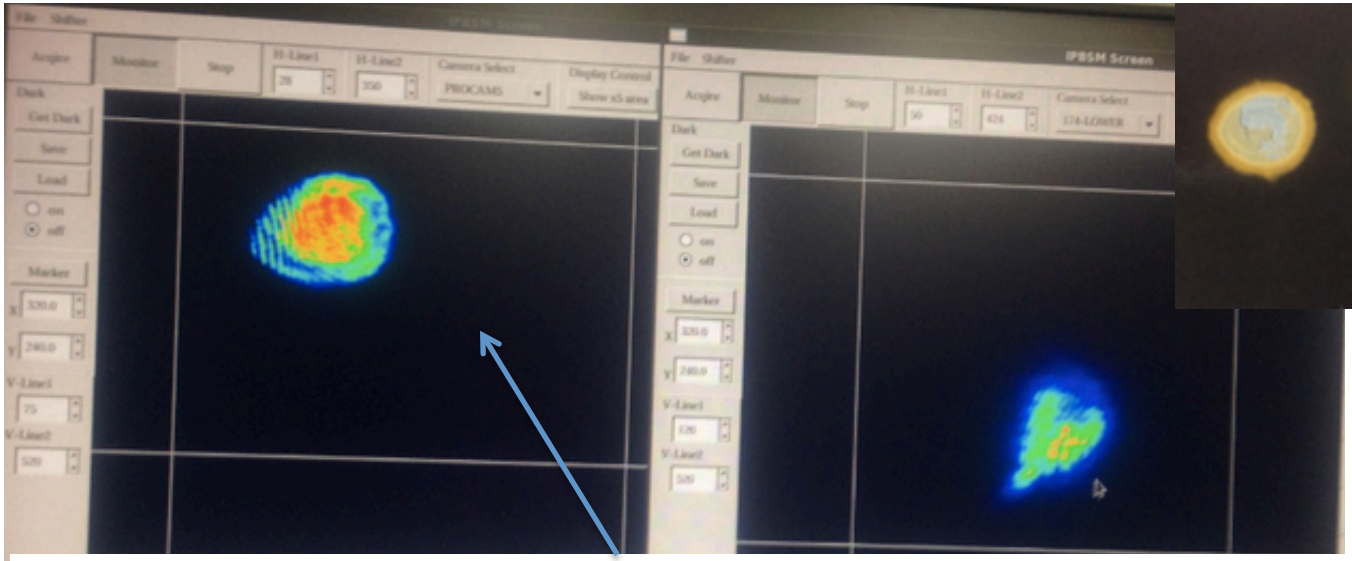
Optics reform in autumn:
Change in Profile after Adjustment by Spectra Physics

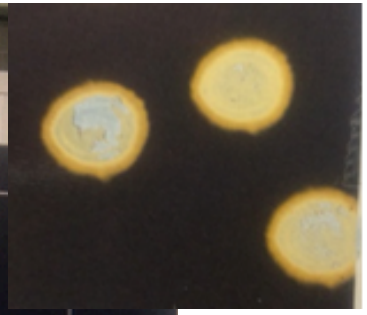
Goal: **Push intensity "hot spots" to center of profile**

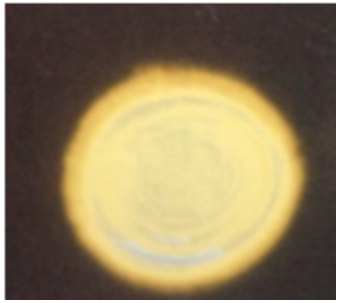
→ (maybe) resolve "two peak" structure in laserwire scan profile

•exchanged rear mirror to curvature is now 2 levels tighter

•Lowered oscillator voltage to prevent unexpected intensity related damage





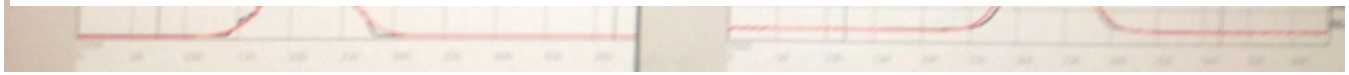


Also visible from burn pattern

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)



SUMMARY on IPBSM: Performance and Goals

174 deg mode:

Dec , 2012 : consecutive measured M corresponding to σy <∼ 70 nm

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

Jan-Feb, 2013:

seemed to have reconfirmed M > 0.2 at 174 deg , but lacking stability

30 (7) deg modes:

Demonstrate stability during continuous ATF2 beam tuning

contributed to meaningful study on : wakefield, beam intensity, multi-knob tests, ect

significant improvement after laser optics reforms

suppress jitters & bias factors, reliability & reproducibility in laser optics alignment

- ❖ **Maintain stable performance of IPBSM for usage in ATF2 studies**
- ❖ **Improve stability to realize measurement of σy < 50 nm**

- **still various systematic errors to be assessed for beam size discreptancies**

→ **Dedicated study and evaluation of potential errors sources**

Backup

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	• focal point scan for all modes • redefine clear reference lines on new base plates
consistency , reproducibility esp. before / after mode switching	• **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

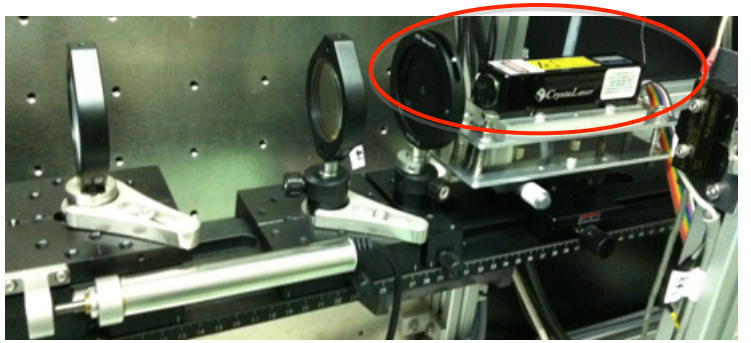
(re) commission various monitors : (CCD, timing system, **PSDs)**

Small linear stage
+ mirror actuator

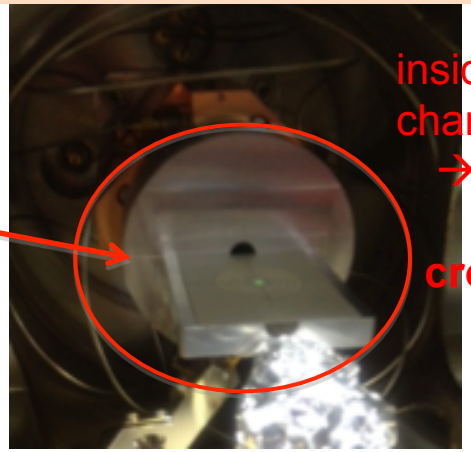
Firm lens holders

check positioning
of lens, mirror, prism

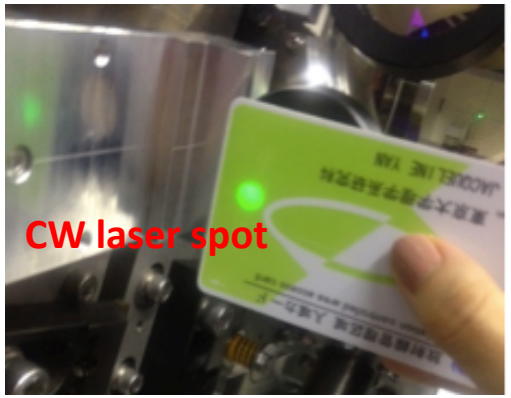
just after injection onto vertical table



Confirm fine alignment using
CW laser and transparent IP target



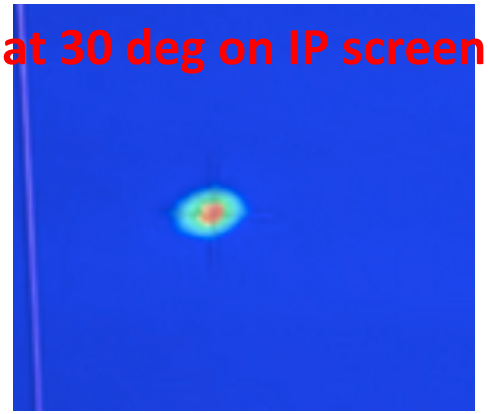
inside IP
chamber
→laser waist
&
crossing point



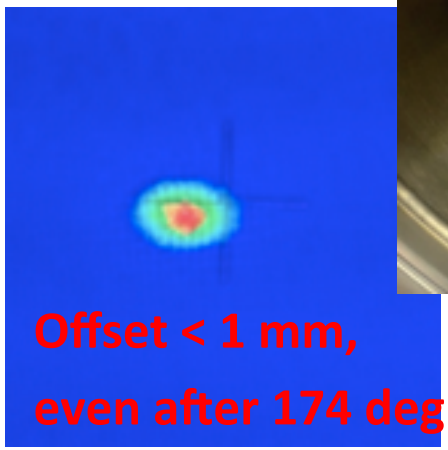
New IP target: Nov 21

- 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

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)

