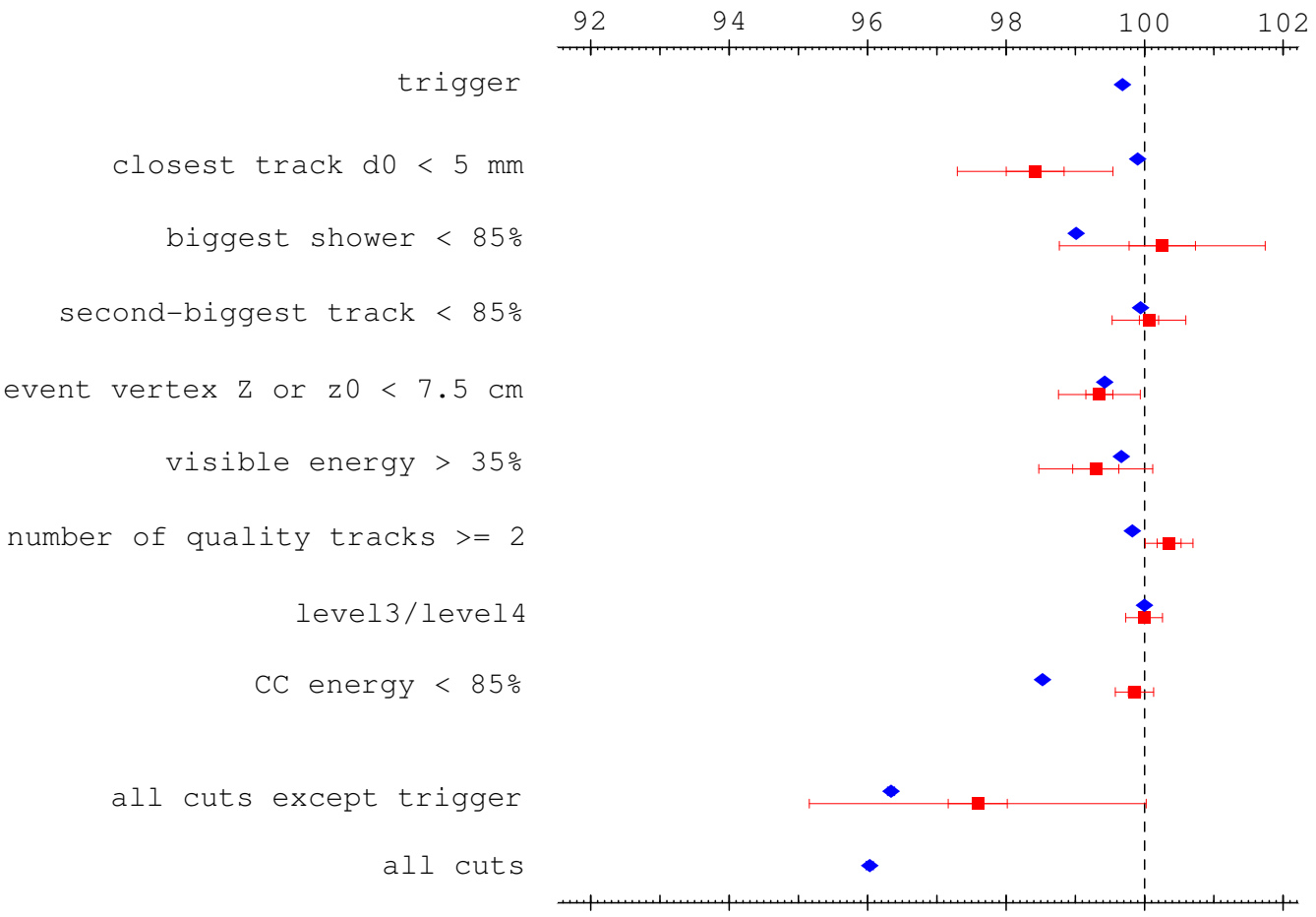
- What is this talk about?
  - Efficiency of cuts for measuring $\int \Upsilon \rightarrow$ hadrons
  - $\Upsilon \rightarrow \ell^+\ell^-$ are background, cascade decays (even to $X\ell^+\ell^-$) are signal; other backgrounds are continuum processes, cosmic rays, beam-gas.

- What's new since last time?
  - Several data/MC disagreement puzzles have been solved
  - A bug in EvtGen has been discovered (and fixed by Anders)
  - Most of the systematic error table has been filled in

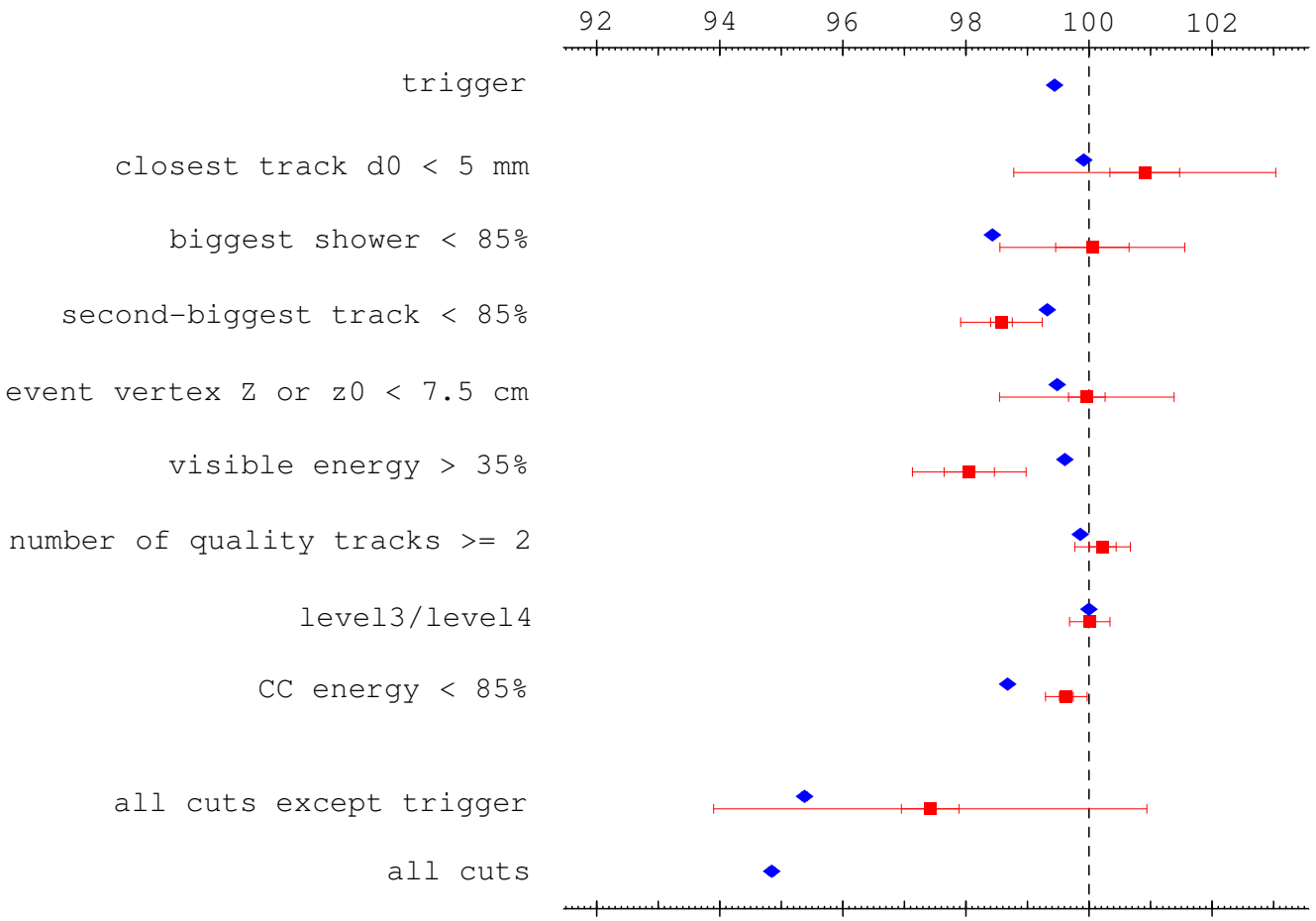
Jim Pivarski

Hadronic efficiencies for each cut: $\Upsilon(1S)$



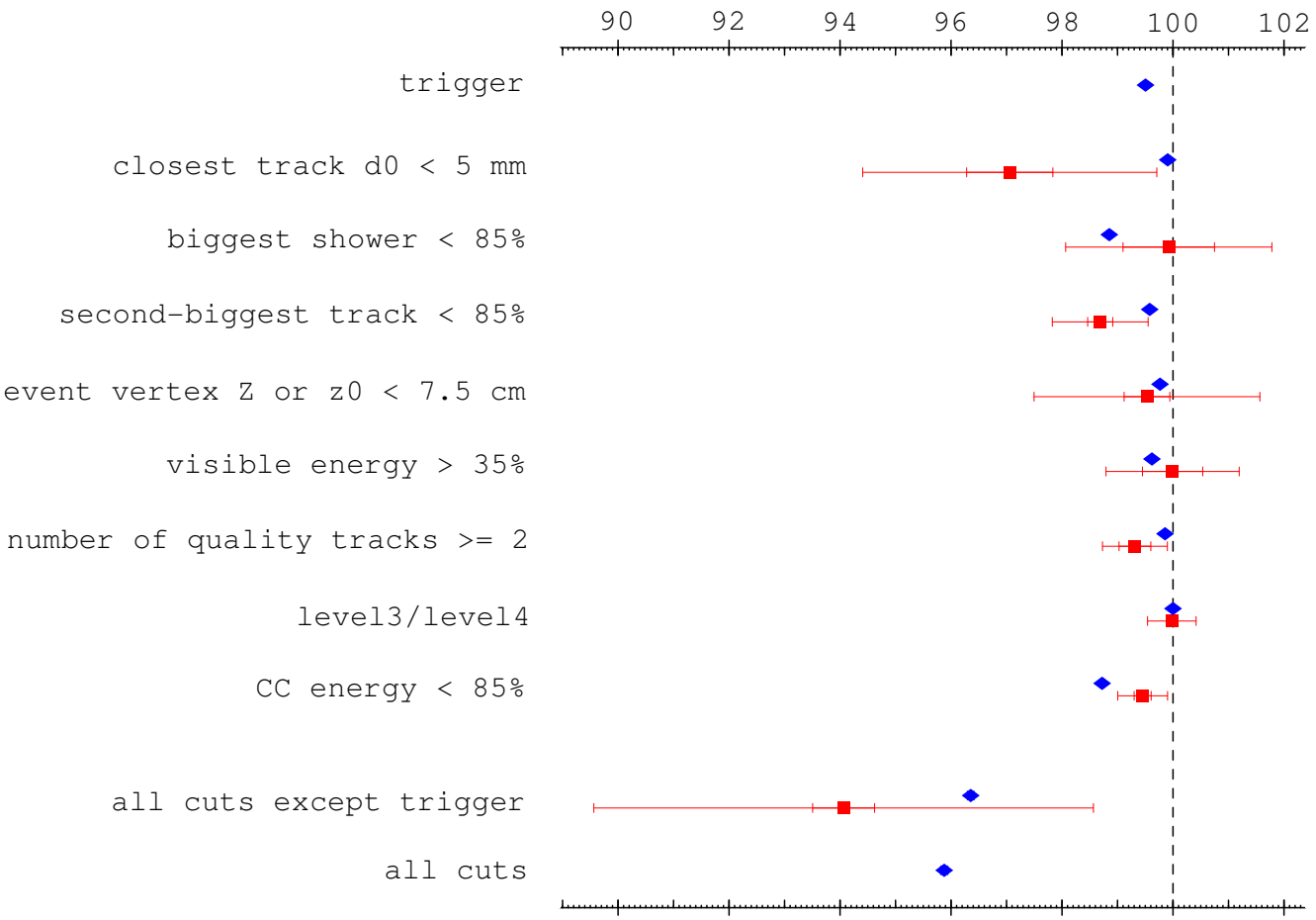

- Blue diamonds are Monte Carlo, red boxes are data $\pm$ *stat* $\pm$ *syst*
- Cuts are applied cumulatively
- Data is $\Upsilon(1S)$ (from random on-resonance runs)
  - continuum (random off-res) – beam-gas (single-beam runs)
  - cosmic rays (no-beam runs) – $\Upsilon(1S) \to \tau^+\tau^-$ (from Monte Carlo)

Hadronic efficiencies for each cut: $\Upsilon(2S)$



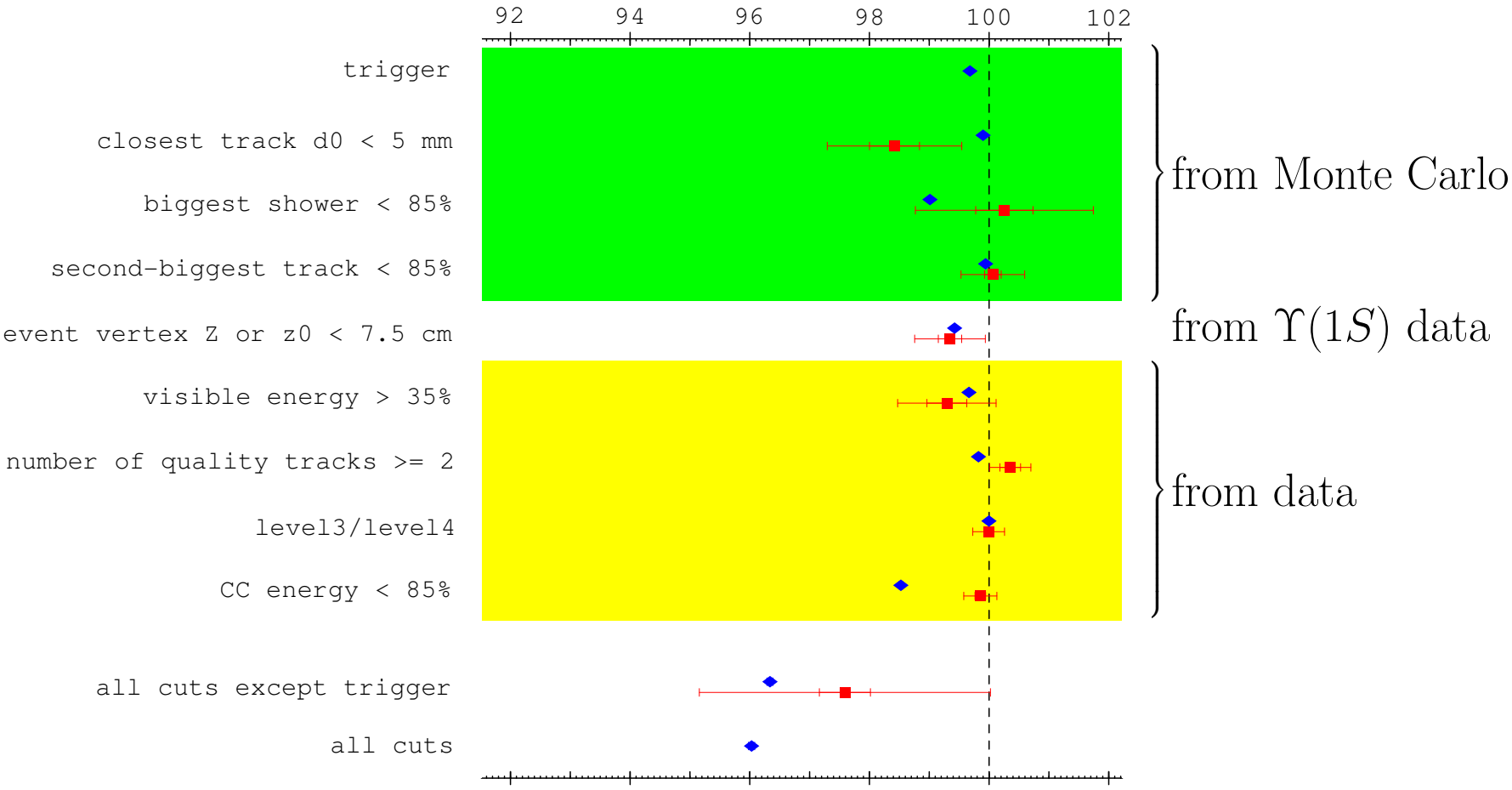

- Blue diamonds are Monte Carlo, red boxes are data $\pm$ *stat* $\pm$ *syst*
- Cuts are applied cumulatively
- Data is $\Upsilon(2S)$ (from random on-resonance runs)
  - continuum (random off-res) – beam-gas (single-beam runs)
  - cosmic rays (no-beam runs) – $\Upsilon(2S) \to \tau^+\tau^-$ (from Monte Carlo)

