First example resolutions of displaced vertices in exclusive B-decays (using Franco's Vertex fitter)

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FCC-ee topical meeting on vertexing, Feb 10, 2021

Many thanks to Roy Aleksan for very useful discussions !

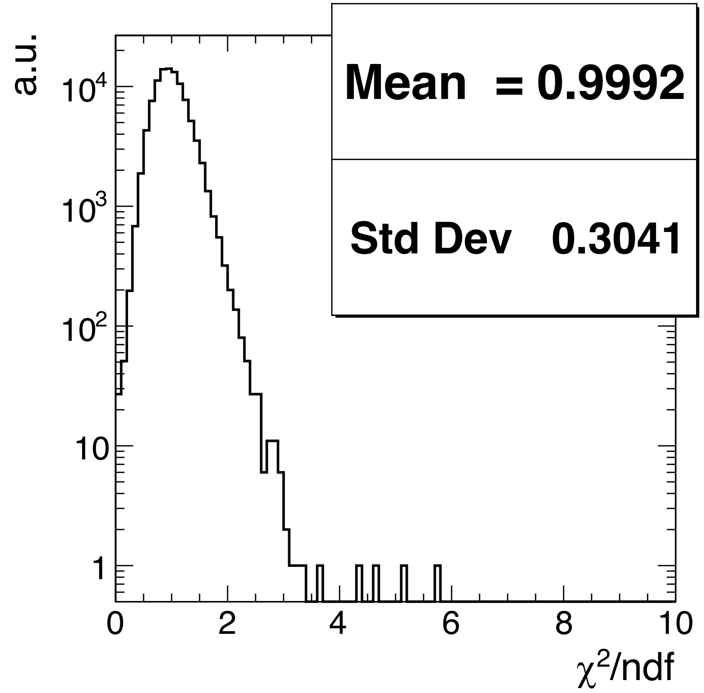
Setup

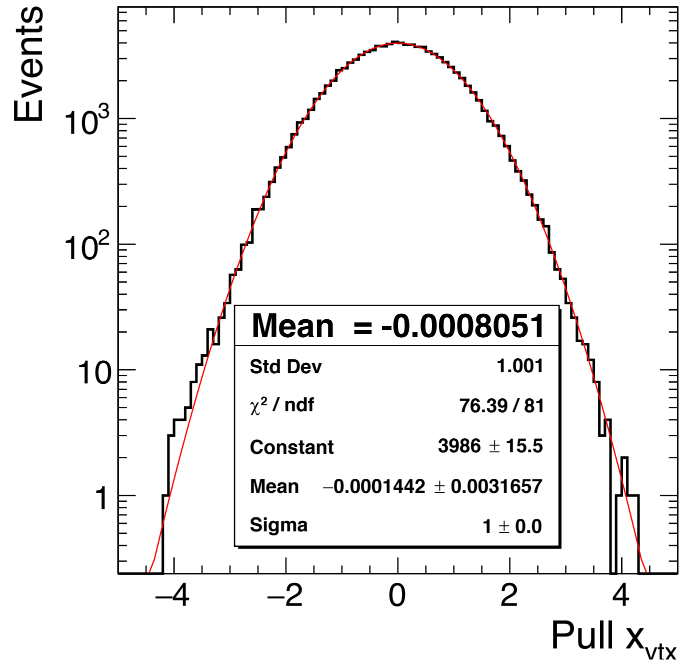
- Delphes samples in the EDM4HEP format
- $Z \rightarrow bb$ events at 91 GeV generated with PYTHIA + EVTGEN. Exclusive decays studied :
  - $Bs \rightarrow J/\psi\ \Phi \rightarrow \mu\mu KK$,
  - Bc or B+ $\rightarrow \tau\ \nu \rightarrow 3\pi\ \nu\nu$,
  - $Bs \rightarrow Ds\ K \rightarrow (\ \Phi\ \pi\ )\ K \rightarrow (\ K\ K\ \pi)\ K$
- Delphes uses the IDEA card, with the TrackCovariance module to produce 5-parameters tracks
- Analysis within the FCCAnalyses framework
  - VertexFitter code from FB implemented
  - Actually not the latest version from his code

Caveats:
Only the diagonal elements of the covariance matrix of the track parameters are stored currently in the EDM4HEP files. May affect a bit the vertex fits shown here.

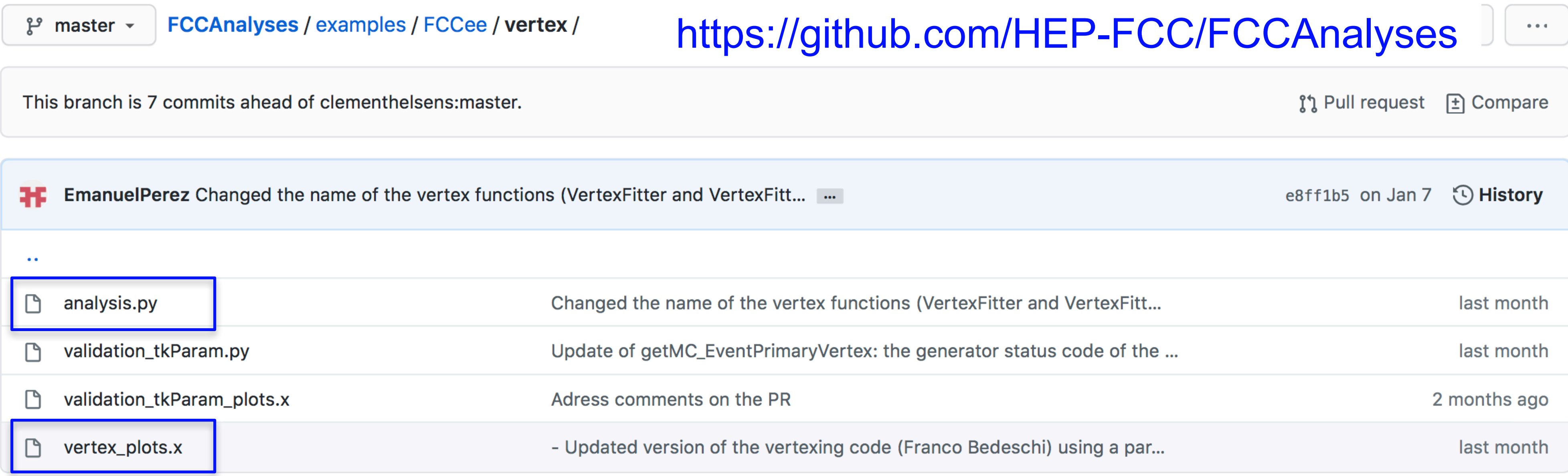
- does not seem to have a large effect when fitting a primary vertex with many tracks. But may have a larger effect here.

Setup validation: primary vertex in $Z \to$ uds events





https://github.com/HEP-FCC/FCCAnalyses



$B_s \rightarrow J/\psi\ \Phi \rightarrow \mu\mu KK$

→ One secondary vertex (Bs), with 4 tracks

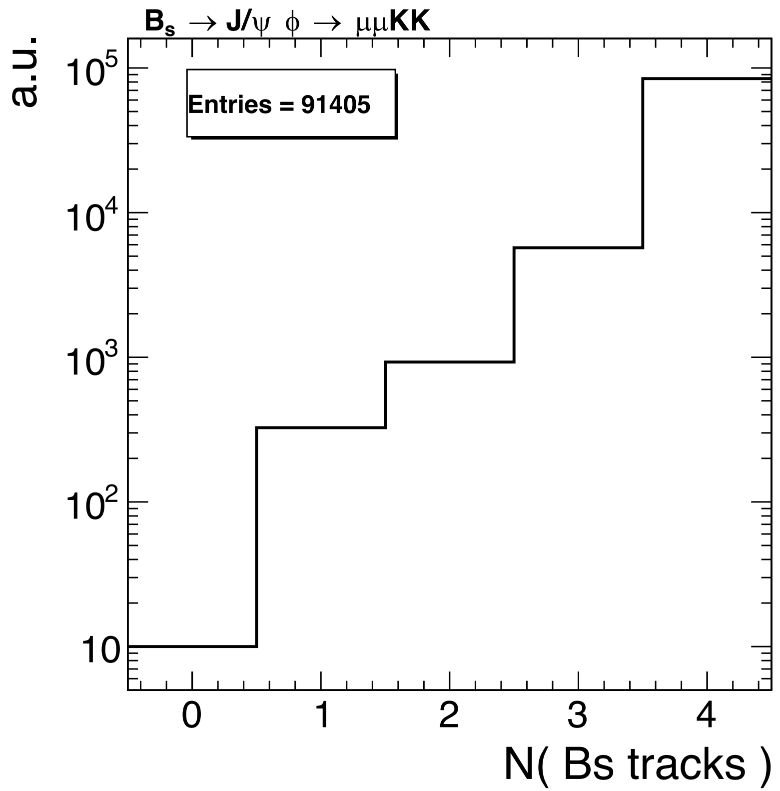
Bs → J/ψ Φ → μμKK

MC-matching : Use the reco'ed tracks that are matched to the muons from the J/ψ and to the kaons from the Φ. No combinatorics for the while.

Four tracks are found in 92% of the cases.

N(tracks) < 4 when one of the final state particules is forward/backward, or has a very low energy (cf Tk efficiency in Delphes).

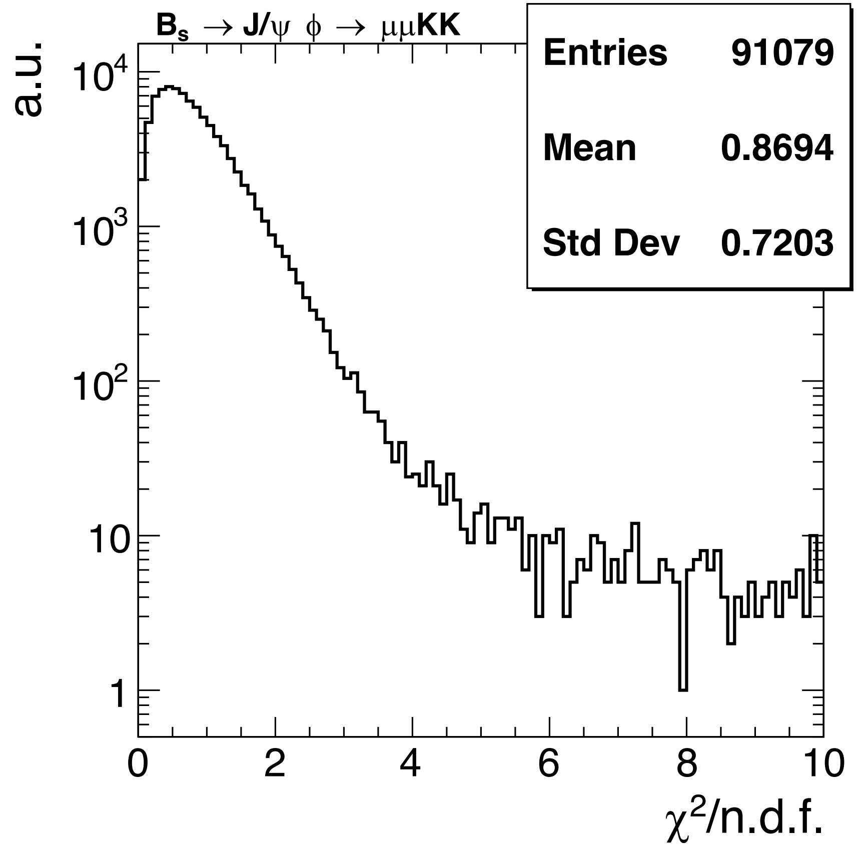
Run the Vertex-fitter code (Franco Bedeschi) over these tracks to determine the Bs decay vertex.

