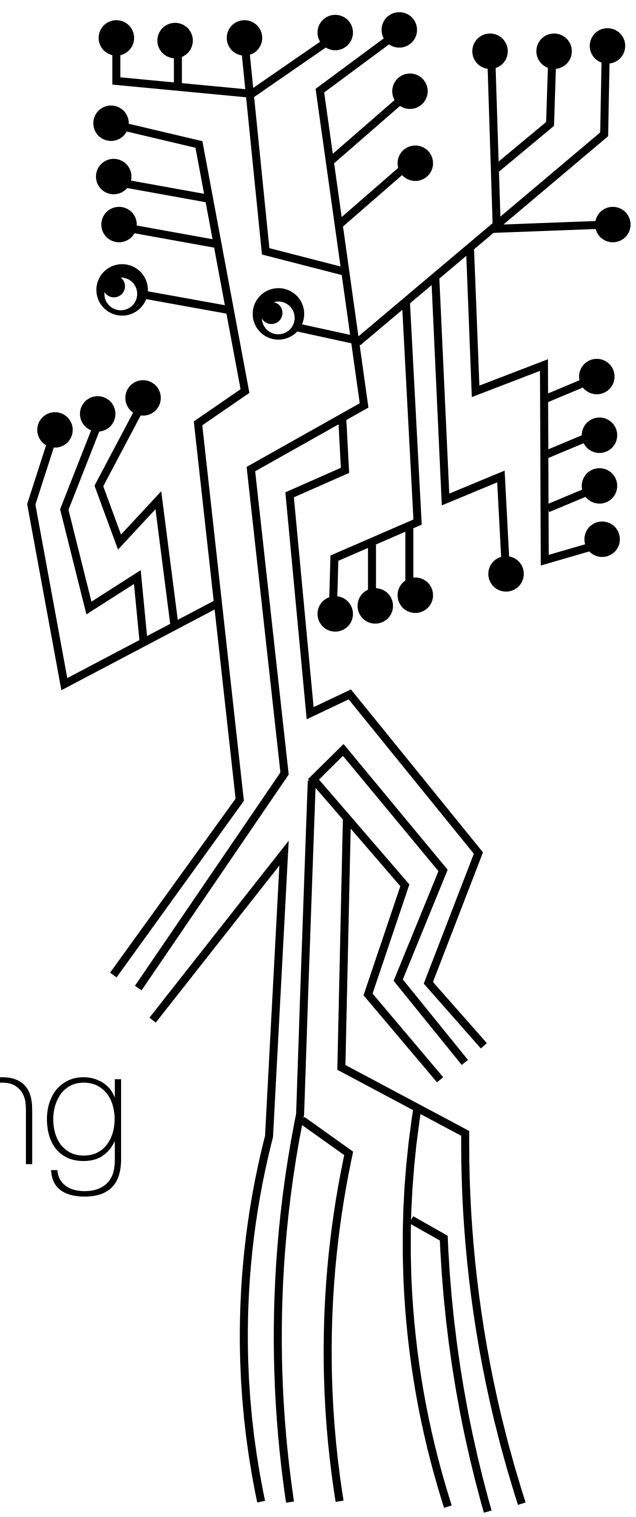
Tracking Machine Learning Challenge



A. Salzburger, CERN

Track reconstruction

pre-LEP/LEP (most of)

finding tracks

↓

fitting tracks

↓

classifying tracks

today

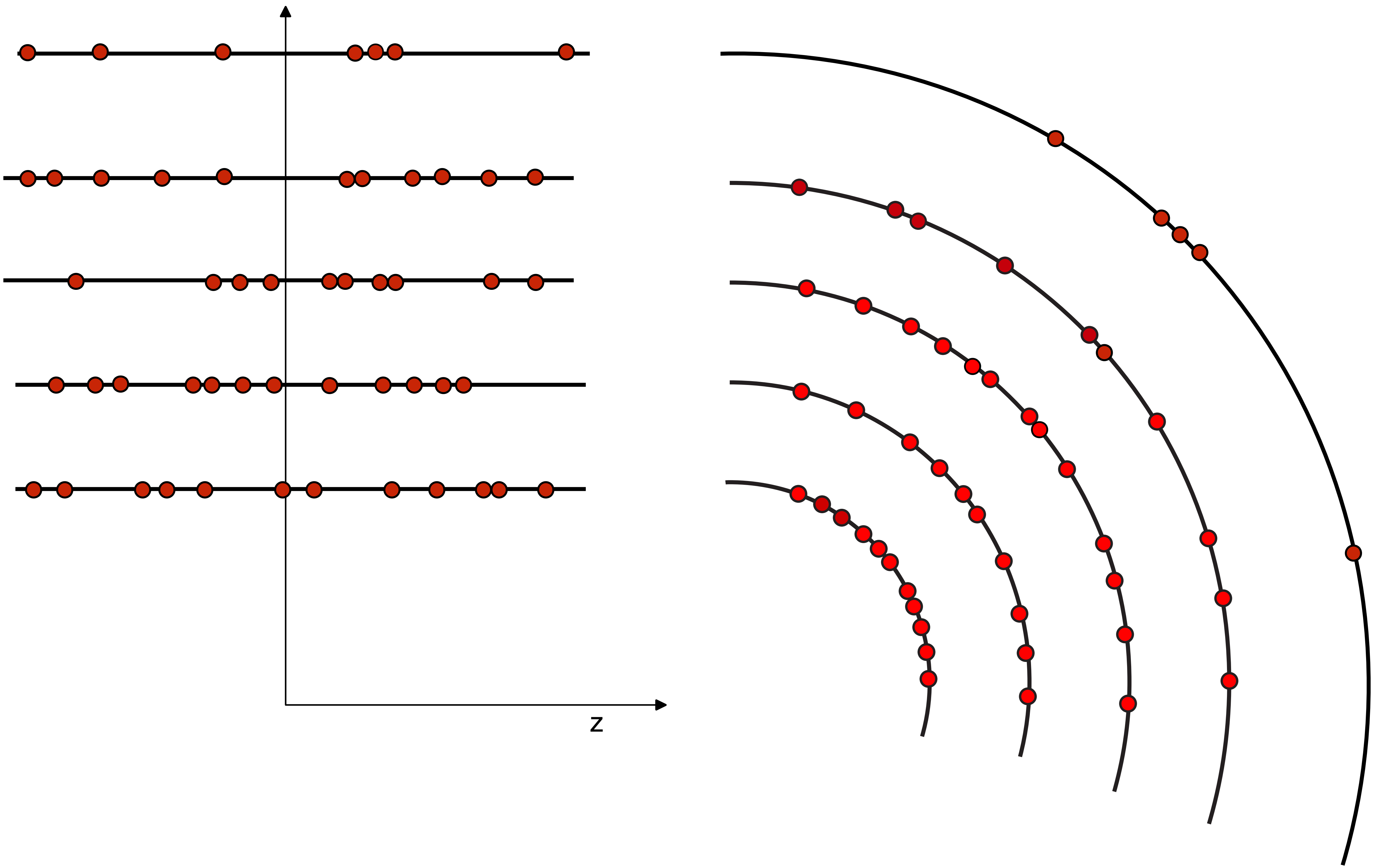
finding

tracks

classifying

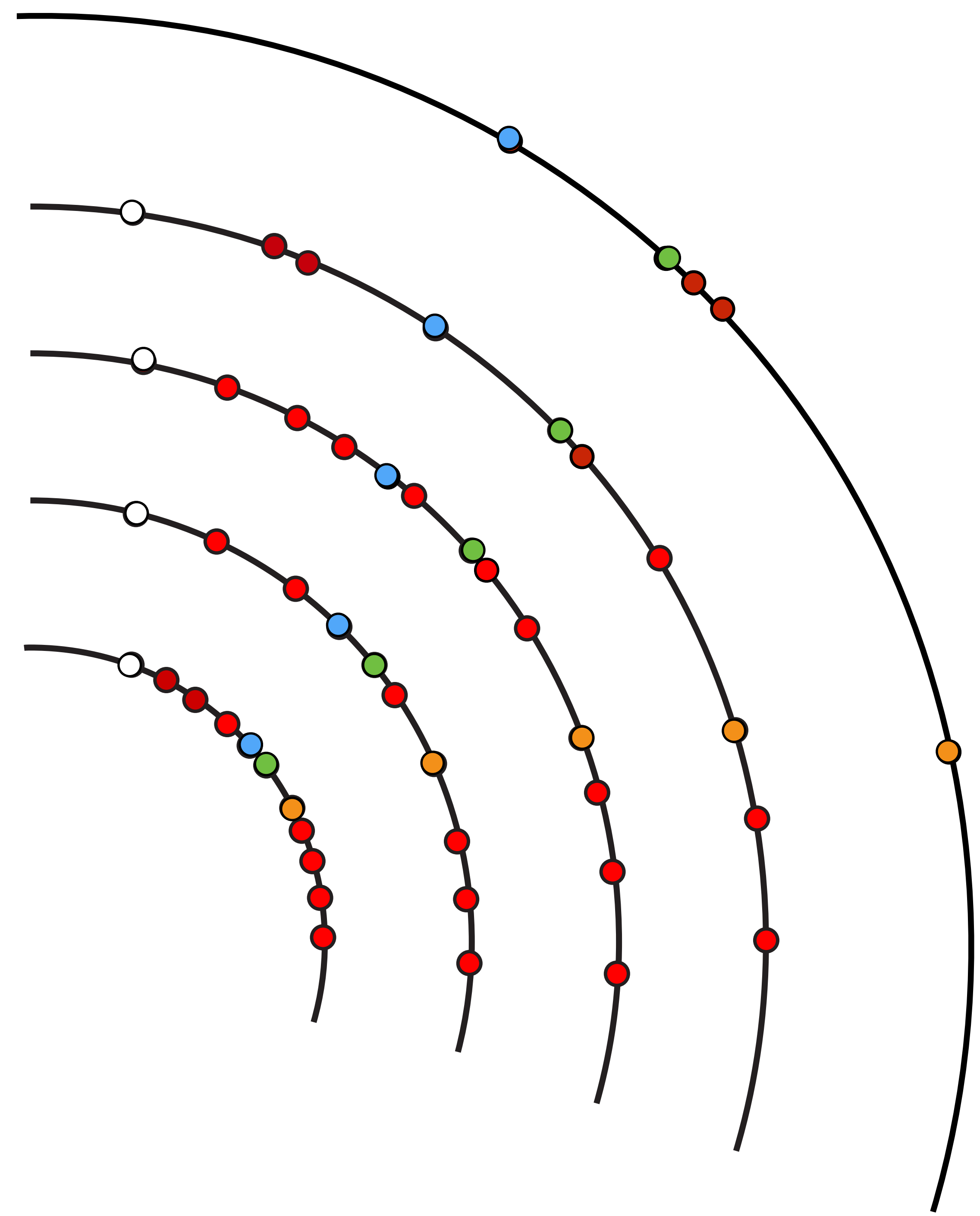
fitting

The problem: finding tracks



Global pattern recognition strategies

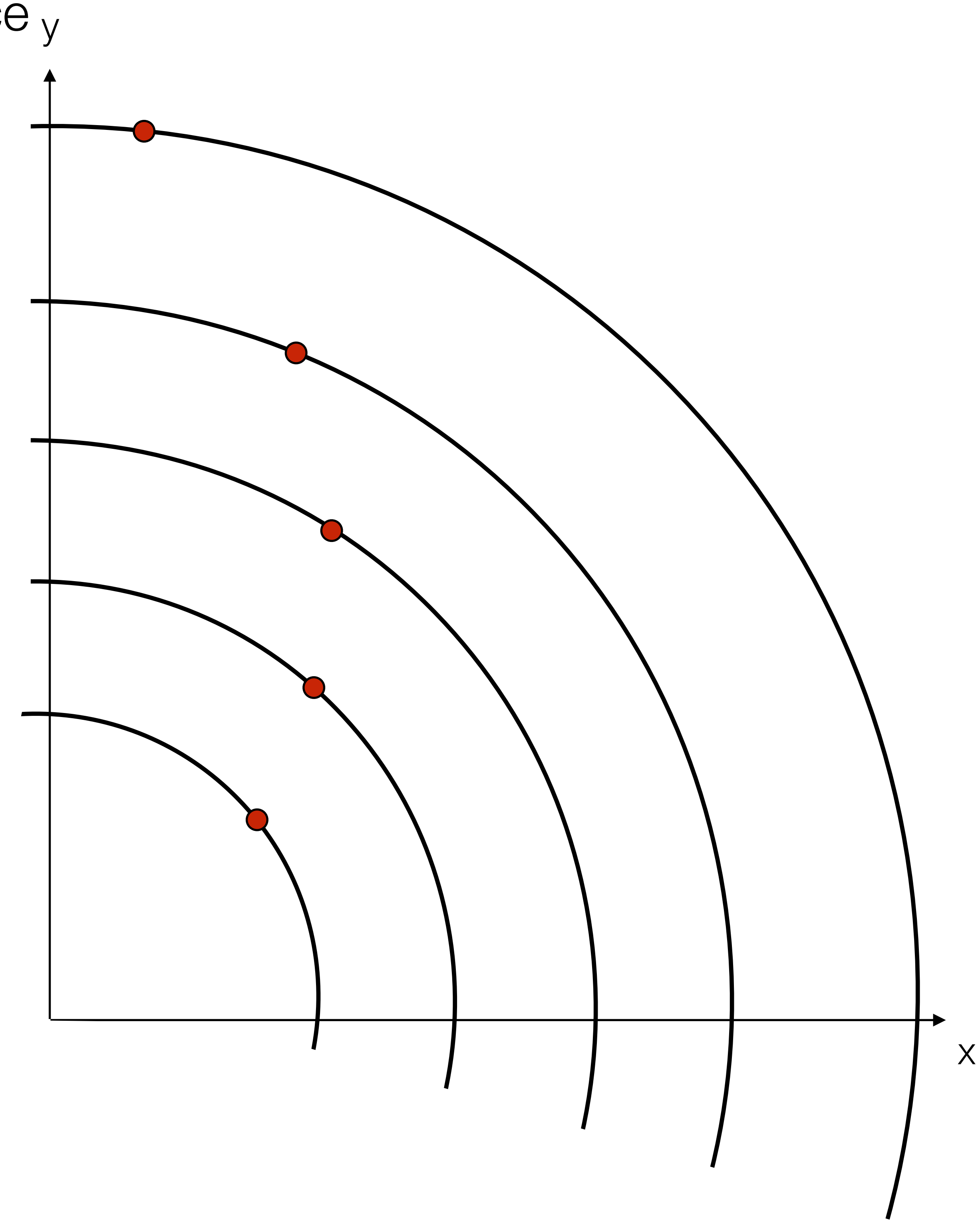
- Conformal mapping
  - the idea of conformal mapping is to transform your hit information into a parameter space, where your groups of hits are visible
  - you need a transformation for it which assumes a track model



Global pattern recognition strategies

- Conformal mapping : <u>Hough transform</u>
  - transform your track hits from the x, y space into a more appropriate space
  - let's assume that particles come from the interaction region + solve in the transverse direction

$$\mathbf{q} = (d_0, z_0, \phi, \theta, q/p)$$



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$$\downarrow$$

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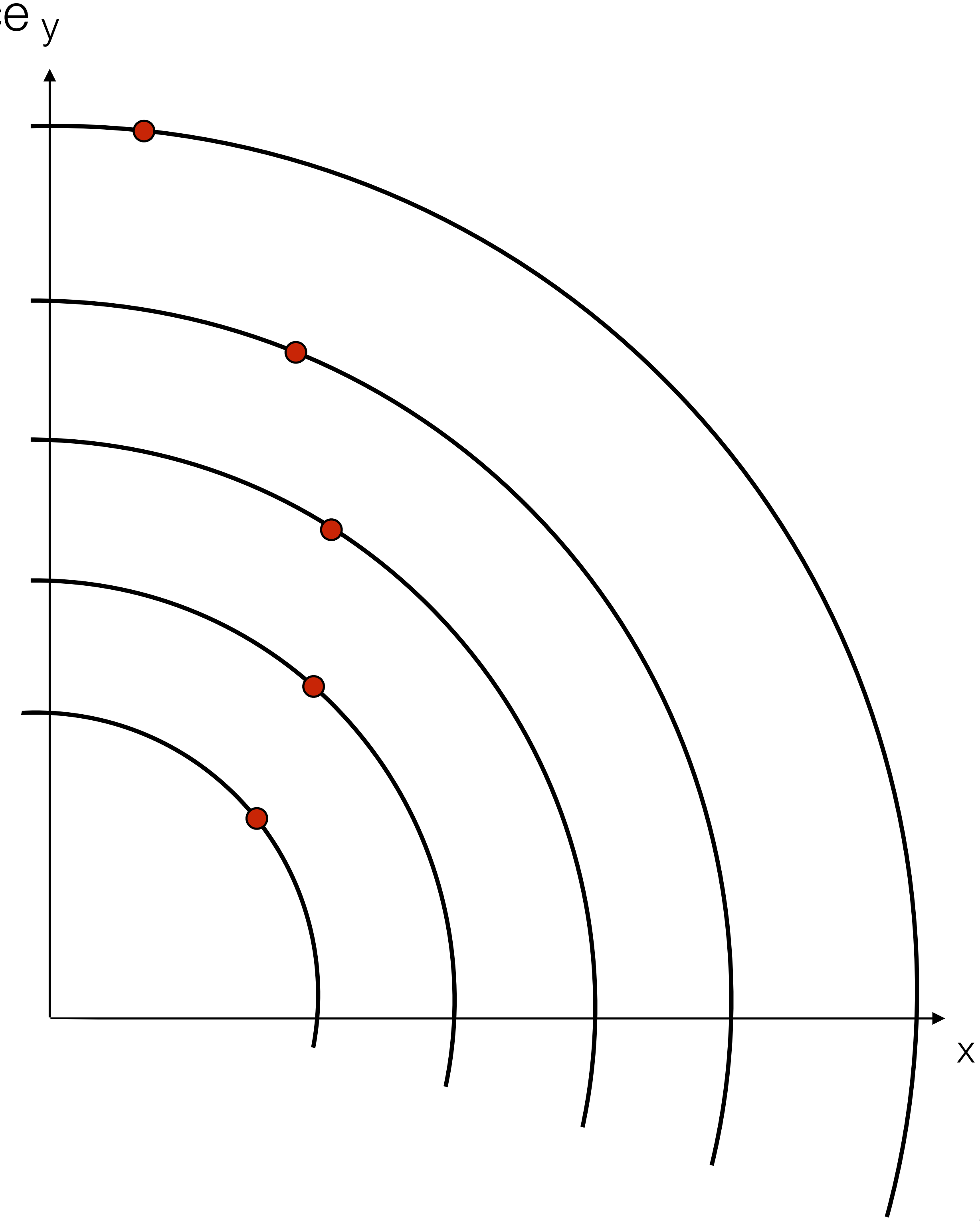

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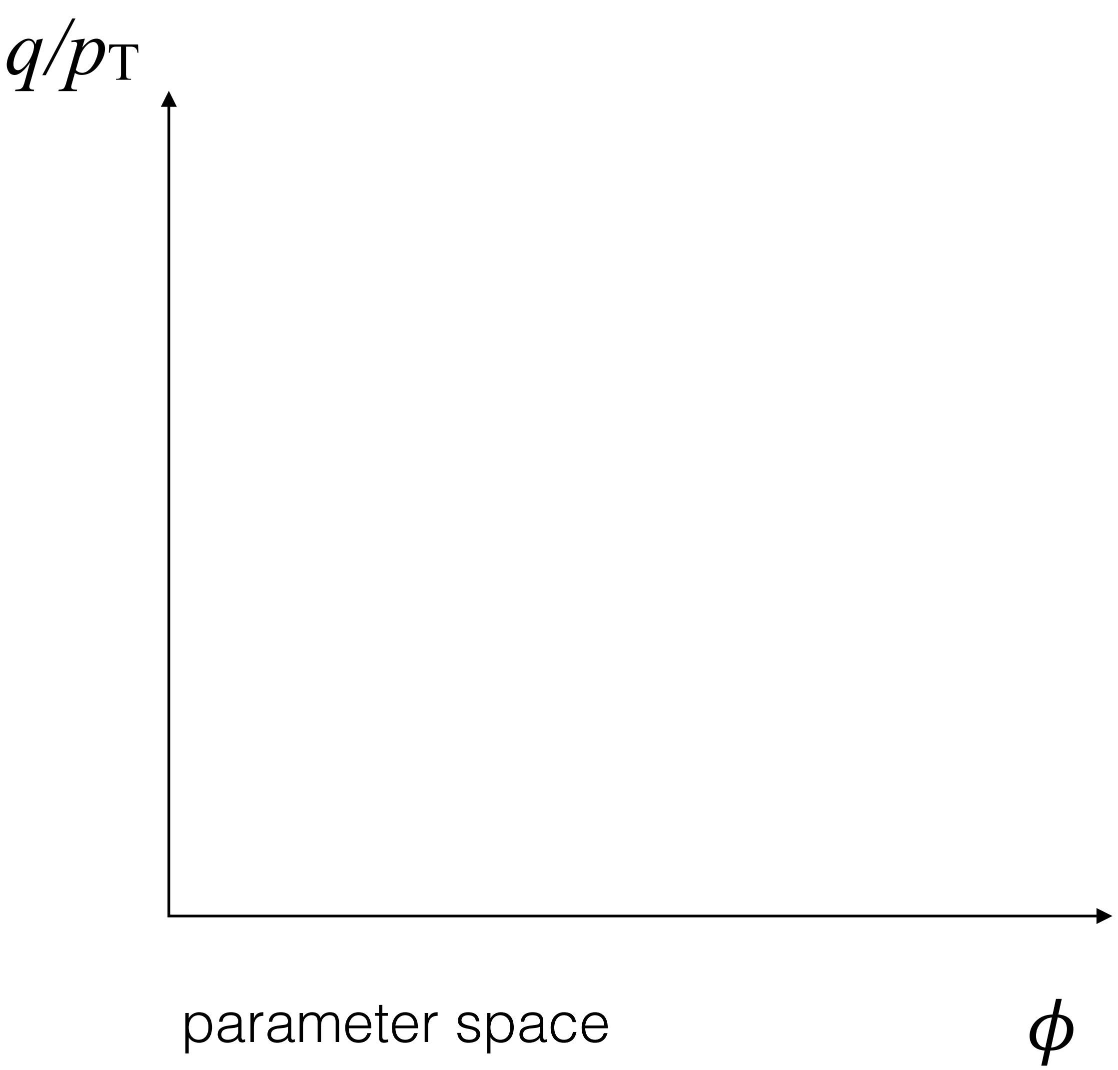

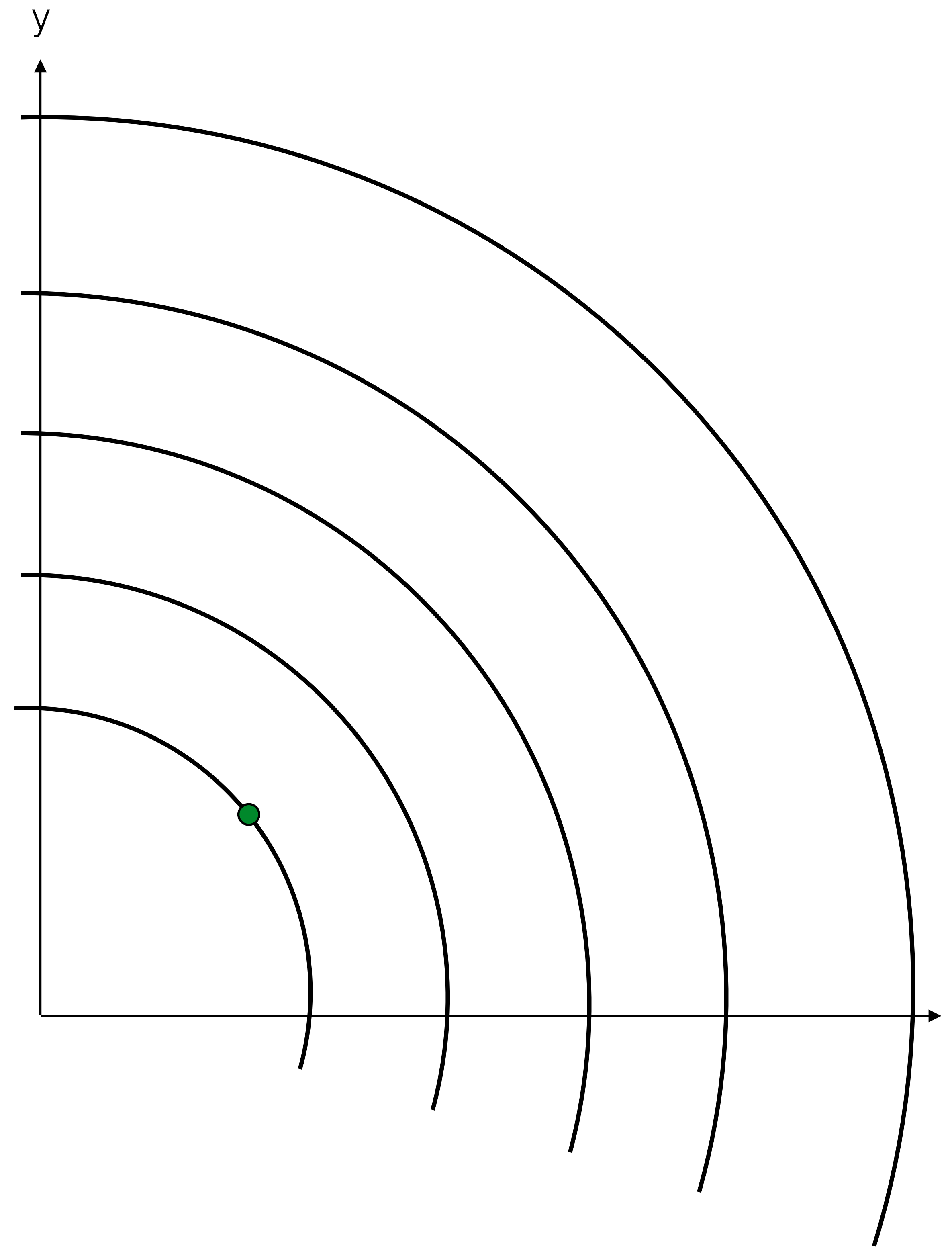

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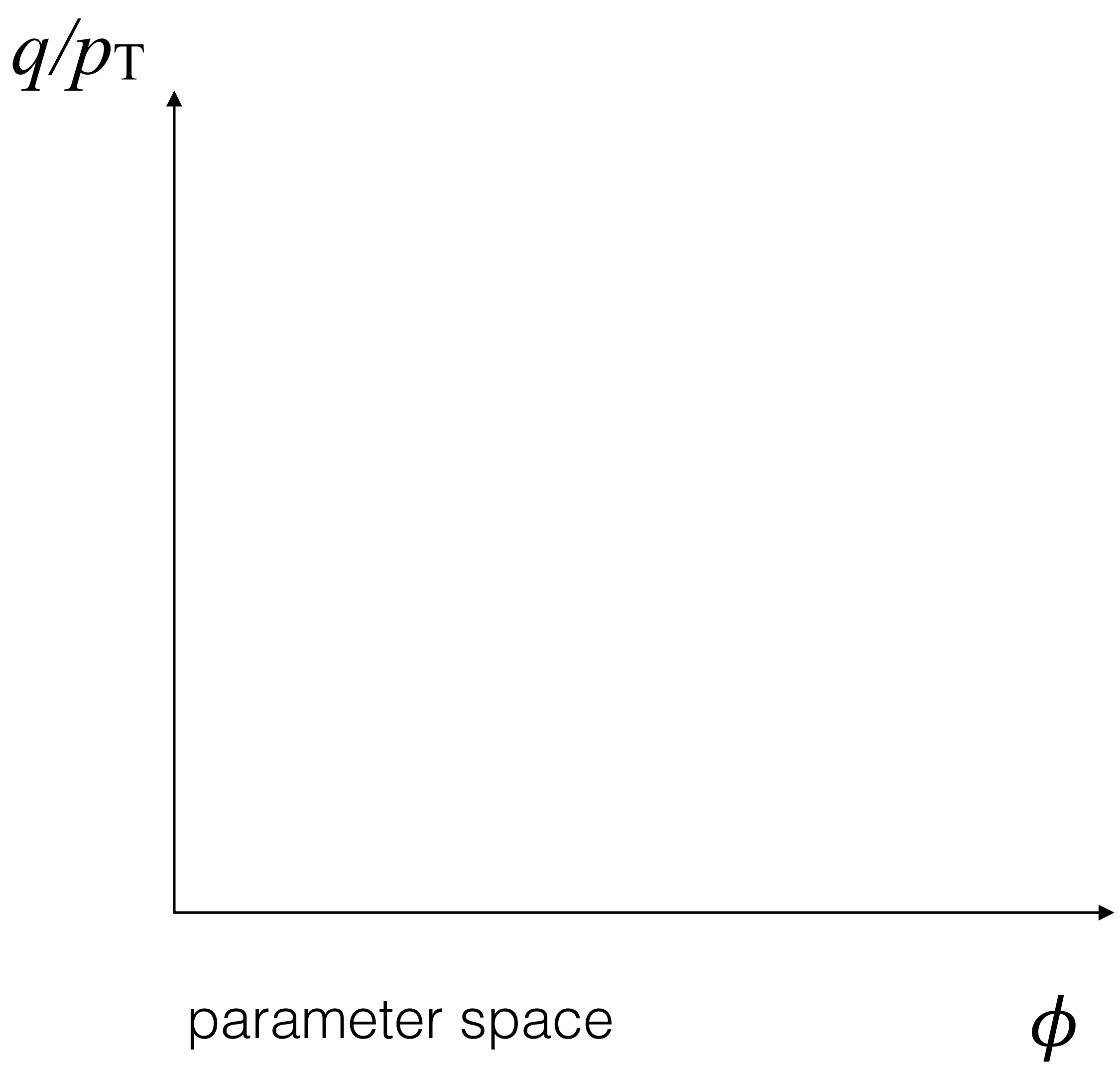

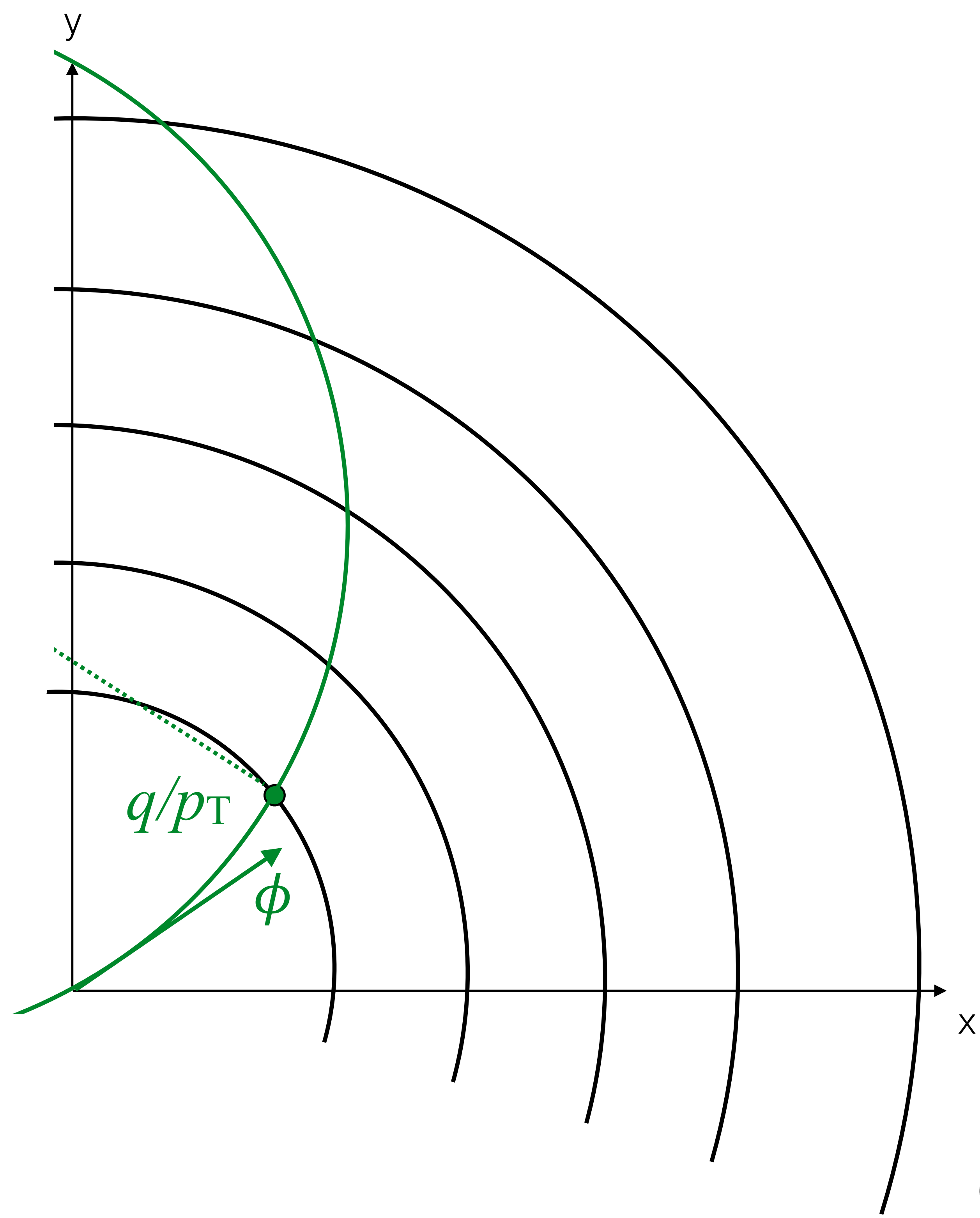

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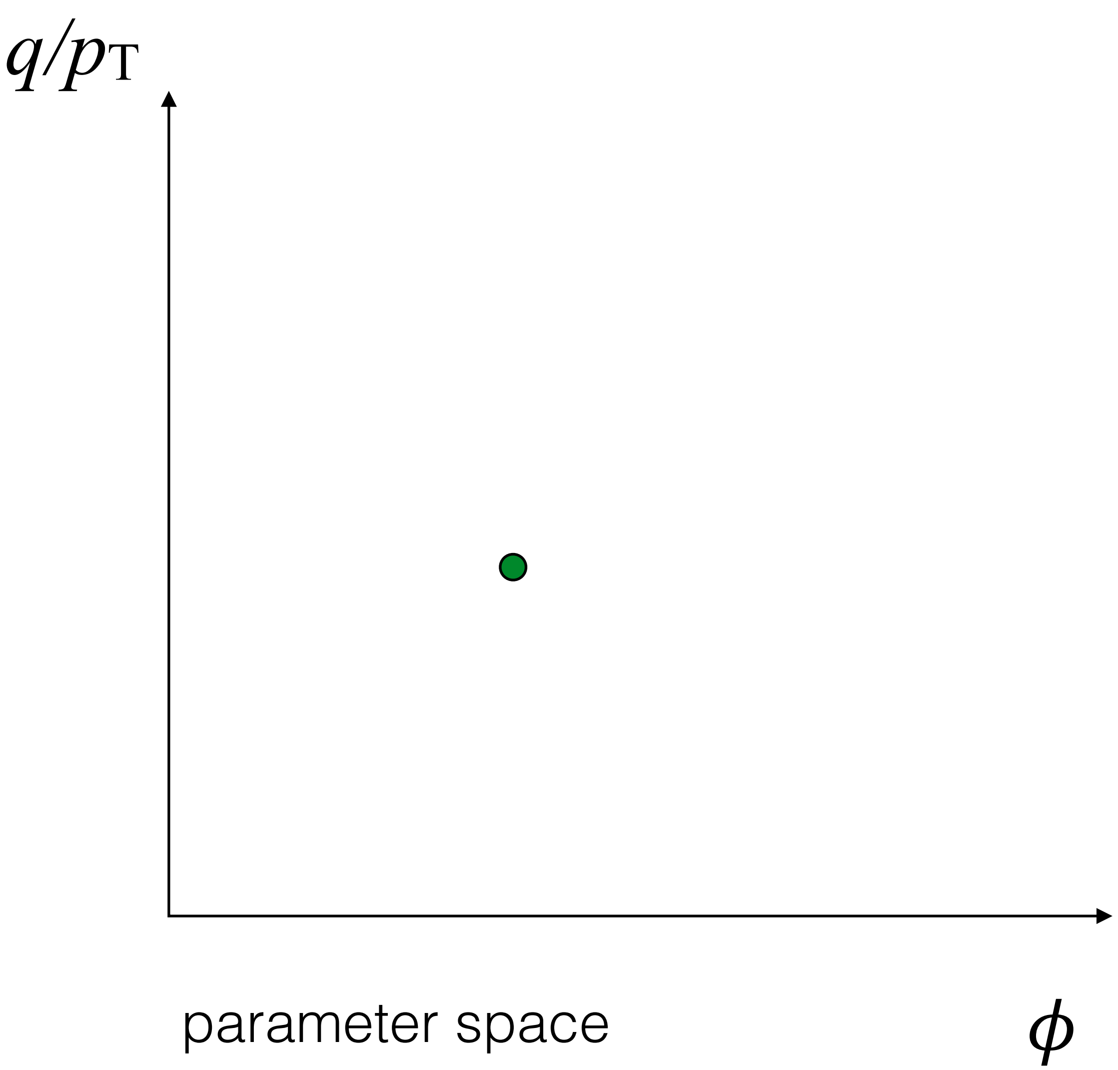

