Looking for extra-dimensions at the weak-scale experimental search for Kaluza-Klein states signatures at the e^+e^- linear colliders

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Some motivations

Exciting piece of superstrings physics !

- string dualities $\rightarrow$ string scale M not at M_{Planck}

  Witten $\rightarrow$ M arbitrary parameter

  Lykken $\rightarrow$ M in the TeV region ?

- superstrings leaves in 10-d space time
- possibility of "opening" δ extra-dimensions at the TeV scale

See also Antoniadis 90' (string compactification)

➡ δ extra-dimensions ➡ Kaluza Klein states

Kaluza-Klein 1921 1926 unification of gravity and e.m in 5 dimensions

assume the ground state of general relativity is

$M^4 \times S^1$

4d Minkowski, circle

generalization: complex quantum field $\phi(x)$ depends not only on the 4d-space time coordinates $X(x_0 \dots x_3)$ but also the δ extra dimension $Y(y_1 \dots y_\delta)$

periodicity of $\phi(x)$ under $y_i \to y_i + 2\pi R$ ➡

$$\phi(x) = \sum_{n_1=-\infty}^{+\infty} \sum_{n_2=-\infty}^{+\infty} \dots \sum_{n_\delta=-\infty}^{+\infty} \phi^{(n)}(X)\, e^{i \frac{n.y}{R}}$$

$n_i \in \mathbb{Z}$

the "4d" fields $\phi^{(n)}(X)$ are the Kaluza Klein modes (or excitations)

$$m_n^2 = m_0^2 + \frac{n^2}{R} \qquad p = \frac{n}{R}$$

momenta appearing as masses for states that are massless from the higher dimensional point of view

impact of extra-dimensions on phenomenology

- grand unification at Tev scales

  Dienes Dudas Ghergetta

- millimeter ranges forces (susy)

  $\delta = 2 \rightarrow \frac{1}{F4}$ ($< mm$)

  $\vdots$

  $\delta = 6 \rightarrow \frac{1}{F8}$ ($< fm$)

  Antoniadis Dimopoulos Dvali

  Antoniadis Arkani-Hamed Dimopoulos Dvali

  See also: Antoniadis Dudas Sagnotti; Antoniadis Quiros; Dudas Grojean

- excitations of KK states at colliders

  Antoniadis Benakli Quiros

  → Giudice Rattazzi Wells Mirabelli Perelstein Peskin Han Lykken Zhang Hewett

A piece of phenomenology at e^+e^-

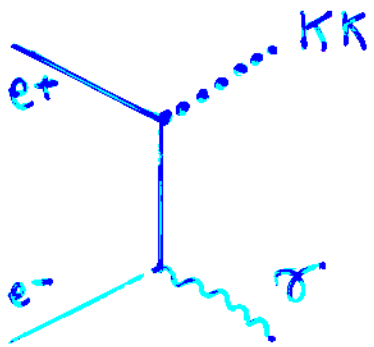
- resonant production of KK gauge bosons

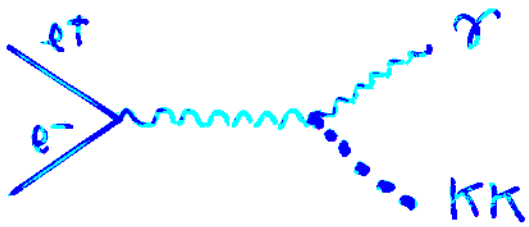
  if accessible in mass

  if not ➡ effective 4f interaction

  look for deviations from the SM

- production of single KK boson





KK ≡ $SU(2) \times U(1)$ gauge bosons (neutral)

higgs

graviton

Lifetime (from hep-ph/9811350) ex:

$$\tau(G_{KK} \to \gamma\gamma) \sim 6\,10^9\,\text{yr}\left(\frac{100\ \text{GeV}}{m_K}\right)^3 \sim \tau(G_{KK} \to f\bar{f})$$

