External Resources: Clouds and HPCs for the expansion of the ATLAS production system at the Tokyo regional analysis center

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On behalf of the ATLAS Collaboration

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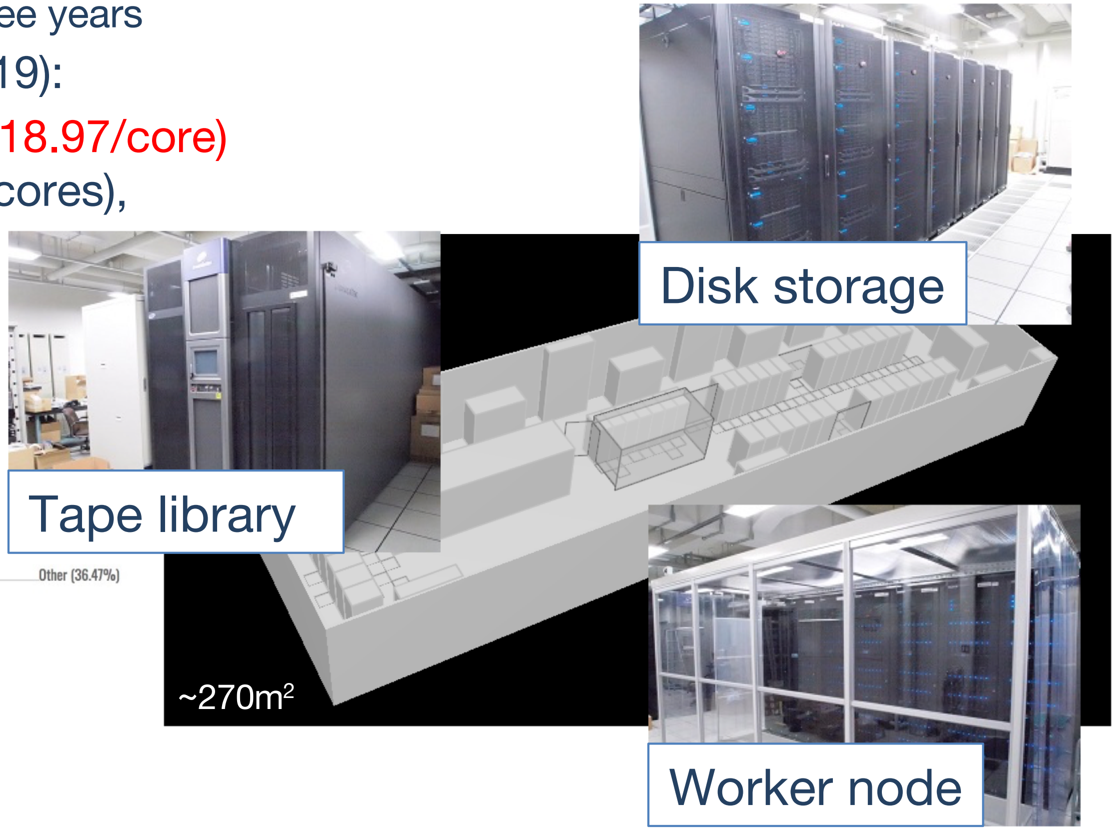
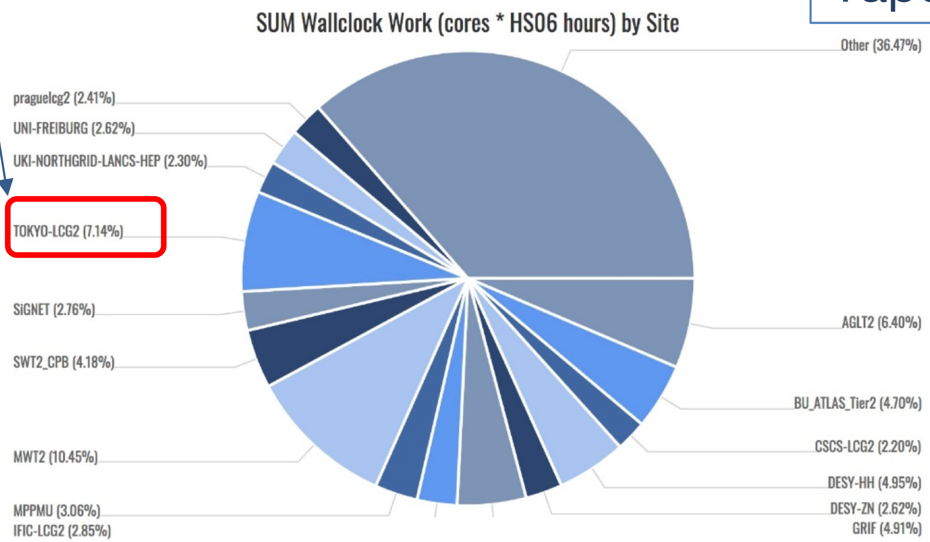
The Tokyo regional analysis center

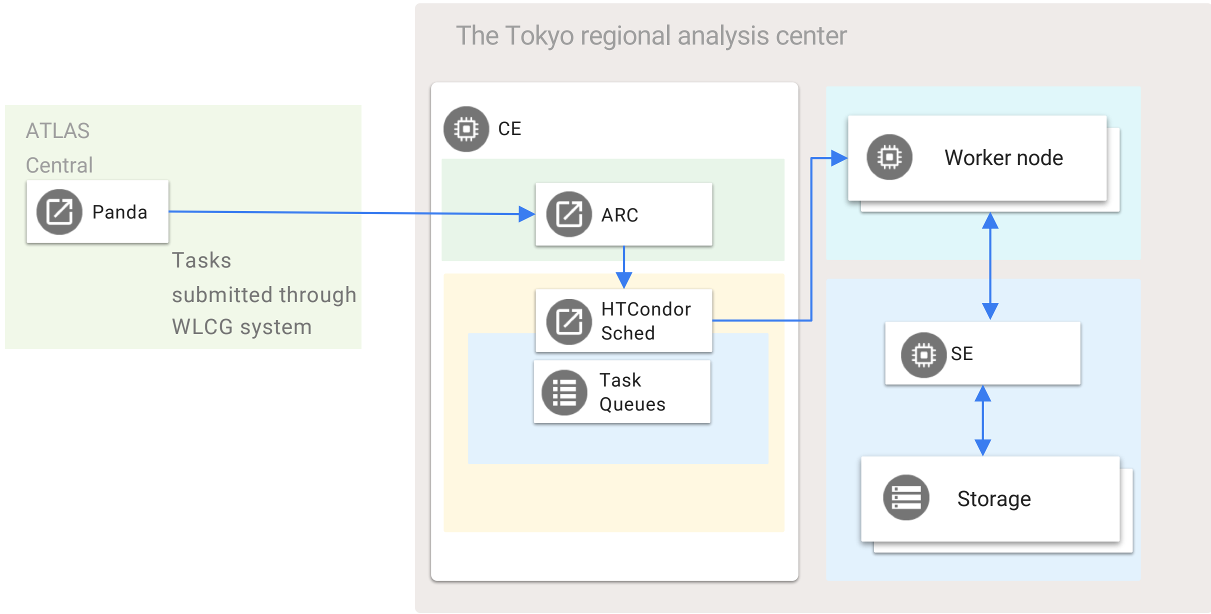
- The computing center at ICEPP, the University of Tokyo
- Supports ATLAS VO as one of the WLCG Tier2 sites
  → Provides local resources to the ATLAS Japan group, too
- All hardware devices are supplied by the three years rental
  → All hardware devices are renewed in three years
- Current system (Starting from Jan/2019):
  → Worker node: 10,752cores (HS06: 18.97/core) (7,680 for WLCG, 145689.6 HS06*cores), 3.0GB/core
  → File server: 15,840PB, (10,560TB for WLCG)



7% of Tier2 sites of ATLAS



Our Local System

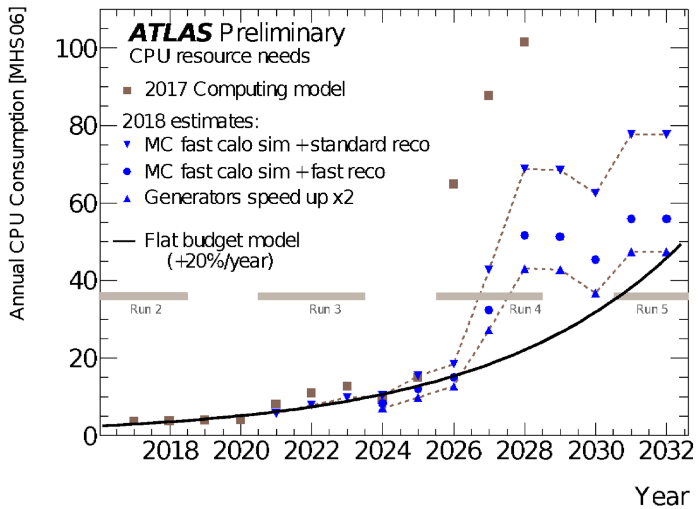


- Panda: ATLAS job management system, using WLCG framework
- ARC-CE: Grid front-end
- HTCondor: Job scheduler

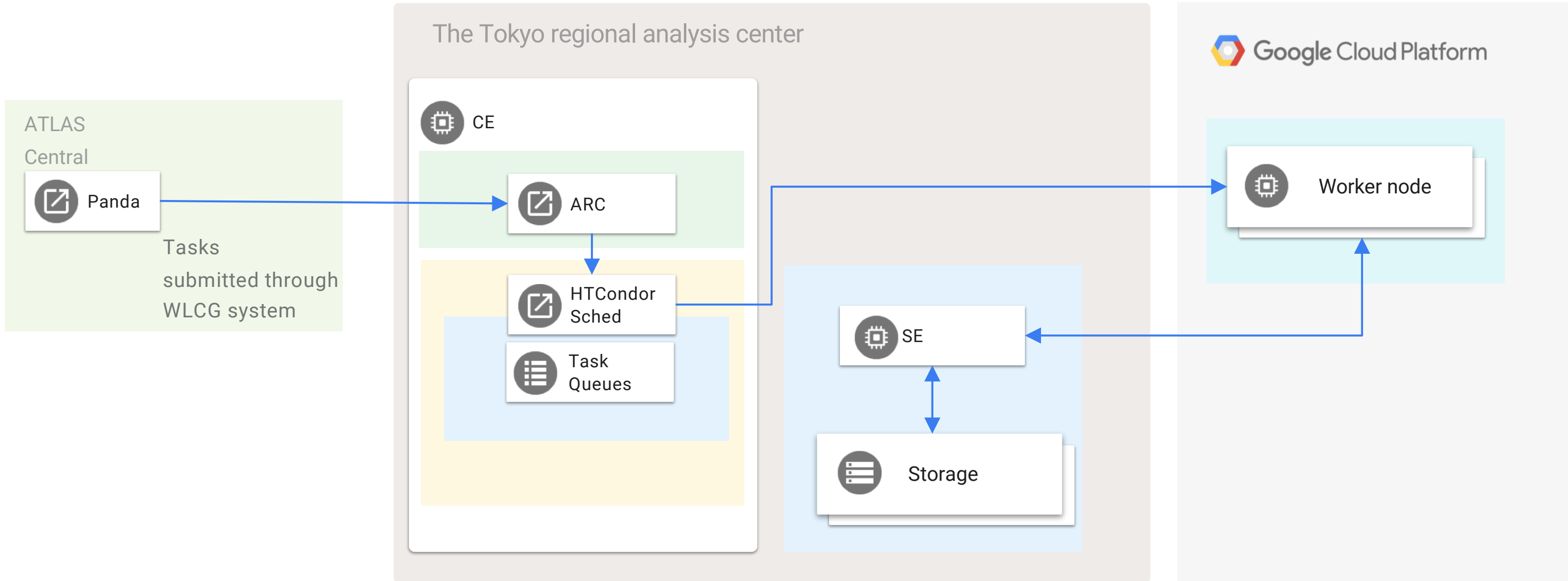
Future Computing Resources

- WLCG have provided enormous computing resources and made it possible to give a lot of results by the LHC experiments
  →But we will need more resources for the future experiments

- CERN plans High-Luminosity LHC in 2026
  →The peak luminosity: x 5
  →The current system cannot provide enough resources with expected budgets
  →More improvements or new ideas are necessary
    →Software update
    →New devices: GPGPU, FPGA, (QC)
    →New grid structure: Data Cloud
    →External resources: HPC, Commercial cloud



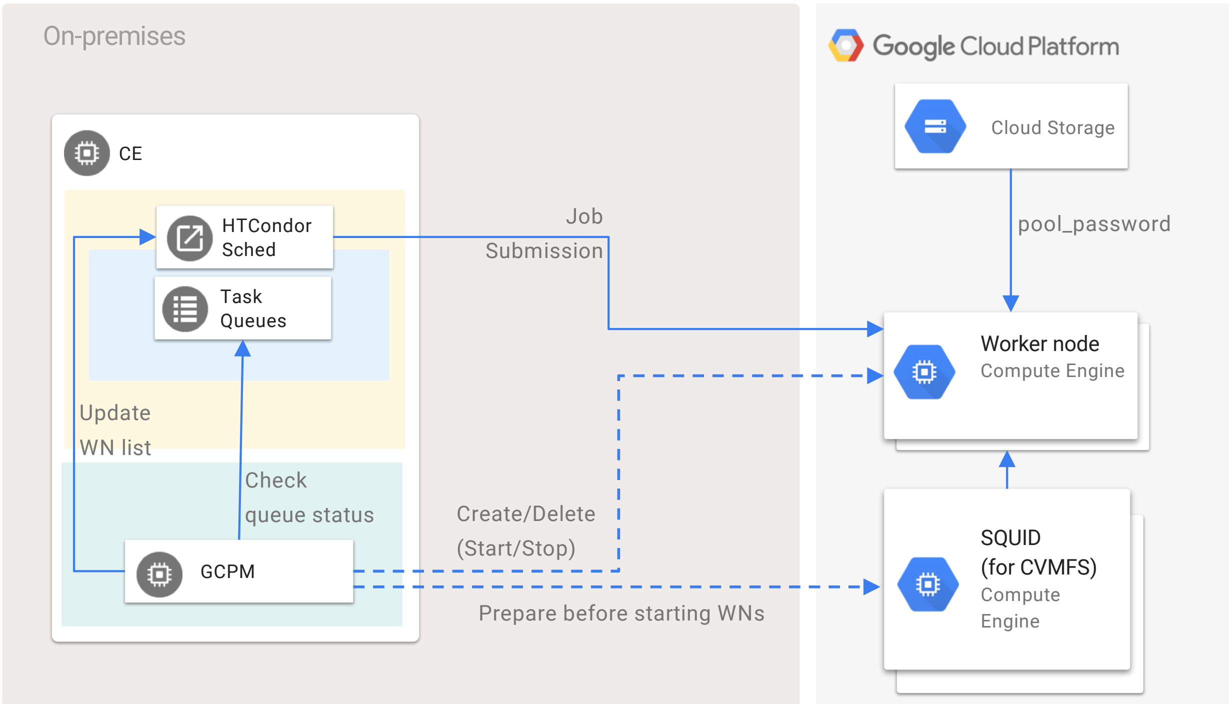
Hybrid System with Google Cloud Platform



