

Computing challenges and prospects for the g-2 experiment

Software and Computing for Small HEP Experiments Workshop - 15 Nov 2021

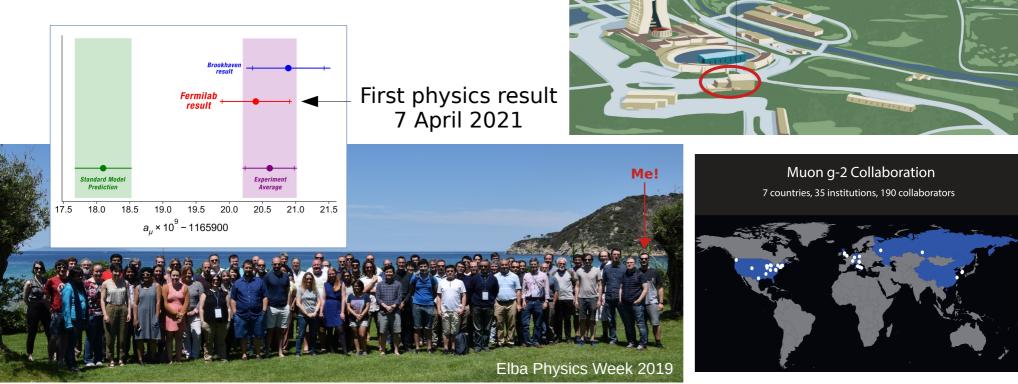
Paolo Girotti (INFN Pisa) on behalf of the Muon g-2 collaboration



CHICAGO 38.5mi (62km

Collaboration

- Muon g-2 is a relatively small HEP experiment
- Part of Fermilab Muon Campus
- ~200 collaborators from 7 countries
- Very young community (40% under 35 yo)



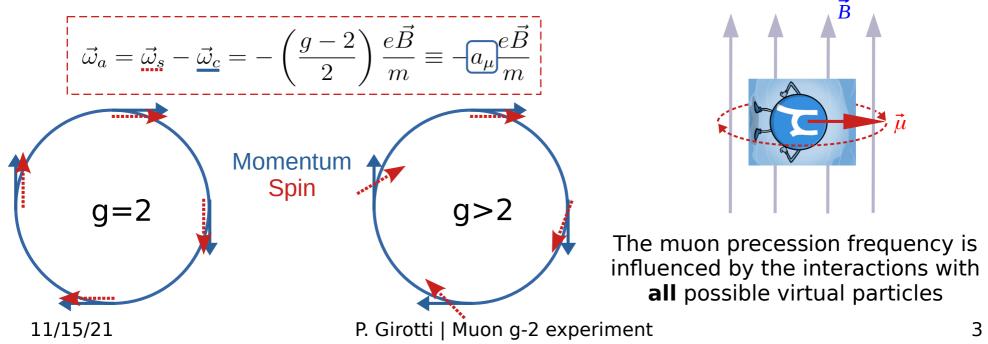
FERMILAB'S WILSON HALL

MIION 6-2



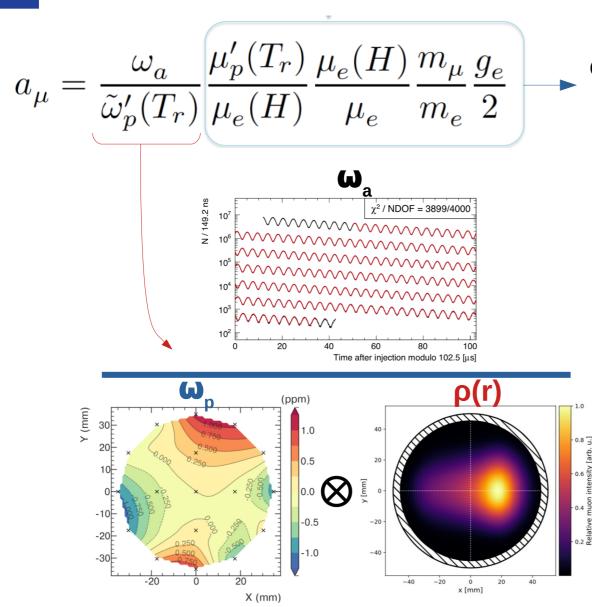
Muon g-2 primer

- The Muon g-2 Experiment (E989) measures the anomalous precession moment of the muon very precisely
 - Goal: repeat and improve BNL (2001) measurement with 4x precision
- A beam of polarized muons circulates inside a storage ring
- The magnetic field is measured by NMR probes
- Decay positrons carry the precession signal and are detected by calorimeters





