



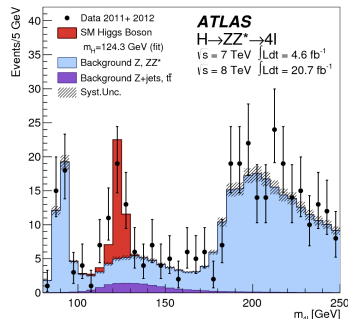
# The ATLAS computing challenge for HL-LHC

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for the ATLAS collaboration

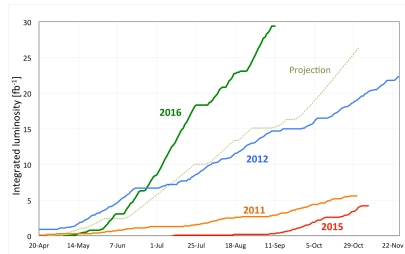


# The Large Hadron Collider at CERN

## Higgs discovery in Run-1



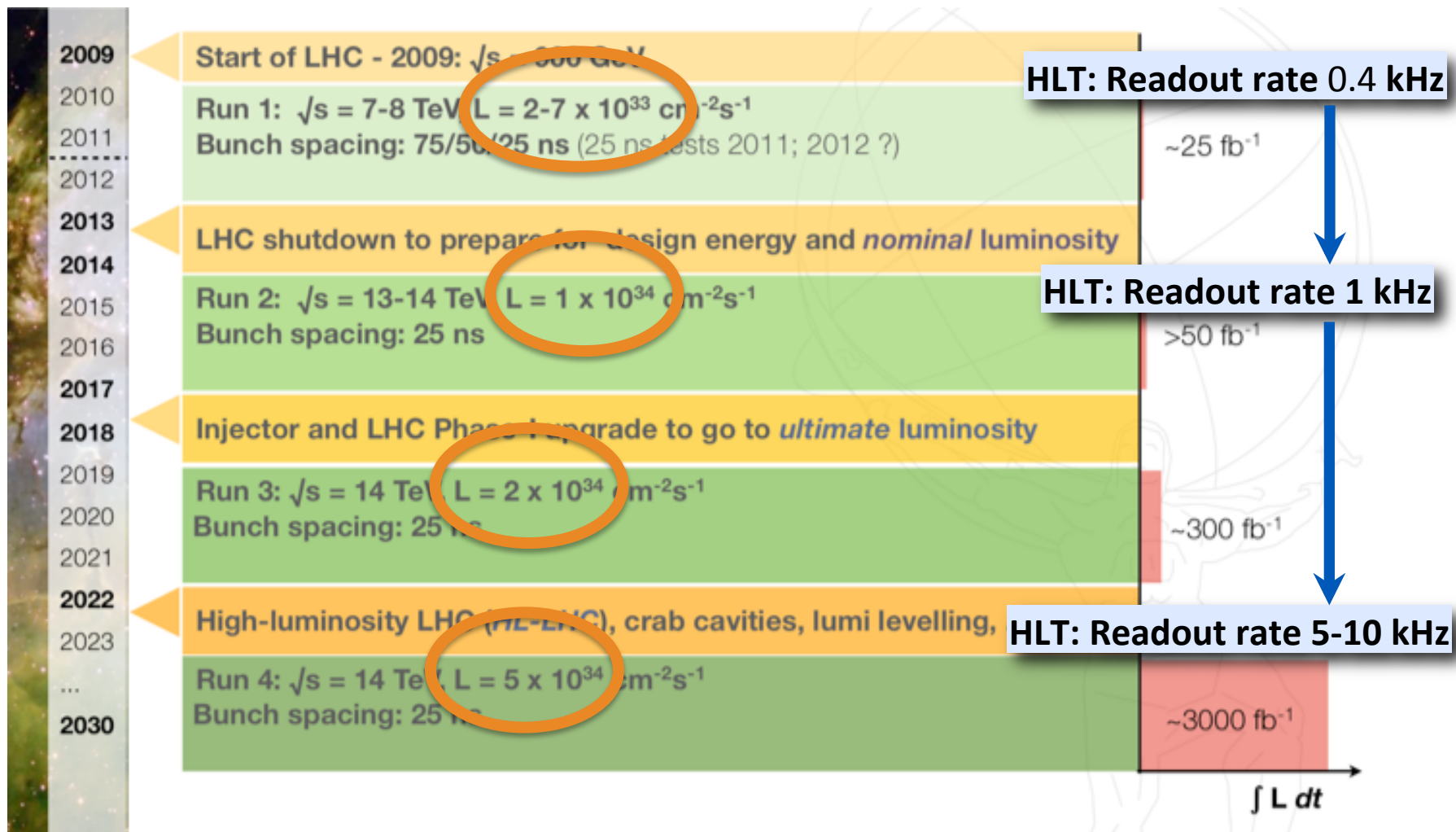
## We are here: Run-2



This talk: computing challenge at HL-LHC in 2026 and beyond



# HL-LHC rates: 10x more data per second



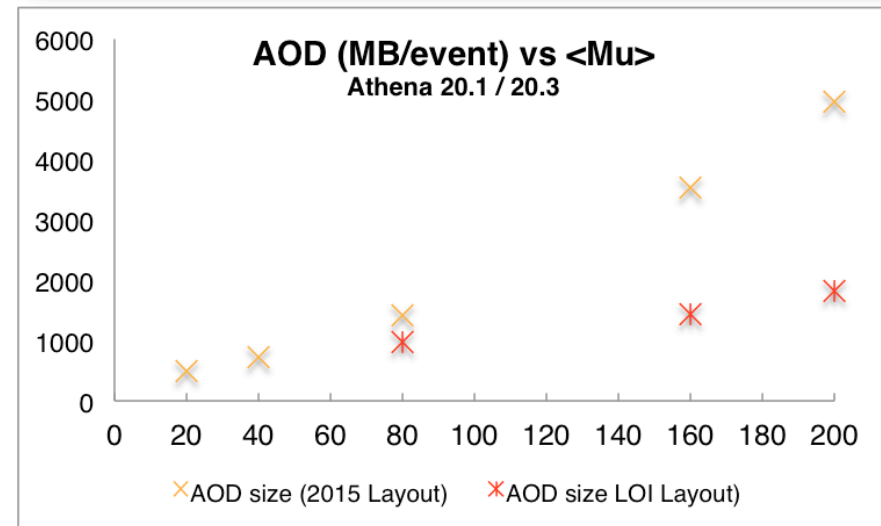
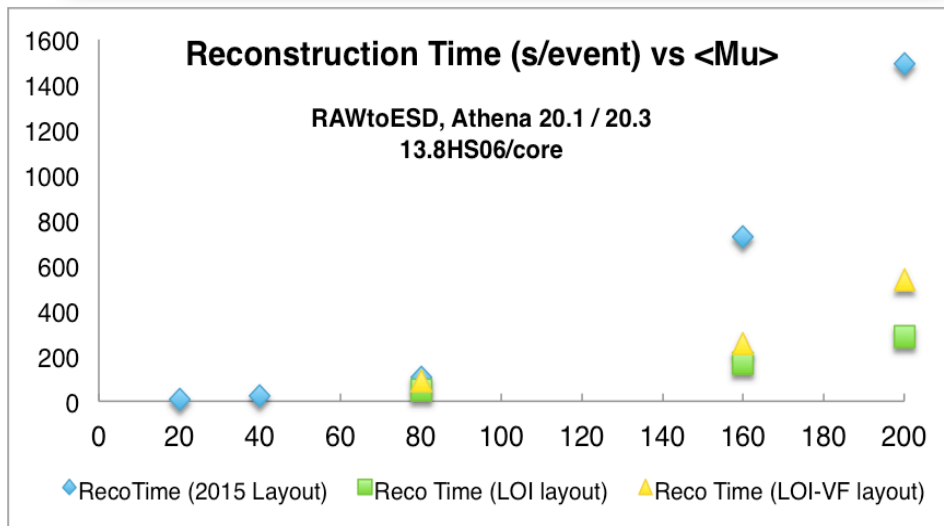
# Effect of pile-up increase

## The average pile-up:

$\langle\mu\rangle=14$  in 2015  
 $\langle\mu\rangle=23$  in 2016  
 $\langle\mu\rangle \approx 35$  in 2017  
...  
 $\langle\mu\rangle$  up to 200 in HL-LHC (10 years)

## Higher pileup means:

Linear increase of digitization time  
Factorial increase of Reco time  
Larger events  
Much more memory





# Input parameters, assumptions, disclaimers

## Input Parameters at HL-LHC (LOI = the ATLAS Letter of Intent for Upgrade Phase-2)

Output HLT rate: 10kHz (5 to 10 kHz in LOI)  
Reco time: 288s/event, Simul Time: 454 s/event at  $\mu=200$   
Nr Events MC / Nr Events Data = 2  
Fast Simulation: 50% of MC events  
LHC live seconds /year: 5.5M

## Simplified Computing Model with respect to 2016/2017 resource requests:

Data from previous years not taken into account  
=> Little difference at the beginning of the Run-4 but huge  
difference for Run-2 and Run-3

