Selected topics in rare B decays at Belle

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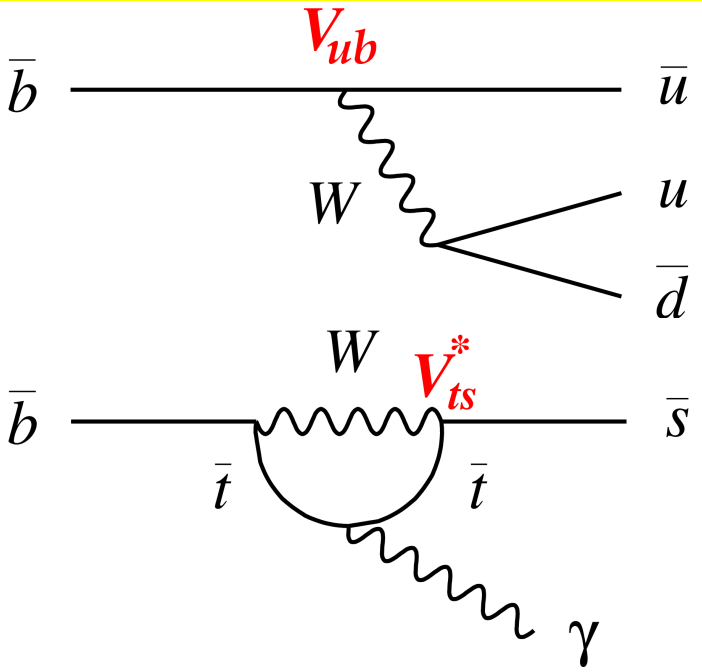
March 4, 2004

Contents

Introduction

What are rare decays?

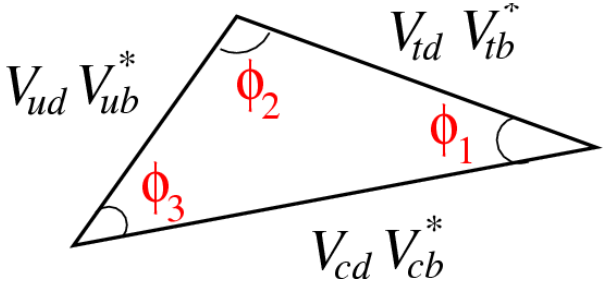
- CKM-suppressed tree decays
- FCNC $\Rightarrow$ loop diagrams (tree/penguin)



What can we learn from them?

- Standard Model:
  - constraints on CKM parameters,
  - alternative measurements of CP
- New physics:
  - New particles hidden in loops?
  - Constraints on new models
- B meson's intimate life
  $\Rightarrow$ constraints on QCD

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



Rare B decays @ Belle

Not exhaustive!

Hadronic decays

Charmless

$B \to PP$	$B \to \pi^0\pi^0$
	$B \to KK/\pi\pi/K\pi$
$B \to PV$	$B \to \rho\pi$
	$B \to \omega K/\omega\pi$
	$B \to \phi K$
$B \to VV$	$B \to \rho\rho$
	$B \to \phi K^*$

Baryonic

2-body	$B \to p\bar{p}/p\overline{\Lambda}/\Lambda\overline{\Lambda}$
3-body	$B \to p\bar{p}h^{(*)}$
	$B \to p\Lambda\pi$

Radiative/EW decays

$b \to s\gamma$	$B \to K^*\gamma$
	$B \to K_2^*\gamma$
	$B \to X_s\ell\ell$
	$B \to K^{(*)}\ell\ell$
	$B \to K\phi\gamma$
	$B \to K\pi(\pi)\gamma$
$b \to d\gamma$	$B \to \rho\gamma$
	$B \to \omega\gamma$
	$B \to \ell\ell$

Rare B decays @ Belle

Not exhaustive!

Hadronic decays

Charmless

$B \to PP$	$B \to \pi^0\pi^0$
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$B \to VV$	$B \to \rho\rho$
	$B \to \phi K^*$

Baryonic

2-body	$B \to p\bar{p}/p\overline{\Lambda}/\Lambda\overline{\Lambda}$
3-body	$B \to p\bar{p}h^{(*)}$
	$B \to p\Lambda\pi$

New $b \to s\gamma$
New $B \to \rho^{\pm}\pi^0$
Update $B \to K^*\gamma$
Update $B \to \rho^0\pi^0$

Radiative/EW decays

$b \to s\gamma$	$B \to K^*\gamma$
	$B \to K_2^*\gamma$
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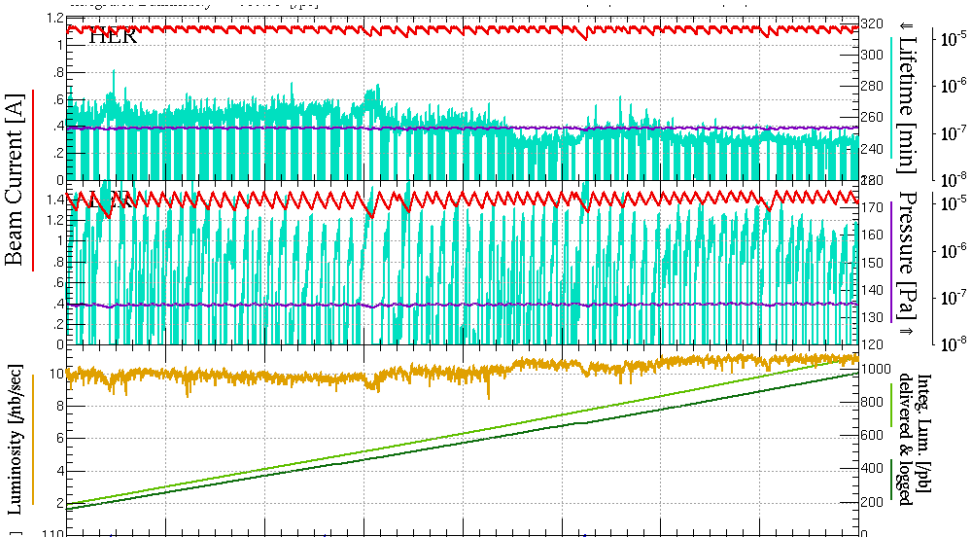
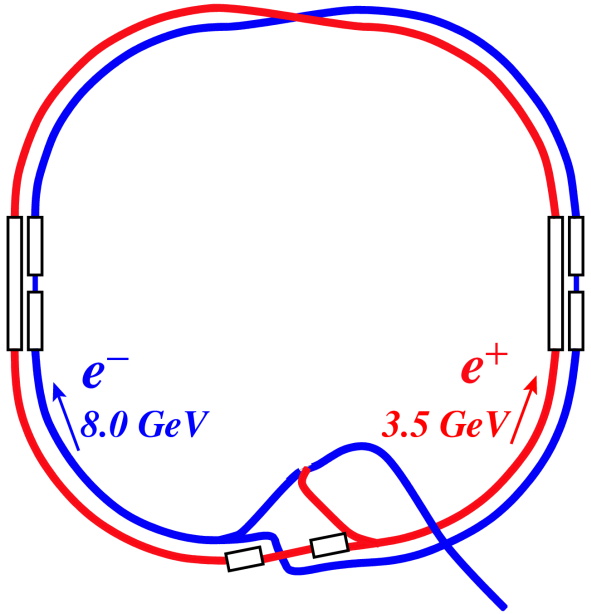
KEK B-factory: mass production!

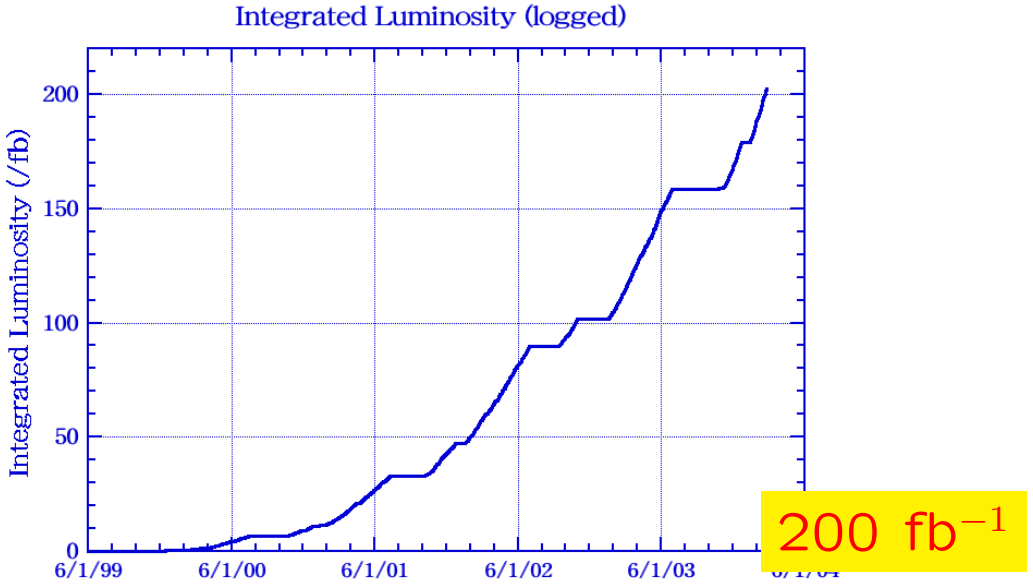
Features:

- "Continuous injection"
- Peak luminosity:

  1.20×10^{34} cm^{-2}s^{-1}
- Total logged: > 205 fb^{-1}
- $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$







