$H \to c\bar{c}$ AT MUON COLLIDER:

First look at vertexing with LCFIPlus

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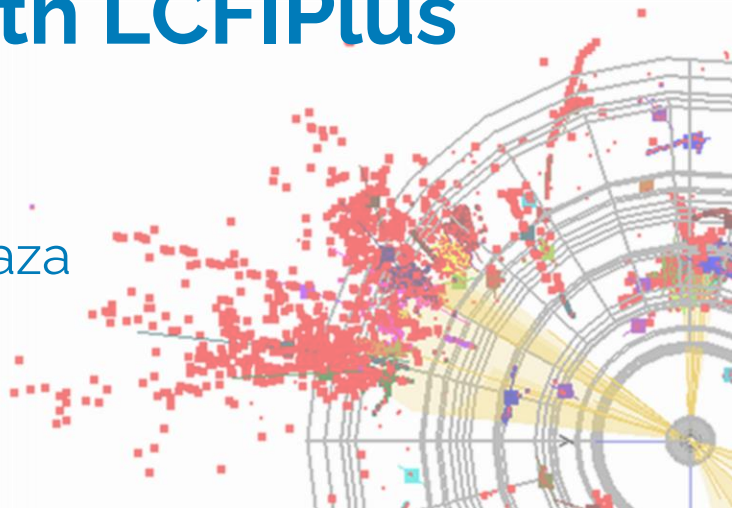


Samples

Goal: c-tagging, b-to-c discrimination

	Cross Section · BR (pb)
$\mu^+\mu^- \to H\nu\bar{\nu} \to c\bar{c}\nu\bar{\nu}$ (WW fusion)	$8.914 \cdot 10^{-3}$
$\mu^+\mu^- \to H\nu\bar{\nu} \to b\bar{b}\nu\bar{\nu}$ (WW fusion)	$1.801 \cdot 10^{-1}$

1000 events generated with Pythia at 1.5 TeV

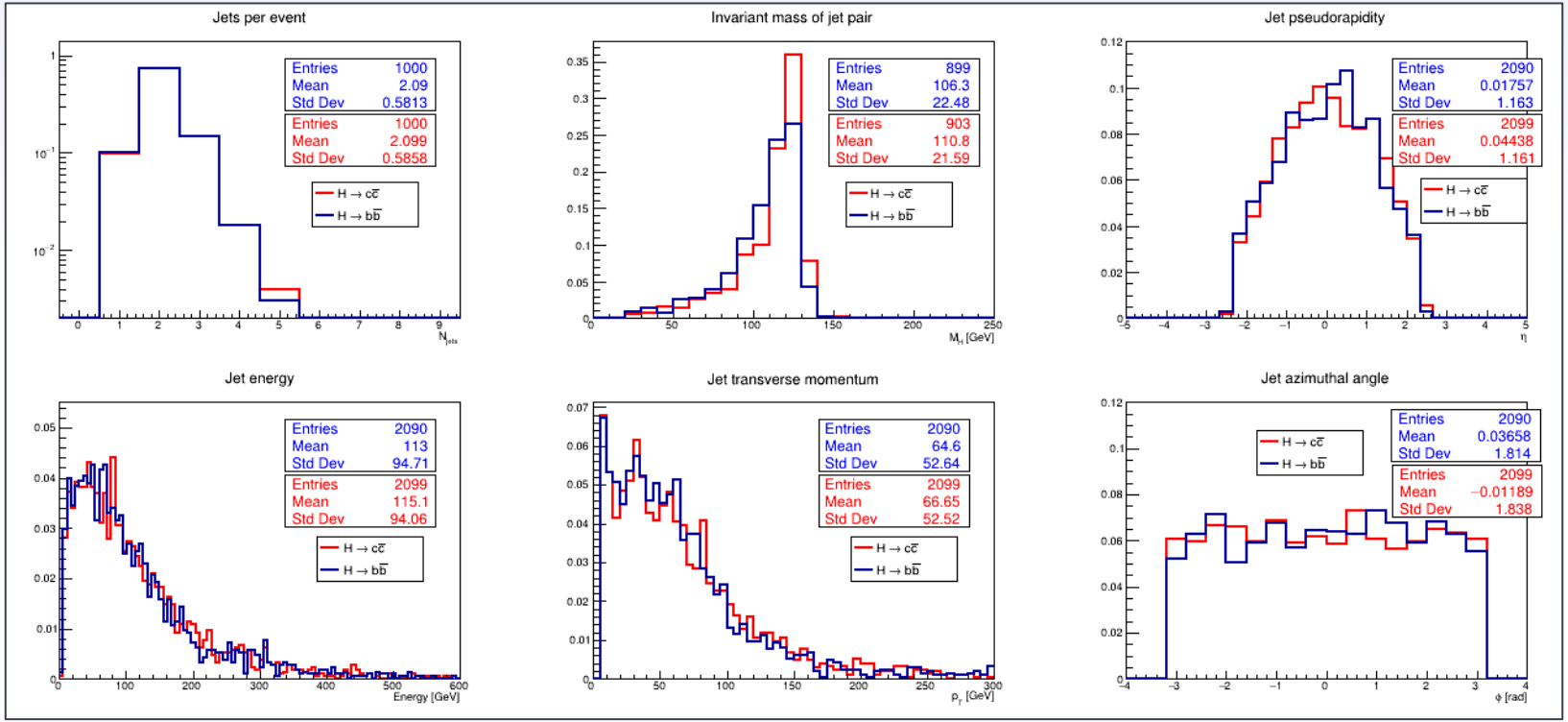
Simulated and reconstructed with the latest detector geometry and software release (v02-05-MC)

1

Jet reconstruction

FastJet Processor: k_T algorithm with R=1.0

c-jet and b-jet kinematic variables are identical
Need for a tagging algorithm to identify c-jets



*Plots are not scaled to cross section · luminosity

*No selection is applied

C-tagging algorithm

- Identify c-jets discriminating them against b-jets and light-flavour jets
- Several variables connected to the properties of heavy-flavour hadrons present in jets need to be combined into a single discriminator using MVA techniques

Track variables

3D/2D Impact Parameter (IP), 3D/2D IP significance, $\mathrm{pT_{rel}}$, η_{rel}, etc.

+

Secondary vertex variables

Number of SV per jet, 3D/2D flight distance (significance), corrected mass, etc.

+

Soft lepton variables

Muon and electron 3D/2D IP (significance), $\mathrm{pT_{rel}}$, η_{rel}, etc.

2

Vertex reconstruction

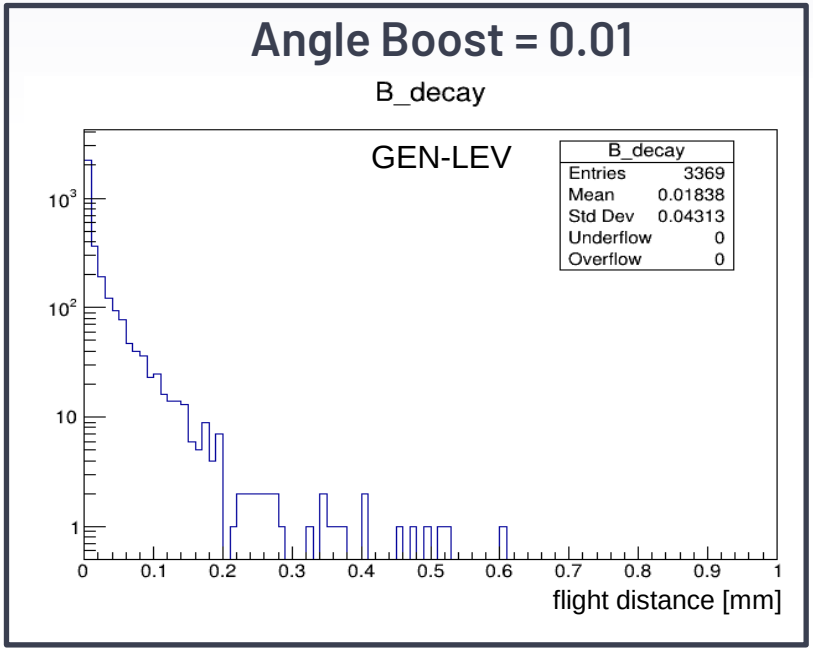
LCFIPlus Processor: PrimaryVertexFinder+BuildUpVertex algorithms

