Challenges in the detection of long lived particles: the Hidden Valley Scenario

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Outline

- The Hidden Valley Scenario
- Trigger selection at ATLAS

Long-Lived Particles and SUSY

Many theories for Physics Beyond Standard Model (PBSM) at LHC energies predict long-lived neutral scalar particles:

- Gauge-mediated SUSY extensions of the MSSM
- MSSM with R-Parity violation
- Split SUSY
- Inelastic dark matter
- Hidden Valley scenarios

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ATLAS detector has been designed and optimized for:

- SM Physics (top, electroweak, beauty)
- Higgs boson searches (SM and MSSM)
- Heavy gauge bosons (Z')
- SUSY (inclusive and exclusive searches)

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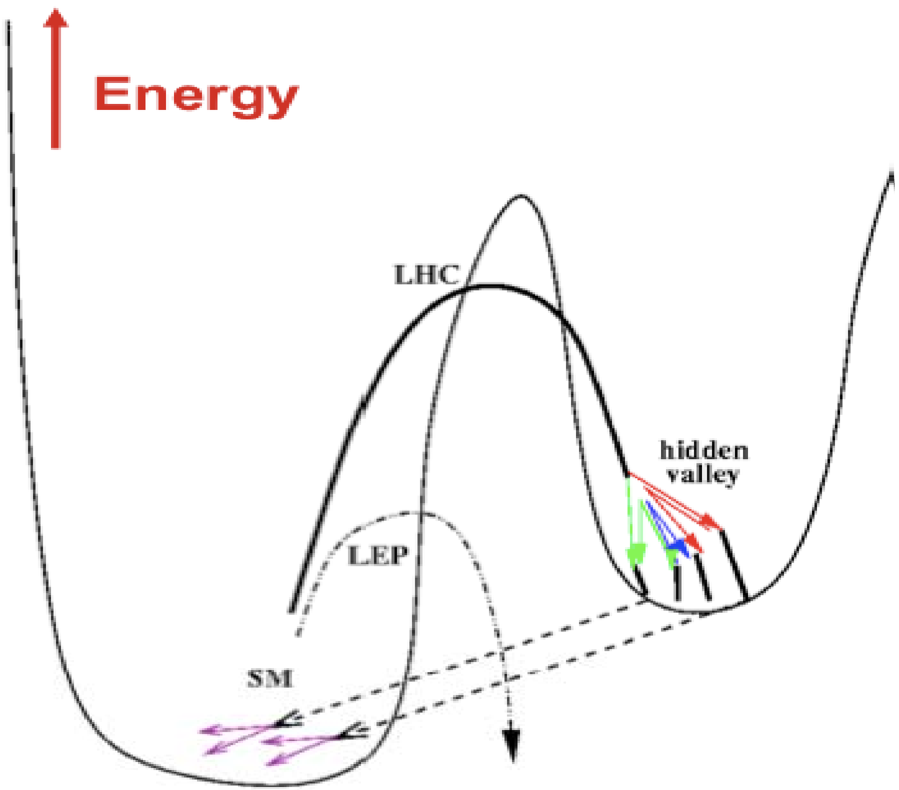
→ Is the ATLAS detector able to cope with “unexpected” long-lived neutral particles?

Hidden Valley Phenomenology



“Hidden Valley” models predict a new dynamic accessible (may be) at LHC energies

Hidden Valley and SM communicate through a mediator communicator(Higgs, Z’,LSP)

All v-particles are neutral under the SM
The lightest v-particles (π_v) are stable in the v-sector and decay (weakly) only in the SM

π_v decay in heavy quarks (heavy leptons) pairs ($b\bar{b}$,$\tau\bar{\tau}$)

M. Strassler and K. Zureck ,
Phys.Lett.B **661**:263(2008)
Phys.Lett.B **651**:374(2007)

Hidden Valley models are a general class of models that give neutral, long-lived particles

Hidden Valley: Parameters of the model

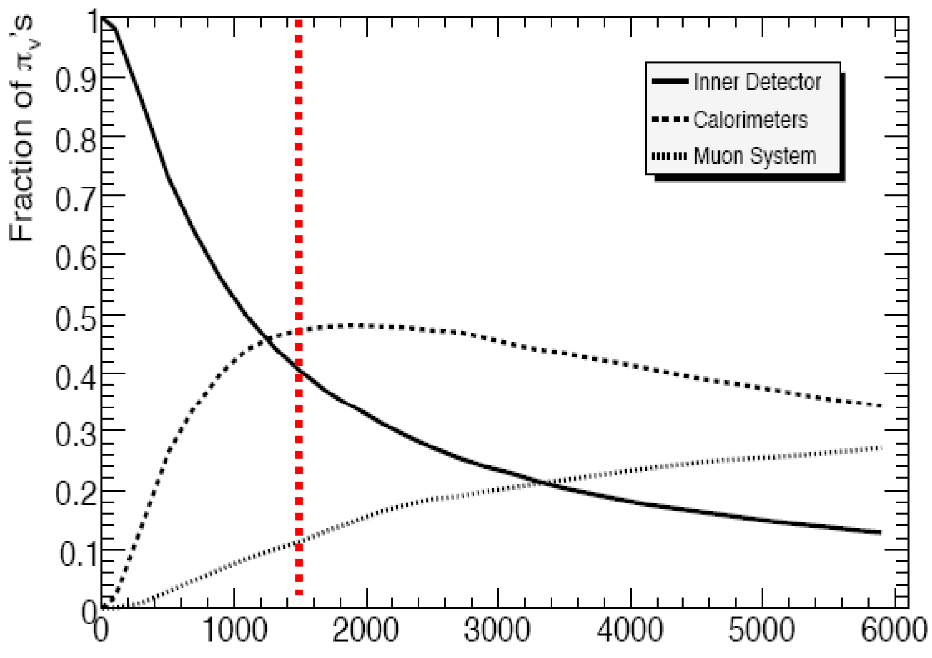
Hidden Valley Monte Carlo simulation based on Pythia (Matt Strassler as theoretical consultant)

Simulated processes:

Higgs $\rightarrow \pi_v \pi_v$

Z' $\rightarrow \pi_v \pi_v \dots \pi_v$

Decay length choosen to provide π_v decays throughout the ATLAS detector



π_v proper decay length

Model parameters:

Z' production:

$M_{Z'}$=2 TeV

g'=0.2 ->$M_{Z'}$ /g' = 10 TeV

M(π_v)=25 GeV

$c\tau$=1500 mm

h_v production and decay:

M($\mathbf{h_v}$)=140 GeV

M(π_v)=40 GeV

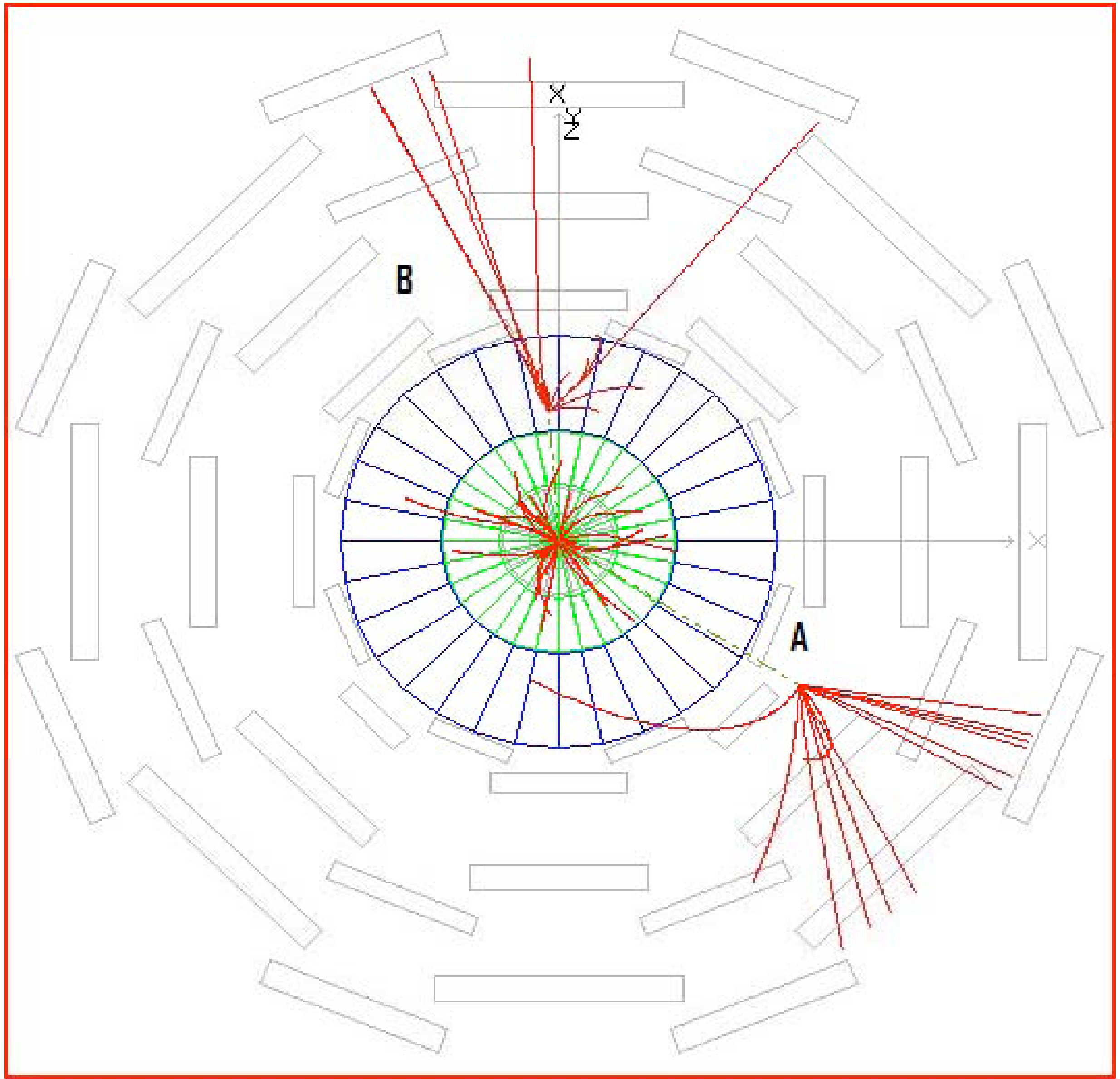
$c\tau$=1500mm

- The Hidden Valley Scenario
- **Trigger selection at ATLAS**

Experimental Signatures

gg→Higgs production

“Pythia” event display (no detector simulation)

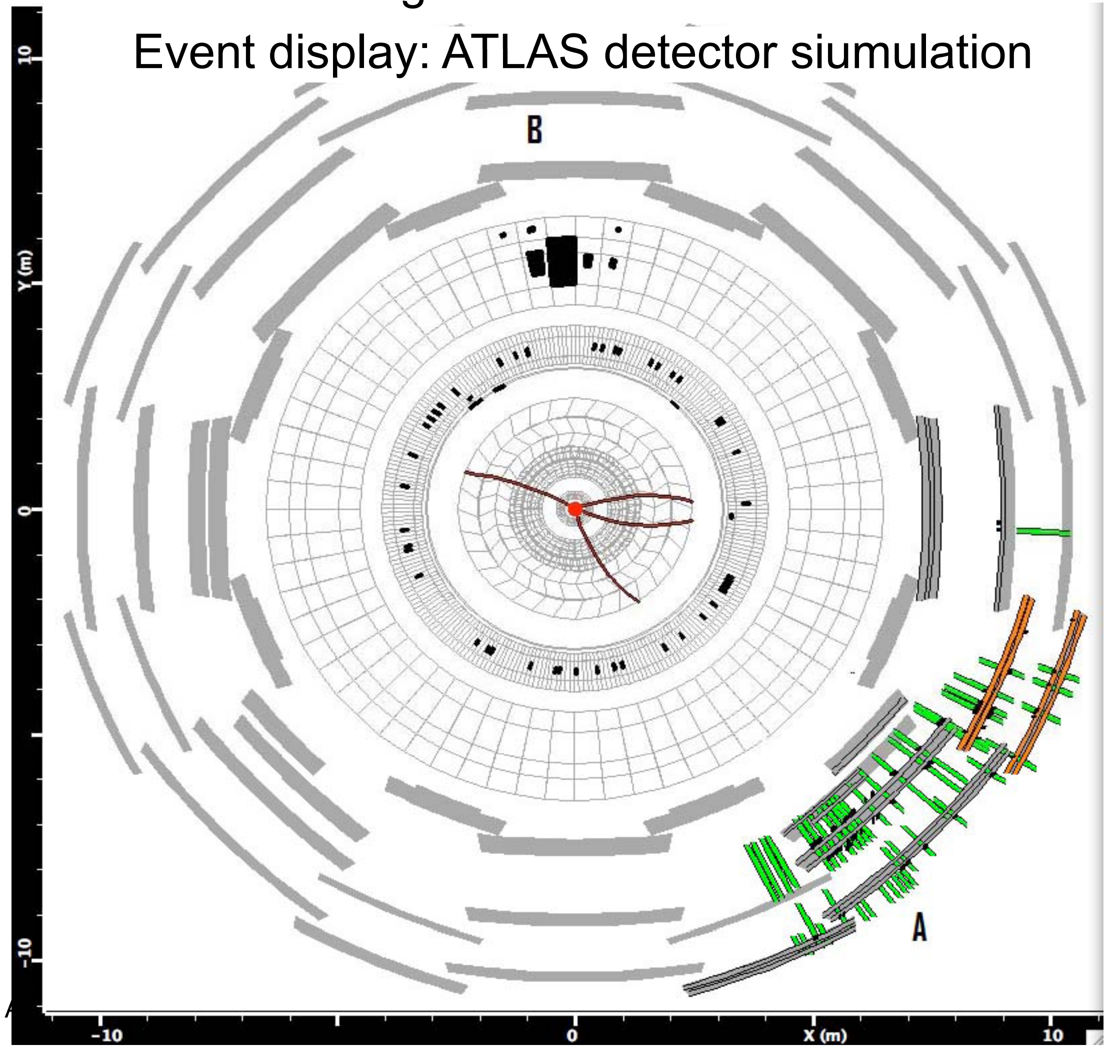


- Unique topological signatures
- No SM process can mimick those signatures
- Hidden Valley processes almost background free

