Risk Assessment and Contingency Analysis for US HL-LHC AUP

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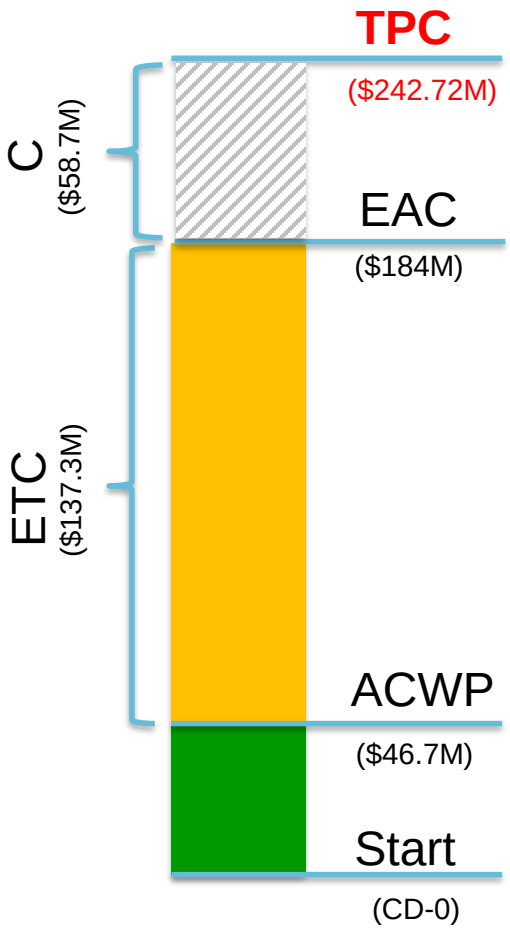
Outline

- Introduction
- Cost Contingency
- Schedule Contingency
- Risk Assessment
- Contingency Analysis
- Summary

Introduction

- US HL-LHC AUP (AUP) was baselined (DOE CD-2 approval) on **February 2019**
  - Project Scope:10 Q1/Q3 cryo-assemblies and 10 RFD dressed cavities
  - Total Project Cost (TPC): **$242.72M**
    - Included **$63.4M** of cost contingency
  - Project Completion Date (CD-4): **March 31st, 2028**
    - Included **38 months** of schedule contingency
- The Threshold Scope, TPC and CD-4 date are a commitment of DOE to US Congress and are **very difficult to change**. Changing these constraints would require a project re-baseline and approval by the DOE Deputy Director for Science Programs
  - Approval is above the DOE Office of High Energy Physics
- Prior to the baseline, Risk Assessment and Contingency analysis were used to help determine adequate cost and schedule contingency plan for the project.
  - Risk Assessment and Contingency Analysis are now being used to make sure the TPC and CD-4 date constraints will not be exceeded during project execution

Cost Contingency



- TPC: **Total Project Cost**
  - Set at CD-2, cannot be exceeded
    - **For AUP, TPC = $242.72M**
  - DOE commitment to US Congress
  - Can only be changed with a project re-baseline (very difficult process)
- EAC: **Estimate at Completion** to execute project scope
  - Changes monthly as a result of actual performance, approved Baseline Change Requests (BCRs), anticipated BCRs, and estimates for future work adjustments based on historical performance
- C: **Cost Contingency**
  - C = TPC – EAC
  - DOE Owns Contingency (not the Project Office)
    - PM authorized to approve up to $1M in BCRs
    - Once the $1M reserve is down to $250K, PM needs to request DOE to replenish reserve
- EAC = ACWP + ETC
  - ACWP: **Actual Cost of Work Performed**
  - ETC: **Estimate to Complete**
    - ETC = EAC – ACWP

