SEED FILTER & TRACK FITTING

Davide Cieri* ESR11

VIII INFIERI Workshop @ Fermilab, US • 19 October 2016

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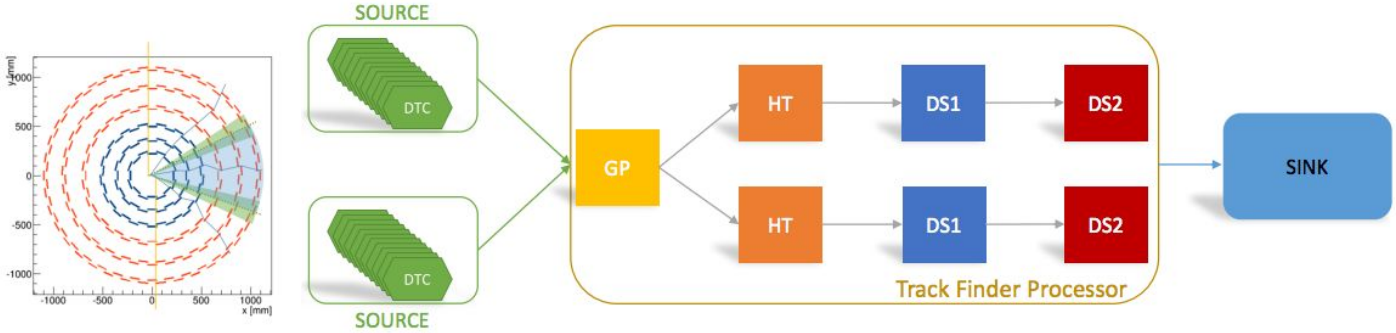
OUTLINE



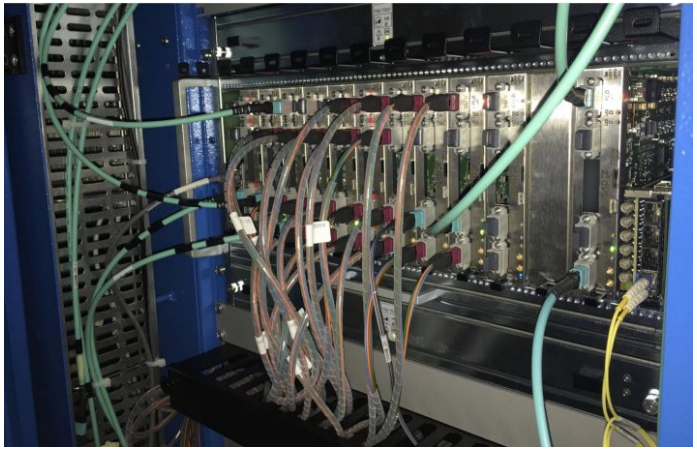
New Demonstrator 2.0 mapping, to set up the downstream chain

Upstream (Luigi's talk):

- Data Source
- Geographic Processor (GP)
- Hough Transform (HT)

Downstream:

- RZ Seed Filter
- Track Fitter
- Duplicate Track Removal **(Luis' Talk)**



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DOWNSTREAM OPTIONS

Seed Filter + Fitter

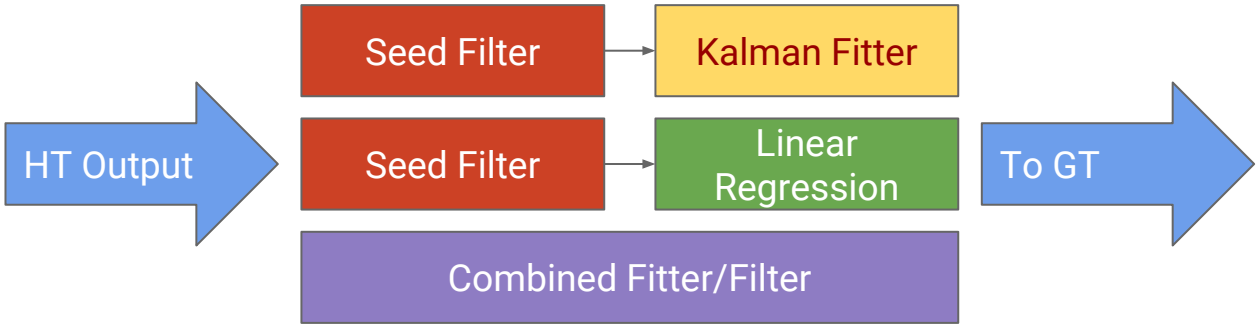
Filtering stage using the z coordinate followed by a fitter (Kalman or Linear Regression)

Combinatorial Kalman Fitter

4 parameters fit, filtering stubs at the same time

Linear Regression Fitter

Fits a straight line through a 2 dimensional data set by minimizing the squared distances between line and data in one dimension



