Vertex detection in strong electroweak symmetry breaking

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Motivation

- $e^+e^- \rightarrow W^+W^-$ is the single largest process at high energies
- $\sigma_{W^+W^-}$ will show deviations from SM in case of very high M_H:
  - Anomalous triple gauge boson couplings
  - $W_L^+W_L^-$ rescattering changes amplitude

Anomalous couplings

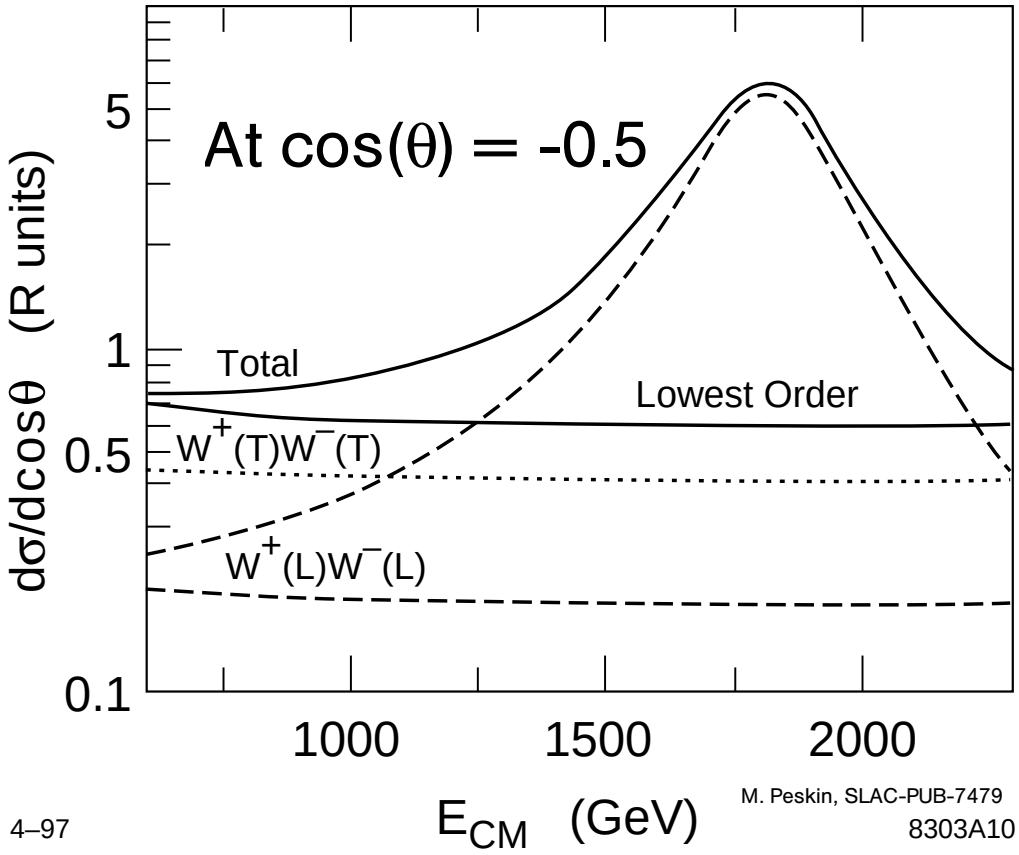
- Modification of WWZ and WWγ couplings in the chiral Lagrangian:

$$\kappa_\gamma = 1 + \frac{e^2}{32\pi^2 \sin(\theta_w)^2}(L_{9L} + L_{9R})$$

$$\kappa_Z = 1 + \frac{e^2}{32\pi^2 \sin(\theta_w)^2}\left(L_{9L} - \frac{\sin(\theta_w)^2}{\cos(\theta_w)^2} L_{9R}\right)$$

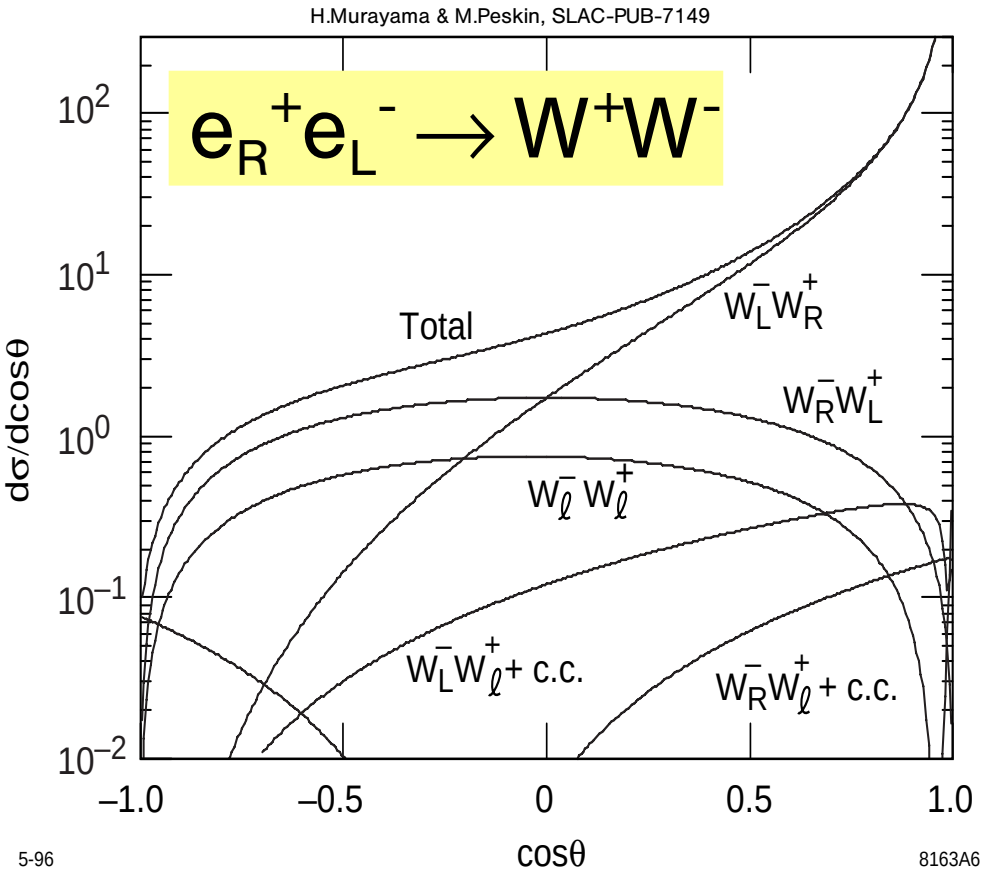
$$g_{1Z} = 1 + \frac{e^2}{32\pi^2 \sin(\theta_w)^2 \cos(\theta_w)^2} L_{9L}$$

