Search for Hidden Valley models via Higgs decays

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CLIC Detector and Physics Collaboration Meeting
03.06.2015

Hidden sector – generic possibility for NP

„Sectors with non-abelian gauge group with a new quantum number „v" (analogous to charge →v = 0, ±1), which couple weakly to the Standard Model via higher dimension operators, and which has a mass gap."

Strassler & Zurek

Consequence of string-theory

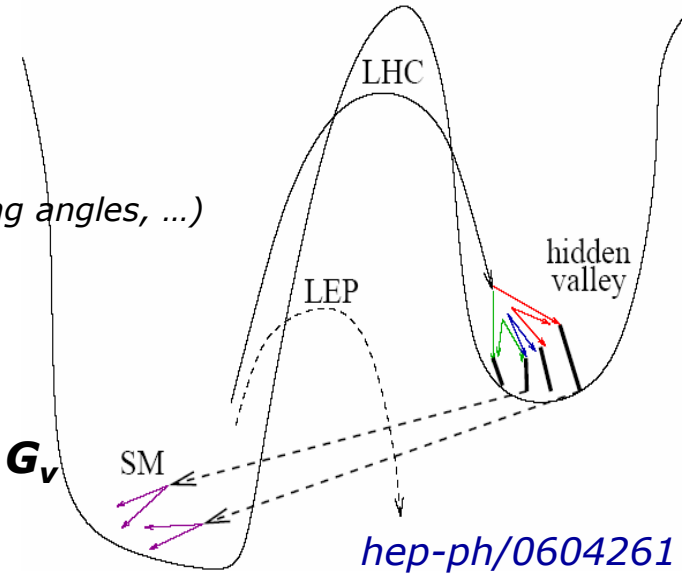
→ additional gauge sectors may be introduced to SM, SUSY, TeV-ED

- hidden sector - *„v-sector"*
- communicator - interacts with both sectors

BARRIER *(communicator's high mass, weak couplings, small mixing angles, …)*

→ weakens the interactions between sectors

→ production of new particles rare at low energy



hep-ph/0604261

SM group G_{SM} extended with non-abelian group G_v

→ all SM particles neutral within G_v

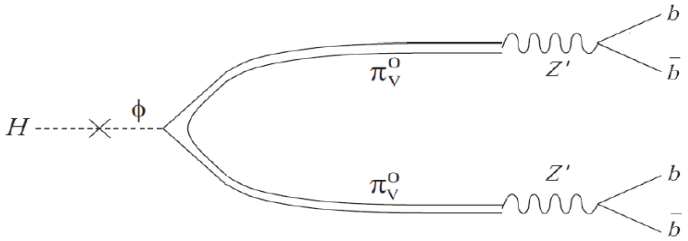
→ if energy sufficient → ***v-particle*** charged within G_v, neutral under G_{SM}

At TeV scale high dimension operators (Z', Higgs) make possible interactions ***SM ↔ v-particles***

Direct production and SM Higgs

- **SM Higgs may decay into 2 *v*-particles, each decaying to *bb(bar)***

$$h^0 \to \pi_V^0 \pi_V^0 \to b\bar{b}b\bar{b}$$



- scalar decaying to the heaviest particles it has access to in order to defeat natural helicity suppression

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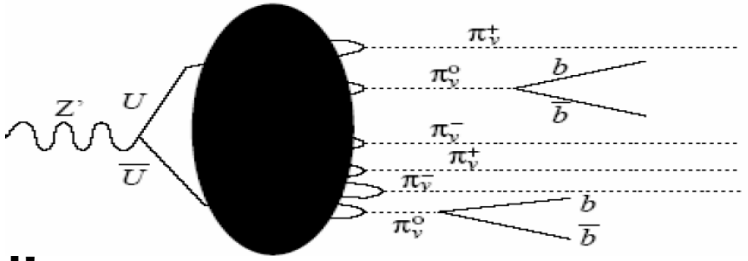
- **Direct multi-π_v production**

$Z' \to \pi_v^0 + \pi_v^+$

$\pi_v^0 \to b\bar{b}$ $\pi_v^+ \to$ *missing energy*



- π_v^0 and $\pi_v^\pm$ are **electrically neutral!**
- *v*-quark production results in multiple *v*-hadron production with ratio $m(Z')/\Lambda_v$ (Λ_v : *v-confinement scale)*

LOOKING FOR: long-lived particles *(LLP's)*

if lifetime between 1 ps and 1 ns *(characteristic for weak decays)* ***can be identified in tracking systems by displaced vertices!***

Idea of Hidden Valley searches at CLIC

Up to now - limits from hadron colliders for $H \to \pi_v^0 \pi_v^0$, $\pi_v^0 \to bb(bar)$

- **Clean experimental environment in e^+e^-**

→ *e^+e^- are point-like*

→ *initial state well defined ($\sqrt{s}$ / polarisation)*

→ *low radiation level*

→ *superior sensitivity to electroweak states*

- **High energy and integrated lumi**

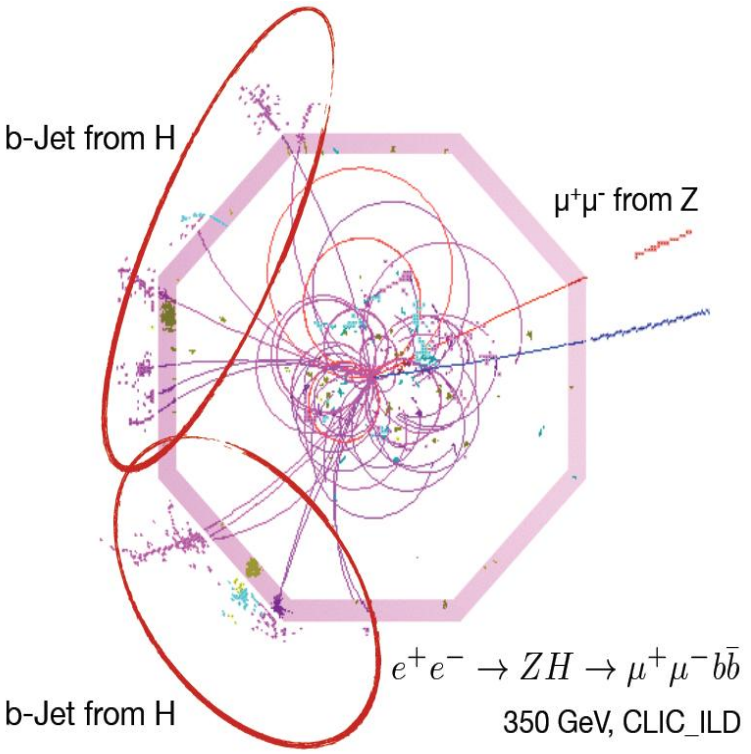
→ *500 fb^{-1} at 350-375 TeV*

→ *1.5 ab^{-1} at ~1.5 TeV*

→ *2 ab^{-1} at ~3TeV*

- **No trigger**

→ ***long-lived states cannot be missed!***



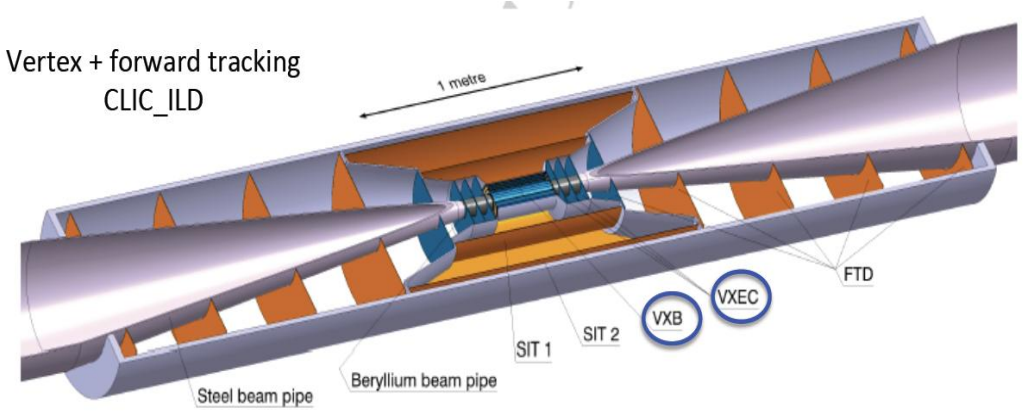
- **Jet reconstruction based on particle flow**

