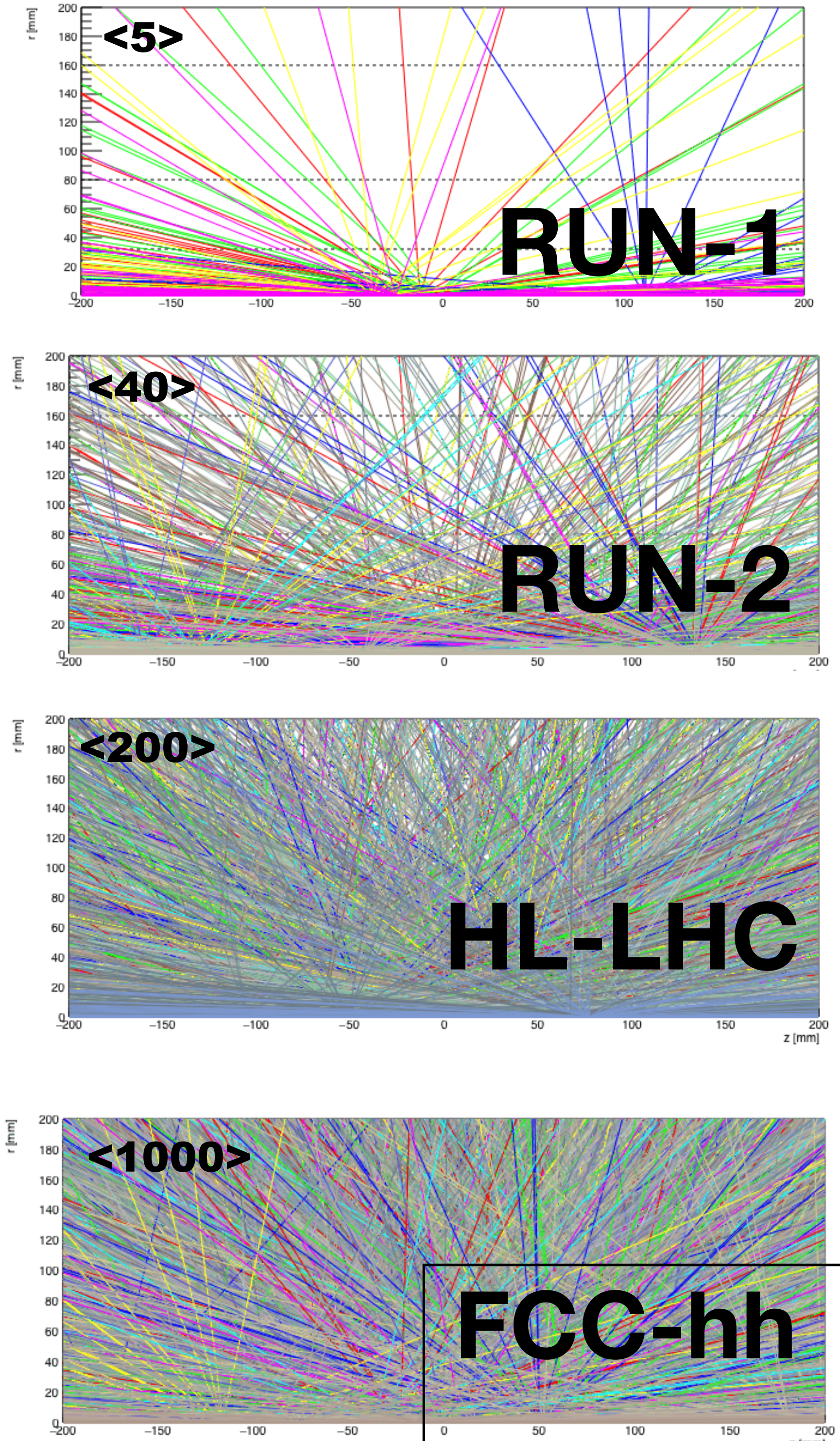