- Cost of storage is high
  →Additional cost to extract data
- Only worker nodes (and some supporting servers) were deployed on cloud, and other services are in on-premises
  →Hybrid system

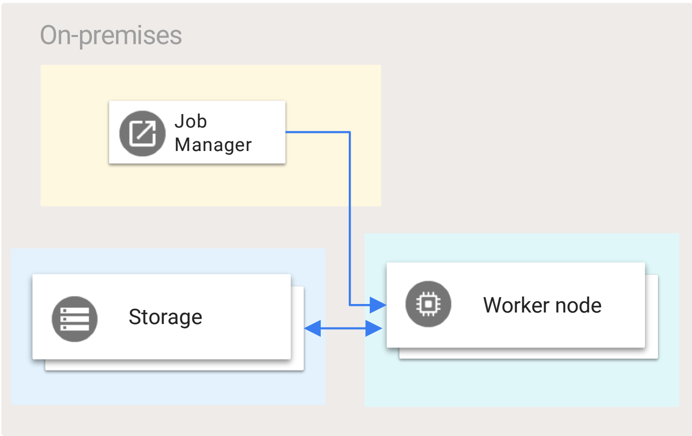
Google Cloud Platform Condor Pool Manager

- Google Cloud Platform Condor Pool Manager (GCPM)
  → https://github.com/mickaneda/gcpm
    → Can be installed by pip:
      → ***$ pip install gcpm***
- Manage GCP resources and HTCondor's worker node list
  → On-demand instance preparation
- Can be used for any of HTCondor systems
  → Useful for high-peak needs of CPUs, GPGPU instances, many cores instances, or high-memory instances which are needed once in a while

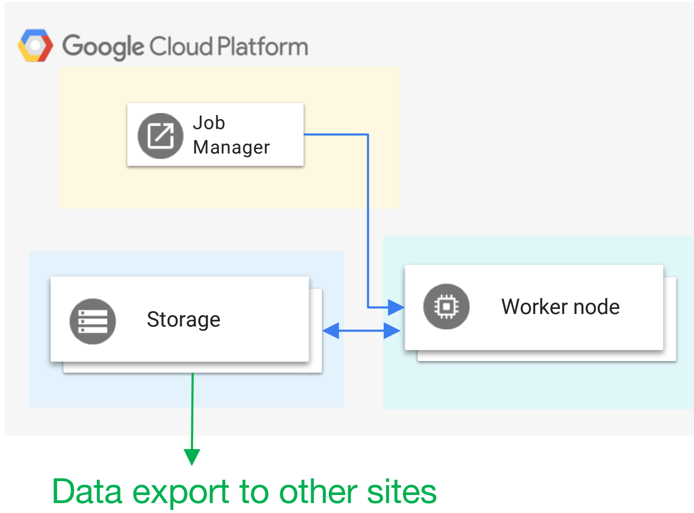


Cost Estimation

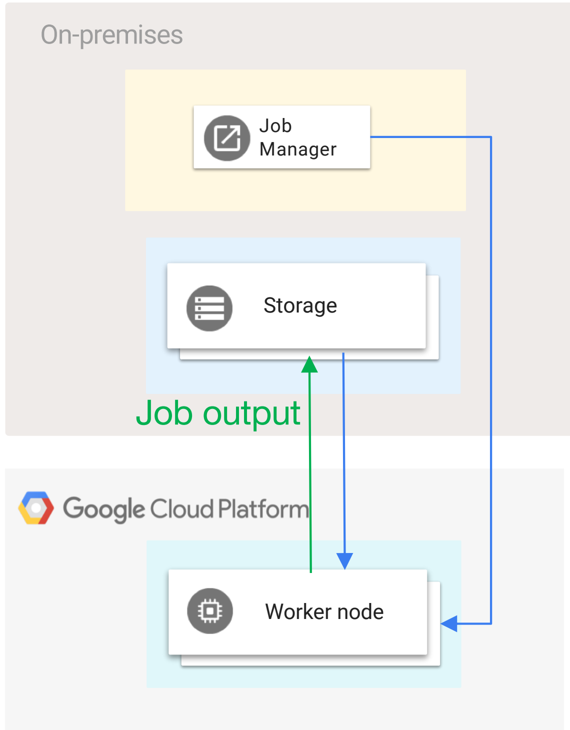
Full on-premises system



Full cloud system



Hybrid System



- Estimated with Dell machines
- 10k cores, 3GB/core memory, 35GB/core disk: $5M
- 16PB storage: $1M
- Power cost: $20k/month

  → For 3 years usage: ~$200k/month (+Facility/Infrastructure cost, Hardware Maintenance cost, etc…)

- For GCP, use 20k to have comparable spec

  → Use Preemptible Instance (Hyperthreading On, half)
- 8PB storage which is used at ICEPP for now
- Cost to export data from GCP

https://cloud.google.com/compute/pricing
https://cloud.google.com/storage/pricing

Cost Estimation

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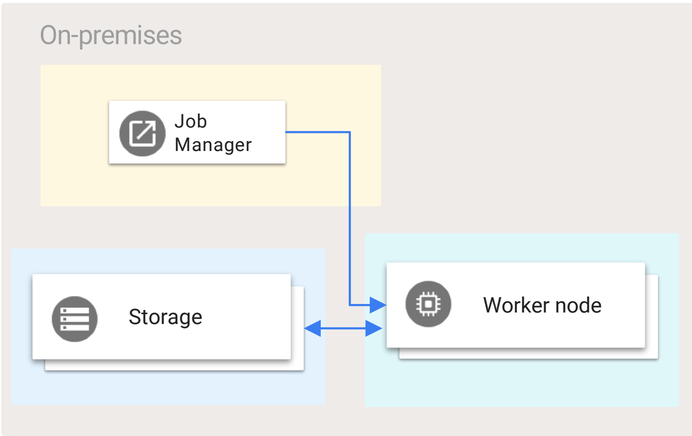

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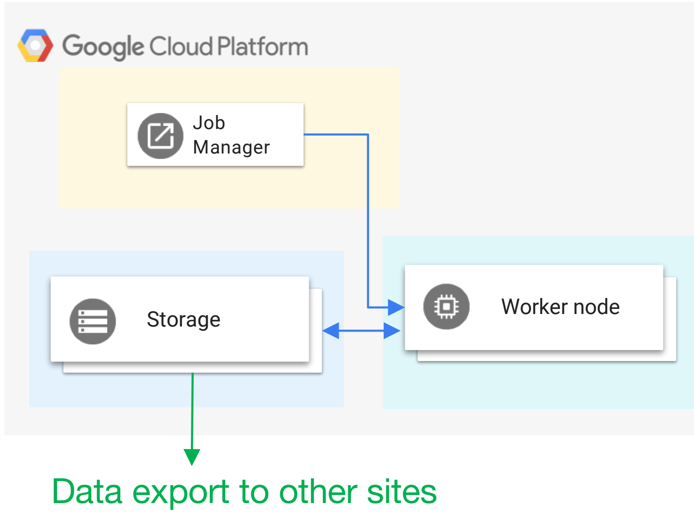
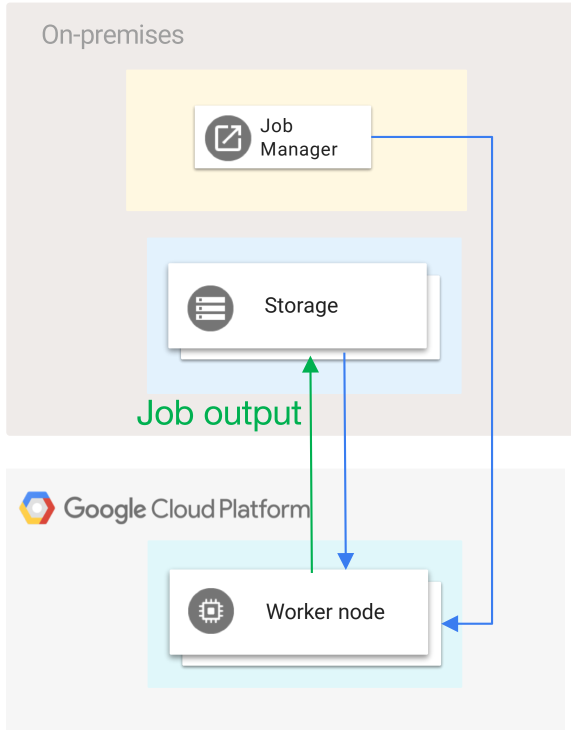


Hybrid System



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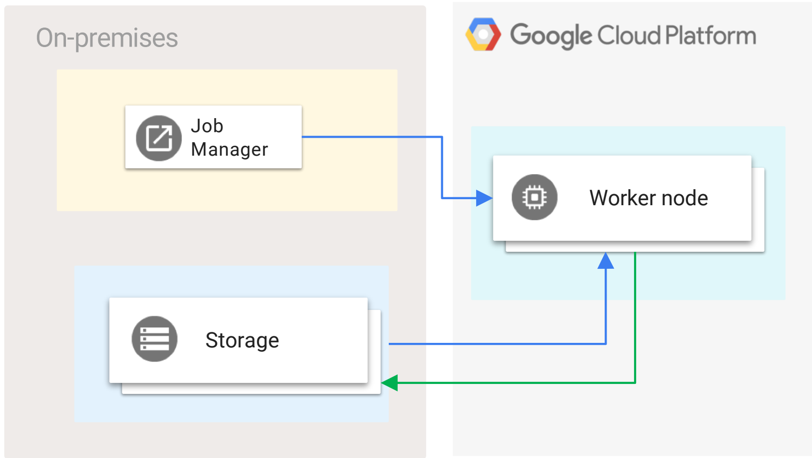
Resource	Cost/month
vCPU x20k	$130k
3GB x20k	$52k
Local Disk 35GBx20k	$28k
Storage 8PB	$184k
Network Storage to Outside 600 TB	$86k

Total cost: $480k/month

Resource	Cost/month
vCPU x20k	$130k
3GB x20k	$52k
Local Disk 35GBx20k	$28k
Network GCP WN to ICEPP Storage 300 TB	$43k

Total cost: $243k/month + on-premises costs (storage $30k/month + others)

1 Day Real Cost



Reduced Hybrid system: 1k cores, 2.4GB/core memory

1 Day Real Cost for 1k cores

	Usage	Cost/day	x30x20
vCPU (vCPU*hours)	20046	$177	$106k
Memory (GB*hours)	47581	$56	$34k
Disk (GB*hours)	644898	$50	$30k
Network (GB)	559	$78	$47k
Other services		$30	$18k
Total		$391	$236k

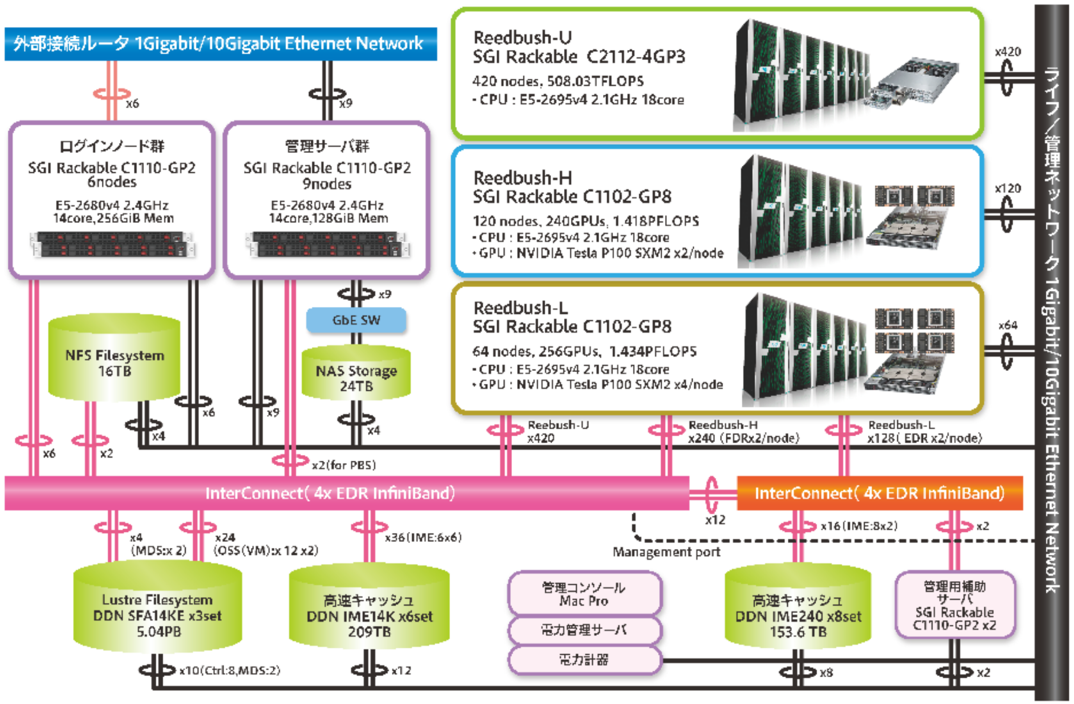
vCPU: 1vCPU instances max 200, 8 vCPUs instances max 100
Memory: 2.4 GB/vCPU
Disk: 50GB for 1vCPU instance, 150 GB for 8 vCPUs instance