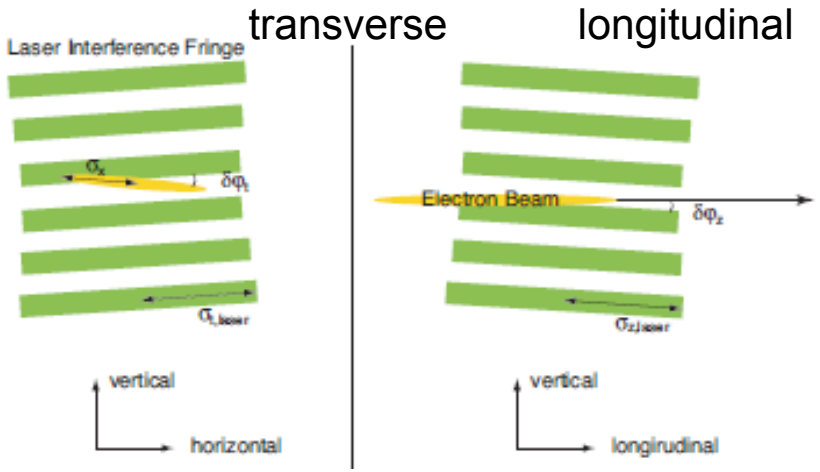
- **Fringe tilt:** intentionally change tilt → observe response in M

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**

Fringe Tilt

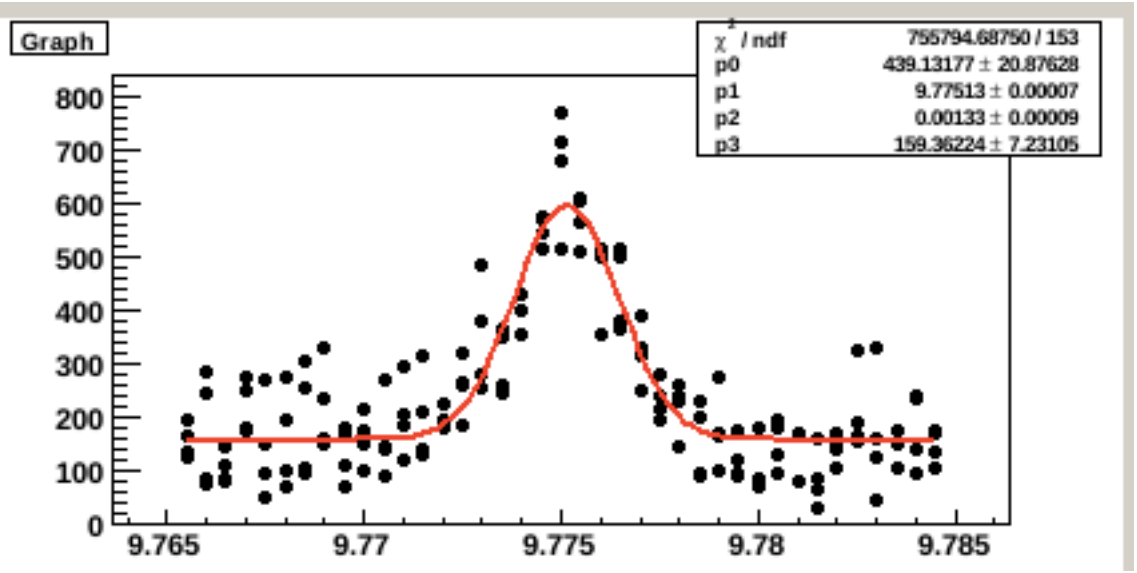


←→ Laser fringes not completely perpendicular to beam axis

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

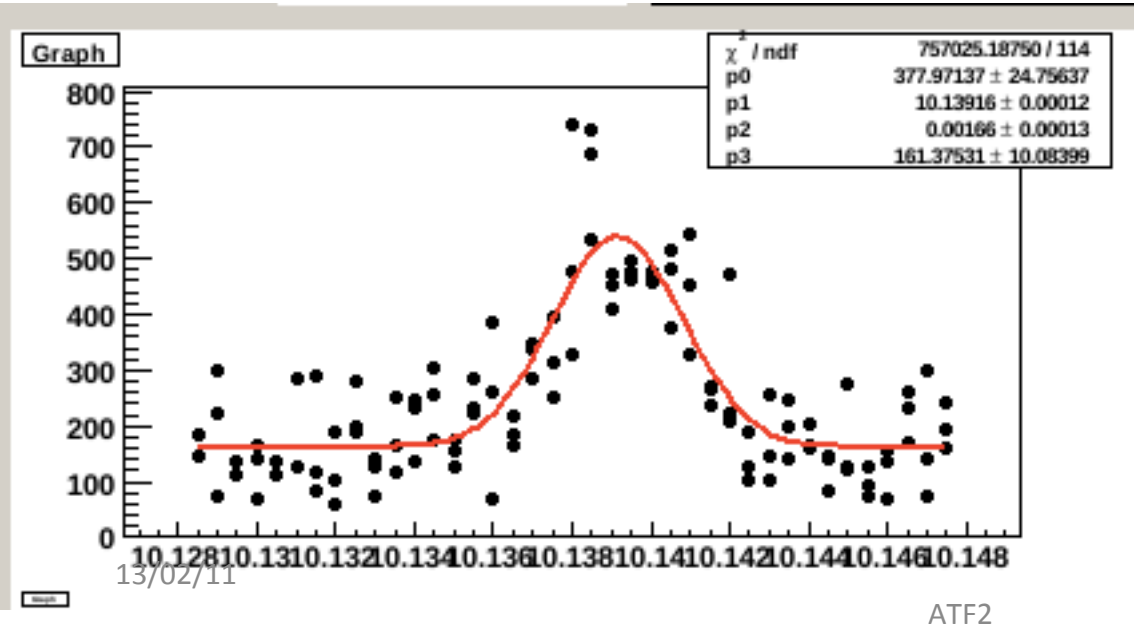
transverse : can tune e beam by rotating → not an issue