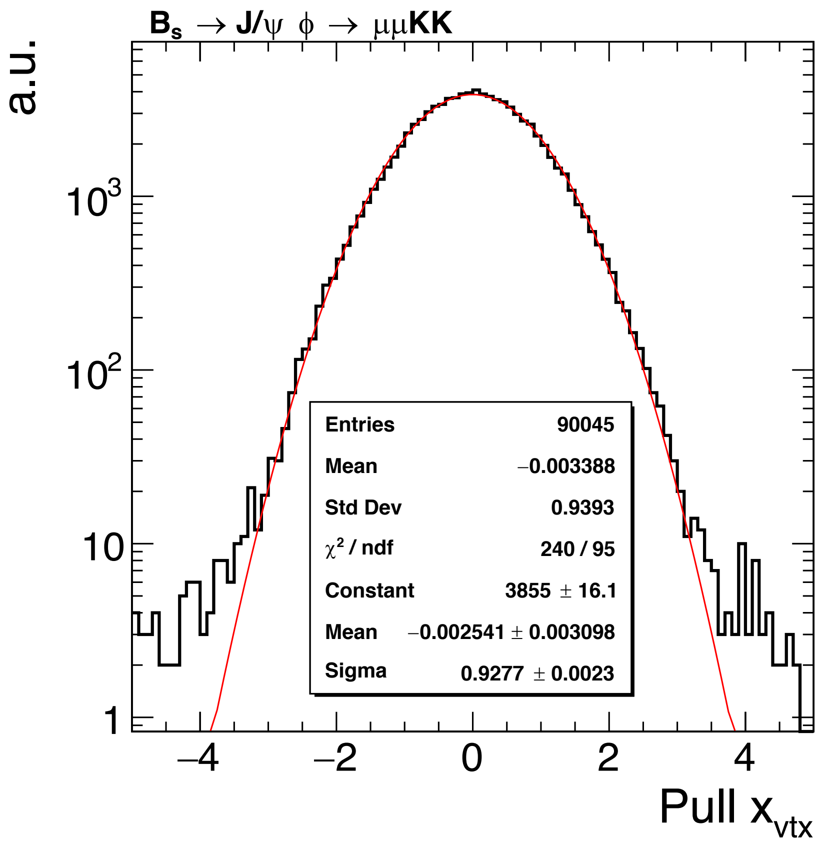


Bs → J/ψ Φ → μμKK: chi2 and pulls

The Bs vertex is reconstructed with a $\chi 2$ / ndf < 10 in 98.5% of the cases.

Not perfect $\chi 2$ distribution – effect of the absence of the non-diag terms in the track covariance matrix ?



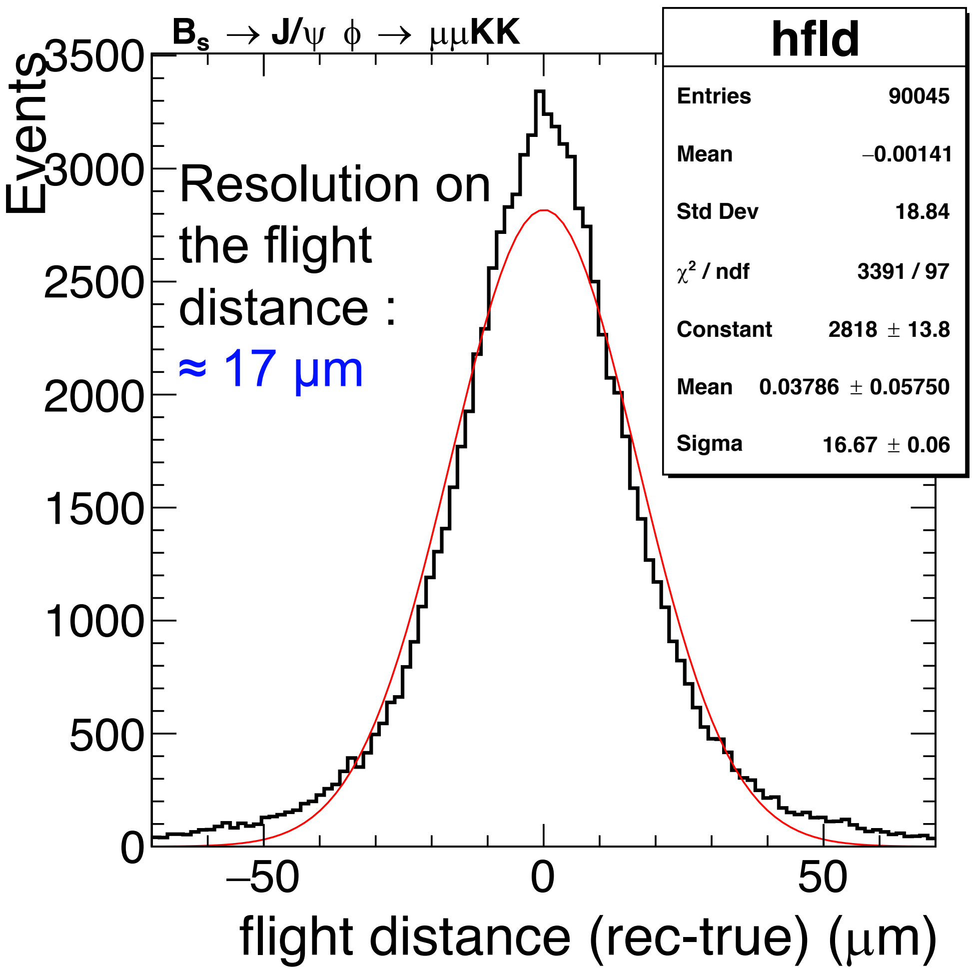


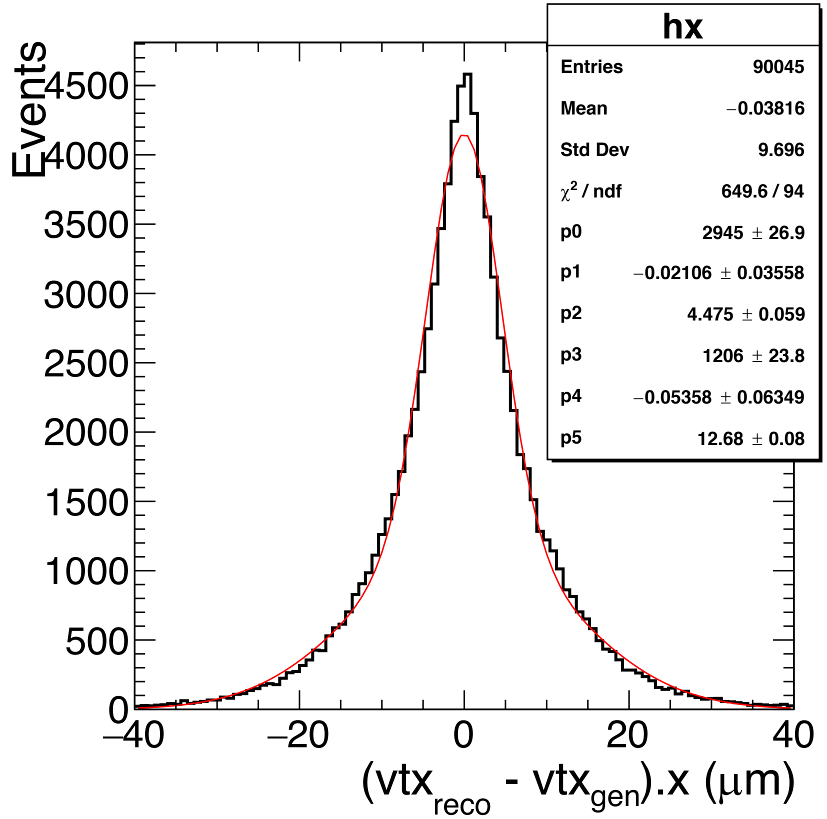
Pulls of the reco'ed vertex position are OK_ish, with a σ ≈ 0.93, similar for x, y and z.

Bs → J/ψ Φ → μμKK: resolutions

Example: resolution in x, fitted with the sum of two Gaussian functions.

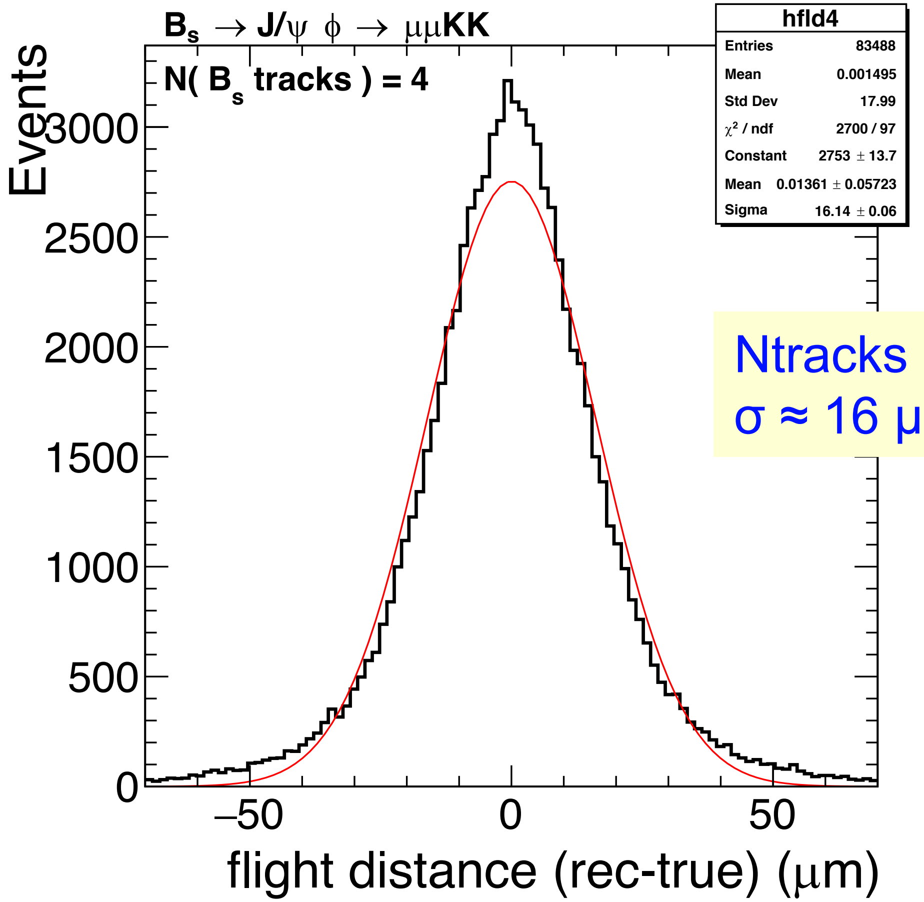
Resolution on the flight distance : ≈ 17 µm



