IP-BSM: Issues on Beam Stability and Statistical Errors

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Layout

Expectations for IPBPM from IPBSM viewpoint

resolution for measuring σy* ~ 37 nm

feedback beam stabilization

Impact of beam position jitter on IPBSM σy* measurements

•signal jitters, BG fluctuation, S/N → **Statistical errors**

•Relative position jitters

Prospects for combined operation

•IPBSM goals and schedule

•Synchronized data taking

- **Goals / requirements for beam time conditions**

Impact of of beam jitter

Systematic errors (morning session)

•**relative position jitters** as 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, low S/N, fluctuating BG levels

•**Beam jitter at IP :** *large phase jitters correlated with heavy signal jitters*

• fluctuate laser intensity "felt" by beam pulse-by-pulse → hinder M detection

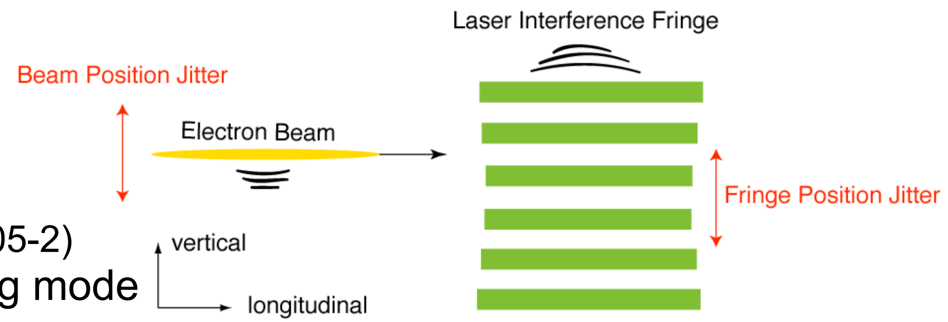
feedback correction to suppress beam jitter

What causes beam position jitter ??

• kicker magnet vibrations , energy errors due to unstable extraction from DR, ect.....

• slower drift effects: RF cooling water, temperature, ground motion, ect.....

Relative position jitter
(morning Goal I session)



General expectation **Δy ~ 0.3 σy**
(B.I. Grishanov et al., ATF2 Proposal, KEK Report 2005-2)
←→ max. Δα~250 mrad (C ~ 0.98) for 174 deg mode

small σy* sensitive

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

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

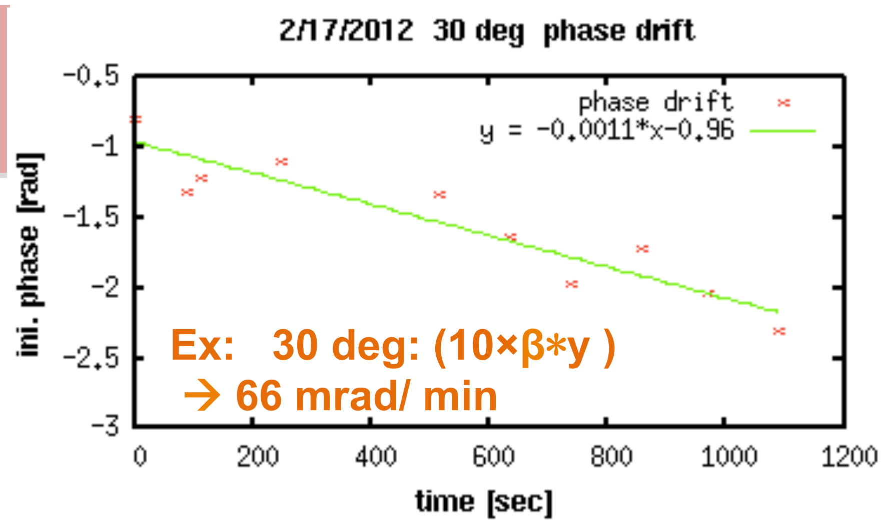
max. Δα from beam time data → translate to Δy

need IPBPM for accurate evaluation !!

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

phase drift
→translate to relative position drift

few % of σy*
→ negligible for now (??)



Relative position jitter
→ Beam and laser

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

- beam pos. jitter at IP "Δy_e" : unknown (→ IPBPM ??)
- phase jitter "Δα" : **derive worst limit from M plot**

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

need feedback correction by IPBPM

Assuming Δye ~ 0.3 σy is actually achieved (B.I. Grishanov et al., ATF2 Proposal, KEK Report 2005-2)

we can estimate laser phase error alone , due to ……

✓ incoherent laser path jitter from mirror/lens vibration

✓ final lens focal point misalignment

- **also try to resume phase monitor usage**

expected relative jitter → $\Delta y \lesssim 0.3\sigma_y$ at IP

Corresponding phase jitter and syst error → $\Delta\alpha$ [mrad], C_{phase}

	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

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

Requirement 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

- **need few nm beam position control at IP → ~ 2 nm IPBPM resolution**

☐ **For beam stabilization with feedback**

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

- 174 deg mode : < 10 nm stability at IP → few nm IPBPM resolution needed
  ($\Delta y < 100$ nm for 2-8 deg, $\Delta y < 30$ nm for 30 deg modes)
- much larger σy upstream, 100 nm BPM resolution enough to show stable beam

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

IP-BSM plan: fully commission 174 deg mode, stable measurement (few weeks operation)

Now: O(10) nm beam position stabilization

Soon: few nm resolution feedback correction for accurately measuring $\sigma y^* <\ \sim 50$ nm

BPM data

Need to encompass BPM data into IPBSM DAQ
Confirm data synchronization

- What is status of BPM data availability ??!!
- Need to keep up with modifications of data flow on EPICS (after earthquake ??)

single array to avoid data de-synchronisation, changing no. of BPMs, IPBPMs, M-PIP , PRE-IP etc

(info. From Stewart / Glen)