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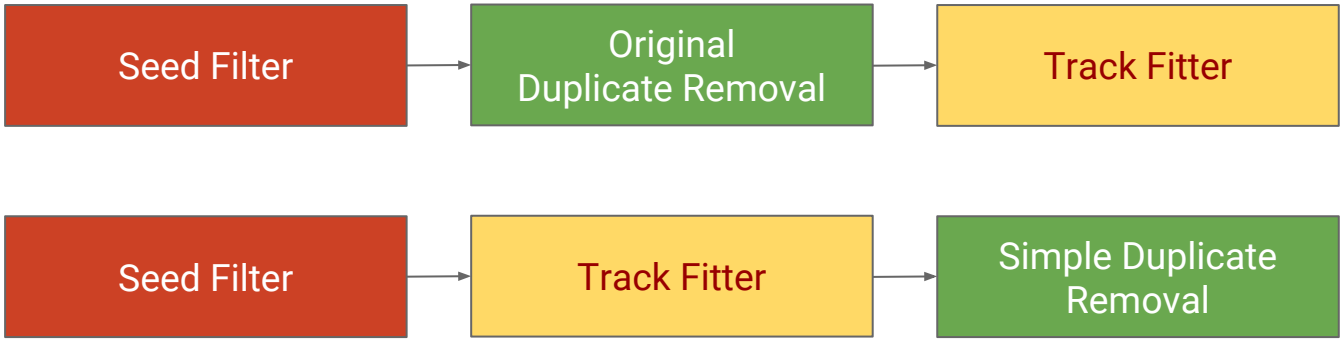
DOWNSTREAM OPTIONS

- Two possible duplicate removal algorithms can be run in different parts of the chain
  - **Original Duplicate Removal:** placed after the Seed Filter
  - **Simple Duplicate Removal:** placed at the end of the chain
- Follow Luis' talk for more details



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RZ SEED FILTER

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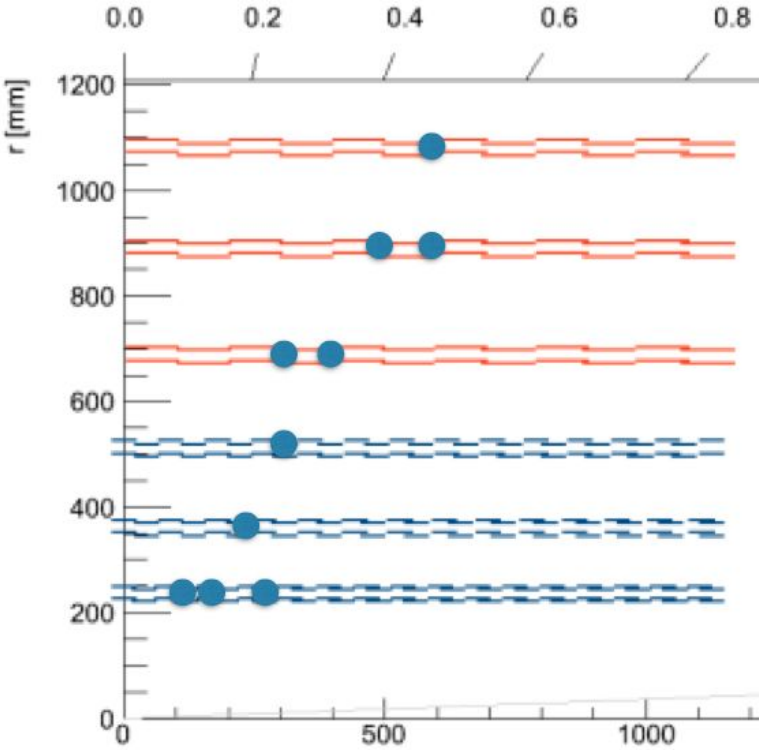
ALGORITHM OVERVIEW

Seed Filter identifies and eliminates stubs assigned to tracks by the HT that lie tens of centimeters from the track in the rz plane

1. Collects pairs of stubs, which belong to different **PS layers**



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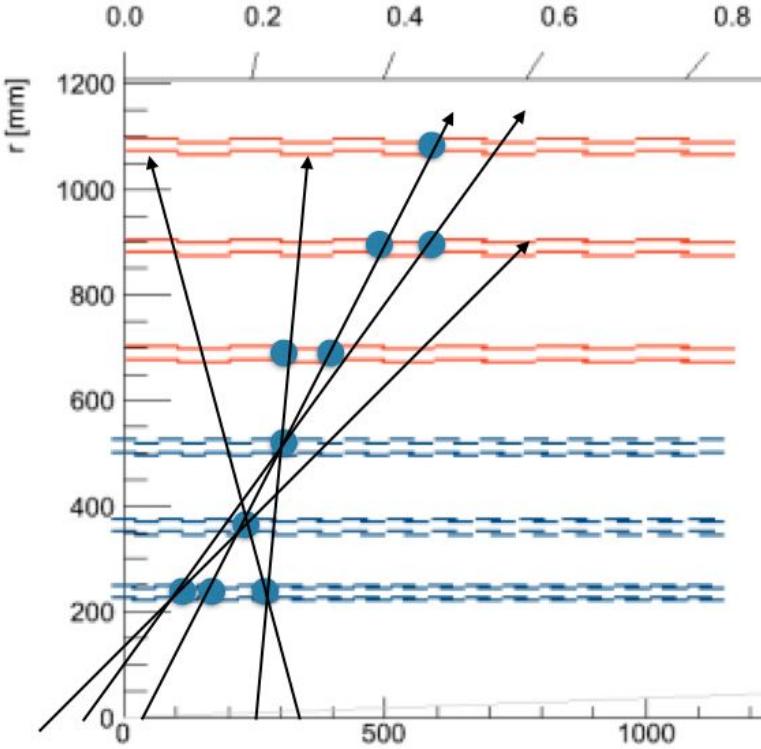
1. Collects pairs of stubs, which belong to different **PS layers**
2. Computes lines passing through those stubs (***seeds***)