$e^+e^- \rightarrow W_L^+ W_L^-$ amplitude



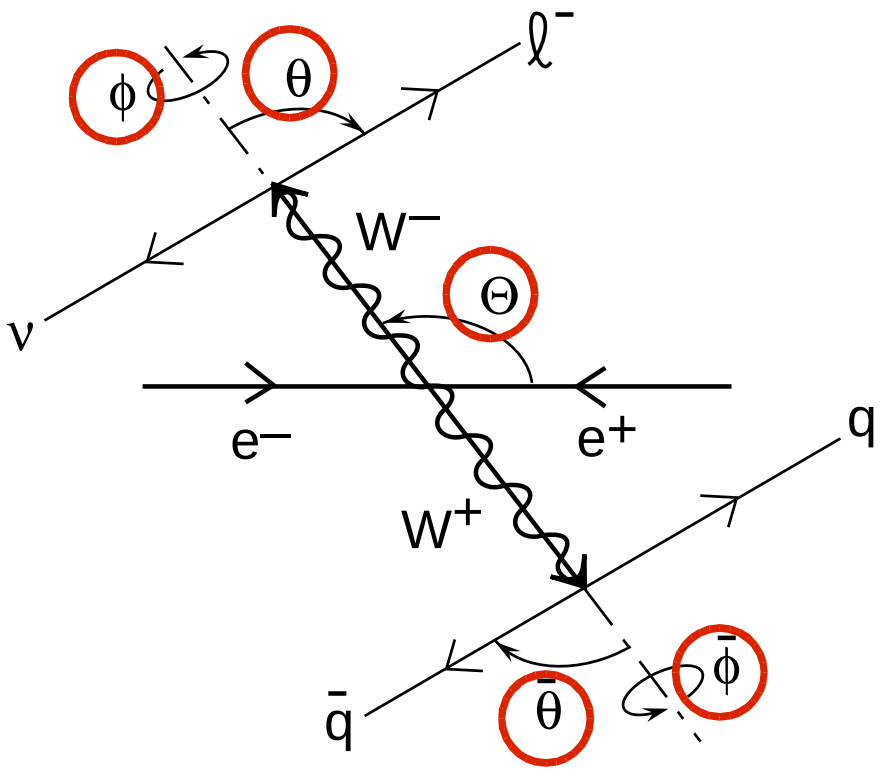
- Multiply SM $\sigma_{W^+W^-}$ with complex form factor F_T.
- Allows for strong EWSB resonances, eg. TechniRho.

Helicity analysis



- Forward WW scattering dominated by T-channel process (ν exchange)
- $\sigma_{W_L W_L} \sim \sin^2(\Theta)$
  - Sensitive to $W_L^+ W_L^-$ in backward direction

Helicity analysis



- Quantities to be measured:
  - cos(Θ) production angle
  - Helicity angles of W decay products in W rest frames: cos(θ), φ, cos($\bar{\theta}$), $\bar{\varphi}$
- Use likelihood fit to extract L_{9R} and L_{9L} or $Re(F_T)$ and $Im(F_T)$.

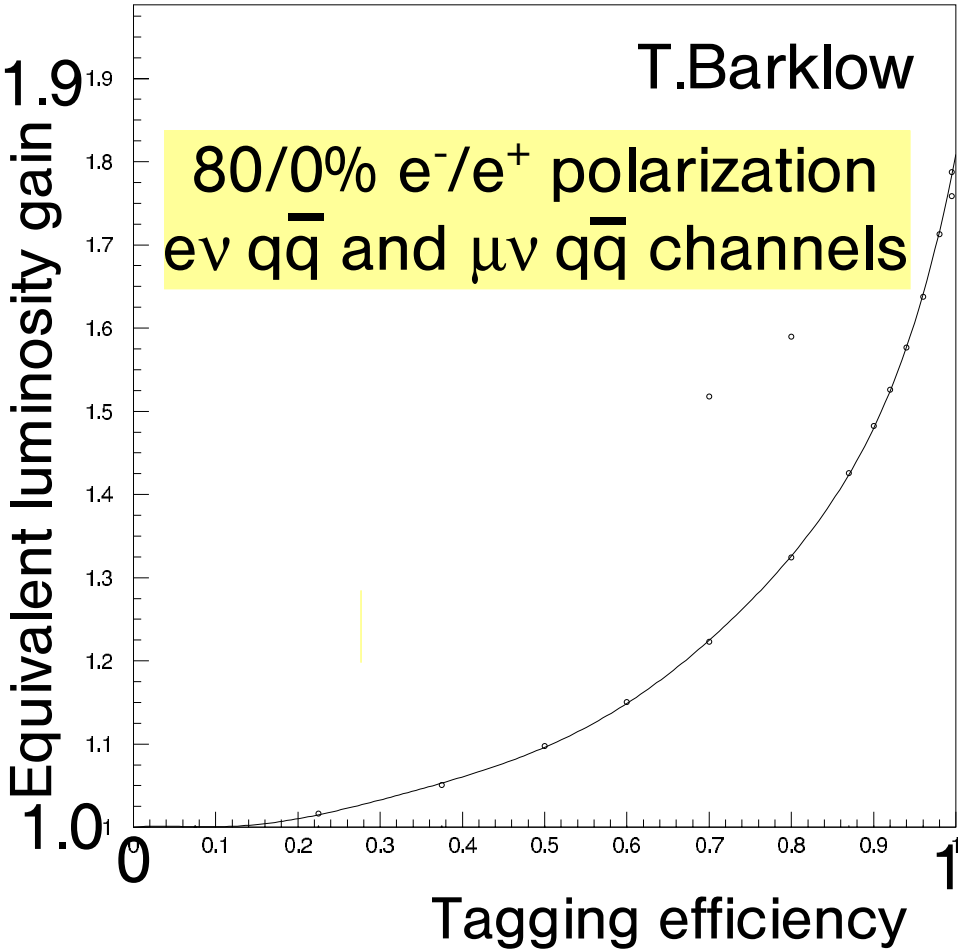
Flavor tagging

- Lepton is expected to be identified, but there is an ambiguity on hadronic side in W decay tensor:

$$\bar{H}^{\bar{\lambda}}_{\bar{\lambda}'} = \left[\bar{D}^{\bar{\lambda}}_{\bar{\lambda}'}(\cos(\bar{\theta}^*), \bar{\phi}^*) + \bar{D}^{\bar{\lambda}}_{\bar{\lambda}'}(-\cos(\bar{\theta}^*), \bar{\phi}^* + \pi) \right]$$

