IP-BSM: Status and Systematic Errors

FJPPL-FKPPL Workshop
on ATF2 Accelerator R&D

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Layout

Beam time status in 2012

first M detection of 30 deg mode:
(10 x β_x*, 10 x β_y* optics)

Error studies at 4 deg , 8 deg mode
(10 x β_x*, 3 x β_y* optics)

174 deg mode (maybe detected)
(10 x β_x*, 3 x β_y* optics)

Systematic errors

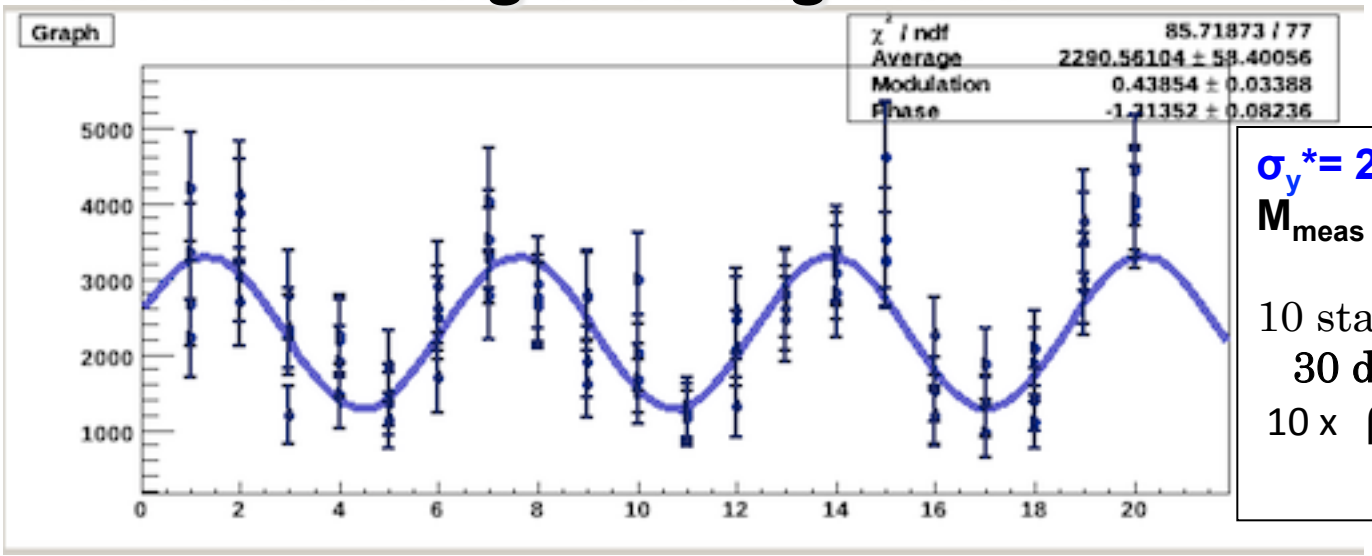
Current laser system condition

To-do + goals

Summary

Statistical errors in afternoon talk

Commissioning of 30 deg mode



σ_y*= 201 ± 4.4 (stat.) nm

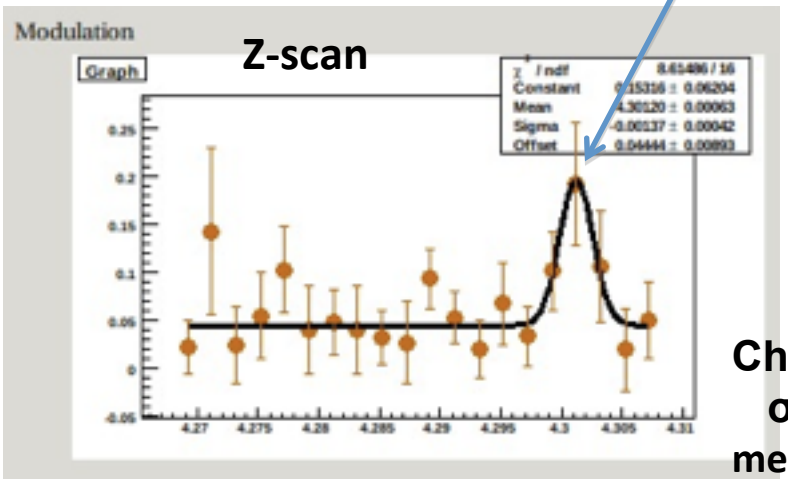
M_{meas} = 0.429 ± 0.012 (stat.)

