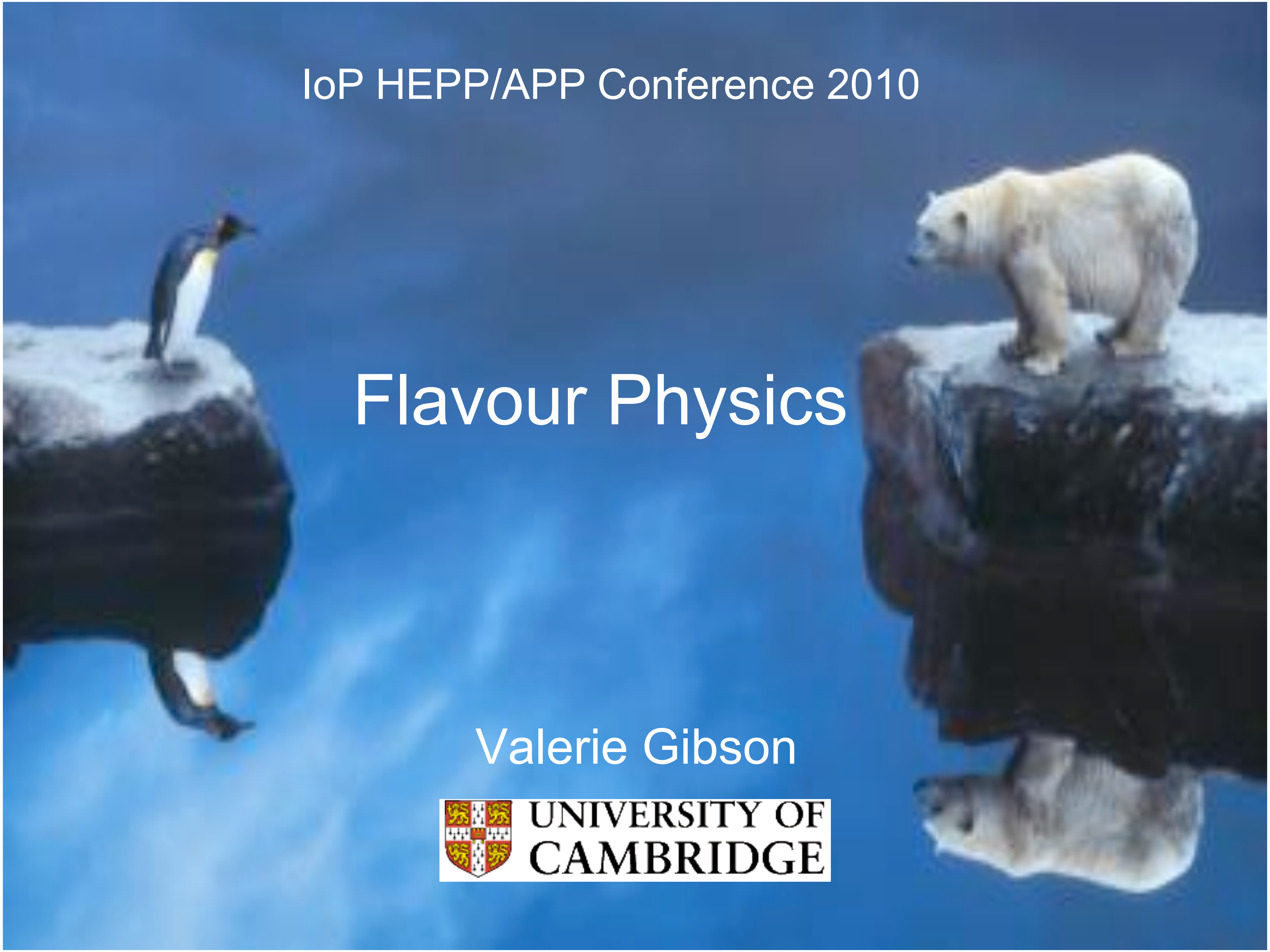


IoP HEPP/APP Conference 2010

Flavour Physics

Valerie Gibson

UNIVERSITY OF CAMBRIDGE

Contents

Flavour Physics covers an enormous range of topics and so I have had to be very selective (my apologies).

Overview :

- Flavour Physics and the Golden Triangle
- Hints of New Physics beyond the SM
- Status of LHCb and its discovery potential
- The Menu for the Future

If you would like to hear more, please listen in to the “Flavour Physics & Rare Decays” and “LHC Results & Commissioning” parallel sessions.

Special thanks go to Adrian Bevan, Tim Gershon, Cristina Lazzeroni, Yoshi Uchida, Guy Wilkinson and all those who unknowingly helped by giving excellent talks at recent conferences, such as Aspen, La Thuile and Moriond 2010.

Flavour Physics

Flavour physics is highly successful. It has led the way to

- The 3 generation Standard Model
- The CKM picture of flavour
- CP Violation

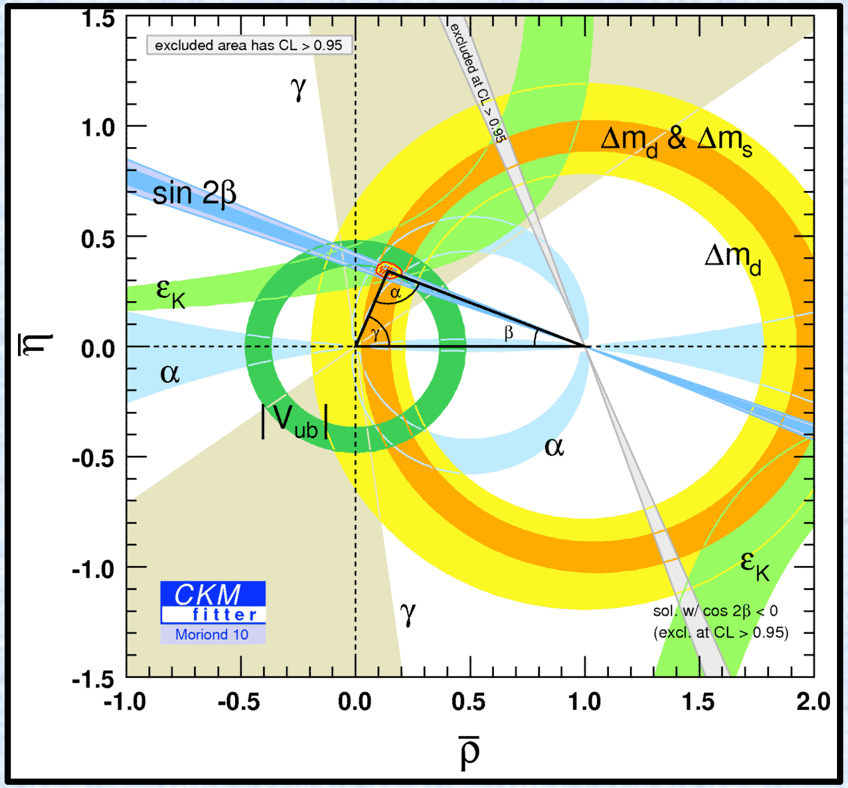
Many open questions found in the flavour sector

- Why are there 3 generations ?
- What determines the hierarchy of fermion masses ?
- What determines the elements of the CKM matrix ?
- What is the relationship between the CKM matrix and the neutrino mixing matrix ?
- What is the origin of CP Violation ?

Flavour physics also helps to understand open questions in cosmology
e.g. SM CPV insufficient to explain matter/antimatter asymmetry

Flavour Physics

The state of the art is encapsulated in the Unitarity Triangle



$$V_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

L.Wolfenstein PRL 51 (1983) 1945

$$A = 0.8123^{+0.0092}_{-0.0244} \quad \lambda = 0.22512^{+0.00074}_{-0.00075}$$

$$\bar{\rho} = 0.139^{+0.024}_{-0.028} \quad \bar{\eta} = 0.342^{+0.016}_{-0.015}$$

$$J_{CP} = \left(2.93^{+0.15}_{-0.16}\right) \times 10^{-5}$$

Flavour Physics

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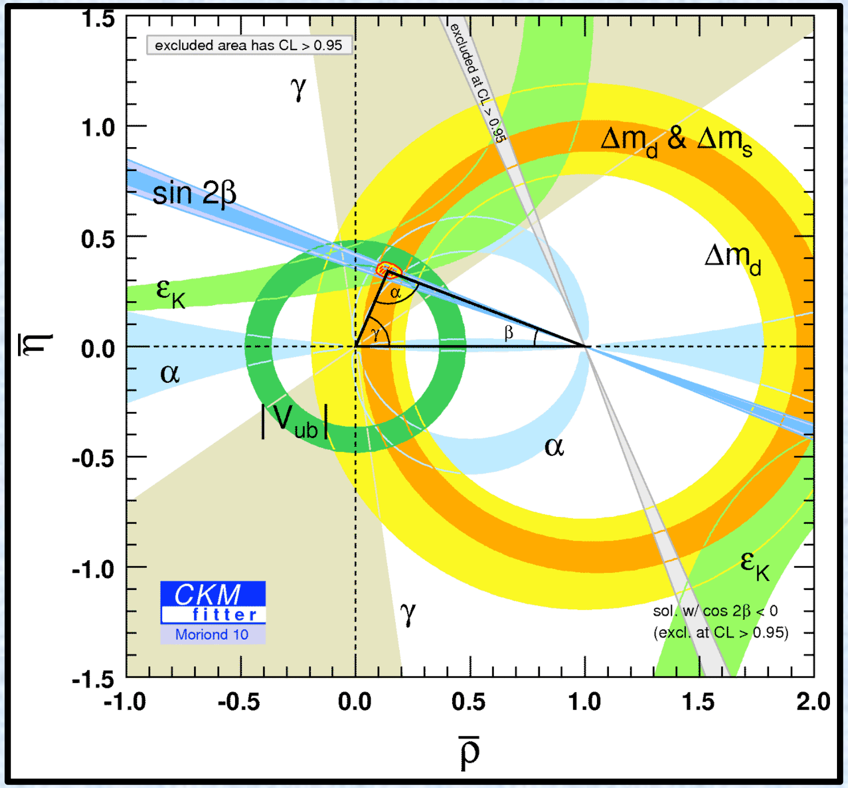

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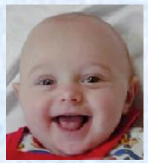
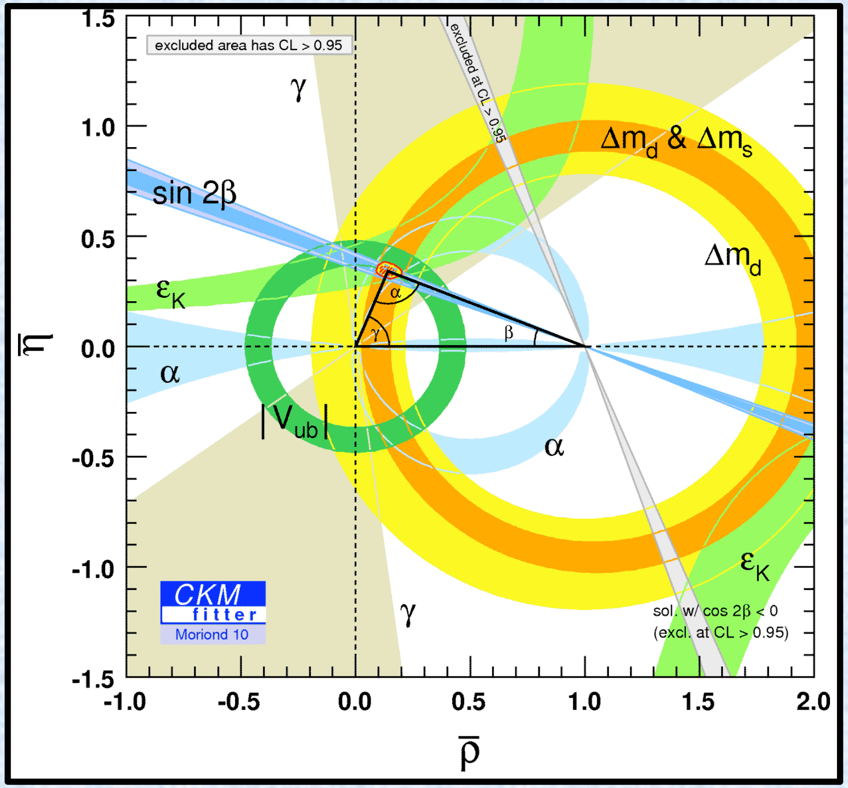


Amazing consistency ! Beautiful validation of CKM picture.

Flavour Physics

The state of the art is encapsulated in the Unitarity Triangle



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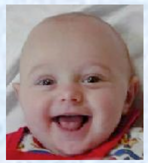
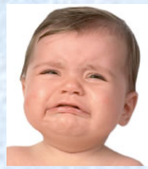


Amazing consistency ! Any New Physics contributions are small.

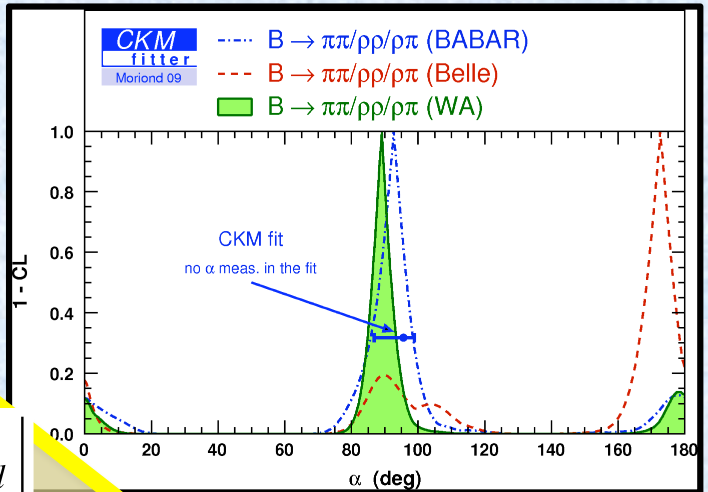


The Golden Triangle

Fantastic achievement by the B Factories to test the SM picture of quark couplings, especially CP Violation.

P. Urquijo, Moriond 2010

	$\lvert V_{cb}\rvert$	$\lvert V_{ub}\rvert$
Inclusive	1-2%	6-7%
Exclusive	3%	10%
Difference	~2σ	~1-2σ



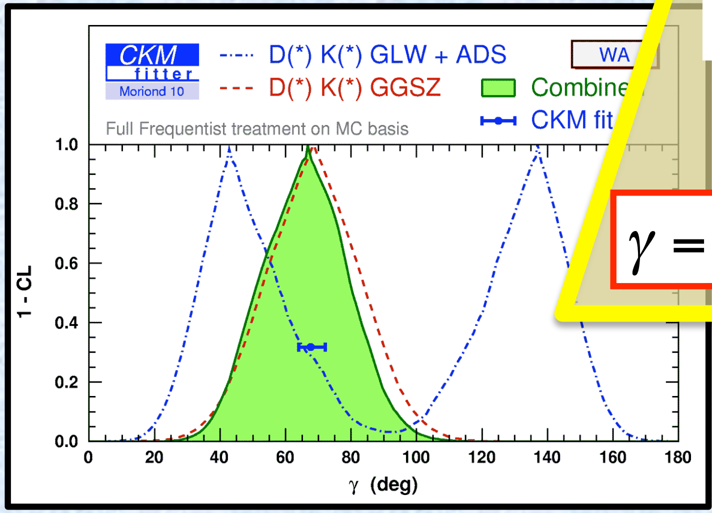
$$\alpha = \left(89.0^{+4.4}_{-4.2}\right)^{\circ}$$

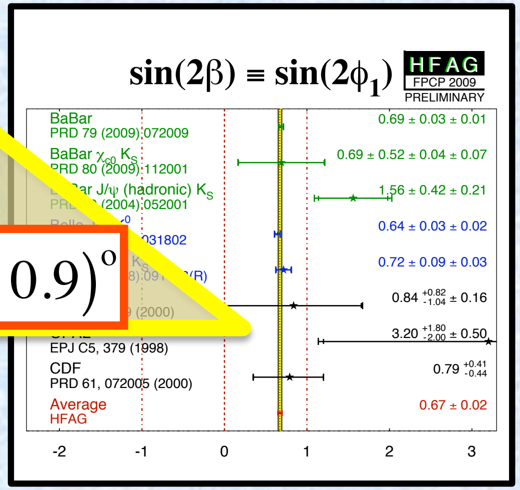
60% c.l.

$$\left|\frac{V_{ub}}{V_{cb}}\right| \qquad \left|\frac{V_{td}}{V_{ts}}\right|$$

$$\gamma = \left(69^{+19}_{-21}\right)^{\circ}$$

$$\beta = \left(21.1 \pm 0.9\right)^{\circ}$$





$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.214\ (1)_{\text{exp.}}\ (5)_{\text{lattice.}}$$

R.Van de Water, FPCP 09

Beyond the SM

NP models introduce new particles which could

- be produced and discovered as real particles
- appear as virtual particles in loop processes → deviations from the SM in flavour physics and CPV

Flavour physics is a proven tool of discovery:
- $Br(K^0_L \rightarrow \mu\mu)$ & GIM → prediction of charm
- CP violation → need for a 3rd generation
- B mixing → top quark is very heavy

NP needs to have a special flavour structure

- to provide the suppression mechanism for FCNC processes already observed.
- Some say it may be too "special"… Minimal Flavour Violation (MFV) models in which the flavour structure of the NP is governed by the CKM matrix.

The only sure way to find out is to look more closely and measure the flavour structure to distinguish between the NP models.

Flavour physics (at the precision frontier) goes hand-in-hand with direct searches (at the energy frontier)

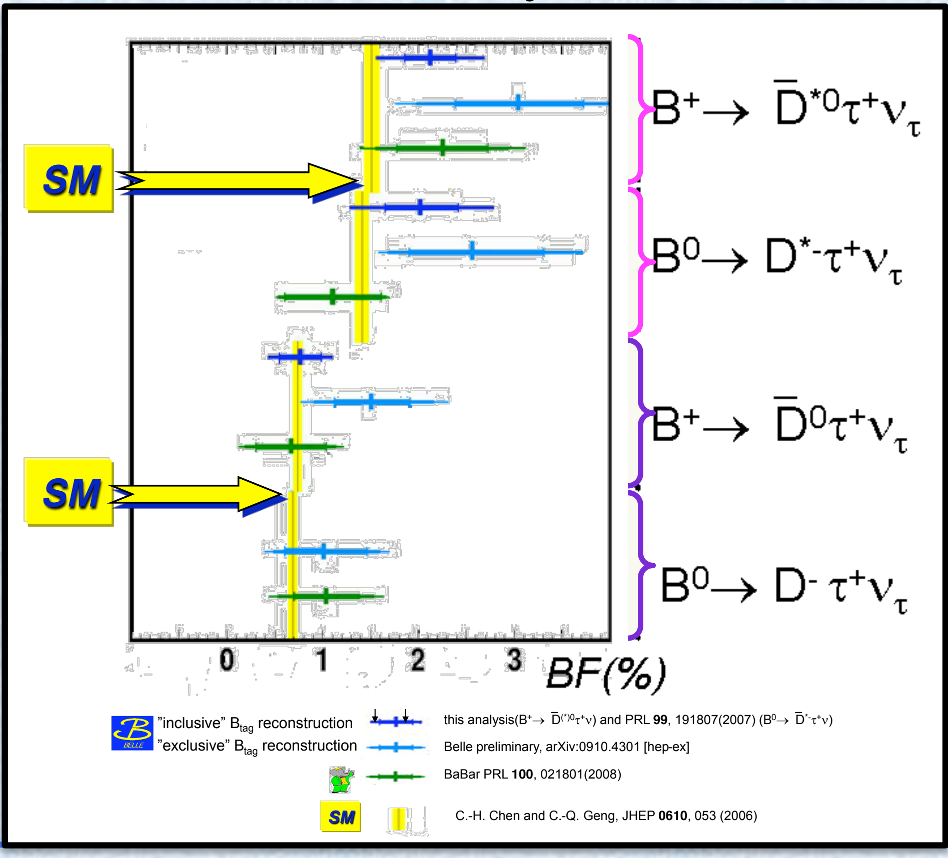
Tensions within the UT

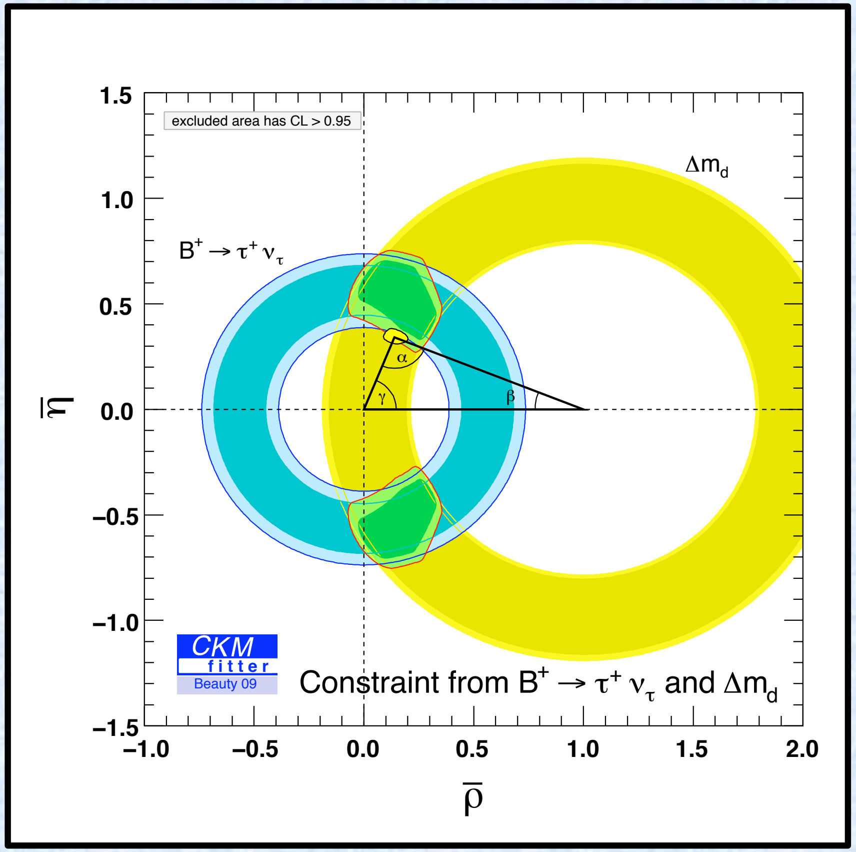
Look further into the measurements that feed into the UT and see that all is not totally consistent.