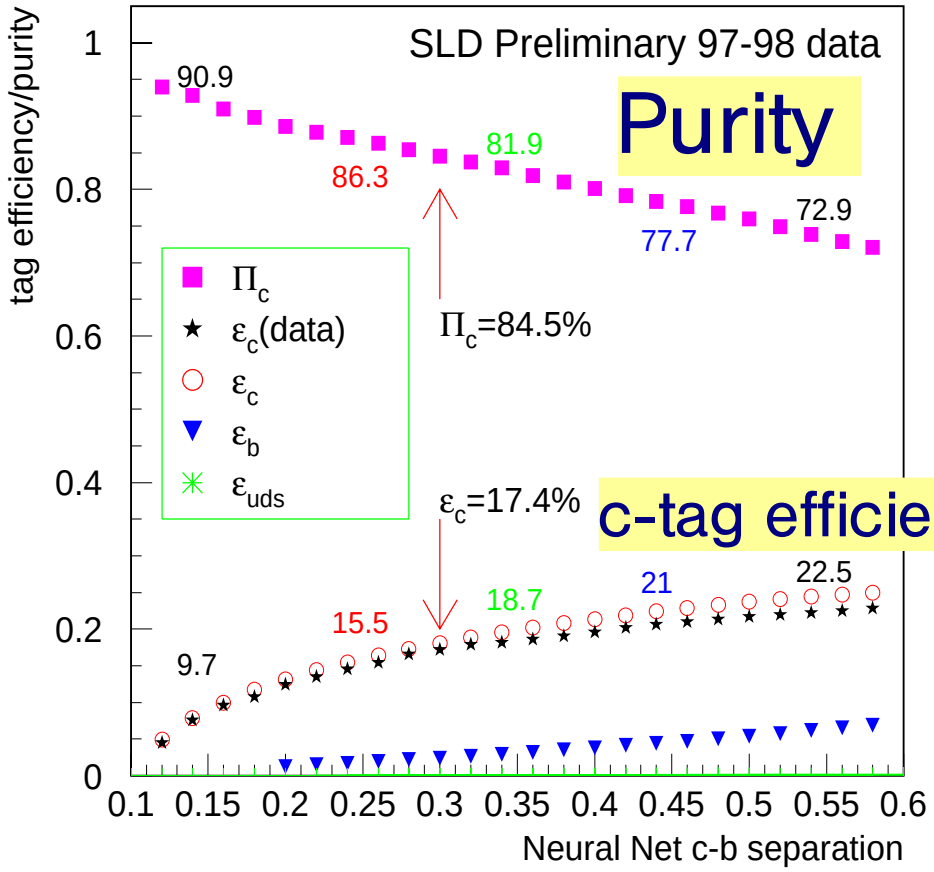
- Loosing information by ´averaging´ over these two states.
- Need flavor tagging to make this information accessible.

Expected effect of c-tagging



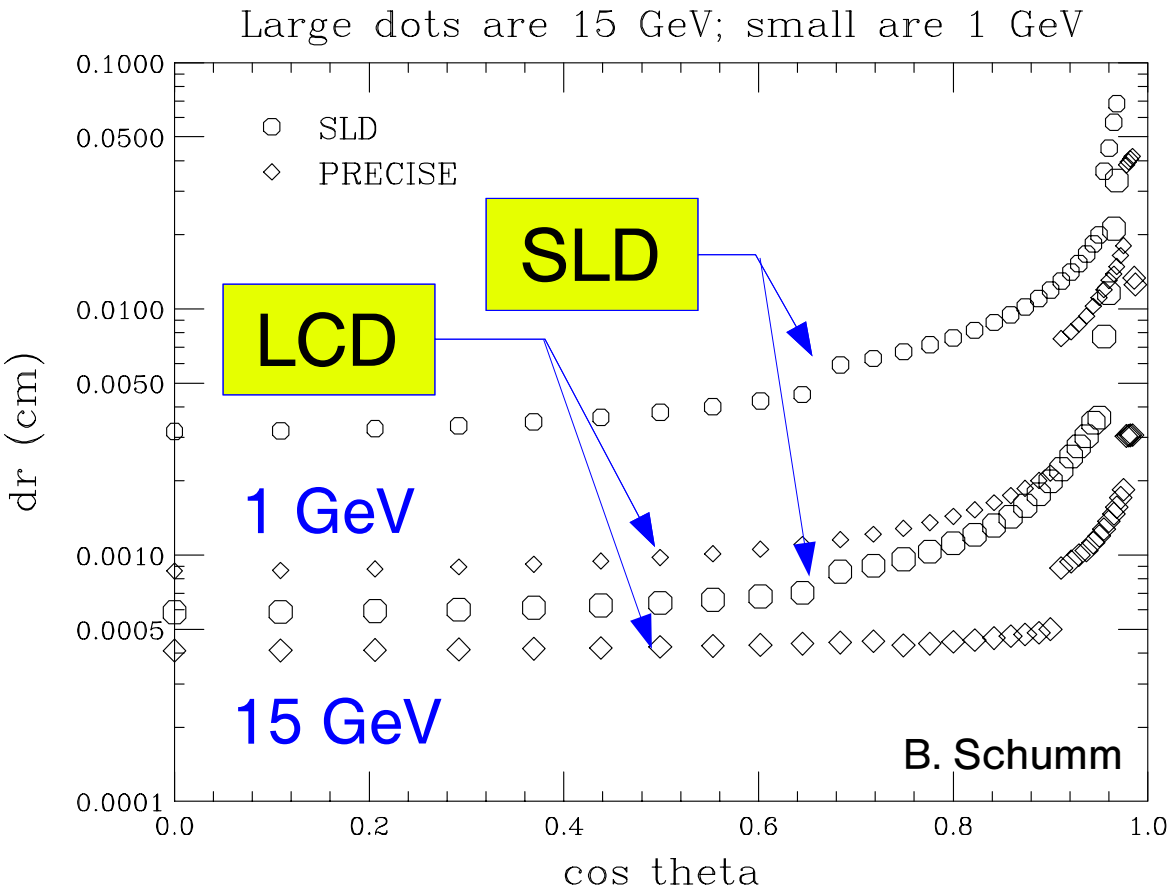
- Tagging efficiency includes mistag
- Equivalent luminosity gain up to a factor 1.8 in case of perfect c-tagging

c-tagging at SLD



- SLD uses topological vertex finder ZVTOP in combination with a neural net to do (b- and) c-tagging
- Up to $\varepsilon_c \approx 23\%$

