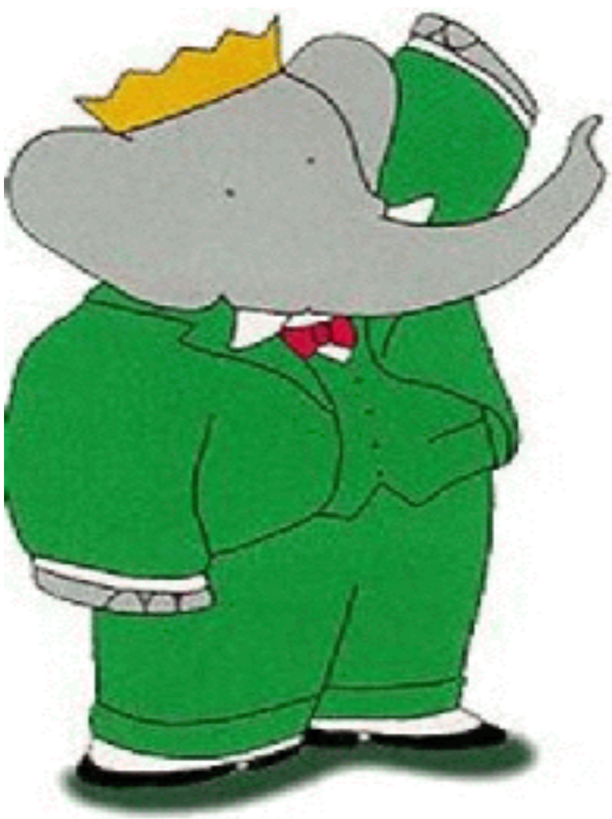
Search for the rare decay $\psi,\psi' \longrightarrow \nu\bar{\nu}$ at the BaBar experiment

Racha Cheaib

McGill University, Montreal



Winter Nuclear and Particle Physics Conference

Saturday, Feb. 25th, 2012

Work done with Dana Lindemann, Steven Robertson, and the BaBar Collaboration.

The Standard Model

Describes the basic constituents of matter and the forces with which they interact.

Matter (spin ½)

u	c	t	+2/3
d	s	b	−1/3
ν_e	ν_μ	ν_τ	0
e	μ	τ	−1

quarks (u, d, c, s, t, b)

leptons (ν_e, e, ν_μ, μ, ν_τ, τ)

Particle interactions are mediated by the exchange of gauge bosons.

Forces (spin 1)

EM:	photon (γ)
Weak:	Z^0 W^+ W^-
Strong:	8 gluons

The Standard Model

Describes the basic constituents of matter and the forces with which they interact.

Weak force is "flavor changing".

Matter (spin ½)

quarks	**u**	**c**	**t**	+2/3
	d	**s**	**b**	−1/3
leptons	ν_e	ν_μ	ν_τ	0
	e	μ	τ	−1

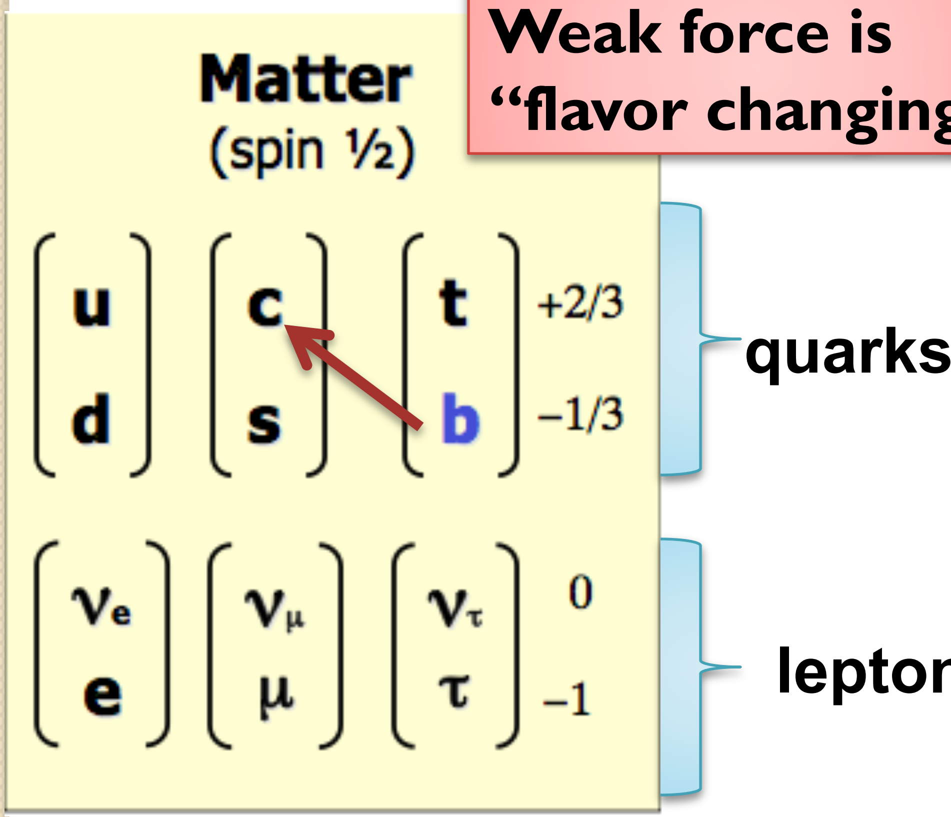
Particle interactions are mediated by the exchange of gauge bosons.

Forces (spin 1)

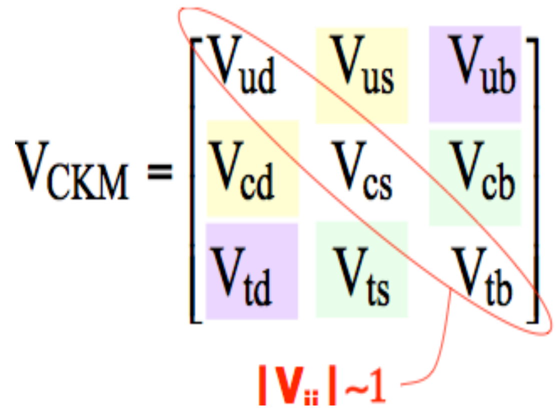
EM:	photon (γ)
Weak:	Z^0 W^+ W^-
Strong:	8 gluons

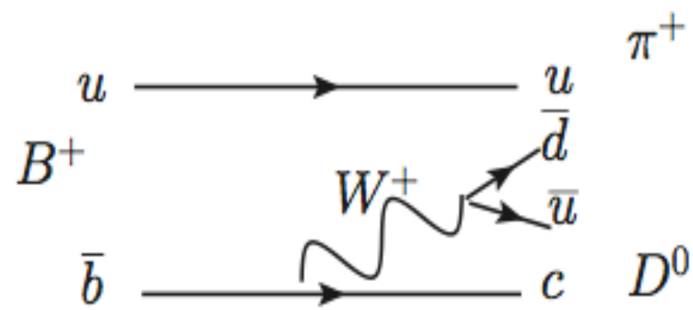
The Standard Model

Describes the basic constituents of matter and the forces with which they interact.



Weak force is "flavor changing".



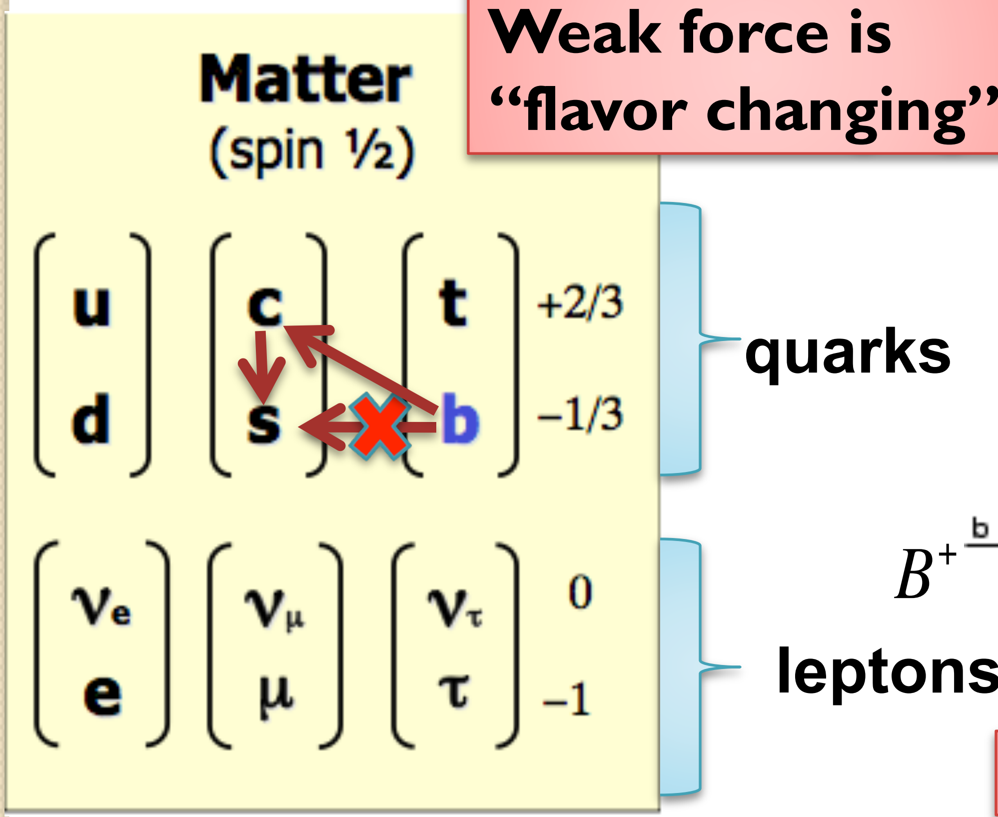


favoured SM decay

The Standard Model

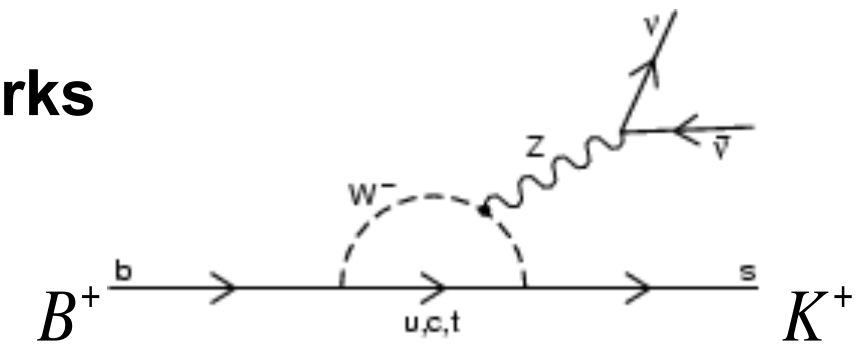
Describes the basic constituents of matter and the forces with which they interact.

