MICE Analysis User Software

Durga Rajaram

Illinois Institute of Technology, Chicago

Adam Dobbs

Imperial College, London

October 10, 2016

CHEP 2016

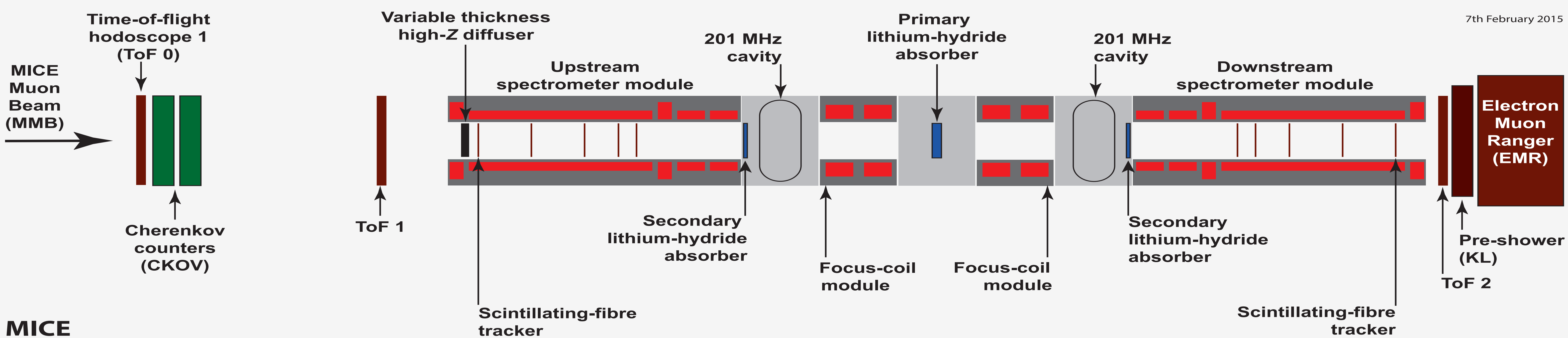
San Francisco

OUTLINE

- MICE
- Software Requirements
- Implementation
  - Design
  - Framework
  - Online
- Performance
- Conclusions

MUON IONIZATION COOLING EXPERIMENT

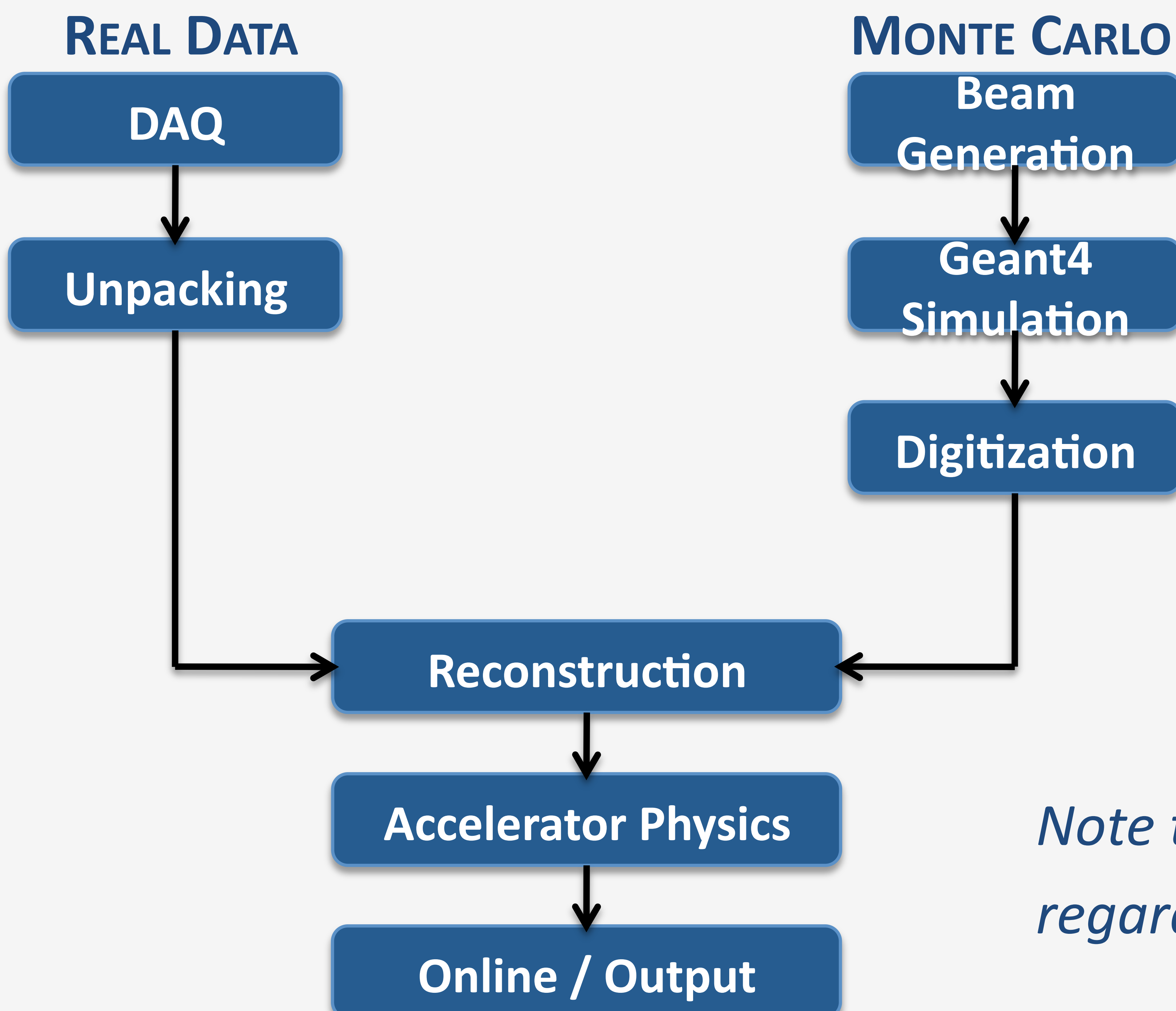
- Muon cooling: essential for future high-luminosity μ-colliders & high-intensity ν-factories
- μ from π decays have large emittance & must be cooled (reduce phase space volume)
- Traditional beam cooling techniques too slow due to the short μ lifetime
- Ionization Cooling is the only practical means:
  - Reduce momentum by dE/dX in absorber, followed by RF reacceleration to restore $p_{||}$
- Design, build & commission a realistic section of cooling channel to precisely measure emittance reduction – Lessons => the design of a full cooling channel for a ν Factory/μ Collider



