IP-BSM Beamtime Performance and Error Evaluations

14th ATF2 Project Meeting

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KEK, Tsukuba

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Layout

Beam time results since Jan 2012

Feb:
- **30 deg mode**: (10 x 10 , 10 x 3) :
  first M detection , M ~ 0.5 easily achieved
- **4-8 deg**: (10 x 3): **M ~ 0.8 ,** Error studies
- **174 deg** (10 x 3): **: maybe detected**

March – May:
many issues in
beam and laser

June (10 x 1)
- **4deg, 6 deg, M ~ 0.9**
  error studies
  reducer optimization
  Multiknob scans (+ training)
- **30 deg : M ~ 0.35**
- **174 deg :**
  System checkup
  focal point scan

Systematic and statistical errors

- **Summary**
- **Summer upgrade plans** → Oroku-san's talk
- **Goals for autumn run**

Highlights of this talk

Beam time Status

Feb

- **30 deg mode: fully commissioned , stably measured M ~ 0.55, σ_y ~ 150 nm**
- **174 deg mode: M maybe detected**

March - May

- **Resolve and stabilize laser system**

June

- **consistently measured M ~ 0.9 at 4 deg / 6 deg modes**

  → systematic error studies

- **Contrast ~ 0.9**
- Major errors: **profile imbalance, fringe tilt,** phase jitter (?)

- **Systematic checkup of 30 deg, 174 deg modes**

  → lead to summer upgrade and goals for autumn

date	notes	beta	M and Beam size
2/17	**1st detection of 30 deg**	10 x 10	σy ~ 200 nm
2/21	Syst error checkup at 4, 8 deg	10 x 3	**Mmax ~ 0.8**
2/23-24	**30 deg**	**10 x 3**	**M ~ 0.55, σy ~ 150 nm**
	174 deg (Maybe detected)	10 x 3	Maybe σy ~ 90 nm *Not certain!!*
March April May	• **Laser buildup (seeder) fluctuations** → **Mirror tuning** → **exchange of seeder, flash-lamps Beamlok PZT mount** • **high laser intensity damaged optics** → Changed reducer lens → 40% (filtered) intensity operation ***after all this laser system stabilized overall*** **beam issues:** • instabilities in timing, current, orbit • tune resonance in DR • multiknob tuning hard to reduce σy (?)	10 x 3 10 x 5 10 x 1	system checkups at 6 deg At 30 deg: M ~ 0.1- 0.2 (300 nm?) • ***Various beam and laser problems delayed progress*** • ***not much meaningful beam time data***

good results in Feb

summary of IPBSM shifts during 2 weeks continuous run (6/4 – 6/15)

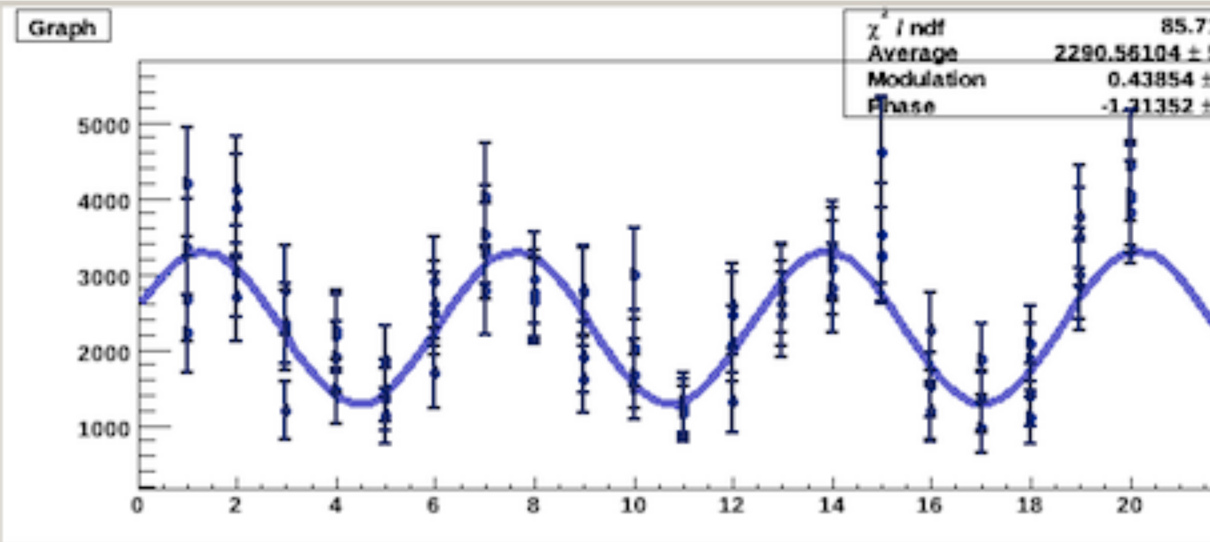
Week 1	contents
6/5 – 7 Startup tuning	DR → EXT→ FF (C wire)
6/7 **IPBSM**	<u>6.3 deg:</u> - Reducer scan **M_{max} ~ 0.9 !!** <u>30 deg:</u> • **upper rotation stage broken !!** • reducer scan for lower path only at 30 deg
6/8 :	• Fixed upper stage • **Reducer scan at 6.3 deg and 30 deg** • **multiknob scan:** but 30 deg M not very high
6/9 - 10	• Issues :Linac , DR freq. change, water temp • **Large EXT orbit offset and y dispersion** had to be fixed More multiknob tuning at 6 deg, 7.8 deg, 30 deg • **M got to 0.3 at 30 deg , σ ~ 230 nm** **but for some reason lost M** • Reducer scan and **sig jitter studies** at 30 deg

Week 2	contents
6/11	tuning start over again from DR → EXT → FF
6/12 - 13	• **Dispersion tuning** (by Glen using C wire) • Multiknob scan using IPBSM, **M ~ 0.4 – 0.5, σ ~ 1 μm** • **Disturbed by large εy, EXT orbit needed retuning**
6/13 -14	• **6.3 deg: Reducer optimization using both laserwire and fringe scans** • 4 deg (smallest possible): **Mmax = 0.9 !!** Take special fine data for error studies, multiknob scans
	• **then switched to 30 deg : M ~ 0.35, σy ~ 250 nm**
6/14 -15	• **30 deg :** also tried to optimize reducer, but **difficult to preserves consistency** • **M > 0.35 could not be recovered** • **Vertical dispersion drifted**
6/15	• 30 deg: reconfirm optimized reducer setting then tried out nonlinear knob tuning • Disturbed by **large signal jitters** 174 deg mode: • Laser divergence measurement → optimize reducer setup • **Focal point scan** for evaluating Rayleigh length, M2 factor

Beam time in February , 2012

Commissioning of 30 deg mode

Feb 17, 2012
(10 x β_x^*, 10 x β_y^* optics)



σ_y^*= 201 ± 4.4 (stat.) nm
M_{meas} = 0.429 ± 0.012 (stat.)

From 10 stable consecutive scans

largest M_{meas} = 0.522 ± 0.042 ←→ $\sigma_{y,meas}$ ~ 165 nm

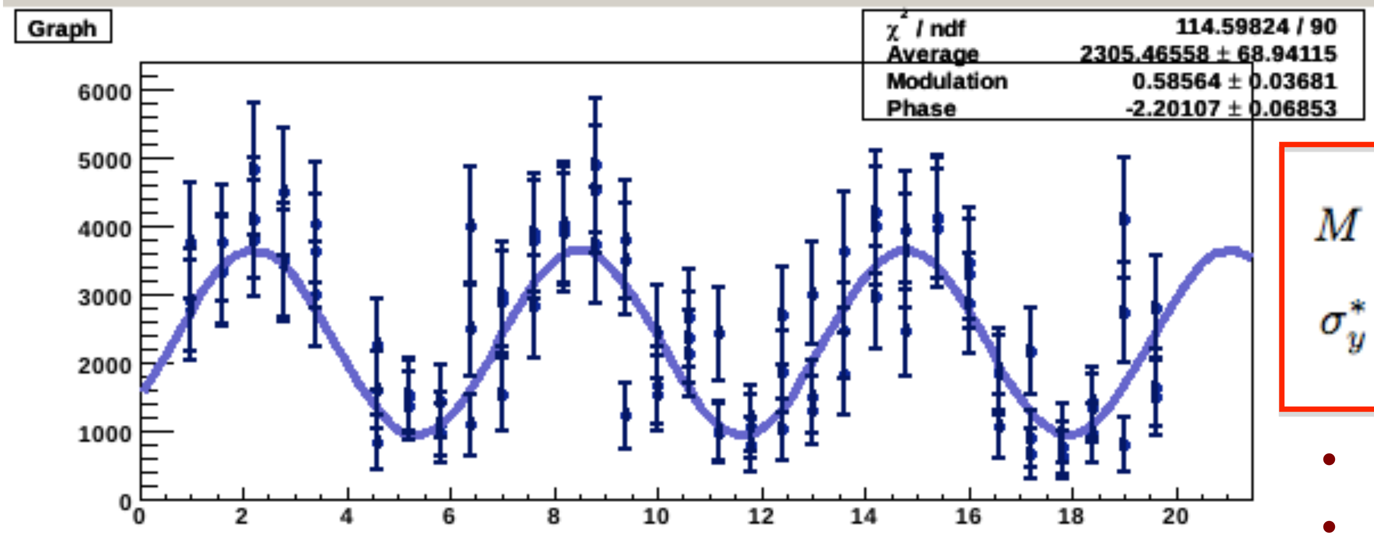
2/17: 30 deg	M	ΔM	σ_y^*	$\Delta\sigma_y^*$	avg E_{sig}/ ICT [GeV / 10^9e]
18:07	0.426	0.039	194.98	6.21	2.359
18:09	0.390	0.043	206.63	6.48	2.403
18:12	0.433	0.036	192.55	5.73	2.269
18:14	0.439	0.034	190.82	5.49	2.290
18:16	0.437	0.038	191.29	6.16	2.303
18:18	0.460	0.040	183.86	6.78	2.267
18:20	0.444	0.035	189.20	5.77	2.450
18:22	0.39	0.042	206.67	6.902	2.292
18:24	0.453	0.037	186.17	6.203	2.356
18:26	0.389	0.042	207.029	6.205	2.360

- *S/N : 4 – 5*
- *Signal jitter ~ 15%*

stable beam current

M > 0.5 (σy ~160 nm) easily achieved in Feb

ex: 10 consecutive 30 deg mode fringe scan on 2/23/2012



$$M = 0.52 \pm 0.010 \text{ (stat)}$$

$$\sigma_y^* = 167.9 \pm 1.8 \text{ (stat) [nm]}$$

- **10 x 3 beta optics**
- **S/N ~ 1**

Switched to 174 deg mode:

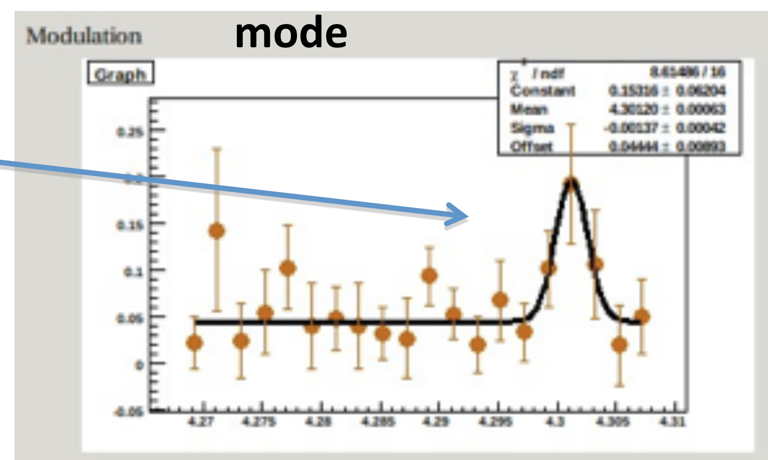
maybe first detection !!??