◆ EPICS PVs for 45 cavity BPMs position : from **cbpm-lxs.atf-local**

cbpm:x (y) pos : x (y) positions for all the cavities

cbpm:name : BPM system ordering array

◆ special EPICS PVs for resolution and jitters. :

need to put code into standard BPM start up scripts (April ?)

cbpm:x(y)res : x (y) resolution *calculated dynamically for 500 pulses*

cbpm:x(y)rms : x(y) rms position

generally resolution ~ 100 nm

(attenuated to increase dynamic aperture, ~ 40 nm if unattenuated)

◆ BPM Calibration Stability : (a few weeks time scale, last confirmed in Dec 2011)

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

IPBPM, unknown *(issues on Q-factor and electronics)*

"Full" data for IPBSM

Need to correlate beam pos. jitter with IPBSM signal fluctuations

extra slots for "ATF2 monitors"

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
```

Data from all BPMs will be put into these PVs

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

Interference mode measurement raw data

before

```
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
```

Statistical Errors (Signal Jitters):

		S/N	BG [GeV]	Sig. jitter	Beam current [10^9 e-]
Spring, 2012	**10x βy*** (ex: 30 deg) **3 x βy*** (ex: 4, 8 deg) **1 x βy*** (ex: 174 deg)	**4** **1** **0.5**	**5** **15** **20**	**20 – 25%**	**4 - 6**
Dec, 2011 (recovered 2- 8 deg mode after earthquake)	2.5 x βy* (ex: 5 deg)	1-2	50 ***BG fluc. : 10 – 15 %***	15-25%	5 - 7

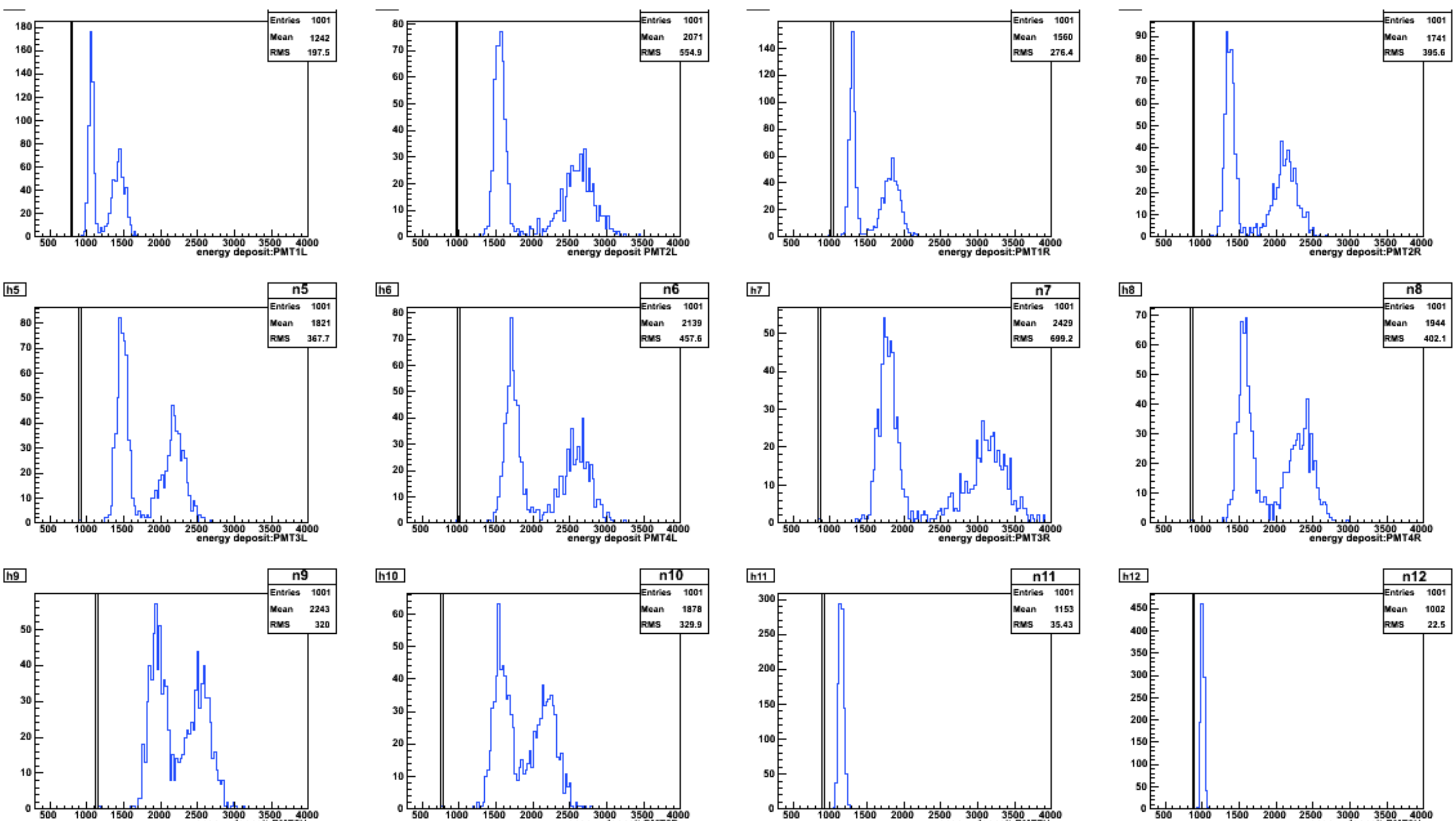
typically neglegible fluctuations (total< 5 % of stat. errors)

- **Laser intensity < 1%**
- **Relative beam-laser timing < 1%**
- **Beam current < 3% (when stable)**

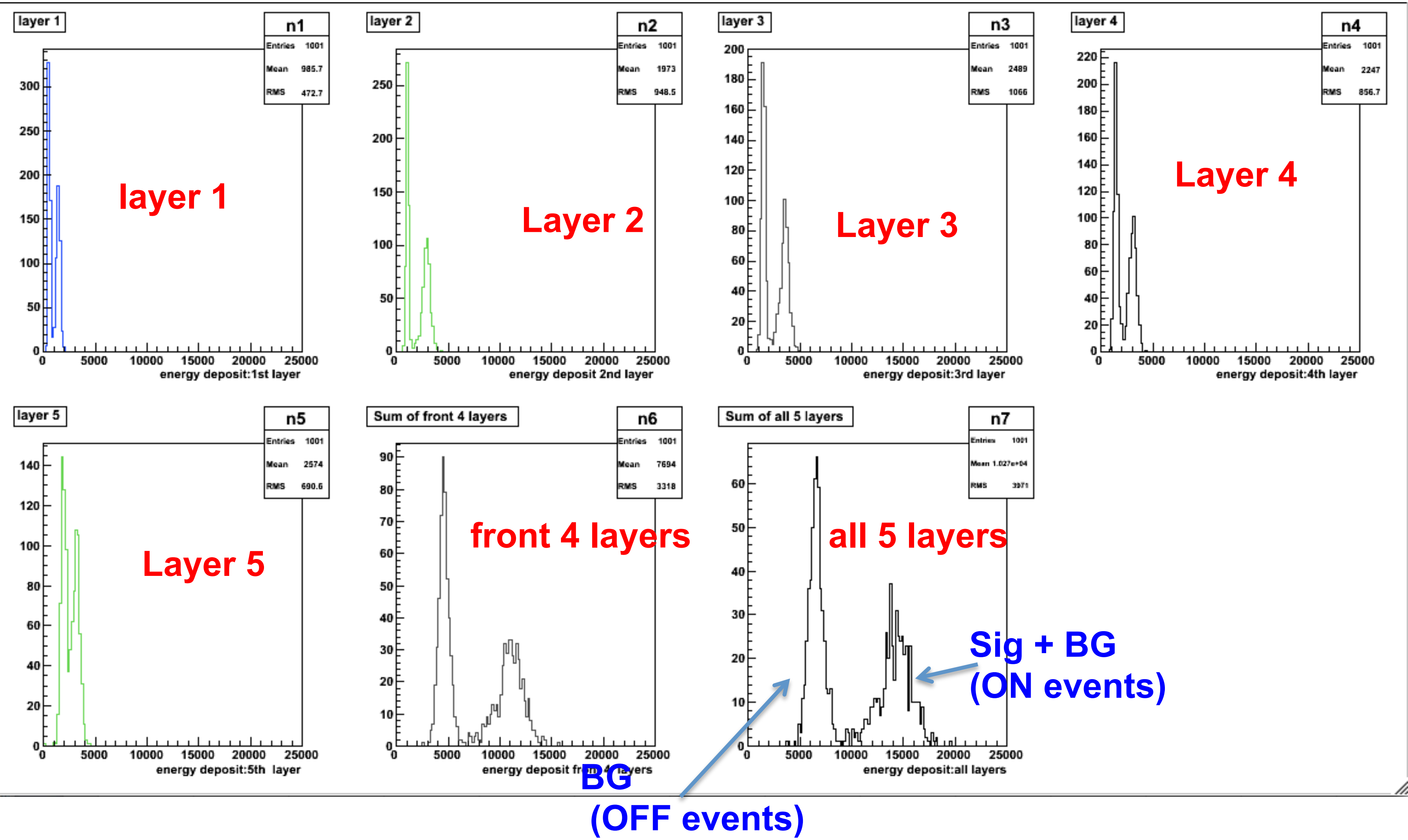
Difficult to evaluate for now:

- **relative position jitter**
  (ex : at worst 10-30% on 2/21@4,8 deg, few % on 2/17@30 deg)
- **laser pointing jitter at IP** : (worst 10 – 15 μm ??)

- **Energy deposit and pedestals of 12 PMTs**
  (L and R PMTs for each of layers 1 ~ 4, 4 PMTs in 5th layer)

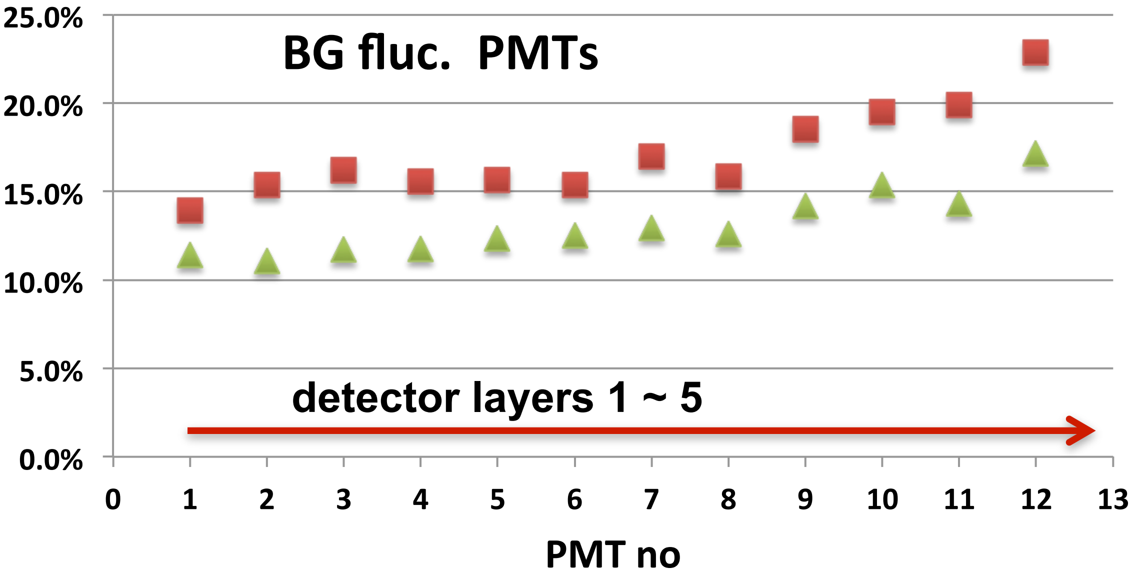


- Energy deposit of each layer 1 ~ 5, and front 4 layers, all 5 layers



<< BG Fluctuation>>