MICE Software Goals

- MICE is both an accelerator physics & a particle physics experiment
  - Beam simulations, emittances, transfer matrices, Twiss parameters
  - Traditional HEP detectors: simulation, track reconstruction, particle identification
  - Need common software scope
- Online reconstruction & monitoring during data-taking
- Wide range of geometries, configurations to book-keep
- Framework for analysis tools
- Code testing, Issue tracking, documentation
- Long-term maintainability: MICE is built & operated in stages

DATA FLOW



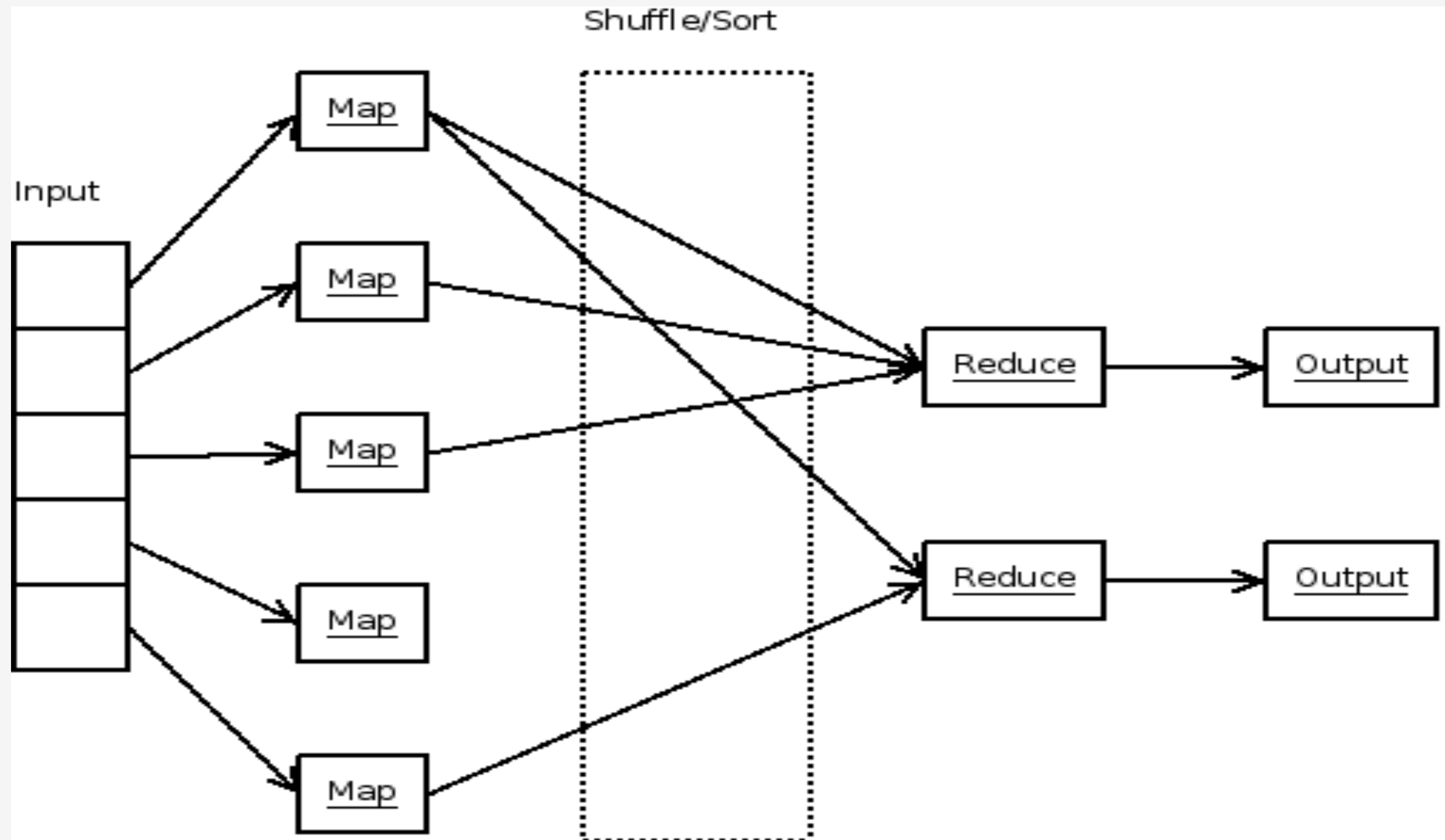
CONFIGURATIONS DB
Cabling, Calibrations, Geometry

