GW followup pipeline and expectations for O3

Niccolò Di Lalla
and many others

niccolo.dilalla@pi.infn.it

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The GW follow-up activity

Fermi GCN with GRB alert

LIGO/Virgo GCN with GW alert

summary / GWFUP

Fermi GCN with analysis results

Automatic analysis pipelines

GWUP pipeline using pipeline-II
link

Alternative pipeline using BA tools
link

Analysis techniques

Reference paper (Vianello, Omodei, Chiang, Digel): https://arxiv.org/abs/1607.01793

Fixed Time Interval (FTI)	Adaptive Time Interval (ATI)	LAT Low Energy events

- Standard unbinned maximum likelihood technique used for LAT data analysis and based on Poisson statistic.
- We include all sources (point-like and extended) from the latest LAT source catalog, as well as the Galactic and isotropic diffuse templates.

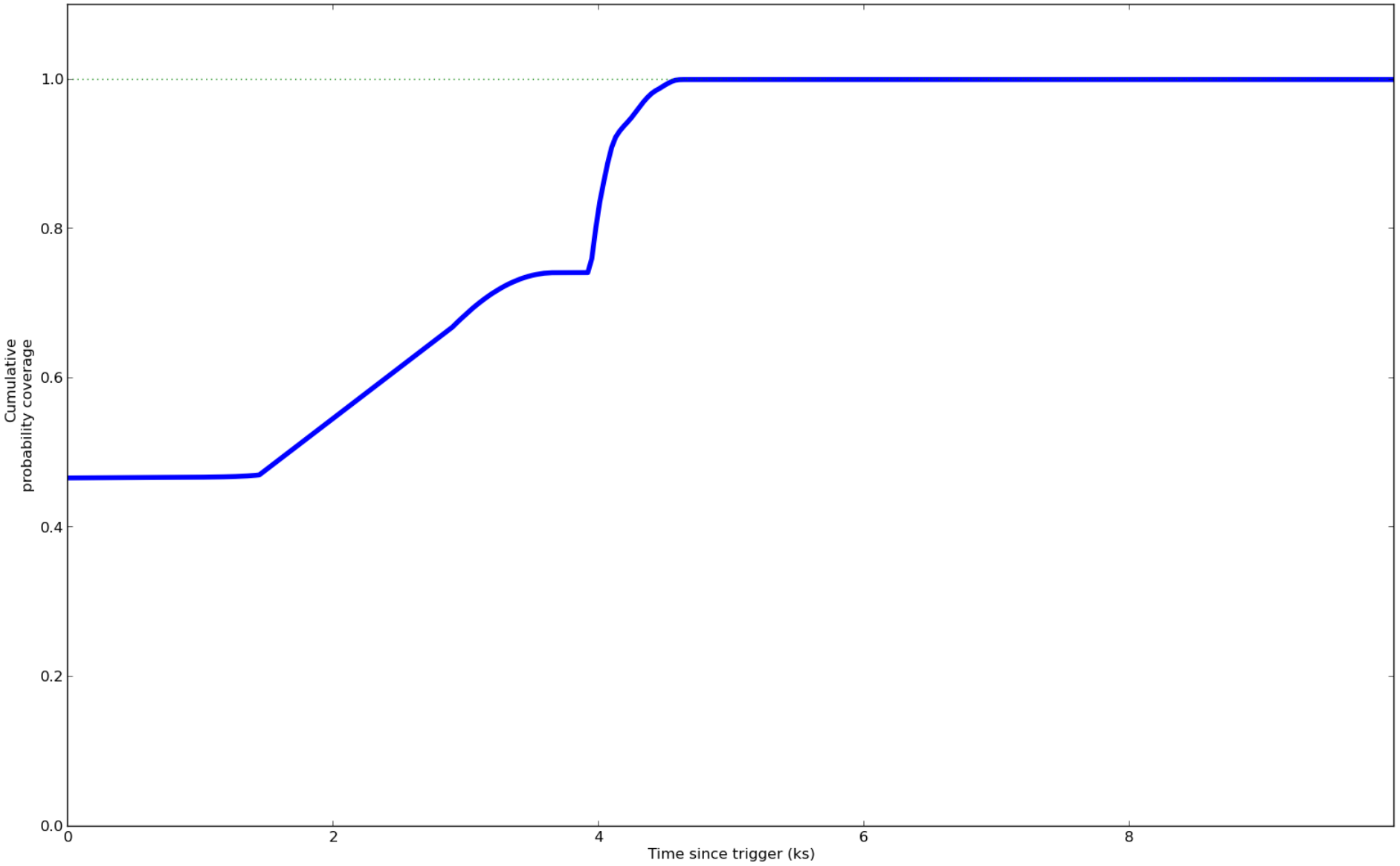
Fixed Time Interval

- Compute the cumulative coverage:

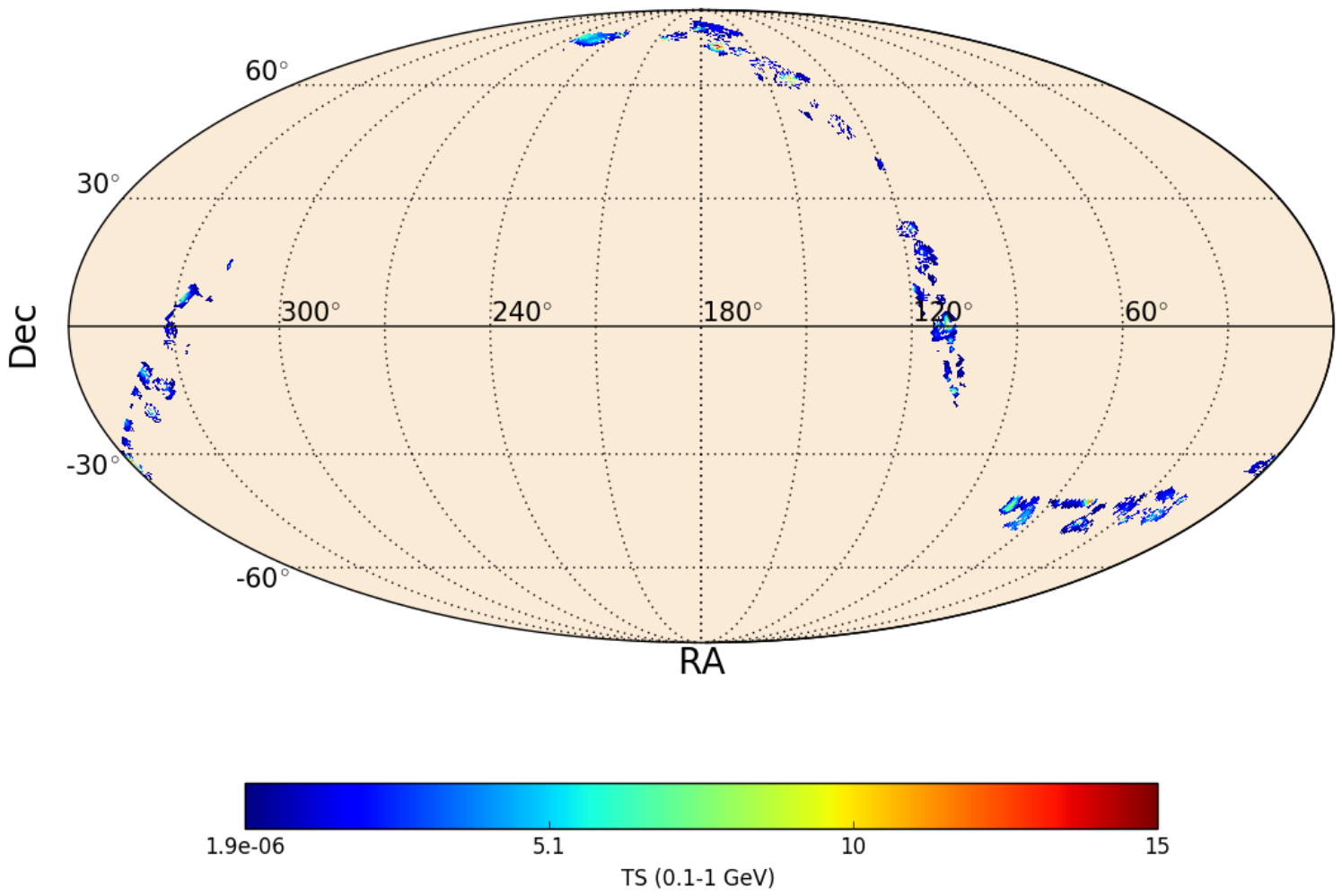
$$C(t) = \sum_{h=0}^{H} p_h w_h(t)$$

- Choose the time window and select all pixels within the 90% containment of the LIGO localization maps
- Run an independent likelihood analysis for each pixel, testing for the presence of a new source at the center of the pixel
- In case of non-detection, compute also a global Bayesian upper bound for the flux.