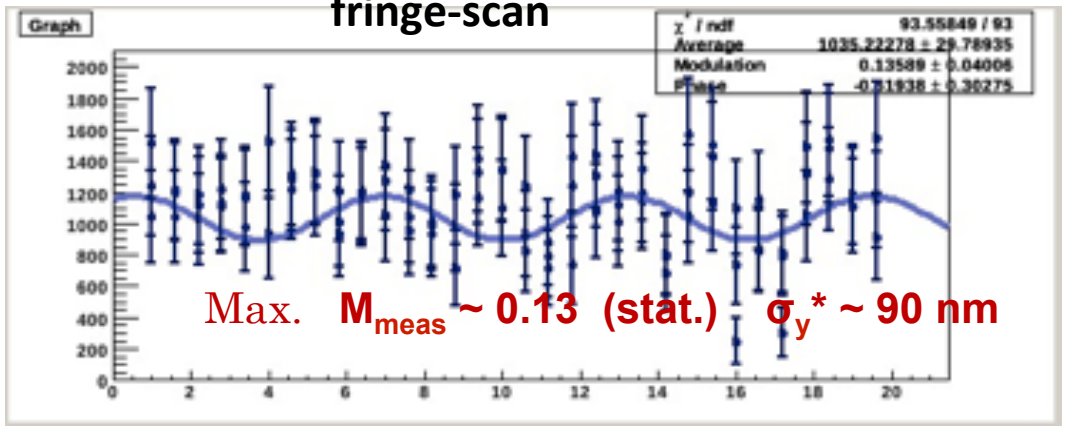
10 stable consecutive scans
30 deg, Feb 17, 2012
10 x β_x*, 10 x β_y* , S/N ~ 4

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

174 deg mode: maybe first M detection

(10 x β_x*, 3 x β_y* , S/N ~ 1)





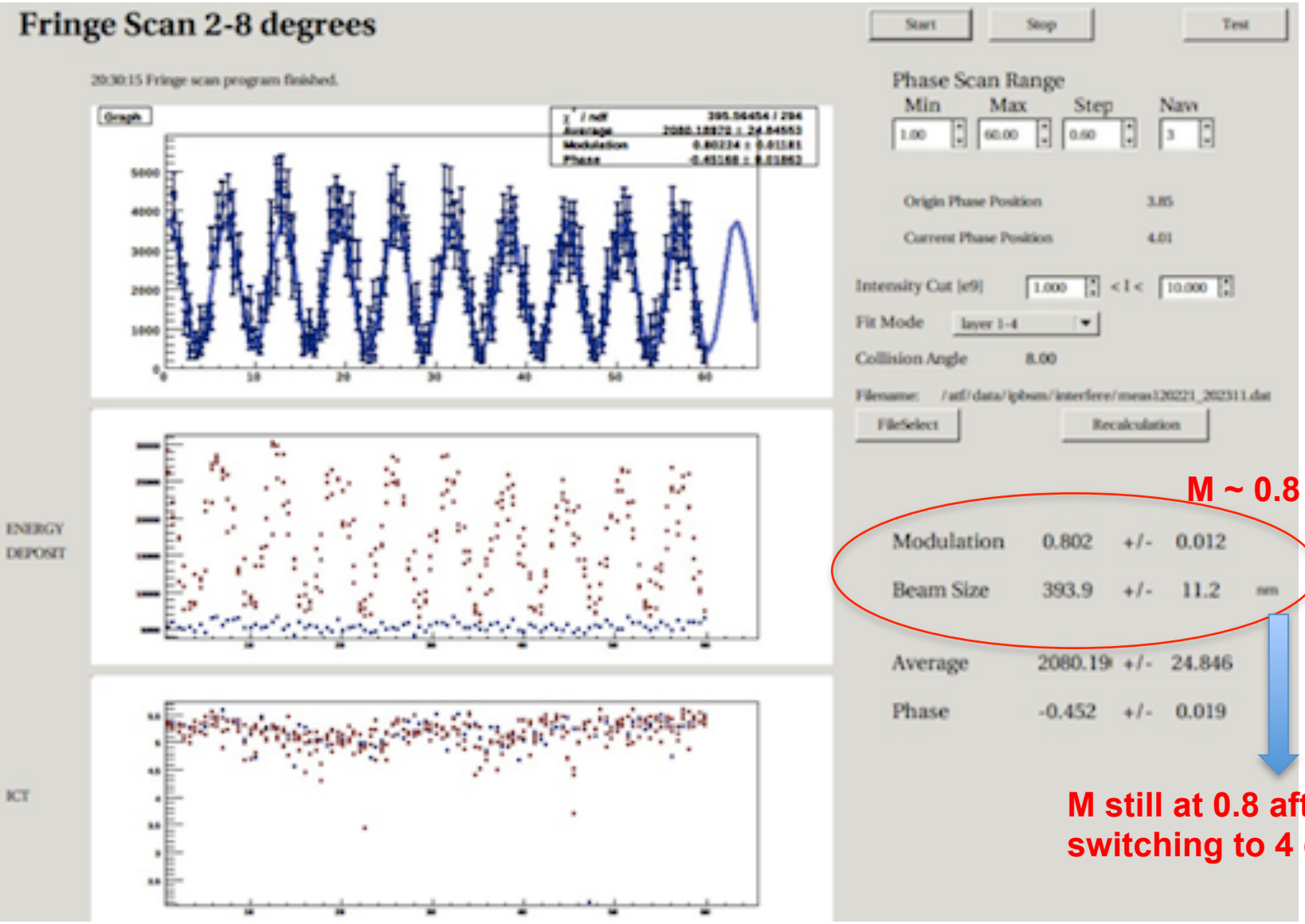
Challenging conditions ……

σ_y* is still large, may have changed over 8 hrs

measured M > 0.1 many times, but not enough reproducibility

Error studies at 4 , 8 deg mode

8 deg mode: $\sigma_y^* = 413.4 \pm 44.4$ nm $M_{meas} \sim 0.79$
From 11 stable consecutive scans
8 deg, Feb 21, 2012 (10 x β_x^*, 3 x β_y^* , S/N ~ 1)