Trigger issues

NEED A SIGNATURE DRIVEN TRIGGER STRATEGY

Main experimental difficulty:
Displaced vertices
→Low efficiencies for “conventional” trigger selections (jet trigger, muon triggers, tracking algorithms in Inner detector) and reconstruction algorithms



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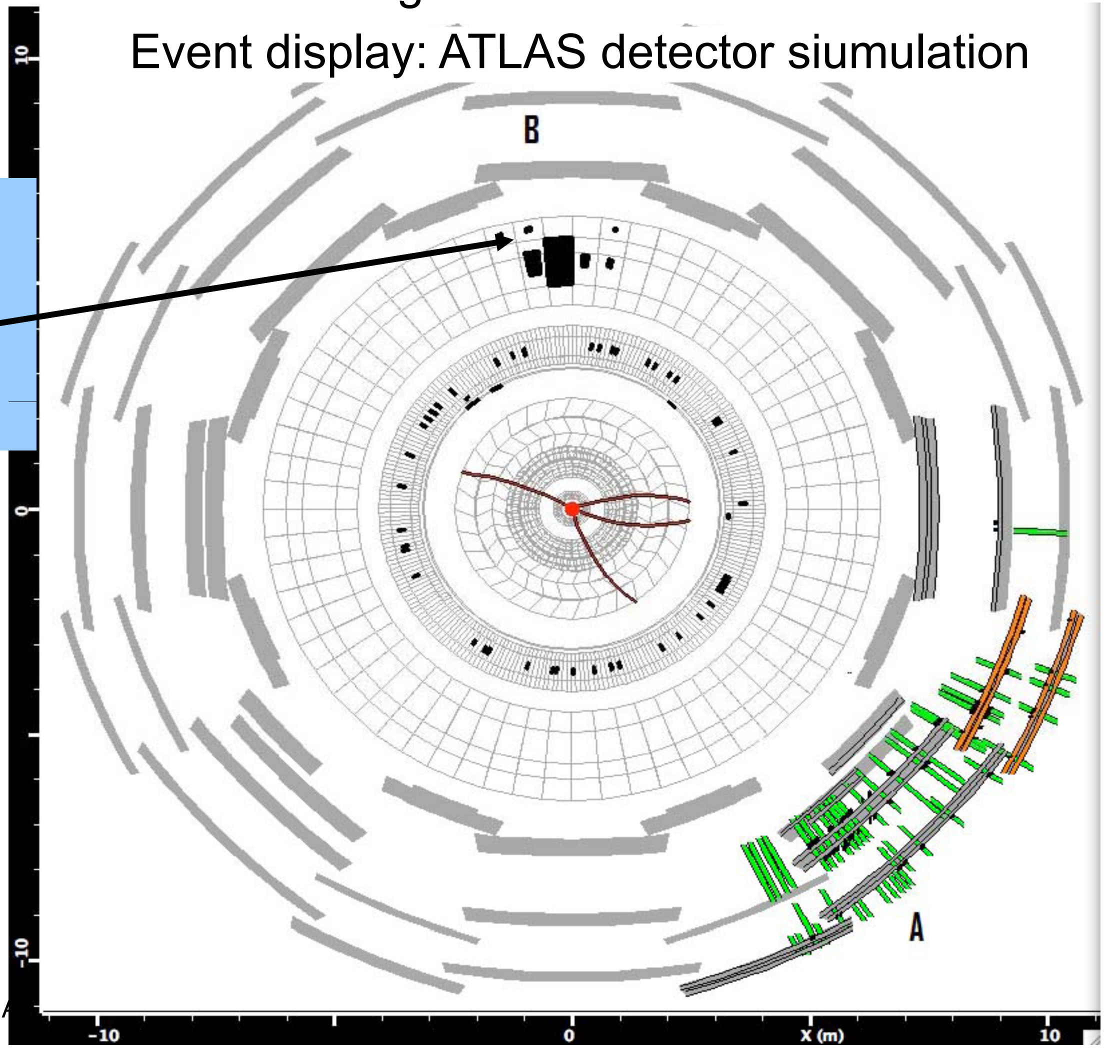
π_v decaying in the calorimeter:
- Small energy deposit in Electromagnetic calorimeters
- Large deposit in Hadronic calorimeters
- No tracks associated in ID



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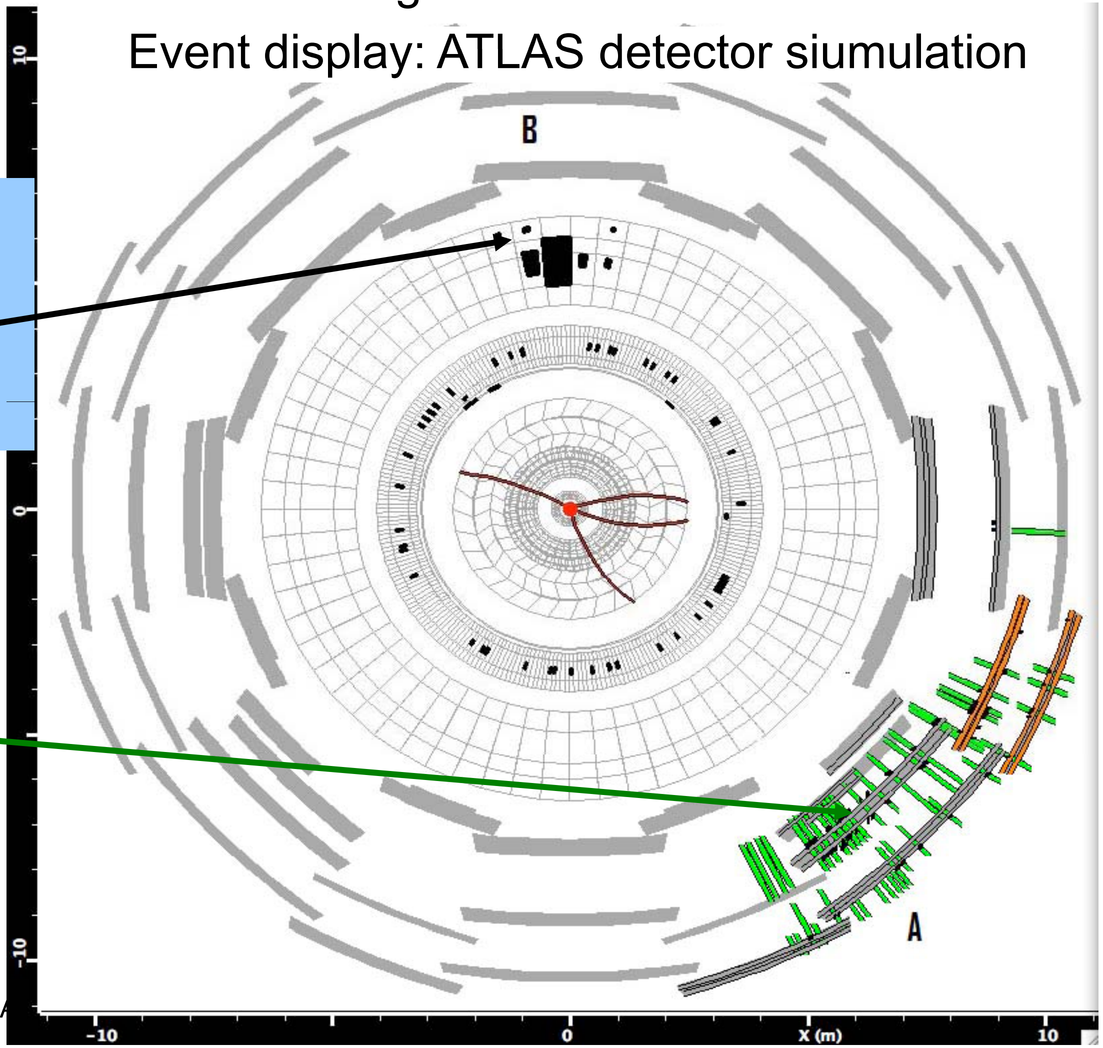

π_v decaying in the calorimeter:
- Small energy deposit in Electromagnetic calorimeters
- Large deposit in Hadronic calorimeters
- No tracks associated in ID

π_v decaying in the Muon Spectrometer:
- Large multiplicity
- Tracks not pointing to nominal interaction vertex
- No tracks in ID
- No energy in calorimeters

Calorimetric Trigger Selection

"Conventional" ATLAS calorimetric trigger selection.

Normalized to all events

	Level-1 and Level-2 (Eff %)			
	E_T>160 GeV	2 Jet (E_T>120 GeV)	3 Jet (E_T>65 GeV)	Total (Overlap removed)
Higgs: Gluon Fusion	3.3	1.7	1.7	4.4
Z prime	46.5	24.5	22.8	53.6

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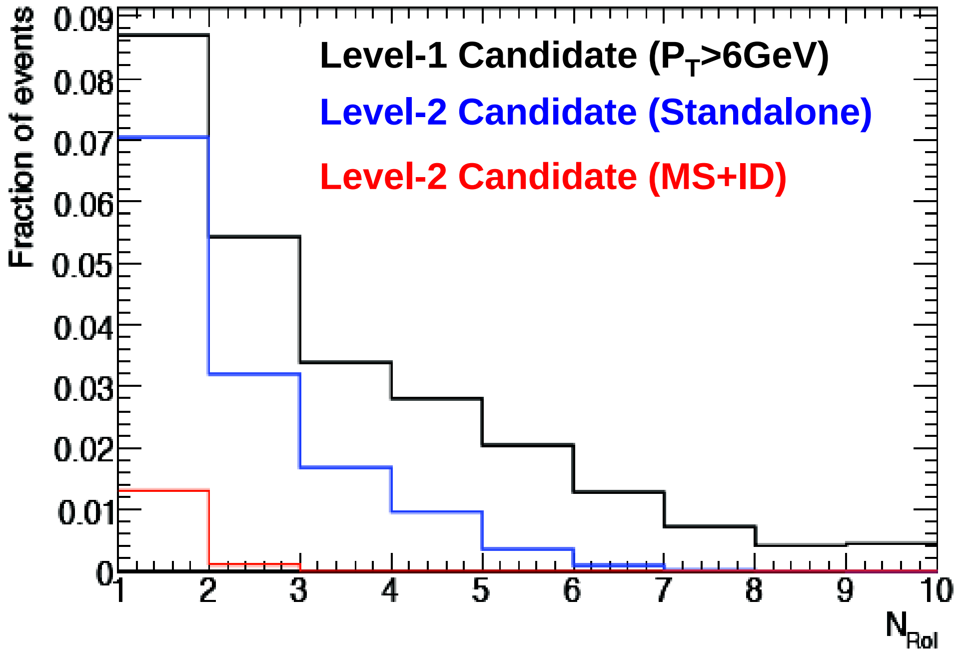
Already at Level-2 output, too small efficiency for Higgs→ π_v π_v decays

Efficiency on Z' decays still acceptable but will decrease for longer π_v decay lengths

Muon Trigger Selection

Number of Muon Level-1 candidates
(P_T>6 GeV/c)



Conventional ATLAS Muon Trigger (Level-1 and Level-2)		
	P_T>6 GeV	P_T>20 GeV
Higgs: Gluon Fusion	2.2	0.3
Z'	4.4	0.84

ATLAS Muon and Jet "conventional" triggers cannot cope efficiently with these HV signatures

	Conventional ATLAS Trigger		
	Jet	Muon	Total
H_V: Gluon Fusion	4.4	2.2	4.7
Z'	53.6	4.4	53.9

