BR(H->cc) With Various Vertex Detector Configurations

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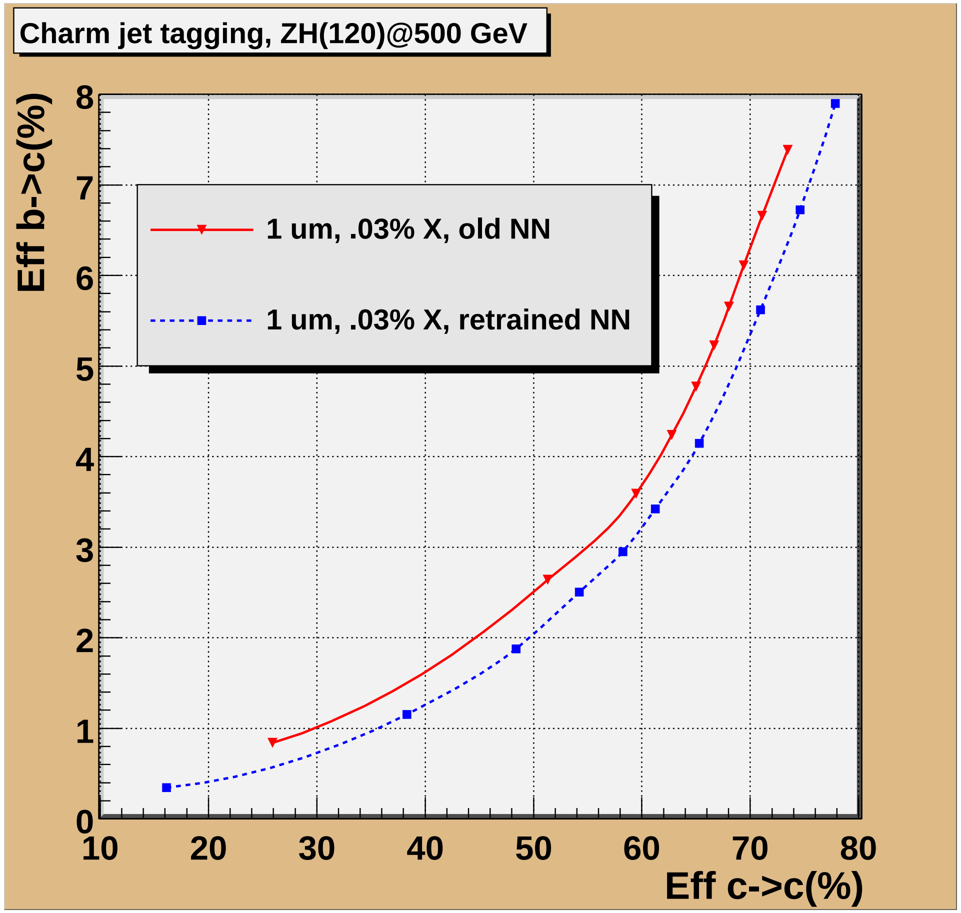
(Many thanks to Toshi Abe, Masako Iwasaki, Chris Potter, Bruce Schumm and Wolfgang Walkowiak.)

Objective: Vary vertex detector configurations to see how much the BR(H->cc) error depends on tracking resolution

- Assume the dependence is mainly in the flavor tagging efficiencies.
- The flavor tagging neural networks need to be retrained for each new detector configuration.
- Standard NN inputs: vertex mass, missing momentum, vertex distance, normalized vertex distance, #tks/vtx, #vtxs, #1-prong vtxs.
  - All depend on tracking resolution