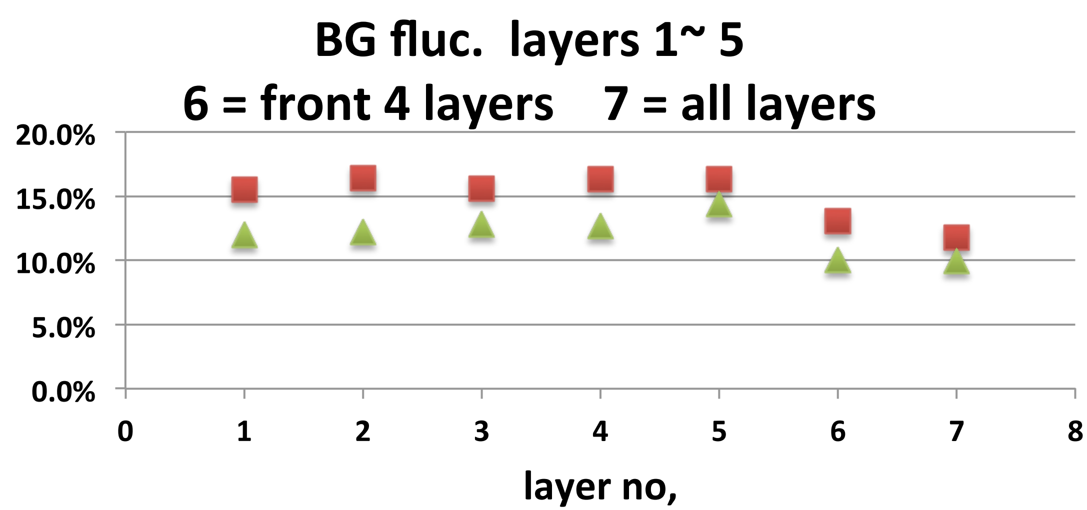
{15 % for 10 x beta_y} vs {10 - 12% for 3 x beta_y } (in front detector layers)



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

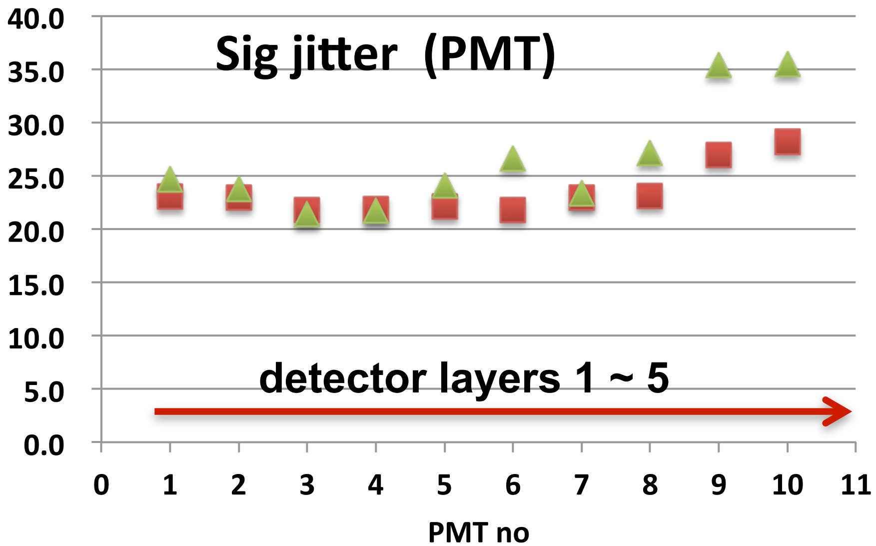
3 x beta_y optics
(30 deg mode, 2/21)

BG fluctuation may be affected by beam stability (current, position, ect..)



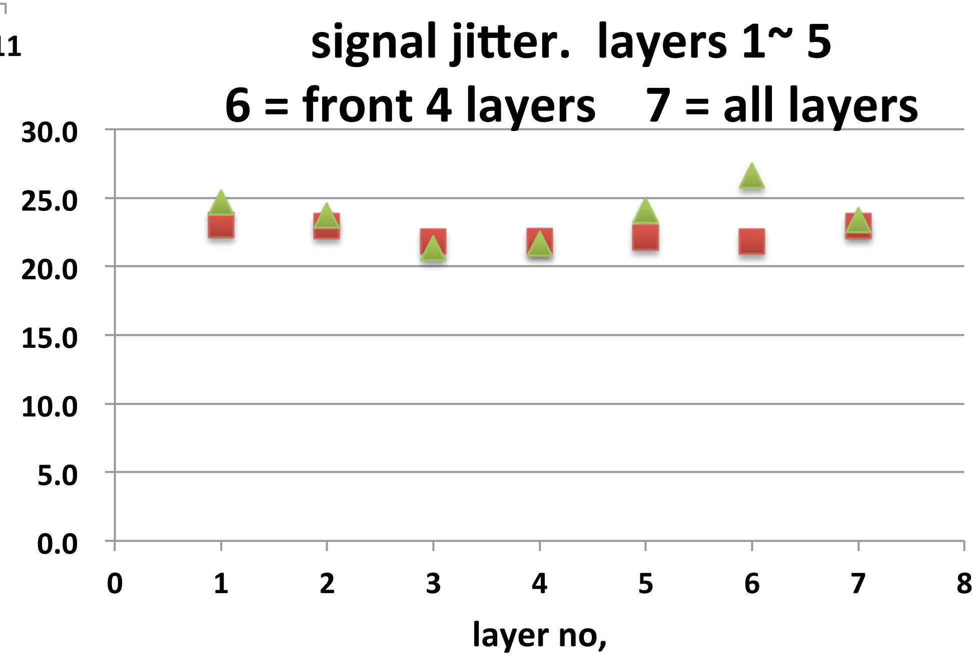
<< Signal jitters>>

- 20 ~ 25 % in front layers,   not much change with βy*



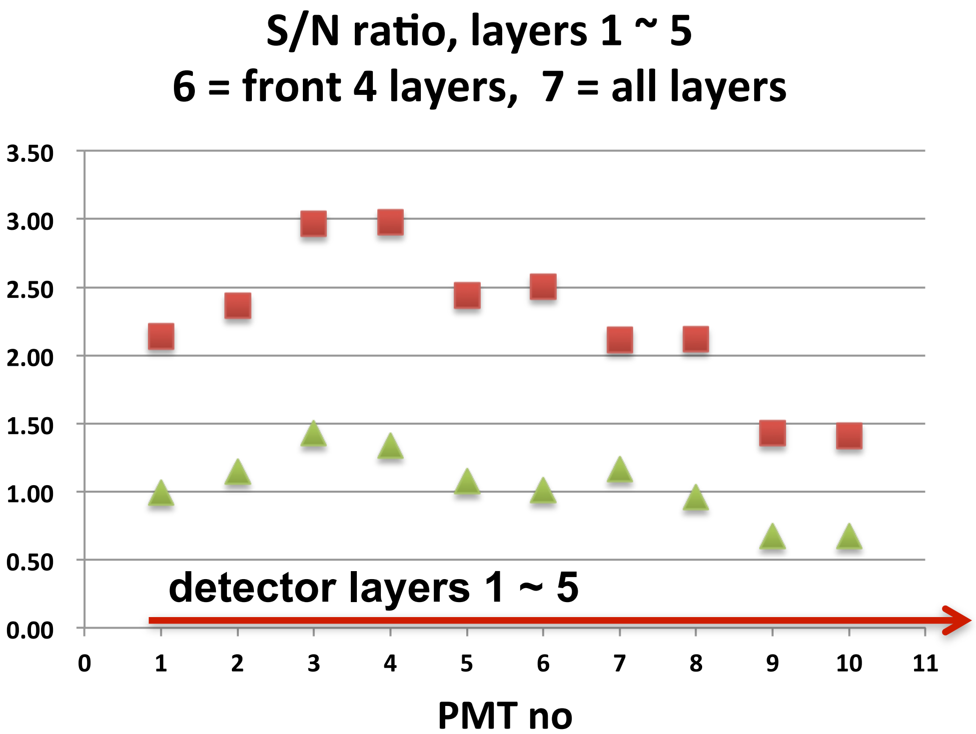
10x beta_y optics: :
(30 deg mode, 12/17)

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



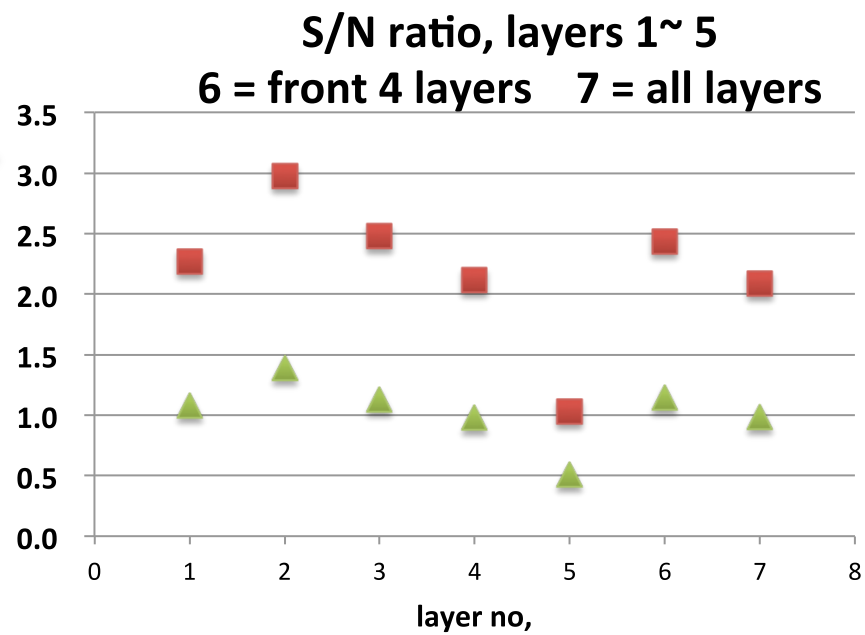
<< S/N ratio>>

- S/N ~ **{ 2.5 – 3** for **10 x beta_y}** **vs {1** for **3 x beta_y }**
- S/N ~ 0.5 for nominal beta_y *decrease about 2 times*



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

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



S/N is highest in 2nd layer and front 4 layers together

Summary and Goals

Beam Stability for IPBSM :

- ❖ Relative position jitter at IP → statistical and systematic errors
