Some Issues for Triggering and Reconstruction at ATLAS

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Motivation

- From picoseconds to nanoseconds, late decays of known and unknown particles pose challenges to triggering and reconstruction, as well as opportunities
- Perusal of existing ATLAS studies (and CMS and CDF/D0 etc) shows gaps, due perhaps to rather few theoretical examples with this phenomenology
- *The absence of examples in the theoretical literature is due to prejudice, not principles*
- New trigger studies are now underway at ATLAS (collaboration of U Washington and Rome La Sapienza) but more are needed
- Outline:
  - A very few words on theory background
  - Problems for triggering on decays inside the detector
  - Reconstruction issues for decays in the beampipe

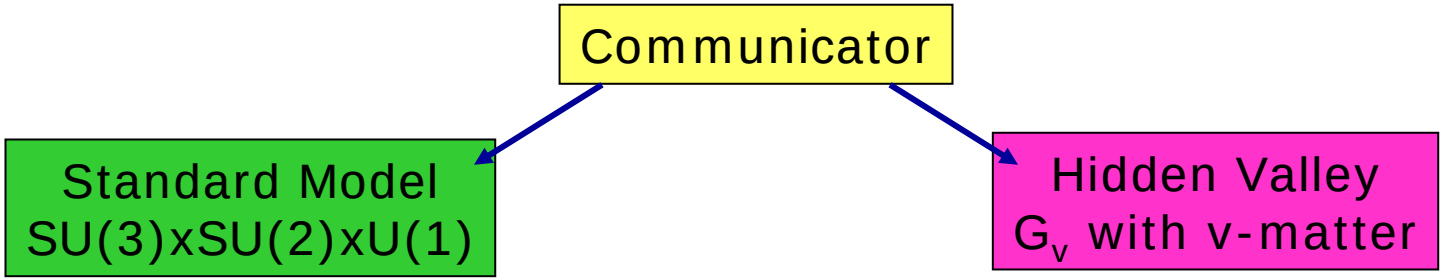
Non-minimal Phenomenology

- **Non-minimal models are disliked; but the SM is non-minimal**
- **Such theories can have drastically non-standard phenomenology!**
- **Example: HIDDEN VALLEY**
  - **LARGE class of non-minimal theories : extra sector of new particles**
- **hep-ph/0604261** : **Echoes of a hidden valley at hadron colliders.** (with Kathryn Zurek)
- **hep-ph/0605193** : **Discovering the Higgs through highly-displaced vertices.** (with Kathryn Zurek)
  - Other relevant papers with similar phenomenology
    - Example mentioned in **hep-ph/0511250, Naturalness and Higgs decays in the MSSM with a singlet.** Chang, Fox and Weiner
    - **hep-ph/0607204** : **Reduced fine-tuning in supersymmetry with R-parity violation.** Carpenter, Kaplan and Rhee
- **hep-ph/0607160 : Possible effects of a hidden valley on SUSY phenomenology.**
- **Hidden Valley Website:** http://www.phys.washington.edu/~strasslr/hv/hv.htm

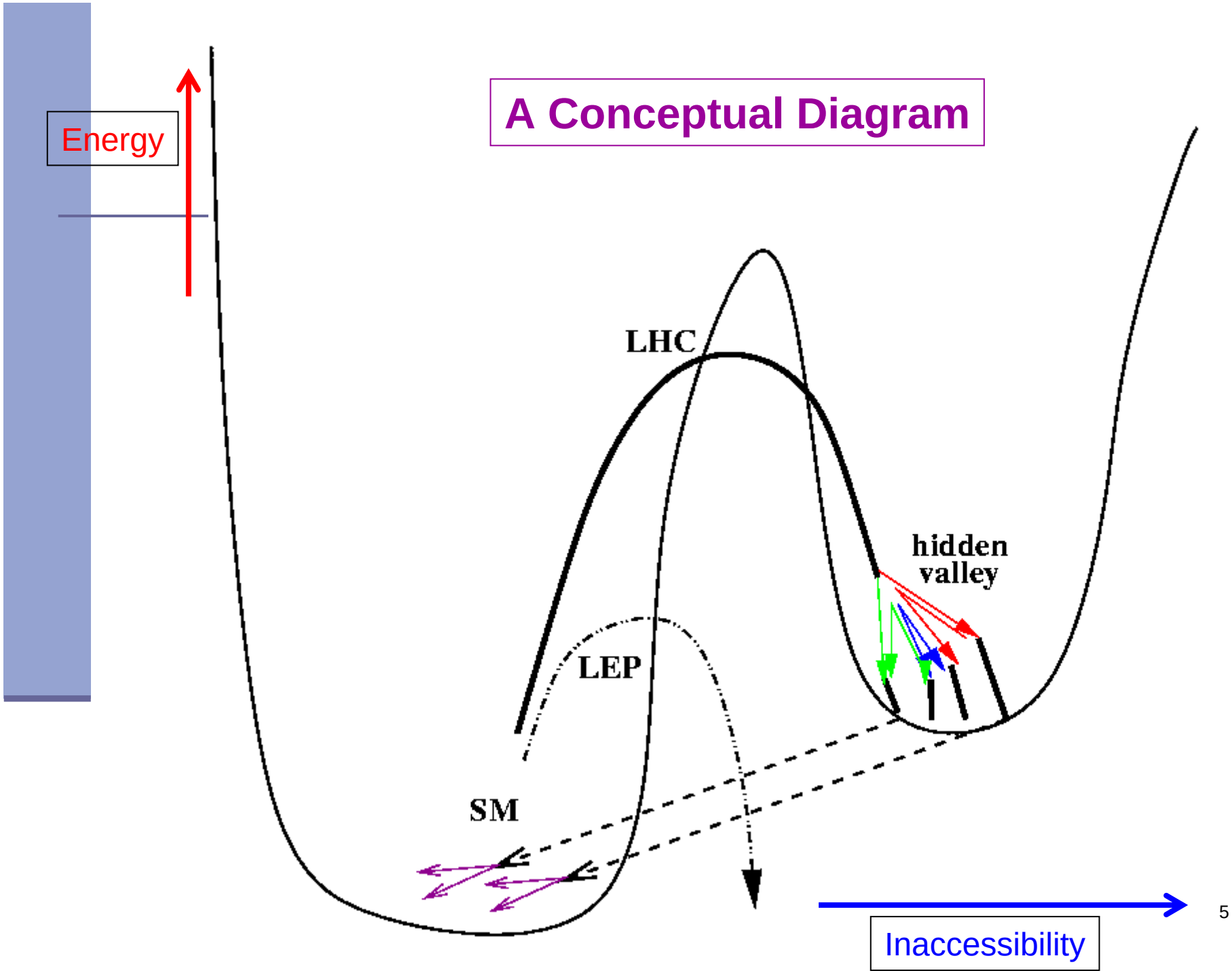
Hidden Valley Models (w/ K. Zurek)

April 06

- Basic minimal structure

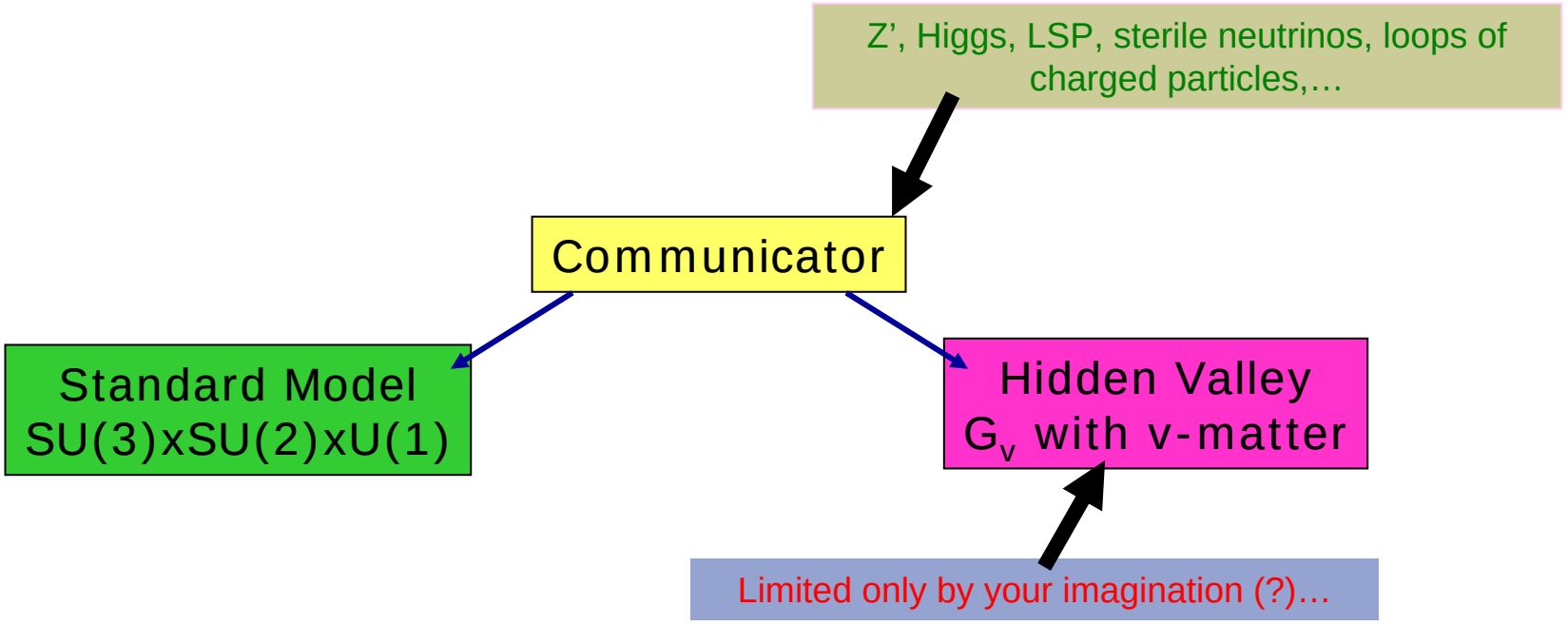


A Conceptual Diagram



Hidden Valley Models (w/ K. Zurek)

- Basic minimal structure



What kind of things might happen?

- ***The LHC could reveal an entirely new sector of particles…***

- A hidden valley involves a new (mostly- or all-neutral) “valley sector” or “v-sector”
  - **Many new “v-particles”** (2? 5? 30?)
  - With range of masses (1 GeV? 10 GeV? 100 GeV? 1 TeV?)
  - And range of lifetimes (fs? ps? ns? μs?)