Master formula



Constants known from other experiments

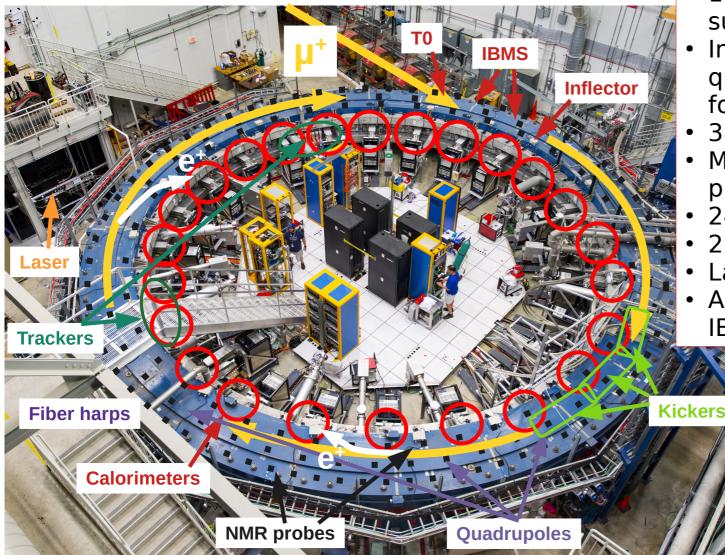
Three quantities measured:

- ω_a: Muon anomalous precession frequency
- ω_p: Larmor precession frequency of protons in water (mapping B)
- p_r: Muon distribution in the storage ring

Goal: measure a_{μ} with 140 ppb accuracy (100 stat + 100 syst)

11/15/21

The Muon g-2 Experiment



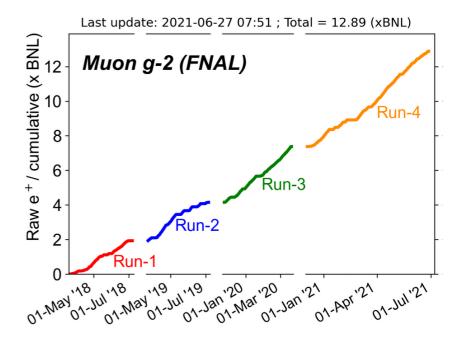


- 15 meter wide dipole superconducting magnet
- Inflector, kickers, quadrupoles, collimators for beam insertion
- 386 NMR probes
- Moving trolley with 17 probes
- 24 calorimeters
- 2 tracker stations
- Laser calibration system
- Auxiliary detectors: T0, IBMs, Fiber harps

A lot of components and detectors → a lot of **data**!

How much data?

- 12 bunches of muons every second
- Muons circulate for 700 $\mu s,$ generating $\sim\!2000$ positron hits on calorimeters
- 1296 calorimeter channels @800 MHz
- 2048 tracker channels @400 MHz
- One subrun (2 GB) every 5 seconds
- 24/7 running for 4-7 months each year
- Currently running 5th year of production
 - → Collected ~6 PB of raw data so far
 - \rightarrow Plus simulation ~1.5 PB



	Raw	Nearline	Offline	Field
Run1	1.0 PB	-	2.2 PB	29 TB
Run2	1.1 PB	11 TB	2.5 PB	48 TB
Run3	1.3 PB	18 TB	2.0 PB*	87 TB
Run4	2.3 PB	35 TB	0.2 PB*	98 TB

*Under production 6 / 20





plotly

How do we see data?