- ❖ Beam position jitters upstream → BG fluctuation , low S/N

Parameters	Requirement / goals for suppressing statistical errors
BG energy	fluctuation < ~ 10-15 %
S/N	> 1 (at least > 0.5 even under nominal β)
Sig. jitter	• < 20 % - 25% for M detection • < 10% for measurement precision
Beam position	• Δy < 0.3 x σy stabilization along beamline • few nm feedback correction for σy* ~ 37 nm
Beam current	~ 6 x 10^9 / bunch , fluc. < few% *now very stable*

Measurement data from BPMs:

- ❖ Synchronize with IPBSM DAQ
- ❖ Apply effectively for investigating IPBSM signal jitters, and improving resolution

BACKUP

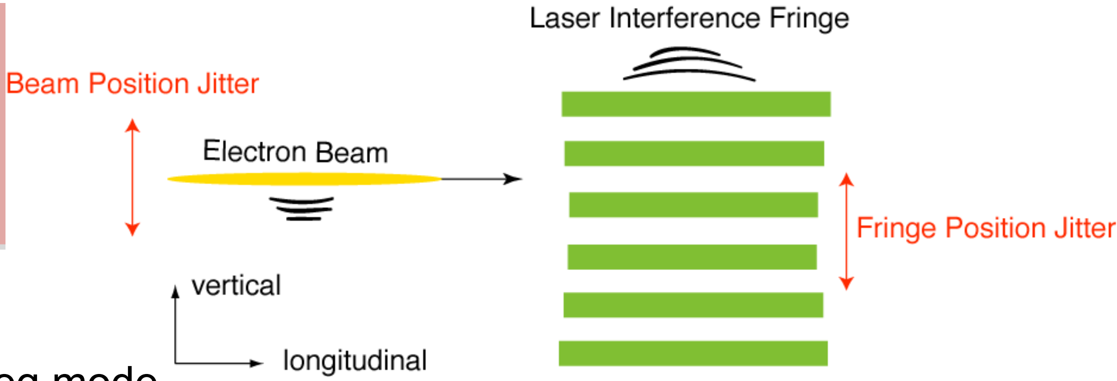
Requirements / goals for beam time conditions

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 to ~ 10%**
S/N	**> 1 (at least > 0.5 even under nominal β)**
Sig. jitter	• < 20 % - 25% for M detection • < 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% ***now very stable***

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

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

