Physics Opportunities At SuperB

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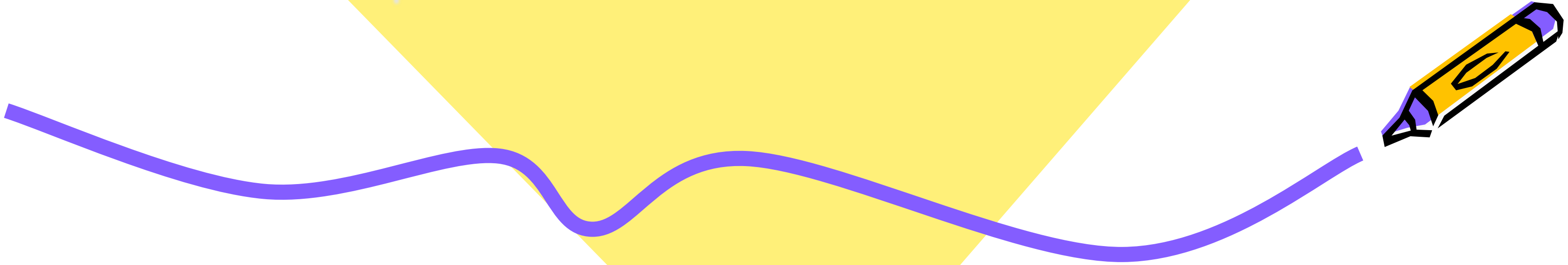
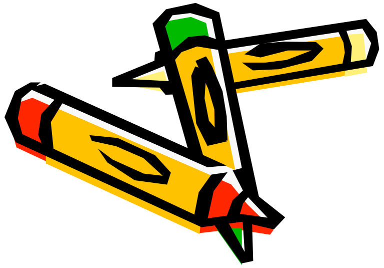


Flavour Physics

$\mathcal{L}_{\sim SM} = -\frac{1}{4} F^a_{\mu\nu} F^{a\mu\nu} + i\bar{\psi} \not{D} \psi$	The gauge sector	LEP 200
$+ \lvert D_\mu h \rvert^2 - V(h)$	The EWSB sector	Tevatron/ LHC
$+ \psi_i \lambda_{ij} \psi_j h + h.c.$	The flavour sector	(This Talk
$+ N_i M_{ij} N_j$	The ν-mass sector (if Majorana)	ν experiments

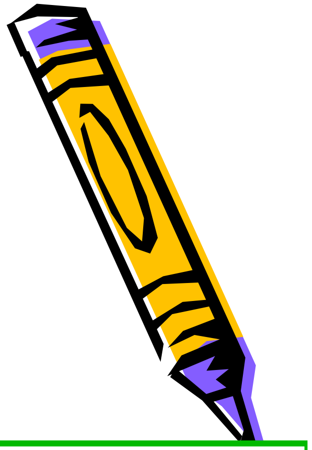


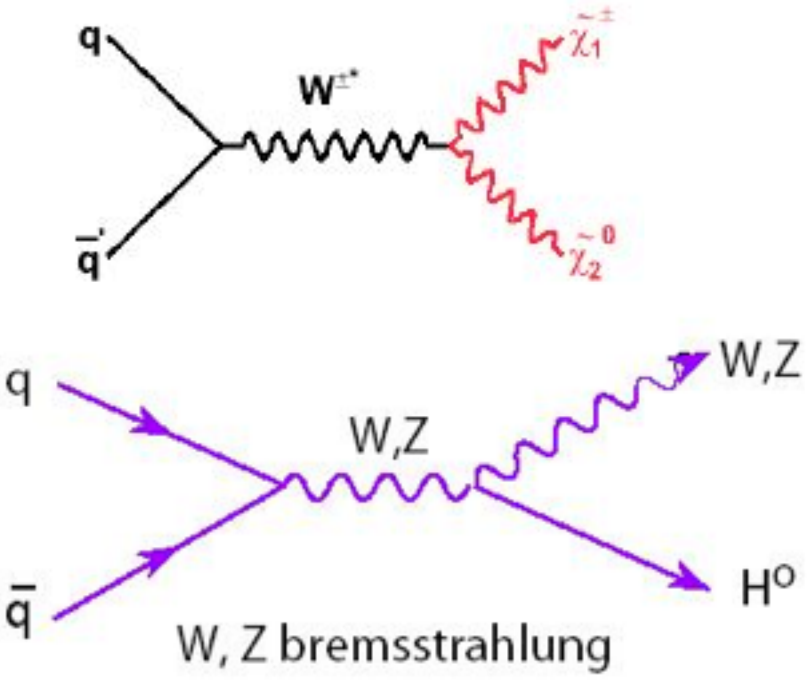
<u>Flavour physics: </u> investigation of couplings of fermions with bosons

→ understand differences between families (and their number)

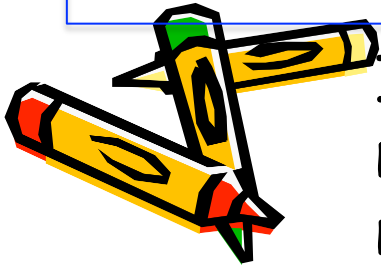
→ measure coupling constants

New Physics Searches

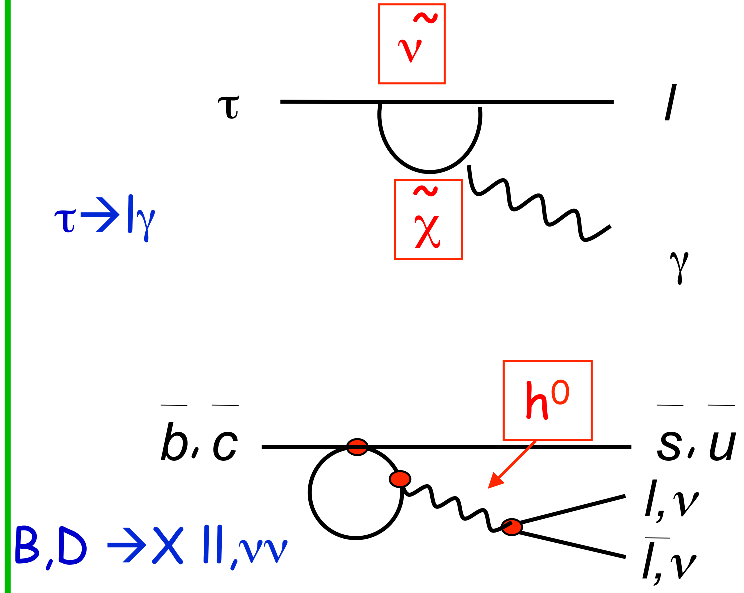




Direct searches: LHC



Indirect searches are needed to disentangle new physics “zoology”



τ→lγ

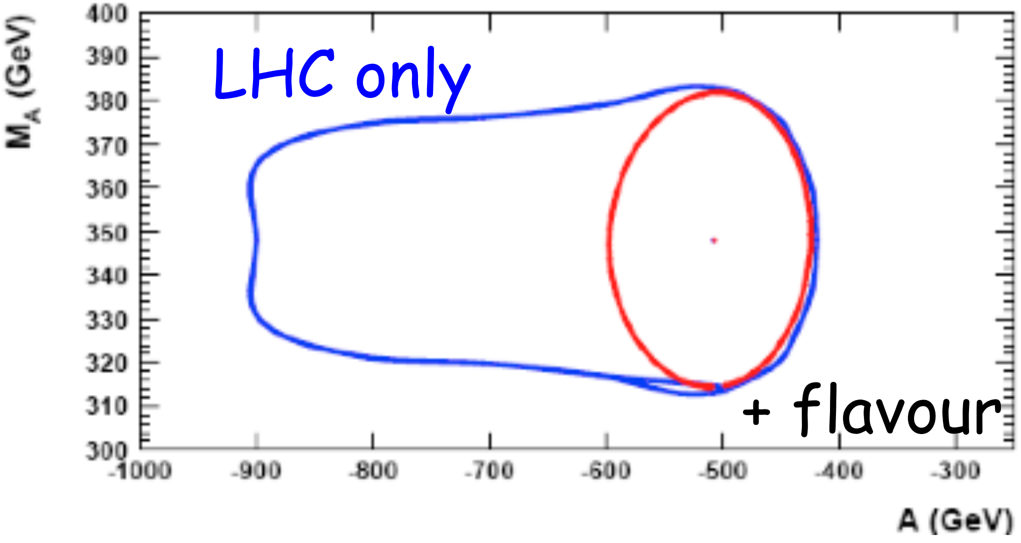
B,D →X ll,νν

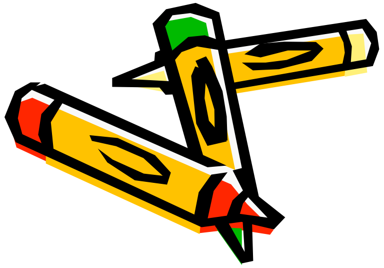
Indirect searches: Flavour Factories

Sensitivity to new physics

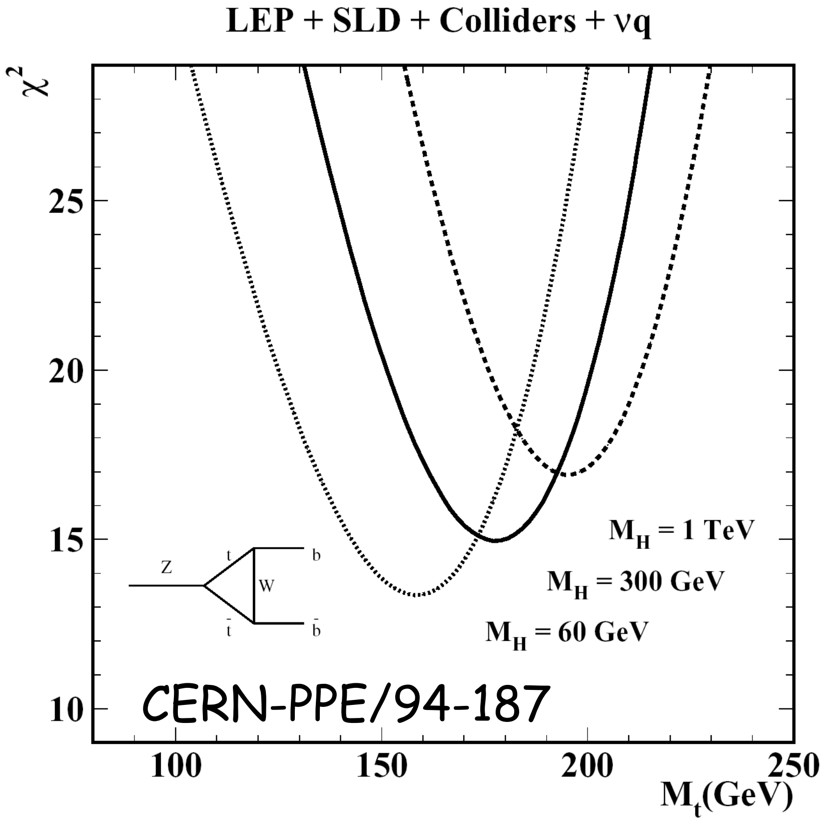
$$\mathscr{L} = \mathscr{L}_{SM} + \sum_k \left(\sum_i c_i^k \, Q_i^{(k+4)}\right)/\Lambda^k$$