- Variety of lifetimes for the many new particles
  - Implies **reasonable probability** of some events with **long-lived particle decays**
  - Long-lived particles may be light, not produced at threshold; ***typically not slow***

- ***Various triggering issues to deal with depending on lifetimes, final states.***
  - L1 objects might not be confirmed at L2, despite being interesting
  - Can L2 detect very-high IP tracks without triggering on every nuclear collision?
  - Quality control must be careful not to discard interesting signals

ATLAS triggering and late decays

Rome/Seattle working group (formed 9/06)

• Current focus is long-lived light neutral particles decaying to jets inside the detector volume
• Hidden Valley models serving as a useful theoretical context in which to explore the challenges of this phenomenology
• Studying production of new particles in Higgs decays and Z' decays.
• Recently joined ATLAS Exotics group.

- Rome La Sapienza
  - *Guido Ciapetti*
  - *Carlo Dionisi*
  - *Stefano Giagu*
  - *Daniele DePedis*
  - *Marco Rescigno*
  - *Lucia Zanello*
  - *Barbara Mele* *****
- U. Washington
  - *Henry Lubatti*
  - *Giuseppe Salamanna*
  - *Laura Bodine*
  - *Dan Ventura*
  - *Matt Strassler* *****

*** serving as theoretical consultant (not a member of ATLAS)**

Today's remarks

- Let me be clear that what I will say today represents my own opinions and in some cases speculations, based on
  - limited MC studies that I have done, without a detector simulation;
  - reading of the ATLAS TDR; and
  - conversations with ATLAS colleagues

- The Rome/Seattle working group is conducting serious trigger studies *(in which I of course am not directly involved)* and I am not presenting results from any of their studies.

- Many members of the working group (and other experimentalists outside the group) have contributed to these comments through their patient and detailed explanations of how the ATLAS detector, and its trigger system, are designed to operate. (I am enormously grateful to them!)

- *But any mistakes and misstatements are to be blamed on the foolishness of a theorist!!*

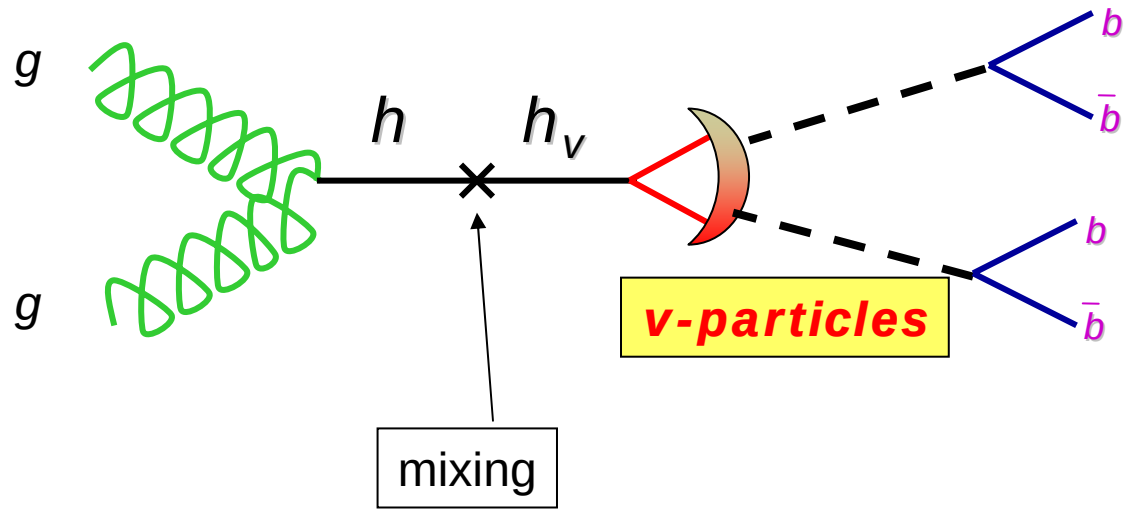
Higgs decays to displaced vertices

- **This can happen in many models**
  - At least one already appeared in the past, focus on LEP
    - **hep-ph/0511250** : Chang, Fox and Weiner
  - Zurek and I wrote down another class, in addition to hidden valley models, emphasized discovery possibilities at Tevatron, LHCb
    - **hep-ph/0605193**
  - New examples recently involving R-parity-violating SUSY
    - **hep-ph/0607204** : Carpenter, Kaplan and Rhee
- **This might be a discovery channel** (at CDF/D0/LHCb – ATLAS too?)
  - For light higgs Br could be 1, 10, 100 %
    - No Backgrounds! Easier than tau tau, gamma gamma?
  - For Higgs ~ 160-180 GeV
    - Br could be only a few times smaller than Br(h→WW→dilepton)
    - It has no SM background, unlike h→ WW
  - For elusive A0 (CP-odd Higgs) discovery channel even if Br is small; Br could be 1, 10, 100 %
  - *But very difficult for the ATLAS/CMS triggers*

Higgs decays to four b's

One example:

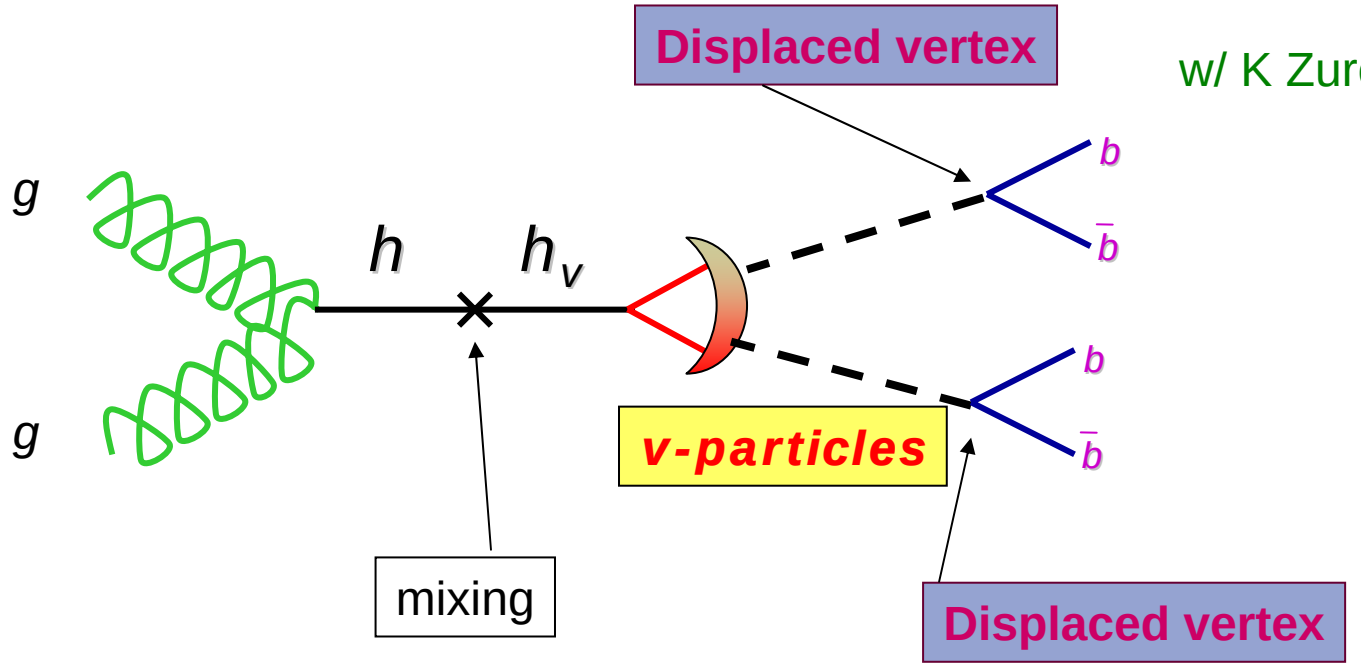
w/ K Zurek, May 06



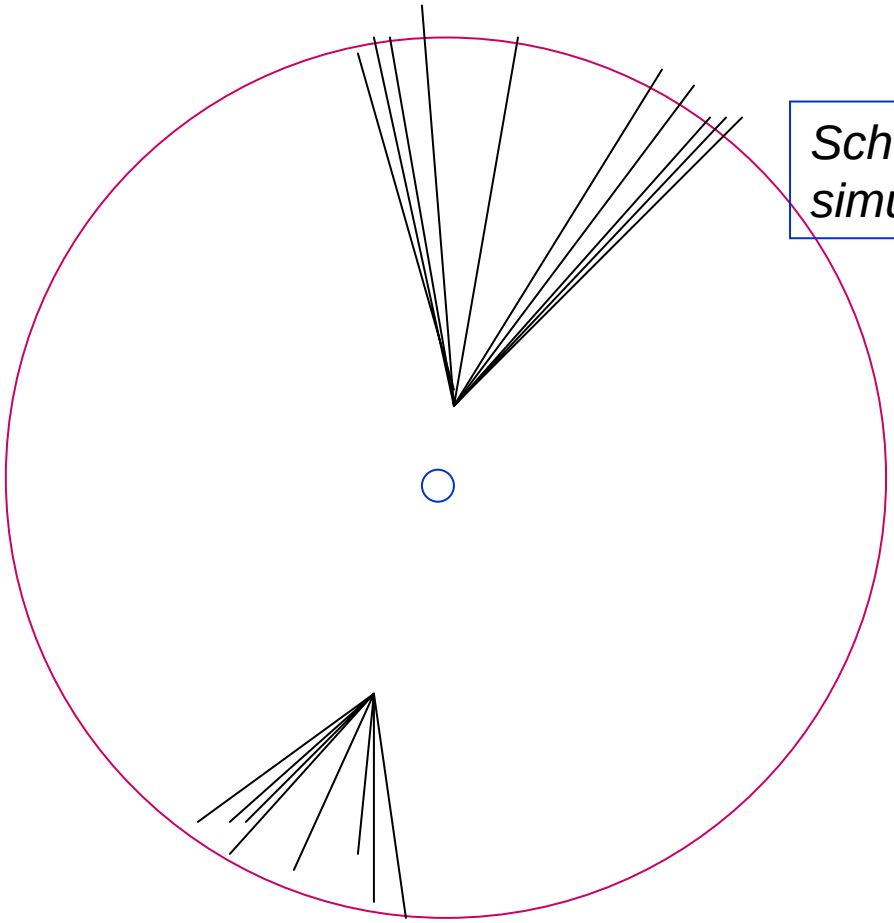
See Dermasek and Gunion 04-06 in SUSY context:
h→ aa → bb bb, bb ττ, ττ ττ, etc. and much follow up work by many authors

