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Centro Nazionale di Ricerca in HPC,  
Big Data and Quantum Computing



Centro Nazionale di Ricerca in HPC,  
Big Data and Quantum Computing

## Flavor physics - searches for rare decays at CMS (UC2.2.2)

Marco Buonsante, Federica Simone, Rosamaria Venditti (INFN e Università/Politecnico di Bari)

Spoke2 WP2 Meeting, 21 Maggio 2024

# Motivations

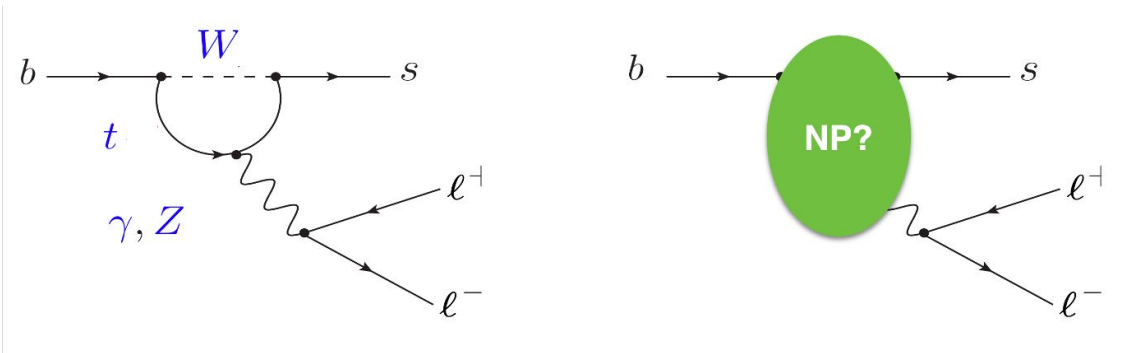
**(Heavy) flavor physics:** study B and D meson decays and look for new physics effects

**Rare processes** - wish list:

- suppressed in the SM
- precise theoretical predictions
- sensitive to new physics
- experimentally accessible

**Examples**

- FCNC transitions  
e.g.  $b \rightarrow s \ell^+ \ell^-$ , also helicity suppressed
- Decays forbidden by (accidental) symmetries of the SM: LUV, LFV and LNV

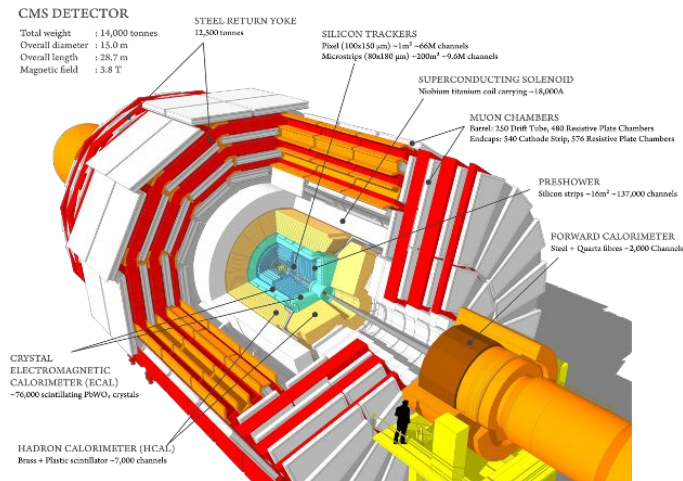
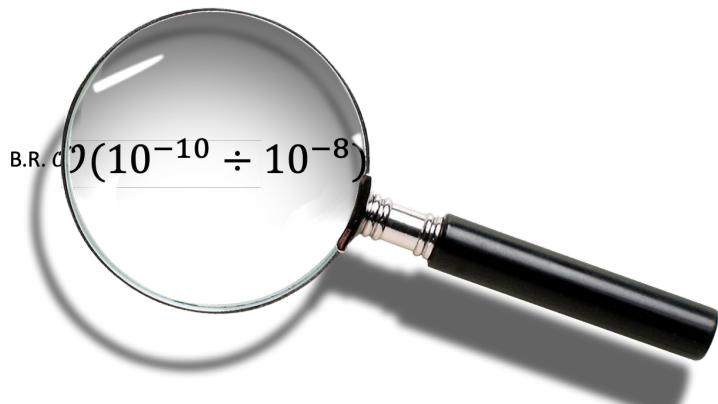