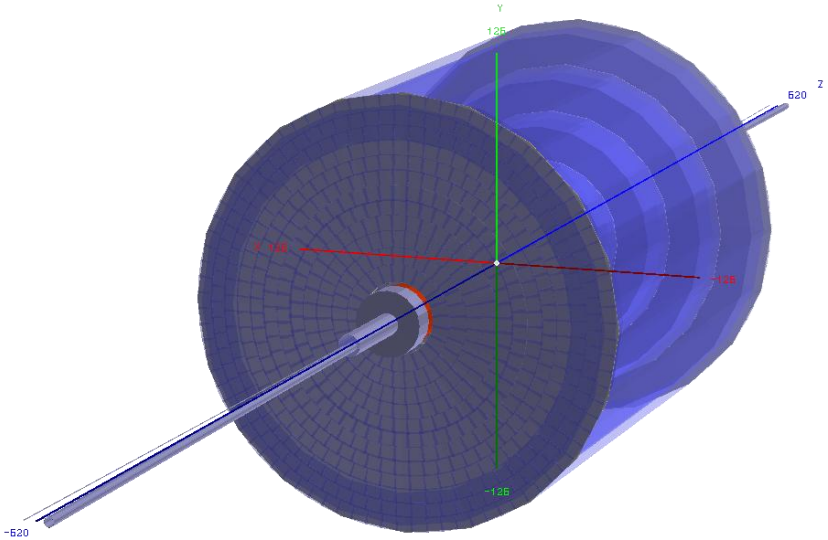
→ *fine-grain calorimetry*

→ *complex forward calorimeter*

Long and precise vertexing + tracking

- ~25x25 μm pixel size → ~2 Giga-pixels
- 0.2% X_0 material per layer (very thin)
- time stamping: 10 ns
- radiation level < 10^{11} $n_{eq}cm^{-2}year^{-1}$
  (~10^4 lower than LHC)





A long main tracker is crucial for the forward tracking performance:

- momentum resolution depends even stronger on the lever arm at lowerangles
- **do not want a tracker shorter than the one of ILD *(2.3 m)***

- **Possible to reconstruct displaced SV's**
- **Ability to measure π_V^0 lifetimes up to 1ns**

Generated samples

GEN

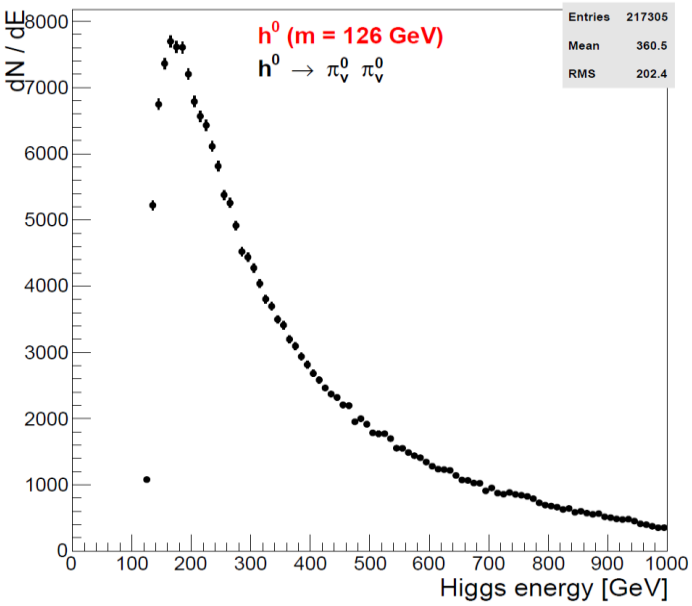
Higgs → $\pi_v^0\pi_v^0$ (at 3TeV)

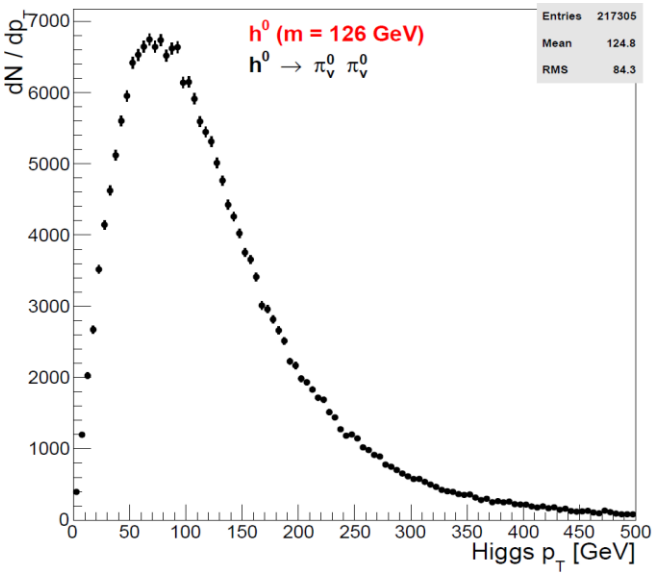
- mass(h^0) = 126 GeV
- mass(π_v^0) = 50 GeV
- π_v^0 lifetimes: 1, 10, 100, 300 ps

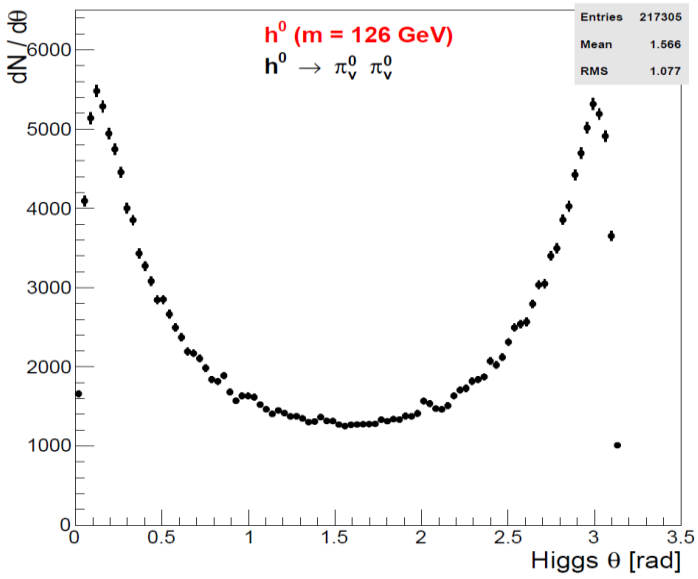
samples **with and without** pileup of $\gamma\gamma \rightarrow$hadrons

Background (at 3 TeV)

