Robust Vertex Reconstruction in Heavy Flavor Events

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Outline

- Introduction.
- Kalman vertex fitting and finding.
- Robust methods for vertex reconstruction: Adaptive fitting
- Application to primary vertex reconstruction in heavy flavor events.
- Summary and conclusions.

Vertex Reconstruction

Vertex Reconstruction consists of two main steps, related each other:

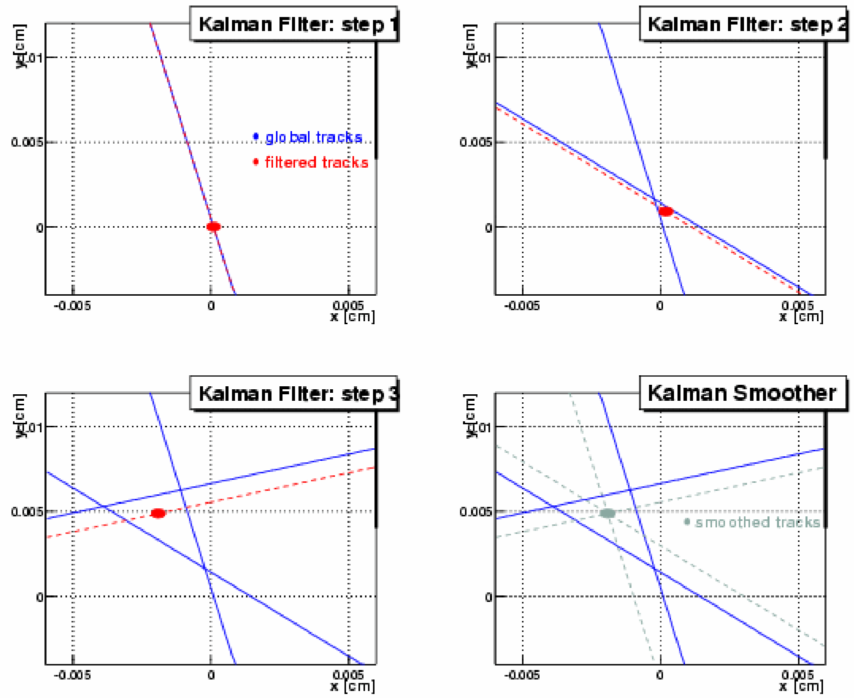
- Vertex Finding:
  - a pattern recognition problem: identification of tracks belonging to the vertex, rejection of outliers (bad measured tracks, tracks belonging to different vertices).
- Vertex Fitting:
  - estimation of the spatial position of the vertex, and the momentum of the tracks at the vertex.

Kalman Filter Vertex Fitting Technique

- Sequential minimization of a local χ^2:

$$\chi^2(x,q)=(x-x_{k-1})^T C^{-1}(x-x_{k-1})+(m_k-h(x,q))^T V_k^{-1}(m_k-h(x,q))$$

- *m, V*: track parameters and errors.
- *x, C*: vertex position and errors.
- *q* : track momentum at the vertex.
- *h(x,q)* : "measurement equation"



Filtering: tracks are added one at the time and the vertex position is updated.
Smoothing: recalculate track momentum at the final vertex position.

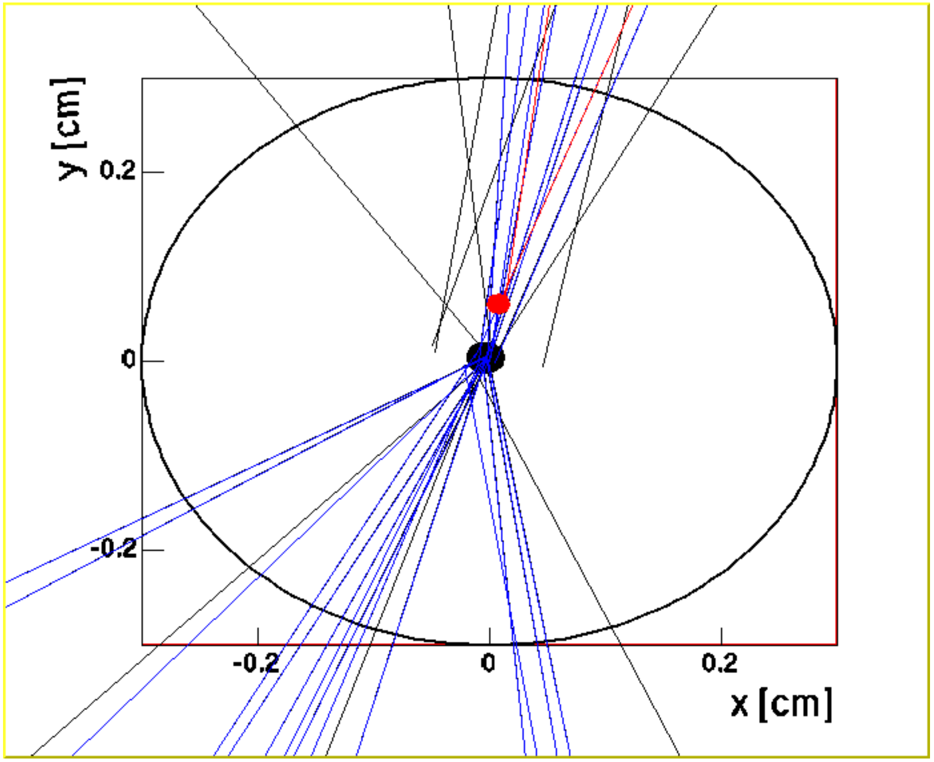
Primary Vertex Finding at D0

• Cluster tracks along the Z direction.