US HL-LHC AUP

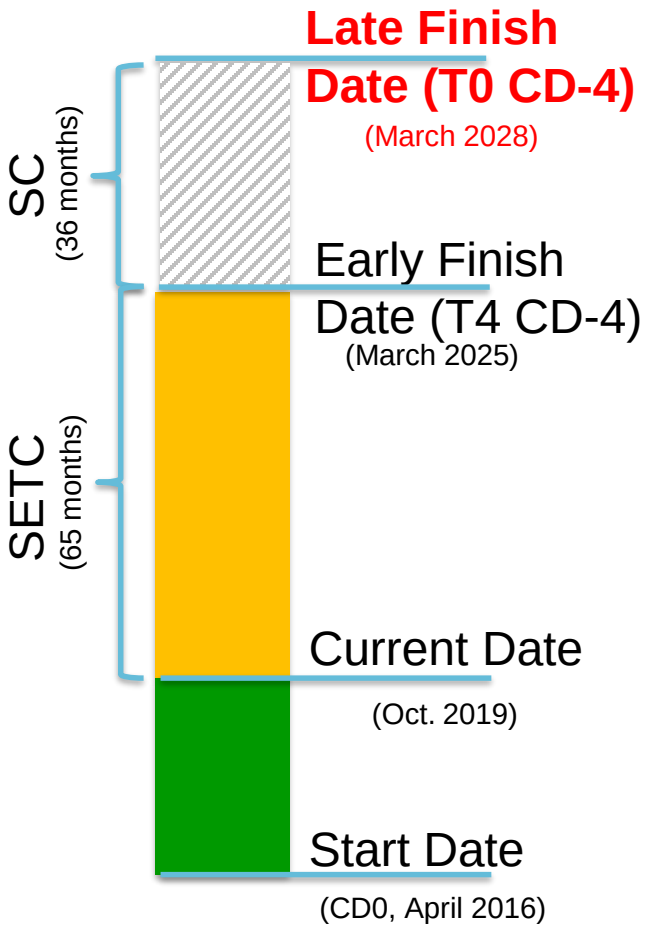
Estimate At Completion (EAC)
EAC = ACWP + ETC

- ACWP: Actual Cost of Work Performed
  - Updated monthly from FNAL, BNL, and LBNL accounting systems
- ETC: Estimate to Complete. Includes:
  - Cost of remaining activities from the P6 Resource Loaded Schedule (RLS)
  - Cost impact of approved Baseline Change Requests (BCRs) not yet implemented in the RLS
  - Adjustments of estimates for future work based on historical performance and forecast analysis
    - For example, adjustments based on actual production yield
- A new EAC is generated monthly as part of the monthly Earned Value report to DOE

AUP EAC (Sept. 2019)	AUP ACWP (Sept. 2019)	AUP ETC (Sept. 2019)	% Spent (Sept. 2019)
$184,020K	$46,741K	$137,278K	25.4%

Available contingency (C= TPC – EAC) changes monthly

Schedule Contingency



- T0 CD-4: **Late Finish Date**
  - Set at CD-2, cannot be exceeded
    - **For AUP: March 31, 2028**
  - DOE Commitment to US Congress
    - High-Level DOE Milestone (T0)
  - Can only be changed with a project re-baseline (very difficult process)
- T4 CD-4: **Early Finish Date**. It is the P6 RLS Finish Date
  - PM Milestone (T4)
  - Can change monthly as a result of approved BCRs, status updates, etc.
- SC: **Schedule Contingency**
  - SC = Late Finish – Early Finish
- SETC: **Schedule Estimate To Complete**
  - SETC = 65 months (5.4 years)

Contingency Analysis

Cost Contingency

AUP C (Sept. 2019)
$58,700K

Schedule Contingency

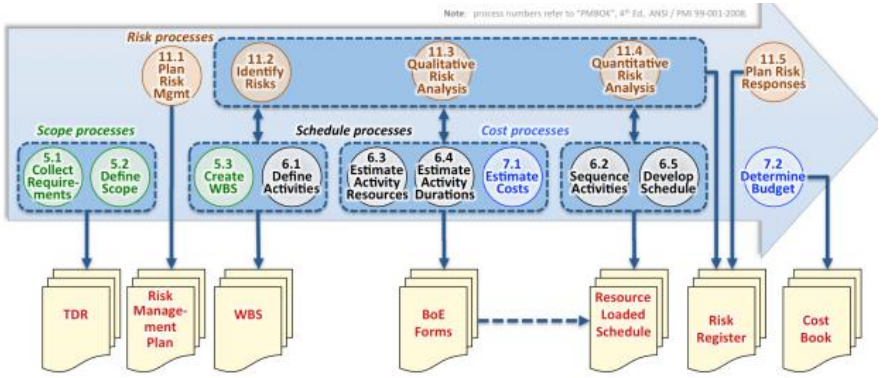
AUP SC (Sept. 2019)
36 months

- Is contingency adequate?
  - Bottom-up quantitative analysis based on Risk Assessment
    - There should be enough contingency to cover identified risks at 90% confidence level (CL)
      - DOE guidance is 70-90% CL, but Fermilab procedures adopted by AUP specify 90% CL