Note that reconstruction is same regardless of MC or real data

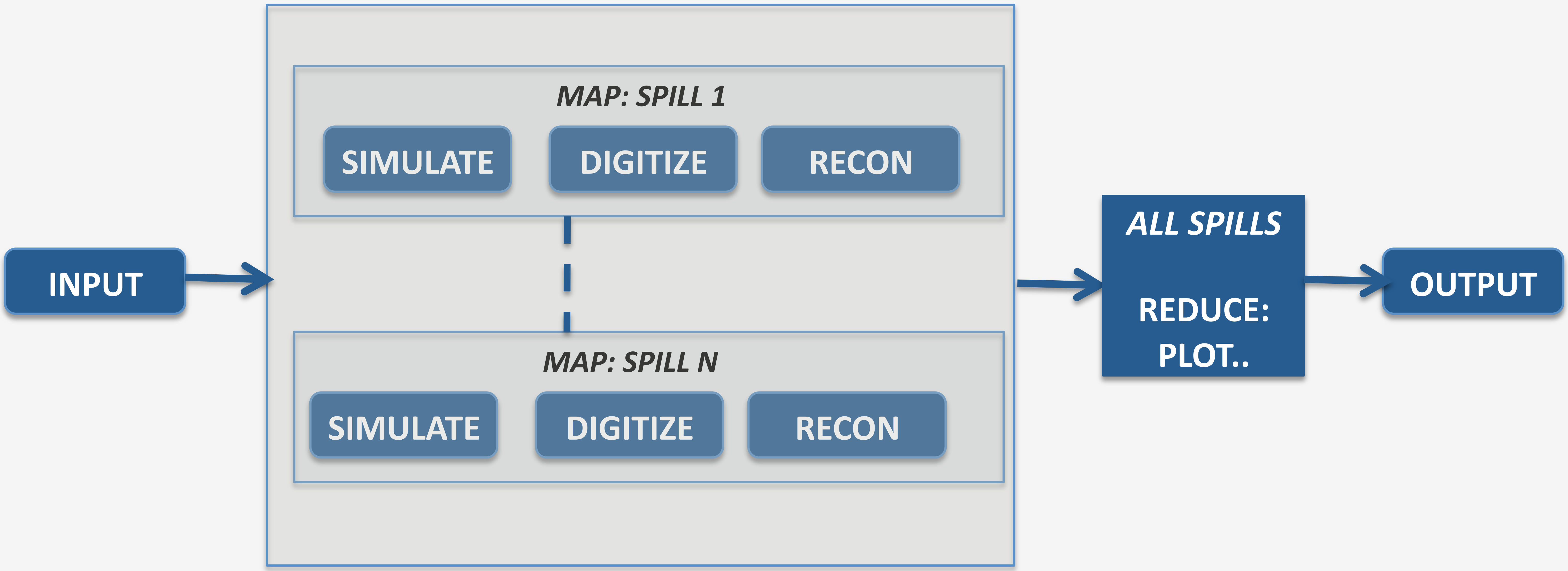
MAUS: MICE Analysis and User Software

- Design inspired by MapReduce

- Map
  - Operate on a single event
  - Can run in parallel
  - e.g. Simulate, reconstruct
- Reduce
  - Operate on a collection of events
  - e.g., Summary histograms



MAUS DESIGN


INPUT
MAP: SPILL 1
SIMULATE
DIGITIZE
RECON
MAP: SPILL N
SIMULATE
DIGITIZE
RECON
ALL SPILLS
REDUCE:
PLOT..
OUTPUT

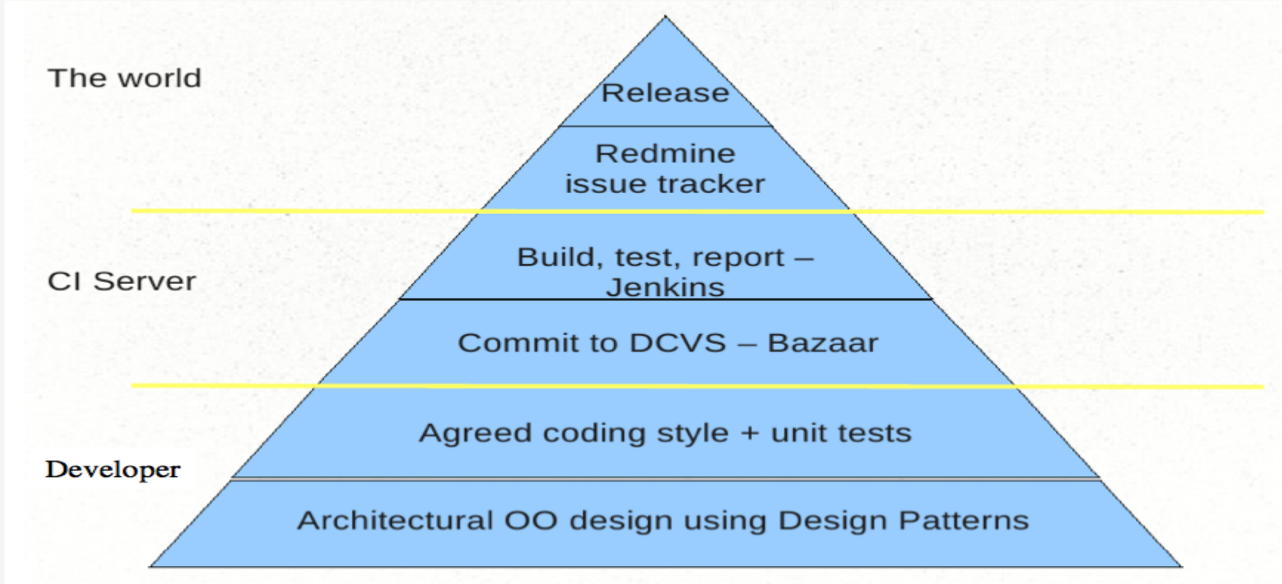
MAUS: MICE Analysis and User Software

- MapReduce
  - *Technically, in MAUS: Input-Transform-Merge-Output*
- **Input:** Read in data
  - DAQ data file, I/O stream, beam library for Monte Carlo
- **Map:** Process spills & return modified data
  - A spill is the primary data block & consists of several event triggers
  - Monte Carlo simulation, Detector reconstructions
  - Mappers have no internal state & can operate in parallel
- **Reduce:** Process accumulated data from *all* mapped spills
  - Summary histograms, run performance plots, etc
- **Output:** Save data
  - Write out in ROOT/JSON format

MAUS Framework

- Framework built on plug-in modules
- Developers write modules in C++ or Python
  - Python for higher-level algorithms, or where development time is a factor
  - C++ for lower-level computationally intensive algorithms: particle tracking, fits, likelihoods
  - C++11 support
  - Python-C++ bindings handled by wrappers
- Data representation: ROOT, JSON
  - Default is ROOT, but developers find JSON quite useful for quick debugging
  - Mapper modules are templated to a data type
  - conversion between data types handled by API
  - Significant performance speedup by removing JSON-C++ conversions

