Stability Studies Based on IPBSM Fringe Pattern Analysis

FJPPL-FKPPL ATF2 Workshop

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LAPP

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message

IPBSM error study is essential for achieving ATF2 Goal 1 !

However we must **suppress signal jitters** first (or simultaneously ?)

This is important for both stable measurement of σ_y^* < 40 nm and error studies

Outline of this talk

Introduction

Recent Beam Time Status

IPBSM Performance Evaluation

Signal Jitters

- Systematic errors
- Phase jitter study

real data analysis & simulation

Summary & Goals

Beam Time Status

10 consecutive scans @174°

however large phase jitters (?)

correspond to

σ_y = 65 +/- 4 (stat) **nm**

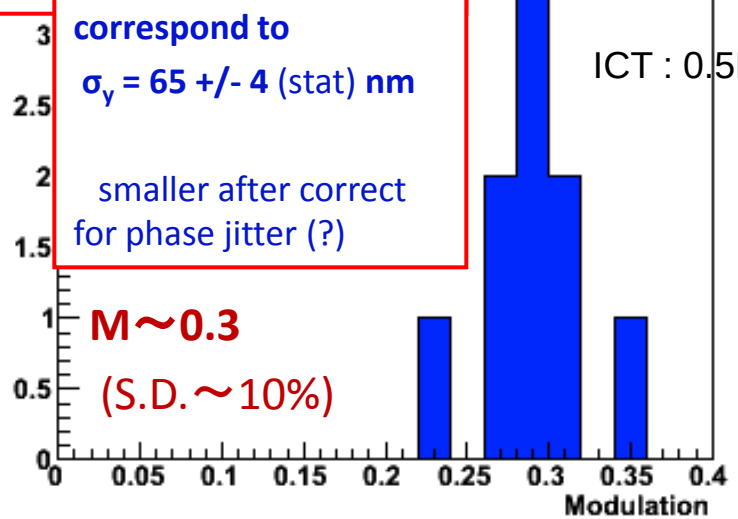
smaller after correct for phase jitter (?)

M～0.3

(S.D.～10%)

Mar 2013

ICT : 0.5E9



Commissioned Cherenkov detector

Stable contribution to wakefield study

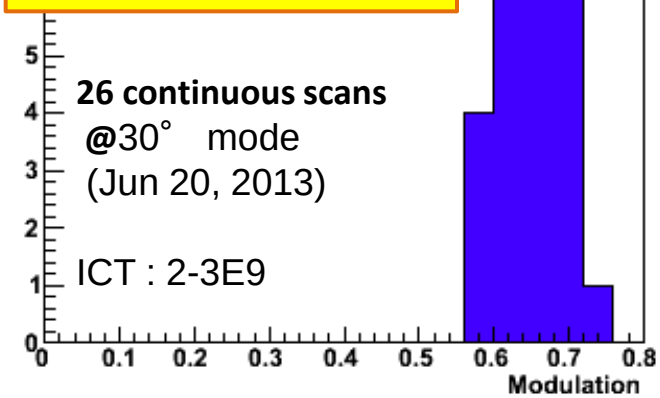
May – Jun 2013

M = 0.65 +/- 0.05 (S.D.)

5% measurement stability

26 continuous scans @30° mode (Jun 20, 2013)

ICT : 2-3E9



Dec 2013 – Feb 2014

- **Significant increase in signal jitters / drifts**

measured M @174° mode but poor consistency

- **various efforts made to tune / stabilize laser**

(→ see Terunuma- san's Project meeting slides)

- **some improvement observed online / offline(?)**

But jitters are still a issue

- **High M measured at 2-8 deg , 30 deg mode**

Mar 2014

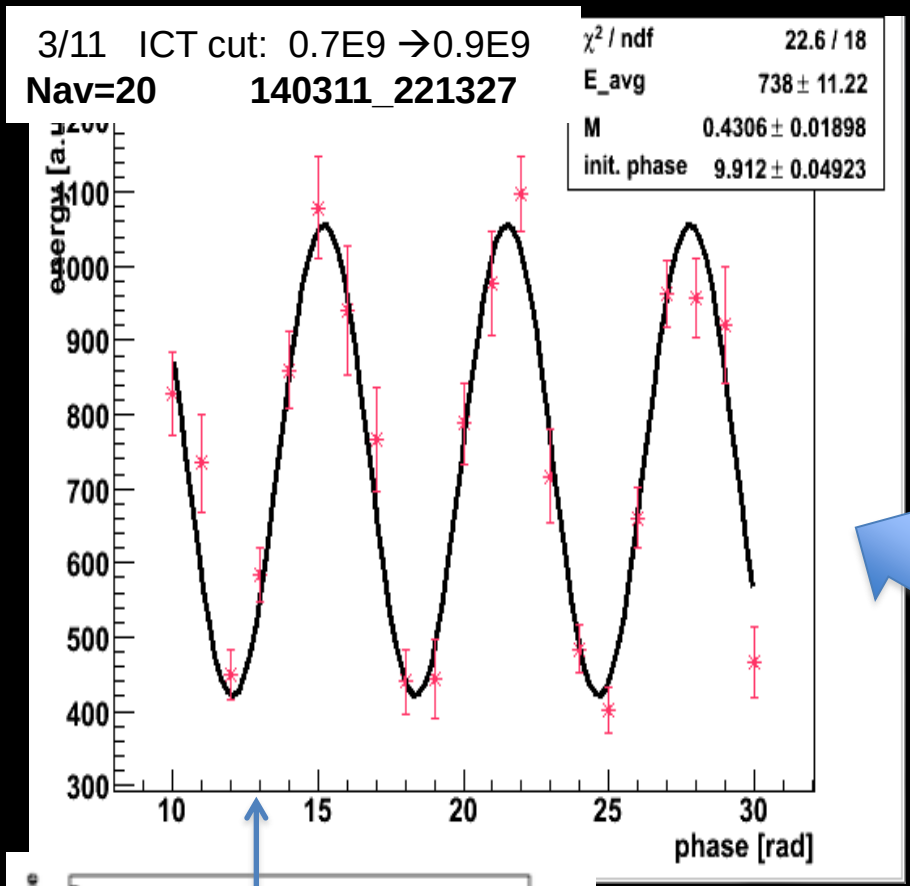
- Changed to CsI detector for low beam intensity operation
- **Effective operation of tilt scan and linear / nonlinear knobs**

Consistent measurement of M > 0.35

(see next page)

3/11 ICT cut: 0.7E9 →0.9E9

Nav=20 **140311_221327**



Best scan so far (?) at 174 deg mode

M,meas = 0.43 +/- 0.02

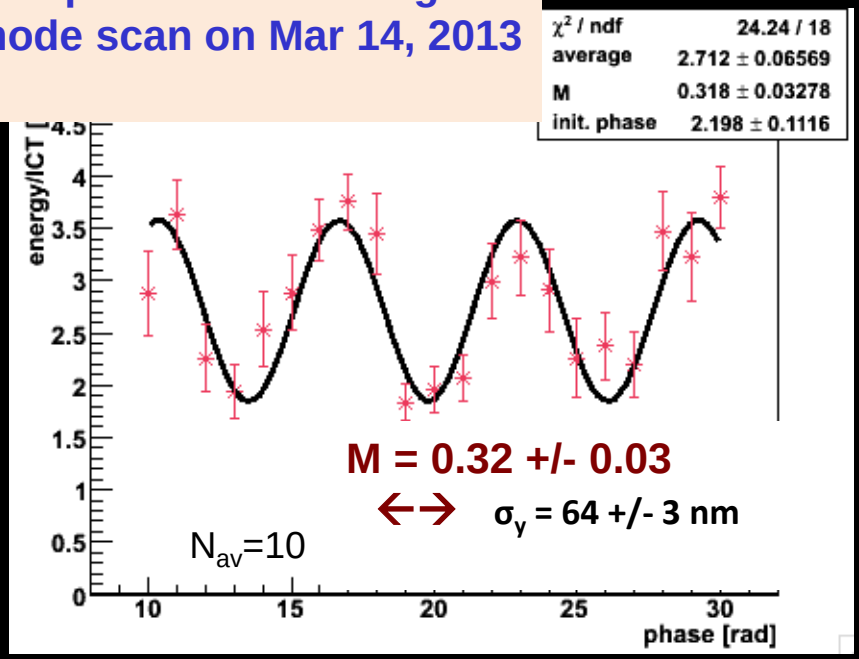
(σy,meas = 55 +/- 2 nm)

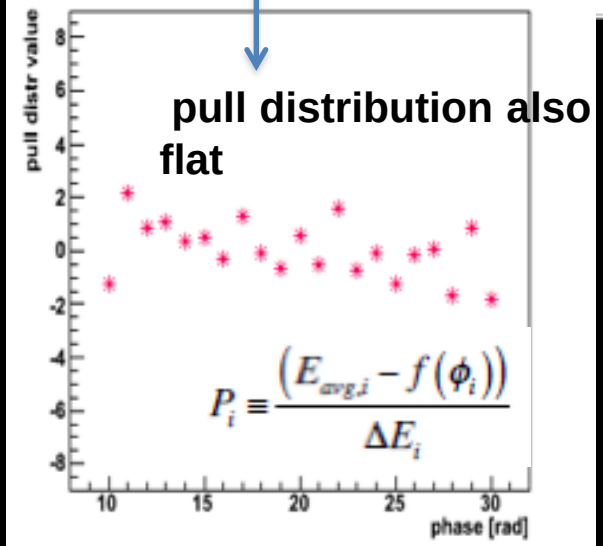
if correct using extracted phase jitter

Δφ = 0.65 +/-0.06 rad

→ σcorr ~ 47 nm (details later)

Comparable to 174 deg mode scan on Mar 14, 2013

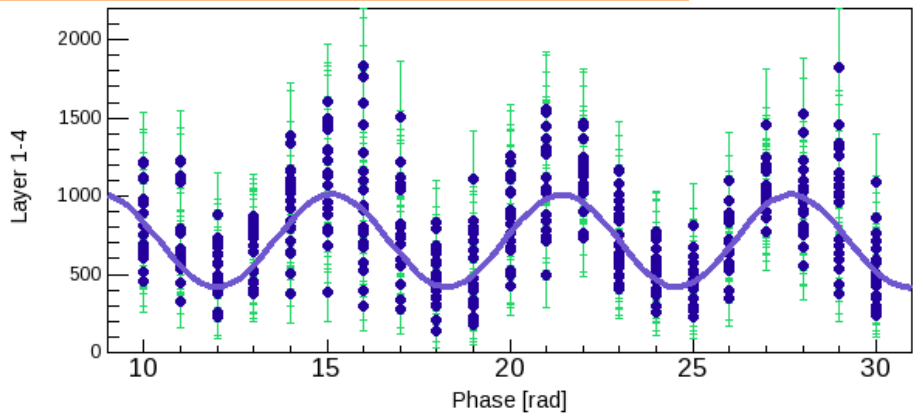




pull distribution also flat

$$P_i \equiv \frac{\left(E_{avg,i} - f(\phi_i)\right)}{\Delta E_i}$$

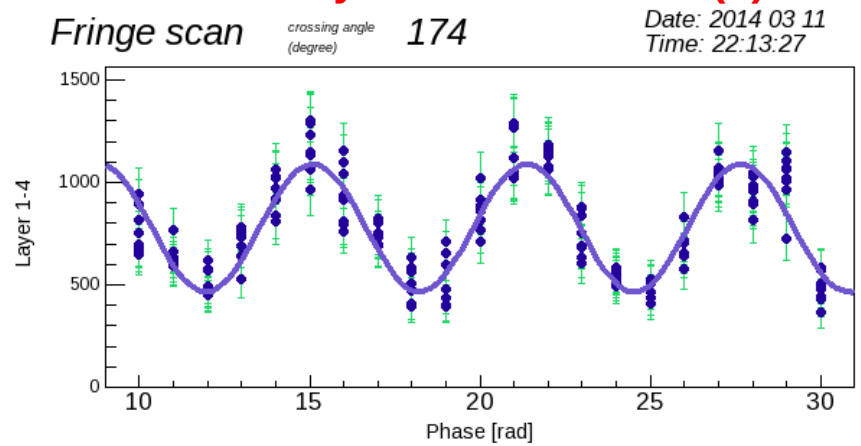
Best scan so far (?) at 174 deg mode



Dataset: base140311_221327.binary
Fit results: Av*(1.0+M*cos(x+Ph))
Event selection
Point/step: 20
Data: Layer 1-4
Modulation: 0.413 +/- 0.023
Beam Size: 56.2 + 1.8 -1.7 nm
Average: 714.693 +/- 12.166
Phase: -2.564 +/- 0.056
Chi2/ndf: 4.3037e+02 / 417

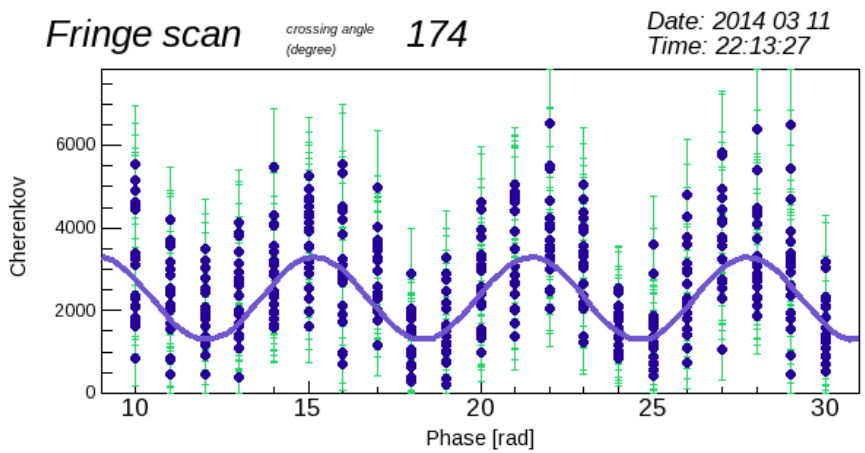
CsI , no cut
M,meas = 0.41 +/- 0.02

Not very much difference (?)



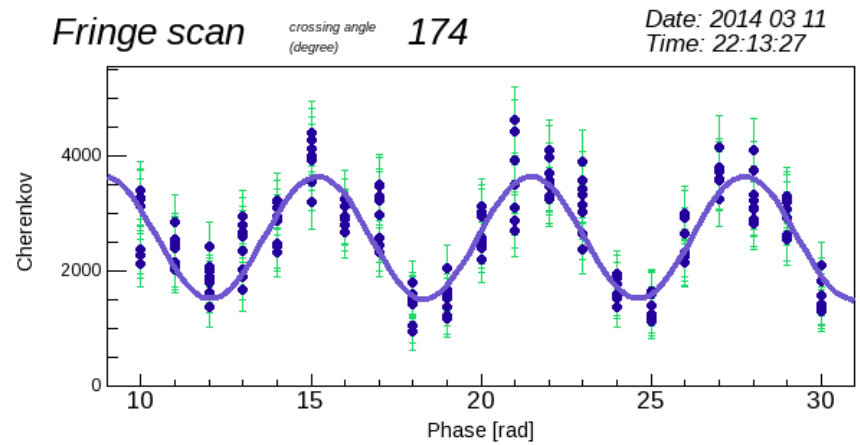
Dataset: base140311_221327.binary
Fit results: Av*(1.0+M*cos(x+Ph))
Event selection
Point/step: 20
Data: Layer 1-4
Modulation: 0.401 +/- 0.015
Beam Size: 57.2 + 1.2 -1.2 nm
Average: 777.362 +/- 8.598
Phase: -2.522 +/- 0.037
Chi2/ndf: 1.6983e+02 / 165

CsI , 30% cut
M,meas = 0.41+/- 0.02



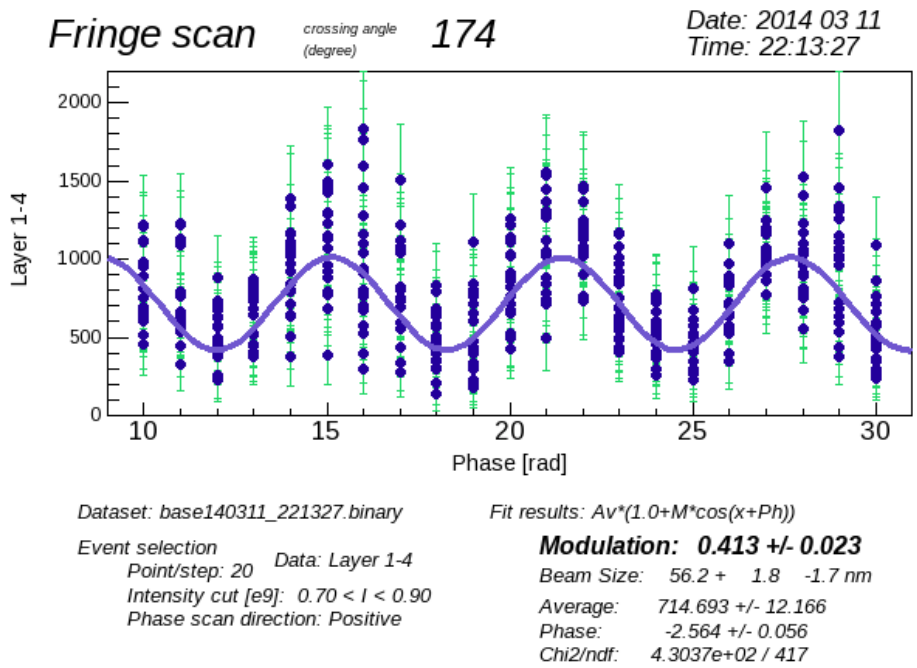
Dataset: base140311_221327.binary
Fit results: Av*(1.0+M*cos(x+Ph))
Event selection
Data: Cherenkov
Modulation: 0.437 +/- 0.029
Beam Size: 54.3 + 2.2 -2.1 nm
Average: 2293.179 +/- 48.300
Phase: -2.612 +/- 0.066
Chi2/ndf: 4.6518e+02 / 417

Cherenkov , no cut
M,meas = 0.44 +/- 0.03



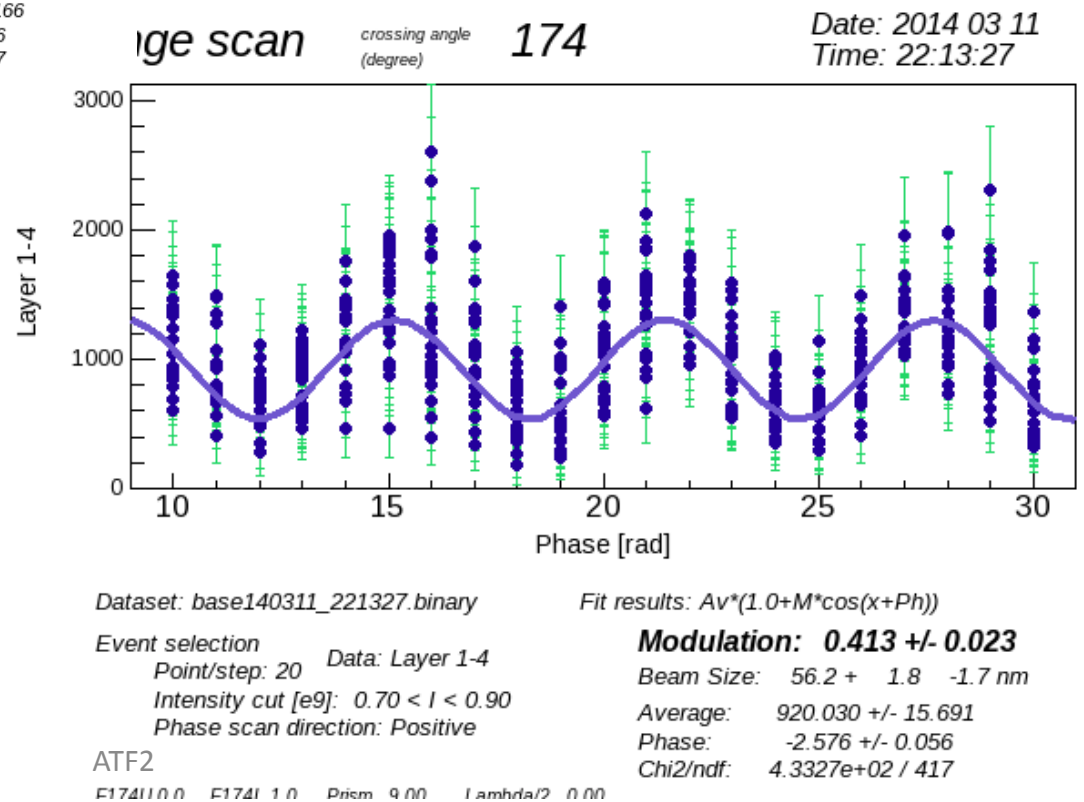
Dataset: base140311_221327.binary
Fit results: Av*(1.0+M*cos(x+Ph))
Event selection
Data: Cherenkov
Modulation: 0.414 +/- 0.018
Beam Size: 56.1 + 1.4 -1.4 nm
Average: 2573.827 +/- 34.380
Phase: -2.623 +/- 0.044
Chi2/ndf: 1.7849e+02 / 165

Cherenkov, 30% cut
M,meas = 0.41 +/- 0.02



CsI , no cut,
no ICT correction
M,meas = 0.41 +/- 0.02

No difference ICT corrected or not



CsI , no cut,
ICT corrected
M,meas = 0.41 +/- 0.02

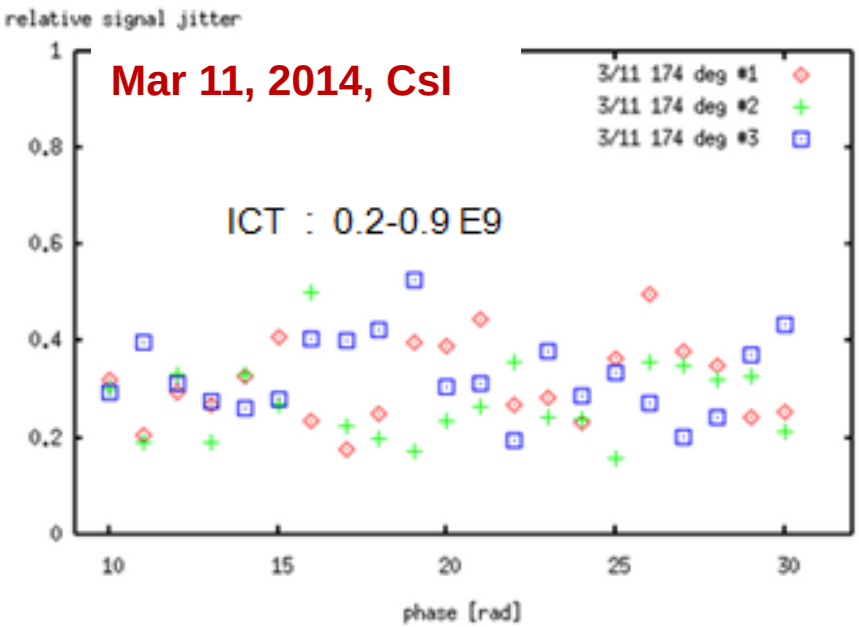
Purpose :

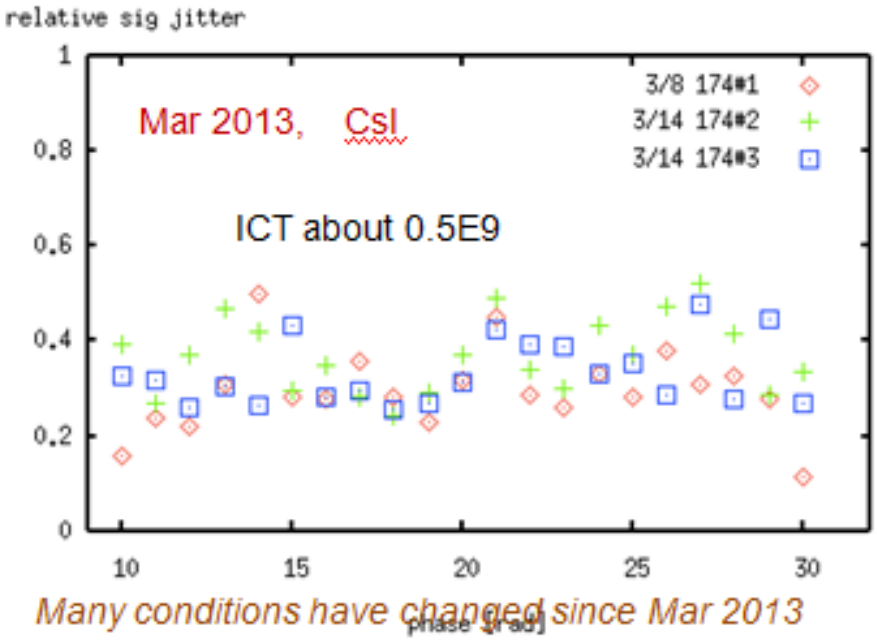
study systematic errors to correct the measured M (beam sizes)

However

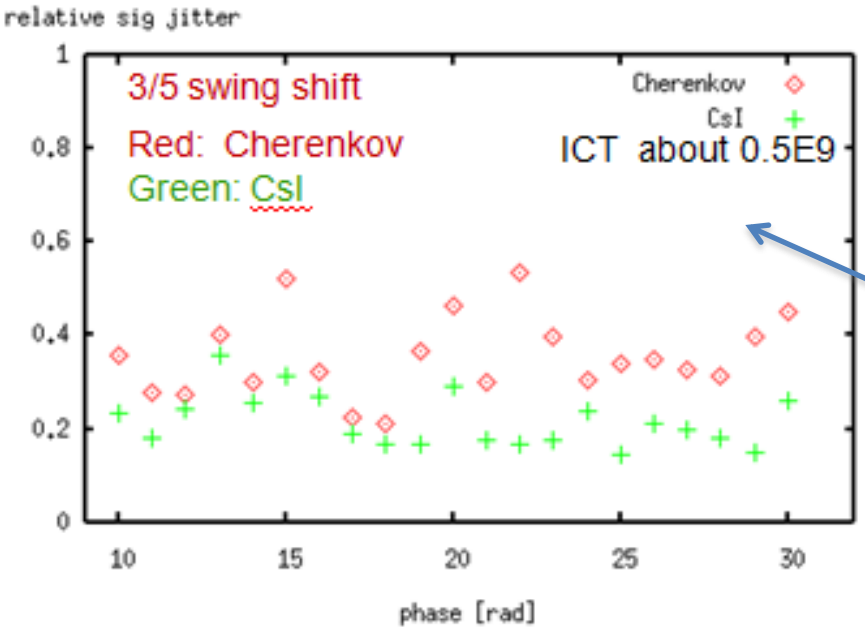
This is affected by stability

e.g. signal jitter / drift

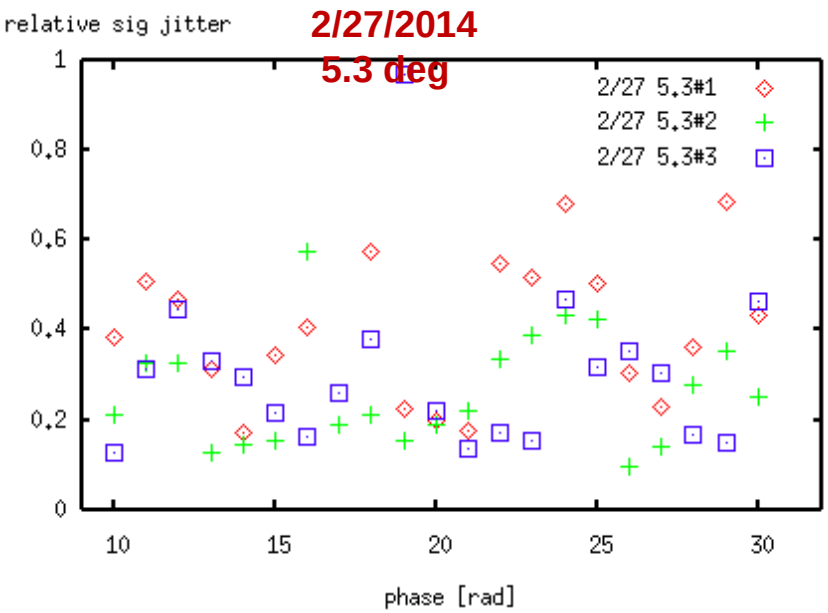


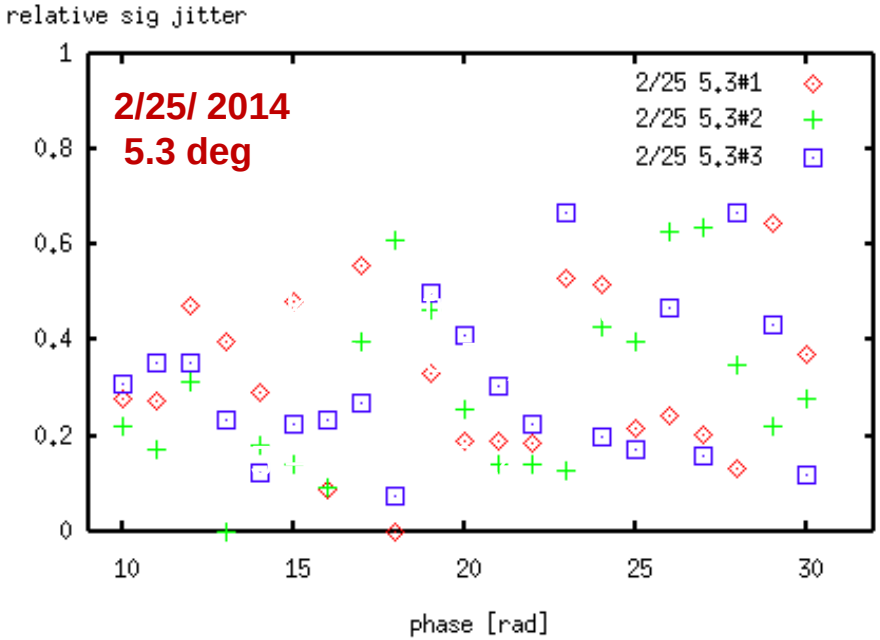


Comparison of overall signal jitter in 174 deg mode for CsI

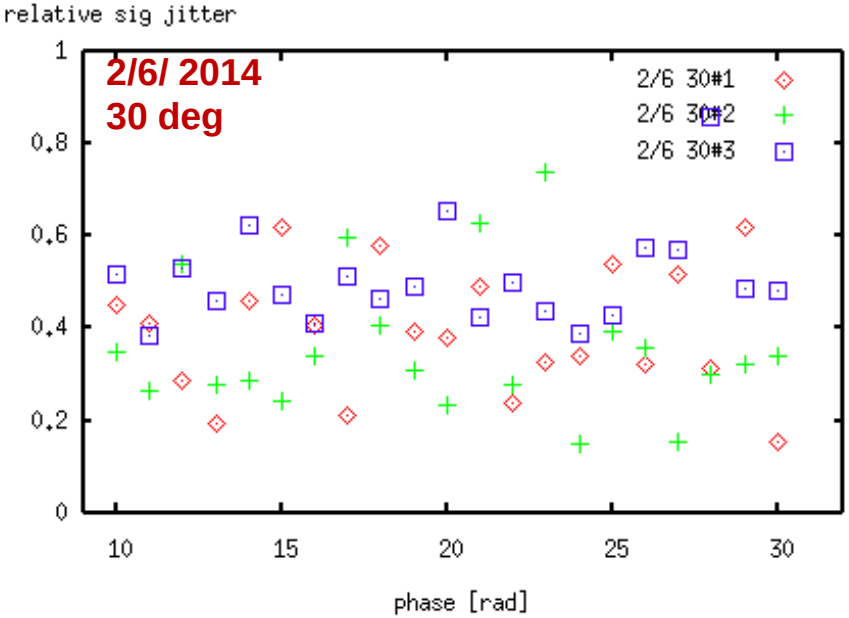


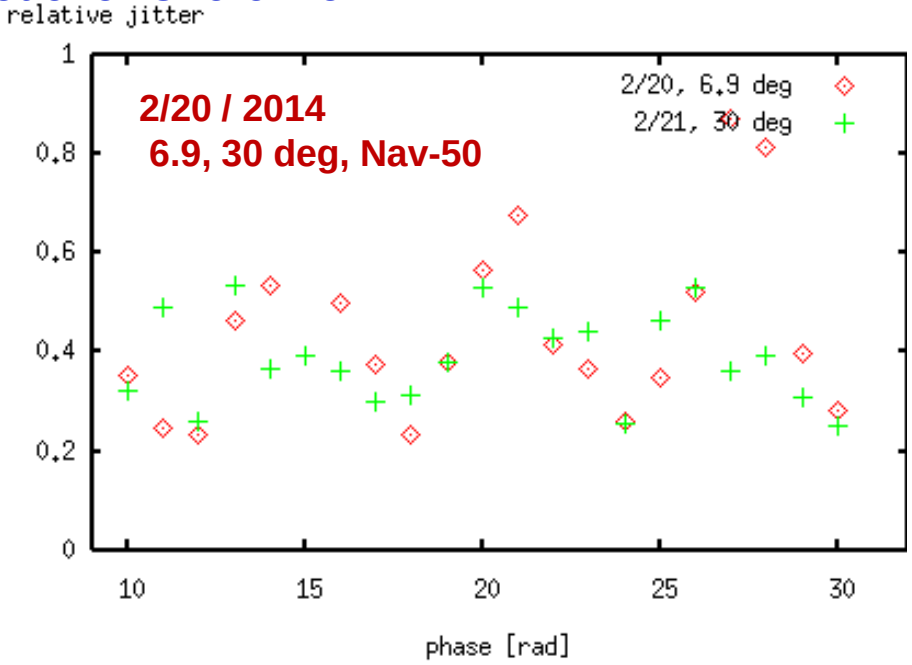
At low beam intensity (e.g. 174 deg) , smaller signal jitter for CsI than Cherenkov