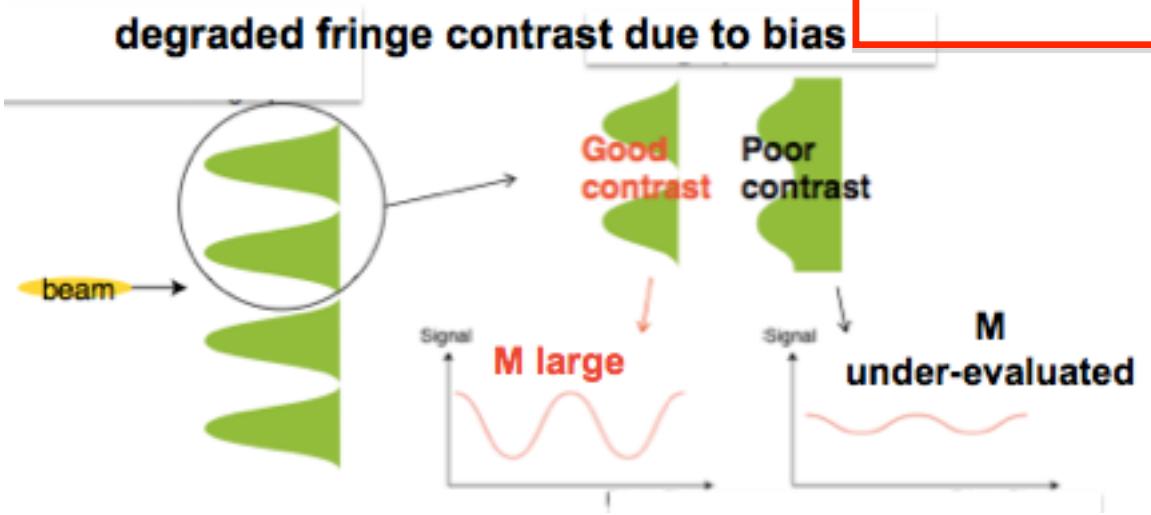


M ~ 0.8 (8 deg)

M still at 0.8 after switching to 4 deg mode

Modulation Reduction Factors

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



σy* over-evaluated

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

Syst. Error studies at 4 deg, 8 deg mode

can $\sigma_{y,meas}$ be reproduced ?

after vertical orbit tuning, coupling, dispersion correction

M_{meas} ~ 0.8 (σy∗ ~ 400 nm) **@ 8 deg mode** (2/21 , 3 x β_y*)

◆ Next switched **to 3.98 (4) deg mode**

If σy∗ ~ 400 nm didn't change

M ~ 0.94 expected, but M only reached 0.75 ~ 0.8

→ **overall M reduction factor** due to syst. errors : **C ~ 0.8** (∴ 0.75 / 0.94)

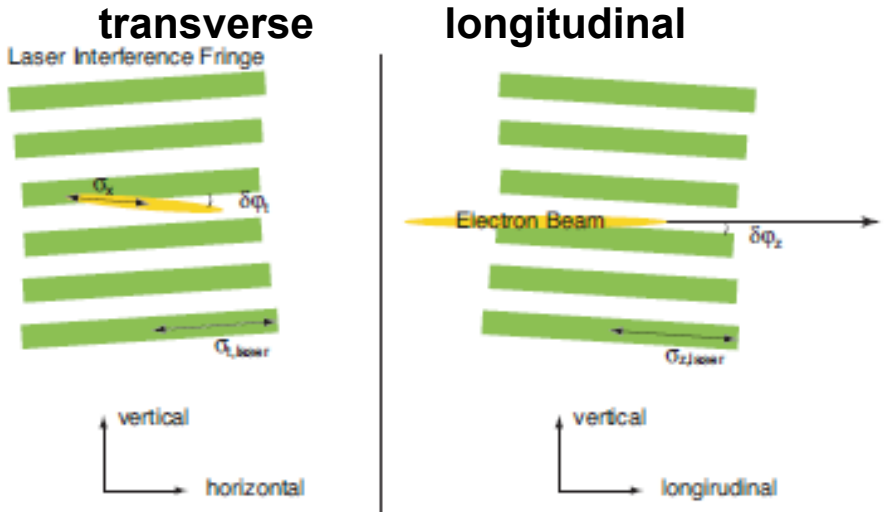
could be worse ∴ 8 deg mode already limited by syst. errors

Fringe Tilt

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

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

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

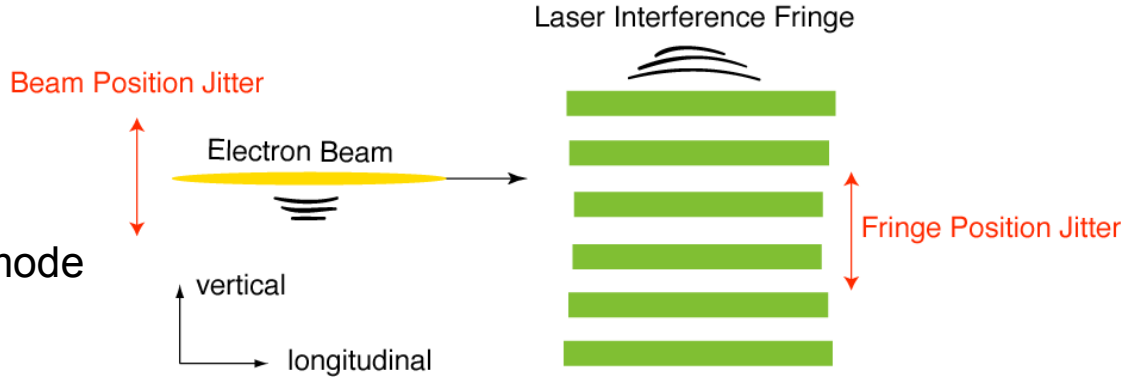


- Longitudinal tilt not a major concern
- large σ_x^* (currently ~ 10 μm) impact tranv.. tilt