>2σ discrepancy between Br(B→ τν) and CKM from other measurements

Persists in B→ Dlν decays

M.Rozanska, Moriond EW 2010



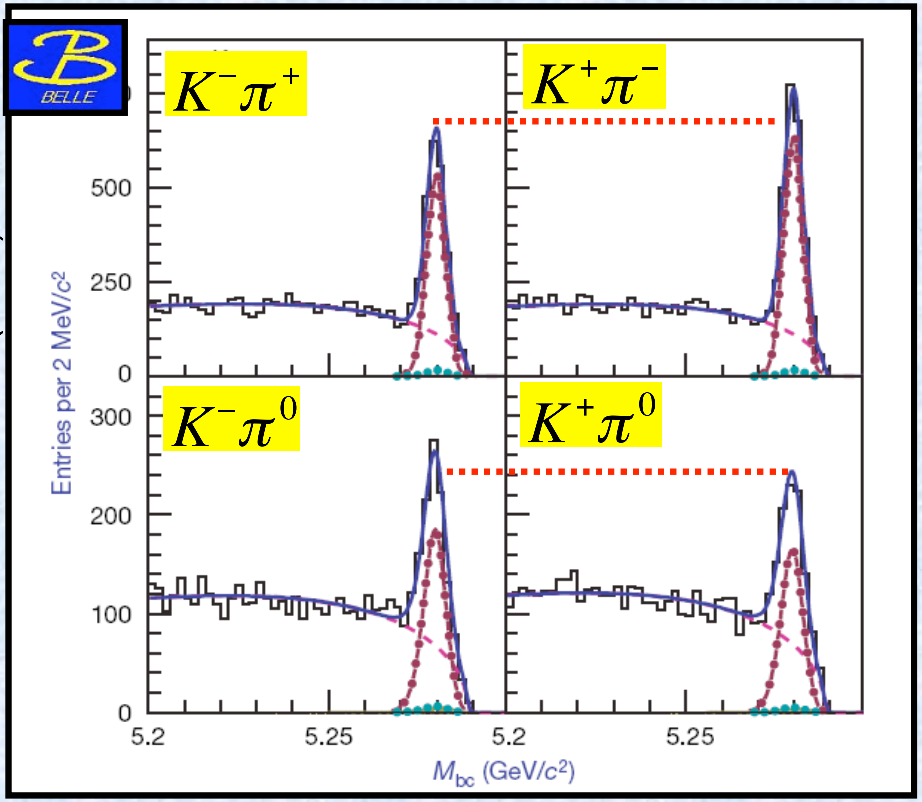


The "Kπ Puzzle"

"Kπ Puzzle" published by Belle in Nature 2008….

Direct CPV asymmetry in $B^0 \to K^+\pi^-$ decays different to $B^+ \to K^+\pi^0$ decays ??

Belle Nature 452 (2008) 332



$$\Delta A_{K\pi} = A_{CP}\left(K^+\pi^-\right) - A_{CP}\left(K^+\pi^0\right) = -0.147 \pm 0.028$$

5.3σ

HFAG

Possible explanations:

- Enhancement of colour suppressed tree amplitude

  Gronau and Rosner, PRD 74 (2006) 057503

- Enhancement of EW penguin amplitude – clear evidence for New Physics

  Fleischer et al (& refs therein); PRD 78 (2008) 111501

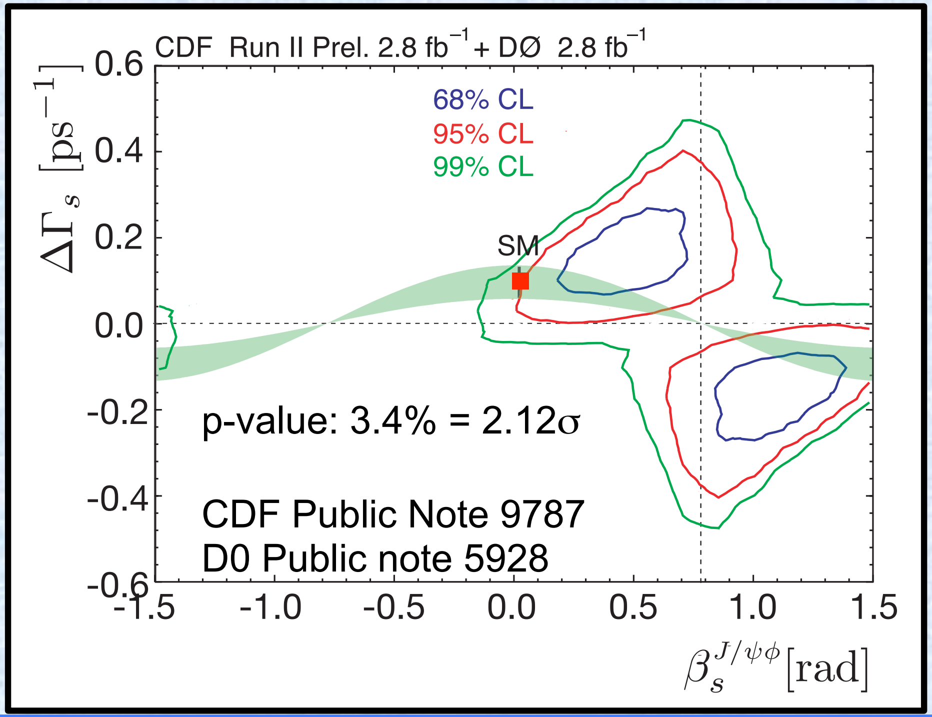
In order to progress need to measure $B^0 \to K^0\pi^0$ (SFF) and use robust model independent approach M.Gronau : PLB 82 (2005) 627

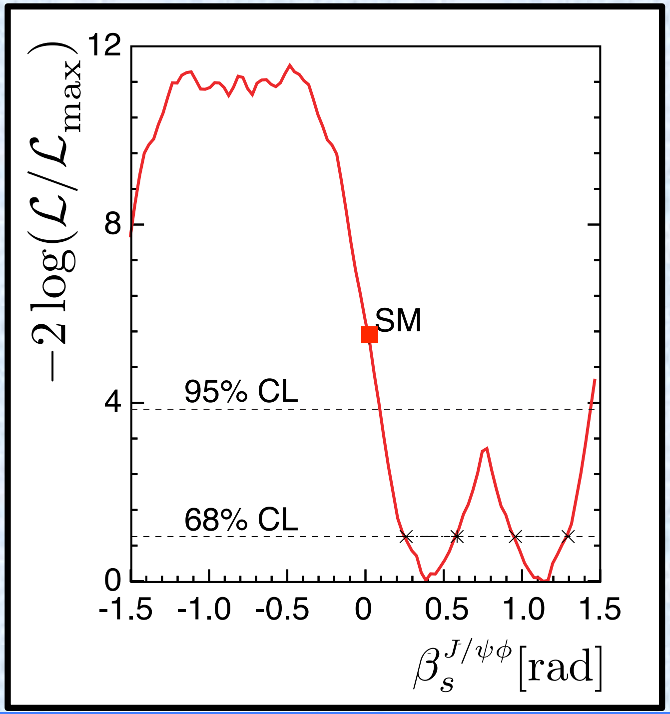
$B_s \rightarrow J/\Psi\phi$

Mixing induced CPV in $B_s \rightarrow J/\Psi\phi$ is a golden mode at hadron machines

- Precisely predicted in SM
- Very small in SM, any signal at present sensitivity is exciting $\beta_S^{SM} \approx 0.02$
- $P \rightarrow VV$ decay, mixture of CP-even and CP-odd final states (angular analysis)

Recent results from Tevatron have understandably caused a lot of interest



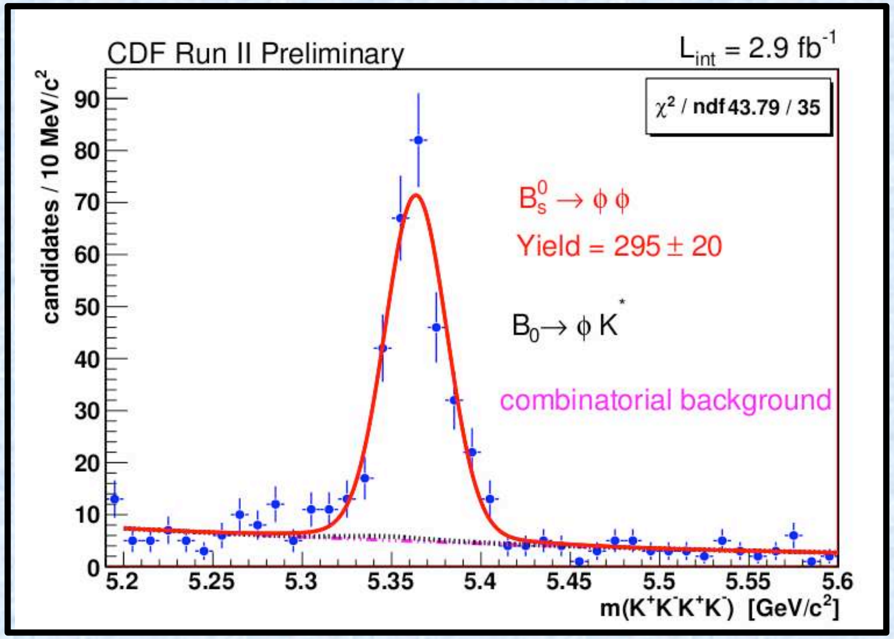


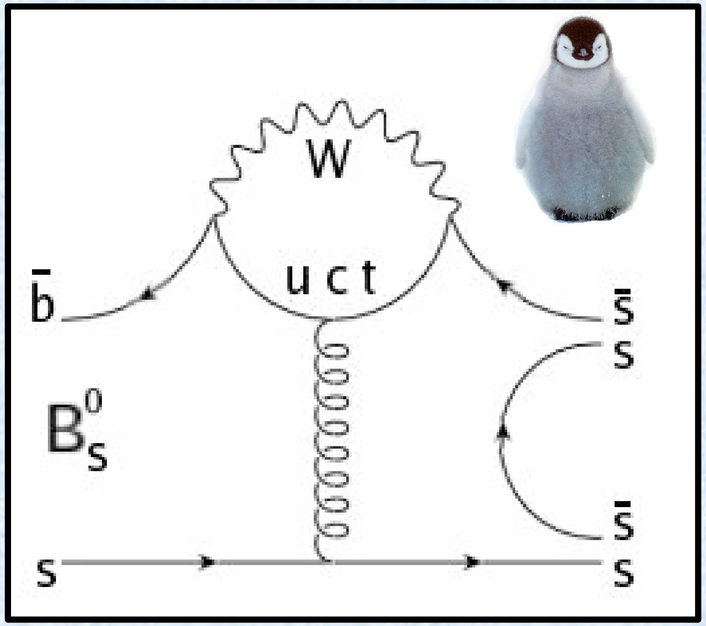
$B_s \to \phi\phi$

$B_s \to \phi\phi$ is the charmless analogue to $B_s \to J/\Psi\phi$

- An independent $P \to VV$ decay; can extract $\Delta\Gamma_s$ and β_s.
- Dominant SM process is $b \to s$ penguin, any signal would indicate NP.
- CDF have performed a first stage measurement of Br.

CDF Public Note 10064



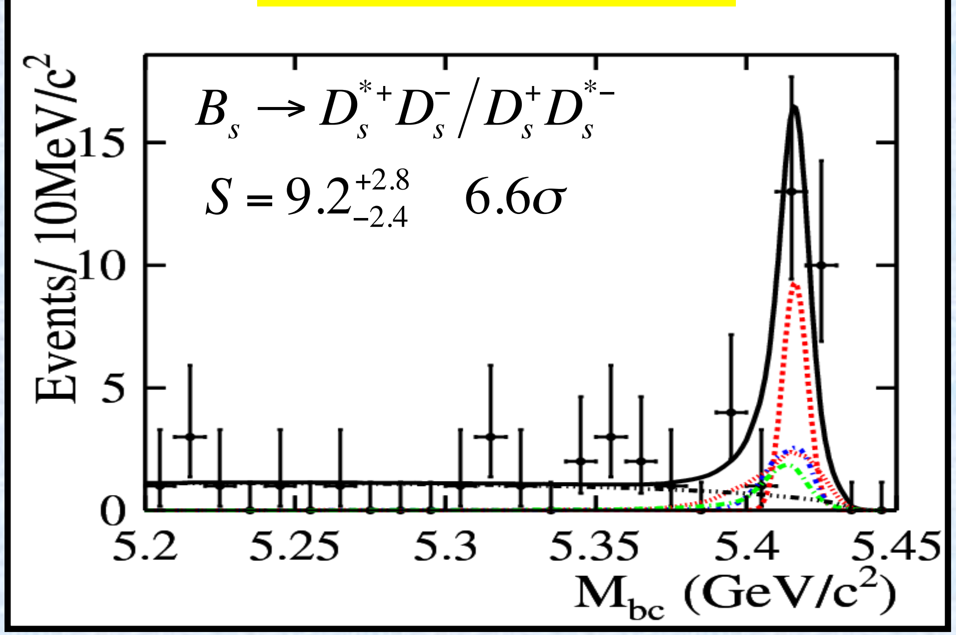


$$\frac{Br(B_s \to \phi\phi)}{Br(B_s \to J/\psi\,\phi)} = \left(1.78 \pm 0.14(stat) \pm 0.20(sys)\right) \times 10^{-2}$$

B_s at the $\Upsilon(5s)$

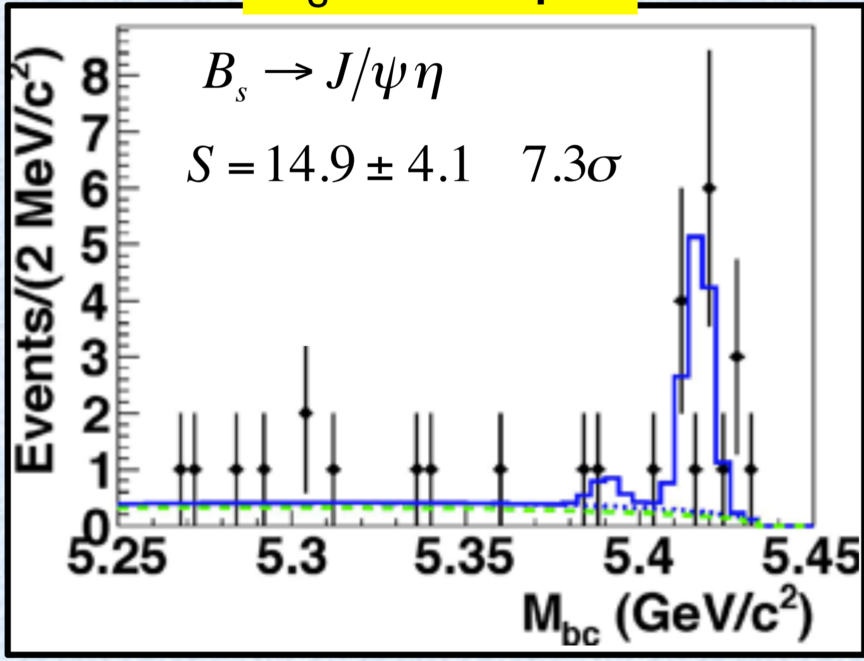
Belle have analyzed 23.6 fb^{-1} data at the $\Upsilon(5s)$, ~100 fb^{-1} yet to be analyzed.

$B_s \to D_s^{(*)+} D_s^{(*)-}$



T.Asiz Moriond QCD 2010

$B_s \to J/\Psi\eta^{(')}$



K.Kinoshita, Moriond EW 2010

$$Br\left(B_s \to D_s^{*+} D_s^{*-}\right) = \left(6.9^{+1.5}_{-1.3} \pm 1.9\right)\%$$

$$\frac{\Delta\Gamma_{CP}}{\Gamma} \approx \frac{2B}{(1-B)} = \left(0.147^{+0.036+0.044}_{-0.030-0.042} \pm 0.004(the.)\right)\%$$

$$Br\left(B_s \to J/\psi\,\eta\right) = \left(3.32 \pm 0.87^{+0.32}_{-0.28} \pm 0.429(f_s)\right) \times 10^{-4}$$

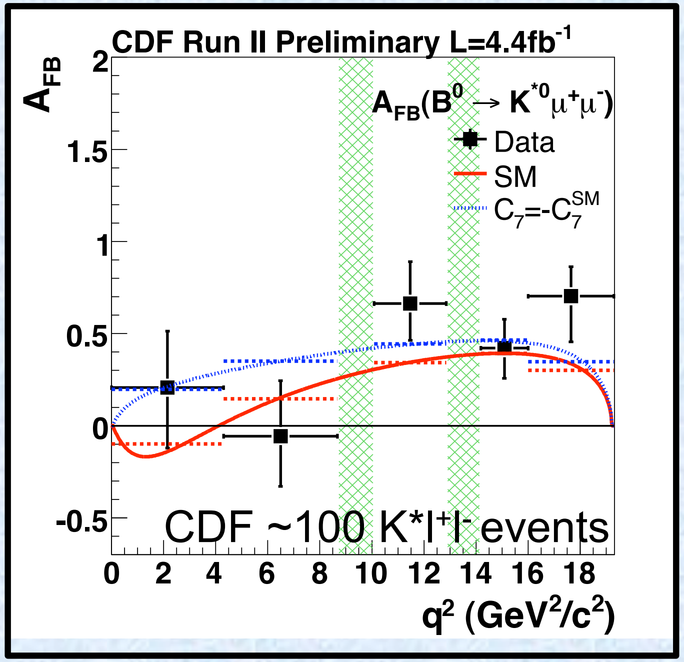
$B \to K^*\mu\mu$

FCNC b→s transition, very sensitive to NP
The forward-backward asymmetry arises from the interference between γ and Z^0 contributions

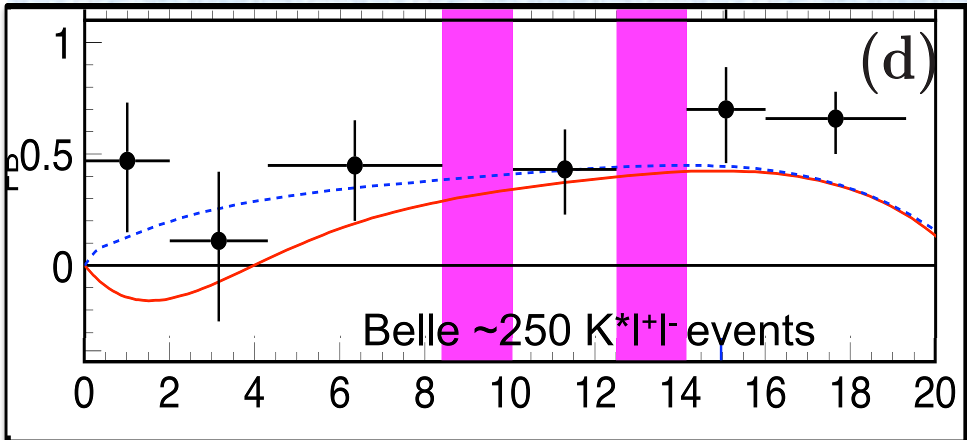
$$A_{FB}\left(q^2 = m_{\mu\mu}^2\right) = -C_{10}\,\xi(s)\left[\mathrm{Re}(C_9)F_1 + \frac{1}{q^2}C_7F_2\right]$$

Most reliable predictions are at low q^2 (1-6 GeV^2)

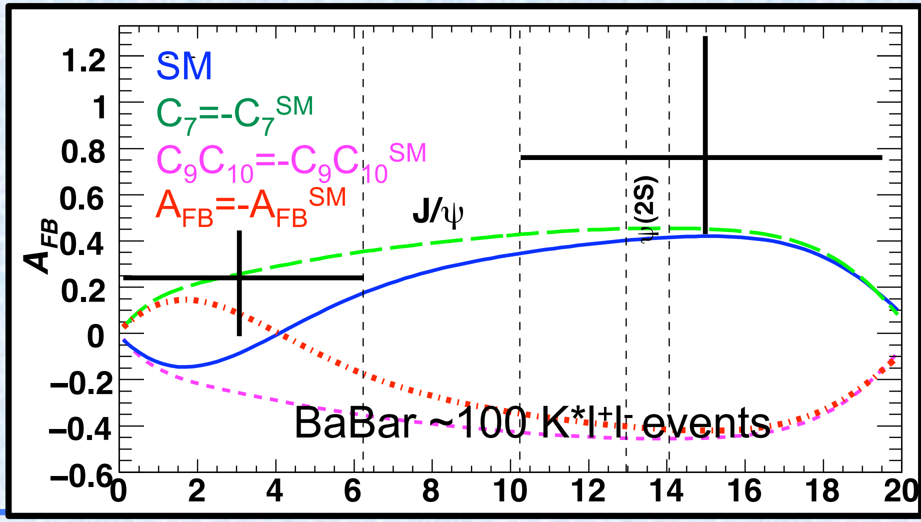
Early results are showing intriguing hints.