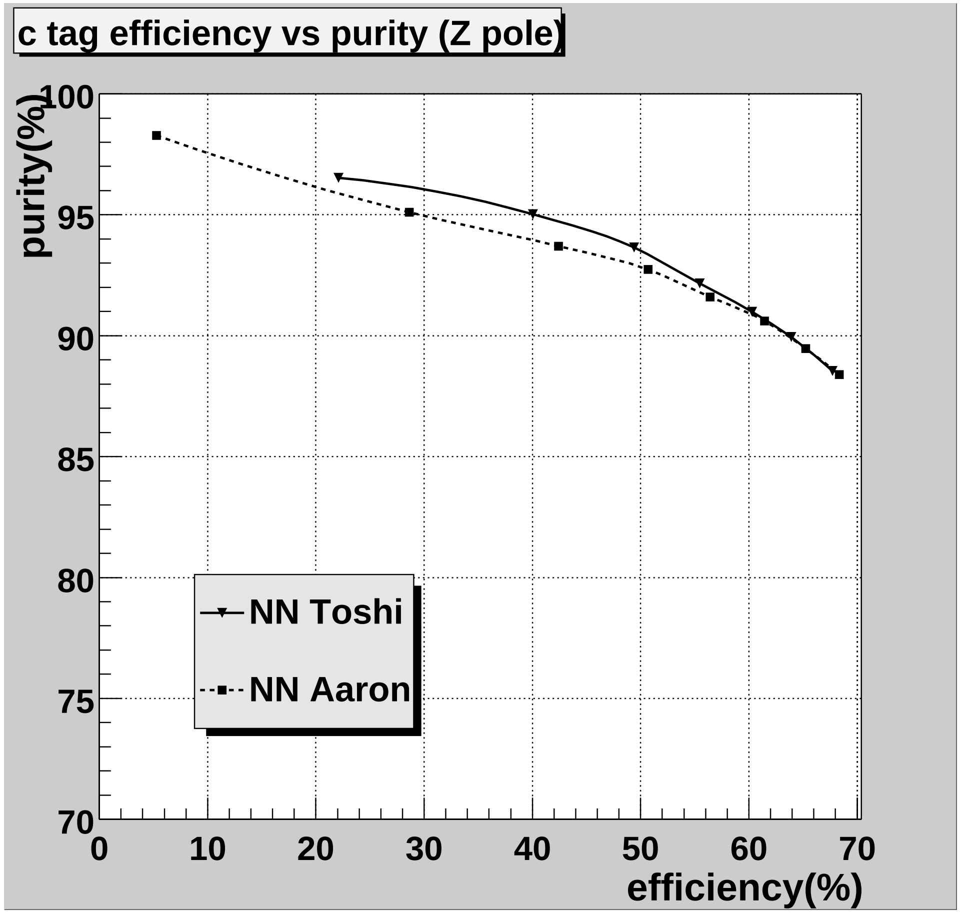
Methodology

- Use Bruce's 'lcdtrk' to create FastMC track smearing tables. (Caveat: all smearing is Gaussian—no tails.)
  - Use extra low momentum points at p=0.4, 0.6 GeV to more accurately simulate scattering.
- Use Pythia/FastMC from Toshi/Masako to generate:
  - 20K ZH(120) @ 500 GeV, Z->qq, H->qq
  - 20K ZH(120) @ 500 GeV, Z->qq, H->cc (for c jet sample)
- Use LCDJetFinder + LCDVToplGhost (ROOT) to find jets and reconstruct vertices in each jet.
- Train NN using Stuttgart program:
  - Use standard seed vertex selection NN. (Too costly to retrain.)
  - Ghost track vertexing does not need track attachment NN, except for 1-prong vertices. Again, use standard NN for this.

→Train only flavor tagging NN.

Neural network training budget

- 40K events not as good as Toshi's 300K, but the study is limited by time and computing resources
- Generate+vertex 40K evts:
  - 40 MB storage
  - 15 hours in Unix batch
- NN training:
  - 1 hour to get patterns
  - 2 hours training
  - 1 hour evaluation
- Turnaround time is 1 day, but can run multiple jobs simultaneously.

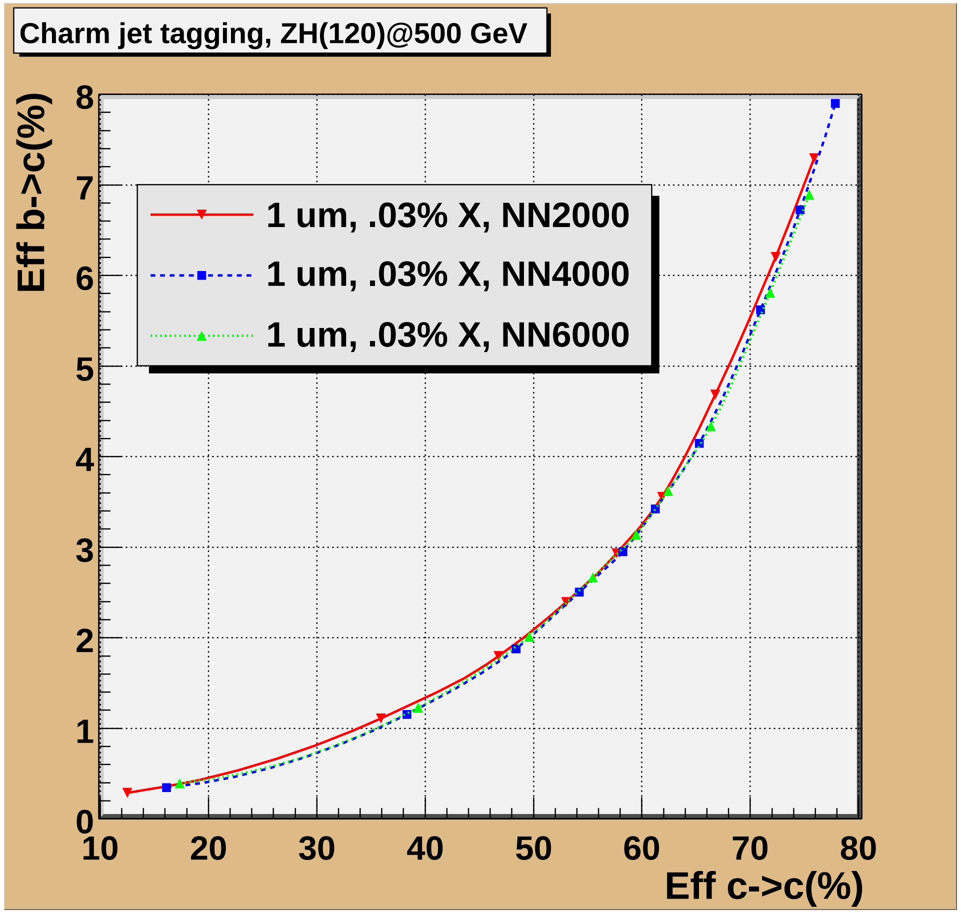


Training Regimen

- 4000 epochs appears to be enough for convergence.