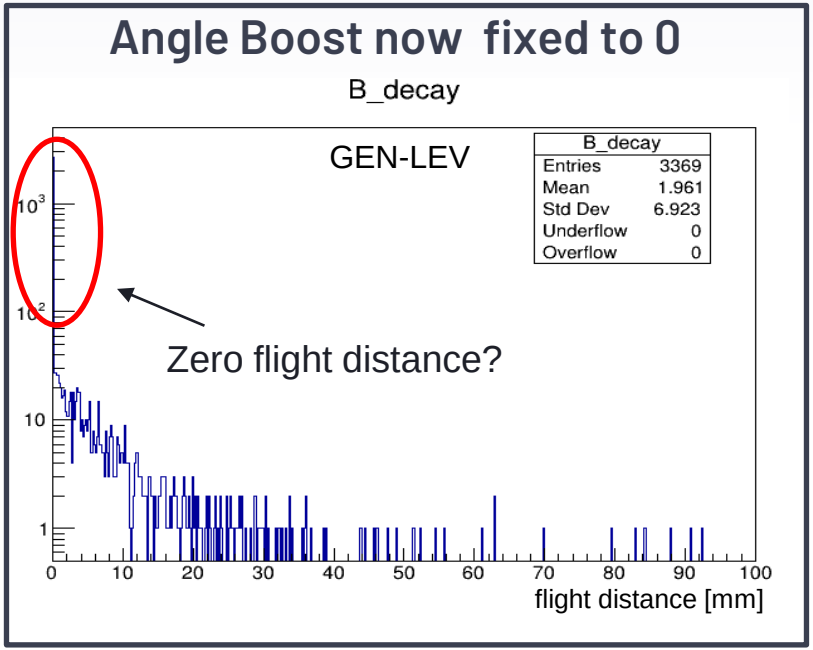
Crossing Angle Boost

At first , it was set to a non-zero value in sim_steer.py

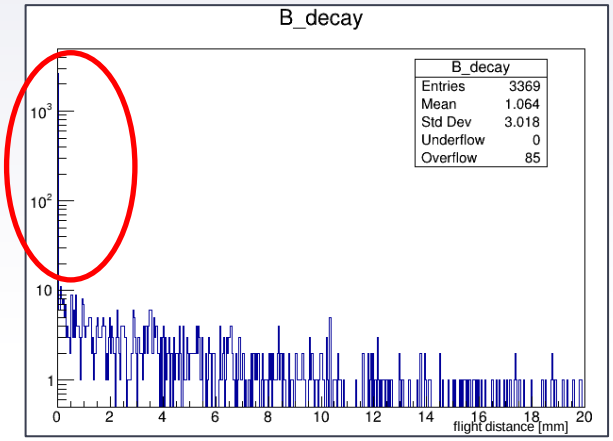
This led to a much smaller flight distance for heavy hadron wrt the expected value:

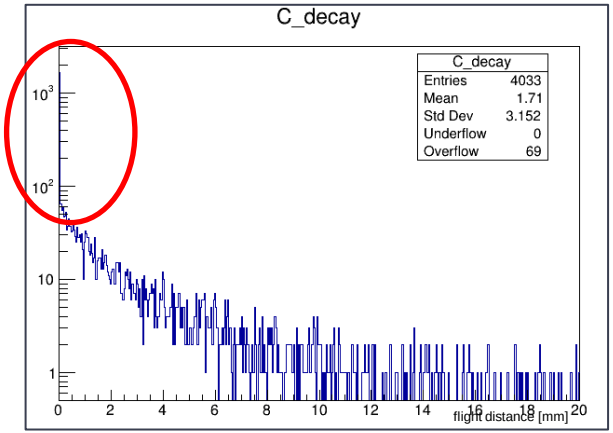
es. B^0 flight distance $= c\tau \cdot \gamma = 455.7\ \mu m \cdot 10 \approx 5\ mm$





Issue at gen-level





B/C hadrons with 0 flight distance at generator level

Some of these hadrons have (0,0,0) MC production point and end point

For $b\bar{b}$ sample they represent the ~25% of C-hadrons and the ~60% of B-hadrons

All events are affected

Does this issue have influence on reconstructed variables?

Do these hadrons degrade the vertex reconstruction?

Issue at gen-level

H decay point: X=-1.00178e-11 Y=1.97362e-11 Z=4.16243e-11
H production point: X=0 Y=0 Z=0
Flight distance H: 4.7143e-11

B decay point: X=-1.00178e-11 Y=1.97362e-11 Z=4.16243e-11
B production point: X=-1.00178e-11 Y=1.97362e-11 Z=4.16243e-11
Flight distance B: 0
Particle ID: -523

B^{*-}

B decay point: X=0 Y=0 Z=0
B production point: X=0 Y=0 Z=0
Flight distance B: 0
Particle ID: 513

B^{*0}

B decay point: X=0 Y=0 Z=0
B production point: X=0 Y=0 Z=0
Flight distance B: 0
Particle ID: -521

B^{-}

Print-out of Higgs and 0-flight-distance B-hadrons

Does this issue have influence on reconstructed variables?

How this impact on vertex reconstruction?
(See slide 20 for the reconstructed flight distance plot)

Track selection for vertexing

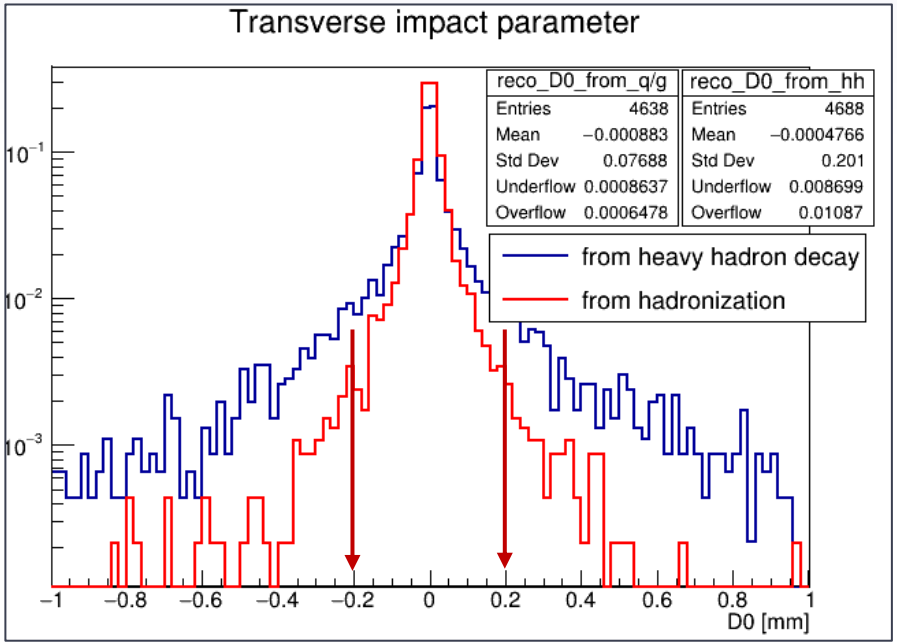
		PRE-SET	SET BY ME
PV	TrackMaxD0	20	0.2
	TrackMaxZ0	20	0.5
	TrackMinD0Err	0	0.02
	TrackMaxInnermostHitRadius	61	31
	TrackMinVtxFtdHits	1	2
SV	TrackMaxD0	10	5
	TrackMaxZ0	20	5
	TrackMinPt	0.1	0.8
	TrackMinVxdFtdHits	1	4

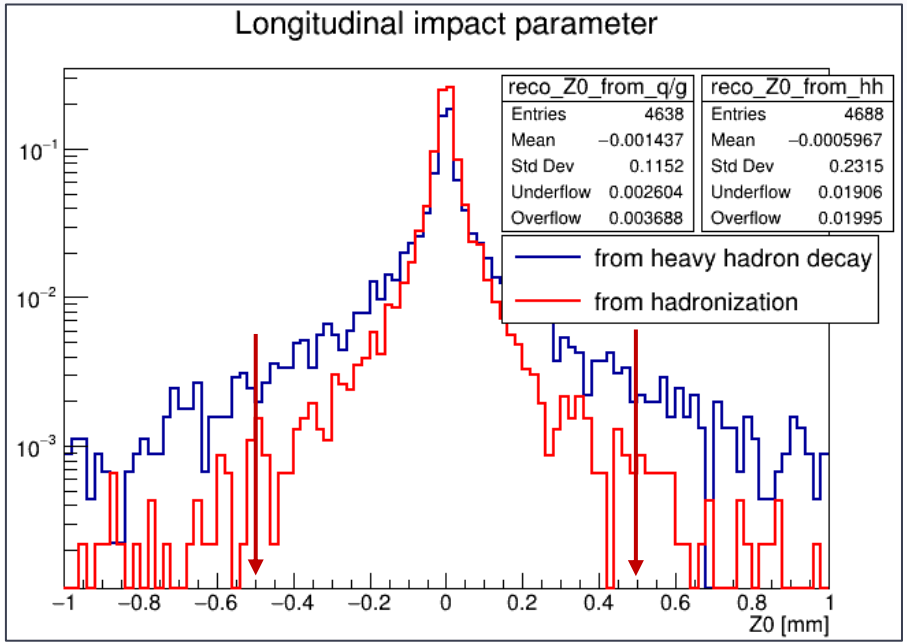
In order to choose these parameters two set of tracks (in bb sample) are selected according to their parent at gen-level:

- Tracks from hadronization have a quark /gluon parent at gen-level (should be used to fit PV)
- Tracks from heavy-hadron decay have B/C – hadron parent at gen level (should be used to fit SV)

Transverse and longitudinal IP

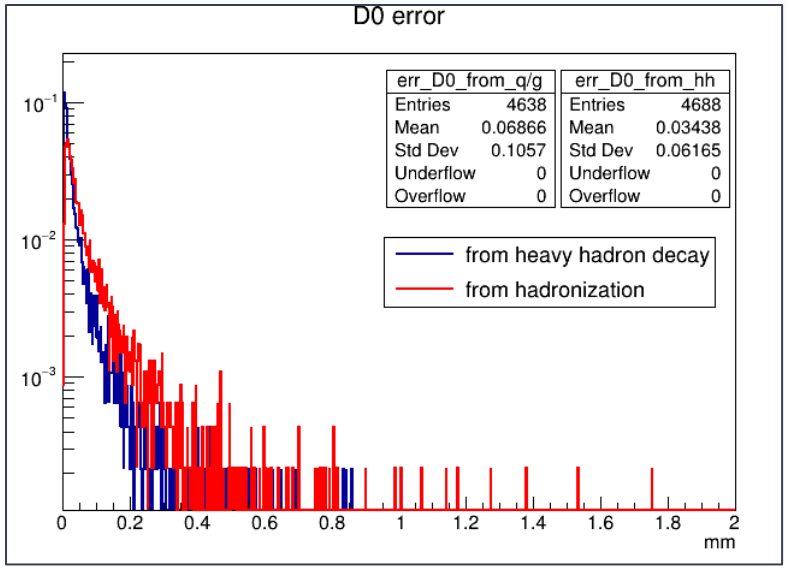
D0 and Z0 cuts for PV are shown
Cuts for SV are at 5 mm