Evaluation from beam time data

from actual data.	4 deg (2/21)	8 deg (2/21)	30 deg (2/17)
$\delta\varphi_t$ [mrad]	29	14	10
$C_{t,tilt}$	96.6%	96.8%	79.8%
$\delta\varphi_z$ [mrad]	4	4	3.3
$C_{z,tilt}$	100%	100%	100%

Relative position jitter



In general: $\Delta y \sim 0.3\,\sigma y$

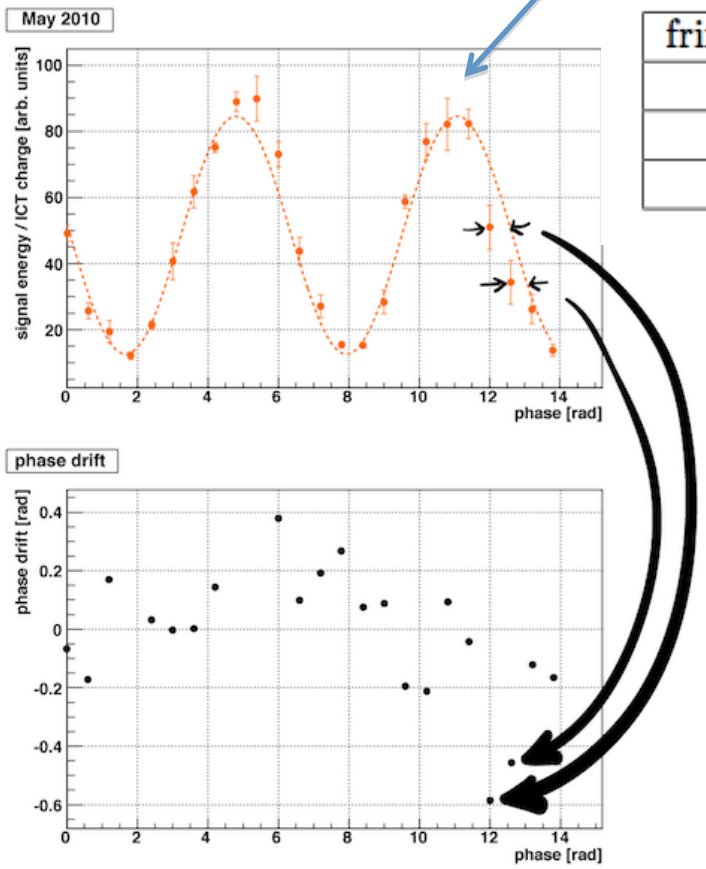
←→ $\Delta\alpha$ > ~ 250 mrad for 174 deg mode

Cphase ~ 98 %

IPBPM data not yet available

➔ Estimate "worst Δα " from M plot:

Small σy* is sensitive



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

feedback correction
beam position measurement
by **IPBPM** ?

(→ afternoon Goal II session)

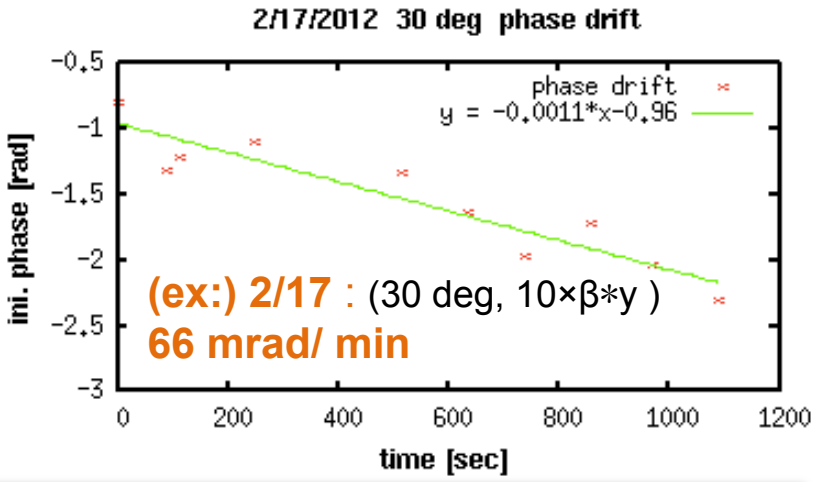
Phase drift

$E_{sig} = E_{av}\{1 + M\cos(\alpha + \alpha_0)\}$
initial phase α_0 vs time

typically
30 - 90 mrad per min
→ neglegible

2/ 21: (3×β*y)

1.8 mrad/ min (8 deg)
24 mrad/ min (4 deg)