Cost Estimation (20k cores/month)

Resource	Cost/month
vCPU x20k	$130k
3GB x20k	$42k
Local Disk 35GBx20k	$28k
Network GCP WN to ICEPP Storage 300 TB	$43k
Total	$243k

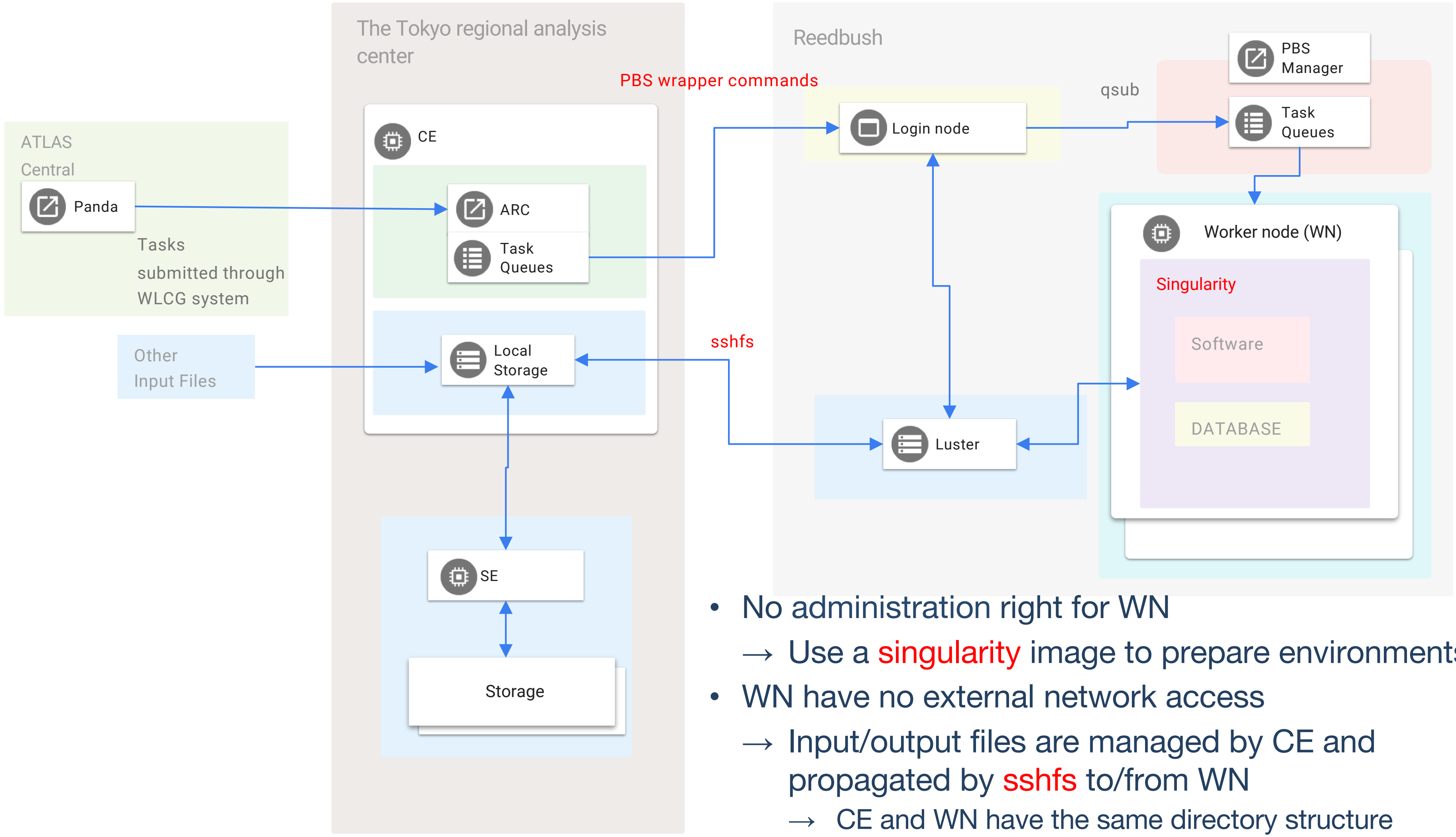
Reedbush

- Supercomputer system @Information Technology Center, The University of Tokyo
  →CPU:Intel Xeon (2CPUs/node (36cores/node))
  →GPU: NVIDIA Tesla P100
- CPU only nodes and GPU nodes
- OS: Read Hat Enterprise Linux 7



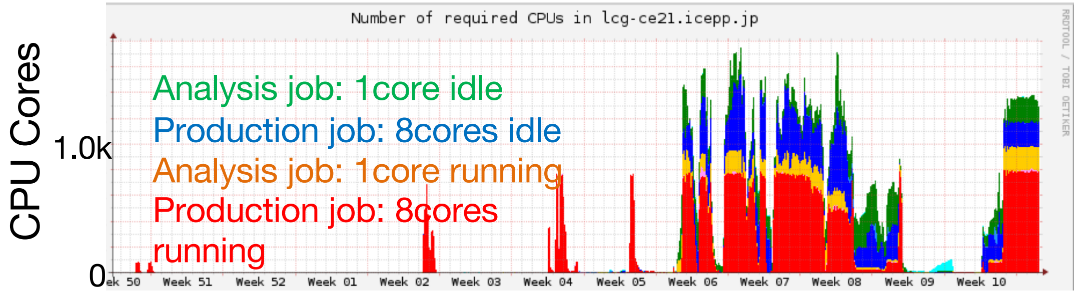
- PBS for the job management
- Lustre file system
- No external network access from each WN

System with Reedbush



- No administration right for WN
  → Use a singularity image to prepare environments
- WN have no external network access
  → Input/output files are managed by CE and propagated by sshfs to/from WN
    → CE and WN have the same directory structure
- Reedbush uses PBS for the job management
  → Available only on the login node
  → To manage jobs from CE, PBS wrapper commands are used
    → qsub:
    `ssh user@reedbush “cd $work_dir && qsub job.sh”`

ATLAS jobs on GCP and Reedbush

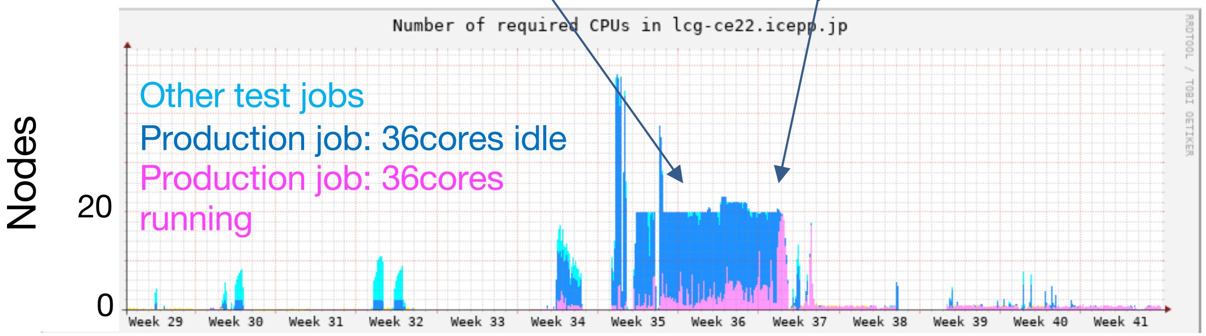


HTCondor status monitor for GCP

Max CPU Cores = 1k

Tested with the small queue (Only a few nodes are available)

Tested with the large queue



PBS status monitor for Reedbush
Max nodes = 20 (=720 CPU cores)

Summary

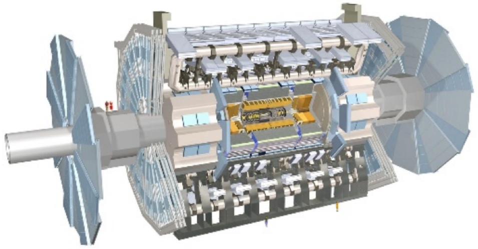
- The Tokyo regional analysis center introduced new systems using external resources
  →Commercial cloud: GCP
    → The hybrid system with cloud WN
    → GCPM has been developed to manage HTCondor job and instances of GCP
      → Can be used not only for WLCG, but also for any of HTCondor systems
  →HPC: Reedbush (@the Univ. Tokyo)
    → WNs of the system have no external network access
    → The system covers such a special situation by using singularity, sshfs and PBS wrapper commands are used
- ATLAS production jobs ran successfully

Future Plan

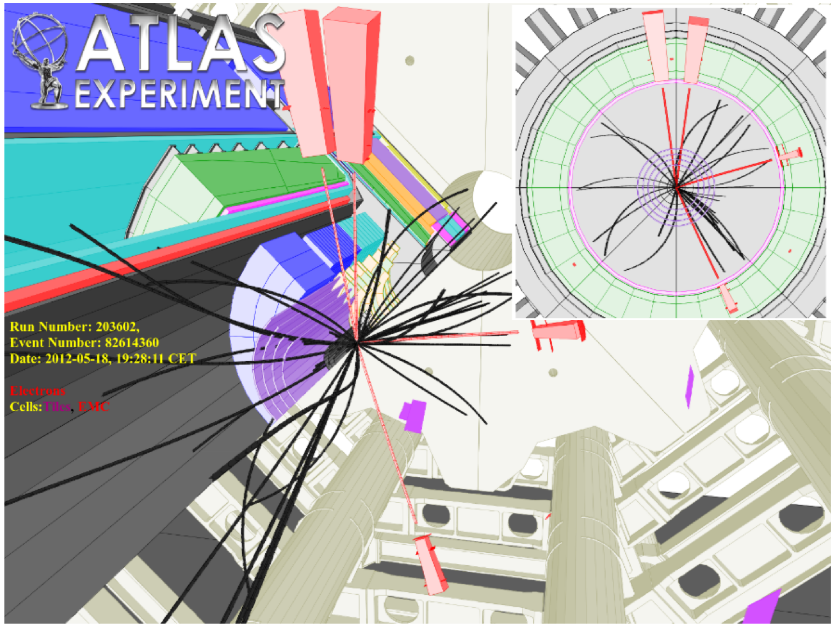
- Deploy other clouds (AWS, Azure, Oracle, …) and other HPCs in Japan
  → And other architectures (GPGPU, FPGA, …)
- Implement MPI for the HPC system

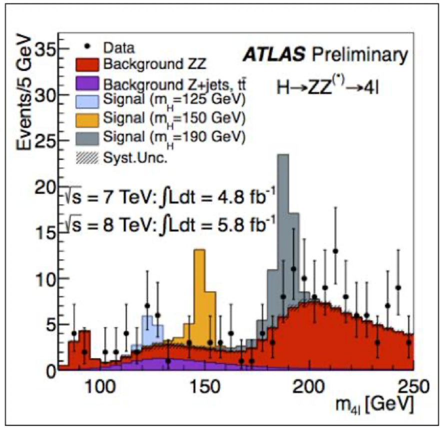
Backup

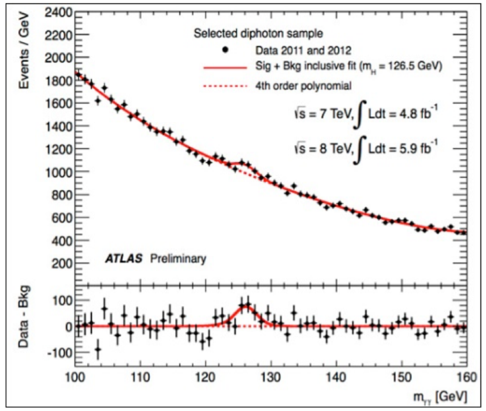
The ATLAS Experiment



Raw data: ~1GB/s

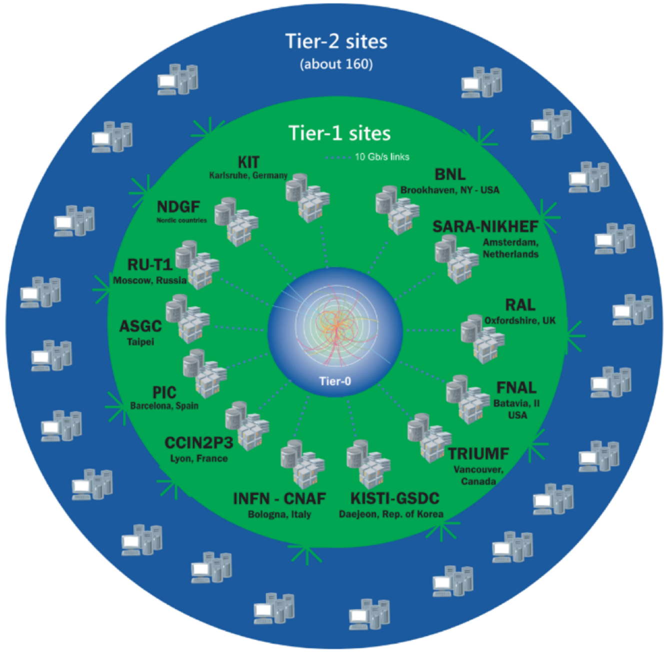






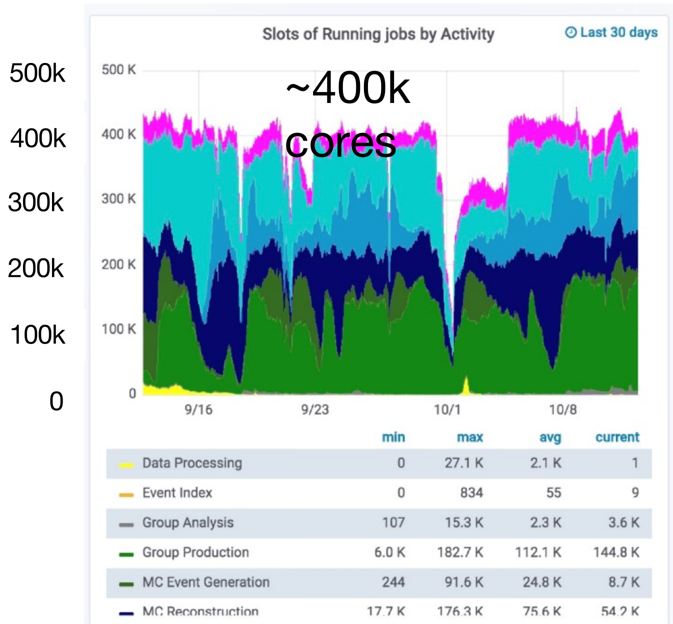
The Higgs Boson Discovery in 2012

Worldwide LHC Computing Grid (WLCG)