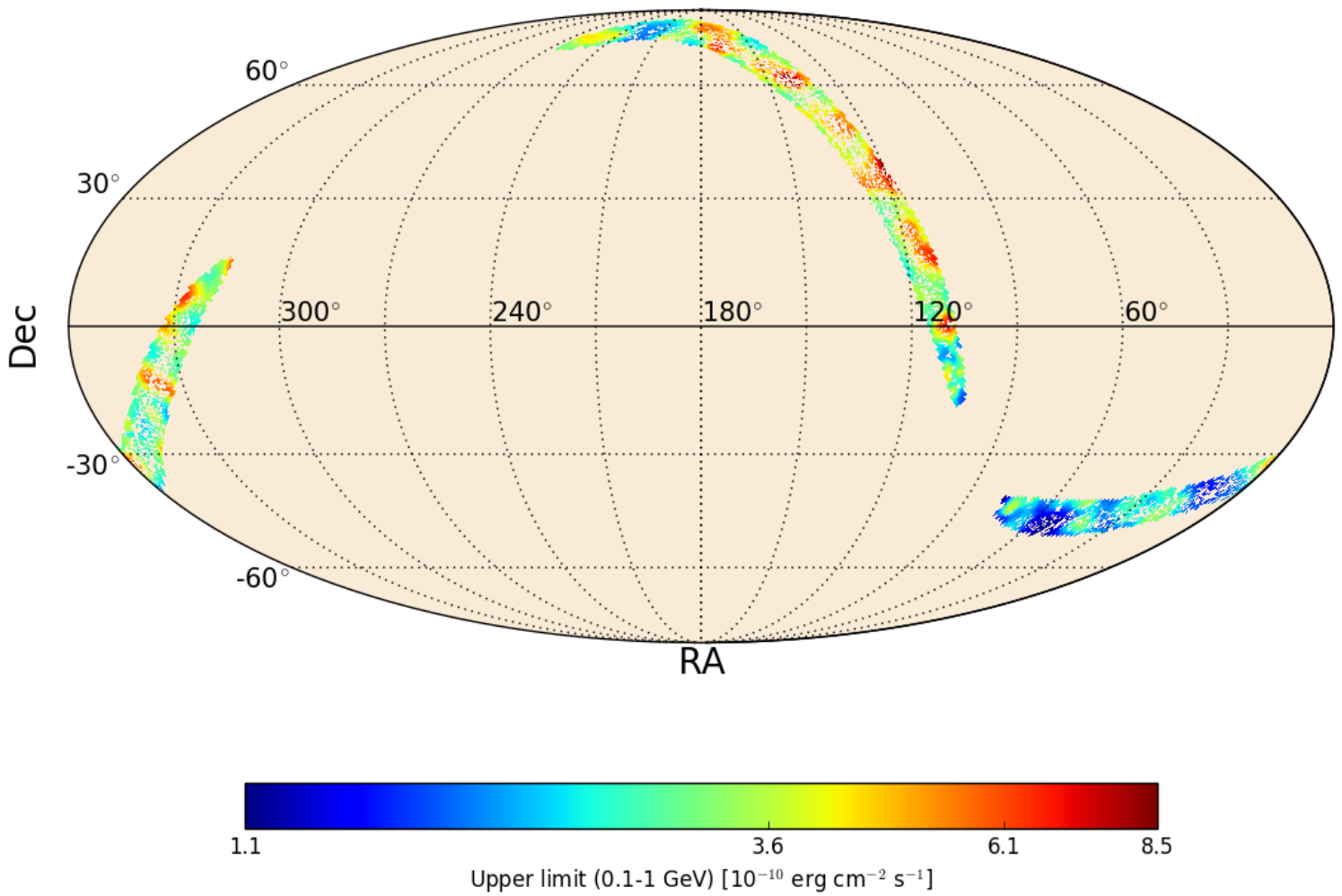
Cumulative coverage



FTI TS map



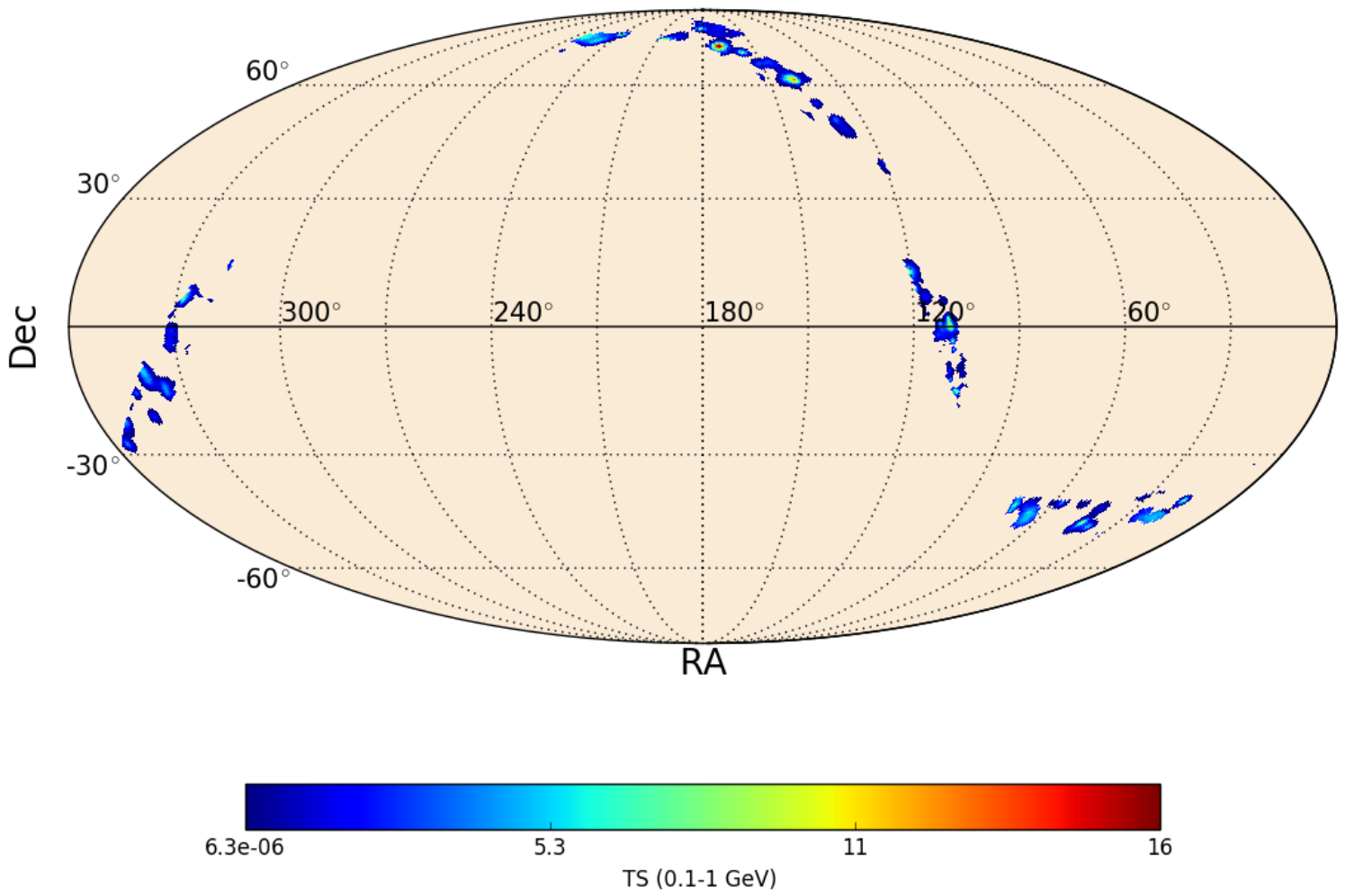
FTI UL map


60°
30°
300°
240°
180°
120°
60°
-30°
-60°
Dec
RA
1.1
3.6
6.1
8.5
Upper limit (0.1-1 GeV) [10⁻¹⁰ erg cm⁻² s⁻¹]