## Projection of available resources in HL-LHC:

20% more CPU/year  
15% more storage/year

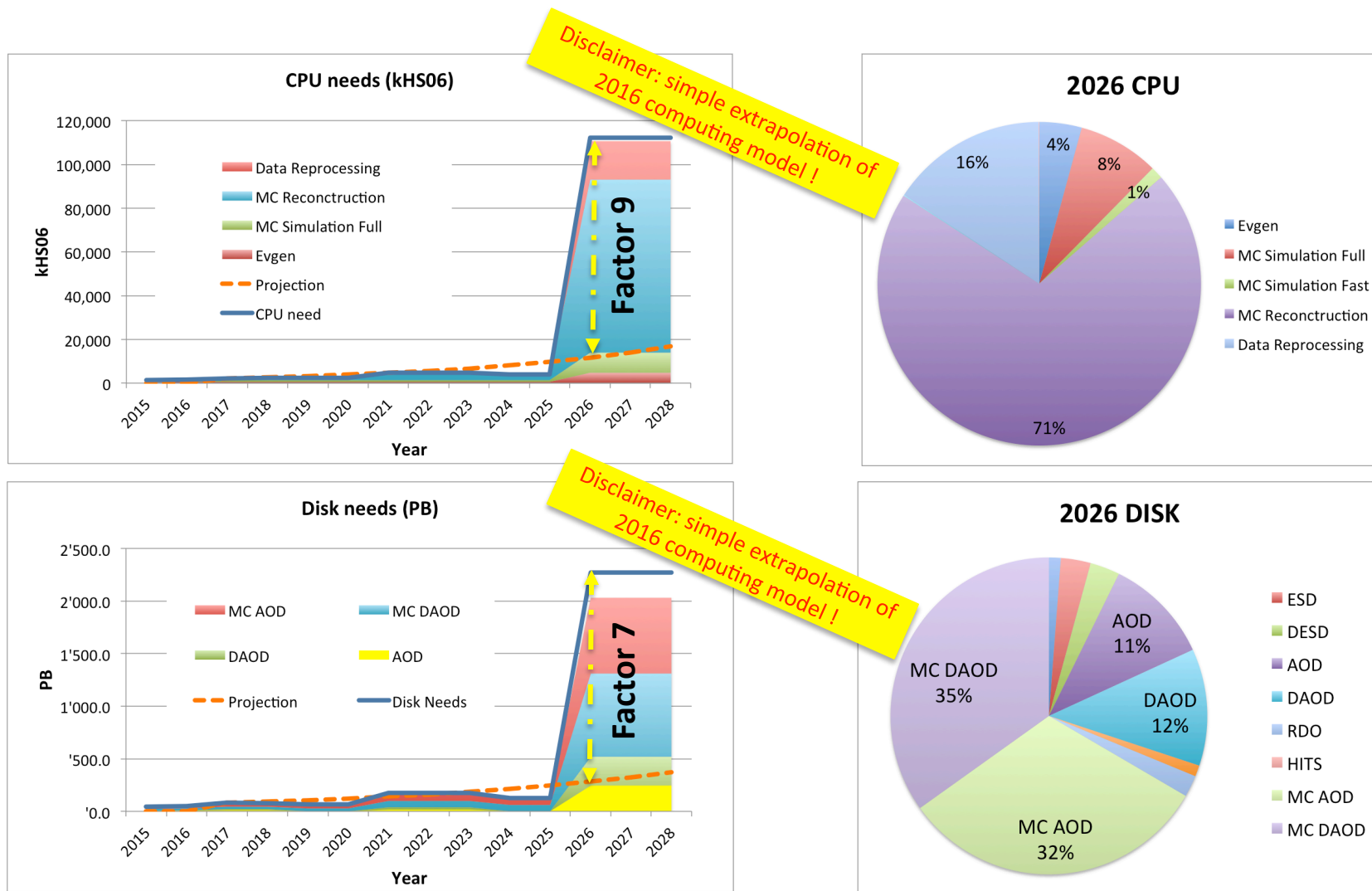
For the same cost

Projections evolve 2017 values  
**OF THIS SIMPLIFIED MODEL**  
**(not the 2017 WLCG pledges)**

**Conclusion: looking at absolute numbers makes little sense.**

**Relative differences between needs and projections at HL-LHC are meaningful. With caveats.**

# HL-LHC baseline resource needs



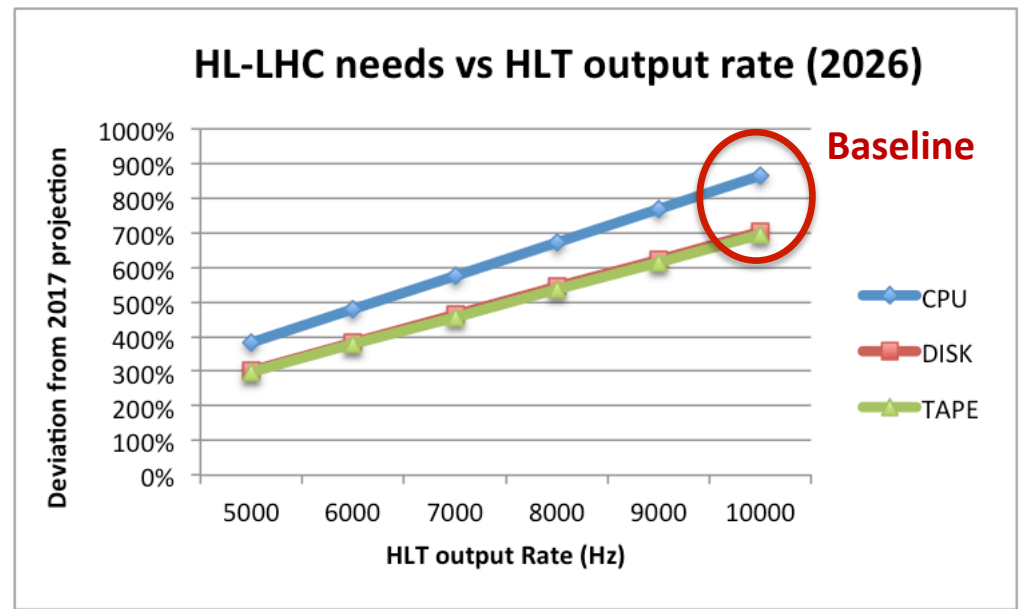
# HLT output rate

The output trigger rate does not determine only the amount of data per year but also the amount of Monte Carlo to be produced.

The LOI foresees a value between 5 kHz and 10kHz. We use the latter as baseline in this study

The possibility to reduce the trigger rate to a lower value without impacting the ATLAS physics program will be analyzed in the years to come

If we consider the lower LOI limit (5kHz) the discrepancy with the projection of available resources reduces to x4 for CPU