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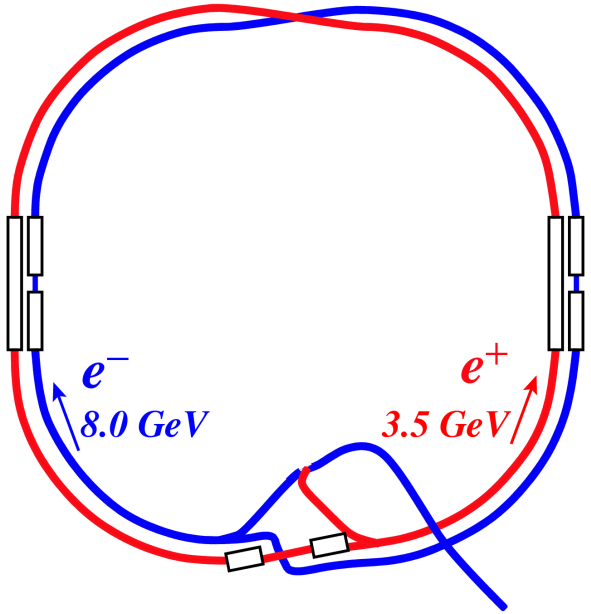
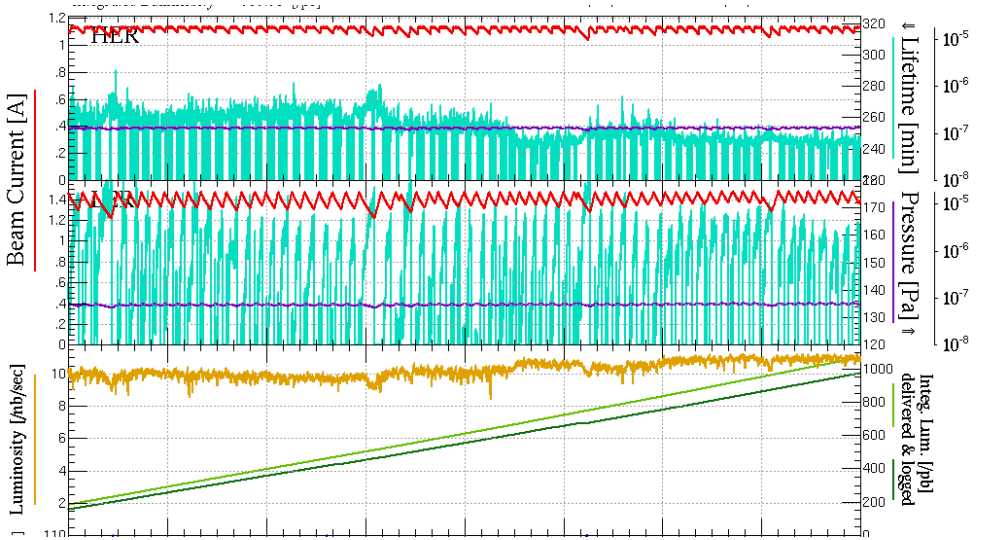
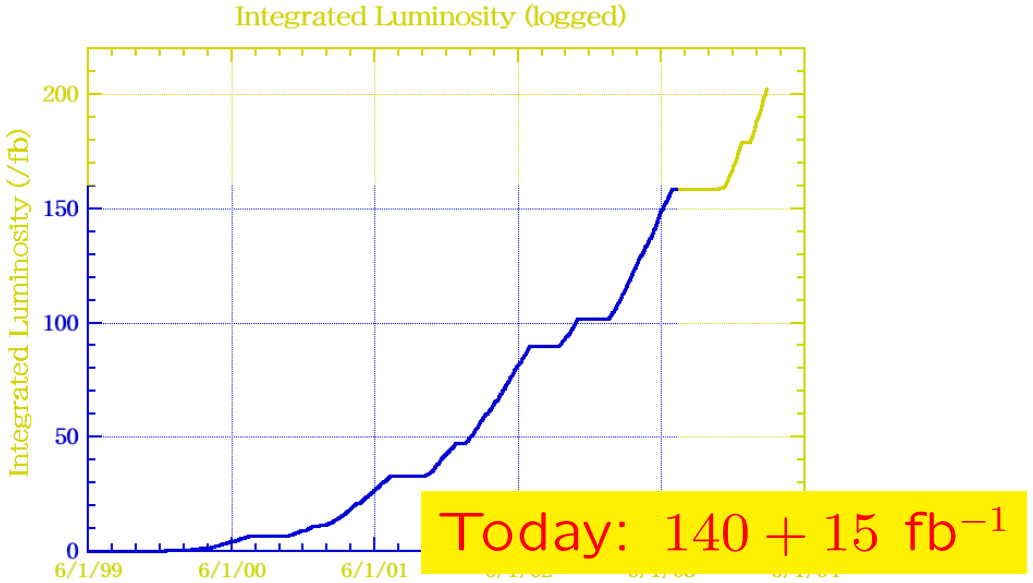
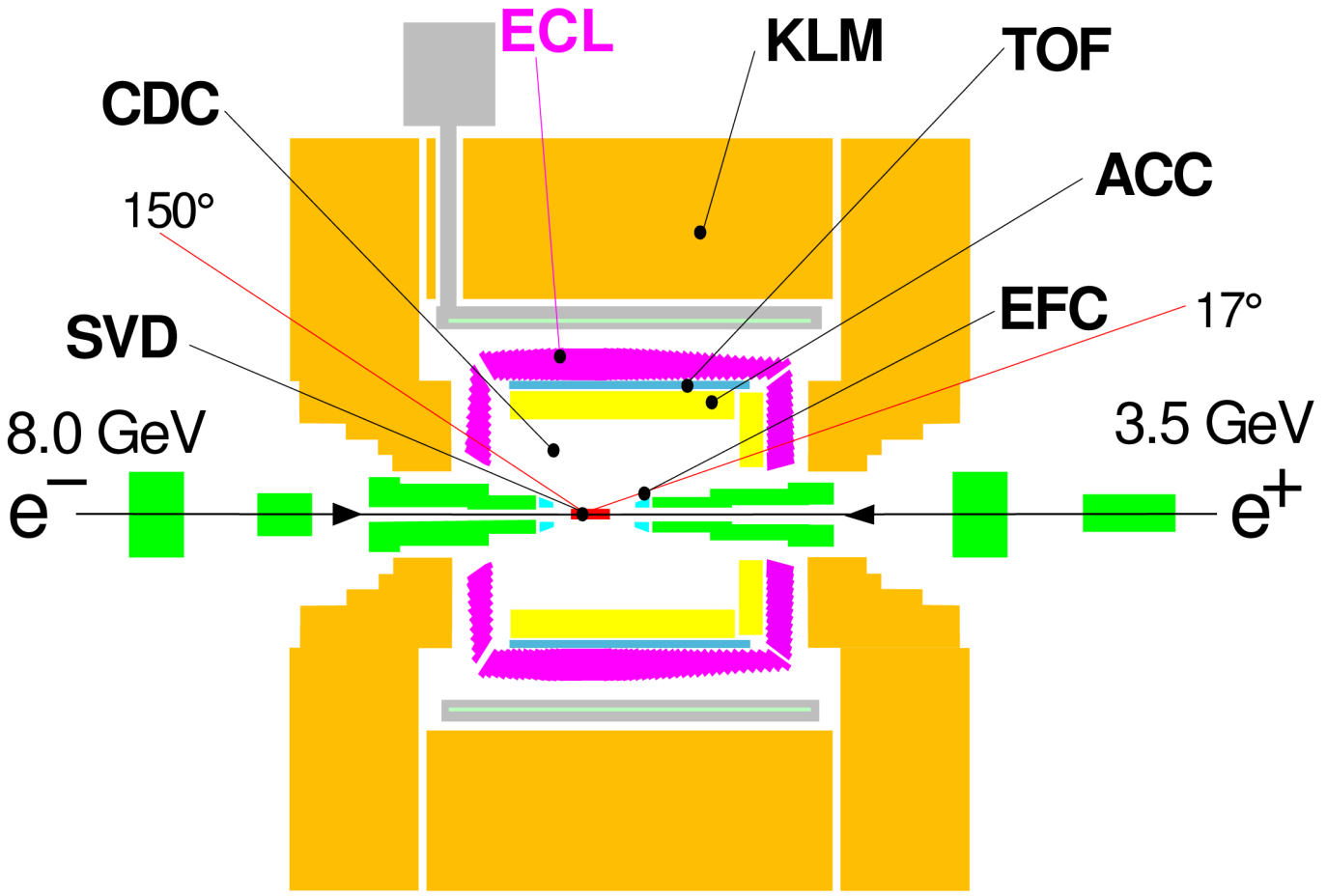






The Belle detector



ECL:

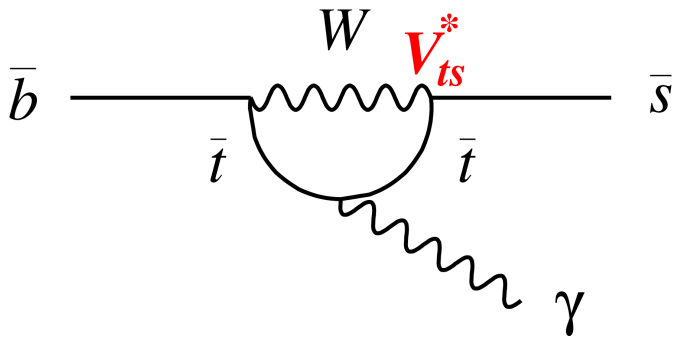
$\sigma_E/E \approx 1.8\%$

@ $E_\gamma \approx 1$ GeV

Motivation for $b \to s\gamma$

Observables:

- Branching fraction:
  - Measures $|V_{ts}|$ (SM)
  - Sensitive to NP (penguin loop)
- Photon spectrum:
  - b dynamics inside the B meson
  - Input to $|V_{ub}|$ measurement



Current status

- Theory[a]: $\mathcal{B}(b \to s\gamma) = \left(3.79^{+0.36}_{-0.53}\right) \times 10^{-4}$
- Experiment[b]: $\mathcal{B}(b \to s\gamma) = (3.3 \pm 0.4) \times 10^{-4}$

$\Rightarrow$ good agreement!

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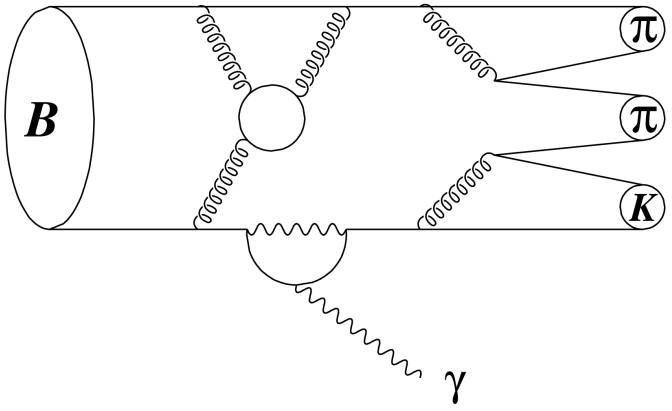
[a] Hurth,Lunghi & Porod, hep-ph/0312260

[b] PDG 2002

The challenge of "inclusiveness"

Theoretically favoured!

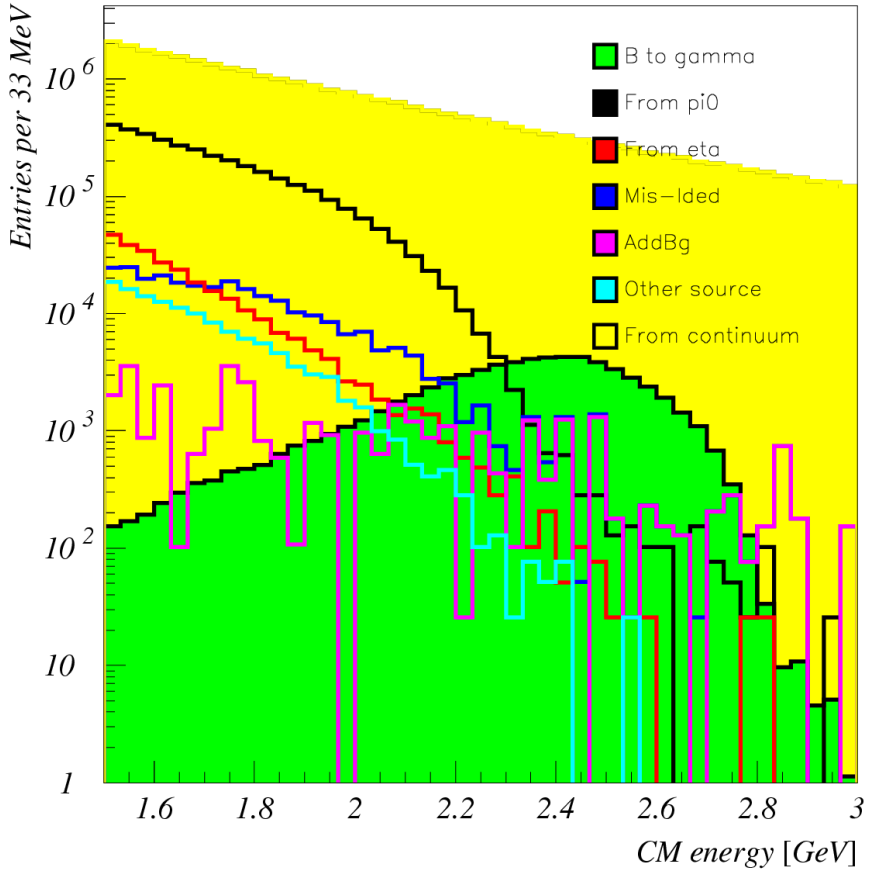


Experimentally challenging...

⇒ trade-off: $E_\gamma^* > E_0$

Current lowest cut-off (CLEO, 2001):

$$E_0 = 2.0 \text{ GeV}$$

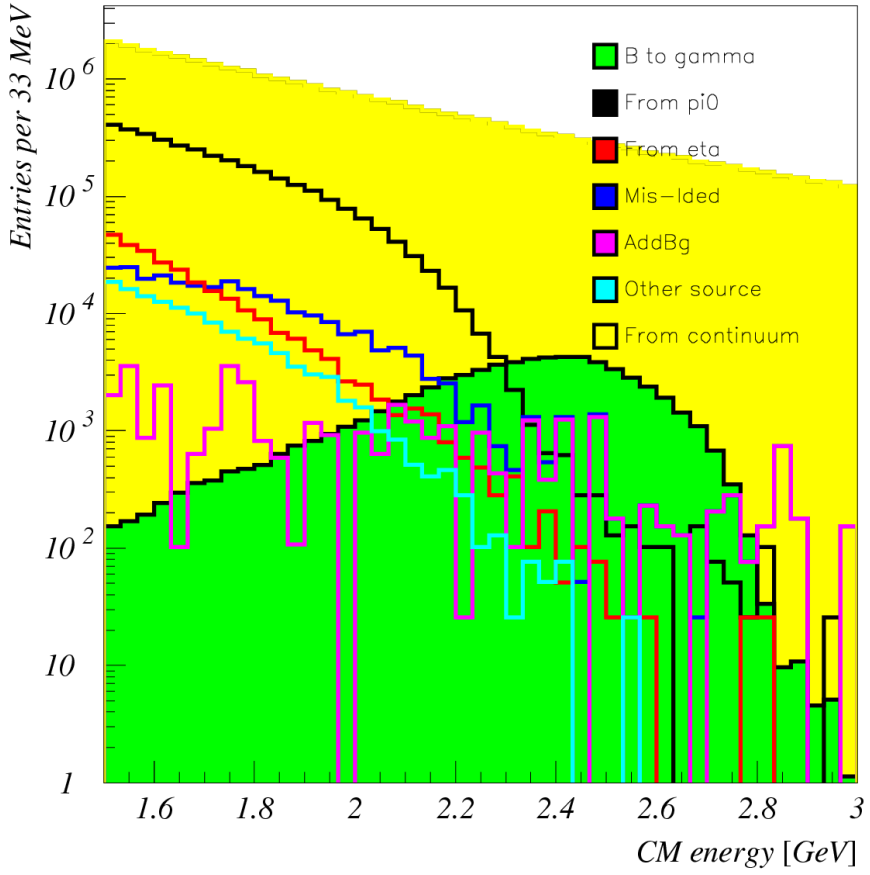


Photon spectrum (MC)

