PSB Beam wire scanner optical position sensor:
Metallic Disks and PMTs Testing

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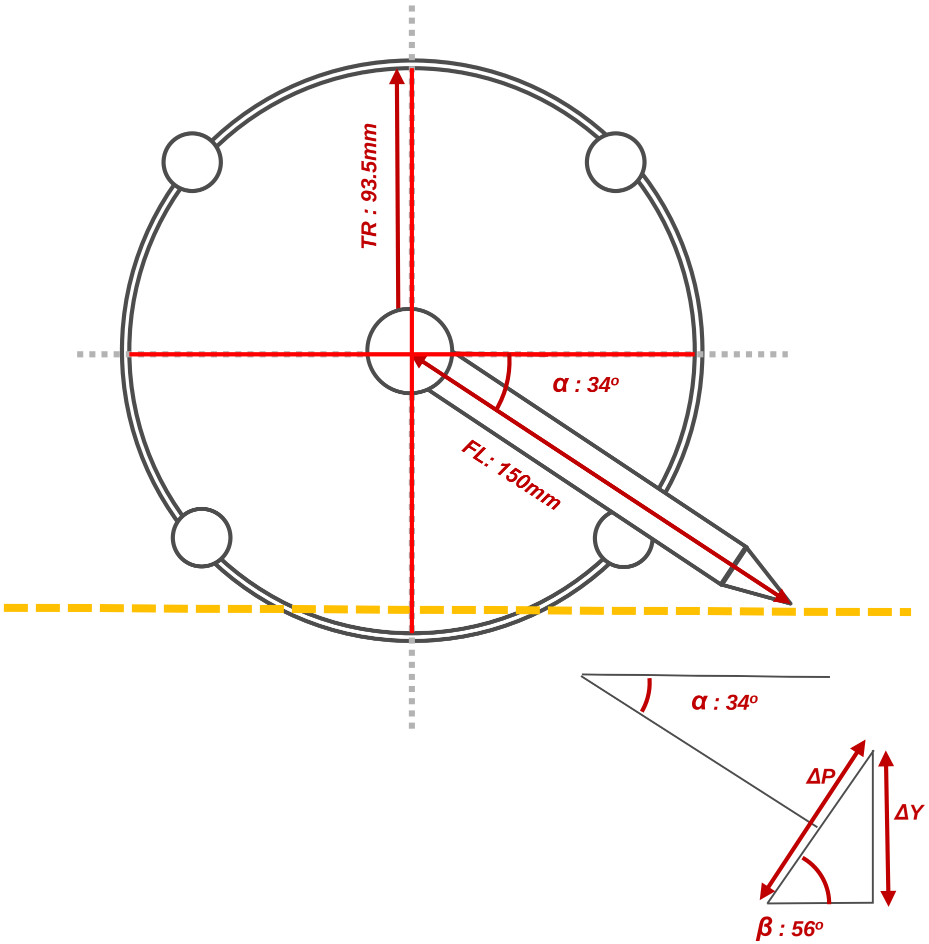
Presentation Outline

- 1. Optical Sensor: New Samples Tests
  - 1.1 Position Sensor Characteristics
  - 1.2 Focal distance tolerances
  - 1.3 The importance of an stable optical signal
  - 1.4 Testing the samples

- 2. Acquisition System: PMT tests status
  - 2.1 The Set-up
  - 2.2

1. Position Sensor Characteristics for PSB

1.1 Resolution versus track pitch



PSB Optical position Sensor Resolution				
Fork Length (FL)	150			mm
Impact Angle (α)	34			deg
Track Radius (TR)	93.5			mm
Slits Pitch	20	30	40	µm
# of slits on disk	29374	19583	14687	slits
Disc angular Resolution	213.9	320.8	427.8	µrad
Linear Resolution (ΔP)	32.09	48.13	64.17	µm
Projected Resolution (ΔY)	**26.6**	**39.9**	**53.2**	**µm**

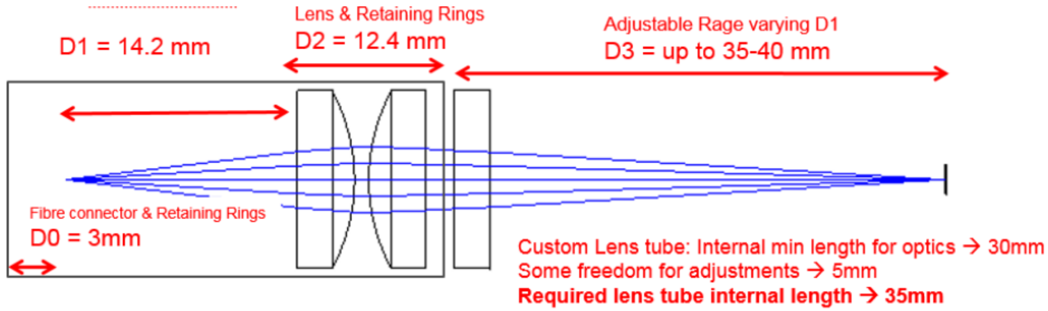
$$\Delta\alpha = \frac{2\pi}{\frac{(2\pi * TR)}{Pitch}} \qquad \Delta P = \Delta\alpha * FL$$

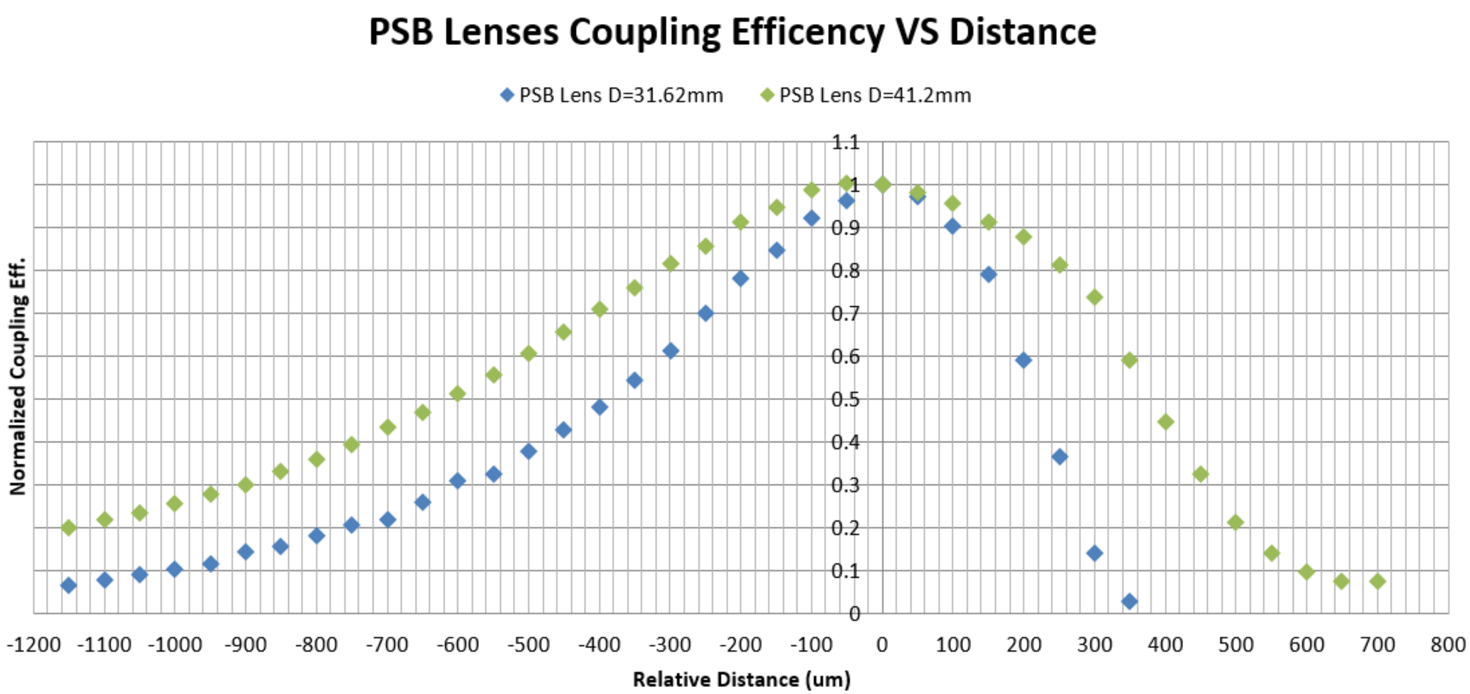
$$\Delta Y = \Delta P * \sin(56) \qquad \Delta Y = K * Pitch$$

$$K = 1.33$$

2. Tolerance Check for PSB Optics

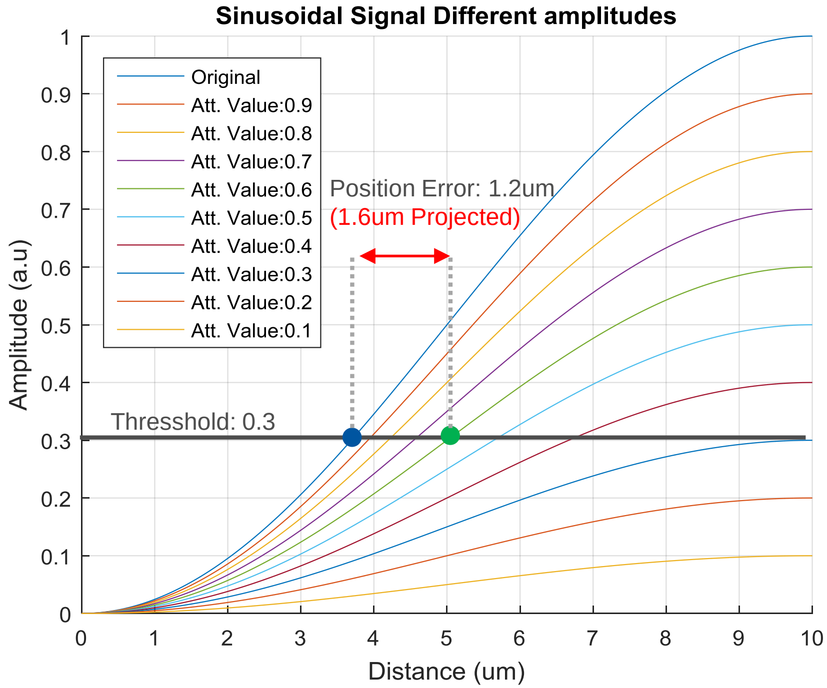
2.1 Practical measurements

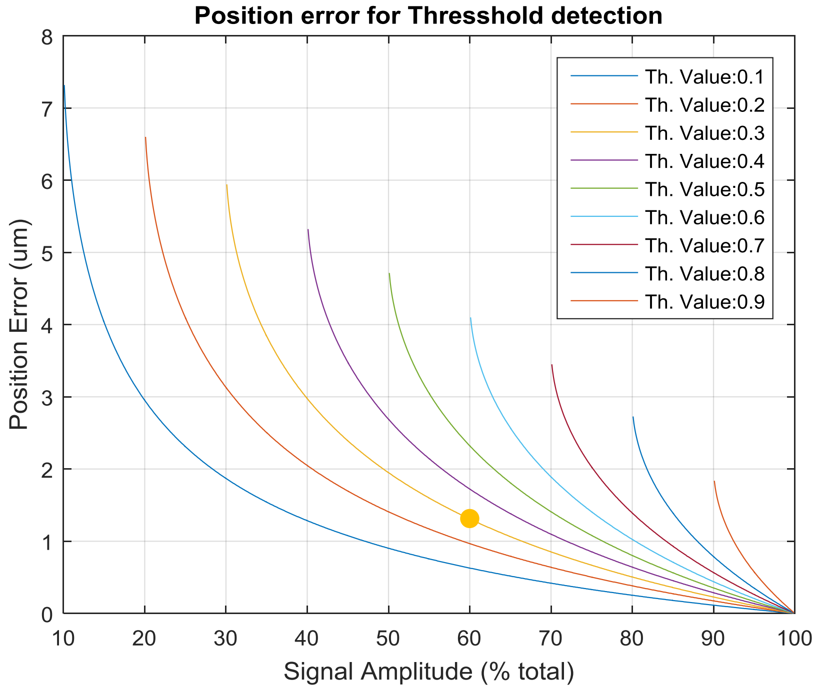




3. The importance of an stable optical signal:

3.1 Example with Thresshold Detection



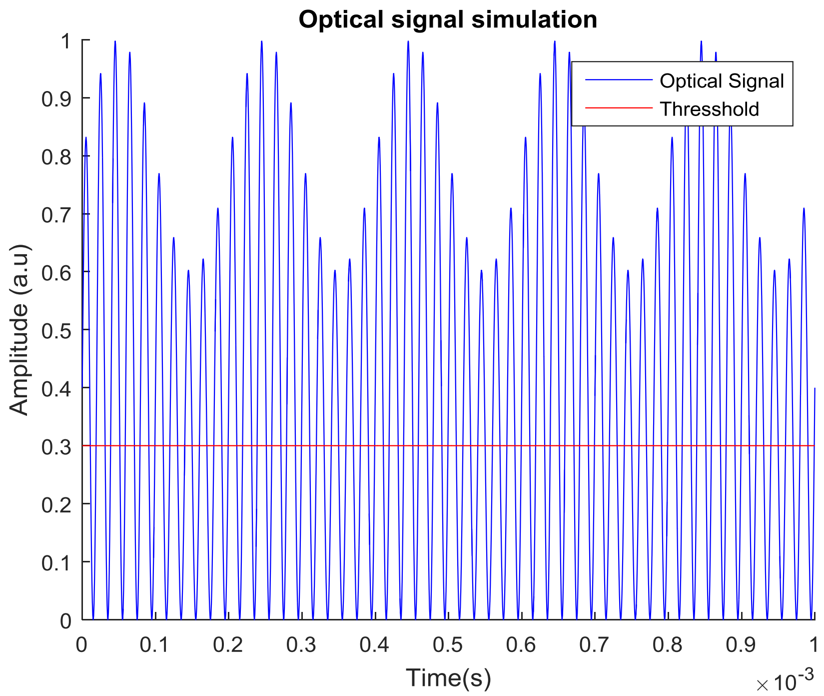


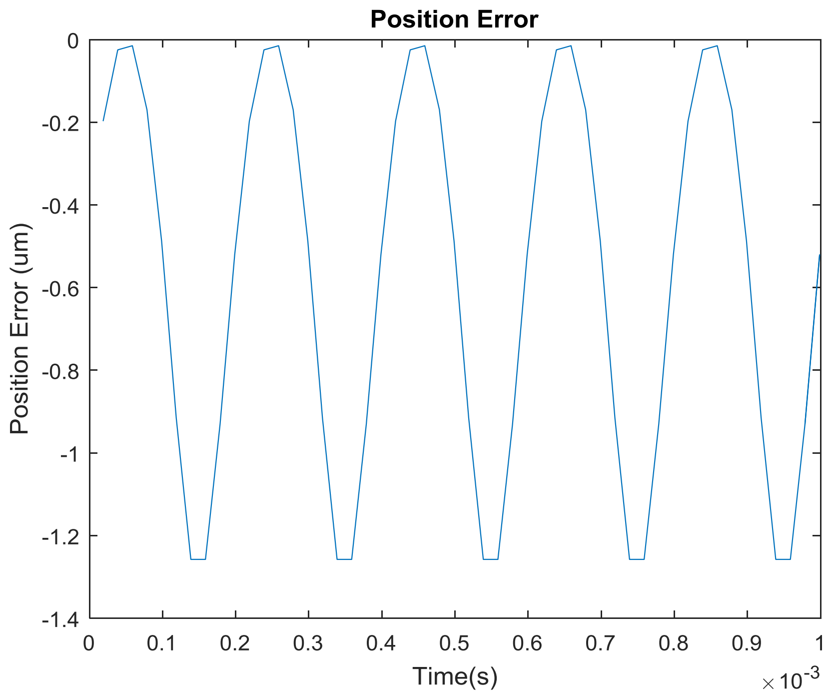
Optical Signal Modulation (Interferometry or Disk surface):

- Leads to position errors → 1.2 um for signal reduction to 60% decay using 0.3 threshold (1.6um proj.)
- “Intelligent” processing algorithms can reduce these errors

3. The importance of an stable optical signal:

3.1 Example with Thresshold Detection





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- “Intelligent” processing algorithms can reduce these errors

4. Testing new samples
4.0 Testing Process (again)

A. Optical signals recording:

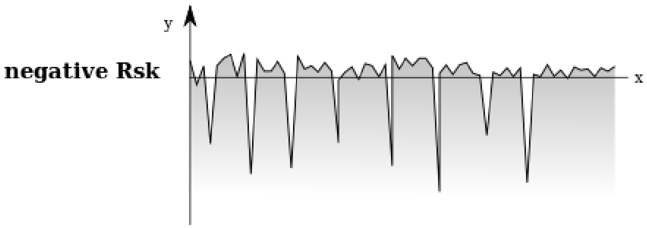
- Sample A:
  - 5 signal samples per treatment
  - Different radial locations
- Sample B:
  - 5 signal samples
  - Different radial locations
  - Full turns recorded

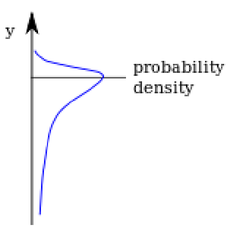
B. Signals analysis (signal as a surface):