# Monte Carlo needs

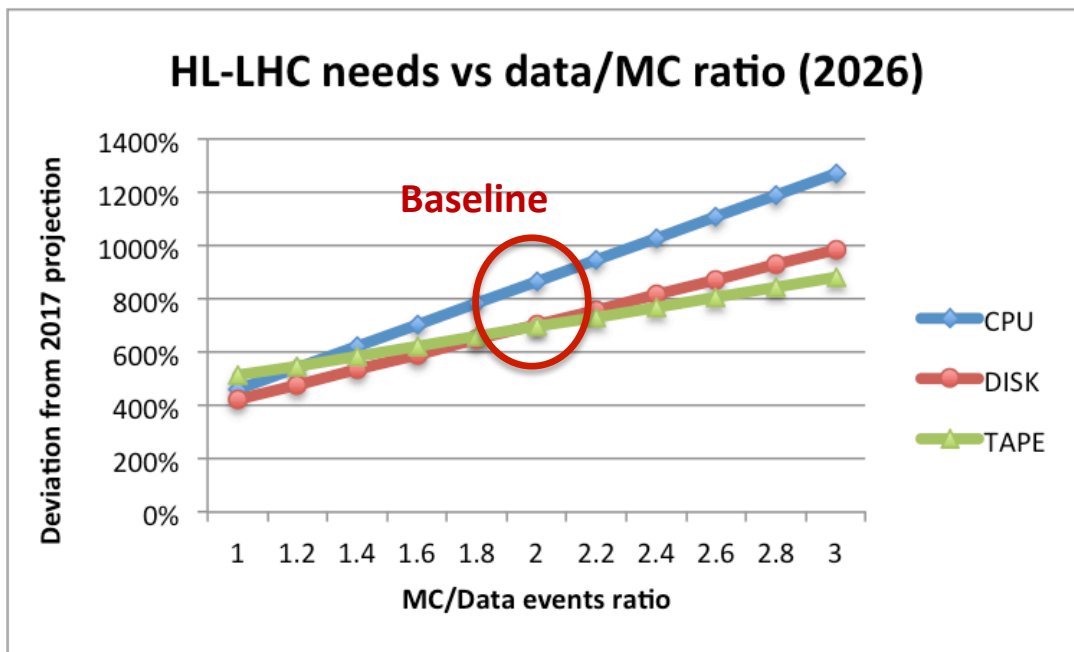
The physics case for HL-LHC will evolve in the next years. The high statistics of data collected in HL-LHC reduces the significance of statistical uncertainties. Therefore one might assume a lower need of MC with respect to data

## HOWEVER

Things might change significantly once the physics case for HL-LHC evolves

Generators might become very expensive if we go to NNLO

In 2004 we expected a factor  $\times 0.3$  MC with respect of data. We are at  $\times 2.0$ .



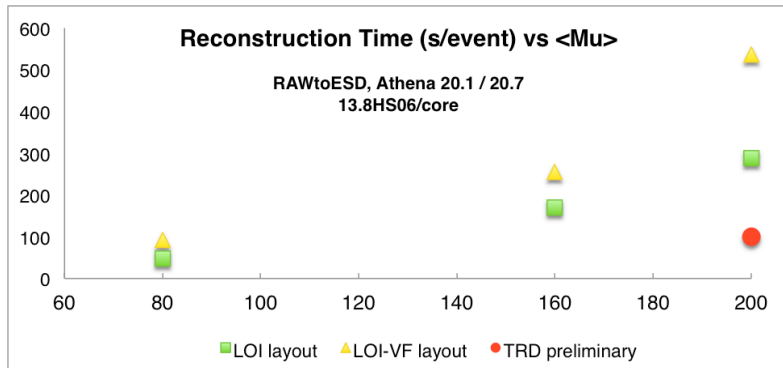
# Layouts and Reconstruction

Reconstruction time dominates the CPU consumption in HL-LHC

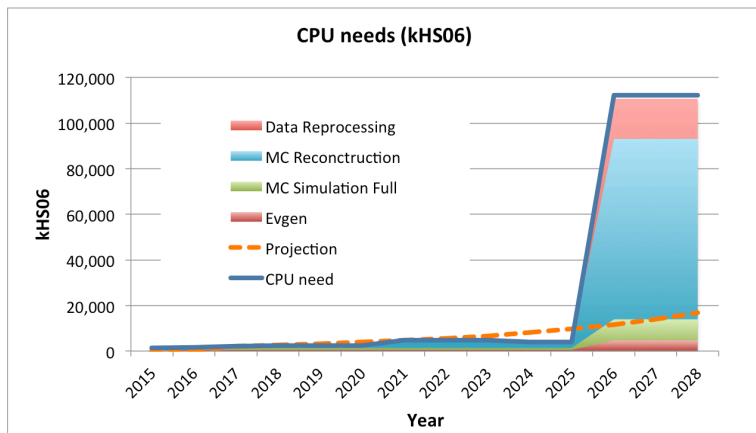
Especially for MC, where trigger simulation utilizes the same offline algorithms (so it impacts twice as much)

The detector layout will play an important role, together with the optimization/tuning of algorithms. Tracking will be the main consumer

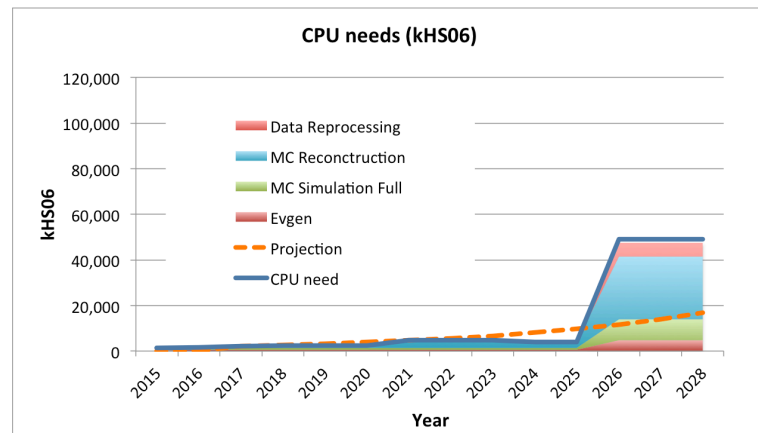
Alternatives are also being investigated as R&D e.g. Machine Learning techniques