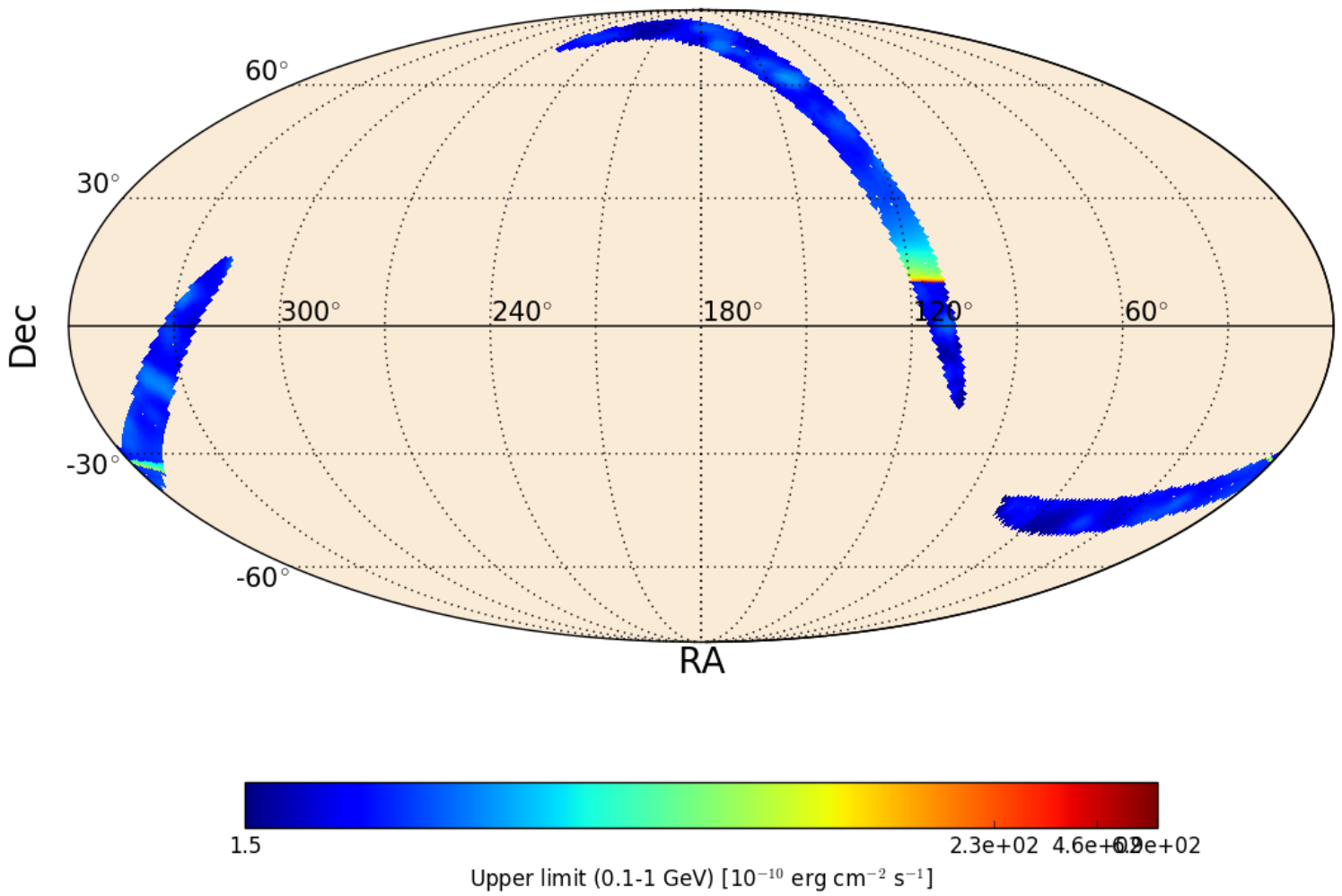
Adaptive Time Interval

- Maximize the time window for each point in the sky separately in order to get the largest possible exposure close to the trigger time:
  - For each pixel the time interval starts when the center of the ROI becomes observable by the LAT and ends when is no longer observable
- Run an independent likelihood analysis for each pixel as before
- In case of non-detection, compute a flux upper bound for each pixel separately.

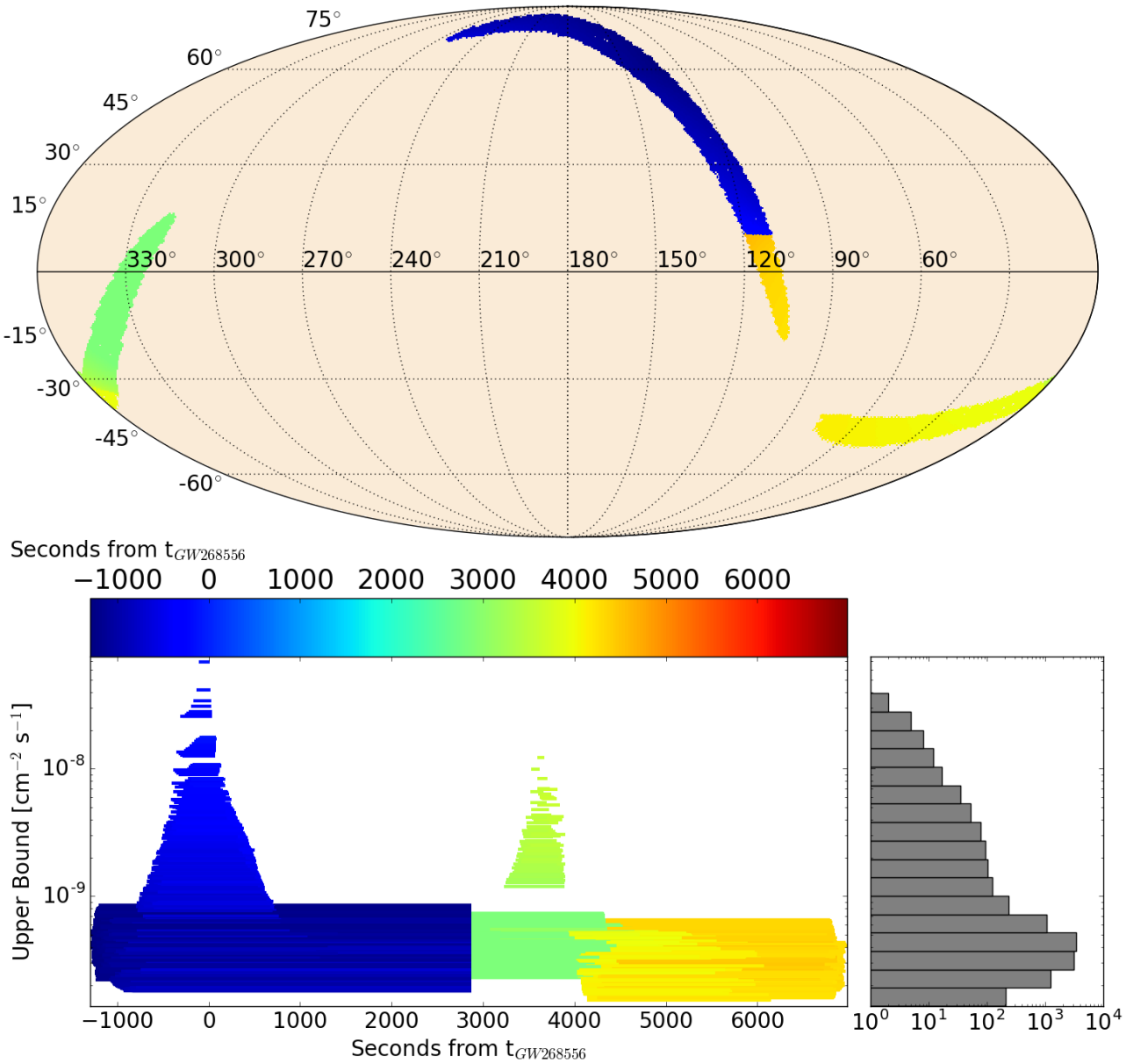
ATI TS map



ATI UL map


60°
30°
300°
240°
180°
120°
60°
-30°
-60°
Dec
RA
1.5
2.3e+02
4.6e+02
Upper limit (0.1-1 GeV) [10⁻¹⁰ erg cm⁻² s⁻¹]

