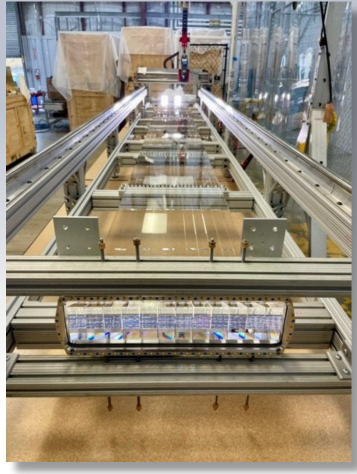
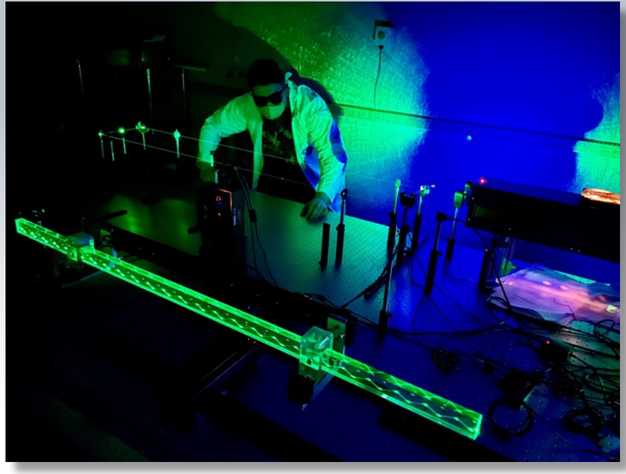
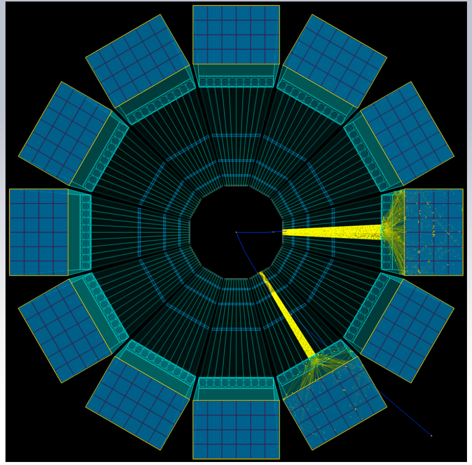
BABAR DIRC bar boxes at SLAC



Opened BABAR DIRC bar box at JLab



BABAR DIRC bar in JLab QA setup



PYTHIA events in ePIC hpDIRC

BABAR DIRC Bar Refurbishment for the ePIC hpDIRC

Selection of slides from the

Final Design Review of the BABAR DIRC Bar Refurbishment for the High-Performance DIRC Particle Identification Detector

April 1-2, 2025

Joe SCHWIENING

GSI Helmholtzzentrum für Schwerionenforschung GmbH

OUTLINE

Introduction

DIRC bar specifications

- DIRC bar fabrication experience
- BABAR DIRC bar specification and quality assurance results
- Simulation: impact of bar imperfections on ePIC hpDIRC performance

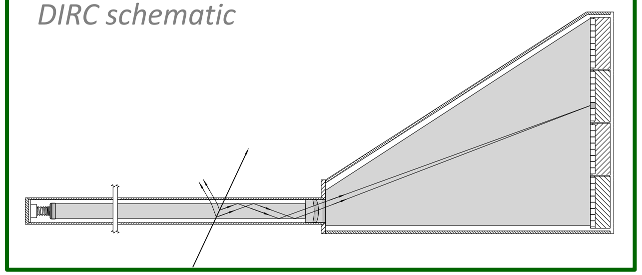
BABAR DIRC bar refurbishment

- Refurbishment strategy
  - Shell disassembly, bar debonding, cleaning, QA
  - Validation, tagging, storage, integration plans
  - Schedule
- In-kind value of bars vs. cost of fabrication of new bars

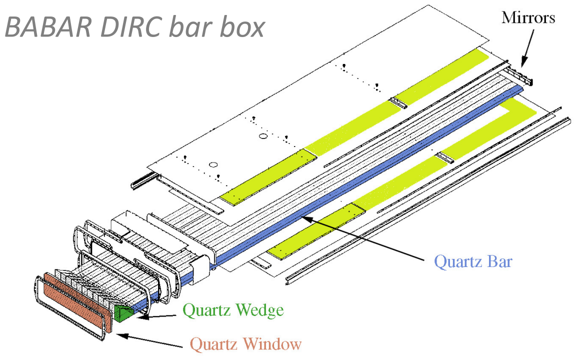
Selection of hpDIRC slides from the Incremental Preliminary Design and Safety Review of the pfRICH, dRICH, and hpDIRC on April 1st, 2025

I have added a few hpDIRC slides shown by Greg Kalicy during the review for context, will skip some of my more boring slides on Cost, Risk registry, ES&H and QA, etc.

DIRC schematic



BABAR DIRC bar box

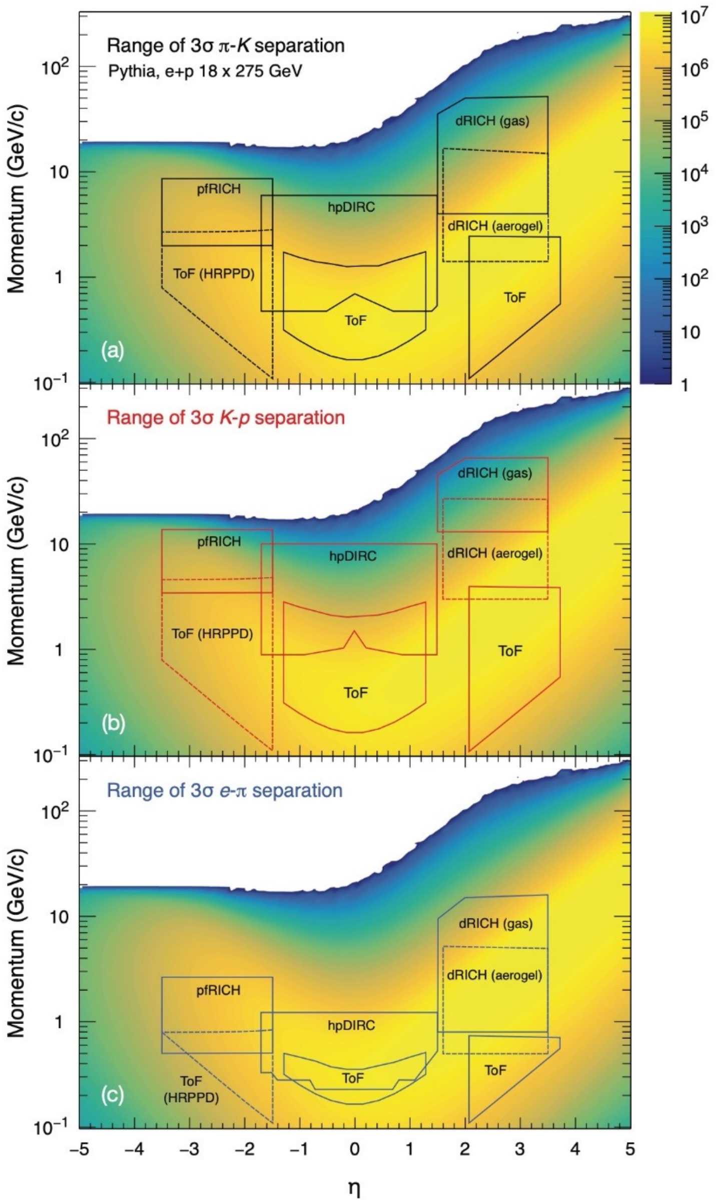


Bar box disassembly at JLab in Dec 2024

OVERVIEW: EPIC HPDIRC

- EIC physics requires clean and efficient PID over a wide angular range
- Hadronic PID required to separate:
  - Electrons from charged hadrons -> electron ID mostly provided by calorimeters, supplemented for lower momenta by DIRC/RICH detectors
  - Charged pions, kaons, and protons from each other
- Requirements for barrel PID ($-1 \leq \eta \leq +1$):
  - Main separation power requirement: $\geq$ 3 s.d. π/K up to 6 GeV/c
  - System needs to be radially compact (impact on cost of outer systems)
  - Minor changes to detector position and dimensions do not impact hpDIRC performance (sensor in B-field and detector integration)
  - Low demand on detector services (simplified integration and operation)
- hpDIRC capable of reaching required performance at 6 GeV/c

Summary of PID requirements in ePIC



Detection of Internally Reflected Cherenkov Light

- DIRC: Compact subtype of RICH detector

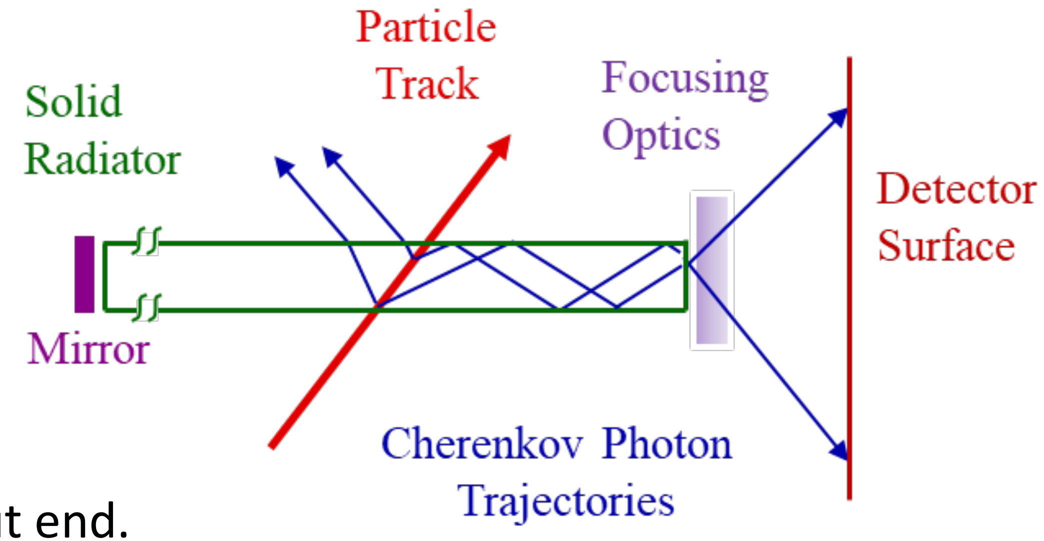
  utilizing total internal reflection of Cherenkov photons in a solid radiator medium

- Charged particle traversing solid radiator, refractive index n
- For n>√2 some photons are always

  totally internally reflected for $\beta \approx 1$ tracks

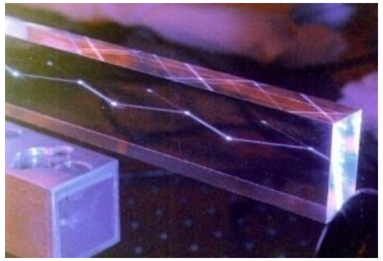
- Radiator: bar, plate, or disk,

  typically made from Synthetic Fused Silica ("Quartz")



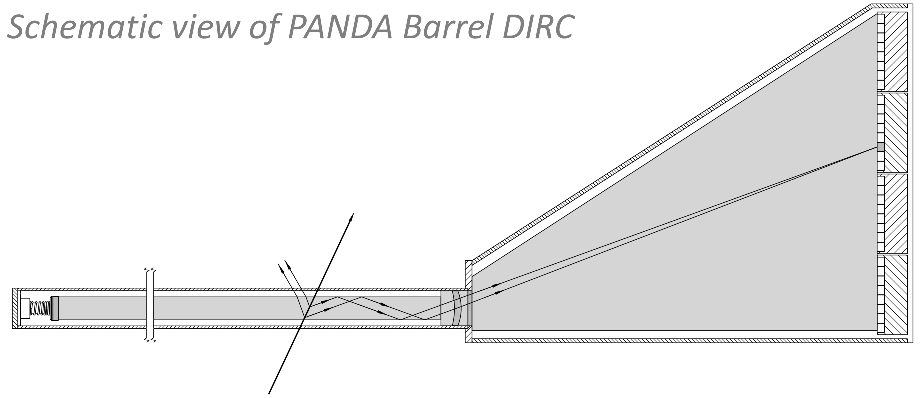
- Mirror attached to one bar end, reflects photon back to readout end.
- Photons exit radiator via optional focusing optics into expansion region,

  detected on photon detector array.



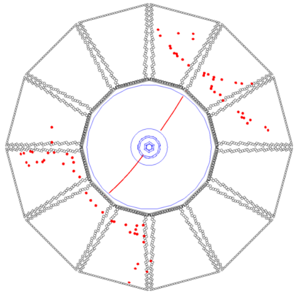
DIRC Concept

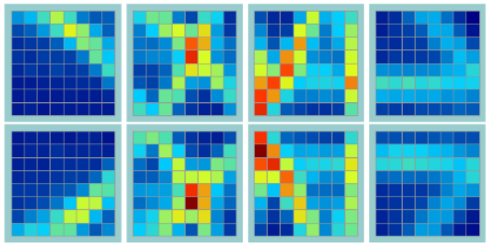
- Magnitude of Cherenkov angle conserved during many internal reflections
  (provided optical surfaces are square, parallel, highly polished)
- Quartz bar/plate/disk both radiator and light guide,
  transporting photons away from crowded central detector
  to suitable sensor location
- DIRC is intrinsically a 3-D device,
  measuring: x, y, and time of Cherenkov
  photons, defining θ_c, ϕ_c, $t_{propagation}$.
- Ultimate deliverable for DIRC: PID likelihoods.