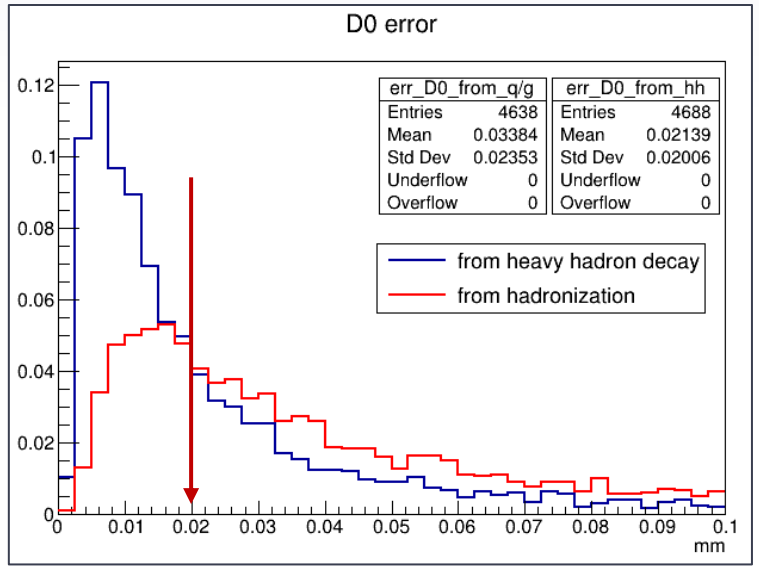




Min D_0 error for PV

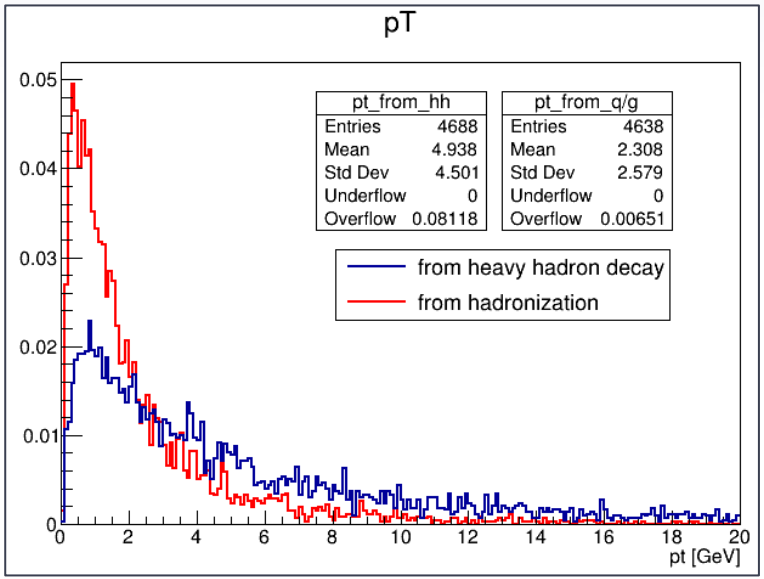
Introduced in the processor to increase SV efficiency

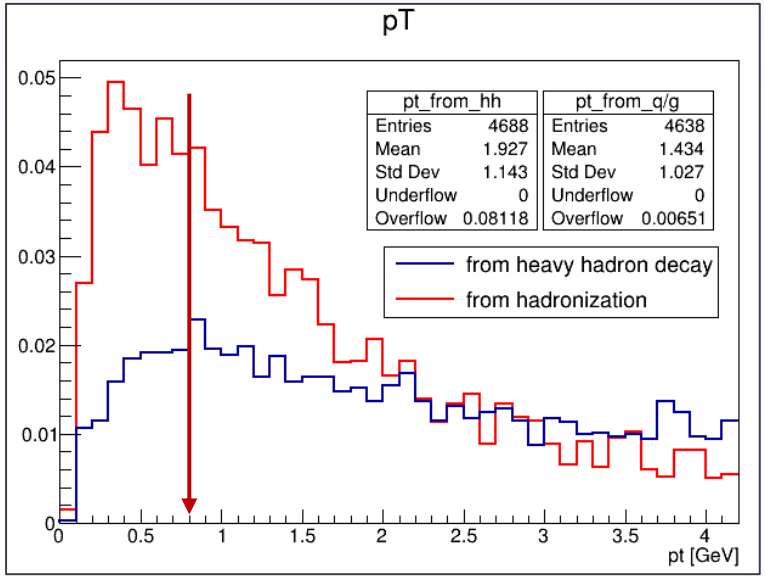




p_T cut for SV

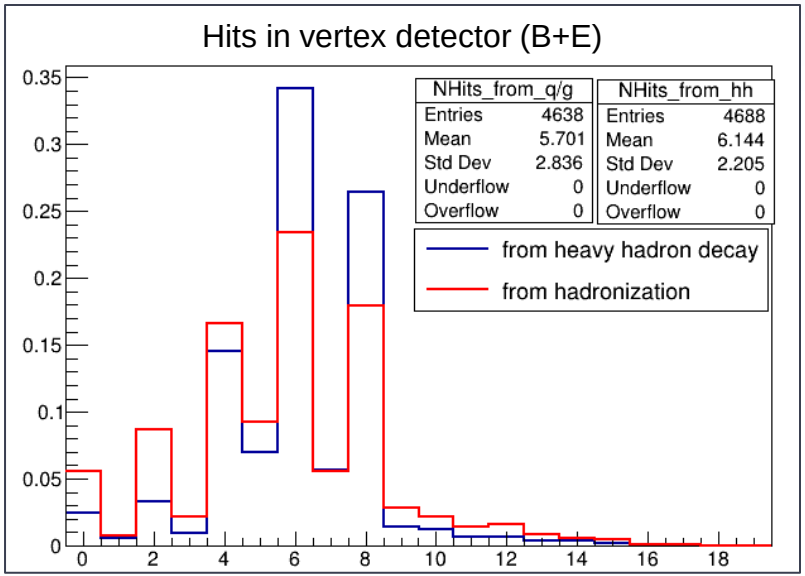
Increased from 0.1 to 0.8 GeV to reduce SV fake rate

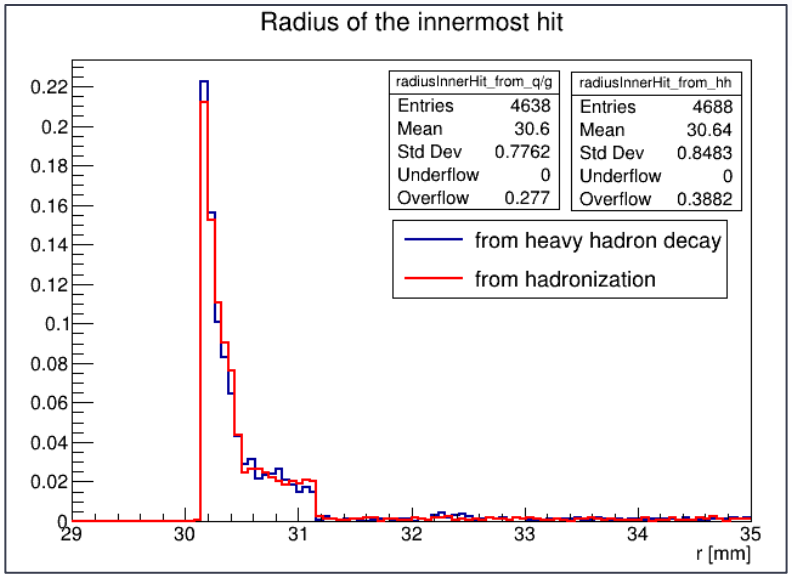




Track Hits

Minimum number of track hits for PV is set to 2
Minimum number of track hits for SV is set to 4
Maximum radius of the innermost track hit for PV is set to 31





Vertexing parameters

PV	Chi2Threshold	10
SV	SecondaryChi2 Threshold	5
	MassThreshold	10
	MinDistFromIP	0.3

Changed wrt last presentation (old value= 0.001 mm)
-> optimization procedure and results in slide 33 in backup