KK graviton emission in the extra-dimension

$e^+e^- \to \gamma$ graviton, from hep-ph/9811291

WITHOUT ISR:

$$\frac{d\sigma}{dx_\gamma d\cos\theta} = \frac{\alpha}{64}\,\frac{2\pi^{\frac{\delta}{2}}}{\Gamma(\frac{\delta}{2})}\,(\frac{\sqrt{s}}{M})^{\delta+2}\,\frac{1}{s}\quad f(x_\gamma, \cos\theta)$$

with $x_\gamma = \frac{2E_\gamma}{\sqrt{s}}$ and assuming $\sum_{k_T} = R^\delta \int d^\delta m$

where $M^{\delta+2}R^\delta = (4\pi G_N)^{-1}$

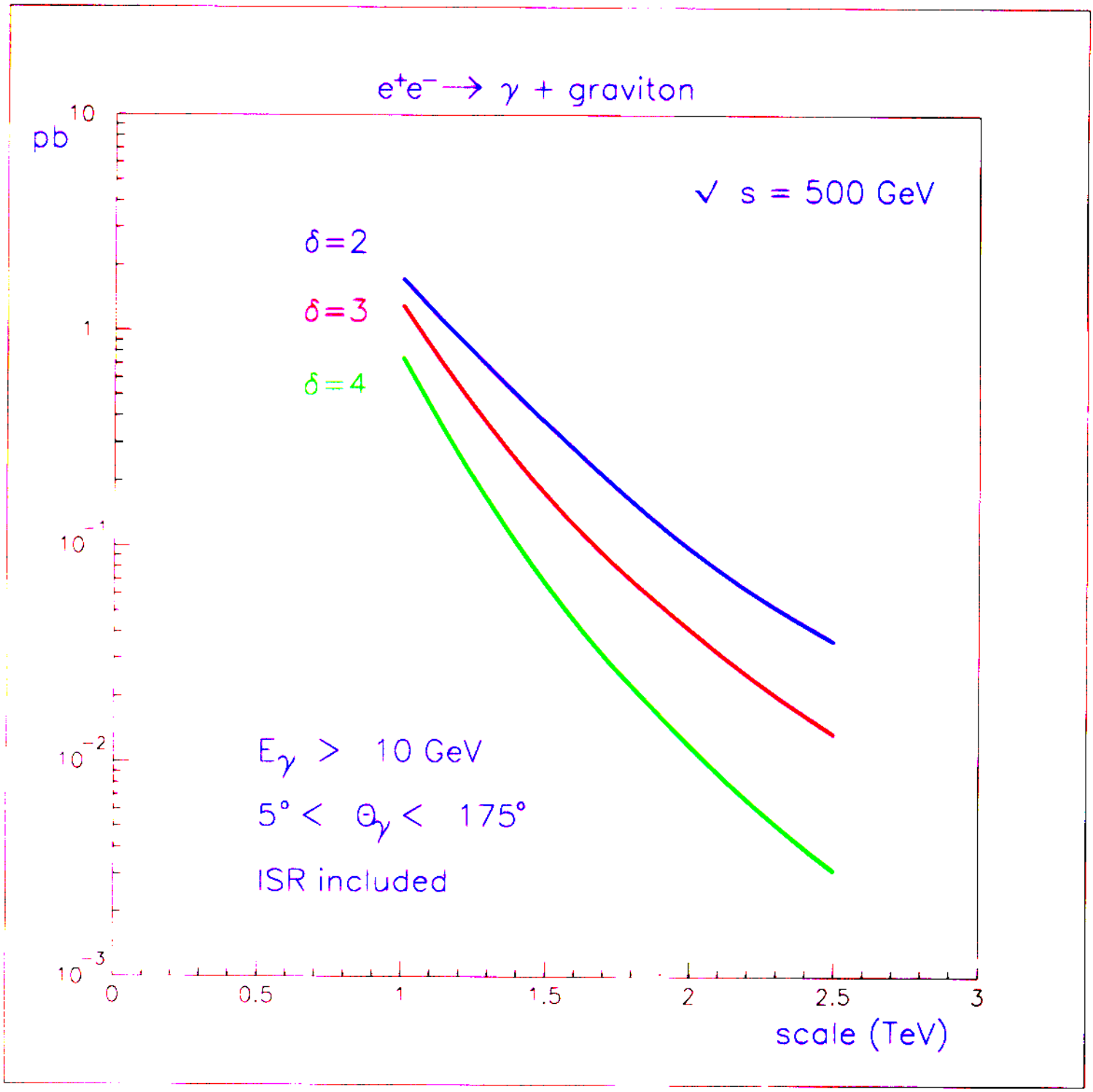
M = scale and δ= number of extra-dimensions