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

- **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

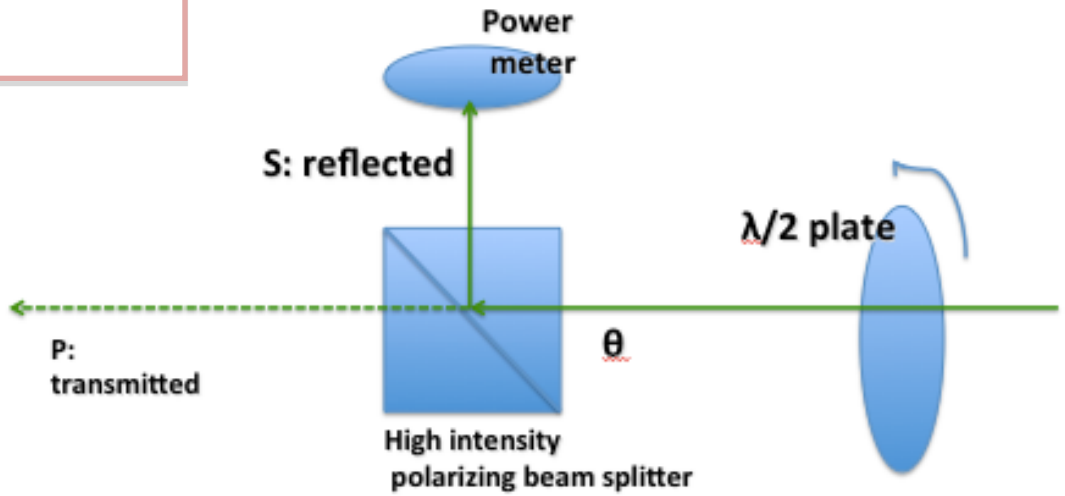
→ syst errors related to polarization

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

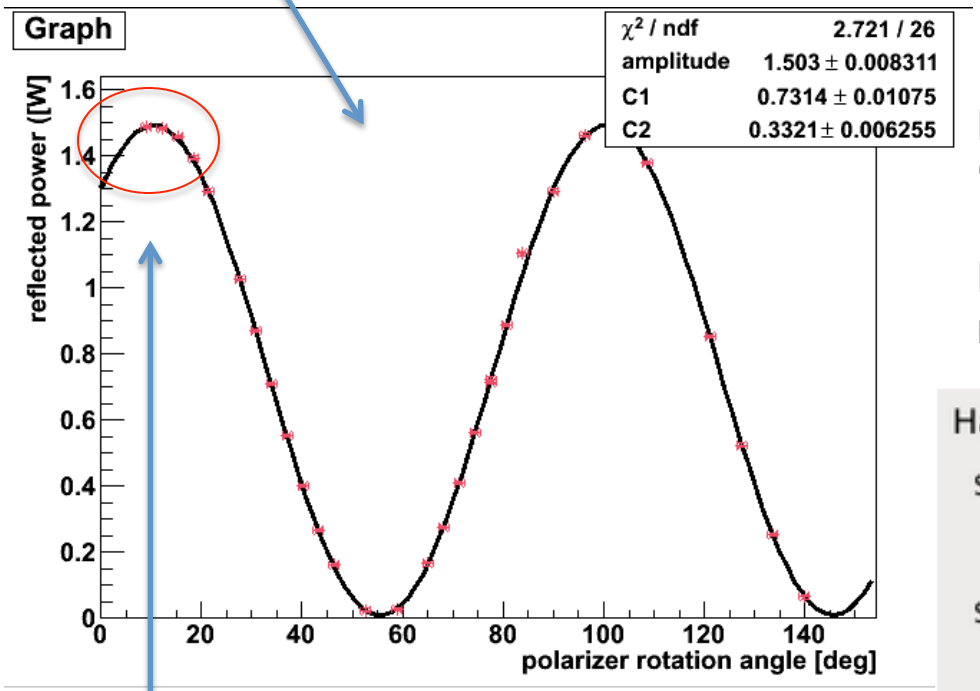
350000 maybe best in terms of power balance, but not highest M

➔ **Measure polarization to confirm**

polarization measurement
Jan 18, 2013



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

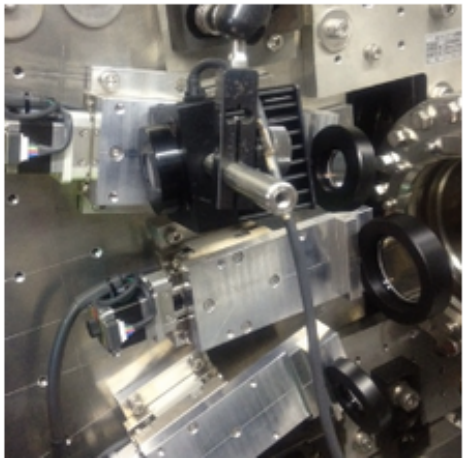


Polarizer (λ/2) angle setting for pure S polarization
(90 deg period)

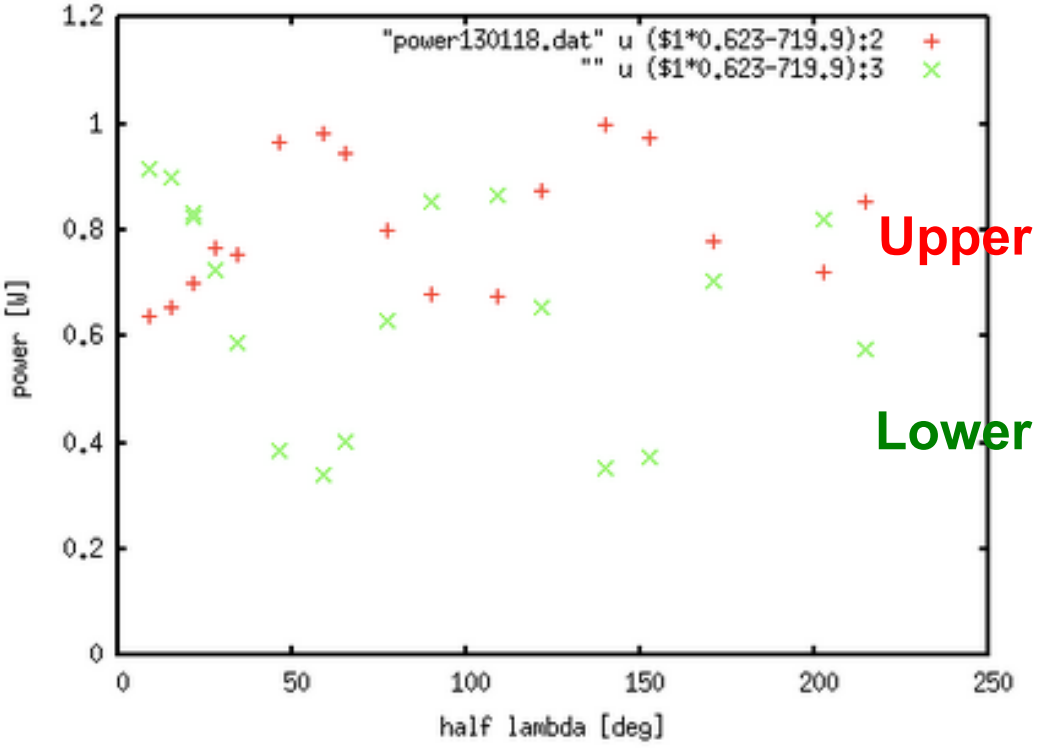
Recalibration of controller "Shot204" vs λ/2 plate rotation angle

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



Upper

Lower

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??)

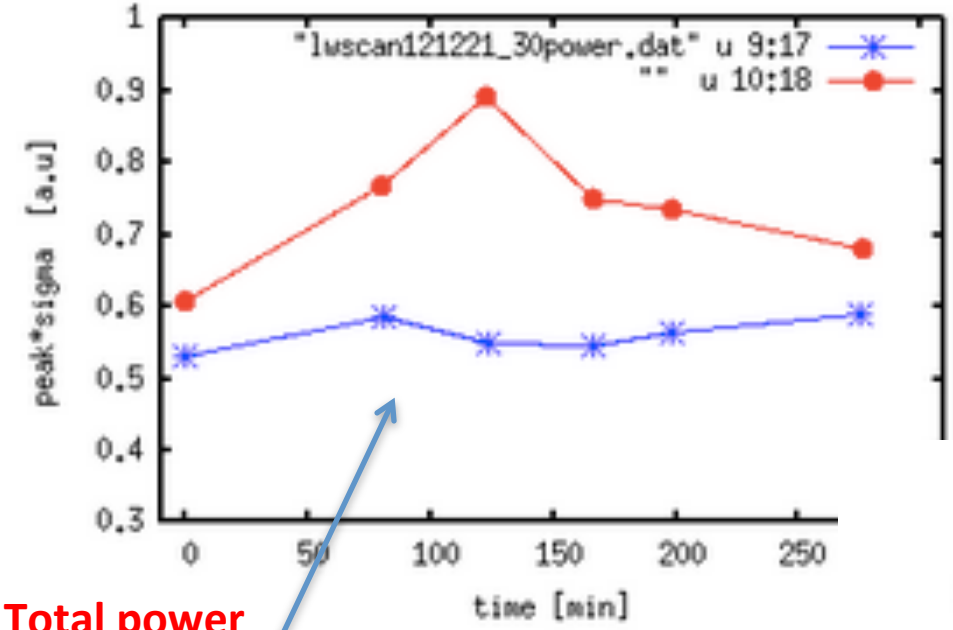
Total power imbalance is negligible compared to polarization related errors

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

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

relatively stable power

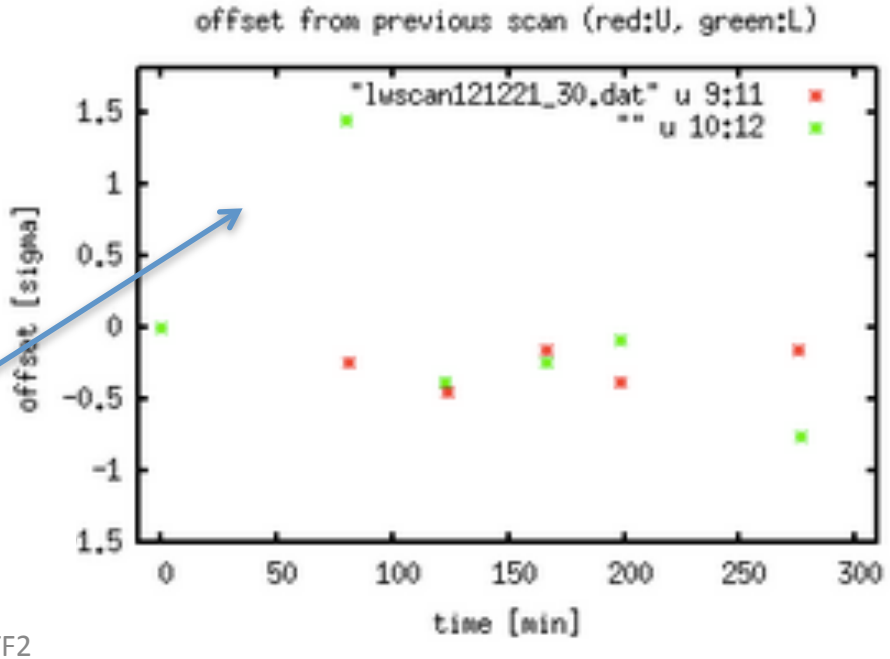
Note: ICT was raised for first part of 30 deg operation and for intensity scan, later lowered



Total power (sigma * peak)

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

maybe laser / e beam became more stable overnight ??

