PARITY BEAM STUDIES

6/09/2016

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BEAM CHARGE ASYMMETRY

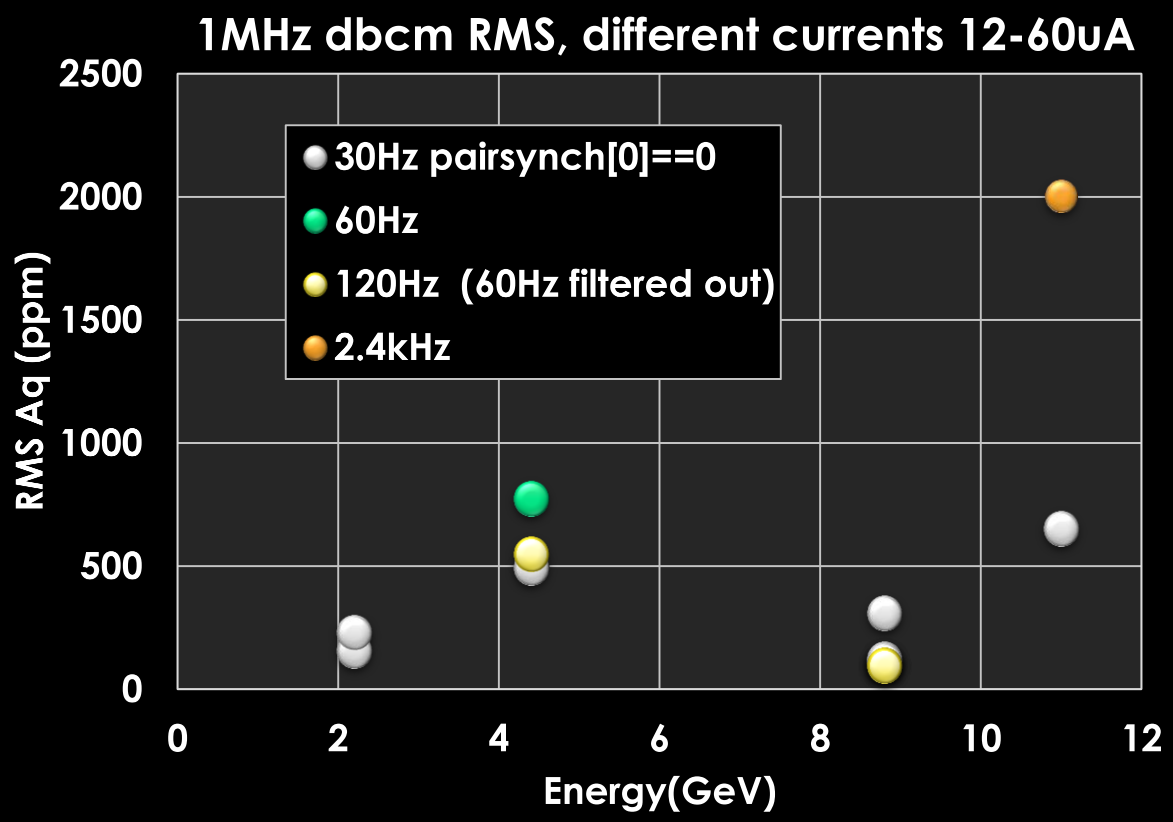
Run	GeV energy	uA current	ppm dbcm 1MHz Aq	ppm dbcm RMS ps=0	ppm dbcm RMS	notes
2333	4.4	12	**62.64**	493.9	576.4	IHWP out
2358	8.8	13.7	**44.7**	309.1	428.6	IHWP out
2488	8.8	60	**30.79**	121.9	326.8	IHWP in
2494	8.8	45	**25.37**	117.7	317	IHWP in
2498	8.8	45	**42.7**	116	314	IHWP in

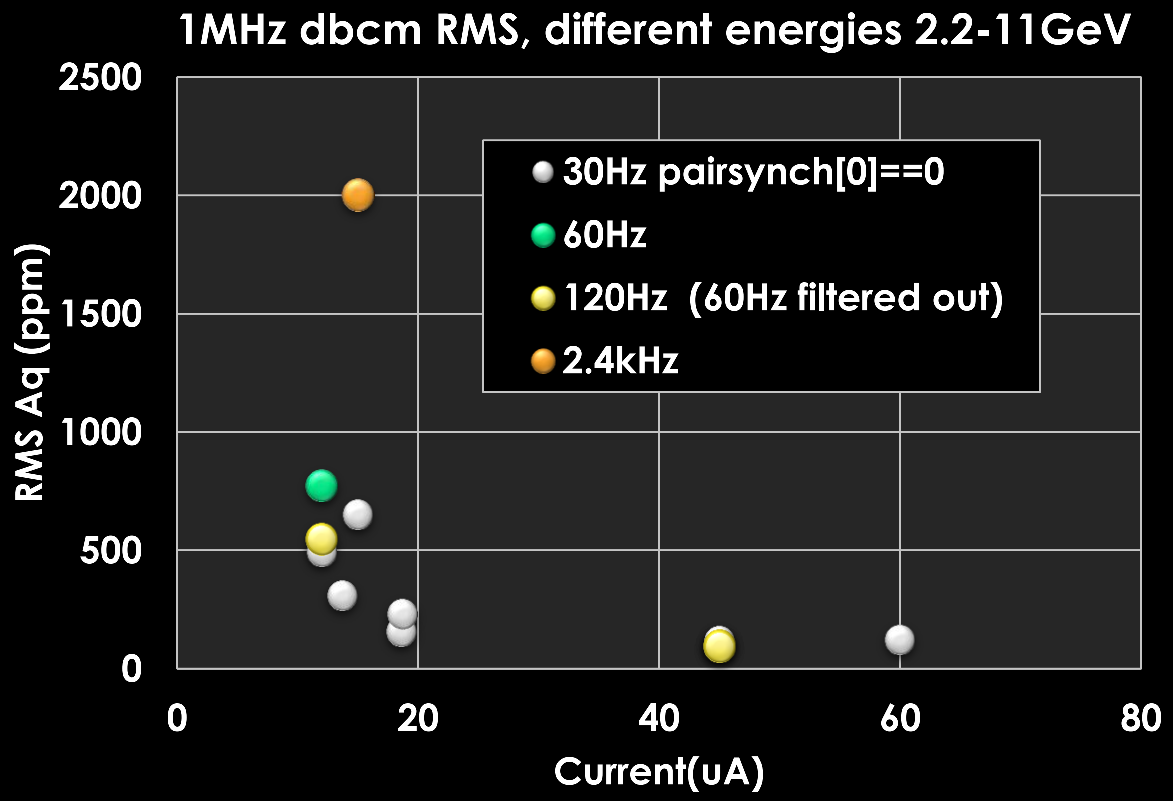
Run	energy	current	Inj bcm Aq	injbcm RMS ps=0	Inj bcm RMS	
1905	8.8	60	**-0.7**		223.9	IHWP in

BEAM ASYMMETRY WIDTHS

- Higher energies don't appear to bear much relationship to widths observed

- Higher currents may generally tend to be associated with smaller widths





BEAM ASYMMETRY WIDTHS
INJECTOR

Injector

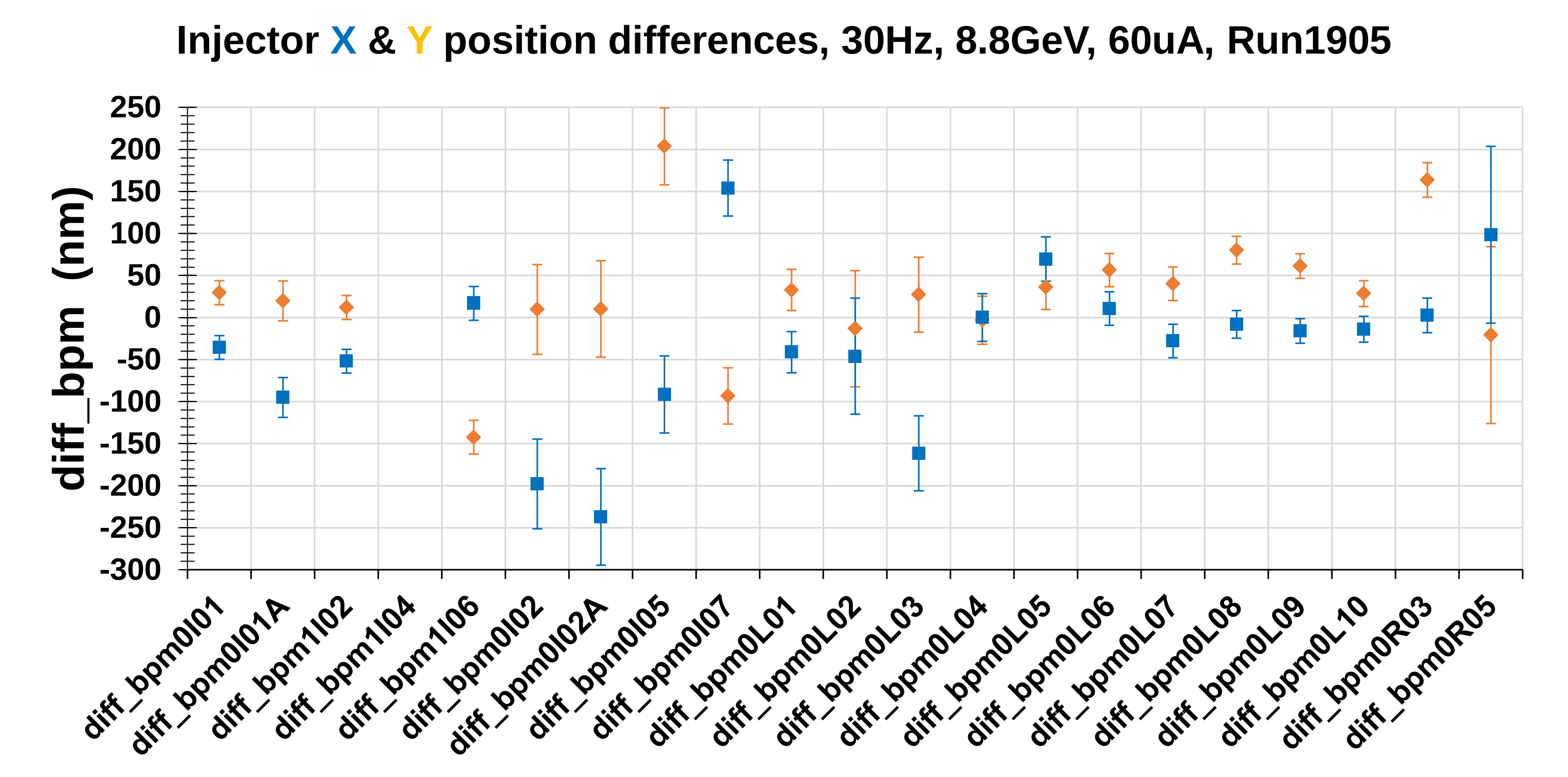
- Higher frequencies tend to result in smaller widths (scaled to counting statistics)