Use:

- Standard backpropagation, 1000 epochs, learn=0.2
- Backpropagation with momentum,1000 epochs, learn=0.1, momentum=0.5
- Backpropagation with momentum, 1000 epochs, learn=0.05, momentum=0.5
- Backpropagation with momentum, 1000 epochs, learn=0.01, momentum=0.5



The dependence of ΔBR(H->cc)/BR(H->cc) on **flavor tagging**

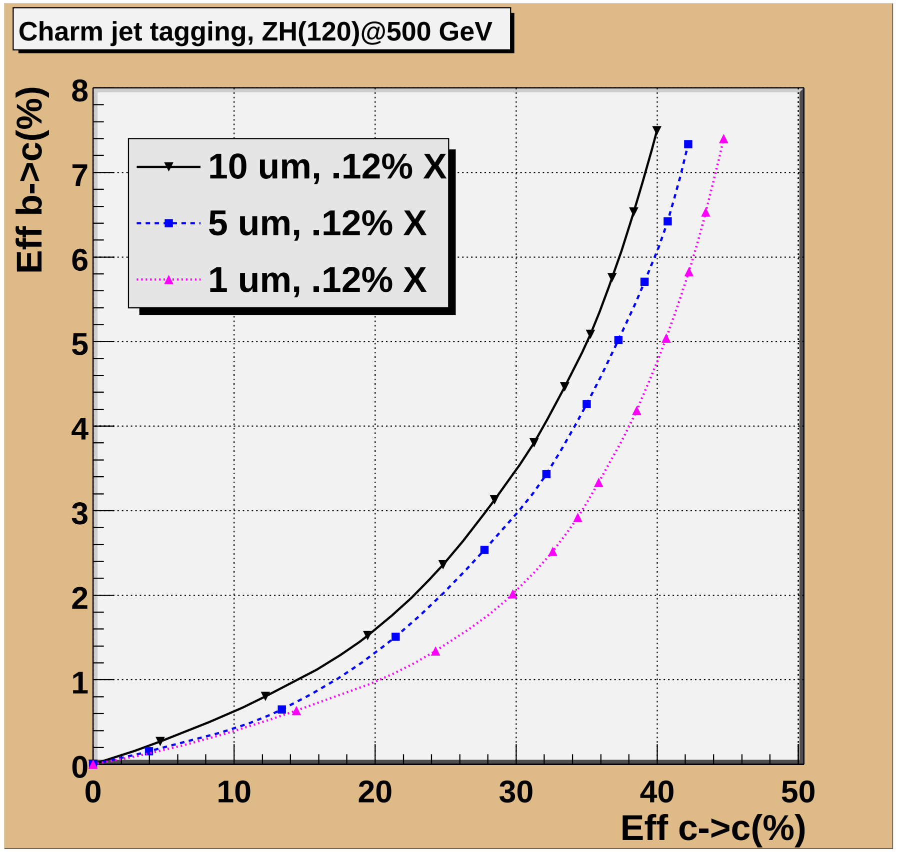
- # Flavor tagged events: $T = (T_b, T_c, T_u)$
- # True flavor events: $N = (N_b, N_c, N_u)$
- $T = E_{flav} \times N + T_{bkgd}$
  - (E_{flav} = flavor tagging efficiency, i.e E_{cc}, E_{bc}, E_{bb}, etc, and T_{bkgd} = tag counts from Z mistagged as H)
- $N = (E_{flav})^{-1} \times (T - Z_{bkgd})$
- Neglecting ΔZ_{bkgd} → $\Delta N \approx (E_{flav})^{-1} \times \mathrm{sqrt}(T)$
- Neglecting ΔT_b, ΔT_u → $\Delta N_c \approx (E_{cc})^{-1} \times \mathrm{sqrt}(T_c)$
  - $T_c = (E_{cc} \times BR_{cc} + E_{bc} \times BR_{bb}) \times N^H + T_{bkgd}$, where N^H = # Higgs