divergence for $x_\gamma \to 0$ and $\cos^2\theta \to 1$

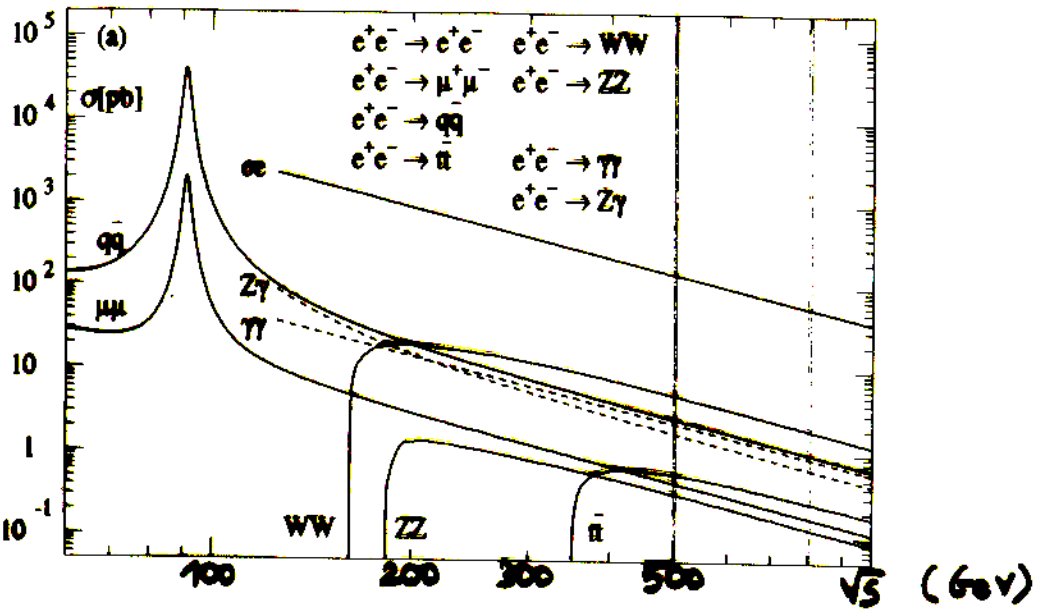
1st task: add ISR $\to$

lowering of Xsection up to 10% or more !

look for signature $(\gamma)_{ISR}\,\gamma\ \not{E}$


$e^+e^- \rightarrow \gamma$ + graviton
pb
10
1
10^{-1}
10^{-2}
10^{-3}
$\sqrt{s}$ = 500 GeV
$\delta = 2$
$\delta = 3$
$\delta = 4$
$E_\gamma > 10$ GeV
$5° < \Theta_\gamma < 175°$
ISR included
0
0.5
1
1.5
2
2.5
3
scale (TeV)

Background From SM processes



PYTHIA 5.7

$\sigma(e^+e^- \to Z\gamma)$	8.2 pb	includes $\nu\bar{\nu}\gamma$
$\sigma(e^+e^- \to ZZ)$	0.55 pb	
$\sigma(e^+e^- \to WW)$	7.7 pb	
$\sigma(e^+e^- \to We\nu)$	5.3 pb	
$\sigma(e^+e^- \to Zee)$	4.4 pb	
$\sigma(e^+e^-$ [2γ process])	3.6 nb	
$\sigma(e^+e^- \to \gamma\gamma(\gamma))$	8.02 pb	←
$\sigma(e^+e^- \to e^+e^-(\gamma))$	3.9 nb	←

SMEARING

- electromagnetic resolution $\frac{10\%}{\sqrt{E}}$
- hadronic resolution $\frac{50\%}{\sqrt{E}}$
- electron identification 90 %