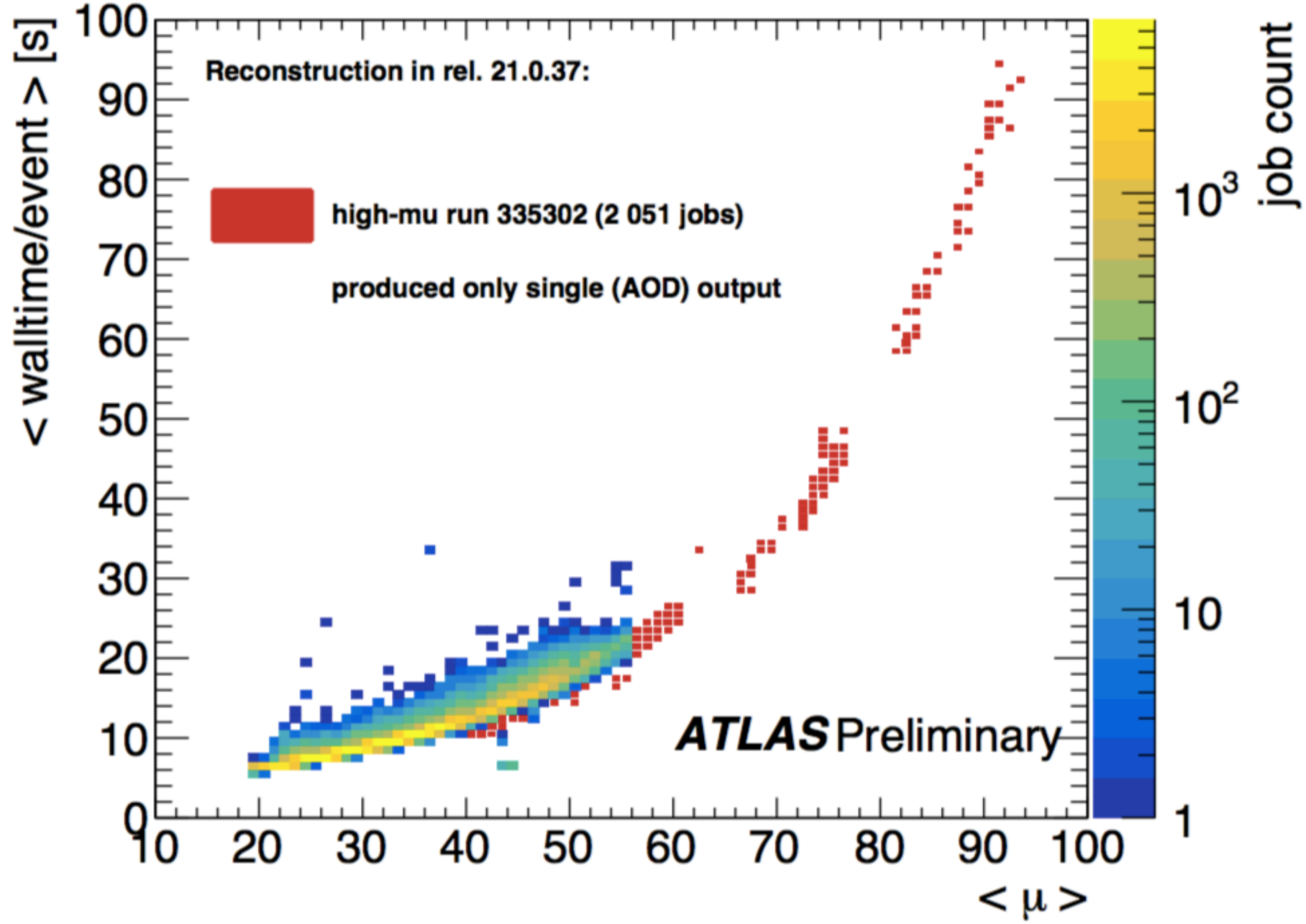