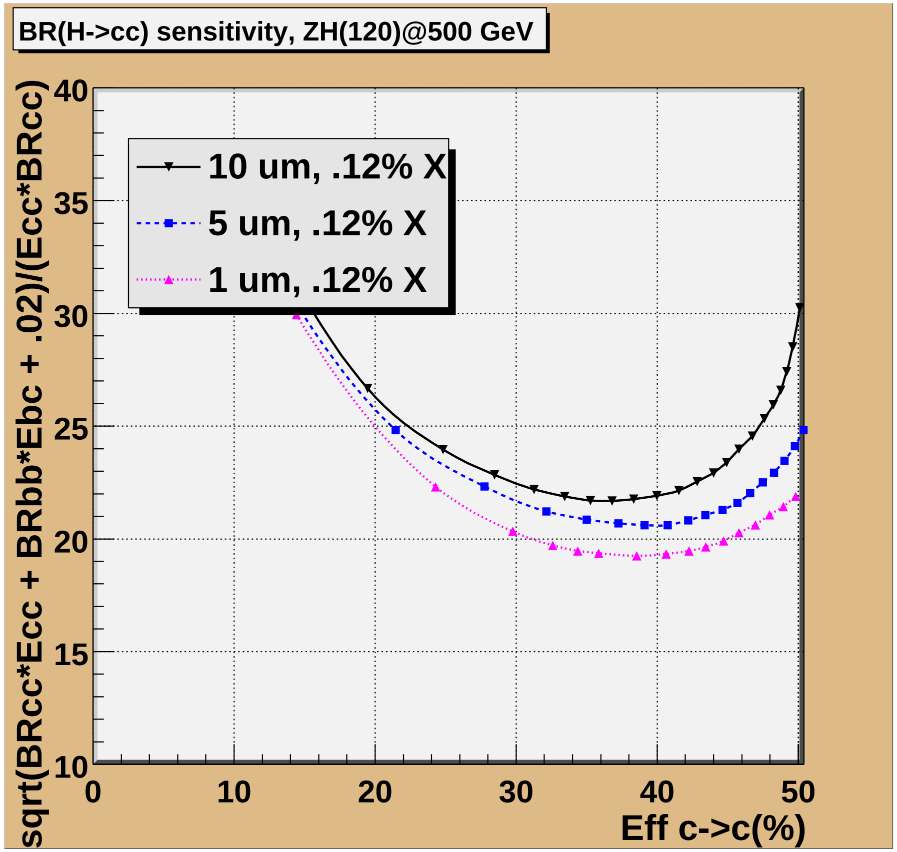
$$\Delta BR_{cc}/BR_{cc} \approx [\mathrm{sqrt}(E_{cc} \times BR_{cc} + E_{bc} \times BR_{bb} + T_{bkgd}/N^H) / (E_{cc} \times BR_{cc})] \times \times 1/\mathrm{sqrt}(N^H)$$

- Same as sqrt(S+B)/S formula that Chris uses. (May need an extra factor of ✠1.2 to account for the neglected error sources.)
- Use $BR_{cc} = 0.03$, $BR_{bb} = 0.72$, $T_{bkgd}/N^H = 0.02$ in following plots.

Vary the CCD hit resolution

(Standard small detector: 5 μm, .12 X^0, R=1.4 cm, pcut=1%)

