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Future of Heavy Flavour Physics

(on the occasion of 70th anniversary of Peter,

Gentleman of Heavy Flavour !!!)

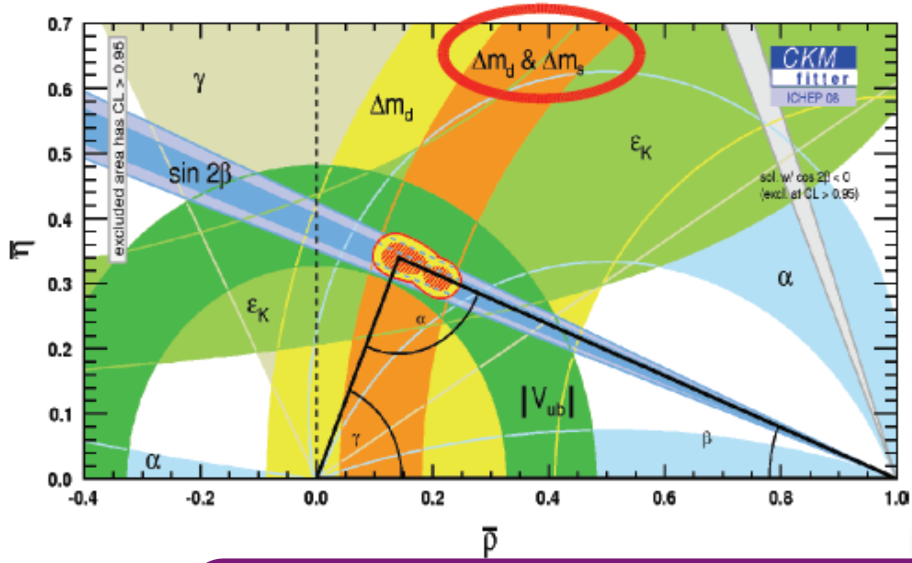
- ***Next 3-5 years:** Prospects to discover New Physics (NP) in heavy flavours (Tevatron & LHCb)*
- ***2012-2020:** If NP found at LHC what are the opportunities with with heavy flavours??? Kaon experiments & SuperB & SuperLHCb Who is the best suited for what?*
- ***If nothing but SM Higgs found at LHC ?** ν**MSM could be an elegant solution to solve the problems of SM Prospects to search for O(1 GeV) neutrino in heavy flavor decays***

Successes of the Standard Model

LEP, SLC, Tevatron and B-factories established that Standard Model really describes the physics at energies up to √s ~ 200 GeV

State-of-art is given by UT:

The quark sector is well described by the CKM mechanism



- *Accuracy of sides is limited by theory:*

  Extraction of $|V_{ub}|$

  Calculation of $\xi^2 = \frac{\hat{B}_{B_s} f_{B_s}^2}{\hat{B}_{B_d} f_{B_d}^2}$

- *Accuracy of angles is limited by experiment:*

  $\sigma(\alpha) \sim 5°, \sigma(\beta) \sim 1°, \sigma(\gamma) \sim 20°$

  ϕ_s (= $2\beta_s$ in SM) is not well measured !
  Hint for a large value (well beyond SM) from Tevatron

Standard Model is a precisely tested theory
however does not provide the whole picture…

- *Neutrino mass & oscillations*
- *Dark matter*
- *Baryon asymmetry of the Universe*
- *Higgs mass divergence (Higgs is not found yet !!!)*

LHC Physics Goals

Main Goals:

- Search for the SM Higgs boson in mass range ~ 115 < m_H < 1000 GeV
- Search for New Physics beyond the SM

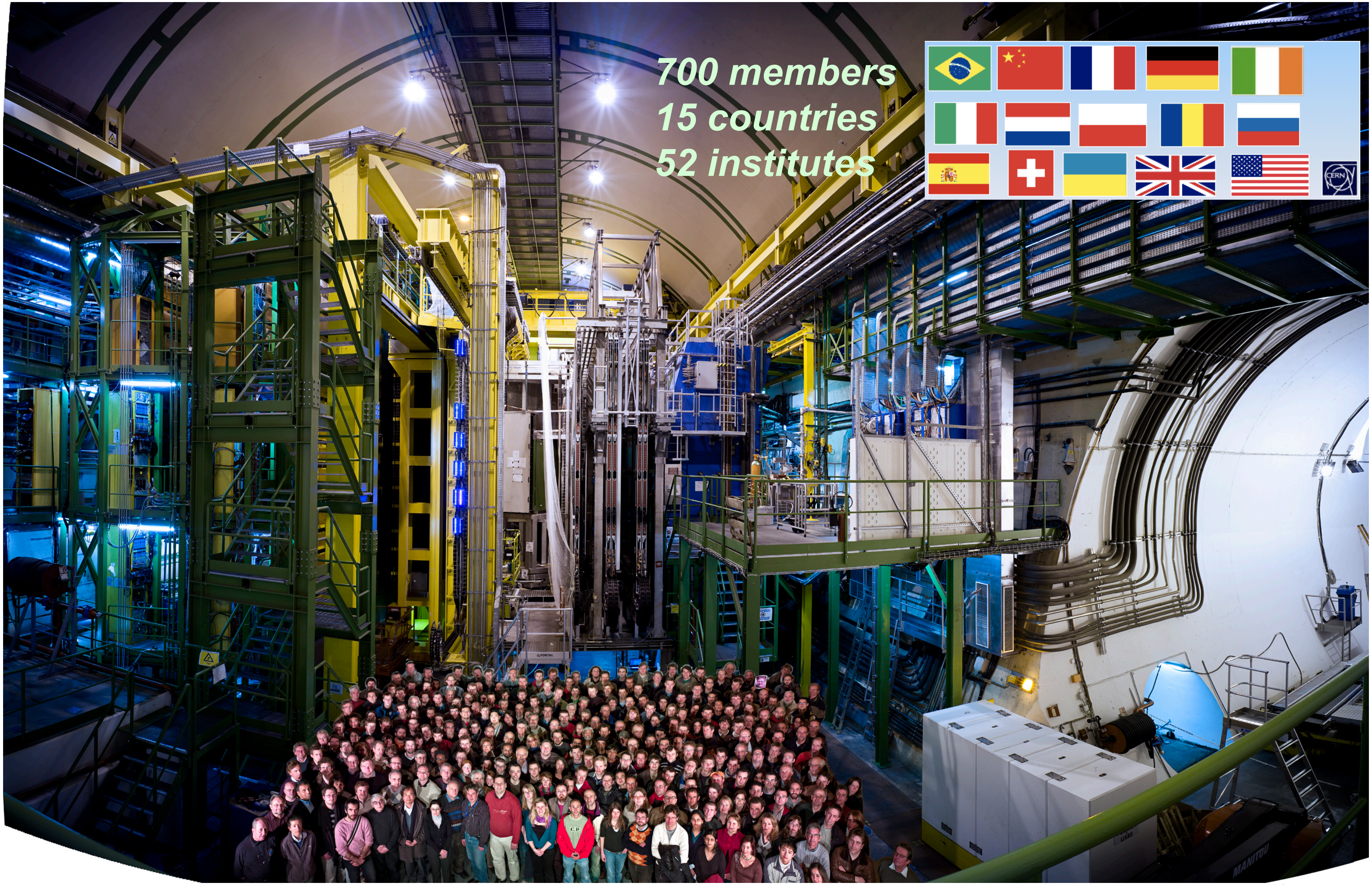
- Explore TeV-scale directly (ATLAS & CMS) and indirectly (LHCb)

No space left for the 4th possibility

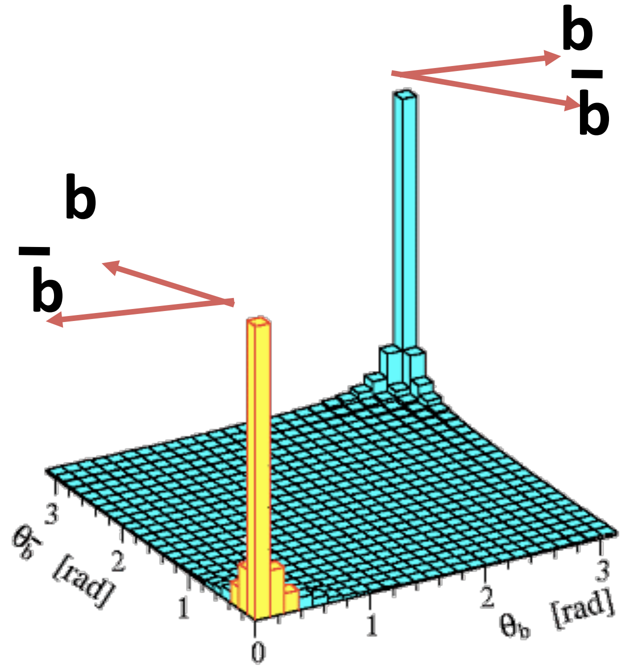
ATLAS CMS high p_T physics	BSM	Only SM	BSM	
LHCb flavour physics	Only SM	BSM	BSM	
Particle Physics	☺	☺	☺	

Even if 4th possibility → Measurements of virtual effects will set the scale of New Physics

LHCb Collaboration

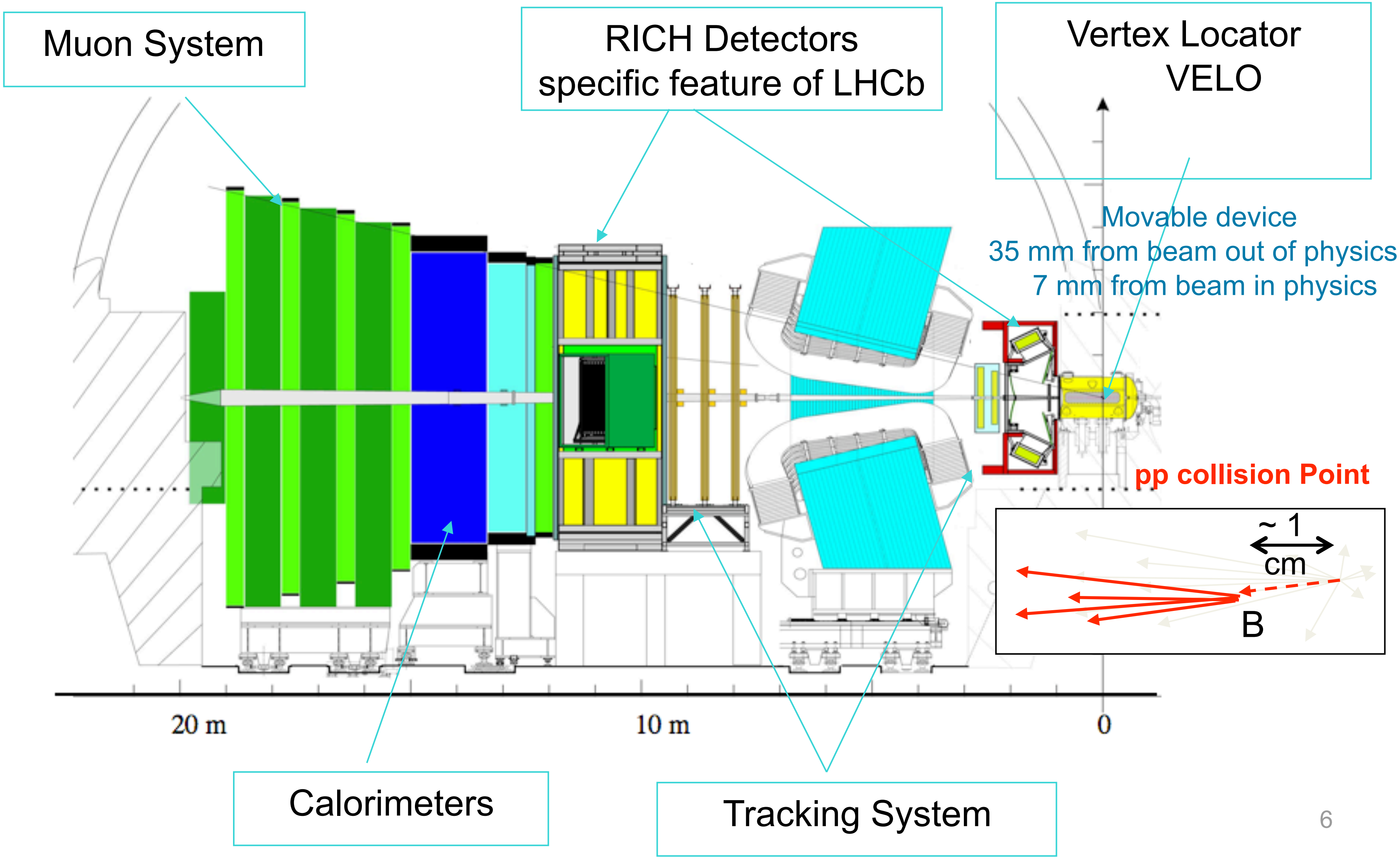


The LHCb Experiment

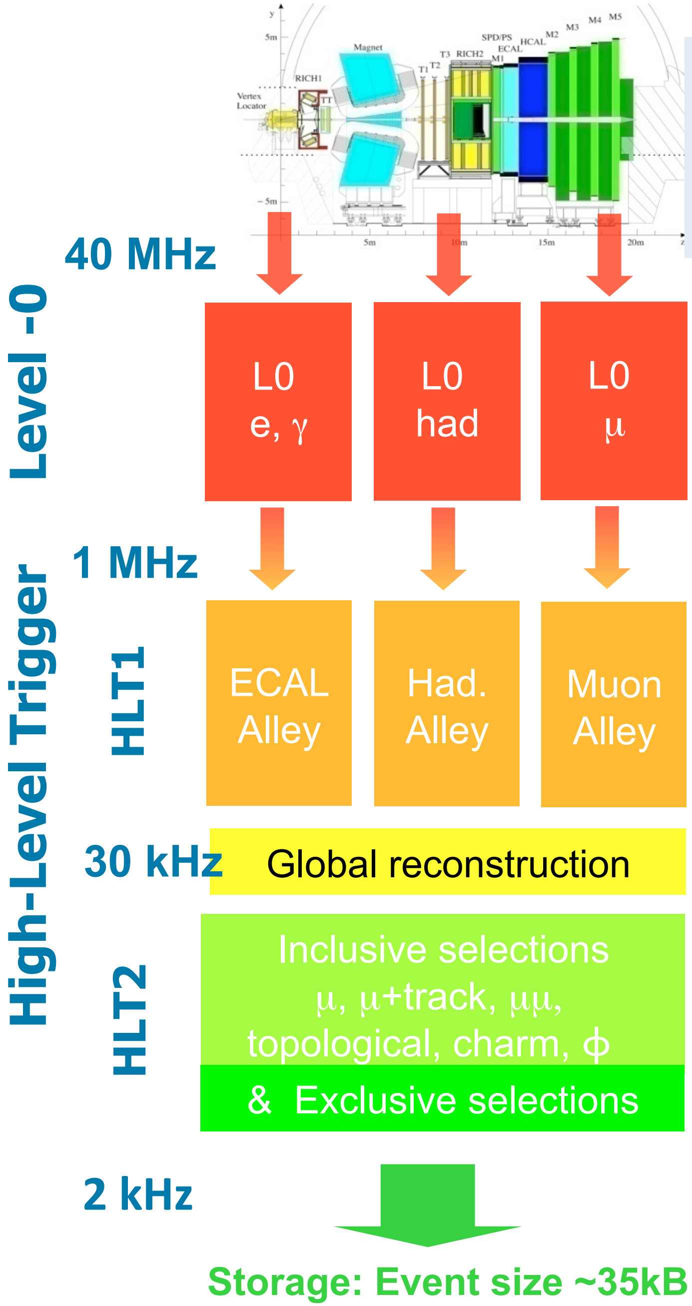


- *Advantages of beauty physics at hadron colliders:*
  - *High value of bb cross section at LHC:*
    σ_{bb} ~ 300 - 500 μb at 10 - 14 TeV
    (e+e- cross section at Y(4s) is 1 nb)
  - *Access to all quasi-stable b-flavoured hadrons*
- *The challenge*
  - *Multiplicity of tracks (~30 tracks per rapidity unit)*
  - *Rate of background events: σ_{inel}~ 100 mb*
- *LHCb running conditions:*
  - *Luminosity limited to ~2×10^{32} cm^{-2} s^{-1} by not focusing the beam as much as ATLAS and CMS*
    - *Maximize the probability of single interaction per bunch crossing*
      At LHC design luminosity pile-up of >20 pp interactions/bunch crossing while at LHCb ~ 0.7 pp interaction/bunch
    - *LHCb will reach nominal luminosity soon after start-up*
  - ***2fb^{-1} per nominal year (10^7s), ~ 10^{12} bb pairs produced per year***

