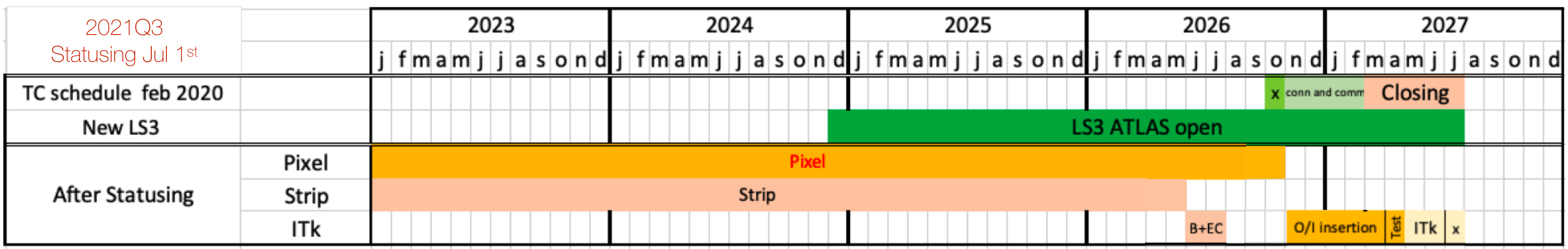
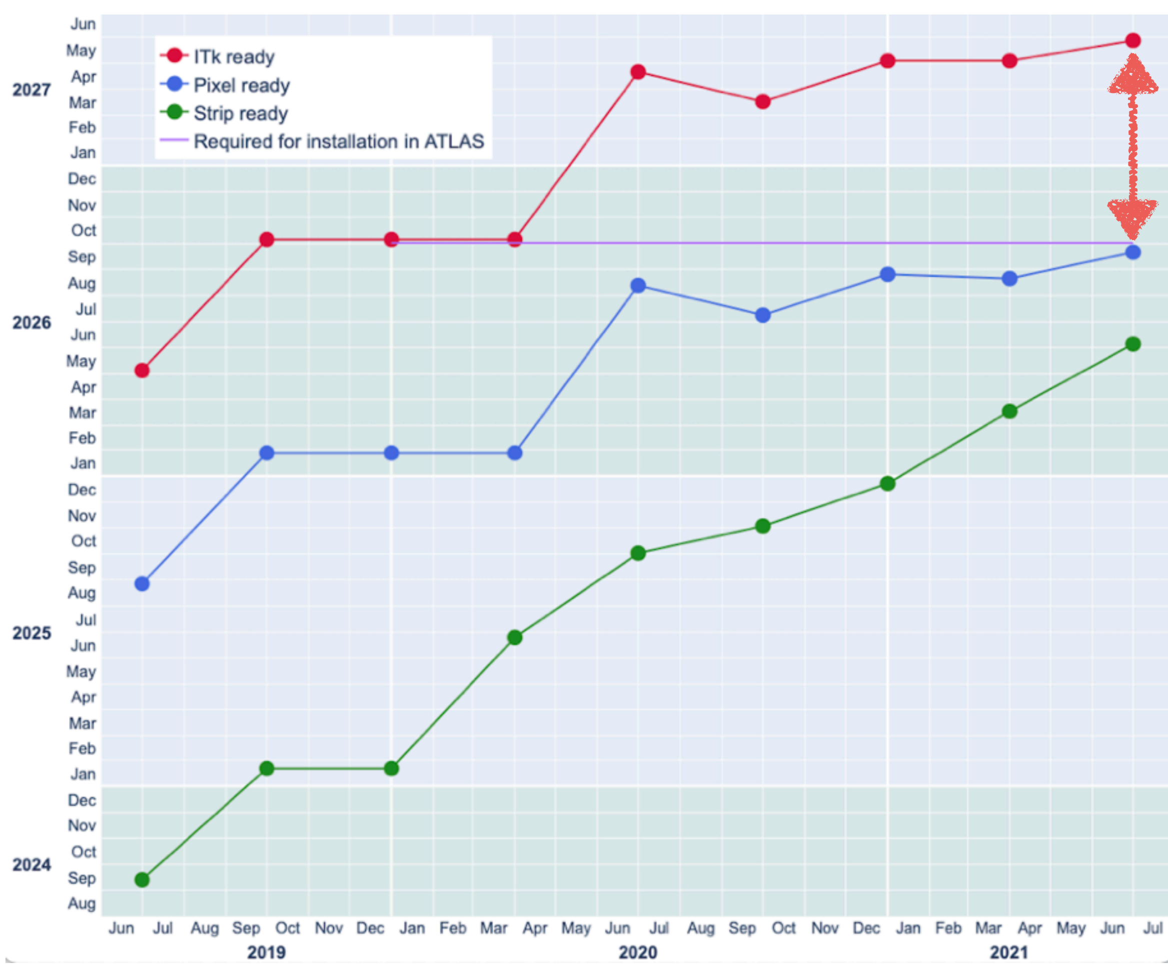
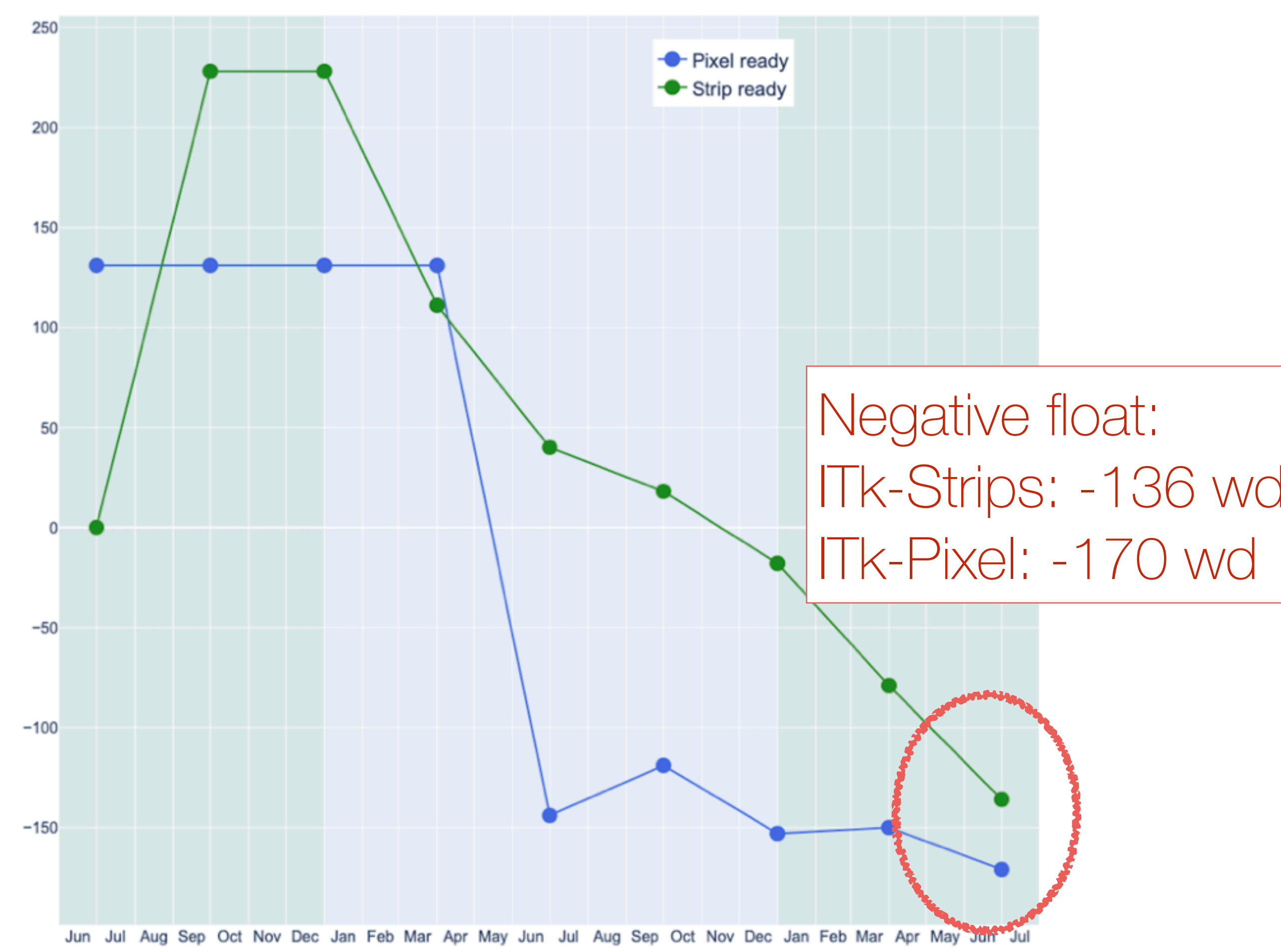
ITk-Pixel
Schedule Optimization

ITk readiness @ beg. 2021Q3

- Integration scheme in SR1:
  - OC → Strip Barrel (from outermost to innermost shells) → Strip EC
  - Assembly Pixel OB (@ CERN) + OEC (Frascati and Liverpool) → OB/OEC integrated in SR1 to finalize Outer System → Integration in ITk
  - Partial assembly of IS @ SLAC (quarter shells) → integration @ CERN SR1 → test and insertion in OS/ITk
  - Final commissioning on surface of the full ITk (2 months) before releasing it to TC for installation in ATLAS







Task-force mandate

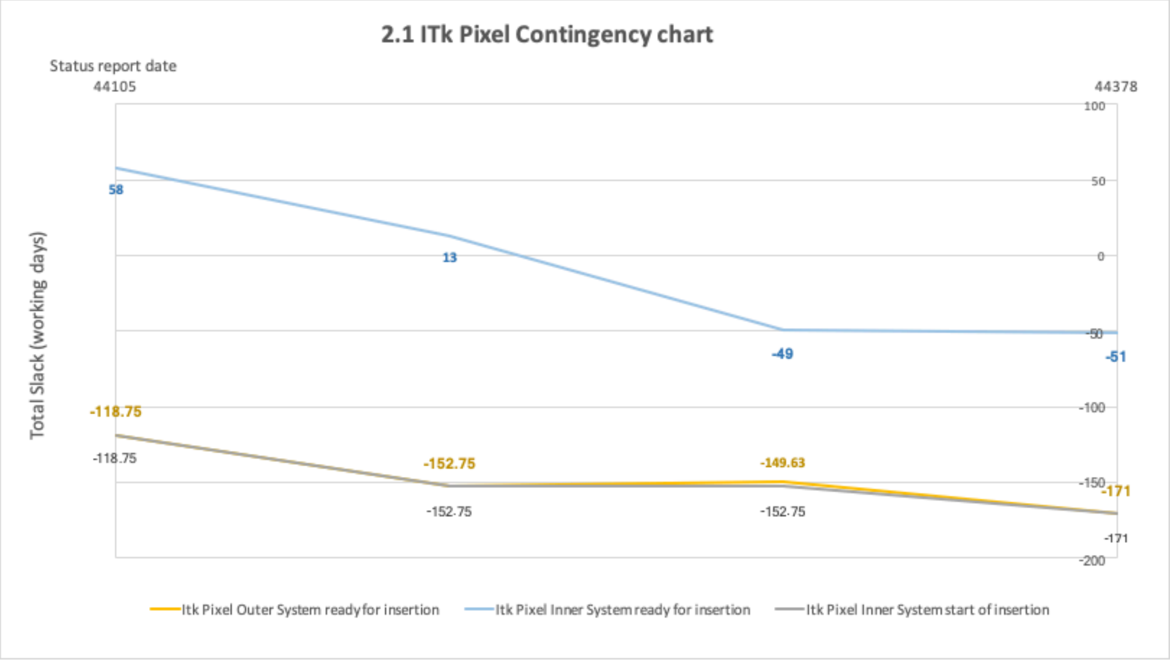
- A schedule Optimization Task Force was setup to prepare the groundwork for ATLAS management to renegotiate the LS3 dates with CERN management.
  1. Investigate the possibility of optimizing the structure and of reducing the complexity of the ITk-Pixel schedule
  2. Analyze risks aiming at estimating the appropriate schedule contingency level. Recommend the necessary float that is necessary for the Project to carry.
  3. Analyze the production flow, verify the schedule, identify bottlenecks and recommend actions for the projects to investigate that can potentially recover schedule float.
  4. Evaluate the feasibility of various installation scenarios incl. staggered (phased) installation and staged (to LS4) approaches.

