# Report on Hidden Valley analysis

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**CLIC workshop**
18-22 January 2016

# Hidden sector – generic possibility for NP

**Consequence of string-theory**

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

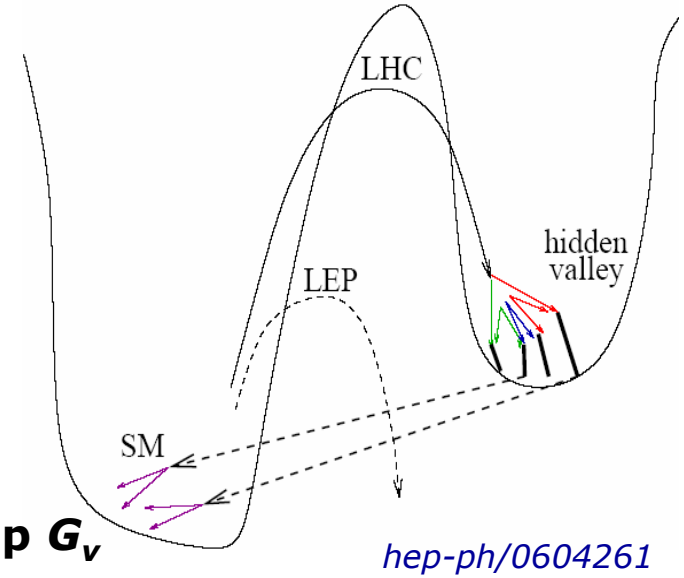
- hidden sector - „*v*-sector"
- communicator - interacts with both sectors

**BARRIER**

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

→ weakens interaction 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 $G_v$

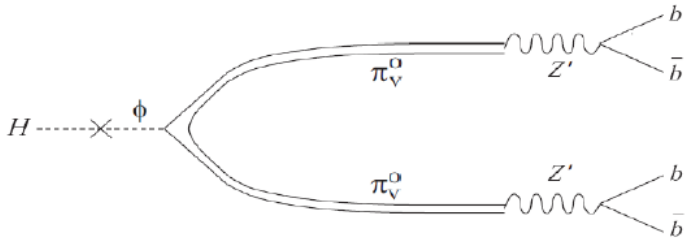
→ if energy sufficient → ***v-particle*** charged within $G_v$, neutral under $G_{SM}$

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

# Direct production and SM Higgs

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

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



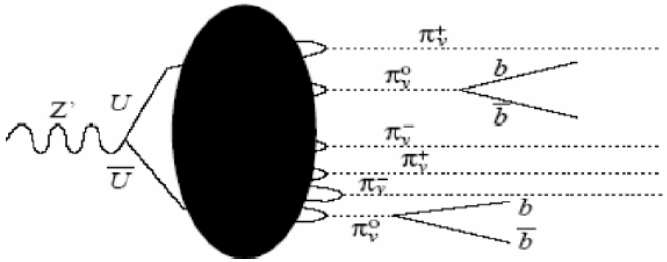

- scalar decaying to the heaviest particles it has access to in order to defeat natural helicity suppression

*Phys. Lett. B651 (2007) 374*

- **Direct multi-$\pi_v$ production**

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

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




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

# Generated samples

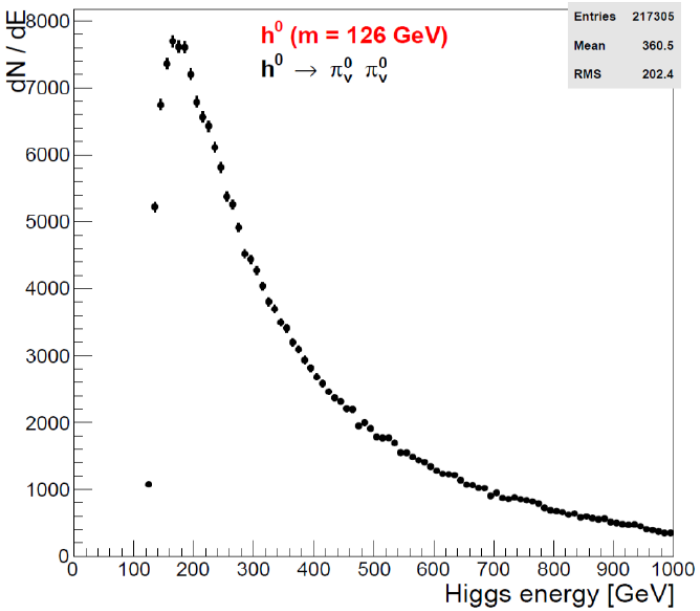
***Higgs → $\pi_v^0\pi_v^0$ (at 3TeV)***

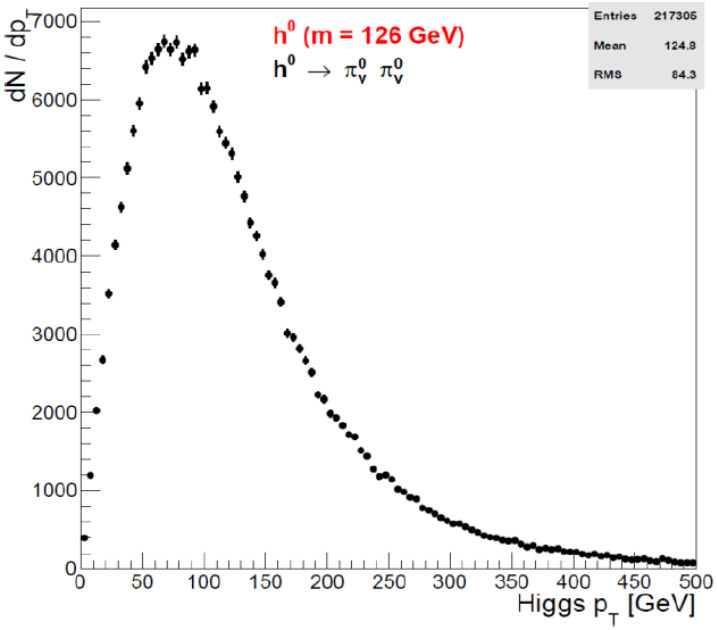
- mass($h^0$) = 126 GeV
- mass($\pi_v^0$) = 50 GeV
- $\pi_v^0$ lifetimes: 1, 10, 100, 300 ps

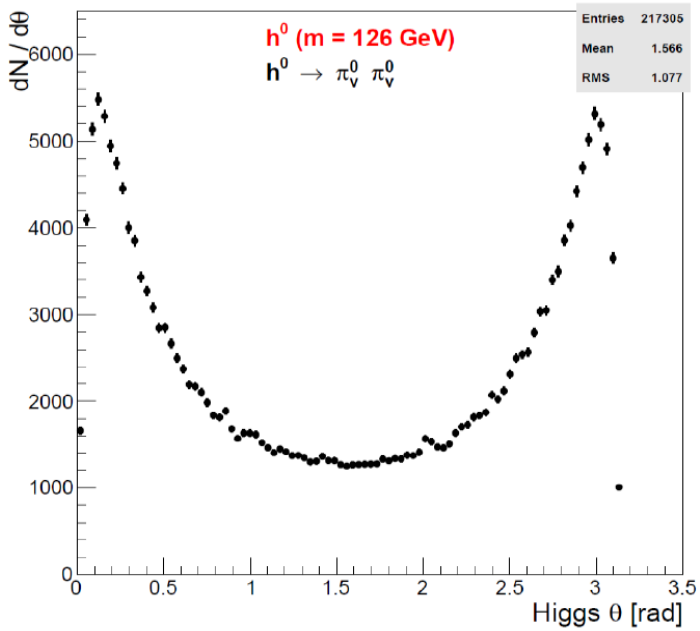
samples **with and without** pileup of $\gamma\gamma$ → hadrons

