Search for Long-Lived Exotics in CMS

- Heavy stable charged particle searches
- Stopped gluinos searches *(very preliminary)*
- Non-prompt photon searches

- Long-lived exotic decays to charged particles inside CMS *(very preliminary)*
  - Theoretical models under study
  - Triggering
  - Reconstruction

N.B. Very preliminary results only approved for this workshop. Please do not show elsewhere.

Heavy `Stable' Charged Particles

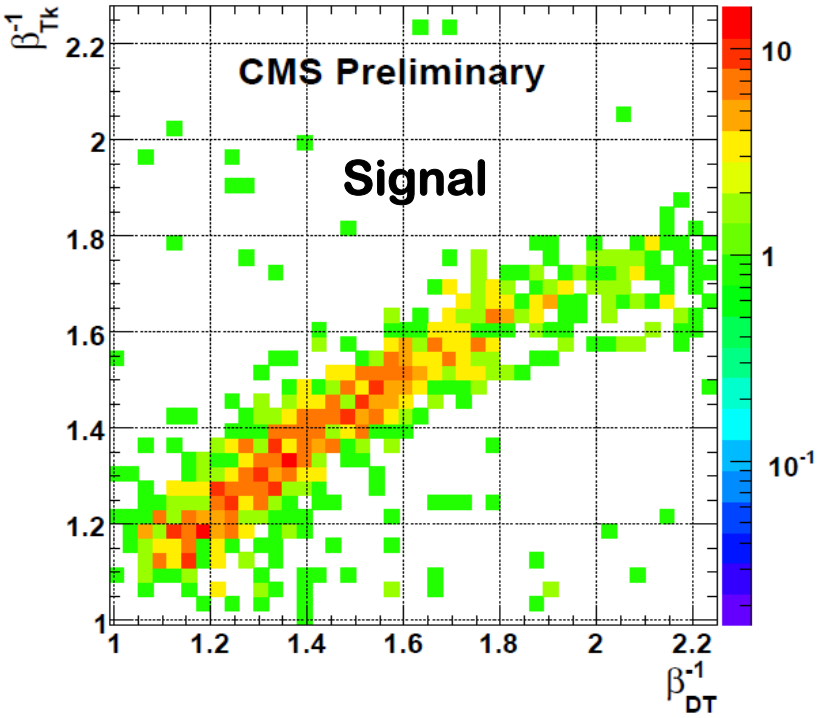
- HSCP models studied:
  1. GMSB stau NSLP (with quasi-infinite decay length to tau + gravitino).
  2. KK tau in *universal* extra dimensions. (Stable because tau's momentum components in extra dimensions must be conserved).
  3. stop is NLSP (so can only decay radiatively to charm + neutralino).
  4. gluino in Split-SUSY. (Squarks very heavy, so gluino can only decay via virtual squarks).

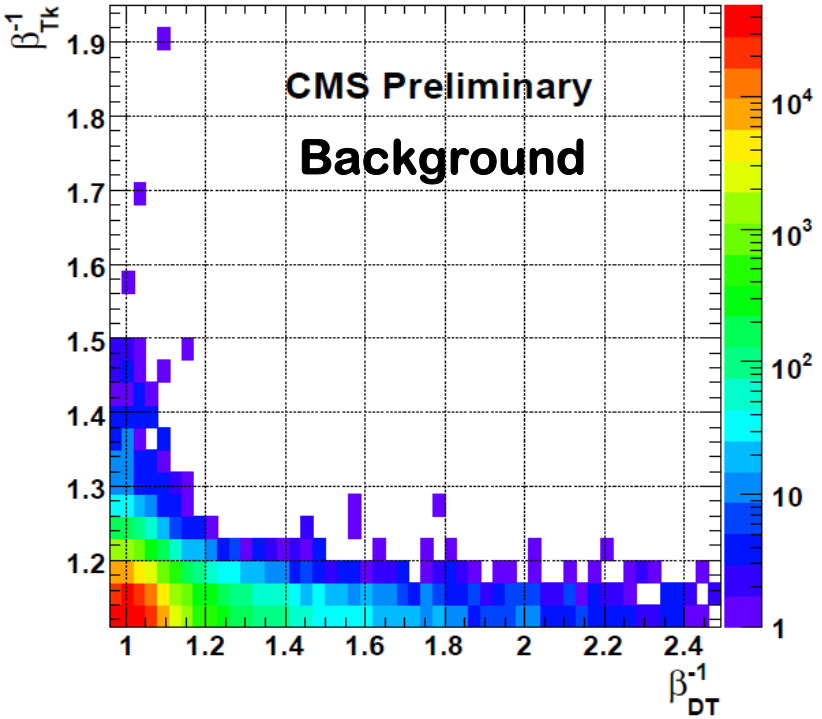
  N.B. Both stop & gluino hadronise to R-hadrons, whose charge changes as it moves through CMS, due to nuclear interactions.

