Radiative Penguin decays at BaBar

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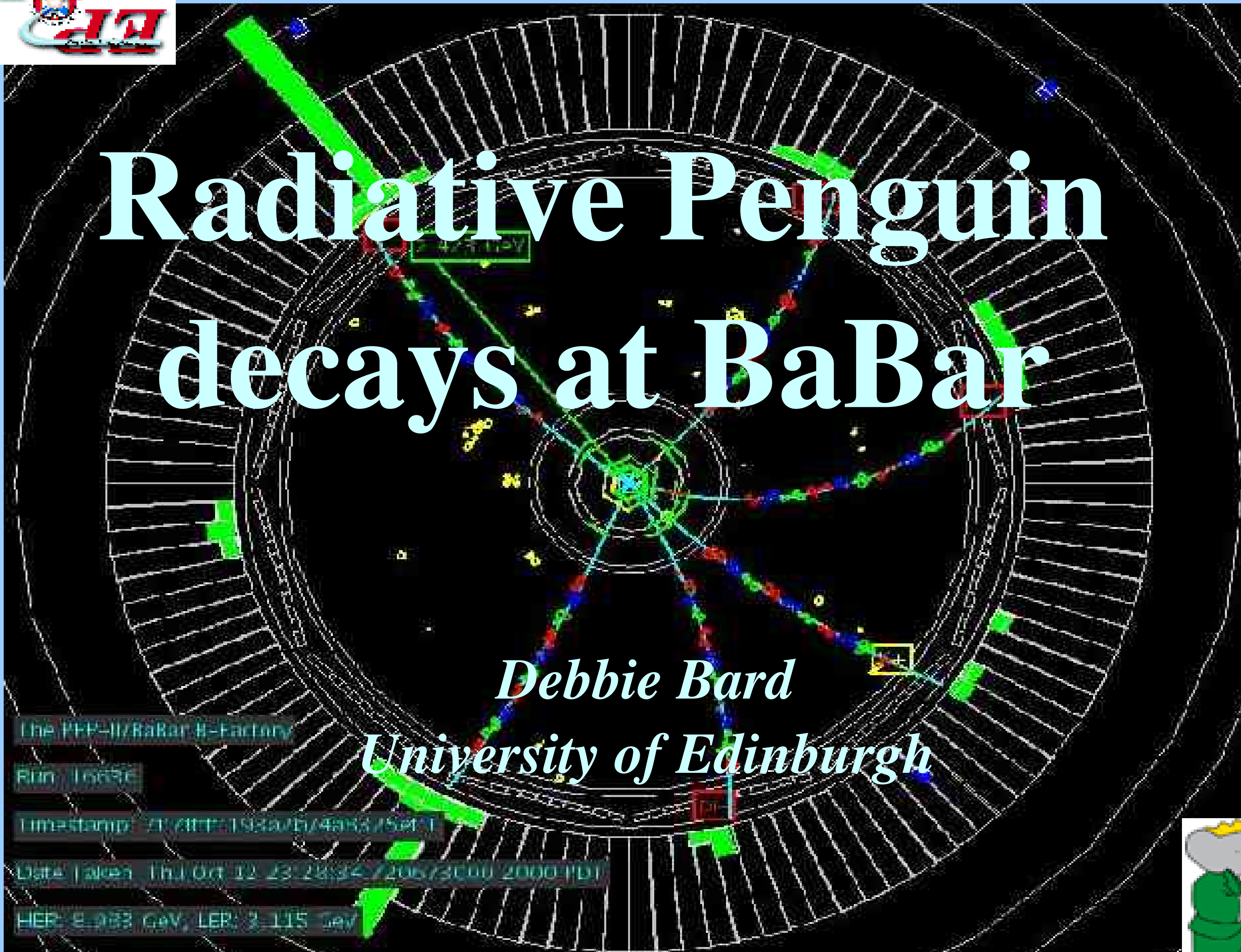
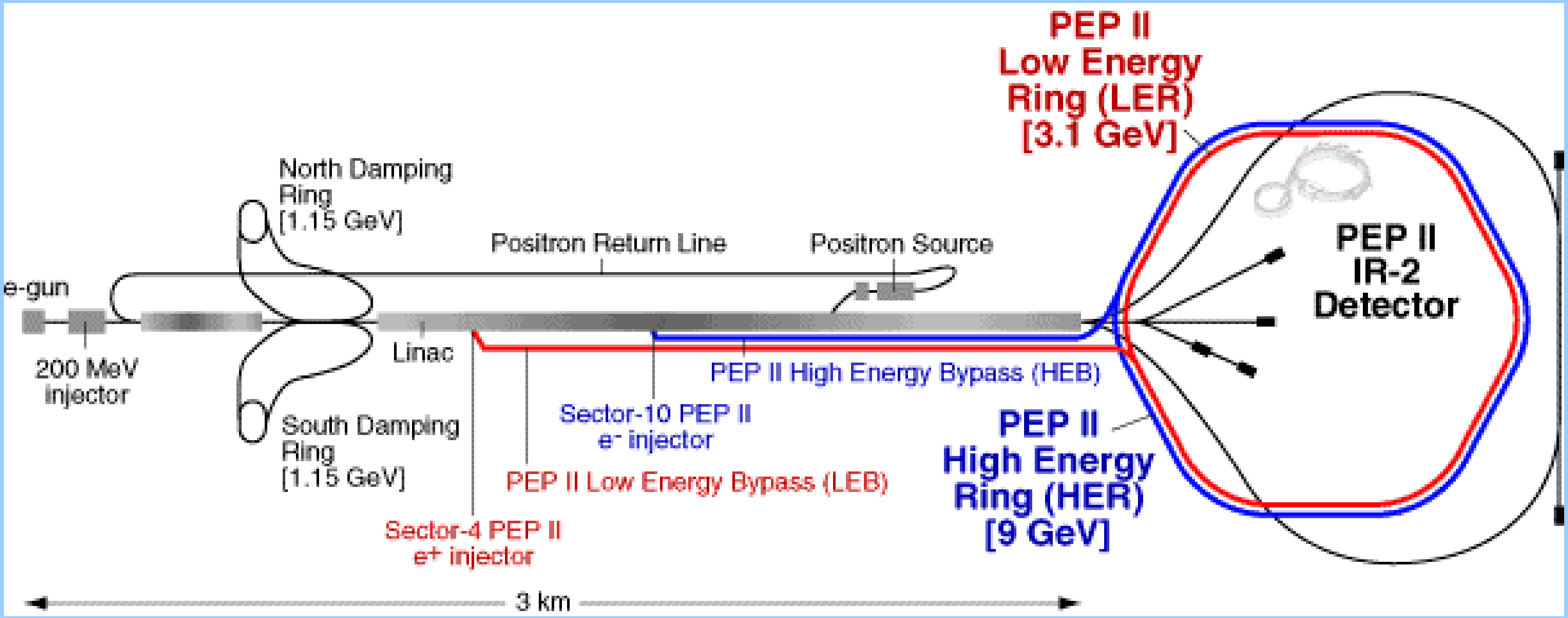
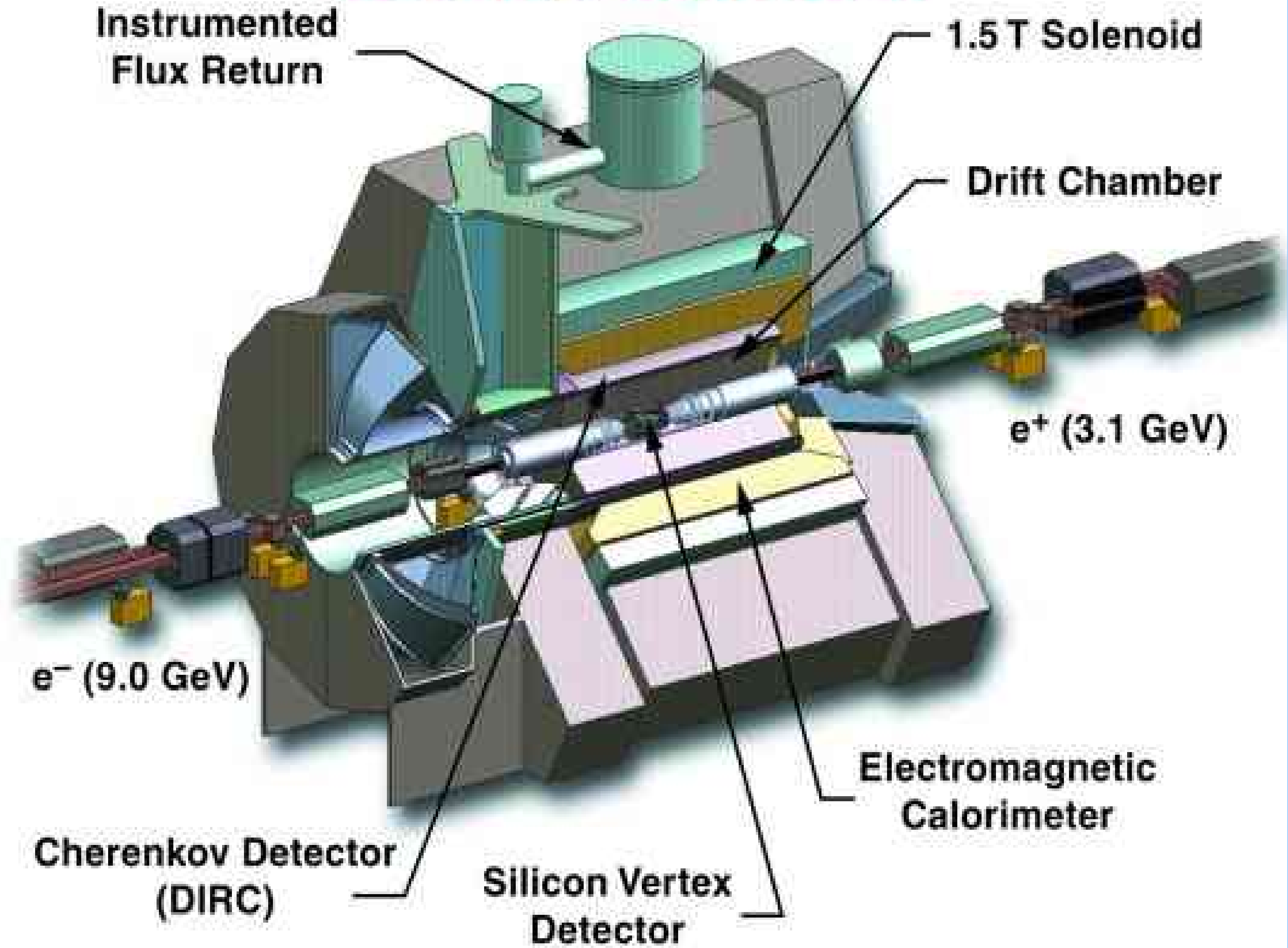


