Brookhaven National Laboratory
Jefferson Lab
U.S. DEPARTMENT OF ENERGY

hpDIRC

Triple I Engineering Meeting Update

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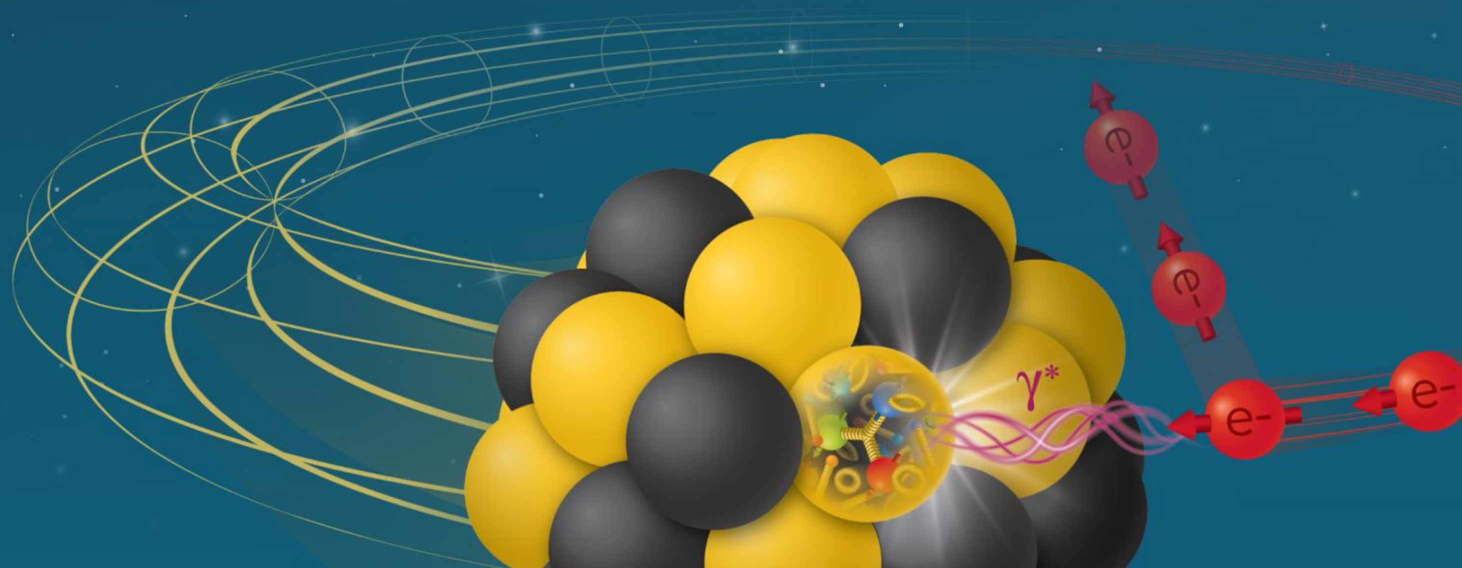
Electron-Ion Collider



hpDIRC Bar Box Concept Development

The project asked whether the BaBar bar box could serve as a proven starting point for the hpDIRC design. That is the right starting point: BaBar provides real detector hardware, not a blank-sheet concept.

However, hpDIRC is not a direct copy:

- Different bar-box width: BaBar used 12 bars per box; hpDIRC uses 10
- Different readout and integration geometry
- Higher performance and alignment sensitivity
- Different material, environmental, and fabrication constraints

Design direction:

Use the right material for the right function, while keeping the design manufacturable, inspectable, and cost-aware.

Constraints

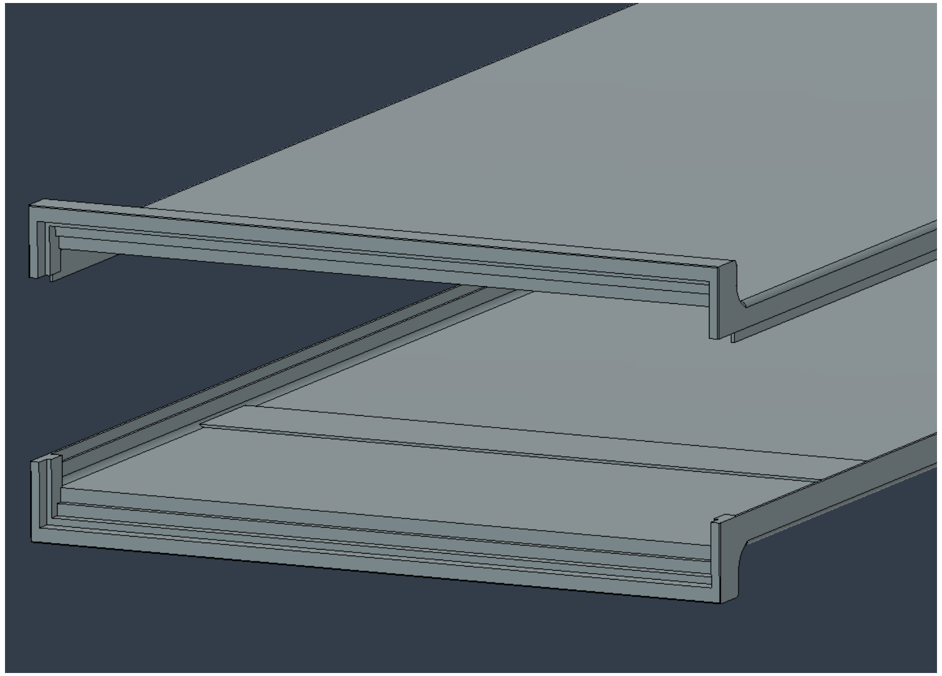
Detector/Alignment	Optics/Physics	Structural Behavior	Environment / Compatibility	Manufacturing / Cost
Fit within the GST envelope	Maintain end-to-end optical joints between bars	Control X-direction motion at the bar support interface	Maintain dry nitrogen environment (slight overpressure)	Avoid unnecessary custom fabrication risk
Maintain required position relative to the IP	Avoid stressing glued bar/lens joints	Limit Z-axis sag/deflection over the full length	Manage humidity and sealing behavior	Use commercial processes where practical
Understand support-tube deflection and its effect on bar box alignment	Maintain no-contact condition between neighboring bar rows	Avoid twist or local deflection that disturbs optical alignment	Consider radiation exposure	Keep the design measurable, manufacturable, and cost-aware
Control how bar-box deflection couples into optical alignment	Preserve minimum residual inter-bar clearance	Support the bar stack without shifting the optical assembly	Consider magnetic-field compatibility	
Remain material-aware at detector scale	Maintain light-tightness		Consider outgassing and material compatibility	

