Improved radiative corrections for $(e, e'p)$ experiments

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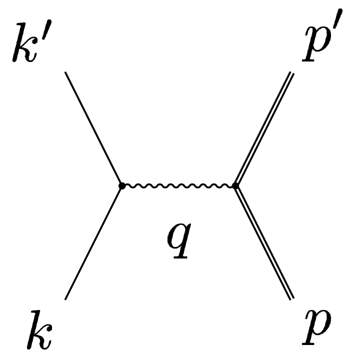
introduction: radiative corrections for $(e, e'p)$ reactions
peaking approximation and soft photon approximation
beyond peaking approximation: full angular Monte Carlo simulation
beyond soft photon approximation: impact on Rosenbluth problem?
conclusions and outlook

introduction

what are (e,e'p) experiments?



why? $\rightarrow$ coincidence reactions off nuclei useful to study:

form factors

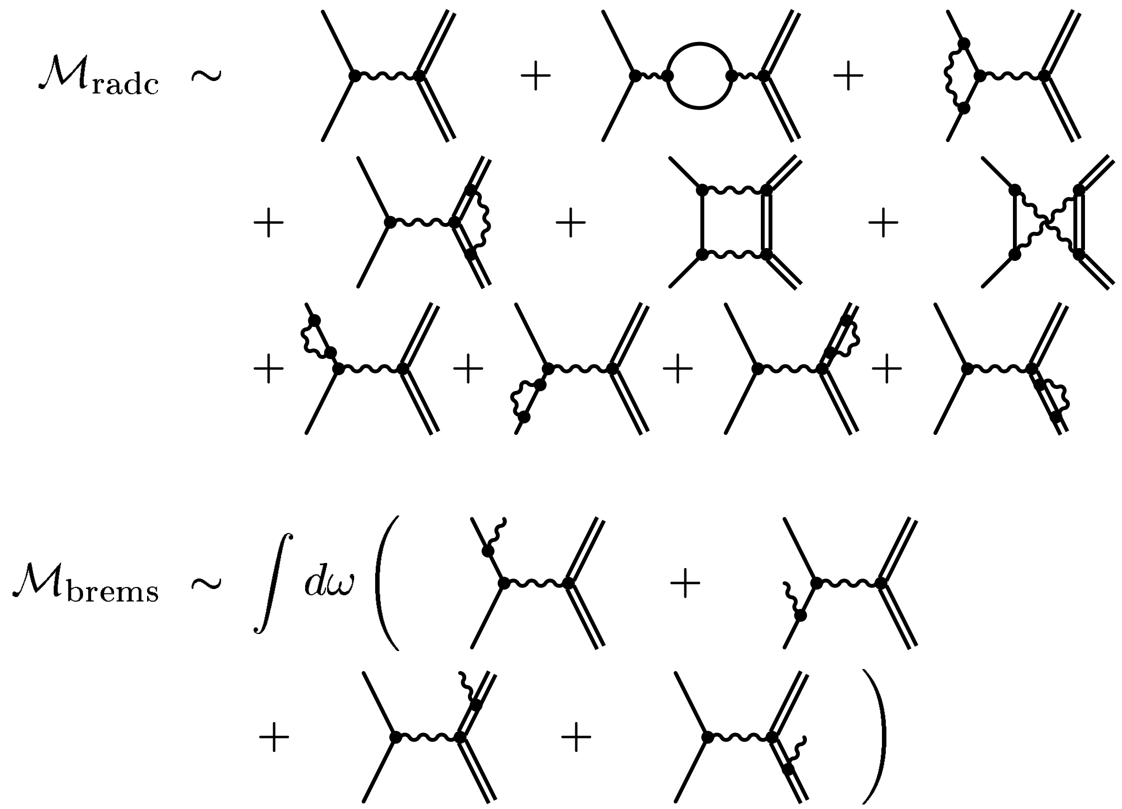
nuclear ground-state wave function

current operators

final state interactions

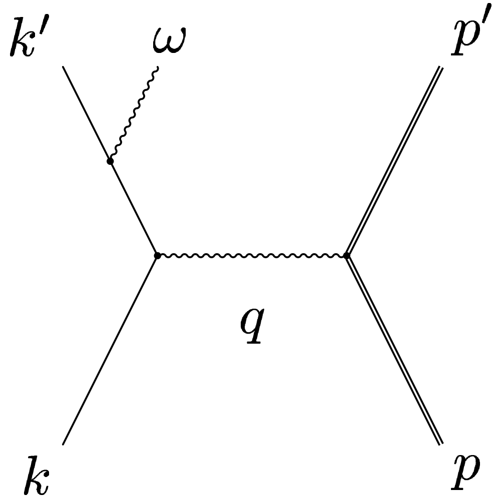
limits of single-particle models,...

via momentum conservation and PWIA

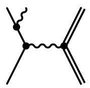
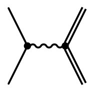