PEP-II



- Asymmetric B-factory: 9GeV e^-, 3.1GeV e^+
- Record instantaneous luminosity just over $1 \times 10^{34} cm^{-2}s^{-2}$
- Total recorded BaBar luminosity runs 1-4: ~240 fb^{-1}

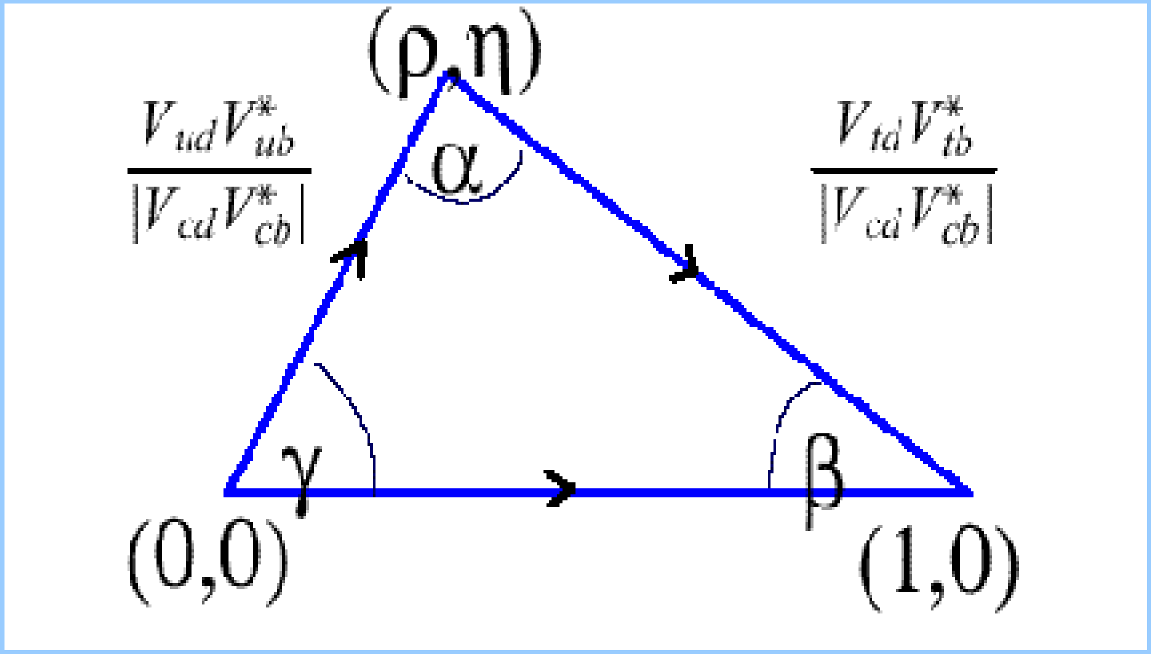
BABAR Detector



CKM parameters

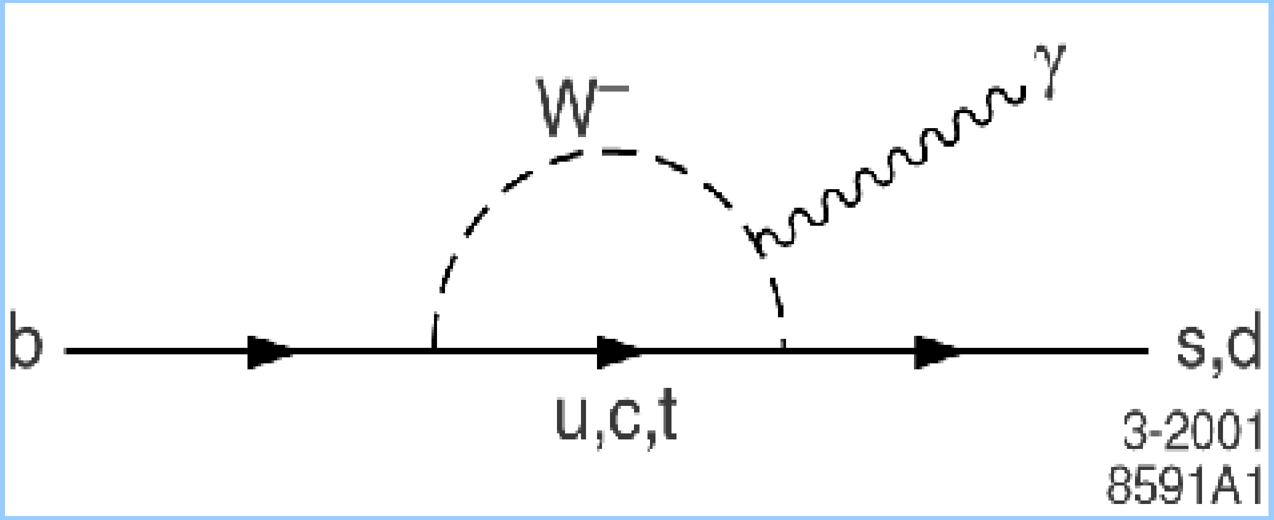
$$V_{CKM} \equiv \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \qquad V_{\mathrm{Wolfenstein}} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