- ee → qqvv *(bb(bar))*
- ee → qqqqvv *(4b, 4c, 2b2c)*







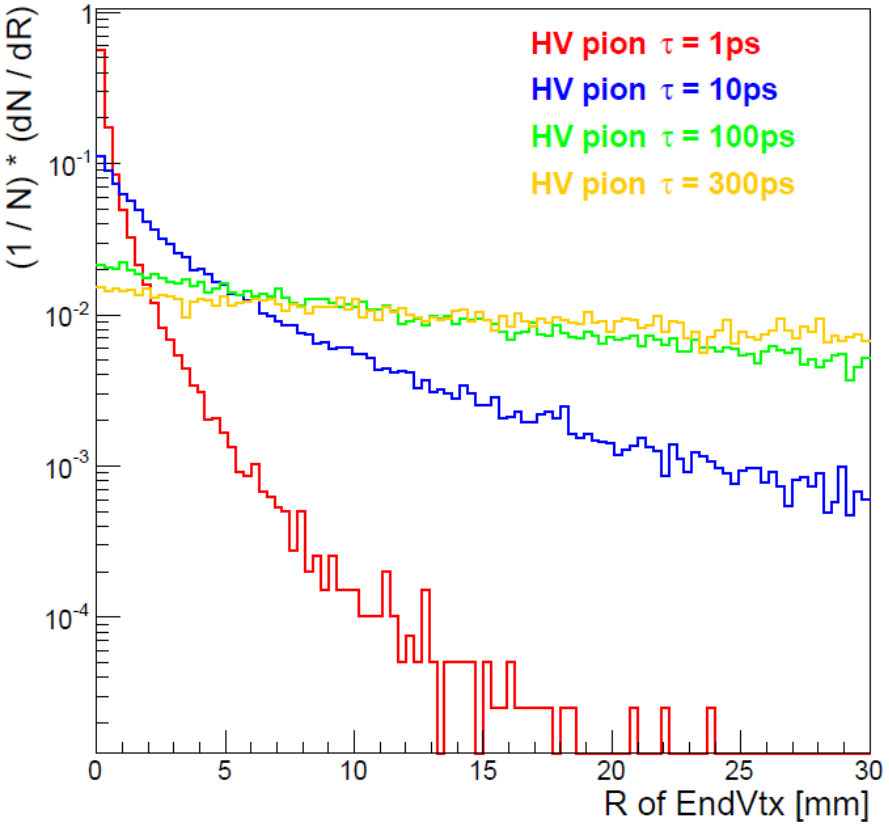
Generated Hidden Valley pions

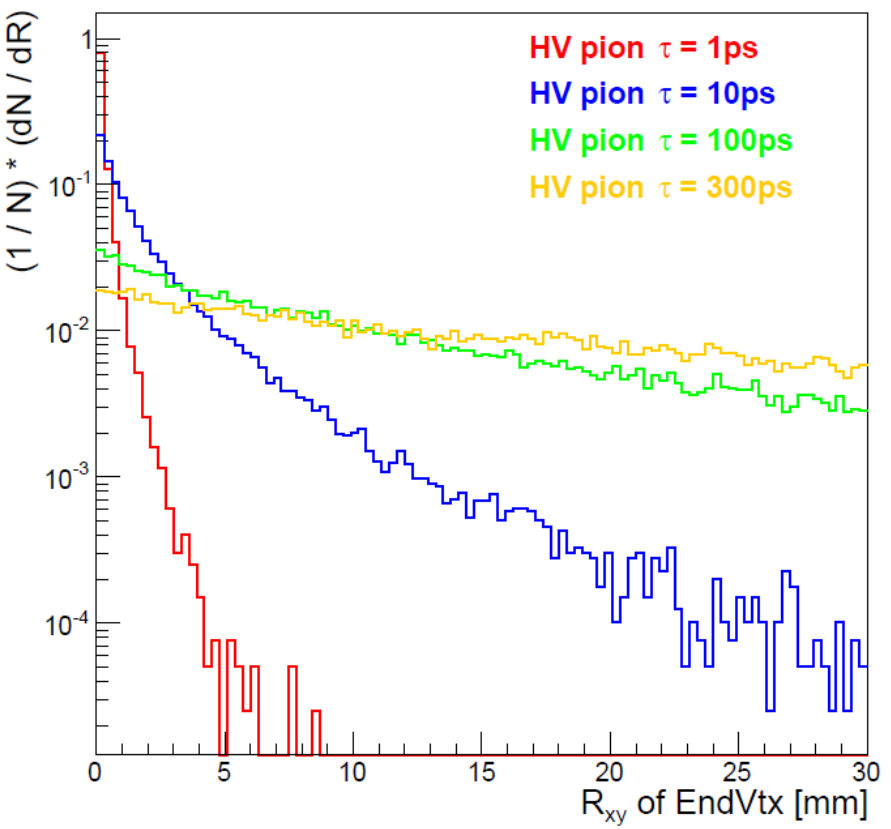
GEN

v-paricles have non-zero lifetime

→ analysis based on reconstruction of SV's „far" from PV and beam axis

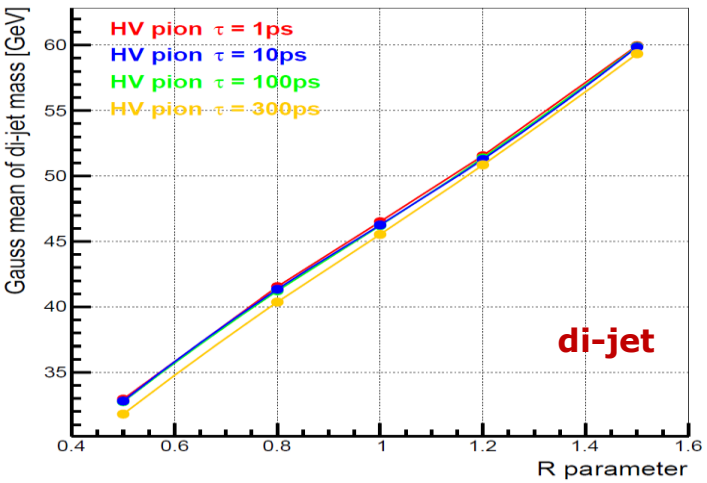
→ displaced vertices *(DV)* – *PV-like*

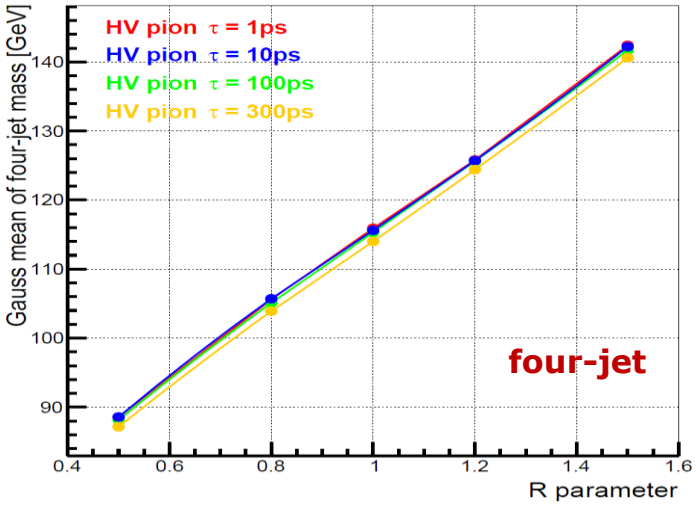


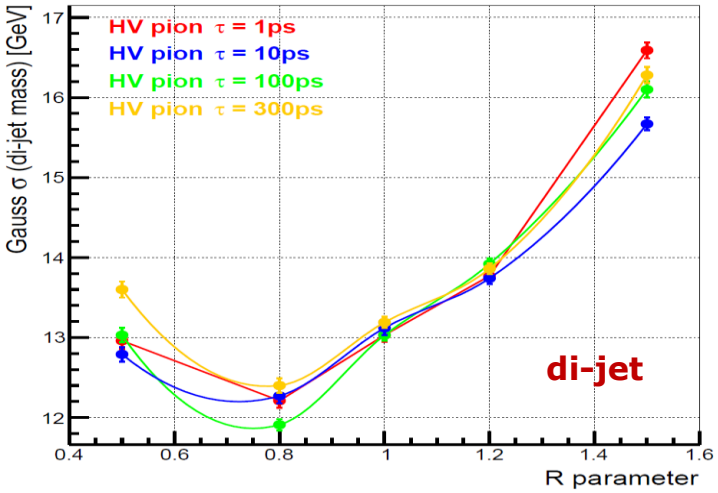


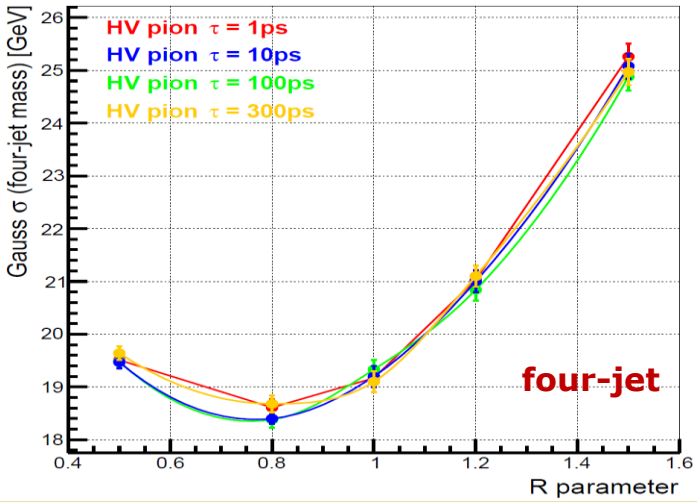
Di-jet and four-jet mass – *R* optimization

- fastjet anti-k_T algorithm
- nr of required exclusively reconstructed jets = 4
- 5 different *R* values tried: *0.5, 0.8, 1.0, 1.2, 1.5*