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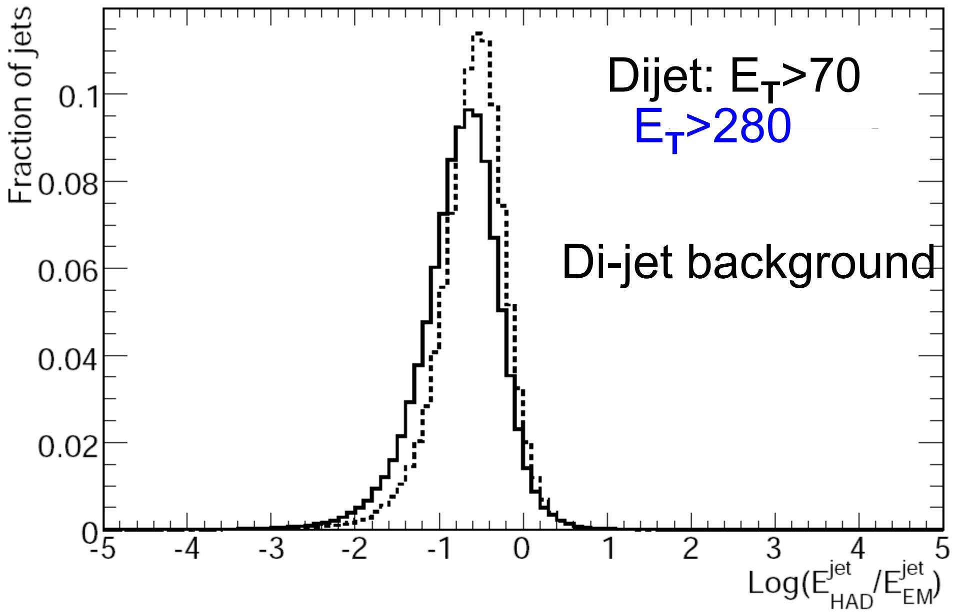
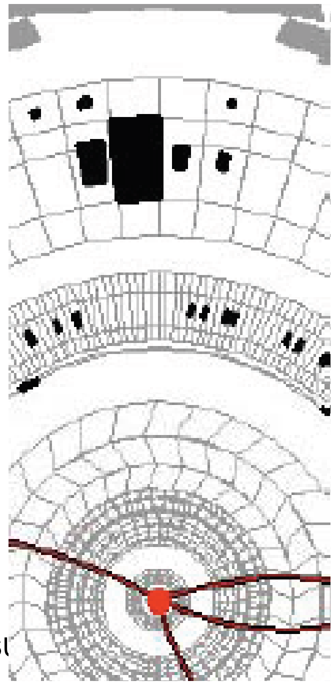
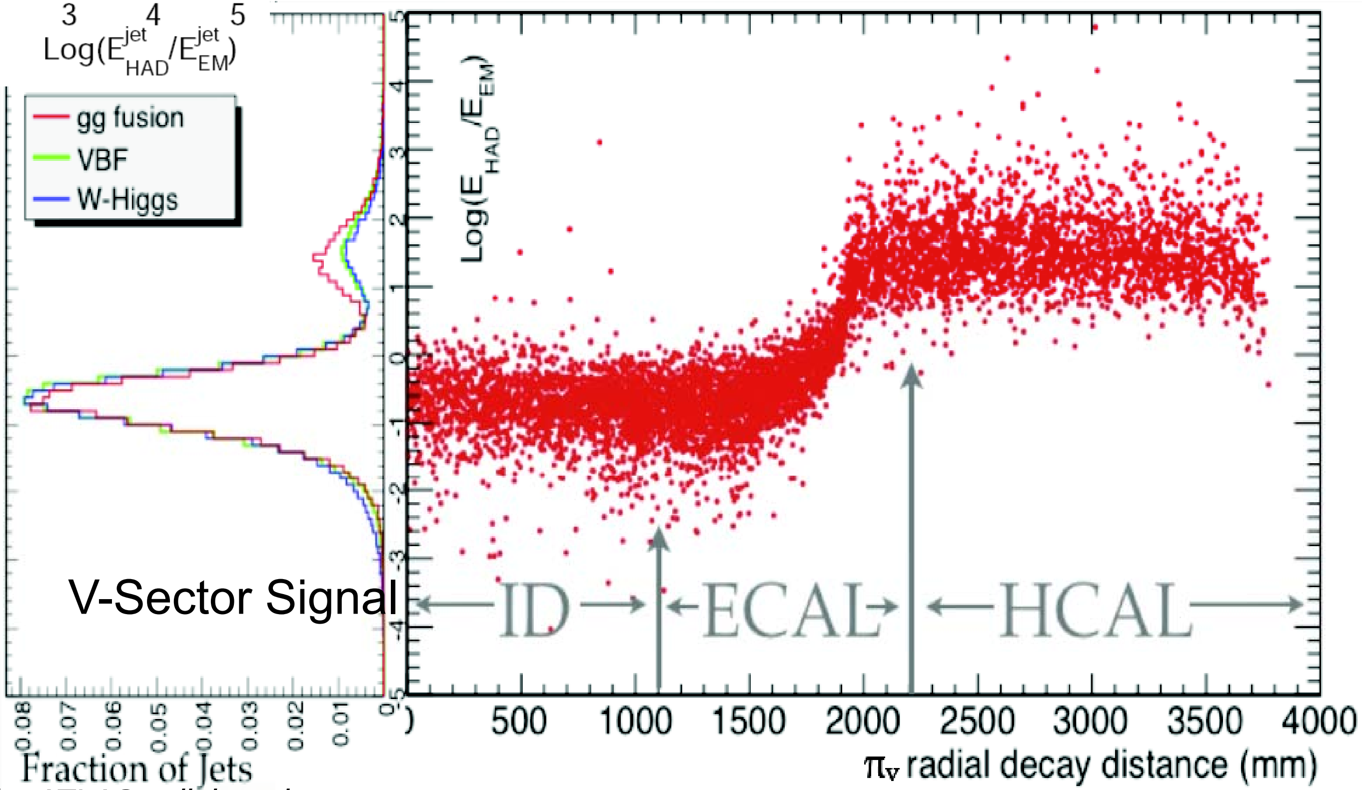
Trigger Handles: Jets

Ratio of energy deposit in calorimeters







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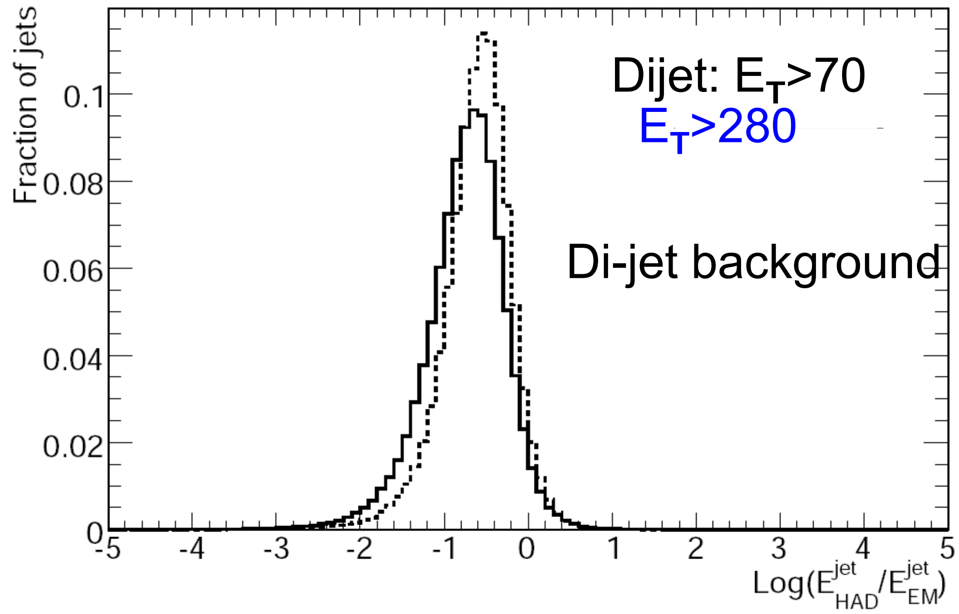
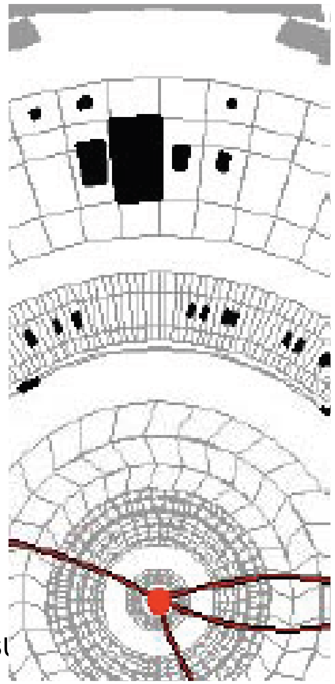
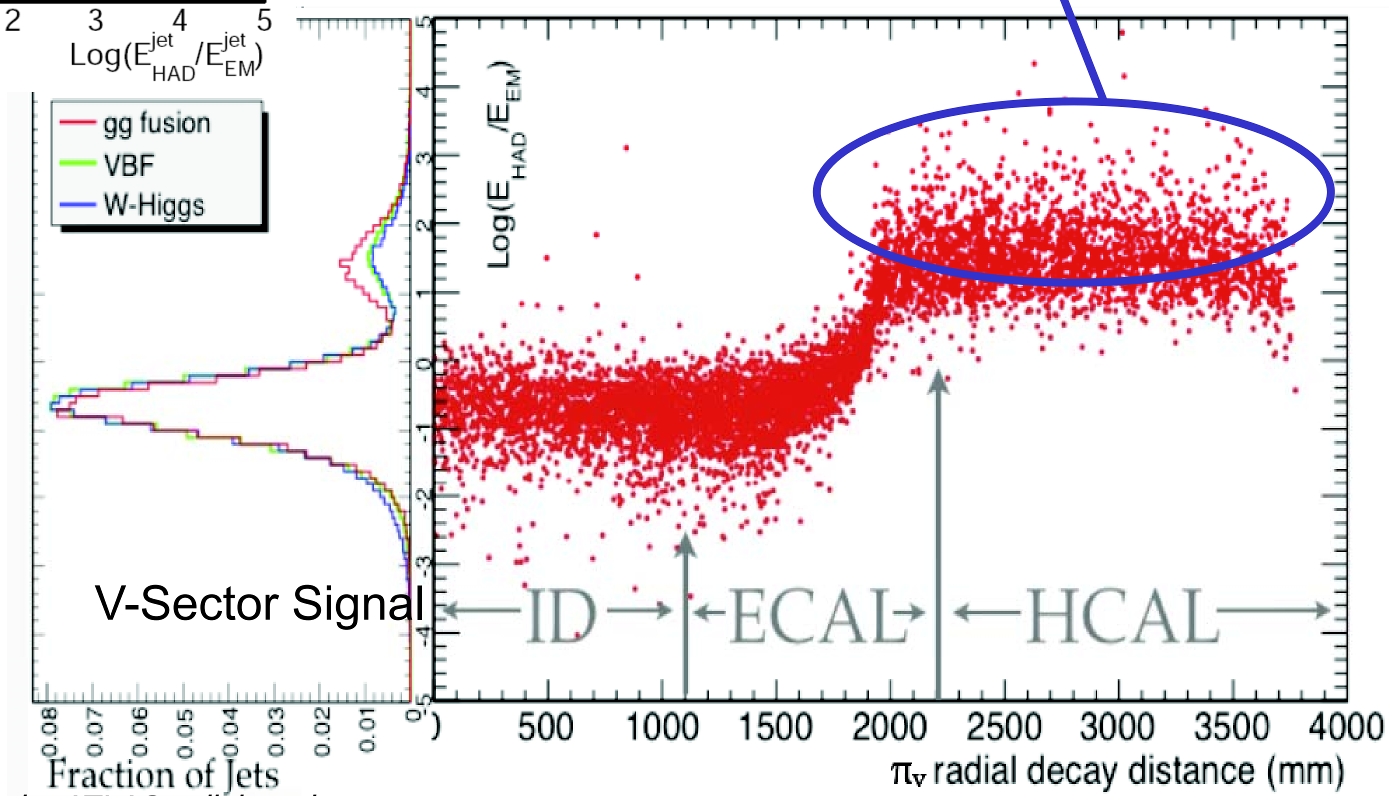