ATI LC map

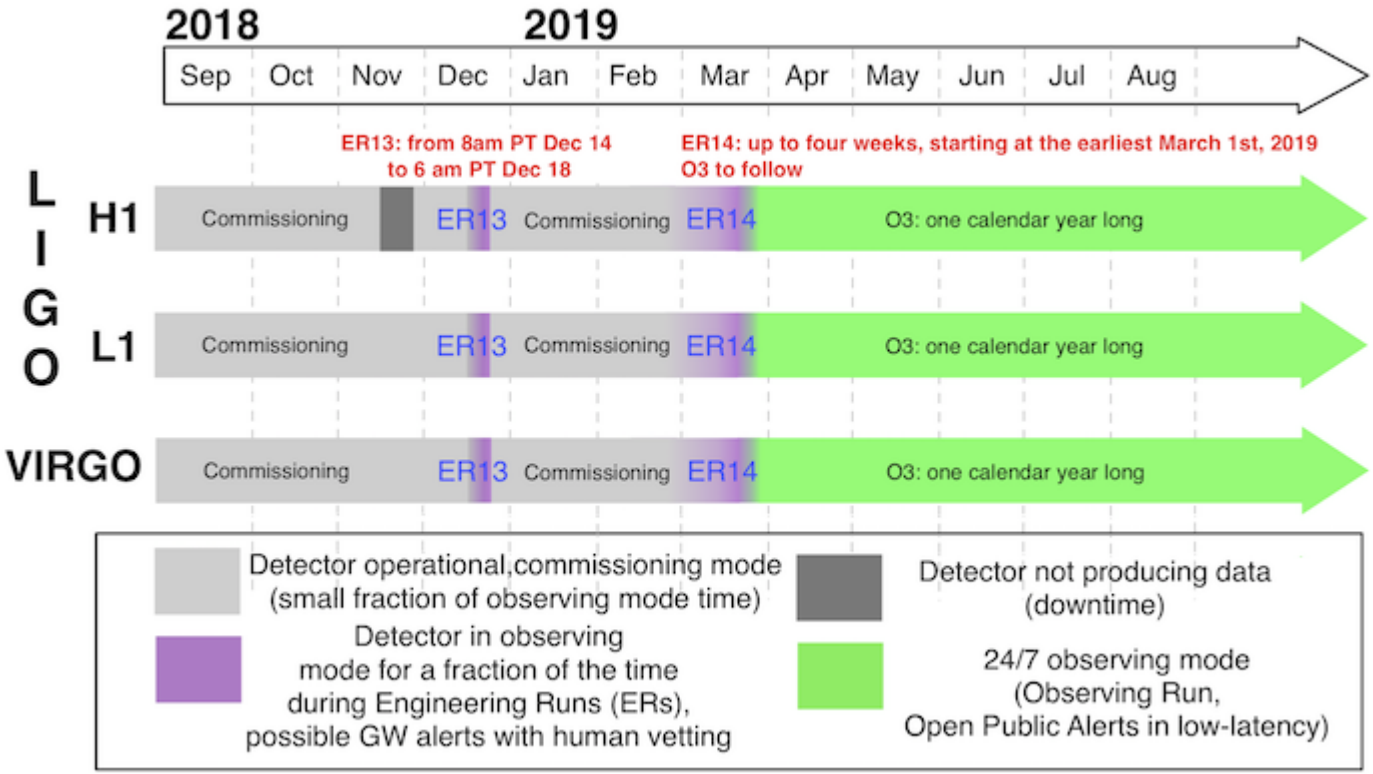

75°
60°
45°
30°
15°
-15°
-30°
-45°
-60°
330°
300°
270°
240°
210°
180°
150°
120°
90°
60°
Seconds from $t_{GW268556}$
−1000
0
1000
2000
3000
4000
5000
6000
Upper Bound [cm^{-2} s^{-1}]
10^{-8}
10^{-9}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
Seconds from $t_{GW268556}$

Low Energy Events

- Extract LLE data (E < 100 MeV) around the time of the trigger for each pixel of the map (downgraded to NSIDE=32) producing light curve and estimating the significance.

LIGO/Virgo schedule for O3

Updated schedule



Open public alerts

LVC will release public alerts for all event candidates considered to be likely real:

- For compact binary coalescences (CBC) the goal is an overall 90% of astrophysical purity

  → False alarm rate (FAR) of ~ 1/month–1/year

- For unmodeled burst sources → FAR of ~ 1/10–1/100 years
- Sub-threshold events can be promoted if associated with a multi-messenger signal.

LVC will consider science-driven MOUs for exchanging additional information (for instance low confidence triggers) only if there is a specific science goal which requires it.

Open public alerts

- Automated preliminary alerts, prior to human vetting, will be released as GCN notices with a latency of ~ 5 minutes

  → they can be retracted after human inspection

- These basically contain the information provided for private alerts in O2: significance, time, GW signal classification, 3D sky position and distance.
- GCN circulars, human readable, will follow in few hours with data quality assessment and updates on the GW candidate.

Expected rates in O3

Depending on the reached sensitivities, the general picture for 3-detectors events is (link):

- BBH: at least few per month, up to few per week
- BNS: possibly up to one per month
- NSBH: still uncertain, maybe one or more during O3
- In addition, 2-detectors events (or 1-detector plus a validated counterpart) are also possible.