Higgs decays to the v-sector

w/ K Zurek, May 06



A Higgs Decay to four b's



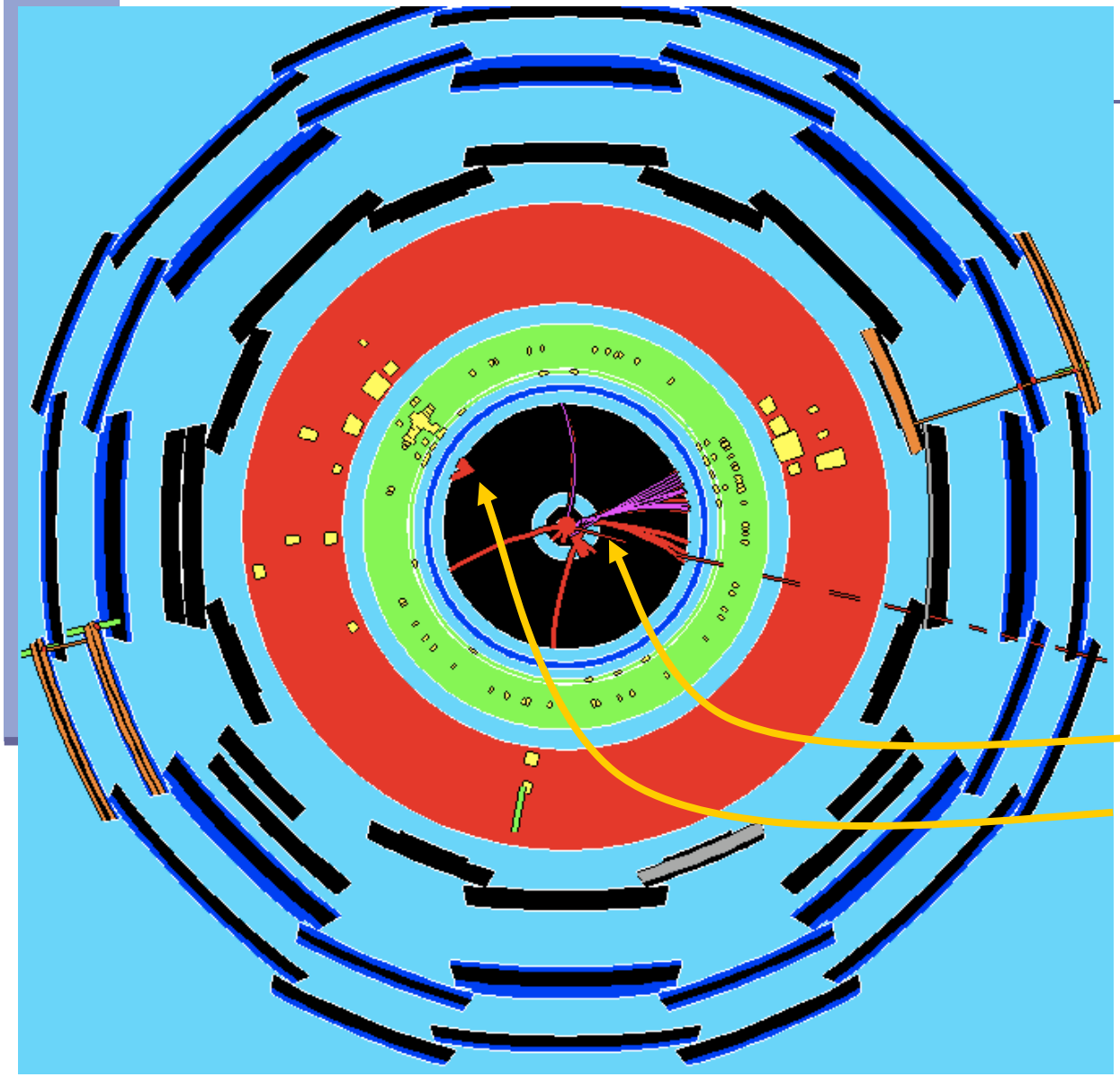
Schematic; not a simulated event!

What are the experimental challenges?

- Easy to set PYTHIA to provide this final state
- The Rome/Seattle ATLAS working group has run a few events through ATHENA
- I am grateful to have been granted permission by the working group and the Exotics Group to show event displays of one simulated event
- This event, though it itself could not pass even the Level 1 trigger, illustrates (better than any drawing I could make) many of the issues, problems and opportunities that are involved with light long-lived particles

- ***NOTE: All event displays shown below are property of the ATLAS collaboration and are not for public distribution; they have not been validated or approved.***
- ***The slides shown below can provide a qualitative understanding, but are not for quantitative use.***
- ***DO NOT REPRODUCE OR USE FOR RESEARCH!***

Higgs → X X ; X → b – anti-b pair



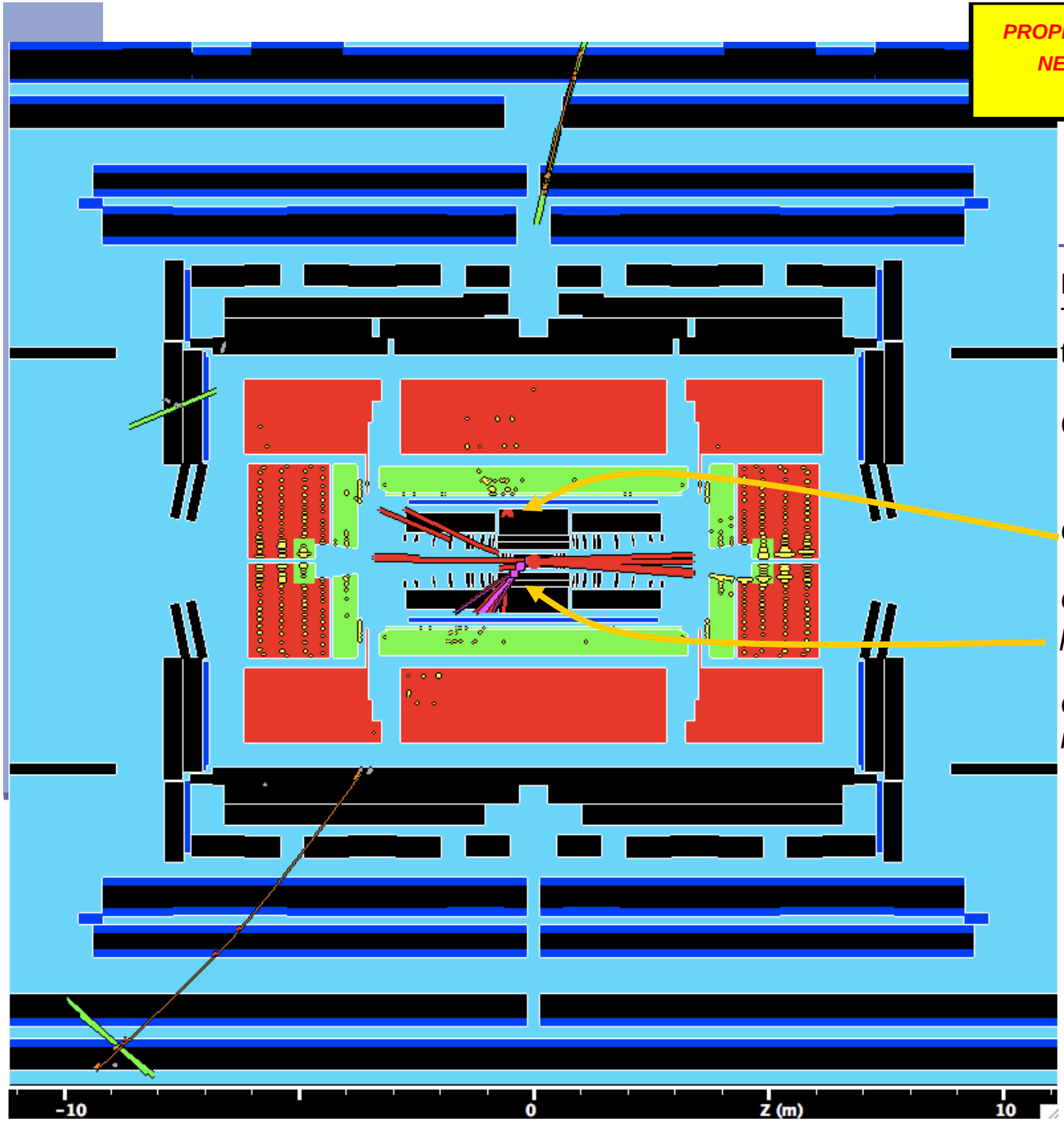
Purple tracks are reconstructed
Thick red lines are “truth” tracks