(10 x 3, S/N ~ 1)

Largest **M_{meas} ~ 0.13 (stat.) σ_y^* ~ 90 nm**

8 hrs period: measured M > 0.1 many times
However not satisfactory reproducibility
Challenging conditions ……
σ_y^* is still large, beam changed over time

Z-scan at 174 deg mode

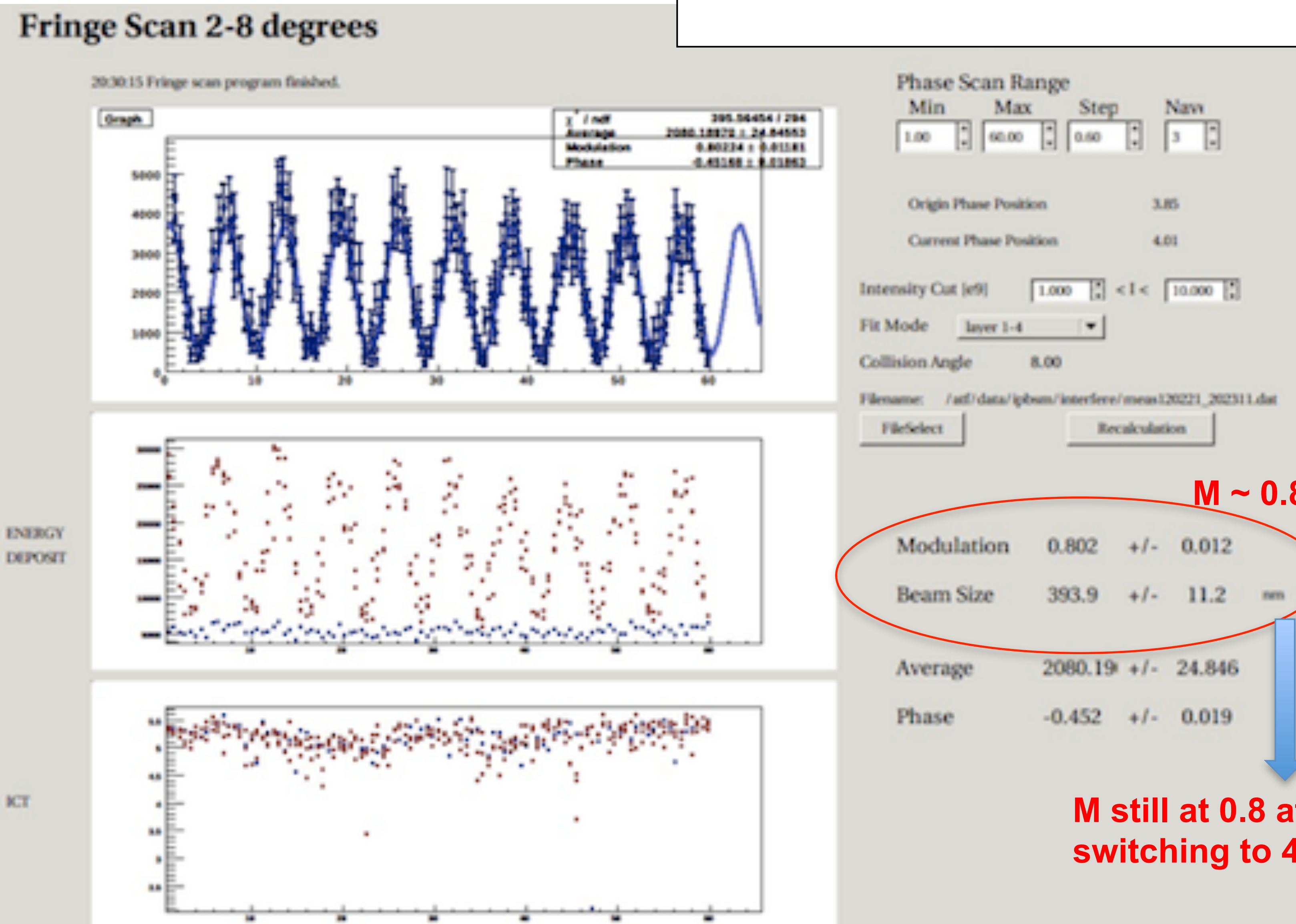


Error studies at 4 , 8 deg mode (Feb 21)

8 deg mode:

σ_y^*= 413 ± 44 nm M_{meas} ~ 0.79

11 stable consecutive scans 10 x 3, S/N ~ 1



M ~ 0.8 (8 deg)

M still at 0.8 after switching to 4 deg mode

Beam time in June , 2012

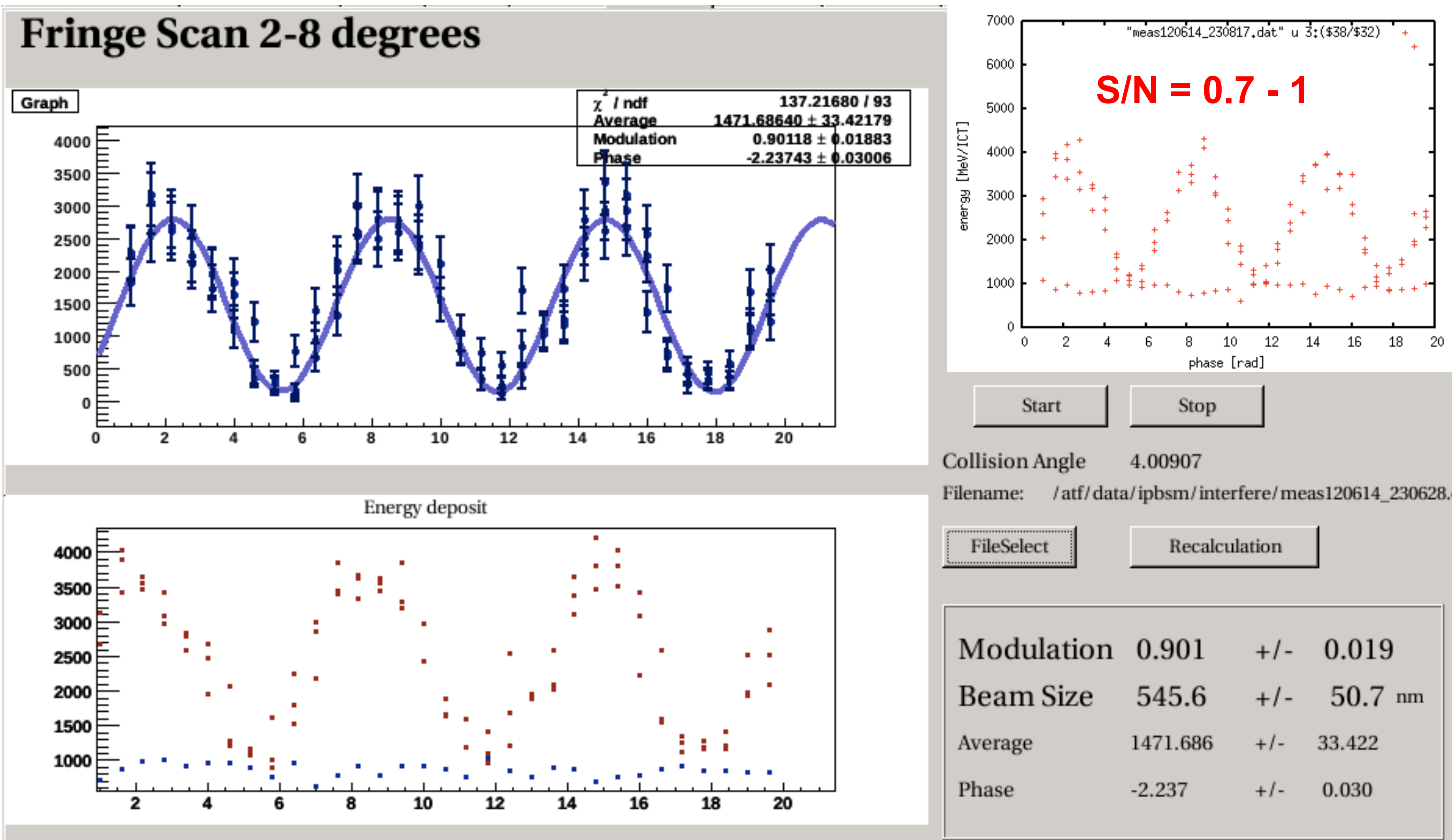
Consistently measured M ~ 0.9 at 4 deg, 6 deg modes

ex) 6 /14 swing shift: many hours of stable beam and laser

After multiknob scan at 4 deg mode:

• 4 times consistent results: **(M1, M2, M3, M4) = (0.89, 0.9, 0.88, 0.89)**

➔switched to 30 deg mode : → Mmax ~ 0.35, σy ~ 220 – 250 nm

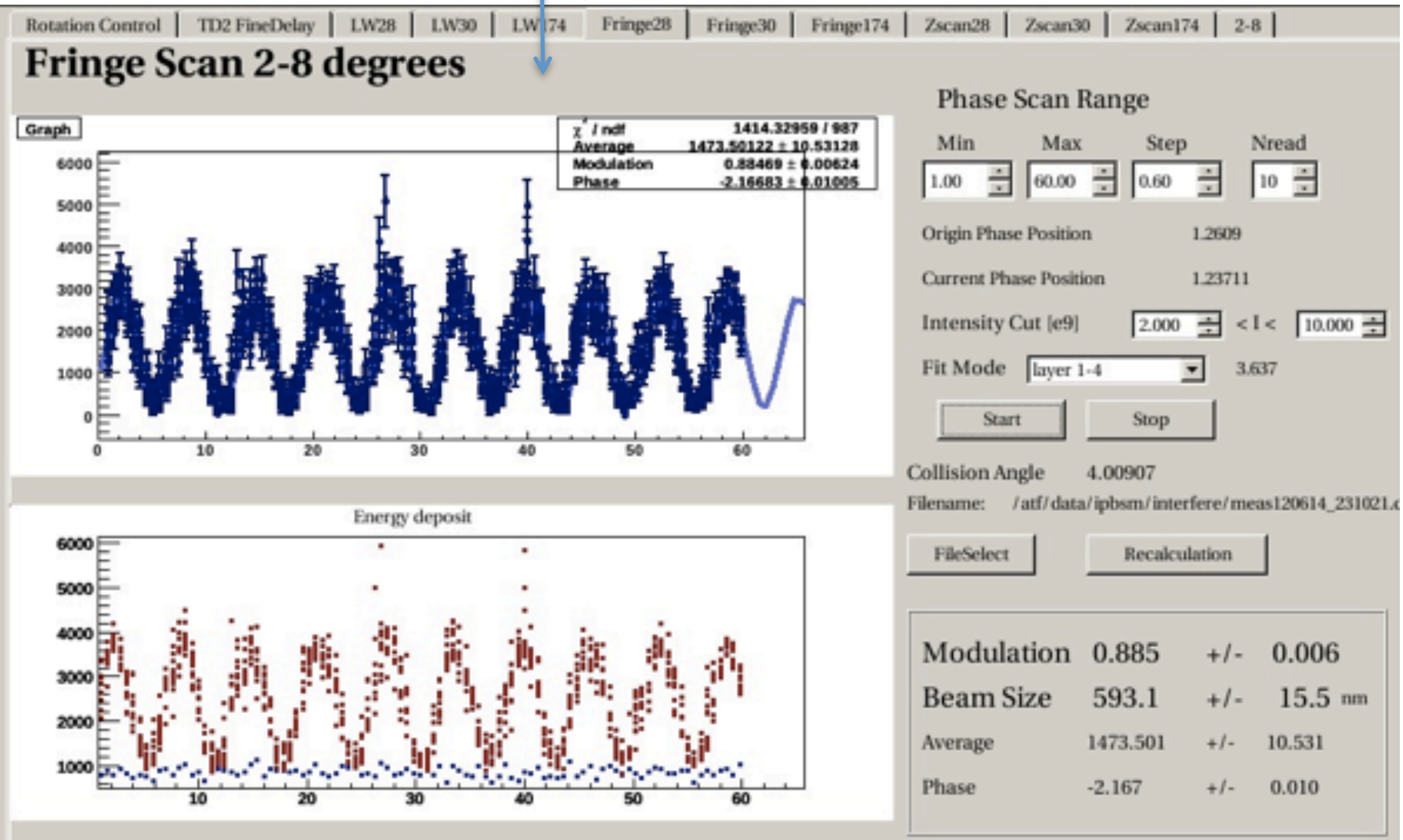


4 consistent measurements at 4 deg mode :

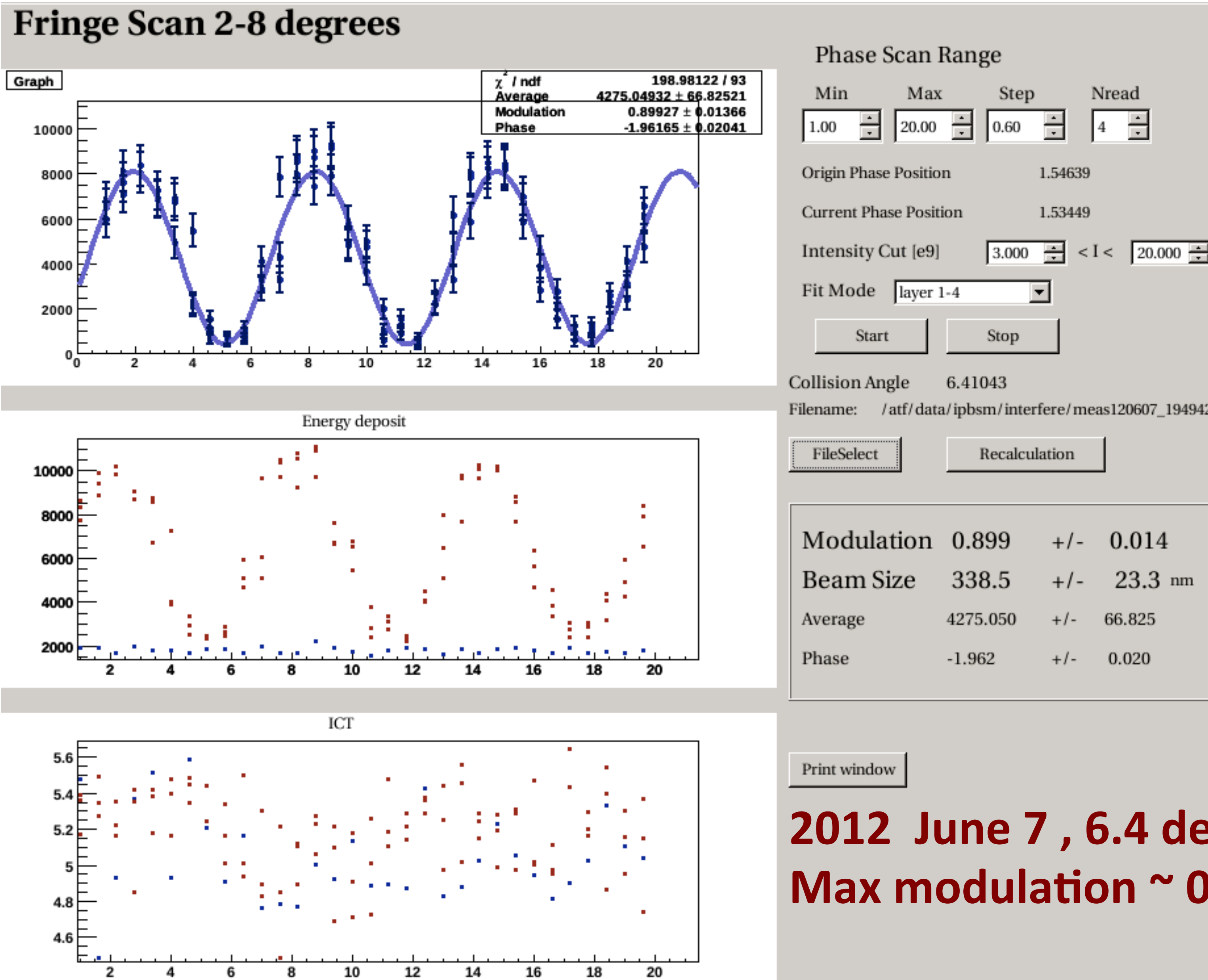
including **long range fine scan** (60 rad, Nav = 10)

M = 0.887 ± 0.005 (stat only) **σy = 589 ± 13 nm**

init. phase: -2.162 ±0.009 rad *phase drift ~ 18 mrad (~ 0.8 % only)*



Some other consistent fringe scans of 0.8 – 0.9 also at 6.3 deg mode



2012 June 7 , 6.4 deg mode

Max modulation ~ 0.9

What is the difference between Feb and June ??