***Background (at 3 TeV)***

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



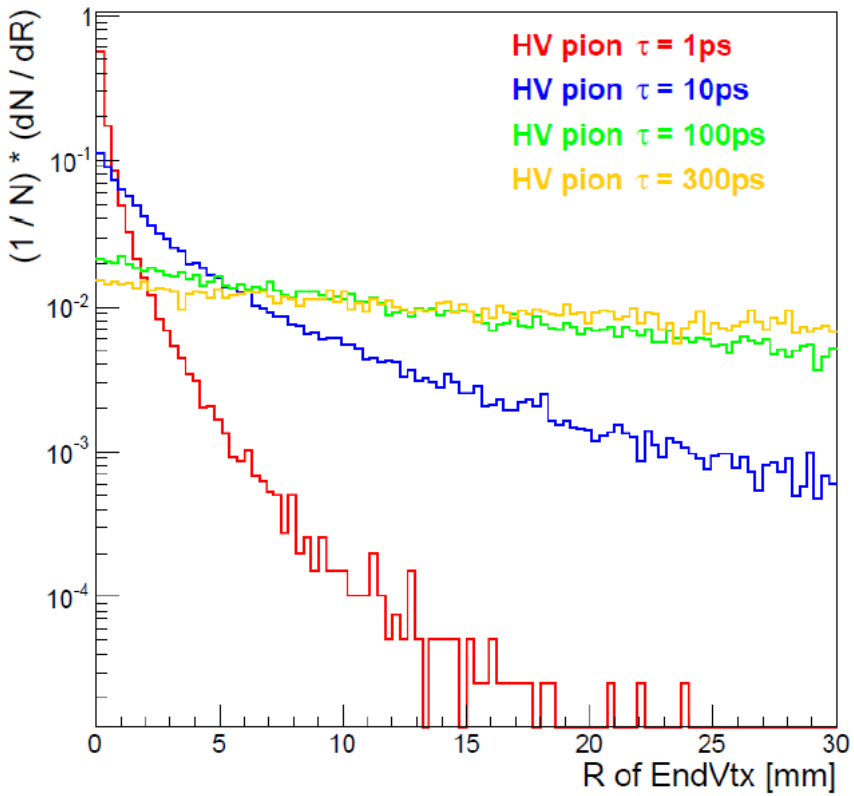



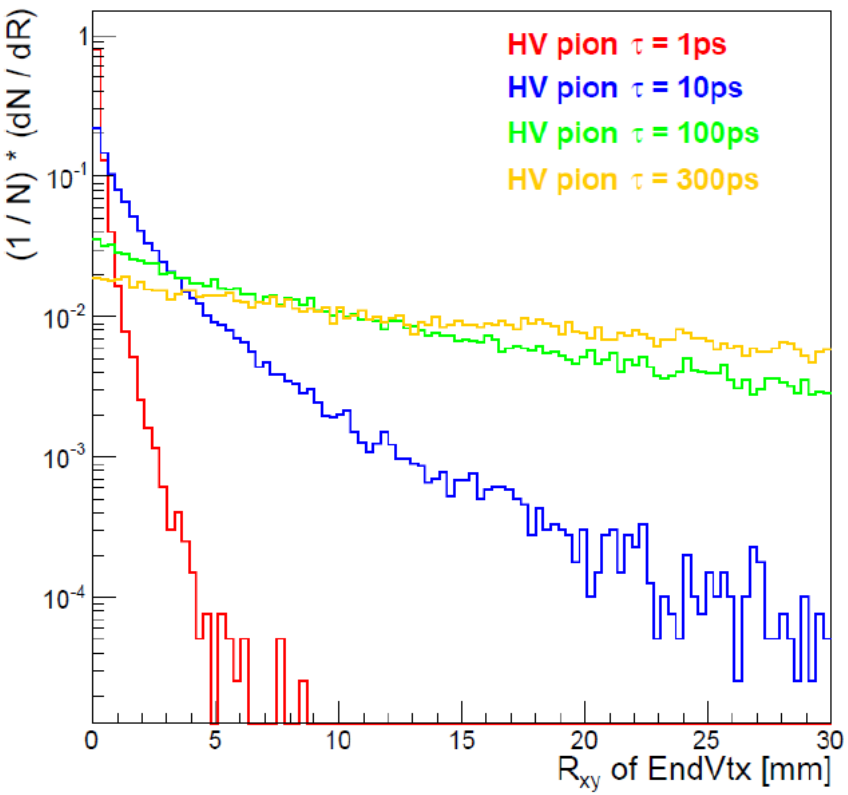
# Generated Hidden Valley pions

**v-paricles have non-zero lifetime**

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

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

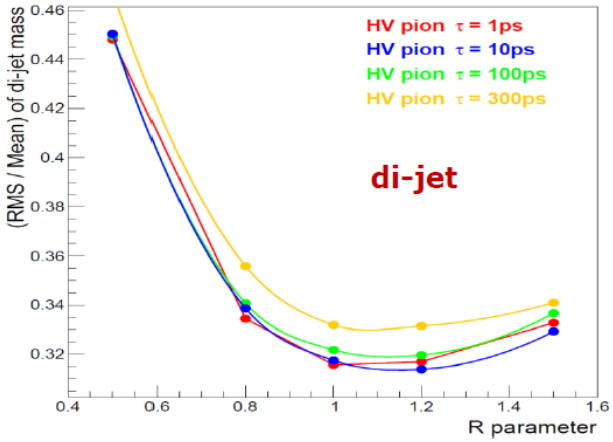


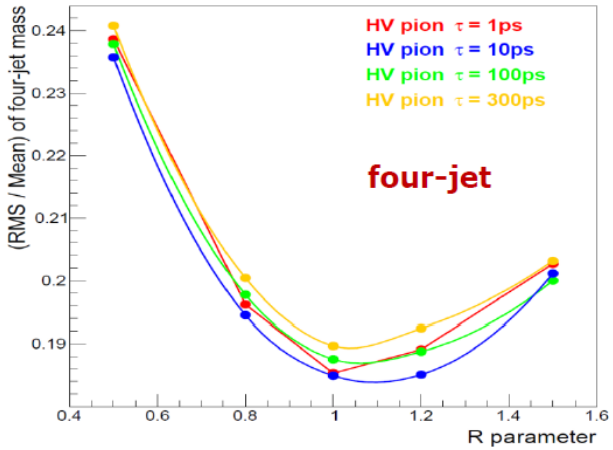



# Di-jet and four-jet mass – *R* optimization

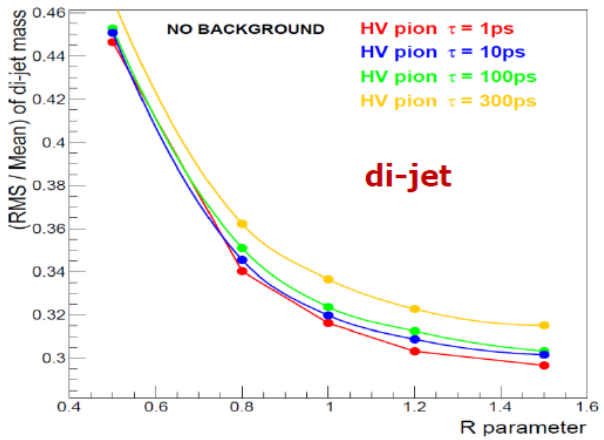
- fastjet $k_T$ algorithm
- nr of required exclusively reconstructed jets = 4