- Online with Midas DAQ / DQM
- Instantaneous feedback from all components
- Fraction of data gets displayed with **Plotly**

MIDAS Run Status Start: Sun Nov 14 10:43:44 2021 Running time: 1h06m52s 46241 Running Alarms: On Restart: Or Data dir: /dataSSD1/gm2 Stop Pause 1636912232 11:50:32.219 2021/11/14 [Logger,LOG] File '/dataSSD1/gm2/gm2 run46241 00270.mid' CRC32C checksum: 0x316b1f1c, 2029888286 bytes Equipment Status Data[MB/s] Equipment -Events Events[/s] EB 56422 16.0 136.939 @g2be1.fnal.g MasterGM2 56406 11.3 0.001 g2be1-pri 56440 17.3 0.023 AMC1300 AMC1300@g2aux-priv 56394 13.3 3.905 AMC1301 AMC1301 AMC1302 AMC1 56406 16.0 5.349 5.401 56406 16.0 56406 16.7 5.425 56400 15.3 4.636 Run Start: Sun Nov 14 11:14:27 2021 Running time: 0h36m46s 5642 24360 Running 5639 Alarms: Or Data dir: /home/newg2/gm2Data Restart: Or Stop 5640 56406 5.455 16.7 1636912089 11:48:09.554 2021/11/14 [Logger,LOG] File '/home/newg2/gm2Data/gm2field_run24360_05.mid' CRC32C checksum: 0x9f9fceb3, 2704036467 bytes 56406 15.3 5.477 56394 13.3 3.763 5639 5640 Events[/s] Data[MB/s] Equipment + Status Events 5640 1832 0.7 Fixed Probes robes@a2field-fe2-pr 2.096 56406 **PS Feedback** 2020 1.0 0.002 PS Feedback@g2field-fe2-n 56406 **Plunging Probe** Frontend stopper 0 0.0 0.000 Surface Coils 56406 Surface Coils@d2field-fe1-p 73 0.0 0.000 148 Fluxgate eld-fe1-pr 0.0 0.000 56406 **Ref Frequency** 221 0.0 0.000 0a2field-fe1-r 56406 TrolleyInterface 17926 34.0 3.144 56408 GalilFerm 674 1.7 0.011 5640 5640 5640 Compr. Disk Level Channel Events MB written P. Girotti | Muon g-2 experiment n24360_06 mir 4306 13222.589 74.7% 39.2%

Lazy Label

Progress

100%

File Nam

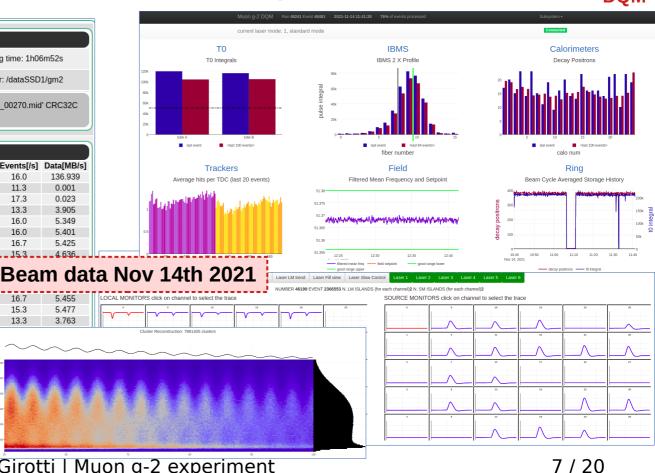
am2field run23940.ison

Files

325630

Total

5570.3%



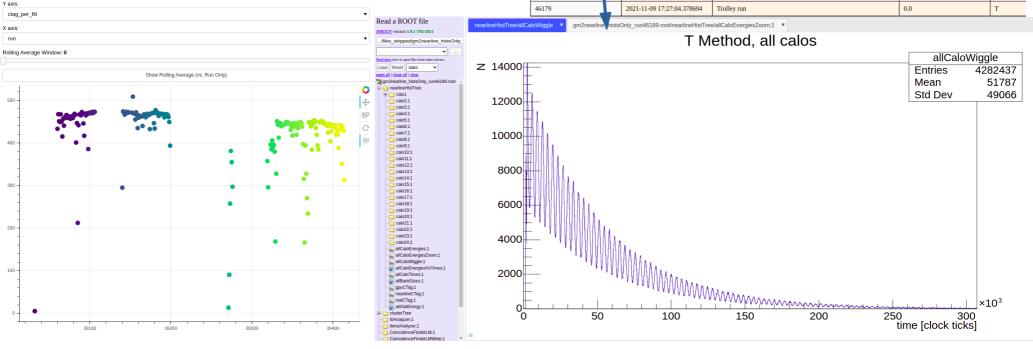
DQM



How do we see data?