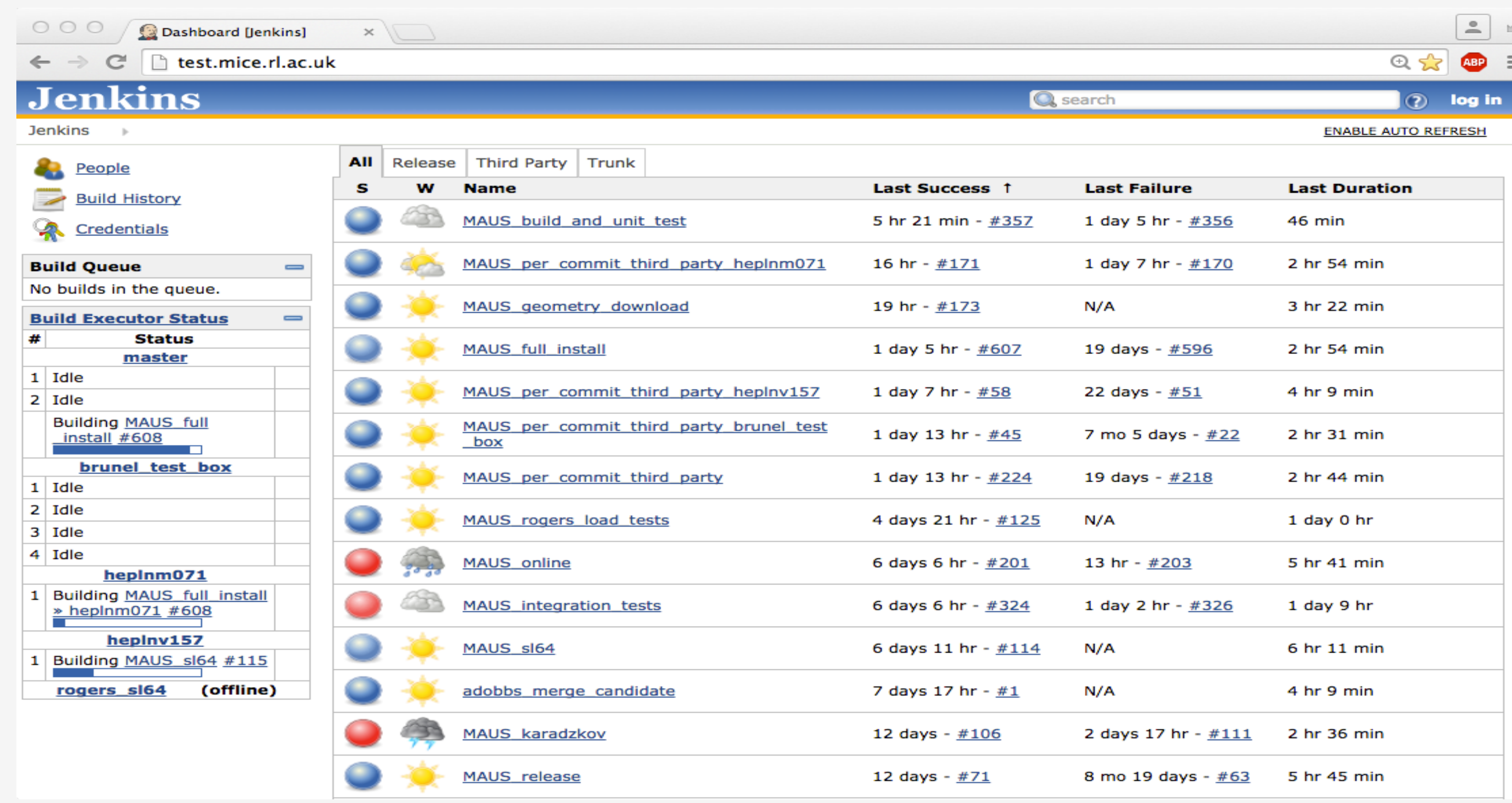
CODE MANAGEMENT



- 10-15 developers in the UK, Europe, USA
  - Headed by Adam Dobbs @ Imperial College
- Distributed version control
  - Bazaar repository, hosted on Launchpad
- SCons build system
- QA:
  - Python/C++ style guidelines
  - Unit testing & integration testing
  - Code monitored for line & function coverage: aim ≥ 70% line coverage
- Redmine wiki & issue tracker
- Scientific Linux 6 is officially supported OS
- Several external dependencies
  - Python, ROOT, Geant4, G4Beamline, XBoa …
  - Dependencies built as “third party” libaries during installation; build scripts come with MAUS

