# TRACKER STATUS REVIEW

## Low $Q^2$ Tracker Meeting

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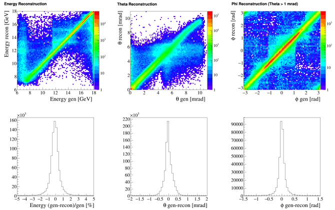
Three main lines of work which require largely independent effort but strongly influence each other. Along with their primary goals, these are:

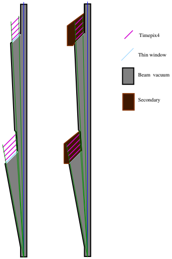
## 1. Detector Performance

Perform full physics analyses with the detector included.



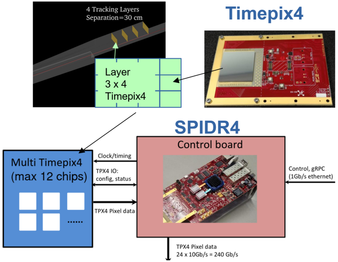

## 2. Detector Integration

Finalise an interface between the detector and machine which satisfies the requirements of both.




## 3. Detector Design

Produce the best detector for purpose given its environment.



# DETECTOR PERFORMANCE

Important to get a workflow through the collaboration software stack in place ASAP as it will:

- Allow physics groups to conduct their analysis with full acceptance.
- Provide us with feedback when making changes to the design.

## Simulation Workflow

1. Event generator
2. Afterburner
3. Simulation
4. Background merging (Any point before digitization)
5. Digitization
6. Track reconstruction
   - 6.1 Pixel clustering
   - 6.2 Space point generation
   - 6.3 Track propagation
   - 6.4 Track fitting
7. Interaction reconstruction (E,$\theta, \phi$)
8. Statistical analysis on large samples of signal and background.

## Status

1. No essential tasks for current goals
2. Low priority
3. Add calorimeter/edit geometry (Where to add charge sharing?)
4. Lots of ongoing issues need resolving for a full analysis.
5. Easy to implement in EICrecon
6. Main holdup for individual event workflow - needing to work out best approach for all steps.
7. Compare Simon/Jarda machine learning and a matrix transport model.
8. Hand over to physics groups...

Output of event generator to hepmc3 file as afterburner/epic simulation input.

### GETaLM

Paper: GETaLM
Code: https://github.com/adamjaro/GETaLM
Quasi-Real - Outputs electrons only
(Bremsstrahlung - Outputs electrons and photons)
(Beam - Shoots un-interacted beam electrons)

### elSpectro

Examples: https://eic.github.io/software/elspectro.html
Code: https://github.com/dglazier/elSpectro
Full spectroscopy event generator

### Pythia8

Need to investigate more and work on including into workflow to make comparisons.

# DETECTOR PERFORMANCE - EVENT COMPOSITION BACKGROUNDS

Events of interest need to be processed alongside all expected background contributions.
Different methods can be deployed to reduce each background contribution.

## IP Bremsstrahlung

Leaves track with identical space and time origin signal events.
Of order 10 tracks expected per bunch crossing.
Separation via statistical methods and exclusivity variables.

## Beam gas interactions

Also mostly Bremsstrahlung.
Track spatial origin will be offset, but not time.
Need study of rates and origin - dependant on vacuum model.
Where is it possible to distinguish origin from track angle?

## Synchrotron Radiation

Should not leave a track but increases data processing and potential false combinations.
**Direct** from Bremsstrahlung and physics electrons. Relatively low rates but focused in same band as electrons with same time signature.
Can be generated directly by the simulation.
**Scattered** off the far edge of the beampipe or elsewhere. Very high rates but path length will be different to electrons so might be able to separate some by time if the sensor resolution allows.

## Sensor electronic noise

Can mostly be removed with pixel threshold. Need experimental/model verification.

# DETECTOR PERFORMANCE - EVENT COMPOSITION STATUS

## Signal Events

Good selection of event generators which seem to perform correctly.

## IP Bremsstrahlung

Good event generator with option to provide Poisson sample into signal events.
Merging events later on would be beneficial - development of podio edm4hep merger.

## Beam gas interactions

Jarda working on this?
hepmc3 needed to study different detector configurations.

## Synchrotron Radiation

**Direct:** Flag in DD4hep has been added but waiting for simpler implemetation.
**Scattered:** Need large sample from synrad.
Merger to produce beam bunch hepmc3 sample exists.
Also needs podio edm4hep merger.
Difficult to know if this will reflect reality.

## Sensor electronic noise

Injection just prior to digitization.
Based on higher level modeling/experimental results.

# DETECTOR PERFORMANCE - AFTERBURNER/BEAM EFFECTS

Crossing angle and beam divergence effects need to be added before the events are parsed to the simulation.

## Afterburner

Can be done directly in the event generator however more easily is implemented with the eic afterburner. https://github.com/eic/afterburner The afterburner parses hepmc3 event files to determine the beam energies then randomly adjusts the angle and vertex to reflect the expected conditions.