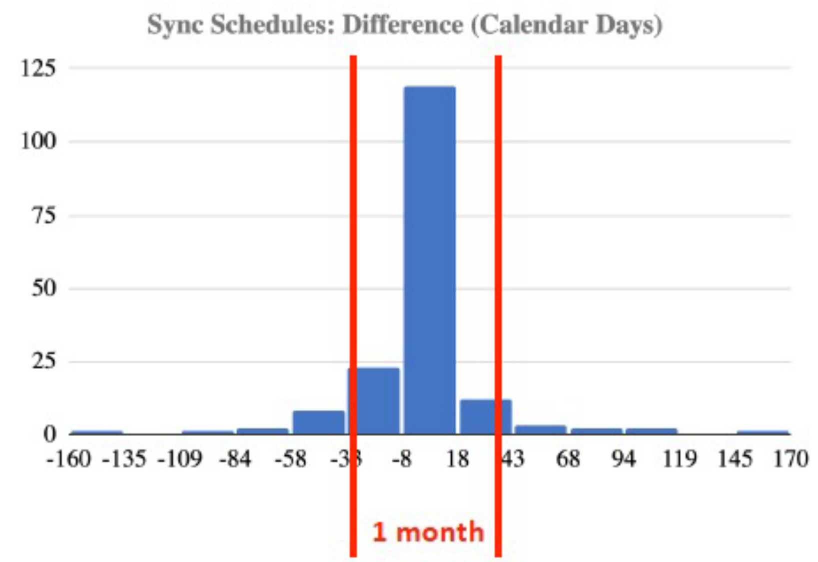
- Task Force members:
  - H. Chen, G. Gilchriese, S. McMahon, M. Nessi, S. Rajagopalan, A. Seiden
  - Ex-officio: M. Aleksa, C. Buttar, C. Gemme, F. Lanni, L. Rossi

- The conclusions by the TF were possible thanks to the whole ITk team (and Pixel in particular) for their constructive engagement and essential contributions to this effort with very detailed analysis and high quality results

1. Lightweight Schedule

- A lightweight schedule was developed by J. Metcalfe: ~1/4 size of the current schedule by simplifying much of the production process
- Validated by comparing P2UG milestones with current schedule
- Used for most of the impact studies of proposed schedule optimizations that forms the basis of this report.
- The simplified schedule has allowed also to identify fixes that were required to feedback in the main Pixel schedule:
  - ✦ From the latest statusing Pixel has -170 w-days float cf. the "needed by" date for installation: the insertion date of Pixel in ITk is statused as Aug. 2026
  - ✦ The corrections required have pushed to Oct. 2026 (i.e. 1.8 calendar years behind schedule if 1 yr contingency is included)



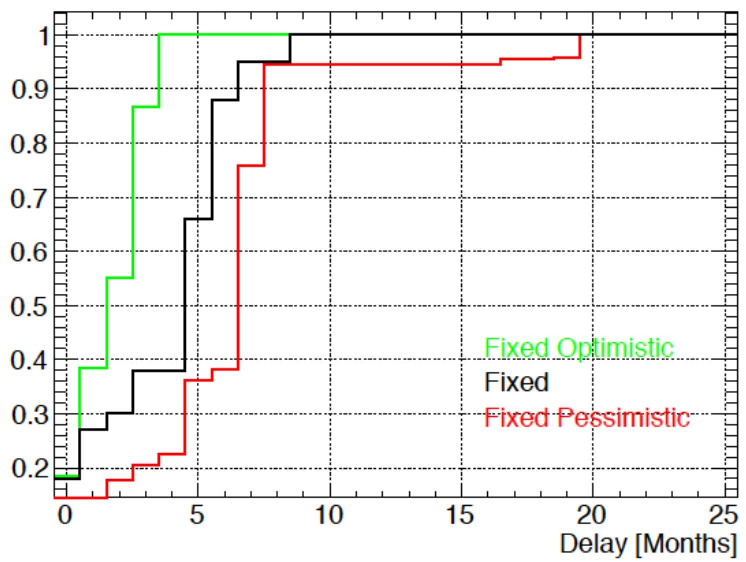


- *The future use of the simplified schedule is to be clarified:*
  - ✦ *the project recognizes the utility to study different scenarios (e.g. for mitigation) but the main question whether to use it as official schedule for monitoring the progress of the project remain, and in case it's not, how to keep it synchronized to the main schedule to keep using as important tool needs to be discussed further*

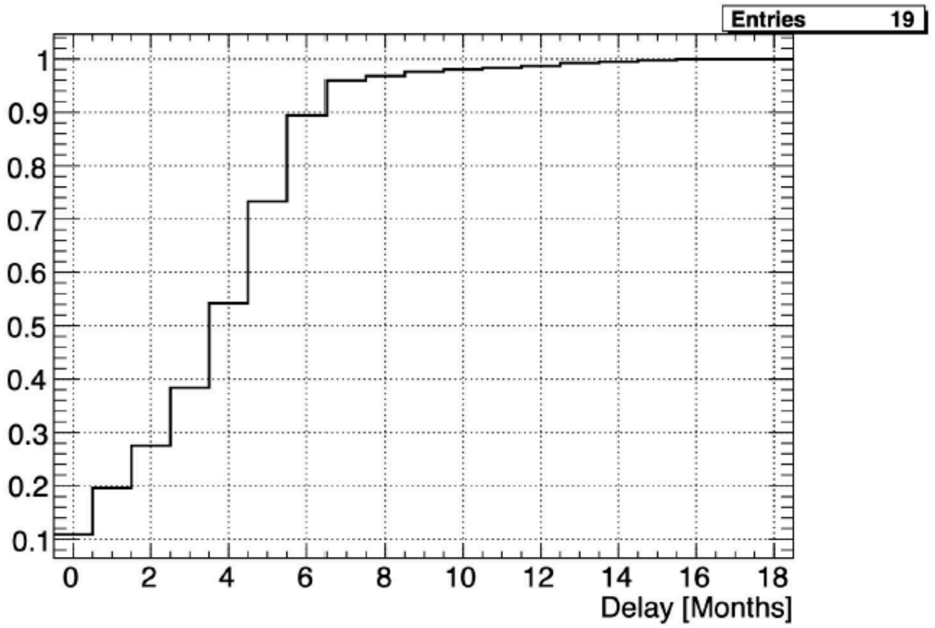
2. Schedule contingency

- To evaluate the level of contingency required Several analysis of the Risk Register were performed:
  - A simple sum of the schedule impact assuming no correlations between risks yields around 10 – 14 months.
  - More complex simulations were performed:
    - Associating the Risks with the Schedule and modifying the duration of tasks by randomly realizing the risks.
    - These experiments 7–8 month delays

Optimistic vs Most-likely vs pessimistic → Suggest 3-10 months delay at 90% CL



'triangular delay in the RR → Suggest 7-8 months delay at 90% CL



- Analysis of the Risk Register requires that the schedule impact for the risks are realistically estimated, but in many cases, it appears to be underestimated.

- At this time, the task force recommends that a 12-month contingency is appropriate and required for the Pixel Project
  - *Note this is the same as the recommendation you gave us in the last in-depth review*

➡ *The potential week points for an estimate of the required contingency are: (i) risks are very subjective, (ii) overall uncertainty probably would be driven by the uncertainties on the durations of the tasks in the baseline schedule rather than by the risks.*

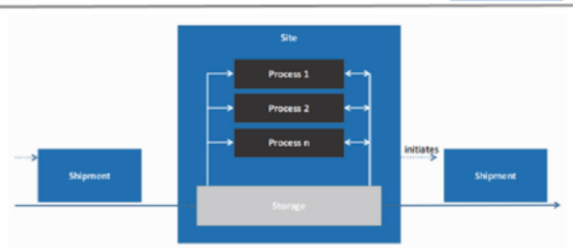
3. Optimizations and bottlenecks

- The analysis of the Pixel schedule has allowed the TF to identify a number of possible optimizations for further study. Two main tools were used:
  1. The schedule impact of each of these proposed optimizations were determined using the lightweight schedule.
  2. D. Pohl developed - based on similar tools done by Strip colleagues - a tool that mimics the production flow from sensors to hybridizations (rest to be implemented) that yielded additional avenues for optimizations.

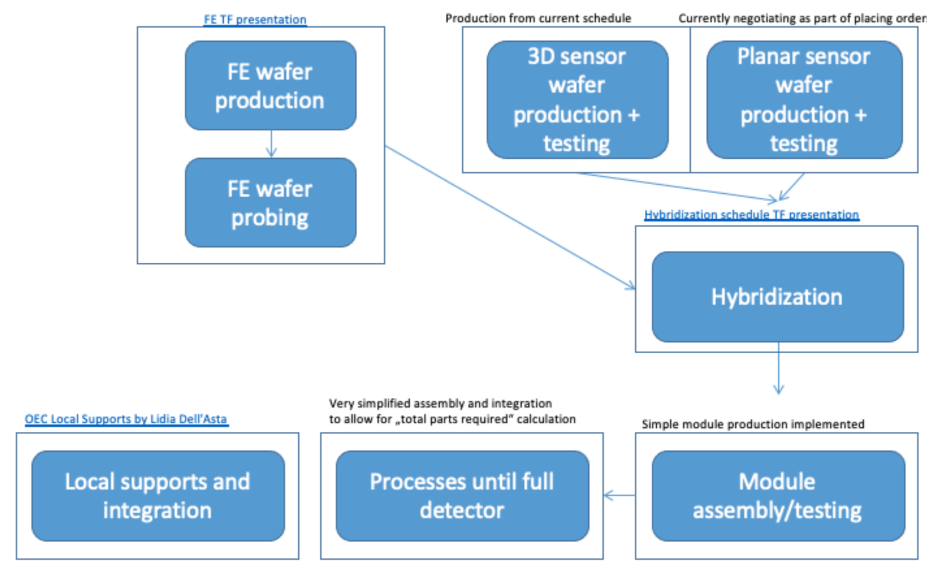
IPPS: **I**Tk **P**ixel **P**roduction **S**imulation: to validate and optimize the pixel production flow

- Code hosted at: https://gitlab.cern.ch/silab/itk-pixel-production-simulation
- Project web-page: https://cern.ch/ipps/

Pixel Production Flow Simulation: Design



- Simulate all production sites and shipments, include production processes that create shipped parts



- Some require follow-ups with the project to confirm the extent of the gains in schedule through the official baseline

- Gains may be counterbalanced by increased risks to the Project. Such risks have not been estimated quantitatively yet
  - ✦ Some require additional resources at sites that have not yet been realized.
  - ✦ Some relax the requirements for the PRR to advance the schedule and thereby can incur additional risks.