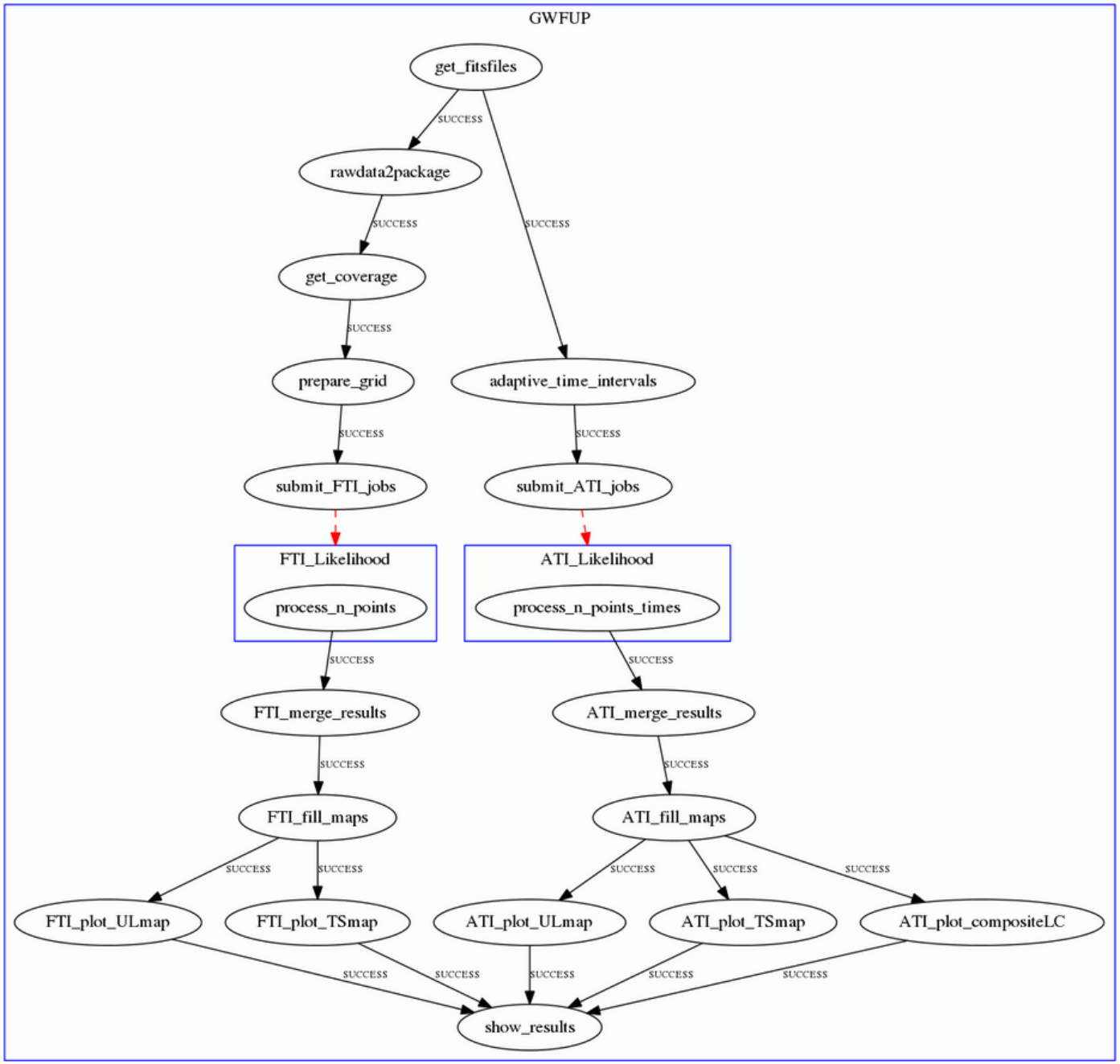
- Notable individual events will be published individually by LVC, including at least the next few BNS
- “Routine” events will be publish periodically in catalog papers.

SPARE SLIDES

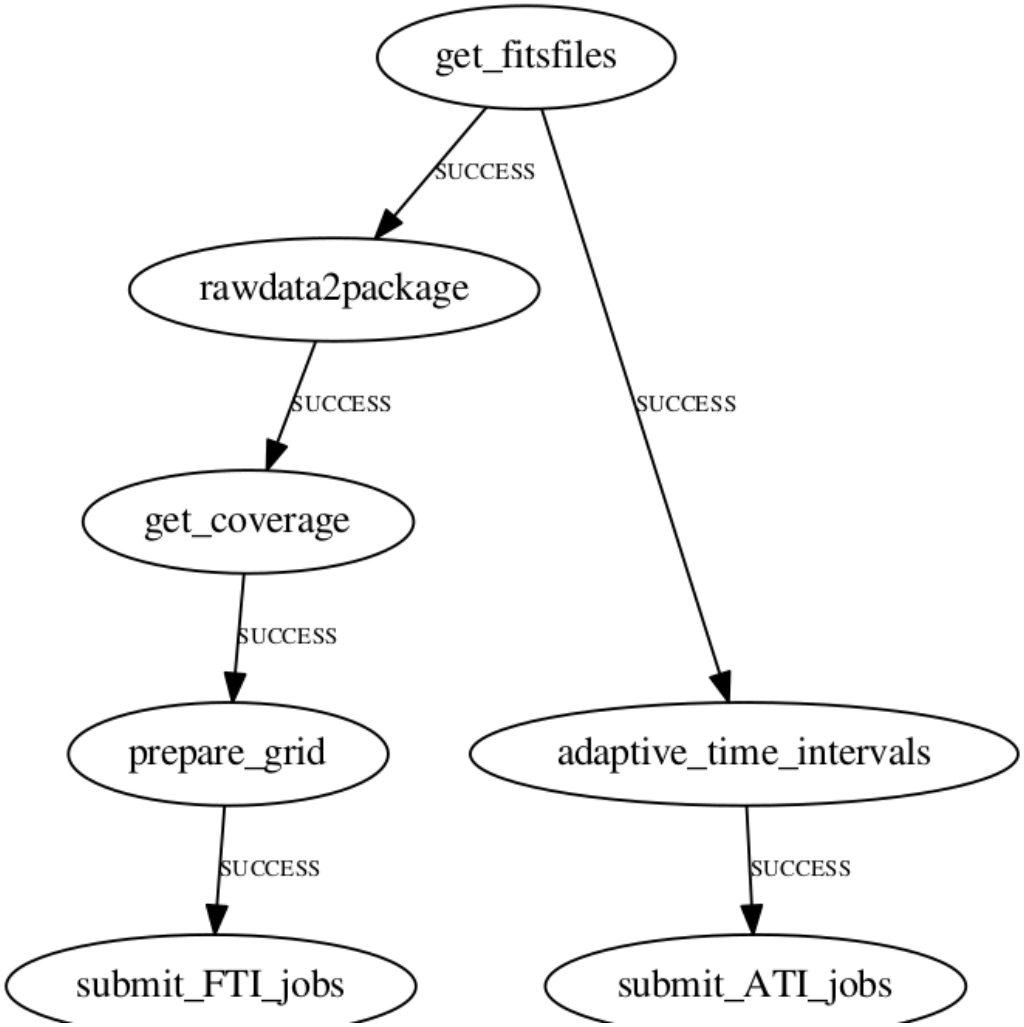
Resources

- Confluence page: link
- Job status page: link
- Output folder (under GRB space): link
- Alternative automatic pipeline using BA tools (Dan Kocevski): link