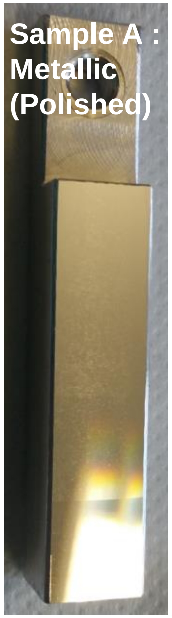
- Visual inspection raw signal
- Calculation of Signal Roughness Average (RA)
- Extraction of signal probability density

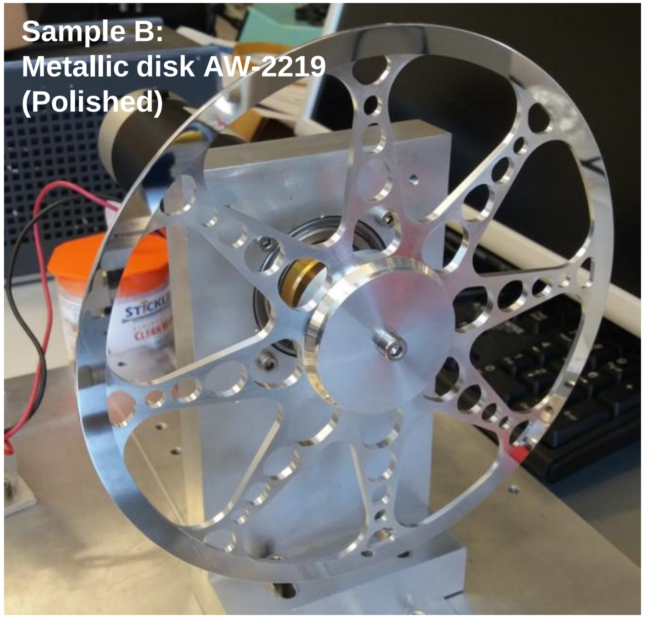
$$R_a = \frac{1}{n}\sum_{i=1}^{n}|y_i - \mu|$$

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \mu)^2}$$

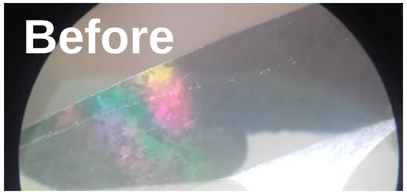








Sample B:
Material grain is still visible
(but not as evident as before)



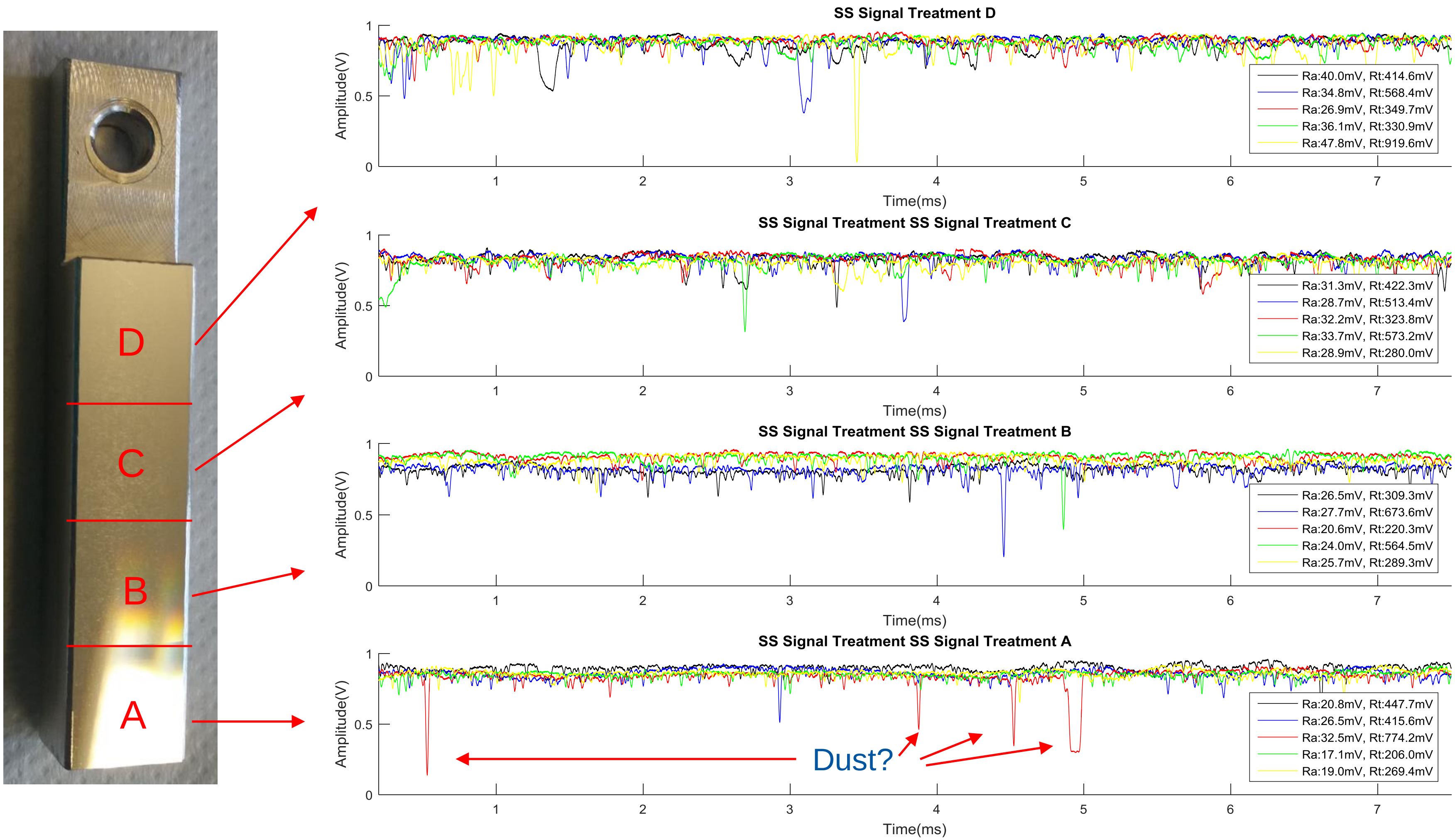
4. Testing new samples

4.1 Rectangular Sample (Raw signals)

The better the treatment the lower Ra

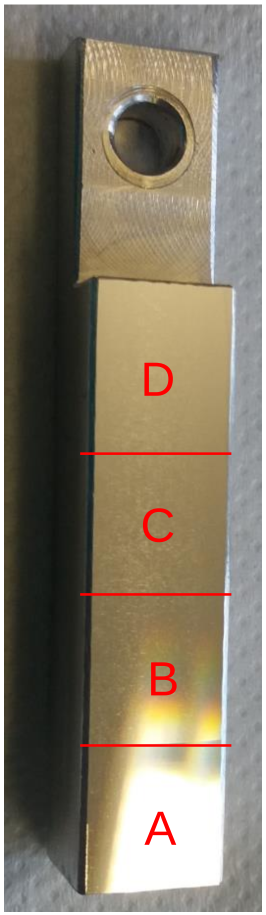
Nice usable value Ra ~ 10-15 mV for μ ~ 0.9V

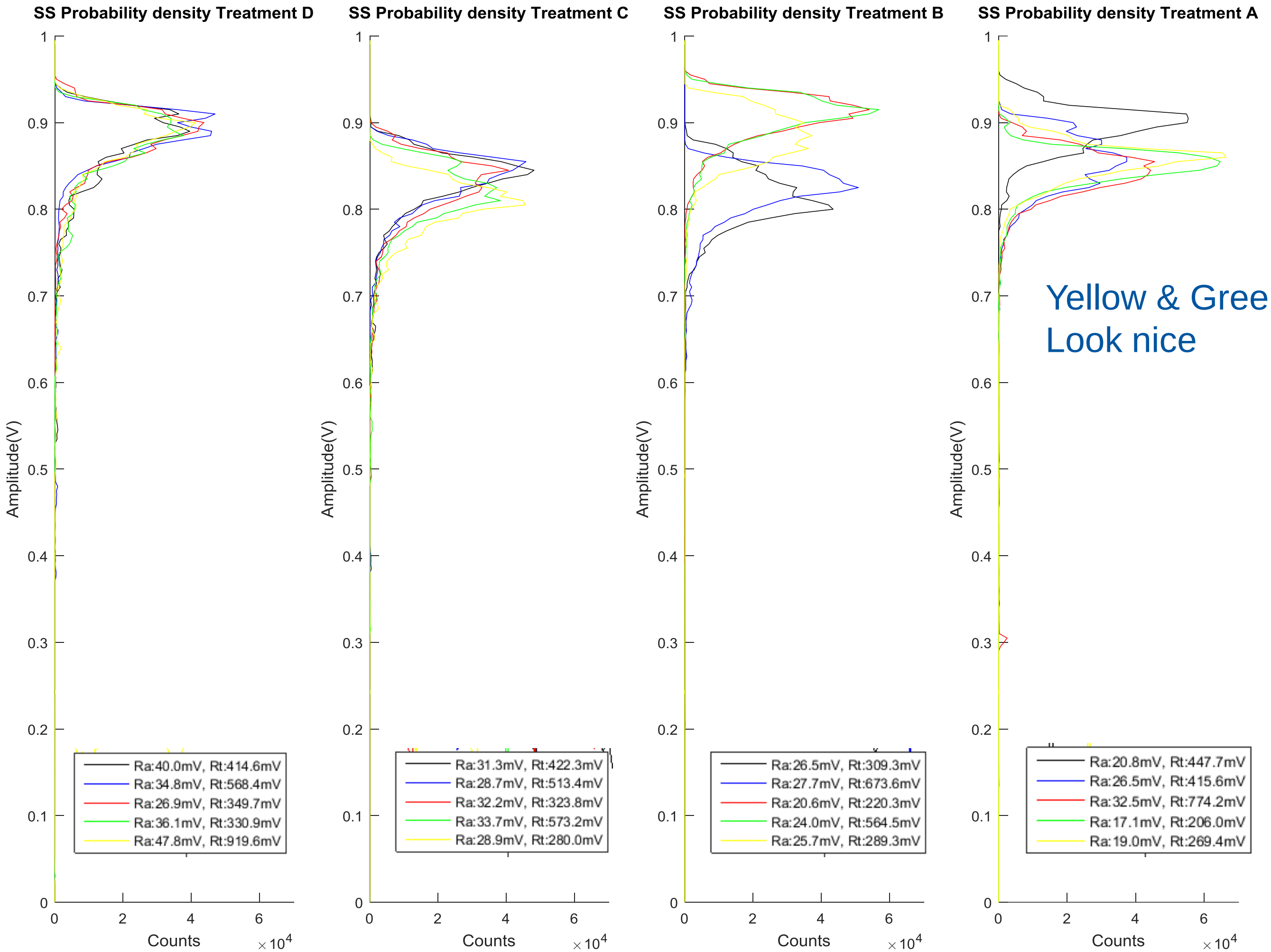
Lower “Peak” allowed 10% (Rt 0.1V for μ ~ 0.9V)