- A global computing collaboration for the LHC experiments

- The Tokyo regional analysis center is one of Tier2 for ATLAS



	min	max	avg	current
Data Processing	0	27.1 K	2.1 K	1
Event Index	0	834	55	9
Group Analysis	107	15.3 K	2.3 K	3.6 K
Group Production	6.0 K	182.7 K	112.1 K	144.8 K
MC Event Generation	244	91.6 K	24.8 K	8.7 K
MC Reconstruction	17.7 K	176.3 K	75.6 K	54.2 K

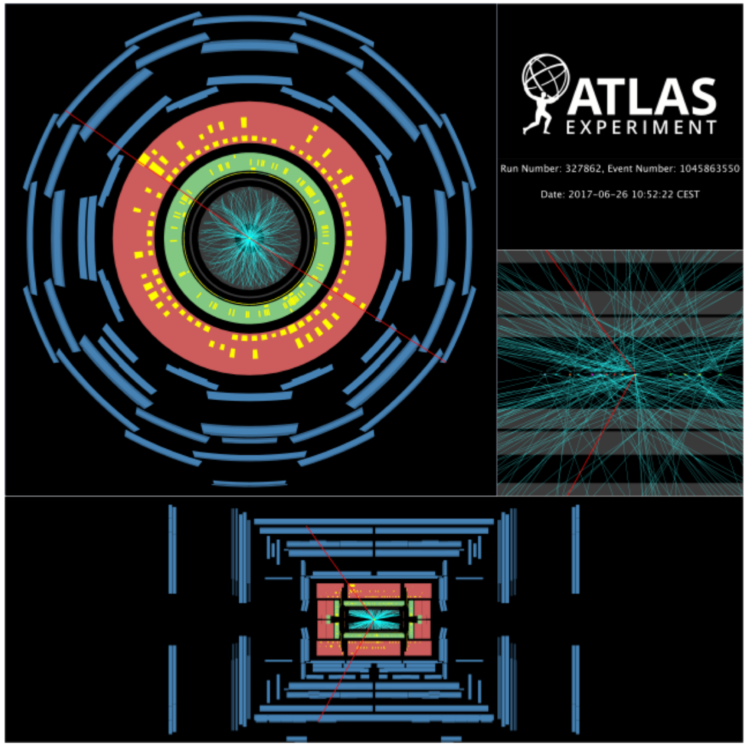
Number of cores used by ATLAS

Commercial Clouds and HPCs

- Commercial Clouds:
  →Many companies have introduced commercial clouds system
    → A lot of providers: AWS, Azure, Google Cloud Platform (GCP), IBM or Oracle…
  →A hybrid system of on-premises and cloud is also on trend
  →A hybrid system using GCP was constructed

- High Performance Computing (HPC):
  →HEP experiments have used "high throughput computing" (HTC) system
    → WLCG
  →But CPU clock did not get faster recently
  →HPC developments are strongly pushed in many countries
    → Need to adopt to these different architectures, MPI and special environments to obtain further computing power
  →Reedbush (HPC@The Univ. Tokyo) was used
    → Intel Xeon CPU (36cores/node)

Data Size



- LHC provides
  →40MHz proton-proton collision
- ATLAS filters events: 1kHz
- Raw event size: 1MB/events
  →1GB/seconds
- 150 days data taking/year:
  →10PB/year

- Current total data size: 200PB

(including Reconstructed data, Monte Carlo simulation)

Commercial Cloud

- Google Cloud Platform (GCP)
  →Number of vCPU, Memory are customizable
  →CPU is almost uniform:
    → At TOKYO region, only Intel Broadwell (2.20GHz) or Skylake (2.00GHZ) can be selected (they show almost same performances)
  →Hyper threading on
- Amazon Web Service (AWS)
  →Different types (CPU/Memory) of machines are available
  →Hyper threading on
  →HTCondor supports AWS resource management from 8.8
- Microsoft Azure
  →Different types (CPU/Memory) of machines are available
  →Hyper threading off machines are available

Performance Comparison

System	Hyper Threading	Core(vCPU)	Memory	CPU	HEPSPEC/ core	ATLAS simulation 1000events (hours)	Walltime*cores/Events
ICEPP local system	Off	32	96GiB	Intel(R) Xeon(R) Gold 6130 CPU @ 2.10GHz	18.97	(8core job) 5.19	0.042
Google Cloud Platform	On	8	24GiB	Intel(R) Xeon(R) Gold 6138 CPU @ 2.00GHz	12.62	(8core job) 9.27	0.074
Reedbush	Off	36	256GB	Intel(R) Xeon(R) CPU E5-2695 v4 @ 2.10GHz	16.78	(36 core job) 1.1	0.040

HEPSPEC (06): Benchmark for HEP

- The ATLAS production jobs can run with multi-processing mode
  →Normally 8 cores are used at WLCG sites
  →Will be multi-threading
- All GCP's instances are set as hyper-threading on
  →~half performance of other systems
- Reedbush nodes have 36 cores
  →Each job occupies all cores in the node: Run 36 processes mode

Google Computing Element

- **HT On**
  - → All Google Computing Element (GCE) at GCP are HT On
  - → TOKYO system is HT off

System	Core(vCPU)	CPU	SPECInt/core	HEPSPEC	ATLAS simulation 1000events (hours)
TOKYO system: HT off	32	Intel(R) Xeon(R) Gold 6130 CPU @ 2.10GHz	46.25	18.97	5.19
TOKYO system: HT on	64	Intel(R) Xeon(R) Gold 6130 CPU @ 2.10GHz	N/A	11.58	8.64
GCE (Broadwell)	8	Intel(R) Xeon(R) CPU E5-2630 v4 @ 2.20GHz	(39.75)	12.31	9.32
GCE (Broadwell)	1	Intel(R) Xeon(R) CPU E5-2630 v4 @ 2.20GHz	(39.75)	22.73	N/A
GCE (Skylake)	8	Intel(R) Xeon(R) Gold 6138 CPU @ 2.00GHz	(43.25)	12.62	9.27

- SPECInt (SPECint_rate2006):
  - Local system: Dell Inc. PowerEdge M640
  - GCE(Google Compute Engine)'s value were taken from Dell system with same corresponding CPU
    - GCE (Broadwell): Dell Inc PowerEdge R630
    - GCE (Skylake): Dell Inc. PowerEdge M640
- ATLAS simulation: Multi process job 8 processes
  - For 32 and 64 core machine, 4 and 8 parallel jobs were run to fill cores, respectively

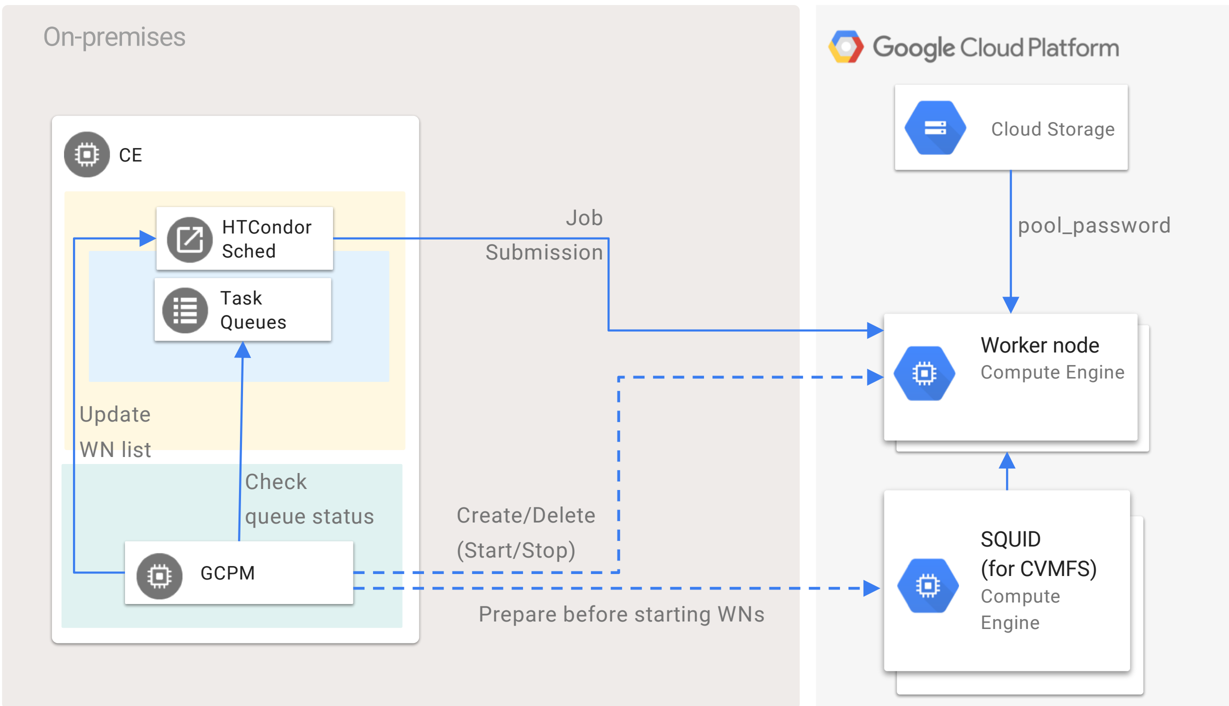
→ Broadwell and Skylake show similar specs
  - → Costs are same. But if instances are restricted to Skylake, instances will be preempted more
  - → Better not to restrict CPU generation for preemptible instances

→ GCE spec is ~half of TOKYO system

- **Preemptible Instance**
  - → Shut down every 24 hours
  - → Could be shut down before 24 hours depending on the system condition
  - → The cost is ~1/3

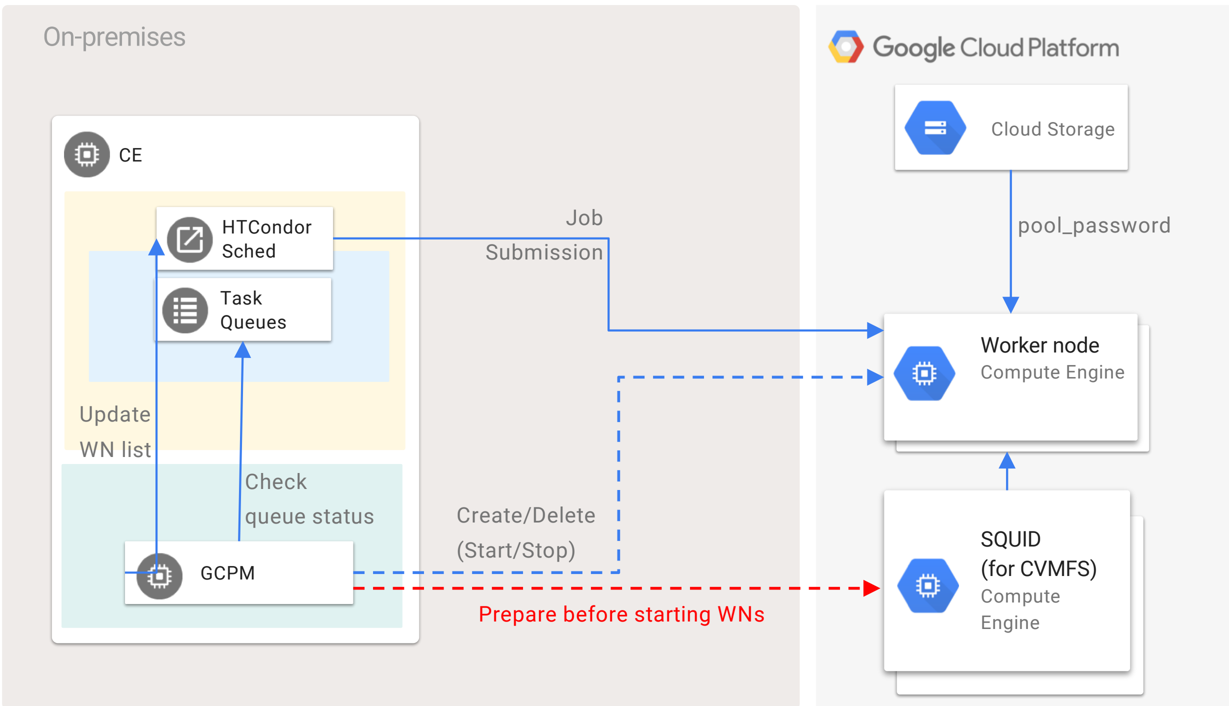
Google Cloud Platform Condor Pool Manager

- https://github.com/mickaneda/gcpm
  → Can be installed by pip:
    → ***$ pip install gcpm***
- Manage GCP resources and HTCondor's worker node list



Google Cloud Platform Condor Pool Manager

- Run on HTCondor head machine
  →Prepare necessary machines before starting worker nodes
  →Create (start) new instance if idle jobs exist
  →Update WN list of HTCondor
  →Job submitted by HTCondor
  →Instance's HTCondor startd will be stopped at 10min after starting
    → ~ only 1 job runs on instance, and it is deleted by GCPM
      → Effective usage of preemptible machine