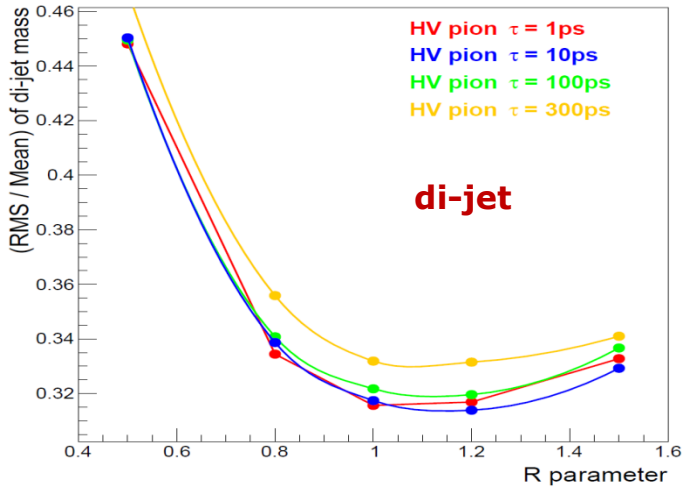


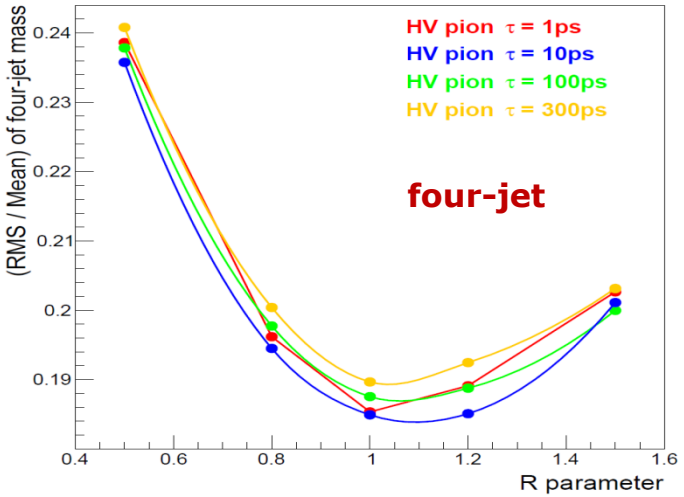


Di-jet and four-jet mass – *R* optimization

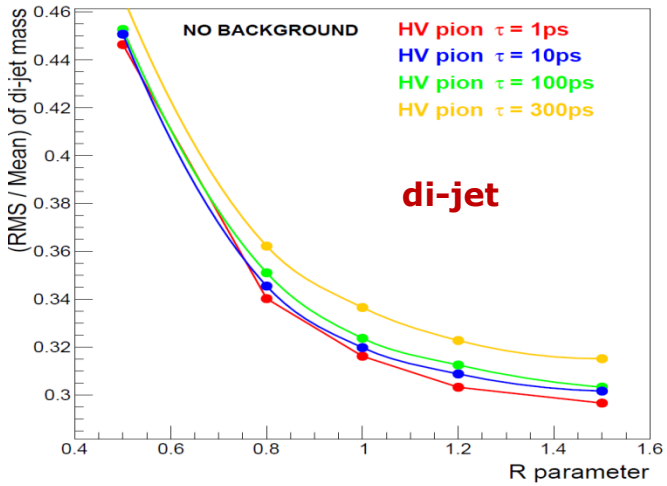
RMS / Mean

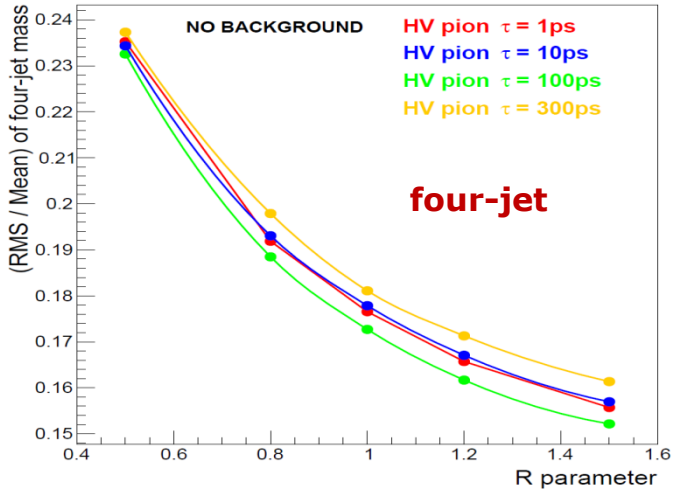
$\gamma\gamma \rightarrow$ hadrons background