Schematic view of PANDA Barrel DIRC

DIRC hit patterns are not typical Cherenkov rings.

Different DIRCs use different reconstruction approaches
to provide likelihood for observed hit pattern (in detector space or in
Cherenkov space) to be produced by e/μ/π/K/p plus event/track background.
DIRC requires momentum and position of particle measured by tracking system.


Hit pattern BABAR DIRC

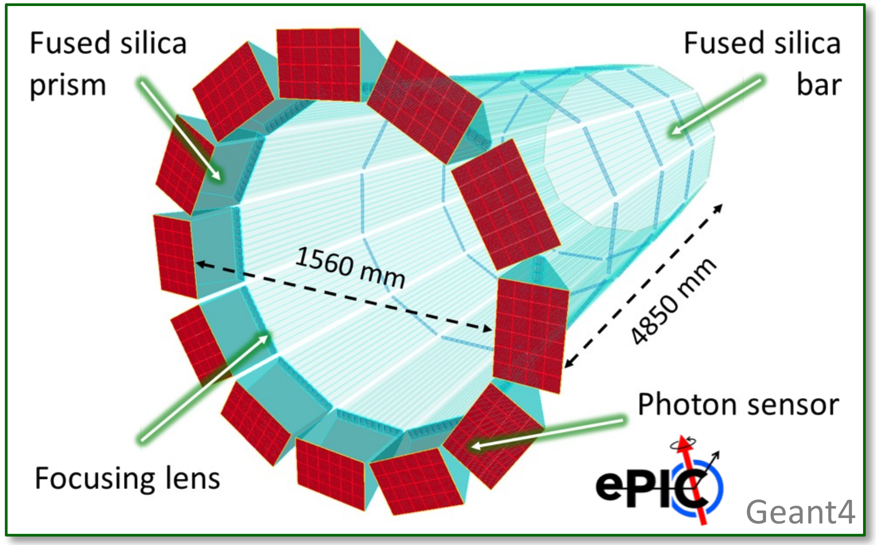

Accumulated hit pattern PANDA Barrel DIRC

slide from Greg's talk

OVERVIEW: EPIC HPDIRC

ePIC high-performance DIRC design concept:

fast focusing DIRC, utilizing high-resolution 3D (x,y,t) reconstruction



DIRC bars:

- Barrel radius: 780 mm, 12 sectors
- 10 long bars per sector, 4500 mm x 35 mm x 17 mm (L x W x T)
- Long bar: 4 shorter bars, glued end-to-end, "radiators" and "light guide"
- Shorter bars made from highly polished synthetic fused silica
- Flat mirror on far end

Focusing optics:

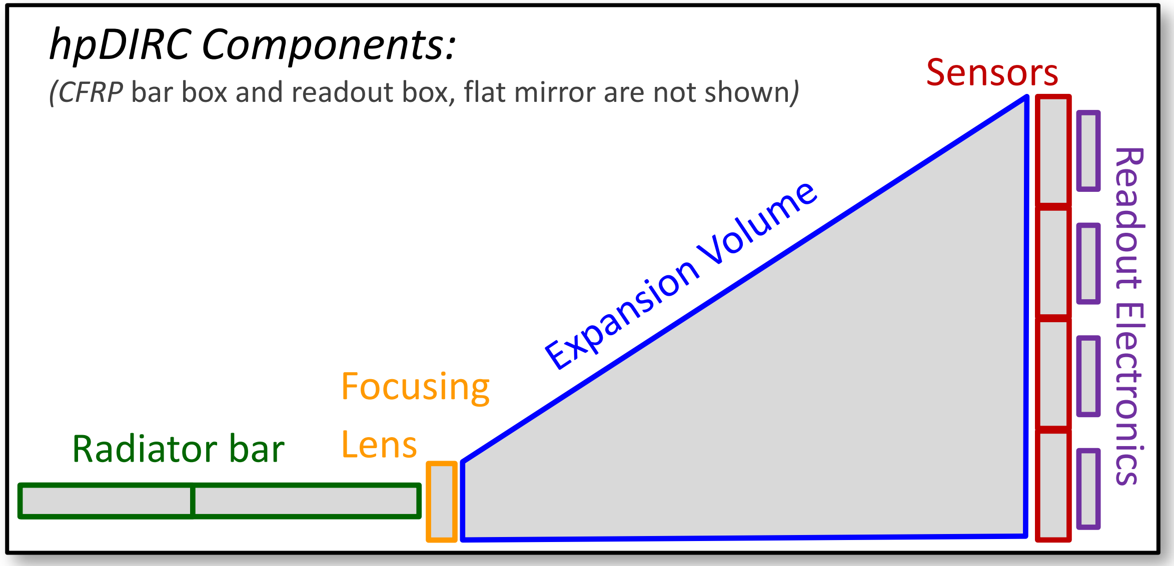
- Radiation-hard 3-layer spherical lens (sapphire)

Expansion volume:

- Solid fused silica prism: 25 x 35 x 30 cm^3 (H x W x L)

Readout system:

- MCP-PMT Sensors (Photek/Incom)
- ASIC-based Electronics (FCFD)



OVERVIEW: BABAR DIRC

First DIRC counter, primary hadronic PID in BABAR barrel (1999 – 2008)

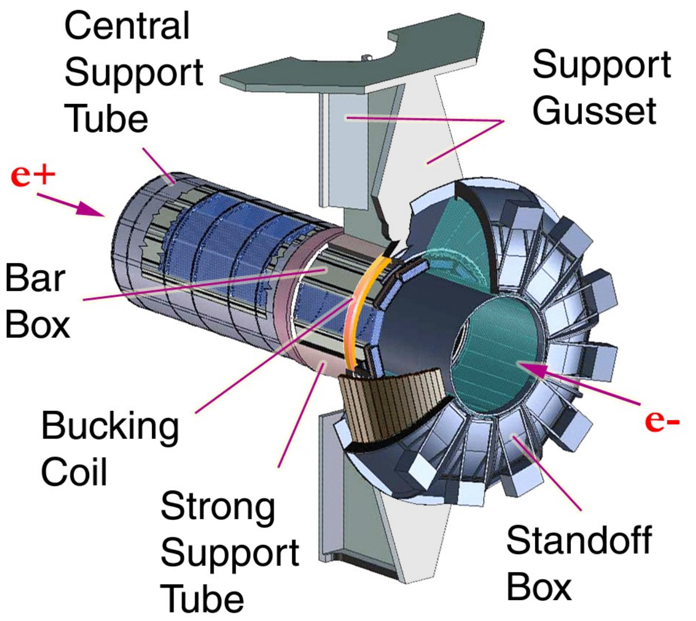
Robust operation, achieved 3σ π/K separation up to 4 GeV/c

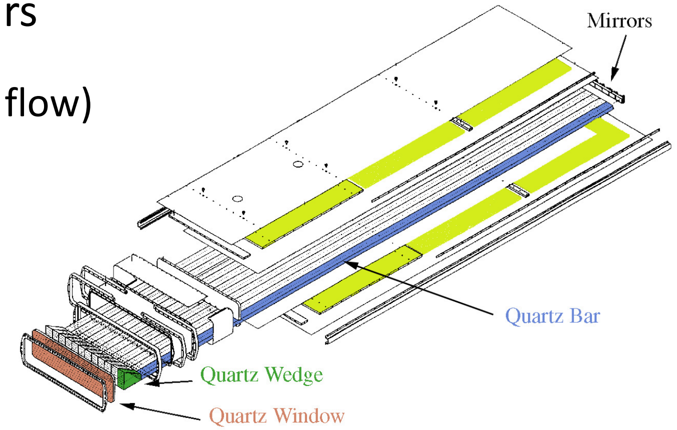
- DIRC barrel with 12 bar boxes, large water tank as expansion volume
- Each bar box contains 12 synthetic fused silica bars (4900 mm long)
  → four short bars glued end-to-end (17 mm x 35 mm x 1225 mm)
- Bar boxes installed 1998/99, total of 576 bars in 12 bar boxes
- BABAR physics running: Nov 1999 – Apr 2008
- No indication of bar quality deterioration during 10+ years
- Bar boxes moved to storage Nov 2010 (remained under N_2 flow)

Oct 2012: SLAC call for EoI for BABAR DIRC bar box reuse

SLAC/DOE OHEP process

- 4 bar boxes transported to JLab in 2017/2018 (GlueX)
- 8 more bar boxes transported to JLab in 2024 (EIC)





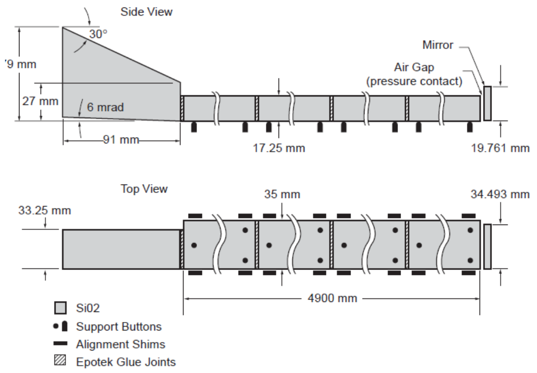


Fig. 20. Schematics of a DIRC radiator bar in side and top view.

DIRC BAR PRODUCTION EXPERIENCE

Production of large fused silica DIRC optics (bars, plates) has been challenging

DIRC bars require mechanical tolerances on flatness, squareness, and parallelism,
for large objects with optical finish and long sharp edges → not a turnkey operation

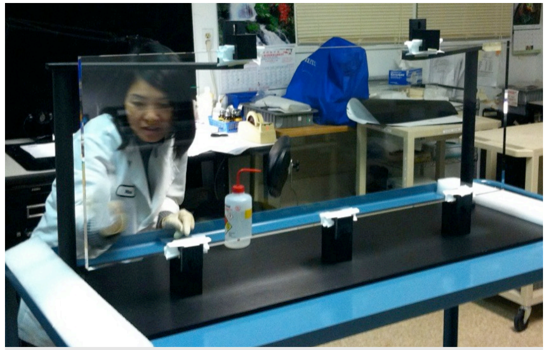
Excellent surface polish required across entire bar, typical local roughness < 5 Å,
to ensure high photon transport efficiency (reflection coefficient > 0.999 at 400 nm)

Parallel and square bar surfaces required to maintain Cherenkov angle during reflections;
non-squareness of cross-section < 0.1 mrad for Belle II TOP, < 0.25 mrad for BABAR DIRC

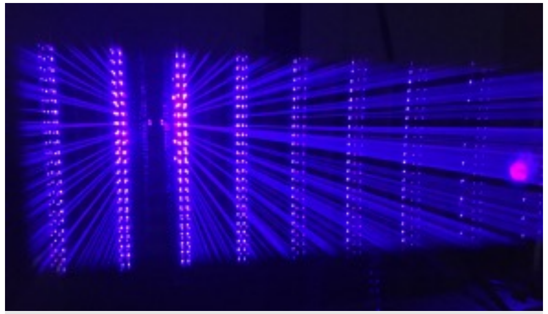
Few qualified vendors → cost and schedule risk

- Zygo Corp. produced 56 prototype bars for BABAR DIRC and 30 plates for the Belle II iTOP
- InSync Inc. (previously part of Boeing Corp.) fabricated 698 bars for the BABAR DIRC
- Aperture Optical Sciences Inc. (with Okamoto Optics) produced 4 plates for the Belle II TOP
- Nikon Corp. produced 112 bars for the PANDA Barrel DIRC
  and few prototype plates for the PANDA Disc DIRC and the LHCb TORCH

4.2m-diameter planetary polisher at InSync Inc.