	Run	GeV energy	uA current	Hz frequency	bcm 0L02 RMS ps0=0	bcm RMS	Analysis with ADC subblocks of helicity window	ppm/sqrt(Hz) RMS/sqrt(f)
Injector, multiple frequencies, 4pass	1905	8.8	60	30	**208.1**		normal	**37.99**
	1905	8.8	60	60		**273.1**	(b1+b2-b3-b4)/(b1+b2+b3+b4)	**35.26**
	1905	8.8	60	120		**212.7**	1/2((b1-b2)/(b1+b2)+ (b4-b3)/(b3+b4)),(60Hz filtered out)	**19.42**
	1902	8.8	60	567		**653.6**	(b1+b2-b3-b4)/(b1+b2+b3+b4)	**27.45**
	1902	8.8	60	1134		**531.3**	(b1-b2)/(b1+b2)	**15.81**

NOW
30Hz fliprate

BEAM POSITION DIFFERENCES

INJECTOR

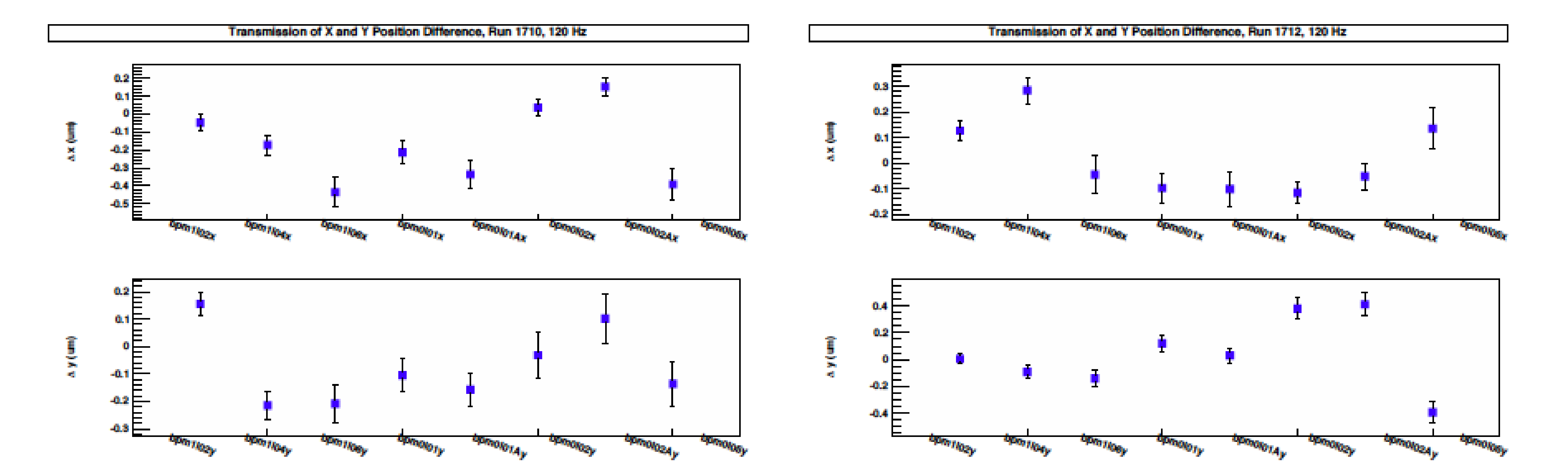


BEAM POSITION DIFFERENCES

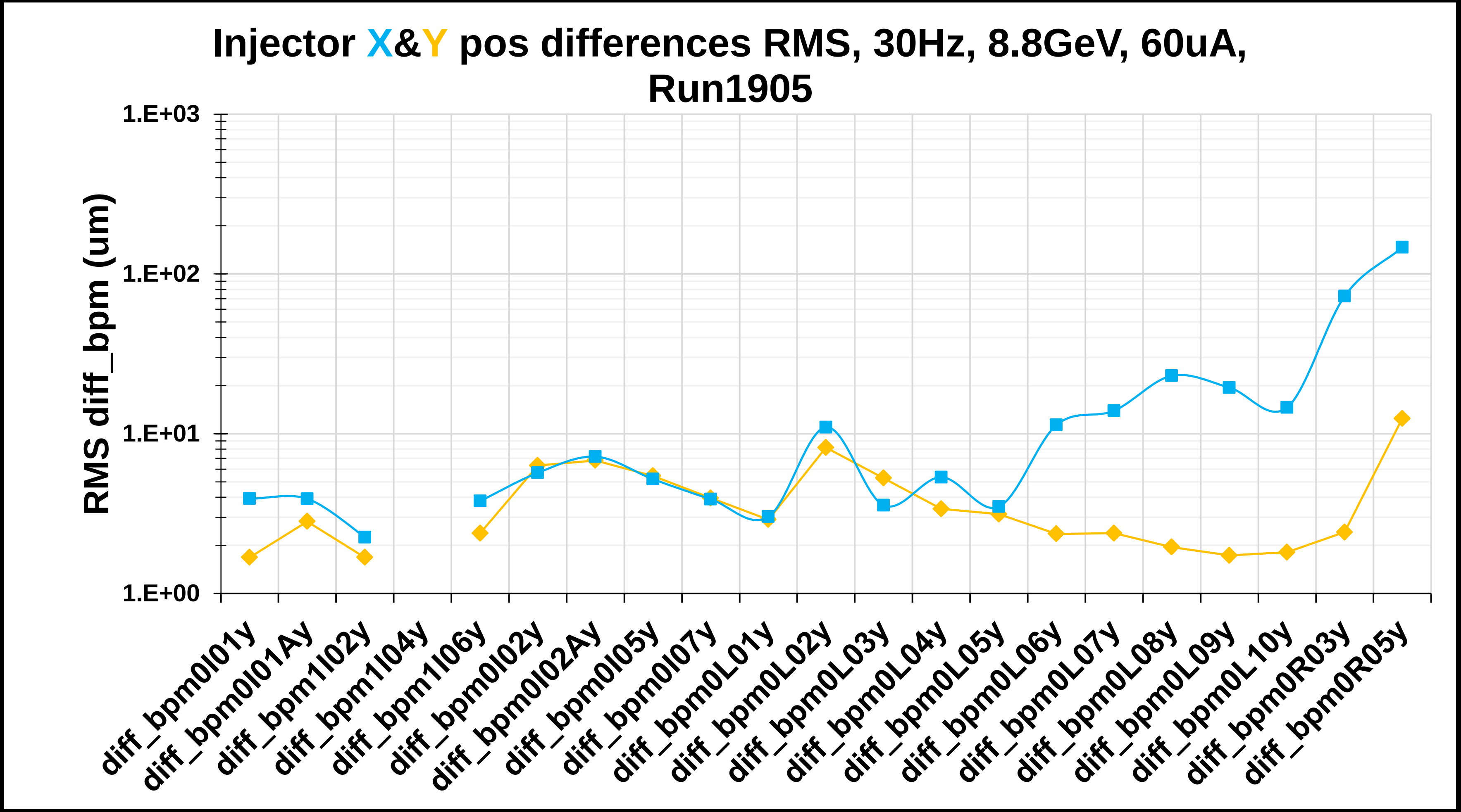
INJECTOR

2010
120Hz fliprate

- **PREXI Ref: Silwal Thesis, Fig. 6.7.5**



BEAM POSITION DIFFERENCE WIDTHS
INJECTOR



BEAM POSITION DIFFERENCE WIDTHS

	GeV	uA	Hz		RMS um	RMS um	RMS um	RMS um	RMS um	RMS um	RMS um	RMS um	RMS um	RMS um
Run	energy	current	frequency	conditions	bpm4ax	bpm4ay	bpm4bx	bpm4by	bpm8x	bpm8y	bpm12x	bpm12y	bpm14x	bpm14y
2347	2.2	18.6	30Hz		*6.395**	*14.23**	11.91	9.46	18.53	8.04	12.41	8.9	-	-
2349	2.2	18.7	30Hz		*6.644**	*12.15**	10.97	7.48	14.83	8.87	7.97	8.08	-	-
2333	4.4	12	30Hz	noisy run, ffb might not be on	*9.805**	*17.5**	15.87	8.95	48.84	9.73	27.14	14.55	-	-
2358	8.8	13.7	30Hz		*10.4**	*34.55**	10.4	13.27	30.96	13.34	15.47	43.87	-	-
2494	8.8	45	30Hz		*11.17**	*24.41**	11.05	13.31	23.34	7.32	12.27	10.15	4.96	8.55
2488	8.8	60	30Hz		*7.22**	*23.48**	*10.27**	*28.27**	21.06	7.12	11.26	10.41	6.51	9.82
2434	11	15	30Hz		-	-	12.91	10.03	21.27	9.76	13.39	21.99	6.55	6.97
2434	11	15	120Hz	1/2((b1-b2)/(b1+b2)+ (b4-b3)/(b3+b4)) (60Hz filtered out)	-	-	10.45	10.81	22.87	6.22	13.8	10.14	4.75	5.58
2437	11	15	2370Hz	(b1-b2)/(b1+b2), pairsynch=0	-	-	26.98	43.32	25.6	26.72	17.98	30.14	6.32	29.39
2434	11	15	120Hz	(b1-b2)/(b1+b2) , pairsynch=0, (60Hz sensitive)	-	-	18.66	16.34	34.27	36.33	19.4	66.9	10.34	15.07