Ratio of energy deposit in calorimeters

π_v decaying in Calorimeters





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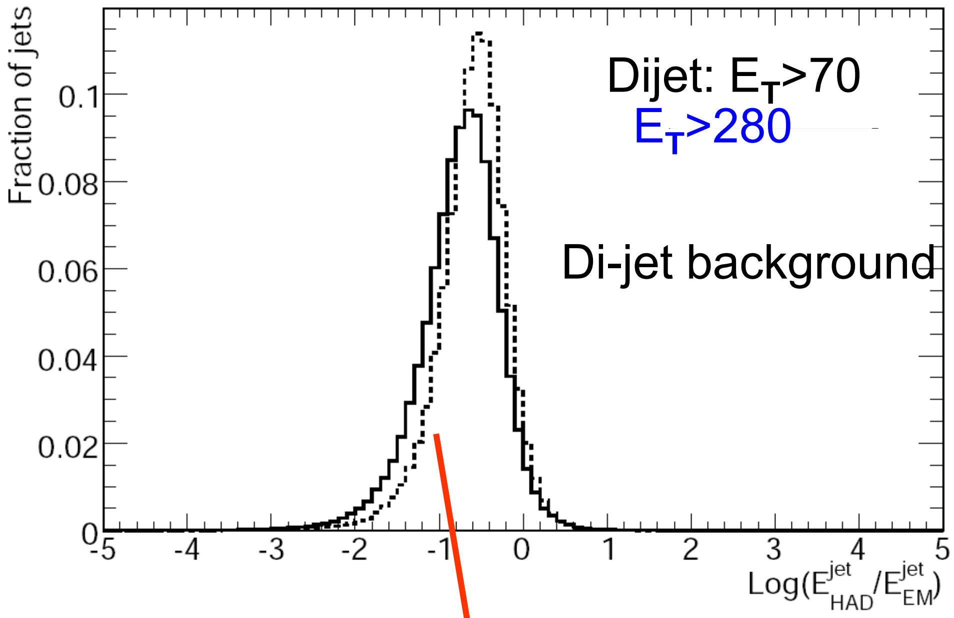
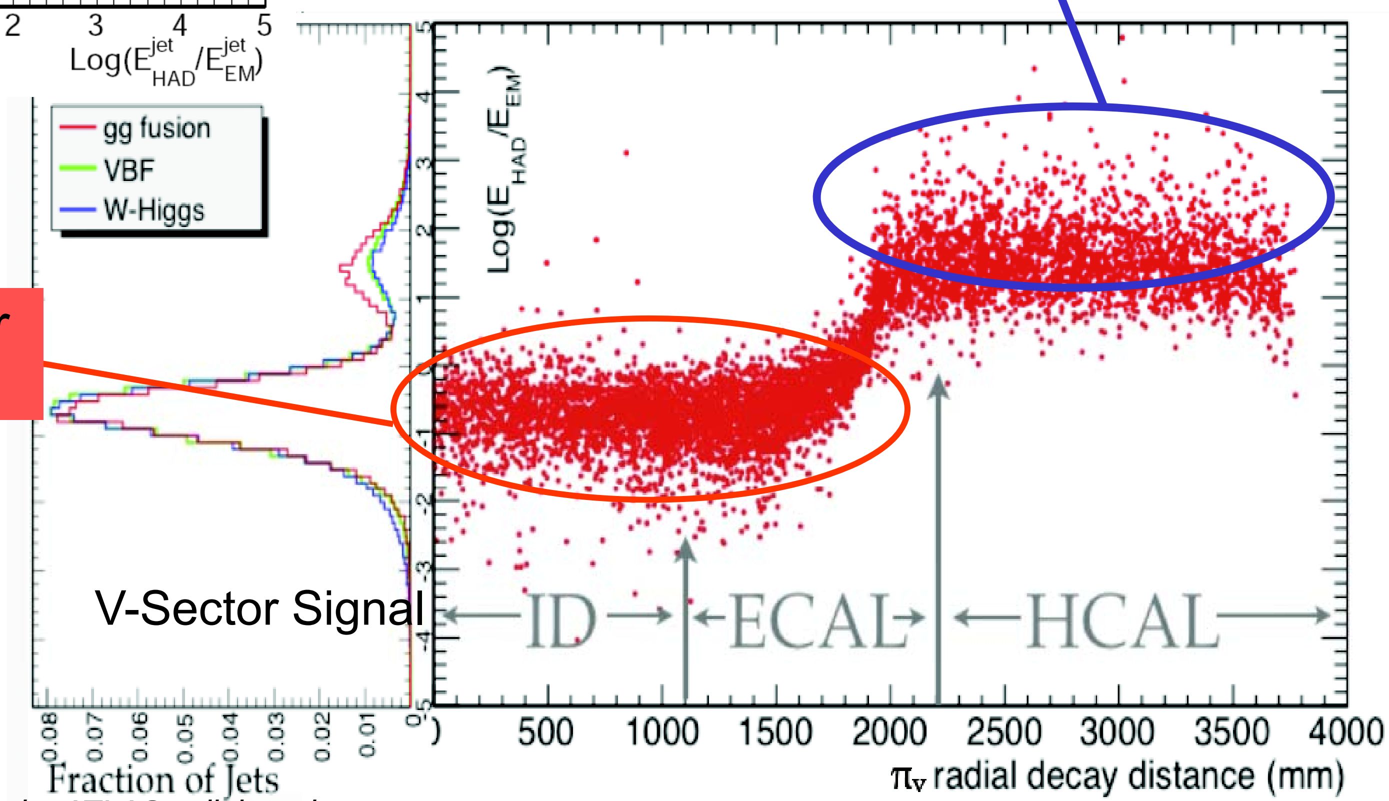


π_v decaying in Calorimeters

π_v decaying in Inner Detector
Appears as "usual" jets



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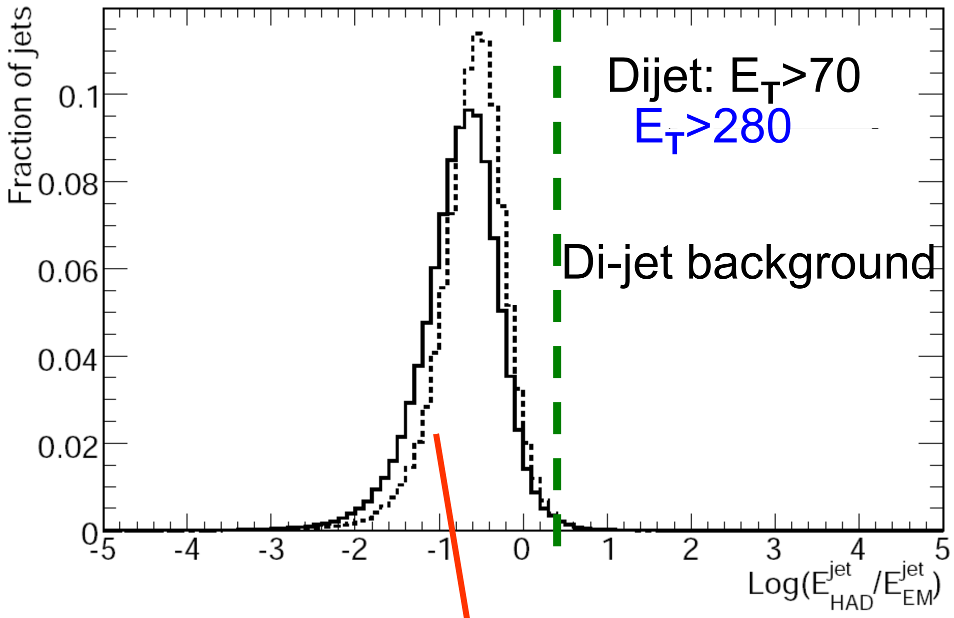

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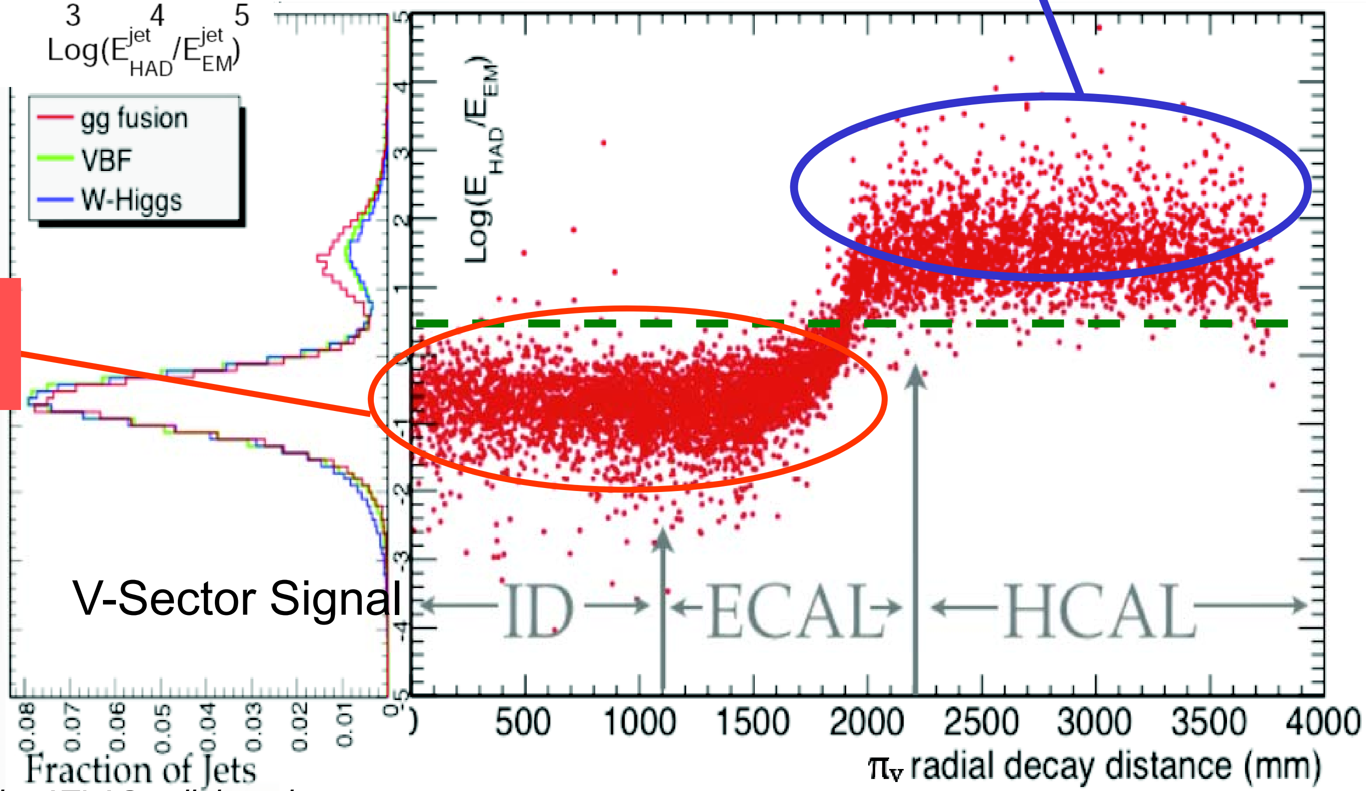

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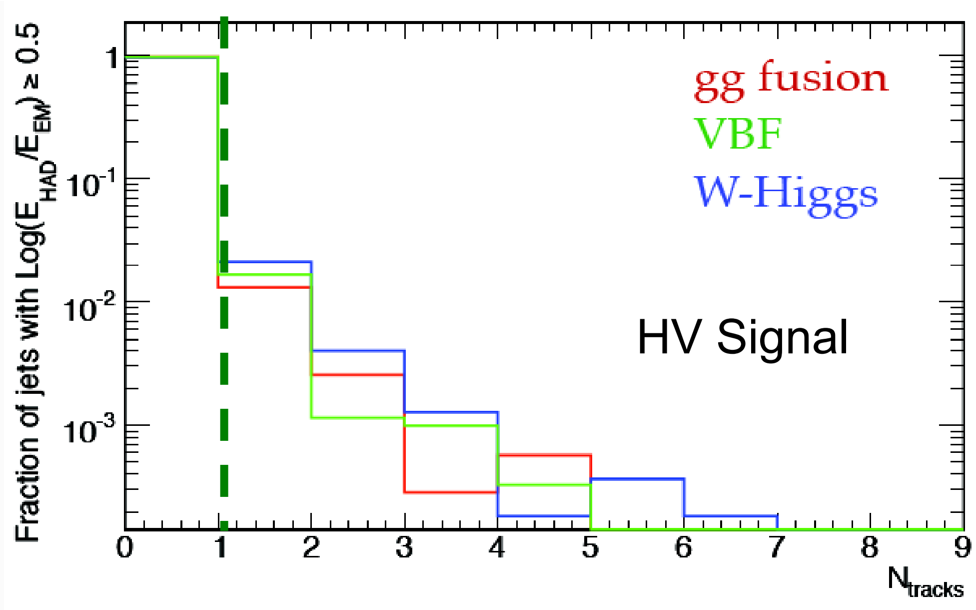
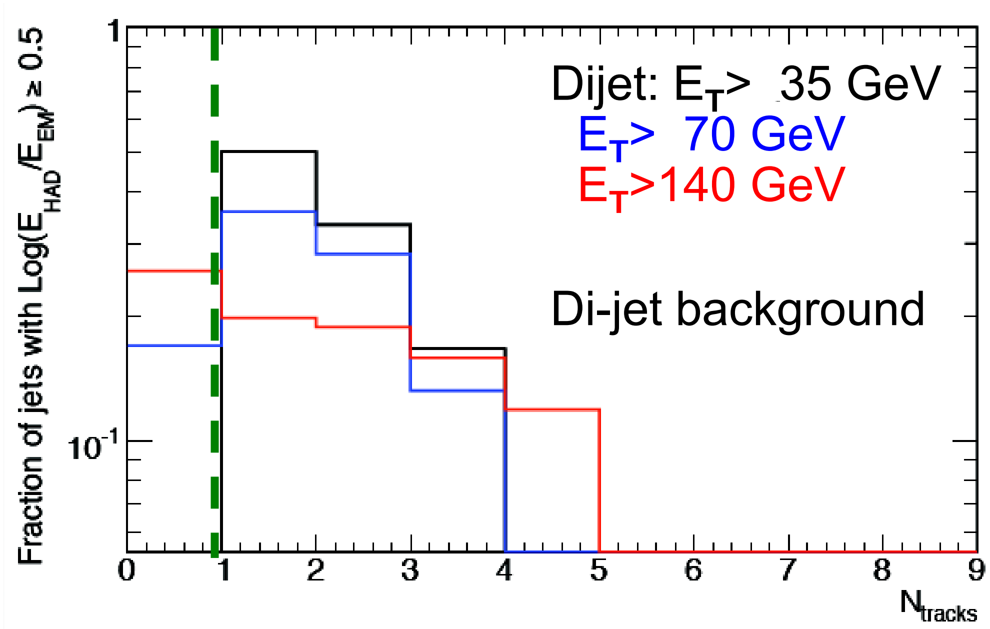


Track Multiplicity Selection:

Number of Tracks (P_T>1 GeV) in cone ($\Delta R(\Delta\eta x \Delta\phi)$=0.4) around jet After log(Had/Em)>0.5

No tracks expected around jet from a π_v decay



The request on log (Had/Em) and “trackless” allows to decrease the trigger jet energy threshold