Cleaning of Belle II TOP plate (Zygo)



PANDA DIRC bar (Nikon) in laser beam

BABAR DIRC Bar Specifications

Bar specifications were a compromise between technology, cost, and performance

- Surface roughness spec and sharp edges to limit photon loss during several hundred internal reflections
- Parallelism and squareness spec to ensure that Cherenkov angle is preserved during internal reflections
- Size tolerances and end-side squareness required for gluing and assembly of bar boxes
- Quality assurance by vendor (measurements and documentation) part of series production contract, cross-checks at SLAC
  - QA integrated into fabrication process, requires expensive equipment (interferometers, autocollimators)

Quantity	Specification/Tolerance	Primary motivation	Challenges
Surface roughness	< 5 Å *rms* (sides, faces) < 20 Å *rms* (ends)	Photon loss	
Edge sharpness	No chamfer, total area of chips < 6 mm^2 per side	Photon loss	Very careful handling of bar
Squareness	Initial spec: <0.25 mrad Revised: rms of face-side angles <0.4 mrad	Angle smearing/Mechanical	Difficult to hold squareness spec, accepted revised spec
Parallelism	Parallel to 25 µm across bar length	Angle smearing	
Surface flatness	Flat to 0.1 mm over entire length	Angle smearing	
Width	35.0 +0/-0.5 mm	Mechanical	Reprocessing created some narrower bars
Thickness	17.25 +0/-0.5 mm	Mechanical	Reprocessing created some thinner bars
Length	1225.0 +0/-0.5 mm	Mechanical	

BABAR DIRC BAR QA

Detailed QA results from manufacturer (Boeing) shared by SLAC group

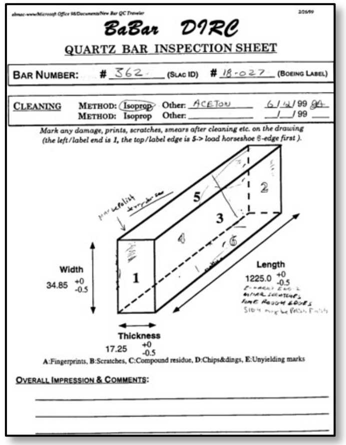
Individual QA documents and high-level summary spreadsheet available for every bar

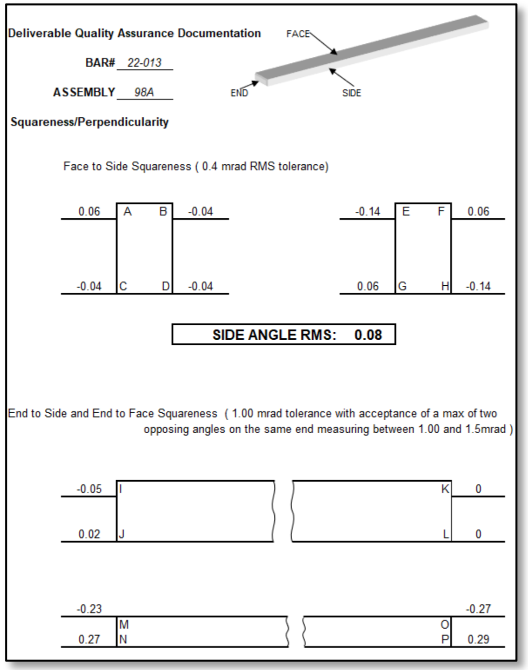
Inspection sheets available for most of the bars

Spreadsheet for long bars and assembled bar boxes available

(crucial to keep track of bar IDs for future assembly for ePIC)

For example: bar number 101-130 (out of 698 produced bars)





Bar #	Boeing Label	4-Bar Ass'y	Date	SLAC Label	Length	Thickness end1	Thickness mid	Thickness end2	Width end 1	Width end1	Width mid	Width end2	Width end2	Face 1	Face 2	Side 1	Side 2	End 1	End 2
101	04-020	10-B	12/17/1998	101	48.199	0.6758	0.6762	0.675	1.3221		1.3243		1.32215	5	5	4.9	5.49	16.33	19.59
102	04-017	10-B	12/17/1998	102	48.199	0.6744	0.674	0.6726	1.3221		1.3243		1.32215	4.93	5	4.9	5.49	16.33	19.59
103	05-008	8-A	12/17/1998	103	48.217	0.675	0.6744	0.6754	1.3402		1.3414		1.3396	4.57	4.34	4.81	4.91	10.3	14.29
104	05-003	8-A	12/17/1998	104	48.217	0.6767	0.6761	0.6765	1.3402		1.3414		1.3396	4	4.74	4.81	4.91	10.3	14.29
105	05-011	8-A	12/17/1998	105	48.217	0.6744	0.6741	0.675	1.3406		1.3418		1.3396	4.74	4	4.82	4.95	10.3	14.29
106	04-029	8-A	12/17/1998	106	48.199	0.6759	0.6765	0.6759	1.3406		1.3418		1.3396	4.01	4.75	4.82	4.95	16.33	19.59
107	12-003	37-A	12/23/1998	107	48.219	0.6485	0.6485	0.6478	1.37505		1.3773		1.3749	4.58	4.56	4.89	4.51	6.96	11.35
108	12-010	37-A	12/23/1998	108	48.219	0.6509	0.6512	0.6511	1.37505		1.3773		1.3749	3.79	4.64	4.89	4.51	6.96	11.35
109	11-002	37-A	12/23/1998	109	48.219	0.652	0.6527	0.6515	1.3749		1.3773		1.3749	4.43	4.88	4.96	4.68	6.96	11.35
110	12-017	37-A	12/23/1998	110	48.219	0.6477	0.649	0.6484	1.3749		1.3773		1.3749	3.65	3.98	4.96	4.68	6.96	11.35
111	12-004	37-B	12/23/1998	111	48.219	0.6484	0.6482	0.6475	1.37505		1.3776		1.3754	3.82	4.54	4.99	4.97	6.96	11.35
112	12-009	37-B	12/23/1998	112	48.219	0.6507	0.6512	0.6512	1.37505		1.3776		1.3754	2.88	4.4	4.99	4.97	6.96	11.35
113	11-001	37-B	12/23/1998	113	48.219	0.6524	0.653	0.6517	1.3754		1.37745		1.37535	4.46	4.67	4.96	4.99	6.96	11.35
114	12-018	37-B	12/23/1998	114	48.219	0.6475	0.6488	0.6482	1.3754		1.37745		1.37535	3.98	4.13	4.96	4.99	6.96	11.35
115	17-016	31-A	12/23/1998	115	48.219	0.6661	0.6673	0.6666	1.37185		1.3747		1.3712	4.87	3.84	4.99	4.98	6.96	11.35
116	17-020	31-A	12/23/1998	116	48.219	0.6623	0.6636	0.6621	1.37185		1.3747		1.3712	4.83	3.73	4.99	4.98	6.96	11.35
117	15-012	31-A	12/23/1998	117	48.219	0.6649	0.6653	0.6655	1.37165		1.3746		1.37105	4.45	4.33	4.52	4.69	6.96	11.35
118	15-005	31-A	12/23/1998	118	48.219	0.6645	0.6643	0.6637	1.37165		1.3746		1.37105	3.71	3.69	4.52	4.69	6.96	11.35
119	17-030	30-A	12/23/1998	119	48.219	0.6667	0.6686	0.6671	1.36355		1.36625		1.3636	4.15	4.46	4.51	4.71	6.96	11.35
120	17-005	30-A	12/23/1998	120	48.219	0.6684	0.6704	0.6689	1.36355		1.36625		1.3636	3.95	4.3	4.51	4.71	6.96	11.35
121	08-006	30-A	12/23/1998	121	48.219	0.6697	0.6699	0.6693	1.36365		1.3662		1.3637	4.06	4.72	4.94	4.3	6.96	11.35
122	17-011	30-A	12/23/1998	122	48.219	0.6668	0.6686	0.6672	1.36365		1.3662		1.3637	4.24	3.45	4.94	4.3	6.96	11.35
123	11-030	32-B	12/29/1998	123	48.219	0.6506	0.6506	0.65	1.3747		1.3768		1.3749	3.03	4.67	4.93	4.56	6.96	11.35
124	11-028	32-B	12/29/1998	124	48.219	0.6509	0.6509	0.6507	1.3747		1.3768		1.3749	4.11	3.42	4.93	4.56	6.96	11.35
125	11-012	32-B	12/29/1998	125	48.219	0.6531	0.6532	0.6538	1.3747		1.37675		1.3746	4.96	4.58	4.98	4.78	6.96	11.35
126	10-014	32-B	12/29/1998	126	48.219	0.654	0.6554	0.655	1.3747		1.37675		1.3746	4.88	4.08	4.98	4.78	6.96	11.35
127	17-015	31-B	12/29/1998	127	48.219	0.666	0.6672	0.6667	1.3713		1.3733		1.37115	4.09	4.84	4.79	4.7	6.96	11.35
128	17-019	31-B	12/29/1998	128	48.219	0.662	0.6634	0.6619	1.3713		1.3733		1.37115	4.98	4.06	4.79	4.7	6.96	11.35
129	15-006	31-B	12/29/1998	129	48.219	0.6644	0.6641	0.6635	1.3712		1.3735		1.37105	3.87	3.61	4.75	4.82	6.96	11.35
130	15-011	31-B	12/29/1998	130	48.219	0.6652	0.6657	0.6658	1.3712		1.3735		1.37105	3.88	4.88	4.75	4.82	6.96	11.35

Bar #		microns	Face to Side Squareness A	B	C	D	E	F	G	H	End to Side Squareness I	J	K	L	End to Face Squareness M	N	O	P	RMS angle	Max angle
101	30.5	55.88	-0.14	0.16	0.16	-0.24	-0.24	0.26	0.26	-0.34	0.02	0.29	0.19	0.03	0.25	0.27	0.29	0.47	0.23	0.34
102	45.7	55.88	-0.34	0.26	0.16	-0.34	-0.34	0.36	0.26	-0.54	0.12	0.11	0.61	0.93	0.16	0.16	0.41	0.61	0.34	0.54
103	25.4	45.72	-0.14	-0.14	-0.34	0.16	-0.14	-0.14	-0.24	0.26	0.04	0.22	0.03	0.26	0.27	0.07	0.1	0.23	0.21	0.34
104	15.2	45.72	0.26	0.06	-0.34	0.46	0.16	0.06	-0.24	0.36	0.04	0.29	0.07	0.29	0.11	0.11	0.2	0.17	0.28	0.46
105	22.9	55.88	0.06	-0.24	-0.54	0.36	0.06	-0.24	-0.44	0.16	0.03	0.21	0.09	0.15	0.11	0.29	0.22	0.1	0.31	0.54
106	15.2	55.88	0.26	-0.04	-0.04	0.06	0.26	-0.04	0.06	0.06	0.16	0.06	0.29	0.29	0.47	0.31	0.36	0.27	0.14	0.26
107	19	60.96	0.46	-0.64	-0.74	0.46	0.36	-0.74	-0.74	0.56	0.05	0.2	0.28	0.55	0.1	0.05	0.05	0.05	0.6	0.74
108	8.9	60.96	0.46	-0.64	-0.64	0.36	0.36	-0.64	-0.54	0.36	0.11	0.14	0.41	0.15	0.05	0.05	0.07	0.05	0.51	0.64
109	30.5	60.96	0.36	-0.74	-0.64	0.46	0.46	-0.64	-0.64	0.46	0.17	0.16	0.44	0.1	0.04	0.16	0.04	0.07	0.56	0.74
110	33	60.96	0.36	-0.64	-0.64	0.46	0.36	-0.74	-0.64	0.46	0.07	0.3	0.44	0.73	0.14	0.16	0.07	0.05	0.55	0.74
111	24.1	64.77	0.26	-0.44	-0.34	0.16	0.36	-0.44	-0.54	0.16	0.03	0.22	0.21	0.55	1.72	1.69	0.73	0.7	0.36	0.54
112	14	64.77	0.16	-0.34	-0.34	0.36	0.26	-0.34	-0.44	0.26	0.07	0.16	0.67	0.41	1.72	1.72	0.73	0.76	0.32	0.44
113	33	53.34	0.36	-0.44	-0.64	0.36	0.46	-0.54	-0.64	0.46	0.29	0.08	0.58	0.32	1.66	1.77	0.7	0.73	0.5	0.64
114	33	53.34	0.46	-0.54	-0.54	0.36	0.46	-0.44	-0.64	0.36	0.23	0.52	0.44	0.67	1.66	1.63	0.79	0.81	0.48	0.64
115	30.5	88.9	0.06	-0.14	-0.24	0.06	-0.04	-0.04	-0.14	-0.04	0.15	0.58	0.2	0.52	0.09	0.11	0.38	0.27	0.12	0.24
116	38.1	88.9	-0.14	-0.04	-0.14	0.06	-0.14	0.06	0.06	-0.14	0.44	0.21	0.47	0.05	0.11	0.05	0.32	0.31	0.11	0.14
117	15.2	90.17	-0.14	-0.14	-0.04	0.06	-0.14	-0.04	0.06	0.06	0.13	0.47	0.07	0.41	0.05	0.05	0.32	0.18	0.1	0.14
118	20.3	90.17	-0.04	-0.04	-0.14	-0.14	-0.04	-0.06	-0.14	-0.04	0.1	0.52	0.11	0.41	0.13	0.2	0.16	0.07	0.09	0.14
119	48.3	68.58	0.16	-0.14	-0.14	0.06	0.06	-0.14	-0.14	-0.04	0.58	0.87	0.7	0.99	0.25	0.25	0.18	0.14	0.12	0.16
120	50.8	68.58	0.16	-0.14	-0.24	0.06	0.16	-0.04	-0.24	-0.04	0.87	0.49	0.93	0.55	0.2	0.22	0.1	0.14	0.16	0.24
121	15.2	64.77	0.06	-0.14	-0.14	0.16	-0.04	-0.14	-0.14	0.16	0.58	0.87	0.55	0.84	0.16	0.27	0.04	0.14	0.13	0.16
122	45.7	64.77	0.16	-0.14	-0.14	0.06	0.06	-0.14	-0.14	0.06	0.81	0.55	0.84	0.55	0.23	0.25	0.13	0.18	0.12	0.16
123	15.2	53.34	0.06	-0.34	-0.24	0.26	0.06	-0.34	-0.24	0.26	0.15	0.38	0.2	0.07	0.58	0.67	0.14	0.23	0.25	0.34
124	5.1	53.34	0.06	-0.14	-0.14	0.06	0.16	-0.24	-0.24	0.16	0.38	0.15	0.02	0.22	0.58	0.47	0.16	0.04	0.16	0.24
125	17.8	54.61	0.16	-0.14	-0.34	0.06	0.26	-0.24	-0.44	0.16	0.03	0.29	0.22	0.05	0.31	0.47	0.1	0.13	0.25	0.44
126	35.6	54.61	0.16	-0.34	-0.24	0.26	0.06	-0.34	-0.14	0.16	0.07	0.38	0.2	0.05	0.23	0.34	0.04	0.04	0.23	0.34
127	30.5	54.61	0.26	-0.34	-0.34	0.36	0.26	-0.24	-0.34	0.26	0.17	0.47	0.14	0.41	0.2	0.25	0.23	0.29	0.3	0.36
128	38.1	54.61	0.26	-0.34	-0.44	0.36	0.26	-0.34	-0.34	0.26	0.16	0.44	0.07	0.38	0.25	0.25	0.27	0.23	0.33	0.44
129	22.9	62.23	0.36	-0.44	-0.44	0.36	0.36	-0.44	-0.44	0.26	0.19	0.23	0.14	0.14	0.07	0.16	0.04	0.04	0.39	0.44
130	15.2	62.23	0.26	-0.44	-0.34	0.46	0.16	-0.44	-0.34	0.36	0.52	0.28	0.49	0.15	0.27	0.14	0.23	0.11	0.36	0.46