Cuts: Track pt > .5 GeV

One X decays just outside pixels

One X decays in TRT

One b from each X produces a muon



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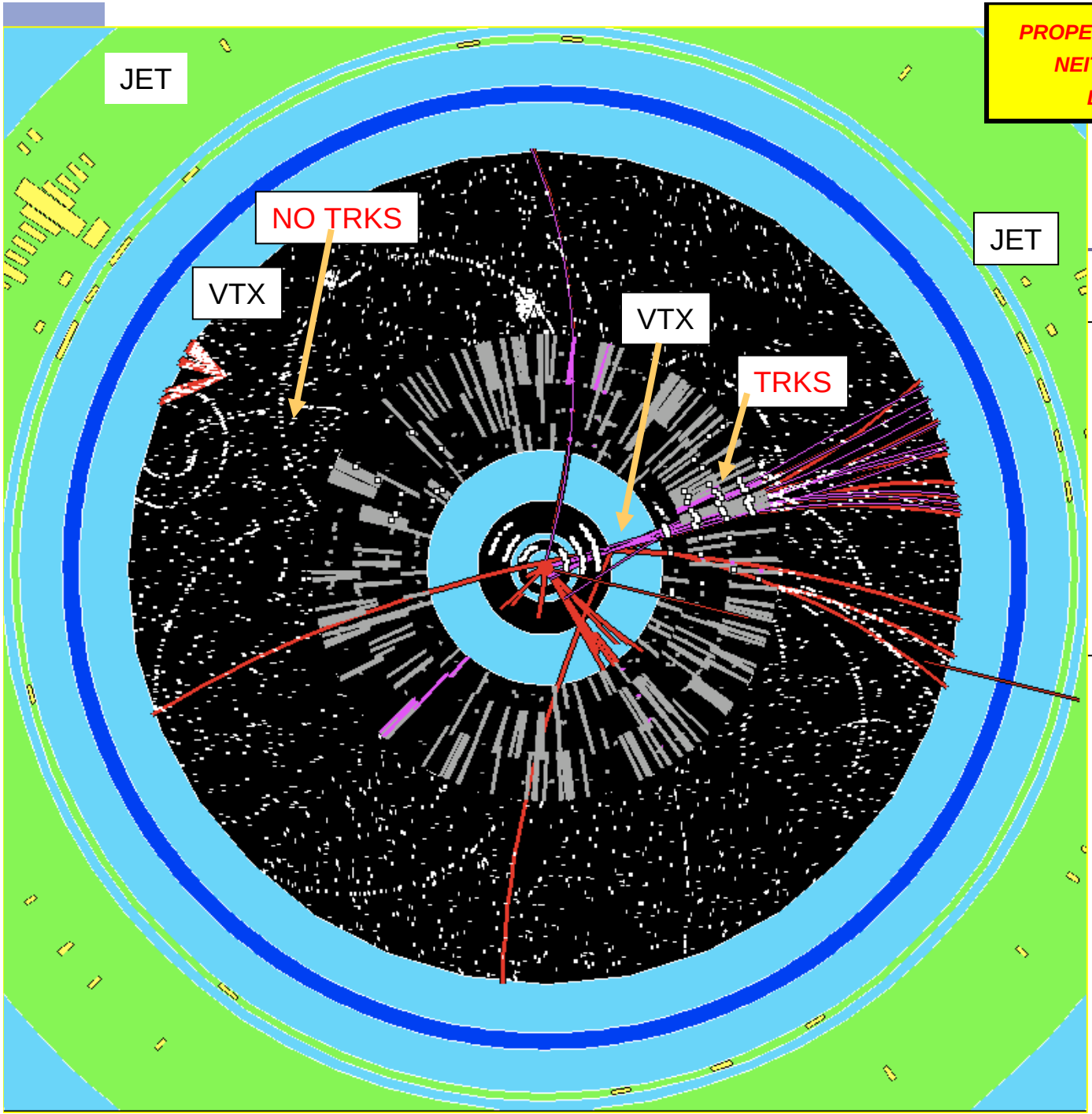
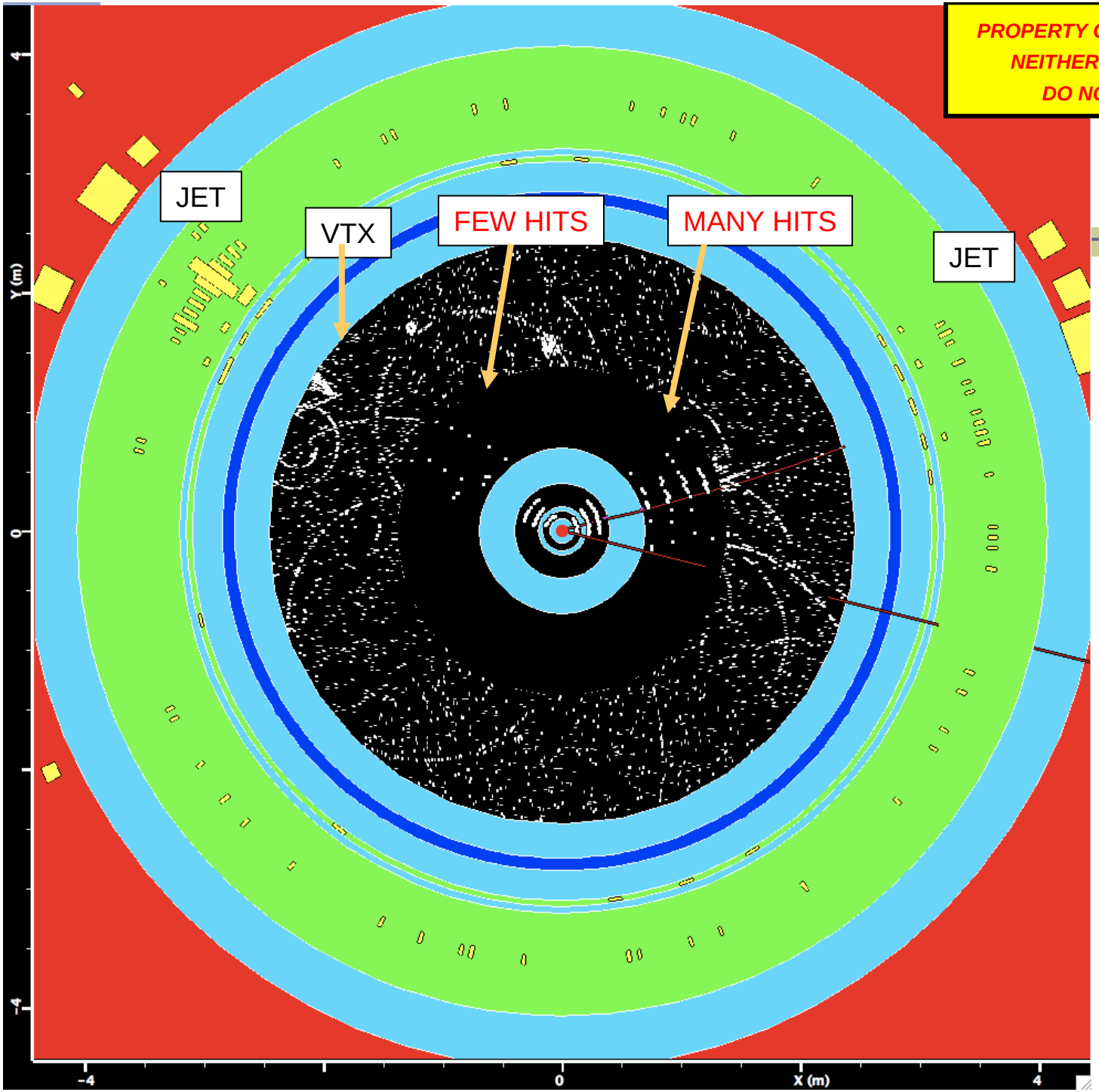
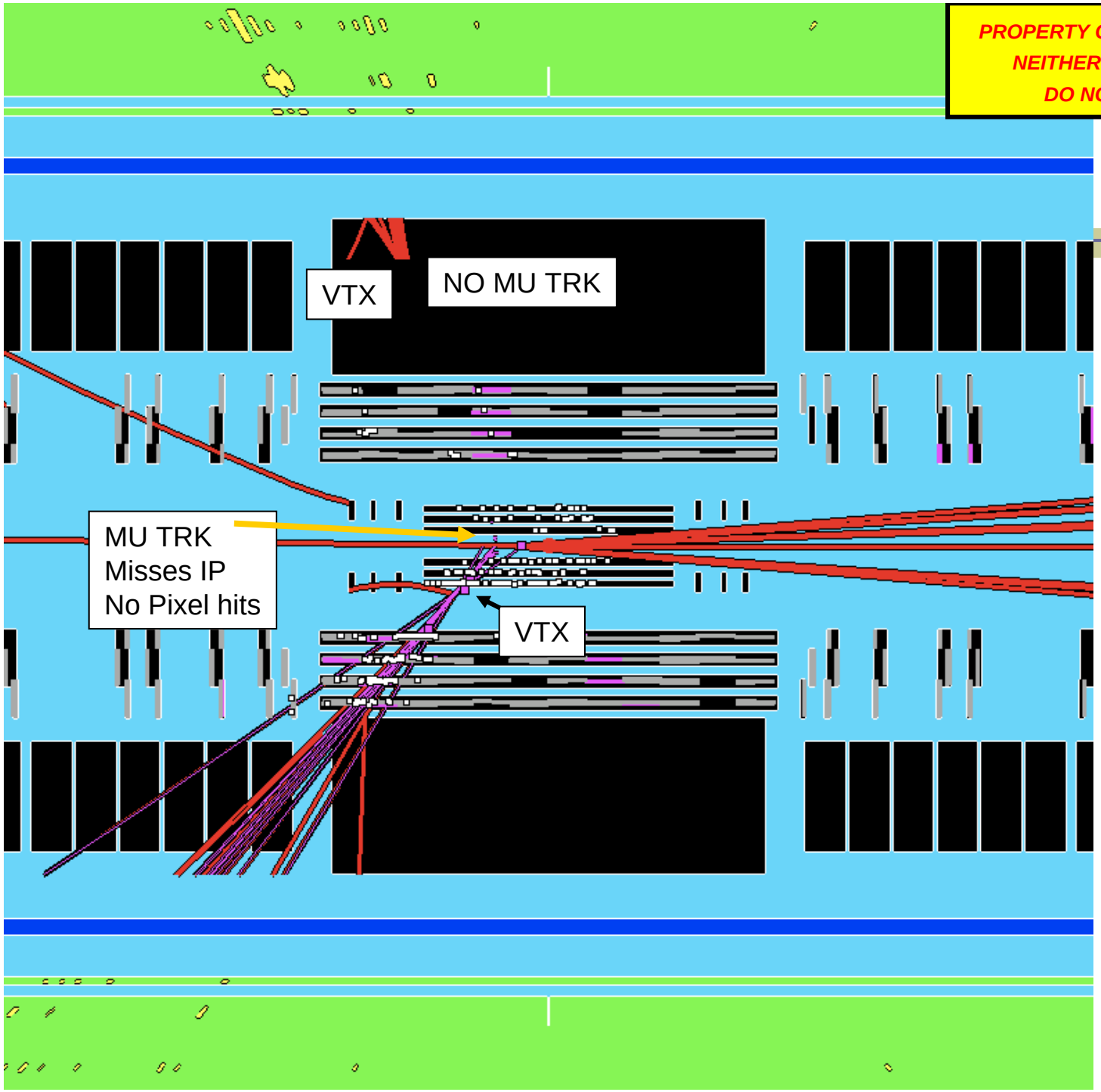


TRT Drift Circles and
Silicon hits

Track Pt >1 GeV

Purple tracks are reconstructed
Thick red lines are “truth” tracks





Even if muons had passed L1 dimuon

One mu has only track stub in TRT

One mu has track that misses IP and has no pixel hits

One jet has no pixel hits but has clear Si strip activity

One jet has no tracks

TRT shows its vertex clearly (see page 18)

But it does not lie in RoI of L1 muon (see page 16)

If L1 were to pass a similar event, will L2 keep it?!