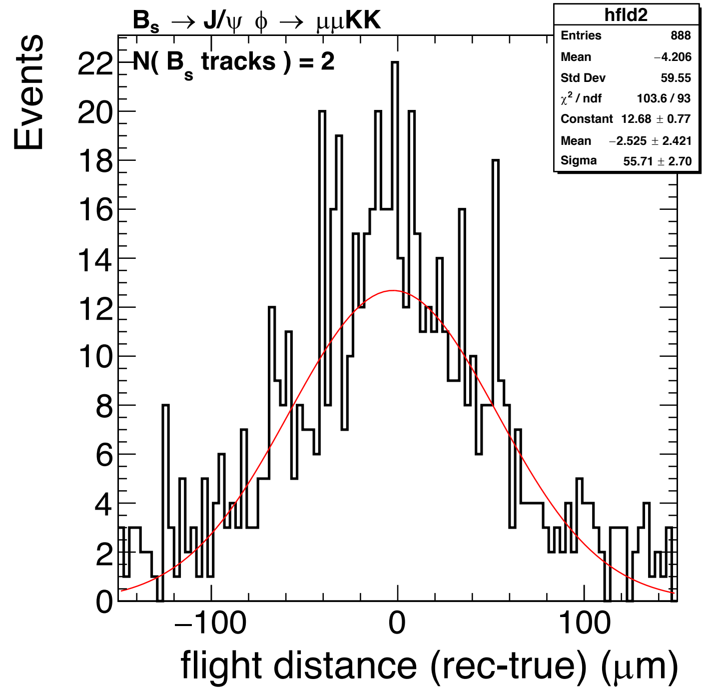


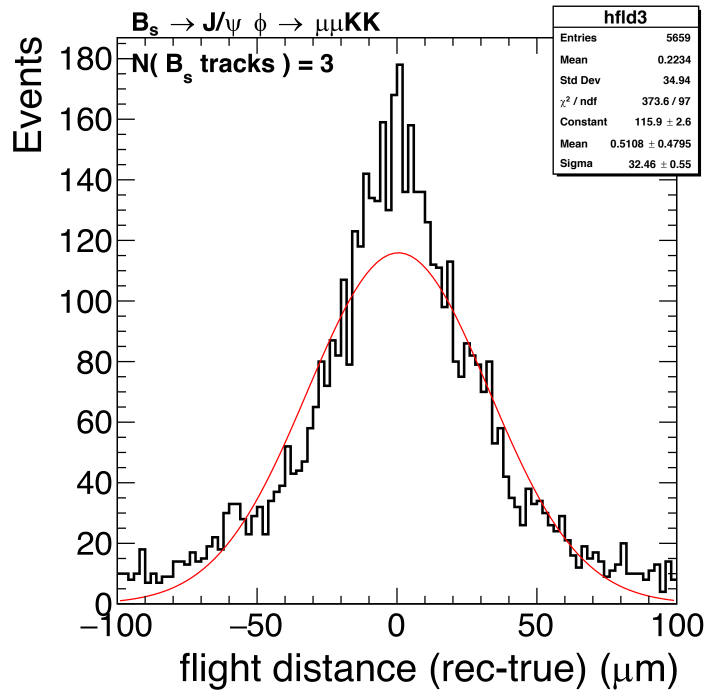
NB: Flight distance: events are generated with PV = (0,0,0), no attempt there o reconstruct the PV (a resolution of 3 µm is expected with the BS constraint, i.e. is negligible in the resolution of the flight distance).

Bs → J/ψ Φ → μμKK: resolutions on flight distance, vs Ntracks



Ntracks = 4 :
σ ≈ 16 μm

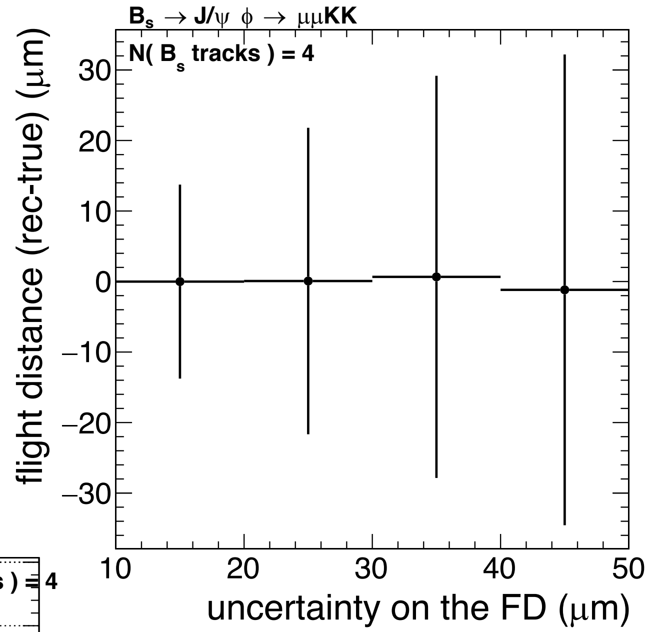


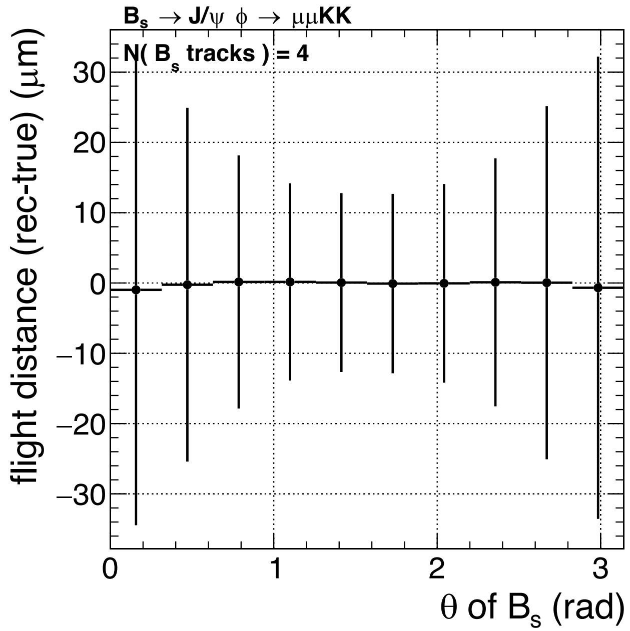


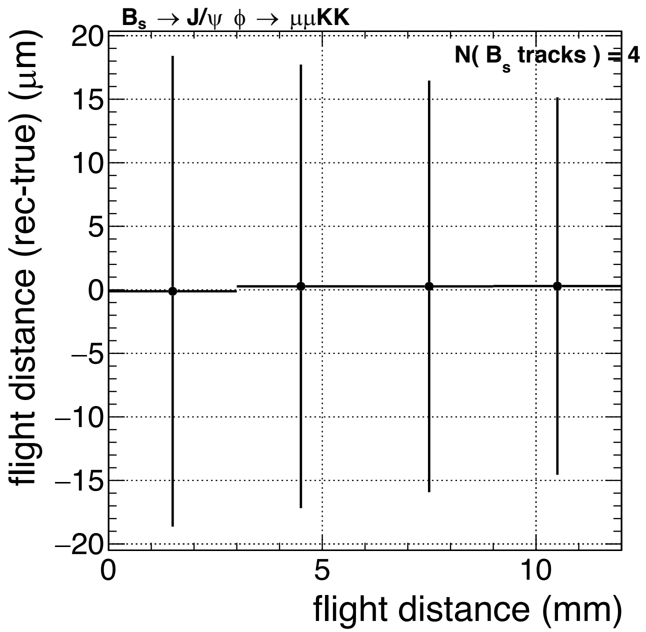
Ntracks	σ on flight dist.
2	56 μm
3	33 μm
4	16 μm

Bs → J/ψ Φ → μμKK, Ntracks = 4

TProfiles of the resolution on the flight distance: error bars show the RMS.



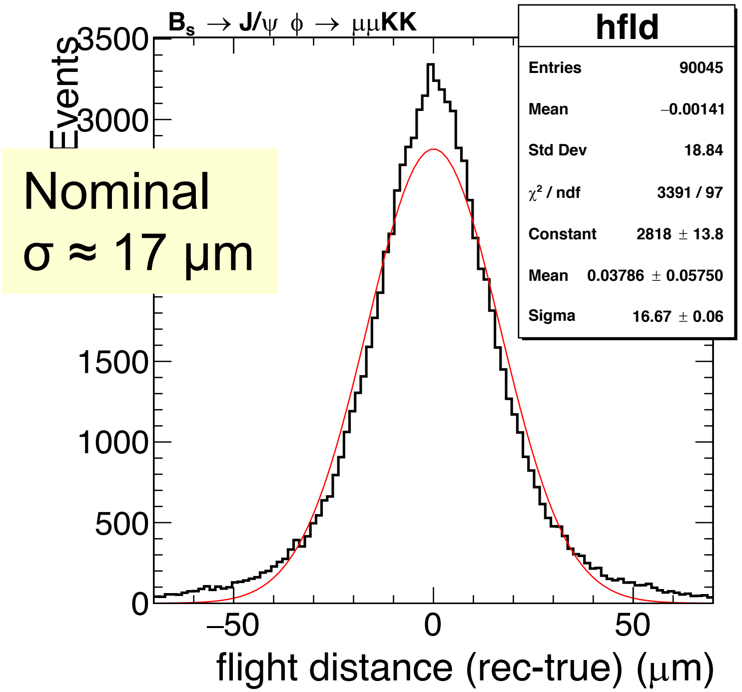


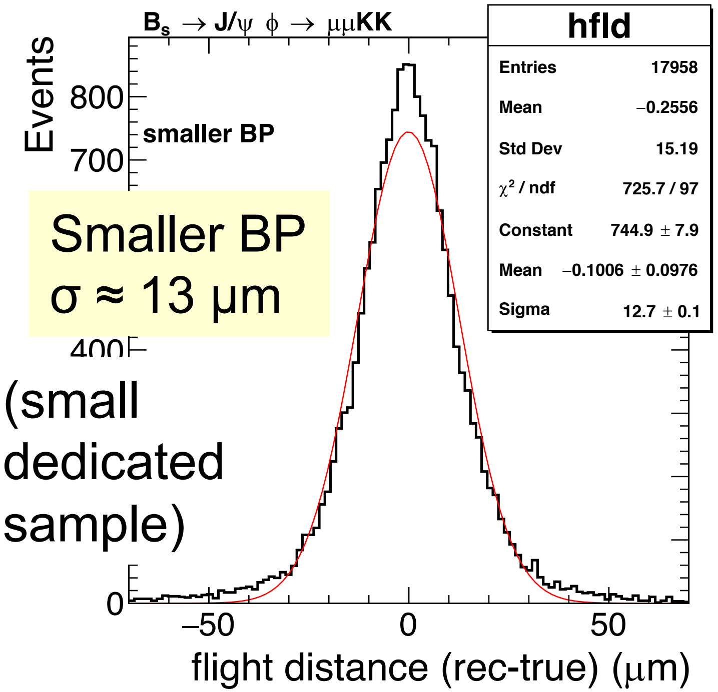


- Better resolution in the central region
- No strong dependence w.r.t. the flight distance itself
- No strong dependence seen either w.r.t. the angular separations between the four tracks.