Feb 2012:
- measured large M～0.8 at 4、8°
- 30° : easily measured
  M～0.5（σ～160 nm)

March – May:
many issues with IPBSM laser system and beam tuning

June :
- Measured M ～ 0.9 at 4°, 6.3°
- M ~ 0.35 at 30° （σ～250 nm)

Our current optics need major upgrades !!
→higher reliability ,consistency in path alignment and beam size measurements

(details coming up in next talk)

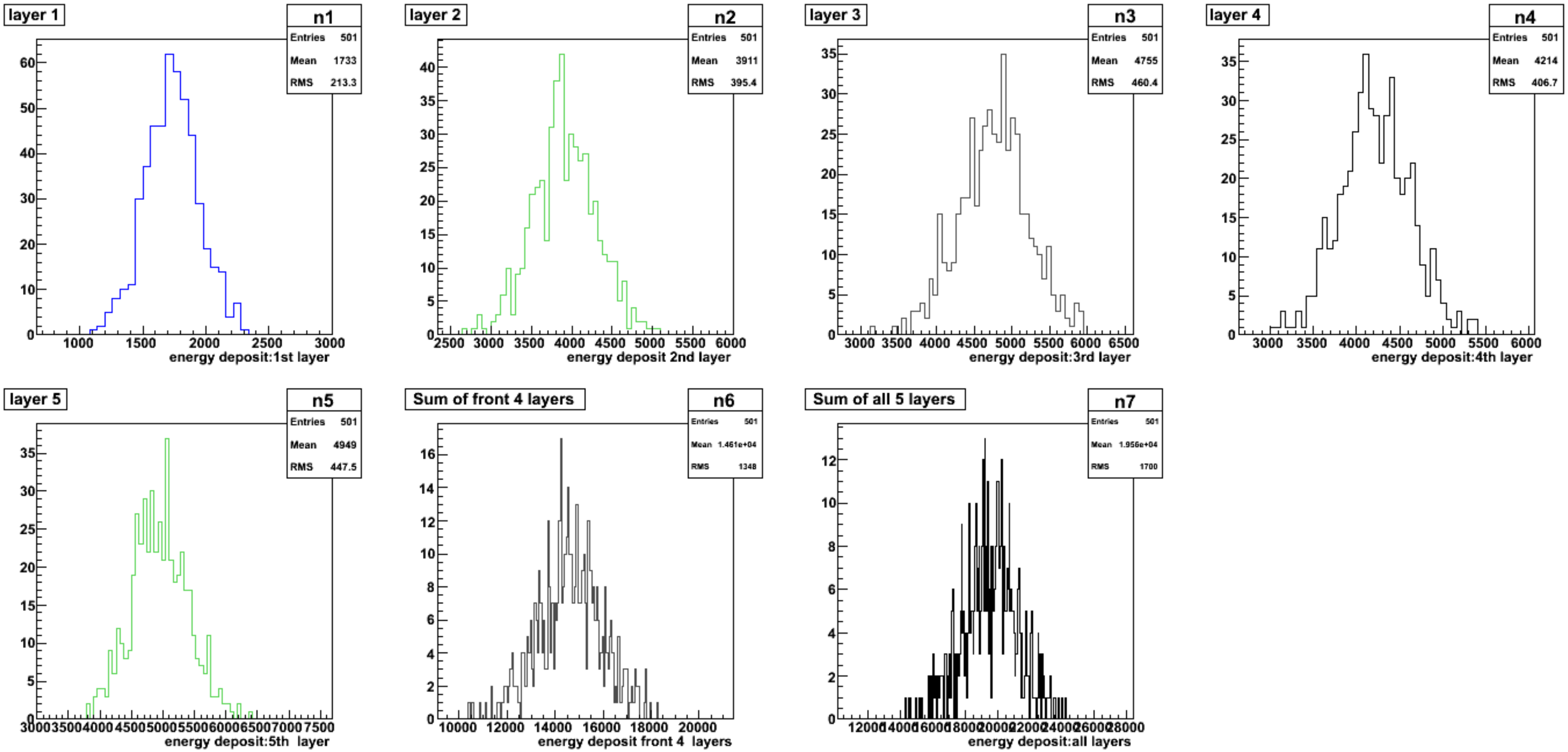
S/N
0.7 ~ 1 for 10x1
1 for 10x3
2.5 for 10x10

Any difference in signal jitters??

	2012		Sig jitter(%)
June	30 deg	10x1	6/10: **9.3%** 6/14: **10.5%** (M ~ 0.9)
	6.3 deg	10x1	6/13: **8.9%**
Feb	30 deg	2/17: 10x10 2/23: 10x3	2/17: **14.6%** (1st 30 deg detection) 2/23: **10.4%**
	174 deg	10x3	2/24: **6.1%**
	8 deg	10x3	2/21: **10.5%** (M ~ 0.8)

energy deposit in detector (each of 5 layers + total)
Errors appear Gaussian distributed

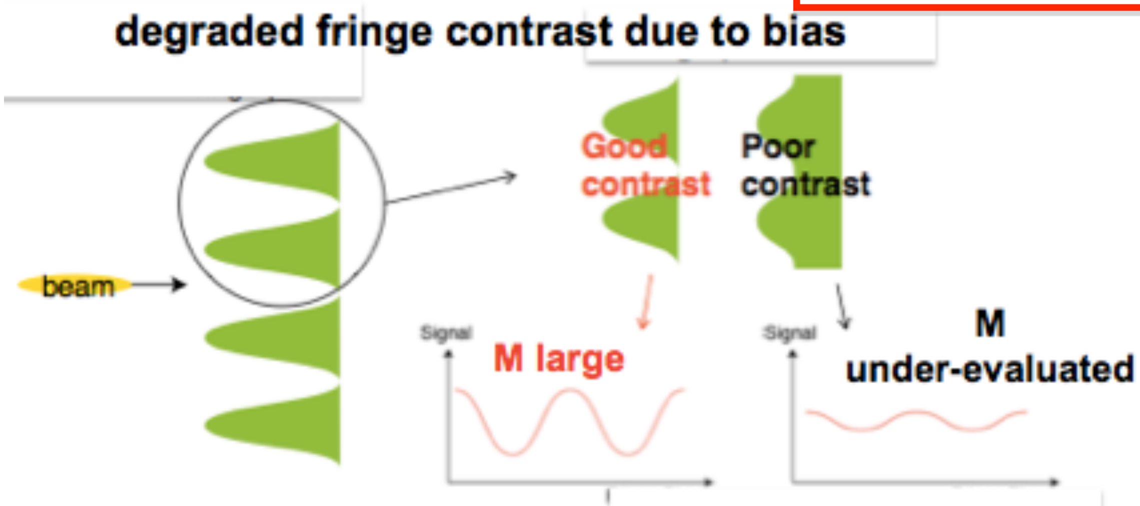
6/10 30 deg mode



Error studies

Modulation Reduction Factors (syst. Errors)

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



σy* over-evaluated

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

- **can $\sigma_{y,meas}$ be reproduced during mode switching?**
- **how large M can be measured ??**

Syst. Error studies at lower modes:

ex1) 2/21 switched from 8 deg (M_{meas} ~ 0.8) to 4 deg mode
σy∗ ~ 400 nm should give M ~ 0.94 , but **M_{meas} only reached 0.75**
→ **overall reduction factor** : **C ~ 0.8** (∴ 0.75 / 0.94)
could be worse ∴ 8 deg mode already limited by syst. errors

ex2) 6/14 M_{meas} ~ 0.35 after switching to 30 deg mode
σy∗ ~ 220 nm should give M ~ 0.98 at 4 deg mode, but **limited at M_{meas} ~ 0.9**
→ **overall M reduction factor** : **C ~ 0.9** (∴ 0.9 / 0.98)

Laser profile imbalance

due to …..

- **misalignment of focal point**
- **reducer setup → affect divergence**

Solutions during previous run:

- **Repeated optimization of lens / reducer setup**

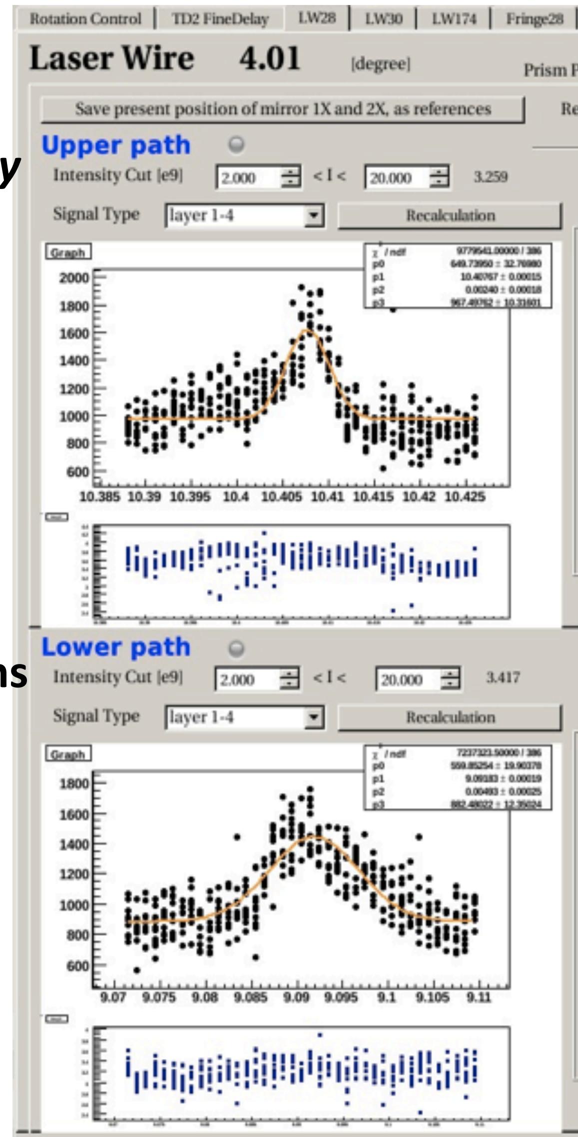
but hard to preserve consistency

- replaced damaged optics

Major optics reform this summer

(details in next talk)

- **Balance profile & path lengths**
- **focal lens alignment**
- Only use reducer for parallel propagation



example: 6/ 15
10 avg laserwire scan

signal amount different by factor of 2 !!