3

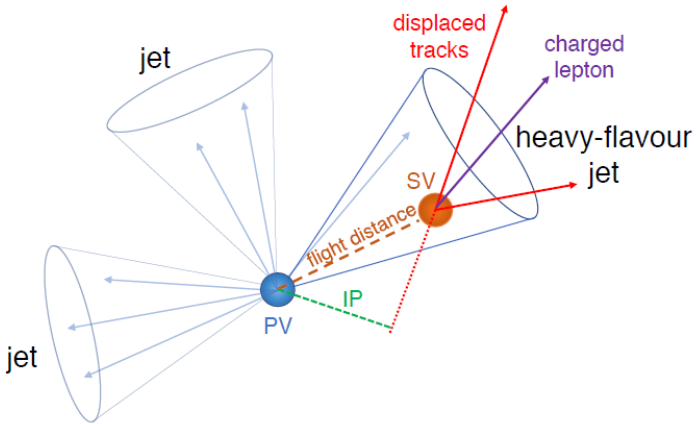
Secondary Vertex variables

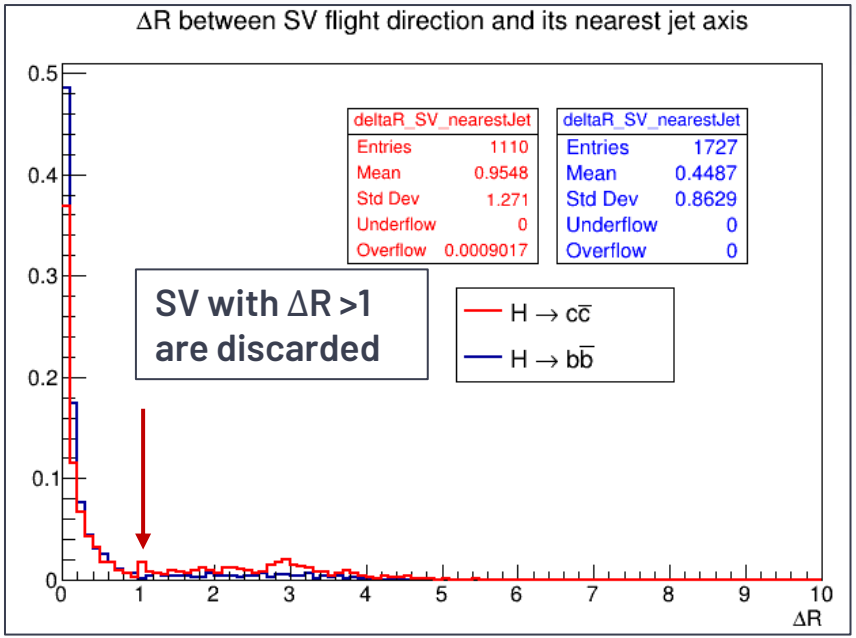
SV-to-jet association

Only b-jets are considered for bb sample, only c-jets for the cc one

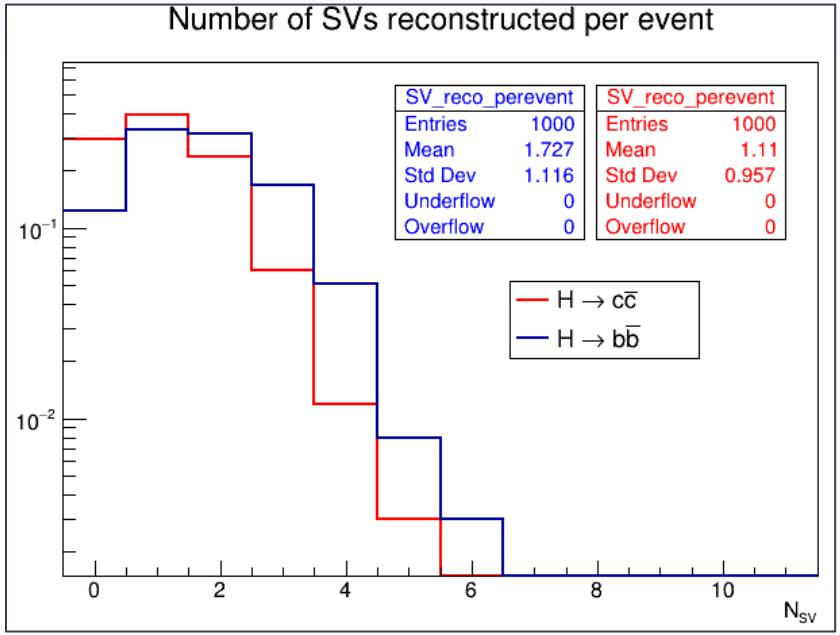
- **Jets containing at least one generated B hadron are defined b-jets**
- **Jets containing at least one generated C hadron and no B hadron are defined c-jets**

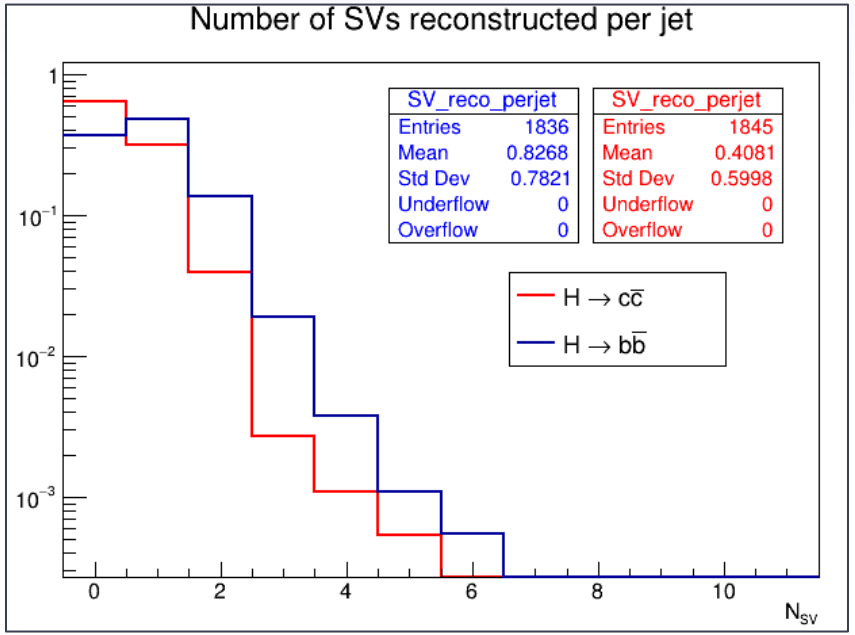
ΔR between the SV flight direction and the jet axis is required to be < 1.0





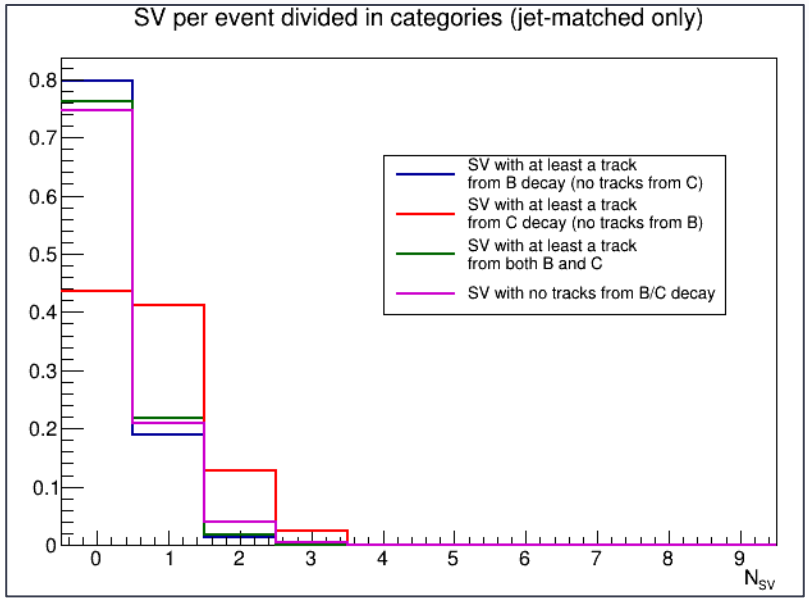
Comparison between $b\bar{b}$ and $c\bar{c}$ samples