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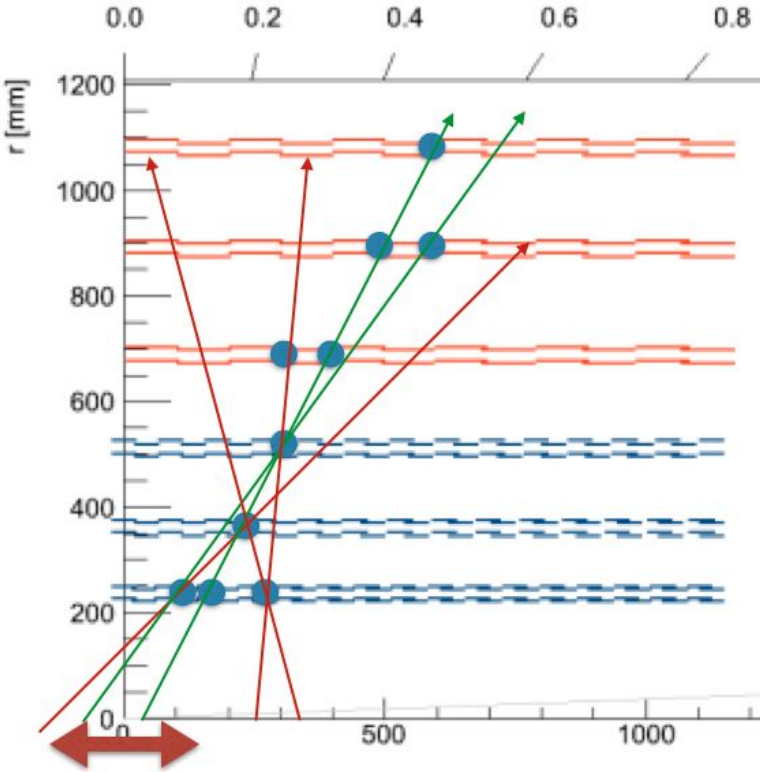
3. Discards seeds that would correspond to tracks out of the **beam spot**



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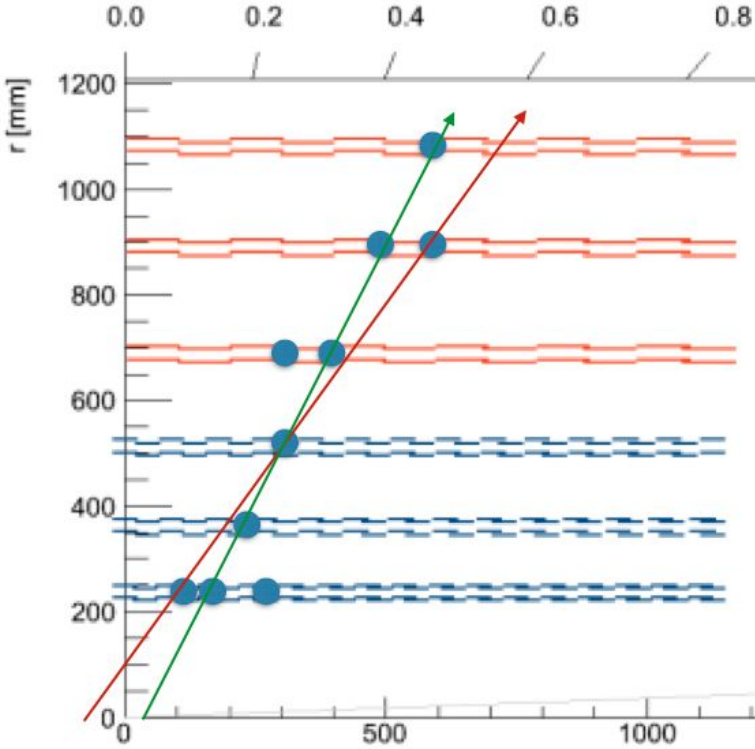
4. Extrapolates surviving seeds to other tracker layers, rejecting stubs **not compatible** with the line



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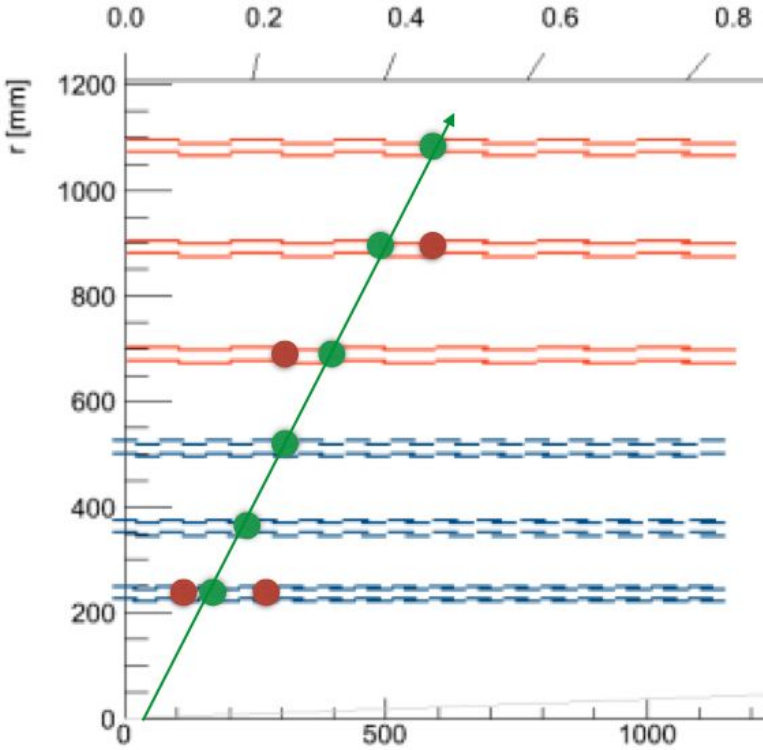
5. Only tracks that still contain **enough** stubs in different **layers** are kept