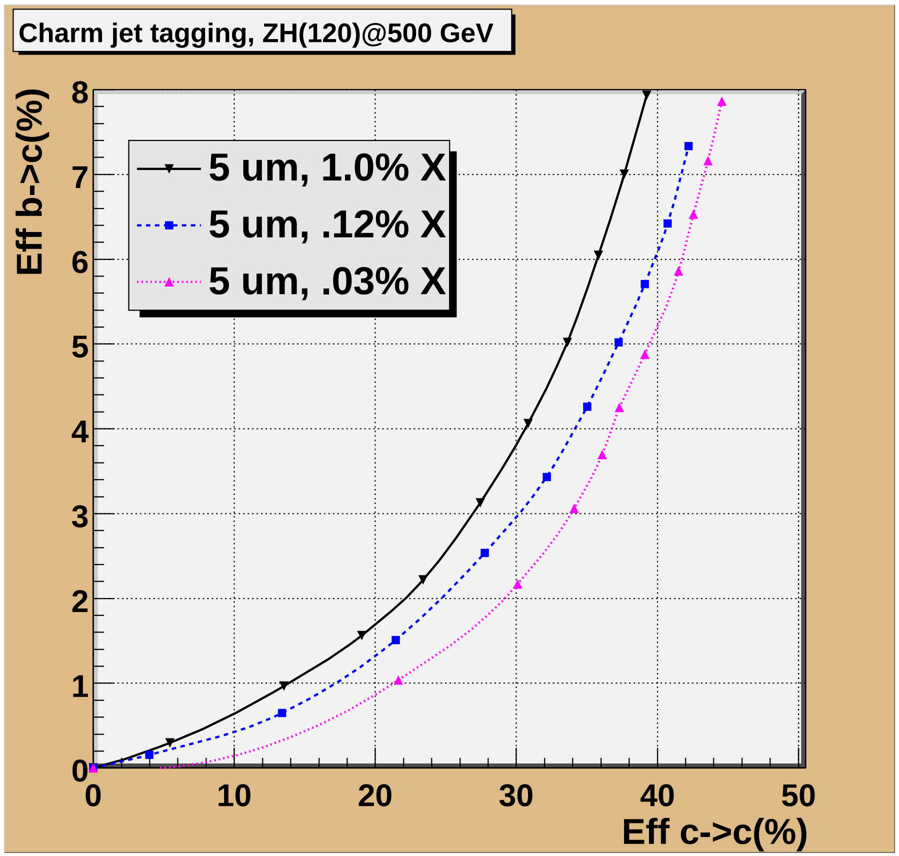


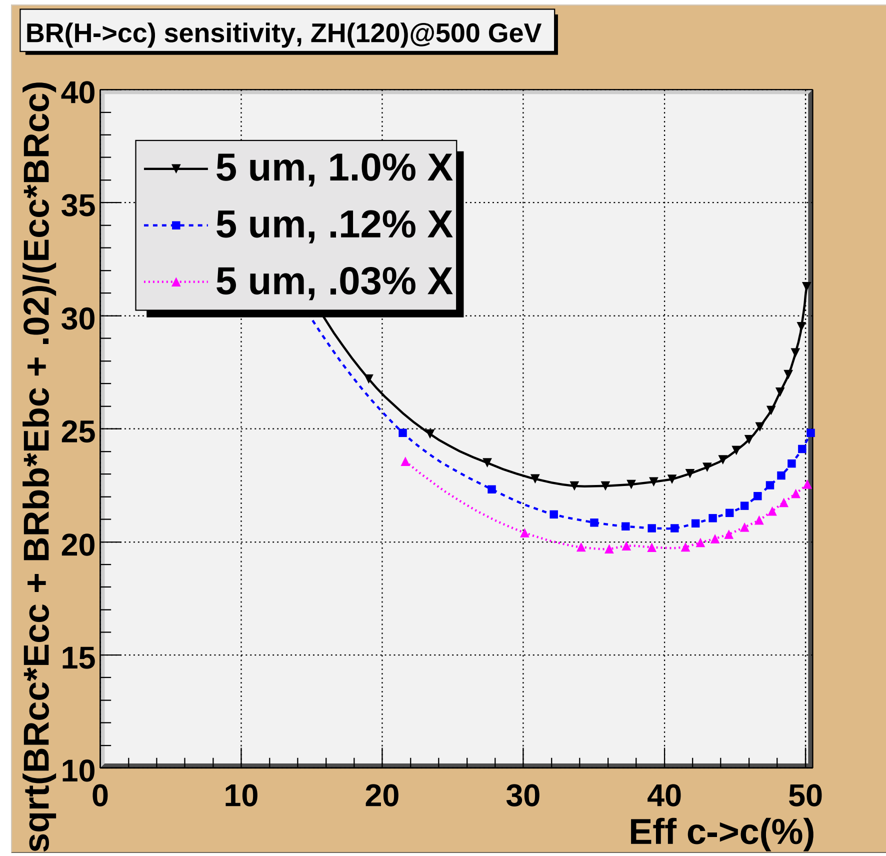


Note 1: Other efficiencies E_{bb},E_{cb} only slightly changed.

Note 2: Only general flavor tagging NN was trained. For sensitivity plots, assume 5% improvement in efficiency for Toshi's1-prong, 0-prongs NNs.