• Preselect tracks with small impact parameter with respect to the estimated beam spot position.

• Vertex fit of all candidate tracks

• Reject the highest χ^2 contributing track and re-fit, until the total vertex χ^2 is smaller than 10.

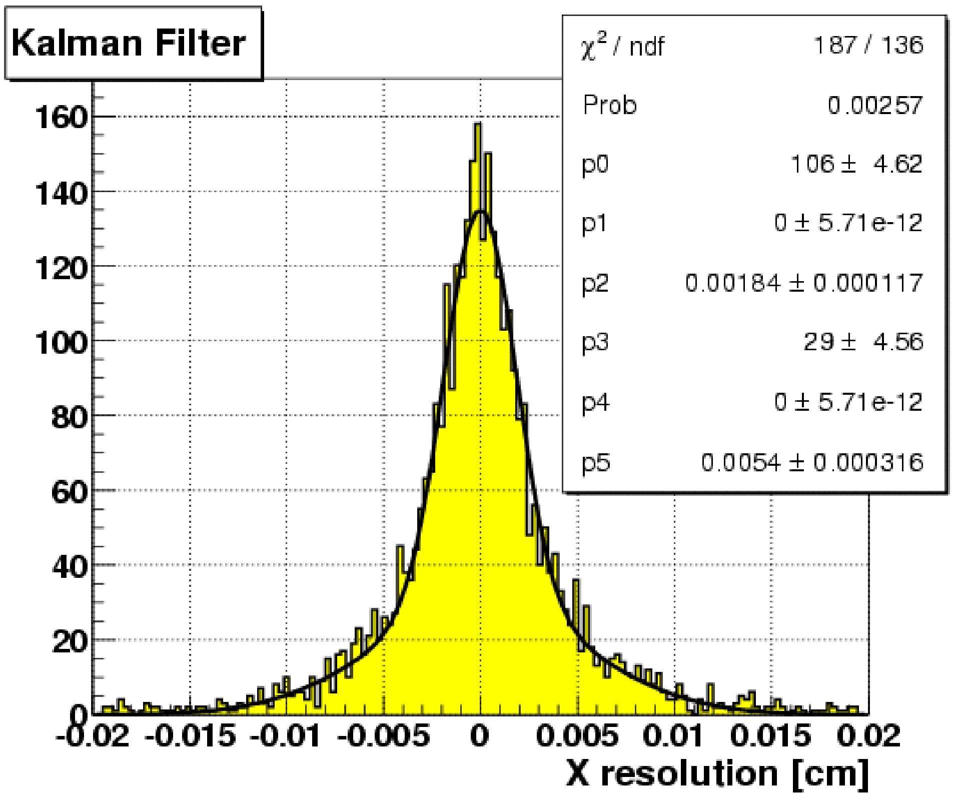


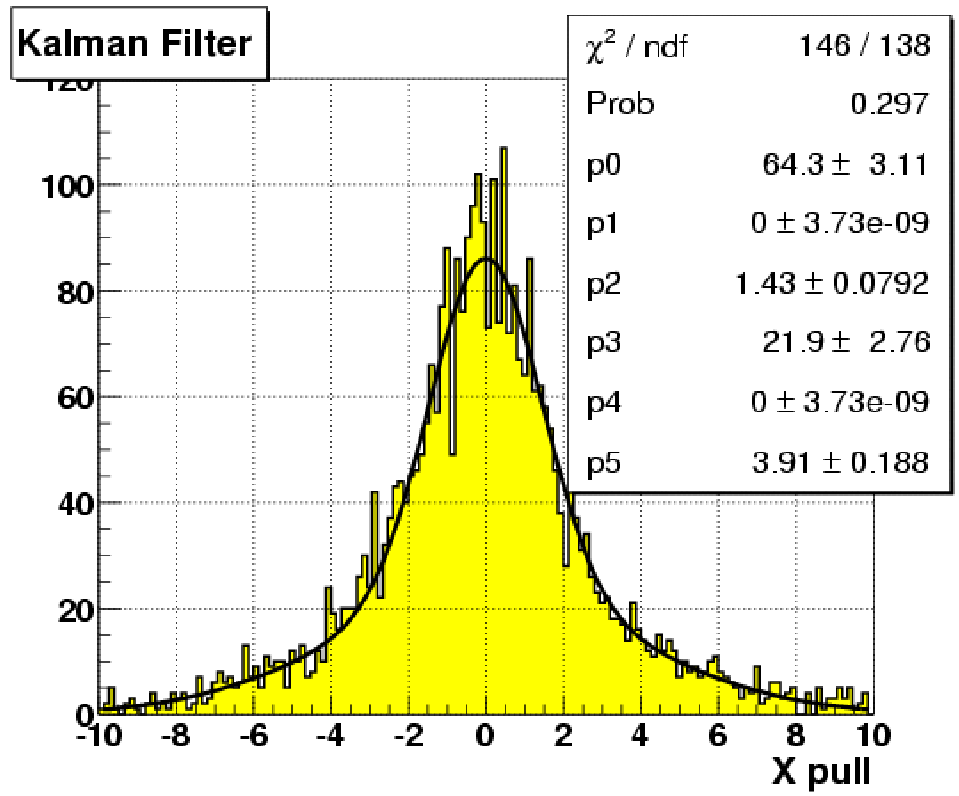
The primary vertex position is biased by the presence of tracks from secondary vertices with small decay length.

