# The High Luminosity LHCb Upgrade

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# Introduction

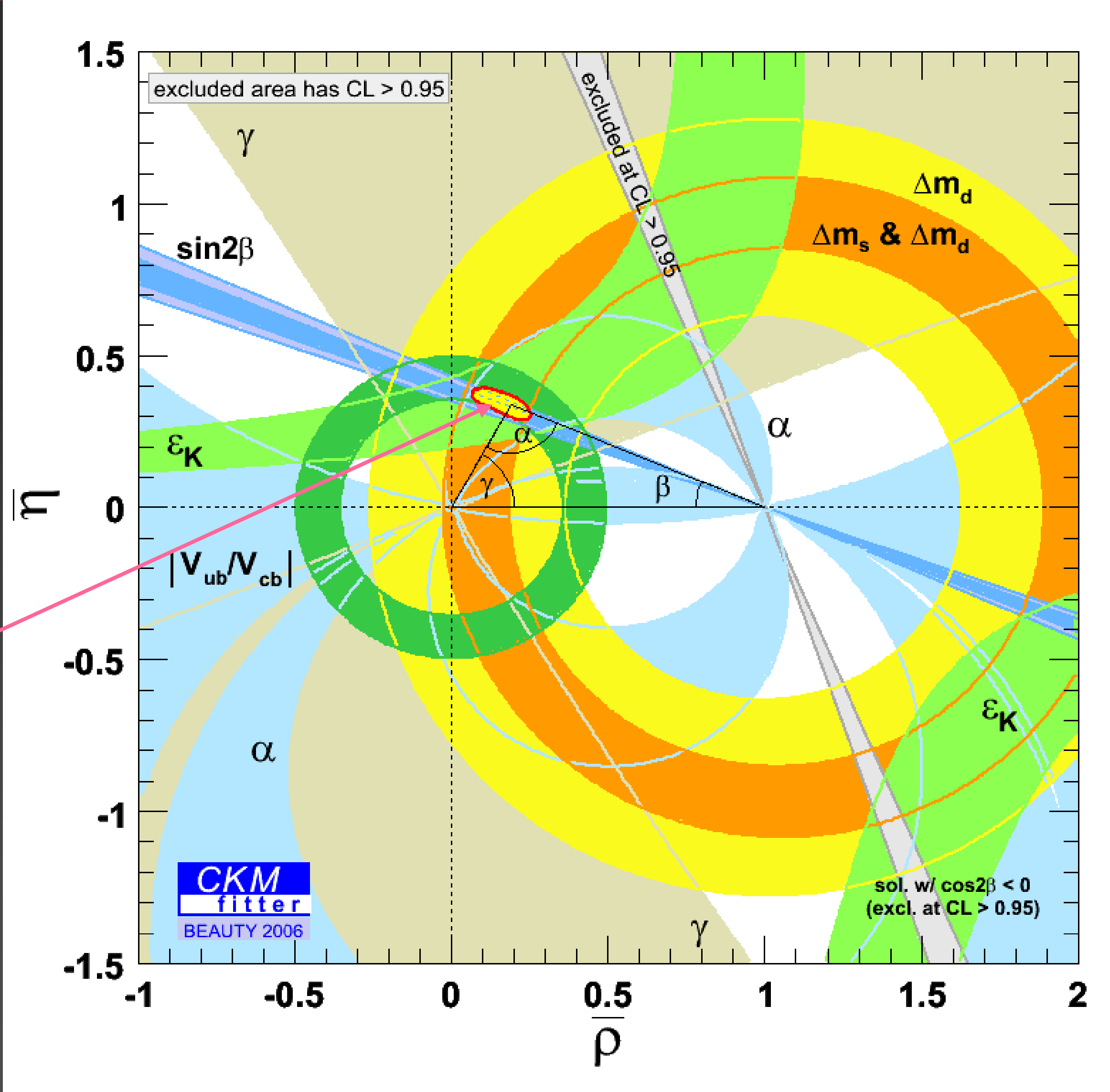
- Why are we talking about an LHCb upgrade?
- Answer: There is some insight that we will not have finished all useful b & c decay measurements
- In fact, why is the LHC considering a high luminosity upgrade before the machine is finished, and why are ATLAS & CMS already doing R&D for high $\mathcal{L}$ detector upgrades?

# General Physics Justification

- Expect New Physics will be seen at LHC
  - Standard Model is violated by the Baryon Asymmetry of Universe & by Dark Matter
  - Hierarchy problem (why $M_{Higgs} << M_{Planck}$)
- However, it will be difficult to characterize this physics
- How the new particles interfere virtually in the decays of b's (& c's) with W's & Z's can tell us a great deal about their nature

# Current Status of CP & Other Measurements

- SM CKM parameters are: A~0.8, $\lambda$=0.22, $\rho$ & $\eta$
- CKM Fitter results using CP violation in $J/\psi\ K_S$, $\rho^+\rho^-$, $DK^-$, $K_L$, & $V_{ub}/V_{cb}$ & $\Delta M_S$
- The overlap region includes CL>95%
- Similar situation using UTFIT
- Measurements "consistent"



# Consistency?

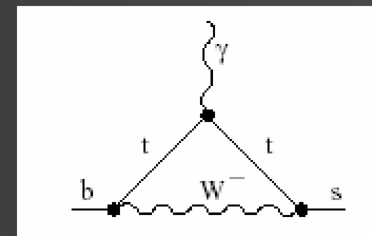
- It is often said that studies of b & c decays are all consistent with the Standard Model
  - Since all measurements are by their nature reflections of nature, i.e. SM + NP, what does this statement actually mean?
  - SM predictions are made using combinations of several measurements since there are 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

# Minimal Flavor Violation

- Def MFV: New physics has exactly the same CKM structure as SM
  - Thus no effects will be seen in CPV
  - An example of such a model is the Universal Extra Dimensions model of Appelquist, Cheng & Dobrescu
- However, effects WILL be seen in the modification of decay rates
- MFV is not so much a model as a declaration. Lets ignore this paradigm for now and look at two examples of B decay processes

# Rare Decay Example: $b \to s\gamma$

- Experiment:
  $\mathcal{B}(b \to s\gamma) = (3.55 \pm 0.26) \times 10^{-4}$

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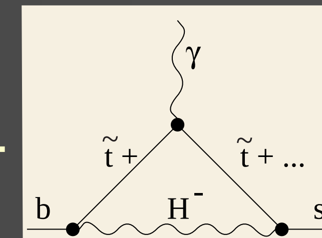
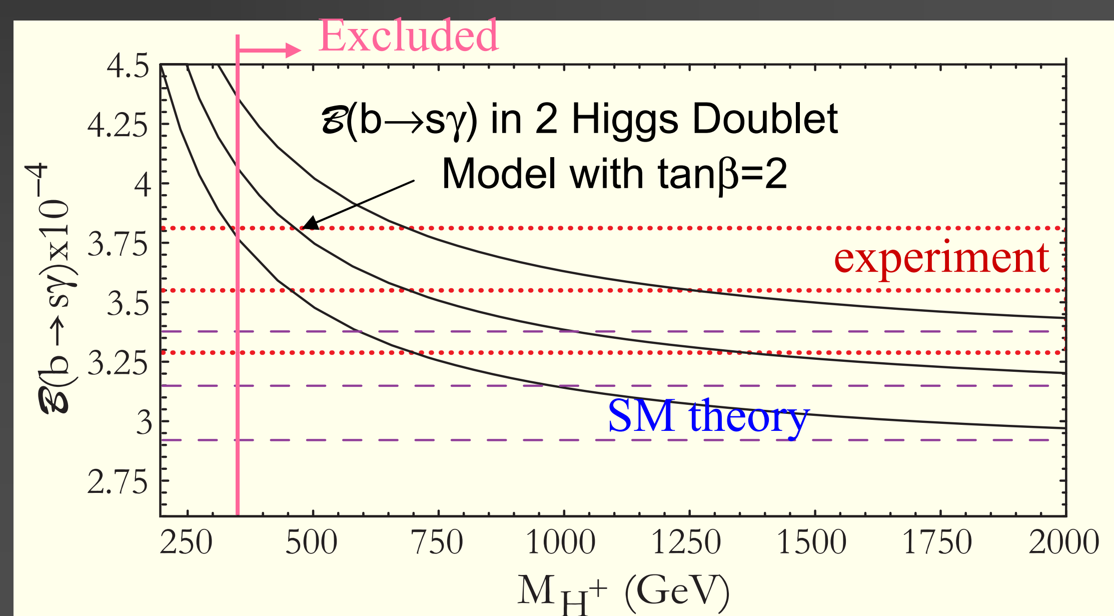



- Theory (Misiak et. al hep-ph/0609232):
  $\mathcal{B}(b \to s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$
- Limit on $H^+$ mass >295 GeV at 95% CL for $\tan\beta >\sim 2$

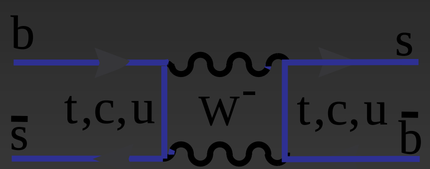
(plot shows central Values & $\pm 1\sigma$ bands)

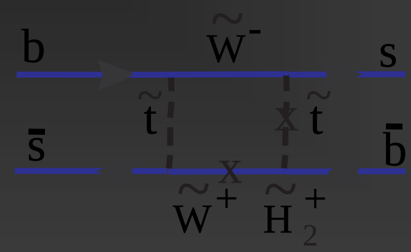
- By far best limit from any source



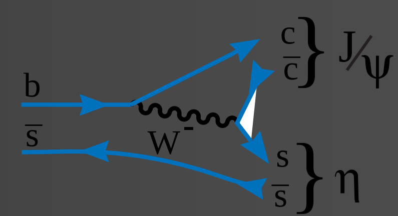
# Another Example

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



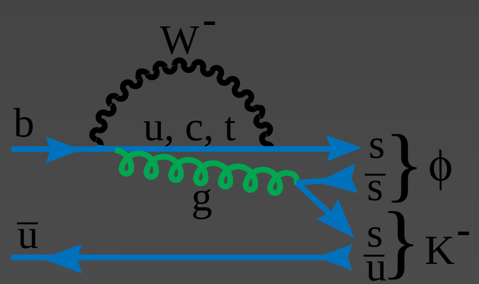

$B_s \to J/\psi\eta$ or $\phi$

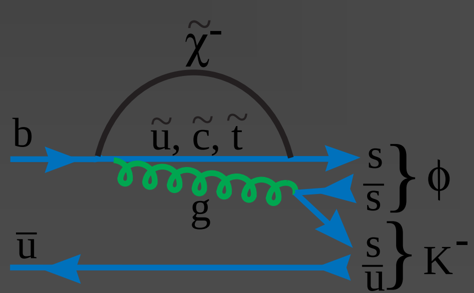



CP asymmetry $\approx 0.1\sin\phi_\mu \cos\phi_A \sin(\Delta m_s t)$, ~10 x SM

- Contributions to direct CP violating decay

$B^- \to \phi K^-$



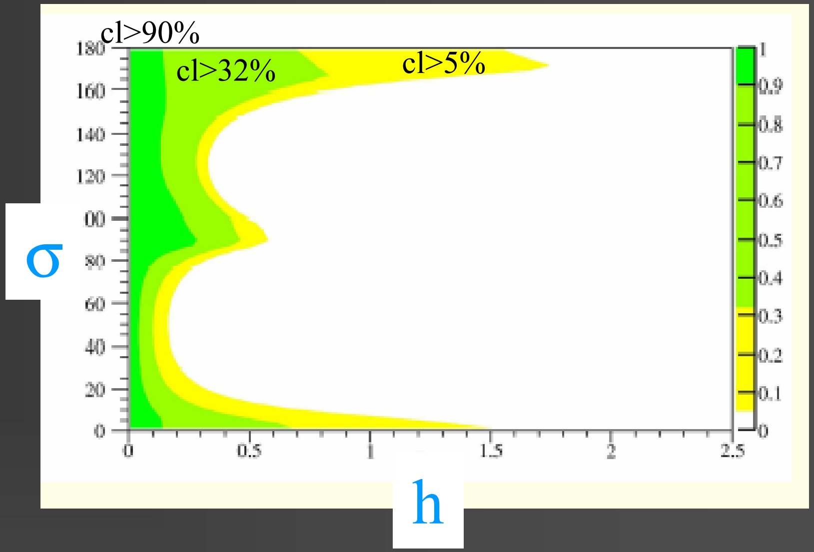




$\text{Asym} = (M_W/m_{squark})^2 \sin(\phi_\mu)$, ~0 in SM

# Limits on New Physics From B$^o$

- Is there NP in B$^o$-$\bar{B}^o$ mixing?
- Assume NP in tree decays is negligible
- $$1+he^{i\sigma}=\frac{\langle B^o|H^{full}|\bar{B}^o\rangle}{\langle B^o|H^{SM}|\bar{B}^o\rangle}$$
- Use $V_{ub}$, $A_{DK}$, $S_{\psi K}$, $S_{\rho\rho}$, $\Delta m_d$, $A_{SL}$
- Fit to $\eta$, $\rho$, h, $\sigma$

"Next to minimum flavor violation"

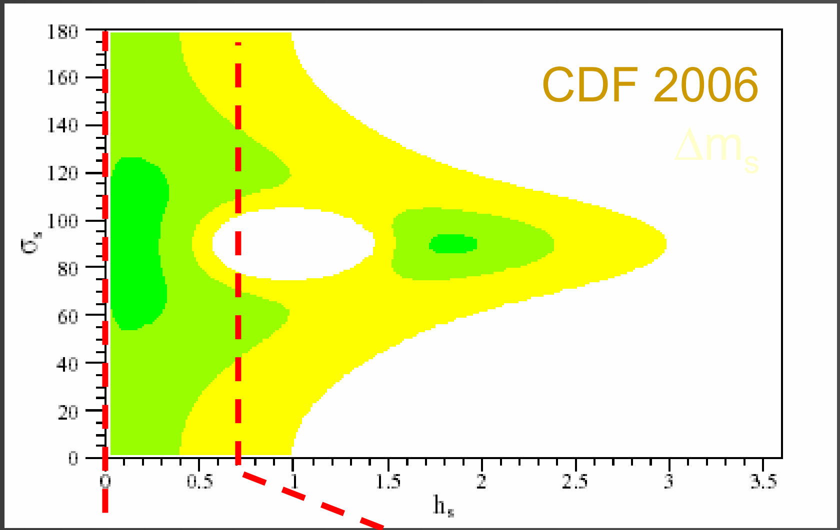



Agahse, Papucci, Perzez, Pirjol hep-ph/0509117

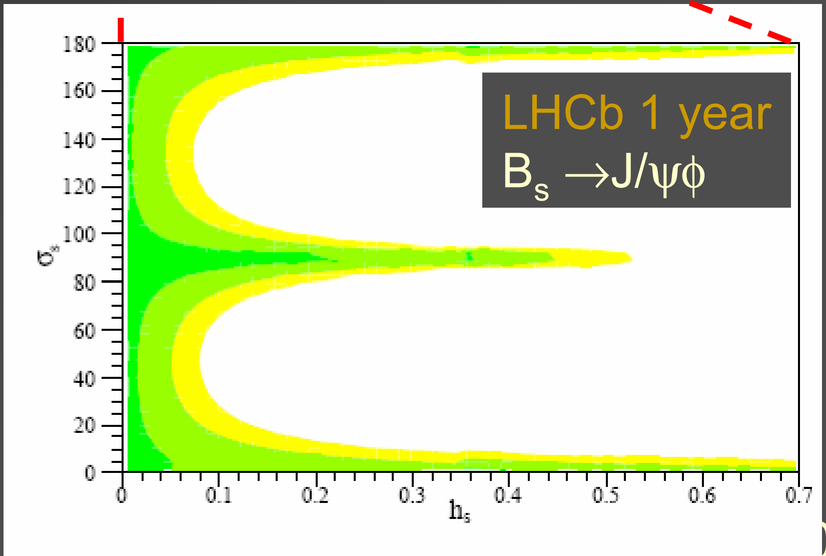
- For New Physics via $B_d^o$ mixing, h is limited to ~<0.3 of SM except when $\sigma_{Bd}$ is ~0$^o$ or ~180$^o$ of SM decays

# Limits on New Physics From $B_s$

- Similar study for $B_s$ decays including $\Delta M_s$ measurement from CDF
- Limits much weaker since phase in $B_s$ mixing ($\phi_s$) is yet to be measured