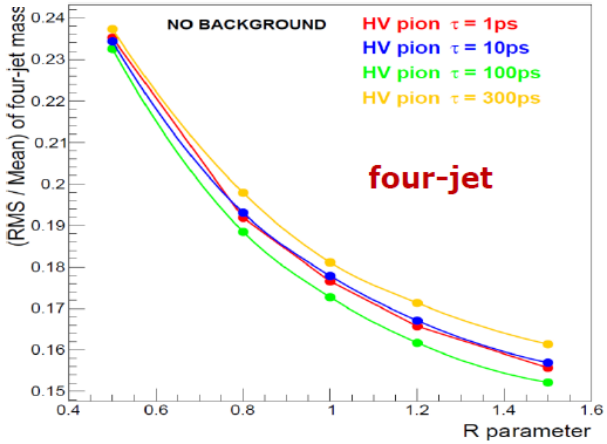
**$\gamma\gamma \rightarrow$ hadrons background**




**NO background**



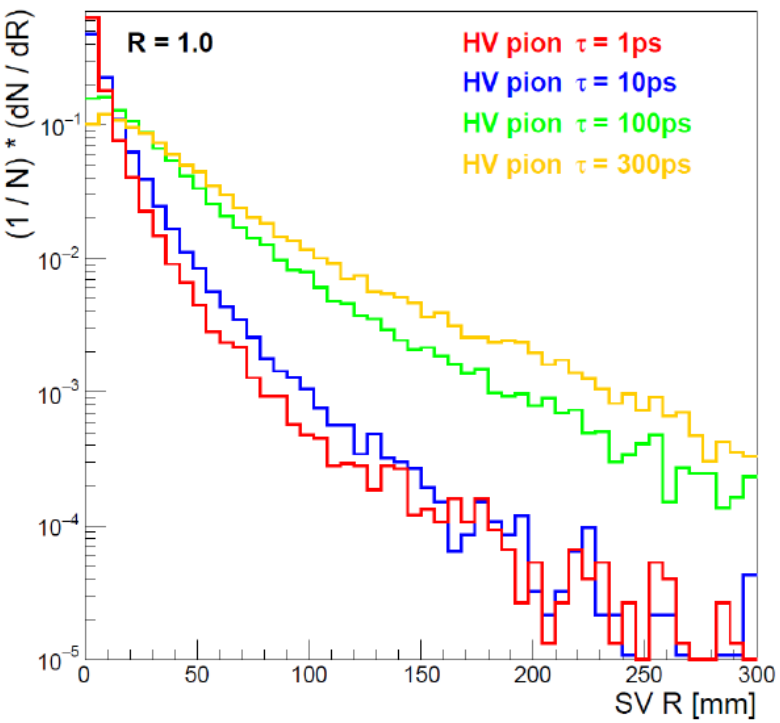



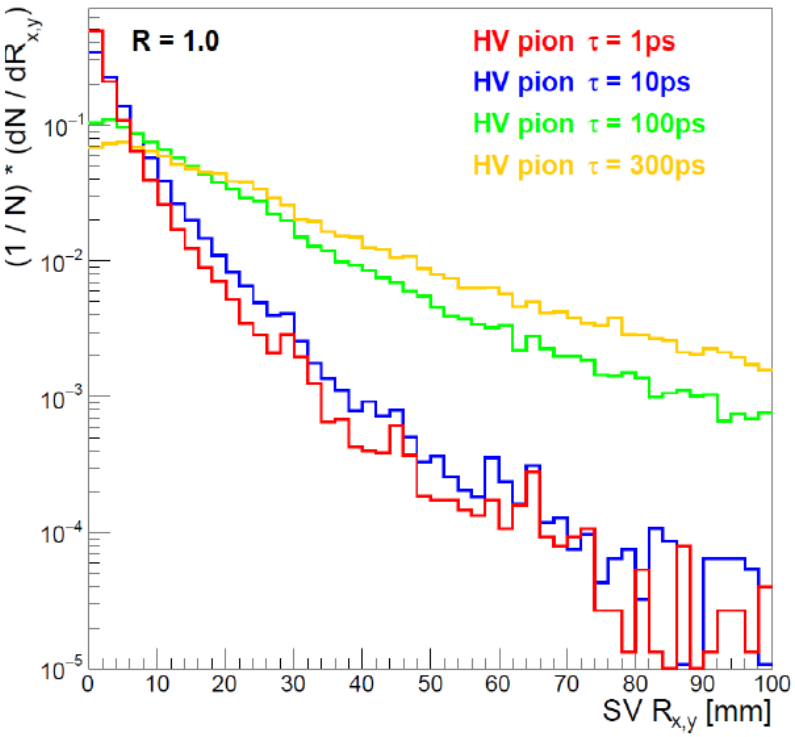

**jet *R* parameter chosen to be = 1.0**

# Secondary vertices

**Default secondary vertex finder used**

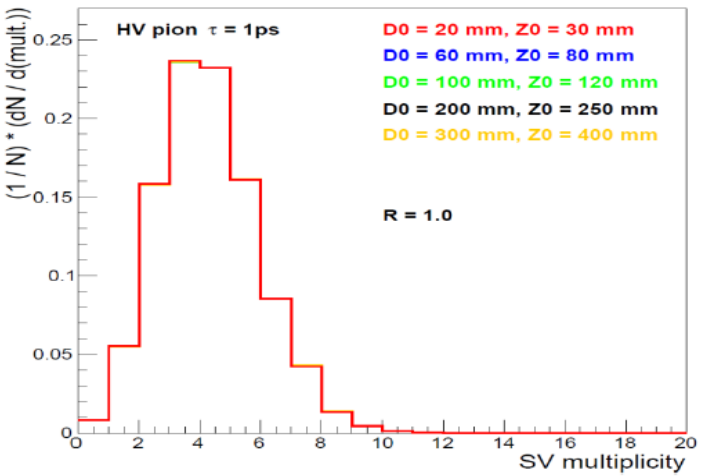
- *initial value of track max. D0 = 10 mm*
- *initial value of track max. Z0 = 20 mm*
- *NO REQUIREMENT TO HAVE HITS IN VERTEX DETECTOR*