Musings on this issue

- *Offline, this event (or a small variant) might have been fairly obvious new physics*

- This particular event would not pass L1 (muons too soft, 4 and 3 GeV), but
- Had the muons been oriented differently and picked up a bit more pT, it might have passed
- But the muon tracks might not have been confirmed at L2 and the event might have been flushed

- ***Could it (or similar events) have been saved?***

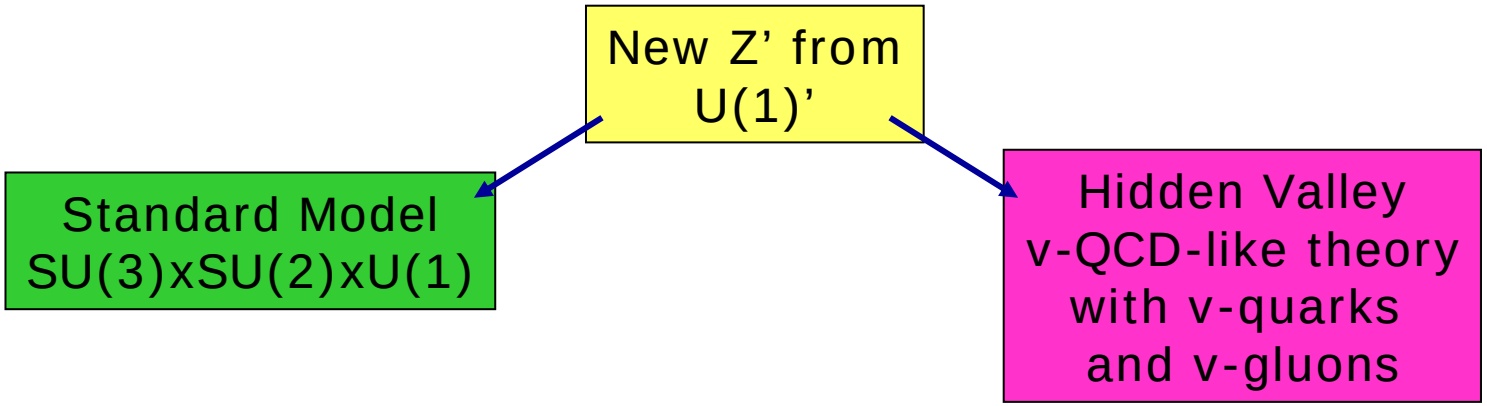
- Here we had X decays just outside pixels and in TRT;
- Other interesting issues raised for X decays
  - in pixels,
  - in ECAL,
  - in HCAL,
  - in muon system

- SEVERAL strange things happened at once in this event;
  - each has backgrounds,
  - *but all of them together?!*
- *Can correlation of L2 trigger **failures** be used for triggering without too much bandwidth?*

- These are the kinds of issues that the members of the Seattle/Rome working group are exploring.

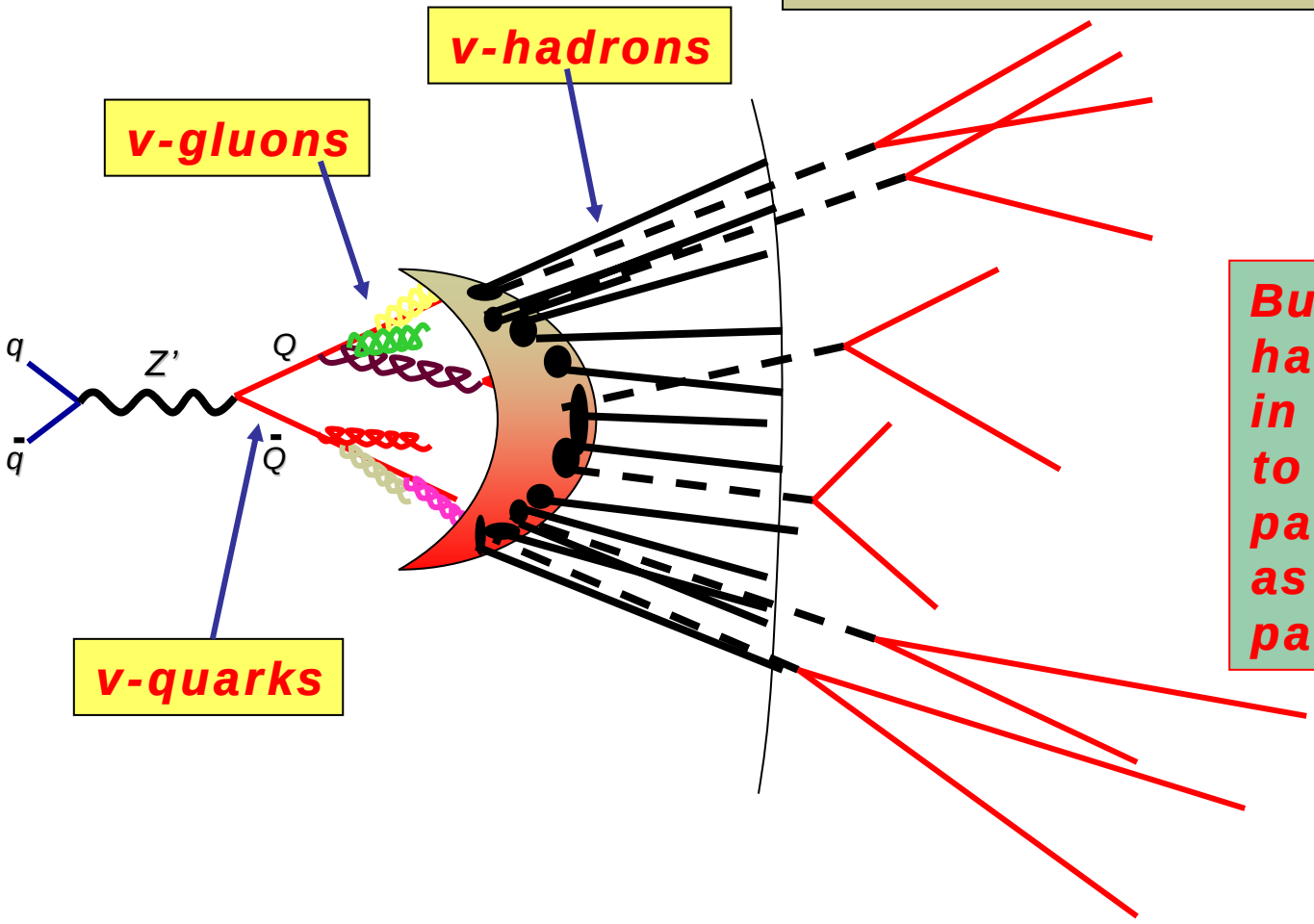
High-Multiplicity Production

- Let's consider a simple model:
  - The v-sector consists of a QCD-like theory
  - The communicator is a Z'
- An example is in the new MC package.

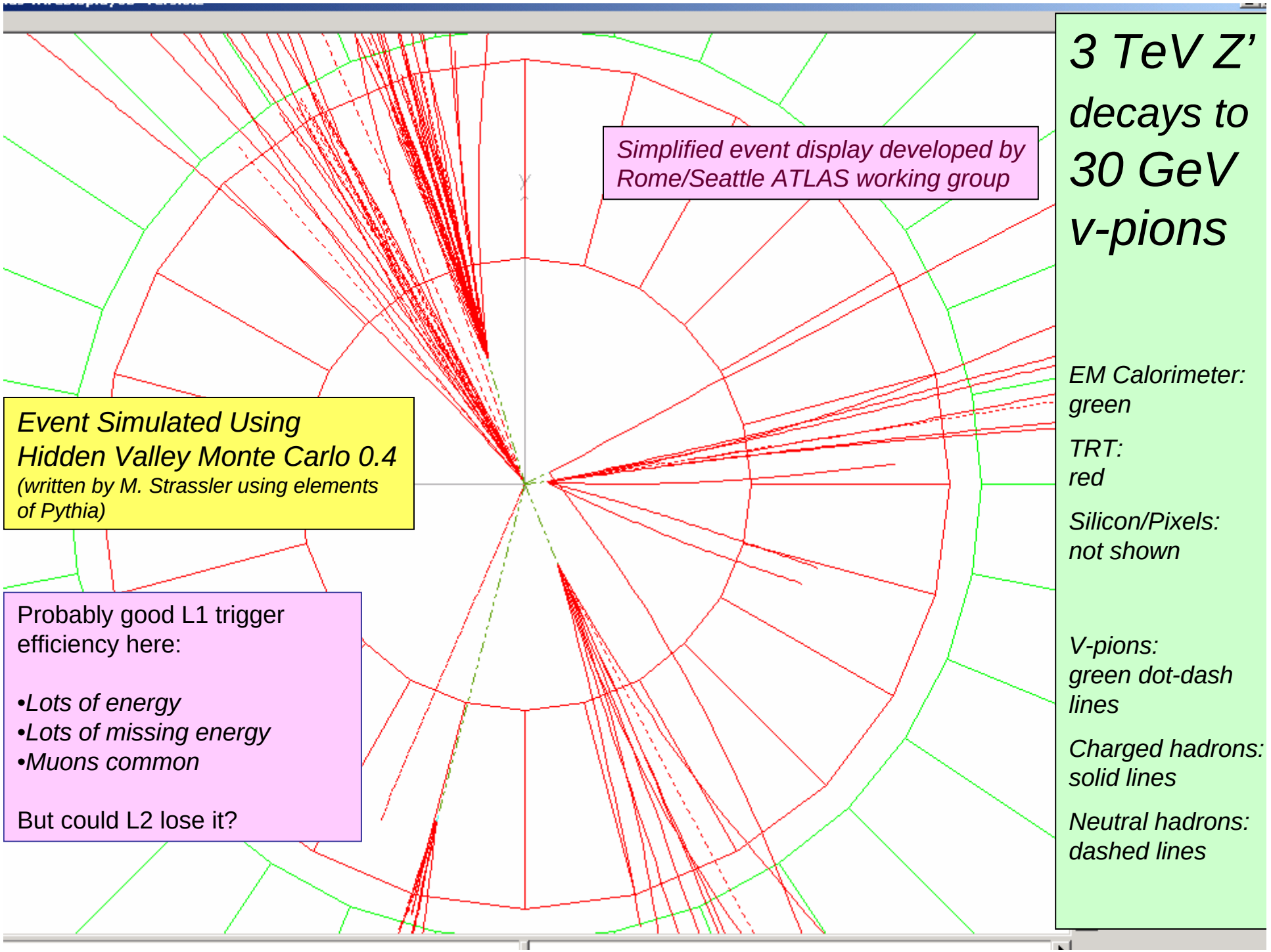


$q\bar{q} \rightarrow Q\bar{Q}$

Some v-hadrons are stable and therefore invisible



But some v-hadrons decay in the detector to visible particles, such as bb pairs, tau pairs, etc.