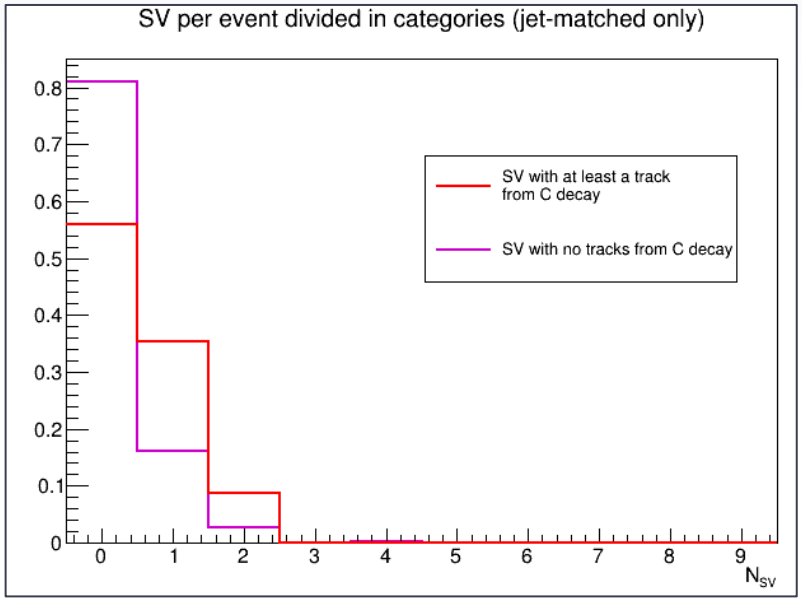


Variables per vertex category

bb sample

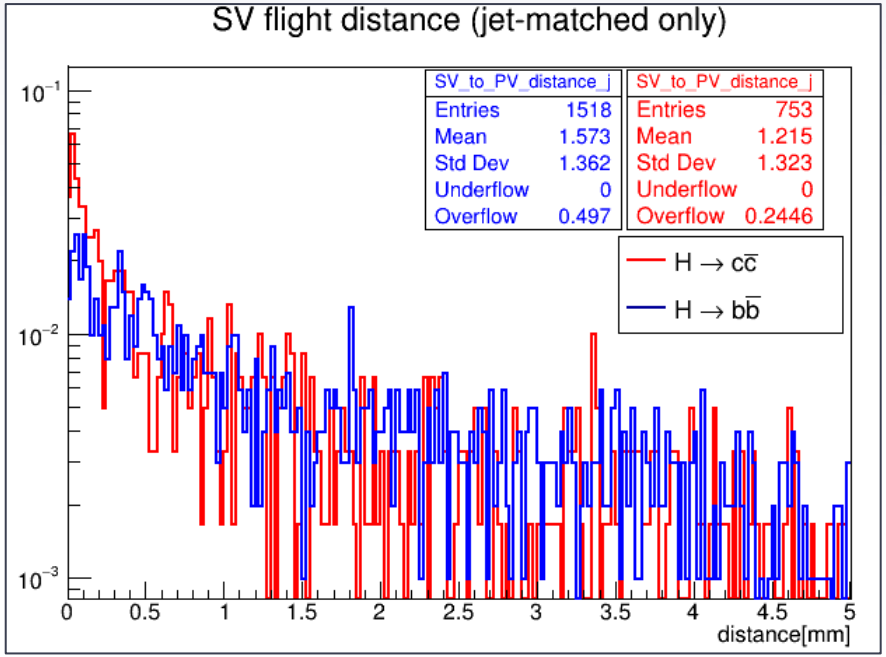


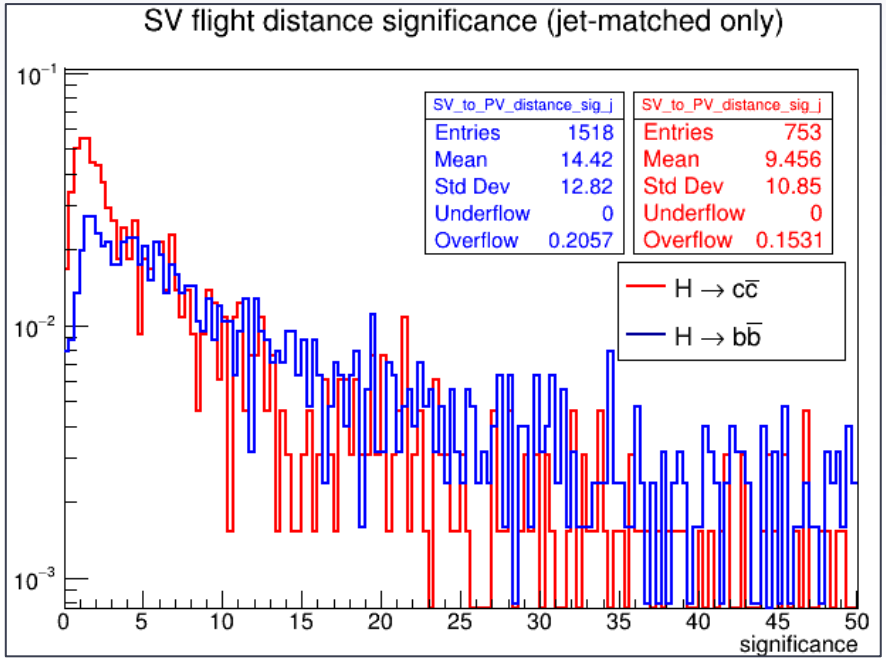
cc sample



Flight distance

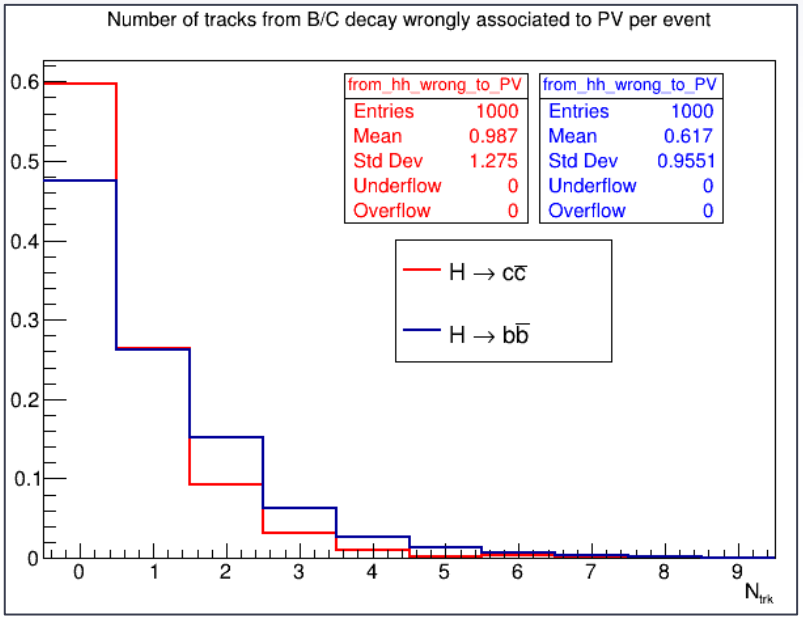
Previous results in slide 34 in backup

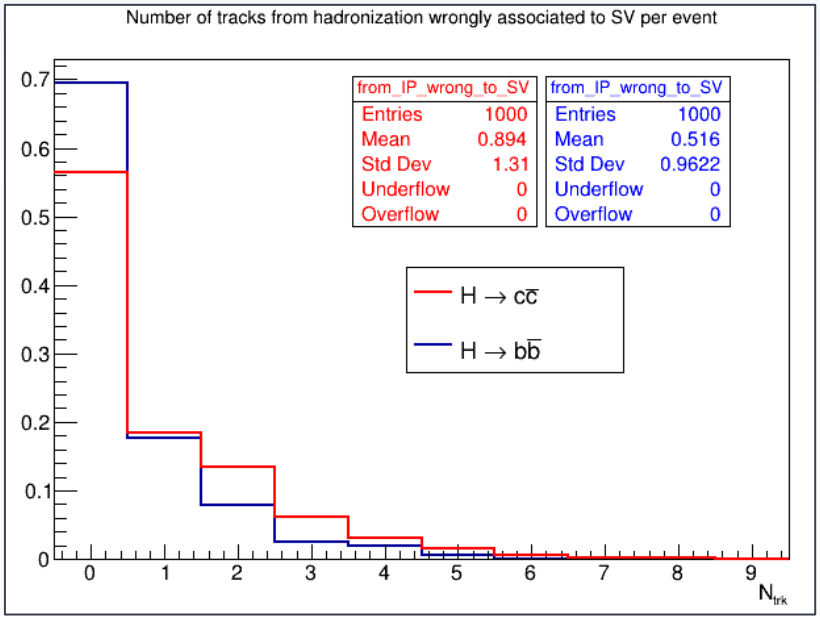




*No kinematic selection on jets is applied

Performance of vertex finding: wrong association





***All secondary vertices are considered here (not only the jet-matched ones)**

Performance of vertex finding

- *Primary*: Tracks that originate from the primary vertex.
- *Bottom*: Tracks whose most immediate parent with a non-zero lifetime containing a bottom quark.
- *Charm*: Same as above, except the parent contains a charm quark.
- *Others*: All the other tracks, such as those from τ decays, strange hadrons, or photon conversions.

Track origin	Primary	Bottom	Charm	Others
Total number of tracks	496897	258299	247352	56432
Tracks in secondary vertices	0.6%	57.5%	64.3%	2.5%
... from the same decay chain	—	56.6%	63.4%	1.9%
... from the same parent particle	—	32.2%	38.9%	1.2%

Table 2: The performance of the LCFIPlus vertex finder evaluated on a sample of $b\bar{b}$ events with $\sqrt{s} = 91.2$ GeV. Refer to the main text for the explanation of the categories.

Reference: Suehara, T., & Tanabe, T. (2016). LCFIPlus: a framework for jet analysis in linear collider studies. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *808*, 109-116.

	bb					cc			
track origin	Primary	Bottom	Charm	Others	track origin	Primary	Bottom	Charm	Others
Total number of tracks	4730	1665	3178	11017	Total number of tracks	6159	4	2655	11282
% Tracks in secondary vertices	10.9091	40.1201	53.8389	23.4819	% Tracks in secondary vertices	14.5153	0	39.2844	17.2487
... from the same parent particle	/	3.66366	15.4185	1.26169	... from the same parent particle	/	0	11.4501	1.04591

***All secondary vertices are considered here (not only the jet-matched ones)**

Summary

- SV are reconstructed using the LCFI processor: an inclusive vertex finding algorithm with configurable parameters
- First attempt to optmize the parameters has been performed looking at the SV reconstruction efficiency and fraction of wrongly associated tracks
- Results are highly impacted by the angle boost (now fixed to 0)
- Open issue: 0-flight-distance heavy hadrons

Next steps

- Fix the gen-level issue
- Optimize vertexing parameters
- Run simulation + reconstruction with 10000 events
- Extract from the sample the variables needed for tagging
- Performe MVA to discriminate between b and c jets
- Prove the discrimination power of the tagging algorithm also against uds jets

THANKS!