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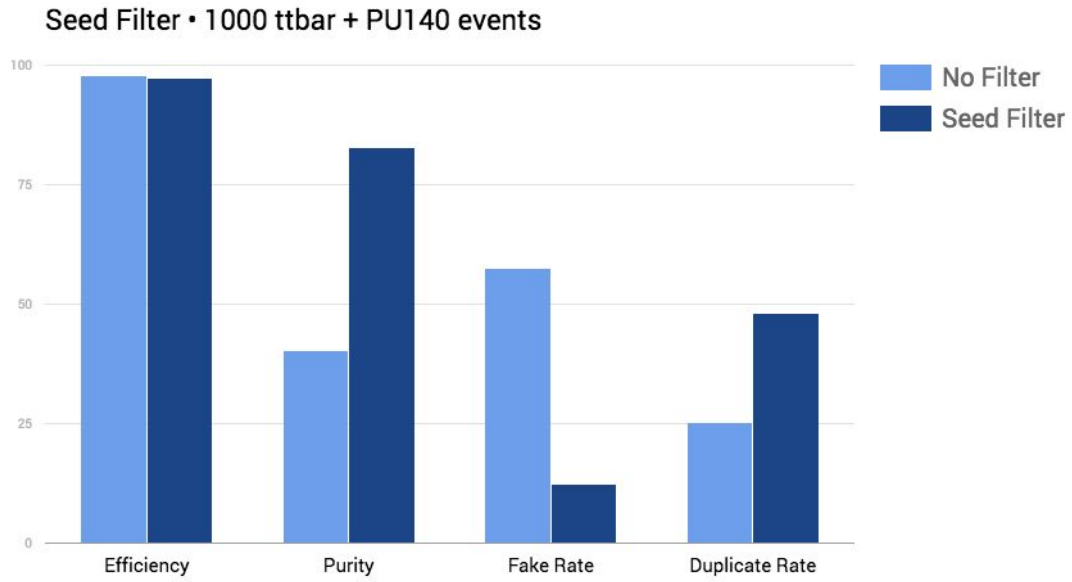
ALGORITHM RESULTS

The Seed Filter reduces the number of track candidates out of the Hough Transform by ~60%



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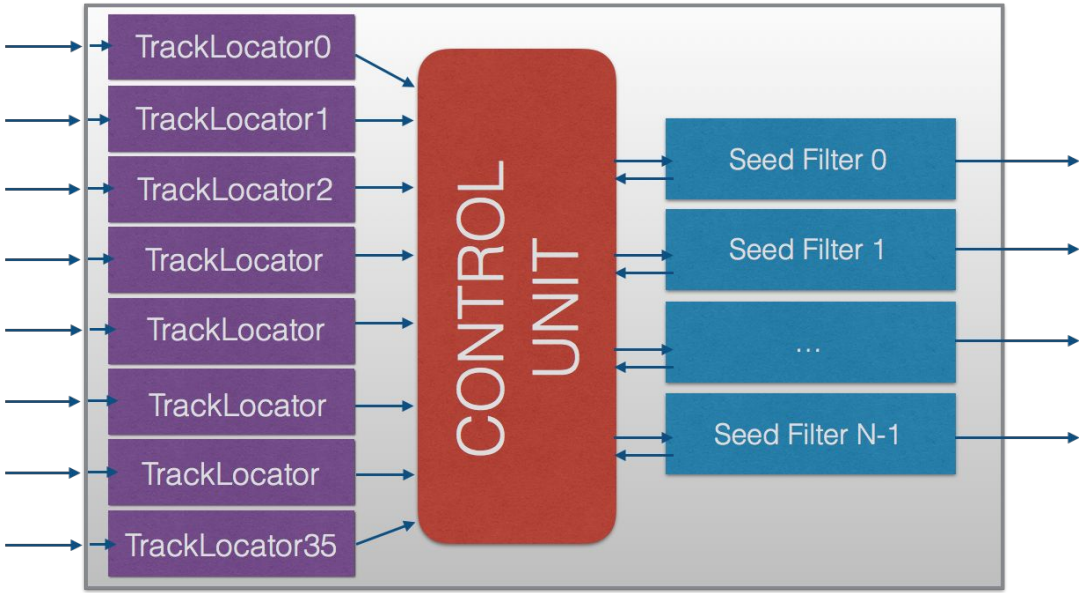
FIRMWARE DESIGN

- Tracks from HT are firstly stored in the **Track Locator**
- The **Control Unit** reads stubs from the track locator and sent them to the first available **Seed Filter** block
- Seed Filters run the algo and buffer out stubs belonging to survived tracks