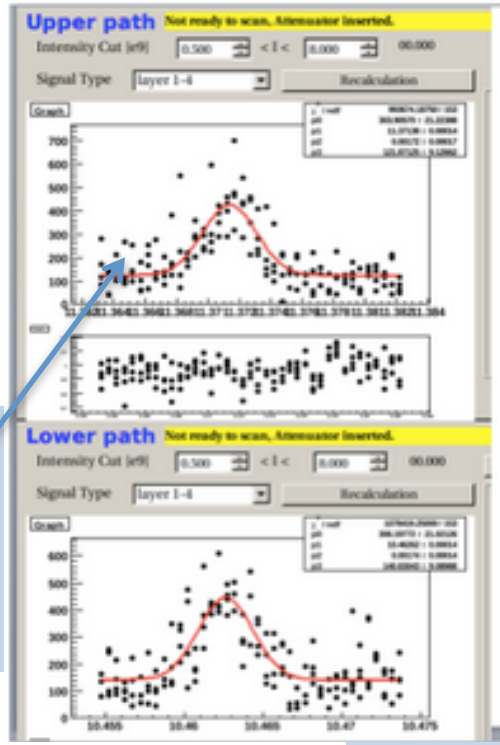


drift in peak position (from previous scan)

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)



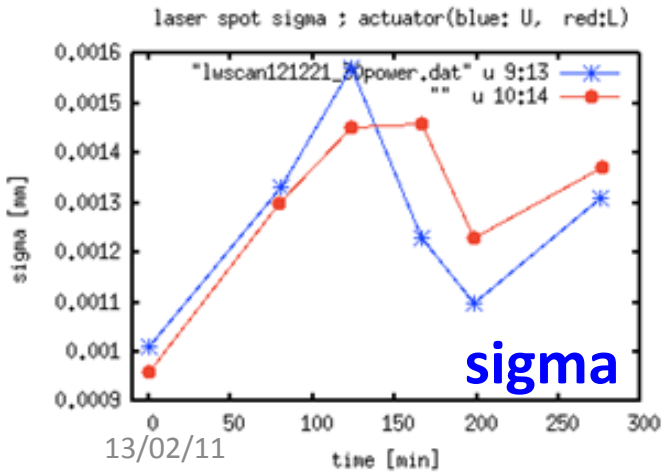
Laserwire scan
Very balanced for 174 deg mode

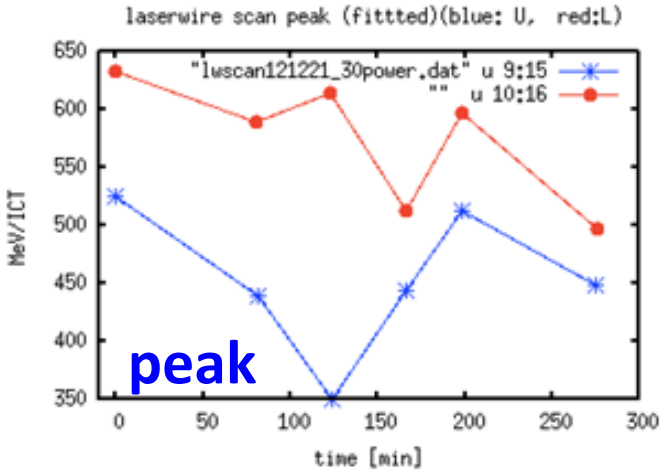
U:
sigma: 0.00172
Peak: 304
sigma*peak=0.523

L:
sigma: 0.00174
Peak: 306
Sigma*peak=0.532

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)

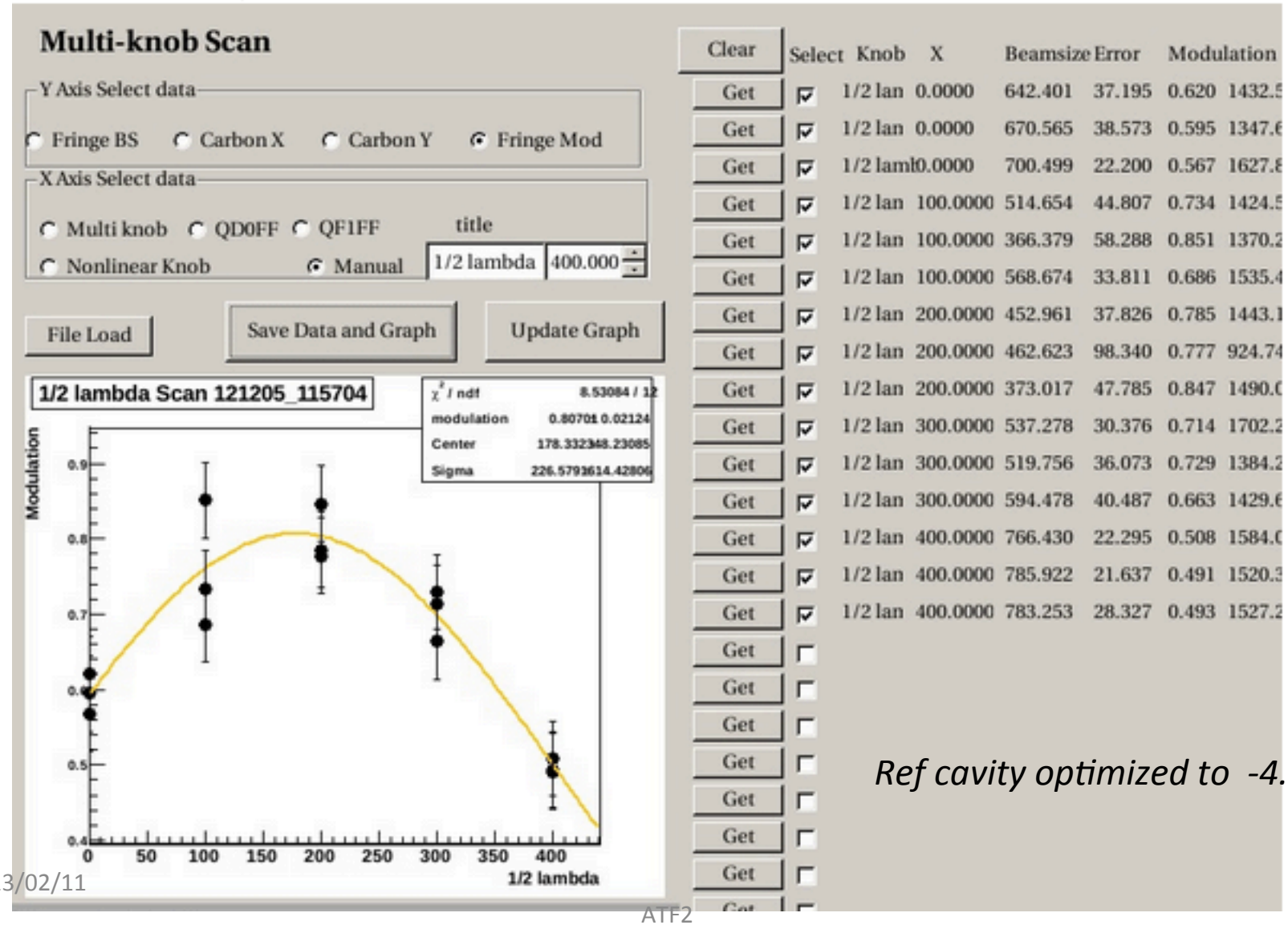




7 deg mode : half lambda scan

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

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

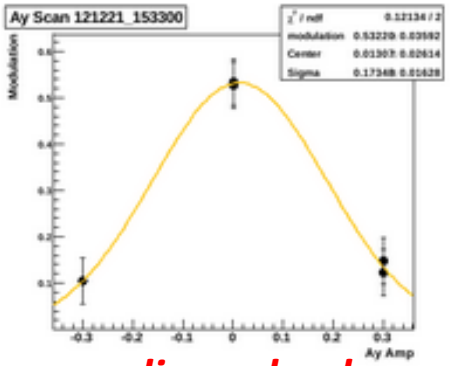
Consistent fringe scans at 174 deg mode #1

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		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 result (RMS)		σy* = 73.4 ± 4.6 nm M = 0.224±0.0420				analyzed result	σy* = 71.6 ± 0.2 nm 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	全画面表示を閉じる	56.61157025		1.22	5
183301	0.197	0.045	76.2	1.1	724.2		62.97520661		1.784	10
analyzed		σy* = 73.0 ± 6.8 nm								
result (RMS)		M = 0.230±0.062								