The LHCb Detector



LHCb Trigger



Trigger is crucial as σ_{bb} is less than 1% of total inelastic cross section and B decays of interest typically have BR < 10^{-5}

- ☐ ***Hardware level (L0)***

  Search for high-p_T μ, e, γ and hadron candidates

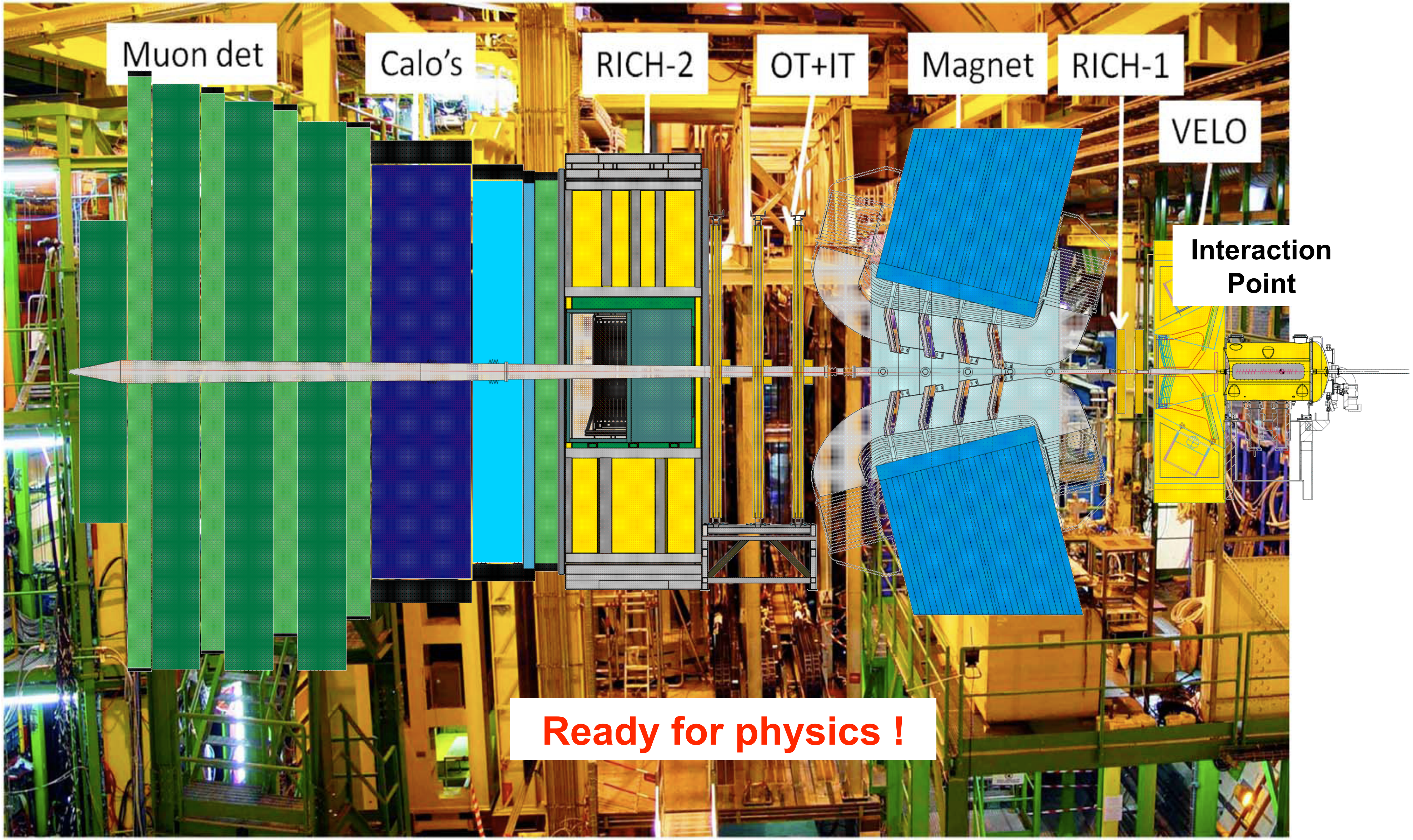
- ☐ ***Software level (High Level Trigger, HLT)***

  *Farm with **O**(2000) multi-core processors*

  HLT1: Confirm L0 candidate with more complete info, add impact parameter and lifetime cuts

  HLT2: B reconstruction + selections

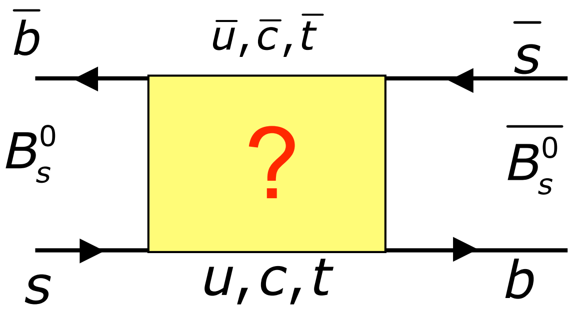
	ε(L0)	ε(HLT1)	ε(HLT2)
Electromagnetic	70 %	> ~80 %	> ~90 %
Hadronic	50 %		
Muon	90 %		


Muon det
Calo’s
RICH-2
OT+IT
Magnet
RICH-1
VELO
Interaction Point
Ready for physics !

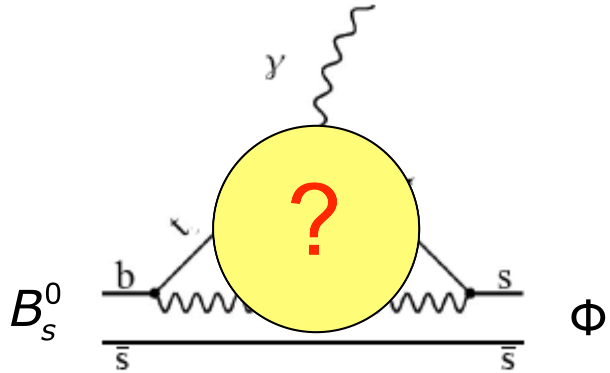
LHCb Physics Programme

- *Main LHCb objective is to search for the effects induced by New Physics in CP violation and Rare decays using the FCNC processes mediated by loop (box and penguin) diagrams*

- *NP effects could be different in boxes and penguins*
  → ***study different topologies separately !***



$\Phi_s \neq \Phi_s^{SM}$



Sensitivity to masses, couplings, spins and phases of New Particles

New Physics Search Strategy

- ***Phases***

  CPV processes are the only measurements sensitive to the phases of New Physics e.g. measurements of ***β , β_s & γ***

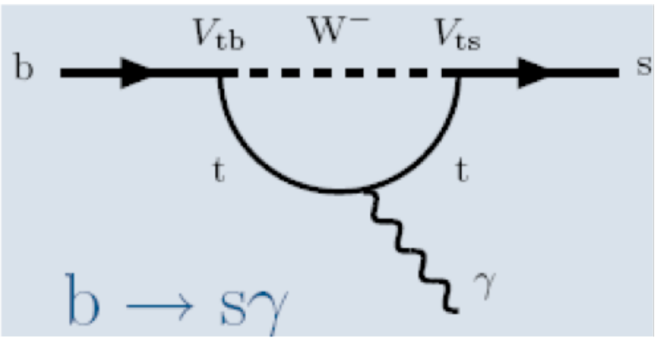
- ***Masses and magnitude of the couplings of new particles***

  Inclusive BR($b \rightarrow s\gamma$) indirectly constrains the scale of NP masses $\Lambda > 10^3$ TeV for generic coupling (flavour problem)

  Look at specific cases with enhanced sensitivity e.g. helicity suppression in ***$B_s \rightarrow \mu\mu$*** *decay gives increased sensitivity to SUSY with extended Higgs sector*

- ***Helicity structure of the couplings***

  Use the correlation between photon polarization and b flavour in ***$b \rightarrow s\gamma$***



$b \rightarrow \gamma_L + (m_s/m_b) \times \gamma_R$

$\phi\gamma$ produced in B_s and $\bar{B}_s$ decays do not interfere

$\rightarrow$ corresponding CP asymmetry vanishes

Significantly non-zero A_{CP} indicates a presence of right-handed current in the penguin loop

Similar study using ***$B \rightarrow K^*\mu^+\mu^-$ & $K^*e^+e^-$***

CPV measurements: UT angles

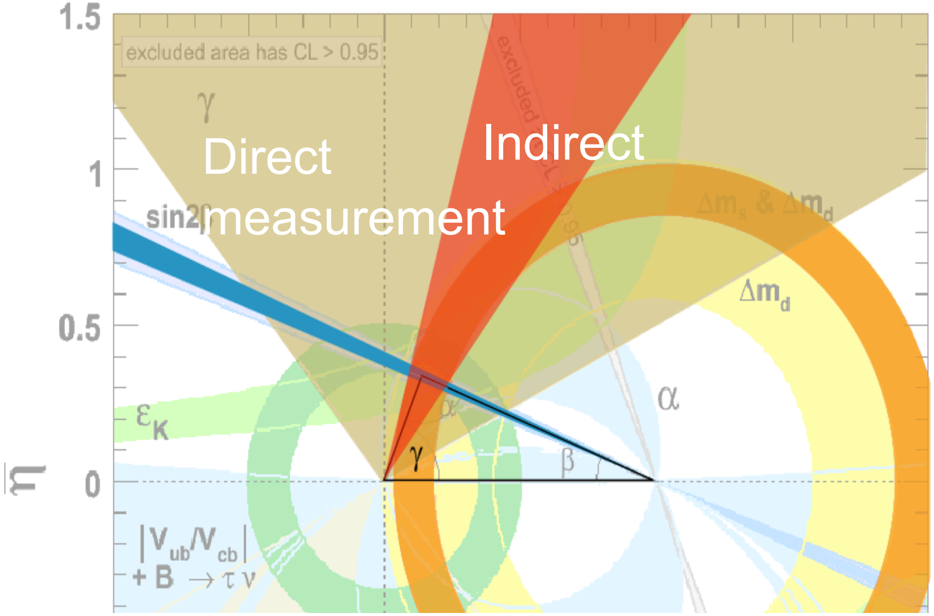
- ***Box diagrams (I)***

Note: UT geometry is such that the main constraint on NP comes from the comparison of the opposite elements i.e. angles vs sides

β **vs** $|V_{ub} / V_{cb}|$ *is largely limited by theory (~10% precision in* $|V_{ub}|$*)*

Note a discrepancy in $|V_{ub}|$ ***determined in inclusive and exclusive measurements :*** $|V_{ub}|$ ***incl ~*** $(4.0\text{-}4.9)\times 10^{-3}$ ***and*** $|V_{ub}|$ ***excl ~*** $(3.3\text{-}3.6)\times 10^{-3}$

γ **vs** $\Delta m_d / \Delta m_s$ *is limited by experiment:* γ *is poorly measured (± 20°)*



Indirectly, γ ***is determined to be (68±5)° from processes involving boxes***

LHCb will measure γ *directly in tree decays using the global fit to the rates of* $B \rightarrow D^0K$*,* D^0K^* *decays and time-dependent measurements with* $B_s \rightarrow D_sK$ *and* $B^0 \rightarrow D\pi$ *decays*

Expected $\sigma(\gamma_{trees}) \approx 4°$ ***with 2*** fb^{-1}

CPV measurements: phase of B_s mixing

- ***Box diagrams (II)***

*$\phi_s^{J/\psi\phi}$ = **-2β_s** in SM is the B_s meson counterpart of 2β*

penguin contribution ≤ 10^{-3}

$\phi_s^{J/\psi\phi}$ is not presently well measured (indication of large value from CDF/D0)

Theoretical uncertainty is very small

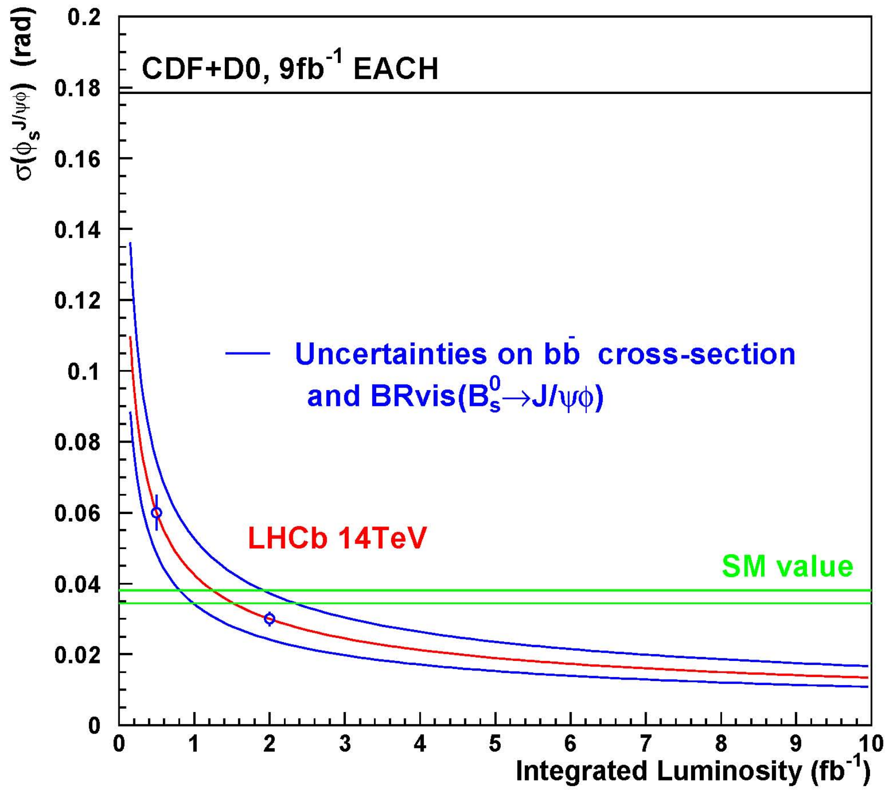
- 2β_s = - 0.0368±0.0017 (CKMfitter 2007)