Kalman Filter fitting is very sensitive to the presence of outliers: all fitted tracks equally contribute to the result.

Primary Vertex Finding Performance in Heavy Flavor Events

Tracks from B decays in Z→bb simulated events introduce large biases in the primary vertex position. Vertex Resolution and Pull are significantly affected.





Resolution = X(reco) - X(true)

Pull = (X(reco) – X(true)] / SigmaX(reco)

Robust Vertex Algorithms

- Standard vertex fitting algorithms:
  - Position is biased if the vertex candidate contains tracks from secondary vertices.
- Robust vertex algorithms: insensitive to outliers.
  - Improve recognition of tracks not belonging to the vertex.
  - Reduce bias in the final fit.
  - Better separation between primary and secondary vertices.
- M-estimator (R. Fruhwirth, P. Kubinec, et.al., 1996)
- Adaptive fitter (CMS). (R. Fruhwirth, W. Waltenberg, et.al, 2003)

Adaptive Vertex Fitting (I)

Reweigh track errors according to their distance to the vertex

- Iterative, re-weighted Kalman Filter fit.
- Weight *w* of track *i* at iteration *k*, depends on the distance to the vertex at iteration *k-1*.
- Iteration of two steps:
  - Kalman Fit: estimation of the vertex position. Tracks are downweighted by their association probabilities *w*.
  - Computation of the weights: *w* is calculated for all tracks with respect to the current vertex position.
- The iteration is stopped when the weights have stabilized.

All tracks are used in the fit ! No square x^2 cut!

Adaptive Vertex Fitting (II)

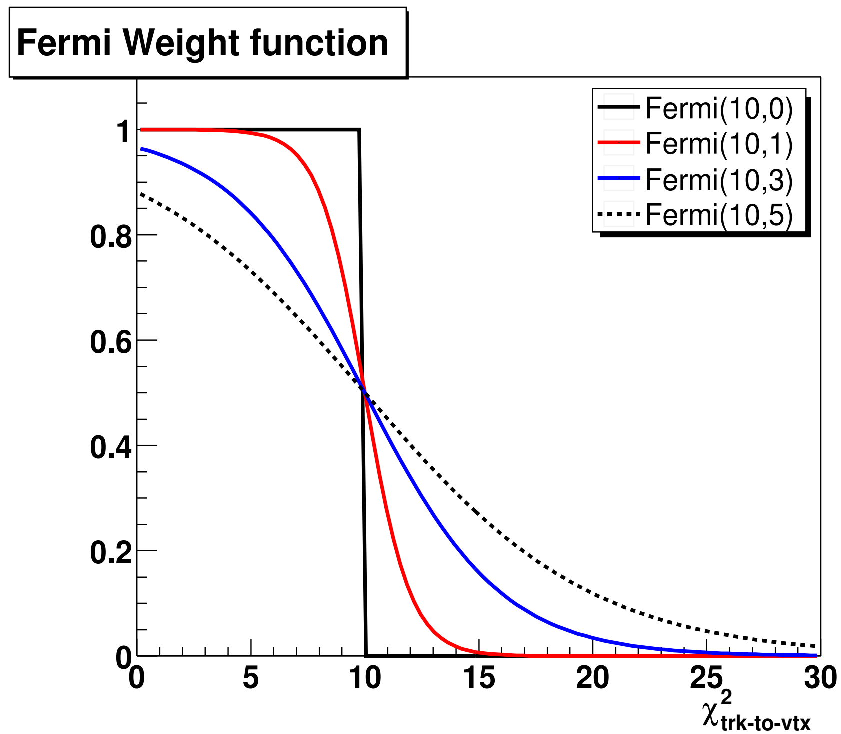
Weights

$$\chi^2(x,q)=(x-x_{k-1})^T C^{-1}(x-x_{k-1})+(m_k-h(x,q))^T w_k V_k^{-1}(m_k-h(x,q))$$

$$w_k=f(\chi_k^2,\theta)$$

χ^2: distance between track m_k and vertex.

θ : parameters (Temperature)