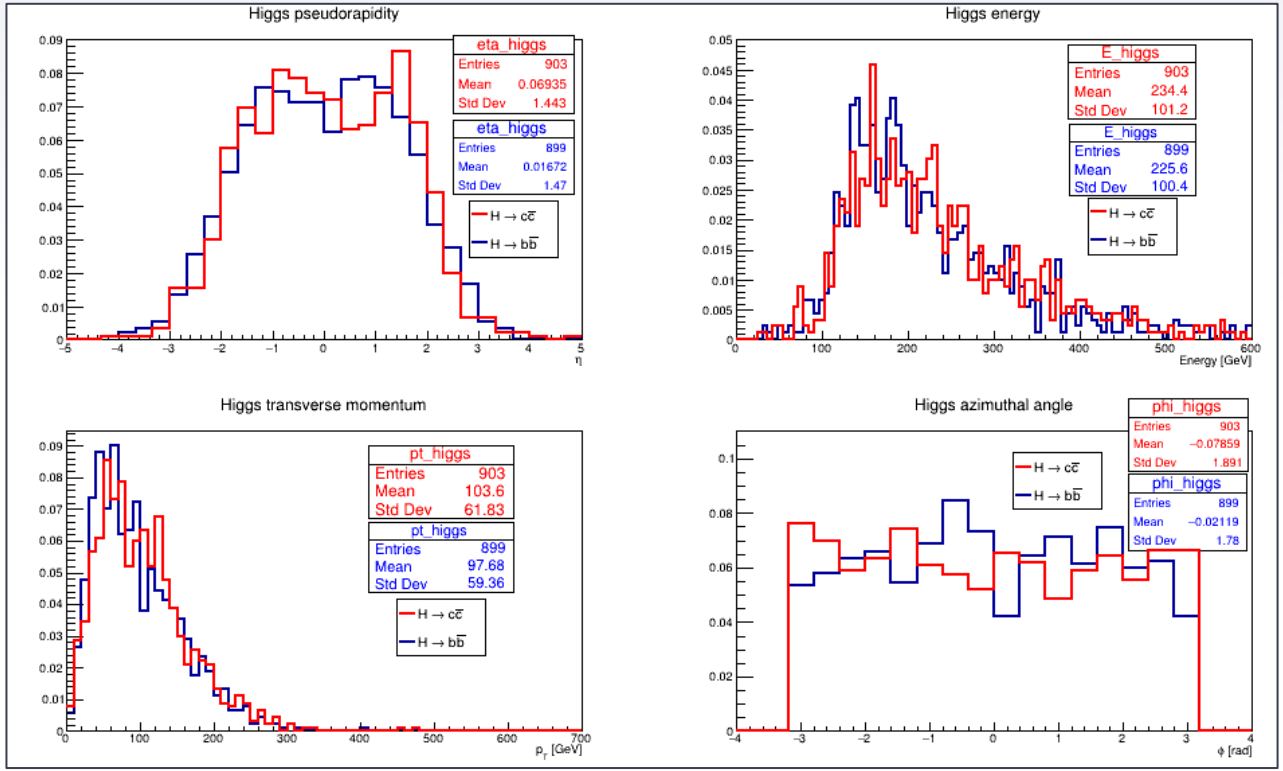
Any questions?

You can find me at:

- paola.mastrapasqua@ba.infn.it

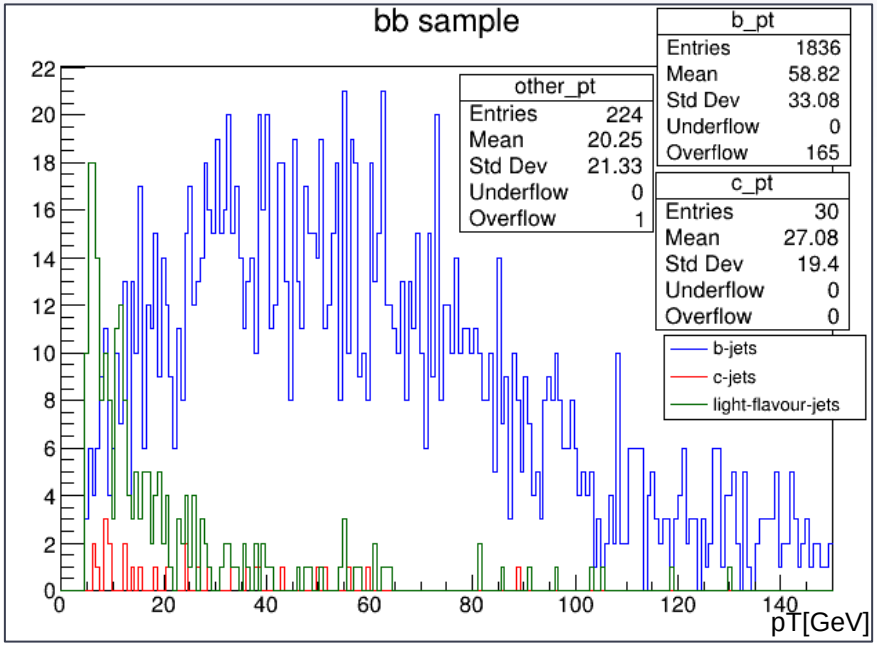
BACKUP

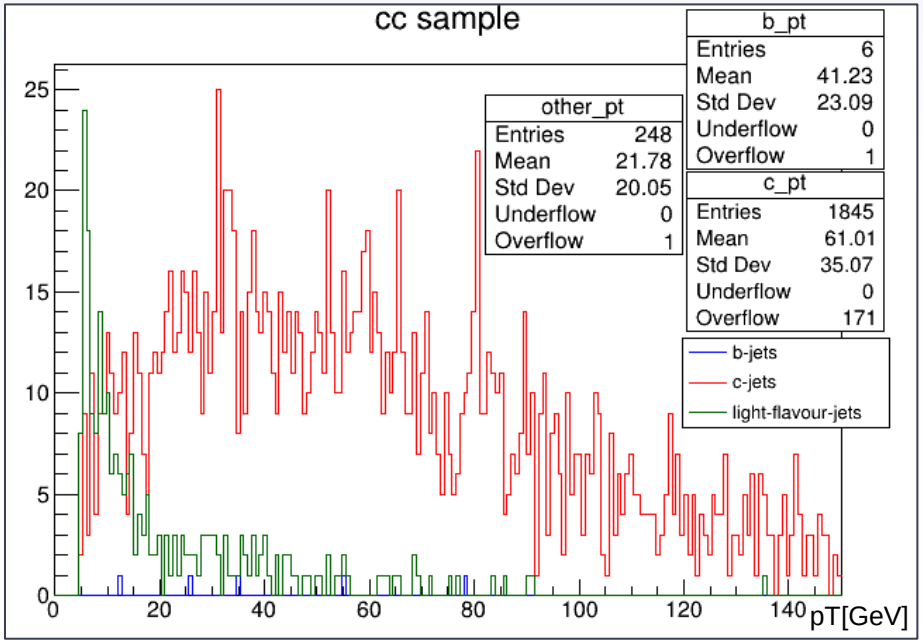
Only events with at least a jet pair are considered
If more then two jets are found, the two with the invariant mass closer to the Higgs mass are chosen



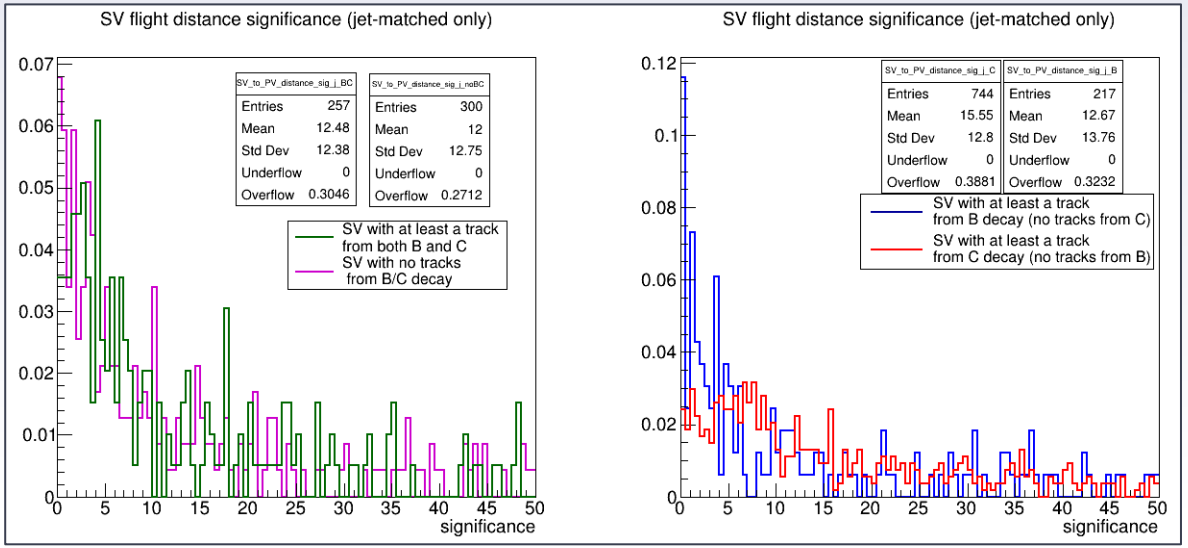
*Plots are not scaled to cross section · luminosity

