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From Quark to Jet: A Beautiful Journey
*Lecture **1***

Beauty Physics, Tracking, and Distributed Computing

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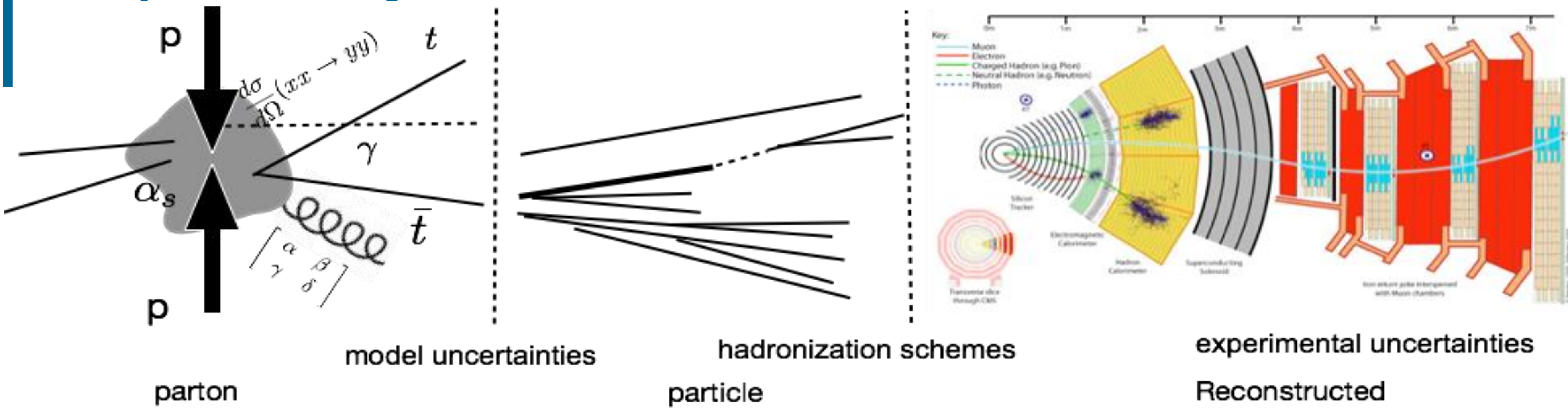
Deutsches Elektronen-Synchrotron (DESY)

Inverted CERN School of Computing, 24-25 February 2014

Explaining the Title: An outline



- **Theoretical**

Quarks

Mathematical Objects:
Matrices, operators, etc.

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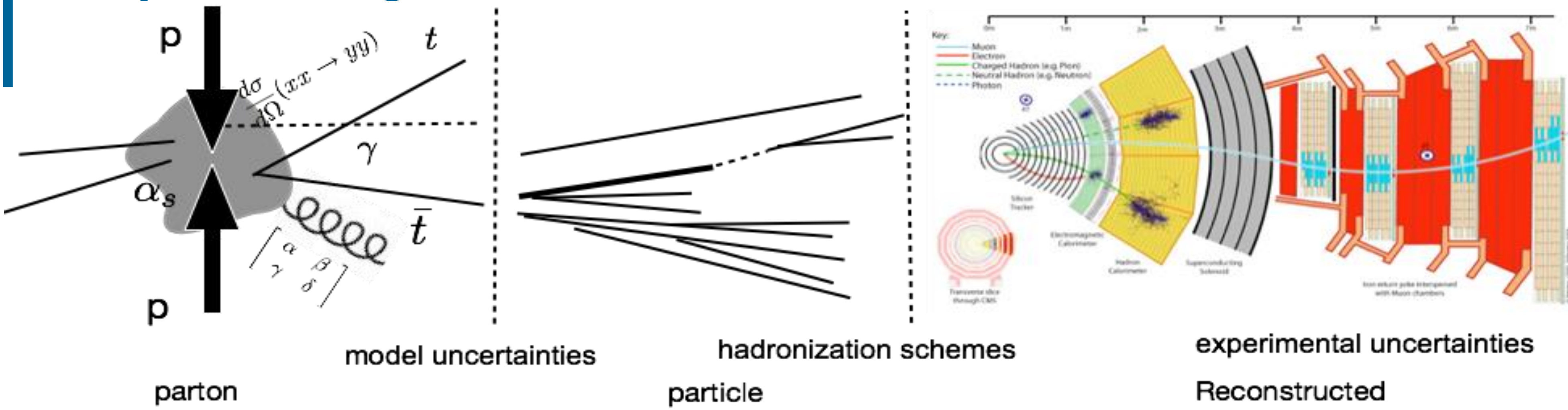

- **Theoretical**
- **Hadronization**

Quarks	Particles
Mathematical Objects: Matrices, operators, etc.	intermediate and quasi-final state objects

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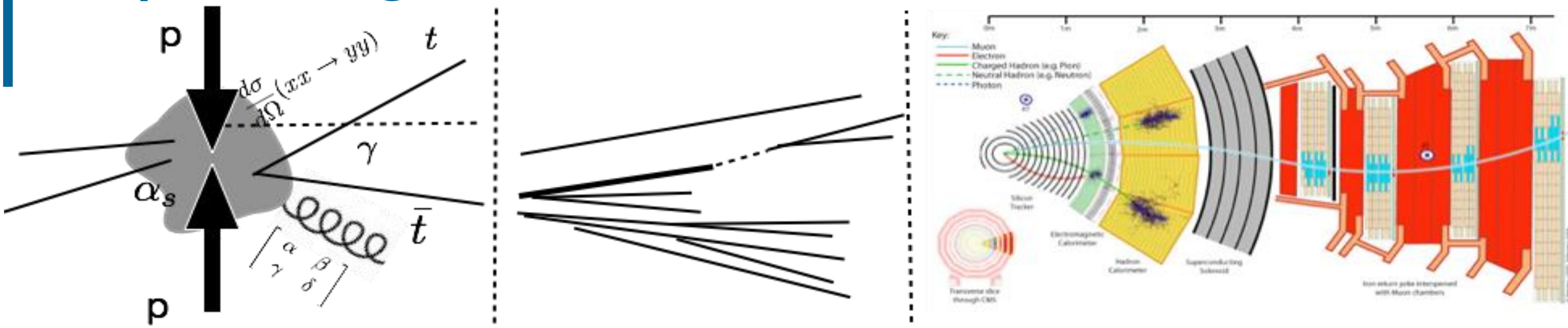

model uncertainties

hadronization schemes

experimental uncertainties

parton

particle

Reconstructed

- **Theoretical**
- **Hadronization**
- **Reconstruction**

Quarks	Particles	Jets
Mathematical Objects: Matrices, operators, etc.	intermediate and quasi-final state objects	Energy deposits in detector used to recreate particles

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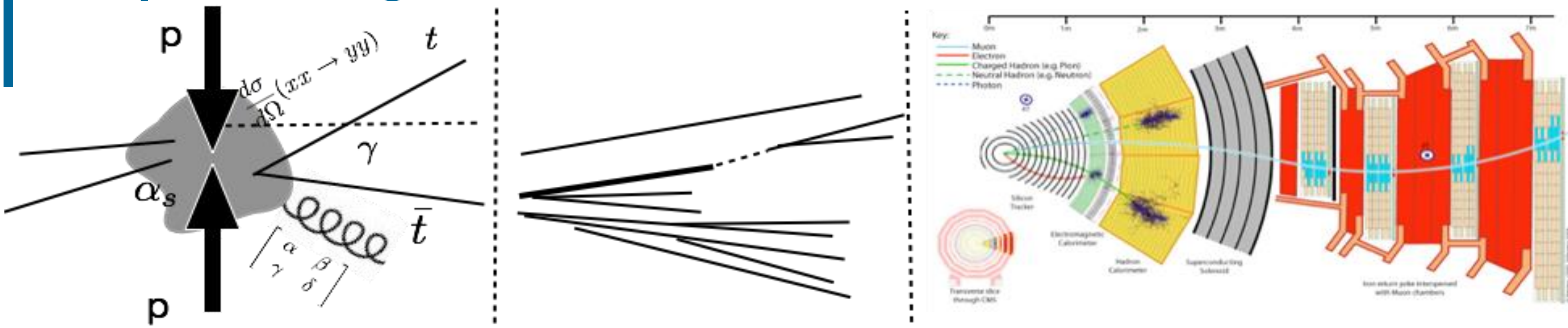

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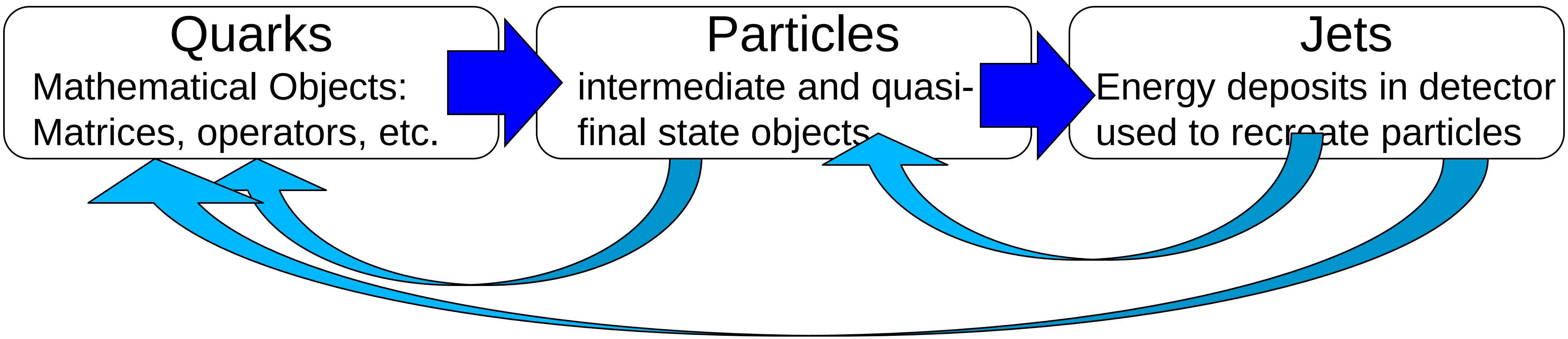

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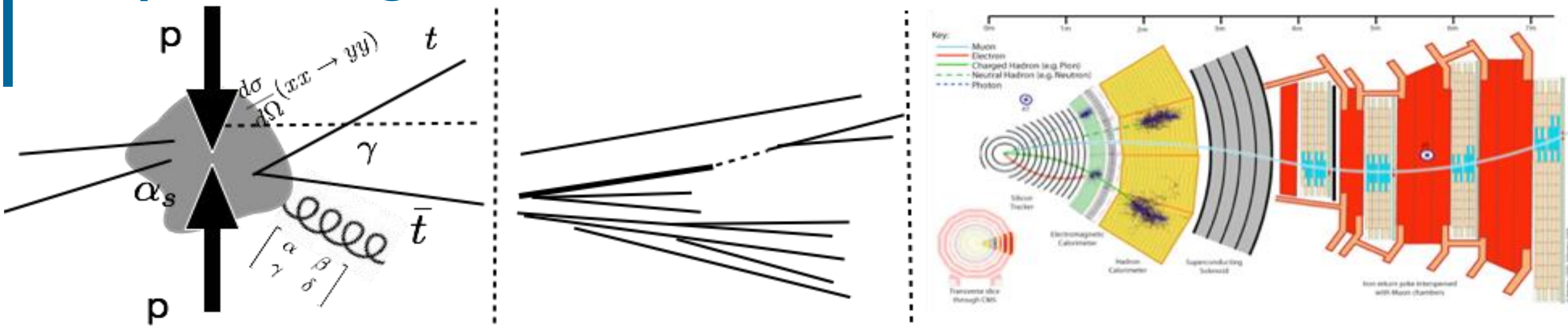

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Quarks	Particles	Jets
Mathematical Objects: Matrices, operators, etc.	intermediate and quasi-final state objects	Energy deposits in detector used to recreate particles