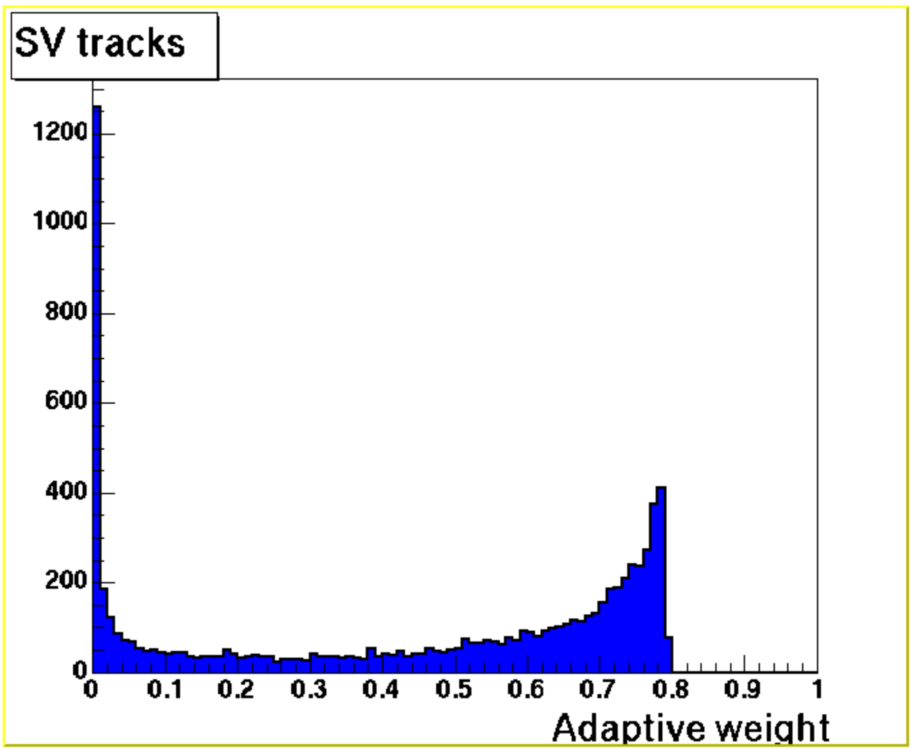


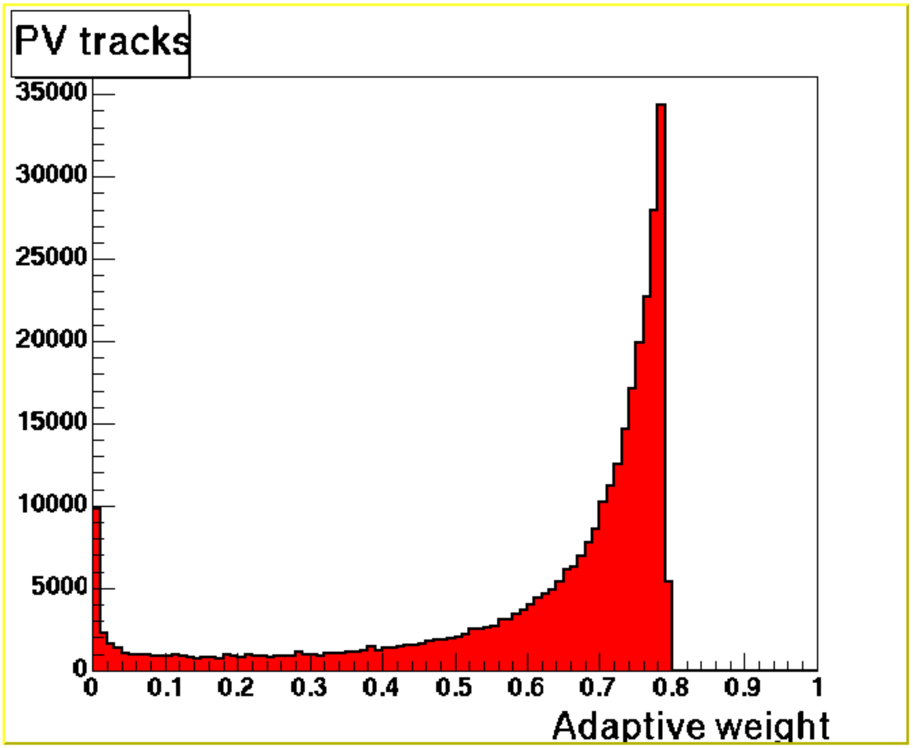
Adaptive Vertex Fitting (III)

Distribution of track weight for SV tracks (incorrectly) associated to the PV and true PV tracks.

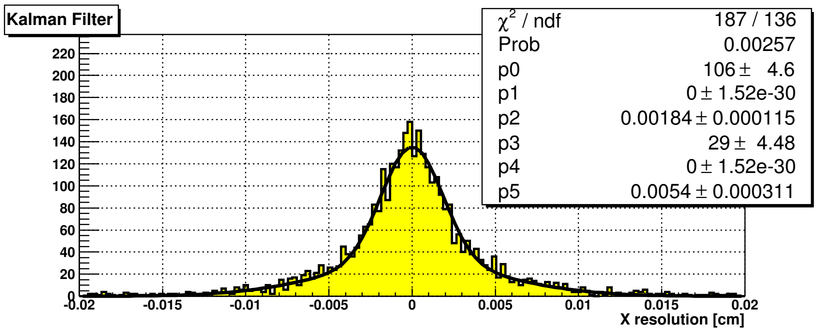
Adaptive algorithm down-weights SV tracks from small decay length vertices.

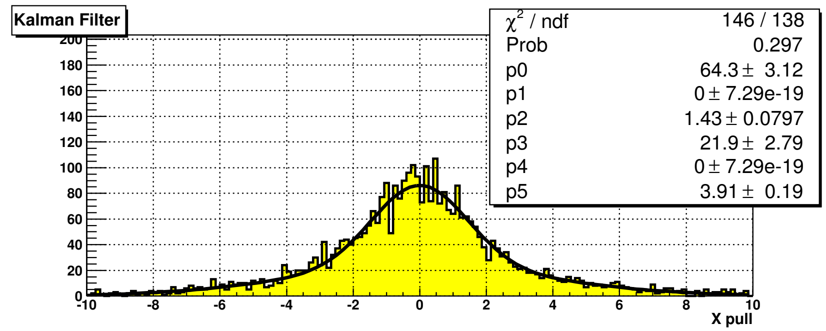
Overall scaling effect (~0.8) from for non-zero Temperature.