Upper:
- **σlaser = 19.2 μm**
- energy/ICT = 649.7
- (peak x sigma = 12474)

Lower:
- **σlaser = 39.6 μm**
- energy/ICT = 559.8
- (peak x sigma = 22168)

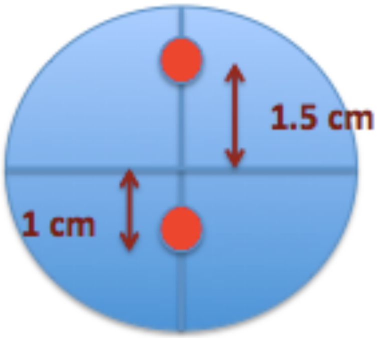
Ct,pro > 94 %- 99 %

assuming similar z-profile

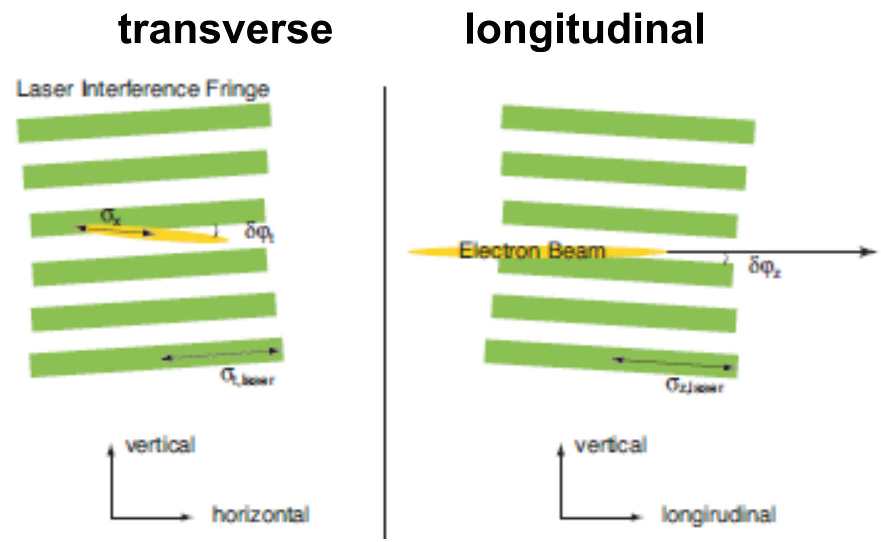
Cz,pro > 89%

Fringe Tilt

alignment precision ;
Δy, Δz (relative offset) :typically 2- 5 mm



$$\delta\varphi = \arctan\left(\frac{\Delta y}{2f\cdot\sin(\theta/2)}\right)$$

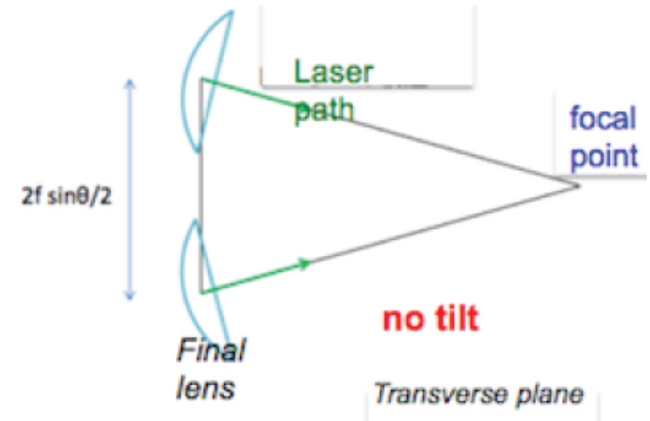


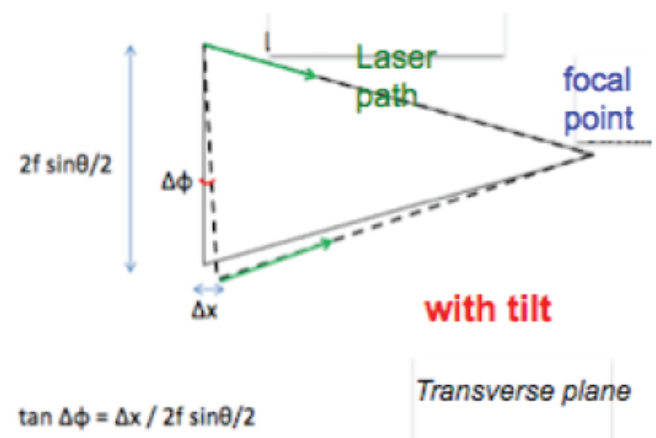
- *σx* impact transv tilt: (currently ~ 8 - 10 μm*
- *σlaser impact z tilt: (currently ~ 10 - 20 μm)*
- Also related to beam rotation → coupling optimized

assume

Δ y, Δz = 3 mm , σx ~ 8 μm、 σlaser ~ 15 μm

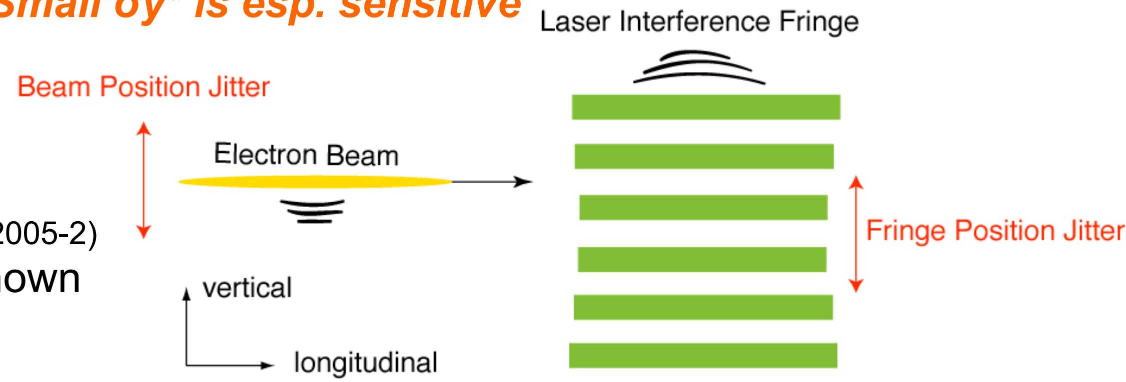
	4 deg	30 deg
(ϕt, Ct,tilt)	(29 mrad, 98%)	(19 mrad, 65%)
(ϕz , Cz, tilt)	(6 mrad, ~100%)	(5 mrad, 90%)



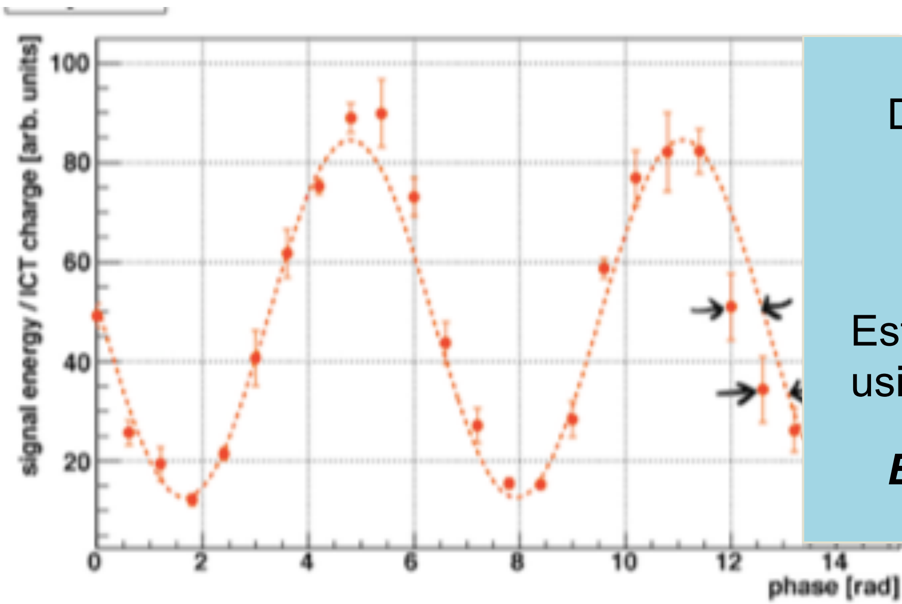


Relative position jitter (phase jitter)

Small σy* is esp. sensitive



- $\Delta y \sim 0.3\,\sigma_y$ along beamline,
(B.I. Grishanov et al., ATF2 Proposal, KEK Report 2005-2)
- but beam position Δy^* at IP is unknown
→ need measurement by **IPBPM**



Difficult to extrapolate / synchronize data from upstream BPMs

Estimate **worst limit of Δα** from phase offset using comparatively stable modulation scans

Examples of worst limit on Δα (Feb 2012) :

	4 , 8 deg (2/21)	30 deg (2/17)
Δα (Δy)	< 310 mrad (←→ 200-300 nm)	< 380 mard (←→ 60 nm)
Cphase	**> 95%**	**> 93%**

could be a major error source

consider phase monitor
or install profile monitor

Estimated systematic errors from June beam time : (using data from 4 deg , M ~ 0.9)

Error types	Modulation reduction
Laser profile imbalance	**Ct,pro > 94%** **Cz,pro > 89%**
Fringe tilt	**Ct,tilt > 98%** **Cz, tilt ~ 100%**
Phase jitter (←→relative pos. jitter)	Cphase > 95%
Laser path alignment	z : > 99.5% t : ~ 100%
polarization	Confirmed to be nearly pure S polarized
Total	**Ctot > 77%**

Note:
these are "**worst limits** " of M reduction factors

Estimated systematic errors from Feb beam time data

Current status	M reduction factors	$\sigma_y^* \lesssim 300$ nm 4 deg	$\sigma_y^* \lesssim 300$ nm 8 deg	$\sigma_y^* \simeq 160-200$ nm 30 deg
polarization	$C_{pow-pol}$	$\sim 98\%$		
relative pos. jitter	$C_{rel-pos}$	$> 95.3\%$	$> 95.2\%$	$> 92.9\% >$
laser path alignment	z: $C_{z,pos}$	$> 99.5\%$		
	t: $C_{t,pos}$	$\sim 100\%$		
laser profile imbalance	t: $C_{t,profile}$	100 %	$> 99.0\%$	$> 99.9\%$
	z: $C_{z,profile}$			
Fringe tilt	t: $C_{t,tilt}$	96.6%	96.8%	79.8%
	z: $C_{z,tilt}$	100 %		
Total	$\prod_i C_i$	$> \mathbf{89.7\%}$	$> \mathbf{88.9\%}$	$> \mathbf{72.1\%}$

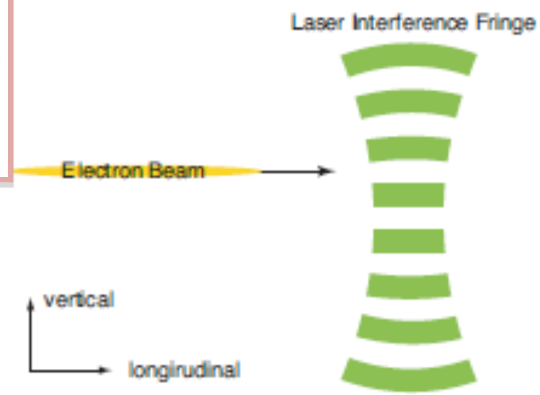
Major syst. errors appear to be

- **relative position jitter (phase jitter)**
- **Fringe tilt:** → improve alignment, tune σ*x smaller , beam coupling / rotation

σy at 30 deg mode may have been much smaller than 200 nm (??!!)*

Note) Not yet adequate data to evaluate all error types

Syst. Errors specific to 174 deg

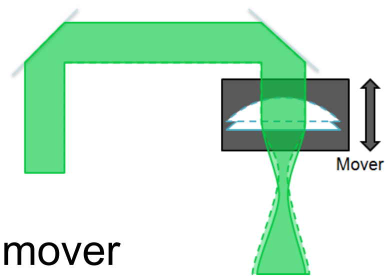


Spherical Wavefront

beam offset vs laser waist

→ distorted fringes

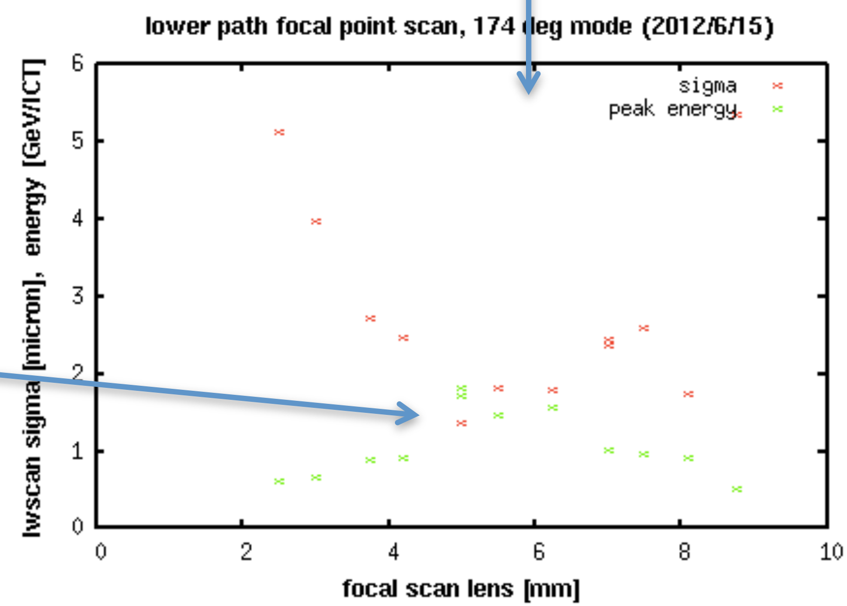
Csphere > 99.7 %



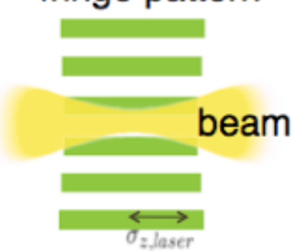
mover
attached to final lens
(stroke 30 mm, res. = 0.1 μm.)

Focal scanner
→ align focal point to IP
expected precision:
< 9% of Rayleigh length Z_R

Waist ω0 ~ 17 μm
Z_R ***~ 2.5 mm***
M2 ~ 2 (?)



fringe pattern



Change of σy* within fringes

due to strong focusing,
Cgrowth ~ 99.7%

Fringe tilt should not be concern with precise alignment

Small σy* is more sensitive to relative position jitter

Current status of laser system

relative timing	Stabilized by **timing scans** **TDC, TD2** modules
Intensity	• **Stability ~ 1%** • optics damaged by high intensity laser in March • Safe at ~ **40% power** for now
Oscillation	**currently stable** •**exchanged flash lamps and seeder** • **cavity mirror tuning**
profile	Triangular (**non-Gaussian**) profile at IP **dark spots** →Improved by **rear mirror tuning**
Major upgrades in laser optics	• **Beamlok** • new laser table box • additional mirror for **precise injection onto vertical table** • changed **reducer and expander lens** (AR coating , magnification)

Stat errors

Laser timing	**1 - 3 %**
Laser intensity	**1.5%**
Beam intensity jitters	**ICT monitor resolution: 2-5%** (Measured energy is normalized by ICT)
Laser pointing stability	**10 ~ 15%**
Beam position jitters	unknown

Summary

Beam time Status

Feb

- **Commissioned 30 deg mode :**
  stably measured M ~ 0.55, $\sigma_{y,meas}$ ~ 160 nm
- **174 deg mode: M maybe detected**

March - May

- **System checkup**
  & treat many issues in laser optics and beam tuning

June

- **M ~ 0.35 ($\sigma_{y,meas}$ ~ 220 nm) at 30 deg mode :**
- **174 deg mode: focal point scan**

Systematic Error studies

- **measured M ~ 0.9 consistently at 4 deg / 6 deg modes**
  Upper limit : **C ~ 0.8 - 0.9** *(depend on condition)*
- Major errors: **profile imbalance, fringe tilt,** phase jitter (?)