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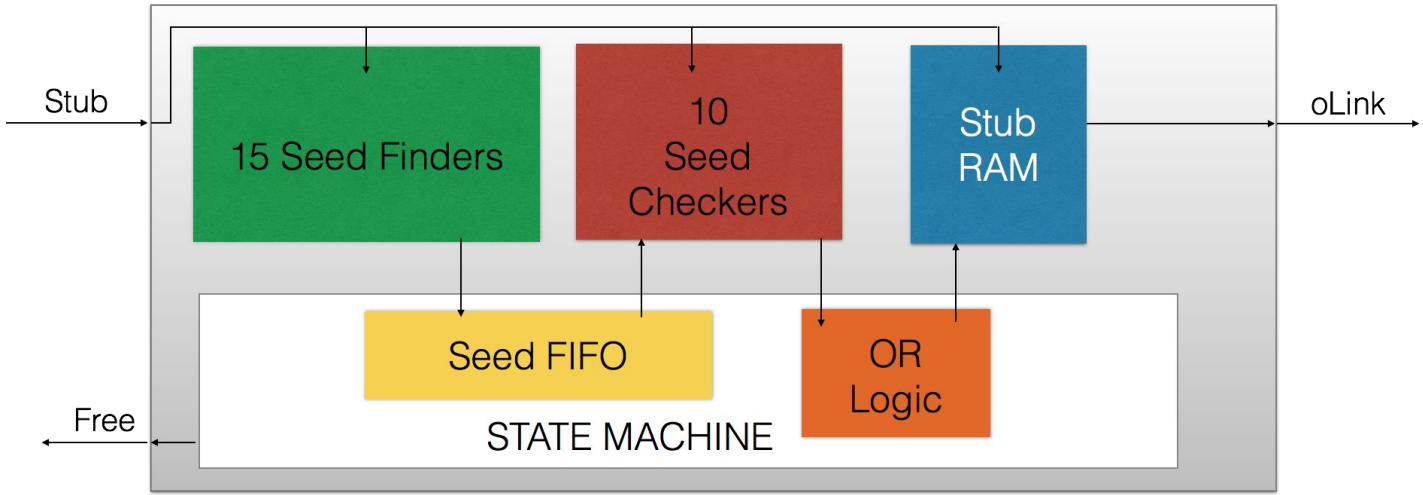
FIRMWARE DESIGN

- A **Seed Filter** block processes a track at a time
- **Seed Finder** finds seeds (up to 15) from pairs of stubs in PS modules
- Using **DSP calculations**, seeds not compatible with the beam spot length are rejected
- Survival seeds (up to 10) are sent to the **Seed Checkers**, where compatibility with the stubs in the other layers is verified
- Stubs associated with good seeds are read out from the **Stub RAM**



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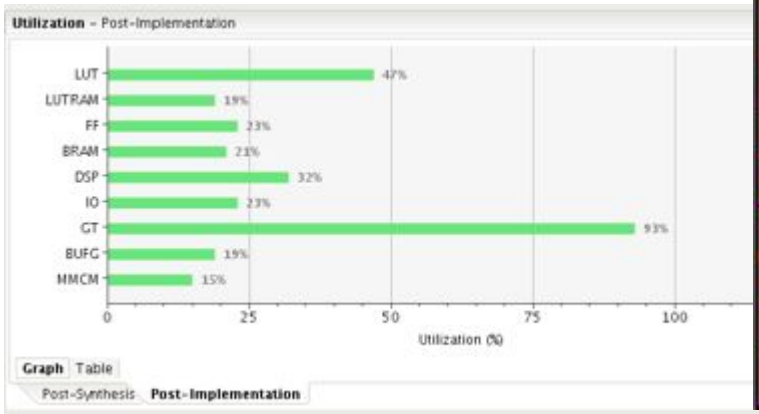
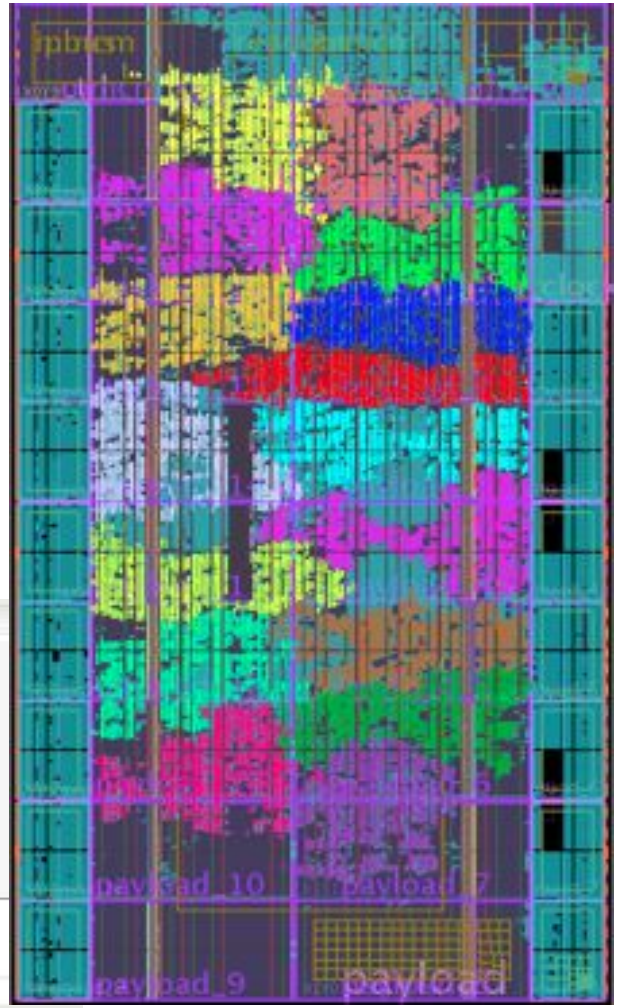
FIRMWARE RESOURCES

Seed Filter firmware implementation with 36 track locators and 18 Seed Filter modules