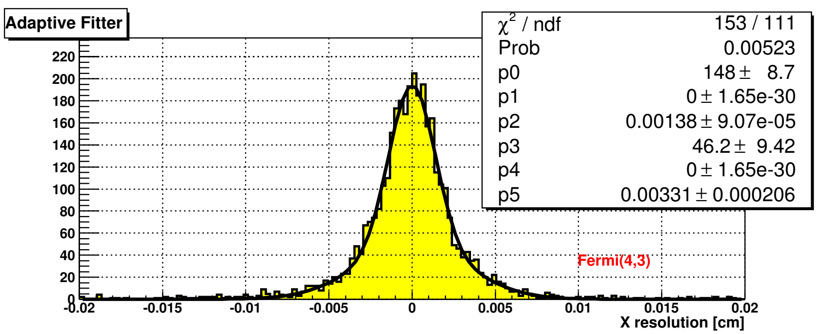


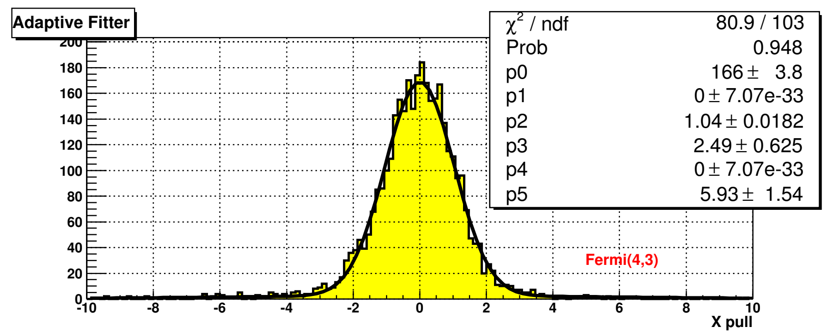


Adaptive Primary Vertex Performance (I)









- Multiplicity = 18.7
- Resolution = 13.8 um.
- Pull = 1.04.
- Tails = 7.9%

Zbb simulated events

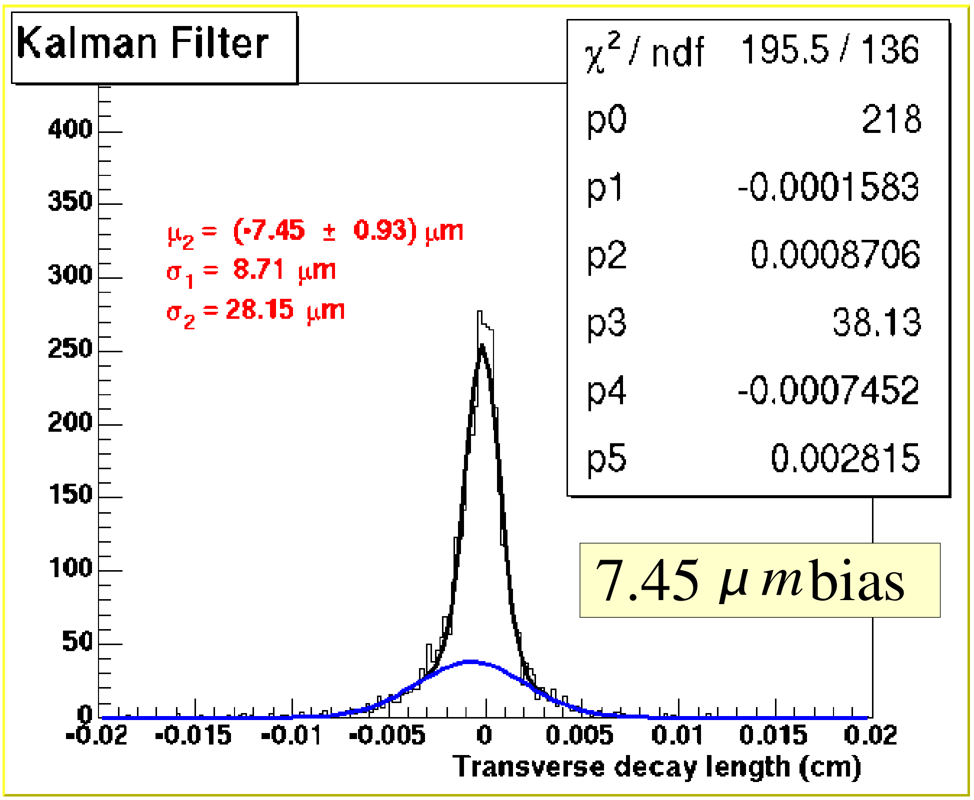
Resolution improvement:	18.3um	13.8um
Pull improvement:	1.43	1.04
Tails improvement:	48.2%	7.9%