LHCb prospects (2 fb^{-1} sample)

Expected yield 117k B_s → $J/\psi\phi$ events

$\sigma(\phi_s)$ ~ 0.03

Other channels are under study e.g.
$B_s \rightarrow J/\psi f^0$, $f^0 \rightarrow \pi^+\pi^-$. Looks promising
if this CP-eigenstate mode has BR indicated by CLEO

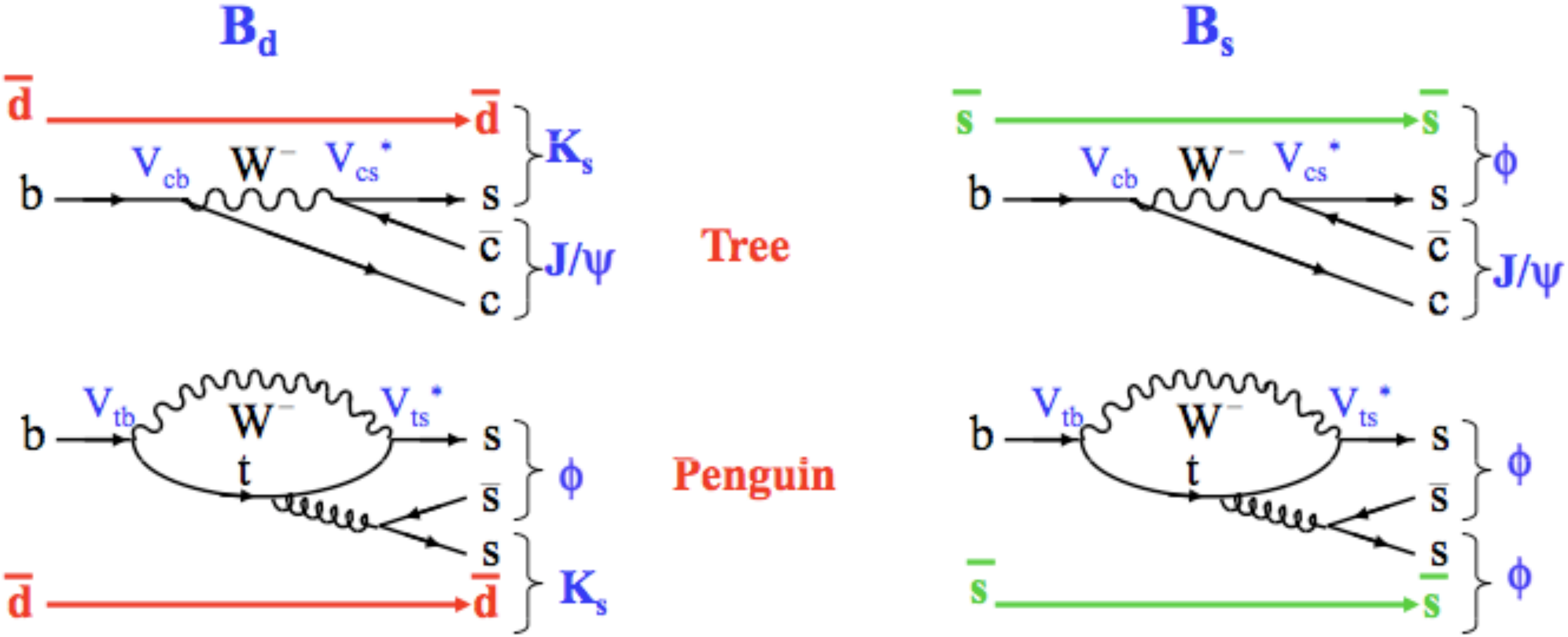


CPV measurements: phases in penguins

- ***Penguin diagrams:***

$$\phi_d(NP) = \phi_d^{\phi K s} - \phi_d^{J/\psi K s}$$
$$\phi_s(NP) \approx \phi_s^{\phi\phi} - \phi_s^{J/\psi\phi}$$

= O(a few degrees) if NP !!!



Thanks to B-factories
$\phi_d(NP)) \sim - 0.23 \pm 0.18$ *rad*

ϕ_s *(NP)) not measured*
LHCb sensitivity with 2 fb^{-1} ~ 0.11 rad
(stat. limited)

Rare Decays: *couplings and their helicity structure*

Current experiments are only now approaching an interesting level of sensitivity in exclusive decays:

- *BR ($B_s \rightarrow \mu\mu$)   (CDF /D0)*
  BR ($B_d \rightarrow \mu\mu$)

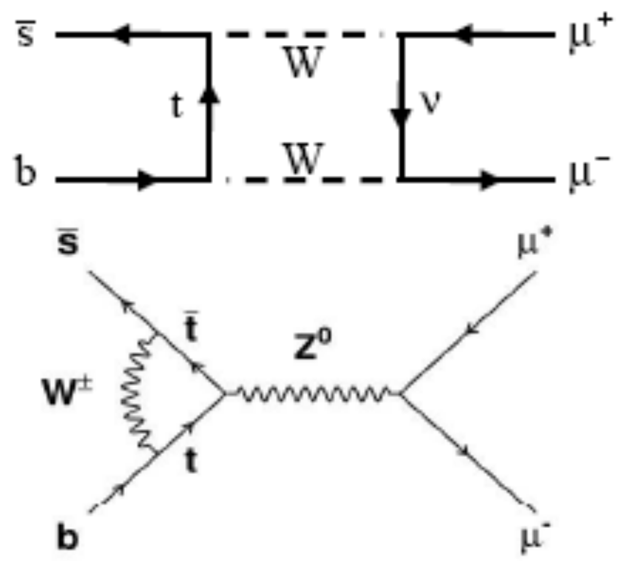
- *Photon polarization in $B \rightarrow K^*\gamma$ (BELLE/BaBar)*

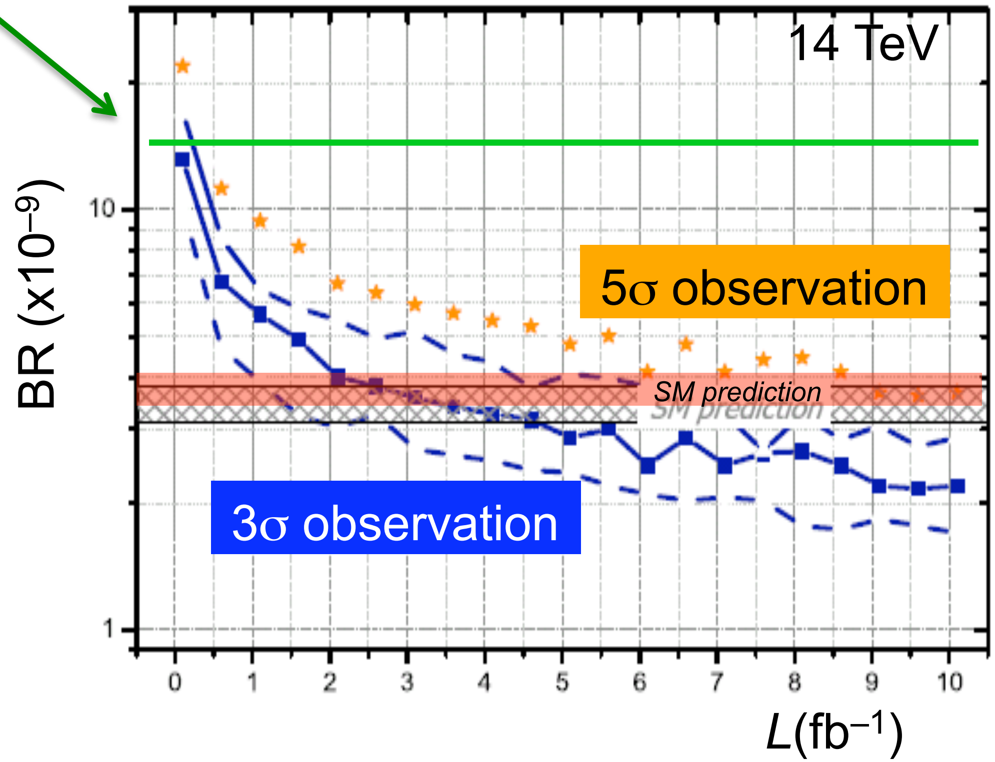
- *A_{FB} in $B \rightarrow K^*\mu\mu$ (BELLE/BaBar)*

LHCb will study rare decays in depth !!!

$B_s \to \mu\mu$

- Super rare decay in SM with well predicted $BR(B_s \to \mu\mu) = (3.55\pm0.33)\times10^{-9}$
- Sensitive to NP, in particular new scalars
  In MSSM: $BR \propto \tan^6\beta / M^4_A$
- Present best limit is from Tevatron:
  $BR(B_s \to \mu\mu) < 4.3\times10^{-8}$ @ 90% CL
- For the SM prediction
  LHCb expects 21 signal and 180 background events with 2 fb^{-1}.
  Background is dominated by muons from two different semileptonic b-decays
- LHCb sensitivity for the SM BR:
  3σ evidence with 3 fb^{-1}
  5σ observation with 10 fb^{-1}





Measurement of the photon polarization in $B_s \rightarrow \phi\gamma$ decay

- *BaBar & BELLE used CPV analysis in $B \rightarrow K^*(K^0\pi^0)\gamma$ decay*
  σ (A ($B \rightarrow f^{CP}\,\gamma_R$) / A ($B \rightarrow f^{CP}\,\gamma_L$) ~ 0.16 (HFAG)
  (~0.03 within SM due to m_s/m_b and gluon effects)

- *CPV analysis in the $B_s \rightarrow \phi\gamma$ decay can be performed without flavour tagging*

$$\Gamma(\mathrm{B}_q(\bar{\mathrm{B}}_q) \to f^{CP}\gamma) \propto e^{-\Gamma_q t}\left(\cosh\frac{\Delta\Gamma_q t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_q t}{2} \pm \pm\mathcal{C}\cos\Delta m_q t \mp \mathcal{S}\sin\Delta m_q t\right)$$

SM:

- *C = 0 direct CP-violation*
- *S = **sin2ψ** sinϕ_s*
- *A^Δ = **sin2ψ** cosϕ_s*

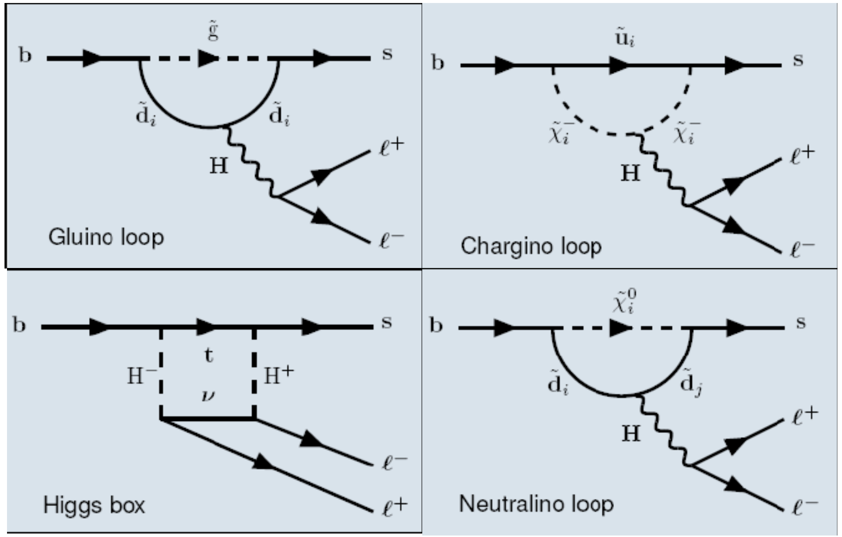
$$\tan\psi \equiv \left|\frac{A(\bar{\mathrm{B}}\to f^{CP}\gamma_R)}{A(\bar{\mathrm{B}}\to f^{CP}\gamma_L)}\right|$$

- ❑ *Expected signal yield at LHCb is 11k for 2 fb^{-1}*

Sensitivity: σ (A ($B \rightarrow f^{CP}\,\gamma_R$) / A ($B \rightarrow f^{CP}\,\gamma_L$) = 0.11 for 2$fb^{-1}$

$B \rightarrow K^*\mu\mu$

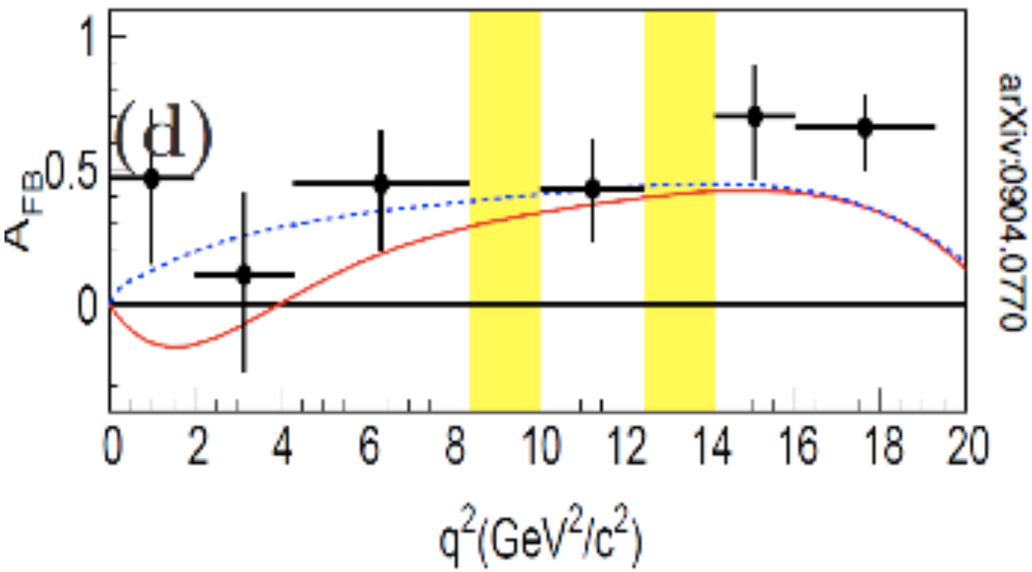
In SM this b→s penguin decay contains well calculable right-handed contribution but corresponding angular distributions could be modified by NP



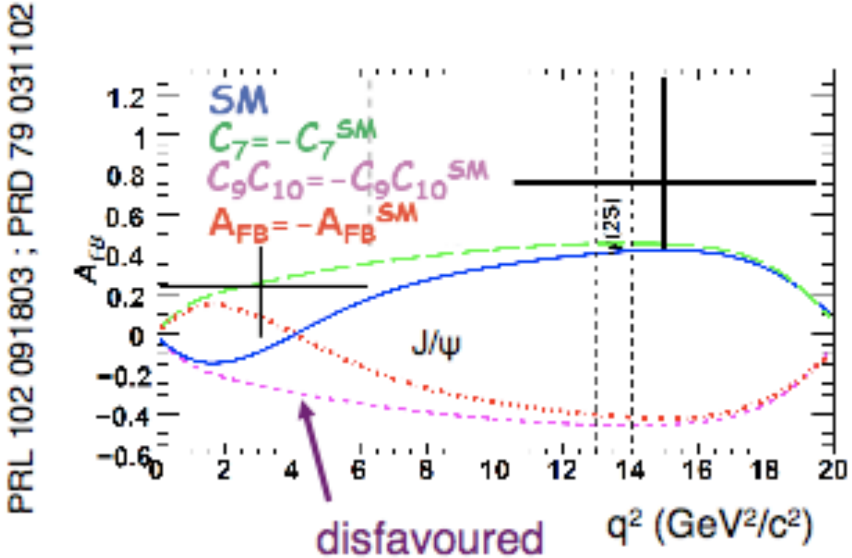
Forward-backward asymmetry A_{FB} ($q^2=m^2_{\mu\mu}$) is of particular interest at zero-point, since dominant theor. uncert. from hadronic form-factors cancels at LO