CDF Public Note 10047



Belle PRL 103 (2009) 171801

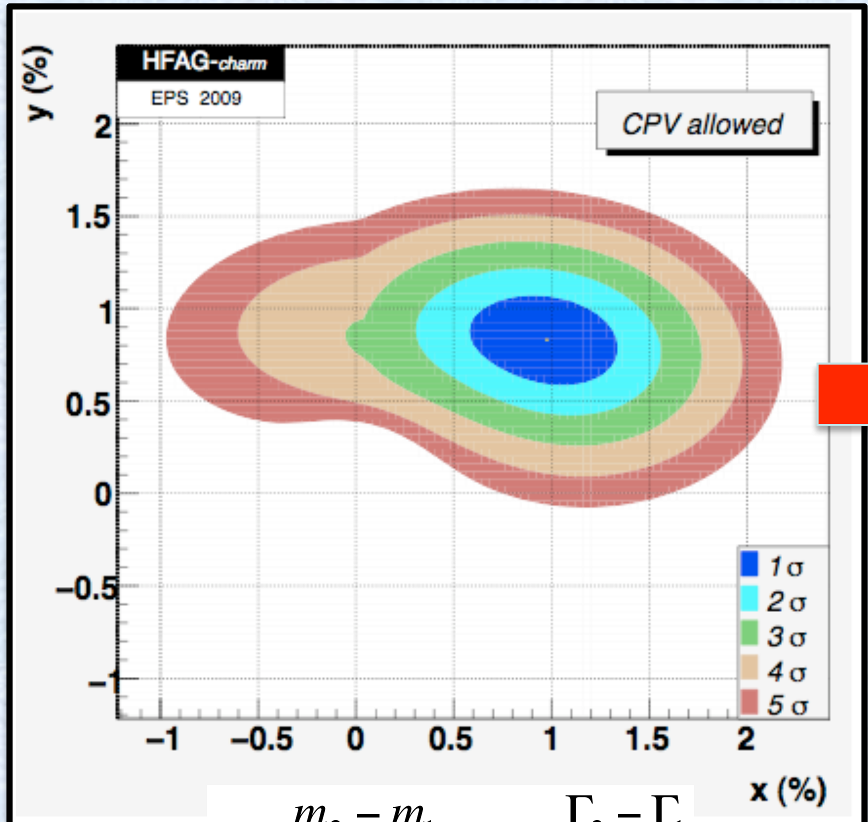


BaBar PRD 79 (2009) 031102

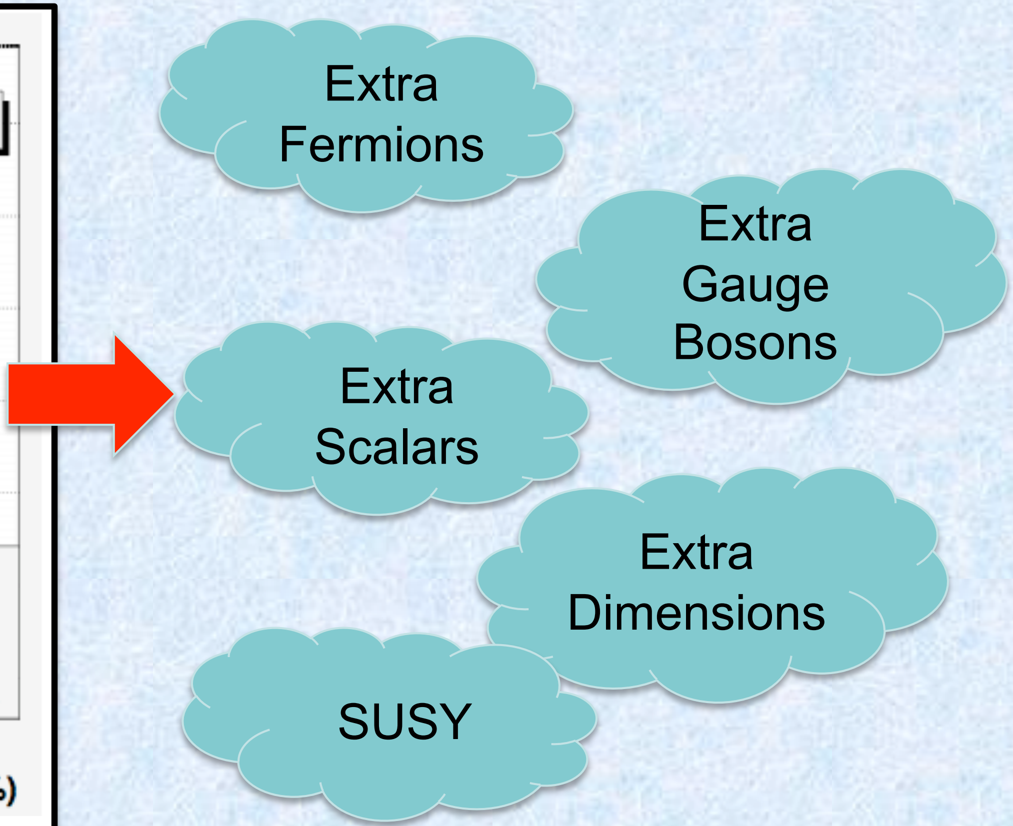
Charm Mixing

Charm offers a unique potential for the discovery of NP

Current measurements of charm mixing exclude many regions of NP space



$$x \equiv \frac{m_2 - m_1}{\Gamma} \qquad y \equiv \frac{\Gamma_2 - \Gamma_1}{2\Gamma}$$



Golowich et al, PRD 76 (2007) 095009

Lepton Flavour Violation

Studies of LFV are setting world class limits on New Physics.

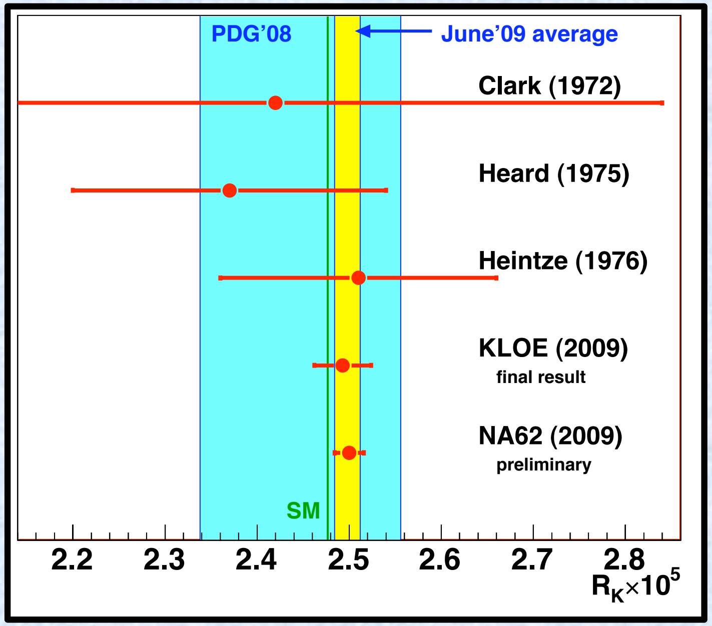
BaBar: $\tau \to e/\mu\ \gamma$ limits ~ 3-4 x 10^{-8} and $\Upsilon(2S/3S) \to e/\mu\ \tau$ limits ~ 3-4 x 10^{-6}

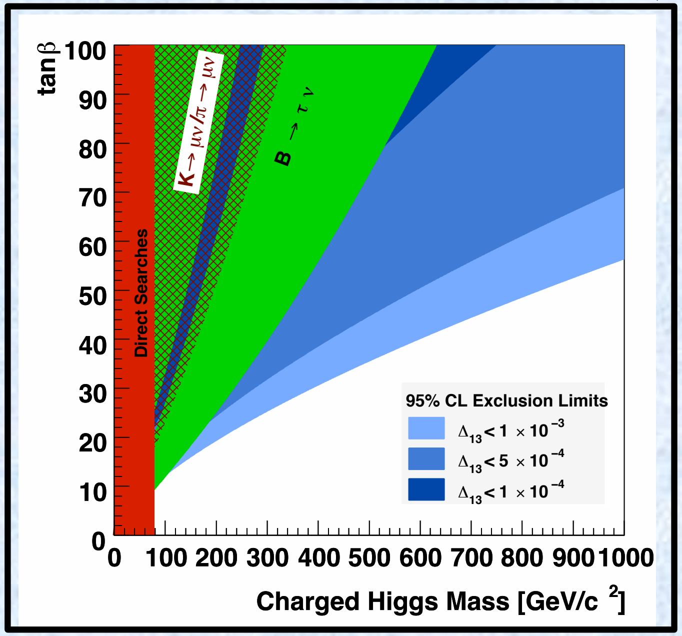
MEG (at PSI): First run (2008) for $\mu \to e\gamma$ has set a BR limit at 2.8×10^{-11}, approaching MEGA limit. Ultimate goal is 10^{-13}.

MEG, arXiv:0908.2594v2

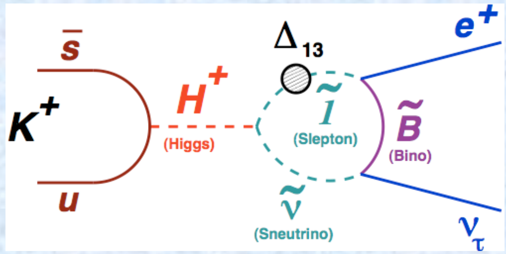
NA62 : Based on 40% of data set has measured $R_K = \Gamma(K^\pm \to e^\pm \nu) / \Gamma(K^\pm \to \mu^\pm \nu)$

E.Goudzofski Moriond EW 2010



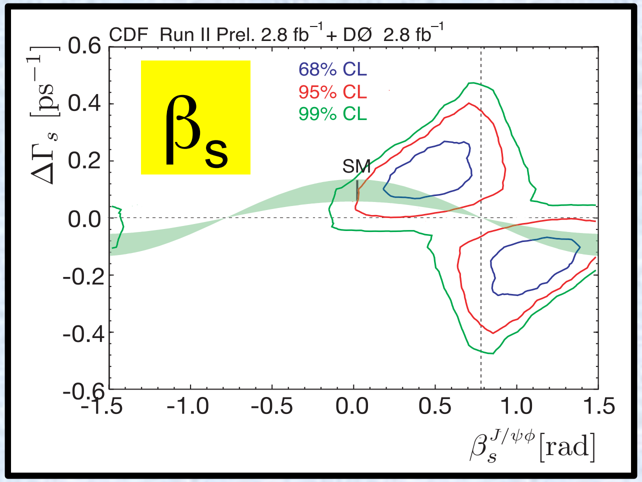


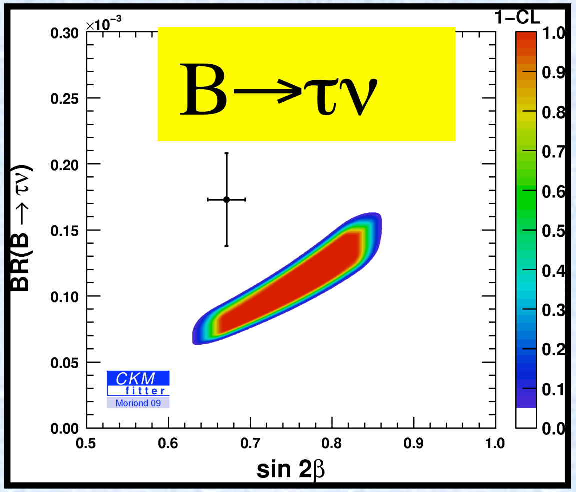
In models with slepton mixing Δ_{13} above 10^{-3}, this sets very stringent bounds on charged Higgs

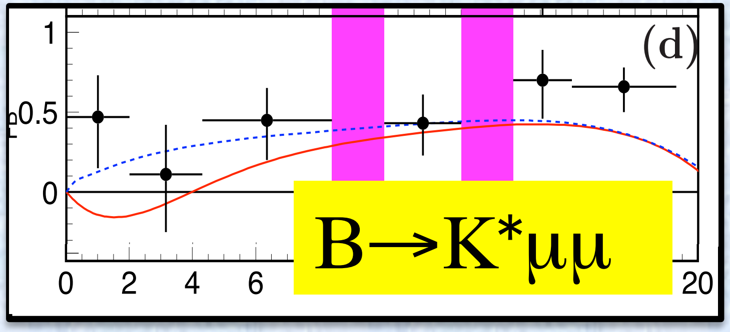


Keep on searching….

Several hints of non-SM behaviour exist in the flavour sector…







"Kπ Puzzle"

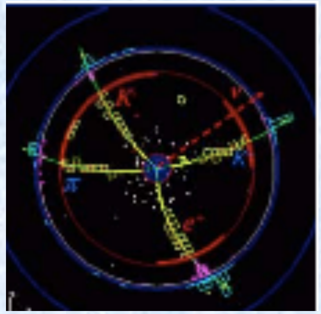
and some others that have not been discussed here e.g. f_{Ds} and β_{eff}

Several of the hints occur in observables that should be sensitive to NP

Another convincing argument to increase statistics in nearly all observables and to search in others.

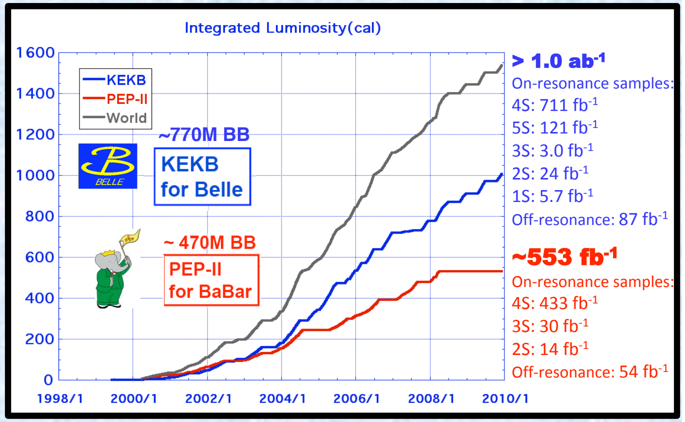
Heavy Flavour Experiments

Open Charm Factories



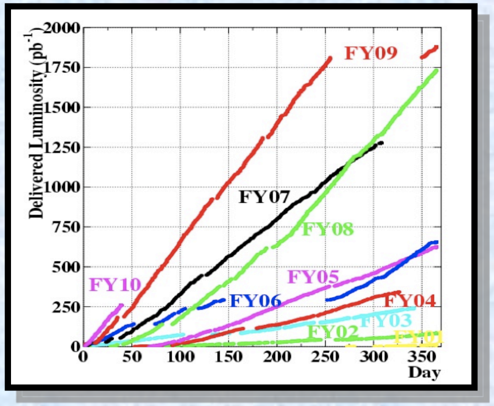
CLEO-c collected 818 pb^{-1} at $\Psi(3770)$ and similar above D_s threshold. BES-III will start operation this year – hope for order of magnitude more data than CLEO

B-Factories



771M+463M BB-bar pairs collected by Belle and BaBar. Belle have another 100 fb^{-1} collected at $\Upsilon(5s)$ (~6M B_s events). Amazing output already, but many analyses still to be completed.

Tevatron



Around 8 fb^{-1} per experiment already collected. Very few results presented so far have more than 3-4 fb^{-1}. One more year (so far) confirmed to provide ~10-12 fb^{-1}. Hope enough manpower remains to fully exploit this gold mine.

Heavy Flavour Experiments (cont)

LHC

Now running ! All LHC experiments will contribute.

Will focus on LHCb…

2008 – 2009 : several million cosmics events, injection line beam dump

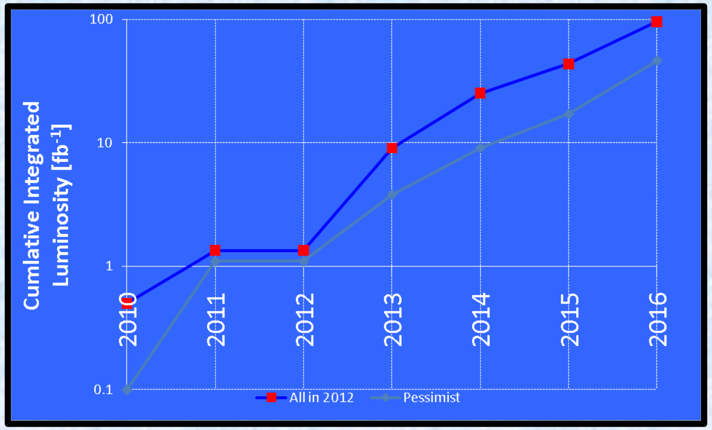
2009 : First events 21st Nov (magnet on, VELO retracted)

Physics run 6-15th Dec, recorded $\sim 7 \mu b^{-1}$

260k pp collisions at 450 GeV, 80k beam-gas events

2010/2011 : Hoping for 200 pb^{-1} /1 fb^{-1} at 3.5+3.5 TeV (VELO closed)

Collisions start today !!