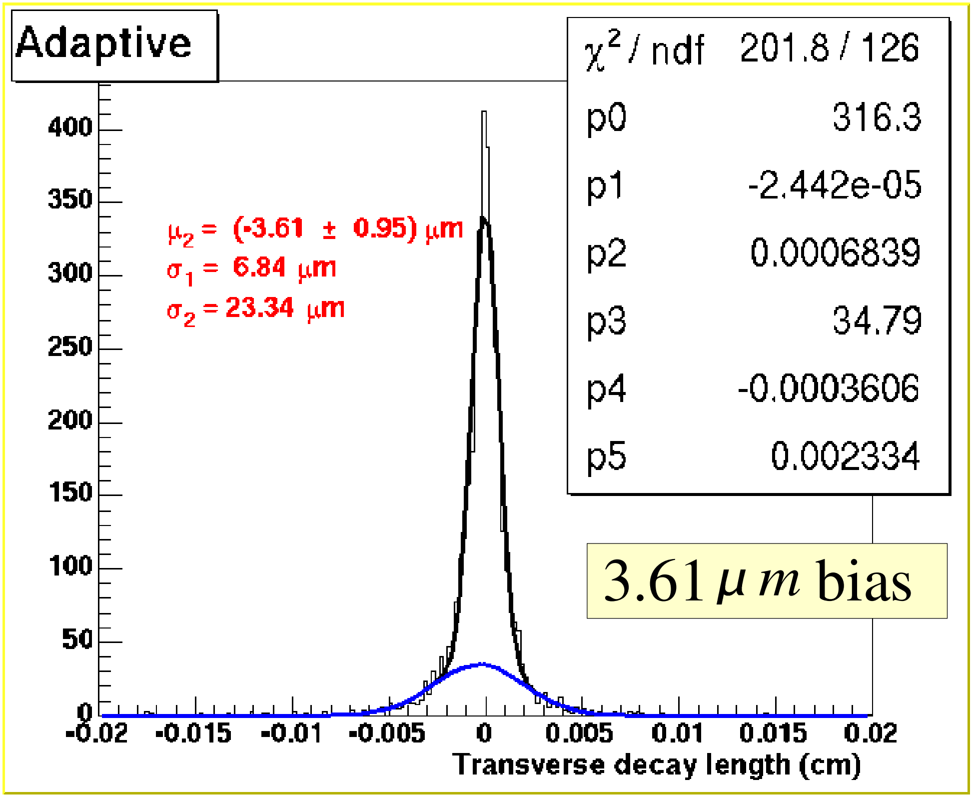
Secondary vertex Decay Length Resolution using Adaptive Primary Vertex

SV decay length bias in Bs events is significantly reduced when Adaptive primary vertexing is used.

$$\vec{L} = \vec{r}_{PV} - \vec{r}_{SV}$$

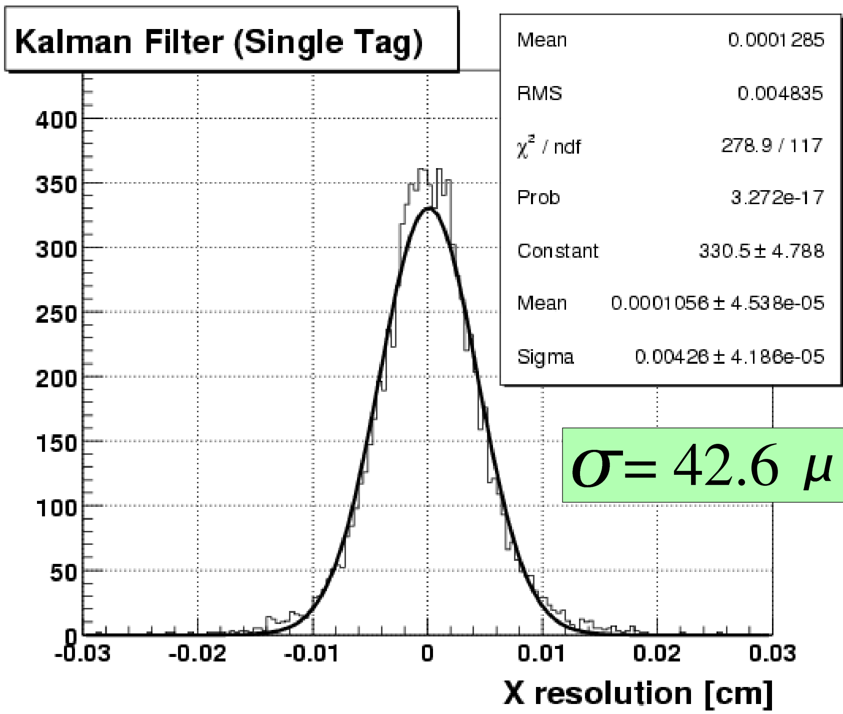
Resolution = L_{xy}(reco) - L_{xy}(true)