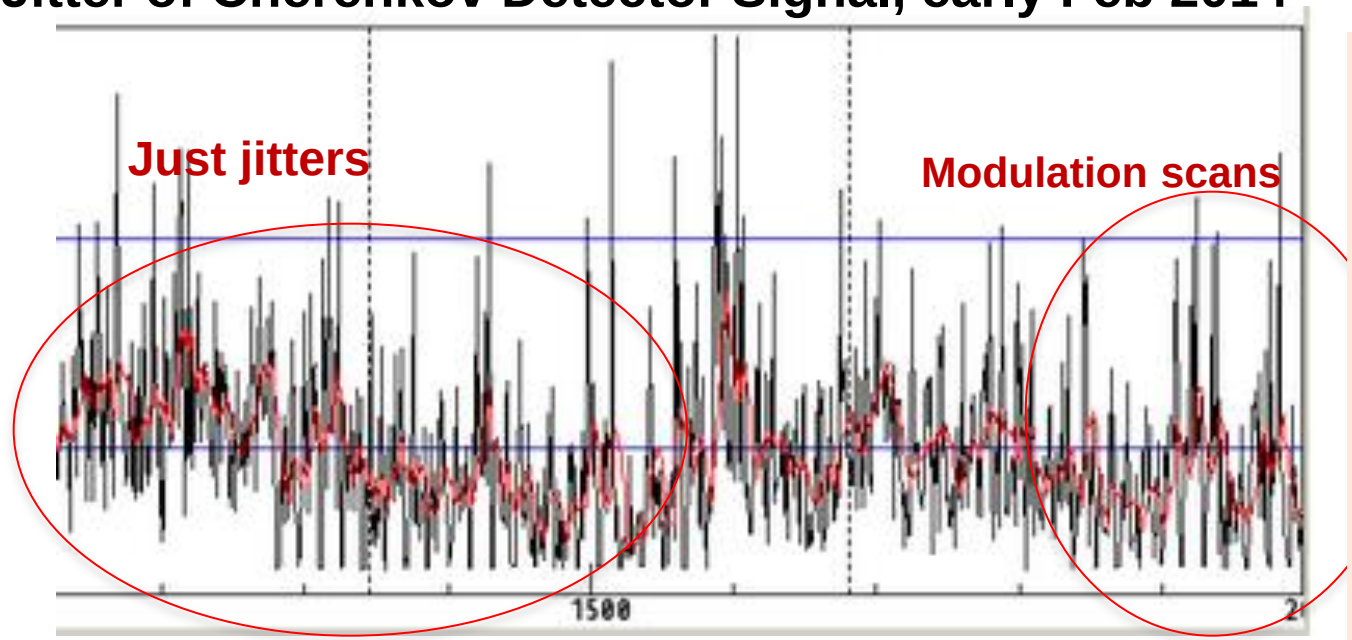


overall signal jitter in 2-8 deg, 30 deg deg mode for Cherenkov



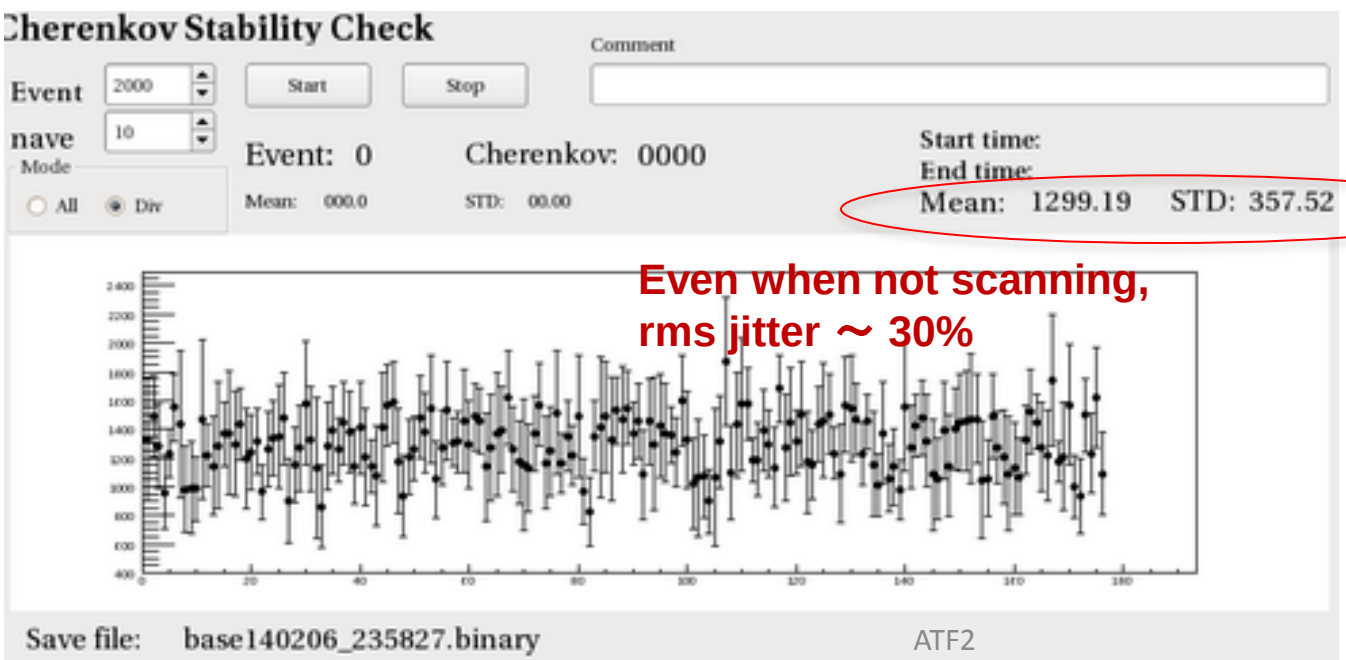


Jitter of Cherenkov Detector Signal, early Feb 2014



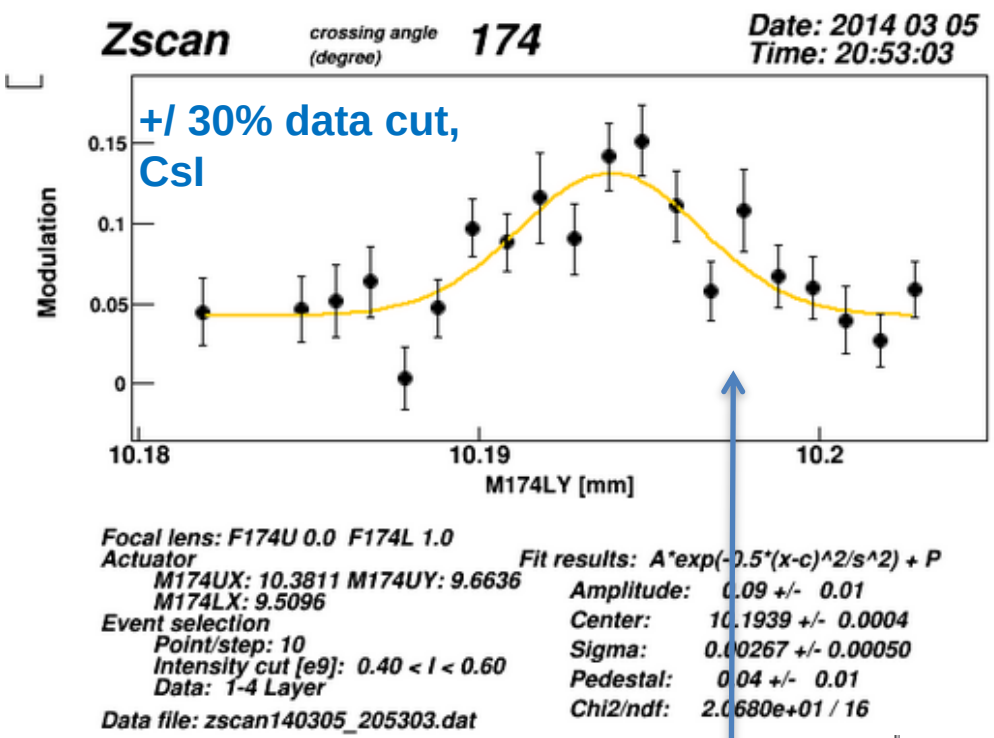
Amplitude and period of jitter is sometimes undistinguishable from fringe scan signal

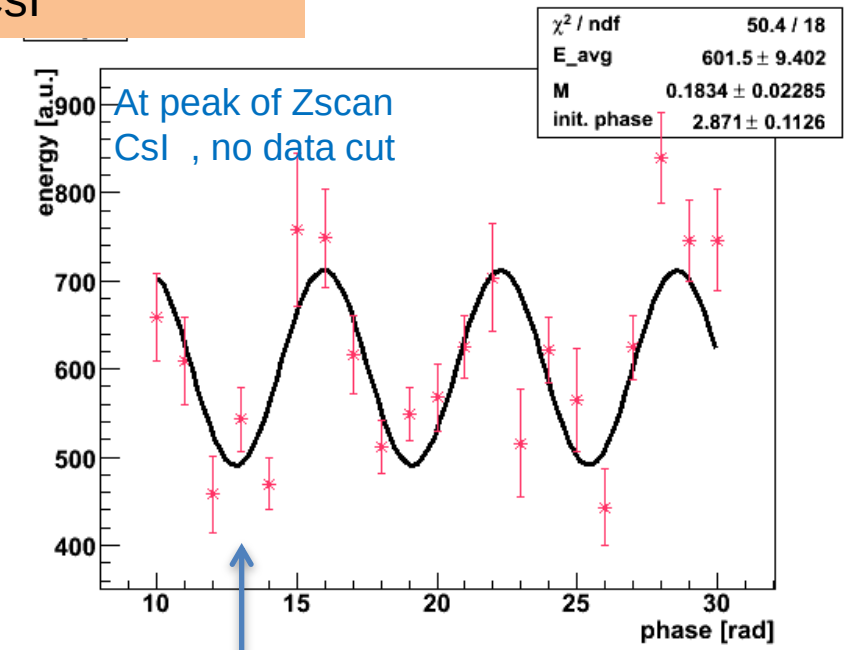
Jitters show clear **dependence on beam intensity** for Cherenkov
→ **Dominated by statistics**



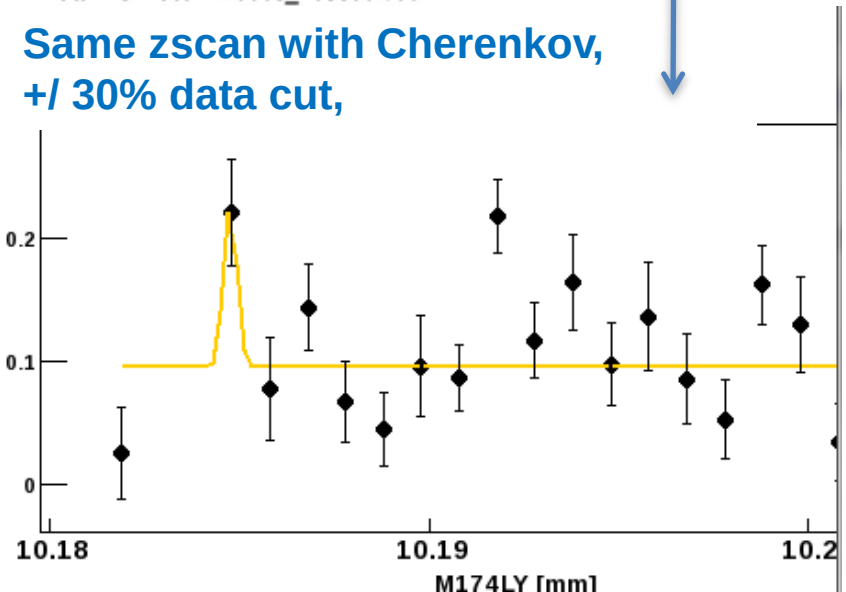
switched to CsI for low beam intensity operation (174 deg)

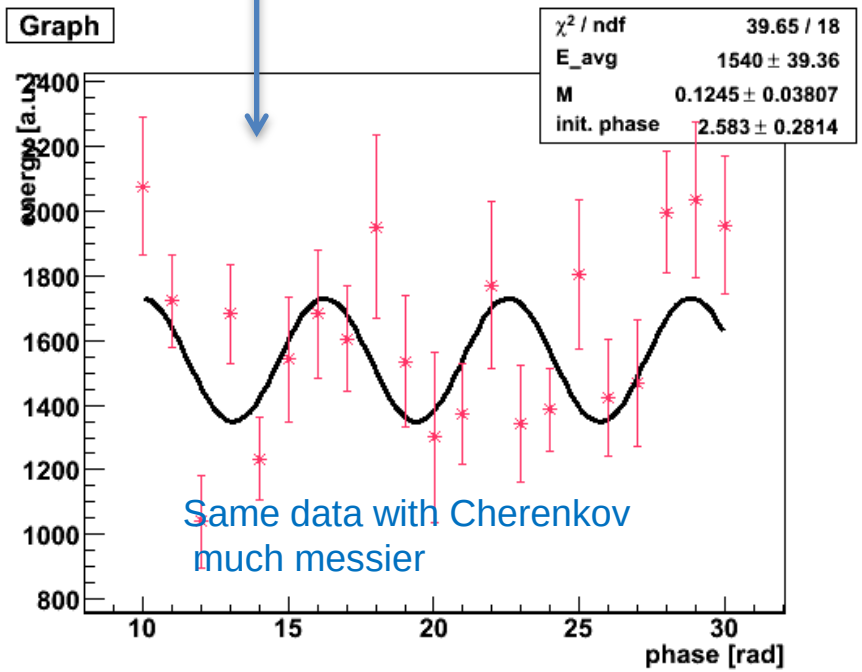
We are able to achieve a clearer Zscan using CsI

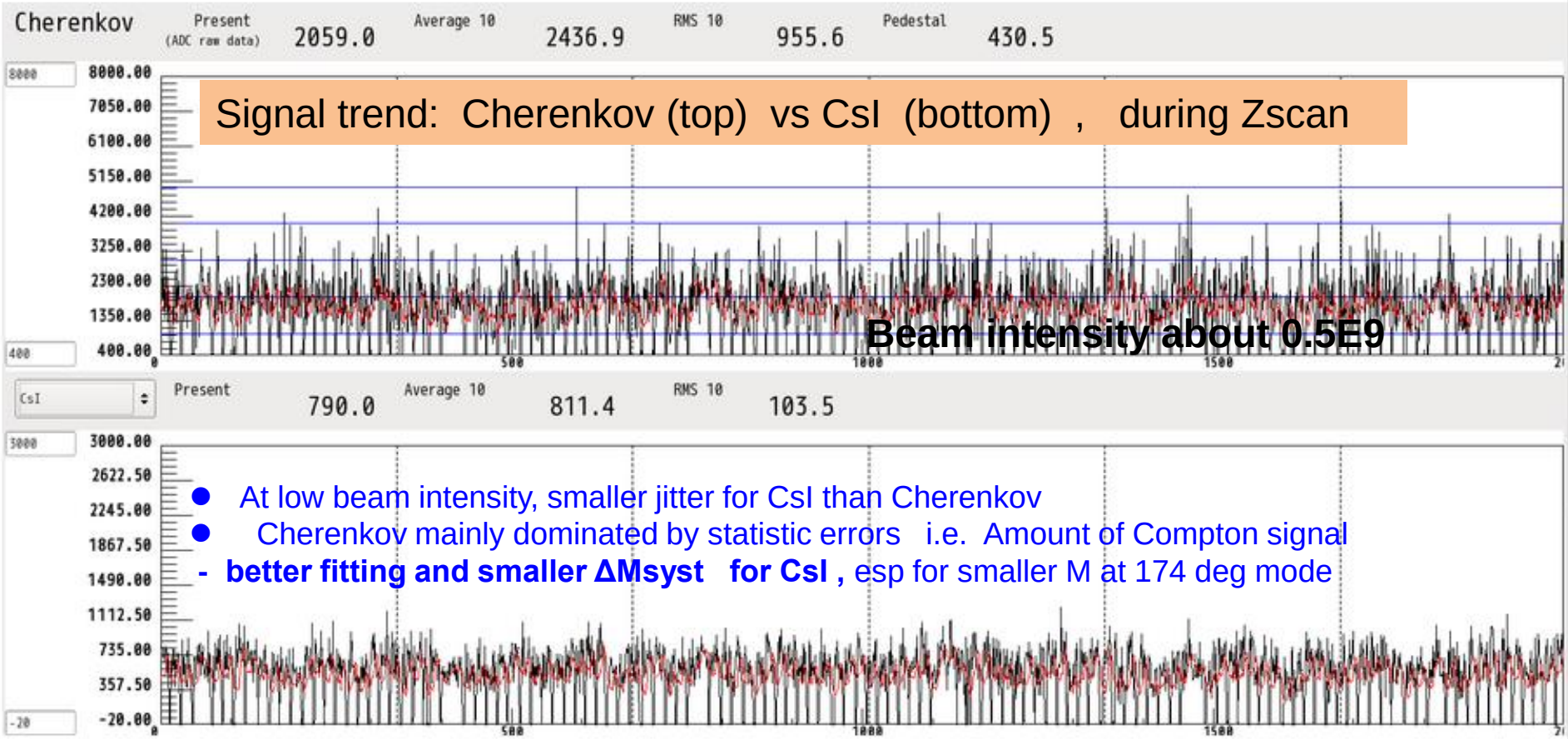




Same zscan with Cherenkov,
+/ 30% data cut,







- **Problems with CsI also !!**

nonlinear response, some PMTs malfunctioning, not capturing all signal photons (?)

- investigations have been going on for both detectors (by Terunuma-san and Okugi-san)

- will try to follow up with simulation studies

- Separate effect from change in laser and detector conditions
- simulation study under different statistical fluctuations, beam intensities ,ect…
- may be difficult to compare data with different detector, laser & beam condition, collimation

More Issues with signal jitter and laser profile

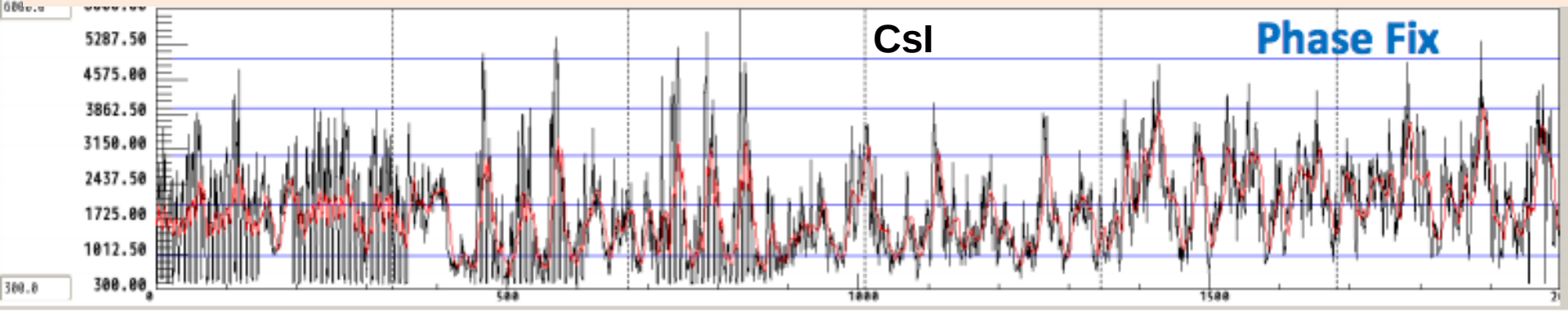
from Okugi-san 's weekly meeting slides

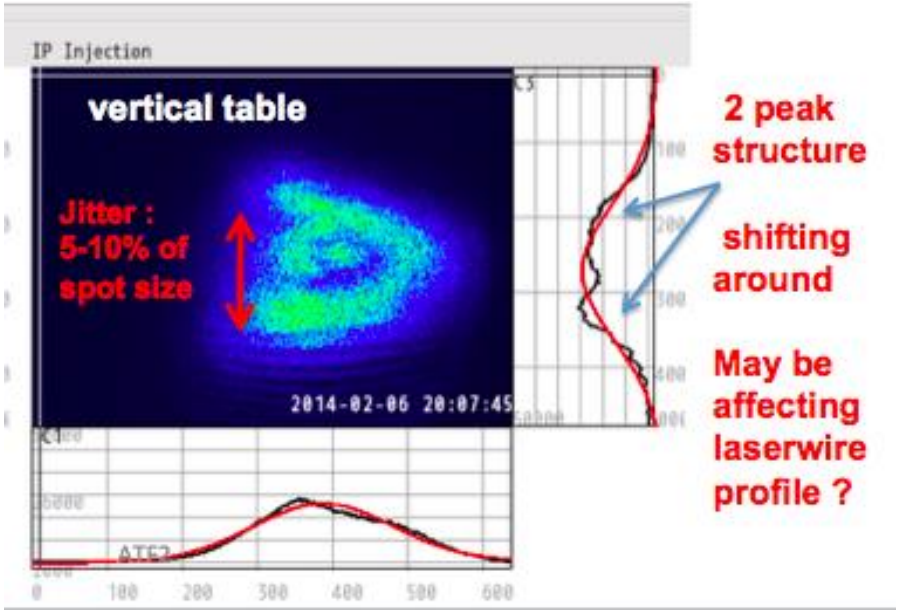
◆**Compton signal jitter observed to oscillate with period of a few min**

For both paths, single path, fixed phase , ect…

◆jitters seem to be related to **complex internal structure of laser profile at IP**

- non-Gaussian components , double peaks, dependence on spot size and lwscan position





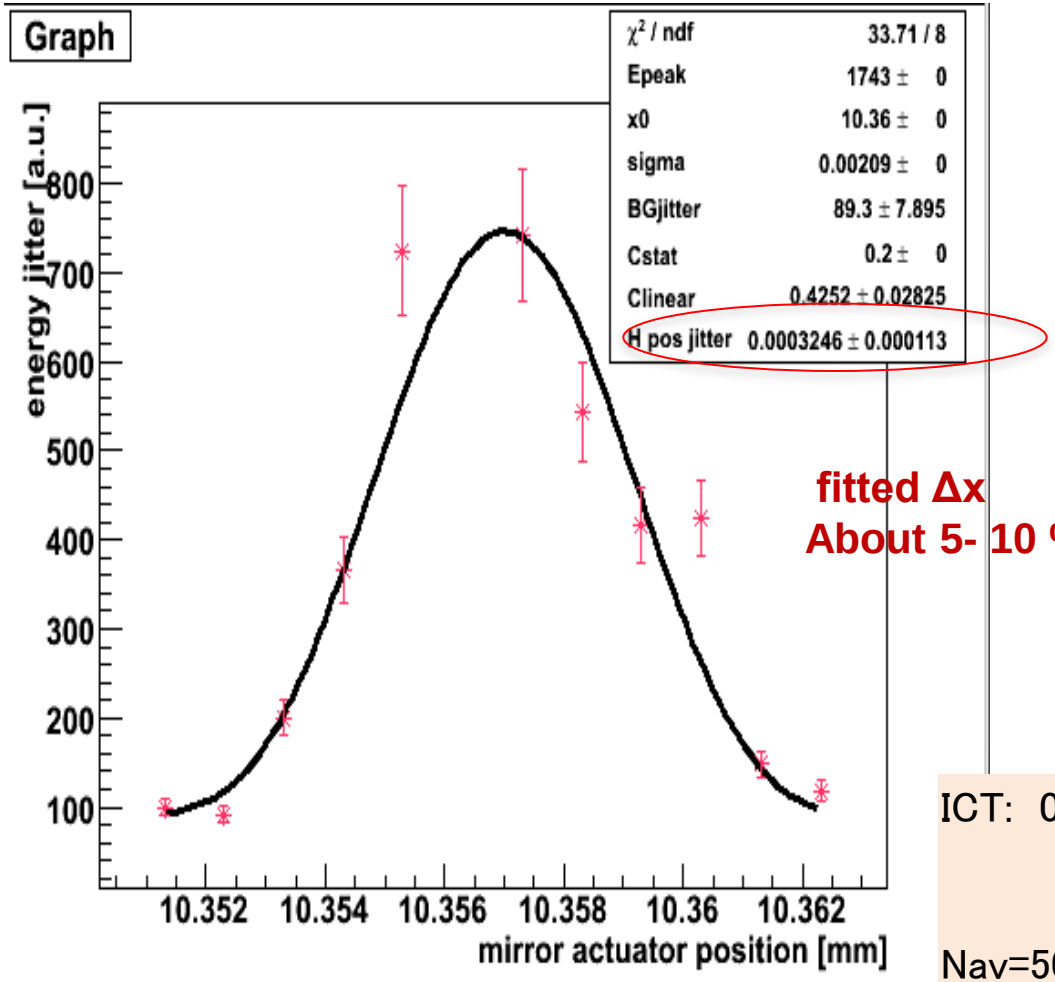
I tried to imitate oscillating jitters in simulation

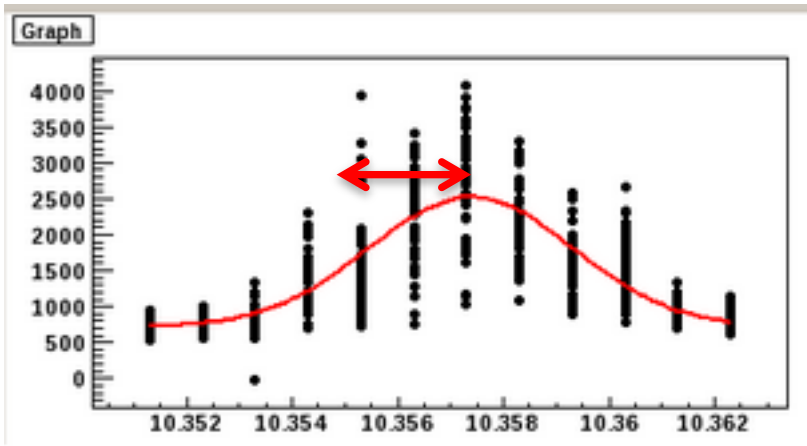
→ Coming up later ……..

compare Laser pointing stability : 3/13

➢ **30 deg mode vs 174 deg mode**

*seen from horizontal relative position jitter **(Δx)** in Nav=50 laserwire scans*





fitted Δx

About 5- 10 % of laser spot radius (2 x of sigma)

Assuming Gaussian laserwire profile (not always so)

From raw data:
RMS jitter at each location about 25%, independent of crossing angle mode

ICT: 0.5E10

Nav=50
upper path

	Δx / σ_laser
	CsI
174 deg	15+/− 5%
30 deg	13+/−6%

Potential Sources of Signal Jitters

	comments
Laser pointing jitters (H relative position jitter) *Change with beam condition*	• observed jitter (CCD) 5-10% of laser profile radius • derived "Δx" using Nav=50 laserwire scan ∼ 15% of laser sigma ←→ add few % to signal jitters
Phase jitter Δϕ (V relative position jitter)	for Δϕ = 0.5 rad , M = 0.5 : < ∼10 %@ peak , <∼20%@mid $\sigma_{E,\Delta f} = E_{avg} M \sqrt{\frac{1}{2}\left[1 - 2\cos^2(f)\exp(-\Delta f^2) + \cos(2f)\exp(-2\Delta f^2)\right]}$
Laser power jitter	< 10% from PIN-PD on laser hut table
Timing jitter	2 – 3 ns peak to peak, add < few % to signal jitters
Compton energy fluctuation	not certain : affected by collimator, detector, beam and laser intensity could exceed 10% if detector not catching enough photons
Other minor factors	
• BG fluctuation	< 5 %, (?) recently, not important when S/N is very high
• e- beam intensity (ICT) monitor resolution	Few % , now not using ICT correction

Add up → ΔE/Eavg = 20 – 30 %

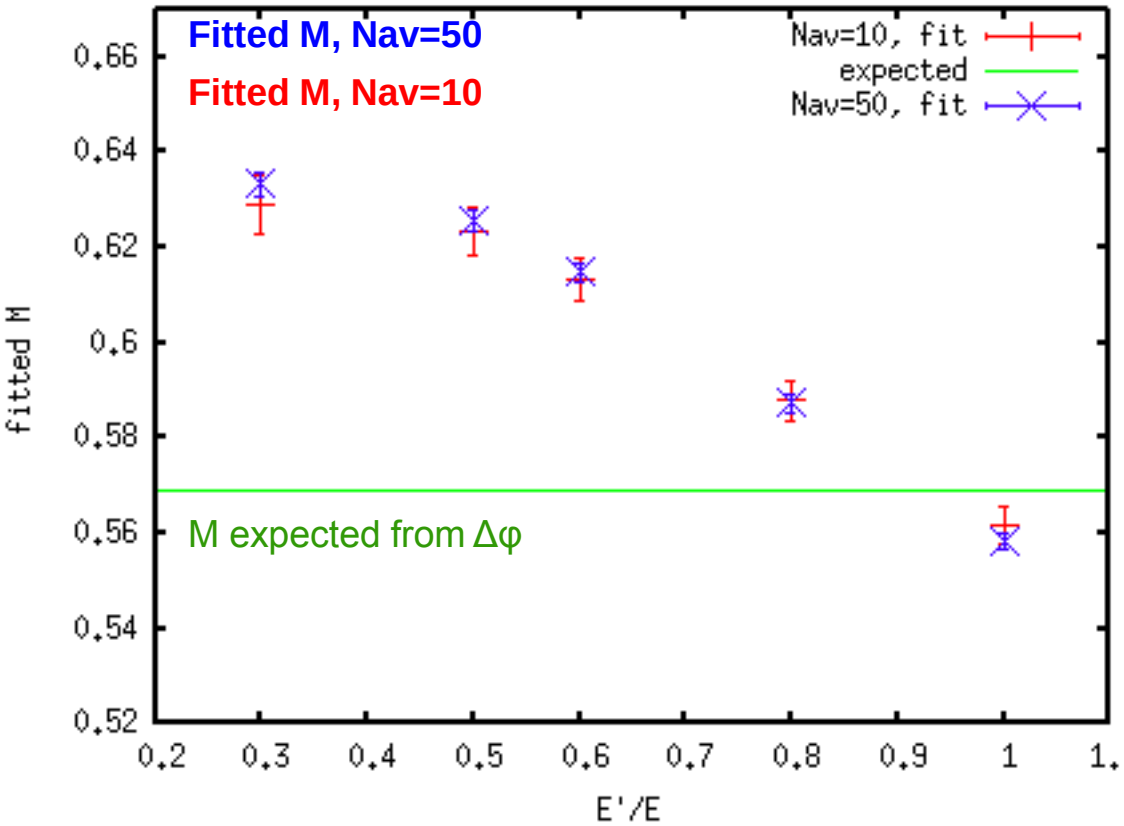
overall sig jitter (CsI) observed to be 20-40% in general, *depend on phase drifts are hard to separate from jitters sometimes*

Error Studies using simulation

Vertical jitters "C factors"

$$s_V = \sqrt{C_{const}^2 + C_{stat}^2 \times \overline{E(j)} + C_{linear}^2 \times \overline{(E(j))^2}}$$

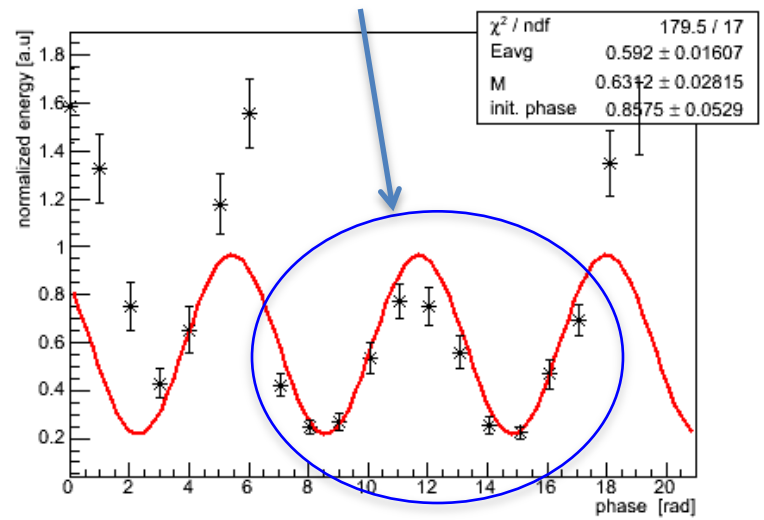
Assume Comp. signal intensity suddenly decrease 50% @ 7 – 17 rad (drift ?)
Include 2 valleys , jump range < ~ 4π



Over evaluation of M in this particular case

Actually we can tell from the large chi^2 / ndf ??