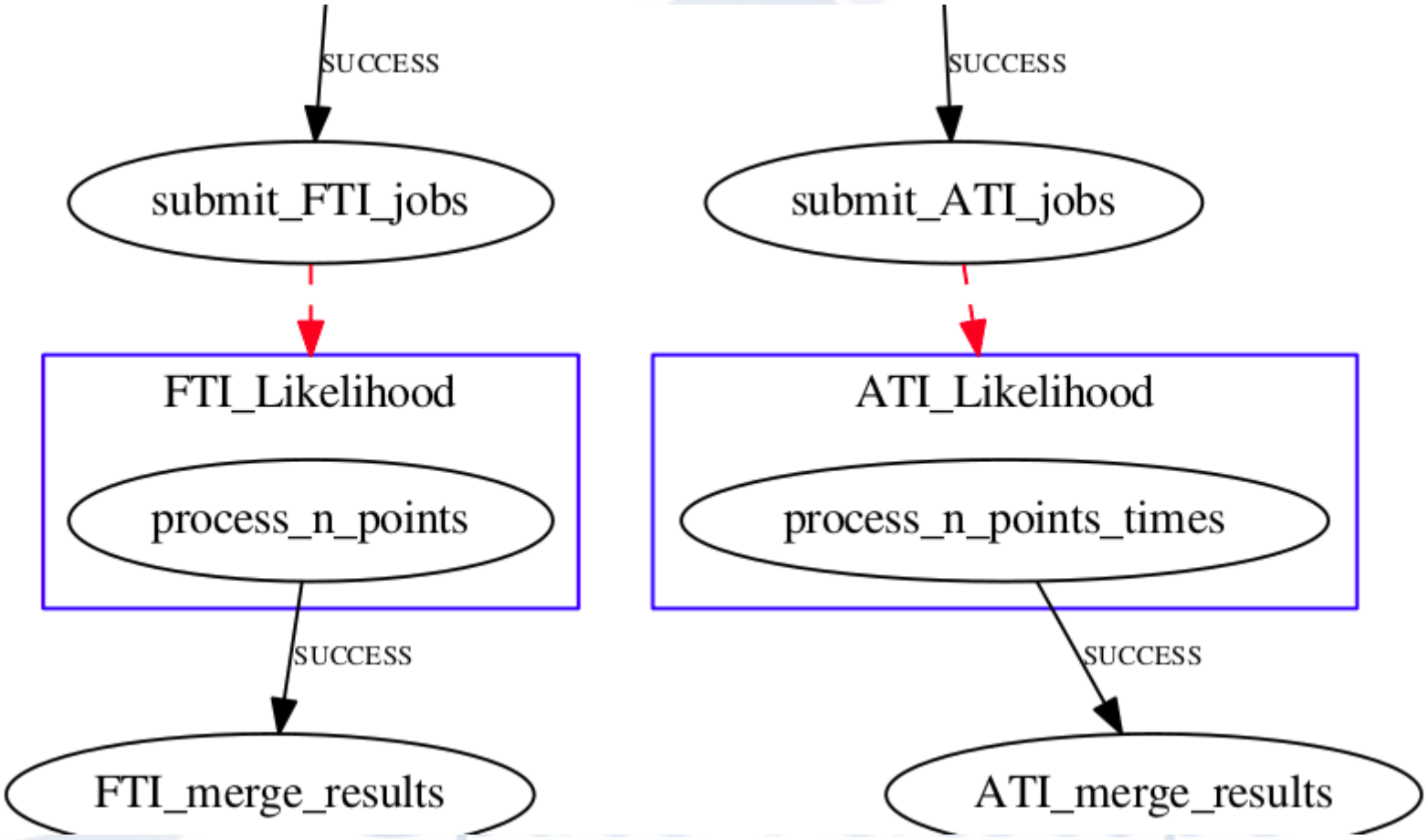
GWFUP pipeline overview



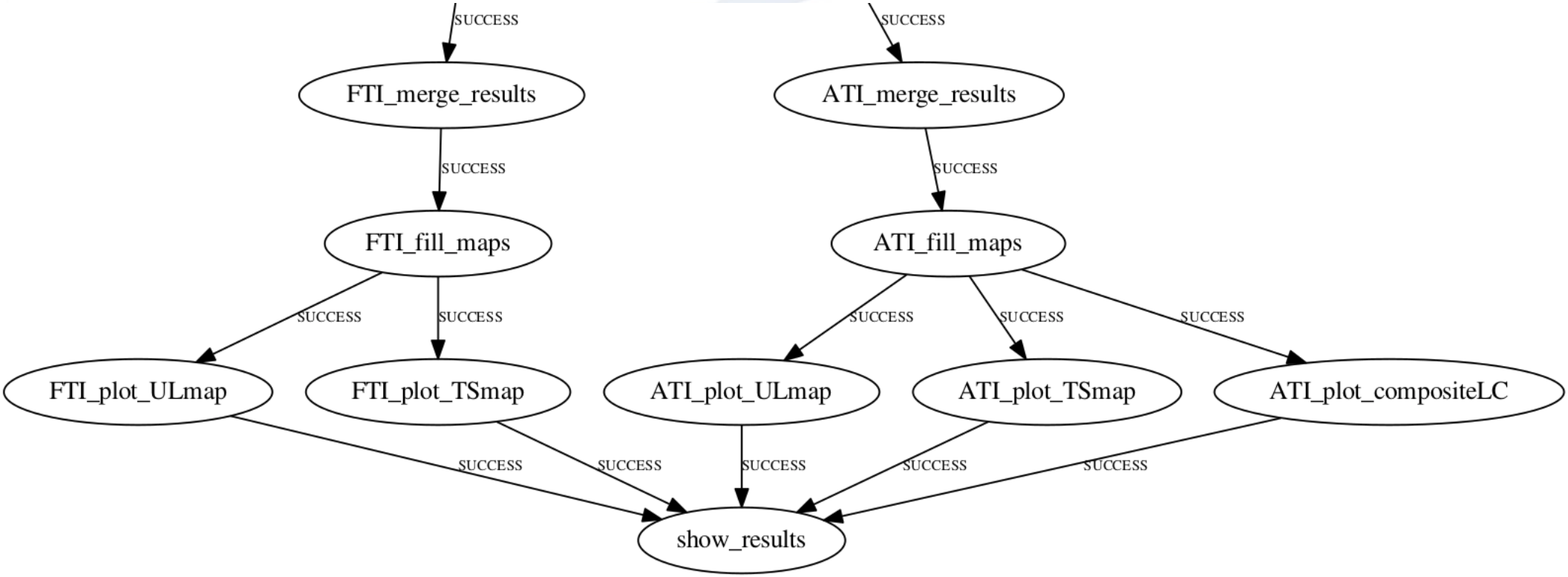
Data preparation



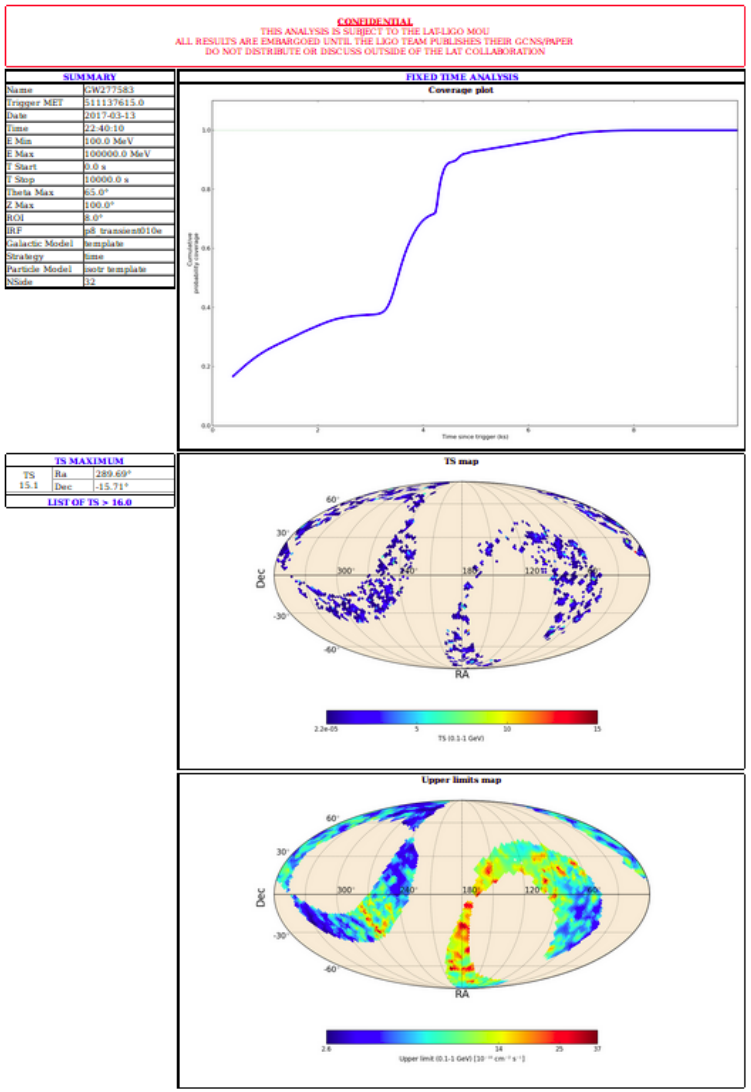
Likelihood analysis

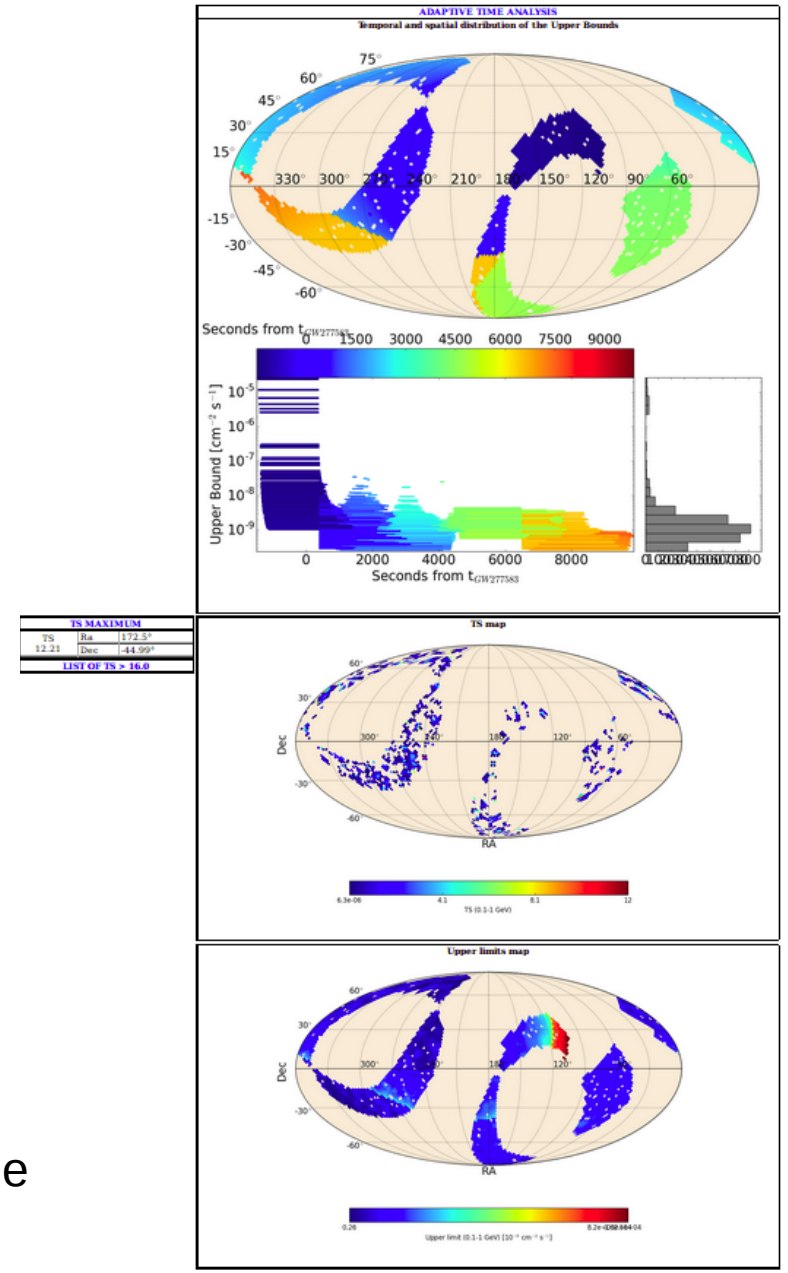


Finalization



Report page (GW277583)





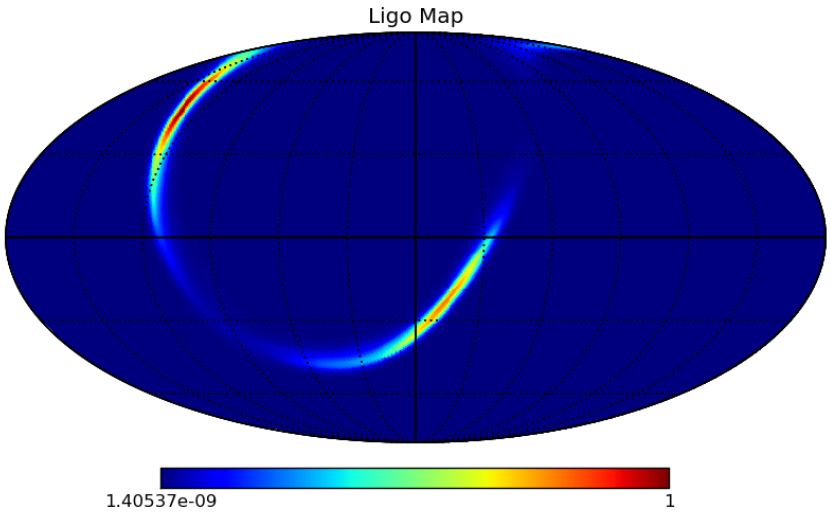
Web page directly available to all the Fermi-LAT Collaboration members

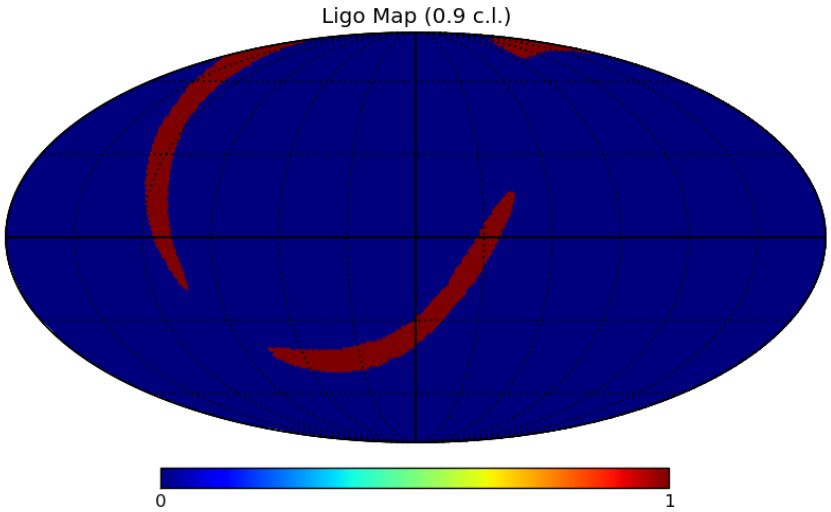
GW170104 (268556)

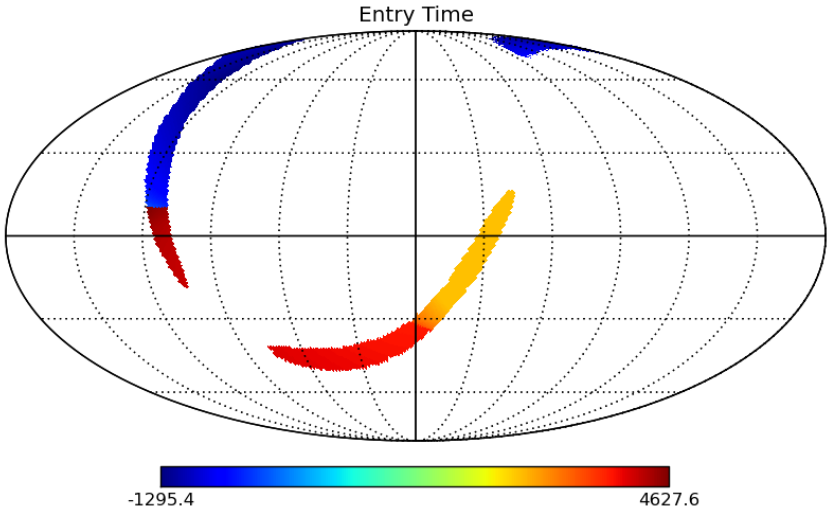
SUMMARY	
Name	GW268556
Trigger MET	505217524.0
Date	2017-01-04
Time	10:11:58
E Min	100.0 MeV
E Max	1000.0 MeV
T Start	0.0 s
T Stop	10000.0 s
Theta Max	65.0°
Z Max	100.0°
ROI	8.0°
IRF	p8_transient010e
Galactic Model	template
Strategy	time
Particle Model	isotr template