Signal MC: Kagan & Neubert, Eur. Phys. J., C7:5–27

Strategy

- Measure raw E_γ spectrum
  single high-energy photon
- Veto π^0 and η
  uses likelihoods on $\gamma\gamma$ pairs
- Suppress continuum
  2 Fisher discriminants
  based on 13 event shape variables
- Subtract off-resonance data
  $\Rightarrow$ removes non-$B\overline{B}$ events
- Subtract measured π^0 and η spectra
  (major $B\overline{B}$ backgrounds)
- Estimate and subtract
  remaining backgrounds



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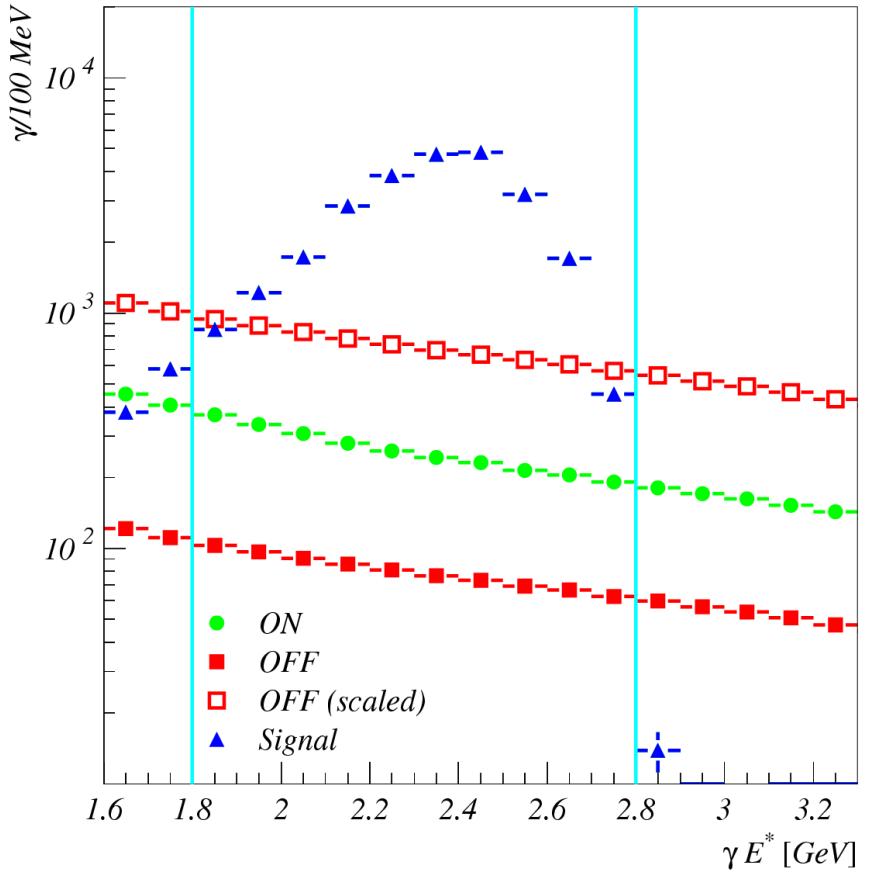


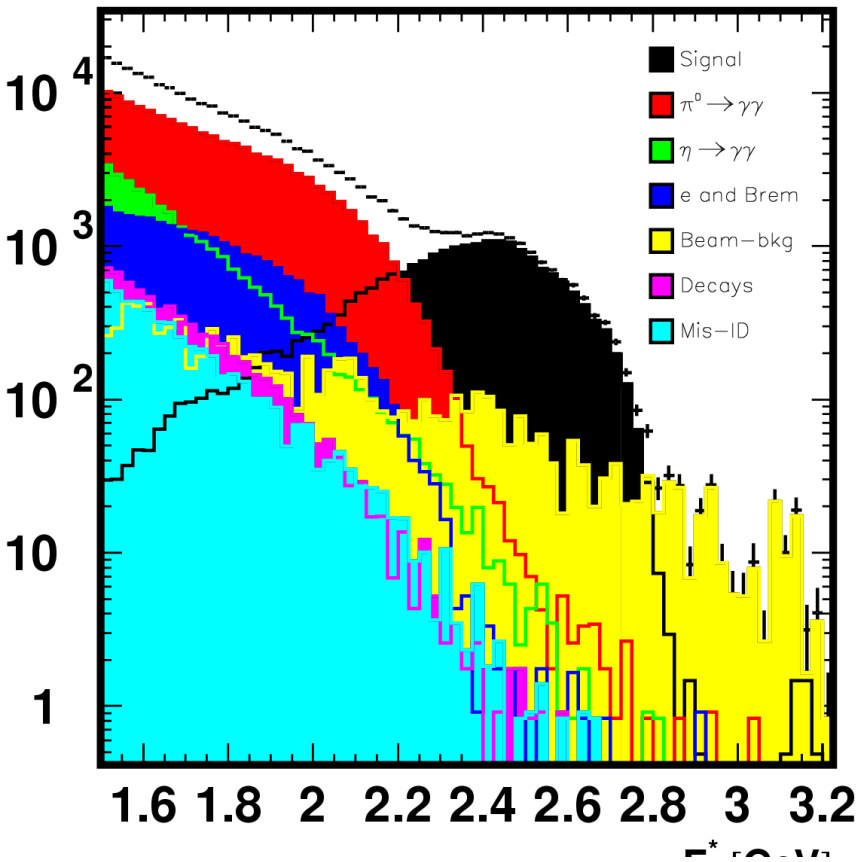
After selection (MC):

Signal and $\sqrt{\text{Background}}$

$B\overline{B}$ background subtraction

Remaining backgrounds

- $\pi^0/\eta \to \gamma\gamma$
- other real γs
- K_L^0, n and e-related clusters
- beam bkgd



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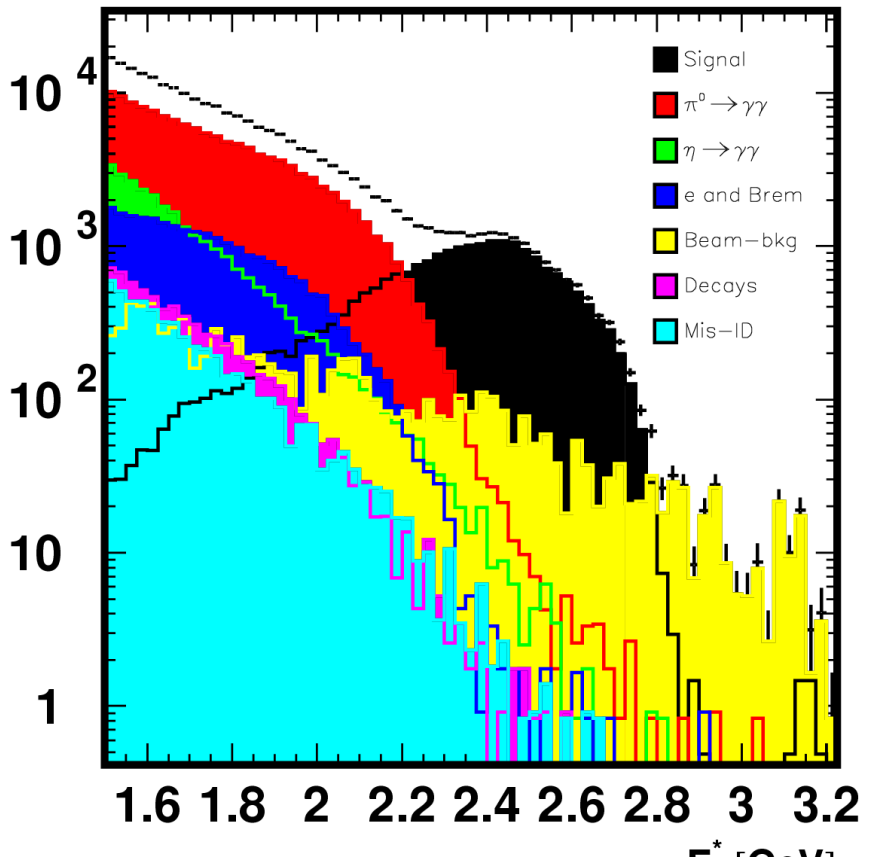

Extracted from MC:
correct efficiencies and yields
from control samples

$B\overline{B}$ background subtraction

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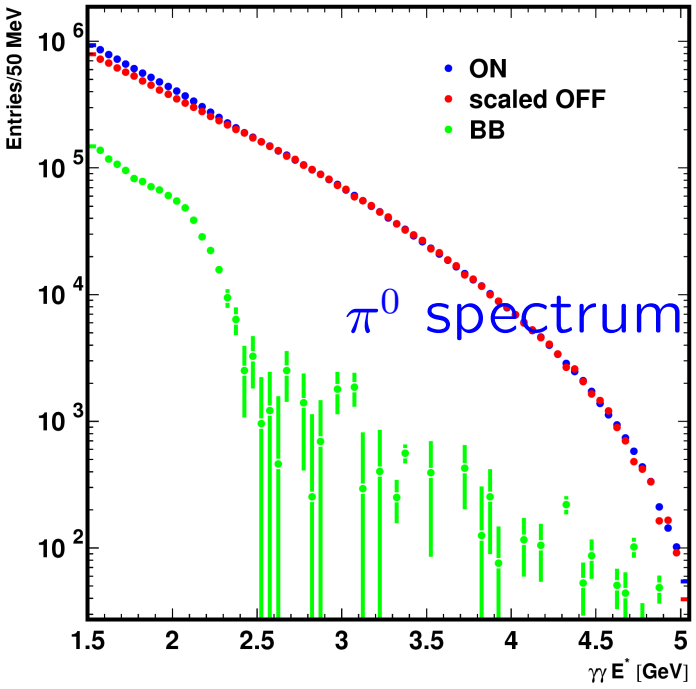

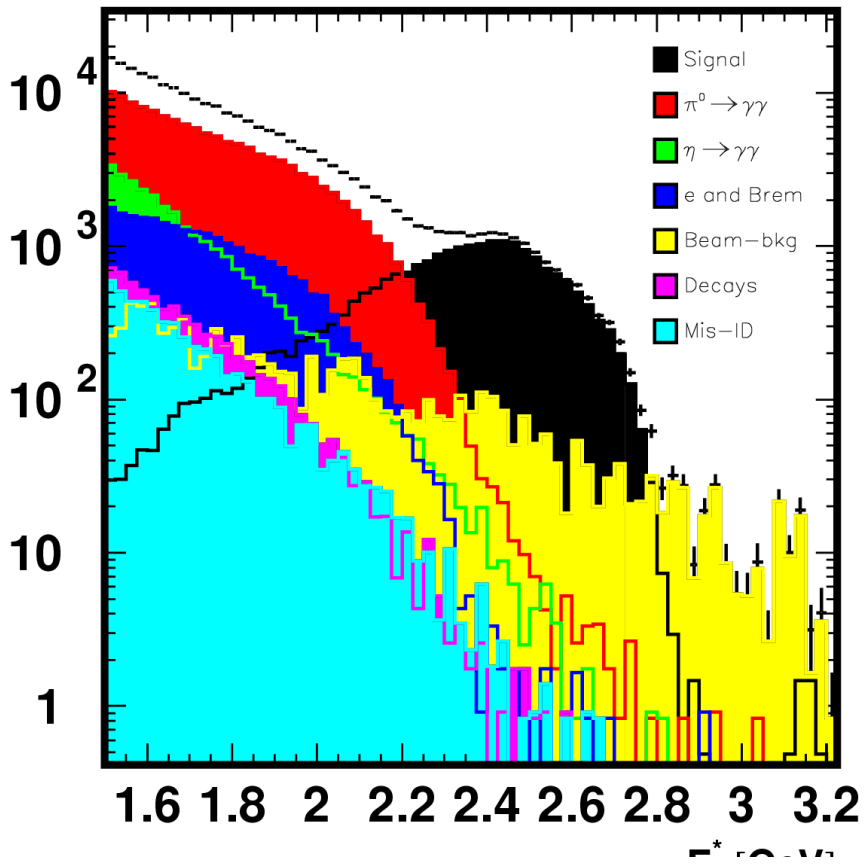

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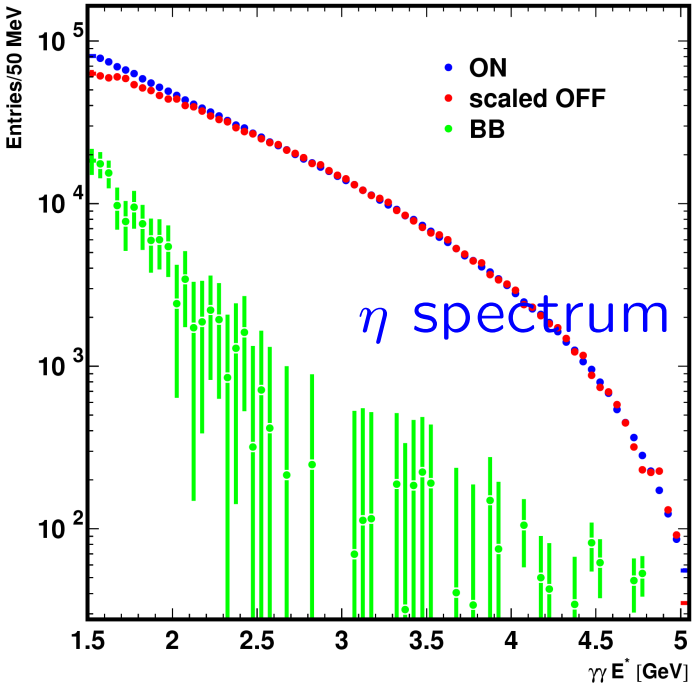