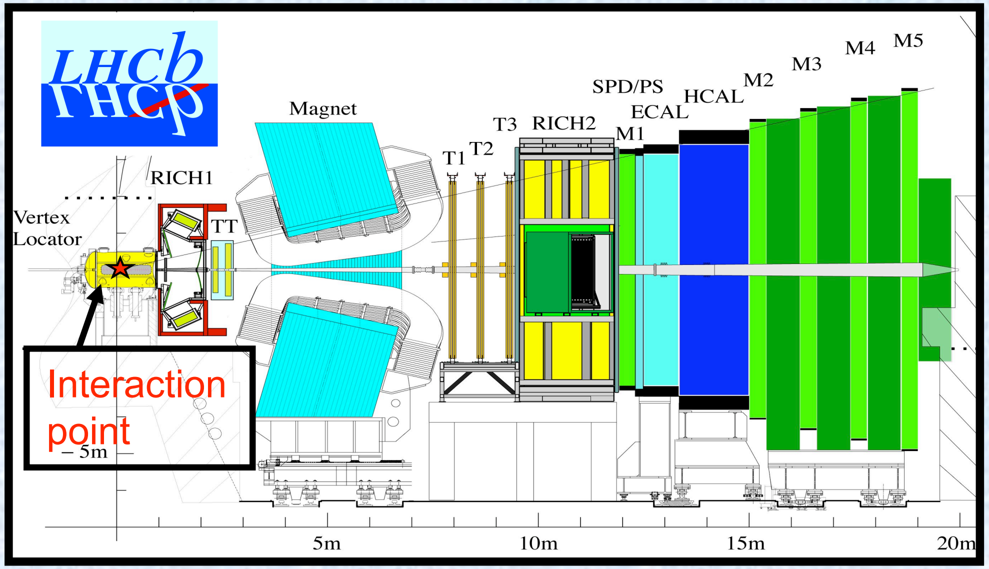


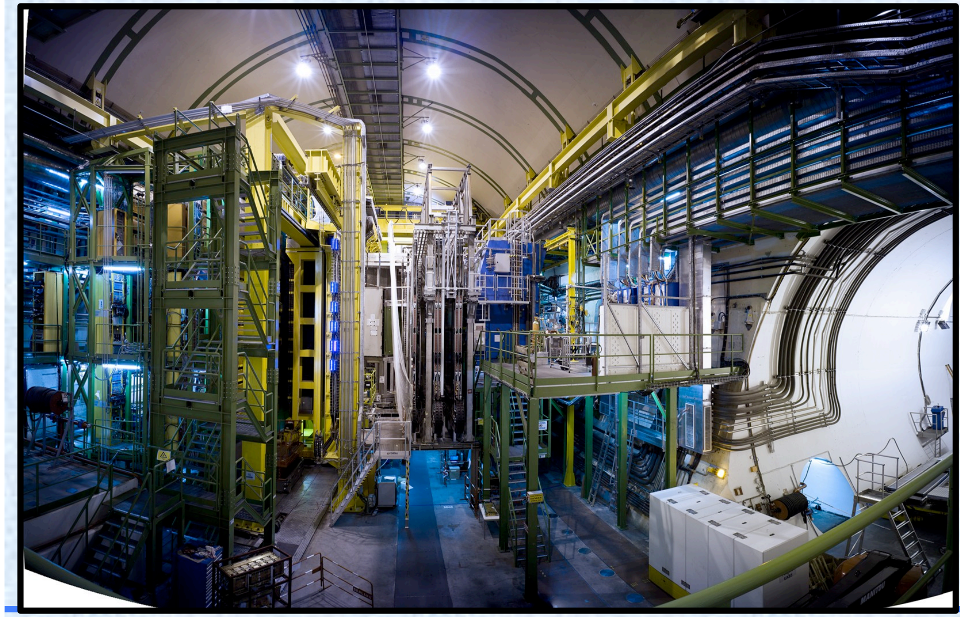
LHCb

An experiment dedicated to the search for New Physics in heavy flavours

Forward single arm spectrometer

Excellent tracking
precision silicon VELO detector

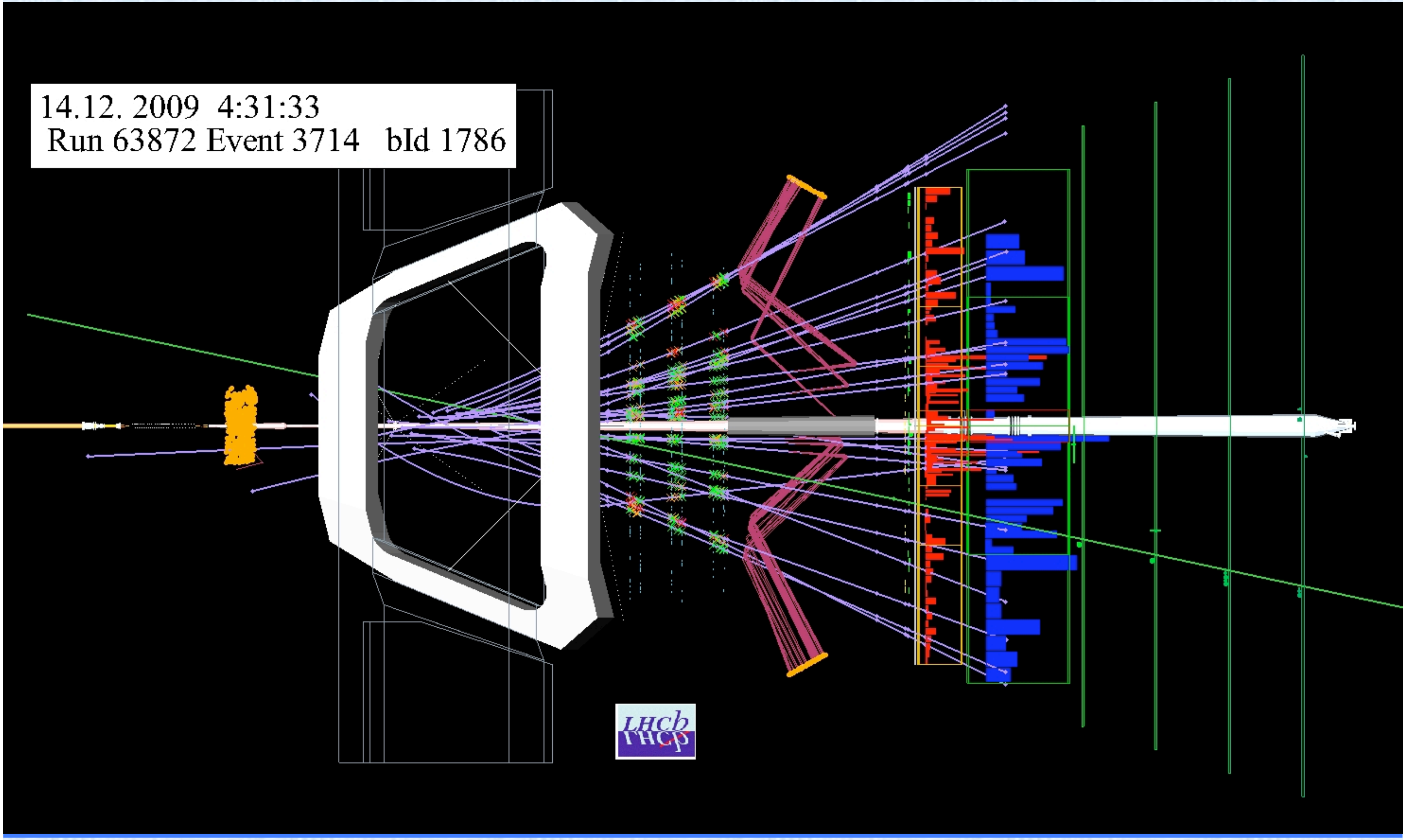




Excellent particle identification
2 RICH detectors
π/K separation over p ~2−100 GeV

Efficient Trigger
Low p_T lepton, γ/π^0 & hadron thresholds

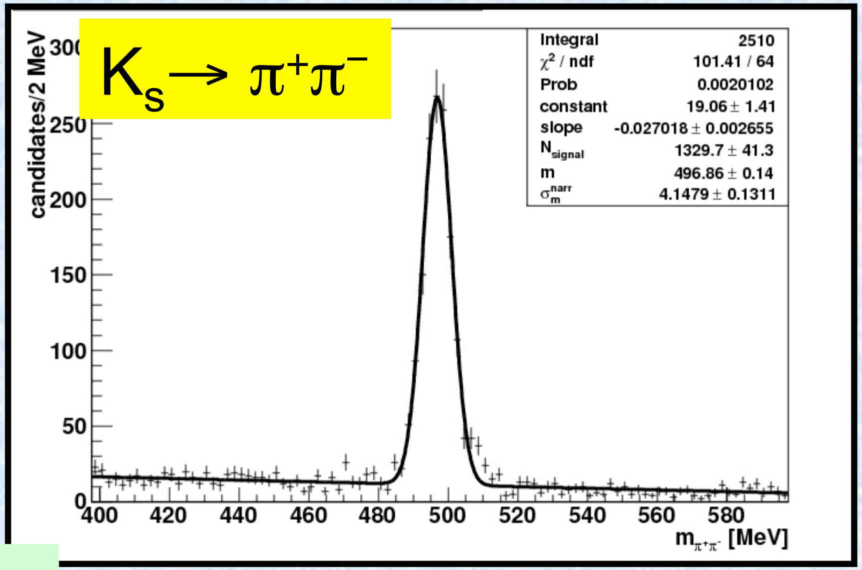
First pp collisions



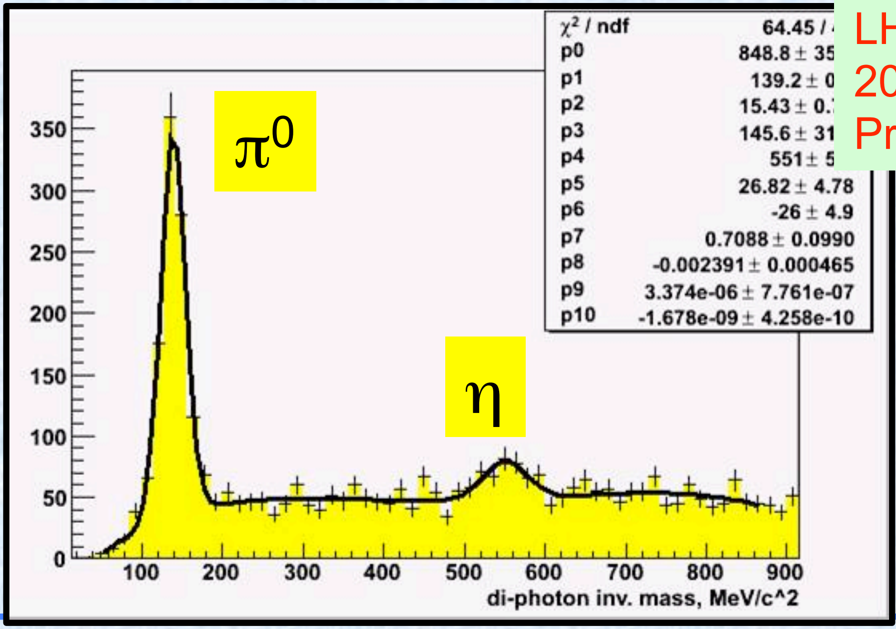
LHCb first results

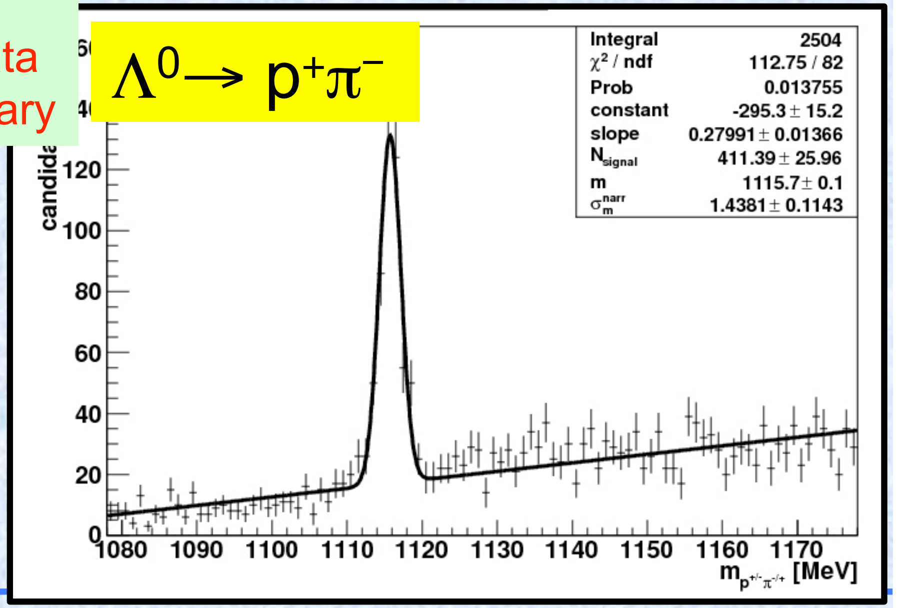
In just 9 days in 2009 LHCb "rediscovered" a major part of 20th century physics….

- Spectrometer performing very well
- Momentum resolution ~20% worse than simulation
- Alignment in full swing
- π^0 resolution expected to improve by ~25%

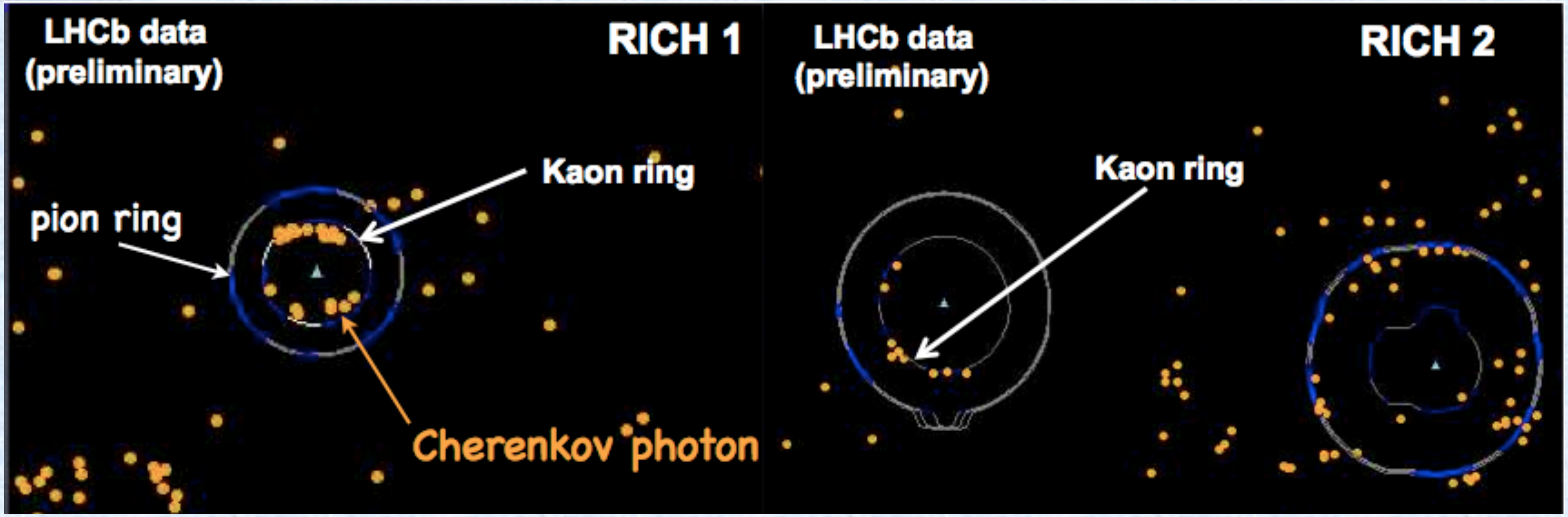


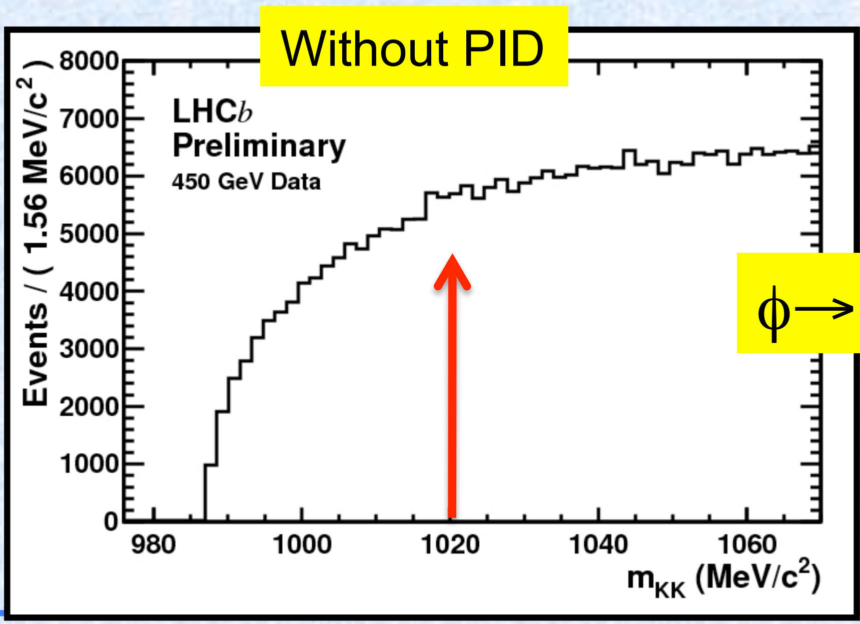
LHCb
2009 Data
Preliminary



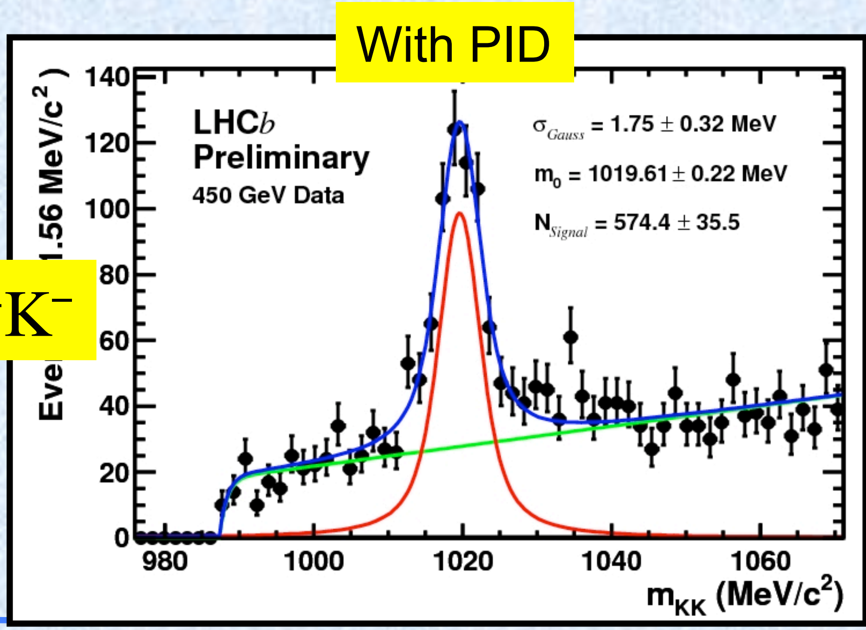


LHCb Particle Identification





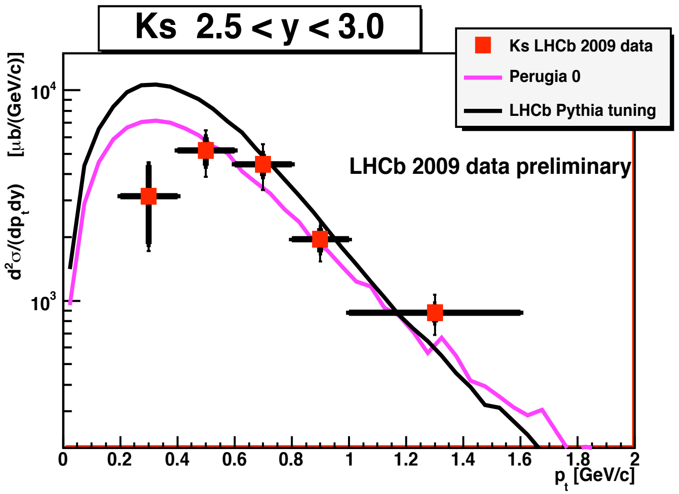
$\phi \rightarrow K^+K^-$

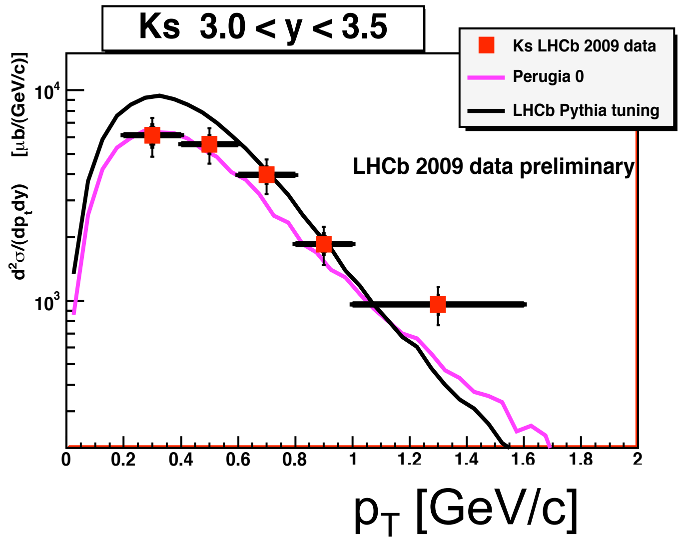


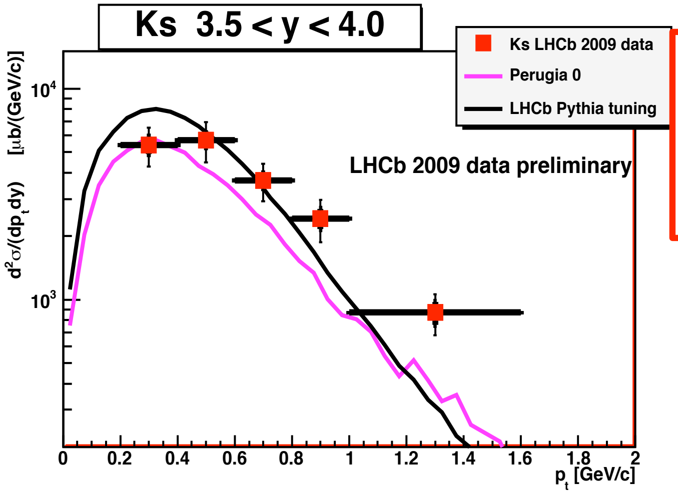
HEPP/APP 2010 IOP

LHCb First Physics Result

First LHCb physics result presented at Moriond QCD, March 14th







Prompt K^0_S production in pp collisions at $\sqrt{s} = 900$ GeV*

Pythia 6.4:
T.Sjostrand et al JHEP 05 (2006) 026.
Perugia tunes :
P.Z.Skands arXiv:0905.3418v1 [hep-ph]

The Road to NP…

The LHCb expectations for key flavour physics channels is well documented in the

Roadmap for selected key measurements of LHCb

LHCb-PUB-2009-029

What can we expect with the 2010/2011 run ($1fb^{-1}$) ?