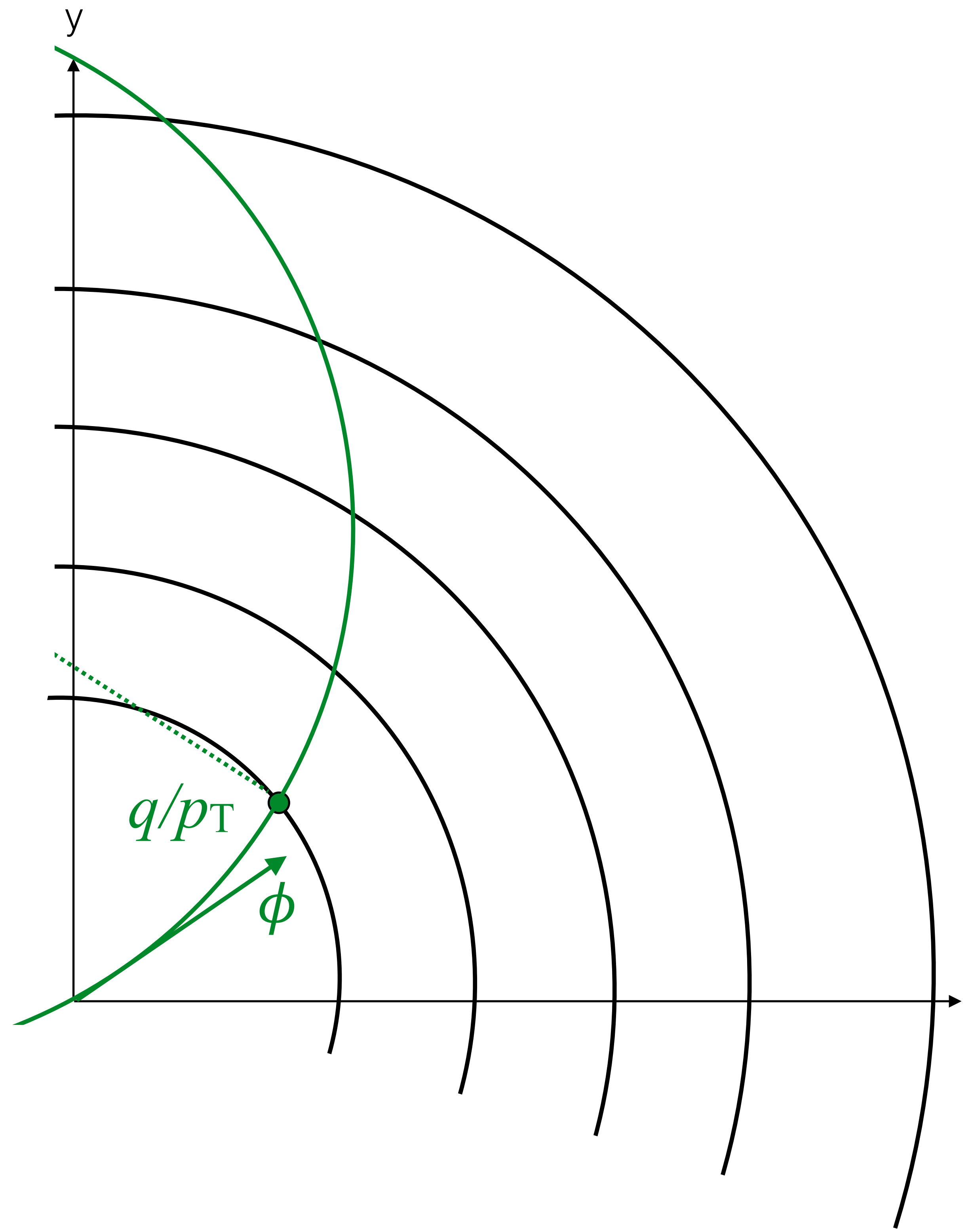

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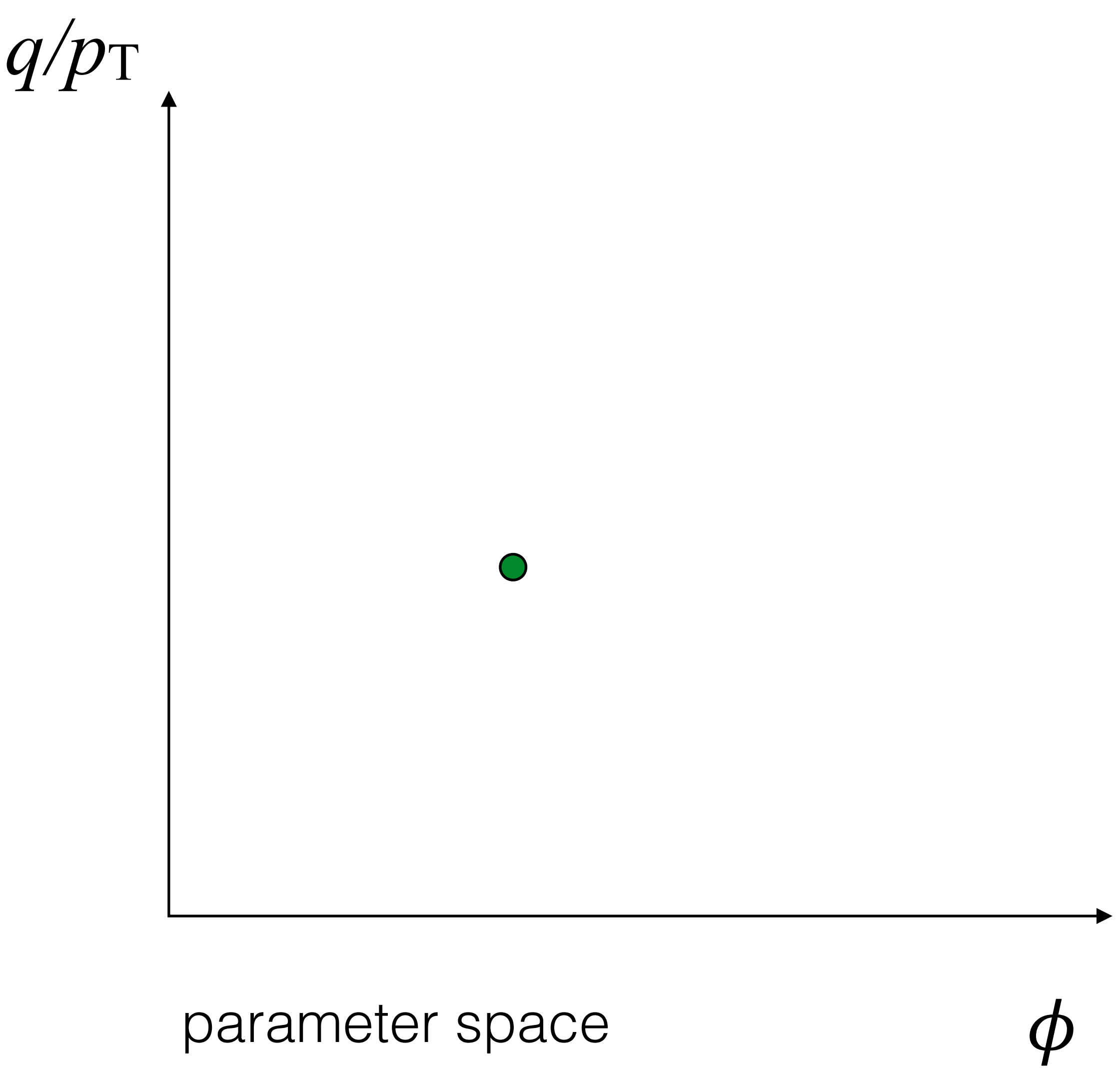

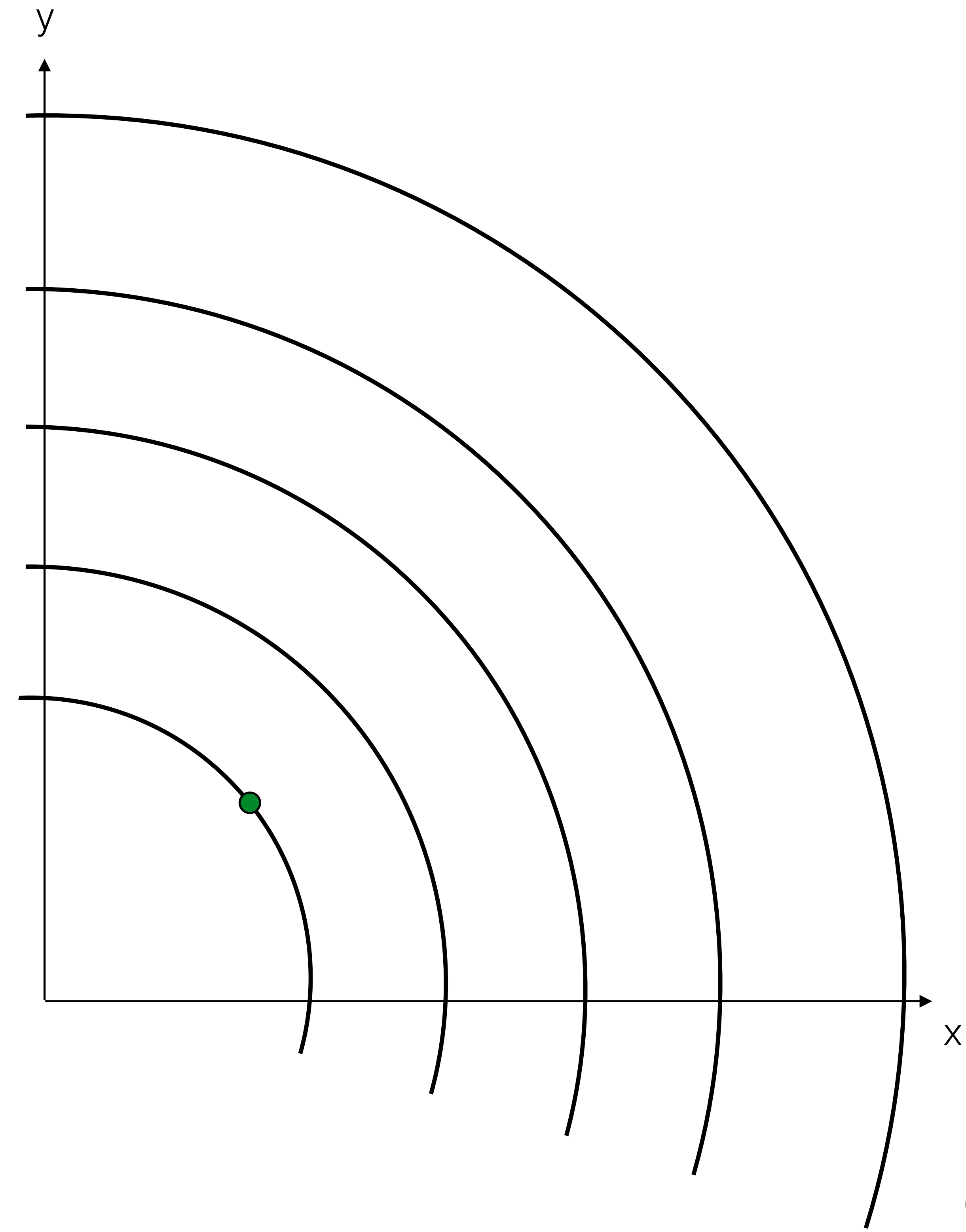

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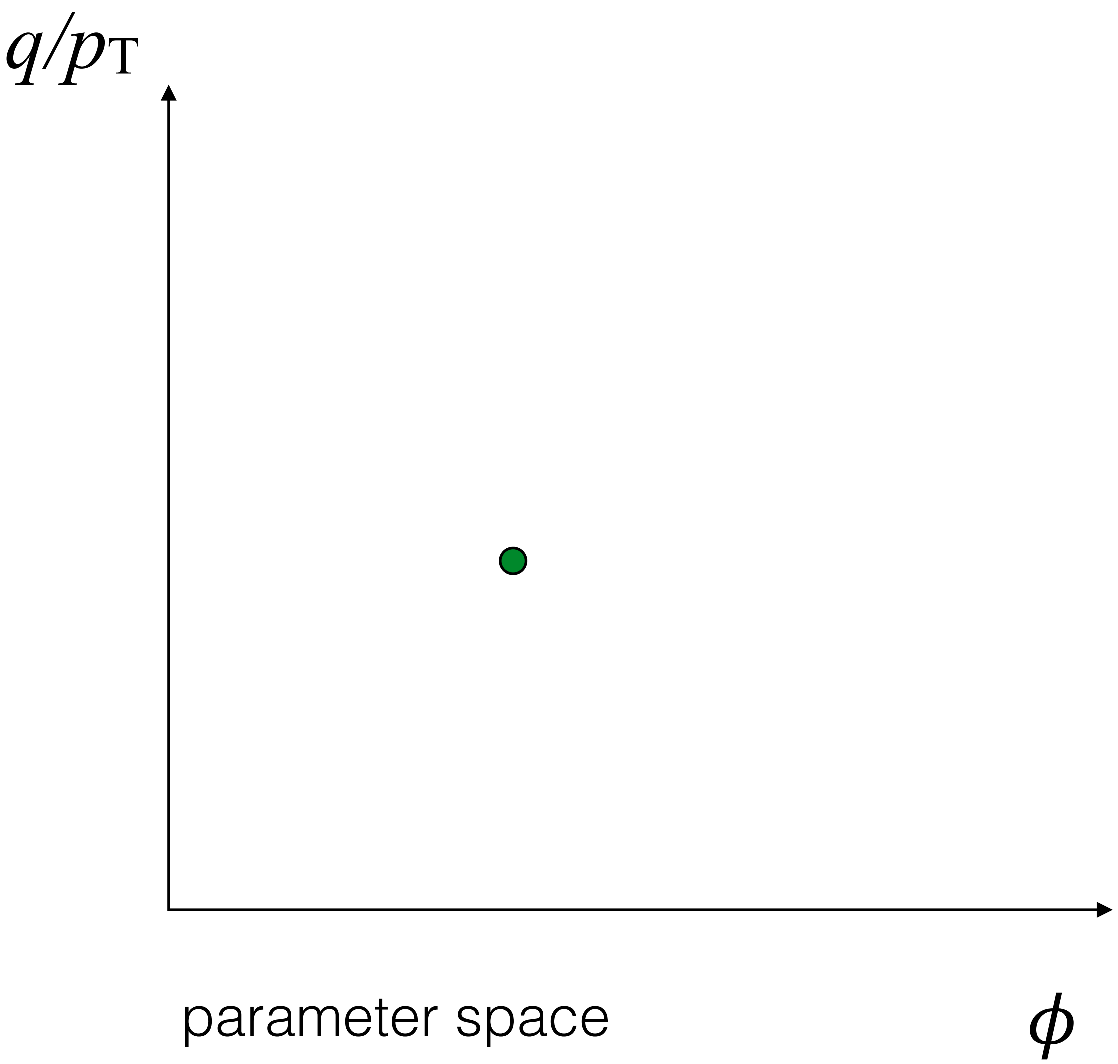

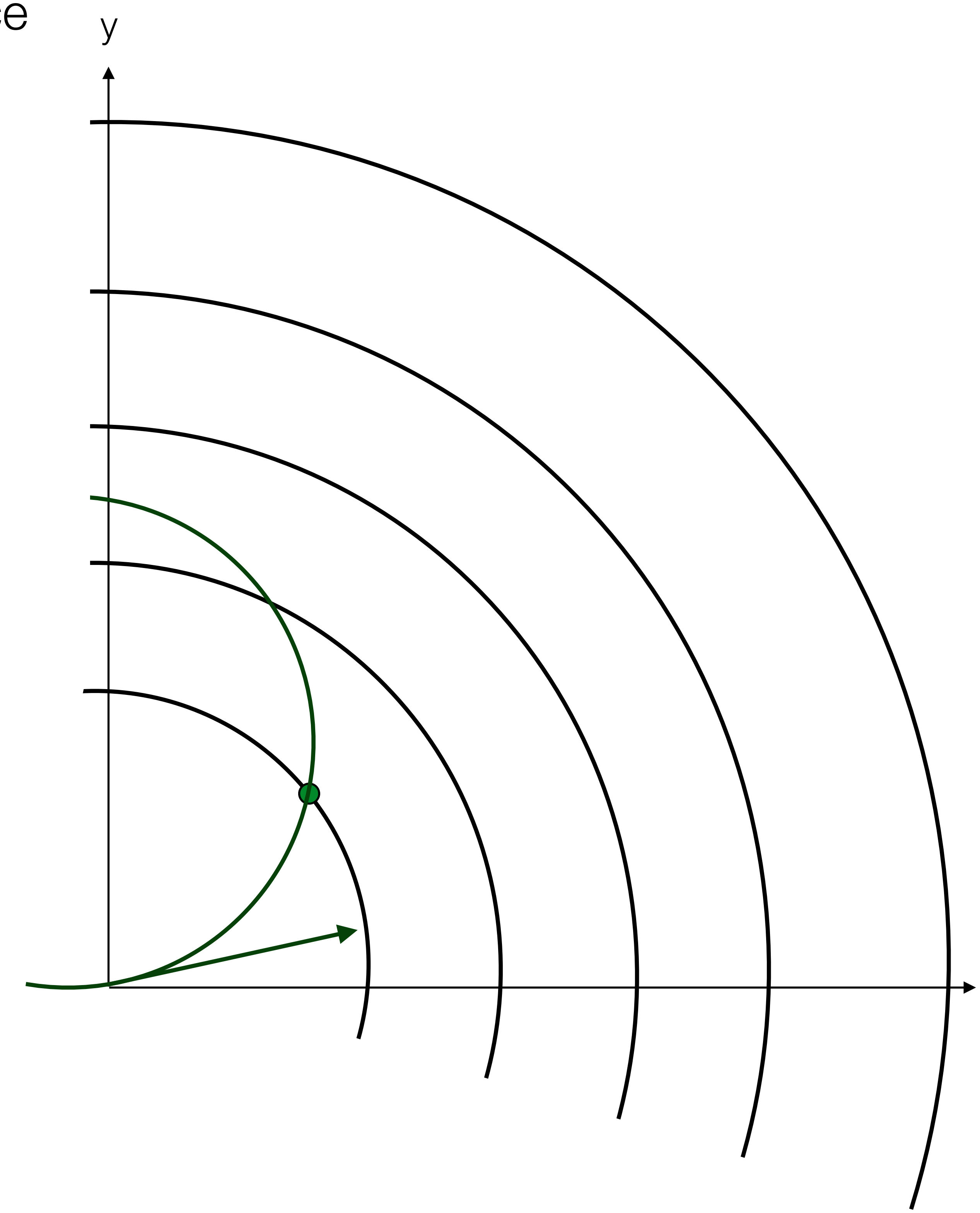

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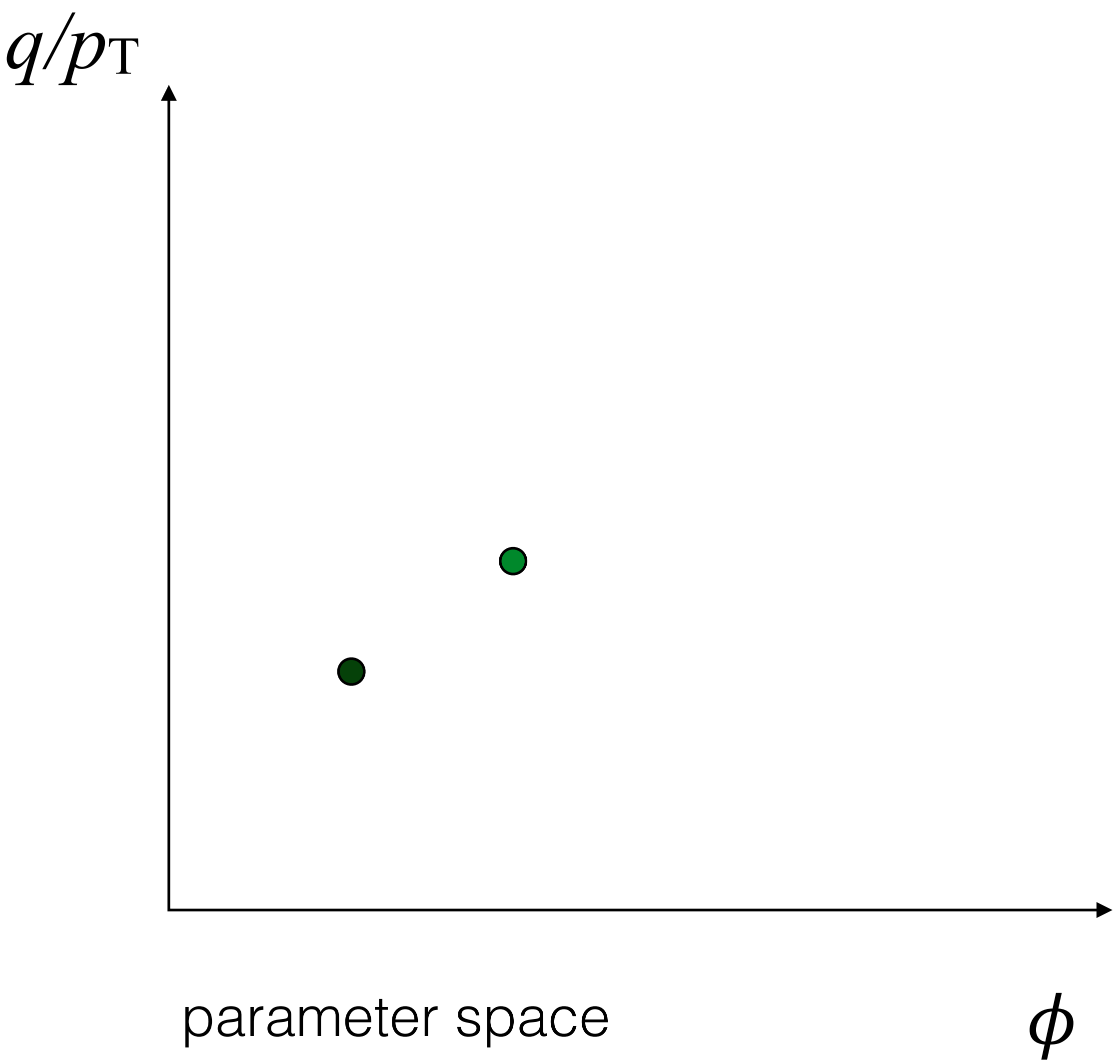

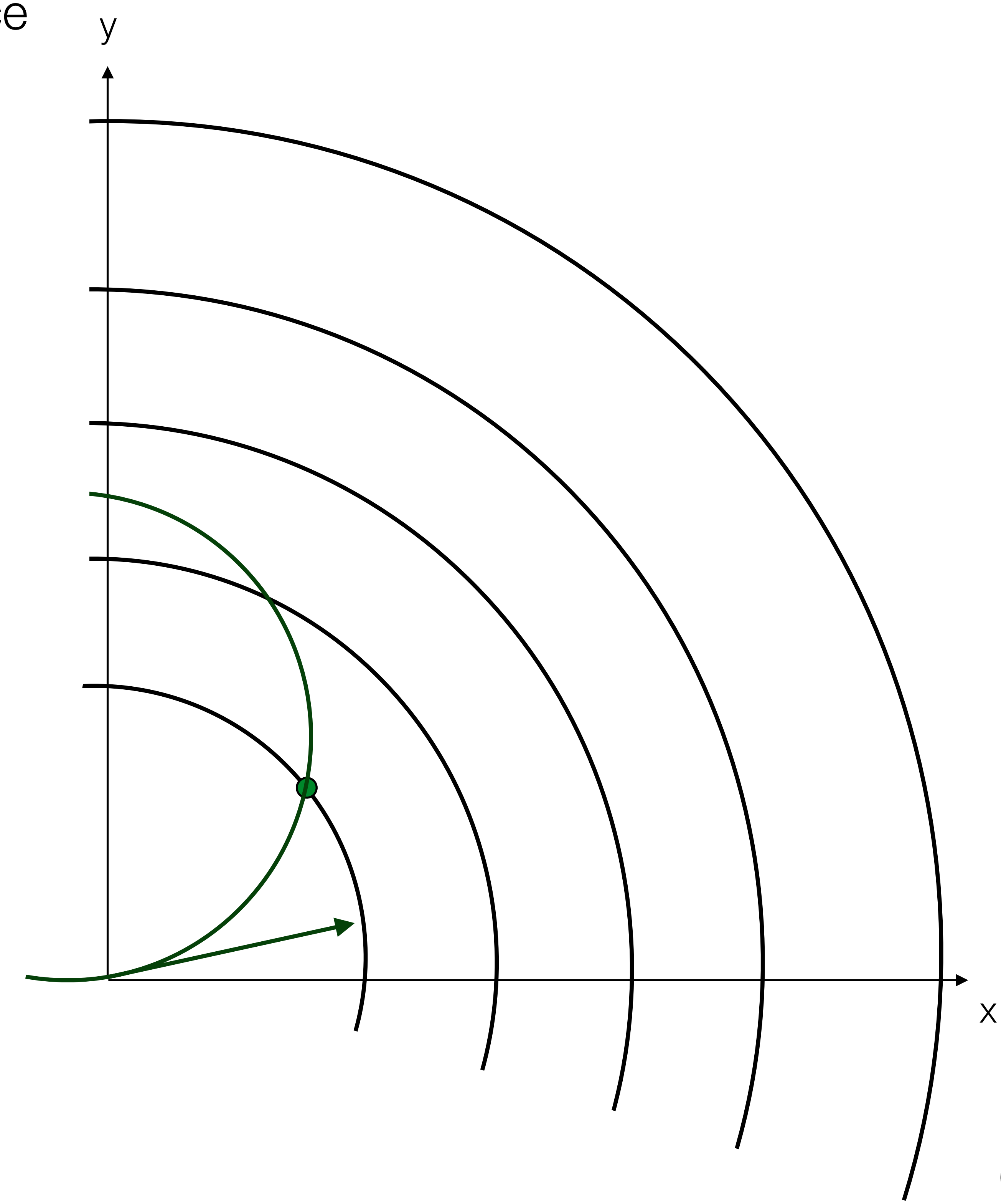

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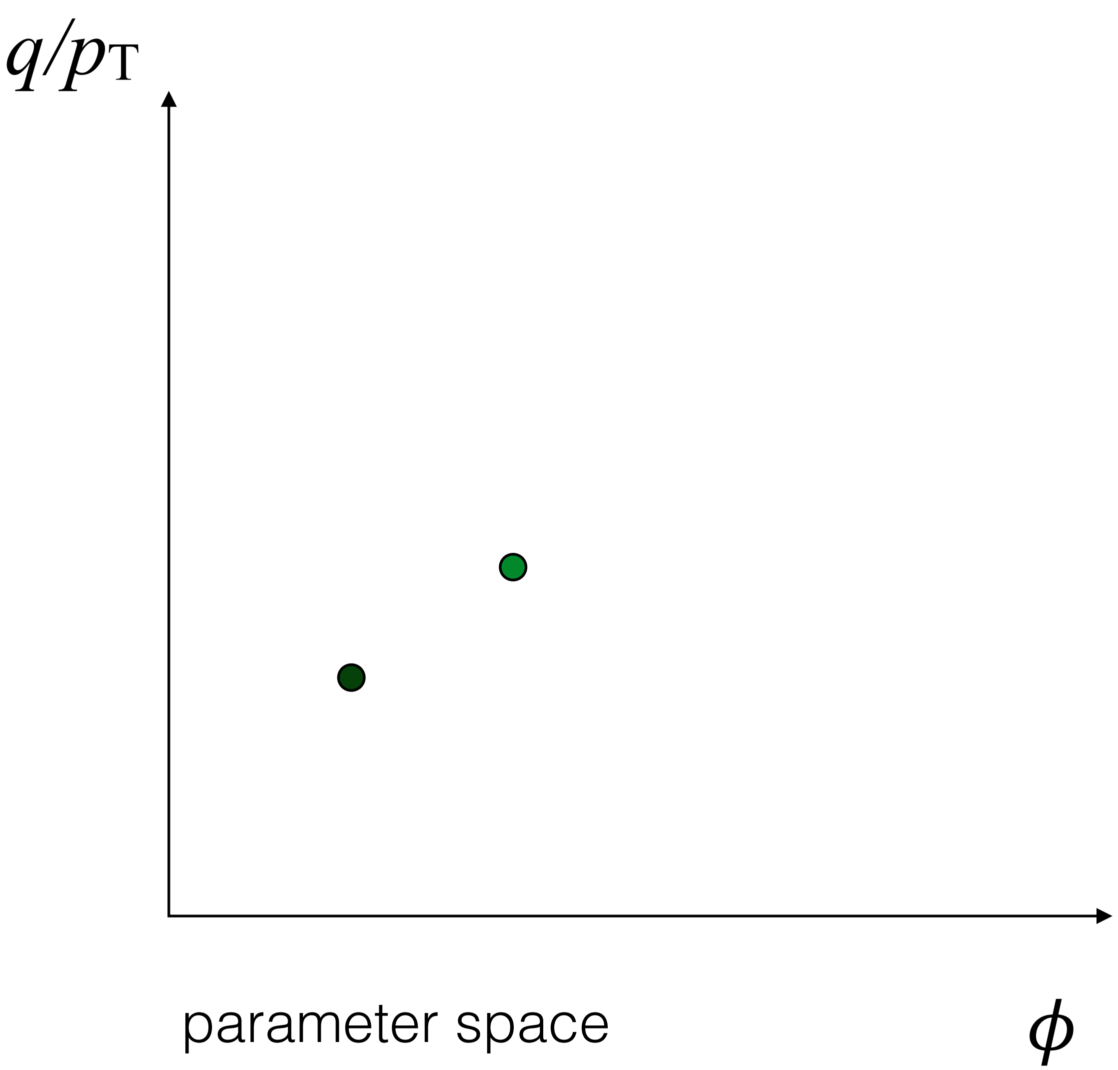

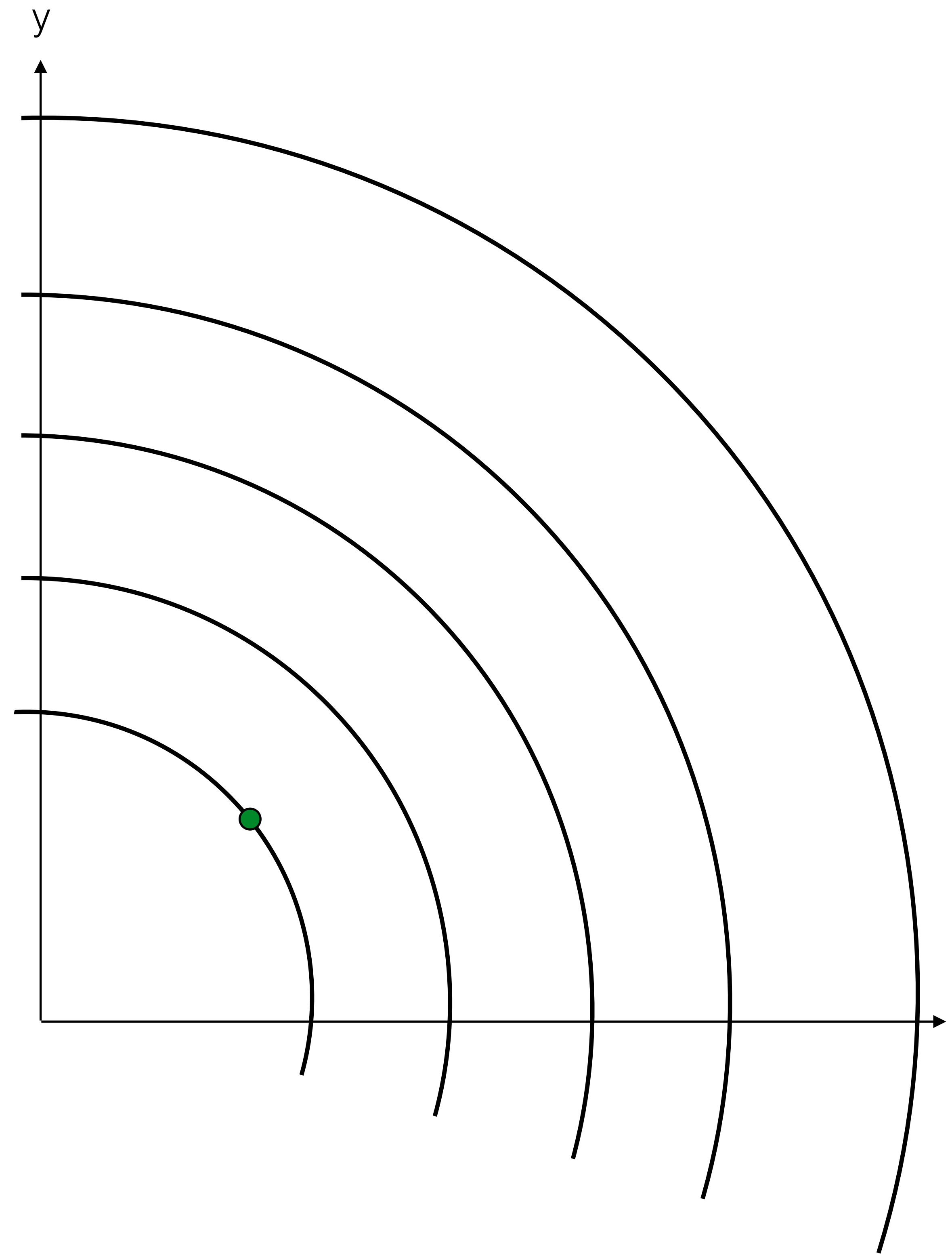

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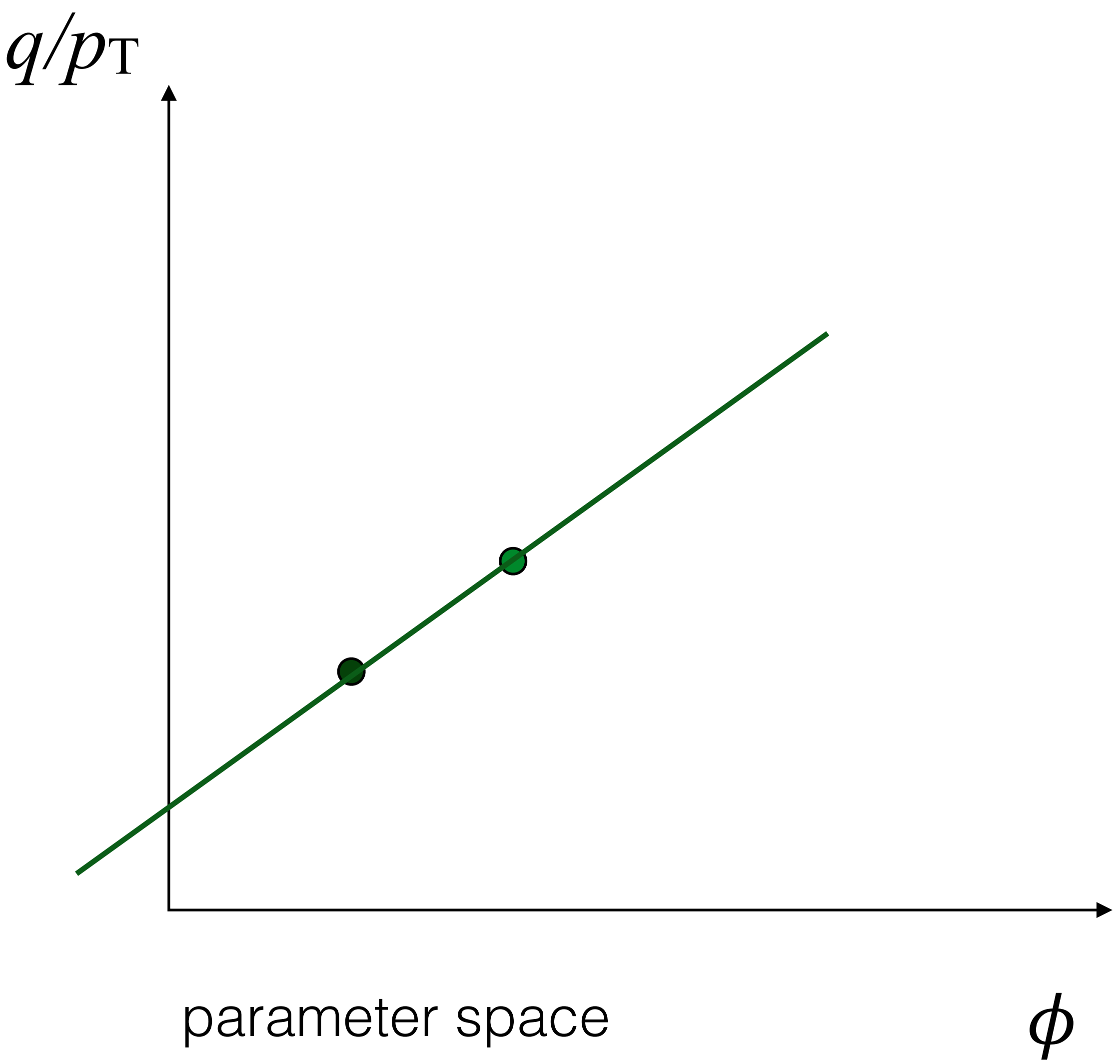
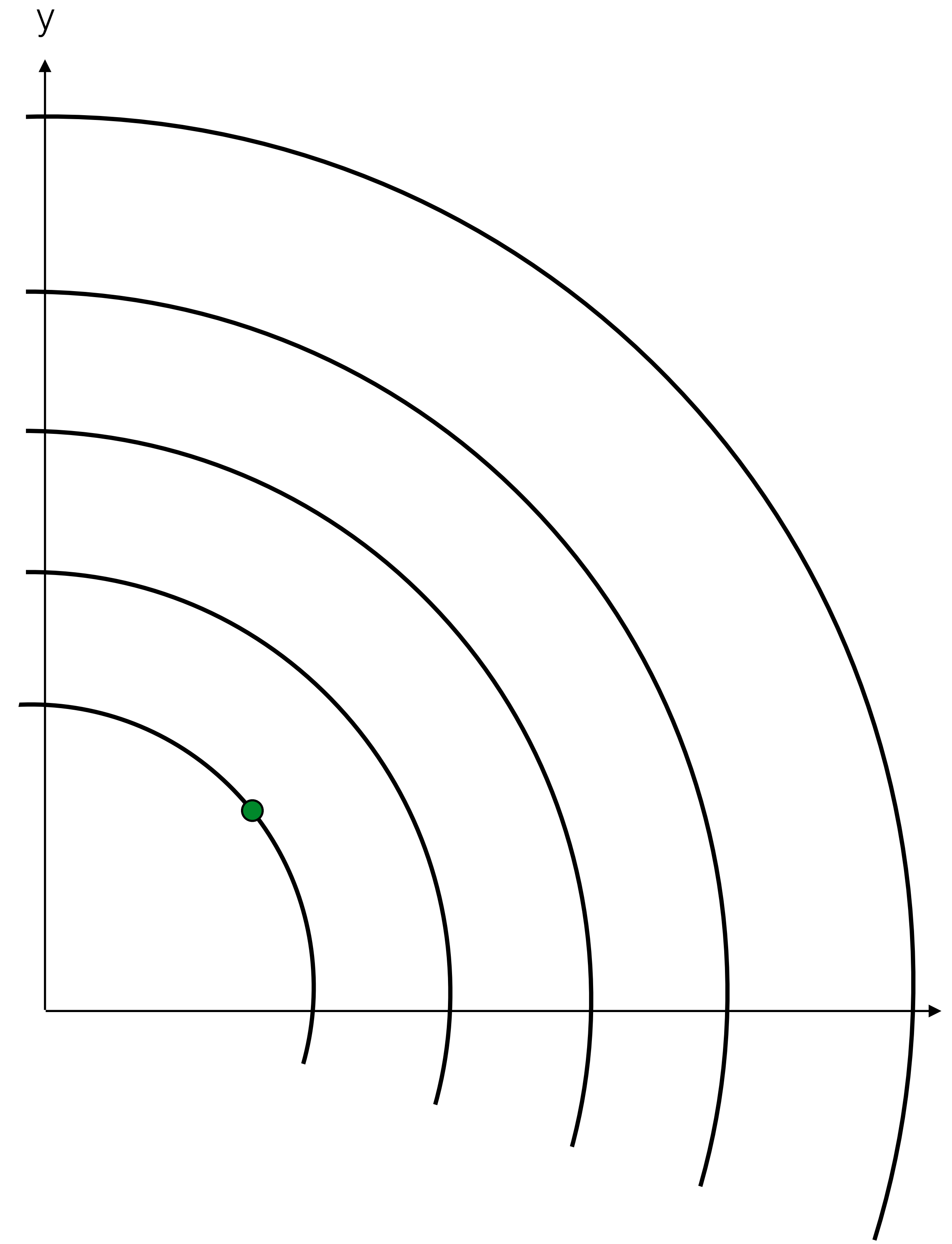


parameter space



Hough transform

In an ideal world …

- Conformal mapping
  - transform your track hits from the x, y space

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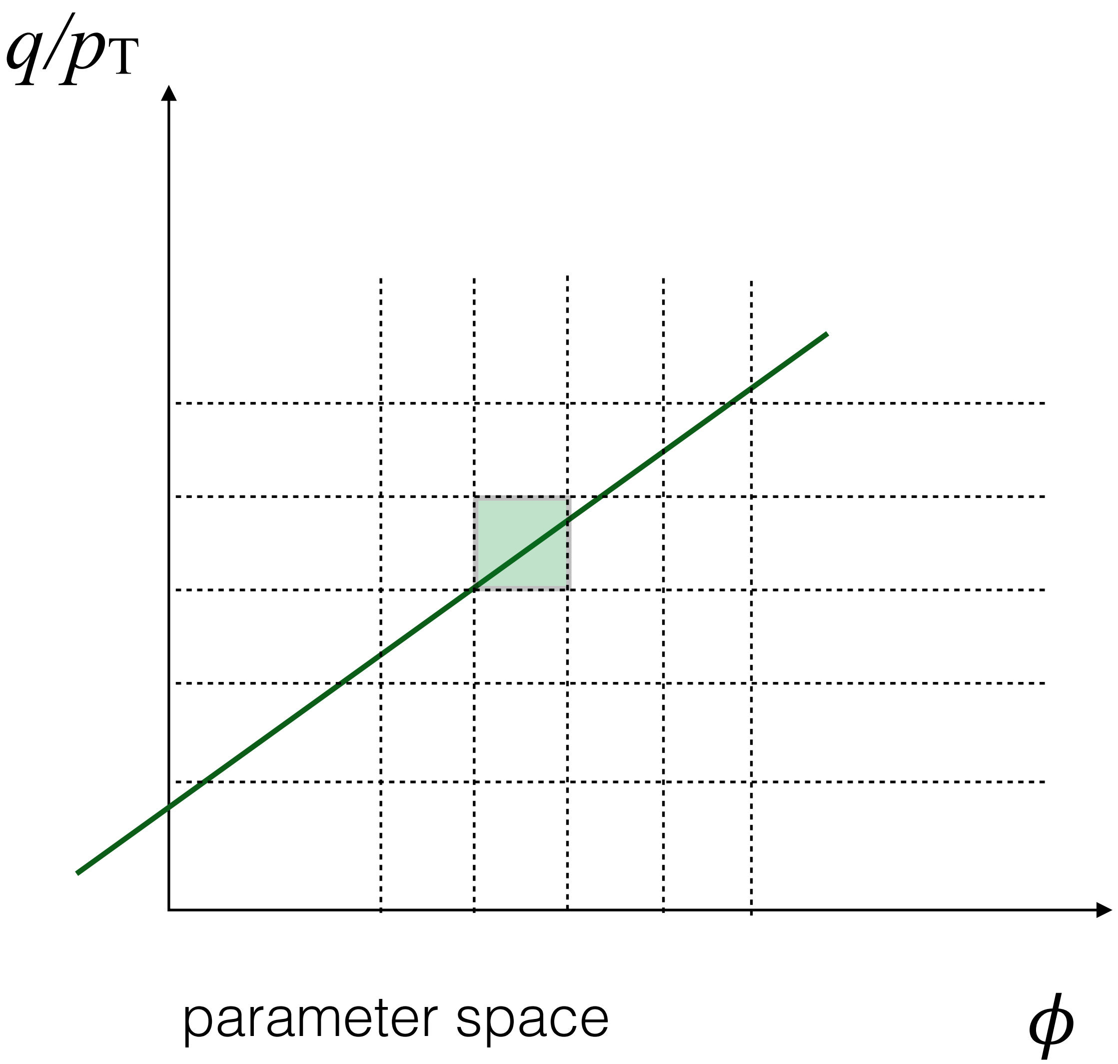

