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Future of Heavy Flavour Physics

- ***<u>Next 3-5 years</u>: Prospects to discover New Physics (NP) in heavy flavours (Tevatron & LHCb)***

- ***<u>2014-2020:</u> If NP found at LHC what are the opportunities with with heavy flavours??? SuperB & SuperLHCb & kaon experiments Who is the best suited for what?***

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:

- *Accuracy of sides is limited by theory:*

  Extraction of $|V_{ub}|$

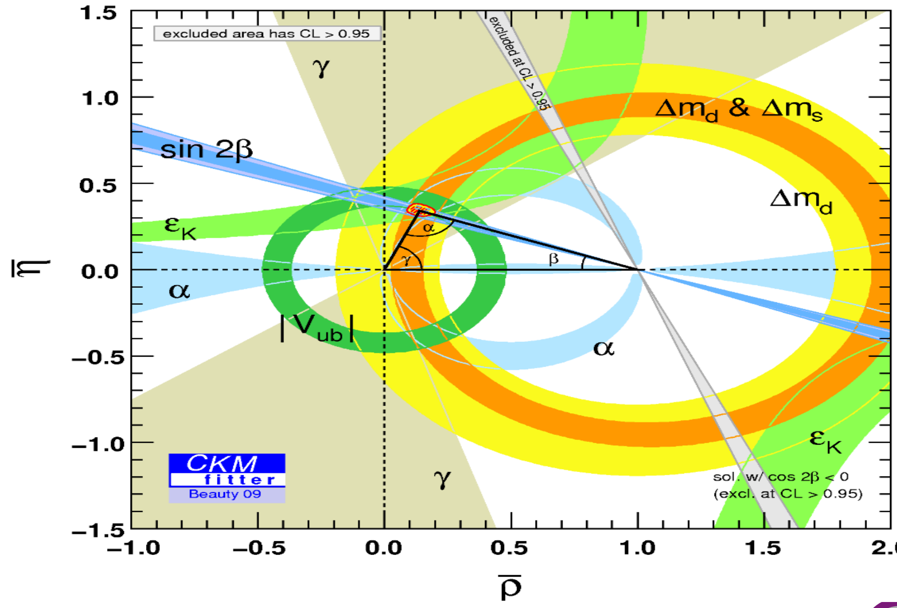
  Calculation of $\xi^2 = \frac{\hat{B}_{B_s} f^2_{B_s}}{\hat{B}_{B_d} f^2_{B_d}}$

- *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

The quark sector is well described by the CKM mechanism



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 !!!)*

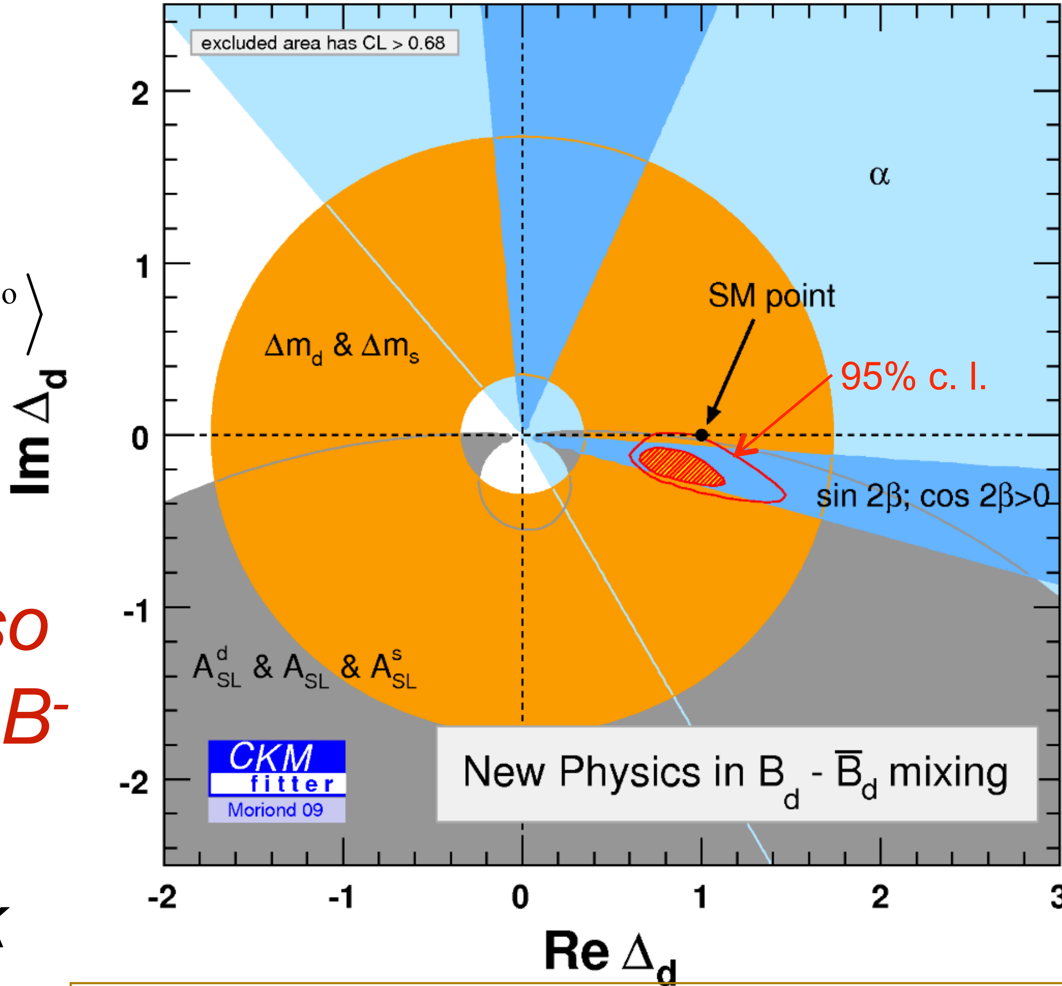
Consistency?

- *It is often said that studies of b & c decays are all consistent with the Standard Model*
  - *Since all measurements are reflections of nature, i.e. SM + NP, what does this statement actually mean?*
  - *SM predictions are made using combinations of several measurements since there are many parameters. It is important to distinguish the type of decay used, i.e. tree or loop, since tree decays are likely to have only small NP contributions compared to loop level processes*
  - *The fit in the previous page doesn't allow for any NP contributions*

Limits on New Physics From B° Mixing

- *Is there NP in B°-$\bar{B}$° mixing?*
- $\langle B^o | H^{SM+NP}_{\Delta B=2} | \bar{B}^o \rangle = \Delta_d^{NP} \langle B^o | H^{SM}_{\Delta B=2} | \bar{B}^o \rangle$

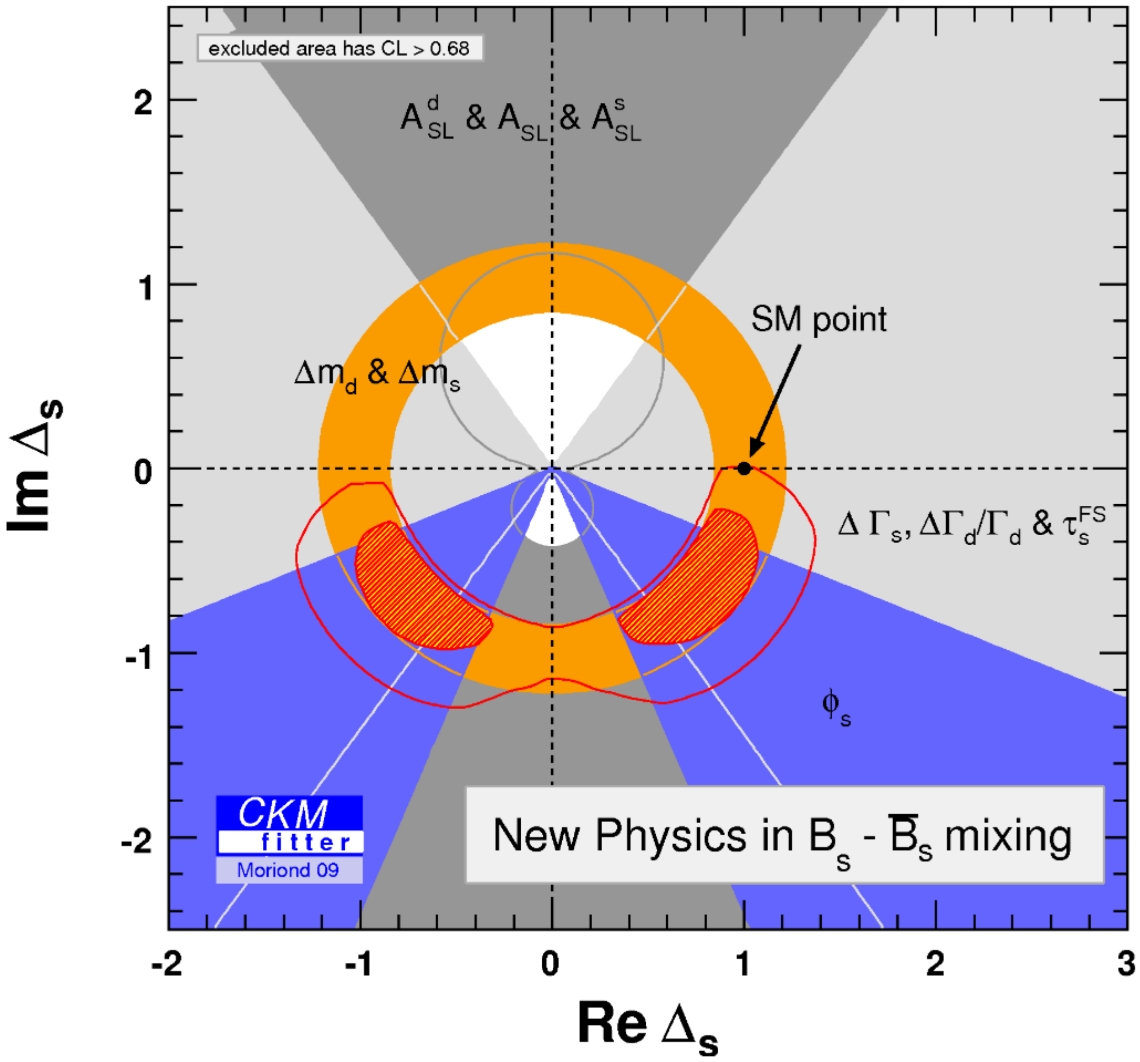
  $\Delta_d^{NP} = \mathrm{Re}\,\Delta_d + i\mathrm{Im}\Delta_d$
- *Assume NP in tree decays is negligible, so no NP in $|V_{ij}|$, γ from $B^- \rightarrow D^o K^-$.*
- *Allow NP in Δm, weak phases, A_{SL}, & $\Delta\Gamma$.*



- *Room for new physics, in fact SM is only at 5% c.l.*

Limits on New Physics From B_S Mixing

- *Similarly*
- *Here again SM is only at 5% c.l.*
- *Much more room for NP due to less precise measurements*



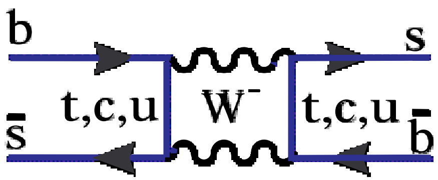
New Physics Models

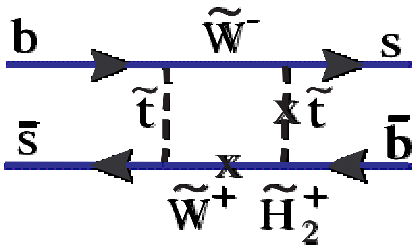
- *There is, in fact, still lots of room for "generic" NP*
- *What do specific models predict?*
  - *Supersymmetry: many, many different models*
  - *Extra Dimensions: 〃*
  - *Little Higgs: 〃*
  - *Left-Right symmetric models: 〃*
- *Lets go through <u>some</u> examples, many other interesting cases exist*

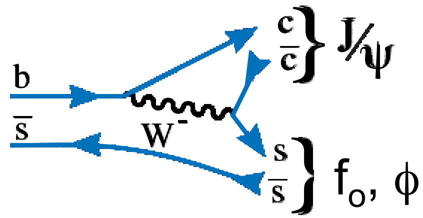
Supersymmetry: MSSM

- *MSSM from Hinchcliff & Kersting* *(hep-ph/0003090)*
- *Contributions to B_s mixing*

$B_s \rightarrow J/\psi f_o$ or ϕ



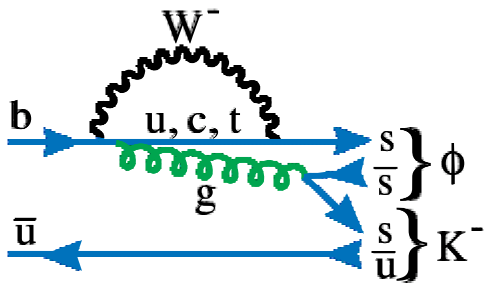


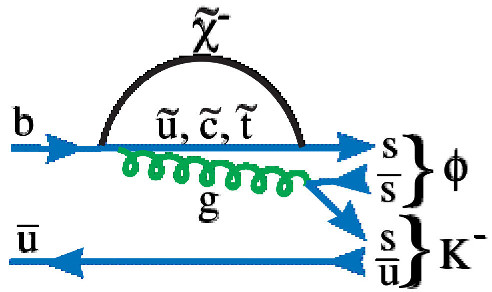


CP asymmetry $\approx$ *0.1*$\sin\phi_\mu \cos\phi_A \sin(\Delta m_s t)$*, ~10 x SM*

- *Contributions to direct CP violating decay*

$B^- \rightarrow \phi K^-$





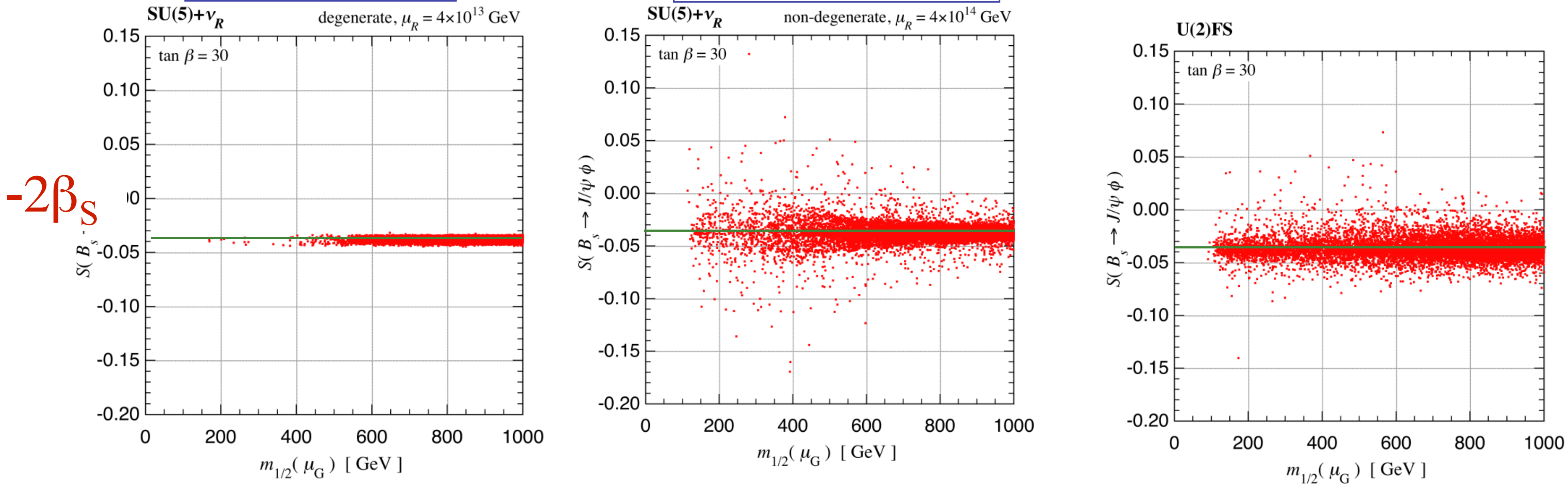
Asym$=(M_W/m_{squark})^2 \sin(\phi_\mu)$*, ~0 in SM*

Supersymmetry: SU(5) &U(2)

SU(5) GUT Degenerate

SU(5) GUT Non-degenerate

U(2) FS

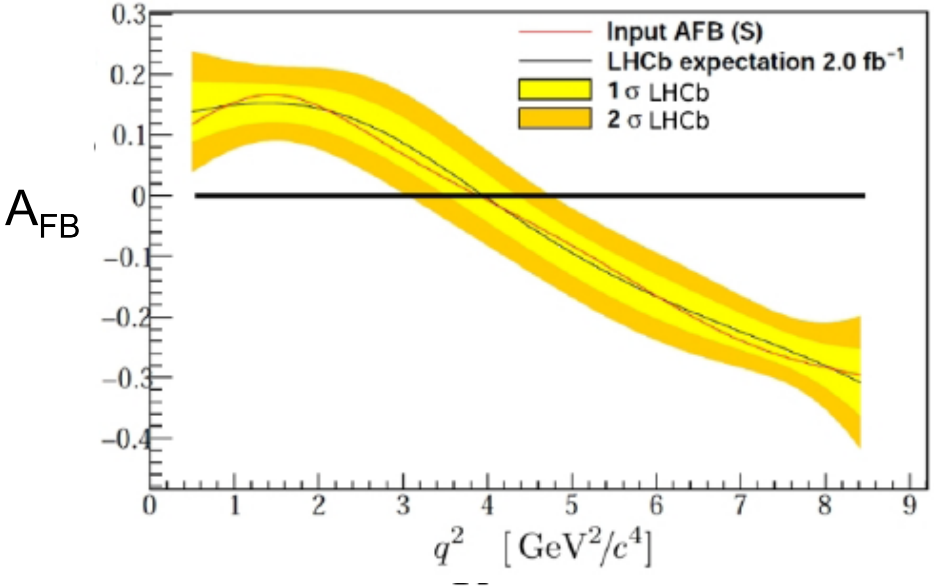


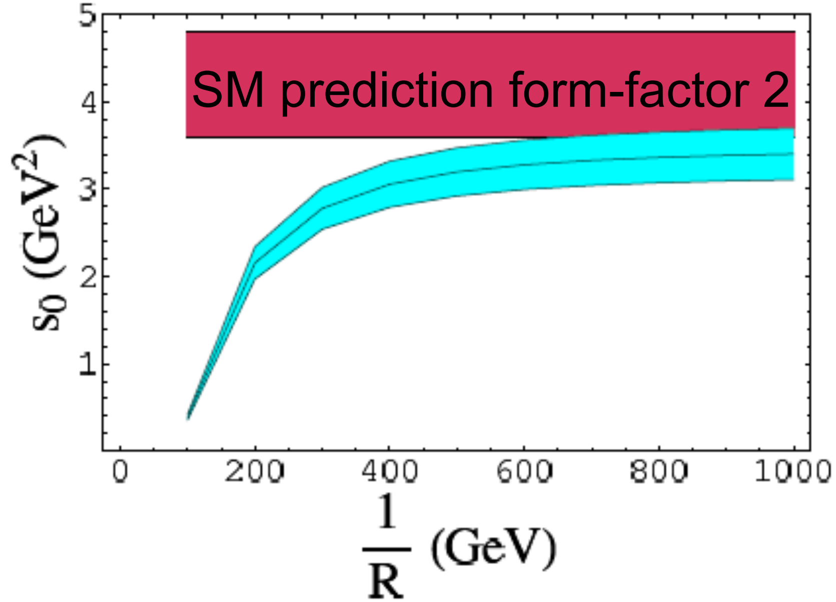
- *$-2\beta_S$ can deviate from the "SM" value of -0.036 in SU(5) GUT non-degenerate case, and the U(2) model. From Okada's talk at BNMII, Nara Women's Univ. Dec., 2006*