The study of min-bias events will continue e.g. track multiplicities, jet structure, $\Lambda/\bar{\Lambda}$ and baryon/meson production.

LHCb will also start its core physics programme of charm and B physics

Charm

Enormous charm statistics expected in 2010/2011 due to a high production cross-section and high trigger efficiencies due to lower trigger thresholds at low luminosity ($<10^{31}$ $cm^{-2}s^{-1}$)

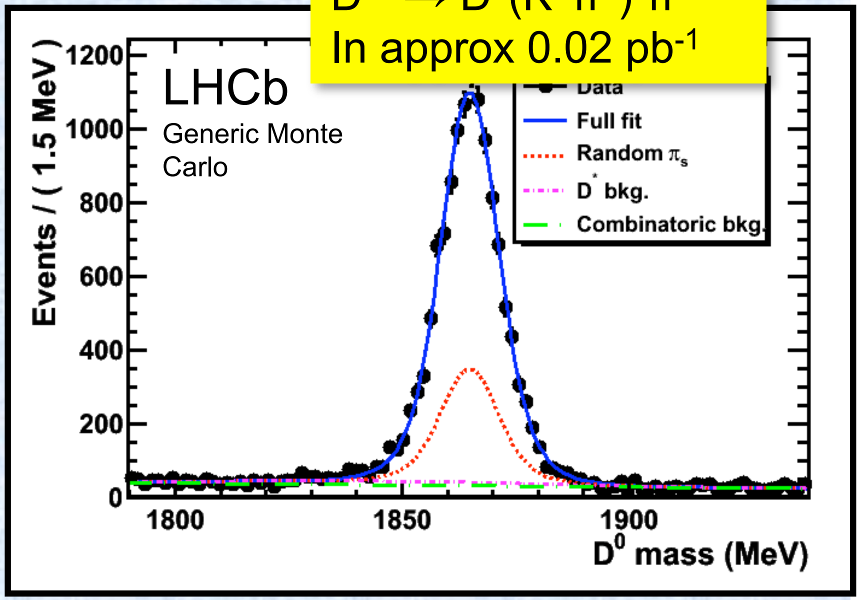
~4M $D^{*+} \rightarrow D^0(K^- \pi^+)\pi^+$ in 100 pb^{-1}

(compared to 0.26M in BaBar's y_{CP} measurement PRD80 (2009) 071103)

Extensive charm physics programme will include:

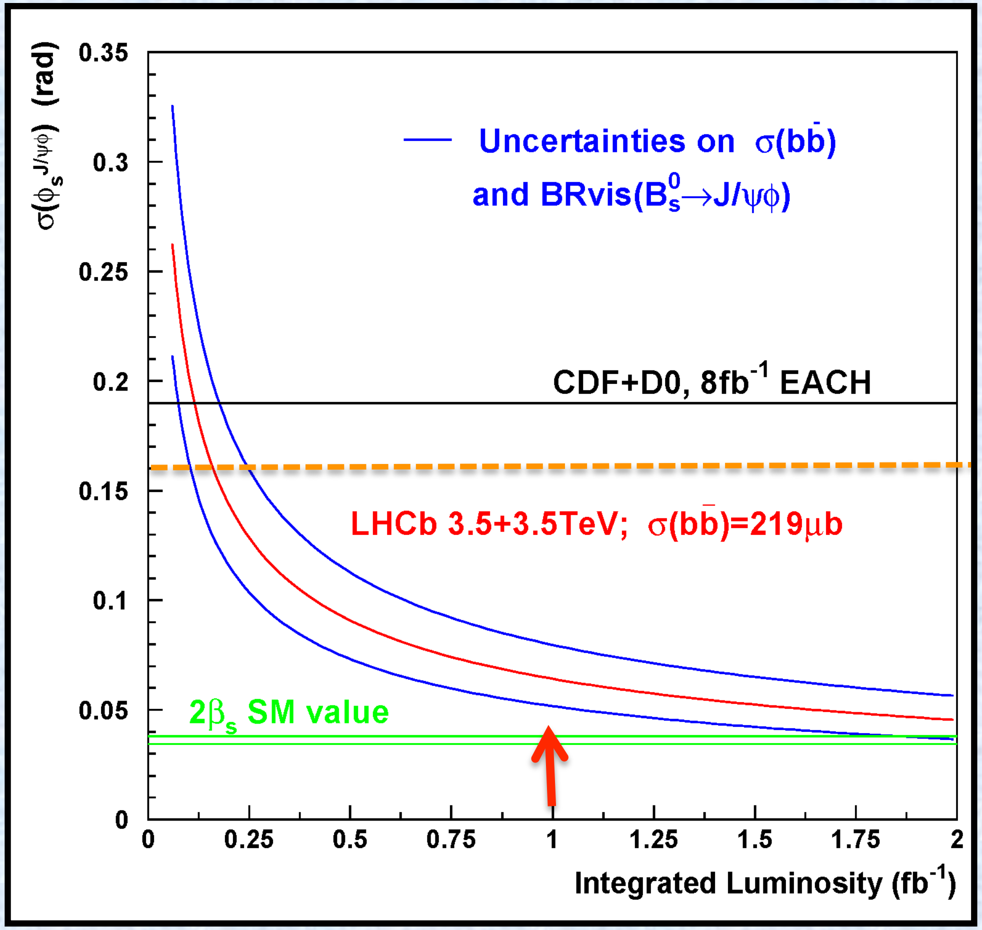
- Measurements of D^0 mixing
  No single measurement is 5σ yet
- Studies of CPV in charm decays
  Negligible in SM, but can be large with NP
- Searches for rare decays
  e.g $D^0 \rightarrow \mu^+\mu^-$, $D^+ \rightarrow h^+ll$

$D^{*+} \rightarrow D^0(K^- \pi^+)\pi^+$
In approx 0.02 pb^{-1}



$B_s \to J/\Psi\phi$

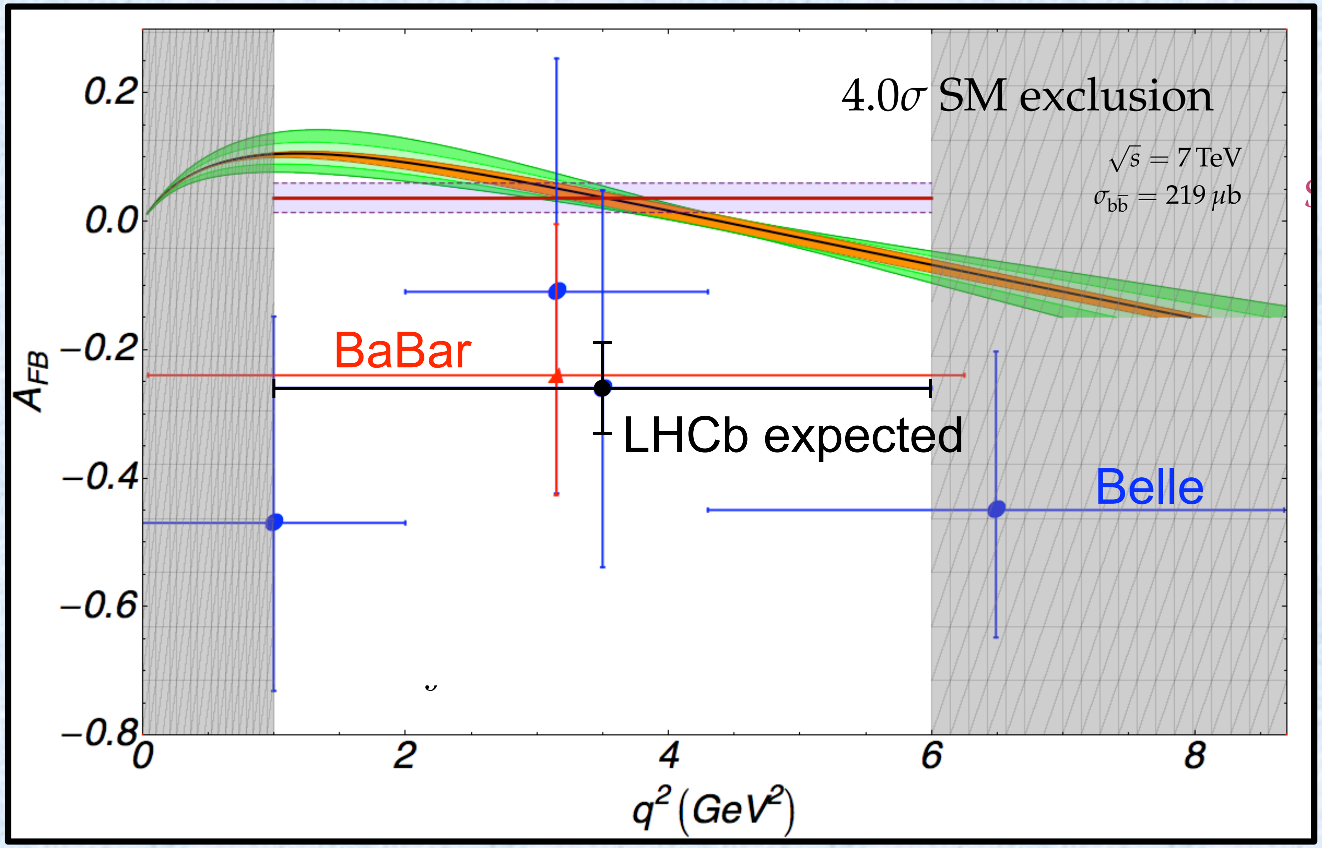
If nature agrees with the Tevatron central value of CPV phase, then LHCb can make a 5σ discovery with the 2010/2011 data. Statistical sensitivity on measured CPV phase ~0.07 with 1 fb^{-1}.



Approximate sensitivity needed to establish non-zero CPV phase if Tevatron central value is true

B →K*μμ

With 1fb^{-1} LHCb expects ~1200 events and should clarify existing situation.



SM average

SM prediction
0807.2589

Note opposite
sign convention
to slide 12

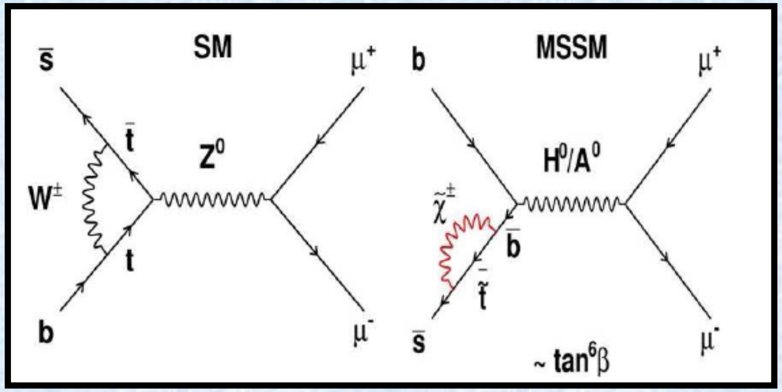
If picture becomes more SM-like, then next task will be to pin-down the position of A_{FB}=0 which is cleanly predicted. Precision of ~0.8 GeV^2 with 1fb^{-1}.

Very Rare $B_s \to \mu\mu$

Very rare and golden FCNC b→s transition

SM prediction $Br\left(B_s \to \mu^+\mu^-\right) = \left(3.35 \pm 0.32\right) \times 10^{-9}$

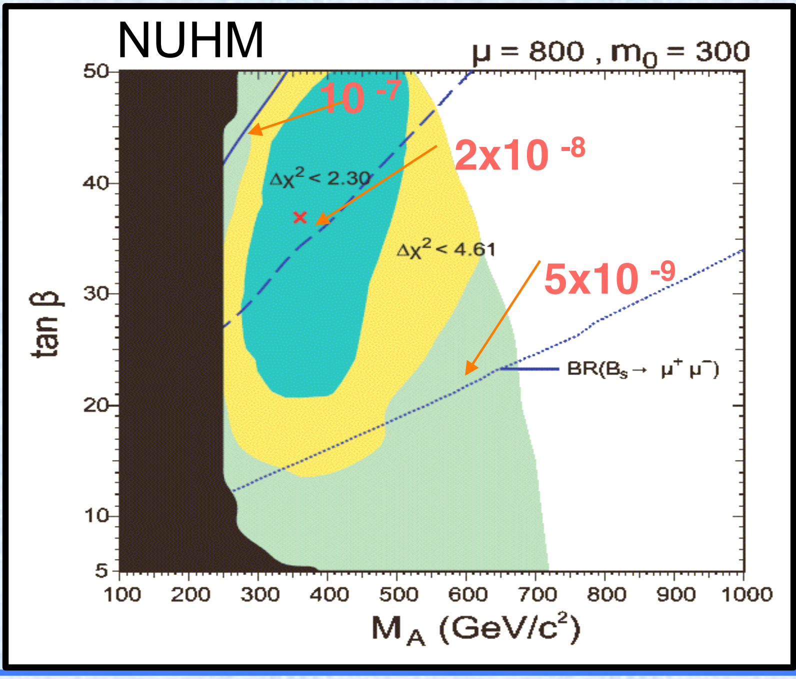
Blanke et al JHEP 0610:003 (2006)



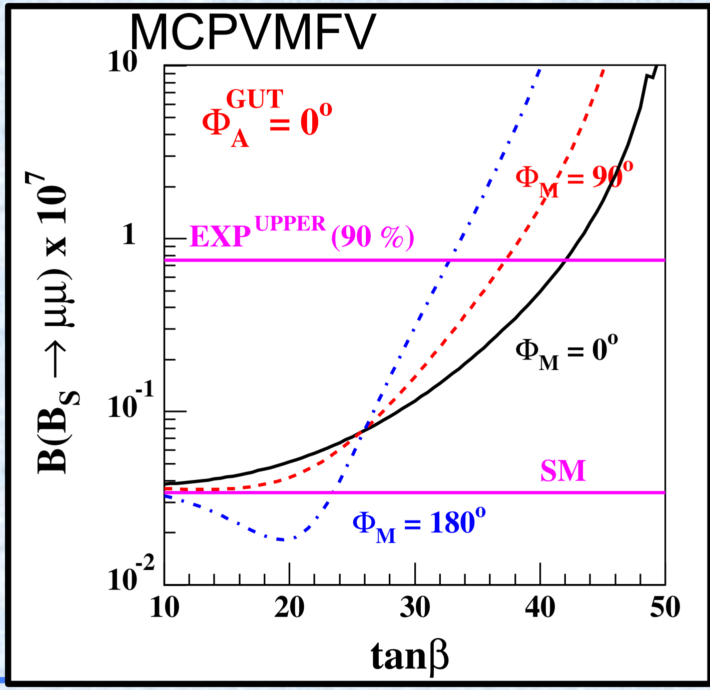
Strong enhancements in SUSY~ $\tan^6\beta$

Current experimental limit: $Br\left(B_s \to \mu^+\mu^-\right) < 4.3 \times 10^{-8}\ \ 95\%\ c.l.$ CDF Public Note 9892

J.Ellis et al; JHEP 0710:92 (2007)



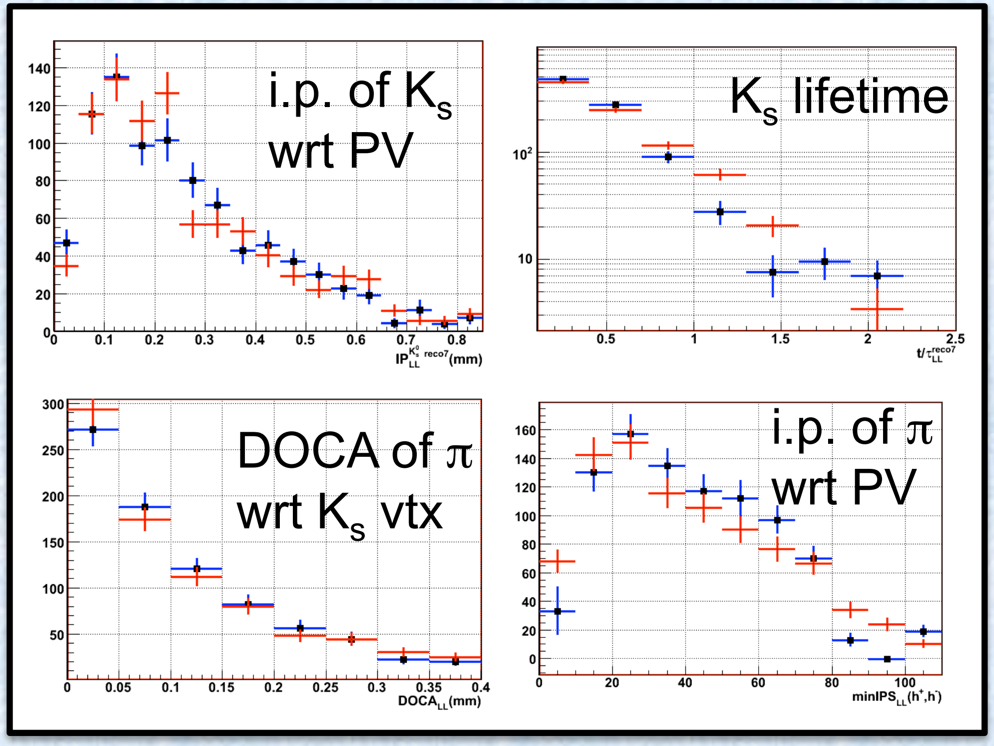
J.Ellis et al; PRD 76 (2007) 115011

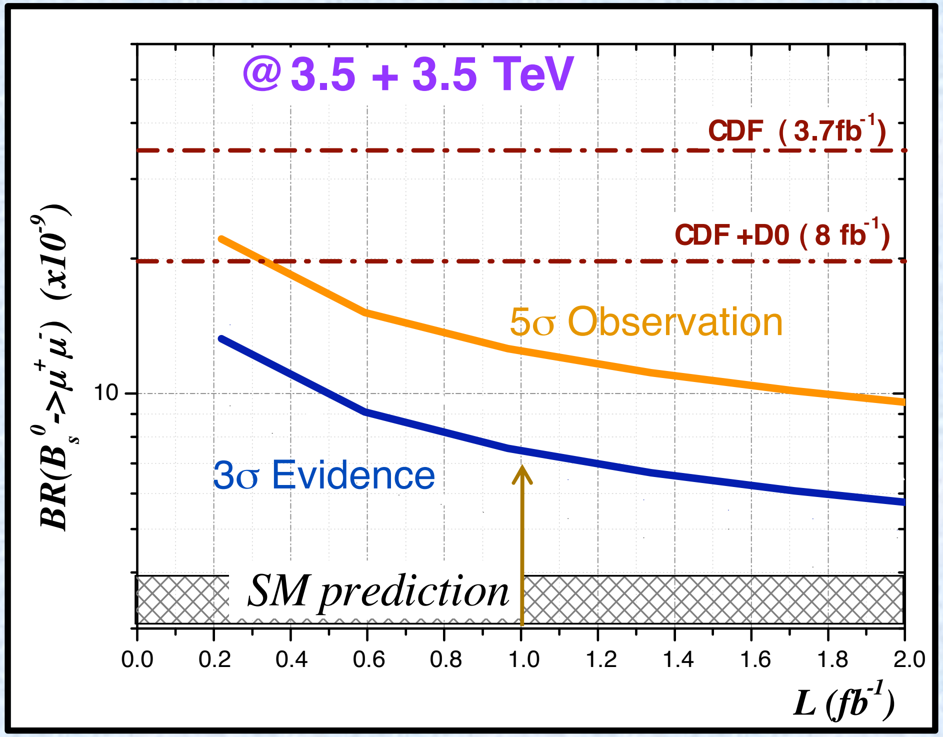


Very Rare $B_s \rightarrow \mu\mu$

Main issue is background rejection

Key variables in $B_s \rightarrow \mu\mu$ likelihood can be tested with K_s decays in 2009 data





LHCb can discover signal down to Br~2×10^{-8} in 2010/2011.