Ligeti, Paucci & Perez, hep-ph/0604112



# 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

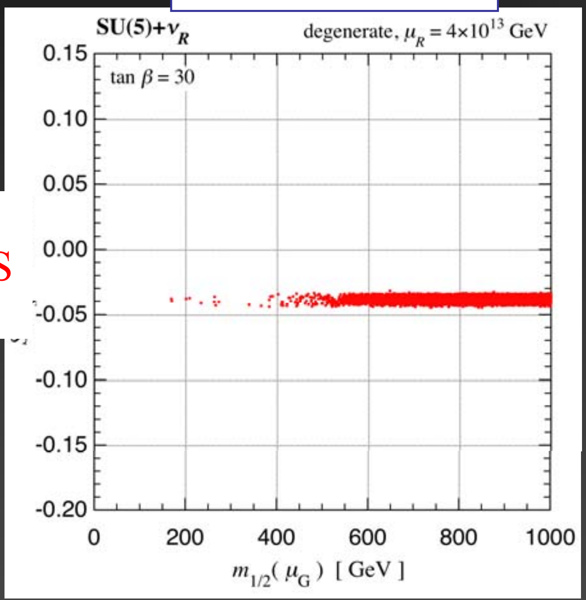
# Supersymmetry

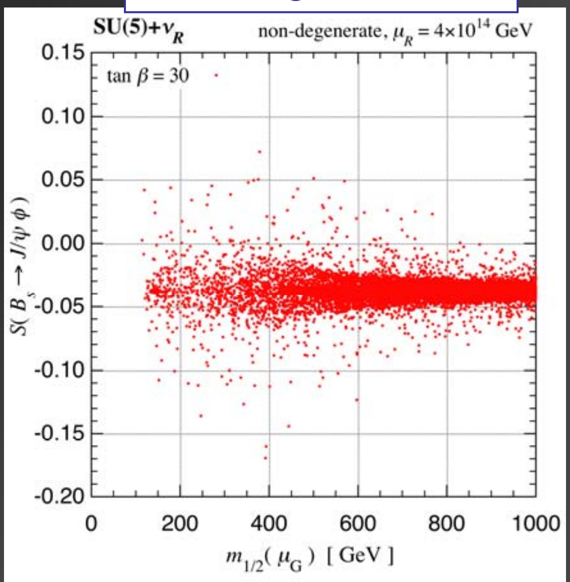
SU(5) GUT
Degenerate

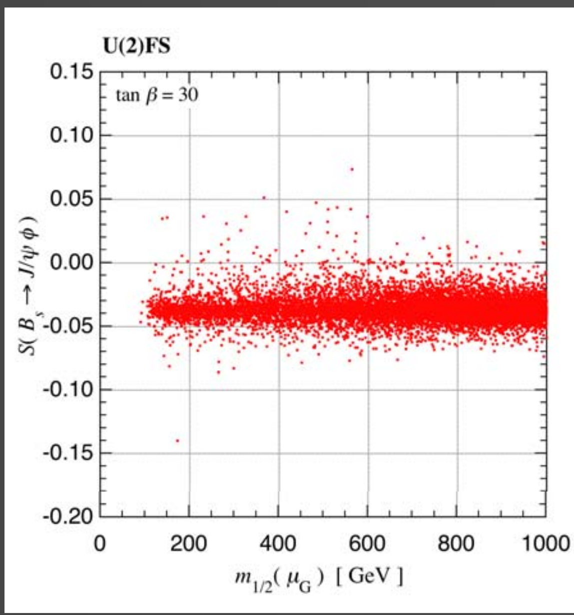
SU(5) GUT
Non-degenerate

U(2) FS

$\phi_S$




- $\phi_S$ can deviate from the SM by 5-10% for SU(5) GUT with non-degenerate case and the U(2) model. From Okada talk at BNMII, Nara Women's Univ. Dec., 2006

# Okada Models Summary

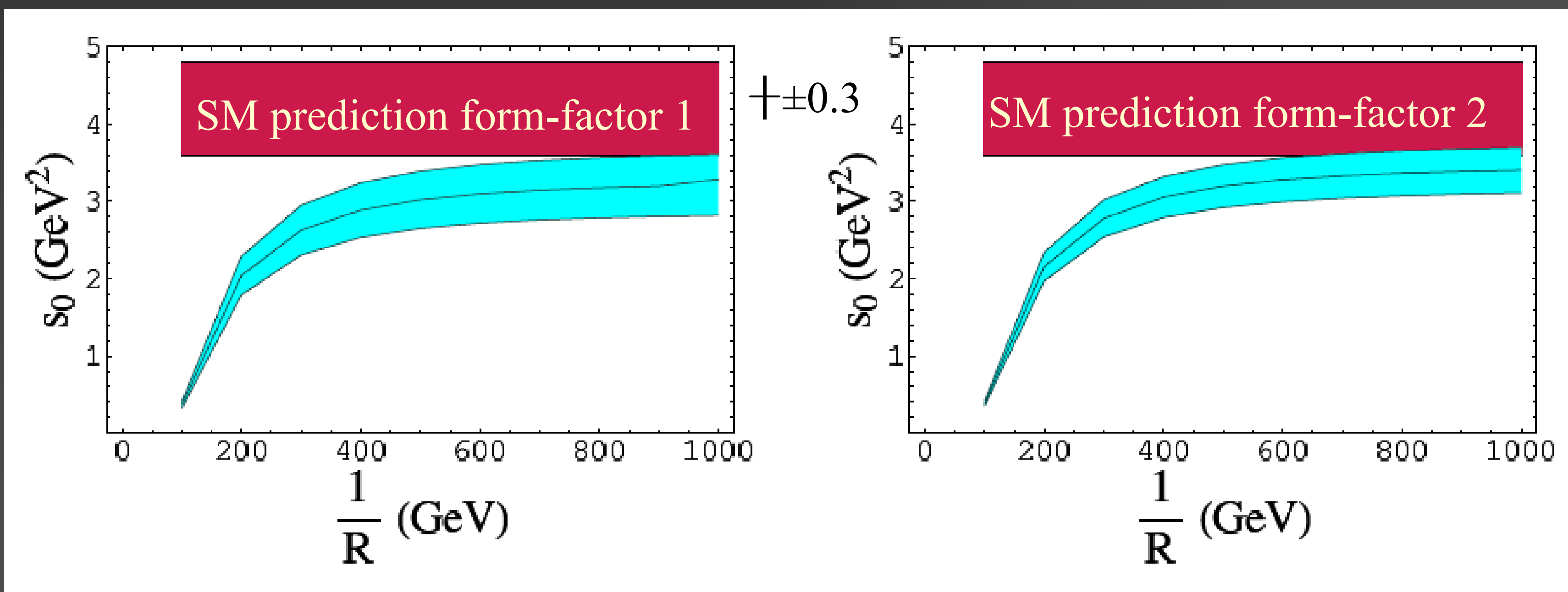
## Possible deviations from the SM prediction

| | $B_d$ - unitarity Triangle test | T-dep CPV in $B \to \phi K_s$, $B \to K^*\gamma$ | $b \to s\gamma$ direct CP | T-dep CPV in $B_S \to J/\psi\phi$ | LFV |
|---|---|---|---|---|---|
| mSUGRA | - | - | - | - | - |
| SU(5)SUSY GUT + $\nu R$ (degenerate) | — | — | — | — | $\mu \to e\gamma$ |
| SU(5)SUSY GUT + $\nu R$ (non-degenerate) | — | <O(10%) | — | <~5% | $\mu \to e\gamma$ $\tau \to \mu\gamma$ |
| U(2) Flavor symmetry | < a few % | <O(10%) | < a few % | <~5% | $\mu \to e\gamma$ $\tau \to \mu\gamma$ |

# 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 calculations improve?*

LHCb measures zero to ±0.3 $GeV^2$ in 10 $fb^{-1}$

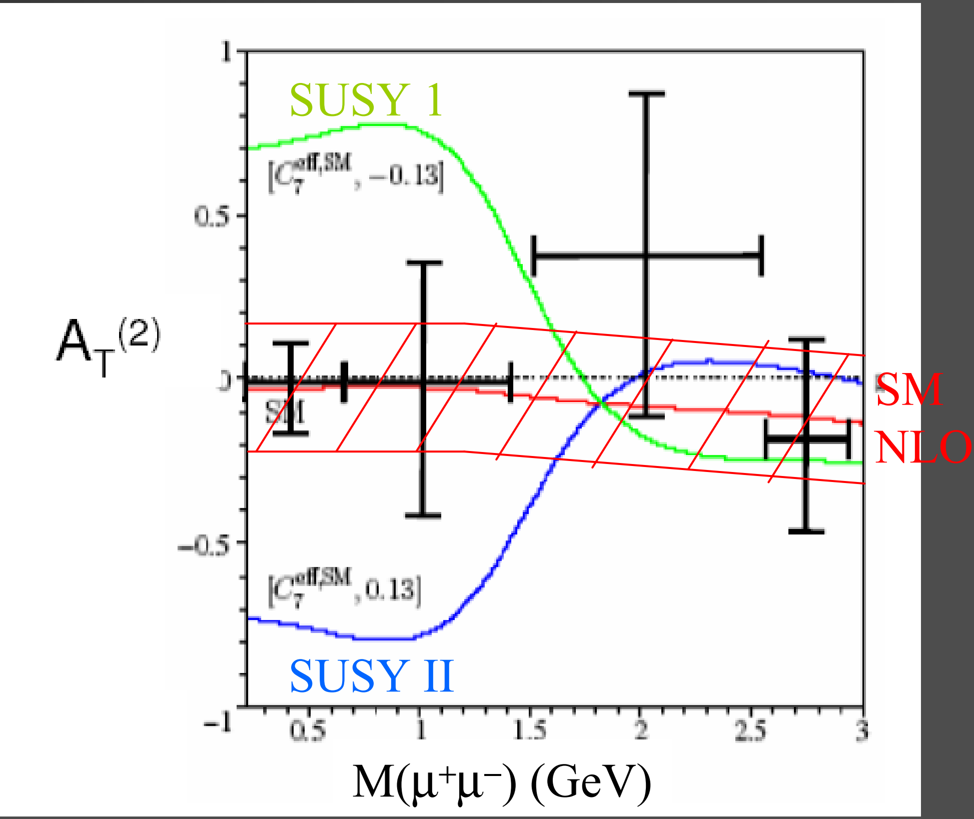


# Other Angular Variables in $K^*\mu^+\mu^-$

- Right handed currents in Supersymmetry (Lunghi & Matias hep-ph/0612166)
- Use transverse polarization

$$A_T^{(2)}(s) = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}$$

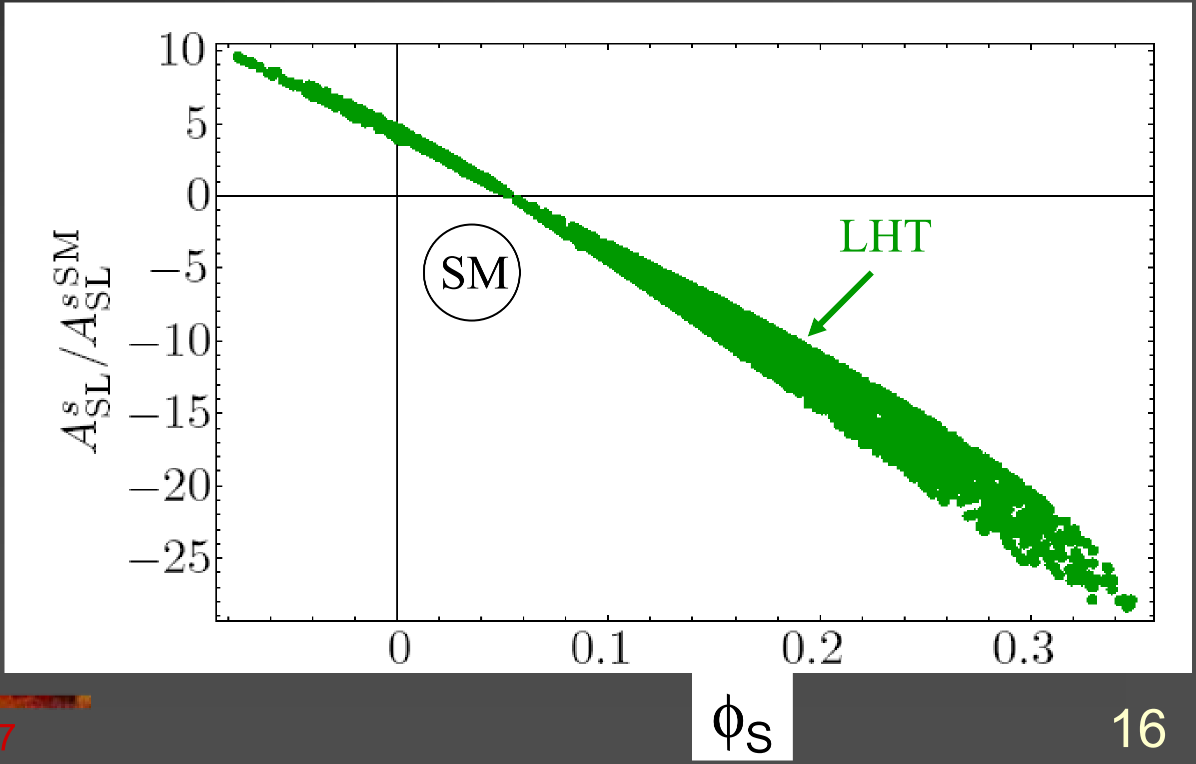
- LHCb simulation for 2 $fb^{-1}$ looks promising



# Little Higgs Model with T Parity

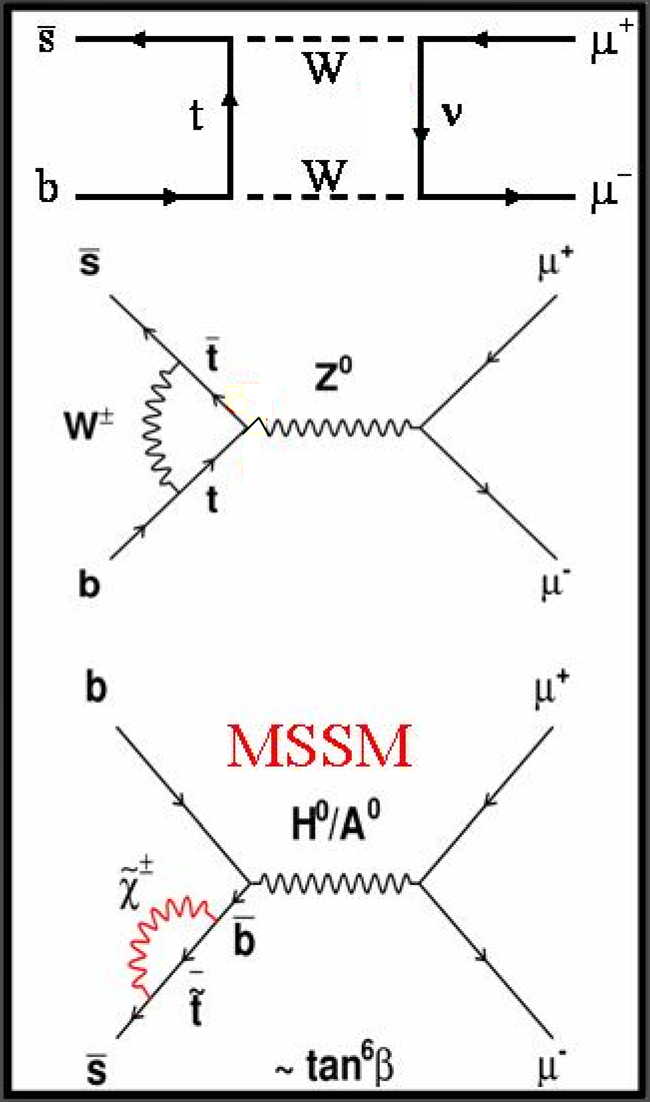
- There exist regions of parameter space consistent with measurement where large $\phi_S$ is predicted & $\Delta M_S$ is found somewhat smaller than in the SM.
- In particular, significant enhancement of $\phi_S$ & the semileptonic asymmetry $A_{SL}^{(S)}$ relative to the SM are found

•From Blanke & Buras, [hep-ph/0703117]