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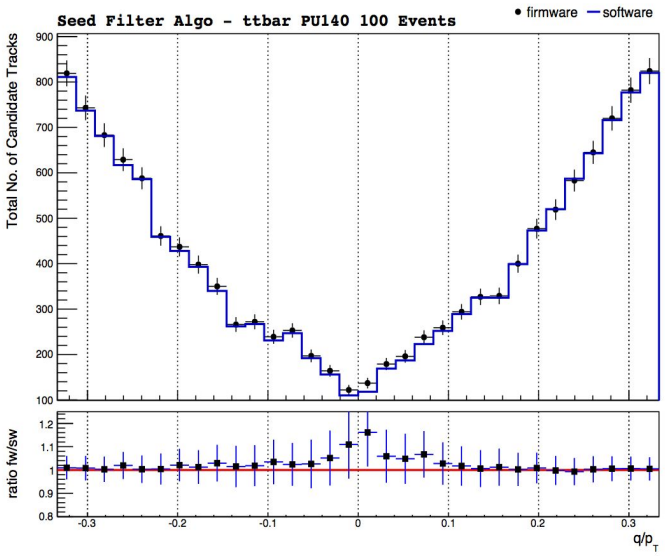
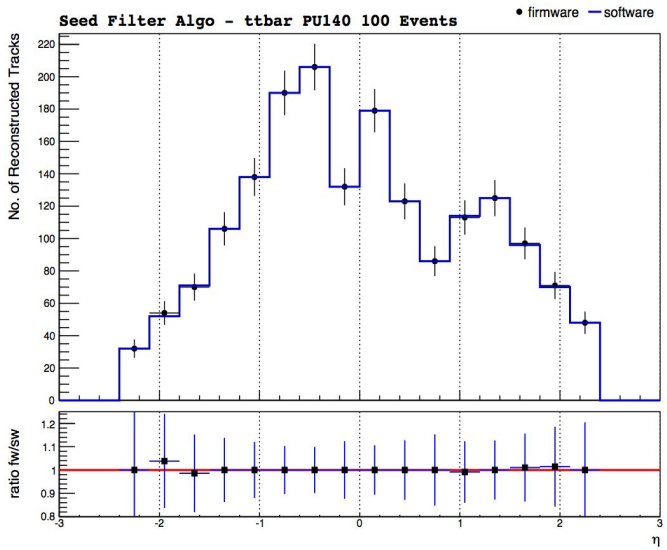
FIRMWARE RESULTS

- Excellent agreement between tracks produced by seed filter running on MP7 hardware vs. predictions from analysis software (99.8%)
- Average First In - First Out Latency = ~292 ns
- Average First Out - Last Out Latency = ~439 ns (far below the 875 ns TM period limit)





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TRACK FITTING
KALMAN FILTER

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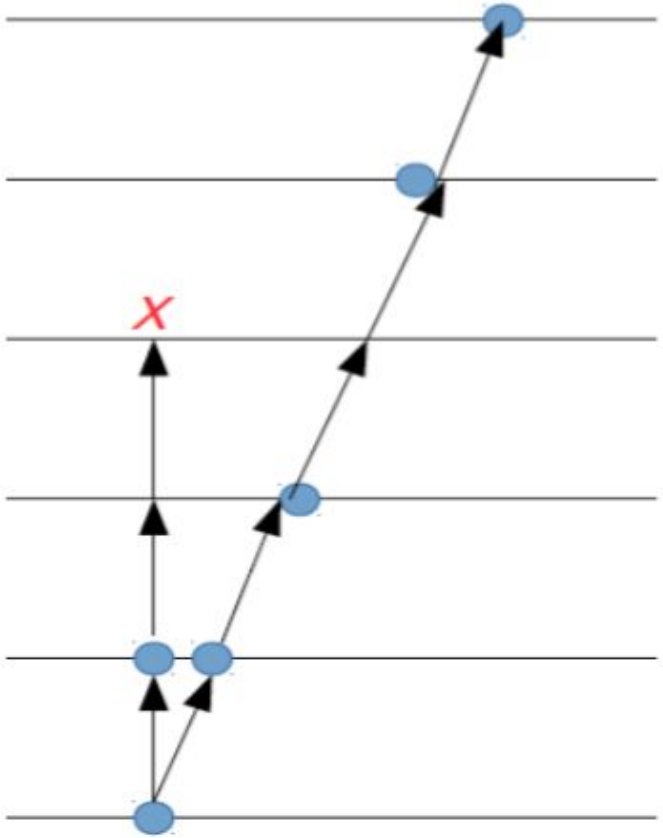
KALMAN FILTER ALGO

Kalman Filter Algorithm steps

1. Initial trajectory estimate from “HT + seed filter” assigned semi-infinite uncertainty
2. One stub from each layer in turn is added to trajectory, with helix parameters updated with each new stub
3. If several stubs are present in one tracker layer, several `track states’ are created, one for each of these stubs
4. If stubs are incorrect, the extrapolated `track state’ will typically find no subsequent compatible stubs, so be killed