## LOI Layout



## Possible TDR Layout



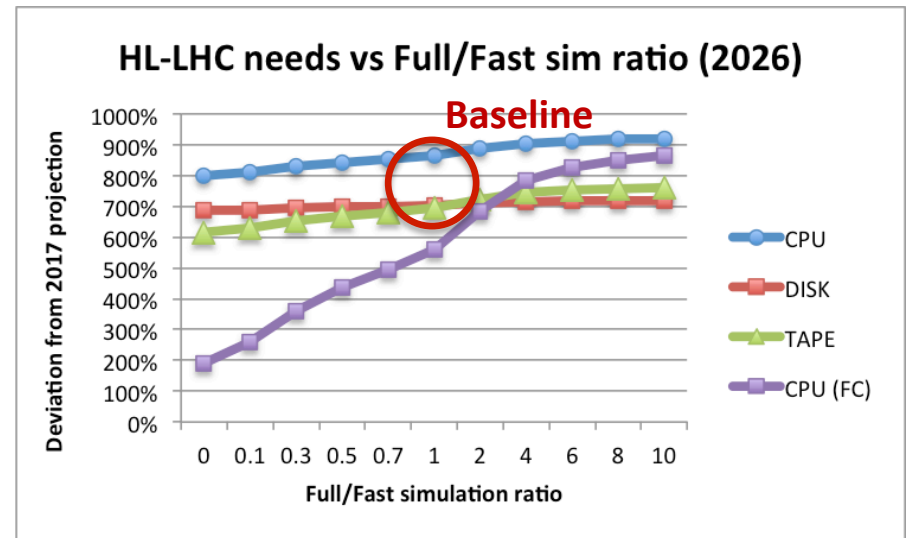
# Fast Simulation and Fast Chain

Fast Simulation in Run-2 is x10 faster than Full Simulation (G4)

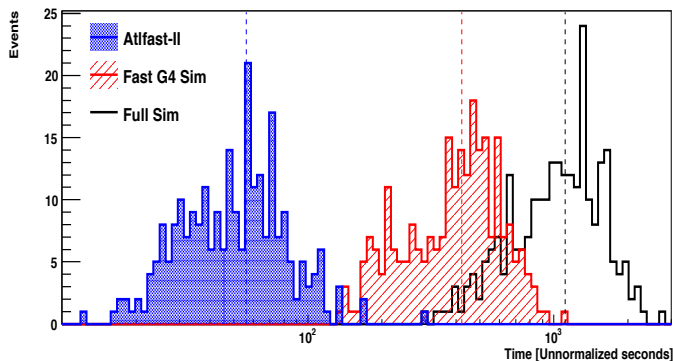
Fast Simulation can be used today only for a subset of analyses