Extra Dimensions

- *Using ACD model of 1 universal extra dimension, a MFV model, Colangelo et al predict a shift in the zero of the forward-backward asymmetry in $B \to K^* \mu^+ \mu^-$*
- *Insensitive to choice of form-factors. Can SM calculations improve?*

LHCb measures zero to ±0.22 GeV^2 in 10 fb^{-1}





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

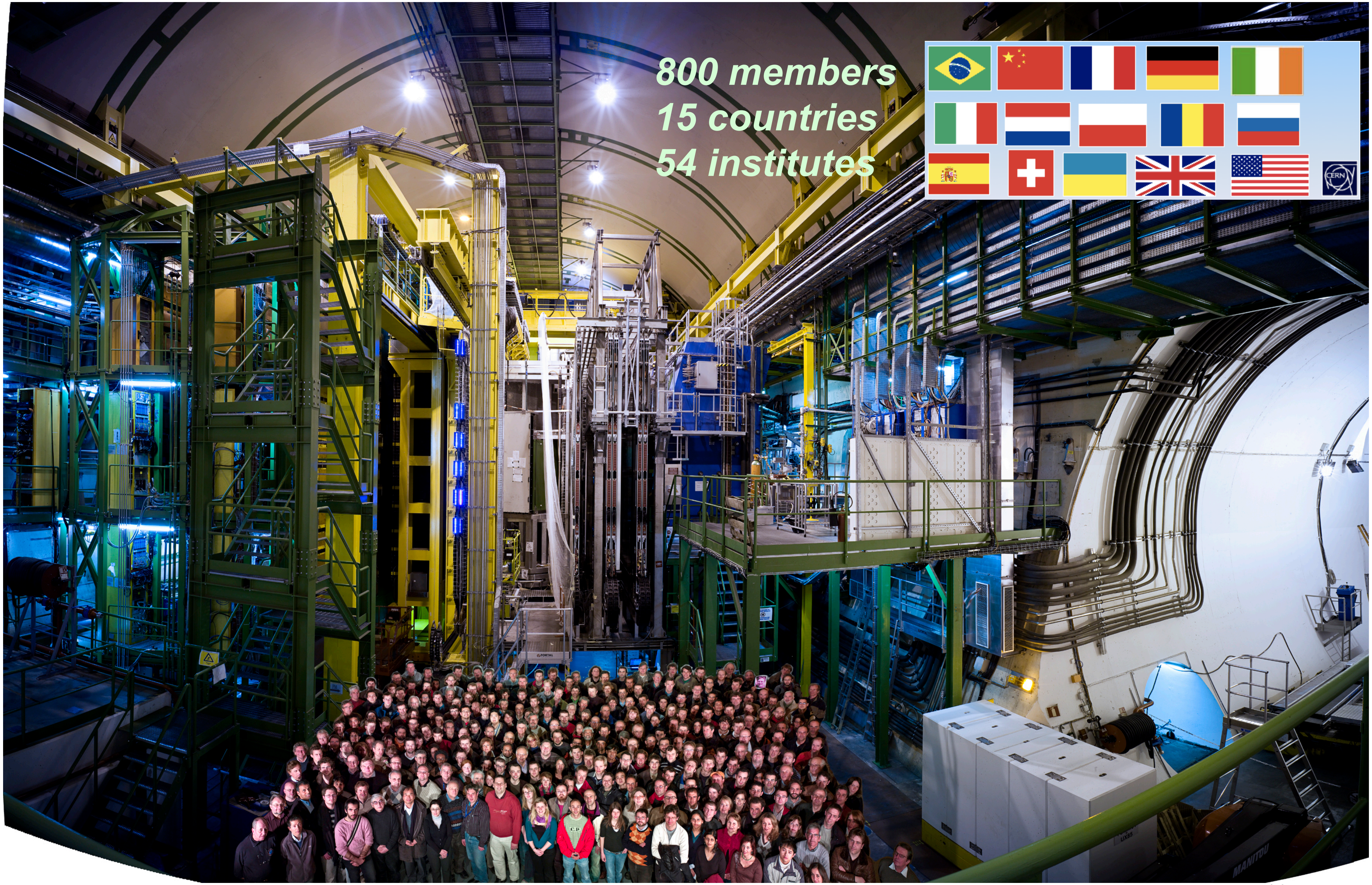
- Explore TeV-scale directly (ATLAS & CMS) and indirectly (LHCb)

No space left for the 4th possibility

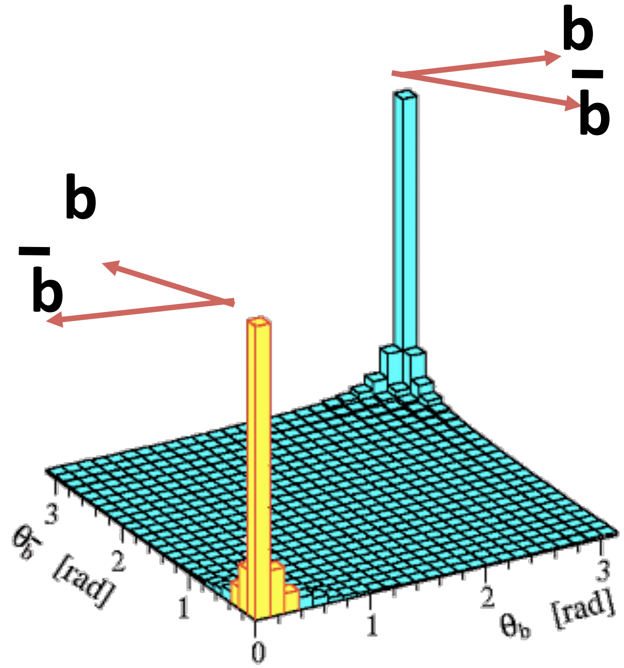
ATLAS CMS high p_T physics	BSM	Only SM	BSM	
LHCb flavour physics	Only SM	BSM	BSM	
Particle Physics	☺	☺	☺	

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

LHCb Collaboration



The LHCb Experiment



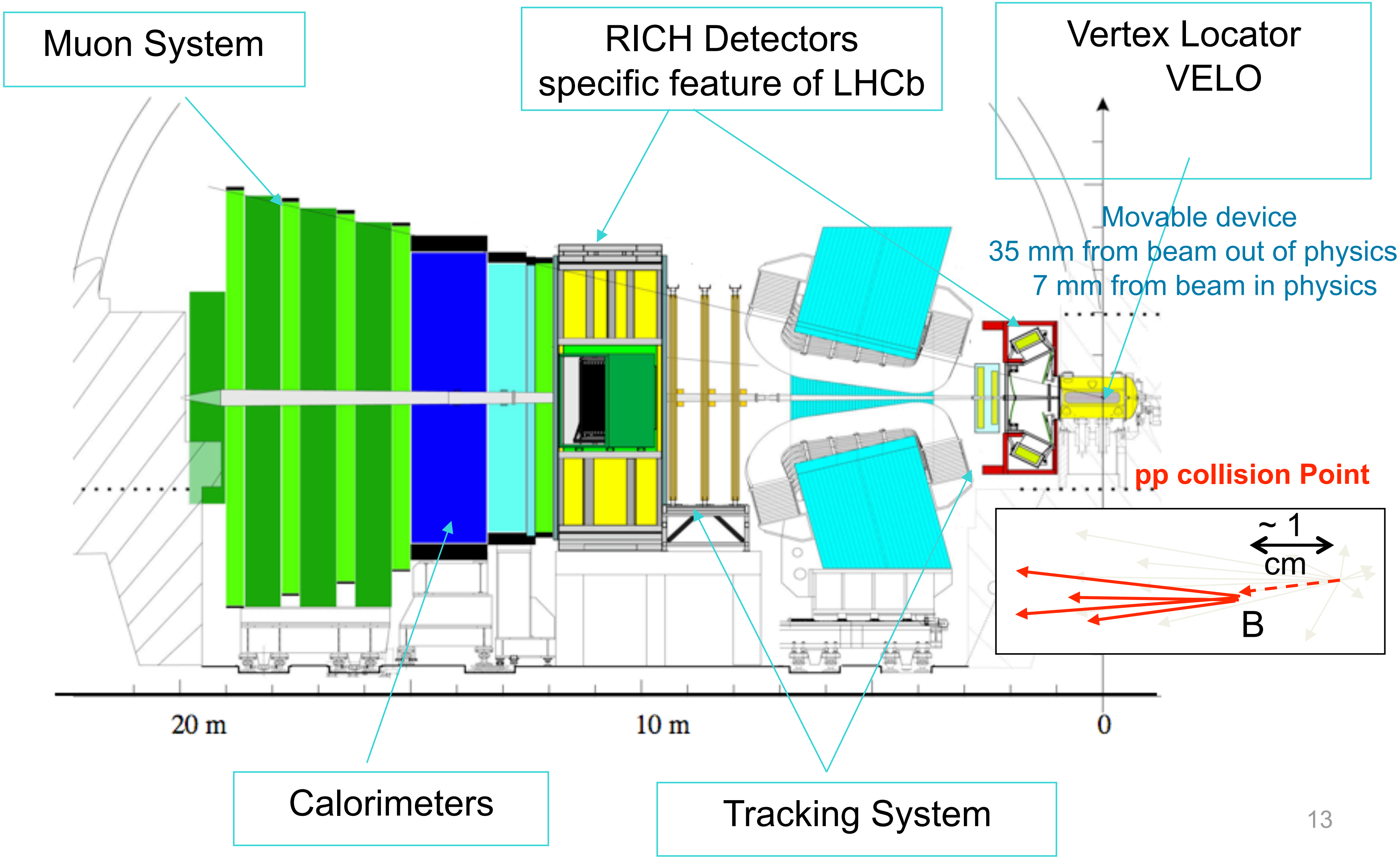
- ☐ *Advantages of beauty physics at hadron colliders:*
  - *High value of bb cross section at LHC:*

    σ_{bb} ~ 300 - 500 μb at 10 - 14 TeV

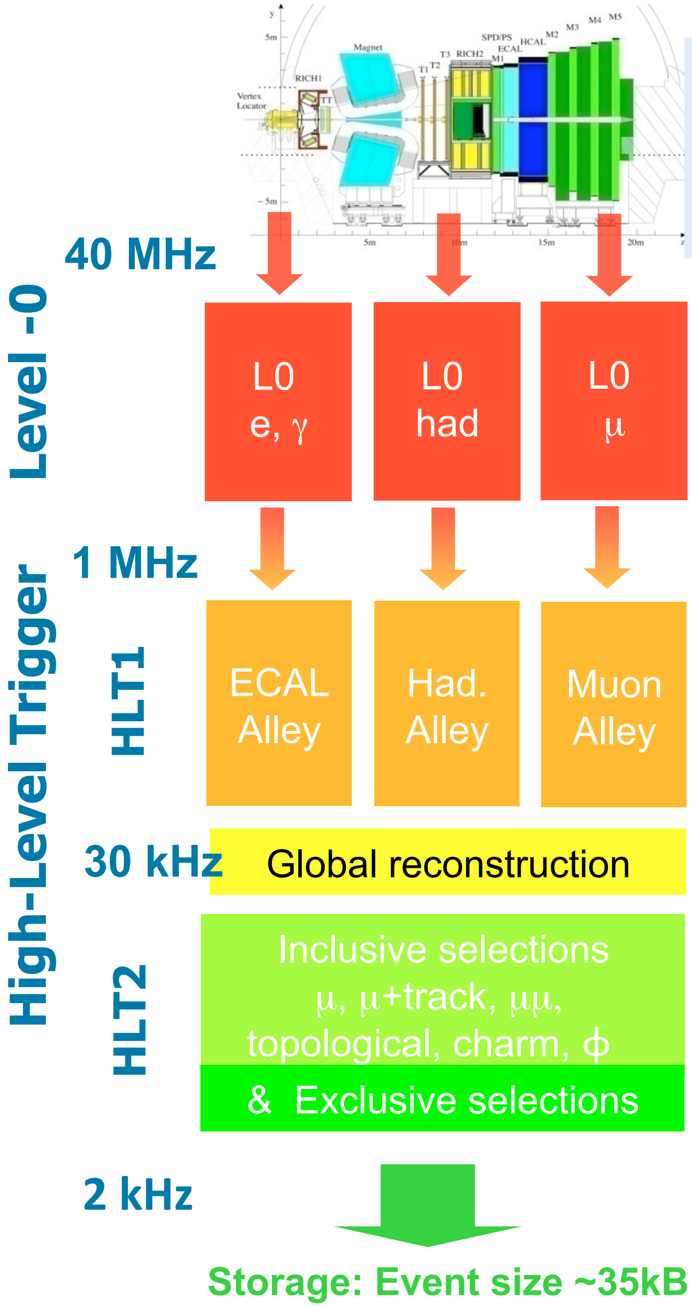
    (e+e- cross section at Y(4s) is 1 nb)
  - *Access to all quasi-stable b-flavoured hadrons*
- ☐ *The challenge*
  - *Multiplicity of tracks (~30 tracks per rapidity unit)*
  - *Rate of background events: σ_{inel} ~ 100 mb*
- ☐ *LHCb running conditions:*
  - *Luminosity limited to ~2×10^{32} cm^{-2} s^{-1} 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

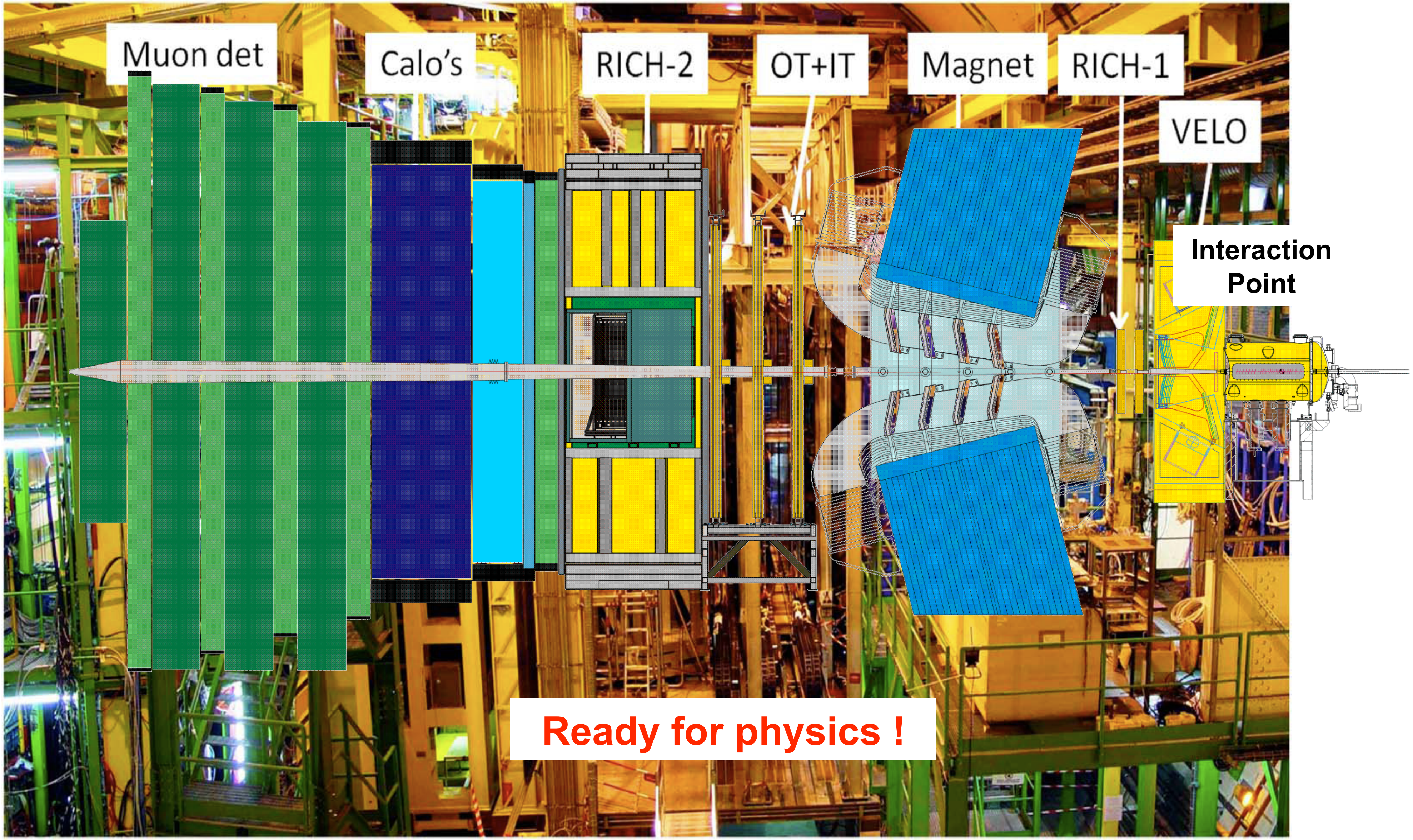
- ☐ ***Software level (High Level Trigger, HLT)***