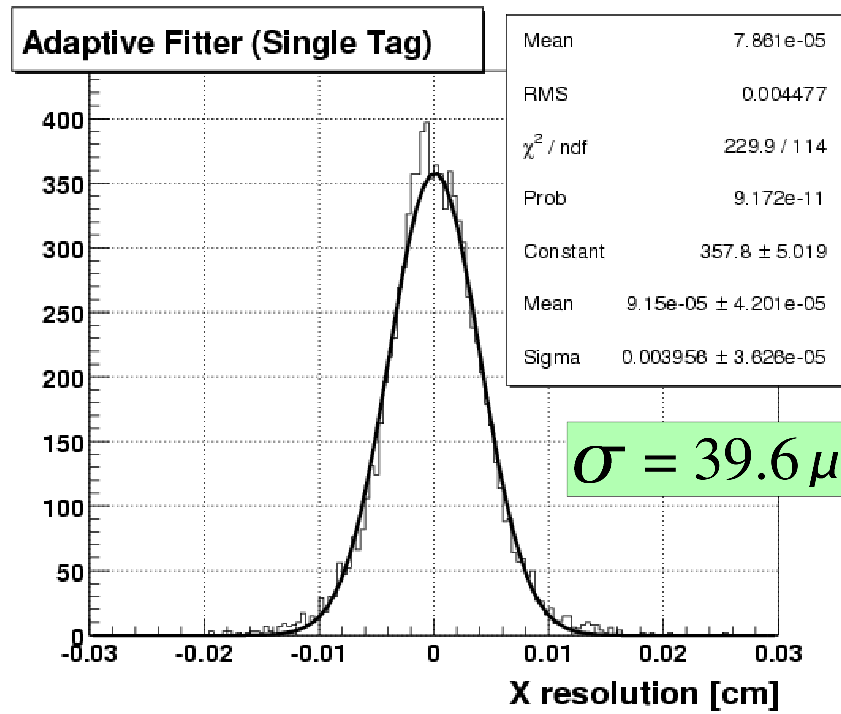


Adaptive Primary Vertex Performance in Heavy Flavor Data (I)

Single-tagged Jet Trigger data (di-jet events)



$\sigma = 42.6\ \mu m$

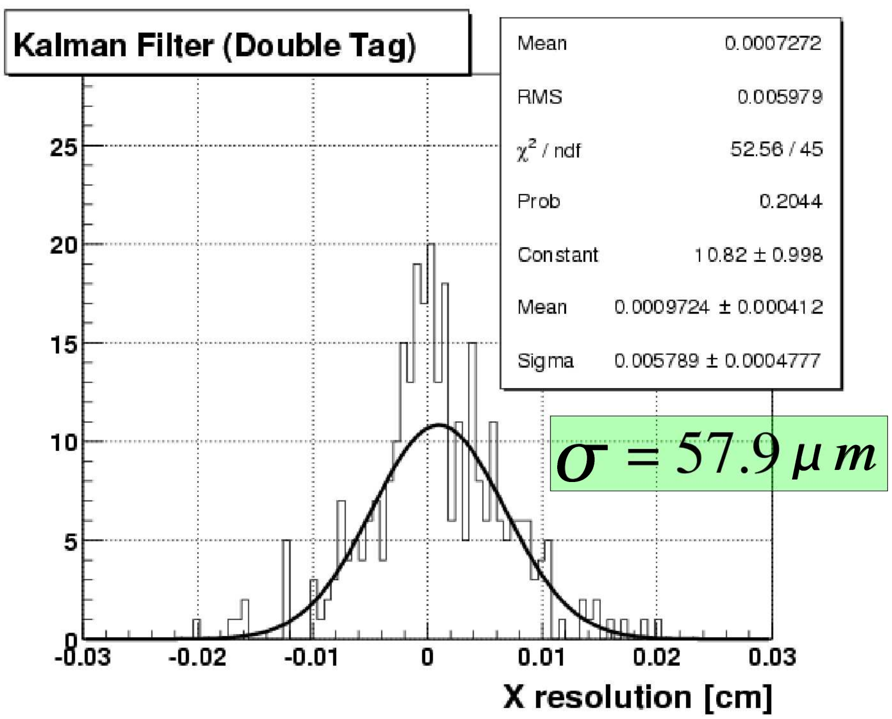


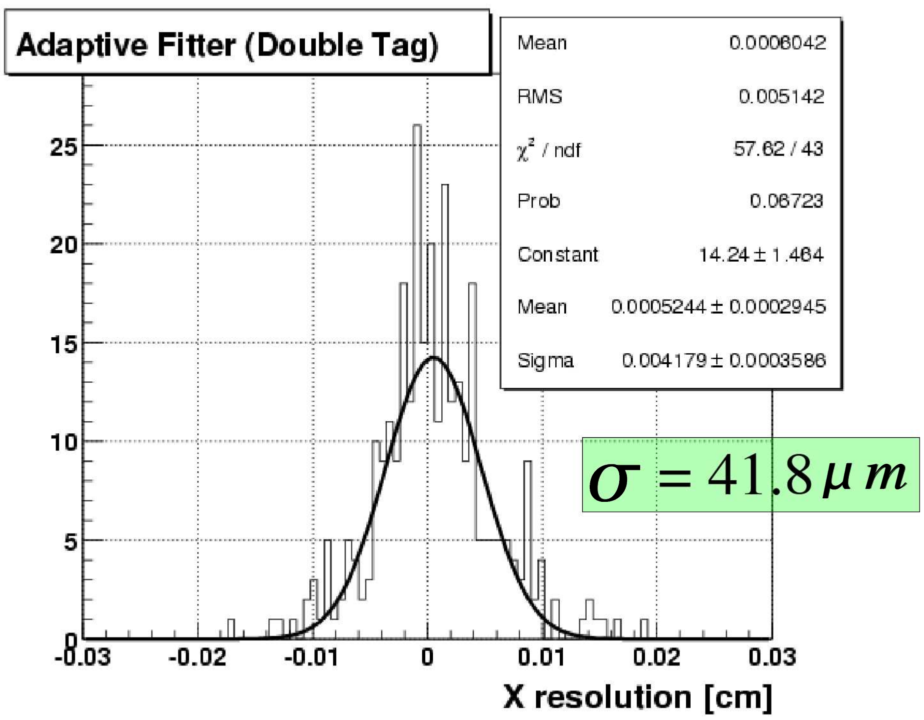
$\sigma = 39.6\ \mu m$

PV resolution in untagged sample is $38.9\ \mu m$ ($38.5\ \mu m$)