This Talk

Risk Assessment

- The US HL-LHC AUP Project must adhere to DOE Order 413.3B “Program and Project Management for the Acquisition of Capital Assets”
  - This DOE order mandates a Risk Management Plan (RMP)
  - Additional guidance provided by DOE G 413.3-7A “Risk Management Guide”
- AUP RMP: US-HiLumi-doc-339
  - AUP adopted the “Fermilab Risk Management Procedure for Projects” (US-HiLumi-doc-89)
    - Follows the DOE Risk Management Guide and the ANSI-standard “Project Management Body of Knowledge” (PMBOK)



AUP has Monthly Risk Management Board (RMB) Meetings

Risk

- A Risk is an uncertain event or condition that, if it occurs, has an effect on at least one project objective
- Three sources of project cost and schedule risk:
  1. **Estimate Uncertainty (EU)**
     - For activities in the baseline scope (i.e., part of the P6 Resource Loaded Schedule)
     - Depend on the activity definition maturity
  2. **Identified Risk Events**
     - Known events that may or may not happen
     - Not included in baseline scope activities
     - Captured in the AUP Risk Register
  3. **Unidentified Risk Events**
     - Unknown events that may or may not happen (“unknown unknowns”)
     - Not captured in the AUP Risk Register

Available Cost and Schedule Contingency should be adequate to cover all three types of Risks

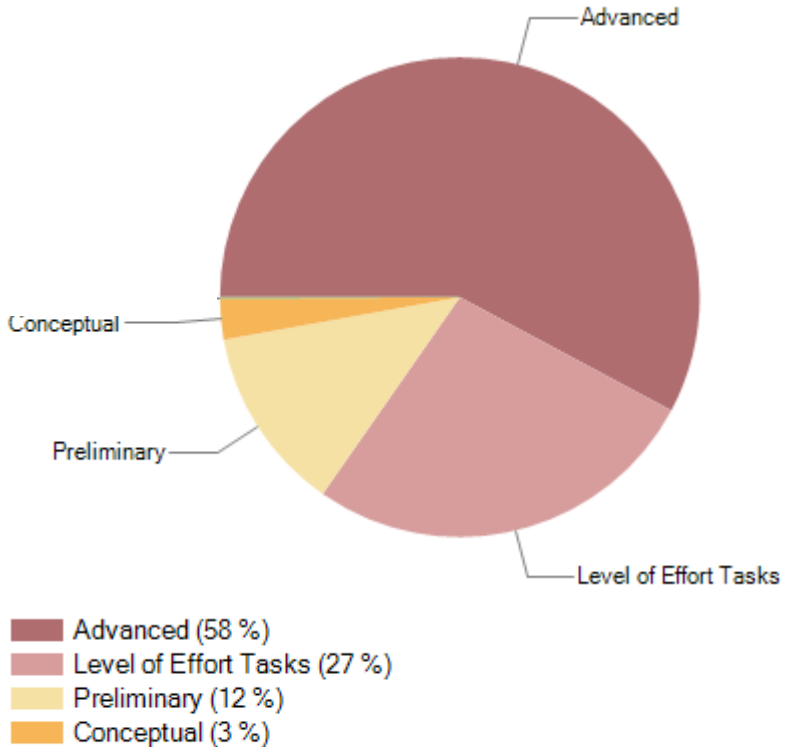
1. Estimate Uncertainty (EU)

Estimate Type	AUP EU Contingency
Actual	0%
Level of Effort	10%
Advanced	15%
Preliminary	30%
Conceptual	50%
Pre-Conceptual	70%
Rough Estimate	90%
Beyond State of the Art	100%

- AUP follows FNAL Office of Project Support Services (OPSS) EU contingency guidelines
  - More details in US-HiLumi-doc-48
- Each of the ~ 6,000 P6 RLS activities is assigned an estimate type
  - The corresponding Contingency % is applied to Labor and M&S
  - The result is added for all activities to determine the total estimate uncertainty contingency amount
- The total EU contingency changes monthly, as more activities are accomplished and BCRs are processed