→Larger Trigger acceptance

→Smaller Trigger rates

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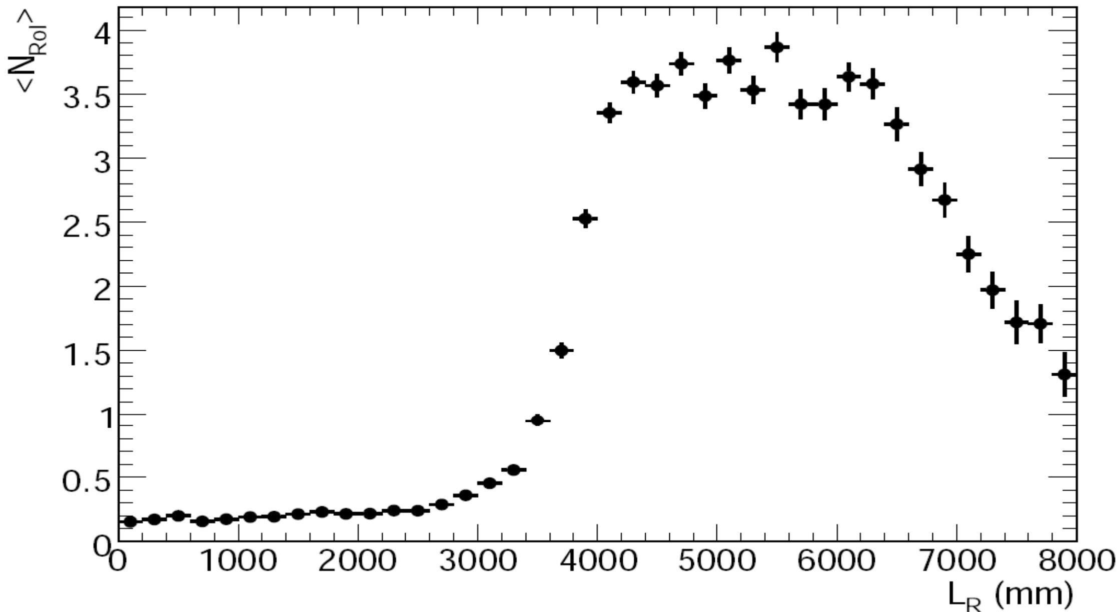
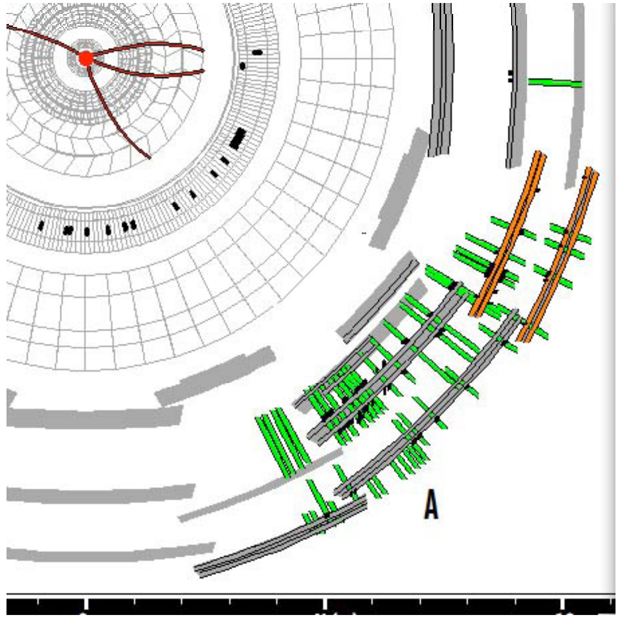
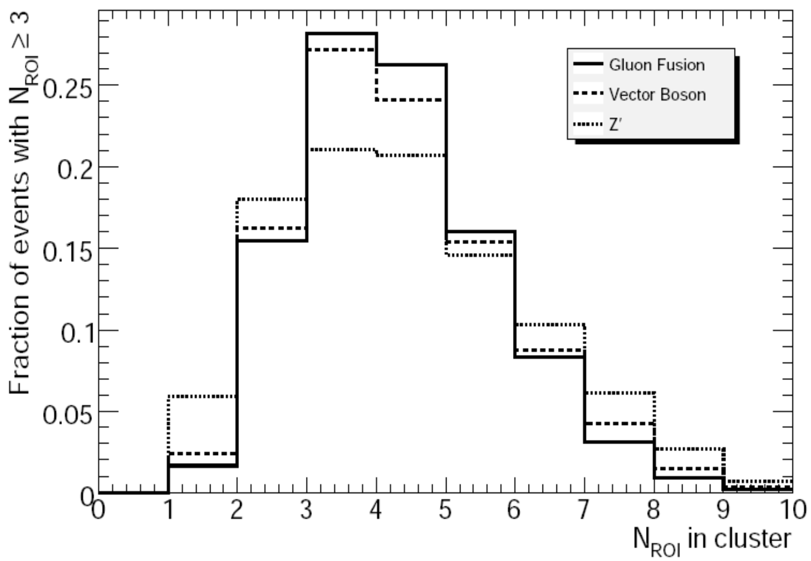
Trigger Handles: Muons





Mean number of Level-1 Muon candidates *vs* π_v decay length
→Large Level-1 multiplicity <#Candidates>~3

Number of LVL-1 Muon Candidates in cluster with Δ**R**=0.4 around π_v



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ATLAS : "Hidden Valleys" Triggers

Implemented Level-2 triggers efficient for Hidden Valley decays

HV Specific Jet Trigger Selection:
- E_T>35 GeV
- $|\eta|$<2.5
- Log(Had/Em)>1
- No Tracks with P_T>1 GeV/c

Muon Cluster:
- At least three Level-1 Muon Candidates
- Contained in a cone of ΔR=0.4
- Isolated (ΔR=0.7) from jets

Trackless Jet with muon:
- Jet:
  - E_T>35 GeV
  - No Tracks with P_T>1 GeV
- Muon:
  - Isolated from jet (to reduce SM background from jet punchtrough)

	Conventional Trigger			HV Specific Trigger Selection (Level-1 Level-2)				
	Jet	Muon	Total	Log (Had/Em)	Trackless jet with muon	Muon RoI Cluster	Total* HV Triggers	Total* all Triggers
H_V: Gluon Fusion	4.4	2.2	4.7	5.0	3.8	9.0	15.7	18.5
Z'	53.6	4.4	53.9	19.3	32.2	13.8	46.4	67.3

Main expected background from QCD di-jets
Trigger Rate @ L=10^{33} $cm^{-2}s^{-1}$~3 Hz evaluated with minimum bias and dijet samples

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Trigger Strategies

	Radius at $\eta=0$ (cm)	Trigger signature
Beam pipe and pixel detector	~13	Almost irreducible from beauty and charm decays
Strips and TRT (Outer part of ID)	~100	Modified tracking algorithms at Trigger level (Outside-In) Caveat: High-Luminosity
Calorimeters	~425	Log(Had/Em), trackless jet
Muon Spectrometer	~1000	Multiplicity Level-1 Clusters isolated from jets, no ID tracks
"Never"	"infinity"	Missing ET (back to "standard" SUSY inclusive searches)

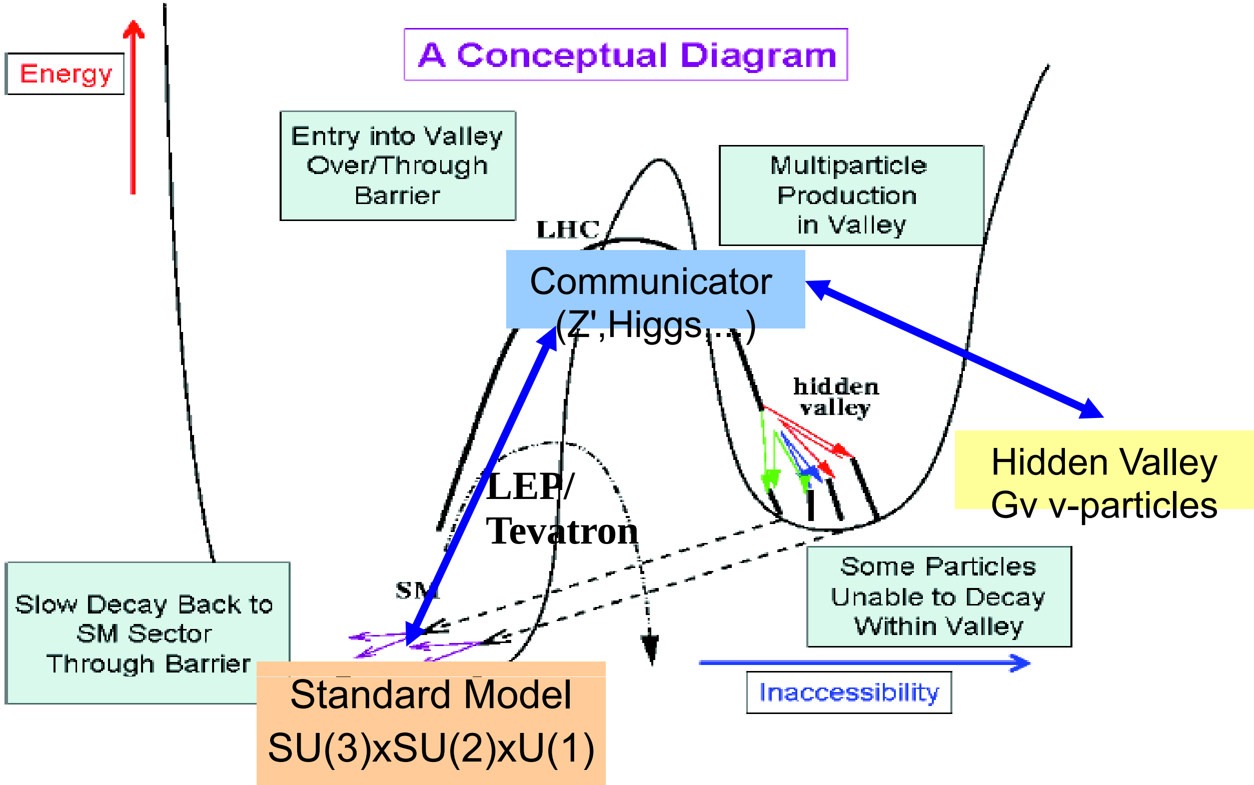
Trigger Strategies vs decay radius of π_v

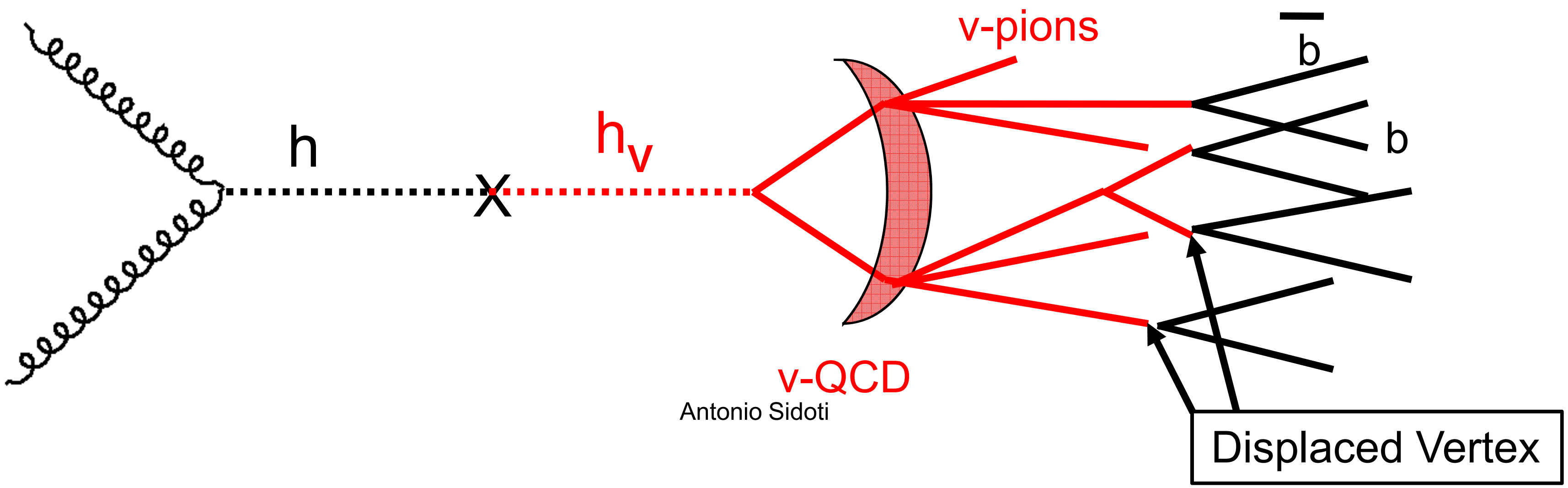
Conclusions

- Hidden Valley decays are early discovery channels since small background from SM processes expected
- Trigger selection is a key issue at LHC
  - Trigger selections have been implemented to efficiently select Hidden Valley events
- Lot of work still to do!