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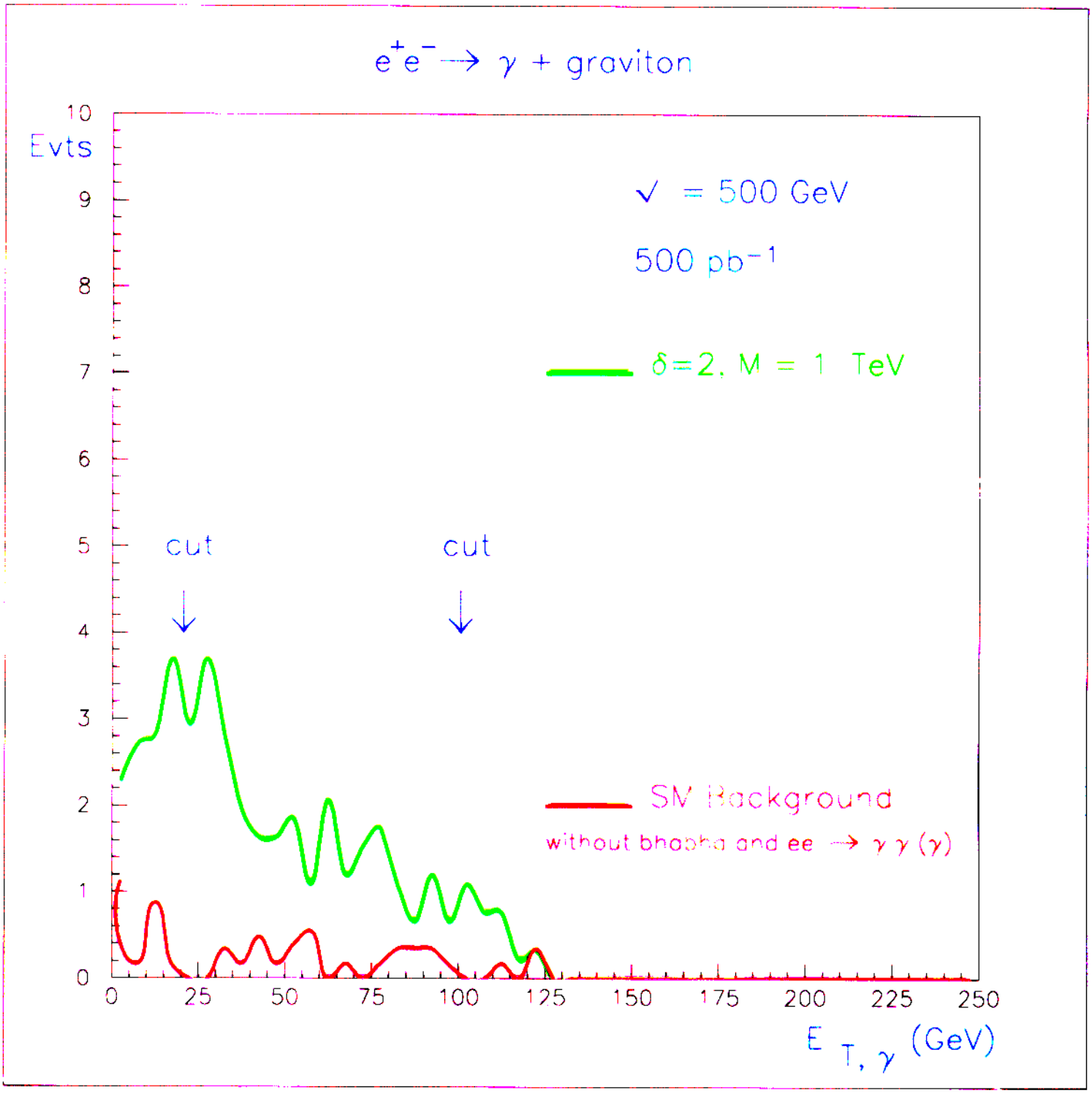
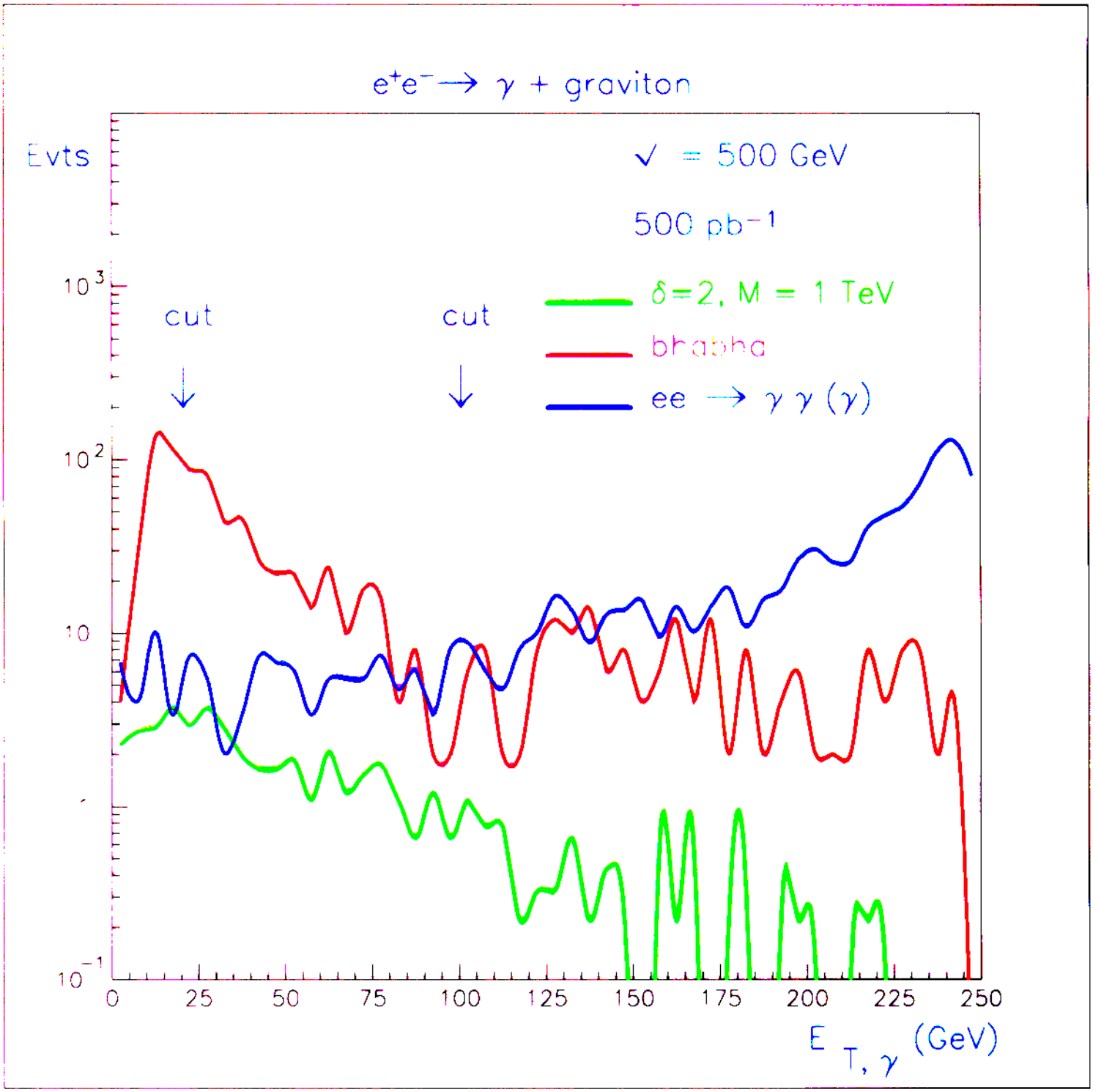
SELECTION