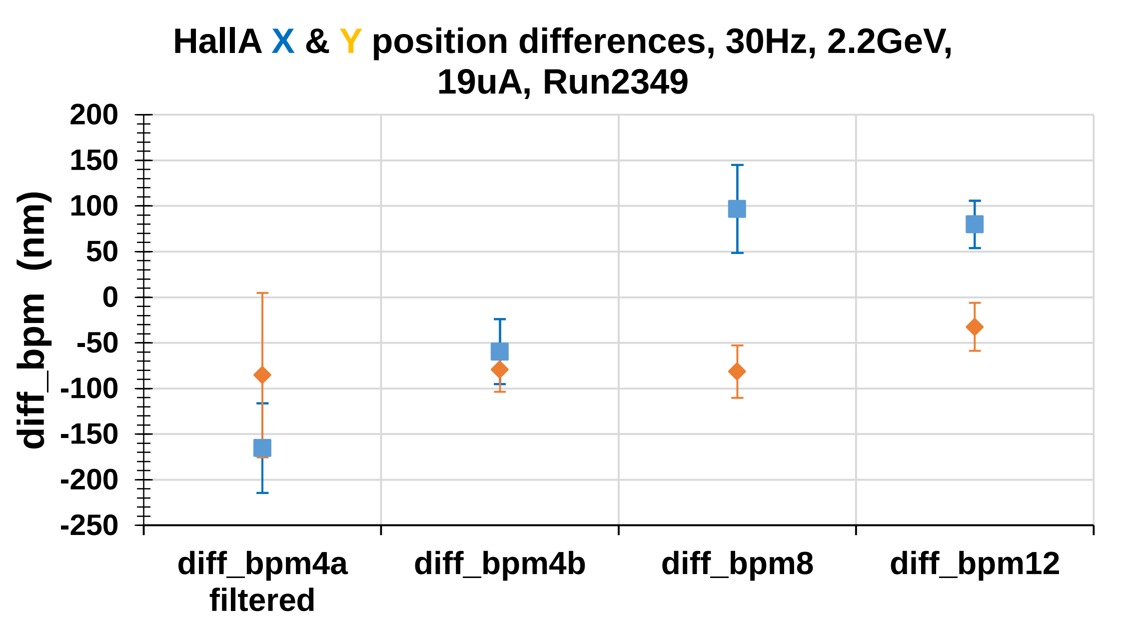
*filtered: evt_bpm4ax[0]<a&&evt_bpm4ax[1]<a

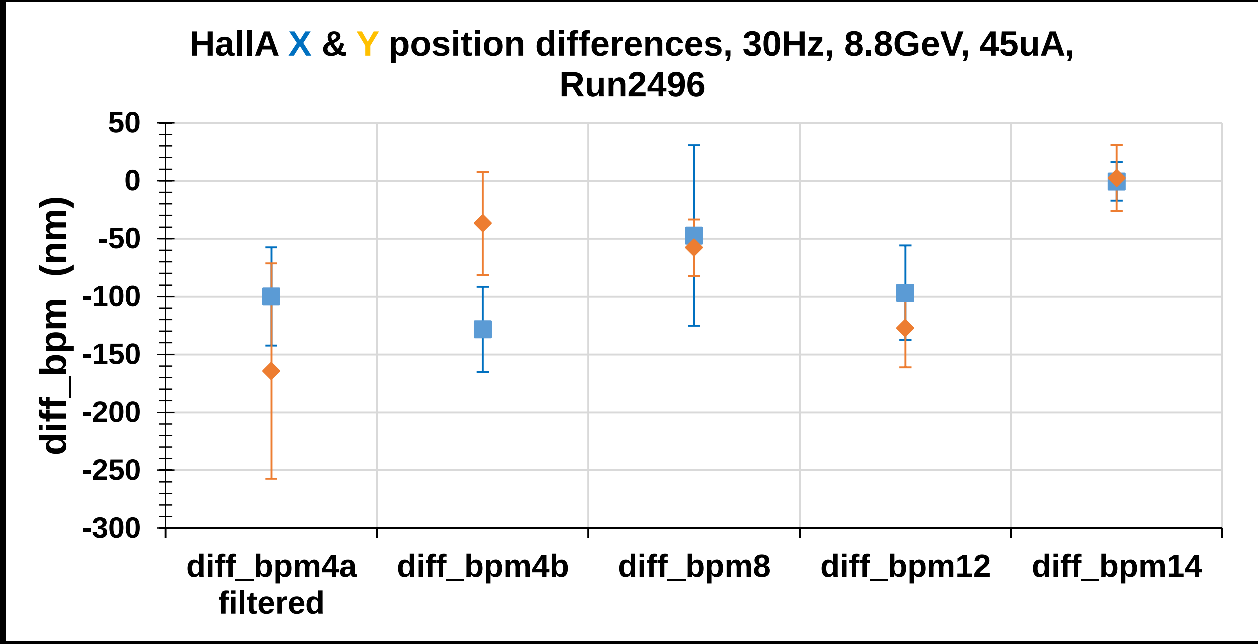
BEAM POSITION DIFFERENCES

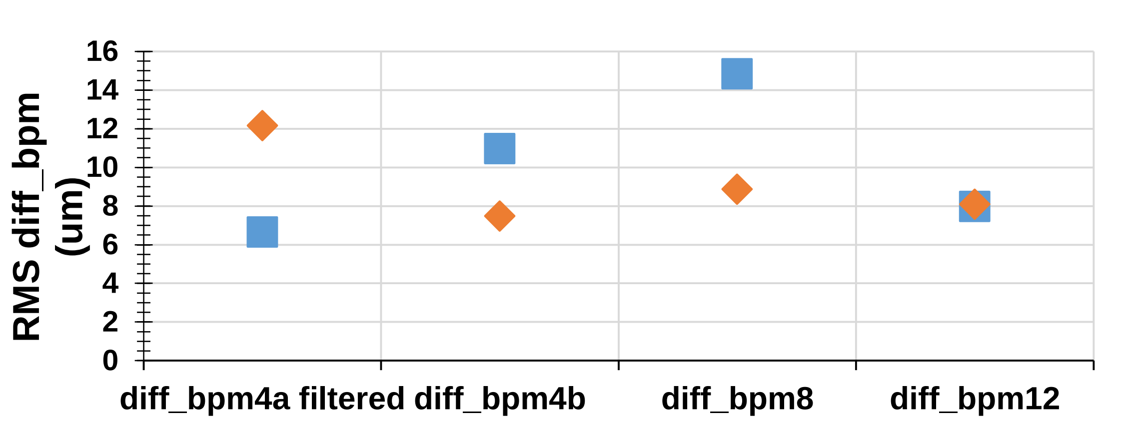
Not very dependent on number of passes

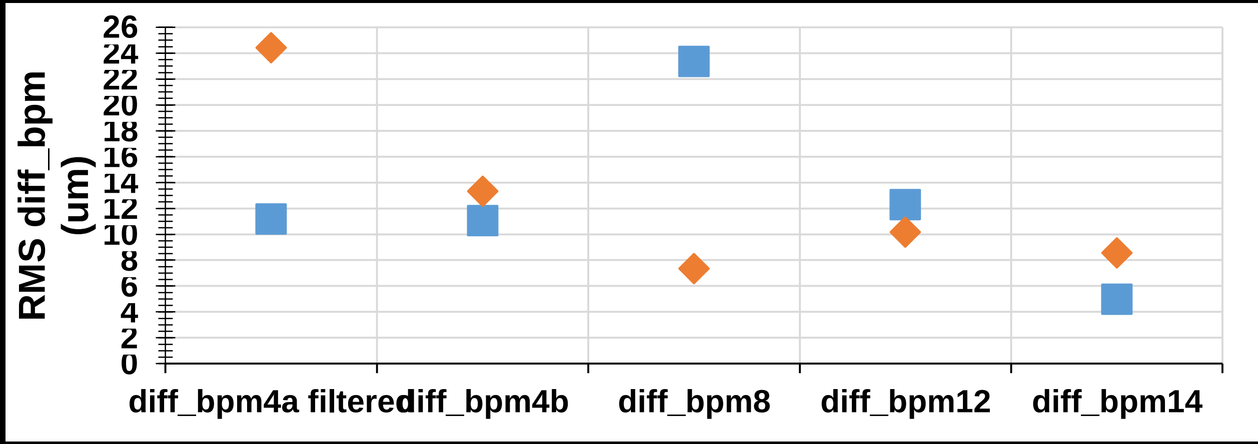
1 pass

4 pass



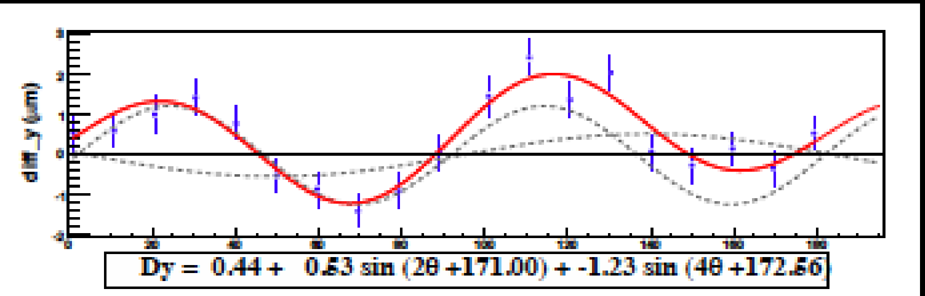






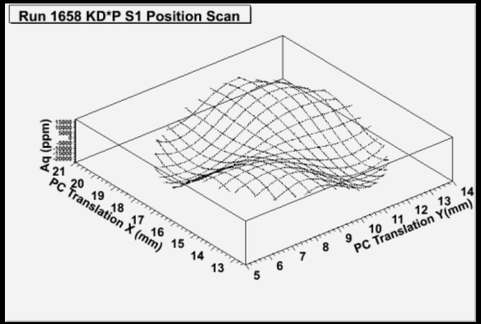
PARITY QUALITY

- Do we have it? We are in a good position to get it.
- We already have small helicity correlated changes in Aq : ~30ppm
- What about the noise? Aq widths and bpm widths look similar to the past: 10's of um
- Increasing the flip rate will improve matters even further
- How will small position differences be achieved? In the usual way: Pockels Cell centering, RHWP & photocathode rotation
- Will we have it? Yes, with some small adjustments to the source alignment.
- Is the beam usable? Yes. If the beam can be delivered to the hall, it is usable for parity experiments.
- Are the monitors working? We have sufficient monitors currently operational to perform a parity experiment. We want to optimize the additional monitors.