Intriguing indications from B-factories :

Belle: 657million BBbars analysed
~250 $K^*l^+l^-$ events

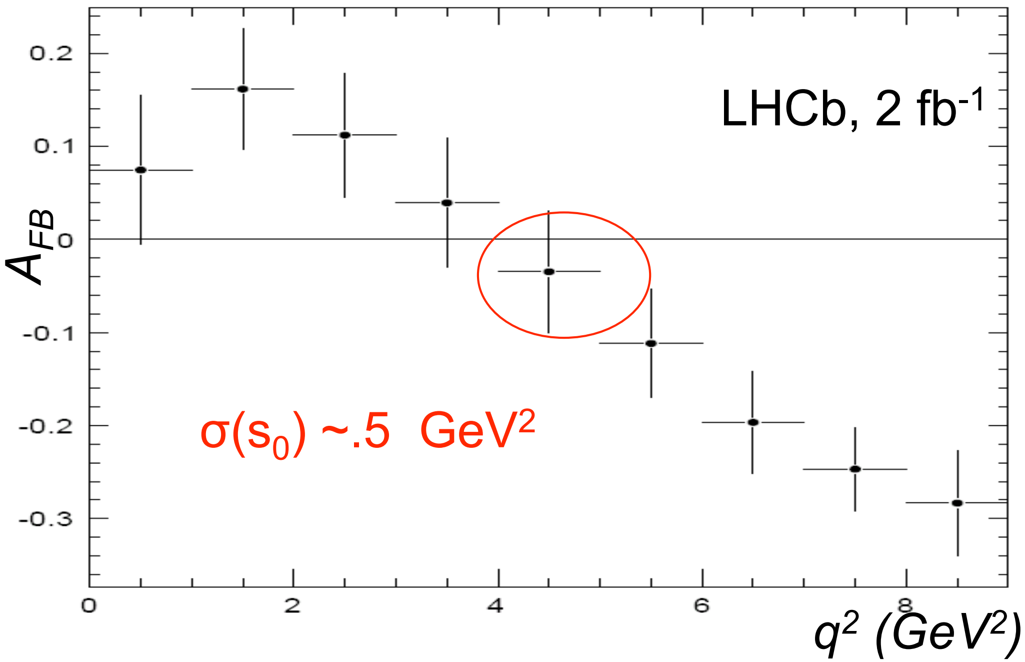


BaBar: 384 million BBbars analysed
~100 $K^*l^+l^-$ events



A_{FB} at B-factories is defined with opposite sign to LHCb

$B \to K^*\mu\mu$



LHCb expects ~7k events / 2fb^{-1} with B/S ~ 0.2 After 2 fb^{-1} zero of A_{FB} will be located to ±0.5 GeV^2. Full angular analysis gives even better discrimination between NP models.

More on photon polarization using $B \to K^*ee$:

- *Contribution not coming from virtual photons can be neglected at low $q^2 < (1\ GeV)^2$ → $B_d \to K^{*0}e^+e^-$ with electrons in the final state can be used to measure photon polarization complementary to $B_s \to \phi\gamma$*

- *Expected LHCb yield with 2 fb^{-1}: ~ 200 – 250 events with B/S ~ 1*
  Expected sensitivity $\sigma(A(B \to f^{CP}\gamma_R)/A(B \to f^{CP}\gamma_L)) \approx 0.1$
  limited by statistics and comparable to $B_s \to \phi\gamma$ accuracy

LHCb key measurements

(to search for NP in CP violation and Rare Decays)

Key Measurements	**Accuracy in 1 nominal year ($2\ fb^{-1}$)**
❑ *In CP – violation*	
✓ ϕ_s	**0.03**
✓ γ in trees	4°
✓ γ in loops	7°
❑ *In Rare Decays*	
✓ $B_s \rightarrow \mu\mu$	**3σ measurement down to SM prediction**
✓ $B \rightarrow K^*\mu\mu$	$\sigma(s0) = 0.5\ GeV^2$
✓ Polarization of photon	$\sigma(H_R/H_L) = 0.1$ (in $B_s \rightarrow \phi\gamma$) $\sigma(H_R/H_L) = 0.1$ (in $B_d \rightarrow K^* e^+ e^-$)

Measurements highlighted in red will become competitive first

LHCb key measurements

(to search for NP in CP violation and Rare Decays)

Key Measurements	Sensitivity with 10 fb^{-1} (few years of data taking)
❑ In CP – violation	
✓ ϕ_s	**0.01**
✓ γ in trees	~2°
✓ γ in loops	~3°
❑ In Rare Decays	
✓ $B \to K^*\mu\mu$	$\sigma(s0)$ = 0.28 GeV^2
✓ $B_s \to \mu\mu$	**5σ measurement down to SM prediction**
✓ Polarization of photon	$\sigma(H_R/H_L)$ = 0.03 (in $B_s \to \phi\gamma$ & $B_d \to K^*e^+e^-$)

If NP is discovered at LHC within a few years *(LHCb will analyze a data sample of about 10 fb^{-1})* ***the NP models should be studied***

What will be the possibilities in heavy flavor physics:

(to measure experimental observables not limited by theoretical uncertainties)

- ***SuperLHCb is being planned in order to collect a data sample of ~ 100 fb^{-1} at LHC***

- ***SuperB (and gradually SuperKEKB) factory is being planned to get 75 ab^{-1}***

- ***Kaon experiments KOTO & NA62 to measure super rare $K \rightarrow \pi\nu\nu$ decays***

Who is best suited for what ?

Super LHCb
(~100 fb^{-1})

Unique for:

- *study of B_s sector*
- *gives access to all b-hadrons*

CP Violation

	Sensitivity with 10 fb^{-1}	Improvement with 100 fb^{-1}?
NP in boxes:		
❑ ϕ_s is the most sensitive measurement	$\sigma(\phi_s) \sim 0.01$	Yes (theor. uncert. 0.002)
NP in penguins:		
❑ Probably the best sensitivity: ϕ_s in $B_s \rightarrow J/\psi\phi$ vs $B_s \rightarrow \phi\phi$	$\sigma(\phi_s(NP)) \sim 0.05$	Yes
or ϕ_d in $B \rightarrow J/\psi Ks$ vs $B \rightarrow \phi Ks$	$\sigma(\phi_d(NP)) \sim 0.1$	Yes

In addition γ will be measured to a precision of ~2° with 10 fb^{-1} data sample

Rare Decays

NP in penguins	**Sensitivity with 10 fb^{-1}**	**Improvement with 100 fb^{-1} ?**
Photon polarization in $B_s \to \phi\gamma$ decay:	$\sigma(H_R/H_L)$= 0.03	Yes ? (theor. uncert. ~0.03)
NP in a mixture of loop diagrams:		
$B \to K^*\mu\mu$, $B_s \to \phi\mu\mu$	$\sigma(s0)$ ~ 0.3 GeV^2. Already very rich choice of observables, e.g. A_T^3, A_T^4 etc…	Yes
$B_s \to \mu\mu$ ($B_d \to \mu\mu$)	>5σ observation if SM	Yes

Charm Physics

Measured CP asymmetries

approach SM prediction

LVF in τ decays

$BR(\tau \to 3\mu) < 10^{-8}$

using τ from $D_s \to \tau\nu$

There could be great possibilities
To be explored !

Super B-factory

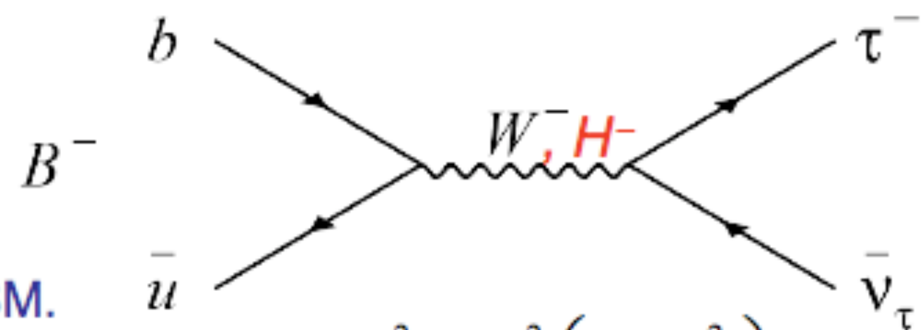
(I do not distinguish here between SuperB & SuperKEKB)

Unique for:

- V_{ub} *determination (one of the two observables, which can be measured in trees)*
- *Study of rare decays with neutrinos and neutrals in the final states*

$B \rightarrow \tau\nu_\tau$ decay

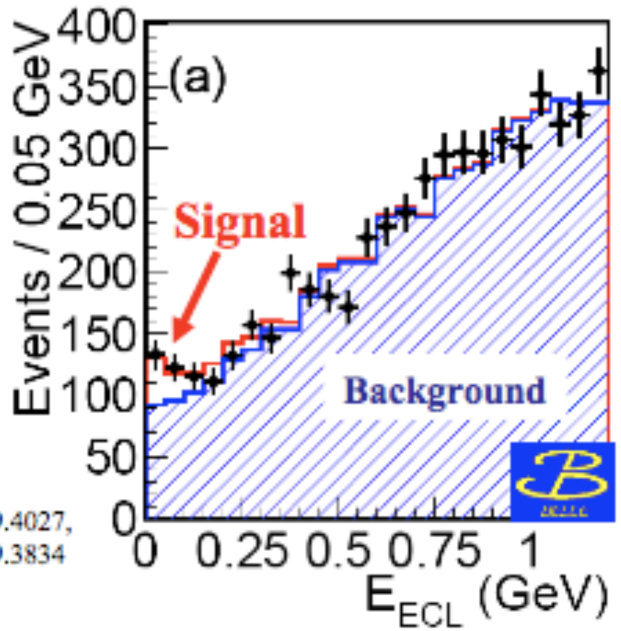
- Within the SM, sensitive to f_B and $|V_{ub}|$: $\mathcal{B}_{SM}$~1.6×10^{-4}.
- $\mathcal{B}$ affected by new physics.
  - MFV models like 2HDM / MSSM.
  - Unparticles.



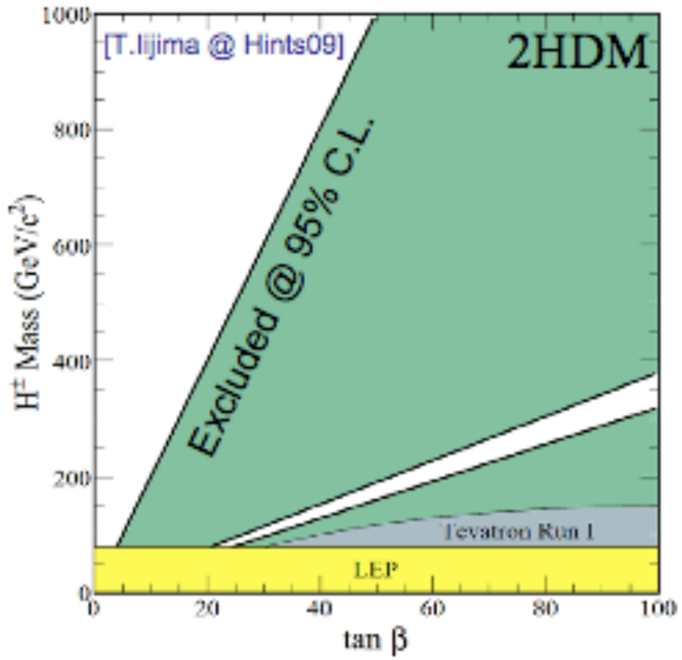
$$\mathcal{B}_{SM}(B^+ \rightarrow l^+\nu_l) = \frac{G_F^2 m_B m_l^2}{8\pi}\left(1-\frac{m_l^2}{m_B^2}\right) f_B^2 \, |V_{ub}|^2 \, \tau_B$$

- Fully reconstruct the event (modulo ν).

$$\mathcal{B}_{WA} = (1.73 \pm 0.35)\times10^{-4}$$



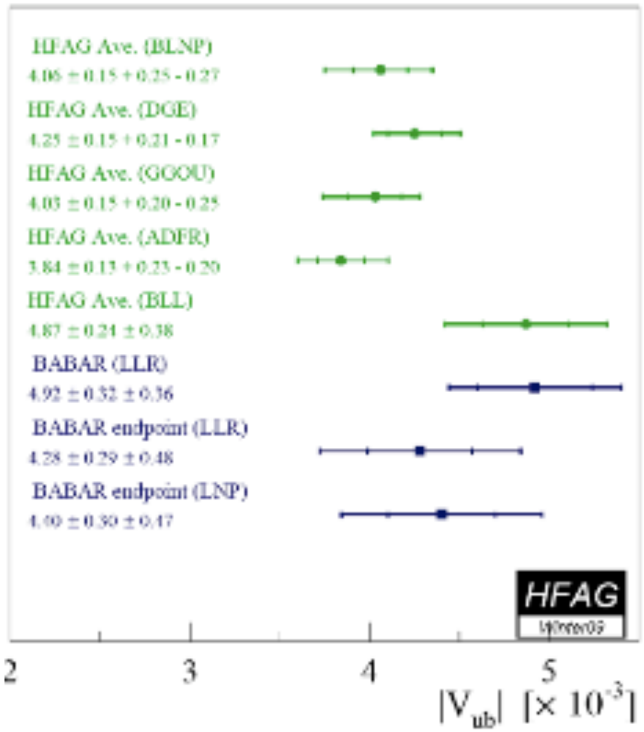
arXiv:0809.4027,
arXiv:0809.3834



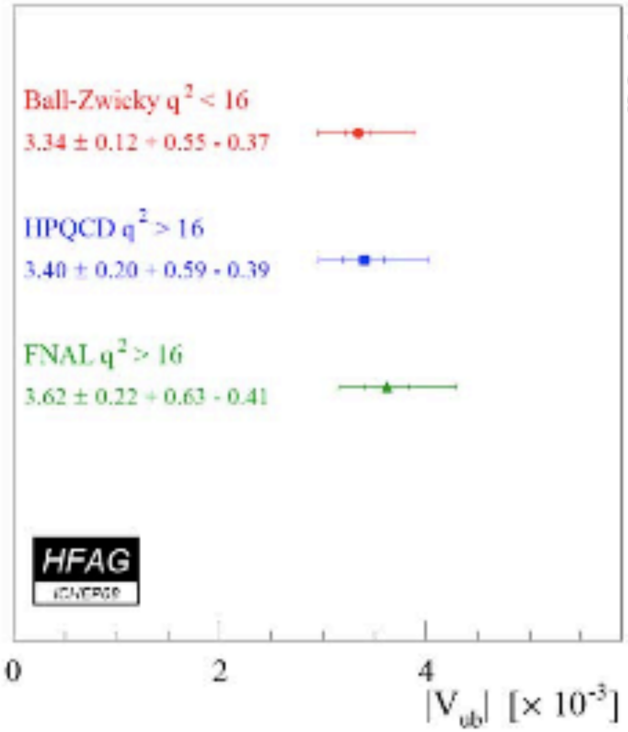
2HDM: W.-S Hou PRD **48** 2342 (1993)
MSSM: G. Isidori arXiv:0710.5377