3. Optimizations and bottlenecks (cont.)

- Two fundamental strategies to the optimization process:
  - ✦ Advance start of the production phase
  - ✦ Increase production rates of the various components
- Start of the production phase held by sensor delivery. FE ASIC is close - no much room to advance the start of the production
- The rate of sensor delivery is the main issue through the hybridization phase.
  - ✦ Accommodate higher sensor rate for the hybridization process (larger vendor capacity + flip-chip institutes) is possible (but historically an issue)
  - ✦ Negotiating with the vendors to increase the sensor production rates is critical, even if it may incur a financial impact
- Once the module assembly production begins, this drives the schedule. There are 13 sites, but the capacity of each production site has not been assessed. Allocation of module production across sites should be based on site capacity, resources and experience.
  - ✦ A comprehensive evaluation of module production and re-allocation of scope has the potential to increase the overall rate of module production rates.
  - ✦ Can be increased by up to ~6 mo. before sensor rates becomes the bottleneck

3. Optimizations and bottlenecks (cont.)

- Local Support Assembly is driven by the availability of modules and services.The start of the production phase for loaded local supports can be advanced significantly (by ~6 mo.) if:
  - Requirements on the MOPS are relaxed for PRR. (i.e. use v2 MOPS rather than waiting for pre-production MOPS).
  - Requirements on using the pre-production PS are relaxed, i.e. commercial off-the-shelf PSU need to be acquired for pre-production phase and the DCS software needs to be adapted. This has a cost impact ~250k.
  - There is not much room to increase the rate of loaded local support production unless an additional site can be added, or the number of shifts are increased at selected sites.

- The major obstacle for the OB integration phase appears to be the availability of resources at CERN.
  - Due to lack of skilled mechanical technicians, activities at CERN are sequenced.
  - CERN is responsible for the production of bare and loaded local support, global mechanics and integration.
  - Hence integration at CERN can only begin after they have completed their share of the local support production for OB.
    - Unless 4 additional technicians can be brought on board over at least a 2-year time frame to assist this process.
    - This can not only help to parallelize the effort, but also to speed up the production phase.
    - A side note: finding skilled people is difficult, accounting for ramp up and training time is essential.

3. Optimizations and bottlenecks (cont.)

- Implementing all the proposed optimizations in the lightweight schedule shows that the readiness for the Pixel detector insertion into ITk can be as early as Jan. 2026 (from Aug (Oct) 2026 in the current status (corrected) schedule [needed date is Feb]
- UC will negotiate w/ ITk management how and in what time scale how to implement each
  - *The following table, prepared by ITk, summarizes the saving of each of the optimizations discussed with the TF*

Scenario	Name	Saving on OS [cd]	Change	Risk in the change	Proposal	Comment
1A	Corrections	44	few small bugs	LOW	Check them and implement	In Aug BCP
1B	MOPS v2	0	use Proto in Preprod	LOW	Opportunity	Implement after FDR - early 2022
1C	FE chip	0	probing time and production mode	LOW	Implement	In Aug BCP
1D	Hybridization rates	-70		LOW	Check it and implement	In Aug BCP structure and assumed rates - then update after tender
1E	Sensor PRR	-19	Reduce Module testing	LOW	Implement	In Aug BCP
1F	Split Module PRR	0	Hybrid and Assembly	LOW	Implement	In Aug BCP
1G	Local support PRRs	0	Split IS and OS	LOW	Check it and implement	Future BCP
1H	Power supplies	0	Use COTS for loading	MEDIUM	Check it and implement	Pretty soon, urgent if nonCORE fundings are needed. Future BCP after PS FDR1 in Sep
1J	GM PRR's	-93	Split IS and OS	LOW	Check it and implement	Not clear yet in main schedule.
1K	Rapid assembly sites	-13	Accelerate fewer sites for PRR	LOW	Check it and implement	In Aug BCP
1L	Services PRR's	-28	Split IS and OS and more	LOW	Check it and implement	Future BCP (opportunity)
1M	MOPS Pre-prod	-39	use Proto in Prod	LOW	Opportunity	Implement after FDR - early 2022
		-218	Readiness Oct to Jan (need Feb)			

3. Main recommendations

General Recommendations

1. **To ITk:** The ITk team shall incorporate the corrections identified during the optimization studies process and listed in Appendix A of the report in the baseline schedule.

2. **To ITk:** The project should incorporate the optimizations recommended in this report to the baseline planning and summarized in Appendix A of the report.

3. **To ATLAS:** management should work with CERN management to negotiate a suitable schedule for LS3 and the start of Run 4 that would allow the successful completion of the ITk detector. The minimum additional time required to complete the ITk upgrade is 1.5 year delay to the start of Run 4 wrt the current schedule.

Specific recommendations on each step of the “Pixel construction” in backup slides #25, #26

Recommendations on Installation

1. Prepare a mitigation plan by October to ensure construction completion within the 18 months extension
   - Reallocating resources to complete the OB and OEC earlier and with higher priority and plan for a phased (later) insertion of the IS during LS3.
   - Prepare for a possible deployment of a partial OEC, with a long-term strategy of its removal and insertion of a completed new OEC that can fit within the current PST volume.
   - Both these scenarios would require highest priority for the completion of the OB construction.

2. Develop a plan for an updated PP1 design, by Sep. 2021, to allow the flexibility of decoupling the barrel and endcap.

Recommendations on Contingency

1. Include 12-month contingency in the current planning and regularly monitor its usage and its consistency with the risk register.

Recommendations on Resources

1. ATLAS management must engage CERN management to secure sufficient resources to allow for the needed parallelization in the production process (see slide #24)

2. The ITk team must verify the availability of skilled resources in a timely manner at all production sites.

3. Other recommendations (WBS specific)

Sensors (WBS 2.1.1):

- Negotiate and secure as fast as possible the rate of delivery of production sensors. Reallocate the volume of sensor production amongst vendors with the aim of optimizing both schedule and cost, rather than solely focusing on the cost aspect.
- Develop a fast-track module testing program to qualify the pre-production sensors and move rapidly towards a PRR.
- Assess the risk and associated mitigation of moving forward with the sensor PRR without adequate module level testing if other mechanisms to achieve the required speed up fail.

FE ASIC (WBS 2.1.2):

- Update wafer probing rates in the schedule.
- Rework the schedule with more realistic assumptions for submission of the engineering and production batches and reoptimize the split amongst production batches.
- Plan ahead of time for SEE testing of the engineering batch prior to the submission of the first batch for production. Re-optimize the batch volumes, with sufficient volume >10% in the first batch, to ensure that they do not hold up the hybridization phase.
- Plan on setting up a fourth wafer probing site at LBNL and work the logistical issues tomake this efficient.

Hybridization (WBS 2.1.3):

- Prepare the hybridization order in such a way to have the maximum efficiency and flexibility, namely:
  - ✦ Define a minimum fraction of the order that should go to a single firm (e.g. 10%) to avoid too much overhead for a minimum contribution. Define also a maximum fraction of the order (e.g. 40%) to avoid depending too strongly on one single vendor.
  - ✦ Define, if possible, a minimum hybridisation rate below which ATLAS has the right to compensation or reduction of the amount ordered. Define a rate above which the firm may get a bonus (e.g. 10% more on the deliveries in advance)
  - ✦ Agree for the possibility of partial delivery (-~30%) in case this is required by a change in the pixel project planning (staging).
- Define the acceptance criteria for bumped parts (sensor tiles, FEchips) in such a way that the flip-chip labs can operate in controlled conditions.
- A risk for lower-than-planned hybridisation rate exists (R1-006). Suggest to revisit this risk (currently qualified as low in schedule impact) and consider that it may have high schedule impact, as it has been the case in previous projects (suggest to use Min/Ave/Max risk of 10%/25%/40% lower hybridisation rate).

3. Other recommendations (WBS specific)

Module Assembly (WBS 2.1.3):

- Evaluate the true module production capacity of the various sites. Optimize the module production allocation amongst sites with the aim of maximizing the module assembly throughput. Rework the module production schedule.
- Develop a comprehensive production plan to manage the logistics of producing modules at all these sites. This should include identifying leading sites that have the resources, infrastructure and expertise to rapidly move forward and plan for an early PRR and an early production launch at these sites, with an appropriate qualification process defined for the slower sites.

Local Support Loading (WBS 2.1.5):

- Rework the requirements for the loaded local support PRR to advance the schedule.
- ATLAS management must investigate the possibility of obtaining additional sites for the loading of the local support to allow additional flexibility to speed up the OB production phase.

Services and DAQ (WBS 2.1.4, 2.1.8, 2.1.11):

- Plan on using the v2 MOPS for pre-production and PRR of services and loaded local supports.
- Plan for acquiring off-the-shelf power supplies for tests required during the pre-production phase of the loaded local support, that is necessary for advancing their PRR. Adapt the DCS software for the off the shelf supplies.
- Investigate the possibility to speed up the post FDR to PRR phase considering that some flavors would have been qualified.
- Ensure that FDR and PRR is not held up by a single or few items. Plan on moving forward with the reviews with the remaining qualified components to advance the production process.

4. Phasing and Staging

- A number of phasing and staging scenarios have been considered that allows the installation of a partial detector initially and completing the remaining installation at a later time (phasing → completing within LS3, staging → in LS4/LS5)

Procedure							***Description***
						BP	
1.0_Ph	Strip	OB	OEC	IS	ISE	VI	Baseline
1.1_Ph	Strip	OB	OEC	IS	ISE	VI	OS On Surface
1.2_Ph	Strip	OB	OEC	IS	ISE	VI	Pixels Underground
1.2_St_OEC	Strip	OB	OEC	IS-B	IS-E	VI	OEC Fully Staged
1.0_St_L4	Strip	OB-B4	OEC-R4	IS-B	IS-E	VI	OS staged w/o the
1.0_St_B4	Strip	OB-B4	OEC	IS-B	IS-E	VI	OB staged w/o the
1.0_St_B3	Strip	OB-B3	OEC	IS-B	IS-E	VI	OB staged w/o the
1.0_St_OEC	Strip	OB	OEC	IS-B	IS-E	VI	OEC Fully staged
1.0_St_R4	Strip	OB	OEC-R4	IS-B	IS-E	VI	OEC staged w/o the

Detector Part	Surface [m^2]
Inner Barrel Flat	0.48
Endcap Inner Rings	1.77
Inner Total	2.26
Outer Barrel Flat	3.69
Outer Barrel Inclined	3.25
Outer Barrel Total	6.94
Endcap Outer Rings	3.64
Barrel Total	7.42
Endcap Total	5.41
Total	12.83

Barrel			
	Total		
B0	288	288	IS-B single
B1	240	240	IS-B quads
B2	960		
B3	1496	4472	OB
B4	2016		
Total	5000		
End-cap			
	Total		
R0	540	900	IS-EC single
R0.5	360		
R1	920	920	IS-EC quads
R2	704		
R3	704	2344	OEC
R4	936		
	4164		