Bs → J/ψ Φ → μμKK: beam-pipe radius

- All what was shown previously corresponds to the "nominal" beam-pipe with an inner radius of 1.5 cm : first layer of the VTX sits at 1.7 cm from the beam-line.
- Under consideration: smaller BP, R = 1 cm → VXD at 1.2 cm





(small dedicated sample)

A setup is in place that allows to study: different radiii, different single-point resolution, the effect of the thickness of the layers / beam-pipe, etc.

Detailed studies can be started right now ! Volunteer ? Contact us !

Bc / B+ $\rightarrow \tau\ \nu \rightarrow$ 3π $\nu\nu$

$\rightarrow$ Can not reconstruct the secondary vertex (Bc) since only the tau track
$\rightarrow$ tertiary vertex (tau decay), with 3 tracks

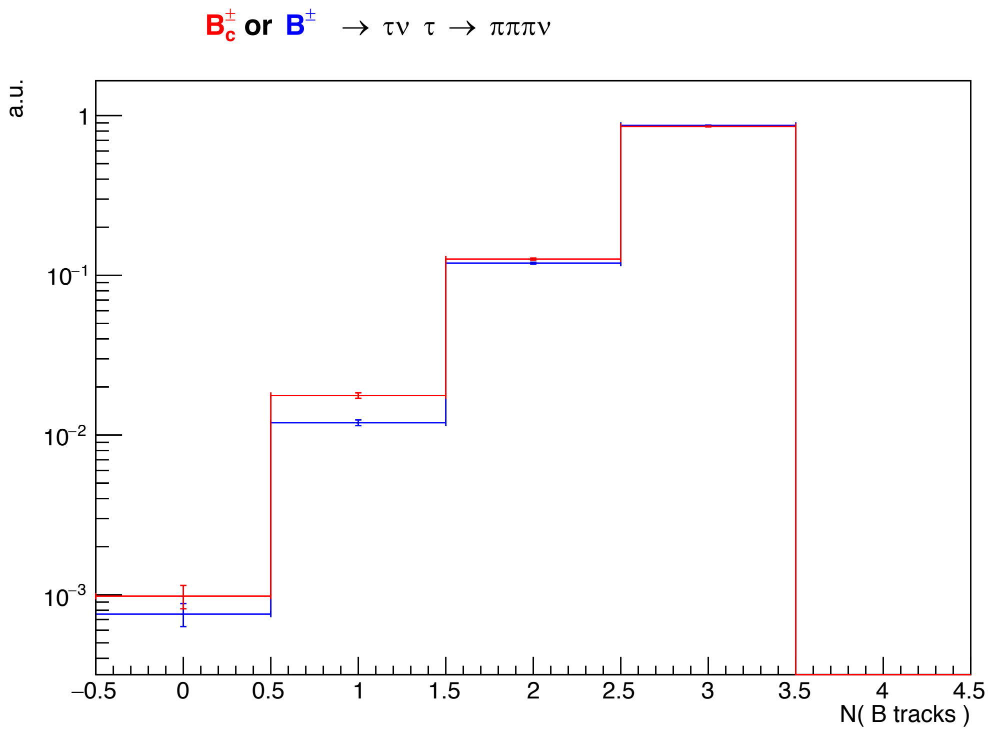
Lifetime will be the key to separate the Bc signal from the B+ background.
Hence both the Bc and the B+ are compared in the next slides.

Bc, B+ $\rightarrow \tau \nu \rightarrow 3\pi\, \nu\nu$

Proceed as before: use the MC-association to find the Delphes tracks that correspond to the pions.

In 15% of the cases, at least one of the charged pions is not reconstructed as a track. That is mainly because of the soft spectrum of these pions.

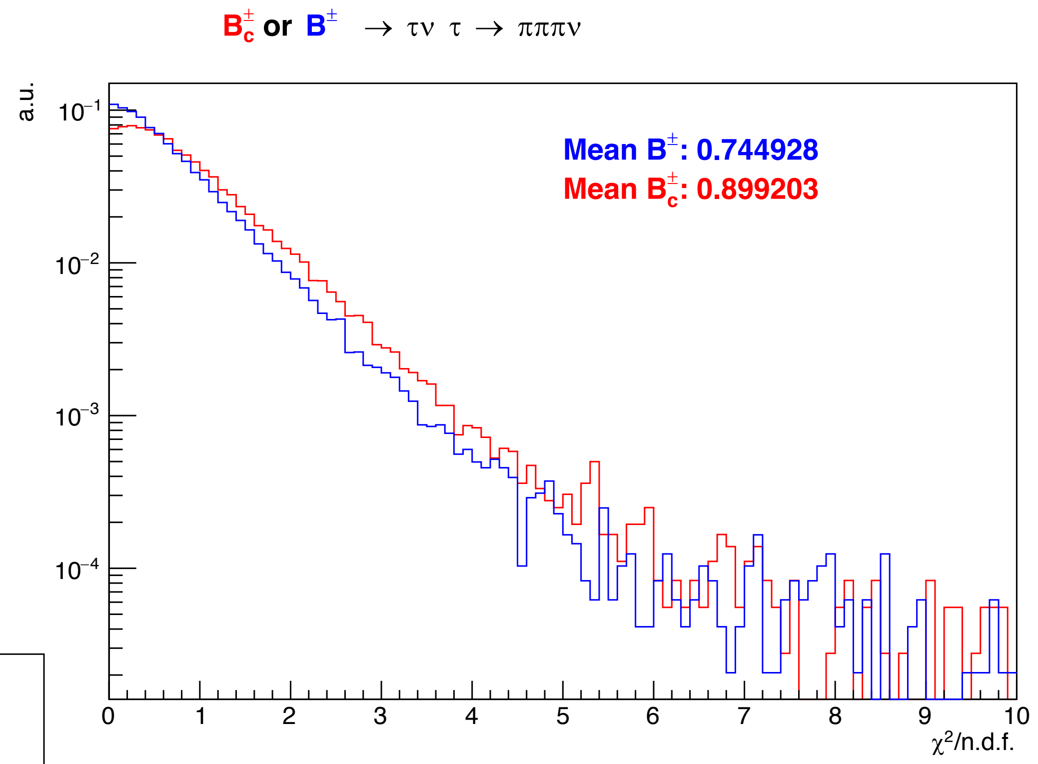
Small differences between the multiplicities of the Bc and the B+ are under investigation.

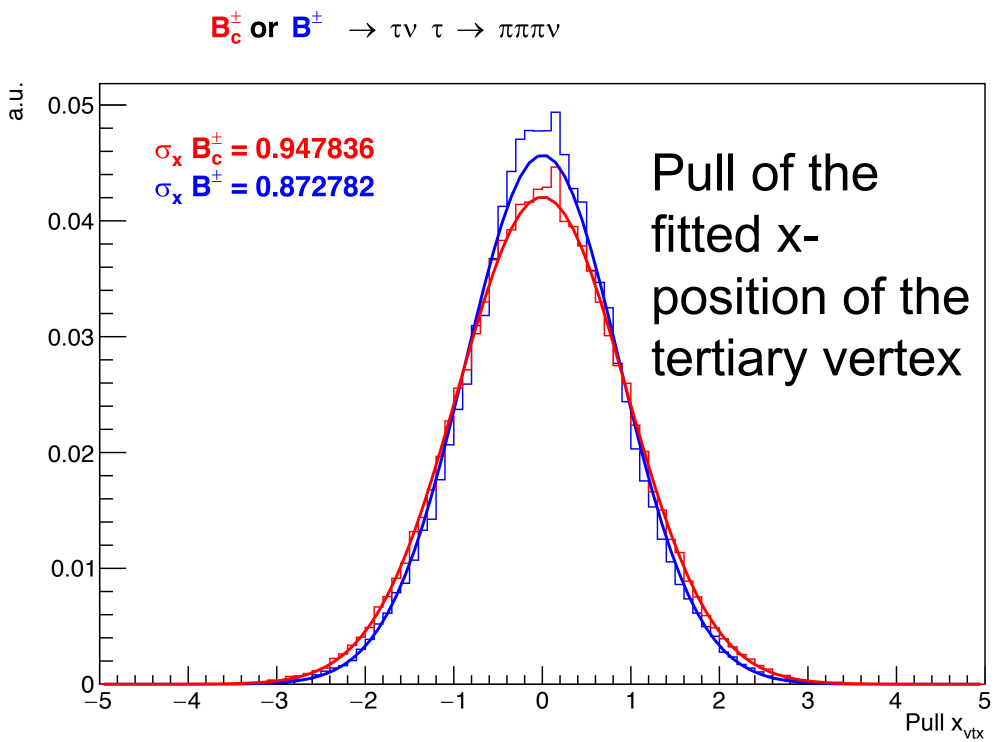


Next: process these tracks through the vertex fitter to reconstruct the tau decay vertex.

Bc, B+ $\rightarrow \tau\, \nu \rightarrow 3\pi\, \nu\nu$: quality of the fits

Same observation as before for the $\chi 2$ / ndf and the pulls – they are a bit low.





Pull of the fitted x-position of the tertiary vertex

The fits are better for the Bc than for the B+ - the reason for this is under investigation.