Weak force is "flavor changing".



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

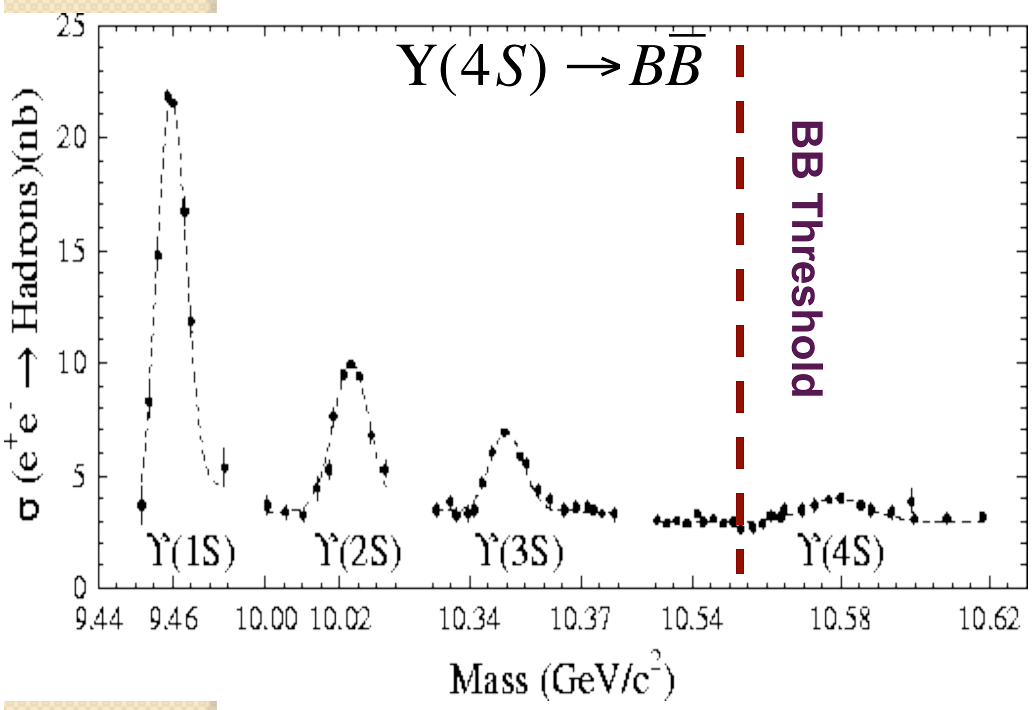
$|V_{ii}| \sim 1$

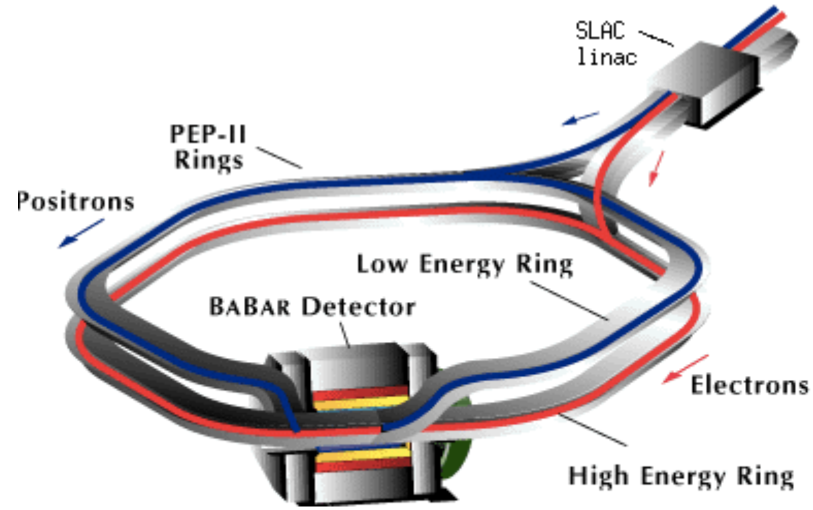


suppressed SM decay

BaBar experiment:

- Located at SLAC National Accelerator Laboratory
- e+e- collisions at CM energy of 10.58 GeV ~ mass of $\Upsilon(4S)$.





High energy ring: 9.0 GeV electrons

Low energy ring: 3.1 GeV positrons

Data Collection: 1999 to 2008

Total integrated luminosity, at the $\Upsilon(4S)$ resonance, of 423 fb^{-1}.

465 million $B\bar{B}$ pairs.

BaBar Detector:

•Asymmetrical about the PEP 2 beam line.

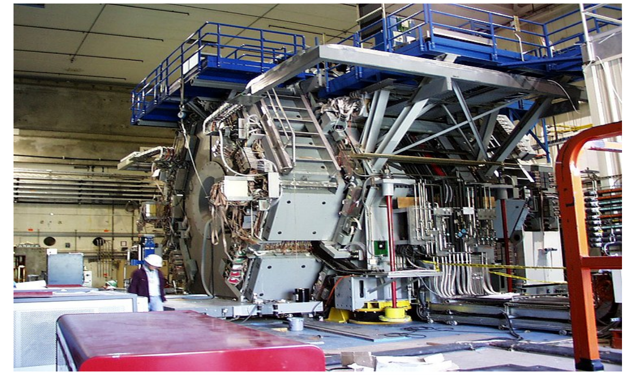
•Ability to resolve the two B verticies: $< 60\mu m$.

•Measure momentum of charged particles with p>60 MeV/c.

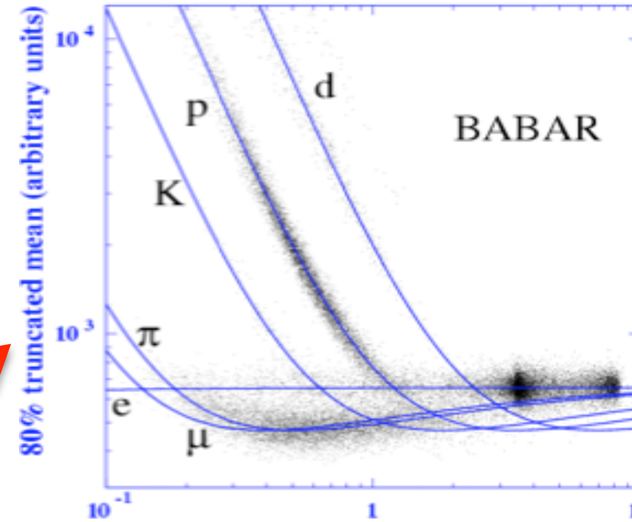
•Measure energy of neutral particles with E>20 MeV.

•Efficient and accurate particle identification:

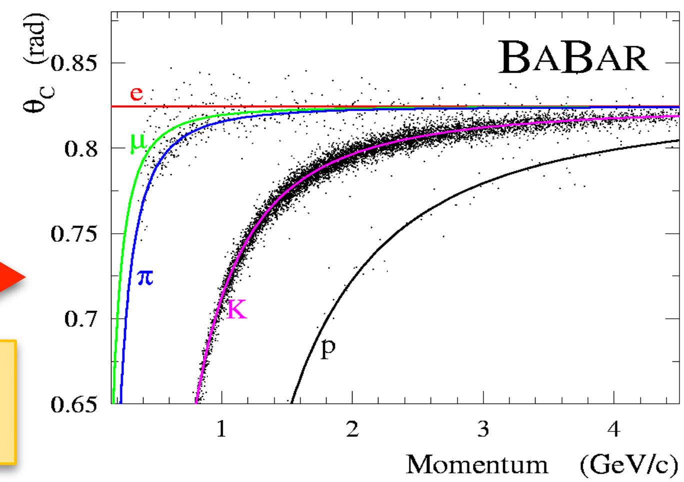
- •Charged lepton
- •Kaon-Pion separation