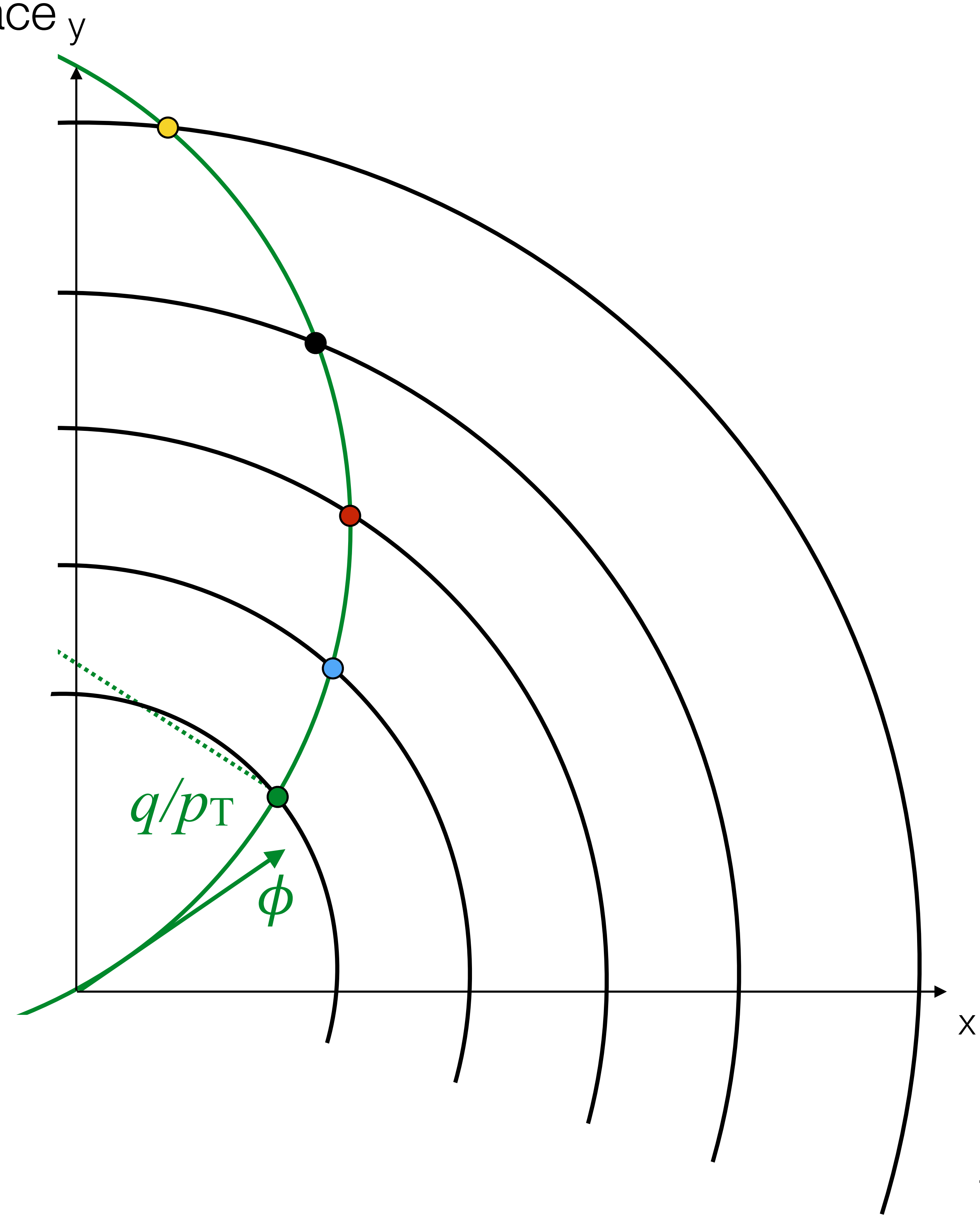

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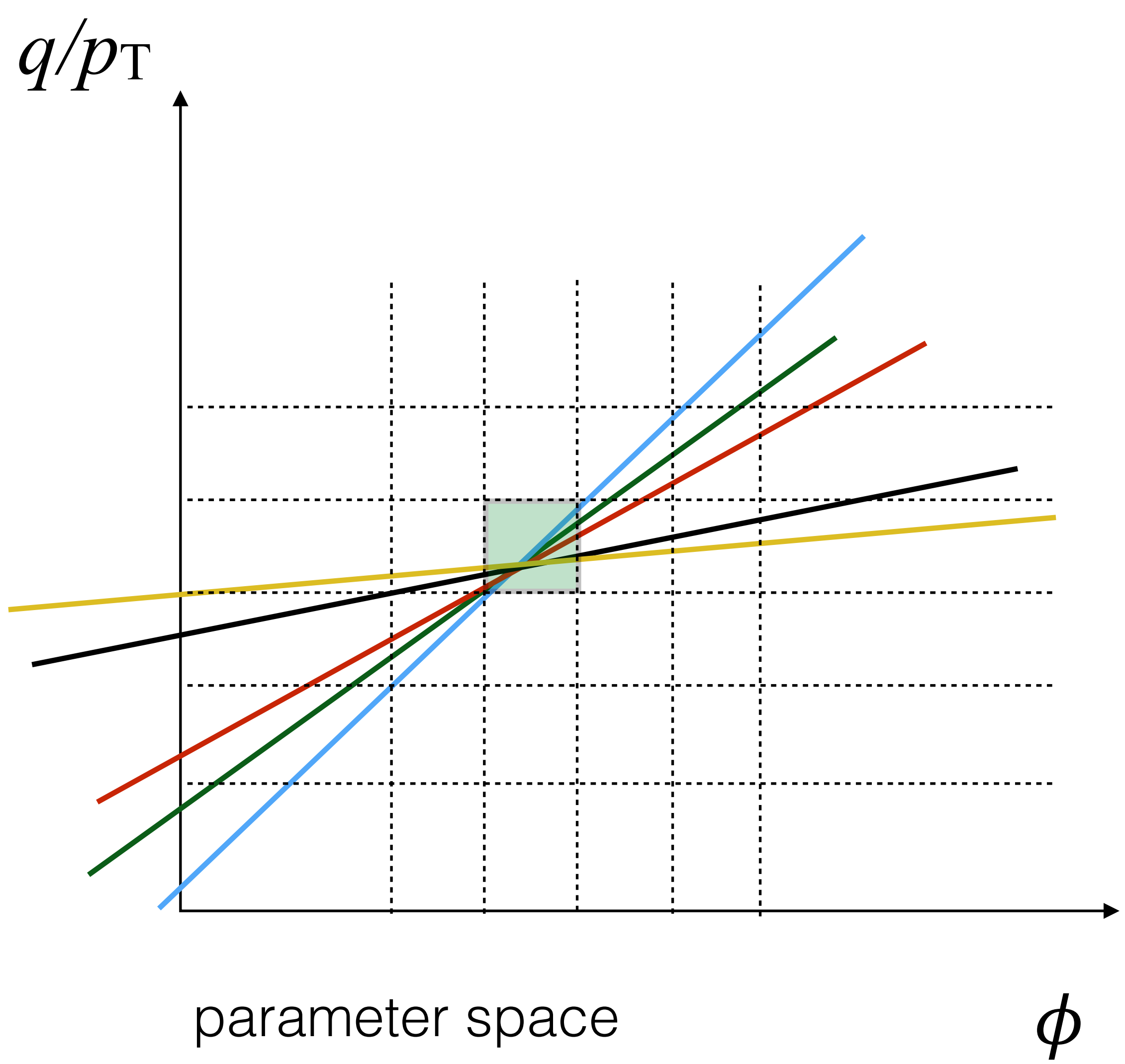
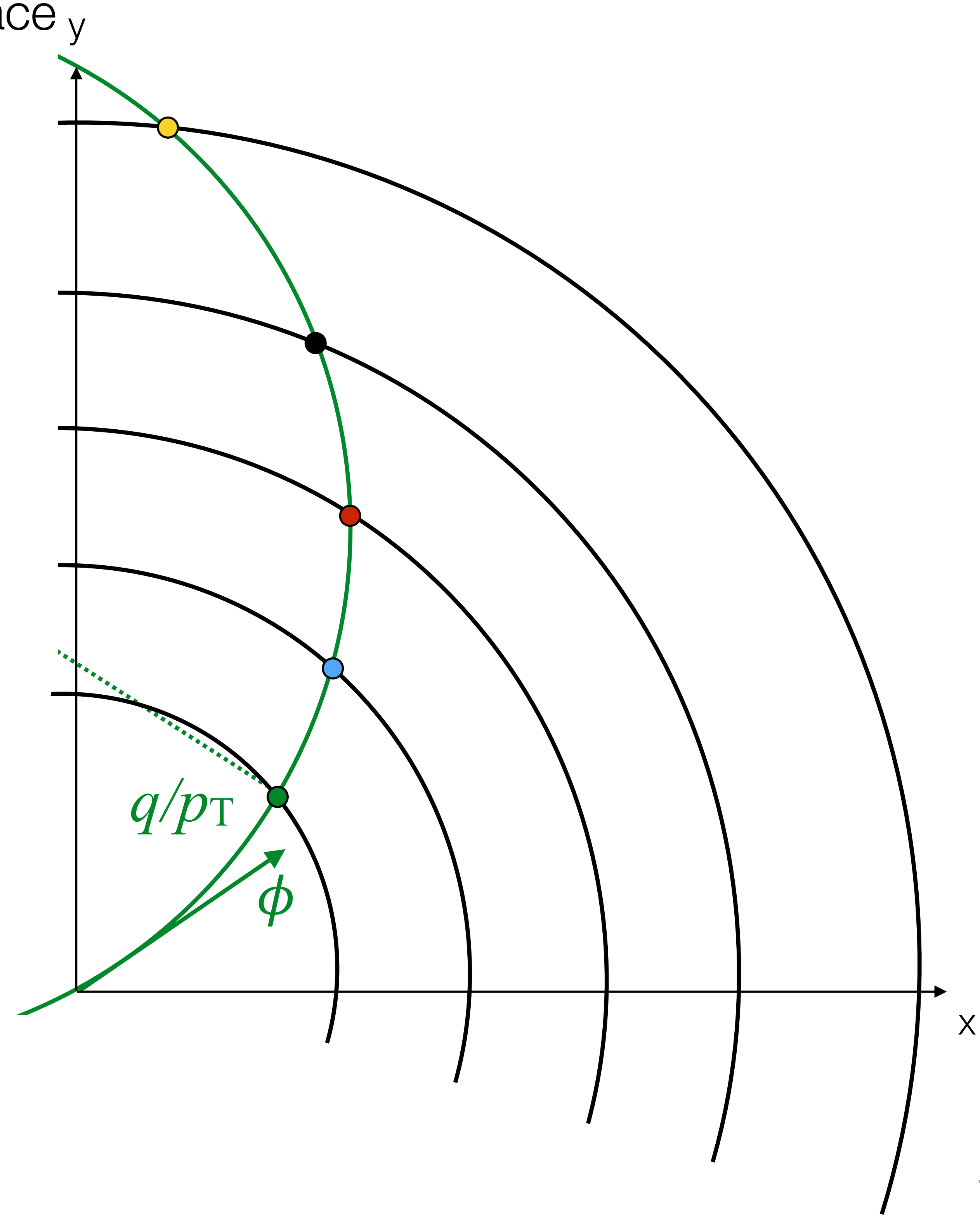
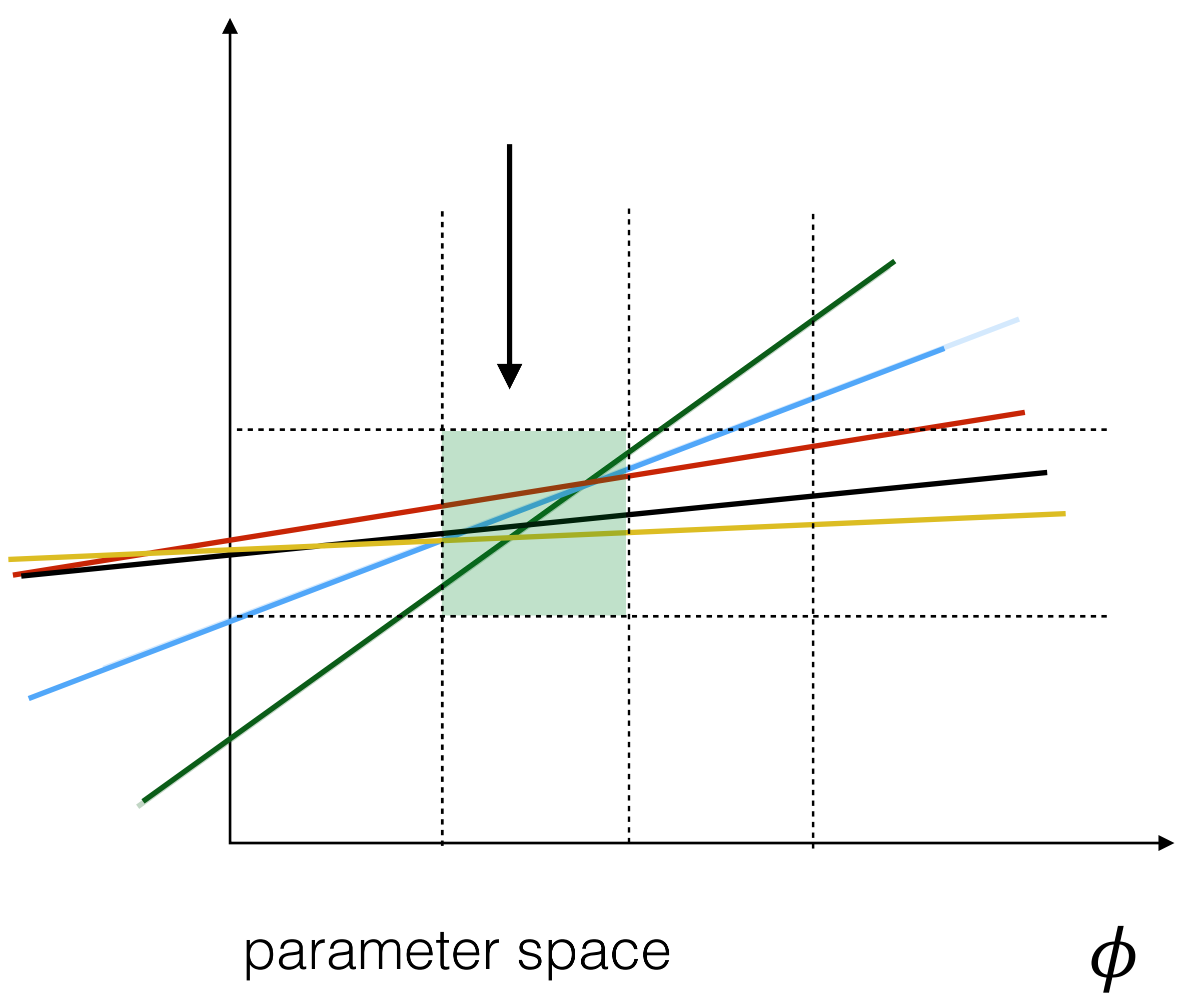
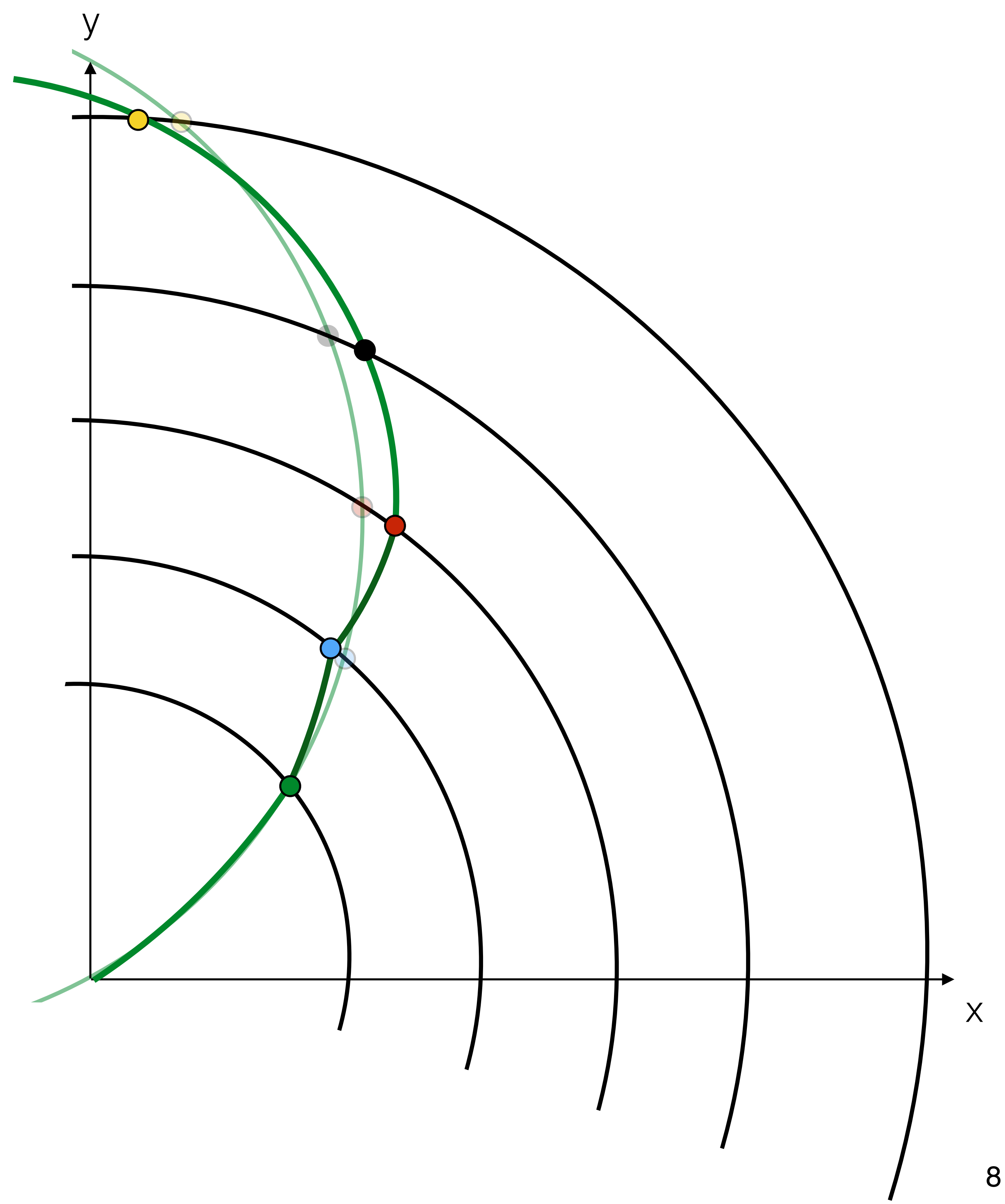




Conformal mapping - the problems

- Conformal mapping works nicely in an ideal world
  - reality is a bitch though:
    material interaction, inhomogenous
    magnetic field

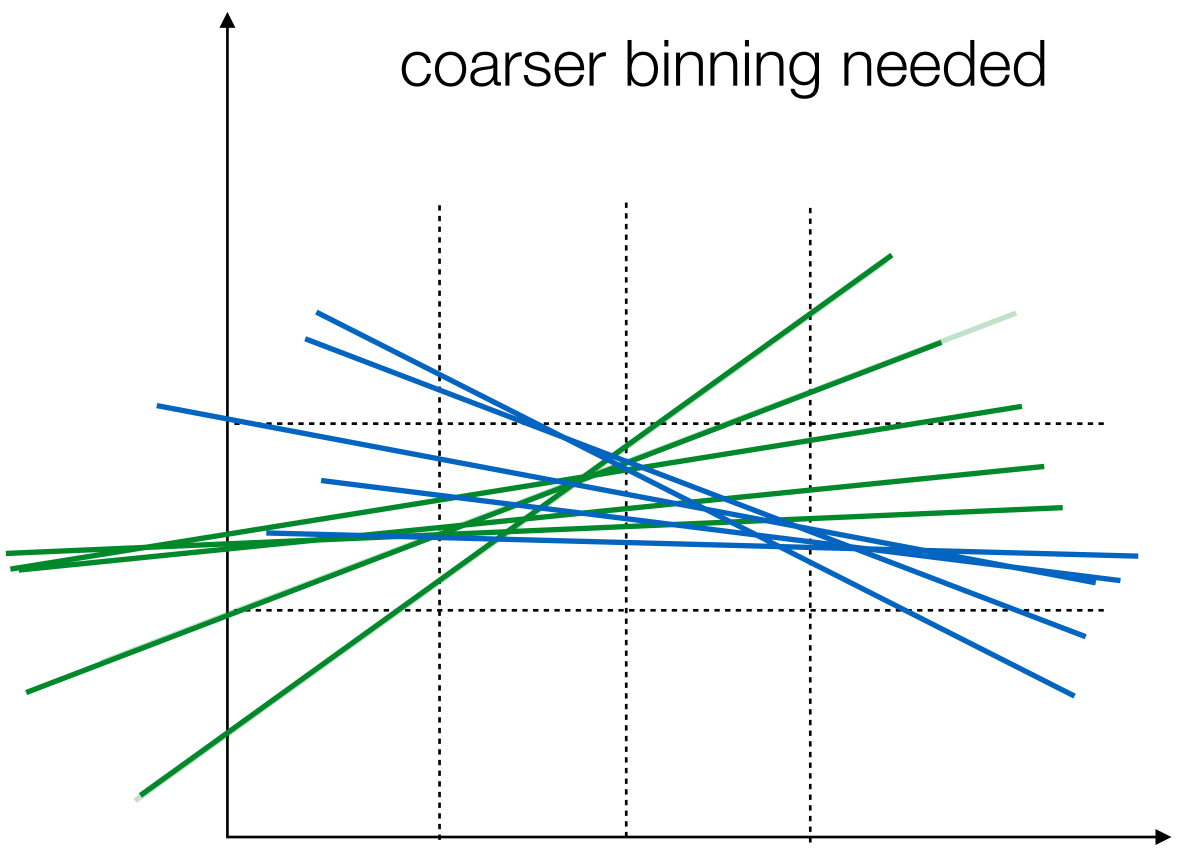




Conformal mapping - the problems

- Conformal mapping becomes difficult with high occupancy and project noise

this leads to inefficiencies



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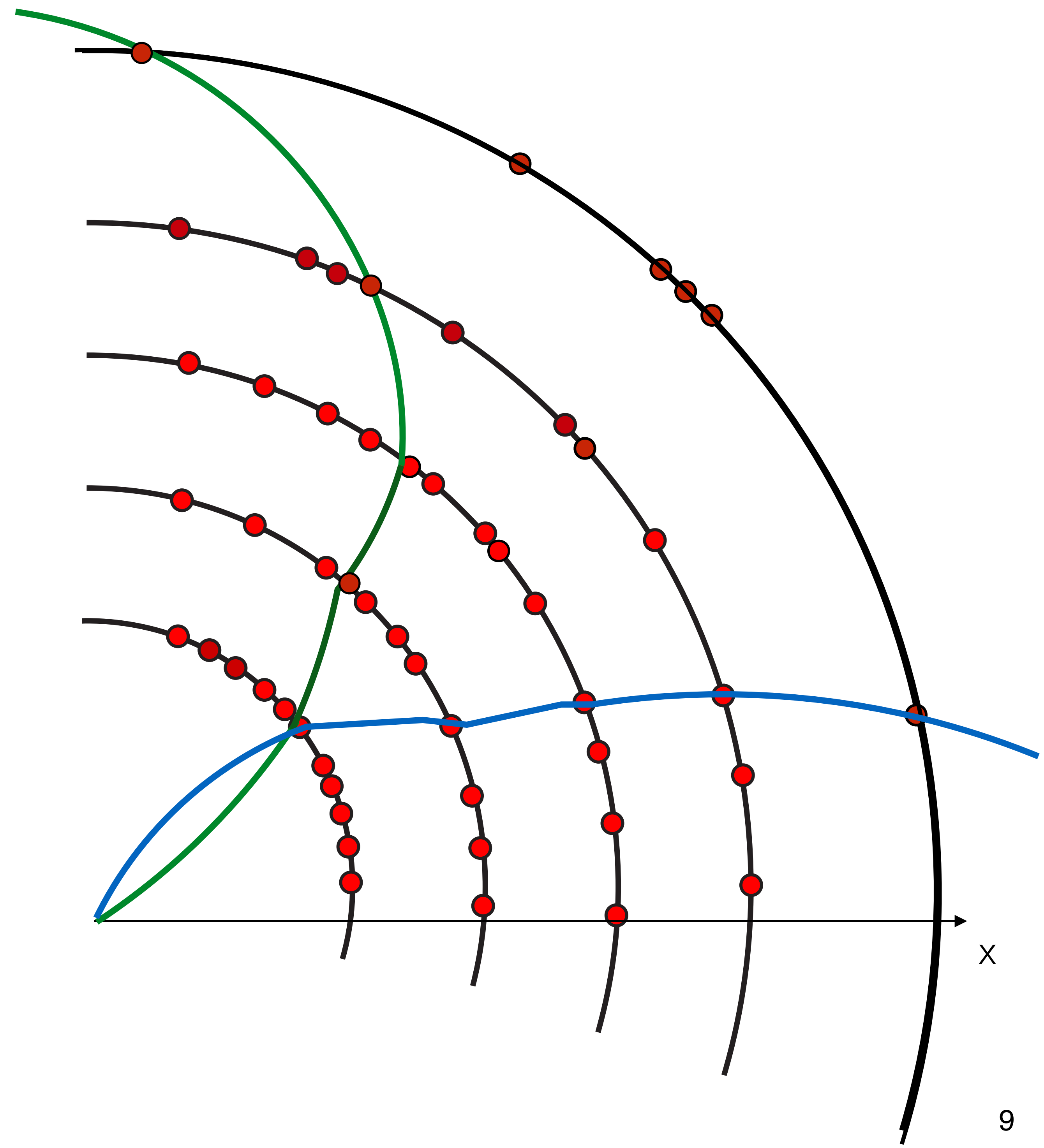
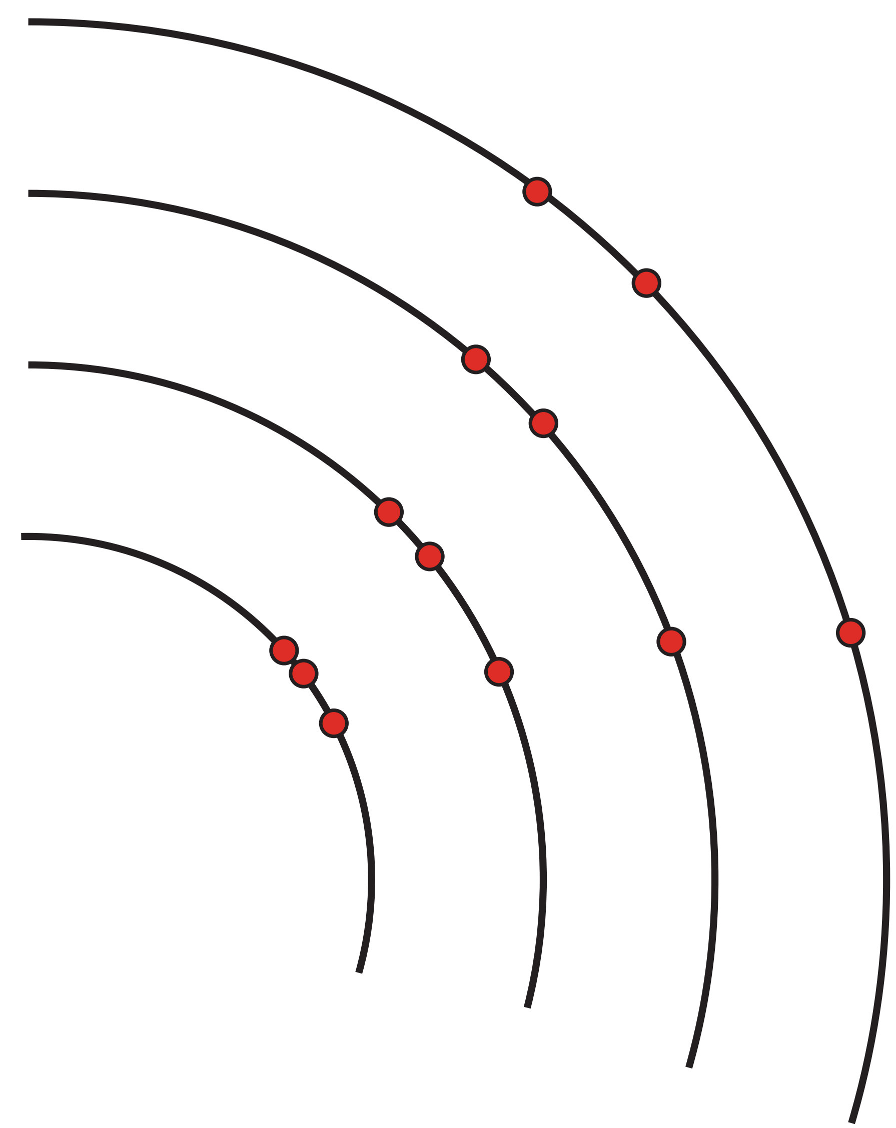


A different approach: seeding & following

- Start of many track finding algorithms is the building of track seeds
  - groups of 2 or 3 measurements that are compatible with a crude track hypothesis
  - seeds are used to build roads to find track candidates



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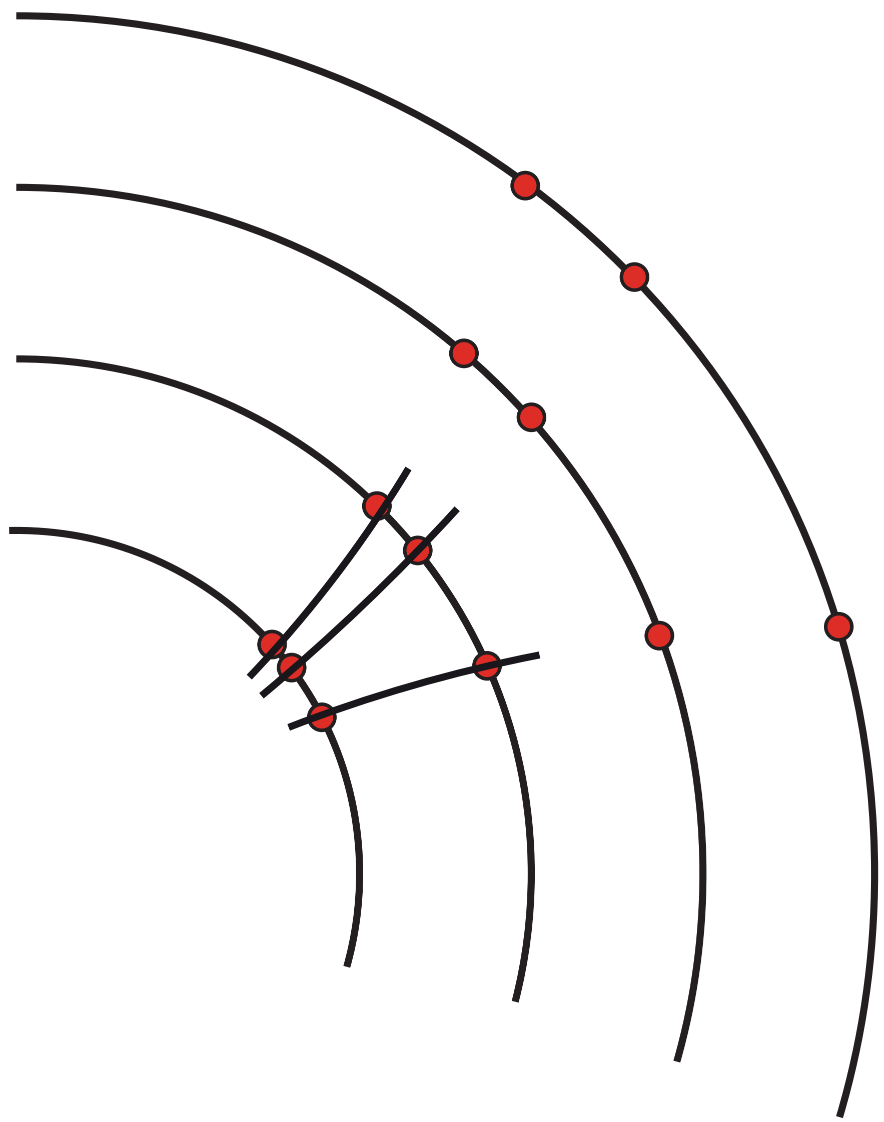

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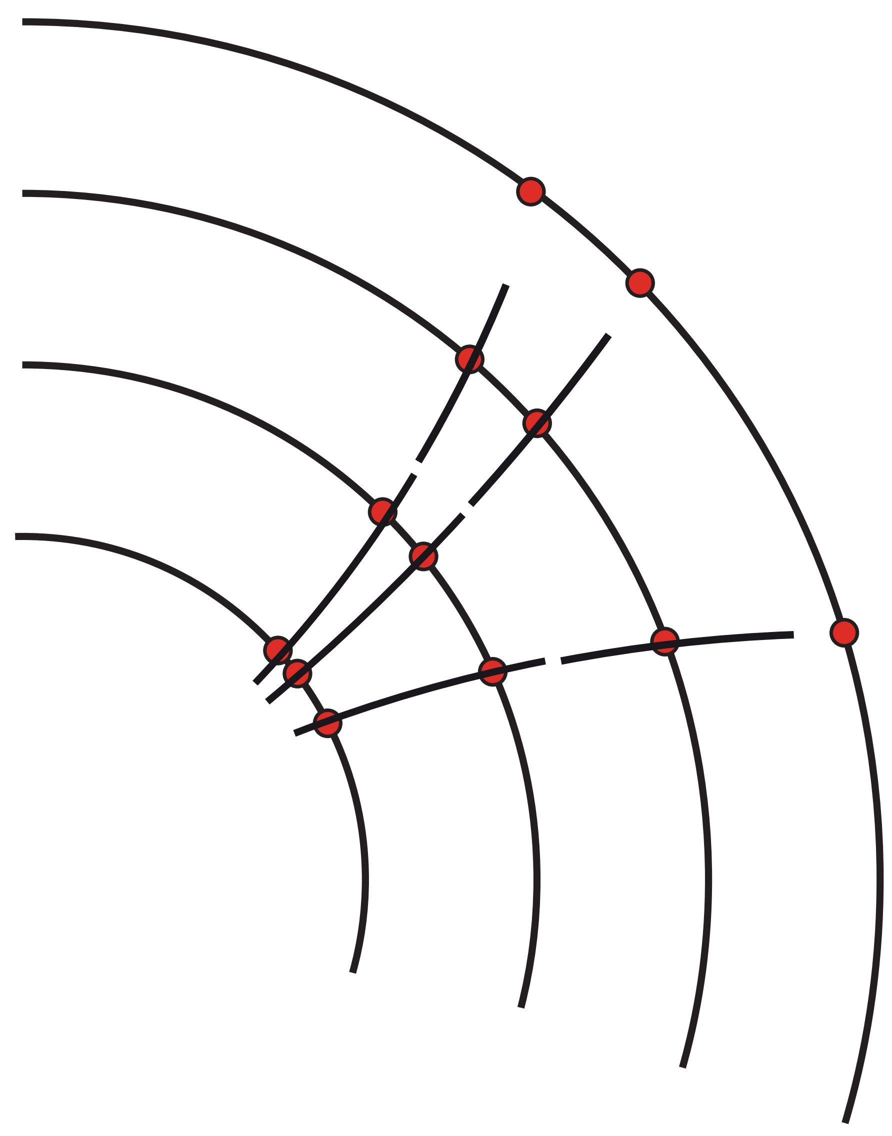

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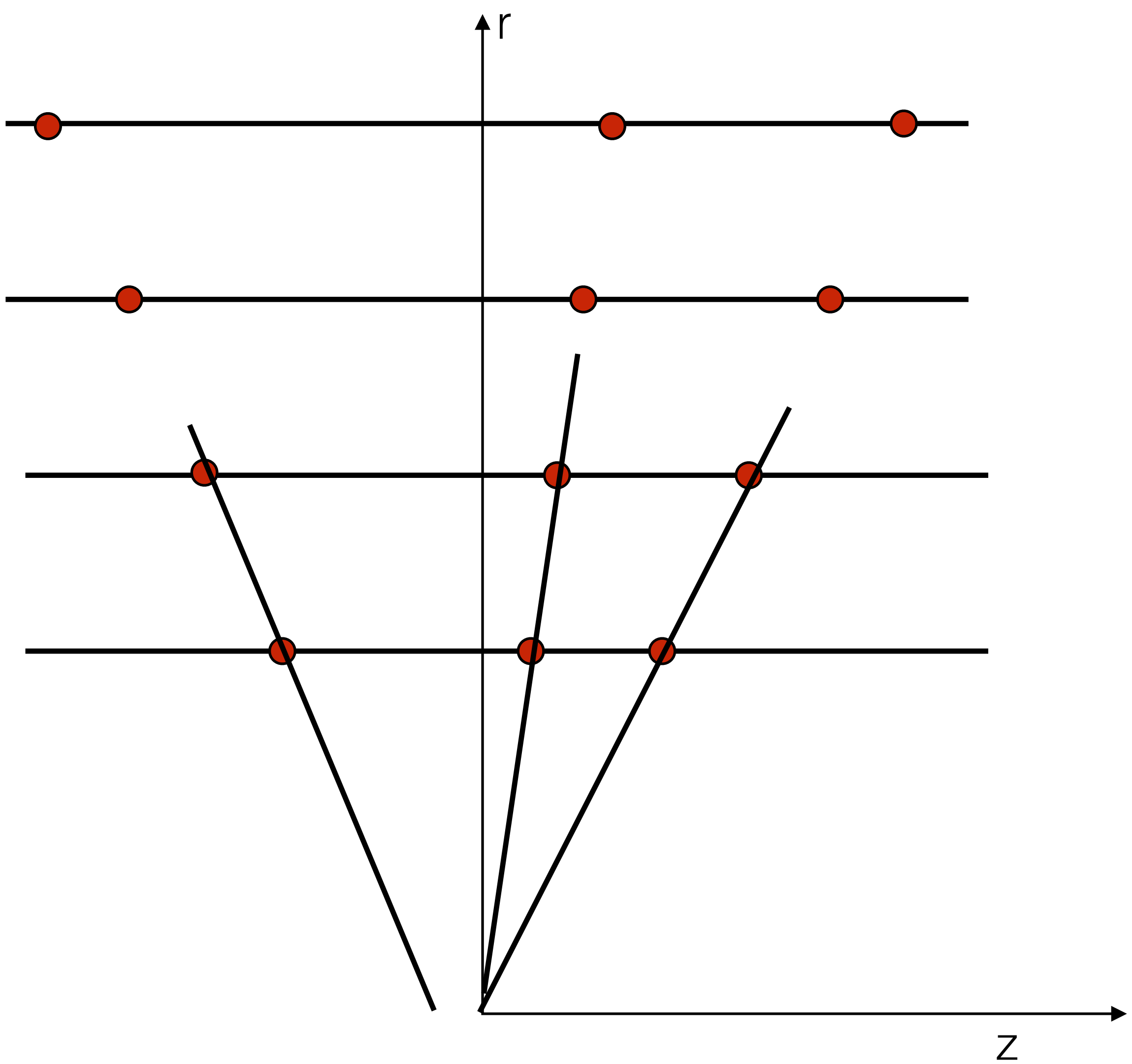

