Precision Magnetic Field Analysis

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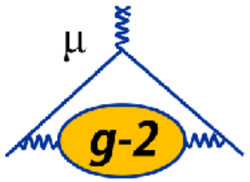
Operational Readiness Review Meeting

02 October 2017

Outline



- Charge Question #4 : “Are there robust plans for data processing and data analysis? Have adequate resources from the laboratory and the collaboration been identified for data analysis to meet these goals? ”
- Overview of the magnetic field analysis
  - Analysis workflow
- Analysis Developments for operation
  - Analysis software framework
  - Progress and readiness for operation
- Analysis plans to achieve the physics goal
- Summary

Overview

ω_a Improvement: 180 ppb -> 70 ppb

$$a_\mu(\mathrm{Exp}) = -\frac{m\omega_a}{eB} \longrightarrow a_\mu(\mathrm{Exp}) = \frac{g_e}{2}\frac{\omega_a}{\tilde{\omega}_p}\frac{m_\mu}{m_e}\frac{\mu_p}{\mu_e}$$

0.26 ppt

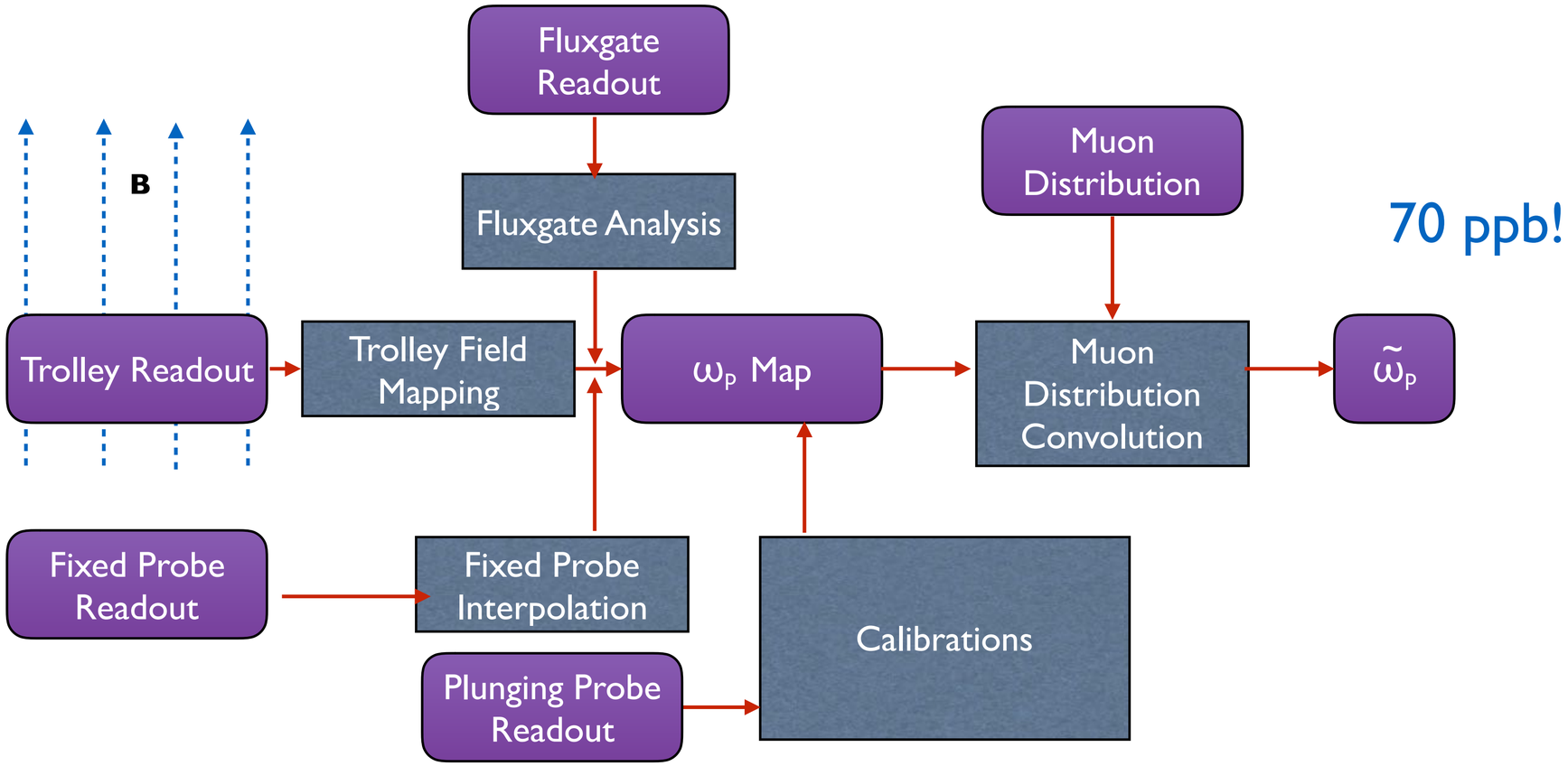
8 ppb

22 ppb

ω_p Improvement: 170 ppb -> 70 ppb

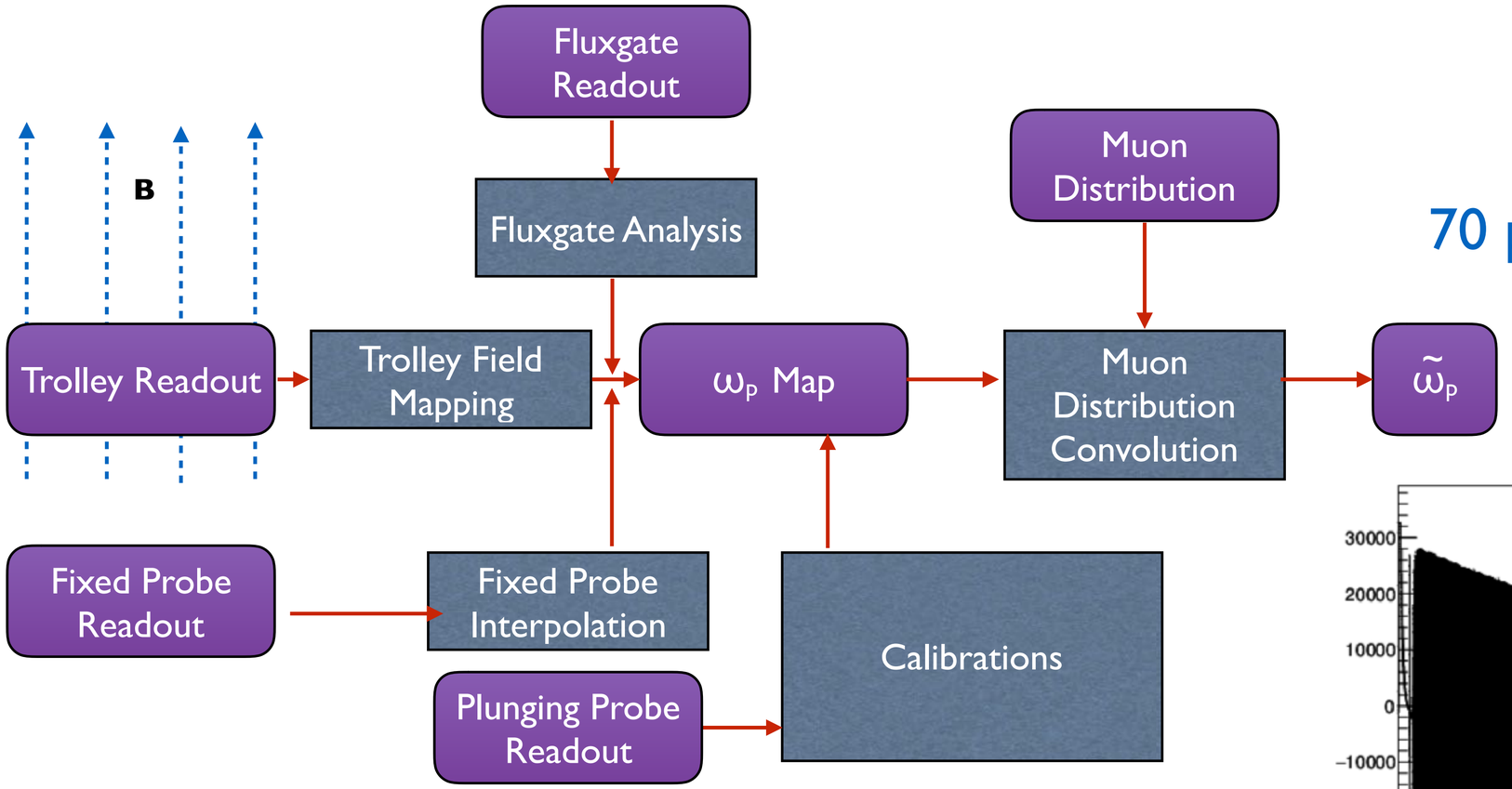
- Magnetic field measurement
  - Magnetic field mapping
  - Interpolation in between measurements
  - Calibration and correction
- Convolution between field map and muon distribution