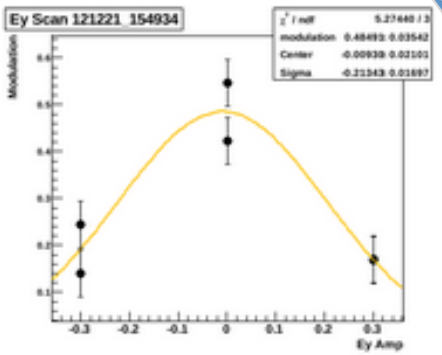
Ay scan, set to 0.01, almost no change



linear knobs

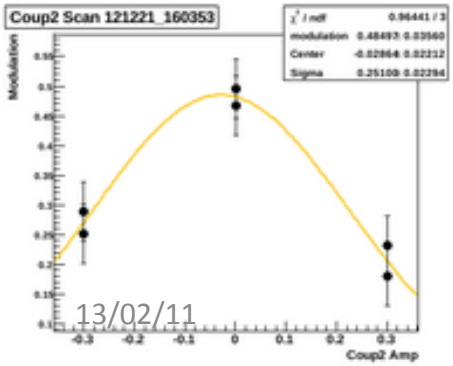
Ey scan

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

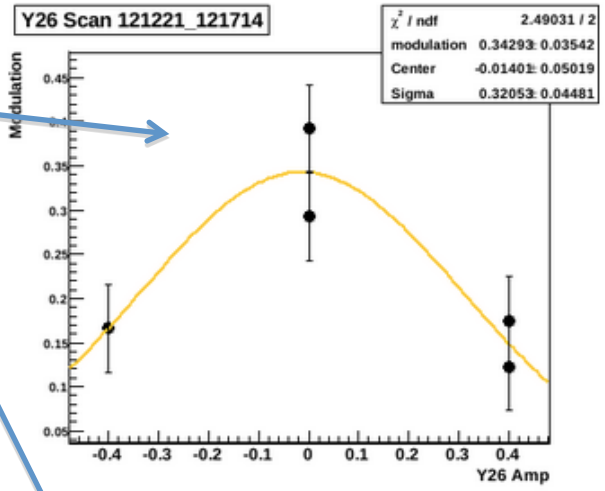
(set at 0.8 < ICT < 1.2)

check linear knob again

This time at low intensity

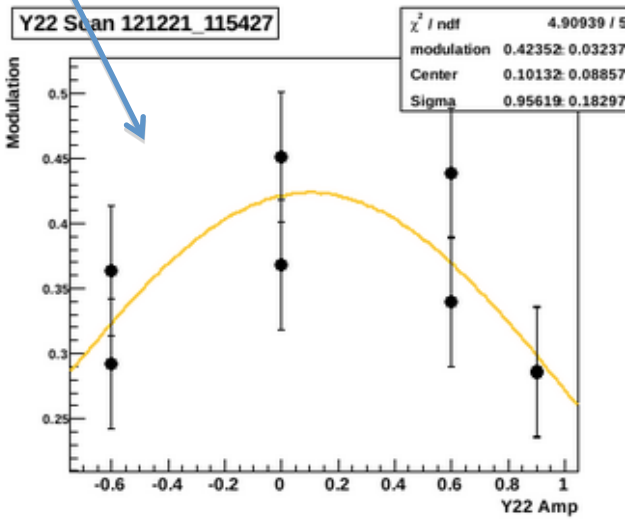
almost no offset at all

Y26 leave at 0



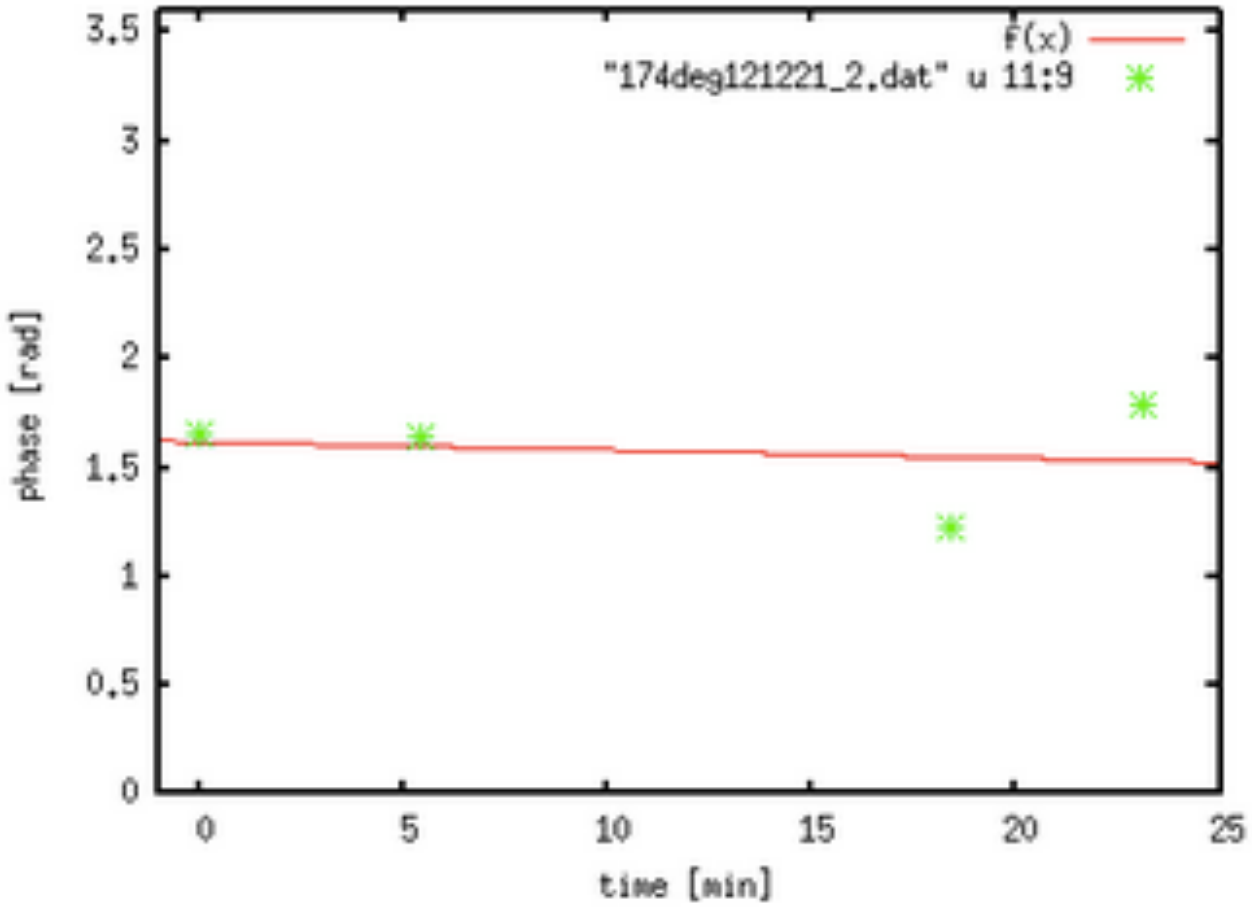
non-linear knobs

Y22: set to 0.1



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

But not always so….



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

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)