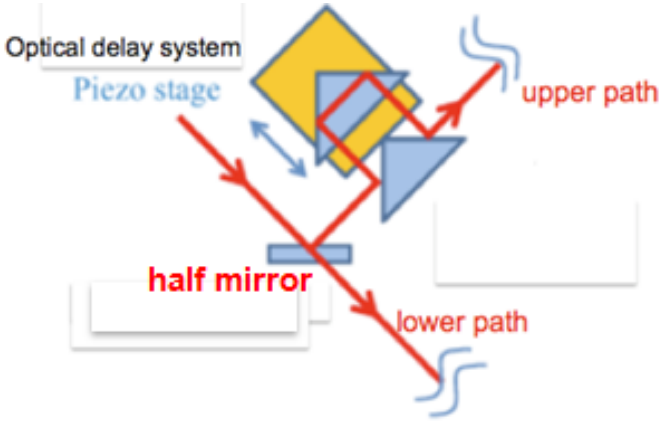
(ex:) 2/17 : (30 deg, 10×β*y)
66 mrad/ min

Polarization related power imbalance

impacts fringe contrast

- **adjust to S state by rotating λ /2 disk**
- **not measured recently**

✓half mirror properties (50% reflection only for pure S)
✓eccentricity（P contamination)



- *measured in past : Cpol ~ 97.8 (2-8, 30 deg) Cpol ~ 97.2 (174 deg)*

for now assume Cpol ~ 98 %

laser profile imbalance

- misalignment of final lens focal point
- divergence angle affected by reducer setup

- replaced damaged optical components
- optimized lens / reducer setup, alignment → **C profile = 99 - 100 %** *not major concern now*

Systematic Errors estimated from actual beam time data

M odulation reduction factors	date/optics	2/21	$3 \times \beta_y^*$	2/17, $10 \times \beta_y^*$
	σ_y^* [nm]	300 - 800		160 - 200
	mode	**4 deg**	**8 deg**	**30 deg**
polarization	$C_{pow-pol}$		~ 98%	
relative pos. jitter	$\mathbf{C}_{rel-pos}$	**> 95.3**	**> 95.2%**	**> 92.9%**
laser path alignment	z: $C_{z,pos}$		> 99.5%	
	t: $C_{t,pos}$		~ 100%	
profile imbalance	$C_{,profile}$	> 99.9%	100 %	> 99.9%
Fringe tilt	**t: $\mathbf{C}_{t,tilt}$**	**> 96.6%**	**> 96.8 %**	**> 79.8%**
	z: $C_{z,tilt}$		~ 100 %	
Total	$\prod_i \mathbf{C}_i$	**> 89.7 %**	**> 88.9%**	**> 72.1%**

- 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:** → *now practicing more precise alignment*, tune σ*x smaller (also issues of rotated beam , coupling) effects

Especially happened to be heavy for 30 deg

Even so detect M at 30 deg → σy* much smaller than 200 nm (?!)

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**
	$\sigma_x^* \simeq 2.2$ μm, $\sigma_{laser} \simeq 15$ μm	$\sigma_x^* \simeq 11$ μm, $\sigma_{laser} \simeq 15$ μm
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	

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

Fringe tilt should not be concern if meet alignment precision

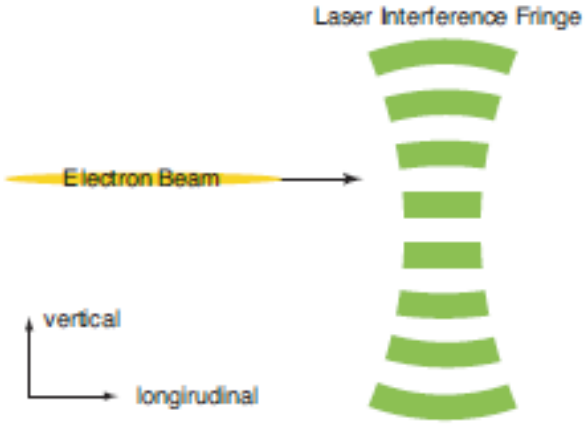
Syst. Errors specific to 174°mode

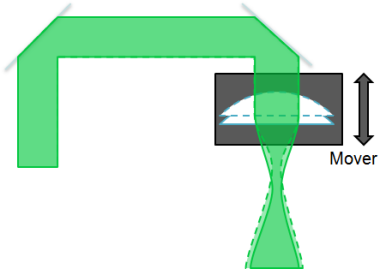
Spherical Wavefront

Offset between beam and laser waist

→ beam "feels" distorted fringes

→ **Csphere > 99.7 %**





Focal scanner → align focal point to IP

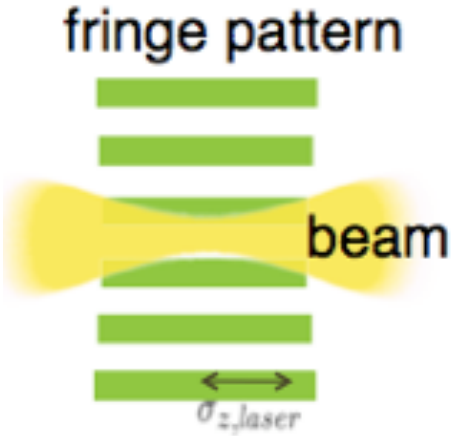
expected precision: < 9% of Rayleigh length