- 2 γ's in $[10^o, 170^o]$ and nothing else
- Energy leading $\gamma > 10$ GeV
- Energy of next to leading $\gamma > 5$ GeV

Look at E_T of the leading γ


$e^+e^- \rightarrow \gamma$ + graviton
Evts
10
9
8
7
6
5
4
3
2
1
0
$\sqrt{}$ = 500 GeV
500 pb^{-1}
δ=2, M = 1 TeV
cut
cut
SM Background
without bhabha and ee $\rightarrow \gamma\gamma(\gamma)$
0
25
50
75
100
125
150
175
200
225
250
$E_{T,\gamma}$ (GeV)


e+e− → γ + graviton
Evts
√ = 500 GeV
500 pb−1
δ=2, M = 1 TeV
bhabha
ee → γ γ (γ)
cut
cut
10 3
10 2
10
10 −1
0
25
50
75
100
125
150
175
200
225
250
E T, γ (GeV)

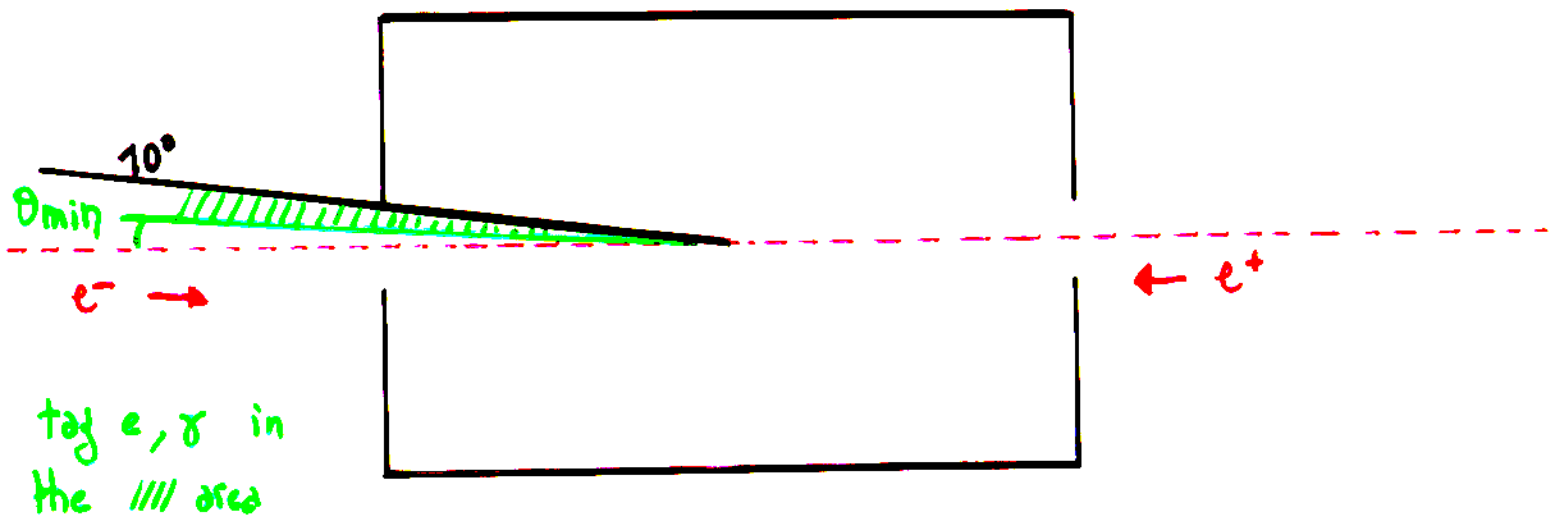
SELECTION (continued)