- VudVub* + VcdVcb* + VtdVtb* = 0

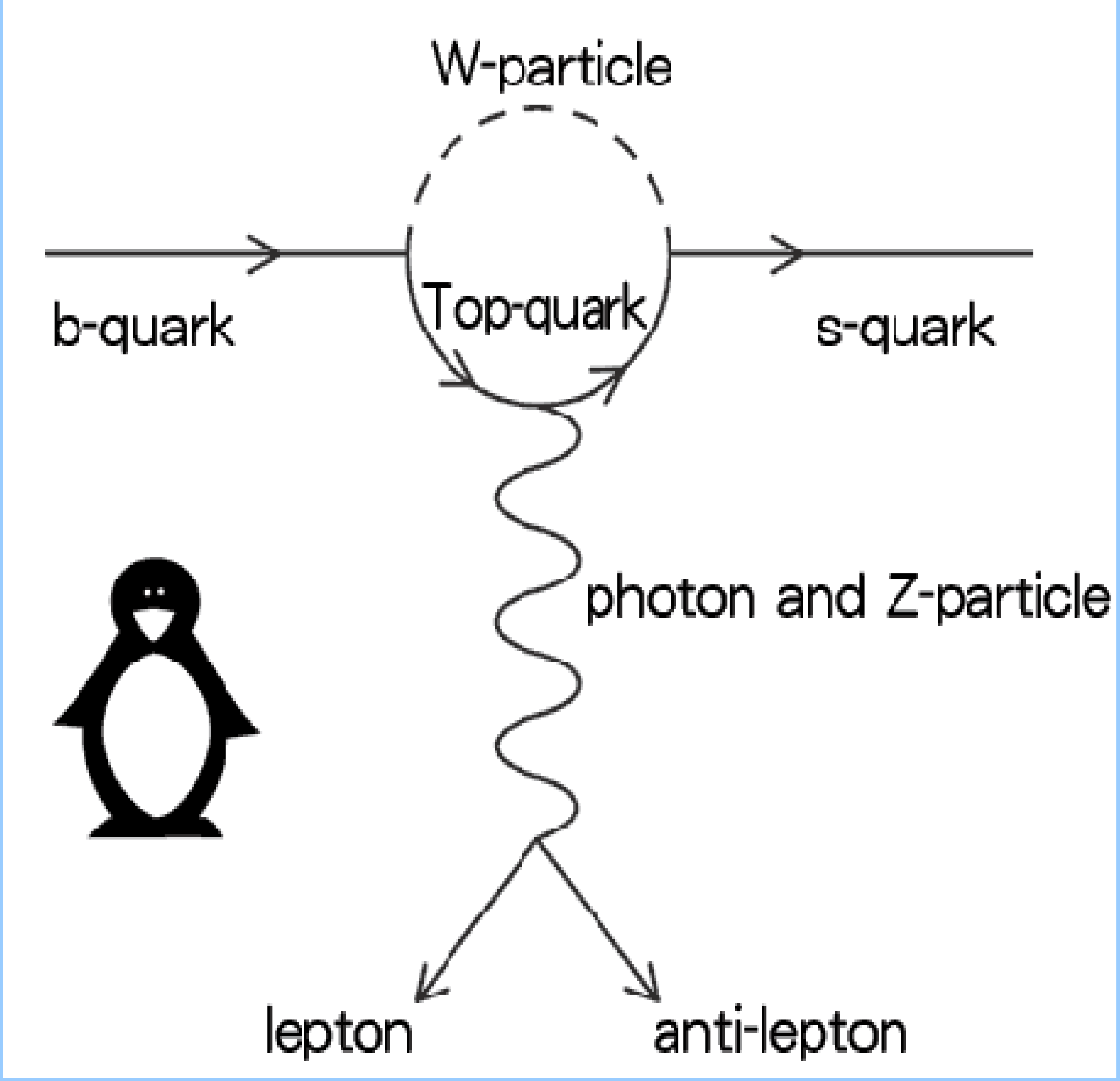


Radiative Penguins

- Flavour Changing Neutral Current (FCNC) transitions
- Forbidden at tree level in SM
- Permitted at loop level
- Photon emitted in loop ∴ radiative

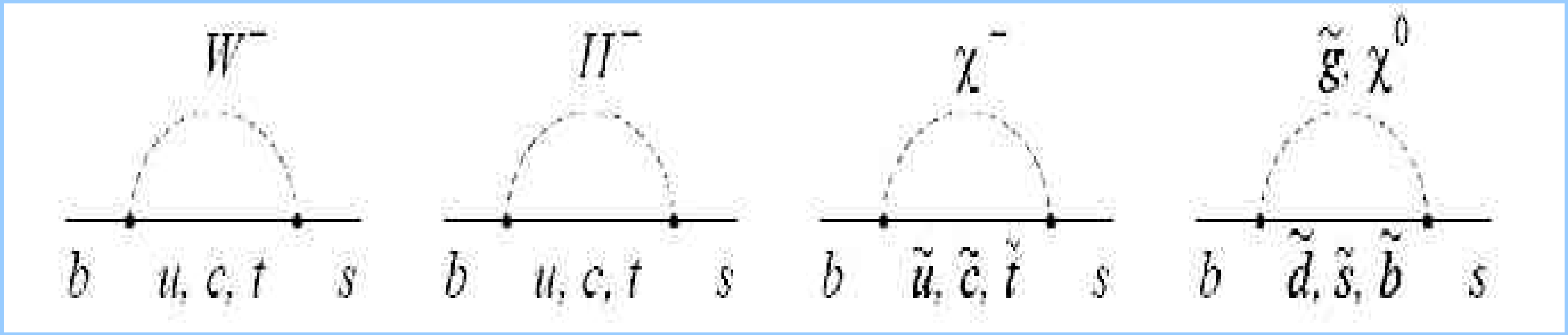


This is why it's a 'penguin' diagram



Physics Interest - $b \to s\gamma$

- Non-SM particles may enter the virtual loop and alter expected Branching Fraction (BF)



- Good agreement between SM theory/experiment in $b \to s\gamma$ constrains new physics at electro-weak scale

Physics Interest - b→dγ

- Very rare decay
- Conflicting experimental results for BF
- SM interest – ratio of V_{td}/V_{ts} not well known

$$\frac{\overline{\mathcal{B}}[B \to (\rho/\omega)\gamma]}{\mathcal{B}(B \to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_\rho^2/M_B^2}{1 - m_{K^*}^2/M_B^2}\right)^3 \zeta^2[1 + \Delta R]$$

  - ζ – SU(3) breaking of form factors in ratio
  - ΔR - non-penguin contribution to loop

Physics Interest - Acp

- Direct probe for new physics

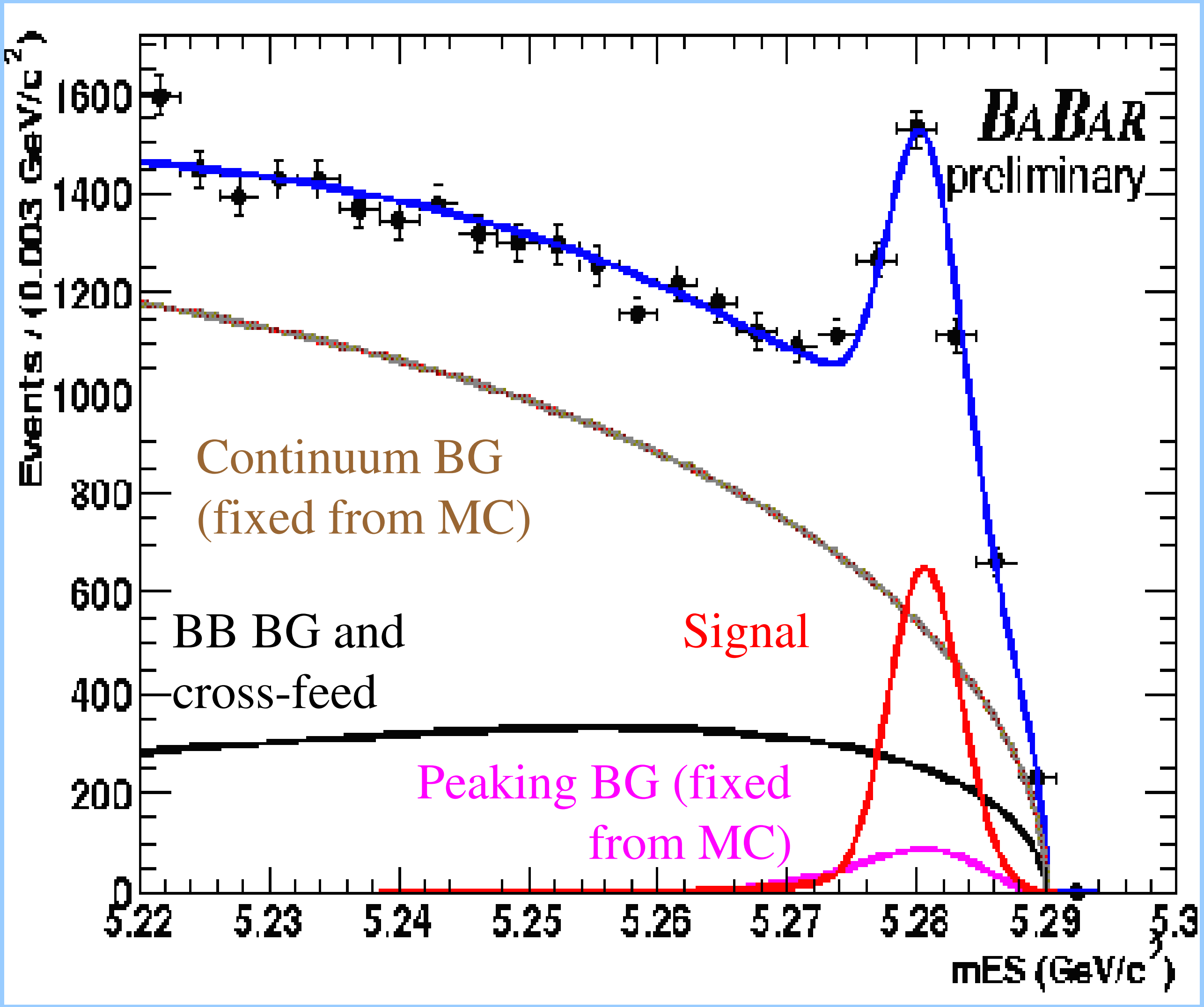
$$Acp = \frac{\Gamma(B) - \Gamma(\text{anti-}B)}{\Gamma(B) + \Gamma(\text{anti-}B)}$$