Sudden decrease E' / E = 0.5



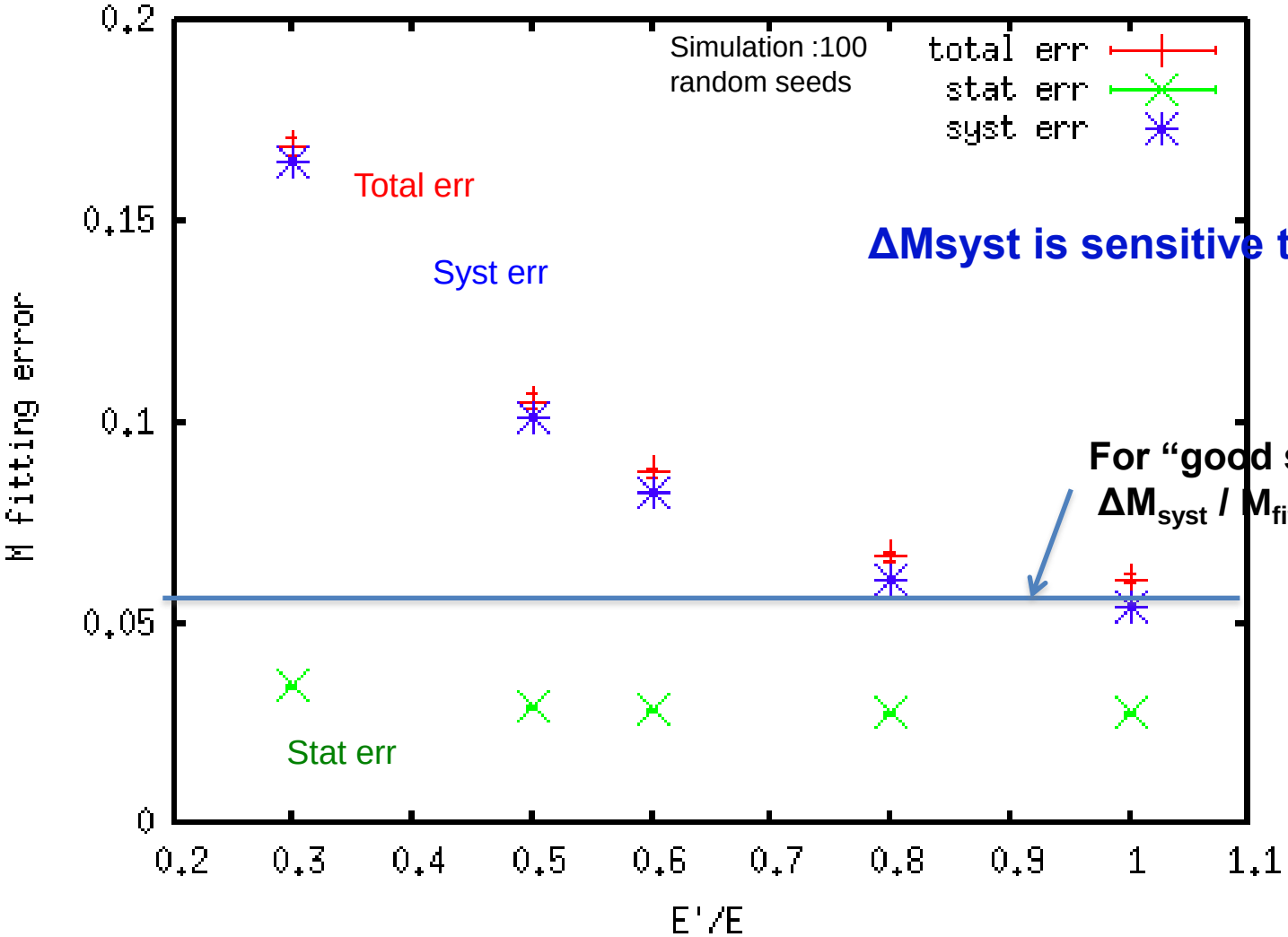
Simulation :100
random seeds

Input : M0 = 0.636, Nav=10, 174 deg mode,
Δφ = 470 mrad,
Clinear = 0.3, Cstat = 0.1, Cconst = 0.05

Compare M fitting error (ΔM) as a function of jump (drift) E'/E

Nav=10

ΔMtot^2 = ΔMstat^2 + ΔMsyst^2



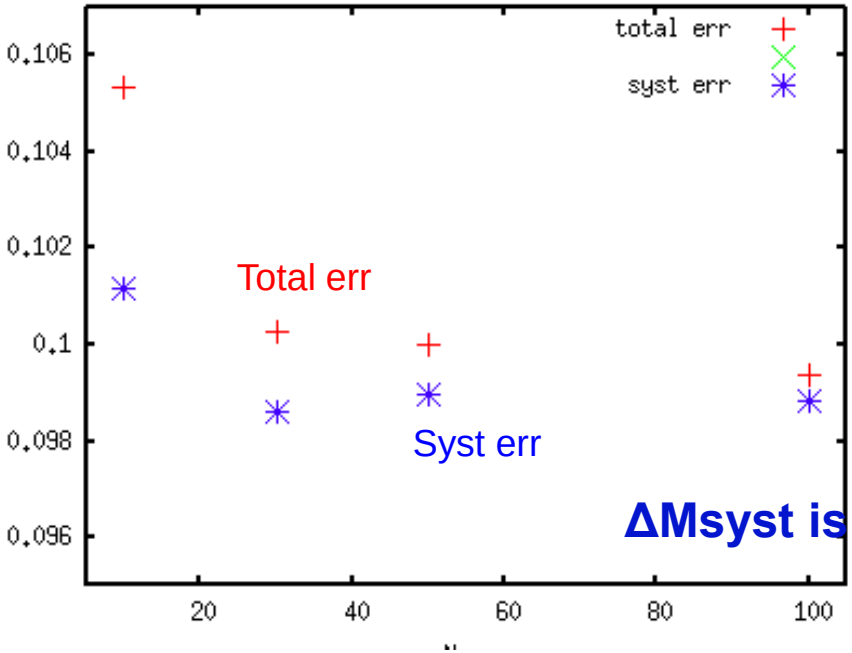
ΔMsyst is sensitive to instability

For "good scans"
$\Delta M_{syst} / M_{fit} < 10\%$

Less than 20% intensity decrease (?)

X axis: Decrease in signal intensity
@ 7 – 17 rad (drift ?)

Input : M0 = 0.636, Nav=10, 174 deg mode,
Δφ = 470 mrad,
Clinear = 0.3, Cstat = 0.1, Cconst = 0.05

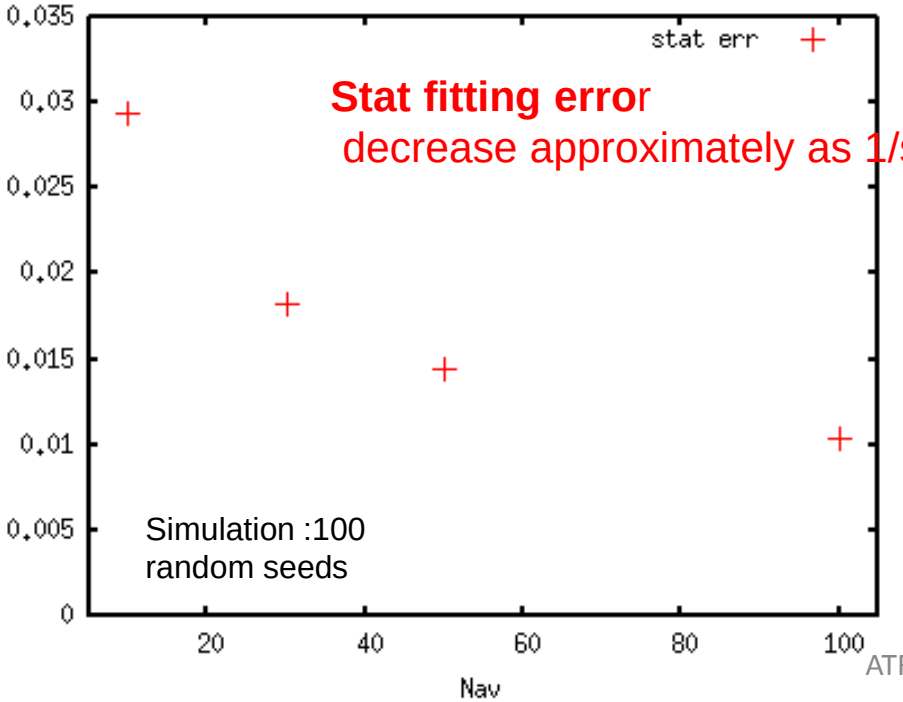


Compare M fitting error (ΔM) as a function of Nav

X axis: Nav=10, 30, 50, 100

ΔMtot^2 = ΔMstat^2 + ΔMsyst^2

ΔMsyst is not so sensitive to Nav



Stat fitting error
decrease approximately as 1/sqrt(Nav)

Simulation :100
random seeds

Assume Comp. signal intensity suddenly decrease 50% @ 7 – 17 rad (drift ?)
Include 2 valleys , jump range < ~ 4π

Input : M0 = 0.636, 174 deg mode,
Δφ = 470 mrad,
Clinear = 0.3, Cstat = 0.1, Cconst = 0.05

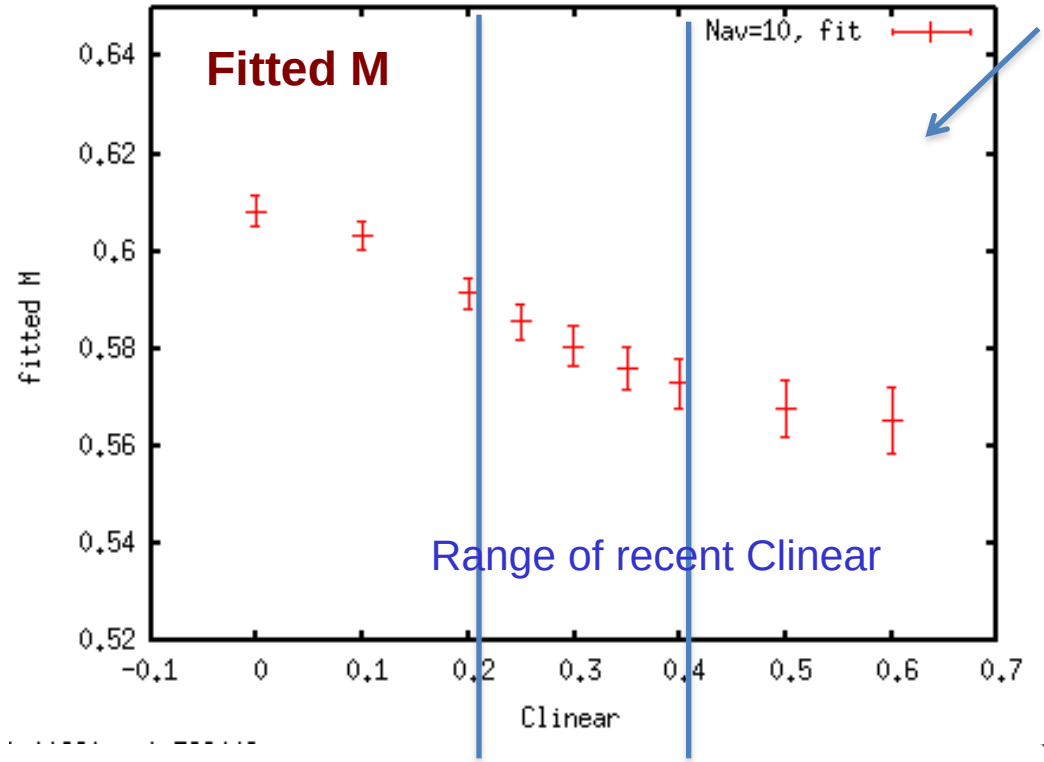
systematic fitting error ΔMsyst (similar to chi^2) for 174 deg mode

Last week is the best so far (?)

Errors are relative to M_fit

	data	ΔMtot	ΔMstat	ΔMsyst	Nav	mode	M_fit
Mar11	_221327	4.9%	4.4%	2.2%	20	174	0.43
	_230748	11.4%	4.9%	10.6%	20	174	0.35
	_234126	10.5%	4.4%	9.6%	20	174	0.39
	_001420	10.6%	6.1%	8.8%	20	174	0.33
Feb27	_090752	26.90%	14.10%	22.9%	5	174	0.31
	_092034	21.60%	14.70%	15.8%	5	174	0.31
	165954	29.80%	23.50%	18.3%	10	174	0.12
Early Feb, very big ΔMsyst , we could barely detect M							
Feb6	_070821	32.60%	21.90%	24.2%	20	174	0.15
Past 174 deg mode scans in 2013							
14-Mar-13	_160045	10.40%	9.10%	5.1%	10	174	0.29
	_161131	27.90%	14.80%	23.6%	10	174	0.23
	20-May-13	11.10%	6.00%	9.3%	10	174	0.37

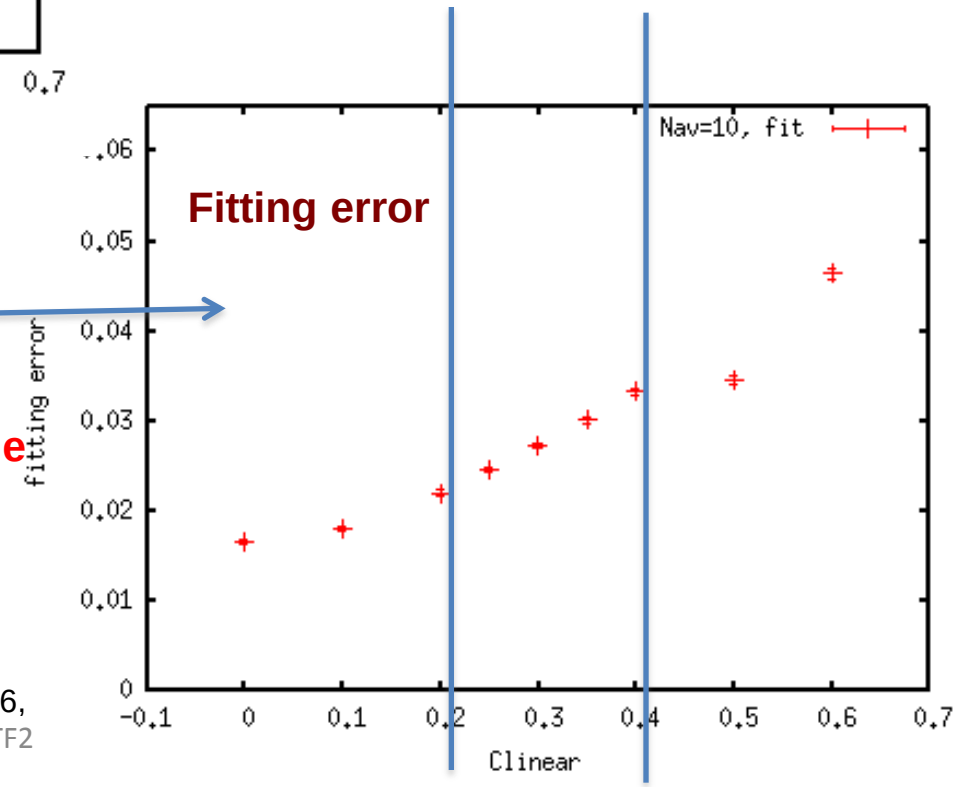
Beam current < 1E9



Effect of Clinear on fitted M

< 5 % systematic M reduction expected from Clinear

Effect of Clinear on M fitting error



ΔMstat = 0.02 - 0.03 for recent Clinear range

about consistent with real data

(c.f. ΔM < 0.02 for more stable scans)

Input : 100 random seeds, Nav=10, 174 deg mode, M0 = 0.636, Cconst = 0.05, Cstat = 0.1, Δφ = 470 mrad

Study of IPBSM Phase Jitter

Tested Method using Simulation

<u>Input conditions:</u>

σ_{0y} = 40 nm, M_0 = 0.636, 174 deg mode

Vary $\Delta\varphi$ = {0.23, 0.47 , 0.70, 0.91, 1.2} rad
<-> Δy = {10 , 20 , 30 , 40 , 50 } nm

About 24% vertical jitter (> ~ typical)
Cstat = 0.07 Cconst =0.05 **Clinear =0.23** ***realistic assumptions??***

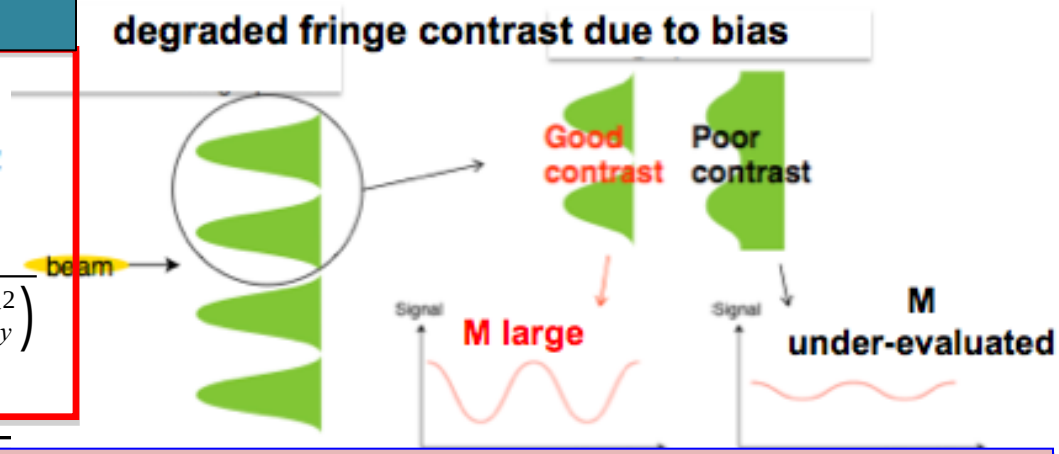
Systematic errors : M reduction Factor

M under-evaluation

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

σ_y over evalution

$$s_y \rightarrow \sqrt{s_y^2 + \sum_i \left| \ln(C_i) \right| / \left(2k_y^2 \right)}$$



Priority is to resolve signal jitters / drifts (→ enable precise evaluation of M reduction factors)

phase jitter (V relative position jitter)	studied using simulation and monitor actual data **Details coming up**
Fringe tilt (z, t)	Optimization by **"tilt scan"** → jitters were too large to try this recently (?)
Laser polarization	polarization measured → optimize by "λ / 2 plate scan "
Misalignment **Laser profile** **Spatial coherence**	profile change shot-by-shot Non-Gaussian profile → sometimes observe 10-20% M reduction
Phase drift	Negligible during typical beam tuning if linear drift < 100 mrad/min maybe partially coupled with laser position drift / jitters → Compton signal intensity drift

Phase jitter Δϕ

(relative position jitter Δy)

- *Hard to separate phase jitter from e-beam jitter and vertical jitters*
- *conditions change over time*

Δφ → M reduction

Small σy especially sensitive !!*

$$y \to y + \Delta y \qquad s_y^2 \to s_y^2 + (\Delta y)^2$$

$$\Delta f = 2k_y \Delta y \qquad k_y = \frac{2p}{l}\sin\left(\frac{q}{2}\right)$$

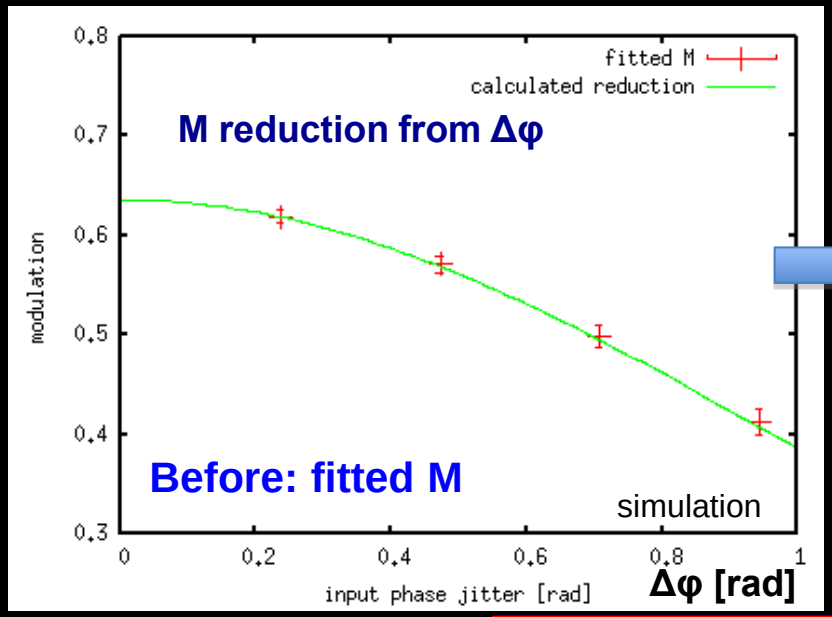
$$C_{\Delta f} = \exp\left(-\frac{\Delta f^2}{2}\right)$$

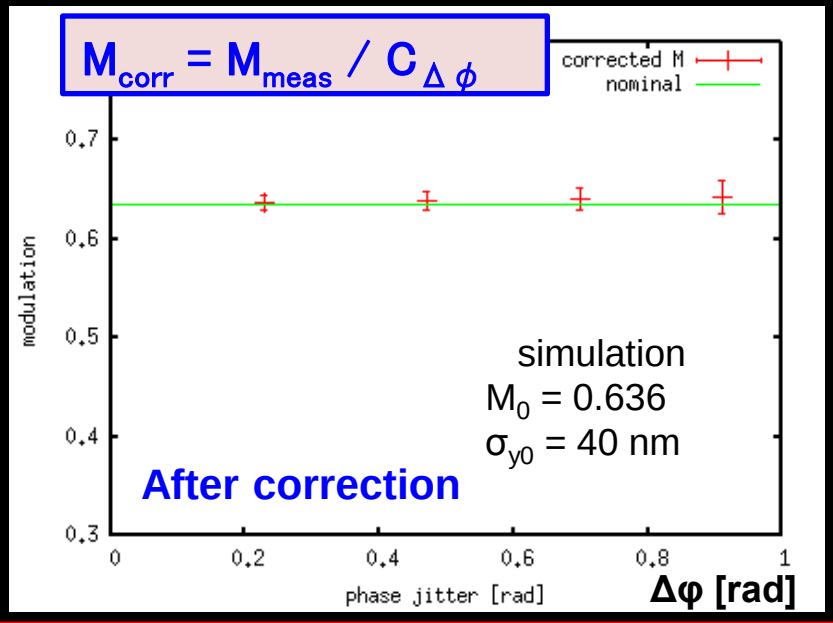
(example)

if Δϕ = 400 mrad, CΔϕ ~ 90.5 %

σ_{y0} = 40 nm → $\sigma_{y,meas}$ = 44 nm

we have developed a method for extracting Δϕ





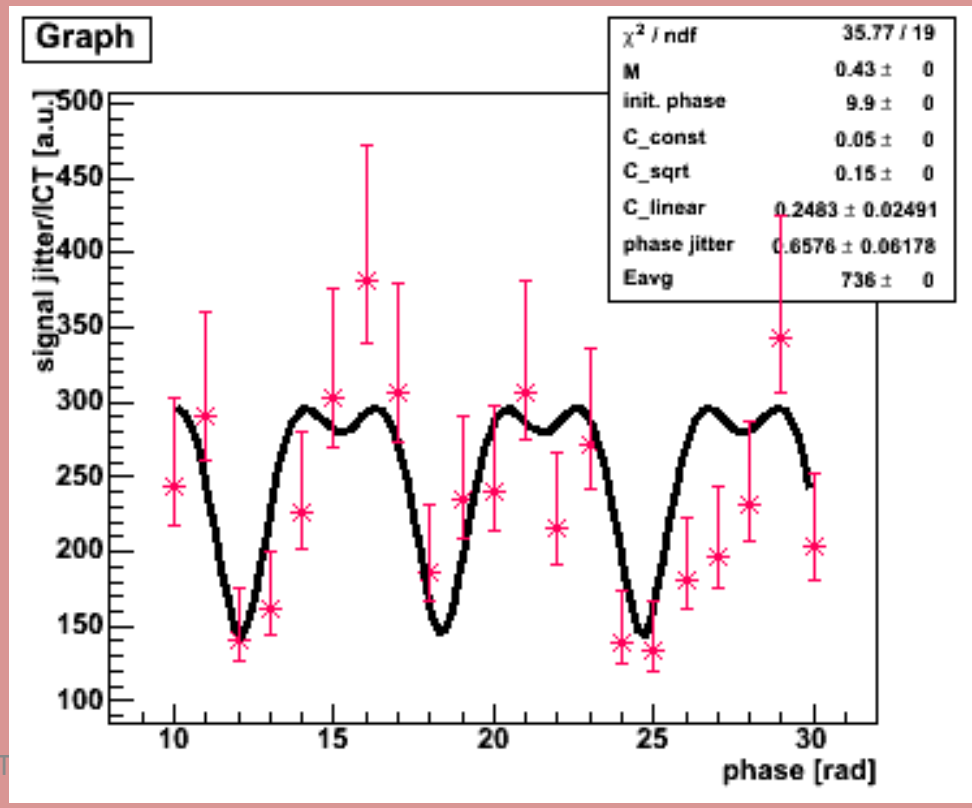
M is corrected almost back to nominal using extracted Δϕ

first look at Δφ and M reduction study @ 174 deg mode since Mar 2013

this week, Cstat is fixed as 0.15 in fitting (CsI, ICT < 1E9)

but actually in general
results stay same when Cstat is fixed to different values (e.g. 0.05 – 0.25) !!