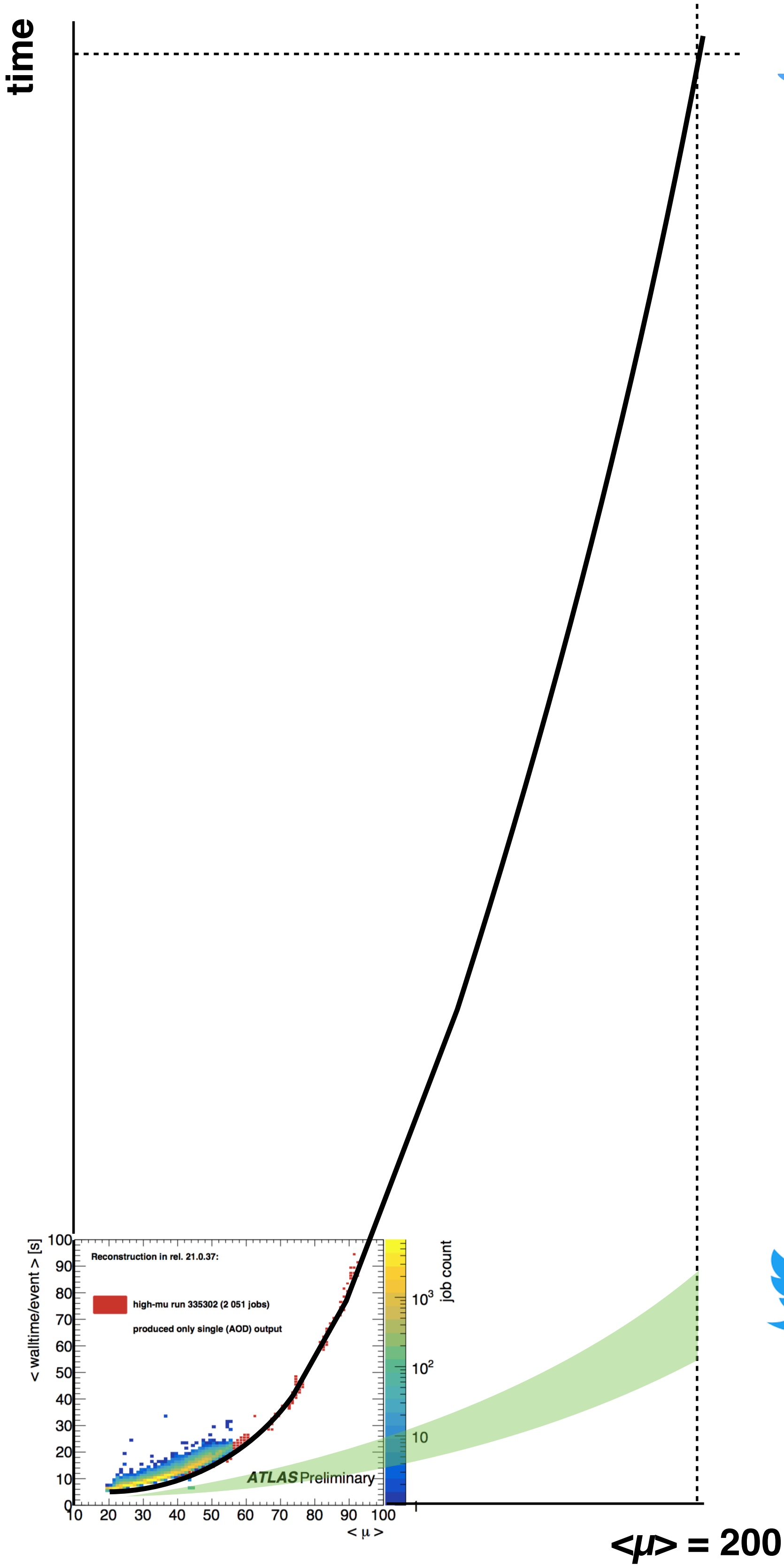


R&D for Future Tracking

A. Salzburger (CERN)

Images:
(left) longitudinal views of vertex region for various scenarios
(right) ALTAS Run-2 CPU scaling with <μ>

Track reconstruction Extrapolation HL-LHC



Naive extrapolation of LHC detector
- full reconstruction
- ATLAS/CMS & software designed for <μ>~23