CONTINUOUS INTEGRATION

- Unit tests
  - Test individual modules/pieces of code
- Integration tests
  - Test if units work together and with external libraries
- Jenkins CI test server with multiple slaves at RAL and Brunel University
  - Developers run jobs on the test servers, validate & test their user branch before proposing to merge in the mainline trunk

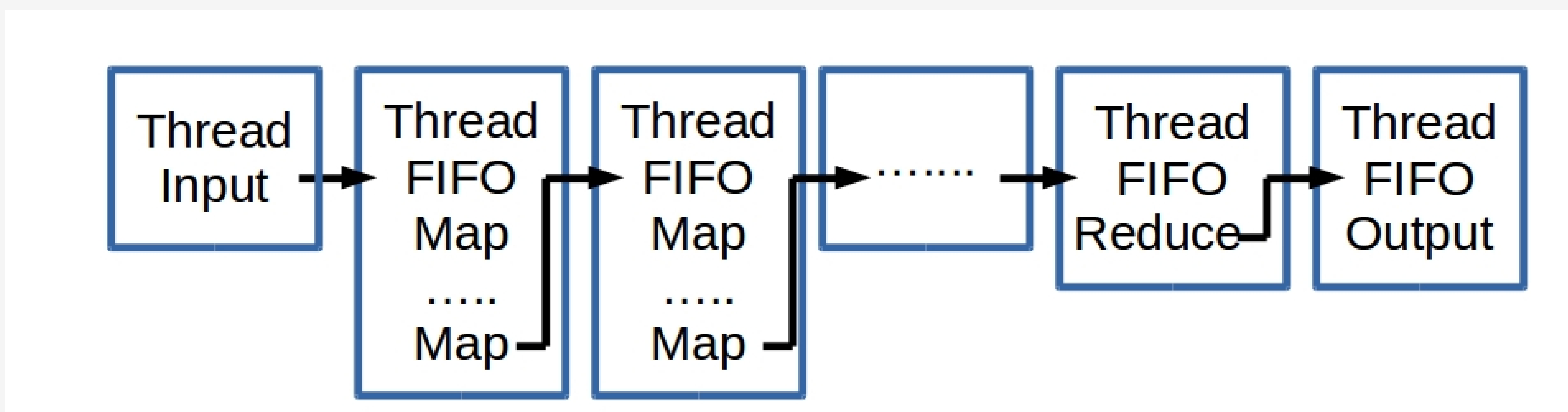


Database

- Varying configurations & running conditions
  - Beam momentum, cooling channel magnets, absorbers, calibrations ….
  - Must be monitored (Controls & Monitoring – EPICS) & stored
- Configuration DB holds
  - Run conditions from data-taking
  - Beamline settings
  - Electronics cabling maps
  - Calibration constants
  - Geometry models
- Postgres DB
- Master DB within control-room LAN, public read-only slave at RAL
- Most APIs in Python, some in C (multi-threaded EPICS does not like Python)
- *See talk by J. Martyniak on Wednesday*