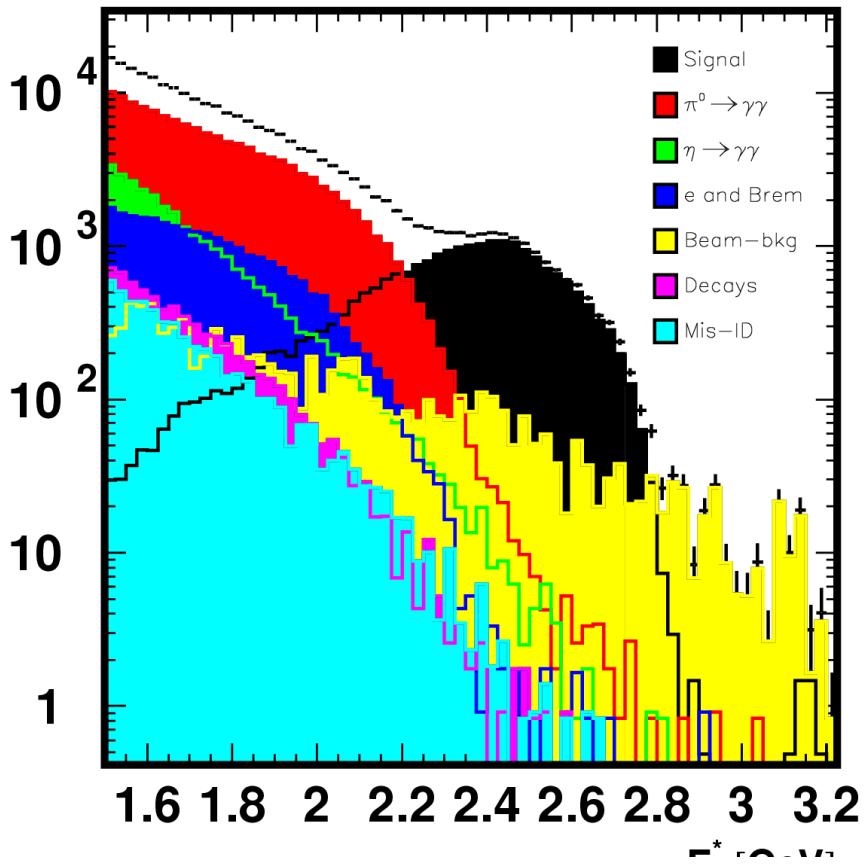

Extracted from MC:
correct efficiencies and yields
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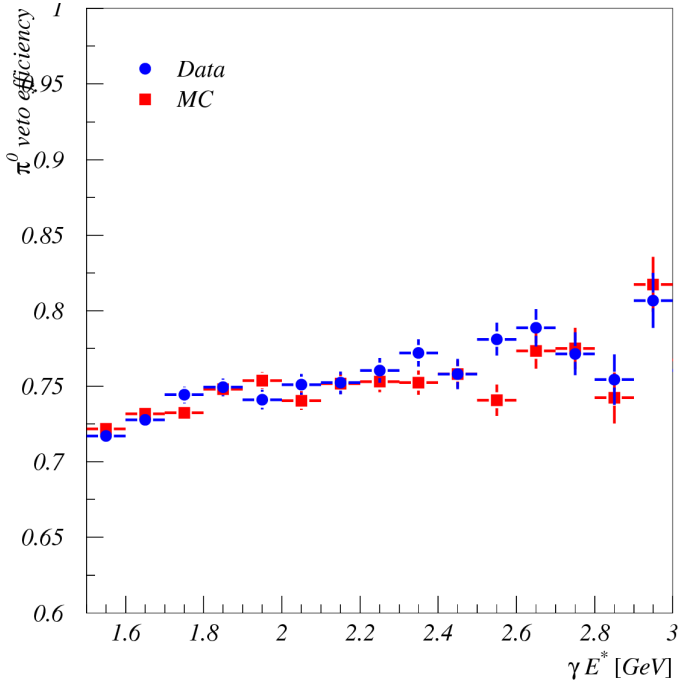
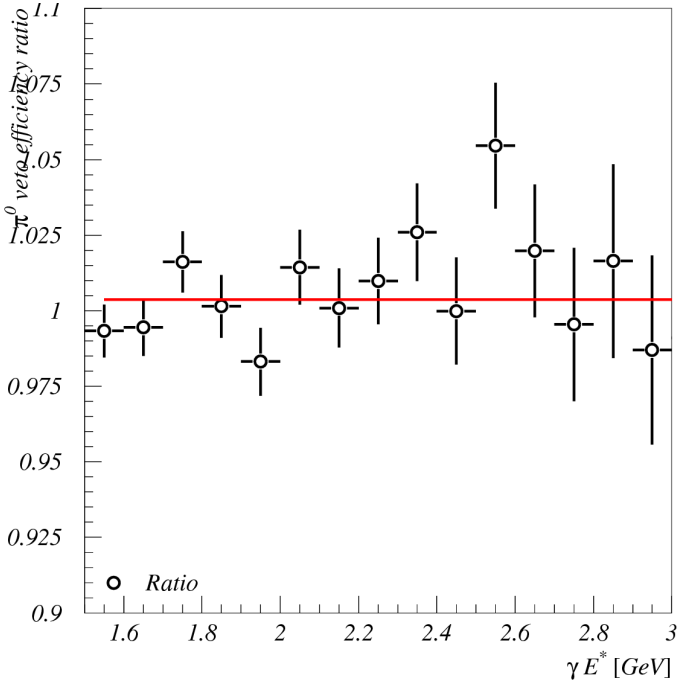
Efficiency correction

Procedure

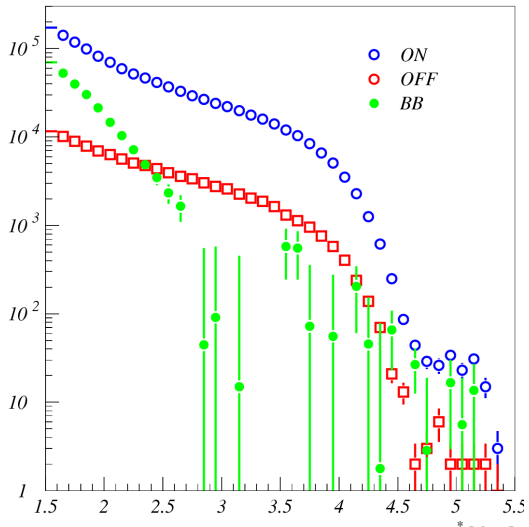
- Get selection efficiency in MC and data control samples
- Fit ratio with 0th-/1st-/2nd-order polynomial
- Scale relevant MC spectrum accordingly

Example: partially reconstructed $D^* \to D \to K\pi\pi^0$, $\pi^0 \to \gamma(\gamma)$



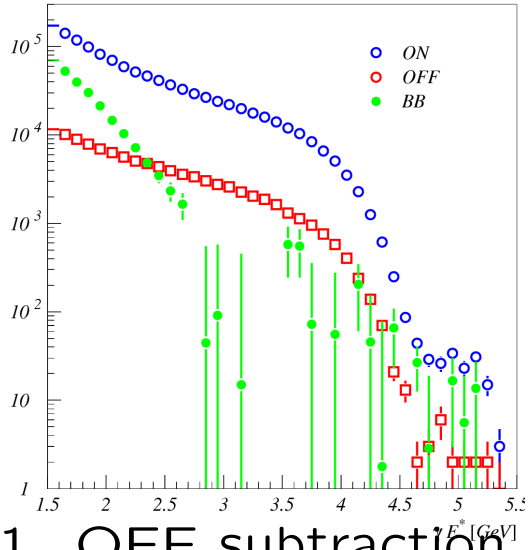


Spectrum extraction



1. OFF subtraction

Spectrum extraction



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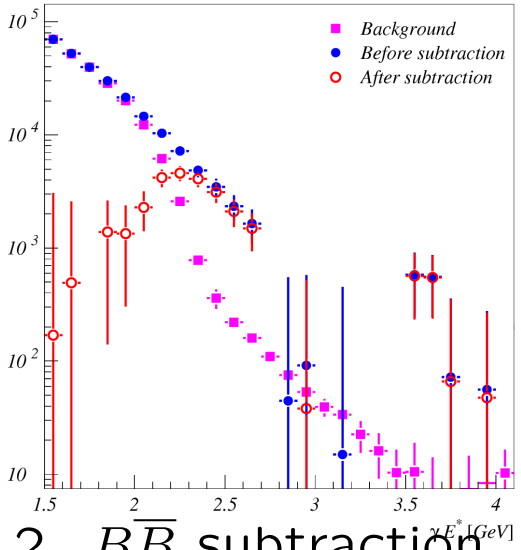
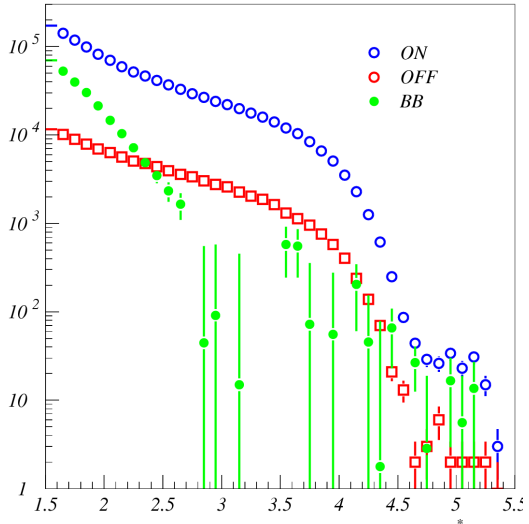


2. $B\overline{B}$ subtraction

Spectrum extraction



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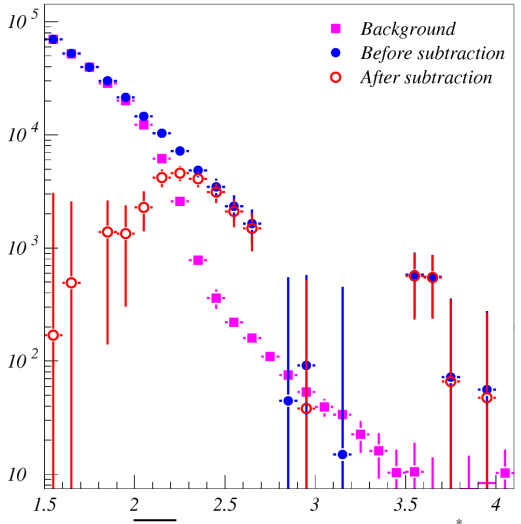