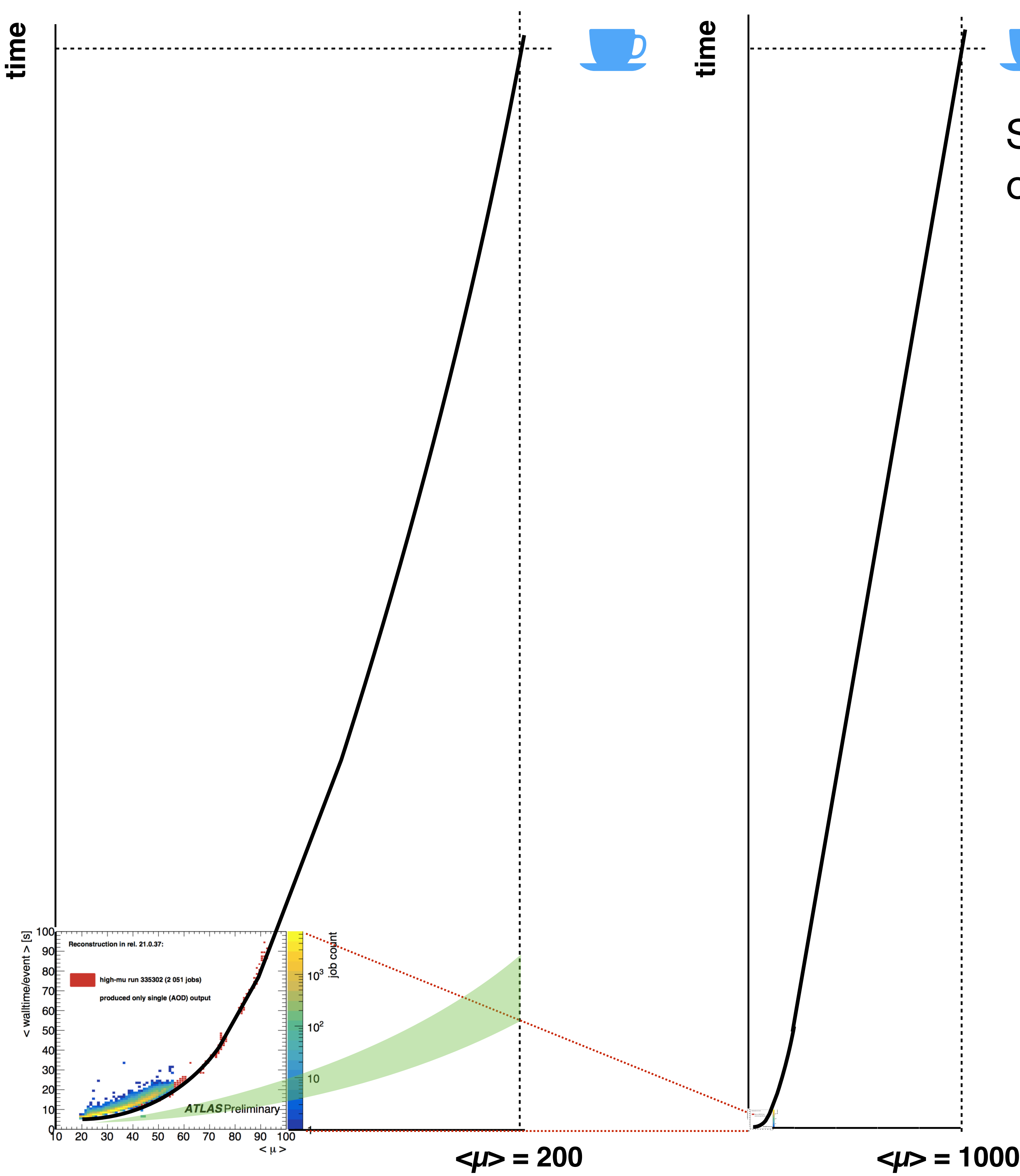
Finding of particle trajectories

- combinatorial problem to solve
- **highly non-linear scaling** of CPU time with increasing event complexity
- dominant CPU consumer

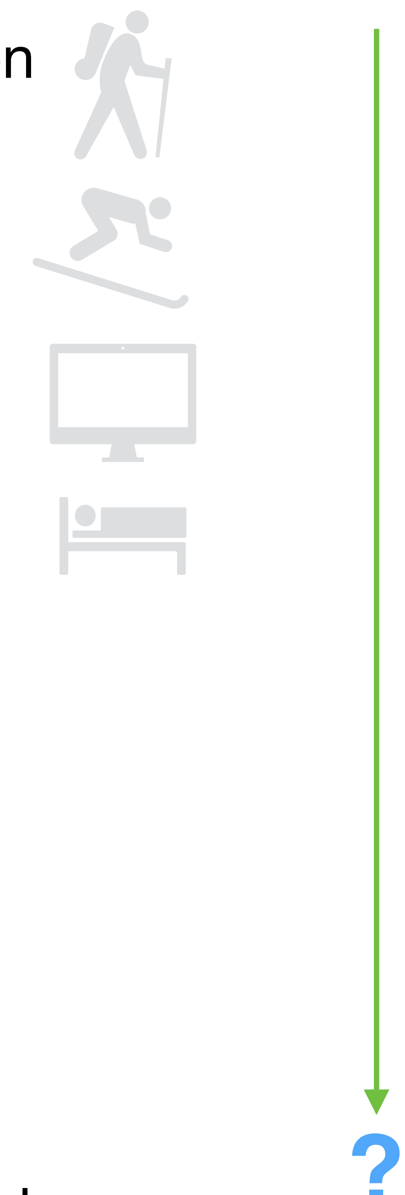
Current numbers for HL-LHC detector
- track reconstruction only
- detector designed for <μ>=200
- current software adapted/optimized for this environment

Factor 10 increase in readout rate from 1kHz to 10 kHz
only partly compensated by hardware speedup

Track reconstruction Extrapolation HL-LHC / FCC-hh



Super-naive extrapolation
of LHC detector



What is possible

- need framework for detector design, performance studies and further software R&D