dE/dx from Drift Chamber

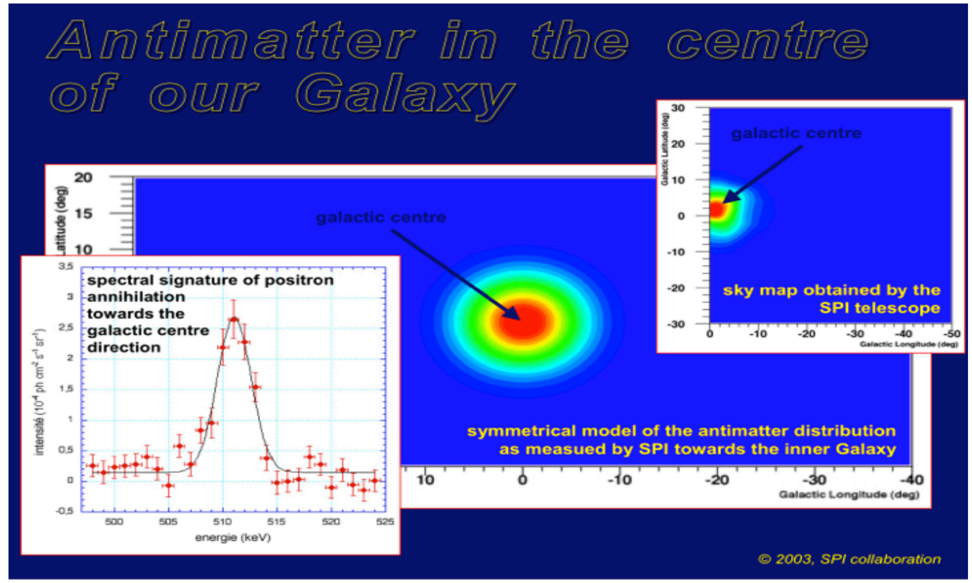


Cherenkov angle from DIRC



Invisible decays and Dark Matter:

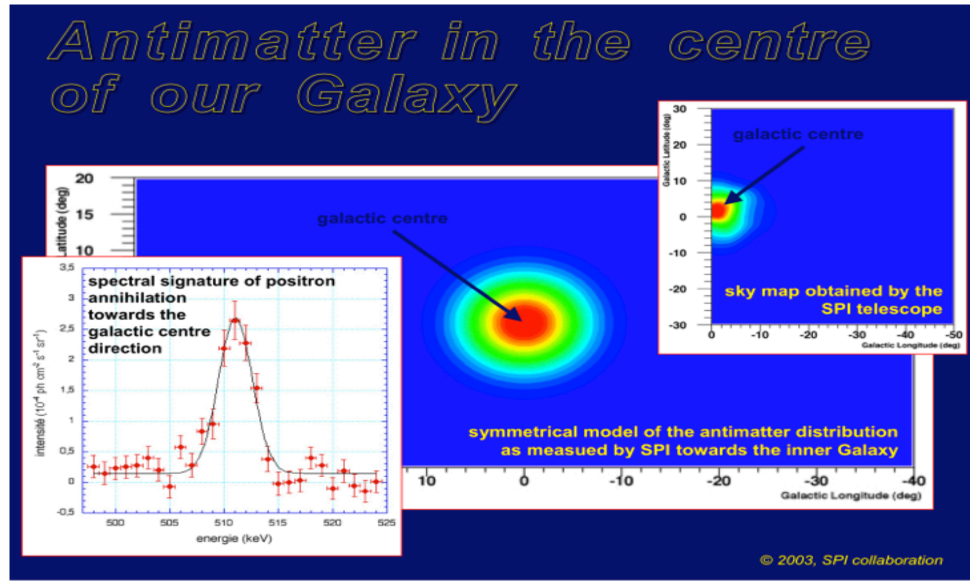
•Astronomical observation of a bright 511 keV gamma ray line by SPI spectrometer at INTEGRAL (International Gamma Ray Astrophysics Lab)



•**Positron flux can be interpreted as the result of the annihilation of Light Dark Matter (LDM) into e+e- pairs.**

Invisible decays and Dark Matter:

•Astronomical observation of a bright 511 keV gamma ray line by SPI spectrometer at INTEGRAL (International Gamma Ray Astrophysics Lab)



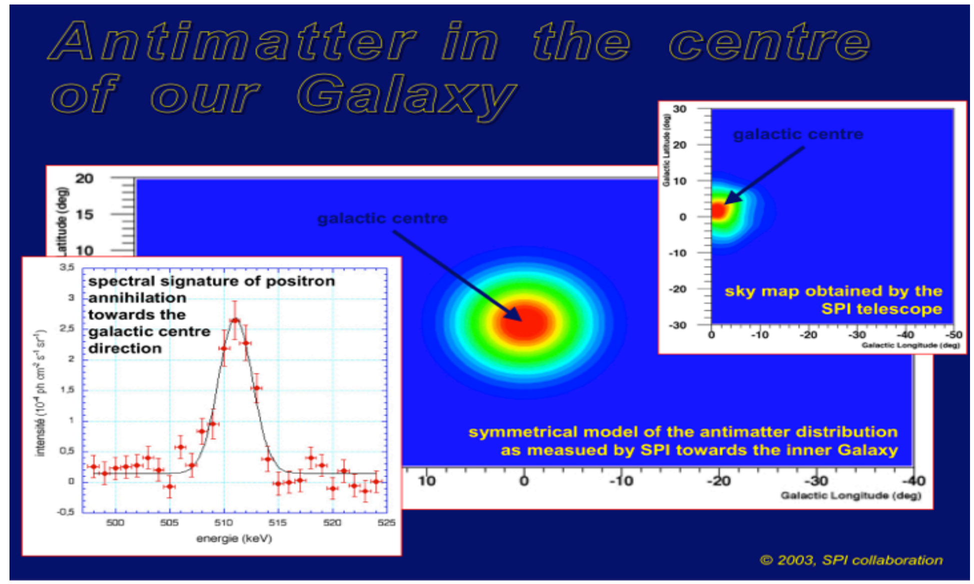
•Positron flux can be interpreted as the result of the annihilation of Light Dark Matter (LDM) into e+e- pairs.

Search for this invisible LDM candidate at collider experiments

Invisible decays of quarkonium states.

Invisible decays and Dark Matter:

•Astronomical observation of a bright 511 keV gamma ray line by SPI spectrometer at INTEGRAL (International Gamma Ray Astrophysics Lab)



•**Positron flux can be interpreted as the result of the annihilation of Light Dark Matter (LDM) into e+e- pairs.**

Search for this invisible LDM candidate at collider experiments

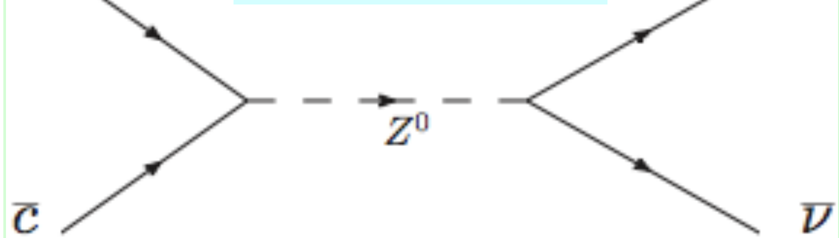
$$\psi,\psi' \rightarrow \nu\bar{\nu}$$

Invisible decays of quarkonium states.

$\psi, \psi' \rightarrow \nu\bar{\nu}$:

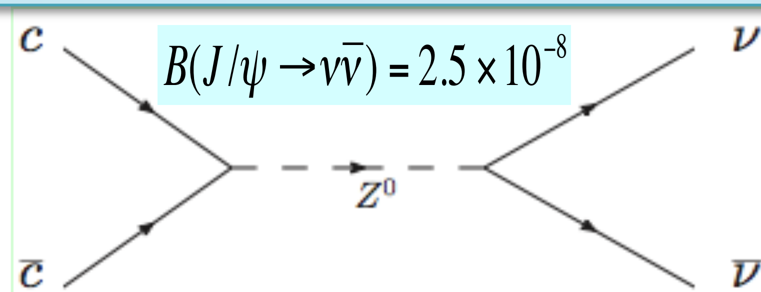
Narrow charmonium resonances.
Invisible decay occurs only through a Z^0 boson into a pair of neutrinos.

$$B(\psi \rightarrow \nu\bar{\nu}) = 2.5 \times 10^{-8}$$



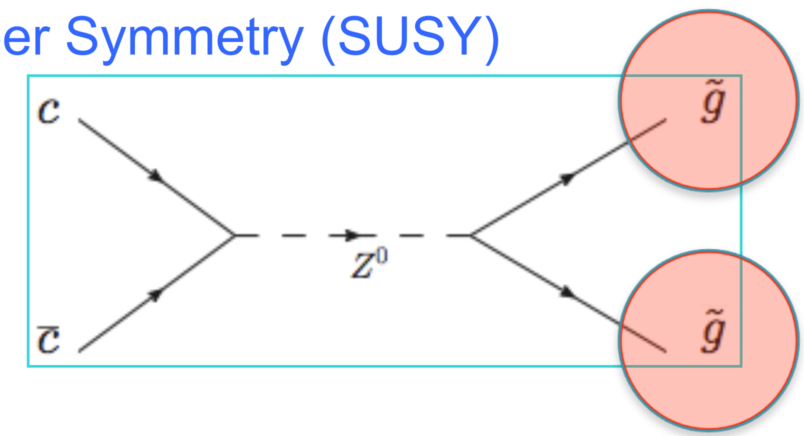
$\psi,\psi' \to \nu\bar{\nu}$:

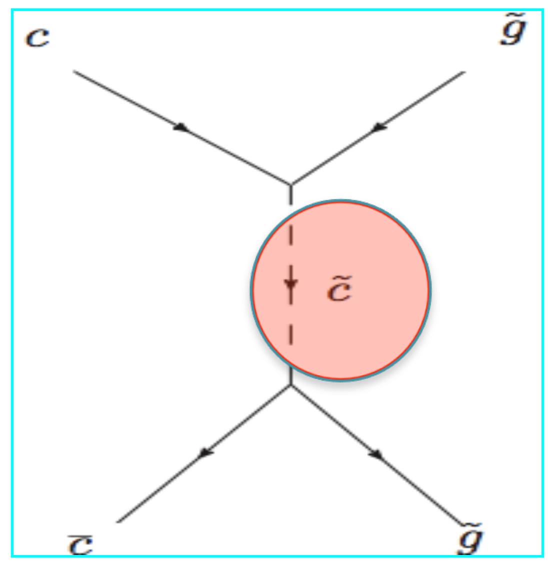
Narrow charmonium resonances.
Invisible decay occurs only through a Z^0 boson into a pair of neutrinos.