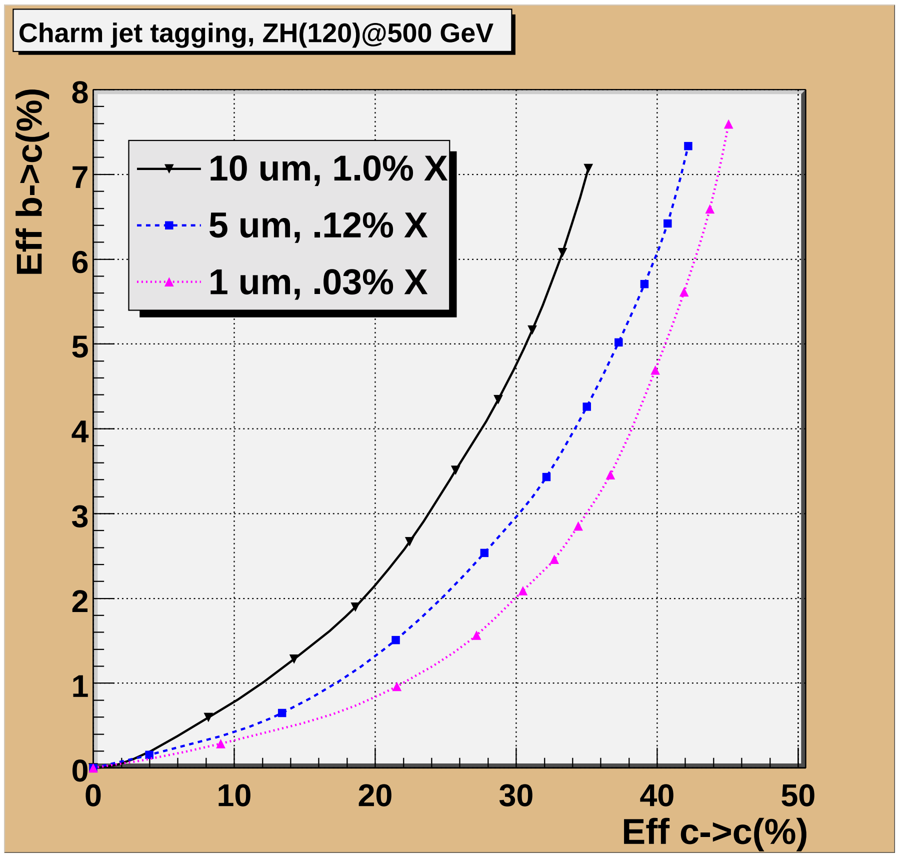
Vary the radiation thickness

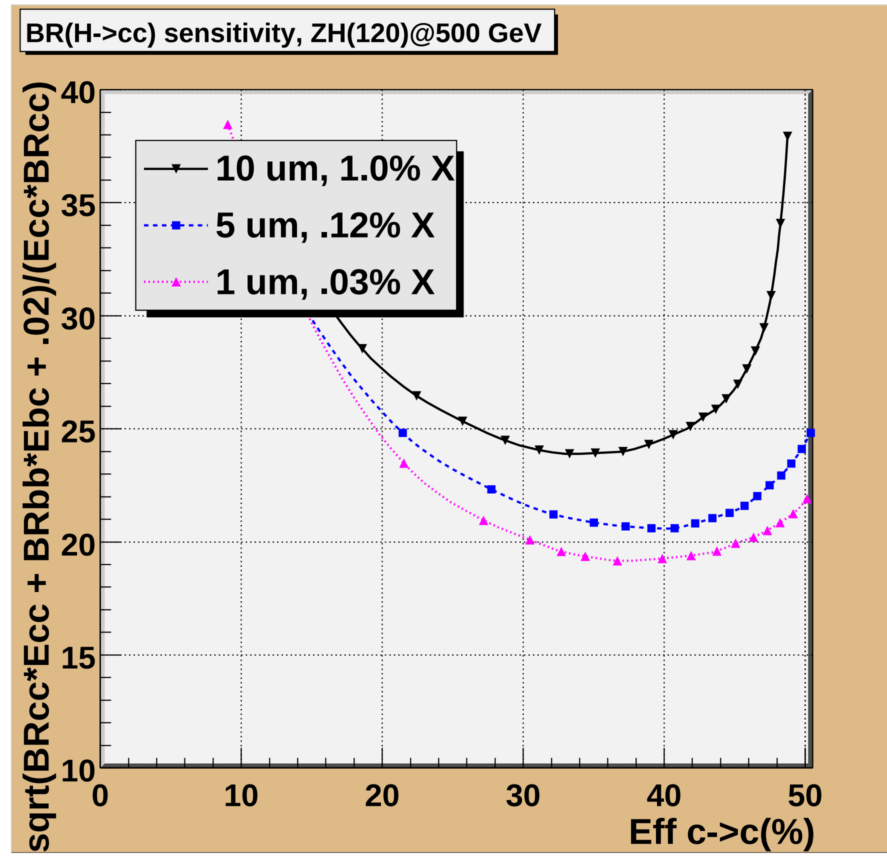




Note: E_{uc} is also improved, but unimportant for BR(H->cc).

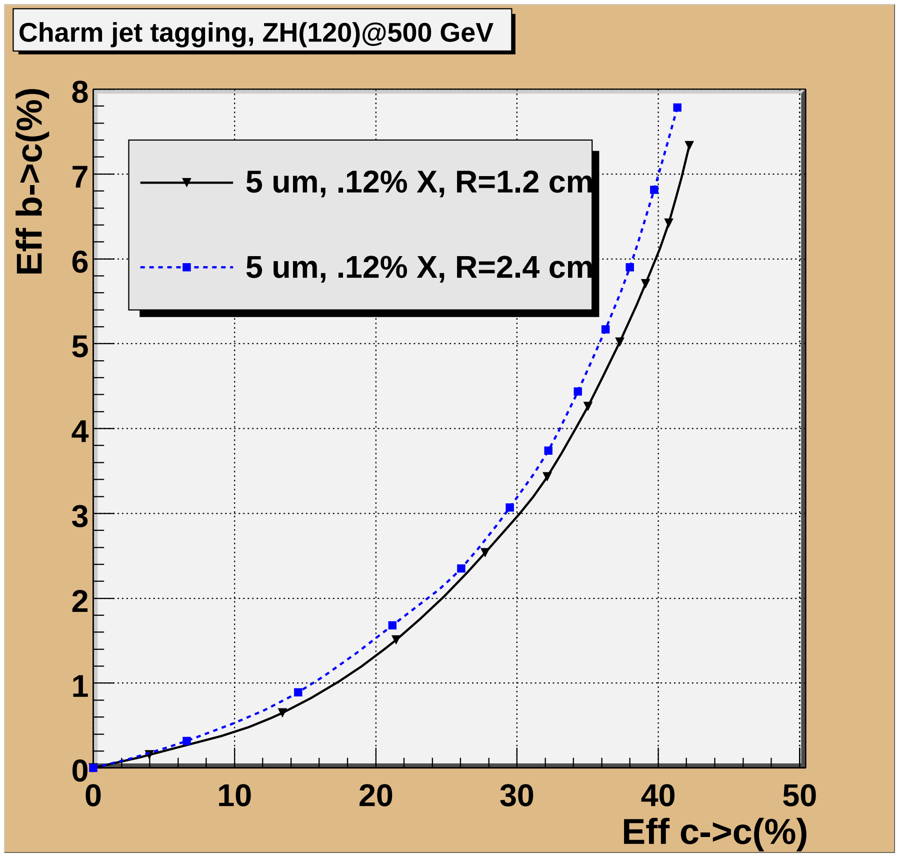
Compare best and worst detector configurations

