APA FDR Costs, Schedule and Risks

Brian Rebel

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Overview

- US and UK APA Responsibilities
- Costs per APA for each country
- APA Production and Installation Schedule with high-level milestones
- APA Risks

This talk addresses item #7 of the charge

UK and US APA Responsibilities

- The UK and US were initially envisioned to produce 150 APAs each for the first two far detectors
- The US production was hoping to secure an NSF mid-scale RI grant through Chicago, but it was declined at the final stage
- About the same time it became clear the UK production would be about 20 APAs short of the 150 needed in time for installation
- The US project was updated to include production of 20 APAs
- It also added testing of 10% of all APAs produced for FD-1
- The US project has covered APA installation from the beginning

Cost Summary

- The UK and US costs are presented in the next slides broken out by components and commodities
- The US set up costs are also shown as they are additions to the project since the PDR
- The installation costs estimates are also provided, although those have more uncertainty
- The total costs are
  - UK: £ 23.7M for APA production and shipping to testing site
  - US: $14.5M for APA production, testing and storage of APAs, shipping to SURF, and installation

Cost Estimate Document on EDMS

UK Cost Per APA

- The materials costs per APA are about £ 103k, including commodities and major components
- The board materials costs include assembly as well in the UK, but not in the US
- The estimated number of hours required by each labor resource type per component are shown
- The UK labor costs are £ 67k

UK Cost Table

Item	Material per APA (including VAT)	Engineer hours	Technician hours	Physicist hours
APA frames	£31,883	78	86	73
Mesh panels	£7,413	17	4	9
Wire	£1,038	0	0	0
Geometry boards	£11,996	21	41	14
Adhesive	£874	0	0	0
Combs & bases	£2,314	0	0	0
Fasteners	£57	0	0	0
Transport frames	£12,947	24	55	21
Shipping cradle	£2,500	0	0	0
Springs	£1,930	0	0	0
Packaging	£2,854	0	0	0
Shipping cost	£3,854	8	38	19
Mill-Max pins (geometry boards)	£649	0	0	0
Mill-Max pins (CR boards)	£250	0	0	0
Mill-Max contacts (G-bias filter boards)	£753	0	0	0
Teeth	£1,662	12	75	0
Adapter boards	£1,682	2	5	2
G-bias filter boards	£3,965	2	5	2
SHV boards	£24	2	4	1
CR boards	£13,809	3	6	2
Cover boards	£1,134.69	0	1	0
Cable harnesses	£50	0	12	0
Board postage	£72	0	0	0
Factory maintenance		58	38	6
APA construction		8	827	63
Management		0	0	188
Total	**£102,575**	**235**	**1195**	**400**

US Cost Per APA

- The materials costs per APA are about $113k, including commodities and major components
- The board materials costs do not include assembly in the US, unlike the UK
- The estimated number of hours required by each labor resource type per component are shown
- The US labor costs average to $134k between the two production sites

US Cost Table

Item	Materials Cost	Engineering Hours	Elec. Technician Hours	Mech. Technician Hours
APA Frames	$22,534	4	0	160
Combs	$3,008	0	0	0
Cable Routing Hardware	$745	0	0	6
Epoxy	$1,136	0	0	0
Grounding Mesh	$7,231	0	0	0
Protection Panels	$3,706	0	0	0
Solder	$74	0	0	0
Cover Boards	$988	0	6	0
CR Boards	$6,250	8	70	0
Electronics Adapter Boards	$1,550	2	30	0
G Layer Boards	$5,177	2	17	10
G-bias Boards	$6,910	2	30	0
SHV Boards and Cable Harness	$483	4	24	0
U Layer Boards	$9,883	2	30	52
V Layer Boards	$9,455	2	39	46
X Layer Boards	$5,308	2	40	10
Assembly		319	0	733
Transportation Frame	$28,419	0	0	0
Total	**$112,855**	**347**	**286**	**1017**

US Set Up Costs

- PSL produced APAs for ProtoDUNE I, which means much of the necessary set up is already done, however
  - A new process cart is needed
  - The winder had to be upgraded and commissioned
  - New equipment for washing boards and making CR boards has to be purchased
  - Total costs are estimated at $120k
- Chicago is starting from scratch, cost drivers are
  - Clean facility and overhead crane: $886k, but will be used for FD2 CRP production as well
  - Winder construction: $372k
  - Equipment, process carts and labor: $408k
  - Total costs are estimated at $1.5M