V_{ub} determination

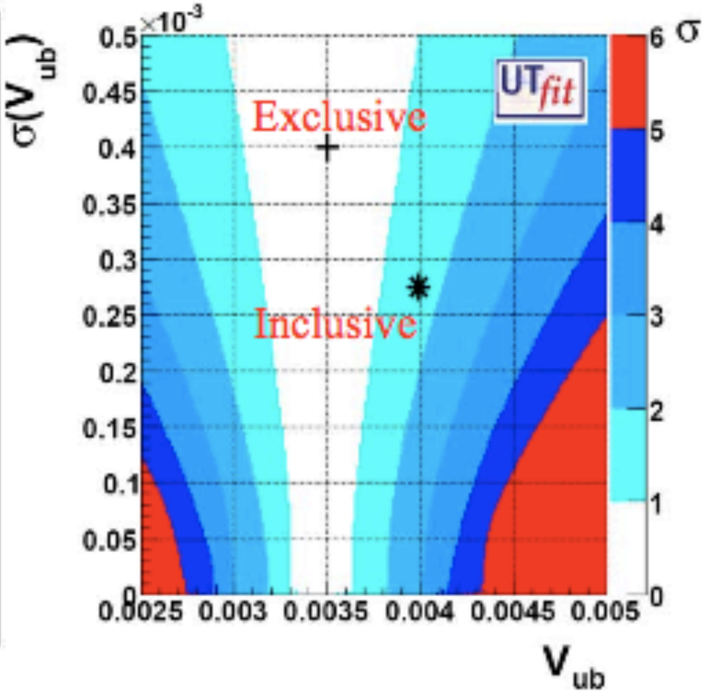
- Tension between inclusive and exclusive results and sin2β.



Inclusive $|V_{ub}|$



Exclusive $|V_{ub}|$



At Super B factory exclusive b→u transitions will be measured in the whole q^2 interval → V_{ub} can be extracted with minimal theoretical uncertainty !

SuperB physics in tables

arXiv:0709.0451
arXiv:0810.1312

B_d physics @$\Upsilon(4S)$

Observable	B factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi K^{*0})$	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi \pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (*)
$S(\eta' K^0)$	0.05	0.01 (*)
$S(K^0_S K^0_S K^0_S)$	0.15	0.02 (*)
$S(K^0_S \pi^0)$	0.15	0.02 (*)
$S(\omega K^0_S)$	0.17	0.03 (*)
$S(f_0 K^0_S)$	0.12	0.02 (*)
γ $(B \to DK, D \to CP$ eigenstates)	$\sim 15^\circ$	2.5°
γ $(B \to DK, D \to$ suppressed states)	$\sim 12^\circ$	2.0°
γ $(B \to DK, D \to$ multibody states)	$\sim 9^\circ$	1.5°
γ $(B \to DK$, combined)	$\sim 6^\circ$	1–2°
α $(B \to \pi\pi)$	$\sim 16^\circ$	3°
α $(B \to \rho\rho)$	$\sim 7^\circ$	1–2° (*)
α $(B \to \rho\pi)$	$\sim 12^\circ$	2°
α (combined)	$\sim 6^\circ$	1–2° (*)
$2\beta + \gamma$ $(D^{(*)\pm}\pi^\mp, D^\pm K^0_S \pi^\mp)$	20°	5°
$\lvert V_{cb}\rvert$ (exclusive)	4% (*)	1.0% (*)
$\lvert V_{cb}\rvert$ (inclusive)	1% (*)	0.5% (*)
$\lvert V_{ub}\rvert$ (exclusive)	8% (*)	3.0% (*)
$\lvert V_{ub}\rvert$ (inclusive)	8% (*)	2.0% (*)
$BR(B \to \tau\nu)$	20%	4% (†)
$BR(B \to \mu\nu)$	visible	5%
$BR(B \to D\tau\nu)$	10%	2%
$BR(B \to \rho\gamma)$	15%	3% (†)
$BR(B \to \omega\gamma)$	30%	5%
$A_{CP}(B \to K^*\gamma)$	0.007 (†)	0.004 († *)
$A_{CP}(B \to \rho\gamma)$	~ 0.20	0.05
$A_{CP}(b \to s\gamma)$	0.012 (†)	0.004 (†)
$A_{CP}(b \to (s+d)\gamma)$	0.03	0.006 (†)
$S(K^0_S \pi^0 \gamma)$	0.15	0.02 (*)
$S(\rho^0\gamma)$	possible	0.10
$A_{CP}(B \to K^*\ell\ell)$	7%	1%
$A^{FB}(B \to K^*\ell\ell)s_0$	25%	9%
$A^{FB}(B \to X_s\ell\ell)s_0$	35%	5%
$BR(B \to K\nu\bar{\nu})$	visible	20%
$BR(B \to \pi\nu\bar{\nu})$	–	possible

charm physics

Mode	Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$D^0 \to K^+K^-$	y_{CP}	2–3×10^{-3}	5×10^{-4}
$D^0 \to K^+\pi^-$	y'_D	2–3×10^{-3}	7×10^{-4}
	x'^2_D	1–2×10^{-4}	3×10^{-5}
$D^0 \to K^0_S\pi^+\pi^-$	y_D	2–3×10^{-3}	5×10^{-4}
	x_D	2–3×10^{-3}	5×10^{-4}
Average	y_D	1–2×10^{-3}	3×10^{-4}
	x_D	2–3×10^{-3}	5×10^{-4}

Channel	Sensitivity
$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K^0_s e^+e^-$, $D^0 \to K^0_s\mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
$D^0 \to e^\pm\mu^\mp$	1×10^{-8}
$D^+ \to \pi^+e^\pm\mu^\mp$	1×10^{-8}
$D^0 \to \pi^0e^\pm\mu^\mp$	2×10^{-8}
$D^0 \to \eta e^\pm\mu^\mp$	3×10^{-8}
$D^0 \to K^0_s e^\pm\mu^\mp$	3×10^{-8}
$D^+ \to \pi^-e^+e^+$, $D^+ \to K^-e^+e^+$	1×10^{-8}
$D^+ \to \pi^-\mu^+\mu^+$, $D^+ \to K^-\mu^+\mu^+$	1×10^{-8}
$D^+ \to \pi^-e^\pm\mu^\mp$, $D^+ \to K^-e^\pm\mu^\mp$	1×10^{-8}

Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 fb^{-1})	LHCb (10 fb^{-1})
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}		6×10^{-5}
	y'	7×10^{-4}		9×10^{-4}
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}		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		$(1-2) \times 10^{-3}$	
	$\cos\delta$		$(0.01-0.02)$	

τ physics

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}
$\mathcal{B}(\tau \to \ell K^0_s)$	2×10^{-10}

+ τ FC physics (CPV, ...)

+B_s physics @$\Upsilon(5S)$

SuperB
a
"treasure chest"
of new
physics-
sensitive
observables

Kaon experiments (KOTO &NA62)

(Crucial element: super high intensity proton beams)

Unique for:

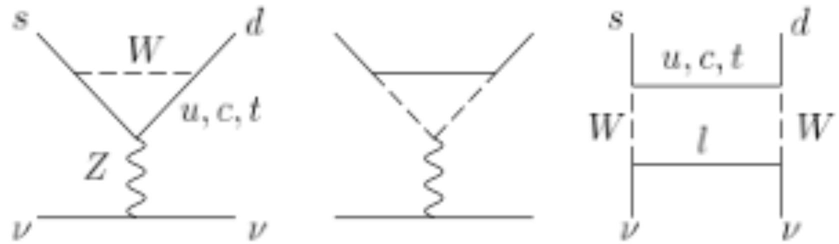
- *Measurements of the super rare K → $\pi\nu\nu$ decays mediated by loop diagrams (penguin & box)*

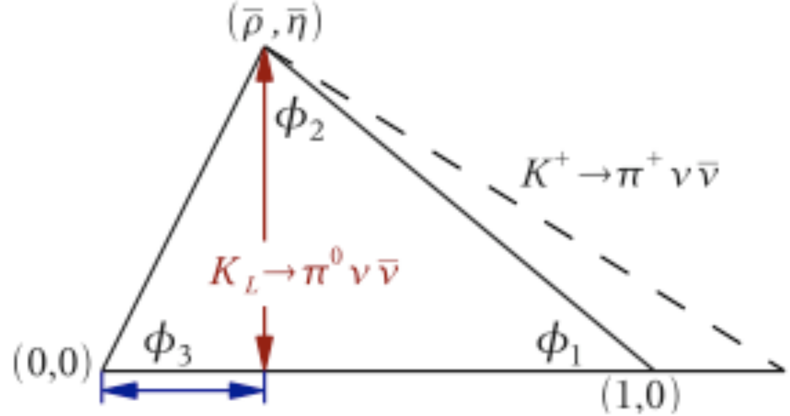
- *Improve predictive power of the Unitarity Triangle test (by releasing some QCD uncertainties)*

- ***Rate is very sensitive to non-SM contributions***

$K \rightarrow \pi\nu\nu$ decays

- *Receive EW loop contribution from boxes and penguins*





- *Strongly suppressed (BR ~ 10^{-11}) and reliably calculated in SM*

NLO Calculation:
Buchalla & Buras: 1993, 1999
Misiak, Urban: 1999

λ = Vcs, λc = Vcs*Vcd, λt = Vts*Vtd)

$$B(K^+ \to \pi^+ \nu\bar\nu) = \kappa_+ \cdot \left[\left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2 + \left(\frac{\mathrm{Re}\,\lambda_t}{\lambda^5} X(x_t) + \frac{\mathrm{Re}\,\lambda_c}{\lambda} P_c(X) \right)^2 \right]$$

$$B(K_L^0 \to \pi^0 \nu\bar\nu) = \kappa_L \cdot \left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2$$

top contribution

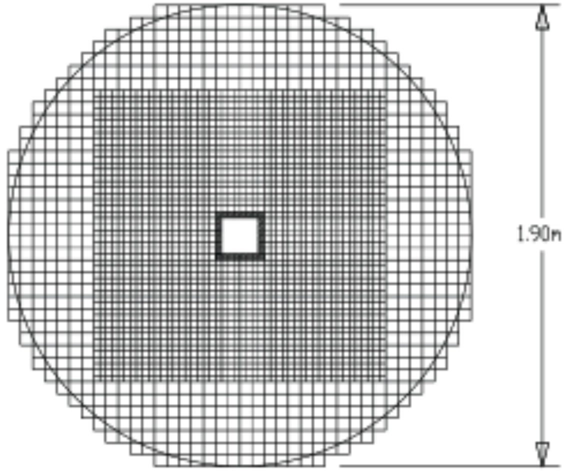
charm contribution NNLO Buras, Gorbahn, Haisch, Nierste hep-ph/0508165 PRL 95

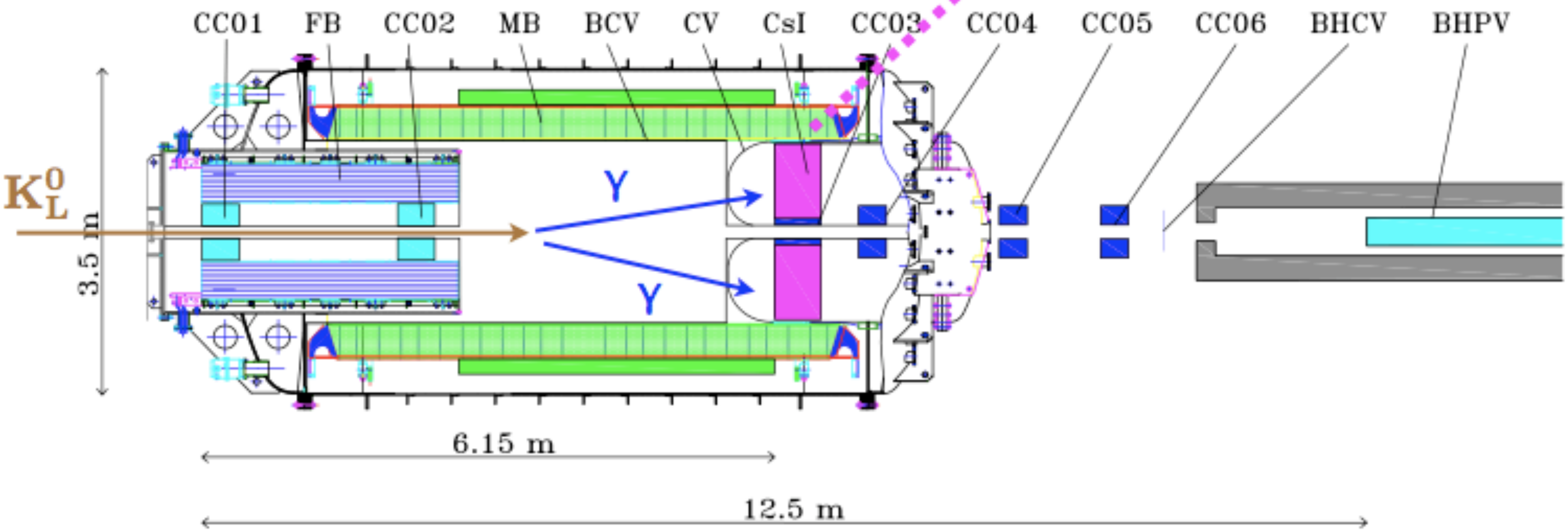
$$\kappa_+ = r_{K^+} \cdot \frac{3\alpha^2 Br(K^+ \to \pi^0 e^+ \nu)}{2\pi^2 \sin^4\theta_W} \cdot \lambda^8$$