Hadronic efficiencies for each cut: $\Upsilon(3S)$




- Blue diamonds are Monte Carlo, red boxes are data $\pm$ *stat* $\pm$ *syst*
- Cuts are applied cumulatively
- Data is $\Upsilon(3S)$ (from random on-resonance runs)
  - continuum (random off-res) – beam-gas (single-beam runs)
  - cosmic rays (no-beam runs) – $\Upsilon(3S) \to \tau^+\tau^-$ (from Monte Carlo)

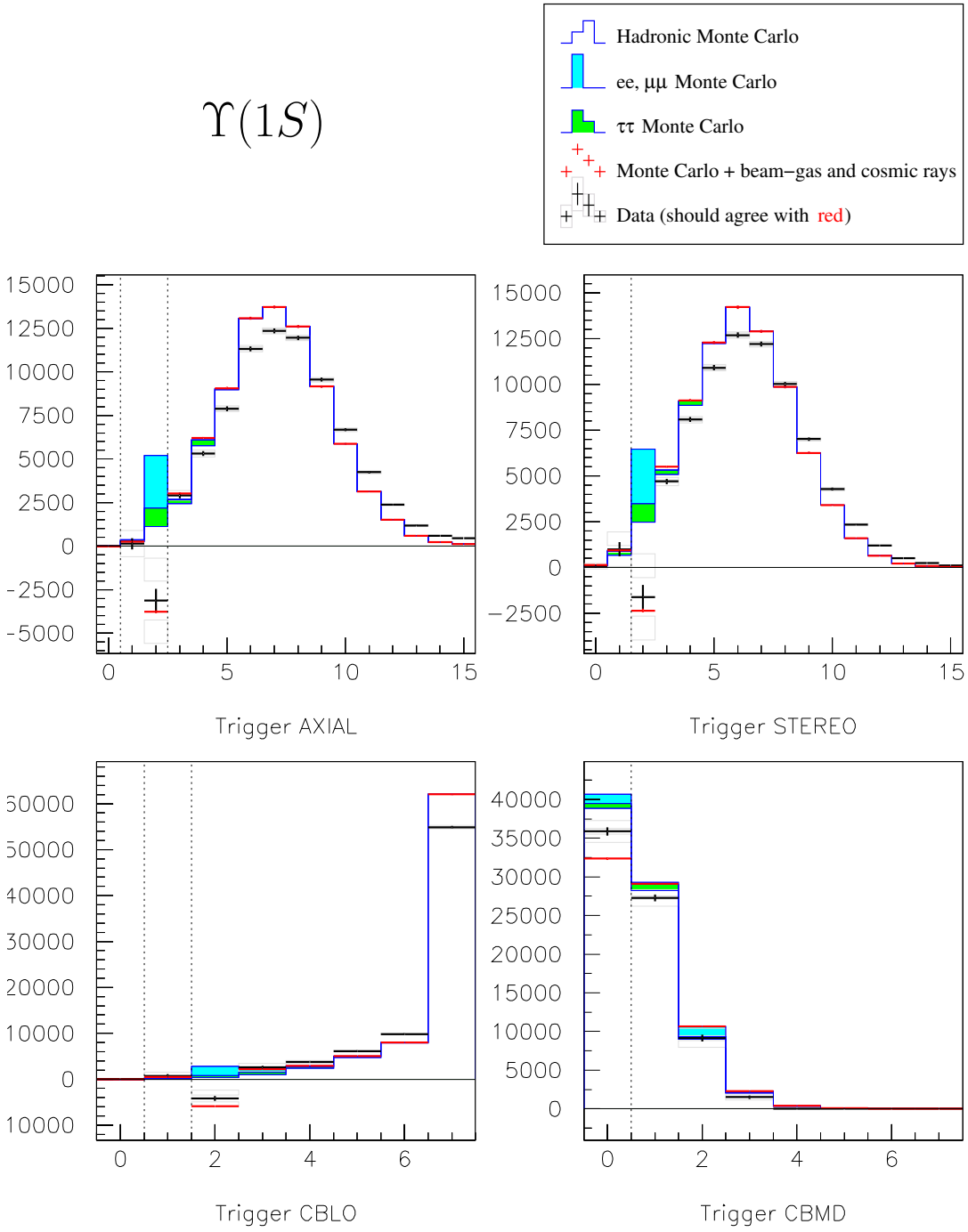
Here's how I will measure efficiency (you're looking at $\Upsilon(1S)$)




- Fraction that passes first four cuts ($\epsilon_{MC}$) is calculated from Monte Carlo; data is used to bound systematic errors
- Fraction that passes Z cut ($\epsilon_Z$) is calculated from $\Upsilon(1S)$ data and applied to all three
- Fraction that passes last four cuts ($\epsilon_{data}$) is calculated from data for each resonance

$$\epsilon_{total} = \epsilon_{MC} \cdot \epsilon_Z \cdot \epsilon_{data}$$

$\Upsilon(1S)$




- Trigger requirement is

  Hadron OR RadTau OR ElTrack

  Hadron = $\geq$3 AXIAL tracks AND $\geq$1 CBLO

  RadTau = $\geq$2 STEREO tracks AND ($\geq$2 CBLO OR $\geq$1 CBMD)

  ElTrack = $\geq$1 AXIAL track AND $\geq$1 CBMD

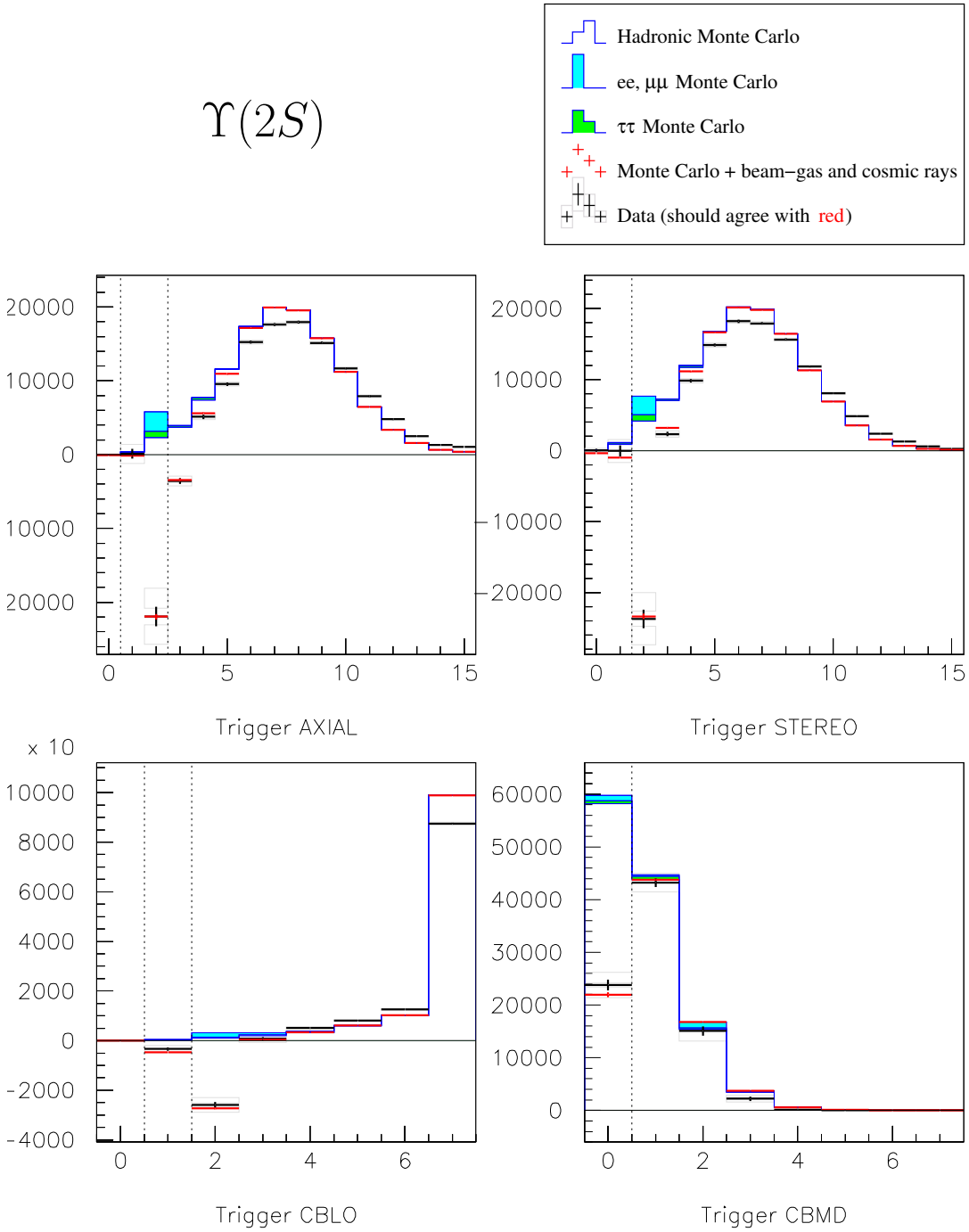
- MC efficiency of trigger is 99.5%

- Shifting CBMD=0 bin to match data changes efficiency by 0.01%

- Shifting CBLO=7 bin to match data changes efficiency by 0.02%

- Work in progress: testing for lost events by looking at correlations between triggers and with TwoTrack

$\Upsilon(2S)$

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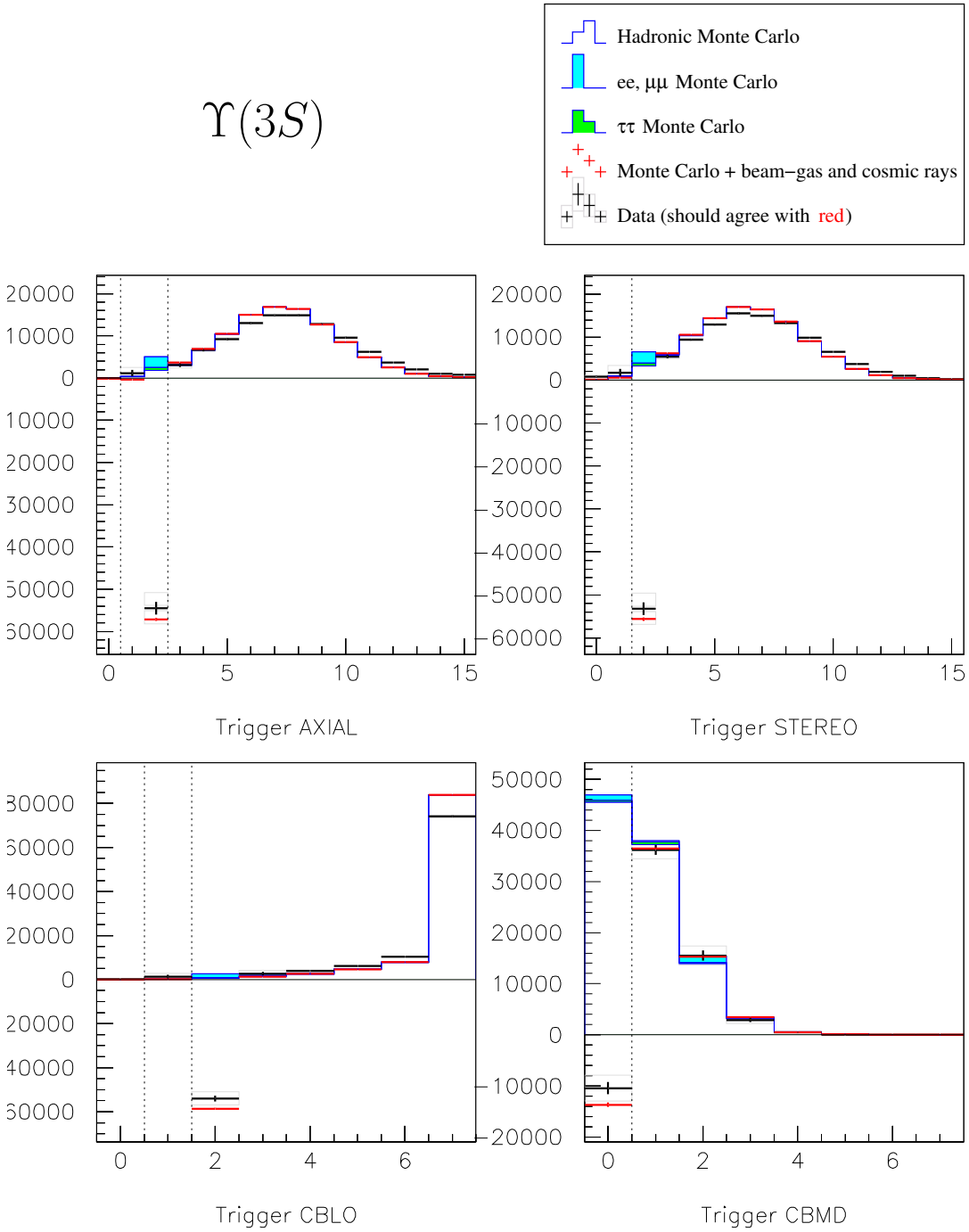
$\Upsilon(3S)$




- Trigger requirement is

  Hadron OR RadTau OR ElTrack

  Hadron = ≥3 AXIAL tracks AND ≥1 CBLO

  RadTau = ≥2 STEREO tracks AND (≥2 CBLO OR ≥1 CBMD)

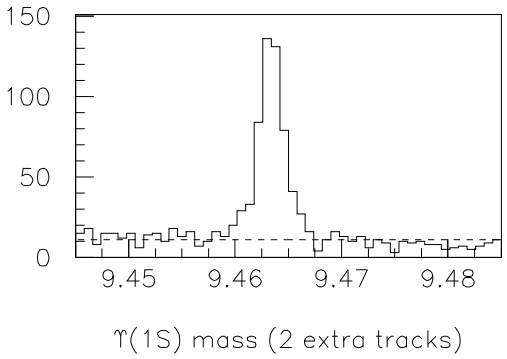
  ElTrack = ≥1 AXIAL track AND ≥1 CBMD

- MC efficiency of trigger is 99.5%

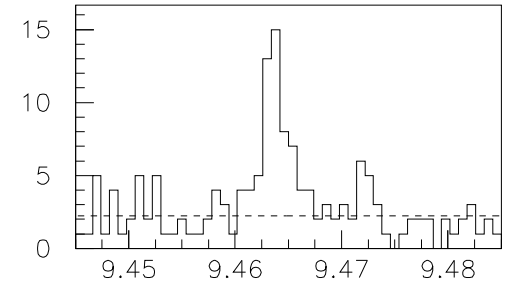
- Work in progress: testing for lost events by looking at correlations between triggers and with TwoTrack