Testing, Storage and Transportation Costs

- We plan on testing 10% of the APAs produced in a cold box, at least an additional 10% would have tensions, leakage current, and electrical isolation tested
  - The tension, leakage current and isolation tests will be done with the DWA designed and built at Harvard
  - The cost and schedule assumes cold testing happens at Fermilab, but it may be at CERN instead
  - Currently estimate $2.2M to set up Fermilab cold testing and storage facility and perform tests
- Transportation costs include shipping US APAs to Fermilab and shipping all APAs to SURF for a total cost estimate is $261k

Installation Costs

- The installation portion of the project includes
  - Hardware, fixtures and tooling for installing APAs in the detector and the shipping costs to get those items to SURF
  - Travel of scientific labor to SURF
  - Technical labor at SURF - 3 techs for each of 2 shifts during the installation phase
- The total cost is $2.7M

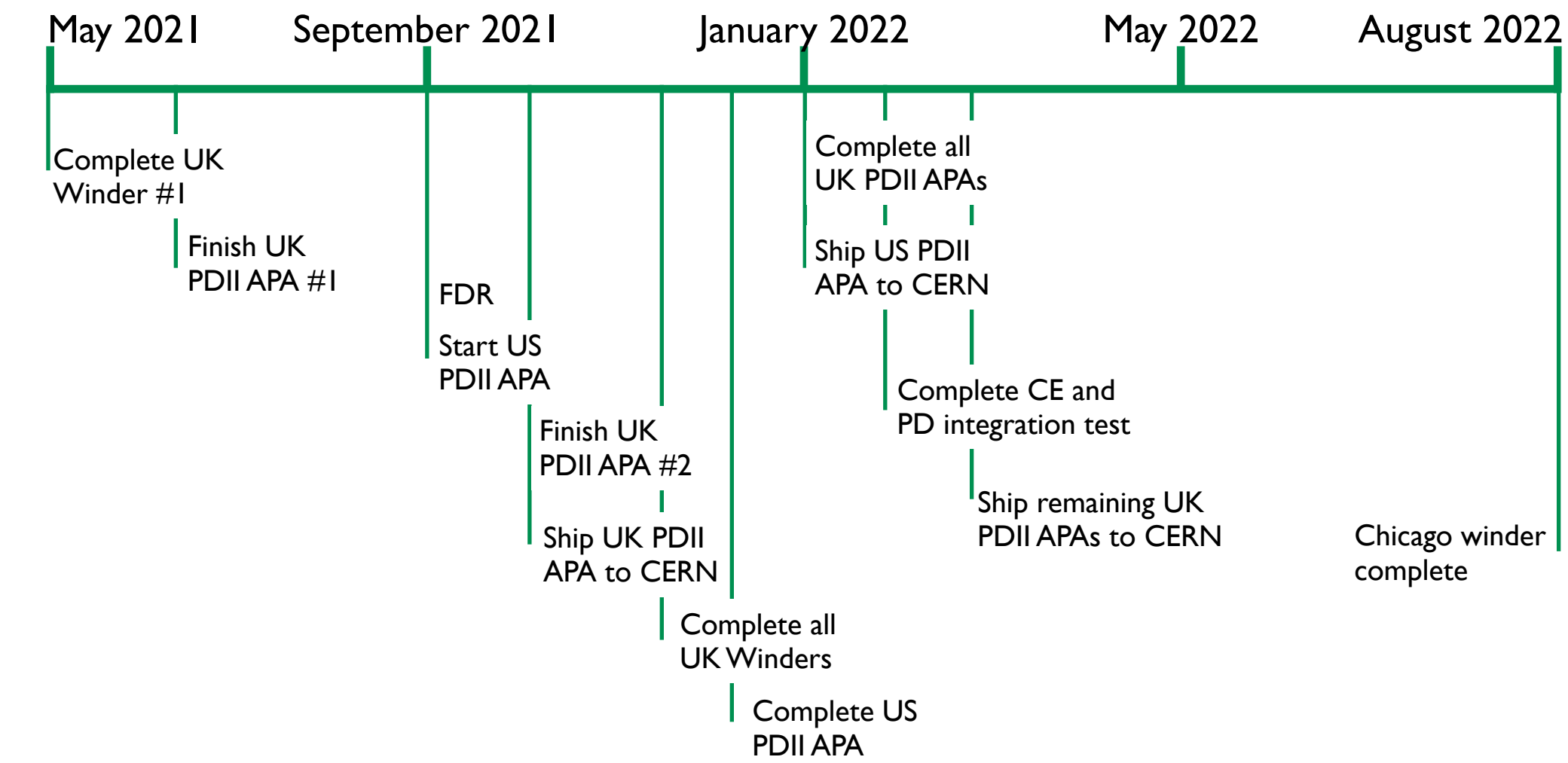
Schedule Milestones - Set Up and ProtoDUNE II