Detector Simulation in general is not the driving cost in HL-LHC

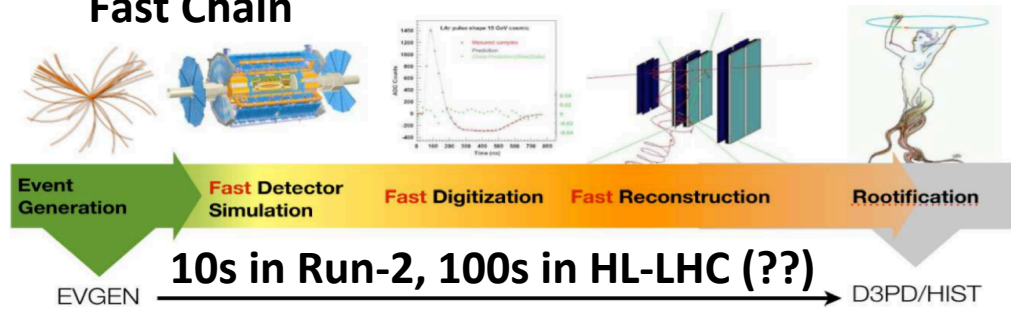
The gain will come with Fast Chain



## Fast Simulation

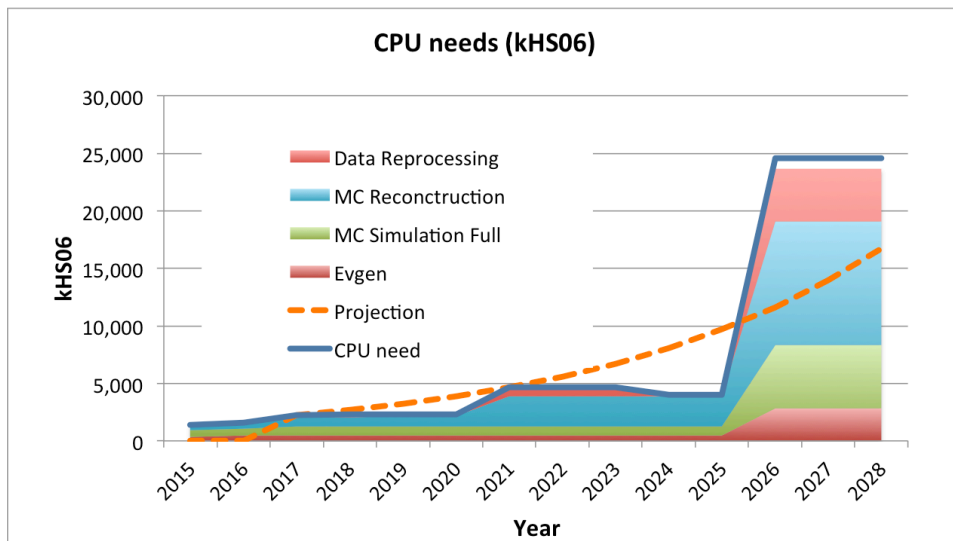


## Fast Chain





# If we want a very optimistic scenario ...



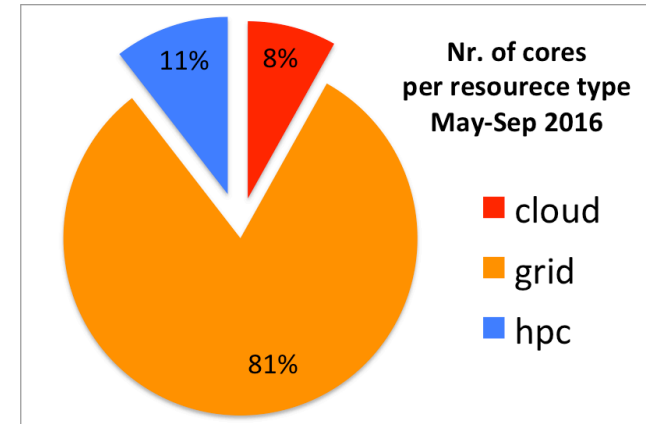
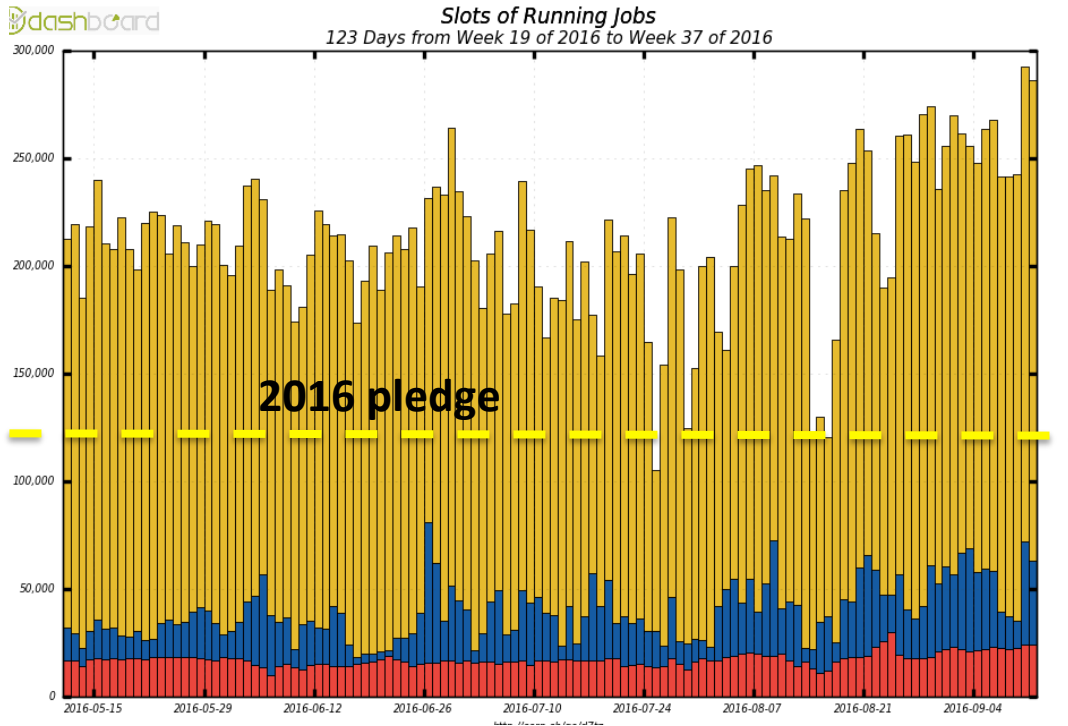
In a very optimistic scenario, the discrepancy for CPUs reduces to 200% (from almost 900%).

Which, given all the uncertainties, means problem solved

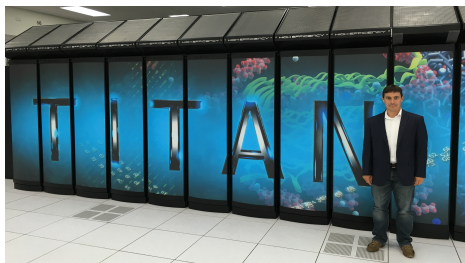