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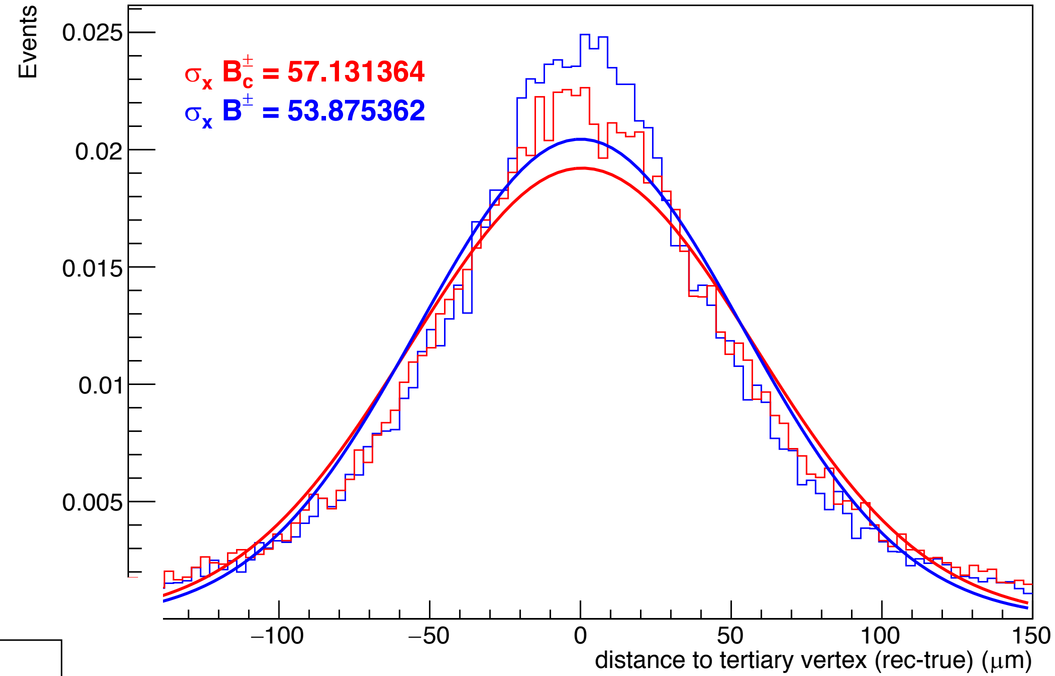
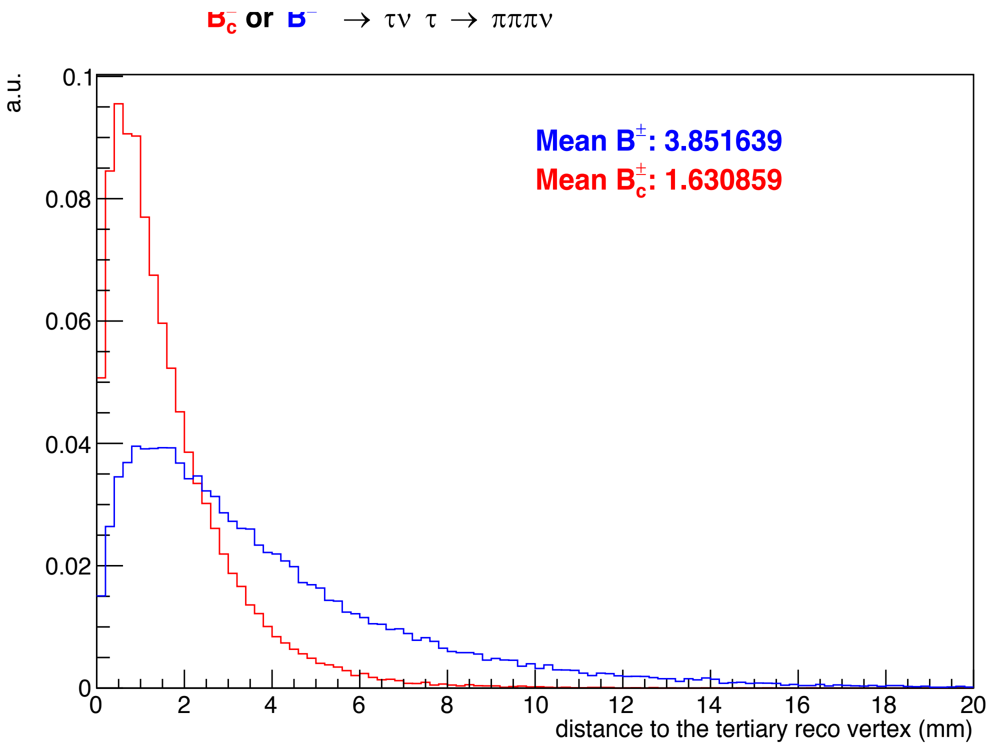
Bc, B+ $\rightarrow \tau\,\nu \rightarrow$ 3π $\nu\nu$: position of the tertiary vertex



Position of the tertiary vertex: reconstructed with a resolution of about 55 μm.



Which offers a handle to separate the Bc signal from the B+ background.

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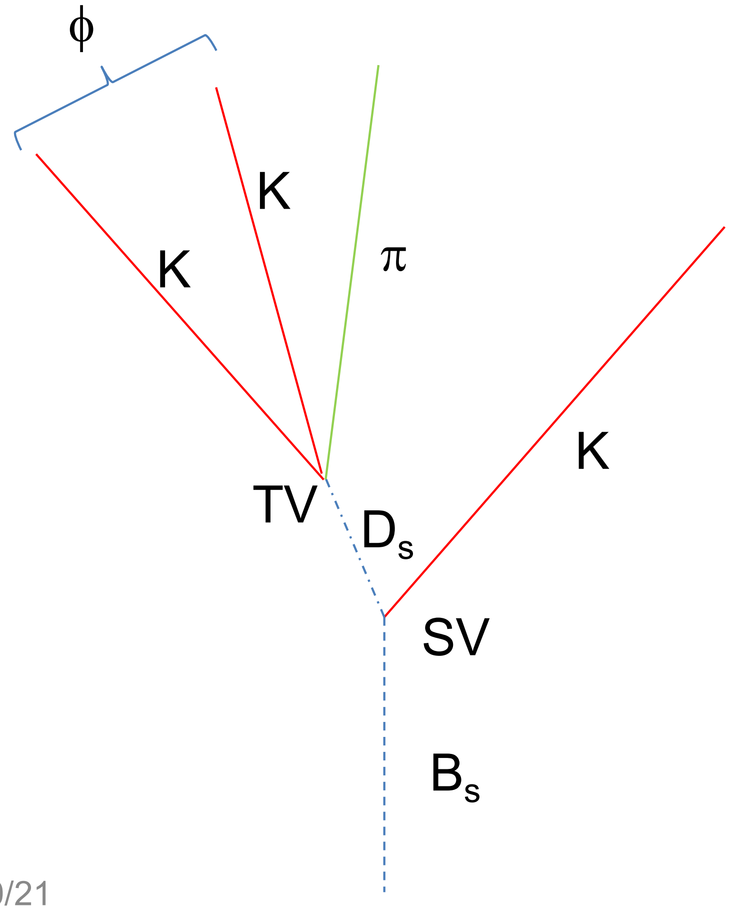
$B_s \rightarrow D_s K \rightarrow (\Phi \pi) K \rightarrow (K K \pi) K$



- a secondary vertex : $B_s \rightarrow D_s K$
- a tertiary vertex, $D_s \rightarrow K K \pi$

Bs → Ds K → (Φ π) K → (K K π) K

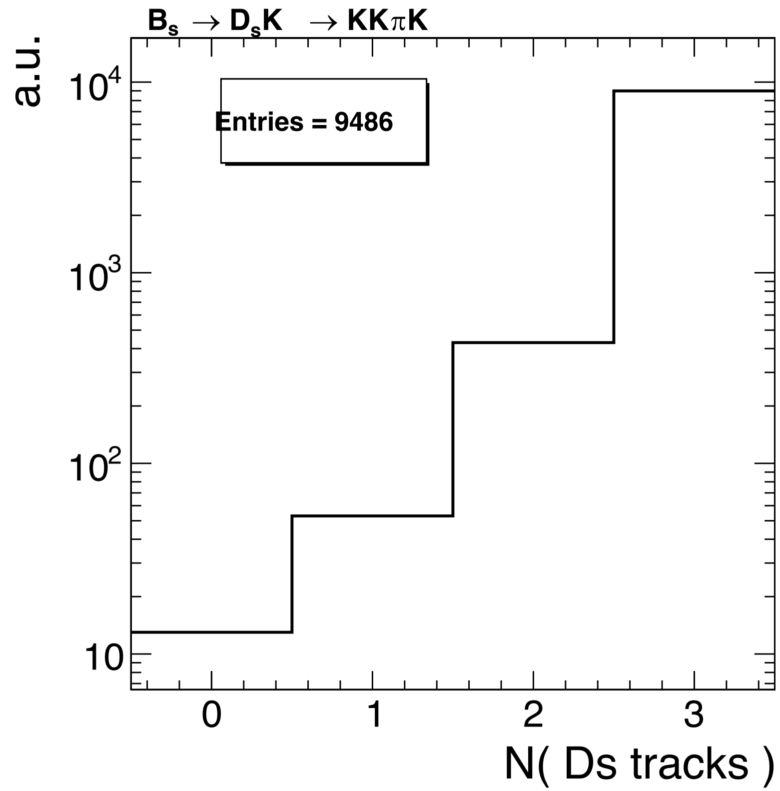
Now we have

- a secondary vertex : Bs → Ds K
- And a tertiary vertex, Ds → K K π

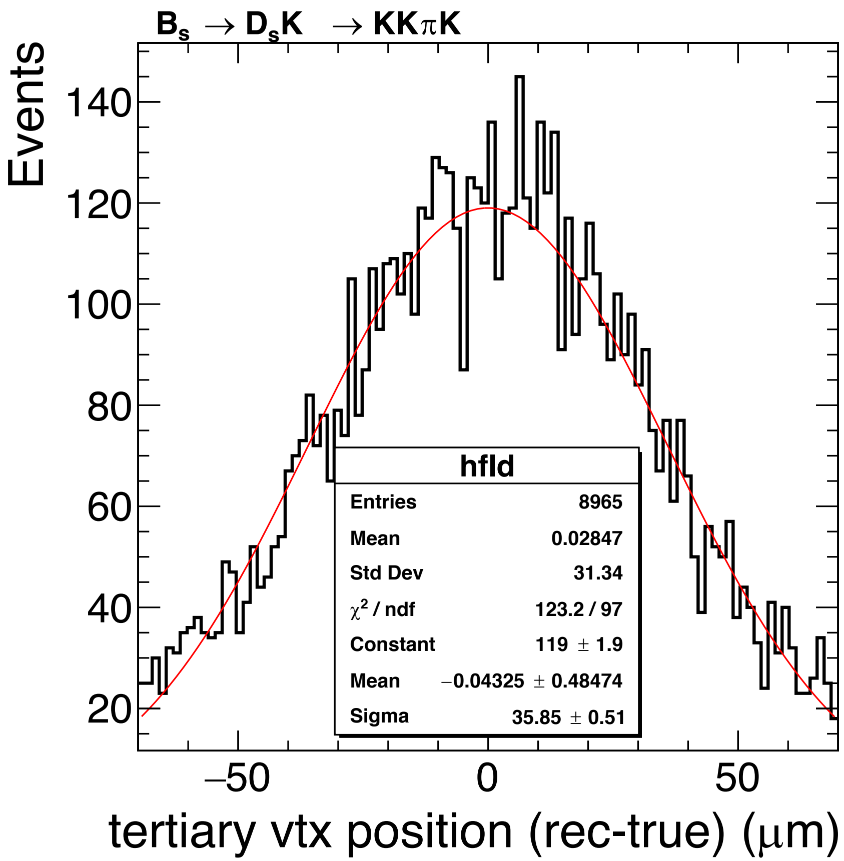
First step: reconstruct the Ds decay vertex. Proceed as previously with tracks matched to MC-truth information, i.e. no combinatorics.