$\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$

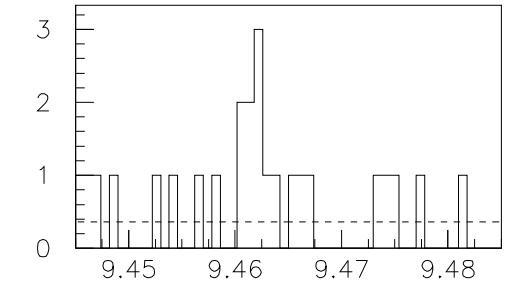
$\Upsilon(1S) \to$ 0, 1, 2 extra tracks



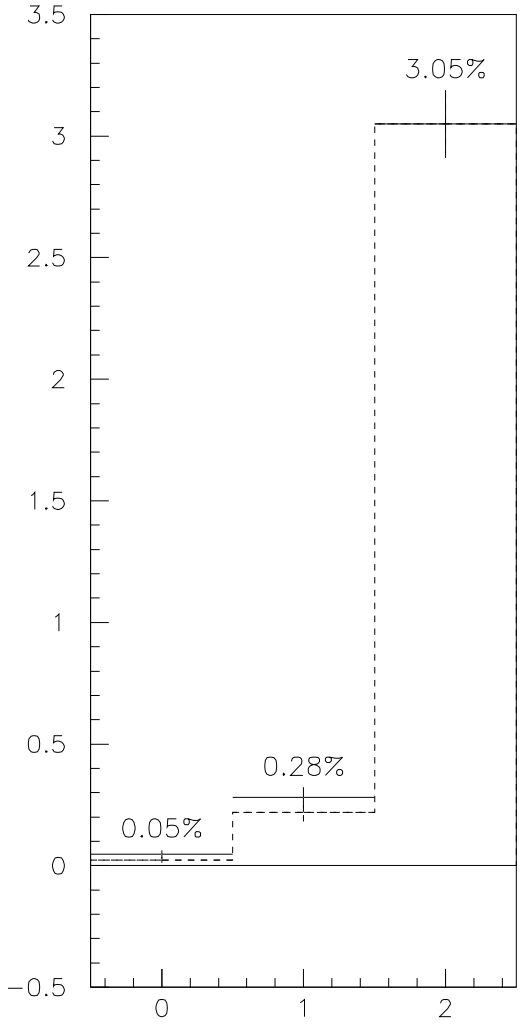

$\Upsilon$(1S) mass (2 extra tracks)




$\Upsilon$(1S) mass (1 extra track)




$\Upsilon$(1S) mass (0 extra tracks)




Percentage of U(1S) decays (data VS MC)

- $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$ can be used to check for missing physics in the Monte Carlo

- Here, $\pi^+$ and $\pi^-$ satisfy

  2 STEREO tracks and 2 CBLO
  2 reconstructed tracks

- The rest of the $\Upsilon(1S)$ must satisfy

  Visible energy $> 20\%$ center-of-mass

  Total CC energy $< 85\%$ center-of-mass

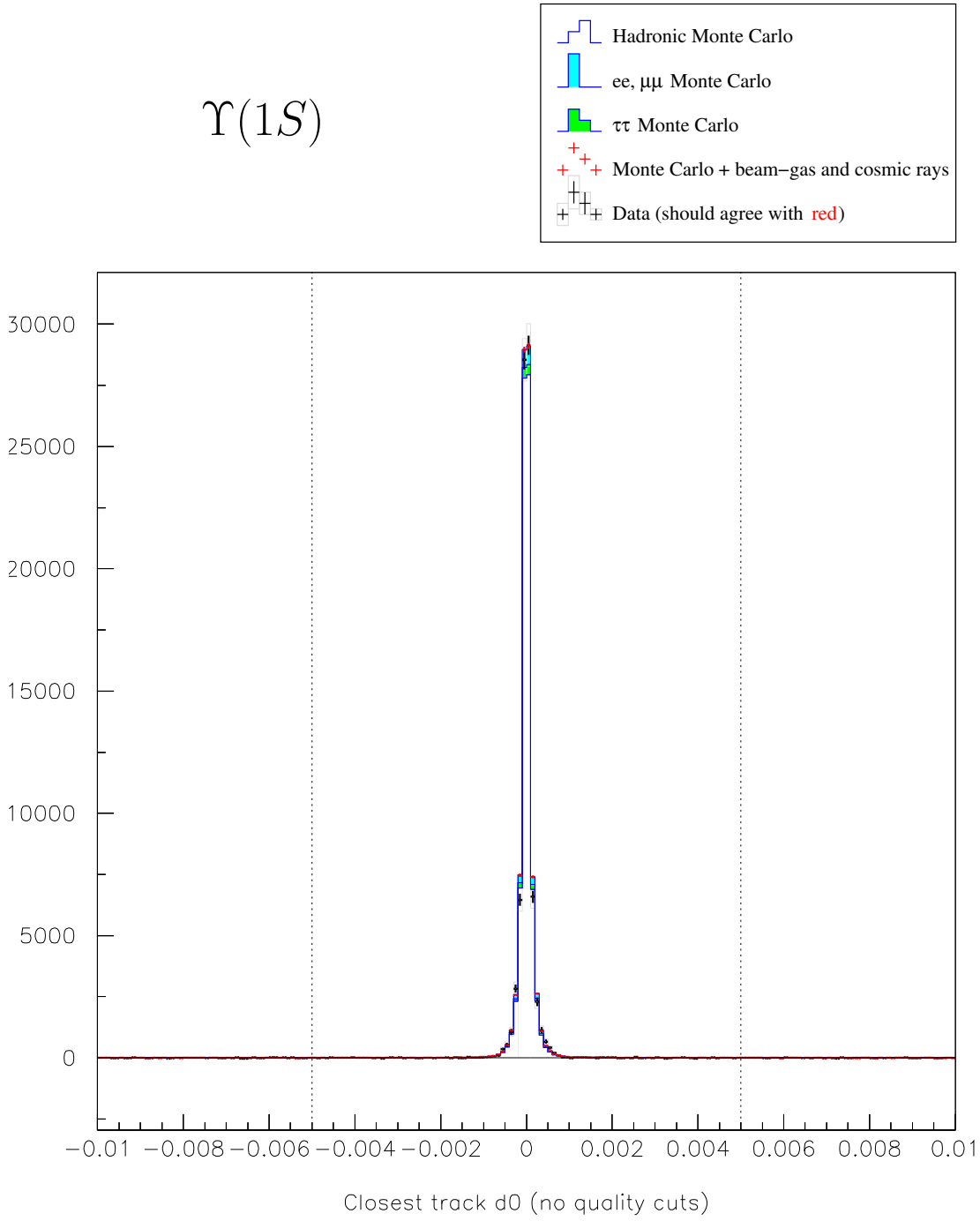
  Biggest shower energy $< 85\%$ beam

  2nd-biggest track momentum $< 85\%$ beam

- Data and MC are normalized at 2-track bin to $\Upsilon(1S) \to 2$ tracks (3.05%, mostly $\tau^+\tau^-$ and hadrons)

- Uncertainty in agreement introduces $\pm 0.07\%$ trigger systematic

$\Upsilon(1S)$

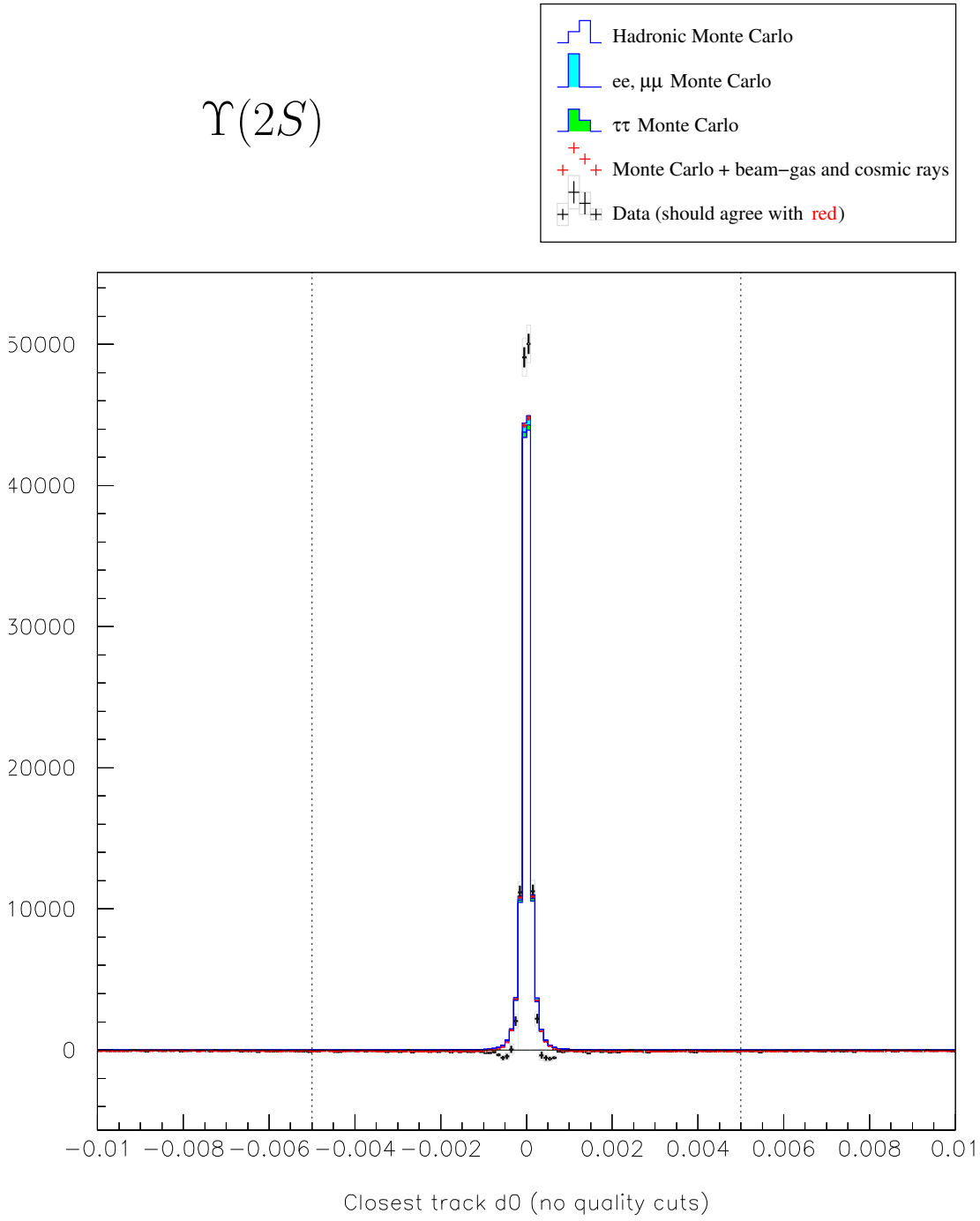



- Trigger has already required one track, use its distance *from the beamspot* to cut out cosmic rays

- MC efficiency is 99.90%

- If this cut is moved out to infinity or in to 2 mm, efficiency changes by $\pm 0.25\%$

$\Upsilon(2S)$

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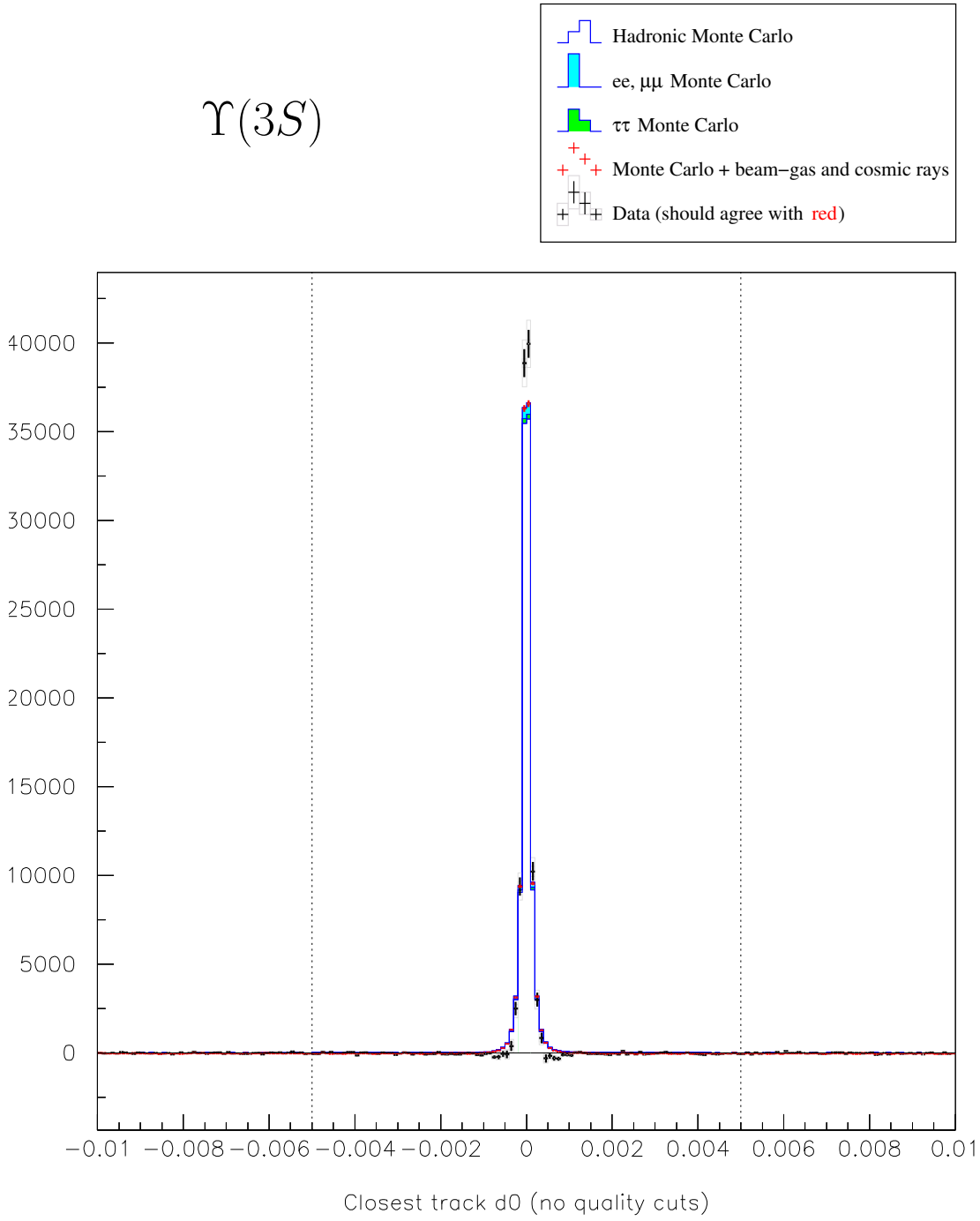
$\Upsilon(3S)$

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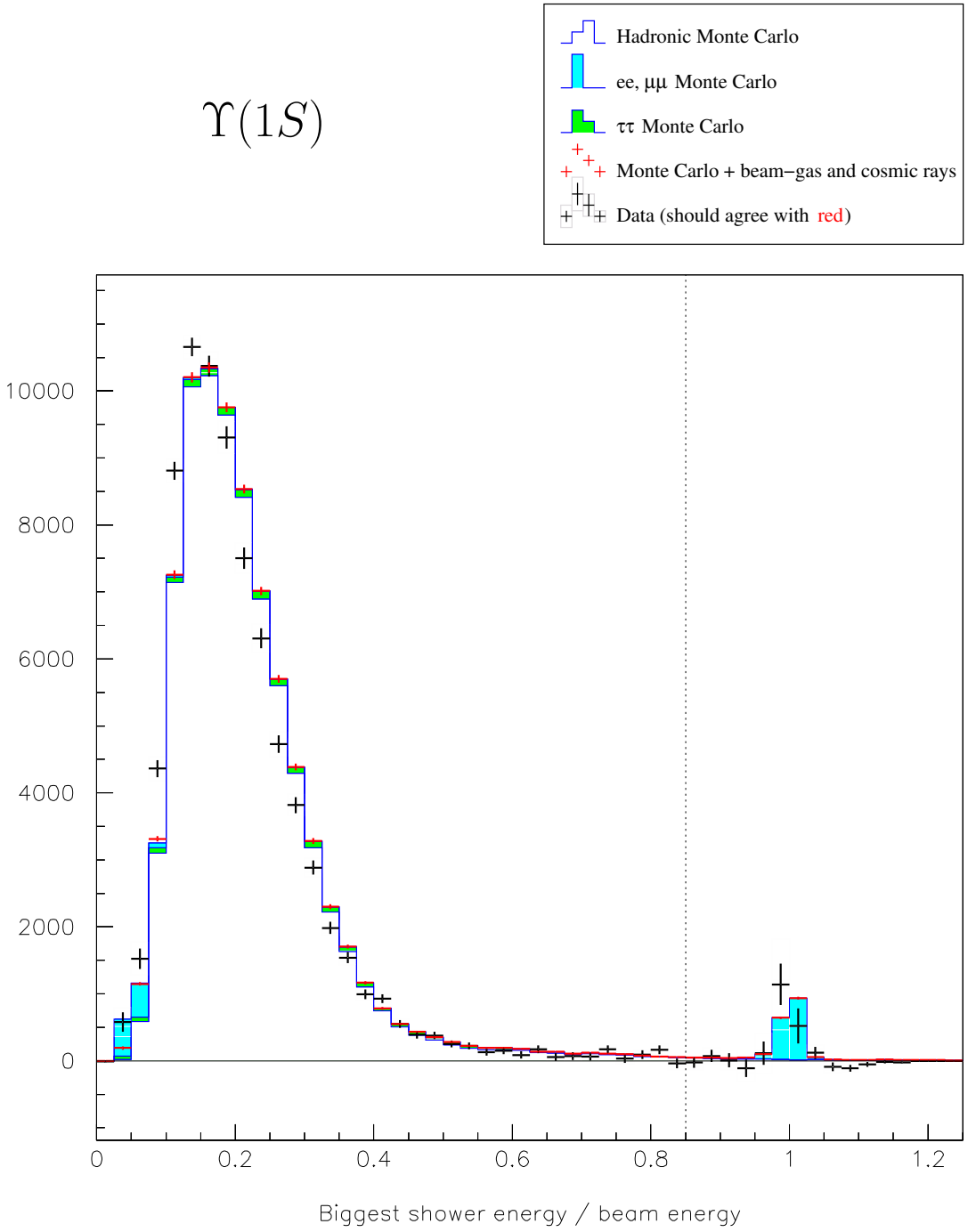
- MC efficiency is 99.90%