LCD vs SLD resolution



- Better tracking resolution for LCD detector.
- Higher c-tagging efficiency expected!
- Aggressive vertexing?

Both Ws decaying hadronically

- Charm tagging allows to make partial use of double hadronically decaying $e^+e^- \rightarrow W^+W^-$ events.
- Events with $W^- \rightarrow \bar{c}s'$ replacing the leptonic W-decay enhance statistics:
  Additional 1.5 times more statistics at max!
- Depends of course on c-tagging efficiency and mistag rate.

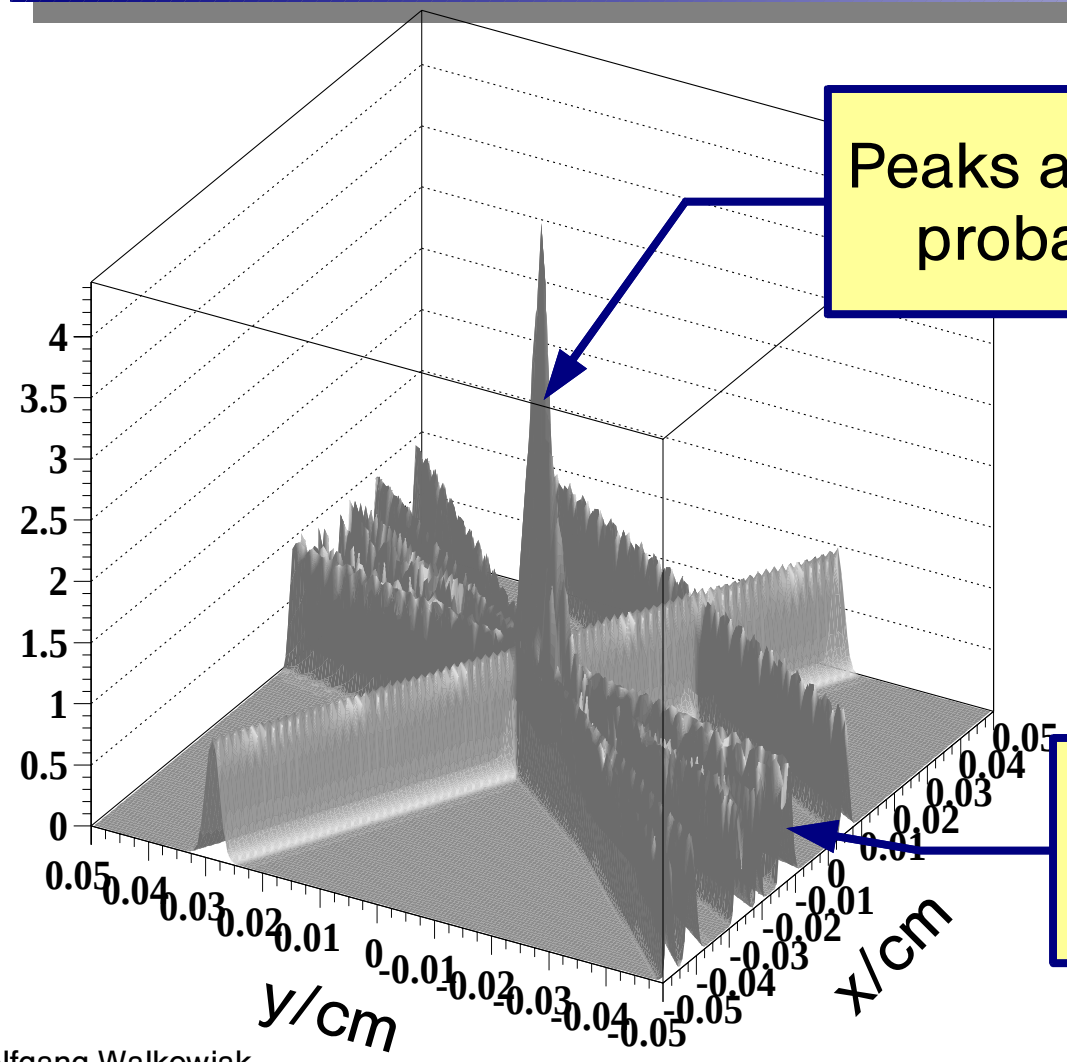
Topological vertex finding

- SLD collaboration has developed a unique topological vertex finding algorithm, named ZVTOP.
  (D.J.Jackson, NIM A388 247-253,1997)
- ZVTOP is used by many collaborations
- Implementations for LCD studies:
  - ROOT implementation by T. Abe
  - JAVA implementation in JAS framework

ZVTOP - functional principle

- ZVTOP operates on tracks from a jet:
  - Probability tubes formed from tracks and the covariance matrices for each track.
  - Overlaps of probability tubes determine vertex significance.
  - Initially two-track candidate vertices are formed.
  - Candidate vertices are checked for being resolved from each other and merged if not.
  - Tracks are assigned to vertices according to vertex significance.
  - Final list of vertices is formed and position is fitted.