contributing QED Feynman diagrams beyond lowest order

why should we worry about radiative corrections?
bremsstrahlung changes kinematics by carrying away momentum and energy!



soft photon approximation (SPA): in the limit of small photon energies, bremsstrahlung amplitudes factorize

 $\approx$  $\times$ something $(\omega^0 \text{ small})$

modified SPA: adjust particle energies, calculate new q^2

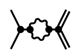
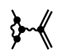
[D. R. Yennie, S. C. Frautschi, H. Tsuura, Ann. Phys. **13**, 379 (1961)]:

multi-photon bremsstrahlung is important and straight-forward in SPA

consider single-photon bremsstrahlung cross section in SPA

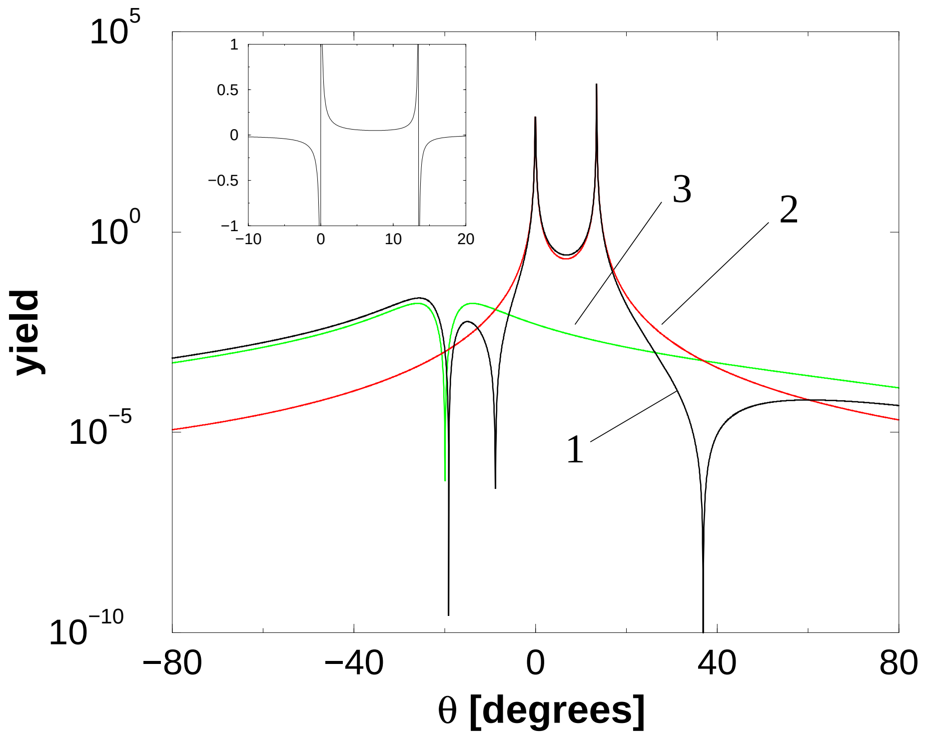
$$\frac{d\sigma}{d\Omega_{\rm e} d\Omega_\gamma d\omega^0} = \left.\frac{d\sigma^{(1)}}{d\Omega_{\rm e}}\right|_{\rm ep} \frac{A(\hat{\omega})}{\omega^0},$$