# Motivations

**(Heavy) flavor physics:** study B and D meson decays and look for new physics effects

**Rare processes** - wish list:

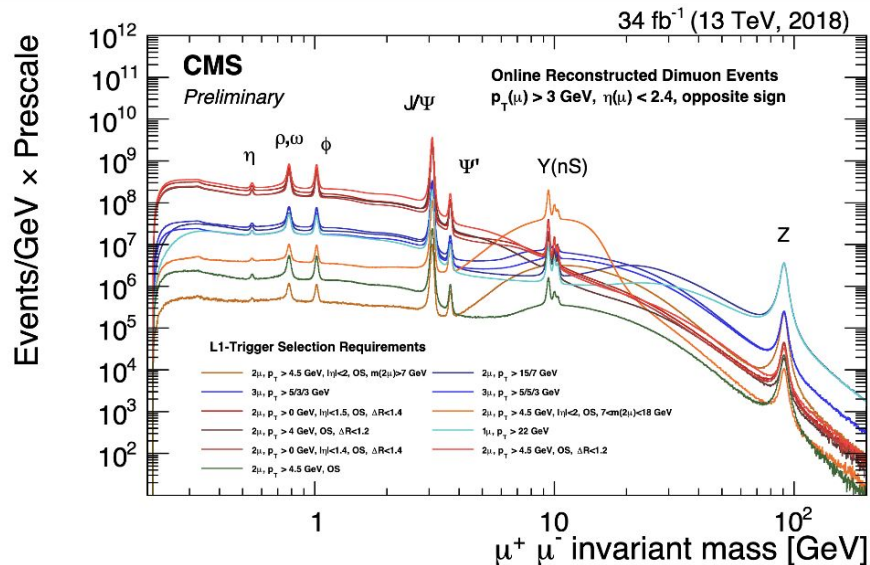
- suppressed in the SM
- precise theoretical predictions
- sensitive to new physics
- **experimentally accessible**



# Triggers

**Experimental signature: Low-pT muons** → need careful trigger strategy

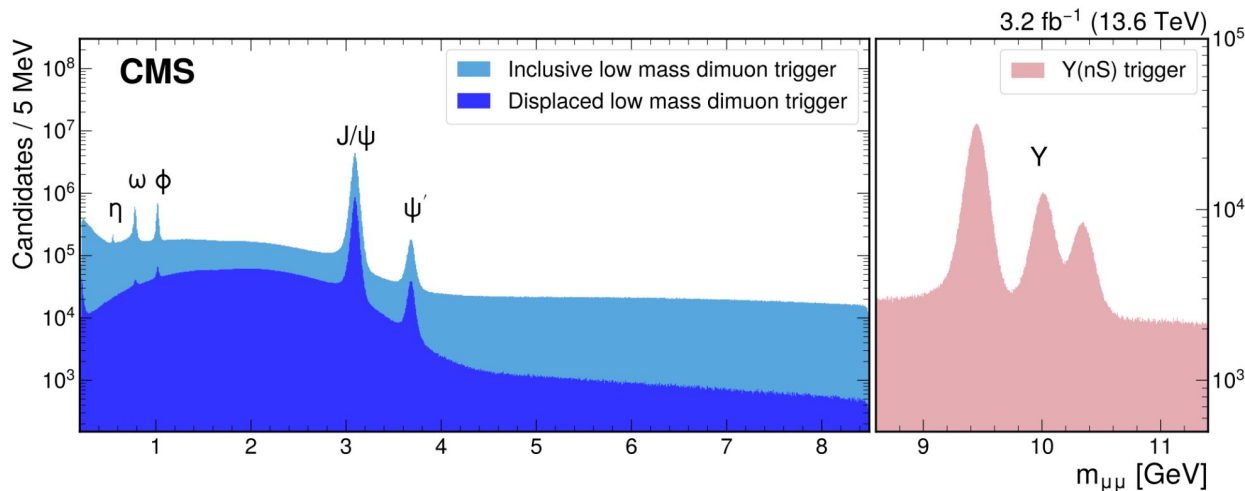
In **Run2**: combination of dimuon triggers with different complementary selections