  *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

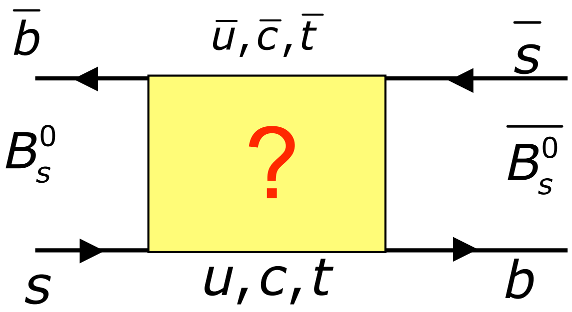
	ε(L0)	ε(HLT1)	ε(HLT2)
Electromagnetic	70 %	> ~80 %	> ~90 %
Hadronic	50 %		
Muon	90 %		


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

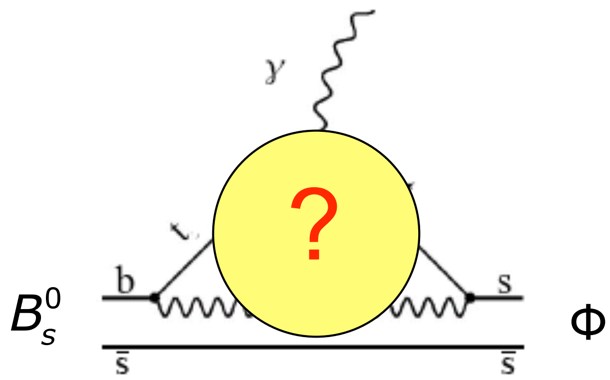
LHCb Physics Programme

- *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***

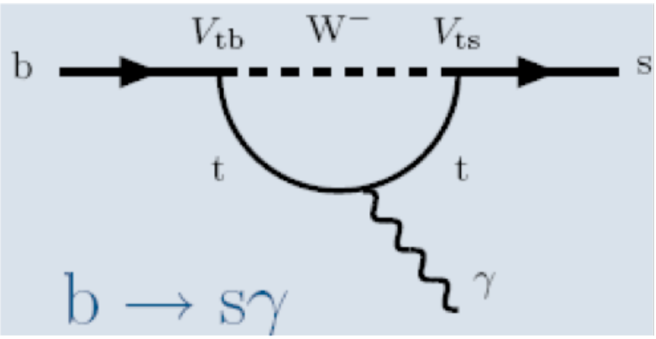
- ***Masses and magnitude of the couplings of new particles***

  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 ***$Bs \rightarrow \mu\mu$*** *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

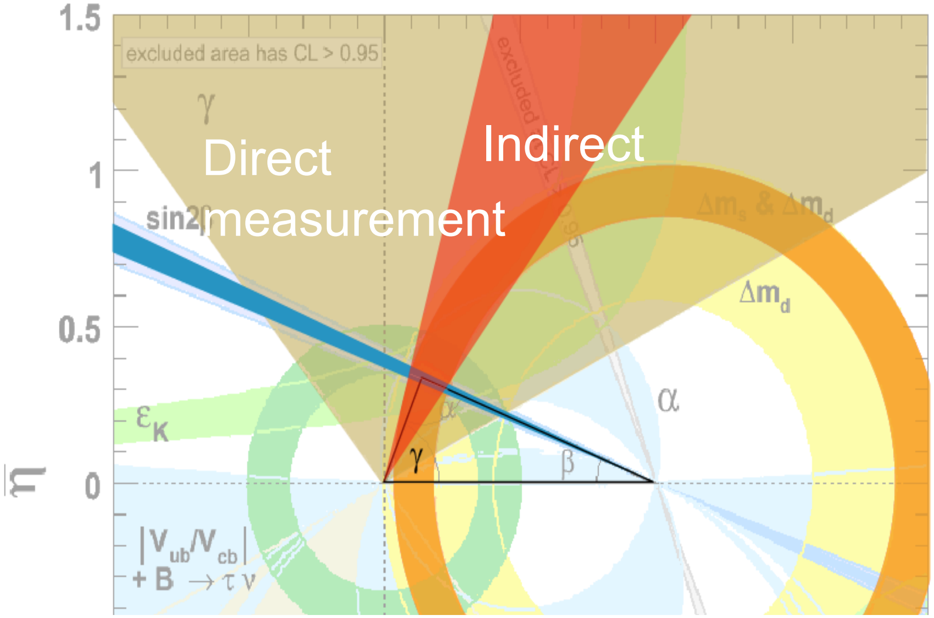
❑ Box diagrams (I)

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*** $(68\pm5)^o$ ***from processes involving boxes***

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

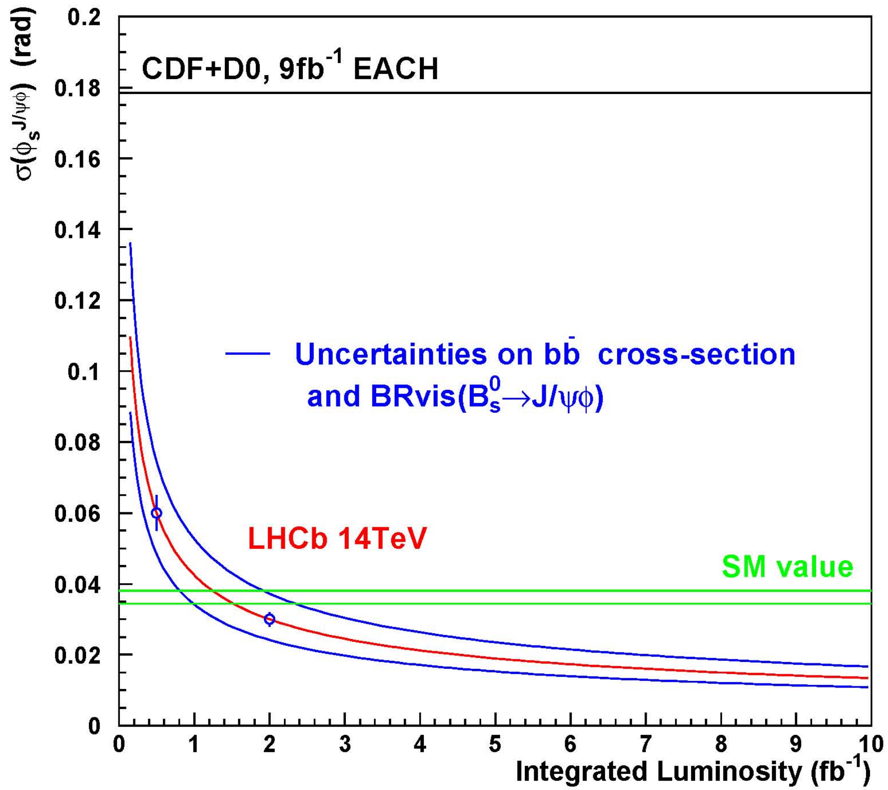
Theoretical uncertainty is very small

- $2\beta_s$ = - 0.0368±0.0017 (CKMfitter 2007)

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

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

$\sigma(\phi_s) \sim 0.03$



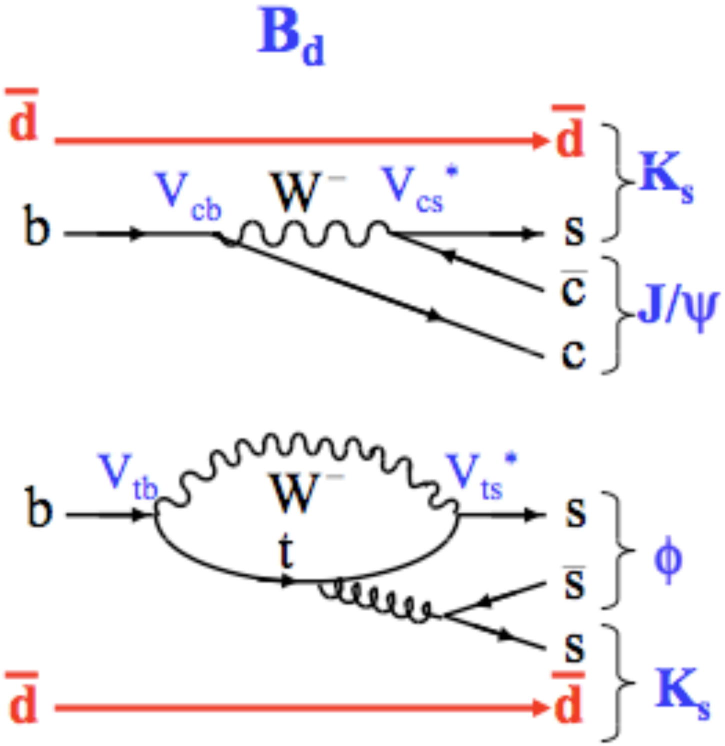
Other channels are under study e.g. $B_s \rightarrow J/\psi f^0$, $f^0 \rightarrow \pi^+\pi^-$. Looks promising if this CP-eigenstate mode has BR indicated by CLEO

CPV measurements: phases in penguins

- **Penguin diagrams:**

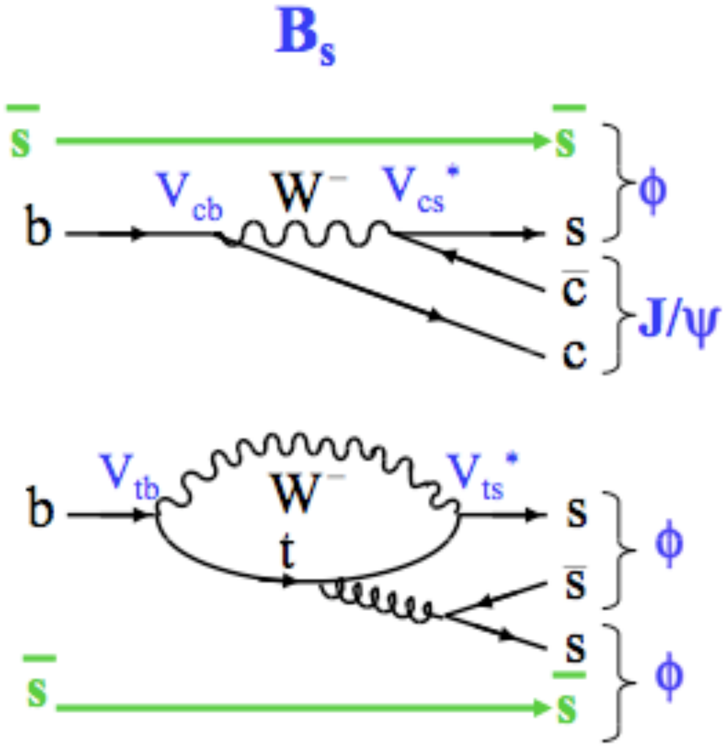
$\phi_d(NP) \;\; = \phi_d^{\phi Ks} - \phi_d^{J/\psi Ks}$

$\phi_s(NP) \;\; \approx \phi_s^{\phi\phi} - \phi_s^{J/\psi\phi}$ **= O(a few degrees) if NP !!!**



Tree

Penguin



Thanks to B-factories
ϕ_d(NP)) ~ - 0.23 ± 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:

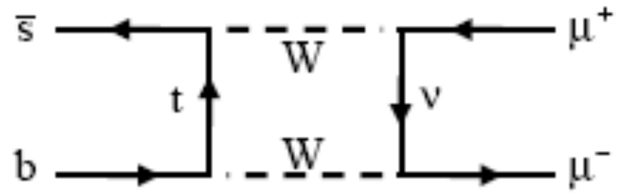
- *BR ($B_s \rightarrow \mu\mu$)   (CDF /D0)*
  BR ($B_d \rightarrow \mu\mu$)

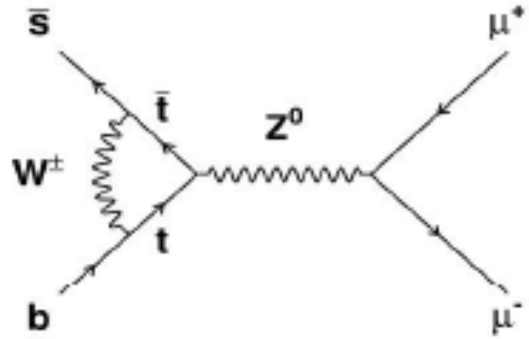
- *Photon polarization in $B \rightarrow K^*\gamma$ (BELLE/BaBar)*

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

LHCb will study rare decays in depth !!!

$B_s \rightarrow \mu\mu$





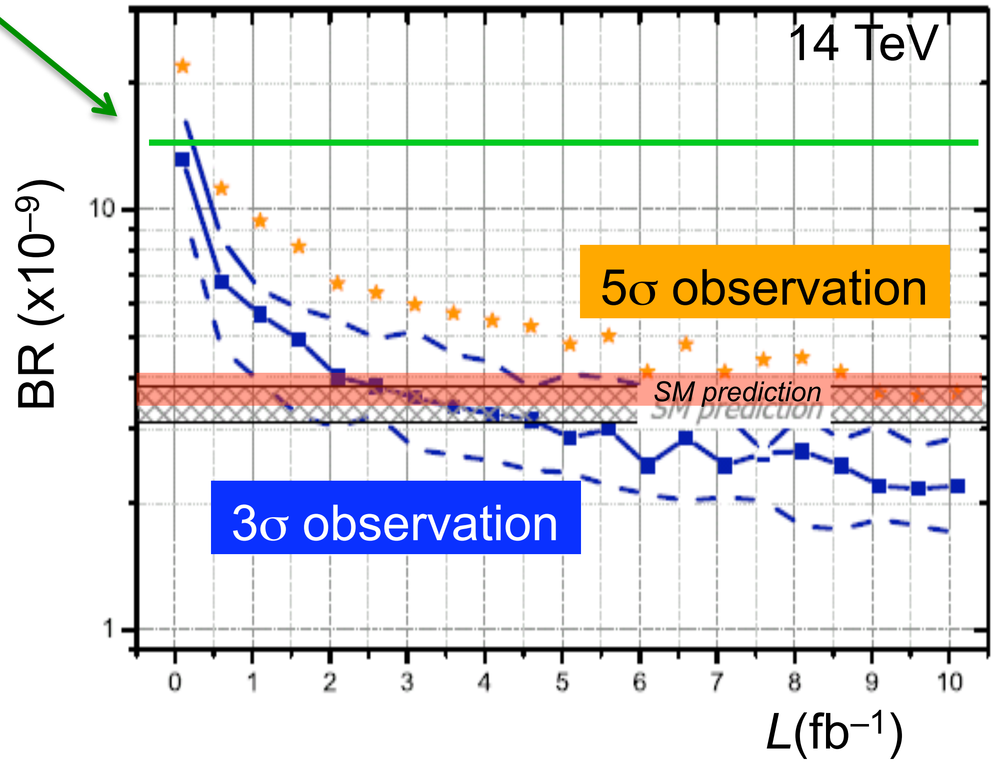
- *Super rare decay in SM with well predicted $BR(B_s \rightarrow \mu\mu) = (3.55 \pm 0.33) \times 10^{-9}$*

- *Sensitive to NP, in particular new scalars*
  In MSSM: $BR \propto \tan^6\beta / M^4_A$

- *Present best limit is from Tevatron:*
  $BR(B_s \rightarrow \mu\mu) < 4.3 \times 10^{-8}$ @ 90% CL

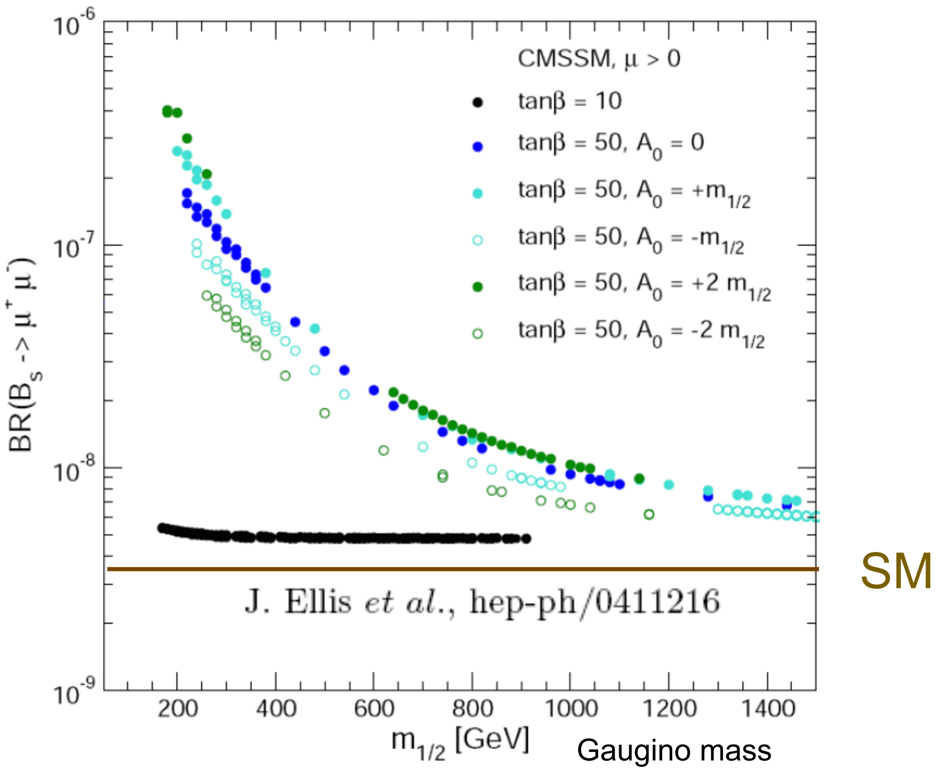
- *For the SM prediction*
  LHCb expects 21 signal and 180 background events with 2 fb^{-1}.
  Background is dominated by muons from two different semileptonic b-decays