Simplified event display developed by Rome/Seattle ATLAS working group
Event Simulated Using Hidden Valley Monte Carlo 0.4
(written by M. Strassler using elements of Pythia)
Probably good L1 trigger efficiency here:
•Lots of energy
•Lots of missing energy
•Muons common
But could L2 lose it?
3 TeV Z' decays to 30 GeV v-pions
EM Calorimeter: green
TRT: red
Silicon/Pixels: not shown
V-pions: green dot-dash lines
Charged hadrons: solid lines
Neutral hadrons: dashed lines

Next: Decays within beampipe

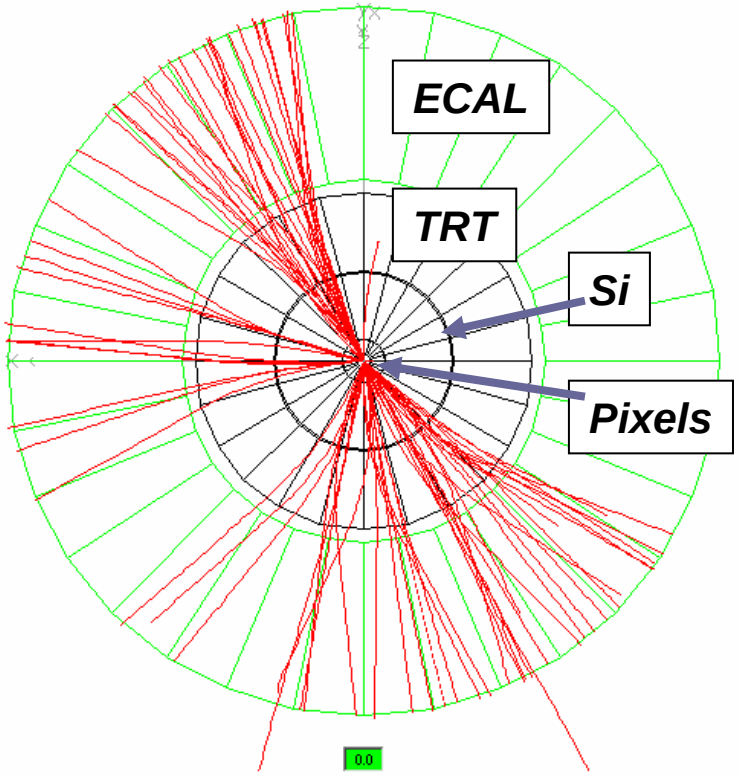
- Easier to find than decays outside,
  - less background from nuclear collisions,
  - but harder to recognize as new
- Events can have unusually large number of high IP tracks –
  - For some signals 30-50 percent of tracks with pT>2 GeV have displaced IP over 150 microns
  - *High-IP-track trigger would be very helpful !!*
- **I'll argue we should not call every jet with a vertex a "b-jet", even in casual conversation**

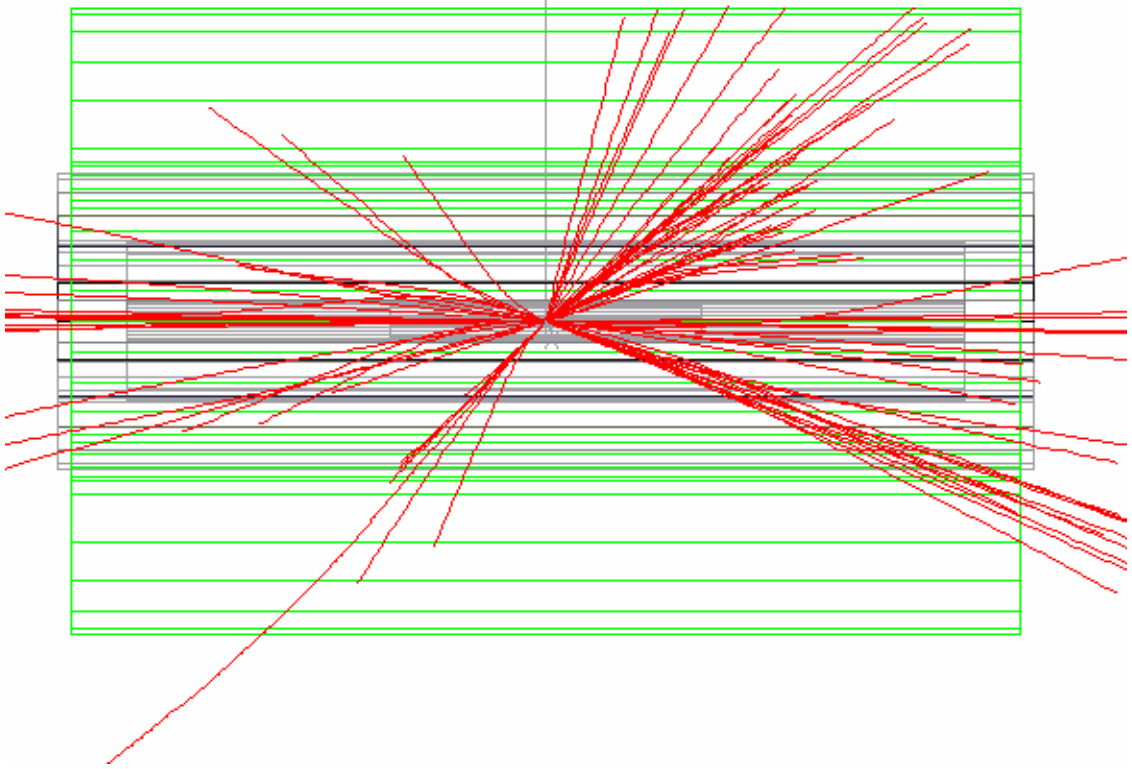
Z' decay to v-pions

Event Simulated Using
Hidden Valley Monte Carlo 0.4
(written by M. Strassler using elements of Pythia)

Simplified event display developed by Rome/Seattle ATLAS working group

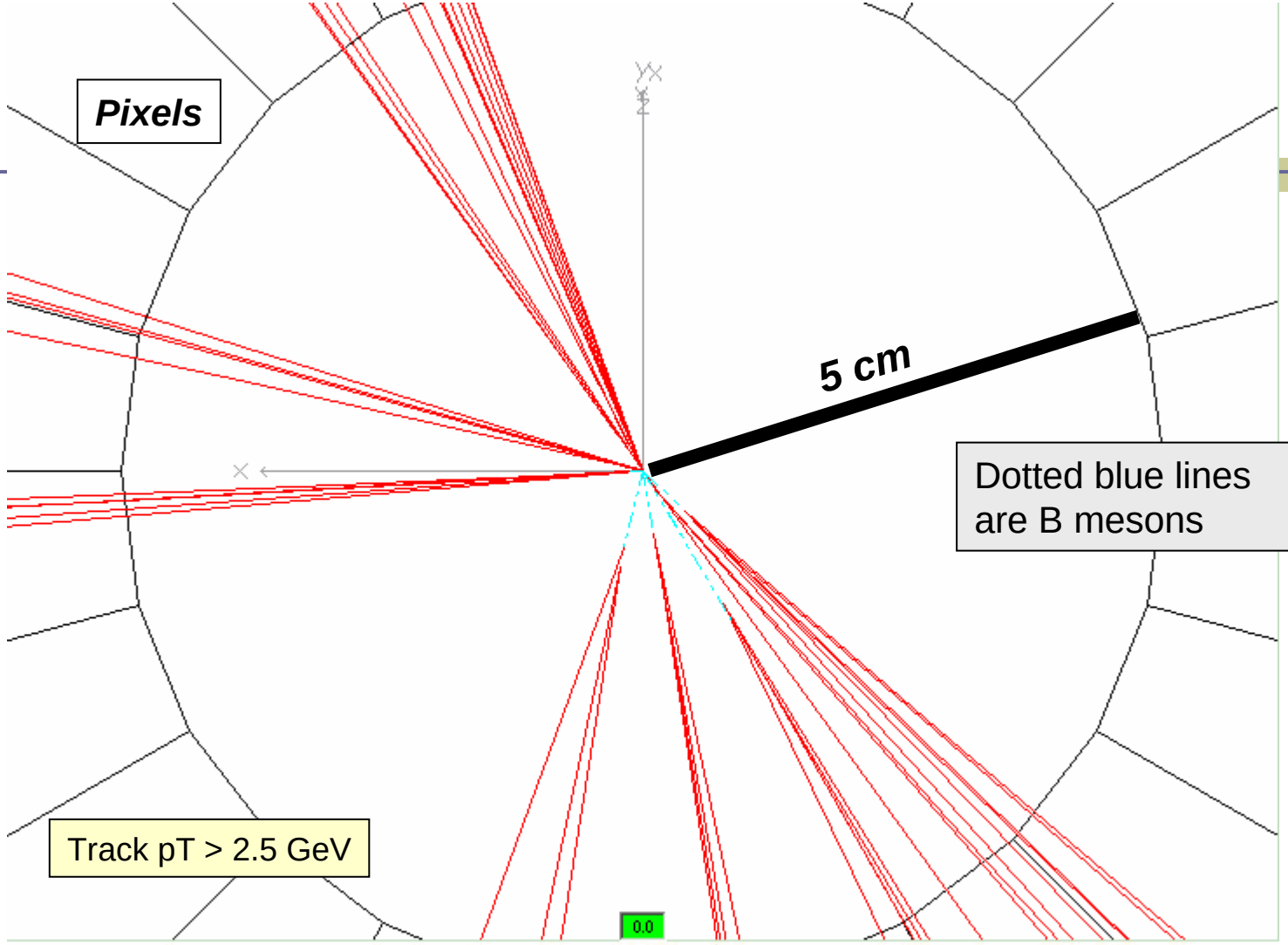
All tracks are Monte-Carlo-truth tracks; no detector simulation





3 TeV Z'
50 GeV v-pions
Prompt v-pion decays to b-bbar

Track pT > 1.0 GeV



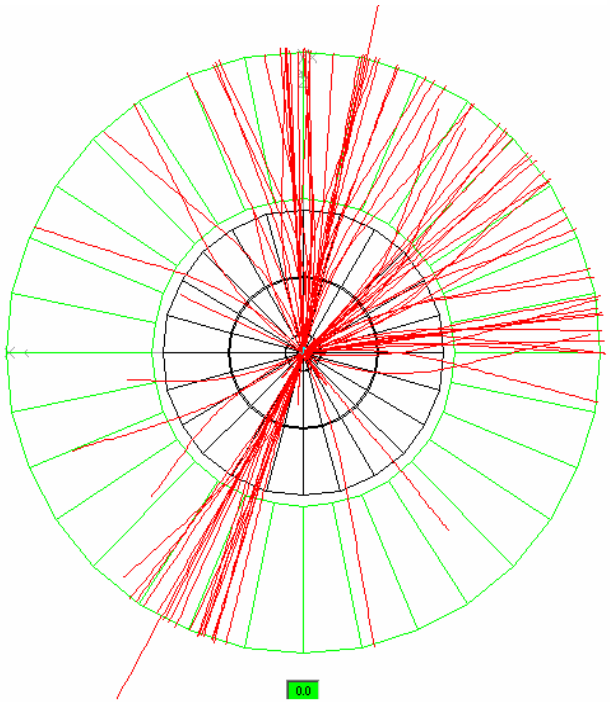
Multiple vertices may cluster in a single jet