Values of Λ up to 100 TeV can be explored

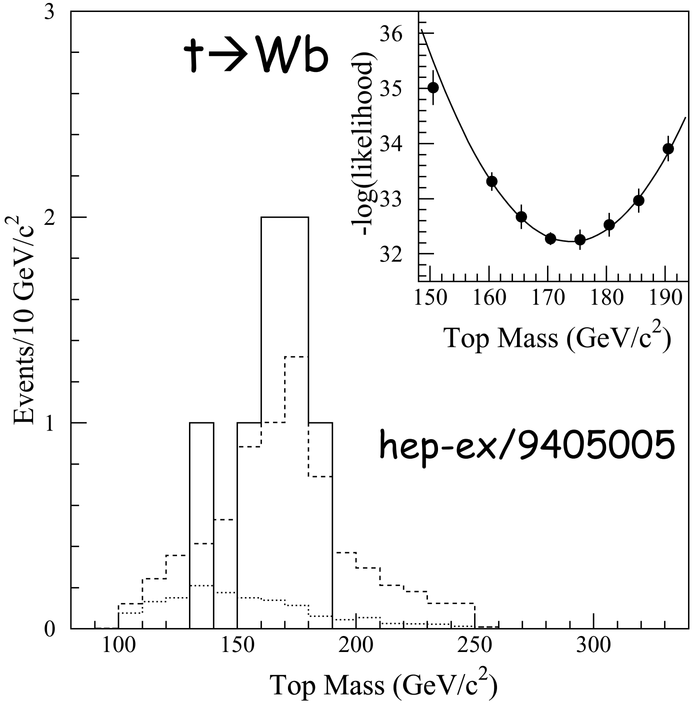




The two paths to New Physics



CERN-PPE/94-187



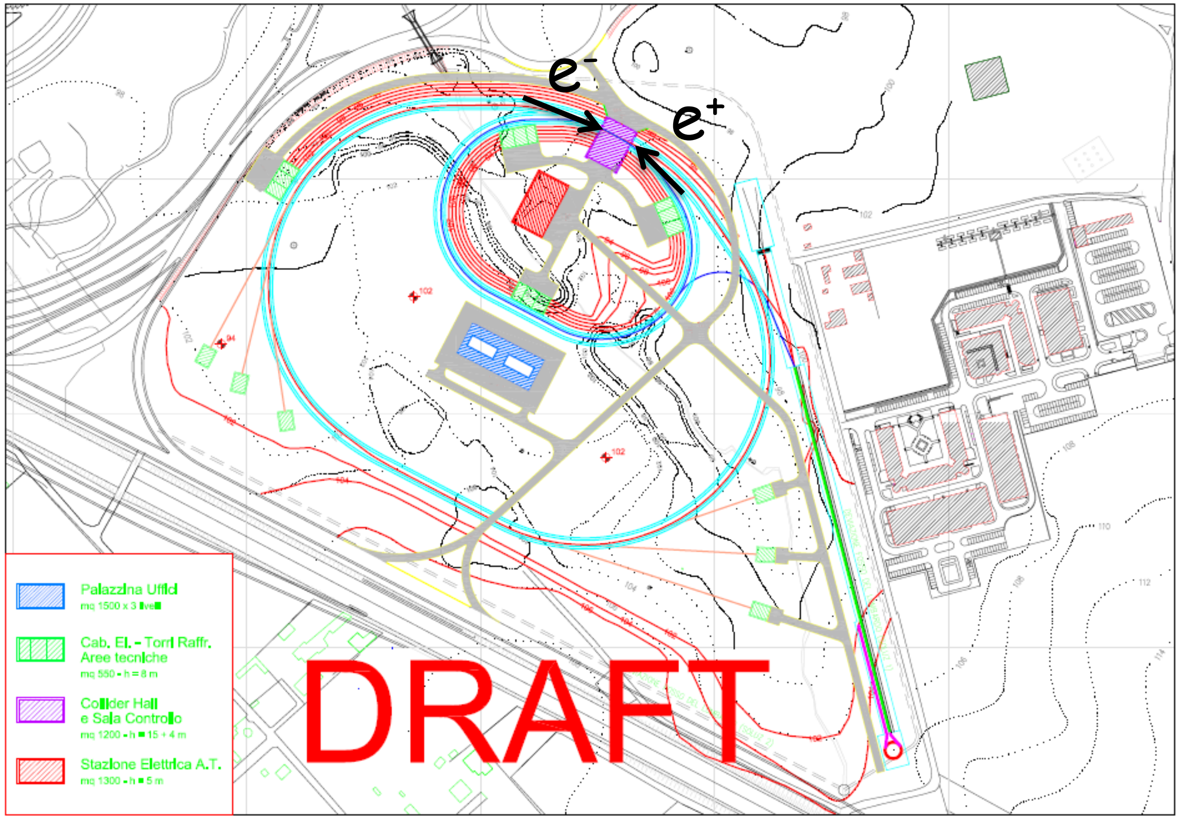
hep-ex/9405005

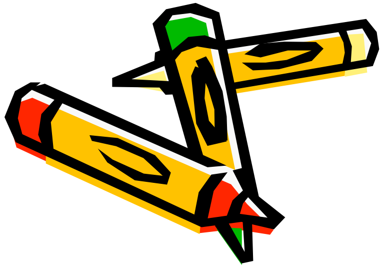
Next generation of
B experiments is
the LEP of Flavour

Flavour & NP Searches: complementarity:

- Don’t trust a discovery till you see the particle
- Don’t understand the new physics until you don’t explore its behaviour

The SuperB project

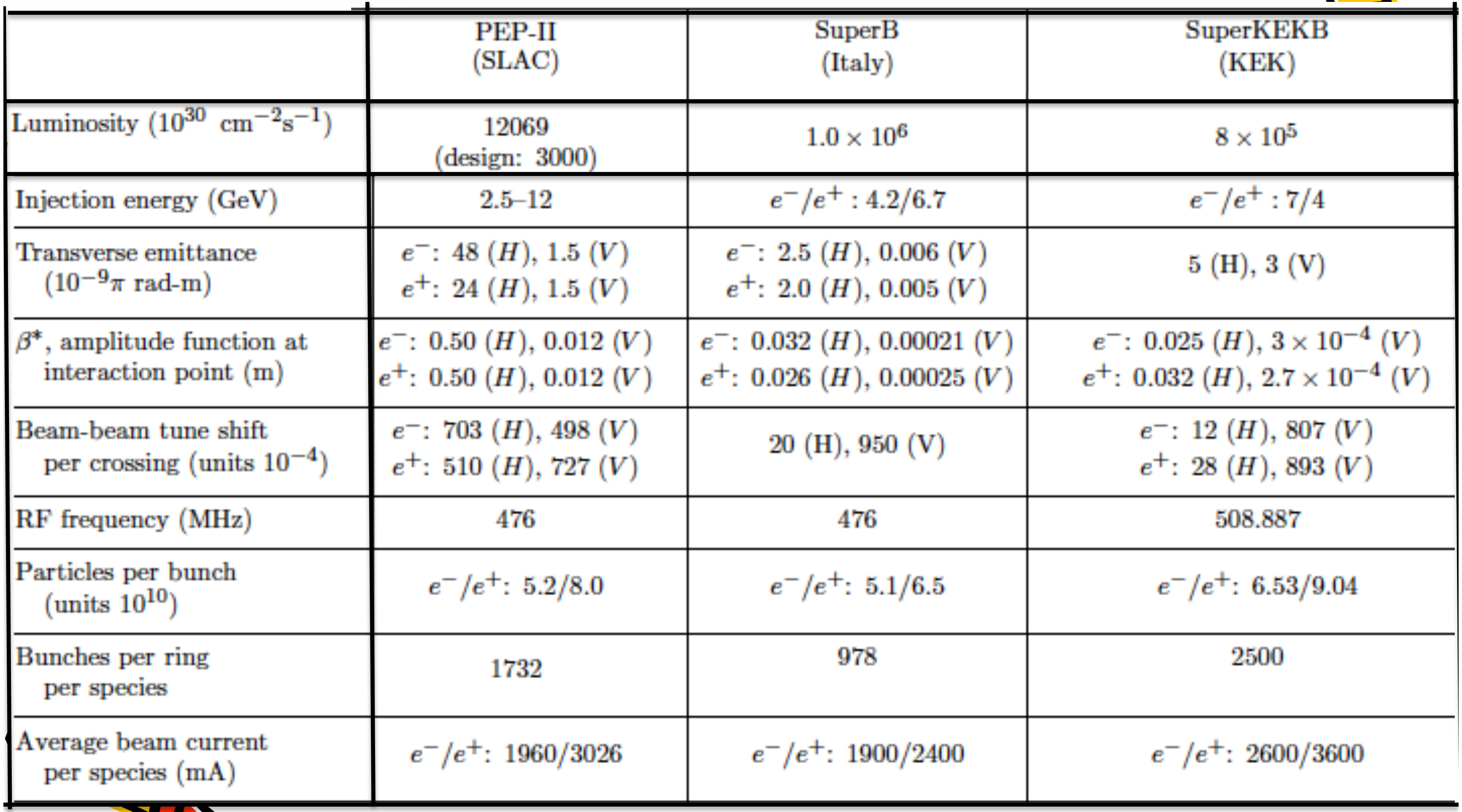




e^+e^- machine in TorVergata (Rome)

E_{CM}=4-12 GeV

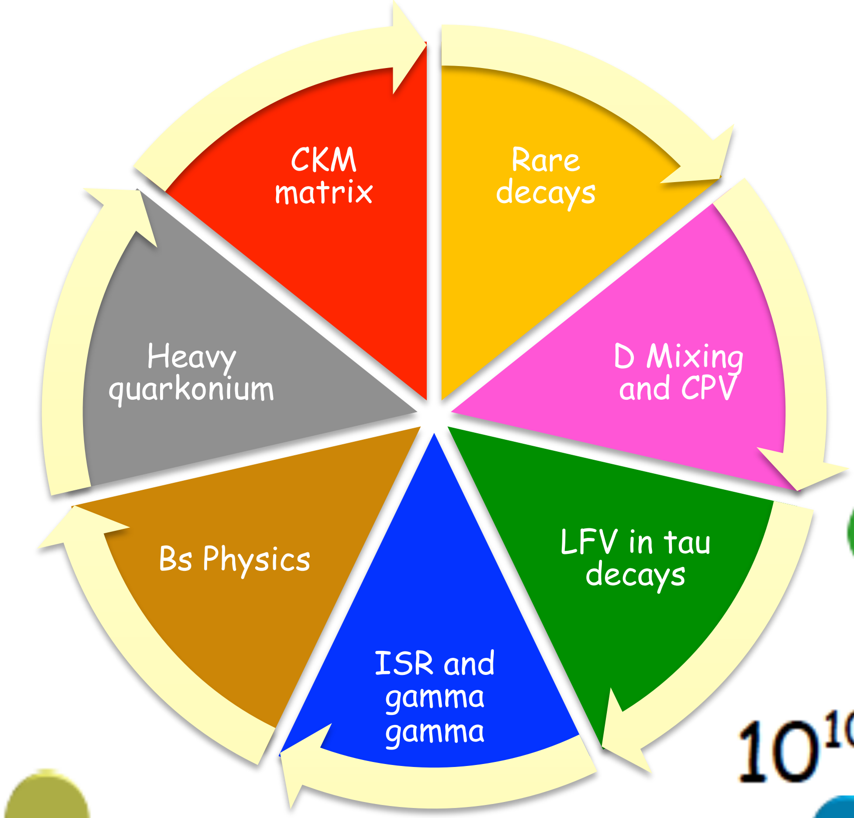
Accelerator Parameters



	PEP-II (SLAC)	SuperB (Italy)	SuperKEKB (KEK)
Luminosity (10^{30} $cm^{-2}s^{-1}$)	12069 (design: 3000)	1.0×10^6	8×10^5
Injection energy (GeV)	2.5–12	$e^-/e^+ : 4.2/6.7$	$e^-/e^+ : 7/4$
Transverse emittance ($10^{-9}\pi$ rad-m)	e^-: 48 (H), 1.5 (V) e^+: 24 (H), 1.5 (V)	e^-: 2.5 (H), 0.006 (V) e^+: 2.0 (H), 0.005 (V)	5 (H), 3 (V)
β^*, amplitude function at interaction point (m)	e^-: 0.50 (H), 0.012 (V) e^+: 0.50 (H), 0.012 (V)	e^-: 0.032 (H), 0.00021 (V) e^+: 0.026 (H), 0.00025 (V)	e^-: 0.025 (H), 3×10^{-4} (V) e^+: 0.032 (H), 2.7×10^{-4} (V)
Beam-beam tune shift per crossing (units 10^{-4})	e^-: 703 (H), 498 (V) e^+: 510 (H), 727 (V)	20 (H), 950 (V)	e^-: 12 (H), 807 (V) e^+: 28 (H), 893 (V)
RF frequency (MHz)	476	476	508.887
Particles per bunch (units 10^{10})	e^-/e^+: 5.2/8.0	e^-/e^+: 5.1/6.5	e^-/e^+: 6.53/9.04
Bunches per ring per species	1732	978	2500
Average beam current per species (mA)	e^-/e^+: 1960/3026	e^-/e^+: 1900/2400	e^-/e^+: 2600/3600