Average: $\Delta\phi$ = 0.72+/−0.04 rad
(Mar 11, 2014)



3/11 swing shift: ICT cut: 0.7E9 →0.9E9, Nav=20

data	Mmeas	Δφ [rad]	Clinear	Δy [nm]	Δy/σmeas	σmeas [nm]	σcorr [nm]
_221327	0.43+/−0.02	**0.65+/−0.06**	0.25+/−0.02	**28**	**0.56**	55	47
_230748	0.35+/−0.02	**0.76+/−0.07**	0.20+/−0.03	**32**	**0.56**	62	53
_234126	0.39+/−0.02	**0.74+/−0.05**	0.15+/−0.03	**31**	**0.58**	58	49

Clinear = 0.20+/−0.04

average Δφ = 0.72+/−0.04 rad Δy = 30+/−1 nm

2- 8 deg: Δφ < 500 mrad, 30 deg: ~ 600 mrad , quite consistent week-to-week

- **How reliable is this Δφ ??** (→ precision demonstrated in LCWS & ATF Meeting slides)
- **Recent issue is fixed Cstat** (~ 1/sqrt(Nγ) if detector is reliable)
- Nγ (entering detector) ~ 100 – 500 / bunch for ICT = 0.5E9 : Cstat = 4 – 10%

HOWEVER :

- nonlinear response of CsI detector
- low statistics for Cherenkov

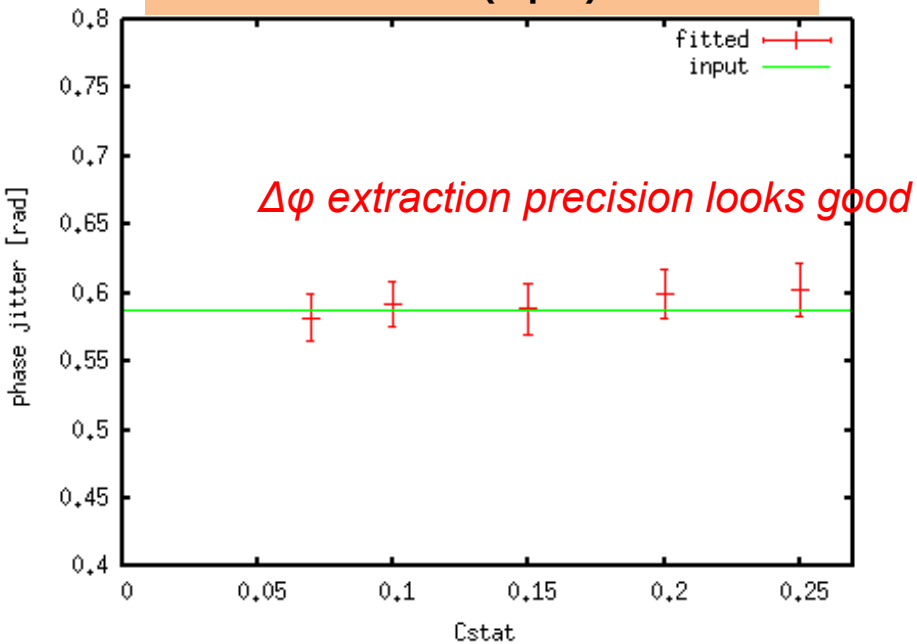
→ **tested limit of Cstat** (see next pages)

$$s_V = \sqrt{C_{const}^2 + C_{stat}^2 \times \overline{E(j)} + C_{linear}^2 \times \overline{(E(j))^2}}$$

ATF2

ATF2

If fix Cstat as real (input) Cstat

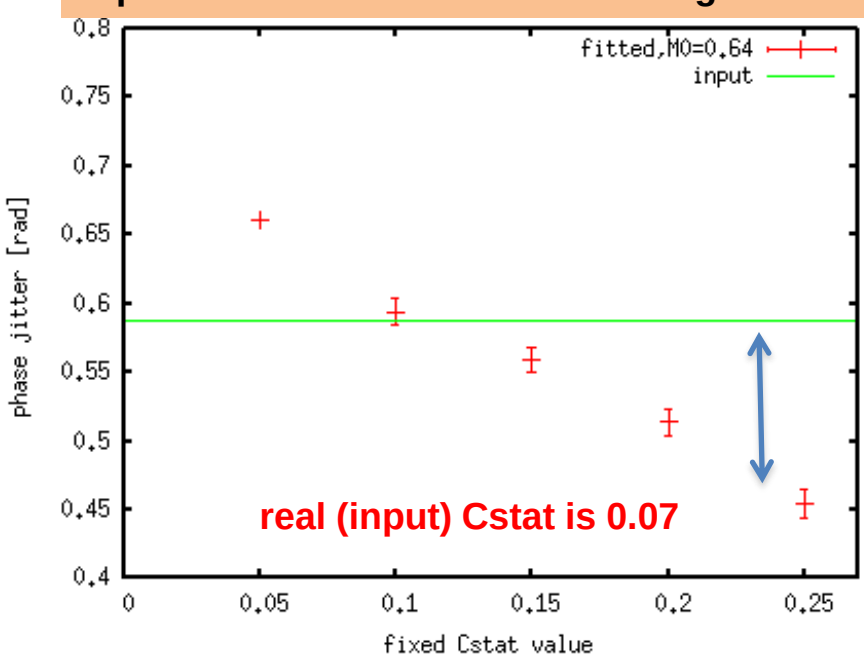


$$s_V = \sqrt{C_{const}^2 + C_{stat}^2 \times \overline{E(j)} + C_{linear}^2 \times \overline{(E(j))}^2}$$

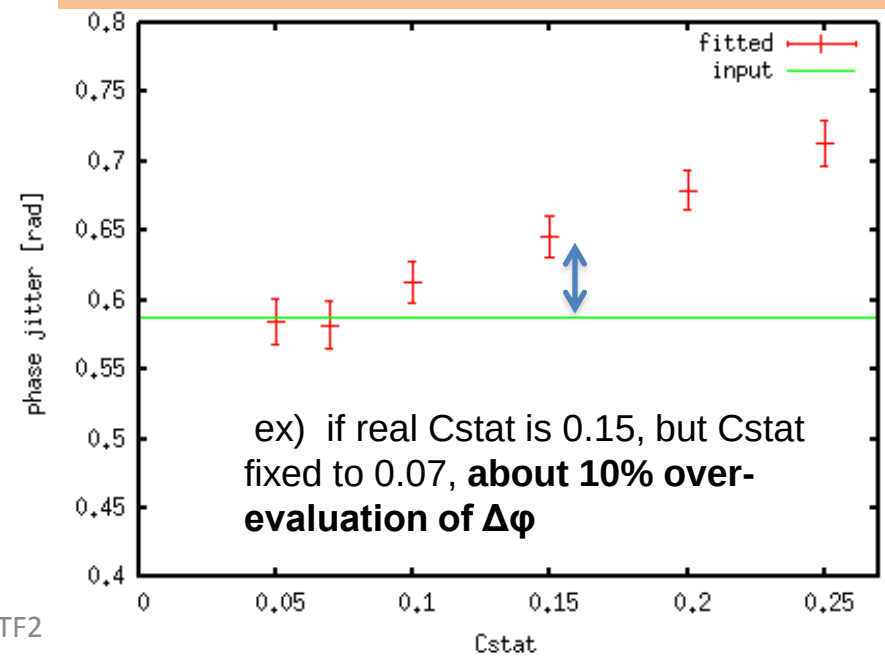
average and rms/sqrt(100) of 100 random seeds

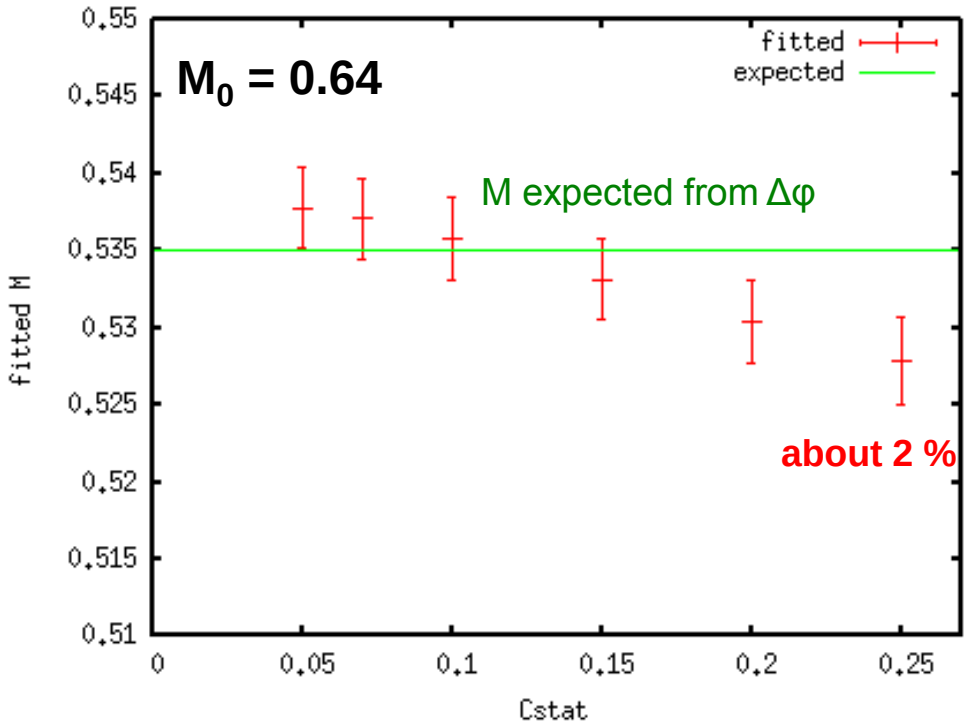
input:
M0 = 0.64, σy0 = 40 nm, 174 deg mode, Nav=20,
Clinear = 0.25, Cconst = 0.05, Δφ = 0. 588 rad

Δφ is under-evaluated if fix too large Cstat



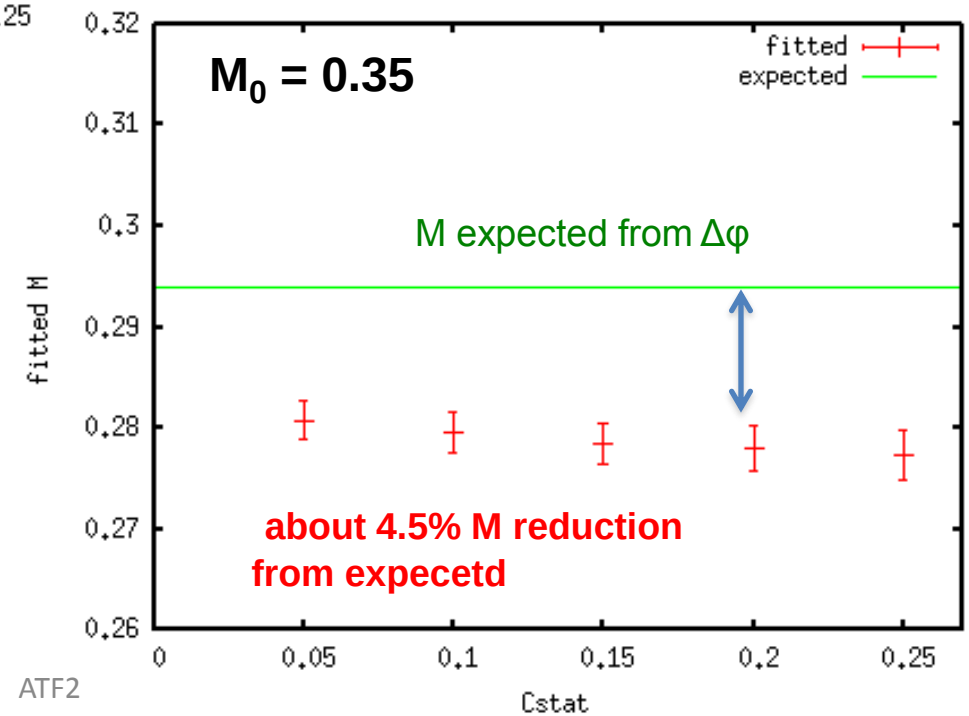
Δφ is over-evaluated if fixed Cstat is too small 0.07 even if real (input) Cstat is larger





higher M_0 receive less effect from systematics due to vertical jitters

about 2 % M reduction from expected

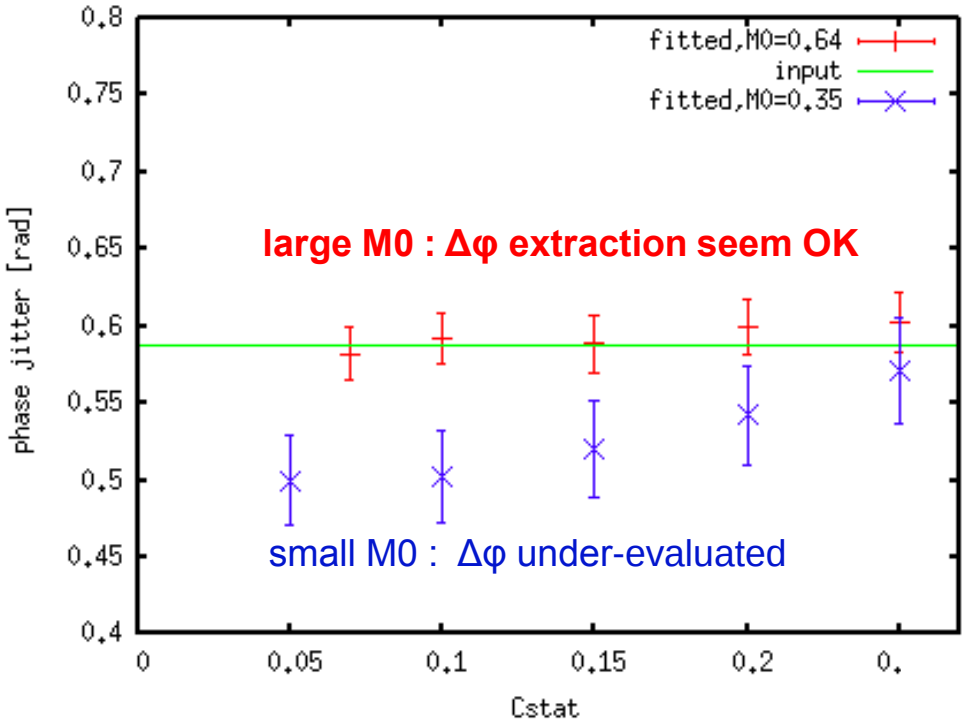


about 4.5% M reduction from expecetd

simulation:
average and rms/sqrt(100) of 100 random seeds

input: 174 deg mode,
Nav=20, Clinear = 0.25, Cconst = 0.05, Δφ = 0. 588 rad

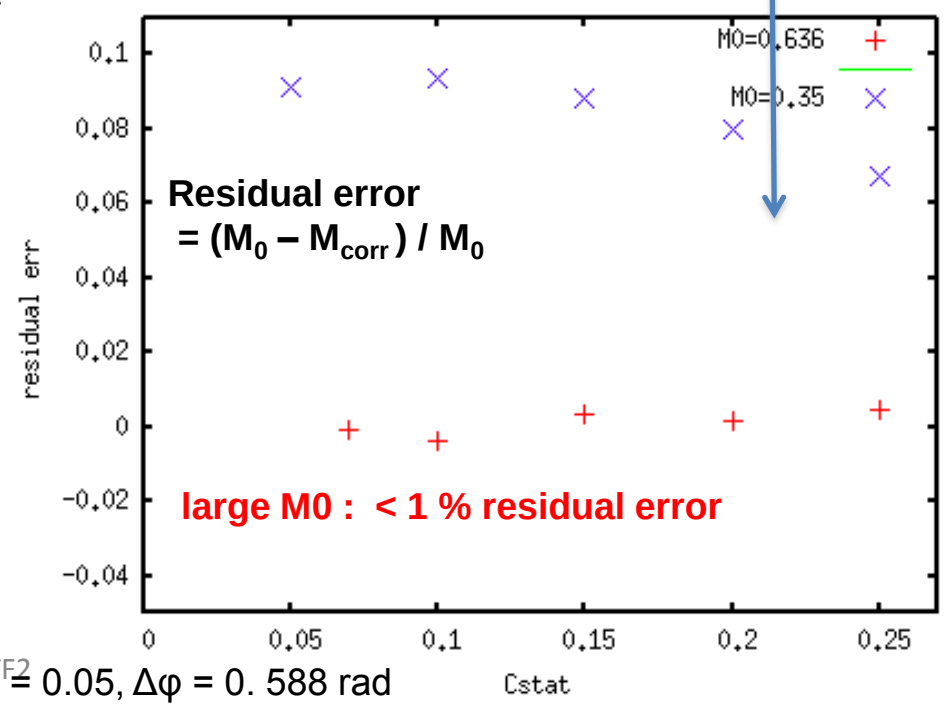
ΔΦ and M precision is better for higher M_0



Need to be careful with
$M_{corr} = M_{meas} / \exp(-\Delta\varphi^2/2)$

How close is M_{corr} to M_0 ??

small M0 : 6-8% residual error
not corrected enough by Δφ



larger Nav give better results for any M_0
(systematics is lighter)

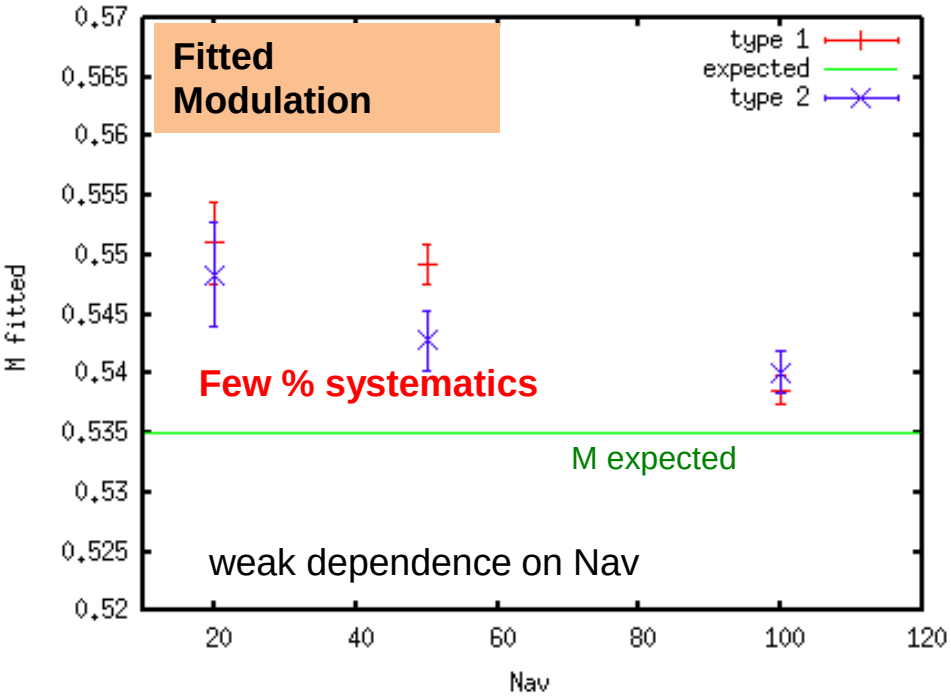
simulation:
average and rms/sqrt(100) of 100 random seeds

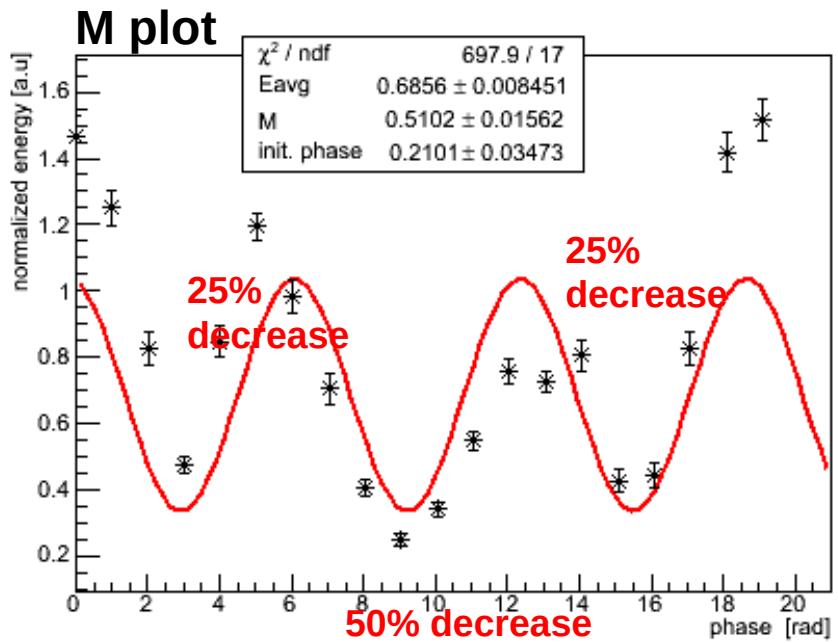
input: 174 deg mode, Nav=20, Clinear = 0.25, Cconst = 0.05, Δφ = 0. 588 rad

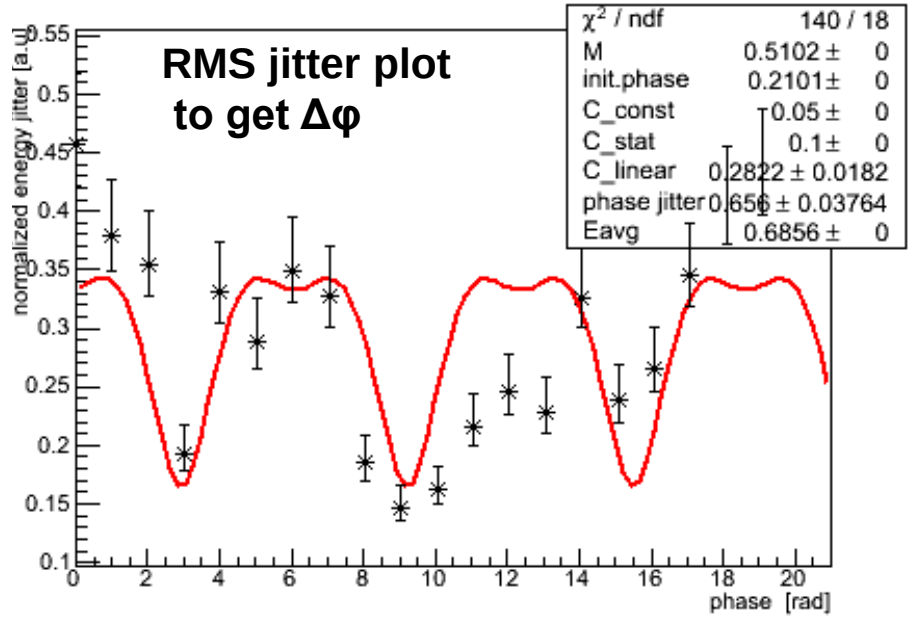
Try to imitate oscillating jitters

Jitter period ~ few min
←→ close to length of fringe scan

type 1: light case:
normal → 85% → 65% → 85% → normal
type 2: heavy case:
normal → 75% → 50% → 75% → normal





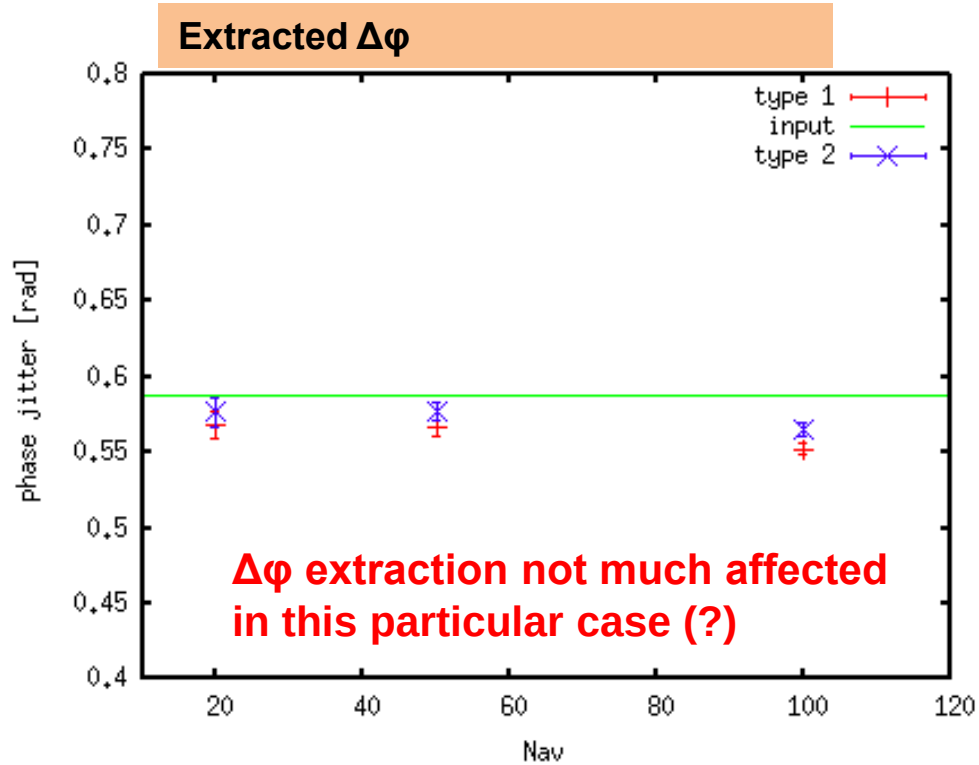


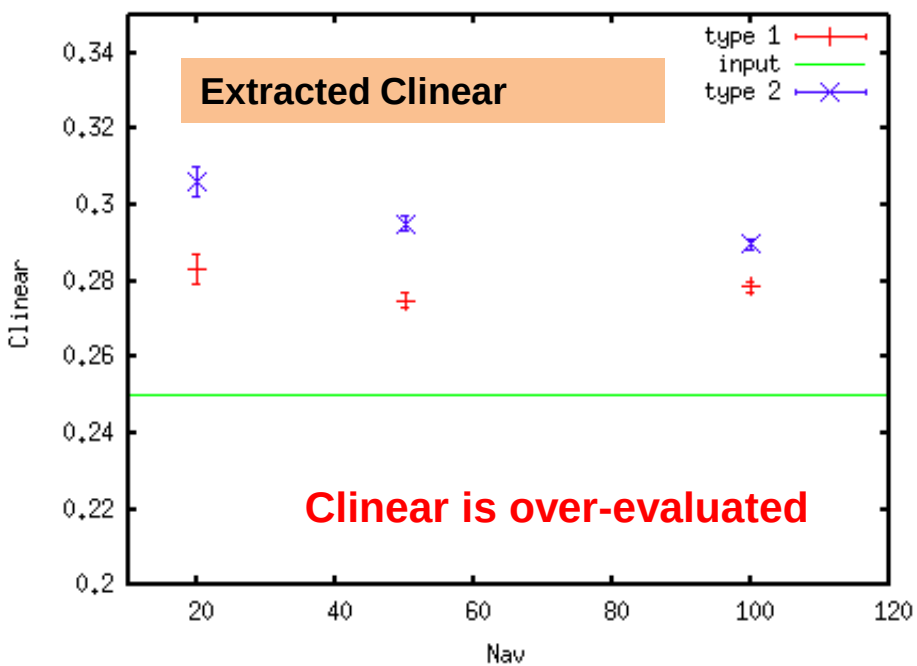
average and rms/sqrt(100) of 100 random seeds
input:
M0 = 0.64, σy0 = 40 nm, 174 deg mode, Nav=20, Clinear = 0.25,Cstat = 0.10, Cconst = 0.05, Δφ = 0.588 rad

Try to imitate oscillating jitters

Jitter period ~ few min
←→ close to length of fringe scan

type 1: light case:
normal → 85% → 65% → 85% → normal
type 2: heavy case:
normal → 75% → 50% → 75% → normal



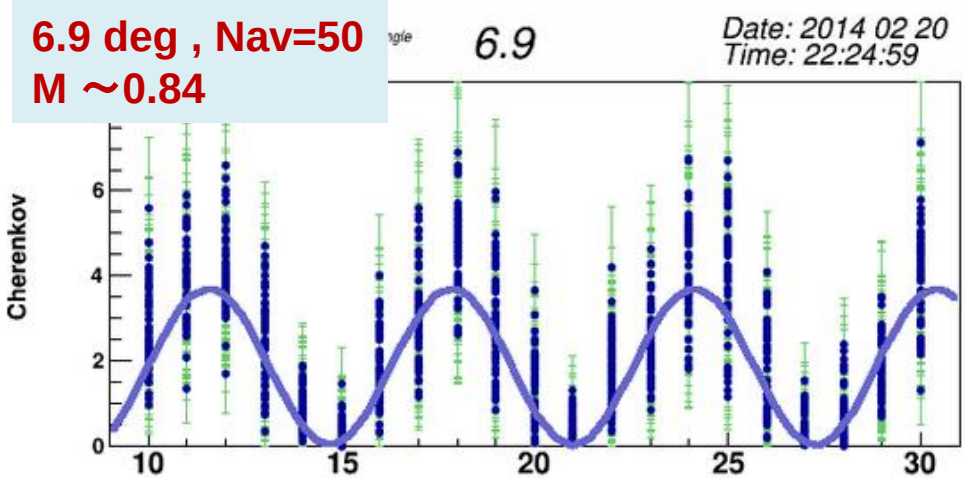


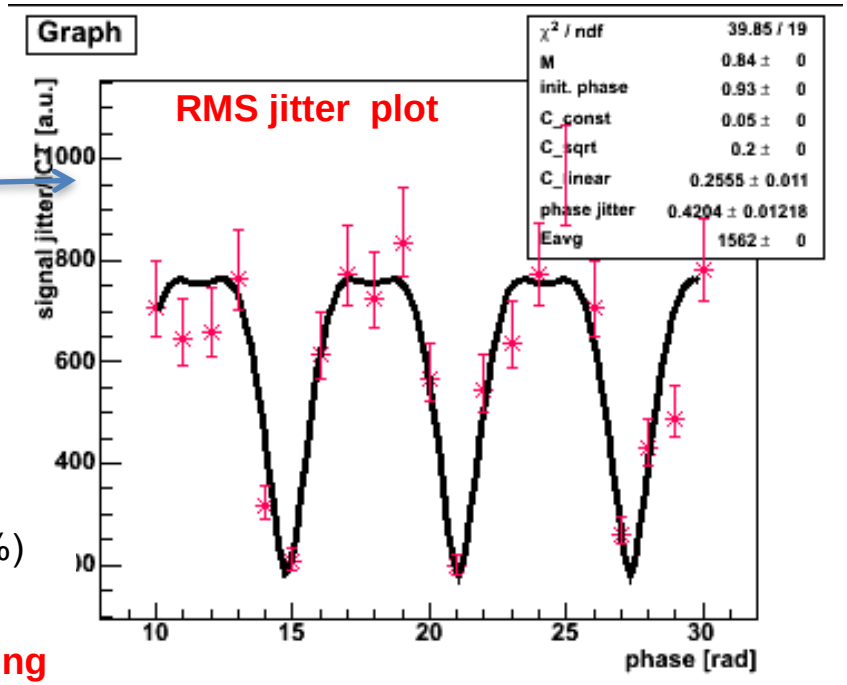
average and rms/sqrt(100) of 100 random seeds
input:
M0 = 0.64, σy0 = 40 nm, 174 deg mode, Nav=20, Clinear = 0.25,Cstat = 0.10, Cconst = 0.05, Δφ = 0.588 rad

Study of M reduction based on

- Mode switching : 6.9 deg → 30 deg data (Feb 20)
- Small σy @ 174 deg (Mar 11)

6.9 deg , Nav=50
M ~0.84



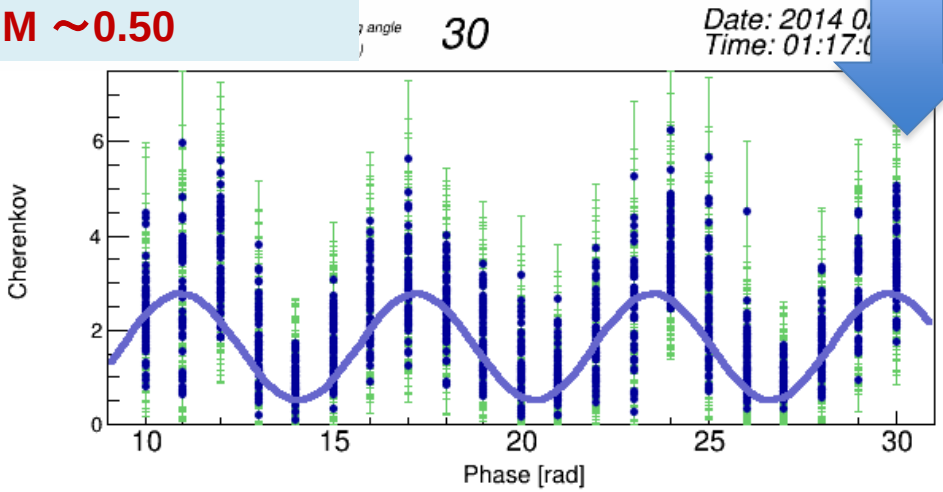


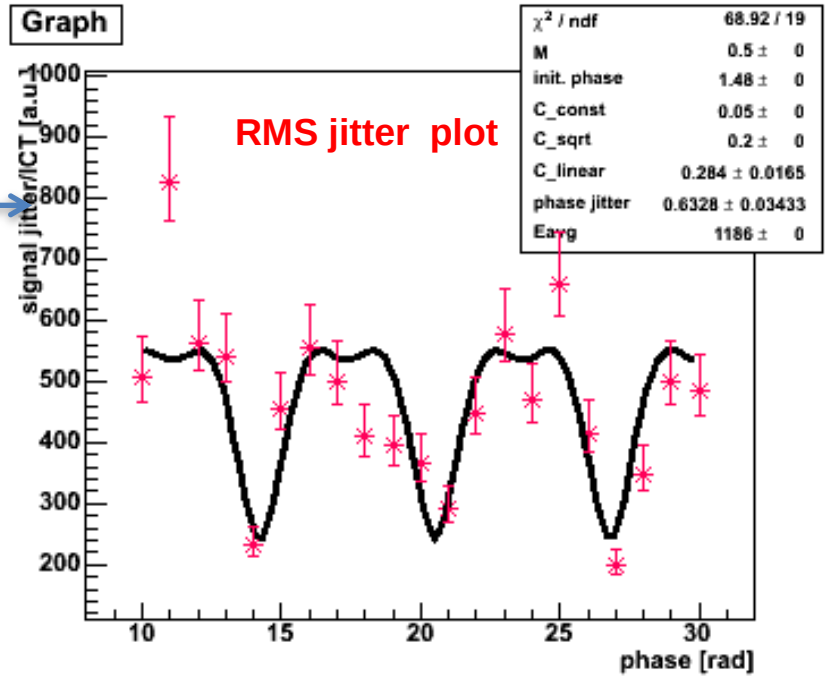
Δφ extracted @ 6.9 deg mode

- 140220_222459: **0.42 +/- 0.01 rad** (Δy /σy,meas =73%)
  Clinear = 0.26 +/- 0.01