Risks & Gains

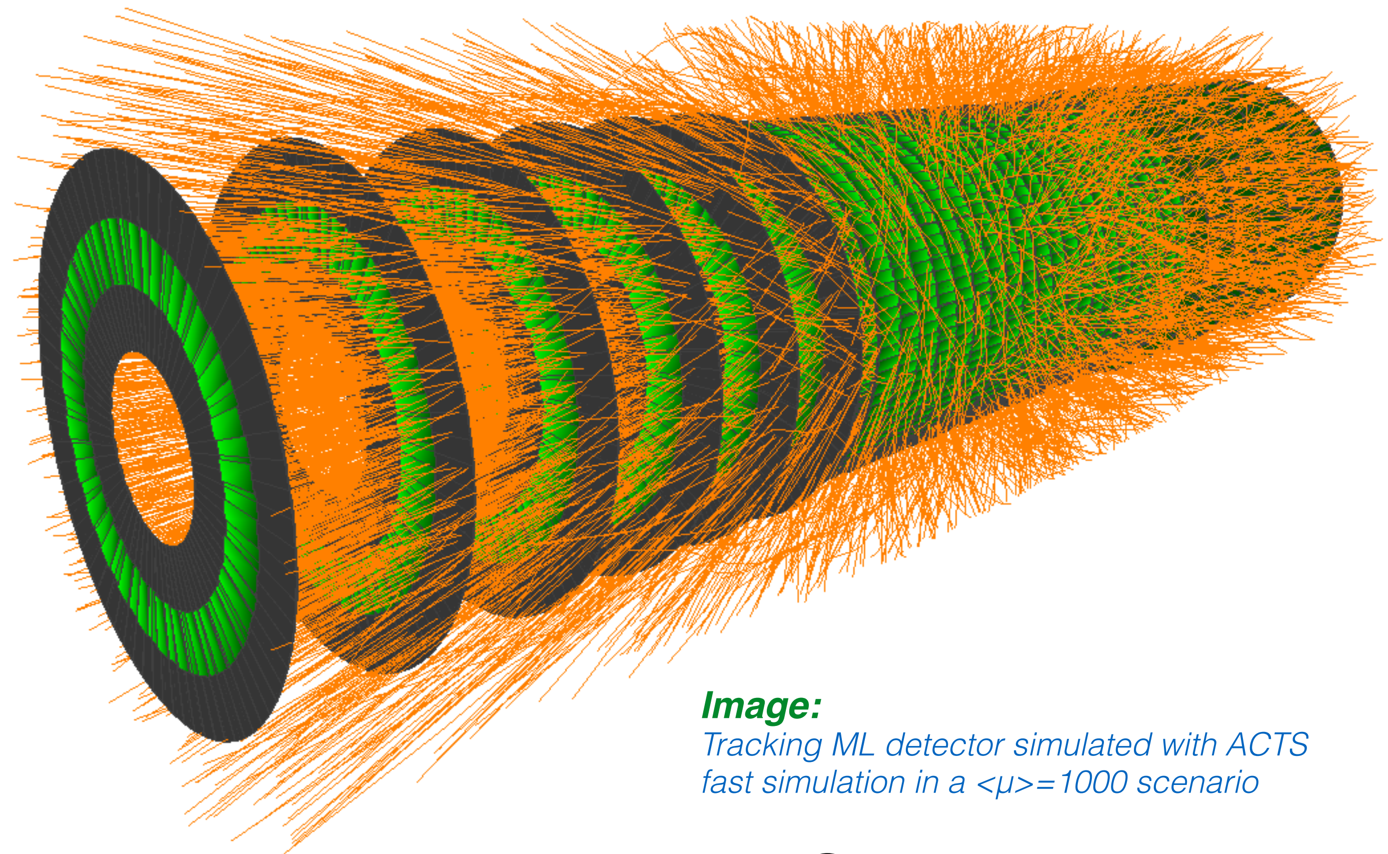


Image:
Tracking ML detector simulated with ACTS fast simulation in a <μ>=1000 scenario

Risk is high

- we *risk* physics potential
  if we do not solve this solve this
- e.g. current LHC analyses saw already the advent of MC statistic limits for certain analyses

Gains are high

Substantial R&D is needed several areas:

Code optimization	algorithmic R&D	(low n) Concurrency	Hardware acceleration	Machine Learning

- great **in-house expertise** at CERN that can be fostered
- **symbiotic projects** with **detector R&D, computing** & **machine learning**
- exciting times for **software and algorithm design**
- strengthen **CERN as excellence lab** for software

Track reconstruction R&D

Code optimization	**algorithmic R&D**	**Concurrency**	**Hardware acceleration**	**Machine Learning**

Community driven common software for track reconstruction

- cutting edge algorithmic solutions for "classical pattern recognition"
  preserving the excellent performance *(physics & failure rate) of LHC experiments*
- expert driven code optimization (strong link to SW R&D)