Stable system important for suppressing stat. errors

Goals and Plans for summer upgrades and 2012 autumn run

- as an effective beam tuning device ……
  accurately reproduce beam sizes in between mode switching

- 174 deg mode
  Commissioning + consistent M-detection
  accurately measure σy* < 100 nm

- resolve and accurately evaluate systematic errors
  including bias factors intrinsic to 174 deg mode

•Need to upgrade
to a more stable and reliable laser optical system

➔ more details on new IPBSM setup coming up

BACKUP

Impact of of beam jitter

Systematic errors (morning session)

•**relative position jitters** as laser fringe phase is scanned against beam

→ smear M curve → over-evaluate σy*

• **accurately measure beam jitter to correct M_{meas} (σ_{meas})**

Statistical errors :

•**Beam jitter along beam line** → extra BG, lower S/N, fluctuating BG levels

•**Beam jitter at IP** : dominate signal jitter source → hinder M detection

cause laser intensity "felt" by beam to fluctuate pulse-by-pulse

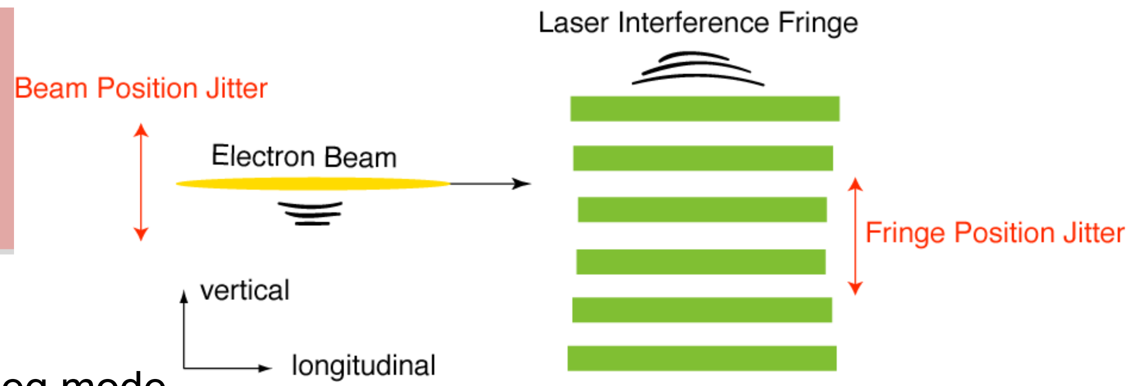
large phase jitters correlated with heavy signal jitters

•Feedback correction to suppress beam jitter

What causes beam position jitter ??

•magnet vibrations , unstable extraction from DR, ect…..

Relative position jitter
→ Translate to phase jitter Δα
(morning Goal I session)



If assume in general: **Δy ~ 0.3 σy**

←→ max. Δα ~ 250 mrad for 174 deg mode

small σy* sensitive

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

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

Evaluate max. Δα from beam time data → translate to Δy

	fringe scans in 2011	2/21 (4 deg)	2/21 (8 deg)	2/17 (30 deg)
phase jitter	$\Delta\alpha$ [mrad]	< 310	< 316	< 384
rel. pos. jitter	Δy [nm]	< 376	< 192	< 62.9
syst error	C_{phase}	> 95.3 %	> 95.2 %	> 92.9 %

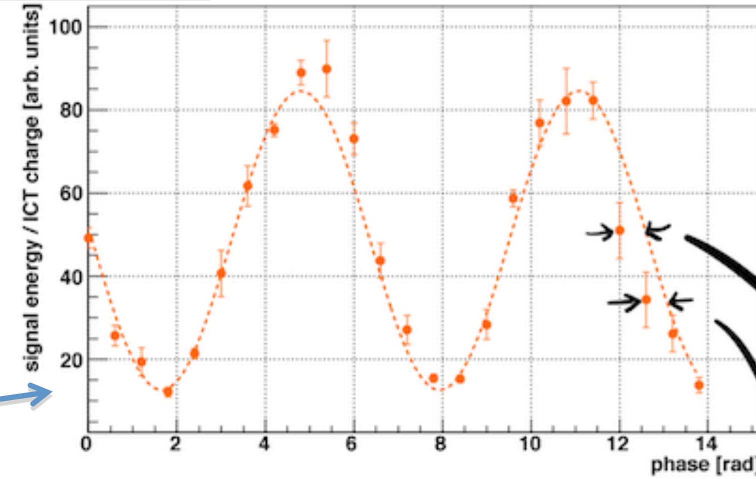
Relative position jitter
➔Beam and laser

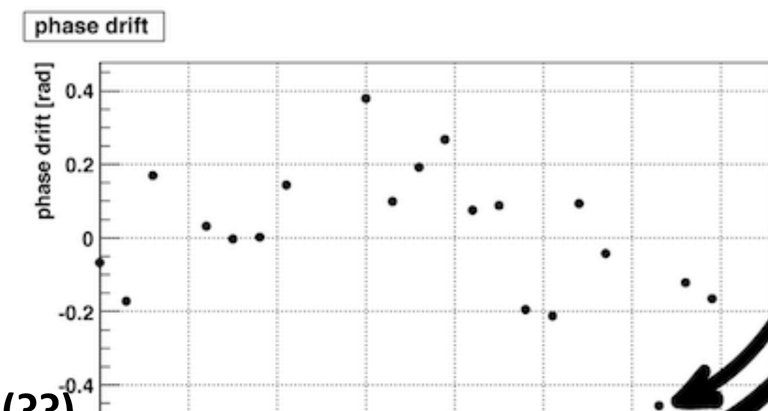
- In general: $$\Delta y = \sqrt{\Delta y_e^2 + \Delta\alpha^2}$$.

beam pos. jitter at IP “Δye” phase jitter “Δα”

- Δye unknown (→ IPBPM ??)

→ **Use M plot to derive “worst Δα”**





Small σy* is more sensitive to relative pos. jitter at IP

IPBPM : **feedback correction**

expect **Δy ~ 0.3 σy**

(B.I. Grishanov et al., ATF2 Proposal, KEK Report 2005-2)

Requirement on IP-BPM resolution : < Δy / 3 (??)

	4 deg	8 deg	30 deg	174 deg
typical σ_y^*	800 nm	500 nm	100 nm	40 nm
$\Delta y \lesssim 0.3\,\sigma_y$ at IP	< 240 nm	< 150 nm	< 30 nm	< 12 nm
$\Delta\alpha$ [mrad]	< 200	< 250	< 180	< 280
C_{phase}	> 96.2%	> 94.1%	> 96.7%	> 92.3 %
IPBPM res. ($\lesssim \Delta y/3$)	< 80 nm	< 50 nm	< 10 nm	< 4 nm

Relative position jitter
➔Beam and laser

$$\Delta y = \sqrt{\Delta y_e^2 + \Delta\alpha^2}$$

if Δye ~ 0.3 σy is actually achieved

we can estimate (worst limit for) lase- related phase error alone , due to ……

✓vibration of optical components

✓ final lens focal point misalignment

ΔL : incoherent laser path jitter per path :

→ optical path delay fluctuation : sqrt(2)* ΔL

➔ **phase jitter $\Delta\alpha = k_y$*sqrt(2)*ΔL**

fringe scans in 2011	2/21 (4 deg)	2/21 (8 deg)	2/17 (30 deg)
Δy [nm] (from M plot)	376	190	63
Δy_e [nm]	< 135	< 65	< 45
"real" $\Delta\alpha$ [mrad]	289	294	289

about same for each mode

◆ BPM Caliberation Stability : (a few weeks time scale)

C-band BPMs : 1% level S-band BPMS : 5% level

IPBPM, unknown

Expectations for BPMs

For resolution of 174 deg mode:

$$37 \pm 1.4\,(stat)^{+0}_{-2}\,(sys)\ \mathrm{nm}$$

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

(ex:)) if $\Delta y = 4$ nm: $\sigma y^* \rightarrow 37 \pm 2$ nm

For beam stabilization with feedback

$\Delta y <= 0.3 \times \sigma y$

- 174 deg mode : 10 nm stability at IP → IPBPM resolution few nm
  (< 100 nm for other modes)
- much larger σy* upstream, 100 nm enough to show stable beam

Can also use other BPMs (Pre-IP, PIP) to reconstruct beam position, angle, resolution !!

IP-BSM Goal: fully commission 174 deg mode ➔ stable measurement

Now: O(10) nm beam position stabilization

Soon: few nm resolution feedback correction for accurately measuring σy* < ~50 nm

“Full” data for IPBSM

combine former meas and raw data
+ extra slots for beam monitors

all BPMs

now

```
array(0-199) IPBSM:Interfere:Raw
array(200-1199) ATF2:monitors
array(1200-1239) IPBSM:Interfere:Meas
array(1240) timing gap between ATF2:monitors' p
```

need BPM data to be put into these PVs

Correlate beam pos. jitter with IPBSM signal fluctuations

IPBSM:Interfere:Raw (200 length float array) (read only)

Interference mode measurement raw data

```
array(0) Laser Crossing Angle [deg]
array(1) Laser Fringe Pitch [nm]
array(2) Laser Fringe Phase [rad]
array(3) Laser Fringe Phase Read [rad]
array(4-19) Detector ADC array(0-15)
array(20-35) Detector ADC Pedestal array(0-15)
array(36-40) Background Shower array(0-4)
array(41-45) Compton Signal Shower array(0-4)
array(46-69) Detector HV array(0-23)
array(70-101) Scan ADC array(0-31)
array(102-133) Scan ADC Pedestal array(0-31)
array(134) TD2 Laser Timing
array(135) TDC Full Scale Range
array(136-143) TDC array(0-7)
array(144) ICT-DUMP Charge [10^9 e-]
array(145) BPM1 X Position
array(146) BPM1 Y Position
array(147) BPM2 X Position
array(148) BPM2 Y Position
array(149-164) Charge ADC array(0-15)
array(165-174) Image Sensor 1 FT array(0-9)
array(175-184) Image Sensor 2 FT array(0-9)
array(185-199) Spare
```

before

Estimating Statistical Errors (Feb, 2012):

- **Laser intensity < 1%**
- **Relative beam-laser timing < 1%**
- **Beam current < 3%**

Altogether less than 5 % to stat. errors

Example: 174 deg	Laser intensity	Beam current	timing (jitter [ps])
00:06	**0.6%**	**2.6%**	**0.8%** (426 ns)
3:12 (2/23 10 x 3 optics)	**0.8%**	**4.8%**	**0.6%** (386 ns)
7:23	**0.7%**	**2.2%**	**0.8%** (452 ns)

Comparing typical beam time conditions

		S/N	BG [GeV]	Sig. jitter	iCT [10^9 e-]
Spring, 2012	10x βy^*: 3 x βy^*: 1 x βy^*	**4** **1** **0.5**	**5** **15** **20**	**10 - 20%**	4 - 6
Dec, 2011 Post-earthquake recommissioned 2- 8 deg mode	2.5 x βy^*	**1-2**	**50**	**15-25%**	5 - 7
Dec , 2010 Unstable era, large sig. jitters	1 x βy^*	**0.5**	**115**	**25 – 30 %**	2 - 3
May 2010 8 deg : σy^* ~ 300 nm	10x βy^*:	**5-10**	**20**	**10%**	4 -5

BG: stable :10 – 15 %
unstable : 20 – 30 %

ICT: stable : 2 -3 %
unstable: > 7 %

<< S/N ratio>>

- S/N (in front layers) about

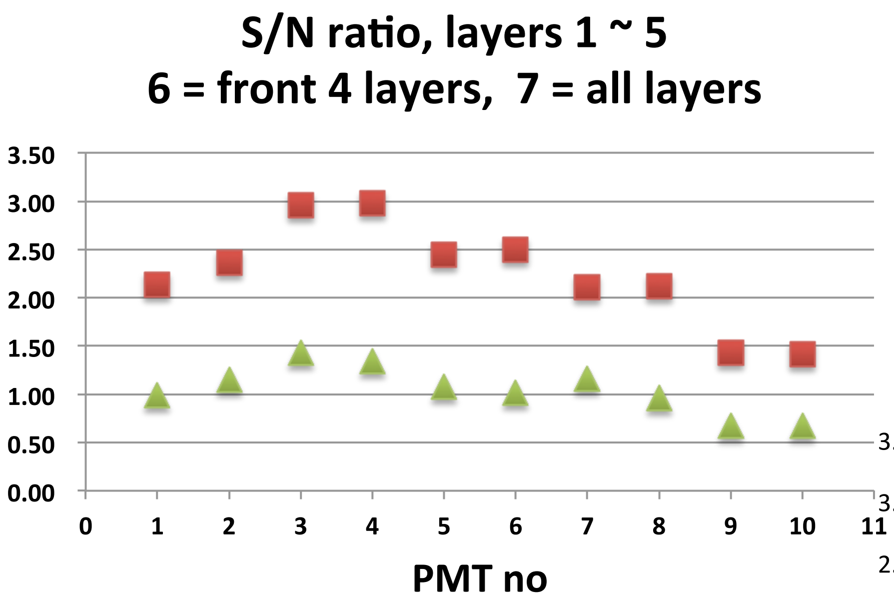
  { 2.5 – 3 for 10 x beta_y} vs {1-1.3 for 3 x beta_y }