ZVTOP - probabilty tubes



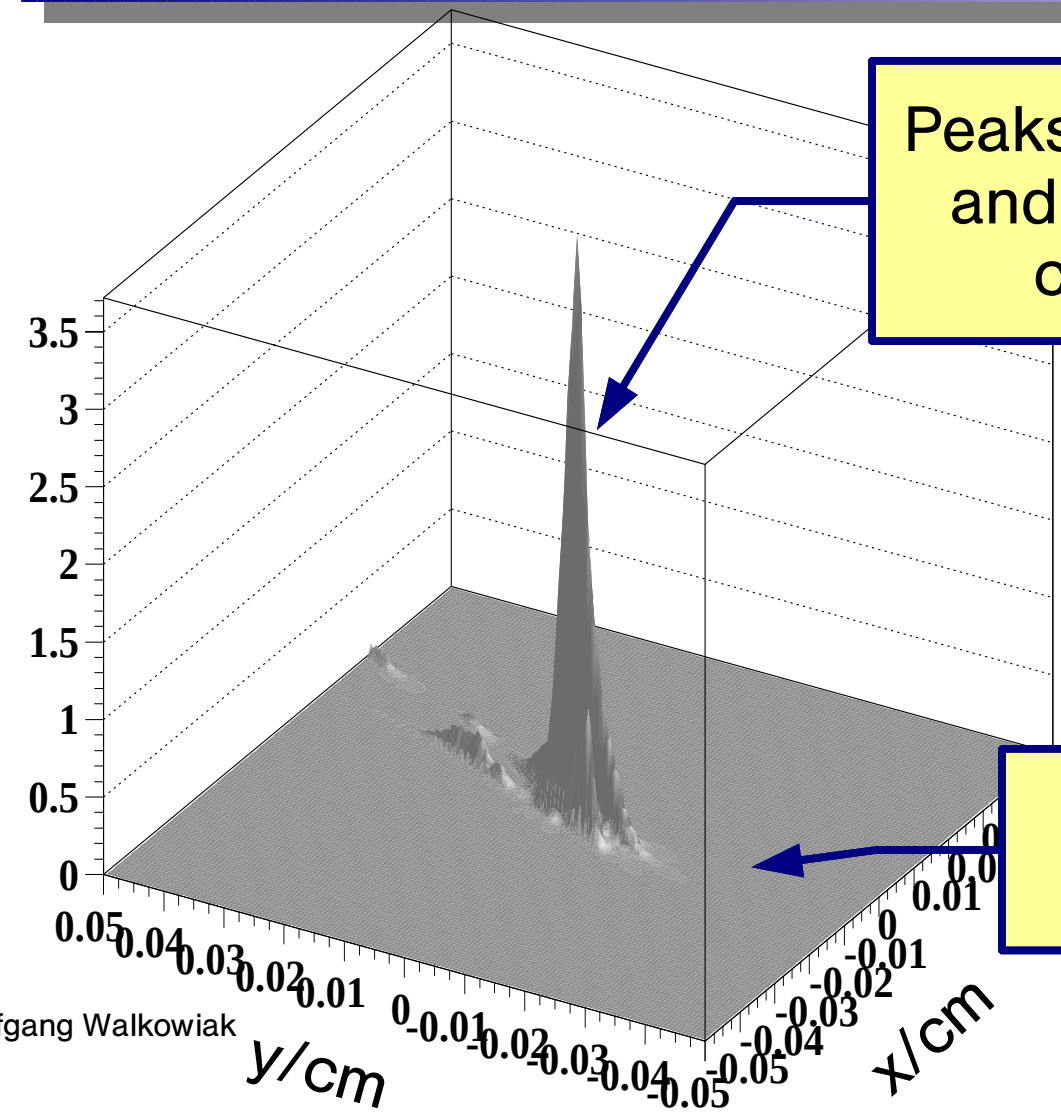
Peaks at crossings of probability tubes

Example:

- Projection of tracks from $c\bar{c}$ event on xy-plane

Gaussian probability (in 2 dimensions)

ZVTOP - vertex significance



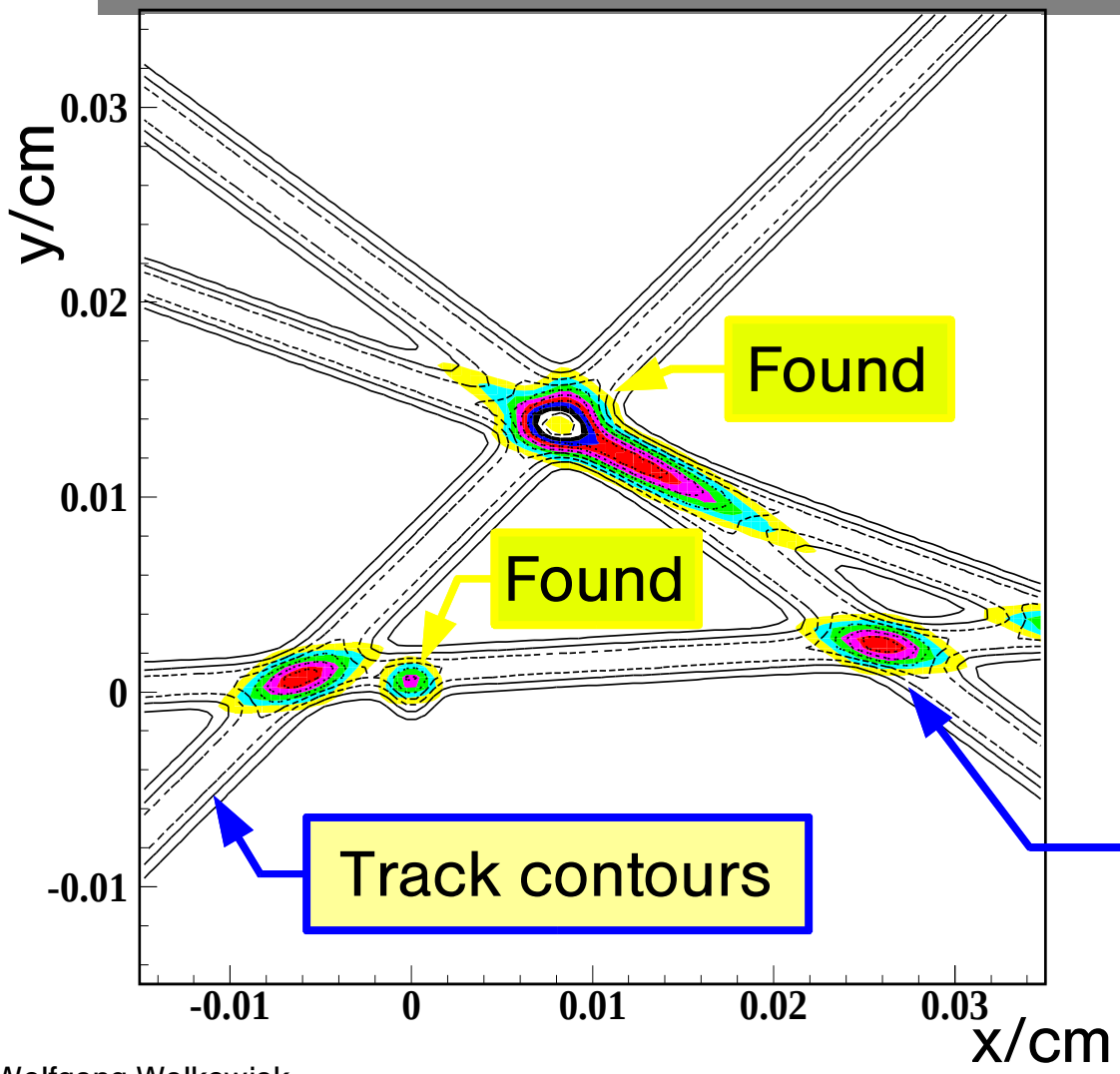
Peaks are enhanced and create vertex candidates.