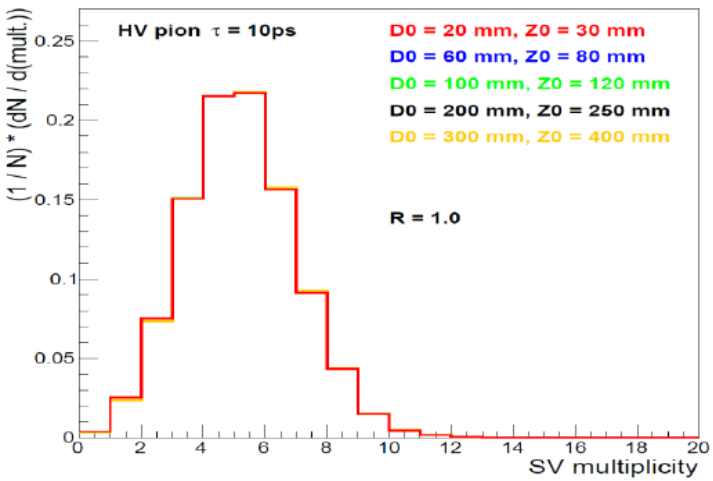


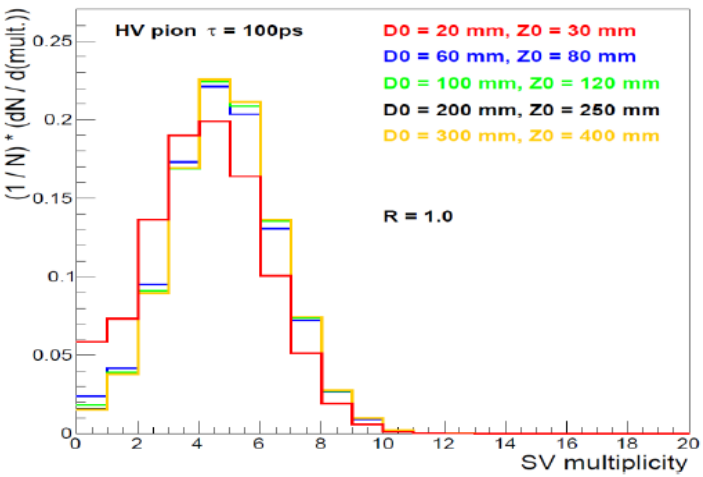



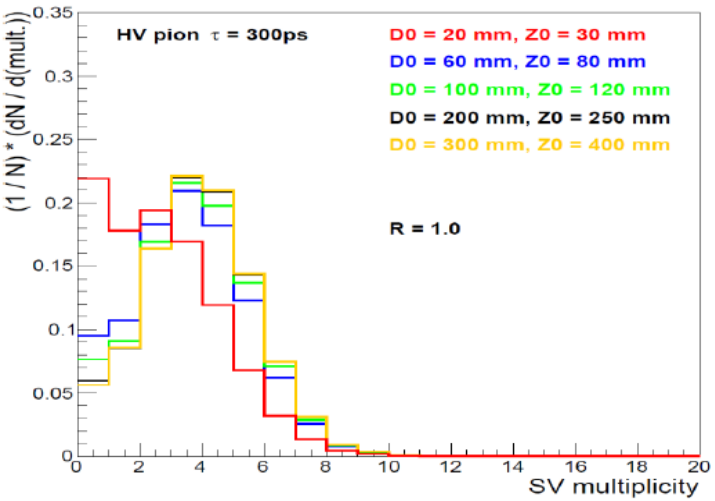
# Track *D0* and *Z0* cuts - optimization

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



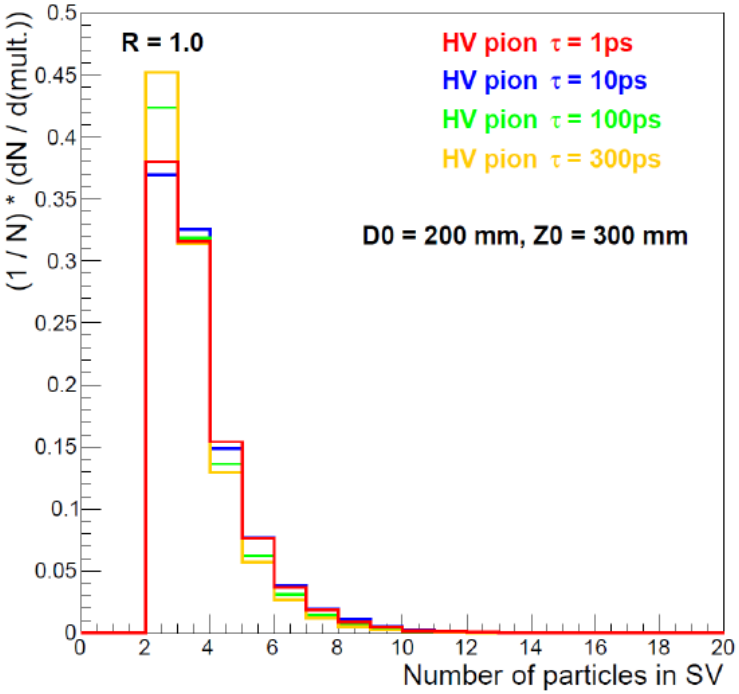



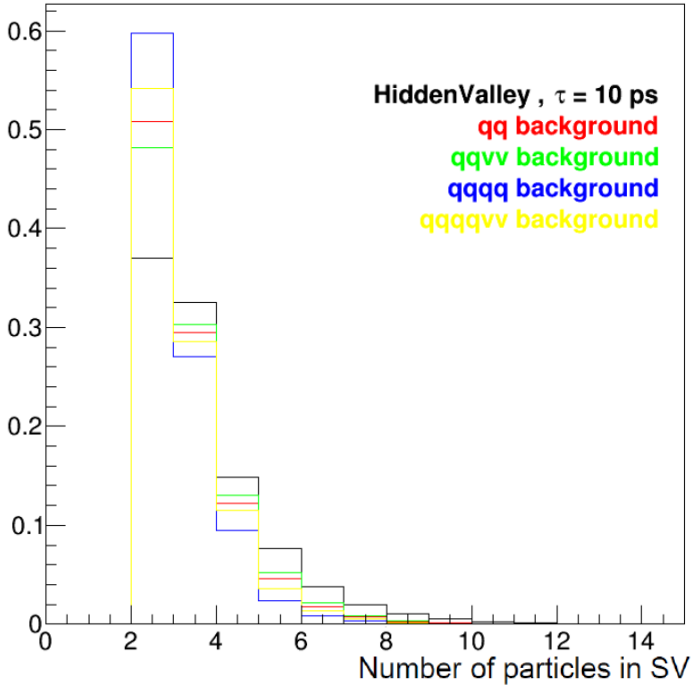
# PROBLEM (1): Multiplicity of particles in SV

Large fraction of SV's with 2 tracks only!