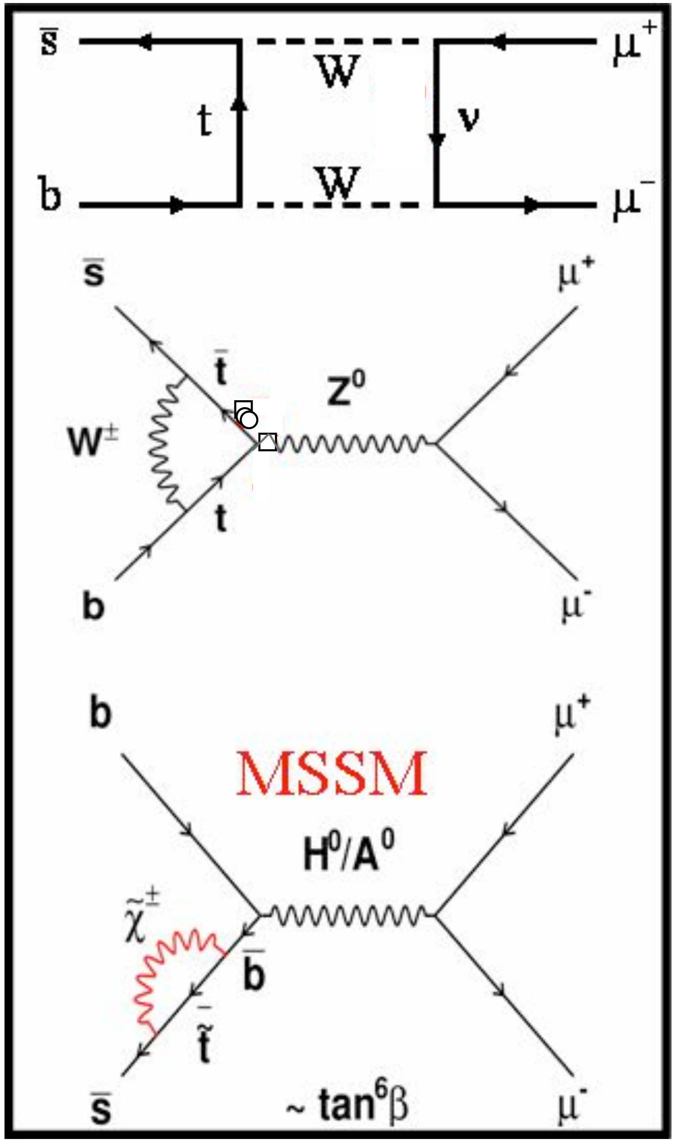
- *LHCb sensitivity for the SM BR:*
  3σ evidence with 3 fb^{-1}
  5σ observation with 10 fb^{-1}



$B_S \to \mu^+\mu^-$ & Supersymmetry

- *Branching Ratio very sensitive to SUSY*
- *In MSSM goes as $\tan^6\beta$*





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*

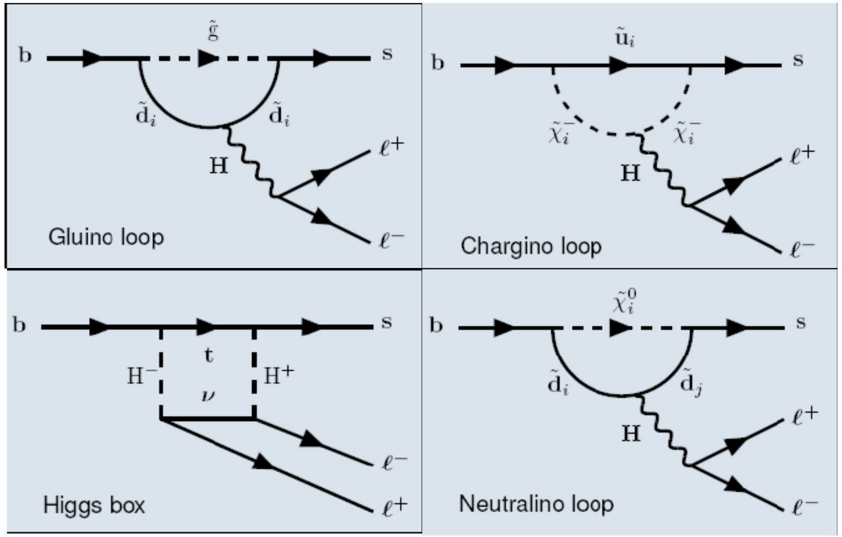
$$\tan\psi \equiv \left|\frac{A(\bar{\mathrm{B}}\to f^{CP}\gamma_R)}{A(\bar{\mathrm{B}}\to f^{CP}\gamma_L)}\right|$$

- ❑ *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$fb^{-1}$

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

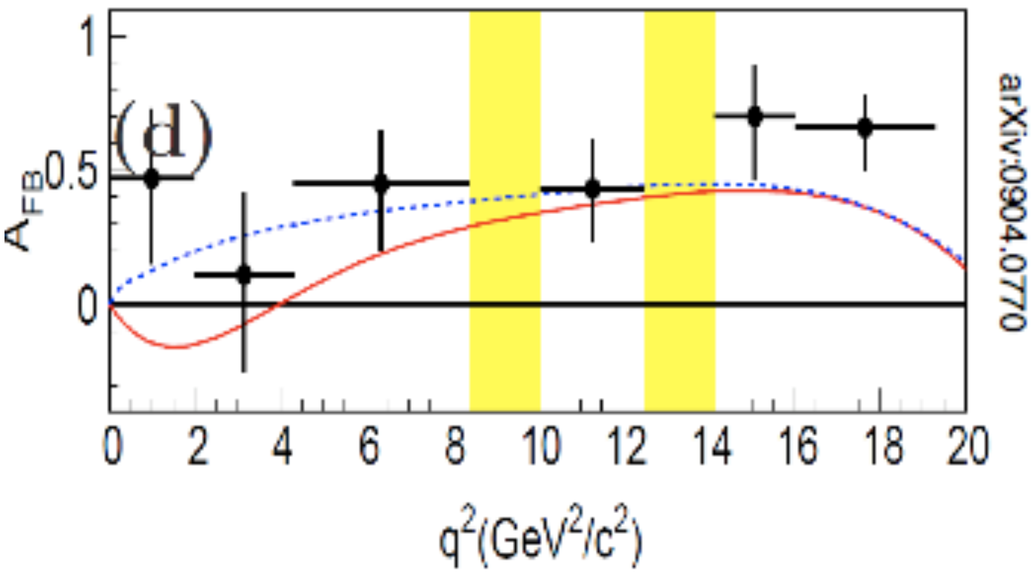
In SM this b→s penguin decay contains well calculable right-handed contribution but corresponding angular distributions could be modified by NP



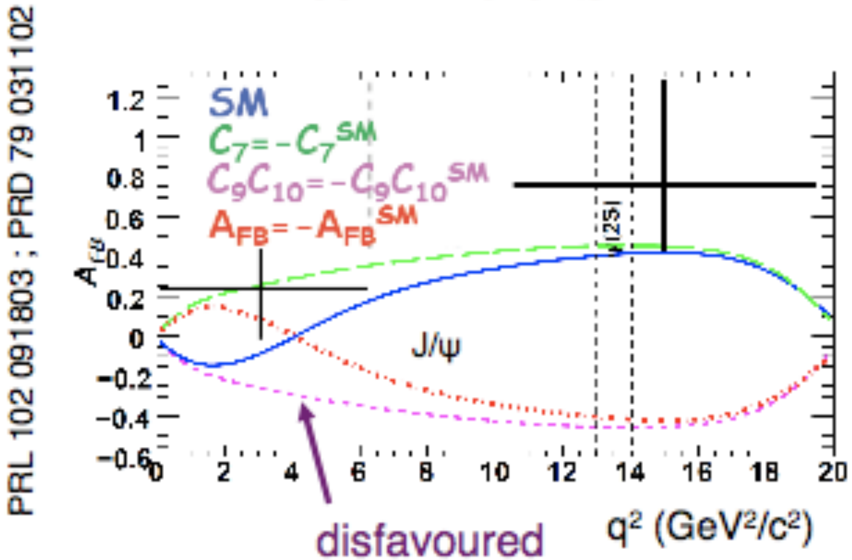
Forward-backward asymmetry A_{FB} (q^2=$m^2_{\mu\mu}$) is of particular interest at zero-point, since dominant theor. uncert. from hadronic form-factors cancels at LO

Intriguing indications from B-factories :

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

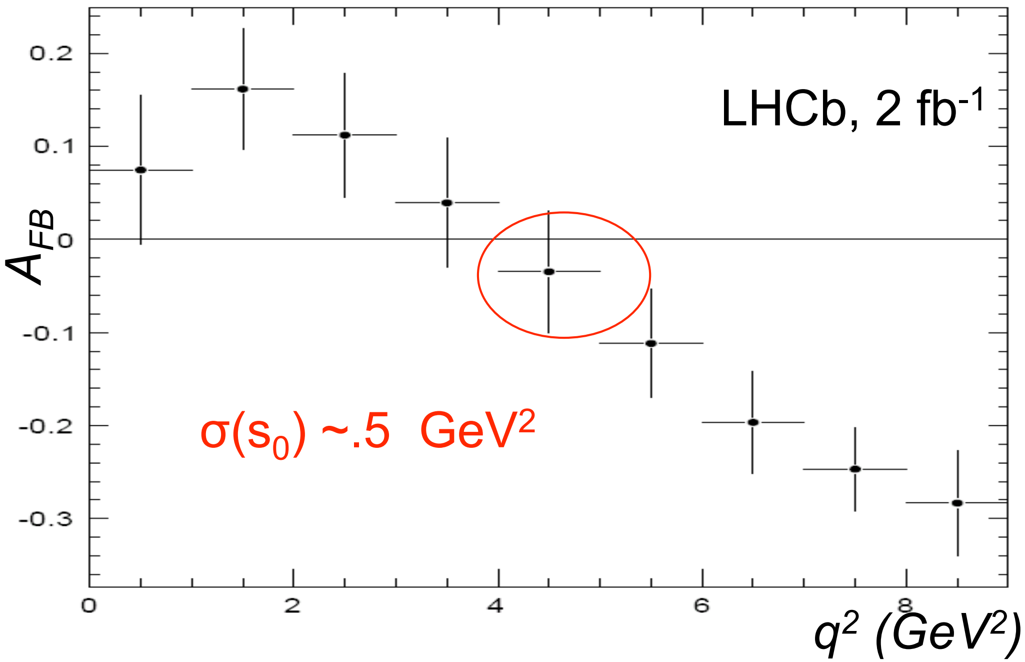


BaBar: 384 million BBbars analysed
~100 $K^*l^+l^-$ events



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

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



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 $B \rightarrow K^*ee$:

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

- *Expected LHCb yield with 2 fb^{-1}: ~ 200 – 250 events with B/S ~ 1*
  Expected sensitivity ***$\sigma(A(B \rightarrow f^{CP}\gamma_R)/A(B \rightarrow f^{CP}\gamma_L)) \approx 0.1$***
  limited by statistics and comparable to $B_s \rightarrow \phi\gamma$ 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	
✓ $B \rightarrow K^*\mu\mu$	$\sigma(s0) = 0.28\ GeV^2$
✓ $B_s \rightarrow \mu\mu$	**5σ measurement down to SM prediction**
✓ Polarization of photon	$\sigma(H_R/H_L) = 0.03$ (in $B_s \rightarrow \phi\gamma$ & $B_d \rightarrow K^*e^+e^-$)

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 $K \to \pi\nu\nu$ 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 $B_s \rightarrow \phi\gamma$ decay:*	$\sigma(H_R/H_L) = 0.03$	Yes ? (theor. uncert. ~0.03)
NP in a mixture of loop diagrams:		
❑ $B \rightarrow K^*\mu\mu$, $B_s \rightarrow \phi\mu\mu$	$\sigma(s0) \sim 0.3\ GeV^2$ Already very rich choice of observables, e.g. A_T^3, A_T^4 etc…	Yes
❑ $B_s \rightarrow \mu\mu$ ($B_d \rightarrow \mu\mu$)	>5σ observation if SM	Yes

Charm Physics

Measured CP asymmetries approach SM prediction

LVF in τ decays

$BR(\tau \rightarrow 3\mu) < 10^{-8}$ using τ from $D_s \rightarrow \tau\nu$

There could be great possibilities To be explored !

Super B-factory

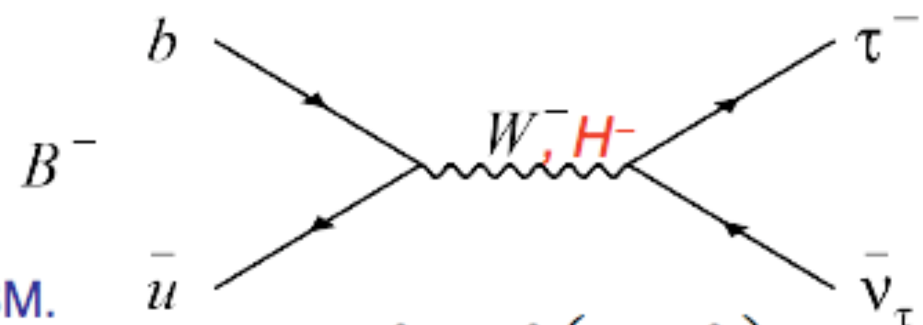
(I do not distinguish here between SuperB & SuperKEKB)

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*

$B \to \tau\nu_\tau$ decay

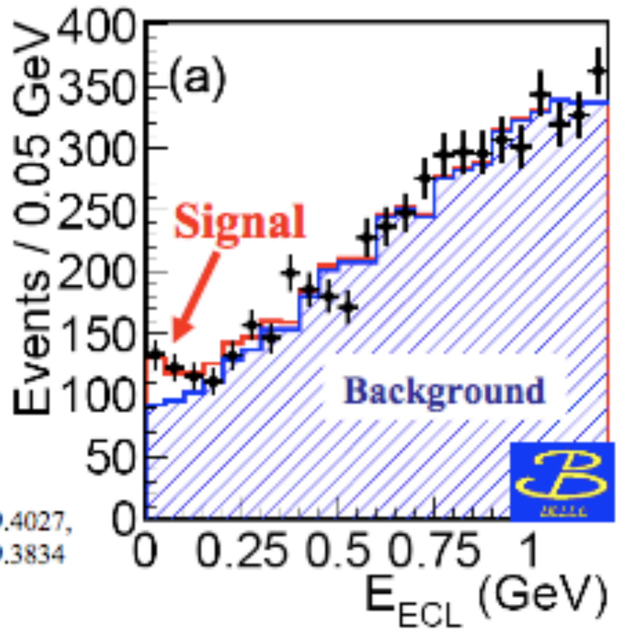
- Within the SM, sensitive to f_B and $|V_{ub}|$: $\mathcal{B}_{SM}$~1.6×10^{-4}.
- $\mathcal{B}$ affected by new physics.
  - MFV models like 2HDM / MSSM.
  - Unparticles.



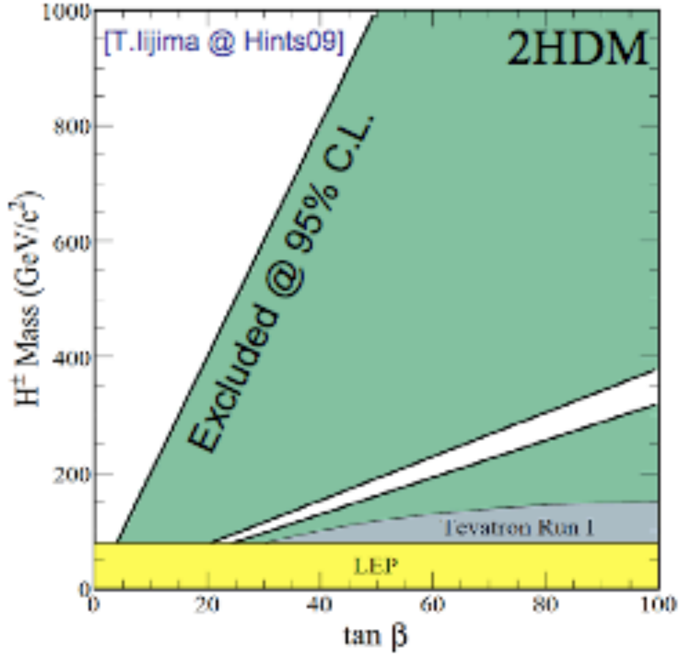
$$\mathcal{B}_{SM}(B^+ \to l^+\nu_l) = \frac{G_F^2 m_B m_l^2}{8\pi}\left(1-\frac{m_l^2}{m_B^2}\right) f_B^2 \, |V_{ub}|^2 \, \tau_B$$

- Fully reconstruct the event (modulo ν).