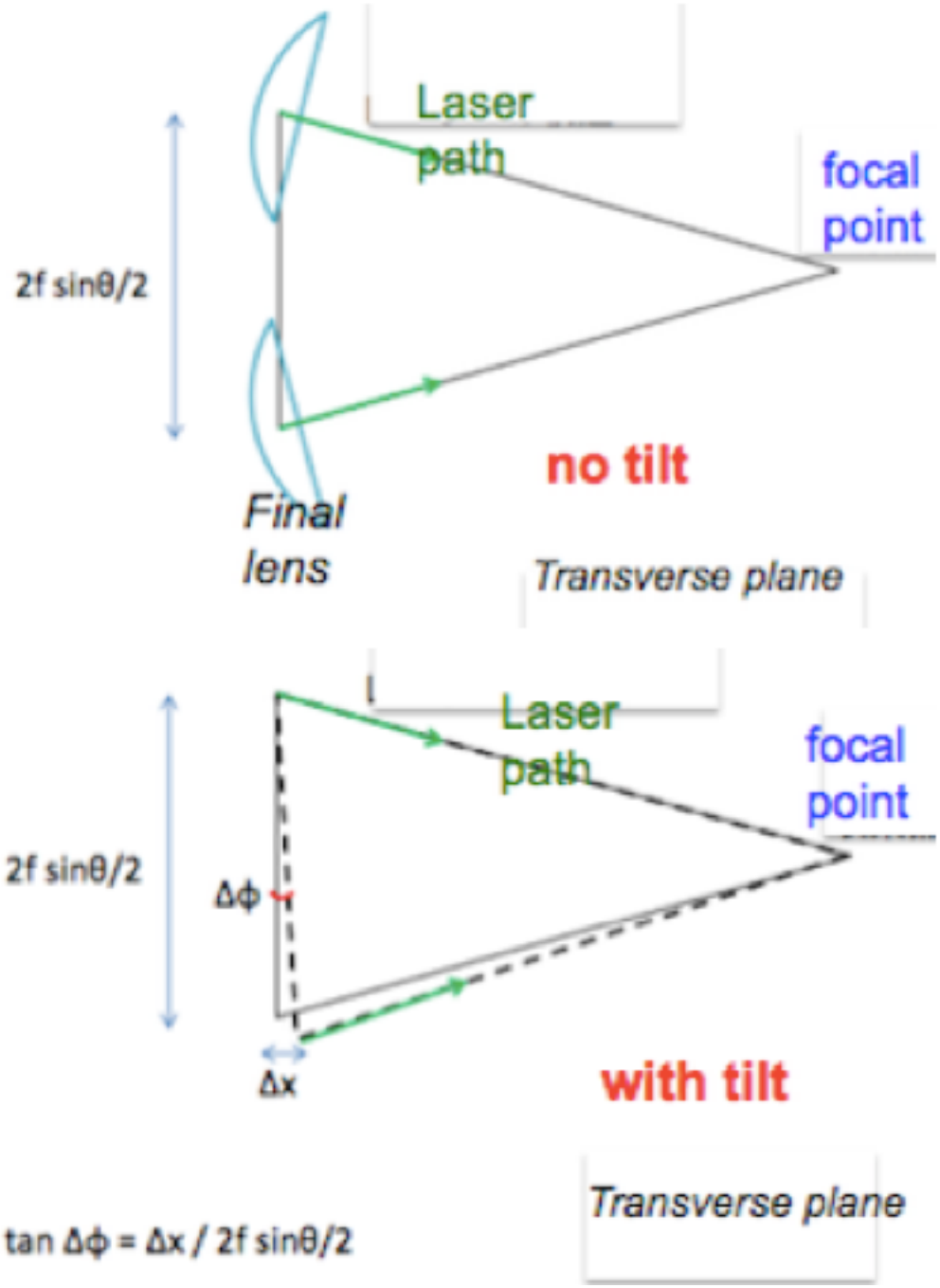
$$\text{longitudinal}: \quad C_{z,profile} = \sqrt{\frac{2\sigma_{1z,laser}\sigma_{2z,laser}}{\sigma_{1z,laser}^2 + \sigma_{2z,laser}^2}}$$

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

Assume similar balance for transv and longitudinal profile:

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

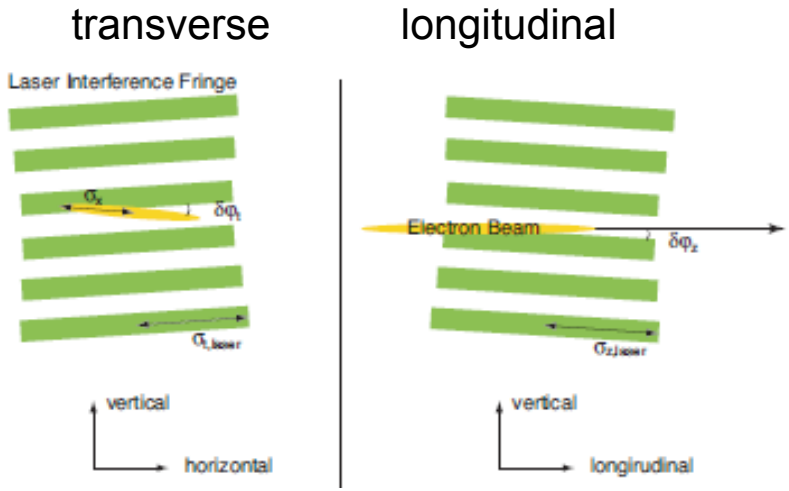
sometimes worse state for 7 deg mode → 3:4 balance



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

Fringe Tilt

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



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

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

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

causes σ_y^* to be over-evaluated as :

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

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

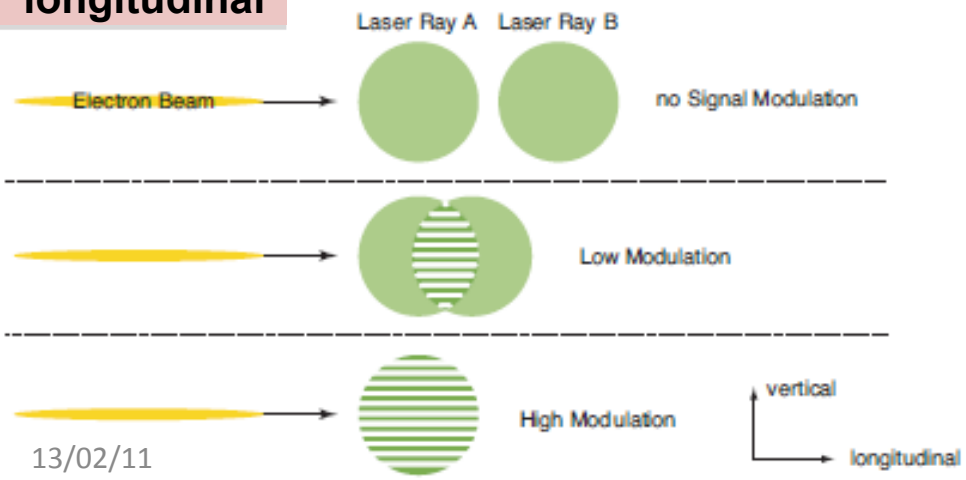
longitudinal **Cz- pos > 98.9 %**

transverse **Ct-pos ~ 99.9 %**

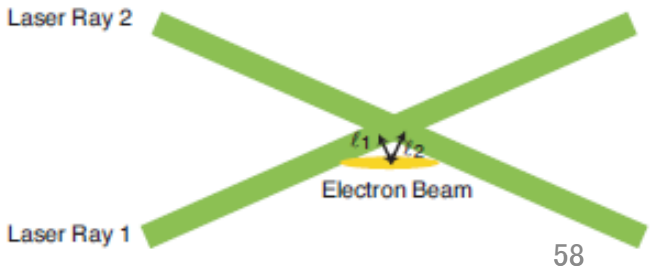
longitudinal : $C_{z,pos} = exp\left(-\frac{z_0^2}{2\sigma_{z,laser}^2}\right)$

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

longitudinal



transverse



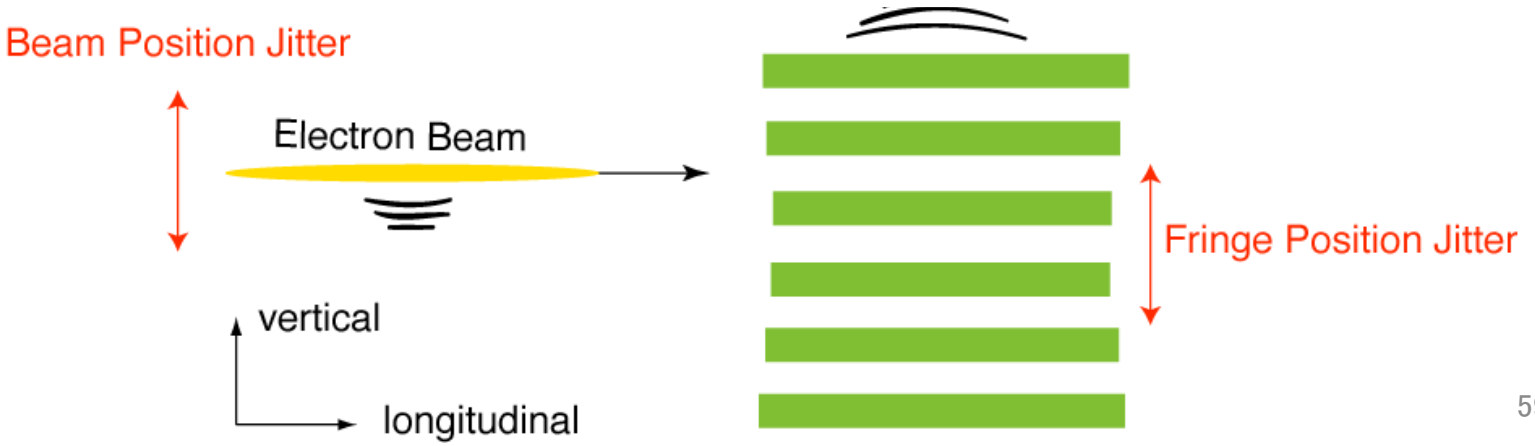
Not certain#2: Phase (relative position) jitter

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 % (????)