Baseline / Carbon-Fiber Concept

The baseline concept uses a primarily carbon-fiber structure for the bar box.

What it does well:

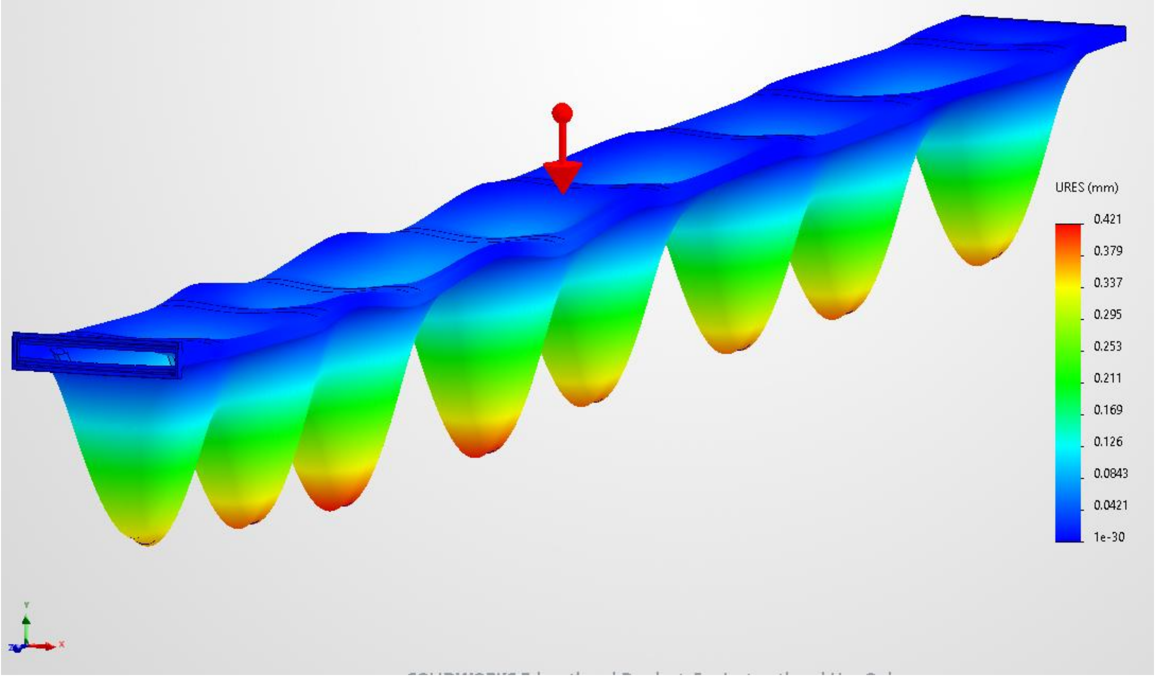
- Low material compared with an all-metal enclosure
- Good stiffness-to-weight potential
- Good dimensional stability when properly designed
- Detector-compatible direction for broad enclosure surfaces
- Avoids adding unnecessary aluminum over large areas



What still needs validation:

- Tooling, mold, and fabrication approach
- How precision datum/support features are implemented
- How button features are adjusted, fixed, and verified
- Assembly sequence for bars and lens gluing
- Gas sealing, leakage, and light-tightness details
- Local inserts, interfaces, and load introduction points
- Cost and schedule risk for full-length fabrication

All-Aluminum Study



Why it was useful:

- Simple material model for first-pass FEA
- Easy to machine, modify, and represent in CAD
- Good local precision for datum/support features
- Natural path for integrated rail or support features
- Helps identify deformation modes before detailed design

Why it is not the full answer:

- Material budget increases at detector scale
- Thermal expansion is higher than carbon fiber
- Full aluminum shell may add unnecessary mass
- Long precision structure still requires careful fabrication
- Does not automatically solve gas sealing, alignment, or assembly sequence

Key takeaway:

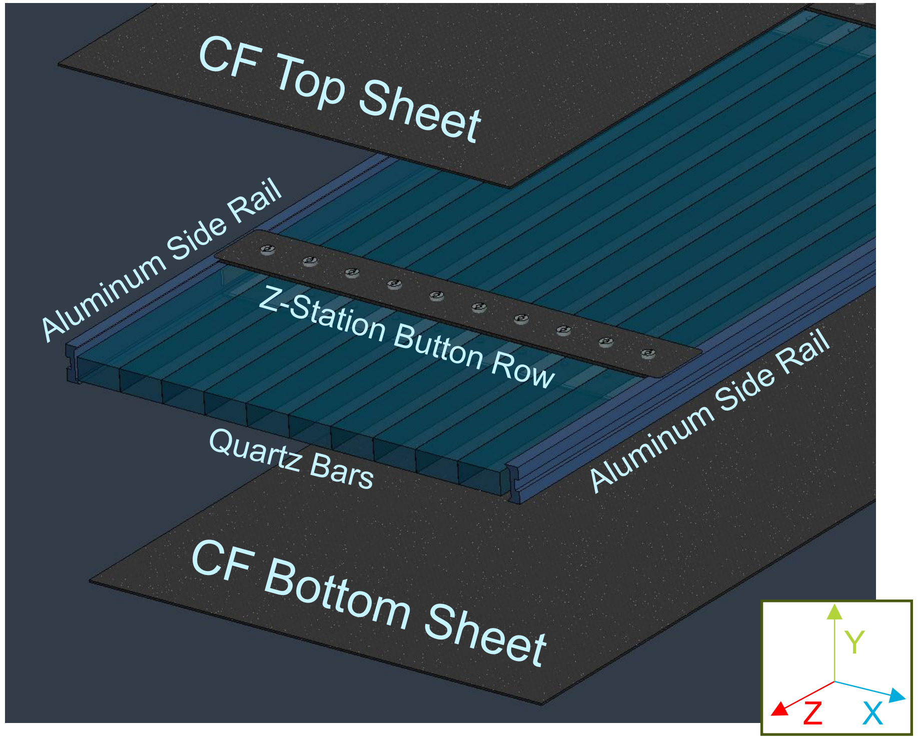
The all-aluminum model is useful for learning structural behavior, but not necessarily as the final construction approach.

Hybrid Approach

Concept:

Use each material where it provides the most engineering value.

- **Aluminum side members:**
  - Precision support and datum features
  - Button/preload interfaces
  - Local stiffness where loads enter the box
  - Potential integral rail/support features
  - Easier machining and design iteration
- **Carbon-fiber panels:**
  - Low-material enclosure surfaces
  - Good stiffness-to-weight potential
  - Reduced aluminum where it is not buying precision
  - Light-tight and gas-boundary surfaces, if detailed correctly
- **Why this direction:**
  - Avoids forcing one material to solve every problem
  - Keeps precision mechanical features manufacturable
  - Keeps radiation-length-sensitive surfaces low-material
  - Keeps costing, fabrication, and validation more modular

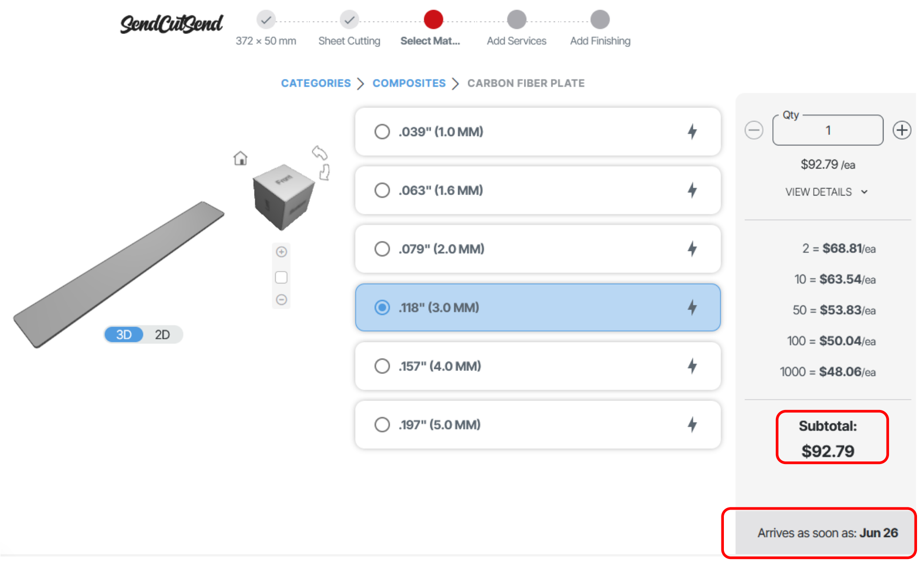


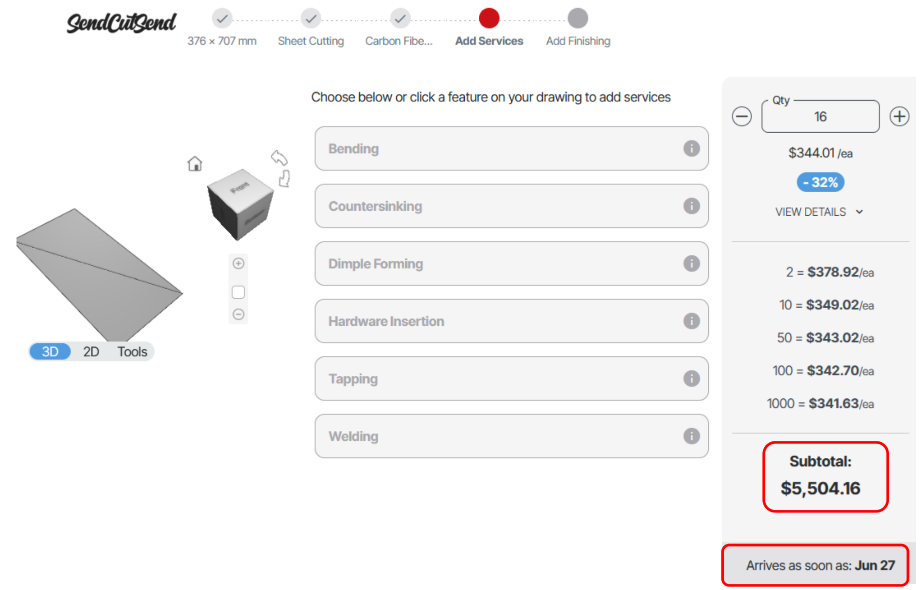
Cost Drivers & Commercial Anchors

- **Cost/risk logic:**
  - Pure CF path may require earlier commitment to tooling, layup, trimming, and late validation
  - Hybrid path separates the expensive precision structure from simpler enclosure panels
  - Flat CF panels are commercially orderable and easy to change
  - Panel thickness, size, count, and hole patterns can be adjusted without redesigning a mold
  - Aluminum side members can use stock, joined stock, machined features, or attached rails

Sample Commercial Website Pricing / Lead Time:

- 1.6 mm CF panels: approximately $340 each at large quantity
- Conservative panel count: 16 panels → approximately $5.4k
- Z-station/support pieces: approximately $1k starting estimate
- Standard aluminum stock is inexpensive compared with custom composite tooling
- Cut CF panels appear orderable on short lead time **(~5 days)**





Cost/risk takeaway:

Do not make the first expensive decision the hardest one to change.