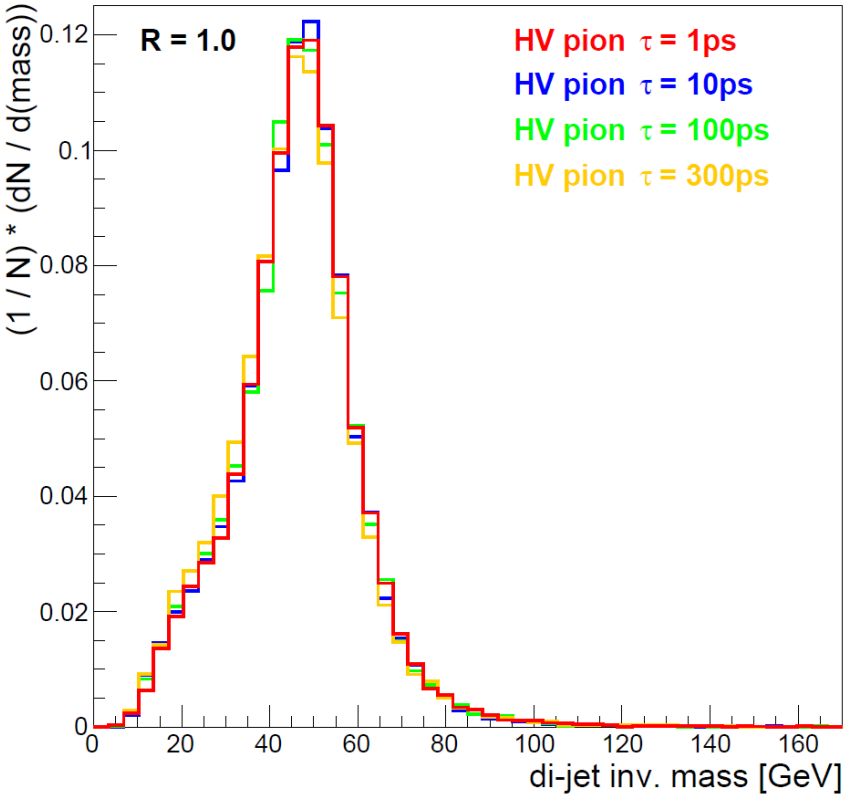
NO background

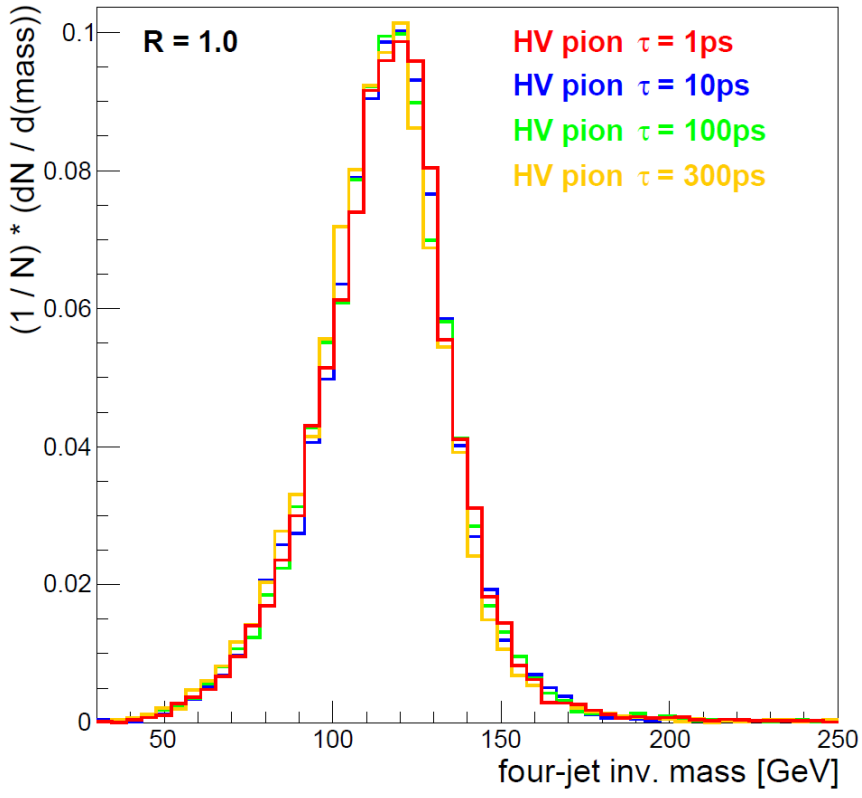




Di-jet and four-jet mass

jet *R* parameter chose to be = 1.0



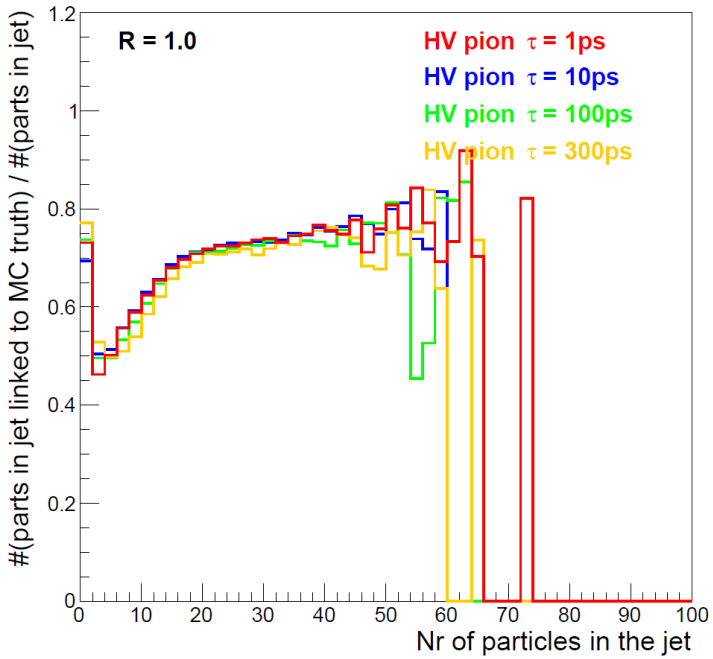


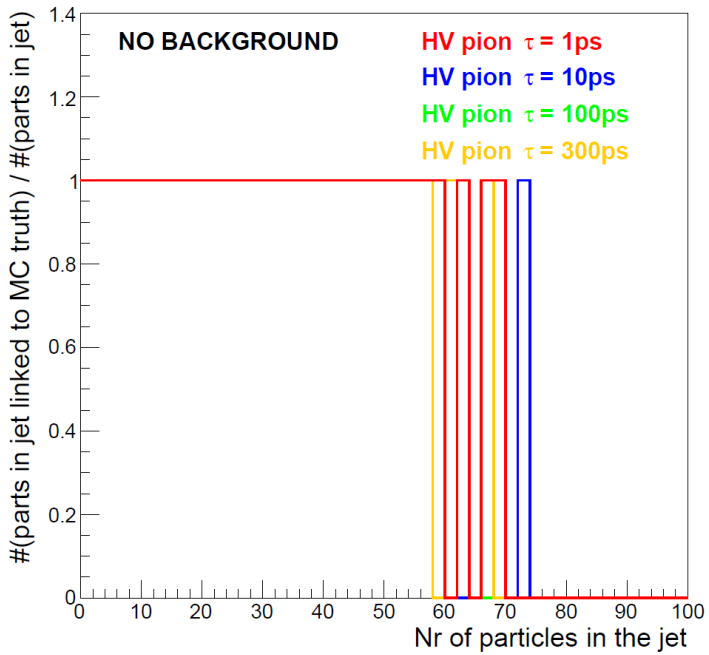
Only jets positively matched to HV pions

→ *jets with > 50% particles originating from same Hidden Valley pion*

Particles in the jet

- particles in the jet positively matched to MC thruth
- with and without pileup of gamma gamma → hadrons
- all four jets in the event





Negligible effects related to the track reconstruction inefficiency

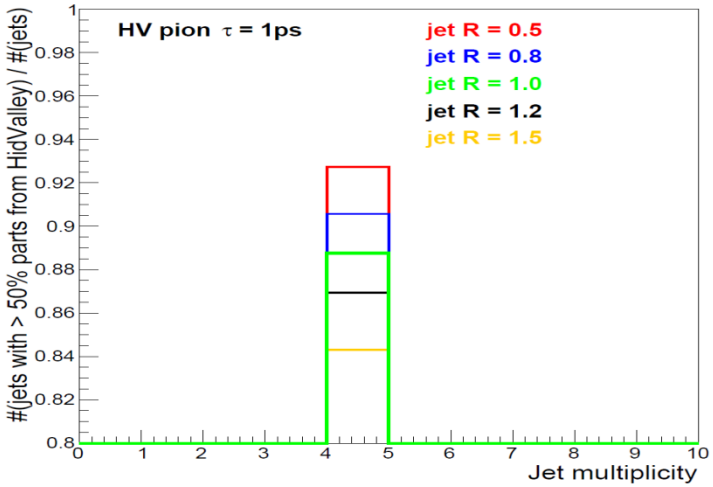
(ghosts, clones, etc.)

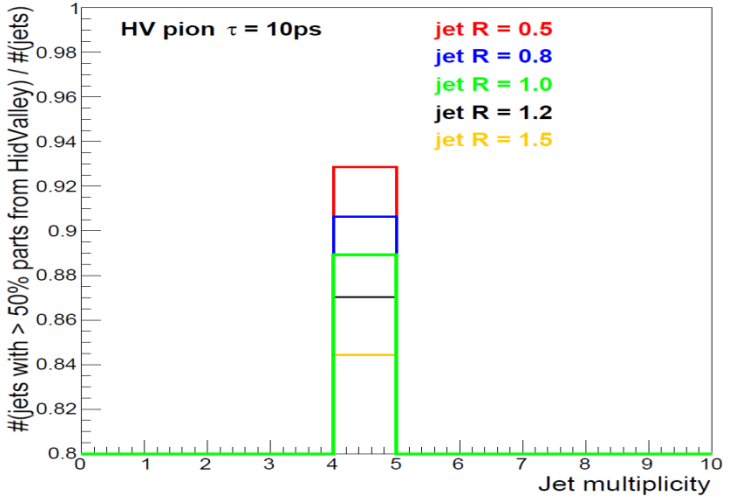
Jet *(hidValley)* reconstruction efficiency

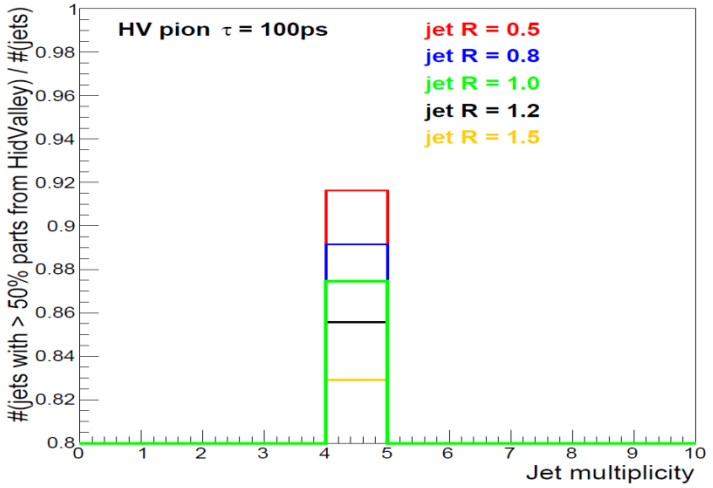
Exactly 4 exclusively reconstructed jets in the event

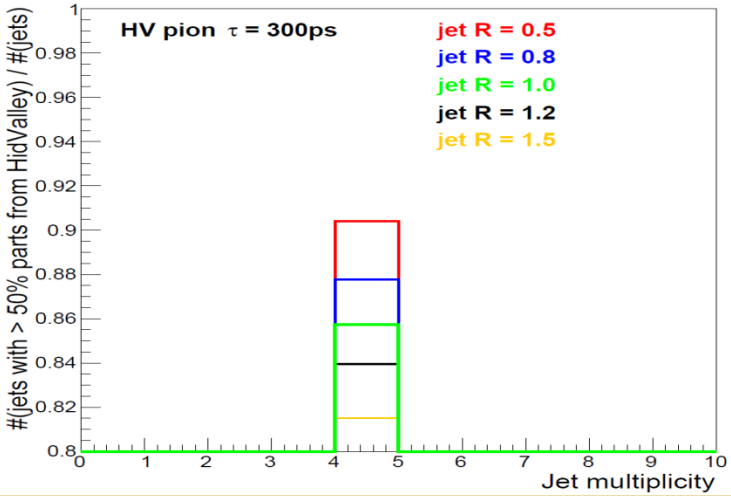
*(no dependence on jet multiplicity – **all at 4!**)*

Eff. = #(jets with > 50% particles from same Hidden Valley pion) / #(jets)