- HSCP give μ-like signals in CMS.
  - Trigger using muon or calorimeter-based Et(miss) signals.

Heavy `Stable' Charged Particles

- HSCP are non-relativistic:
  - Highly ionizing → large dE/dx in Silicon Tracker.
  - Slow moving → T.O.F. measured in muon drift-tubes is *late*.



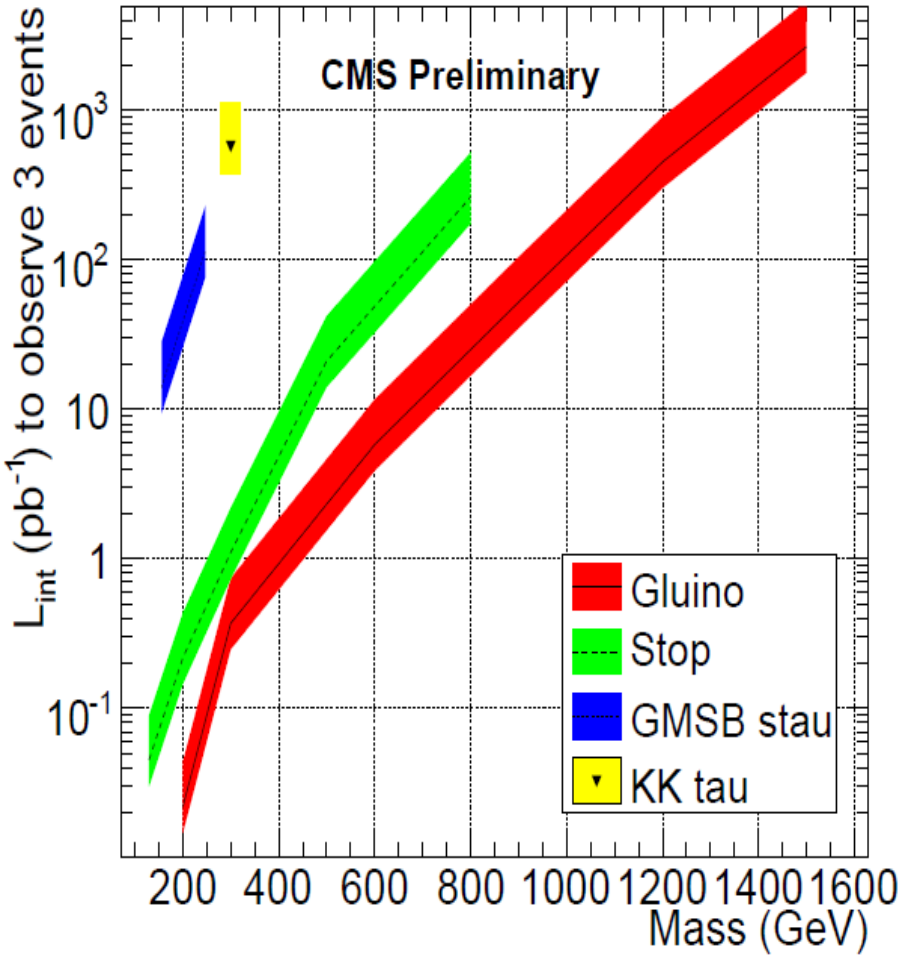


Heavy `Stable' Charged Particles

- With 1 fb^{-1}, expect 0 background events, but > 3 signal events.