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

Change of beam size within fringe

Strong focusing,
change in σy* within laser fringes
no longer neglegible

Cgrowth ~ 99.7%



Current status : laser system

region	status
1 relative timing	**Stability ~ 500 ps : ~ 1.5% on stat.errors**
2. Intensity ***intensity issues!!***	**Stability ~ 1% : ~ 1 % on stat. errors** optical components, viewport damaged by high intensity laser Reducer setup, final lens, flash-lamp exchange **~ 50% power operation for now**
3. temperature	constantly monitored according to standards for stable operation
4. Oscillation	flash lamp exchanged seeder malfunction occasionally →Inspection by technician
5. profile	Triangular (non-Gaussian) on vertical table, dark spots Improve by **cavity rear mirror tuning**
6. Laser position stability	Added **Beamlok**

Summary

Status :

- Commissioned 30 deg mode : M ~ 0.5
  stably measured σy* ~ 200 nm
- Error studies at 4 deg, 8 deg mode
- 174 deg mode: M maybe detected

Systematic Errors:

- Upper limit on M : C ~ 0.8
  (from 4, 8 deg mode studies; depend on condition)
- Relative position jitters, fringe tilt

Solutions:

- Improvements in alignment , hardware/ software upgrade
- Accurately estimate syst. errors to correct σ_{meas}
  important for mode switching, precision at 174 deg mode

Goal and Plans for 2012 spring run

- **As effective beam tuning device :**
  Reproduce beam sizes in between mode switching
- **Fully commission 174 deg mode**
  Consistent M-detection
  accurate measure σy* < 100 nm at 174 deg
- **resolve and accurately evaluate systematic errors**
- **bias factors intrinsic to 174 deg mode**

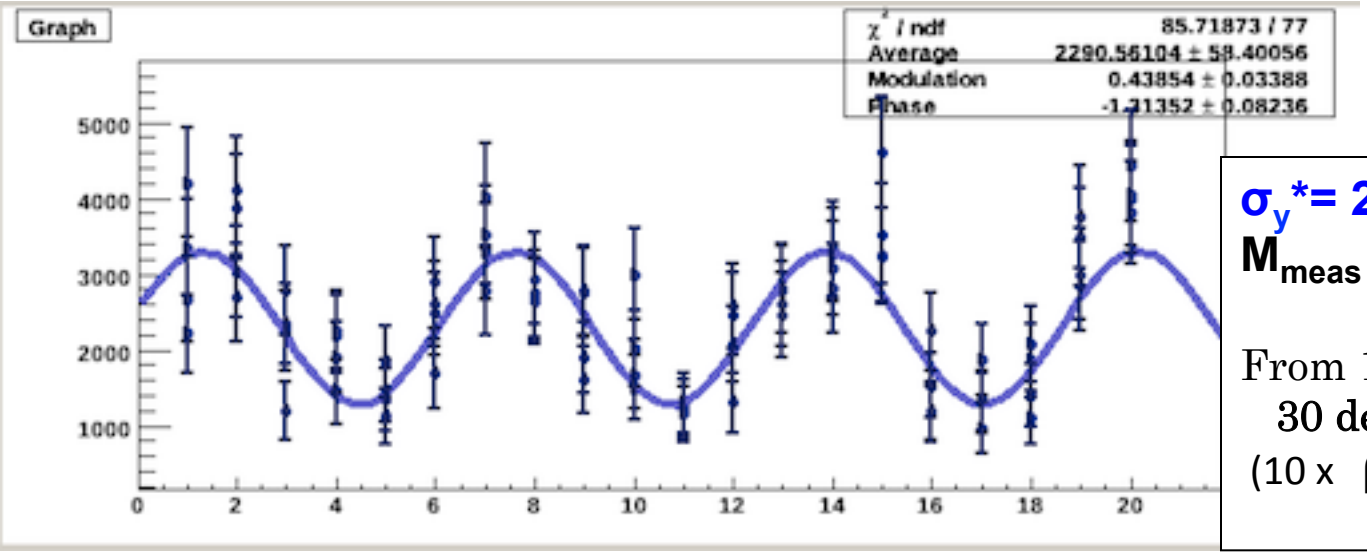
More on beam stability
coming up in afternoon talk

Laser issues
- **Maintain stable system**
- **Improve profile**
- **Optimize setup of reducer, final lens**

- **Intensity control**
  Important for nominal beam operation !!!