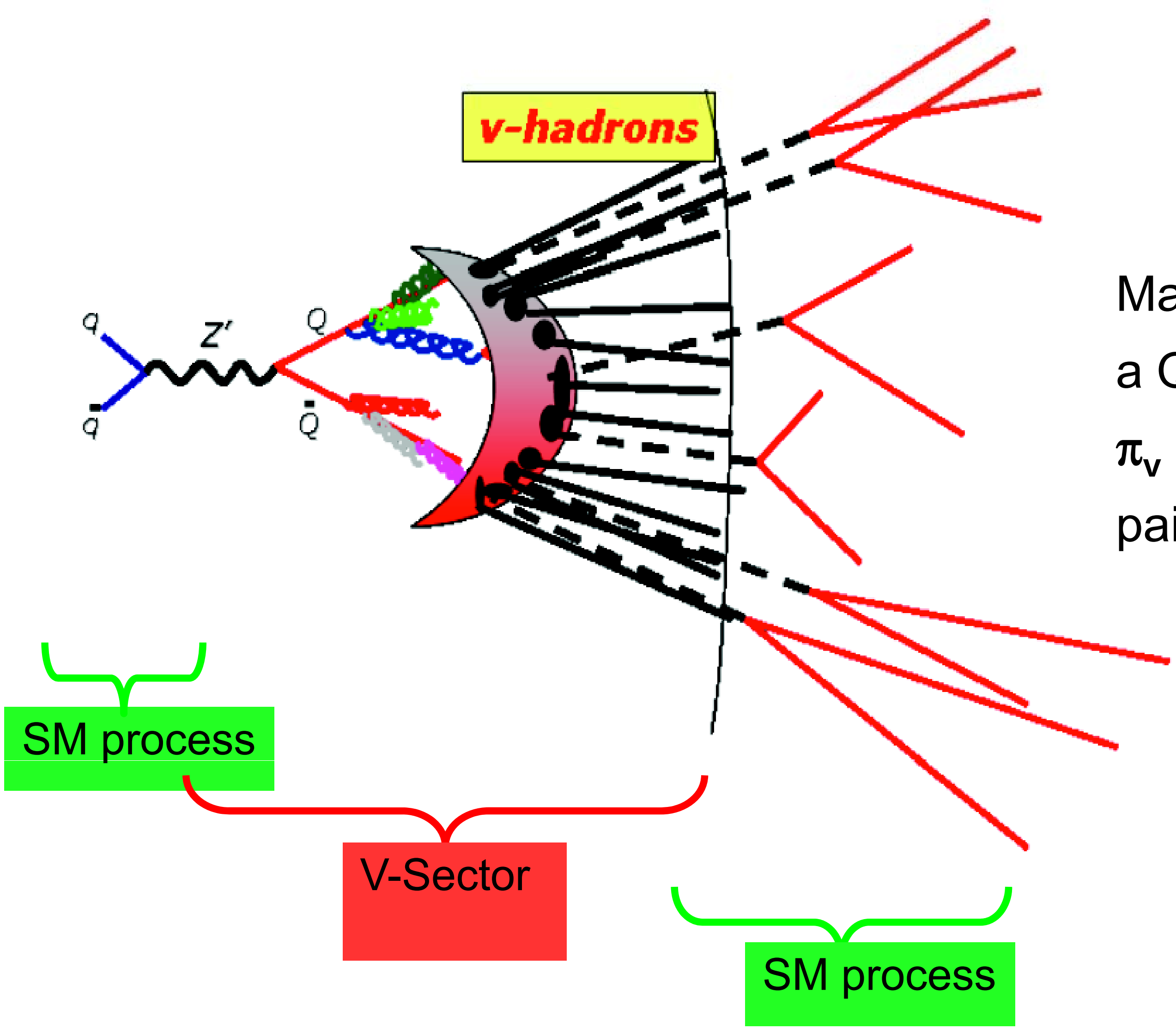
BackUp

Hidden Valley Phenomenology: 101





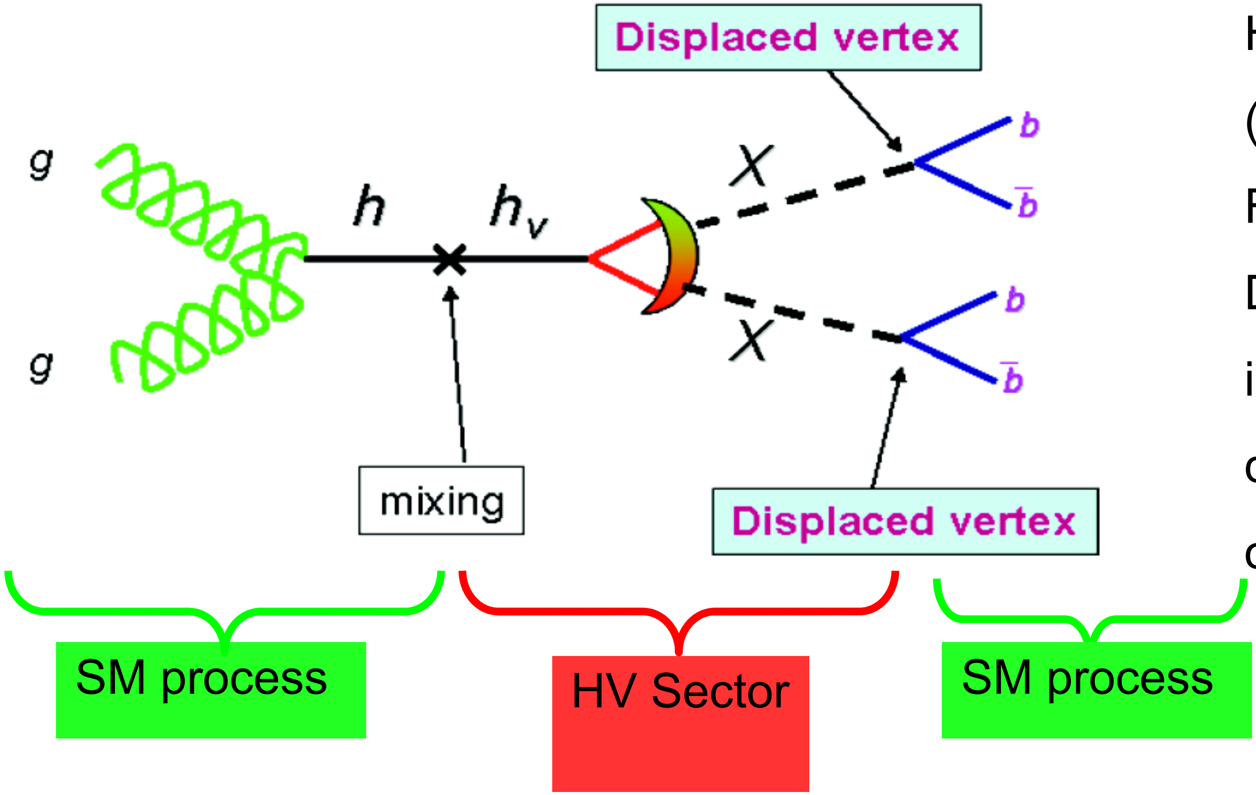
Hidden Valley Processes: Z' production



Many v-hadrons production trough a QCD-like dynamics in v-sector

π_v decaying in multi bb, $\tau\tau$ *etc* pairs in SM final state

Hidden Valley Processes: Higgs production



Higgs production from SM

(gluon fusion, Vector Boson

Fusion and Higgs-*strahlung*)

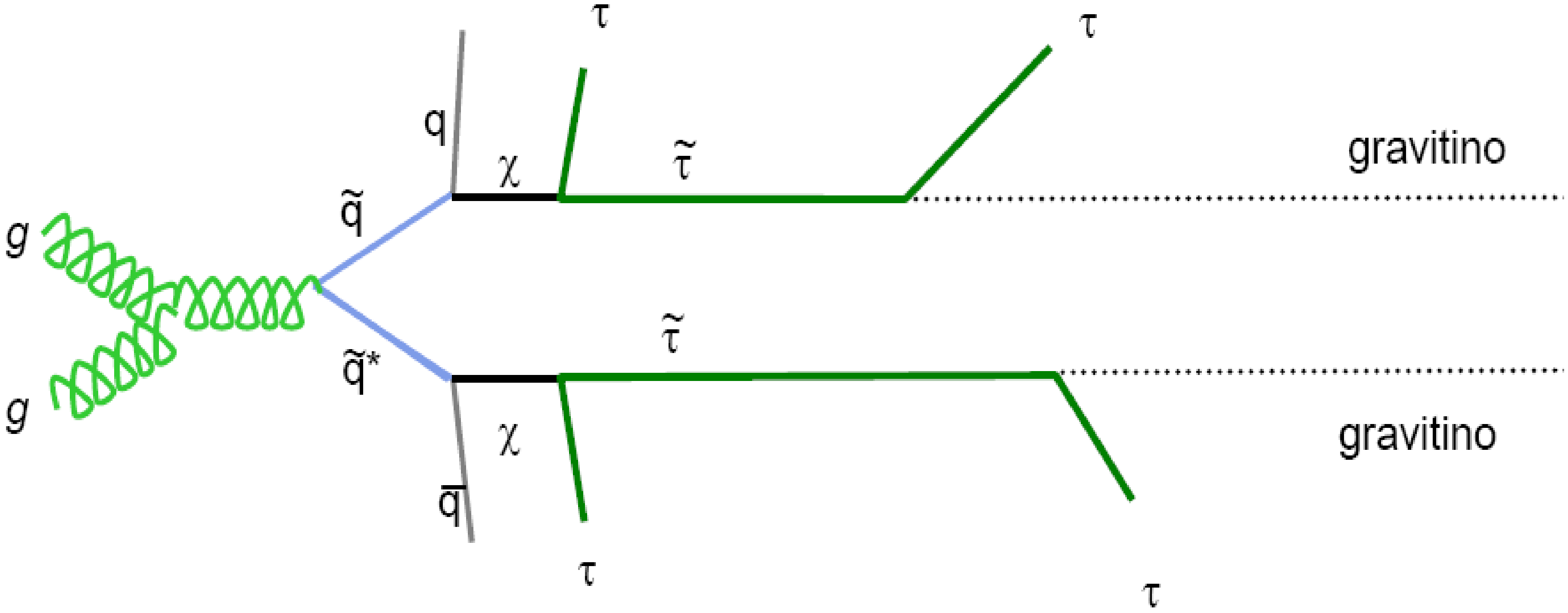
Decaying exactely

in two v-particles in v-sector

decaying in two heavy quarks

or heavy letpons (bb or ττ)

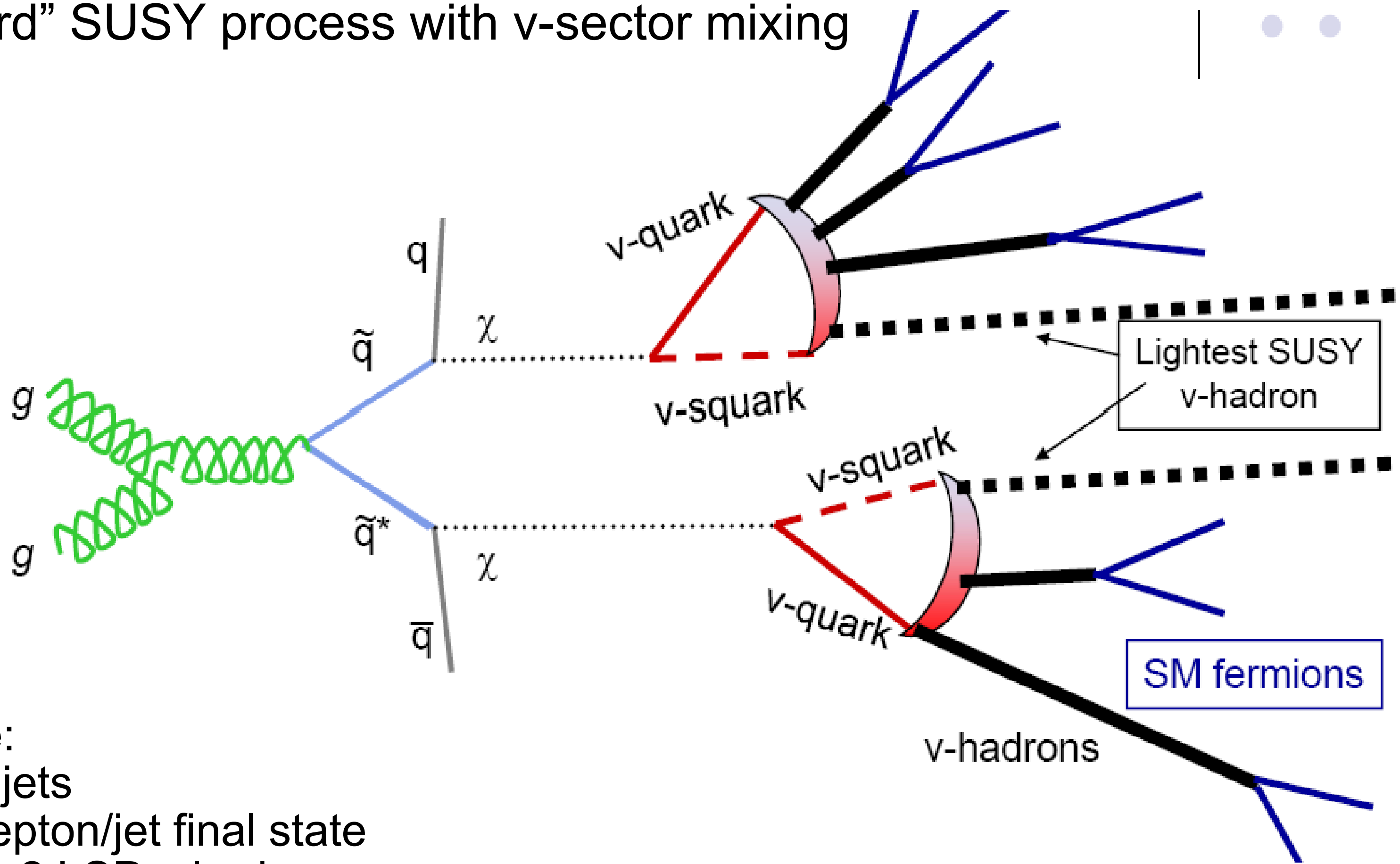
"Standard" SUSY with long lived particles