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

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



$$\alpha \rightarrow \alpha + \Delta\alpha \qquad y \rightarrow y + \Delta y \qquad \sigma_y^2 \rightarrow \sigma_y^2 + (\Delta y)^2$$

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

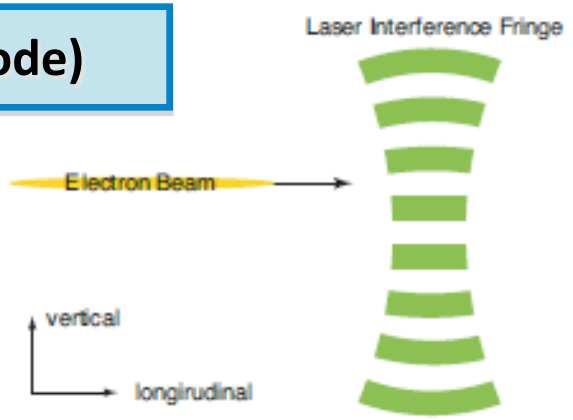
→ **Phase jitter Δα tolerance : 200 – 300 [mrad]**

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

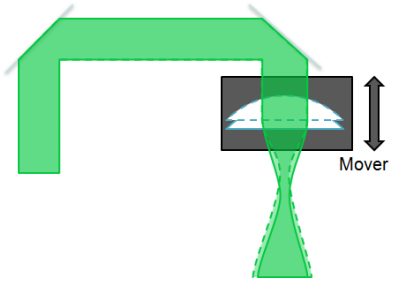
Spherical wavefronts

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

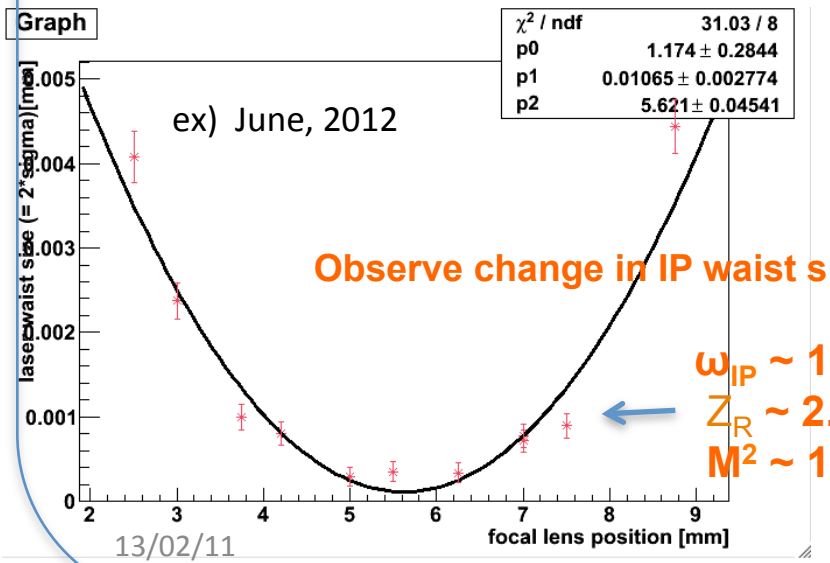
Csphere > 99.7 %



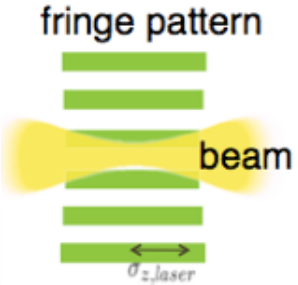
Solution is **focal point scan**



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



Change of σy* within fringes



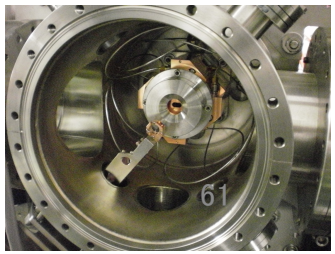
due to strong focusing,

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

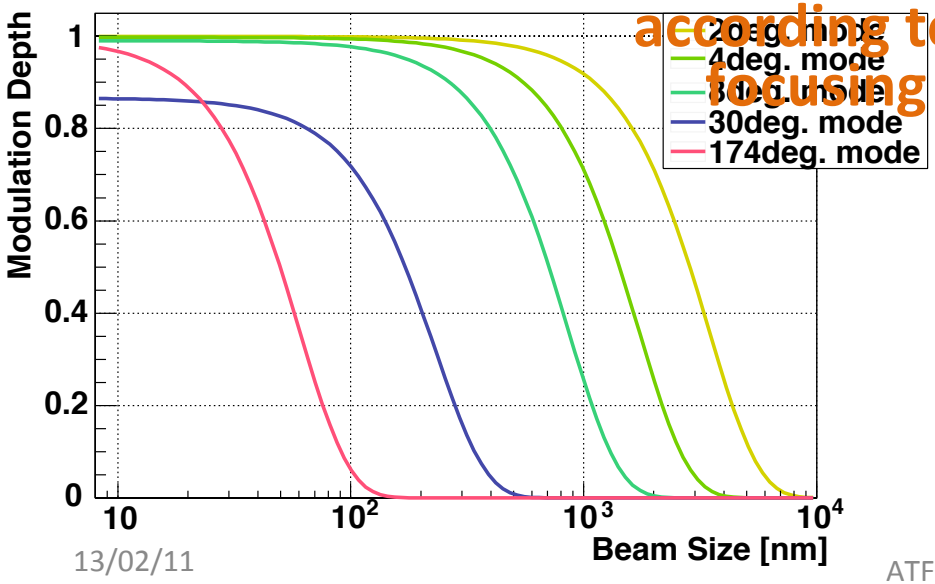
$$37 \pm 2\,(\text{stat.})\,{}^{-0}_{+4}\,(\text{syst.})\ \text{nm}$$

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

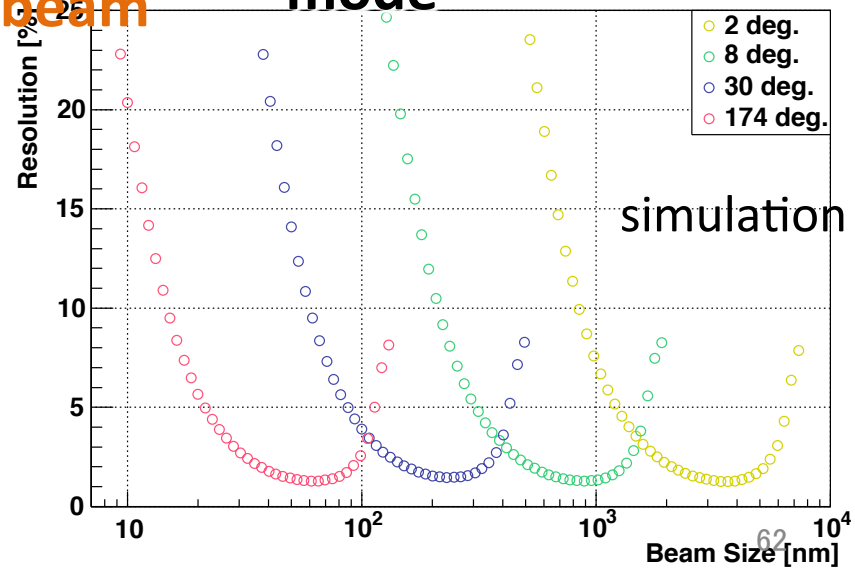
$$\sigma_y = \frac{d}{2\pi}\sqrt{2\ln\left(\frac{|\cos(\theta)|}{M}\right)}$$