where $A(\hat{\omega}) \equiv -\frac{\alpha {\omega^0}^2}{4\pi^2}\left[\left(\frac{k'}{\omega\cdot k'}-\frac{k}{\omega\cdot k}\right)^2 - 2\left(\frac{k'}{\omega\cdot k'}-\frac{k}{\omega\cdot k}\right)\left(\frac{p'}{\omega\cdot p'}-\frac{p}{\omega\cdot p}\right)+\left(\frac{p'}{\omega\cdot p'}-\frac{p}{\omega\cdot p}\right)^2\right]$

define $\delta_{\rm soft} \sim$ ( +  +  + )^2 and $\delta_{\rm hard} \sim$ ( +  + )^2

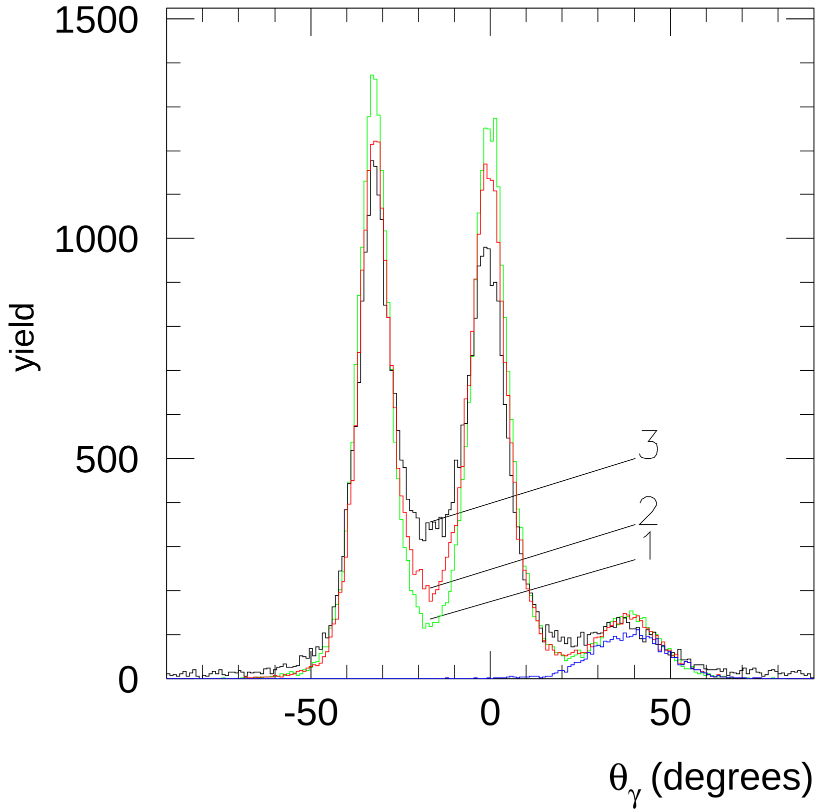
single-photon total cross section: $\frac{d\sigma}{d\Omega_{\rm e}}(\omega^0 < E_0) = \frac{d\sigma^{(1)}}{d\Omega_{\rm e}}[1-\delta_{\rm soft}(E_0)-\delta_{\rm hard}]$

multi-photon total cross section: $\frac{d\sigma}{d\Omega_{\rm e}}(\omega_i^0 < E_0) = \frac{d\sigma^{(1)}}{d\Omega_{\rm e}}\exp[\delta_{\rm soft}(E_0)] \times [1-\delta_{\rm hard}]$