Not a single flagship analysis

$10^{10}\ B\bar{B}$



CKM matrix

Rare decays

D Mixing and CPV

LFV in tau decays

ISR and gamma gamma

Bs Physics

Heavy quarkonium

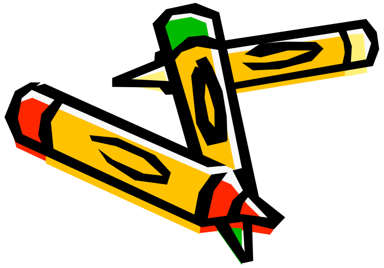
$10^{9}\ D\bar{D}$

$10^{10}\ \tau^{+}\tau^{-}$

$10^{10}\ B_s\bar{B}_s$

B_D PHYSICS

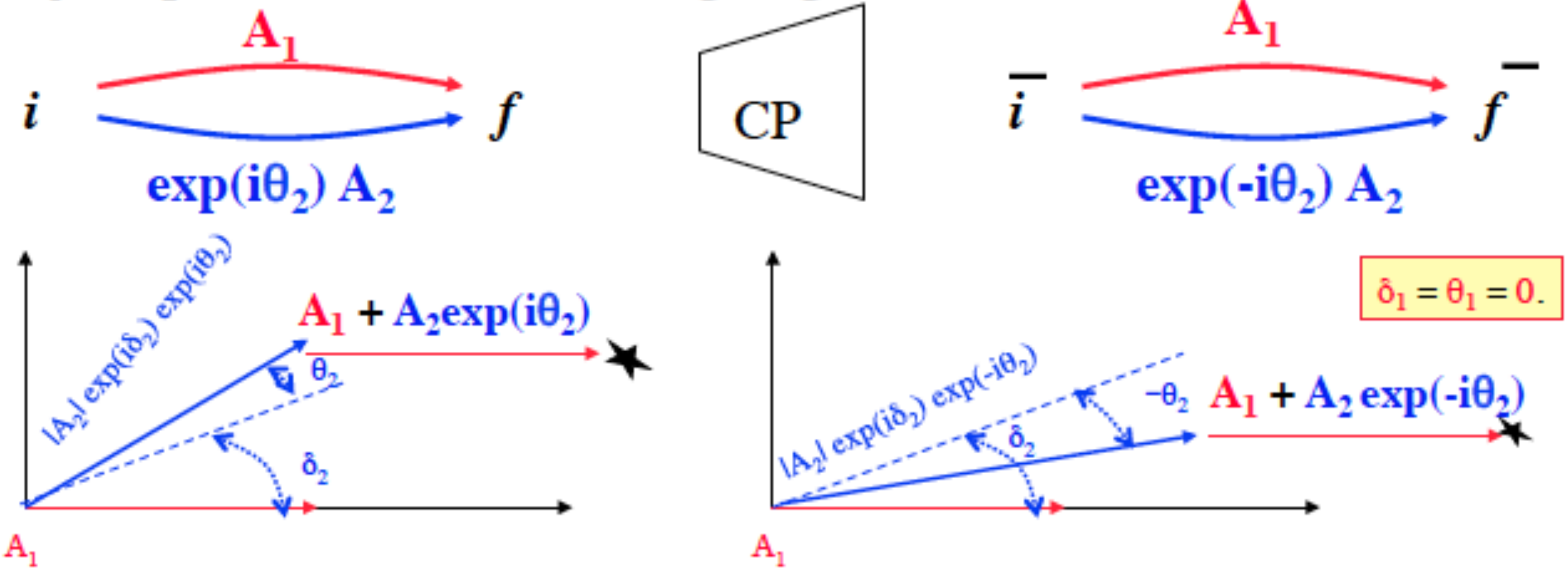
- CP violation (CKM)
- Rare Decays



How to observe CP-violating effects

θ_i is a phase that does change sign under CP;

δ_i is a phase that does not change sign under CP.



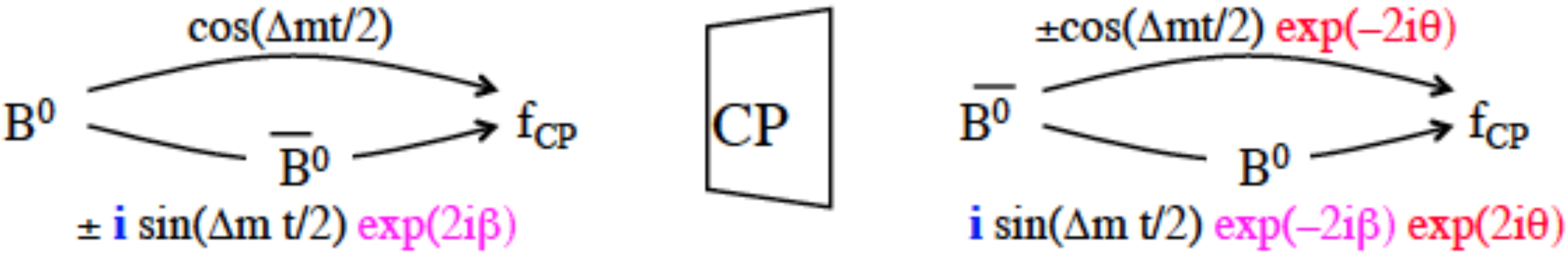
$\delta_1 = \theta_1 = 0.$

$$P(i \rightarrow f) - P(\bar{i} \rightarrow \bar{f})\ \alpha\ \ 2\,|A_1\ A_2|\,[\cos(\delta_2-\theta_2)-\cos(\delta_2+\theta_2)] = 2\,|A_1\ A_2|\,\sin(\delta_2)\,\sin(\theta_2)$$

⇒ CP-violating asymmetries between the decay of a particle and its antiparticle can arise from the interference between two decay amplitudes with relative CP-violating and non-CP-violating phases.

Example: time-dependent decays

The interference between $B^0 \leftrightarrow \overline{B^0}$ mixing and decays into a CP eigenstate (accessible to both B^0 and $\overline{B^0}$) provides the cleanest theoretical predictions:



$\cos(\Delta m t/2)$

B^0 $\overline{B^0}$ f_{CP}

$\pm i \sin(\Delta m\, t/2) \exp(2i\beta)$

CP

$\pm\cos(\Delta m t/2) \exp(-2i\theta)$

$\overline{B^0}$ B^0 f_{CP}

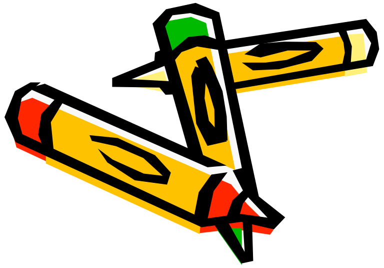
$i \sin(\Delta m\, t/2) \exp(-2i\beta) \exp(2i\theta)$

with a CP-violating asymmetry ≈ $\sin 2(\beta - \theta)$.

The CKM angle ϕ is associated with the mixing box diagram.
The CKM angle θ depends on the final state f_{CP}

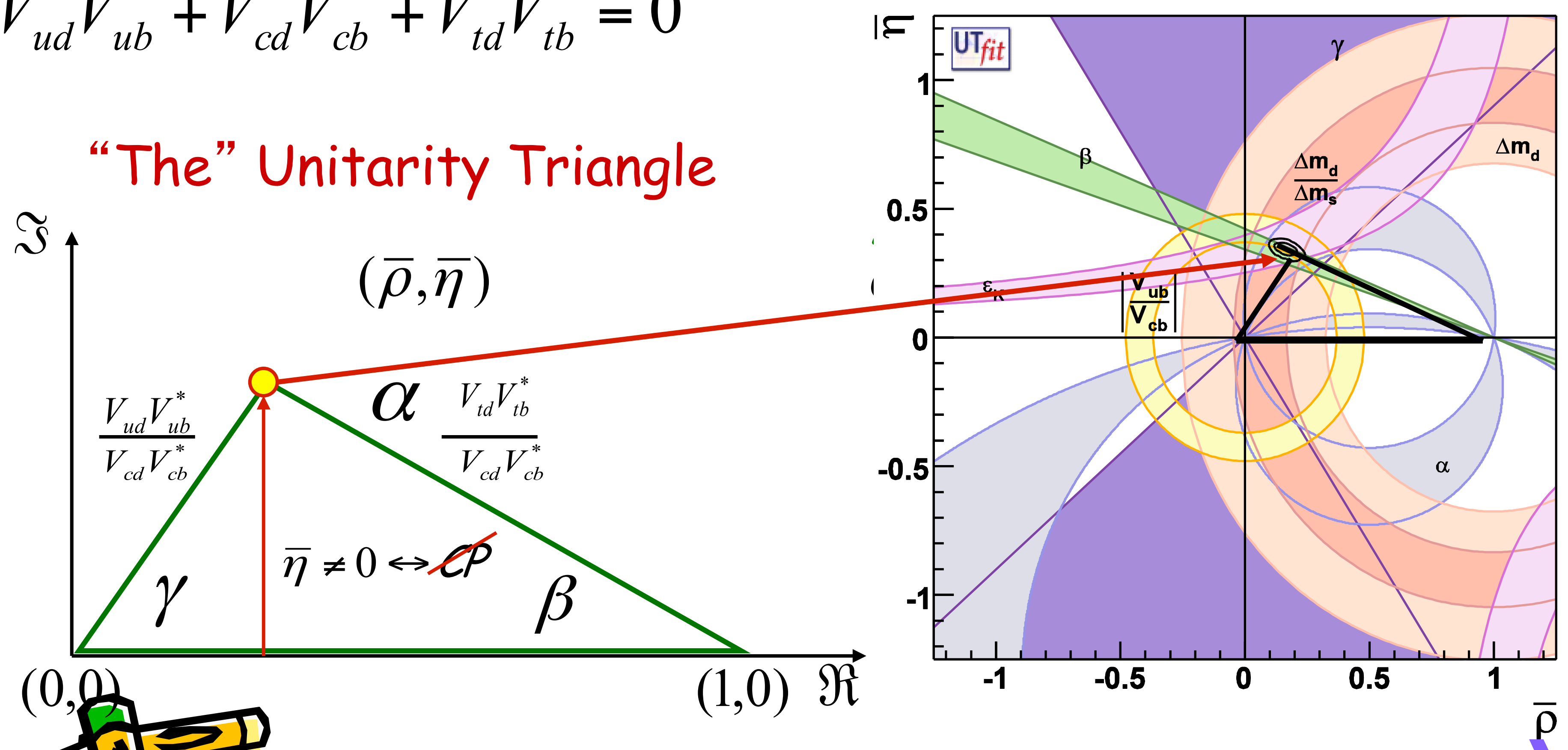
$$2\theta = Arg\left(\frac{A(B^0 \to f)}{A(\overline{B}^0 \to f)}\right)$$

DK



CP Violation and the Unitarity Triangle

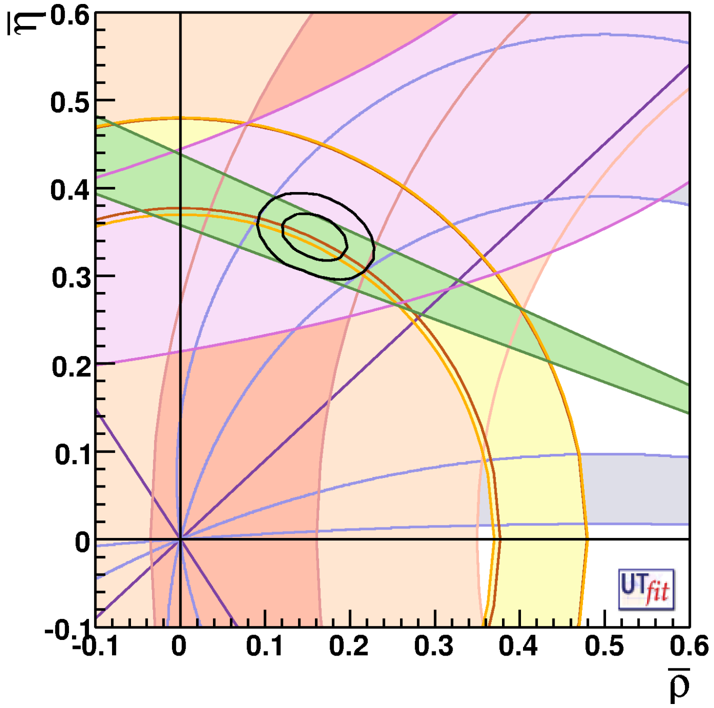
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$


“The” Unitarity Triangle

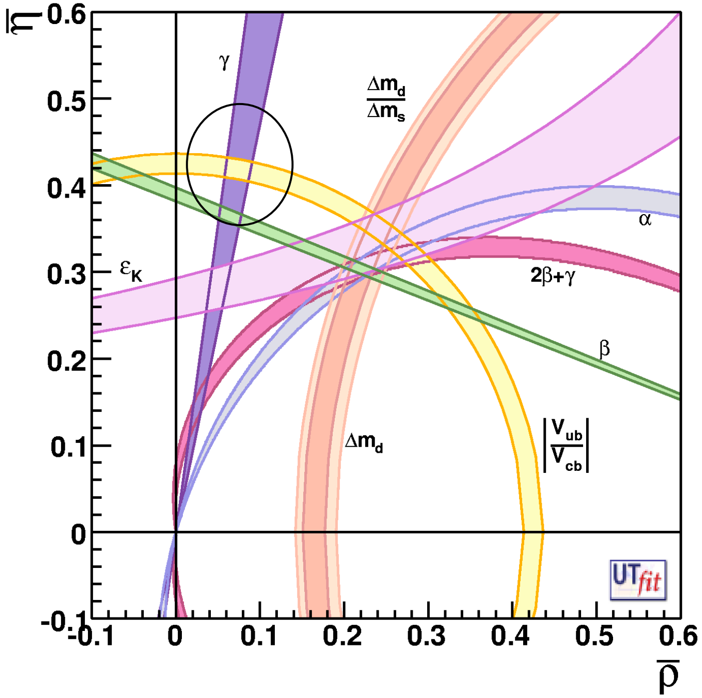
overconstrain the apex (ρ,η) and look for inconsistencies → New Physics!