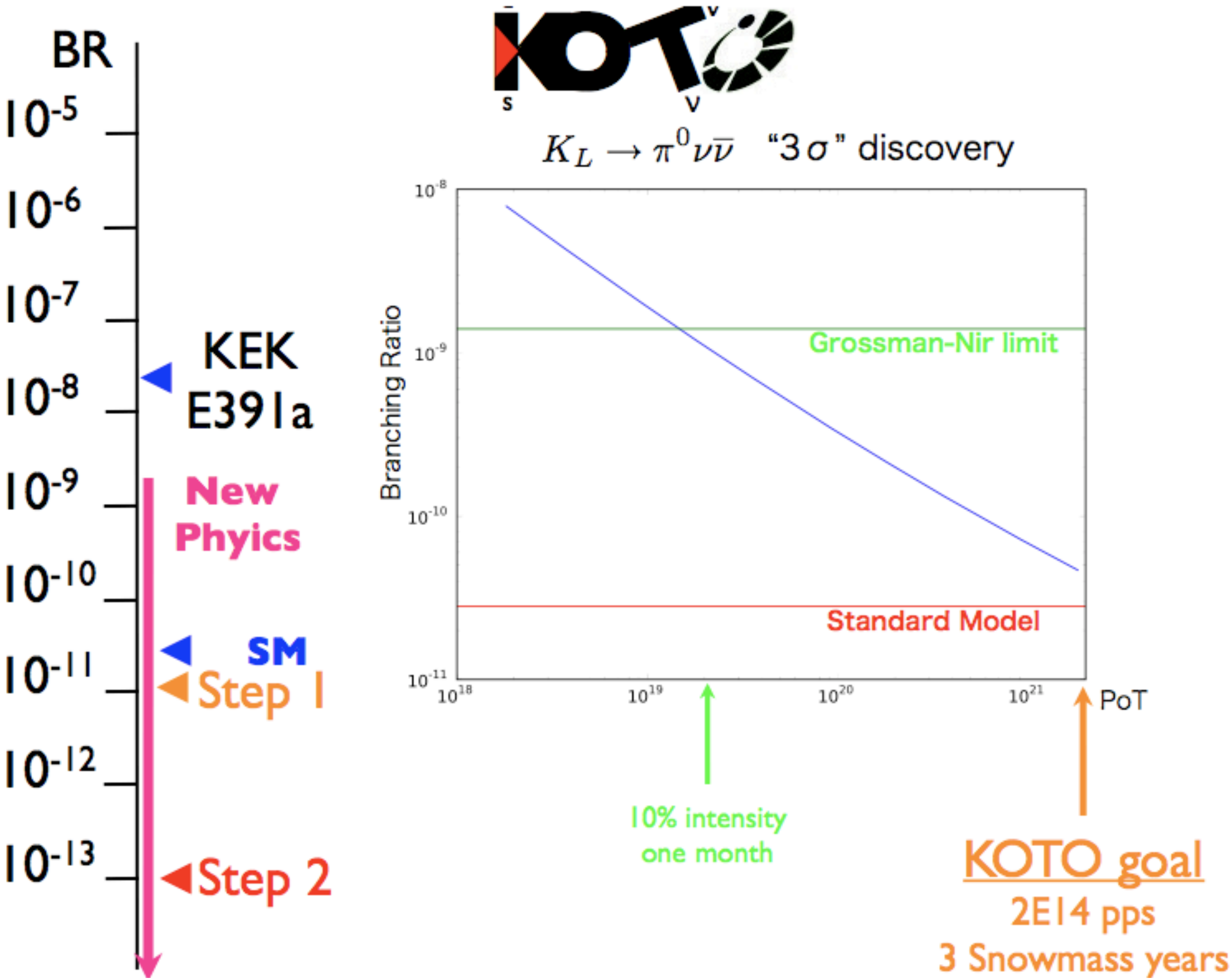
E14: K0 at TOkai for $K_L \to \pi^0 \nu \bar{\nu}$

a long Japanese musical instrument (zither) with thirteen strings

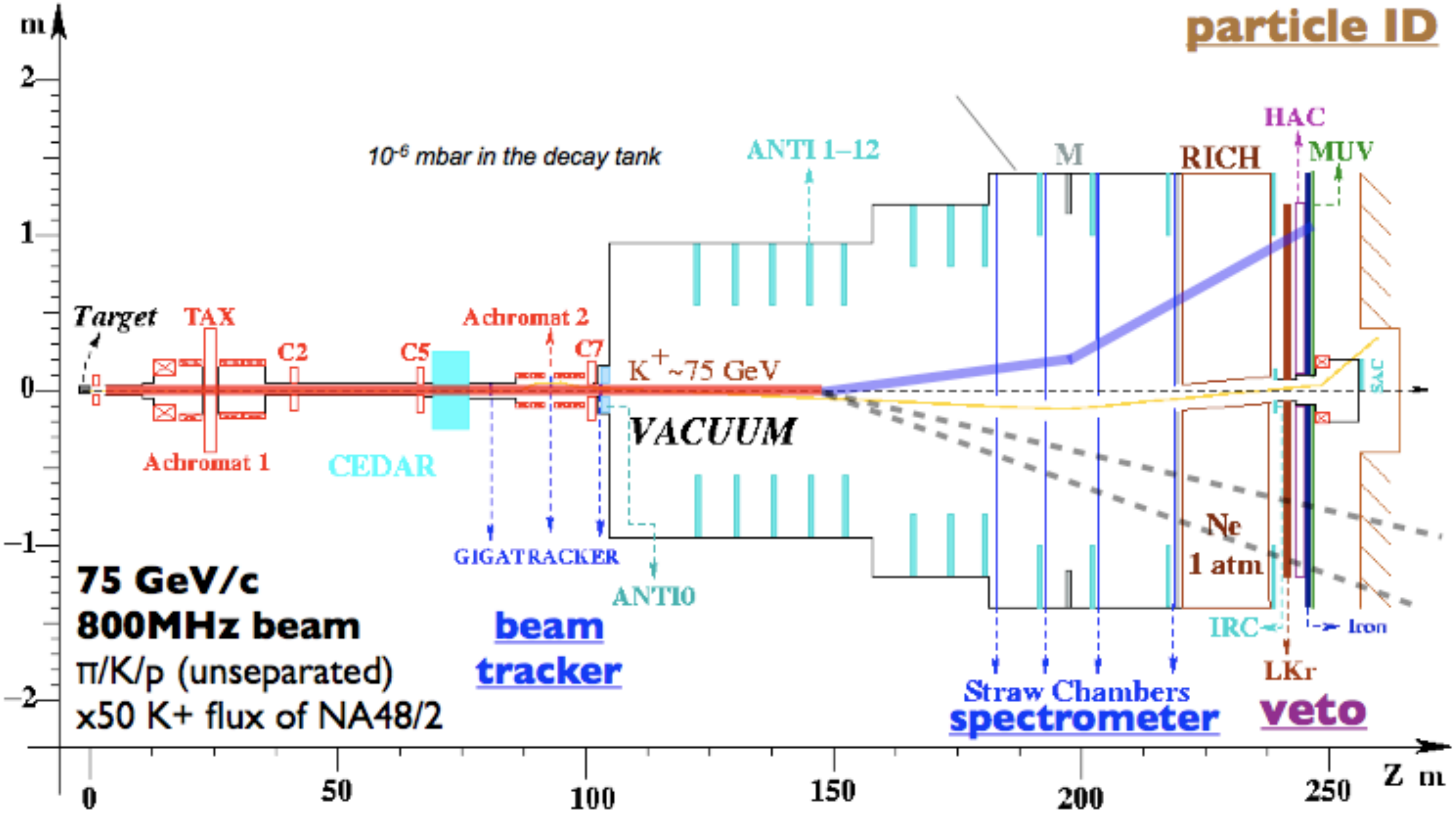
- new beamline
- Move and modify E391a detector
  - CsI calorimeter (KTeV crystals)
  - readout: waveform digitization
  - photon veto in the beam



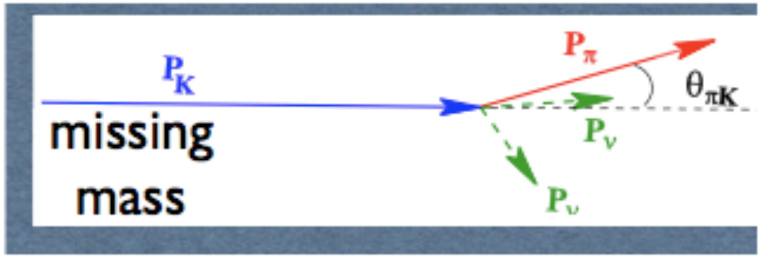


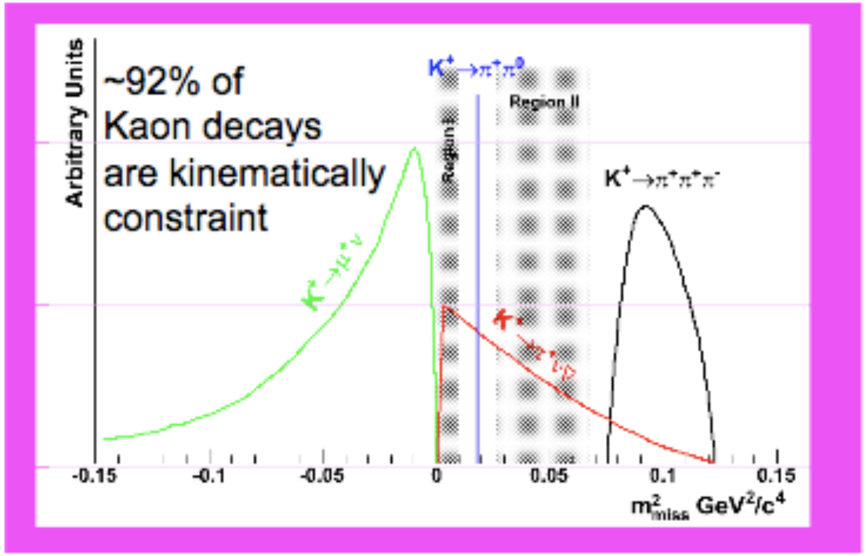

BR
10-5
10-6
10-7
10-8
10-9
10-10
10-11
10-12
10-13
KEK
E391a
New
Phyics
SM
Step 1
Step 2
KOTO
$K_L \to \pi^0 \nu\bar{\nu}$ "3σ" discovery
Branching Ratio
Grossman-Nir limit
Standard Model
PoT
10% intensity
one month
KOTO goal
2E14 pps
3 Snowmass years

decay in flight to π^+ plus “nothing”



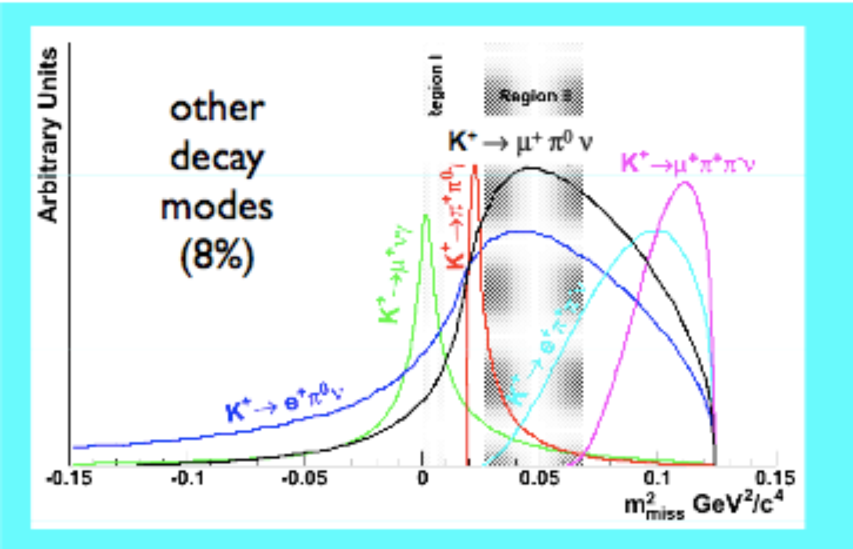
Background rejection





- timing
- tracking
- veto

Decay Mode	Events
Signal: $K^+\to\pi^+\nu\bar{\nu}$ *[flux = 4.8×10^{12} decay/year]*	55 *evt/year*
$K^+\to\pi^+\pi^0$ [$\eta_{\pi 0}$ = 2×10^{-8} (3.5×10^{-8})]	4.3% (7.5%)
$K^+\to\mu^+\nu$	2.2%
$K^+\to e^+\pi^+\pi^-\nu$	≤3%
Other 3 – track decays	≤1.5%
$K^+\to\pi^+\pi^0\gamma$	~2%
$K^+\to\mu^+\nu\gamma$	~0.7%
$K^+\to e^+(\mu^+)\,\pi^0\nu$, others	negligible
Expected background	≤13.5% (≤17%)



- veto
- particle ID

What can be done in flavour physics
(with very modest investment)
If nothing but SM Higgs is found at LHC

We all know that SM has problems !!!

SM problems and possible solutions

Hierarchy problem: stability of the Higgs mass against radiative corrections

Possible solutions:

- *Compensation of divergent diagrams by new particles at TeV scale (supersymmetry, composite Higgs boson).* ***Consequence: new physics at LHC !!!***

Alternative

- *New symmetry – exact, but spontaneously broken scale invariance. Higgs mass is kept small as photon mass kept zero by gauge invariance.* ***Consequence:*** *validity of SM all the way up to the Planck scale; nothing but the SM Higgs at LHC in the mass interval $m_{min} < m < m_{max}$*

$$m_{\min} = [126.3 + \frac{m_t - 171.2}{2.1} \times 4.1 - \frac{\alpha_s - 0.1176}{0.002} \times 1.5]\ \mathrm{GeV}$$

$$m_{\max} = [173.5 + \frac{m_t - 171.2}{2.1} \times 1.1 - \frac{\alpha_s - 0.1176}{0.002} \times 0.3]\ \mathrm{GeV}$$

SM problems and possible solutions

Neutrino masses and oscillations

Possible solutions:

- *See-saw mechanism: Existence of several super heavy ($M \sim 10^{10}$ GeV) neutral leptons. Direct experimental consequences: none, as the mass is too large to be accessed*

Alternative

- *Existence of new lepton flavours with masses similar to those of known quarks and leptons → **possibility of direct experimental search !!!***

SM problems and possible solutions

Dark matter

Possible solutions:

- *WIMPs with masses of the order of 100 GeV and roughly electroweak cross-sections (e.g. SUSY neutralino).*
  Consequences:
  new particles at LHC, success of WIMP searches

Alternative

- *Super-WIMPs (non-stable, very long life-time) with masses in keV range*
  Natural possibility: new lepton flavour with a mass of a few keV

  Consequences: *no Dark Matter candidates at LHC, failure of WIMP searches. Possibility of search through radiative processes N → $\nu\gamma$, which leads to existence of narrow X-ray line in direction of DM concentrations*

SM problems and possible solutions

Baryon asymmetry of the Universe

Possible solution:

- *Baryogenesis due to new physics above the electroweak scale*

  Potential consequences: *new particles at LHC (for electroweak baryogenesis)*

Alternative

- *Baryogenesis due to new neutral lepton flavours with masses in the range from m_π to a few GeV* → ***possibility of direct experimental search in heavy flavours decays***

Search for neutral lepton flavours in heavy flavour decays

*ν **M**inimal **S**tandard **M**odel :*

- *Takehiko Asaka, Steve Blanchet, Mikhail Shaposhnikov   March 2005*
  Published in Phys.Lett.B631:151-156,2005
- *Takehiko Asaka, Mikhail Shaposhnikov, May 2005*
  Published in Phys.Lett.B620:17-26,2005

νMSM can simultaneously explain

- *neutrino masses & oscillations,*
- *dark matter*
- *baryon asymmetry of the Universe*

*ν **M**inimal **S**tandard **M**odel realization:*

SM fermions

quarks						
left	u	d	c	s	t	b
right	u	d	c	s	t	b
left	ν_e	e	ν_μ	μ	ν_τ	τ
right		e		μ		τ

leptons

νMSM fermions

quarks						
left	u	d	c	s	t	b
right	u	d	c	s	t	b
left	ν_e	e	ν_μ	μ	ν_τ	τ
right	N_e	e	N_μ	μ	N_τ	τ

leptons

✓ ***Role of*** N_e, *with mass in keV range → dark matter*

✓ ***Role of*** N_μ, N_τ, *with mass in O(1GeV) range → "give" masses to neutrinos and generate baryon asymmetry of our Universe*