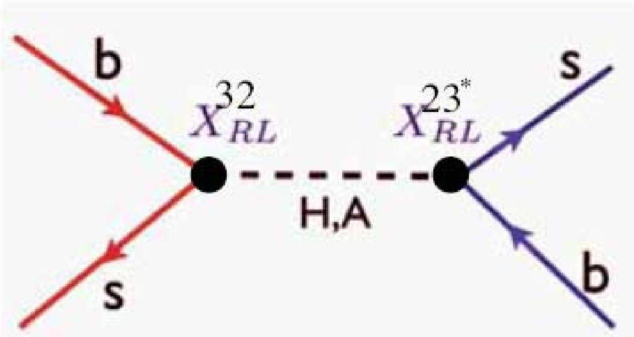


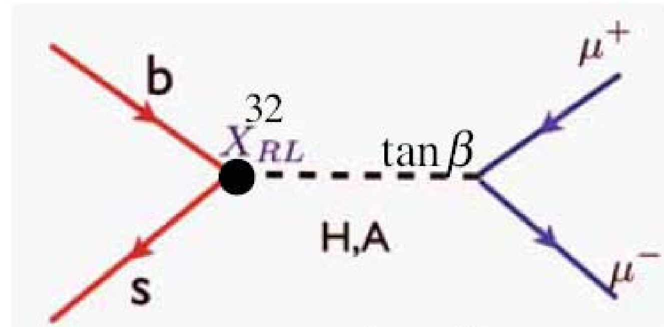
# $B_s \to \mu^+\mu^-$ & Supersymmetry

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



# Correlations Between $\Delta M_S$ & $B_S \to \mu^+\mu^-$




$$(\Delta M_{B_s})^{SUSY} \propto \ominus \frac{X_{RL}^{32} X_{LR}^{32}}{m_A^2}$$

Negative sign with respect to SM

$$BR(B_s \to \mu^+\mu^-)^{SUSY} \propto \frac{|X_{RL}^{32}|^2 \tan\beta^2}{m_A^4} \propto \frac{|\mu A_t|^2 \tan\beta^6}{m_A^4}$$

with $$(X_{RL}^{H/A})^{ji} \approx -\frac{\bar{m}_{d_j} h_t^2 \varepsilon_Y x_{\phi_1}^{H/A} \tan\beta^2}{v(1+\varepsilon_0^j \tan\beta)(1+\Delta_b)} V_{CKM}^{3j*} V_{CKM}^{3i} \Longrightarrow \frac{\Delta M_{B_s}}{BR(B_s \to \mu^+\mu^-)} \propto \frac{m_A^2}{\tan\beta^2}$$

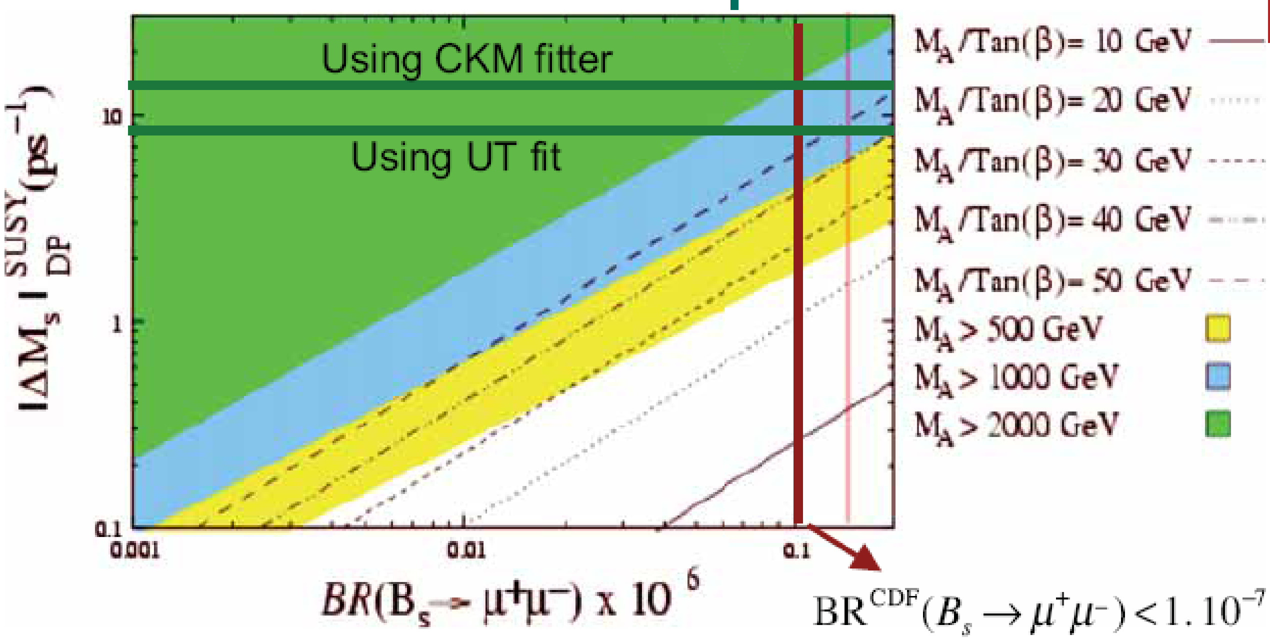
- In MSSM, SUSY contributions strongly correlated; from M. Carena (Moriond 2007).

# How Strong is the Bound on $\mathcal{B}(B_S \to \mu^+\mu^-)$?

Upper bound on NP from CDF ==> $\Delta M_s = 17.7 \pm 0.10 \pm 0.07\, ps^{-1}$

$\Delta M_S^{CKM} = 18.9^{+12.2}_{-5.5}\, ps^{-1}$

$\Delta M_S^{UT} = 20.9 \pm 5.2\, ps^{-1}$




$BR^{CDF}(B_s \to \mu^+\mu^-) < 1.10^{-7}$

D0 <0.93x10$^{-7}$

M. C., Menon, Papaqui, Zsynkman, Wagner 06

$BR(B_s \to \mu^+\mu^-)_{SM}$ of order $10^{-9}$

↓

at the reach of LHC with about 10fb$^{-1}$

↓

SUSY corrections can enhance it by 2 orders of magnitude.

For natural values of $m_A$< 1000 GeV ==> largest contributions at most a few ps-1

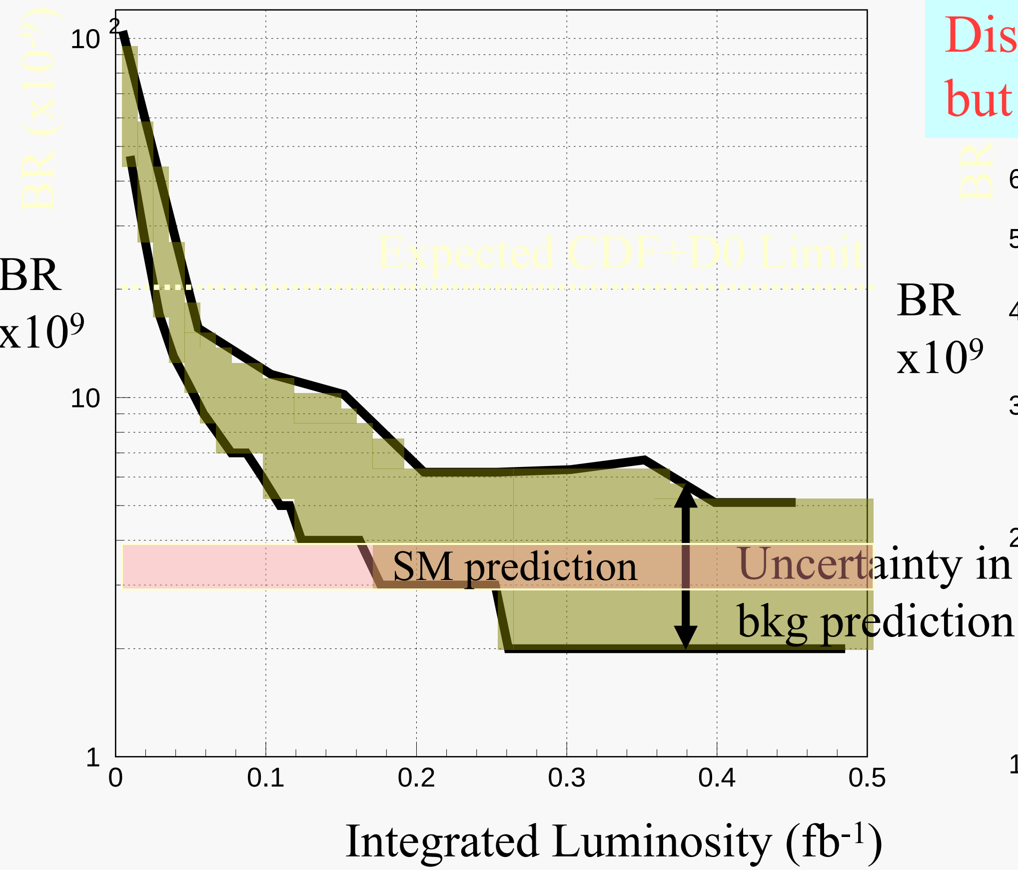
↕

A/H at the reach of the Tevatron or the LHC <==> strong constraints on $|\Delta M_S|^{SUSY}_{DP}$

# Precision Measurement of $\mathcal{B}(B_s \to \mu^+\mu^-)$

## Limit at 90% C.L.

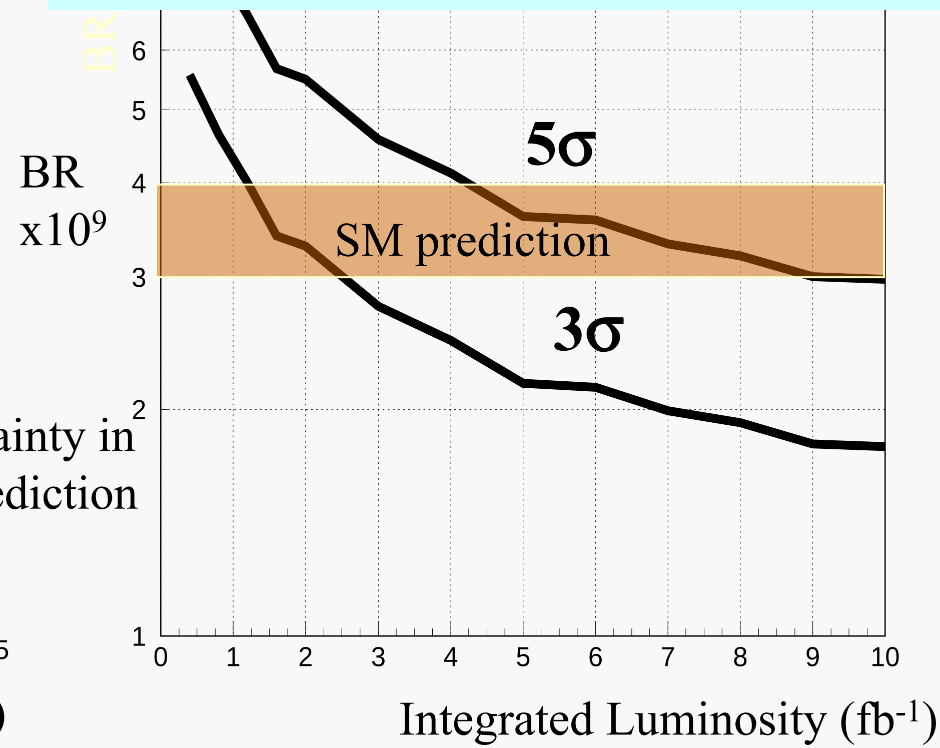
**(only bkg is observed)**




## LHCb Sensitivity

**(signal+bkg is observed)**

Discovery by LHCb expected in 10 $fb^{-1}$, but 100 $fb^{-1}$ needed for precise measurement



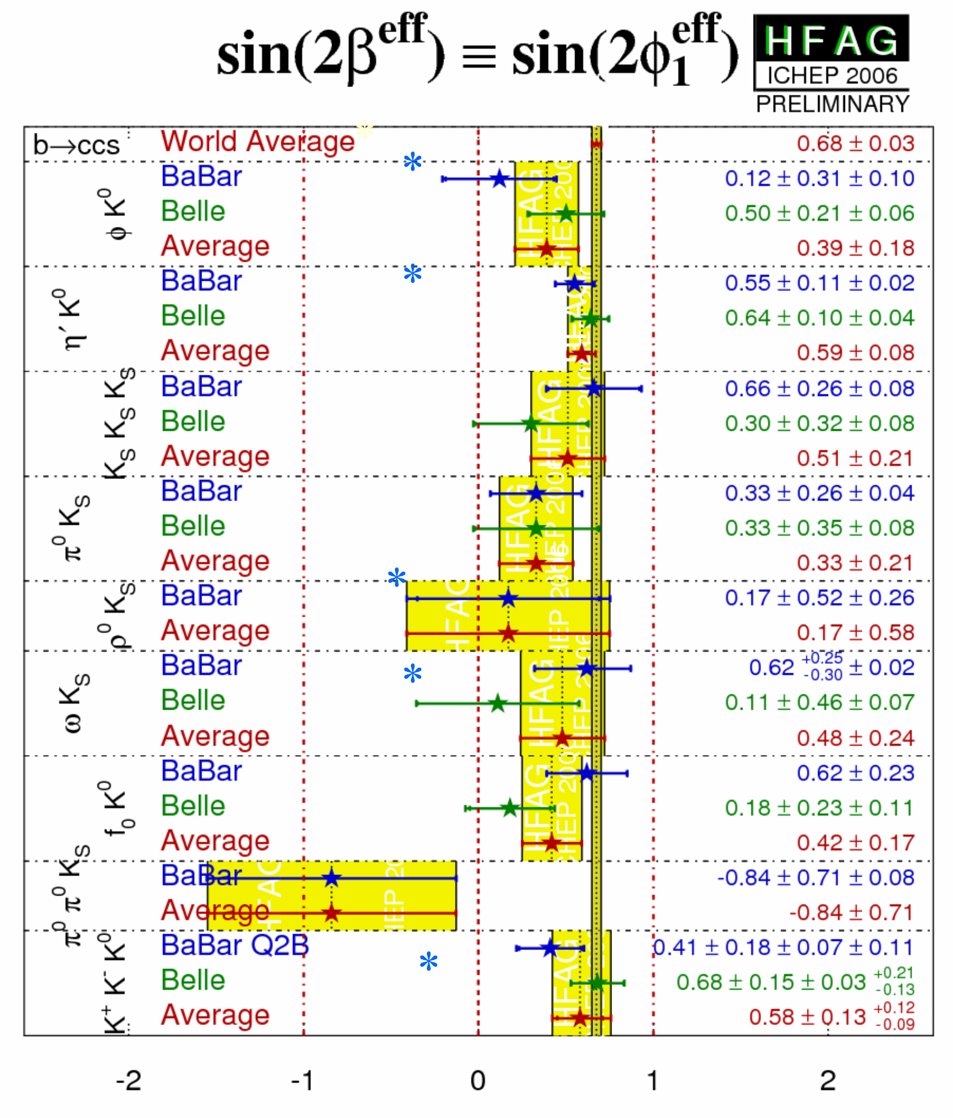

***Background is dominated by combinations of $b \to \mu^- X$ $b \to \mu^+ X$ events.***

# Most Currently Desirable Modes

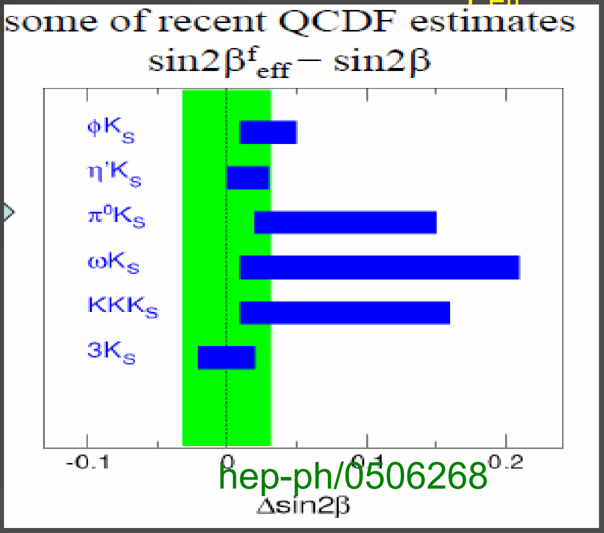
- $B_{(s)} \to \mu^+\mu^-$
- High Statistics Measurement of forward-backward asymmetry in $B \to K^*\mu^+\mu^-$
- Precision measurements of CP ∠'s
  - CP violating phase in $B_s$ mixing using $B_s \to J/\psi\phi$
  - $\gamma$ (or $\phi_3$) Using $B^- \to D^o K^-$ tree level decays
  - $\gamma$ using $B_s \to D_s^+ K^-$ time dependent analysis
  - $\alpha$ especially measurement of $B^o \to \rho\pi$ & $B^o \to \rho^o\rho^o$
  - $\beta$ at high accuracy to pin down other physics
- CPV in various rare decay modes including $M\gamma$, $\Lambda\gamma$
- $B_s \to \phi\phi$
- Important: Other modes, not currently in vogue