Huge numbers of complex equations

Entirely Simulated, particles are subjected to decay conditions

Detector simulation, Algorithmic reconstruction

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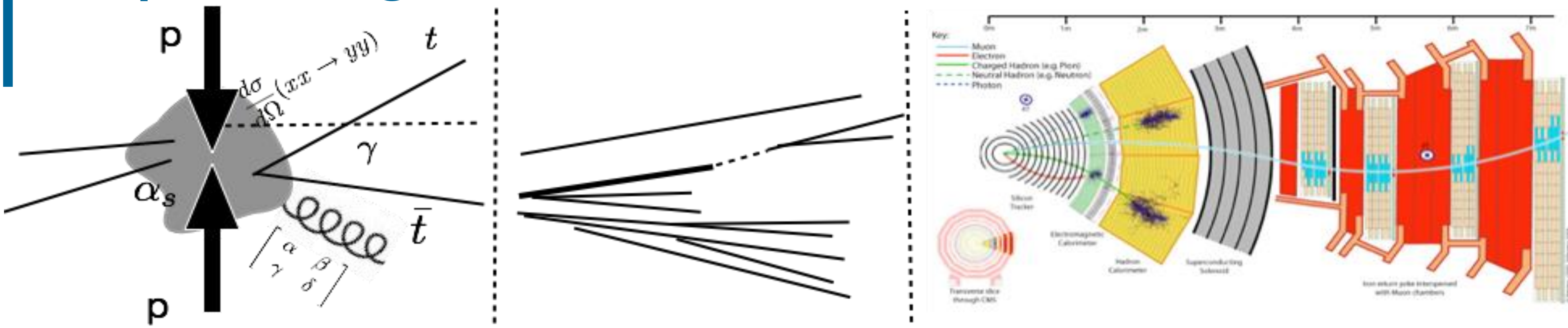

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Reconstructed

- **Theoretical**
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Quarks

Mathematical Objects:

complex equations

Particles

intermediate and quasi-

particles are subjected to decay conditions

Jets

Energy deposits in detector

Algorithmic reconstruction

Different computing solutions used to tackle the unique challenges at each step

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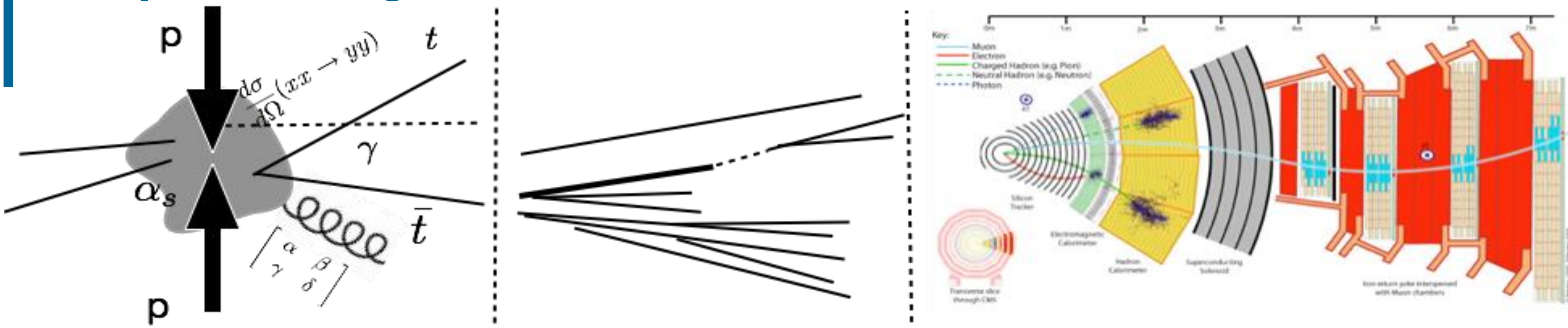

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Reconstructed

- **Theoretical**
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Quarks
Mathematical Objects:

Particles
intermediate and quasi-

Jets
Energy deposits in detector

Different computing solutions used to tackle the unique challenges at each step

The firstlecture will explore a bit more theory, tracking and how to cope with the increased demands of new physics environements

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Ask Questions here

- **Use theory to make predictions for observables of particles**
- **Design detectors to detect these observables**
- **Algorithms to remake the objects**

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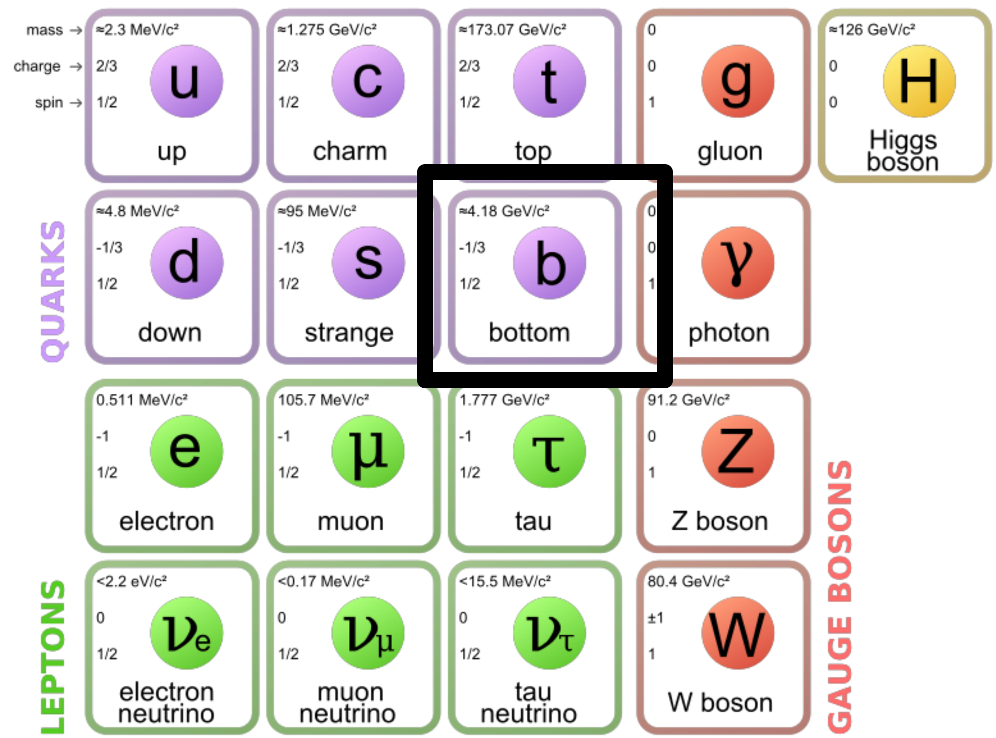
Beauty Physics - Theory

- **Beauty quark discovered in 1977 at Fermilab**
- **Lighter than top quark and W/Z/H bosons**
  - Significant decay channel
- **Beauty (and charm) quarks have a lifetime that allows for decay lengths of a few millimeters**
  - Top is too short, up/down/charm is too long



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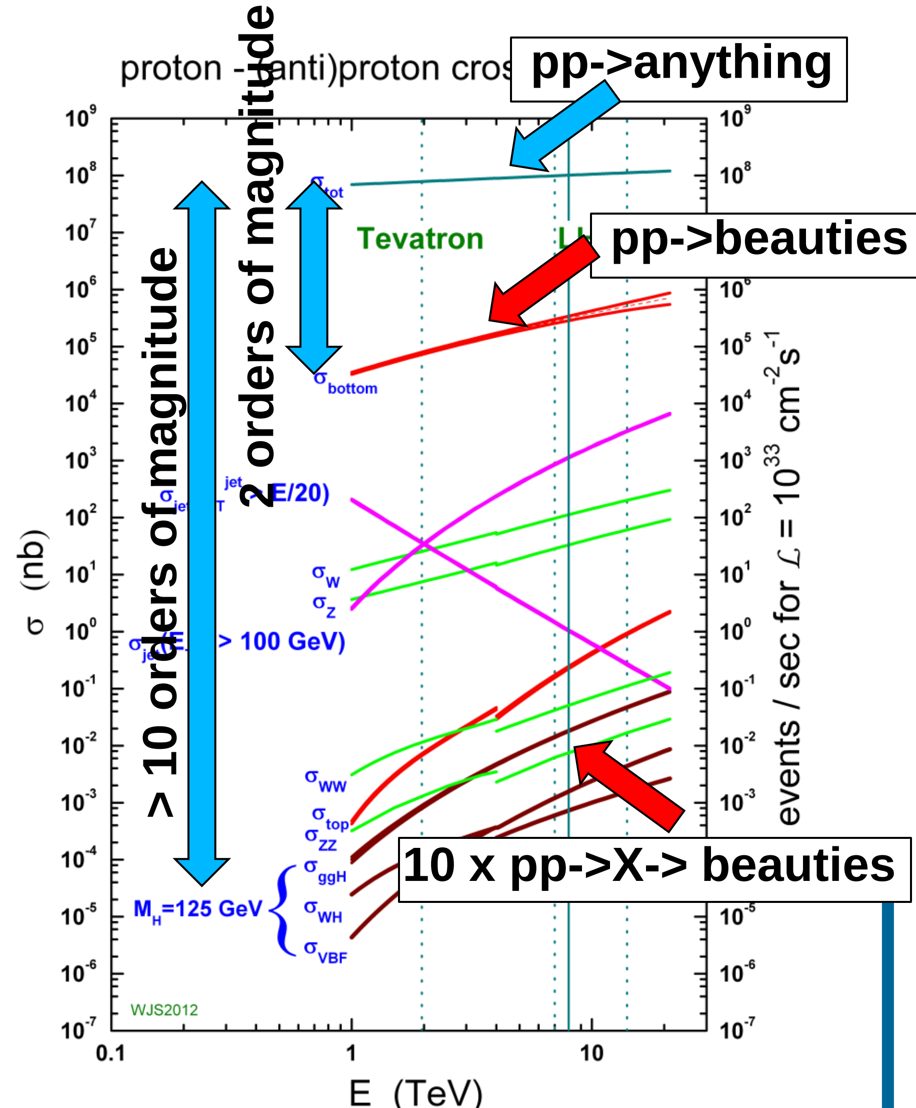
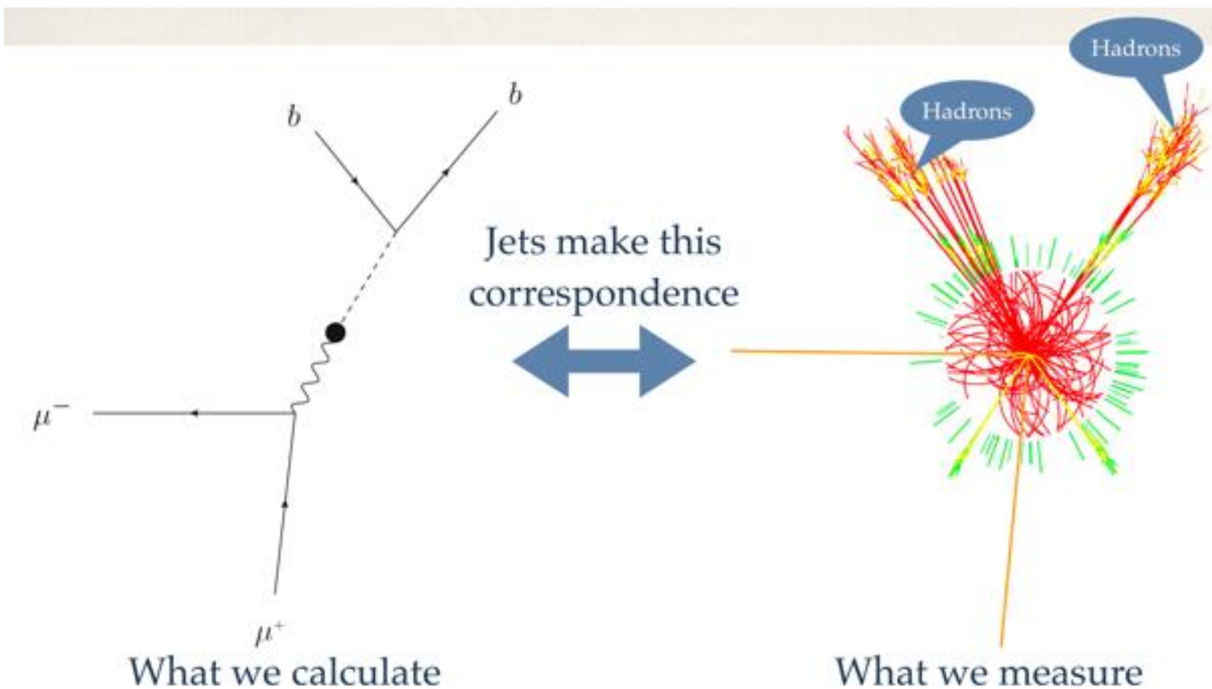
Beauty Physics - Theory