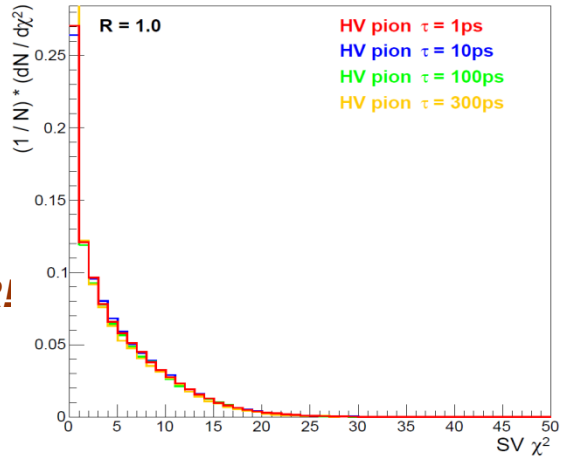


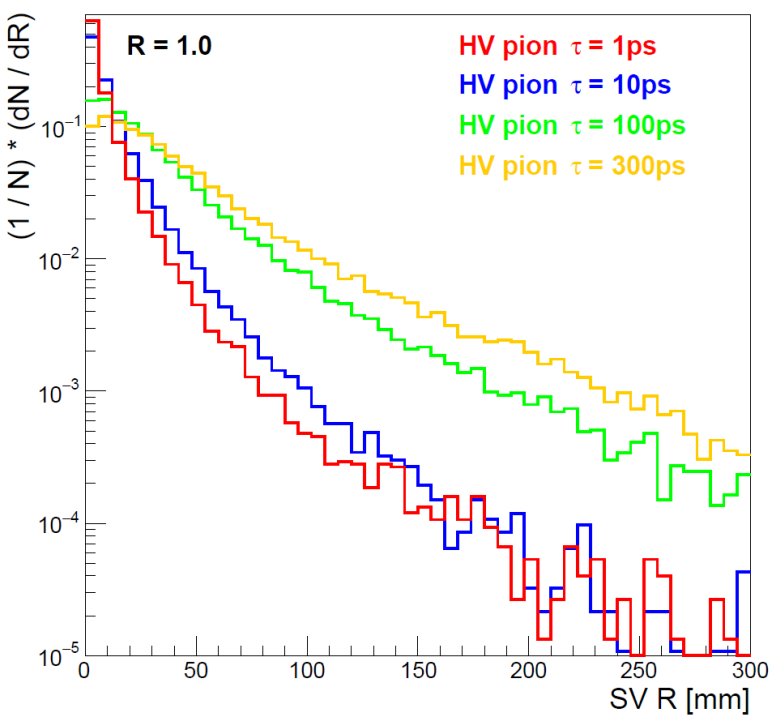
Secondary vertices

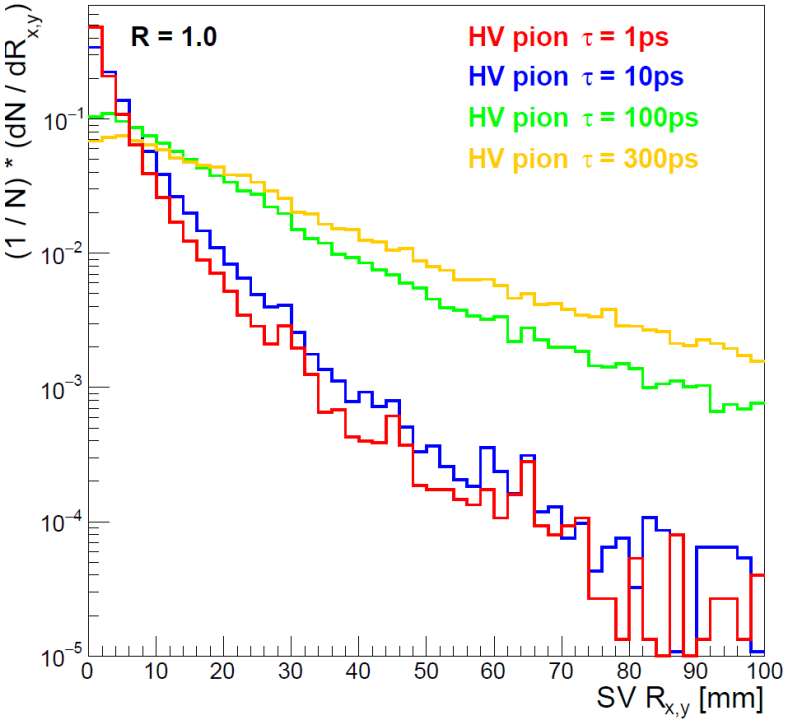
Default secondary vertex finder used

- *initial value of track max. D0 = 10 mm*
- *initial value of track max. Z0 = 20 mm*
- ***NO REQUIREMENT TO HAVE HITS IN VERTEX DETECTOR!***

displaced secondary vertices – ***DISPLACED VERTICES***

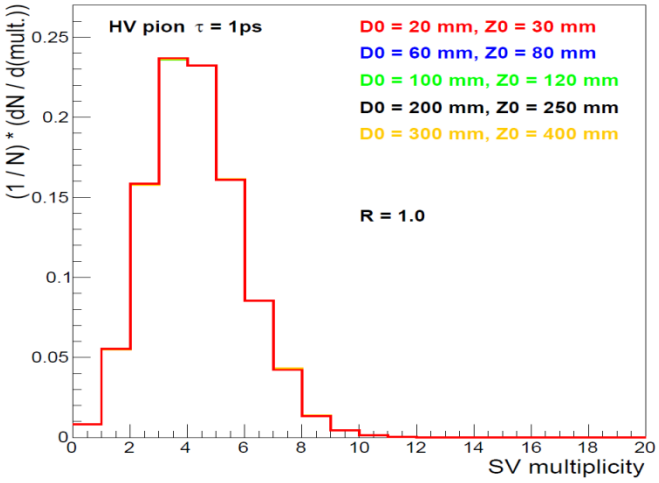


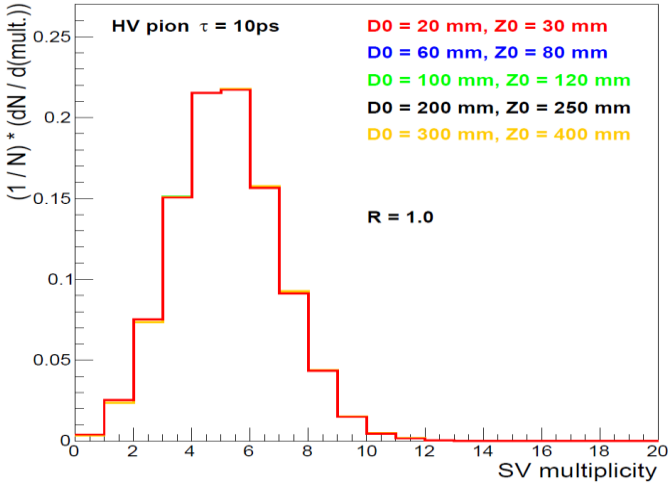


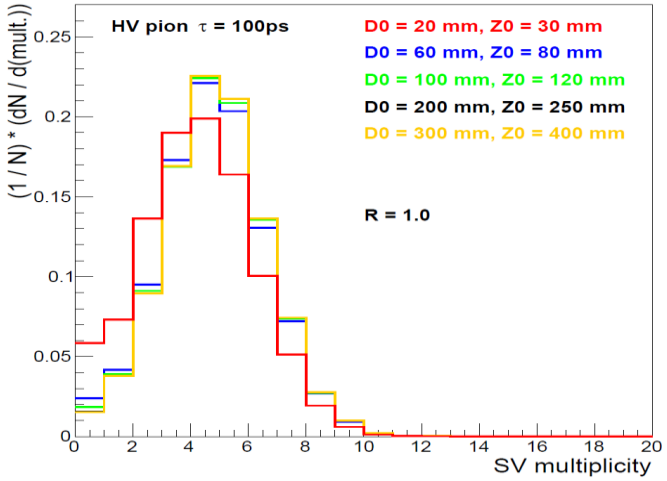


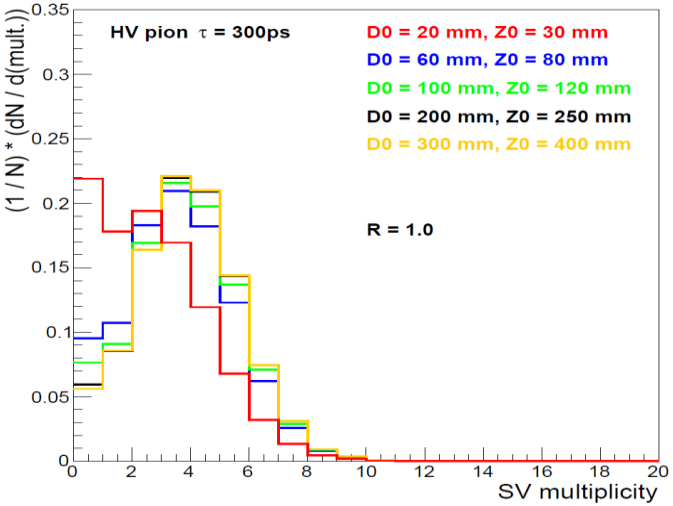
Track *D0* and *Z0* cuts - optimization

- 5 different D0 values tried: *20, 60, 100, **200**, 300 mm*
- with 5 different values of Z0: *30, 80, 120, **250**, 400 mm*