Common effort of **online and offline reconstruction** software

- incentives towards tracking at L1 trigger level / trigger-less readout

Inclusion of **timing information** in track finding & fitting

- synergies with detector R&D for timing detectors

On demand track reconstruction

- region or physics driven reconstruction setups

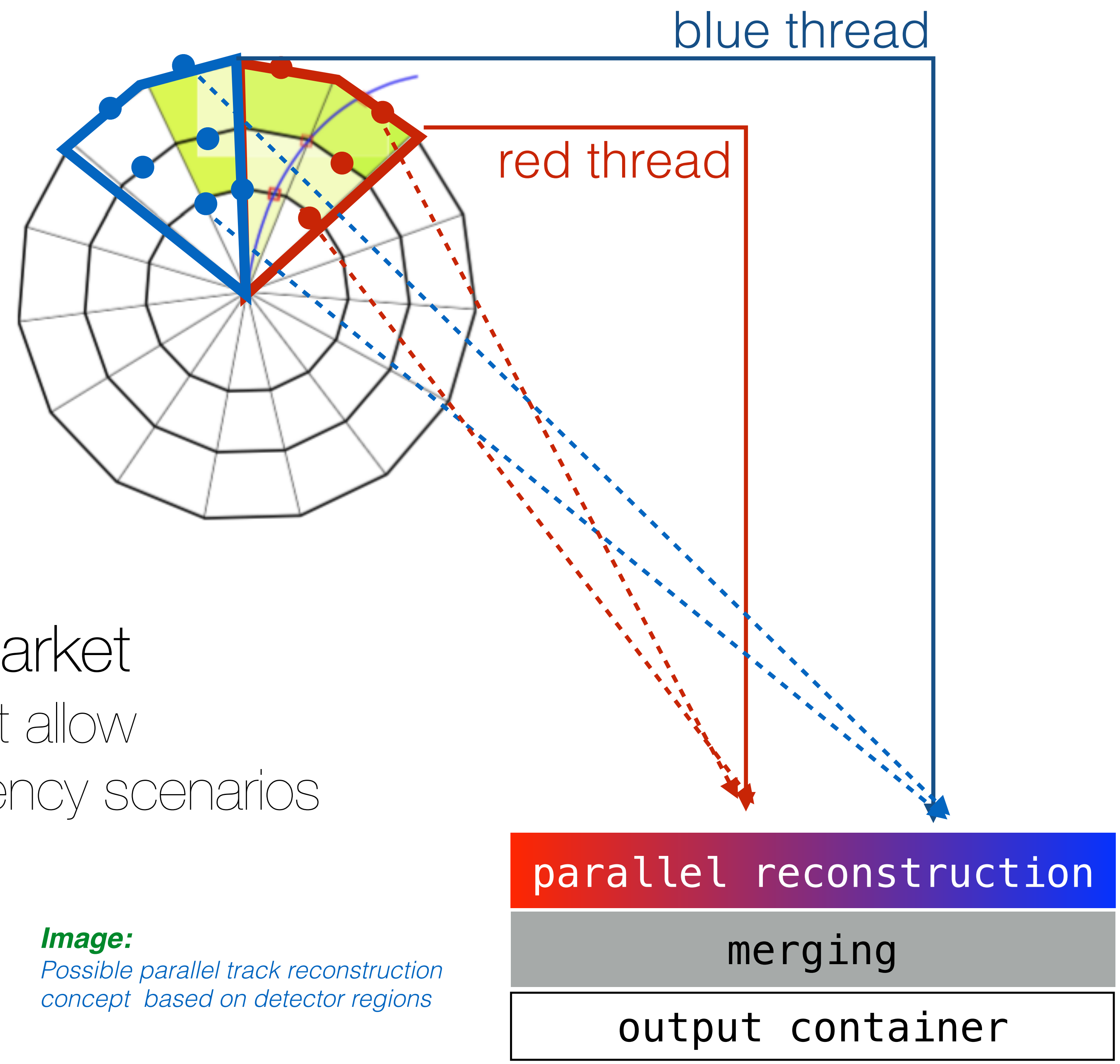
Overall need for an R&D platform for track reconstruction

Track reconstruction R&D

Code optimization	algorithmic R&D	Concurrency	Hardware acceleration	Machine Learning

Adapt track reconstruction for **concurrent execution**

- needs **substantial** work on current algorithms, data structures and data flows (vectorization)



Uncertainty in hardware market

- prepare **flexible toolkits** that allow adaption to several concurrency scenarios

Image:
Possible parallel track reconstruction concept based on detector regions

Example:
ACTS
https://indico.cern.ch/event/699252/contributions/2881457/attachments/1594869/2525543/2018-02-05-ACTS-Lightening.pdf

Track reconstruction R&D

Code optimization	algorithmic R&D	Concurrency	Hardware acceleration	Machine Learning

GPUs in track reconstruction

- several areas where GPUs could be effectively used
- GPUs **work extremely** well for **certain algorithms/data flow**
  - *e.g. clustering, cellular automaton, hough transform, Kalman filter*
- Machine learning applications are "designed" for GPUs