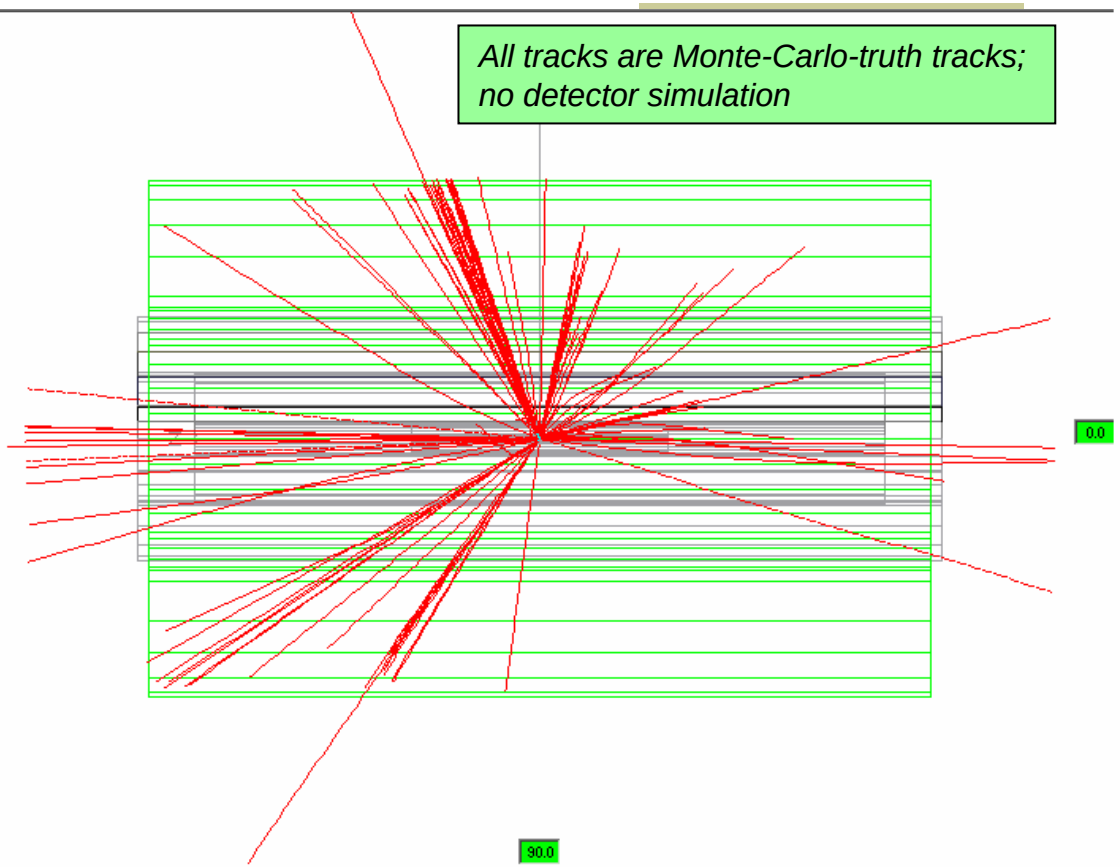
Z’ decay to v-pions

Event Simulated Using
Hidden Valley Monte Carlo 0.4
(written by M. Strassler using elements of Pythia)

Simplified event display developed by Rome/Seattle ATLAS working group

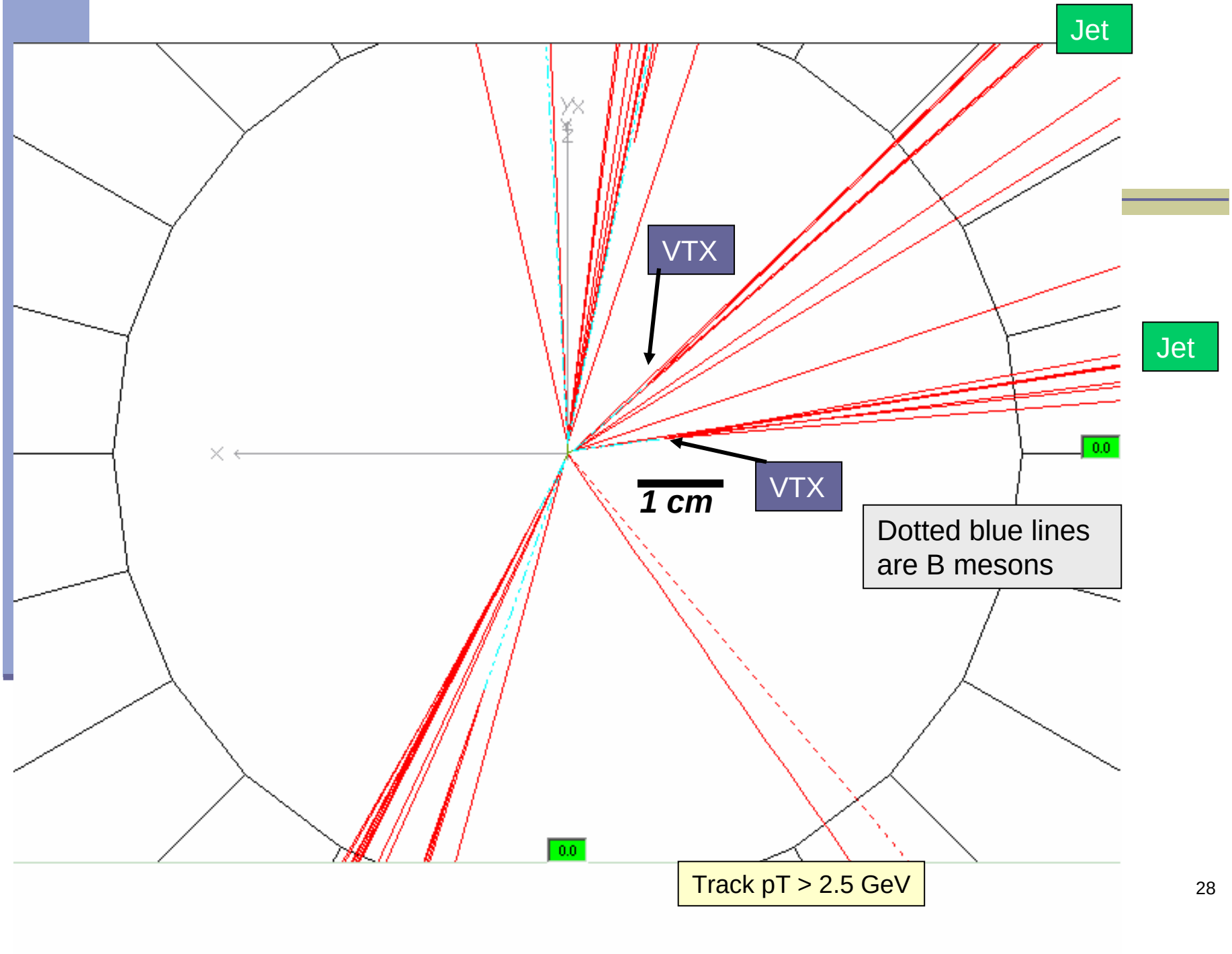
All tracks are Monte-Carlo-truth tracks; no detector simulation

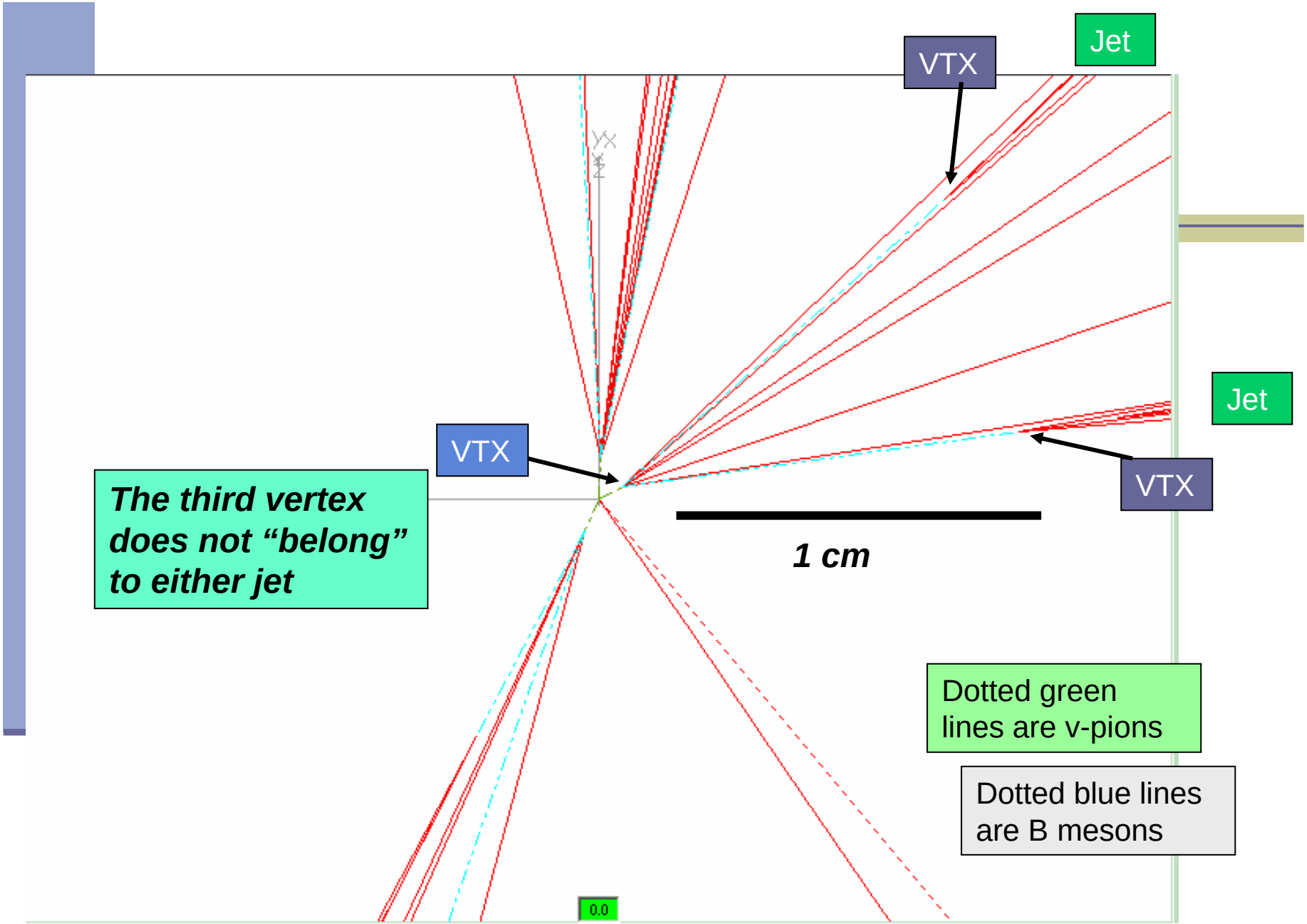




4 TeV Z’
120 GeV v-pions
Picosecond v-pion decays to b-bbar

Track pT > 1.0 GeV


Jet
VTX
Jet
0.0
1 cm
VTX
Dotted blue lines
are B mesons
0.0
Track pT > 2.5 GeV


Jet
VTX
Jet
VTX
VTX
The third vertex does not “belong” to either jet
1 cm
Dotted green lines are v-pions
Dotted blue lines are B mesons
0.0
Track pT > 2.5 GeV

Prompt decays to soft heavy flavor

- This shows the interesting physics of multiple high-pT B mesons, or of new heavy decaying particles.
  - Many vertices, often more than one per jet
  - Fractions of vertices per jet
- What about low-pT B mesons?
- For instance Higgs → 8b;
  - Cheng Fox Weiner **hep-ph/0511250**
  - Strassler Zurek **hep-ph/0605193**
  - Each B has pT of 20 GeV or less?
  - Tagging reduced by low-pT
  - Don't get anywhere near 8 jets
- Is this hopeless?!