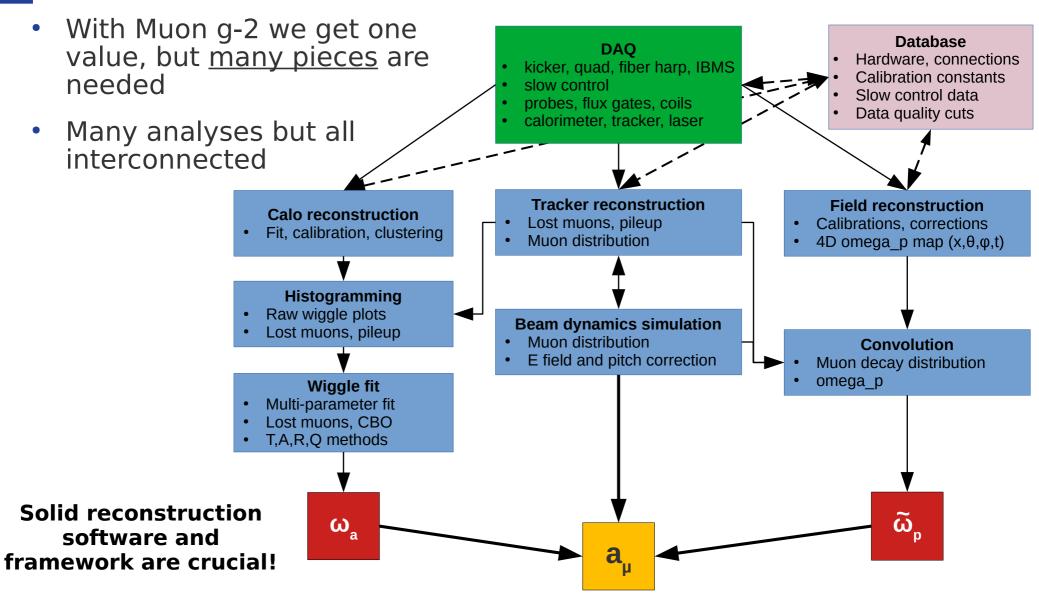
- Nearline for fast turnaround analyses
- Simplified reconstruction of the data ~30 minutes after acquisition
- Interactive plots with Bokeh
- Web visualization of ROOT trees

Run number	·▼ time ≑	comment \$	nEvents	
Search	Search	Search	Search	Search
46188	2021-11-10 01:32:11.796052	production	103545.0	Y
46187	2021-11-09 23:32:05.258684	production	102702.0	Y
46186	2021-11-09 21:02:09.319796	idle run	0.0	Т
46185	2021-11-09 20:47:04.427447	idle run	0.0	Т
<u>46184</u>	2021-11-09 19:42:12.897917	alternative mode run	100461.0	Т
<u>46183</u>	2021-11-09 18:07:05.400655	alternative mode run	2287.0	Т
46182	2021-11-09 17:52:10.623573	standard mode run	0.0	Т
46181	2021-11-09 17:42:04.655508	Double Pulse Odd=0 Even=60	0.0	L
46180	2021-11-09 17:37:10.919716	Double Pulse Even=0 Odd=65000	0.0	S
46179	2021-11-09 17:27:04.378694	Trolley run	0.0	Т





Reconstruction flow

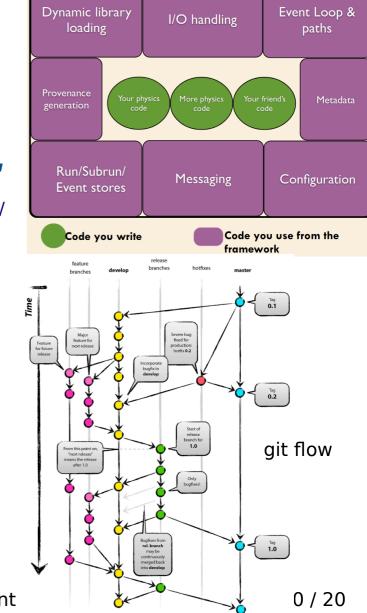




Data reconstruction

- Offline with full reconstruction of the data for full-fledged analyses
- We use *art* framework
 - Highly modular
 - Made for HEP physics
 - Seamless transition between simulation and real data
 - Non trivial learning-curve to climb
- ROOT/C++ based software
- Code repository with version control
 - One of the first Fermilab experiments to use **git**
 - Hosted by Redmine