Mode switching

30 deg , Nav=50
M ~0.50





Δφ extracted @ 30 deg mode

- 140221_011707: **0.63 +/- 0.03 rad** (Δy /σy,meas =60%)
  Clinear = 0.28 +/- 0.02

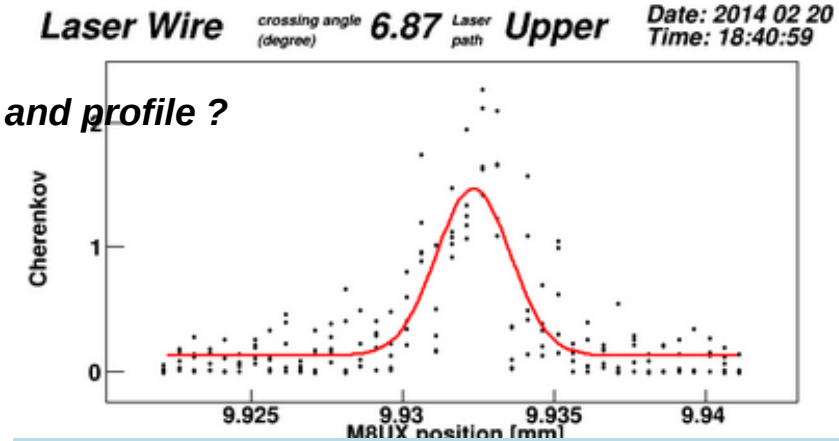
M reduction study using fringe scans before /after mode switching : 6.9 deg → 30 deg (2/20/ 2014)

Before mode switching	From 4 consecutive scans		
6.9 deg	M,meas	0.88 +/− 0.03	
	M,expected	> 0.99	Compared to 30 deg results
	C,total	0.89 +/− 0.03	
M reduction from Δφ , alignment, profile	(Δ ϕ [rad] , C Δ ϕ)	(0.35+/−0.05, 0.94+/−0.02)	
	C, pos, pro	～ 0.98	
	C,residual	> 0.91	Maybe from fringe tilt, extra misalignment , drifts ??
After mode switching			
30 deg	M, meas	0.64+/−0.07	
	(Δ ϕ [rad] , C Δ ϕ)	(0.63+/−0.03, 0.82 +/− 0.02)	
	M,corrected	$0.78^{+0.08}_{-0.10}$	

"overall" M reduction @ 6.9 deg : **Ctotal ~ 0.90**

Reduction from Δφ : CΔφ ~ 0.94

out of the rest, ***how much M reduction from misalignment and profile ?***

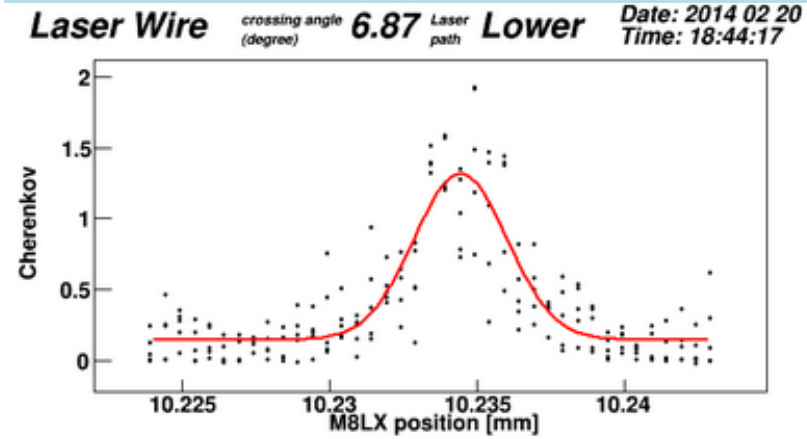


	result from laserwire scan			
		actuator	IP	profile ratio
[mm]	U	0.0012	0.0099	0.77
	L	0.0016	0.0128	

transvers	precison	0.0001	[mm]
	about 1/10 of laser spot		
	Ct,pos	0.999	
longitudinal	precision	0.0001	[mm]
	about 1/5 – 1/10 of laser spot sigma		
	Cz,pos	0.999	
profile imbalance			
	Ct,pro	0.992	
	Cz,pro	0.984	

Note:

- assumed Gaussian profile (not strictly so)
- assume no large drifts from peak of alignment (lwscan & zscan)



total M reduction due to profile and alignment

$$C_{z,pro} = \sqrt{\frac{2\sigma_{1z,laser}\sigma_{2z,laser}}{\sigma_{1z,laser}^2 + \sigma_{2z,laser}^2}}$$

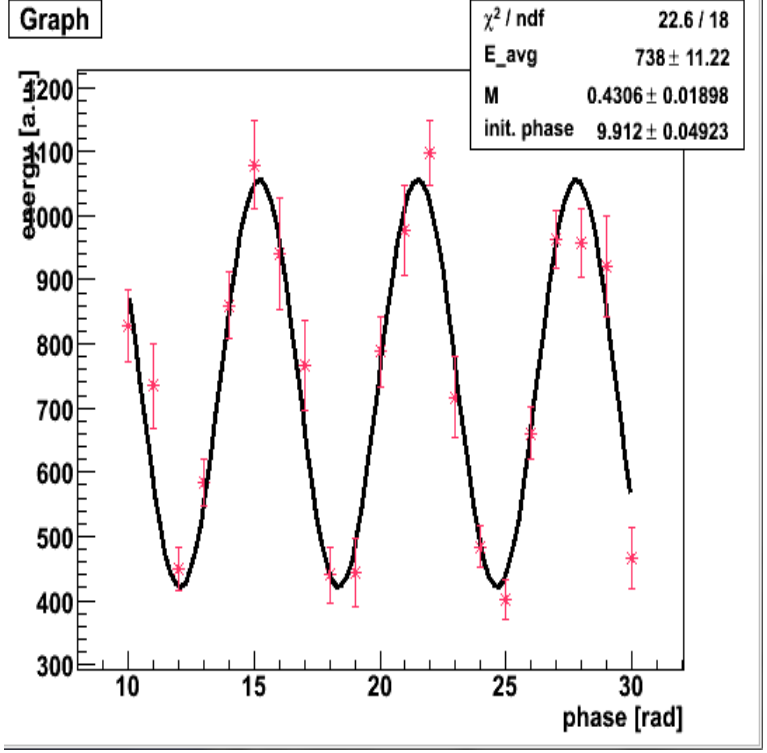
$$C_{t,pro} = \frac{2\sqrt{\sigma_{1t,laser}\sigma_{2t,laser}}}{\sigma_{2t,laser} + \sigma_{1t,laser}}$$

$$C_{z,pos} = \exp\left(-\frac{z_0^2}{8\sigma_{z,laser}^2}\right)$$

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

Feb 20, 2014

Assume Gaussian profile and no large drift and jumps



Correction of σ_{meas} using estimated M reduction factors : 1 74 deg mode

M,meas = 0.43 +/- 0.02
(σy,meas = 55 +/- 2 nm)

M,meas = 0.54 +/- 0.04
(σy,meas = 47 +/- 3 nm)

Assumptions:
- Gaussian – like profile
- pointing jitter ～15% of σlaser
- Alignment precision based on lwscan & zscan

Measured	M,meas	0.43 +/− 0.02
	σ meas [nm]	55 +/− 2
	(Δφ [rad] , CΔφ)	(0.65+/−0.06, 0.81+/−0.03)
	C, pos, pro	0.99
	C,total	**0.80 +/− 0.03**
corrected	**M,corr**	**0.54+/−0.04**
	σ corr [nm]	**47 +/− 3**

Summary

stable measurement and offline error study of IPBSM must go hand in hand in order to achieve ATF's Goal 1

< Status >

- ❖ continuous scan @174° in Mar 2013 M = 0.30 +/- 0.04 (stat)
- ❖ **～ 5 % measurement stability** in Jun 2013, using Cherenkov detector
- ❖ **Dec – early Feb 2014: significant increase in signal jitters / drift**
- ❖ **recently (late Feb 2014～) :**

  more stable operation after various efforts to stabilize laser by Terunuma-san and Okugi-san

- **investigation of laser stability and CsI / Cherenkov detectors** on-going

< error studies>

- **simulation on effect of vertical jitters, jumps, oscillating jitters**

  → effect on precision of Mmeas and Δϕ analysis

- **phase jitter studies : Δϕ typically 0.4 - 0.7 rad,** regardless of vertical jitters

Goals

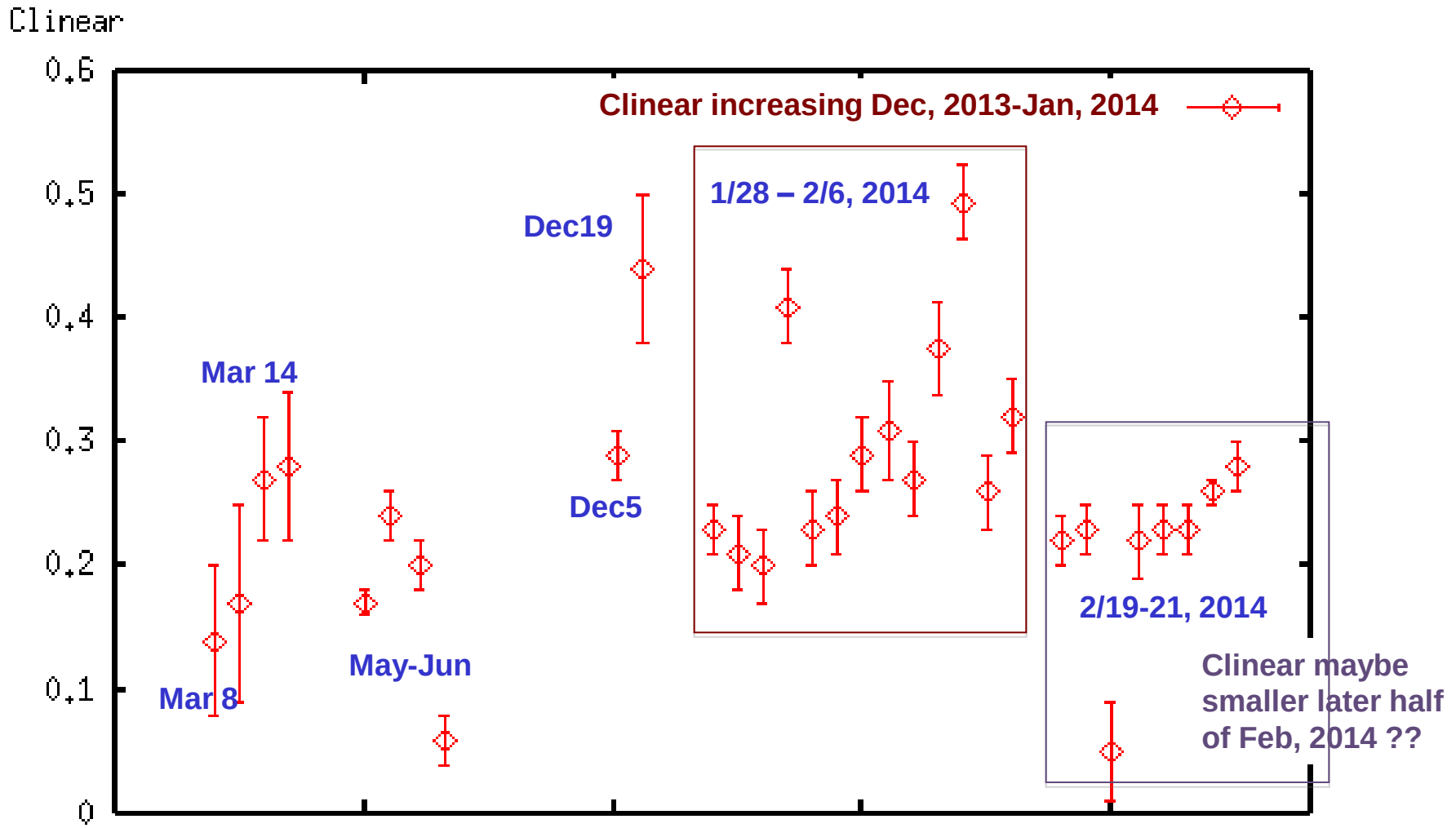
- **identify and suppress sources for jitters / drifts is a priority**

  must be achieved before other M reduction factors can be evaluated precisely to correct the measured beamsize

- **analyze data before/ after to evaluate effect of hardware upgrades**
- **Simulation studies to determine "limit" for instabilities**

BACKUP SLIDES

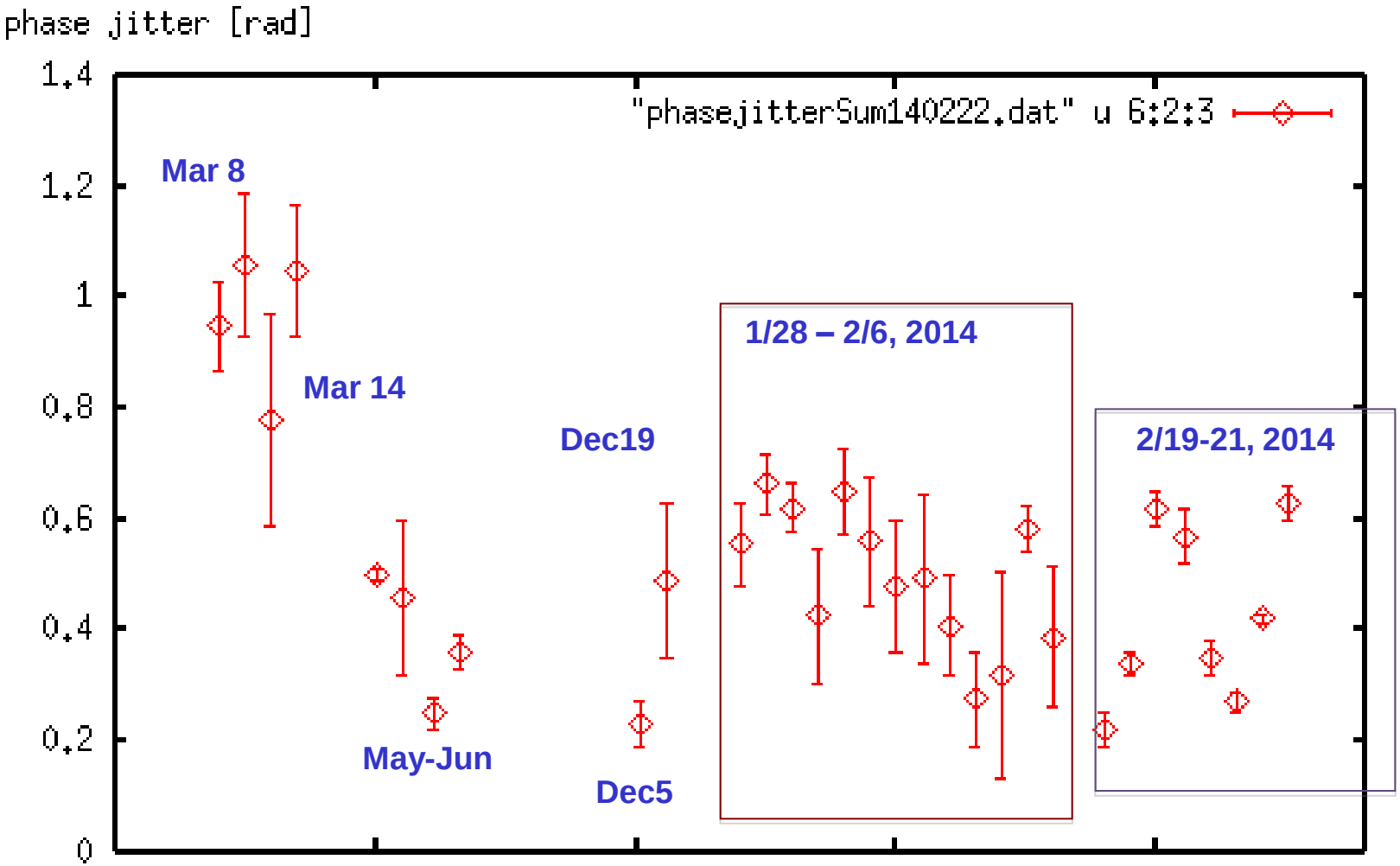
History of Clinear from March 2013 - Feb 2014



This week (2/27) :
Δφ = 0.19 +/- 0.02 for 5.3 deg
Δφ = 0.21 +/- 0.02 for 30 deg

$$s_V = \sqrt{C_{const}^2 + C_{stat}^2 \times \overline{E(j)} + C_{linear}^2 \times \overline{(E(j))^2}}$$

History of Phase Jitter from March 2013 - Feb 2014



This week (2/27) :

Δφ = 0.47 +/- 0.08 for 5.3 deg

Δφ = 0.63 +/- 0.03 for 30 deg

M reduction due to phase jitter

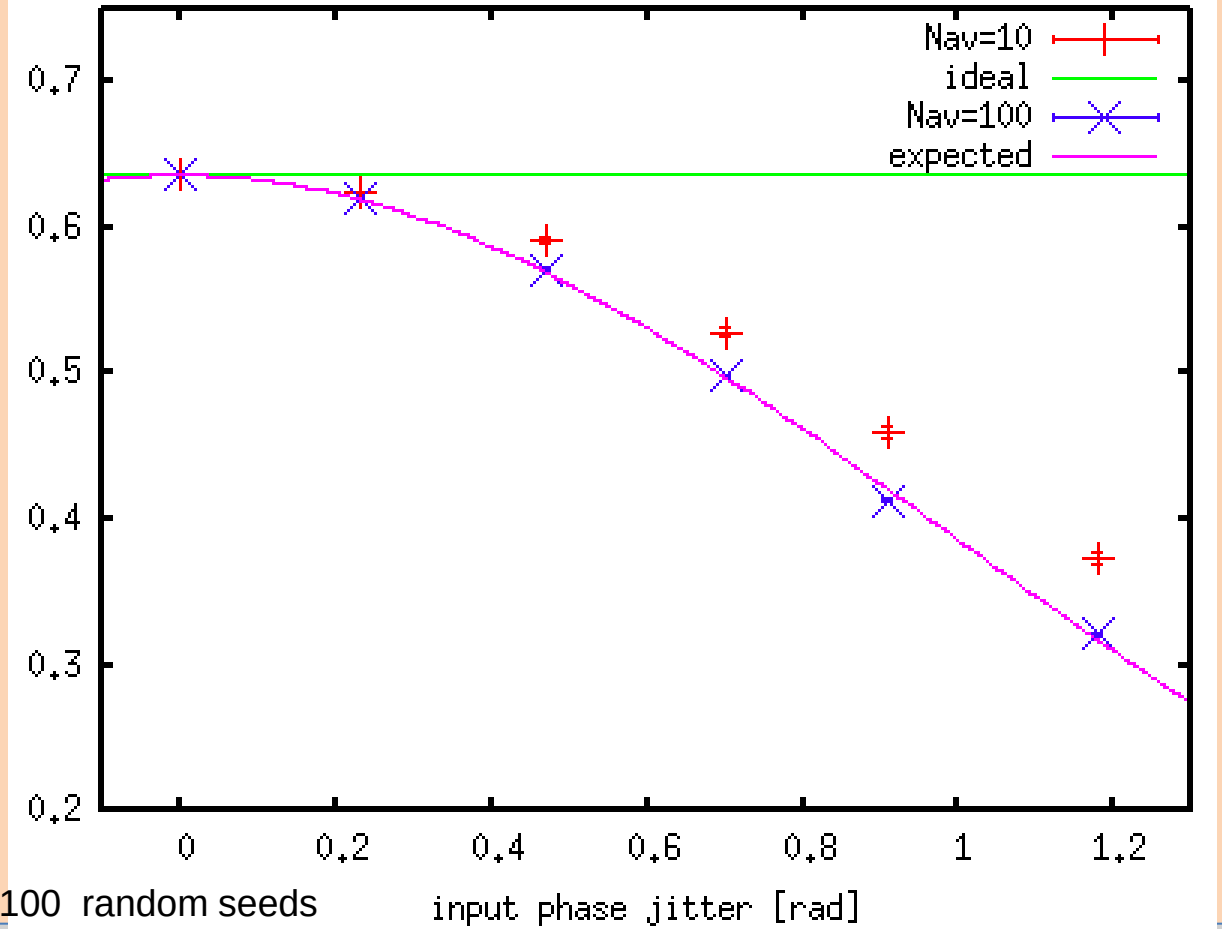
x: axis: input Δφ (0 – 1.18 rad)
y axis: fitted M

M0 = 0.636, Eavg = 1, φ0 = 0
Vertical jitter = 0

Nav = 10 has bias
→will over-correct if we do "M correction " using extracted Δφ

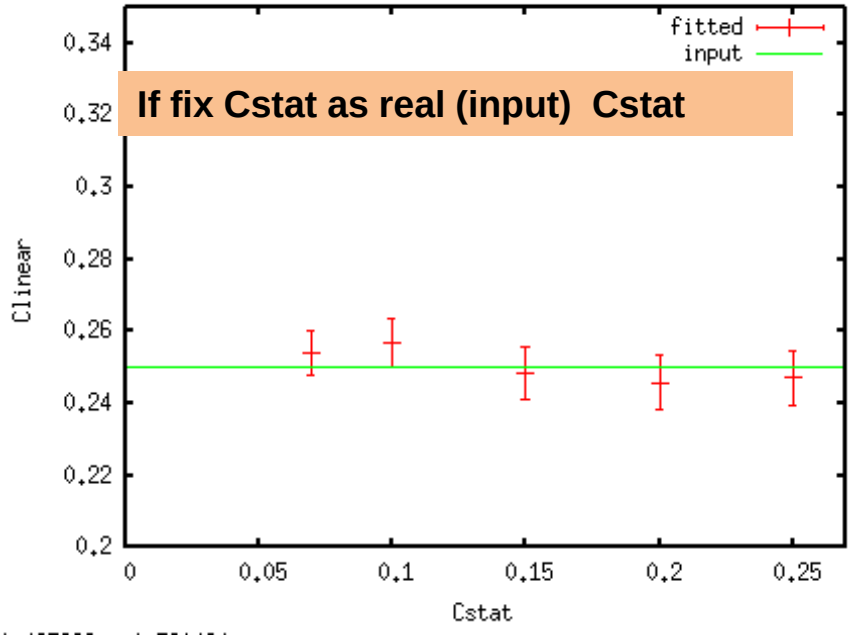
Should take Nav=100 data for "final" measurements

Nav = 10 has bias



Simulation: Mean & RMS (S.D.) of 100 random seeds

$$s_V = \sqrt{C_{const}^2 + C_{stat}^2 \times \overline{E(j)} + C_{linear}^2 \times \overline{(E(j))}^2}$$

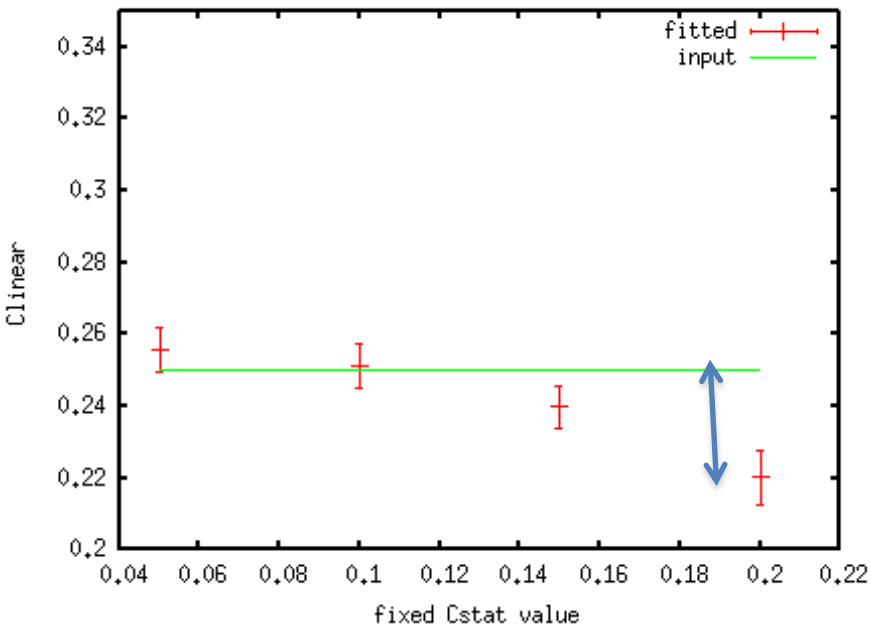


If fix Cstat as real (input) Cstat

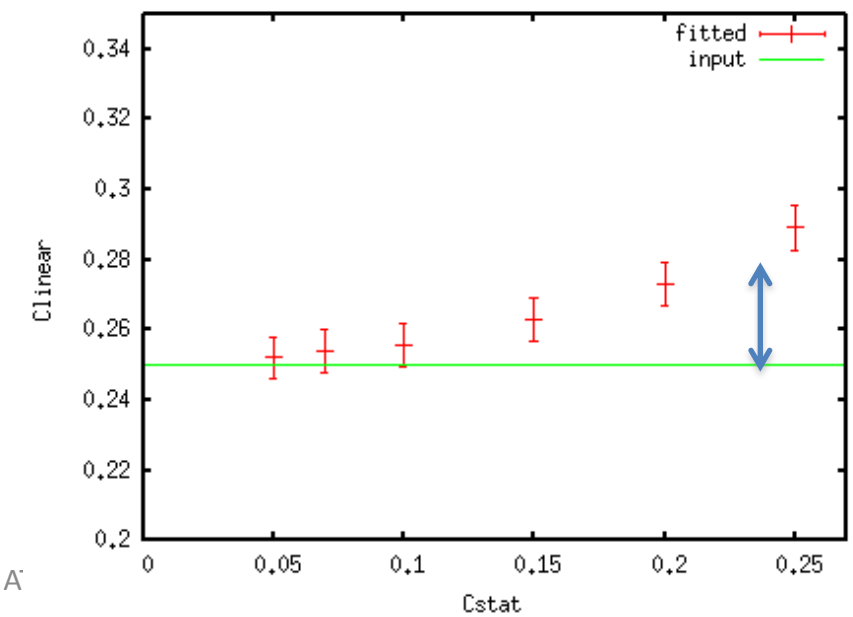
average and rms/sqrt(100) of 100 random seeds

input:
M0 = 0.64, σy0 = 40 nm, 174 deg mode, Nav=20,
Clinear = 0.25, Cconst = 0.05, Δφ = 0. 588 rad

Clinear is under-evaluated if fix too large Cstat



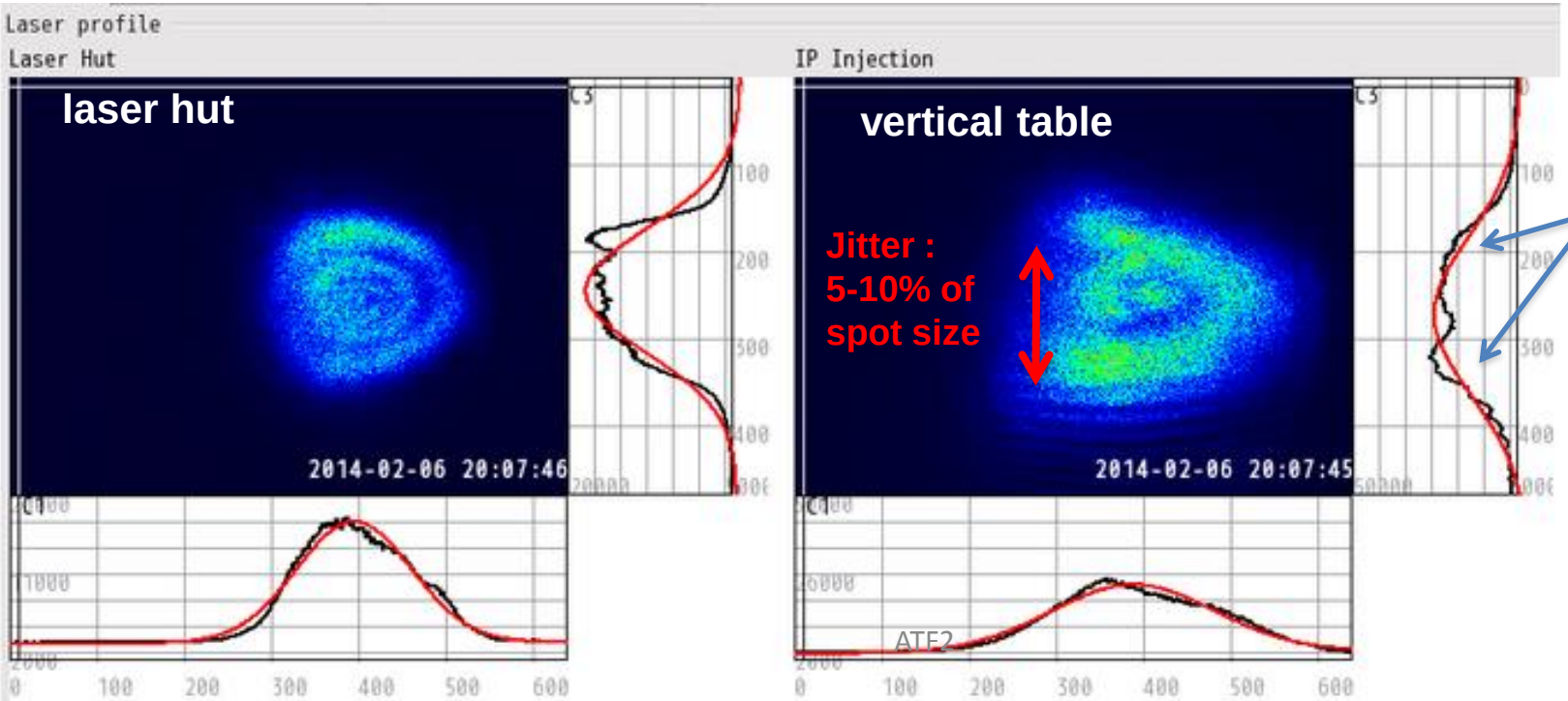
Clinear is over-evaluated if Cstat is fixed to a too small 0.07 even if real (input) Cstat is larger



Laser Profile

before tuning
(remove cylindrical lens)

after

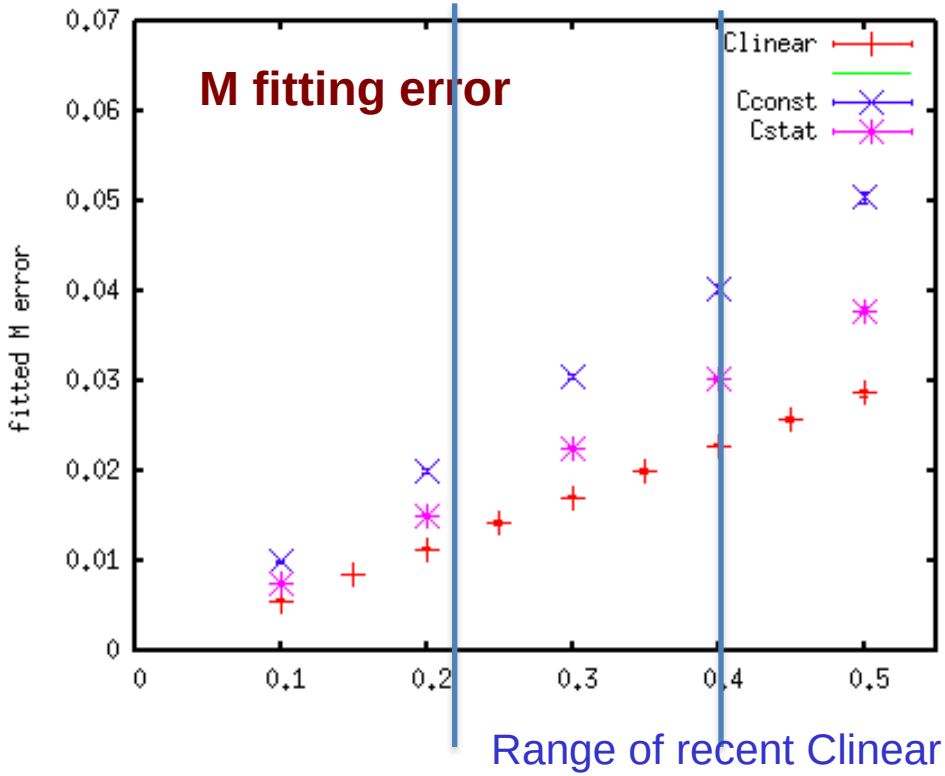


2 peak structure

shifting around

May be affecting laserwire profile ?