CKM matrix

Today

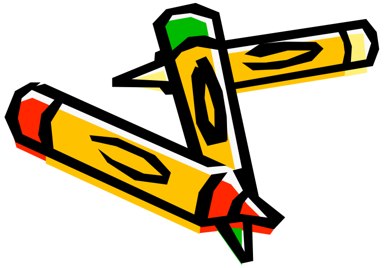


SuperB+Lattice improvements

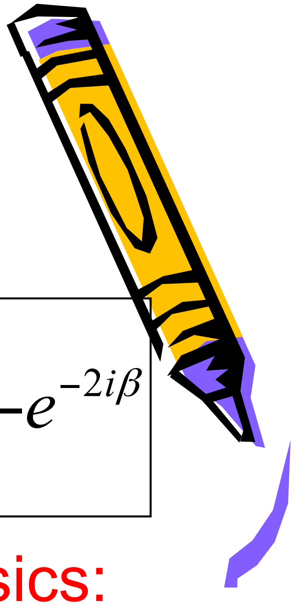


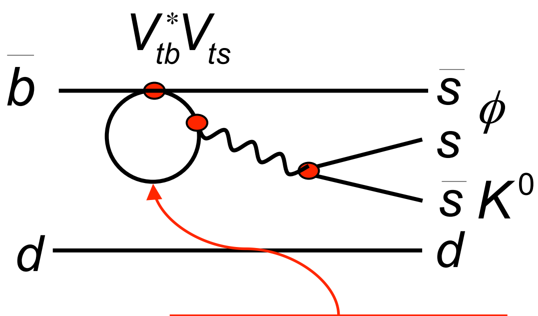
ρ = 0.163 ± 0.028
η = 0.344± 0.016

ρ = ± 0.0028
η = ± 0.0024



Penguins and new physics





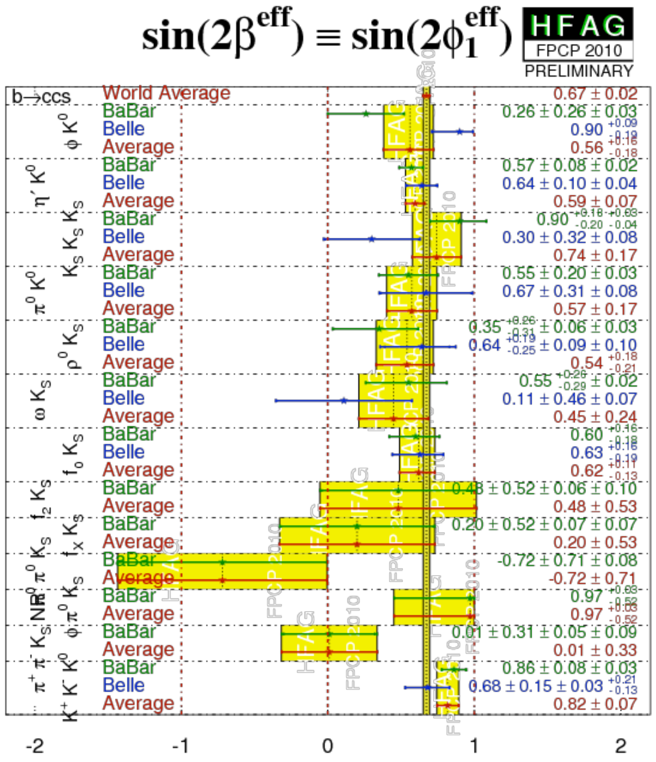
W + New Physics?

$b \to s\bar{s}s$

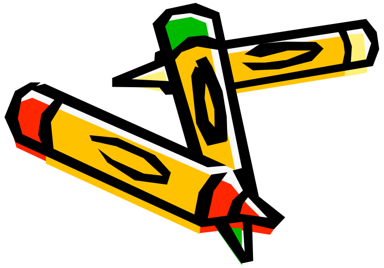
$$\lambda_{\phi K_S} = +\left(\frac{q}{p}\right)_B \left(\frac{V_{tb}V_{ts}^{*}}{V_{tb}^{*}V_{ts}}\right)\left(\frac{p}{q}\right)_K \approx -e^{-2i\beta}$$

In general case of New Physics:

$$\lambda_{J/\psi K_S} \neq \lambda_{\phi K_S}$$

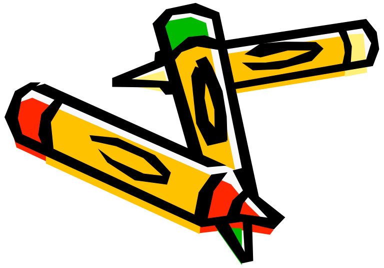


Much more statistics is needed to be conclusive on presence of New Physics

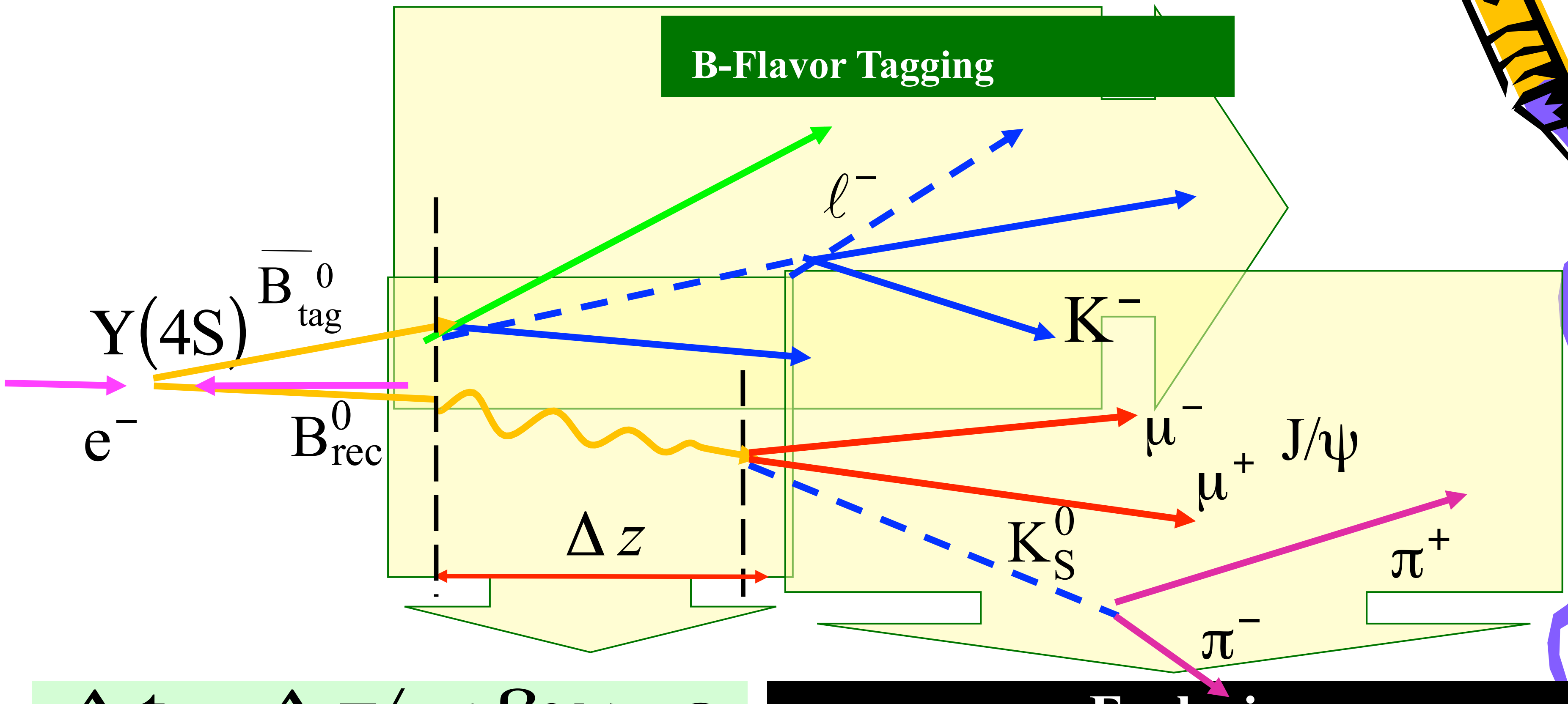


Rare decays

Mode	BR_{SM}	Notes on NP
$b \to s\gamma$	$\sim 3\ 10^{-4}$	BF, $A_{CP,}$ and A_{FB} important
$b \to sg$	$\sim 10^{-5}$ each	BF not critical. Need events to measure S_{CP}
$B \to Xll$	$\sim 10^{-6}$ each	BF, $A_{CP,}$ and A_{FB} important
$B \to X\nu\nu$	$\sim 10^{-6}$ each	Up to 10^{-5} each
$B \to \tau\nu$	$\sim 10^{-4}$	Experiments close to SM sensitivity
$B \to ll$	$<10^{-11}$	Up to 10^{-5}



Requirements from B physics



$$\Delta t \approx \Delta z / < \beta\gamma > c$$

Exclusive
B Meson Reconstruction

Asymmetric beams

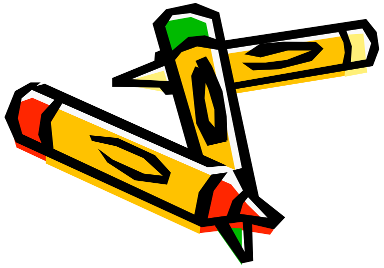
Good vertex measurement

High luminosity

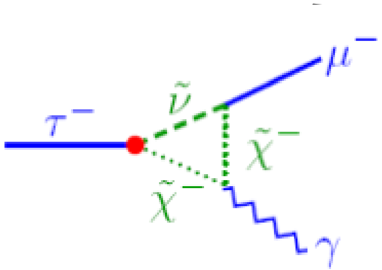
Detector hermeticity

TAU PHYSICS

- Lepton flavour violation

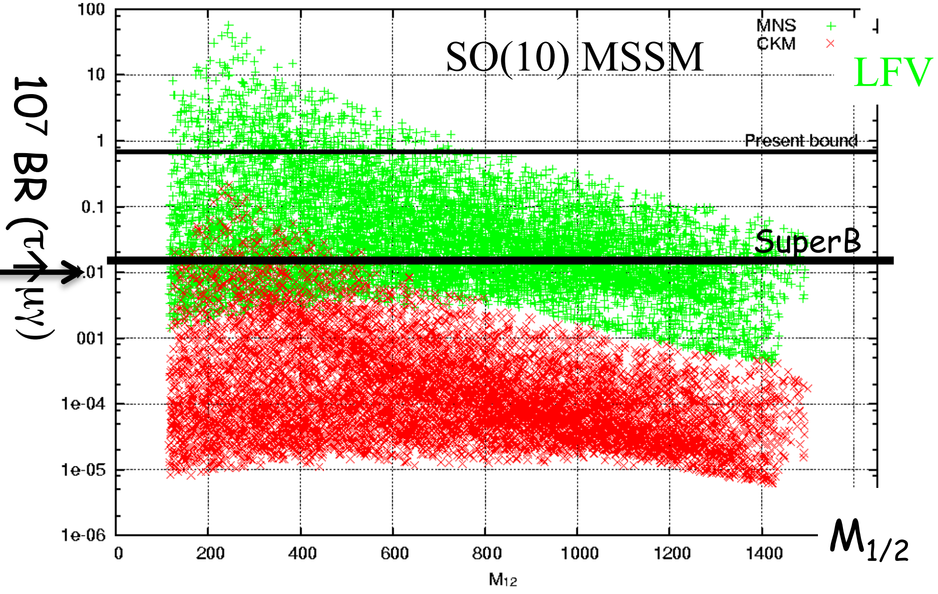


Lepton Flavour Violation τ→ μ γ. We can gain a very important order of magnitude $10^{-8} \rightarrow 10^{-9}$
Complementarity with μ → e γ