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

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 %

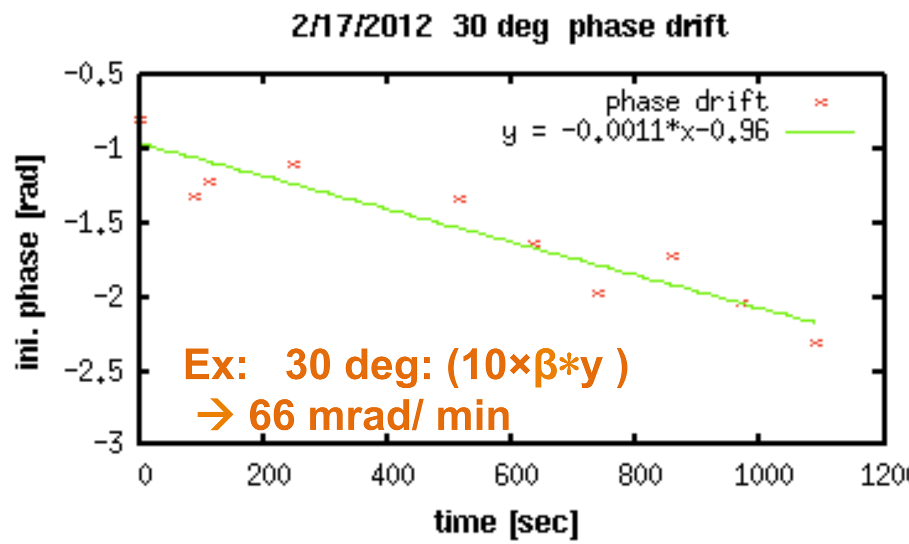
phase drift
→translate to **relative position drift**
between beam and laser phase

Initial phase drift
Esig = Eav {1 + Mcos (α + α0)}

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

beam position drift
< few % of σy*

→ neglegible for now (??)



fringe scans in 2011	2/21 (4 deg)	2/21 (8 deg)	2/17 (30 deg)
phase drift [mrad / min]	24	1.8	66
relative pos. drift [nm / min]	28	1.1	10

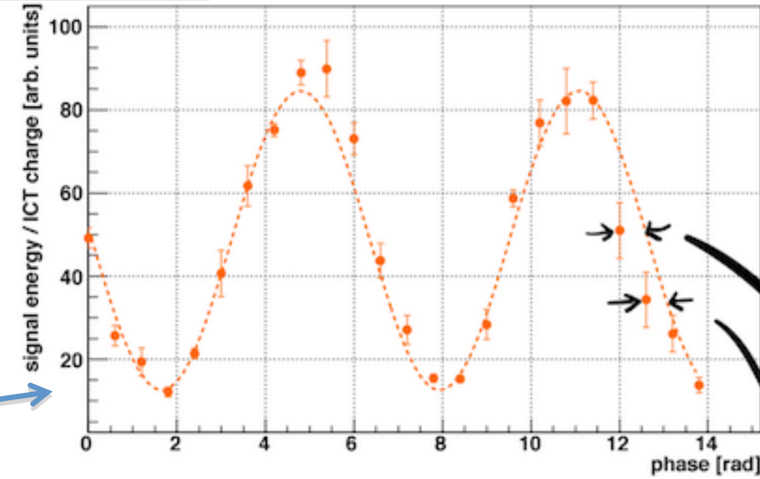
Relative position jitter
➔Beam and laser

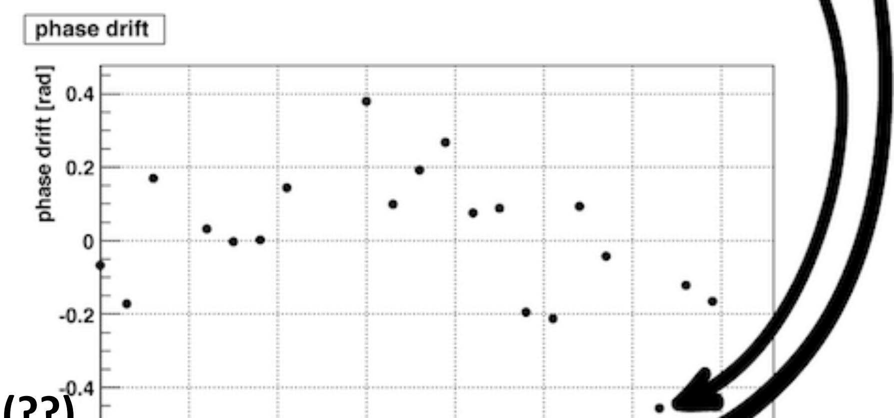
- In general: $$\Delta y = \sqrt{\Delta y_e^2 + \Delta\alpha^2} .$$

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 $\Delta ye \sim 0.3\ \sigma y$ is actually achieved

we can estimate (worst limit for) laser- 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

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: $E_{sig} \rightarrow E_{sig}^{*} = E_{sig} + \Delta E$