No. of modules per detector region

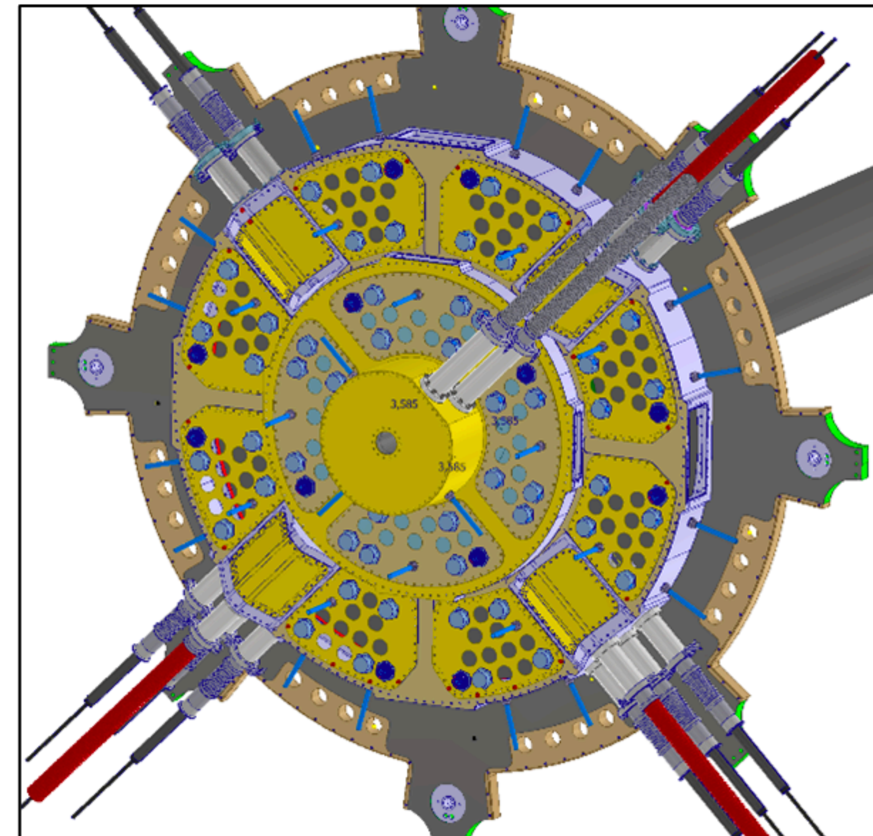
- Each scenario was studied in detail by ITk with evaluation of many required steps
  - Redesign of detector elements (e.g. PP1, and for an "independent" EC installation in ITk also PST, OB services, EC Envelopes w/o huge impact)
  - Estimate of tasks durations
  - ALARA estimates and additional resources required
  - Sensor damage enhanced @ warm during the staging operations
- All staging scenario imply long time and large risks for resources and detector may easily turn into descoping

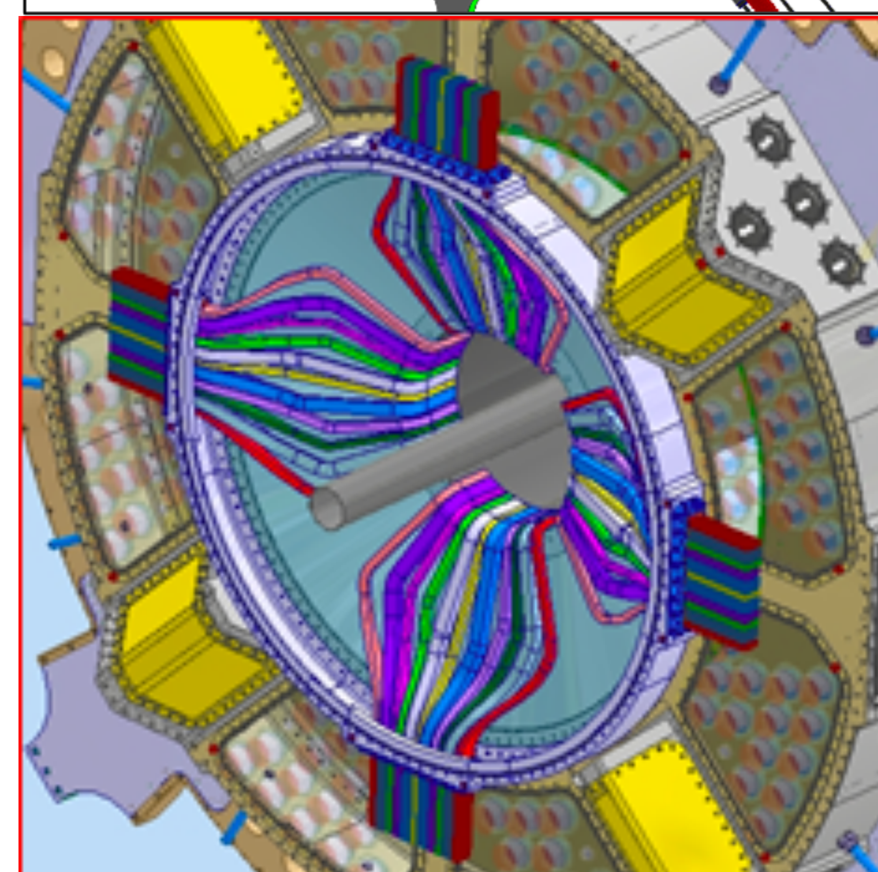
PP1 design changes

Several challenges in the PP1 design changes required for any staged/phased scenario

1. The IS has been designed to be replaceable in the pit.
   - Design assumes a replacement with a new set of services, i.e. the extraction does not preserve the services.
   - PP1 design requires to cut at least the DATA links to remove the IS. DATA links reach PP0 without breaks and they would need to be be replaced entirely if cut.
2. OS PP1 has been designed to be permanent .
   - OS has a large pipework to be cut, removed, re-installed and re-welded.
3. Redesign of the DATA links feedthrough:
   - removable feedthroughs were discarded in the early design phase due to the poor leak-tightness experienced.
   - Tentative method could be explored splitting the large feedthrough into smaller ones.
   - A large number of DATA links will still be cast together when they are arranged on the services trolley. Bending the bundle would require more space since its bending radius is larger than the single cable. This is a relevant issue.

   ➡ A time required to redesign the feedthroughs and perform leak tests to qualify the new design would be about 4-5 months.





PP1 design changes

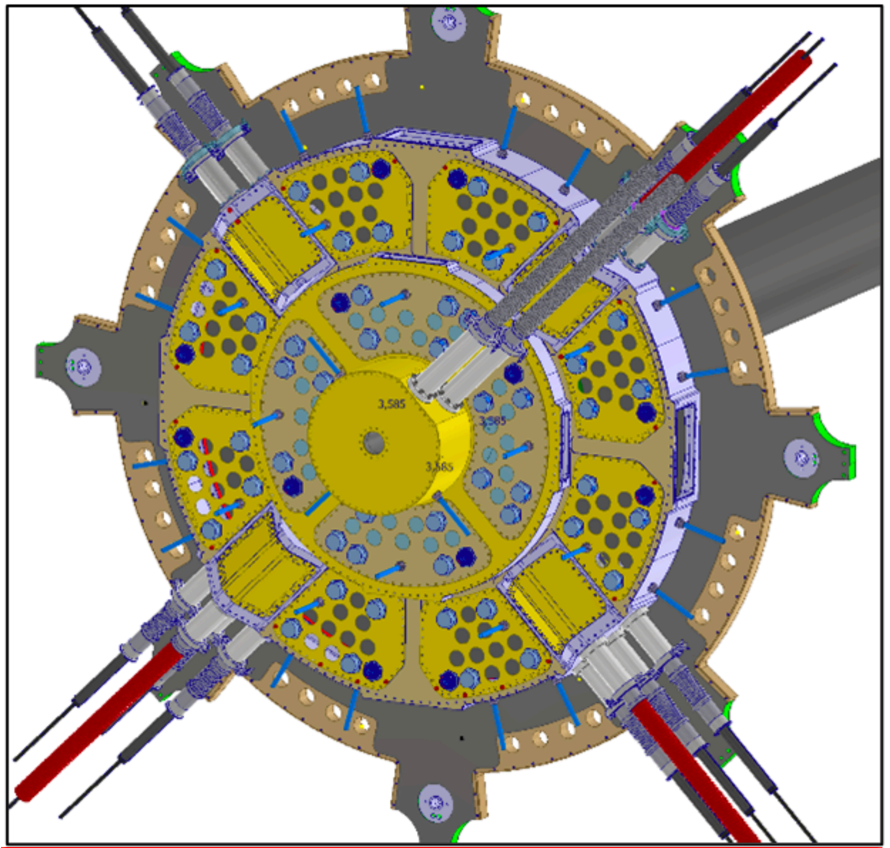
4. Bending irradiated cables.
   - The DATA links have been already qualified at the expected radiation dose. The irradiation has been performed coiling up the cable at the minimum bending radius needed for storing it in the Services Trolley.
   - Tests have shown that the cable keeps functioning properly but the dielectric was noticed to become brittle. Some cracks have been observed that do not compromise the transmission until the cable is uncoiled.
   - Undoing PP1 requires to bend several times irradiated cables. This is not consistent with what qualified so far.

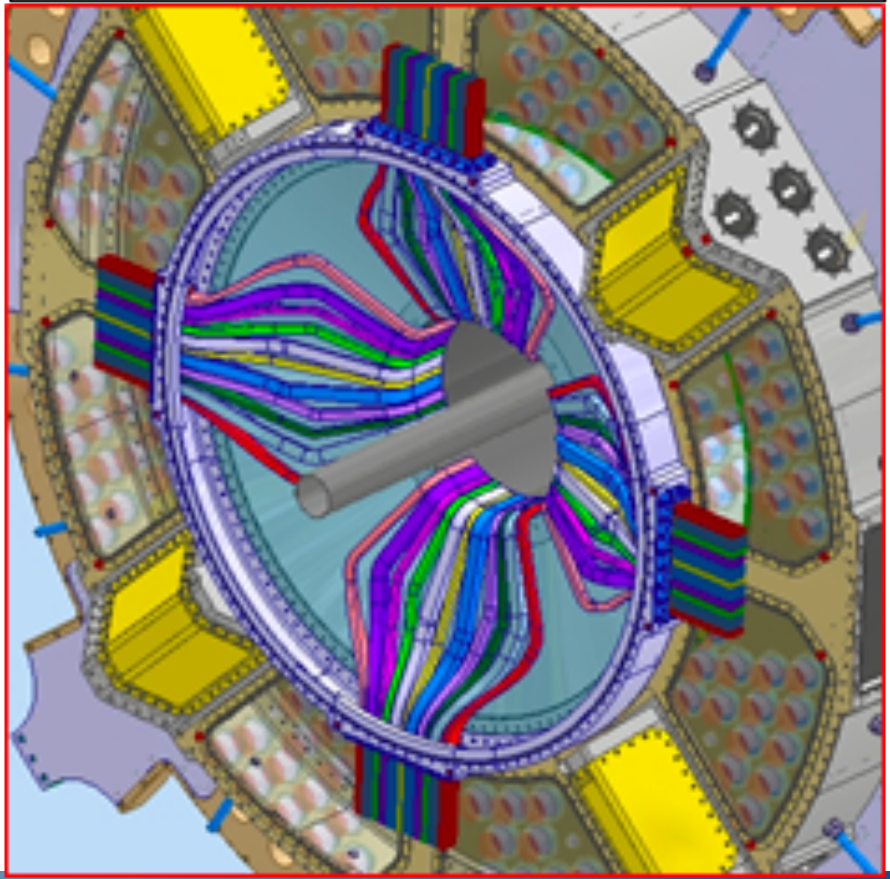
5. Cable re-arranging in the "Services Trolley":
   - Extremely high risk of damaging the cables regardless the weakening induced by the radiations in some of them.