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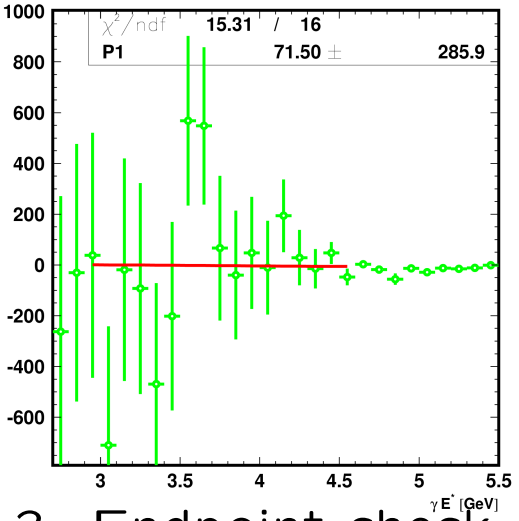
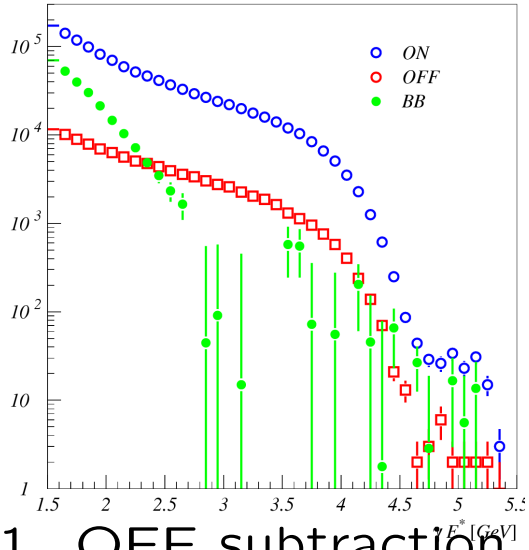


3. Endpoint check

Spectrum extraction



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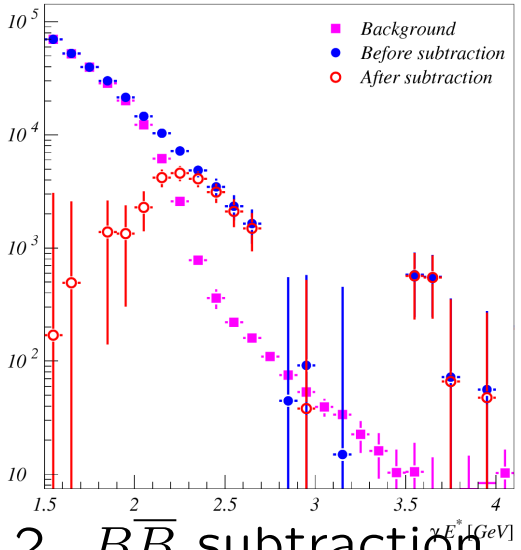

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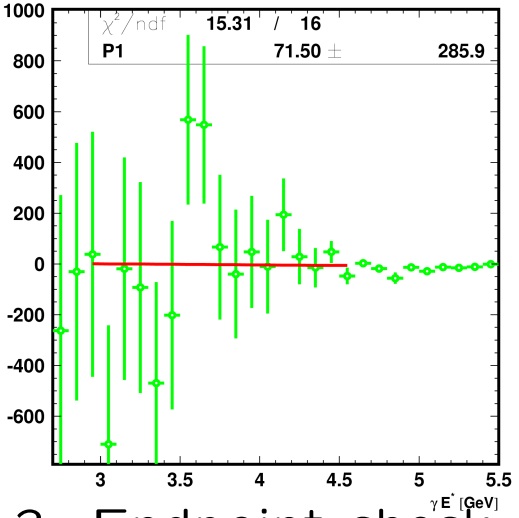

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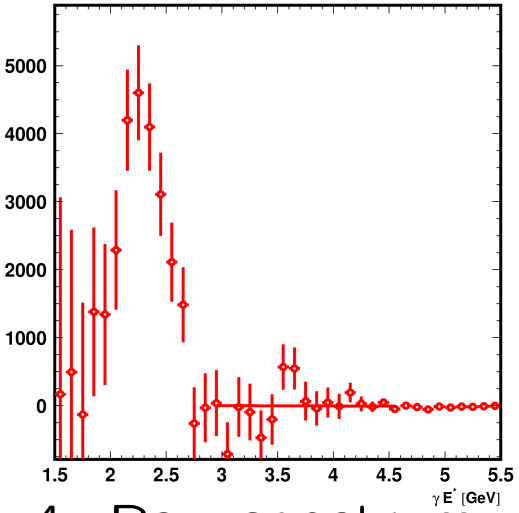
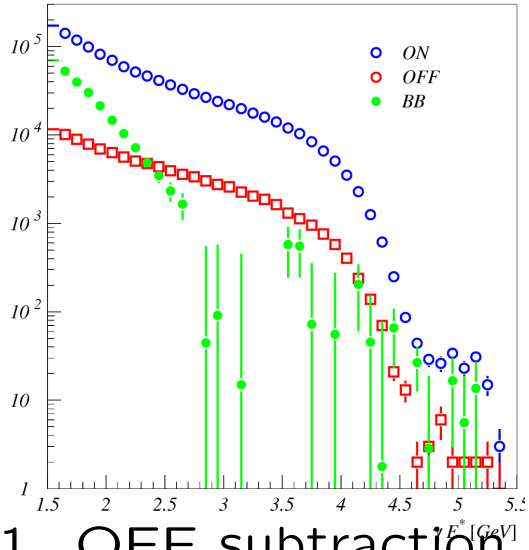


4. Raw spectrum

Spectrum extraction



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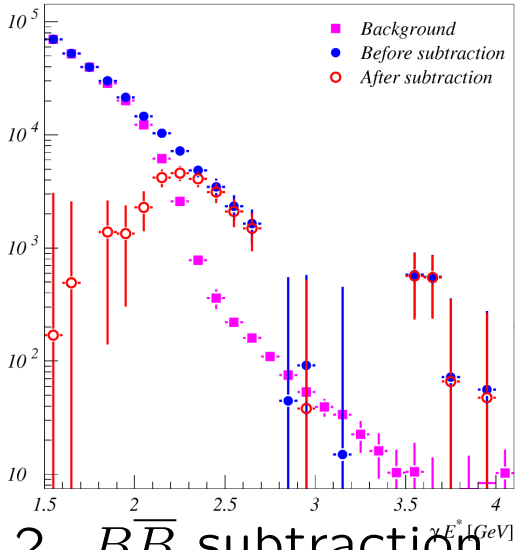

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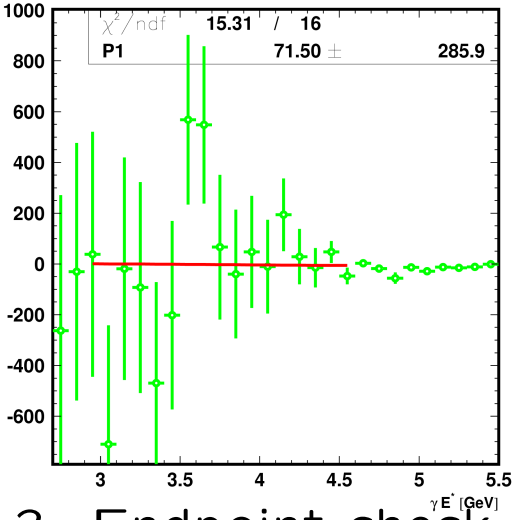

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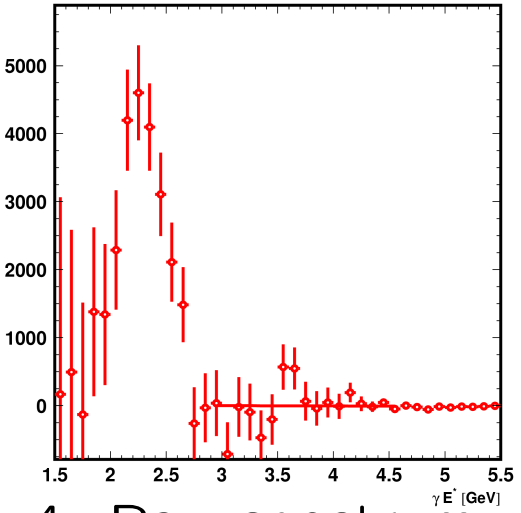

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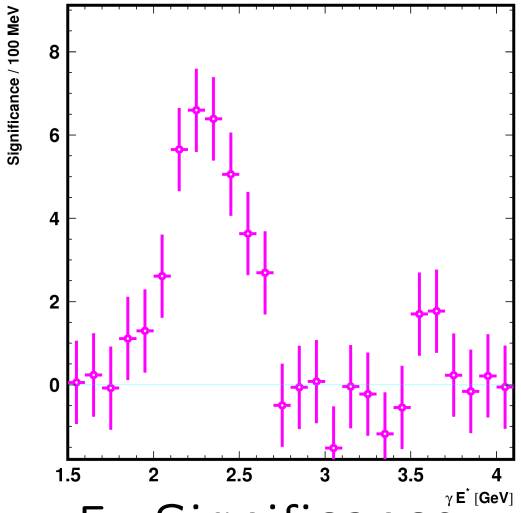
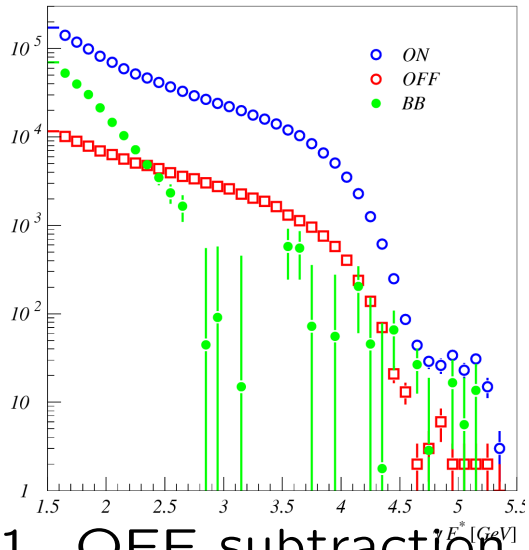


5. Significance

Spectrum extraction



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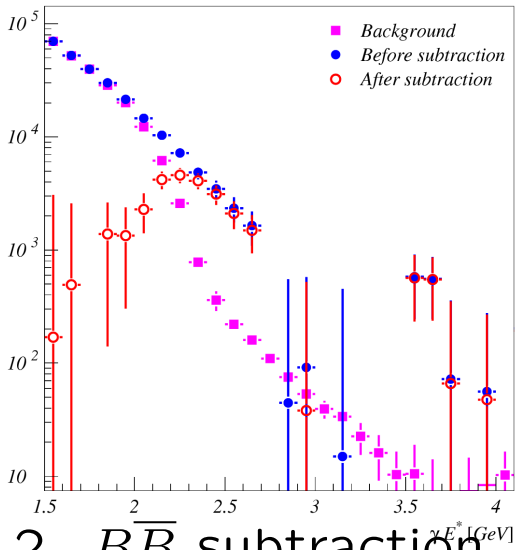

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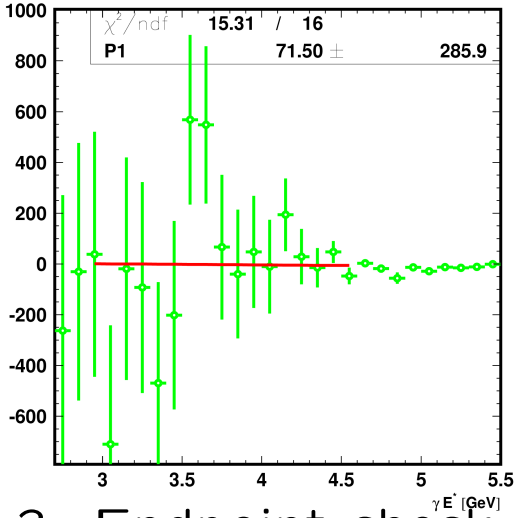

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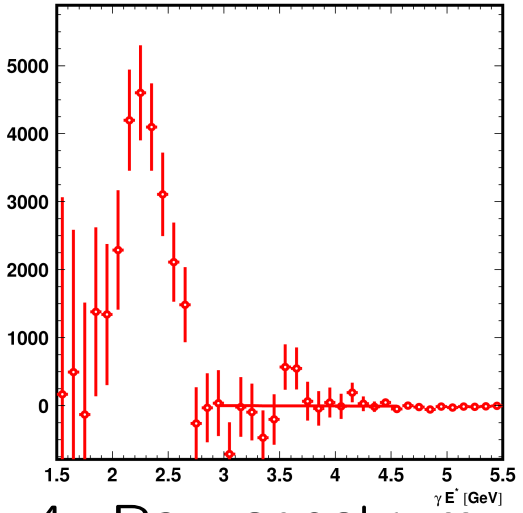