Process	Sensitivity
$\mathcal{B}(\tau \to \mu\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell K_S^0)$	2×10^{-10}

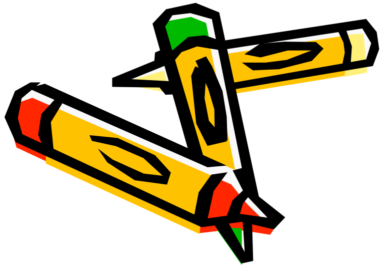
SuperB



LFV from CKM

LFV from PMNS

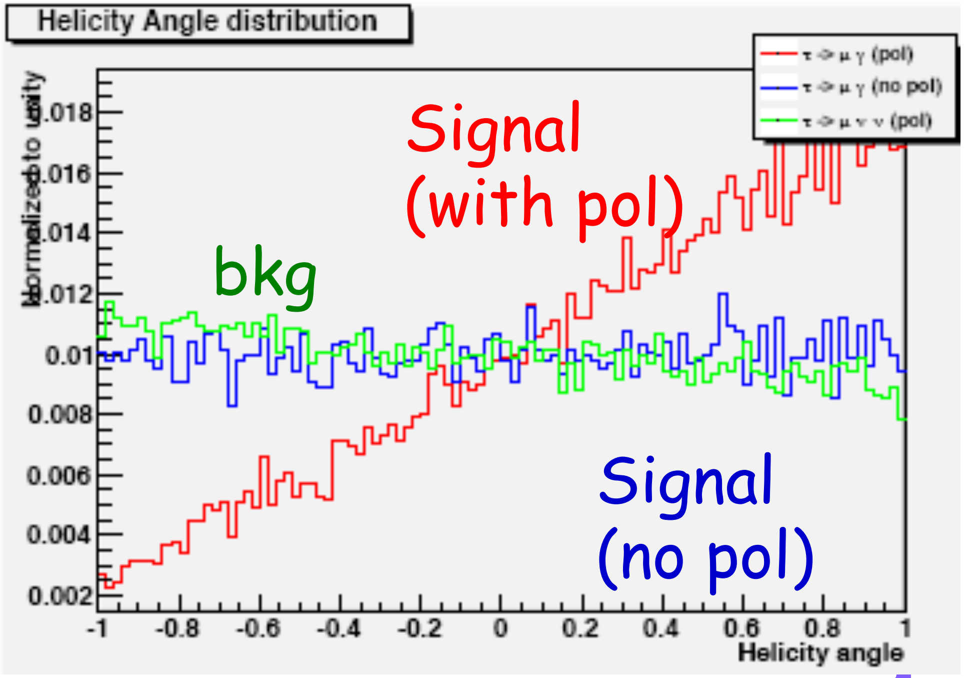
MEG sensitivity μ→eγ $\sim 10^{-13}$

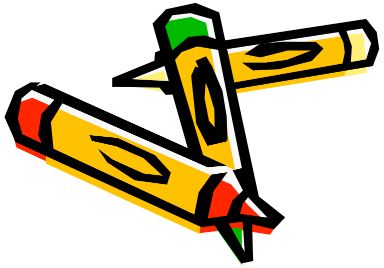


Polarized beams allow also measurement of electric dipole moments and $(g-2)_\tau$.[FIRST TIME]

Requirements from τ physics

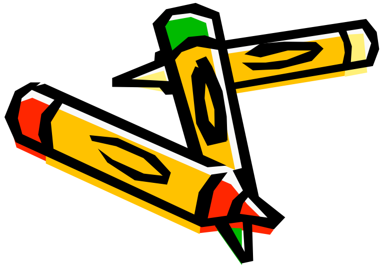
- High luminosity
- Beam polarization





CHARM PHYSICS

- CP violation
- Charm Threshold Physics
- Exotic charmonium spectroscopy

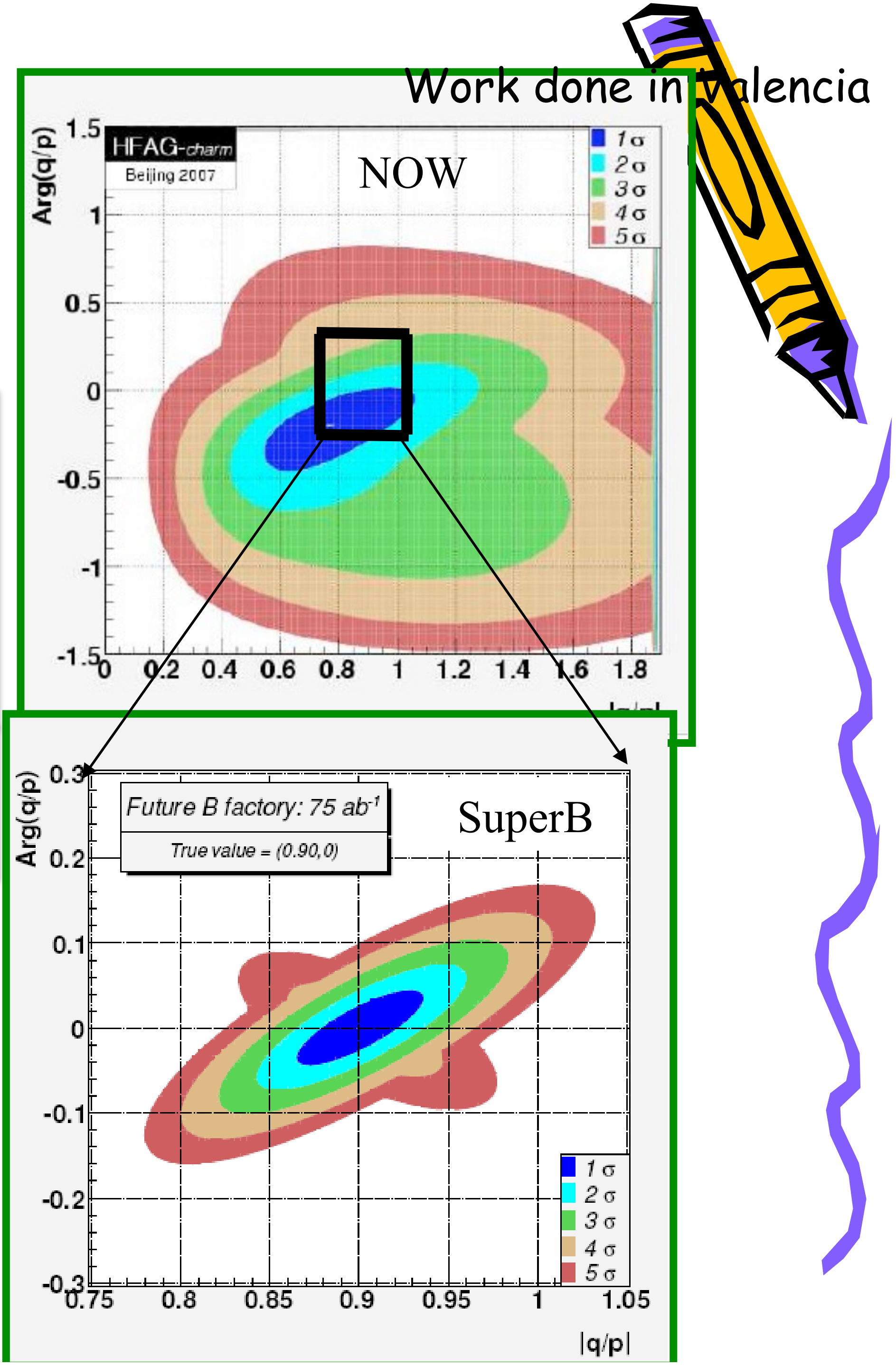


CP Violation in charm

Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 fb^{-1})
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}	
	y'	7×10^{-4}	
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}	
$D^0 \to K^0_S\pi^+\pi^-$	x	4.9×10^{-4}	
	y	3.5×10^{-4}	
	$\lvert q/p \rvert$	3×10^{-2}	
	ϕ	2°	
$\psi(3770) \to D^0\overline{D}^0$	x^2		$(1-2) \times 10^{-5}$
	y		$(1-2) \times 10^{-3}$
	$\cos\delta$		$(0.01-0.02)$

Charm Threshold physics

+ Measurements of phases needed for a precision measurement of γ


Work done in valencia

Exotic spectroscopy

the 1^{--} family

Z: charged candidates

Z(4430)

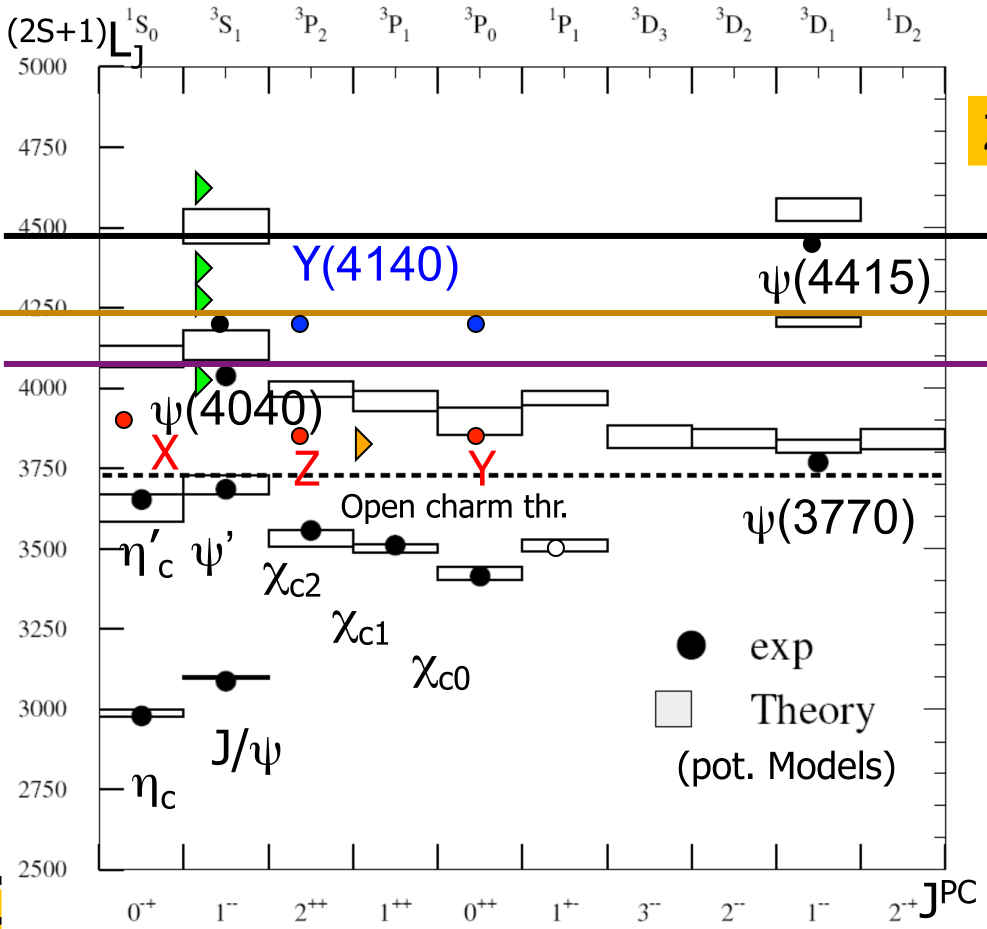
Z(4250)