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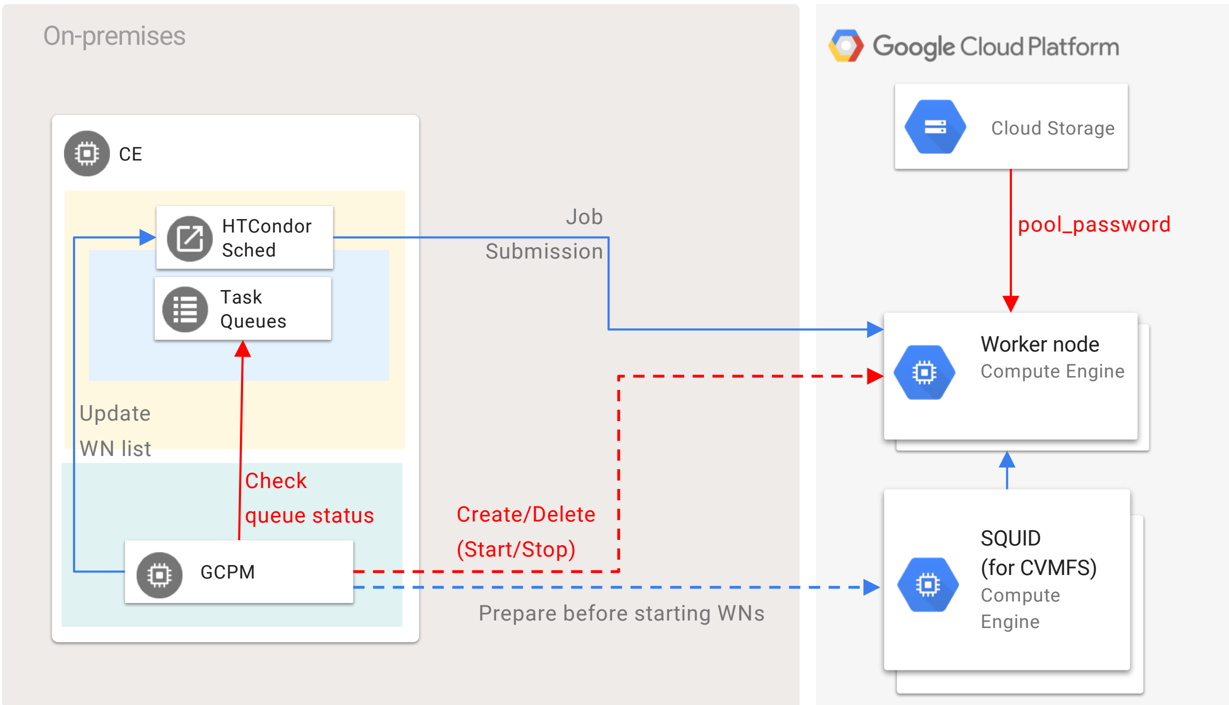

pool_password file for the authentication is taken from storage by startup script

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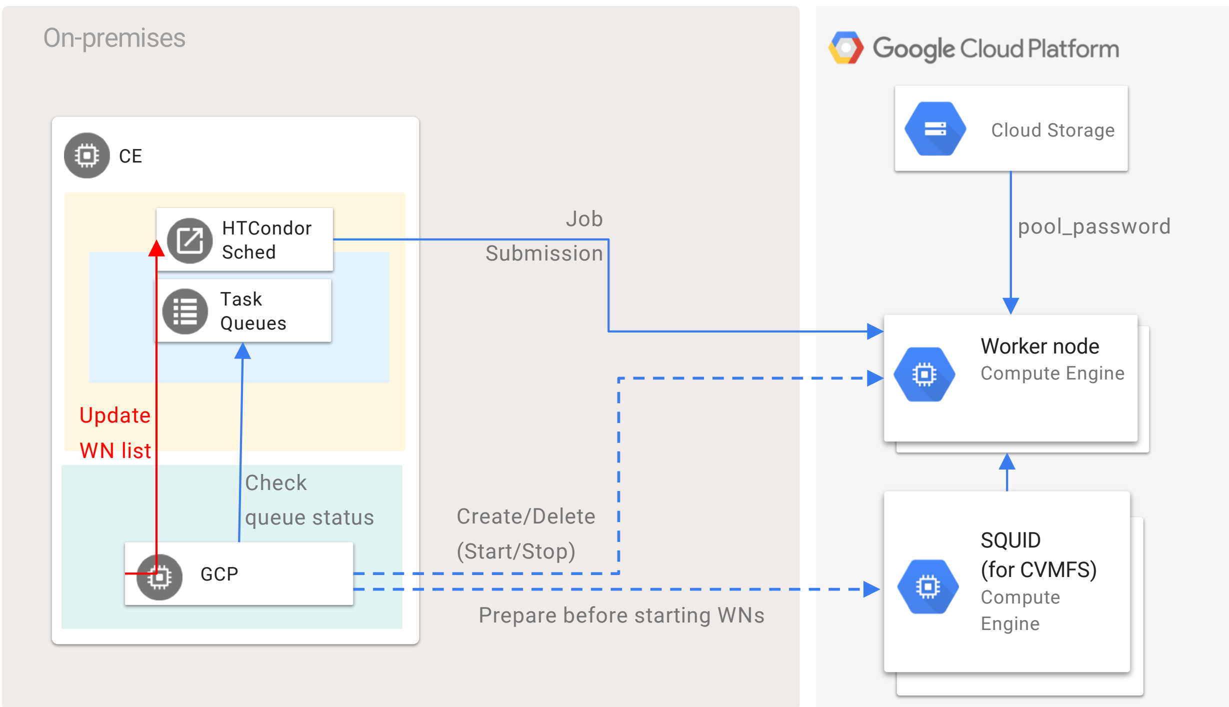

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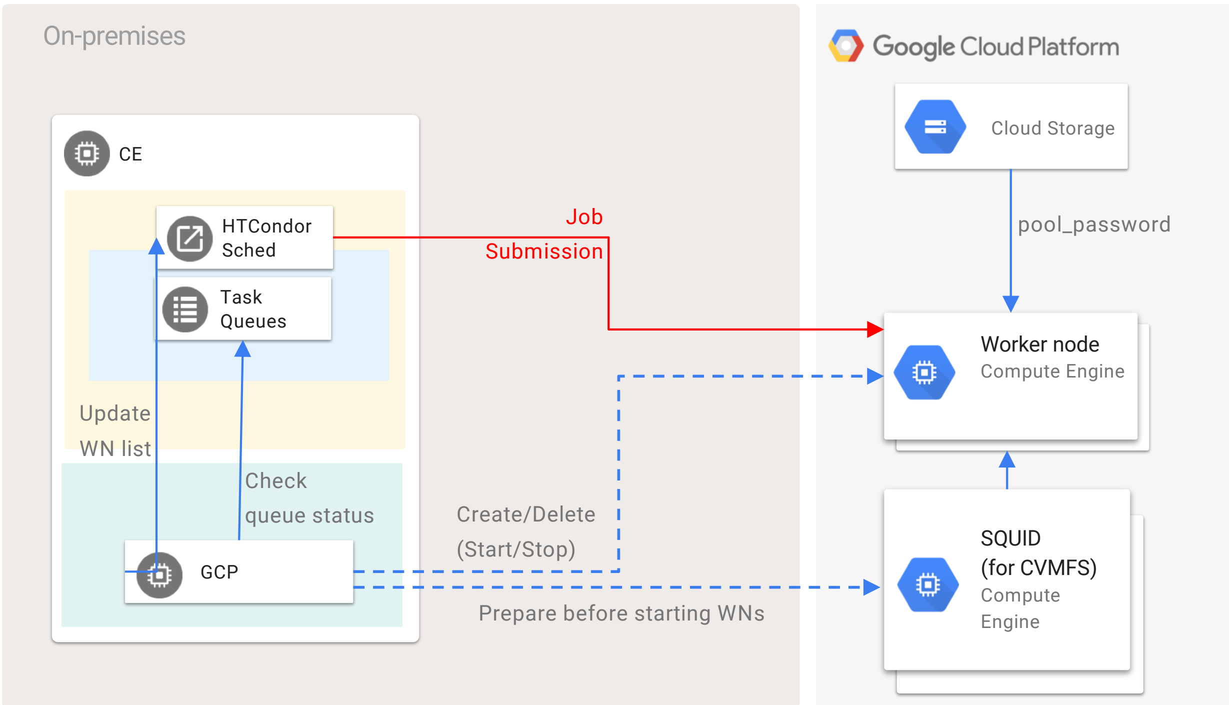


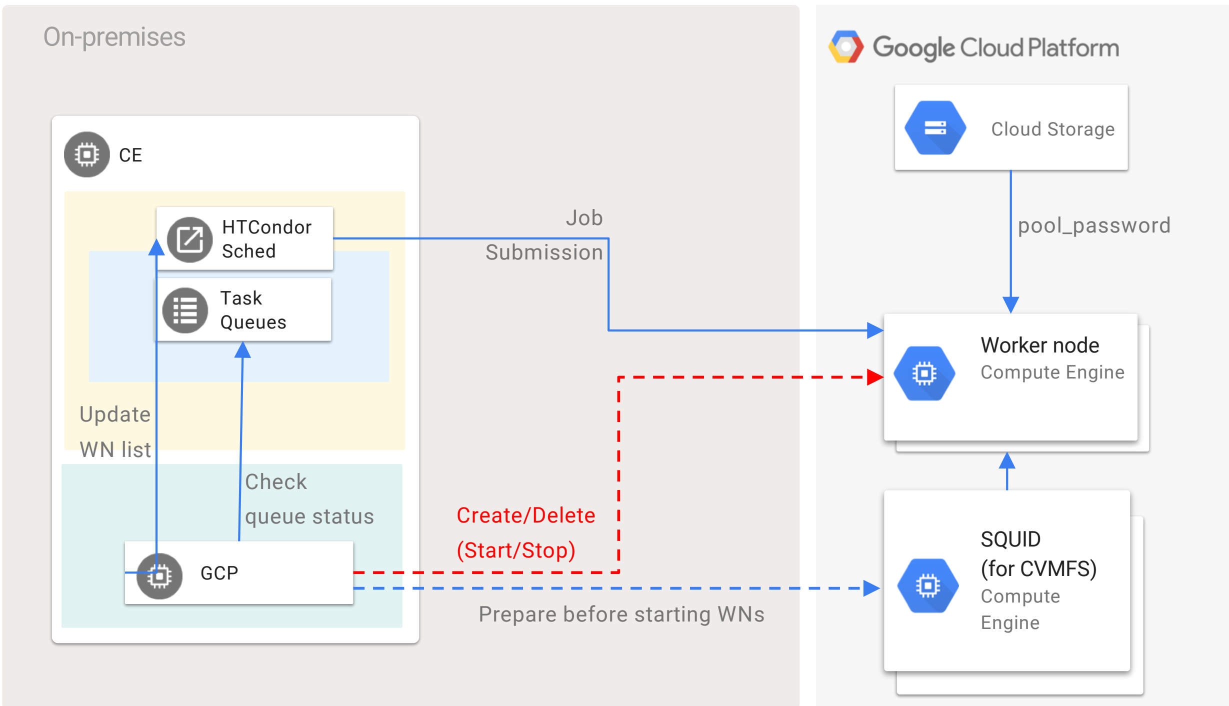
Google Cloud Platform Condor Pool Manager

- Set to execute `*condor_off -peaceful –startd*` after 10min by the startup script for GCE instance
- When a job finished, the instance is removed from `*condor_status*` list
- Then GCPM deletes (sotps) the instance

→ Instance's HTCondor startd will be stopped at 10min after starting

→ ~ only 1 job runs on instance, and it is deleted by GCPM

→ Effective usage of preemptible machine



ARC CE Hacking

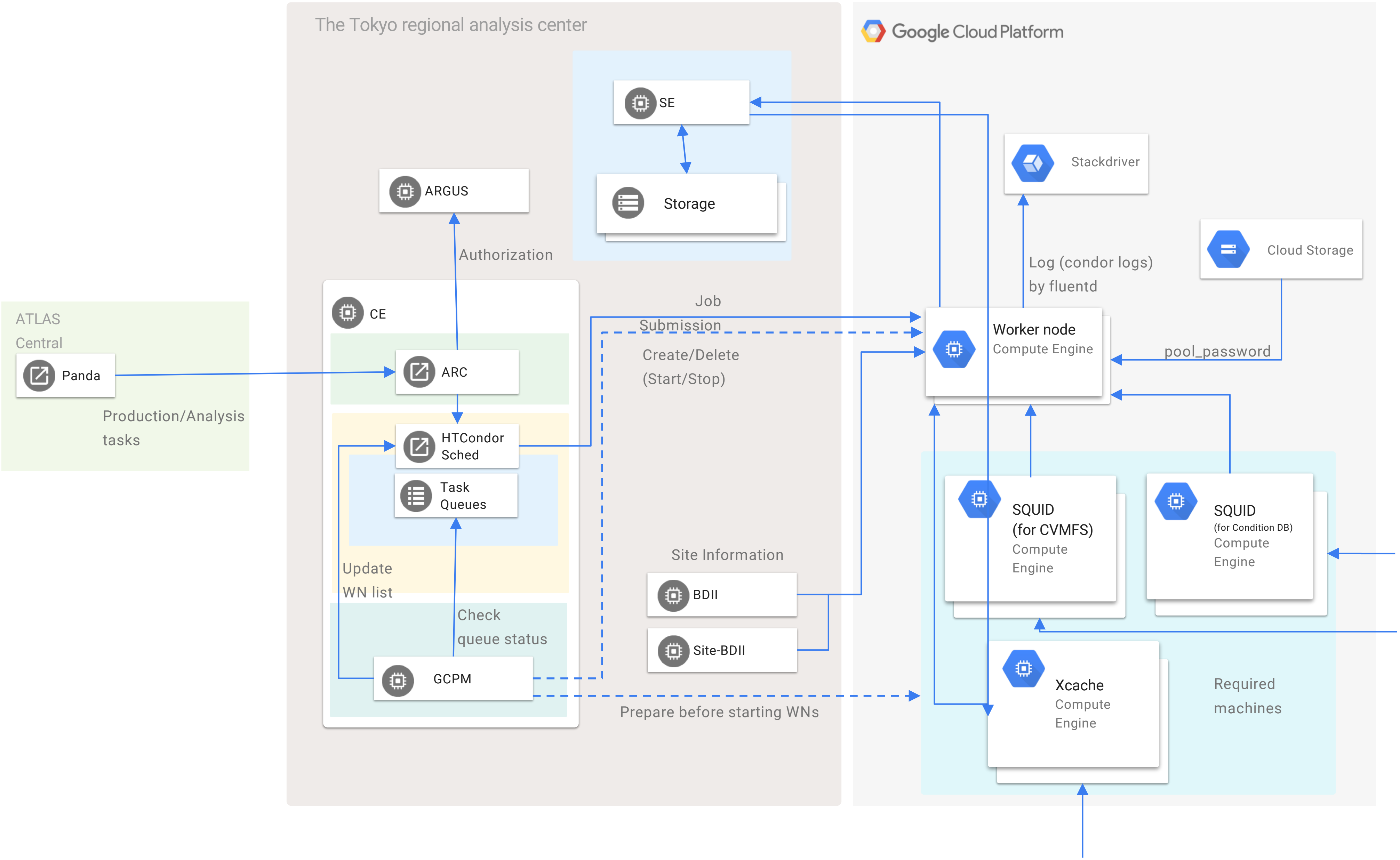
- ARC checks a number of available slots before submitting jobs
  → If a job specifies a number of CPUs and there are not enough slots, job submission fails
  → GCP pool has no slot at the start, jobs cannot be submitted
  → Hack /usr/share/arc/Condor.pm to return non-zero cpus if it is zero

```
#
# returns the total number of nodes in the cluster
#
sub condor_cluster_totalcpus() {
    # List all machines in the pool. Create a hash specifying the
TotalCpus
    # for each machine.
    my %machines;
    $machines{$$_{machine}} = $$_{totalcpus} for @allnodedata;

    my $totalcpus = 0;
    for (keys %machines) {
        $totalcpus += $machines{$_};
    }

    # Give non-zero cpus for dynamic pool
    $totalcpus ||= 100;
    return $totalcpus;
}
```