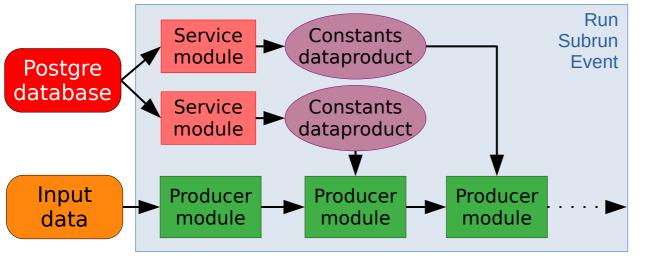
art



Database

- Database estensively used for both online DAQ configuration and offline data reconstruction
- Big effort during last year to transition critical reconstuction parameters and calibrations to a condition database supported by Fermilab SCD
- **PostgreSQL** interface
- Interval Of Validity based on run, subrun, event numbers





Terminal interface with **psql**

-		> select calonum,xtalnum,oofcorre
		ction_data,oof_correction_iovs wh
re begin_t	ime = 243	370196 and calonum=1 and iov_id=1
limit 10:		
calonum	xtalnum	oofcorrection
+		+
1	Θ	0.932184
1 1	1	0.94373
1	2	
1	3	0.928901
1	4	0.930891
1	5	0.918331
1		0.940355
1	7	0.901765
1	8	0.93363
1	9	0.939446
(10 rows)		

11/15/21



Running on GRID

- Production jobs run on Grid
 - Both onsite and offsite
 - 5000 reserved slots for g-2 at all times
- POMS interface



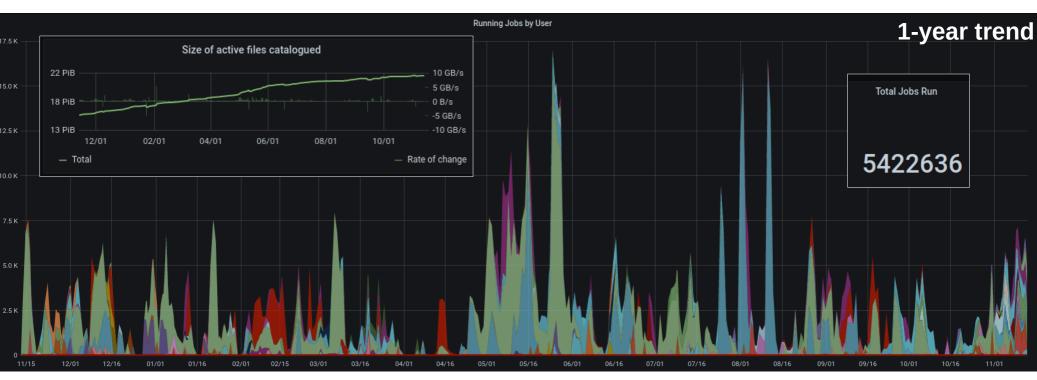
- Useful tool to keep track of which version a dataset has been reconstructed with
- Automatic slicing of dataset, recovery of failed jobs and grid submissions with crontabs
- Frequent monitoring is useful to ensure job success