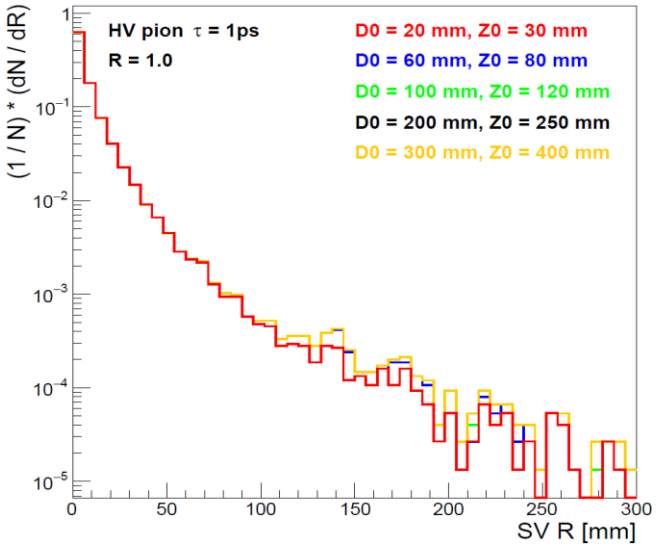


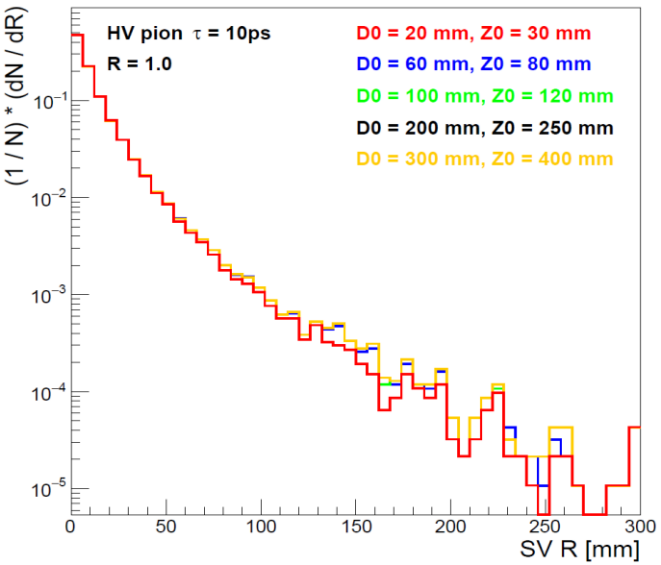


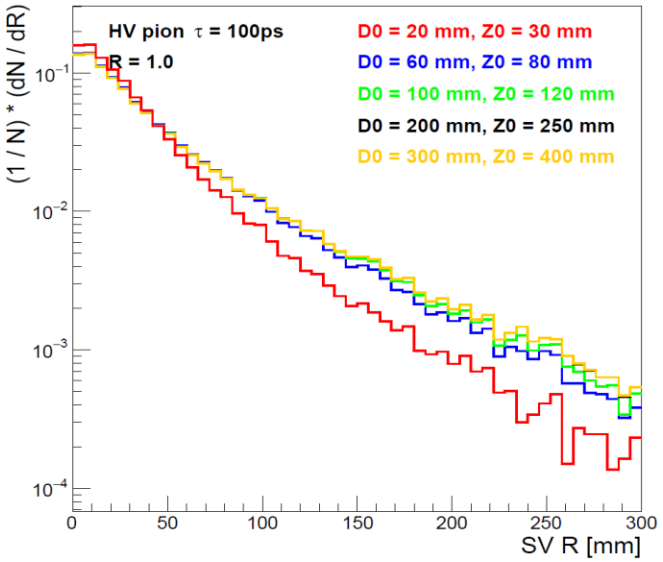


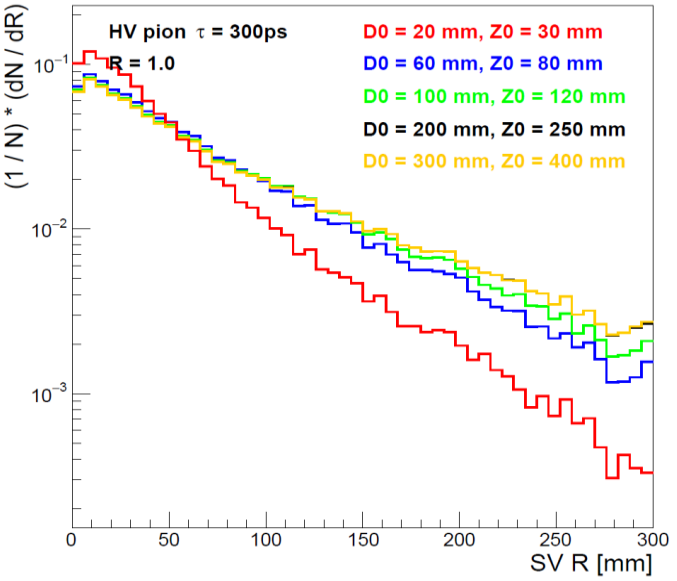


Track *D0* and *Z0* cuts - optimization



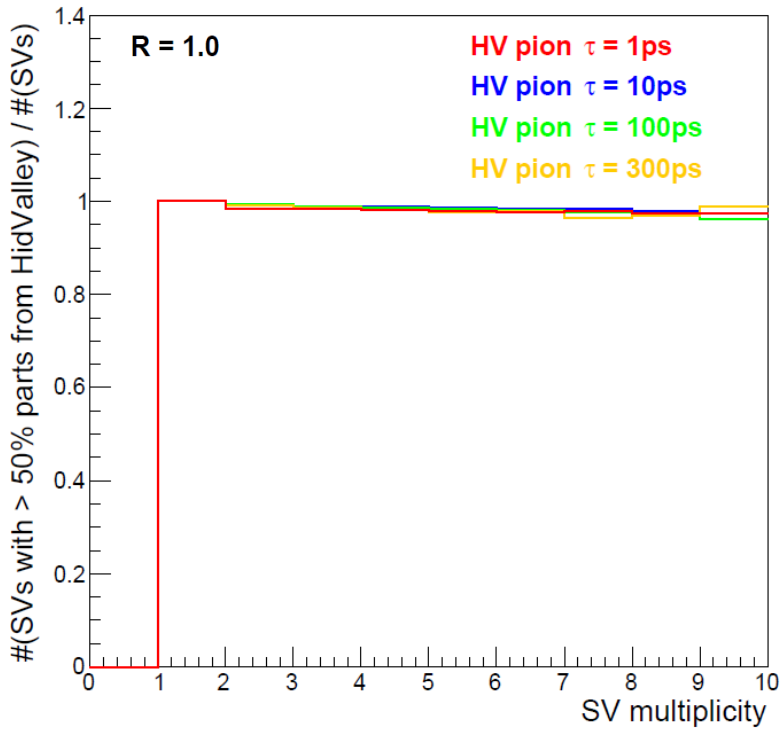


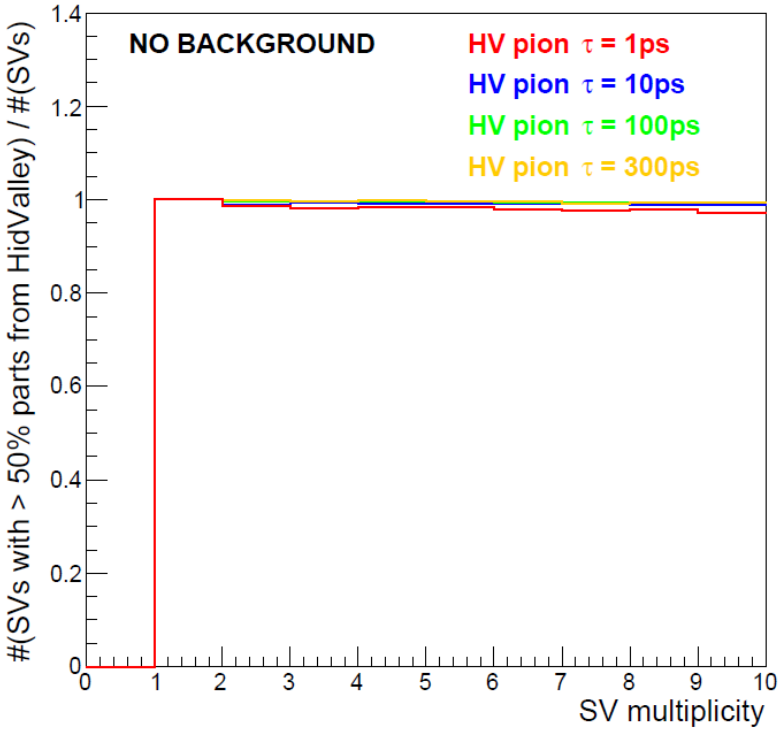




SV *(hidValley)* reconstruction efficiency

Eff. = #(SVs with > 50% particles from same Hidden Valley pion) / #(SVs)