6. Cutting irradiated pipe.
   - To extract the OS, several irradiated pipes must be cut. Cutting generate radioactive debris.

7. Welding irradiated pipes.
   - Once the staged OS are installed back into ITk, the pipes previously cut need to be welded. Welding on active pipes (at list the ones on the detector size will be irradiated) is again complicated in SR1.

8. IST flange:
   - bonded in place before dressing up the cables in PP1. Design needs to be modified to make it removable.





OEC Staging

- Two main aspects of the current Pixel design prevent the installation of the outer End-caps (OEC) into ITk without extracting the Outer Barrel (OB) first, namely:
  - The Inner Support Tube (IST) is supported by the ECs.
  - The service support shells, which contain the Type-1 services and the cooling pipe extensions for the Outer Barrel, are directly bolted to the outermost shell of the End-caps
- IST Support:
  - There is only a 2 mm gap between the IST and the outer system. This is insufficient to allow safe insertion along the full 6 m length and bare Si is located at inner radii of the inclined rings in the barrel.
  - Therefore the insertion of the IST from the end of the detector is not considered a viable solution. The lack of insertion gap in the current design requires that the second half of the Outer Barrel must be assembled around the IST.
  - Thus, to make possible an independent installation of the Endcaps, **the weight of the IST (and in the end that of the Inner System) would have to be supported by the Outer Barrel in the final detector configuration**.
  - In theory such a change in the support scheme is feasible, **but would require heavy modifications in the mechanical design of the Outer Barrel and the Patch Panel 1 (PP1)/Bulkhead area.**
- PST modifications:
  - would need to be modified to allow the EC-A, OB and EC-C to be aligned separately when installed.
- Service Support shells:
  - The PST would need to be modified to allow the EC-A, OB and EC-C to be aligned separately when installed.
  - Insertion space for the EC would have to be found, this would require changes to the envelopes for the EC, OB-services and the PST.
  - This is not feasible without changes to the envelopes for the EC, PST and OB-services. Changes to the envelopes is a major redesign: the PST would impact on the Strip, the OB-services would have to be reduced, thus reducing the data throughput, the EC would require to redesign the local support which are constrained by the module size, etc …
  - It would require changes to the PST to support the OB services shells.

ALARA

- TC and HSE (R. Froeschel): simulations different scenarios for staging in LS4
  - ✦ FLUKA geometry from the ATLAS Radiation Simulation WG (Step 3.1 quick model, version 6 (S3.1Q6))
  - ✦ HL-LHC luminosity profiles extracted from HL-LHC TDR
  - ✦ Cool-down grid 1-12 months, 1 month step

		Nominal		***Ultimate***	
		Lumi/Year	Integrated Lumi	Lumi/Year	Integrated Lumi
Run 4	2027	18.5	18.5	18.5	18.5
	2028	73.8	92.3	73.8	92.3
	2029	215	307	215	307
	2030	254	**561**	254	**561**
Run 5	2032	270	831	270	831
	2033	327	1158	405	1236
	2034	327	**1485**	405	**1641**
Run 6	2036	311	1796	385	2026
	2037	360	2156	445	2471
	2038	360	2516	445	2916
	2039	360	2876	445	3361
	2040	360	**3236**	445	**3806**

- Calculation of exposure maps for the ALARA for the following detector configurations
  1. Full ITk in the cavern with calorimeter end-caps moved to standard opening and with the beam pipe
  2. Full ITk in the cavern with calorimeter end-caps moved to standard opening and the beam pipe removed
  3. ITk without the Inner System and the beam pipe in the cavern with calorimeter end-caps moved to standard opening
  4. ITk without the Inner System in SR1 (= configuration 6+7)
  5. Inner System only in SR1
  6. ITk Strips only in SR1
  7. Outer System only in SR1
  8. Full ITk without the beam pipe in SR1

Activities Duration

- Project has studied w/ some level of details the sequence of the operations to un-stage and re-integrate the staged detector in ITk

Duration [wd]	Detailed Staging L4	Detailed Staging OEC
ITk De-Installation	29	29
Pixel De-Integration	44	39
Pixel Staging	273	9
Pixel Integration	75	75
ITk Installation	33	33
Total [wd]	454	185
Total [mo]	23	9

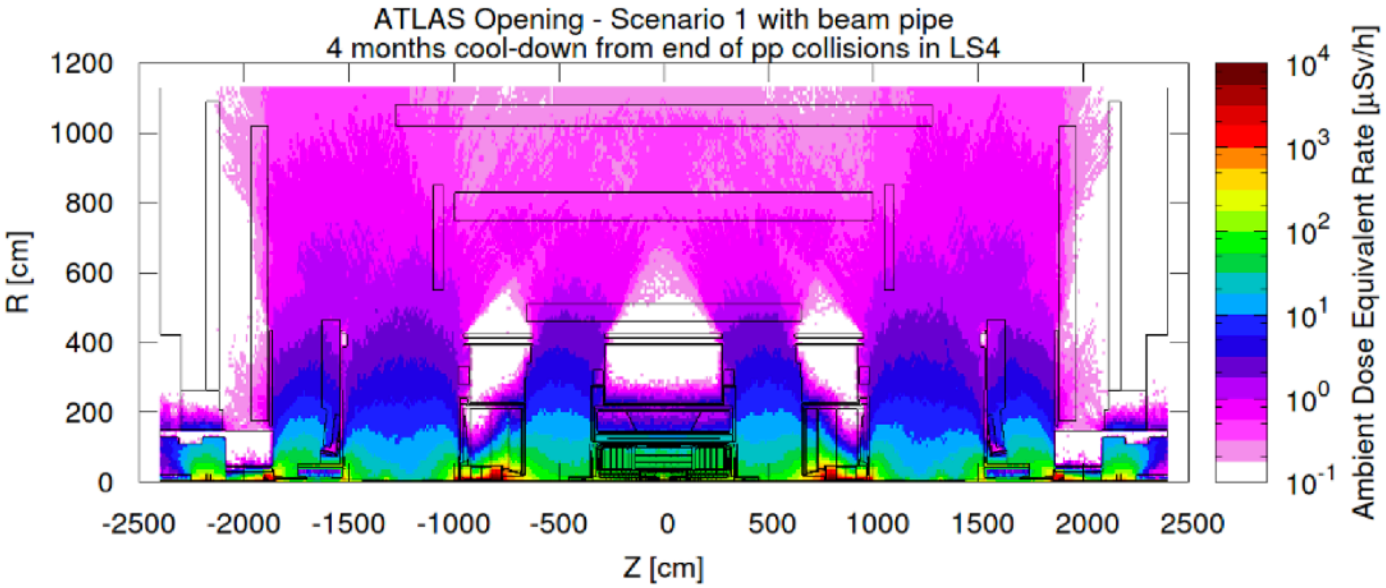
The Detailed estimates for the integration, installation phases are more aggressive and yield:

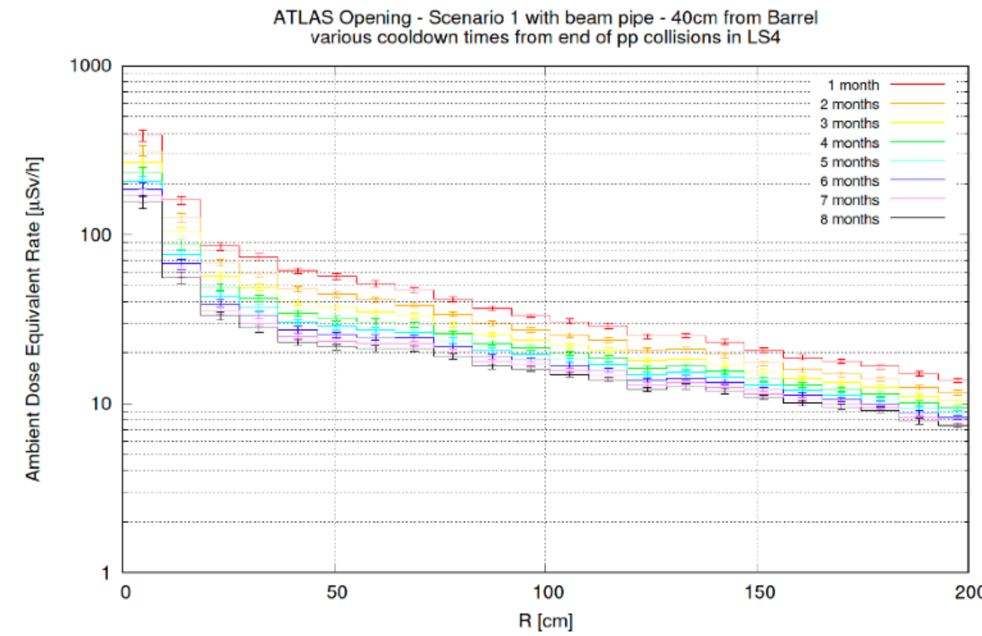
- 4 months from the beginning of the ITk detector deinstallation to the start of the Pixel staging (ITk up) ,
- Staging time can vary from less than 1 month to 14 months or more according to the scenarios.
- 5 months to reintegrate the Pixel in ITk and install back the detector (ITk down).
- On top of that a minimum cool-down period has to be added

Staging

Type	*Step*	*Resp*		*Basline wd*	w/ SF	From staging L4	From staging OEC
ITk de-Installation					0.3		
	OSV opening	CM	UG	9	3	9	9
	Beam pipe removal	CM	UG	2	1	1	1
	Pixel deconnection	CM	UG	38	11	9	9
	Strip deconnection	CM	UG	28	8	5	5
	deInsertion and back on surface	CM	UG	20	6	5	5
				97	29	29	29
					0.4		
De-Integration pixel in ITk	Introduction in SR1 and setting on the	CM	SR1	8	3	3	3
	DeConnection of IS Services (pipe welc	Pixel	SR1	35	14	7	7
	deInsertion of ITk IS into ITk	CM	SR1	13	5	6	6
	deConnection of Services (pipe weldin	Pixel	SR1	45	18	25	20
	deInsertion of ITk OS into ITk	CM	SR1	8	3	3	3
				109	44	44	
					1		
De-integration Pix	OB-EC Separation	Pixel	SR1			18	9
	Integration of OB L4 OBH2	Pixel	SR1			101	0
	Integration of OB L4 OBH1	Pixel	SR1			93	0
	Integration of EC L4 C	Pixel	SR1			144	0
	Integration of EC L4 A	Pixel	SR1			144	0
	Re-integration of the Outer System an	Pixel	SR1			61	0
						273	9
					0.6		
Integration pixel in ITk	Insertion of ITk OS into ITk	CM	SR1	8	5	4	4
	Connection of Services (pipe welding a	Pixel	SR1	45	27	34	34
	Insertion of ITk IS into ITk	CM	SR1	13	8	6	6
	Connection of Services (pipe welding a	Pixel	SR1	35	21	20	20
	PP2, PP3 and cooling connection of IS	Pixel	SR1	10	6	6	6
	Pixel Test 12.5%	CM	SR1	20	12	0	0
	ITk commissioning	CM	SR1	0	0	0	0
	Disconnection and packaging of servic	CM	SR1	8	5	5	5
				139	83	75	75
					0.3		
ITk Installation	Lowering and Insertion	CM	UG	20	6	5	5
	Strip connection	CM	UG	28	8	5	5
	Pixel connection	CM	UG	38	11	9	9
	Beam pipe insertion	CM	UG	1	1	5	5
	OSV sealing	CM	UG	9	3	9	9
				96	30	33	33

- Examples:





- Work packages and individual and collective doses for the different tasks. Examples of OS-B/L4 and OEC staging (no mitigations)

Team	Total dose per team for L4 staging [mSv]	Total dose per team for OEC staging [mSv]
ITk Integration	18.4	20.8
ITk Pixel	53.6	14.0
ITk/TC	1.4	1.4
RadioProtection	0.6	0.6
Supervisor	0.6	0.6
Beam Pipe	0.9	1.0
Total	75.4	38.4

Table 3.2: Collective dose for different staging scenarios listed by intervening team

Team	Total dose per operation for L4 staging [mSv]	Total dose per operation for OEC staging [mSv]
ITk De-Installation	13.3	13.3
Pixel De-Integration	6.4	6.0
Pixel Staging	46.4	1.3
Pixel Integration	3.8	11.0
ITk Installation	5.6	6.8
Total	75.4	38.4

Table 3.3: Collective dose for different staging scenarios listed by major operation.