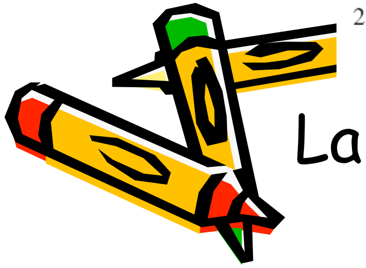
Z(4050)

X(3872)

the 3940 family

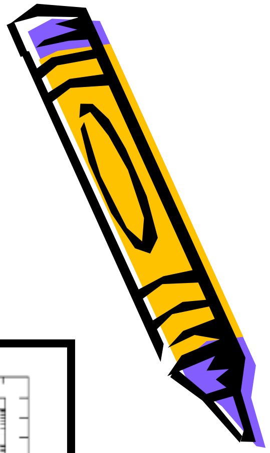
Regular charmonium



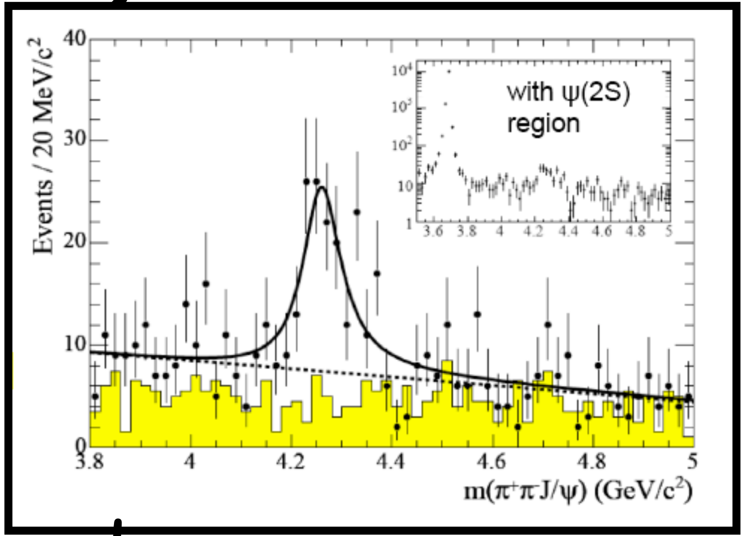


Large number of unexpected/unconventional states

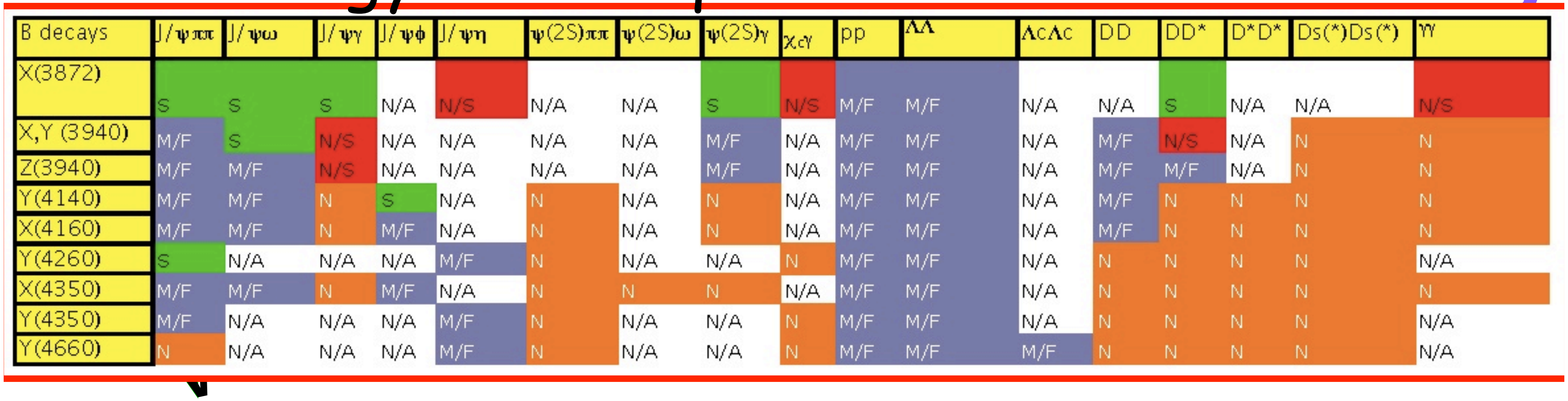
Exotic Spectroscopy (future)



- Low statistics
- Huge number of missing modes to study



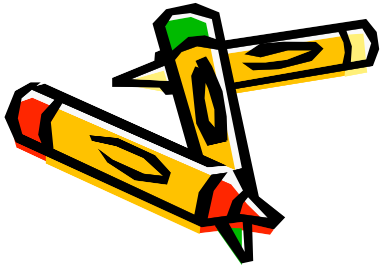
- Energy scan required



B decays	$J/\psi\pi\pi$	$J/\psi\omega$	$J/\psi\gamma$	$J/\psi\phi$	$J/\psi\eta$	$\psi(2S)\pi\pi$	$\psi(2S)\omega$	$\psi(2S)\gamma$	$\chi_c\gamma$	pp	ΛΛ	ΛcΛc	DD	DD*	D*D*	Ds(*)Ds(*)	γγ
X(3872)	S	S	S	N/A	N/S	N/A	N/A	S	N/S	M/F	M/F	N/A	N/A	S	N/A	N/A	N/S
X,Y (3940)	M/F	S	N/S	N/A	N/A	N/A	N/A	M/F	N/A	M/F	M/F	N/A	M/F	N/S	N/A	N	N
Z(3940)	M/F	M/F	N/S	N/A	N/A	N/A	N/A	M/F	N/A	M/F	M/F	N/A	M/F	M/F	N/A	N	N
Y(4140)	M/F	M/F	N	S	N/A	N	N/A	N	N/A	M/F	M/F	N/A	M/F	N	N	N	N
X(4160)	M/F	M/F	N	M/F	N/A	N	N/A	N	N/A	M/F	M/F	N/A	M/F	N	N	N	N
Y(4260)	S	N/A	N/A	N/A	M/F	N	N/A	N/A	N	M/F	M/F	N/A	N	N	N	N	N/A
X(4350)	M/F	M/F	N	M/F	N/A	N	N	N	N/A	M/F	M/F	N/A	N	N	N	N	N
Y(4350)	M/F	N/A	N/A	N/A	M/F	N	N/A	N/A	N	M/F	M/F	N/A	N	N	N	N	N/A
Y(4660)	N	N/A	N/A	N/A	M/F	N	N/A	N/A	N	M/F	M/F	M/F	N	N	N	N	N/A

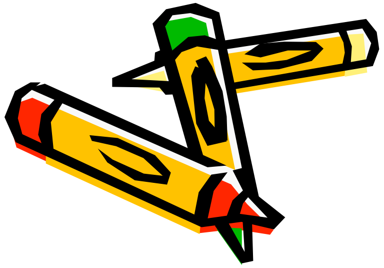
Requirements from charm physics

- High luminosity
- Scan energy from charm threshold (3.5 GeV) to $\Upsilon(4S)$



ABOVE Υ(4S) PHYSICS

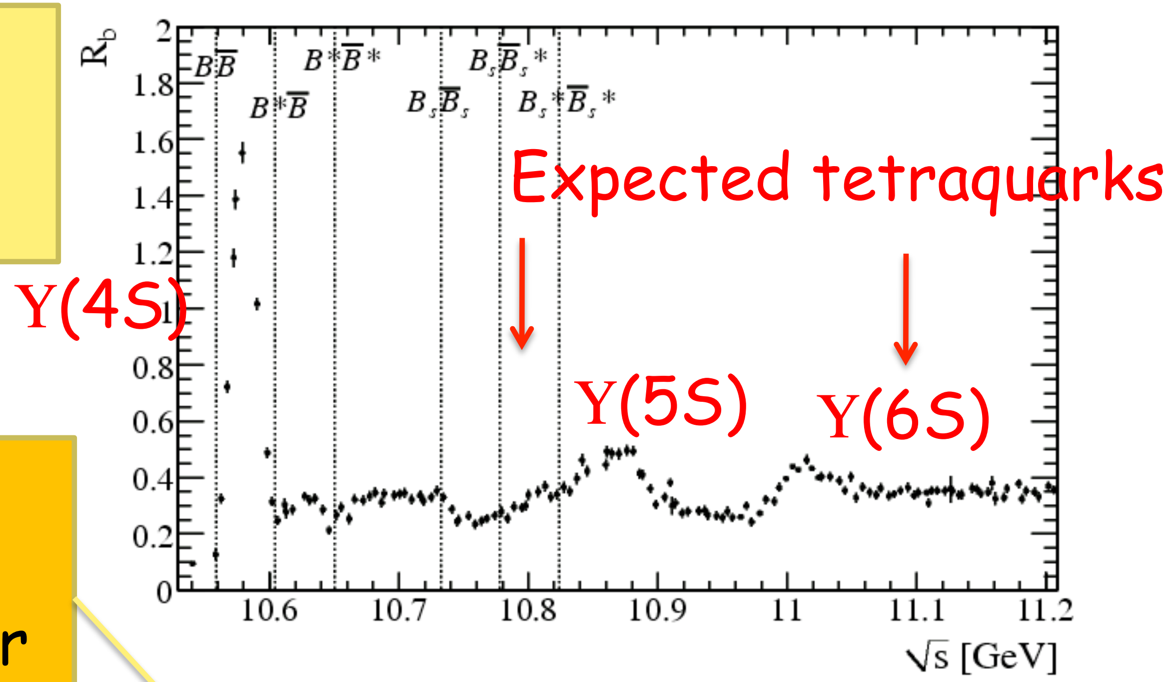
- Exotic Bottomonium
- Bs Physics



Scan between Υ(4S) and $\Lambda_b\Lambda_b$

Inclusive scan did not show effects

Exclusive analyses requires larger luminosity



Expected tetraquarks

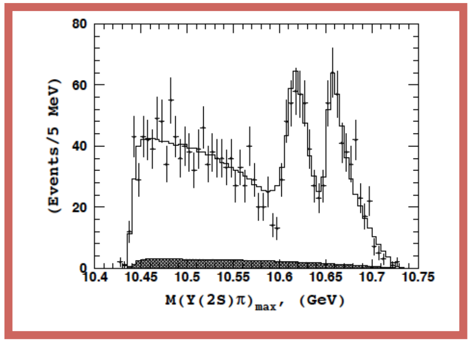
Υ(4S)

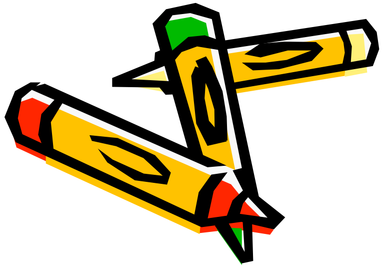
Υ(5S)

Υ(6S)

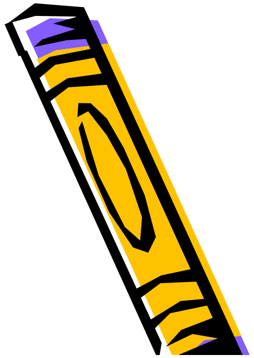
E.g. Belle at Υ(5S)