- **b-jets are extremely powerful background reducers**
  - Many important signals have b-quarks
- **Huge order of magnitude reduction from identifying b-quarks**
- **Very important tool**



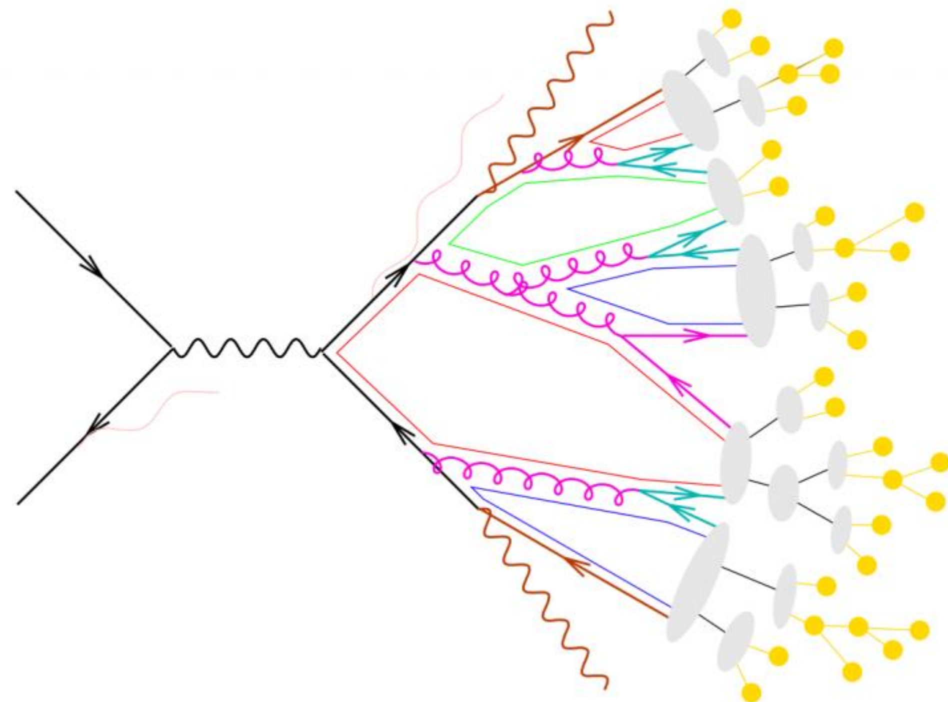
Hadronization

- **Most calculations are confined to simple elements**
- **What we actually measure is much more complicated**



Hardonization

- **We know that as quarks get further away from each other they make pairs with other quarks**
  - These are called hadrons
- **Hadronization depends on many experimentally adjusted factors**
- **Most importantly we can begin to look at event topology**



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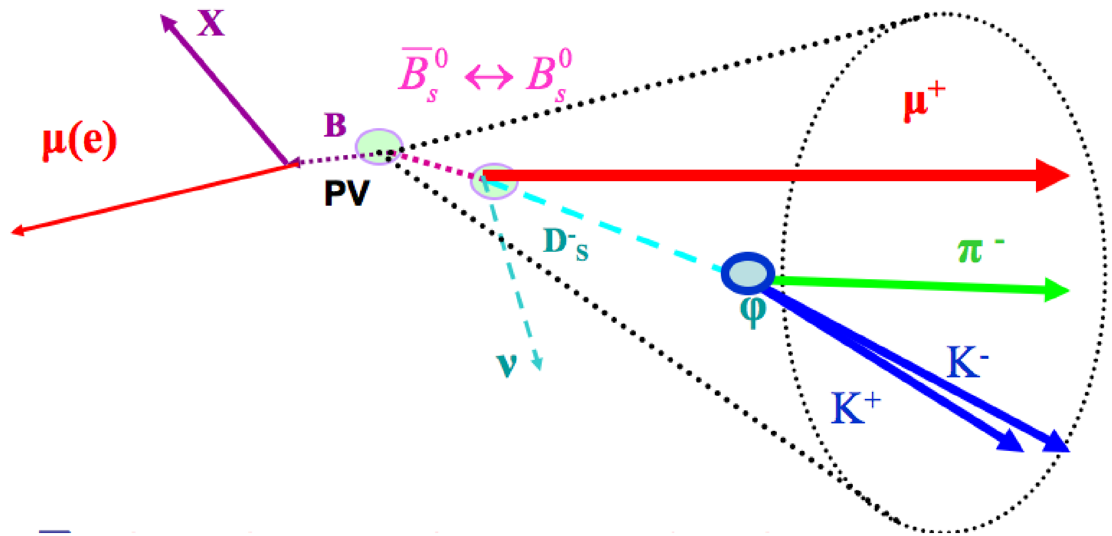
Beauty Physics – Particle Level

- If a b-quark is paired with an s-quark the resulting meson, B_s, has a long lifetime, and some very interesting decay signatures
- We use these particular decay signatures to determine what experimental signature we want to see



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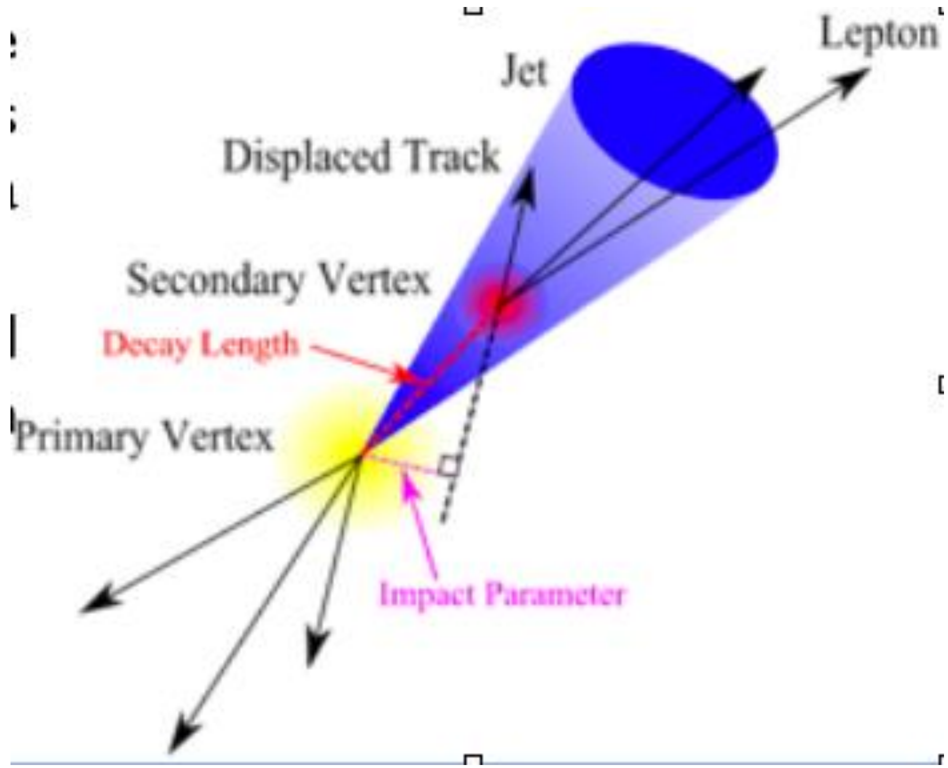
Experimental signature

- **Now we have a distinct signature to search for**
  - A secondary vertex
  - Jet
  - Displaced track
  - Lepton
- **Rare, but not unique**
  - We will use different techniques to classify
  - Essentially a probability the jet came from a b-quark



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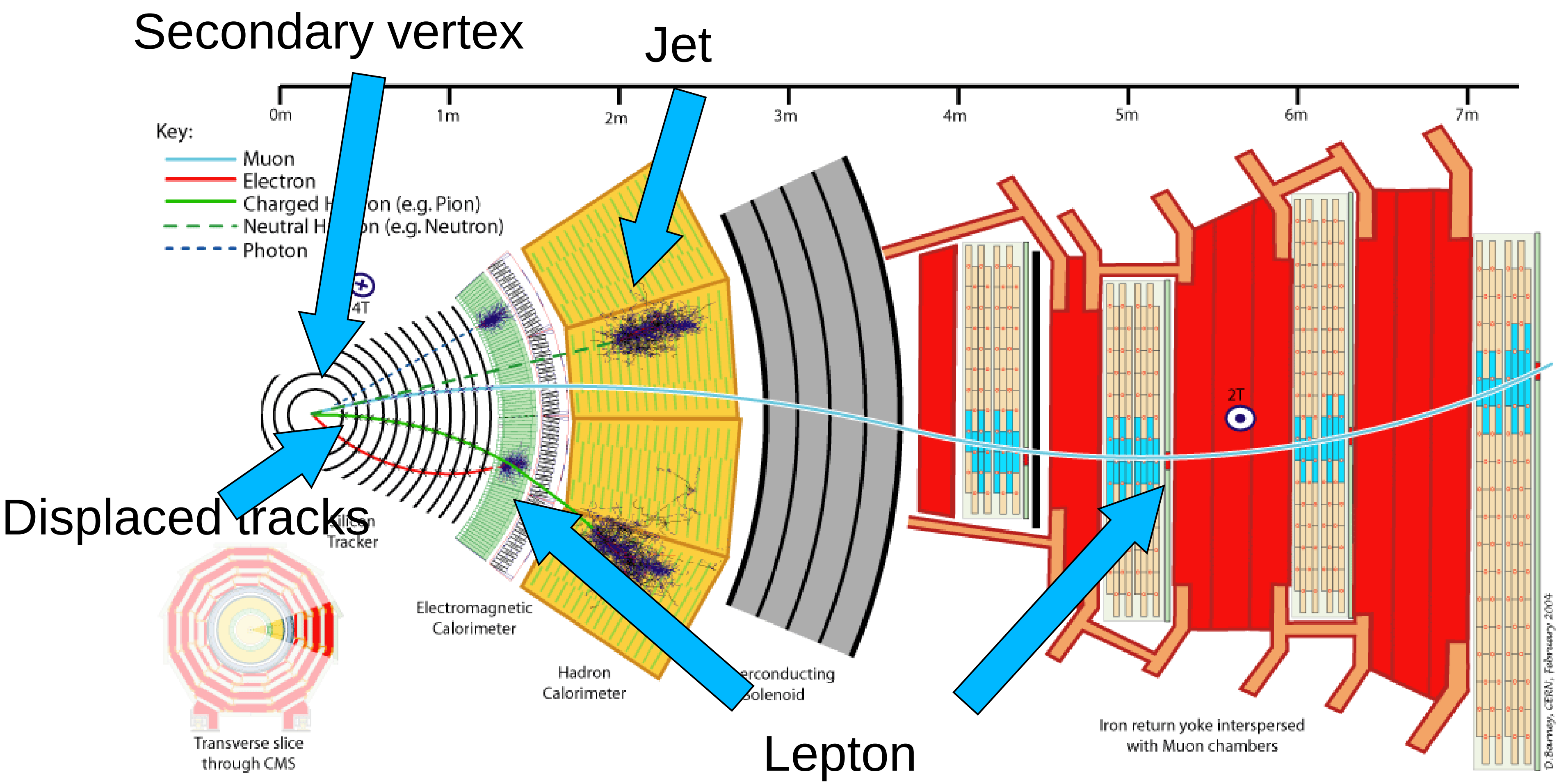
Beauty Physics – Detector Level