pT distribution of jets

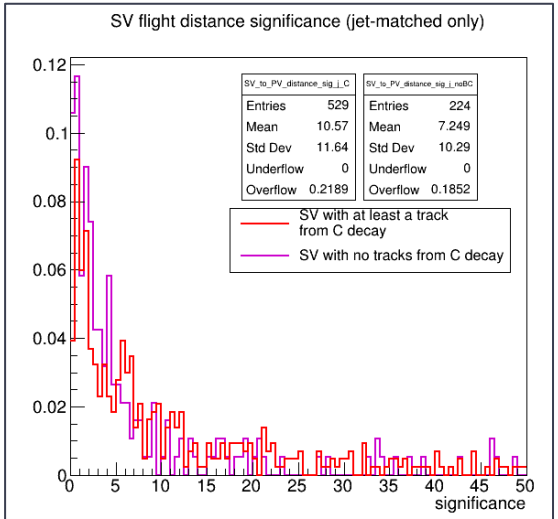




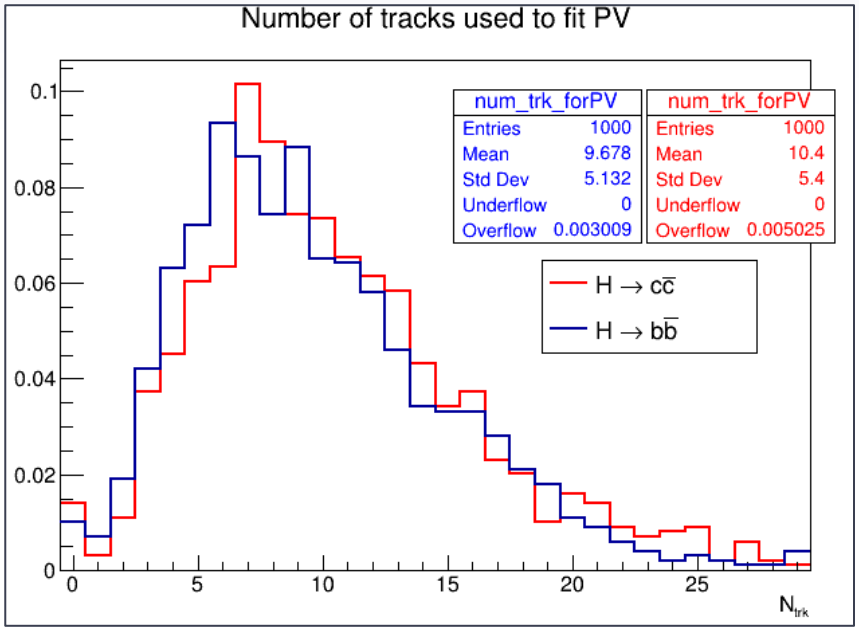
bb sample

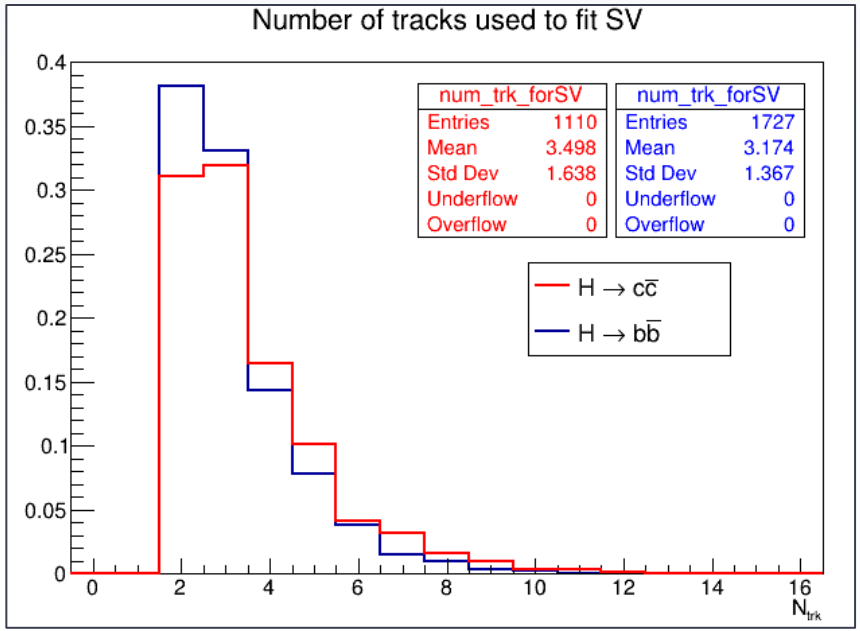


cc sample



Number of tracks to fit PV and SV





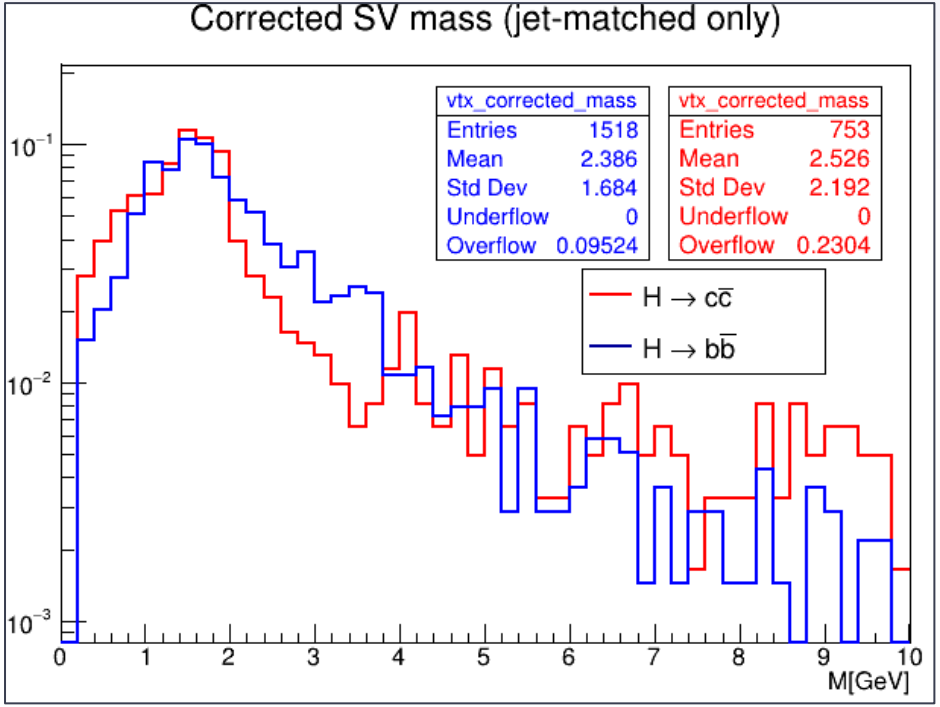
Corrected mass

Directly related to the mass of the heavy-flavour hadron

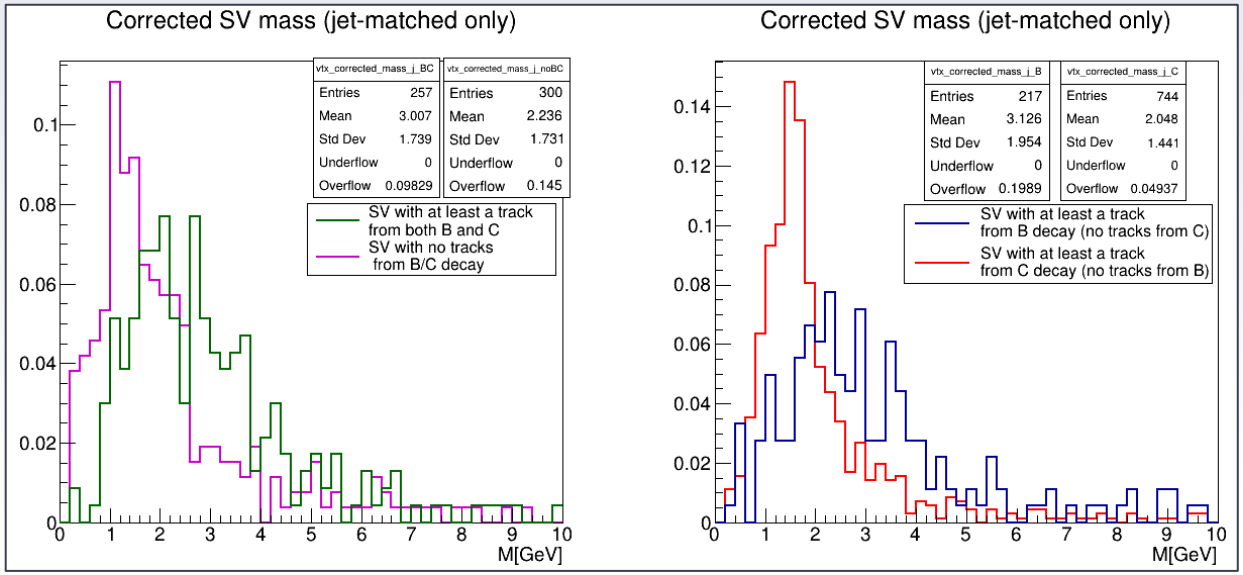
Defined as:

$$\sqrt{M_{SV} + p^2 sen^2\theta} + psen\theta$$

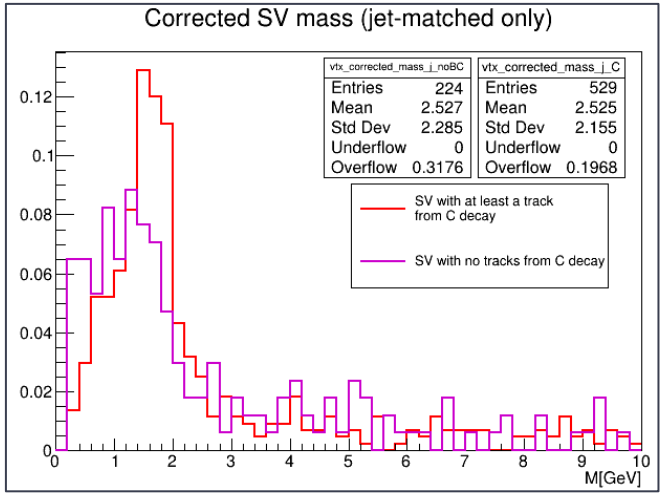
SV mass is corrected for the observed difference between the SV flight direction and SV momentum