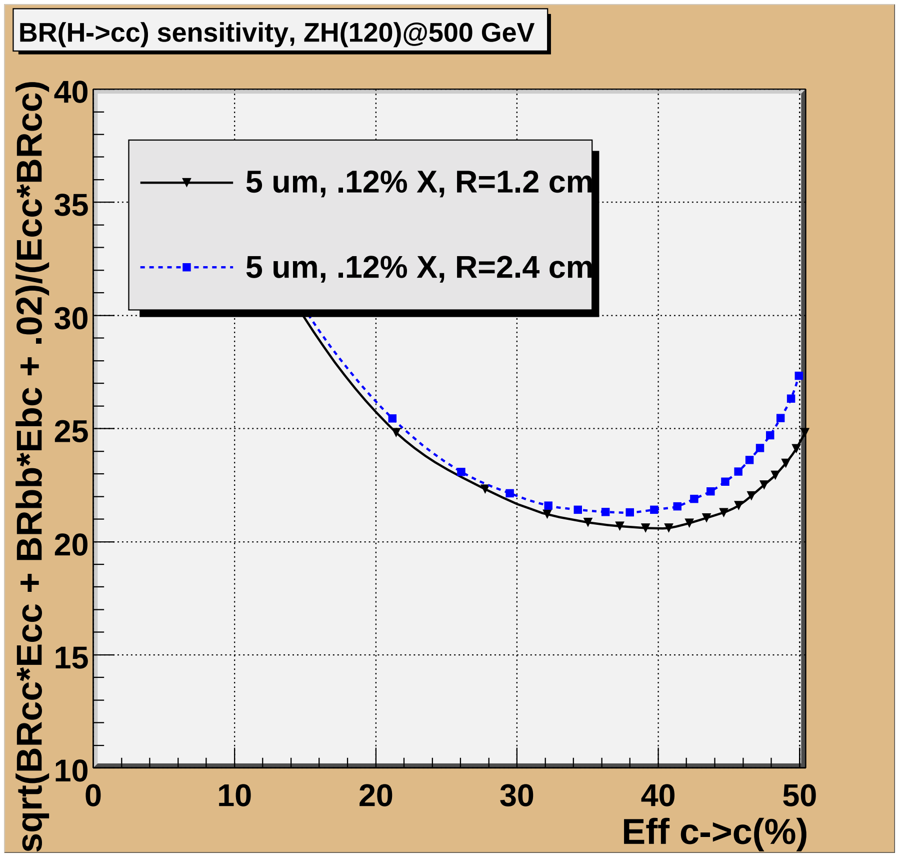




Dependence on inner radius:

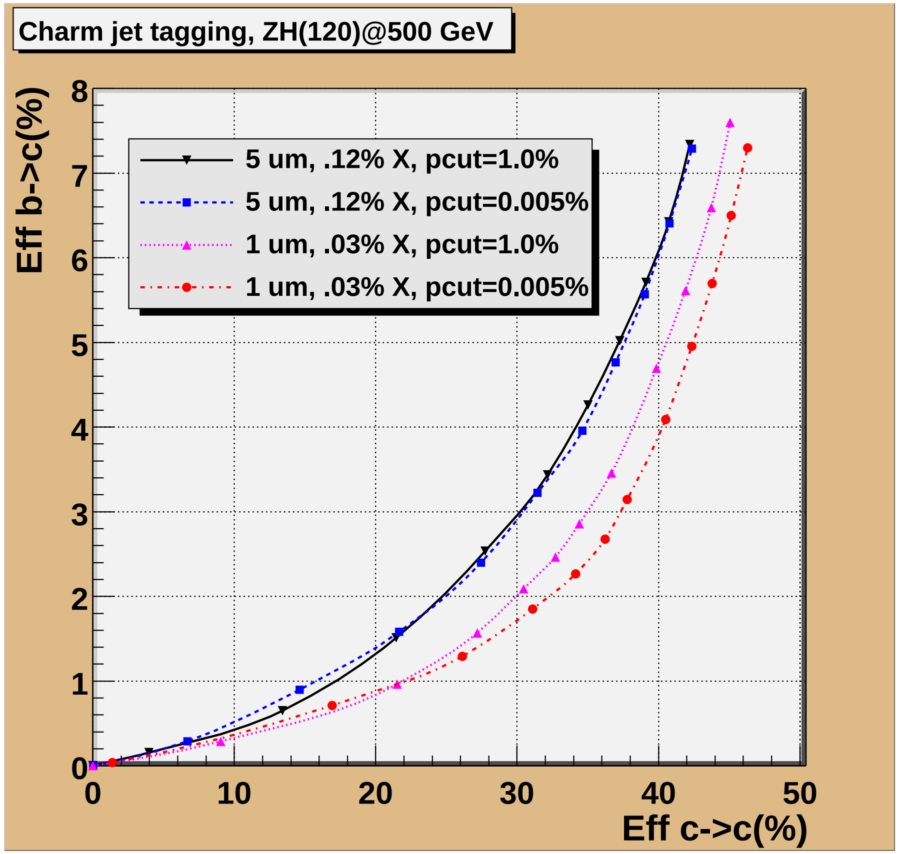
remove layer 1 (1.2 cm) and add layer 6 (7.2 cm, just inside cryo)
with z_{max}=15 cm to get the same acceptance