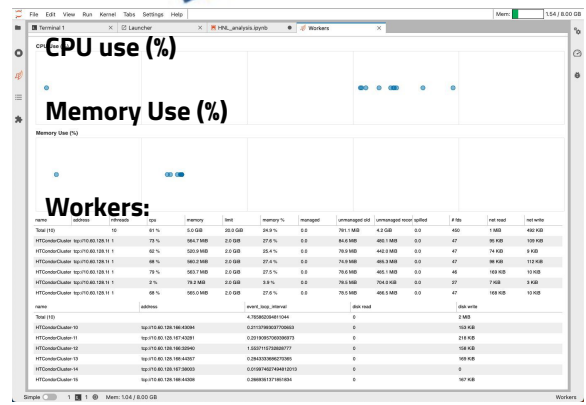
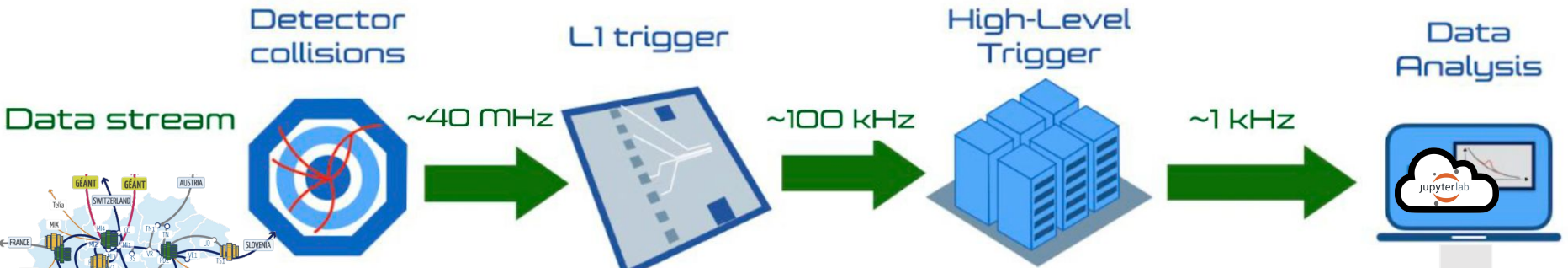
# Triggers

**Experimental signature: Low-pT muons** → need careful trigger strategy

In **Run3**: “inclusive” dimuon trigger → dataset **5 times larger**,  
**parked for delayed reconstruction**