Overview

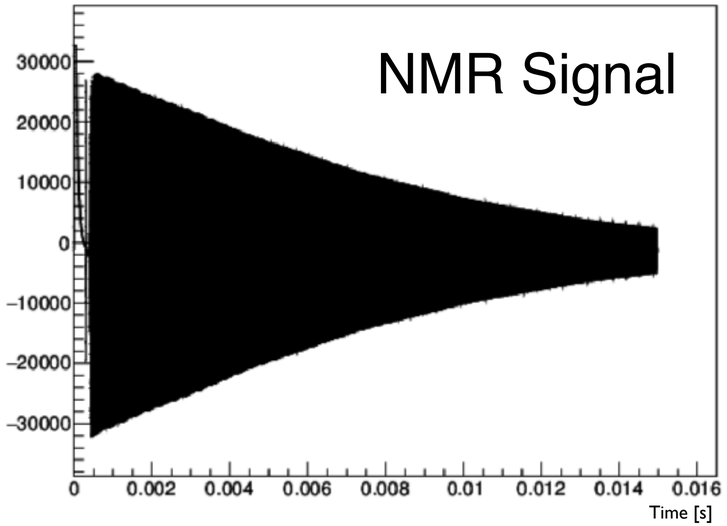


70 ppb!

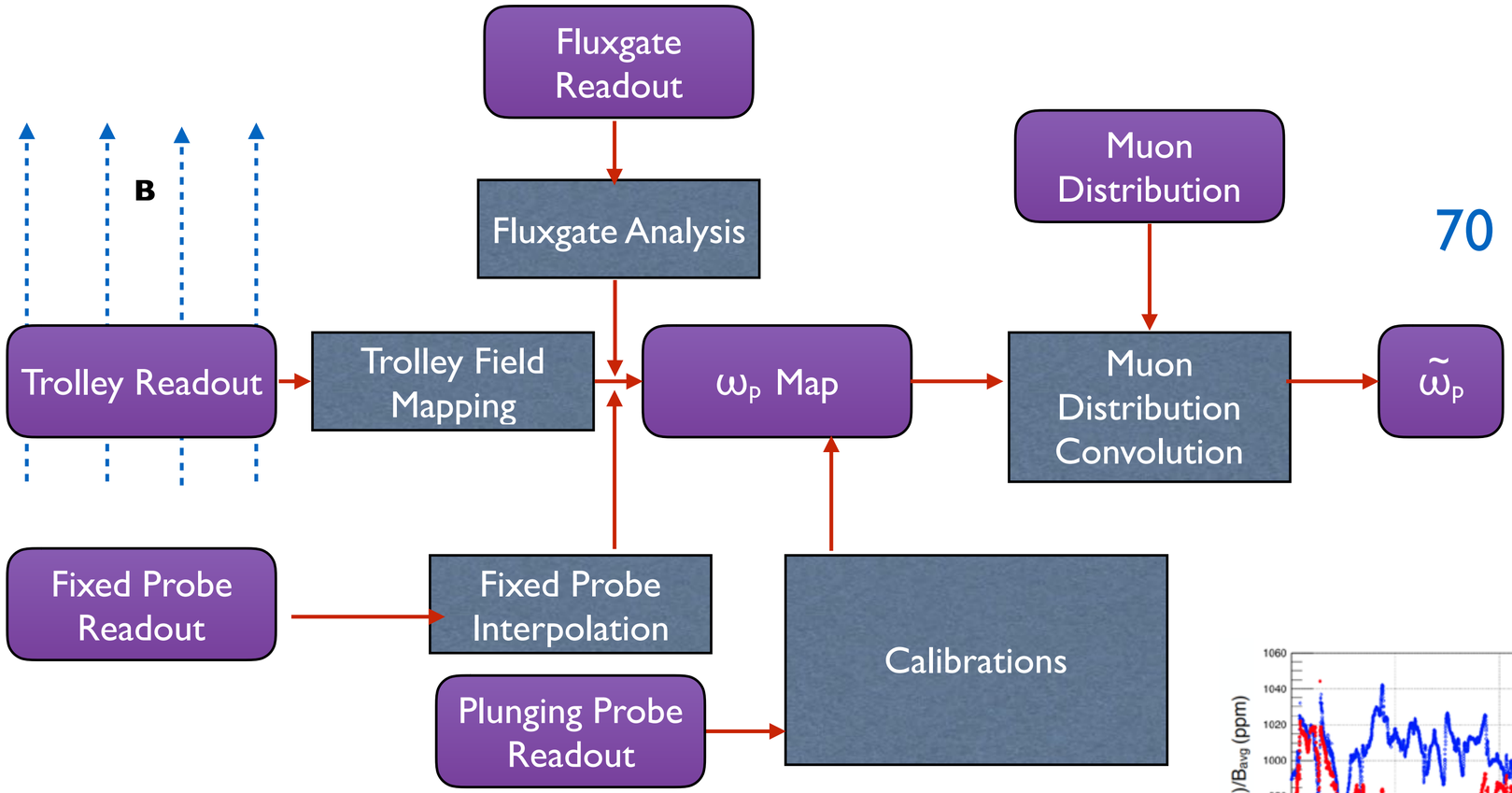
Overview



70 ppb!

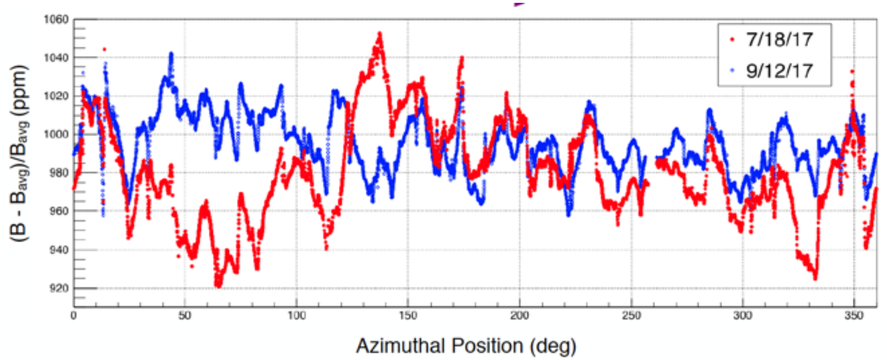


Overview



70 ppb!

Field Map



Fermilab

Overview

Source of uncertainty	R99 [ppb]	R00 [ppb]	R01 [ppb]	E989 [ppb]
Absolute calibration of standard probe	50	50	50	35
Calibration of trolley probes	200	150	90	30
Trolley measurements of B_0	100	100	50	30
Interpolation with fixed probes	150	100	70	30
Uncertainty from muon distribution	120	30	30	10
Inflector fringe field uncertainty	200	–	–	–
Time dependent external B fields	–	–	–	5
Others †	150	100	100	30
Total systematic error on ω_p	400	240	170	70
Muon-averaged field [Hz]: $\widetilde{\omega}_p/2\pi$	61 791 256	61 791 595	61 791 400	–

Overview

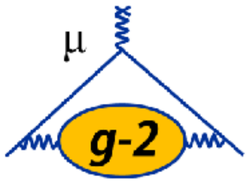
Our Team (ANL, UMass, FNAL, UW, UMichigan, UT-Austin)

- Faculty/Senior Scientists
  - Peter Winter, David Kawall, Brendan Kiburg, Alejandro Garcia, Erik Swanson, Martin Fertl, Tim Chupp
- Postdocs
  - Joe Grange, Ran Hong, David Flay, Matthias Smith, Jimin George
- Graduate students
  - Alyssa Conway, Rachel Osofsky , Alec Tewsley-Booth, Midhat Farooq
- Interns
  - 3 more undergraduates

Analysis Developments for operation

- Online Analysis Required for Operations
  - For hardware operation
    - Fixed probe NMR frequency extraction (Time scale: 100ms)
    - Trolley Position
    - Field averaging for power supply feedback
  - For Data Quality Monitoring (Time scale: 5s)
    - DQM Pages and data publishing modules
    - All NMR frequency extraction
  - Data Storage: 500 TB in total, Tapes at Fermilab, using FTS to transfer data
- Nearline data production (Needed for operation, executed after each run)
  - All NMR frequency extraction (Data reduction: dropping off wave forms)
  - Data unpacking and saving
  - Trolley field mapping, multipole expansion
  - Trend plots: fixed probe, power supply feedback current, etc.