# One Big Hint: Penguins

*LHCb can measure $B_S \to \phi\phi$ & compare with $J/\psi\phi$*




- **Compare sin2β measurements**
  - in $B_d \to \phi K_S$ with $B_d \to J/\psi K_S$
  - Individually, each decay mode in reasonable agreement with SM
  - But all measurements lower than sin2β from $J/\psi K_S$
- **Naïve b → s penguin average**
  - $\sin 2\beta_{eff} = 0.52 \pm 0.05$
  - 2.6 σ discrepancy from SM
- **Theory models**
  - Predict to increase $\sin 2\beta_{eff}$ in SM




* LHCb accessible

# Detector Requirements - General

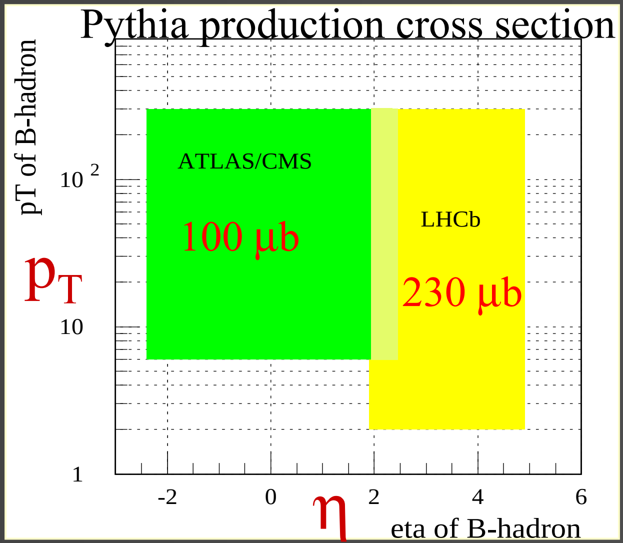
- Every modern heavy quark experiment needs:
  - Vertexing: to measure decay points and reduce backgrounds, especially at hadron colliders
  - Particle Identification: to eliminate insidious backgrounds from one mode to another where kinematical separation is not sufficient
  - Muon & electron identification because of the importance of semileptonic & leptonic final states including $J/\psi$ decay
  - $\gamma$, $\pi^o$ & $\eta$ detection
  - Triggering, especially at hadronic colliders
  - High speed DAQ coupled to large computing for data processing
  - An accelerator capable of producing a large rate of b & anti-b hadrons in the detector solid angle

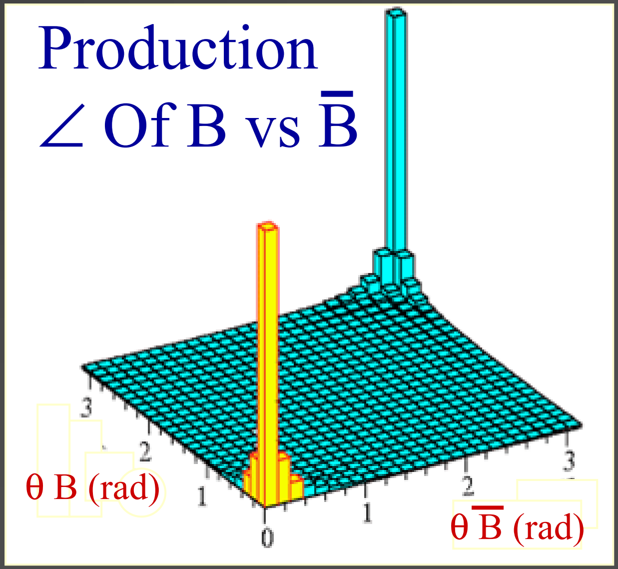
# Basics For Sensitivities

- # of b's into detector acceptance
- Triggering
- Flavor tagging
- Background reduction
  - Good mass resolution
  - Good decay time resolution
  - Particle Identification

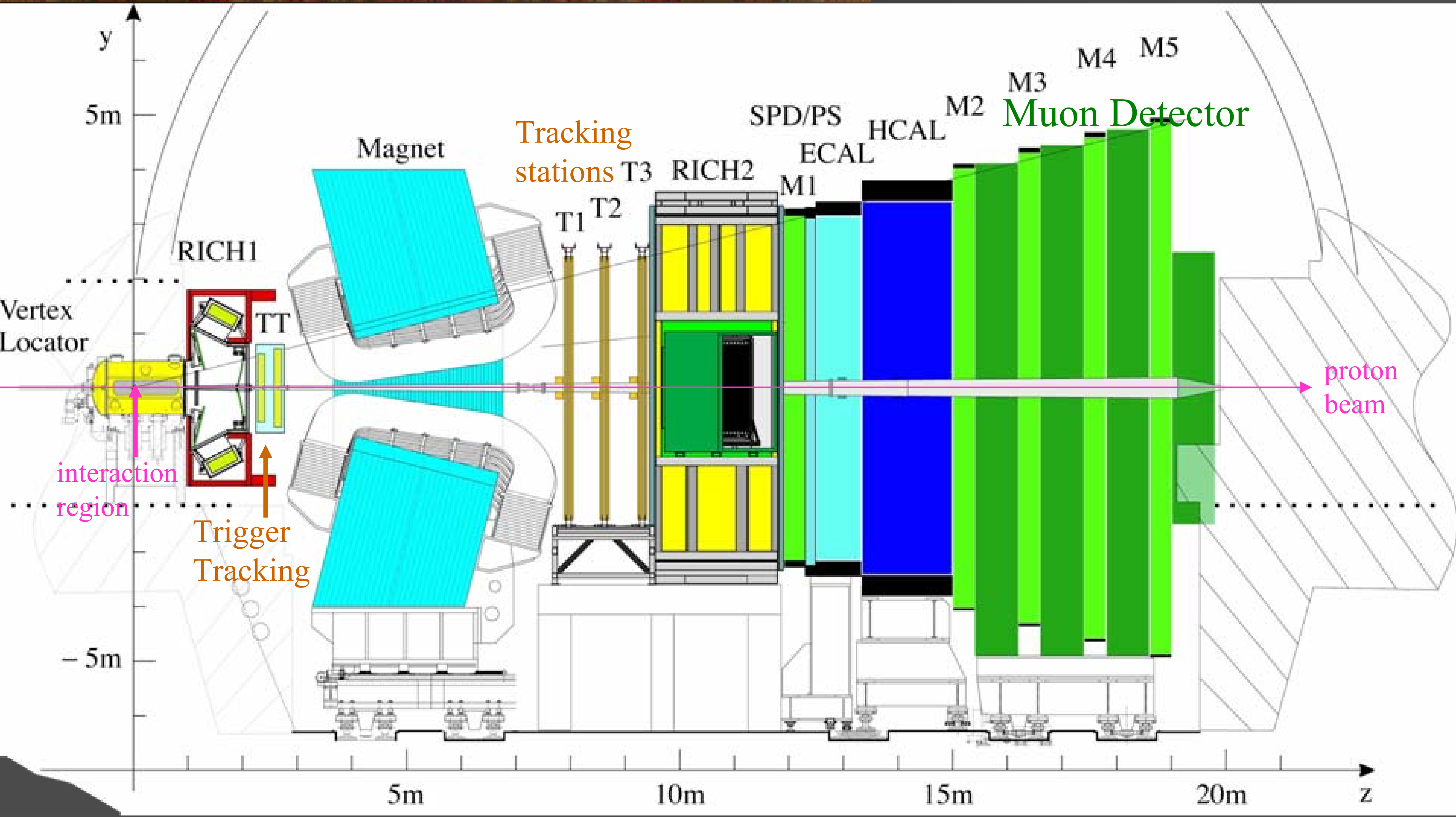
# The Forward Direction at LHC

- In the forward region at LHC the $b\bar{b}$ production $\sigma$ is large
- The hadrons containing the b & $\bar{b}$ quarks are both likely to be in the acceptance
- LHCb uses the forward direction, 4.9 > $\eta$ >1.9, where the B's are moving with considerable momentum ~100 GeV, thus minimizing multiple scattering
- At $\mathcal{L}$=2x10$^{32}$/cm$^2$-s, we get 10$^{12}$ B hadrons in 10$^7$ sec

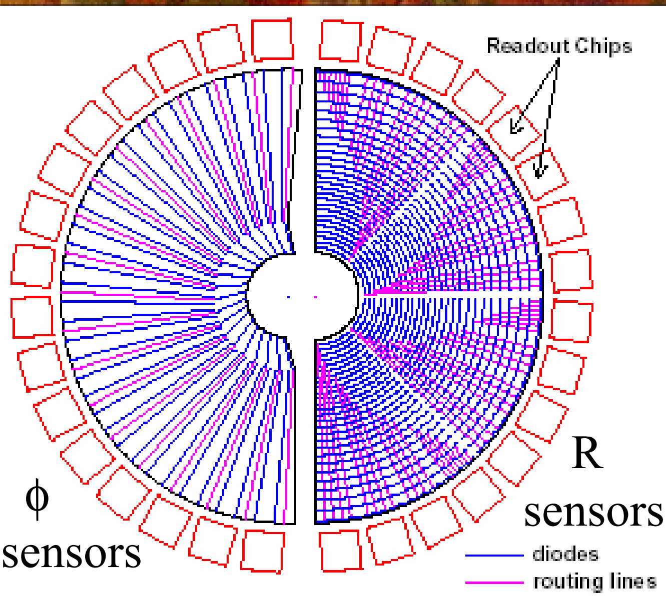


# The LHCb Detector

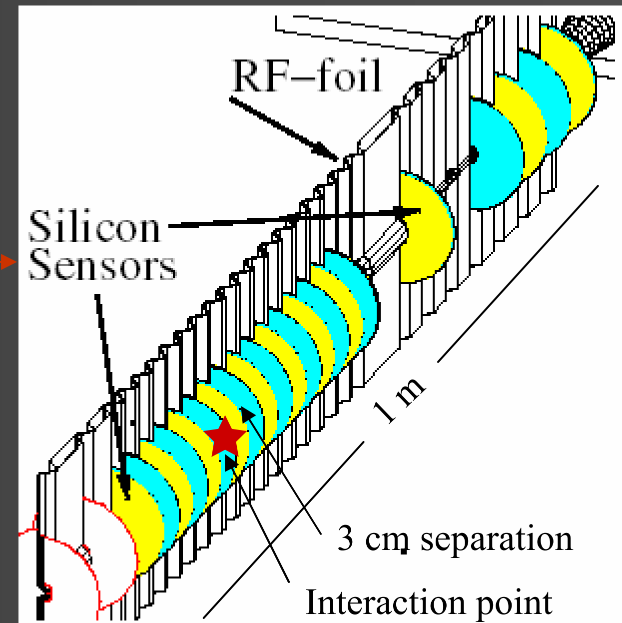


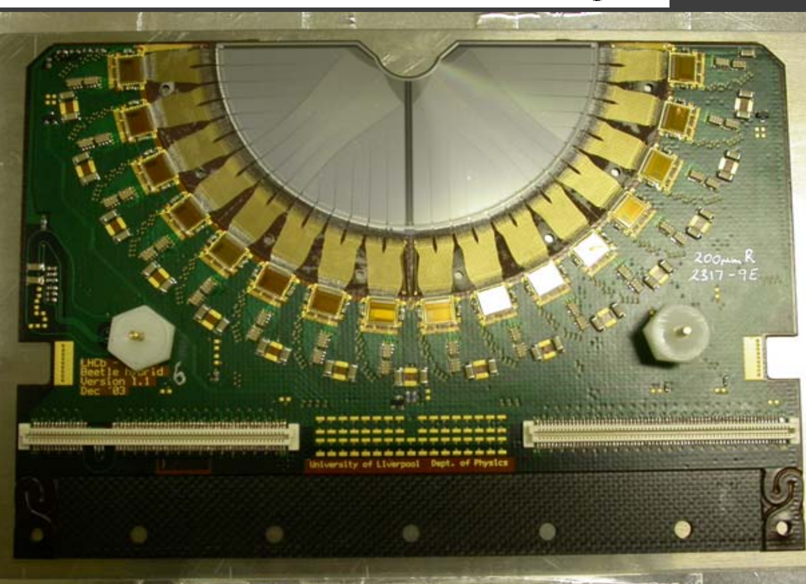
# The VELO

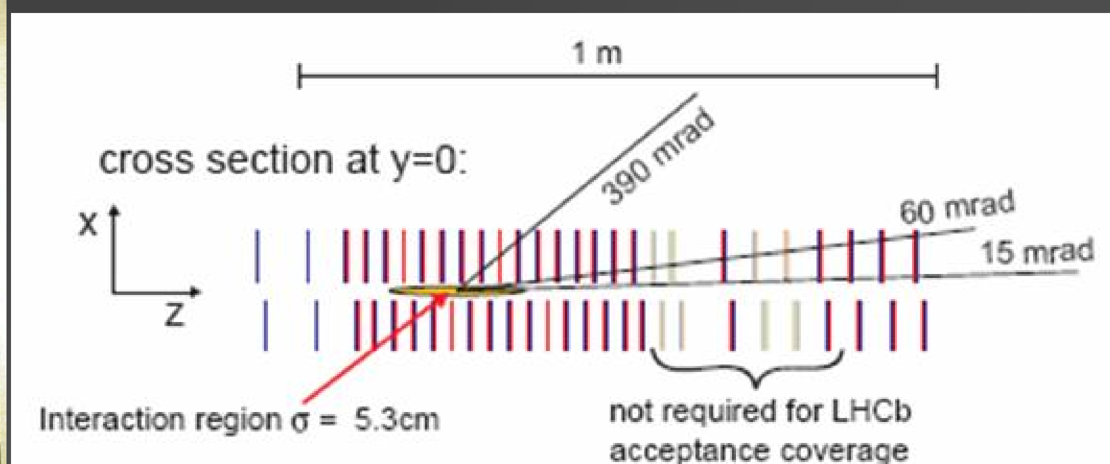



Geometry

R sensor: 38 µm pitch inside to 103 µm outside
ϕ sensor: 39 µm pitch inside to 98 µm outside





# Triggering

- Necessary because b fraction is only ~1% of inelastic cross-section
- At peak luminosity interaction rate is ~10 MHz, need to reduce to a few kHz. The B hadron rate into the acceptance is 50 kHz
- General Strategy
  - Multilevel scheme: 1st level Hardware trigger on "moderate" $p_T$ $\mu$, di-muons, e, $\gamma$ & hadrons, e.g. $p_T$ $\mu$ >1.3 GeV/c; veto on multiple interactions in a crossing except for muon triggers.
  - Uses custom electronics boards with 4 $\mu$s latency, all detectors read out at 1 MHz
  - Second level and Higher Level software triggers

# Software Triggers

- Second Level: All detector information available. Basic strategy is to use VELO information to find tracks from b decays that miss the main production vertex; also events with two good muons are accepted & single muon with $p_T > 2.1$ GeV/c. Strategies are constantly being improved.
- Higher Level Triggers: Here more sophisticated algorithms are applied. Both inclusive selections and exclusive selections tuned to specific final states done after full event reconstruction has finished. Output rate is ~2 kHz