- SM predicts:
  - $Acp(b \rightarrow s\gamma) \sim 0.006$
  - $Acp(b \rightarrow d\gamma) \sim -0.160$
  - $Acp(b \rightarrow (s+d)\gamma) = 0$
- Non-SM loop contributions could alter Acp~10%

What's a Semi-Inclusive analysis?

- Exclusive analysis:
  - exclusive hadronic modes eg. $B \rightarrow K^* \gamma$
  - cleaner BF measurement both experimentally and theoretically
- Inclusive analysis
  - measure photon spectrum, inclusive BF
- Semi-Inclusive analysis
  - sum of exclusive hadronic modes
  - can measure BF of individual modes *and* inclusive BF
  - can measure photon spectrum

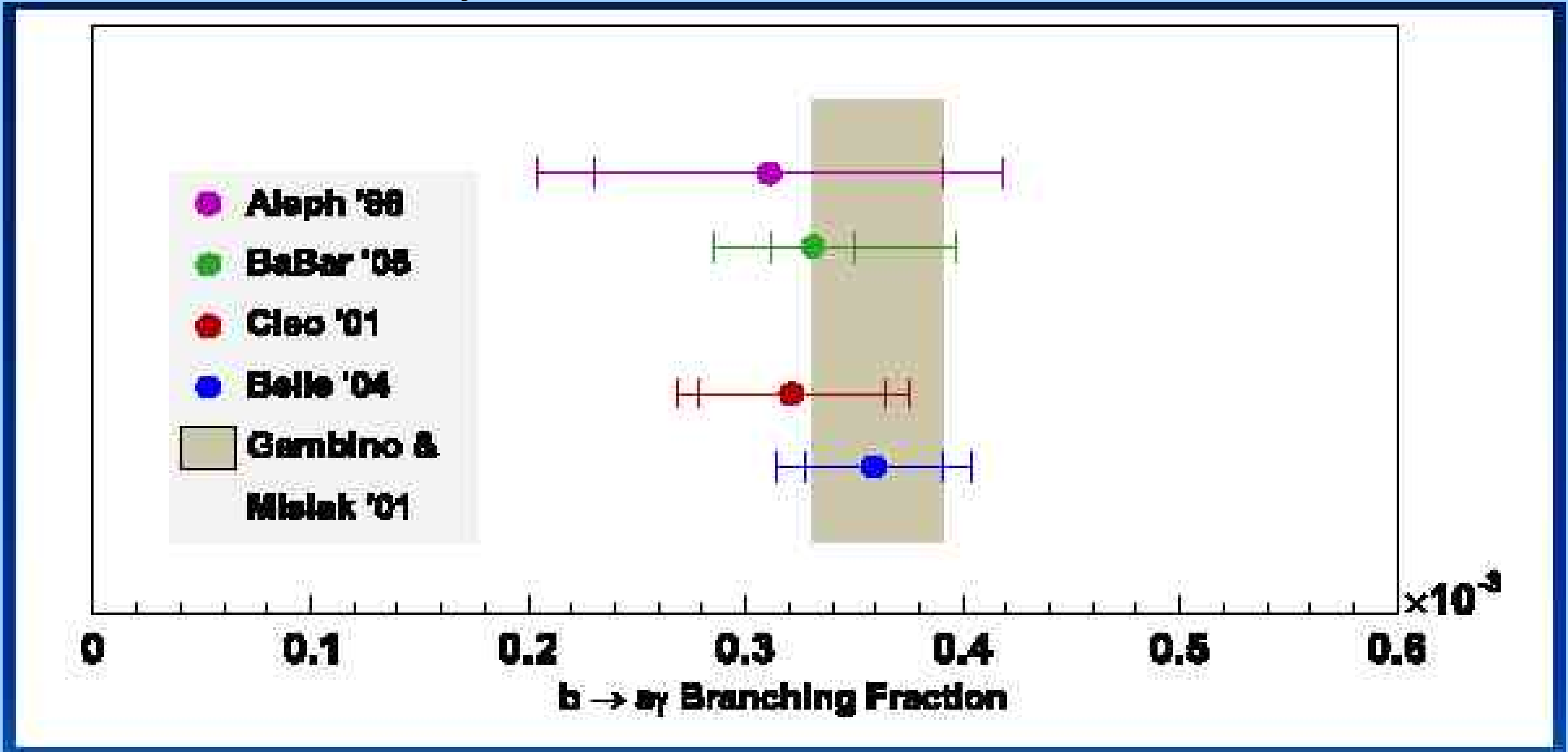
$b \rightarrow s\gamma$ Semi-inclusive - *BF*



- Sum of 38 exclusive modes
- Hadronic mass range M_{Xs} 0.6-2.8GeV
- 89 million BBbar pairs

- Single bin fit to all events

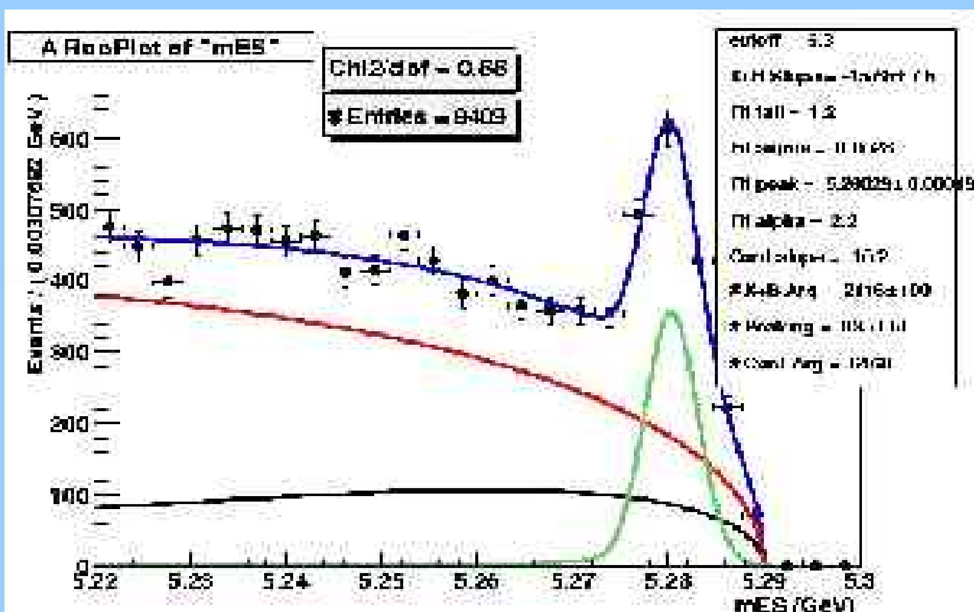
$b \rightarrow s\gamma$ Semi-inclusive - *BF*