				n Stage FullPr iign run_v9_71		Run3C-5218A 11920 uction 5751					
ß	Batch Job Status			i idla iaba	Active Job Status		k.	Batch Job Efficiency			
	- Ca Fai He Su	celled 58 422 d 58	1% 5% 1% 94%	idle jobs		running jobs		ciency 89%	memory efficiency		
statistics for last 30 days											
Reports/Status					Action						
Production Shifter Page (Landscag Mapangin Stage Statis (Landscag) Campaign Stage Submissions (1wk Campaign Stage Submission Files					 Laun Laun Kill ru Hold r Release Sched 	ampaign Stage ch Campaign Stage Jobs Now ch Campaign Stage Test Jobs Now ining/idle Jobs for Campaign Sta unning/idle Jobs for Campaign Stage le held Jobs for Campaign Stage le Future Job Launches	ge				
Campaign Stage Name: FullProduction-Run3C-5218A Id:11920 Experiment: gn/2pro_dac_raw_run3_Proc Software Version: v9_71.00 VO Role: Production Param Overrides: [mardataset: "3/datasetly] [mbclifie]; "gn/2offilie, umasking.run3fcd.gm/20		ın3a.fcl.gm2offline	_Qcaloreco_ru	n3.fcl,gm2offline_	trackreco_ru	/gridSetupAndSubmitGM2Dat Definition Parameters: [['rioifdh_art', ''] ['noifdh_art', ''] ['nenbyone', ''] ['remory, ', '2000'] ['gracem', '4000']	e/gm2pro/Production/v9	9_71_00/srcs/gm2a	nalyses/ProductionScripts/produce		
Recent Launch Outputs					Campa	ign run_v9_66_00_	Broduction	Save			
 20211102_213551_gm2pro 20211102_190548_gm2pro 20211102_190348_gm2pro 20211101_120233_lineit]. 20211101_160544_gm2pro 20211101_0093552_gm2pro 20211101_00940603_gm2pro 20211031_203550_gm2pro 20211031_202560_gm2pro 20211031_095640_lineit]. 20211031_094953_lineit[. 	1052424 into F 1052422 into F 105140 into F 1051622 into F 1051622 into F 1051381 into F 1051392 into F 1051070 into F 1050716 into F			iv iv <th>Ø E</th> <th>tit COF-Pursc-5213P</th> <th>PreFroduction-1 Pre-Production-1 PCC-Ptum3G-5213P</th> <th></th> <th></th>	Ø E	tit COF-Pursc-5213P	PreFroduction-1 Pre-Production-1 PCC-Ptum3G-5213P				
	IS ro n2pro						FGC-Run3H-5213P	QDB-Run3H-52			

- gm2shifter
- gm2analysis

Running on GRID

- Production job monitoring
 - Grafana for user efficiency and trend plots
 - More than 5 million jobs over the last year





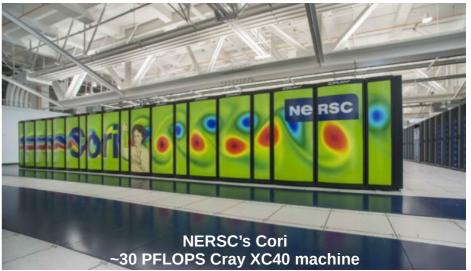


11/15/21



Simulation

- Important piece for g-2 physics, parallel to data taking
- Many simulation packages for the various parts of the beamline and the storage ring
 - MARS (Proton target)
 - <u>BMAD</u> (beamlines & g-2)
 - <u>G4beamline</u> (beamlines)
 - <u>Gm2ringsim</u> (injection & g-2)
 - <u>COSY</u> (g-2 storage ring)



- Complete simulation of fields, beam dynamics, muon decays, and detector interactions in the storage ring
- Making use of HPC computing @NERSC New!
 - Via HEPCloud

First production completed with 10 B events
 11/15/21 P. Girotti | Muon g-2 experiment



Challenges (1)

Challenge:

 Many datasets (~50), each of them has to pass through a 4step procedure

• Solution:

- Rolling production, with well defined steps and parallel execution of them
- Requires good coordination and many people looking at different datasets every time