- Such expected exposure will lead to a classification as ALARA level 3
- Given the duration and the amount of personnel involved in the tasks, both scenarios do not seem to be impossible from the ALARA point of view, but would need a thorough preparation of work procedures together with CERN and ATLAS safety teams, including mitigation measures:
  - ➡ Optimization of work procedures to reduce exposure, preparation of protective equipment such as shieldings, as well as the use of dedicated distance tools or robots. To consider such a scenario strong performance and schedule arguments would be needed.

Sensor damages

- Sensors radiation damage will limit the "warm time" and also imply a max lumi at which staging can occur.
- Launched work in late May

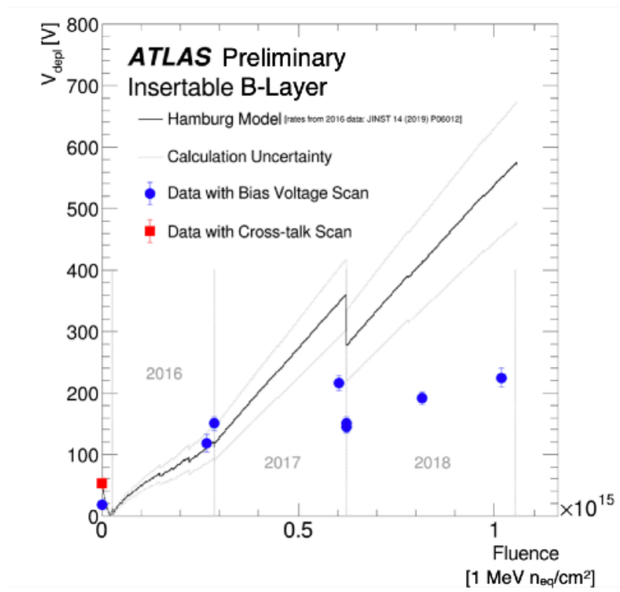
V2- Staging L4	Strip	OS Unstaged	OS Staged	IS	Staging L4
OSV open, BP removal, Pixel disc		19	19	19	19
Strip disc, Transfer on surface	10	10	10	10	10
IS Pixel out of ITk		16	16	16	16
OS Pixel out of ITk	28	28	28		28
Staging			273		273
OS integration in ITk	38	38	38		38
IS integration in ITk and readiness		37	37	37	37
Lowering and insertion	5	5	5	5	5
Services connection	28	28	28	28	28
Total Warm [wd]	109	181	454	115	
Total Warm [mo] no staging	5	9	23	6	

V2- Staging OEC	Strip	OS Unstaged	OS Staged	IS	Staging OEC
OSV open, BP removal, Pixel disc		19	19	19	19
Strip disc, Transfer on surface	10	10	10	10	10
IS Pixel out of ITk		16	16	16	16
OS Pixel out of ITk	23	23	23		23
Staging			9		9
OS integration in ITk	38	38	38		38
IS integration in ITk and readiness		37	37	37	37
Lowering and insertion	5	5	5	5	5
Services connection	28	28	28	28	28
Total Warm [wd]	104	176	185	115	
Total Warm [mo] no staging	5	9	9	6	

- Estimates for Strip are reassuring.
  - Annealing studies on irradiated mini-sensors have demonstrated that the charge collected in the regions w/ the highest fluence ($8x10^{14}$ n/cm^2) corresponding to detector end-of-life, to satifsy the requirements of Q_{coll} >6350 electrons at a bias voltage of 500V (x2 SF).

Total Fluence	LS4	LS4->LS5	LS5	End of Life
8e14	14.8	14.9	12.9	10.
16e14	11.5	11.6	10.2	6.6

- For Pixel there are only very preliminary results that seem to indicate to be rather marginal:
  - To be discussed by the sensors group, better validated by Sep.
  - Simulation may be very conservative (x2.5 on IBL) - TBC



4. Phasing and Staging: Conclusions

- The TF believes that staging scenarios that have been studied carry significant technical risks and may have an irreversible negative impact on the experiment.
  - The staging of Layer 4 of the Pixel Outer System, considered as having the least negative physics impact compared to all other scenarios, carries significant technical risks and requires the ITK to be raised back to the surface and reintegrated. It will gain approximately 6 months in schedule but cost over 2 years of challenging operations during LS4.
    - ➡ The staging of L4 of the OB is strongly discouraged. The ITk team must therefore make every effort to reallocate the resources to complete the OB with high priority and on schedule.
  - The staging of the Pixel OEC carries both technical challenges and will have a significant impact on the physics.
  - While it is acknowledged that an in-situ installation of the OEC would require major rework of the design and layout of the detector, it would be prudent for the ITk team to consider such an option for an eventual replacement of the OEC. A possible option to consider is the installation of a partial OEC in LS3 (that can be completed within schedule) followed by an in-situ installation in the cavern of a completely redesigned OEC in LS4.

- Any staging option will require significant discussions with all concerned national entities and funding agencies to renegotiate the scope of the contributing partners.

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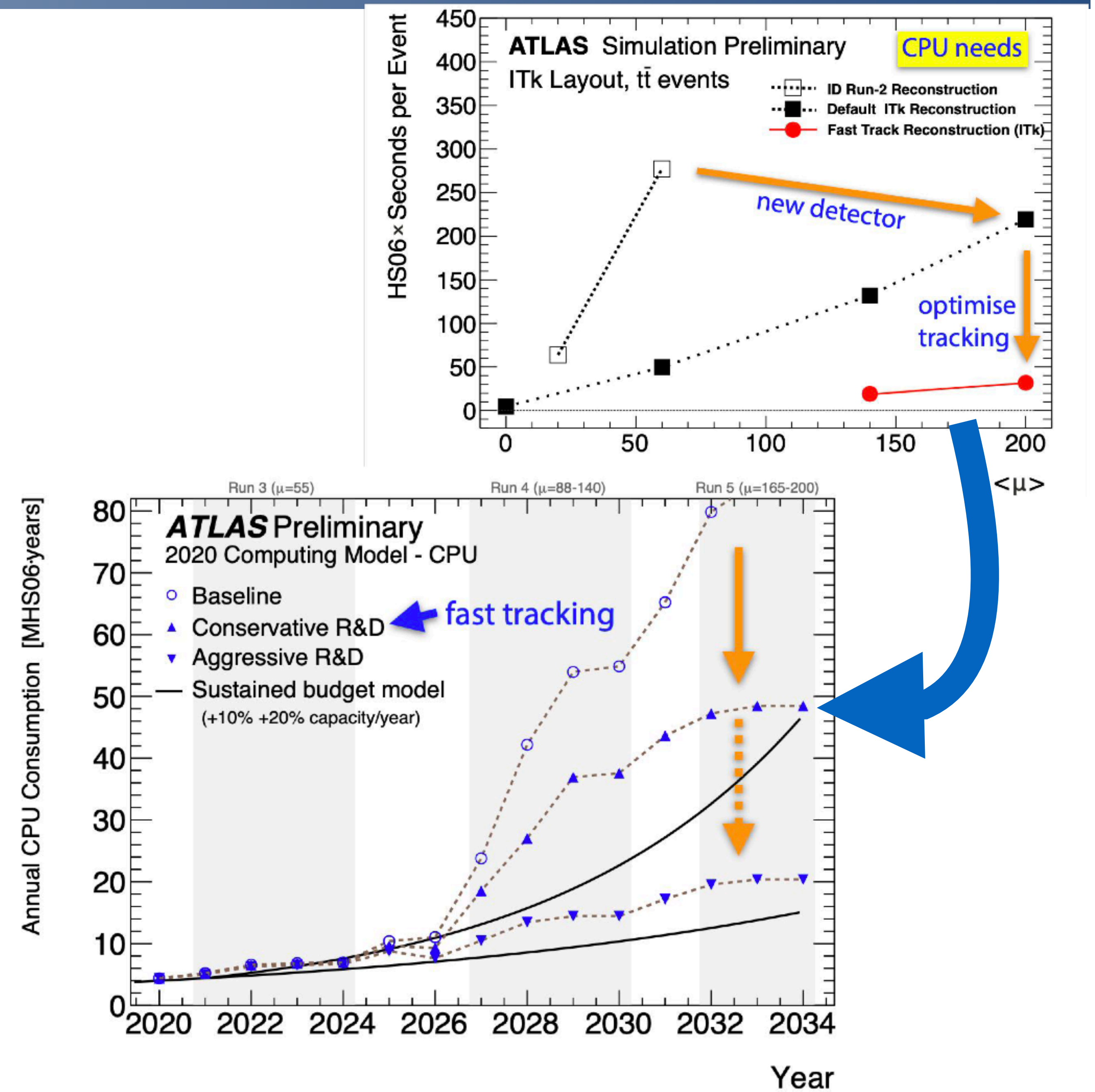
4. Phasing and Staging: Conclusions

- Any staging option will require significant discussions with all concerned national entities and funding agencies to renegotiate the scope of the contributing partners.
- Additional resource for deinstalling the detector ~ 5 mo – 18 mSV, at least 8 persons, reinstalling at least 4 months
- L4 Staging
  - ✦ Extremely long in surface (14mo) and shutdown (LS4) of more than 2yrs. Easily turns into a descoping.
  - ✦ ITk is redundant by construction, therefore basic tracking performance are not affected very much. More studies on tracking reconstruction performance, and robustness must be injected.
  - ✦ Not very motivating- although a new technology is used
- OEC staging
  - ✦ Short on surface as may be prepared during Run4 Shutdown of 1 yr is sufficient
  - ✦ However, tracking performance are compromised up in the eta coverage.
  - ✦ The saving in reducing to 35% of the OS detector area will not be recovered completely anyway.
  - ✦ Resources should be diverted from the OEC to the OB (implying an MoU revision)

Performance studies of staging scenarios

- Objectives of Phase-II ITk can be summarized as:
  - ✦ Tracking performance optimization despite harsh pile-up environment (excellent track reconstruction, high-purity for b-tagging and pile-up rejection, extended coverage for VBF processes, redundancy to cover defects and failures)
  - ✦ Need to keep CPU for tracking under control: exponential growth would be major issue for offline computing model and for online reconstruction for trigger selection