1. Present Estimate Uncertainty in AUP

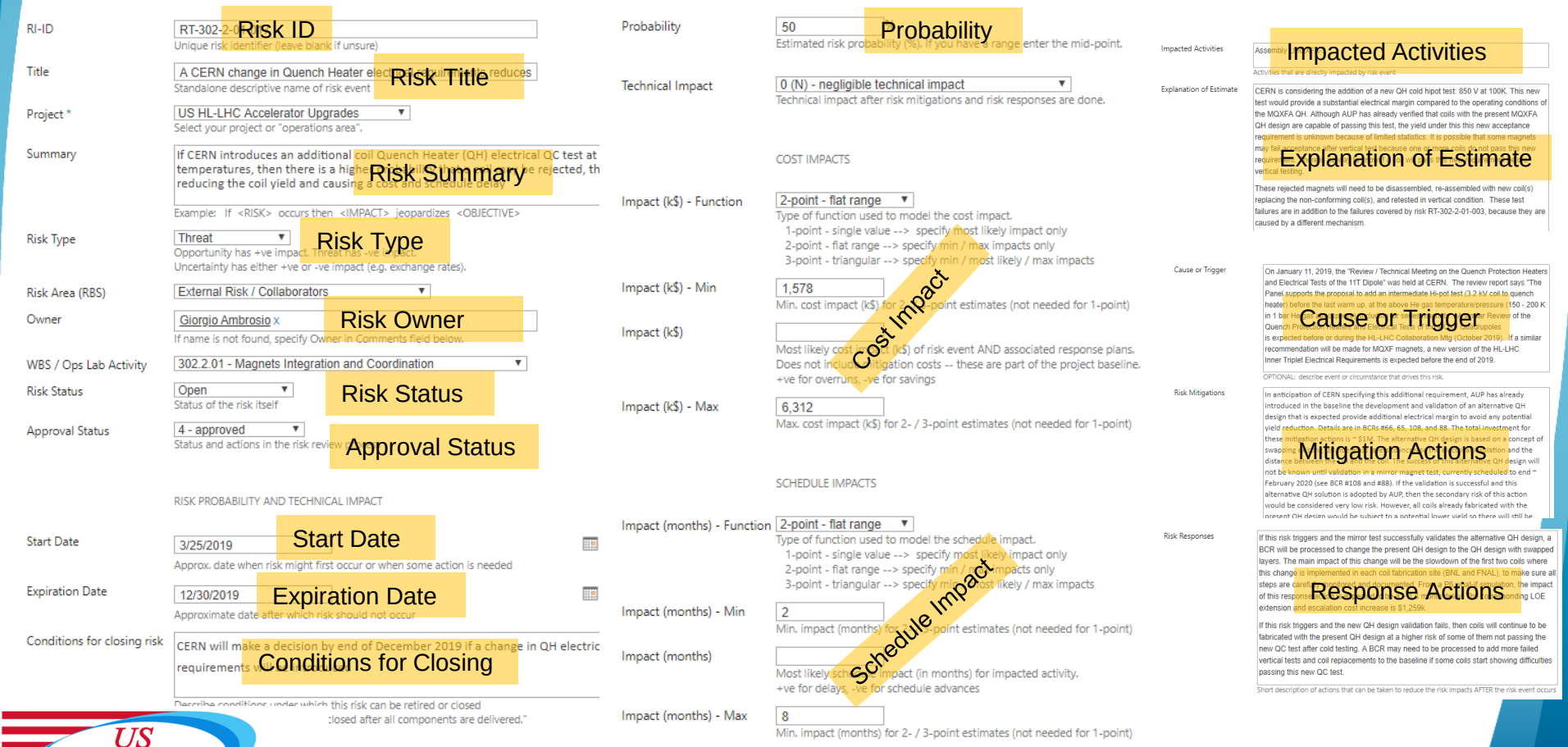
- AUP EU dominated by Advanced, Level of Effort (LOE), and Preliminary Estimates