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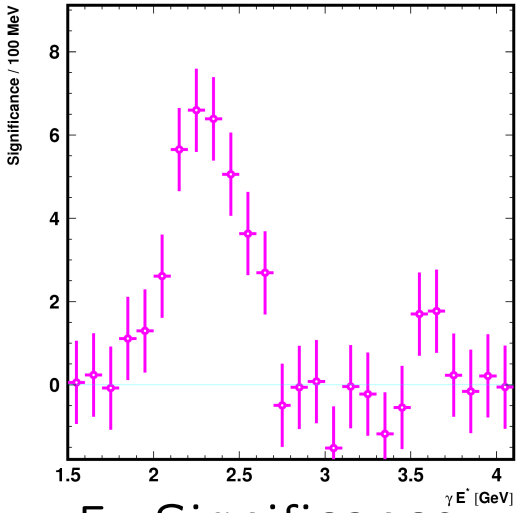

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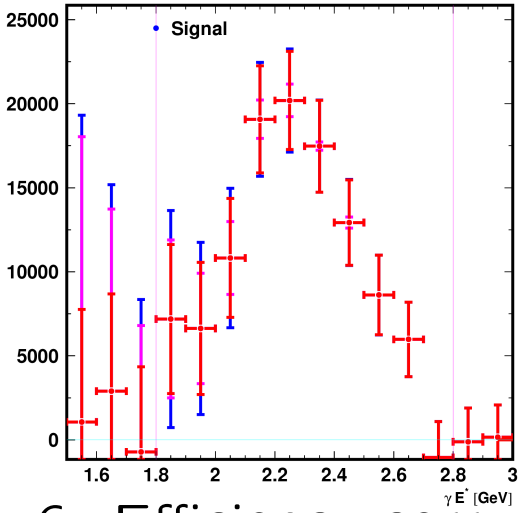


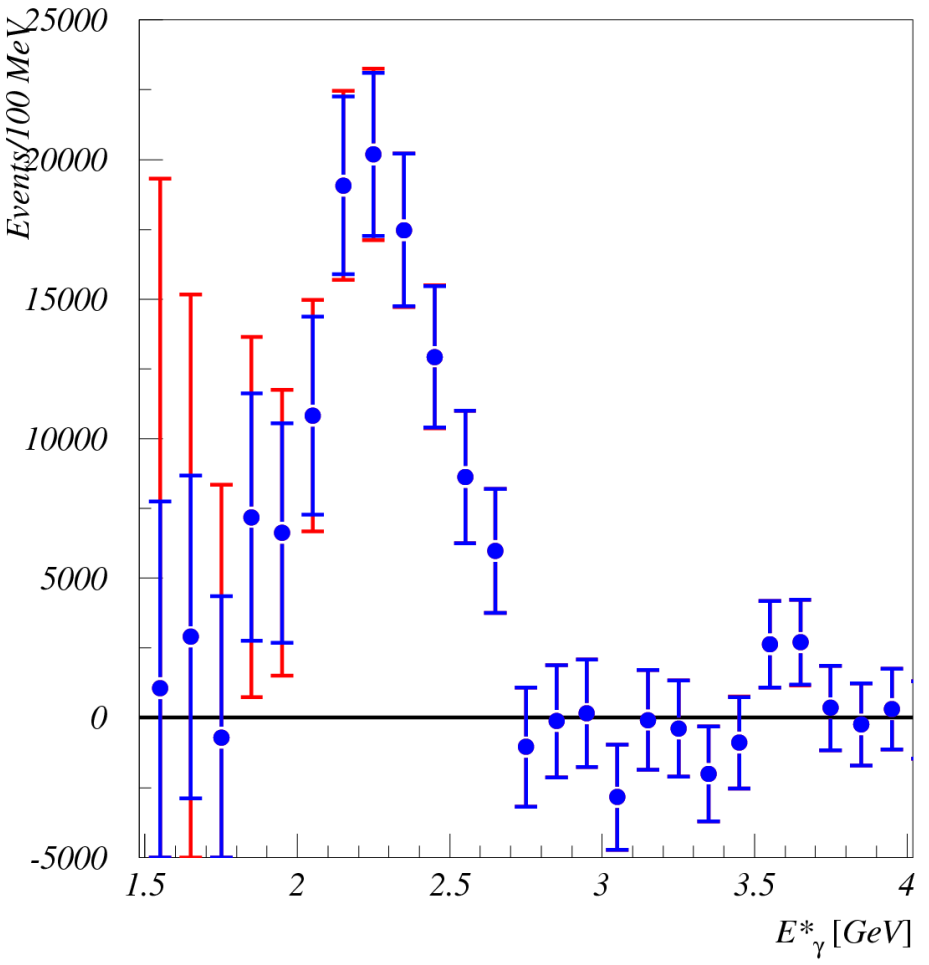
6. Efficiency-corr.

*** Results ***

[hep-ex/0403004]

Range: $1.8 < E_\gamma < 2.8$ GeV

($> 95\%$ of the spectrum!)



*** Results ***

[hep-ex/0403004]

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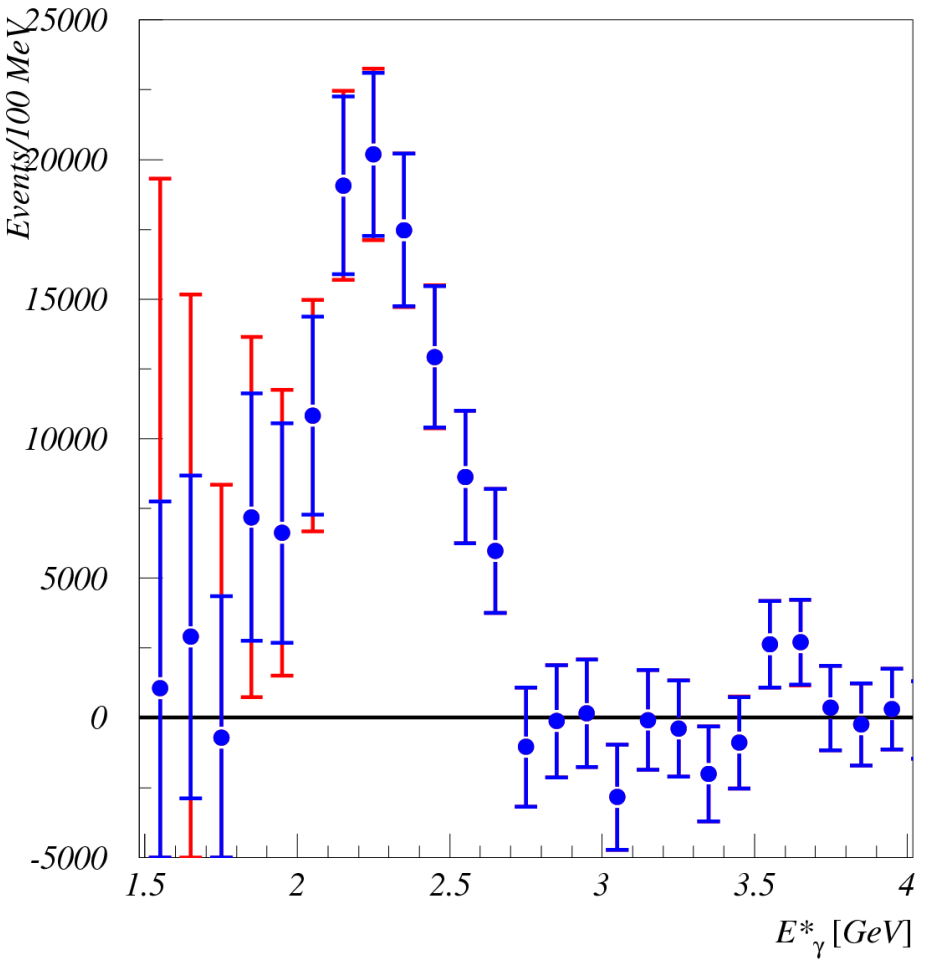
($> 95\%$ of the spectrum!)

Partial $\mathcal{B}$ for $E_\gamma > 1.8$ GeV:
$(3.55 \pm 0.32^{+0.29}_{-0.30}) \times 10^{-4}$



*** Results ***

[hep-ex/0403004]

Range: $1.8 < E_\gamma < 2.8$ GeV
($> 95\%$ of the spectrum!)

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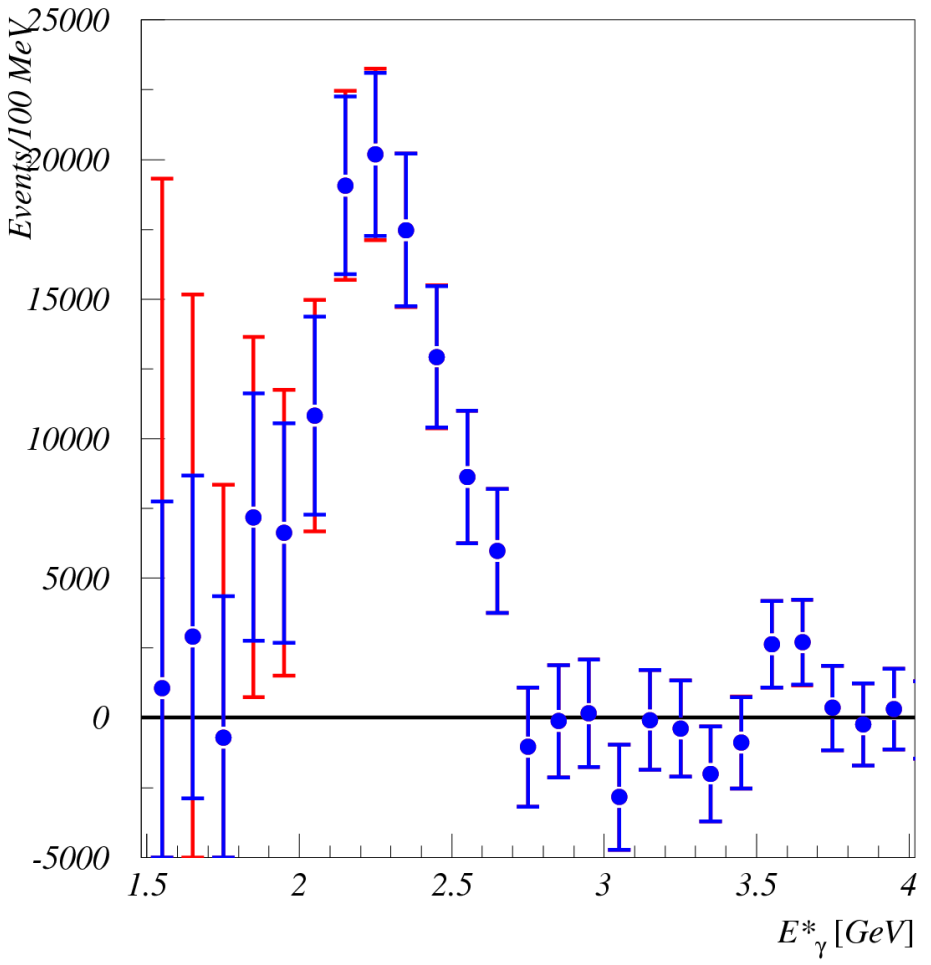
Full $\mathcal{B}(b \to s\gamma)$:

$$(3.59 \pm 0.32^{+0.30}_{-0.31}{}^{+0.11}_{-0.07}) \times 10^{-4}$$

stat syst theo



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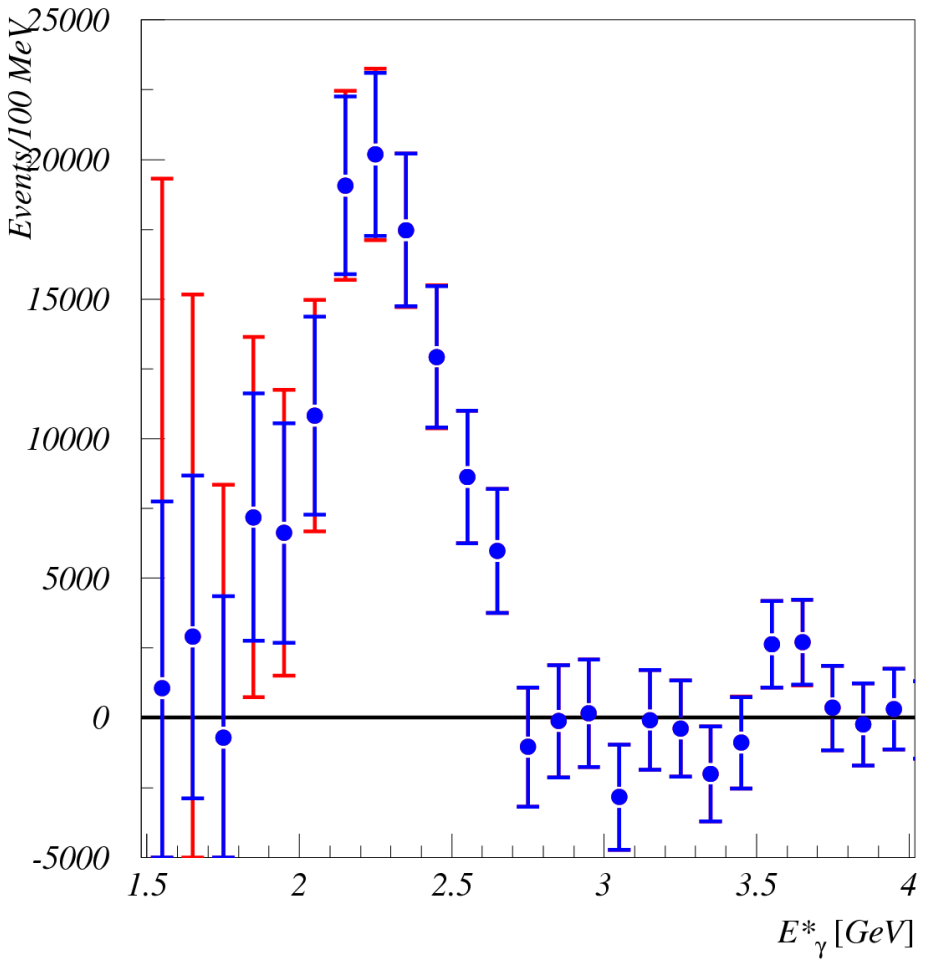