$\Upsilon(5S) \rightarrow Z_b^+\pi^- \rightarrow \Upsilon(2S)\pi^+\pi^-$





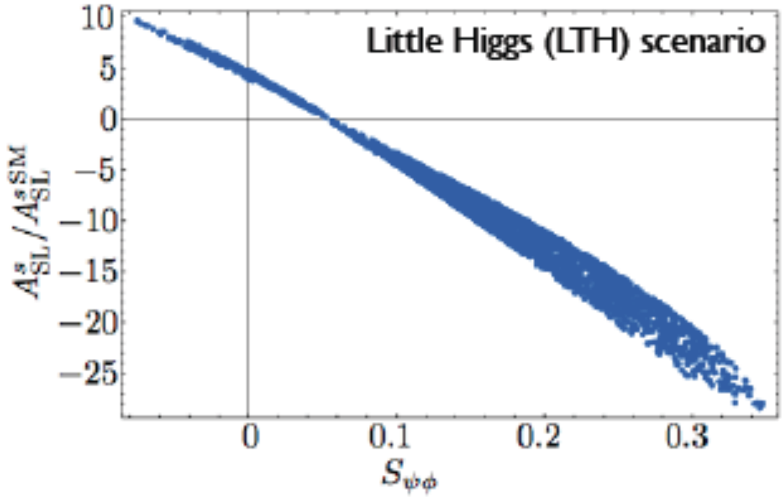
Bs Physics

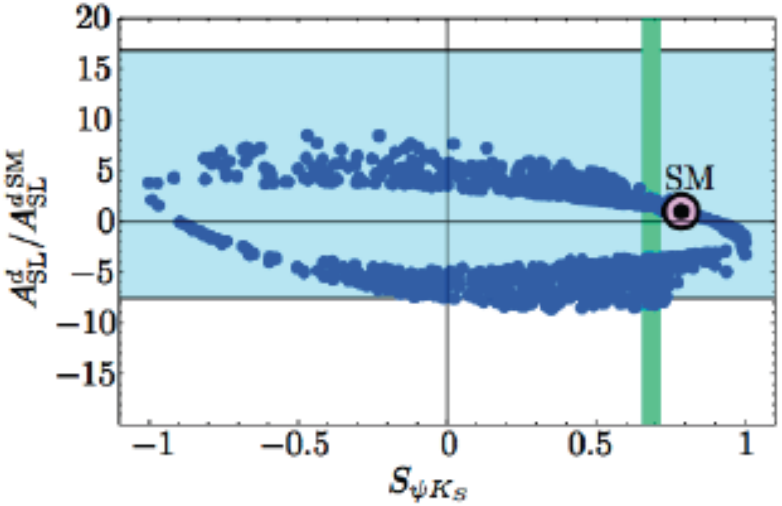


- Can cleanly measure A^s_{SL} using 5S data

$$A^s_{SL} = \frac{\mathcal{B}(B_s \to \overline{B}_s \to X^-\ell^+\nu_\ell) - \mathcal{B}(\overline{B}_s \to B_s \to X^-\ell^+\nu_\ell)}{\mathcal{B}(B_s \to \overline{B}_s \to X^-\ell^+\nu_\ell) + \mathcal{B}(\overline{B}_s \to B_s \to X^-\ell^+\nu_\ell)} = \frac{1 - |q/p|^4}{1 - |q/p|^4}$$

$$\sigma(A^s_{SL}) \sim 0.004 \text{ with a few } ab^{-1}$$

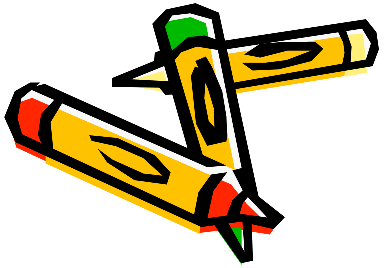




- SuperB can also study rare decays with many neutral particles, such as $B_s \to \gamma\gamma$, which can be enhanced by SUSY.

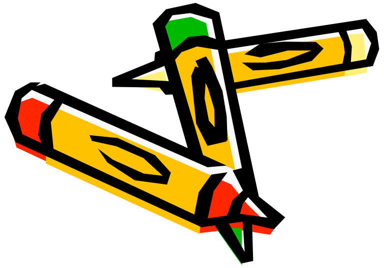
Requirements from above Υ(4S) physics

- High luminosity @ Υ(5S)
- Scan energy from Υ(4S) to 11 GeV

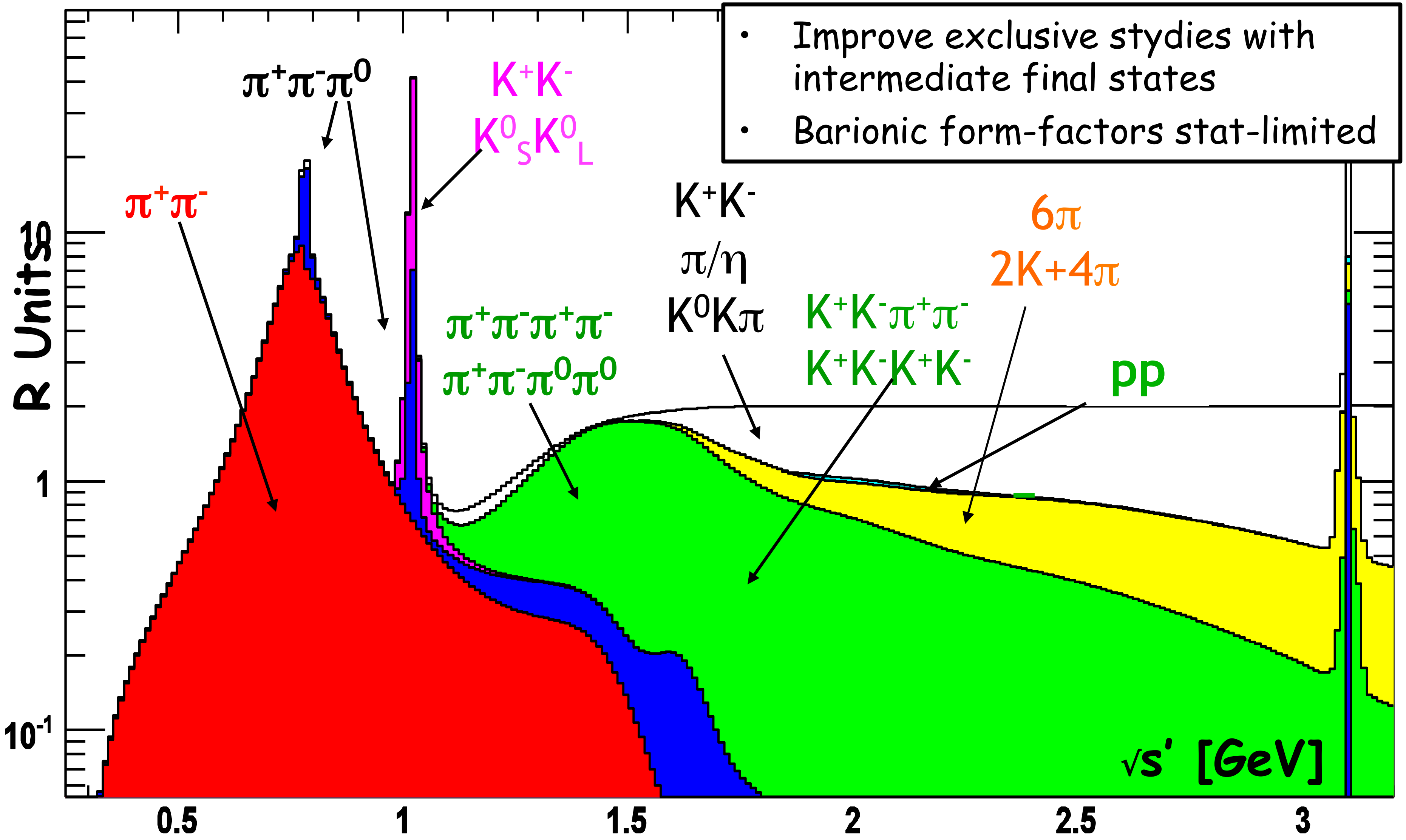


OTHER PHYSICS

- ISR
- γγ physics
- Electroweak physics
- Direct searches for exotics (light higgs, dark forces, invisible Υ decays)



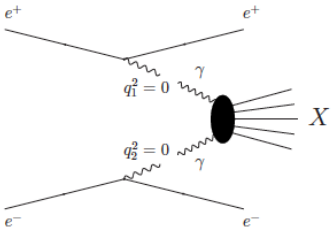
$e^+e^- \to \gamma_{ISR} X_{light}$



- Improve exclusive stydies with intermediate final states
- Barionic form-factors stat-limited

↔ Critical region for δa_μ

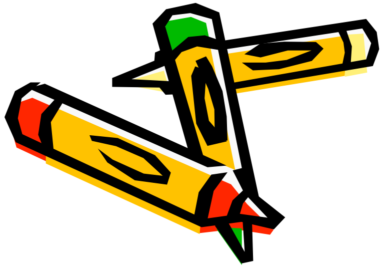
↔ Critical region for $\Delta\alpha_{had}$



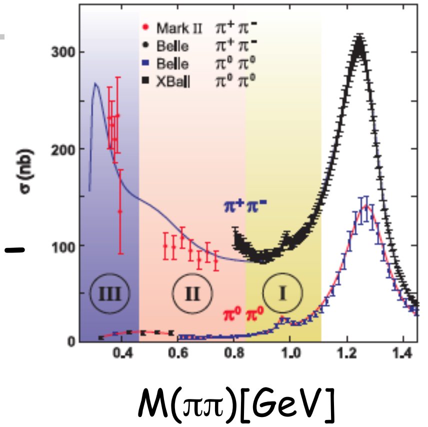
γγ physics

- Study of resonances γγ width
- Measurement of form factors
- Search for new states with C=+ (e.g. hybrids with X=ηπ)

Would profit from lowering the minimal triggered invariant mass



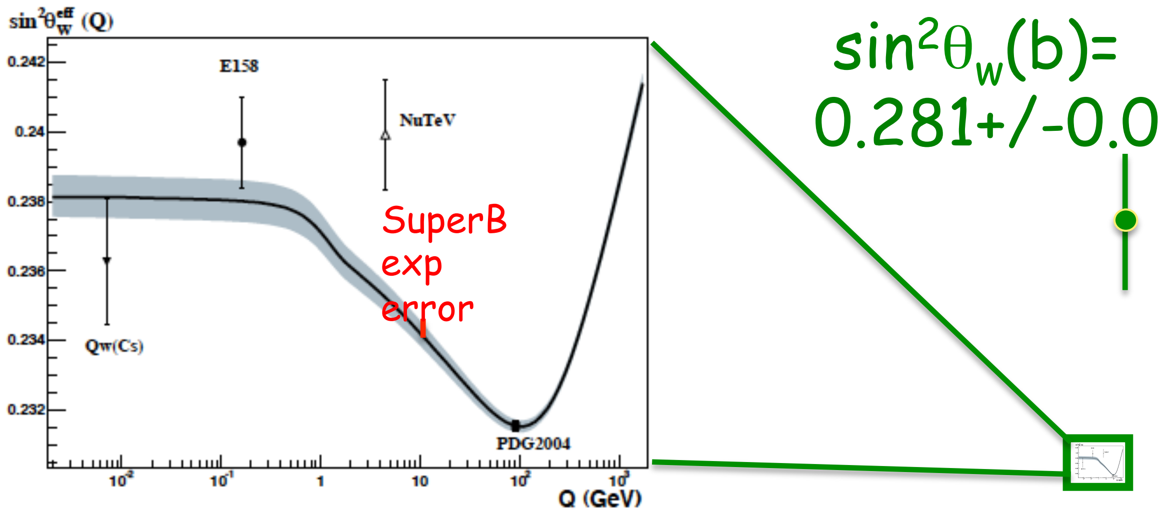
e+e- → e+e-π+π-



O. Vive
M. Rone

Electroweak

- Inconsistencies among $\sin^2\theta_W$ measurements at LEP could be further investigated with precise $A_{LR}(f)$, $A_{pol}(\tau)$ measurements at SuperB



SuperB exp error

Note:
$\sin^2\theta_W(b)=$
$0.281+/-0.016$

- Without polarization measurement dominated by measurements of g_A(=-0.5 in SM). Second order sensitivity to $\sin^2\theta_W$ → polarization is critical

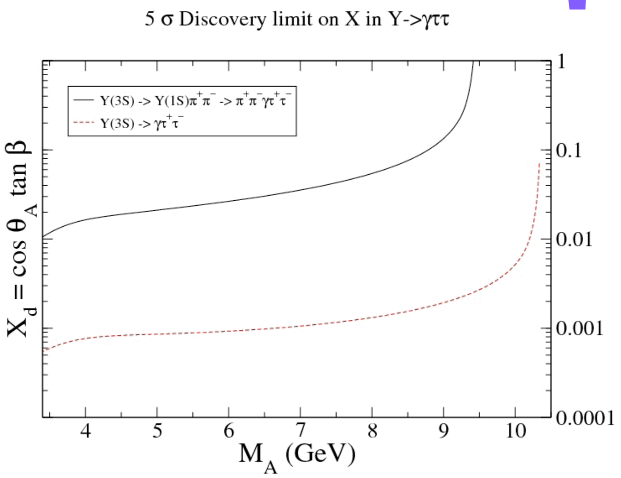
Light higgs

- There are models (eg NMSSM) where LEP cannot exclude completely CP-odd Higgs with $m_A<2m_B$

$$\Upsilon(nS) \rightarrow A\,\gamma \rightarrow \tau\tau\,\gamma$$

$$\boxed{R_{\tau/\ell} = \frac{\Gamma_{\Upsilon(nS)\to\gamma_s\tau\tau}}{\Gamma_{\ell\ell}^{(em)}} = \frac{B_{\tau\tau}-B_{\ell\ell}}{B_{\ell\ell}} = \frac{B_{\tau\tau}}{B_{\ell\ell}}-1}$$

- Two approaches:
  - ◆ Search for deviations from lepton universality in ϒ decays
    - ☹ Dominated by systematics
  - ◆ Search for monochromatic photon
    - ☹ Large background from $e^+e^- \rightarrow \tau\tau\gamma$
    - ☺ Use cascade $\Upsilon(3S)\rightarrow\Upsilon(1S)\pi\pi\rightarrow A\gamma\,\pi\pi$



Dark matter searches

DM

Dominant mode $\Upsilon(3S) \to \Upsilon(1S)\pi\pi \to \chi\chi\pi\pi \to$

THE STANDARD MODEL

$$BR(\Upsilon(1S) \to \nu\bar{\nu}) = \frac{N_\nu G_F^2}{48\pi} \left| 1 - \frac{4}{3}\sin^2\theta_W \right|^2 \frac{f_{\Upsilon(1S)}^2 M_{\Upsilon(1S)}^3}{\Gamma_{\Upsilon(1S)}}$$

$$BR(\Upsilon(1S) \to \nu\bar{\nu}) = (1.03 \pm 0.04) \times 10^{-5}$$

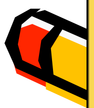
LOW-MASS DARK MATTER

Fayet, McElrath, Yeghiyan, ...