- If this cut is moved out to infinity or in to 2 mm, efficiency changes by $\pm 0.25\%$

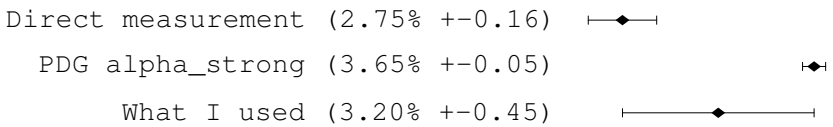
$\Upsilon(1S)$




- Little $\Upsilon(1S) \rightarrow e^+e^-$ peak is a background

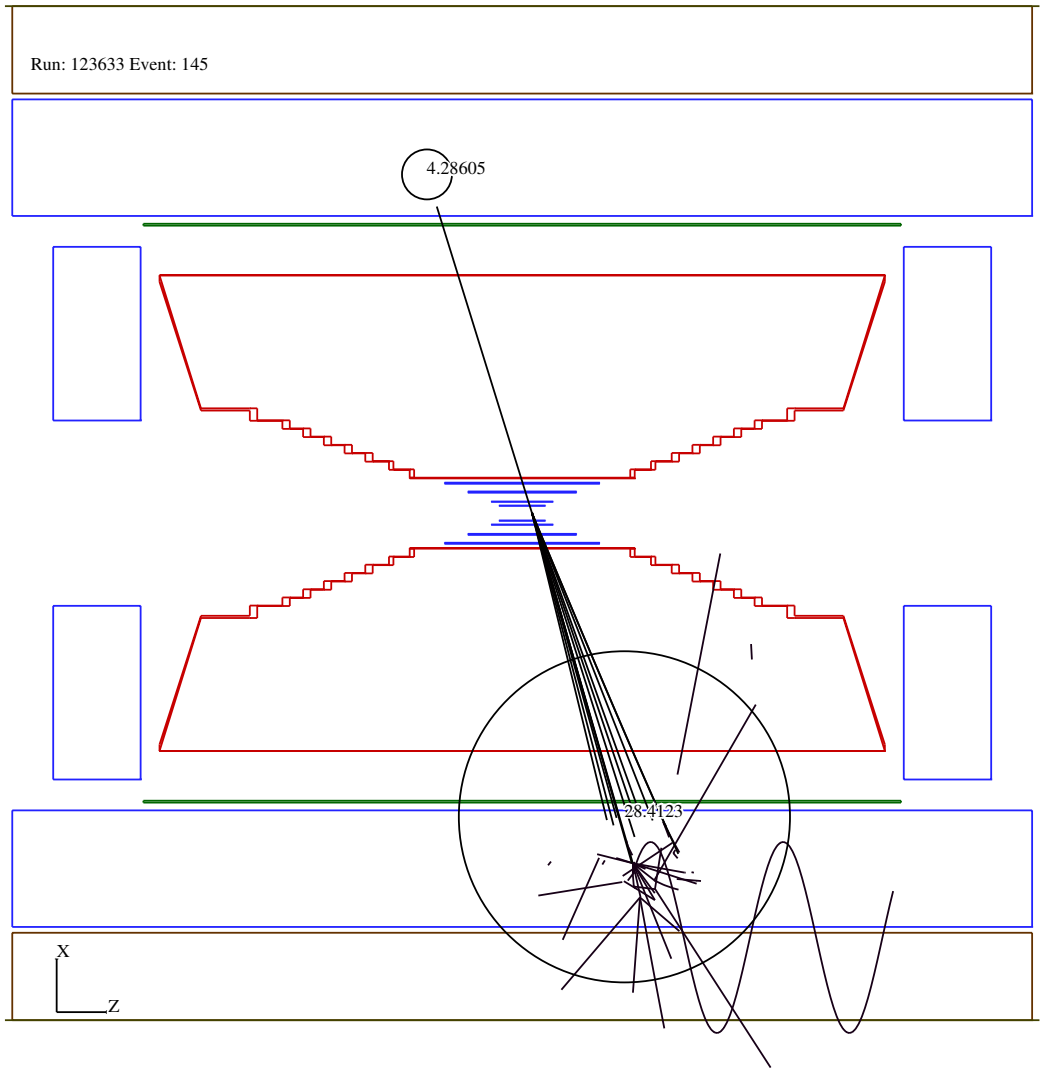
- $gg\gamma$ span the cut boundary, all other hadrons are well to the left

- $\Gamma_{gg\gamma}/\Gamma_{ggg}$ is precise?




- Introduces $\pm 0.08\%$ systematic

# Aside: EvtGen Bug




- $gg\gamma$ events were not modelled correctly in EvtGen: boost of $gg$ was done in the wrong direction

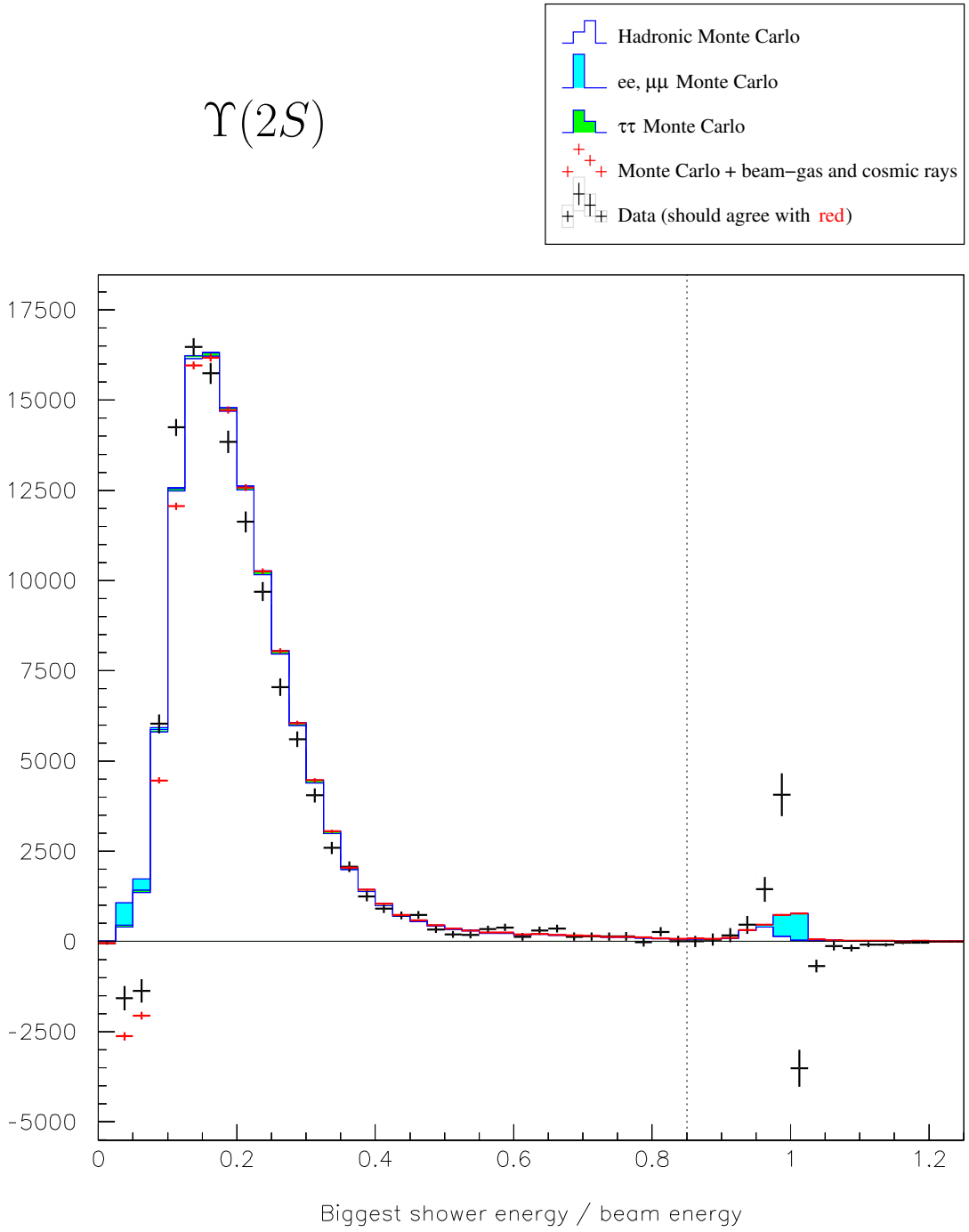
- This event had a 4 GeV photon on one side and 28 GeV of pileup on the other. (Biggest shower distribution was distorted.)

- For the purposes of this talk, $gg\gamma$ efficiency is measured from `QQ`.

- Bug is corrected in

  EvtGenModels `v01_02_01`

$\Upsilon(2S)$



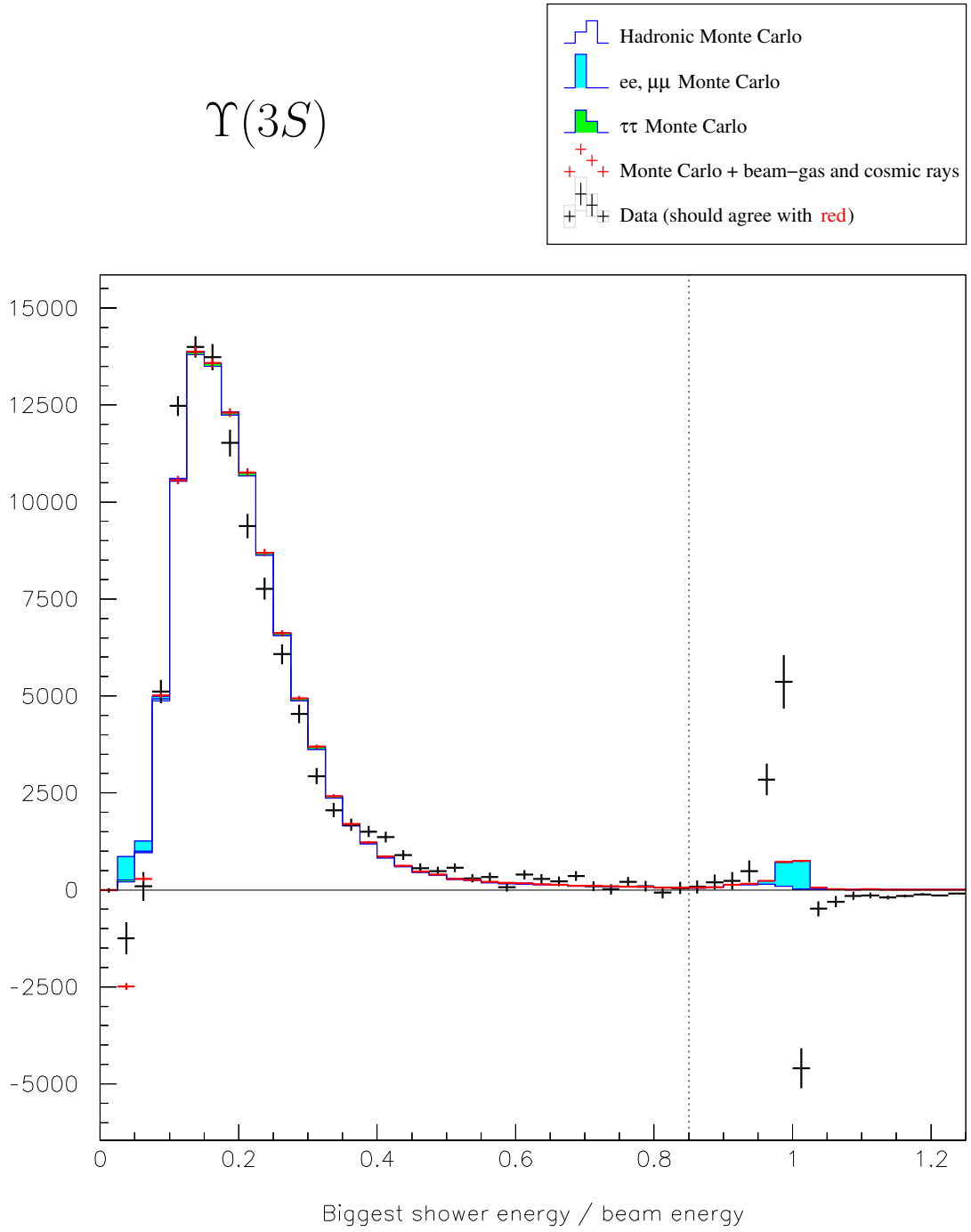

- Residuals add to zero on both sides of the cut threshold

- Bhabha peak energy differs by 3 MeV between on- and off-resonance

- Cascades to electrons (signal) are all to the right of the threshold

- Vary $\mathcal{B}_{\mu\mu}$ and cascade $\mathcal{B}$'s by their uncertainties: $\pm 0.06\%$ in $\epsilon_{MC}$