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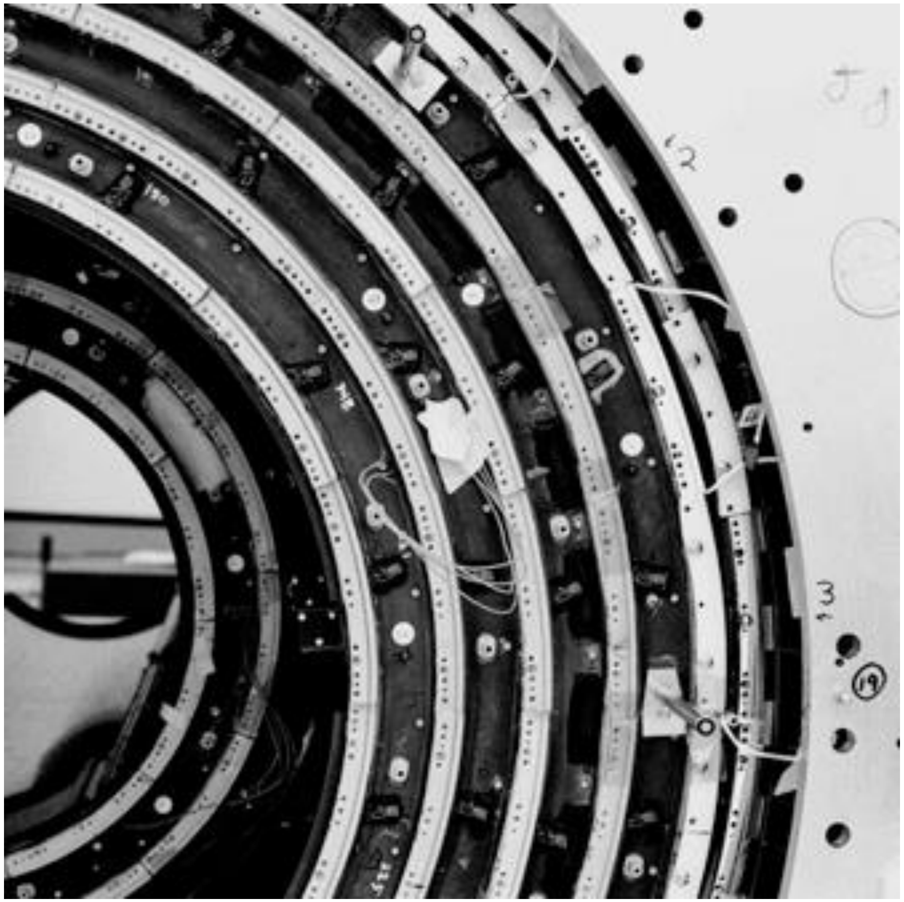
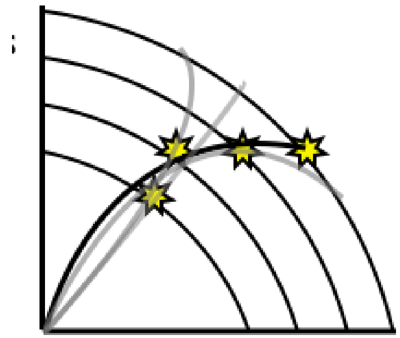
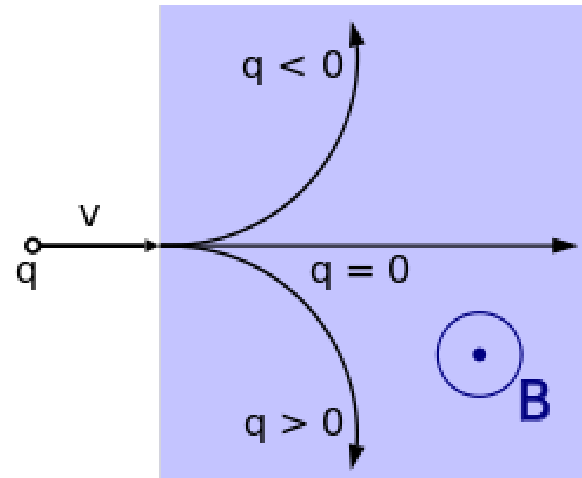
Theory Questions

- **Use theory to make predictions for observables of particles**
- **Design detectors to detect these observables**
- **Reconstruction algorithms to remake the objects**

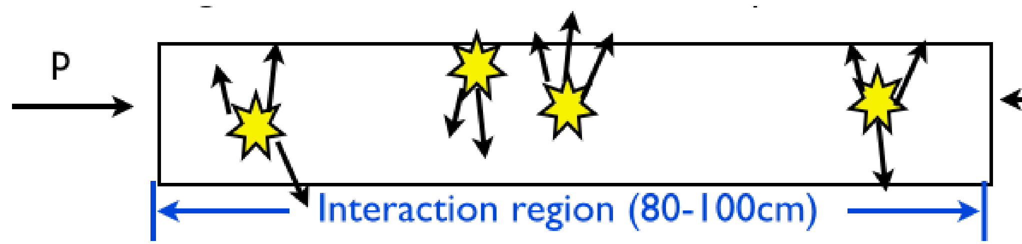
Tracking - an Introduction





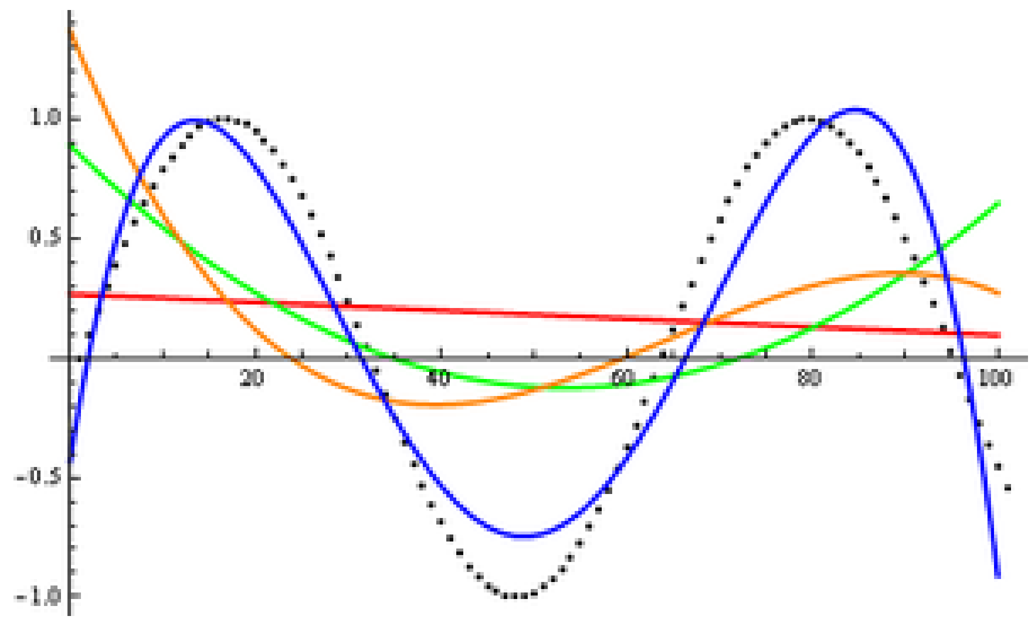


$$r = \frac{p}{BQ}$$



Fitting

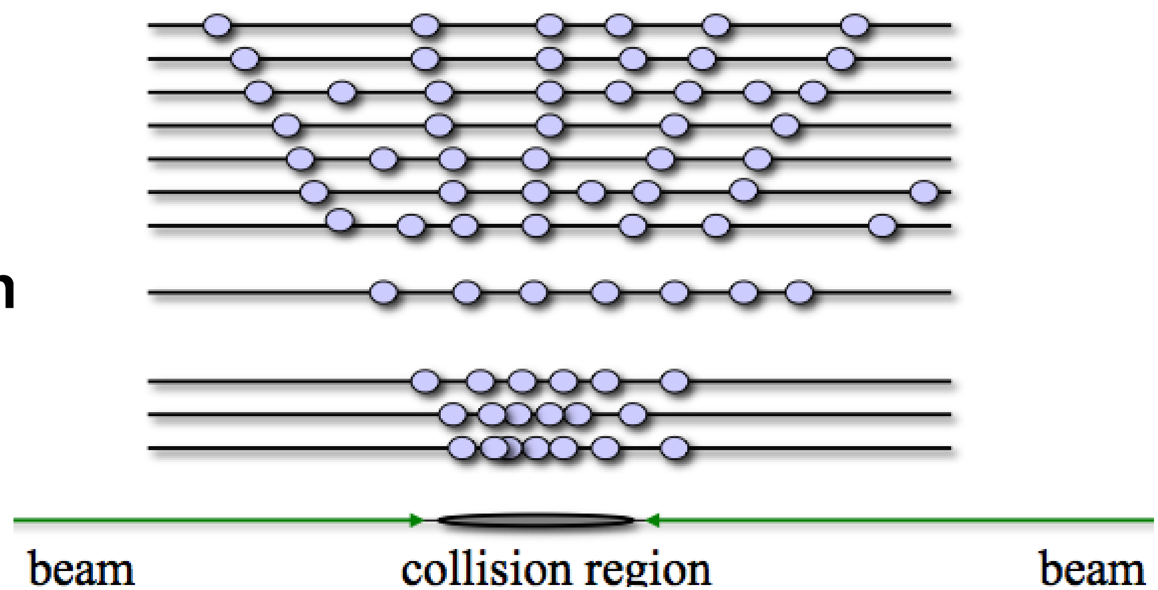
- An nth degree polynomial will exactly fit (n+1) points
- Therefore, any three points can be fit with a circle
- Fits generally classified by distances of points to fitted curve (chi-squared)
- For nth degree polynomial, n+2 … n+m points are degrees of freedom



Polynomial fits to a sine curve

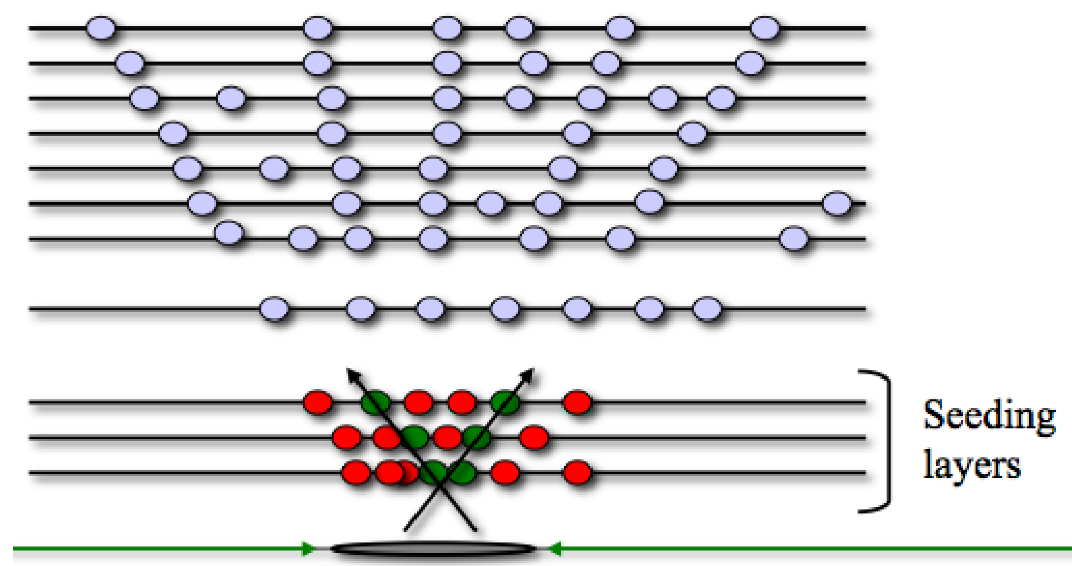
Track Seeding and Reconstruction

- **Inside of the collision region we will have many hits we can associate with a primary vertex**