Signature:
2 high-Pt jets
2 taus (prompt)
2 taus (displaced)
MET from gravitinos

Mixing "Standard" SUSY with Hidden Valleys

"Standard" SUSY process with v-sector mixing

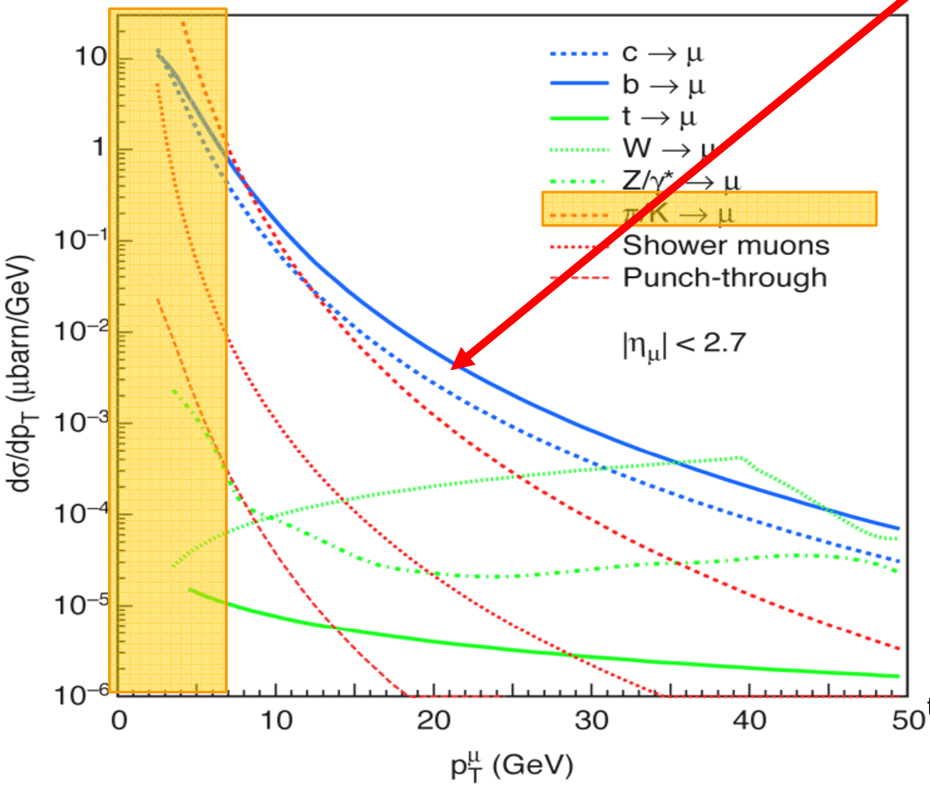


Signature:
2 high-Pt jets
Multiple lepton/jet final state
MET from 2 LSP v-hadrons

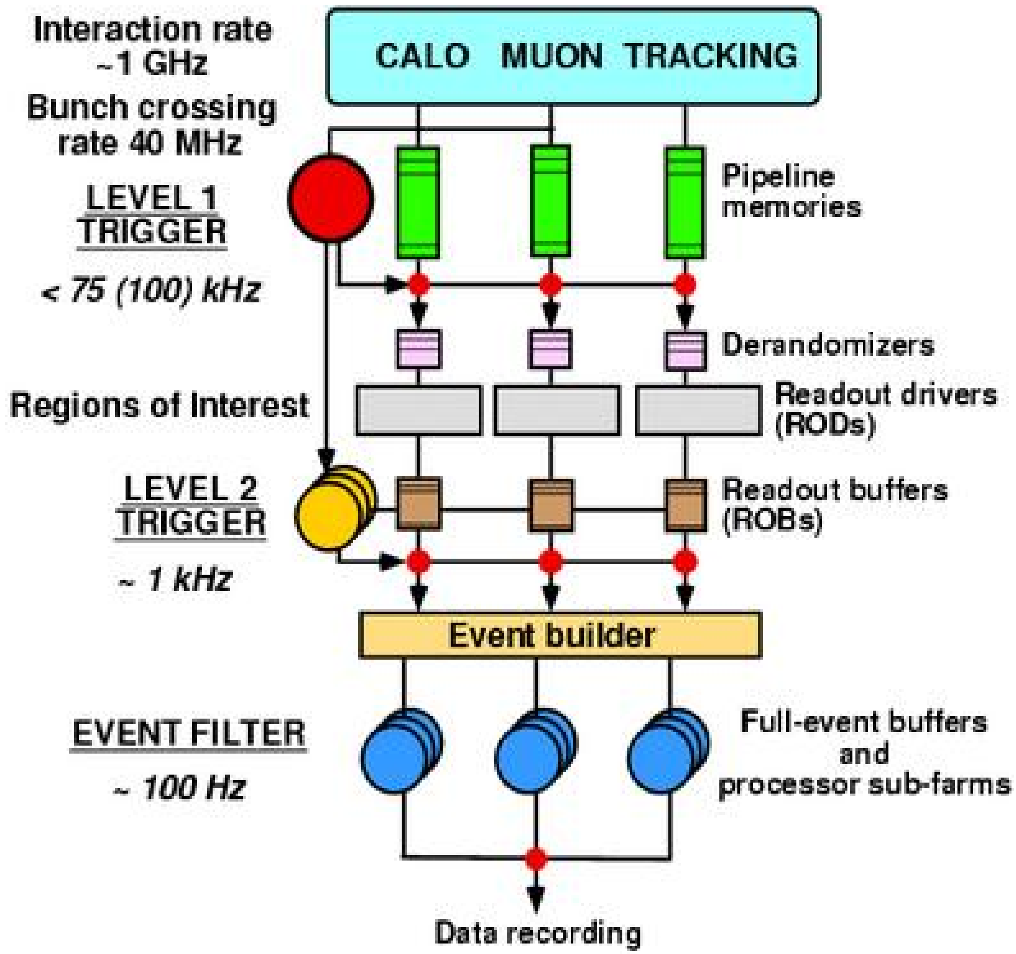
Performances: Efficiencies and Rates

- Large single muon samples are simulated with pT =2, 2.5, 3, ... 1000GeV in the CSC productions.
- Used to derive efficiency curves as a function of Pt.
- Used to calculate the expected rates using evaluated production cross sections.

$$R_i = \mathcal{L} \int_{p_{T\_\inf}}^{p_{T\_cutoff}} \frac{d\sigma_i}{dp_T} \cdot \varepsilon(p_T)\, dp_T$$



The ATLAS Trigger

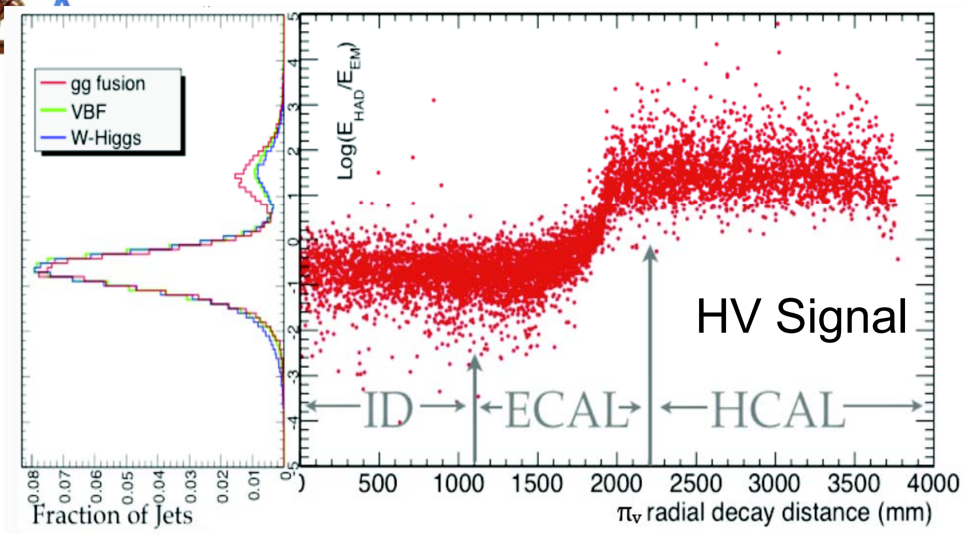


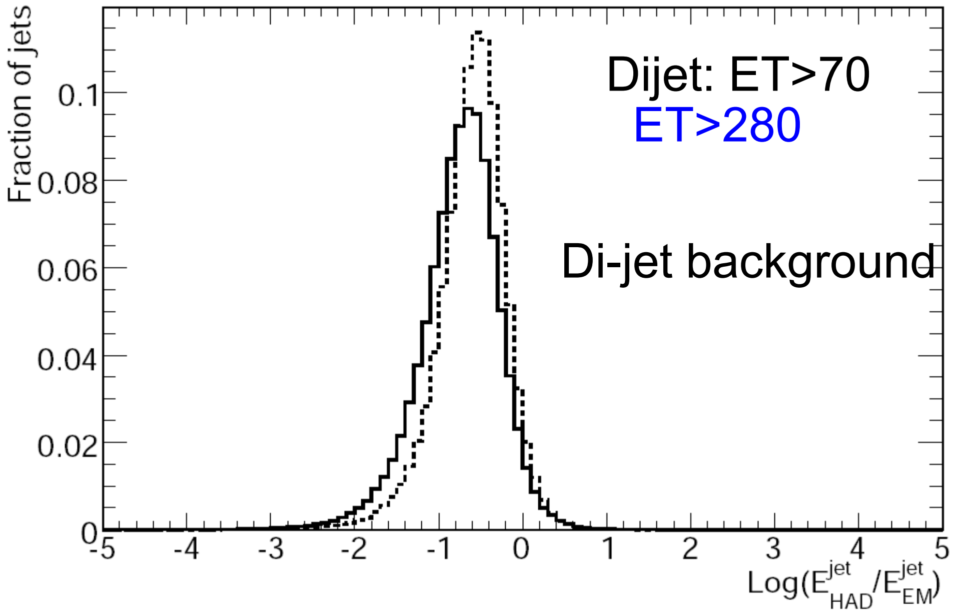
Level-1Trigger:
Provided by Calorimeters (EM and HAD) and Muon Spectrometer (RPC and TGC).
Coarse grained granularity.
Selects Regions of Interests (RoI) and identifies Bunch Crossing (BC)

Level-2 Trigger:
Access data in selected RoI.
Fine grained granularity.
Combination with other subdetectors, (e.g. ID Tracker)

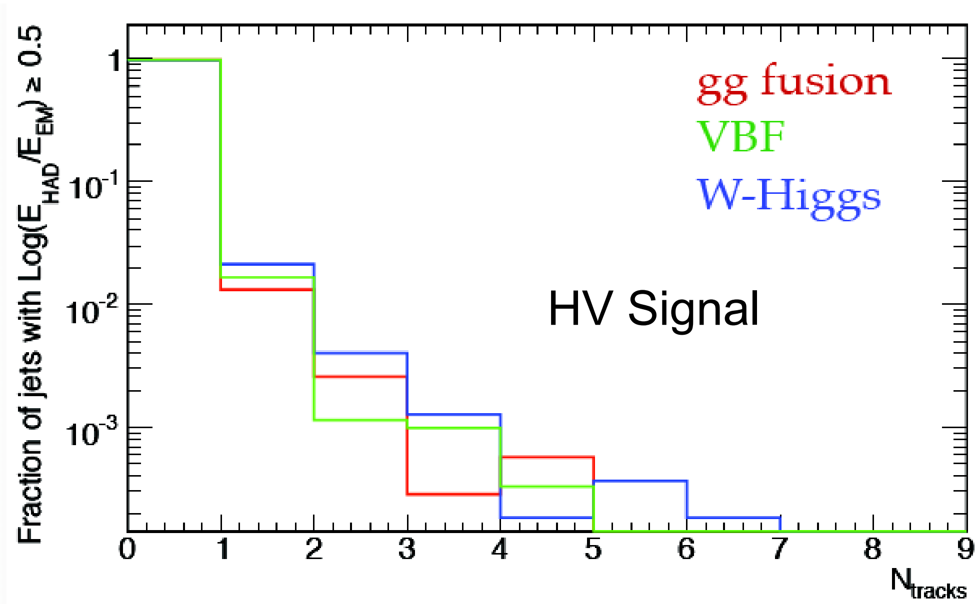
Event Filter:
Access full event with full granularity