Significant input from ATLAS/CMS expected

Potential to be LHC's first "big discovery"

Flavour Menu

Starter

B Factories and Tevatron early running

Validate CKM picture of CPV

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Main Course

Tevatron later running and LHCb

Discover New Physics (hopefully!)

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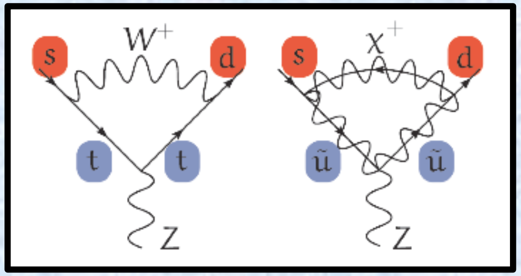
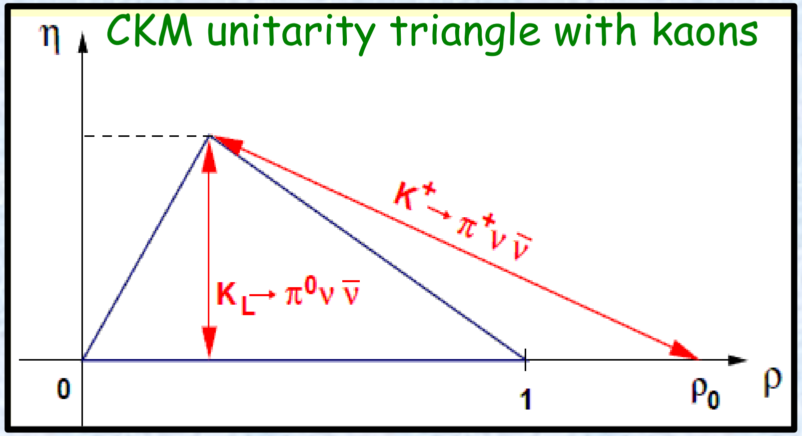
Ultra rare kaon decays (NA62 and KOTO)

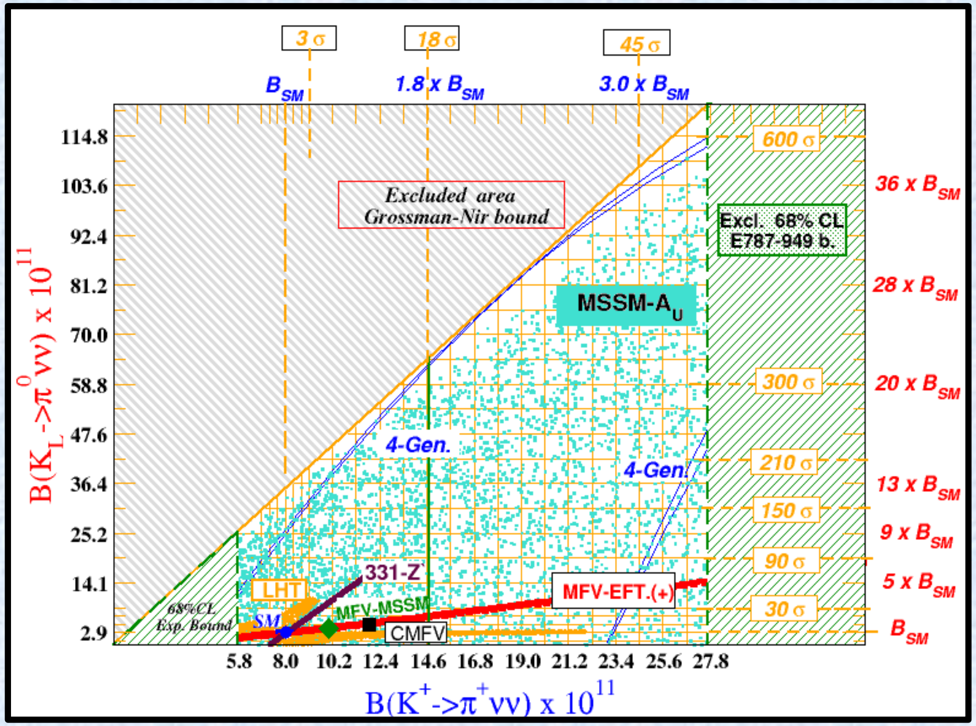
Ultra Rare Kaon Decays

NA62 (CERN) and KOTO (JPARC) will make stringent tests of the SM by measuring the ultra rare $K^+\to\pi^+\nu\nu$ and $K^0_L\to\pi^0\nu\nu$ decays.

SM prediction is highly suppressed ($<10^{-10}$) and calculable with % precision.







NA62 is designed to collect ~100 $K^+\to\pi^+\nu\nu$ candidates with 10% background in 2-3 years of data-taking (start 2012). Sensitivity ~10%.

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LHCb upgrade and Super Flavour Factories

Characterize nature of New Physics

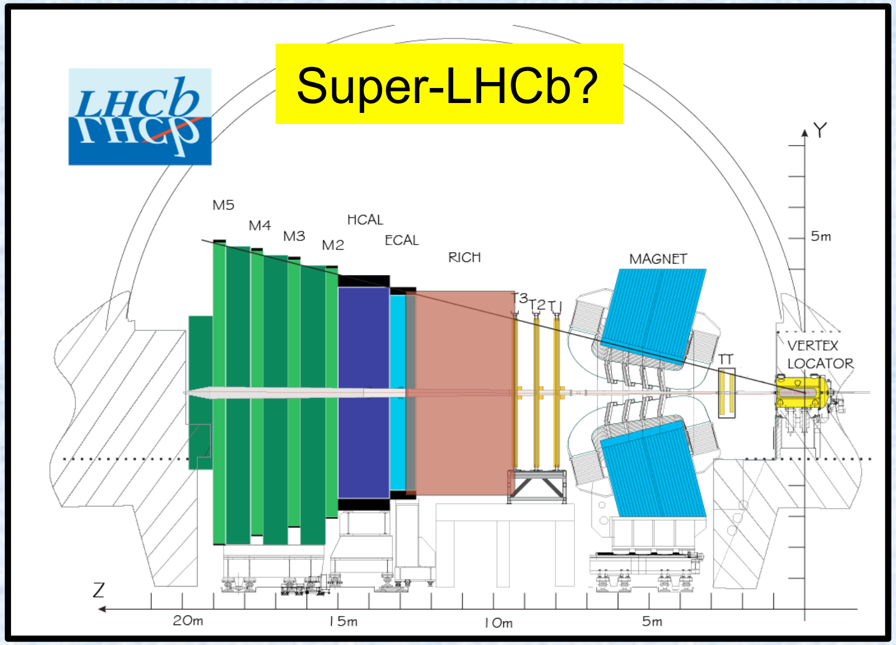
LHCb Upgrade

In the next few years LHCb will accumulate 5-10 fb^{-1}, making more precise measurements in topics already discussed, plus in CKM angles esp. γ (few deg), $B \to hh$, $B \to hhh$ and $B_s \to \phi\gamma$.

LHCb also plans to upgrade to run at 10x higher luminosity and collect 100 fb^{-1}, thereby fully exploiting the flavour potential of the LHC.

The trigger is key to the upgrade
→ readout of whole detector at 40 MHz
→ software based displaced vertex trigger.

Overall yields wrt LHCb :
→ 10x leptonic modes
→ 20x hadronic modes



TDR is being written now with a view to upgrading as soon as plausible given the R&D and construction required and the LHC schedule.

Super Flavour Factories

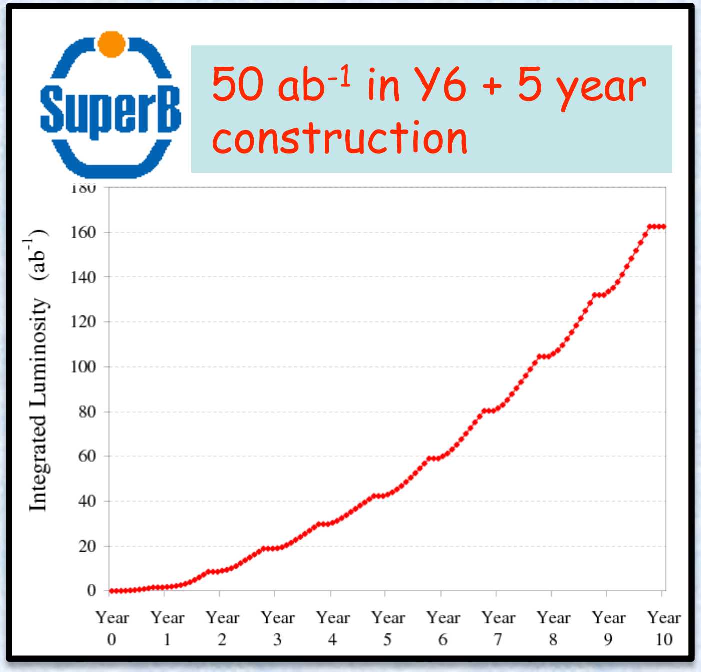
The Super Flavour Factories offer a complementary flavour physics programme, especially for inclusive rare processes and LFV.

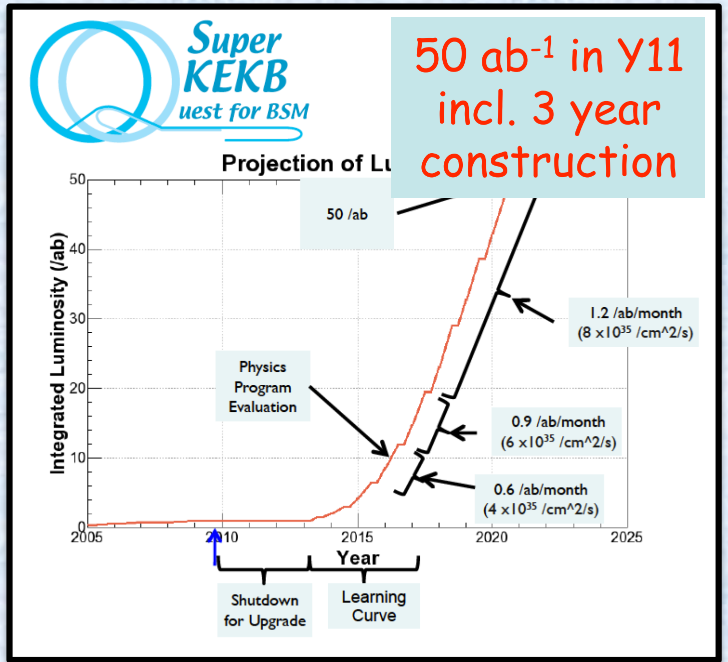
Two options:

Asymmetric energy (~4x7 GeV),
low emittance machines

Luminosity 10^{36} $cm^{-2}s^{-1}$

50-100x
Belle/BaBar statistics





D.Hitlin, Aspen 2010

SuperB : INFN provided R&D funds in FY09, project recommended for funding and decision on approval is anticipated within the next few months.

SuperKEKB: Funding has been provided for the Damping Ring in FY10. MEXT is seeking full approval of the project

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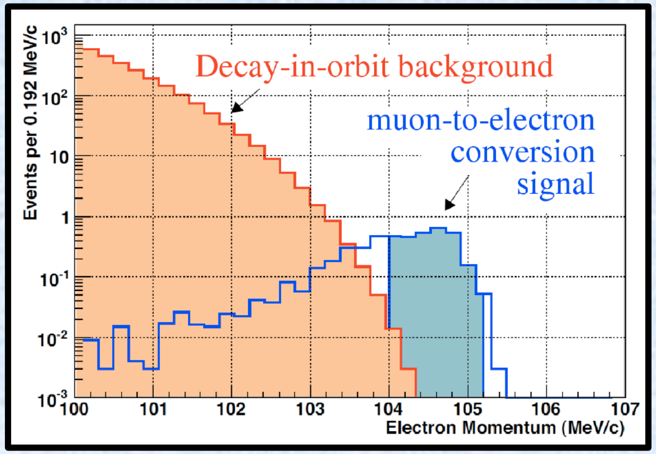
Coffee & Mints

LFV in $\mu \rightarrow e\gamma$ (COMET/PRISM and Mu2e)

Lepton Flavour Violation

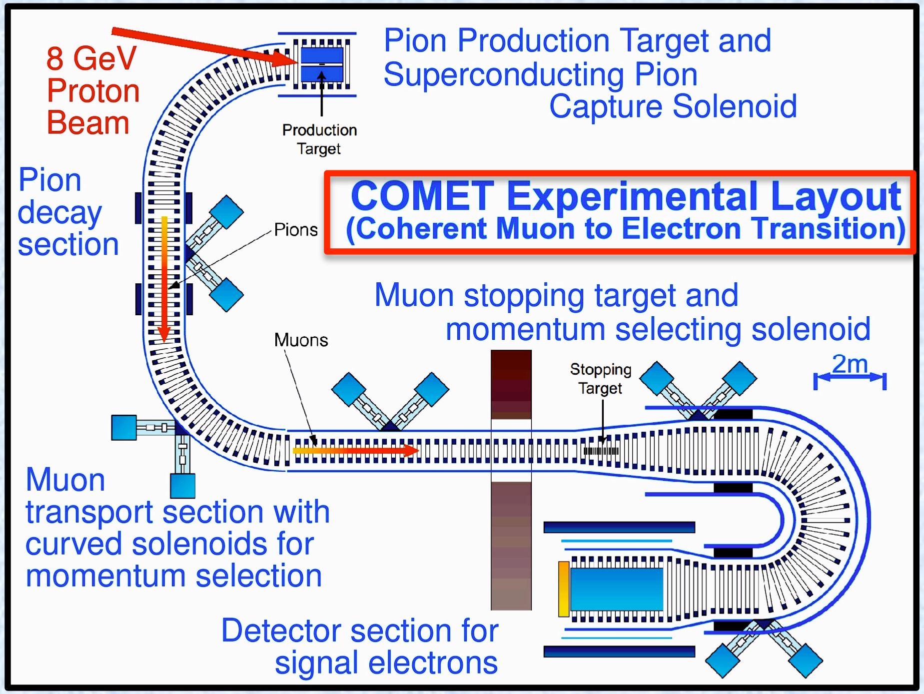
Charged LFV in μ→eγ decays is highly promising for a huge leap in NP sensitivity.

$$\mu^- + N(A,Z) \rightarrow e^- + N(A,Z)$$



e^- emission is delayed by ~1 μs allowing use of pulsed primary beam to reduce background.

Current limit (SINDRUM PSI) < 7×10^{-13}



COMET (JPARC) & μ2e (FNAL) :

10^4 improvement in sensitivity.

JPARC stage-1 and FNAL-CD0 approvals

Start data-taking 2016/17.

PRISM : Adding an FFAG μ storage ring provides an additional 10^2 improvement in sensitivity.

Task force led by the UK.

Conclusions

- Flavour physics is important ! An excellent way to search for and characterize the nature of New Physics.
- The present picture provided by the B-Factories & Tevatron is broadly consistent, but contains several interesting hints.
- LHCb now offers the next level of precision – Flavour physics ***is*** the discovery frontier of the first LHC run.
- But still higher precision is needed and work is underway to prepare the way forward for the LHCb upgrade, Super Flavour Factories and LFV experiments..
- The future of Flavour physics looks very promising….

And finally….

Polar bears finally migrate to Antarctica

And finally….

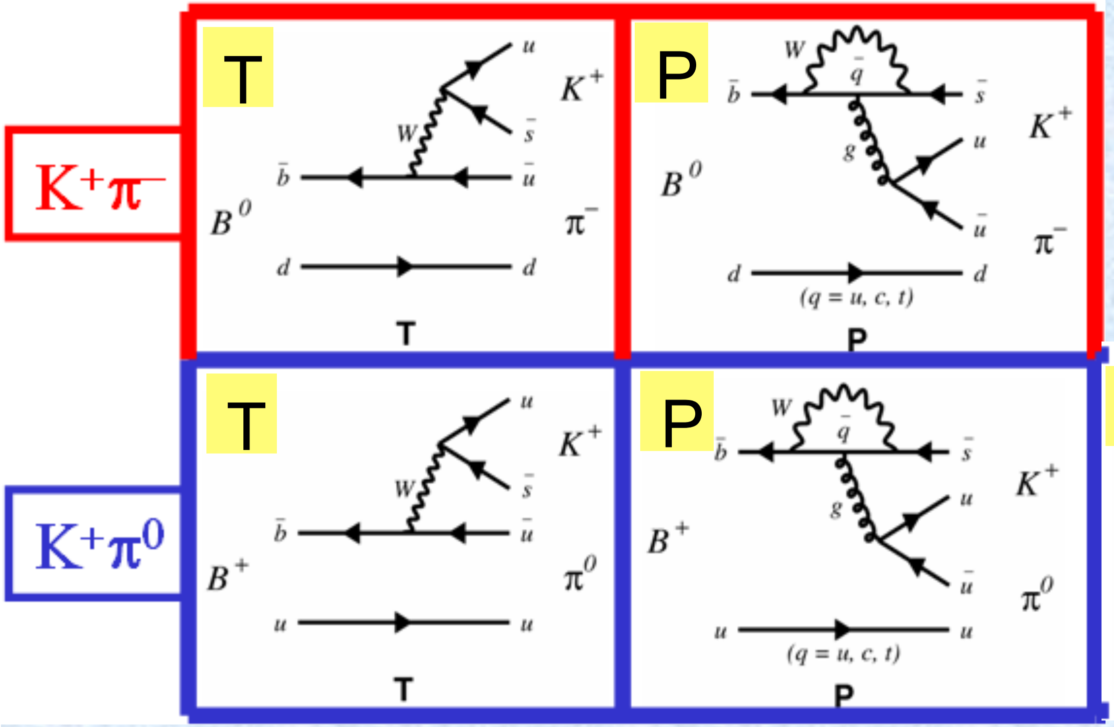
When the penguins and the polar bear met….

New Physics discovered in Flavour !!!

Solutions to the "Kπ Puzzle"

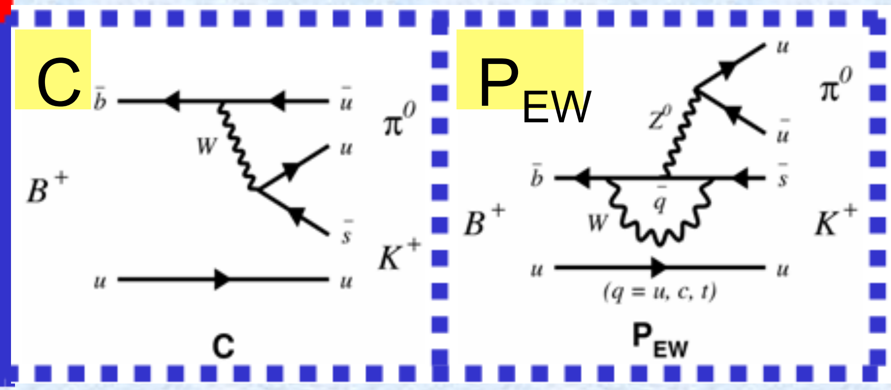
See Nature commentary by Michael Peskin

M.Peskin : Nature 452 (2008) 293



If T and P dominant then $\Delta A_{K\pi} \cong 0$ (recent expectation)

Gronau & Rosner : PRD59 (1999) 113002



Enhancement of C with large strong phase to T ⇒ strong Interactions ??