BABAR Bar Production QA

Examples of Boeing QA results

Boeing frequently checked dimensions and
angles during fabrication process

Most tolerances were unproblematic

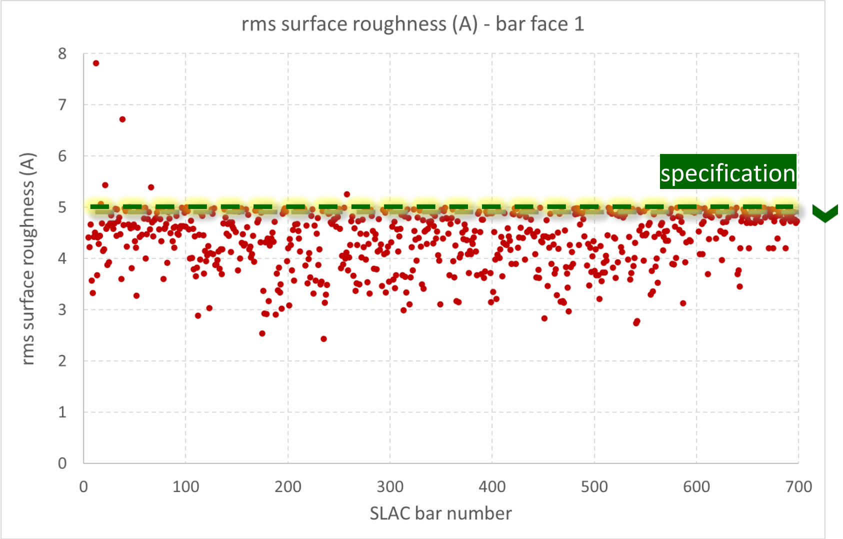
Main vendor concerns about sharp corners,
turned out to be a non-issue

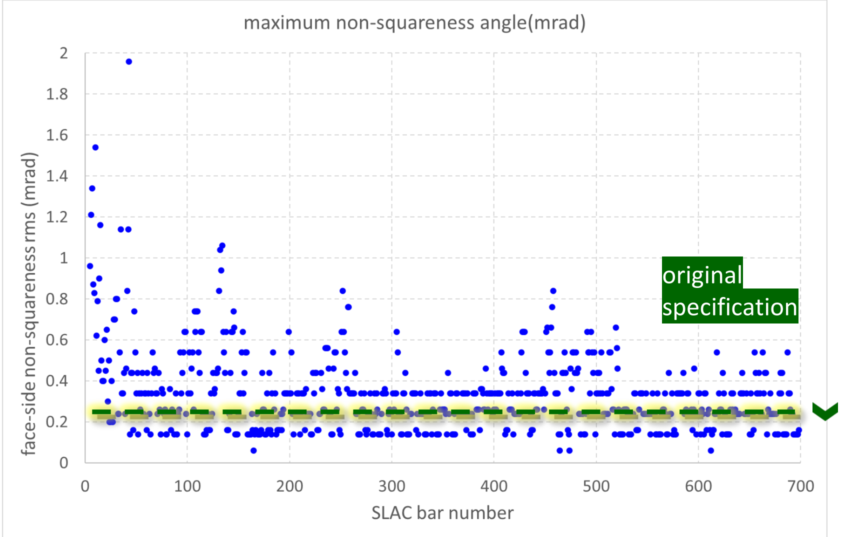
Processing of bar sides was main challenge,
difficult to hold specs on face-side squareness
or surface roughness of sides

Decision to revise some spec/acceptance criteria
to keep production going

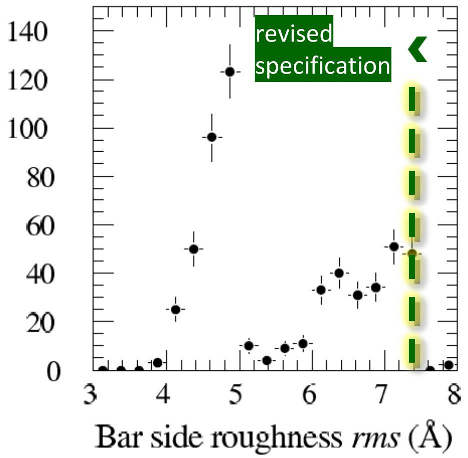
No significant impact on DIRC performance

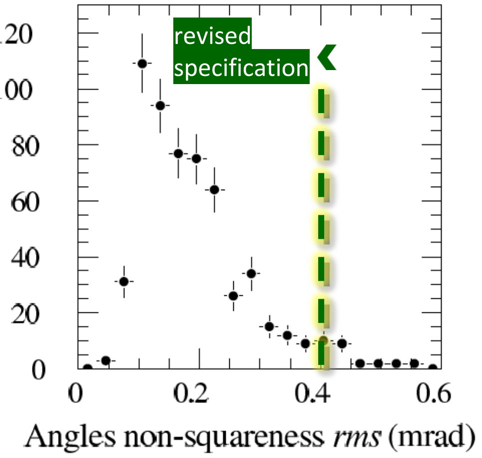
QA vs. original specifications





QA revised specifications





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Out-of-spec quantities

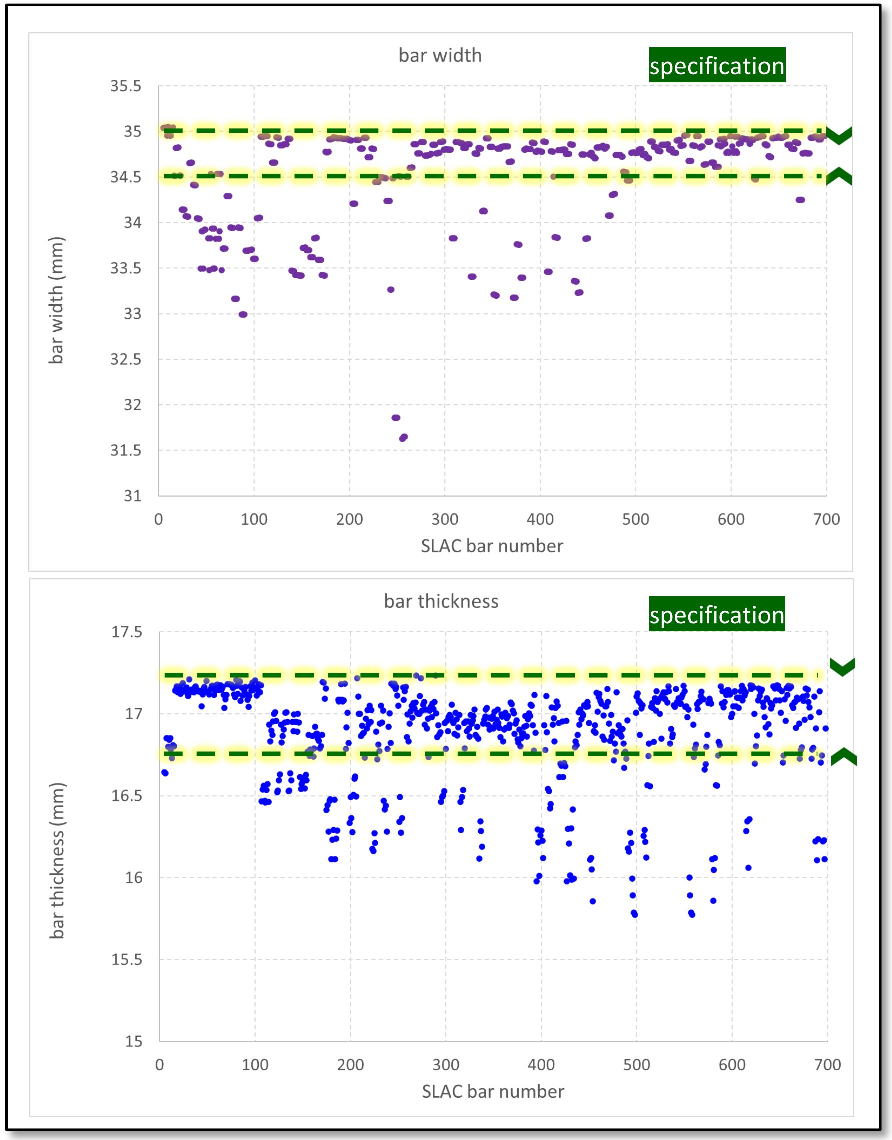
- Some bars were reprocessed to correct scratches, chips, angle deviations
  → many bars are significantly thinner and narrower than specified
- End polishing initially produced large non-squareness values
- Bars were still accepted to keep schedule
- Challenges during assembly of bar boxes, had to select matching bars
  - to create parallel end surfaces, required for capillary bar gluing
  - to optimize long bar geometry, produce shims, set correct button height
- Spreadsheet with "solved bar box assembly puzzle" available (shared by SLAC)

"Shimology":	Wedge	Shim widths (Segment-A)			Shim widths (Segment-B)			Shim widths (Segment-C)			Shim widths (Segment-D)			
BAR NUMBER	gaps	a	b	c	a	b	c	a	b	c	a	b	c	Max.shim thickness
12	101	514			513			512			511			
Gap —>	0.0684	0.0065	0.0065	0.0064	0.0063	0.0063	0.0064	0.0067	0.0066	0.0062	0.0061	0.0060	0.0060	0.0067
11	100	456			454			453			451			
Gap —>	0.0729	0.0079	0.0079	0.0080	0.0064	0.0061	0.0060	0.0067	0.0067	0.0062	0.0072	0.0067	0.0067	0.0080
10	99	506			505			504			503			
Gap —>	0.0718	0.0062	0.0058	0.0062	0.0060	0.0058	0.0060	0.0061	0.0058	0.0063	0.0060	0.0057	0.0062	0.0063
9	98	462			461			460			459			
Gap —>	0.0692	0.0064	0.0063	0.0062	0.0063	0.0055	0.0063	0.0062	0.0060	0.0064	0.0060	0.0060	0.0062	0.0064
8	97	500			465			464			463			
Gap —>	0.0761	0.0095	0.0090	0.0094	0.0065	0.0058	0.0060	0.0064	0.0059	0.0061	0.0063	0.0059	0.0060	0.0095
7	103	470			469			467			468			
Middle gap —>	0.0690	0.0060	0.0063	0.0063	0.0066	0.0066	0.0070	0.0072	0.0069	0.0073	0.0069	0.0067	0.0072	0.0073
6	95	482			481			480			479			
Gap —>	0.0694	0.0062	0.0060	0.0060	0.0071	0.0079	0.0079	0.0073	0.0076	0.0077	0.0073	0.0071	0.0072	0.0079
5	94	501			486			485			483			
Gap —>	0.0613	0.0064	0.0058	0.0060	0.0066	0.0062	0.0062	0.0064	0.0063	0.0066	0.0062	0.0060	0.0061	0.0066
4	93	490			489			488			487			
Gap —>	0.0685	0.0062	0.0060	0.0060	0.0064	0.0062	0.0063	0.0063	0.0060	0.0061	0.0066	0.0062	0.0060	0.0066
3	88	510			509			508			507			
Gap —>	0.0699	0.0068	0.0062	0.0062	0.0060	0.0061	0.0062	0.0062	0.0058	0.0067	0.0062	0.0060	0.0066	0.0068
2	84	499			498			497			496			
Gap —>	0.0580	0.0064	0.0059	0.0060	0.0065	0.0060	0.0063	0.0064	0.0060	0.0063	0.0064	0.0064	0.0065	0.0065
1	82	494			493			492			491			
TOTAL SHIM SUM [inch]:	0.7547	0.0745	0.0717	0.0727	0.0708	0.0684	0.0706	0.0721	0.0697	0.0719	0.0712	0.0688	0.0708	0.0787