**DO NOT GET TOO EXCITED AND LISTEN TO THE REST OF THE TALK**

	Baseline Scenario	Optimistic Scenario
HLT output rate	10kHz	7.5kHz
Reco and Simul Time/Evt	from LOI	From preliminary TDR studies
Nr. Events MC / Nr. Events Data	2.0	1.5
Fast Simulation	50% of MC events	50% of MC events
Fast Chain	None	50% of MC events
LHC live seconds/year	5.5M	5.5M

# Heterogeneous Resources

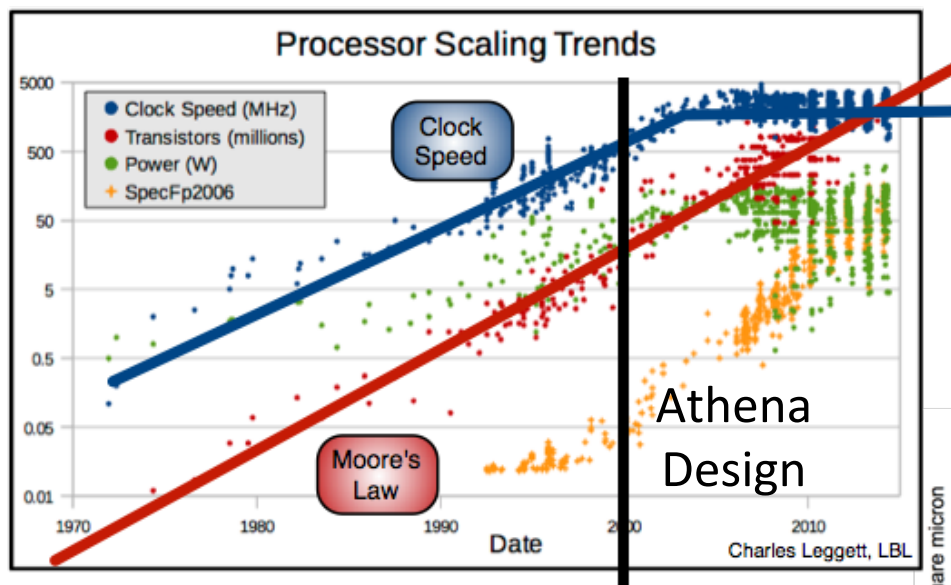


Integration of non Grid resources  
in ATLAS is a big investment with  
the potential of a big return