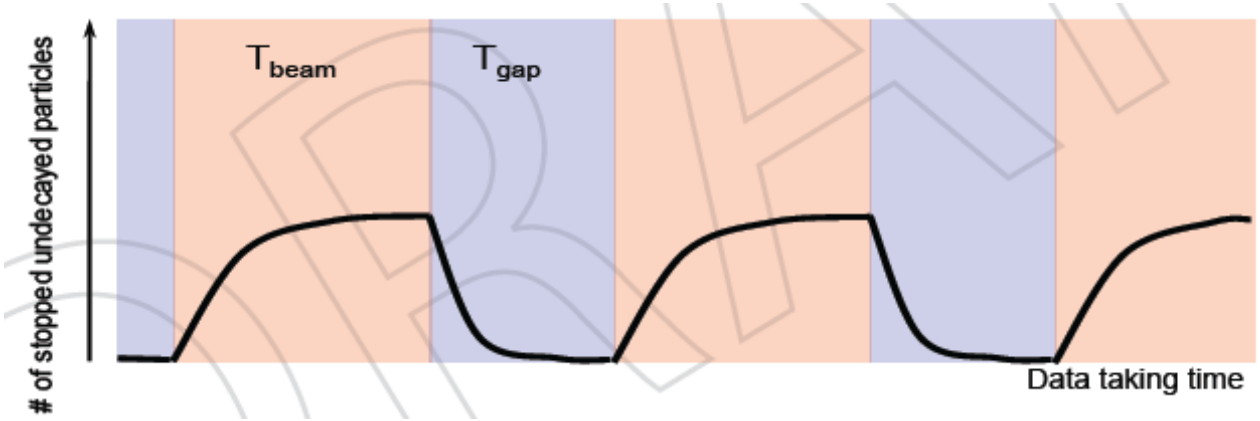
  i.e. 95% c.l. exclusion possible.

- Sensitivity largest for stop/gluino due to QCD cross-section.



Stopped Gluinos

- The long-lived gluino in Split-SUSY hadronizes into R-hadron.
- If very non-relativistic, will lose so much energy by ionization that it will stop before leaving CMS.
- Decay to gluon/quarks + neutralino can take micro-seconds → days. Observe it during beam-gaps or shutdowns.



- Trigger using jet-trigger + beam veto (using orbit monitors).
- Background rate measured during 2008 data taking !!!
- **Public results ready soon.**

Non-Prompt Photons

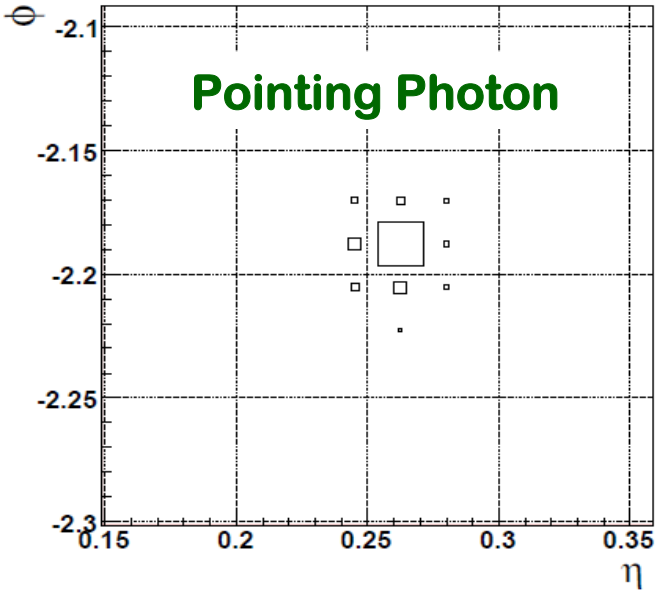
- GMSB neutralino NLSP (visible decay length to gravitino + photon)