bb sample



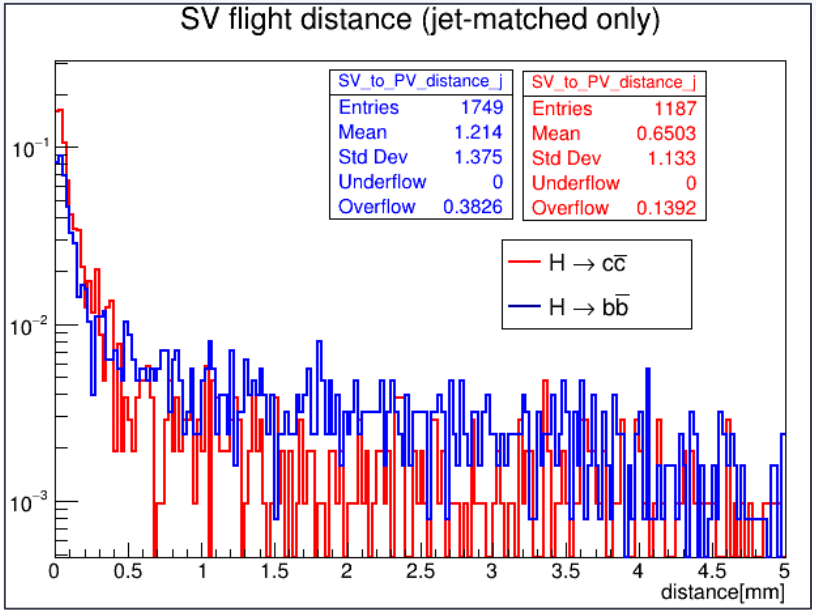
cc sample

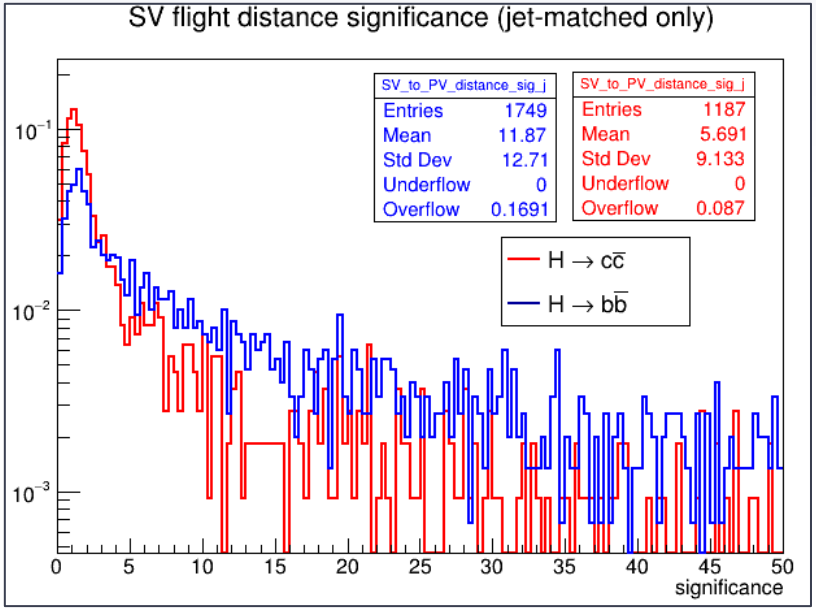


Efficiency and fake-rate

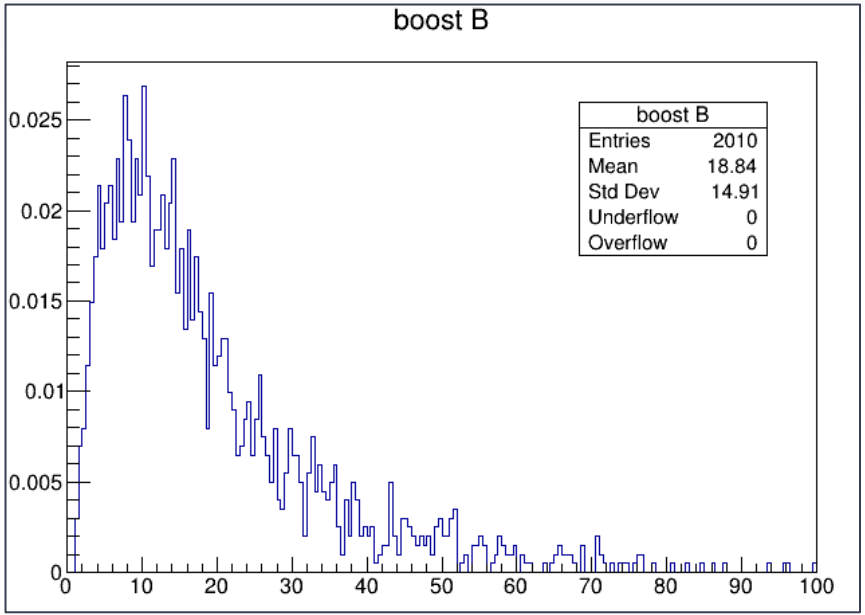
Min dist from IP →	0.001 mm		0.1 mm		0.3 mm	
	bb	cc	bb	cc	bb	cc
FAKE RATE SV (wrong/tot)	0.40595	0.61414	0.28266	0.42523	0.15974	0.25157
EFFICIENCY (SV per jet)	0.9325	0.6146	0.8916	0.529	0.8268	0.4081
SIGNAL EFFICENCY (% of jets with a SV)	0.68028	0.50569	0.66449	0.44661	0.63508	0.35827
BKG EFFICIENCY	0.40595	0.61414	0.28266	0.42523	0.15974	0.25157
SIG EFF/√BKG EFF	1.06771	0.64528	1.24984	0.68489	1.589	0.71429

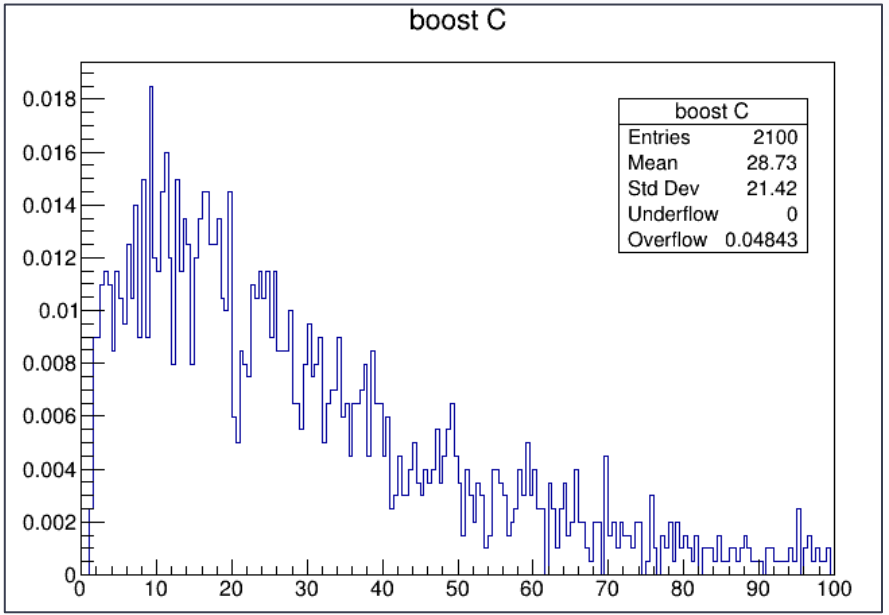
Flight distance - OLD



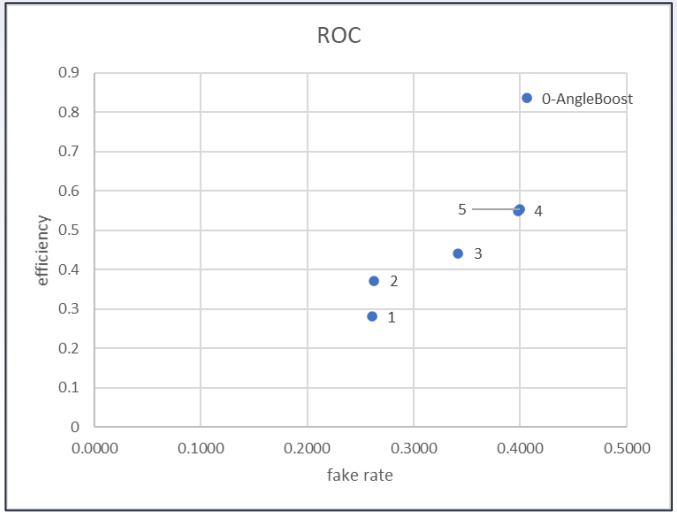


Lorentz factor for B/C hadrons





Attempts with different parameters



	1	2	3	4	5	Zero-Angle Boost
FAKE RATE SV (wrong/tot)	0.2607	0.2631	0.3419	0.3984	0.3998	0.4060
EFFICIENCY (SV per jet)	0.2808	0.3725	0.4422	0.5497	0.5540	0.8368
SIGNAL EFFICIENCY (% of recovertex)	0.2646	0.3281	0.3940	0.4532	0.4551	0.6158
BKG EFFICIENCY (=fake rate SV)	0.2607	0.2631	0.3419	0.3984	0.3998	0.4060
SIG_EFF/SQRT(BKG_EFF)	0.518125648	0.639673509	0.673748101	0.718009576	0.71973706	0.96648292

Parameters

Pink highlights the parameters changed from one attempt to the next one

		1	2	3	4	5	Zero_Angle Boost
PV	TrackMaxD0	0.02	20	20	20	0.2	0.2
	TrackMaxZ0	0.05	20	20	20	0.5	0.5
	TrackMinD0Err	0	0.015	0.02	0.02	0.02	0.02
	TrackMinVtxFtdHits	3	3	2	2	2	2
SV	TrackMaxD0	5	5	5	5	5	5
	TrackMaxZ0	5	5	5	5	5	5
	TrackMinPt	0.8	0.8	0.8	0.8	0.8	0.8
	TrackMinVtxFtdHits	1	1	4	4	4	4
	MassThreshold	100	100	100	10	10	10