System for R&D



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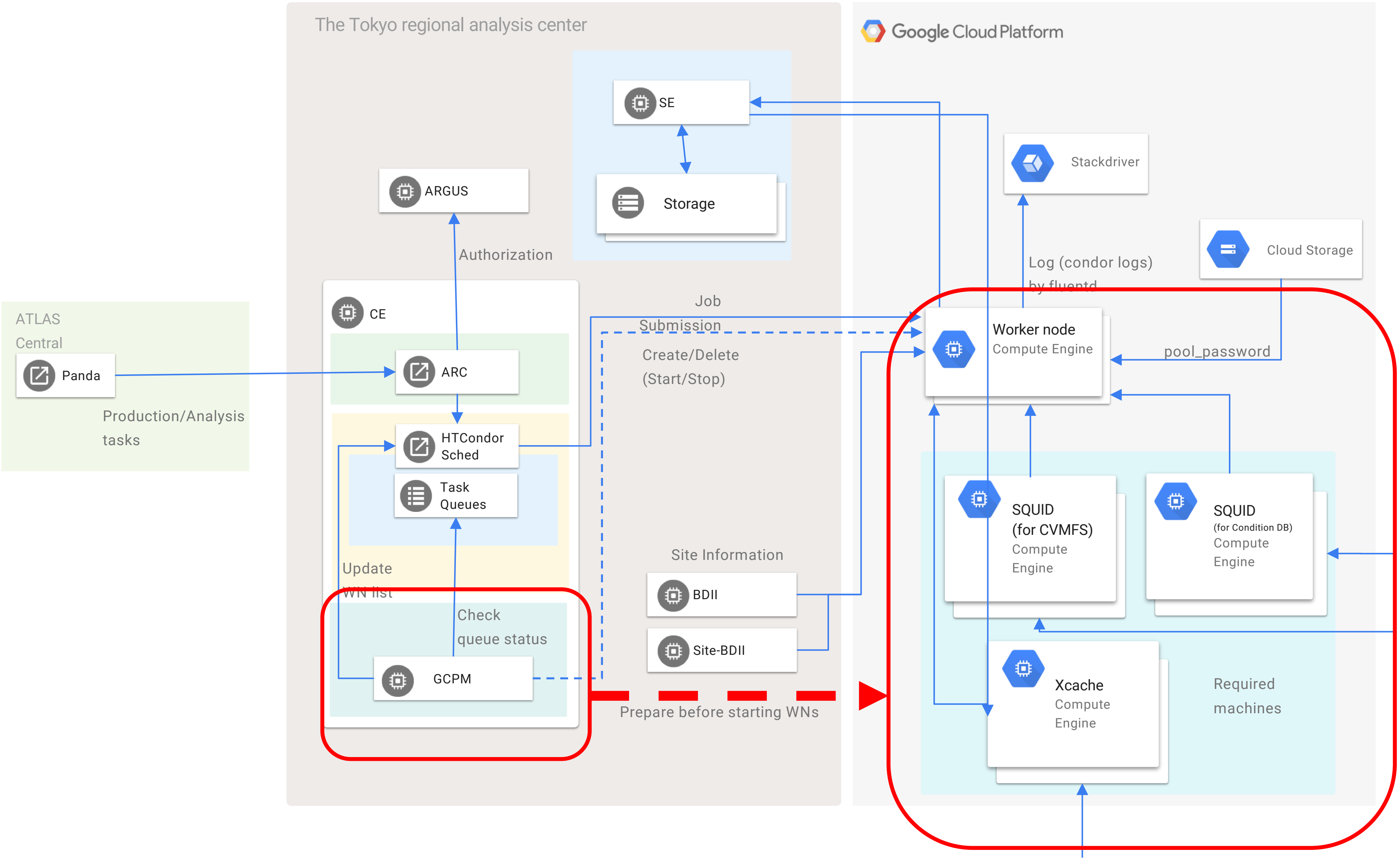

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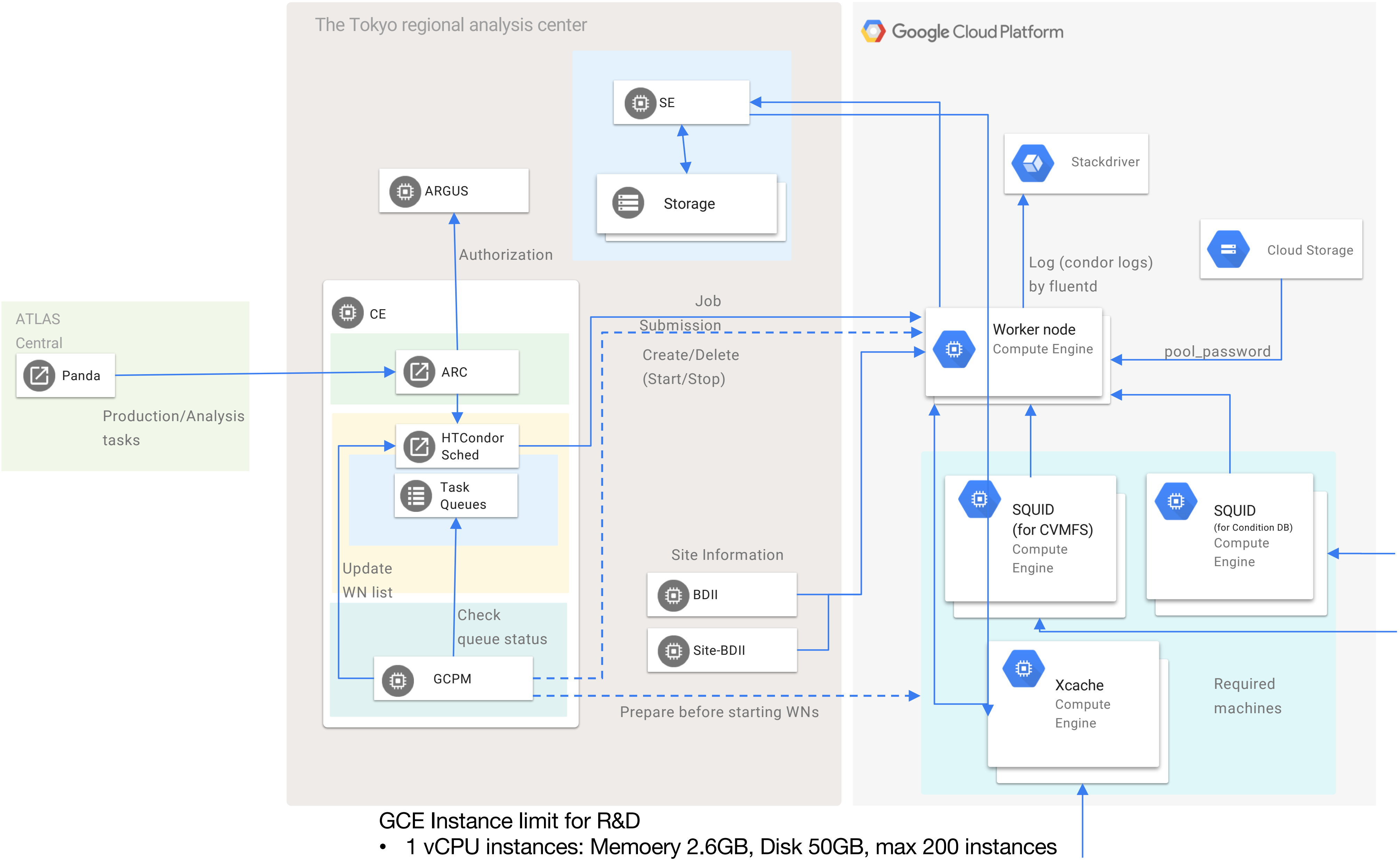


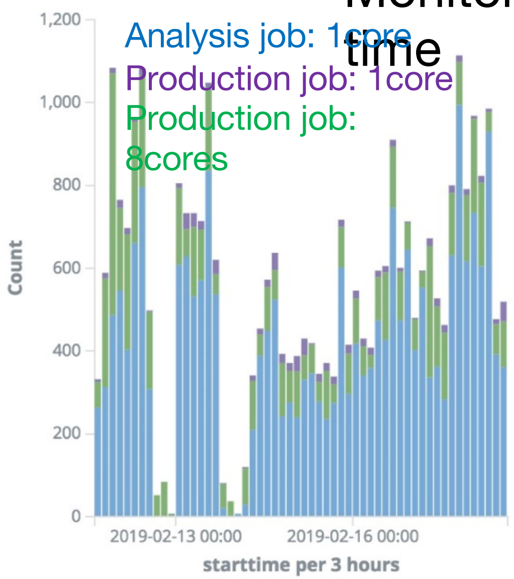
GCE Instance limit for R&D

- 1 vCPU instances: Memoery 2.6GB, Disk 50GB, max 200 instances
- 8 vCPU instances: Memory 19.2GB, Disk 150GB, max 100 instances

→ Total vCPU max: 1000

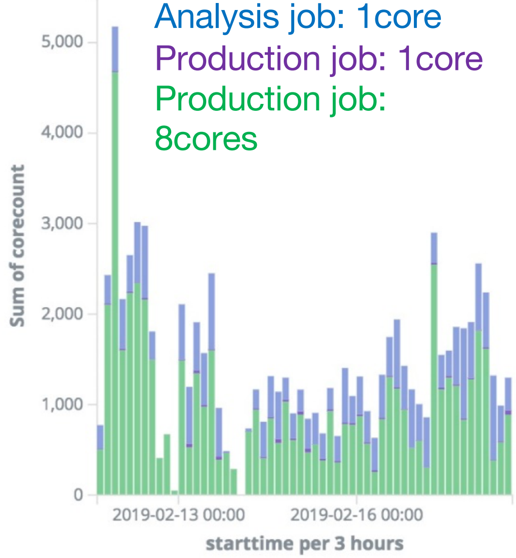
Jobs Running on GCP

Monitors of job starting time



Analysis job: 1core
Production job: 1core
Production job: 8cores

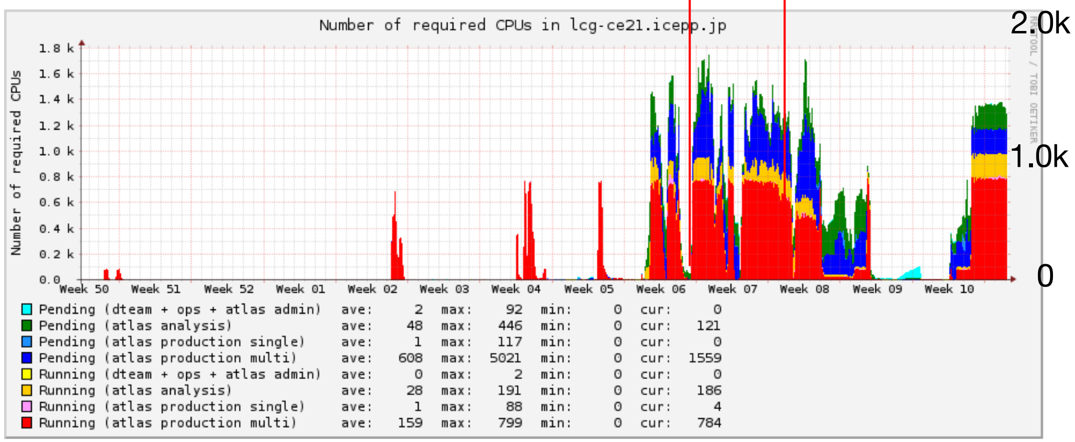
Number of jobs



Analysis job: 1core
Production job: 1core
Production job: 8cores

Number of vCPUs

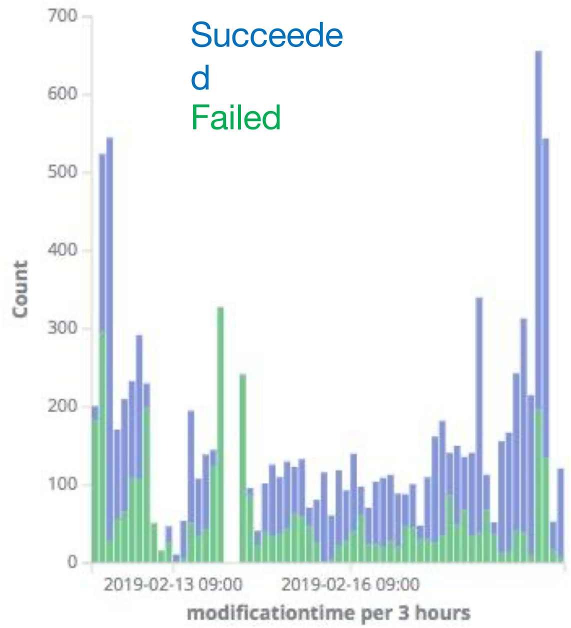
vCPUs



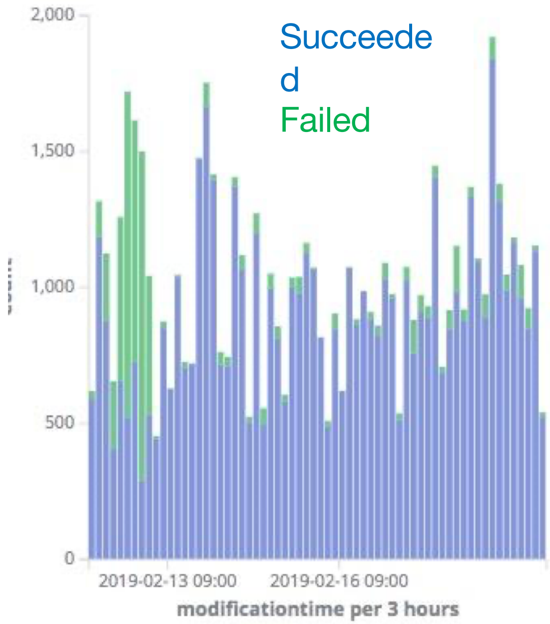
HTCondor status monitor

Analysis job: 1core idle
Production job: 8cores idle
Analysis job: 1core running
Production job: 8cores running