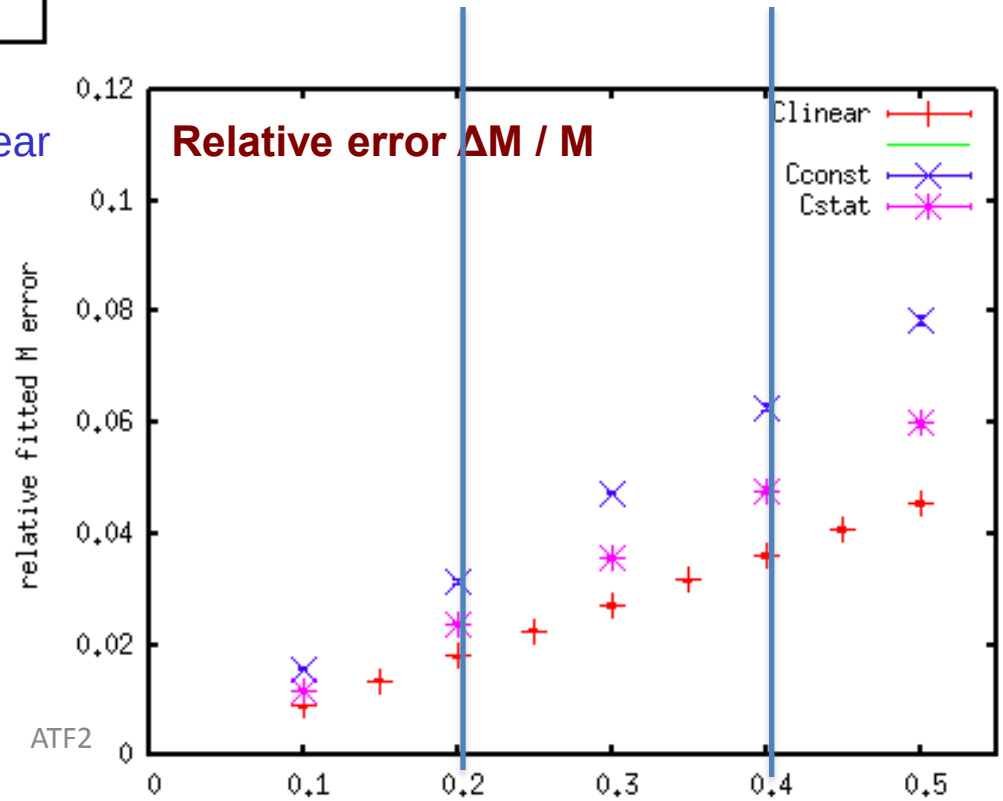
Effect of vertical jitters on M fitting error



Cconst has largest effect (?)
but in Jan-Feb, 2014 BG fluctuation is not a problem owing to high S/N

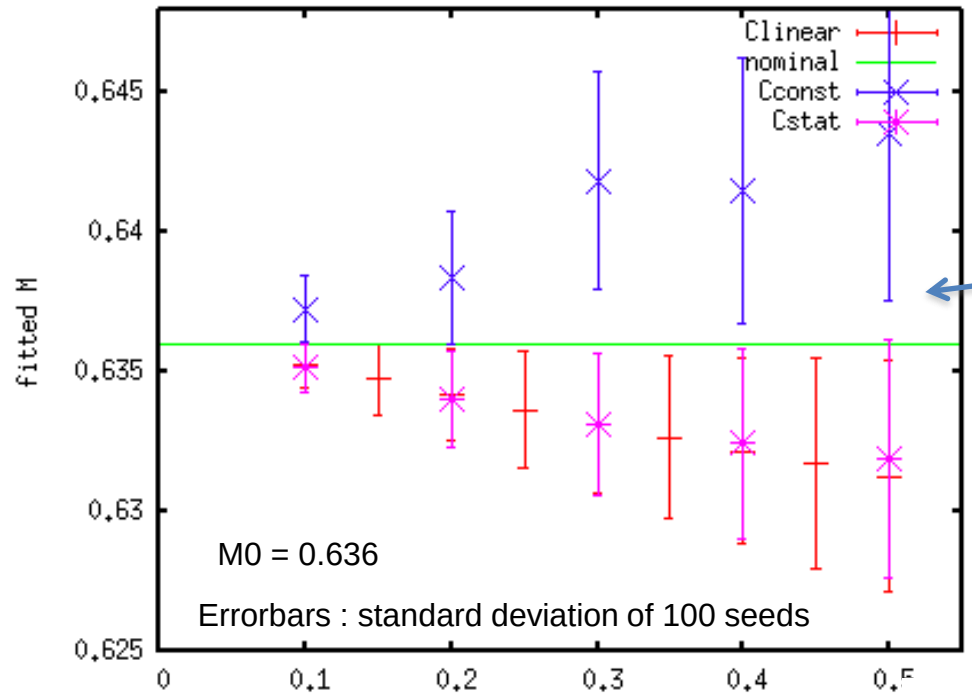
Clinear is the issue at present !!

$$s_V = \sqrt{C_{const}^2 + C_{stat}^2 \times \overline{E(j)} + C_{linear}^2 \times \overline{(E(j))^2}}$$



Input : 100 random seeds
M0 = 0.636, Nav=10, 174 deg mode,
Change 1 C factor type at a time, Keep others to 0

Effect of vertical jitters on fitted M

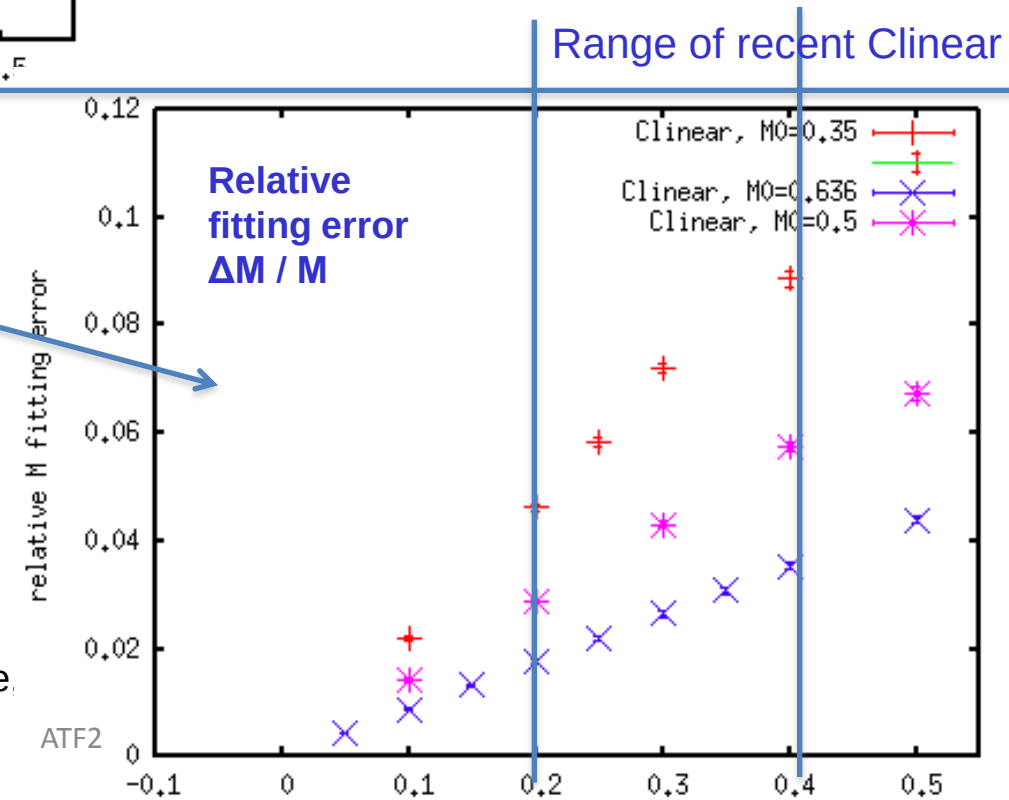


- **Over-evaluation for Cconst**
- **M reduction for Clinear and Cstat**

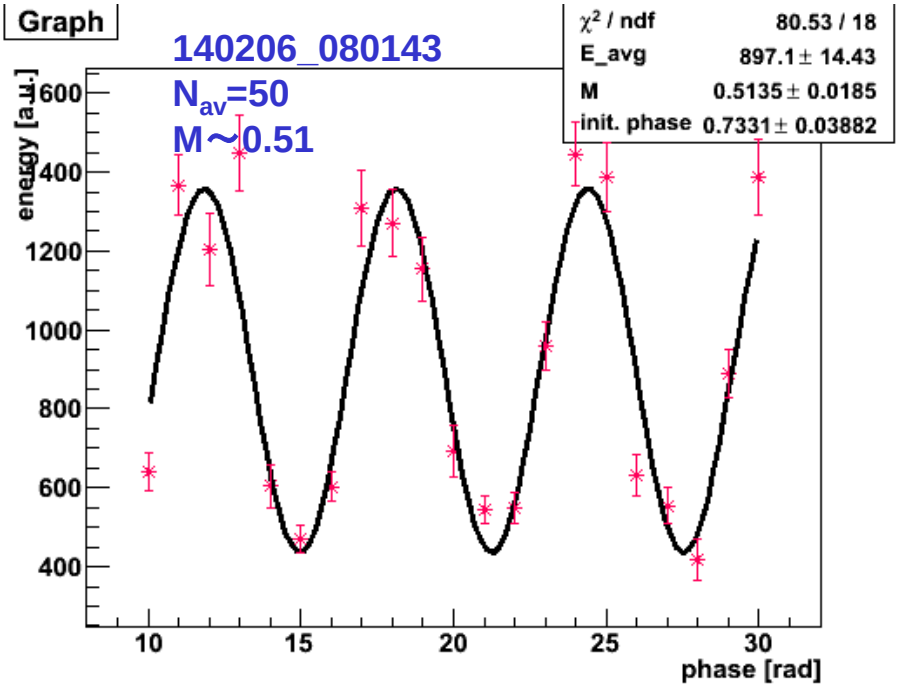
systematic error < few %

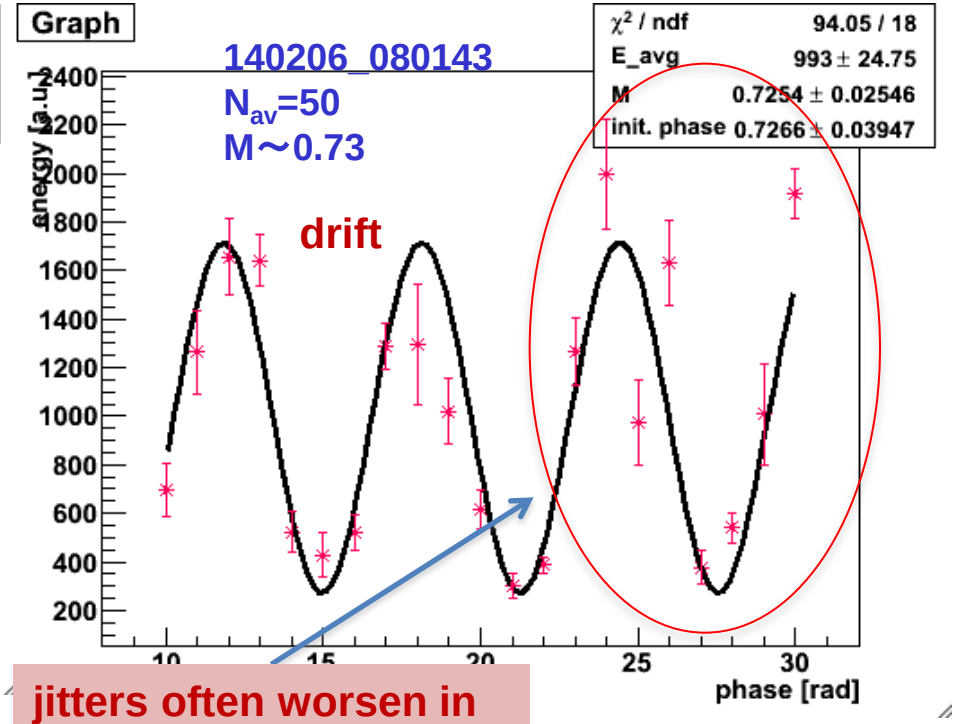
Not serious bias (?)

Clinear cause larger ΔM/M for smaller M_0

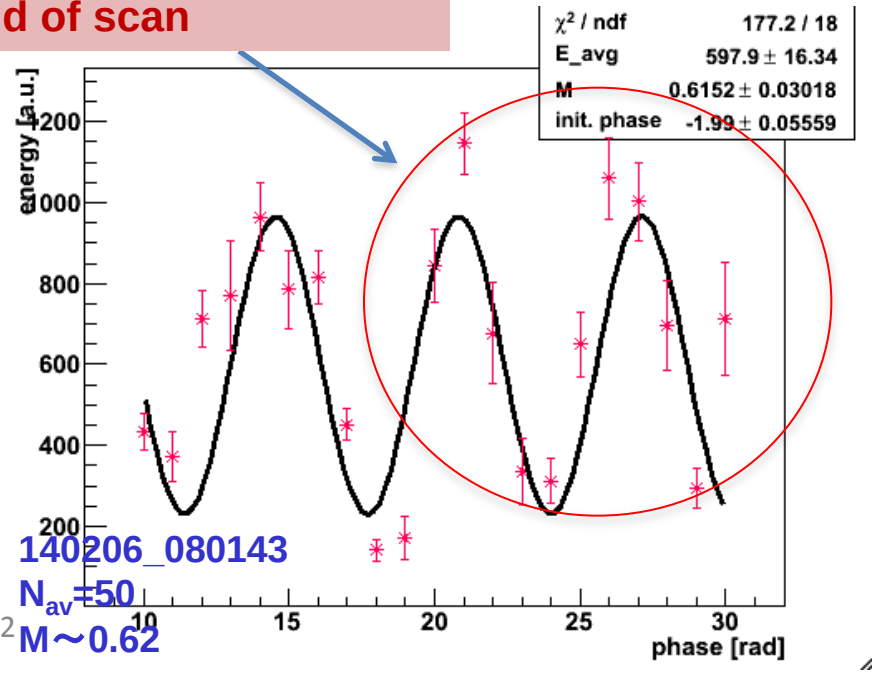


Input : 100 random seeds, Nav=10, 174 deg mode
Change 1 C factor type at a time, Keep others to 0





jitters often worsen in mid of scan



Drift and jitters are problems for 30 deg mode also

- **effect is smaller since M is larger**
- **But makes multi-knob tuning hard**

Hardware improvement attempts (by Terunuma-san, Okugi-san, and others)

•changed laser Q-SW trigger system → timing stabilized

•Removed cylindrical lens on laser hut table → reduced intensity bias in profile

•Adjusted gate width and variable attenuator of detector read-out module

<u>Laser cooling water system</u>

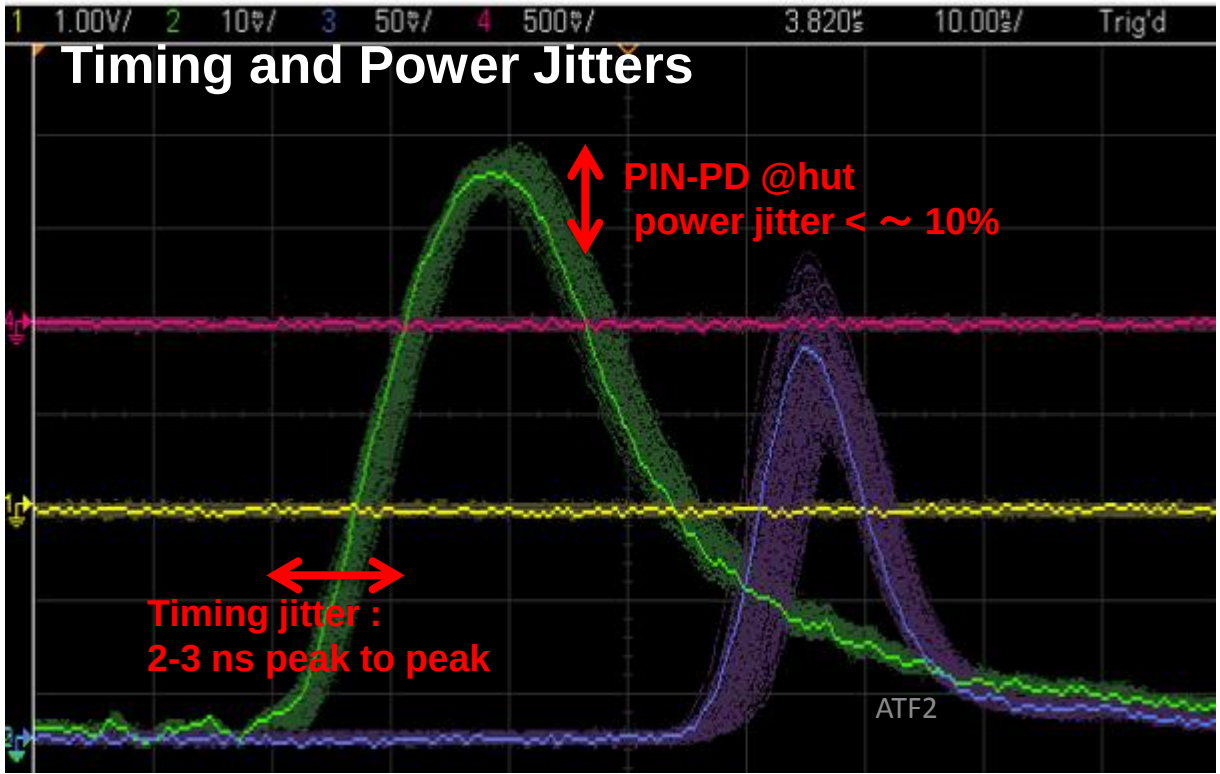
◆Tried various external cooling water temp. 18 – 29 deg (default 21 deg)

effect is unclear → inspection/repair by laser company

◆ Other attempts → no clear improvement

adjust Nitrogen flow , cool power supply source with fan, move sensor away from hot pump

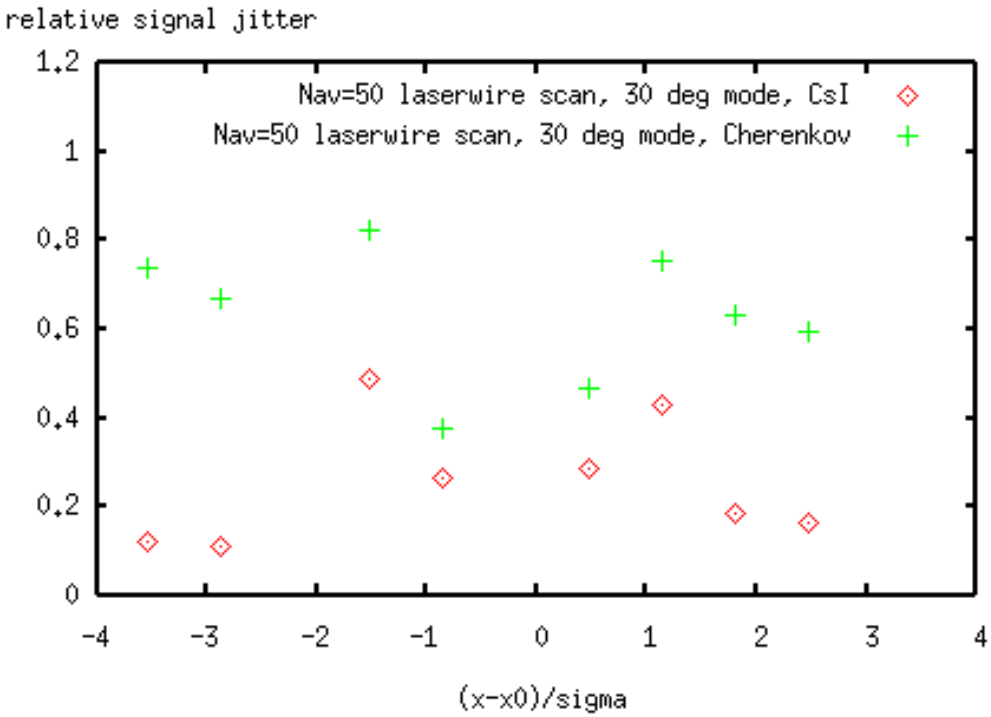
Laser cavity tuning (e.g. rear mirrors) , ect…

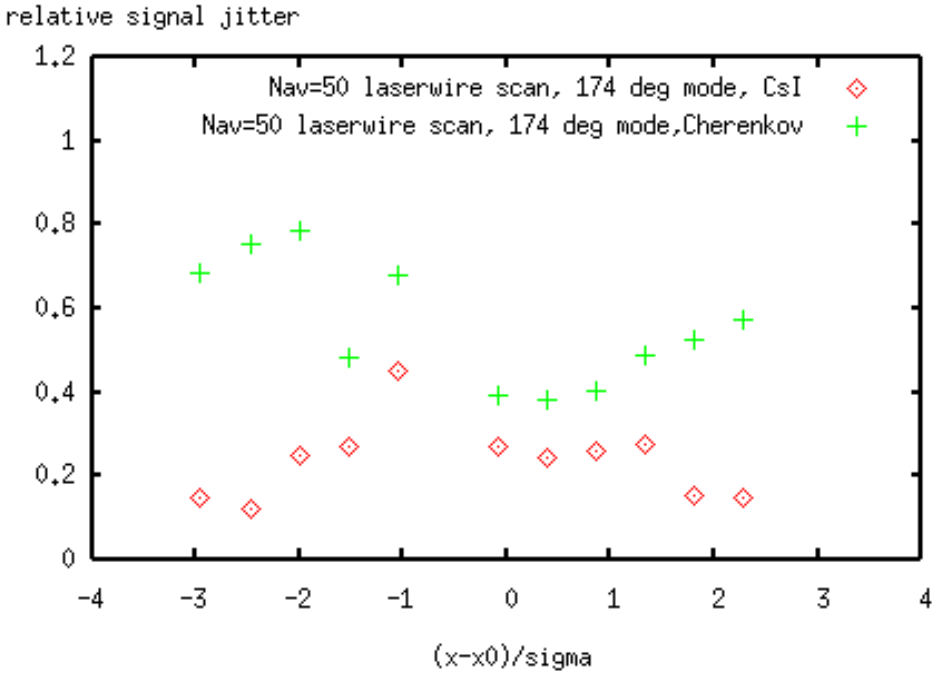


laser tuning , filter exchange by Spectra Physics

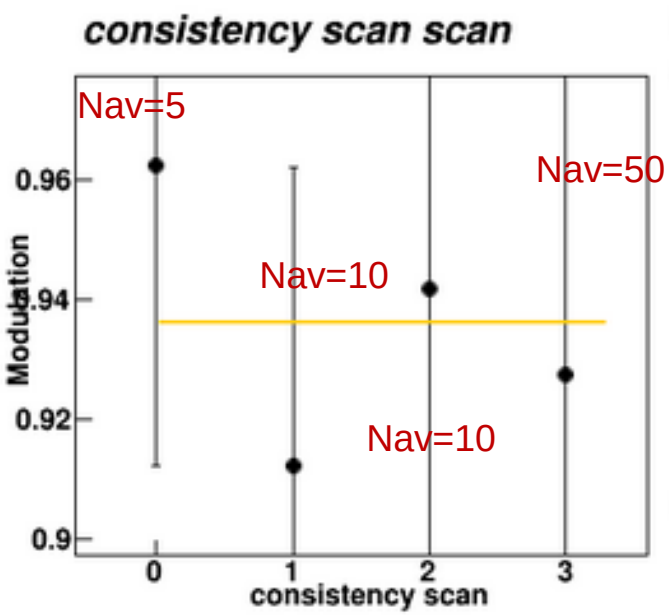
→ improved buildup and timing stability

Note: due to sensor size < laser spot size, part of "vertical jitter" may be pointing jitter


relative signal jitter
Nav=50 laserwire scan, 30 deg mode, CsI
Nav=50 laserwire scan, 30 deg mode, Cherenkov
1.2
1
0.8
0.6
0.4
0.2
0
-4
-3
-2
-1
0
1
2
3
4
(x-x0)/sigma


relative signal jitter
Nav=50 laserwire scan, 174 deg mode, CsI
Nav=50 laserwire scan, 174 deg mode,Cherenkov
1.2
1
0.8
0.6
0.4
0.2
0
-4
-3
-2
-1
0
1
2
3
4
(x-x0)/sigma

Very large & consistent M,meas before switching to 30 deg → M reduction studies

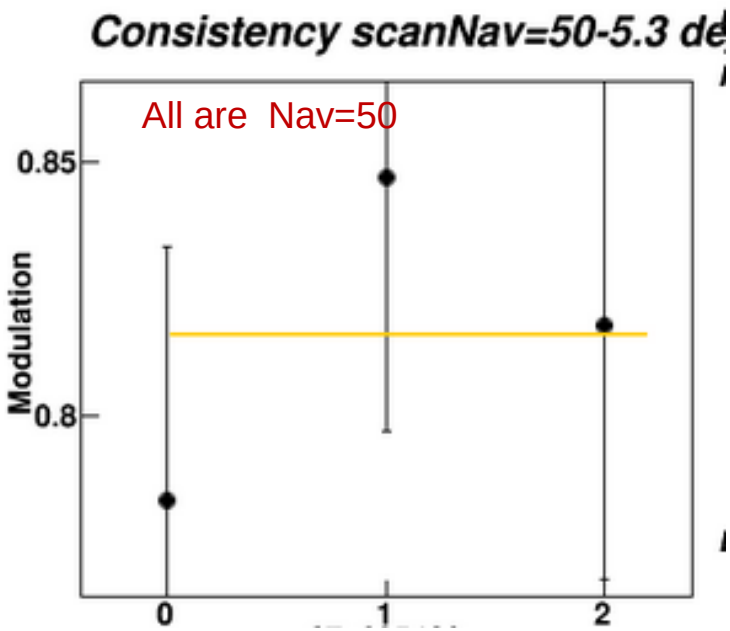


summary of consistency scan140220_221459

data	M	Δ φ	Clinear	Nav
221459	**0.925**			5
221736	**0.842**	0.35	0.23	10
222119	**0.925**	0.27	0.23	10
222459	**0.842**	0.42	0.26	50
Avg	**0.88**	0.35	0.24	
ERR=STD/sqrt(N−1)	**0.03**	0.05	0.01	

Data file:
consistency_scan_fringe_140220_2

2/20 , 6.9 deg ,
M = 0.88 /- 0.03



summary of consistency scan140220_221459

data	M	Δ φ	Clinear	Nav
35100	**0.761**	0.549	0.17	50
40832	**0.848**	0.34	0.22	50
41849	**0.776**	0.51	0.17	50
Avg	**0.80**	0.47	0.19	
ERR=STD/sqrt(N−1)	**0.03**	0.08	0.02	

2/27 5.3 deg ,
M = 0.80 /- 0.03

ΔMsyst is much smaller for CsI
(esp for 174 deg mode, smaller M)

mainly dominated by difference in statistics (lower statistic error for CsI)

data		detector	Δ Msyst/Mfit	Δ M_stat	M_fit
140305_212930	174deg	CsI	10%	14%	0.16
		Cherenkov	43%	41%	0.09
140305_213219	174deg	CsI	17%	13%	0.18
		Cherenkov	35%	32%	0.12
140306_191009	30deg	CsI	2.2%	1%	0.75
		Cherenkov	3.3%	2%	0.74

Propose using "systematic error ΔM_syst" as a quantitative "scan quality selection" criteria.