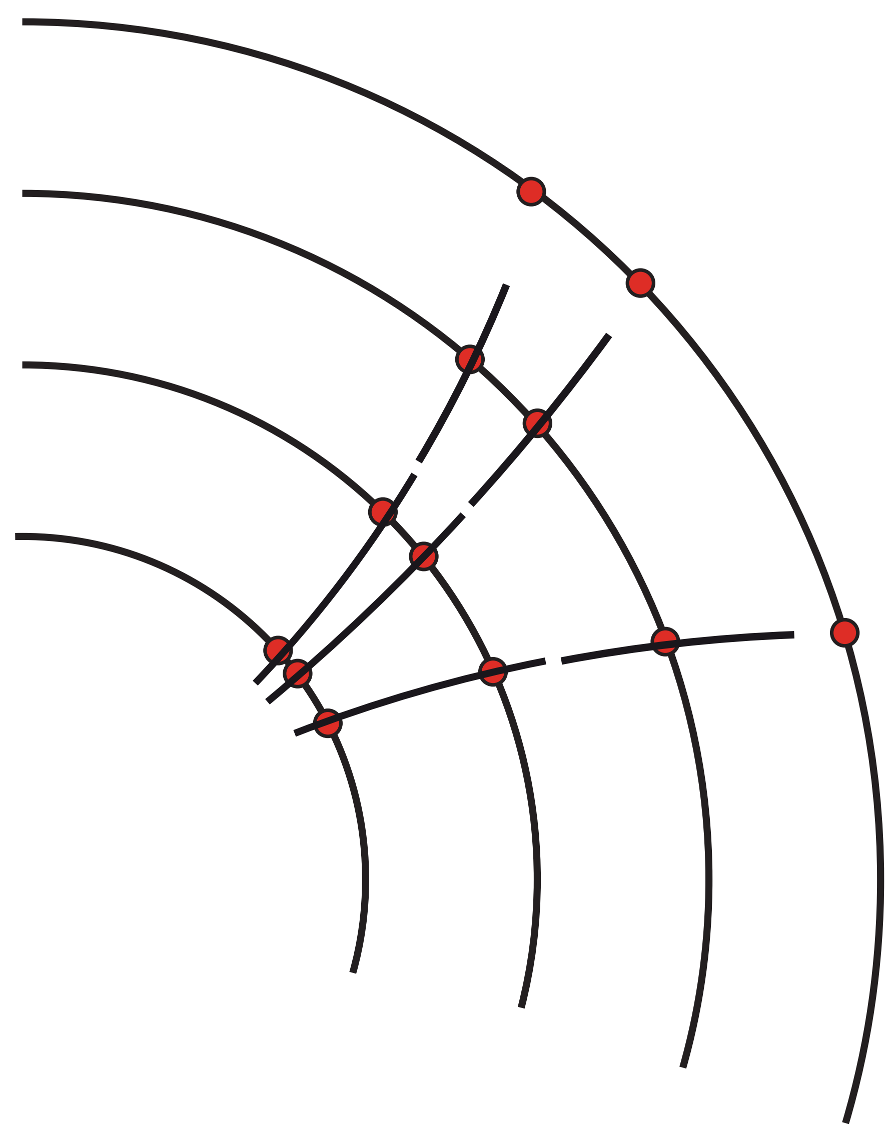

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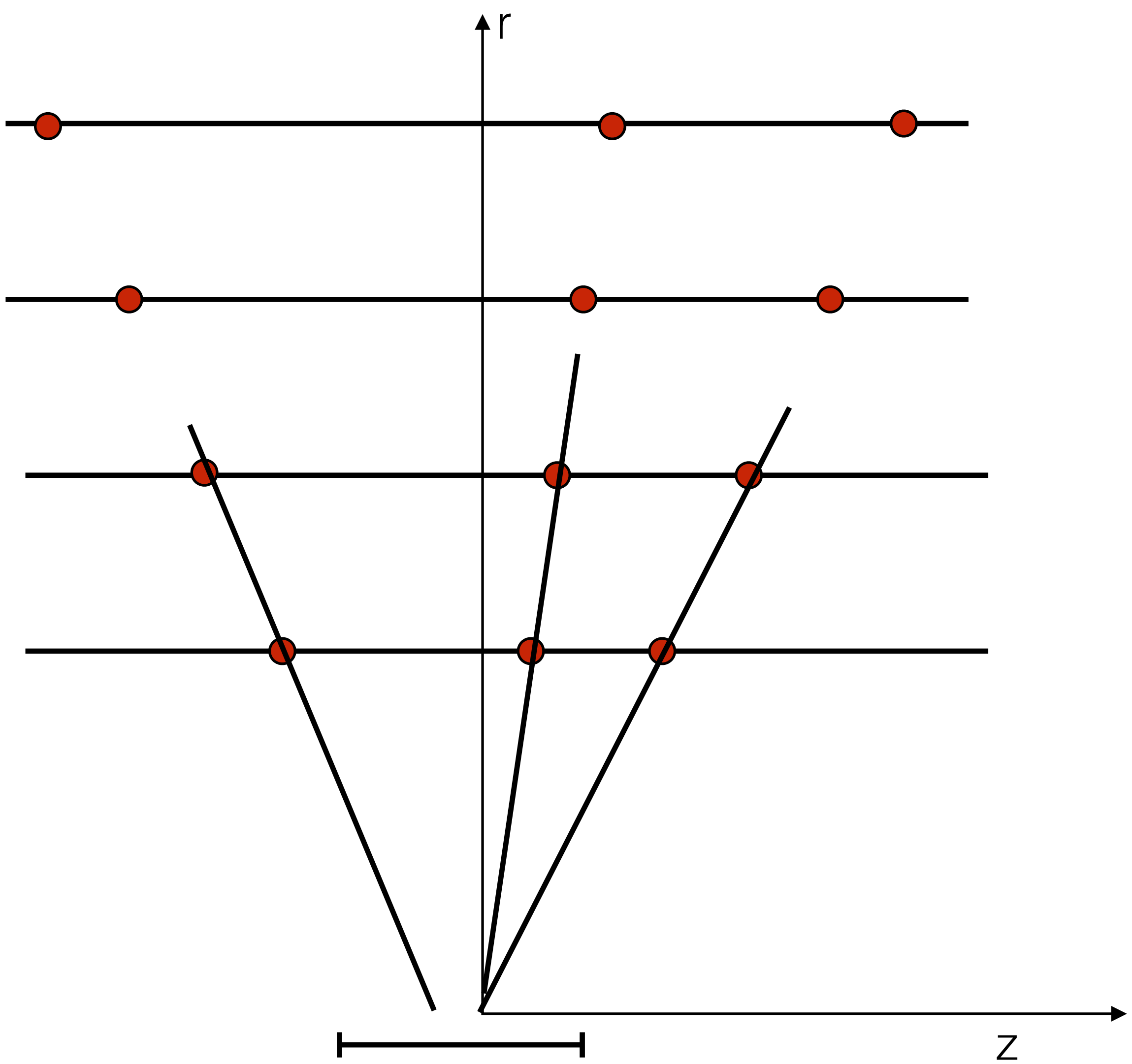
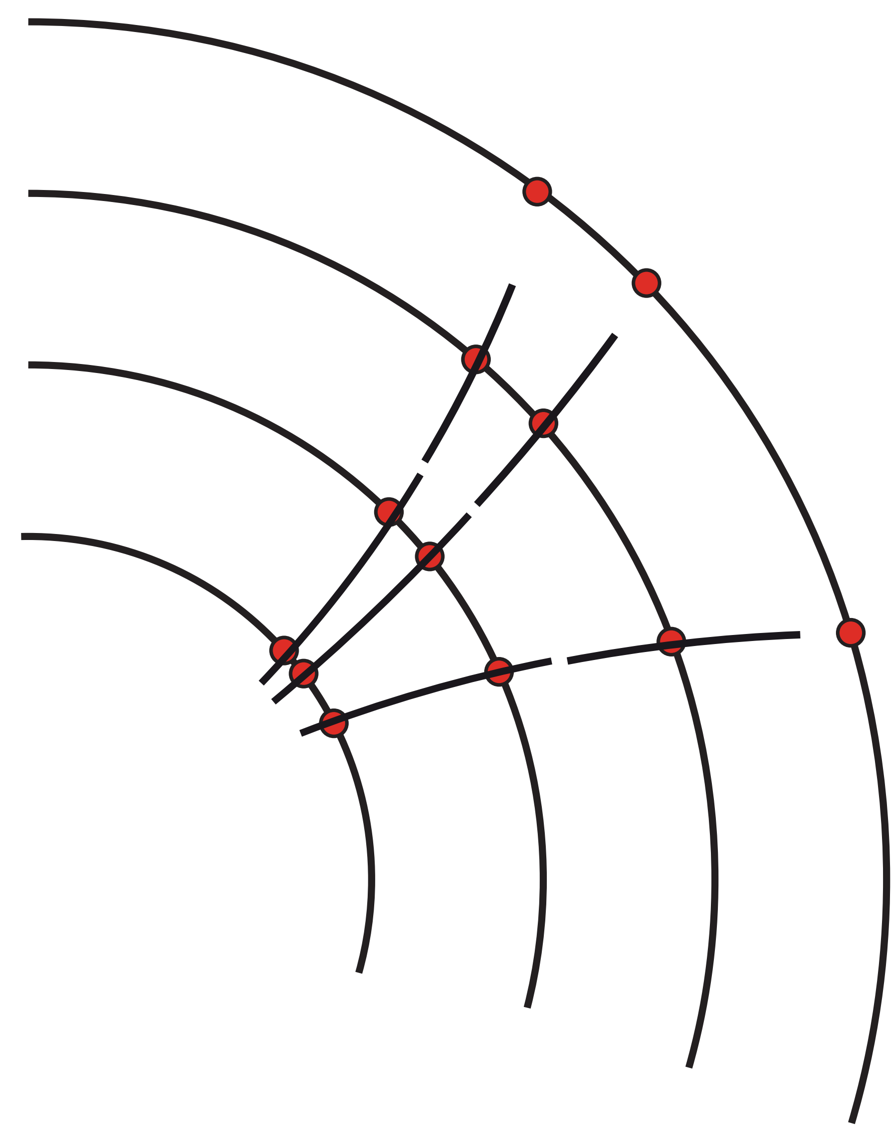


loose requirement
on interaction region



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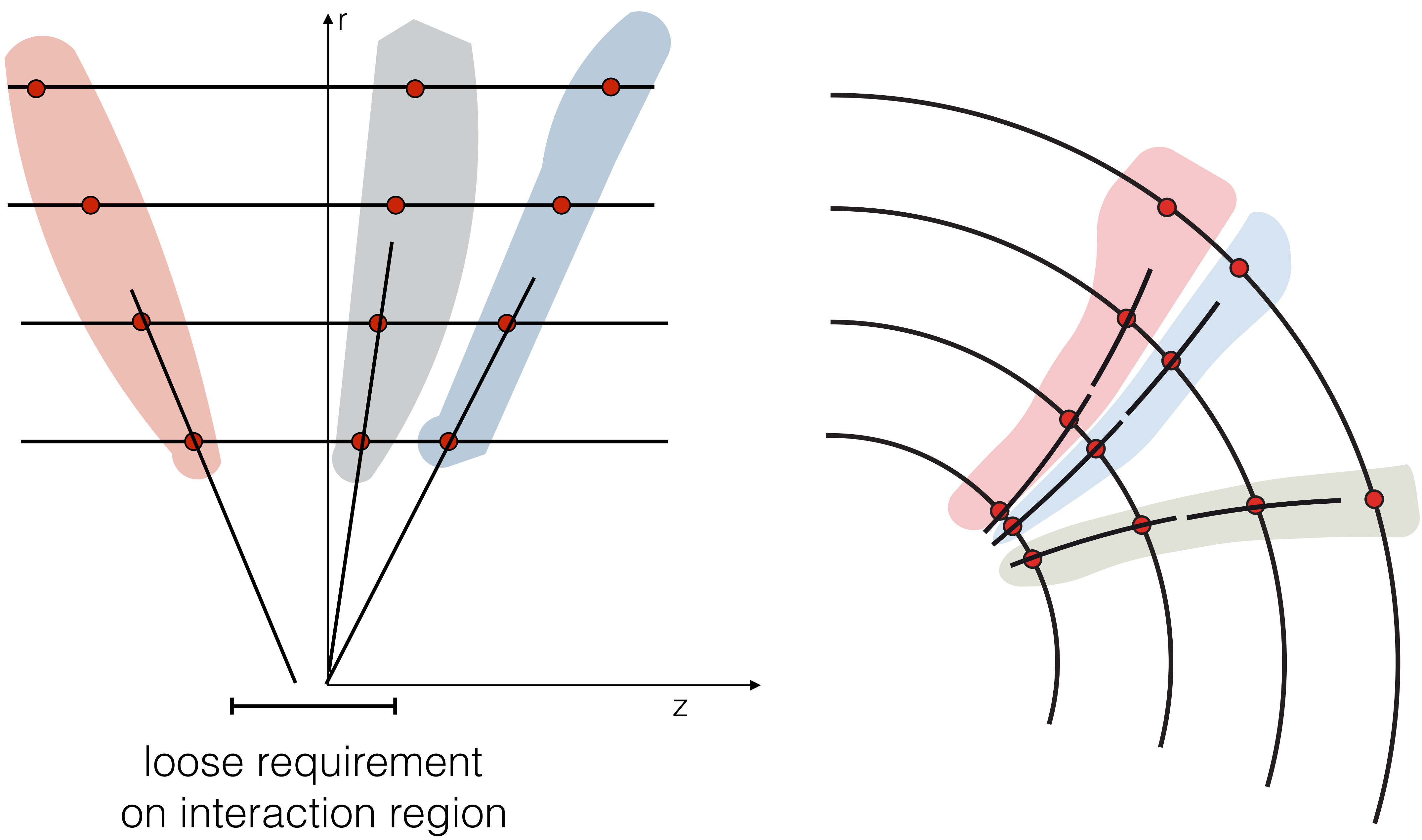

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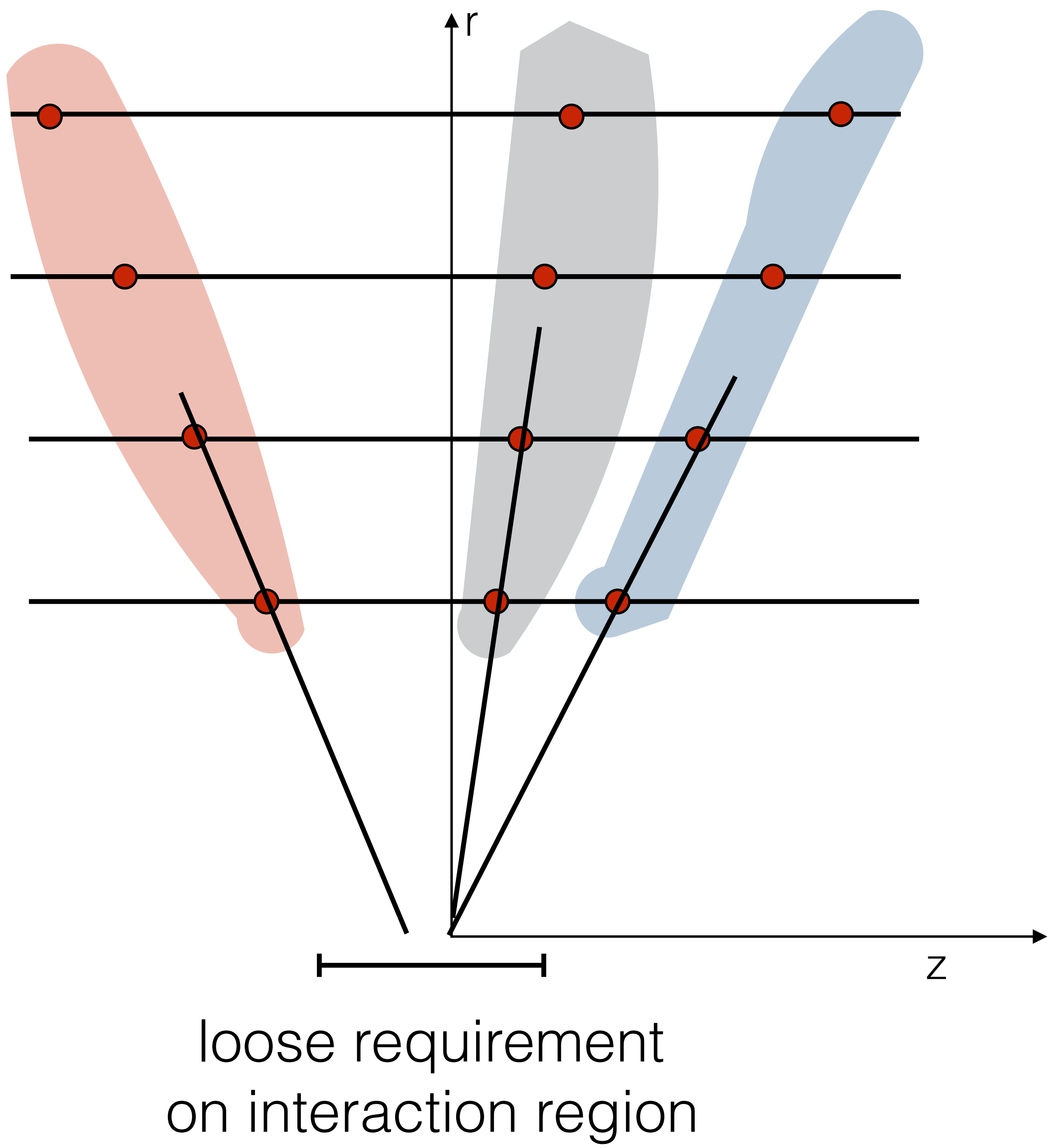
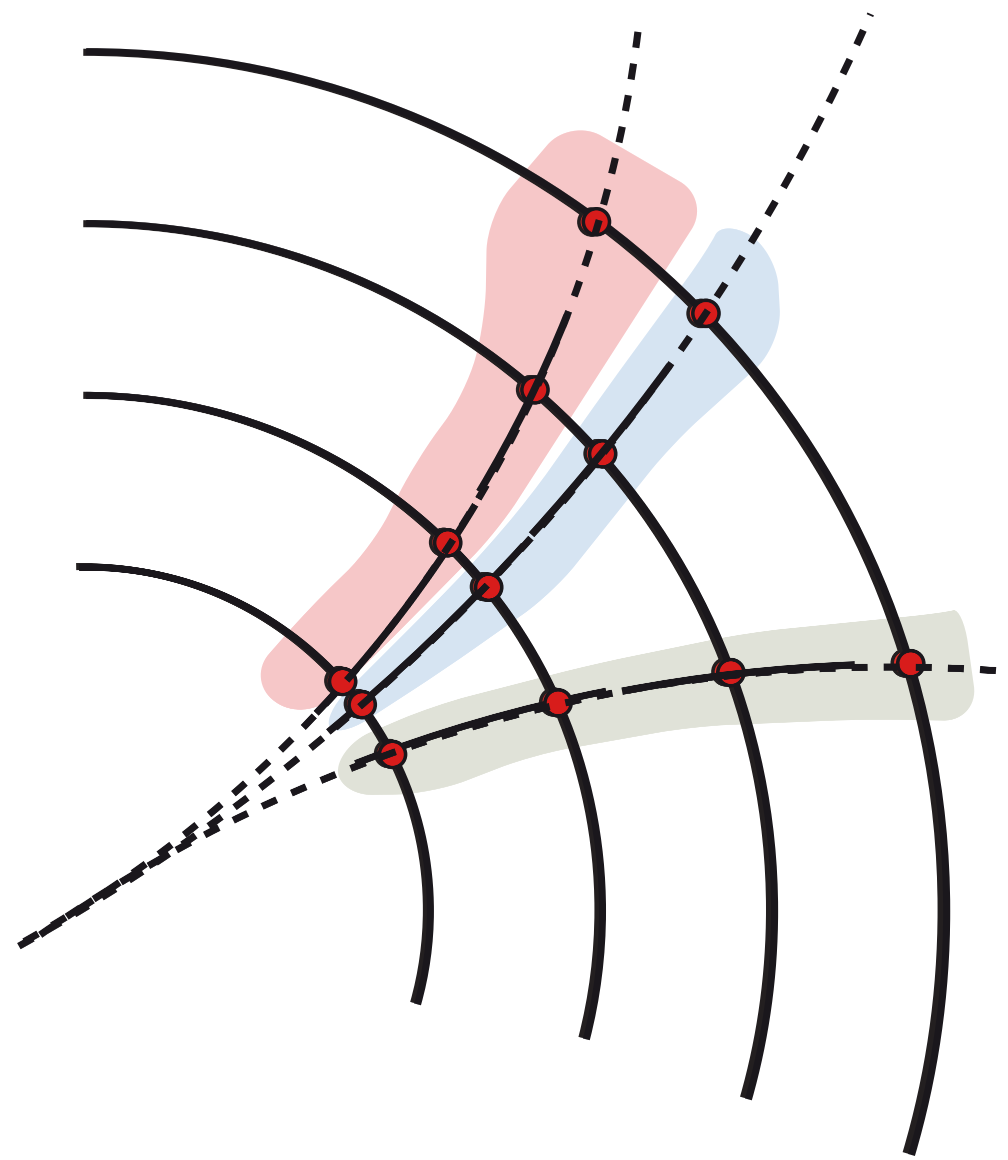




From seeds to track candidates

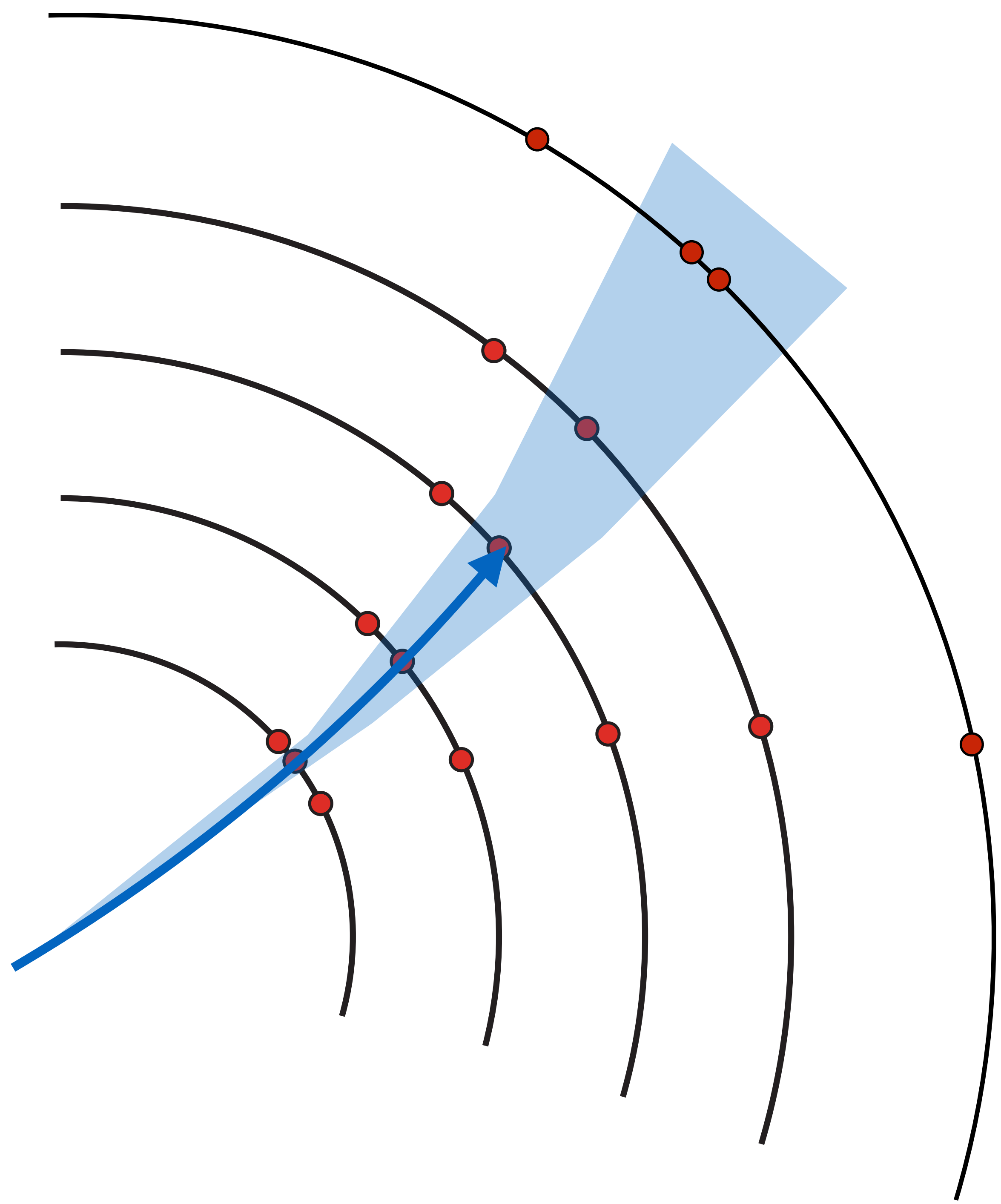
ATLAS/CMS offline approach

- The progressive filter
  - roads are built from track seeds and define a search window
  - **following** the road direction to find hits that are ***compatible*** with the track

    needs a measure to define compatibility
  - a found hit used to ***update*** the track to follow to the next measurement layer

    needs a mechanism to update a track hypothesis
  - multiple hypothesis can be tested for one layer
  - only one track hypothesis is followed further

    needs a measure which candidate is better



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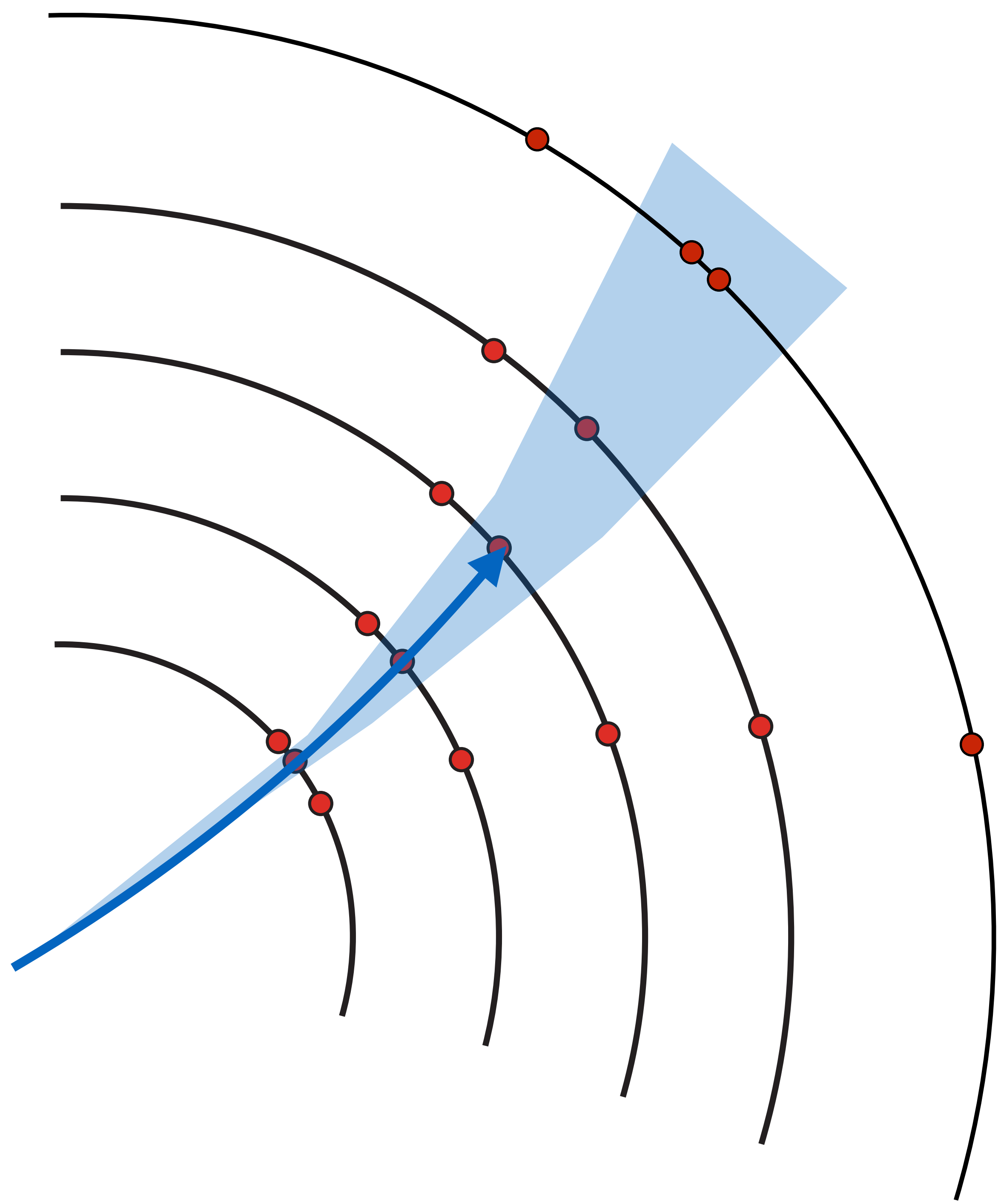

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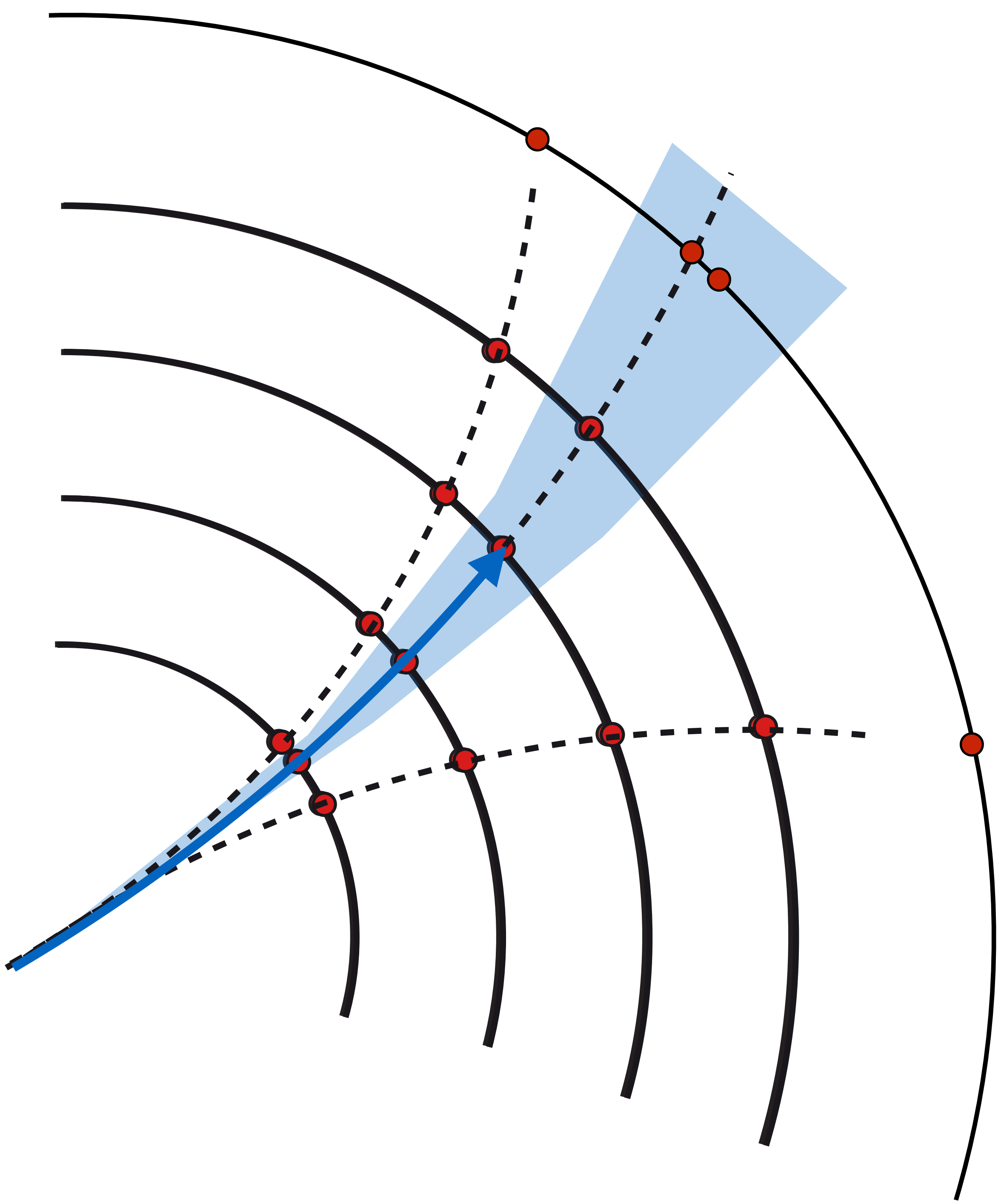

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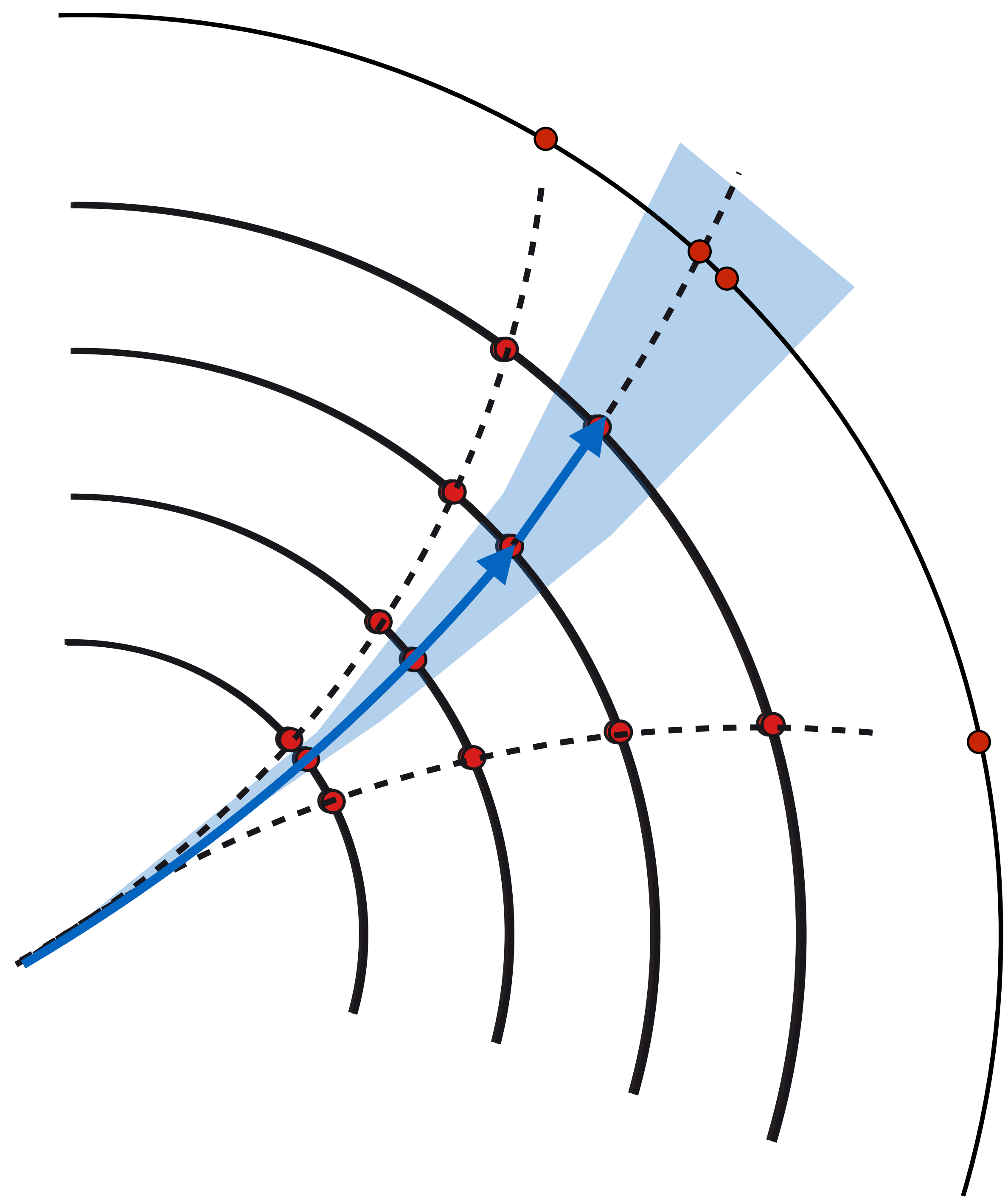

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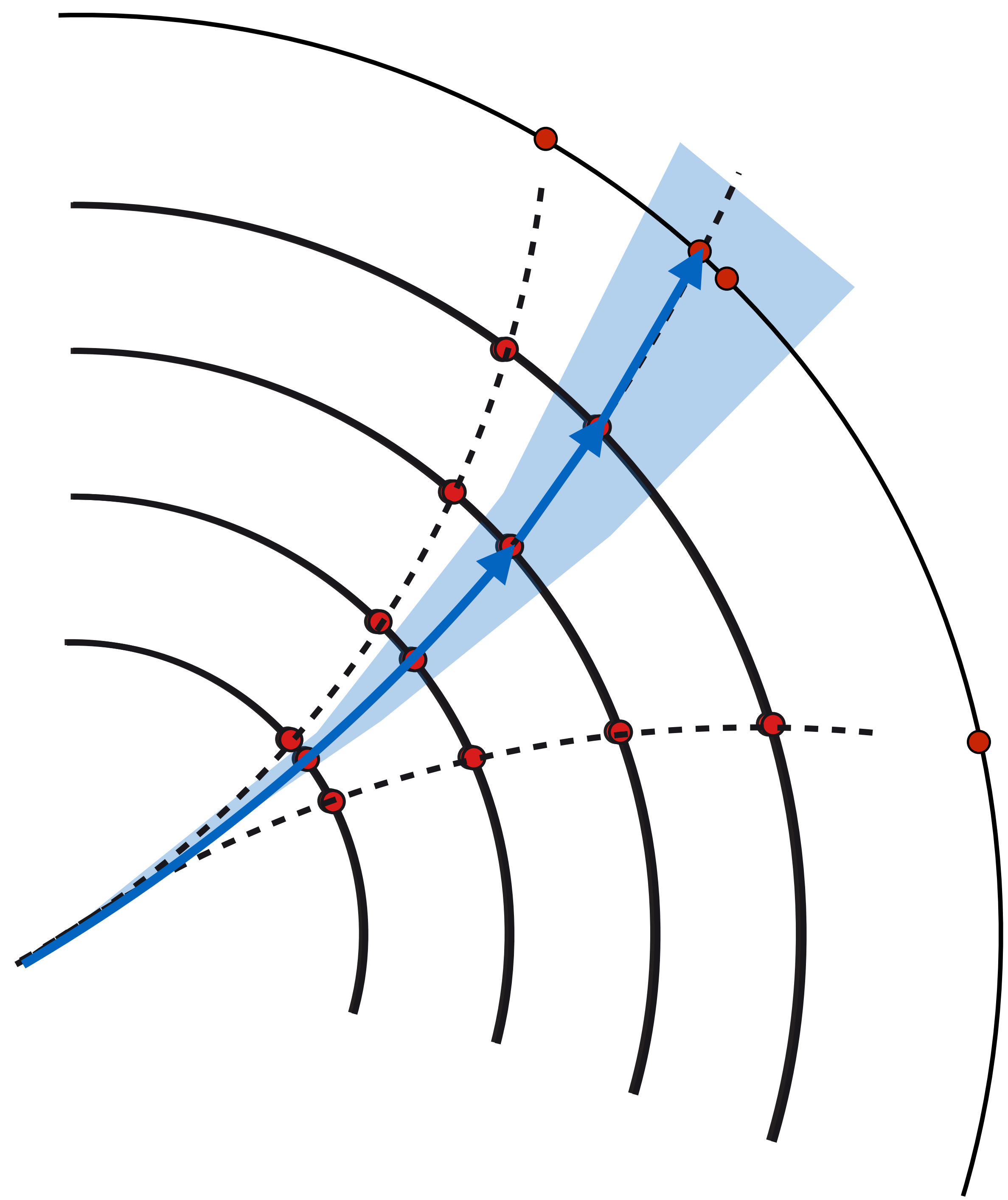