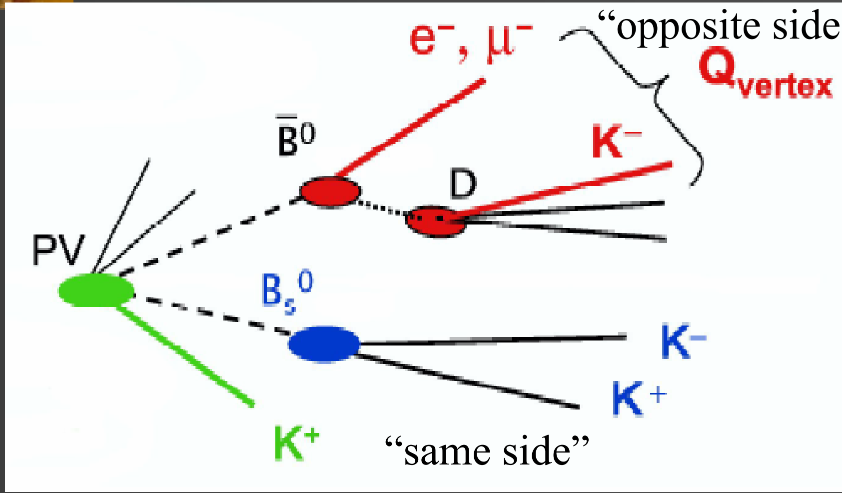
# Trigger Output

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

- Rough guess at present (split between streams still to be determined)
- Large inclusive streams  to be used to control calibration and systematics (trigger, tracking, PID, tagging)

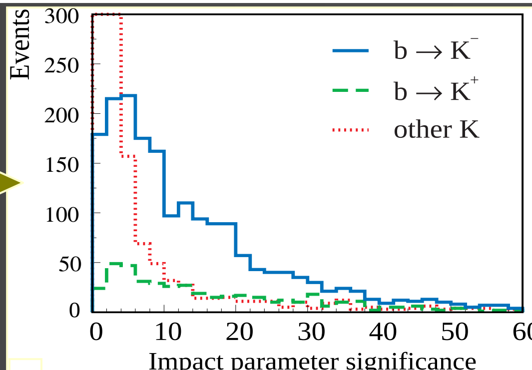
# Flavor Tagging

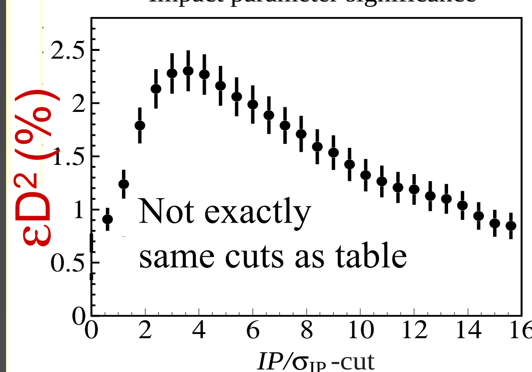
- For Mixing & CP measurements it is crucial to know the b-flavor at t=0. This can be done by detecting the flavor of the other B hadron (opposite side) or by using $K^\pm$ (for $B_S$) $\pi^\pm$ (for $B_d$) (same side)
- Efficacy characterized by $\varepsilon D^2$, where $\varepsilon$ is the efficiency and D the dilution = $(1-2\omega)$
- Several ways to do this




| Method (For $B_S$) | $\mu^\pm$ | $e^\pm$ | $K^\pm$ same | $K^\pm$ opp | Jet charge |
|---|---|---|---|---|---|
| $\varepsilon D^2$(%) | 1.5 | 0.7 | 3.1 | 2.5 | 0.8 |

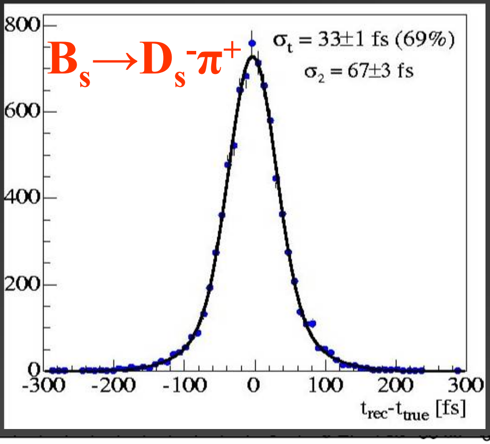
Expect $\varepsilon D^2 \sim 7.5\%$ for $B_S$ & $4.3\%$ for $B_d$

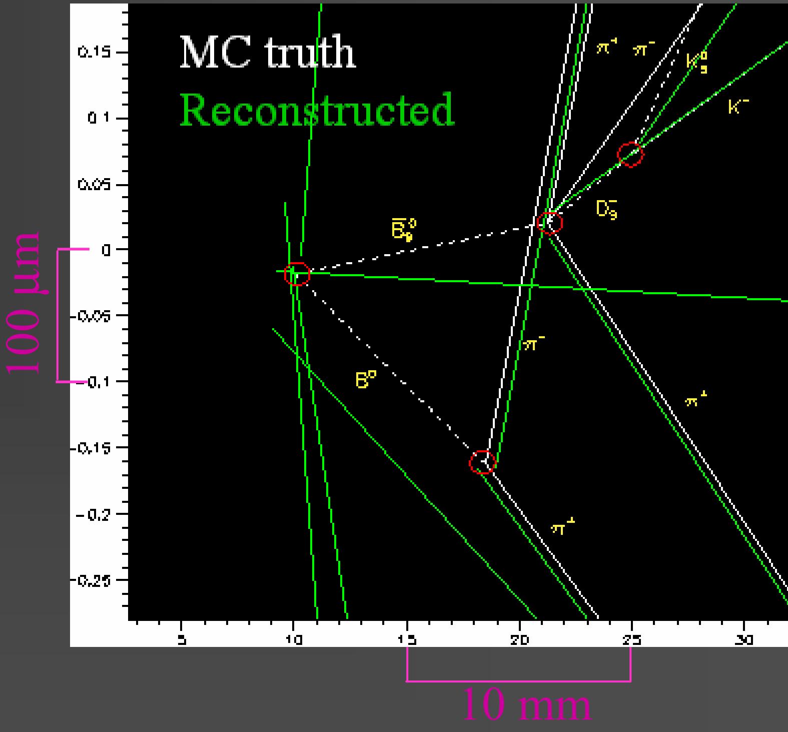


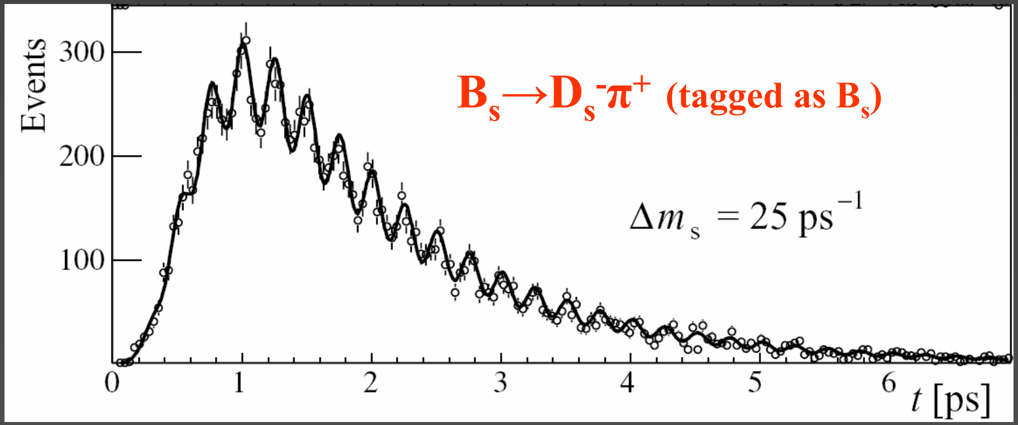



# Background Reduction Using $\sigma_t$

- Excellent time resolution ~40 fs for most modes based on VELO simulation
- Example $B_s$ mixing

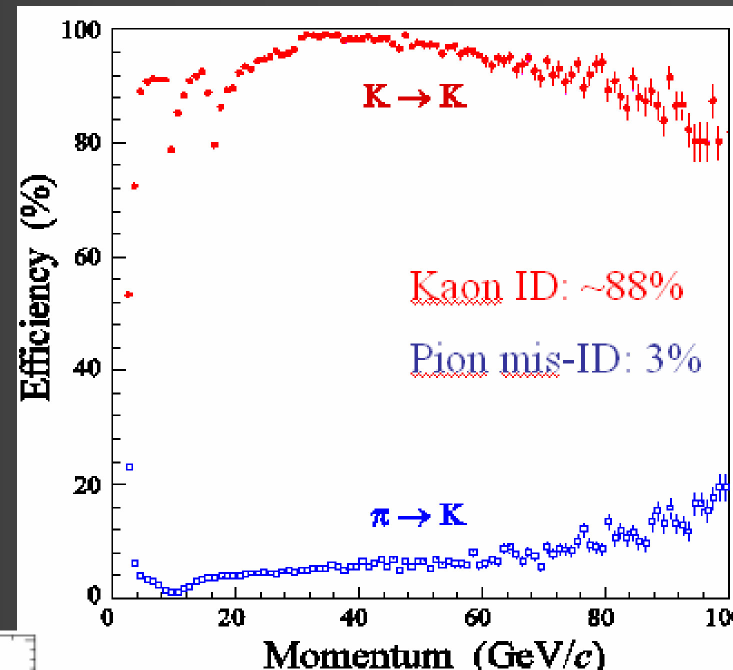


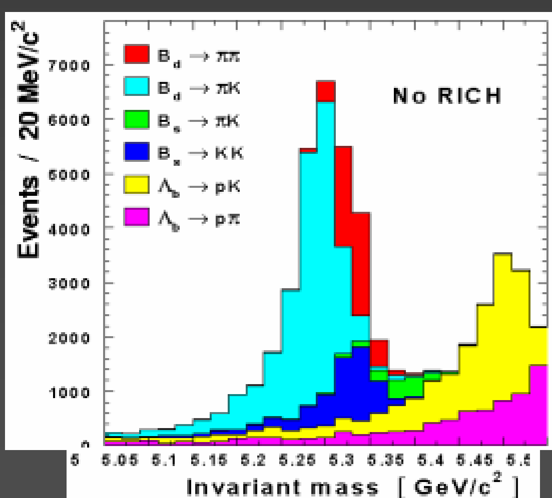



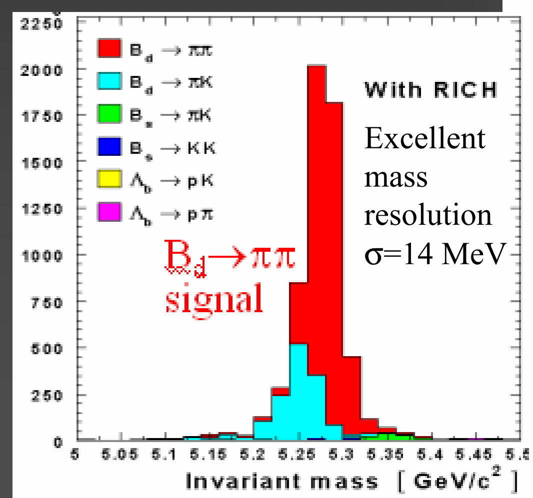



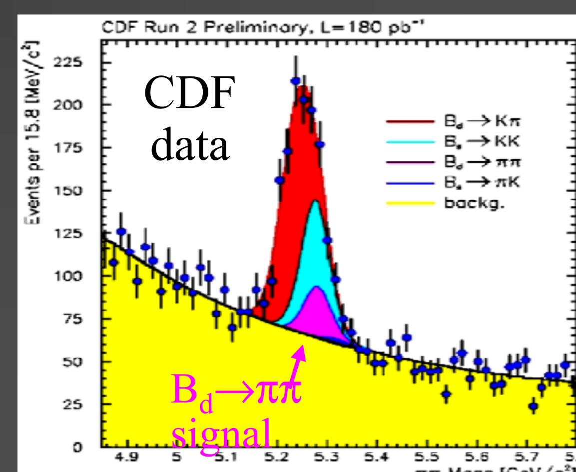
# Background Reduction from Particle ID

- LHCb identifies most tracks in range 100>P>2 GeV/c. Tagging kaons at lower momentum < 20 GeV/c; $B \to h^+h^-$ up to 200 GeV/c, but most below 100 GeV/c
- Good Efficiencies with small fake rates



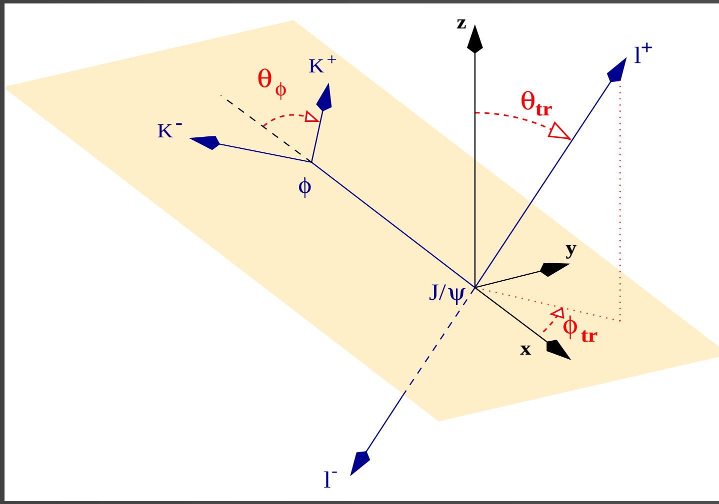



# Particle Identification

- RICH detectors: two separate photon detectors and 3 Cherenkov radiators
  - Aergoel n=1.03
  - $C_4F_{10}$ n= 1.0014
  - $CF_4$ n= 1.0005
- Identifies $\pi$, K, p over "entire" momentum range (2-100 GeV/c)
- $\therefore$ a heavy charged particle, e.g. stau, will not radiate but anything normal, i.e. e, $\pi$, K, p, will in all 3 radiators. Thus we will know that we have new massive particle. *(Reminiscent of Sherlock Holmes: The dog did not bark.)* Tracks also will deposit energy in calorimeters & muon detector, so may get some idea of its energy and good measurement of its momentum

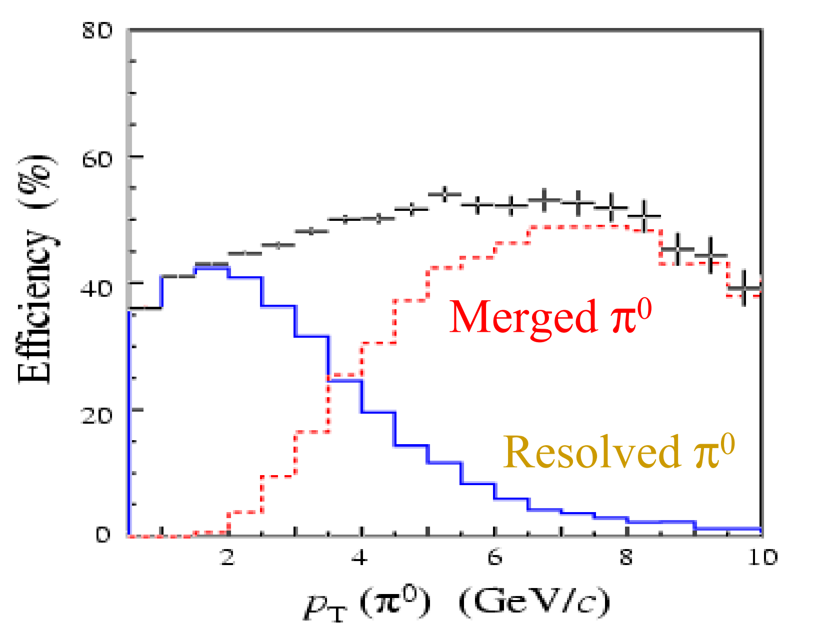
# CP Asymmetry in $B_S \rightarrow J/\psi\ \phi$