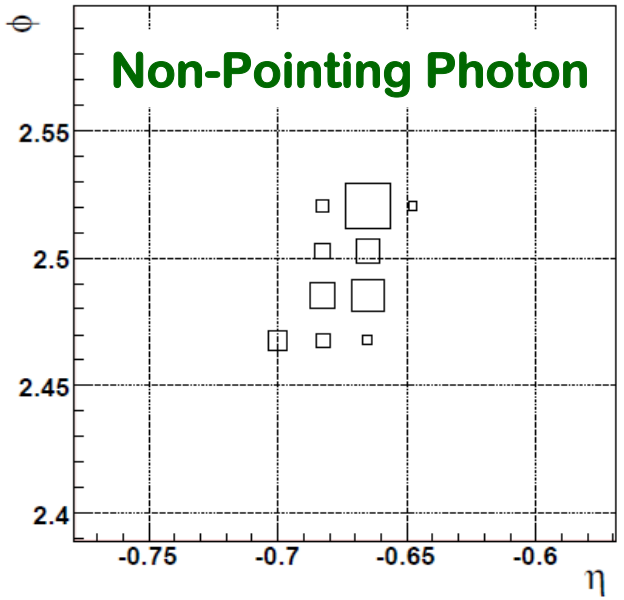
  Large (QCD) cross-section, due to production from squarks/gluinos decay.

- Signal selection:
  - Energetic, isolated photon
  - Energetic multijets from squark/gluino decay.
  - Large Et(miss) from gravitinos.
  - *Optionally, measure γ direction using ECAL & loosen other cuts.*

Non-Prompt Photons

- CMS ECAL made of 76k PbW crystals.
- Electrons deposit energy in clusters of a few crystals.
- Non-symmetric cluster indicates electron didn't come from P.V.
  (except that cluster asymmetries parallel & perpendicular to z-axis can be caused by γ-conversions or crystal geometry).