# HEP data analysis with ICSC



A screenshot of a JupyterLab interface showing a code cell for 'HNL CMS Analysis'. The code includes a 'Dask cluster configuration' section with a note that the cell below will be changed every time the Dask cluster is recreated. The code defines a client and a scheduler, and lists the packages and versions used in the environment.

```

client = Client("localhost:2032")
client

~/usr/local/share/miniconda/lib/python3.10/site-packages/distributed/client.py:1389: VersionMismatchWarning: Mismatched versions found
Package | Client | Scheduler | Workers
---|---|---|---
lz4 | 4.8.0 | None | 4.8.0
msgpack | 1.0.2 | 1.0.5 | 1.0.2
python | 3.10.12.final.0 | 3.10.5.final.0 | 3.10.12.final.0
tornado | 6.12.0 | 6.11.1 | 6.12.0
Notes
-----
msgpack: Variation is ok, as long as everything is above 4.6
warnings.warn(version_module.VersionMismatchWarning(msg))

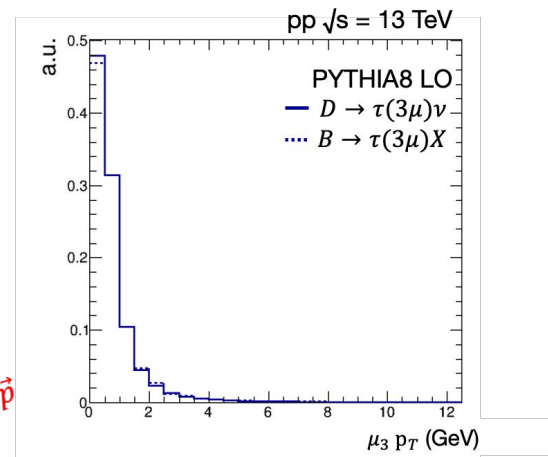
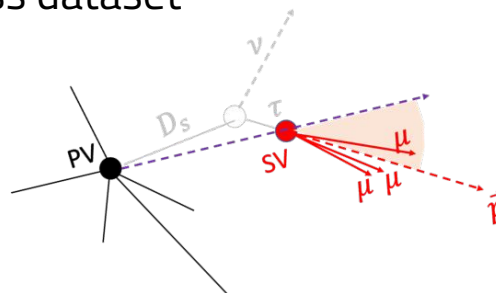
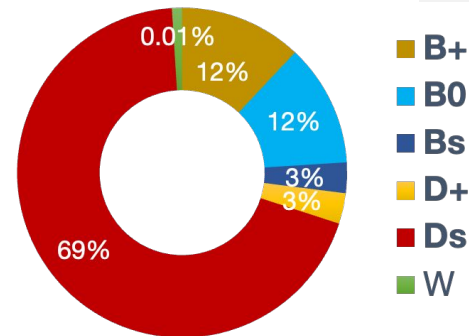
Client
Client-0f739808-e288-11ed-8160-7a3936ca282f
Connection method: Direct
Dashboard: http://localhost:3042/status
Scheduler Info
Scheduler
Client-0f739808-e288-11ed-8160-7a3936ca282f
Mode: Command
Ln: Ln18
HNL_analysis.ipynb

```

# The physics use-case

## Search for Lepton Flavor Violating decays $\tau \rightarrow 3\mu$

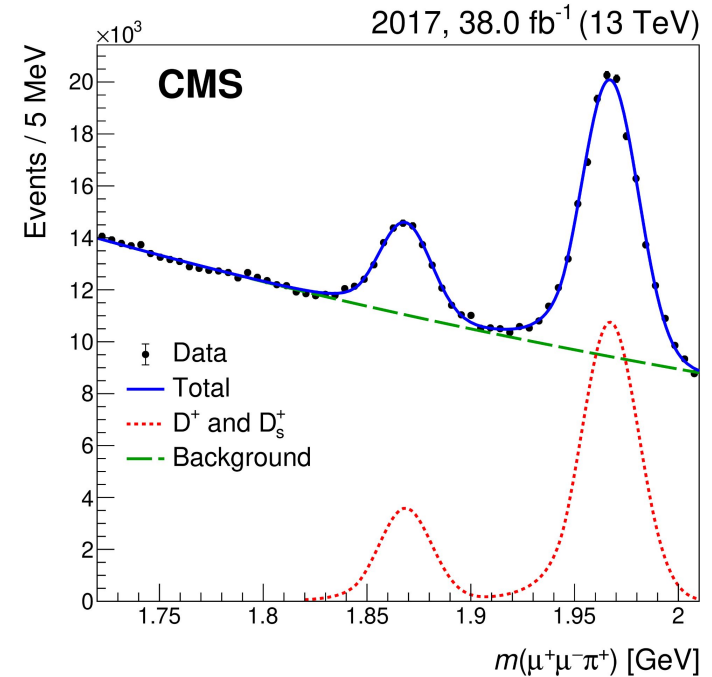
- Tau leptons produced by D and B decays with very low momenta
- Run2 analysis recently published
  - (Phys. Lett. B 853 (2024) 138633)
- Run3 analysis ongoing
  - Uses "inclusive" L1 dimuon triggers to seed custom HLT path
  - ParkingDoubleMuonLowMass dataset