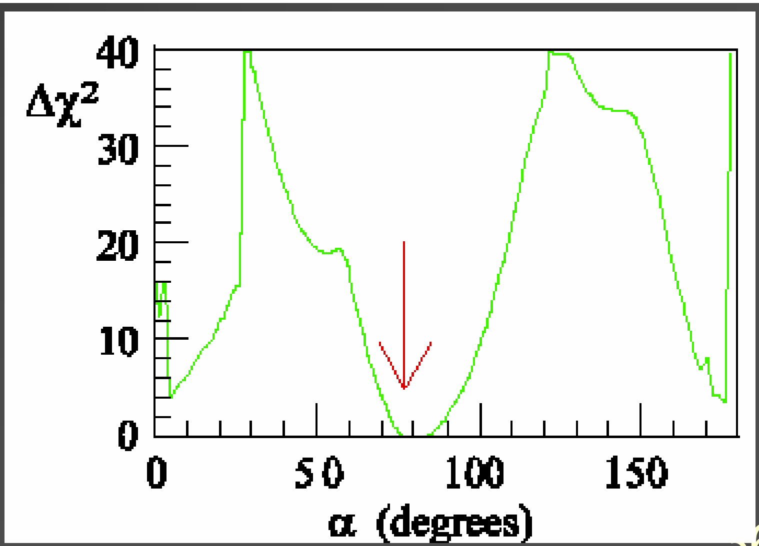
- Just as $B^o \rightarrow J/\psi\ K_S$ measures CPV phase $\beta$ $B_S \rightarrow J/\psi\ \phi$ measures CPV $B_S$ mixing phase $\phi_S$
- Since this is a Vector-Vector final state, must do an angular (transversity) analysis
- The width difference $\Delta\Gamma_S/\Gamma_S$ also enters in the fit
- LHCb will get 131,000 such events in 2 fb$^{-1}$. Projected errors are ±0.023 in $\phi_S$ & ±0.011 in $\Delta\Gamma_S/\Gamma_S$
- With 100 fb$^{-1}$ (LHCb upgrade) error in $\phi_S$ decreases to ±0.003 (only $\mathcal{L}$ improvement), useful to distinguish among Supersymmetry models (see slide 12)



# Neutral Reconstruction

- Mass resolution is a useful ~9-12 MeV $\sigma$
- Efficiency within solid angle is OK using both merged and resolved $\pi^o$'s
- Example: time dependent Dalitz Plot analysis ala' Snyder & Quinn for $B^o \rightarrow \rho\pi \rightarrow \pi^+\pi^-\pi^o$
- 14K signal events in $10^7$ s with S/B 1/3, yielding $\sigma(\alpha)=10^o$



# Other Physics Sensitivities

| | Channel | Yield | B/S | Precision |
|---|---|---|---|---|
| $\gamma$ | $B_s \to D_s^{-+} K^{+-}$ | 5.4k | < 1.0 | $\sigma(\gamma) \sim 14^o$ |
| | $B_d \to \pi^+ \pi^-$ | 36k | 0.46 | $\sigma(\gamma) \sim 4^o$ |
| | $B_s \to K^+ K^-$ | 36k | < 0.06 | |
| | $B_d \to D^0\ (K\pi, KK)\ K^{*0}$ | 3.4 k, 0.5 k, 0.6 k | <0.3, <1.7, < 1.4 | $\sigma(\gamma) \sim 7^o - 10^o$ |
| | $B^- \to D^0\ (K^-\pi^+, K^+\pi^-)\ K^-$ | 28k, 0.5k | 0.6, 1.5 | $\sigma(\gamma) \sim 5^o - 15^o$ |
| | $B^- \to D^0\ (K^+K^-, \pi^+\pi^-)\ K^-$ | 4.3 k | 1.0 | |
| | $B^- \to D^0\ (K_S\pi^+\pi^-)\ K^-$ | 1.5 - 5k | < 0.7 | $\sigma(\gamma) \sim 8^o - 16^o$ |
| $\alpha$ | $B_d \to \pi^+ \pi^- \pi^0$ | 14k | < 0.8 | $\sigma(\alpha) \sim 10^o$ |
| | $B \to \rho^+\rho^0, \rho^+\rho^-, \rho^0\rho^0$ | 9k, 2k, 1k | 1, <5, < 4 | |
| $\beta$ | $B_d \to J/\psi(\mu\mu)K_S$ | 216k | 0.8 | $\sigma(\sin 2\beta) \sim 0.022$ |
| $\Delta m_s$ | $B_s \to D_s^- \pi^+$ | 120k | 0.4 | $\sigma(\Delta m_s) \sim 0.01\ ps^{-1}$ |
| $\phi_s$ | $B_s \to J/\psi(\mu\mu)\phi$ | 131k | 0.12 | $\sigma(\phi_s) \sim 0.023$ |
| **Rare decays** | $B_s \to \mu^+\mu^-$ | 17 | < 5.7 | |
| | $B_d \to K^{*0} \mu^+\mu^-$ | 4.4 k | < 2.6 | Zero to $\pm 0.3\ GeV^2$ |
| | $B_d \to K^{*0} \gamma$ | 35k | < 0.7 | $\sigma(A_{CP}) \sim 0.01$ |
| | $B_s \to \phi\ \gamma$ | 9.3 k | < 2.4 | |
| **charm** | $D^{*+} \to D^0\ (K^-\pi^+)\ \pi^+$ | 100 M | | |

- Only a subset of modes
- For ~ 2 $fb^{-1}$

# Status

- Magnet installed

& mapped

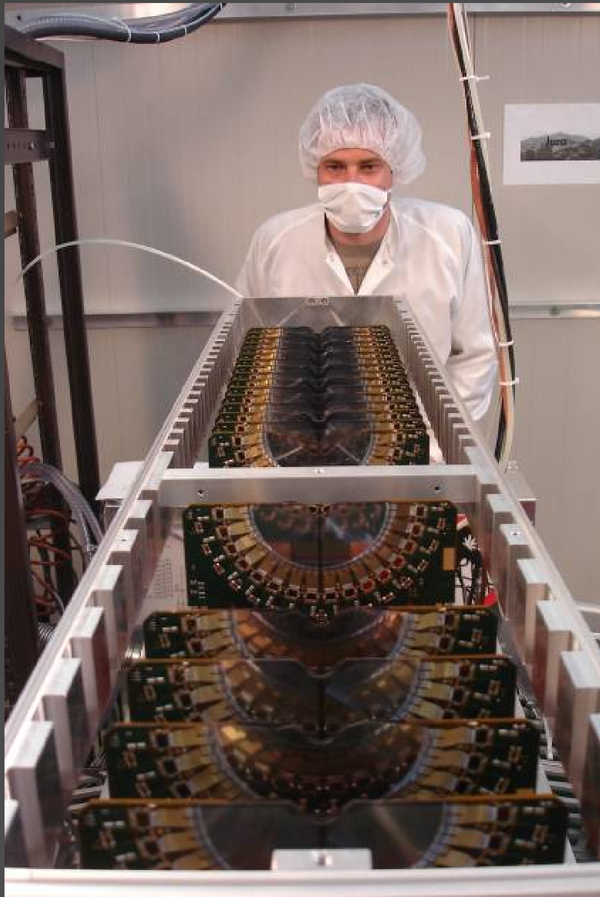
- ECAL, HCAL, RICH II

  & Muon Filter Installed

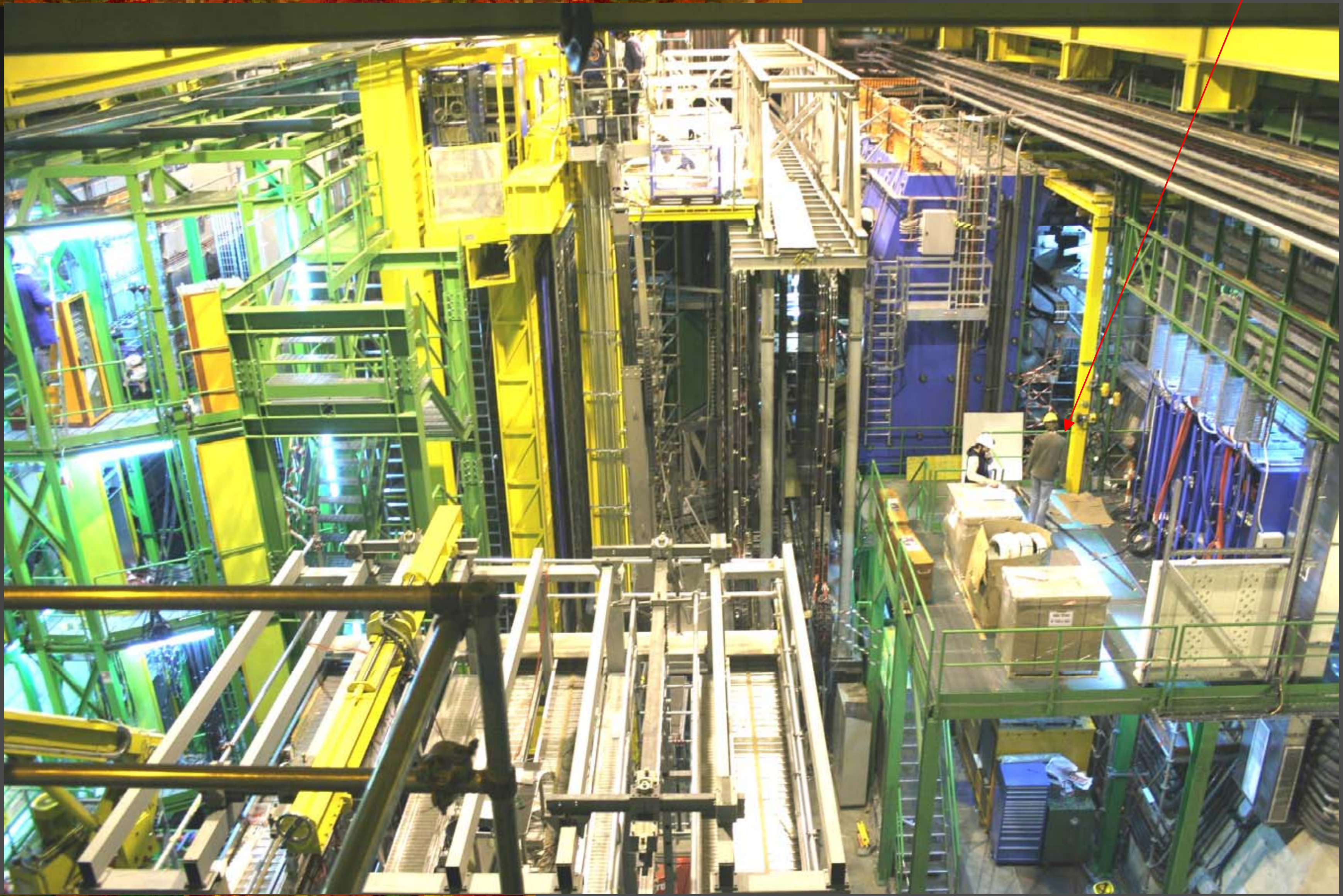
- VELO modules have all been mounted
- Construction on all

other items proceeding

- Software is progressing
- Detector should be complete and installed for Engineering Run

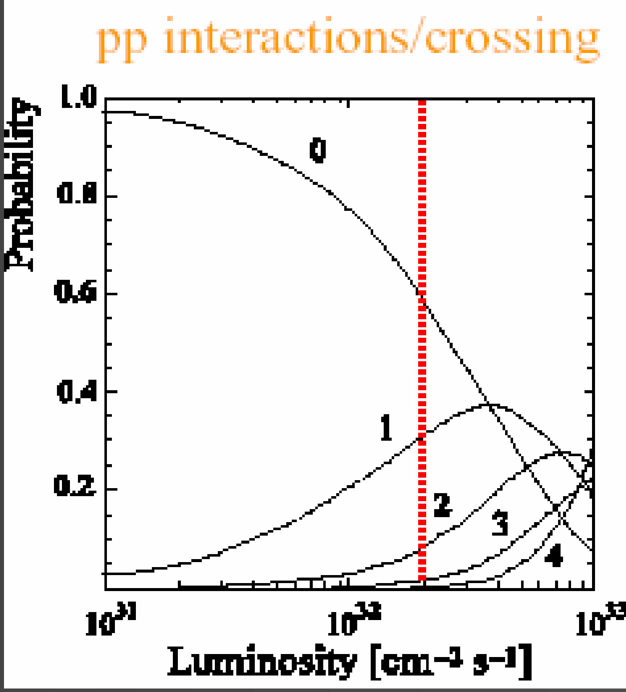


# View of the Pit



# How to Improve Sensitivity

- Must show greatly improved reach for upgrade
  1. Increase luminosity
  2. Allow triggers on multiple int/xing. (Currently limit hadronic modes by insisting on only 1)
  3. Improve trigger efficiency by using detached vertex trigger in 1st trigger level
  4. Improve vertex resolution & ∴ selection ε
  5. Improve EM calorimeter (segmentation in center)



# Example $B^+ \rightarrow D(K\pi)K^+$

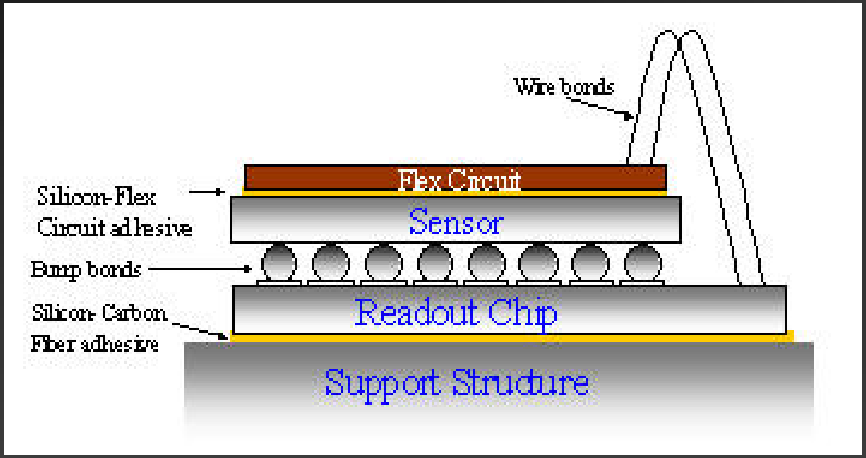
- Signal Yield = $\mathcal{L} * \sigma_{B+} * \mathcal{B} * \varepsilon_{TOT}$, with $\varepsilon_{TOT}$=0.5%, the signal efficiency
- $\varepsilon_{TOT}$ = 8.2% (geometry) × 87.8% (reconstruction) × 28.4% (selection) × 25.0% (trigger)
- Improve $\mathcal{L}$x10, selectionx2? (from better vertex resolution) , triggerx3? Total=x60
- Also Ecal improvement for neutral and $e^-$ modes

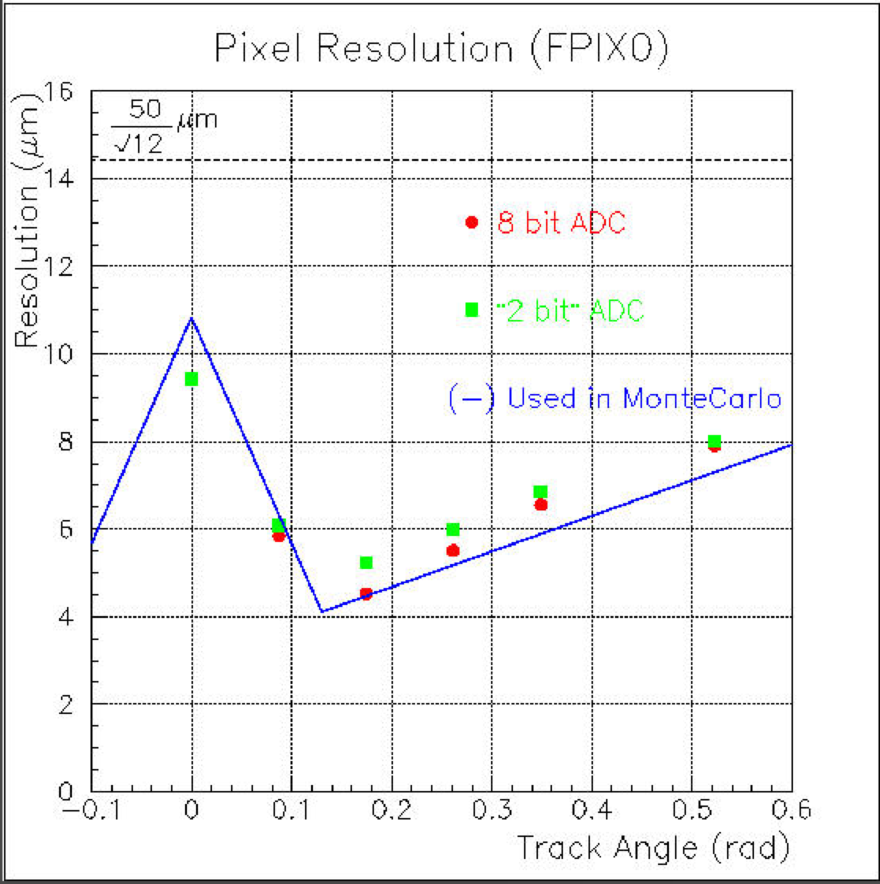
# Possible Upgrade Path

- VELO needs to be replaced after ~6-10 $fb^{-1}$ due to radiation damage, ∴ need rad hard technology
  - Are considering hybrid Silicon pixels as a replacement since they are much more rad hard than current VELO, we could move closer to the beam getting better vertex $\sigma$ and run at higher luminosity
  - Investigating the possibility that VELO be embedded in a ~1 T field to help vertex triggering
- EM calorimeter upgrades such as having better segmentation in the central region
- Major modifications to readout including long digital pipelines running at 40 MHz that would enable extensive 1st level vertex triggering and allow higher luminosity running