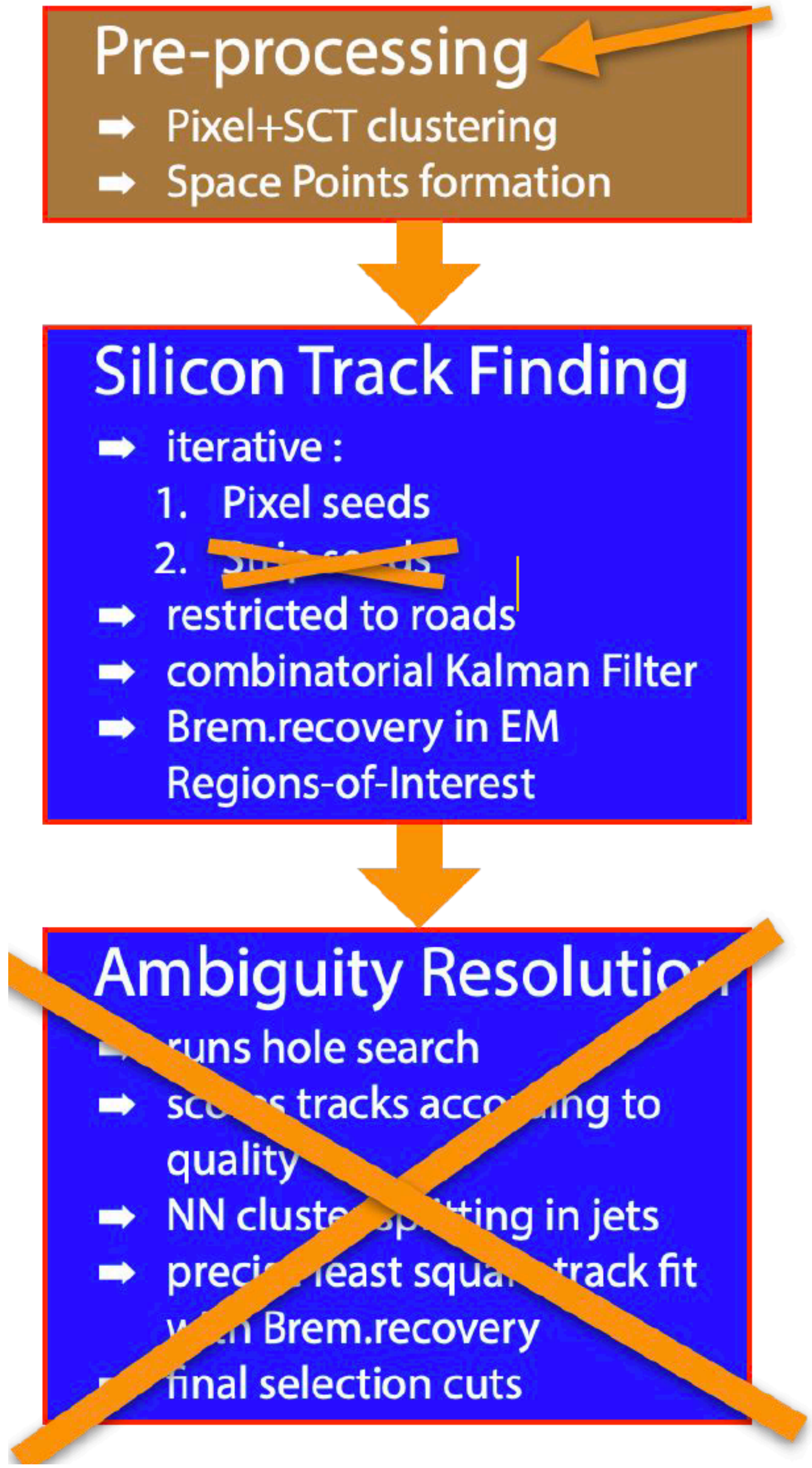


- Fully functional fast ITk tracking prototype has been developed recently
  - ✦ Key is the 5 layer Pixel system

Fast ITk Reconstruction

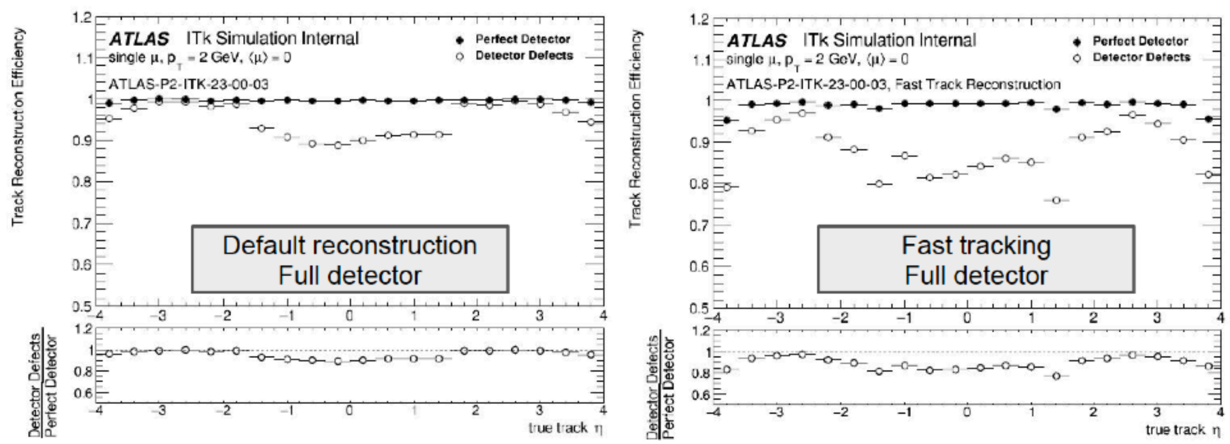
Key to the Fast ITk Reconstruction is the 5 layer Pixel system

- Seed finding in 5 Pixel layers (redundancy) allows to drop iteration of seed finding in Strips
- 5 layers allow to confirm 3 layer seeds in 4th layer with good efficiency, resulting in high efficiency (performance) and high purity (CPU) seeding
- High purity Pixel seeded track finding (and improvements in track fitting during track finding) allows to also drop Ambiguity Resolution step without major performance impact, leading to an overall CPU gain of a factor 8 w.r.t. default tracking



Fast ITk Reconstruction

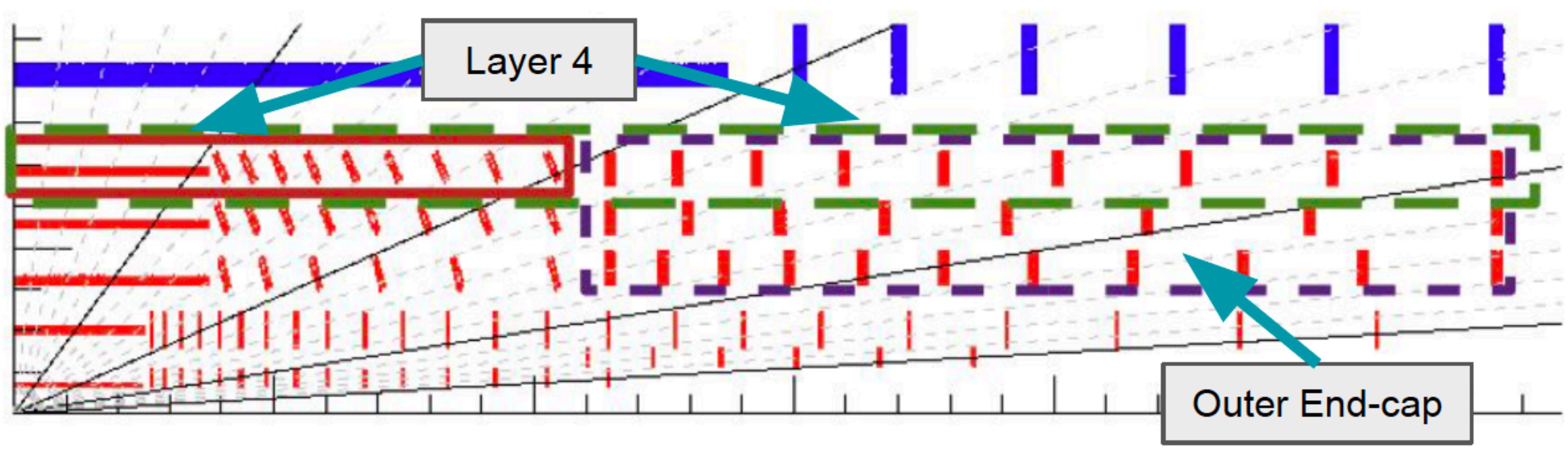
- Fast reconstruction is more sensitive to inefficiencies and failures:
  - ✦ Modeled in simulations (from Pixel TDR) with 3% random inefficiencies in Pixels + 1% in Strips, and 15% random sensor failures in both Pixels and Strips

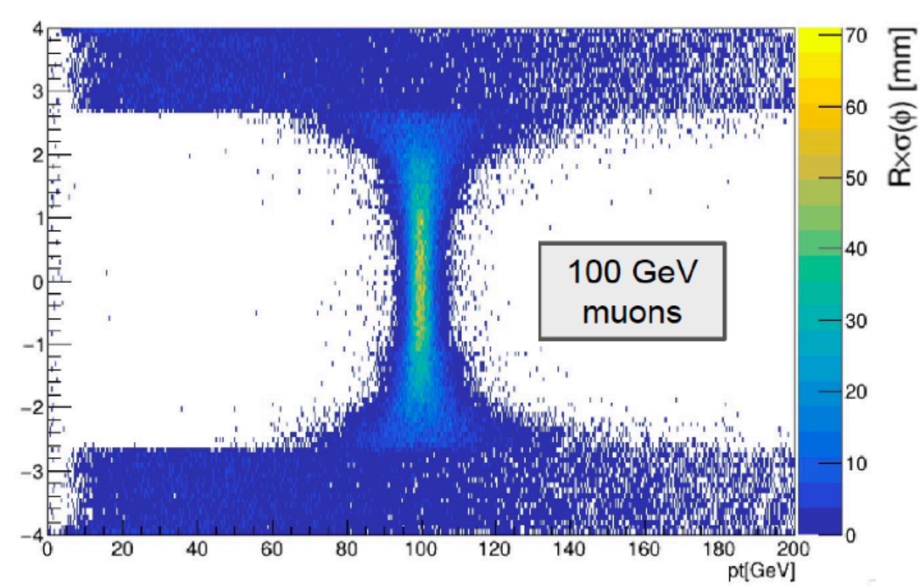


- **Default tracking**: reduction of ~10% for in the barrel section (|η|<1.6)
- **Fast tracking**: stronger effect, reduction up to ~20%