Most recently, Yeghiyan calculated from an effective theory that:

$$BR(\Upsilon(1S) \to \phi\bar{\phi}) = \frac{C_3^2}{\Lambda_H^4} \frac{f_{\Upsilon(1S)}^2}{48\pi\Gamma_{\Upsilon(1S)}} \left| M_{\Upsilon(1S)}^2 - 4m_\phi^2 \right|^{3/2}$$

where the production of the dark matter is mediated by heavy degrees of freedom whose mass scale is Λ_H and where C_3 is the (real-valued) Wilson coefficient for the term in the effective theory that leads to this final state.

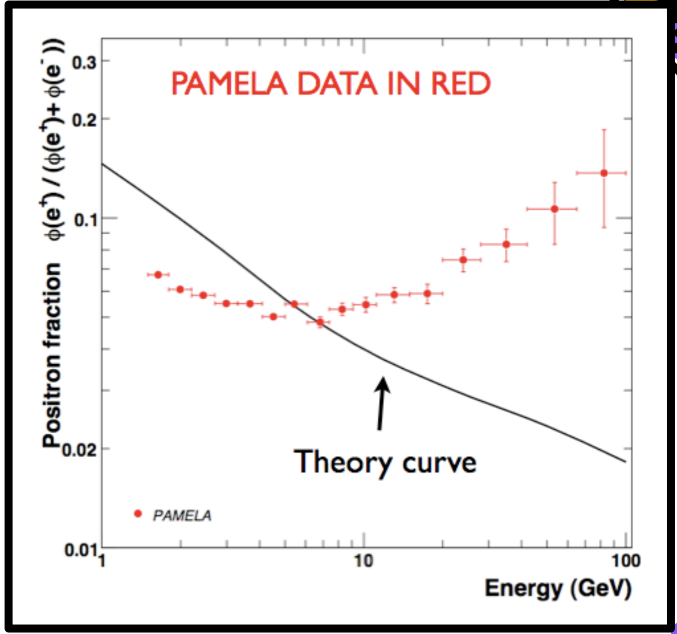


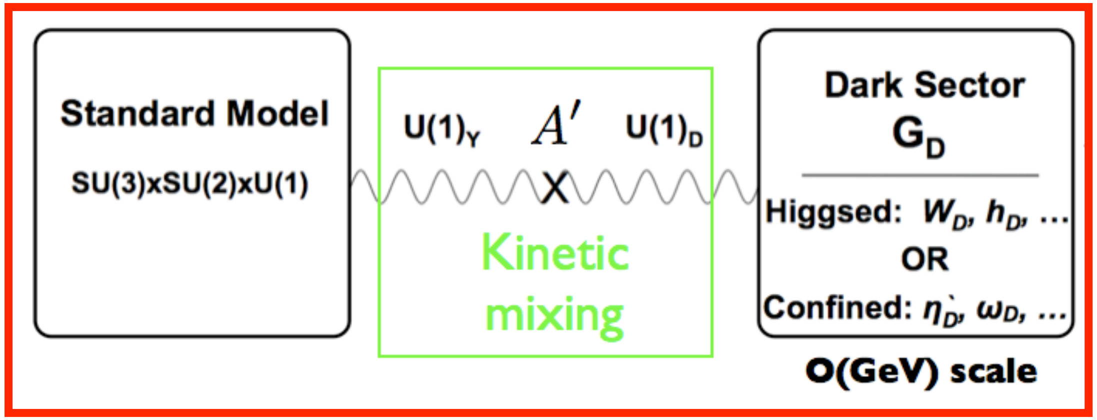
Search for Dark Forces

Results from Pamela/Fermi: excess of positrons of astrophysical origin

➔Due to particles decaying into e^+e^- with $m<2m_p$?

➔ "Dark" gauge sector





Standard Model

SU(3)xSU(2)xU(1)

$U(1)_Y$ A' $U(1)_D$

X

Kinetic mixing

Dark Sector

G_D

Higgsed: W_D, h_D, …

OR

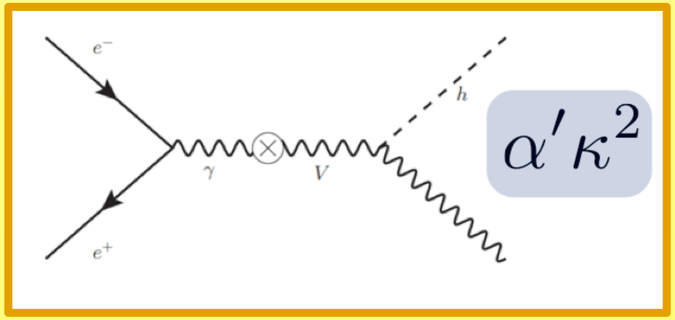
Confined: η_D', ω_D, …

O(GeV) scale

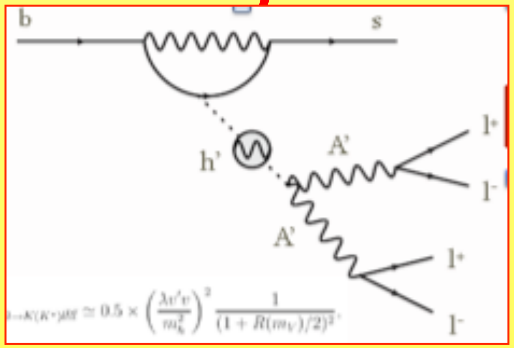
Sensitivity to dark forces

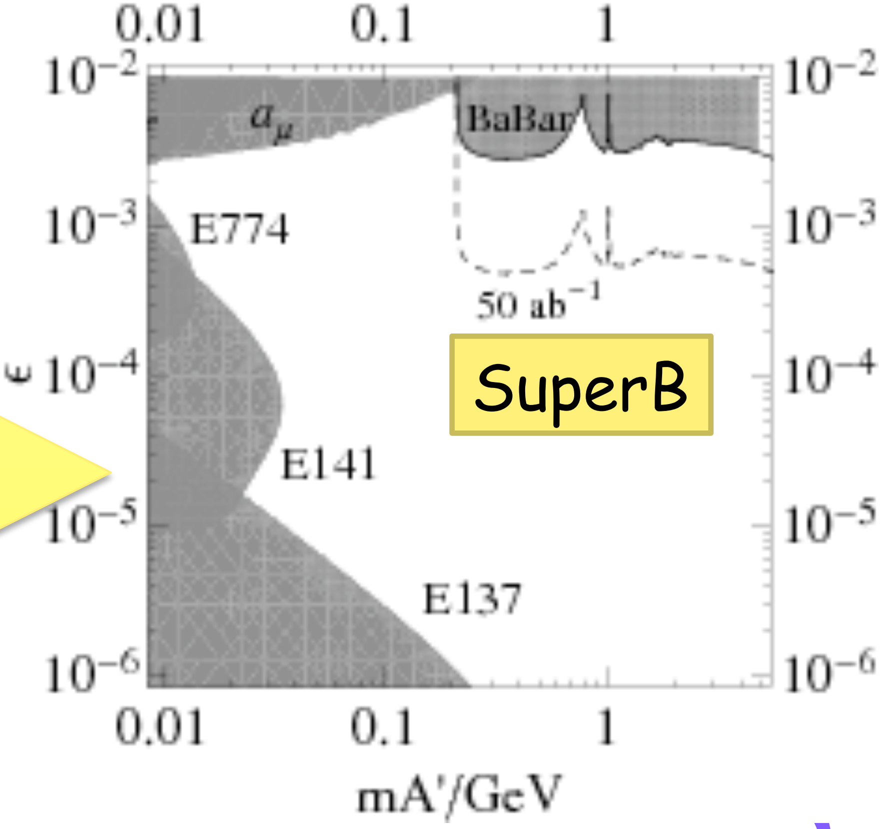
Discovery modes:

- Direct production



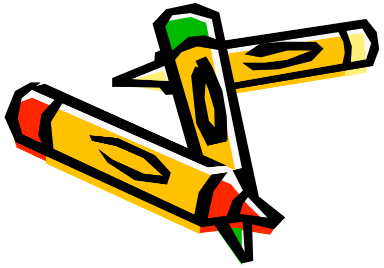
- B decays





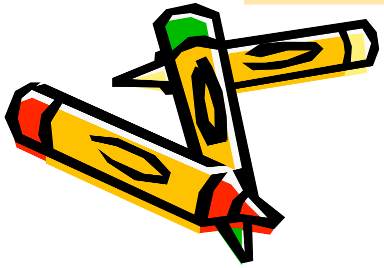
Requirements from "other" physics

- High luminosity
- Customed triggers

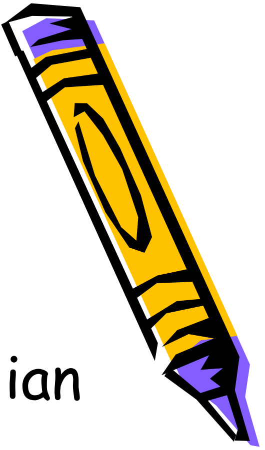


Requirements and competitors

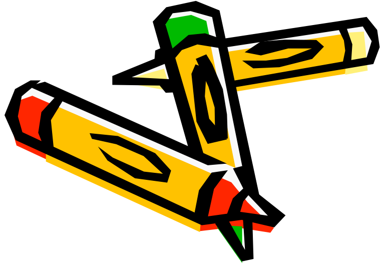
Requirements	Competitors
High luminosity @ $\Upsilon(4S)$ Asymmetric beams Good vertex resolution	Belle II (1/4 lumi, starting earlier) LHCb (dirty environment, limited number of channels accessible)
polarization	nobody
Energy scan	BES III (up to 4 GeV) Panda (ppbar@threshold) –much lower stat/ only conventional J^{CP}



Status of the project



- SuperB has been approved within the new italian research plan.
- Reasearch plan endorsed by “CIPE” (the institution responsible for infrastructure long term plans)
- A financial allocation of 250 Million Euros from the italian government in about five years approved for the “superb flavour factory”
- Site established in May 2011



- **Currently:**
  - Building the international collaboration on the detector
  - Finalizing machine design
  - Aiming at writing the TDR by 2012

Summary

SuperB is a Super-Flavour-Factory

- Produces huge numbers of B_d, B_s, D, τ, $\gamma\gamma$, and continuum events
- Searches for impact of new physics in flavour decays but not only

SuperB presents unique characteristics:

- Luminosity
- Beam polarization
- Energy scan potentialities

Ifs game:

- if LHC sees NP you want to know the impact on flavour
- if LHC does not see NP, it might have a mass visible only in flavour
- if LHCb sees NP you want confirmation in e+e-

→ SuperB & LHCb wanted anyhow