Failure Rate (Production Jobs)



GCP Worker Nodes
(Production Job)

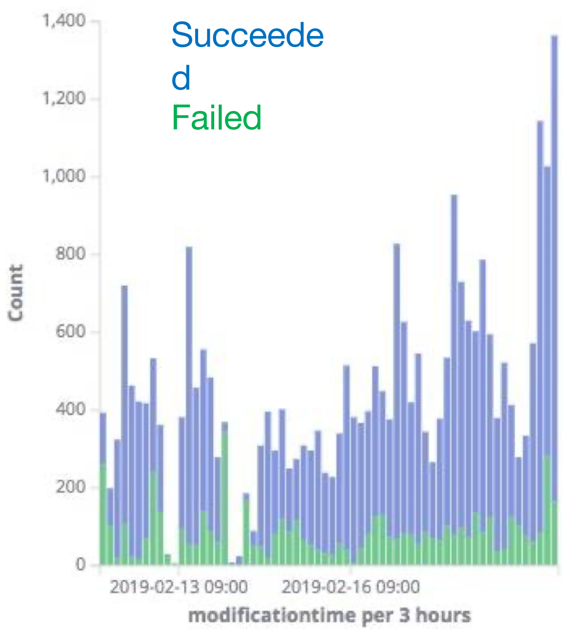


ICEPP Worker Nodes
(Production Job)

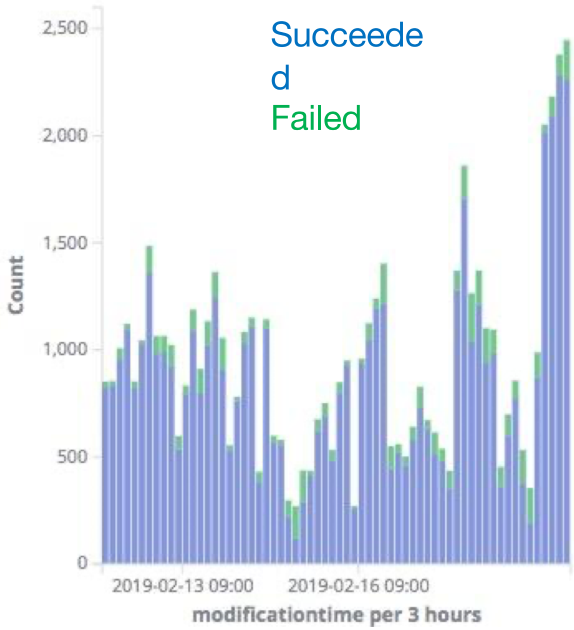
Job Type	Error rate
GCP Production (Preemptible)	35%
GCP Production (Non-Preemptible)	6%
Local Production	11%

Mainly 8 core jobs, long jobs (~10 hours/job)

Failure Rate (Analysis Jobs)



GCP Worker Nodes
(Analysis Job)



ICEPP Worker Nodes
(Analysis Job)

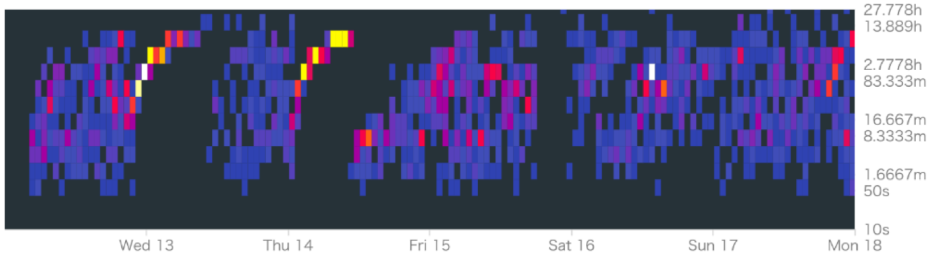
Job Type	Error rate
GCP Analysis (Preemptible)	19%
GCP Analysis (Non-Preemptible)	14%
Local Analysis	8%

Only 1 core job, shorter jobs

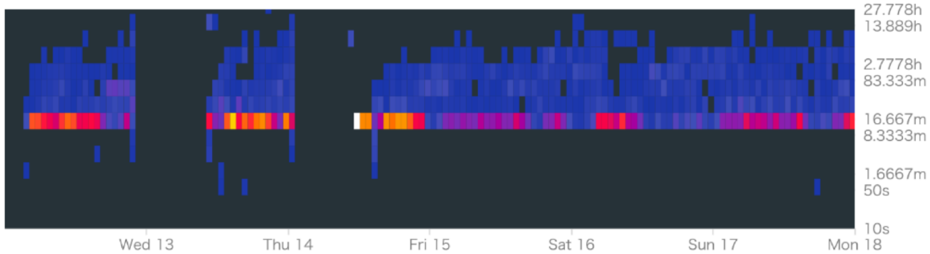
Preemption

1 core instances

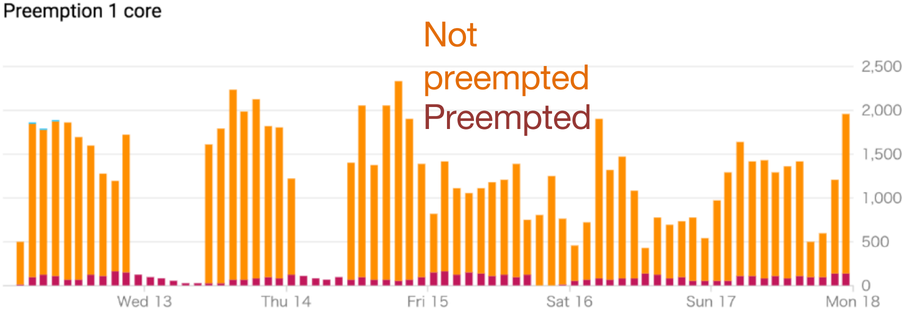
Uptime: 1 core, Preempted



Uptime: 1 core, Not preempted

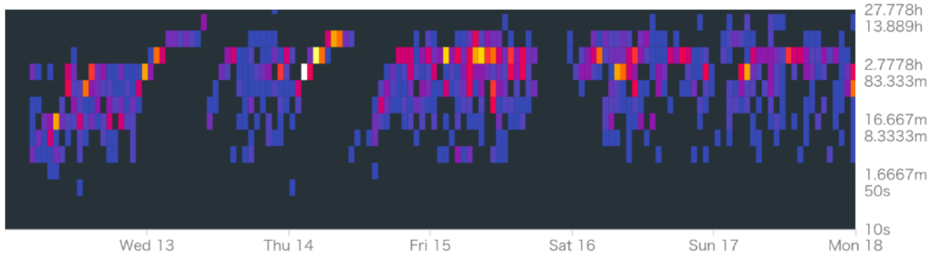


Preemption 1 core

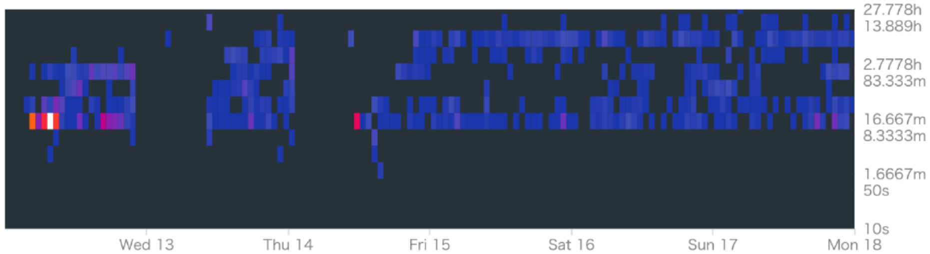


8 core instances

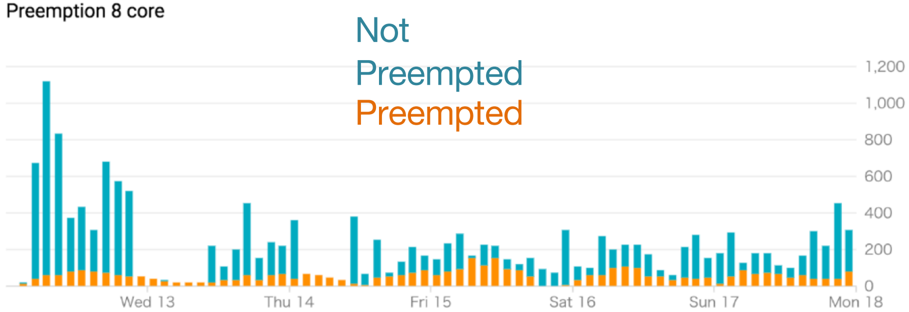
Uptime: 8 cores, Preempted



Uptime: 8 cores, Not preempted

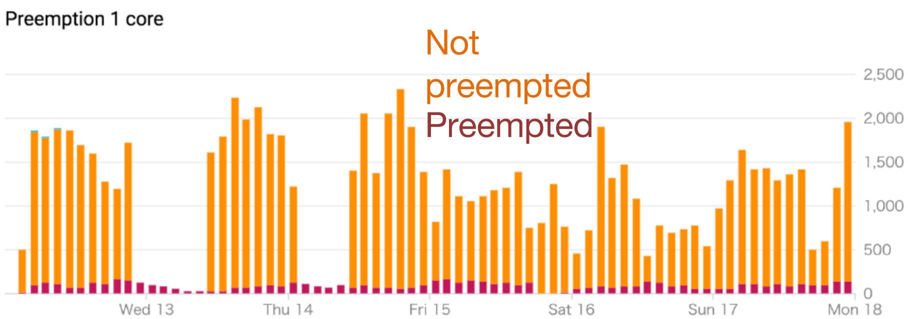


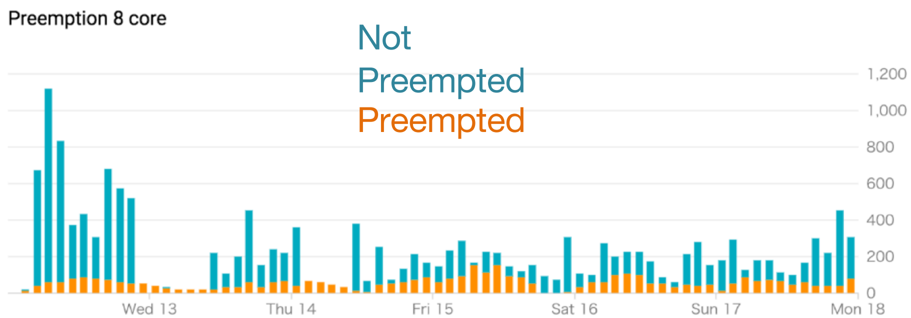
Preemption 8 core



Preemption v.s. Failure jobs

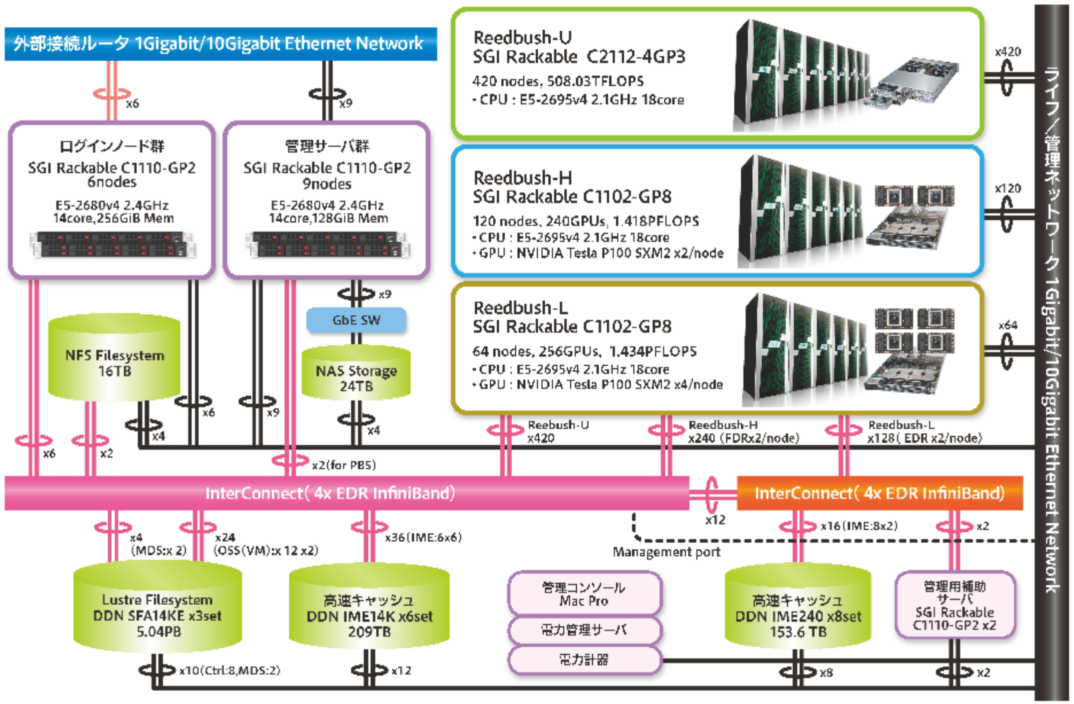
- 5~30 % instances were shut down by Preemption
  →Made failure jobs
- Typically shut down around 3~10 hours
  →Some instances were shutdown before 1 hours running
- More preemptions in 8 core jobs (production: reco/sim) because job running times are longer