TOP VIEW - wedges point up								Wedges	BAR NUMBERING
								<-- Ref. edge	
511		512		513		514		101	<-- Bar #12, BaBar #35
0.0060	0.0061	0.0062	0.0067	0.0064	0.0063	0.0064	0.0065	<-- Shims	
451		453		454		456		100	<-- Bar #11, BaBar #34
0.0067	0.0072	0.0062	0.0067	0.0060	0.0064	0.0080	0.0079	<-- Shims	
503		504		505		506		99	<-- Bar #10, BaBar #33
0.0062	0.0060	0.0063	0.0061	0.0060	0.0060	0.0062	0.0062	<-- Shims	
459		460		461		462		98	<-- Bar #9, BaBar #32
0.0062	0.0060	0.0064	0.0062	0.0063	0.0063	0.0062	0.0064	<-- Shims	
463		464		465		500		97	<-- Bar #8, BaBar #31
0.0060	0.0063	0.0061	0.0064	0.0060	0.0065	0.0094	0.0095	<-- Shims	
468		467		469		470		103	<-- Bar #7, BaBar #30
0.0072	0.0069	0.0073	0.0072	0.0070	0.0066	0.0063	0.0060	<-- Shims	
479		480		481		482		95	<-- Bar #6, BaBar #29
0.0072	0.0073	0.0077	0.0073	0.0079	0.0071	0.0060	0.0062	<-- Shims	
483		485		486		501		94	<-- Bar #5, BaBar #28
0.0061	0.0062	0.0066	0.0064	0.0062	0.0066	0.0060	0.0064	<-- Shims	
487		488		489		490		93	<-- Bar #4, BaBar #27
0.0060	0.0066	0.0061	0.0063	0.0063	0.0064	0.0060	0.0062	<-- Shims	
507		508		509		510		88	<-- Bar #3, BaBar #26
0.0066	0.0062	0.0067	0.0062	0.0062	0.0060	0.0062	0.0068	<-- Shims	
496		497		498		499		84	<-- Bar #2, BaBar #25
0.0065	0.0064	0.0063	0.0064	0.0063	0.0065	0.0060	0.0064	<-- Shims	
491		492		493		494		82	<-- Bar #1, BaBar #24

example of available bar box information

BABAR DIRC QA results for width and thickness



BABAR DIRC BARS IN EPIC

DIRC bars performed very well in BABAR, but the required Cherenkov angle resolution per photon in ePIC is factor 2-3 better than in BABAR to reach hpDIRC 6 GeV/c π/K separation goal

Geant4 simulation for the BABAR bars in the ePIC hpDIRC:

Photons have long propagation paths with many internal reflections, 100 - 400 on average, can exceed 1000 reflections for some polar angles

The surface quality is crucial for the photon transport efficiency T_{eff}

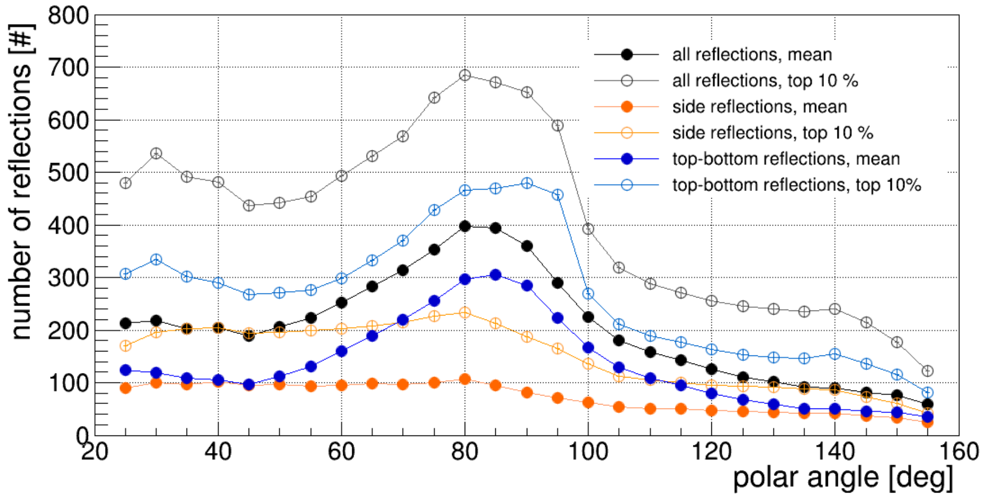
$T_{eff} \approx R^N$ N: number of reflections, R: reflection coefficient

R can be related to the surface roughness H via the scalar theory

$$1 - R \approx \left(\frac{4\pi \cdot H \cdot \cos\alpha \cdot n(\lambda)}{\lambda}\right)^2$$

In practice, the photon transport efficiency can be affected by pollution and by subsurface damage inside the DIRC bar, created during lapping/polishing

Geant4 simulation of ePIC hpDIRC



Quantity	Specification/Tolerance
Surface roughness	< 5 Å *rms* (sides, faces) < 20 Å *rms* (ends)

Main QA effort at SLAC: measurement of reflection coefficient using HeCd laser (325 nm, 442 nm)

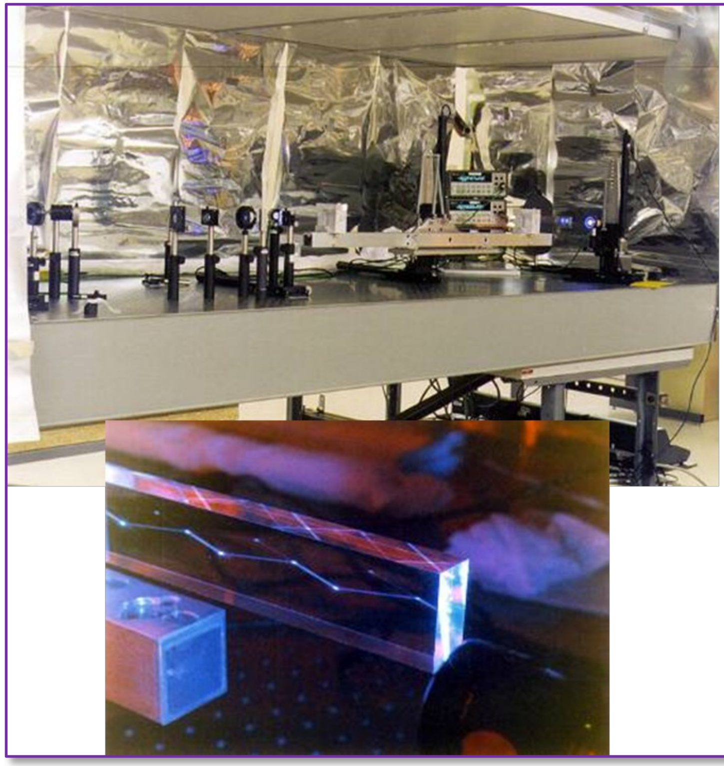
Motion-controlled setup to scan bar, measure bar transmission and surface reflectivity, recreated setup at JLab

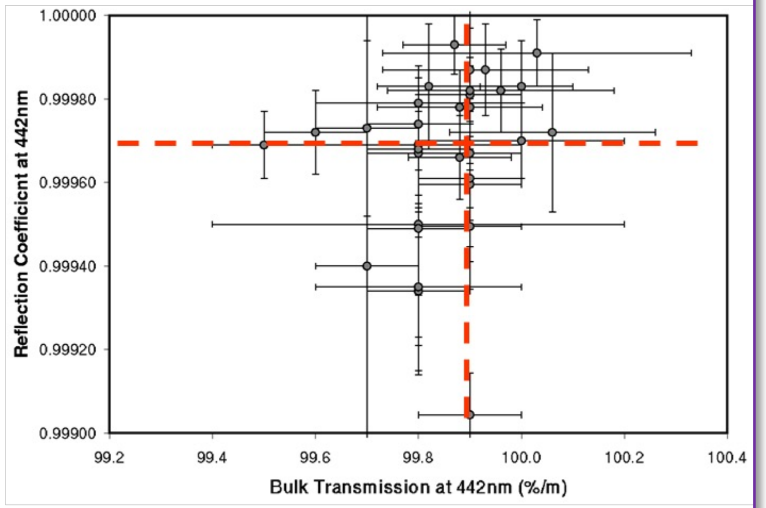
Two BABAR DIRC bars, never used for BABAR, are available as reference bars to commission JLab QA setup

(one of them was measured at 442 nm in SLAC QA setup 25+ years ago, old result available)

Benchmark: $R^{442nm} = 0.9997$

Setup and results from SLAC

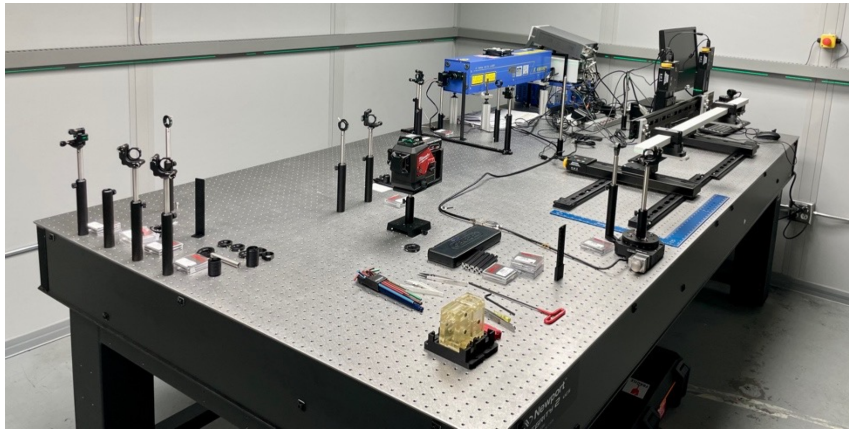


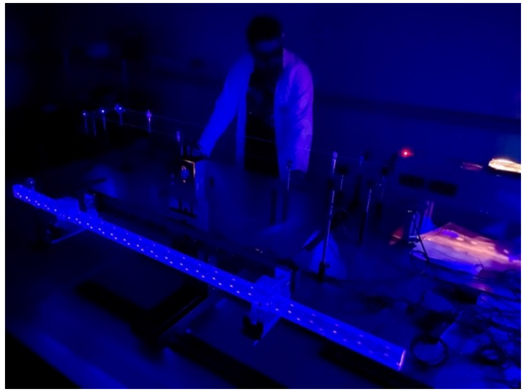


Average at 442nm:

Transmission	99.9±0.1%/m
Reflection coefficient	0.9997±0.0001

New QA setup at JLab





Geant4 simulation comparing ideal bars to as-build BABAR DIRC bars

SLAC laser measurements deviated from scalar theory below 400 nm

→ Cannot only rely on "external" surface roughness (interferometer) alone, QA needs to measure internal reflection coefficient using laser as well

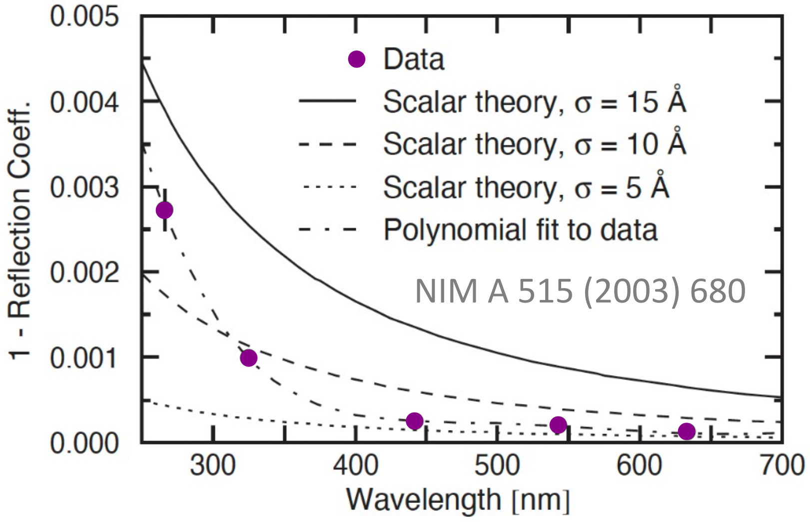
Calculate wavelength-dependent photon transport efficiency for each photon reflection based on fit to old SLAC data, implement in Geant4

Simulated performance for $R^{442nm} = 0.9980 \ldots 0.9999$

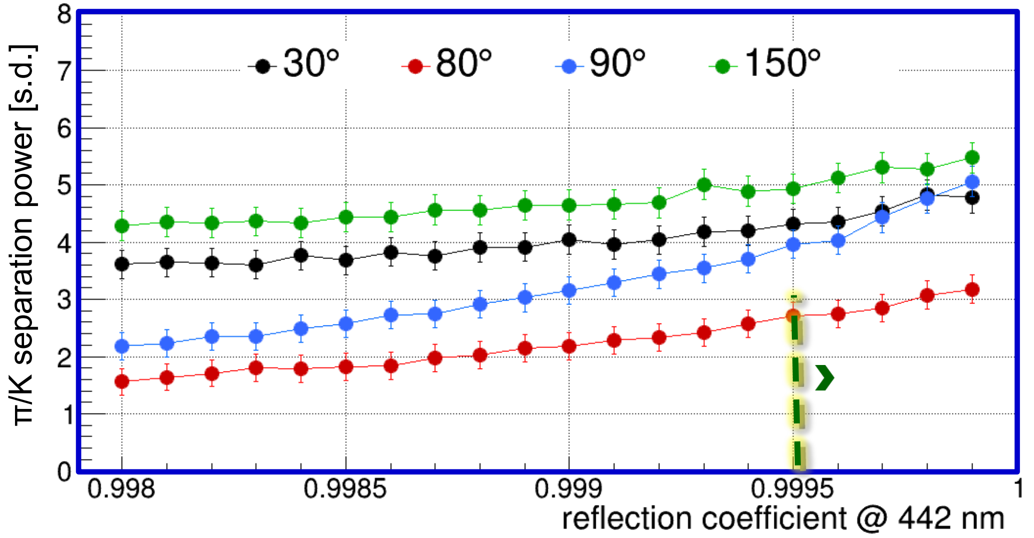
(very large range, expect value > 0.9995 for cleaned bars at JLab)

Clear impact of photon transport efficiency for long photon paths

Expected loss of π/K separation power at 6 GeV/c less than 10% for $R^{442nm} \geq 0.9995$