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



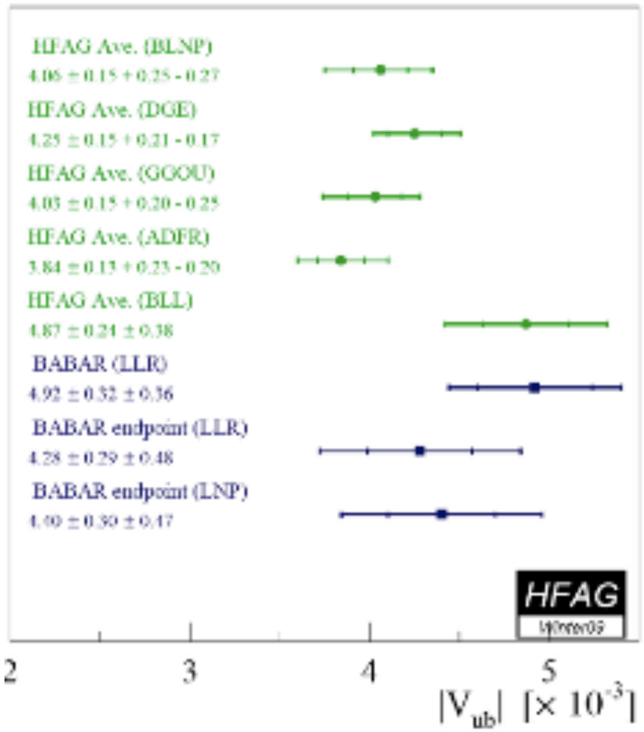
arXiv:0809.4027, arXiv:0809.3834



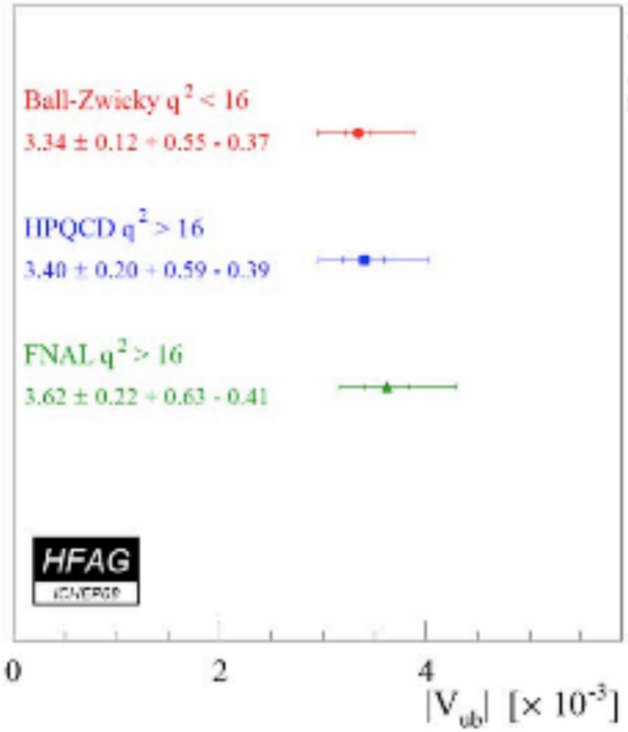
2HDM: W.-S Hou PRD **48** 2342 (1993)
MSSM: G. Isidori arXiv:0710.5377

V_{ub} determination

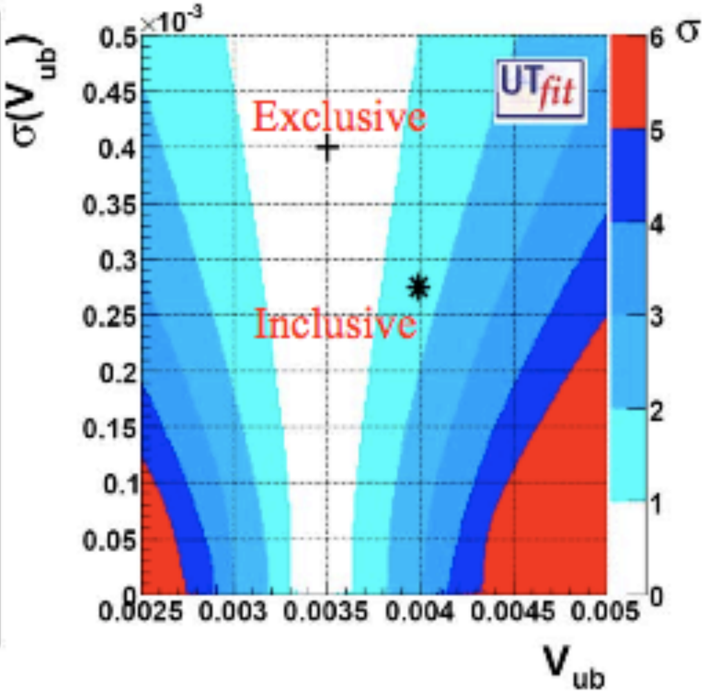
- Tension between inclusive and exclusive results and sin2β.



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°
$\|V_{cb}\|$ (exclusive)	4% (∗)	1.0% (∗)
$\|V_{cb}\|$ (inclusive)	1% (∗)	0.5% (∗)
$\|V_{ub}\|$ (exclusive)	8% (∗)	3.0% (∗)
$\|V_{ub}\|$ (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%
$BR(B\to K\nu\overline{\nu})$	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 $\times 10^{-3}$	5×10^{-4}
$D^0\to K^+\pi^-$	y'_D	2–3 $\times 10^{-3}$	7×10^{-4}
	x'^2_D	1–2 $\times 10^{-4}$	3×10^{-5}
$D^0\to K^0_S\pi^+\pi^-$	y_D	2–3 $\times 10^{-3}$	5×10^{-4}
	x_D	2–3 $\times 10^{-3}$	5×10^{-4}
Average	y_D	1–2 $\times 10^{-3}$	3×10^{-4}
	x_D	2–3 $\times 10^{-3}$	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}		
	$\|q/p\|$	3×10^{-2}		
	ϕ	2°		
$\psi(3770)\to D^0\overline{D}^0$	x^2		$(1-2)\times10^{-5}$	
	y		$(1-2)\times10^{-3}$	
	$\cos\delta$		$(0.01-0.02)$	

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)

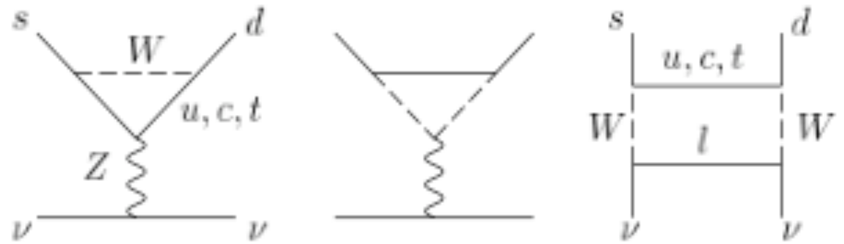
(Crucial element: super high intensity proton beams)

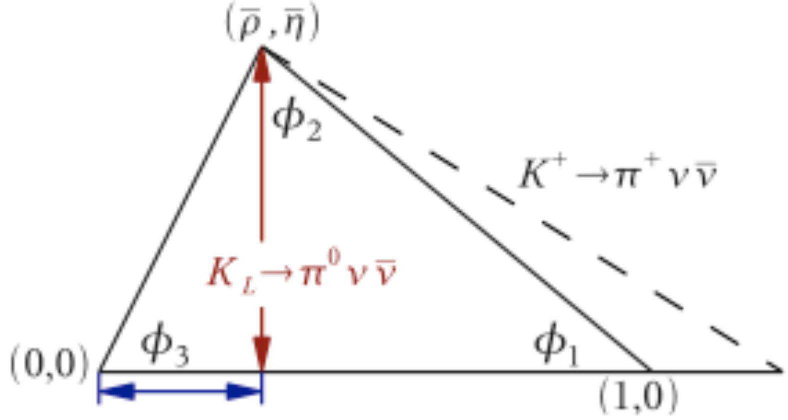
Unique for:

- *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***

$K \to \pi\nu\nu$ 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)

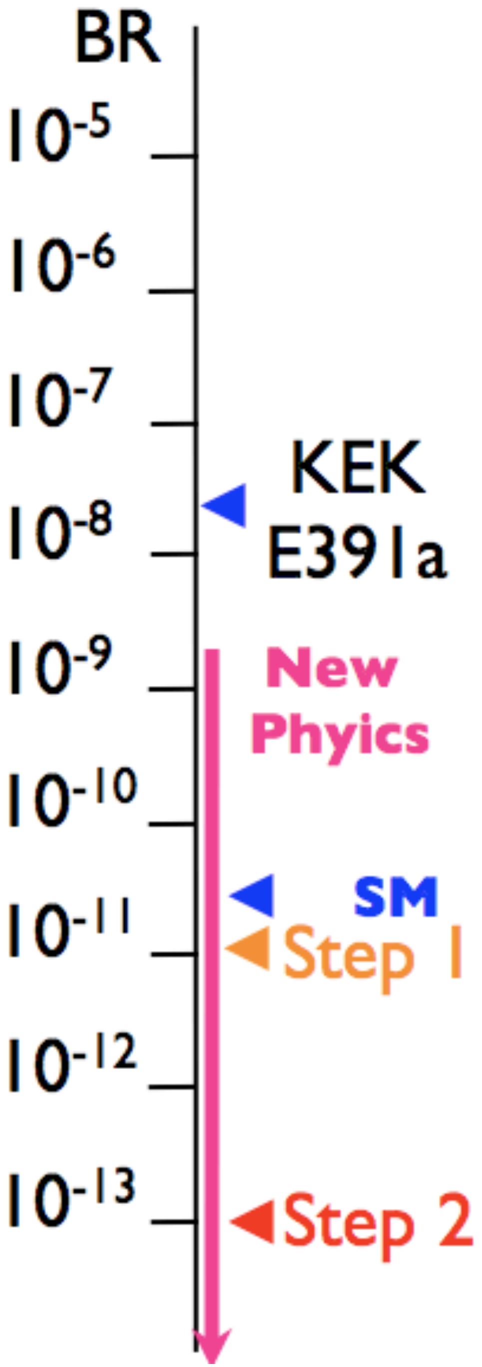
$$B(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+ \cdot \left[\left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2 + \left(\frac{\mathrm{Re}\,\lambda_t}{\lambda^5} X(x_t) + \frac{\mathrm{Re}\,\lambda_c}{\lambda} P_c(X) \right)^2 \right]$$

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

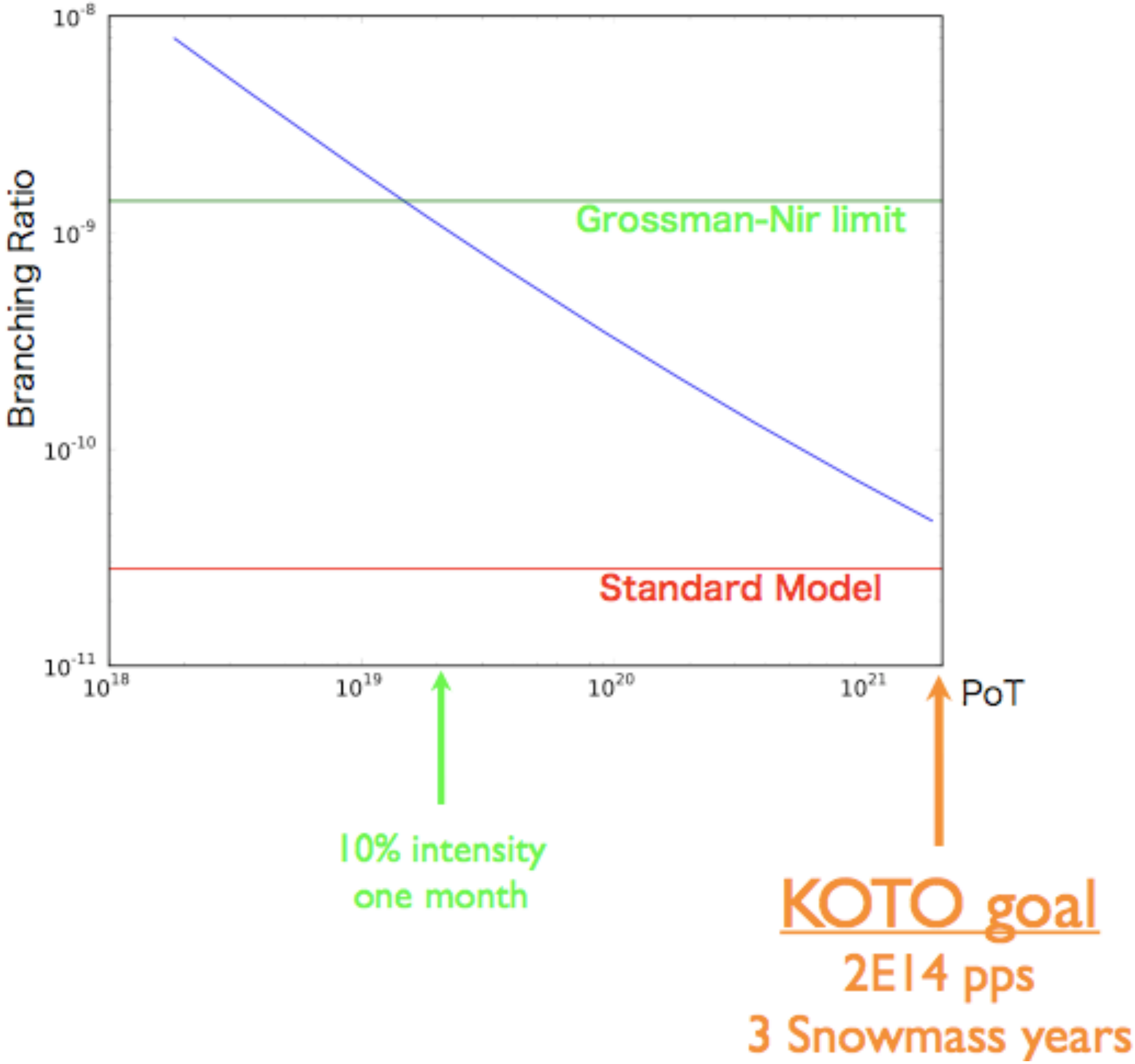
top contribution

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

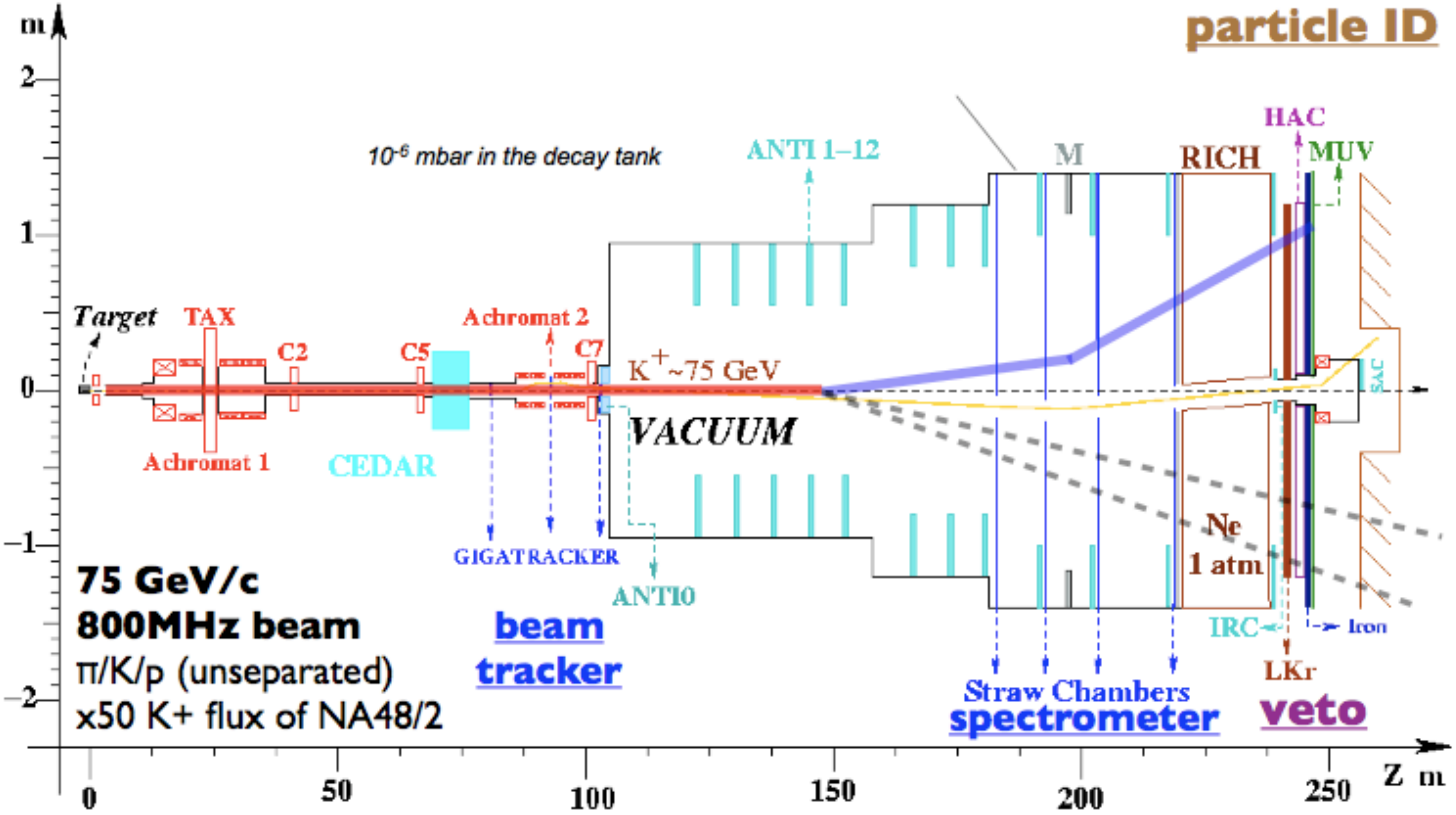
$$\kappa_+ = r_{K^+} \cdot \frac{3\alpha^2 Br(K^+ \to \pi^0 e^+ \nu)}{2\pi^2 \sin^4 \theta_W} \cdot \lambda^8$$



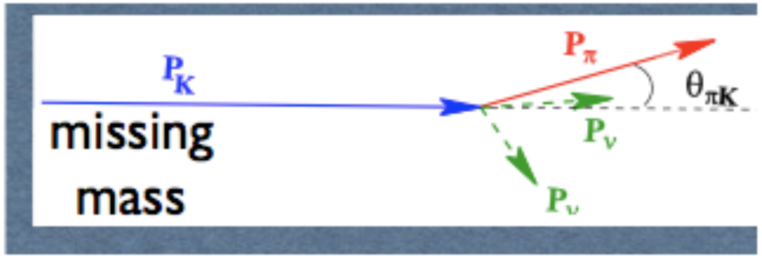
$K_L \to \pi^0 \nu \bar{\nu}$ "3σ" discovery