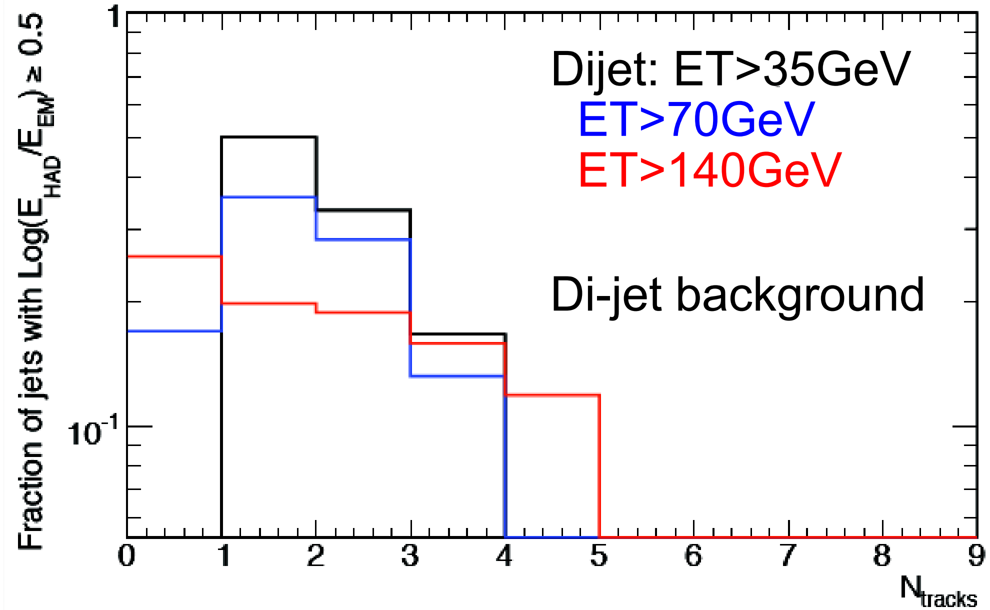
Improving Calorimetric Triggers





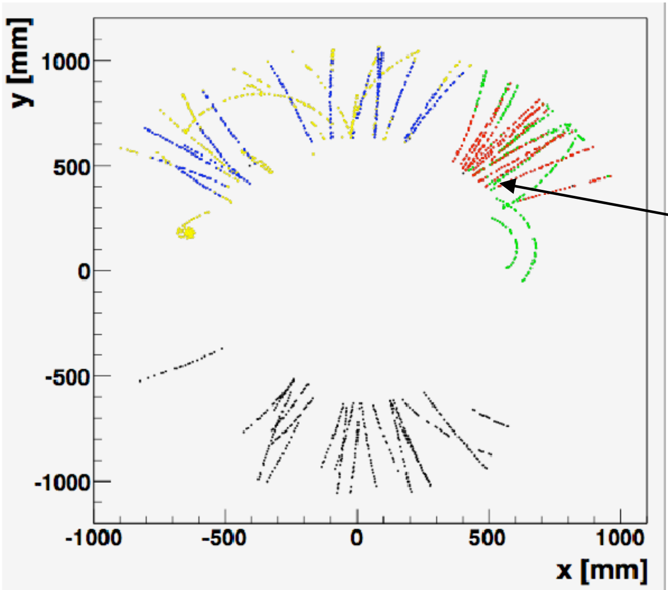
log(HAD/EM) *vs* v-pi decay length





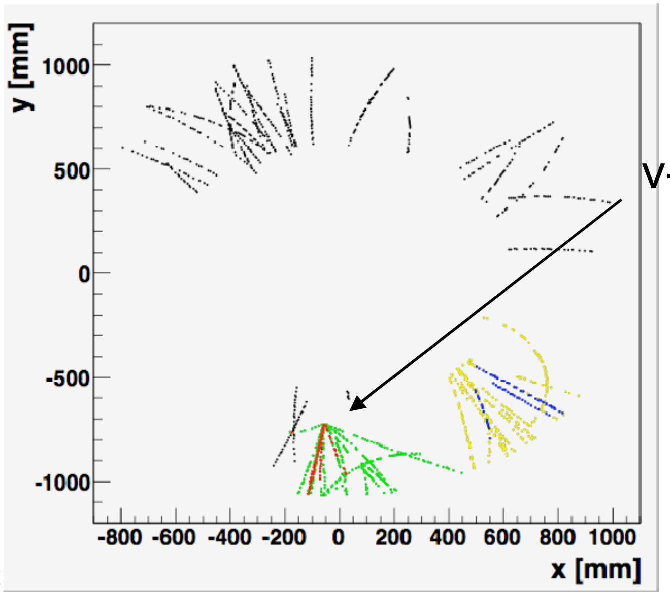
Number of Tracks (PT>1 GeV) in cone (DR=0.4) around jet

Inner Detector Tracking Triggers



V-pion decaying inside
the SCT (Silicon Tracker)

Conventional tracking algoritms



v-pion decaying in TRT

Inner Detector tracks
reconstructed starting with TRT
~35% efficiency per track issued
from v-pion decay
Luminosity issue

Antonio Sidoti

Timing Issues

At $\eta=0$ $\beta=1$ particle takes:

3.5 ns to exit inner detector tracker

14 ns to exit the Calorimeter system

33ns to leave the outer stations
of the Muon Spectrometer

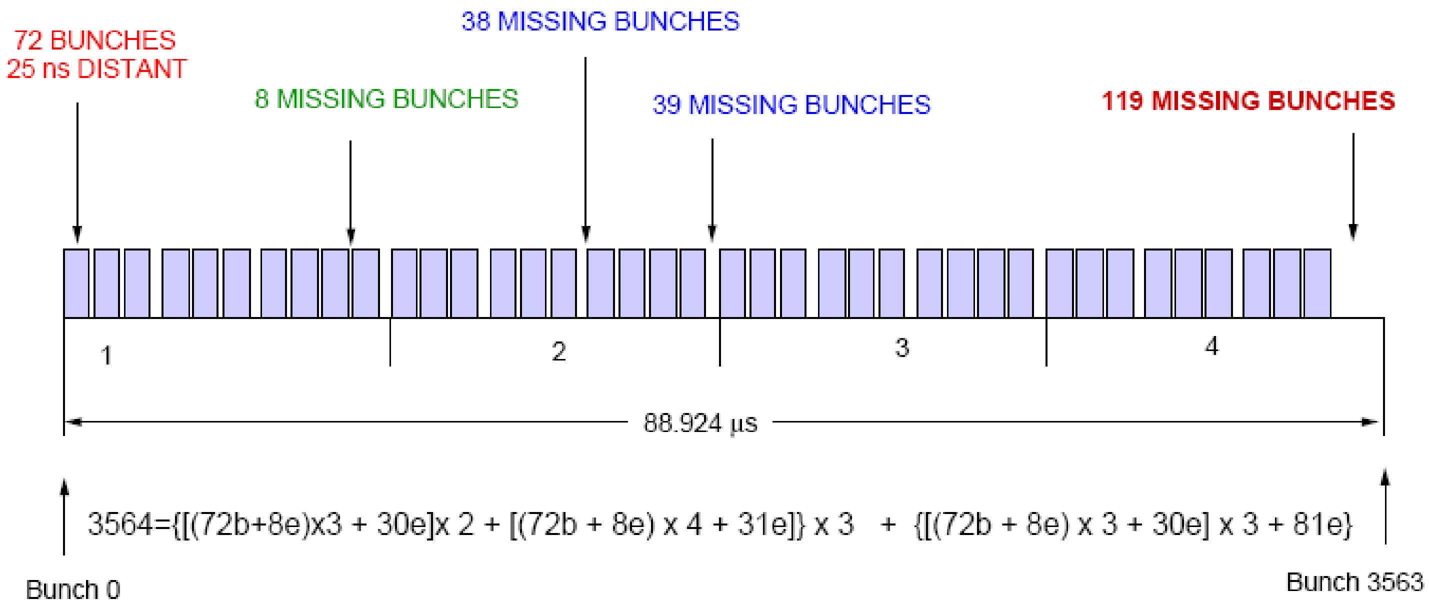
1 LHC bunch crossing interval is 25 ns. Detectors are precisely synchronized using $\beta=1$ particles (usual ones!)

Timing Issues

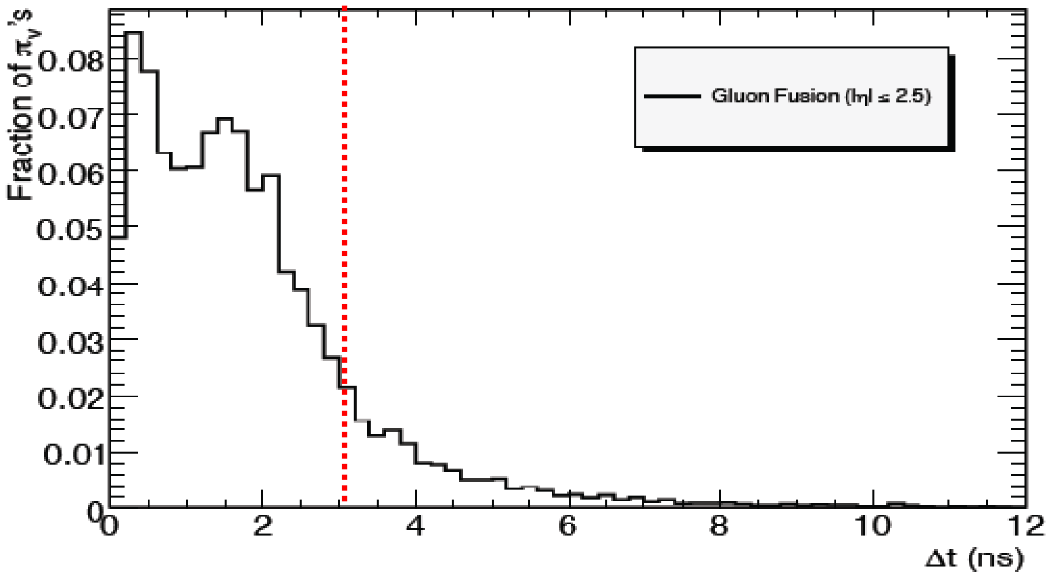
"Slow" Hidden Valley particles could:

- Go partially out of read-out time window:
  - -> Energy measured by calorimeters, systematically smaller
- Detector signal completely out of read-out time:
  - The Muon Spectrometer part of the event assigned to:
  - Future bunch crossing -> Muon spctrometer triggers event in ID in the previous bunch crossing
  - Empty bunch crossing-> Event identified as cosmic

The LHC bunch structure

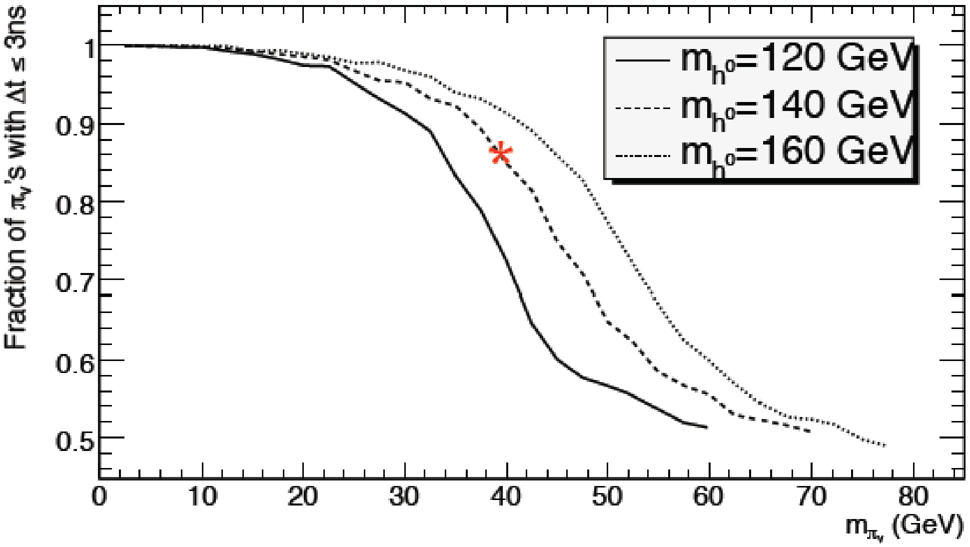


Timing Issues: Calorimeter

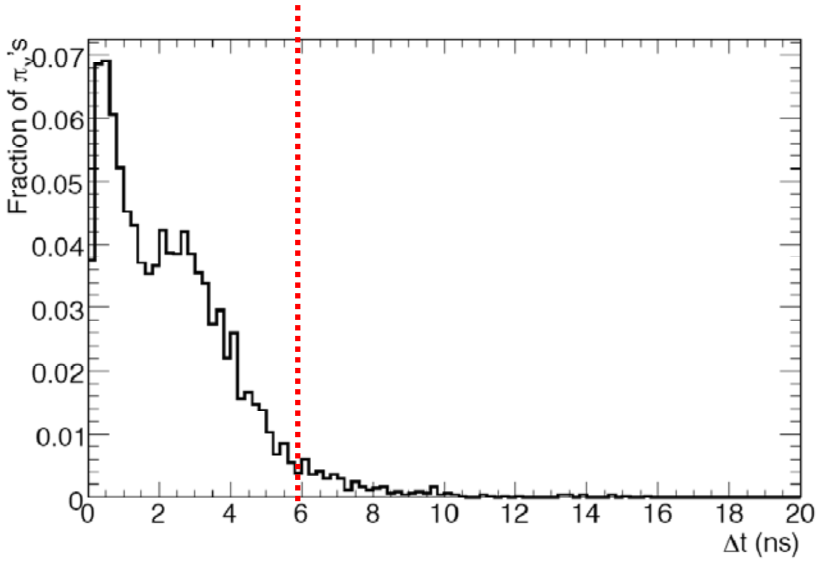


More than 80% of π_v with $M\pi_v < MH_v/3$ reach the calorimeter within 3ns of $\beta=1$ particles

For time shifts of $\Delta t < 3$ns the effect on measured $E_T \sim 2$ %



Timing Issues: Muon System



For the Muon Trigger Δt=6ns gives 95% Bunch Crossing ID efficiency

~95% of π_v with v-pi<mh/3 reach the muon spectrometer within 6ns of β=1 particles