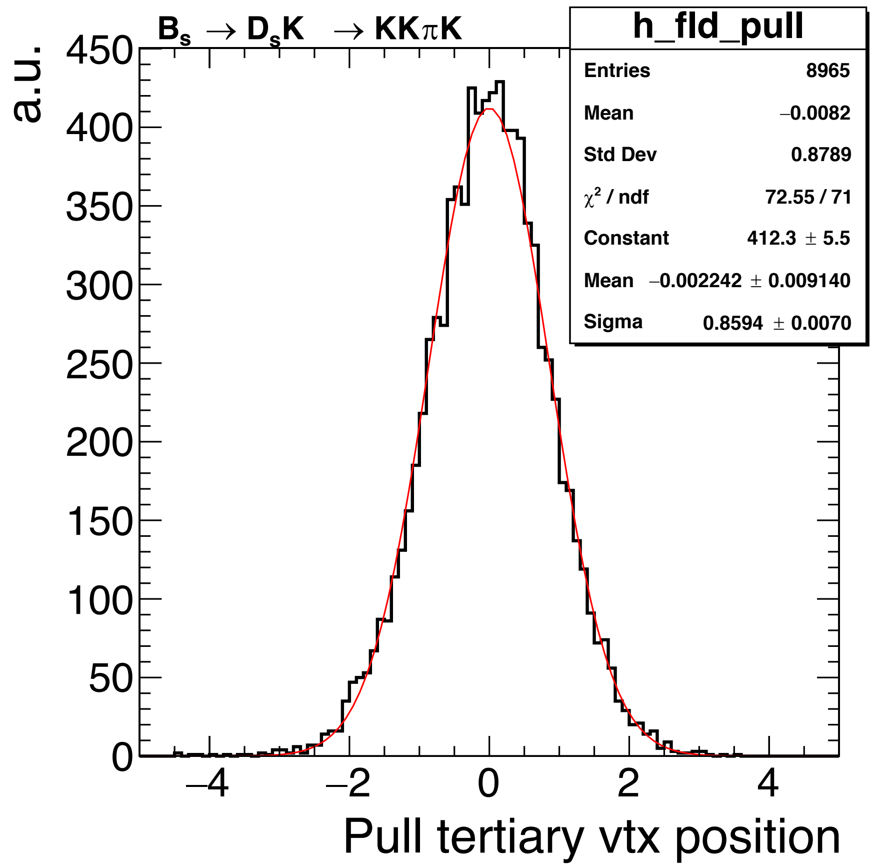
In 95% of the cases, 3 tracks are found.

Require N(Ds Tracks) = 3 in the following.



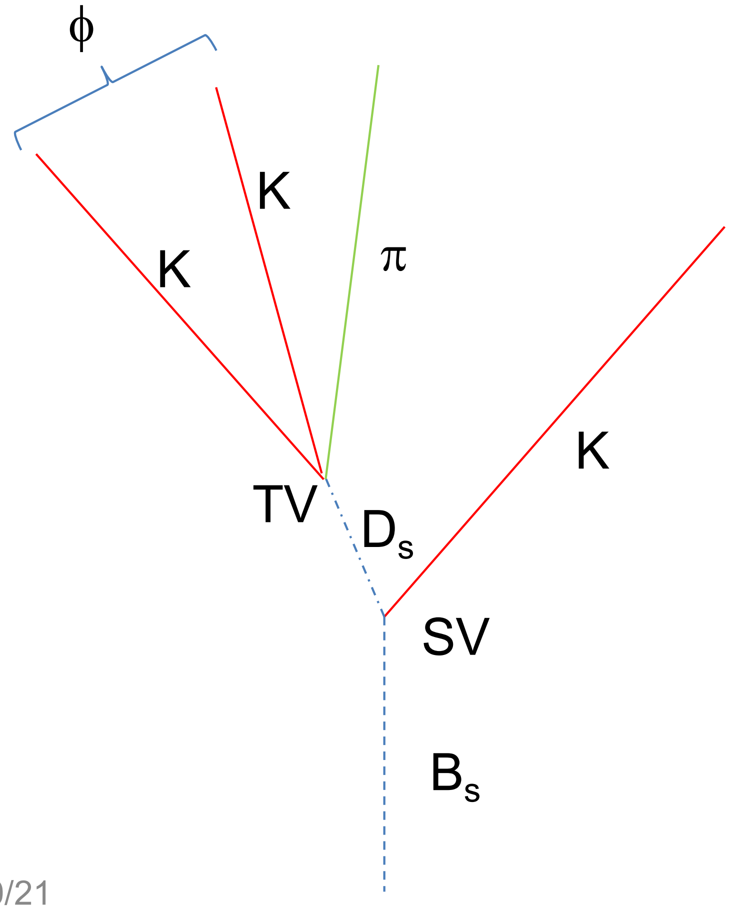
Bs → Ds K → (Φ π) K → (K K π) K : Ds decay vertex





- The Ds decay vertex is reconstructed with a resolution of about 35 μm
  - Comparable to Bs → μμKK with 3 tracks
- Pulls are not perfect again, σ is about 0.86

Now that we have the TV :



Determine the momentum that comes out from the TV, so we can reconstruct a Ds track and use it, together with the "bachelor K", to fit the SV.

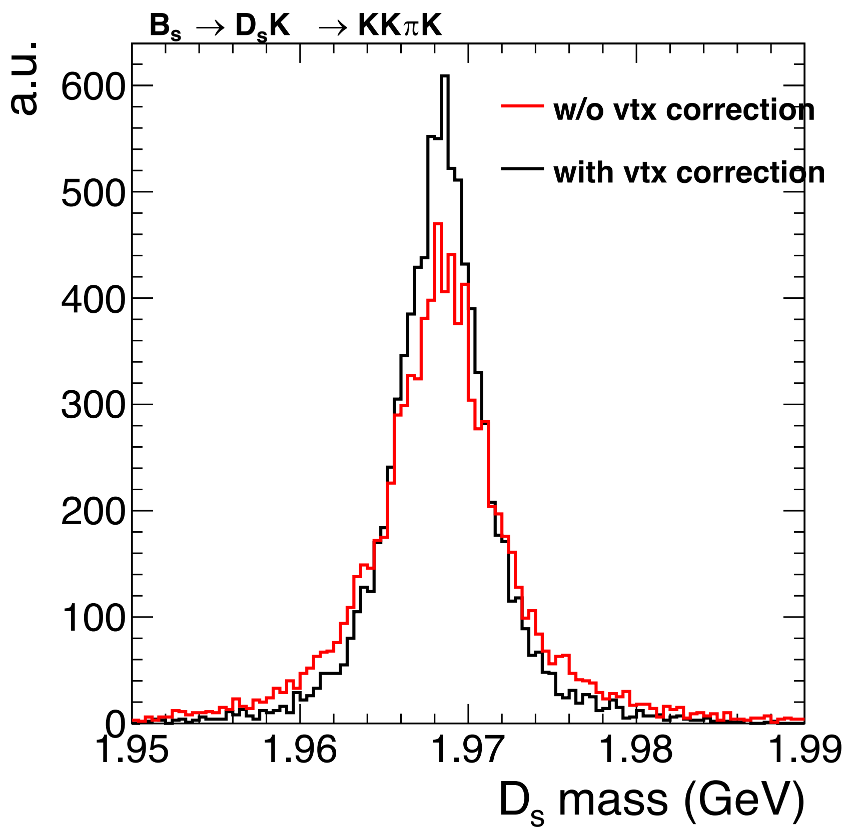
$B_s \rightarrow D_s K \rightarrow KK\pi K$: reconstruct the Ds

We have the 3 tracks from the Ds and their (px, py, pz) at their point of dca.

To reconstruct

p(Ds) = p (K-) + p(K+) + p(Pi+)

at the Ds decay vertex:
first need to propagate these 3 tracks from their dca to the Ds decay vertex



σ(Ds) ≈ 2.8 MeV with the propagation, 3.8 MeV without

Bs → Ds K → KKπK : the Ds “pseudo-track”

Now we have the (px, py, pz) of the Ds at its decay point. From the Ds momentum and its decay vertex, we can create a “pseudo-track” – i.e. a set of 5 parameters (d0, φ, rho, z0, tanLambda).

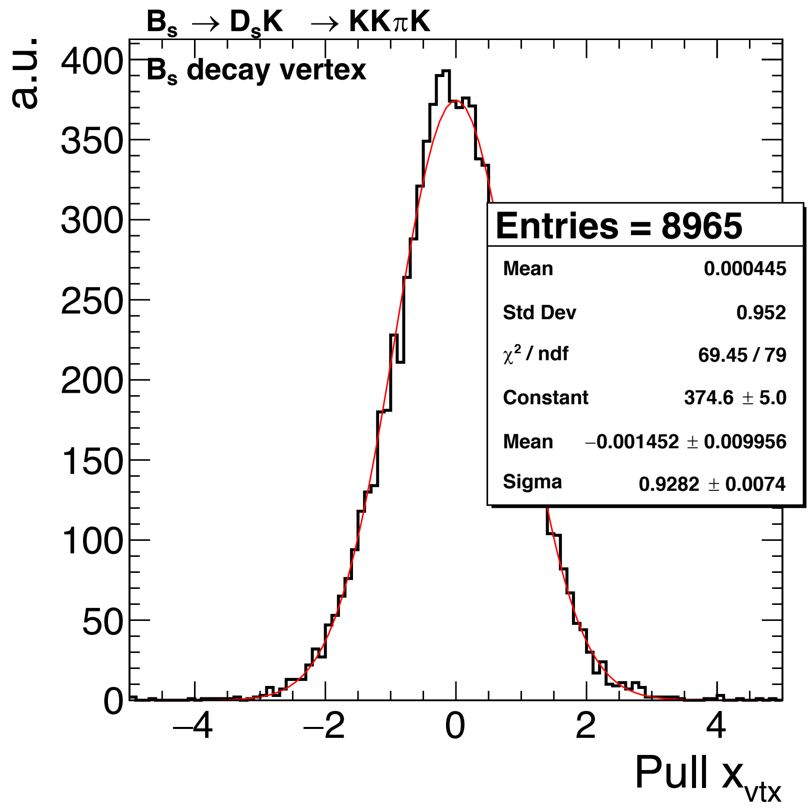
To run the vertex fitter over this Ds pseudo-track + the track of the bachelor K : need a covariance matrix for the parameters of the Ds pseudo-track.