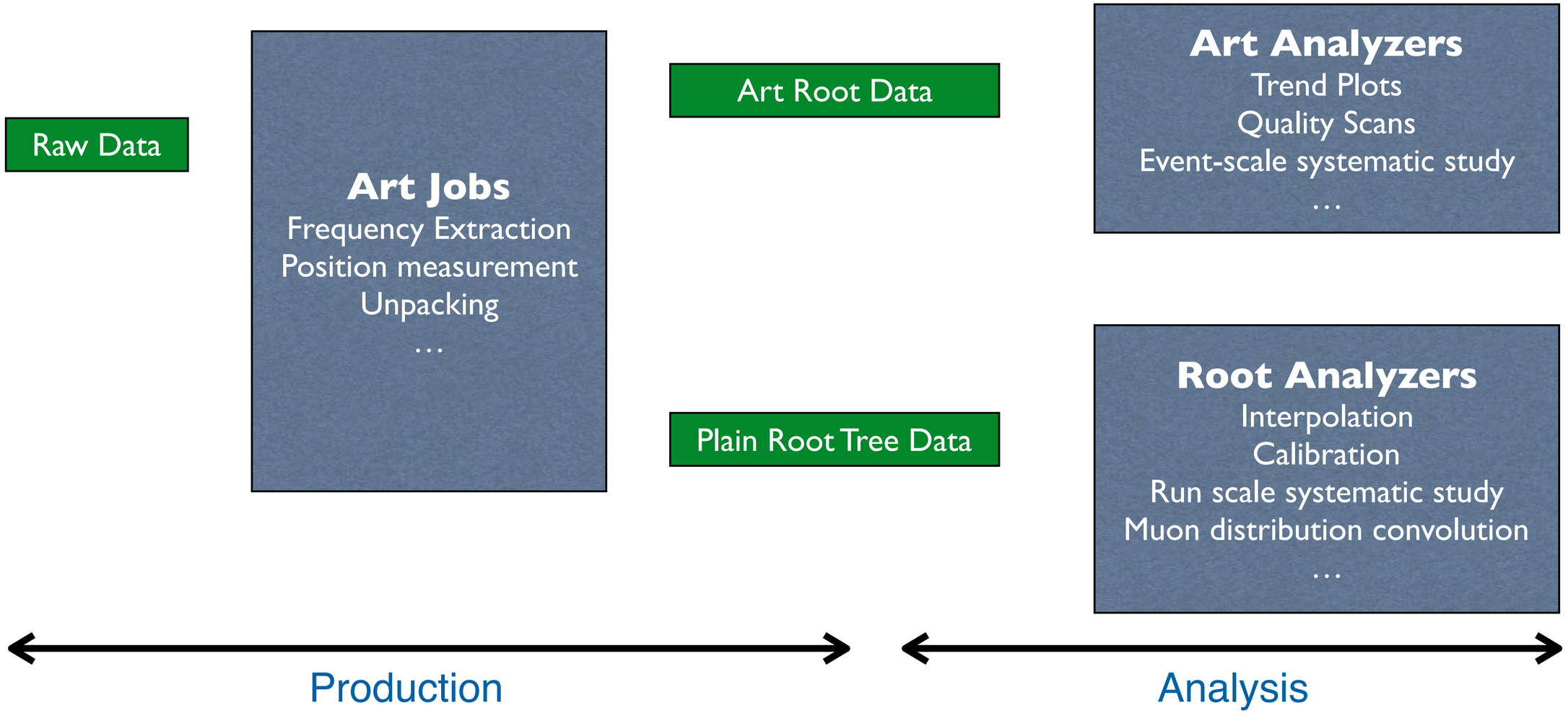
Analysis Developments for operation



- Offline analyses (Not needed for operation)
  - Run quality summarizing: getting a list of good runs
  - Data reprocessing: reprocess raw data (like NMR frequency extraction) if algorithm is improved
  - Field interpolation using fixed probe
  - Fluxgate transient field study
  - Calibrations
  - Correlate with slow control database
  - Systematic uncertainty studies for each system
  - Muon distribution convolution