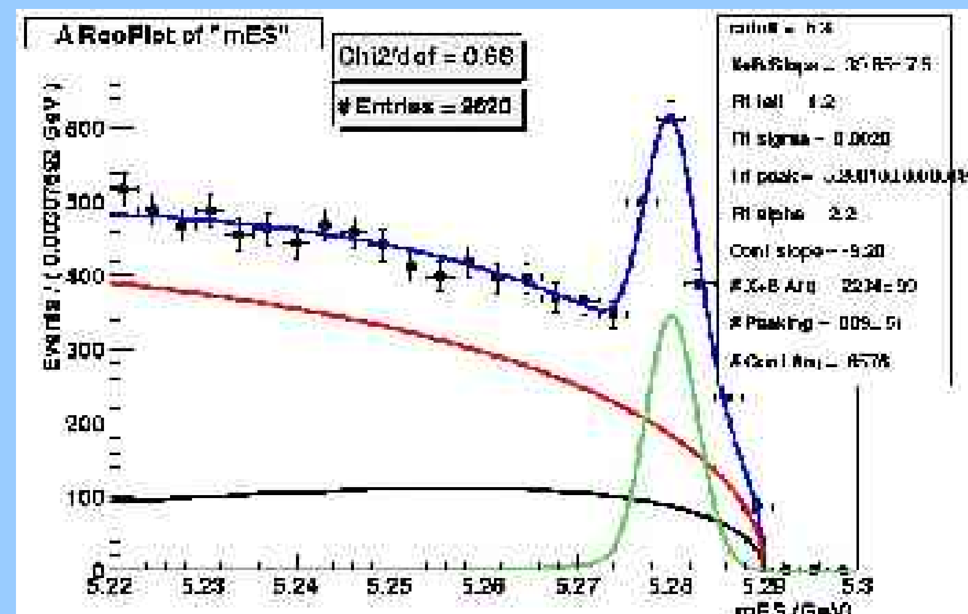


- **BF = (3.31±0.19 +0.64 -0.42)x10^{-4}**
- Consistent with Standard Model prediction of BF($b \rightarrow s\gamma$) = 3.60±0.30 x10^{-4} (Gambino & Misiak '01)
- World average: 3.47±0.36 (HFAG)

b→sγ Semi-inclusive - *Acp*

- Used 12 exclusive final states
- Hadronic mass range M_{Xs} 0.6-2.3GeV
  - B mesons
  - anti-B mesons



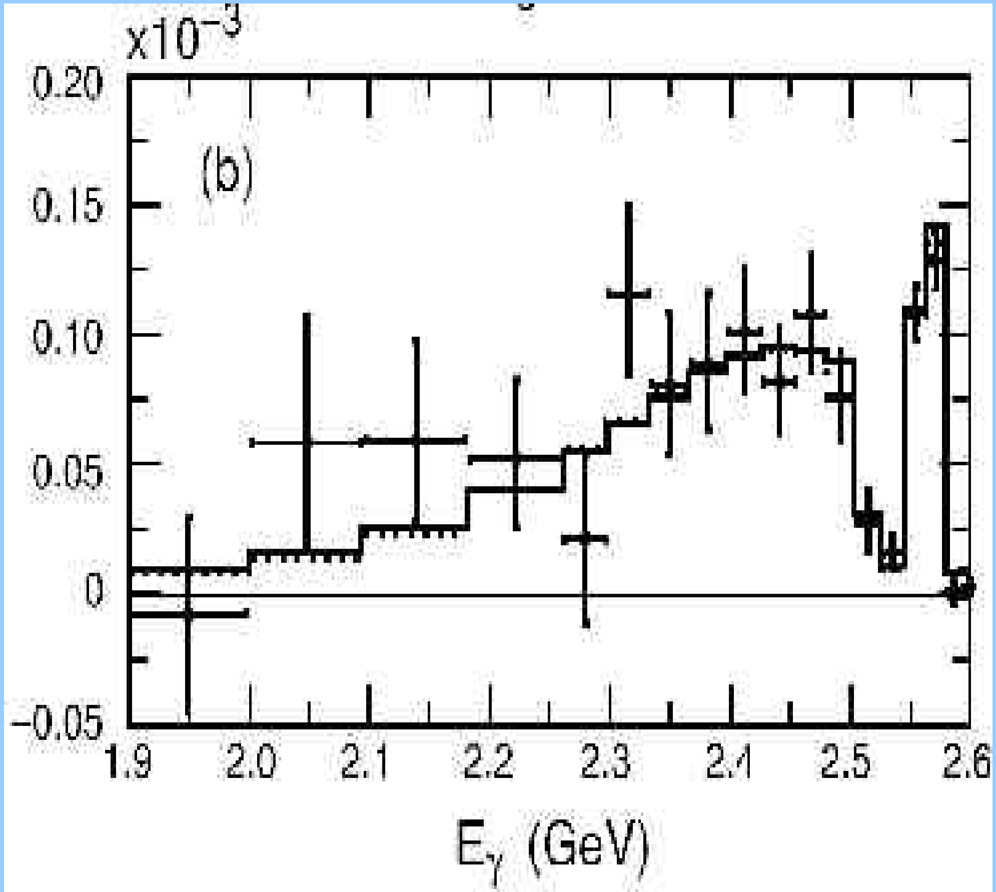


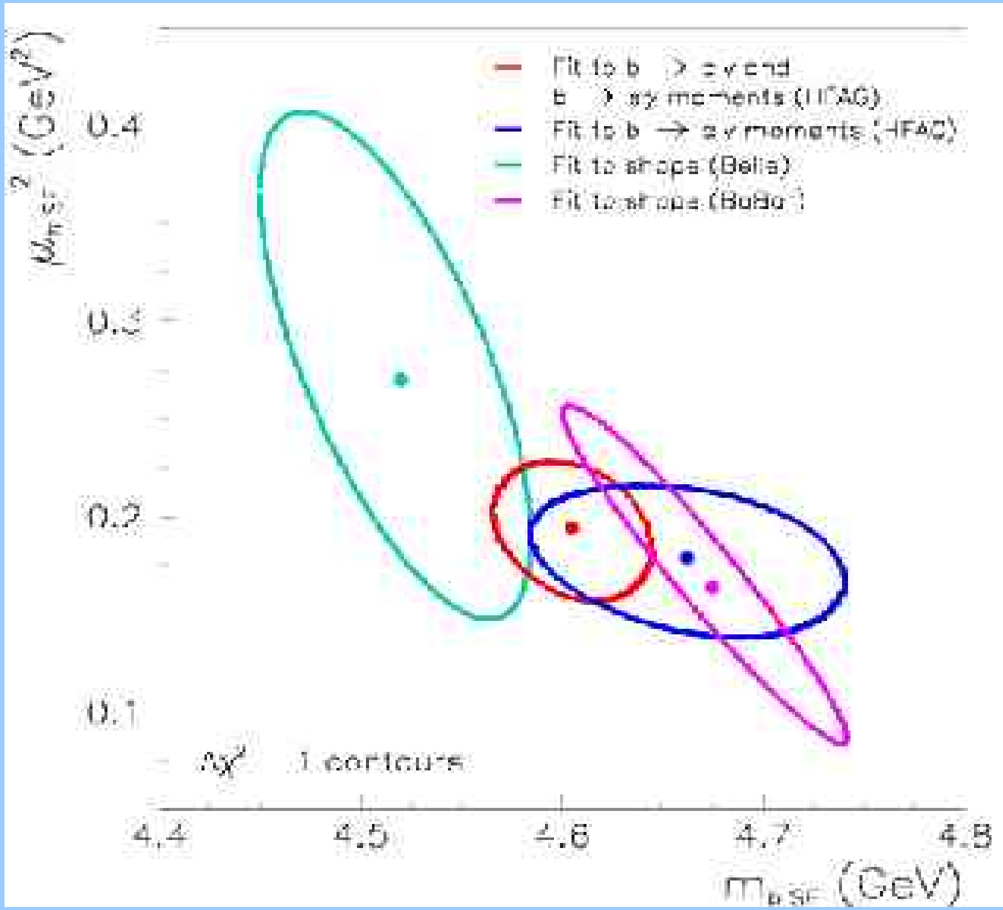
- **Acp = 0.025 ±0.050 ±0.015**
- Recent Belle result: Acp = 0.004 ±0.051 ±0.038
- Consistent with standard model prediction of 1%