AUP EU (Sept. 2019)
$26,381K

2. Identified Risk Events: AUP Risk Register

- Each identified risk event is fully documented and quantified in the AUP Risk Register.
  - Example: Risk RT-302-2-01-017: “A CERN change in Quench Heater electrical requirements reduces coil yield”



AUP Risk Register

- Risk Ranking Criteria (matrix from “Risk Management Plan” at US-HiLumi-doc-339):

Risk Impact Scoring		Low Impact	Medium Impact	High Impact
Technical Impact		Slightly sub-standard	Moderately sub-standard	Significantly sub-standard or KPP in jeopardy
Cost Impact	HL-LHC AUP	< 0.5 M$	(0.5 - 2) M$	> 2 M$
Schedule Impact	HL-LHC AUP	< 6 months	(6-9) months	> 9 months

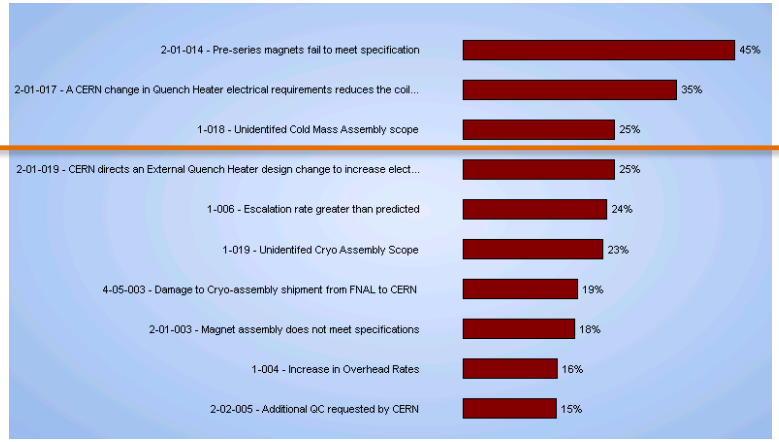
Maximum value of all impacts (above) determines overall risk impact (below)

Risk ranking matrix (Probability vs. Impact)		Low Impact	Medium Impact	High Impact
Very High	64 - 100%	Medium Rank	High Rank	High Rank
High	39 - 64%	Medium Rank	High Rank	High Rank
Medium	21 - 39%	Low Rank	Medium Rank	High Rank
Low	9 - 21%	Low Rank	Medium Rank	Medium Rank
Very low	0 - 9%	Low Rank	Low Rank	Medium Rank

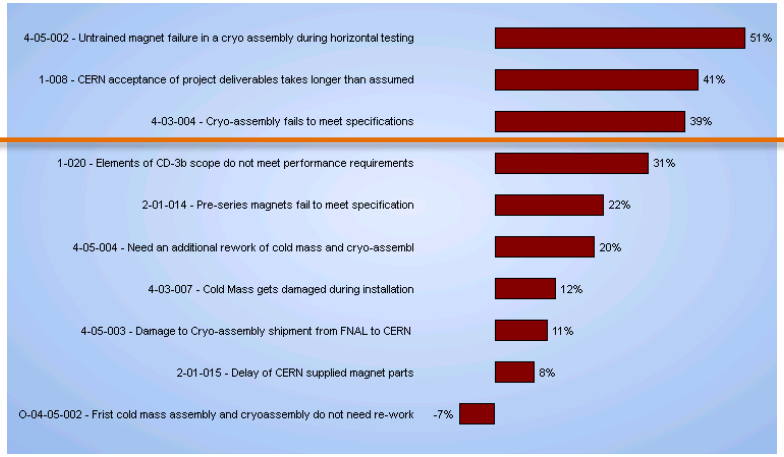
- Risk Count and Ranking in AUP Risk Register:

Open Risks	High	Medium	Low	Total
Threats	19	43	24	86
Opportunities	3	9	2	14
Total	22	52	26	100