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

*CUTS ON D0 & Z0 NOT RESPONSIBLE FOR THIS EFFECT!*



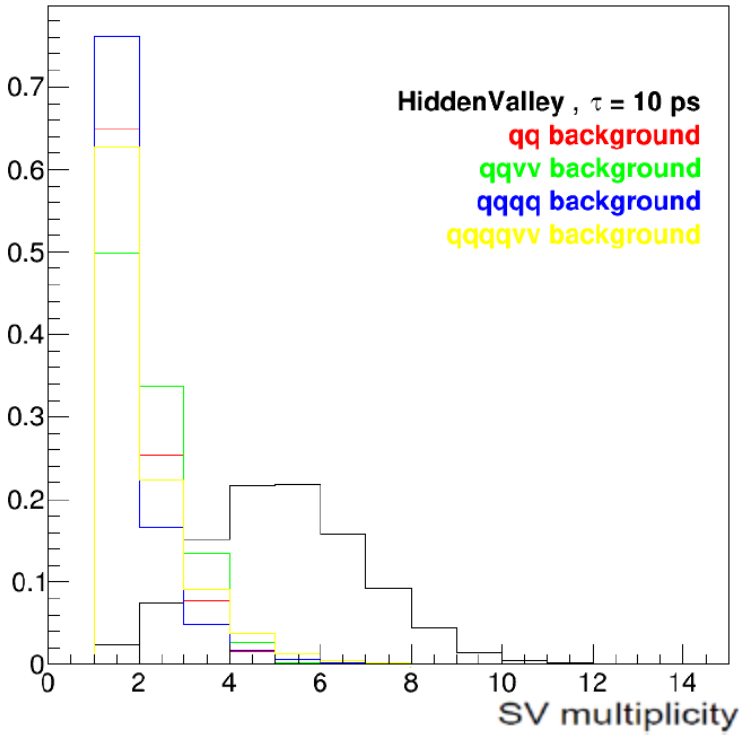



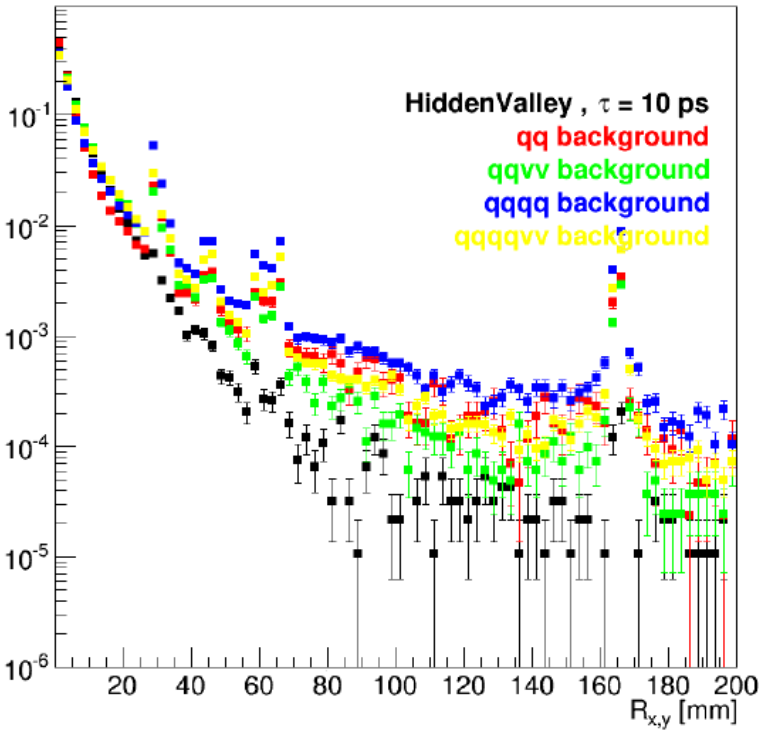

Not enough efficient SV reconsctruction algorithm for long-lived particles (?)

# PROBLEM (2): Distance to the PV

Distance to PV for background close to the one for Hidden Valley

*plots from A. Bialek's slides*




Peaks correspond to detector material

# Possible solutions

***Tried:***

(1) cut on Higgs θ to be in barrel region (0.8 < θ < 2.4)

*cannot solve the problem with track mult. in SV*

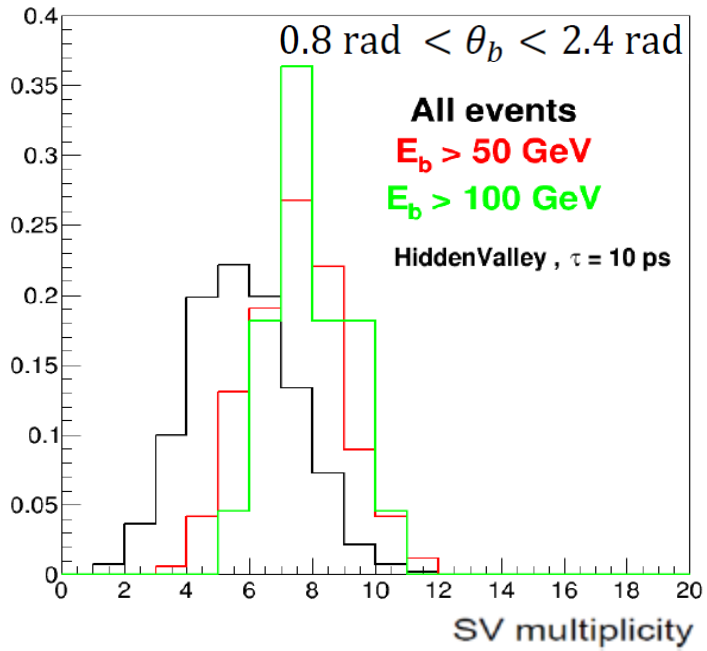
(2) cut on the b-quark energy (> 50 GeV, > 100 GeV)

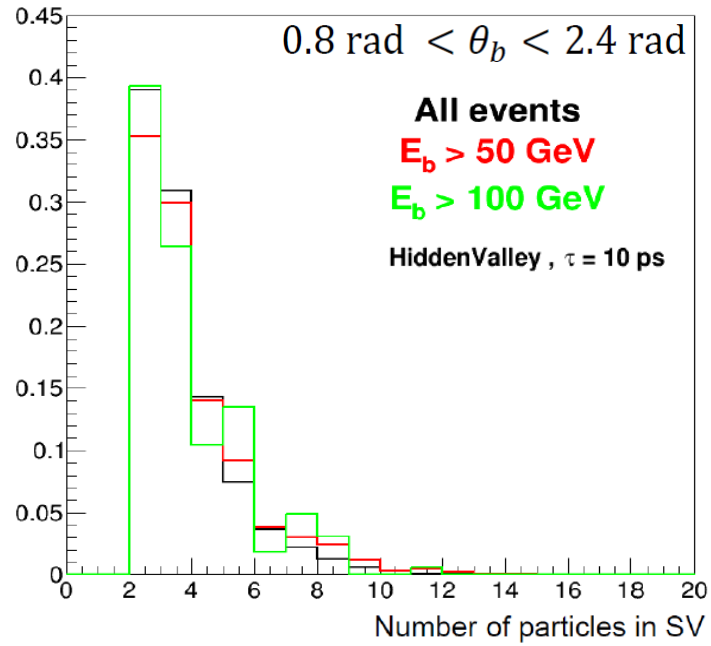
*cannot solve the problem with track mult. in SV*

(3) cut on the track multiplicity in SV

*cannot solve the problem with SV distance to PV*

*plots from A. Bialek's slides*



# Change the SV finding strategy

**Displaced vertices *(DVs)***

→ rather PV-like objects to cumulate as many as possible tracks from Hidden Valley pions