Search for N_e

X-ray telescopes similar to Chandra or XMM-Newton but with better energy resolution to identify narrow X-ray line from the $N_e \rightarrow \nu\gamma$ decay

One needs:

- *Improvement of the spectral resolution up to the natural line width ($\delta E/E \sim 10^{-3}$)*

- *FoV ~ 1° (size of a dwarf galaxies)*

- *Wide energy scan from O(100 eV) to O(50 keV)*

Search for N_μ , N_τ

Challenge (from baryon asymmetry): $\theta^2 \leq 5 \times 10^{-7}$ **(GeV / M)**

$(\theta = m_D / M)$

- *Experimental signature:*

peak in 2-body decay and missing energy signal in 3-body decays of K, D and B mesons (sensitive to θ^2*)*

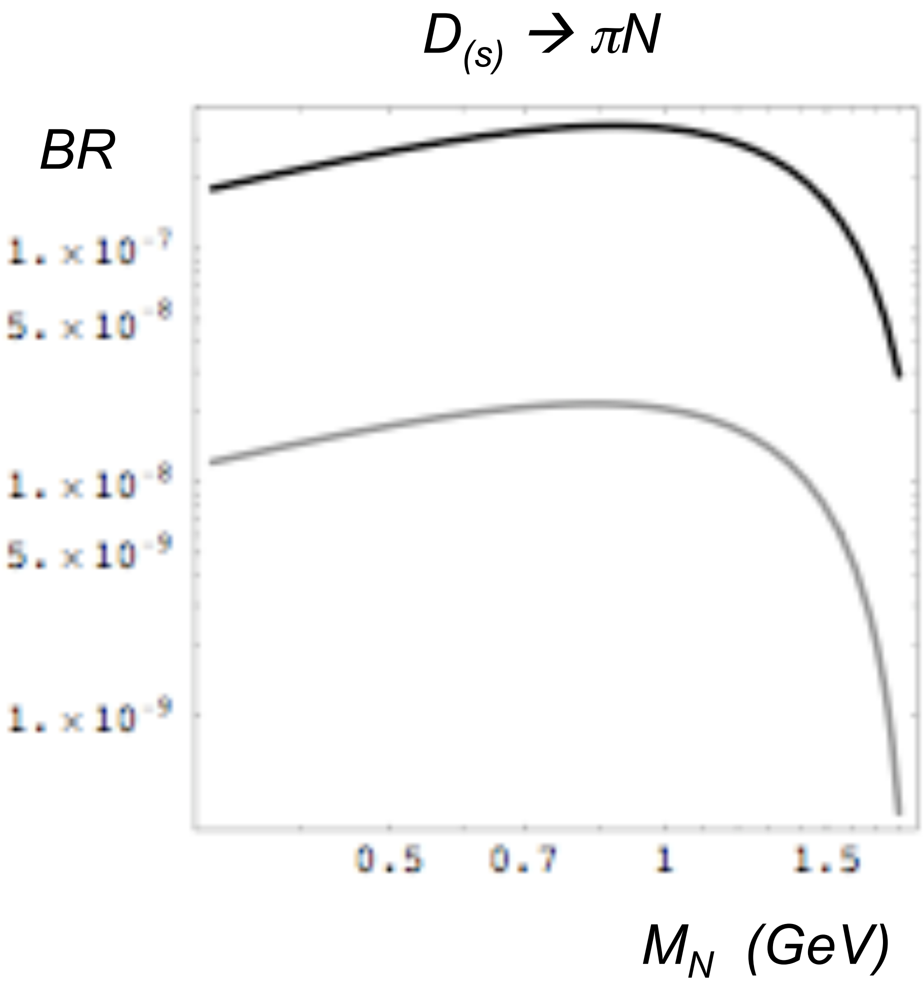
Example:

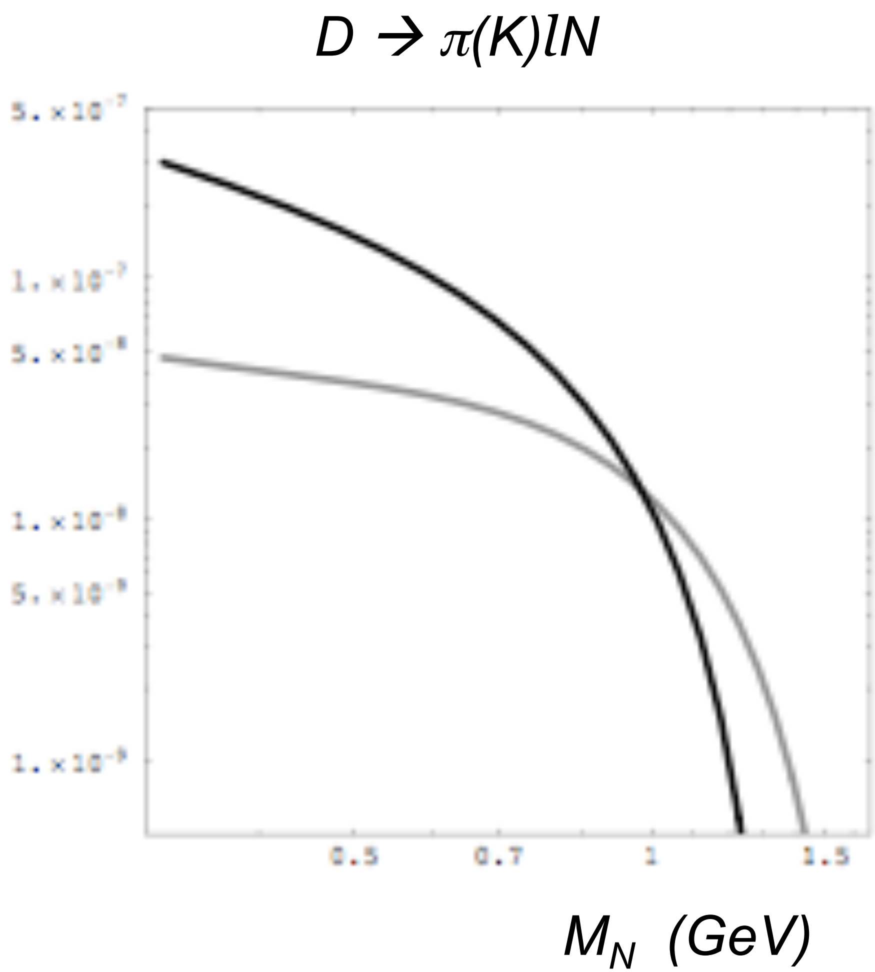
$K^+ \rightarrow \mu^+ N, \ \ M^2 = (p_K - p_\mu) \neq 0$

- *Similar for charm and beauty decays:*

  - $M_N < M_K$ — *KLOE, NA62, E787, K0TO*
  - $M_K < M_N < M_D$ — *charm- & τ-factories, CLEO-II*
  - $M_N < M_B$ — *(super) B-factories*

Typical decay BR's expected in νMSM range from 10^{-9} to few × 10^{-7} depending on M_N





Search for N_μ , N_τ

- *Two charged tracks from a common vertex*

  Decay processes:

  N → $\mu^+\mu^-\nu$, etc. (sensitive to θ^4)

  First step: *N is produced in the decays of K, D or B mesons (θ^2)*

  Second step: *search for decays of N in a near detector (θ^2)*

  - *$M_N < M_K$ Any intense source of K-mesons*
  - *$M_N < M_D$ CERN SPS beam + near detector*
  - *$M_N > M_D$ Very difficult experimentally*

Conclusion

- *LHCb is ready for data taking*

- *First data will be used for calibration of the detector and trigger in particular. First exploration of low Pt physics at LHC energies. High class measurements in the charm sector may be possible*

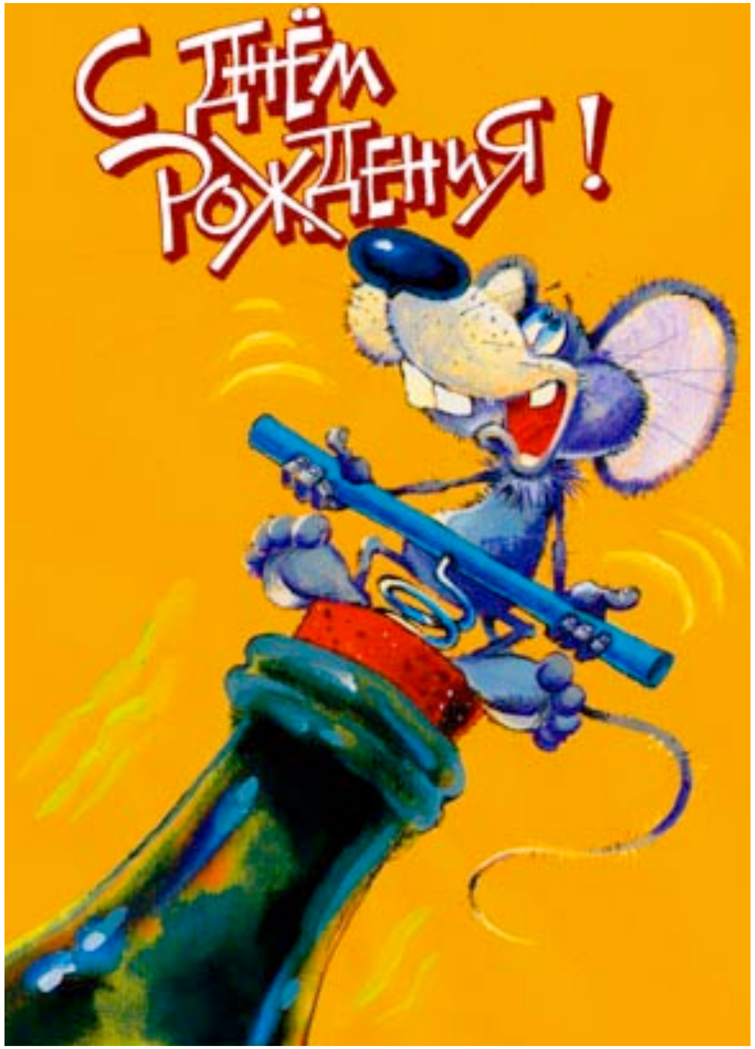
- *With 150 – 200 pb^{-1} data sample LHCb will reach Tevatron sensitivity in a few golden channels in the beauty sector*

- *With 10 fb^{-1} LHCb has an excellent opportunity to both discover New Physics and to elucidate its nature. LHCb have an important role to complement physics programme of ATLAS and CMS*

Dear Peter,

LHC experiments are opening
a nice bottle of NP for your health

Happy Birthday to You !!!



Next 5 years will be very exciting for physics, and for heavy flavour physics as well

→ Good occasion to get together with Peter in 5 years to review progress and to agree on future strategy !!!

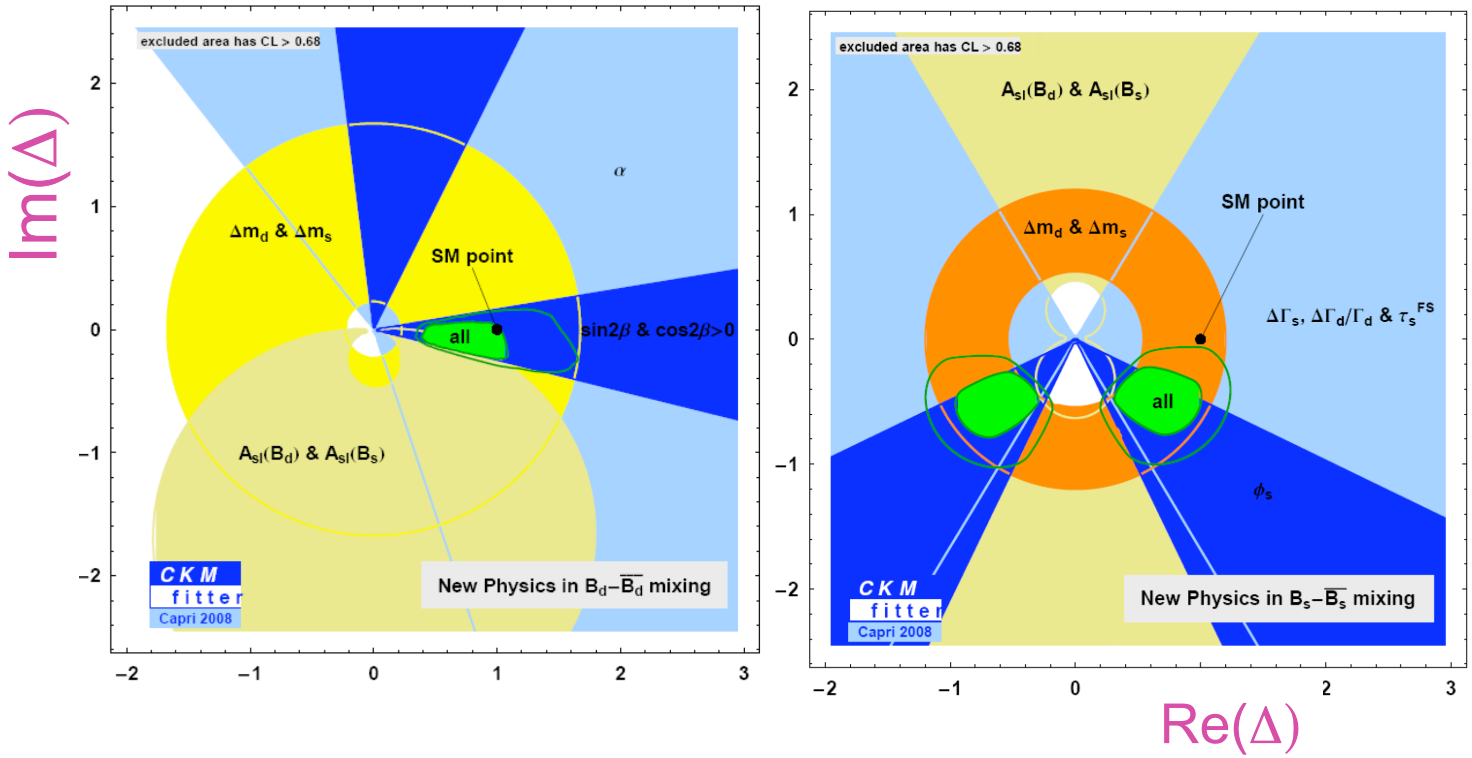
Spare Slides

Still a lot of room left for New Physics in heavy flavor sector

Thanks to B-factories and CDF/D0 the CKM mechanism of CP violation is proven to be the leading one

Extend the parameterization to include possible New Physics contributions to B-B̄ oscillations