- The UK has already completed one ProtoDUNE II APA and has started its second
- The PSL facility is finishing the winder commissioning and is on track to start its ProtoDUNE II APA in September, finishing in December
- All UK winders will be ready in November
- All ProtoDUNE II APAs will be at CERN by early next year
- The Chicago winder will be ready in August 2022

Milestone	Date
Complete UK winder #1	May 2021
Finish UK PDII APA #1	July 2021
APA Final Design Review	September 2021
Start US PDII APA	September 2021
Finish UK PDII APA #2	October 2021
Ship UK PDII APA to CERN for cold test	October 2021
Complete all UK winders	November 2021
Complete US PDII APA	December 2021
Complete all UK PDII APAs	January 2022
Ship US PDII APA to CERN	January 2022
Complete integration test with CE and PD at CERN	February 2022
Ship remaining UK PDII APAs to CERN	March 2022
Chicago winder completed	August 2022

Schedule Document on EDMS

Schedule Milestones - Set Up and ProtoDUNE II

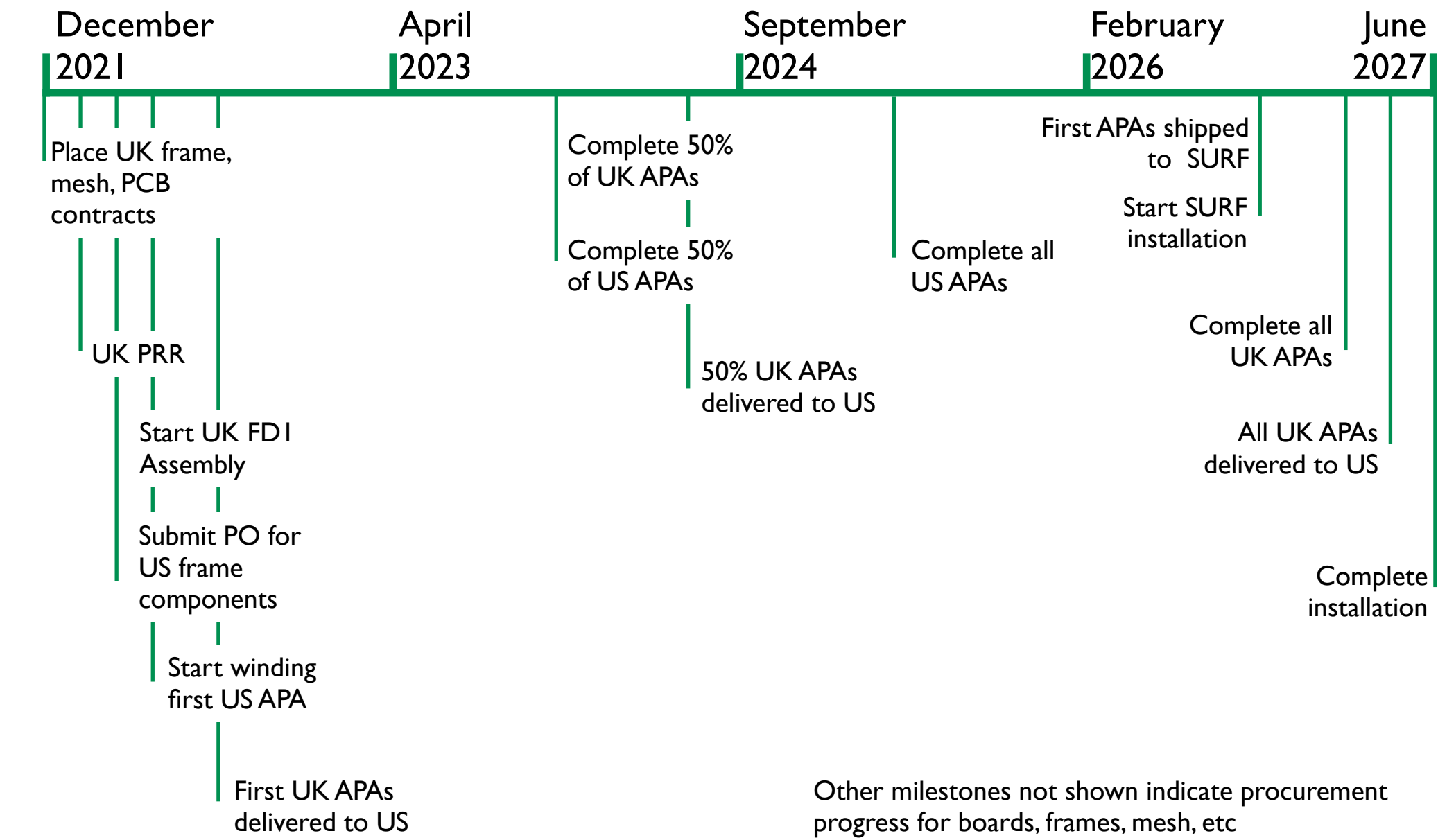


Schedule Milestones - Production and Installation

- The UK places contracts for major components at the end of CY21
- The UK starts FDI assembly in February 2022
- The US winds one pre-production APA at each site in 2022
- UK and US complete 50% of their APAs in April 2024
- The US finishes winding in July 2025
- Installation starts August 2026
- The UK finishes winding in April 2027
- Installation finishes June 2027

Milestone	Date
Place UK APA frame contract	December 2021
Place UK grounding mesh panel contract	December 2021
Place UK PCB boards contract	December 2021
UK Production Readiness Review	January 2022
Start UK APA assembly for Far Detector	February 2022
Submit PO for initial US APA frame components	February 2022
Start winding first US APA	March 2022
First UK APAs delivered to US	July 2022
Complete winding 50% of UK APAs	April 2024
Complete winding 50% of US APAs	April 2024
Complete winding US APAs	July 2025
Start APA Installation at SURF	August 2026
Complete winding UK APAs	April 2027
Receive 100% of UK APAs in US	May 2027
Complete APA Installation	June 2027

Schedule Milestones - Production and Installation



Other milestones not shown indicate procurement progress for boards, frames, mesh, etc

Risks

- The risks are pulled from the DUNE/LBNF risk register and represent the highest risk levels for APAs
- The last column gives a probable cost if the risk is realized
- The development of assembly procedures and engineering analysis for transport should mitigate most of the highest risks
- We have to monitor steel commodity fluctuations closely
- We will work to ensure sufficient scientific labor for installation