→ DV track multiplicity should be > 4 *(to remove b-hadron background)*

***DV reconstruction based on seeding + SV fitting (e.g. adaptive, annealling)***

**Seeds:** candidates for displaced vertices

→ points at which a sufficient number of tracks pass close to each other

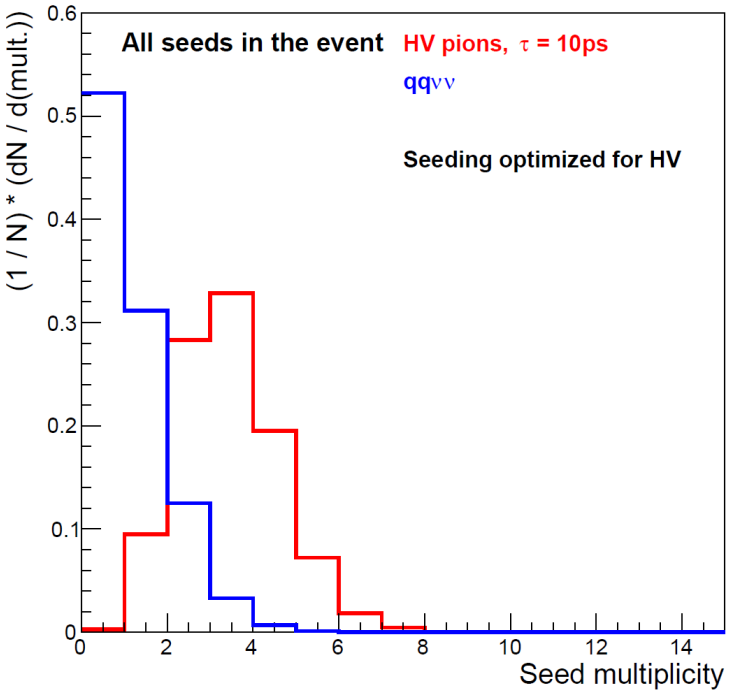
**Seeding procedure:**

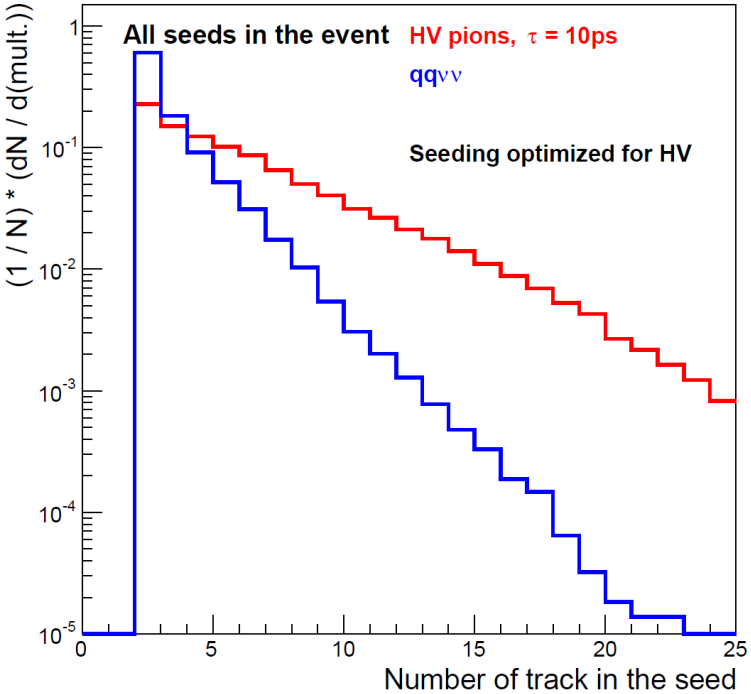
- select charged tracks with high IP wrt PV
- for each track *(base track)* a set of close tracks is determined
- track is defined as close if its distance of closest approach *(DOCA)* to the base track is less than 1 mm
- for such track pair the point of closest approach *(POCA)* is calculated - **seed**
- all tracks close enough to this POCA are marked as used
- then the loop over tracks is continued and the tracks marked as used are skept

*Finally, SV fitting using set of tracks assigned to the seed (or to seed position)*