4. Testing new samples

4.1 Rectangular Sample (Probability densities)



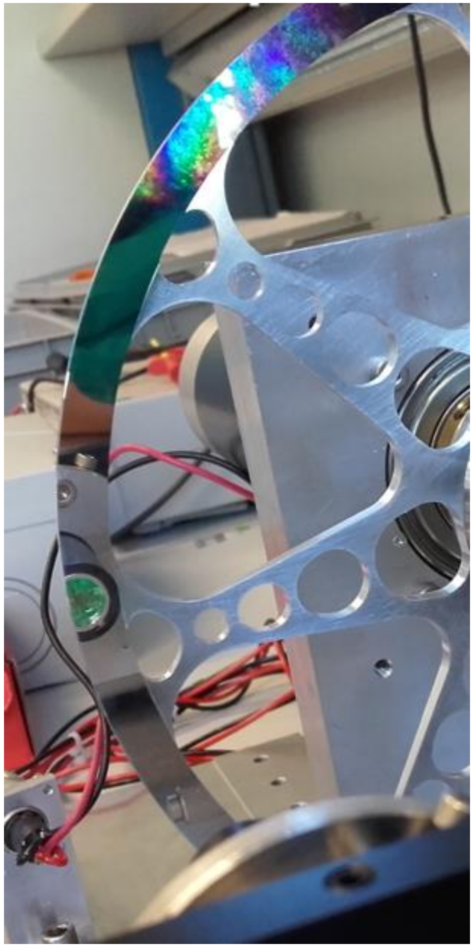


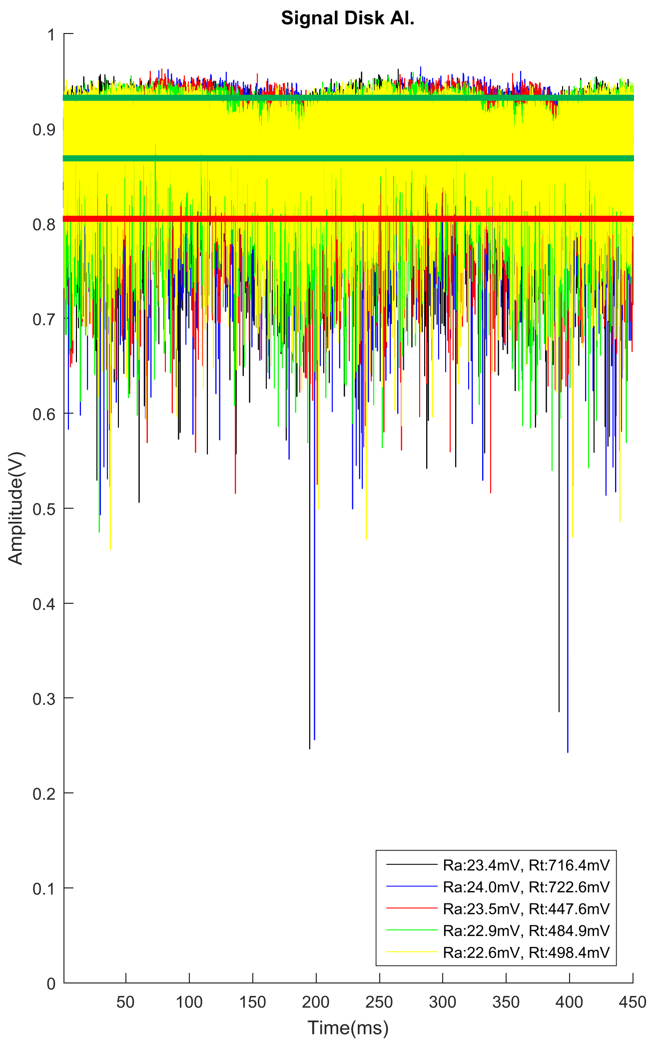
Yellow & Green
Look nice

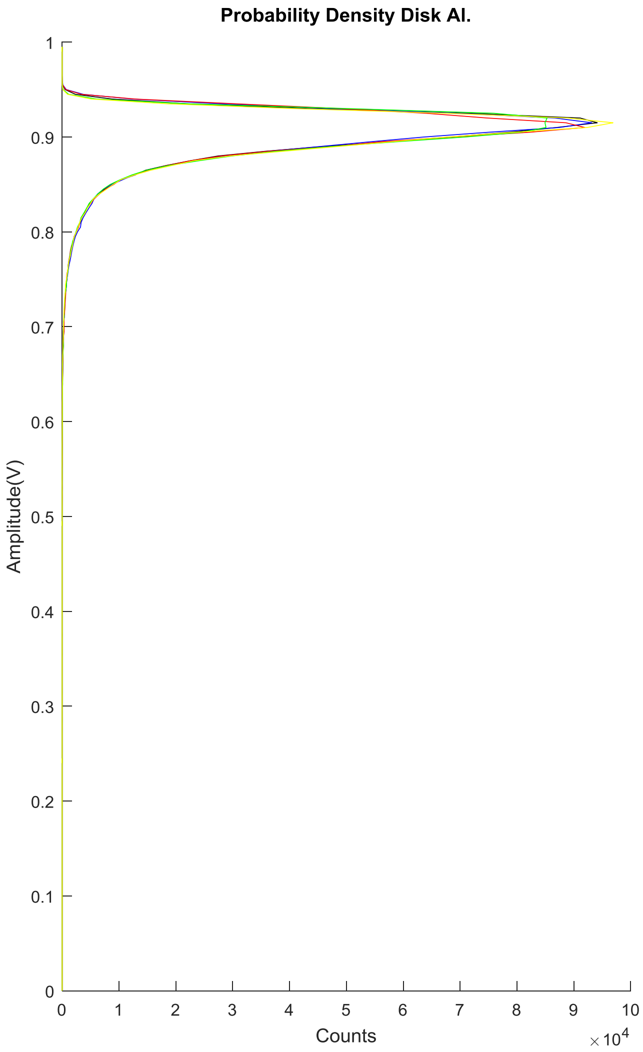
4. Testing new samples

4.2 Full Size ~~Polished~~ Aluminium Disk (AW-2219)

Full Revolution **Before Unpolished**



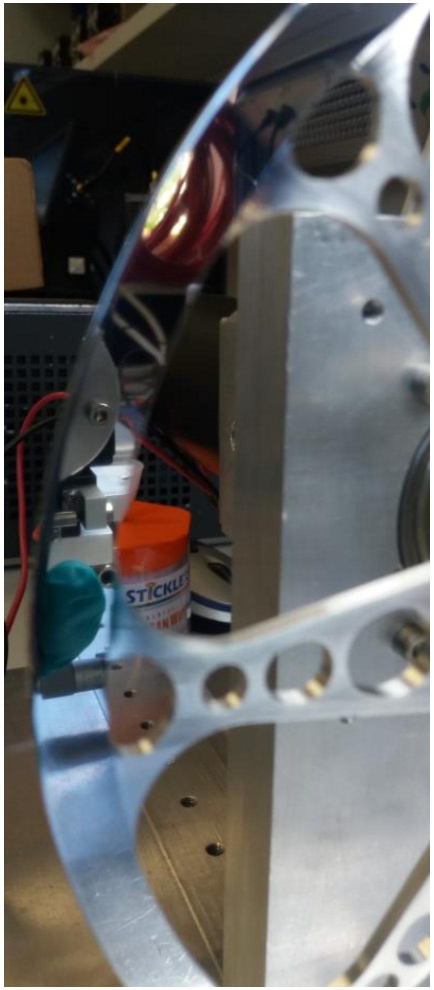


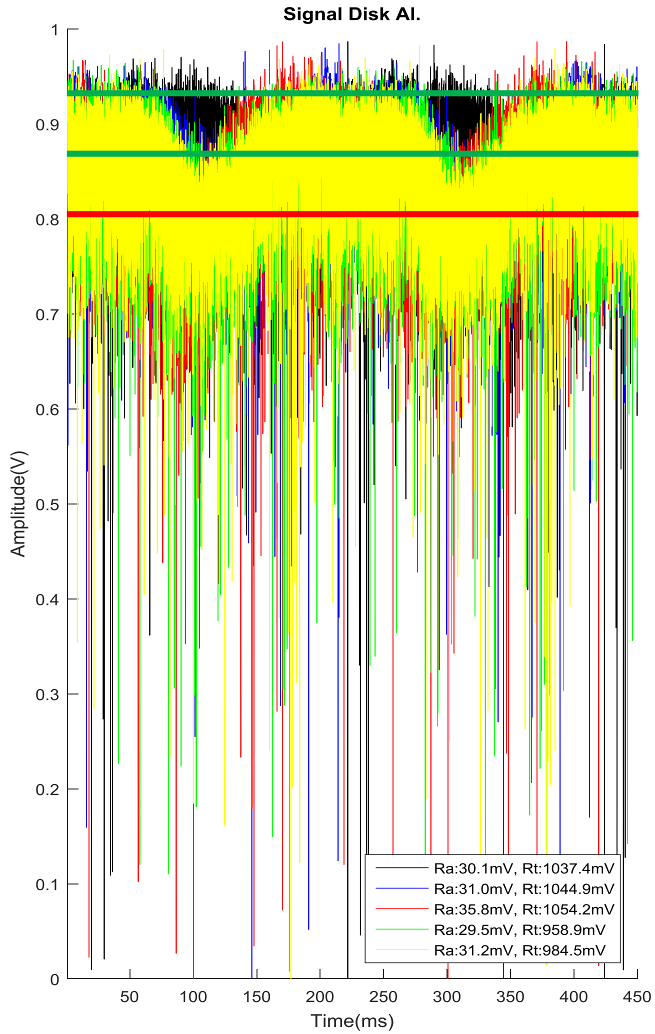


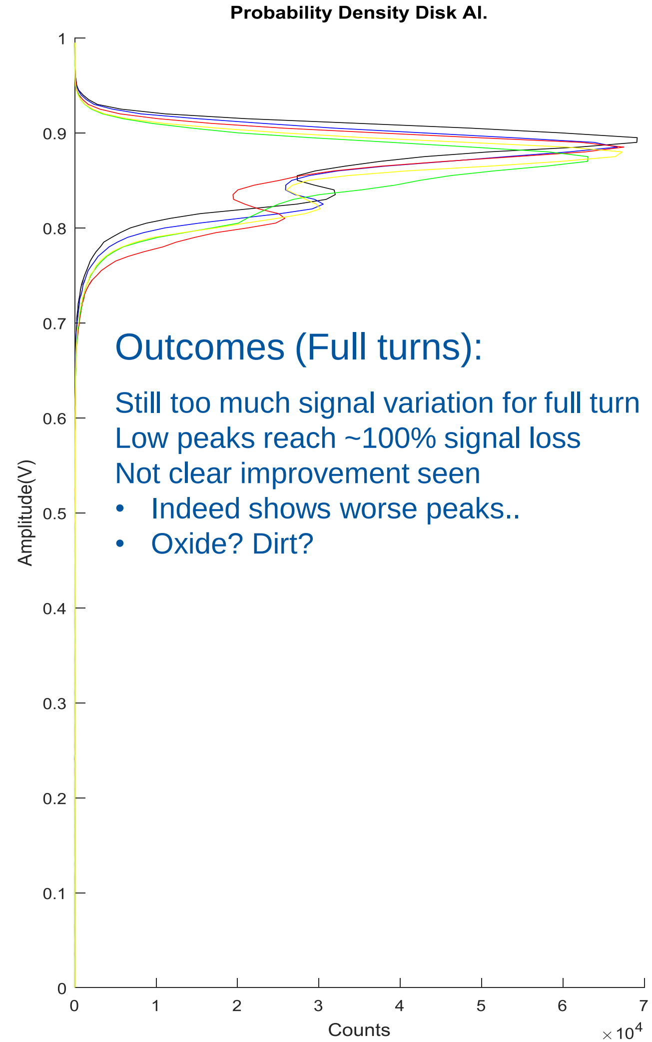
4. Testing new samples

4.2 Full Size Polished Aluminium Disk (AW-2219)

Full Revolution **Now Polished**







Outcomes (Full turns):

Still too much signal variation for full turn
Low peaks reach ~100% signal loss
Not clear improvement seen

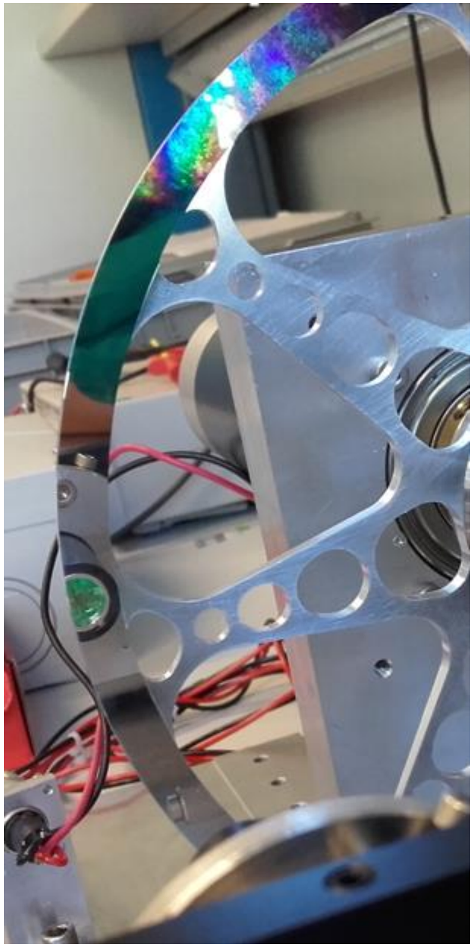
- Indeed shows worse peaks..
- Oxide? Dirt?

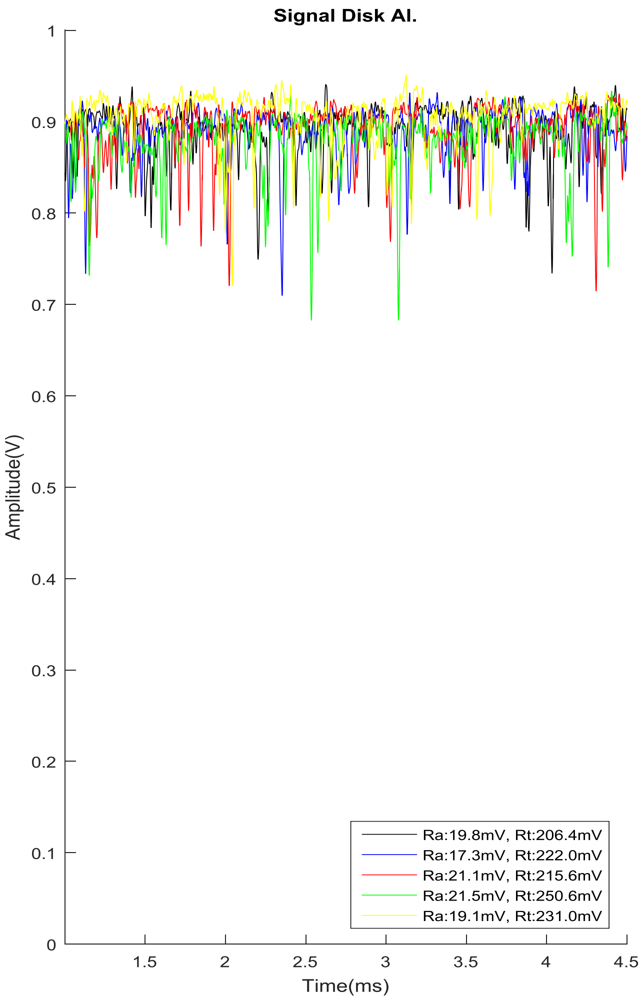
4. Testing new samples

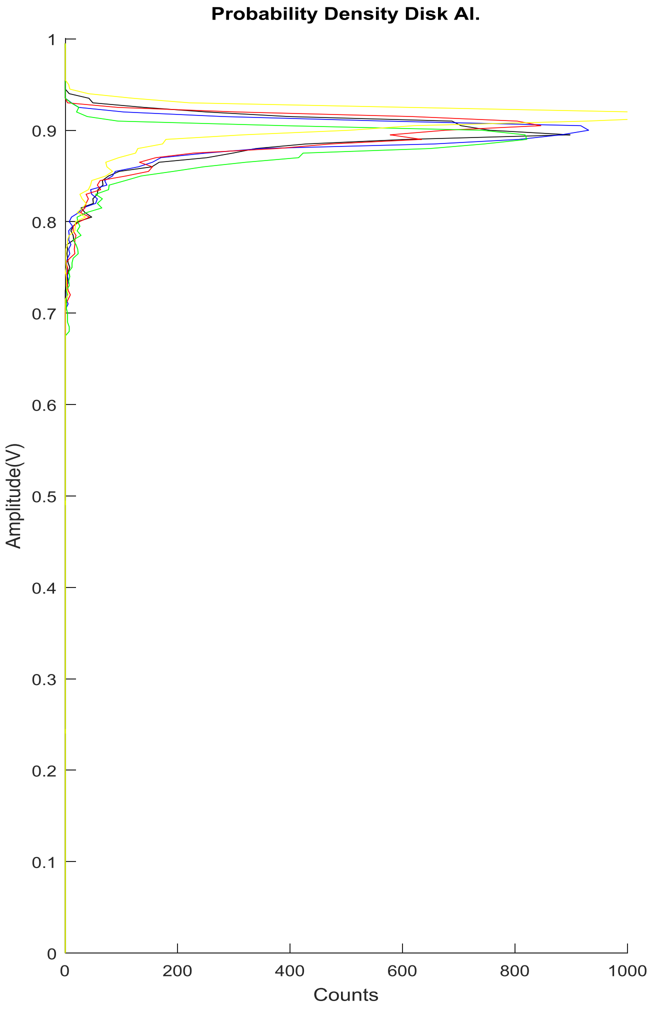
4.2 Full Size Polished Aluminium Disk (AW-2219)

~1cm Sample

Now Polished





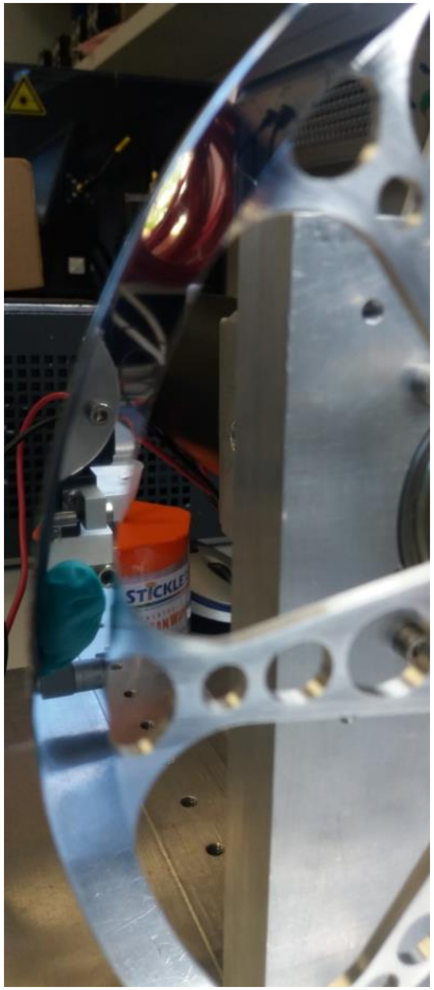


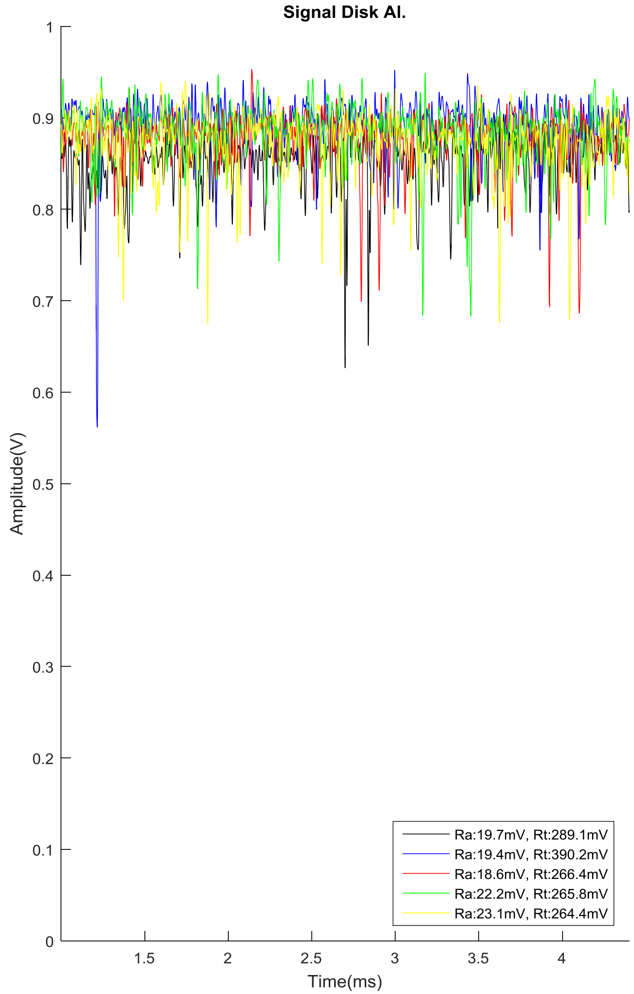
4. Testing new samples

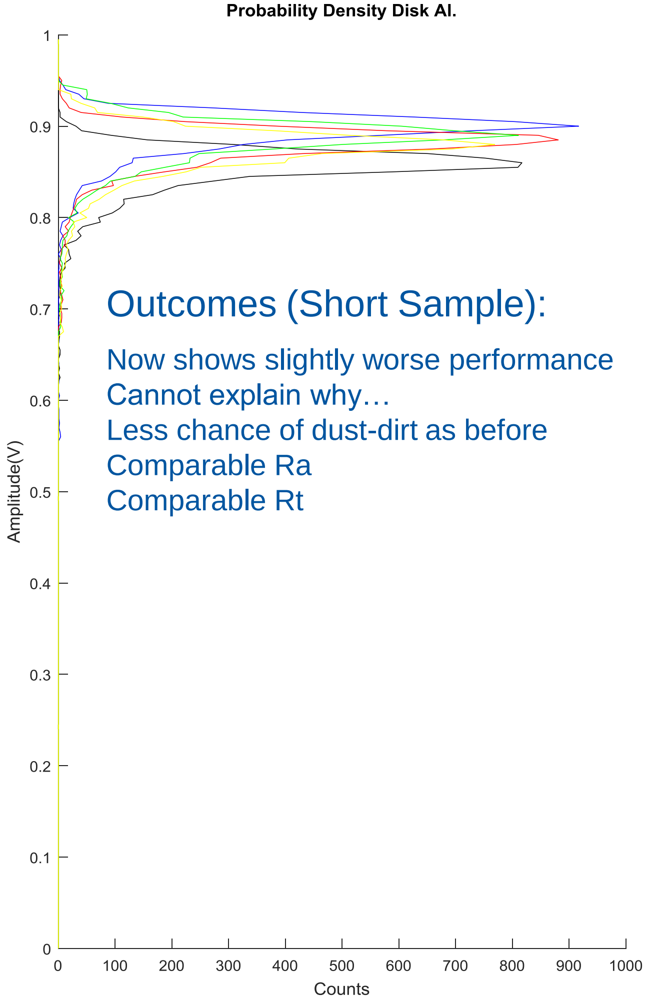
4.2 Full Size Polished Aluminium Disk (AW-2219)

~1cm Sample

Now Polished



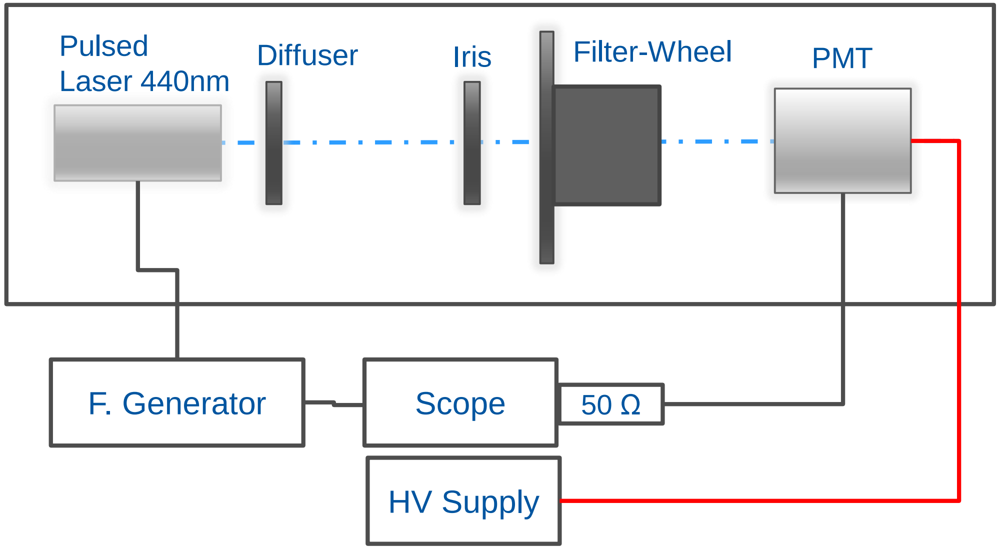




Outcomes (Short Sample):

Now shows slightly worse performance
Cannot explain why…
Less chance of dust-dirt as before
Comparable Ra
Comparable Rt

5. Progress on PSB Prototypes:
5.1 Acquisition system: Photo-Multiplier test bench



Tests Scheduled:

- Anode Linearity (Short pulsed signals 50ns)
  - Limited by Space-Charge effects
  - Large current in dynodes
- Saturation Point (Long train of pulses)
  - Limited by Discharge on HV last stages
- Dynamic range

Systems under Test:

1. Standard PSB PMTs (R9880-U)
2. MaPMT (R7600U-00-M4)
3. Hybrid Photo-Detectors (HPD-PP0475C)

Strategies under evaluation:

a) Several equal PMT's with different Filters/Gains
b) Several PMTs with different size/gain.
c) Single MaPMT with different filters.
d) Single HPD with large dynamic.