"New Physics" can increase/decrease the branching fraction:

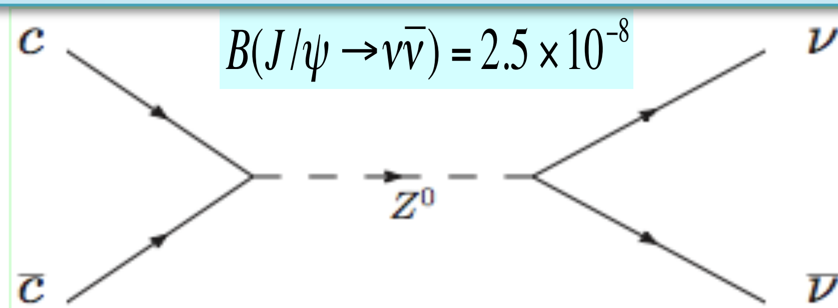
- Super Symmetry (SUSY)





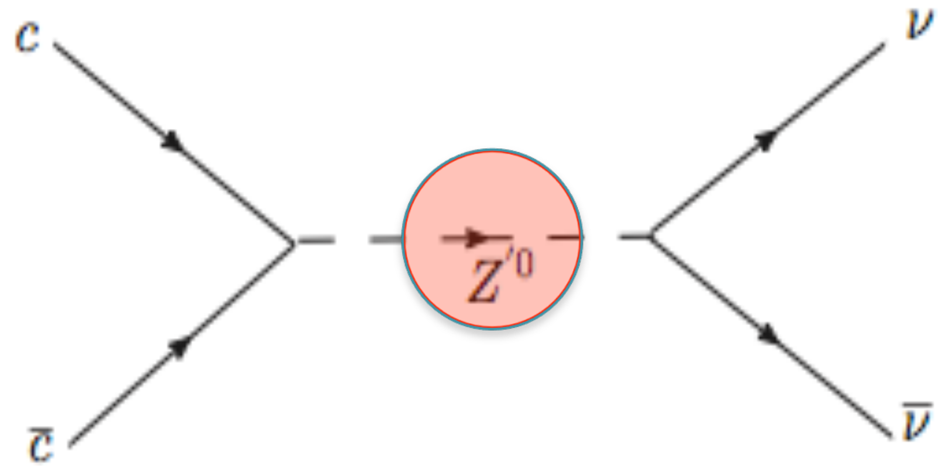
$\psi, \psi' \rightarrow \nu\bar{\nu}$:

Narrow charmonium resonances.
Invisible decay occurs only through a Z^0 boson into a pair of neutrinos.



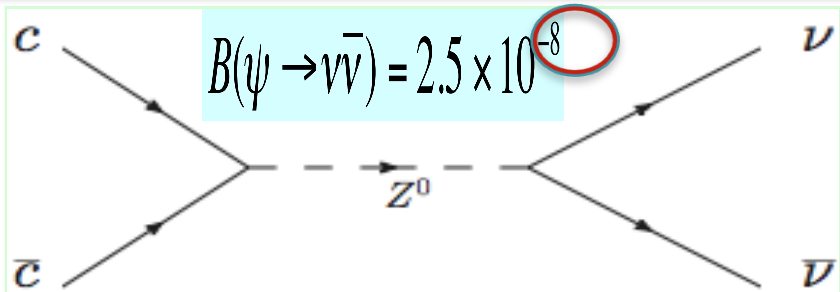
"New Physics" can considerably increase/decrease the branching fraction:

- Super Symmetry (SUSY)
- Left-right symmetric models



$\psi, \psi' \to \nu\bar{\nu}$:

Narrow charmonium resonances.
Invisible decay occurs only through a Z^0 boson into a pair of neutrinos.



"New Physics" can increase/decrease the branching fraction:

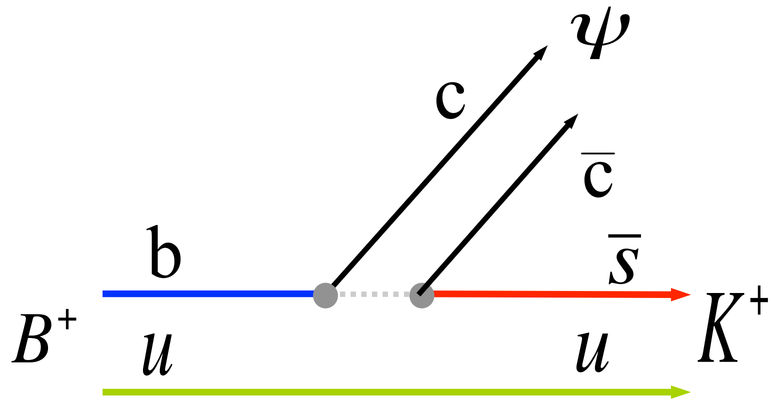
- Super Symmetry (SUSY)
- Left-right symmetric models
- Light dark matter couplings

$$B(\psi \to \chi^0 \bar{\chi}^0) \approx 2.5 \times 10^{-5}$$

Precision measurement → **New Physics**

Signal Modes:

Search for $\psi,\psi' \rightarrow \nu\bar{\nu}$ **in** $B^{\pm,0} \rightarrow K^{(*)}c\bar{c}$ **:**



Golden mode for CPV studies

Previously published limits:

BES: $\frac{B(\psi \rightarrow \nu\bar{\nu})}{B(\psi -> \mu^+\mu^-)} < 1.2 \times 10^{-2}$

No previous limits on:

$\psi' \rightarrow \nu\bar{\nu}$

Charged Modes:

$B^{\pm} \rightarrow K^{\pm}c\bar{c}$

$B^{\pm} \rightarrow K^{*\pm}c\bar{c}$

1. $K^{*\pm} \rightarrow K_s^0\pi^{\pm}$
2. $K^{*\pm} \rightarrow K^{\pm}\pi^0$

Neutral Modes:

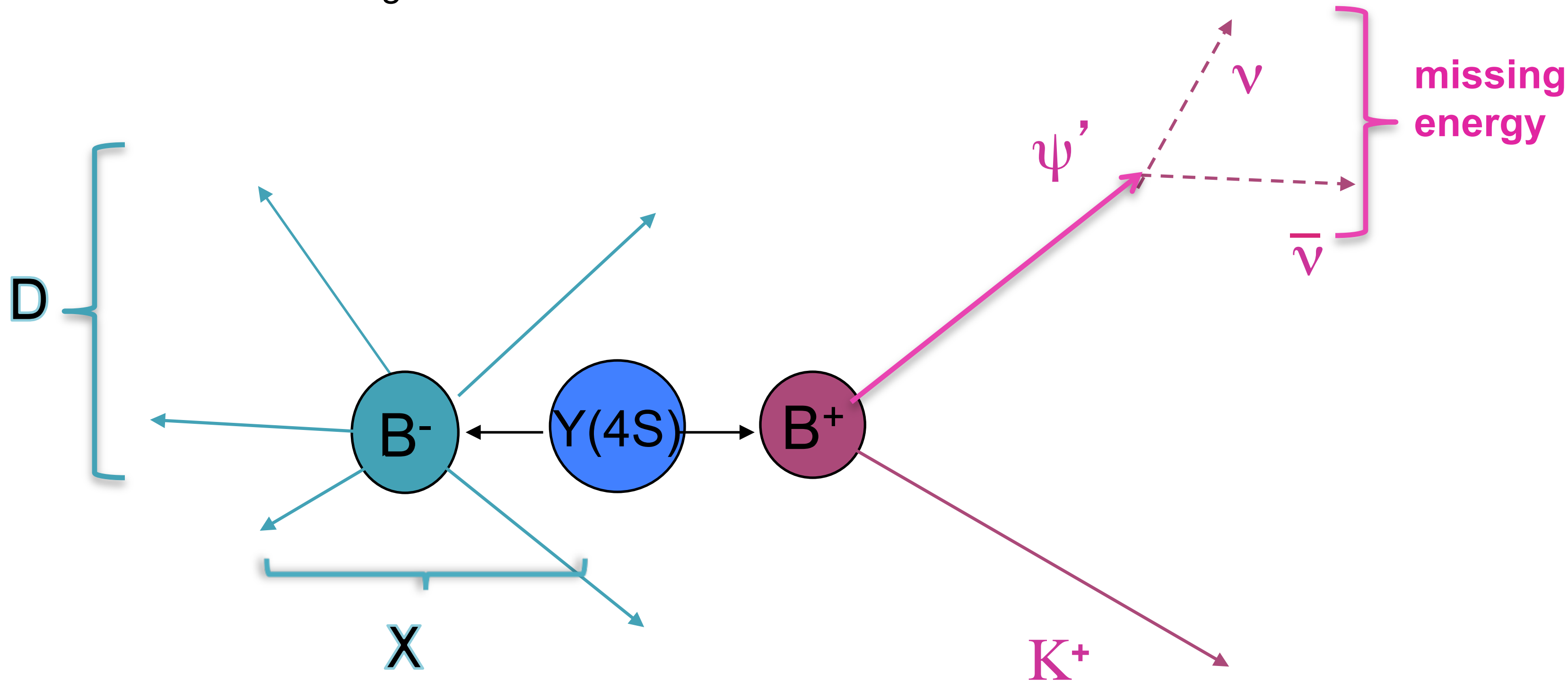
$B^0 \rightarrow K_s^0 c\bar{c}$

$B^0 \rightarrow K^{*0}c\bar{c}$

1. $K^{*0} \rightarrow K_s^0\pi^0$
2. $K^{*0} \rightarrow K^{\pm}\pi^{\mp}$

Hadronic B_{tag} reconstruction:

•Reconstruct first B, B_{tag}, from hadronic modes, using B →D+X.