# Seeding optimized for hidden valley

All seeds reconstructed in the event

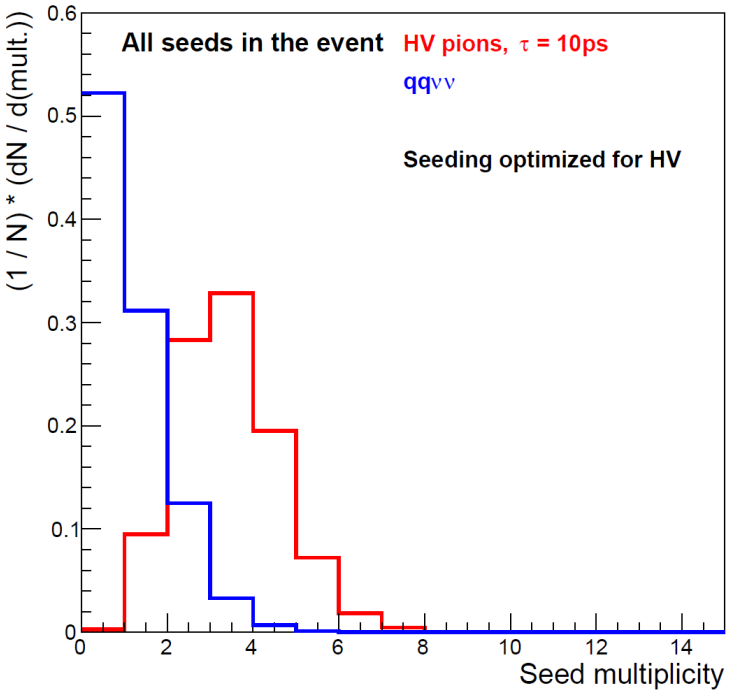


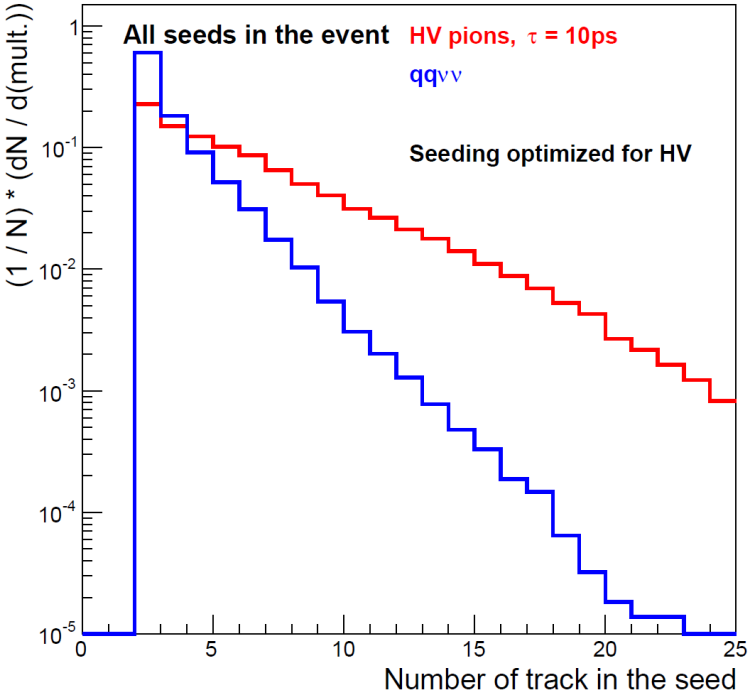




*Now the difference also in the nr of tracks assigned to SEED*

# Seeding optimized for hidden valley

All seeds reconstructed in the event



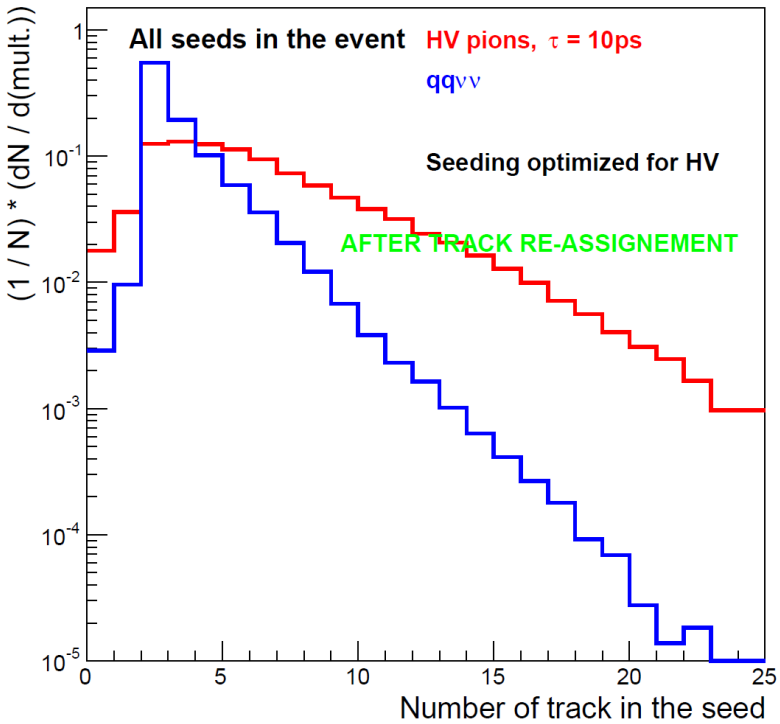



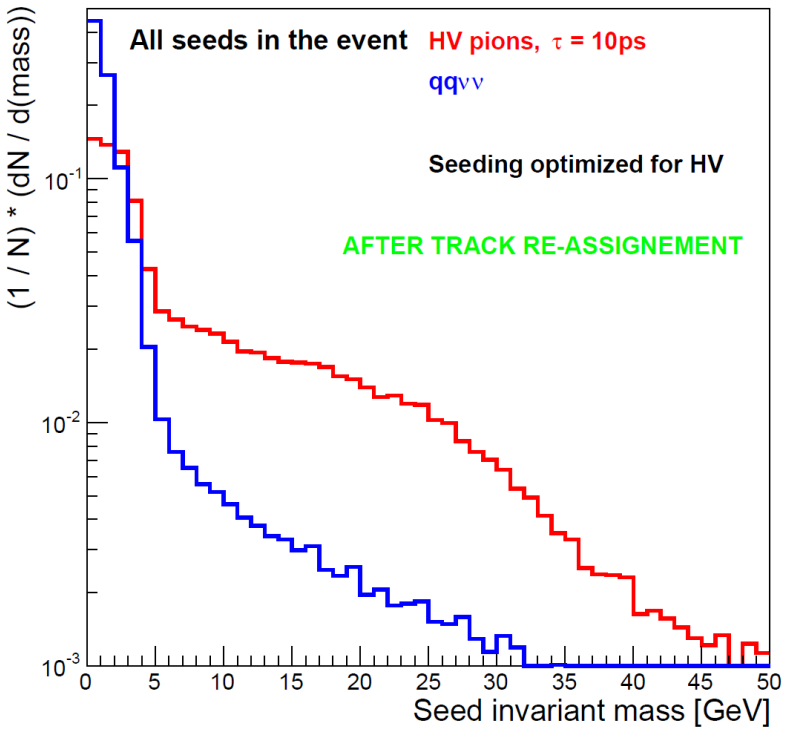

*Now the difference also in the nr of tracks assigned to SEED*

# Seeding optimized for hidden valley

All seeds reconstructed in the event

*Reassignement of tracks to the seeds starting from initial set of charged tracks with cut on $IP_{PV}$*



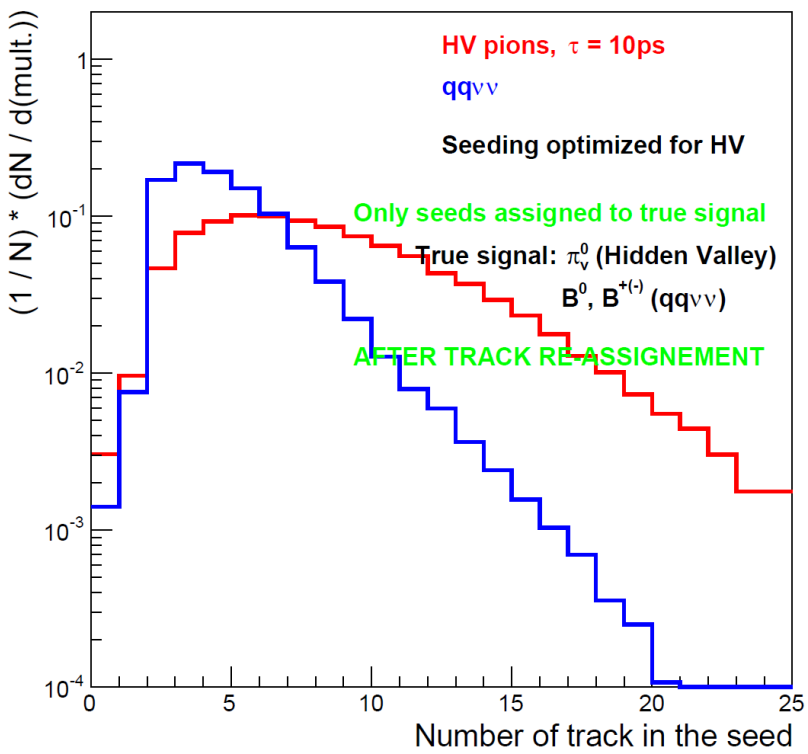



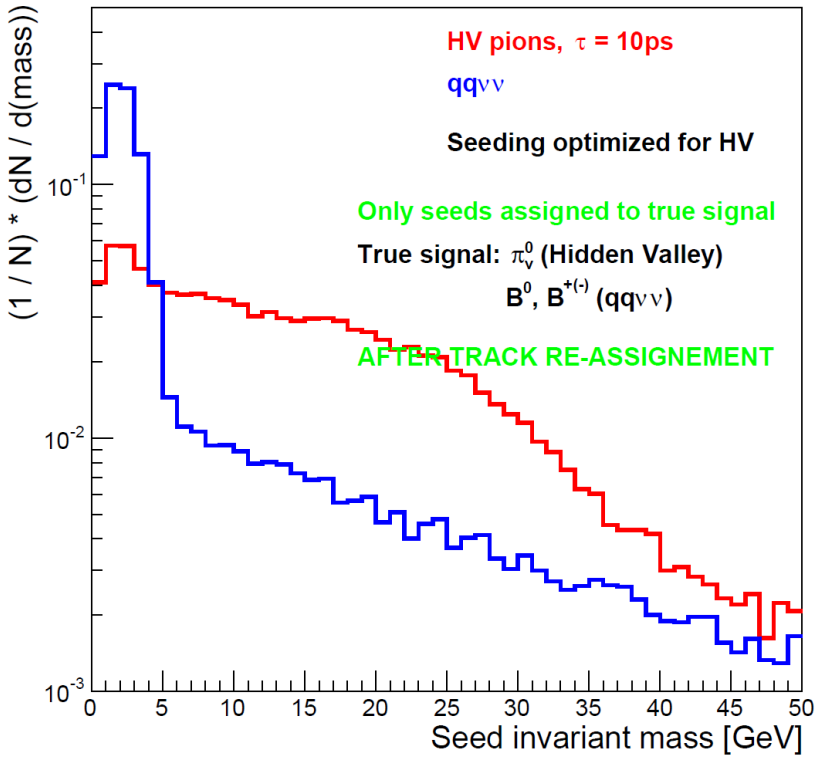
# Seeding optimized for hidden valley

**Only seeds assigned to true signal**

- $\pi_v^0$ *(Hidden Valley)*
- $B^0$ or $B^{+(-)}$ *(qqvv)*

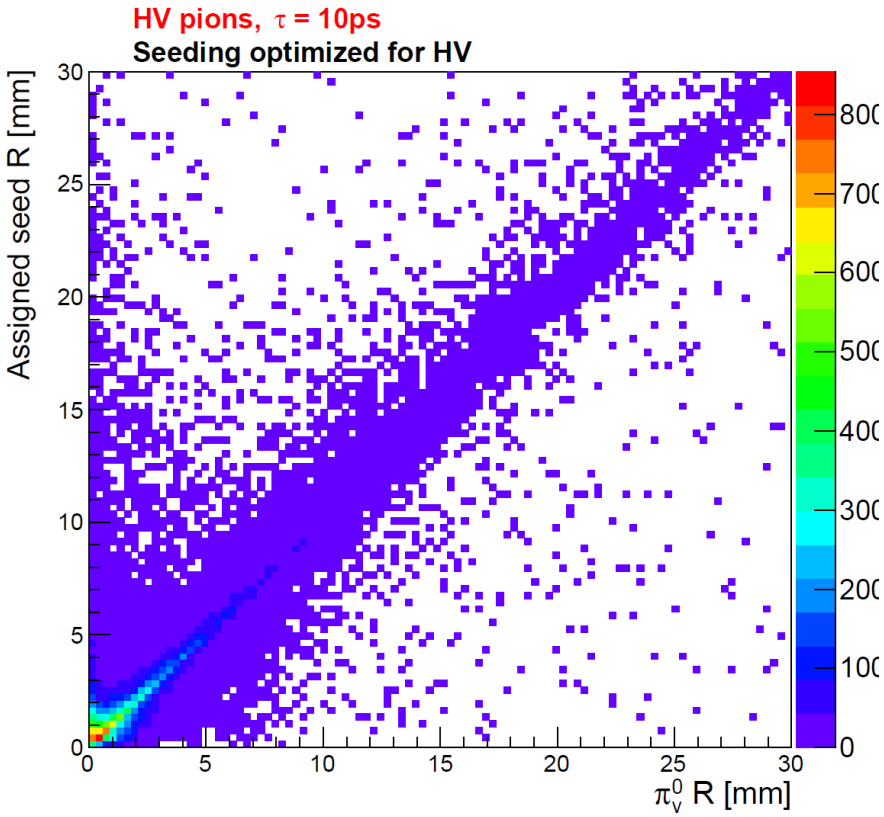
*Reassignement of tracks to the seeds starting from initial set of charged tracks with cut on $IP_{PV}$*