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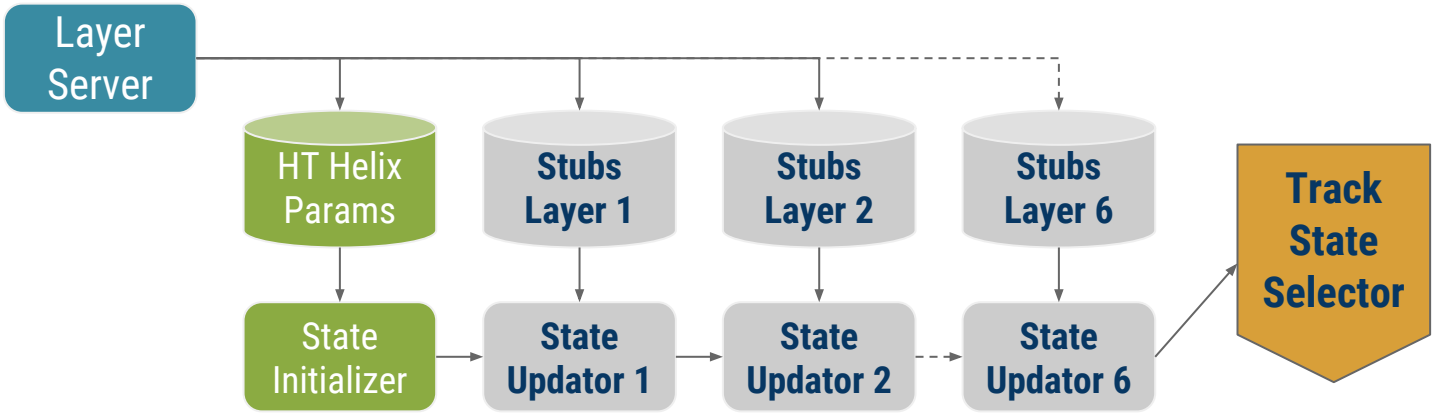
KF FIRMWARE DESIGN

- Each **Kalman Filter** block processes data from 6 sectors (6 blocks/octant)
- **Layer Server** reads HT data from all 6 sectors simultaneously
  - It sends HT estimate of tracks helix params to “HT Helix Params” block
  - Stubs assigned to a track by HT are sent to ”Stub Layer N” block if they are in tracker layer N. (where N ≤ 6)

1. **State initializer** gets initial estimate from HT Helix Params
2. **State Updator** *i* updates parameters using layer *i* stubs
3. If a track has more than a single state, **Track State Selector** choose the best one



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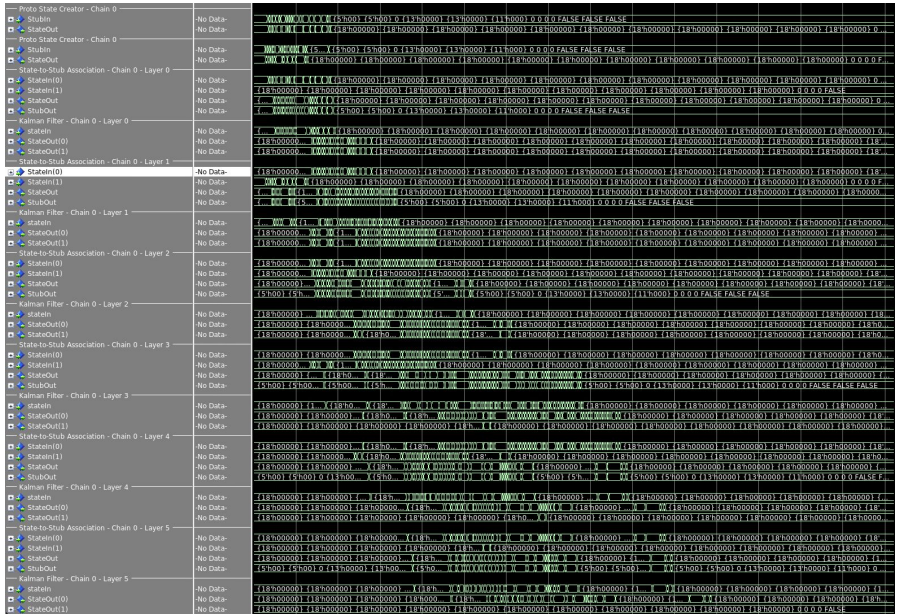
KF FIRMWARE STATUS

- **Kalman Filter** partially written using a high-level language based on Java
  - **MaxCompiler** https://www.maxeler.com/products/software/maxcompiler
- Firmware completed expected for Track State Selector
- Resource usage: ~49% DSPs in Virtex 7 FPGA
- Behaviour tested via ModelSim using data from ttbar+PU140 events



Estimated Latency ~1 us

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TRACK FITTING

LINEAR REGRESSION

LR ALGO OVERVIEW

- Tracks with sufficient p_T should draw a straight line on both rφ and rz planes
- Fit helix parameters using **independent** straight line fit in the two planes with **Linear Regression** technique
  - No use of hit resolution → Simpler math

r-φ plane

$$m = \frac{\overline{n}\,\overline{r\phi} - \overline{r}\,\overline{\phi}}{\text{denom}}$$

$$c = \frac{\overline{r^2}\,\overline{\phi} - \overline{r}\,\overline{r\phi}}{\text{denom}}$$

r-z plane

$$m = \frac{\overline{n}\,\overline{rz} - \overline{r}\,\overline{z}}{\text{denom}}$$

$$c = \frac{\overline{r^2}\,\overline{z} - \overline{r}\,\overline{rz}}{\text{denom}}$$

$$\text{with} \quad \text{denom} = \overline{n}\,\overline{r^2} - \overline{r}^{\,2} \qquad \text{and} \quad \overline{x} = \sum_{i=0}^{n-1} x_i$$