Adaptive Primary Vertex Performance in Heavy Flavor Data (II)

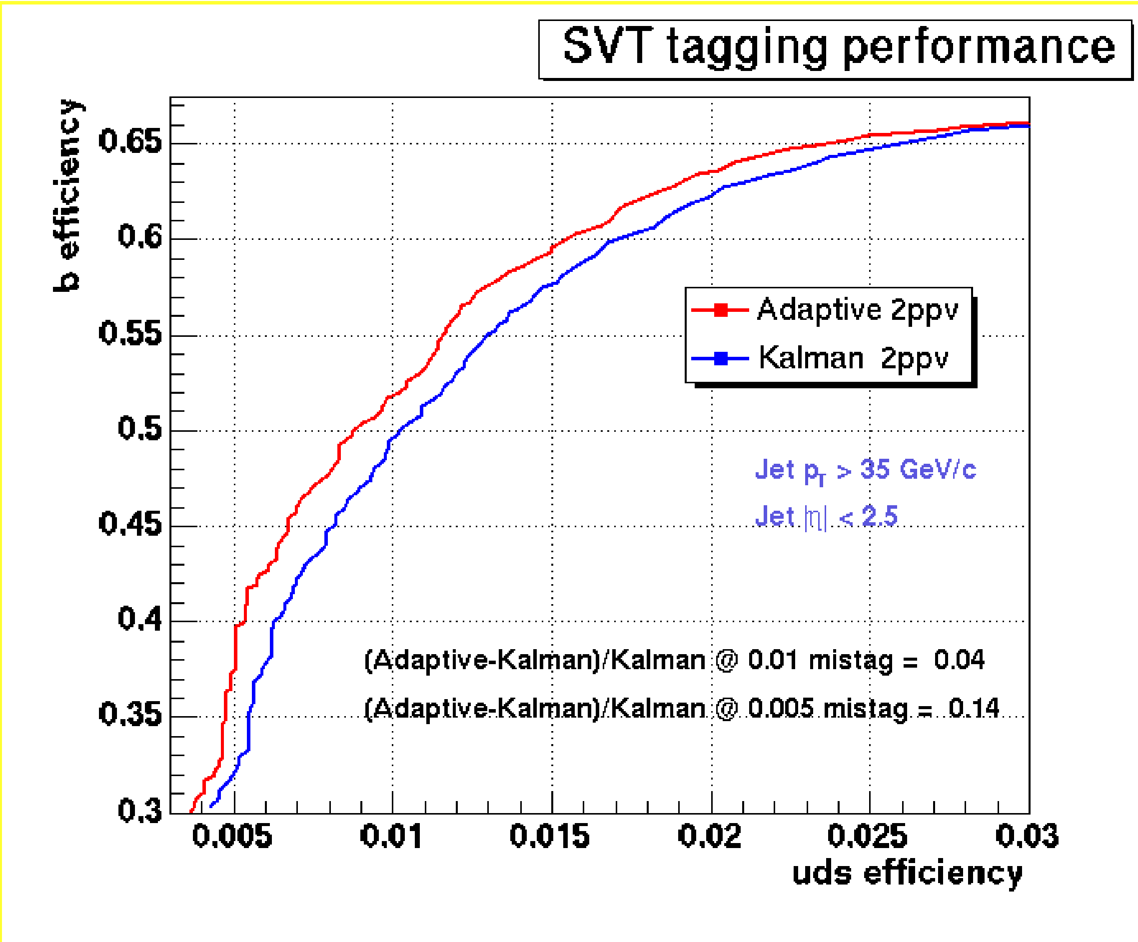
Double-tagged Jet Trigger data (di-jet events)





PV resolution effect due to tagging: 19 μm (Kalman), 3.2 μm (Adaptive)

Secondary Vertex Performance using Adaptive Primary Vertexing



New Adaptive PV allows a better separation between primary and secondary vertices.

At a same mistag rate, secondary vertex b-tagging efficiency in the simulation is improved.

Further improvement expected by using SV adaptive fitting.

Future Plans: The Adaptive Multi-Vertex Finder

- Also proposed and implemented in CMS.

- Adaptive fitting can be extended to simultaneously find primary and secondary vertices.

- Initially, vertex candidates (PV and Svs) can share tracks.

- Each track is weighted according to its distance to each vertex (a same track has a different weight for each vertex: w_{ij})

- Iteration procedure allows to “swap” tracks between vertices.

Summary and Conclusions (I)

- Standard methods for primary vertex reconstruction:
  - Biased by the presence of secondary vertex tracks. Square cuts designed to reject outliers have the effect of reducing the vertex resolution by removing true primary vertex tracks.
- The Adaptive Fitter:
  - Robust, iterative Kalman Filter. Secondary vertex tracks are down-weighted, depending on the x^2 contribution to the vertex and the presence of all other neighbor tracks. All tracks are considered in the fit.

Summary and Conclusions (II)

- Adaptive primary vertex finder results:
  - Bias from secondary vertex tracks and Resolution are significantly improved.
  - Pull distributions with sigma ~1.0.
  - Tails are reduced from 50% to less than 8%. Very effective in down-weighting secondary vertex tracks.
  - Slower than Kalman Filter, if T>0. On average it requires 6-7 Kalman Filter iterations to reach convergence.
  - Provides the basis for a Multi-Vertex finder, currently under development at DØ.