MAUS Online

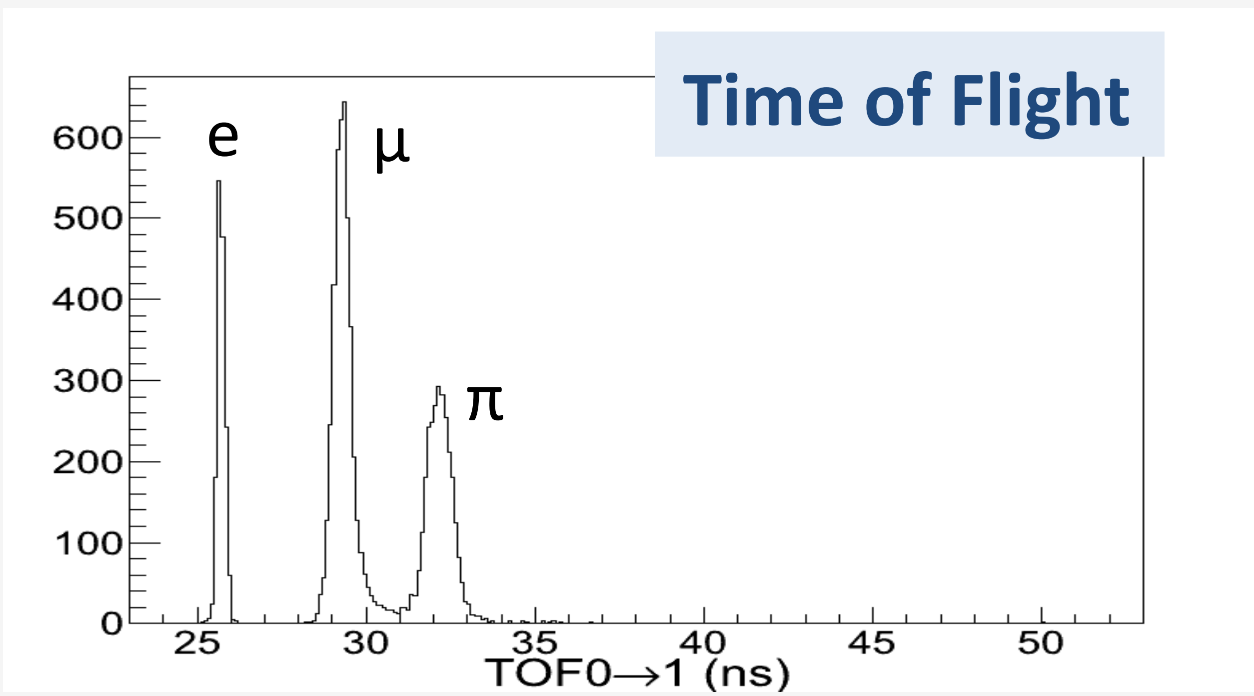
- In classic MapReduce, map operations have to terminate before reduction
- However, for online reconstruction:
  - Want to visualize/plot (reduce) continuously as data flows (~after each map operation)
  - Speed was also an issue with more computationally intensive modules coming into MAUS
- New parallel C++ API developed:
  - Interfaces with MAUS modules
  - Jobs distributed by conveyer-like implementation
- Allows either single or multi-threaded
  - Multi-threaded mode during live data-taking



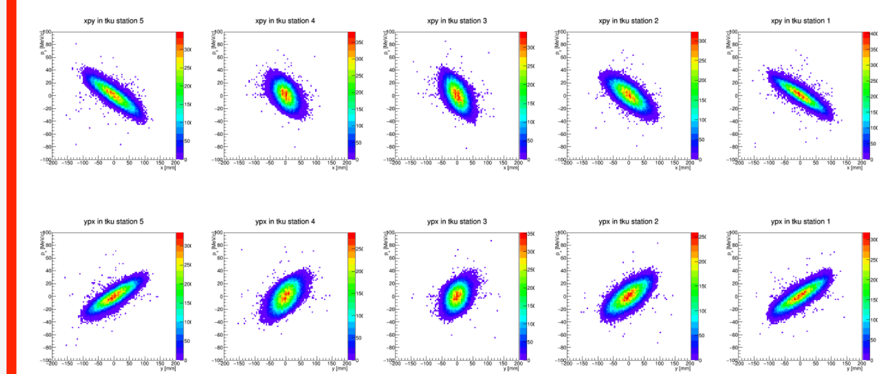
MAUS In Action

- Offline reprocessing & simulation with MAUS performed on GRID
  - Batch production & re-processing on Tier-2 sites
  - MAUS installation for GRID via CVFMS at RAL
- During data-taking, ``live'' reconstruction happens on a dedicated resource in the control room
  - Reconstruction speed ~ data-taking rate