- Suppose `PHOTOS` is 50% wrong: $\pm 0.03\%$ in $\epsilon_{MC}$

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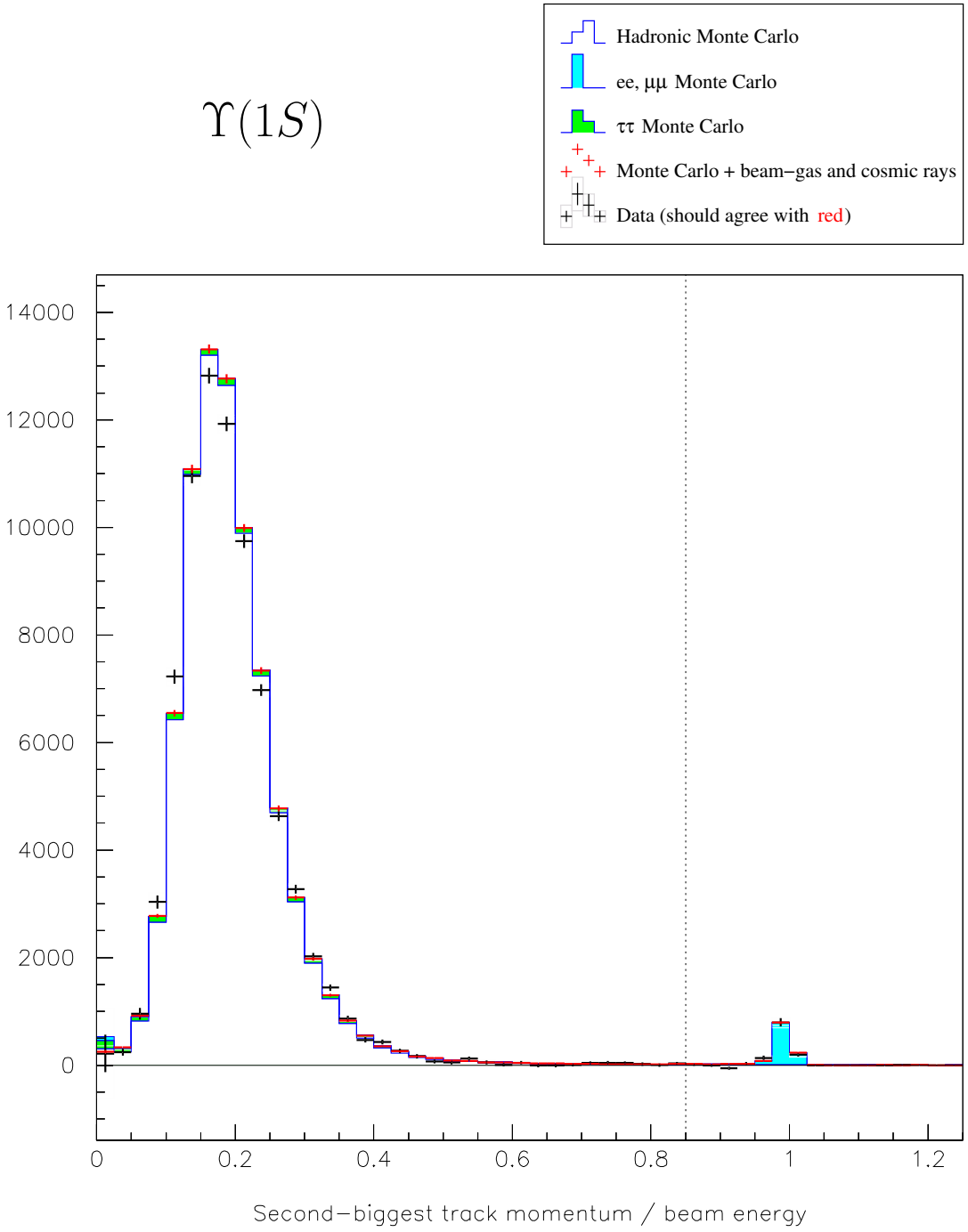
- Vary $\mathcal{B}_{\mu\mu}$ and cascade $\mathcal{B}$'s by their uncertainties: $\pm 0.05\%$ in $\epsilon_{MC}$

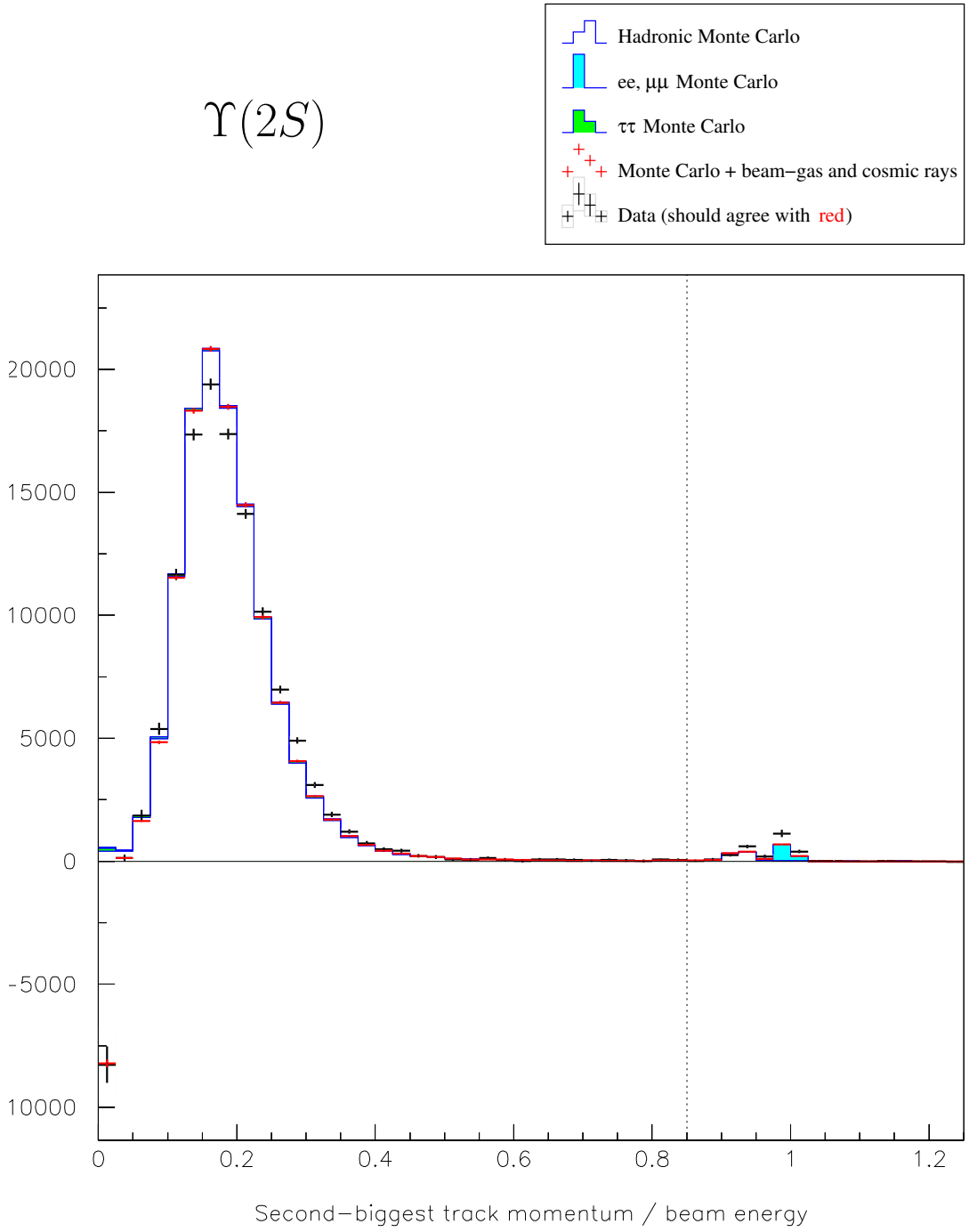
- Suppose `PHOTOS` is 50% wrong: $\pm 0.01\%$ in $\epsilon_{MC}$

$\Upsilon(1S)$




- If there is no second track, this is automatically satisfied

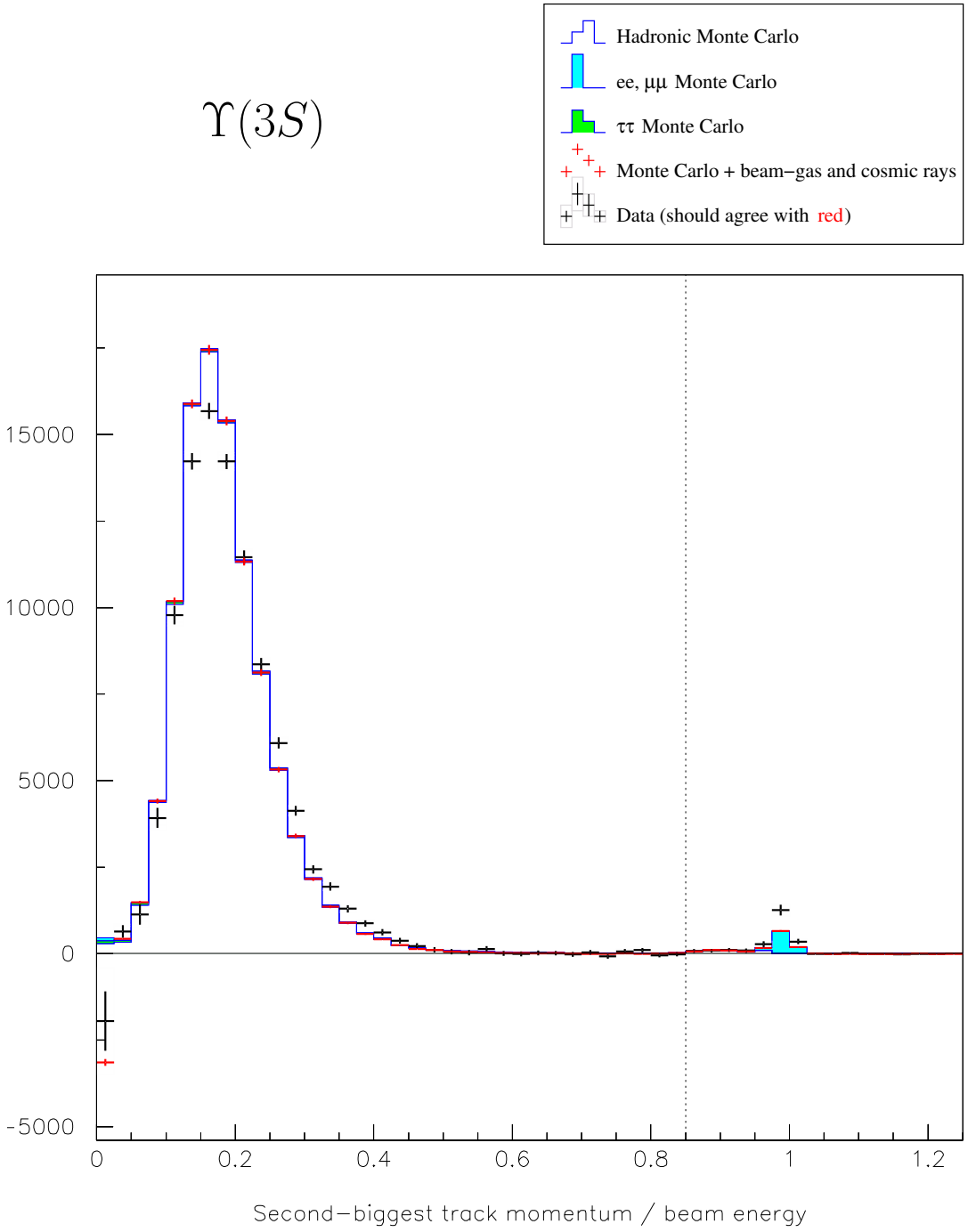
$\Upsilon(2S)$




- If there is no second track, this is automatically satisfied

- $\mathcal{B}_{\mu\mu}$ in MC is 1.5%, Istvan found 2.03%

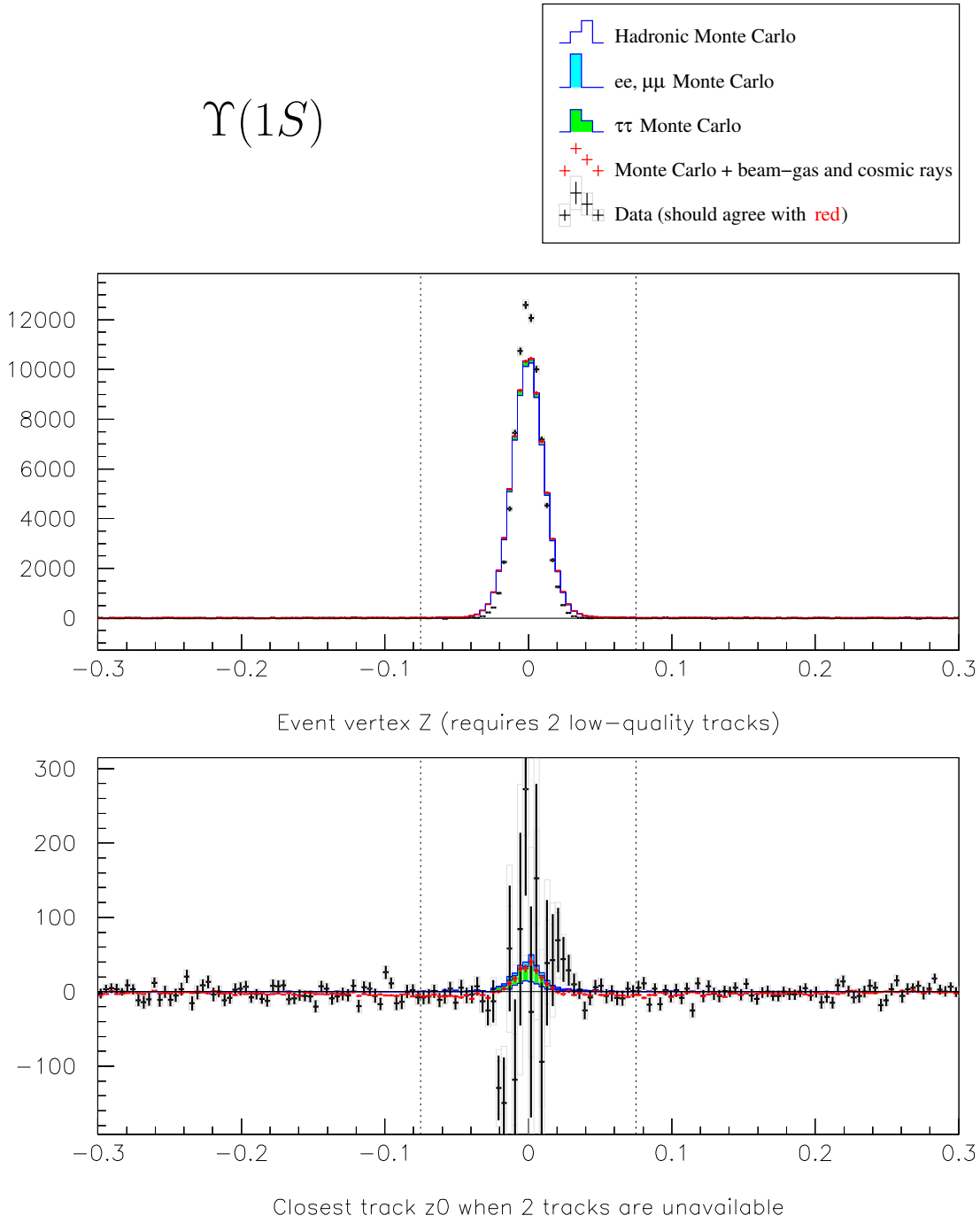
$\Upsilon(3S)$




- If there is no second track, this is automatically satisfied

- $\mathcal{B}_{\mu\mu}$ in MC is 1.81%, Istvan found 2.39%

$\Upsilon(1S)$




- Suppress beamgas by cutting *around beamspot* in Z

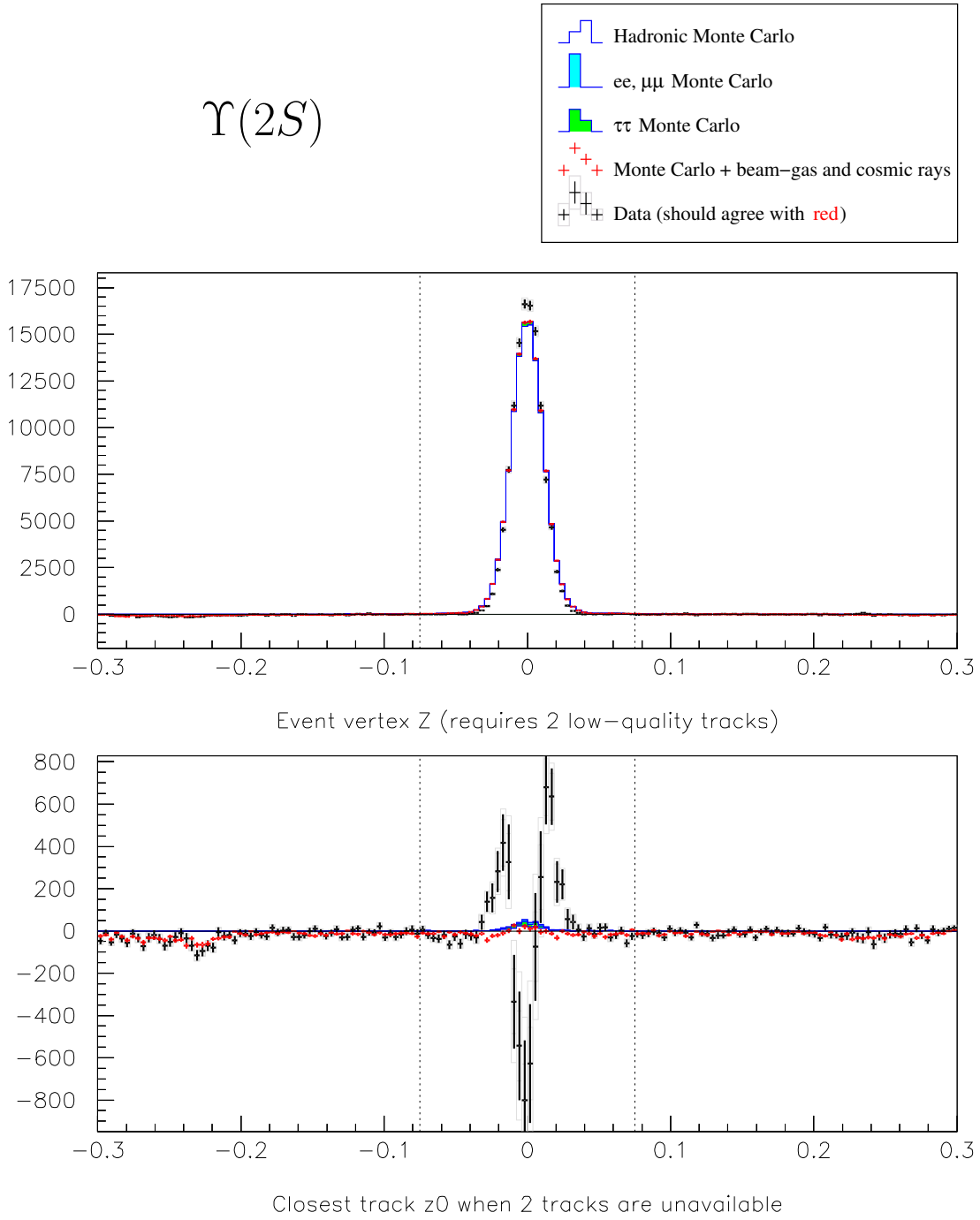
- Fallback on closest track z0 is included to keep from implicitly requiring two tracks (I forgot to move z0 to the beamspot)