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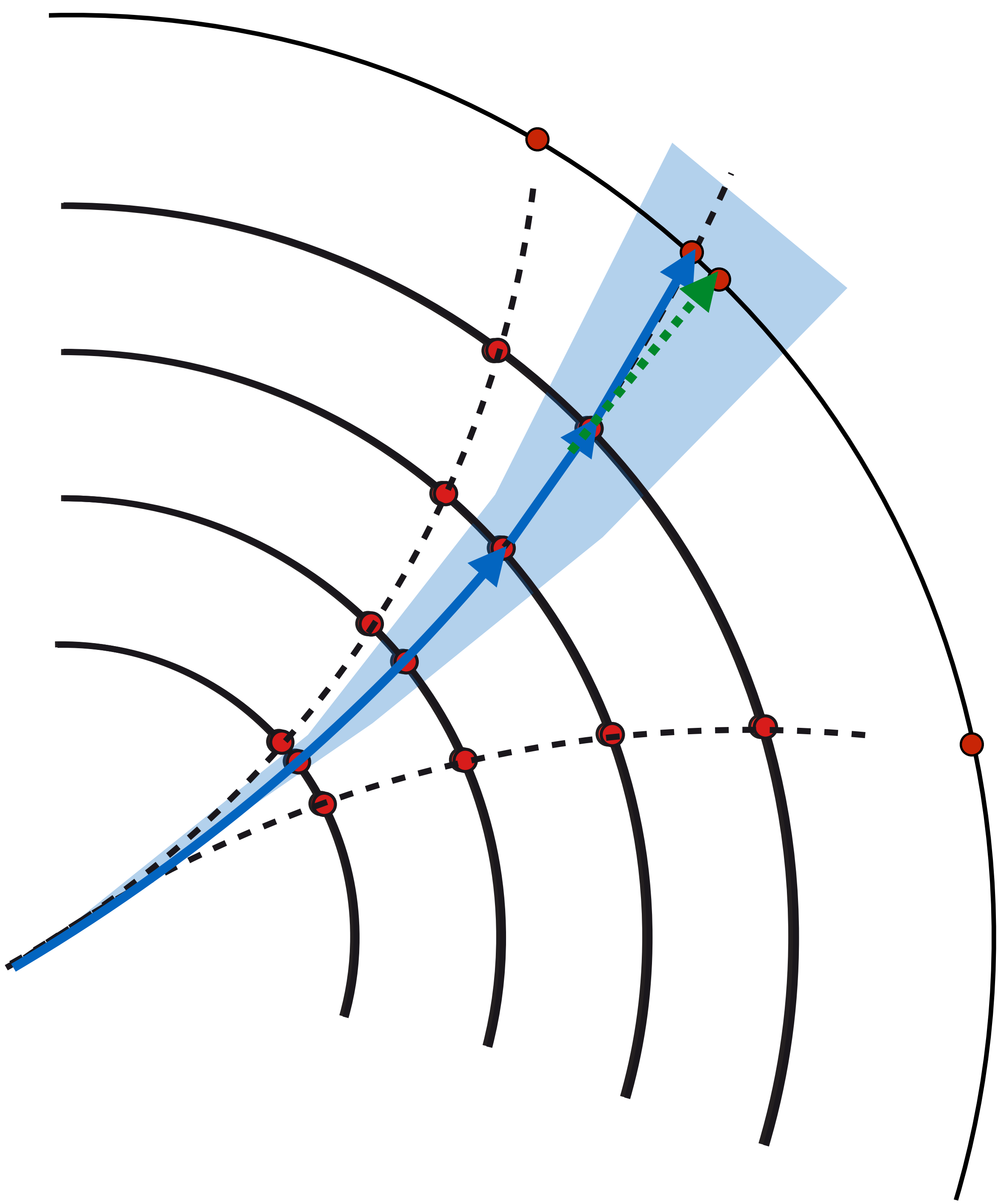

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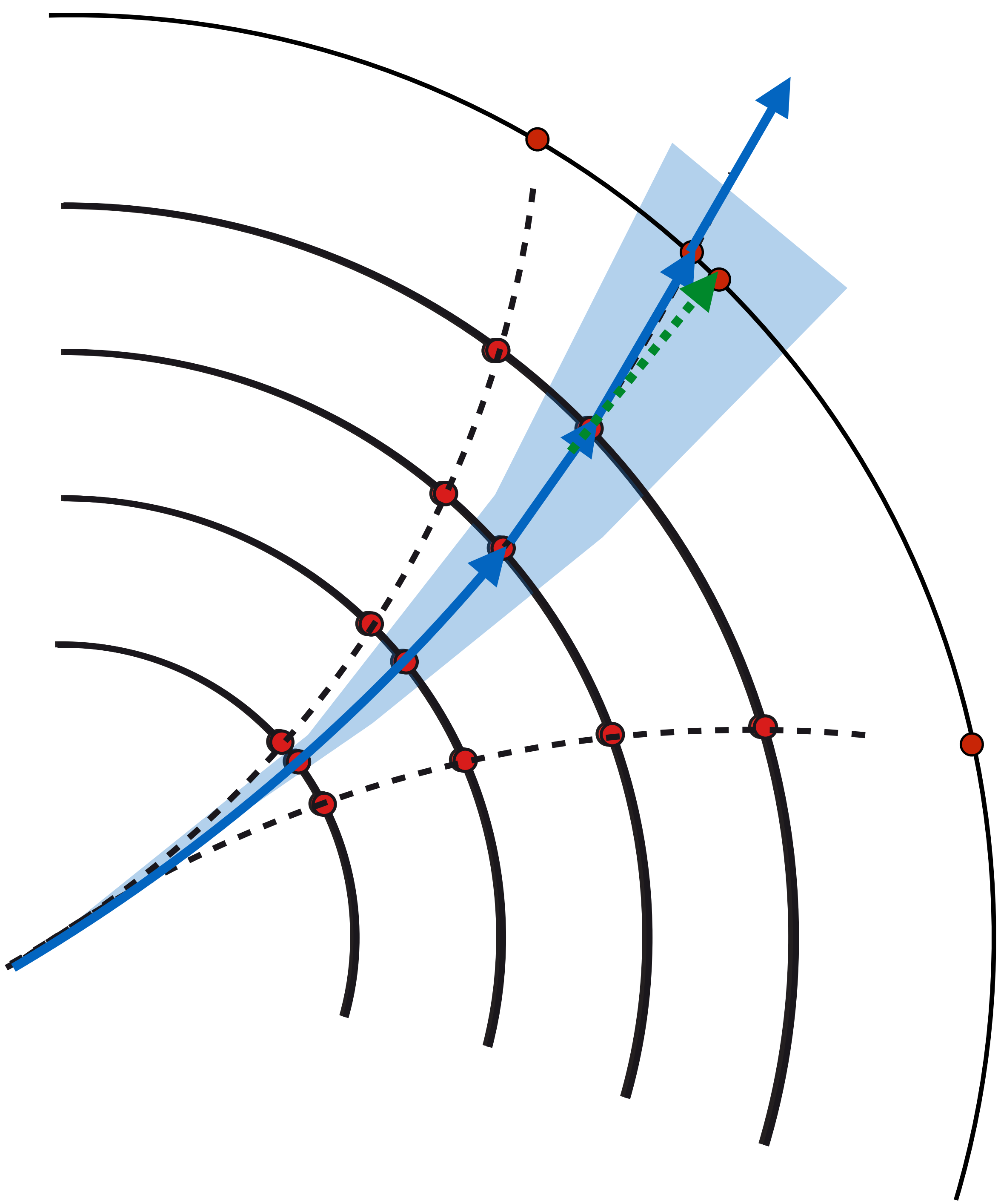
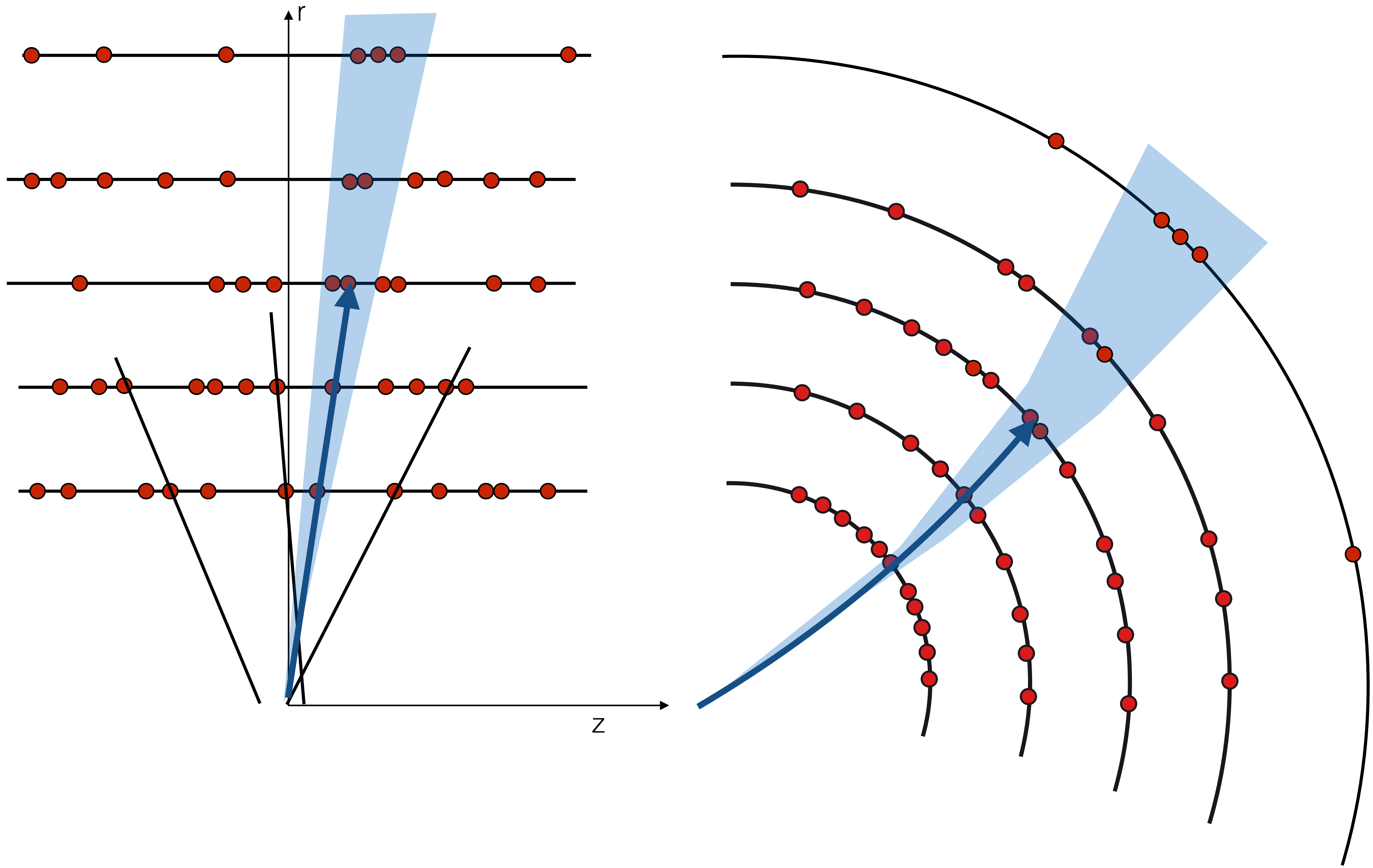


From seeds to track candidates

- Dense environments create problems for the progressive filter
  - there may not always be one obvious path to be followed: The combinatorial filter



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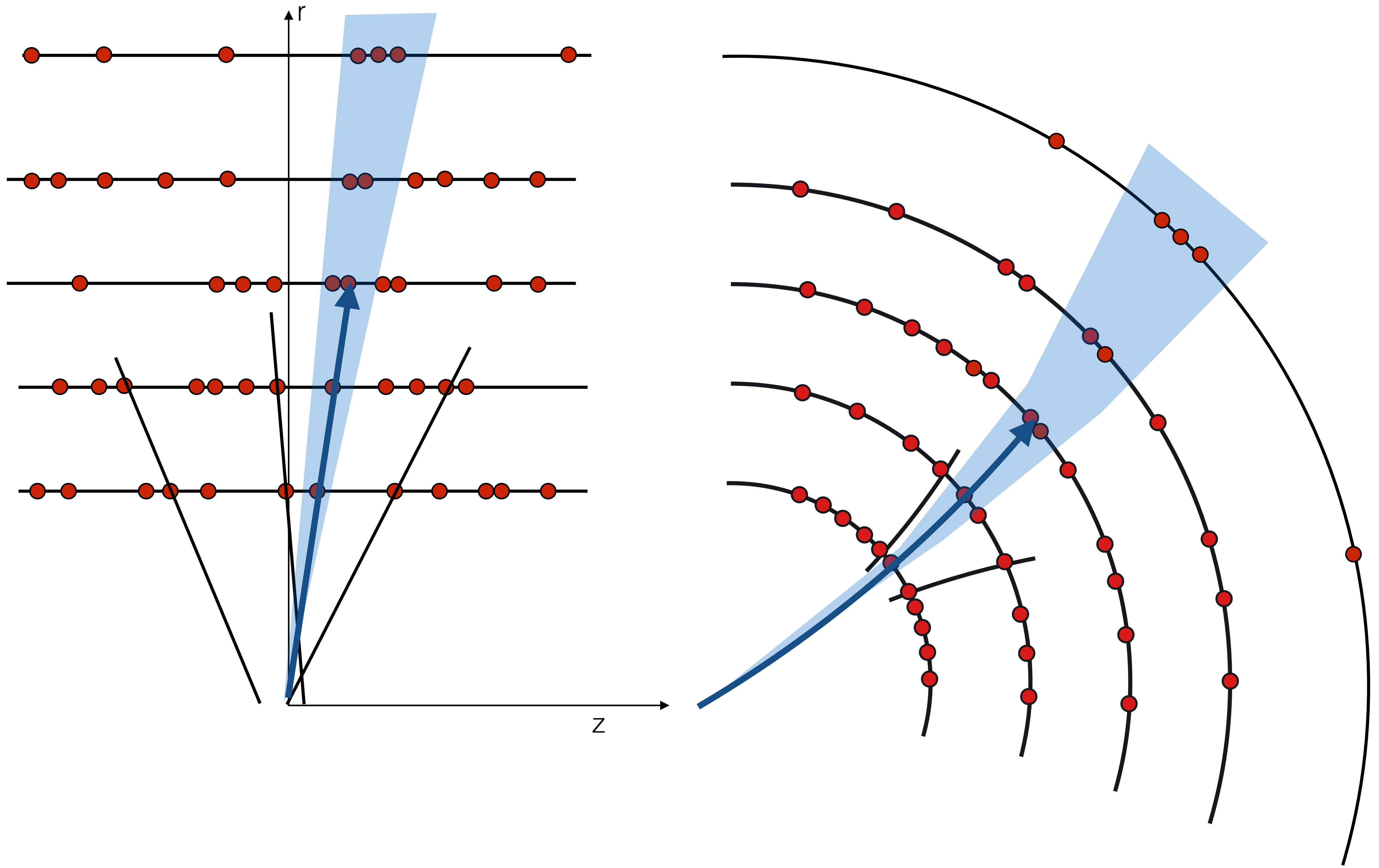

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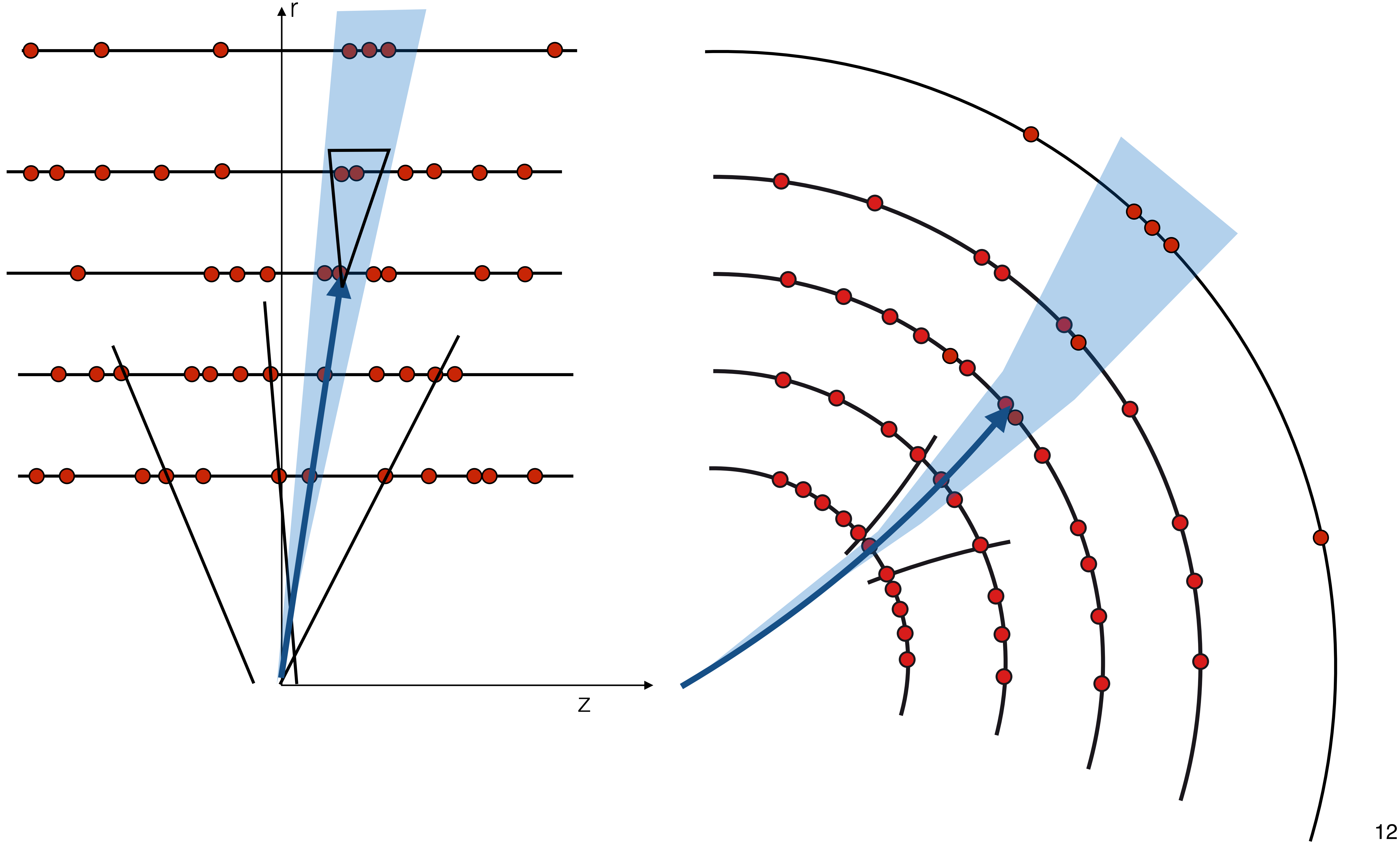

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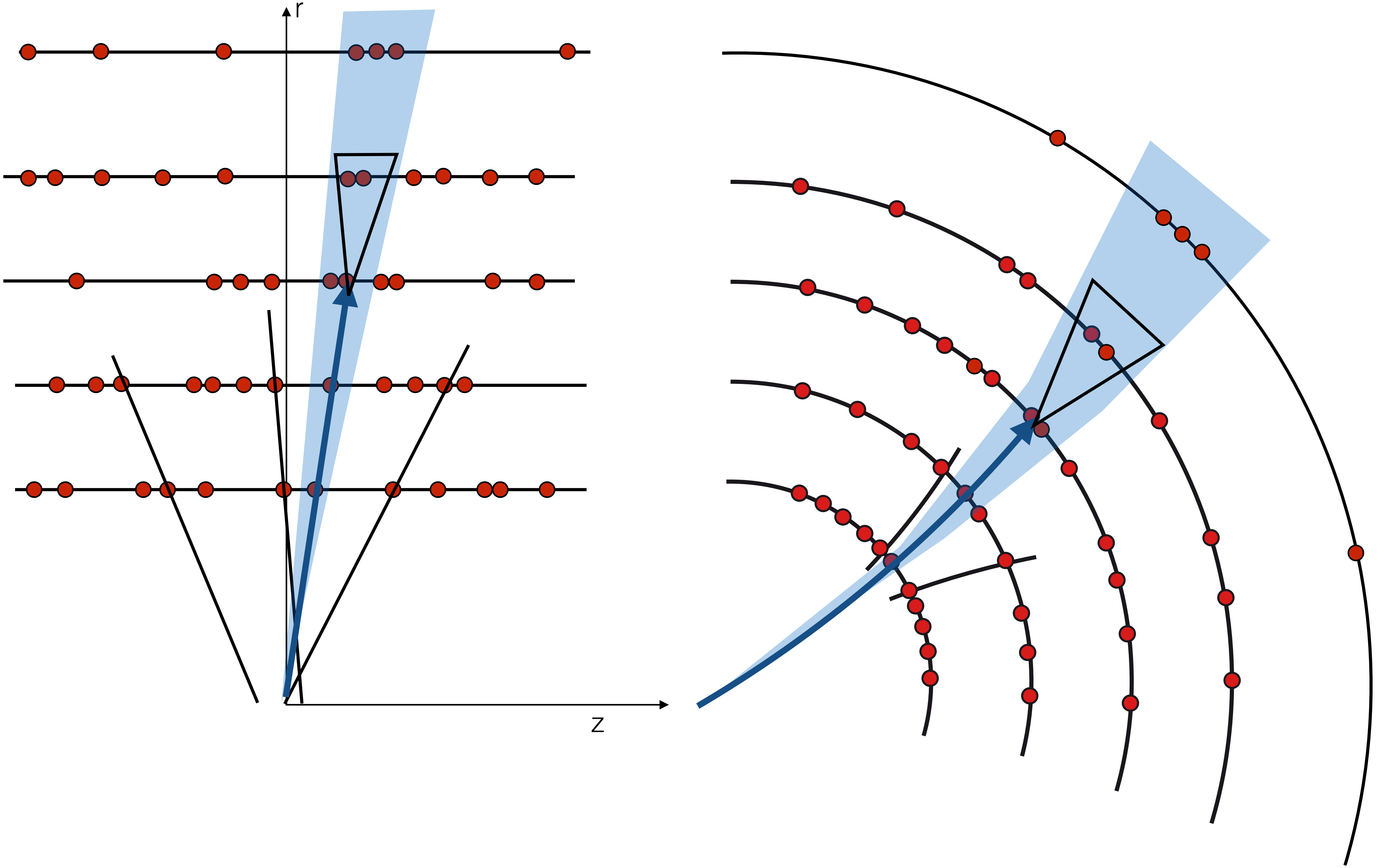

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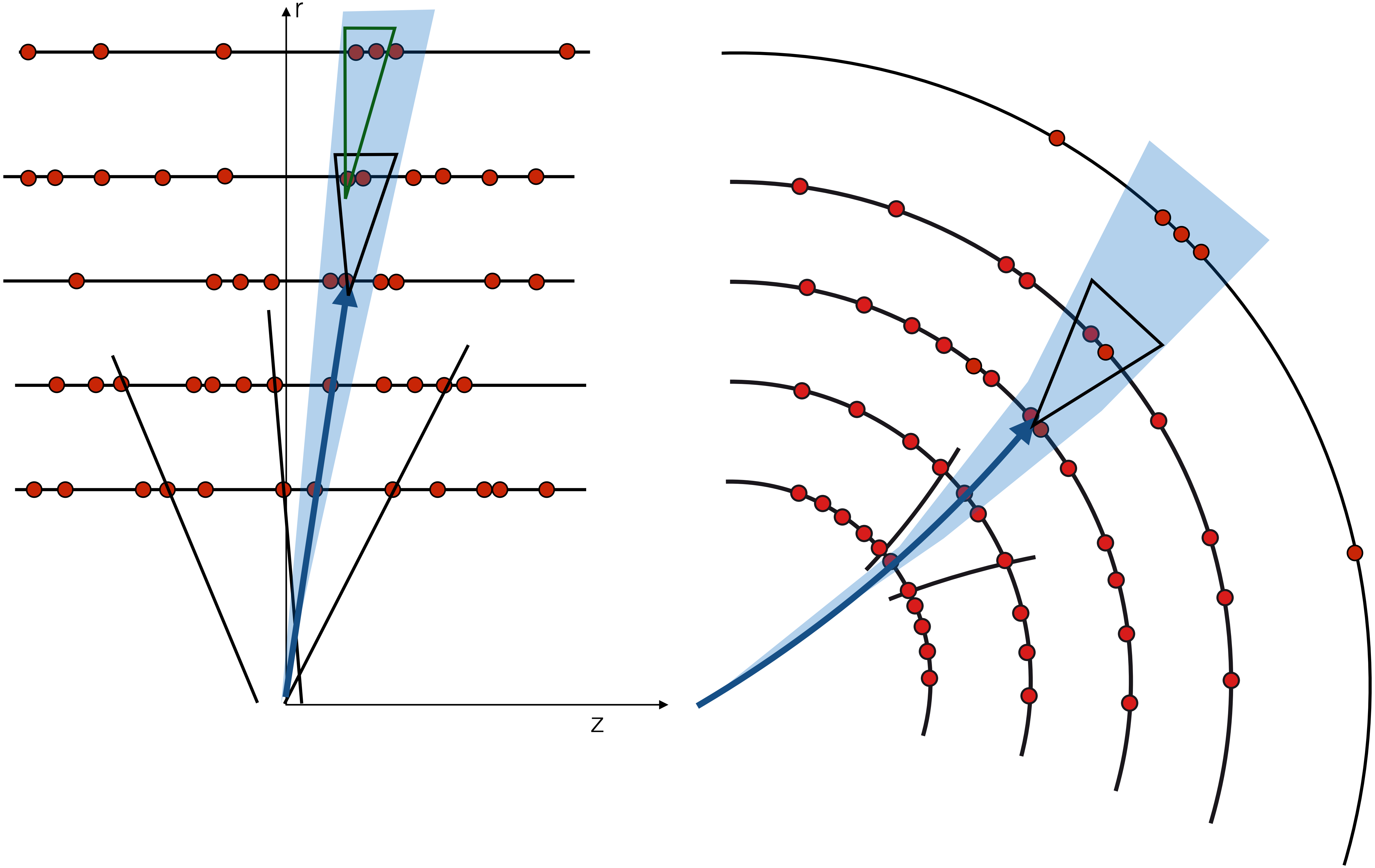

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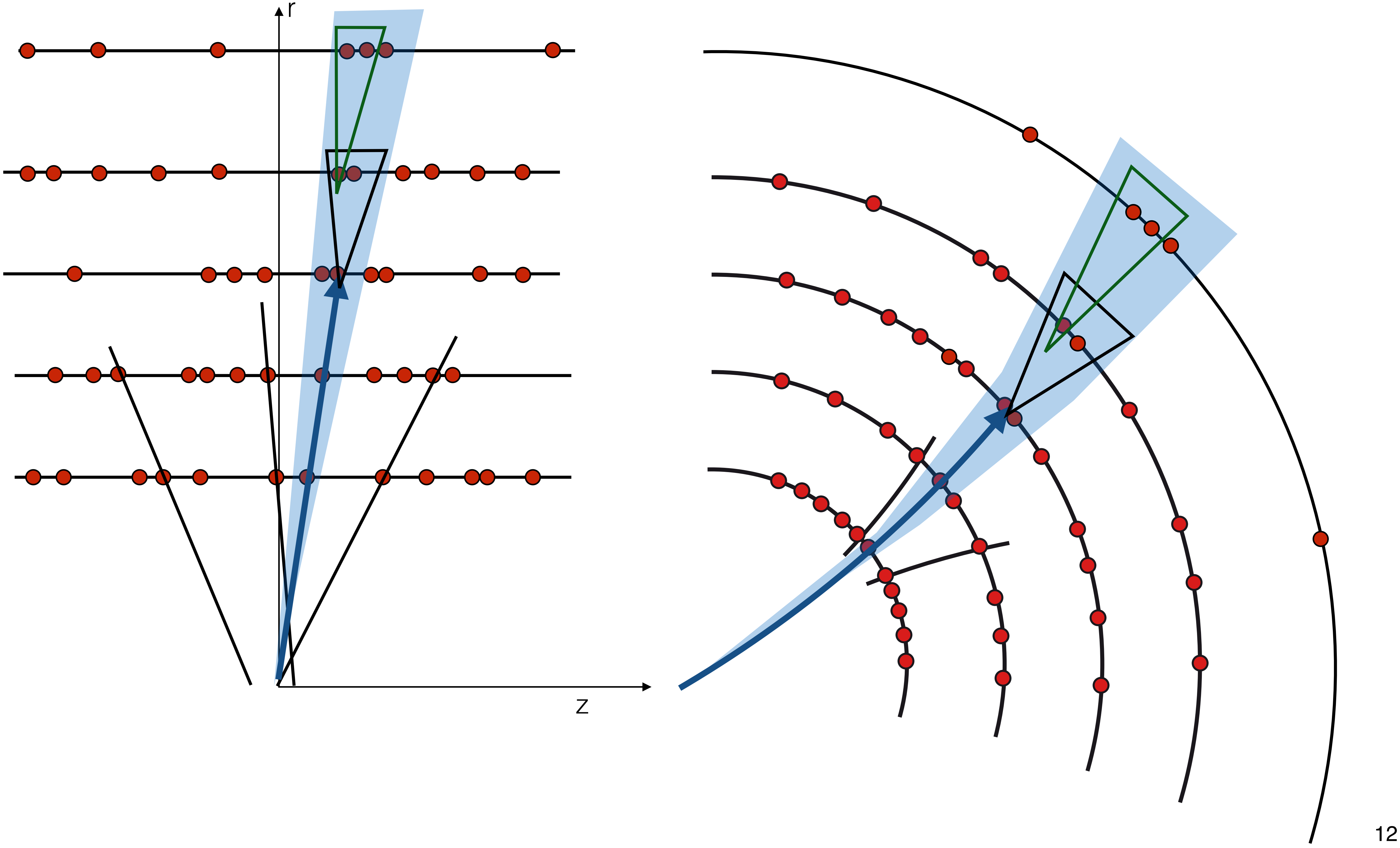

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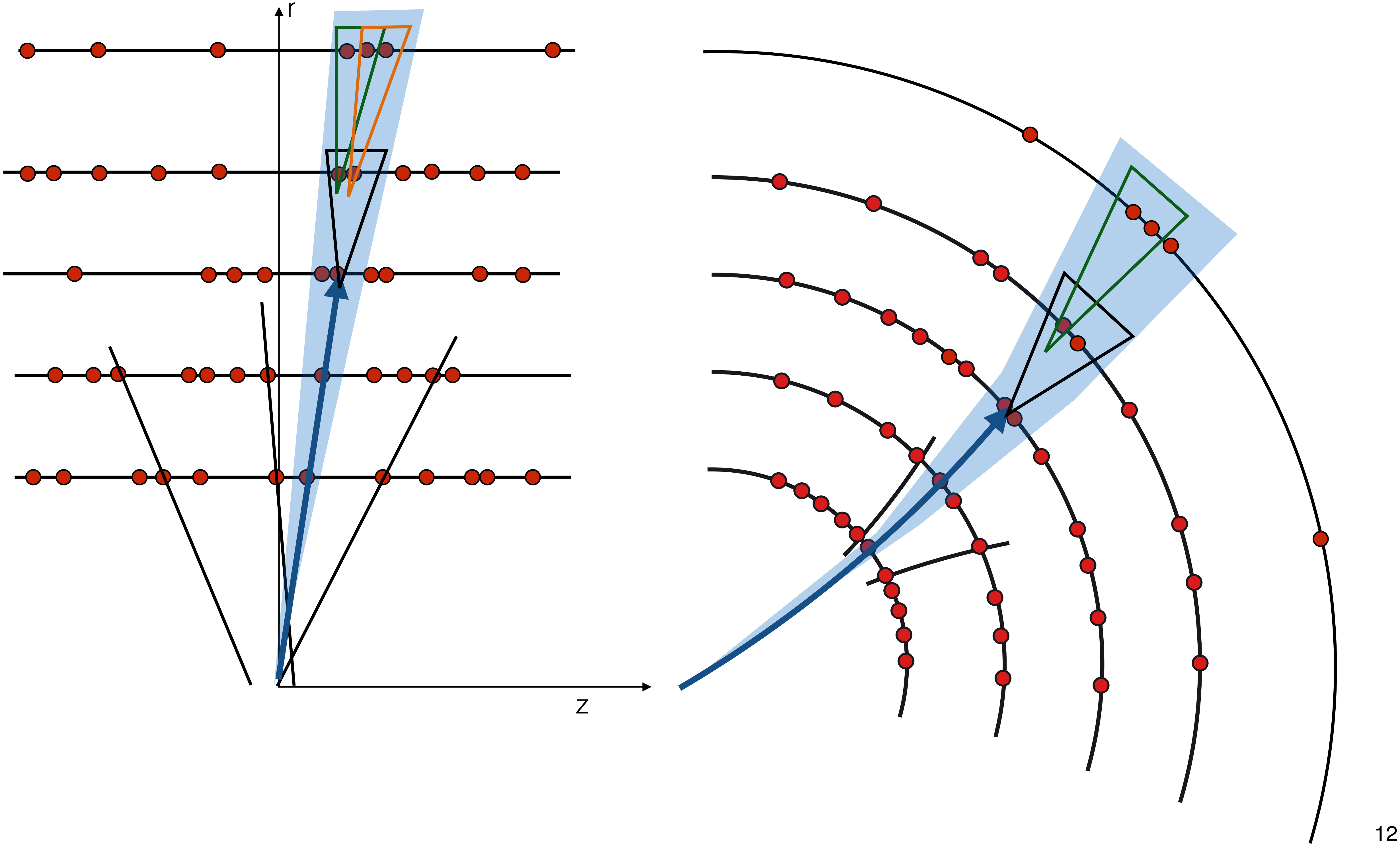
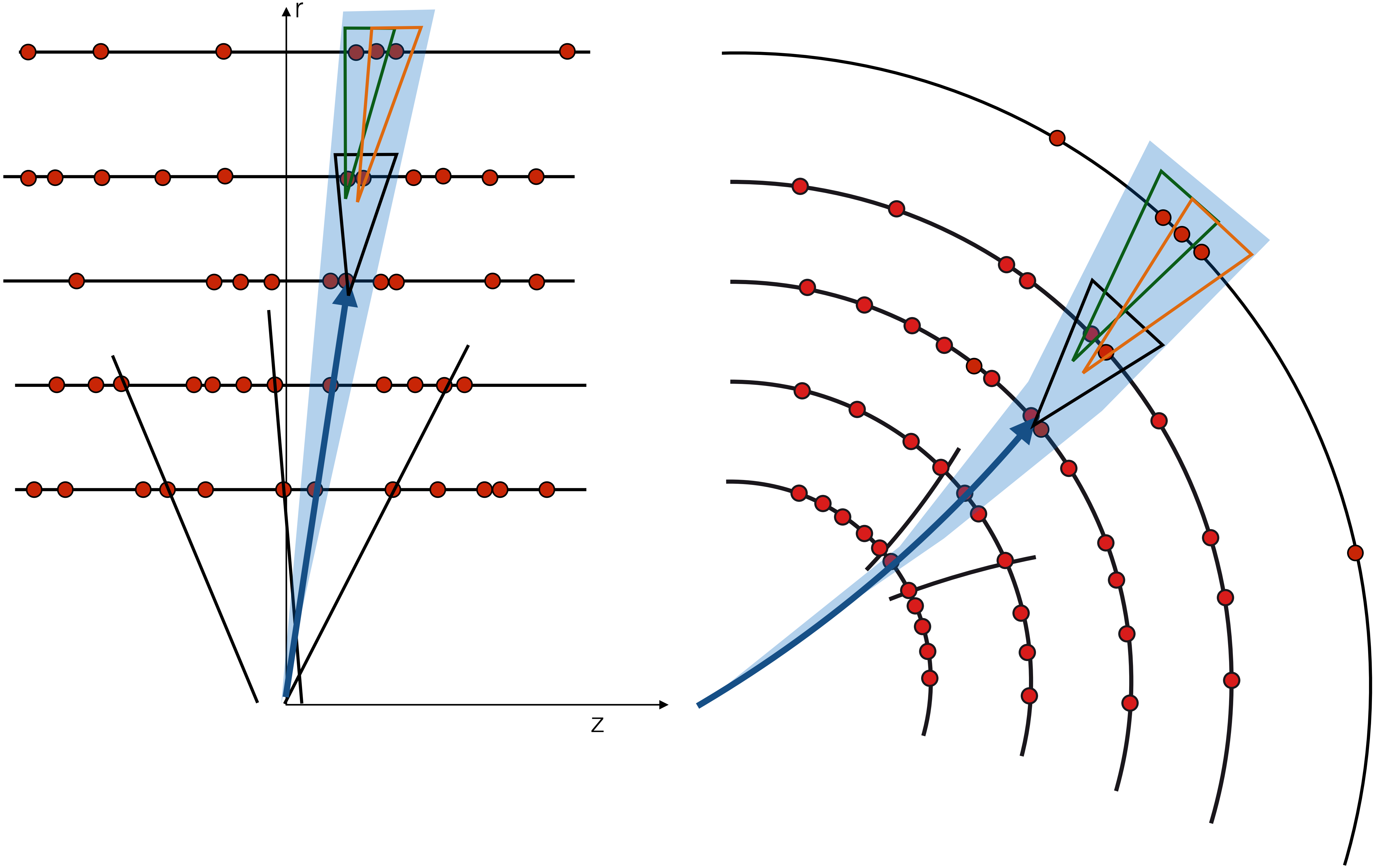


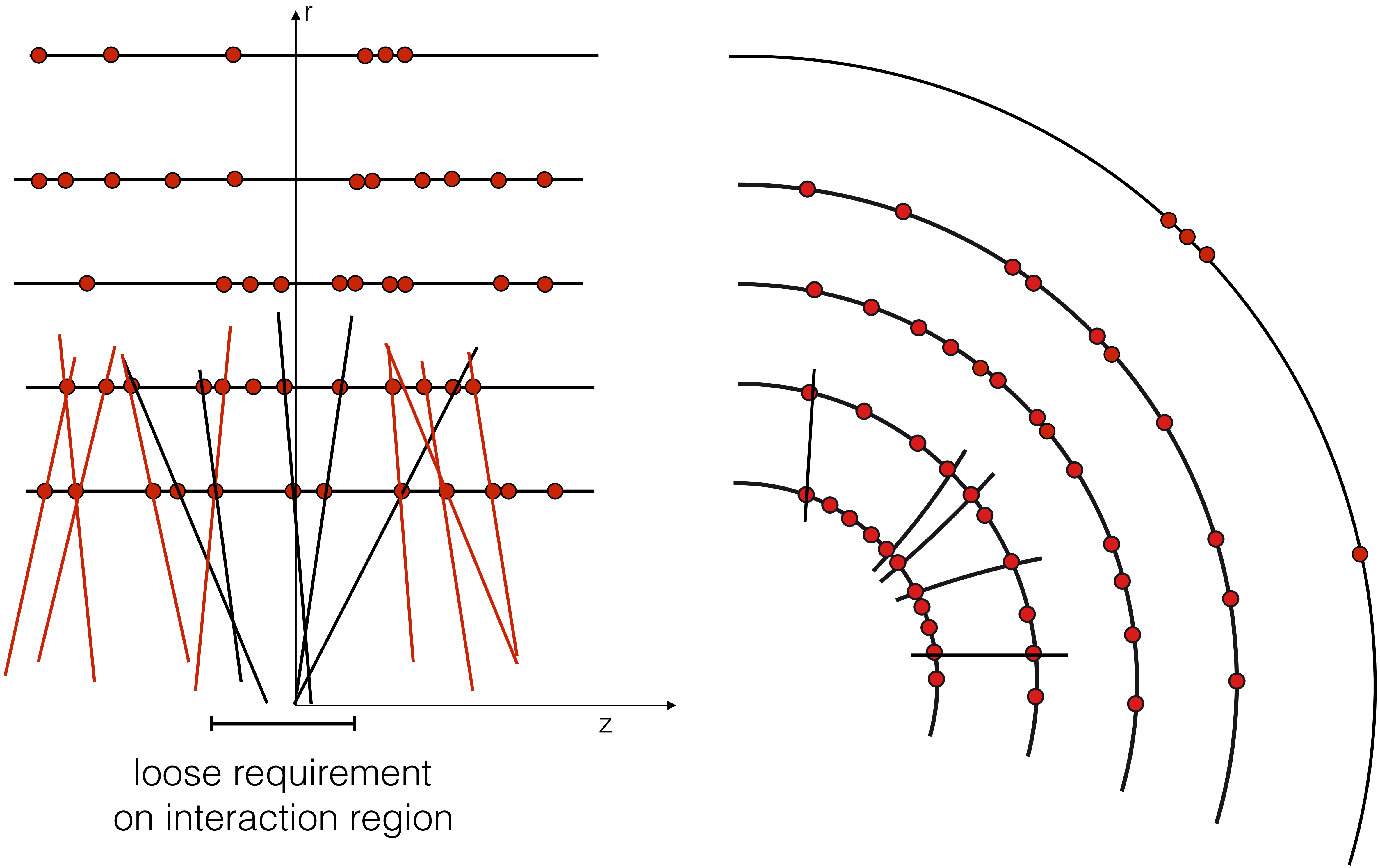
From seeds to track candidates

- Dense environments create problems for the progressive filter
  - there may not always be one obvious path to be followed: <u>The combinatorial filter</u>