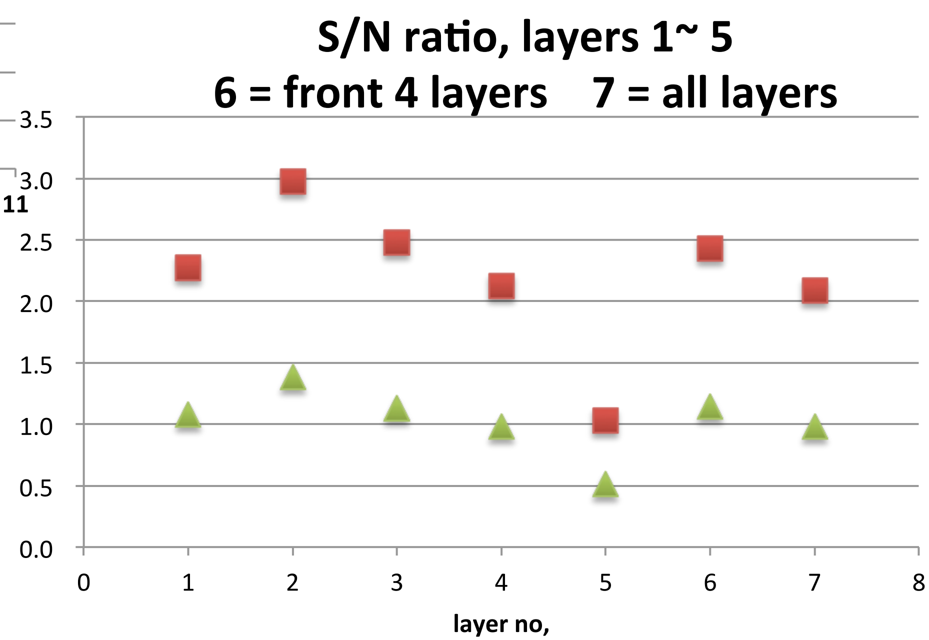
  about 2 times difference

S/N ~ 0.5 for nominal beta_y (???)

10x beta_y optics: :
(30 deg mode, 12/17)

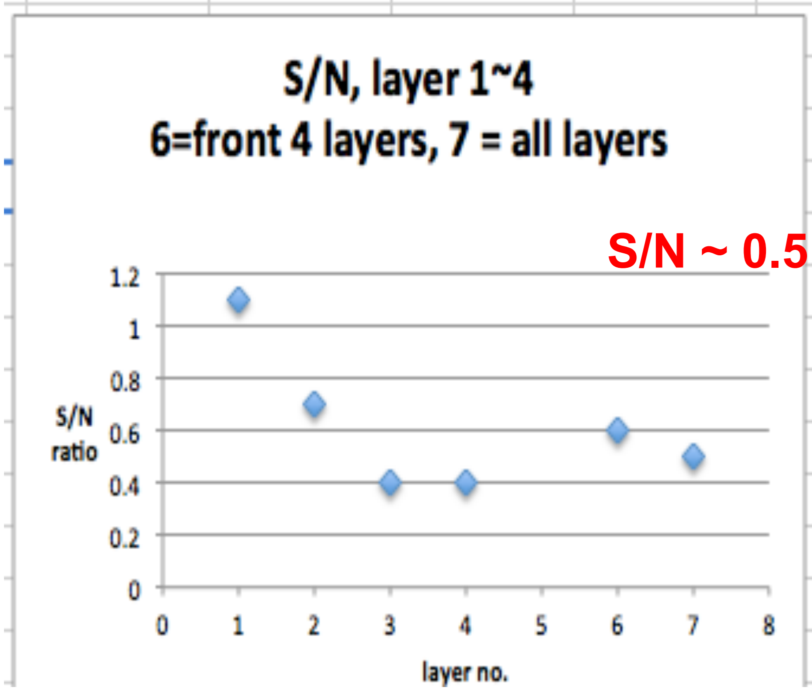
3 x beta_y optics
(30 deg mode, 2/21)

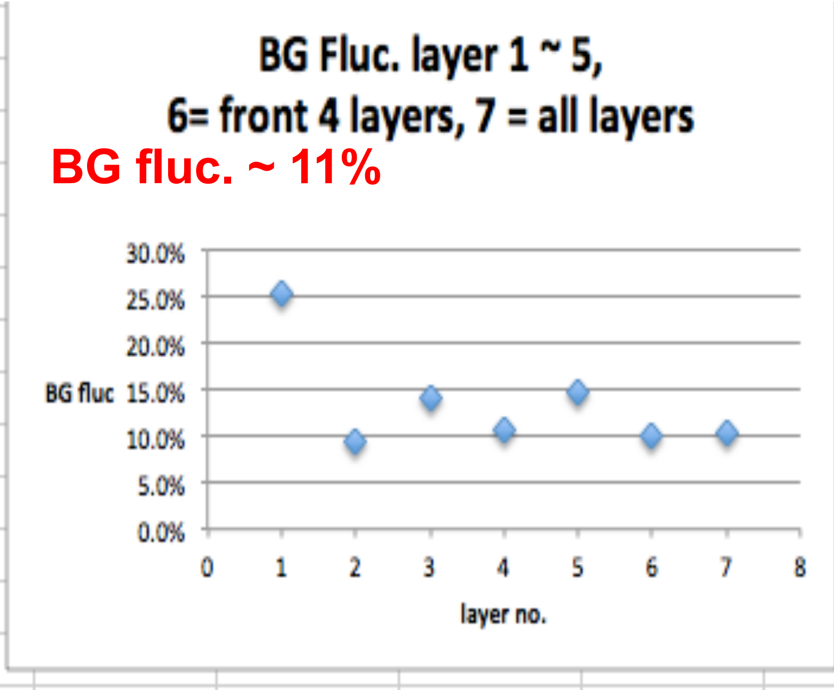




2nd layer and
front 4 layers
have highest S/N

1x beta_y optics: (3/8) 30 deg





S/N ratio decreased to about 0.5 for nominal beta_y

{ 2.5 – 3 for 10 x beta_y} ,
{1-1.3 for 3 x beta_y }

Requirements / goals for beam time conditions

Parameters	Requirement / goals
Beam position	**$\Delta y < 0.3 \times \sigma y$ along beamline → affect BG, S/N, sig. jitters** **few nm stabilization for 37 nm**
BG energy	**suppress fluctuation**
S/N	**> 1 (at least > 0.5 even under nominal β)**
Sig. jitter	< 20 % -for M detection aim for < 10% for measurement precision
Laser spot size At IP	10 – 15 μm ***high intensity at IP important for S/N, need compromise reducer setting with safety of optical components***
Laser pointing stability	< 1 μm @ IP (< 50 μm @ other upstream PSDs)
Beam current	~ 6 x 10^9 / bunch , fluc < few%

Estimating laser pointing stability at IP for 174 deg mode:

Δ = 15.4 μm

assume most of signal jitter 21% is attributed to laser pointing jitter

laser wire scan signal: $E_{sig} = E_{\max} \exp\left(-\frac{(x-x_0)^2}{2\sigma_{laser}^2}\right)$

signal jitter: $E_{sig} \to E_{sig}^{*} = E_{sig} + \Delta E$

laser pos. jitter at IP: $\Delta \mathrm{x}$

lwmon data taken at laser peak : $\left|\frac{E_{sig}^{*}}{E_{sig}}\right| = \exp\left(-\frac{\Delta x^2}{2\sigma_{laser}^2}\right)$

for 174 deg: ΔE/E ~ 21% , $\sigma_{laser} \sim 25\ \mu\mathrm{m}$

$\therefore\ \Delta x = \sigma_{laser}\sqrt{2\ln(1.21)} = 15.4\ \mu\mathrm{m}$

phase drift
➔translate to **relative position drift**
between beam and laser phase

laser drift
←→ 2*ky * (relative pos. drift)

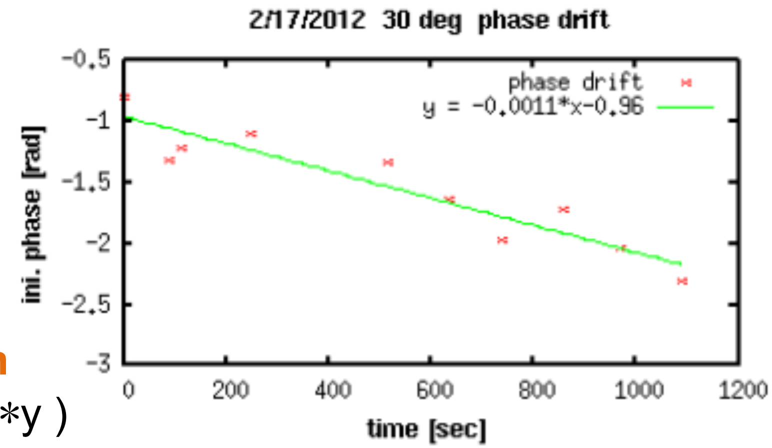
beam position drift
< few % of σy*

→ neglegible for now (??)

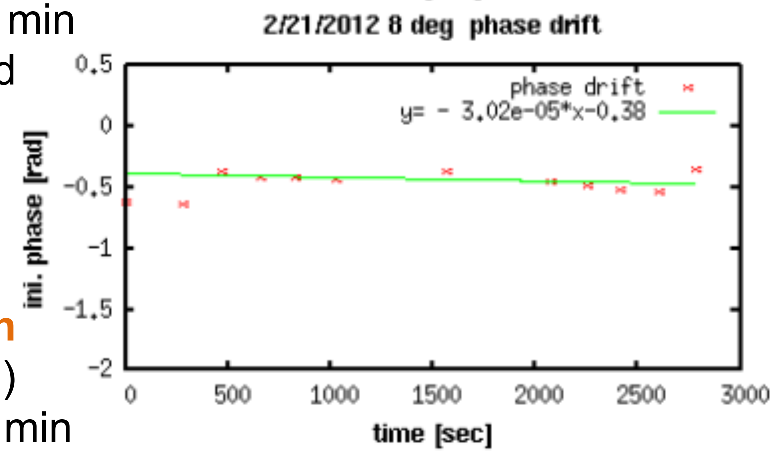
$$\mathbf{E_{sig} = E_{av} \{1 + M\cos(\alpha + \alpha_0)\}}$$

- Plot **initial phase α_0** against time
- typically drift 30 - 90 mrad per 1 min. scan

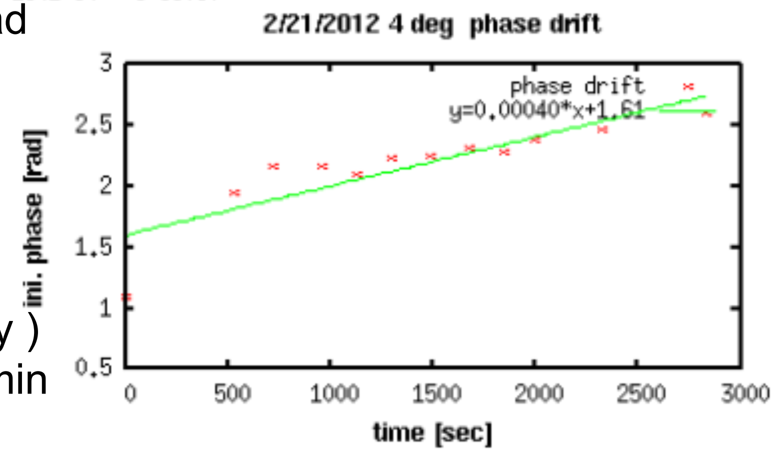
2/17 :
66 mrad/ min
(30 deg,10×β*y)
10 scans , 18 min
drifted 1.2 rad



2/ 21:
1.8 mrad/ min
(8 deg, 3×β*y)
11 scans , 46 min
drifted 84 mrad



2/21
24 mrad/ min
(4 deg, 3×β*y)
11 scans, 47 min



Less concerning syst. errors

Laser position offset
from IP (beam center)

→ not a concern,

mirror actuators finely adjust

to 1/10 of σlaser

long. : Cz- pos > 99.5 %

transv : Ct-pos ~ 100%

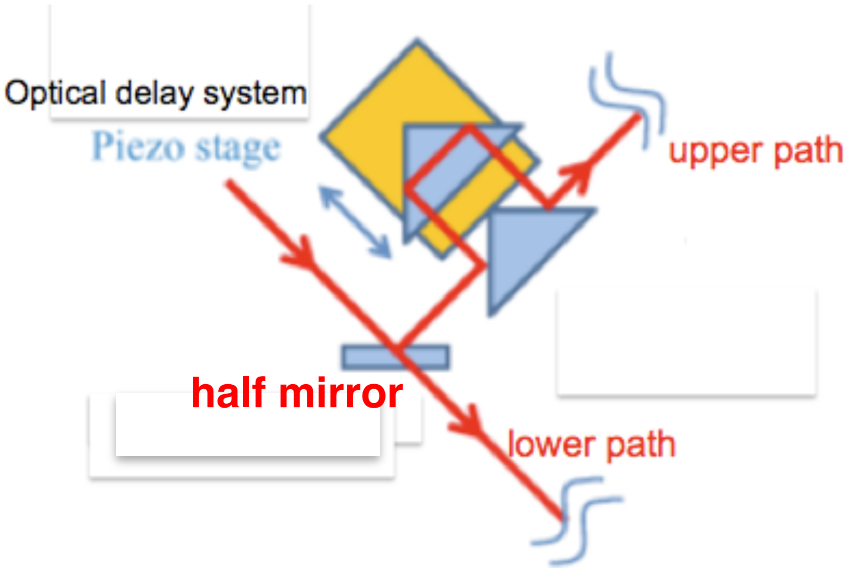
Polarization related errors

Impacts contrast with intensity imbalance

✓half mirror possess 50% reflection rate
only for pure S state

adjust to S state by rotating λ /2 wave plate

- **→ confirmed to be nearly pure S state**
- *maybe remains* **Cpol ~ 98 %**



Systematic errors : Fringe Tilt

transv : $\delta\varphi_t = \arctan\left(\frac{\Delta y}{2f \cdot \sin(\theta/2)}\right)$ long. : $\delta\varphi_z = \arctan\left(\frac{\Delta z}{2f}\right)$