Risk	Rank	Probability x Impact
Insufficient scientific labor for installation	High	$746k
Loss of APA shipment due to accident	High	$440k
Loss of APA due to production accident	Medium	$132k
Production quality does not meet requirements	Medium	$367k
Reduction in assembly time (opportunity)	Medium	$113k (saved)
Winder construction takes longer than expected	Medium	$83k
Steel commodity fluctuations	Not Assigned	Uncertain
Chicago factory takes too long to begin production	Not Assigned	Uncertain

Risks - Insufficient Scientific Labor

Risk	Rank	Probability x Impact
Insufficient scientific labor for installation	High	$746k

- The highest impact risk is that we don't get sufficient scientific labor for installation
- Our plans indicate that for each of two shifts we need
  - 11 students/postdocs
  - 1 senior researcher (postdoc, faculty etc)
- The APA consortium cannot supply this effort alone, will need involvement of full collaboration
- We will advertise the need well in advance so people can plan for grant renewals, etc

Risks - Loss of APA Shipment

Risk	Rank	Probability x Impact
Loss of APA shipment due to accident	High	$440k

- This one is tricky both because the APAs are expensive, but also because if a later shipment were lost it might be hard to ramp up to produce more APAs
- The cost could be higher if the accident happened during ocean transport and more than one shipment of APAs was affected
- We can mitigate the risk by having a robust shipping frame, specifying where the container should be on the ship, and insuring the shipments

Risks - Steel Prices

Risk	Rank	Probability x Impact
Steel commodity fluctuations	Not Assigned	Uncertain

- This risk is very uncertain and could be bad (or good if prices fluctuate low) - we use steel in everything from the winders to the transport frames
- The recent history of steel pricing has been volatile to say the least
- The market might be starting to return to a more normal level, but it is too soon to tell
- One mitigation is to put off ordering steel in the hopes of riding out the fluctuations, but that cannot be done indefinitely - we need to set up production in the US and start making APAs for the FD in the UK

Conclusions

- The UK is producing 130 APAs and the US is producing 20
- The costs based on the current design are acceptable to the funding agencies
- The schedule milestones enable us to track the procurement, production and installation well
- The main risks have been identified and are being mitigated through a combination of procedures and design analysis
- We believe the state of the cost, schedule and risk registry are sufficient to meet the requirements for the final design review