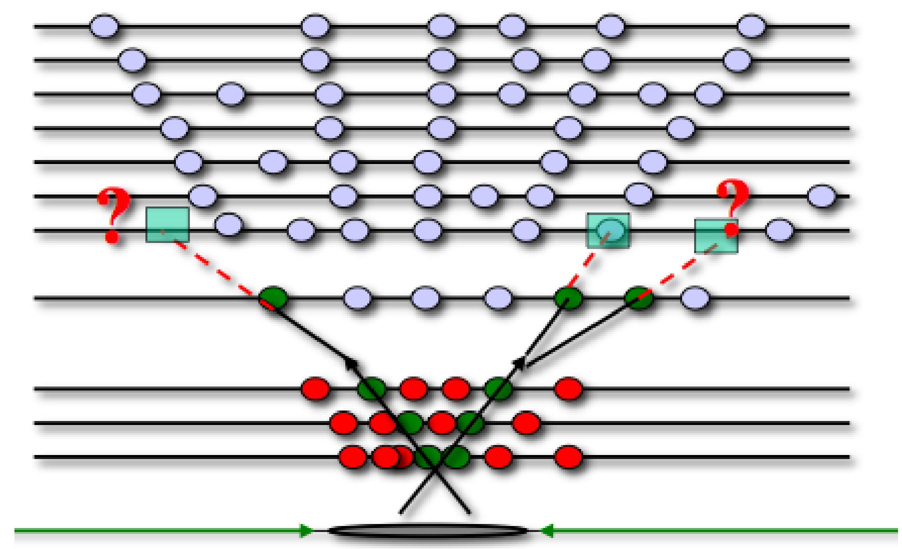
Track Seeding and Reconstruction

- **Choose an initial set of layers that we name the “seeding layers” that provide an initial estimate of track parameter**



Track Seeding and Reconstruction

- **Choose an initial set of layers that we name the "seeding layers" that provide an initial estimate of track parameter**
- **Then collect all possible hits associated with different seeds**



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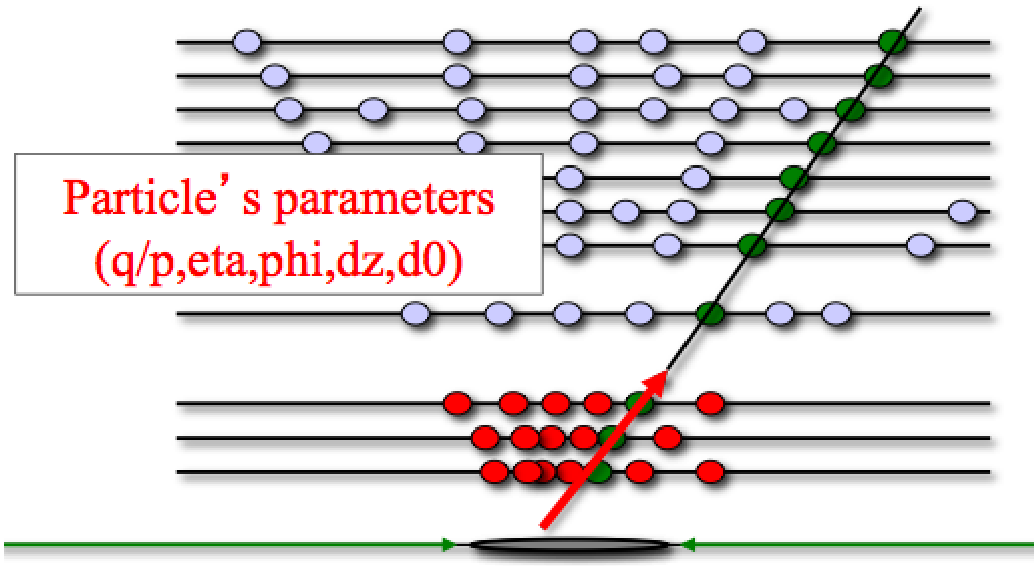
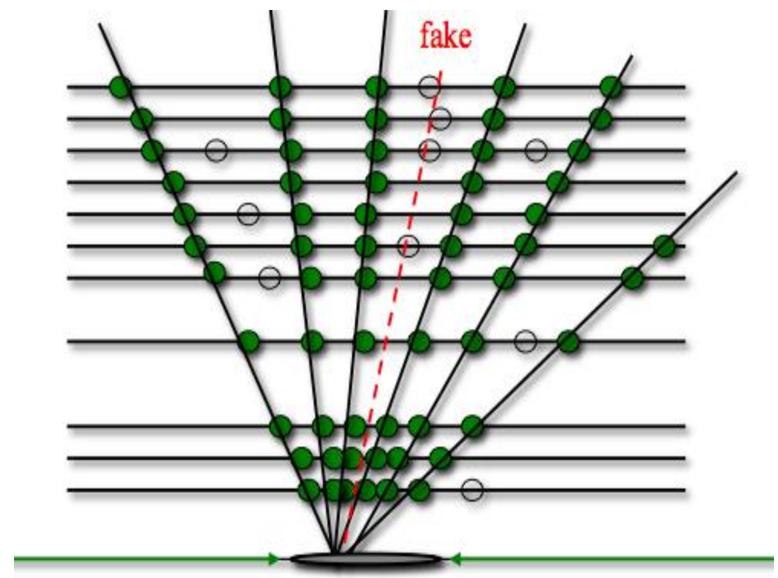
Track Seeding and Reconstruction

- **Choose an initial set of layers that we name the "seeding layers" that provide an initial estimate of track parameter**
- **Then collect all possible hits associated with different seeds**
- **Using techniques to estimate the goodness of the fit we can then estimate the final track parameters**



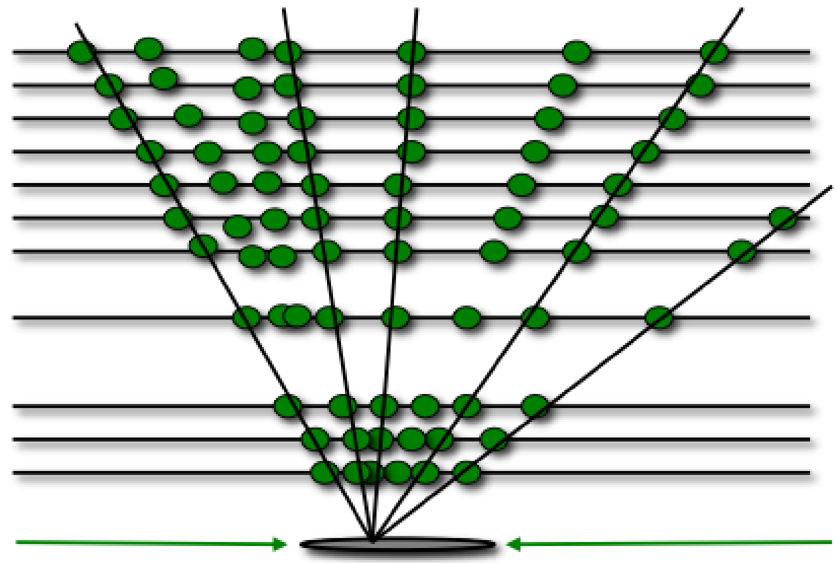
Fake Removal

- **Choose an initial set of layers that we name the "seeding layers" that provide an initial estimate of track parameter**
- **Then collect all possible hits associated with different seeds**
- **Using techniques to estimate the goodness of the fit we can then estimate the final track parameters**
- **And remove hits not associated with good tracks**



Iterative Tracking

- **With iterative tracking certain quality tracks can be chosen and then removed from further inspection**



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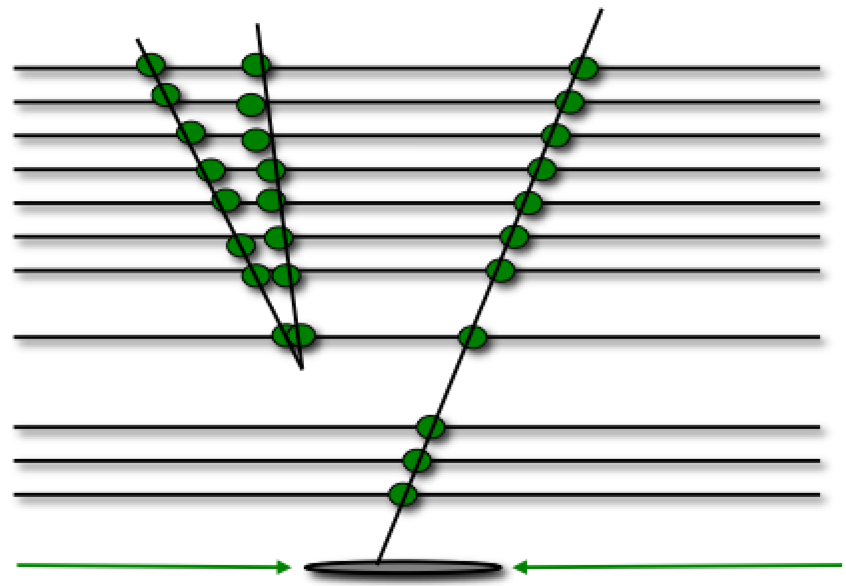
Iterative Tracking

- **With iterative tracking certain quality tracks can be chosen and then removed from further inspection**
- **Then use the remaining hits to create the remaining tracks**
- **After many iterations we end with the final set of tracks**