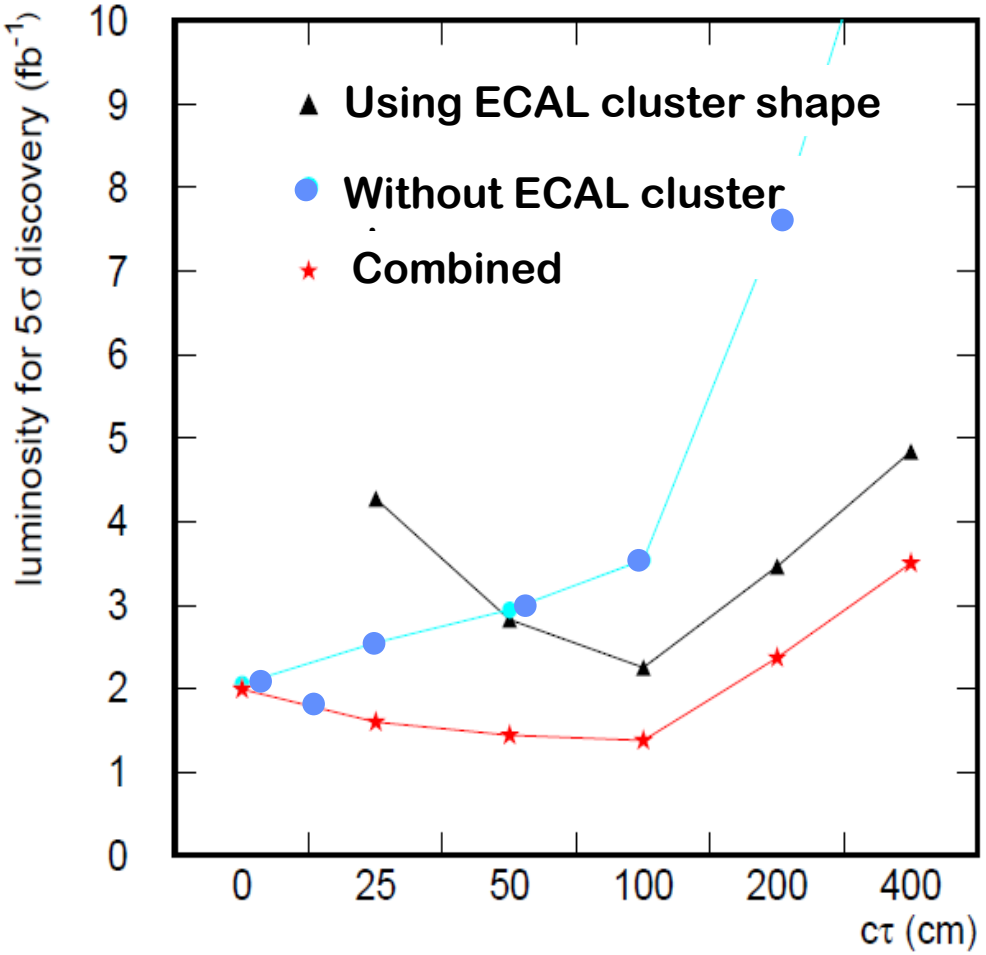




Non-Prompt Photons

Snowmass SUSY benchmark "SPS8 with Λ = 140 TeV" would be discovered with L ~ 1 fb^{-1}.

With L ~ 10 fb^{-1} can also measure cτ with ~20% precision using ECAL cluster energy and asymmetry.



Long-Lived Exotic Decays inside CMS: Models Considered

- Pairs of long-lived, neutral, massive exotics, each decaying to difermions. Generated with:

1. Neutralino pair production in Pythia, forced to decay to difermions (!) by editing SLHA decay table. All other SUSY masses set to ~infinity.

   Exotic M = 165 GeV/c^2, $\langle Et \rangle$ = 400 GeV, $\langle L_\perp \rangle$ = 24 cm.

2. Little Higgs model with T-parity contains a T-odd heavy photon. Because T-parity is slightly violated, this can decay (with long lifetime) to W+W- or ZZ, or (with longer lifetime) via loop to ff.

   Exotic M = 152 GeV/c^2, $\langle Et(f) \rangle$ = 400 GeV, L = 0-400 cm.

   Used CalcHep + Pythia

Long-Lived Exotic Decays inside CMS: Models Considered

- Hidden Valley particles: generator "hv0.960" (from Matt Strassler)
  http://www.physics.rutgers.edu/~strassler/hv/hvmc/

- Extension of S.M. with extra $U(1)_{B-L}$.
  - Requires Z' and 3 long-lived, heavy neutrinos.
  - Mass of light neutrinos generated through see-saw mechanism.
  - Heavy neutrino decays mainly to $W^{\pm} l^{\mp}$, with coupling proportional to ratio of light to heavy neutrino masses.
  - Events contain 2 massive, neutral, long-lived exotics, each decaying to 3 fermions.

  Used CalcHep + Pythia

Long-Lived Exotic Decays inside CMS: Triggering on Dijet Final State

Trigger efficiencies studied using trigger scheme for first year's running.

Calorimeter-based jet triggers work well for decay lengths L < 300 cm.

Preliminary plot only available during workshop

Long-Lived Exotic Decays inside CMS: Triggering on e^+e^- Final State

- Electron trigger requires ECAL energy + track with pixel hits (left).
- Prefer photon trigger *(right)*. Perhaps need something better in 2011+

Preliminary plot
only available
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Long-Lived Exotic Decays inside CMS: Triggering on $\mu^+\mu^-$ Final State

Standard muon trigger muon-chamber track confirmed by Pixel-seeded track in Tracker.

➔ Fails for long decay lengths.

Preliminary plot only available during workshop

Long-Lived Exotic Decays inside CMS: Triggering on $\mu^+\mu^-$ Final State

- Can also trigger using muon-chambers alone.
  Works well for L < 400 cm *(left)*, But needs high threshold in 2011+ ?
- Or can build track in Tracker going outside → in *(right)*.
- Have not yet checked time-window acceptance.