Vendor / Industry Feedback

Industry discussions reinforced that the baseline CF approach is feasible, but not simple.

General feedback:
- Full-length composite structures require early tooling and process decisions
- Layup, cure, trimming, handling, and inspection drive cost/schedule risk
- Inserts, interfaces, sealing, and local precision features need to be defined early
- Late geometry changes can become expensive
- Initial vendor discussions did not reveal an obvious low-risk shortcut from the submitted baseline concept

Design implication:
The baseline CF path remains possible, but it may lock critical decisions earlier than the requirements are mature.

Hybrid implication:
The hybrid concept keeps more of the design commercially adjustable while still using CF where it provides value.

Rail Interface Opportunity

Inherited CAD condition:

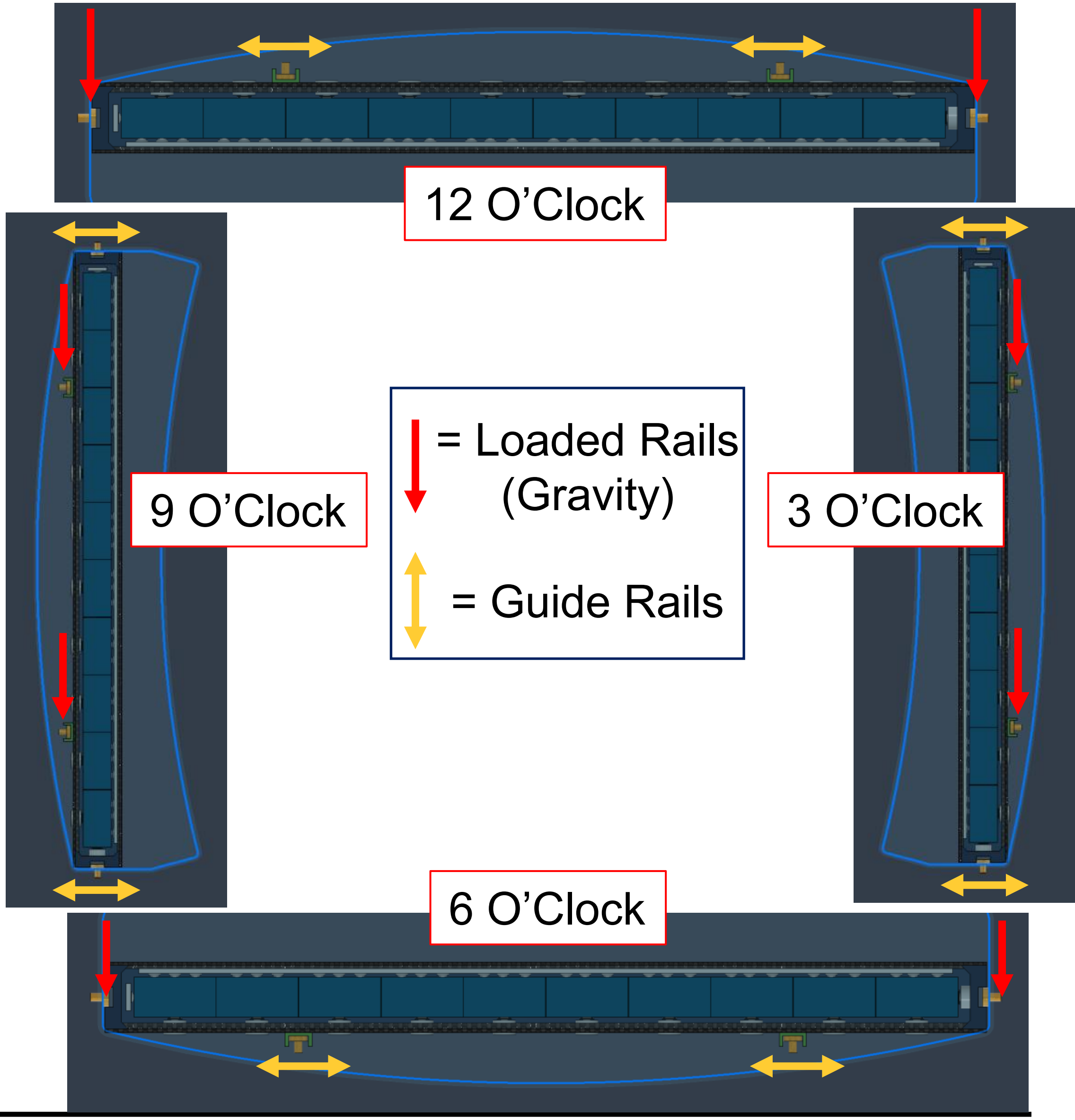
- CAD appeared to use low-profile LPM17-style catalog sliders
- Existing checks appear to rely on that assumed rail concept
- Initial review raised concerns with load capacity, moment capacity, clearance, and rail length

Design opportunity:

- Since the bar box design was already being revisited, the rail interface was reconsidered at the same time
- A modified BaBar-style rail pattern was adapted to the hpDIRC box geometry
- Aluminum side extrusions can potentially act as integral rail features
- Bearing blocks may be moved outboard onto the GST/support structure

Current status:

- This is not yet a validated rail solution
- Analysis is still required
- GST/support deflection information is needed (and requested) to understand bearing-block misalignment under load



Hybrid Approach Assessment

- **Why the hybrid direction is reasonable:**
  - Uses carbon fiber where low-material / large panels provide value
  - Uses aluminum where precision, support, and interface features are needed
  - Reduces dependence on early custom composite tooling decisions
  - Keeps panel geometry, thickness, and layout commercially adjustable
  - Creates options for rail/support integration without committing to one catalog slider
  - Supports faster design iteration while requirements are still maturing

What still needs validation:

- Hybrid FEA with actual material distribution
- GST/support deflection impact on rail and box alignment
- CTE mismatch between aluminum and carbon fiber
- Galvanic corrosion and isolation strategy
- Gas sealing, leakage, and light-tightness details
- Final mass/material estimate

Proposed Next Steps / Requested Direction

Decision needed:

- Does the group agree the hybrid approach is a reasonable primary development path against the baseline CF concept?

Near-term work:

- Develop comparable cost estimates for baseline CF and hybrid paths
- Confirm optical/mechanical requirements
- Complete hybrid FEA with realistic boundary conditions
- Incorporate GST/support deflection inputs
- Refine rail/support interface options
- Continue commercial/vendor feedback

Representative Section Study:

A small representative section could evaluate several high-risk details before committing to full-length fabrication

Questions?

CF vs. Aluminum...

¿Por qué no los dos?

Backup

BaBar Details from NIM Paper

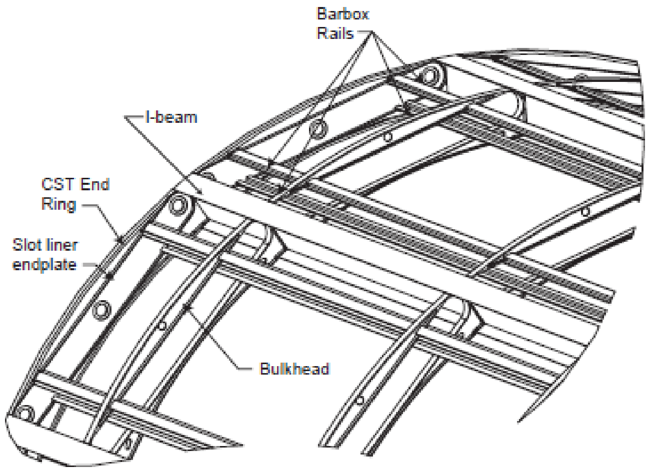


Fig. 10. Details of the Central Support Tube assembly near the end opposite the Transition Flange. The inner and outer skins have been removed, as well as the four pieces of stainless steel sheet metal that form the slot liners when bolted to the rails. The rails and slot liners extend all the way through the Transition Flange.

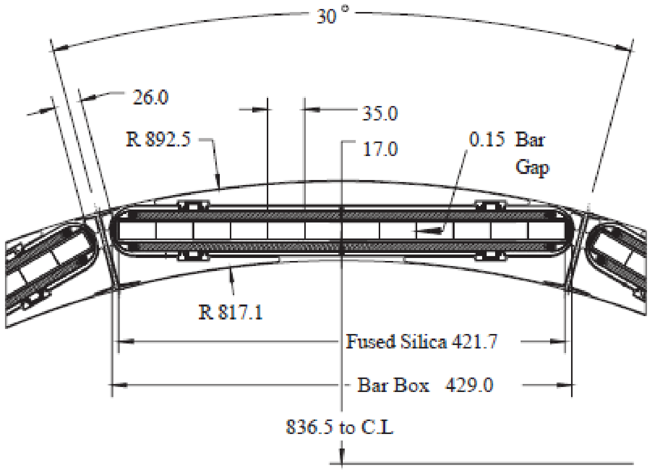


Fig. 11. Cross section through the Central Support Tube showing a bulkhead, the slot liner and a bar box. The inner and outer skins are not shown. All dimensions are in millimeters.

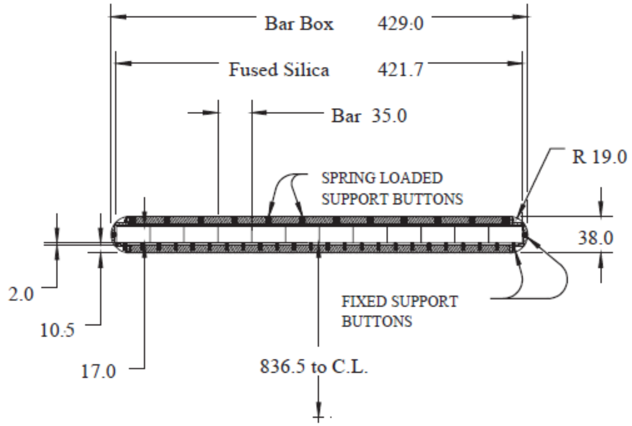


Fig. 26. Cross section of a bar box in the active region of the detector. All dimensions are in millimeters.