•Here, X is any combination of pions and kaons that can be joined to form a proper B_{tag} candidate.

•The remaining tracks and clusters are attributed to B_{sig}

Hadronic B_{tag} reconstruction:

Advantages:

• Clean separation between B_{sig} and B_{tag}.

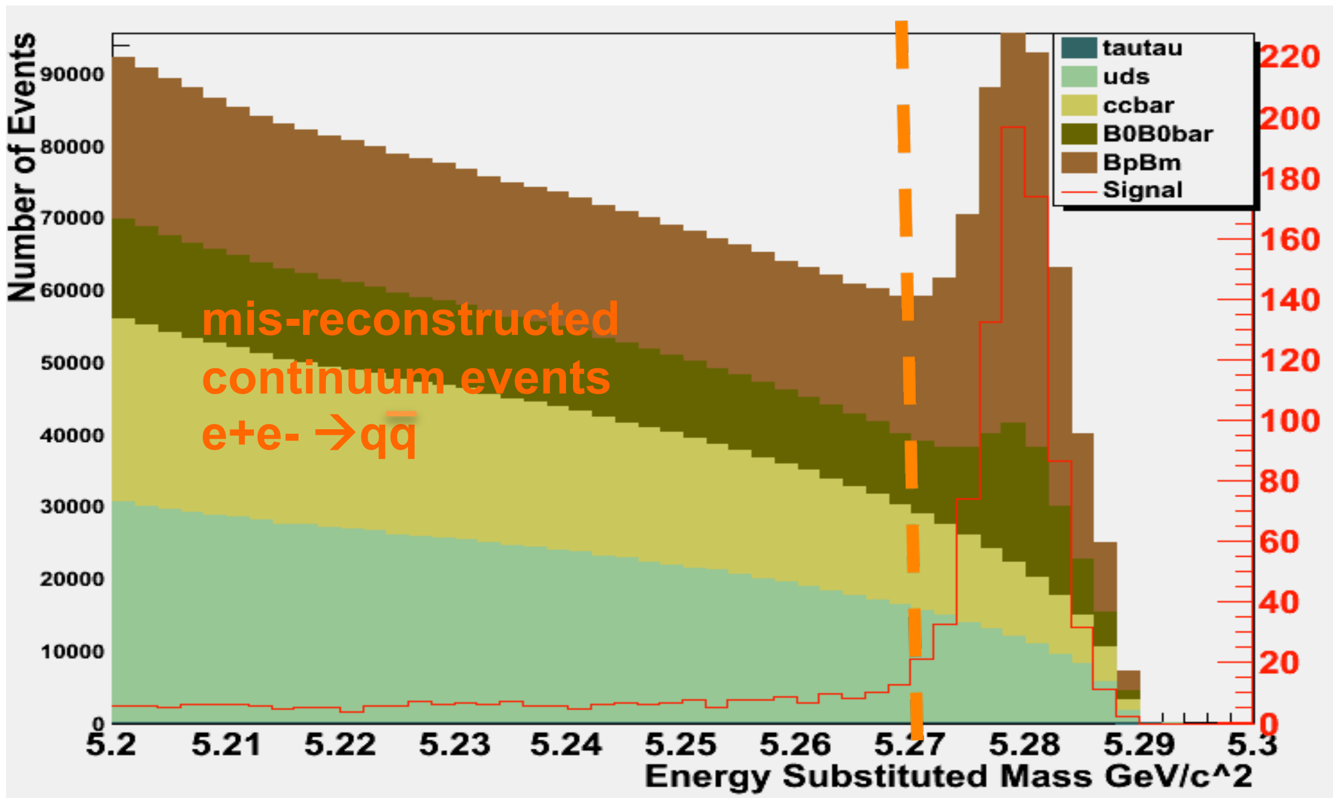
• Ideal for decays with missing energy.

$$m_{ES} = \sqrt{\left(\frac{E_{CM}}{2}\right)^2 - p_{Btag}^2}$$

• Four momentum of both B mesons is fully determined.

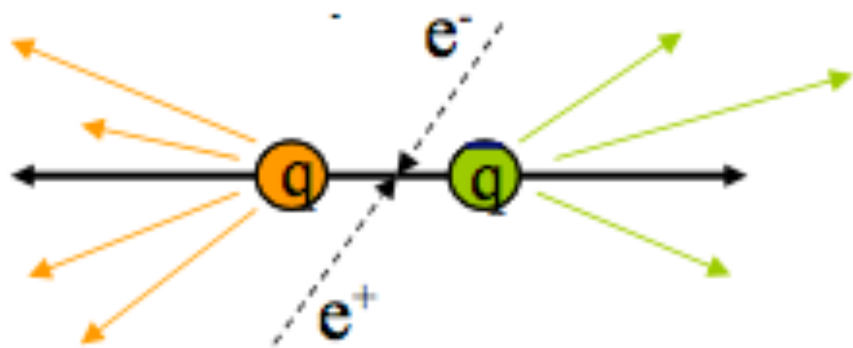
Disadvantages:

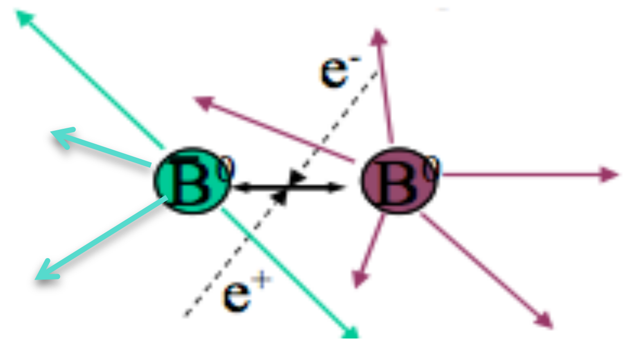
Very low efficiency.



Background Suppression

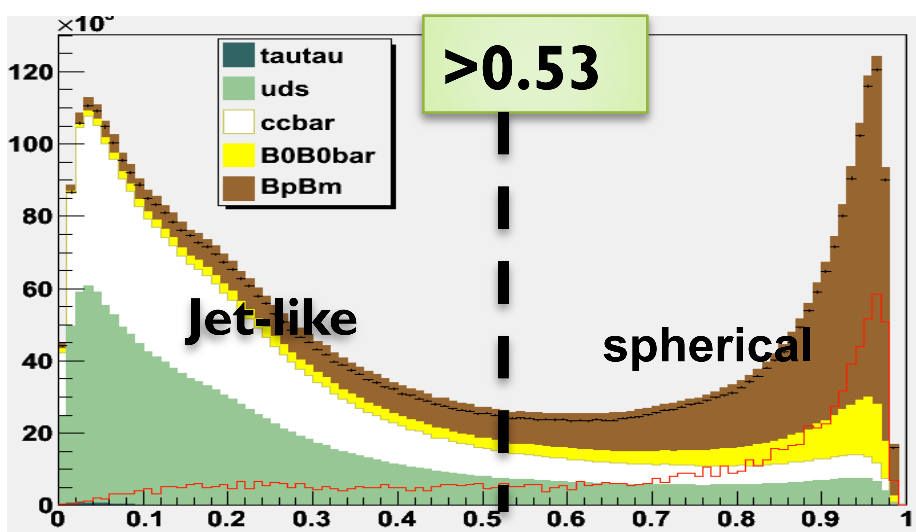
- Based on differences in event topology.
  - Multivariate technique using 5 event shape variables:



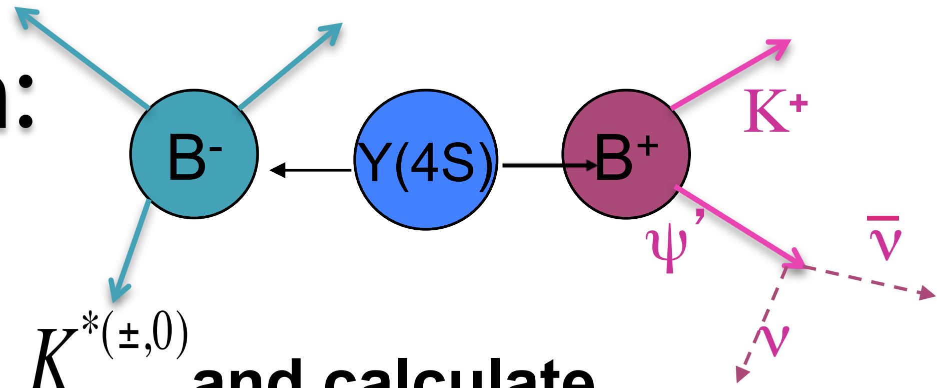


e+e-→$q\bar{q}$, where q=u,d,s,c,τ.