BACKUP

Commissioning of 30 deg mode



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

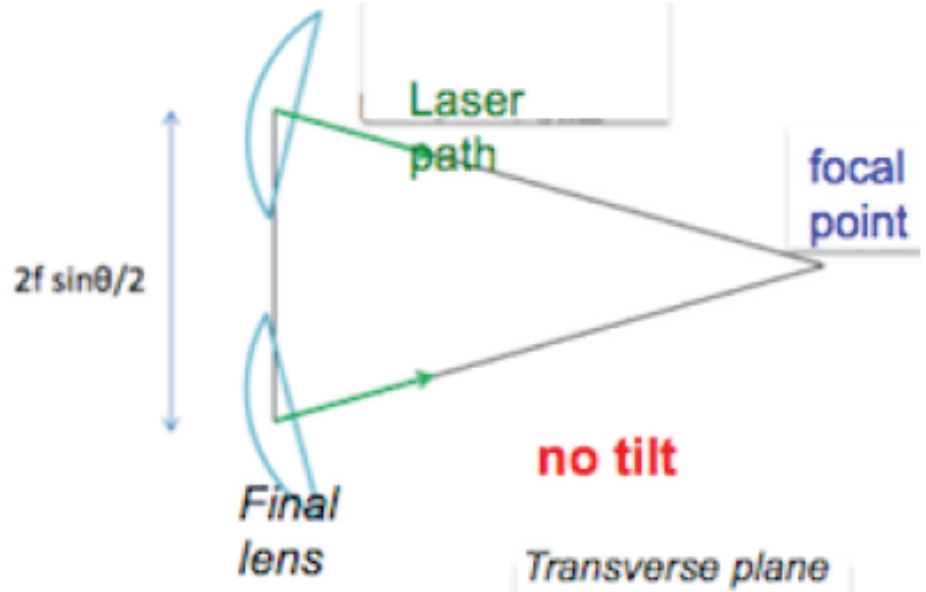
From 10 stable consecutive scans
30 deg, Feb 17, 2012
(10 x β_x*, 10 x β_y* optics)

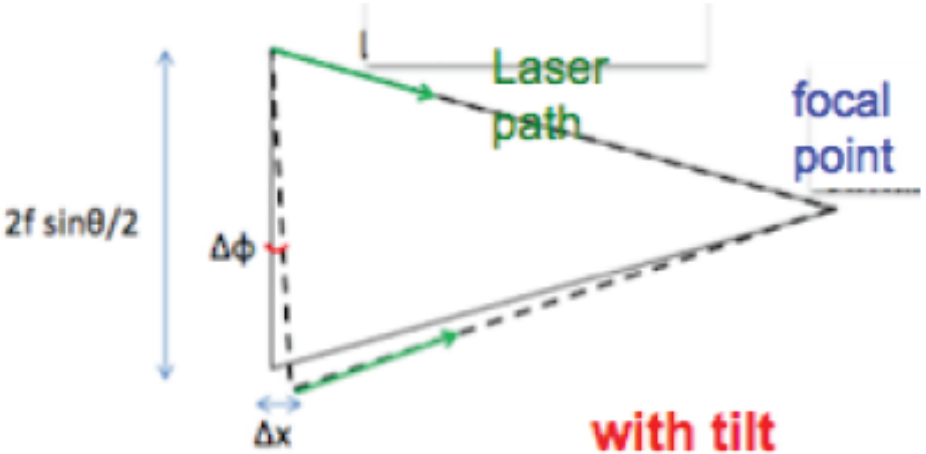
largest M_{meas} = 0.522 ± 0.042 ←→ $\sigma_{y,meas}$ ~ 165 nm