"simulation" : observe fitting error ΔM_total , ΔM_stat , calculate ΔM_syst

ΔM_syst is not sensitive to Nav, instead depend on instabilities

common input conditions are 174 deg, M0 = 0.636 (40 nm beamsize), Cconst = 5%, Cstat = 10%, Clinear=30%, Δφ = 470 mrad

50% sudden decrease (drift / jump) @ 7−17 rad

		Δ Mtot	Δ Mstat	Δ Msyst
Nav=10	abs. error	0.105	0.029	0.101
	relative error	16.9%	4.7%	16.2%
Nav=50	abs. error	0.100	0.014	0.099
	relative error	16.0%	2.3%	15.8%
Nav=100	abs. error	0.099	0.010	0.099
	relative error	15.9%	1.7%	15.8%

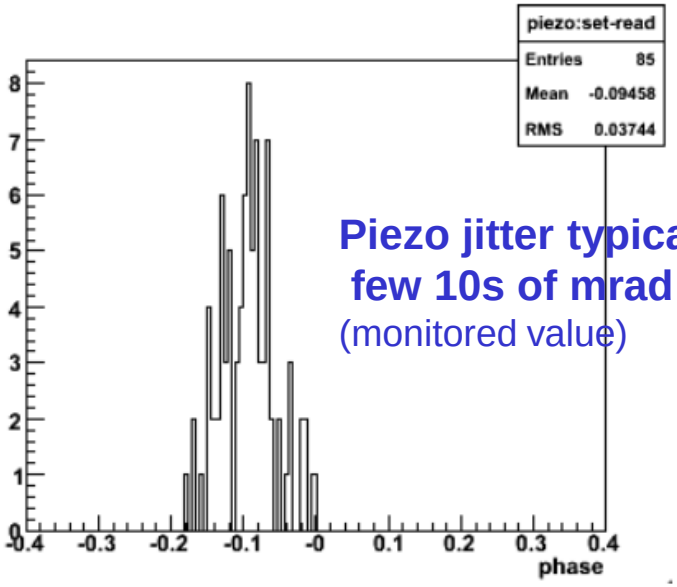
(A) scan with sudden signal intensity decrease @ 7-17 rad : ΔMsyst > 15%

no jump

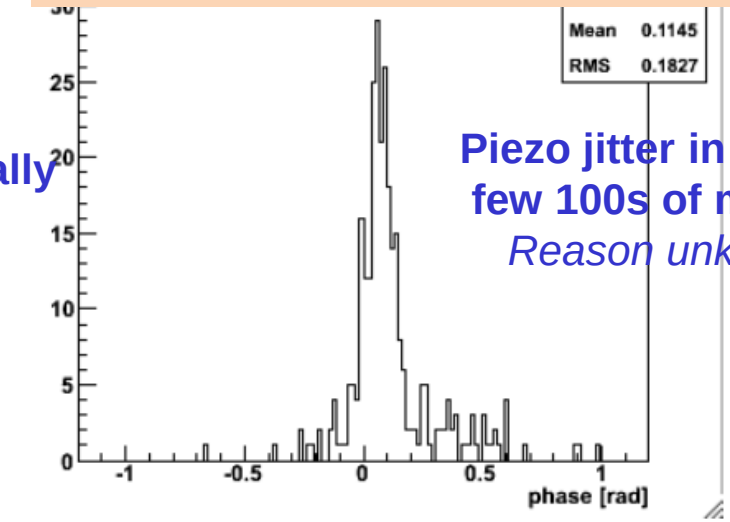
		Δ Mtot	Δ Mstat	Δ Msyst
Nav=10	abs. error	0.061	0.028	0.054
	relative error	10.9%	4.9%	9.7%
Nav=50	abs. error	0.054	0.014	0.052
	relative error	9.7%	2.5%	9.4%
Nav=100	abs. error	0.054	0.010	0.053
	relative error	8.7%	1.6%	8.5%

(B) no jump : ΔMsyst < 10%

big Δφ in Mar 2013, maybe due to piezo jitter (?)

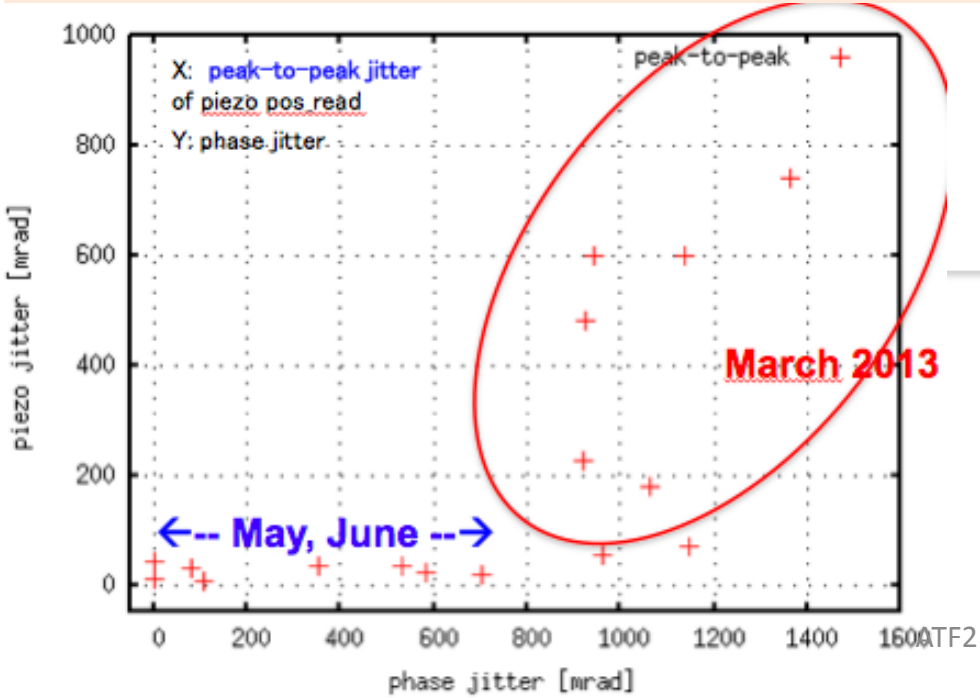


Piezo jitter typically
few 10s of mrad
(monitored value)



Piezo jitter in Mar 2013
few 100s of mrad
Reason unknown

Mar:	phase jitter ～1 rad	Avg piezo jitter ～ 250 mrad
May, Jun:	phase jitter : 200 – 500 mrad	Avg piezo jitter ～ 25 mrad



can neither claim nor reject correlation (??)

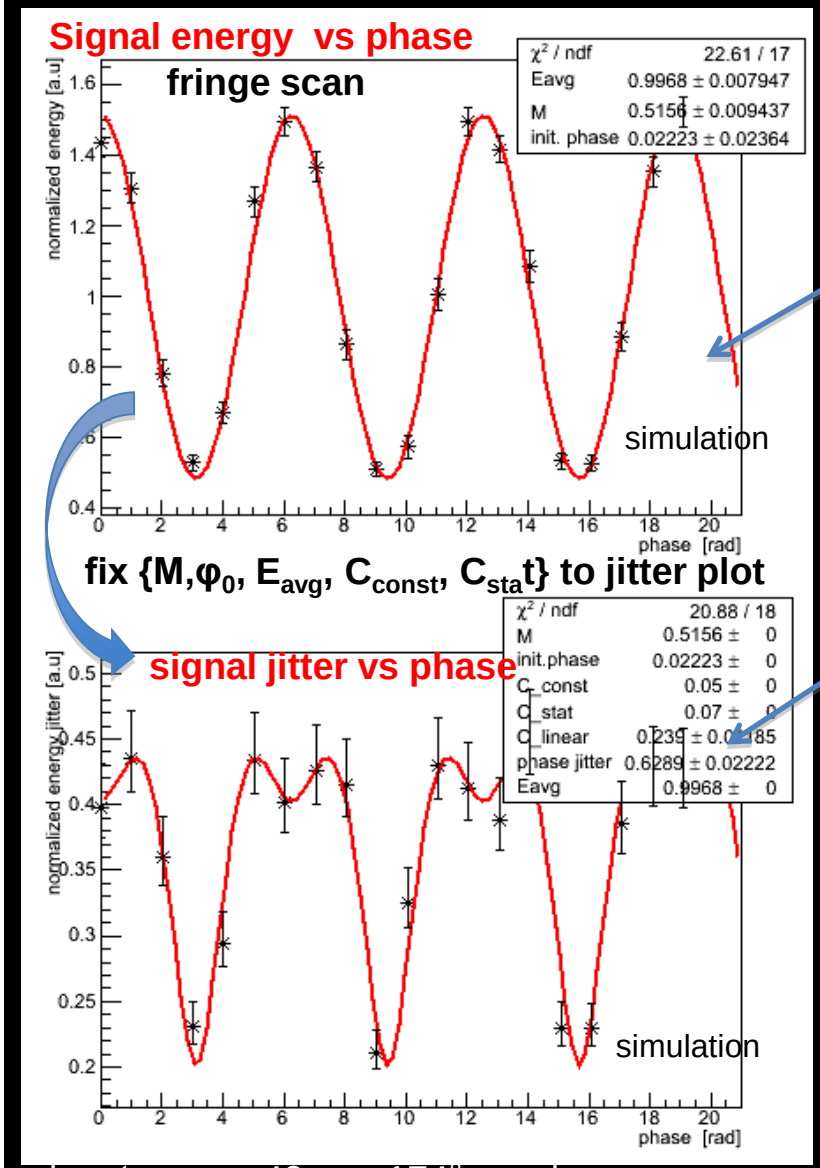
Maybe ADC mal-functioning, noise from nearby devices / cables during beam time , ect…

this is all we can investigate for now

(option: cut events with large piezo jumps)

more important to ensure piezo controller and monitor works for current beam run (next page)

Reliability test of Δφ extraction using simulation



input: σ_{y0} = 40 nm, 174° mode
Δφ = 0.7 mrad , 24.5 % vertical jitter

STEP1: generate signal energy

reflect "realistic condition"

$$E = E_{avg} \cdot \{1 + M \cdot \cos j\} \qquad j \equiv j_{set} + j_0$$

$$j \rightarrow j \pm \mathrm{D}j$$ **Δφ input**

$$E_{avg} \cdot \left\{1 + M \cdot \cos\left(j + \left(Random \rightarrow Gaus(0, s_j)\right)\right)\right\}$$

$$s_{V,input} = \sqrt{C_{const}^2 + \left(C_{stat}\sqrt{E}\right)^2 + \left(C_{linear} \times E\right)^2}$$ **Input vertical jitters**

STEP2: fit jitter plot

→ extract **Δφ , Clinear** (2 free parameters)

Model

$$\mathrm{D}E \equiv s_{tot} = \sqrt{s_V^2 + s_p^2}$$

Jitter from Δφ

$$s_p = E_{avg} M \sqrt{\frac{1}{2}\left[1 - 2\cos^2 j \exp\left(-\mathrm{D}j^2\right) + \cos(2j)\exp\left(-2\mathrm{D}j^2\right)\right]}$$

vertical jitter

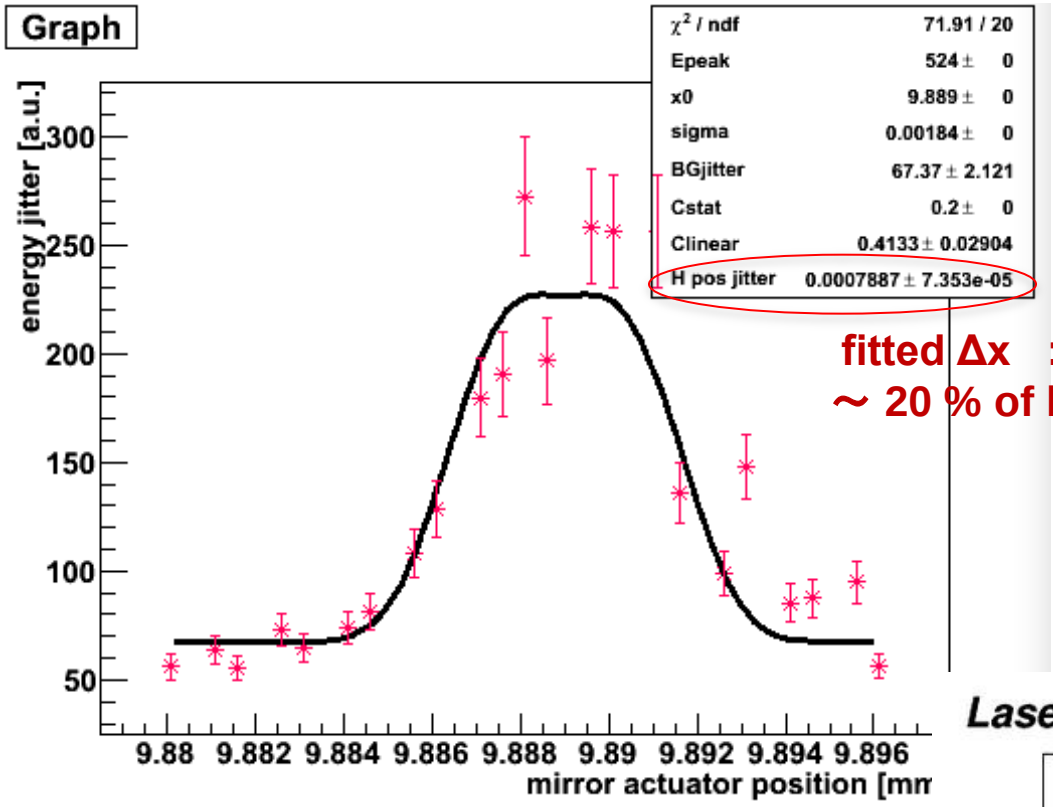
$$s_V = \sqrt{C_{const}^2 + C_{stat}^2 \times \overline{E(j)} + C_{linear}^2 \times \overline{\left(E(j)\right)^2}}$$

fixed parameters:

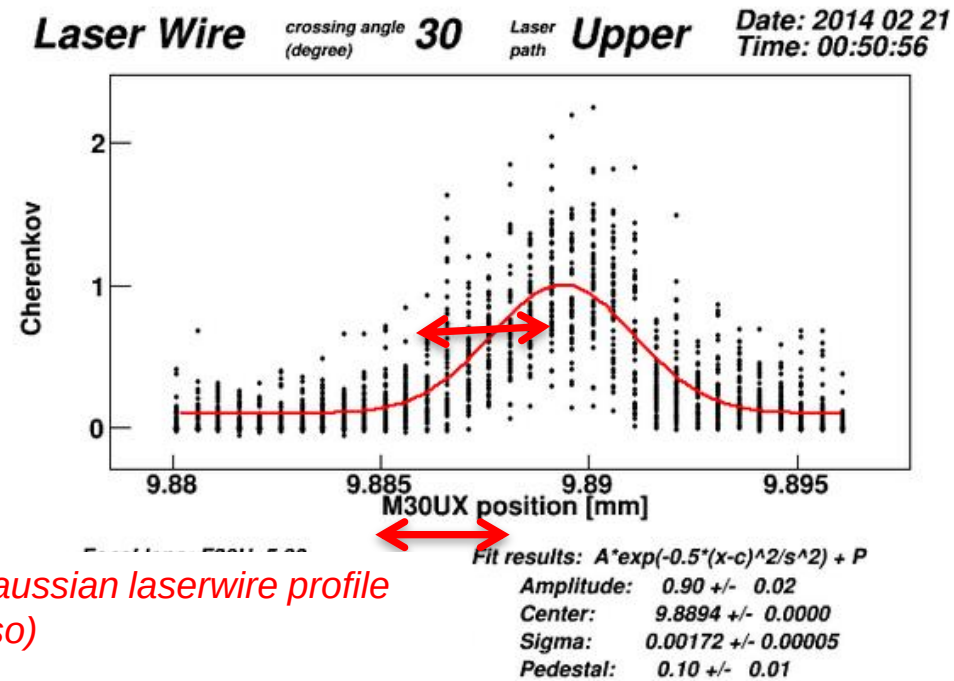
- M, φ_0, E_{avg} : from STEP 1
- Cconst, Cstat: estimated (slight uncertainties are negligible)

Laser pointing stability
2/21 30 deg mode

seen from horizontal relative position jitter ***(Δx)*** *in Nav=50 laserwire scans*



fitted Δx : 7∼9 μm
∼ 20 % of laser spot radius

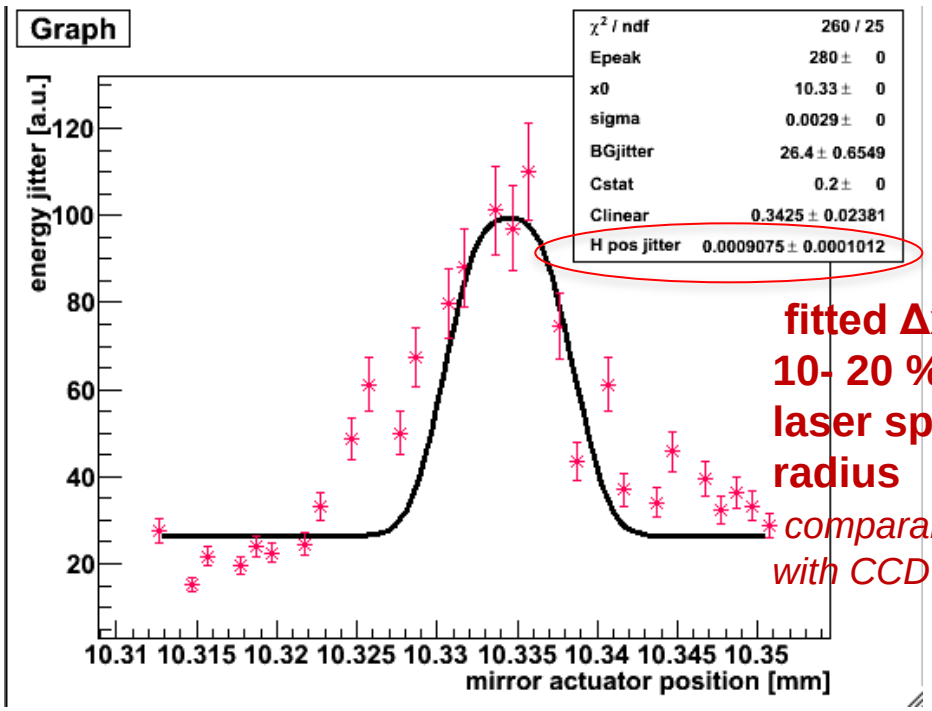


not that much difference from January ?

Assuming Gaussian laserwire profile (not always so)

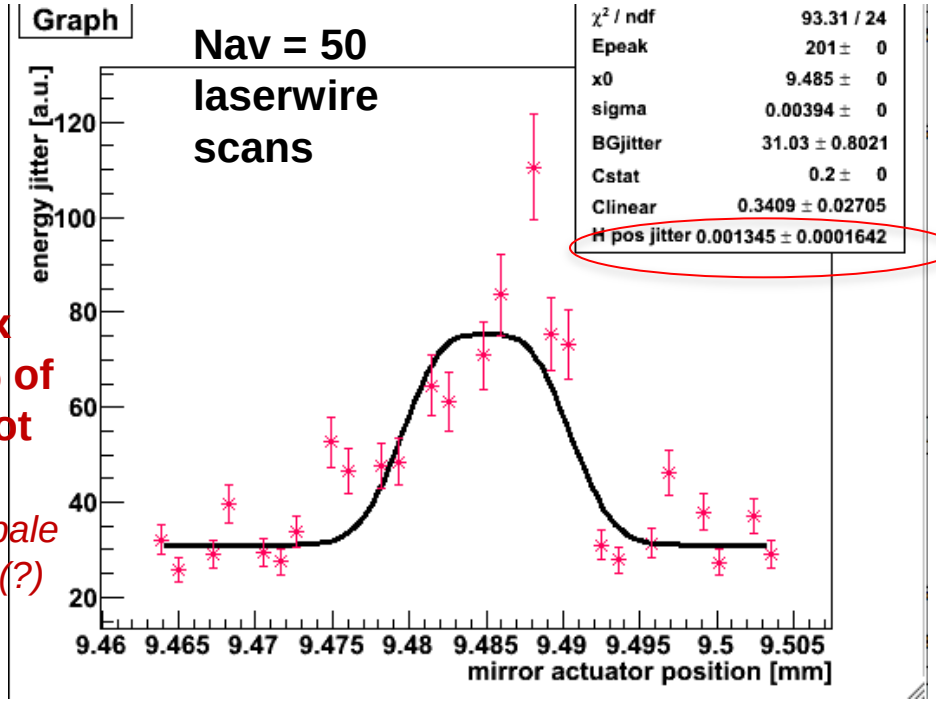
Laser pointing stability : 1/30 174 deg mode

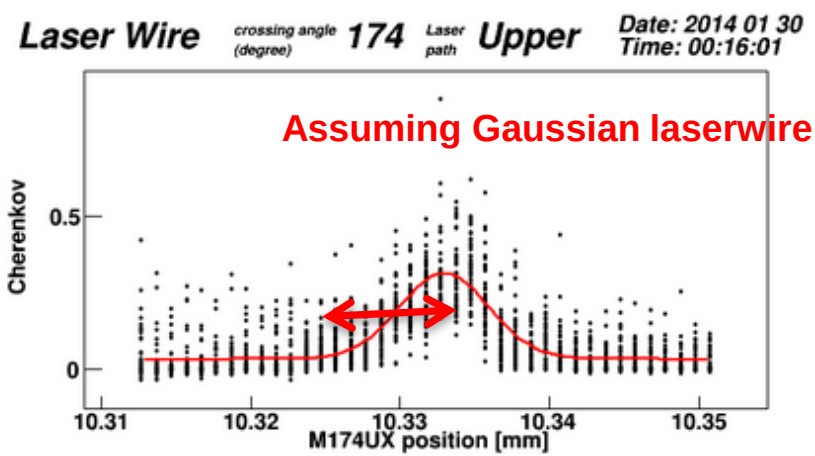
seen from horizontal relative position jitter ***(Δx)*** *in Nav=50 laserwire scans*



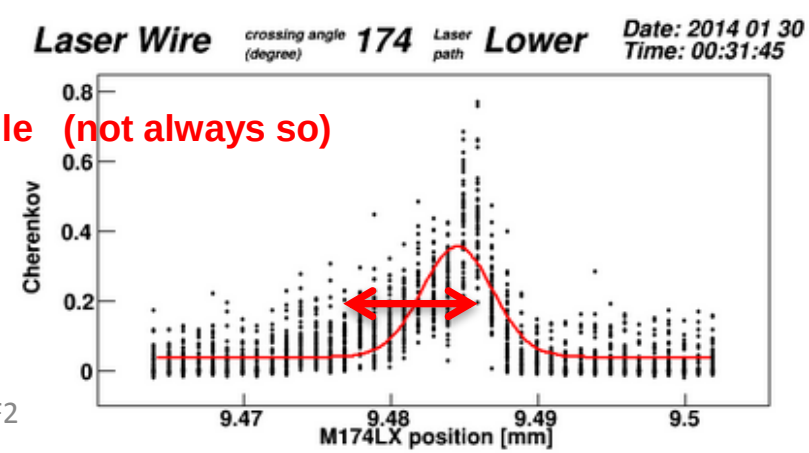
fitted Δx 10- 20 % of laser spot radius

comparabale with CCD (?)



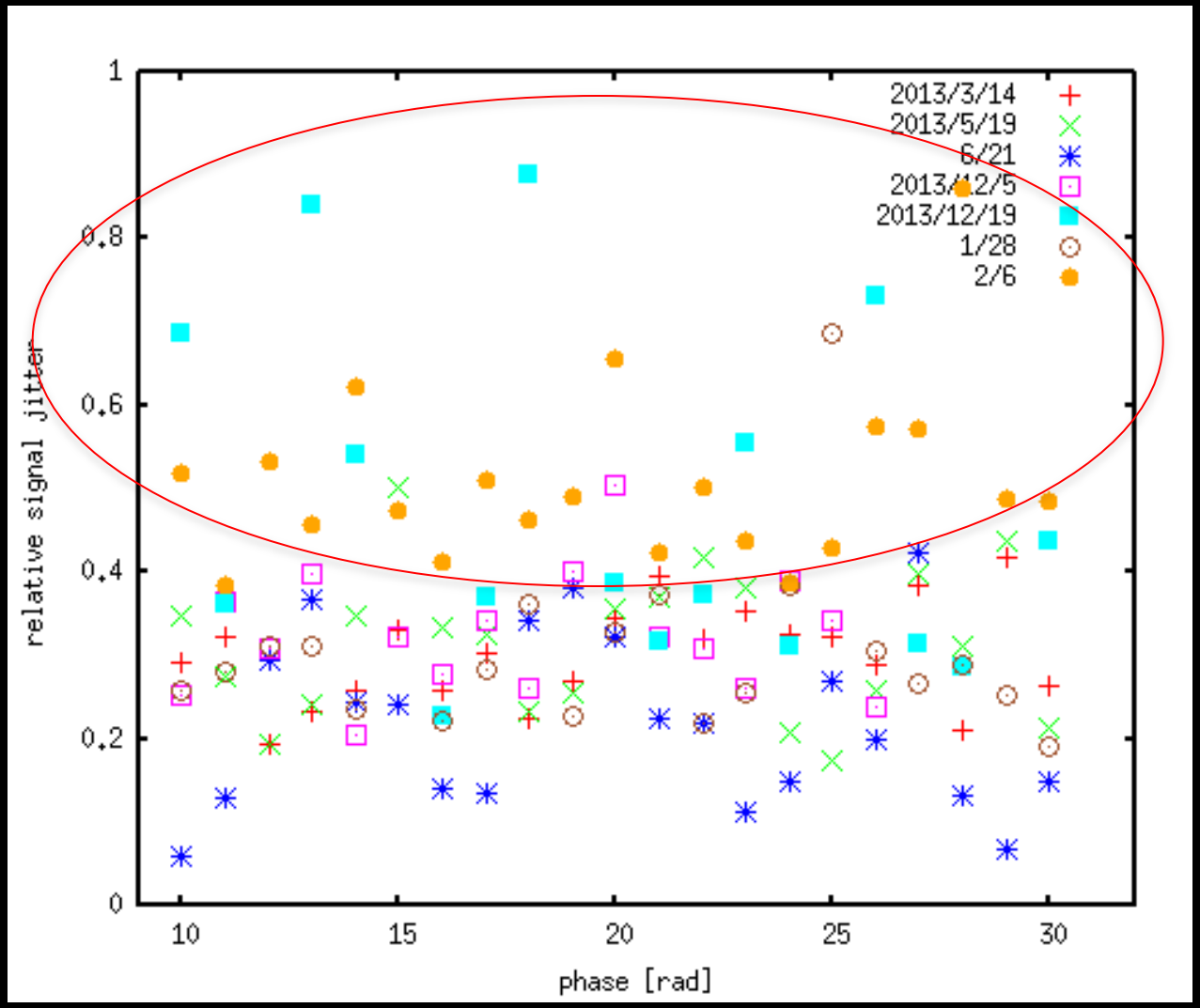


Assuming Gaussian laserwire profile (not always so)



History of signal jitter status in IPBSM fringe scans (Mar 2013 – Feb 2014)

Recent Increase in sig jitters

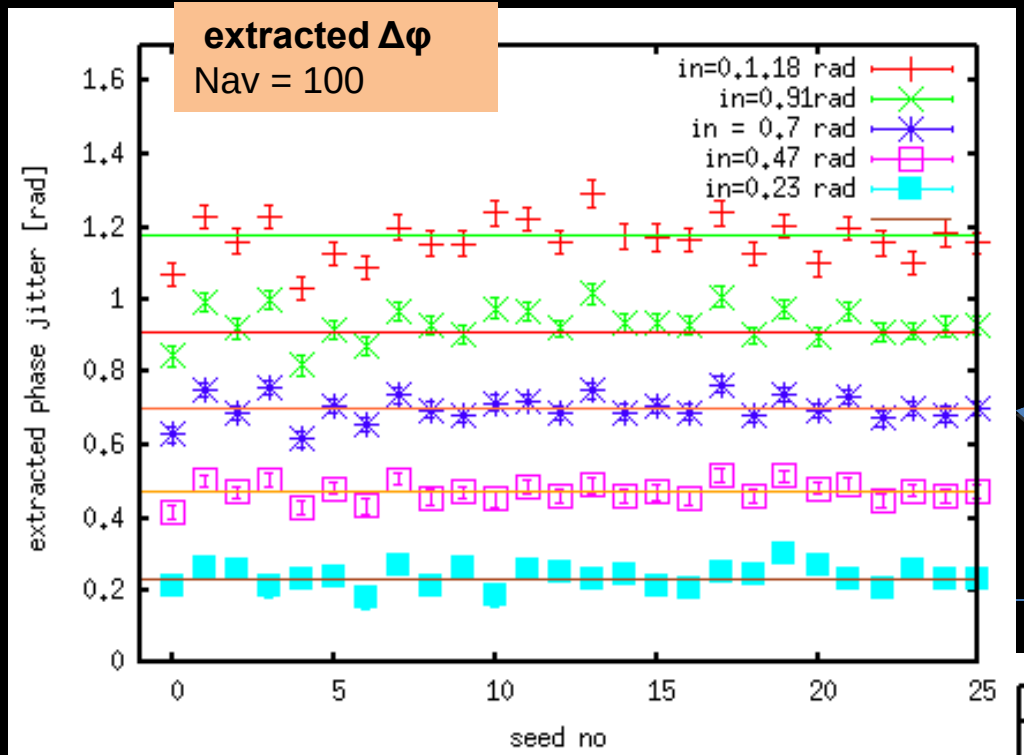


Dec 2013 :

- Collimator (→ optimized by scan)
- Low S/N, BG fluctuation

Jan, Feb 2014 :

laser related factors

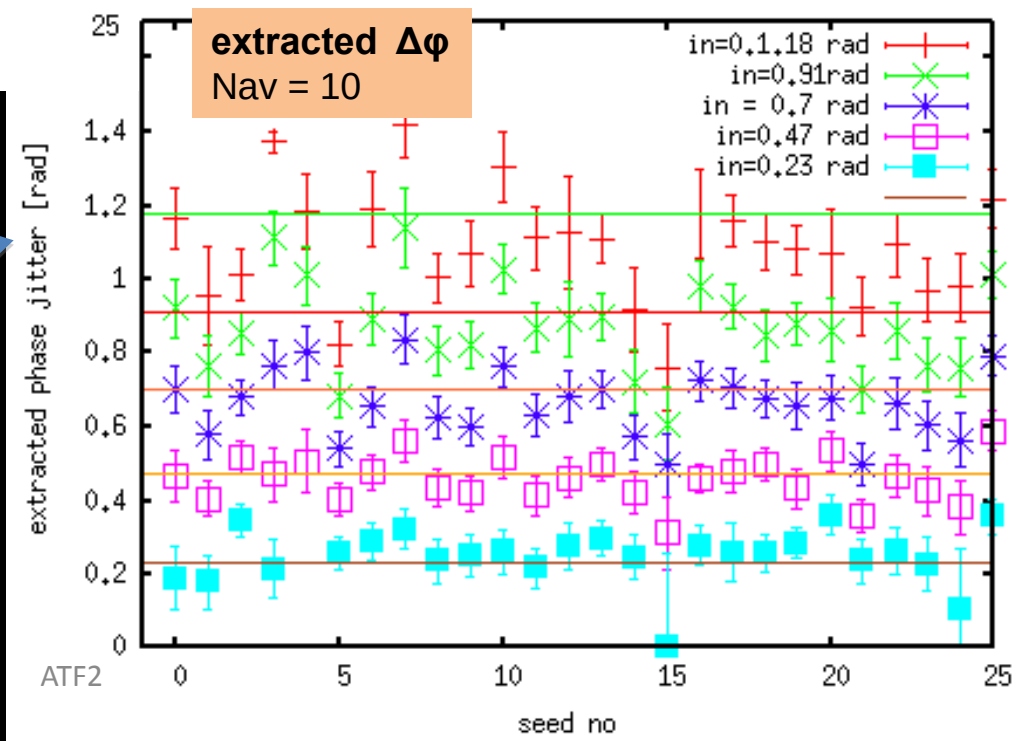


cannot take many scans during beam time
→Need to **observe random distribution**

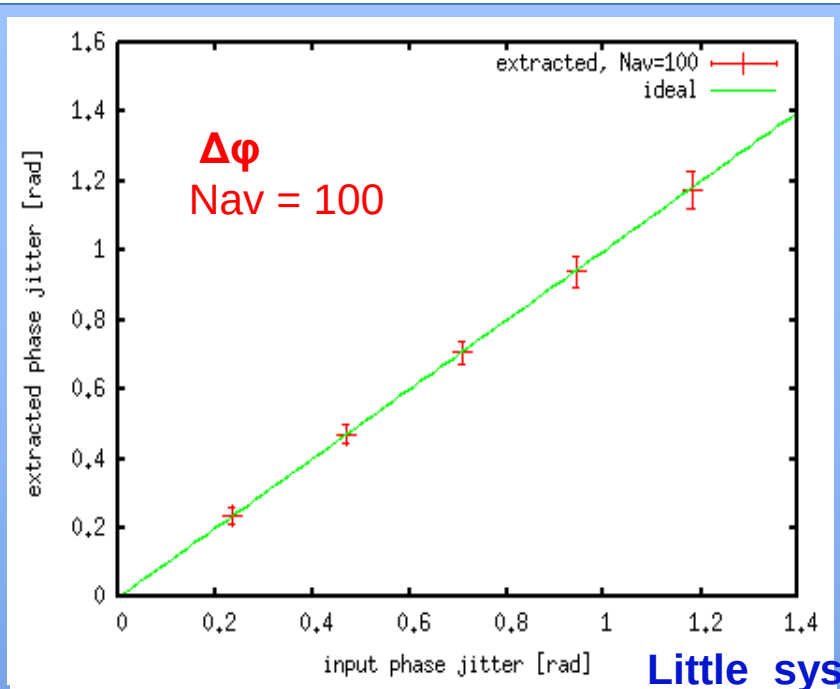
- X axis: 25 random simulation seeds represent **individual scans**