σy* and M for each θ mode

must select appropriate mode according to beam focusing



Resolution for each θ mode

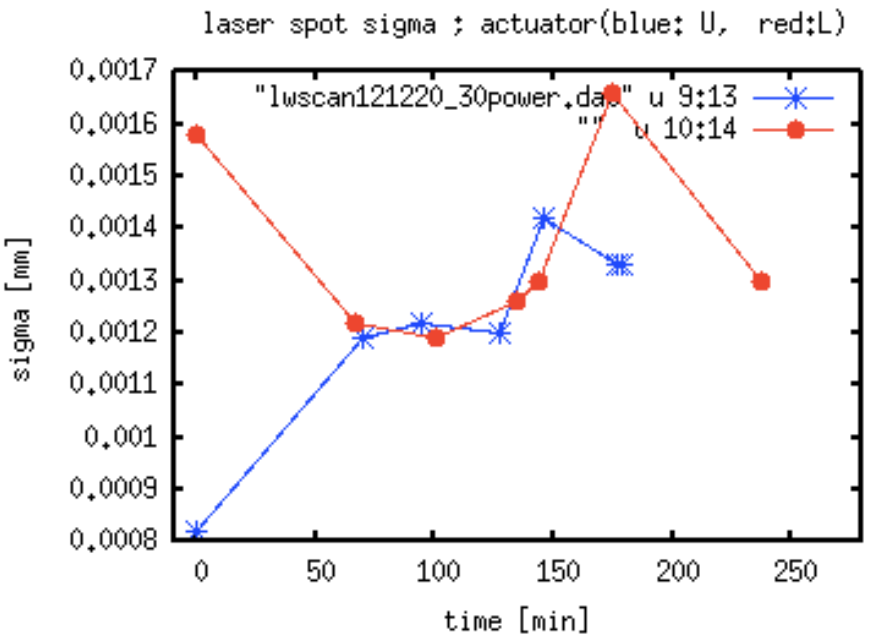


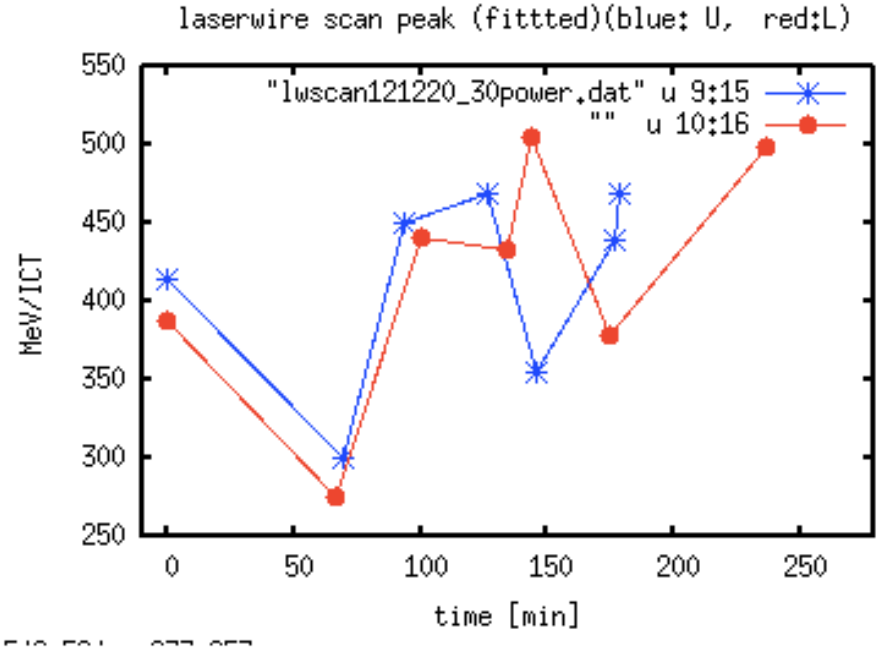
12/20 Day 30 deg mode

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)

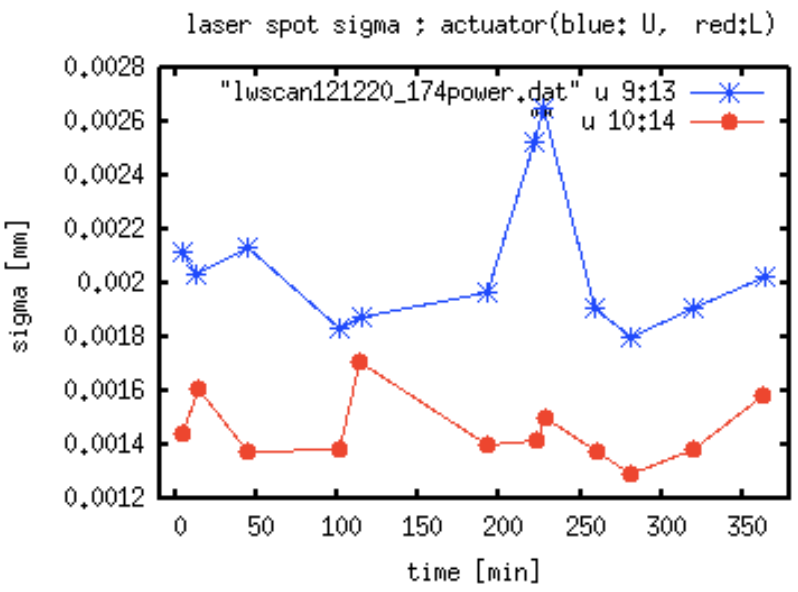


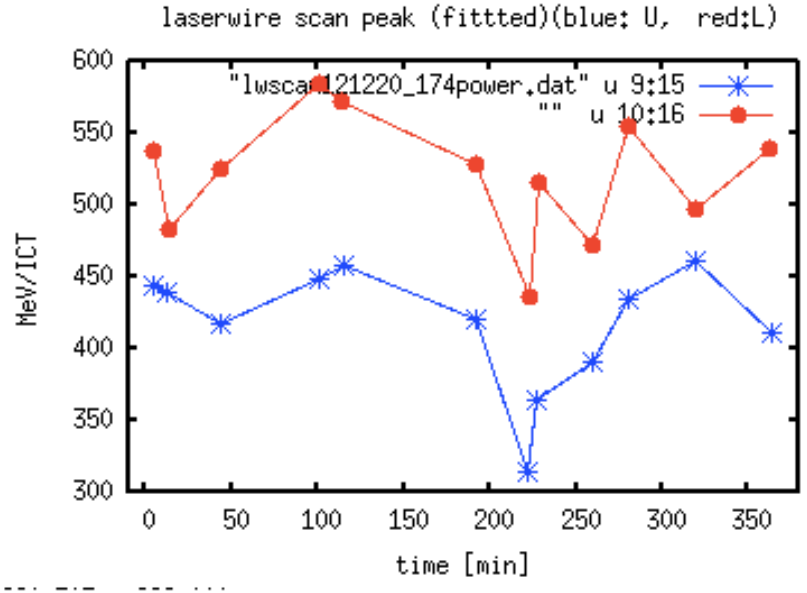


12/20 Day 174 deg mode

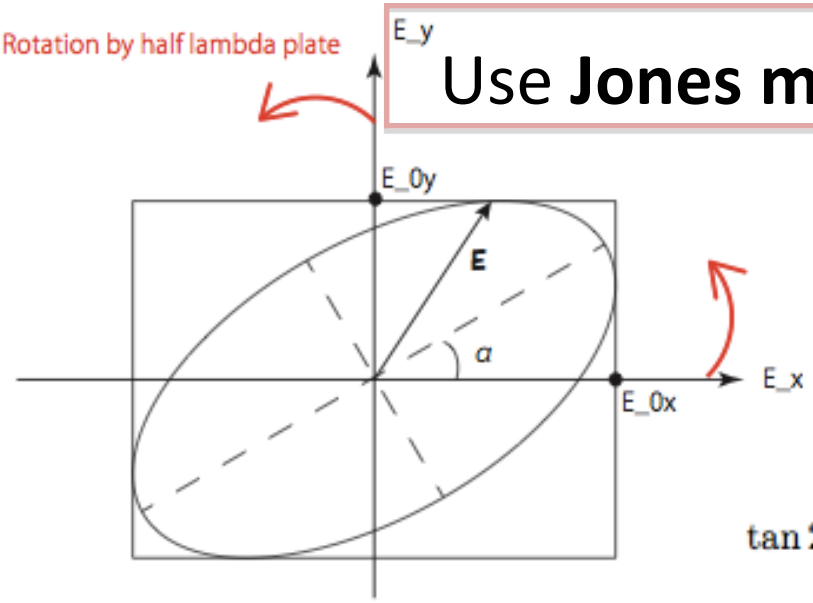
worst limits for syst error:

- **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

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**

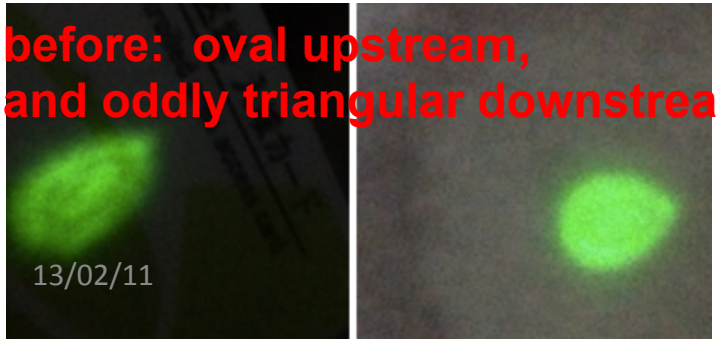
•More freedom to align a good path into expander (irises) and absorb offset from upstream
expander, reducer : lens distance, angle, holders

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

Profile on injection mirrors

On 2-8 deg lens



before: oval upstream,
and oddly triangular downstream

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