Example: π/K separation power
for selected polar angles at 6 GeV/c momentum

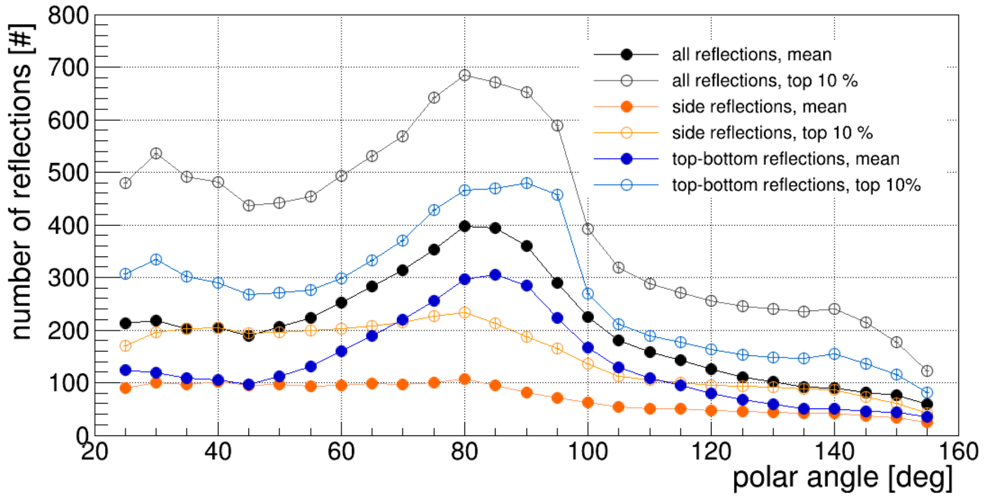


Geant4 simulation comparing ideal bars to as-build BABAR DIRC bars

Cherenkov angle preserved during reflections if bar surfaces are square

BABAR DIRC bar face-side squareness known to be below initial spec

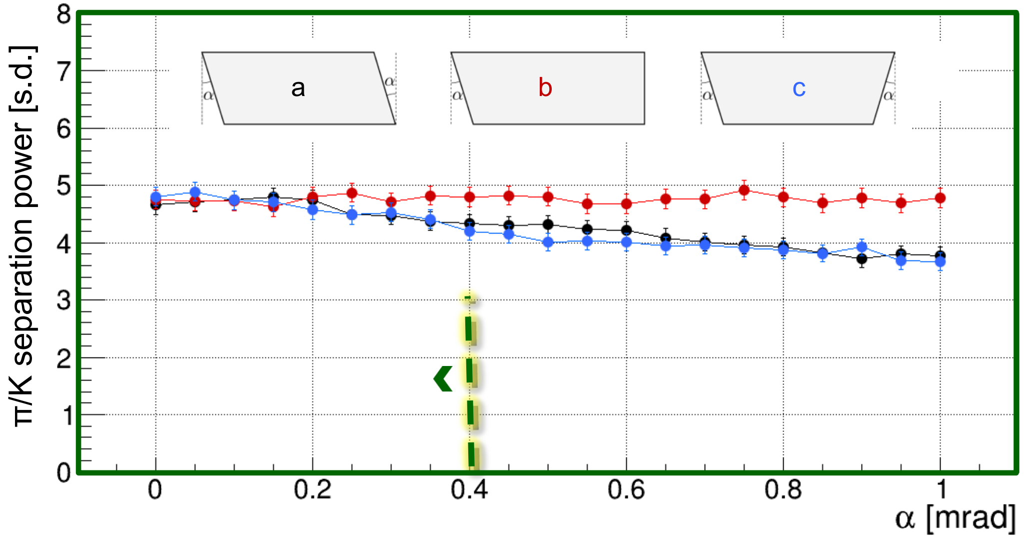
Quantity	Specification/Tolerance
Squareness	Initial spec: <0.25 mrad Revised: rms of face-side angles <0.4 mrad



Deterioration expected for large number of side reflections

Simulated several simplified types of face-side non-squareness shape imperfections in Geant4

Example: π/K separation power for 30° polar angle at 6 GeV/c momentum



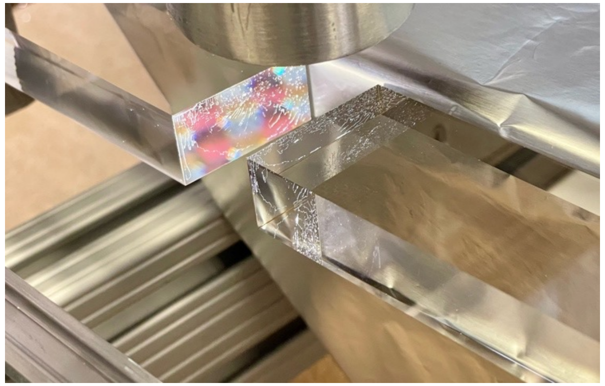
Expected loss of π/K separation power at 6 GeV/c less than 10% for face-side non-squareness < 0.4 mrad

Key performance parameter reached in simulation for realistic bar imperfections (surface quality, squareness)

Bar box transport and disassembly procedure discussed in detail with SLAC experts

- ePIC hpDIRC barrel requires total of 360 short bars (1225 mm length)
- Eight BABAR DIRC bar boxes, containing 384 short bars available from SLAC
- BABAR bar boxes are too long (over 5000 mm), do not fit into ePIC barrel, existing wedges at readout end are incompatible with lens focusing
  → need to disassemble bar boxes and extract individual 1225 mm-long bars
- Proof-of-principle from SLAC: decouple glued bars using heat gun and traction

- Eight BABAR DIRC bar boxes transported to JLab in April 2024
- Identified space at JLab, built tooling, defined procedure, passed safety inspections
- First bar box disassembled without CNC cutting, aluminum shell safely removed
- So far, 6 bars successfully debonded using heat gun/traction method, no failures



- Plan to keep applying same methods for remaining bar boxes and bars
- Clean bar ends, then entire bar, visually inspect bar
- Measure reflection coefficient in laser lab
- Wrap bar, apply ID tag, place in storage cabinet, keep track of data in spreadsheet

BABAR Bar Box Transport to JLab

Successful transport of 8 DIRC bar boxes in April 2024

- Followed procedure from bar box transfer for GlueX in 2017/2018
- Low altitude road from SLAC, CA to JLab, VA
- Goal: Kept shocks on bar box below 1g

(Transportation crates with inner suspension, shock-absorbing foam, hydraulic shocks, air shocks, shock-absorbing donuts, air-ride and temperature control trucks, detailed monitoring)

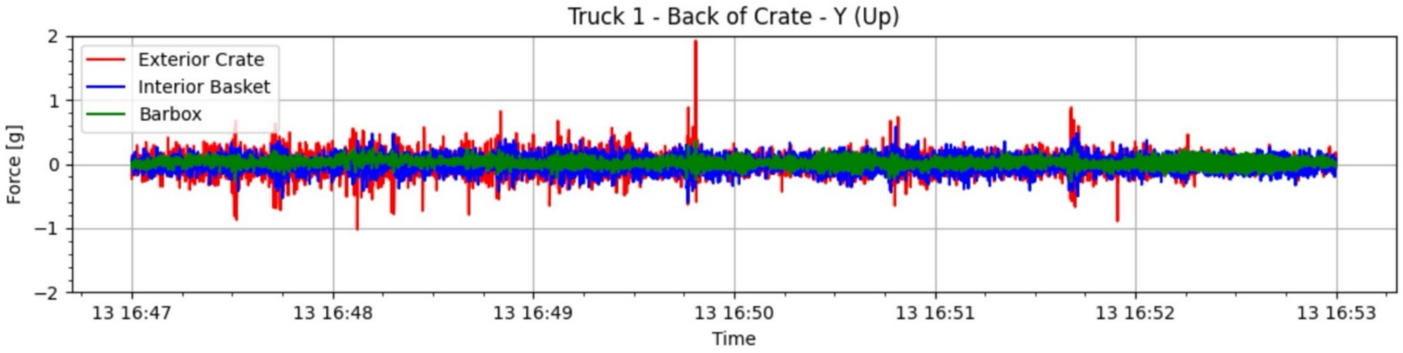
Inside of transportation crates

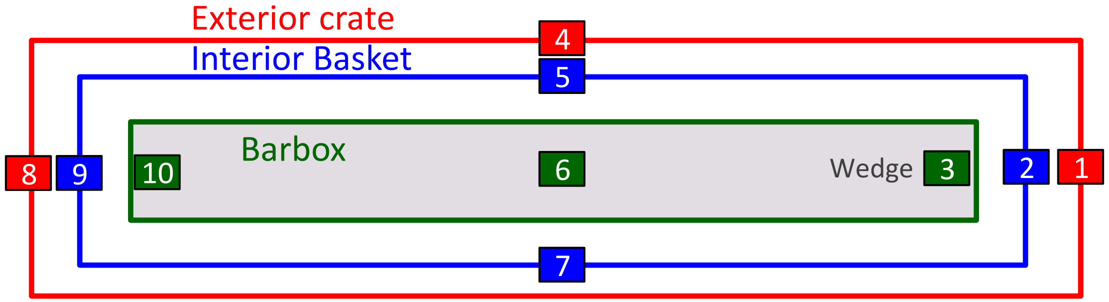
Loaded bar boxes ready for transport

8 bar boxes in two trucks

Bar boxes at JLab ready for disassembly

Sample of vibrations during transport and location of accelerometers

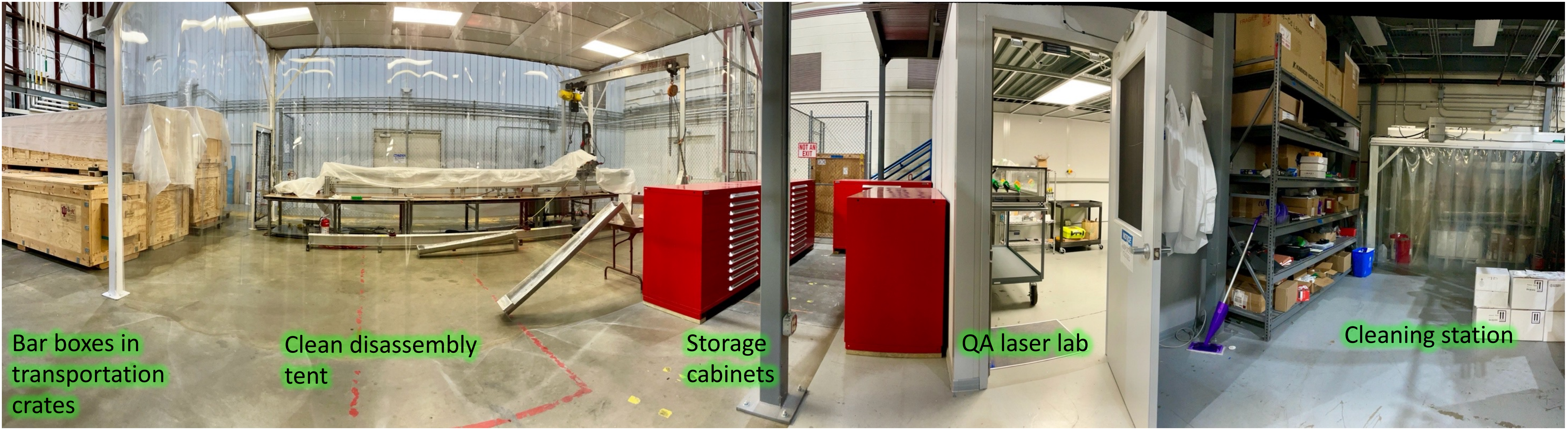




Andrew Lumanog (JLab), Tyler Lemon (JLab), Greg Kalicy (CUA), Joe Schwiening (GSI)

REFURBISHING FACILITY AT JLAB

Panoramic view of hpDIRC lab space in the EEL building



Refurbishing process at JLab:

- Clean tent for removal of bar box shells and debonding of bars
- Cleaning station in tent to remove glue/pollution, visually inspect bars
- QA laser lab to inspect quality of the bars (transmission, reflection coefficient)
- Measured bars are wrapped, tagged, and stored in four storage cabinets
- Spreadsheet keeps track of bar tag ID, Boeing/SLAC data, QA results, location

Team currently working on disassembly:

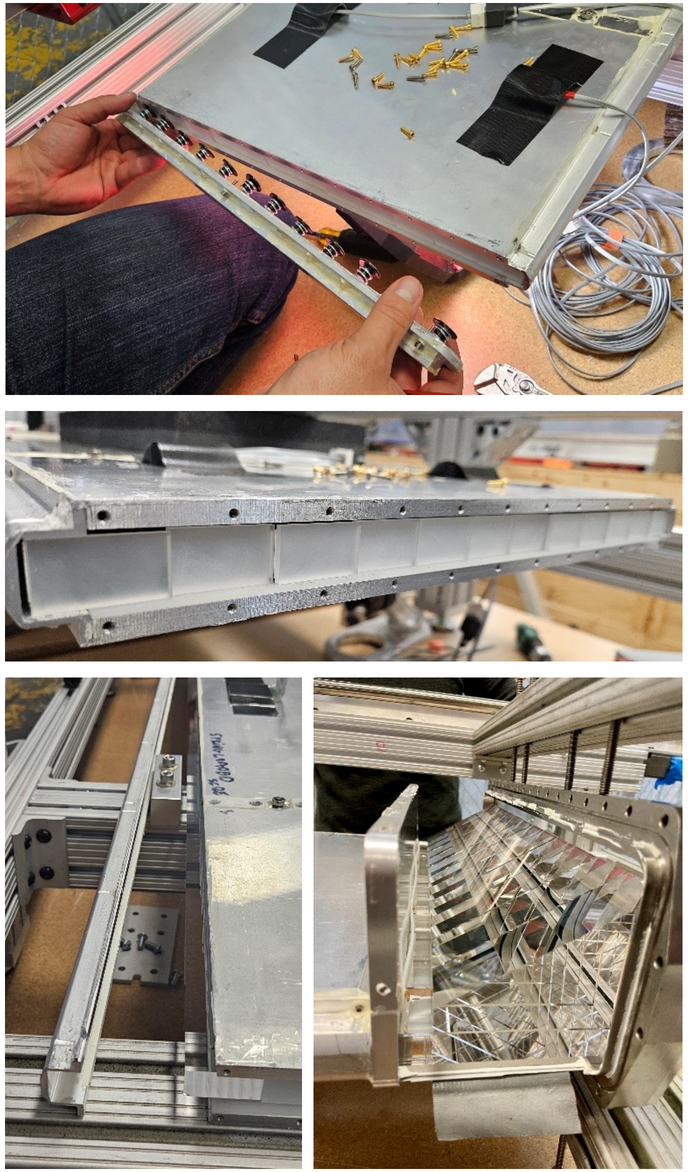
- 3 JLab Technicians:
  Andrew Lumanog, Caleb Graham, David Edwards
- 2 Scientists:
  Greg Kalicy (CUA), Sourav Tarafdar (JLab)
- JLab DSG Group:
  Tyler Lemon, George Jacobs, Mindy Leffel
- Graduate Student: Shelby Arrigo (W&M)

slide from Greg’s talk

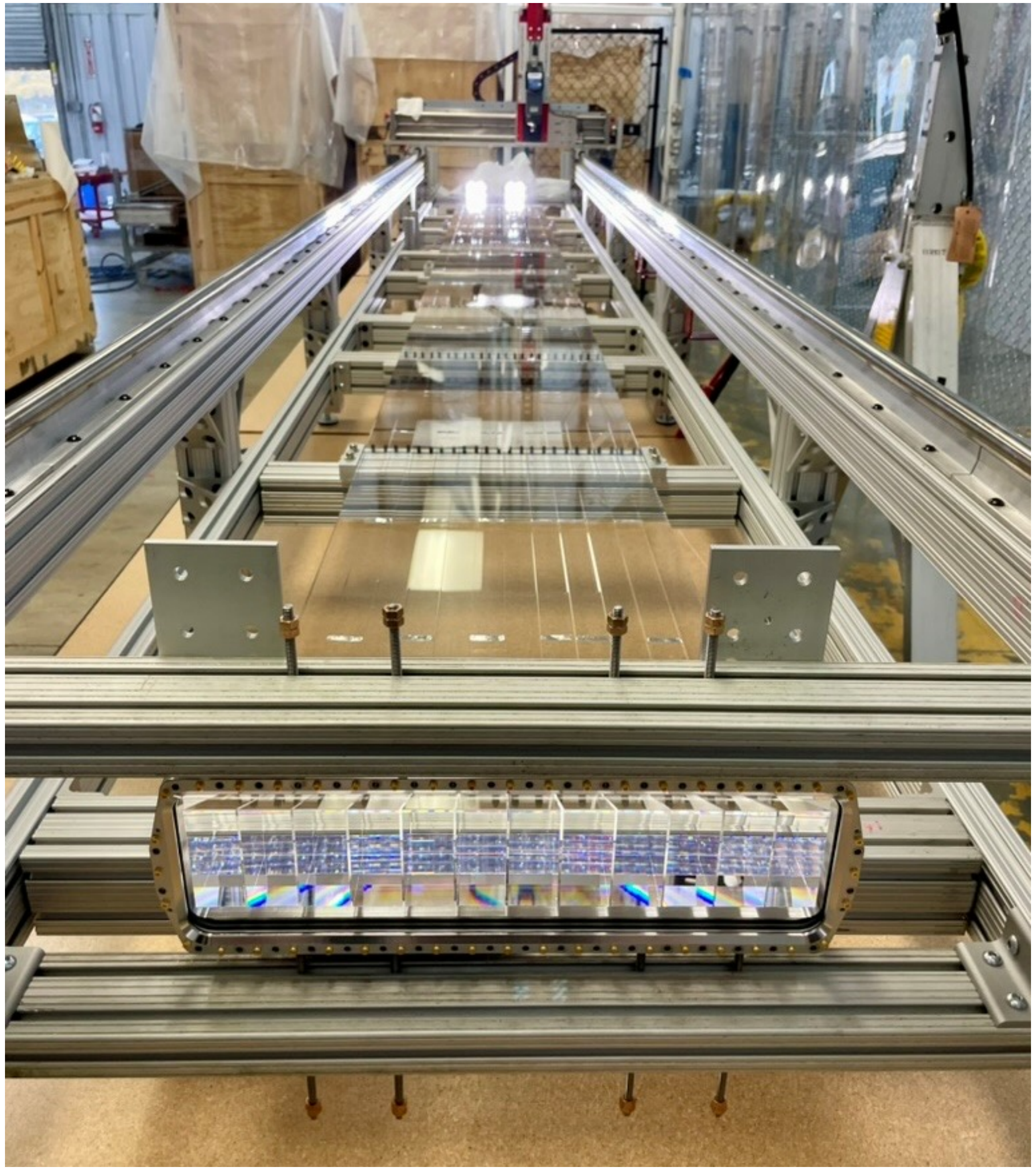
BABAR Bar Box Disassembly

Bar box on CNC

Removing aluminum shell



Bar box with disassembled aluminum shell

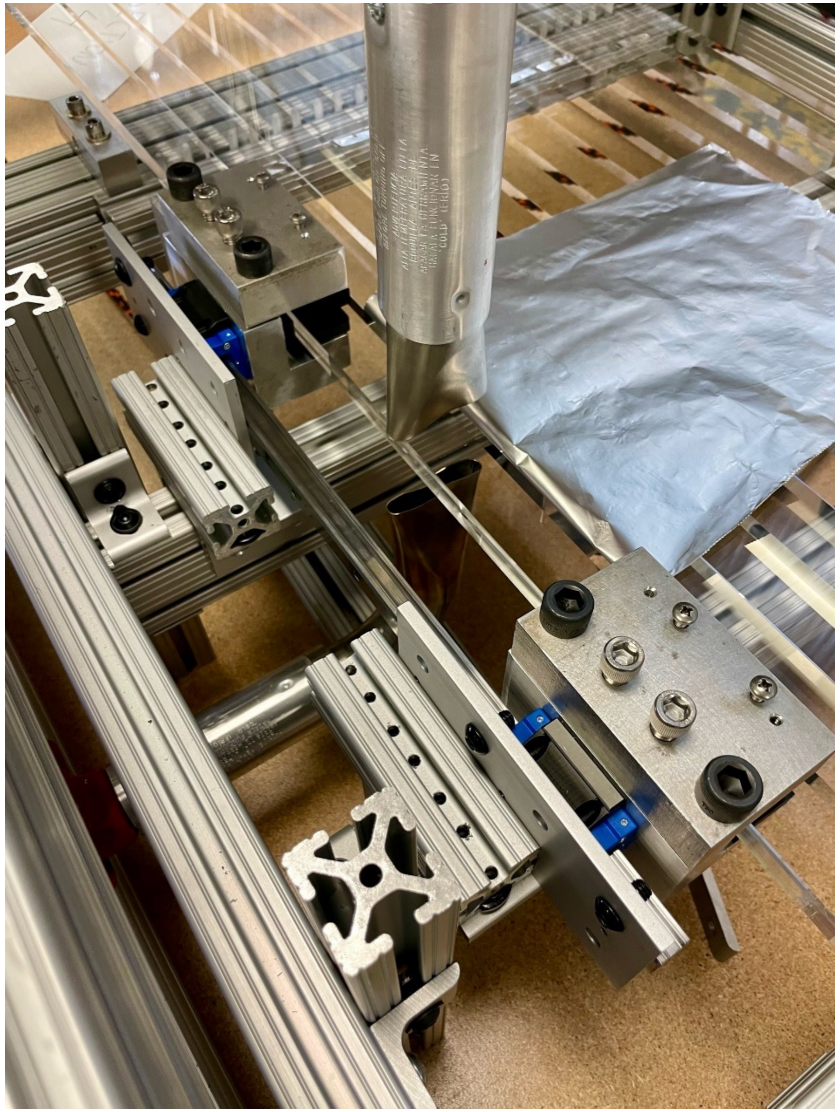


slide from Greg's talk

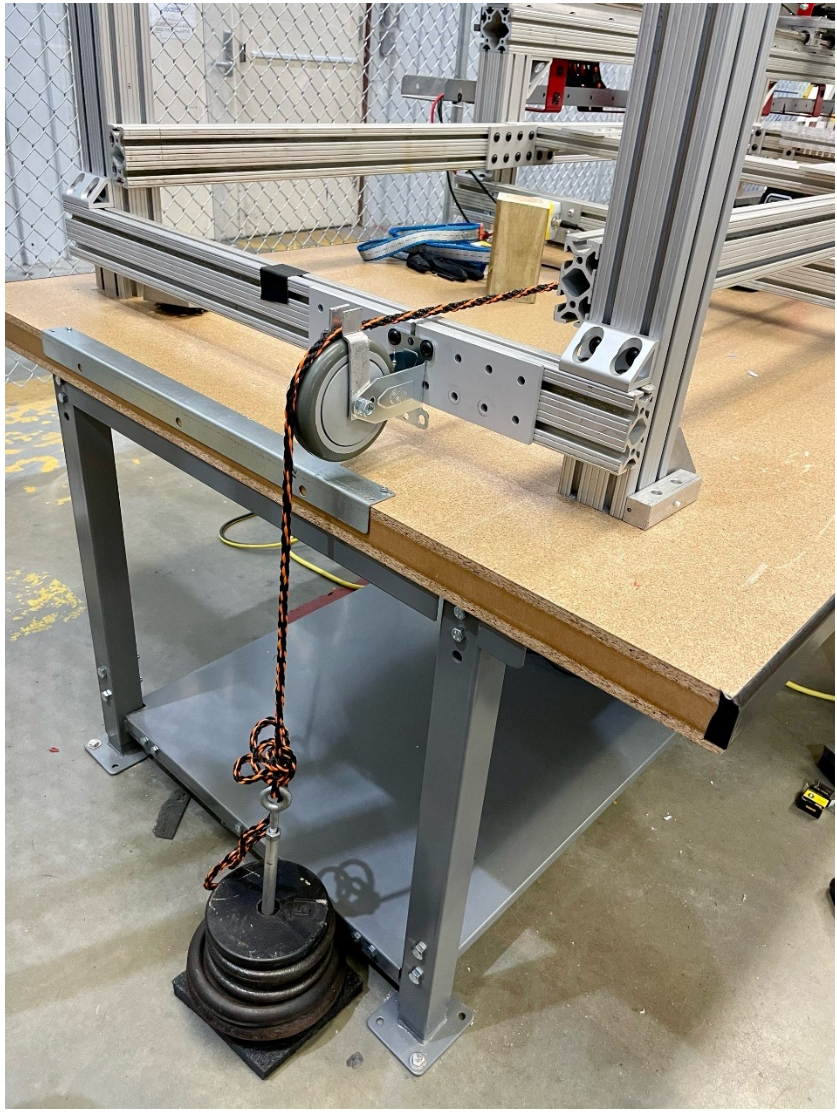
BABAR Bar Debonding

Heat guns softening glue joints between bars

Adjustable clamps to separate bars



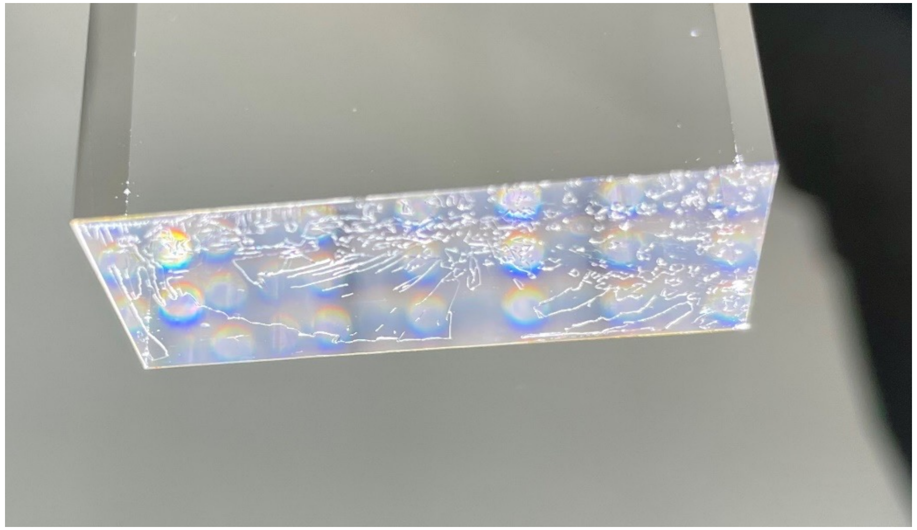
Weight with short travel pulling on clamp