Preliminary plot
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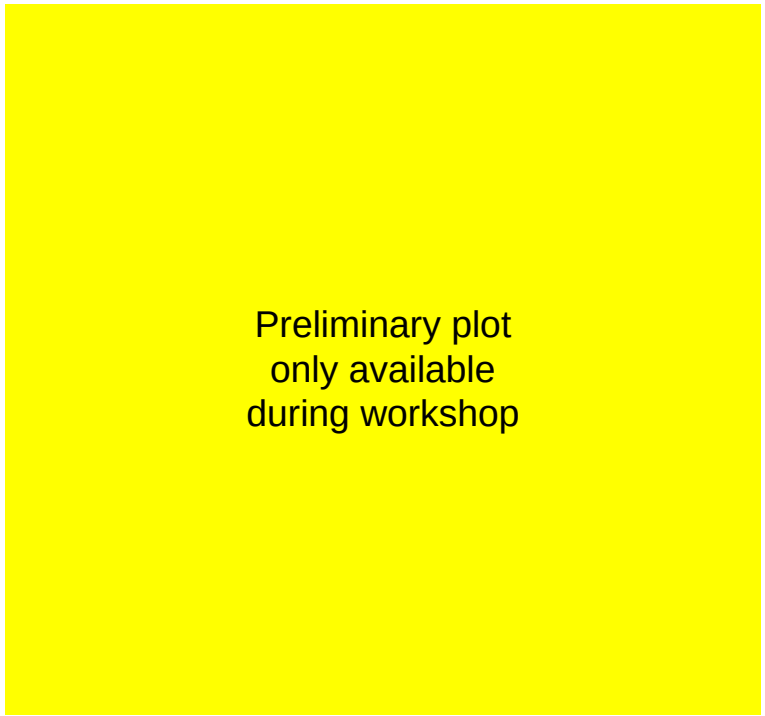
Long-Lived Exotic Decays inside CMS: Triggering on $\tau^+\tau^-$ Final State

- Standard τ trigger requires narrow calorimeter energy deposit, confirmed by pixel-seeded track from τ decay, so poor performance.
- Calorimeter-only-based τ trigger works well *(below)*, but rate may be too high for 2011+.