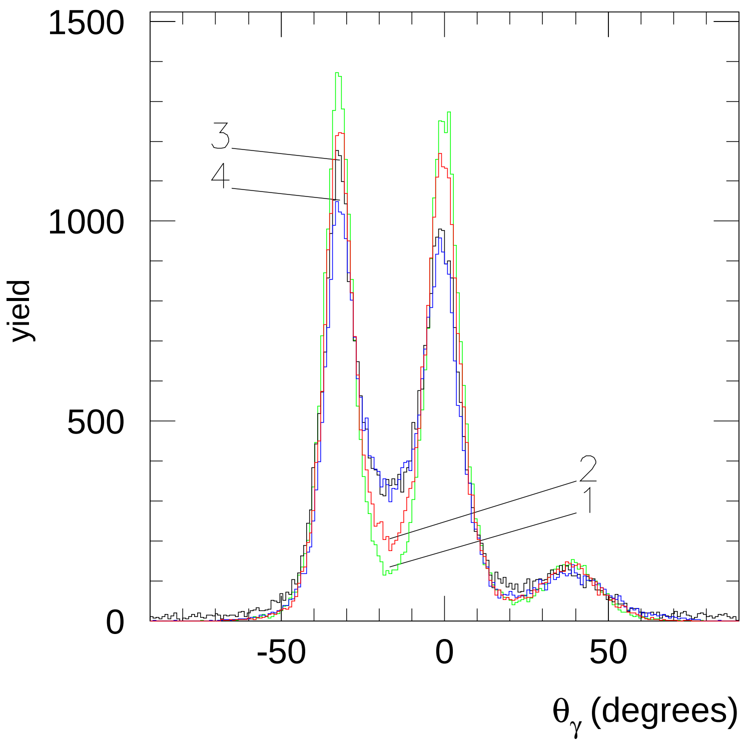
angular distribution $A(\hat{\omega})$ for $Q^2 = 15\,\mathrm{GeV}^2$ $(\phi = 0)$
(1) $A_{\mathrm{tot}}(\hat{\omega})$, (2) $A_{\mathrm{e}}(\hat{\omega})$, (3) $A_{\mathrm{p}}(\hat{\omega})$, inset: $A_{\mathrm{ep}}(\hat{\omega})$

SPA plus peaking: $A(\hat{\omega}) = \lambda_{\mathrm{e}}\delta(\omega - k) + \lambda_{\mathrm{e}'}\delta(\omega - k') + \lambda_{\mathrm{p}'}\delta(\omega - p')$



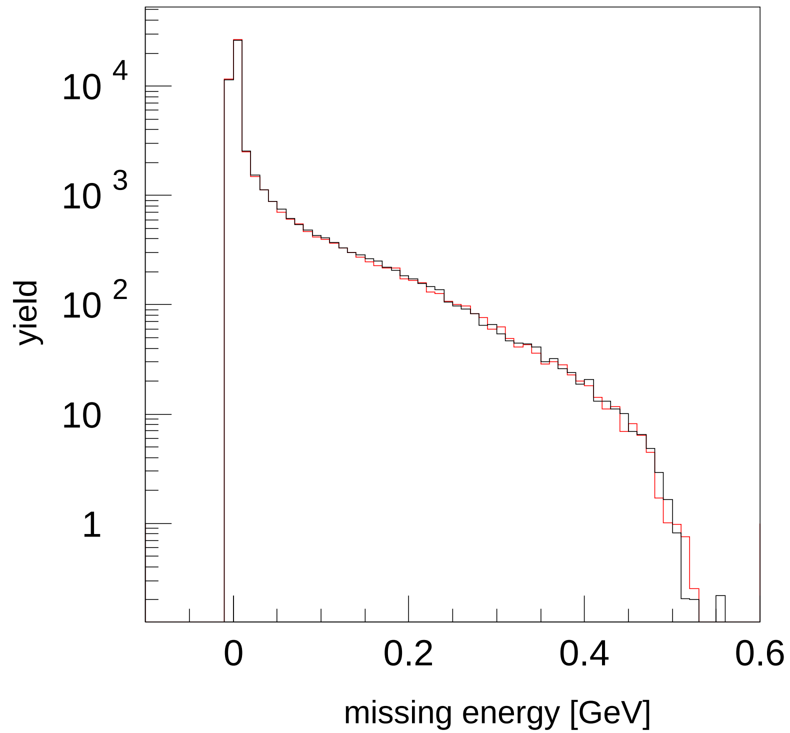
photon angular distribution using peaking approximation underestimates radiation between e and e' direction (1,2) peaking, (3) reconstructed data