1	Simulation Prod Data Production	0	Simulation Production : 02/16/2020 - 02/16/2020 Data Production : 02/16/2020 - 06/07/2021		Rol	ling produc	tion schen	ne
2.1	Run 2	0	Run 2 + 02/16/2020 - 11/25/2020	_				
2.1.1	PreProduc	0	PreProduction 02/16/2020 - 09/03/2020					
2.1.1.1	Run2B	0	<u> </u>					
2.1.1.2	Run2C	0	R	Pre-production	Subset A	Subset B	Subset C	Subset D
2.1.1.3	Run2D	0	Run2D					
2.1.1.4	Run2E	0	Run2E					
2.1.1.5	Run2F	0	Runze					
2.1.1.6	Run2G Run2H	0	Contract Con					
2.1.1.7	Constants	0	Constants Analysis (02/27/2020 - 09/18/2020	Calibration		Subset A	Subset B	Subset C
2.1.2	E Constants	0	Constants Annugate 1 022 11 2020 - 00 202020	canoración				
2.1.2.1	Run2C	0	Pup2C	4				
2.1.2.3	Run2D	0	Run2D					
2.1.2.4	Run2E	0	Run2E					
2.1.2.5	Run2E	0	Run2F	Full production			Subset A	Subset B
2.1.2.6	Run2G	0	Run2G	r an produceion				
2.1.2.7	Run2H	0	Run2H					
2.1.3	Production	0	Production + 03/05/2020 - 11/08/2020					
2.1.3.1	Run2B	0	Run2B					Subset A
2.1.3.2	Run2C	0	Run2C	DQC analysis				Subset A
2.1.3.3	Run2D	0	L Run2D	= (• • • • •) • • •				
2.1.3.4	Run2E	0	Run2E					
2.1.3.5	Run2F	0	Run2F					
2.1.3.6	Run2G	0						
2.1.3.7	Run2H	0	Rue -					
2.1.4	Subrun DQC	0	Subrun DQC + 03/14/2020 - 11/25/2020					
2.1.4.1	Run2B	0		Run				
2.1.4.2	Run2C	0	Run2C					
2.1.4.3	Run2D	0	Run2D	P. Girotti Muon g-2				



Challenges (2)

Challenge:

- Too few production experts and too much data to process

• Solution:

- Implemented a shift calendar similar to online-DAQ shifts
- Whole collaboration is now involved with institution quotas
- Big effort in making documentation and checklist <u>user-friendly</u> and optimized!

-> Jump to this week <-	te from the pull-down menu. Begin typ	ing your name and the list of options	will autocomplete.		
Production shifts	November				Dece
Week Of (Starting Day)	16 Nov 2021	23 Nov 2021	30 Nov 2021	7 Dec 2021	14 Dec 2021
Pre-Production	BU ~	FNAL	Institute	Institute	U of Kentucky
0.80 pts	· · · · · · · · · · · · · · · · · · ·	*	· · · · · · · · · · · · · · · · · · ·	*	
Expert on call	· · · · · · · · · · · · · · · · · · ·	¥	· · · · · · · · · · · · · · · · · · ·	¥	· · · · · · · · · · · · · · · · · · ·
Full-Production (shifter A)	Institute	Institute	Cornell *	Institute	U of Kentucky *
1.00 pts	· · · · · · · · · · · · · · · · · · ·	*	· · · · · · · · · · · · · · · · · · ·	¥	I
Full-Production (shifter B)	Johannes Gutenberg University Main: *	Institute	Institute	U of Massachusetts *	FNAL *
1.00 pts		*		·	
Expert on call	· · · · · · · · · · · · · · · · · · ·	*	v	¥	
Subrun DQC (shifter A)	U of Washington 👻	U of Virginia. 👻	U of Michigan 👻	Johannes Gutenberg University Main: *	Johannes Gutenberg University Main: *
0.50 pts	· · · · · · · · · · · · · · · · · · ·	•	· · · · · · · · · · · · · · · · · · ·	•	
Subrun DQC (shifter B)	Institute	U of Michigan 👻	Institute	ANL	U of Massachusetts
0.50 pts	· · · · · · · · · · · · · · · · · · ·	•	· · · · · · · · · · · · · · · · · · ·	· · · ·	L
Expert on call	······· ······························	· · · · · · · · · · · · · · · · · · ·	······································	· · · · · · · · · · · · · · · · · · ·	
		please sign up! er 3 shifts until Feb 28 2022		Shif	t calendar