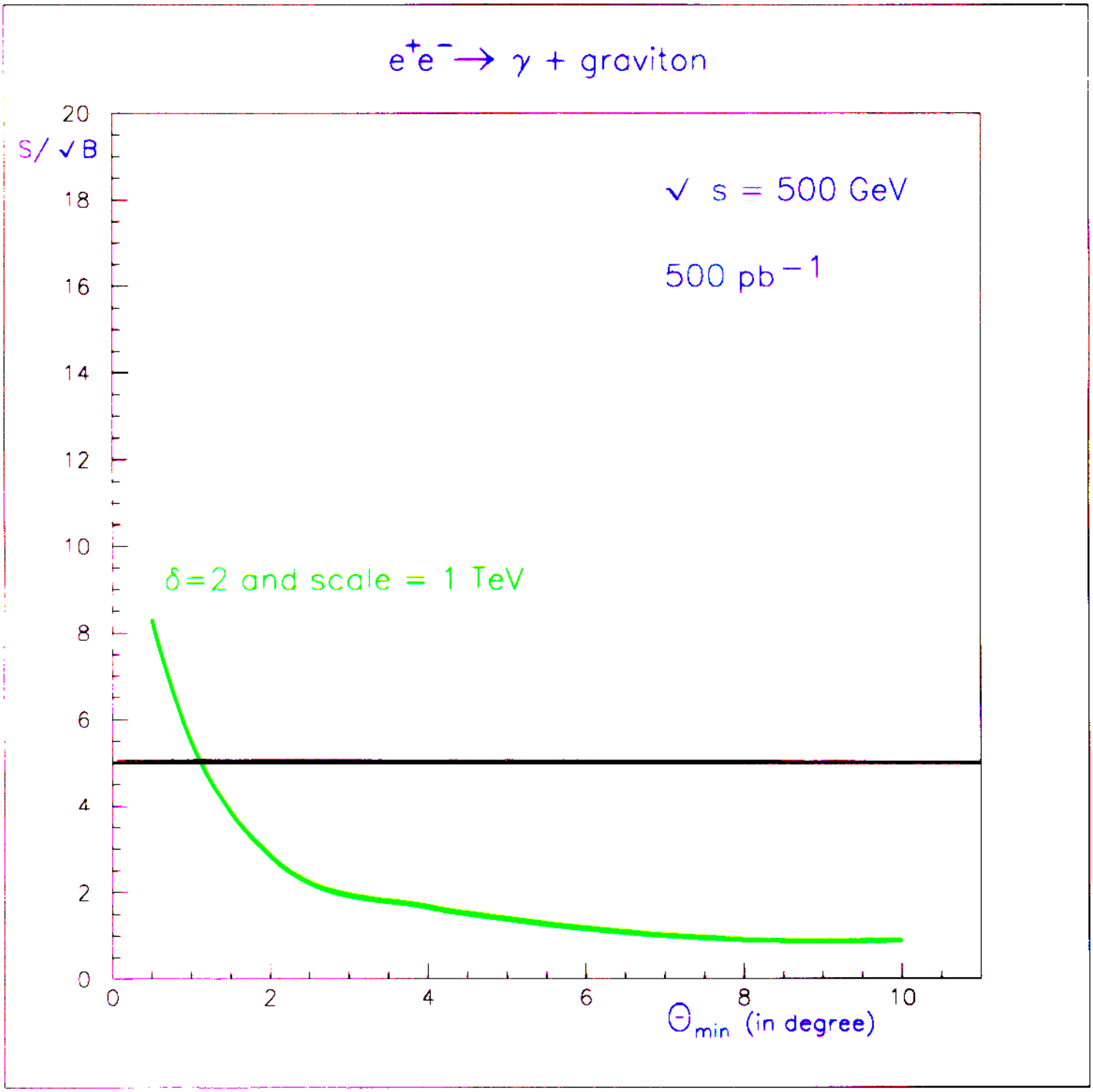
The situation may not be hopeless

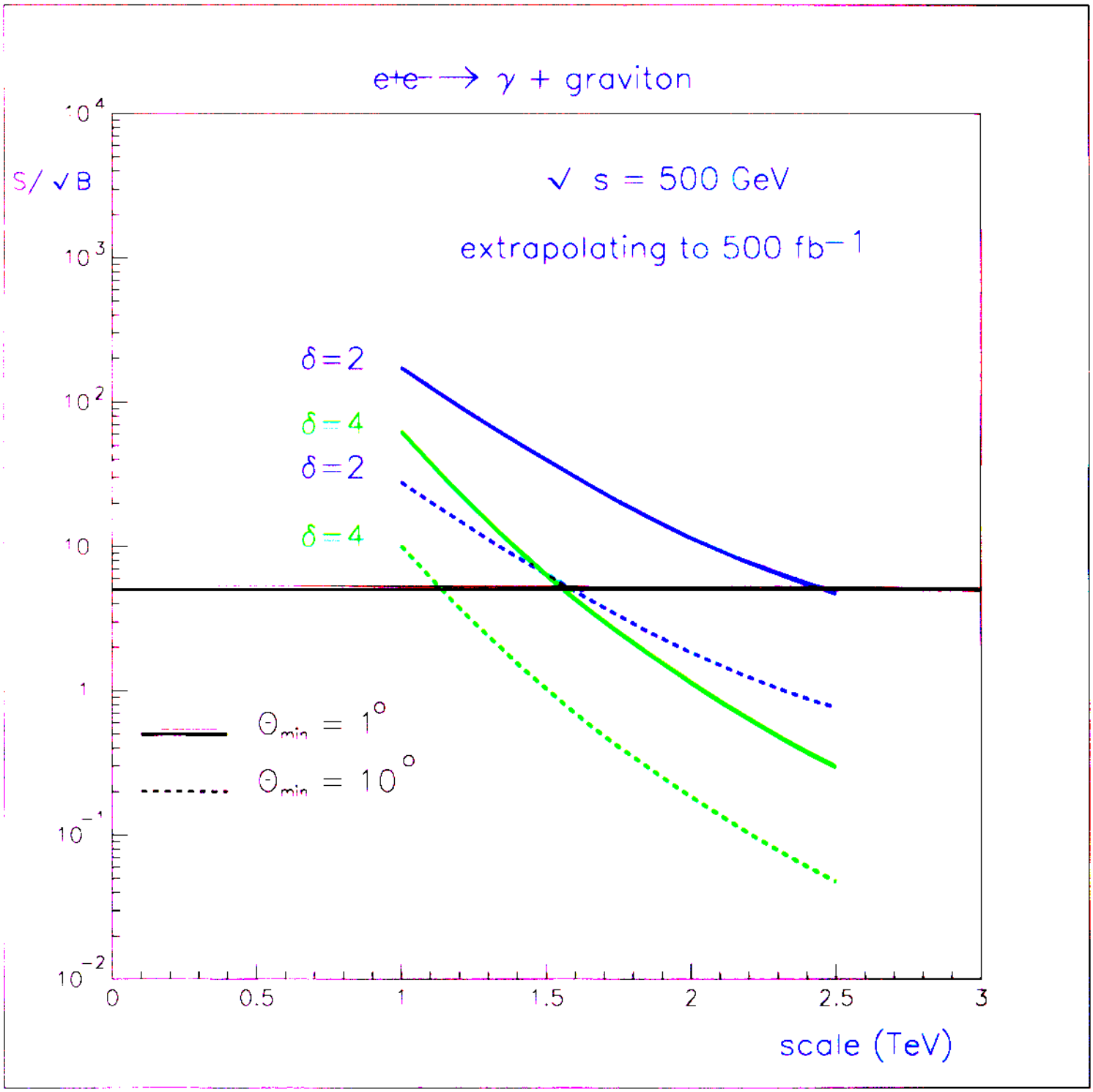
- 20 GeV $< E_T$ of leading $\gamma <$ 100 GeV
- 10 GeV $< E_{missing} <$ 150 GeV
- no electron tagged in $[\theta_{min}, 10^o]$
- $\sum E_\gamma$ in $[10^o, 170^o] + \sum E_\gamma$ in $[\theta_{min}, 10^o] <$ 150 GeV

Tagging and measurement of electron and γ below 10^o down to θ_{min} required

Try $\theta_{min} = 0.5^o\ 1^o\ 1.5^o\ 2^o\ 4^o\ 5^o$ and 10^o




$e^+e^- \rightarrow \gamma$ + graviton
S/ √B
√ s = 500 GeV
500 pb^{-1}
δ=2 and scale = 1 TeV
Θ_{min} (in degree)
0
2
4
6
8
10
12
14
16
18
20


e+e− → γ + graviton
S/√B
√ s = 500 GeV
extrapolating to 500 fb−1
δ=2
δ=4
δ=2
δ=4
Θmin = 1°
Θmin = 10°
10^4
10^3
10^2
10
1
10^−1
10^−2
0
0.5
1
1.5
2
2.5
3
scale (TeV)

Conclusions

- The search for Kaluza-Klein states at present/future colliders is an exciting piece of (experimental) string physics !
- At the e^+e^- collider the search for $e^+e^- \rightarrow \gamma$ graviton seems a promising way to look for extra-dimensions at the TeV scale
- Xsections have been calculated
  inclusion of ISR → Xsections are 10% -15% lower
- From the present Monte Carlo study this signal can be extracted from the $\nu\bar{\nu}\gamma(\gamma)$ background as well as, **provided that one can tag e and γ below 10^o**, bhabha and $e^+e^- \rightarrow (\gamma)\gamma\gamma$ backgrounds
- **For example tagging e and γ down to 1^o allows for an efficient veto which in turn allows to explore the 2.5 TeV string scale domain for 2 extra-dimensions at the linear collider after 500 fb^{-1}**
- Additionnal direct search for Kaluza-Klein states signatures can be provided by the search for $e^+e^- \rightarrow Z$ graviton where the SU(2) gauge boson Z decays as usual into quarks or leptons giving 2 jets or 2 leptons + missing energy
  help from theoreticians in the calculation of Xsection welcome !