# Pixels

## Pixel Module Construction



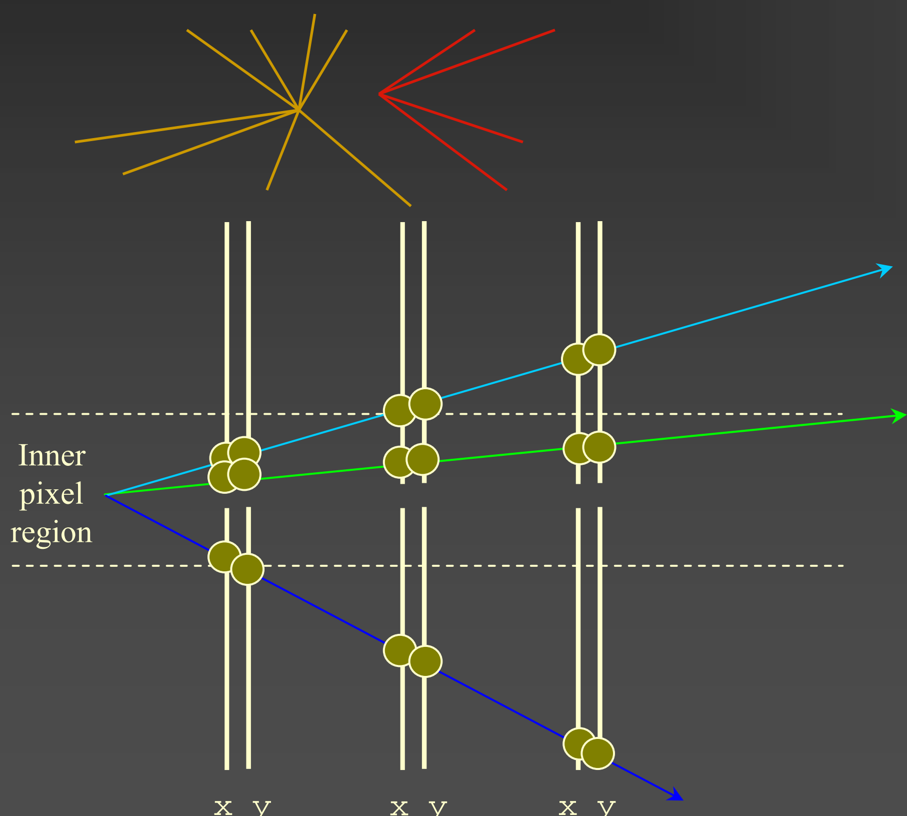




- Analog pixel's – working systems studied in beams, including "almost" final electronics

FNAL, Iowa, Milano, Syracuse
J. Appel et al., NIM **A485, 411 (2002)** **[hep-ex/0108014]**

# Possible Vertex Triggering

◆ Idea: find primary vertices & detached tracks from b or c decays




- Pixel hits from 3 stations are sent to an FPGA tracker that matches "interior" and "exterior track hits
- Interior and exterior triplets are sent to a CPU farm to complete the pattern recognition:
  - interior/exterior triplet matcher
  - fake-track removal
- *See E. Gottschalk, Nucl.Phys.Proc.Suppl. 156, 252 (2006).*

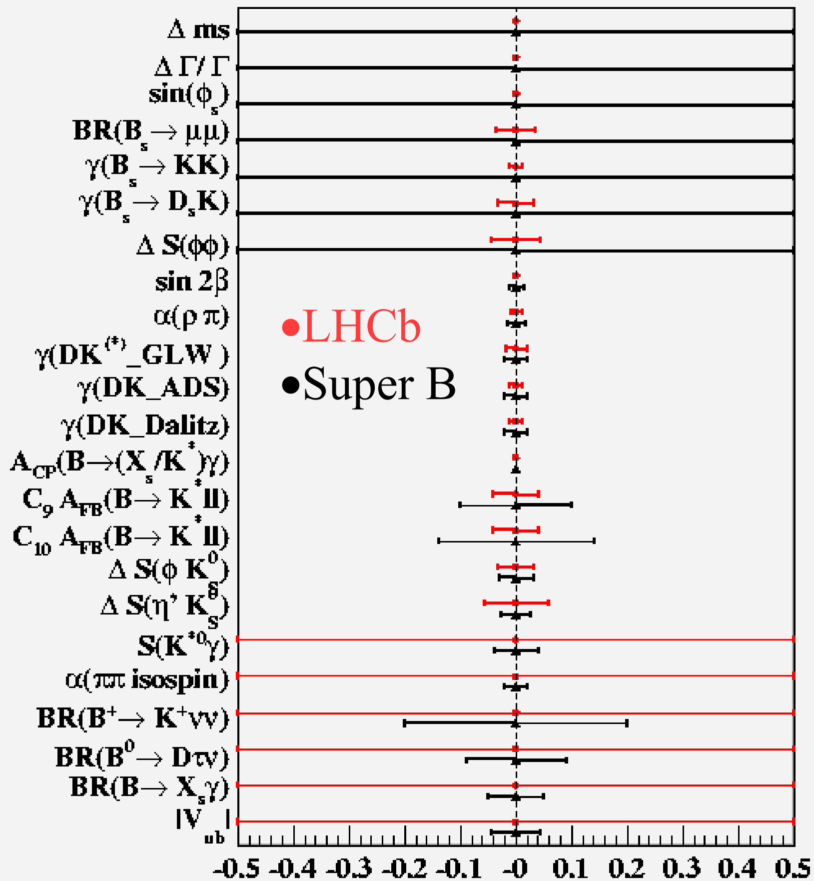
# Upgrade Plans

- LHCb upgrade group has been established
- Simulations required
- R & D including beam tests are being planned
- Data, of course, would be useful to test these concepts

# Comparison with Super B factory

**Sensitivity Comparison ~2020**

LHCb 100 fb$^{-1}$ vs Super-B factory 50 ab$^{-1}$




Preliminary

SuperB numbers from M Hazumi - Flavour in LHC era workshop; LHCb numbers from Muheim

**B$_s$ only accessible at LHCb**

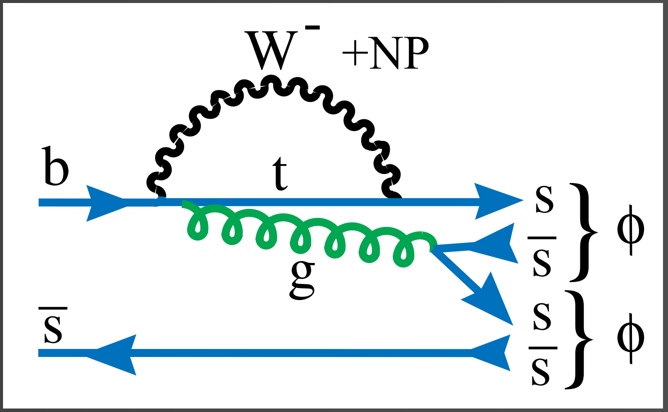
Common

No IP

Neutrals, ν

# One Comparison

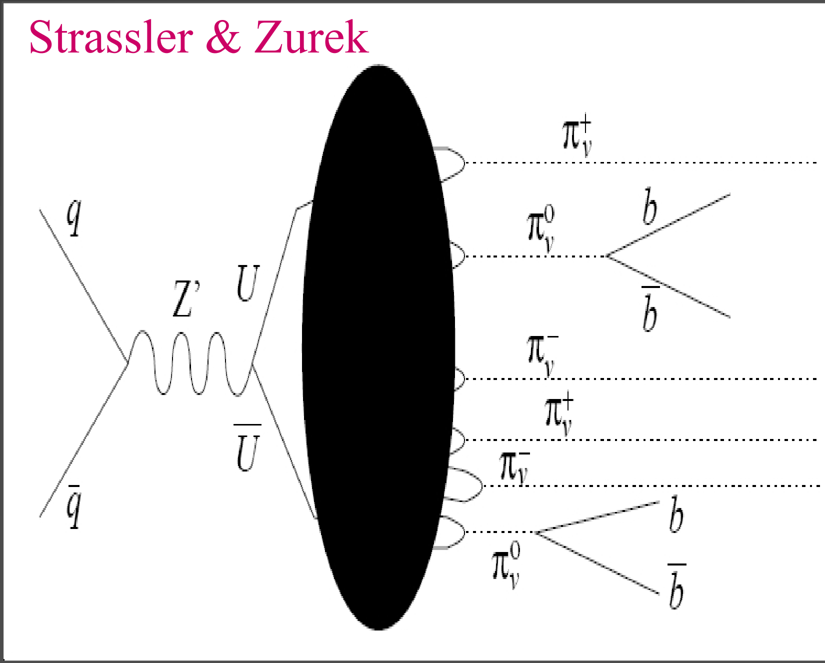
- $B_S \rightarrow \phi\phi$, versus $B^o \rightarrow \phi K_S$
- Purpose: measure difference in CP violation between Color Suppressed Tree + Penguin and CST ≡ A (recall slide 22)




- Might think that Vector-Vector state is much worse due to angular analysis, but this method automatically ensures that any $K^+K^-$ S-wave is taken care of
- Super B $B^o \rightarrow \phi K_S$, estimated error in A for 50 $ab^{-1}$ is ±0.03
- LHCb $B_S \rightarrow \phi K_S$, estimated error for 100 $fb^{-1}$ is ±0.019-0.045
- LHCb $B_S \rightarrow \phi\phi$, estimated error for 100 $fb^{-1}$ is ±0.006-0.014,
- where larger error is due to $\mathcal{L}$ increase only

# Other Possibilities: "Hidden" Gauge Sectors

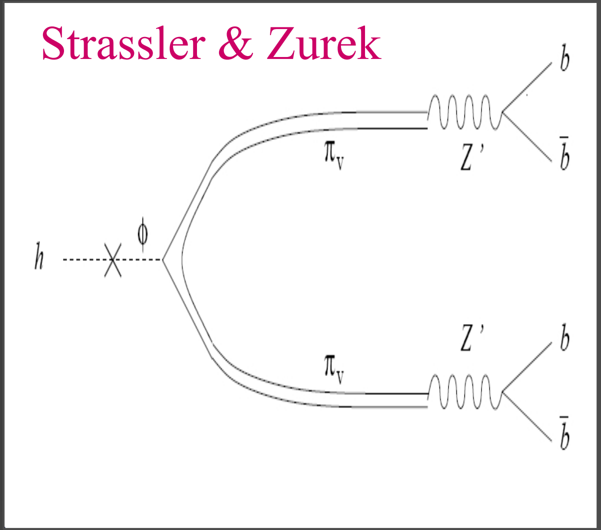
- Many possible extensions to SM, SUSY, ED, etc…
- Consider here adding a U(1)′ Gauge group with a color charge v, useful for generating Electroweak Baryogenisis
  - e. g. : Barger et al [hep-ph/0702001]. Carpenter et al [hep-ph/0607204], Strassler & Zurek [hep-ph/0604261, & 0605193] & many others
  - Produce new quark(s) $U_i$ via $Z' \to U\overline{U}$, fragmentation causes lots of particle production, with some particles containing new $U_1$ & $U_2$ with v=0. These scalar particles $\pi_v^o \to b\overline{b}$ preferentially due to helicity conservation if $2m_B < m(\pi_v) < m_{WW}$



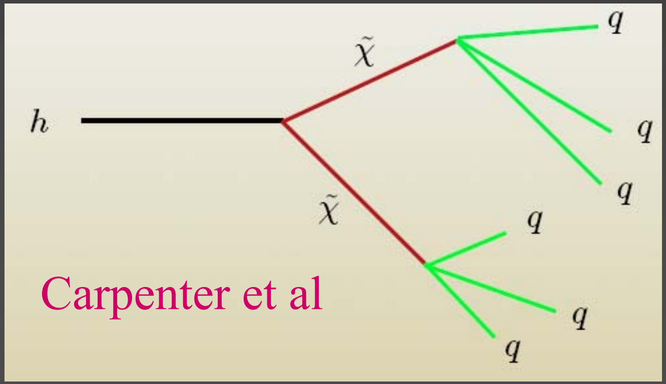
# Higgs decays

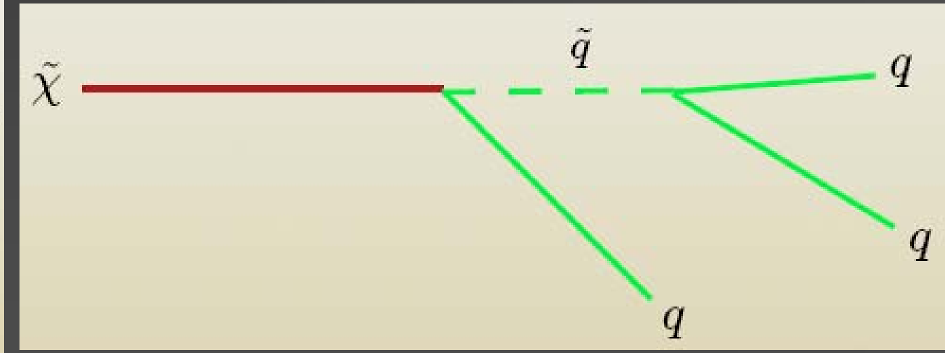
- $\pi_v$ lifetime can be large or small
- Can also have

  Higgs$\rightarrow \pi_v \pi_v \rightarrow b\bar{b}\, b\bar{b}$




  - Or




  - Again lifetime (decay length) is unknown

# Generalized Search

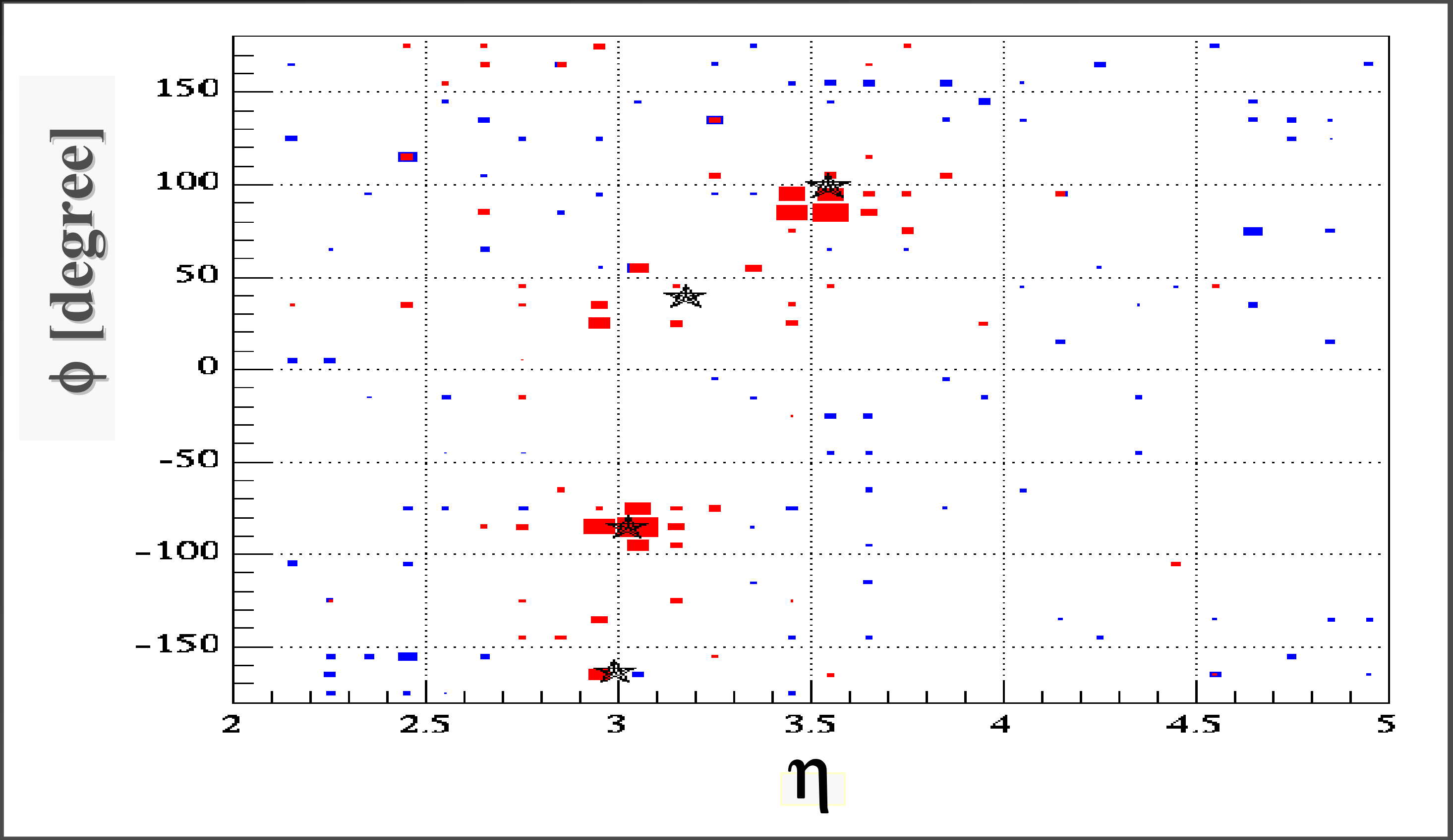
- Many models, many possibilities
- We need to search for anything new that decays to $b\bar{b}$
  - Need to do this as a function of lifetime and mass
  - We don't know branching ratio for Higgs decay or production cross-section for hidden valleys so we start with a few model dependent cases
- Disclaimer: All of these simulations are extremely preliminary first looks