- Efficiency of this cut is measured from $\Upsilon(1S)$ data:

$$99.35\% \pm 0.20\% \pm 0.56\%$$

$\uparrow$ *sample stat* $\quad$ $\uparrow$ *scaling error*

$\Upsilon(2S)$

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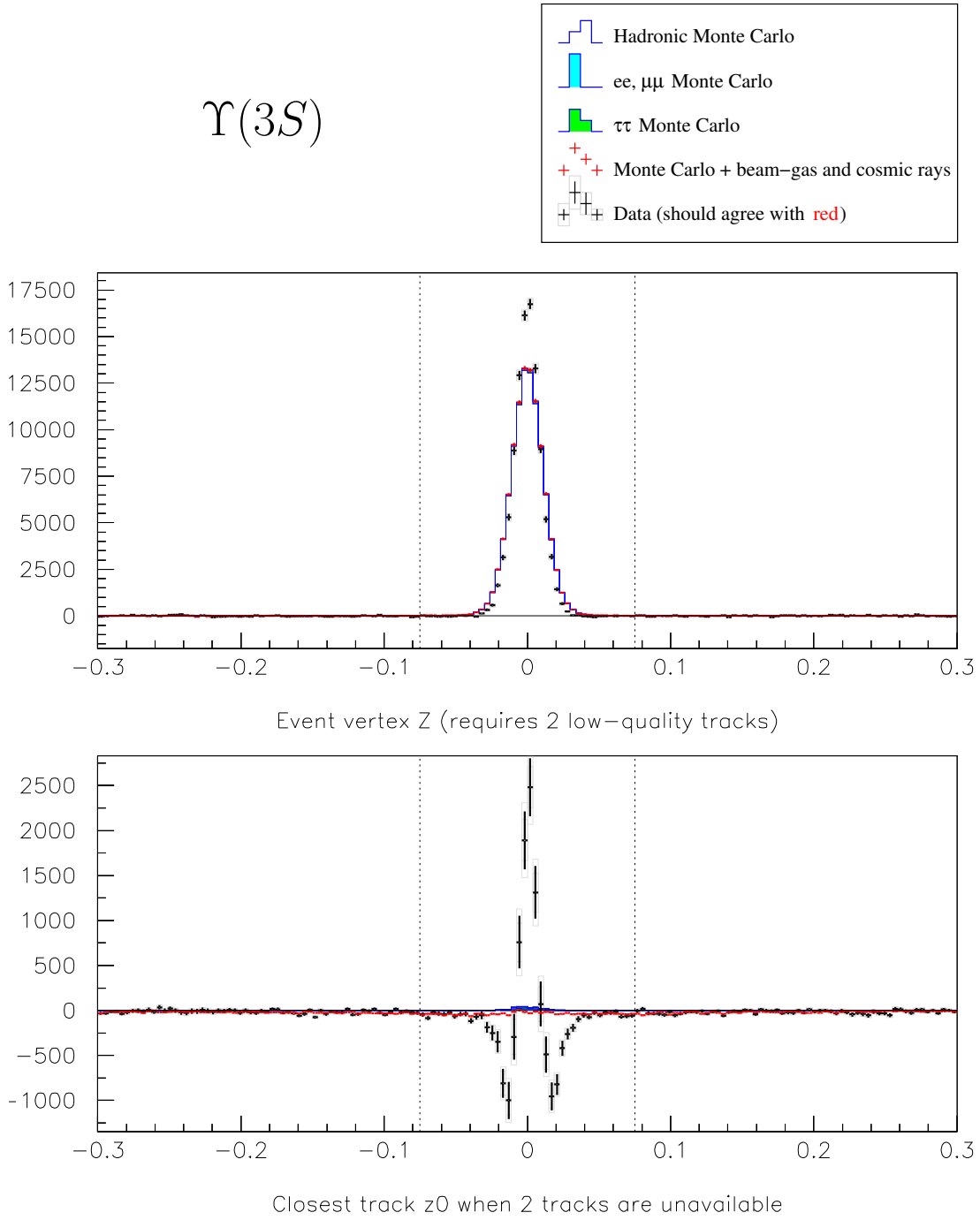
$\Upsilon(3S)$

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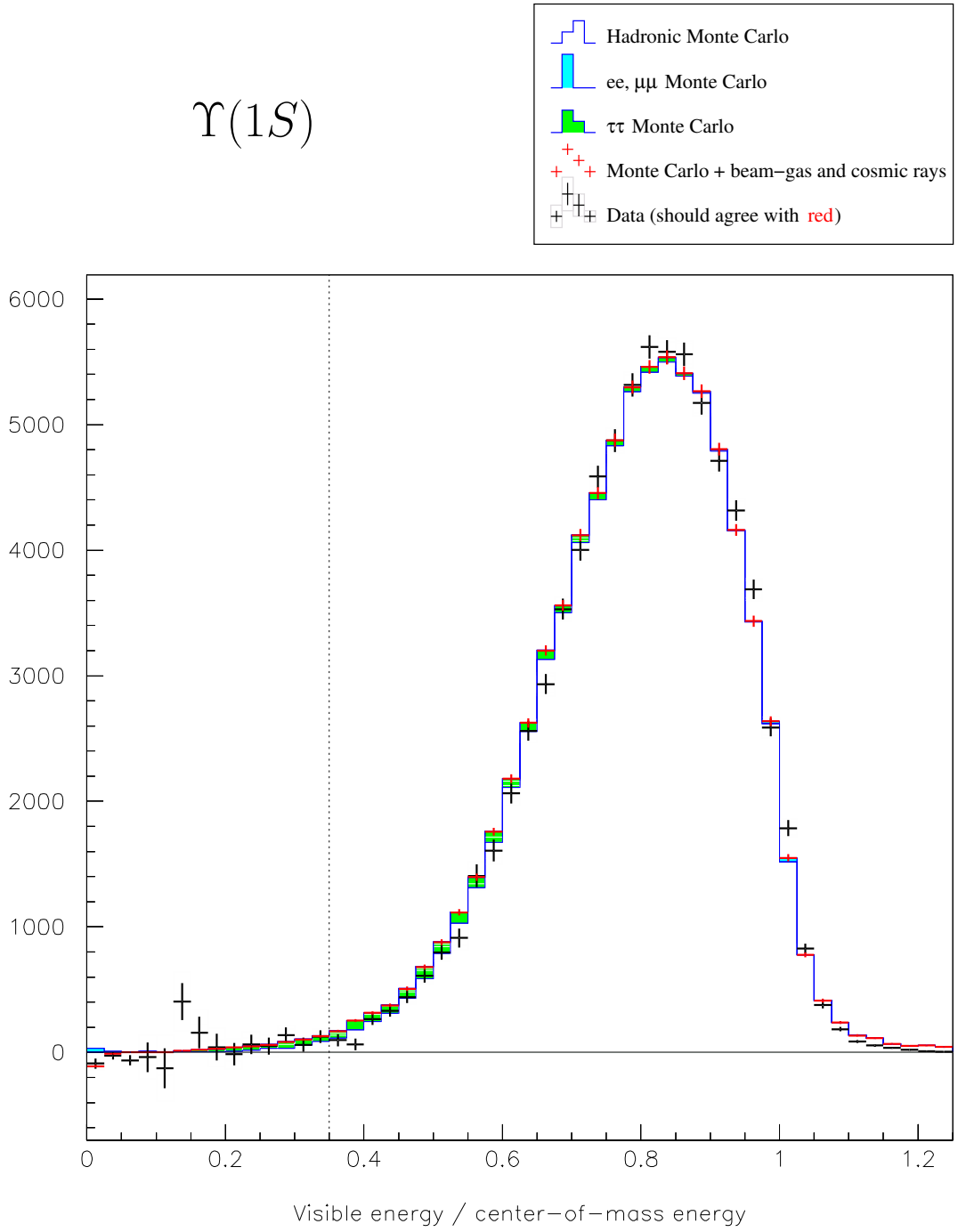
$$99.35\% \pm 0.20\% \pm 0.56\%$$

$\uparrow$ *sample stat* $\quad$ $\uparrow$ *scaling error*

$\Upsilon(1S)$



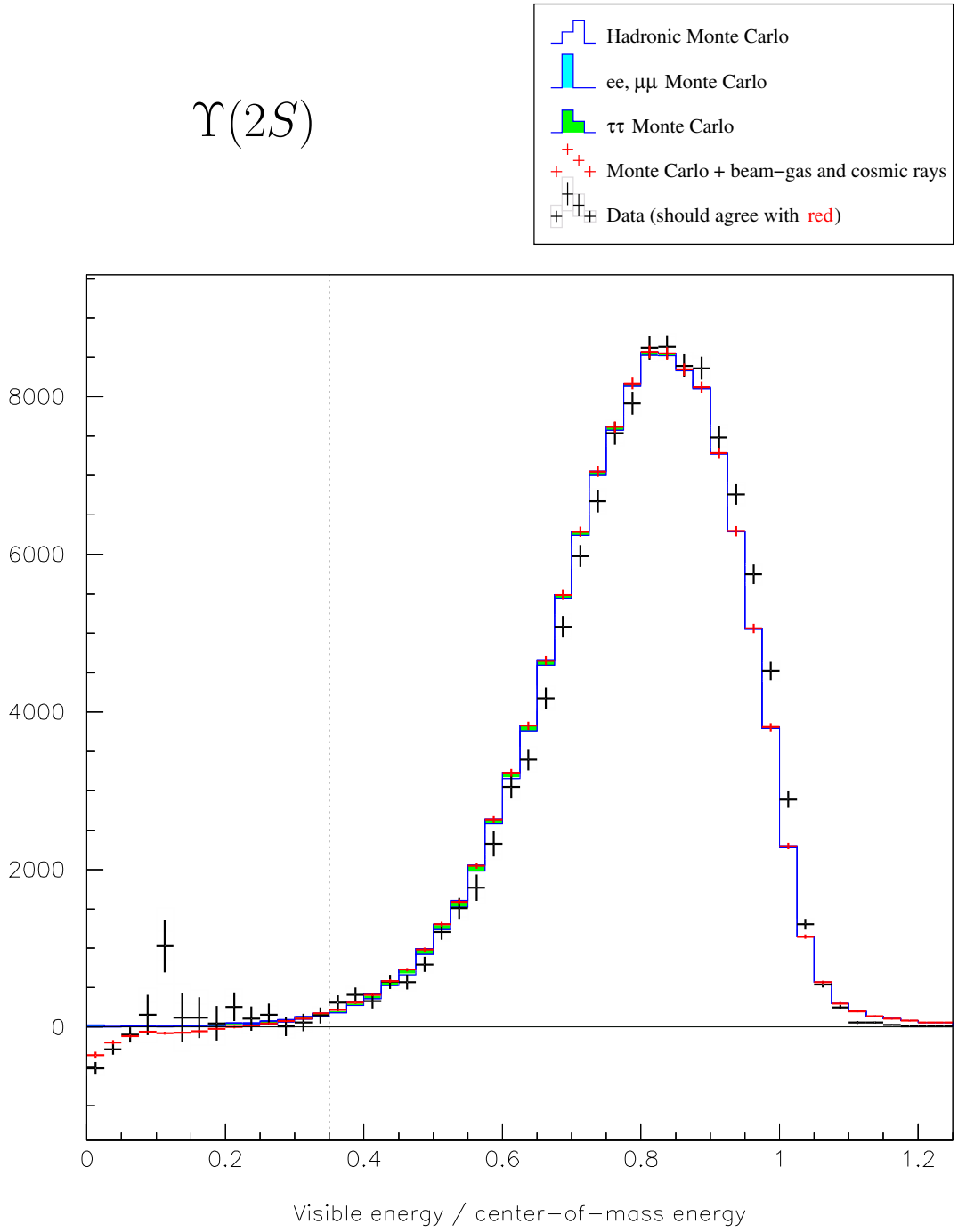

- Efficiency is measured from data:

$$99.29\% \pm 0.33\% \pm 0.75\%$$

- Residual below threshold sums to zero, within errors ($280 \pm 350$)

- Bin on top of cosmic ray peak is $2.6\sigma$ high

$\Upsilon(2S)$



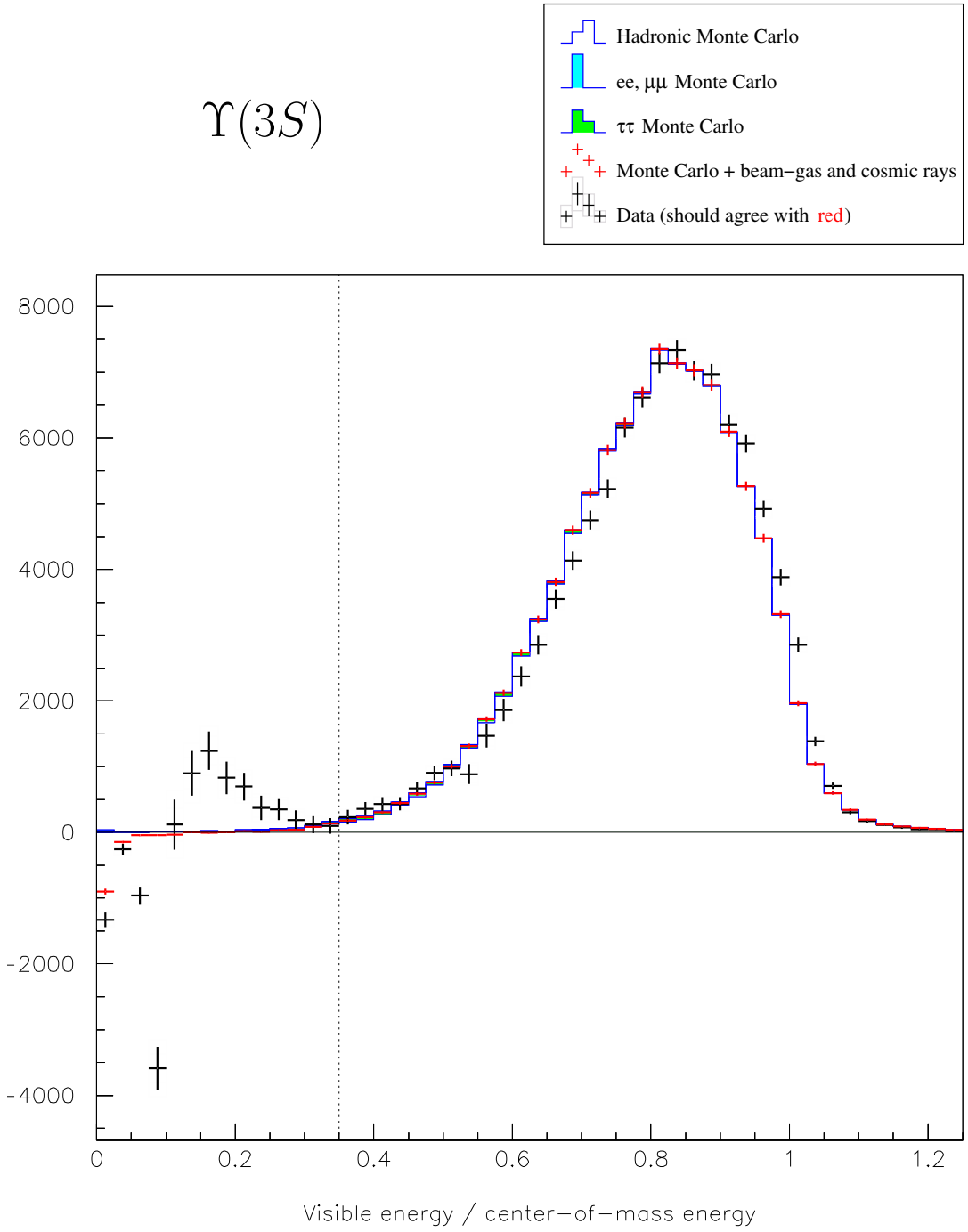

- Efficiency is measured from data:

$$98.05\% \pm 0.41\% \pm 0.83\%$$

- Residual below threshold sums to $1840 \pm 720$

- Bin at top of cosmic ray peak is $3.3\sigma$ high: scaling cosmics incorrectly?