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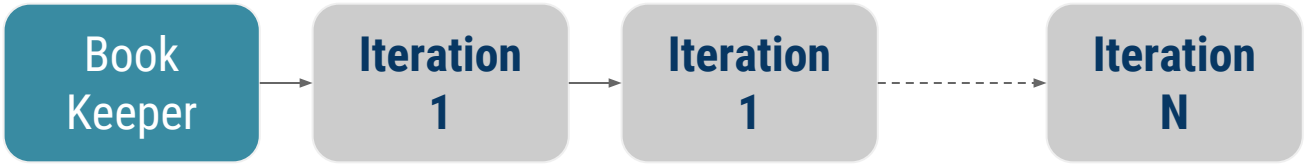
LR FIRMWARE OVERVIEW

- Fully pipelined design, fitting each track in a fixed time
- A Linear Regression segment for each HT segment



- Several Track Fit iteration in series, each capable to reject a bad stub from the track
- Latency proportional to number of iterations (currently ~1 us)

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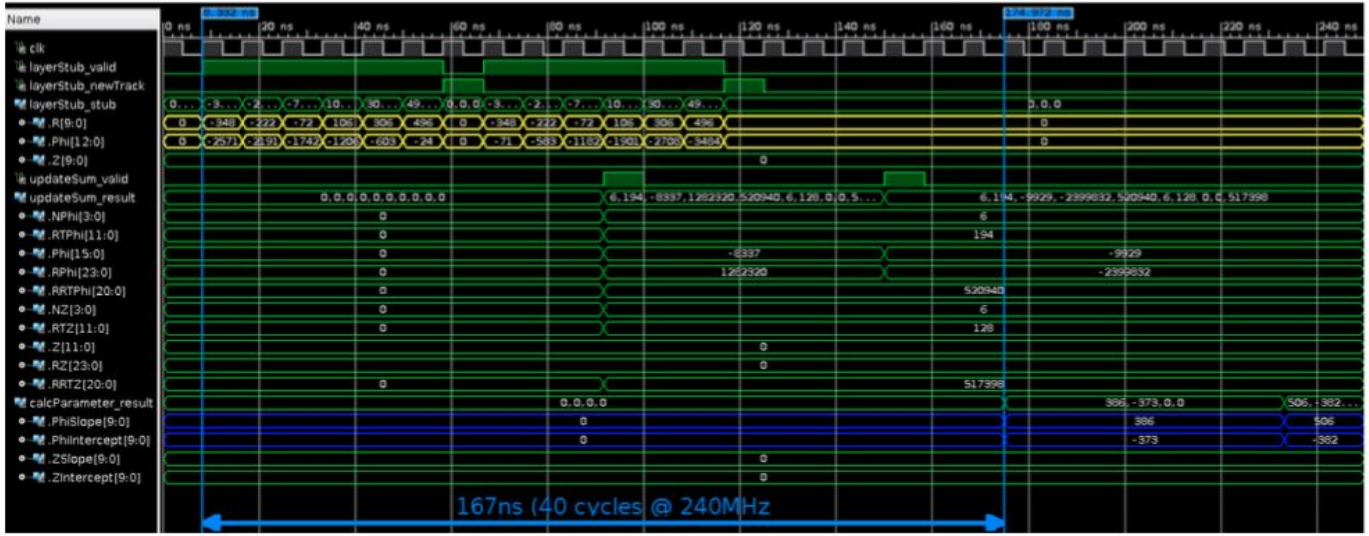
LR FIRMWARE STATUS

- Firmware developed in just two months
  - Only missing component : Book Keeper
- Expecting utilisation of 100% DSPs
- Currently tested in modelsim with a set of 6 stubs



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SUMMARY & CONCLUSIONS

Seed Filter

- Firmware completed and running in our demonstrator chain
- Results validated against simulation (99.8% matching)
- Few more ideas to improve latency, dups removal

Kalman Filter

- Firmware almost completed (Track State Selector missed)
- Behaviour tested in ModelSim with ttbar+PU140 events
- Expected to be integrated in demonstrator chain by end of the month

Linear Regression

- Book Keeper only missing block
- Algorithm tested using a set of 6 sample stubs
- Expected to run on real hardware next week

- Final decision on demonstrator chain layout will be taken after hw estimation of fitters latency

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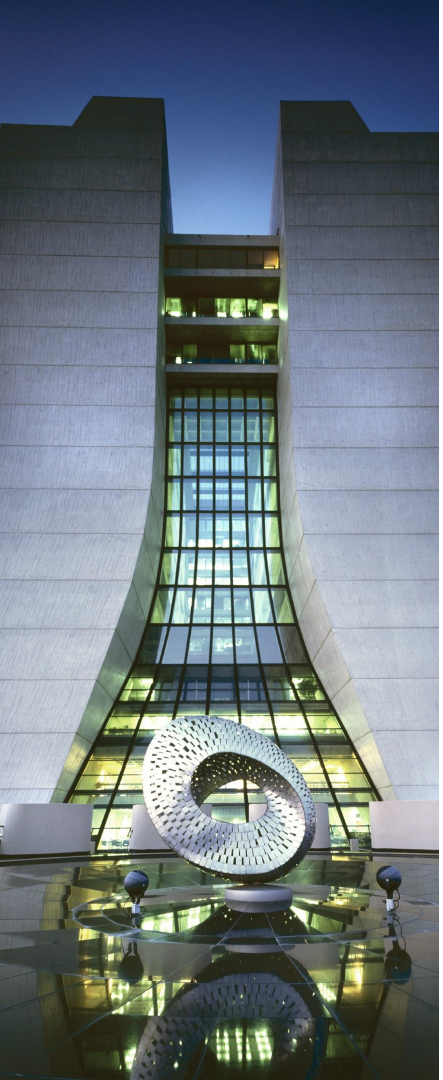

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