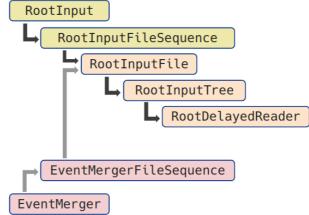
	TODO In progress	Task to be done Ongoing (long tas	k)	Please update each time you work on a task! Experts: please put "Uploaded" when you upload new constants								Datase	t status						
Legend	Held	Uh-oh problem en			Experts: please of		>"Done" when mig									spreadsheet			
	Uploaded	Uploaded (to be n	nigrated)												spreausheet				
	Done	All done!													L				
							stants analysis (e)			1									
Pre-staging	Pre-production	2nd stages	hadd stages	IFG	OOF	QMethod	Laser DQC	Kicker DQC	T0 DQC	Channel status	Pre-staging	Full production (test)	DQC (test)	Full production	Recovery	Subrun DQC	Dataset delivered		
*	*	v	×		· ·	×	*	×		· ·	*	v	*	v	Ψ	v	Ψ		
Ŧ	Ť	Ŧ	v		r	Ŧ	Ψ	*		r	*	v	*	Ψ	Ŧ	*	~		
Done *	Done 👻	Done *	Done *	Done 📑	Done *	Done *	Done 👻	Done 👻	Done 📑	Done *	Done 👻	TODO 👻	*	¥	¥	*	*		
Done *	Done 👻	Done *	Done 👻	Done 🕙	Done 👻	Done *	Done 👻	Done 👻	Done 📑	Done -	Done 👻	Done 👻	Done 👻	Done *	Done 👻	In progress 💌	~		
Done 🔹	Done 👻	Done *	Done *	Done *	Done 👻	Done *	Done -	Done 👻	Done *	Done -	Done 👻	TODO 🔫	~	-	Ψ	~	~		
n progress 👻	Done 👻	v	×		Done *	Done *	In progress 💌	Done -	Done *	Done -	Done 👻	*	~	Ψ	Ψ	~	~		
Done *	Done 👻	Done *	Done -	Done .	Done *	Done *	In progress 💌	Done -	Done .	Done T	*	*	*	*	v	~	*		
Done *	Done 👻	Done *	Done 👻	Done •	Done 👻	Done *	In progress 👻	Done -	Done .	Done 👻	In progress 🔻	*	*	· ·	×	*	~		
Done 👻	Done 👻	Done *	Done 👻	Done 📑	Done 👻	Done *	Held 👻	Done 👻	Done 💌	Done -		· ·	~	Ψ.	Ψ				



Challenges (3)

Challenge:

- When an error is uncovered, a dataset is reprocessed using the full reconstruction
- Solution:
 - Expanded *art* to include data merger mechanism
 - Tracker data (which is computing intensive) will be processed separately and then merged with the production files
 - Ongoing progress

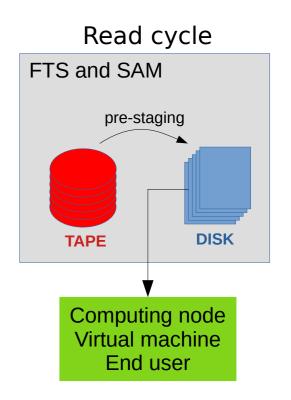


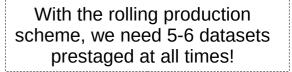
Challenges (4)



Challenge:

- All production data is backed up on tape, and fast-acces disks can't hold all the data (many PBs!)
- When files are needed, pre-staging process copies them to disks (dCache).
- Experiments typically compete in a queue to get access to the common read disk pools
- The system is not designed for peak loads
- Can experience pre-staging delays during these peak periods
- Solution:
 - Working with Fermilab Scientific Computing Division to mitigate







Challenge (5)

Challenge:

- File bookkeeping and metadata is handled by SAM (Sequential Access via Metadata)
- It's an evolution of the Fermilab Tevatron Run 2 storage system
- SAM is unlikely to scale in the long term future of huge datasets
- **Solution** (proposed):
 - Upgrade to RUCIO



- Modern, file-based, quotas and lifecycle management
- "Manages multi-location data in a heterogeneous distributed environment"
- No metadata catalog, working on integrating metadata into RUCIO to eventually completely replace SAM



Summary

- Muon g-2 is a relatively small experiment, but <u>all</u> the data must be produced and analyzed with precision and reliability
- A lot of improvements in the software since the first data acquisition (2017)
- Highlights:
 - Database integration
 - Data reconstruction shifts and Grid interface with POMS
 - Simulation running at HPC centers
- Some challenges with I/O and data handling but we are working on them
- Run 2-3-4 data under reconstruction and analysis

Thank you!

https://muon-g-2.fnal.gov/ pgirotti@fnal.gov