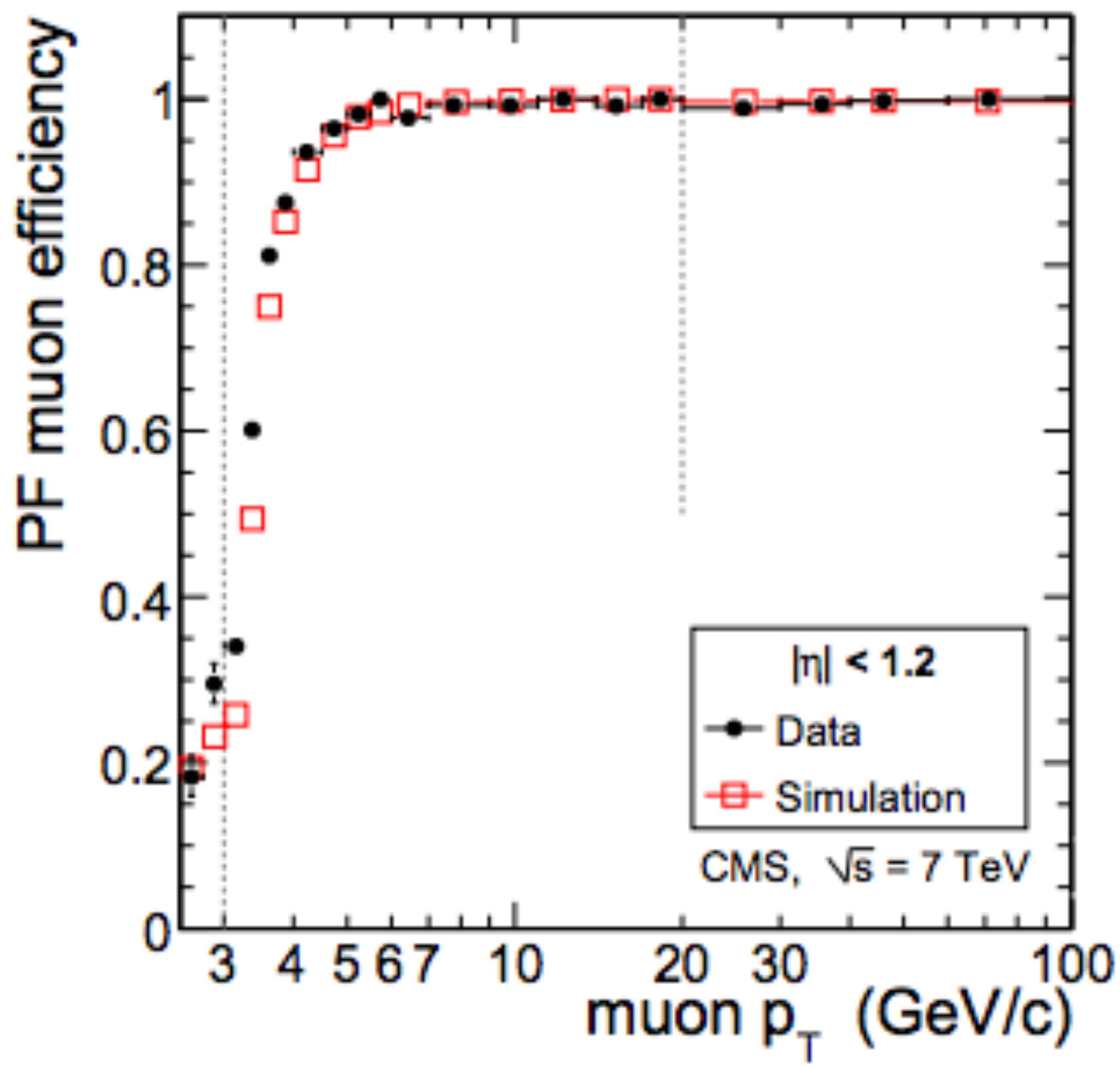
Enemy No. 2: ghosts

- avoid ghosts, i.e. fake combinations from simply combinatorial grouping
  - start off with high quality seeds (clearly 2 hit seeds are not very stringent)



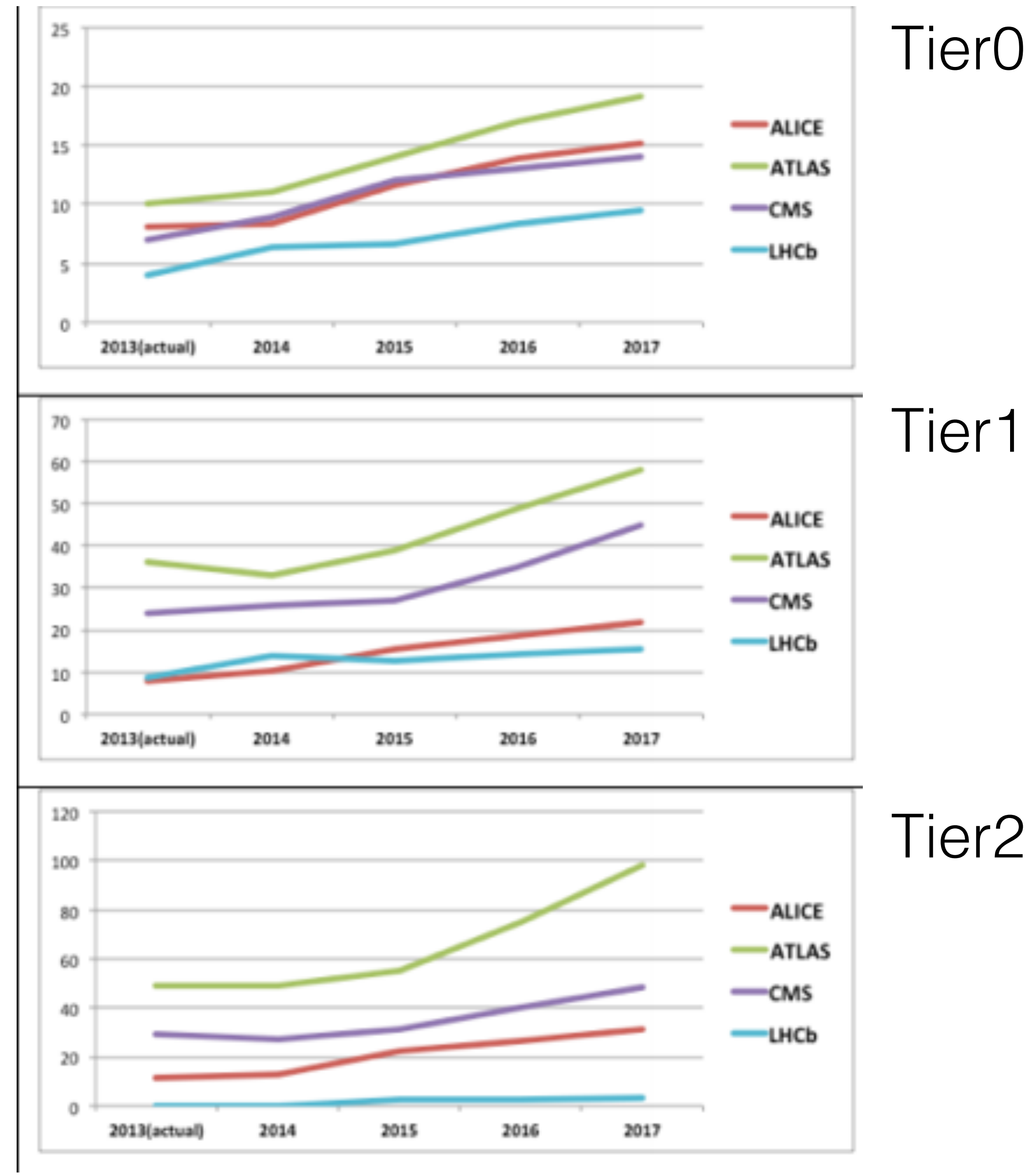
How are we doing ?

- Excellent !
  - performance is basically limited by material in the detector



[source]

- So why ?

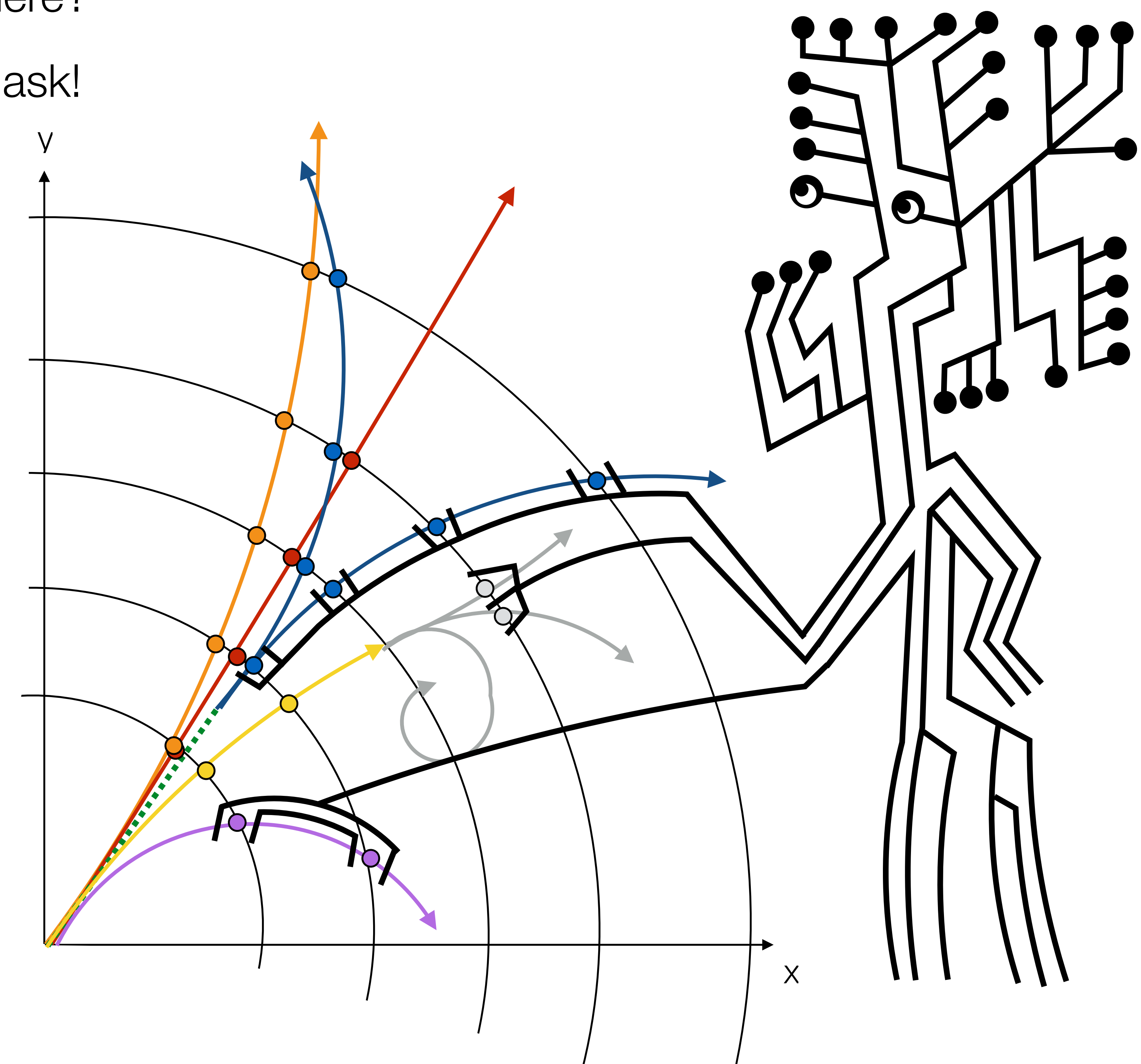


[source]

A new challenge lies ahead

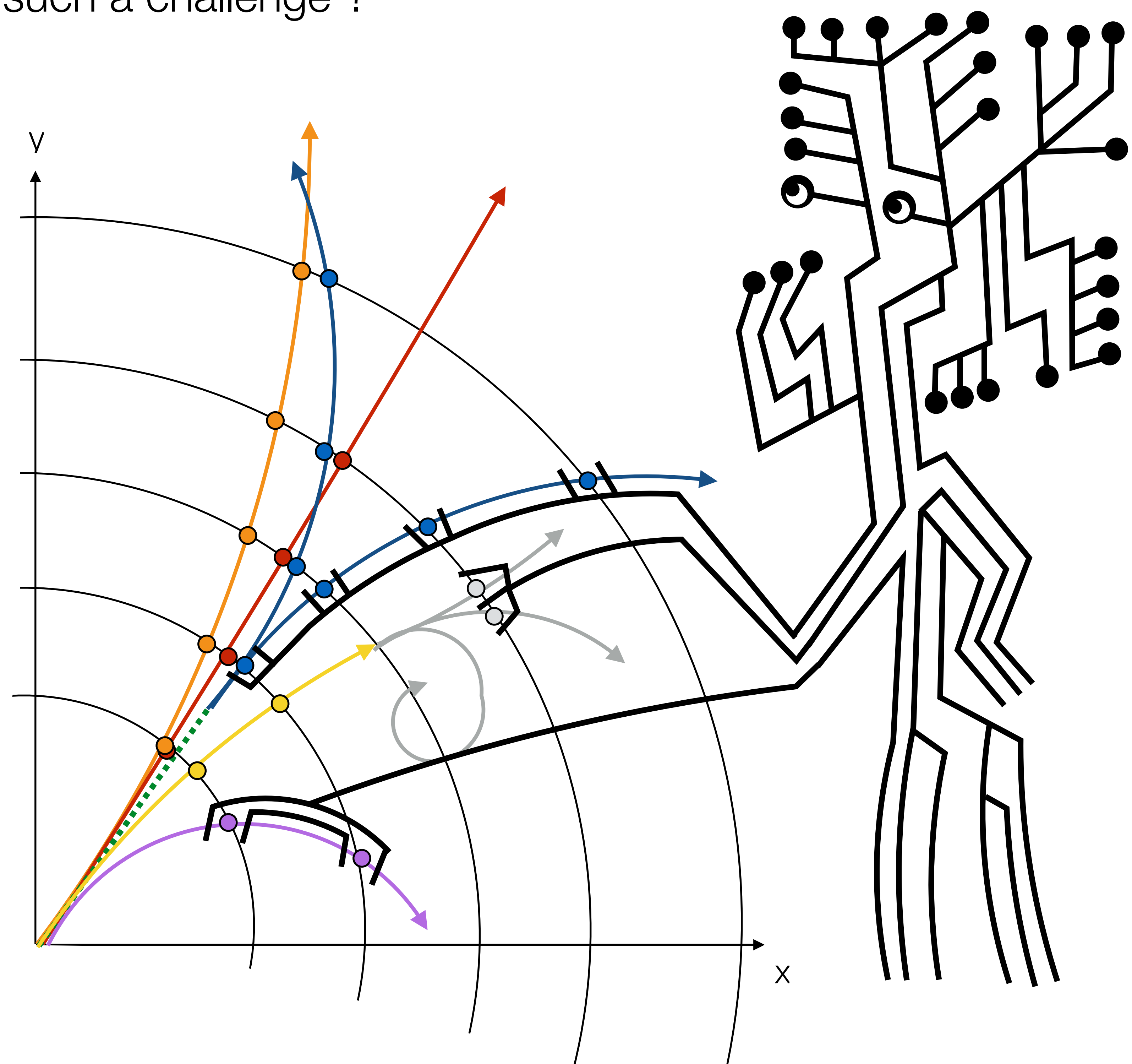
- Are we using the most up-2-date approaches ?
  - are there smarter kids out there?
  - we never know if we do not ask!

- HEP pattern recognition techniques are more than 25 years old
  - machine learning techniques are flooding the market
  - are they suitable for our complex problems ?



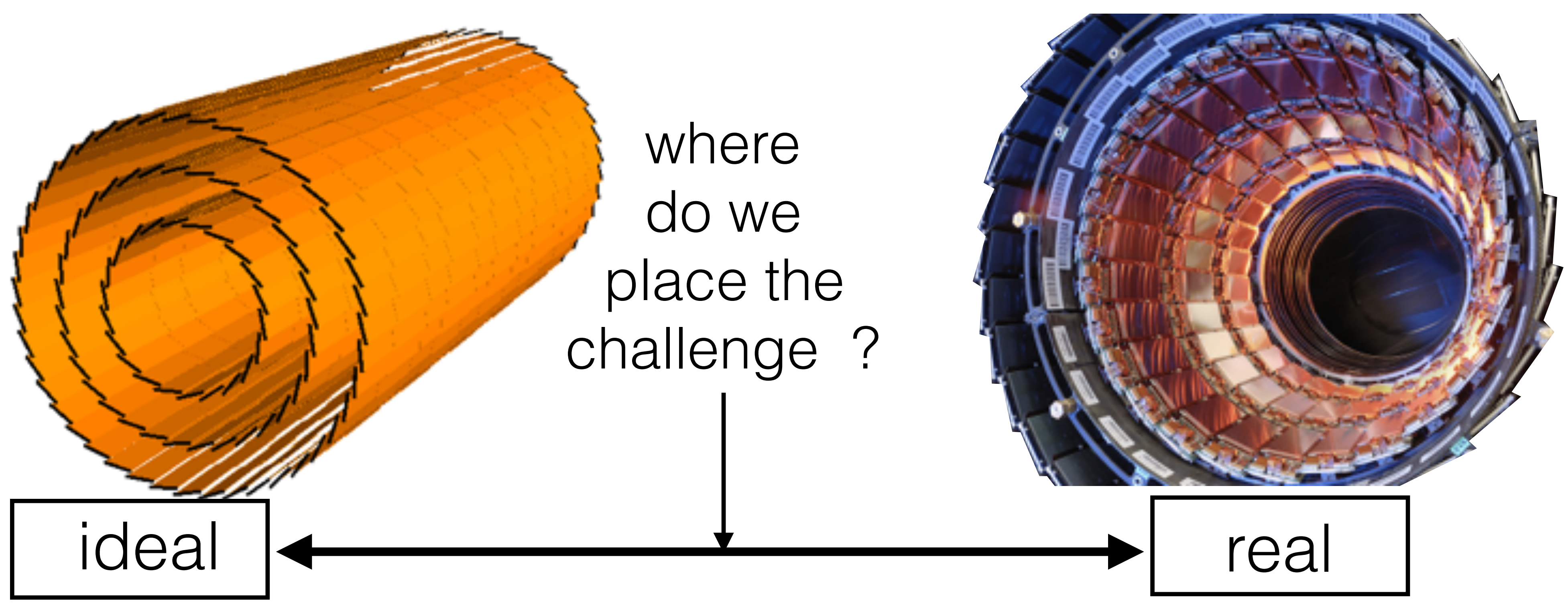
A HEP Tracking Machine Learning Challenge (1)

- Can we teach the computer to find tracks for us ?
  - what is the minimal input for such a challenge ?
- Formulation of the challenge is a challenge itself
  - balance of simplification versus complexity must be met to make such a challenge useful
  - formulation of the goal is similarly difficult
  - how can we take timing aspects into account ?



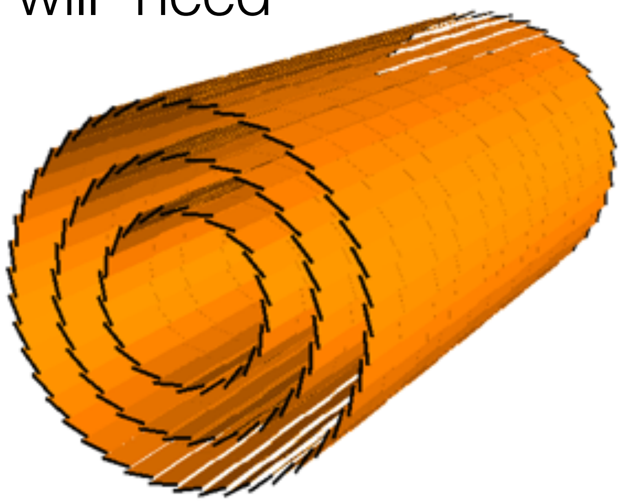
A HEP Tracking Machine Learning Challenge (2)

- Our current understanding - preconditions
  - difficulty of pattern recognition is not only due to combinatorics
  - ideal world (perfect magnetic) field and no process noise, there is an ideal solution:
    conformal mapping techniques have been successfully used in the past,
    e.g. Hough transformation, Riemann sphare
  - yet, only TPC-like detectors currently allow such semi-algorithmic approaches
    FCC detector concepts actually bring more complexity rather than simplicity
  - process noise is a problem, they make the problem messy
    multiple coulomb scattering, energy loss effects, hadronic interactions

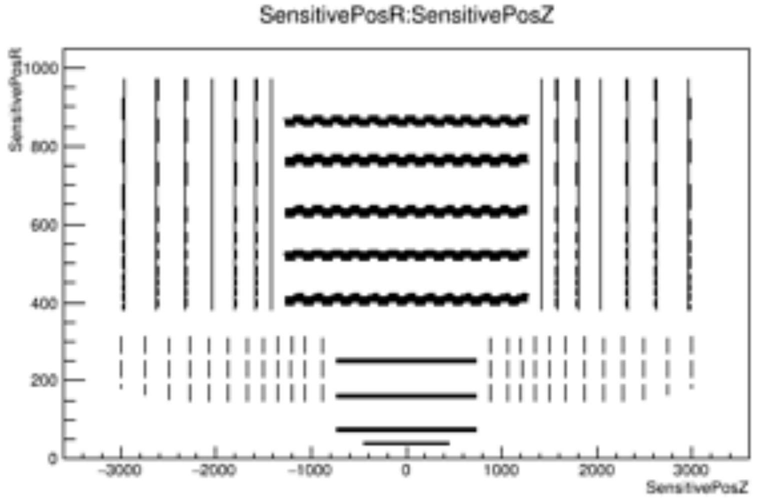


A HEP Tracking Machine Learning Challenge (3)

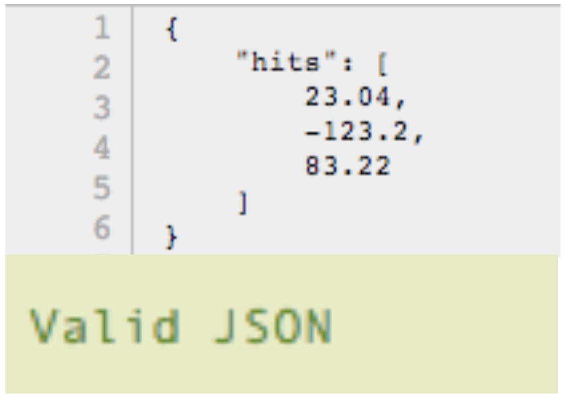
- Requirements
  - we will need



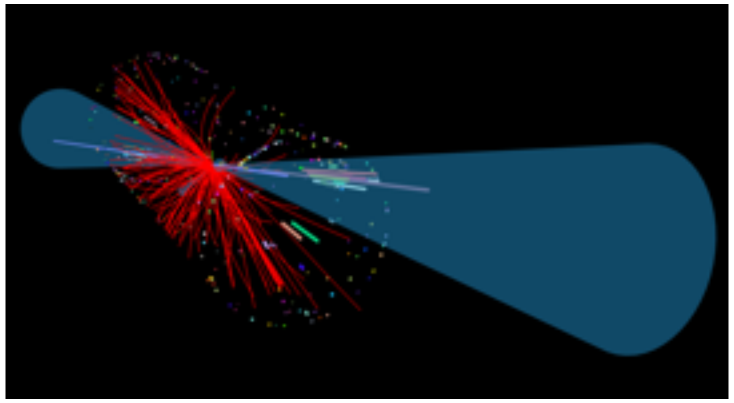
detector geometry
planar barrel/EC type detector
pixel/strip system



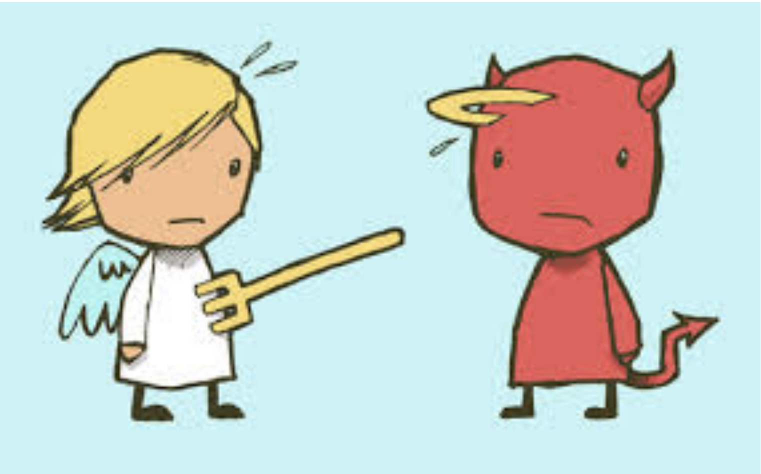
simulation
with the possibility to
simplify where possible



event data
easily readable,
platform independent



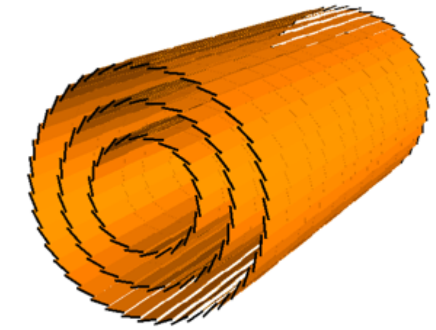
visualisation
of geometry,
hits & found tracks



well defined goal
what is success
and how we measure them

different categories
for different
solutions

(1) Detector geometry



- Phase 2 and FCC tracker geometries are aiming into a similar direction
  - system of solid state planar detector sensors
  - high granularity (pixels) at inner and lower granularity (strips) at outer radii
  - material budget of such detectors can be well estimated

- Magnetic field setup will not homogenous
  - ATLAS/CMS Phase-2 aim towards |eta| < 4.0

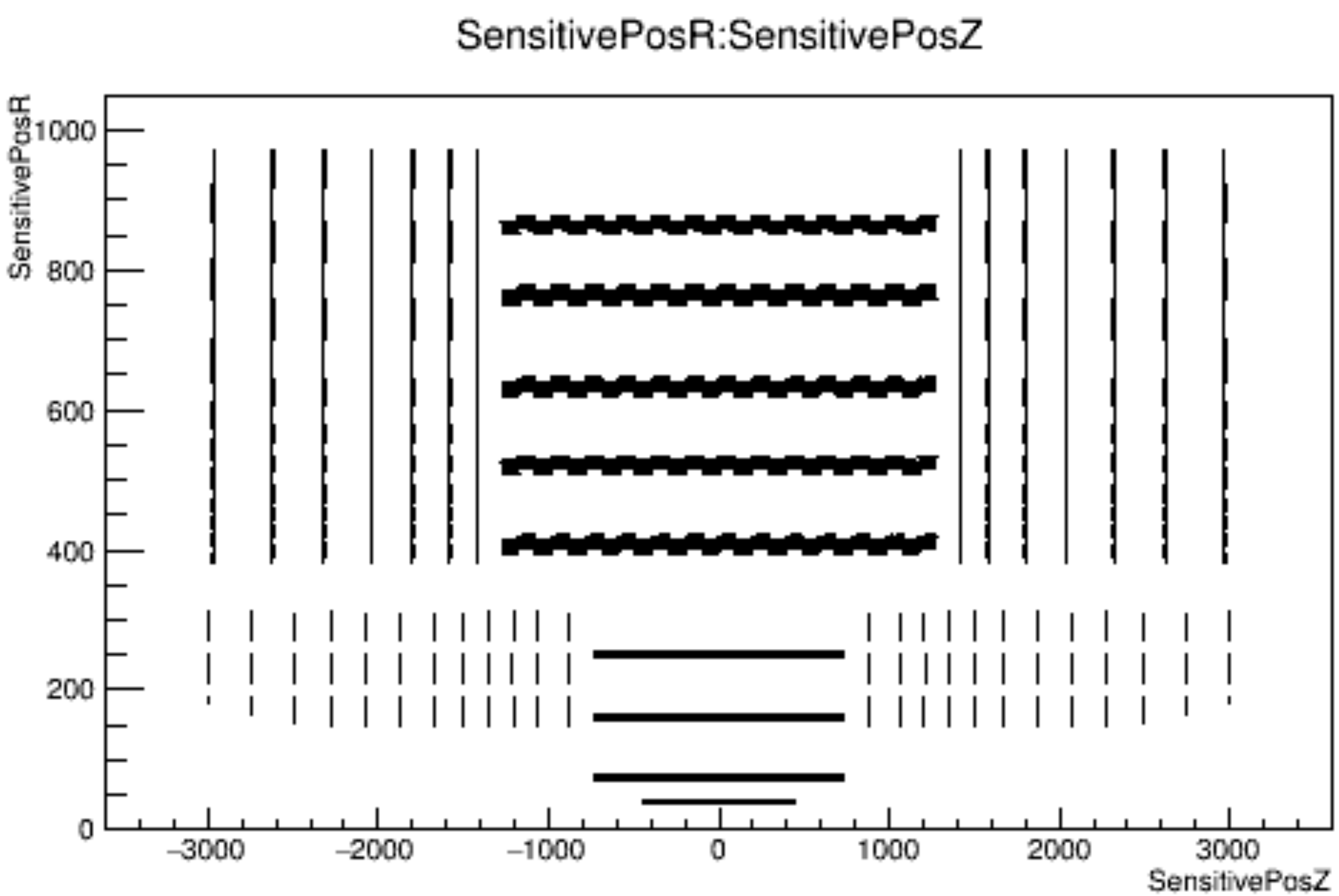
    ATLAS solenoid reaches 0 field strength, CMS solenoid strongly different from 4 T
  - FCC-hh is planning a solenoid with forward dipole setup to exploit forward region

- <u>Proposal</u> of a n-layer cylindrical detector with pixels, strips
  - 9 layer setup (~ 13 hits)
  - ATLAS-like magnetic field

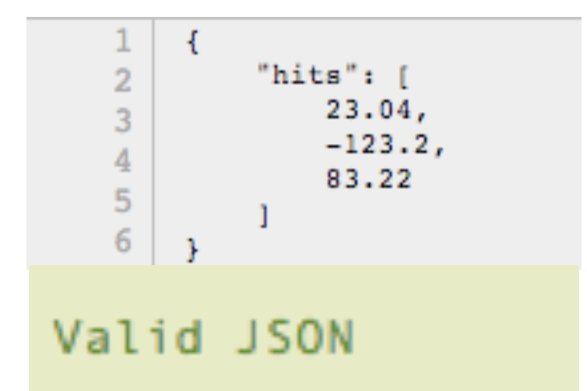
(2) Simulation, (3) Event Data

- Have established running this in the ATLAS Fast Track simulation
  - within the FCC context trying to feed that also into Geant4
  - limited material effects, but good to 5 % level

    multiple scattering, ionising energy loss, radiative energy loss, hadronic interaction (with possibility to switch on/off)

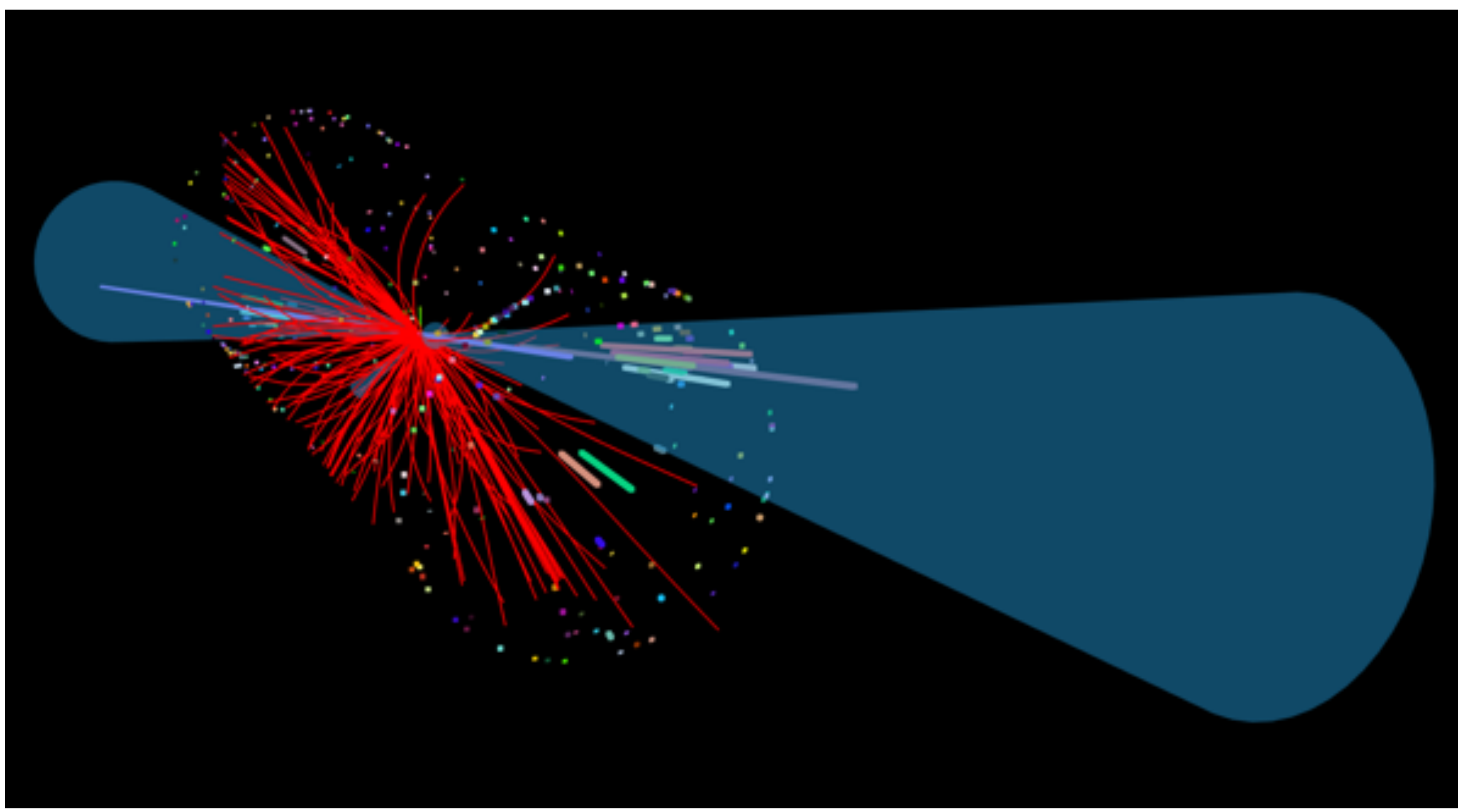


ROOT, JSON



(4) Visualisation

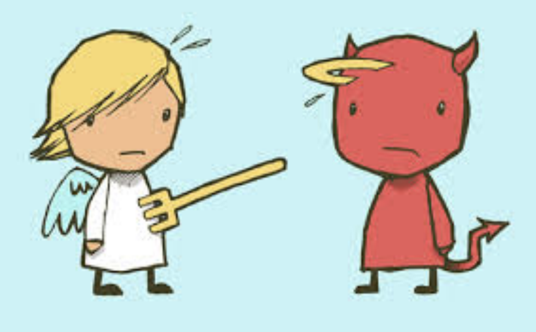
- Visualisation is absolutely necessary
  - with possibility to show geometry, hits, tracks (truth and found)
  - very simple web-based display developed by Edward Moyse




```
{
    "hits": [
        23.04,
        -123.2,
        83.22
    ]
}
```

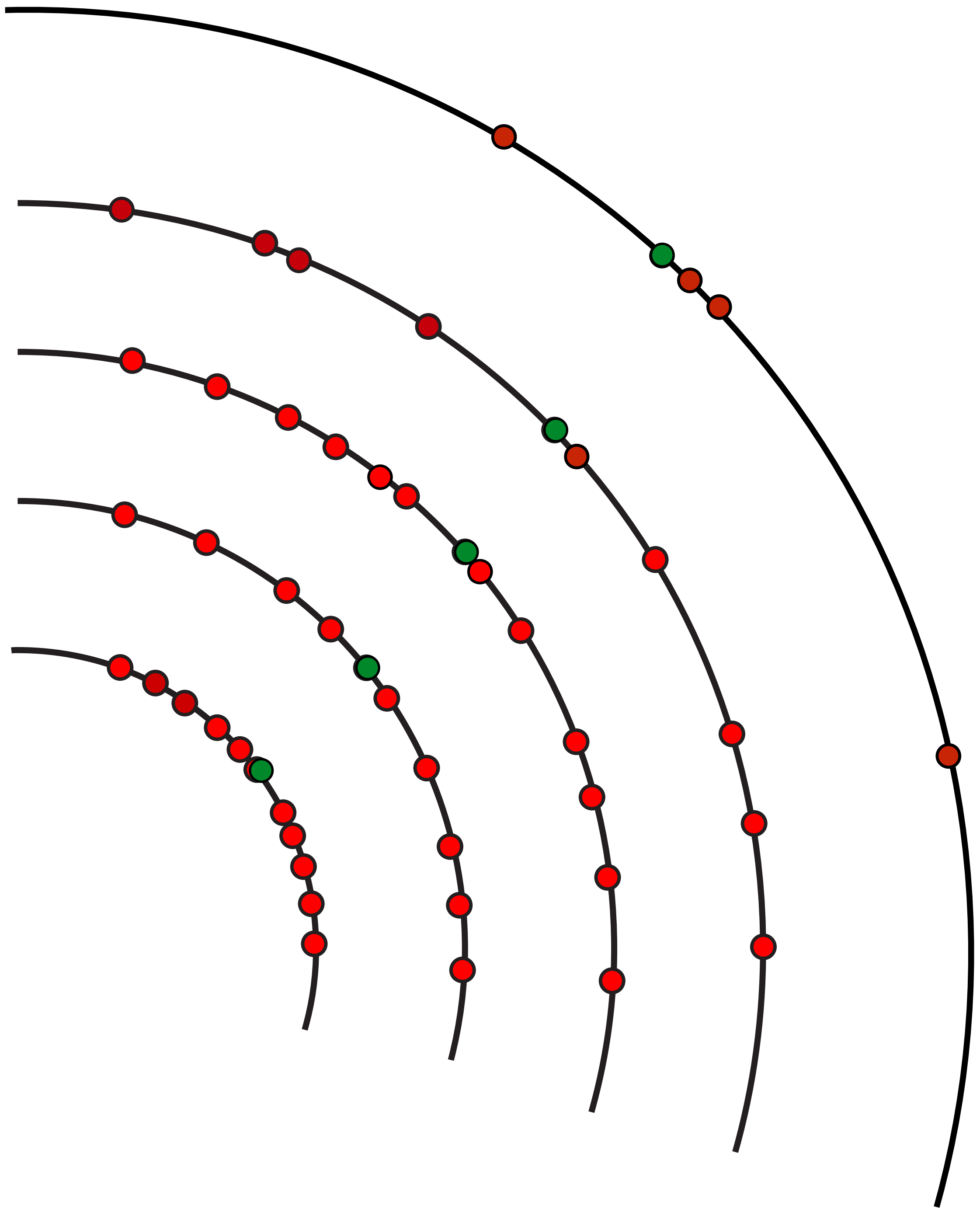

Valid JSON

(5) Goals - based on Run-1 experience



- muon tracking efficiency even at pile-up ~ 200 is close to 100 %
- pion tracking efficiency even at pile-up ~200 is dominated by hadronic interaction
- **fake rate** in Run-1 conditions at O(1%), same aim (globally) for pile-up 200

good track **not so good track**



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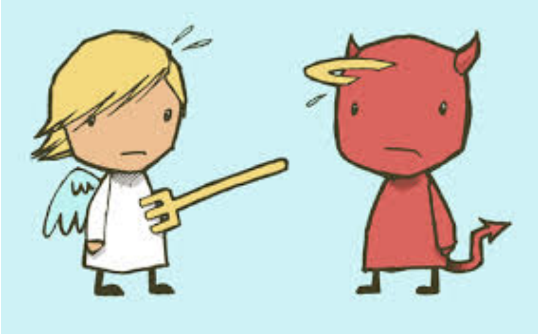

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good track **not so good track**

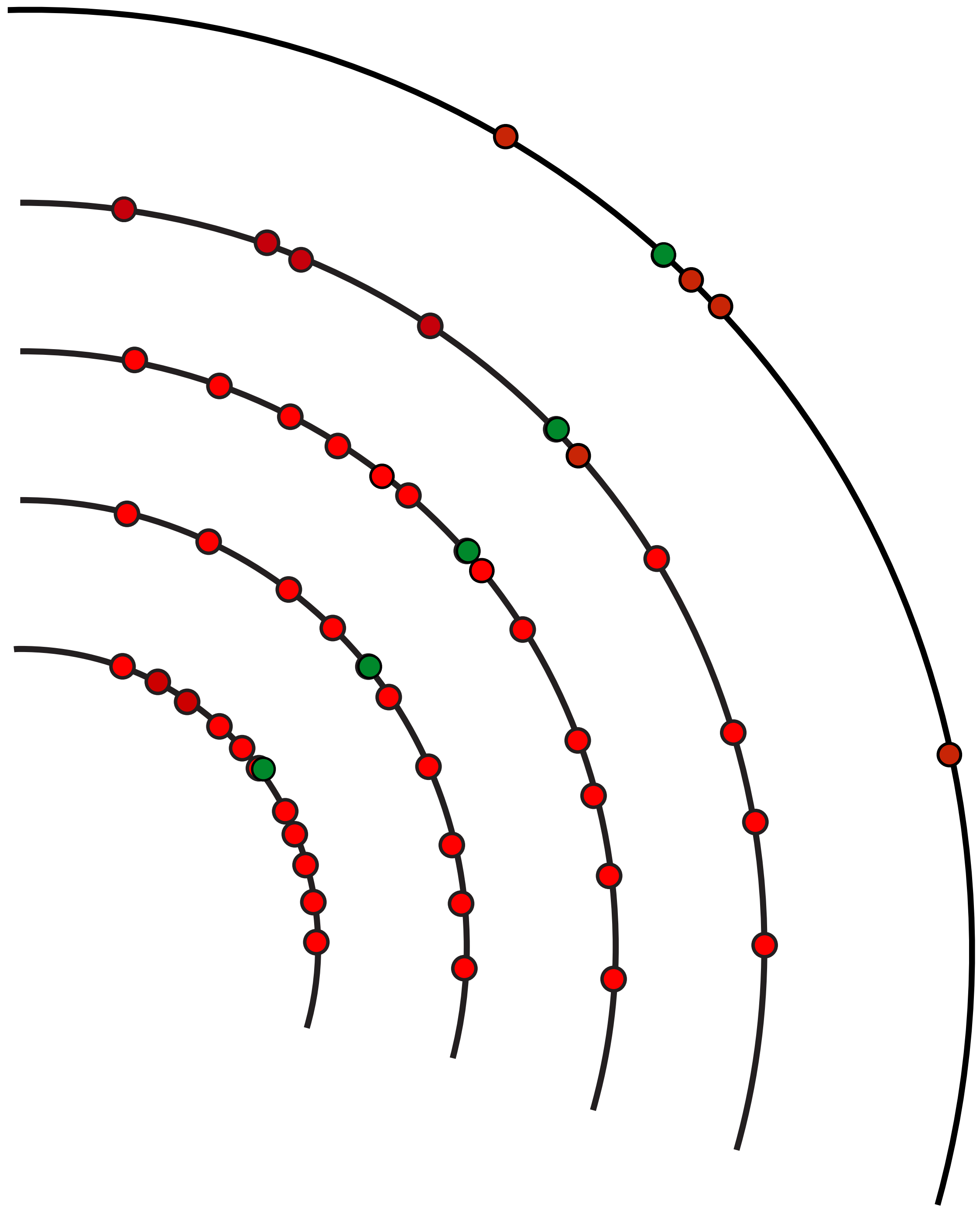
many compatible hits

completeness

uniqueness

low χ^2/ndf

small impact parameter (for primaries)