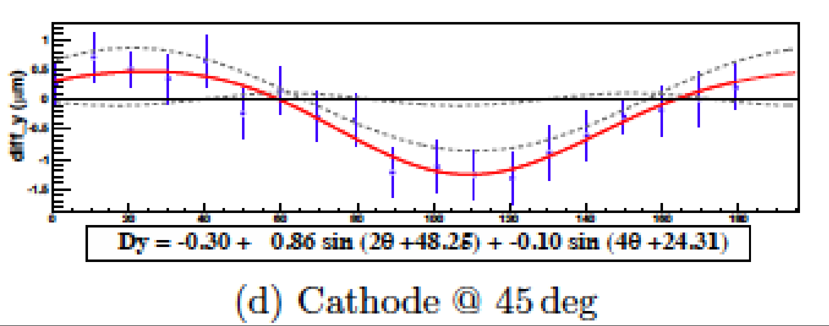


RHWP scan

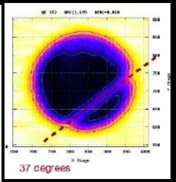
Ref: Silwal Thesis, Fig 6.8



PC centering



Photocathode rotation



Ref: Silwal Thesis, Fig 6.7.2

MONITOR TESTS

PITA SCAN

Test

- PITA scan functions as a test of the monitor linearity, test of the calibrations, and assesses the analyzing power of the photocathode
- We performed a PITA scan at 30Hz, 8.8GeV, 45uA, with IHWP in, LH2 target in, and SAMs on
- Range: +- 2000 counts (65535counts/4000V conversion factor)

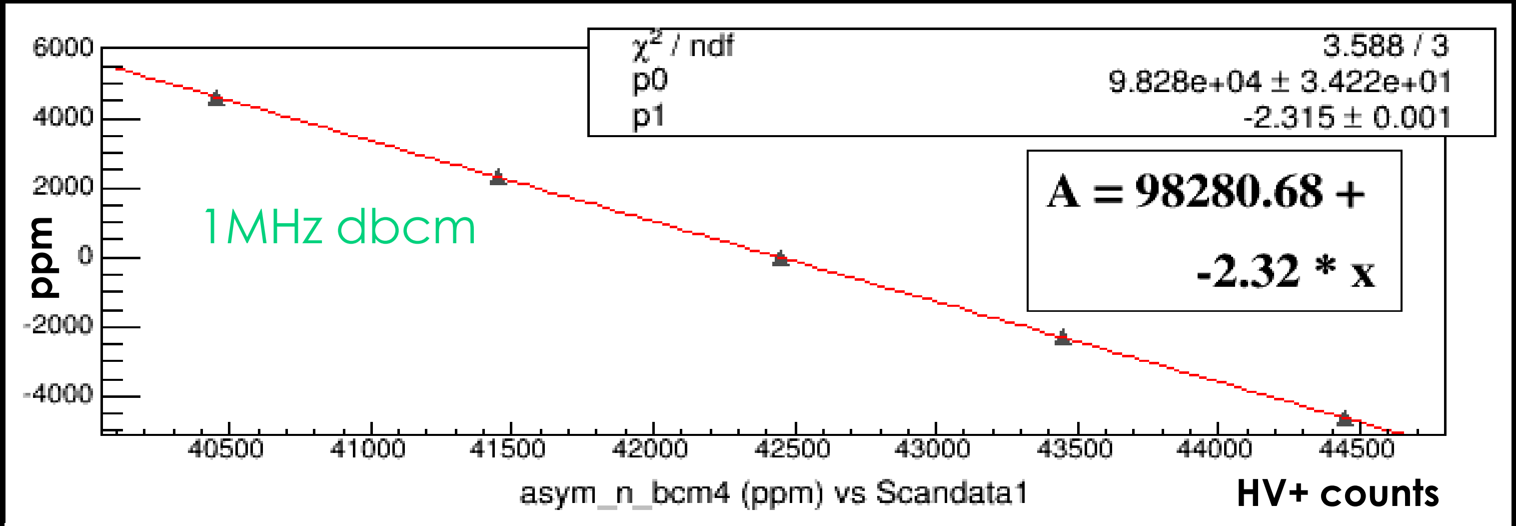
Results

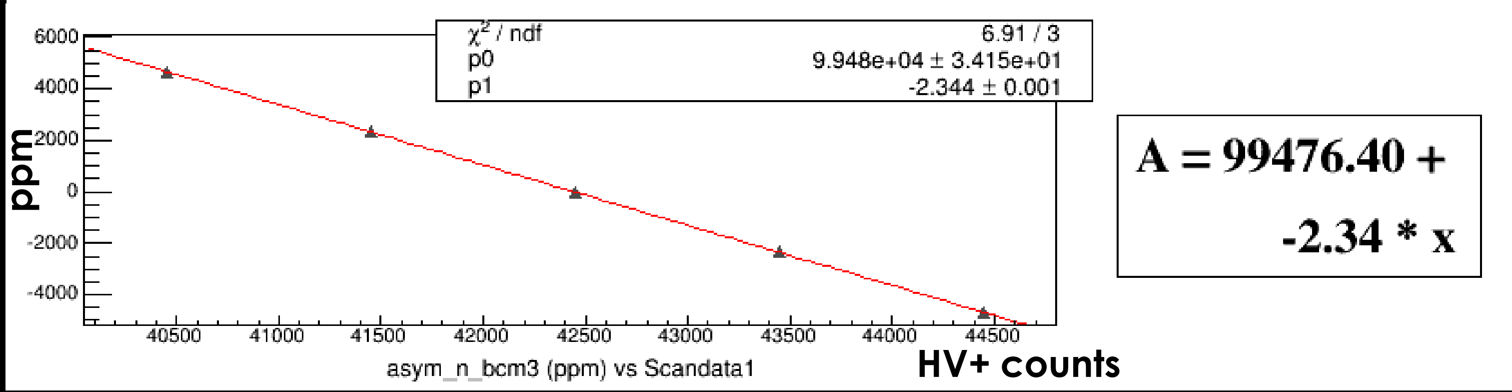
- 1MHz dbcm indicates PITA slope of -38ppm/V (+-2000ppm measurement)
  - PREX I (2010), observed PITA slopes of 22-31ppm/V which corresponded to a photocathode analyzing power of ~6% (Ref: Silwal Thesis)
  - Suggests photocathode analyzing power of 8-10%
- Position Differences – go through 0, have slopes of ~0.1-1nm/ppm
- SAMs – slopes reveal non-linearity of up to several % for various HV settings

PITA SCAN

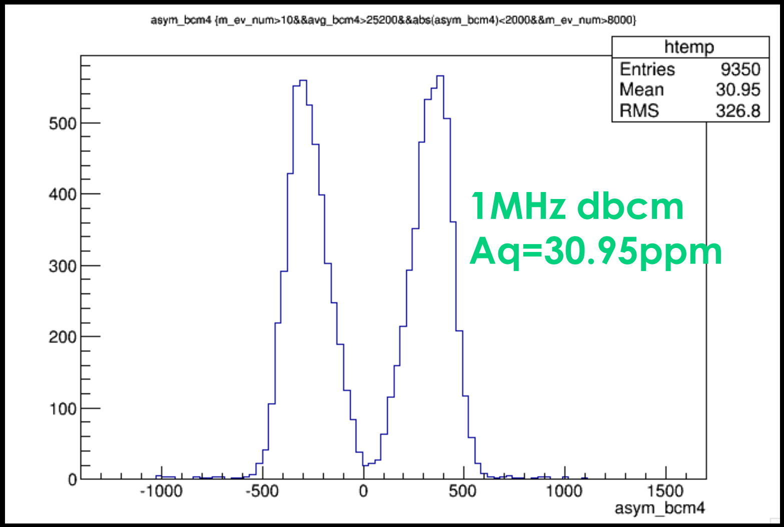
- **1MHz dbcm indicates PITA slope of -38ppm/V**

(+-2000ppm measurement, 65535counts/4000V conversion factor)





- **Central value of Aq 30.95ppm**



BEAM CURRENT MONITORS

DIGITAL BCMS DELAY & LINEARITY

- The **1MHz system has a small ~10us delay = 2.5us(latency)+7-8us(risetime)**
- New digital receiver system has 3 outputs– 'fast'/OPS, 'adjustable','slow'/EPICS
- Digital reciever slow'/EPICS output setting has a 5.1 ms delay(measured with tune beam) due to low pass filters and additional latency
- By changing the output mode to 'fast', removing many of the applied low-pass filters, we can reduce the delay to ~16-18us(relative to the 1MHz system) and ~26-28us total delay relative to beam
- We can further reduce the delay by bypassing several filters in 'straight through' mode,

delay down to 1us (relative to the 1MHz system)

and 11us total delay =4.5us(latency)+ 6.5(risetime)

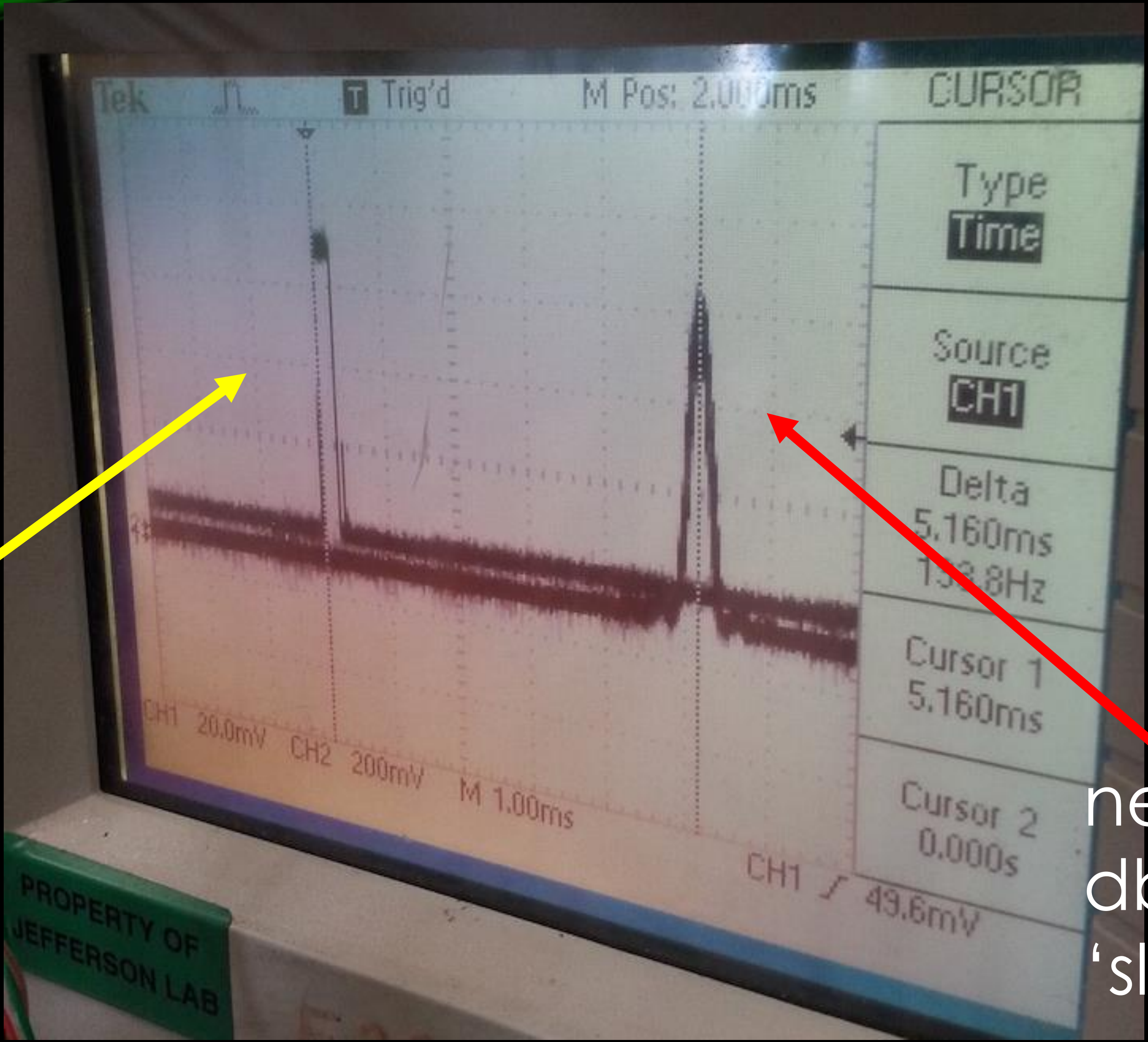
- Comparing both 1MHz and digital reciever systems, we – we can adjust the gate delay on our ADCS by 0us or 2us and adjust the receiver gain to keep output below 10V(our ADC limit) and **we'll be set.**
- New Mussons saturated at 40uA for a particular gain setting during running, but the gain settings were simply adjusted. We are going to put some attenuators on the receiver input and adjust the internal attenuators to make it physically impossible for any experiment to saturate the receivers in the future If we properly make use of the digital system settings, it looks nice and linear