angular distribution of photons revisited



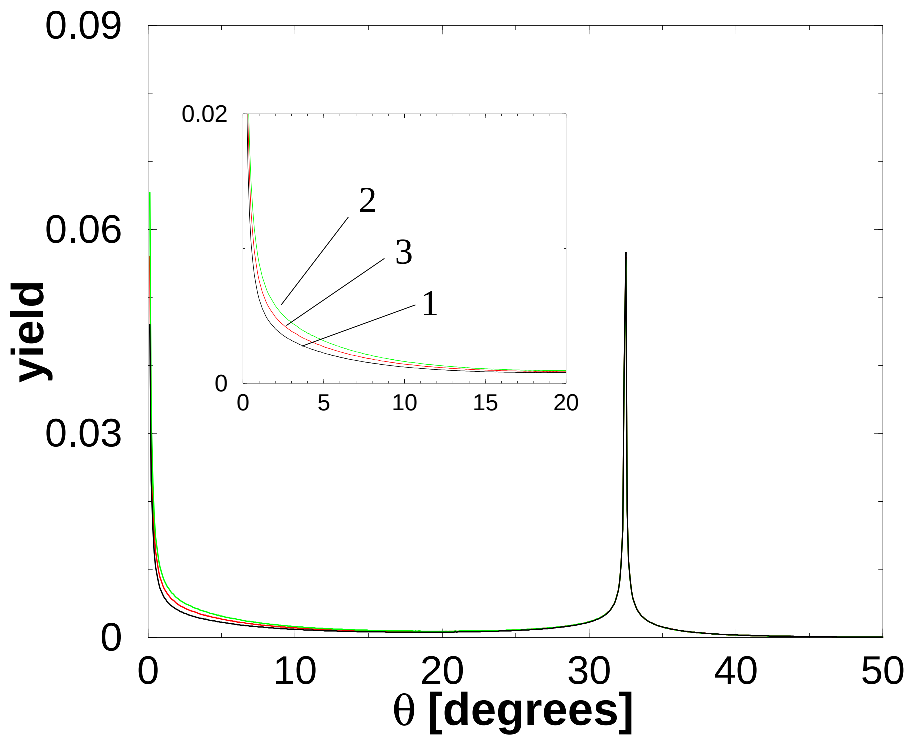
blue: full angular Monte Carlo simulation fits data better
(1,2) peaking, (3) reconstructed data, (4) full angular MC

impact on missing energy and total yield?



missing energy: black: peaking red: full angular

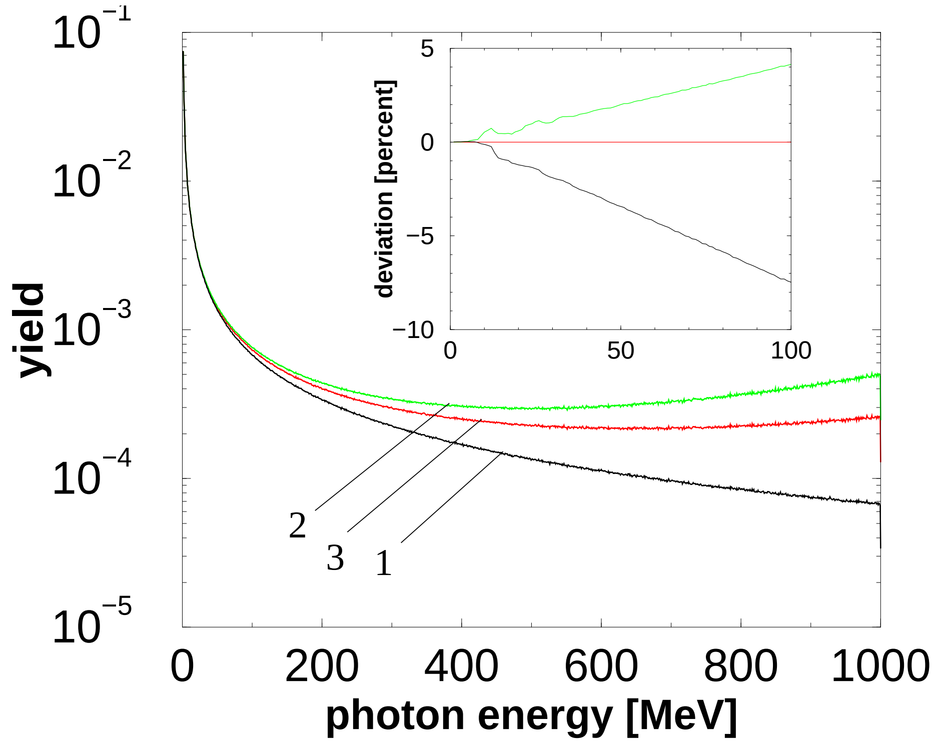
Applicability of SPA?