Long-Lived Exotic Decays inside CMS: Large Impact Parameter Tracking

Iterative Tracking

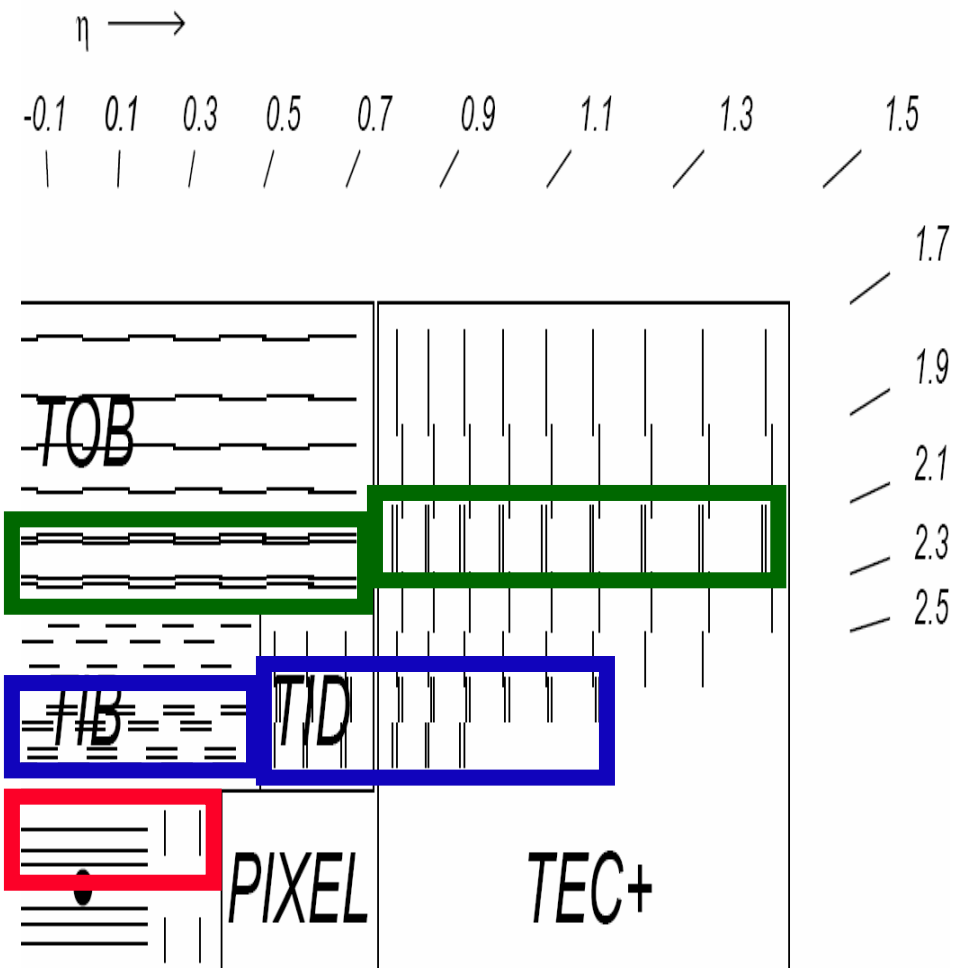
Iter. 0-2: Normal tracks, pixel seeding

Iter 3: Large d0 tracks, pixel seeding

Iter 4: Large d0 tracks, TIB/TID/TEC seeding

Iter 5: Large d0 tracks, TOB/TEC seeding

Hits assigned to tracks in one iteration, can't be used in subsequent ones.



Long-Lived Exotic Decays inside CMS: Large Impact Parameter Tracking

Tracking efficiency

Preliminary plot only available during workshop

Long-Lived Exotic Decays inside CMS: Large Impact Parameter Tracking

Tracking fake rate

Preliminary plot only available during workshop

Long-Lived Exotic Decays inside CMS: Reconstruction of Dijet Final State

- Search for exotic decay vertex using tracks associated to any of the jets it decays to.

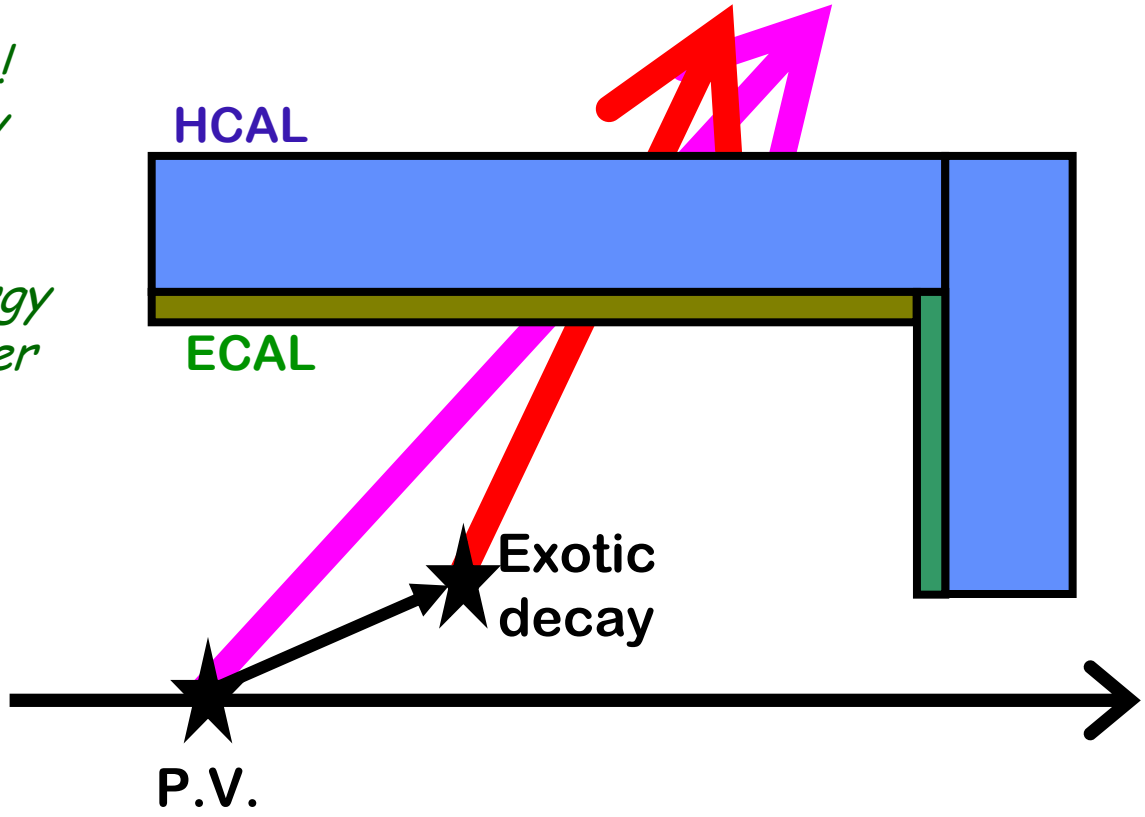
- Use *adaptive* vertex finder.
  - Tracks far from vertex given small weight.
  - All tracks fit to single vertex.
  - Tracks with small weight removed & fitted to second vertex.
  - Repeat until all vertices found.