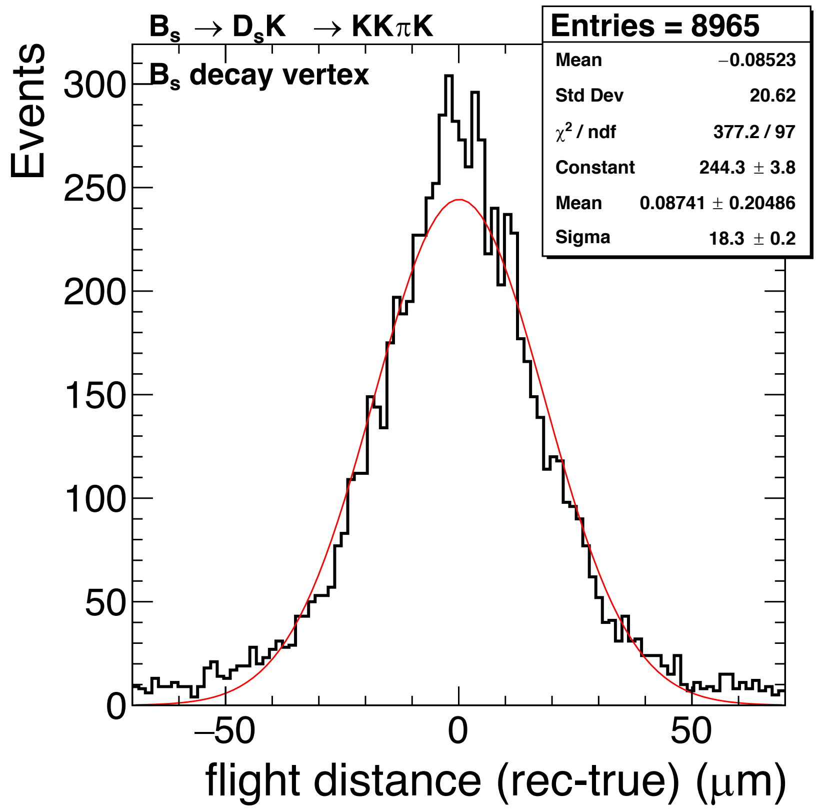
Brute force method:

- Smear the parameters of the Ds legs, according to their covariance matrix
- Re-fit a Ds vertex with these smeared tracks
- Propagate the tracks to this vertex to reconstruct the Ds momentum
- Hence the 5-parameters of the Ds tracks
- Do this NN times and determine the variances of the Ds-track parameters

Bs → Ds K → KKπK: the Bs vertex

Finally: run the vertex fitter over the bachelor-K track & the Ds pseudo-track





- Pulls are OK-ish
- Resolution on the Bs flight distance is about 18 μm.

Conclusions

The vertex fitter of Franco allows several interesting studies to be made

- a determination of the expected resolutions on displaced vertices in chosen examples, as shown here
  - Very first results presented here, to be consolidated & pursued
  - The analysis shown here will be put in the central repository and documented

- An estimation of the effect of variations of the detector model: change the radii of the layers of the vertex detector, the thickness of the layers or the BP, the single-hit resolution
  - This can be pursued already now with the tools that are in place !

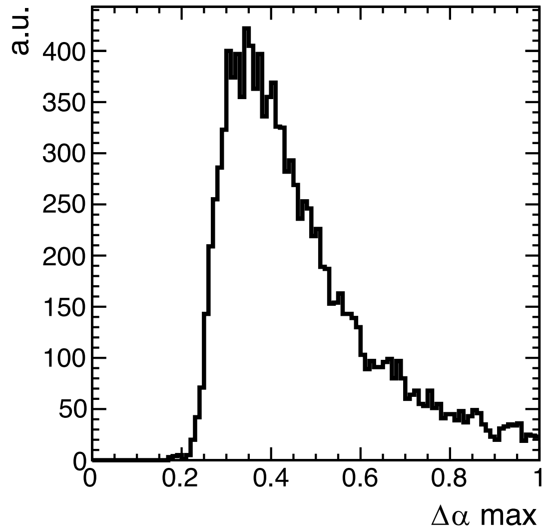
- Other short term projects: e.g. write a vertex-finding algorithm that runs the fitter iteratively, to determine first the primary vertex, and then displaced vertices, in order to tag “b-jets” inclusively.
  - Could be started now.

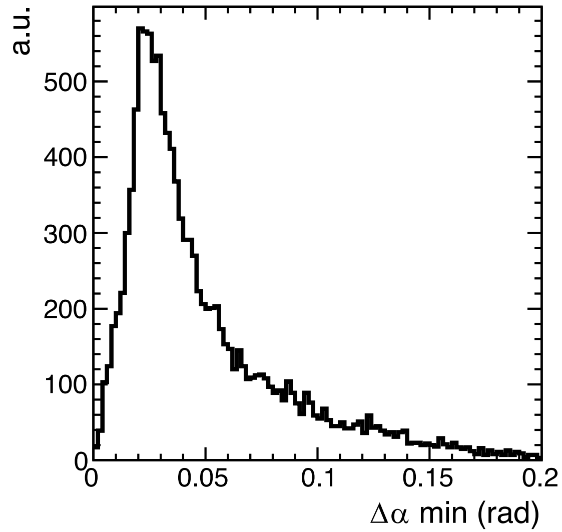
And other projects within, or in conjunction with, the other algorithms that will be described in the next talks.

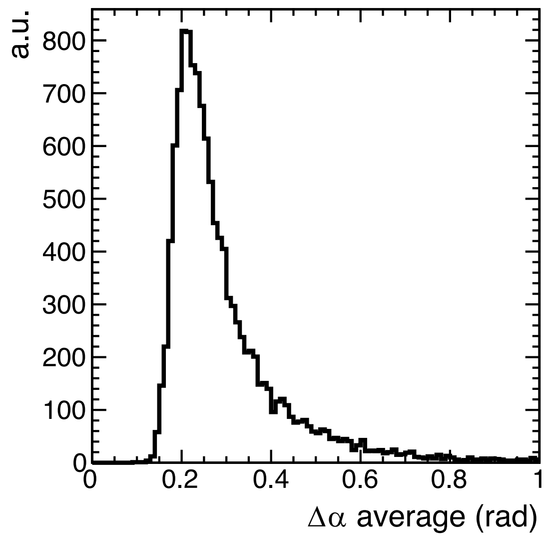
Backups

Bs2JPsiPhi: angular separation between the 4 legs

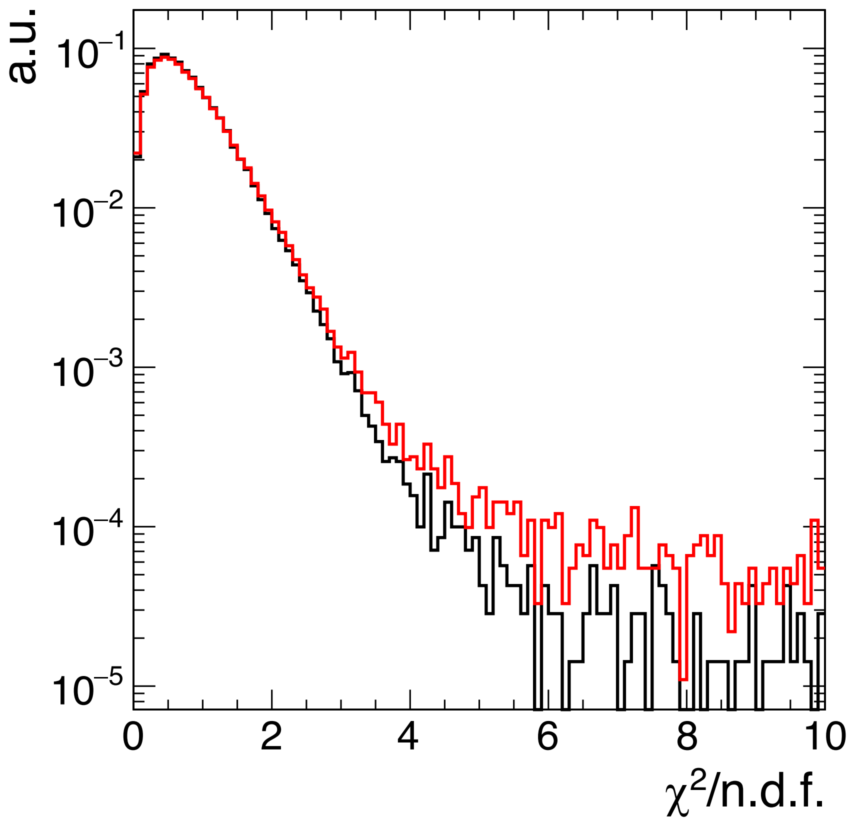
Look at the maximal, minimal, and average angular separation (3d angles) between the 4 legs of the Bs