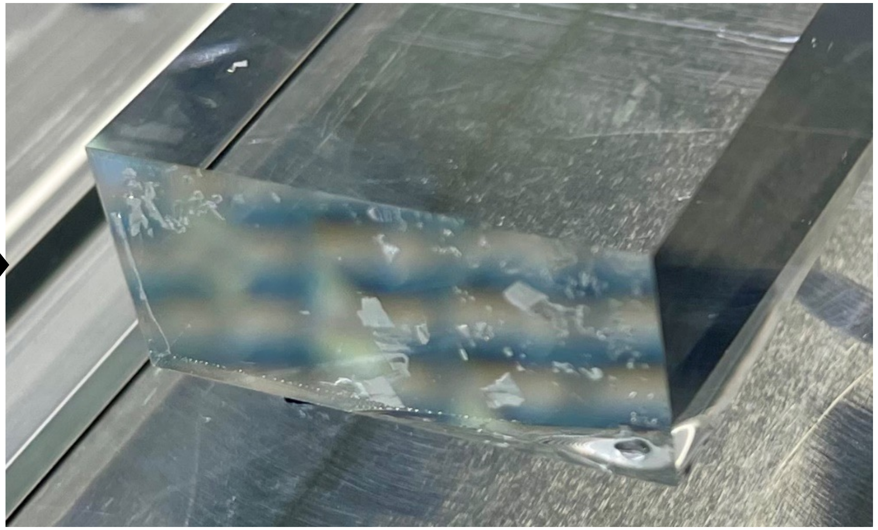
slide from Greg’s talk

BABAR BAR CLEANING

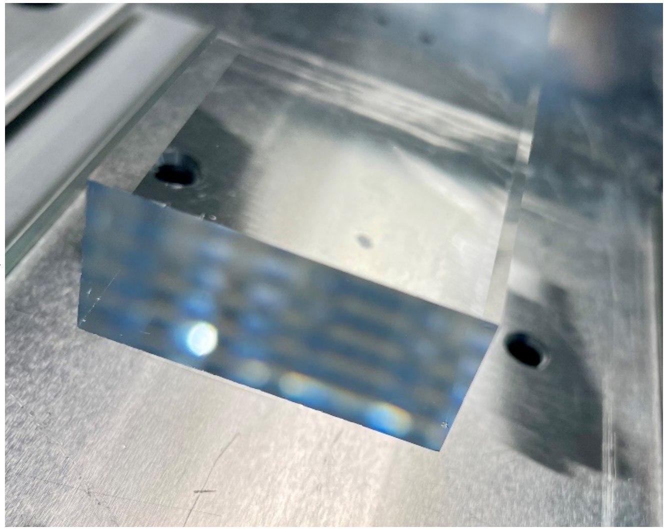
Glue residue after separation



Glue residue mid-way through cleaning



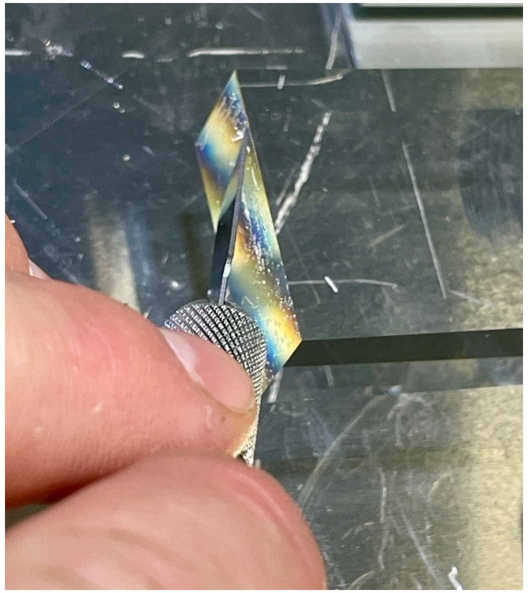
Cleaned bar end



Bar end immersed in acetone bath

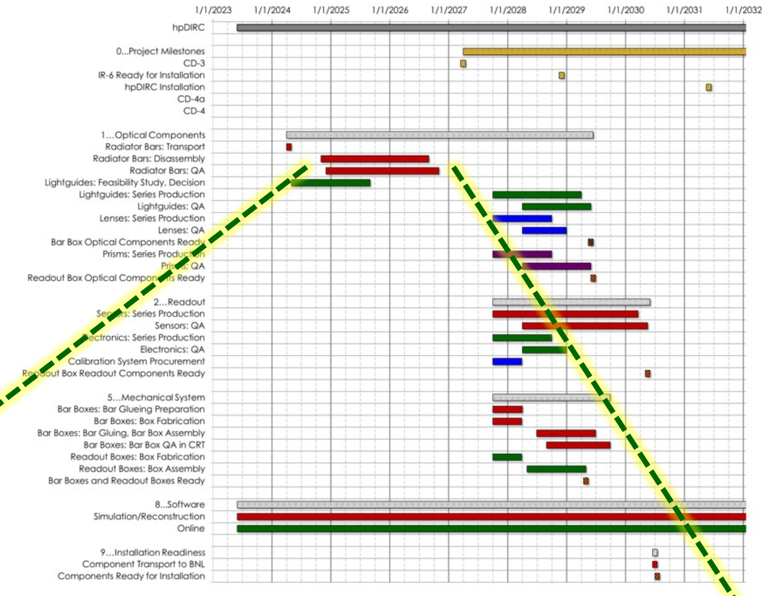
"Bathtub" in position for glue removal

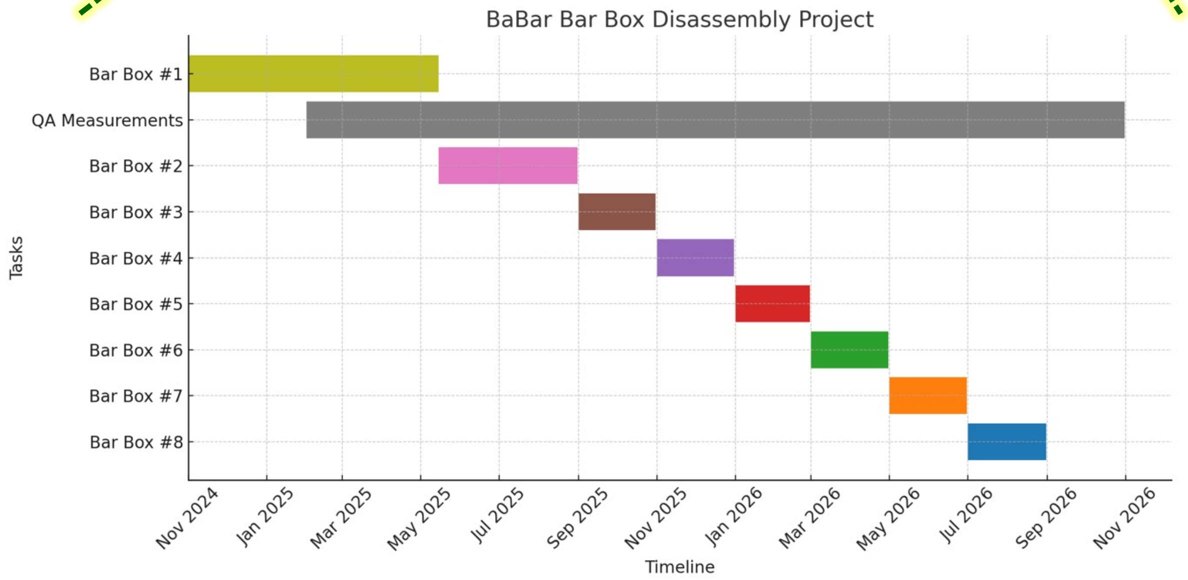
Glue removal



Resource-loaded schedule for refurbishment

- Expect work on each bar box to take about 2 months
  - Disassemble and remove one bar box shell: 2 weeks
  - Decouple 3 bar-bar joints, clean bar ends: 2 days
  - Clean and visually inspect one bar, tag ID, place bar in holder: ½ day
  - Laser QA measurement, wrap, move to storage: 1 day
- Spreadsheet keeps track of bar tag ID, properties, location
- Some of the task executed in parallel
- Task completion expected by Nov 2026





Refurbishment schedule fits overall ePIC hpDIRC schedule

COST OF DIRC BARS

Production of DIRC bars has been costly and time-consuming

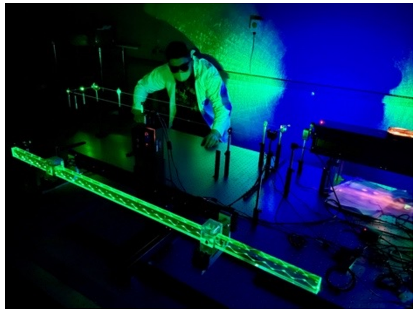
- BABAR schedule was under significant pressure due to DIRC bar production
  Delays due to change in company ownership, staffing changes
  - Capital invest cost of fused silica material and bar fabrication for 698 bars approx. $5,500 (1998 USD) per bar
  - In-kind value of 8 BABAR DIRC bar boxes estimated at $5,000,000 (2025 USD)
- Positive recent experience from PANDA experiment: series fabrication of 112 DIRC bars for Barrel DIRC
  - Nikon Corp. fabricated 112 bars from Aug 2019—Feb 2021, tolerances comparable to BABAR DIRC
  - On schedule, on budget, cost per bar approx. €20,000 (2019 EUR) or about $28,000 (2025 USD)
- Cost has increased significantly since PANDA bar production (pandemic, energy cost, less competition)
  - Cost of new bar estimated to be approx. $40,000 (2025 USD)
  - Cost of series production of 360 new bars estimated at $14,000,000 (2025 USD)

ES&H

Work on refurbishing in compliance with all applicable ES&H and OSHA regulations

- CNC as backup method for opening bar box, removing bar box shell
  - emergency stops, proximity sensors, covers/guards, gantry crane to lift bar boxes, PPE
- Heat guns for debonding bars
  - custom clamps for holding bars, PPE
- Chemicals (acetone, isopropanol) and scalpels to clean bar surfaces
  - safe storage and disposal, PPE
- Class 3B HeCd laser to measure bar surface reflectivity
  - warning beacon, safety shutoff, non-reflective surfaces, remote operation, PPE

- Detailed safety analysis prior to start of construction of setups
- Access to area limited to authorized personnel
- Operation only for trained personnel with PPE
- Setups and procedures passed multiple JLab safety reviews, separate ePAS for all activities



SUMMARY

Expected PID performance of hpDIRC design meets ePIC requirements (Yellow Report)

separation: ≥ 3 s.d. π/K up to 6 GeV/c, ≥ 3 s.d. e/π up to ~1.1 GeV/c

Key component: DIRC radiator bars – hpDIRC requires 360 long, narrow, highly-polished synthetic fused silica bars

Technical specifications for DIRC radiator bars known

BABAR DIRC bars available, expected to meet quality requirements, 8 boxes (384 bars) transported to JLab in 2024

R&D on disassembly of first bar box and debonding of first bars shows that process works

Quality assurance process known

SLAC/Boeing data for BABAR DIRC bars and assembled bar boxes available, setup for optical QA at JLab operational

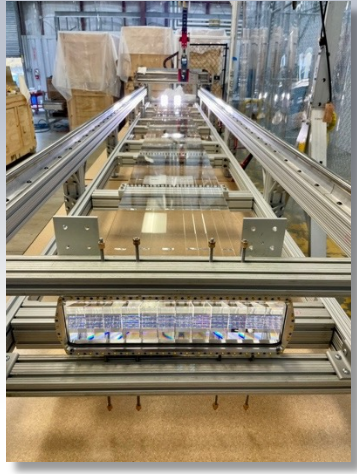
Goal: extract and process at least 360 bars from all 8 available BABAR DIRC bar boxes

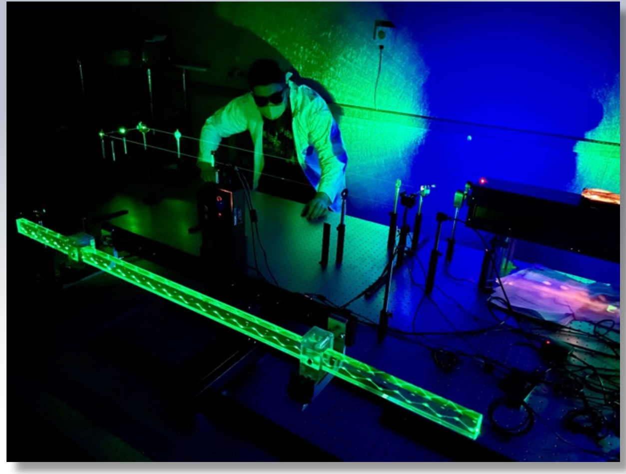
Place bars in storage to be ready for start of construction after CD-3

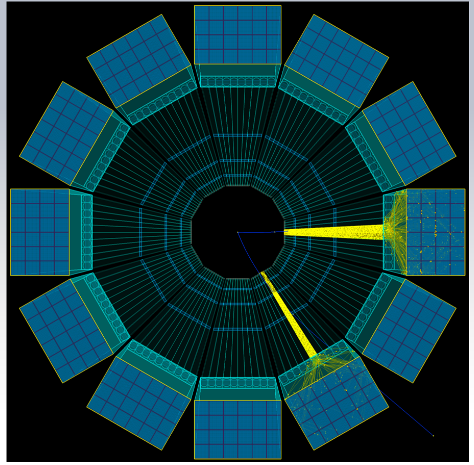
During the closeout of the review, the committee recommended

that the refurbishing of the BABAR DIRC bars is included in the CD-3B scope


BABAR DIRC bar boxes at SLAC


Opened BABAR DIRC bar box at JLab


BABAR DIRC bar in JLab QA setup


PYTHIA events in ePIC hpDIRC

BABAR DIRC Bar Refurbishment for the ePIC hpDIRC

Selection of slides from the

Final Design Review of the BABAR DIRC Bar Refurbishment for the High-Performance DIRC Particle Identification Detector

April 1-2, 2025

Thank You For Your Attention