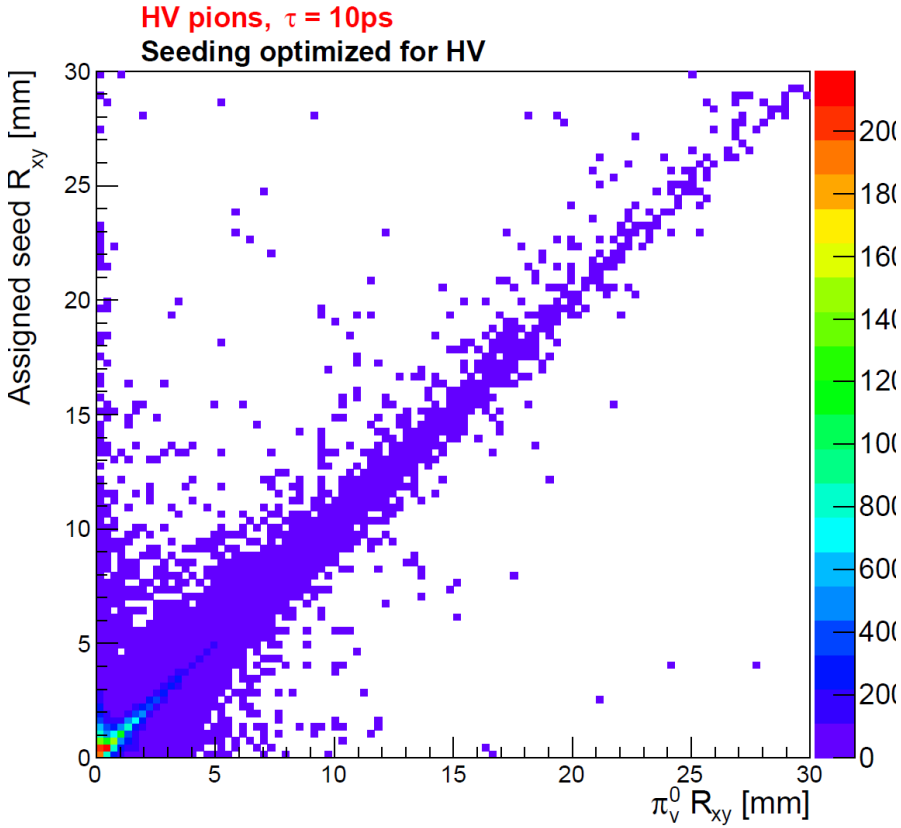


# Seeding optimized for hidden valley

Distance to PV



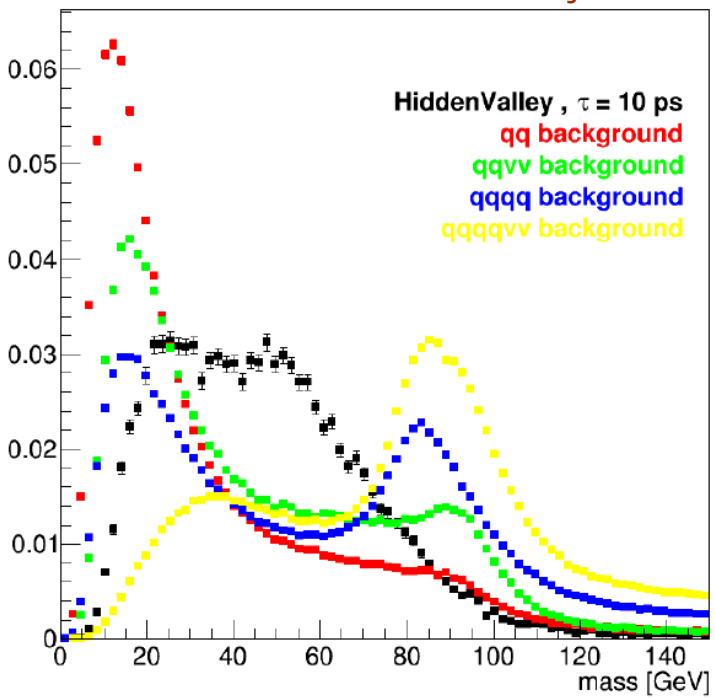



# Assignement of 2 jets to the same seed

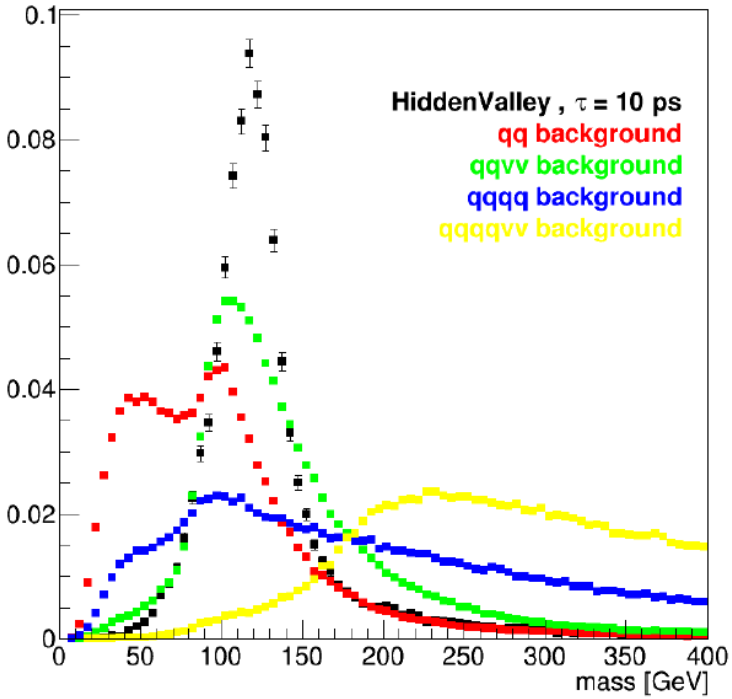
Last step *(to be done)* is to assign 2 rec. jets to the same seed

For now: dijets - pairing two jets with similar masses

di-jet mass




four-jet mass




*plots from A. Bialek's slides*

# Conclusions

- Hidden sector generic possibility for BSM physics
- Signal and background samples 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!**
- Several trials to solve this problem using existing SV fitter

  → no satisfactory solution
- Change the SV finding strategy

  → seeding *(SV finder)* + SV fitting *(e.g. adaptive, annealling)*

  → optimized for Hidden Valley *(to be improved → track reassignement)*

  → to be optimized also for bbIncl.
- Generate samples for direct searches via Z'