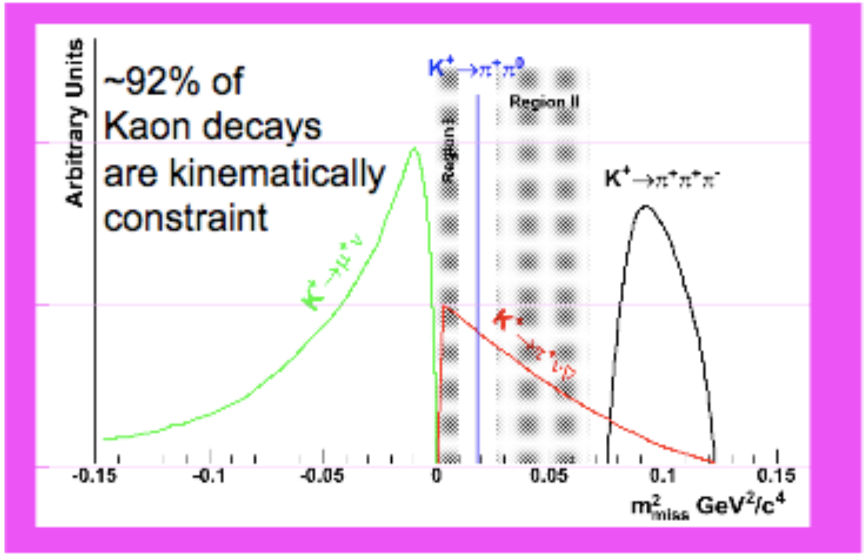


decay in flight to π^+ plus “nothing”

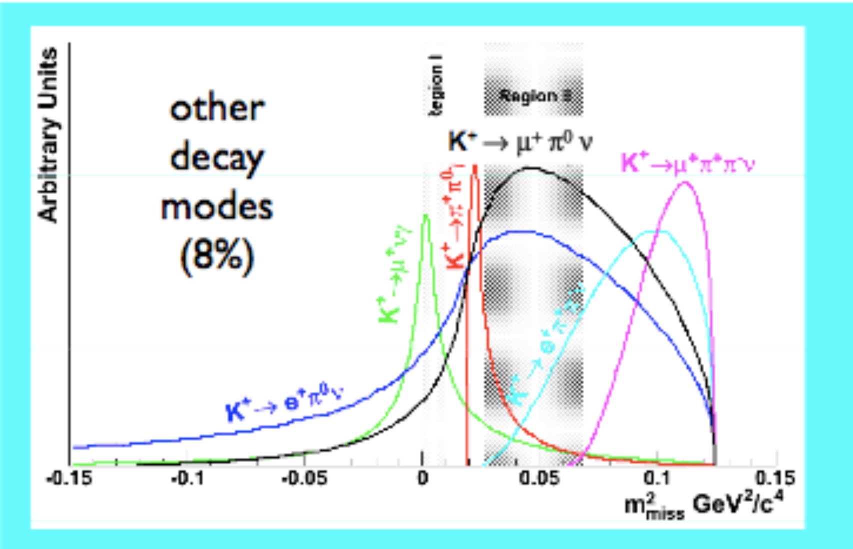


Background rejection





- 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

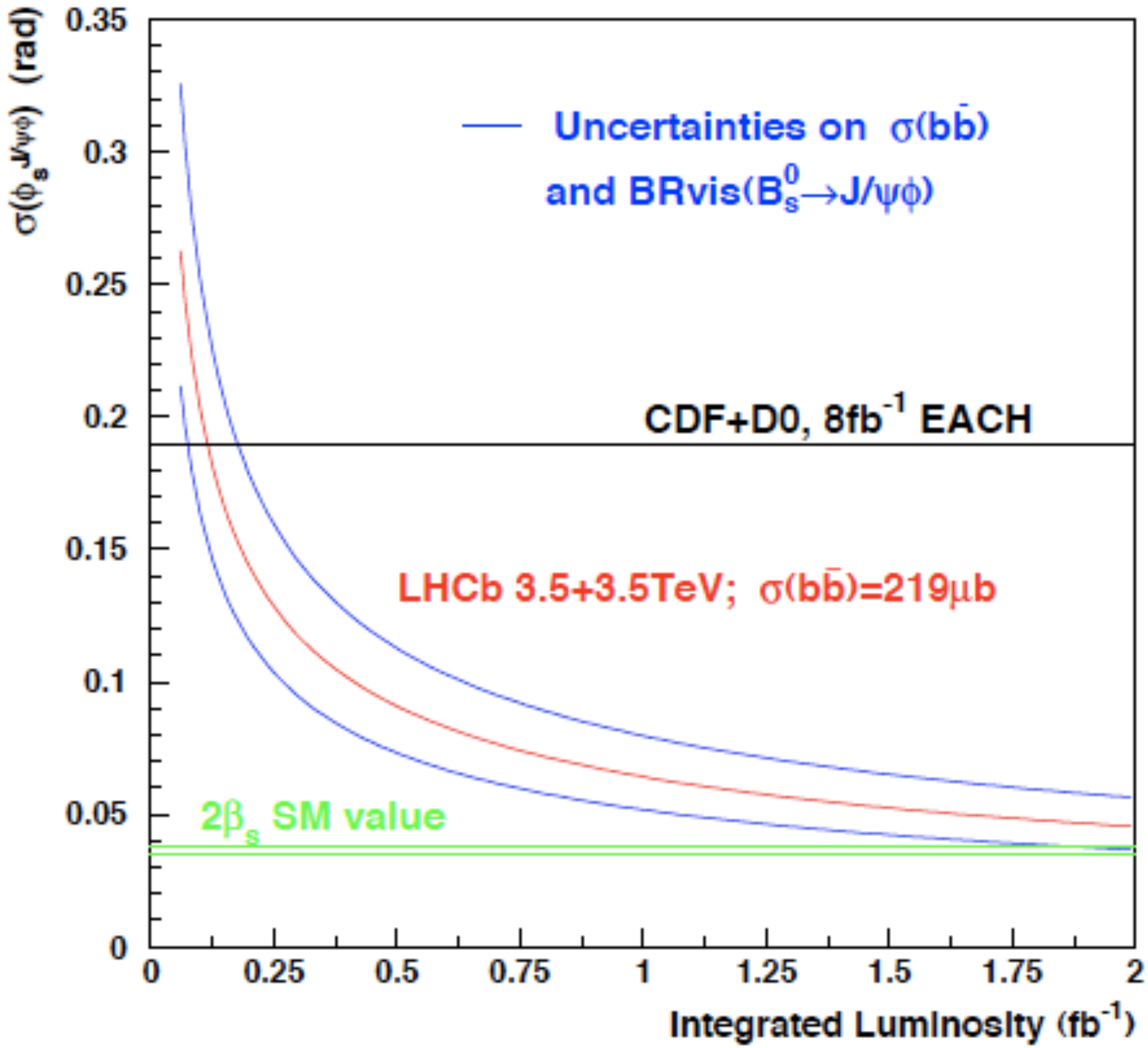
Conclusion

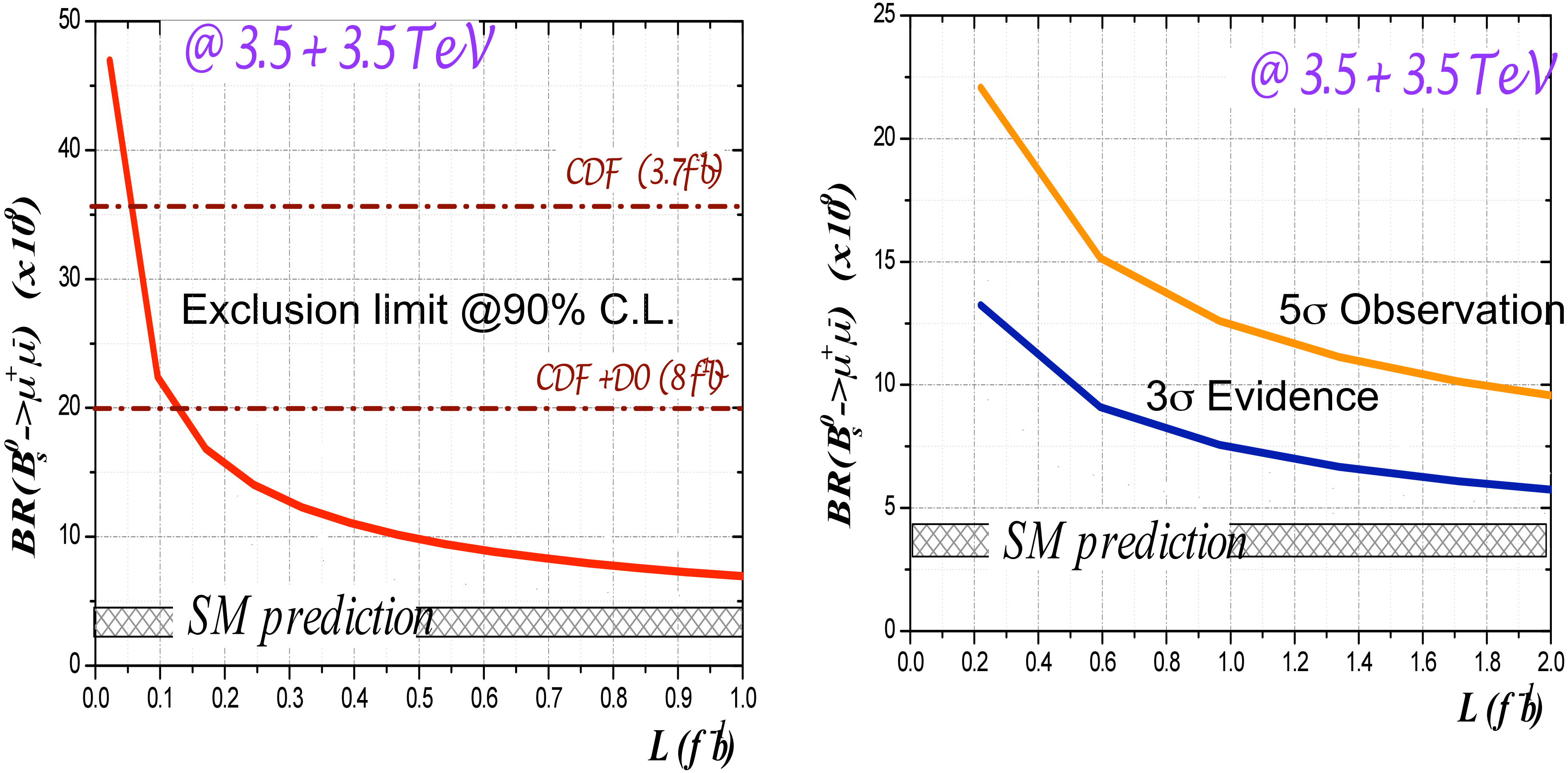
- *LHCb is ready for data taking*

- *First data are being 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*

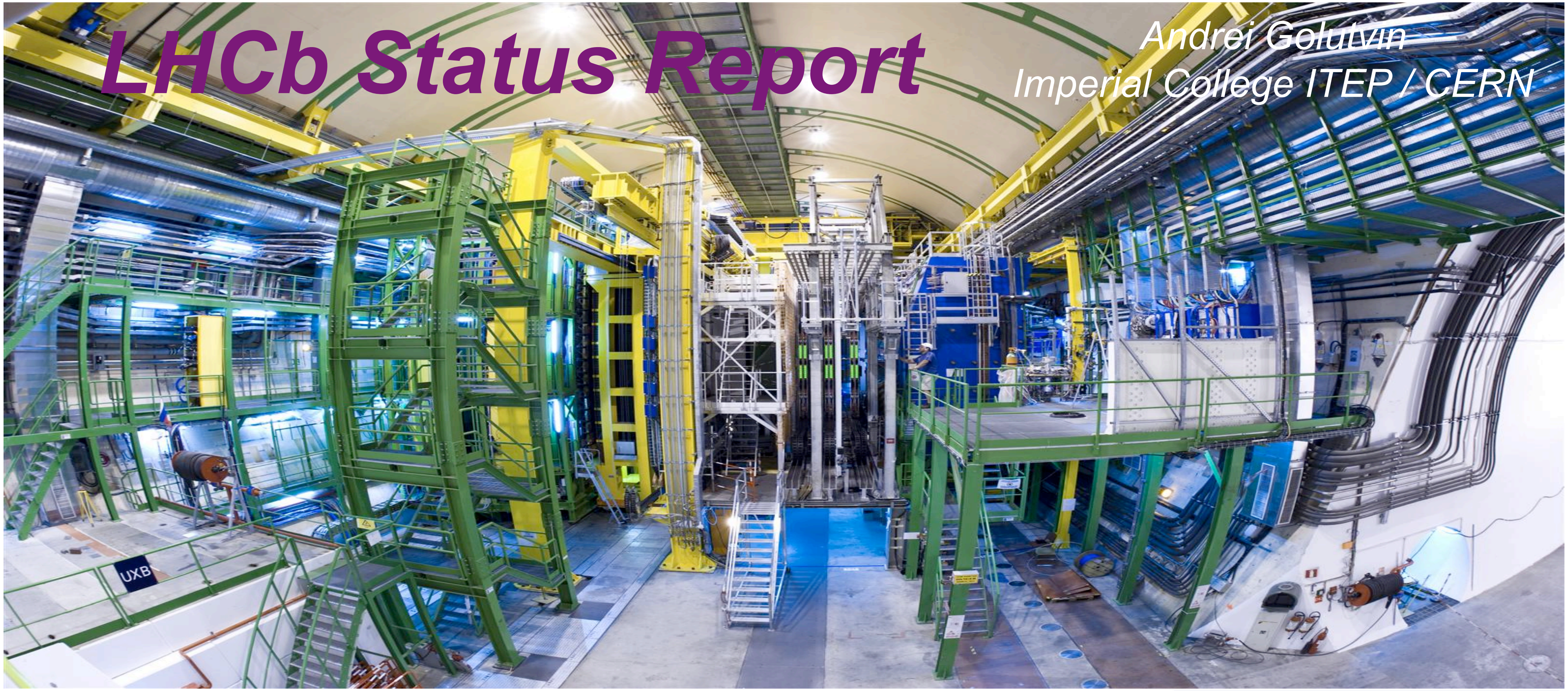

σ(φ_s J/ψφ) (rad)
Uncertainties on σ(bb̄)
and BRvis(B_s^0→J/ψφ)
CDF+D0, 8fb^-1 EACH
LHCb 3.5+3.5TeV; σ(bb̄)=219μb
2β_s SM value
Integrated Luminosity (fb^-1)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.25
0.5
0.75
1
1.25
1.5
1.75
2

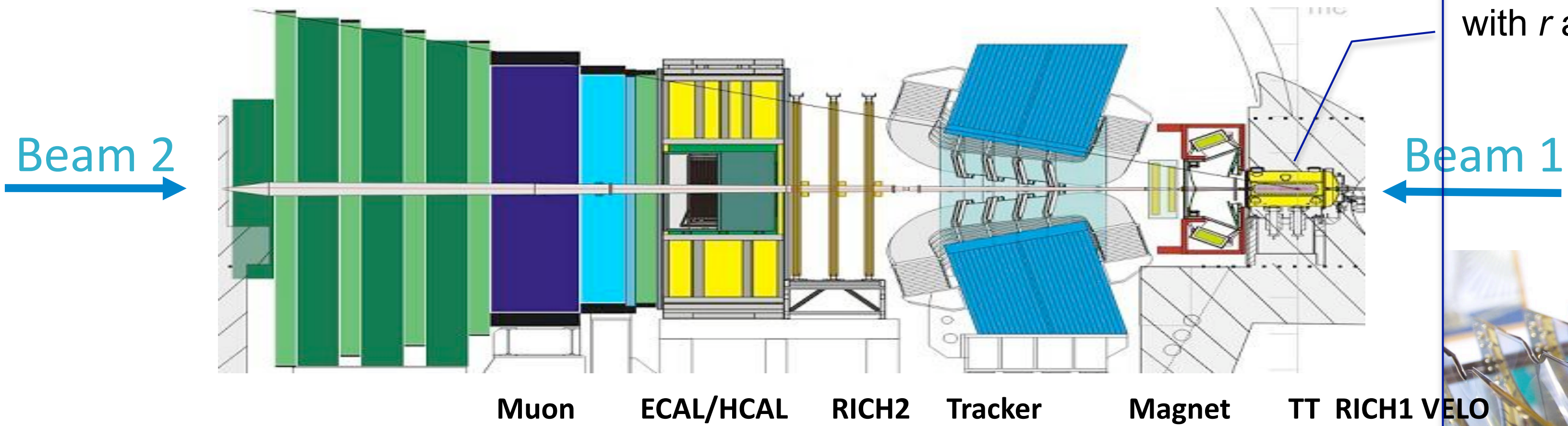


@ 3.5 + 3.5 TeV
CDF (3.7fb-1)
Exclusion limit @90% C.L.
CDF +D0 (8 fb-1)
SM prediction
BR(B_s^0->μ+μ-) (x10^-9)
L (fb-1)
@ 3.5 + 3.5 TeV
5σ Observation
3σ Evidence
SM prediction
BR(B_s^0->μ+μ-) (x10^-9)
L (fb-1)