Example:

- Projection of tracks from $c\bar{c}$ event on xy-plane

Single tracks do not contribute.

Vertex finding example



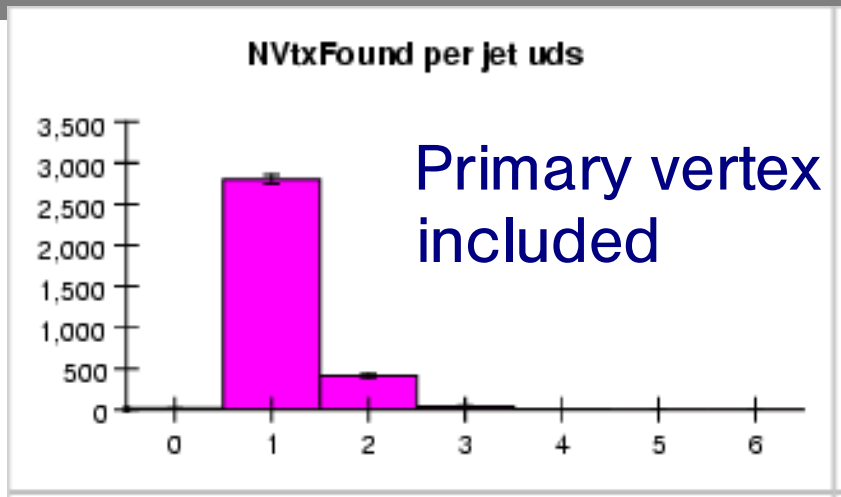
Example:

- 4 diagnostic tracks restricted to xy-plane

Found vertices:

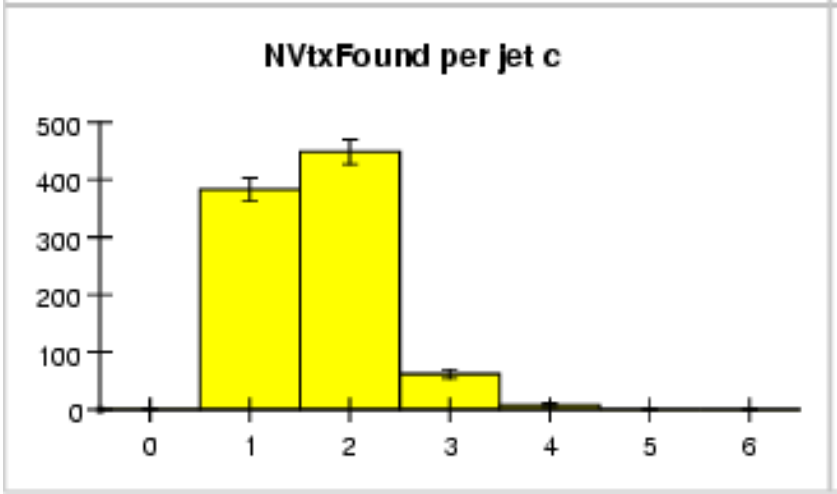
- Vertex with 3 tracks
- Vertex with IP + 1 tracks

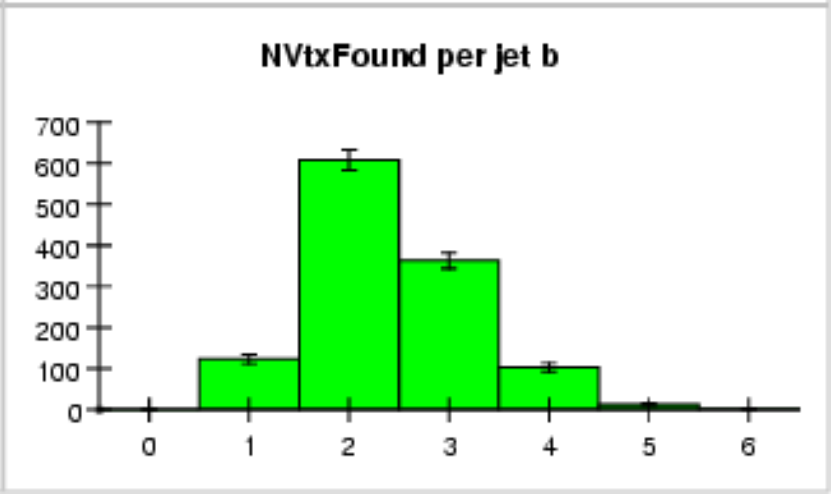
Vertex multiplicities in $q\bar{q}$



Primary vertex included

Sample:
2500 $q\bar{q}$ events at
500 GeV (Pythia)
(q = u,d,s,c,b)





Status of ZVTOP in Java

ZvTopVertexer is coded and operational

- Finds vertices (verified with single events).
- Gives reasonable output for vertex multiplicities.
- Checks of fitting results (deviation from MC origin, vertex fitting χ^2) need to be done systematically.
- Ghosttrack algorithm is not yet implemented.