5. Progress on PSB Prototypes:
5.1 Acquisition system: **R9880-U**

R9880-U Studies: Pulsed Linearity Check

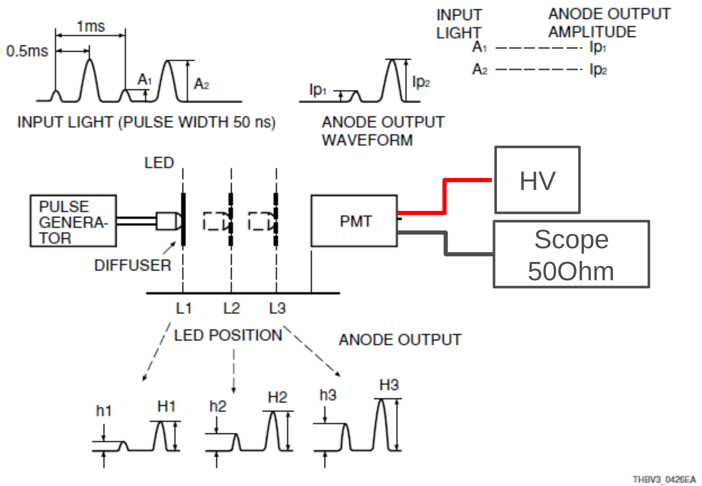
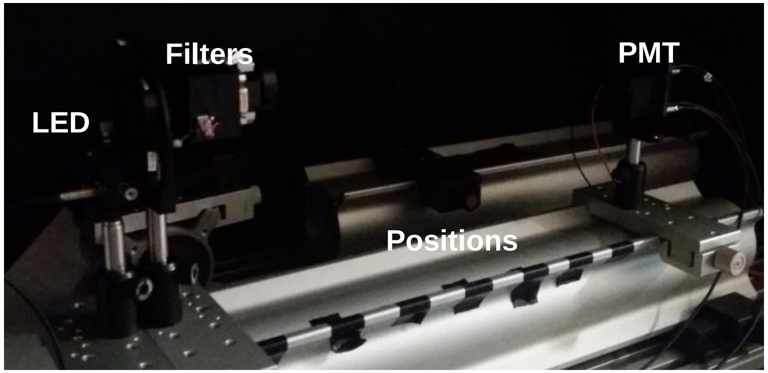
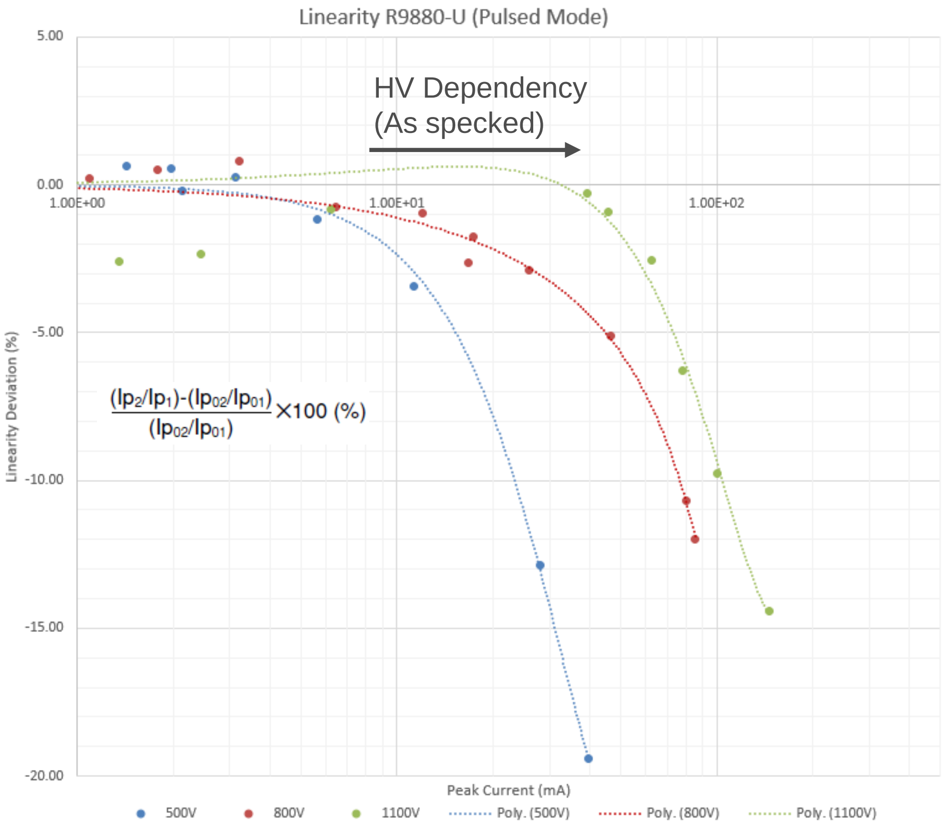


Figure 4-26: Block diagram for pulse mode linearity measurement





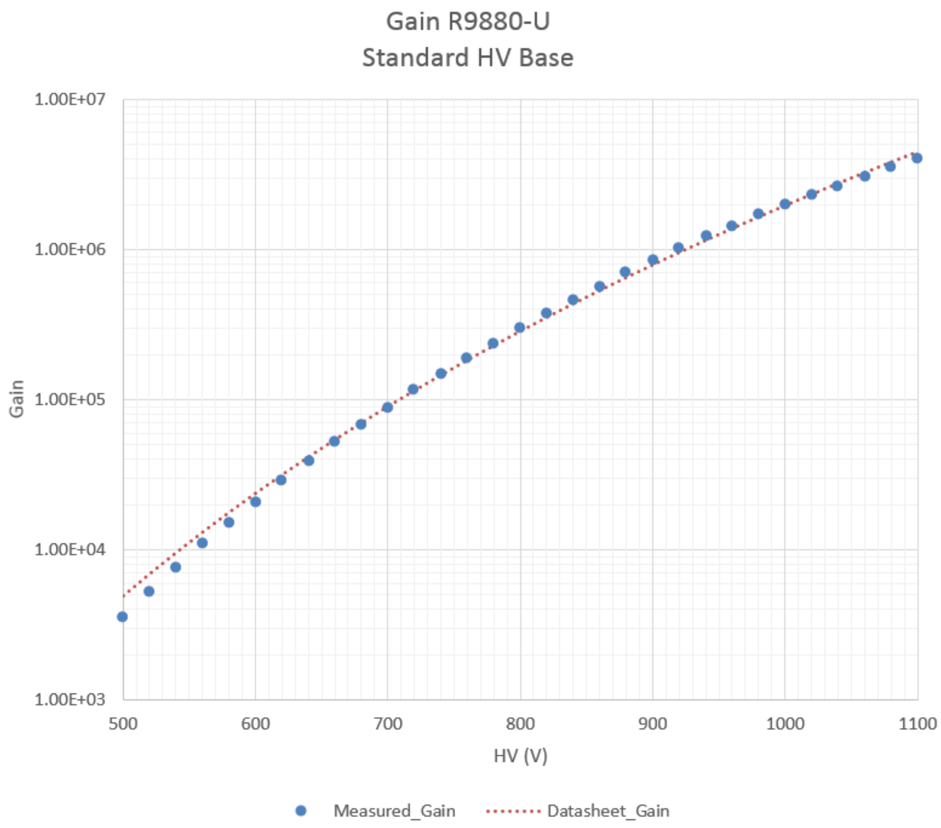
*Pulsed linearity can be enhanced with a tapered HV base

5. Progress on PSB Prototypes:

5.1 Acquisition system: **R9880-U**

R9880-U Studies: Gain Check (Relative Gain)

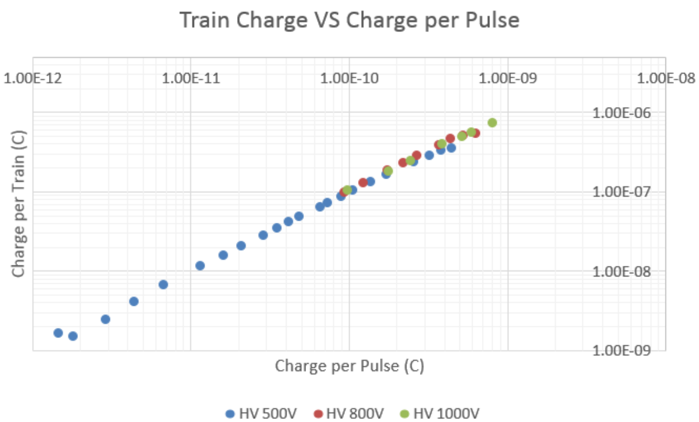
- LED at fixed position and power
- Pulsed operation
  - Pulse FWHM: 50ns
  - Repetition Freq.: 1Khz.
- Variable Gain
  - Calibrate LED power to remain on pulsed linear region during the HV Sweep.
- Curve normalization to 1000V.

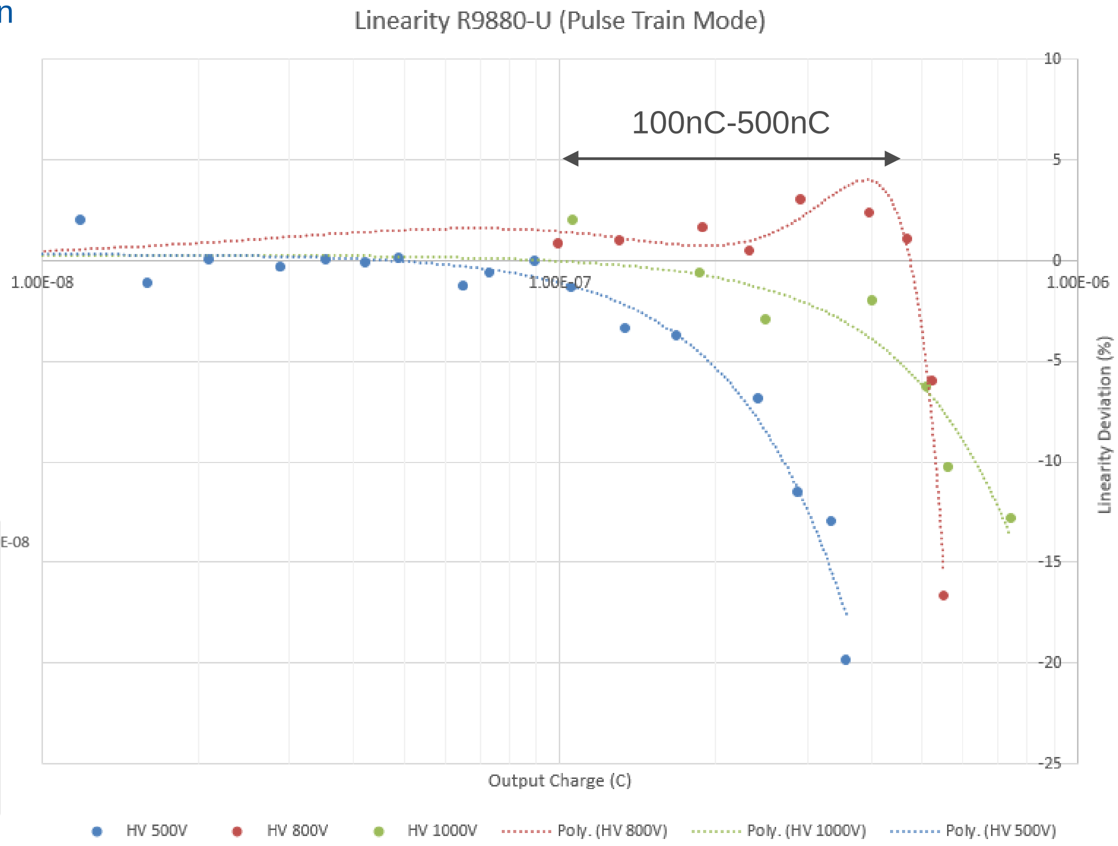


5. Progress on PSB Prototypes:
5.1 Acquisition system: **R9880-U**

R9880-U Studies: HV Saturation Point (Standard base)

- Study of max. charge available per scan
- PMT Mean Anode current < 100uA
- Used trains of 1000 pulses
  - 50ns FWHM
  - 1us pulses separation
  - 1ms trains length
  - 300ms trains separation
  - Pulses amplitude on linear region
- Studied relationship:
  - Charge 1st pulse Vs Charge Train





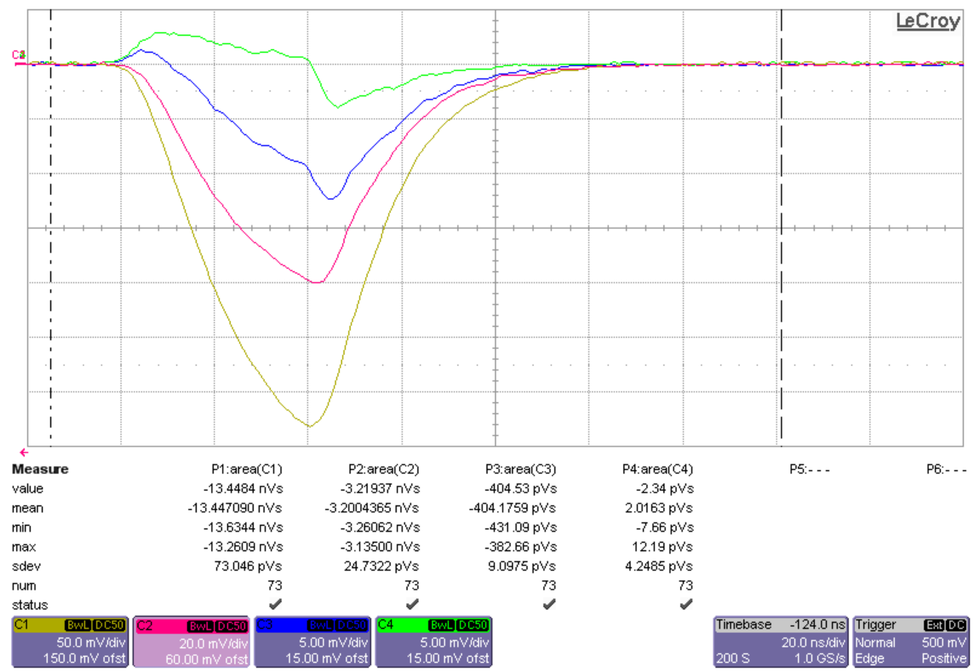
*Can be improved with bigger capacitors on last stages

5. Progress on PSB Prototypes:
5.1 Acquisition system: **R7600U**

R7600-U Studies: Pulsed Linearity Check

- Same procedure as before (Double pulse ratio)
- Different LED positions
- This is a MaPMT, it has been set-up as:

CH1 100%	CH2 31%
CH3 6%	CH4 1.2%



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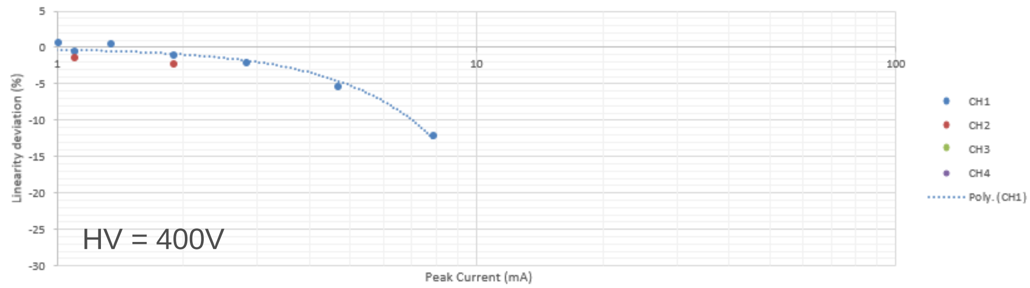
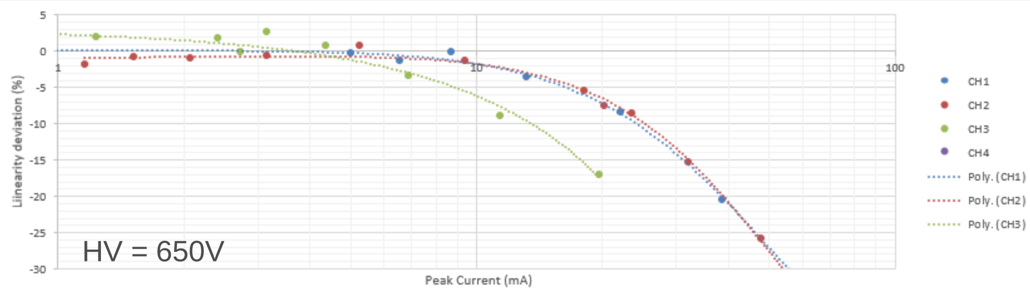
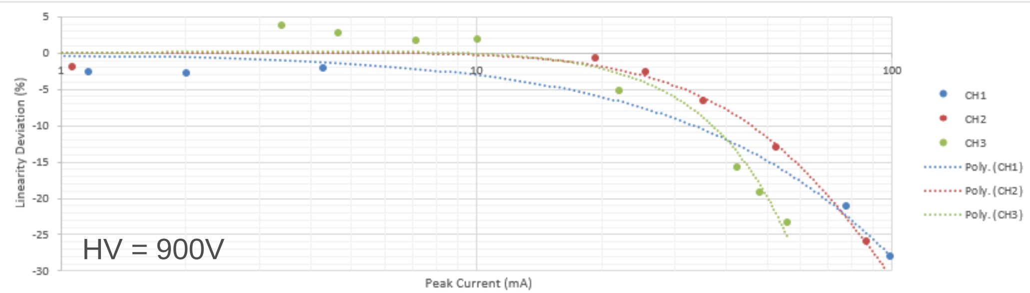






Pulsed Linearity agrees DS:

- 5% Deviation for 30mA output @ 800V

<u>Outcome</u>

Each Channel behaves independently:

- When CH1 is saturated, CH2,3,4 still linear

5. Progress on PSB Prototypes:

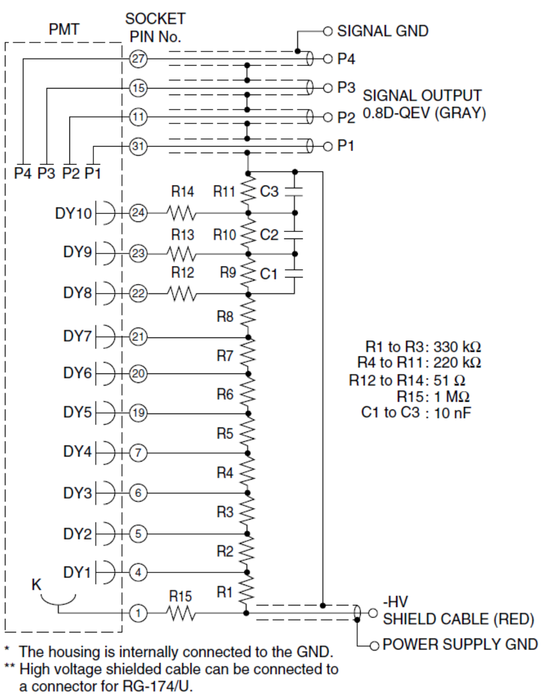
5.1 Acquisition system: **R7600U**

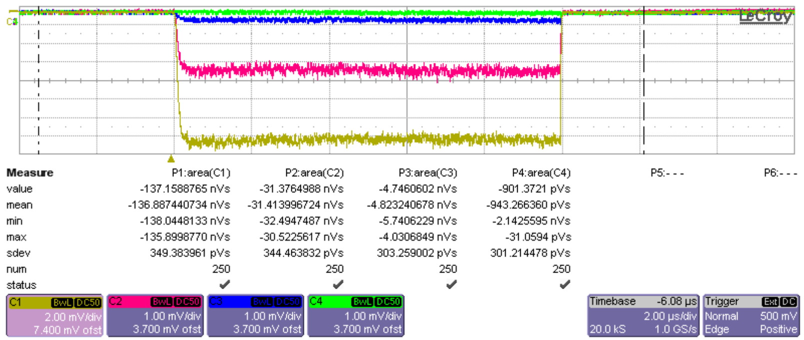
R7600-U Studies: HV Saturation Point (Standard base)

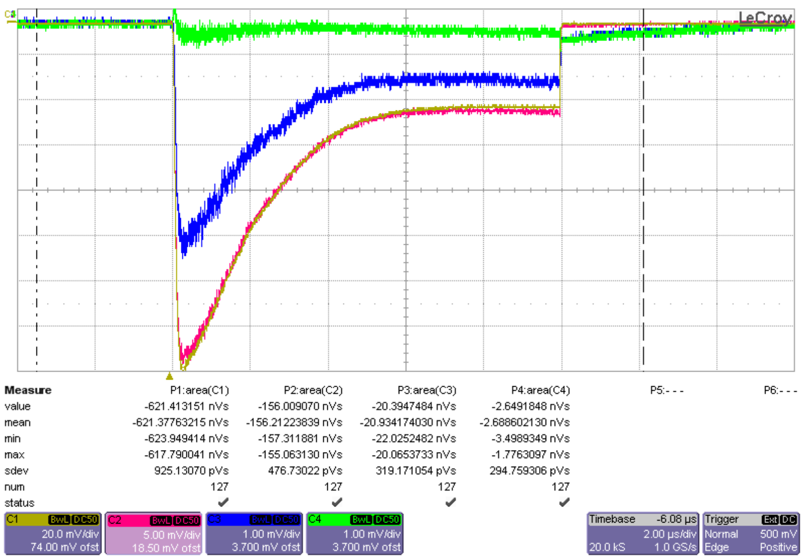
HV saturation affects all anodes equally

Limited amount of charge available on lasts stages (well known)

When CH1 saturates the other saturates as well…as specked







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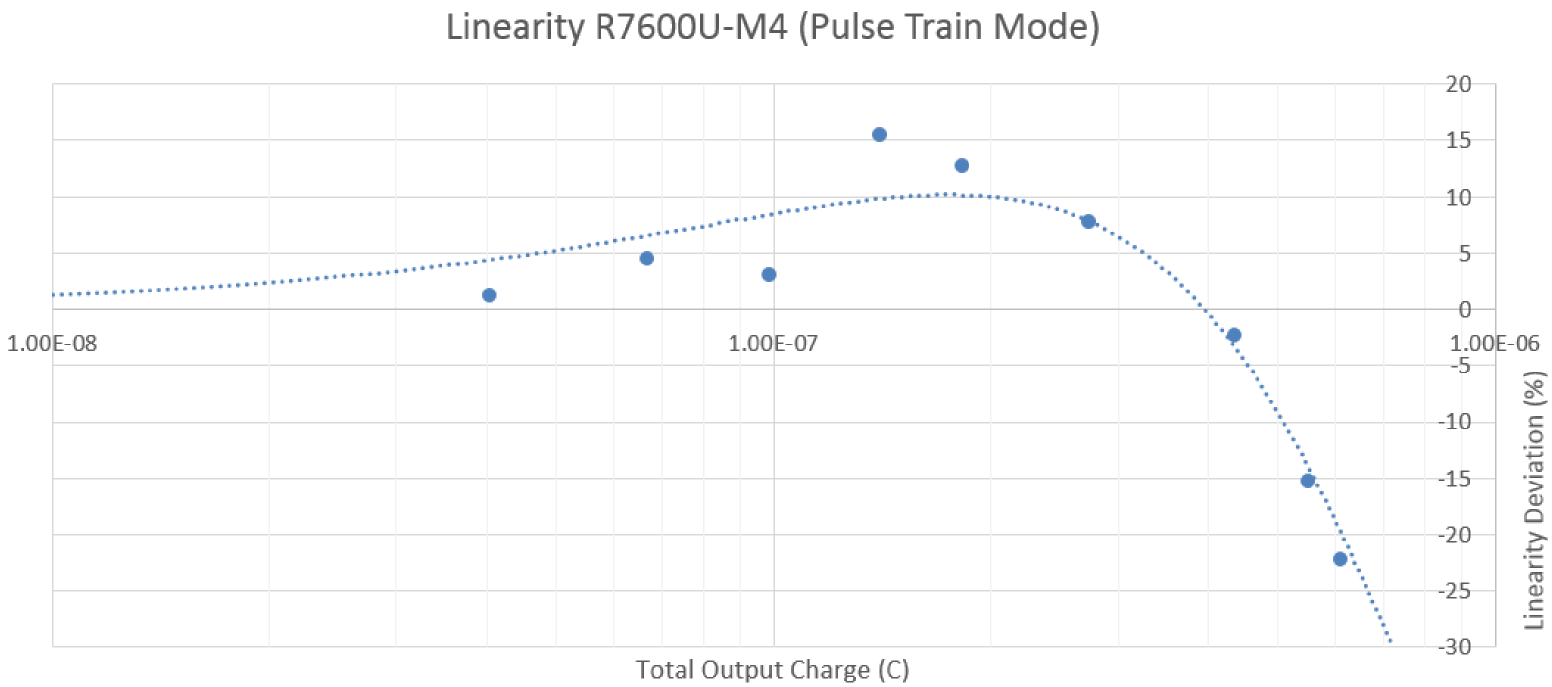


6. Next steps.

- Change Capacitors standard bases

  Increase Train mode linearity

  Keep max pulses amplitude during ~1ms

  See if MaPMT can work with max intensity beams and not saturate…
- Check photo-cathodes damage threshold

  For PMT direct exposure to different beams
- Check photon yield approx. limits for PSB

Hamamatsu Specs:

Mean Anode DC current: 0.1mA

- Which period of time? What is max current with no damage?

Mean Cathode DC current density: 250nA/cm2 (S20 type) (ET Enterprises)

- Complex to work out when a PMT would be damaged…

- **Proton Synchrotron Booster (SPB):**

		PSB BEAM OPERATIONS SPECIFICATIONS FORM 2016						
		Intensity [e11 p/ring]	**H.Emittance* [mm mrad]**	**V.Emittance* [mm mrad]**	**Rings Used**	**B.Lenght [ns]**	**Mom.Spread [Δp/p]**	**Kin. Energy [GeV]**
ISOLDE BEAMS	NORMGPS	90	15	8	1,2,3,4	230	1.1e-3	1.4
	STAGISO	20 – 35	5	4	2,3,4	230	1.4e-3	1.4
PS BEAMS	AD	40	9	5	1,2,3,4	170	< 1.0e-3	1.4
	EAST1	5	1.5	1.5	3	170	< 1.0e-3	1.4
	EAST2	5	1.1	1.1	3	170	< 1.0e-3	1.4
	SFTPRO_MTE	240	12	7	1,2,3,4	160	1.1e-3	1.4
	TOF	90	12	9	2	210	1.e-3	1.4
LHC BEAMS	BCM25	8.5	1.1	1.8	1,2,3,4	150	0.8e-3	1.4
	LHC25NS	16.5	3	2	1,2,3,4	180	1.0e-3	1.4
	LHC50NS	8	1.5	1	1,2,3,4	85	1.0e-3	1.4
	LHCINDIV	0.2 – 1.2	2	1.5	3	85	0.55e-3	1.4
	LHCPROBE	0.05 – 0.2	0.8	0.8	3	70	0.45e-3	1.4

* Normalized emittance

Table 5.2 PSB Operational beams on 2016 and main characteristics

Optics parameters on PSB Beam Wire Scanners				
Scanner Name	**Location / s[m]**	**β_h[m]**	**β_v[m]**	**D_h[m]**
4 x BR.BWS.2L1.V_ROT	2L1 / 10.735	5.71	4.25	1.46
4 x BR.BWS.2L1.H_ROT	2L1 / 10.833	5.69	4.23	1.46
4 x BR.BWS.4L1.H_ROT	4L1 /30.34	5.72	4.26	1.46
4 x BR.BWS.11L1.V_ROT	11L1 / 99.06	5.71	4.25	1.46

Table 5. Optics parameters for the PSB beam wire scanner positions

Beam profiles and Bunch densities for PSB Beam Wire Scanners per Beam type									
		σ_h [mm]		**σ_v [mm]**		**HD Bunch [10^{11}/mm]**		**VD Bunch [10^{11}/mm]**	
ISOLDE BEAMS	NORMGPS/HRS	6.36	13.5	3.9	8.5	2.65	5.65	4.23	9.27
	STAGISO	4.10	8.0	2.7	6.0	0.99	3.41	1.33	5.10
PS BEAMS	AD	4.98	10.5	3.1	6.7	1.52	3.20	2.38	5.21
	EAST1	2.43	4.5	1.7	3.7	0.44	0.82	0.54	1.19
	EAST2	2.22	3.9	1.4	3.1	0.51	0.90	0.63	1.39
	STFPRO	5.69	12.1	3.6	7.9	7.90	16.82	12.06	26.43
	TOF	5.69	12.1	4.1	9.0	2.96	6.31	3.99	8.74
LHC BEAMS	BCMS 25	2.03	3.8	1.8	4.0	0.89	1.67	0.84	1.85
	LHC 25NS	3.11	6.2	1.9	4.2	1.06	2.11	1.55	3.40
	LHC50NS	2.43	4.5	1.4	3.0	0.71	1.31	1.06	2.33
	LHCINDIV	2.39	5.0	1.7	3.7	0.02	0.20	0.02	0.29
	LHCPROBE	1.57	3.2	1.2	2.7	0.01	0.05	0.01	0.07
	Total Dynamics	**1.57**	**13.5**	**1.2**	**9.0**	**0.01**	**16.82**	**0.01**	**26.43**

Table 5.3 Beam profiles and bunch intensities for PSB beam wire scanners per beam type

Scintillator Material Characteristics		
Material	BC-408	
Density	1.032	g/cm3
Refractive index	1.58	
Rise Time	0.7	ns
Decay Time	2.1	ns
FWHM	2.5	ns
Att. Length	210	cm
Wavelength	425	nm
Photon Yield	64	% Antrh
Photon Yield	11136	ph/MeV
Photon Yield Anthr	17400	ph/MeV

Beam Parameters		
Bunch Intensity	2.40E+13	Protons
Bunch Length	160	ns
Beam Sigma	3.6	mm
Rep. Period	1	us
Scan Speed	20	m/s
Wire Diam	30	um
Max Interacting P.	7.98E+10	Prim
Total Interacting P.	3.6E+13	Prim
Time 4 Sigma	0.72	ms
PpS	720	Points

PMT Parameters		
Effective area	0.50	cm2
Photo Cathod Qeff	0.25	
Gain	1.00E+04	e-/e-
Attenuation	1	