# The physics use-case

## Search for Lepton Flavor Violating decays tau -> 3mu

- Tau leptons produced by D and B decays with very low momenta
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- Normalisation channel of this analysis:  
Ds->phi(mumu)pi decays





# Legacy analysis workflow

- Start from CMS MINIAOD data tier
- Data compression into ROOT ntuple
- Loop-based analysis implemented using ROOT TTree:MakeClass
  - **what:** define high-level variables, apply selections, apply scale factors, select best Ds candidate per event
  - **how:** split computation in batches of input files, run separately as HTCondor jobs, gather the output rootfiles

RECAS



ROOT  
Data Analysis Framework

# New analysis workflow

- Start from CMS MINIAOD data tier
- Data compression into ROOT ntuples
- Ntuples read as RDataFrame
  - Almost all operations "lazy" → no loop triggered till the end
  - One single output (e.g. histogram) produced
  - Option 1: use the MultiThreading capability of RDF
  - Option 2: go distributed using Dask



## Dataset size

- CMS MINIAOD data tier
  - **Run2:** "DoubleMuonLowMass"
    - UL2018A → 1.5 TB / 14 fb<sup>-1</sup> = ~ 500 GB / fb<sup>-1</sup>
  - **Run3:** "ParkingDoubleMuonLowMass"
    - Prompt2022C → 3.2 TB \* 8 streams / 18 fb<sup>-1</sup> = ~ 1.4 TB / fb<sup>-1</sup>
- Data compression into ROOT ntuples → ~ 3 GB / fb<sup>-1</sup>
  - to be taken with a grain of salt:
    - at ntuple/NANOAOD level we select events with 3 muons (or 2 muons + 1 track) within our mass region of interest, forming a good vertex etc
    - plain data format

## Event selection

Apply per-event requirements (HLT, L1)

## Apply event weighting

Pile-up reweighting, scale factors etc

## Selections on muons and tracks

Per-object cuts (ID, pT, eta etc)

Topological cuts (collimation, displacement).

## Selections on Ds candidate

SV quality, displacement, invariant mass

Select best candidate per event based on vertex chi2

## Mass plot

Fit to extract  
Ds  $\rightarrow$   $\phi(\mu\mu)\pi$   
yield

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Mass plot

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Analysis Facility  
(CMS INFN AF, ICSC AF under maintenance)

# Setup

- CMS AF: <https://cms-it-hub.cloud.cnaf.infn.it/> (ICSC highrate AF under maintenance)
- Image: [unpacked.cern.ch/registry.hub.docker.com/dodasts/root-in-docker:ubuntu22-kernel-v1-monitoring](https://unpacked.cern.ch/registry.hub.docker.com/dodasts/root-in-docker:ubuntu22-kernel-v1-monitoring)

The screenshot shows a monitoring dashboard with several components:

- Navigation Menu:** A vertical list of menu items including COMPUTE TIME PER KEY, CPU, GPU MEMORY, GPU UTILIZATION, GRAPH, GROUPS, LOGS, MEMORY BY KEY, NPROCESSING, OCCUPANCY, PROFILE, PROFILE SERVER, PROGRESS, SCHEDULER SYSTEM, TASK STREAM, WORKERS, WORKERS CPU TIMESERIES, WORKERS DISK, WORKERS DISK TIMESERIES, WORKERS MEMORY, WORKERS MEMORY TIMESERIES, WORKERS NETWORK, and WORKERS NETWORK TIMESERIES.
- Workers Table:** A table showing worker node details.
 