Preliminary plot only available during workshop

Long-Lived Exotic Decays inside CMS: Reconstruction of Dijet Final State

Jet 4-momenta reconstructed using calorimeter energy deposits.
Normally assumed to originate at P.V.

For us, this is wrong ! Knowing exotic decay vertex & making assumption about depth in CAL of energy deposit, we can better reconstruct jet direction.



Long-Lived Exotic Decays inside CMS: Reconstruction of Dijet Final State

Comparison of exotic's jet direction resolution (left) assuming it comes from P.V & (right) assuming it comes from exotic decay vertex,

Preliminary plot
only available
during workshop

Preliminary plot
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Outlook

- Thanks to large impact parameter tracking, can find exotic decaying to dileptons inside Tracker.

  Hope to publish these results outside CMS soon.

- Ongoing work to reconst exotics with longer decay lengths.
  - Muons found with muon-chambers alone.
  - Electrons found with ECAL alone (= photons)
  - Jets with no tracks or no ECAL energy.
  - Use time-of-flight info. Resolutions approximately …
    - ECAL: < 1 ns (published resolution soon)
    - HCAL ~ 2 ns (unpublished)
    - Muon drift chambers ~ 1 ns.
  - + ……

Conclusions

- 1 TeV/c^2 HSCP can be discovered with L = 0.1 fb^{-1} (= 1st year).
- Search for stopped gluinos proceeding. *(very preliminary)*
- GMSB (SPS8 with Λ = 140 TeV) non-prompt photons can be found with L = 1 fb^{-1}.

- Long-lived decays to charged particles *(very preliminary)*:
  - Triggering works, although work may be required (especially for e/τ at higher luminosities).
  - Vertex reconstruction possible using Tracker for transverse decay lengths < 50 cm.
  - (Currently exploring use of calorimeter/muon chambers for longer decay lengths).

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Questions

Theory:

- What is theoretically possible/impossible ?
  e.g. Singly produced long-lived exotic decaying to dileptons with no missing Et in event ?
- Do we have MC generators for all interesting possible models ?

- What is ruled out by existing experimental results ?
  e.g. Should CMS do a search for long-lived exotics with QCD cross-section decaying to dileptons with <Pt> ~ 30 GeV, or do D0/CDF rule this out ?

Quoting limits:

- How quote limit ? – Too many parameters …
- How combine limits between CMS/ATLAS ?
- How combine limits between CMS/ATLAS/CDF/D0 ?