**Challenges: resource provisioning, non standard architecture, GPU processing capacity, memory**

# Hardware trend and implications



**Clock Speed stalled but transistor density keeps increasing. Exploiting hardware becomes more complicated (vectors, memory...)**

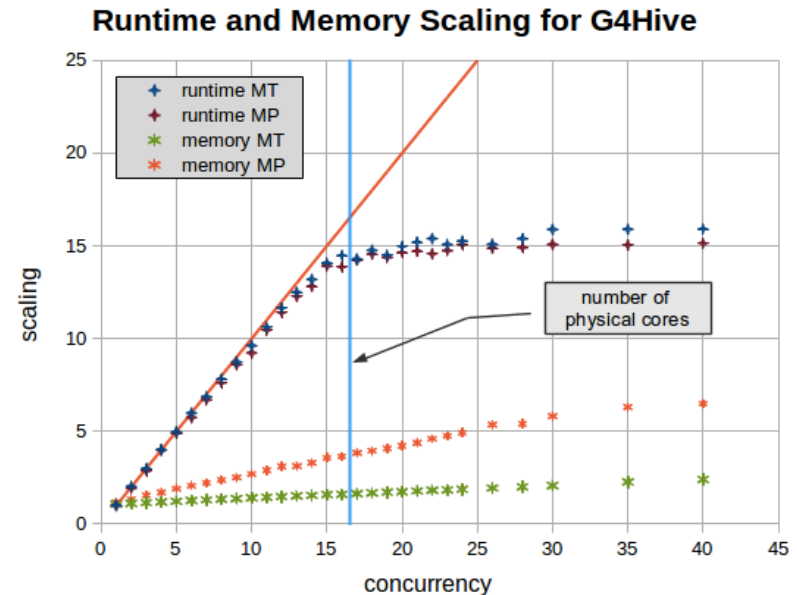
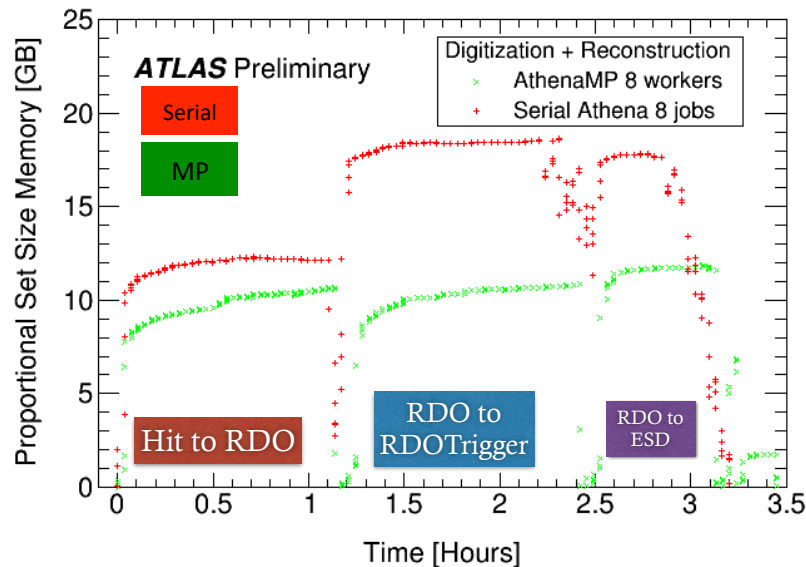
**Example: Cori@NERSC (Intel Knights Landing)**  
**1PB of Memory, 9304 nodes**  
**68 cores/node, 4 HW threads/core**  
**=> Approx 300 MB/thread**



# From Multi Processing to Multi Threading

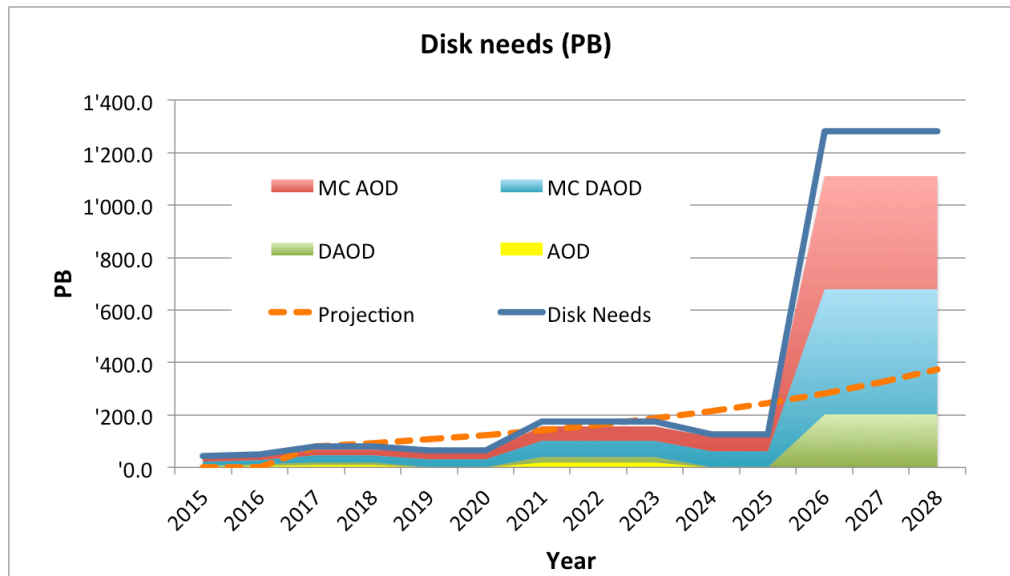
AthenaMP (multiprocessing) will not be sufficient anymore. We will need (and we are developing) AthenaMT (multithreading). Will be in production for Run-3 (2020) already.