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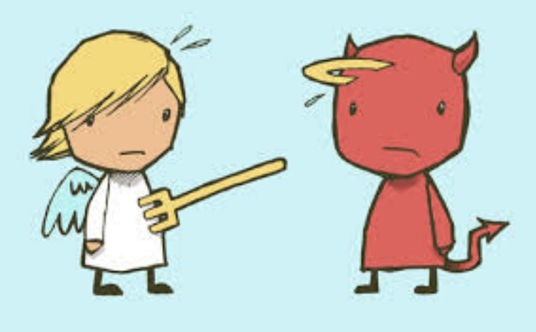

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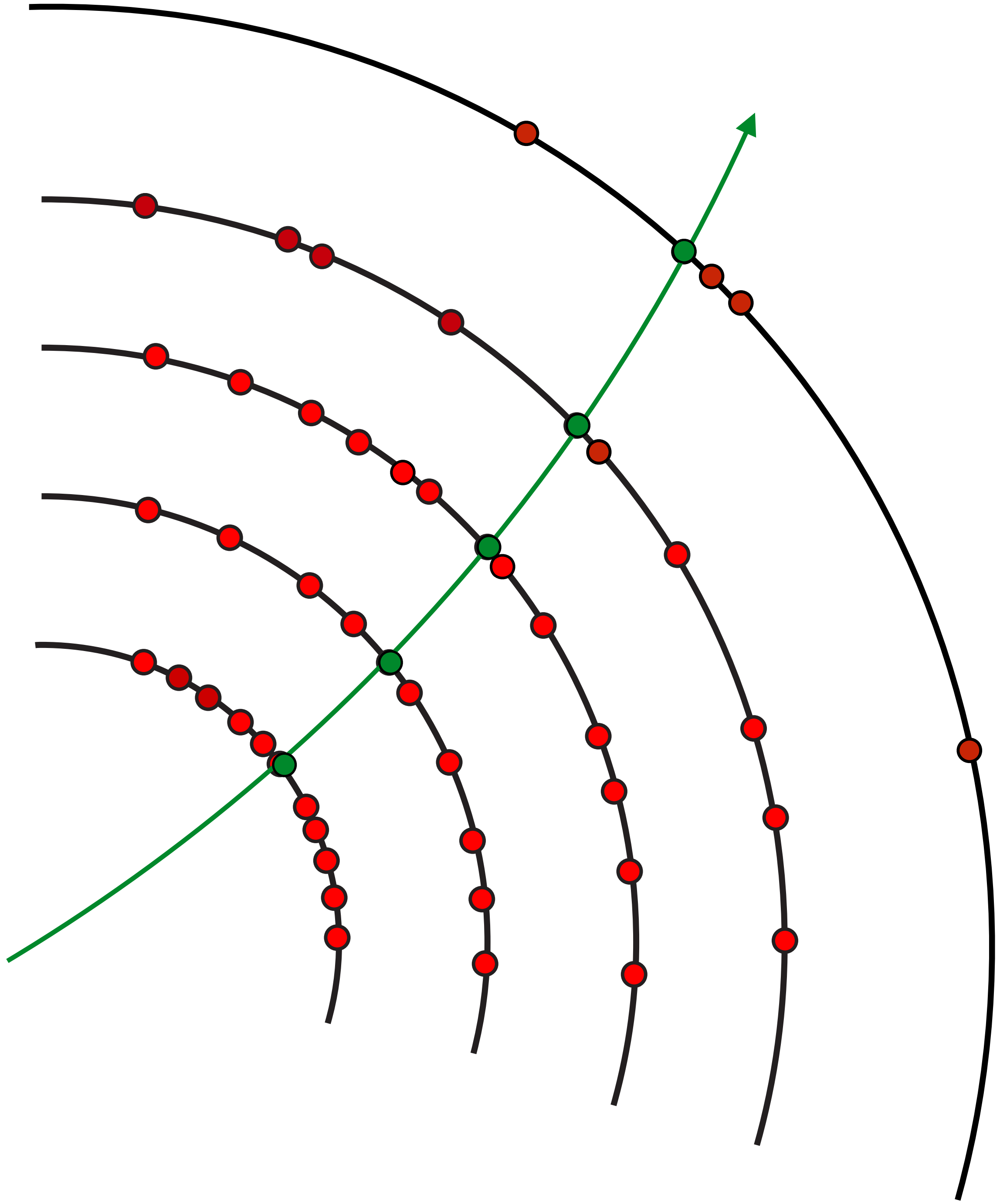

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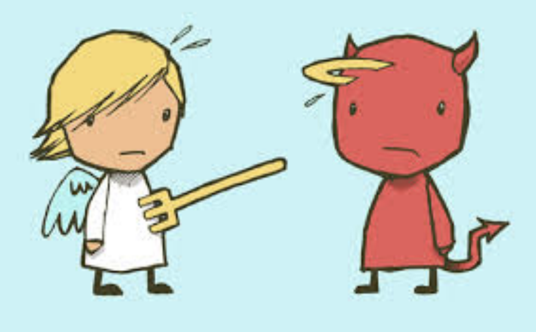

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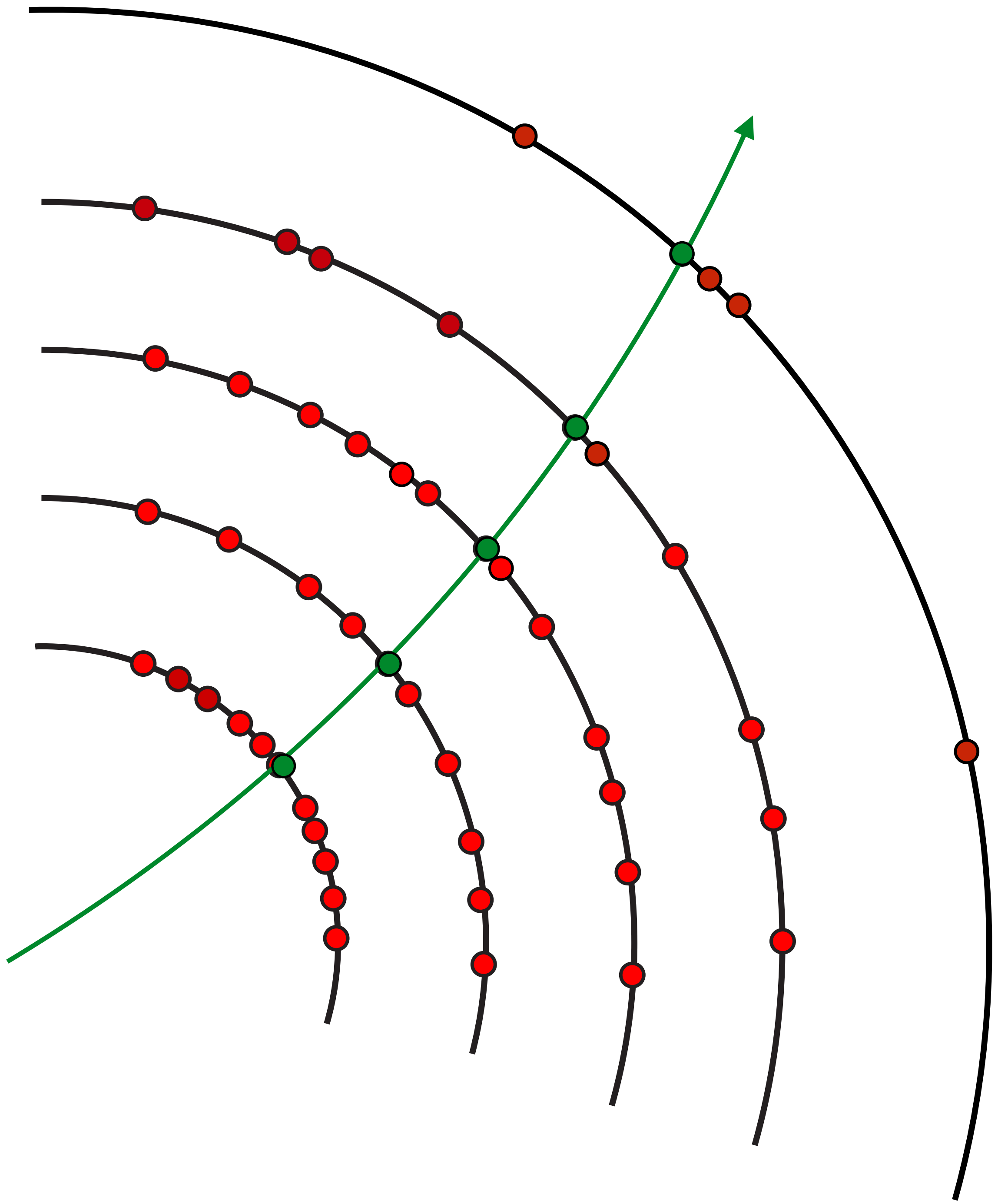
good track	**not so good track**
many compatible hits	short tracks
completeness	holes
uniqueness	shared hits
low χ^2/ndf	bad fit quality, outliers
small impact parameter (for primaries)	



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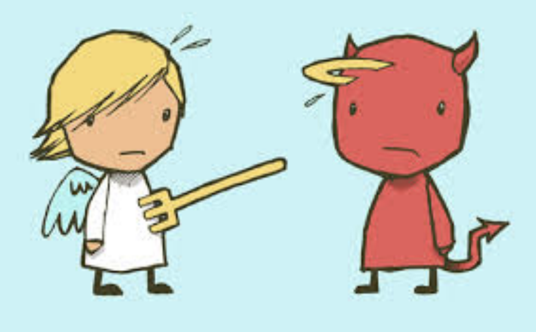

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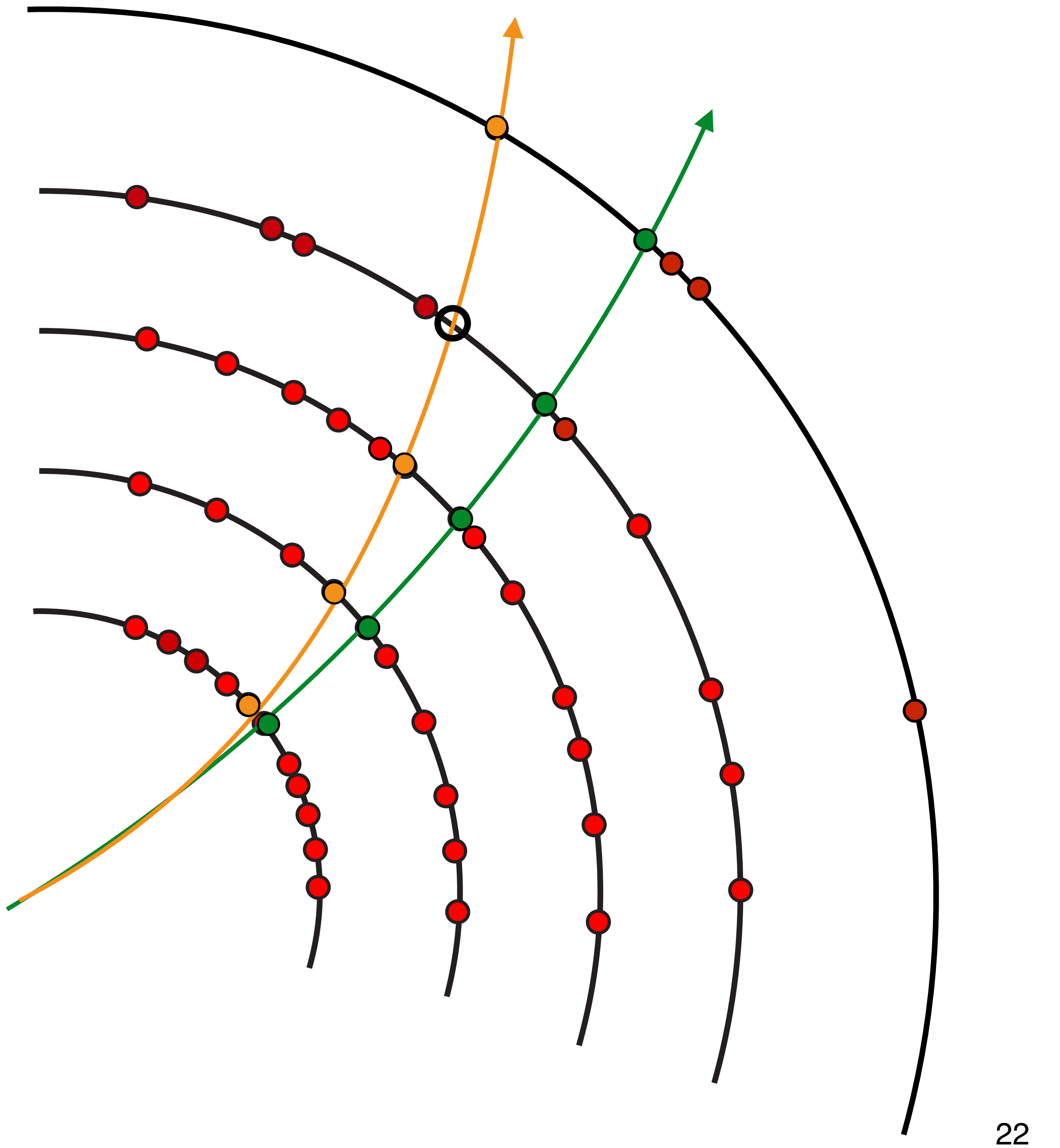

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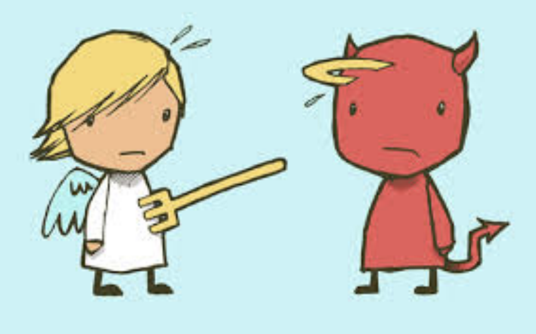

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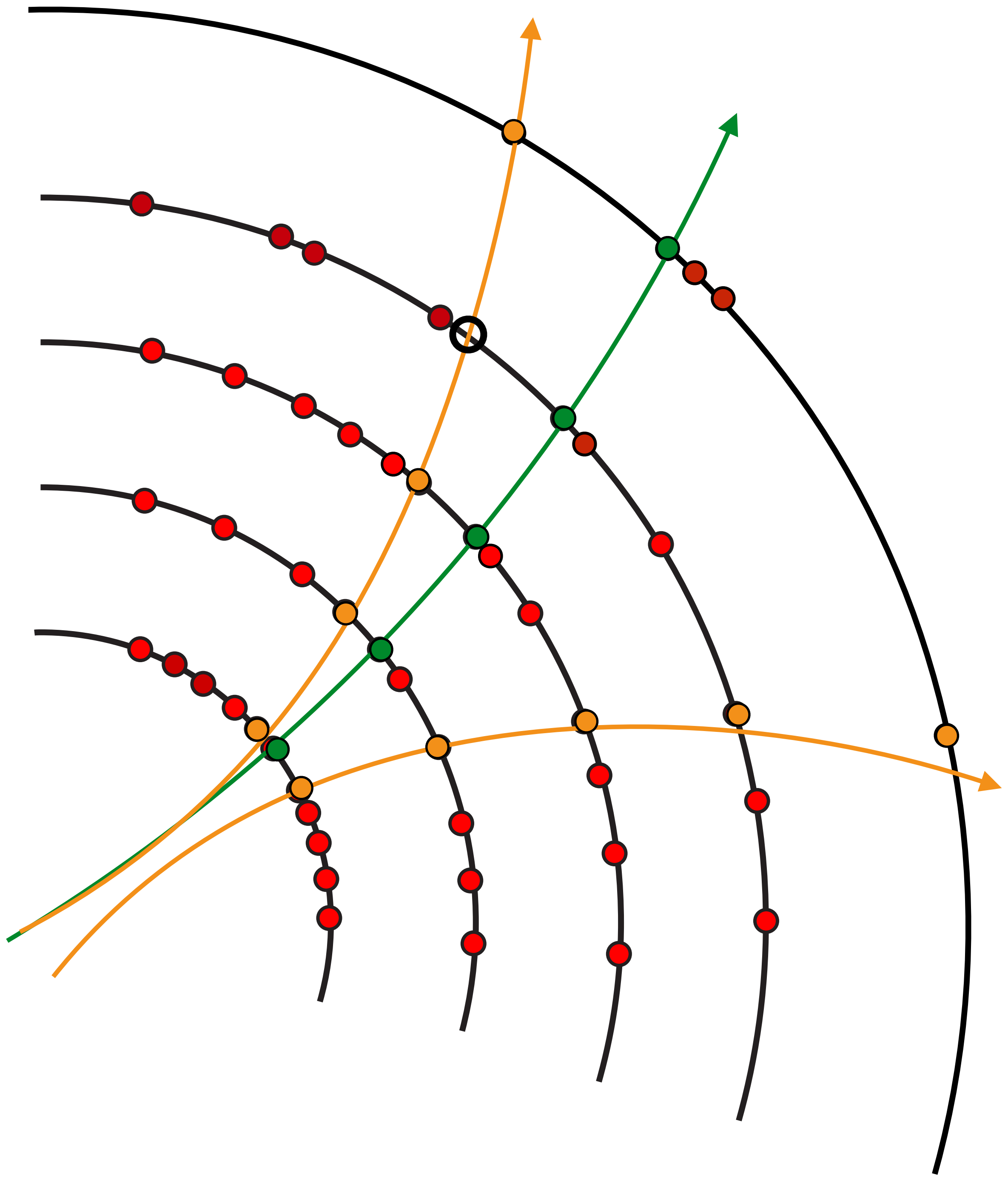

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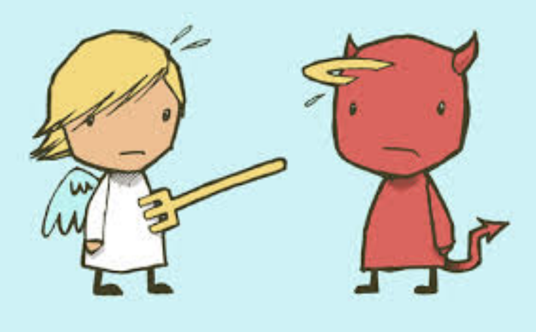

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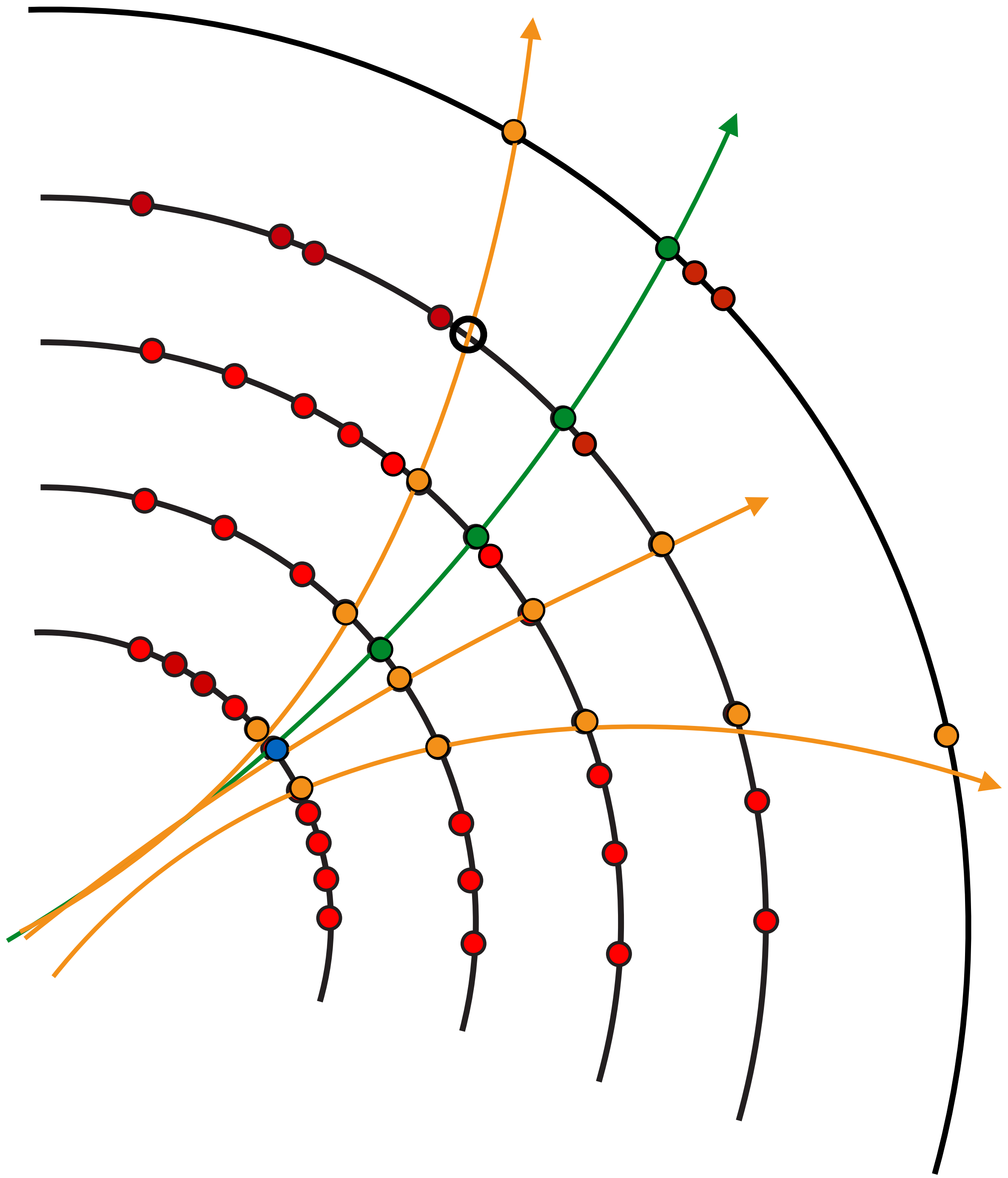

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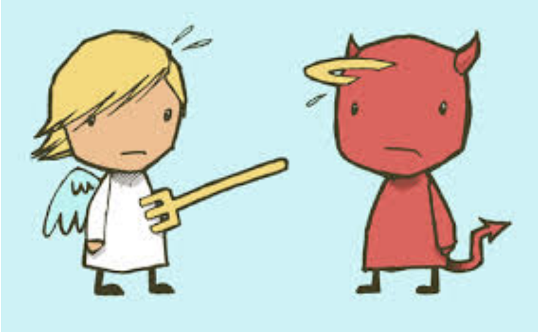

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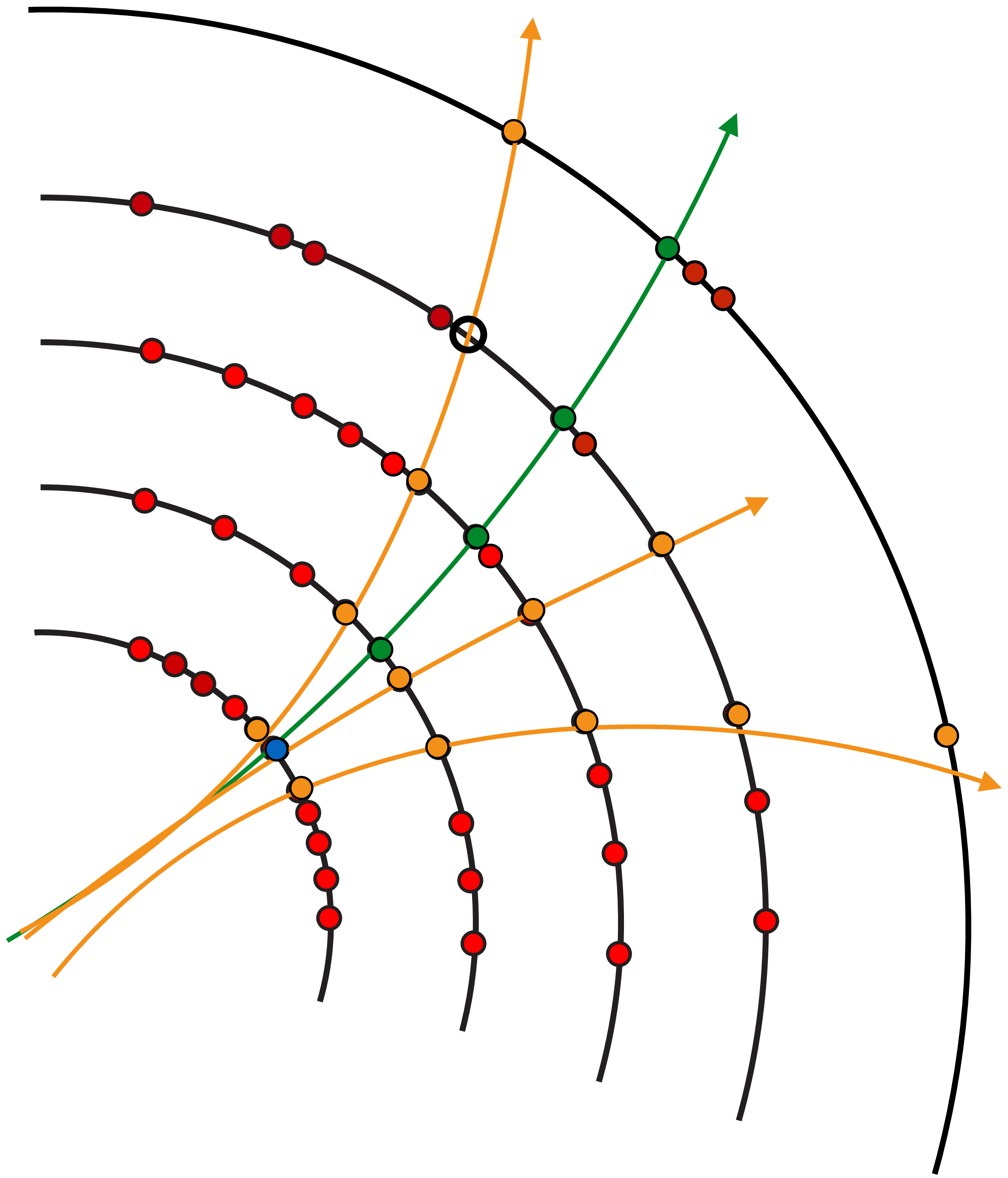
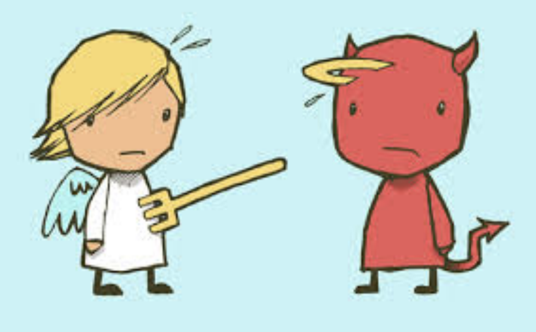


- Can we be sure ?

(5) Goals - based on Run-1 experience



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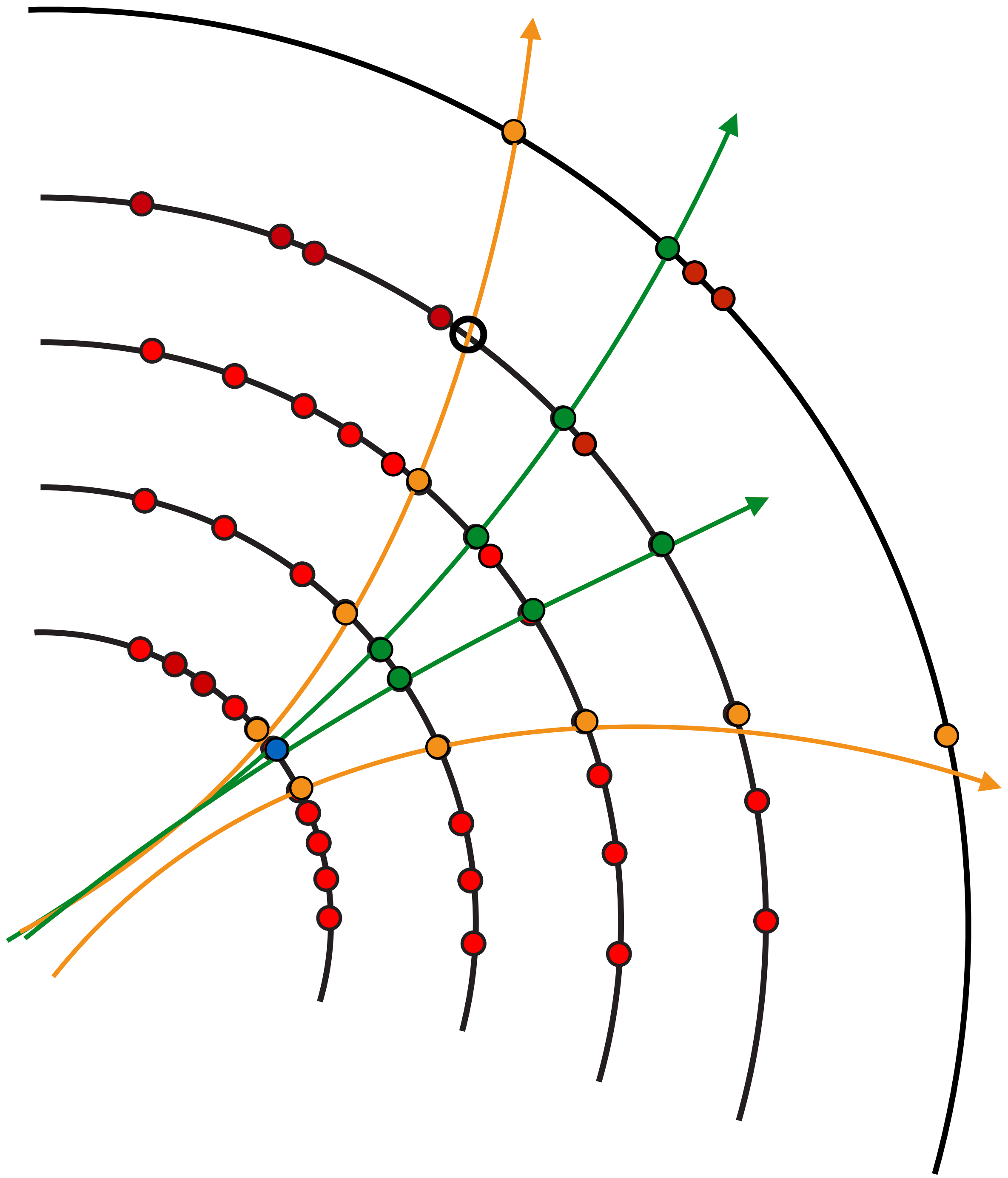

- Can we be sure ?

Good tracks and not so good tracks

- Some of the characteristics can only be checked after all track candidates are found

good track	**not so good track**
many compatible hits	short tracks
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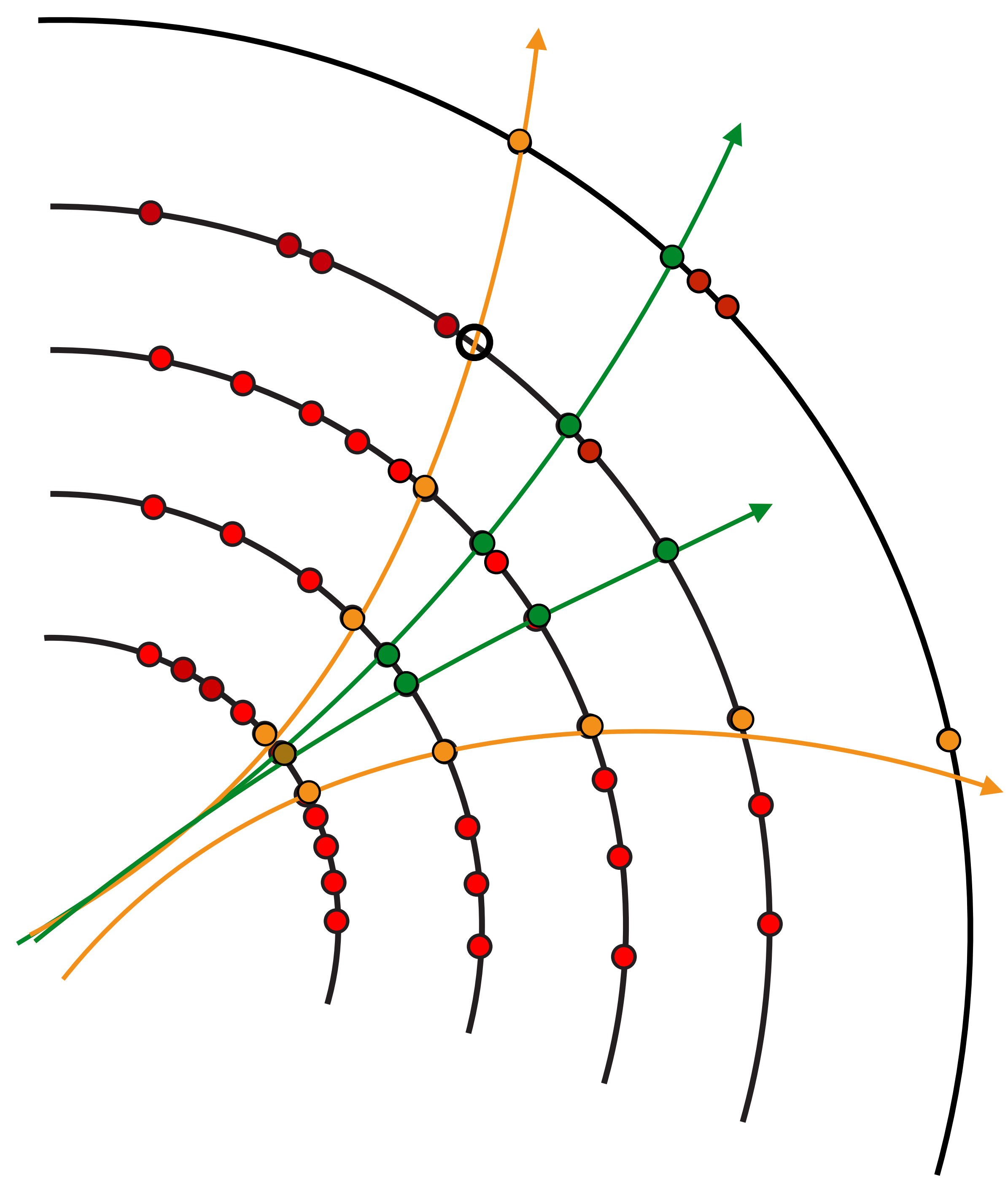

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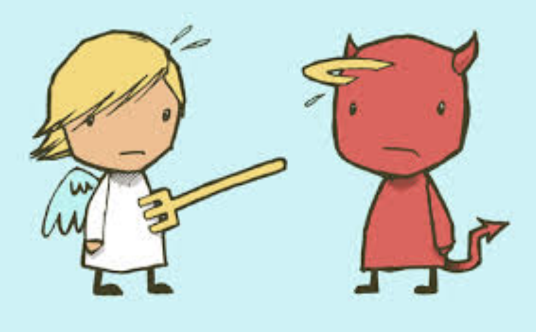

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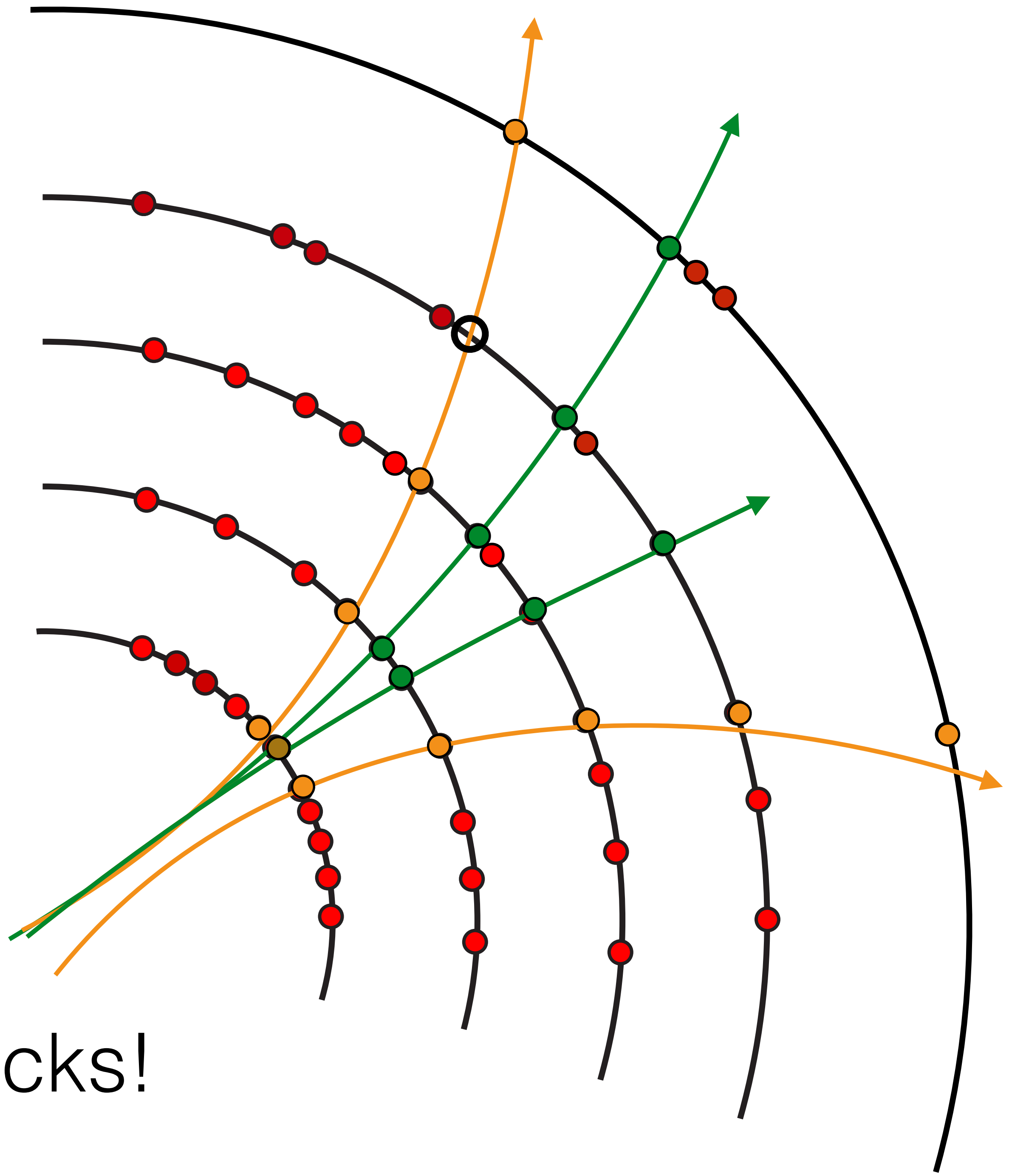
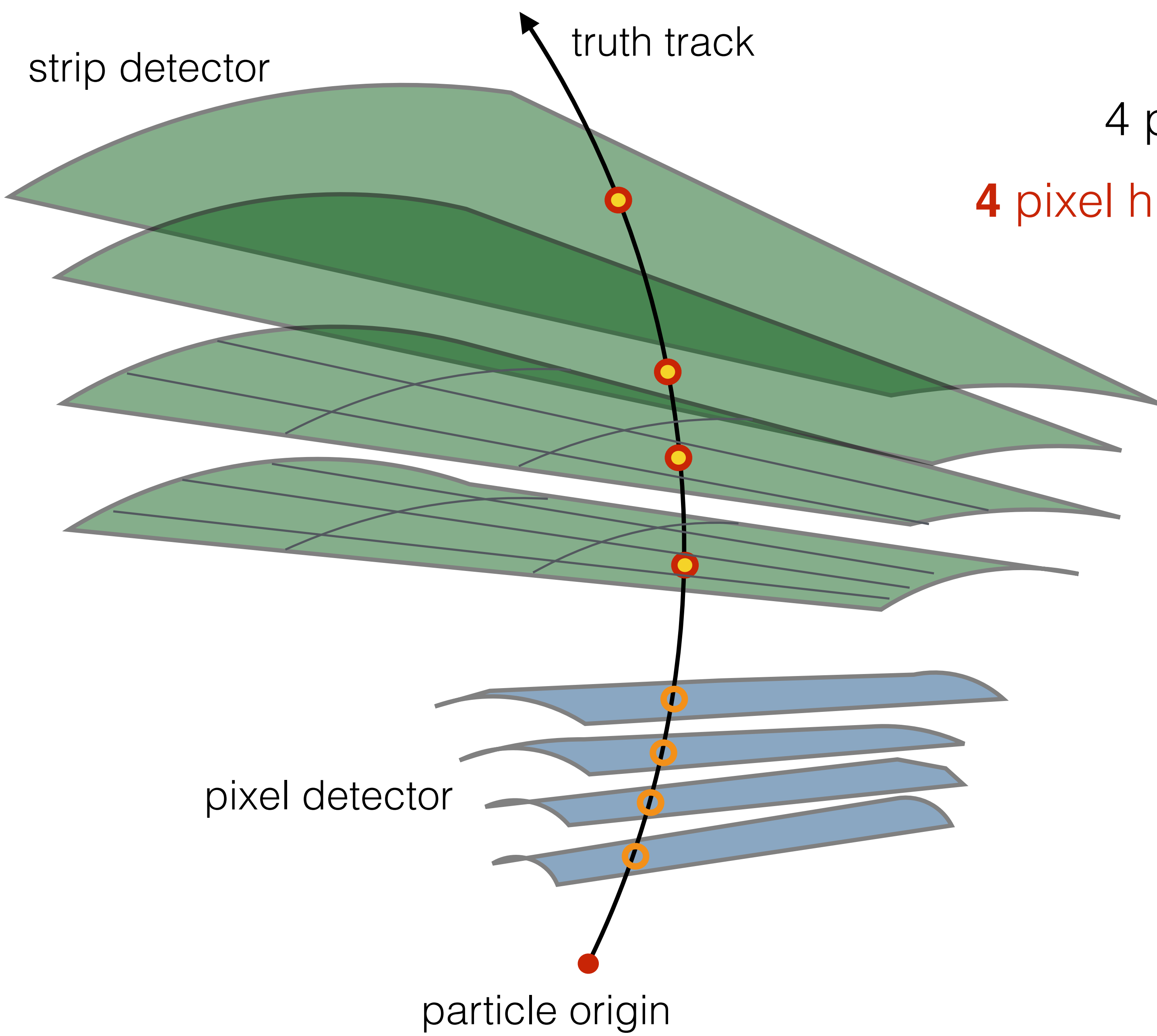


give scores and rank the tracks!