Use of FPGAs and associative memory in track reconstruction

- particular in trigger

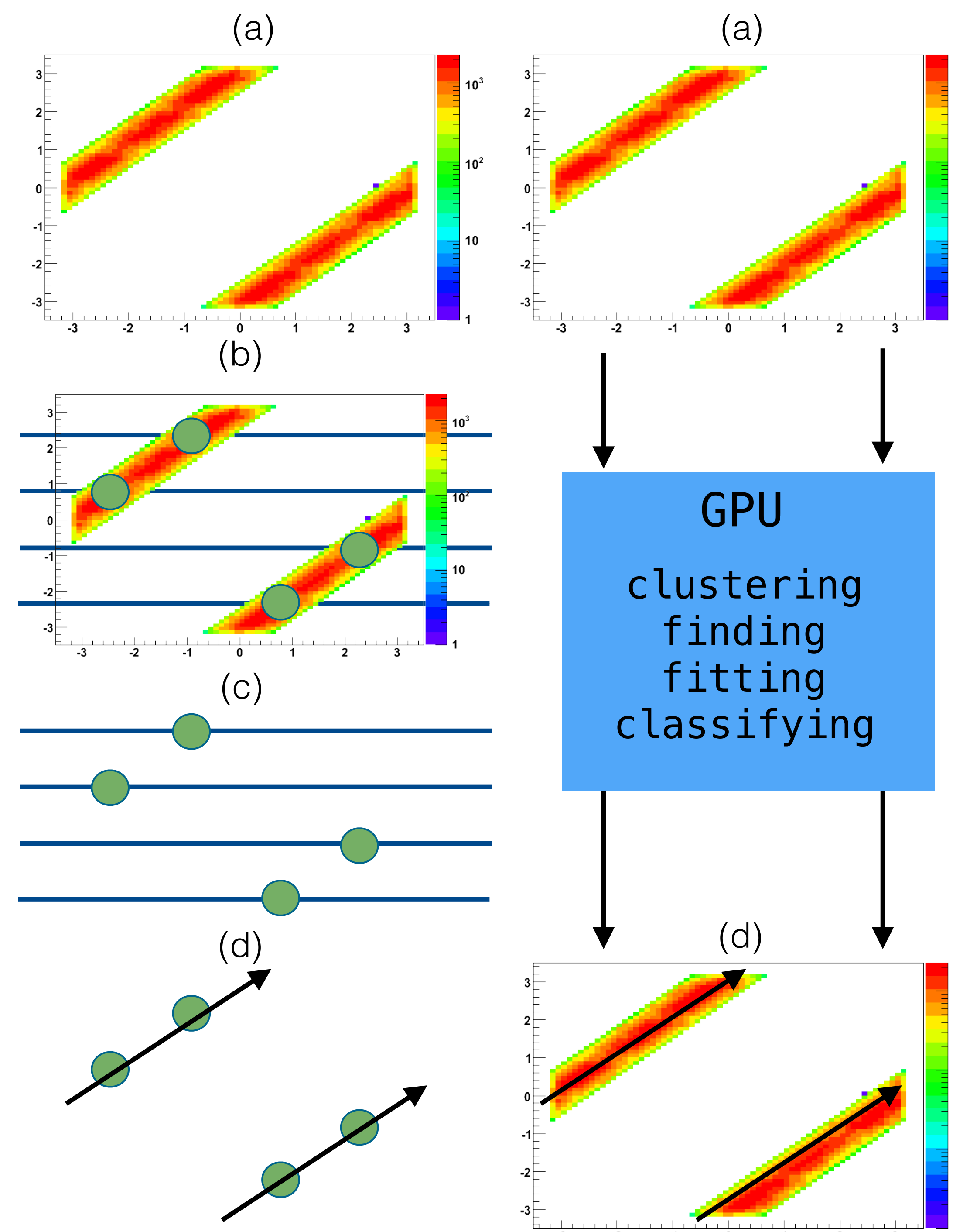


Image:
Traditional path to track finding (left),
GPU enabled path directly on charge input (right)

Examples:
CMS cellular automaton on GPUs
Clustering & Tracking GPUs/ML
https://indico.cern.ch/event/702570/contributions/2905391/attachments/1606480/2549157/2018-02-26_CERN_RnD_Proposal.pdf

Track reconstruction R&D

Code optimization	algorithmic R&D	Concurrency	**Hardware acceleration**	**Machine Learning**

Clustering hits together is typical ‘unsupervised learning’

- take advantage of the recent advances in the field

  integrate into current track reconstruction software stacks

Convolutional/Recurrent Neural Networks (CNNs/RNNs)