$b \rightarrow s\gamma$ – *Photon Spectrum*

- HQET expands around limit of static b quark
- motion of b is universal – information from $b \rightarrow s\gamma$ can be used for extraction of Vub/Vcb in $B \rightarrow xl\nu$
- Spectral shape independent of new physics, expressed in terms of HQET parameters, dependent on scheme

b→sγ – *Photon Spectrum II*





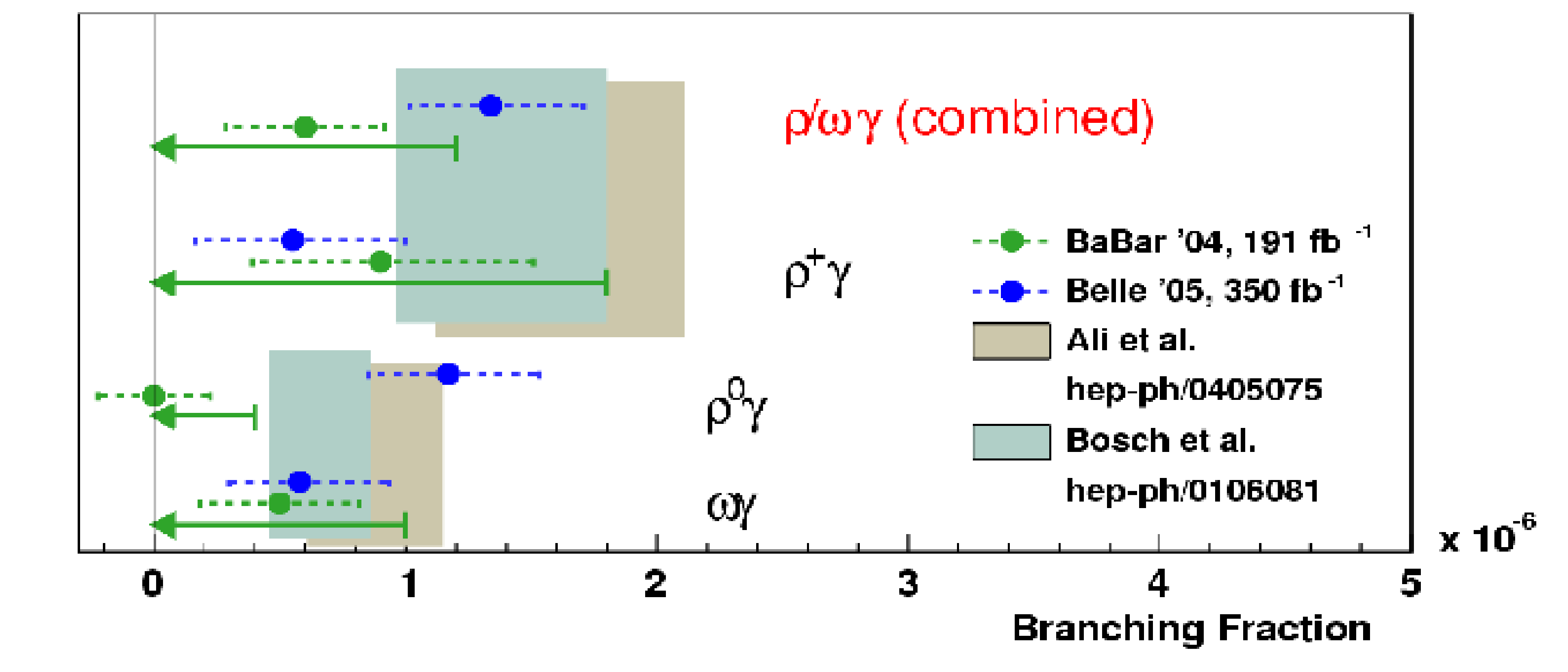
- Fit to photon spectrum
- Fit to HQET parameters in Shape Function scheme

Exclusive $B \to (\rho/\omega)\gamma$

- Simplest and most common $b \to d\gamma$ exclusive decays
- Reconstruct
  - $B \to \rho\gamma$ with $\rho^\circ \to \pi^+\pi^-$ and $\rho^+ \to \pi^+\pi^\circ$,
  - $B \to \omega\gamma$ with $\omega \to \pi^+\pi^-\pi^\circ$
- Theory predicts $BF[B \to (\rho/\omega)\gamma] = (0.9\text{–}1.8)\times10^{-6}$
- Use full run 1-4 dataset: 211 million $\Upsilon(4S) \to B\bar{B}$ pairs

Exclusive B→(ρ/ω)γ

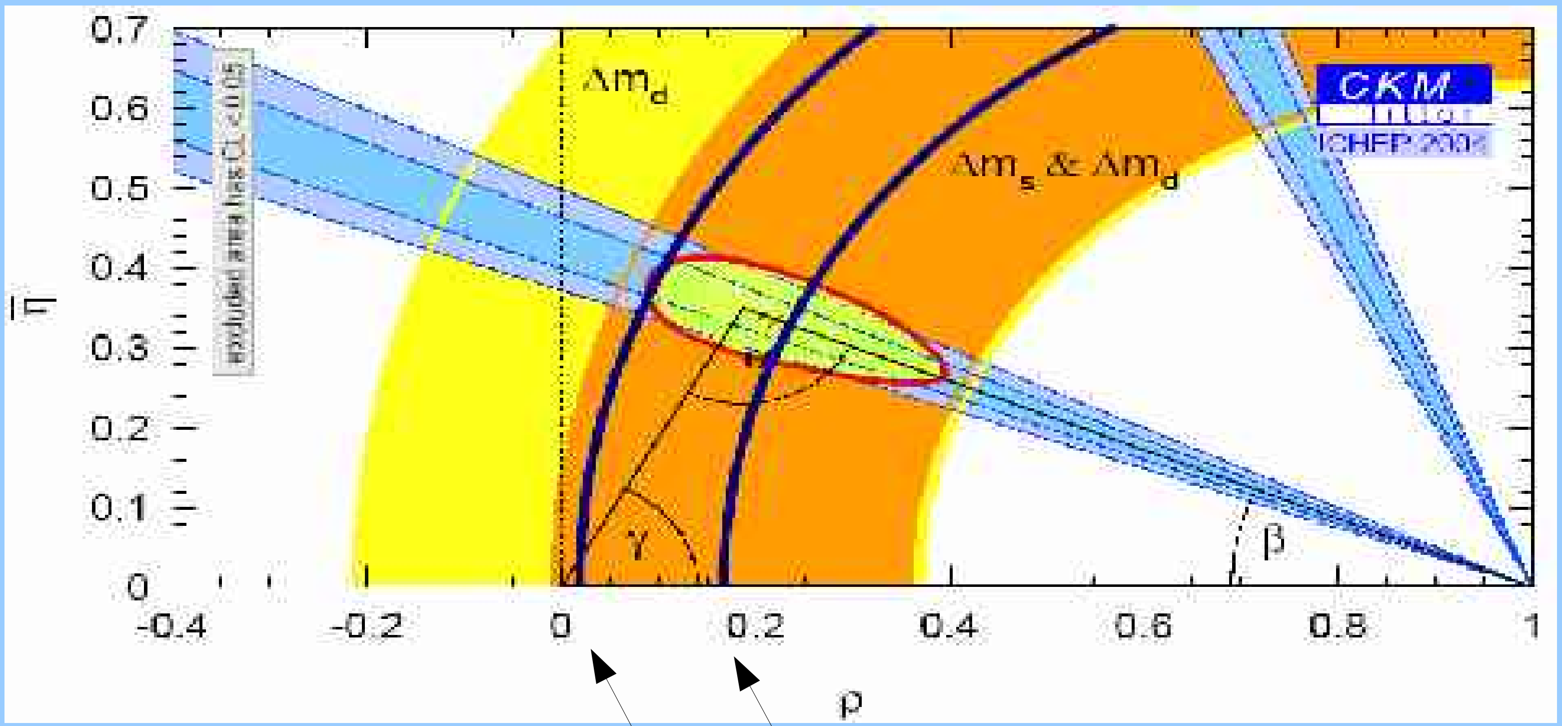
- BaBar results: no evidence for decays found



- Improved upper limits (at 90% CL)
  - $B^+ \to \rho^+\gamma$ BF($<1.8\text{x}10^{-6}$)
  - $B^0 \to \rho^0\gamma$ BF($<0.4\text{x}10^{-6}$)
  - $B^0 \to \omega\gamma$ BF($<1.0\text{x}10^{-6}$)
  - **B→(ρ/ω)γ BF($<1.2\text{x}10^{-6}$)**

CKM constraints from B→ρ/ωγ

- BF ratio limit: $\frac{BF(B\rightarrow\rho/\omega\gamma)}{BF(B\rightarrow K^{*}\gamma)} < 0.029$ (90% CL)
- Neglecting theoretical errors $\frac{|V_{td}|}{|V_{ts}|} < 0.19$