Moments: $(1.8 < E_\gamma < 2.8$ GeV)

$\langle E_\gamma \rangle = 2.289 \pm 0.026 \pm 0.034$ GeV

$\langle E_\gamma^2 \rangle - \langle E_\gamma^2 \rangle^2 = 0.0311 \pm 0.0073 \pm 0.0063$ GeV^2

Exclusive: the $K^*\gamma$ case

[hep-ex/0402042]

78 fb^{-1}

Selection

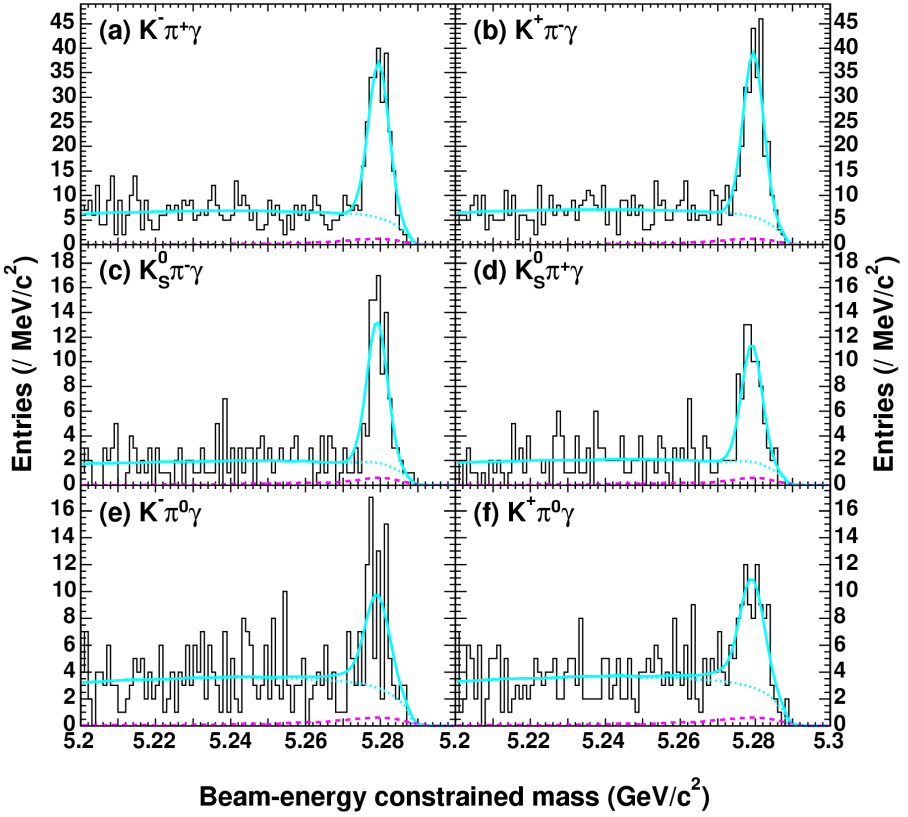
- $1.8 < E_\gamma < 3.4$ GeV (π^0/η vetos)
- K^* to $K^+\pi^-$, $K^0_S\pi^0$, $K^0_S\pi^+$, $K^+\pi^0$

$$|M_{K\pi} - M_{K^*}| < 75 \text{ MeV}/c^2$$

- $-200 < \Delta E < 100$ MeV

$$\Delta E = E^*_B - E^*_{\rm beam}$$

$$M_{\rm bc} = \sqrt{E^{*2}_{\rm beam} - |\vec{p}^{\,*}_B|^2}$$



Results

$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (4.01 \pm 0.21 \pm 0.17) \times 10^{-5}$$

$$\mathcal{B}(B^+ \to K^{*+}\gamma) = (4.25 \pm 0.31 \pm 0.24) \times 10^{-5}$$

$$\Delta_{0+} = +0.012 \pm 0.044 \pm 0.026$$

$$= \frac{\Gamma(B^0 \to K^{*0}\gamma) - \Gamma(B^+ \to K^{*+}\gamma)}{\Gamma(B^0 \to K^{*0}\gamma) + \Gamma(B^+ \to K^{*+}\gamma)}$$

$$A_{CP} = -0.015 \pm 0.044 \pm 0.012$$

$$= \frac{\Gamma(B \to K^*\gamma) - \Gamma(\overline{B} \to \overline{K}^*\gamma)}{\Gamma(B \to K^*\gamma) + \Gamma(\overline{B} \to \overline{K}^*\gamma)}$$

Motivation for $B \to \rho\pi$

- Extraction of ϕ_2 angle (similar to $\pi\pi$)
  - using all possible $\rho\pi$ charge assignements
  - using $\rho^{\pm}\pi^{\mp}$ and $\rho^0\pi^0$
- Tree–penguin interference: direct CP violation

Additionally:

- $\rho^{\pm}\pi^0$ is the dominant background for $B \to \pi^0\pi^0$

$B^+ \to \rho^+\pi^0$ strategy

Selection

- Select $\pi^0 \to \gamma\gamma$: $|m_{\gamma\gamma} - m_{\pi^0}| < 3\sigma_{\pi^0}$ and $p^*_{\pi^0} > 0.35$ GeV
- Form ρ^+ from π^+ and π^0 with $|m_{\pi^+\pi^0} - m_\rho| < 0.150$ GeV
- Select B^+ using $\Delta E = E^*_B - E^*_{\rm beam}$ and $M_{\rm bc} = \sqrt{E^{*2}_{\rm beam} - |\vec{p}^{\,*}_B|^2}$
- Suppress dominant continuum background:
  - event shape variables
  - include B-flavour tagging (cf. $\sin(2\phi_1)$ analyses)

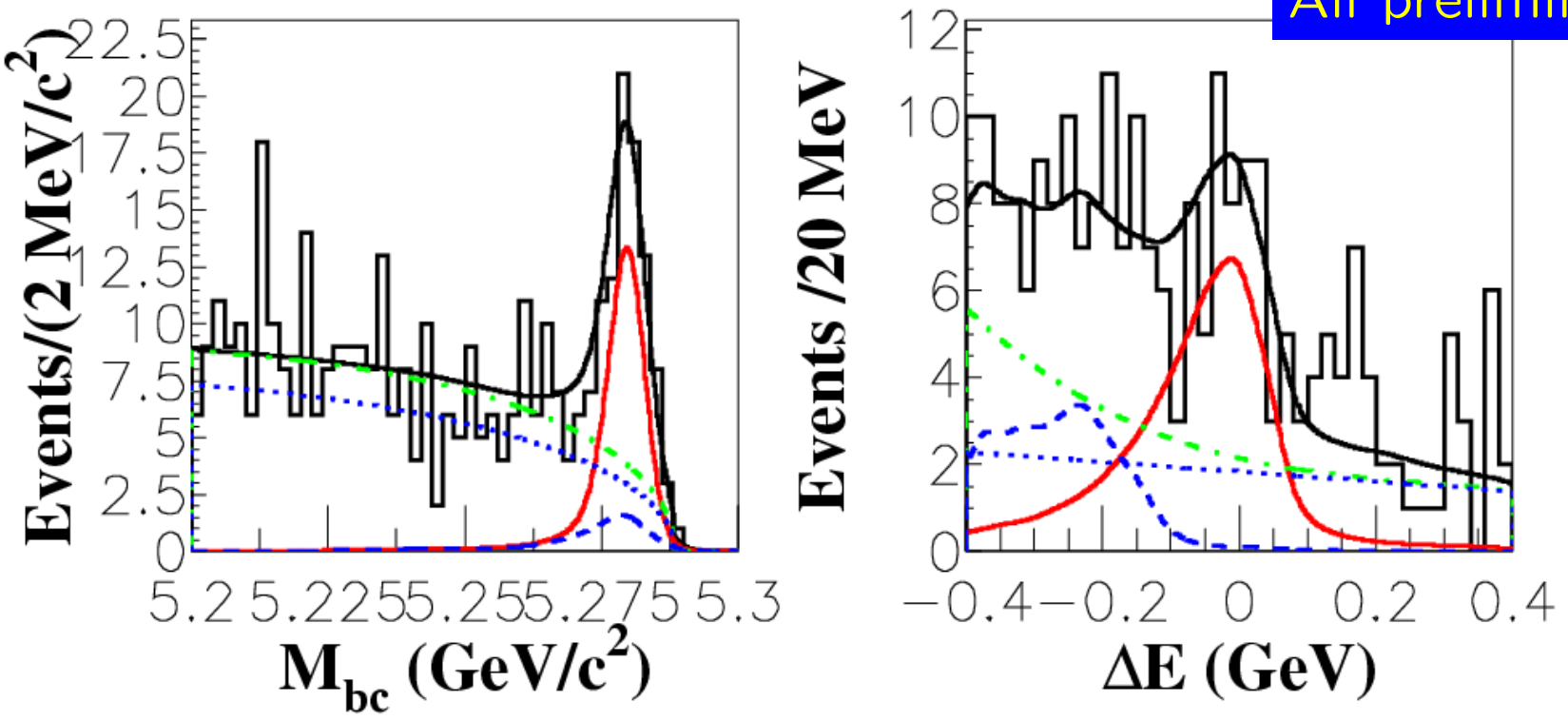
Signal yield extraction

Unbinned 2D maximum likelihood fit (ΔE, $M_{\rm bc}$)

- Signal, rare B background: from MC (calibrated)
- Continuum, charmed B background: shape from MC

$B^+ \to \rho^+\pi^0$ fit result

All preliminary!