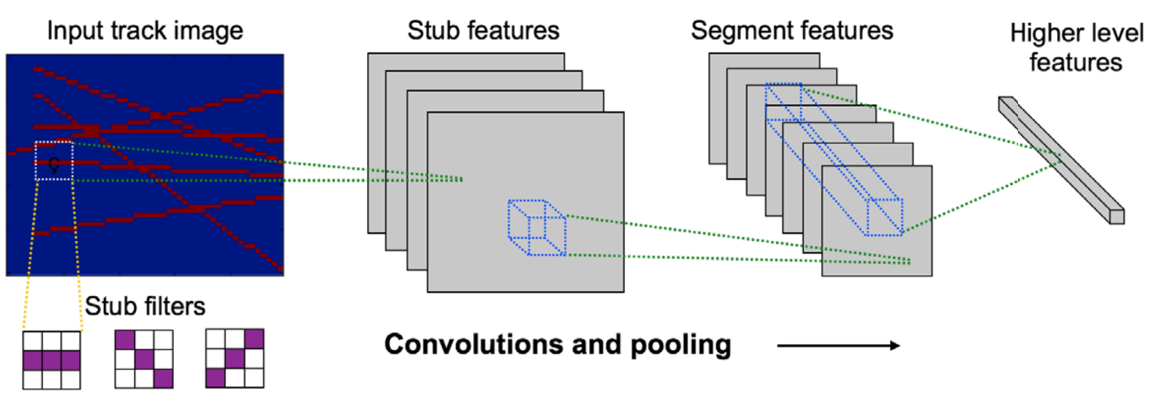


Image:
Convolutional Neural network for track finding via (sub-)feature pooling

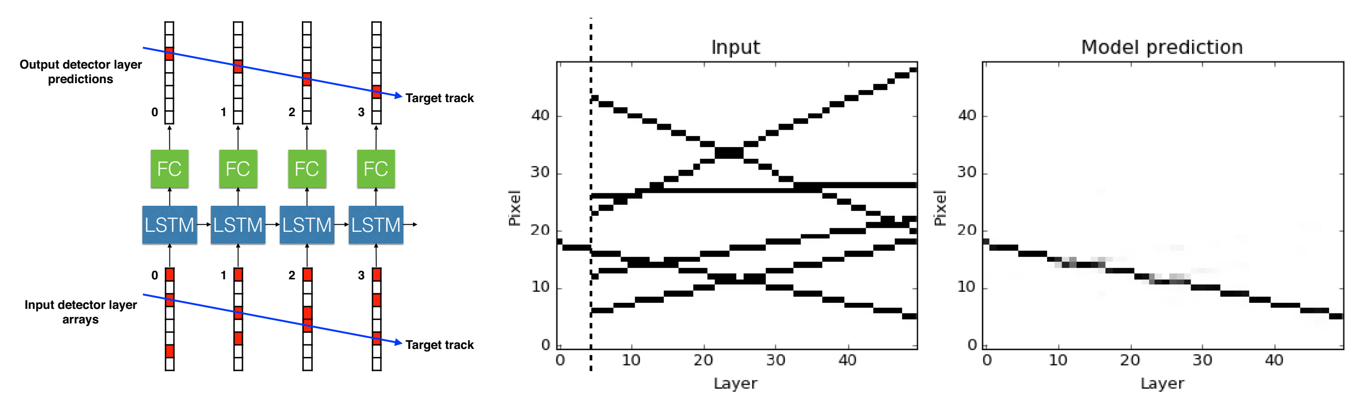
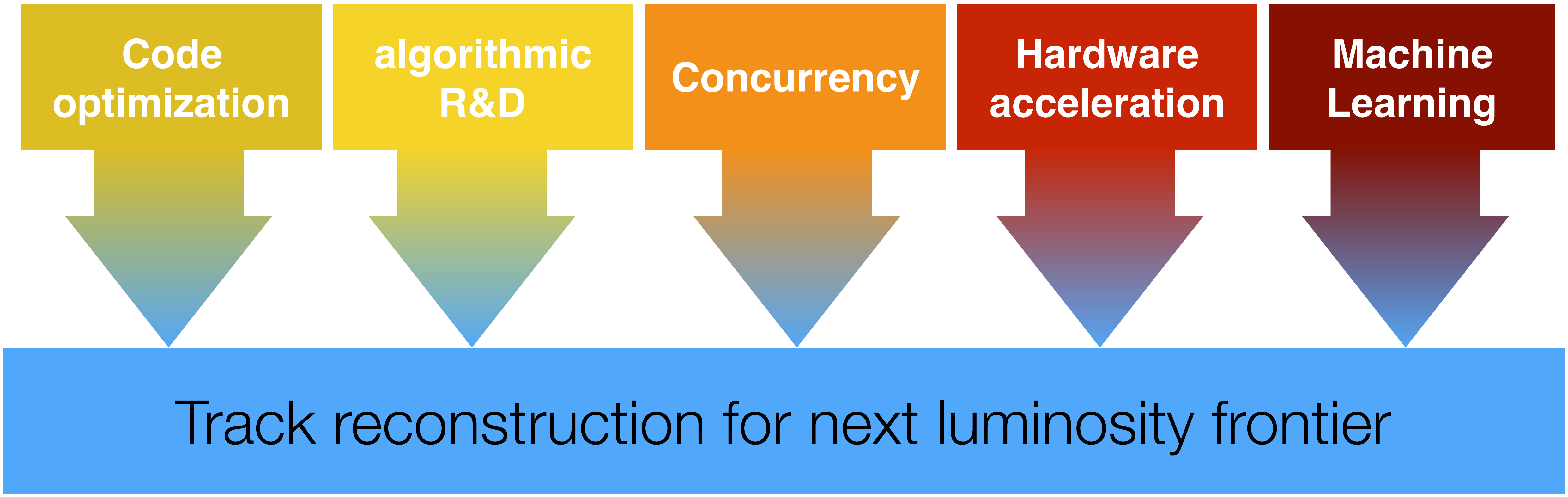


Image:
Recurrent Neural network for prediction via Long Short Term Memory (LSTM)

Examples & more information:
See talk by Maurizio
CERN co-organized, Tracking Machine Learning Challenge (Apr 2018)

Summary



Achieving this will gain great physics potential, though requires

- R&D in all of these areas
- *preserve* the excellent LHC physics performance of track reconstruction
- *foster* and *strengthen* in-house expertise
- *work closely* with and alongside detector R&D lines
- *profit from*, *coordinate with* and *participate in* ML R&D
- *strengthen* common, community-driven and open software

Backup

HL-LHC CPU extrapolation

Based on ATLAS ITk estimates

- similar picture for CMS