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: $\Delta \mathrm{E/E} \sim 21\%$, $\sigma_{laser} \sim 25\ \mu\mathrm{m}$

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

Current confirmation status

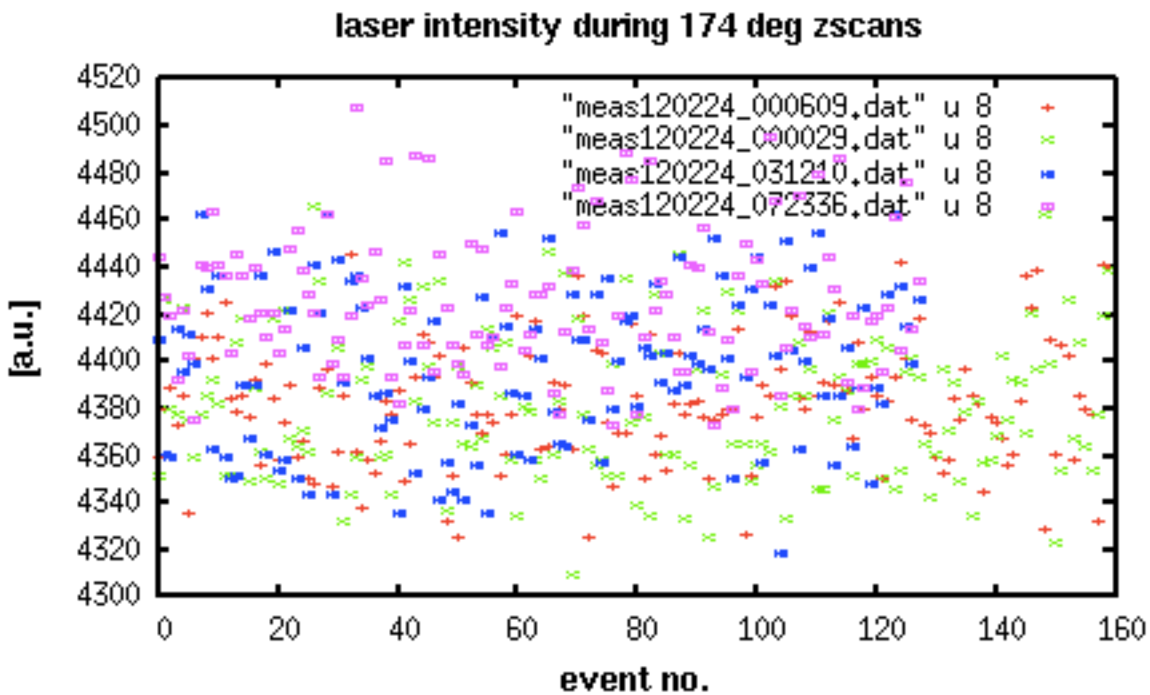
region	confirmed	still to be resolved
1 laser table	Oscillator, flash lamp Timing, power Temp dependence	
2. DAQ, control system	DAQ modules (ADC, VME,...) Controller stages Thorlab actuators EPICS, data logger	status read out from ATF-menu
3. transport	Laser profile interlock attenuator	
4. vertical table	Optical components path for each mode PSD , PD signals	PSD caliberation
5. IP	IP mover, screen monitor	PSD caliberation Viewport safety test
Post-IP	Detector *comprehensively!!* BG monitor	Collimator scan

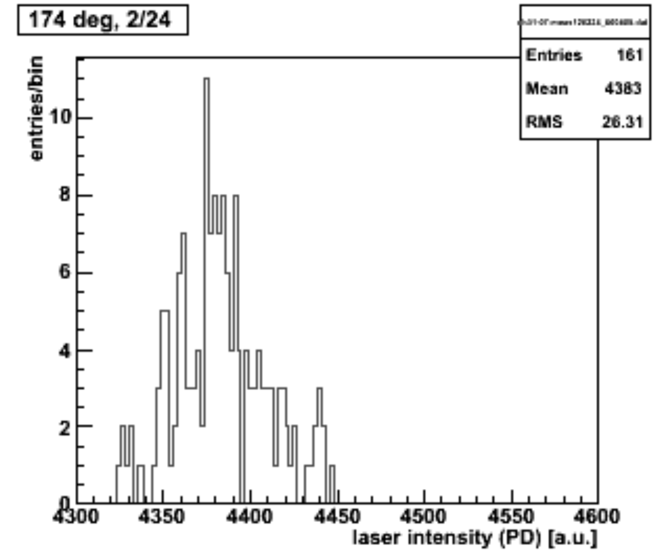
Will finish these up soon before beam run begins

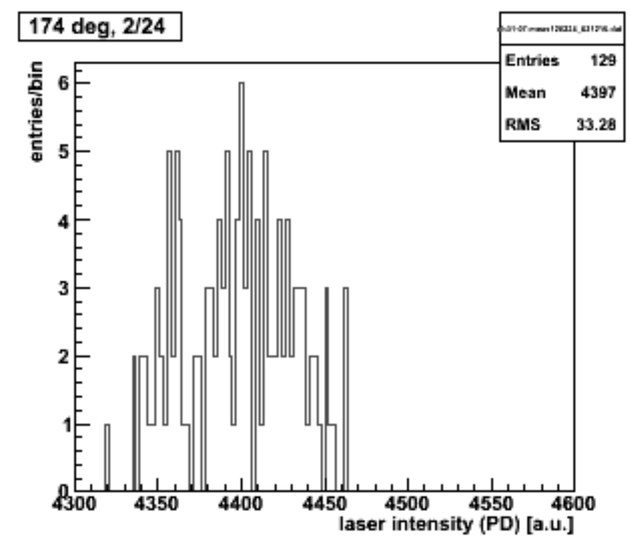
Reference

Laser intensity

Stable throughout
174 deg mode fringe scans, zscans







Estimating Statistical Errors (Signal Jitters):

Fringe scan time	4, 8 deg (3 x βy)	30 deg (10 x βy)	174 deg (3 x βy)