# Adapt Strassler – Zurek Models

- Start with the simple parameter sets, recommended by M. Strassler, taking into account some LHCb features
- Unstable v-pions decay to $b\bar{b}$-pairs
  - Strong interaction parameter $\Lambda_v$ in the interval 35-120 GeV
- $\tau_v$ in the interval 0.1ps-100ps & infinity
- Require at least 3 b-quarks in LHCb acceptance

# $E_t$ Flow Example for Higgs

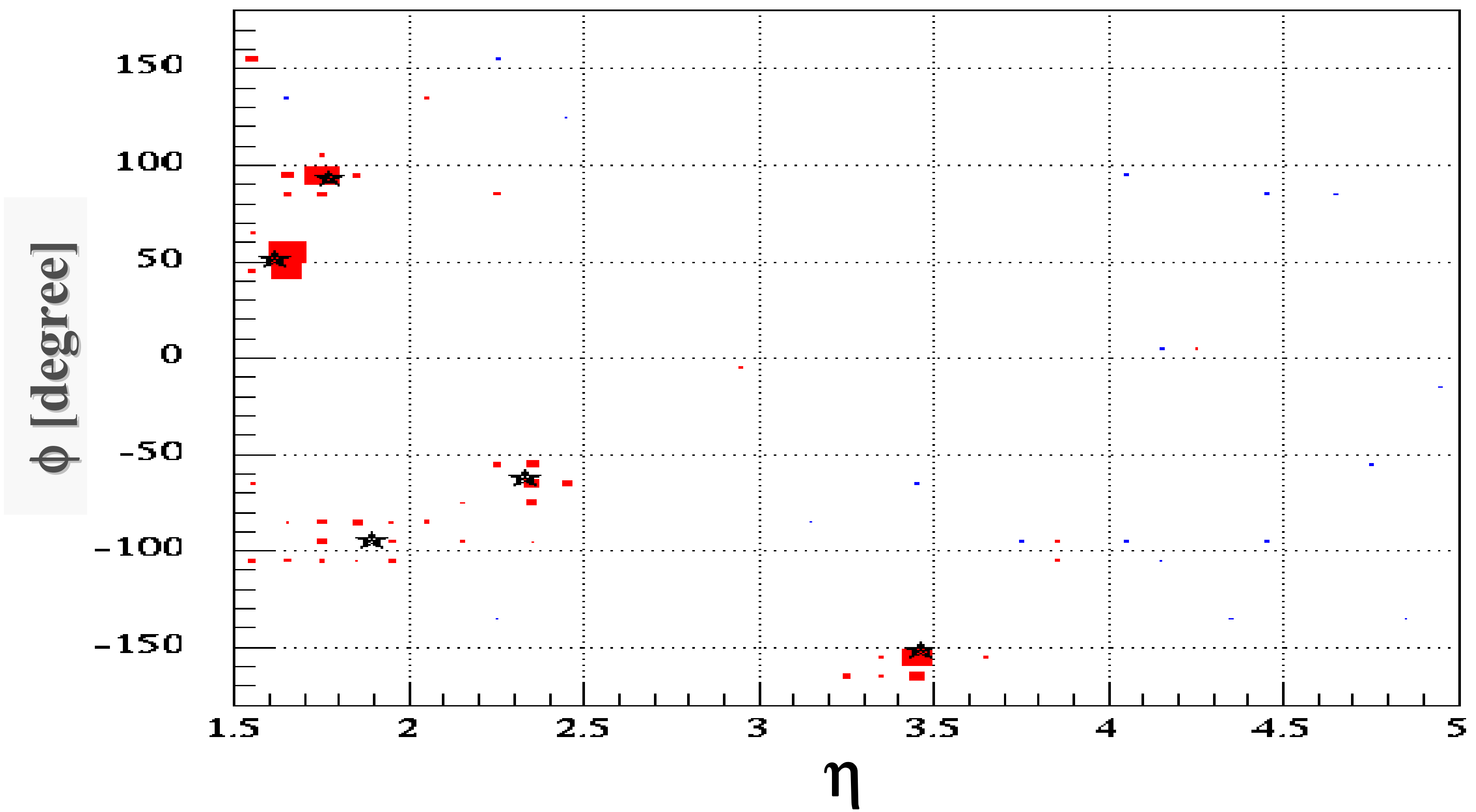
## $M(H^0)$=120 GeV, $m(\pi_v^o)$=35 GeV, $\tau(\pi_v^o)$=1 ps




Calorimeter energies much larger than underlying event

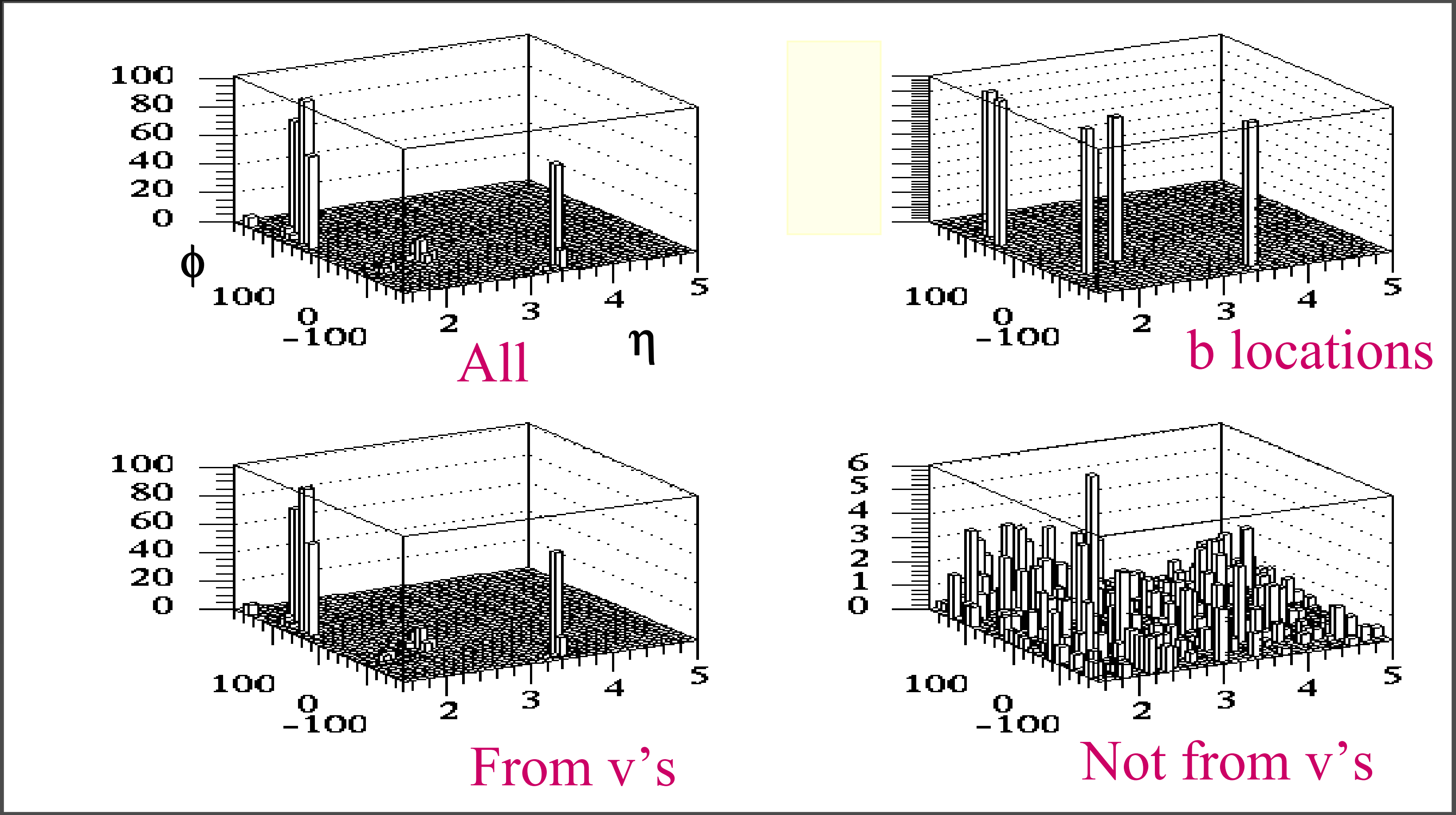
# $E_t$ Flow Example for Hidden Valley

## $m(\pi_v^o)$= 120 GeV, $\tau(\pi_v^o)$=0.1 ps, $\tau(\pi_v^+)$=10 ps



# $E_t$ versus $\phi$ & $\eta$

- Most of $E_t$ in event is in b jets

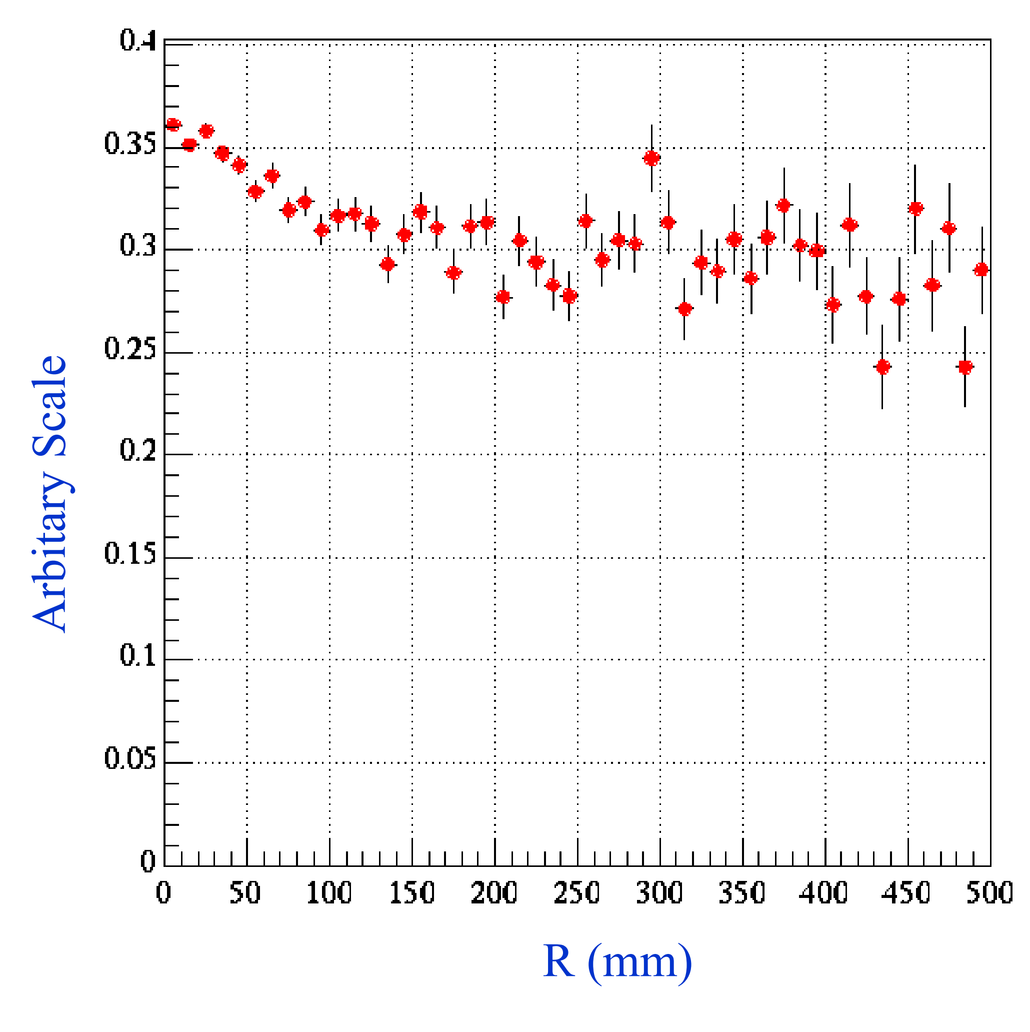



- Must do background simulations

# Efficiencies

- $1^{st}$ level trigger (L0) efficiency is very high >80% for 3 or more jets in 8.2% geometrical acceptance
- Efficiency to reconstruct jets decreases slowly as a function of the ν decay length once L0 is satisfied
- Higher trigger levels can be adjusted in order to accept these events

Jet Efficiency vs ν Flight Distance



# Conclusions

- What do we hope to learn from LHC & LHCb
  - ATLAS/CMS: Electroweak Symmetry breaking: the Higgs, + New Physics: either SUSY, ED, or little higgs, etc…
  - LHCb: CP violation: $\phi_s$, $\gamma$ in Bs→DsK, $\alpha$ in B→$\rho\pi$, $B_{(S)} \rightarrow M\gamma$, dilepton asymmetry in $B_S$ decays, $B_S \rightarrow \phi\phi$, $B \rightarrow \phi K_S$; Rare Decays: polarization in $K^* \mu^+\mu^-$, $B_{(S)} \rightarrow M\gamma$, $B_{(S)} \rightarrow \mu^+\mu^-$. $D^o$ mixing & CP violation, (Hidden Valleys?)

# Conclusions II

- Possible outcomes
  - ATLAS/CMS see Higgs & NP & LHCb sees some NP effects that constrain NP models – *more sensitivity required to further elucidate NP*
  - ATLAS/CMS see Higgs & NP & LHCb sees nothing beyond SM - *more sensitivity required to further elucidate NP*
  - ATLAS/CMS see Higgs but no NP & LHCb sees some NP effects that constrain NP models – *more sensitivity required to further elucidate NP*
  - ATLAS/CMS see Higgs but no NP & LHCb sees nothing beyond SM – *more sensitivity required to further elucidate NP & to try and estimate mass scale for NP*
- In all cases it is likely that *more LHCb sensitivity required to further elucidate NP*

LHCb Ski Outing
March 2007
Photo credit: Tomasz Skwarnicki

# *The End*

A Hidden Valley?


16th International Workshop on Vertex Detectors
Vertex 2007
September 23 - 28, Lake Placid, NY
To review progress on Silicon based Vertex detectors with emphasis on existing & future detectors, new materials, software, alignment, electronics, triggering, 3D devices, monolithic structures, new developments, applications to medical & other fields
International Organizing Committee
Marina Artuso, Syracuse Univ., Co-chair
Gian Mario Bilei, INFN Perugia
Daniela Bortoletto, Purdue Univ.
Richard Brenner, Uppsala Univ.
Massimo Caccia, Univ. of Insubria
David Christian, Fermilab
Paula Collins, CERN
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Els Koffeman, NIKHEF
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Sheldon Stone, Syracuse Univ., Co-chair
Toru Tsuboyama, KEK
Local Organizing Committee
(Syracuse University)
Marina Artuso, Co-chair
Sheldon Stone, Co-chair
Steven Blusk
Ray Mountain
Jianchun Wang
By invitation only. Those wishing to attend should contact the organizing committee chairs
http://Vertex2007.syr.edu