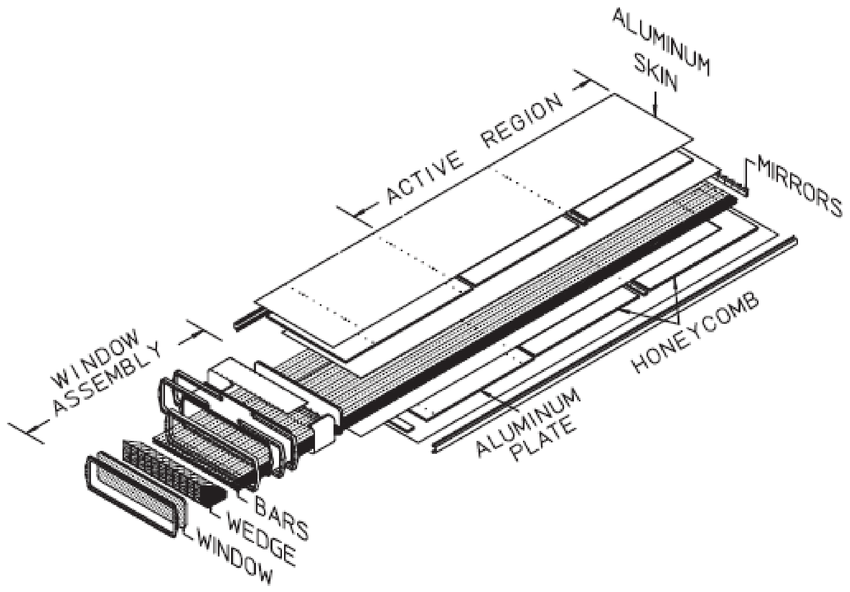
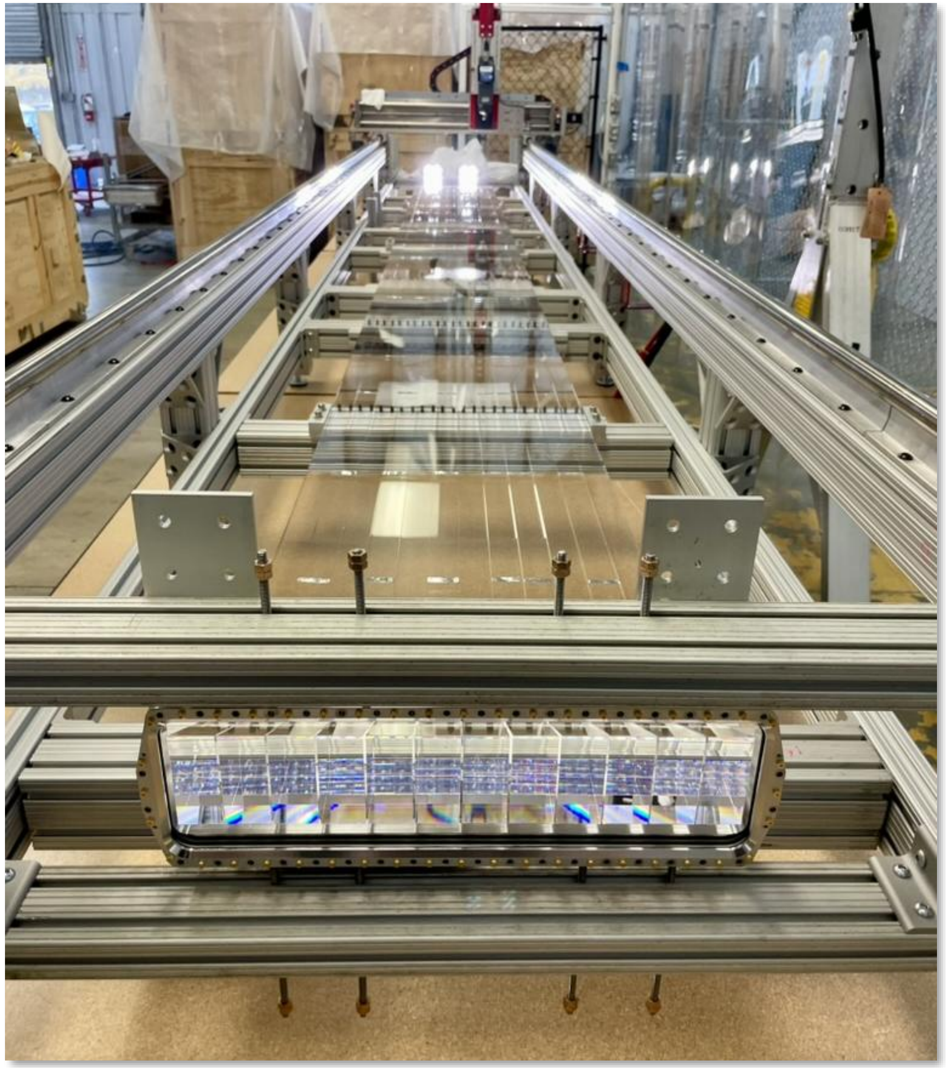
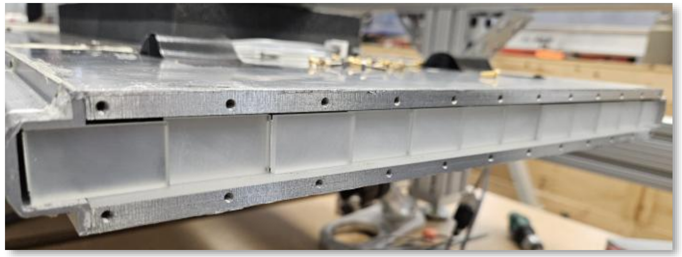
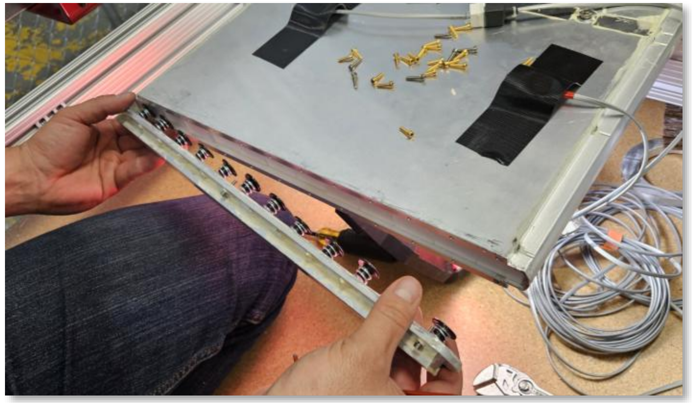


Fig. 25. 3D schematic drawing of a bar box showing the active region, mirror end and window ends.