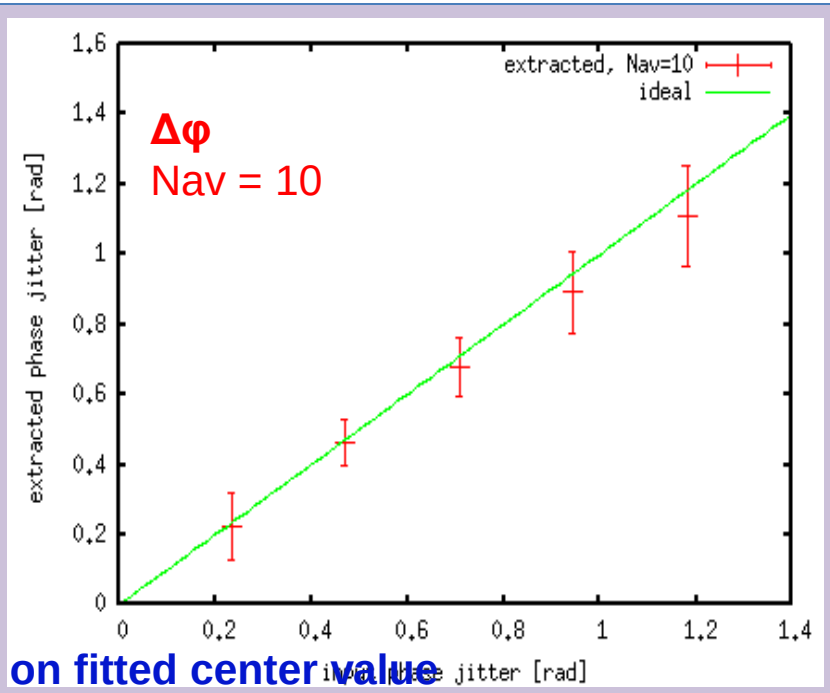
Nav=100 : small deviation from input
(δ<100 mrad even for heavy Δφ)

Nav=10 :
large deviations
for heavy Δφ (> 700 mrad)

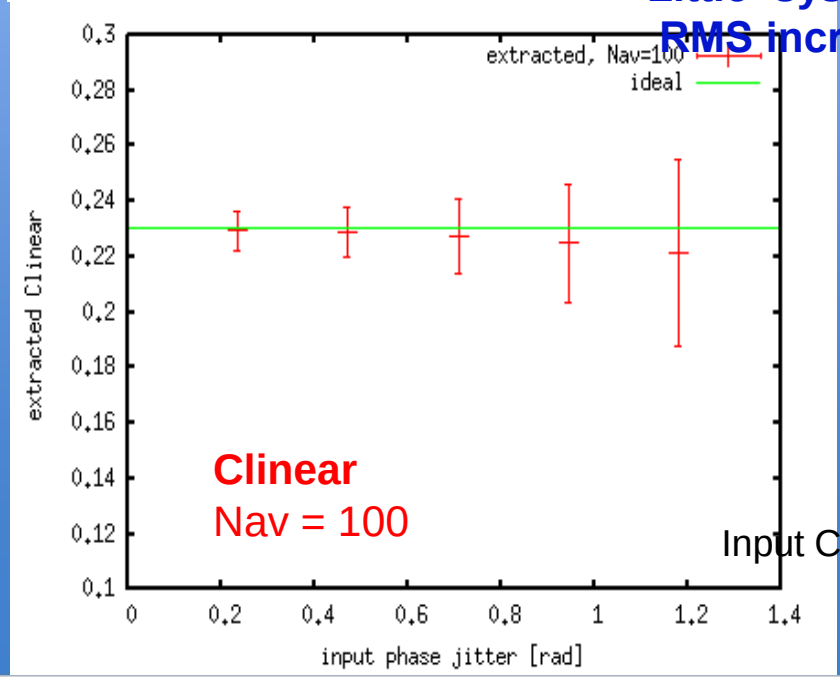


Simulation test： Mean & RMS (S.D.) of 100 random seeds

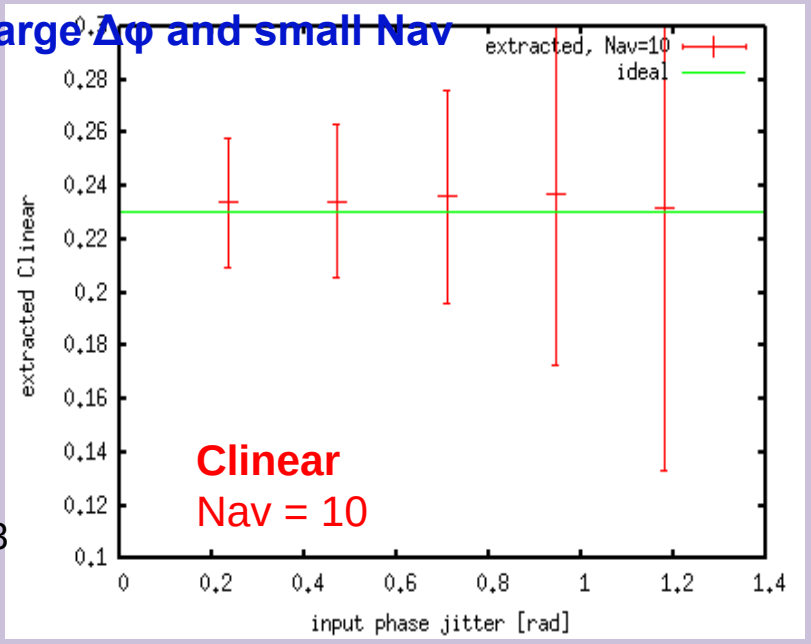




Little systematics on fitted center value
RMS increase for large Δφ and small Nav

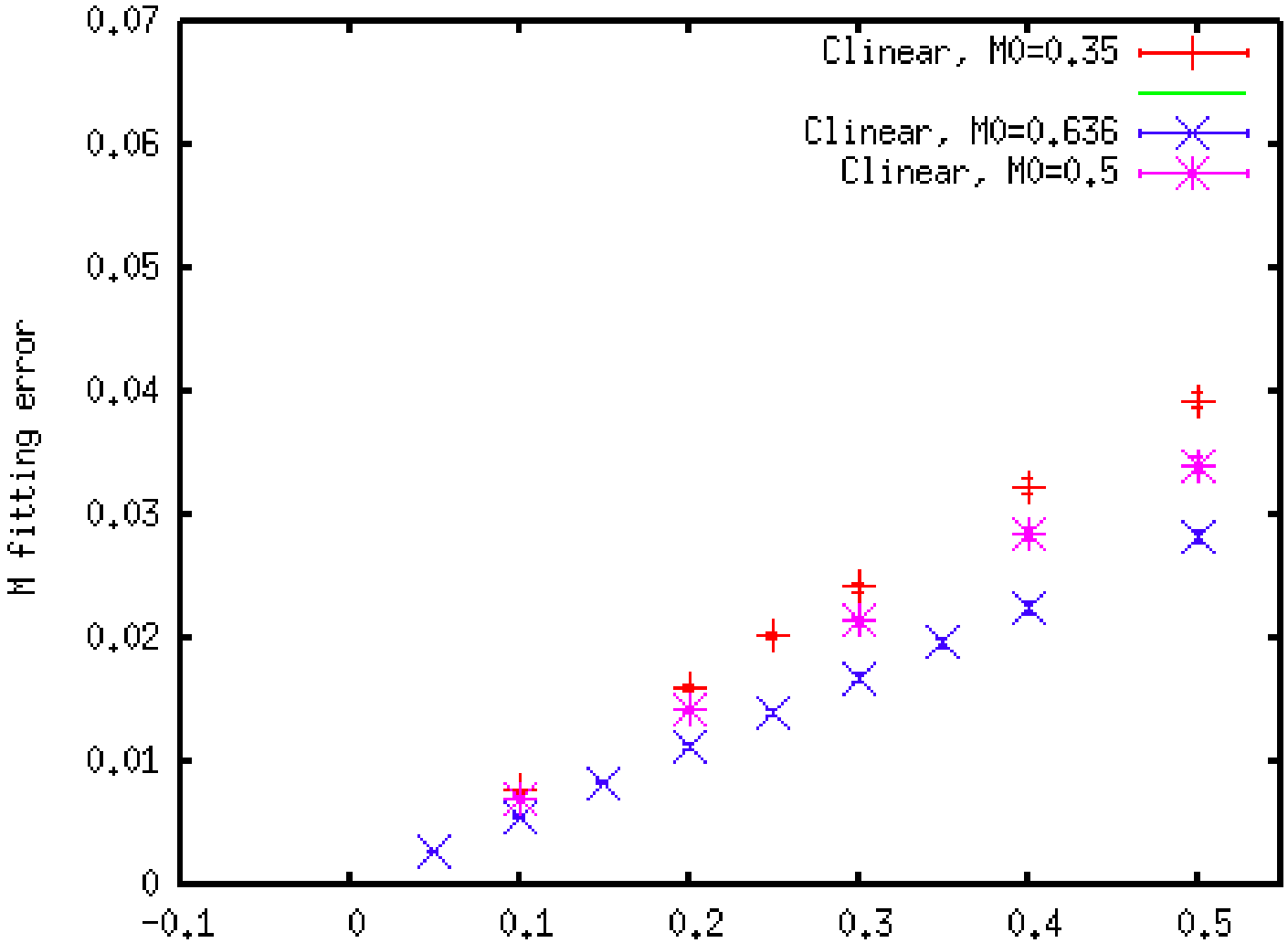


Input Clinear = 0.23

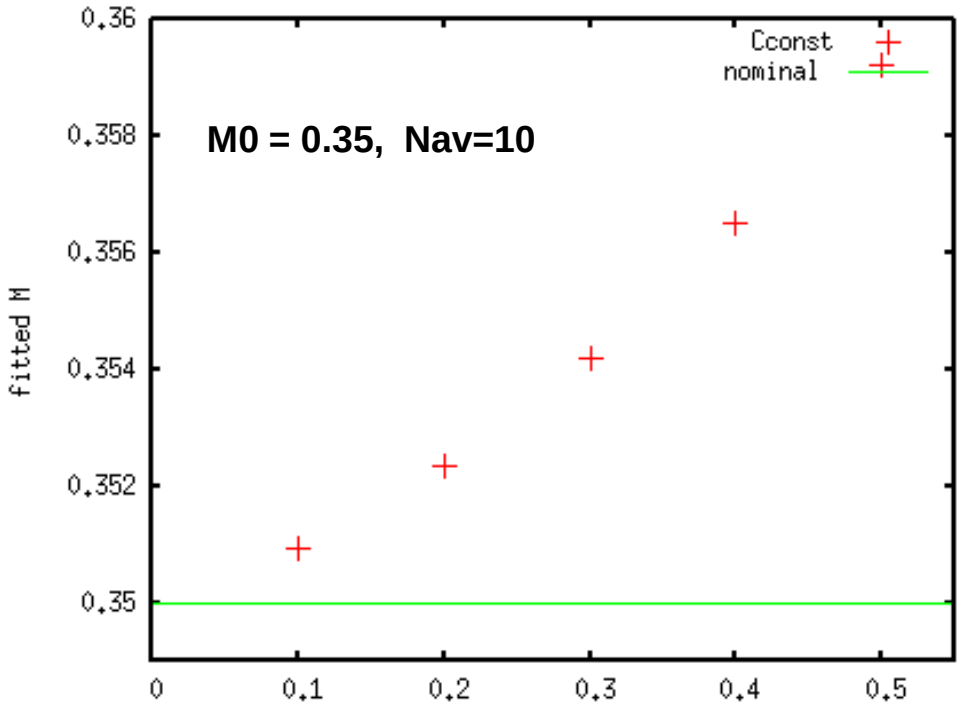


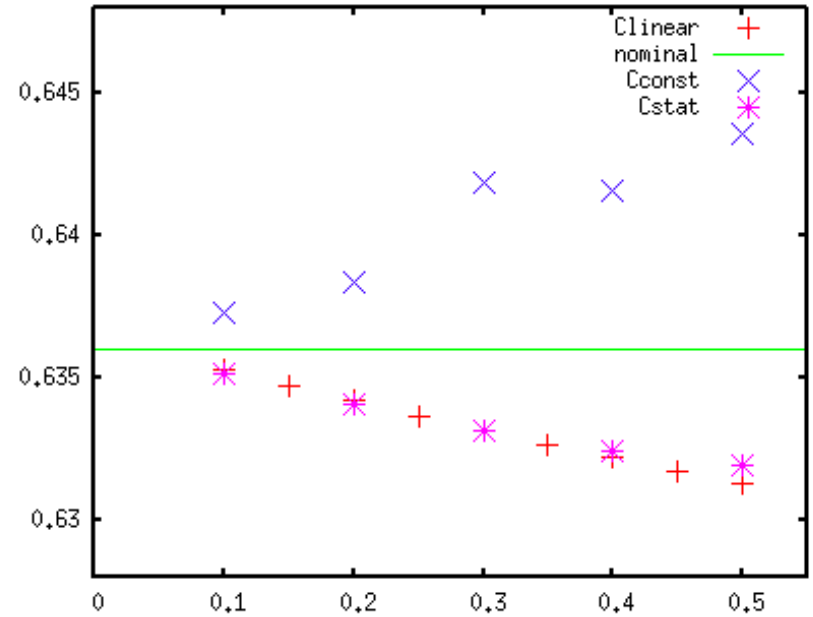
Fitting error has larger effect for smaller M_0

M fitting error



Input :
Nav=10, 174 deg mode,
Change linear ,
Keep others to 0

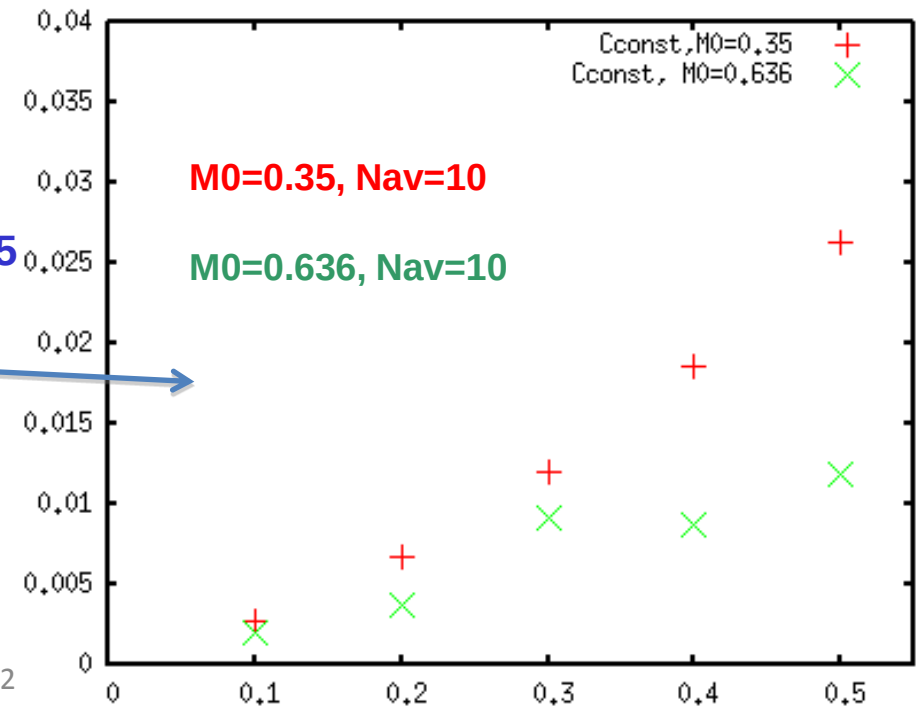




Confirmed over-evaluation effect of Cconst using smaller M0 = 0.35

Compare M0 = 0.636 and M0 = 0.35

X axis: Cconst
Y axis: (M_fit – M0)/M0



Input :
Nav=10, 174 deg mode,
Change 1 C factor type at a time,
Keep others to 0

Proposal by Kubo-san on more accurate fitting function for signal jitters

$$\sigma_E^2 = \sigma_{E,\text{vertical}}^2 + \sigma_{E,\text{phase}}^2$$

Convolution of phase jitter and vertical jitters

$$\sigma_{E,\text{phase}}^2(\varphi_0) = \overline{\left(E(\varphi_0) - \overline{E(\varphi_0)}\right)^2}_{\text{phase}}$$

$$= \frac{1}{2} E_{ave}^2 M^2 \left[1 - 2\cos^2\varphi_0 \exp\left(-\sigma_\varphi^2\right) + \cos(2\varphi_0)\exp\left(-2\sigma_\varphi^2\right)\right]$$

Signal jitter due to phase jitter

Vertical jitters

$$\sigma_{E,\text{vertical}}^2 = C_{\text{const}}^2 + C_{\text{stat}}^2 \overline{E(\varphi_0)} + C_{\text{lin}}^2 \overline{\left(E(\varphi_0)\right)^2} \quad . \qquad (5)$$

$\overline{E(\varphi_0)}$ and $\overline{\left(E(\varphi_0)\right)^2}$ are given by [1] as,

$$\overline{E(\varphi_0)} = E_{ave}\left[1 + M\cos\varphi_0 \exp\left(-\frac{\sigma_\varphi^2}{2}\right)\right] \qquad (6)$$

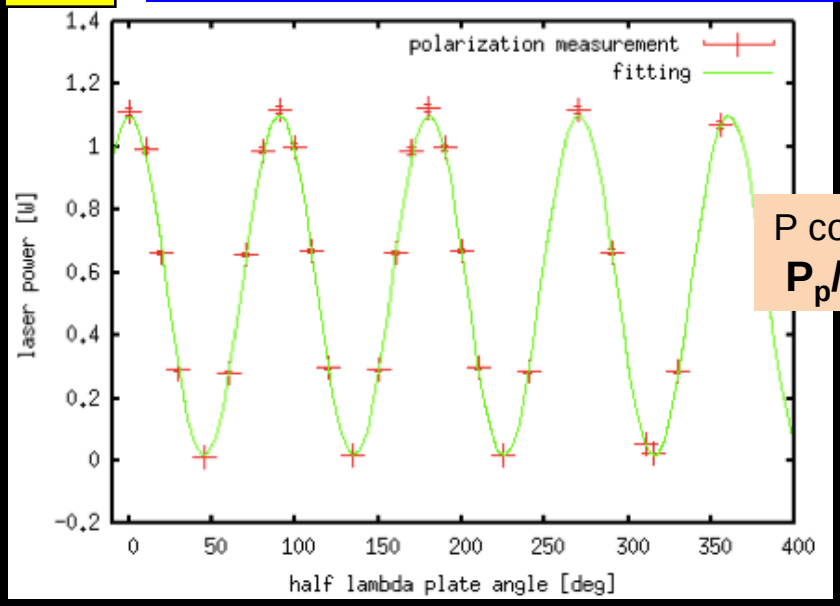
before, I used just

E = Eavg*(1+ M*cos(ϕ + ϕ 0))

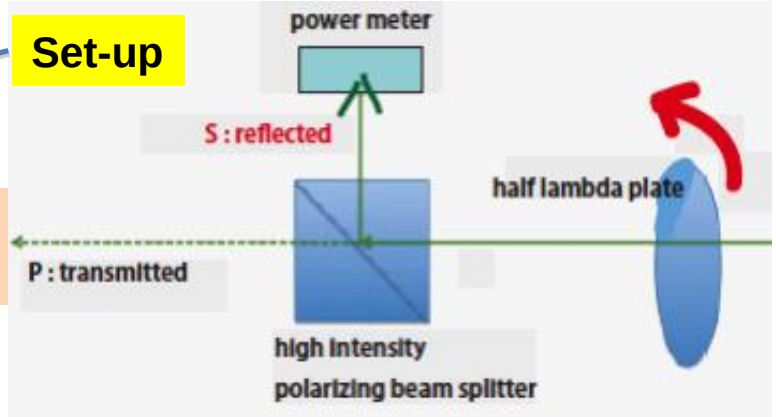
$$\overline{\left(E(\varphi_0)\right)^2} = E_{ave}^2\left\{1 + 2M\cos\varphi_0 \exp\left(-\frac{\sigma_\varphi^2}{2}\right) + \frac{1}{2}M^2\left[1 + \cos(2\varphi_0)\exp\left(-2\sigma_\varphi^2\right)\right]\right\} \qquad (7)$$

#2 Polarization Measurement

IPBSM optics designed for linear S polarization



Set-up

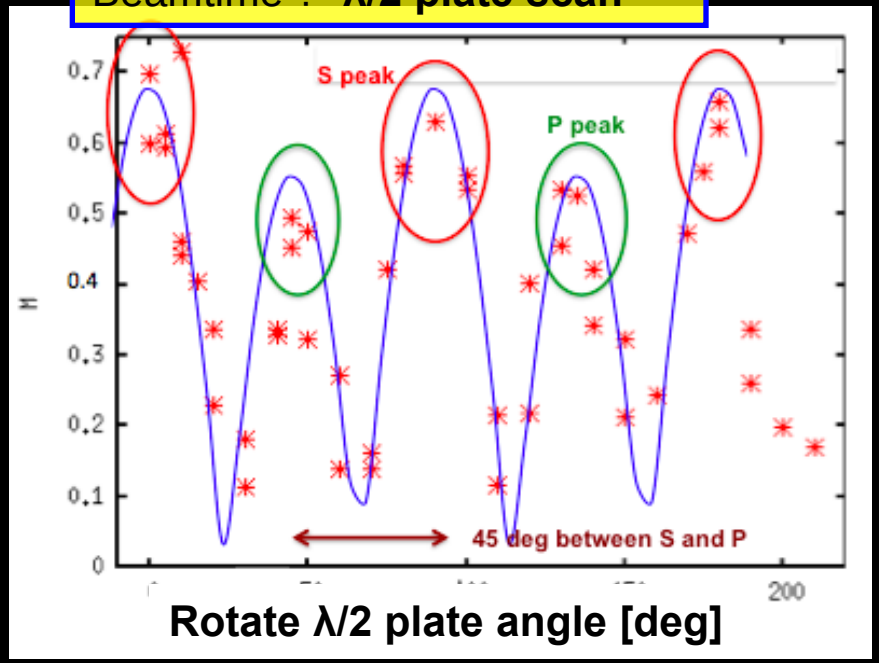


P contamination :
P_p/P_s < 1.5 %

power ratio

almost no M reduction due to polarization

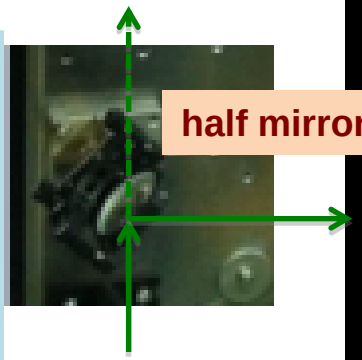
Beamtime : **"λ/2 plate scan**



confirmed "S peaks" maximize M

Also measured "half mirror" reflective properties

Rs = 50.3 %,
Rp = 20.1 %
→ match catalogue value



S peaks" also yields best power balance between 2 paths !!

evaluate laser pointing jitter using Nav=50 laserwire scans

in the form of horizontal relative position jitter between laser and beam

$$E(x) = E_0 \exp\left(-\frac{(x-x_0)^2}{2\sigma_{t,laser}^2}\right)$$

$$\Delta E_{rel}(x) = \frac{dE(x)}{dx}\Delta x = \frac{d}{dx}\left(E_0 \exp\left(-\frac{(x-x_0)^2}{2\sigma_{t,laser}^2}\right)\right)\Delta x$$

$$= E_0\left(-\frac{x-x_0}{\sigma_{t,laser}^2} \exp\left(-\frac{(x-x_0)^2}{2\sigma_{t,laser}^2}\right)\right)\Delta x$$

$$\Delta E_{ON}^2(x) = \Delta E_{sig}^2(x) + \Delta E_{BG}^2$$

$$\Delta E_{sig}^2(x) = \Delta E_{stat}^2(x) + \Delta E_{laser}^2(x) + \Delta E_{rel}^2(x)$$

$$= \left(C_{stat}\sqrt{E(x)}\right)^2 + \left(C_{laser}E(x)\right)^2 + \left[E_0\left(-\frac{x-x_0}{\sigma_{t,laser}^2} \exp\left(-\frac{(x-x_0)^2}{2\sigma_{t,laser}^2}\right)\right)\cdot \Delta x\right]^2$$

evaluate laser pointing jitter using Nav=50 laserwire scans

in the form of horizontal relative position jitter between laser and beam

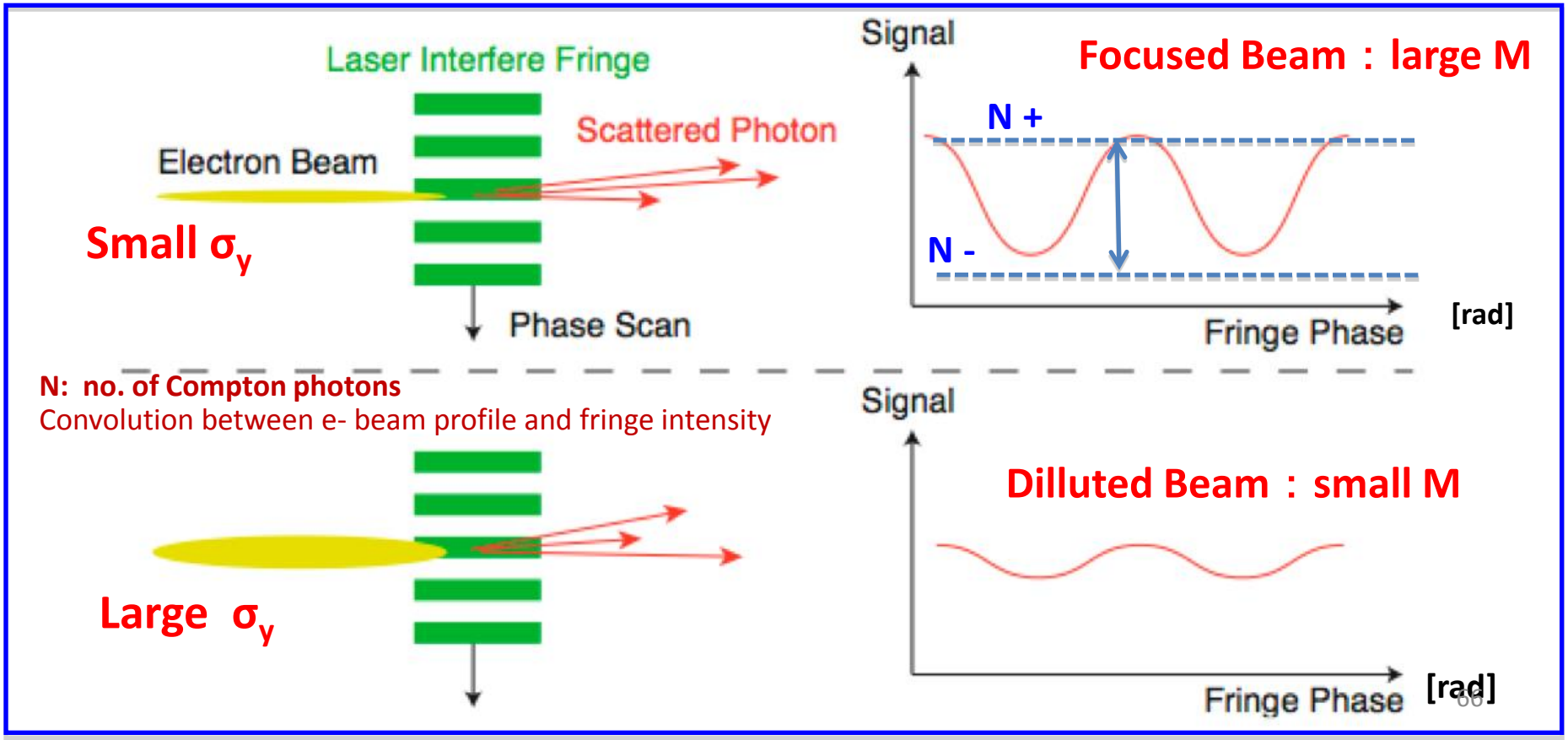
$$\Delta P(\Delta t) = \sqrt{\left\langle P(\Delta t)^2 \right\rangle - \left(\left\langle P(\Delta t) \right\rangle\right)^2}$$

$$= P_0 \sqrt{\sum_{n=0}^{\infty} \frac{(2n-1)!!}{n!} \left(-\frac{\sigma_{\Delta t}^2}{\sigma_t^2}\right)^n - \left\{ \sum_{n=0}^{\infty} \frac{(2n-1)!!}{n!} \left(-\frac{\sigma_{\Delta t}^2}{2\sigma_t^2}\right)^n \right\}^2}$$

$$\left\langle P(\Delta t) \right\rangle \approx P_0 \left\{ 1 - \frac{1}{2}\frac{\sigma_{\Delta t}^2}{\sigma_t^2} + \frac{3}{2}\left(\frac{\sigma_{\Delta t}^2}{\sigma_t^2}\right)^2 - \ldots\ldots \right\}$$

$$\frac{\Delta P(\Delta t)}{P_0} \approx \frac{\sigma_{\Delta t}^2}{\sqrt{2} \cdot \sigma_t^2} \sqrt{1 - 3\frac{\sigma_{\Delta t}^2}{\sigma_t^2} + \ldots\ldots}$$

$$\frac{! \; E_{pos}(! \; x)}{E} \,\text{''}\, \frac{(! \; x)^2}{\sqrt{2}! \;\; {}^2_{laser}} \sqrt{1 \# 3 \frac{(! \; x)^2}{! \;\; {}^2_{laser}} + \ldots\ldots}$$



Detector measures
signal **Modulation Depth "M"**

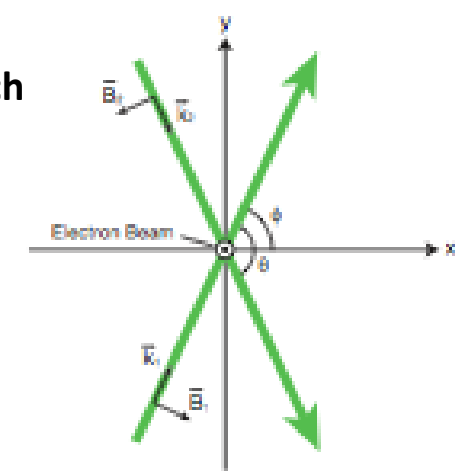
$$\mathbf{M} = \frac{N_+ - N_-}{N_+ + N_-} = \left|\cos(\theta)\exp\left(-2(k_y\sigma_y)^2\right)\right|$$

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

measurable range
determined by **fringe pitch**

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

depend on
crossing angle θ (and λ)



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	70 nm	170 nm	700 nm
Upper limit	90 nm	340 nm	1.3 μm	5.2 μm

Expected Performance

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

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

σ_y and M for each θ mode

select appropriate mode according to beam focusing