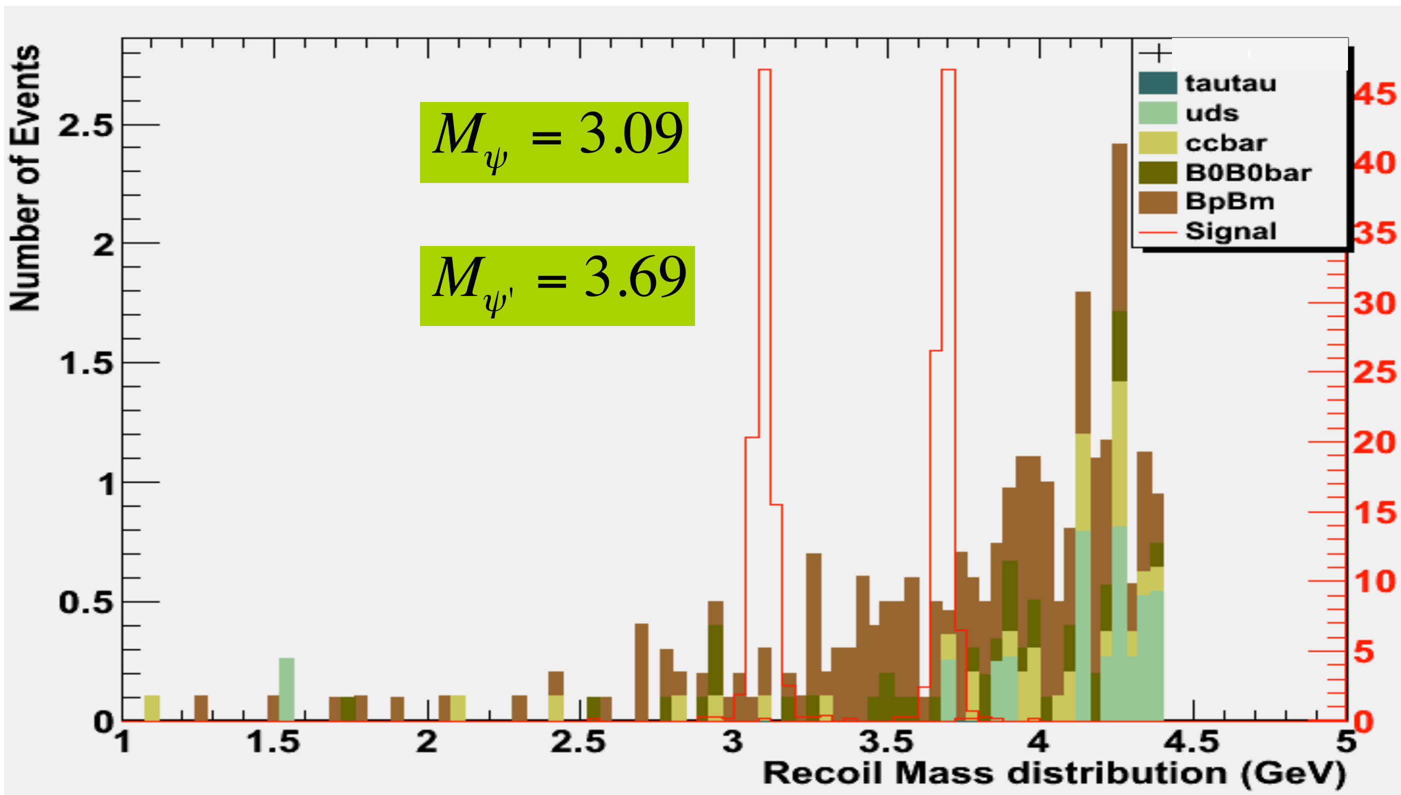
e+e-→ϒ(4S)



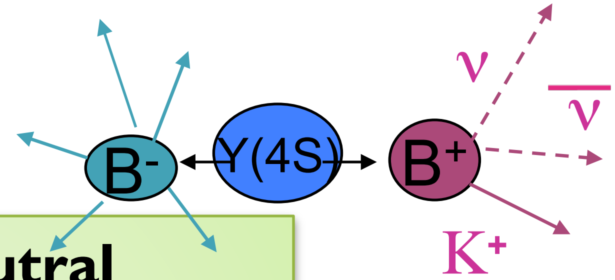
Signal Selection:

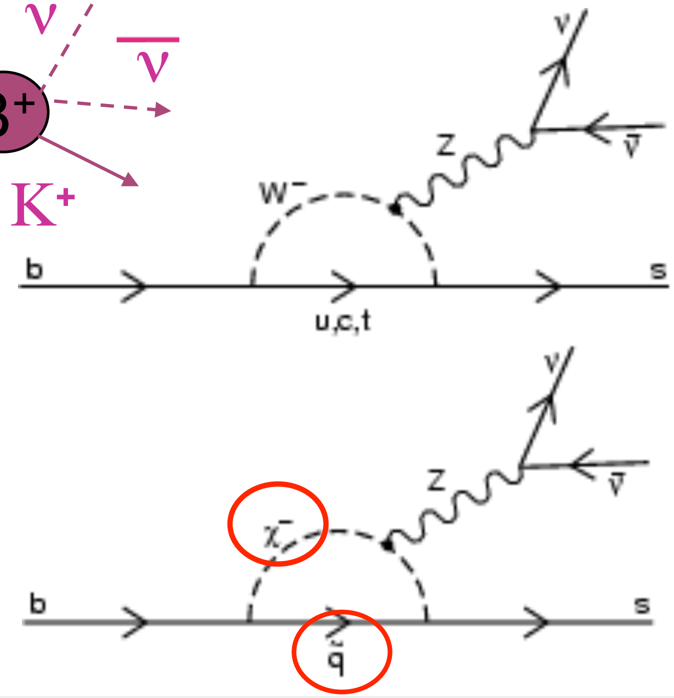


Reconstruct the $K^{\pm,0}$ or $K^{*(\pm,0)}$ and calculate the recoil mass: $M_{c\bar{c}} = M_{B_{sig}} - M_{K^{(*)}}$



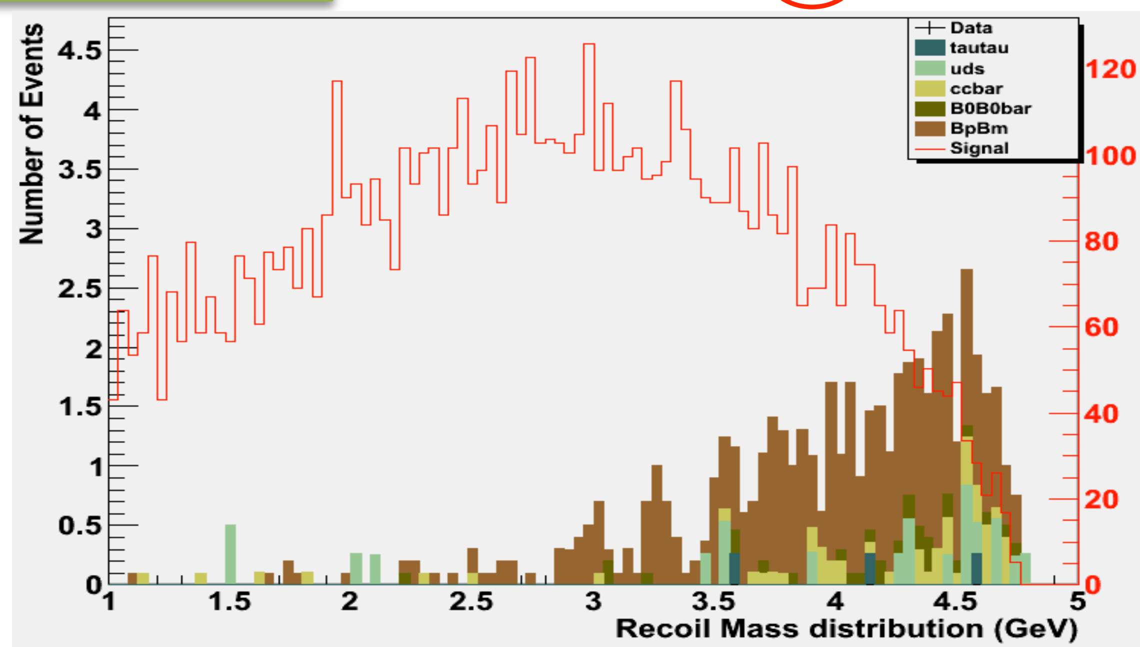
$B \to K^{(*)}\nu\bar{\nu}$:





- **Flavour changing neutral current (FCNC) highly suppressed in SM.**
- **Significant enhancement from Non SM modes and dark matter contributions.**