NSide	128

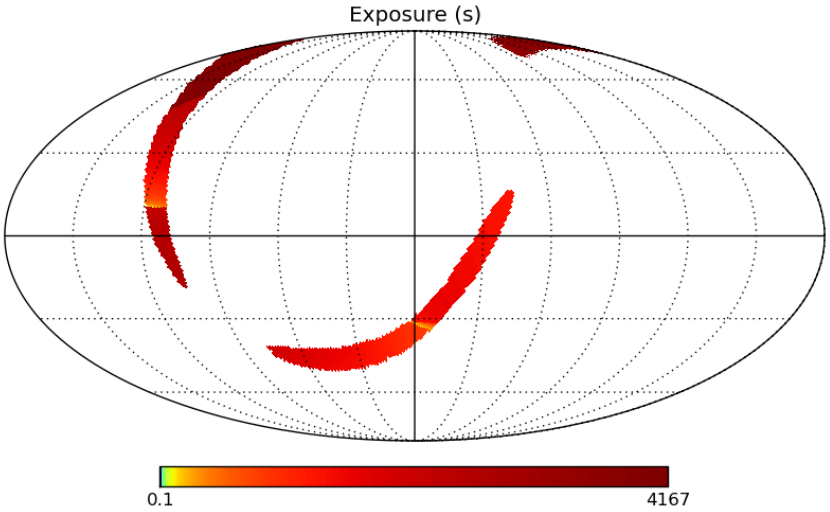
Paper just submitted to ApJ
https://arxiv.org/abs/1706.00199

Exposure


Ligo Map
1.40537e-09
1


Ligo Map (0.9 c.l.)
0
1


Entry Time
-1295.4
4627.6


Exposure (s)
0.1
4167

Pipeline II

Fermi LAT Pipeline-II

summary / GWFUP

Task Summary: GWFUP 1.9 (XML)

Created by omodei at 2017-03-21 11:42:07.0 with comment: *Follow up GW events*

Versions: (1.6) (1.7) (1.8) **(1.9)** (2.0) ....more versions Subtasks: FTI_Likelihood ATI_Likelihood

Task Summary: Canceled: 0, Canceling: 0, Failed: 0, Queued: 0, Running: 0, Success: 2, Terminated: 0, Terminating: 0, Waiting: 0, Total: 2

To filter by status click on the count in the status column. To see all streams click on the name in the Name column.