Top Risks



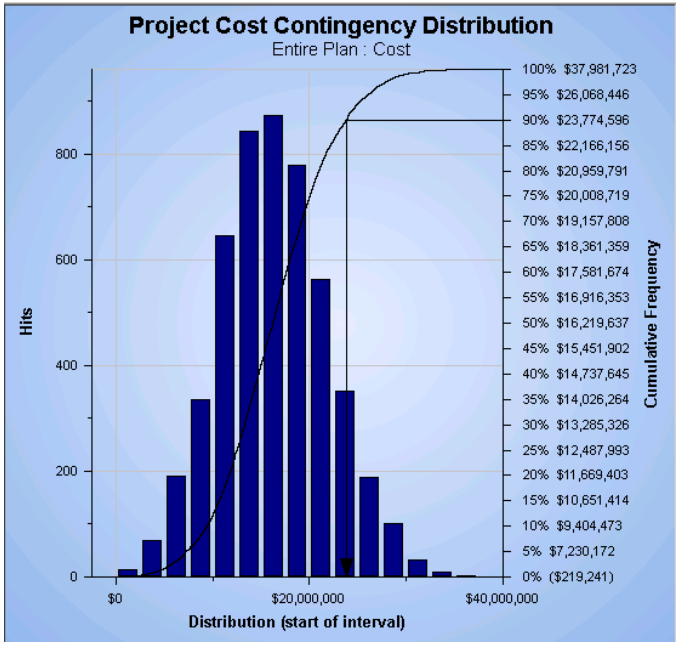
- Top 3 Cost Risks:
  1. RT-302-2-01-014 Pre-series magnets fail to meet specification
  2. RT-302-2-01-017 A CERN change in Quench Heater electrical requirements reduces the coil yield
  3. RT-302-1-018 Unidentified Cold Mass Assembly scope



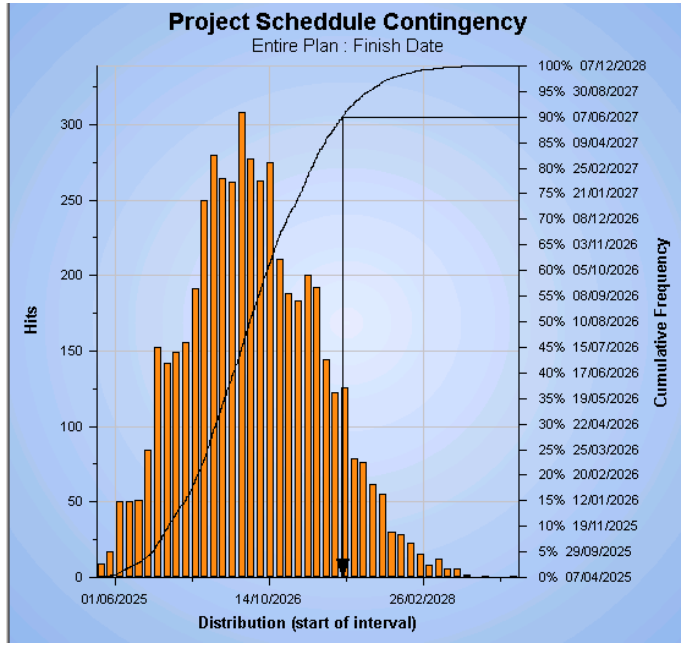
- Top 3 Schedule Risks:
  1. RT-302-4-05-002 Untrained magnet failure in a cryo assembly during horizontal testing
  2. RT-302-1-008 CERN acceptance of project deliverables takes longer than assumed
  3. RT-302-4-03-004 Cryo-assembly fails to meet specifications

Risk Analysis

- Monte Carlo simulations are performed on all Open Risks in the Risk Register
  - AUP uses “Primavera Risk Analysis” (PRA)
  - Cost and Schedule contingency is determined at 90% Confidence Level (CL)
    - CL specified in the “Fermilab Risk Management Procedure”



Risk Cost Contingency @ 90% CL (September 2019)
$23,775K



Risk Schedule Contingency @ 90% CL (September 2019)
26 months

Cost of Schedule Delay

- The Risk Cost Contingency does not include increased "Level of Effort" (LOE) cost associated with schedule delays (Management "Standing Army" cost)
  - Examples of LOE cost includes the Project Office and WBS management
    - It does not include technician "standing army" impact
  - For AUP, this cost is ~ $340K/month on average for the last 26 months of the project (the 90% CL schedule contingency duration)

Cost of Schedule Delay (September 2019)
26 months @ $340K/month = $8,840K

For AUP, time is money!