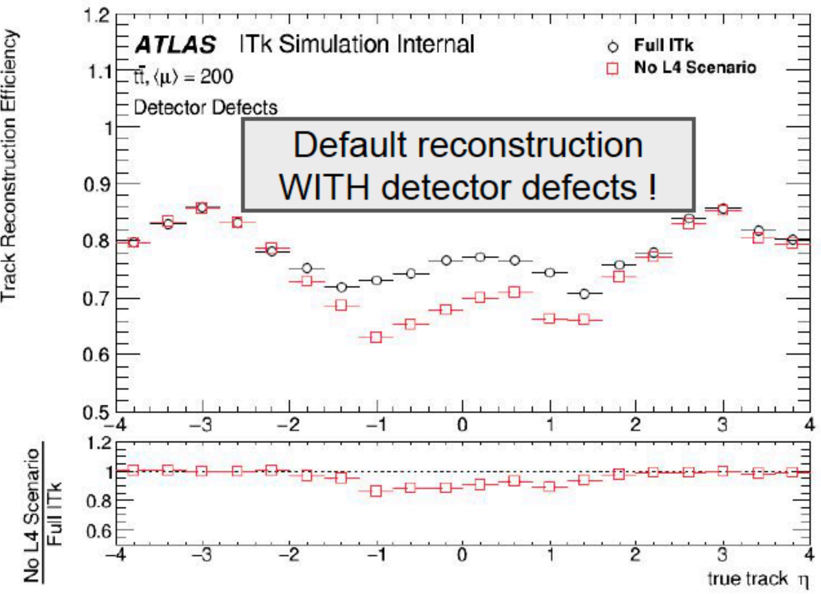
(No modifications to tracking code)

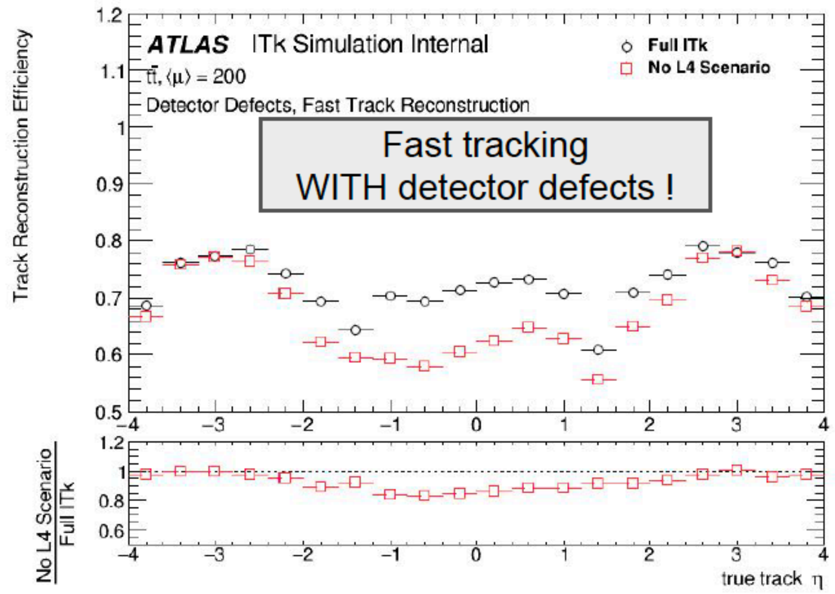
- Staging (or descoping) makes the degradation in performance much more severe in a realistic scenario that simulates both inefficiencies and failures
- Two scenarios considered: staging of L4 and of the full Outer Endcap (OEC) but the latter has a dramatic impact/loss of momentum and impact parameter resolution for 2.7 < |η| < 3.6 and huge loss in precision of extrapolation to HGTD ➞ focus only on the L4 descoping



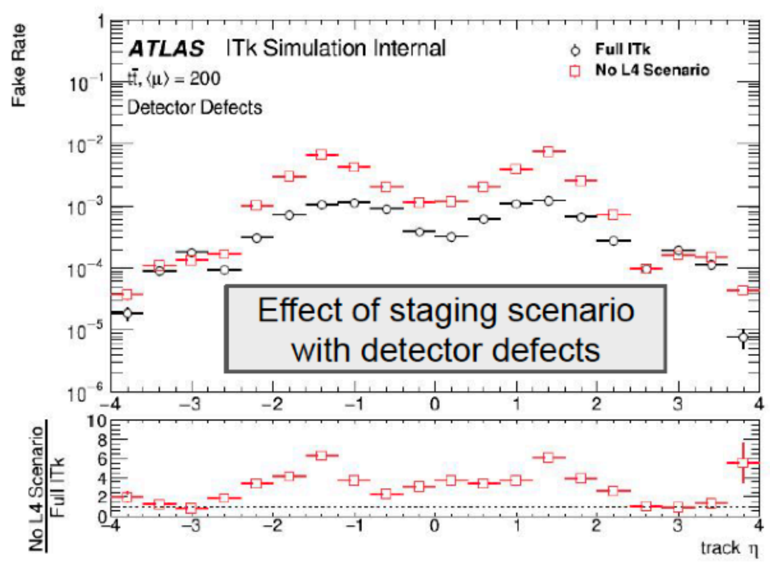


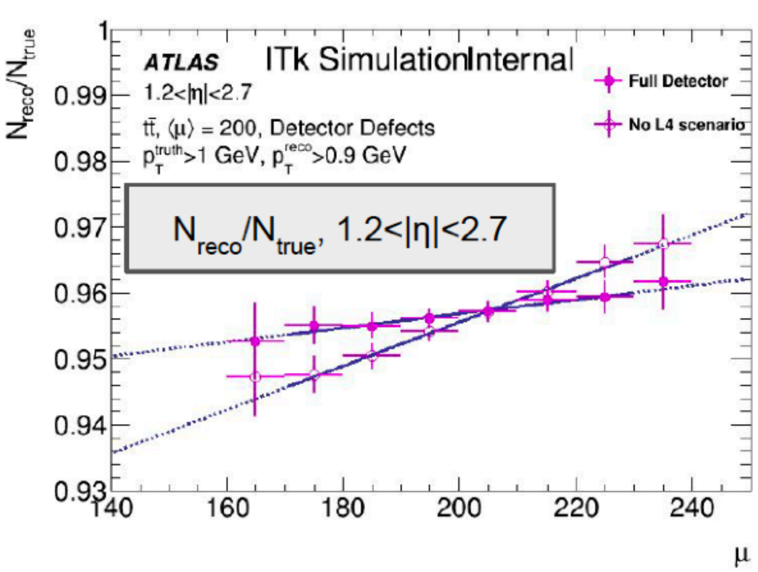
A few plots

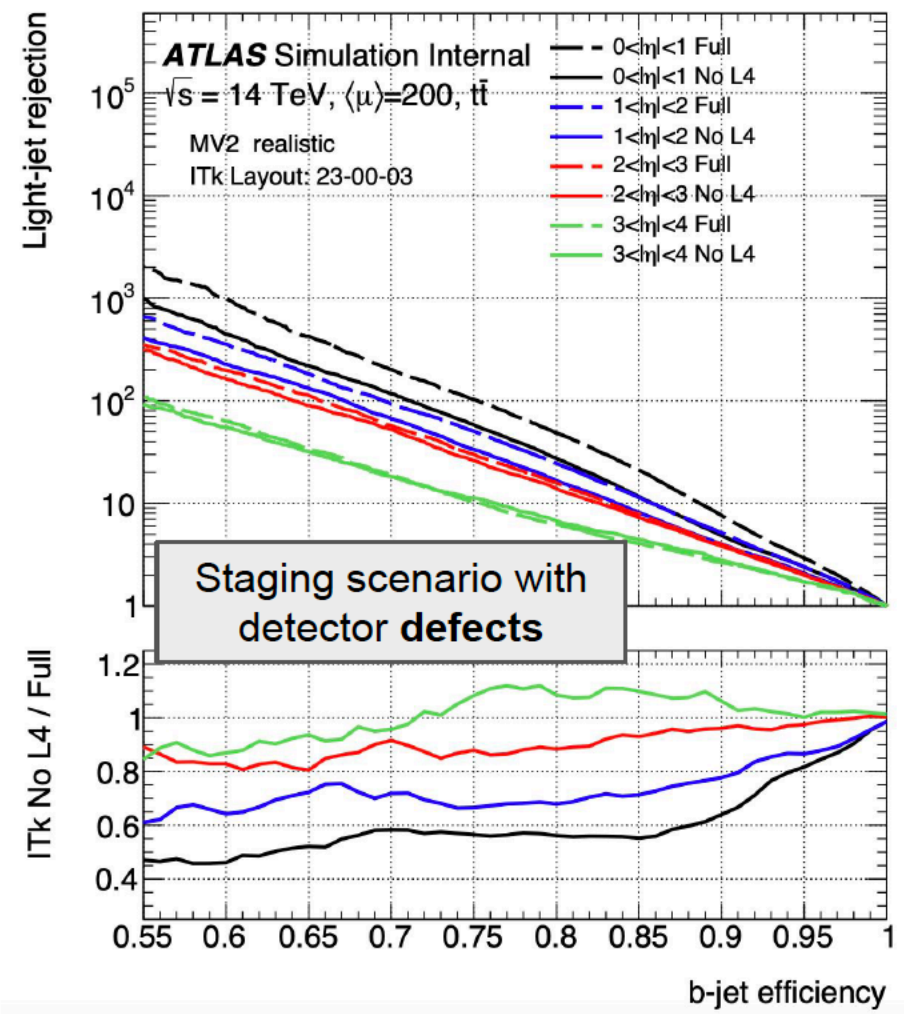




- **Full ITk**: Fast tracking has only slightly reduced efficiency compared to default tracking
- **No L4 Scenario**: efficiency is further reduced despite the relaxed seed requirement, now reaching only 60% for |η|<2 !







- Limited performance loss for staged scenario with perfect detector, BUT dramatic effects once detector defects are included
  - Increase of ~x3-6 in |η|<2.8 in fake rates
  - Slope in Nreco/Ntrue indicates effects of pattern recognition confusion and wrong hit assignments because of the missing pixel measurement !
  - light-jet rejection reduced by up to 50% or efficiency reduced by up to 5% in central region
  - EDQ PUB note: -2-3% in b-jet efficiency ⇒ 5% loss in significance for HH→4b ⇒ 340 fb-1 extra data to recover equivalent significance

Performance Studies Conclusions

- 5 layer Pixel vital for offline and trigger fast reconstruction
- Staging L4 would have severe consequence on physics and technical performance:
  - Would require to compromise on Pixel seeding (+45% CPU)
  - With emulator detector defects the efficiency loss due to staging L4 becomes dramatic, additional fakes and clear sign of a much increased pile-up dependency
  - b-tagging loss of 40% in the ROC
- Even the 7x1.4=10 times slower default ITk reconstruction does not allow to fully recover the tracking performance if detector defects are taken into account, calling for even more involved reconstruction strategies.
- Such a scenario would lead to significant additional offline CPU needs beyond budget and would require a much larger trigger farm that would exceed the cooling limit for an installation at Point-1.

Conclusions

- Project should include 12-month contingency in the current planning and regularly monitor its usage and its consistency with the risk register.
  - Review the current risk register to ensure realistic schedule impacts and regularly update them to determine the required schedule contingency.
- Resources:
  - ATLAS management must engage CERN management to secure sufficient resources to allow for the needed parallelization in the production process.
  - The ITk team must verify the availability of skilled resources in a timely manner at all production sites.
- Technical risks and severe impact performance advise against staging:
  - The Schedule Optimization TF believes that staging scenarios that have been studied carry significant technical risks and may have an irreversible negative impact on the experiment
  - Tracking performance will degrade significantly when a realistic detector that includes radiation damages and failures (dead channels)
- There are a couple of strategies that should be considered only as mitigation in case the installation of ITk in LS3 can't be guaranteed:
  - Reallocating resources to complete the OB and OEC earlier and with higher priority and plan for a phased (later) insertion of the IS during LS3.
  - Prepare for a possible deployment of a partial OEC, with a long-term strategy of its removal and insertion of a completed new OEC that can fit within the current PST volume.
  - Both these scenarios would require highest priority for the completion of the OB construction.