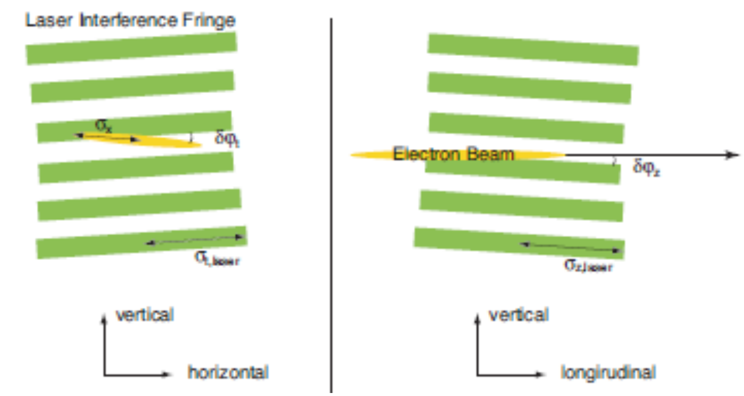
Table "tilt2" : bias due to fringe tilt expected from alignment precisions of $(\Delta y, \Delta z) = (3\,\mathrm{mm}, 1\,\mathrm{mm})$

expectation from alignment precision	8 deg ($f = 250$ mm)	30 deg ($f = 300$ mm)	174 deg ($f = 250$ mm)
$\delta\varphi_t$ ($\Delta y \simeq 3$ mm) [mrad]	85	19	6.0
$C_{t,tilt}$	95.4%	96.8%	95.3%
$\delta\varphi_z$ ($\Delta z \simeq 1$ mm) [mrad]	29	6.4	2.0
$C_{z,tilt}$	100%	99.8%	99.8%

aim for **alignment precision (Δy, Δz) ~ (1-3 mm, 1 mm)**

•Longitudinal tilt not a major concern
•*large σx* (currently ~ 10 μm) impact tranv tilt*

transverse **longitudinal**



Evaluation from beam time data

evaluated using actual data.	4 deg ($f = 250$ mm)	8 deg ($f = 250$ mm)	30 deg ($f = 300$ mm)
$\delta\varphi_t$ ($\Delta y \simeq 3$ mm) [mrad]	29	14	10
$C_{t,tilt}$	96.6%	96.8%	79.8%
$\delta\varphi_z$ ($\Delta z \simeq 1$ mm) [mrad]	4	4	3.3
$C_{z,tilt}$	100%	100%	100%

date	notes	Beta	M/ Beam size
4/12	6 deg **Seeder still very unstable**	**10 x 5**	M ~ 0.4 1 micron
4/17	6 deg	**10 x 5**	M ~ 0.6 780 nm
4/19 -20	6 deg **Exchanged seeder!!** Tuned mirrors Now Fringe scans became more stable	**10 x 1**	M ~ 0.45 1 micron
	30 deg • issues with beam timing jumps •**Unstable beam current and orbit**,tune resonance in DR • multiknob tuning not able to reduce beam size	**10 x 1**	~ 300 nm Difficult condition since M was small
4/26 -27	8 deg	**10 x 1**	M ~ 0.75 450 nm
	30 deg	**10 x 1**	M ~ 0.1 350 nm
	6 deg (system checkup)	**10 x 1**	M 0.5 – 0.7
5/16 - 18	• Exchanged Beamlok PZT mount, flash lamps • Laser system overall stable 7.3 deg **Unstable beam current and orbit**,tune resonance in DR	**10 x 1**	M : 0.25 – 0.45 Beam size > 850 nm

Systematic Errors estimated from actual beam time data

Current status	M reduction factors	$\sigma_y^* \lesssim 300$ nm 4 deg	$\sigma_y^* \lesssim 300$ nm 8 deg	$\sigma_y^* \simeq 160-200$ nm 30 deg
polarization	$C_{pow-pol}$	$\sim 98\%$		
relative pos. jitter	$C_{rel-pos}$	$> 95.3\%$	$> 95.2\%$	$> 92.9\% >$
laser path alignment	z: $C_{z,pos}$	$> 99.5\%$		
	t: $C_{t,pos}$	$\sim 100\%$		
laser profile imbalance	t: $C_{t,profile}$	100 %	$> 99.0\%$	$> 99.9\%$
	z: $C_{z,profile}$			
Fringe tilt	t: $C_{t,tilt}$	96.6%	96.8%	79.8%
	z: $C_{z,tilt}$	100 %		
Total	$\prod_i C_i$	$> \mathbf{89.7\%}$	$> \mathbf{88.9\%}$	$> \mathbf{72.1\%}$

Fringe tilt and phase jitters happened to be large for 30 deg scans
(*now practicing more precise path alignment*)
Even so was able to detect M at 30 deg → σy* was much smaller than 200 nm (??!!)

- total M reduction close to, but not agree with estimated upper limit C ~ 0.8
- **Not adequate data to accurately evaluate all error types** (ex:) Cpol > 98%, phase drift (few% ?)

largest syst. errors appear to be

- **relative position jitter (phase jitter)** → feedback correction of beam position
- **Fringe tilt:** → improve alignment, tune σ*x smaller (also issues of rotated beam , coupling) effects

Syst. Errors for 174 deg mode

Small σy* sensitive to relative position jitter

	expected	actual evaluation
174 deg mode	$\sigma_y^* \simeq 40$ nm , **nominal beta optics**	$\sigma_y^* \simeq 90$ nm , **10 x 3 beta optics**
	$\sigma_x^* \simeq 2.2\ \mu$m, $\sigma_{laser} \simeq 15\ \mu$m	$\sigma_x^* \simeq 11\ \mu$m, $\sigma_{laser} \simeq 15\ \mu$m
polarization $C_{pow-pol}$	99.8% (*)	adjusted to S polarization ellipticity not measured recently
$C_{rel-pos}$	> 98.0%	
laser position alignment ($C_{t,pos}$, $C_{z,pos}$)	($\simeq$ 100%, > 99.5%) fine alignment of O($\sigma_{t,laser}$ /10)	using 10 nm res. mirror actuators
profile imbalance ($C_{t,profile}$, $C_{z,profile}$)	(99,6%, 99.2%) assuming 1:1.2 balance	> 99.9%
tilt : ($C_{t,tilt}$, $C_{z,tilt}$)	(> 99.9%, $\simeq$ 100%)	nearly zero offset
C_{sphere}	> 99.7%*	
C_{grow}	99.7%	
C_{coh}	> 99.9%	
total $\prod_i C_i$	**> 95.4**	

Fringe tilt should not be concern if meet alignment precision

Some errors intrinsic to 174 deg mode
→ Special hardware upgrades (coming up)

Expected performance and resolution

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

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

Crossing angle θ	174°	30°	8°	2°
Fringe pitch d	266 nm	1.028 μm	3.81 μm	15.2 μm
Lower limit	25 nm	80 nm	350 nm	1.2 μm
Upper limit	100 nm	360 nm	1.4 μm	6 μm

Assuming ~ 4 % res.

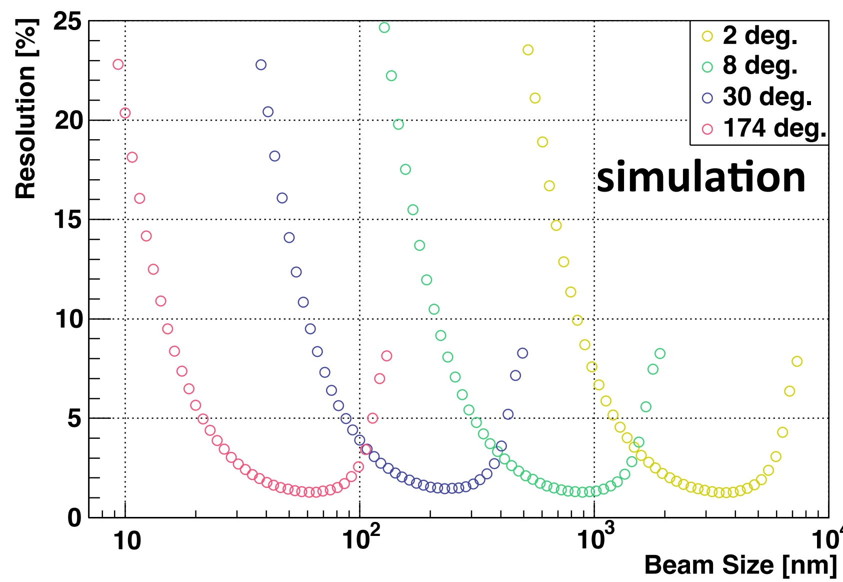
$37 \pm 1.4\,(\text{stat})\,^{+0}_{-2}\,(\text{sys})$ [nm]

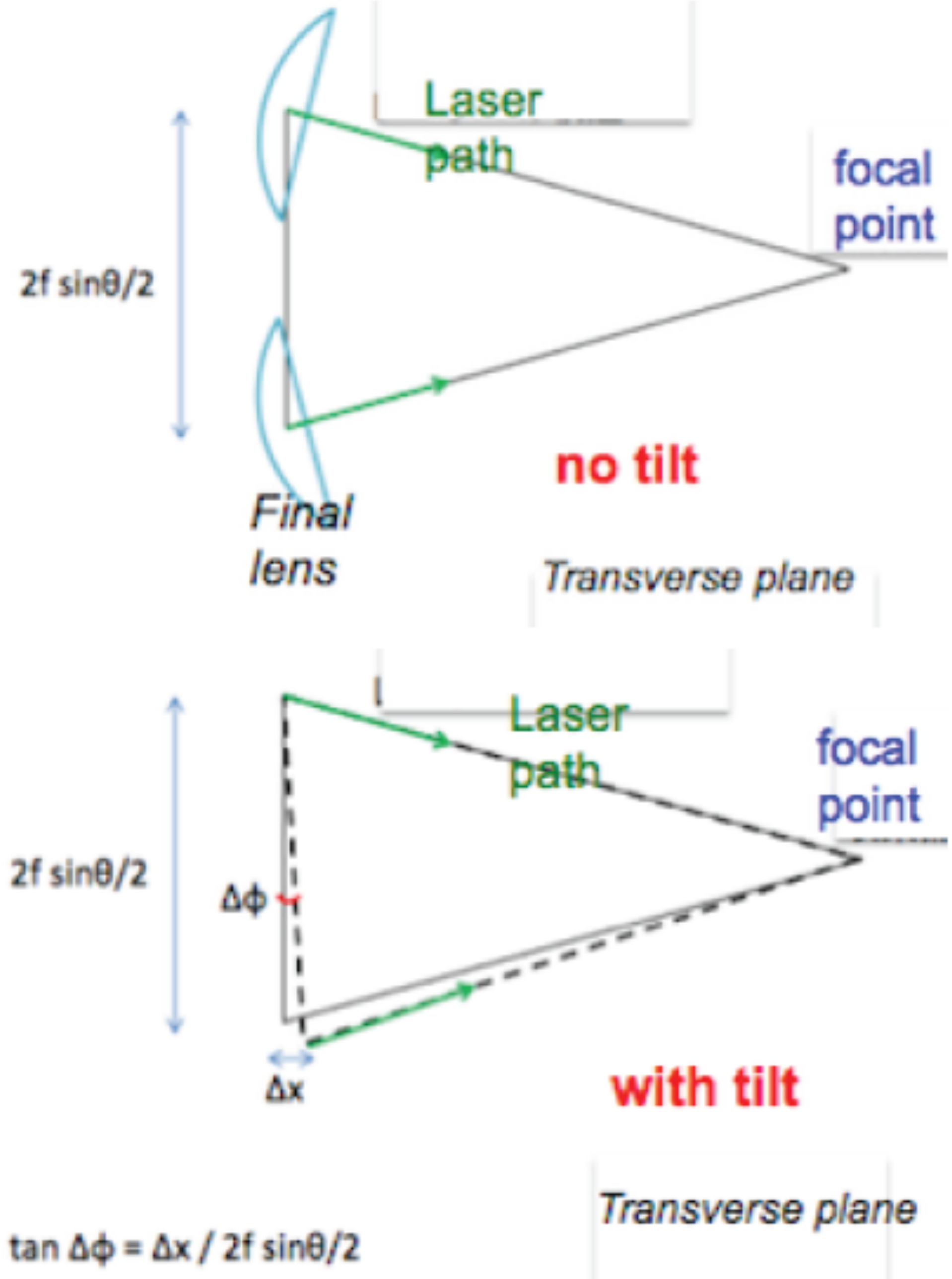
Resolution < 10% expected for σy 25 nm ∼6 μm

However…….