name	address	nthreads	cpu	memory	limit	memory %	managed	unmanaged old	unmanaged recent	spilled	# files	read	write
Total (40)		40	37%	20.3 GiB	80.0 GiB	25.3%	624.0 B	3.6 GiB	16.7 GiB	0.0	1511	2 MiB	2 MiB
HTCondorCluster-0	tcp://10.60.128.10x-1	1	102%	525.4 MB	2.0 GiB	25.7%	0.0	91.6 MB	433.8 MB	0.0	40	53 KiB	53 KiB
HTCondorCluster-1	tcp://10.60.128.10x-2	1	100%	521.5 MB	2.0 GiB	25.5%	0.0	91.7 MB	429.8 MB	0.0	37	45 KiB	45 KiB
HTCondorCluster-1	tcp://10.60.128.10x-1	1	88%	520.7 MB	2.0 GiB	25.4%	0.0	92.0 MB	428.6 MB	0.0	38	68 KiB	68 KiB
HTCondorCluster-1	tcp://10.60.128.10x-1	1	92%	529.2 MB	2.0 GiB	25.8%	0.0	91.9 MB	437.3 MB	0.0	38	62 KiB	62 KiB
HTCondorCluster-1	tcp://10.60.128.10x-1	1	102%	523.0 MB	2.0 GiB	25.5%	0.0	91.8 MB	431.2 MB	0.0	38	41 KiB	41 KiB
HTCondorCluster-1	tcp://10.60.128.10x-2	1	2%	529.3 MB	2.0 GiB	25.8%	48.0 B	92.0 MB	437.3 MB	0.0	37	45 KiB	45 KiB
- Clusters Table:** A table showing cluster node details.
 

name	address	read_bytes_disk	write_bytes_disk
Total (40)		0	655382.2877561491
HTCondorCluster-0	tcp://10.60.128.10-46316	0	16435.40295409006
HTCondorCluster-1	tcp://10.60.128.10-36658	0	16414.81566298732
HTCondorCluster-10	tcp://10.60.128.10-46194	0	16387.53982712826
HTCondorCluster-11	tcp://10.60.128.10-44740	0	16378.291052456214
HTCondorCluster-12	tcp://10.60.128.10-46112	0	16380.008765014561
HTCondorCluster-13	tcp://10.60.128.10-35829	0	16412.094969243804
- Cluster Info:** A box showing details for 'RemoteHTCondor 8 - T2\_LNL\_AF20'.
 

Status: Running  
 Scheduler Address: localhost:22657  
 Dashboard URL: http://localhost:22784/status  
 Controller Address: http://localhost:39617  
 Number of Cores: 40  
 Memory: 80.00 GiB  
 Number of Workers: 40

Create new cluster

Factory

Name:

- Select Item
- T2\_LNL-TestBed
- T2\_LNL-Production
- T2\_BA-Production
- T2\_PI-Production
- T2\_RM-Production
- PD-k8s
- Local

VM Image

# Code

[https://github.com/fsimone91/  
BPH\\_interactive\\_analysis/tree/  
main](https://github.com/fsimone91/BPH_interactive_analysis/tree/main)

to be then included in the central  
repo

## BPH\_interactive\_analysis

Porting typical BPH analysis cutflow to RDF for testing on highrate platforms. This activity is framed in the Spoke 2 of the ICSC – Italian Research Center on High Performance Computing, Big Data and Quantum Computing (<https://www.supercomputing-icsc.it/en/>), specifically under WP2, UC2.2.1

### 🔗 Use case

The selected use-case is the analysis of  $D_s \rightarrow \phi(\mu\mu)\pi$  decays, that serve as control and normalisation channel for the  $\tau \rightarrow 3\mu$  search (PLB 853 (2024) 138633).