- The **Total Risk Contingency Cost** is the sum of the Risk Cost Contingency and the Cost of Schedule Delay:

Total Risk Contingency Cost @ 90% CL (September 2019)
$23,775K + $8,840K= $32,615K

Cost Contingency Breakdown

(dollar amounts in $K)

Contingency	CD-2 (Feb. 2019)	Sept. 2019	Δ
Available Cost Contingency (TPC – EAC)	**$63,437**	**$58,700**	**-$4,737**
1. Estimate Uncertainty (EU)	$29,136	$26,381	-$2,755
2. Total Identified Risks Contingency Cost	$28,257*	$32,319**	$4,062
3. Available for Unidentified Cost Risks	$6,044	$0	-$6,044

*At 90% CL

**Slightly below 90%CL ($32,615K at 90% CL, or $296K higher)

- Cost Contingency available for Unidentified Risks (“Top-Down” cost contingency) is the remaining available contingency after accounting for EU and Total Risk Contingency
- At CD-2, about 9.5% of the total cost contingency was available for Unidentified Risks
- In September 2019, there is no longer any contingency left for Unidentified Risks
- Between CD-2 and Sept. 2019, % spent increased from 8.1% to 25.4%

Schedule Contingency Breakdown
(duration in months)

Contingency	CD-2 (Feb. 2019)	July 2019
Available Sch Contingency (T0 CD-4 – T4 CD-4)	**38**	**36**
Schedule Risk Contingency at 90% CL	23	26
Available for Unidentified Schedule Risks	15	10

- Schedule contingency available for unidentified schedule risks (“Top-Down” schedule contingency) is the remaining available contingency after accounting for schedule risk contingency at 90% CL
- About 28% of the total schedule contingency is available for unidentified schedule risks
  - This is mostly top-down contingency to assure the DOE project completion commitment to the US congress is met.
- See next slide for CERN deliverables schedule contingency

Schedule Contingency for CERN Deliverables

- AUP has adequate schedule contingency for the DOE CD-4 date
- The current AUP P6 RLS schedule meets the CERN Early Need By delivery dates (see table below) **with no float**
- Schedule contingency to CERN Late Need-by dates is tight (~ 11 months float)

Q1/Q3 Cryoassembly	Early Need By	Late Need By
LQXFA/B01	Mar. 2022	Feb. 2023
LQXFA/B02	Jun. 2022	May 2023
LQXFA/B03	Jan. 2023	Dec. 2023
LQXFA/B04	Mar. 2023	Feb. 2024
LQXFA/B05	Jul. 2023	Jun. 2024
LQXFA/B06	Sep. 2023	Aug. 2024
LQXFA/B07	Dec. 2023	Nov. 2024
LQXFA/B08	Feb. 2024	Jan. 2025
LQXFA/B09	Jul. 2024	Jun. 2025
LQXFA/B10	Nov. 2024	Oct. 2025