We can tailor digital filters applied to suit our needs

This low-latency setting will work for us in PREXII

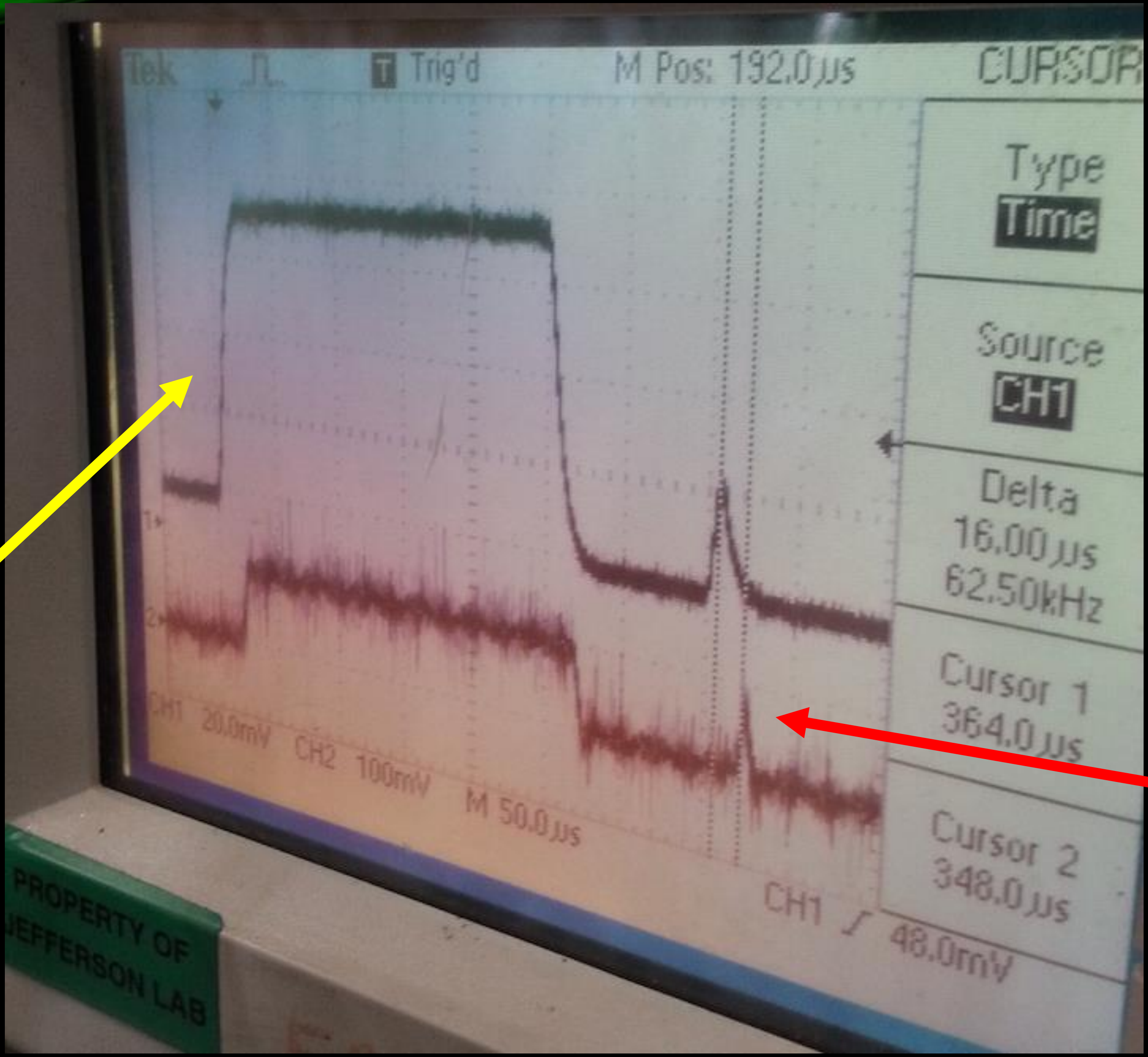
DBCM 'SLOW'

1MHz dbcm tune beam



new dbcm 'slow'

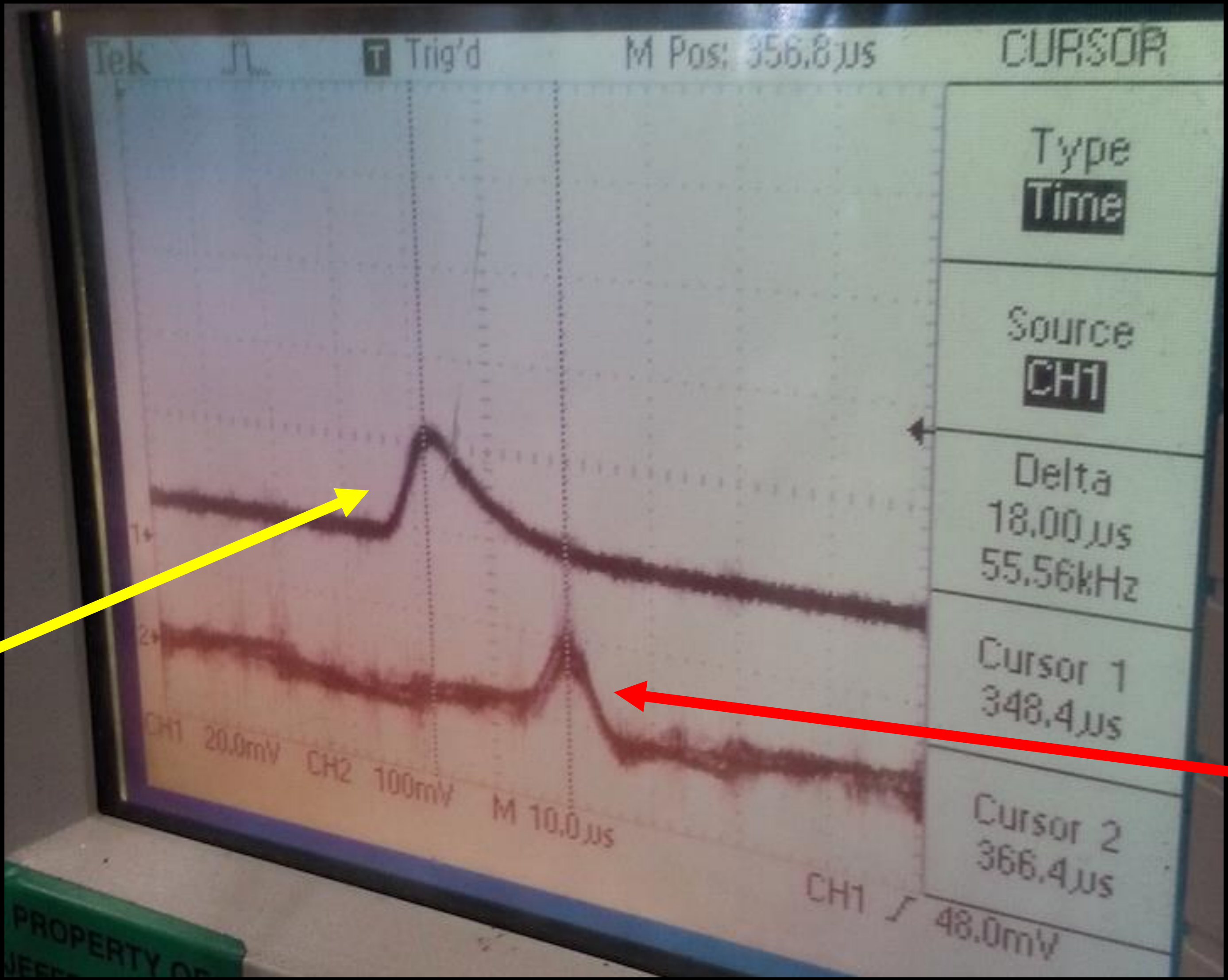
DBCM NO FILTER



1MHz dbcm
tune beam

new
dbcm
no filter

DBCM NO FILTER



1MHz dbcm tune beam

new dbcm no filter

EVIDENCE LEADING UP TO BCM DELAY MEASUREMENT

- There were many symptoms which indicates delay was happening with the digital receivers
- It is important to make note of these symptoms so that we can diagnose delay in other signals
- The evidence appeared as

1. Less correlation with other monitors, more uncorellated noise, wider DDs
2. 60Hz signal (detected by beat oscillation between near120Hz subblock rep rate) showed phase delay relative to other signals
3. Earlier (sub-block) data points showed more correlation with other monitors than same-event (sub-block) data points
4. Beam trips weren’t happening at the same event (or subblock event) as other signals
5. (Smaller PITA slopes)

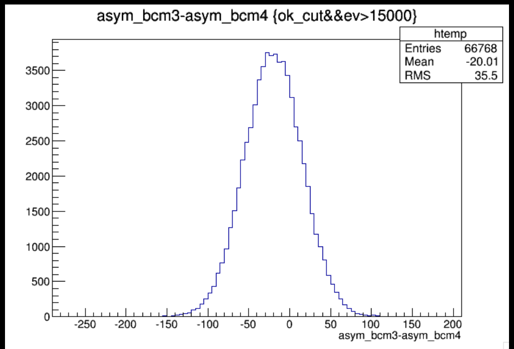
BCM RESOLUTION

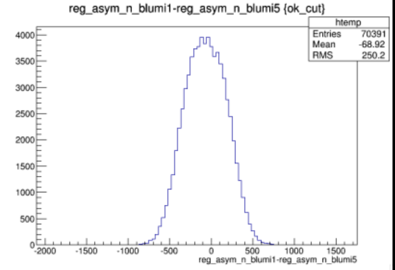
- 1MHz Bcm's behave well most of the time and **resolution looks good**
- Resolution of 1 MHz system improves with higher current and improves with higher frequency
- Resolution can be assessed from double difference widths of upstream and downstream 1MHz bcms
  - For 120Hz, at 12uA, we have a resolution of ~43ppm
  - For 30Hz, at 60uA, we have a resolution of ~11ppm
- Resolution measurement can be independently checked using the SAMs
  - For 30Hz, 20uA, we have a resolution of ~30ppm
  - For 30Hz, 45uA, we have a resolution of ~13ppm