(ζ^2,ΔR) = (0.75,0.00) – with theory error

(ζ^2,ΔR) = (0.85,0.10) - no theory error

Semi-inclusive $b \rightarrow d\gamma$

- $B^0 \rightarrow \pi^+(K^+)\pi^- \gamma$
- $B^+ \rightarrow \pi^+(K^+)\pi^0 \gamma$
- $B^+ \rightarrow \pi^+(K^+)\pi^-\pi^+ \gamma$
- $B^0 \rightarrow \pi^+(K^+)\pi^-\pi^0 \gamma$
- $B^0 \rightarrow \pi^+(K^+)\pi^-\pi^+\pi^- \gamma$
- $B^+ \rightarrow \pi^+(K^+)\pi^-\pi^+\pi^0 \gamma$
- $B^+ \rightarrow \pi^+(K^+)\eta \gamma$

- Sum of 7 Exclusive modes
- Also reconstruct 7 equivalent $b \rightarrow s\gamma$ modes
- Measure ratio of branching fractions

$$\frac{BF(b \rightarrow d\gamma)}{BF(b \rightarrow s\gamma)} \quad \text{gives} \quad \frac{|V_{td}|}{|V_{ts}|}$$

  - Theoretically clean
  - Experimentally clean (systematic errors cancel)

Semi-inclusive $b \rightarrow d\gamma$ - background suppression

- Continuum
  - Dominant background
  - From ISR, π^0/η decays
  - Use event-shape variables in neural net
  - Tagging variables
- Peaking backgrounds
  - Cross-feed
    - From mis-identified $b \rightarrow s\gamma$ decays
    - Particle ID kaon/pion
  - Generic B decays
    - π^0/η vetos

Expected Yields

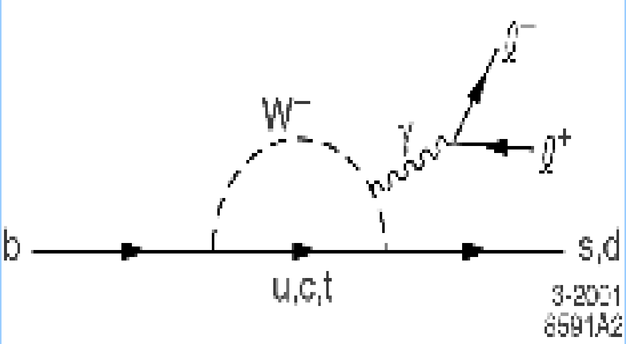
- All cuts incl. best cand selection
- Scaled to 211 million BB pairs
- Assume signal BF = $1e^{-5}$
- Signal efficiency over whole hadronic mass region M_{Xd}=1.0-1.8 GeV
- Signal box: |ΔE|<0.1, 5.274<mES<5.286
  - $\Delta E = E^*_B - E^*_{beam}$
  - $mES^2 = E^{*2}_{beam} - p^{*2}_B$

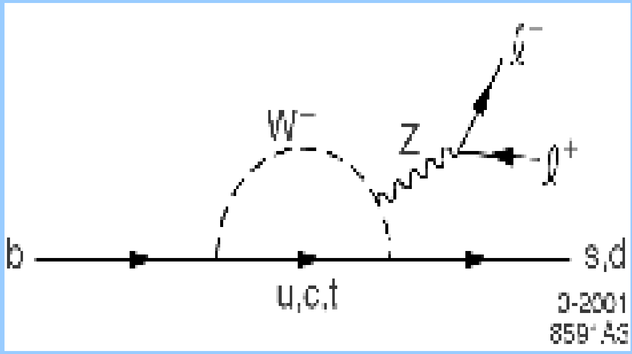
	Scaled n events Expected	Scaled in Signal box
Signal	31	24
Uds	15067	488
Ccbar	1480	50
Generic B	4220	38
Xs gamma	19	11

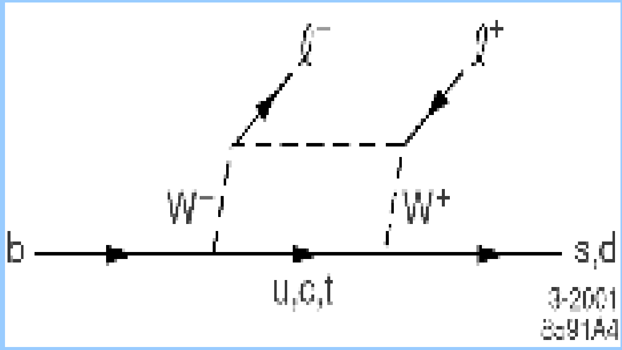
- simple cut and count significance: ~1σ
- including ρ region: ~2σ
- 2D LH fit should take us to > 3σ significance

More interesting hints of New Physics...

$b \to s l^+ l^-$



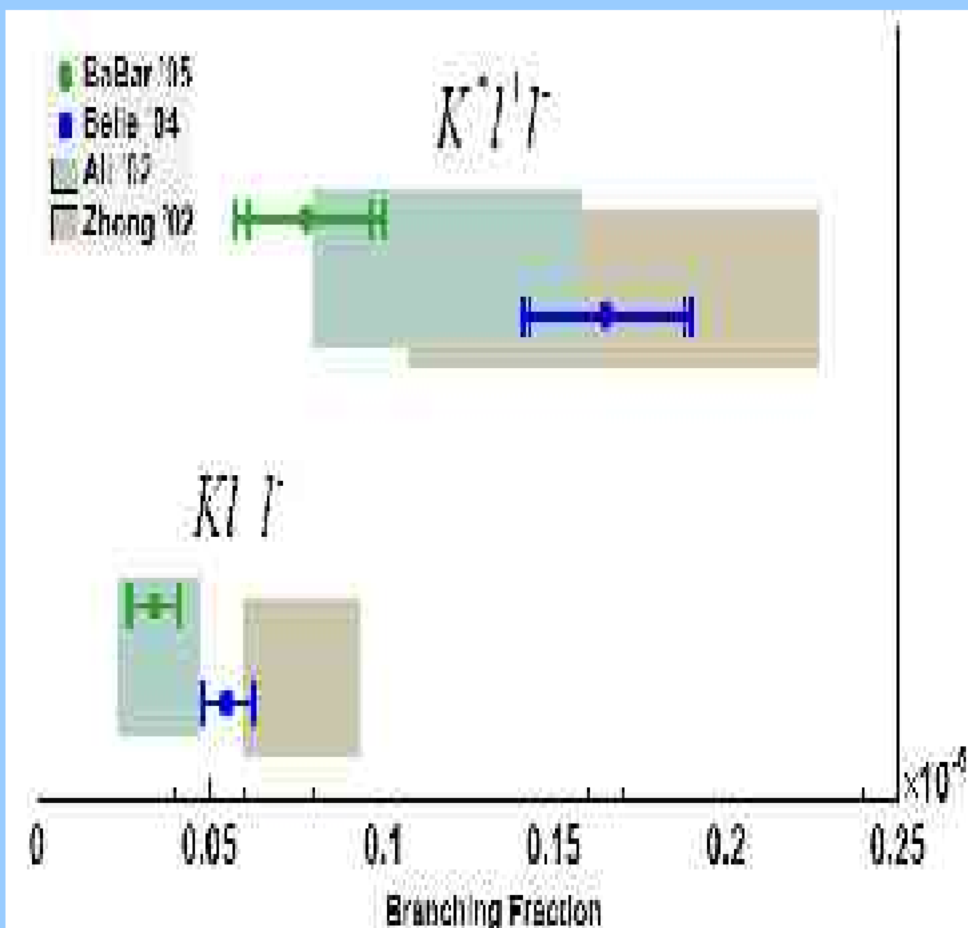




- SM Predictions for many observables
  - BF ~ 10^{-6}, negligible direct Acp
  - Ratio of e/μ sensitive to h^0 contribution in loop
  - q^2 distribution and Afb sensitive to relative contribution of γ, Z penguins and box diagram
    - q^2(Afb=0) well predicted in SM
    - sign of Afb sensitive to relative signs of Wilson coefficients C9/C10 and C7

Interesting Experimental Results

- BF Discrepancy!