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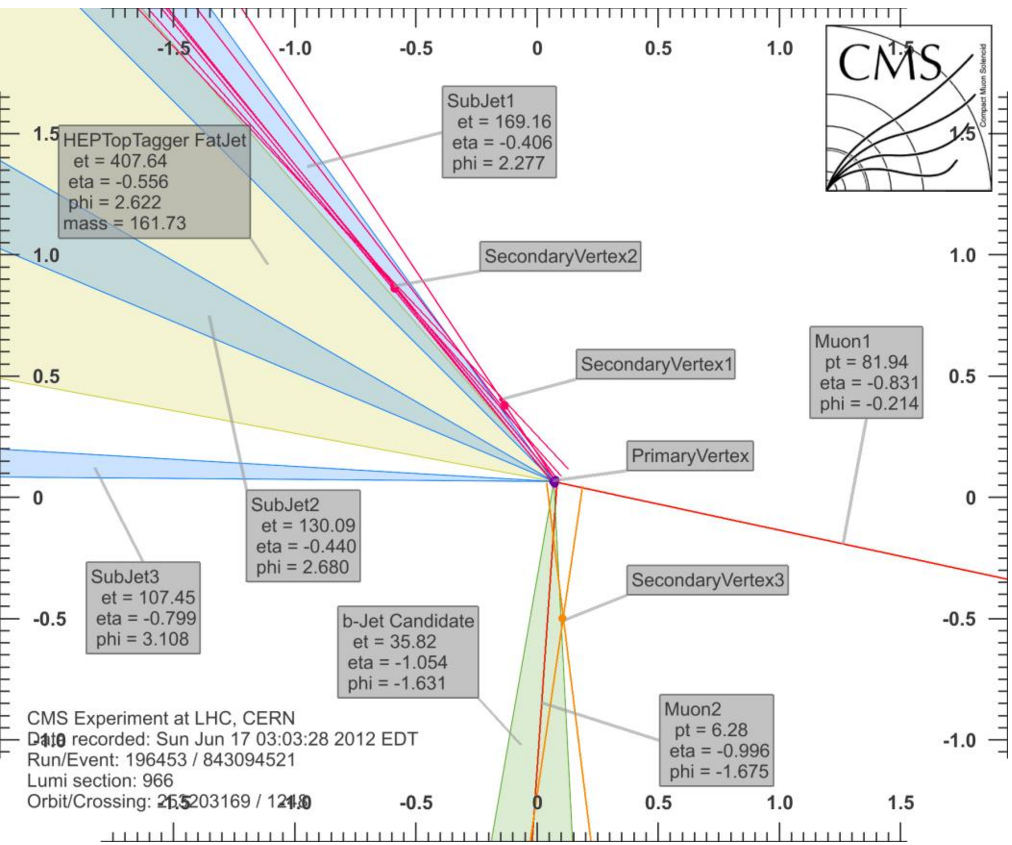
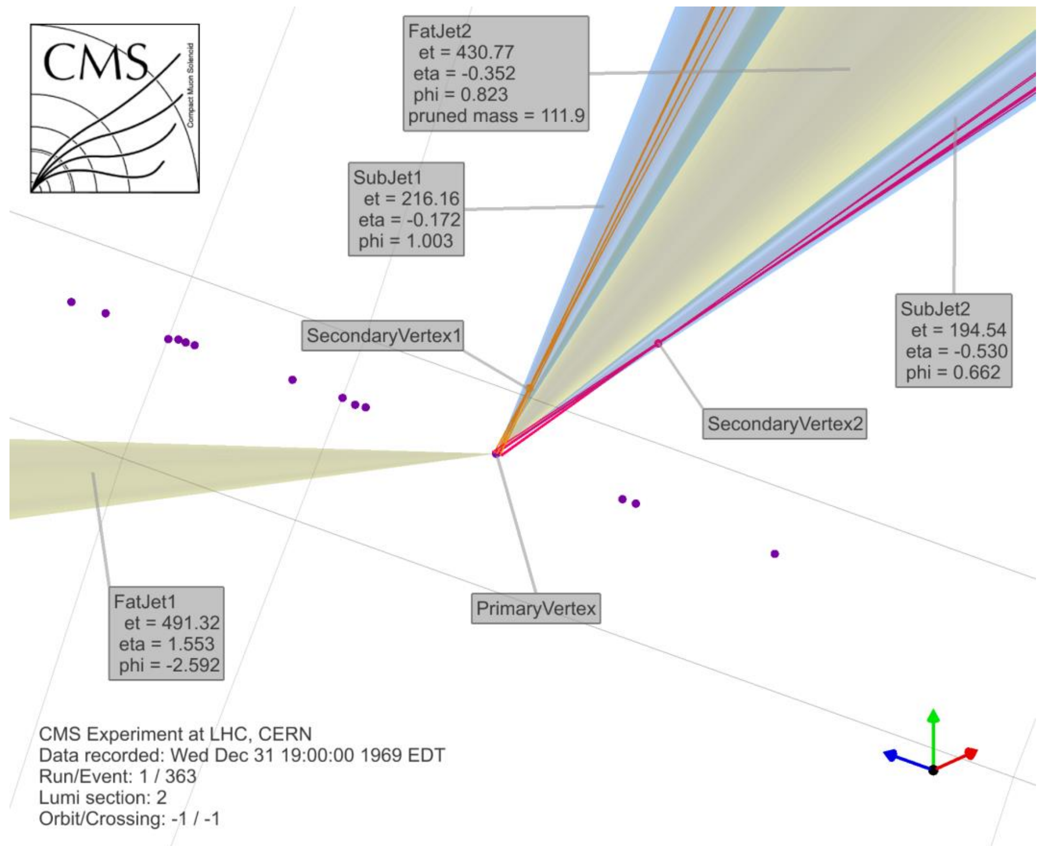
Real data examples





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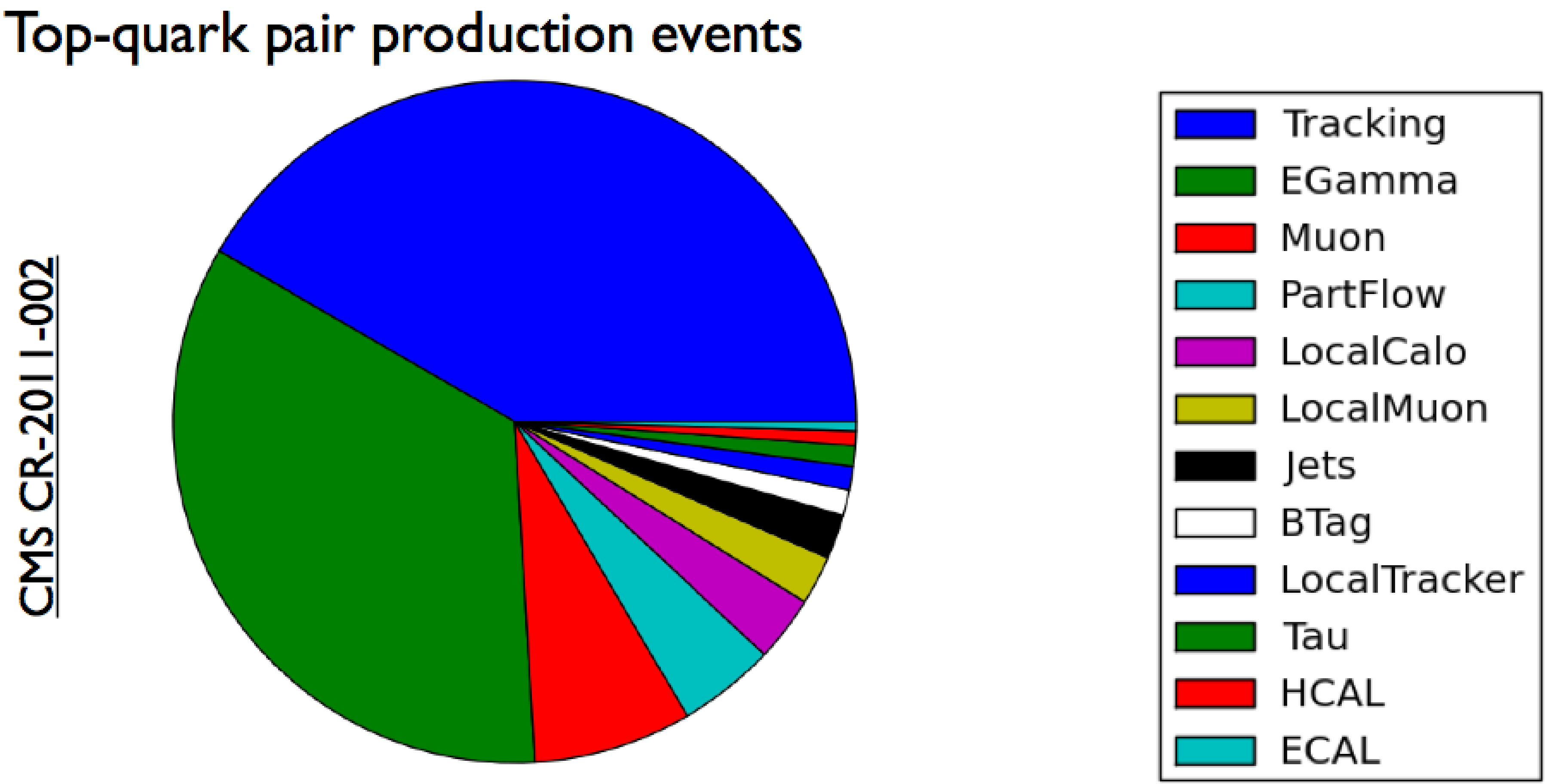
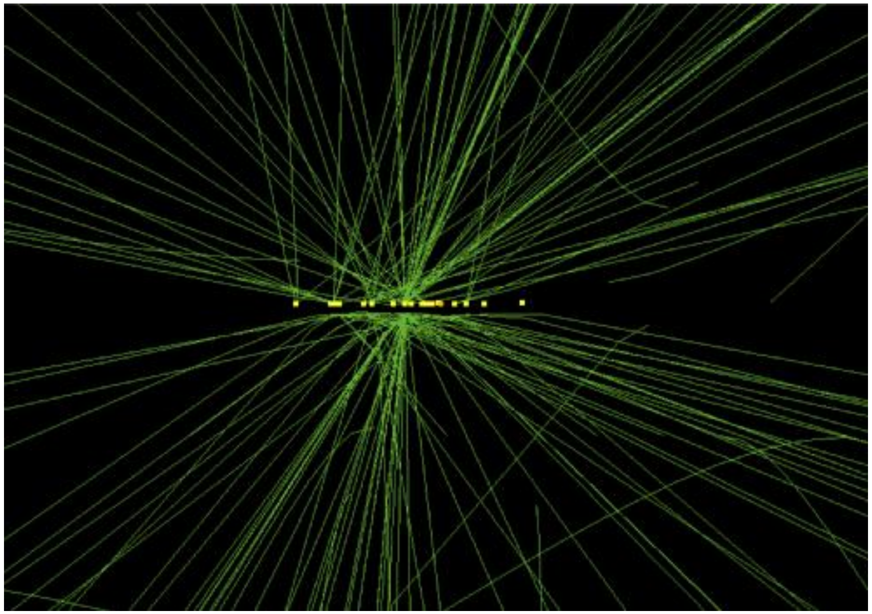
Tracking as a primary time user

Time Spent on which part of reconstruction



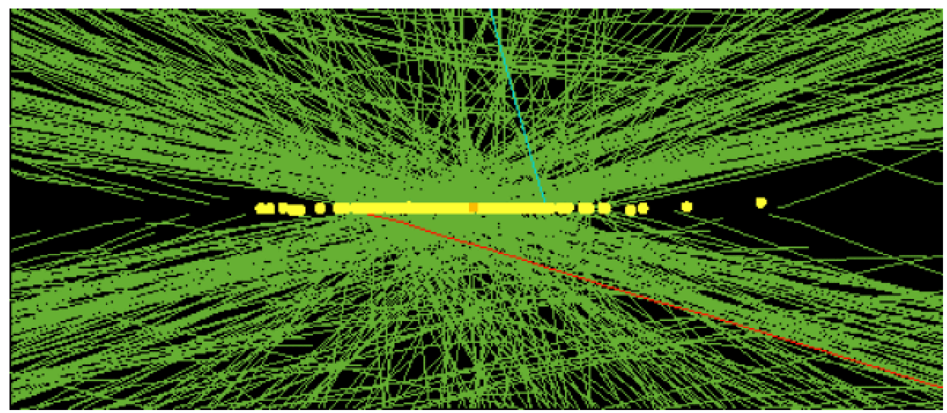
Looking Towards 2015



Current algorithms were developed considering the run conditions for 2011-2012 where there was an average of 20 interactions per bunch crossing

For 2015, there could be over 40 interactions on average

With no changes, the computing power needed could be 6 times what is currently used