Also explains pattern of B→ππ and B→ρρ Br's

Li & Mishima : ArXiv 0901.1272

Enhancement of P_{EW} from ⇒ New Physics

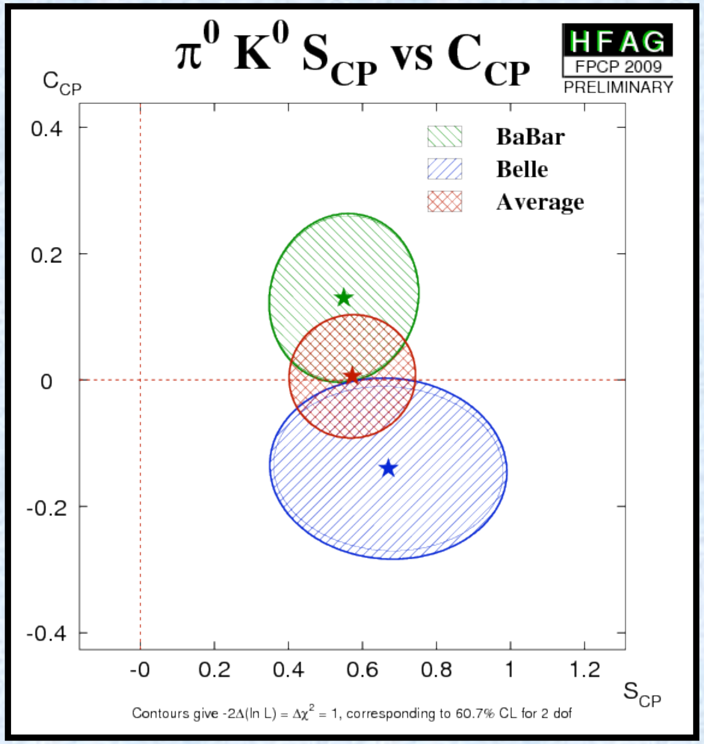
Fleischer et al (& ref therein) : ArXiv 0806.2900

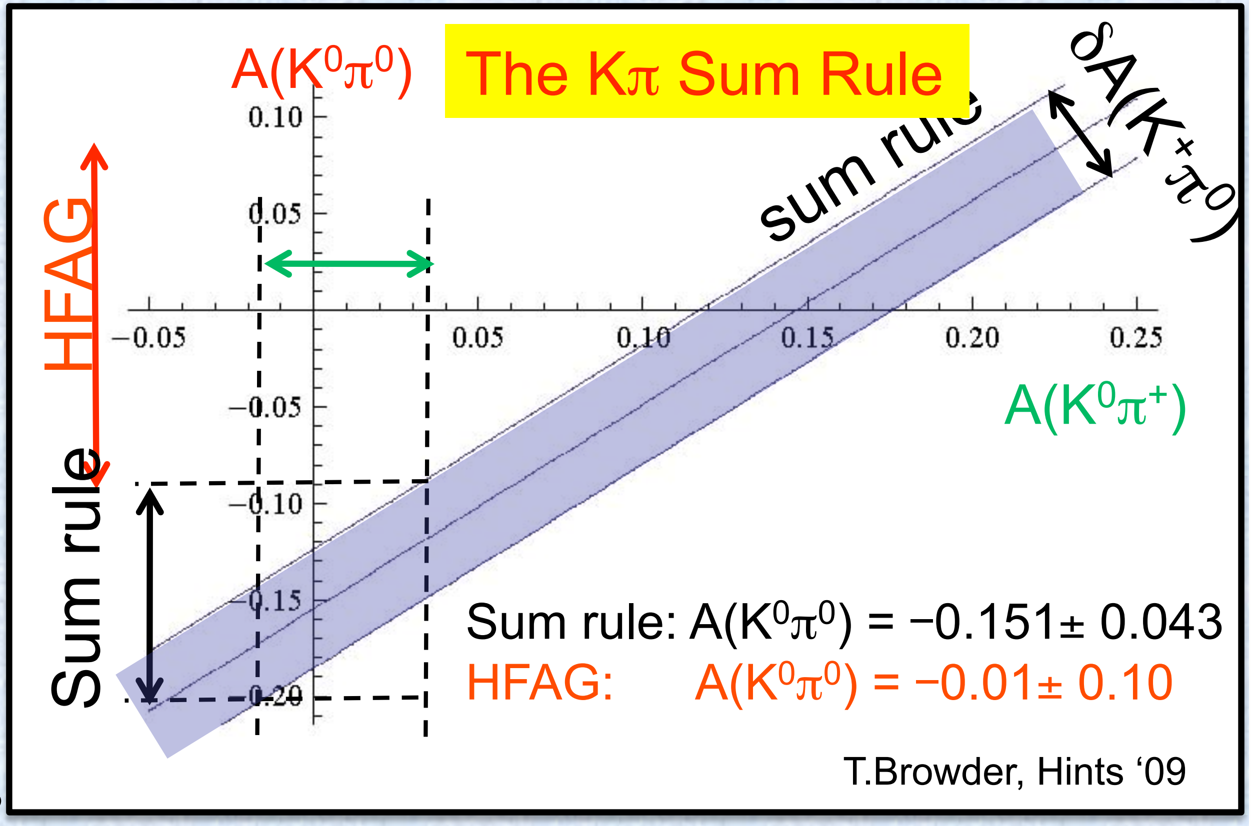
Solutions to the “Kπ Puzzle”

Model independent method to detect NP

M.Gronau : PLB82 (2005) 627

$$\mathcal{A}_{CP}(K^+\pi^-)+\mathcal{A}_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+}=\mathcal{A}_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+}+\mathcal{A}_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$





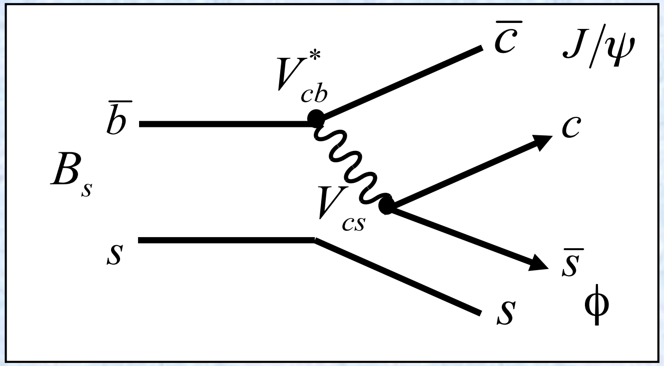
BaBar : 467M BB; PRD79 (2009) 052003

Belle : 657M BB; ArXiv:0809.4366

β_s

$B_s \rightarrow J/\Psi\phi$ "Gold-plated" decay equivalent to $B_d \rightarrow J/\Psi K_s$ for $\sin(2\beta)$

Measures CP violating phase due to interference of mixing and decay amplitudes



$$\beta_s^{SM} = \arg\left[-V^*_{tb}V_{ts}/V^*_{cb}V_{cs}\right]$$

Neglecting SM penguins

Expected to be very small in the SM

$$\beta_S^{SM} \approx 0.02$$

Note: CP violating phase in flavour mixing is also very small in the SM

$$\phi_s^{SM} = \arg\left(-M_{12}/\Gamma_{12}\right) \approx 0.004$$

NP contributions would effect both phases by same quantity

A.Lenz, ArXiv:0705.3802v2

$$2\beta_s = 2\beta_s^{SM} - \phi_s^{NP}$$
$$\phi_s = \phi_s^{SM} + \phi_s^{NP}$$

$$\Rightarrow\ 2\beta_s = -\phi_s$$

If NP phase is dominant

β_s

However, $B_s \rightarrow J/\Psi\phi$ analysis is non-trivial.

$P \rightarrow VV$ decay, hence a mixture of CP-even and CP-odd final states with significant width $\Delta\Gamma_s$ and mass splitting Δm_s

- $B_s \rightarrow J/\Psi\Phi$ decay rate as function of time, decay angles and initial B_s flavor:

$$\frac{d^4P(t,\vec{\rho})}{dt d\vec{\rho}} \propto |A_0|^2\mathcal{T}_+ f_1(\vec{\rho}) + |A_\parallel|^2\mathcal{T}_+ f_2(\vec{\rho}) + |A_\perp|^2\mathcal{T}_- f_3(\vec{\rho}) + |A_\parallel||A_\perp|\mathcal{U}_+ f_4(\vec{\rho}) + |A_0||A_\parallel|\cos(\delta_\parallel)\mathcal{T}_+ f_5(\vec{\rho}) + |A_0||A_\perp|\mathcal{V}_+ f_6(\vec{\rho}),$$

time dependence terms

angular dependence terms

terms with β_s dependence

$$\mathcal{T}_\pm = e^{-\Gamma t} \times [\cosh(\Delta\Gamma t/2) \mp \cos(2\beta_s)\sinh(\Delta\Gamma t/2) \mp \eta\sin(2\beta_s)\sin(\Delta m_s t)],$$

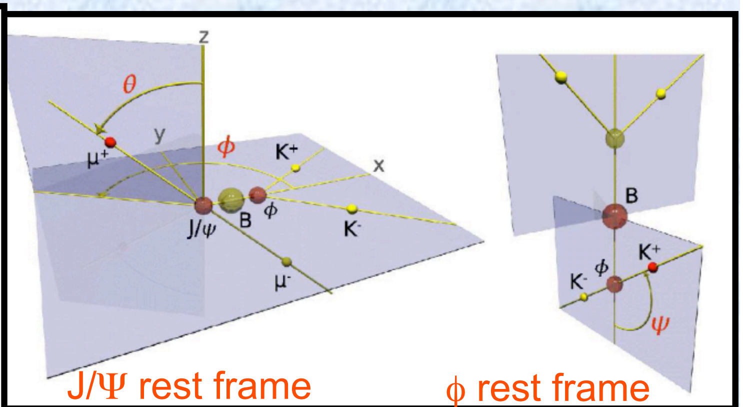
terms with Δm_s dependence present if initial state of B meson (B vs anti-B) is determined (flavor tagged)

$$\mathcal{U}_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp - \delta_\parallel)\cos(2\beta_s)\sin(\Delta m_s t) \pm \cos(\delta_\perp - \delta_\parallel)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)]$$

$$\mathcal{V}_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp)\cos(\Delta m_s t) - \cos(\delta_\perp)\cos(2\beta_s)\sin(\Delta m_s t) \pm \cos(\delta_\perp)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)].$$

'strong' phases:

$$\delta_\parallel \equiv \mathrm{Arg}(A_\parallel(0)A_0^*(0))$$
$$\delta_\perp \equiv \mathrm{Arg}(A_\perp(0)A_0^*(0))$$



3 angles (θ, ϕ, ψ) describe direction of final decay products

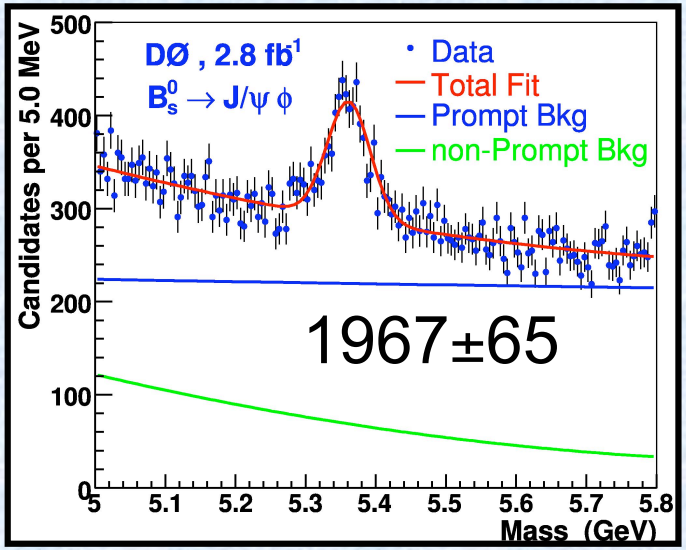
G.Giurgiu, FPCP 2009

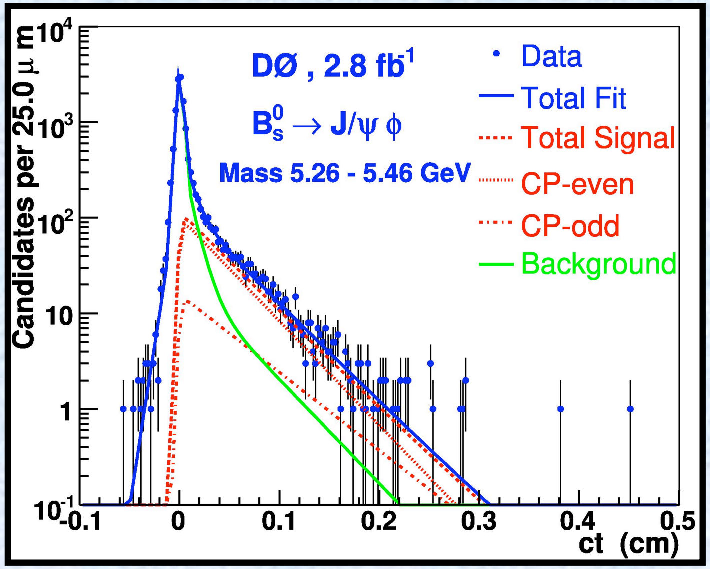
β_s sensitivity has angular dependence, rapidly oscillating in proper time.

β_s

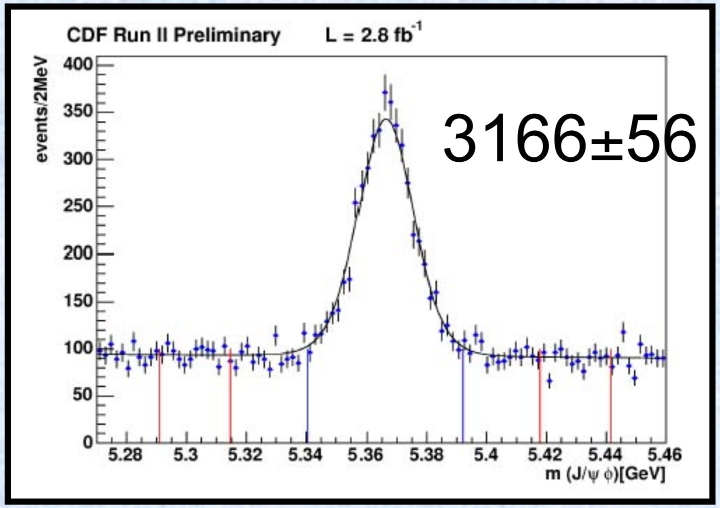
$B_s \to J/\Psi\phi$ signal reconstruction

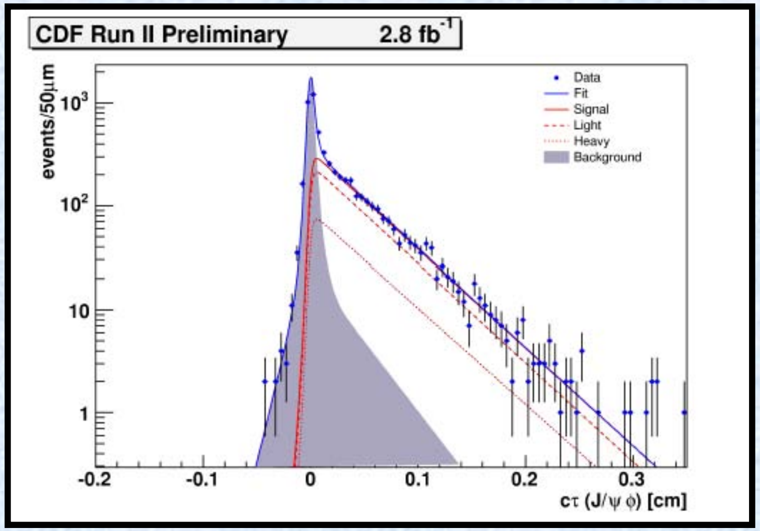
$2.8\ fb^{-1}$





$2.8\ fb^{-1}$





Trigger

Trigger crucial to the successful operation of LHCb

- B fraction is only ~1% of inelastic cross-section.
- Br's of interesting B decays $<10^{-4}$
- Properties of minimum bias similar to B's

First Level Trigger (Level-0, hardware)

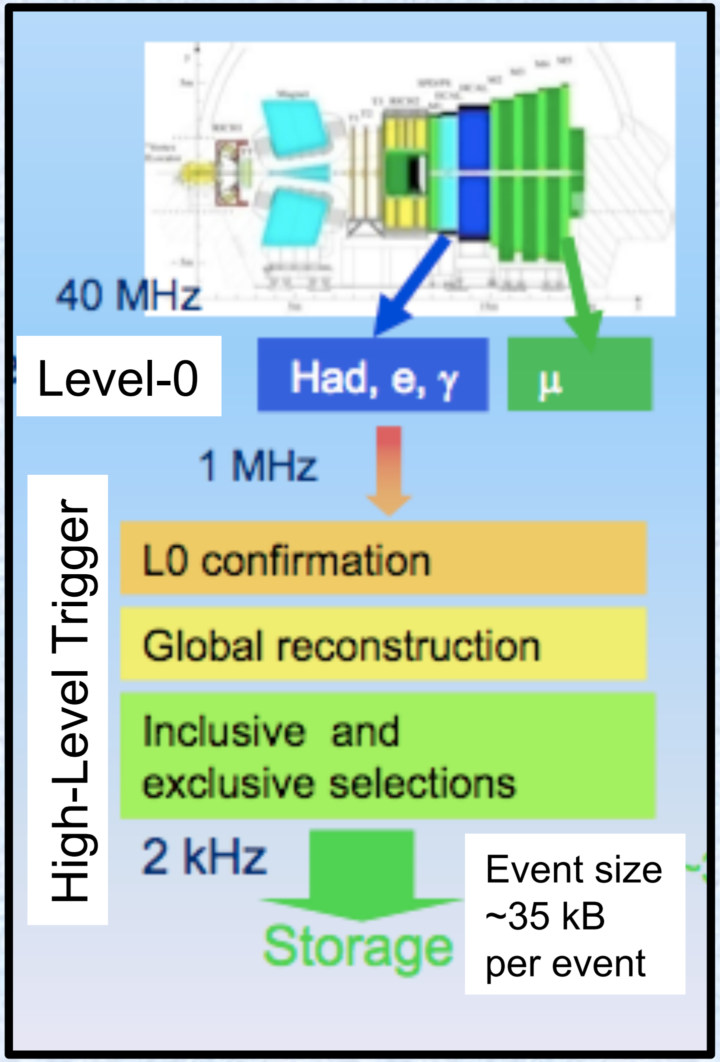
- Largest E_T hadron, $e(\gamma)$ and (di-)μ
- Pile-up system (not for μ trigger)

Reduces 10 MHz inelastic rate to 1MHz

High Level Triggers (HLT, software)

- Run on CPU farm (1800 nodes)
- Access to all detector data
- Use more tracking to re-confirm L0 decision
- Full event reconstruction; inclusive and exclusive selections

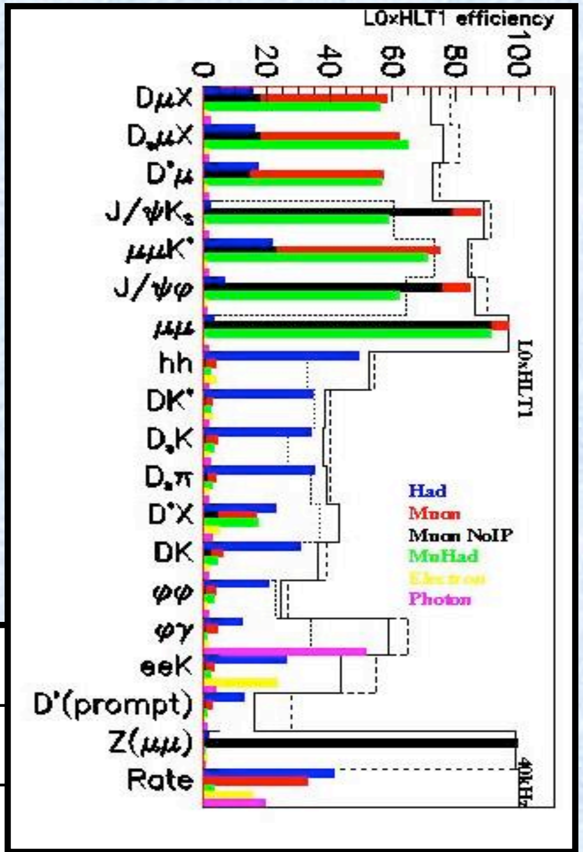
Output rate 2 kHz



Trigger

Expected trigger performance

	e(L0)	e(HLT)	e(total)
Hadronic	50%	80%	40%
Electromagnetic	70 %	60%	40%
Muon	90%	80%	70%