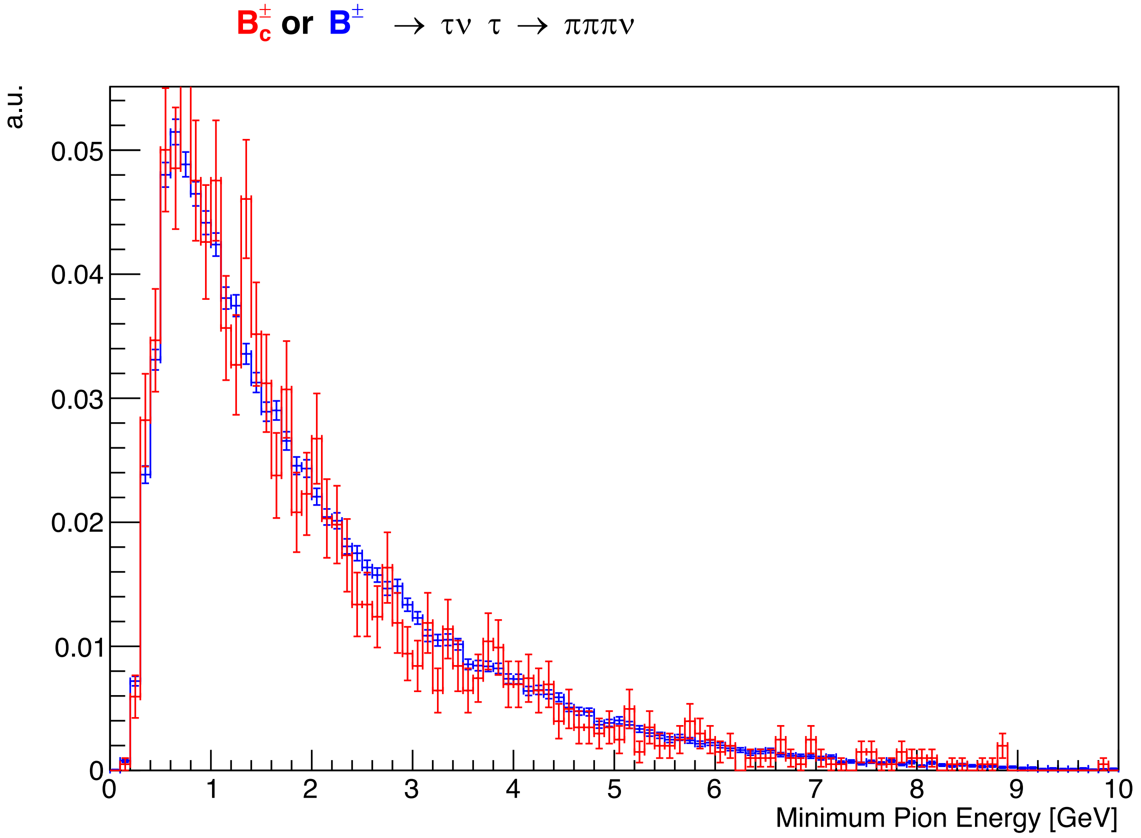
More info on Bs2JPsiPhi



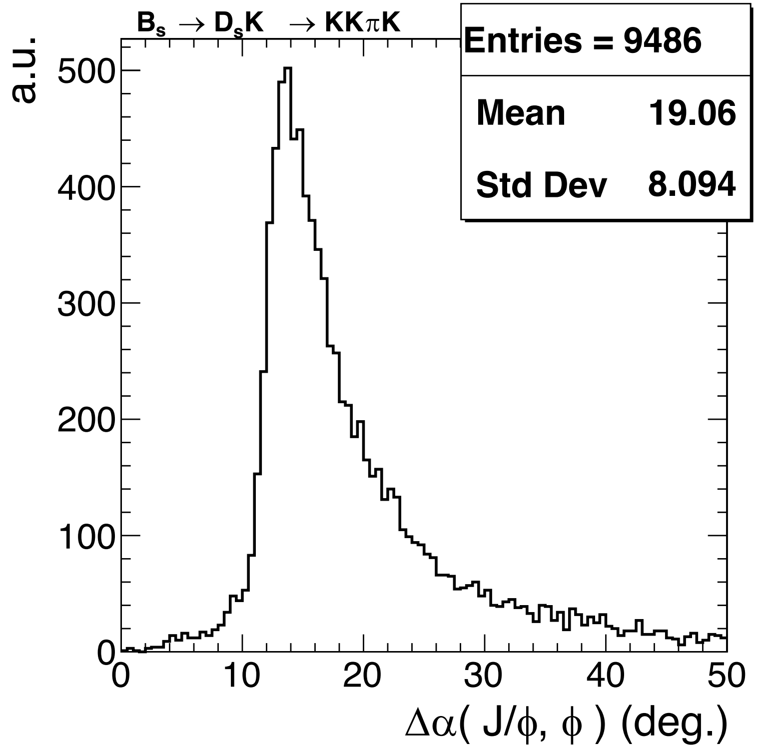
Red = all events
Black = require | cos theta | < 0.94 for the four MC legs of the Bs.

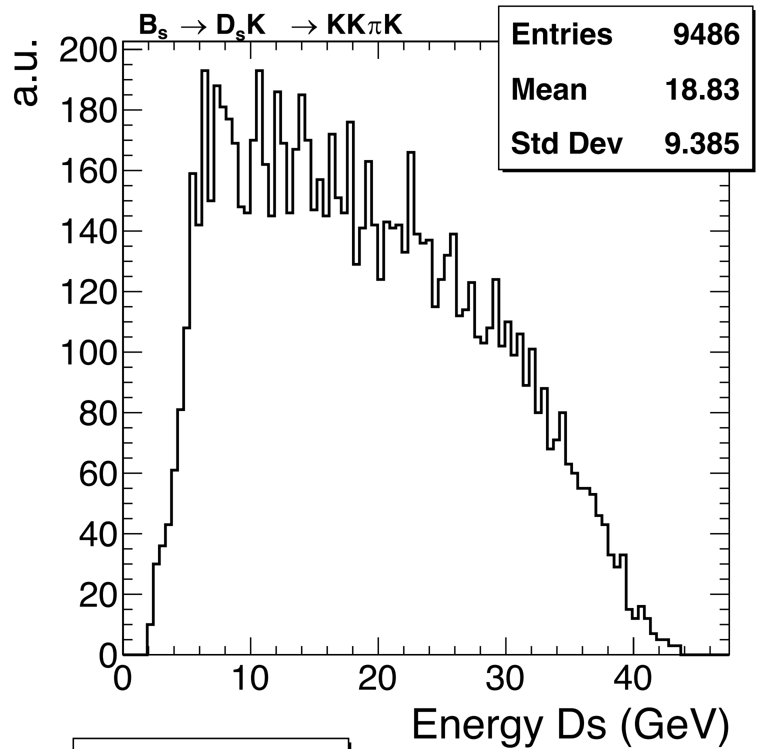
More info on Bc2TauNu

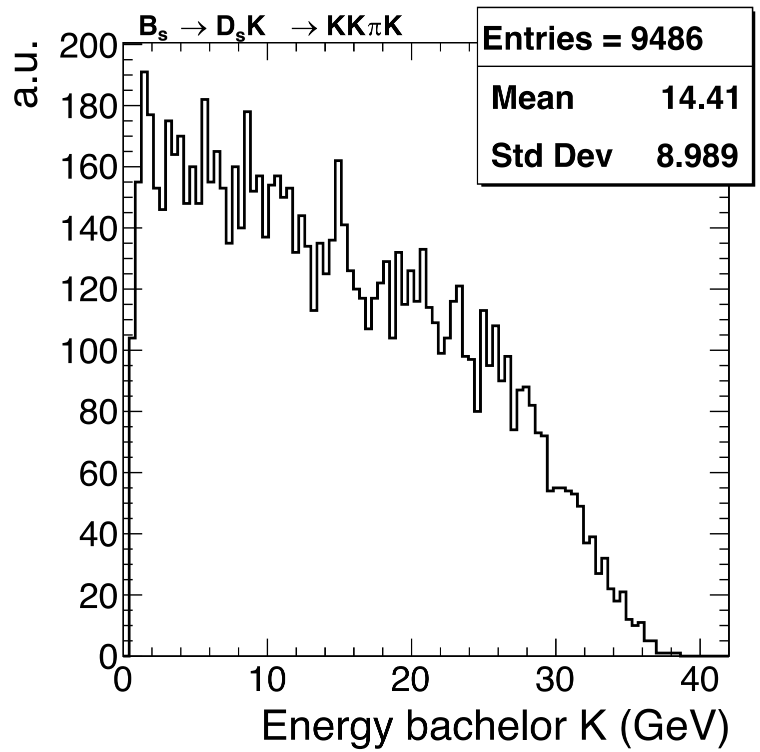
The softest pion from the tau decay (RecoParticle level, hence spectrum below 500 MeV is truncated) : very soft !



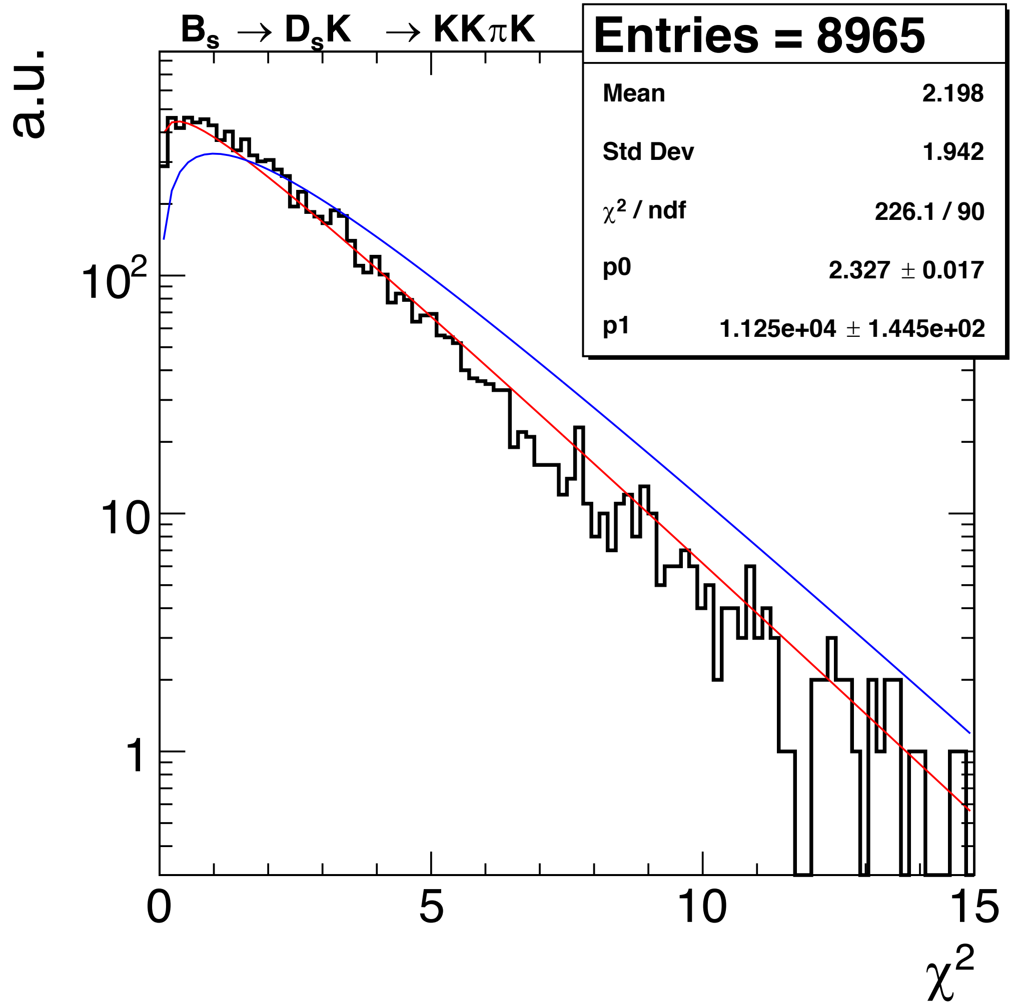
More info on Bs2DsK : some kinematic plots







More info on Bs2DsK: the chi2 of the fit to the Ds decay vertex



The n.d.f. of the fit is equal to 3 (3 tracks here).

Red curve = a chi2 function is fitted to the distribution. Fitted ndf = 2.3.

Blue curve = a chi2 function with 3 degrees of freedom.