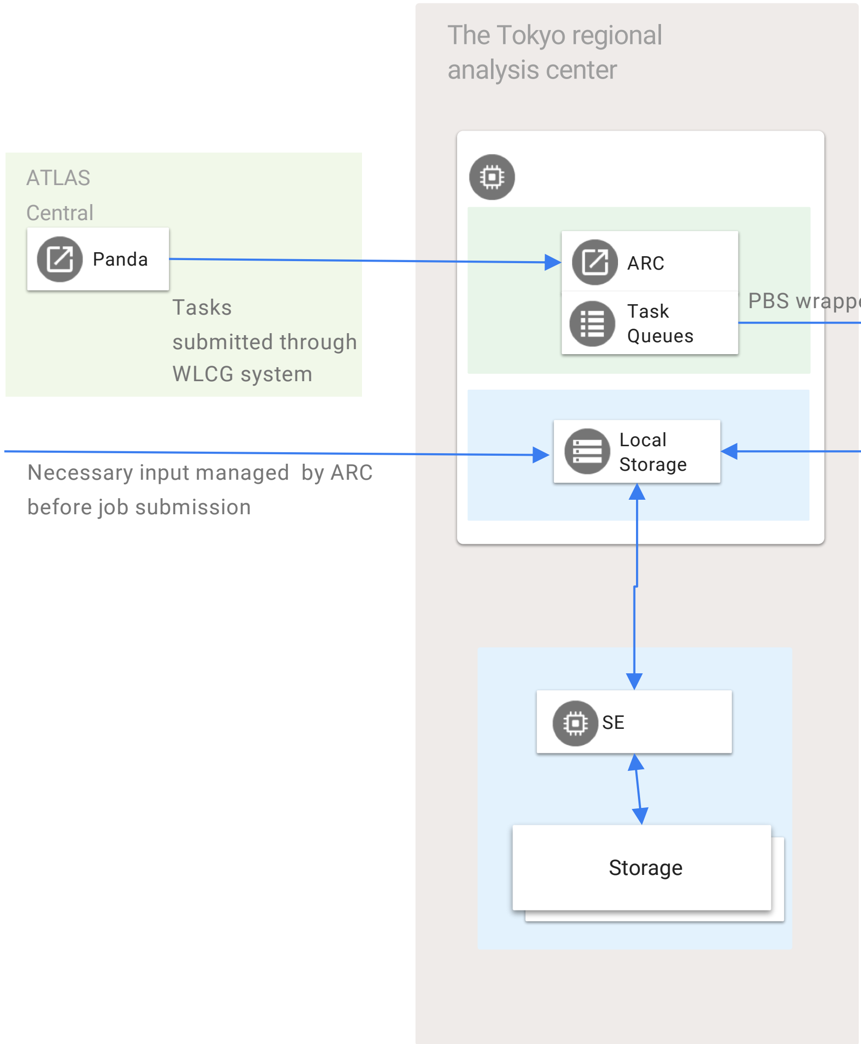
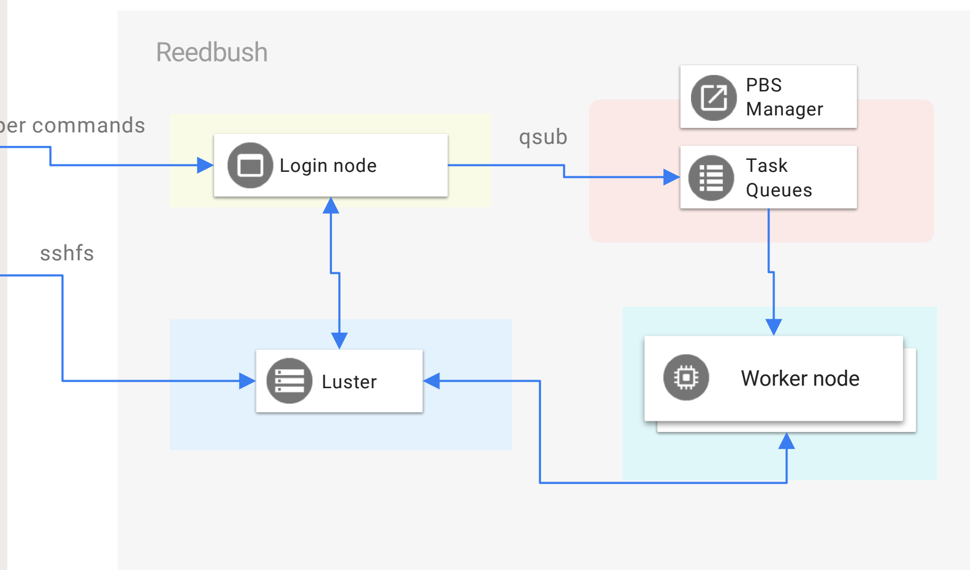
Reedbush

- Supercomputer system @Information Technology Center, The University of Tokyo
  →CPU:Intel Xeon (2CPUs/node (36cores/node))
  →GPU: NVIDIA Tesla P100
- CPU only nodes and GPU nodes
- OS: Read Hat Enterprise Linux 7

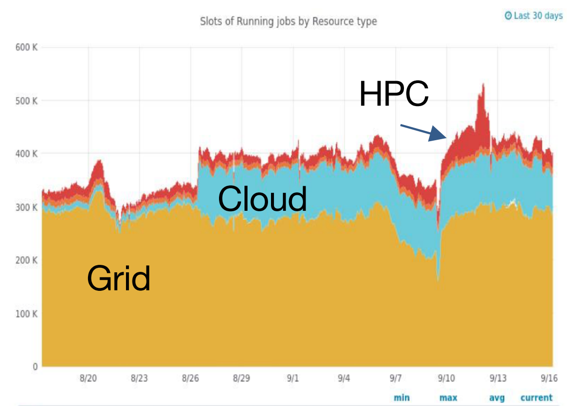


- PBS for the job management
- Lustre file system
- No external network access from each WN

Reedbush System

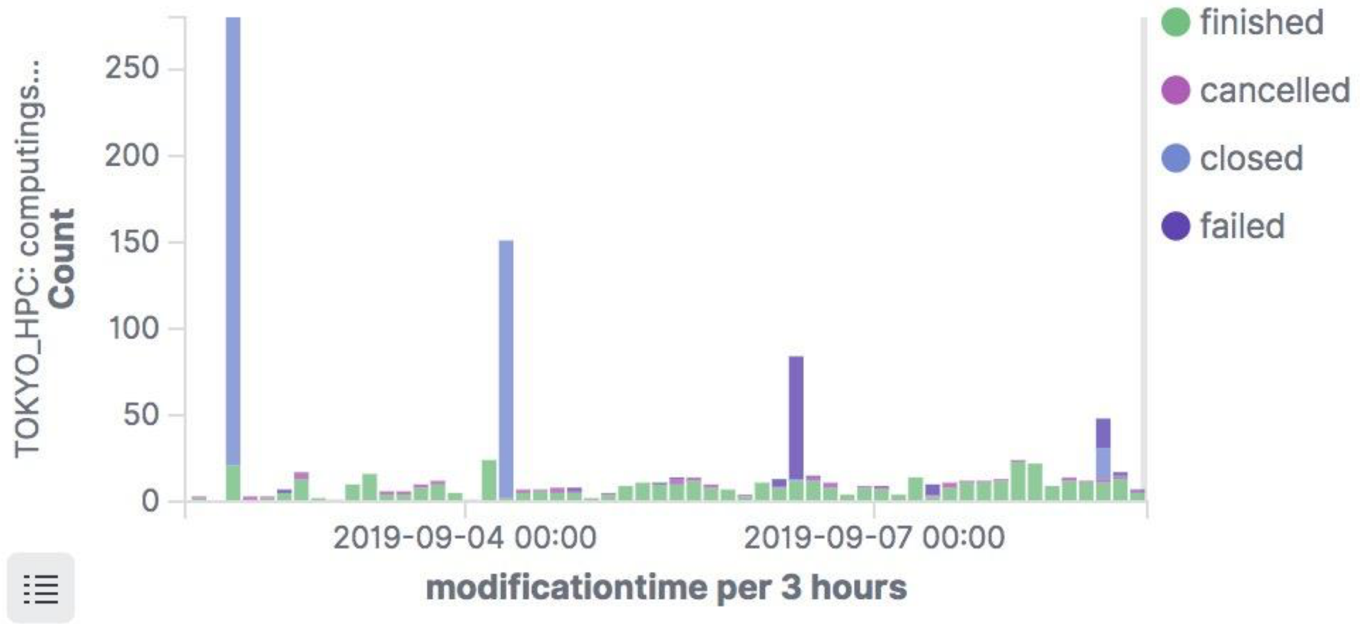



4484564357 Attempt 0 of 0	gangarbt		Sim_tf.py	finished	2019-09-15 06:59:30	0:0:07:16	0:0:12:00	2019-09-15 07:34:24	FR TOKYO_HPC test HC.Blacklist.set.test	10000	2 (1)
	Job name: 50691303-db54-485b-9b36-6e2cce1afb8f_79286#0										
	Datasets: **In:** hc_test:mc15_13TeV.361106.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Zee.evgen.EVNT.e3601_tid04972714_00 || Rucio link **Out:** hc_test.gangarbt.hc20145990.tid957.TOKYO_HPC.166										

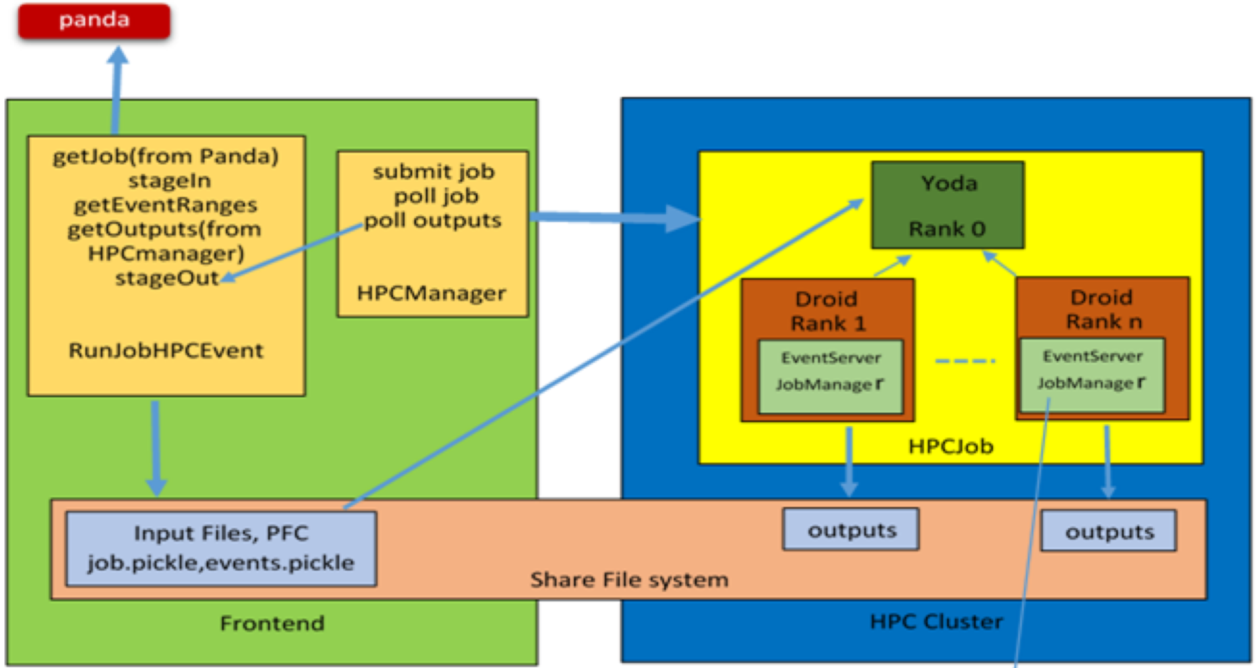


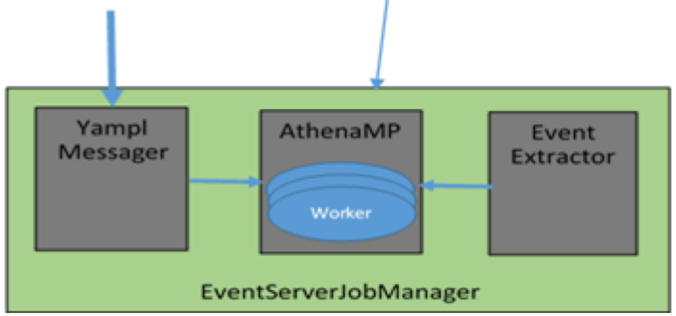
Usage of HPC by ATLAS

Reedbush Failure rate



MPI Job





- Yoda:
  - →A tool for Message Passing Inerface (MPI) developed by ATLAS
  - →We will try to deploy the tool in our system

Cost Comparison

System	Cost for 10k cores/Month
On-premises	$200k
Reedbush	$40k
Google Cloud Platform	$250k

- On-premises:
  - → Total server cost of 10k cpu cores, 16PB storage (Dell)/3 years
  - → Additional cost: infrastructure, maintenance
- Reedbush:
  - → Price as a user
  - → Non-university groups also can apply to use the system (price: x1.2)
  - → Only limited number of resources
    - → Currently max number of nodes is ~ 20 (~700cores)
  - → Additional cost: on-premises storage and other service components
  - → Cost of Reedbush itself is ~50k/month for 10k cores
- GCP:
  - → Hyper Threading On: Need double number of CPU cores (calculated by assuming 20k cores)
  - → Reduced cost by using preemptible instances
  - → Including network cost
  - → Additional cost: on-premises storage and other service components