$\Upsilon(3S)$



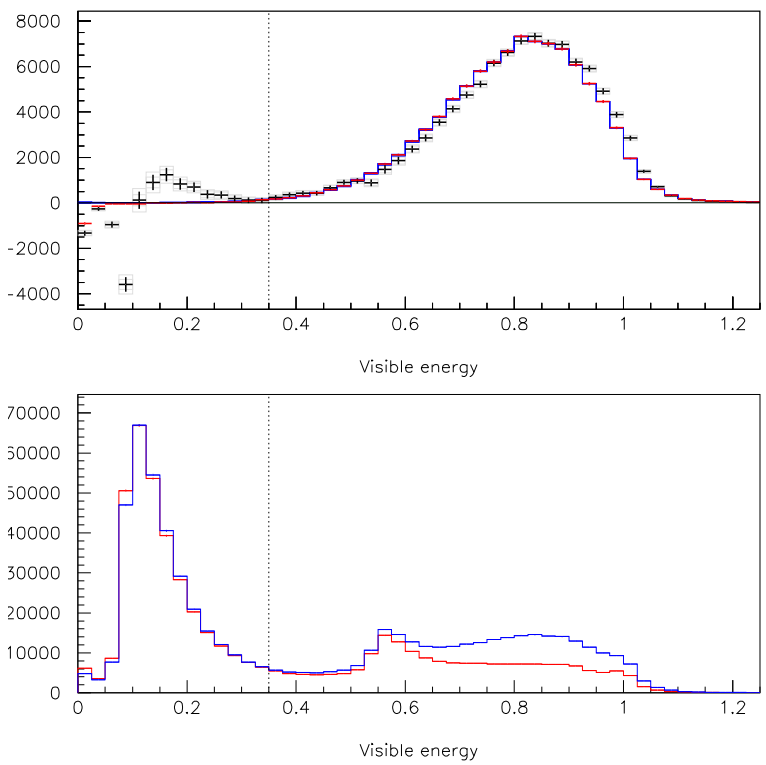

- Efficiency is measured from data:

$$99.99\% \pm 0.54\% \pm 1.07\%$$

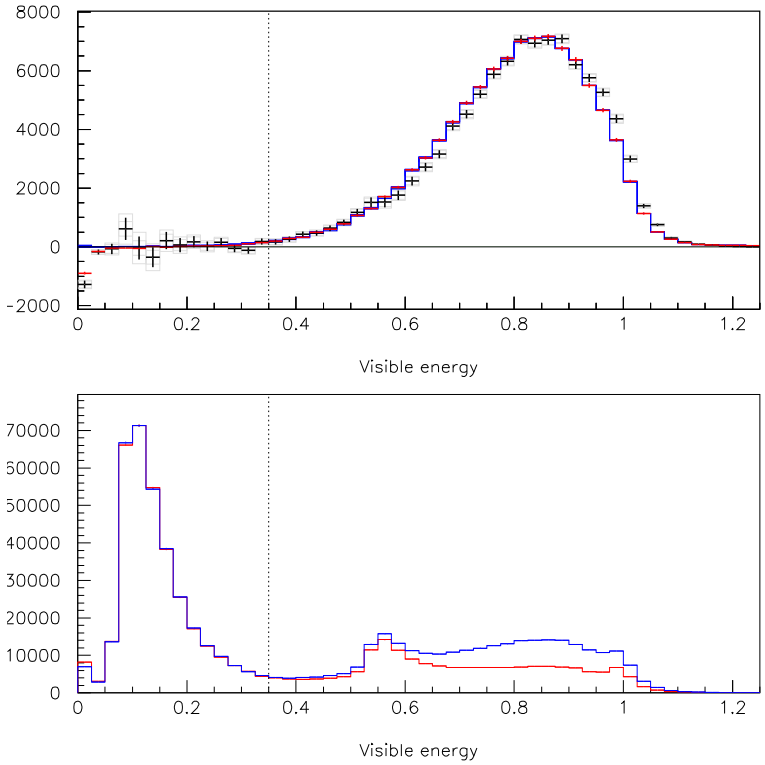
- Residual below threshold sums to zero (-380 ± 850)

- But that wiggle is getting out of hand!

No wiggle without hot showers



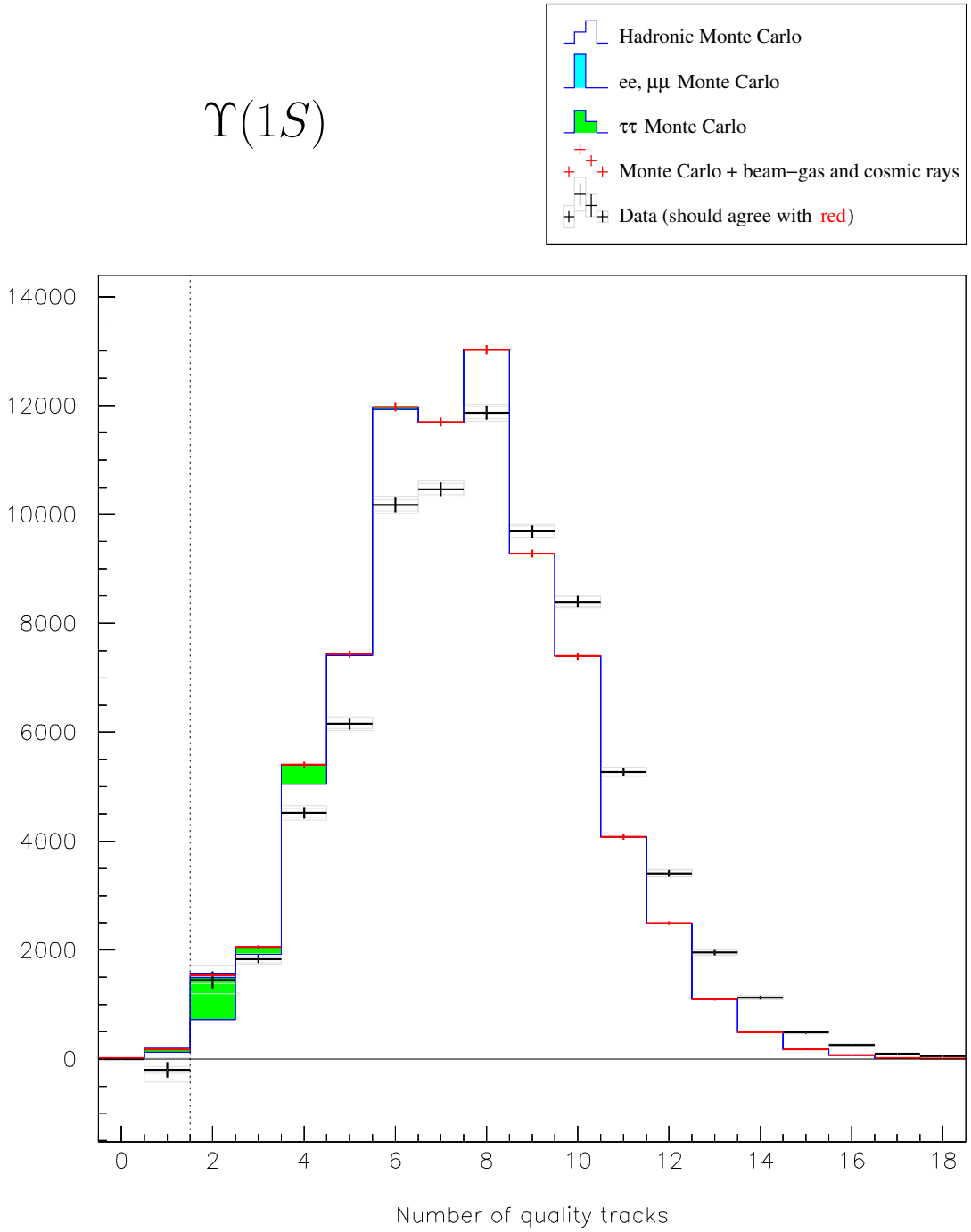

Normal visible energy




No hot showers

- Bottom plots are before continuum subtraction: there's a large peak of continuum processes (look like two-photon events) below the 35% of center-of-mass energy cut.
- Difference in hot showers between on- and off-resonance shifts one peak 23 MeV relative to the other
- This answers $\Upsilon(1S)$ and $\Upsilon(3S)$ discrepancies, but not $\Upsilon(2S)$.

$\Upsilon(1S)$

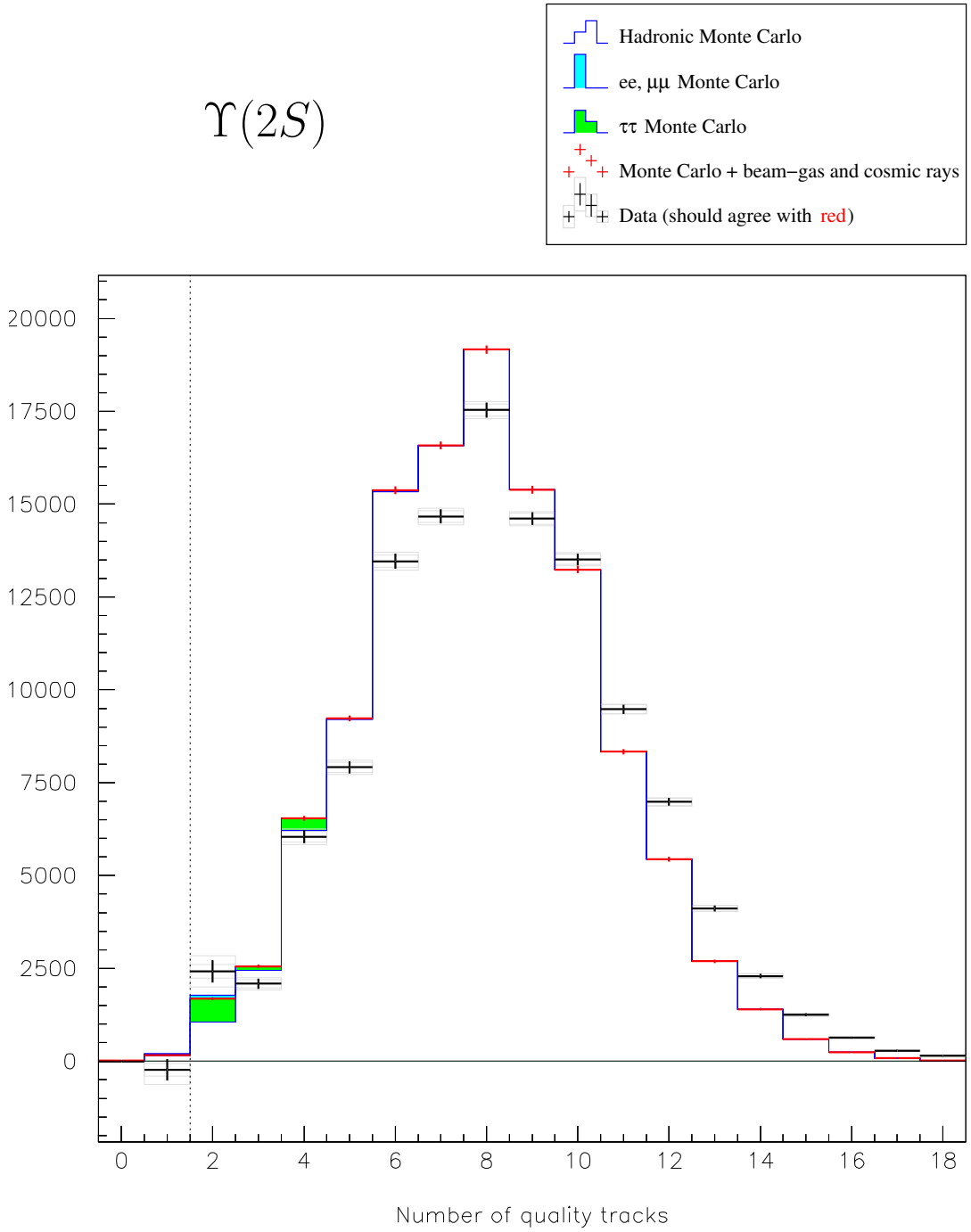



- Efficiency is measured from data:

$$100.35\% \pm 0.17\% \pm 0.30\%$$

- Data/MC disagreement no longer matters because I'm not using MC

$\Upsilon(2S)$

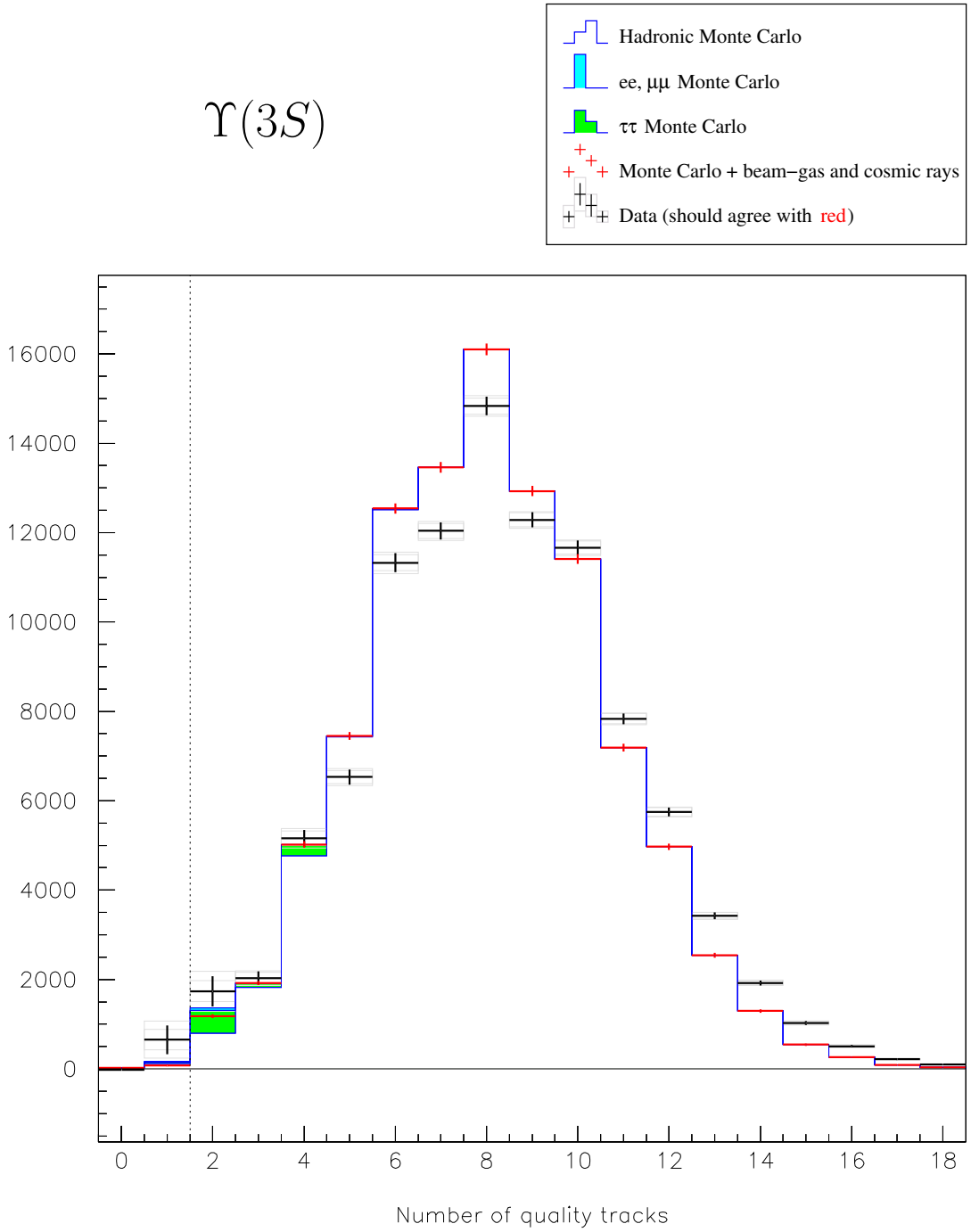



- Efficiency is measured from data:

$$100.22\% \pm 0.22\% \pm 0.39\%$$

- Data/MC disagreement no longer matters because I'm not using MC

$\Upsilon(3S)$

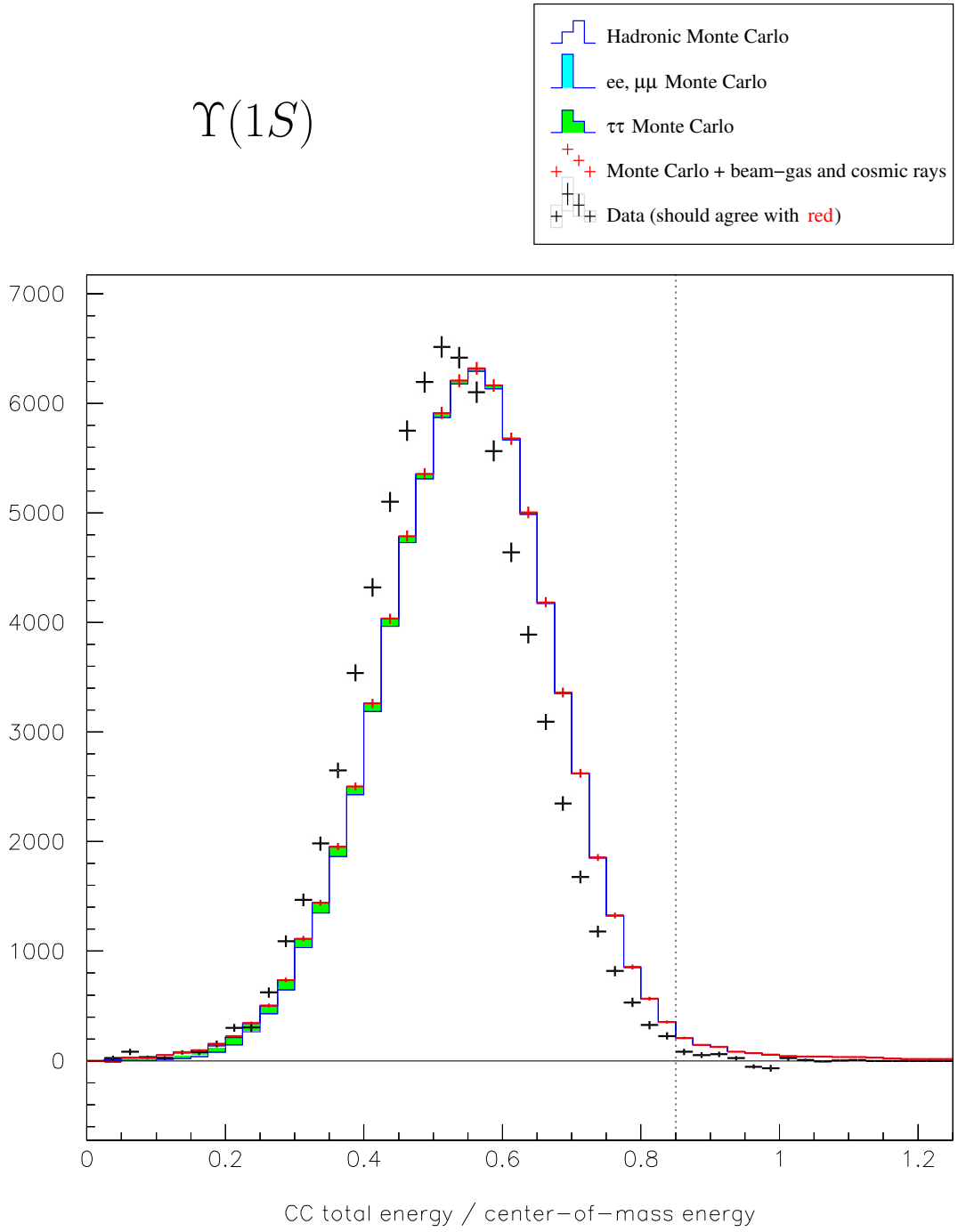



- Efficiency is measured from data:

$$99.31\% \pm 0.29\% \pm 0.51\%$$

- Data/MC disagreement no longer matters because I'm not using MC

$\Upsilon(1S)$

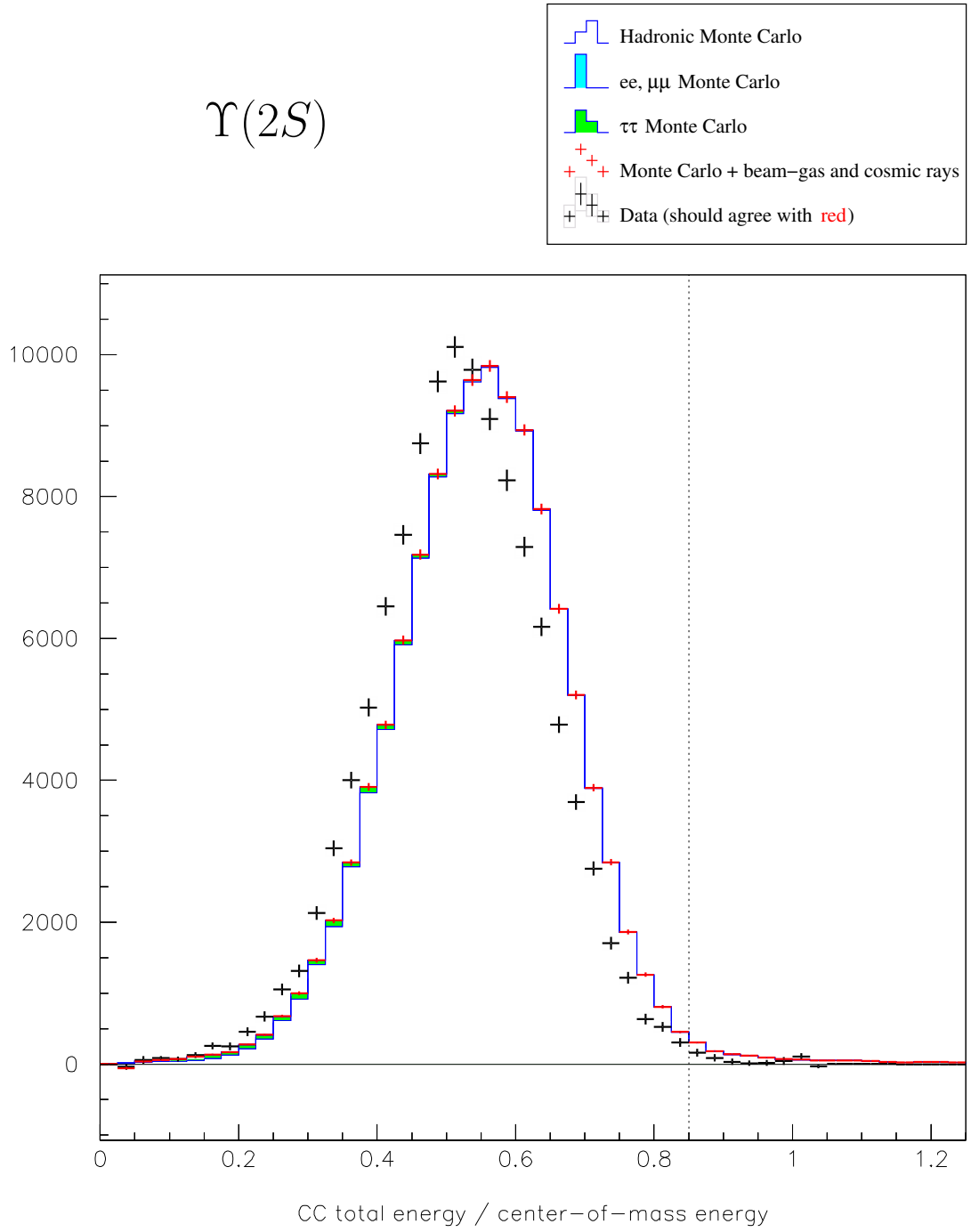



- Efficiency is measured from data:

$$99.85\% \pm 0.09\% \pm 0.26\%$$

- Data/MC disagreement no longer matters because I'm not using MC

$\Upsilon(2S)$

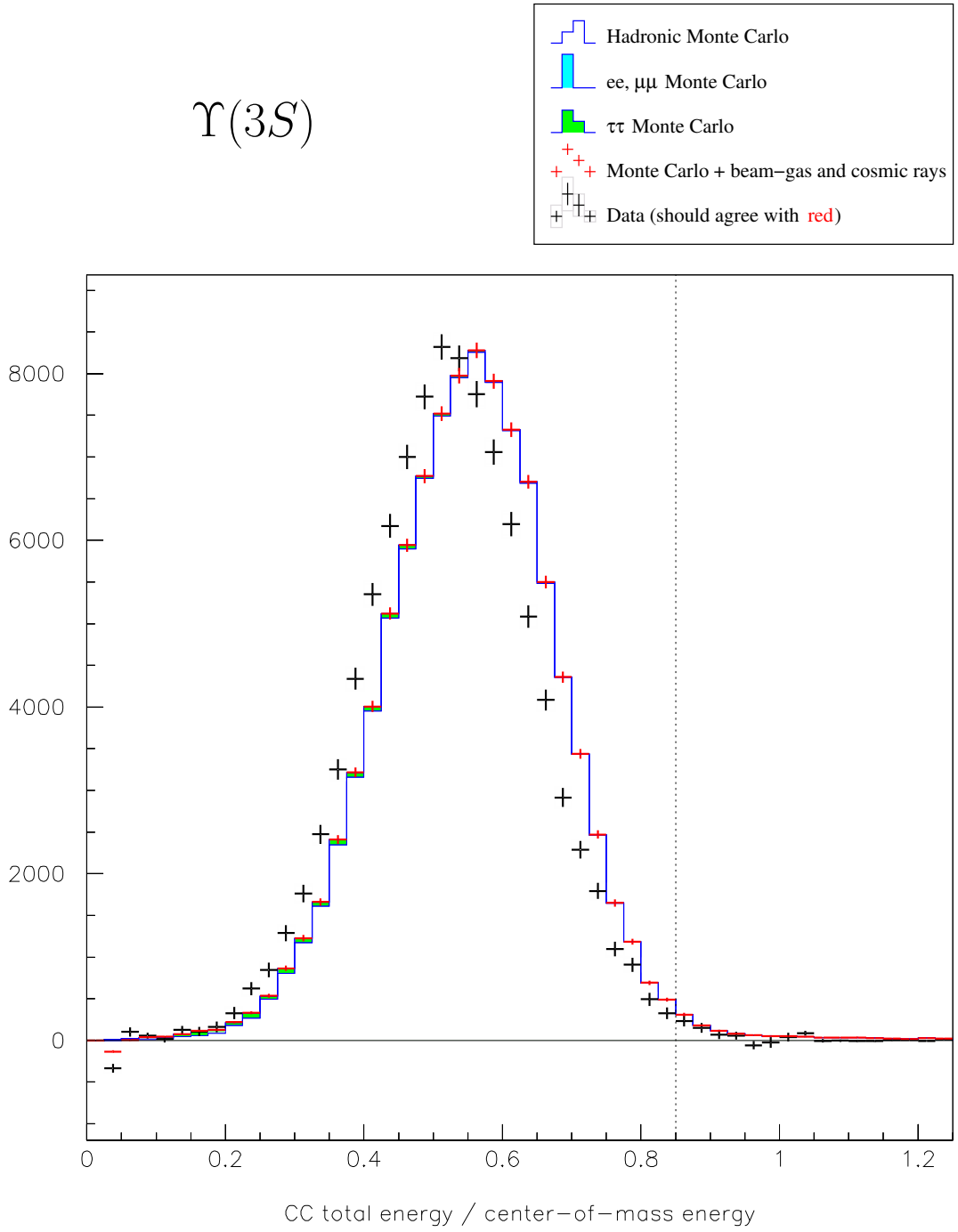



- Efficiency is measured from data:

$$99.63\% \pm 0.11\% \pm 0.32\%$$

- Data/MC disagreement no longer matters because I'm not using MC

$\Upsilon(3S)$




- Efficiency is measured from data:

$$99.45\% \pm 0.15\% \pm 0.42\%$$

- Data/MC disagreement no longer matters because I'm not using MC

| | $\Upsilon(1S)$ | $\Upsilon(2S)$ | $\Upsilon(3S)$ |
|---|---|---|---|
| $\epsilon_{MC}$ | 99.03% | 97.62% | 98.24% |
| what's the trigger uncertainty? all of itself? | $\sim 0.50\%$ | $\sim 0.50\%$ | $\sim 0.50\%$ |
| limit on untriggerable zero-track events | $\pm 0.07\%$ | $\pm 0.07\%$ | $\pm 0.07\%$ |
| closest track to beamspot | $\pm 0.25\%$ | $\pm 0.25\%$ | $\pm 0.25\%$ |
| $gg\gamma$ events straddle biggest-shower energy threshold | $\pm 0.09\%$ | $\pm 0.08\%$ | $\pm 0.08\%$ |
| cascade decays to $e^+e^-$ fail biggest shower cut, | | $\pm 0.06\%$ | $\pm 0.05\%$ |
| cascade decays to $\mu^+\mu^-$ fail second-biggest track cut | | | |
| assume `PHOTOS` to be 50% wrong | | $\pm 0.03\%$ | $\pm 0.01\%$ |
| Peter Onyisi's EvtGen-bunchfinder bug | $\pm 0.17\%$ | $\pm 0.30\%$ | $\pm 0.13\%$ |
| I need to generate separate $\Upsilon \to q\bar{q}$ samples with the | | | |
| right branching fractions, but here are some bounds | $< 0.19\%$ | $< 0.44\%$ | $< 0.44\%$ |
| I placed on how much difference that will make | | | |
| $\epsilon_Z$ | 99.35% | 99.35% | 99.35% |
| sample statistics | $\pm 0.20\%$ | $\pm 0.20\%$ | $\pm 0.20\%$ |
| scaling systematics | $\pm 0.56\%$ | $\pm 0.56\%$ | $\pm 0.56\%$ |
| $\epsilon_{data}$ | 99.49% | 97.92% | 98.74% |
| sample statistics (combined) | $\pm 0.34\%$ | $\pm 0.39\%$ | $\pm 0.55\%$ |
| scaling systematics (combined) | $\pm 0.81\%$ | $\pm 0.88\%$ | $\pm 1.10\%$ |
| | 97.88% | 94.97% | 96.37% |
| Totals | $\pm 0.39\%$ | $\pm 0.44\%$ | $\pm 0.59\%$ |
| | $\pm 1.15\%$ | $\pm 1.30\%$ | $\pm 1.44\%$ |