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 ~ 22%*
- *BG fluc. ~ 15%*

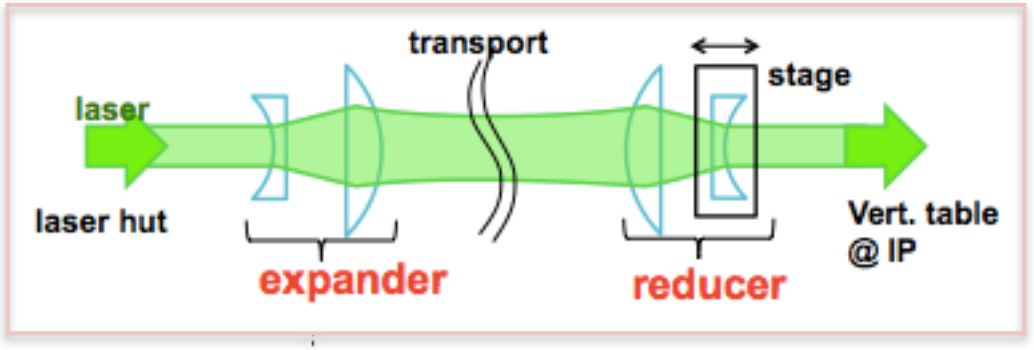
stable beam current





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

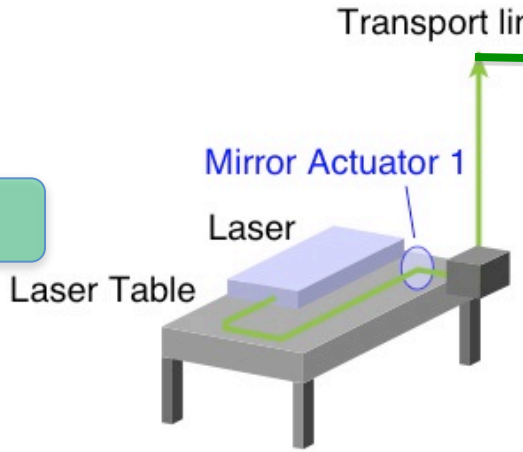
レーザー光学系

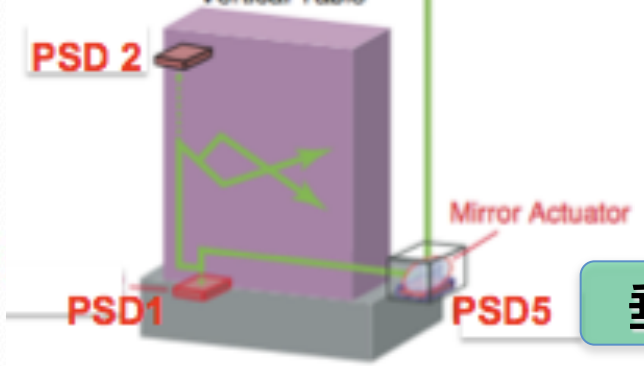


レーザー定盤

-- Laser 源

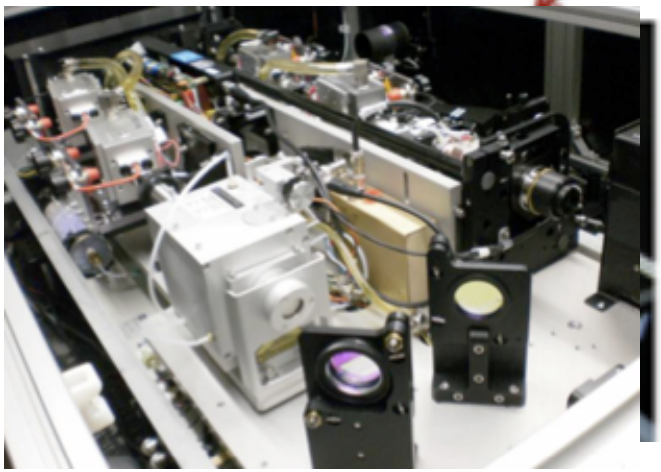
-- 運送前の状態
を調整・監視



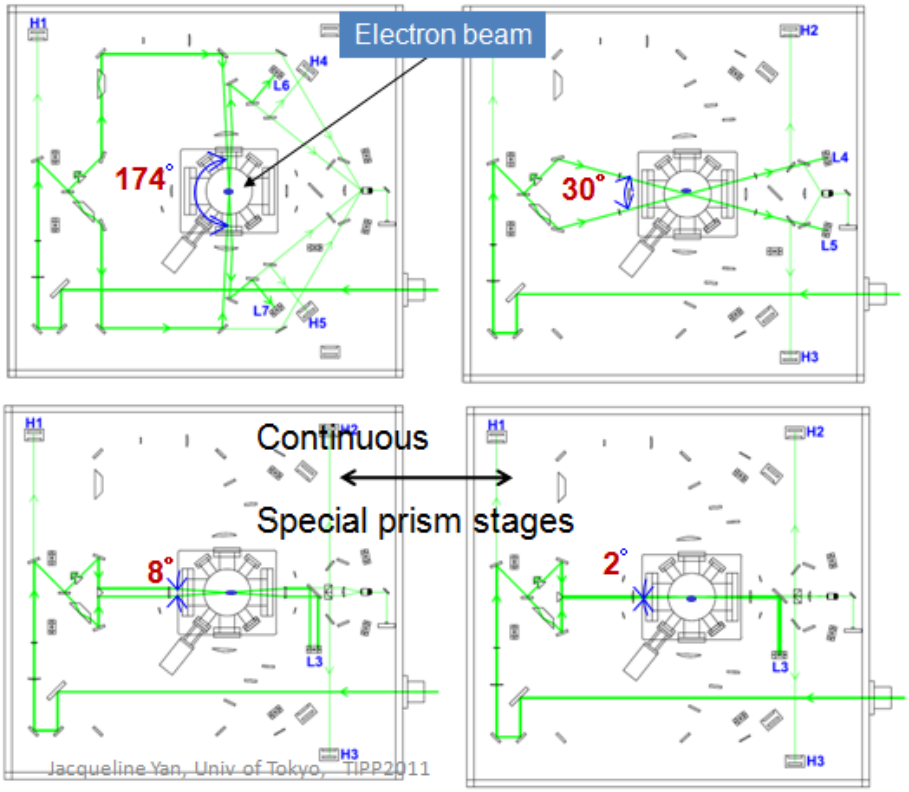


垂直定盤

干渉縞の形成



Vertical table



Nd :YAG

Q-Switch laser

PRO350

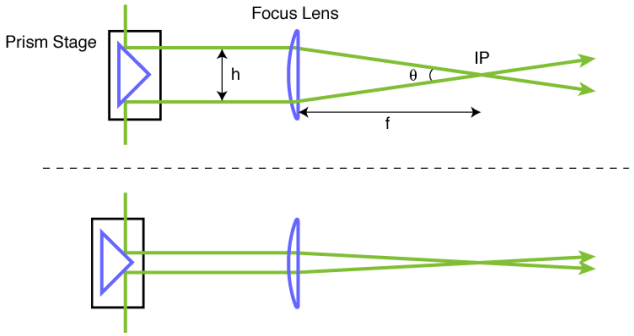
Spectra Physics

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%

X and Y actuators

-- 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**



Rotation stage

vertical

horizontal

修士学位論文

Requirements for beam time conditions

Parameters	Requirement / goals
BG energy	**suppress fluctuation**
S/N	**3 – 4 (> 1 at least)**
Sig. Energy	**Should meet expectation 40- 50 GeV in laser wire peak**
Sig. jitter	< 20 % better to be around 10%
Laser spot size	10 – 15 μm ***now OK***
Laser pointing stability	< 1 μm @ IP (< 50 μm @ other PSDs on optical tables)
ICT [10^9 e-/bunch]	6 – 7 x 10^9 / bunch , fluc < few% ***now OK***

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.

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

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

However…….

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

Resolution for each mode