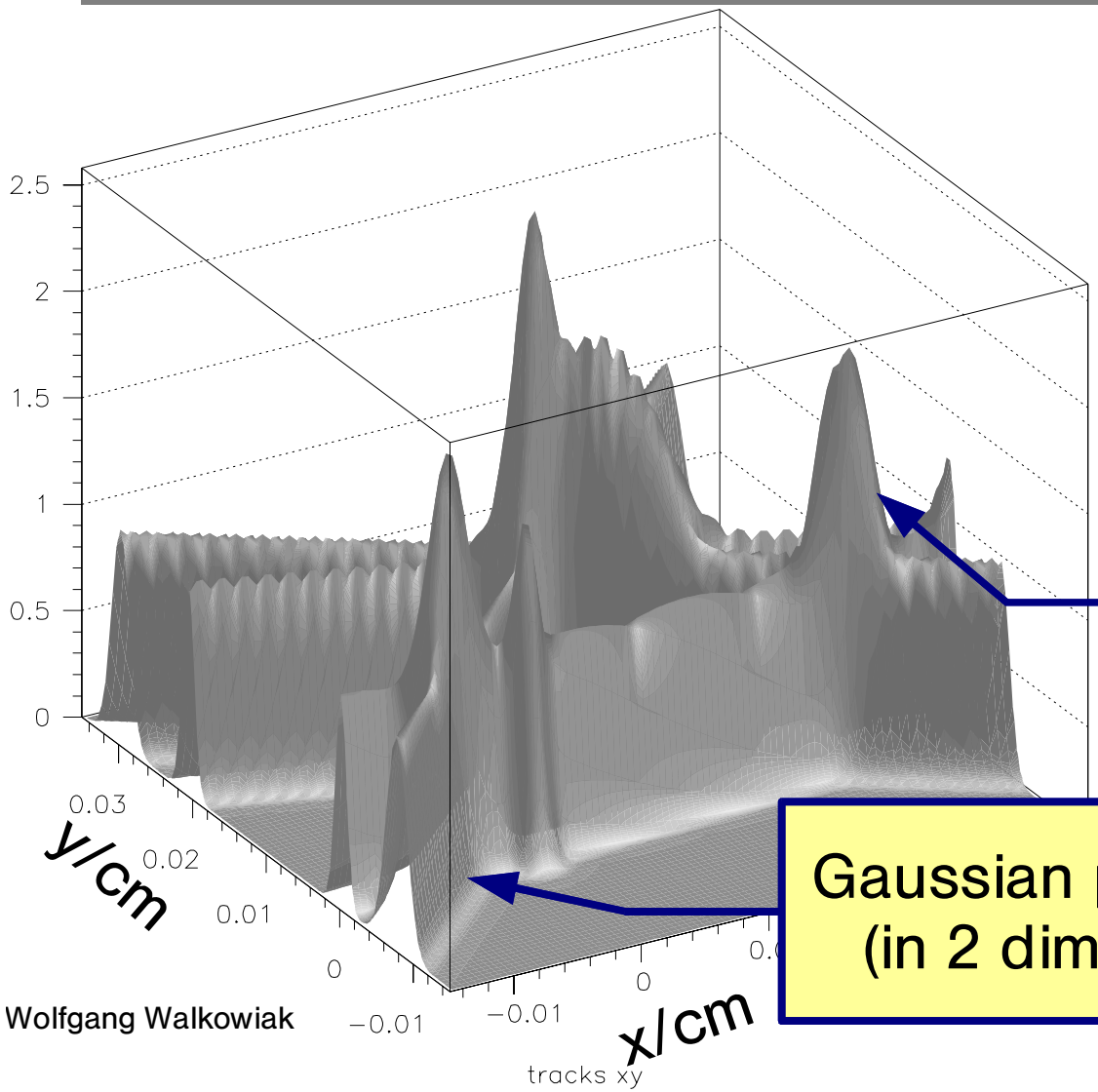
Plans for $e^+e^- \rightarrow W^+W^-$ analysis

- Study c-tagging efficiency for $e^+e^- \rightarrow W^+W^-$ events using Fast MC and ZvTopVertexer:
  Which level of equivalent lumi gain is reachable?
- $W_L W_L$ analysis: Begin with having one W decay leptonically, the other one hadronically.
- Then, in addition use events with both Ws decaying hadronically with c-tags at both sides:
  - Study influence of mistags.
  - Study feasibility with respect to backgrounds.
- Consider aggressive vertexing.

Summary

- $e^+e^- \rightarrow W_L^+W_L^-$ promises interesting physics.
- Charm-tagging helps by increasing equivalent luminosity gain, especially if both Ws are allowed to decay hadronically,
- Flavor tagging needs vertex finding:
  SLD's ZVTOP is ported to Java environment.
- Study of c-tagging capablities of the LCD detector designs , especially for $e^+e^- \rightarrow W_L^+W_L^-$ is planned.