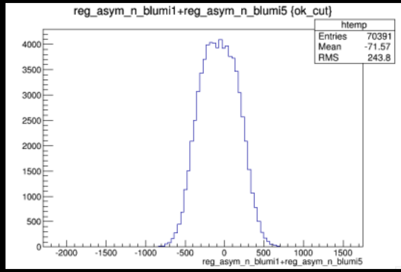
This is sufficient bcm resolution for PREXII (>70uA, 120Hz)

BCM 1MHZ NOISE FROM SAMS

$$S_{+} = SAM_1 + SAM_5 - 2S_{bcm}$$
$$S_{-} = SAM_1 - SAM_5$$
$$\sigma_{+}^2 = \sigma_1^2 + \sigma_5^2 + 4\sigma_{bcm}^2$$
$$\sigma_{-}^2 = \sigma_1^2 + \sigma_5^2$$
$$\sigma_{bcm}^2 = (\sigma_{+}^2 - \sigma_{-}^2)/4$$
$$\sigma_{bcm} \sim (\sigma_{ubcm} - \sigma_{dbcm})/\sqrt{2}$$







Run 2347 – carbon 2.2GeV 18.6uA 30Hz , regress with 4a,4b,12x

regressed after reanalysis with pairsynch normal maxevent 5000	RMS ppm
(asym_bcm3-asymbcm4)/sqrt(2)	25.1
reg_asym_n_blumi1+reg_asym_n_blumi5	250.2
reg_asym_n_blumi1-reg_asym_n_blumi5	243.8
sqrt(pow(250.2,2)-pow(243.8,2))/2	28.1

- regress with all bpms except 14

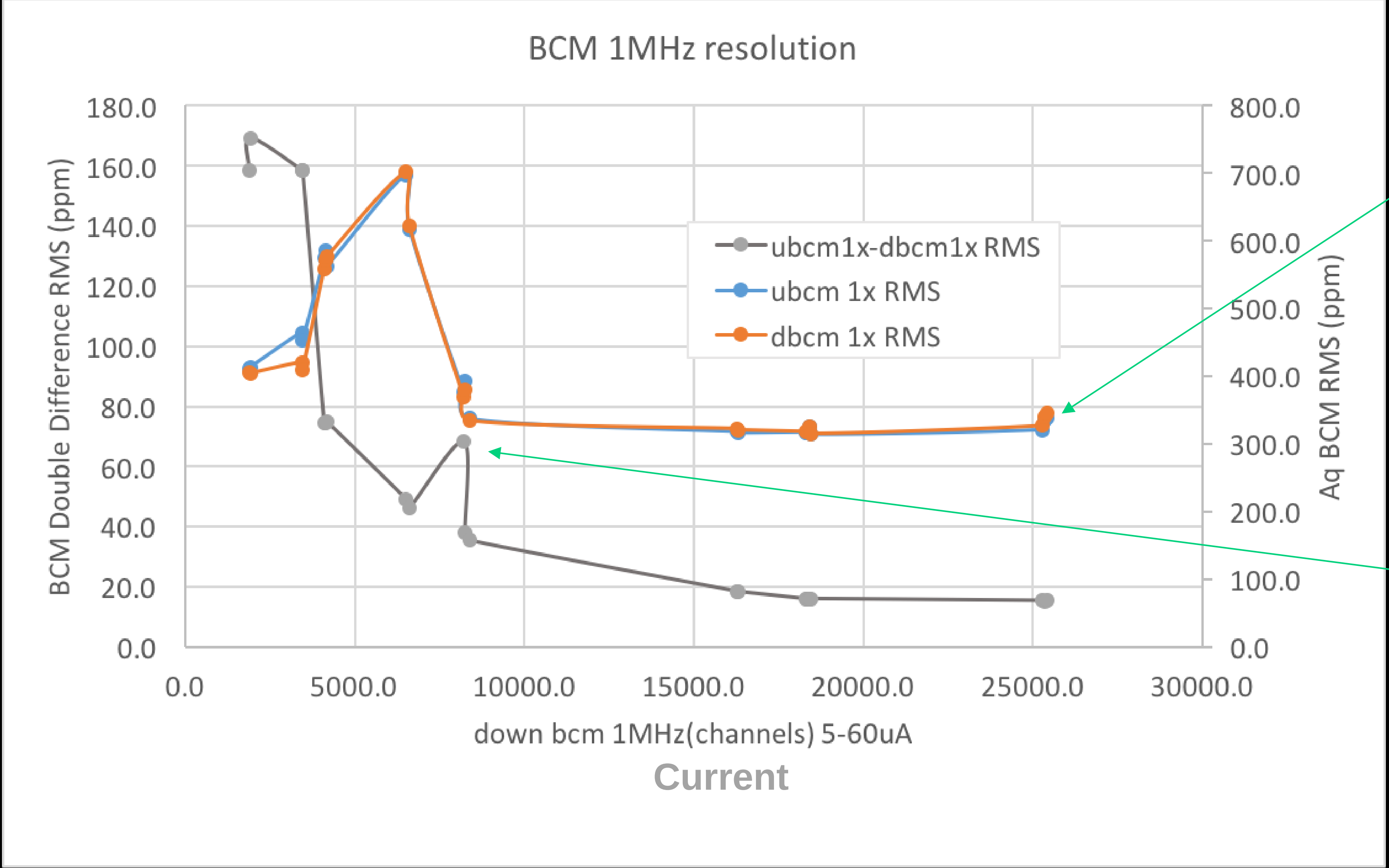
reg_asym_n_blumi1+reg_asym_n_blumi5	234.7
reg_asym_n_blumi1-reg_asym_n_blumi5	225.2
sqrt(pow(234.7,2)-pow(225.2,2))/2	33.0

Run 2503 – Al dummy 8.8GeV 45uA 30Hz, regress with all bpms

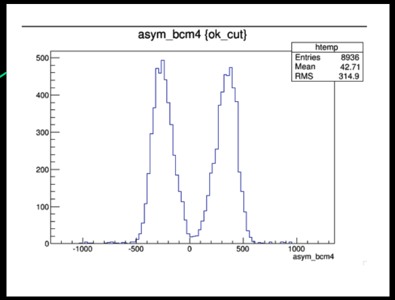
regressed after reanalysis with pairsynch normal maxevent 5000	ppm
(asym_bcm3-asymbcm4)/sqrt(2)	13.1
reg_asym_n_blumi1+reg_asym_n_blumi5	98.61
reg_asym_n_blumi1-reg_asym_n_blumi5	95.37
sqrt(pow(98.61,2)-pow(95.37,2))/2	12.5

BCM 1MHZ RESOLUTION

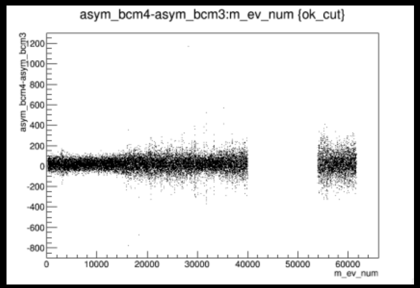
$\sigma_{bcm} \sim (\sigma_{ubcm} - \sigma_{dbcm})/\sqrt{2}$



Wide because of P.C.4 peak effect



Jump because of noise later in run



BCM 1MHZ RESOLUTION

$\sigma_{bcm} \sim (\sigma_{ubcm} - \sigma_{dbcm})/\sqrt{2}$

Run	target	I(uA)	E(GeV)	dbcm1x mean	ubcm 1x RMS	dbcm 1x RMS	ubcm1x-dbcm1x RMS	DD RMS/sqrt(2)	
2345	carbon hole	5.0	2.2	1876.0	411.7	405.9	158.6	112.1	d1x vqwk0_1
2346	carbon hole,	5.0	2.2	1916.0	413.3	404.4	169.2	119.6	failure ev>35000
2343	carbon hole	5.0	2.2	3444.0	464.9	420.7	158.5	112.1	d1x vqwk0_1
2344	carbon hole	5.0	2.2	3462.0	453.2	410.0	158.5	112.1	d1x vqwk0_1
2331	LH2	12	4.4	4096	574.2	559	74.47	52.7	d1x vqwk0_1
2332	LH2	12	4.4	4143	586.5	570.8	74.66	52.8	d1x vqwk0_1
2333	LH2	12	4.4	4164	562.7	576.4	74.98	53.0	d1x vqwk0_1
2434	LH2	15.0	11.0	6504.0	696.2	702.3	49.2	34.8	d1x vqwk0_3
2435	LH2	15.0	11.0	6618.0	617.1	622.5	46.3	32.7	d1x vqwk0_3
2349	LH2	20.0	2.2	8212.0	376.6	369.8	68.2	48.2	d1x vqwk0_1
2348	LH2	20.0	2.2	8253.0	392.6	381.0	38.0	26.9	d1x vqwk0_1
2347	carbon foil	20.0	2.2	8384.0	337.5	334.4	35.4	25.0	failure ev<40000
2503	dummy Al	40	8.8	16270	318.0	322.3	18.5	13.1	d1x vqwk0_3
2504	dummy Al	40	8.8	16300	316.4	320.6	18.4	13.0	d1x vqwk0_3
2493	LH2	40	8.8	18300	317.4	318.0	16.0	11.3	d1x vqwk0_3
2494	LH2	40	8.8	18350	317.0	317.6	15.9	11.3	d1x vqwk0_3
2496	LH2	40	8.8	18430	325.8	326.5	15.9	11.3	d1x vqwk0_3
2498	LH2	45	8.8	18440	314.2	314.9	16.1	11.4	d1x vqwk0_3
2488	LH2	60.0	8.8	25270.0	321.0	326.8	15.4	10.9	d1x vqwk0_3
2487	LH2	60.0	8.8	25370.0	334.2	340.3	15.2	10.8	d1x vqwk0_3
2489	LH2	60.0	8.8	25410.0	338.9	344.9	15.4	10.9	d1x vqwk0_3