Analysis Developments for operation

- Framework for nearline production and offline analysis



Analysis Developments for operation

- Progress and readiness for operation

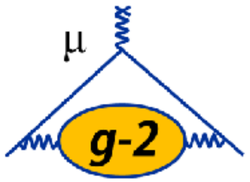
Category	Task	Expert Oncall	Readiness
Online	All NMR probe Frequency	R. H. , D. F.	100%
Online	Trolley Position	R. H.	100%
Online	Field Averaging	D. F.	100%
Online	DQM Pages	R. H.	100%
Nearline	Art modules for data production	R. H. , D. F. , R. O.	95%

Analysis Developments for operation

Remaining tasks for operation (Done before Oct. 15th)

- Fluxgate data unpacking and nearline analysis
- Documentations for data production and trouble shooting
- Further improvements (Done before Nov. 1st)
  - More and better looking DQM Pages
  - Train people (and develop documentations) to do nearline production
  - Faster fixed probe frequency extraction
- Maintenance (1 Person every day during the run)
  - Sorting out good runs
  - Data quality control
  - Data base managing

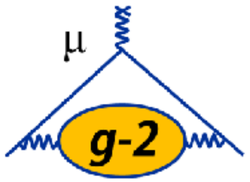
Analysis plans to achieve the physics goal



Interpolation in between trolley runs (30ppb)

- Basic Plan
  - Interpolate the field cross-section map (averaged in azimuthal direction)
  - Interpolate lower order multipoles versus azimuth
  - Correlate with the fluxgates
- Advanced Plan
  - Use machine learning to interpolate field in finer scale
    - Use trolley runs as training data set
    - Predict the field at any position when trolley is not present

Analysis plans to achieve the physics goal

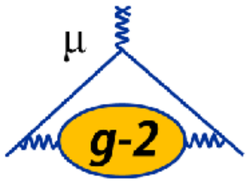


- Calibration (30+35 ppb)

- Basic Plan
  - Use water probe
  - Study material perturbation, chemical shift, mirror effect.
  - Position uncertainty

- Advanced Plan
  - Absolute calibration using 3He probe

Analysis plans to achieve the physics goal

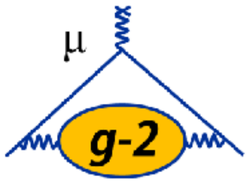


- Frequency extraction and trolley field mapping (30 ppb)

- Basic Plan
  - Study how different algorithms affect the frequency extraction
  - Simulate the NMR probes and understand the systematic biases
  - Study frequency extractions in present of strong field gradient
  - Systematics related to trolley position measurements

- Advanced Plan
  - Independent studies of each issue
  - Blinding

Analysis plans to achieve the physics goal



- Muon distribution convolution (10 ppb)

- Basic Plan
  - Convolute the measured muon beam distribution (cross-section) and the averaged field map (cross-section)

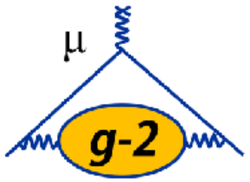
- Advanced Plan
  - Beam dynamics simulation in non-uniform field
  - 3-d muon distribution convoluted with 3-d magnetic field map

Analysis plans to achieve the physics goal

- Developers and time frame

Task	Developers	Estimated time for Basic Plan	Estimated time for Advanced Plan
Field Interpolation	R. H. , R. O., J. George, A. T.	1 month	9 months
Calibrations	D. F. , R. H.	2 months	6 months
F-extraction and Field Mapping	R. H. , D. F. , R. O.	2 months	6 months
Muon Convolution	J. Grange	1 month	6 months

Summary



- Robust plans for data processing and data analysis?
  - Analysis programs necessary for operations are >95% ready for operation by now,
  - Will be fully ready before the October run
  - Data production scheme is developed to store raw data and provide unpacked data for down stream analyses
- Have adequate resources from the laboratory and the collaboration been identified for data analysis?
  - Experts are appointed to be ready to maintain the analysis system during the operation
  - Nearline analysis computer is configured and ready
  - Data storage requirement is identified
  - Clear plans to achieve the final physics goal