angular **single**-photon distribution

black (1): naive SPA green (2): modified SPA red (3): exact calc.

Applicability of SPA?



single-photon missing energy

black (1): naive SPA green (2): modified SPA red (3): exact calc.

Exact multi-photon calc. possible?

- QED scattering amplitudes get too complicated for several bremsstrahlung photons

- combination feasible: one 'hard' photon (treated exactly) plus soft photon background (treated within SPA, without peaking)

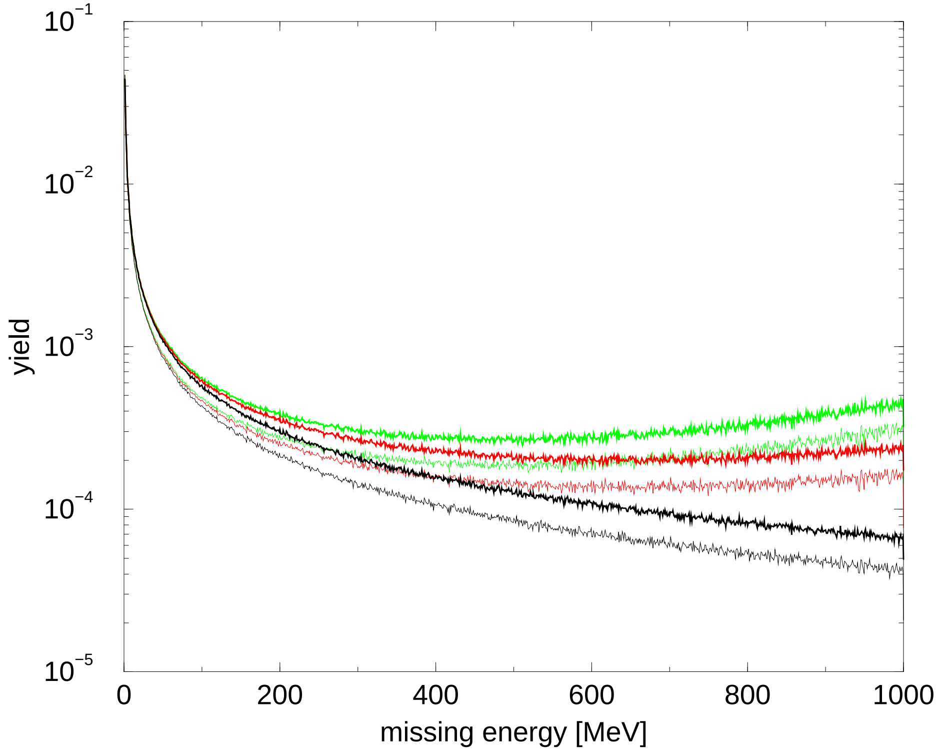
- $1/\omega^0$ distribution selects one hard plus several soft photons

- how do we choose the hard photon?
  largest energy ω^0, highest q^2 deviation, $\omega_{\rm tot}$-kinematics