Show running jobs . Show streams . Summary plots

Show processes by status: Waiting Ready Queued Submitted Running Success Failed Terminated Canceling Canceled Skipped [ALL] [All not SUCCESS]

Task	Version	Process	Type												Total	Links
GWFUP	1.9	get_fitsfiles	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		rawdata2package	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		get_coverage	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		prepare_grid	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		submit_FTI_jobs	Script	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		FTI_merge_results	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		FTI_fill_maps	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		FTI_plot_ULmap	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		FTI_plot_TSmap	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		adaptive_time_intervals	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		submit_ATI_jobs	Script	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		ATI_merge_results	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		ATI_fill_maps	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		ATI_plot_ULmap	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		ATI_plot_TSmap	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
		ATI_plot_compositeLC	Batch	0	0	0	0	0	2	0	0	0	0	0	2	Plots
FTI_Likelihood	1.5	process_n_points	Batch	0	0	0	0	0	6513	0	0	0	0	0	6513	Plots
		bayesian_ul	Batch	0	0	0	0	0	6513	0	0	0	0	0	6513	Plots
ATI_Likelihood	1.5	process_n_points_times	Batch	0	0	0	0	0	6513	0	0	0	0	0	6513	Plots
			Totals	0	0	0	0	0	19,571	0	0	0	0	0	**19,571**	

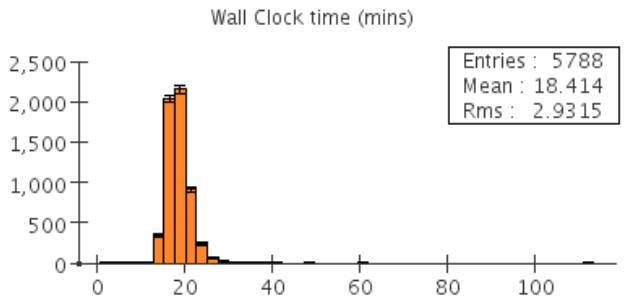
Main advantages:

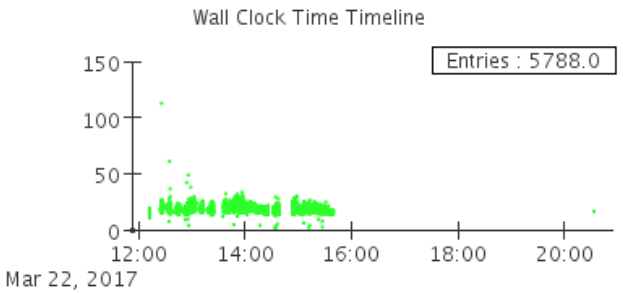
- High priority jobs
- Roll-back feature

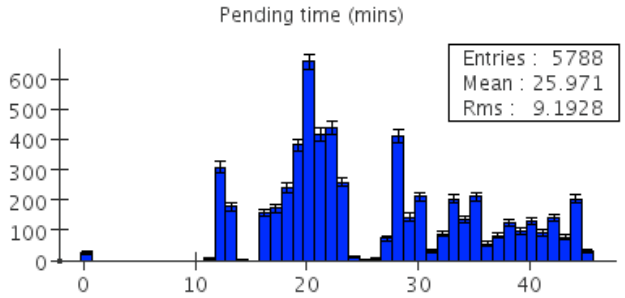
Performance

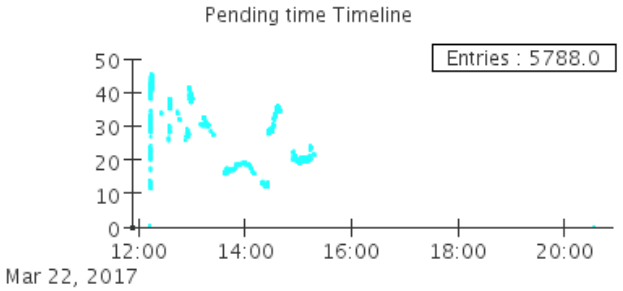
- Order of 2000 jobs submitted per event candidate
  - About 5-6000 in the worst case scenario
- Fixed time interval:
  - Average time: ~ 18 min/job
  - Longest job: ~ 2 hrs
  - Total time: ~ 4 hrs
- Adaptive time interval:
  - Average time: ~ 8 min/job
  - Longest job: ~ 2 hrs
  - Total time: ~ 3 hrs
- The pipeline is now fully up and running!

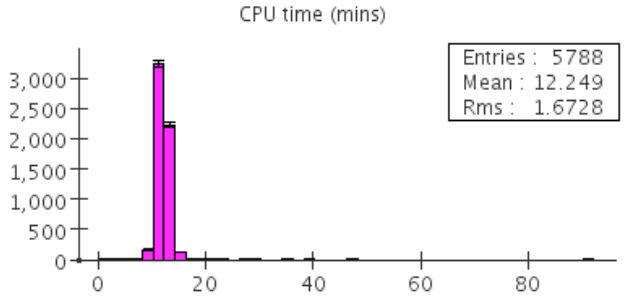
Performance plots (FTI)

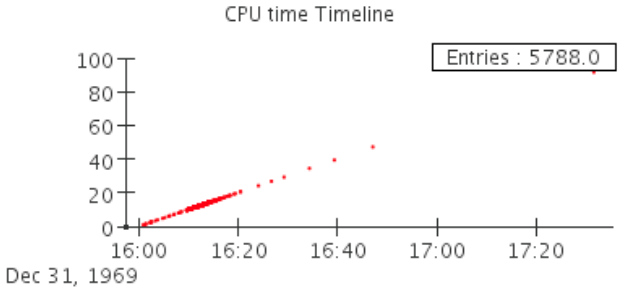


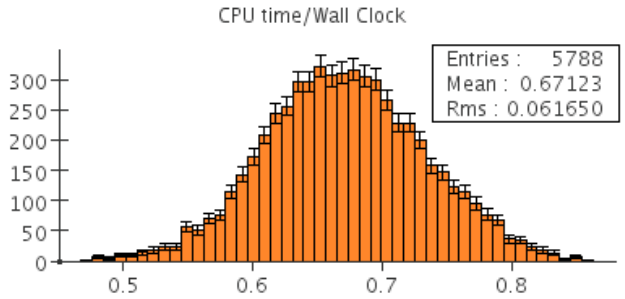


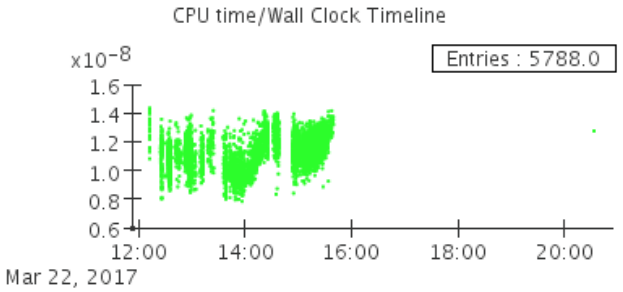












Performance plots (ATI)