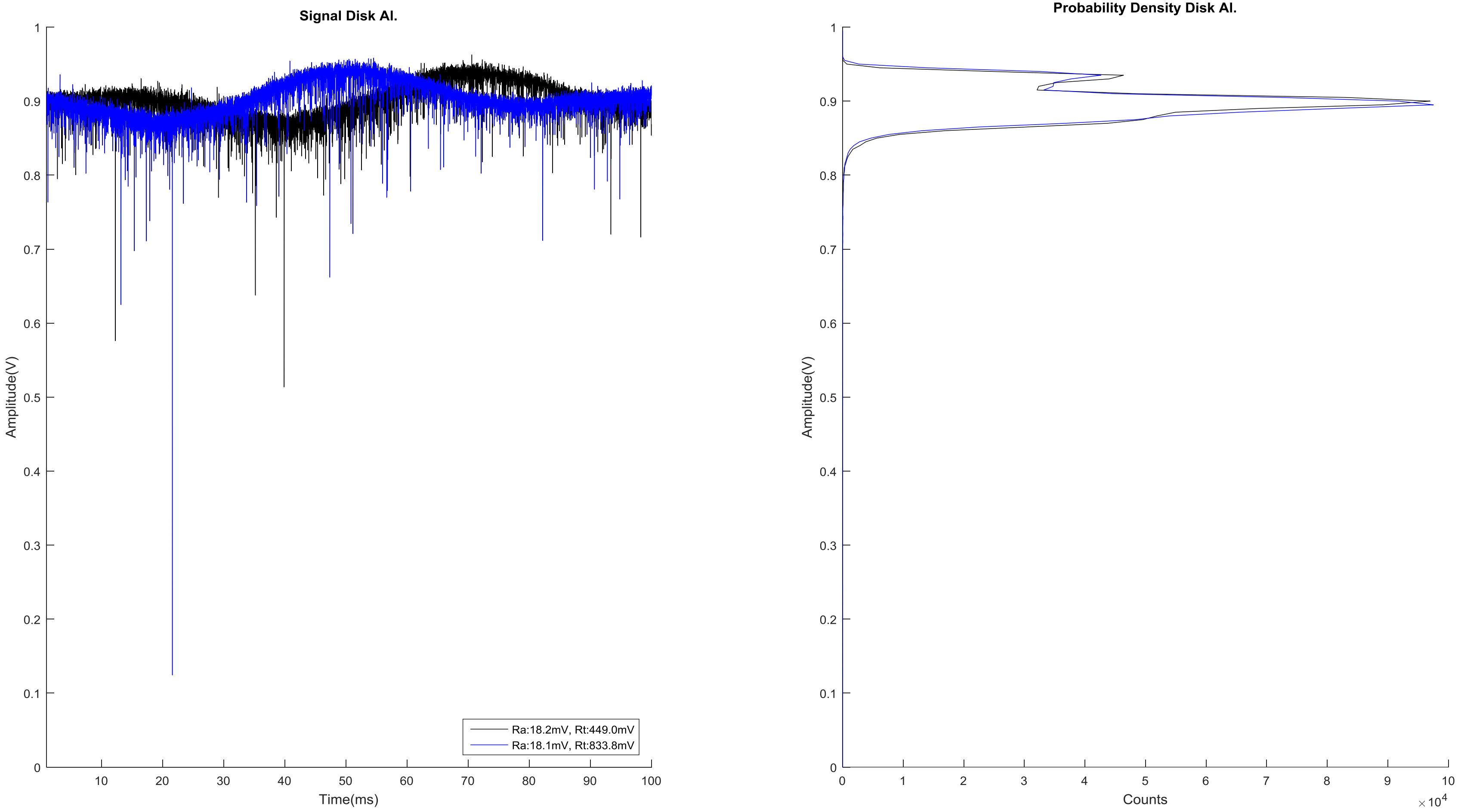
FLUKA Simulations (15cm)		
100MeV fluence	5.40E+11	part/cm2*prim
100MeV dose	1.50E-20	Gy/prim
1.4GeV fluence	8.58E-08	part/cm2*prim
1.4Gev dose	5.34E-17	Gy/prim

Scintillator Geometry #1		
Shape	Cylindrical	
L	30	mm
D	30	mm
Volume	21.21	cm3
Mass	0.02	Kg
Ef.Area	9	cm2
Transport Eff.	0.3	
Cilinder Area	7.07	cm2

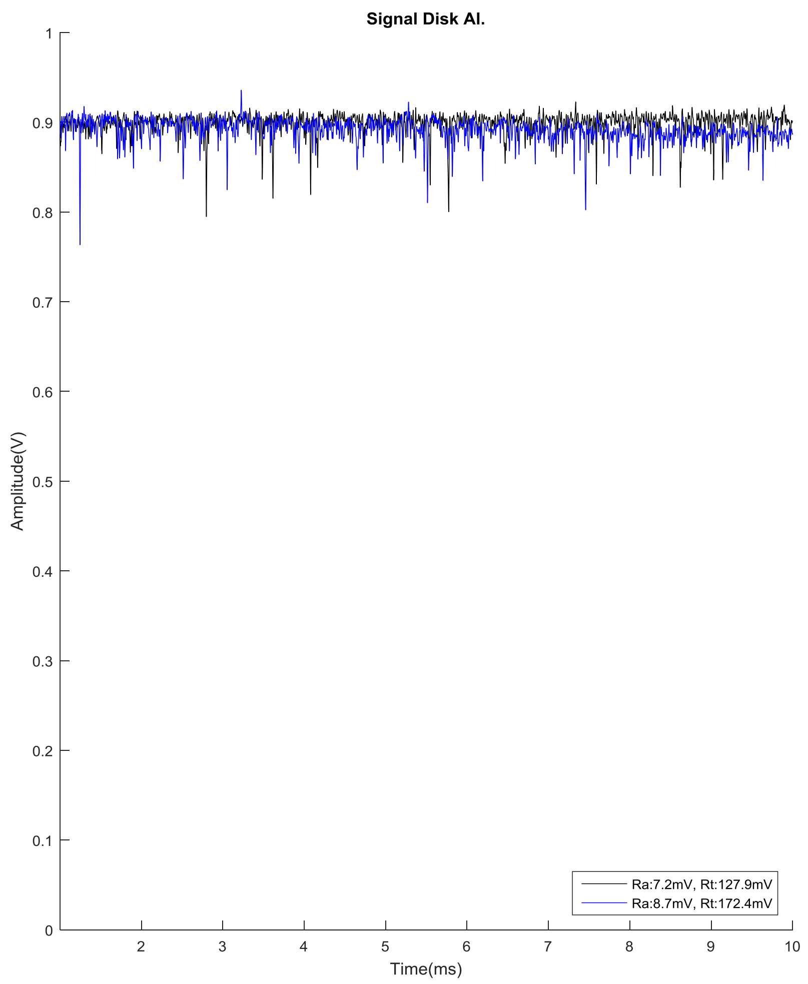
Injection E = 100MeV		
E. Deposited	163.44	MeV
Light Yield S.	1.8E+06	ph
Light Yield P.	3.9E+04	ph
PMT phe	9.7E+03	e-
PMT Q	1.6E-11	C
PMT I	9.7E-05	A
PMT Qmax25	2.4E-12	C

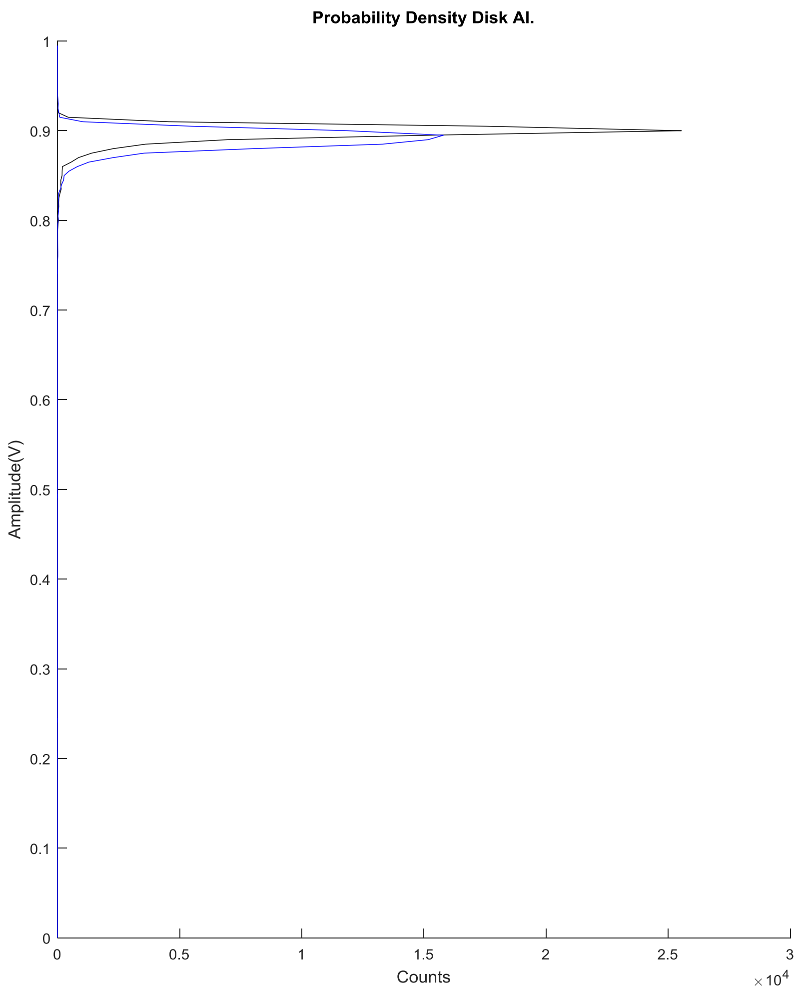
Extraction E = 1.4 GeV		
E. Deposited	581834.21	MeV
Light Yield S.	6.E+09	ph
Light Yield P.	1.4E+08	ph
PMT phe	3.5E+07	e-
PMT Q	5.5E-08	C
PMT I	3.5E-01	A
PMT Qmax25	8.6E-09	C

Dundee / LasterTech Aluminium



Dundee / LasterTech Aluminium

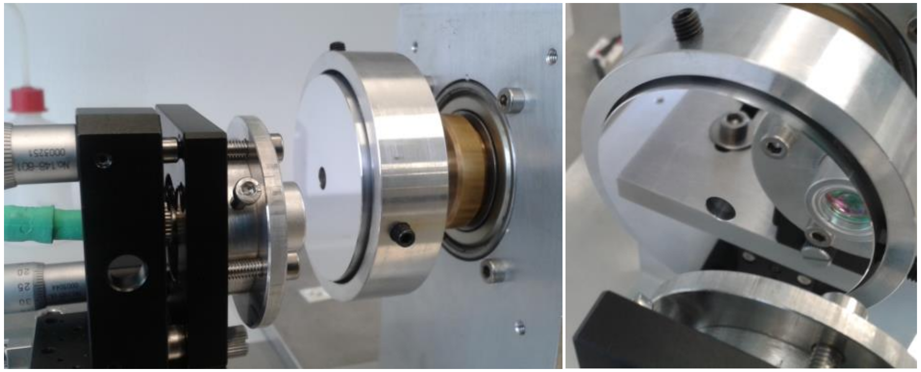




4. The Set-Up and testing process

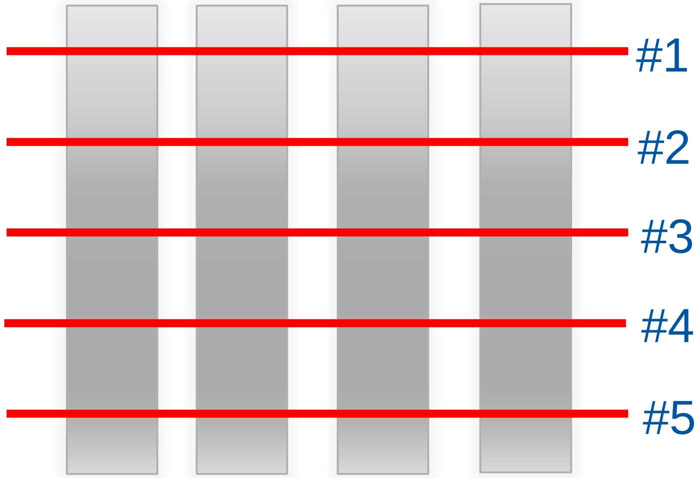
Test Objectives:

- Determine **resolution limitations** with metallic disks.
- Determine which sample show **best accuracy**.
- Determine which sample show **better slits quality**.
- Check **processing algorithms** for metallic disks.
- Asses the usage of metallic disks for PSB BWS.



Testing process:

- Samples tested three times:
  - As they came, after US. cleaning and after Vacuum cleaning.
- Samples on holder rotate at constant speed.
- Five data samples per track at different locations.
- Three processing algorithms for slit detection:
  - **Threshold detection**: Precise but strongly dependent of signal envelope.
  - **Peak detection**: Robust but strongly dependent peaks sharpness.
  - **Constant Discrimination Factor**: Easy and fast to implement.
- Study of slit period spread → accuracy on slits placement.

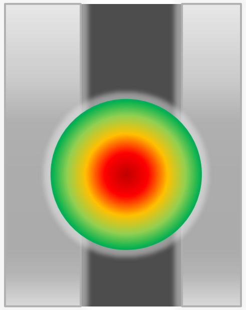


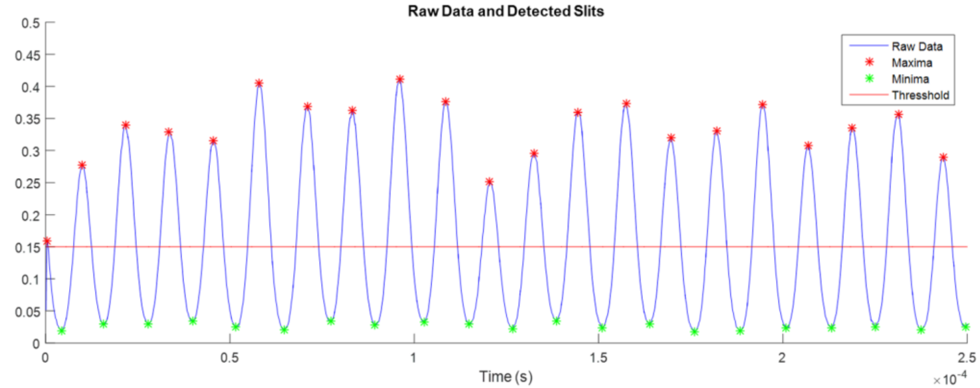
5. Comparing Disks: **20um** Pitch

Metal Region
Slit Region

Pr. Y 20um Pitch:

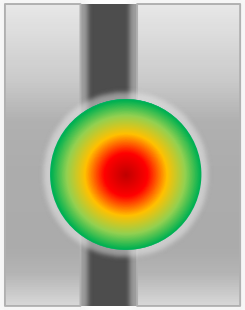
- Slit > Period/2
- Metal regions too narrow
- Leads to drastic signal loss

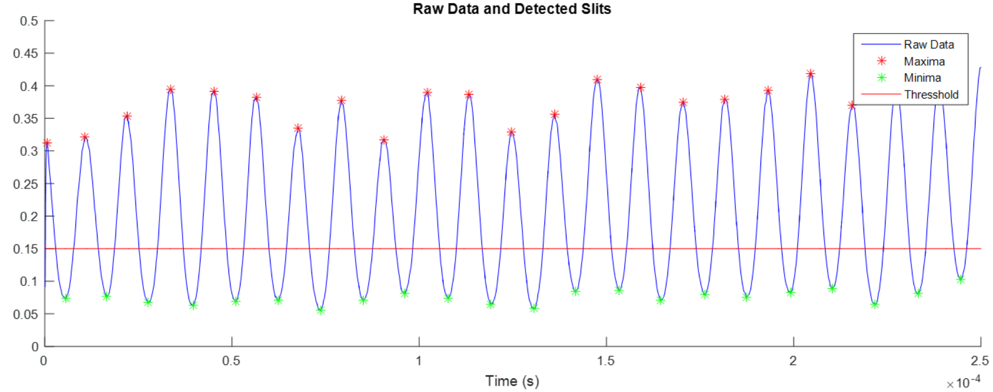




Pr. X 20um Pitch:

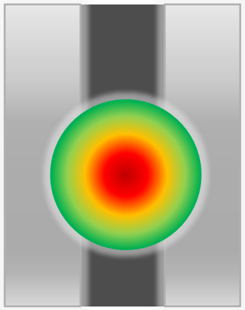
- Slit < Period/2
- Offset due to narrower slit
- Better uniformity, thinner slits

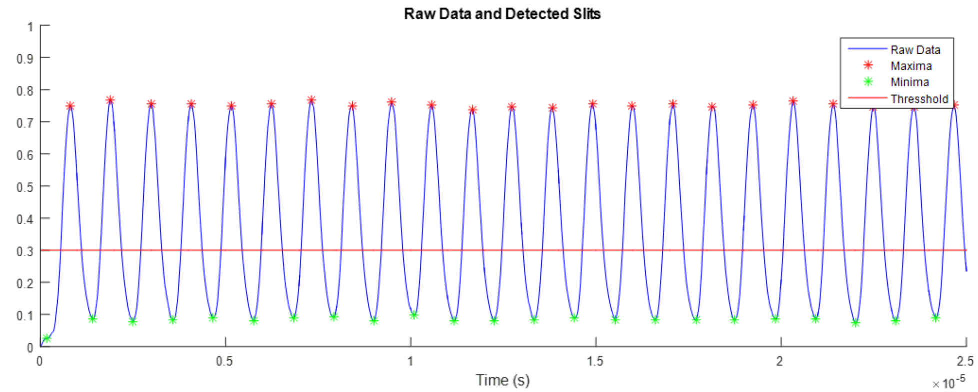




Glass Disk 20um Pitch:

- Slit = Period/2
- Good reflection uniformity.
- No appreciable roughness
- No light dispersion.