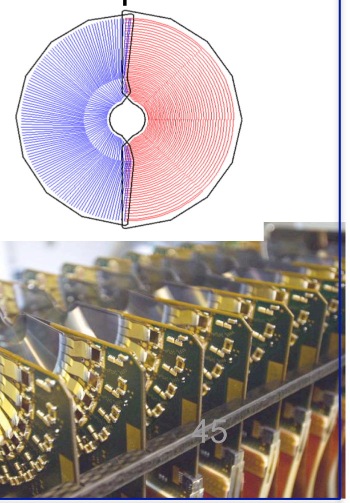
LHCb Status Report

Andrei Golutvin
Imperial College ITEP / CERN

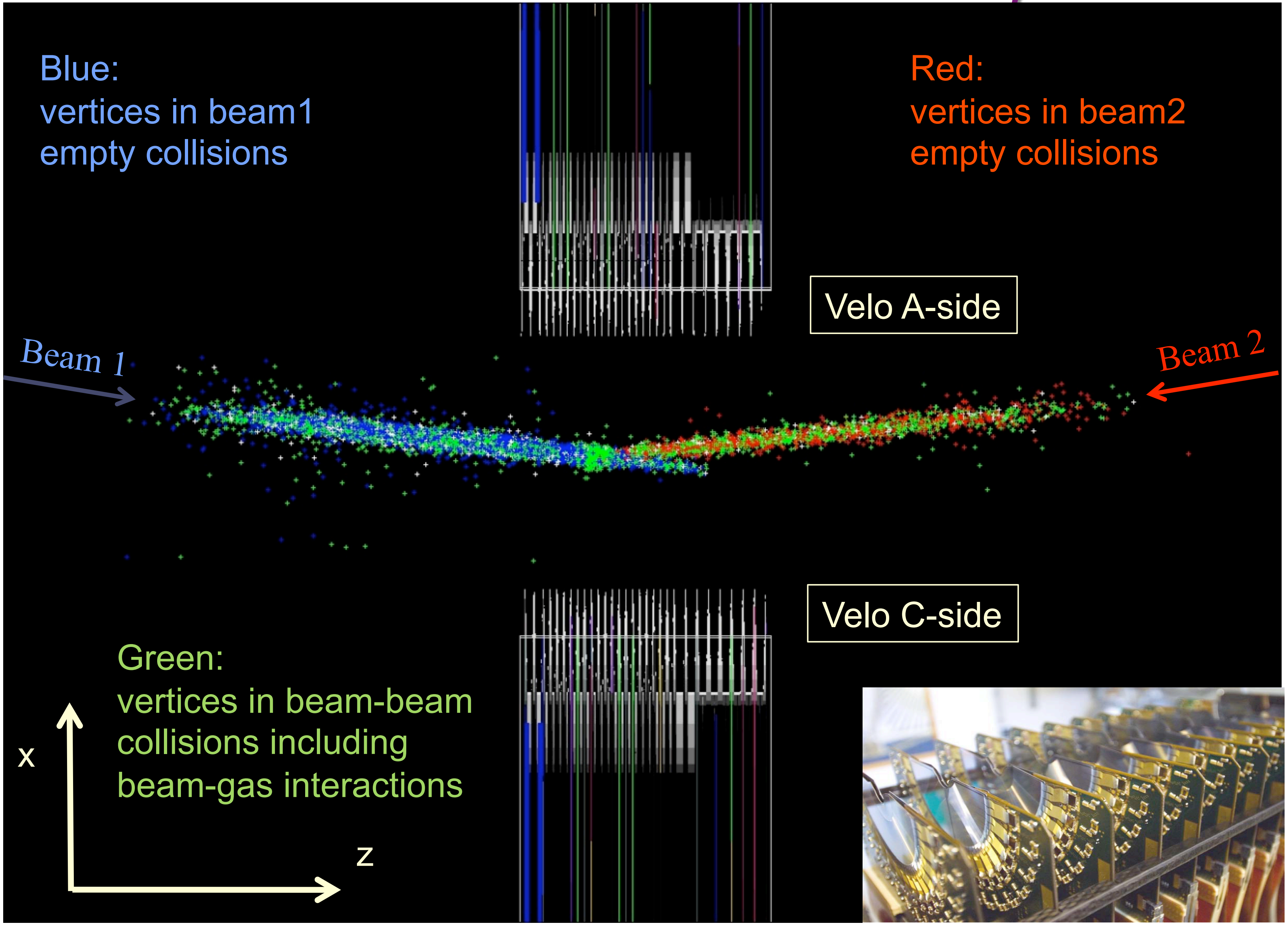




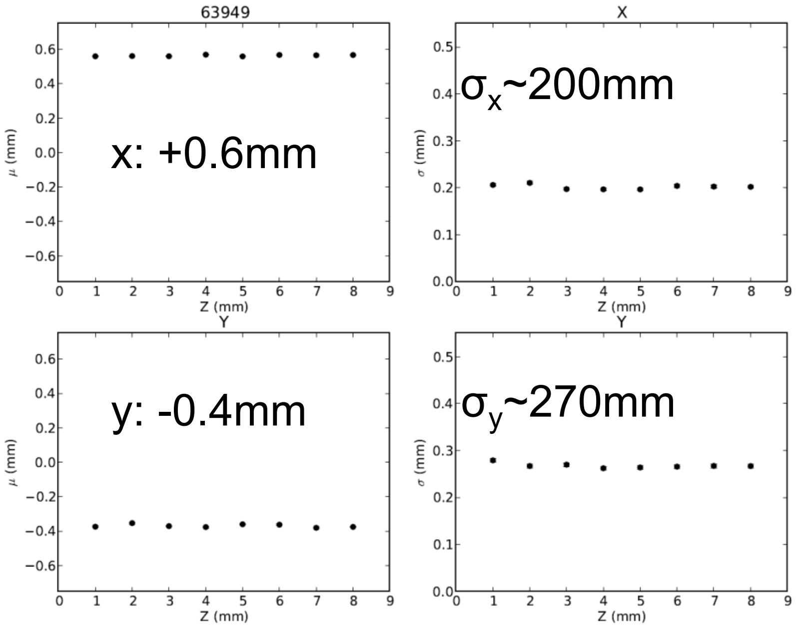
21 stations of Si wafer pairs with *r* and f strip readout



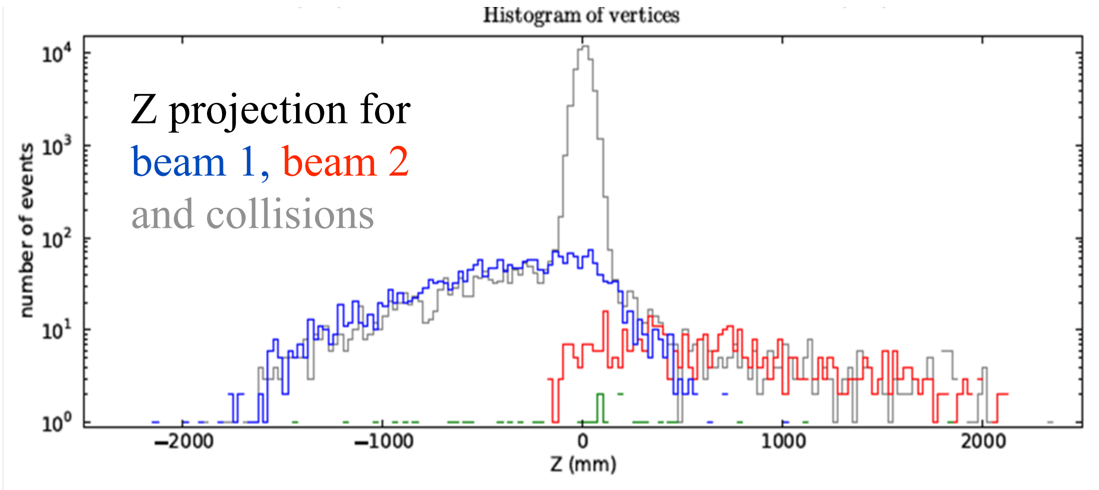
VELO 15mm from nominal closed position

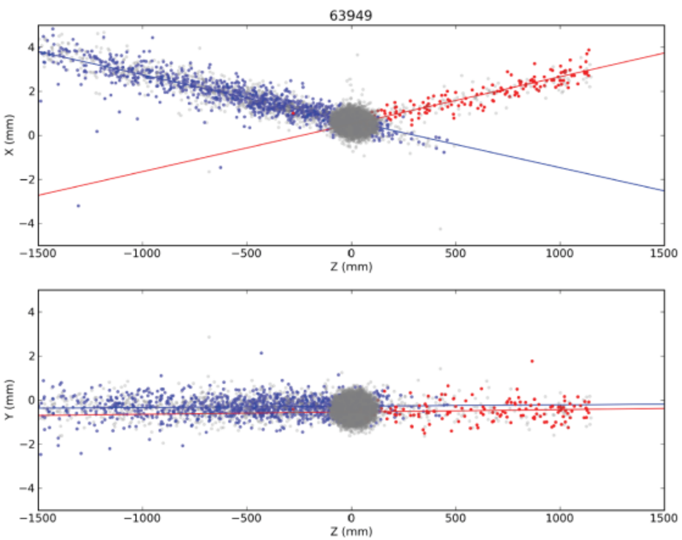


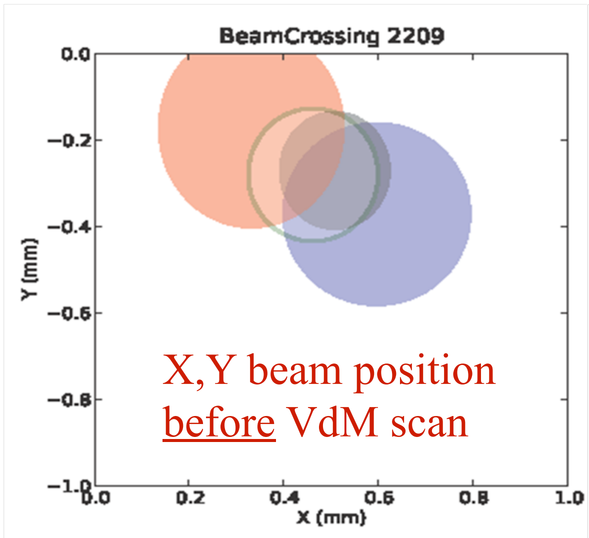
Vertex reconstruction of beam-gas and beam-beam

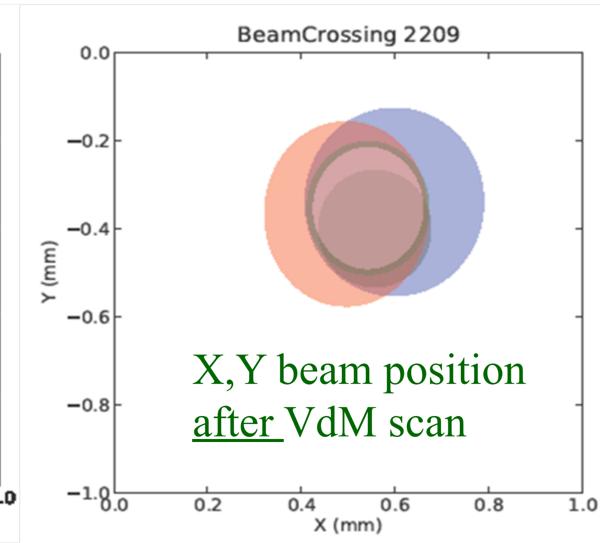


- Position and width for 8 bunches colliding in LHCb



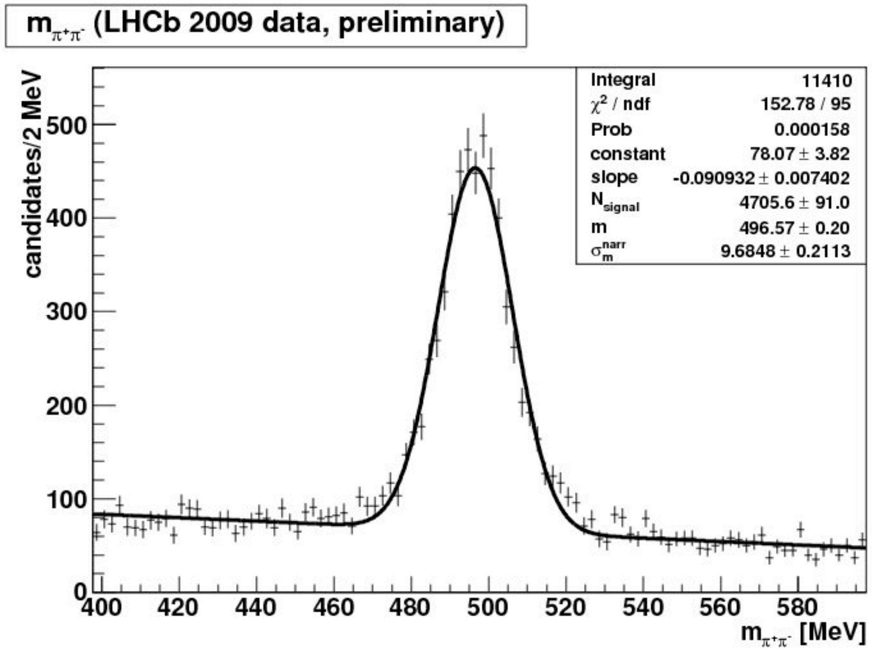


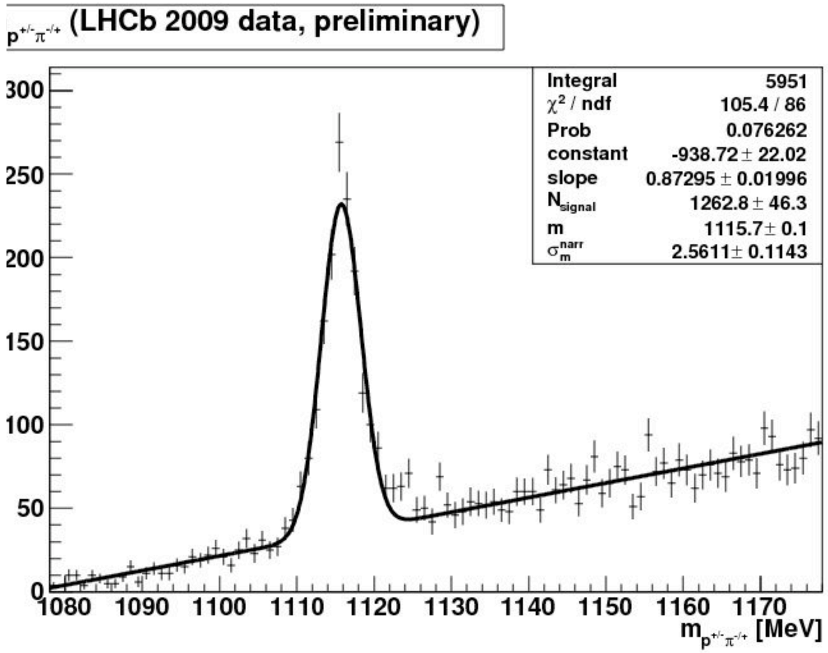




Reconstructed K_s and Λ masses

Tracking without VELO



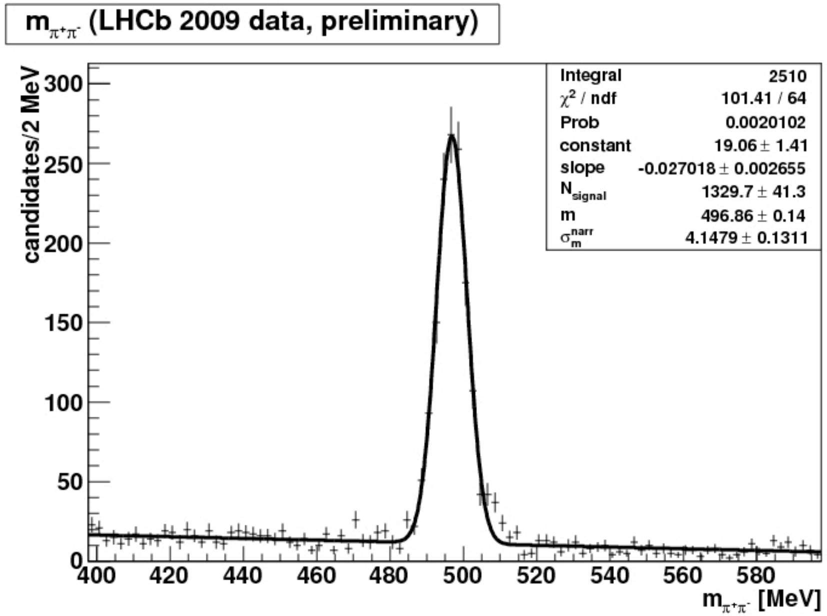


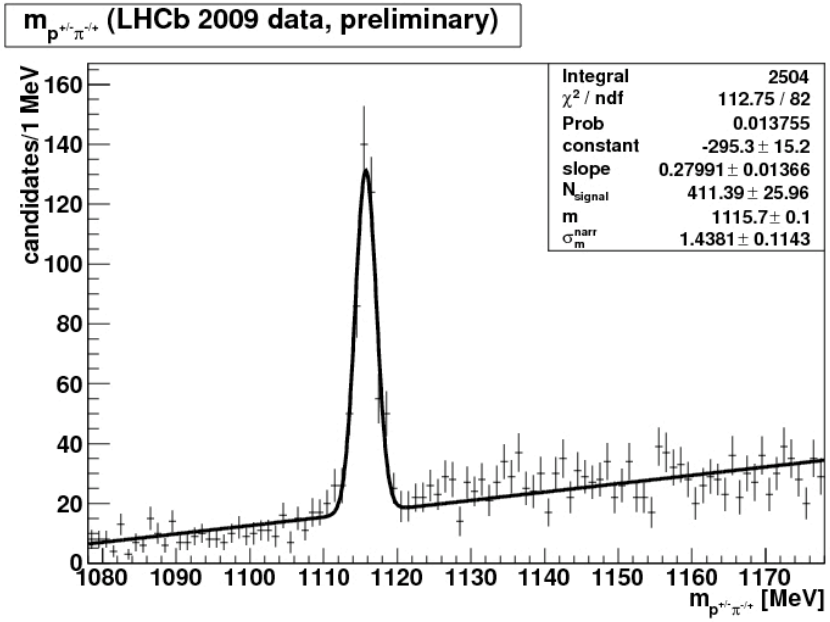
$m = (496.6 \pm 0.2_{stat.})$ MeV/c^2
$\sigma = (9.7 \pm 0.2_{stat})$ MeV/c^2
PDG: 497.61(2) MeV/c^2

$m = (1115.7 \pm 0.1_{stat.})$ MeV/c^2
$\sigma = (2.6 \pm 0.1_{stat})$ MeV/c^2
PDG: 1115.683(6) MeV/c^2