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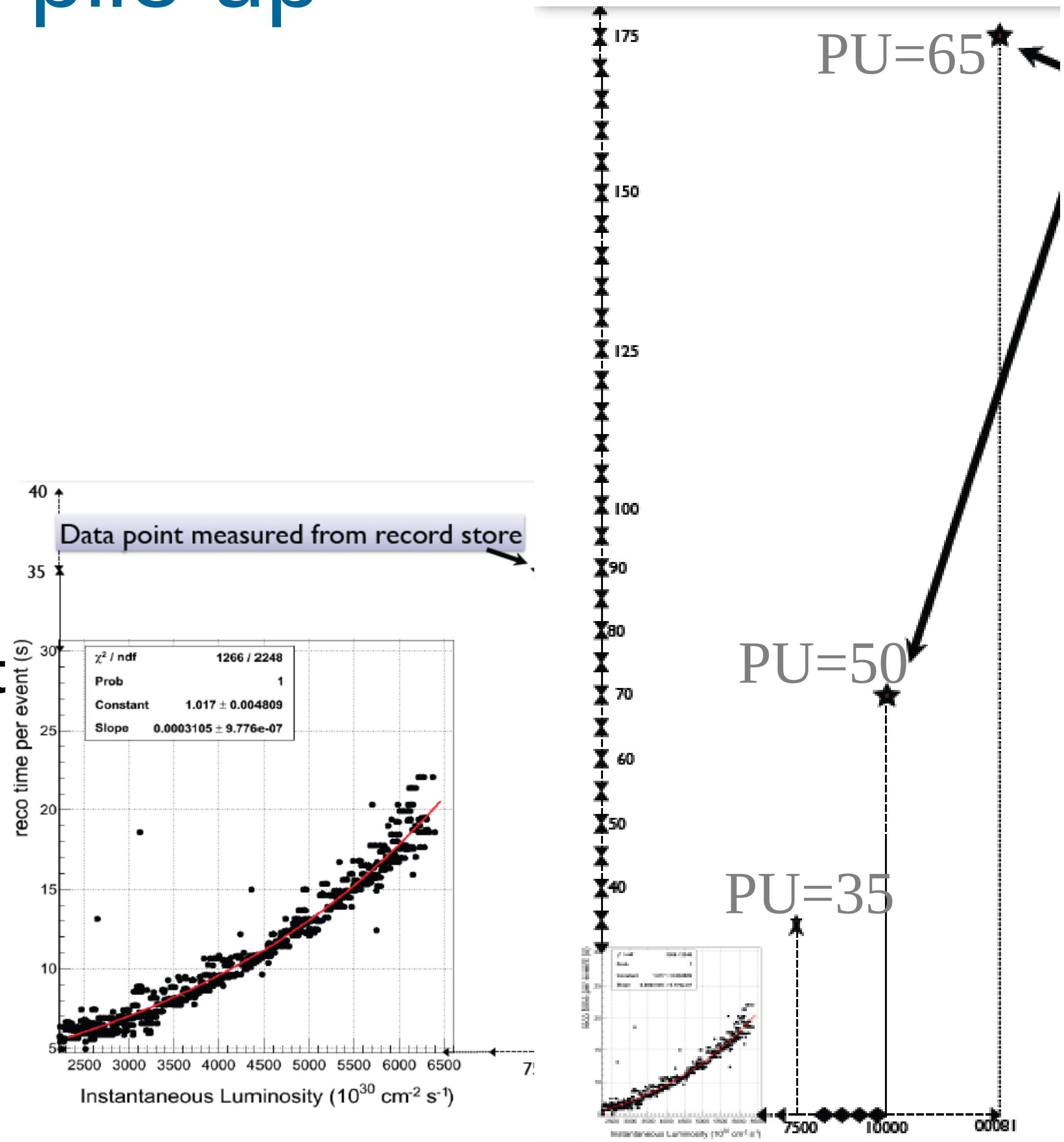
Tracking

- **Charged particles make curves in magnetic fields**
- **Basic algorithms can be used to find tracks**
- **Tracking one of the largest time consumers and sensitive to pileup**

Problems with pile up

- **Higher and higher luminosity means we have longer event reconstruction times**
- **New event architecture might be able to help**



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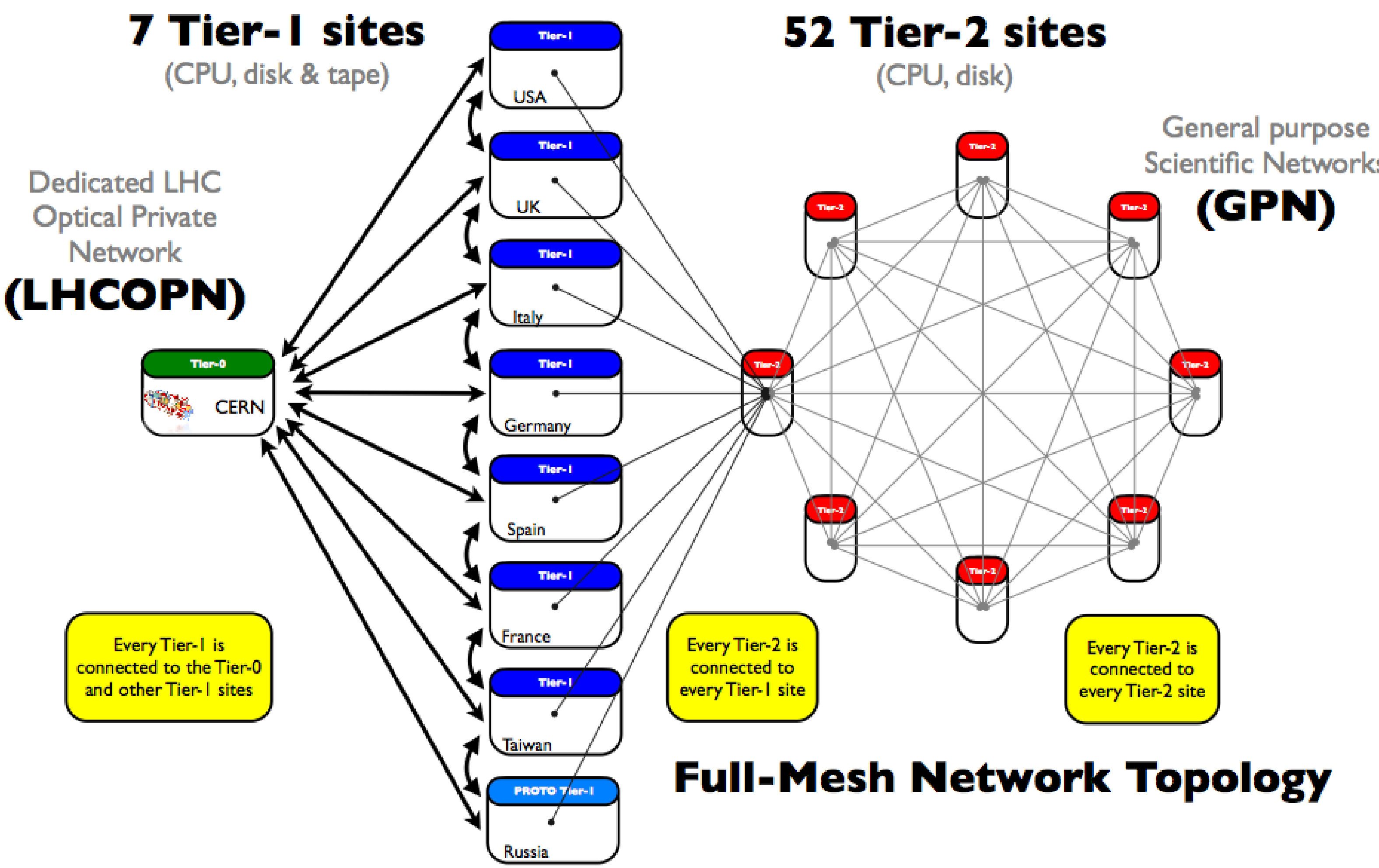
CMS Computing Network



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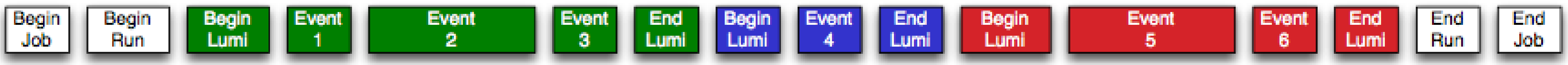
CMS Current Event Model



- **Global configurations are loaded into memory**
  - Then configurations specific to the specific time of running
- **Events then processed serially**
- **The most time intensive part of event reprocessing is tracking**

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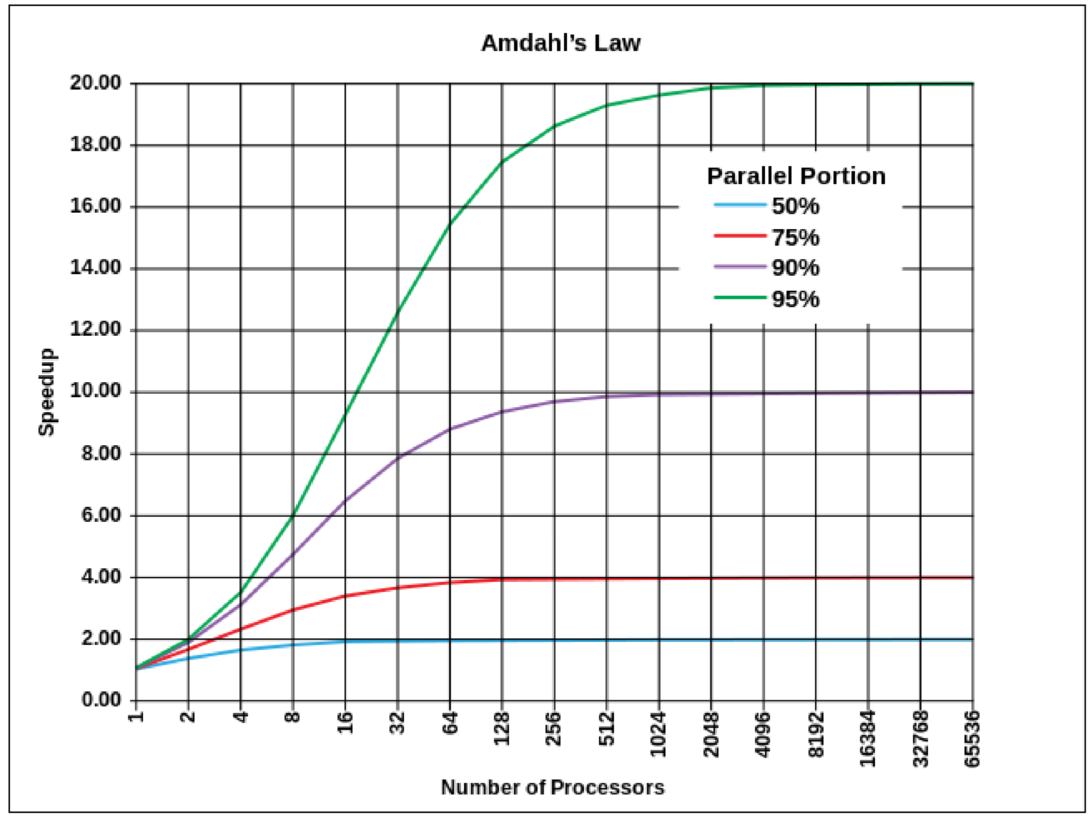
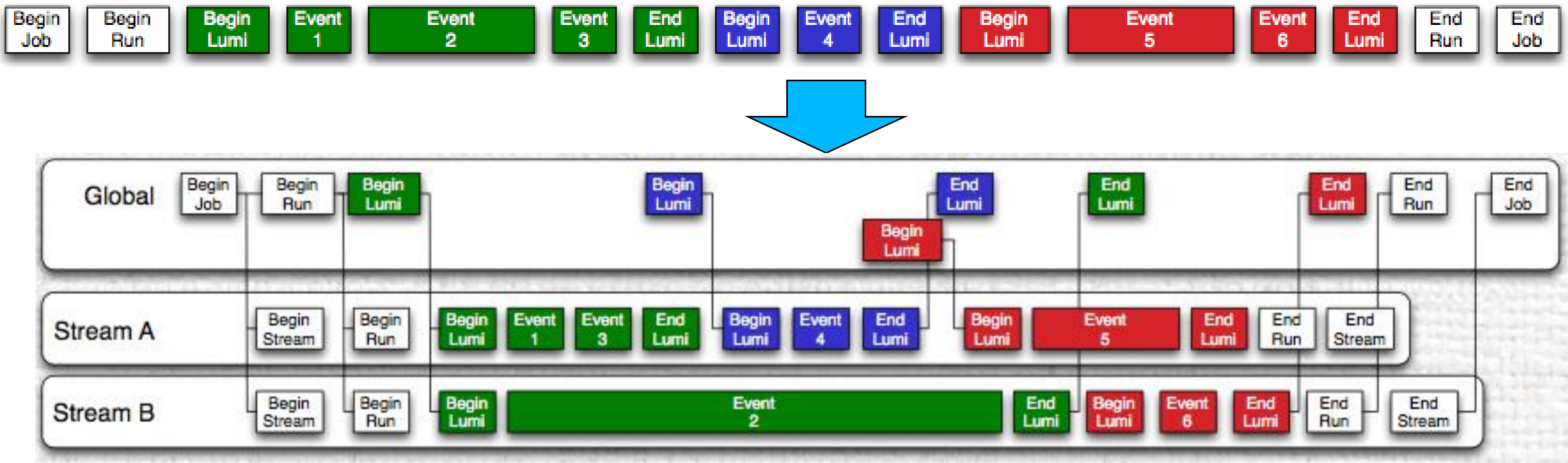
Amdahl's Law