[CMS-BPH-21-005\\_Figure\\_001](#)

### The analysis platforms

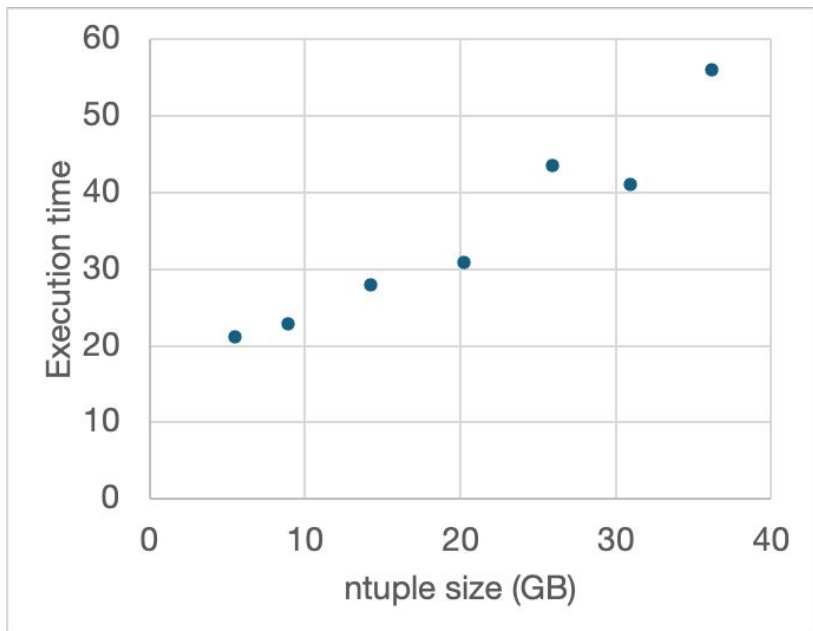
The starting point is a prototypal CMS high throughput analysis platform, offloaded on local Tier-2: <https://infn-cms-analysisfacility.readthedocs.io/en/latest/>

Within ICSC a new platform is being developed as documented here: <https://icsc-spoke2-repo.github.io/HighRateAnalysis-WP5/sections/intro.html>