BCM 1MHZ RESOLUTION FREQUENCY

BCM Double Differences - Resolution

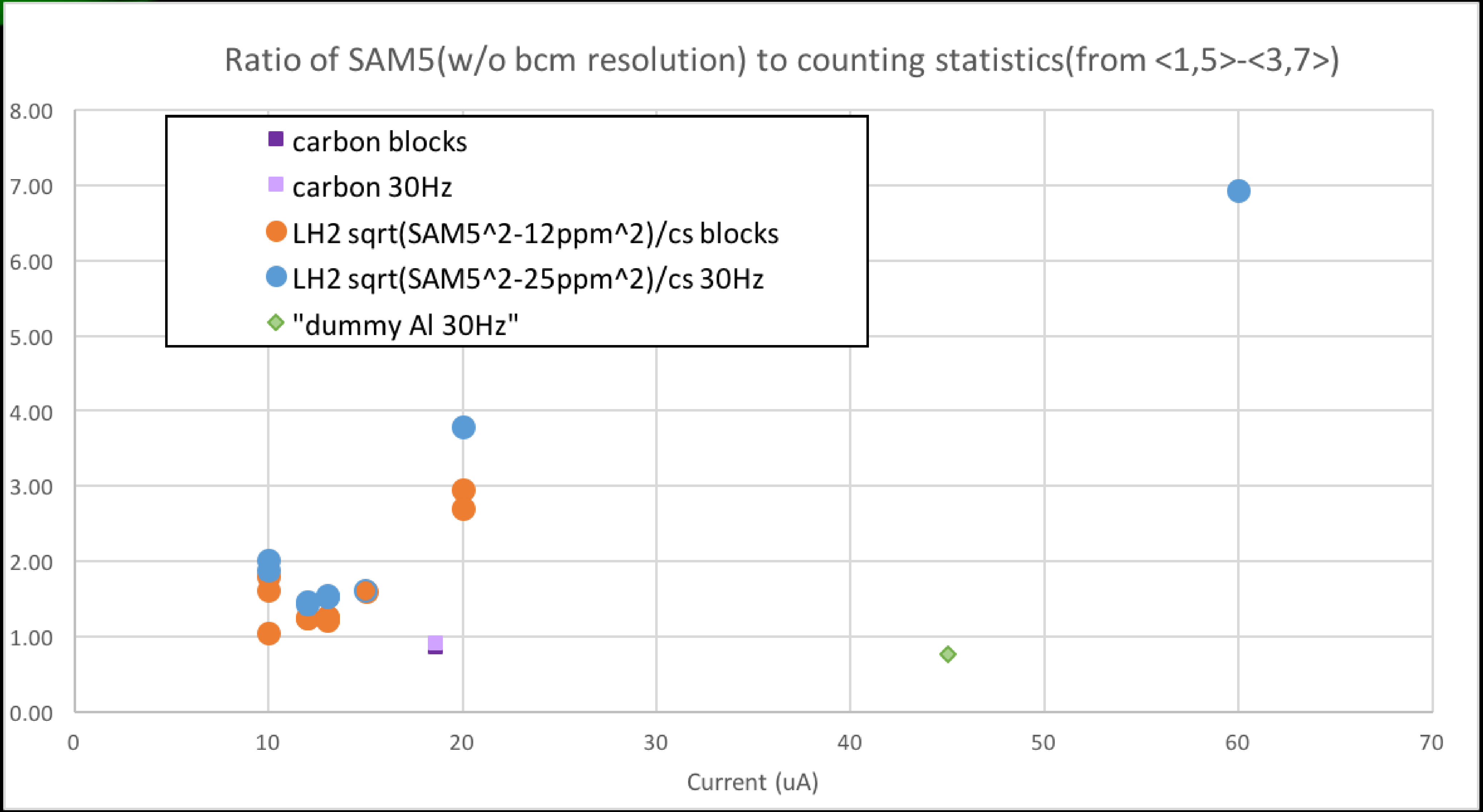
- Higher frequencies tend to result in smaller widths (scaled to counting statistics)
- DD in 1MHz system beats $\sqrt{N}$ statistics from number of samples in integration time-> as we increase rep rate, we are 'winning' in that the level of noise at 30Hz is more than at 60Hz, 120Hz

$$\sigma_{bcm} \sim (\sigma_{ubcm} - \sigma_{dbcm})/\sqrt{2}$$

	Run	GeV energy	uA current	Hz frequency	ubcm-dbcm DD RMS	RMS/$\sqrt{2}$	Analysis with ADC subblocks of helicity window	ppm/$\sqrt{Hz}$ RMS/sqrt(f)
2pass, multiple frequencies	2333	4.4	12	30	75.0	37.5	normal	6.85
	2333	4.4	12	60	93.5	46.75	(b1+b2-b3-b4)/(b1+b2+b3+b4)	6.04
	2333	4.4	12	120	85.6	42.8	1/2((b1-b2)/(b1+b2)+ (b4-b3)/(b3+b4)),(60Hz filtered out)	3.91

SMALL ANGLE MONITORS

SAM ASYMMETRY WIDTHS



SAM LINEARITY

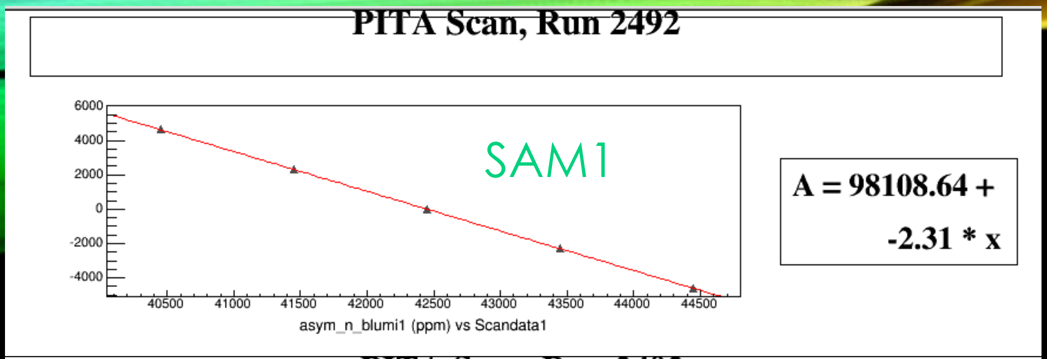
PITA SCAN

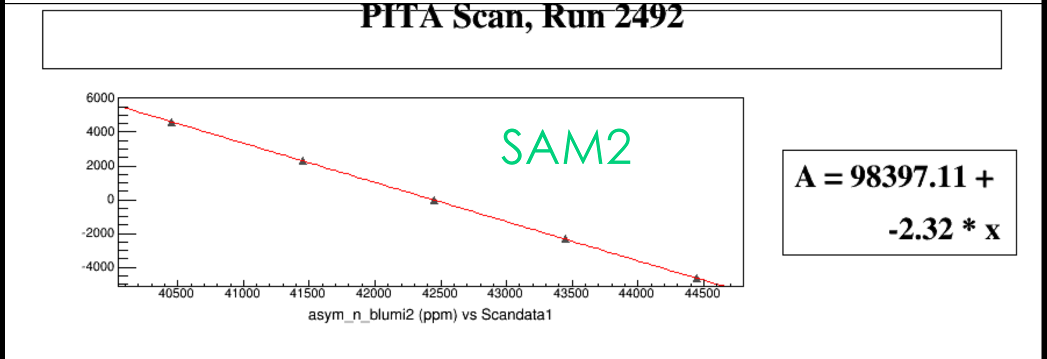
Settings during PITA scan

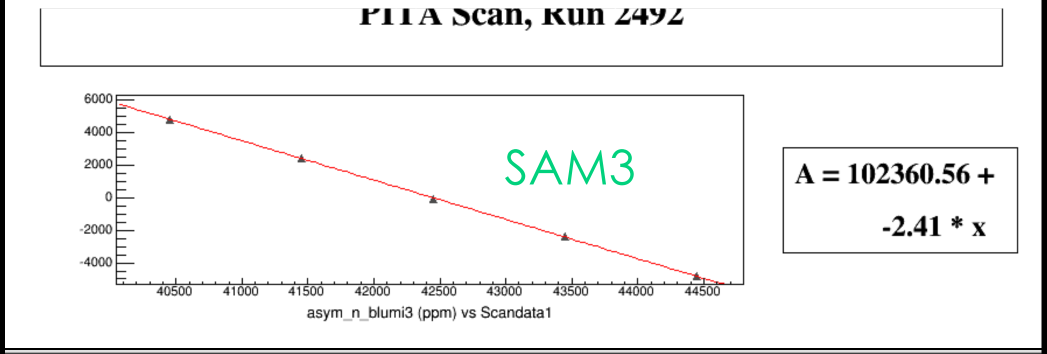
- LH2 target, 45uA, 8.8GeV
- Bases: SAM1/3/5/7=R7723, SAM2/6=R375&UNITY GAIN, SAM4/8=R375
- Preamps: SAM1/5=100kOhm, SAM2/6=5MOhm, SAM3/7=36kOhm, SAM4/8=300kOhm
- HVs: SAM1/5=600V, SAM2/6=75V, SAM3/7=700V, SAM4/8=350V
- Layout:SAM1=TOP,SAM2=TR, SAM3=RIGHT,SAM4=BR,SAM5=B,SAM6=BL,SAM7=L,SAM8=TL
- Pedestals: calculated from beam trips during PITA scan

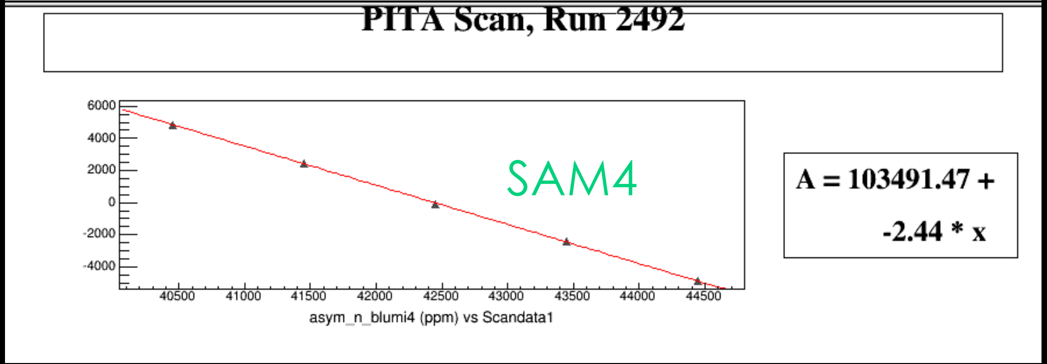
Analysis

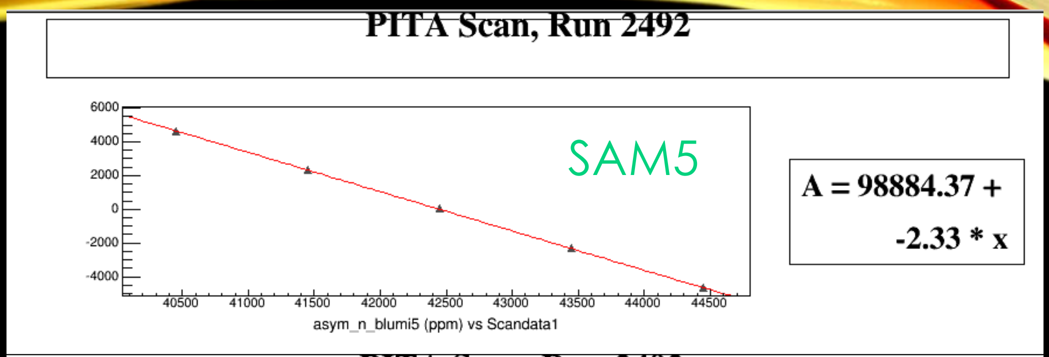
- Because SAMs are also sensitive to position differences, must use regression with respect to bpms to get best estimate of actual SAM non-linearity
- Lower slopes than bcm indicate either pedestal error, SAM saturation
- Higher slopes than bcm indicate either pedestal error or nonlinearity