Reconstructed K_s and Λ masses

Using full tracking power, including VELO

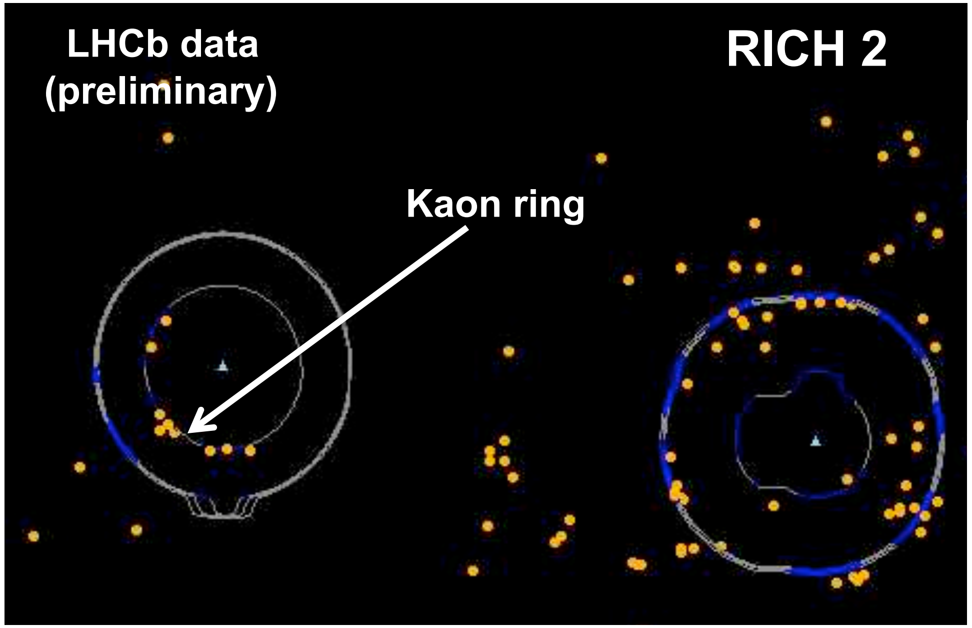




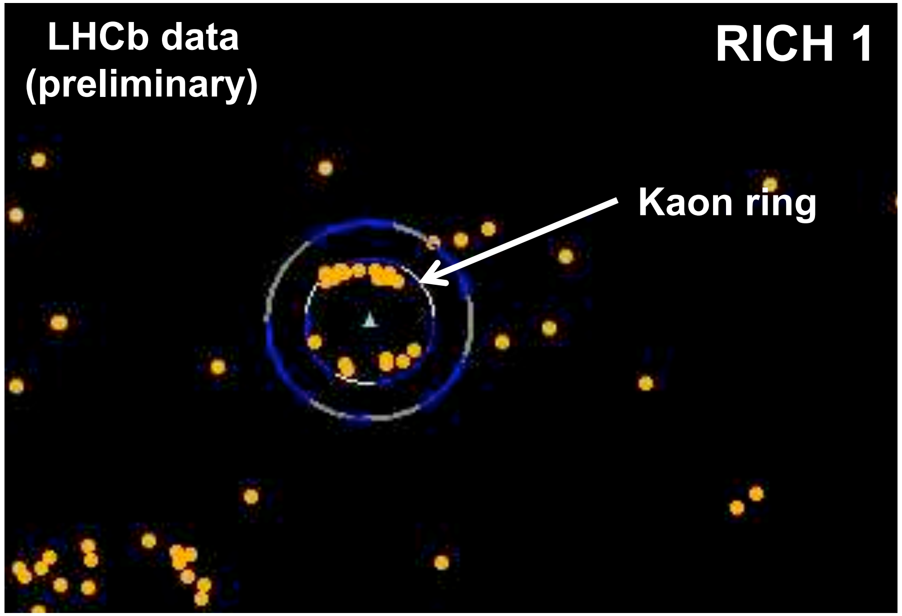
m = (496.9 ± 0.2$_{stat.}$) MeV/c^2
σ = (4.1 ± 0.1$_{stat}$) MeV/c^2
MC: (3.6 ± 0.2$_{stat}$) MeV/c^2
PDG: 497.61(2) MeV/c^2

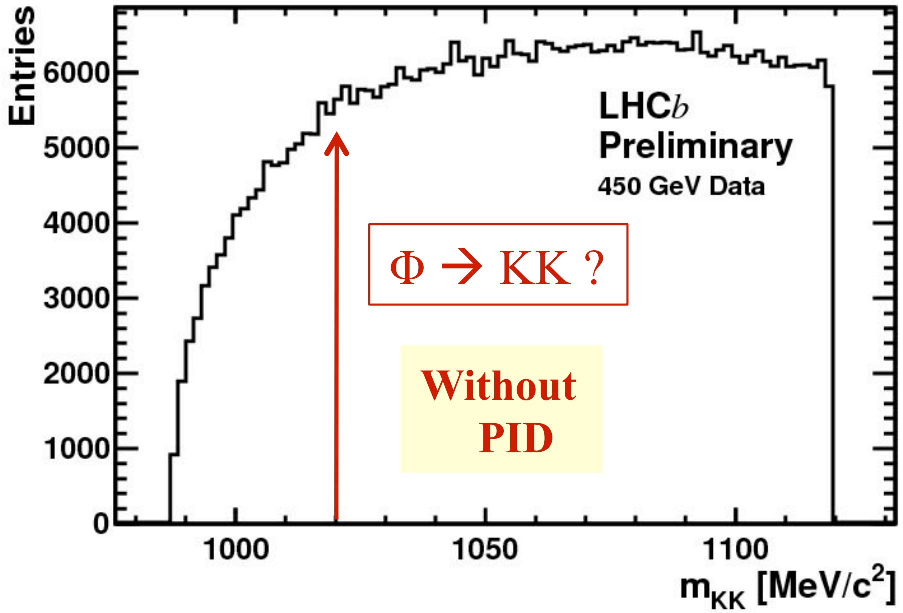
m = (1115.7 ± 0.1$_{stat.}$) MeV/c^2
σ = (1.4 ± 0.1$_{stat}$) MeV/c^2
MC: (1.2 ± 0.2$_{stat}$) MeV/c^2
PDG: 1115.683(6) MeV/c^2

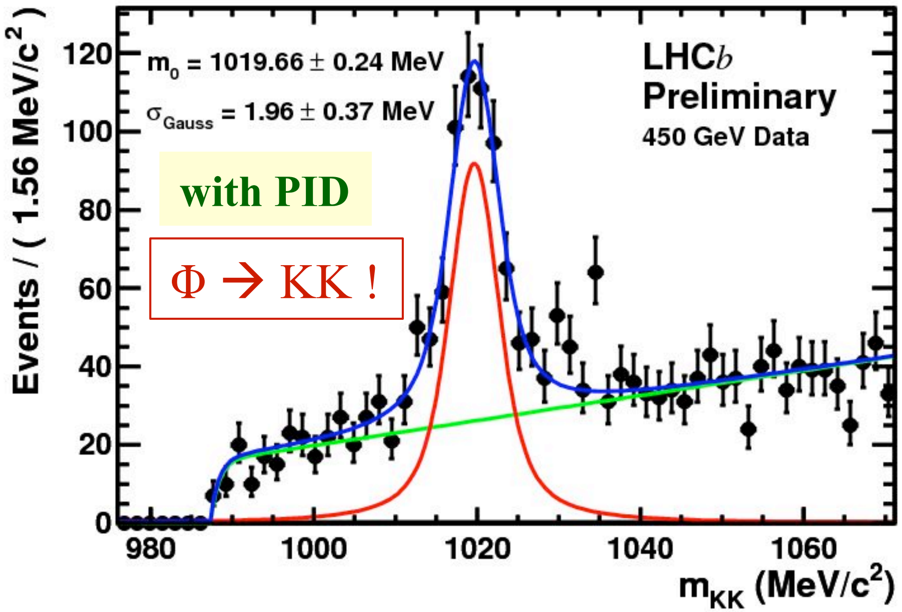
PID with RICH



- Orange points → photon hits
- Continuous lines → expected distribution for each particle hypothesis (proton below threshold)



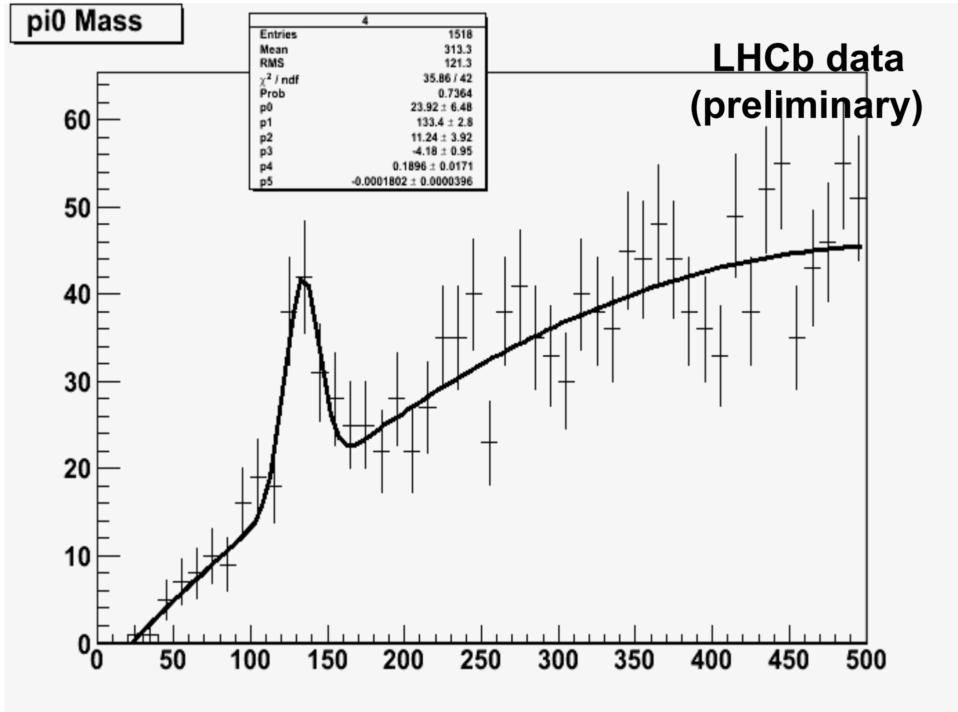




ECAL reconstructs π^0 signal

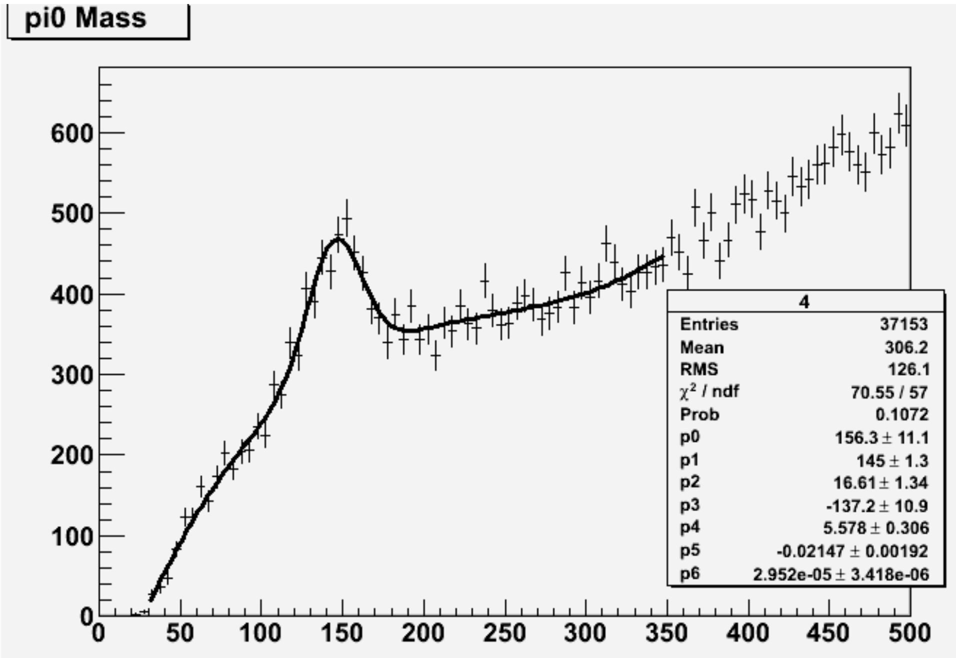
Very first data : 23 November 2009, No B-field

<m> = (133 ± 3) MeV/c²
(perfect agreement with the PDG value)
σ = (11 ± 4) MeV/c²



$M_{\gamma\gamma}$ (MeV/c²)

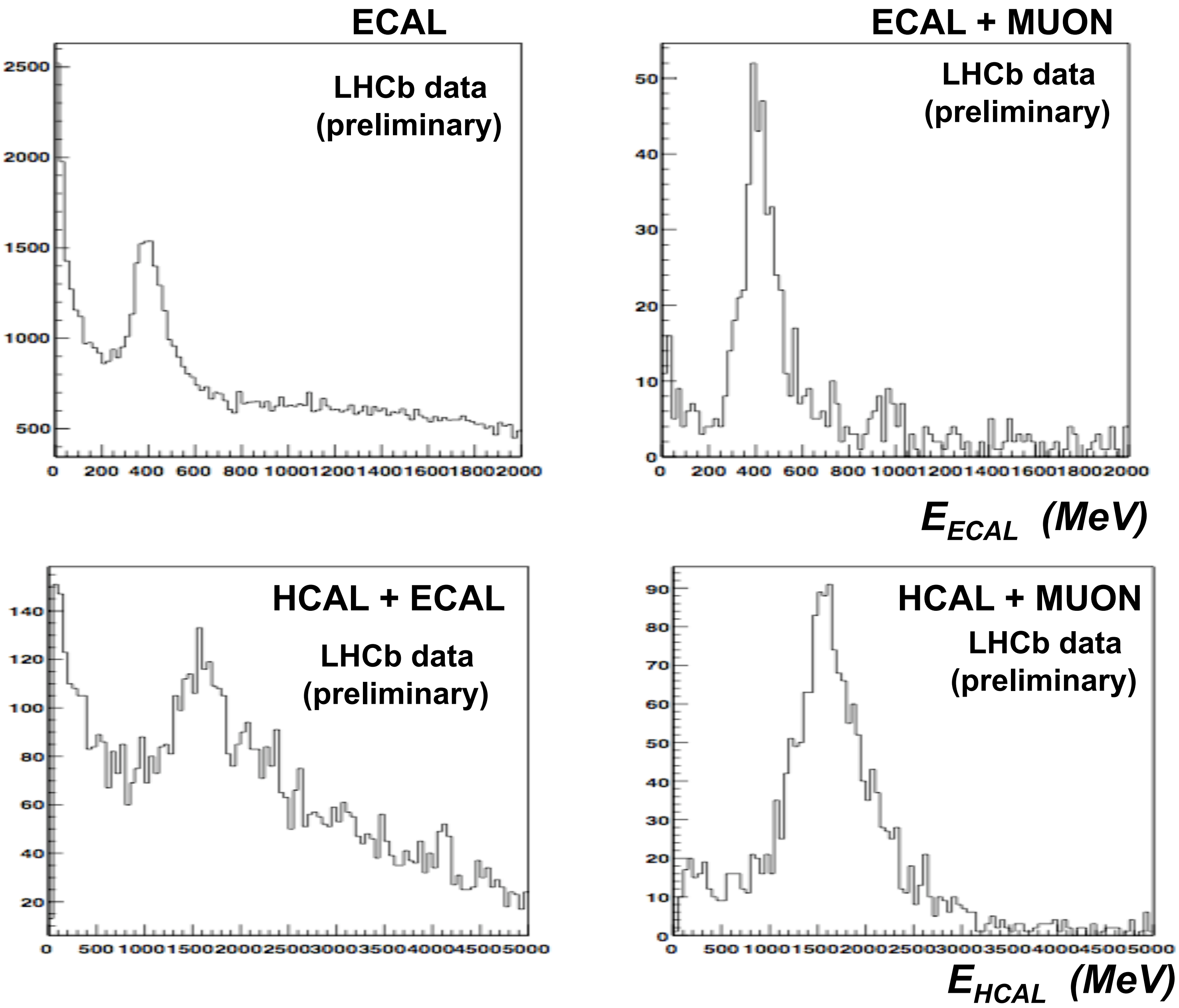
Now π^0 peak can be routinely monitored on-line:



$M_{\gamma\gamma}$ (MeV/c²)

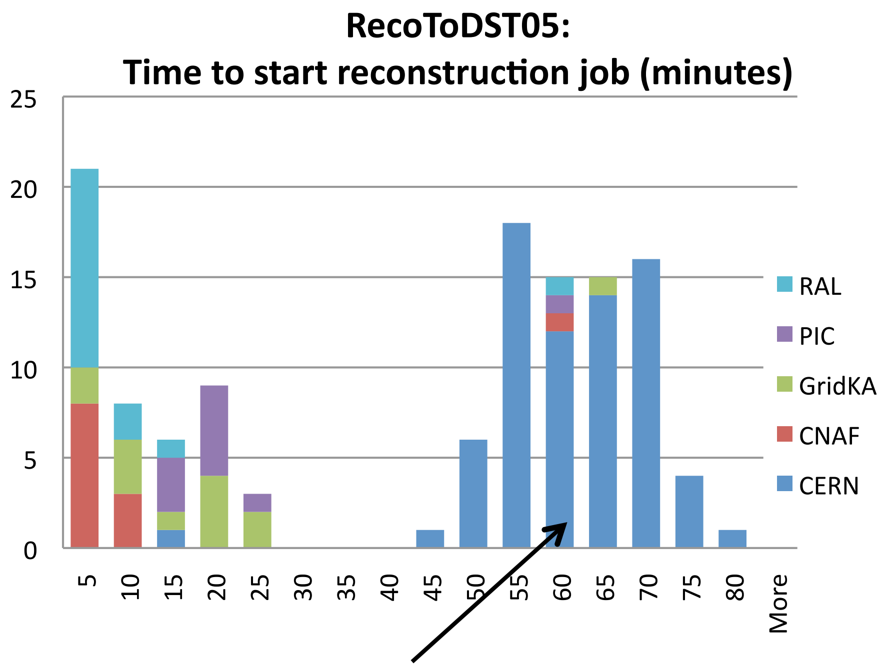
MIP identification using ECAL, HCAL & Muon

(MIP = Minimum Ionizing Particle)



Very Efficient Data Processing

- ***Two copies of raw data are made***
  - *One copy at CERN*
  - *One copy distributed over tier1 sites*
- ***Reconstruction automatically triggered by presence of new raw data file***
  - *DST typically available for physics analysis within one hour of file closed at the pit*
    - *Dominated by migration time to mass storage (longer wait for small files)*
    - *Reconstruction jobs last a few minutes (small files, low multiplicity events). Design is 24 hours*
- ***2 Reprocessings of full dataset***
  - *Completed on the grid in <2 hours*



CERN site busy with user analysis

Thanks to the team effort the LHCb detector works very well !
We are ready for the Long Physics Run in 2010