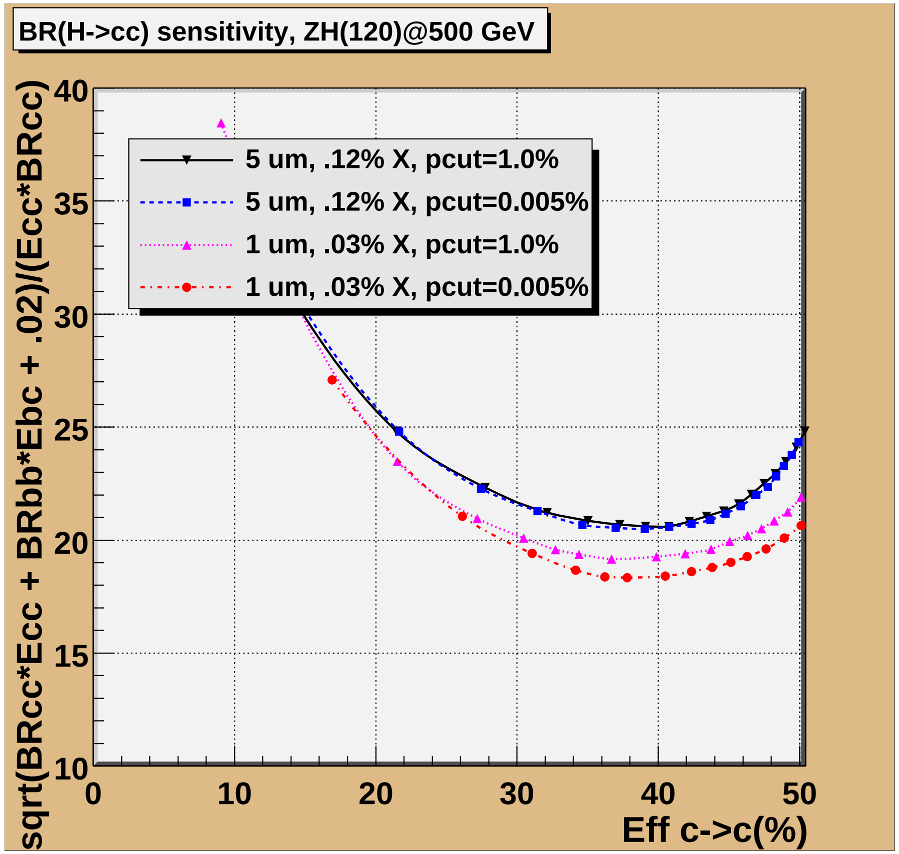




Dependence on vertex probability cut:

Idea: Capture the track error tails by going to better resolution, but then giving up the resolution by cutting much further in the tails of the track error distribution.





Why is the detector dependence so small?

- Average track resolution ≈ 10 μm << cτ of heavy hadrons.
- Track errors = σ_0 🖐 σ_{MS}/P

(hit res,	thickness,	inner radius)	σ_0	σ_{MS}
(10.0 μm,	0.12% X_0,	1.2 cm)	4.7 μm	11.7 μm×GeV/c
(5.0,	0.12,	1.2)	2.5	8.0
(1.0,	0.12,	1.2)	0.7	4.8
(5.0,	1.00,	1.2)	2.5	16.0
(5.0,	0.03,	1.2)	2.5	6.0
(10.0,	1.00,	1.2)	4.7	20.4
(1.0,	0.03,	1.2)	0.7	3.1
(5.0,	0.12,	2.4)	2.6	12.7

Summary

- Varying the detector configuration changes the measurement error by only 5-15% (relative).
  - For example, $\Delta BR_{cc}/BR_{cc} \approx 24/\mathrm{sqrt}(N^H) \rightarrow 21/\mathrm{sqrt}(N^H)$.
- Explanation? Average track resolution ≈ 10 μm << cτ of heavy hadrons. The Higgs boost helps. Having 5 layers also really helps.
- Detector compromises seem possible.

- Caveats:
  - Flavor tagging efficiencies were evaluated at the jet level. Event level efficiencies should be better since there is more info.
  - Only Gaussian smearing was used, and so the track error estimators were exact. In real life, higher mistag rates are expected, and so radiation thickness may be more important.
  - Studies were done with only 40K FastMC events.
  - Studies were done at E_{cm}=500 GeV. Going to lower energies such as the ZH threshold would lower the average track momentum and worsen the average resolution.