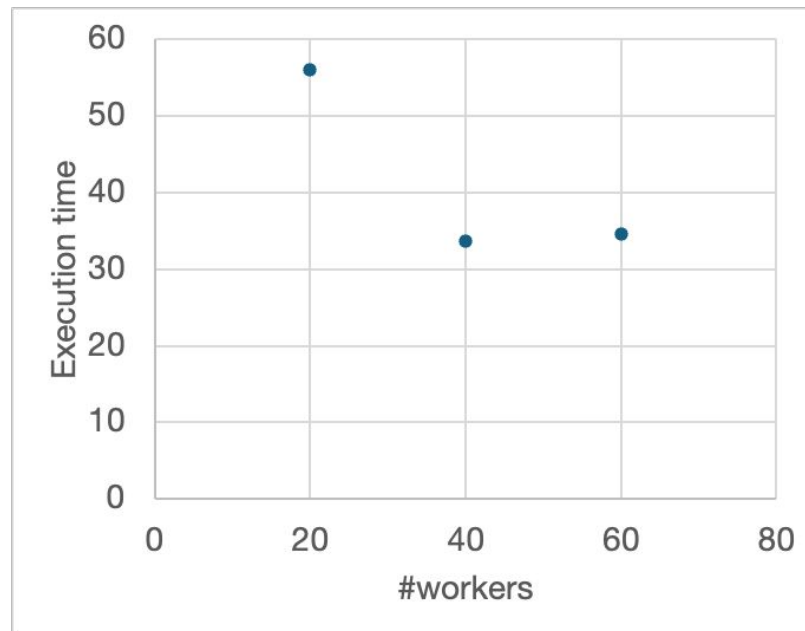
### References

- <https://doi.org/10.1016/j.physletb.2024.138633>

## Simple and preliminary tests



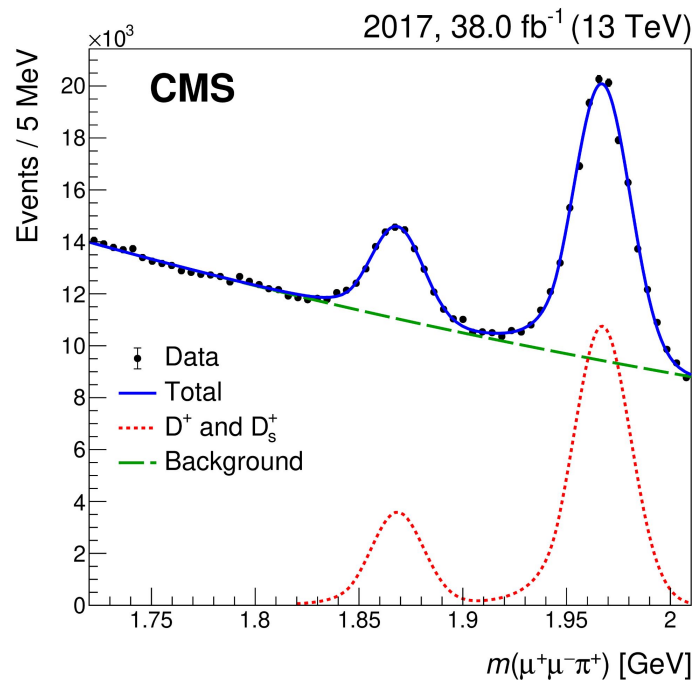
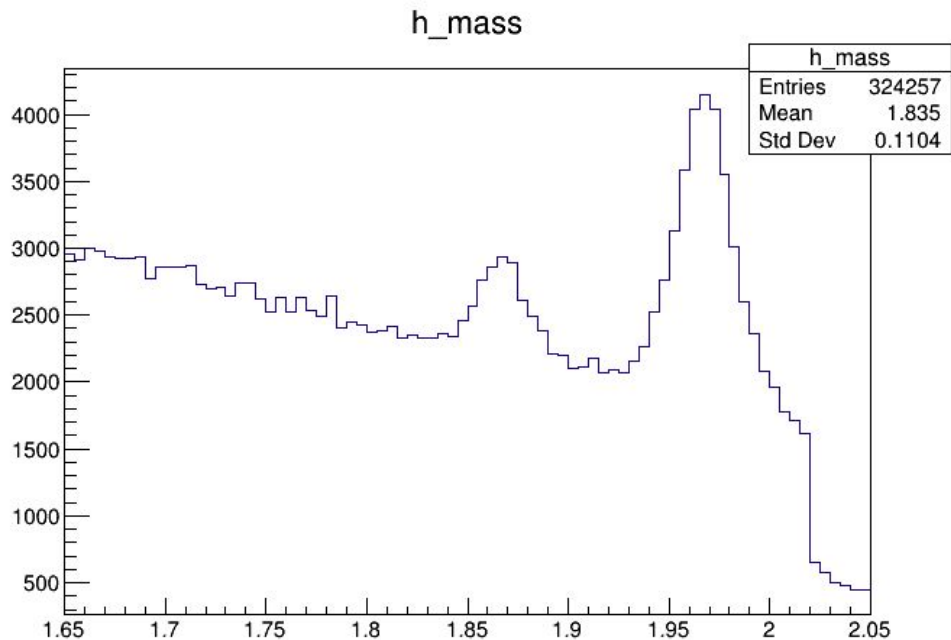
20 workers, 20 RDF partitions



RDF partitions = #workers, 36 GB input



# Output



# User-experience and summary

- User experience (CMS AF):
  - some instabilities when increasing # workers
  - strongly depends on the Site, difficult to debug
- Plans:
  - include fit step (need newer ROOT version with “pythonised” RooFit, NOT distributed though!)
  - reproduce approved plots for validation
  - scale to Run3
- Abstract submitted to CHEP2024 <https://indico.cern.ch/event/1338689/abstracts/175102/>