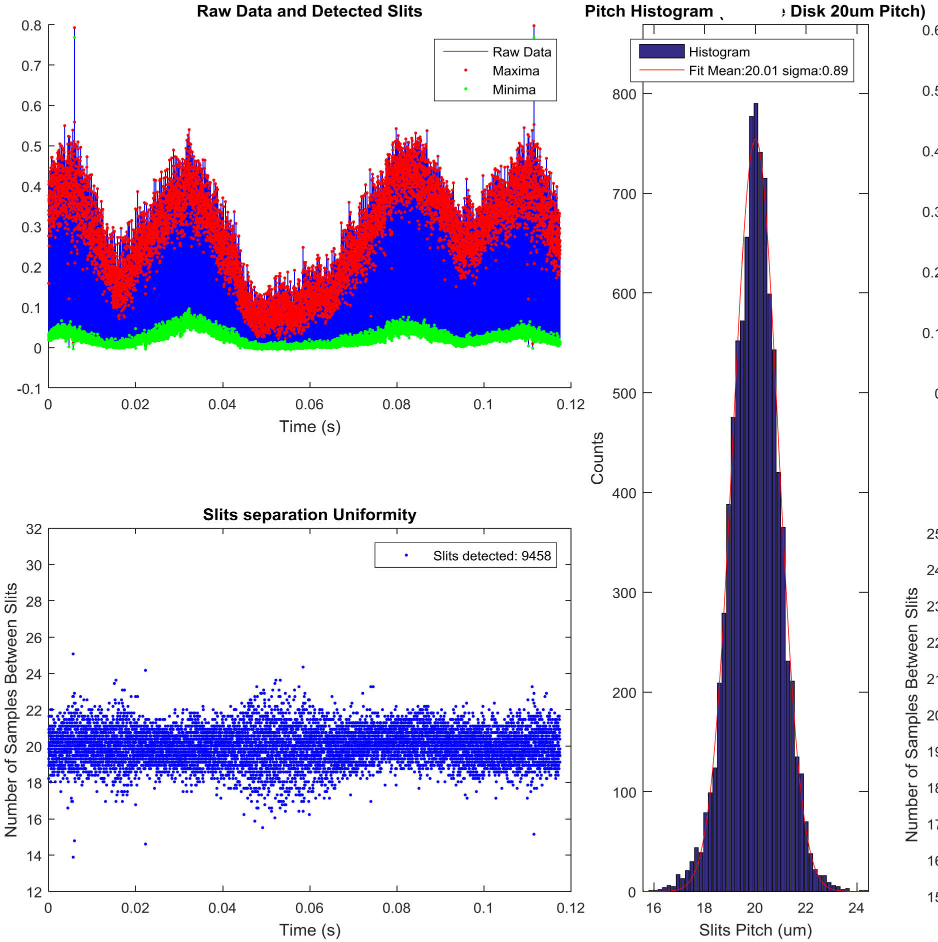




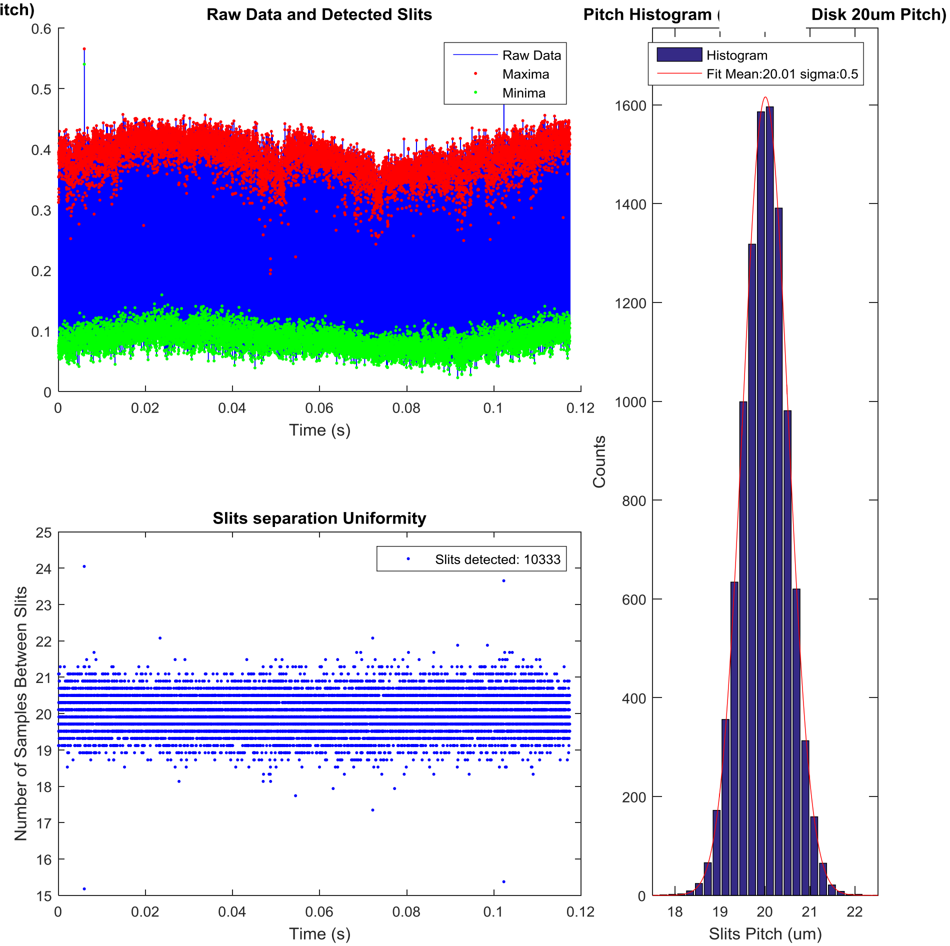
5. Comparing Disks: **20um** Pitch

5.2 Signal processing: Raw signal, track uniformity and accuracy

Pr. Y 20um Pitch



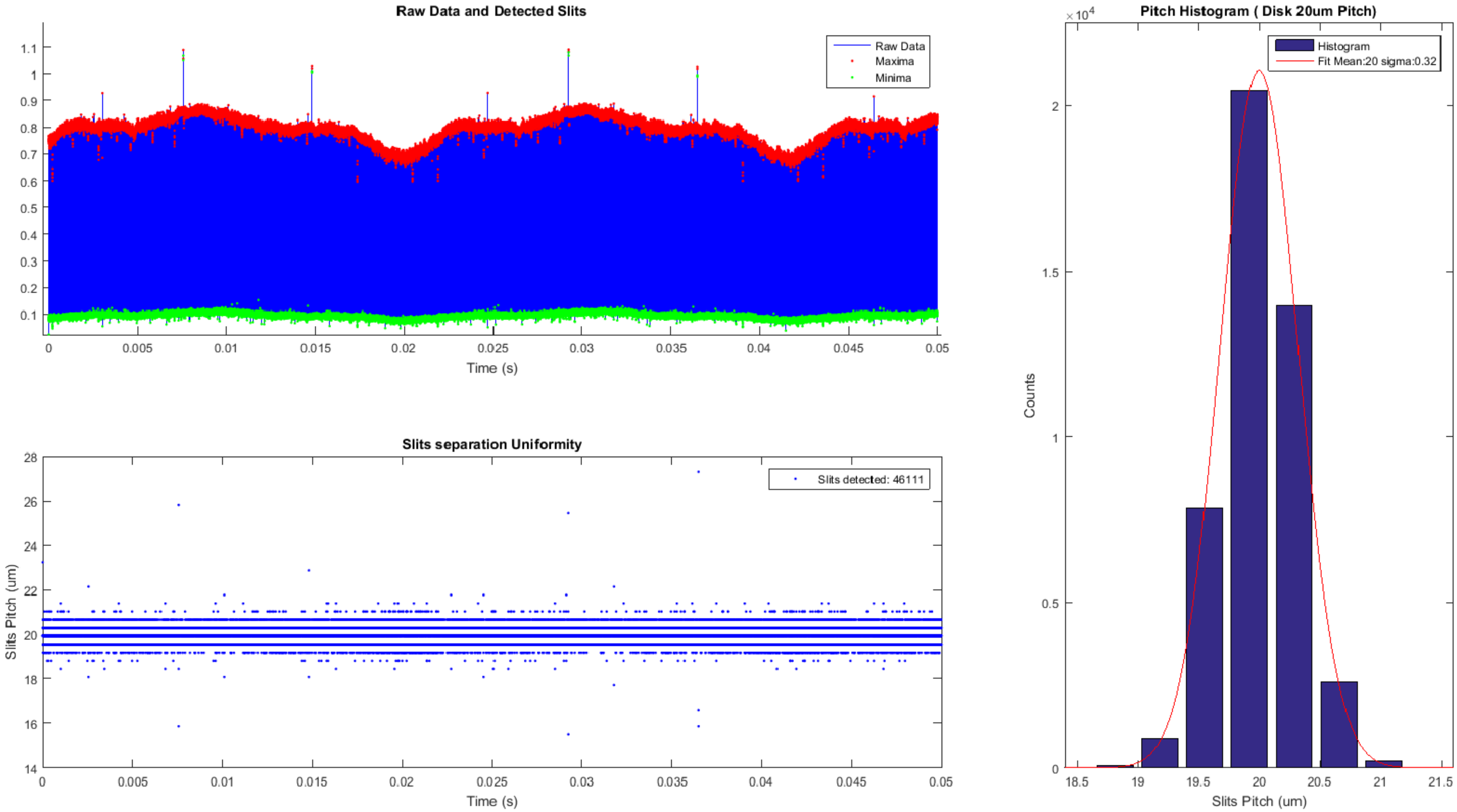
Pr. X 20um Pitch



5. Comparing Disks: **20um** Pitch

5.2 Signal processing: Raw signal, track uniformity and accuracy

Glass Disk for comparison 20um Pitch

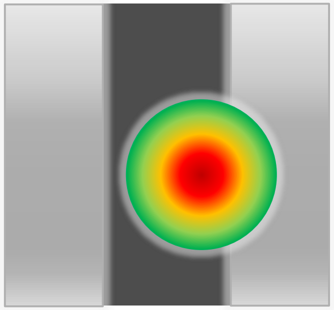


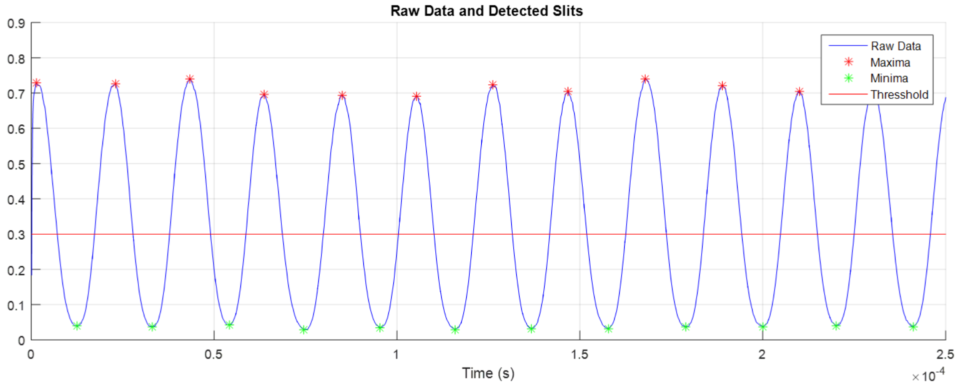
5. Comparing Disks: **30um** Pitch

5.2 Signal processing: Raw signal, track uniformity and accuracy

Pr. Y 30um Pitch:

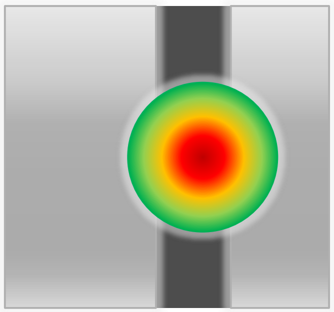
- **Slit ~ Period/2**
- More stable envelope
- Few count loss

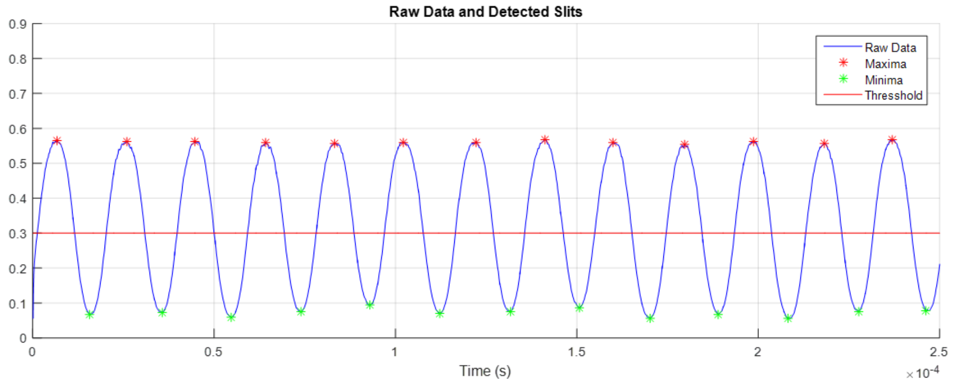




Pr. X 30um Pitch:

- **Slit < Period/2**
- More stable envelope
- Few count loss

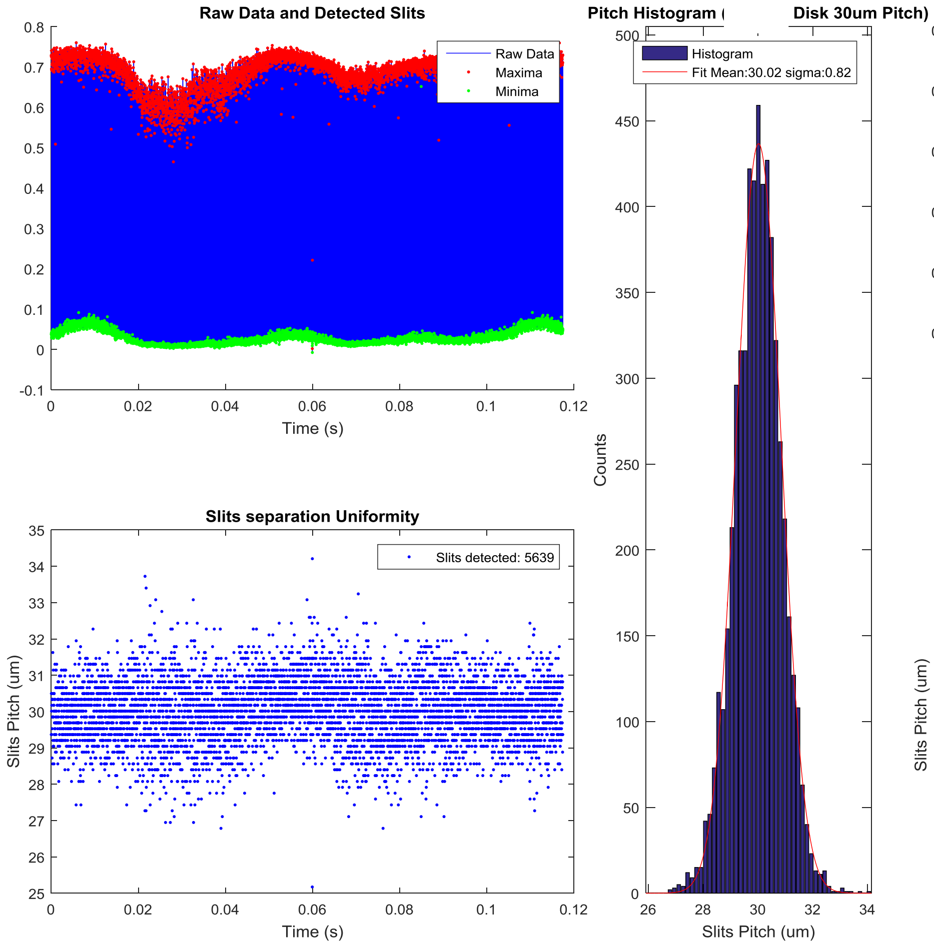




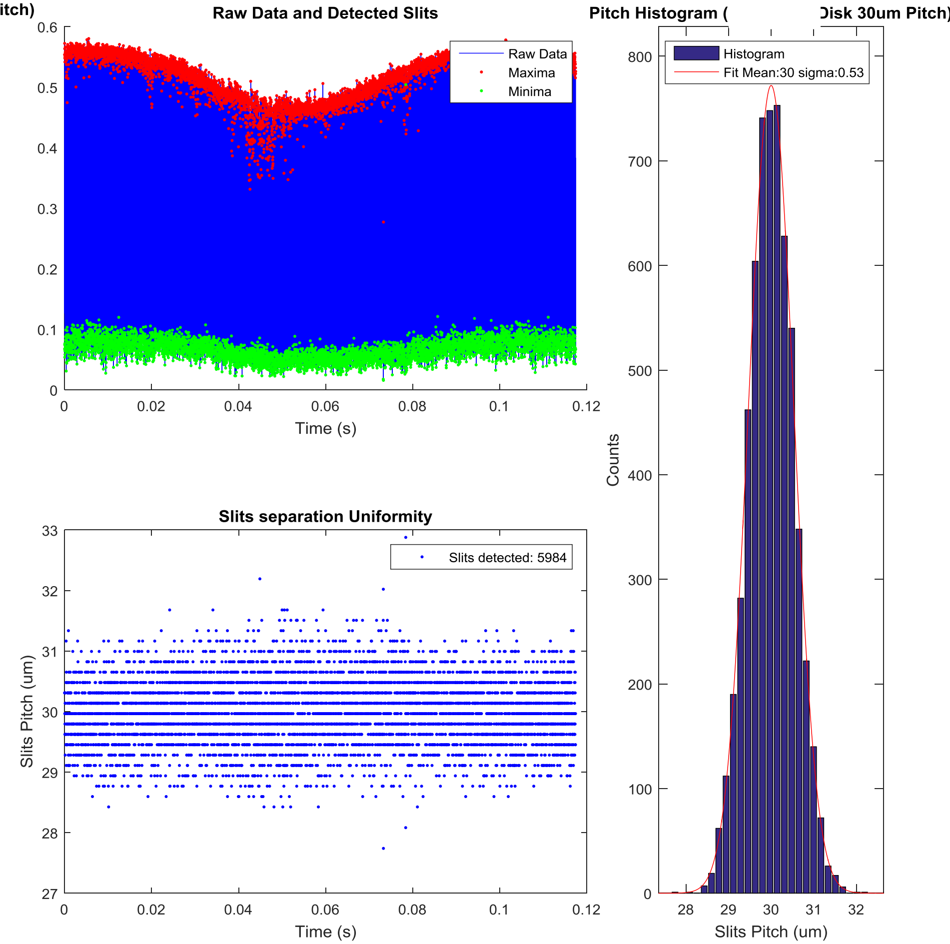
5. Comparing Disks: **30um** Pitch

5.2 Signal processing: Raw signal, track uniformity and accuracy

Pr. Y 30um Pitch



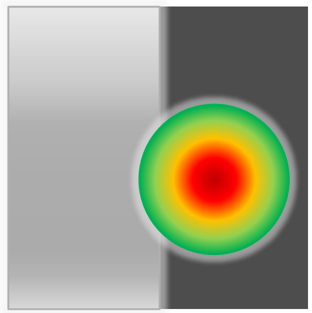
Pr. X30um Pitch

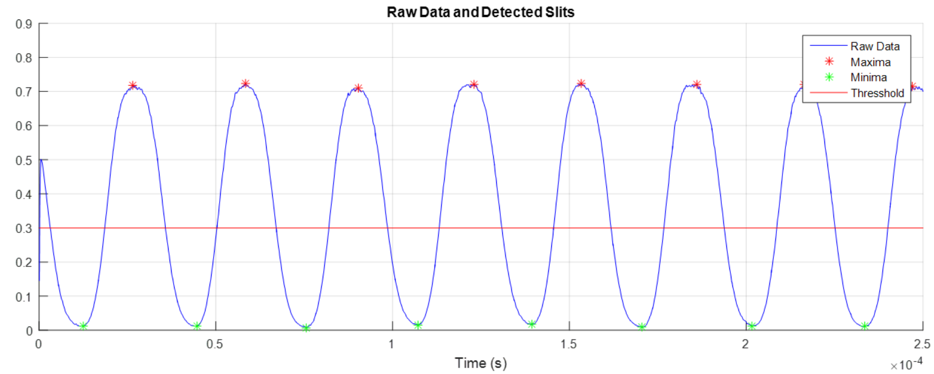


5. Comparing Disks: **40um** Pitch

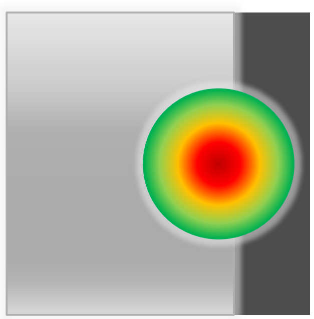
5.2 Signal processing: Raw signal, track uniformity and accuracy