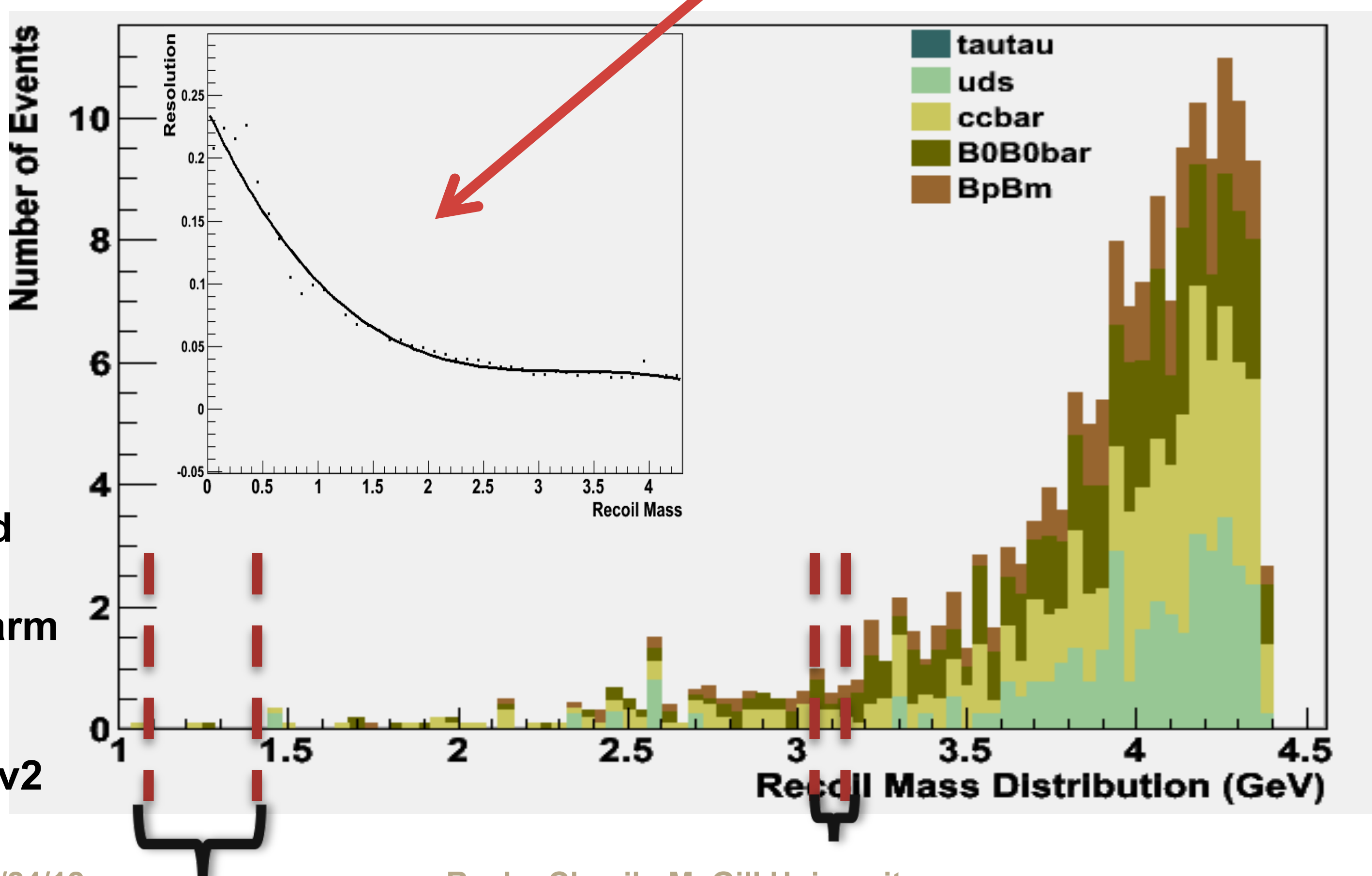
"Dark matter pair production in b→s transitions"
C.Bird, R.Kowalewski, M. Pospelov.



Even more: $B \to K^{(*)}X, X \to \chi^0\overline{\chi}^0$

- Scan entire distribution.
- Look for peaks in a sliding mass window

Resolution improves with increasing mass, low $K^{(*)}$ momentum



"Light Higgs and Dark Matter at Bottom and Charm Factories"
Bob McElrath
arXiv:0712.0016v2

Outlook:

On the hunt for new physics.

$$\psi,\psi' \rightarrow \nu\bar{\nu}$$

$$B \rightarrow K^{(*)}\nu\bar{\nu}$$

$$B \rightarrow K^{(*)}X, X \rightarrow \chi^0\bar{\chi}^0$$

Analysis completion "expected" by this summer.

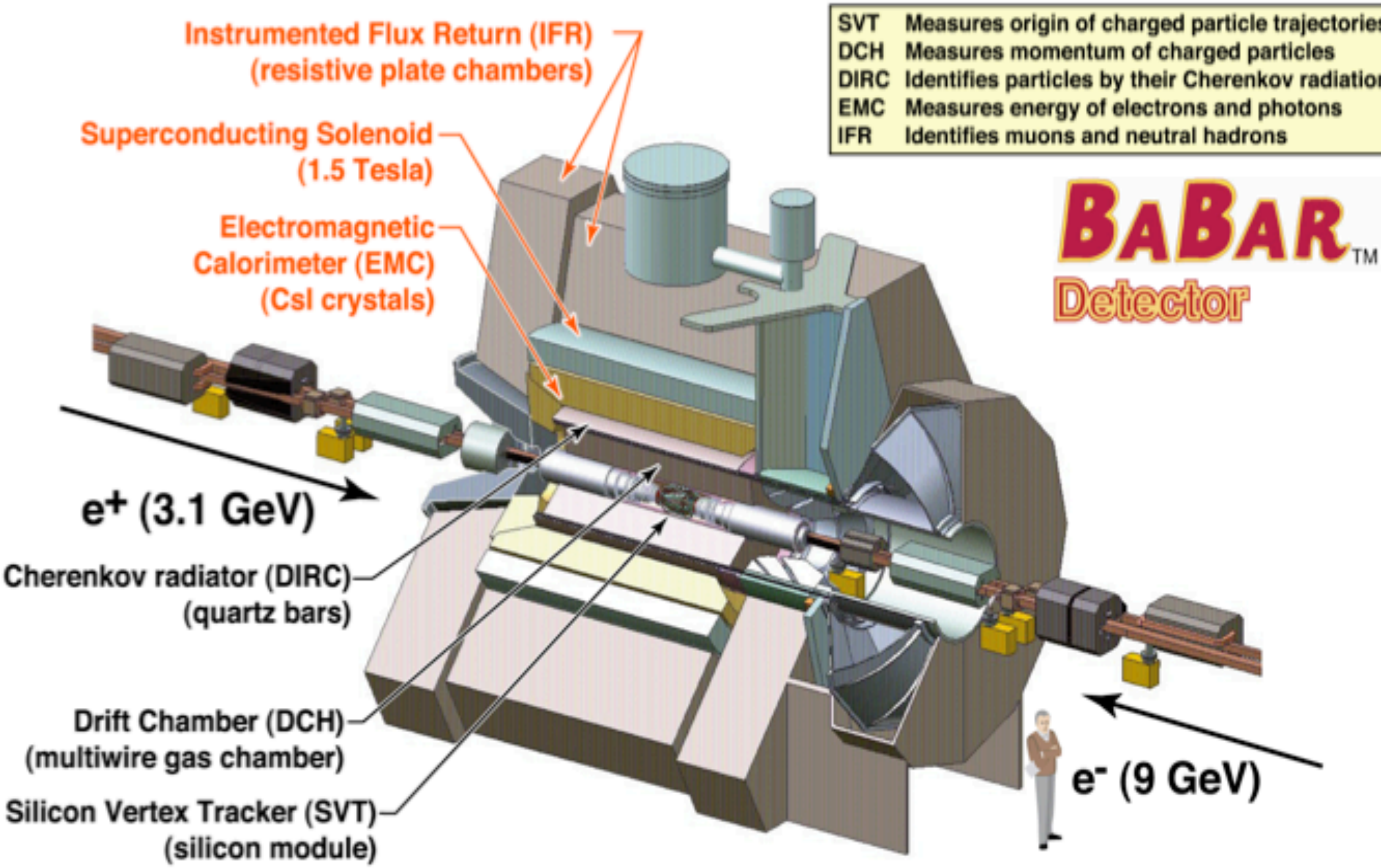
Lots of more interesting Physics at B factories.

"LOTS OF THINGS ARE INVISIBLE, BUT WE DON'T KNOW HOW MANY BECAUSE WE CAN'T **SEE** THEM."

Extra Slides

BaBar Detector:

SVT	Measures origin of charged particle trajectories
DCH	Measures momentum of charged particles
DIRC	Identifies particles by their Cherenkov radiation
EMC	Measures energy of electrons and photons
IFR	Identifies muons and neutral hadrons



Related Studies

Collaboration	$q\bar{q}$	Decay Mode	Results (90% CL)
BES	J/ψ	$\psi(2S) \to \pi^+ \pi^- J/\psi$	$\frac{\mathcal{B}(J/\psi \to \nu\bar{\nu})}{\mathcal{B}(J/\psi \to \mu^+\mu^-)} = 1.2 \times 10^{-2}$
BELLE	$\Upsilon(1S)$	$\Upsilon(3S) \to \Upsilon(1S) \pi^+ \pi^-$	$\mathcal{B}(\Upsilon(1S) \to \nu\bar{\nu}) < 2.5 \times 10^{-3}\%$
BES	η	$J/\psi \to \phi \eta$	$\frac{\mathcal{B}(\eta \to \nu\bar{\nu})}{\mathcal{B}(J/\psi \to \gamma\gamma)} = 1.65 \times 10^{-3}$
BES	η'	$J/\psi \to \phi \eta'$	$\frac{\mathcal{B}(\eta' \to \nu\bar{\nu})}{\mathcal{B}(J/\psi \to \gamma\gamma)} = 6.69 \times 10^{-2}$
CLEO	$\Upsilon(1S)$	$\Upsilon(2S) \to \Upsilon(1S) \pi^+ \pi^-$	$\mathcal{B}(\Upsilon(1S) \to \nu\bar{\nu}) < 0.39\%$