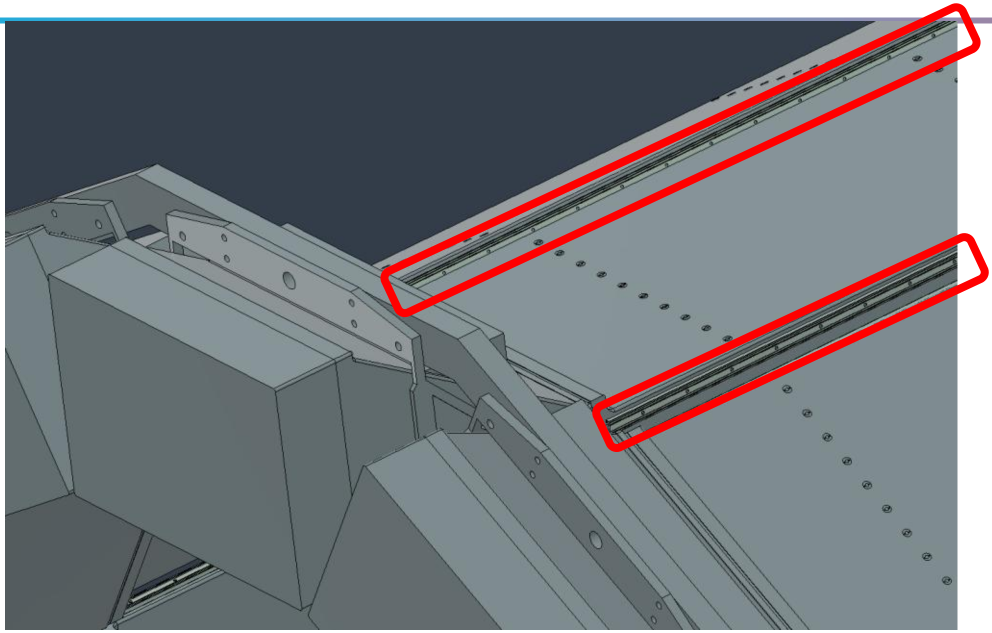
What's in the Box?





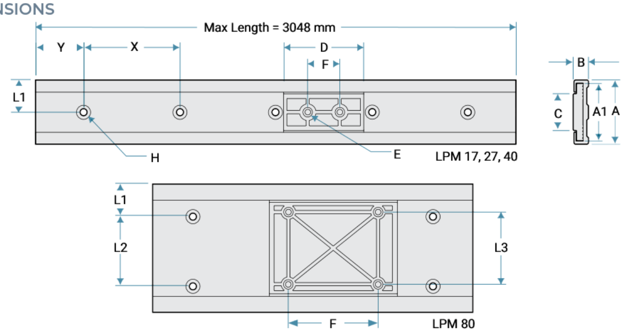


Rail Datasheet Concerns



Low Profile Mini-Rail

DIMENSIONS



Materials: Polymer slider (UL 94 HB flammability rating)
Molded-in stainless steel thread inserts
Anodized aluminum rails

Running Clearance: Less than or equal to 0.5 mm

Maximum Velocity: 10 m/s

Load Reduction Factor: 0.7-1.0 for low speed application; 0.4-0.7 for medium speed application; 0.1-0.4 for high speed application

Part Number	A1	A	B	C	D	E	F	H C'Bore	L1	L2	L3	Y	X	Carriage Wt.	Rail Unit Wt.	Load Capacity									
																Fy		Fz		Mx		My		Mz	
	mm	mm	mm	mm	mm	mm	mm		mm	mm	mm	mm	mm	g	g/mm	N	lb.	N	lb.	N-m	lb.-in	N-m	lb.-in	N-m	lb.-in
LPM17	14.6	17	6.0	9.6	25	M3 x 0.5	14	M3 SBHCS	8.5	N/A	N/A	20	60	1.1	0.15	35	8	10	2.5	0.2	1.5	0.3	2.5	0.2	1.5
LPM27	24	27	9.5	14	40	M4 x 0.7	20	M4 SBHCS	13.5	N/A	N/A	20	60	4.8	0.33	130	30	85	20	1.0	10	2.5	20	1.0	10
LPM40	36	40	9.5	23	50	M4 x 0.7	20	M4 SBHCS	20	N/A	N/A	20	60	9.8	0.38	270	60	150	35	2.5	25	5.0	50	2.5	25

MINI-RAIL
LP MINI-RAIL
LP UNI-GUIDE
UNI-GUIDE
MINI-RAIL

Part Number	A1	A	B	C	D	E	F	H C'Bore	L1	L2	L3	Y	X	Carriage Wt.	Rail Unit Wt.	Load Capacity									
																Fy		Fz		Mx		My		Mz	
	mm	mm	mm	mm	mm	mm	mm		mm	mm	mm	mm	mm	g	g/mm	N	lb.	N	lb.	N-m	lb.-in	N-m	lb.-in	N-m	lb.-in
LPM17	14.6	17	6.0	9.6	25	M3 x 0.5	14	M3 SBHCS	8.5	N/A	N/A	20	60	1.1	0.15	35	8	10	2.5	0.2	1.5	0.3	2.5	0.2	1.5