- Belle finds in 350 fb^{-1} *(prelim., hep-ex/0508009)*

$$A_{FB}^{bkg-sub}(B \to K^- \ell^+ \ell^-) = 0.09 \pm 0.14(\text{stat.})$$

  - SM: Afb(Kll)=0

$$A_{FB}^{bkg-sub}(B \to K^* \ell^+ \ell^-) = 0.56 \pm 0.13(\text{stat.})$$

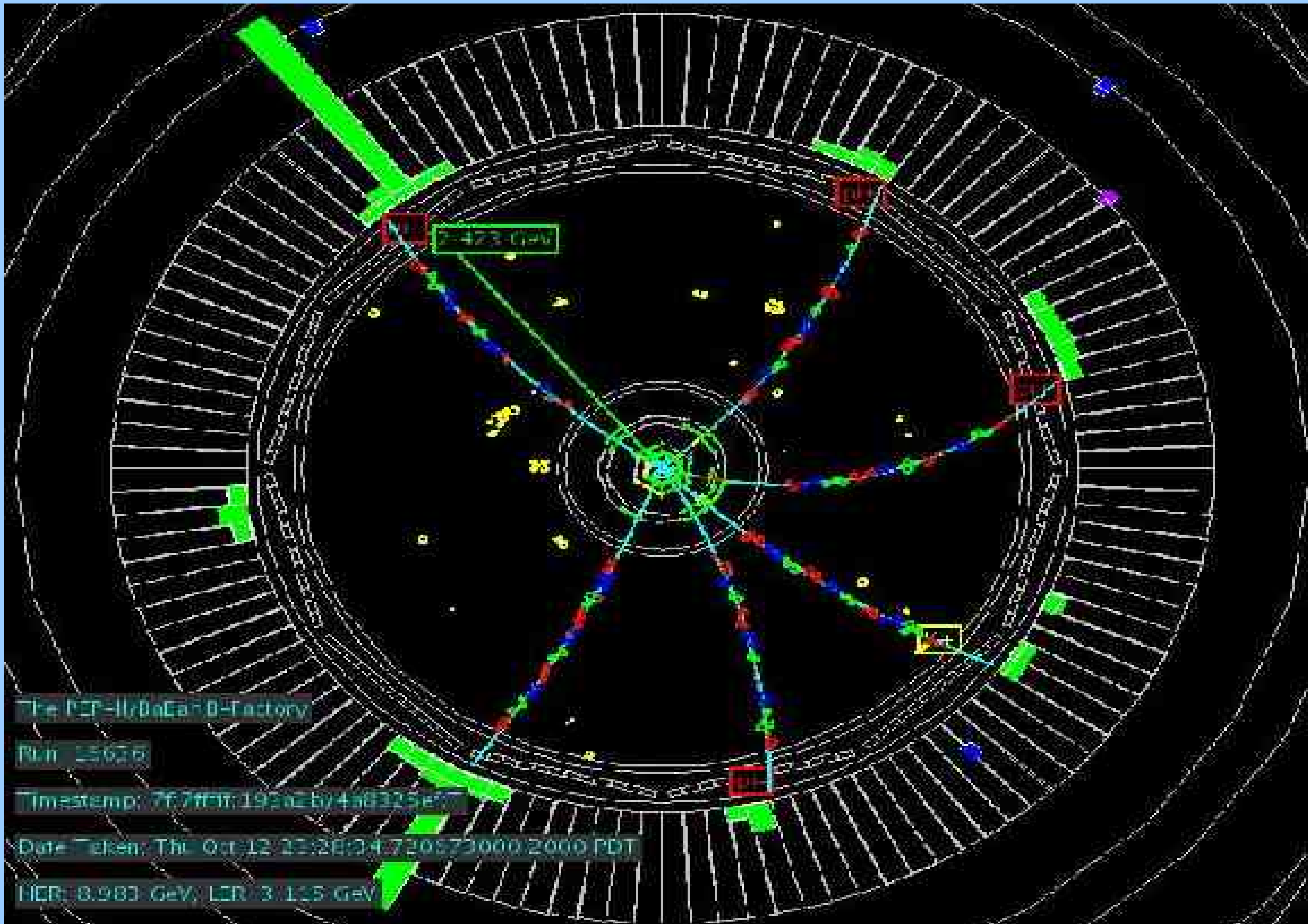
  - SM: integrated Afb(K*ll) =0.16-0.20
    - excludes charmonium resonances

Conclusion

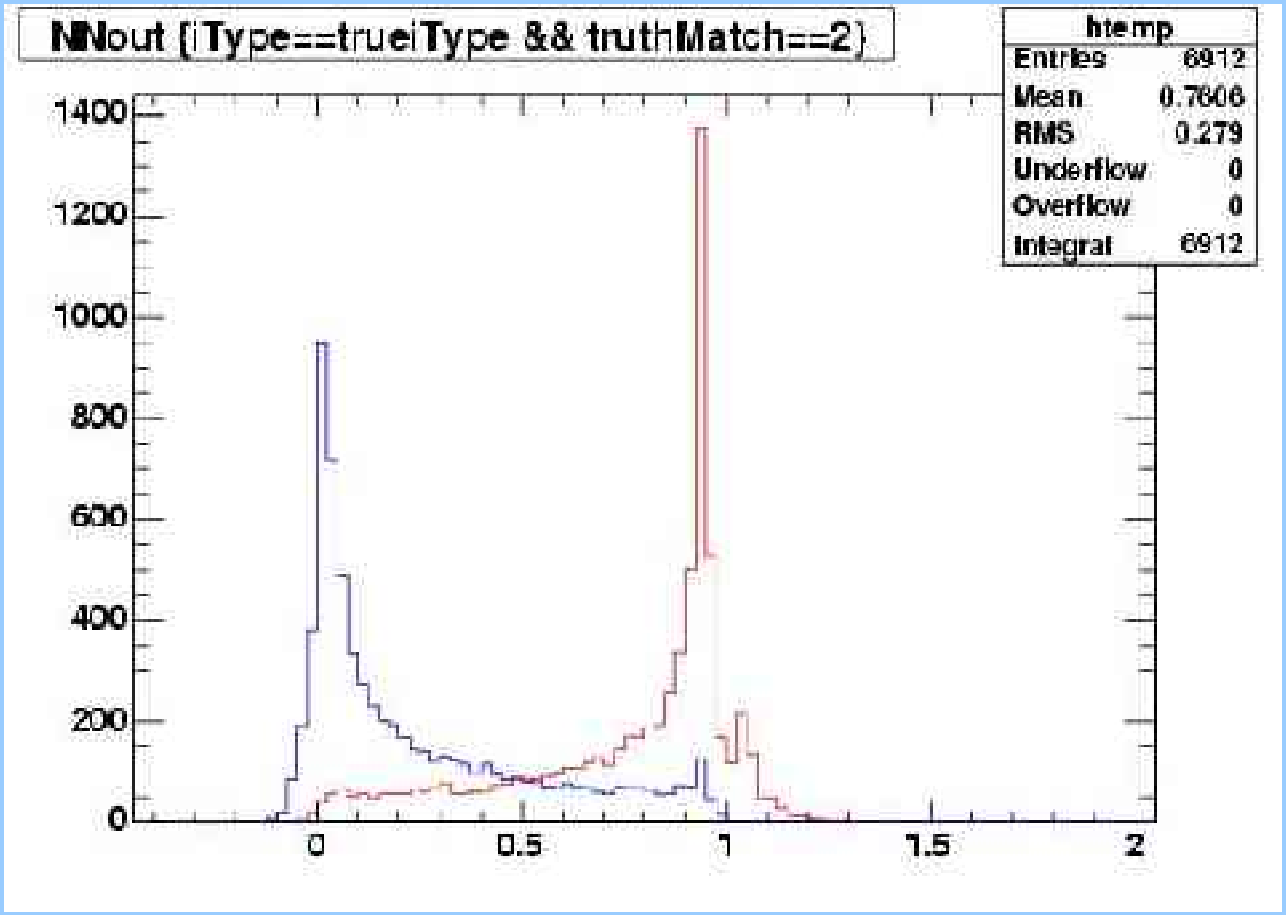
- Radiative penguin decays starting to provide stringent (and interesting!) constraints of SM parameters
- Close to more exciting results
- First signs of non-SM behaviour could be seen here!

Backup slides

$B \to K\pi\pi\gamma$



b→dγ Neural Net performance



- NN cut @ 0.85: 94% continuum rejection, lose 55% signal.

- NN output: signal in red, uds in blue, scaled to equal area

Afb:

⇒ Forward-Backward Asymmetry

$$A_{\rm FB}(z) = \frac{\int_0^1 \left(\frac{d\Gamma}{dz\,d\cos\theta}\right) d\cos\theta - \int_{-1}^0 \left(\frac{d\Gamma}{dz\,d\cos\theta}\right) d\cos\theta}{\int_0^1 \left(\frac{d\Gamma}{dz\,d\cos\theta}\right) d\cos\theta + \int_{-1}^0 \left(\frac{d\Gamma}{dz\,d\cos\theta}\right) d\cos\theta}$$