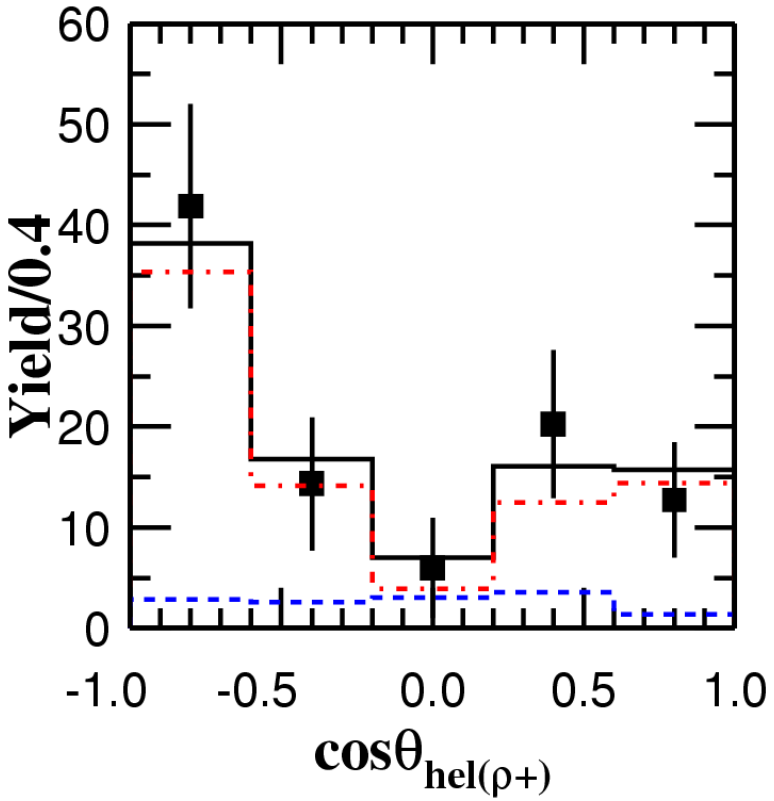


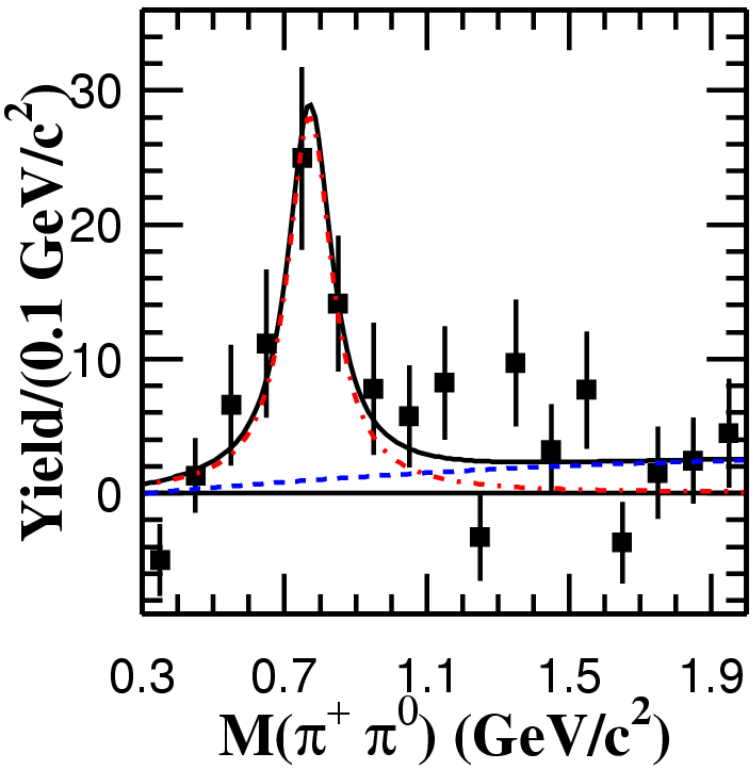
- Fit yield: 87 ± 15 $\Rightarrow$ significance: 8.1σ
- Branching fraction: $\mathcal{B}(B^\mp \to \rho^\pm\pi^0) = \left(13.8 \pm 2.4^{+1.5}_{-1.6}\right) \times 10^{-6}$
- Main systematic errors:

π^0 recon. efficiency, cont. suppression, non-resonant bkgd

$B^+ \to \rho^+\pi^0$ – helicity and asymmetry

All preliminary!





$A_{CP} = 0.06 \pm 0.19 \pm 0.04$

$= \frac{\Gamma(B^- \to \rho^-\pi^0) - \Gamma(B^+ \to \rho^+\pi^0)}{\Gamma(B^- \to \rho^-\pi^0) + \Gamma(B^+ \to \rho^+\pi^0)}$

Main systematic errors:

- fit bias (from control sample)
- fit procedure (vary parameters)

$B^0 \to \rho^0\pi^0$ strategy

Selection

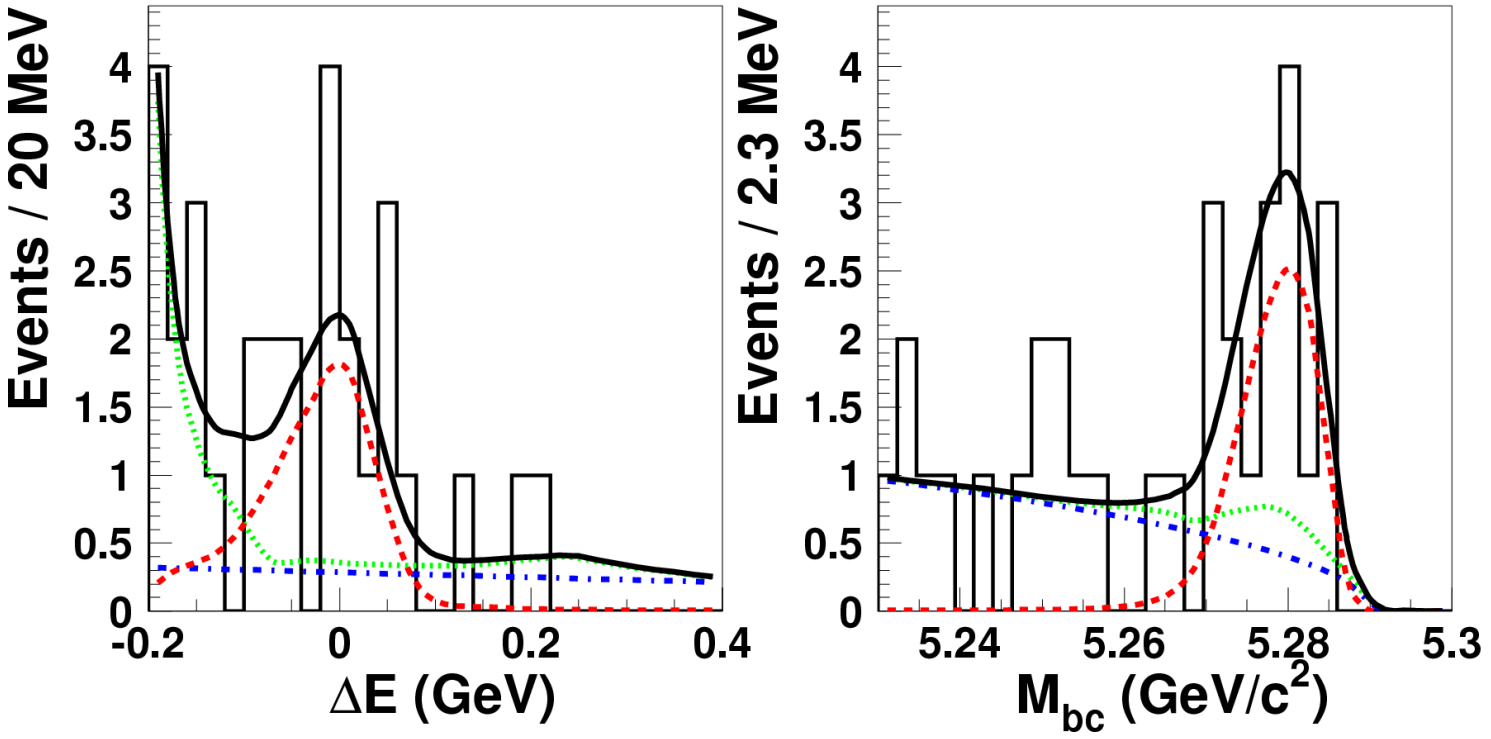
- Select neutral pion $|m_{\gamma\gamma} - m_{\pi^0}| < 3\sigma_{\pi^0}$
- Form $\rho^0\pi^0$ from $\pi^+\pi^-\pi^0$ with $0.5 < m_{\pi^+\pi^-} < 1.1$ GeV and $|\cos\theta^{\rho}_{\rm hel}| > 0.5$
- Additional $\rho^+\pi^-$ veto
- Select B^0 using ΔE and $M_{\rm bc}$
- Suppress dominant continuum background

Signal yield extraction

Unbinned 2D maximum likelihood fit (ΔE, $M_{\rm bc}$)

- Signal, rare B bkgd: from calibrated MC
- Continuum, charmed B bkgd: shapes from MC

$B^0 \to \rho^0\pi^0$ fit result



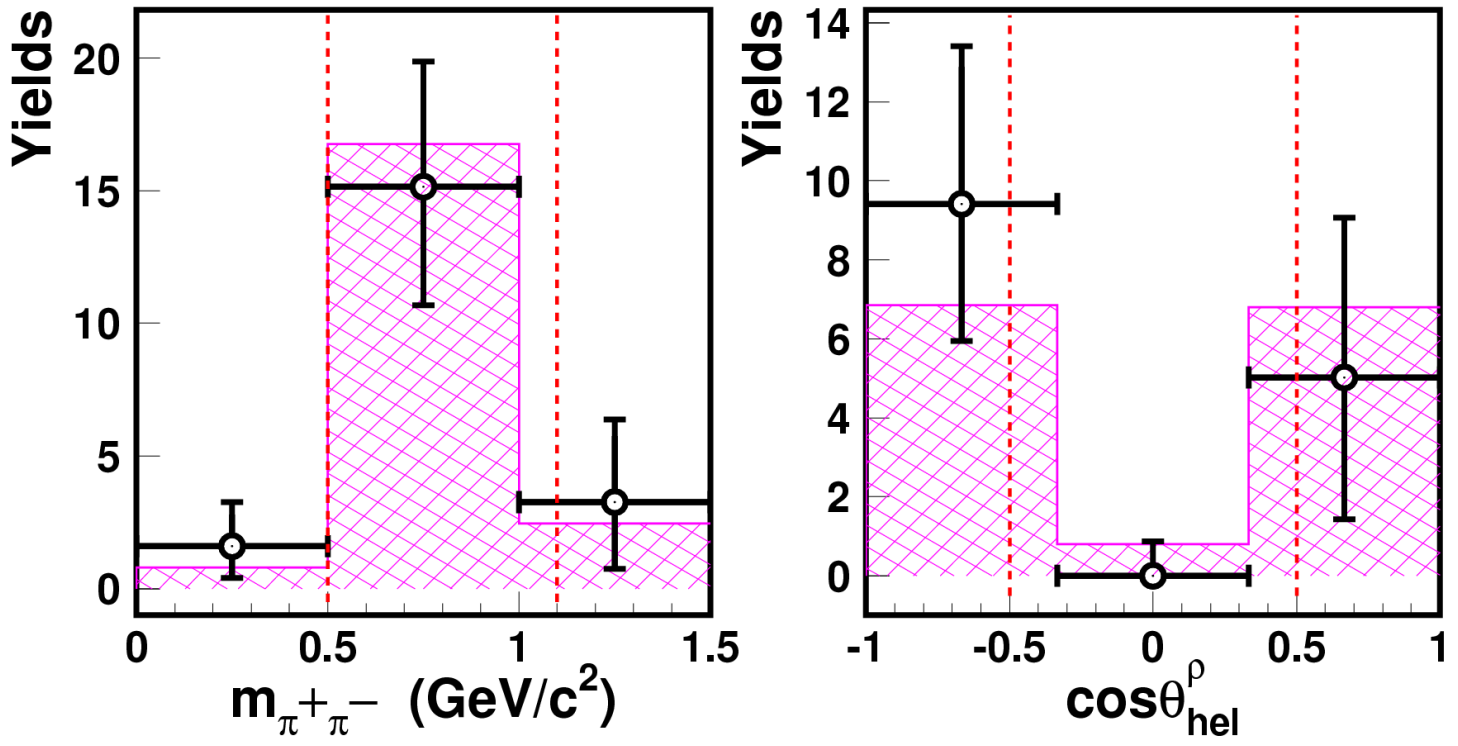
- Fit yield: 15.1 ± 4.8
- Significance: 3.5σ (w/fit syst.)
- Branching fraction:

$$\mathcal{B} = (5.1 \pm 1.6 \pm 0.8) \times 10^{-6}$$

Prediction: $\leq \mathcal{O}(10^{-6})$

$B^0 \to \rho^0\pi^0$ checks

Helicity and $\pi\pi$ invariant mass



- Compatible with the ρ mass
- Compatible with $P \to VP$

Summary

Radiative rare decays

- Brand new $b \to s\gamma$ spectrum measurement with $E_\gamma > 1.8$ GeV

$\Rightarrow$ Current best! Agrees with SM

- Exclusive $K^*\gamma$: measurements of A_{CP} and Δ_{0+} (78 fb^{-1})

$\Rightarrow$ consistent with SM

Charmless hadronic decays

- Brand new $B^\pm \to \rho^\pm\pi^0$ branching fraction

- Evidence of $B^0 \to \rho^0\pi^0$ @3.5σ

$\Rightarrow$ greater than expected

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Stay tuned: more data and results to come!

Main systematic errors on $b \to s\gamma$

Raw branching fraction

Total #(B events)	$^{+0.14}_{-0.16}$
γ detection eff.	± 0.073
MC reweighting	± 0.21
Fitting functions	± 0.05
Signal MC description	± 0.09
"Other real γs"	± 0.05

Raw branching fraction

Additional theoretical uncertainty:

- $R_{d/s} = (3.8 \pm 0.6)\%$
- $R_{1.8}$ from 3 theo. calculations

Moments	$\langle E_\gamma \rangle$	ΔE_γ^2
MC reweighting	± 0.02	± 0.005
Energy resolution	± 0.02	± 0.002
Binning		± 0.0008
Fitting functions	± 0.001	± 0.0008
Signal MC description	± 0.004	± 0.0006
"Other real γs"	± 0.009	± 0.0017