Parallel processing in a multithreaded environment will come with its challenges both for developers, operations and infrastructures



# What about Storage ?

## Optimistic Scenario + No AOD on disk



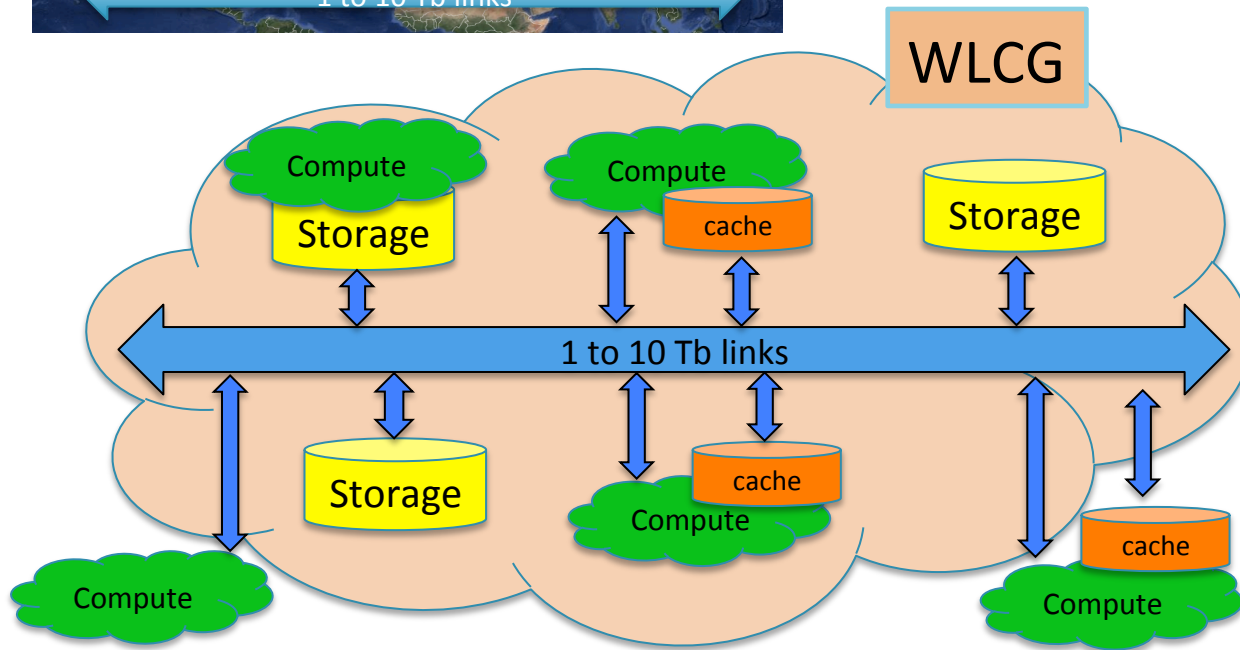
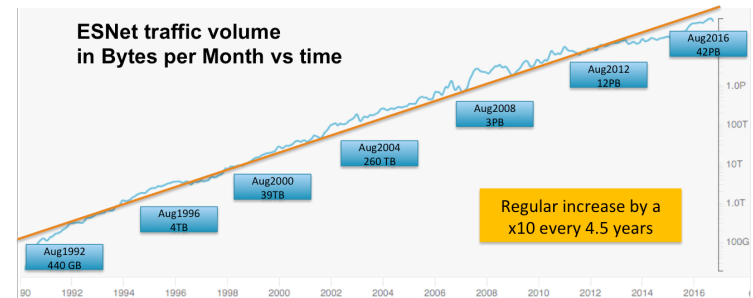
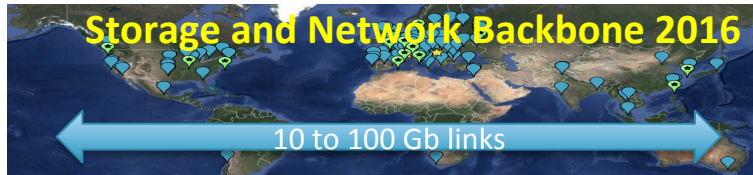
**Even in the optimistic scenario, we are still far from solving the problem**

**AODs and DAODs are the main consumers.**

**With no AOD on disk (run Train Analysis from AODs on TAPE) you get x4 above the resource projection**

**The remaining gain must come from re-thinking of distributed data management, distributed storage and data access. A network driven data model allows to reduce the amount of storage, particularly for disk. Tape today costs at least 4 times less than disk.**

# Computing infrastructure in HL-LHC



## A data cloud for science

Storage and Compute loosely coupled but connected through a fast network

Heterogeneous Computing facilities (Grid/Cloud/HPC/ ...) both in and outside the cloud

Different centers with different capabilities, for different use cases



# Data Management: Challenges and Opportunities

- “Funny how tape never seems like the cheap option when you have to pay for it”. One could say the same about network
- A fast WAN does not imply fast data access. The infrastructure and the I/O layers need to be optimized from end to end
- Multilevel caching should be built **IN** the infrastructure rather than **ON** top of it
- A unique opportunity to define and implement a common data management and data access layer
- Today WLCG is a data Grid. Tomorrow we will have a data cloud  
The challenge is always the data

# Conclusions

- We identified a concrete set of steps in preparation for computing at HL-LHC
- To keep cost of computing under control in 2026 we need to invest effort from now
- The effort spans many areas: online, offline software, distributed computing, physics, infrastructure and facilities. The detector layout will play a crucial role
- It is important to consider cost of computing when choices are made
- We are on schedule to define a computing model for HL-LHC in the next two years