ZVTOP - probabilty tubes



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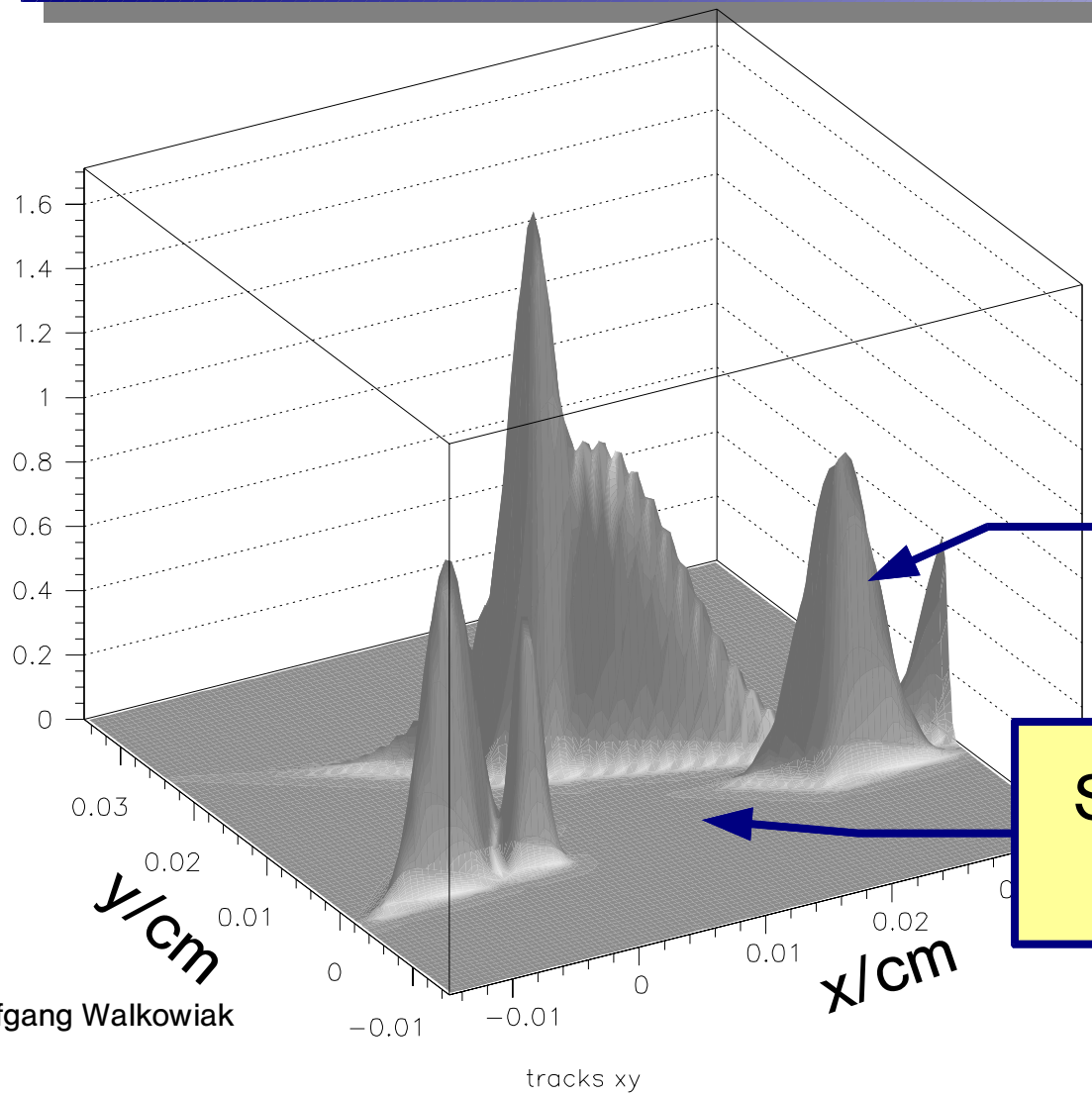
ZVTOP - vertex significance



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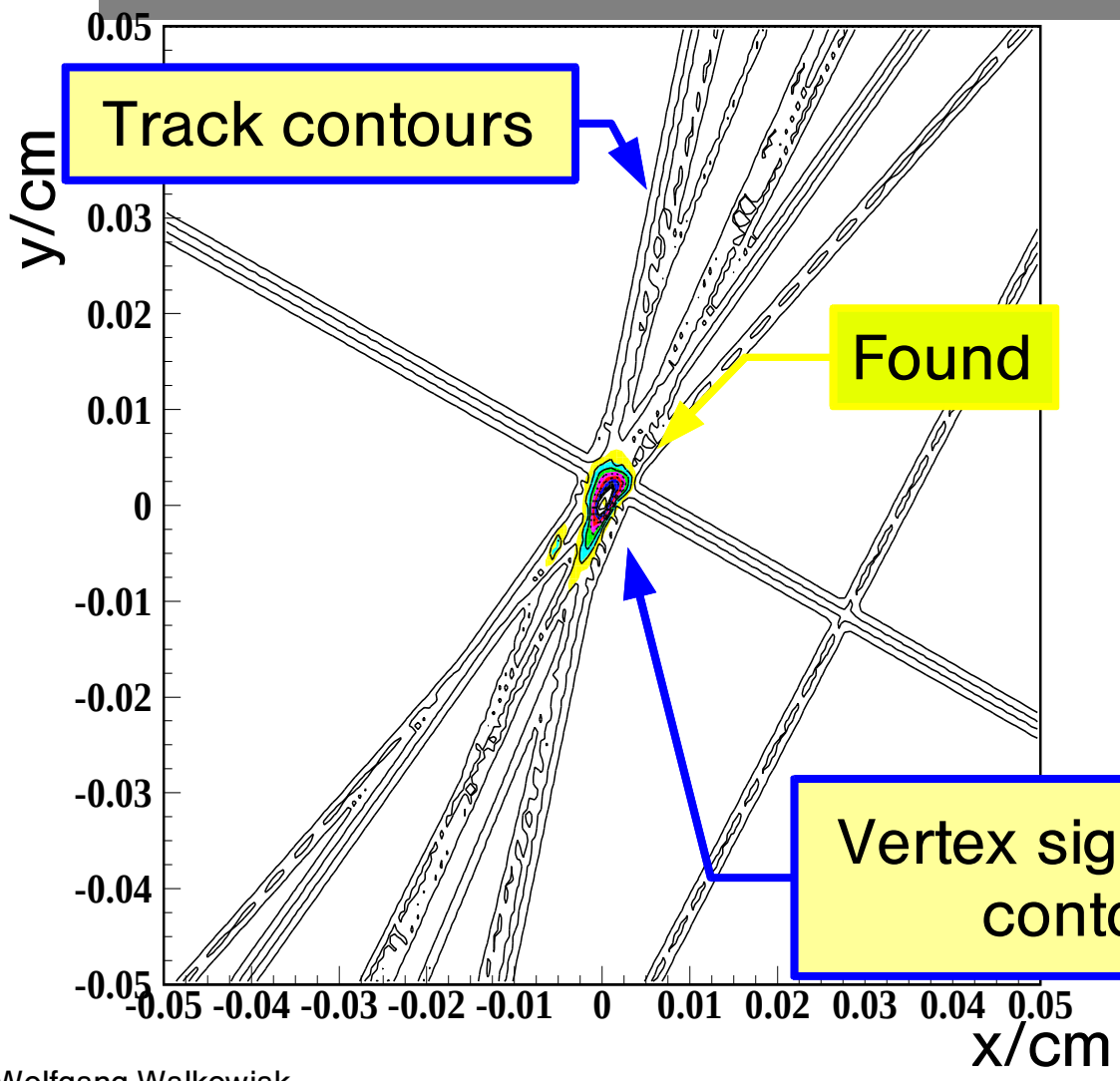

Example:

- Projection of tracks from $c\bar{c}$ event on xy-plane

Found vertices:

- Vertex with IP+ 7 tracks
- Vertex with 3 tracks (not in picture)