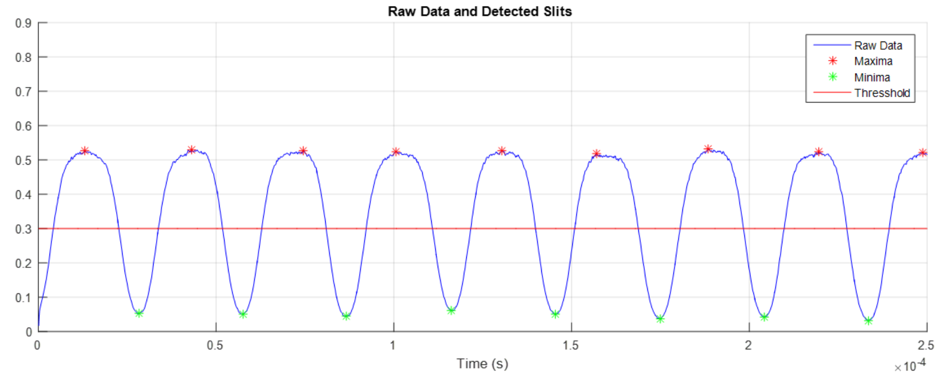
Pr. Y 40um Pitch:
- **Slit ~ Period/2**





Pr. X 40um Pitch:
- **Slit << Period/2**

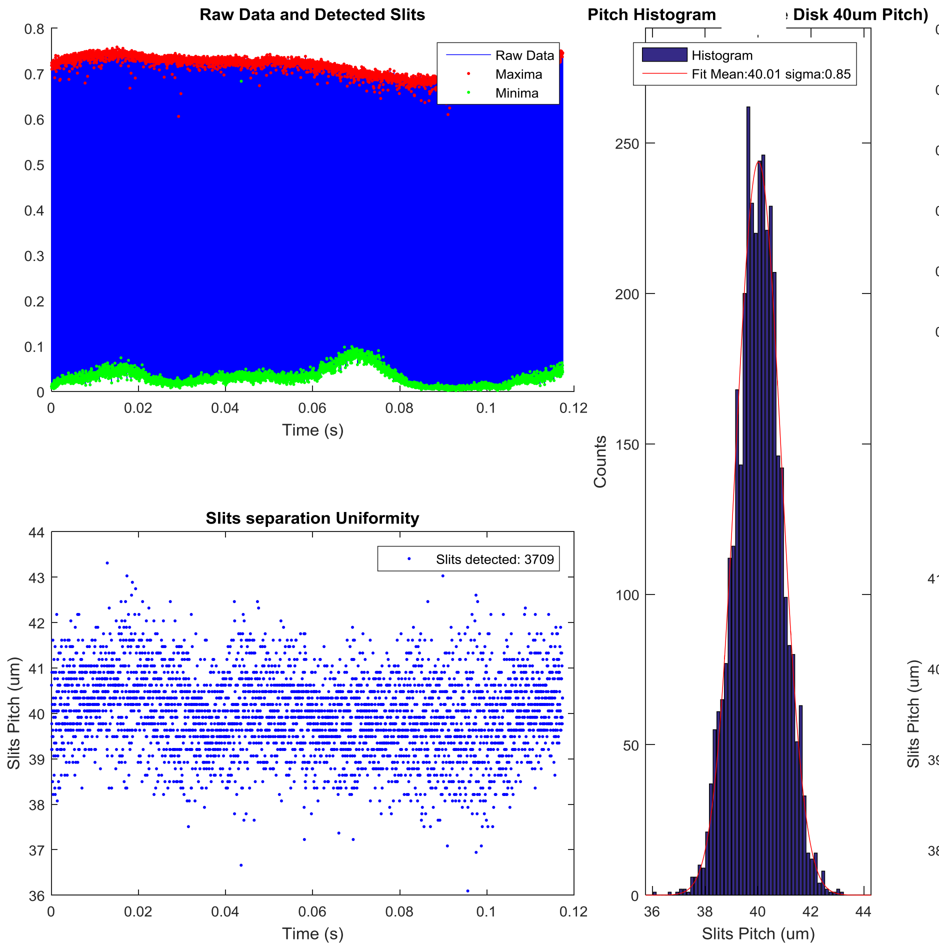




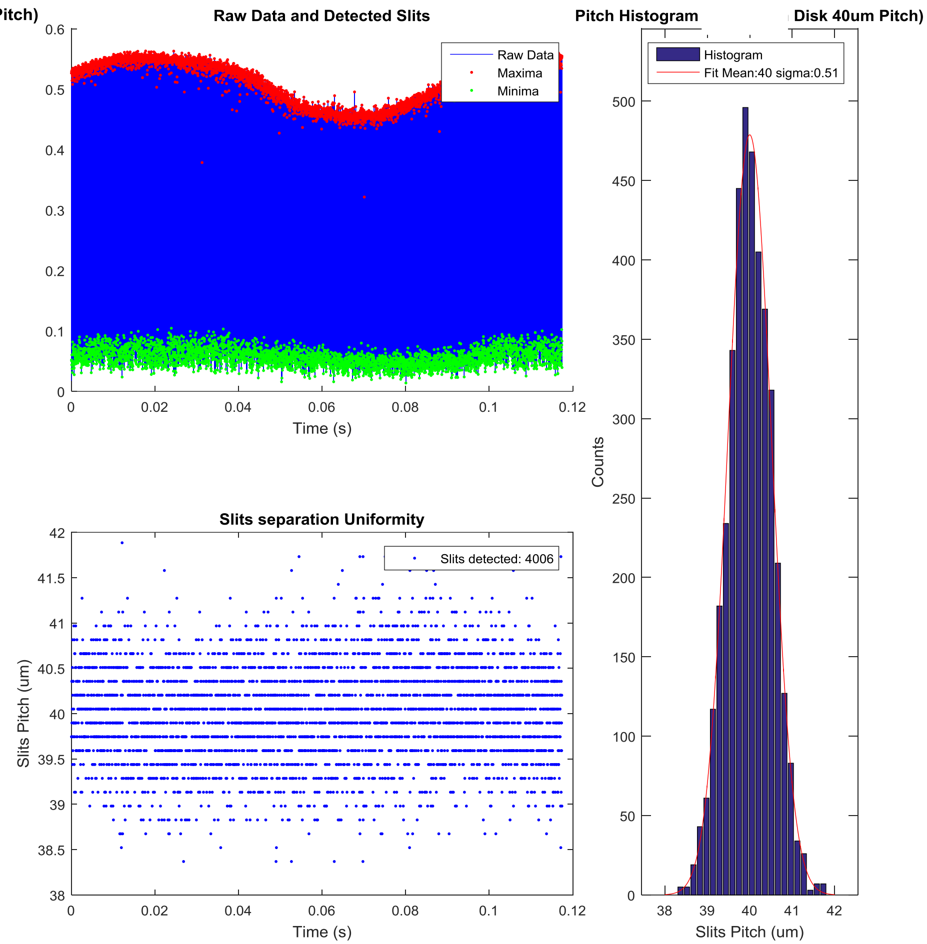
5. Comparing Disks: **40um** Pitch

5.2 Signal processing: Raw signal, track uniformity and accuracy

Pr. Y 40um Pitch



Pr. X 40um Pitch



6. Numeric summary

6.1 Processing results of disks and algorithms.

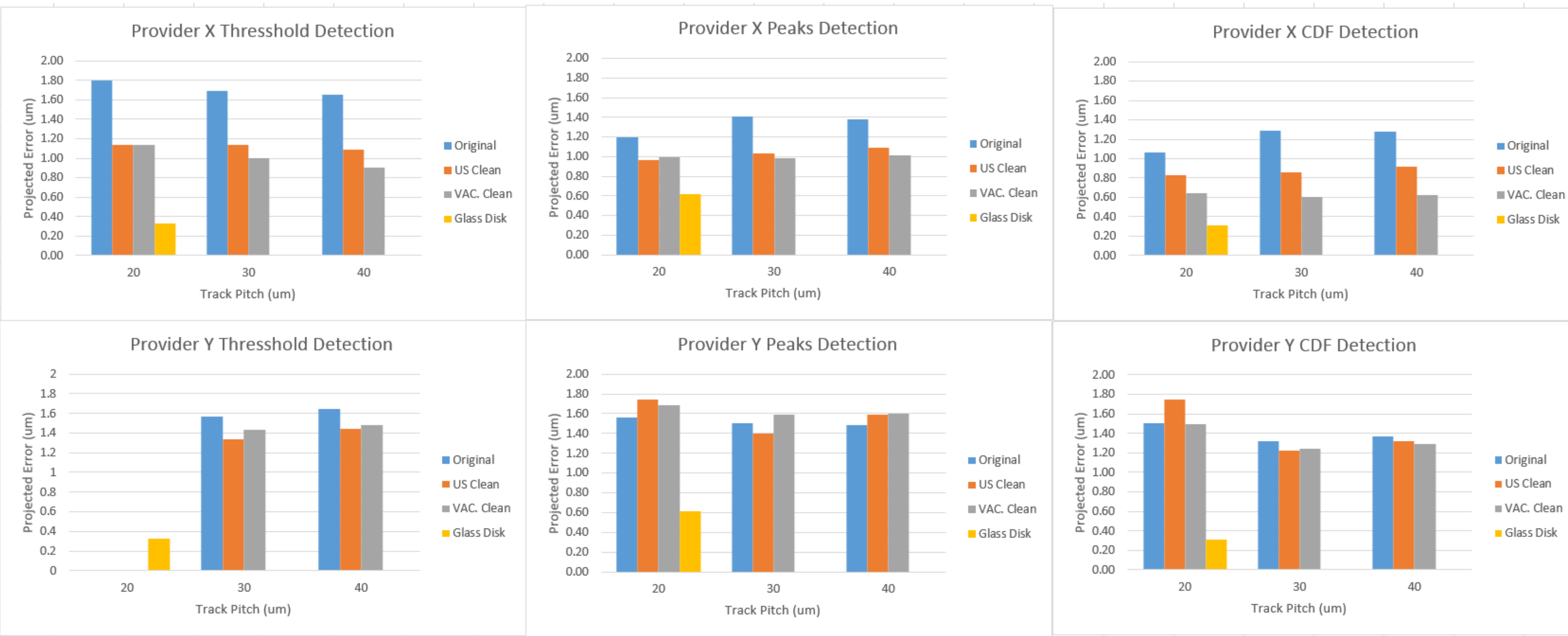
Pitch (um)	Status	PROVIDER X						PROVIDER Y					
		Threshold Det.		Peaks Det.		CDF Det.		Threshold Det.		Peaks Det.		CDF Det.	
		Slit σ (um)	Pr.Err (um)	Slit σ (um)	Pr.Err (um)	Slit σ (um)	Pr.Err (um)	Slit σ (um)	Pr.Err (um)	Slit σ (um)	Pr.Err (um)	Slit σ (um)	Pr.Err (um)
20	Orig.	0.96	1.80	0.64	1.20	0.57	1.07	NA	NA	0.83	1.57	0.8	1.50
	US Cl.	0.60	1.14	0.51	0.97	0.44	0.83	NA	NA	0.93	1.74	0.93	1.75
	Vac Cl.	**0.61**	**1.14**	**0.53**	**0.99**	**0.35**	**0.64**	**NA**	**NA**	**0.90**	**1.69**	**0.79**	**1.49**
30	Orig.	0.90	1.69	0.75	1.41	0.68	1.28	0.83	1.57	0.80	1.50	0.70	1.32
	US Cl.	0.60	1.13	0.55	1.03	0.46	0.86	0.71	1.34	0.74	1.40	0.65	1.22
	Vac Cl.	**0.53**	**1.00**	**0.52**	**0.99**	**0.32**	**0.60**	**0.76**	**1.44**	**0.85**	**1.59**	**0.66**	**1.24**
40	Orig.	0.88	1.66	0.74	1.38	0.68	1.28	0.86	1.65	0.79	1.49	0.73	1.36
	US Cl.	0.58	1.09	0.58	1.09	0.49	0.91	0.77	1.44	0.84	1.59	0.70	1.32
	Vac Cl.	**0.48**	**0.90**	**0.54**	**1.02**	**0.33**	**0.62**	**0.79**	**1.49**	**0.85**	**1.60**	**0.68**	**1.29**

Pitch (um)	Status	GLASS DISK					
		Threshold Det.		Peaks Det.		CDF Det.	
		Slit σ (um)	Pr.Err (um)	Slit σ (um)	Pr.Err (um)	Slit σ (um)	Pr.Err (um)
20	Sample	**0.17**	**0.33**	**0.33**	**0.61**	**0.16**	**0.31**

$$Pr_{.err} = \sqrt{2}\sigma \ * 1.33$$

6. Numeric summary

6.1 Processing results of disks and algorithms.



4. Numeric summary

6.2 Comments and conclusions

Sample	Resolution & Accuracy Limits		Pattern	Signal Stability	Loss Counts
	Disk	Projected			
Pr. Y	>= 30 +- 1.2 um	>= 39.9 +- 1.6 um	~ Symmetric	Average	Some
Pr. X	>= 20 +- 0.8 um *	>= 26.6 +- 1.1 um *	Asymmetric	Average	Some
Glass Disk	~ 20 +- 0.24 um	~26.6 +- 0.3 um	Symmetric	Excellent	None

* With risk of losing some counts

Dirtiness, dispersion?

Resolution / Accuracy / Slits quality:

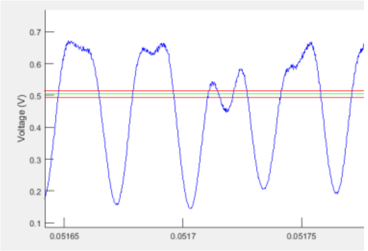
- Pr. X Disk:
  - 26.6um projected resolution (risk of some count loss)
  - Lower projected incertitude (0.6 – 1.1 um)
  - Very narrow slits ~8um
- Pr. Y Disk:
  - 39.9um projected resolution (for proper processing)
  - Higher projected incertitude (1.3 - 1.6 um)
  - Wider slits ~15um

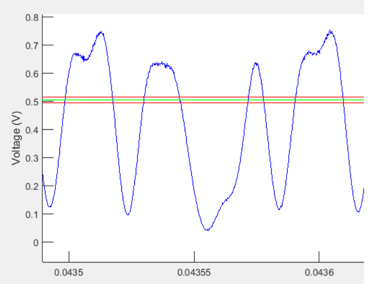
Metallic disc can be used but involves the following:

- Accuracy reduced ~ factor 2-3 with respect to Glass disks.
- Risk of loss counts on 20um pitch for metal disk.
- More processing power required (Peak detection)

Processing algorithm:

- Threshold detection:
  - Easy to implement in hardware
  - Very low threshold for metal disk
  - Results in better accuracy
  - Risk of loss counts
- Peak detection:
  - Processing required
  - Accuracy dependent on pulse width
  - Robust to signal loss
- CDF detection:
  - Easy to implement and more robust.
  - Shows the better accuracies.
  - “Independent” to envelope variation.





Some Loss Counts