Output rate	Trigger Type	Physics Use
200 Hz	Exclusive B candidates	Specific final states
600 Hz	High Mass di-muons	J/ψ, $b \to J/\psi X$
300 Hz	D* Candidates	Charm, calibrations
900 Hz	Inclusive b (e.g. $b \to \mu$)	B data mining

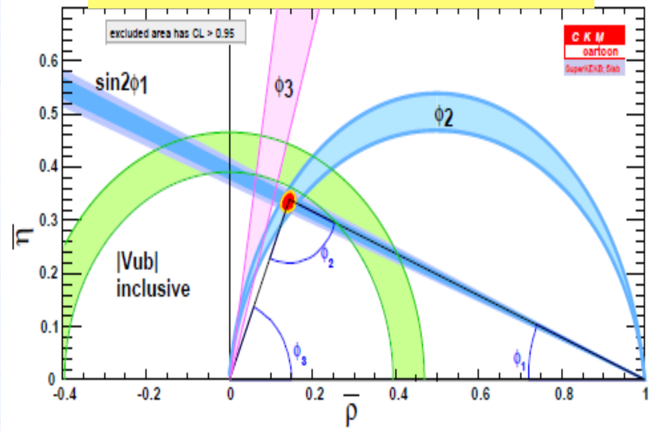
Total 2000 Hz

LHCb Sensitivities

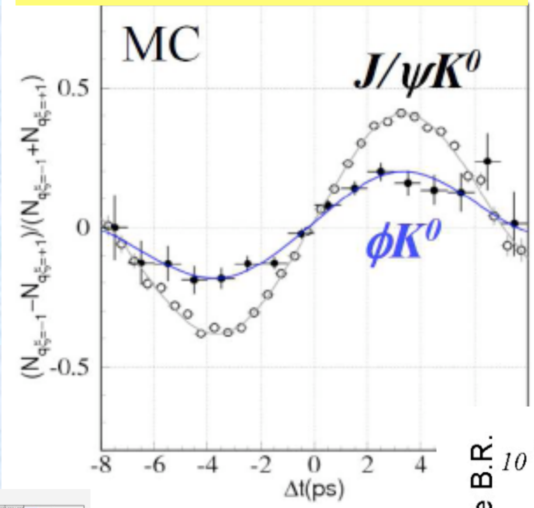
	Measurement	Current precision	LHCb ($10\ fb^{-1}$)	**LHCb upgrade ($100\ fb^{-1}$)**	Irreducible theory error	Competition
E/W Penguins	s_0 A_{FB} ($K^*\mu\mu$)	Unmeasured	4%	**1%**	7%	None
	$A_T^{(2)}$ ($K^*\mu\mu$)	Unmeasured	0.10	**0.03**	0.05	None
Right-handed currents	S ($B_s\to\varphi\gamma$)	Unmeasured	0.05	**0.01**	<0.01	None
	$A^{\Delta\Gamma}$ ($B_s\to\varphi\gamma$)	Unmeasured	0.10	**0.02**	0.02	None
Higgs penguins	$B(B_d\to\mu\mu)/B(B_s\to\mu\mu)$	Unmeasured	Unmeasured	**~20%**	~5%	ATLAS, CMS
Gluonic penguins	$\beta_s^{NP}(B_s\to K^{0*}\overline{K}^{0*})$	Unmeasured	5°	**1°**	<1°	None
	$\beta_s^{NP}(B_s\to\phi\phi)$	Unmeasured	5°	**1°**	~1°	None
	$\beta^{NP}(B_d\to\phi K_S)$	8°	8°	**2°**	~1°	SFF
SM bench-marks	γ ($B\to DK$)	~25°	~2°	**<1°**	Negligible	None
	β ($B_d\to J/\psi\ K_S$)	1°	0.2°	**<0.1°**	~0.1°	None
	β ($B_d\to D\pi^+\pi^-$)	Unmeasured	1°	**0.2°**	Negligible	None
NP in Bs mixing	β_s ($B_s\to J/\psi\ \varphi$)	20°	0.3°	**≤0.1°**	~0.1°	None
CPV in charm	A_Γ ($D\to KK$)	$25\cdot10^{-4}$	$3\cdot10^{-4}$	**$0.7\cdot10^{-4}$**	$\sim10^{-4}$	None

Flavour Physics 2020?

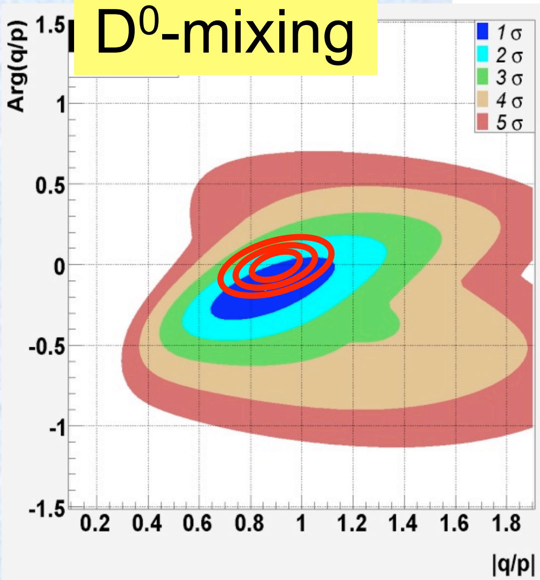
CKM UT triangle



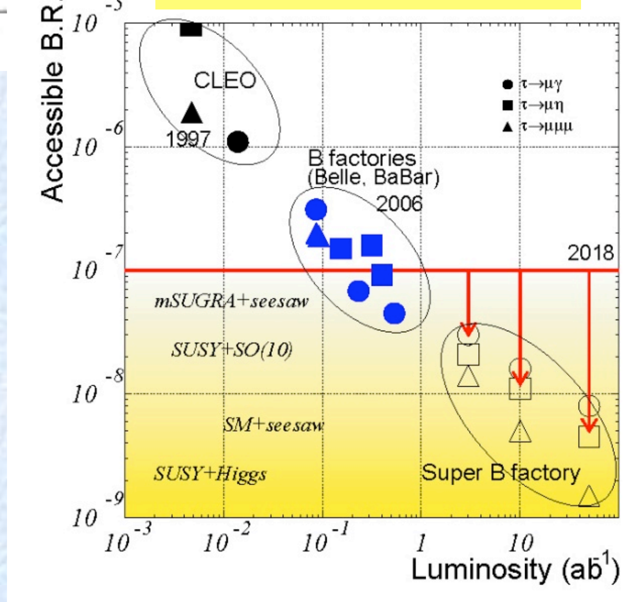
b→sqq penguins



D0-mixing



τ LFV decays



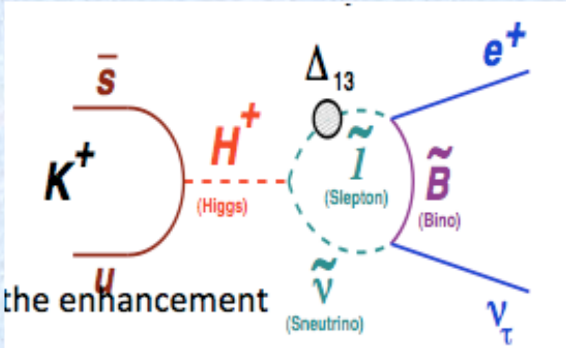
LFV in K→lν decays

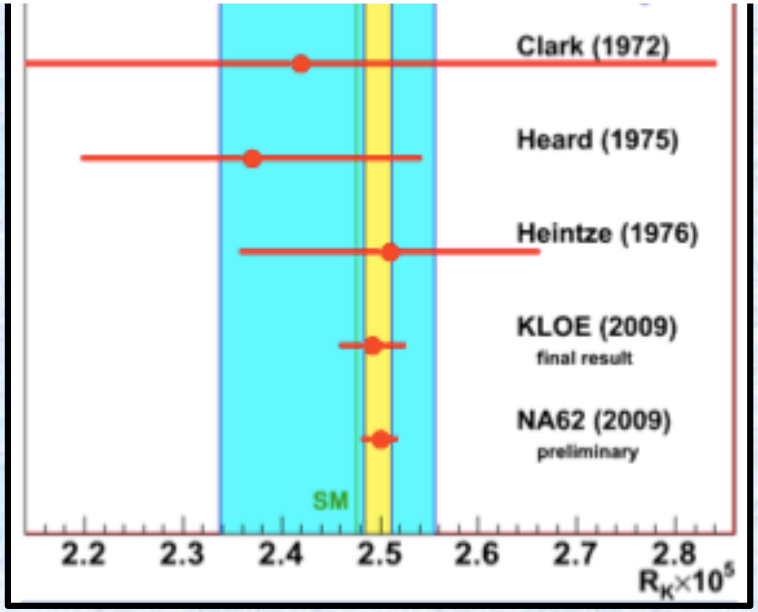
Kaon experiments have a long history (ε'/ε and rare K decays). NA62 Phase 1 collected data in 2007 and 2008 to measure LFV.

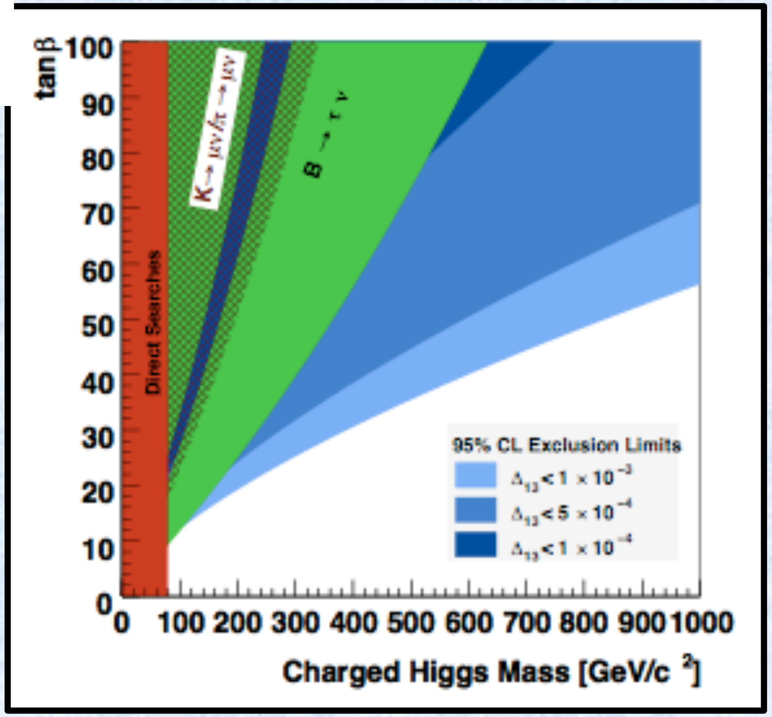
$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot (1 + \delta R_K^{rad.corr.})$$

$$= (2.477 \pm 0.001) \times 10^{-5}$$

$$R_K^{LFV} \approx R_K^{SM} \left[1 + \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{M_e^2}\right) |\Delta_{13}|^2 \tan^6 \beta\right]$$



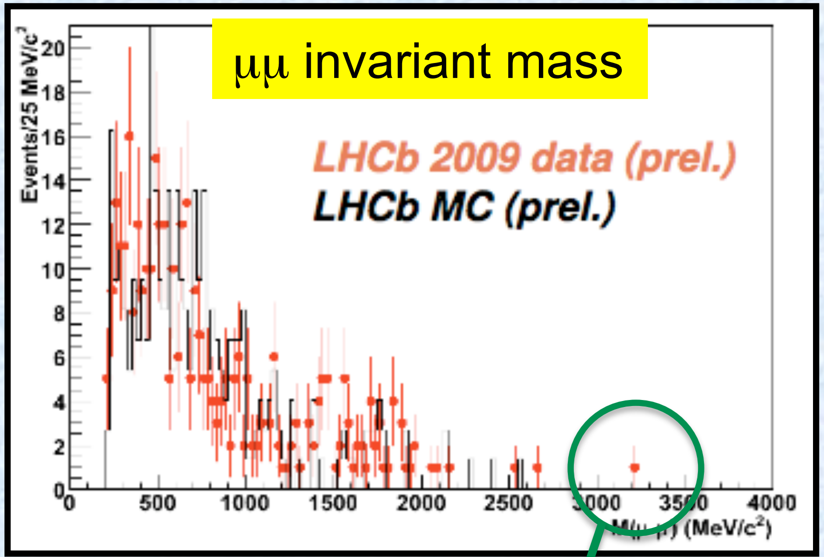


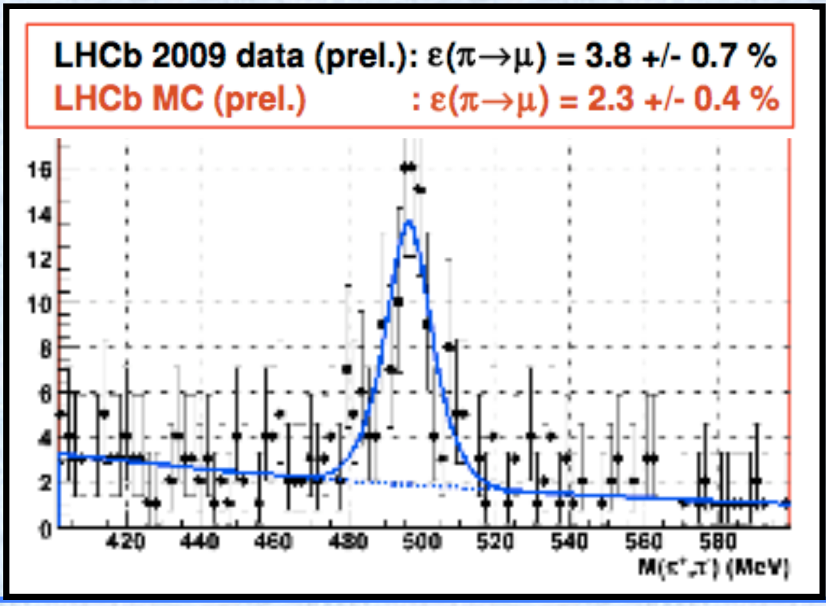


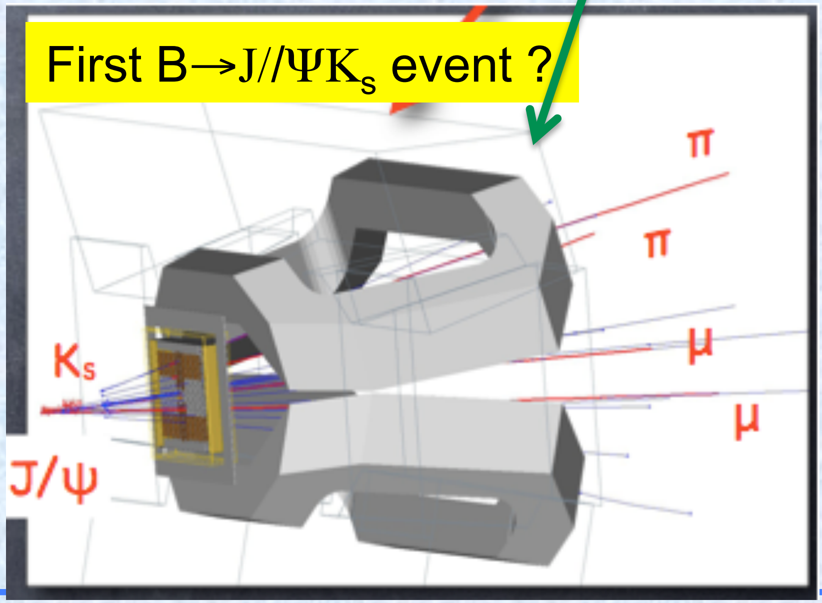
LHCb first results

Muon system fully functional

- Efficiency of detector planes > 99%
- Waiting for J/Ψ to complete detector alignment
- First estimate of muon mis-ID rate extracted from $K_s \rightarrow \pi^+\pi^-$







$\mu \to e\gamma$ (cLFV)

cLFV is a forbidden process in the SM

If SM is minimally extended for m_ν and oscillations, $Br(\mu \to e\gamma) \sim 10^{-50}$

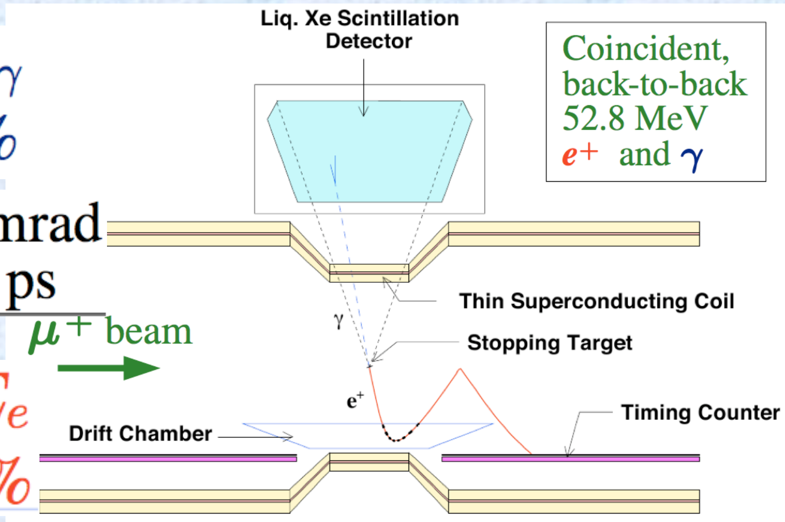
BSM processes enhance the rates
e.g. SUSY $Br(\mu \to e\gamma) \sim 10^{-15}$

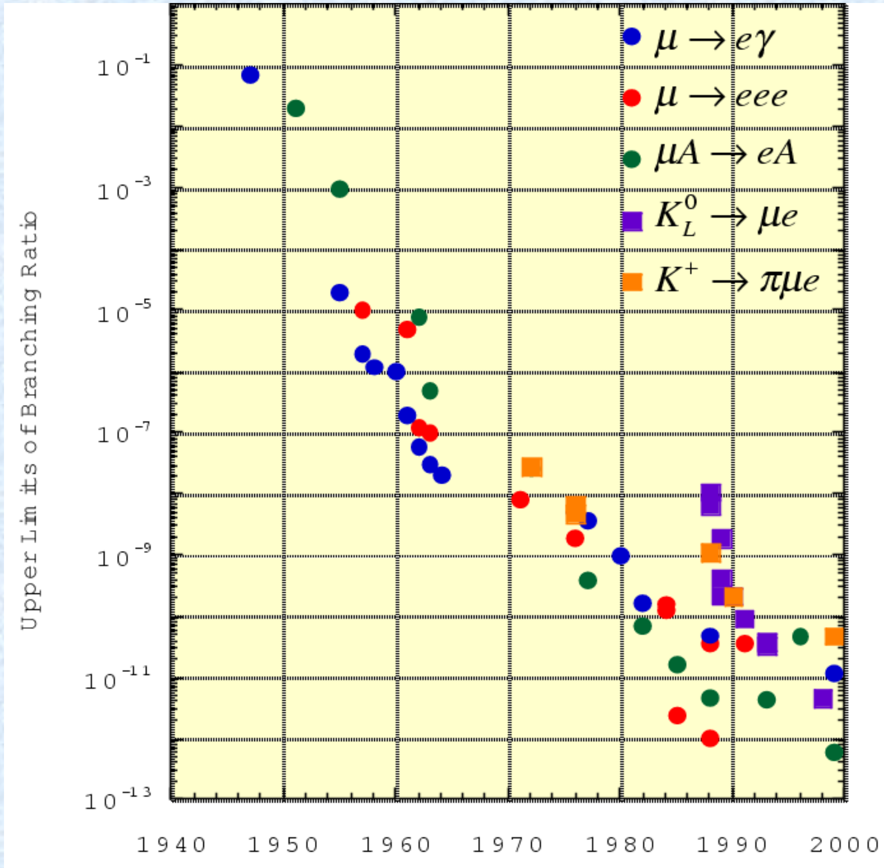
MEG at PSI

$\Delta E_\gamma / E_\gamma = 4.0\%$

$\Delta\theta = 19$ mrad
$\Delta t = 150$ ps

$\Delta E_e / E_e = 0.8\%$





2008 data : $Br(\mu \to e\gamma) < 2.8 \times 10^{-11}$ 90% c.l.
2011 : Expected precision < 10^{-13}

MEG Collaboration, arXiv:0908.2594v2

PRISM

PRISM FFAG-based Second Phase Experiment

(FFAG storage ring provides a further two orders of magnitude sensitivity)