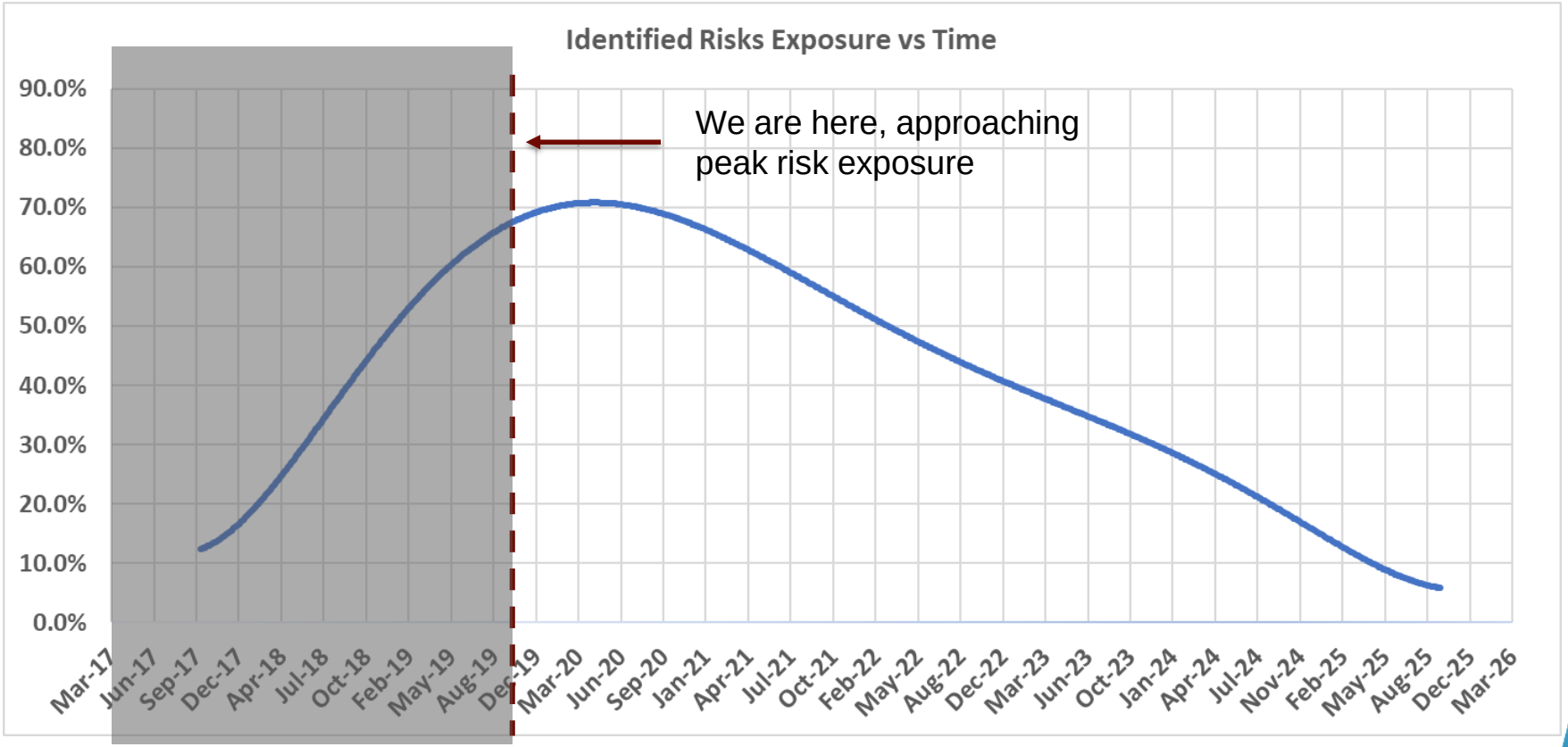
AUP is strongly schedule-driven to meet the CERN early Need By dates for LS3

Changes since CD-2 Baseline

- Changes on **EAC** includes impact of:
  - Make-up of rejected AUP coils above baseline production yield assumption
    - ~ $1.6M for 3 coils
  - Mitigation actions for possible new QH cold hipot electrical requirement
    - ~ $1M for QH internal layers “swap” design change option validation with short coils and mirror cold test
  - CERN cryostat tooling delivery schedule delay
    - ~ $0.5M for CD-4 schedule delays
  - Miscellaneous BCRs
- Changes on **Risk Contingency** includes impact of:
  - Increased threat of more pre-series cycles needed to meet requirements as a result of prototype performance shortcomings
    - No prototype has been able to fully demonstrate currently approved acceptance criteria
  - Threat of reduced coil yield because new QH cold hipot electrical requirements
    - Up to 4 coils may not pass the new cold hipot test during vertical testing (guess).
    - If “swap layers” mitigation actions underway are successful in increasing margin, then this risk can be retired
  - Miscellaneous Risk Register updates

Identified Risks Exposure vs Time

- Each risk in the Risk Register has a Start Date and an Expiration Date. Aggregating risks exposure over time yields the following curve:



Summary

- HL-LHC AUP is a baselined project (DOE CD-2 approved) with a fixed Threshold Scope, Total Project Cost (TPC) and End Date
- The TPC and End Date include cost and schedule contingency that must remain adequate for the entire project execution duration
- Risk Assessment and Contingency Analysis are performed on a monthly basis to monitor contingency adequacy
  - Monthly AUP Risk Management Board (RMB) Meetings
- Compared to CD-2, the available contingency is no longer enough to support unidentified risk events with Top-down contingency
  - Project is more vulnerable if significant new risks are identified
  - Identified risks are now supported slightly below the 90% CL
- AUP is entering a period of maximum risk exposure
  - Risk exposure starts to decrease in 2021 as open identified risks start to expire and can be retired