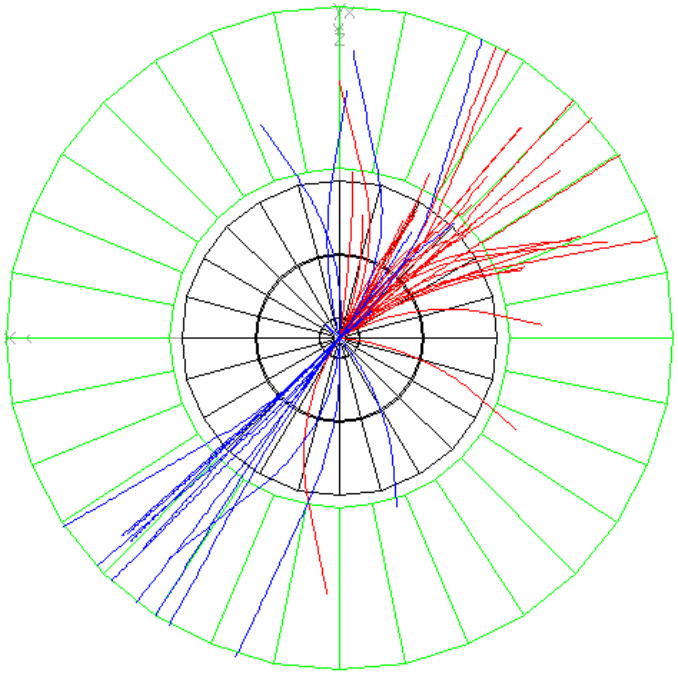
p p → W h ; h → 8 b's

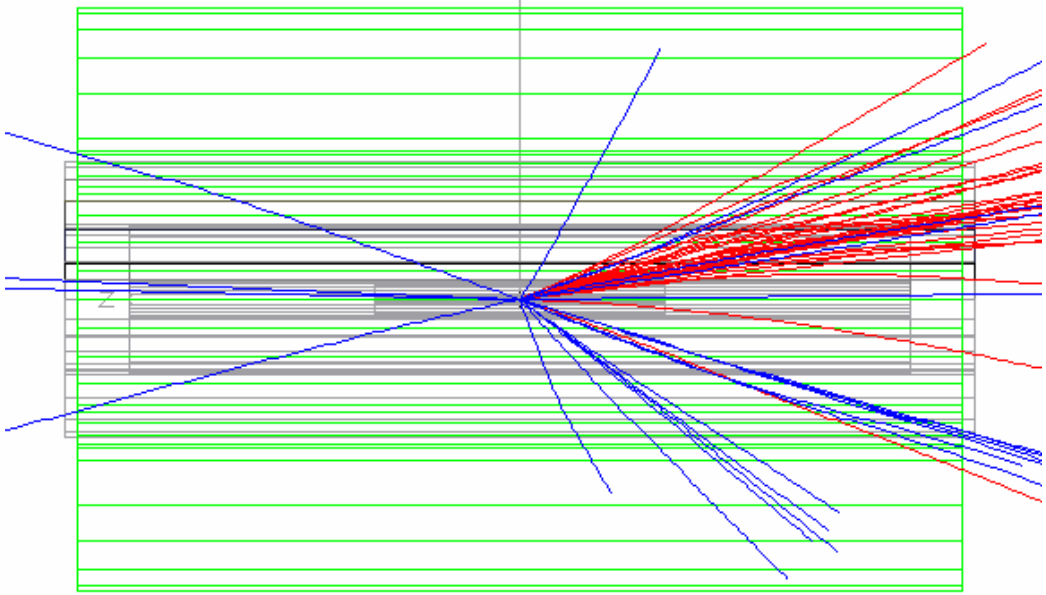
But the LHC is an **asymmetric collider**

Often pushes all vertices, tracks in one direction
Pixels for 3d IP determination, vertexing?

Event Simulated Using Pythia Card

Simplified event display developed by Rome/Seattle ATLAS working group

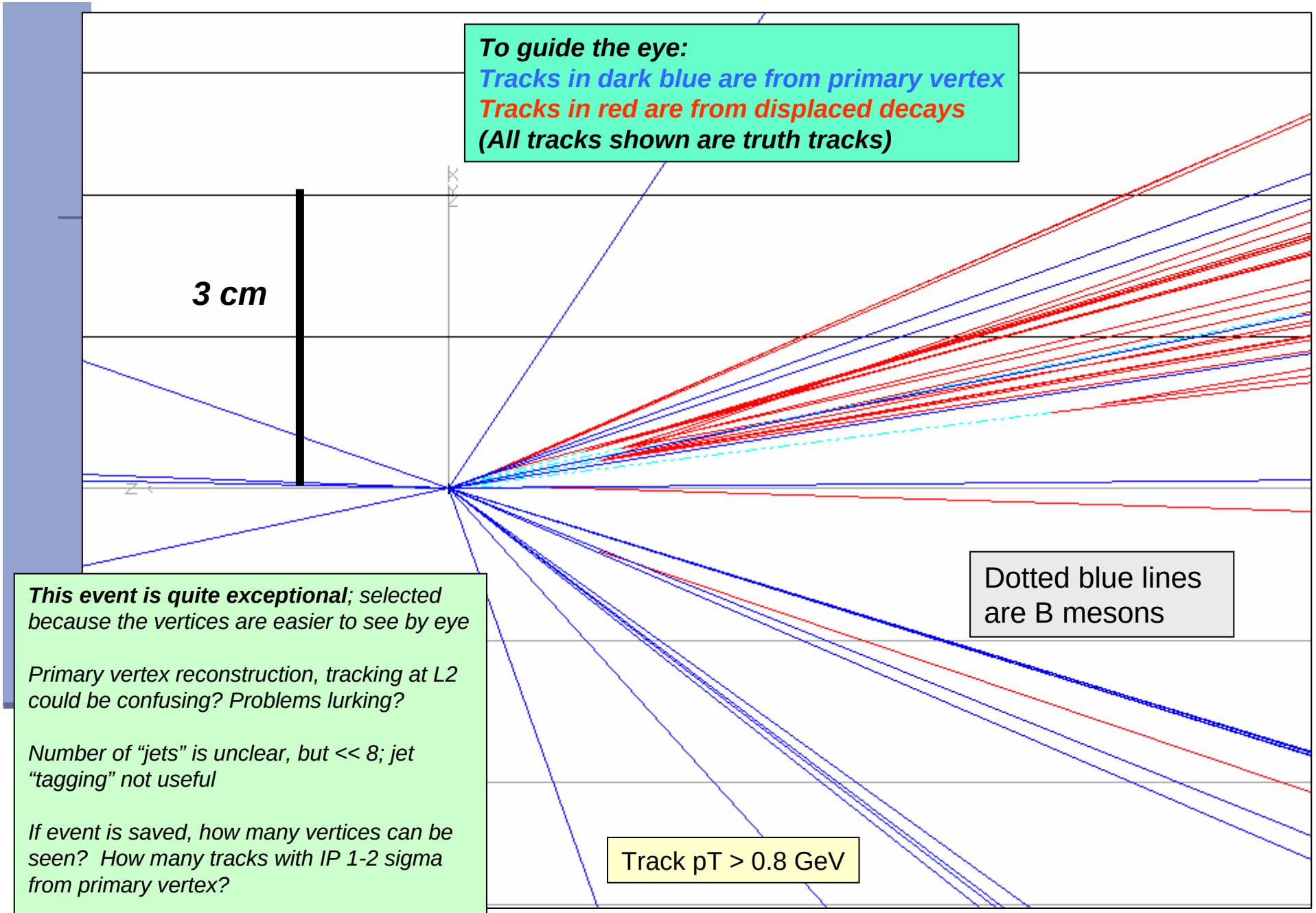




h → XXXX (prompt); X → b bbar (prompt)
M_h = 130 GeV; M_X = 20 GeV

Track pT > 0.8 GeV

To guide the eye:
Tracks in dark blue are from primary vertex
Tracks in red are from displaced decays
(All tracks shown are truth tracks)



***This event is quite exceptional**; selected because the vertices are easier to see by eye*

Primary vertex reconstruction, tracking at L2 could be confusing? Problems lurking?

Number of "jets" is unclear, but << 8; jet "tagging" not useful

If event is saved, how many vertices can be seen? How many tracks with IP 1-2 sigma from primary vertex?

Background (W+QCD with many heavy flavor mesons) not known

Vertices, Jets and Event Storage

- Reconstruction and Compressed Event Storage:
  - How could the strange features of events like these be retained in compressed event storage?
  - Simply storing “Objects” will not work; need much more information
  - Perhaps these events can be “flagged” at initial reconstruction as deserving of a special-purpose analysis? Are there too many of them?
- Offline analysis: need to consider
  - Are vertices consistent with
    - b → c → …?
    - g → b b, c c ? Z → b b ?
    - X → b b displaced ?
    - Accidental superposition of b’s ?
    - Extra min bias collisions ?
  - Jets and vertices deserve sophisticated global treatment as a **collective entity**
- When looking for many vertices may not want to use tight tags
  - Charm, tau may be as good a signal as bottom.
- Large backgrounds to multiple vertices from
  - gluons splitting to heavy flavor,
  - heavy flavor in underlying event?

Summary and Outlook

- Long-lived particles are not rare among particle physics models – just among minimal ones
  - Little study on neutral particles decaying to heavy flavor
  - Highly displaced vertices can cause problems for triggering – deserves additional attention
- Even prompt decays to b's/c's/tau's means a complex array of vertices can emerge
  - Multiple vertices might have interesting effects on triggering and on reconstruction
- Jets may have multiple vertices, vertices may have multiple jets (or leptons);
  - need to store both in easily-obtained formats
- Discussed two classes of examples
  - Higgs decays to displaced vertices [moderate rate, low pT]
  - Z' decays to high multiplicity events, possibly displaced vertices [low rate, high pT]
- *Did not discuss*
  - *LSP decays to moderate multiplicity, possibly displaced vertices [high rate, moderate pT]*
- Many possible Higgs decays can be quite challenging for the trigger;
  - Perhaps useful to explore systematically; Rome/Seattle ATLAS working group studying

  -- and decays to long-lived particles or to many-vertex final states may be important
- The Z' and LSP decays are probably relatively easy to trigger on –
  - But this is not confirmed yet… Rome/Seattle ATLAS working group studying
  - Reconstruction, event storage, analysis have some nontrivial features