- **Amdahl's Law is the upper limit on the speedup gained by a number of processors**

$$S(N) = \frac{1}{(1-P) + \frac{P}{N}}$$



CMS Threaded Design



- **Events are not seen globally**
- **Multiple events are run concurrently**
  - Less backup from very complicated events
- **Streams still process serially**

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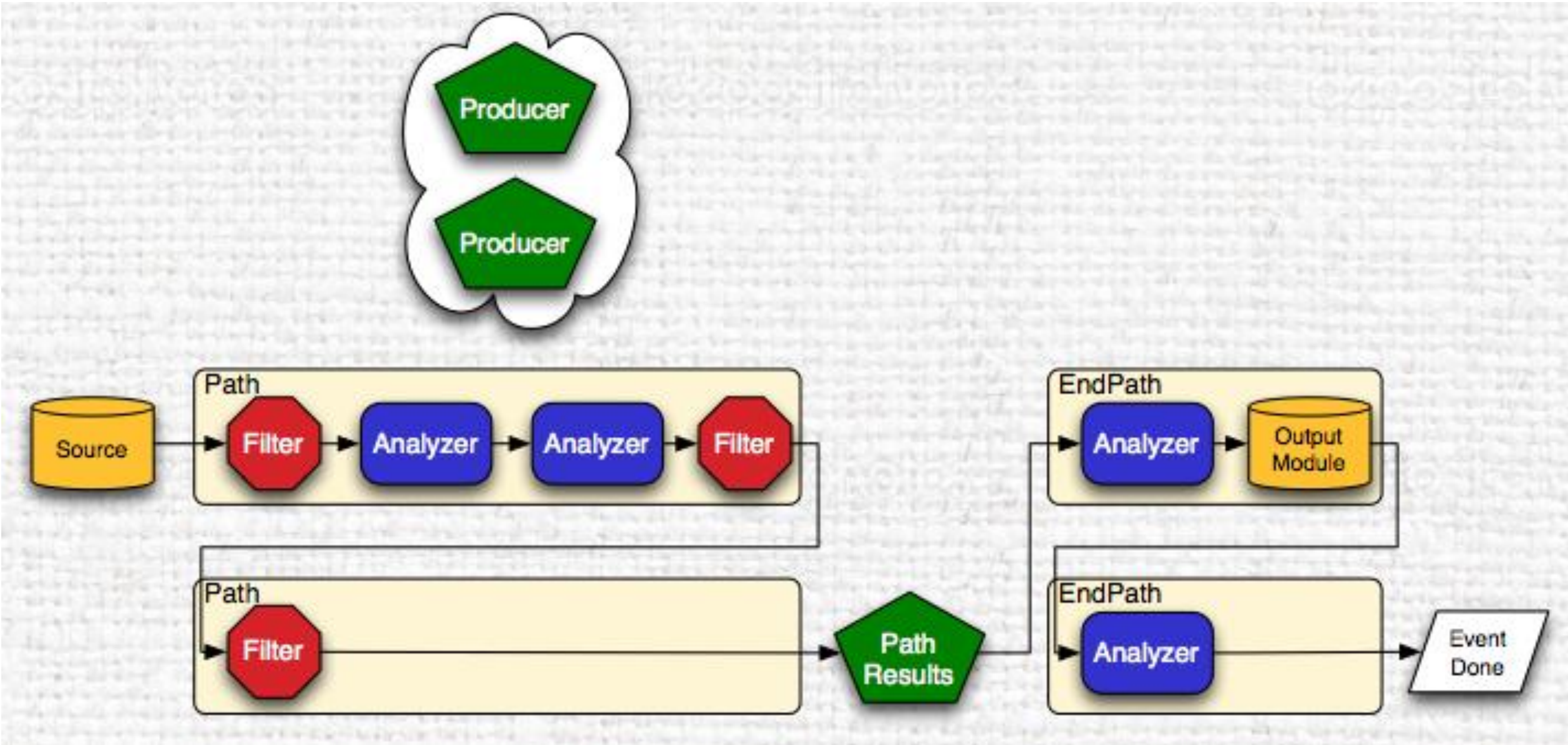
Concurrent Processing Inside an Event

- **Current event Processing**



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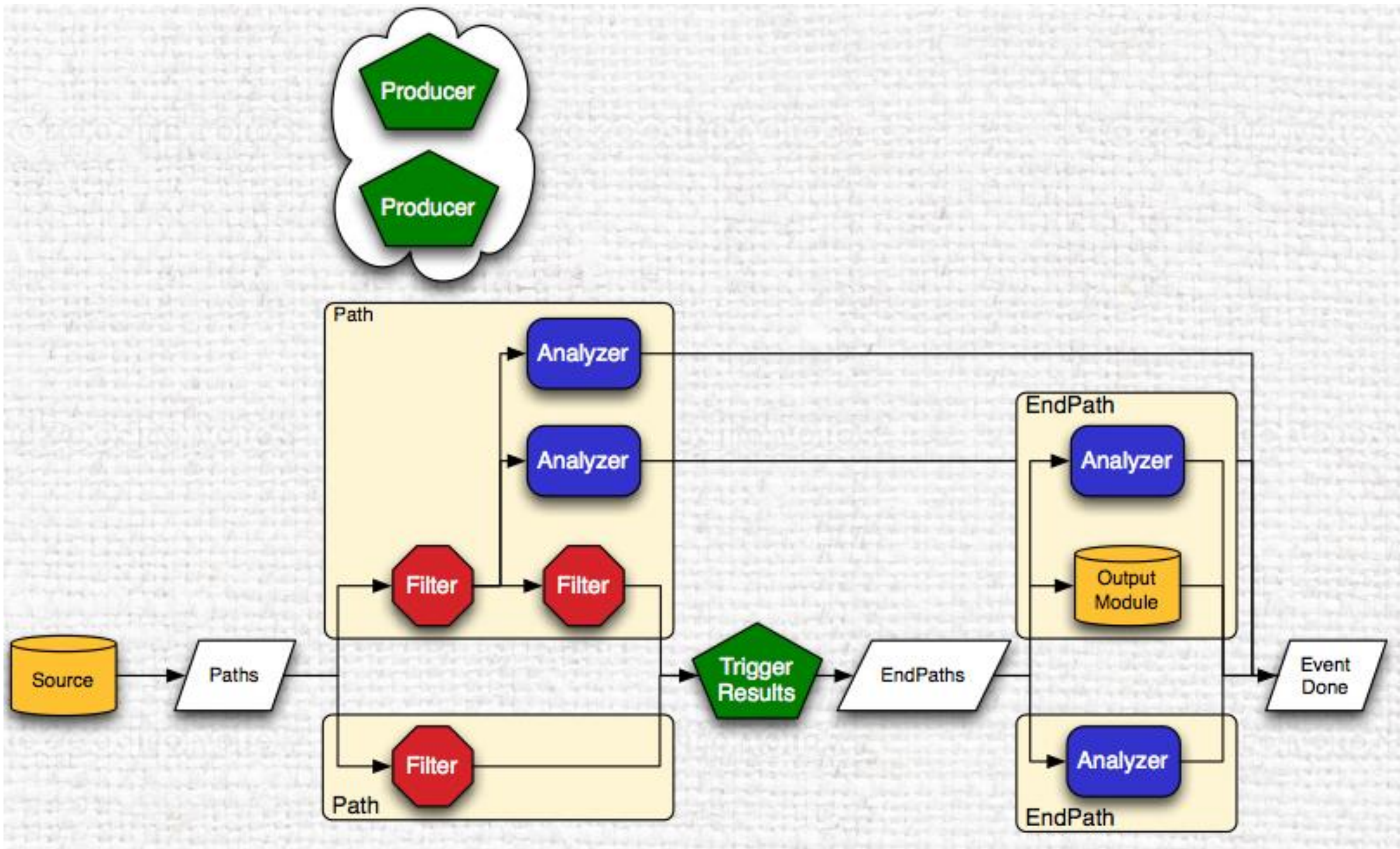
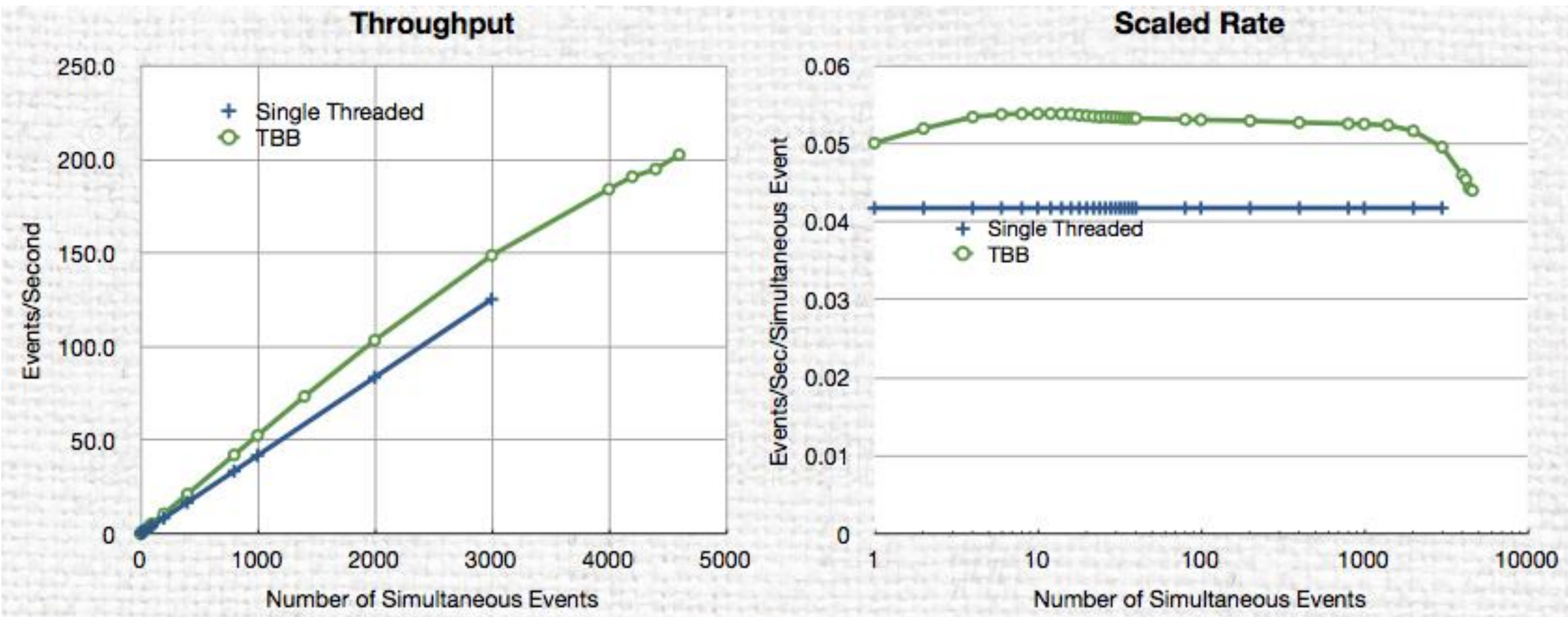
Concurrent Processing Inside an Event

- **Threading inside of a module**



Performance Results

- **Single threaded runs out of memory at 3000 simultaneous events**
- **Definite improvement through multithreading**



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Conclusions

- **Beauty physics is a very diverse and large part of high energy physics**
- **B-Hadrons have distinguishing traits we can use to make b-jets very power tools for background reduction**
- **To make use of this, we must use information from many parts of the detector which all require their own reconstruction algorithms and different levels of computing resources**
- **By restructuring the event processing structure to accommodate threaded applications we can meet the demands required for tracking in the future**

Speedup from