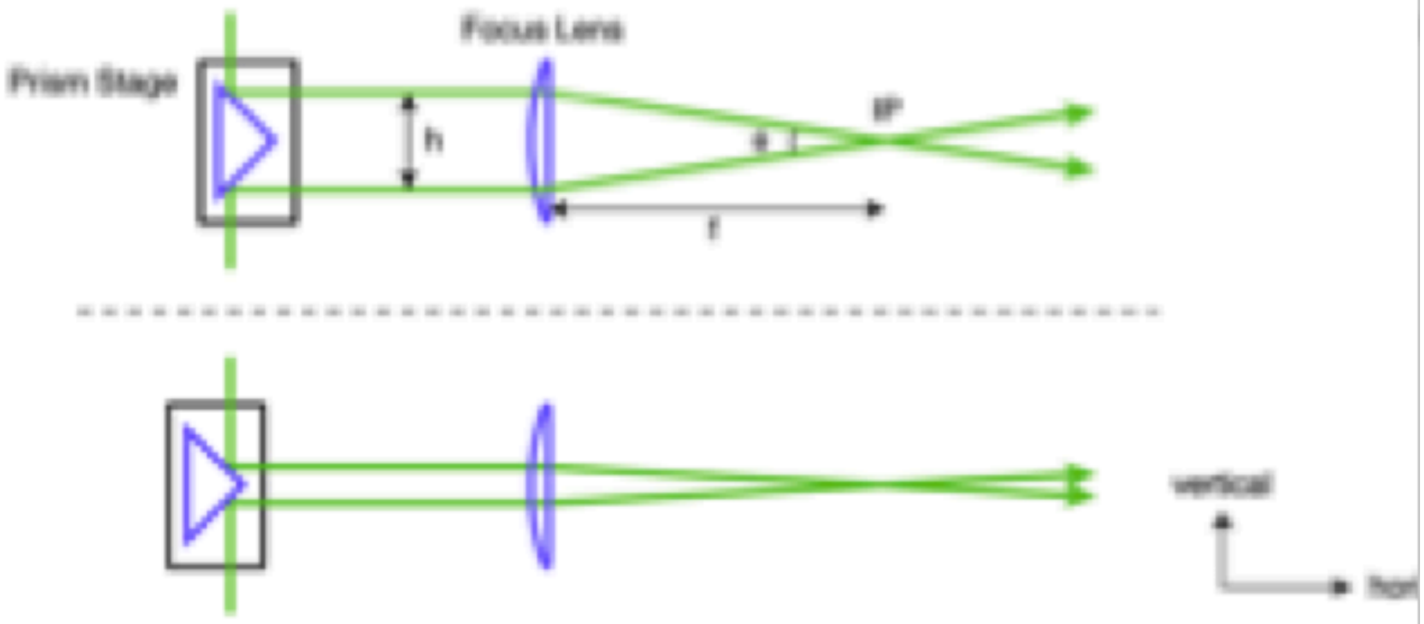
- **degraded for low S/N**
  ~ 15% in Dec, 2010

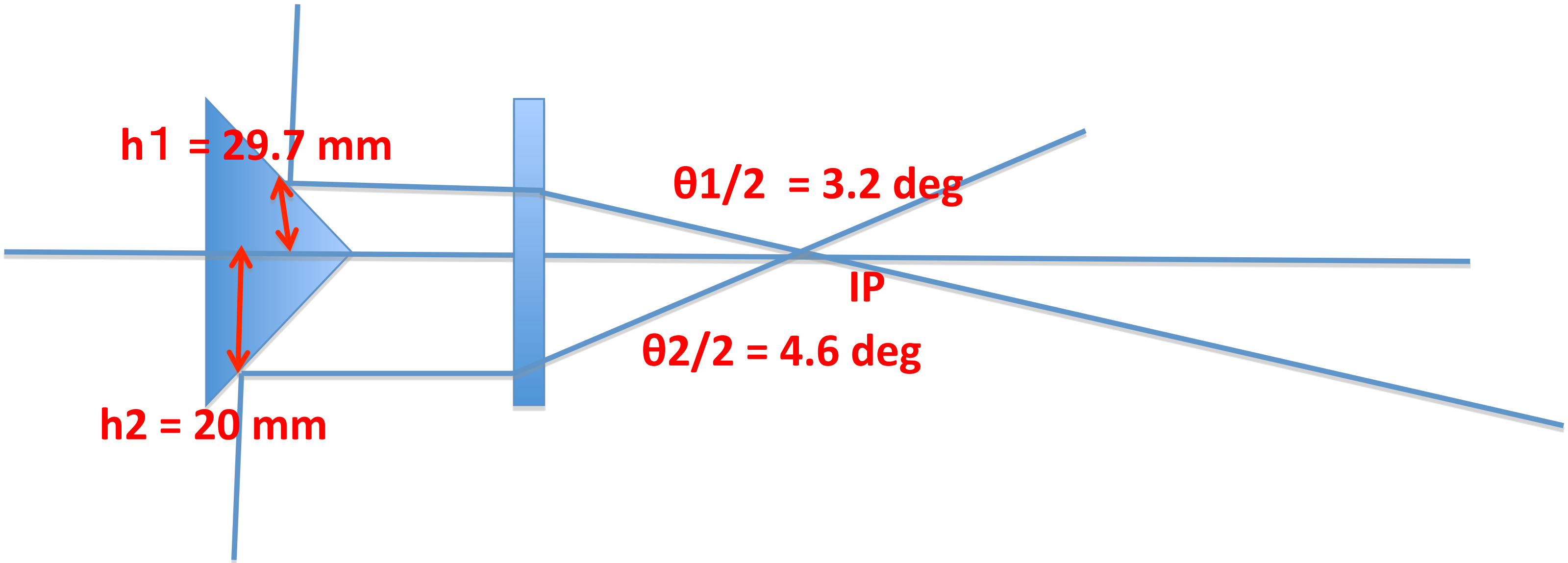
Resolution for each mode



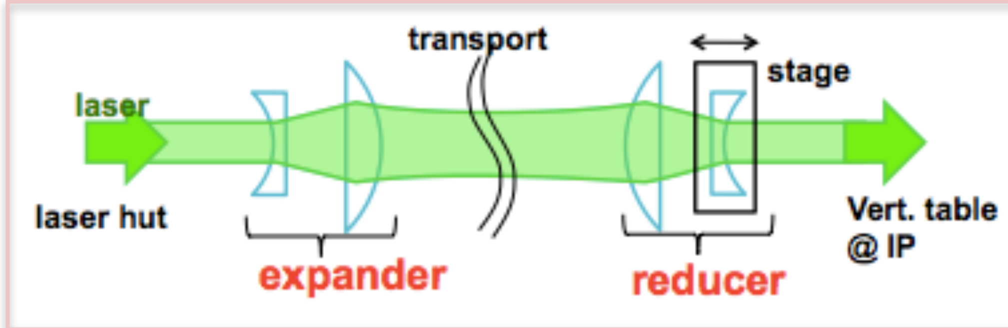


$\tan \Delta\phi = \Delta x / 2f \sin\theta/2$


Prism Stage
Focus Lens
h
IP
f
vertical

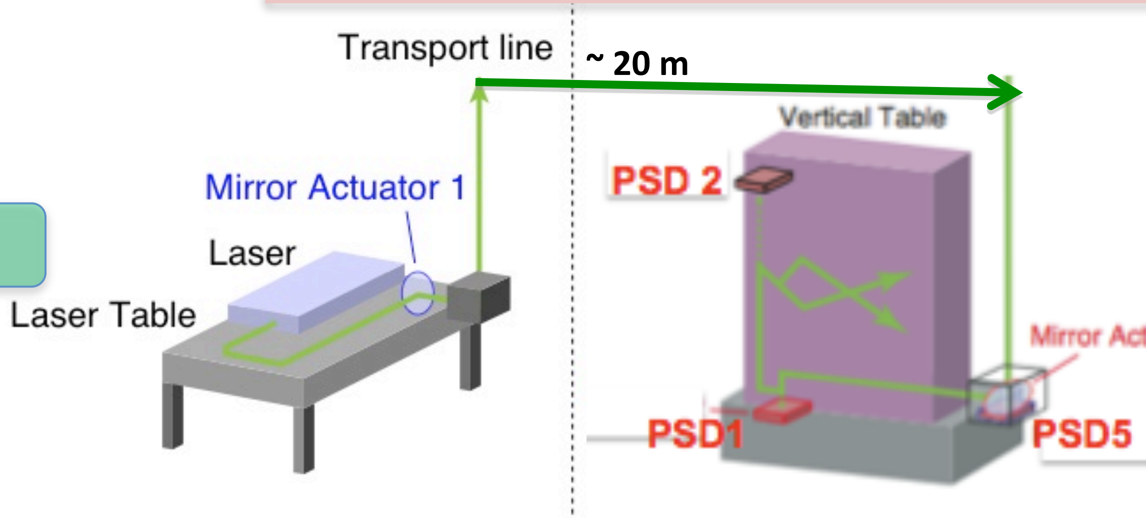

h1 = 29.7 mm
θ1/2 = 3.2 deg
IP
θ2/2 = 4.6 deg
h2 = 20 mm

レーザー光学系



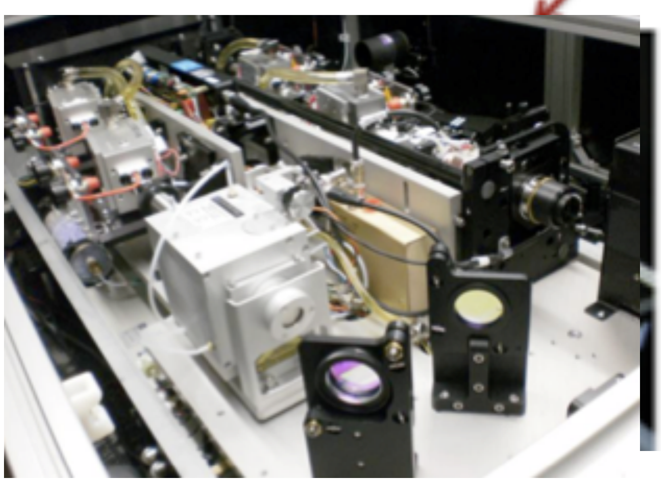
レーザー定盤

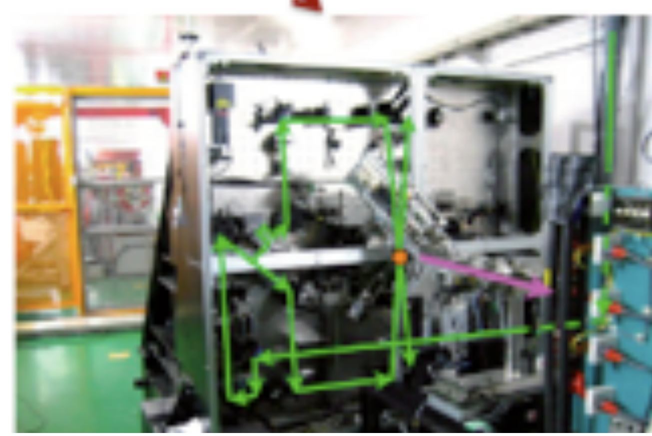
-- Laser 源
-- 運送前の状態
を調整・監視



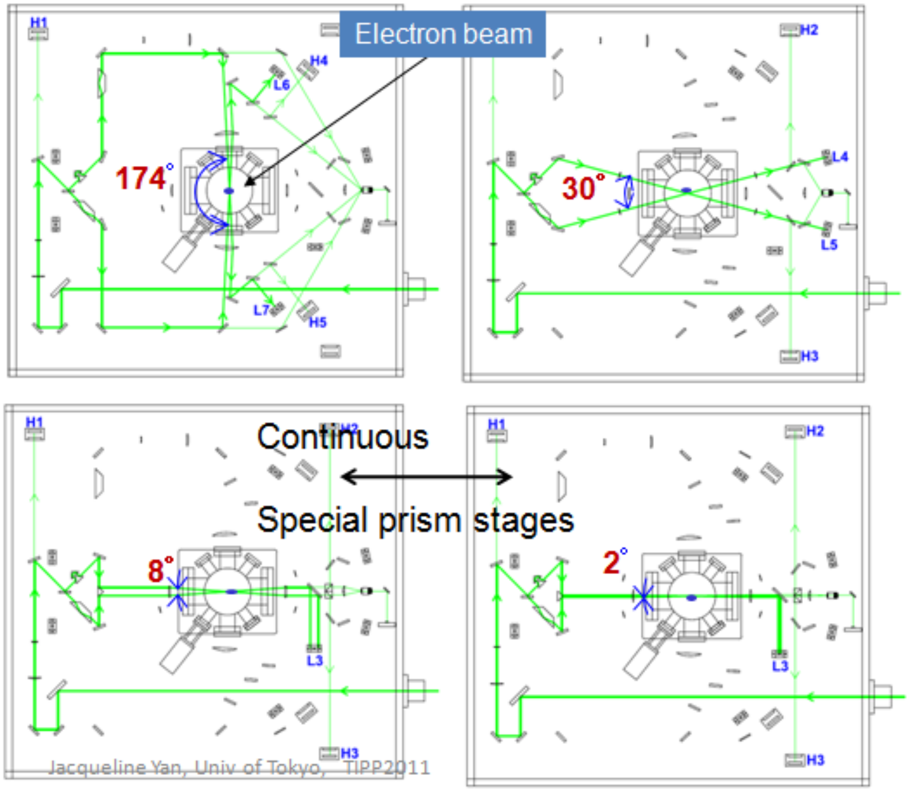
垂直定盤

干渉縞の形成





Vertical table



Nd :YAG
Q-Switch laser
PRO350
Spectra Physics

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

-- Piezo stage による位相制御

-- 回転ステージ、prism stage とmirror actuator で各モードの光路を作る