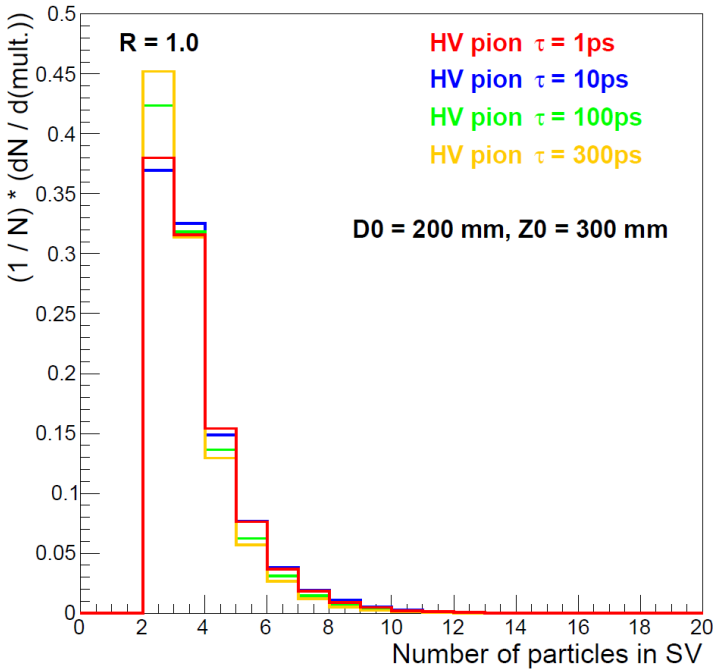


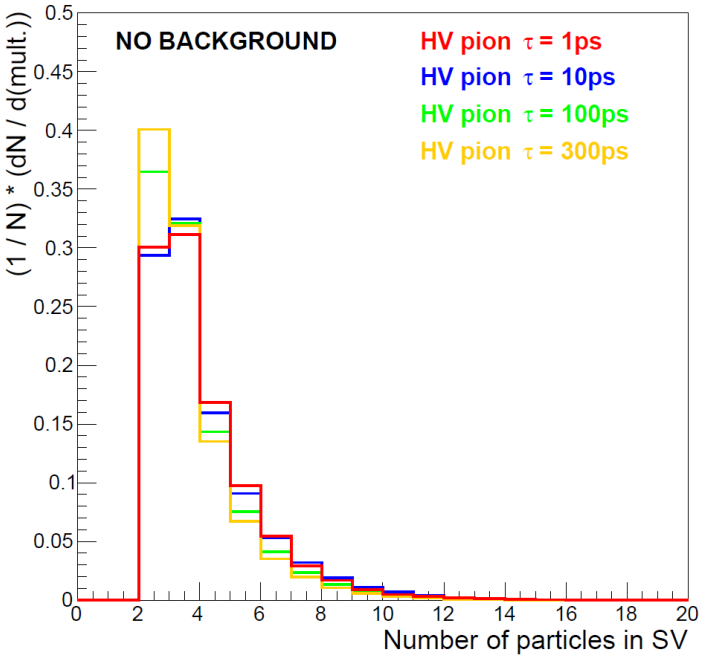
Multiplicity of particles in SV

Large fraction of SV's with 2 tracks only!

- background ***(partially responsible)***

CUTS ON D0 & Z0 NOT RESPONSIBLE FOR THIS EFFECT!





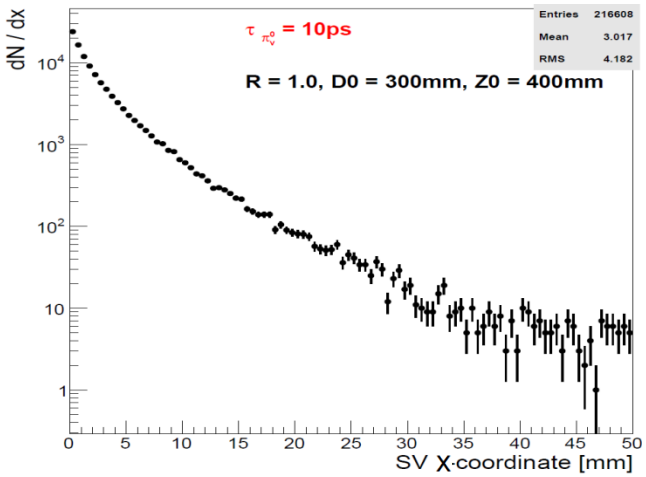
Not enough efficient SV reconsctruction algorithm for long-lived particles (?)

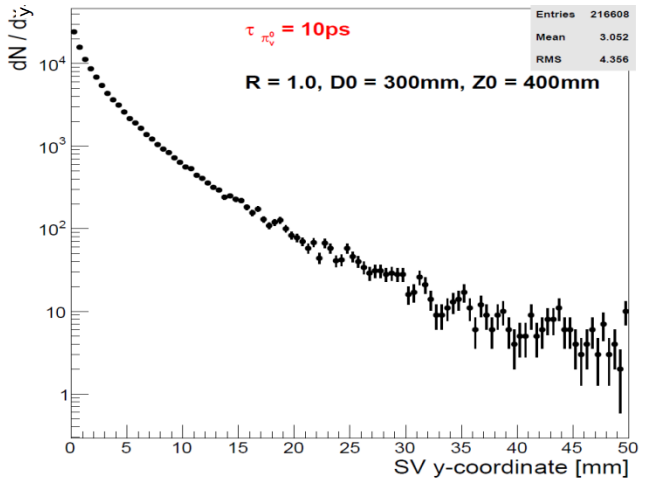
- *look deeper into the SV finder code*
- *write rec. algorithm dedicated to displaced vertices*

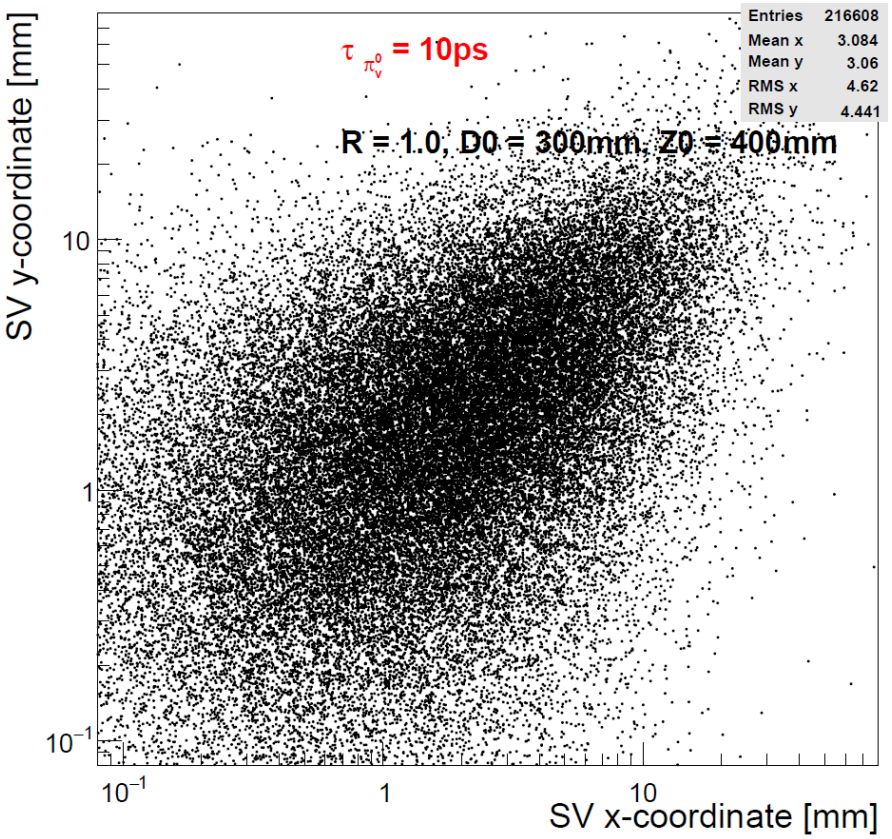
Interactions with detector material

No structure visible!!!

- negligible background from secondary interactions with detector material
- x-check using *bb*-inclusive events needed…







No material-veto needed (???)

Summary and plans

- Hidden sector generic possibility for BSM physics
  → motivated by dark matter
- Good prospects for e^+e^- colliders
  → clean experimental environment
  → high energy and statistics to be collected
  → long vertexing + tracking
- Signal samples for different lifetimes properly generated
- Jet *R* parameter value optimized *(R = 1.0)*
- Secondary vertex optimization finished *(D0 = 200mm, Z0 = 250mm)*
  → very high SV reconstruction efficiency
  → *(BUT…)* **low particle multiplicity in SV for all lifetimes!**

Plans

→ look at the background from *bb, 4b, 4c, 2b2c*
→ x-check if it is needed to impose material veto
→ *(if needed)* develop SV finder dedicated for displaced vertices
→ generate samples for direct searches via Z'