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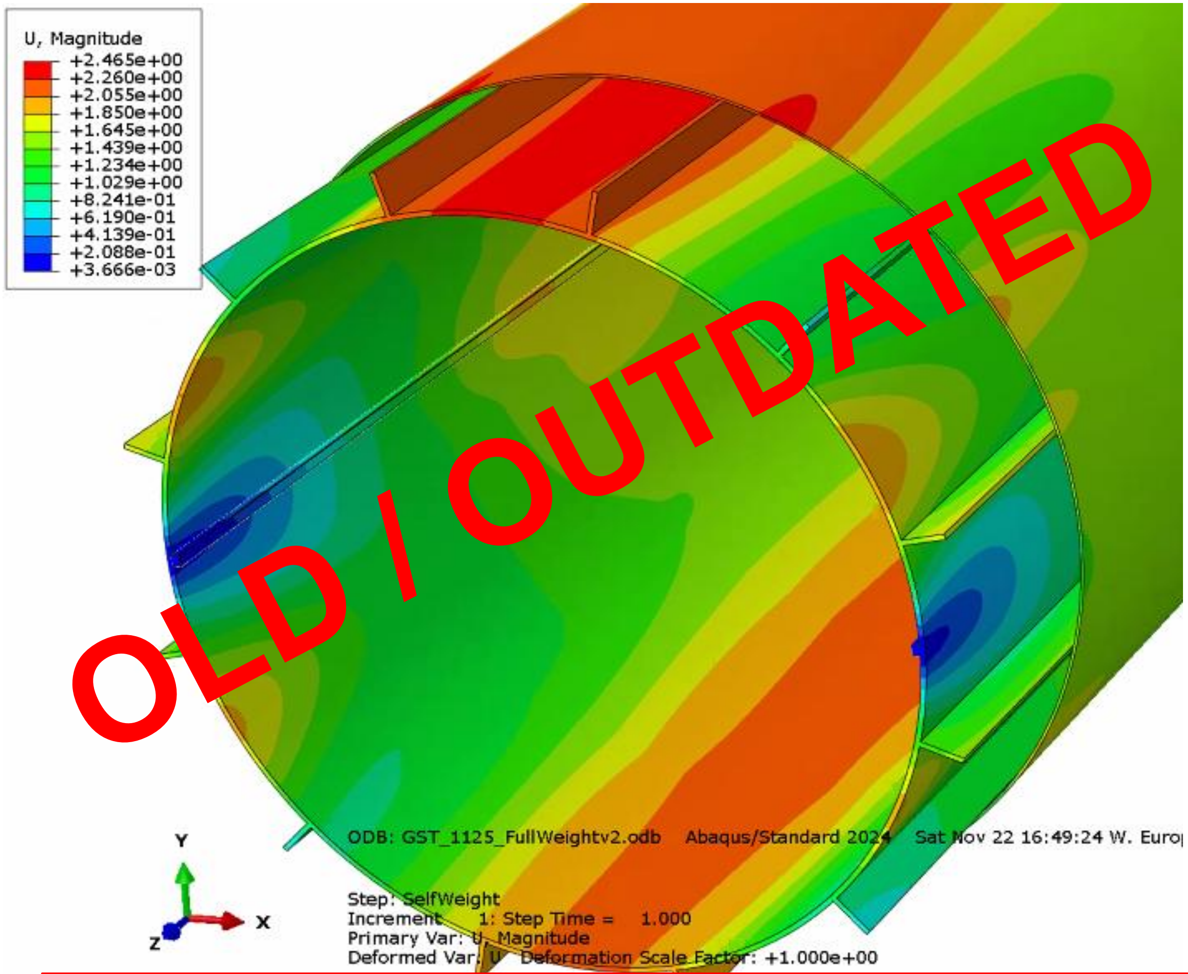
https://media.pbclinear.com/pdfs/pbc-linear-catalogs/gliding-surface-technology-catalog.pdf

GST FEA (ao Nov ’25)



GST FEA used to help determine global stiffness and support behavior

Requirement / Assumption Table

Item	Assumption / Requirement
Bar Box Length	~4.62m / ~14 ft
Support Interface	Current concept assumes rail/GST interface
IP Alignment	Required position relative to IP must be maintained (very tight tolerance; otherwise, recalibration is required)
Support-tube deflection	Input requested. Max deflection was quoted ~2.5mm from outdated info
Inter-bar Clearance (X)	150 microns minimum residual clearance assumed
Bar Contact	**NO**-contact condition required between neighboring bars
End-to-End Optical Joints	Must avoid stressing glued bar-to-bar joints
Lens/bar glue joints	Must avoid support loads or deformation that stresses the glue joints
Critical Motion Direction	X-direction motion at bar support interface (“Z-Stations”)
Z-axis behavior	Sag/deflection over full length must be evaluated
Gas Environment	Dry nitrogen environment required
Overpressure / Leakage	Low overpressure expected; leakage definition still needed
Light-tightness	Required
Material compatibility	Radiation, magnetic field, outgassing, humidity, sealing
Current rail component	CAD rail/slider choice <u>not</u> validated
Hybrid Concept Status	Promising path, not final’d or baselined

Risk Mitigation Matrix

Risk	Why It Matters	Mitigation/Validation Path
Support-tube deflection	Affects rail alignment and IP position	Use GST deflection in FEA
Rail/Component Selection	CAD slider is not validated	Compare rail options against load, clearance, length and moment needs
Hybrid structural behavior	Material split changes stiffness/load path	Run FEA with actual hybrid material distribution
X-direction motion	Can reduce bar clearance	Evaluate bar support interface displacement
Z-axis sag/twist	Can disturb optical alignment/joints	Evaluate full-length deflection modes
CTE Mismatch	Al and CF move differently with temperature	First-pass thermal estimate & joint strategy
Galvanic Corrosion	CF/Al may need isolation	Define isolation/coating/sealing solution
Gas Sealing/leakage	Dry N2 environment needs to be maintained	Define flow-in / flow-out / leakage model
Light-tightness	Optical performance risk	Detail seals, overlaps, joints, and closure features
Glue Joint Loading	Bonded optical joints must not be overstressed	Check support reactions and deformation at bar/lens interfaces
Fabrication path	Cost/Schedule risk depends on process choice	Compare CF shell vs hybrid commercial fabrication paths
Late Design Changes	Molded CF changes can be expensive	Keep panels and interfaces adjustable where practical