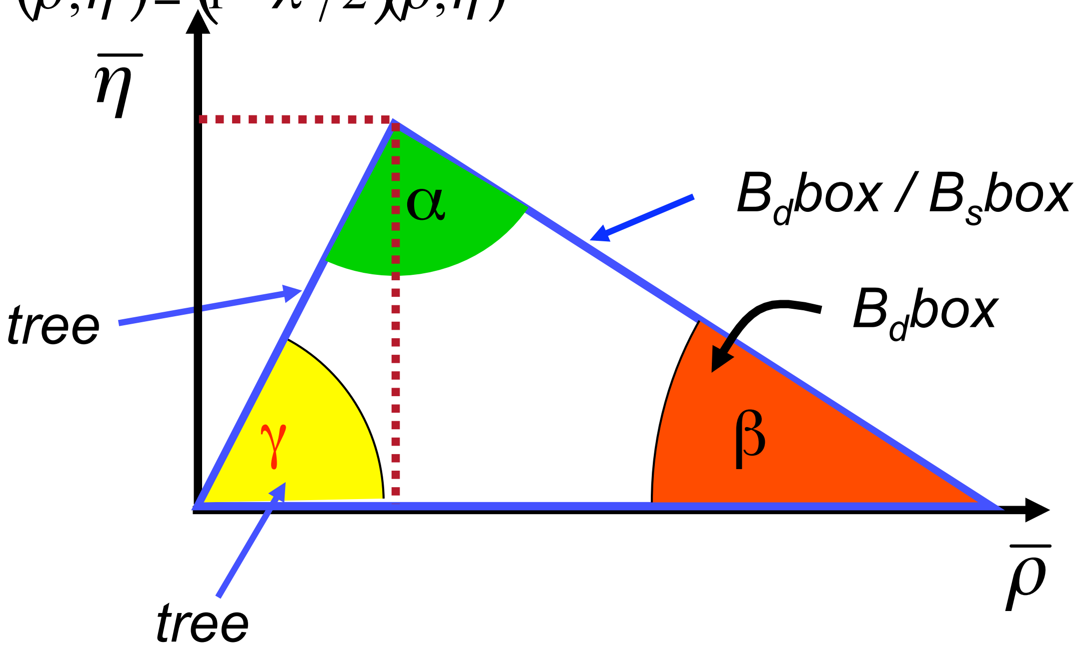
$$\mathrm{Re}(\Delta_q)+i\,\mathrm{Im}(\Delta_q)=\frac{\langle B^o|H^{full}|\bar{B}^o\rangle}{\langle B^o|H^{SM}|\bar{B}^o\rangle}$$

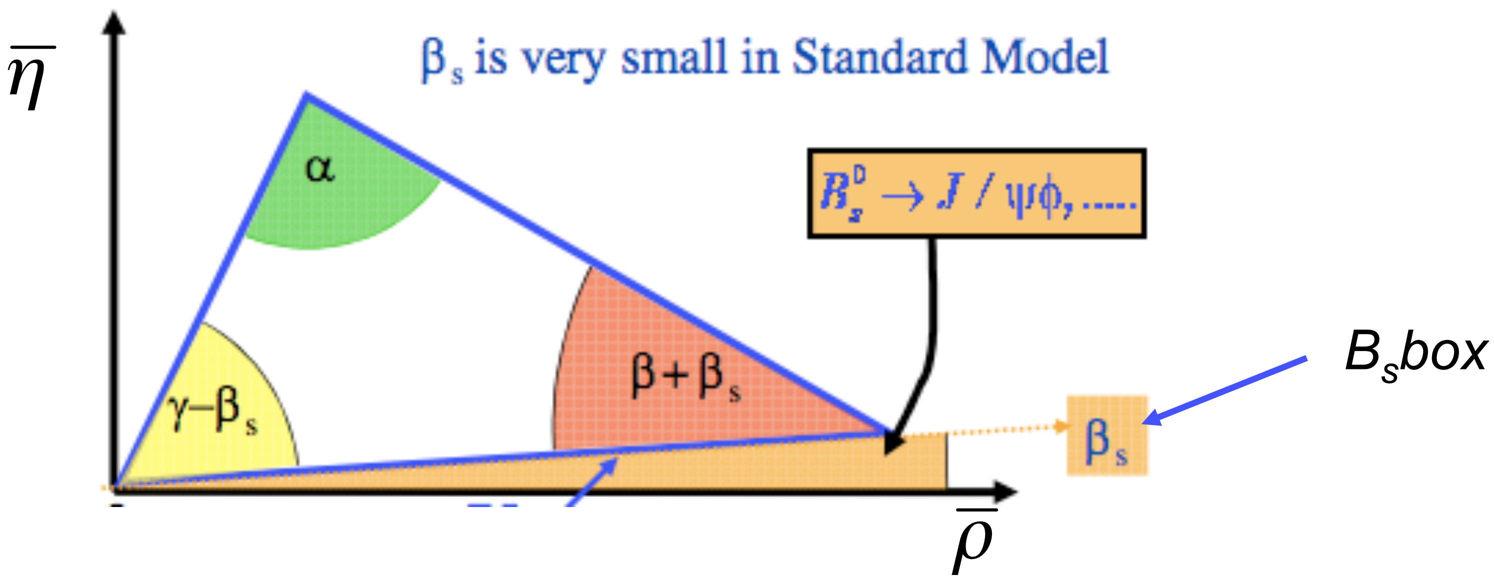


Large range of NP allowed !

Phases of New Particles
(CPV measurements)

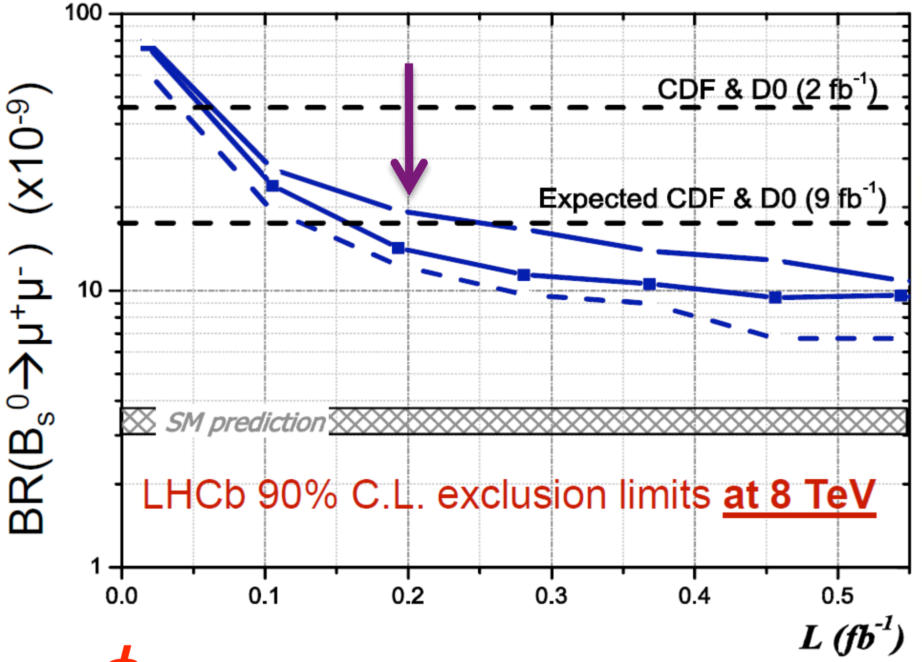
$$(\bar{\rho},\bar{\eta}) \equiv (1-\lambda^2/2)(\rho,\eta)$$



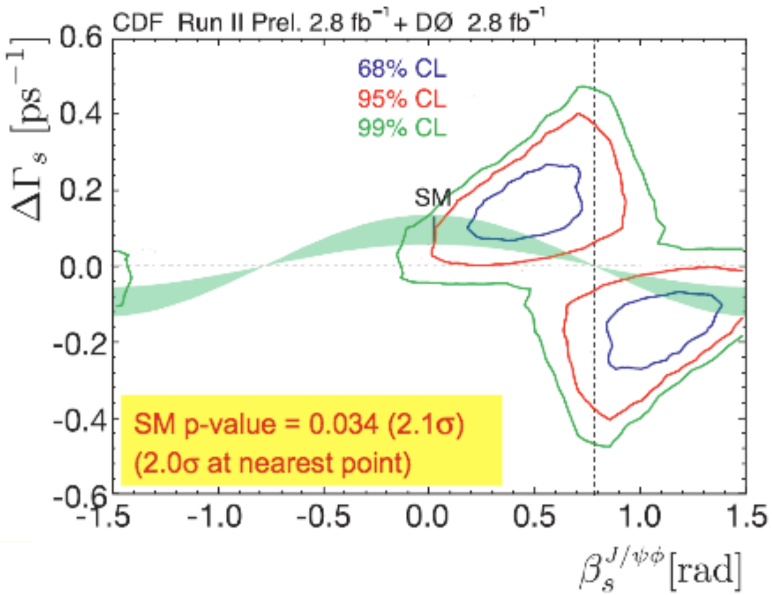


Prospects for most competitive measurements in 2010

$B_s \rightarrow \mu\mu$

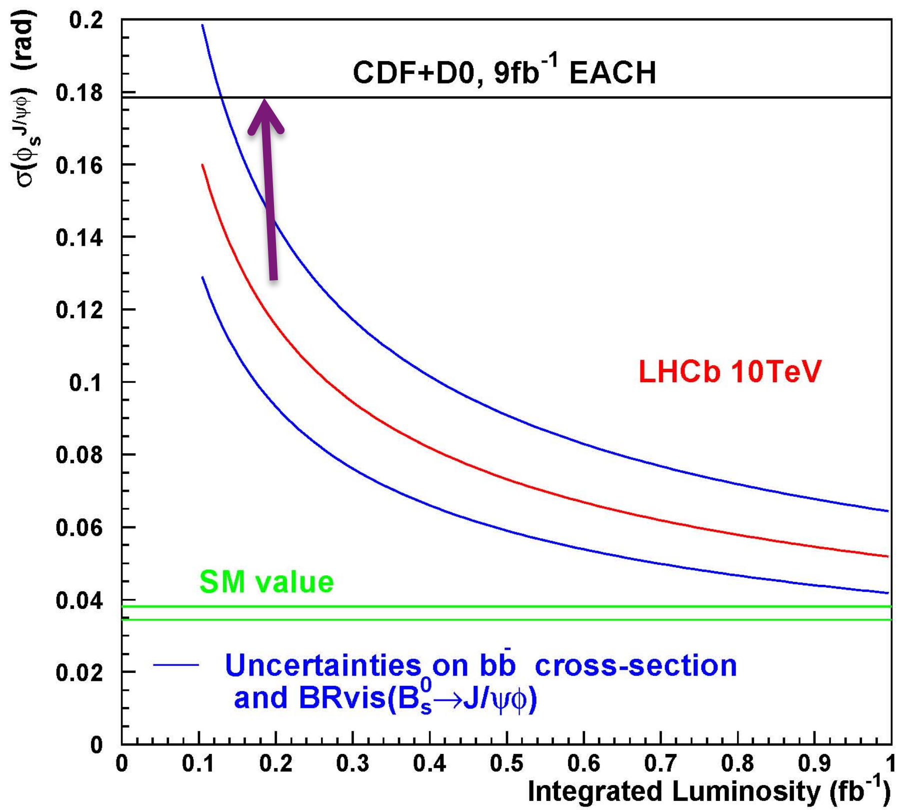


ϕ_s



With data sample of ~200 pb^{-1} LHCb should be able to improve Tevatron sensitivity for $B_s \rightarrow \mu\mu$ and ϕ_s

(present 'central' value from Tevatron would be confirmed at 5σ level)



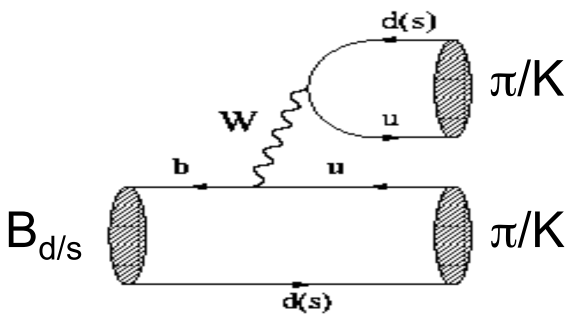
LHCb sensitivities for integrated lumi of 100 fb^{-1}

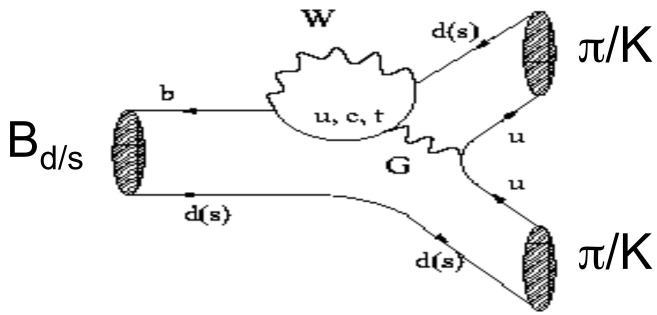
Observable	Sensitivity
$S(B_s \to \phi\phi)$	$0.01 - 0.02$
$S(B_d \to \phi K_S^0)$	$0.025 - 0.035$
ϕ_s $(J/\psi\phi)$	0.003
$\sin(2\beta)$ $(J/\psi K_S^0)$	$0.003 - 0.010$
γ $(B \to D^{(*)}K^{(*)})$	$< 1^\circ$
γ $(B_s \to D_s K)$	$1 - 2^\circ$
$\mathcal{B}(B_s \to \mu^+\mu^-)$	$5 - 10\%$
$\mathcal{B}(B_d \to \mu^+\mu^-)$	3σ
$A_T^{(2)}(B \to K^{*0}\mu^+\mu^-)$	$0.05 - 0.06$
$A_{\rm FB}(B \to K^{*0}\mu^+\mu^-)$ s_0	0.07 GeV^2
$S(B_s \to \phi\gamma)$	$0.016 - 0.025$
$A^{\Delta\Gamma_s}(B_s \to \phi\gamma)$	$0.030 - 0.050$
charm x'^2	2×10^{-5}
mixing y'	2.8×10^{-4}
CP y_{CP}	1.5×10^{-4}

Also studying Lepton Flavour Violation in $\tau \to \mu\mu\mu$

CPV measurements: γ in penguins

- ***Large penguin contribution in both $B^0 \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$***
  ⟶ sensitive to NP





- *<u>Time-dependent CP asymmetries</u>* $A_{CP}(t) = A_{dir}\cos(\Delta mt) + A_{mix}\sin(\Delta mt)$
  depend on γ, mixing phases, and ratio of penguin to tree = $d\,e^{i\theta}$

- *exploit "U-spin" symmetry (d↔s) [R.Fleischer, Phys.Lett. B459, 306 (1999)]*
  - ✓ *assume $d_{\pi\pi} \approx d_{KK}$ within ±20% and $\theta_{\pi\pi} \approx \theta_{KK}$ within ±20°*
  - ✓ *4 measurements and 3 unknowns, if mixing phase 2β taken from $B^0 \rightarrow J/\psi K_S$*

- *<u>Expected sensitivity:</u>*
  59k $B^0 \rightarrow \pi^+\pi^-$ with B/S~0,5
  72k $B_s \rightarrow K^+K^-$ with B/S~0.07

⟶ ***$\sigma(\gamma)$ ~ 7° in 1 year/2fb^{-1}***
assuming U-spin symmetry
to be held within 20%
$\sigma(\phi_s^{J/\psi\phi})$ ~ 0.05 rad comparable
to J/$\psi\phi$ analysis