## Limitation

Merging events after random beam effects have been added (or the simulation has been run) means potential correlations within bunches can be investigated.

## Low Priority Task

Acquire expected individual bunch parameters and variation and develop multi-particle afterburner.

## ePIC detector simulation

https://github.com/eic/epic
All detectors included, needed for full physics reconstruction.

## lmon

https://github.com/adamjaro/lmon
Stand alone Geant4 implementation of taggers and luminosity.
Much faster than full simulation.
Limited to studies of far-backwards detectors.

## Status

Good status to carry out studies of detector configurations.
Need to check if issue with DD4hep magnetic fields has been fixed:
https://github.com/AIDASoft/DD4hep/issues/1073

# DETECTOR PERFORMANCE - DIGITIZATION & CHARGE SHARING

## Digitization Tasks

Add time and charge digitization factory to EICrecon.
Secondary - Replicate real ToA/ToT signal distributions expected once detector design is better pinned down.

## Charge sharing

Currently only pixels which the electron passes through are included in simulation output.
Additional signals are expected also in neighbouring pixels due to electron drift in the silicon.
Depends strongly on detector design but an initial implementation is very useful to gauge resolution.
At what step is this to be included?
Secondary - Simulate with real fields and distributions across each chip.

Currently two stand alone codes for reconstructing tracks.
It is essential to get something into EICrecon but the current implementations might not be appropriate, could considerably slow down already slow reconstruction.

## Stand alone reconstructions

Jarda - part of lmon repository.
Simon - script can be found here.
Not a long term solution but **much** faster than even a minimal EICrecon analysis.
Checking all combinatorics is ugly and very time consuming even without full backgrounds.

## Acts

Would seem natural solution as used by the rest of the tracking detectors.
Designed with computational efficiency in mind.
Only need a limited set of the functions as there is no field and the final interaction parameters can be obtained via other methods.
DD4hep interface seems very restrictive, needs barrel or barrel and 2 endcaps. No scope for stand alone detectors.
**Task** Is it possible to use this functionality without re-coding everything. Using pixel clustering, space point formation and Kalman filtering would be ideal to reduce combinatoric overheads.

# DETECTOR PERFORMANCE – TRACKING DAQ

Additional tracking considerations in regards to real data processing and the DAQ.
Implementation in EICrecon should mirror that of the real detector.
Any sorting/reduction/other processing of the data before storing to disk needs to be fast.

Currently 2 methods which reconstruct the initial interaction vector based on machine learning.

## ROOT TMVA DNN

No binning of data.
Needs optimization for reconstruction and computation performance. Example

## Custom ML implementation

Fast trained look up table. Also part of lmon
Probably could be implemented to some extent on FPGA.

## Matrix Transport Model

Roman Pots/Off Momentum Detectors in Far-Forward use matrix transport.
(Limited understanding warning) This seems impractical long term solution due to number of matrices needed, binned kinematics and computation times.
Would be good to reproduce this for taggers anyway to investigate performance.

## Task - Important

Implement in EICrecon to reconstruct (weighted) particles

# DETECTOR INTEGRATION

Requires input and approval from several parties with conflicting ideologies.
Primary focus for us detector performance.
Cross-cutting working group forming to address these issues.

Considerations:

- Beam Impedance
- Vacuum integrity
- Material before taggers
- Cost/complexity of detector adaptations
- Background removal

## Accelerator ideal

Smooth straight, thick walled beampipe.
Not an option for a functional Low-$Q^2$ Tagger due to low angle electrons.

## Tagger ideal

Planes of tagger in the beam vacuum, perpendicular to beam and as close as possible.
Not an option for accelerator, increases beam impedance, destroying quality of beam in future cycles.
Difficult to service.

## Possible Compromises

**Very** thin foil beampipe (10 $\mu m$) with secondary/shared vacuum for detectors.
Larger primary vacuum with thin wire/foil pipe with perpendicular exit window.

# DETECTOR INTEGRATION - VACUUM

Exposed to different environments, given by level of vacuum and expected backgrounds, the detector may need specialised adaptations

# DETECTOR INTEGRATION - BACKGROUND REMOVAL

Thoughts Additional material before the taggers can reduce the synchrotron background but increase secondaries and reduce resolution.
Antichambers definitely worth investigating to reduce scattered synchroton, increading beampipe complexity, who?

# DETECTOR DESIGN

The importance of different detector design parameters are heavily dependant on the integration with the accelerator describing the operational environment. However we need to strive for the best performing detector in any integration state.

- Sensor
- Readout
- Cooling
- Vacuum capabilities
- Mechanical movement

## Baseline sensor

Thin Silicon $\sim 50\ \mu$m
Timing resolution of order 1 ns
Charge collection time? 10s/100s ns?

## LGAD sensor

Timing resolution order 20 ps
Similar charge collection time.
Standard LGAD sensors do not work with small pixels.
Ongoing research in Glasgow producing 55 $\mu$m pitch LGADs.
Ongoing work in Glasgow along with Micron Semiconductors for LHCb on Inverse LGAD and Trench LGAD.