(5) Goals - track ranking (1)

- There is no unique truth matching to define a found track
  - we use truth matching per hits



The perfect track

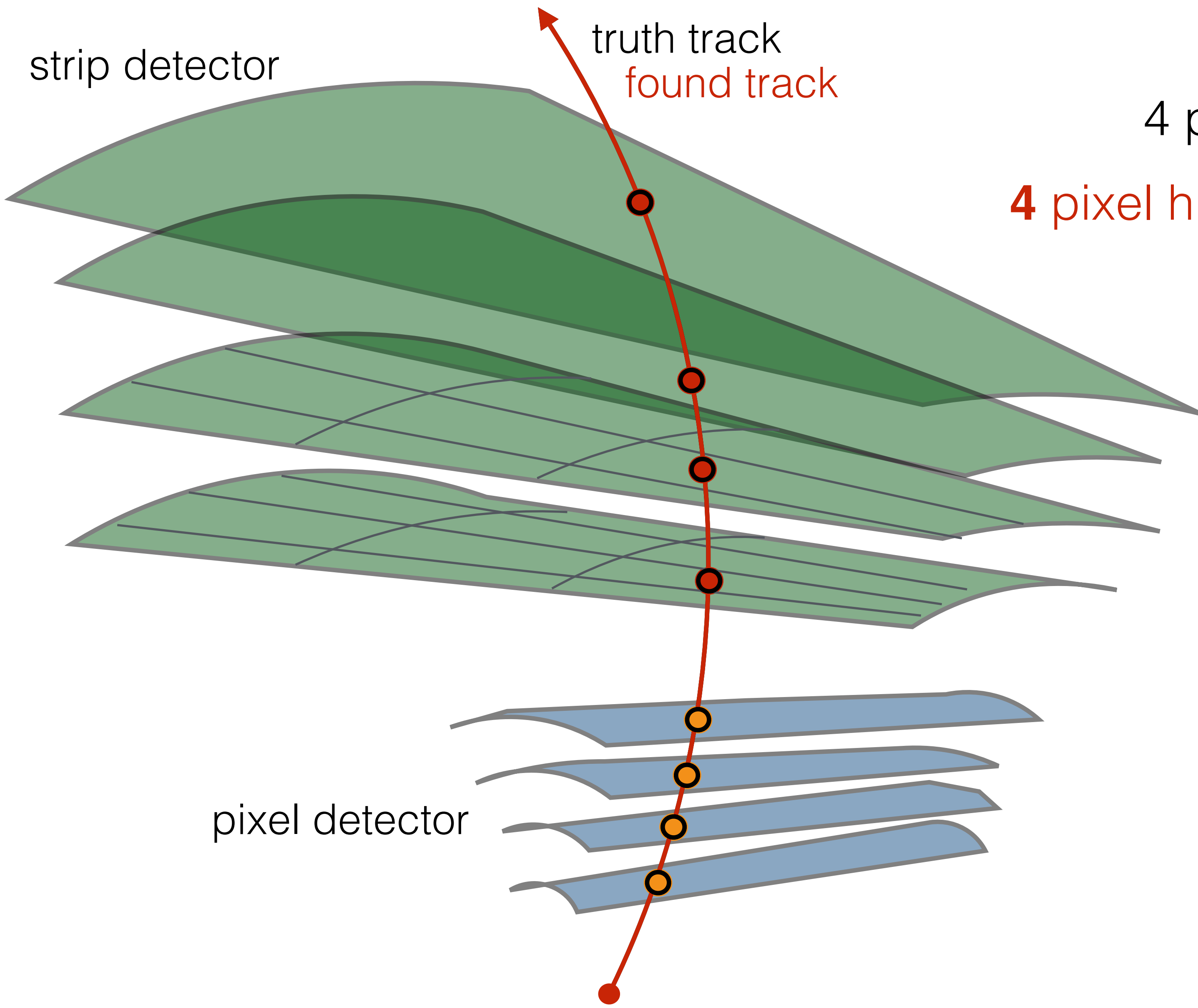
4 pixel hits, 4 strip hits created

4 pixel hits, **4** strip hits found and assigned

you can't do better,
score = 1

(5) Goals - track ranking (1)

- There is no unique truth matching to define a found track
  - we use truth matching per hits



The perfect track

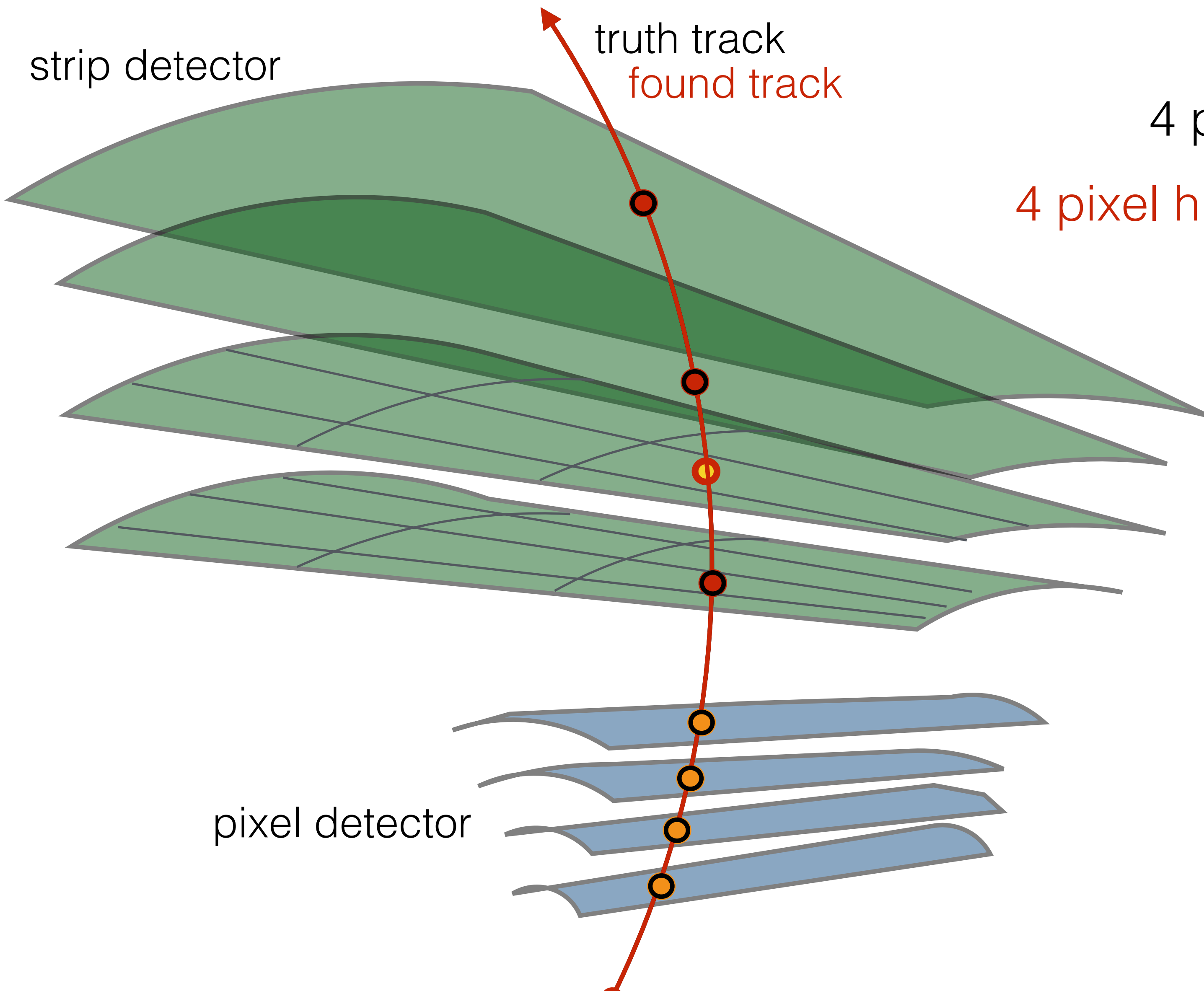
4 pixel hits, 4 strip hits created

4 pixel hits, **4** strip hits found and assigned

you can't do better,
score = 1

(4) Goals - track ranking (2)

- There is no unique truth matching to define a found track
  - we use truth matching per hits



A good track

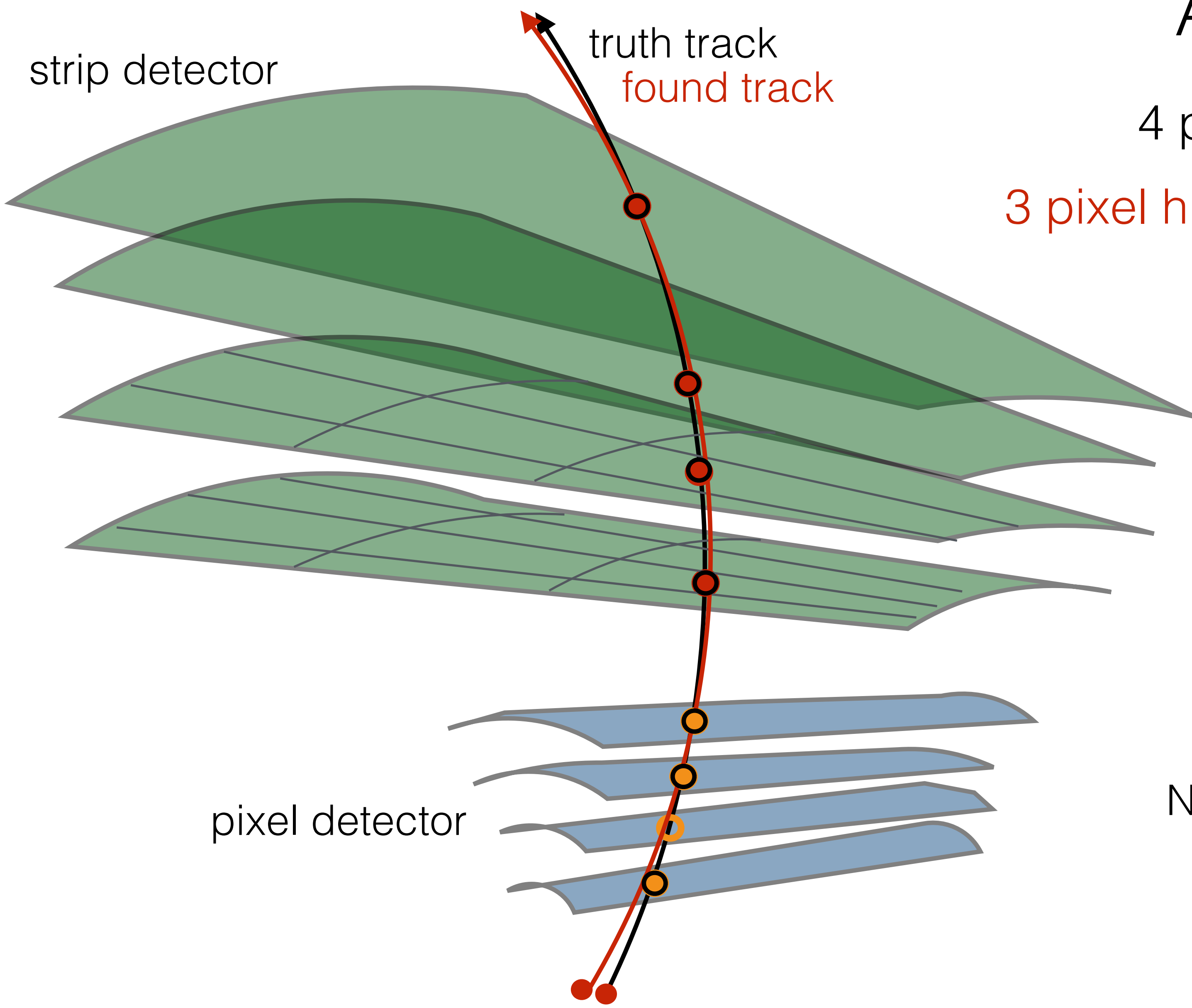
4 pixel hits, 4 strip hits created

4 pixel hits, 3 strip hits found and assigned

that's an ok track,
you got 7 out of 8,
naive score = 7/8 = 0.875

(4) Goals - track ranking (3)

- There is no unique truth matching to define a found track
  - we use truth matching per hits



Another good track

4 pixel hits, 4 strip hits created

3 pixel hits, 4 strip hits found and assigned

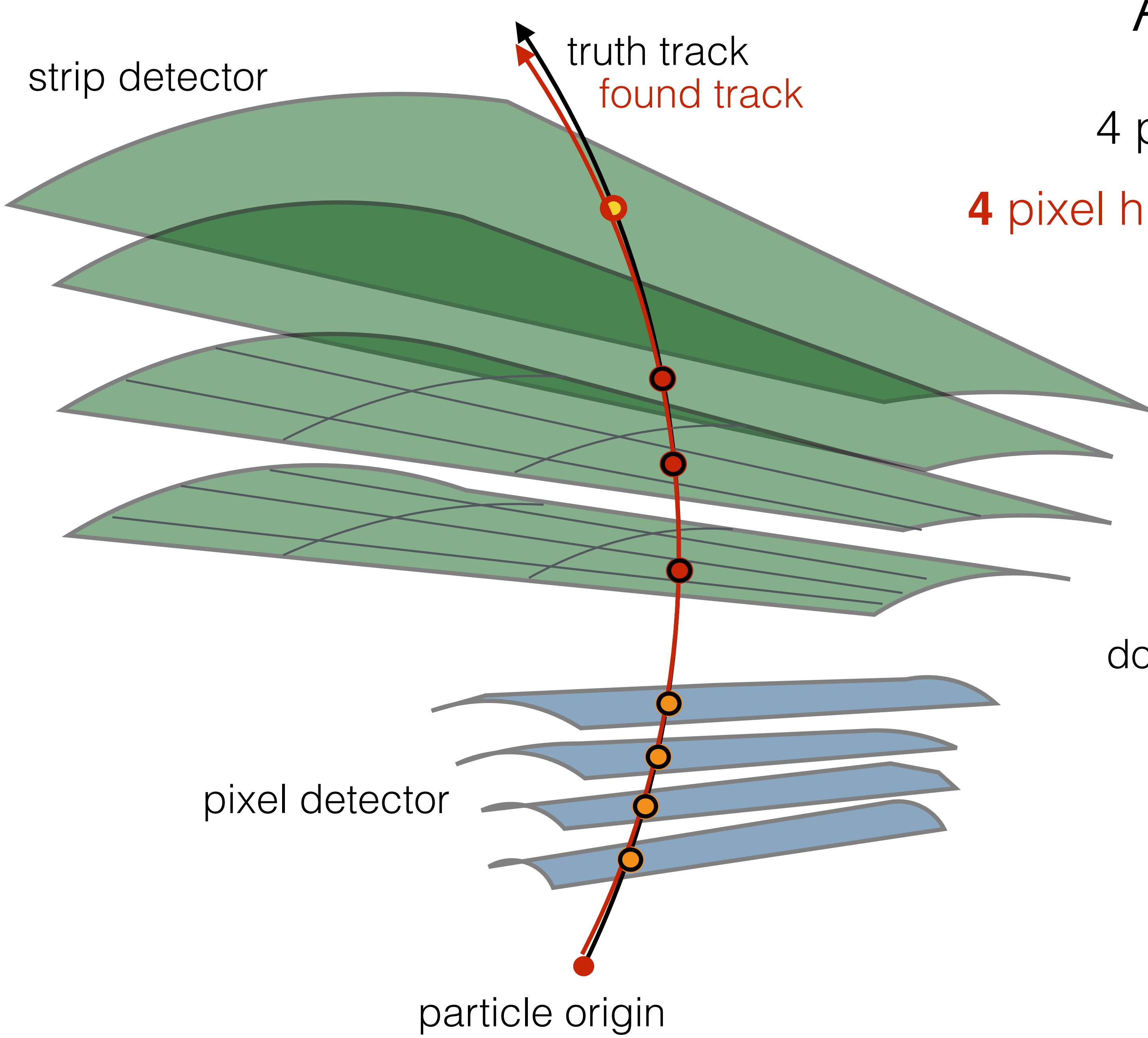
that's an ok track,
you got 7 out of 8,
naive score = 7/8 = 0.875

does a pixel hit weigh the same
as a strip hit ?

NOT if we want to measure primary
particles !!!

(4) Goals - track ranking (4)

- There is no unique truth matching to define a found track
  - we use truth matching per hits



Another good track

4 pixel hits, 4 strip hits created

4 pixel hits, **3** strip hits found and assigned

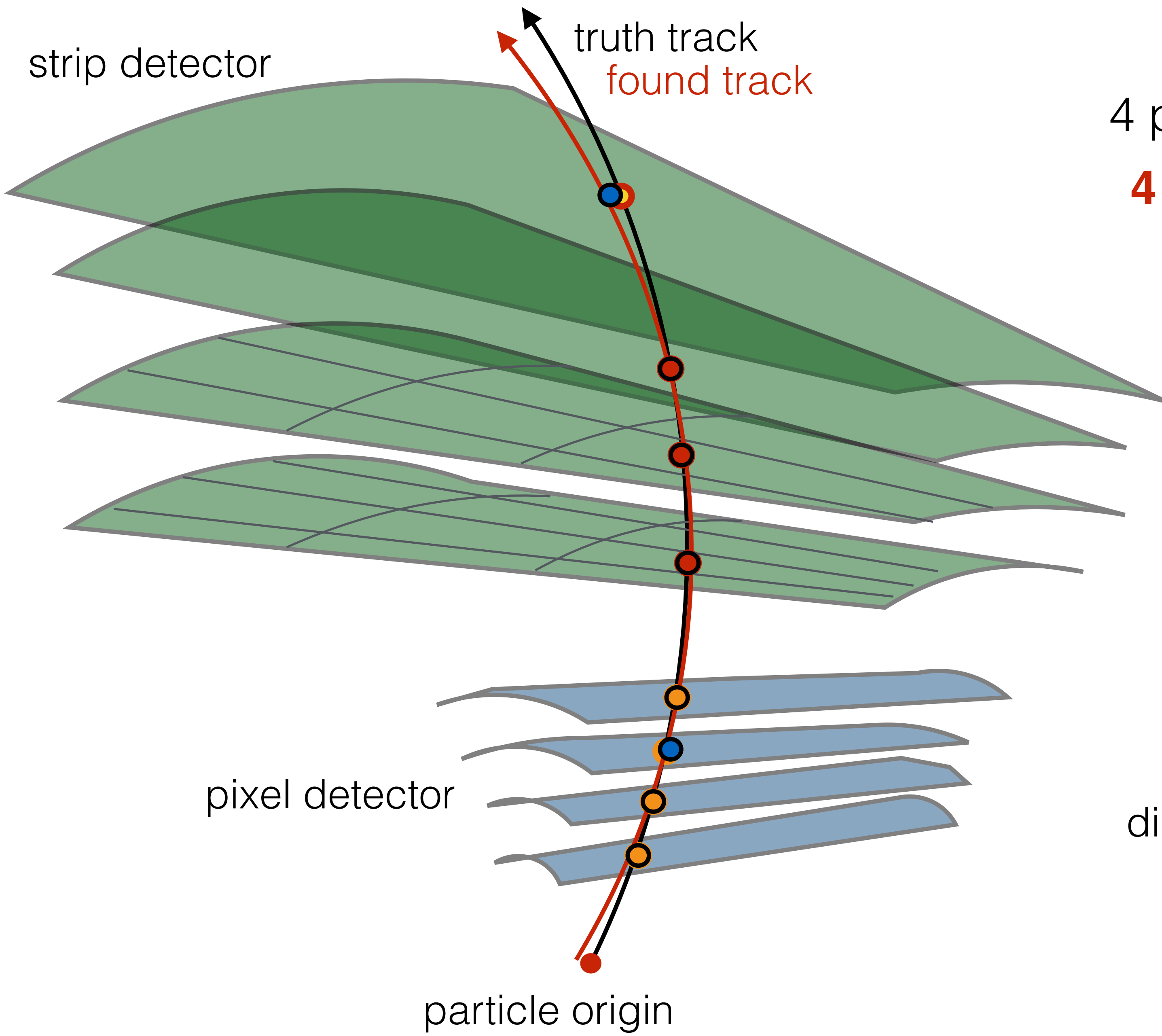
that's an ok track,
you got 7 out of 8,
naive score = 7/8 = 0.875

does a hit at the end weigh the same
as a strip hit ?

NOT if we want to
measure the momentum
precisely !!!

(4) Goals - track ranking (5)

- There is no unique truth matching to define a found track
  - we use truth matching per hits



A disturbed track

4 pixel hits, 4 strip hits created

4 pixel hits, **4** strip hits found

2 wrongly associated

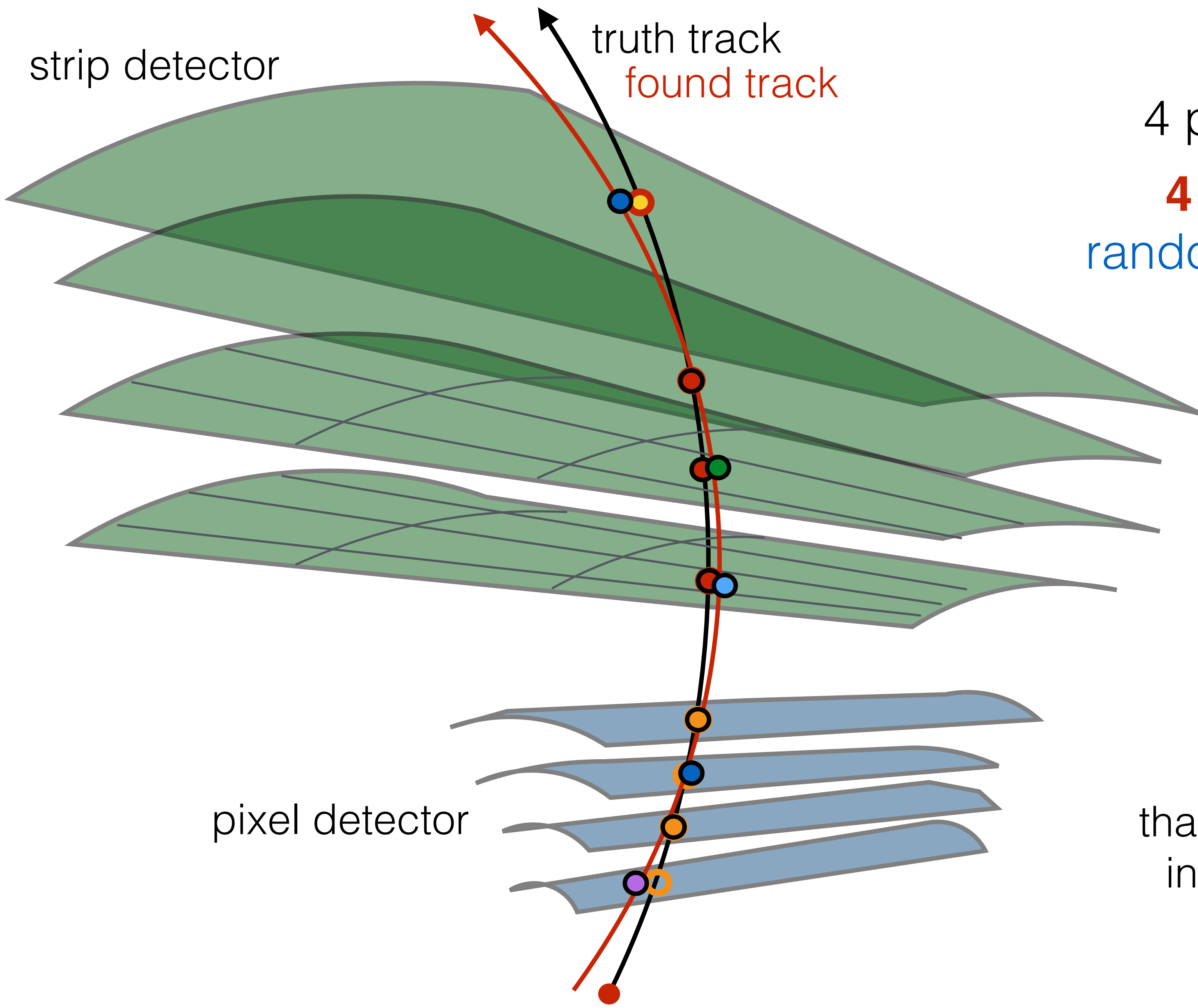
that's not very good
you got 6 out of 8,
naive score = 6/8 = 0.75

your track is rather distorted

did you really measure the particle ?

(4) Goals - track ranking (6)

- There is no unique truth matching to define a found track
  - we use truth matching per hits



A ghost track

4 pixel hits, 4 strip hits created

4 pixel hits, **4** strip hits found
randomly associated (3 associated)

that's garbage
you got 3 out of 8,
naive score = 3/8 = 0.375

your track is a ghost

that should not even give you a score !
in fact, it should count as score = -1

(5) Categories

Efficiency ?

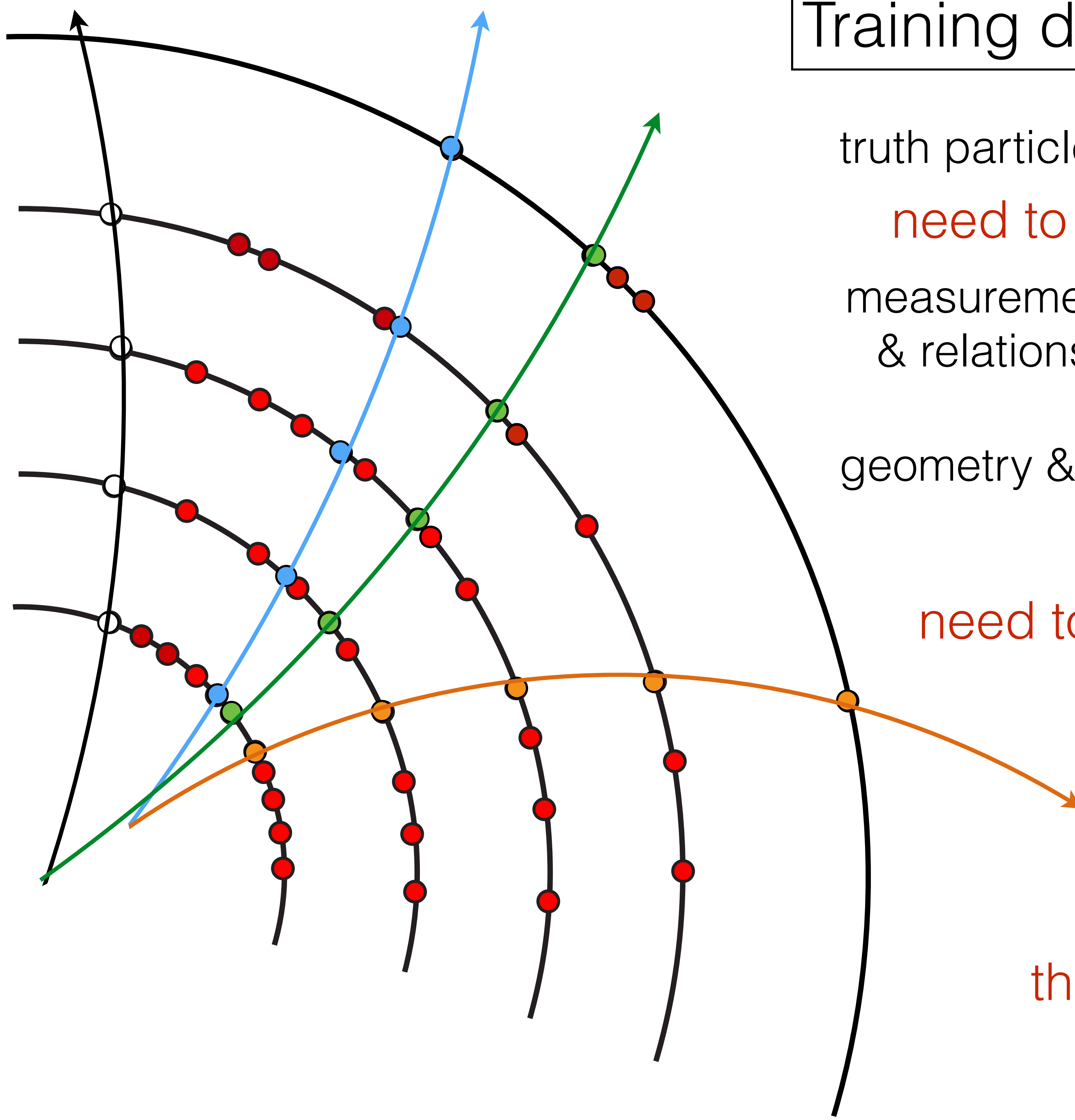
Timing ?

Purity ?

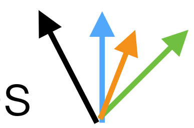
different categories
for different
solutions

How could the challenge look like (1)

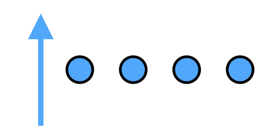
- We simulate a training sample with our generic, but realistic detector



Training dataset

truth particles & their properties 

need to define what we want to find

measurement sets, their errors
& relations to truth particles 

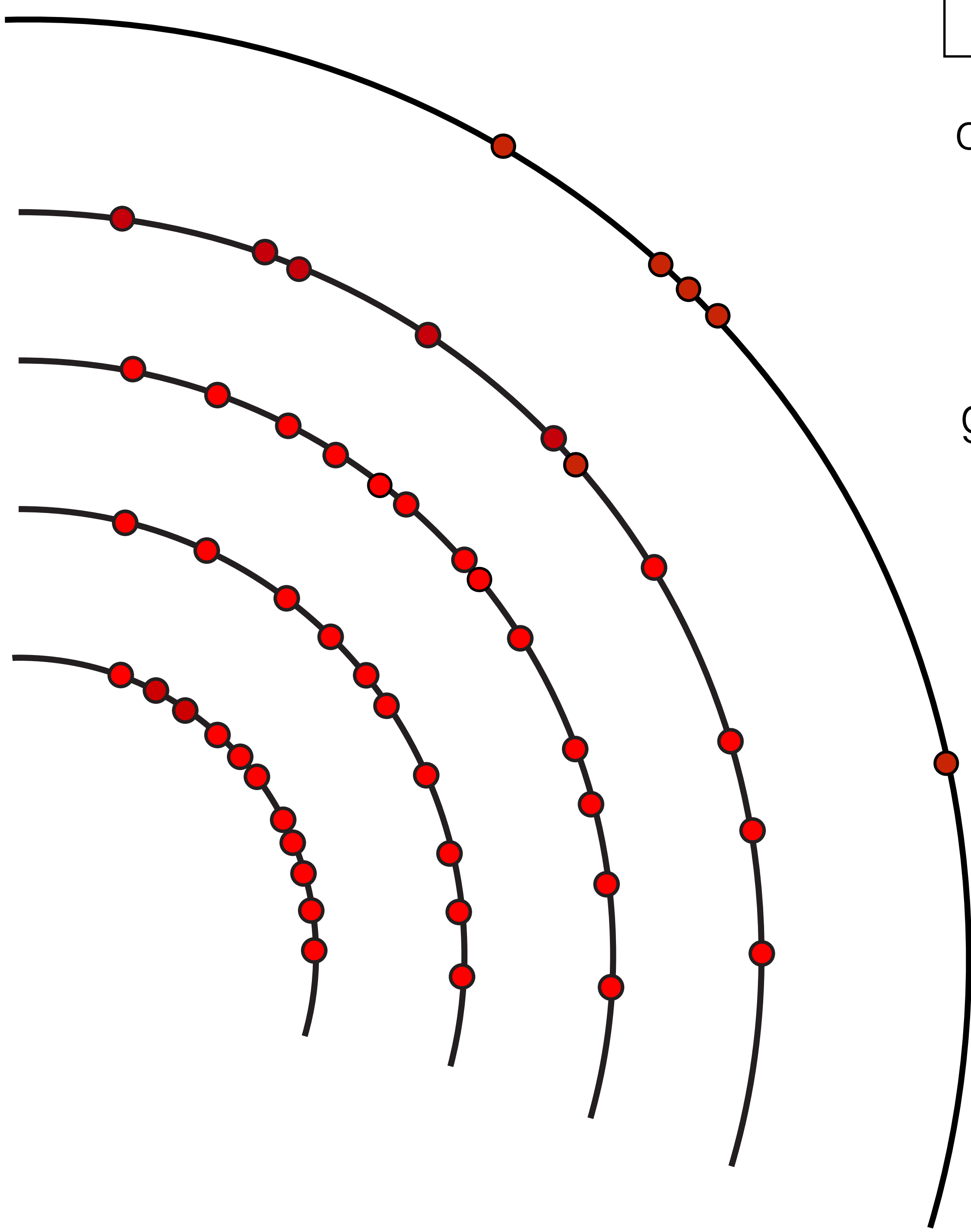
geometry & magnetic field setup

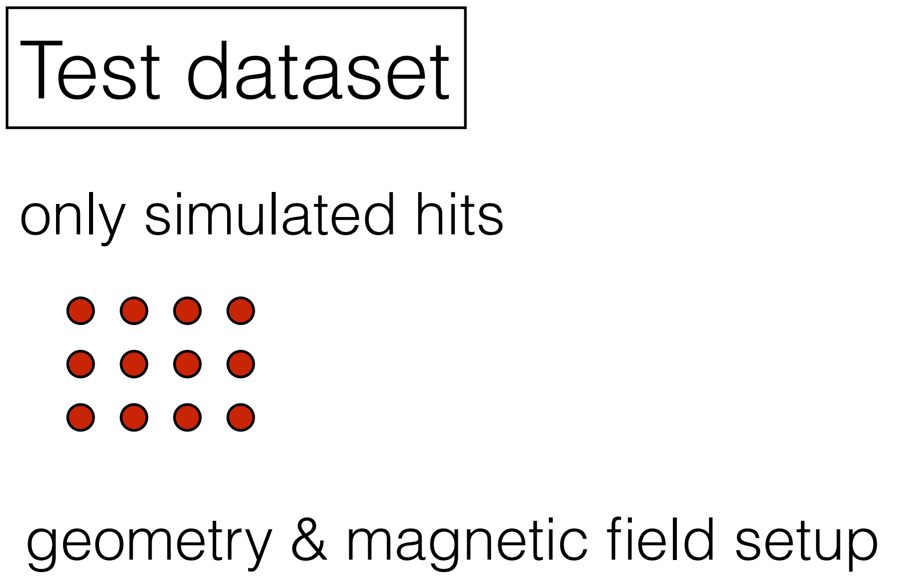
need to give them a scoring function

need to understand
the necessary statistics

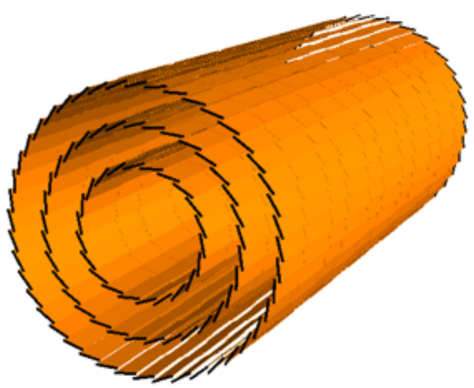
How could the challenge look like (2)

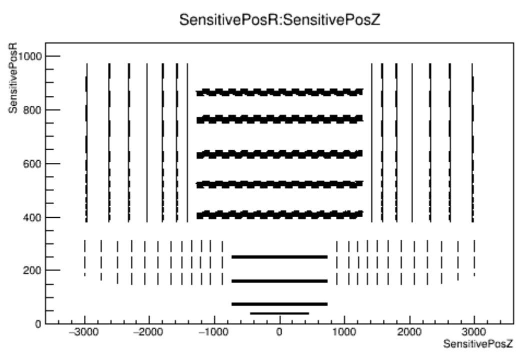
- We simulate a test (physics) sample with our generic, but realistic detector

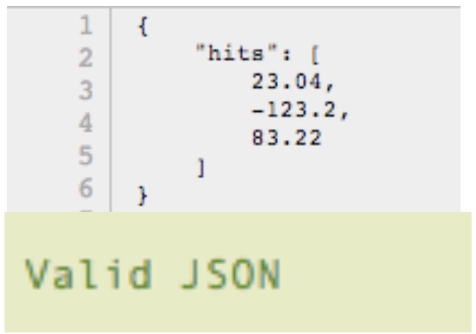


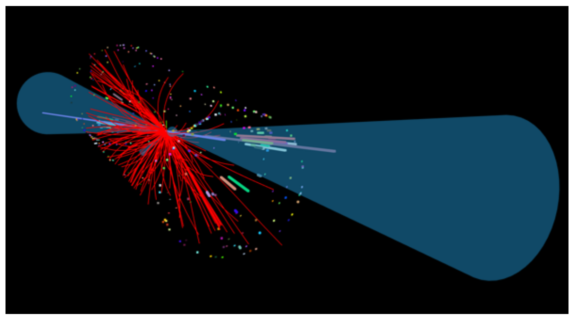


Some vague timescale considerations

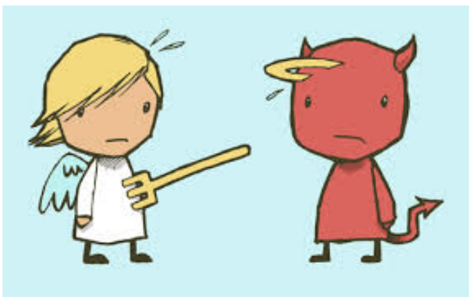








finalize dec 2015/jan 2016



finalize Q1/2016

finalize 04/2016

Training dataset

Q2/2016