Reconstruction Performance



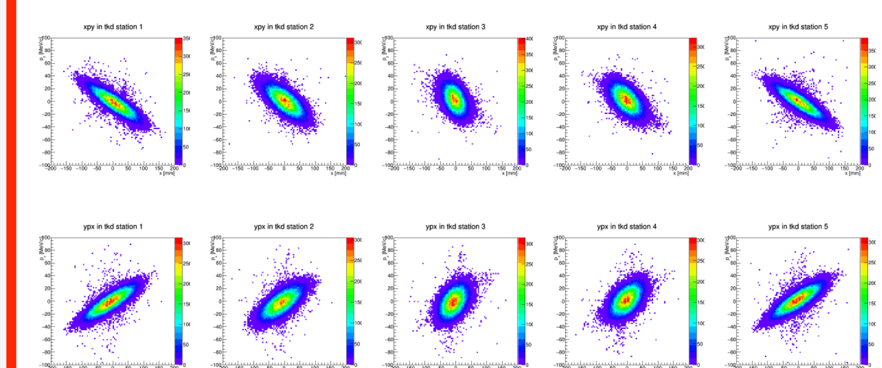
Polarity in the upstream tracker



$$\hat{L} = \langle x p_y \rangle - \langle y p_x \rangle < 0 \quad (3)$$

→ Anticlockwise rotation, **normal** polarity

Polarity in the downstream tracker



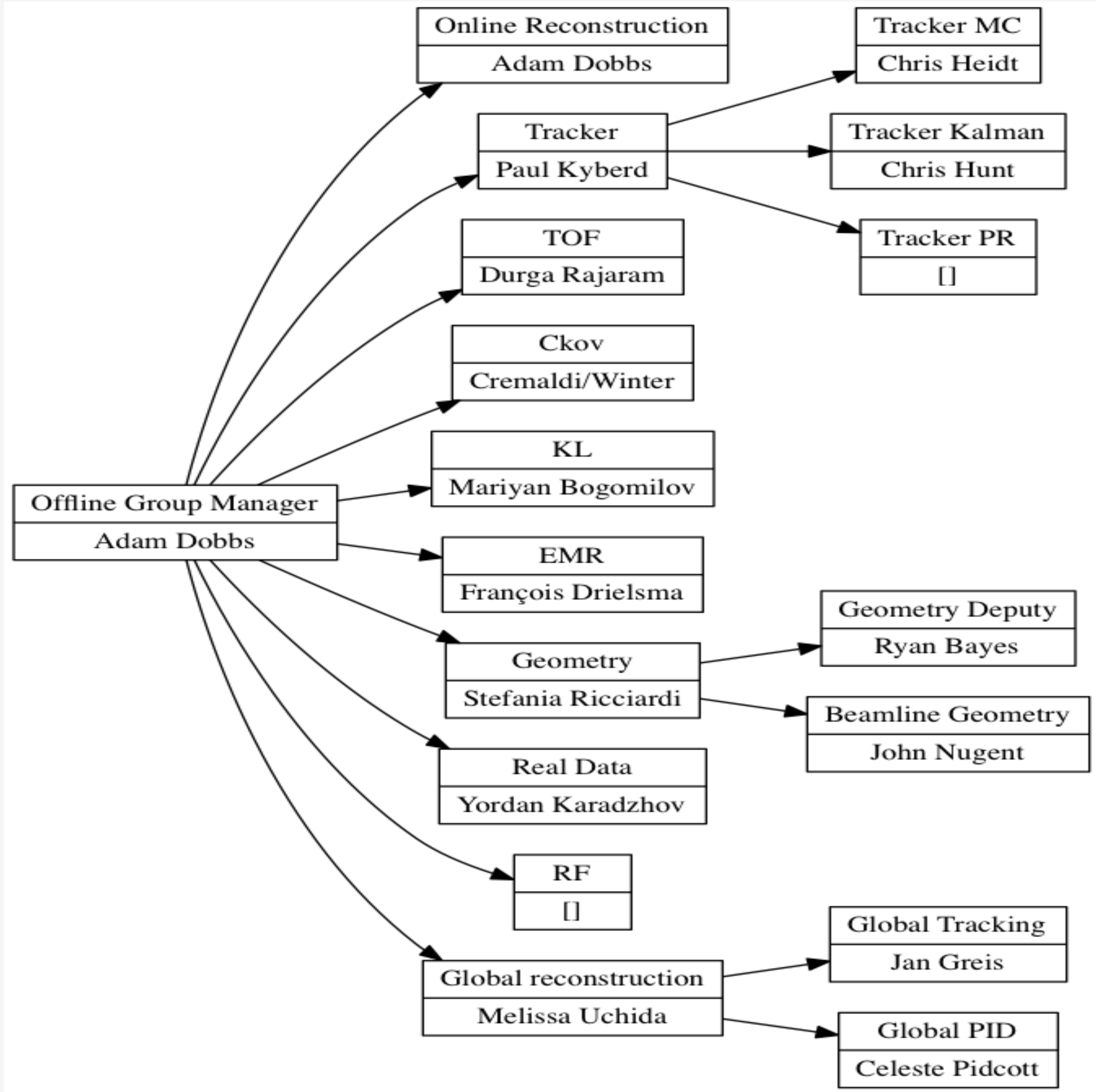
$$\hat{L} = \langle x p_y \rangle - \langle y p_x \rangle < 0 \quad (4)$$

→ Anticlockwise rotation, **normal** polarity

SUMMARY

- MAUS provides a simulation, reconstruction, and accelerator physics analysis framework for MICE
- Implemented based on MapReduce
- Online parallel processing capabilities
- Well-defined & yet flexible framework
- Several industry-standard QA practices adopted
  - Code coverage, continuous integration testing
- Simulation and reconstruction software in place
- Data-taking underway & MAUS is in action feeding analysis

Thanks To All MAUS Developers



And many more..