- three methods yield same results

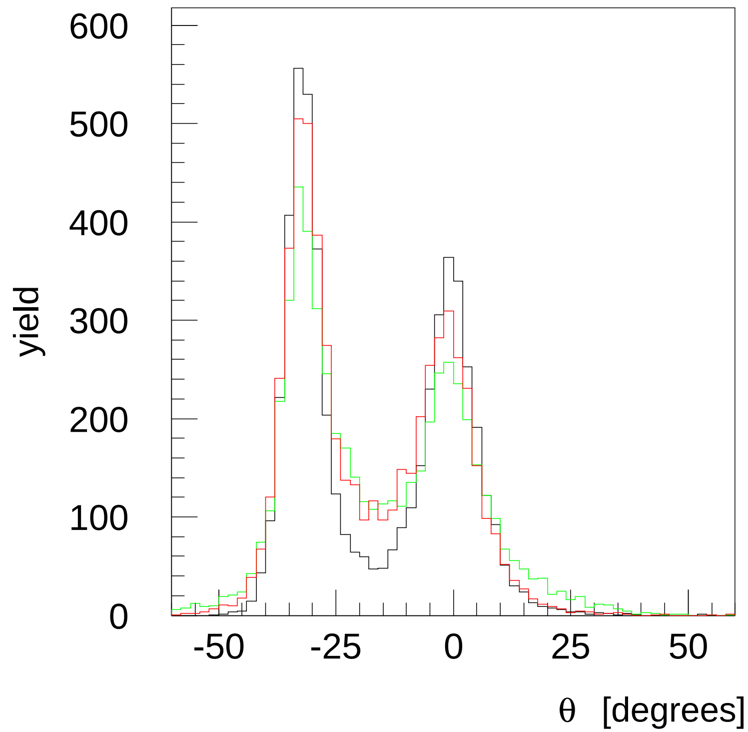
- random selection of hard photon differs considerably

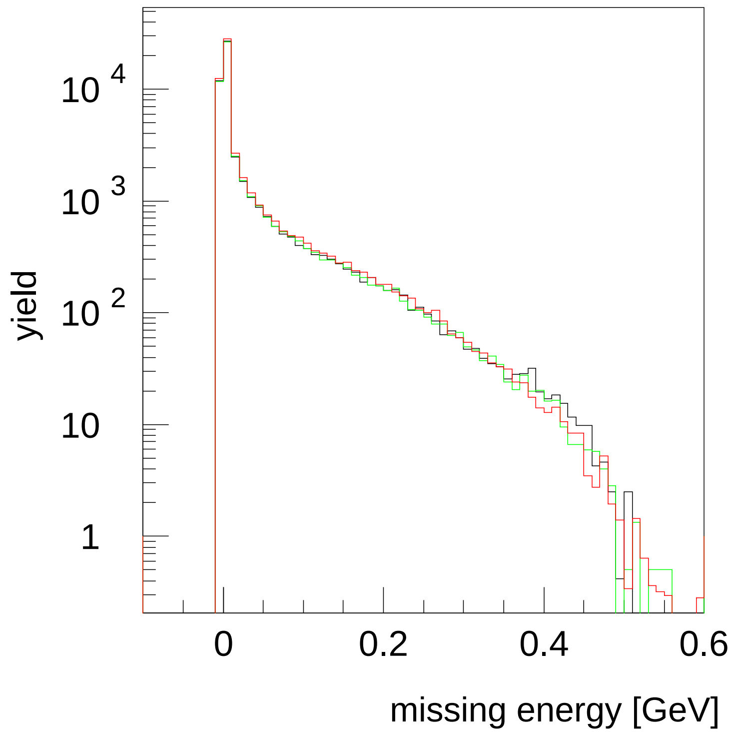
Combined “exact plus SPA” calculation



missing energy: black: naive SPA green: mod. SPA red: exact/comb. calc.
multi-photon pushes up radiative tails (no pure Poisson distr.)

insert this into SIMC (preliminary results)





multi-photon angular distribution and missing energy

black: peaking, green: SPA, red: combined method

conclusions and loose ends

- removal of peaking approximation is possible
- check against E97-006 $(e, e'p)$ data from JLab with SIMC successful
- scope of SPA is limited, SPA can be removed for one 'hard' photon, combination "exact plus SPA background" feasible
- combined calculation might have impact on Rosenbluth problem
- we shall check that