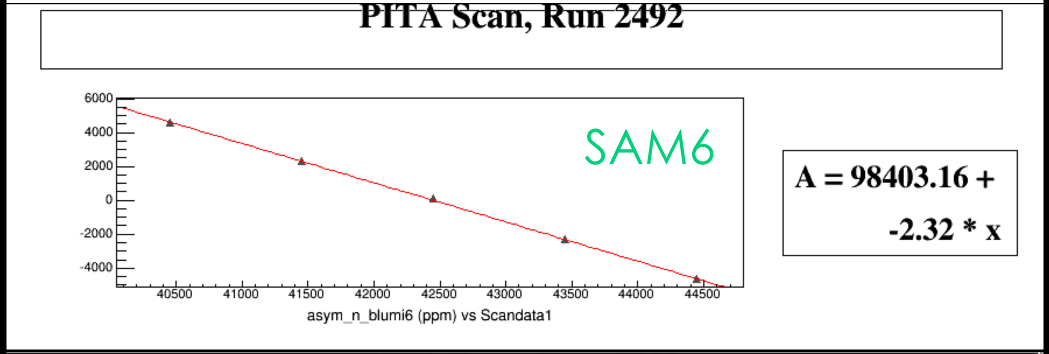

PITA Scan, Run 2492
SAM1
A = 98108.64 +
-2.31 * x
asym_n_blumi1 (ppm) vs Scandata1

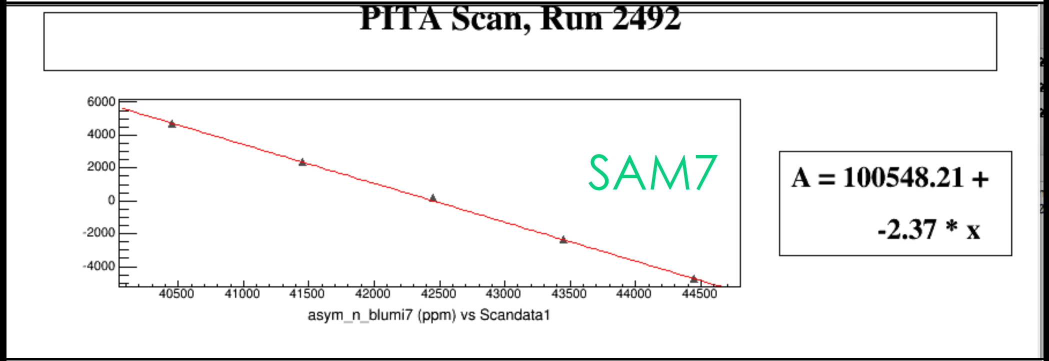

PITA Scan, Run 2492
SAM2
A = 98397.11 +
-2.32 * x
asym_n_blumi2 (ppm) vs Scandata1

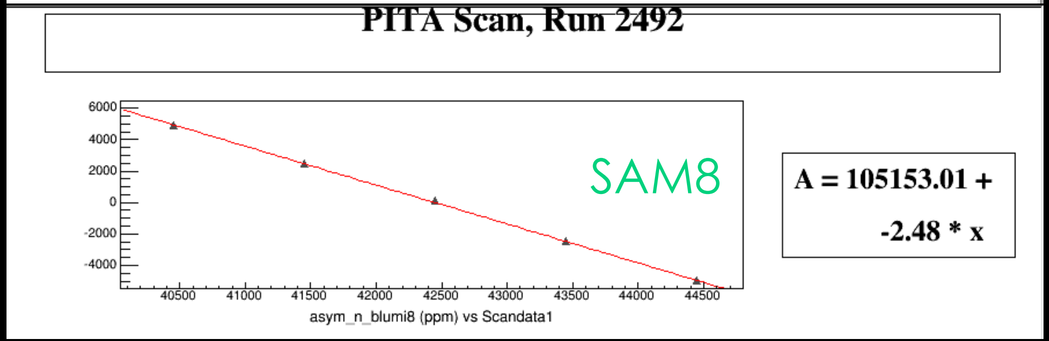

SAM3
A = 102360.56 +
-2.41 * x
asym_n_blumi3 (ppm) vs Scandata1


PITA Scan, Run 2492
SAM4
A = 103491.47 +
-2.44 * x
asym_n_blumi4 (ppm) vs Scandata1


PITA Scan, Run 2492
SAM5
A = 98884.37 +
-2.33 * x
asym_n_blumi5 (ppm) vs Scandata1


PITA Scan, Run 2492
SAM6
A = 98403.16 +
-2.32 * x
asym_n_blumi6 (ppm) vs Scandata1


PITA Scan, Run 2492
SAM7
A = 100548.21 +
-2.37 * x
asym_n_blumi7 (ppm) vs Scandata1


PITA Scan, Run 2492
SAM8
A = 105153.01 +
-2.48 * x
asym_n_blumi8 (ppm) vs Scandata1

SAM LINEARITY
PITA SCAN

Rate 1.3-2GHz

PITA Slope	dbcm 1MHz	ubcm 1MHz
dAq/dPITA from dbcm	**-2.3156ppm/V**	-2.34356ppm/V
Max error on PITA slope meas (%)	**1.21%**	

- Put bound on sam nonlinearity, factoring in the possible error in PITA slope measurement from bcms and possible pedestal error of SAMs
- Assume max pedestal error of 100ch on SAMs (from beam trip decay)

	SAM1	SAM5	SAM2	SAM6	SAM3	SAM7	SAM4	SAM8
SAM base type	R7723	R7723	R375	R375	R7723	R7723	R375	R375
HV setting (V)	-600V	-600V	-75V	-75V	-700V	-700V	-350V	-350V
anode current (uA)	27.7uA	36.0uA	0.0011uA	0.0016uA	73.6uA	55.7uA	8.6uA	11.6uA
gains estimate	2.08E+04	2.71E+04	1	1	5.53E+04	4.18E+04	6.43E+03	8.73E+03
Max pedestal error(%)	**0.28%**	**0.21%**	**14.38%**	**9.54%**	**0.29%**	**0.38%**	**0.30%**	**0.22%**
SAM PITA slopes	SAM1(PITA slp)	SAM5(PITA slp)	SAM2(PITA slp)	SAM6(PITA slp)	SAM3(PITA slp)	SAM7(PITA slp)	SAM4(PITA slp)	SAM8(PITA slp)
dAsam/dPITA	-2.31111ppm/V	-2.32939ppm/V	-2.32183ppm/V	-2.31818ppm/V	-2.41158ppm/V	-2.3687ppm/V	-2.43821ppm/V	-2.47723ppm/V
d(Asam-Aq)/dPITA	0.00425ppm/V	-0.014ppm/V	-0.00304ppm/V	-0.0029ppm/V	-0.096ppm/V	-0.053ppm/V	-0.123ppm/V	-0.162ppm/V
d(regressed (Asam-Aq))/dPITA	0.00272ppm/V	-0.00752ppm/V	-0.01866ppm/V	0.01980ppm/V	-0.10737ppm/V	-0.0161ppm/V	-0.12680ppm/V	-0.11845ppm/V
SAM implied nonlinearity (%)	SAM1(nonlin)	SAM5(nonlin)	SAM2(nonlin)	SAM6(nonlin)	SAM3(nonlin)	SAM7(nonlin)	SAM4(nonlin)	SAM8(nonlin)
from dAsam/dPITA	-0.20%	0.59%	0.27%	0.11%	4.14%	2.29%	5.29%	6.98%
from d(Asam-Aq)/dPITA	-0.43%	1.40%	0.30%	0.29%	9.60%	5.30%	12.30%	16.20%
from d(regressed (Asam-Aq))/dPITA	**-0.27%**	**0.75%**	**1.87%**	**-1.98%**	**10.74%**	**1.61%**	**12.68%**	**11.85%**
factoring out max sam ped errors	0.00%	0.54%	0%	0%	10.45%	1.23%	12.38%	11.63%
MINIUMU NON LINEARITY (%)	**0%**	**0%**	**0%**	**0%**	**9.24%**	**0.02%**	**11.18%**	**10.42%**

(factoring out max PITA slp error)

SAM LINEARITY
PITA SCAN

Results

- The high gain SAMs with the R375 bases show a positive non-linearity of
  - >10% (when run at 350V, 10uA anode current, gain~7k)
- The unity gain SAMs have a non-linearity of
  - 0%(<1.5%)(when run at 75V, 1-2nA anode current, 1.3-2GHz rates)
- The high gain R7723 base SAMs have a positive non-linearity of
  - 0-1% (when run at 600-700V, 26-36uA, gain~25k)
  - 0.02-2%(when run at 700V, 56uA anode current, gain ~42k)
  - 10% (when run at 700V, 74uA anode current, gain ~55k)

BEAM POSITION MONITORS

BPM STATUS

- Previously had an auto gaining issue near 20uA, there was a transition in gain setting near that current region producing 1V square waves in the wire channel signal every second or so. The settings were changed, and the problem was solved.
- Now we have a very small jumping issue (50mV jumps in x wire channels every couple seconds) which is not always present (went away in 4a and showed in in 4b for 60uA) and is likely also caused by some sort of internal setting
- Pete Francis going replace IF modules during summer, so this may go away after that
- If the 50mV wire channel shifts are still present in the RF injected noise tests after IF modules are replaced, then need to examine internal settings, how IF gain and gain interplay with FFB, etc.
- Musson cavity bpms– being commissioned