Sig jitters	**25%**	**23%**	**21%**
BG fluc.	**15%**	**15%**	**11%**
Relative pos. jitter *(worst limit from M plot)*	**200 – 350 nm / scan (←→ 10 - 30%)**	**60 nm / scan (←→ 4-7 %)**	

also laser pointing jitter at IP !! Difficult to estimate (worst 10 - 15.4 μm)

- **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	**0.8%**	**4.8%**	**0.6%** (386 ns)
7:23 10 x 3 optics)	**0.7%**	**2.2%**	**0.8%** (452 ns)

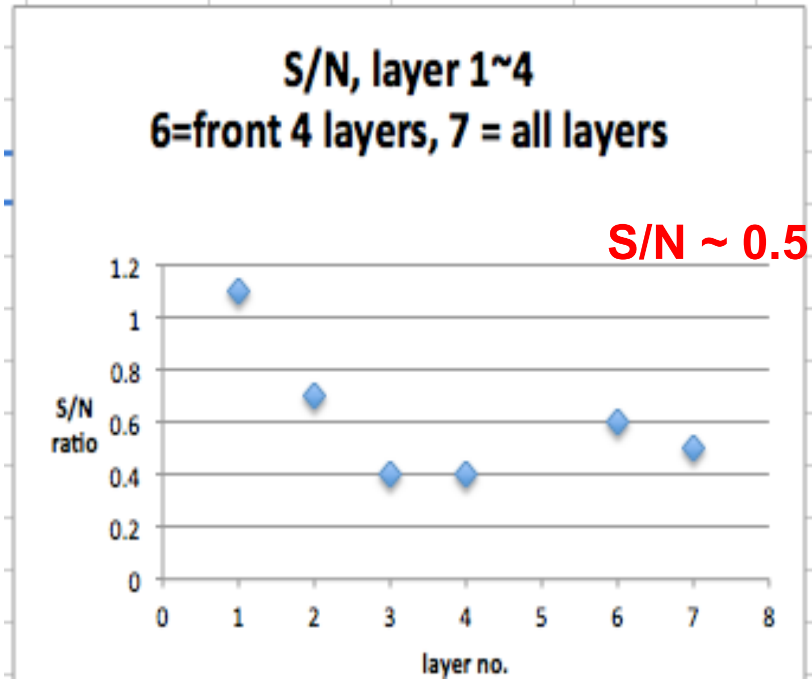
Comparing typical beam time conditions

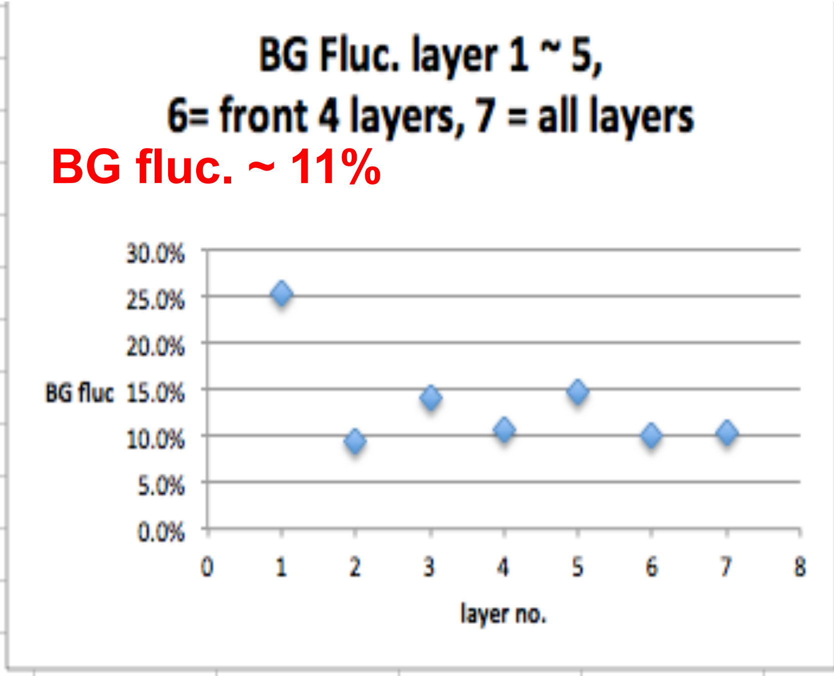
		S/N	BG [GeV]	Sig. jitter	iCT [10^9 e-]
Spring, 2012	10x βy*: 3 x βy*: 1 x βy*	**4** **1** **0.5**	**5** **15** **20**	**20 – 25%**	4 - 6
Dec, 2011 Post-earthquake recommissioned 2- 8 deg mode	2.5 x βy*	**1-2**	**50**	**15-25%**	5 - 7
Dec , 2010 Unstable era, large sig. jitters	1 x βy*	**0.5**	**115**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

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

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

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 }