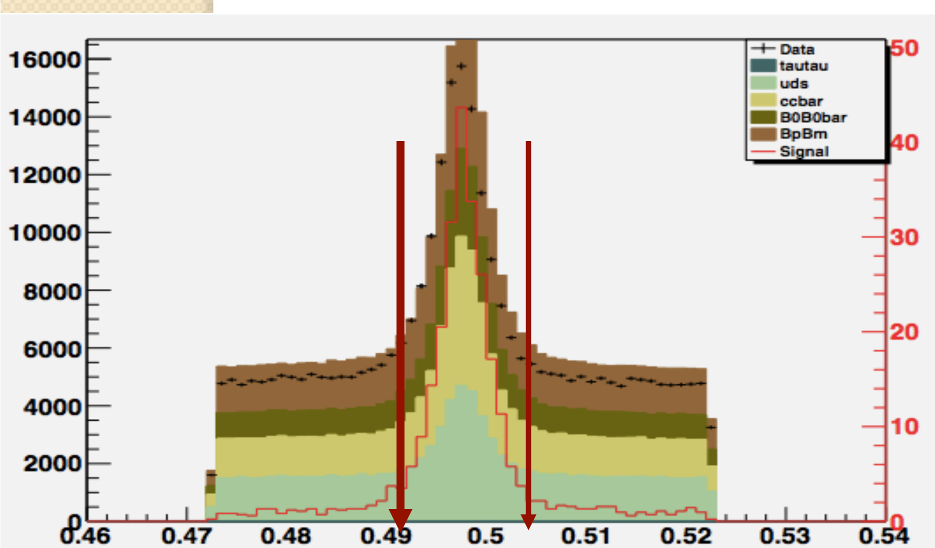
Signal Selection:

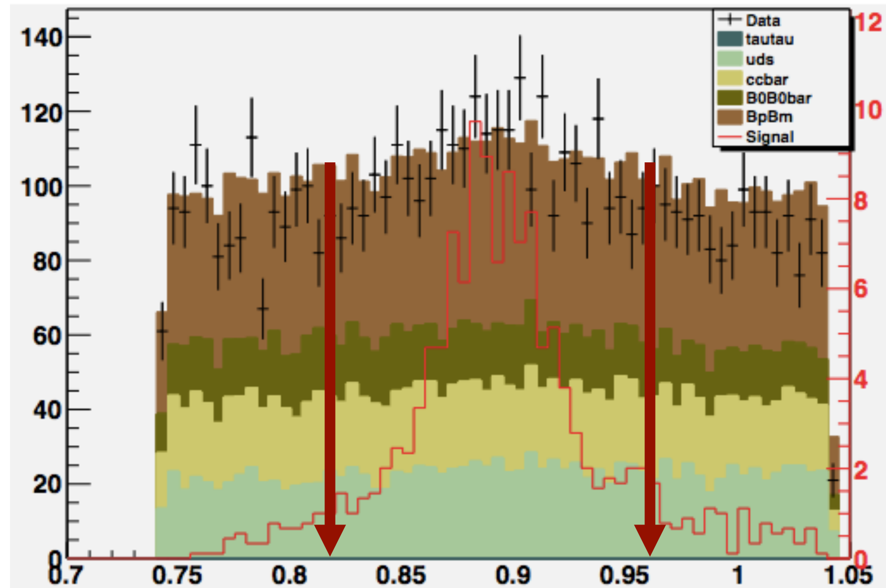
- Reconstruct the $K^{\pm,0}$ or $K^{*(\pm,0)}$ in the event and calculate the recoil mass using : $M_{c\bar{c}} = M_{B_{sig}} - M_{K^{(*)}}$

Mode 1: $B^{\pm} \to [K_s^0 \pi^{\pm}] c\bar{c}$

Exactly three tracks that satisfy a pion PID.

Two of which must form of a Ks: oppositely charged pair with common vertex and mass sum at +/- 7 MeV from the Ks mass.





$K_s^0 \pi^{\pm}$ pair must have an invariant mass at +/- 70 MeV.

Signal Selection:

- Reconstruct the $K^{\pm,0}$ or $K^{*(\pm,0)}$ in the event and calculate the recoil mass using : $M_{c\bar{c}} = M_{B_{sig}} - M_{K^{(*)}}$

Mode 2: $B^{\pm} \rightarrow [K^{\pm}\pi^{0}]c\bar{c}$

Exactly one track that satisfies a kaon PID.

π^0 **is reconstructed from 2 photons with:**

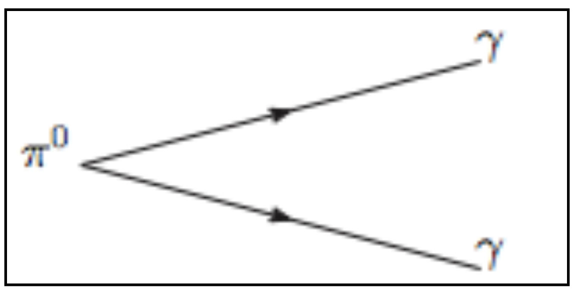
1.E_1>30 MeV

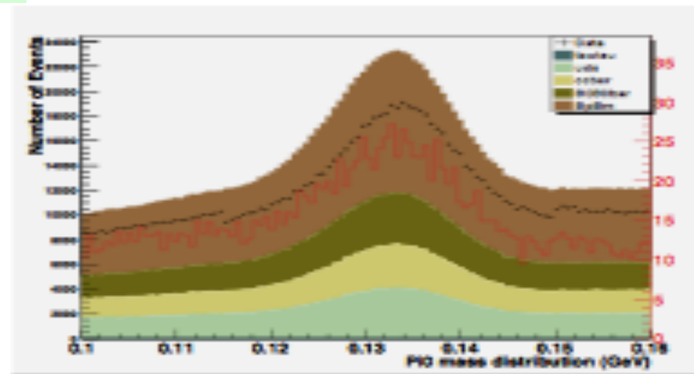
2.E_2>30 MeV

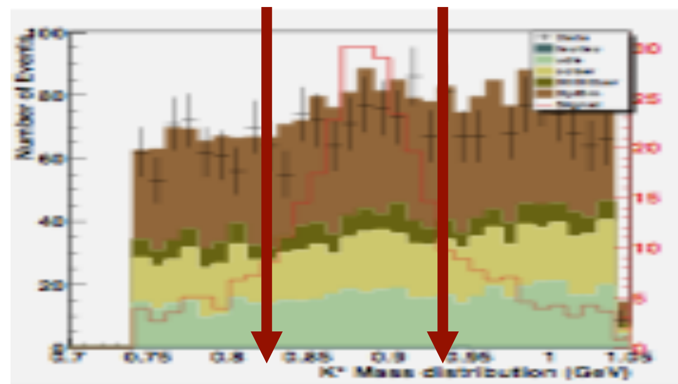
3.(E_1+E_2)>200 MeV

4.100<Mass<160 MeV

5.0<lateral moment<80







$K^{\pm}\pi^{0}$ **pair must have an invariant mass at +/- 70 MeV.**

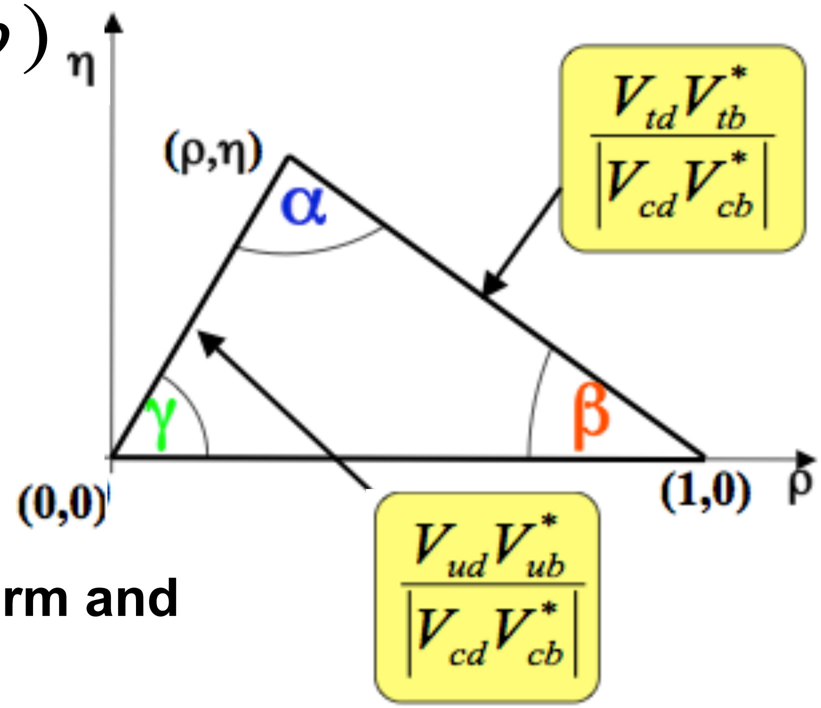
Physics at BaBar:

- **Measure CP-violation in the Standard Model using B mesons.**

$$B^+(u\bar{b}), B^0(d\bar{b})$$

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

$\beta = 0$ → **no CP violation**



- **Large sample of tau leptons, charm and charmonium mesons.**

- **Rare decays of B mesons: physics beyond the Standard Model**

- **And much more…**