New Physics Signals via b-quarks at the LHC

b Physics at the LHC: Constraining New Physics or Spectacular Discoveries

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Introduction

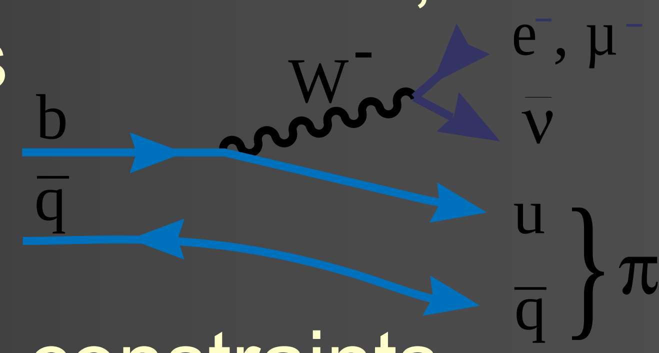
- Introduction: How do B decays reveal new information about TeV scale physics?
  - Indirectly through loops
    - already severe constraints on many NP models
    - more precision means probing toward higher masses
    - Just started exploring B_S system
  - Directly by having new Particles that can decay into $b\,\bar{b}$

"Classical" B Physics Justification

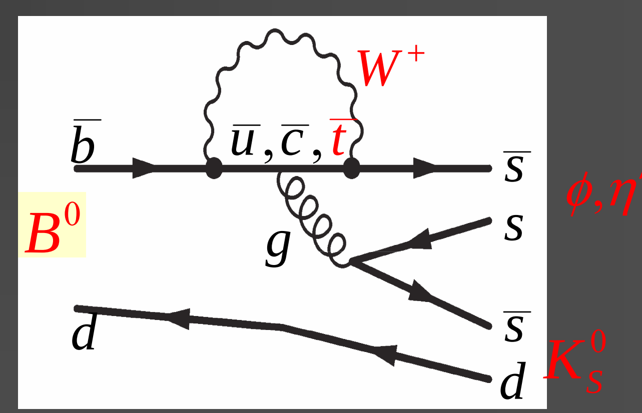
- Expect New Physics will be seen at LHC
  - Standard Model is violated by the Baryon Asymmetry of Universe & by Dark Matter
  - Hierarchy problem (why $M_{Higgs} << M_{Planck}$)
- However, it will be difficult to characterize this physics
- How the new particles interfere virtually in the decays of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

B Decays a Quick Introduction

- b & c decays are used to find CKM matrix elements, fundamental SM parameters, usually via tree-level decays
  - e.g. $B \to \pi \ell \nu$ used for V_{ub}

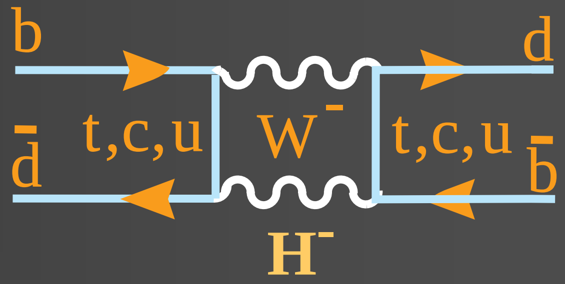


- Also used for New physics (NP) searches & failing that, constraints
  - Here can use Rare decays involving loops, because new particles can contribute.
  - Must measure difference with SM predictions



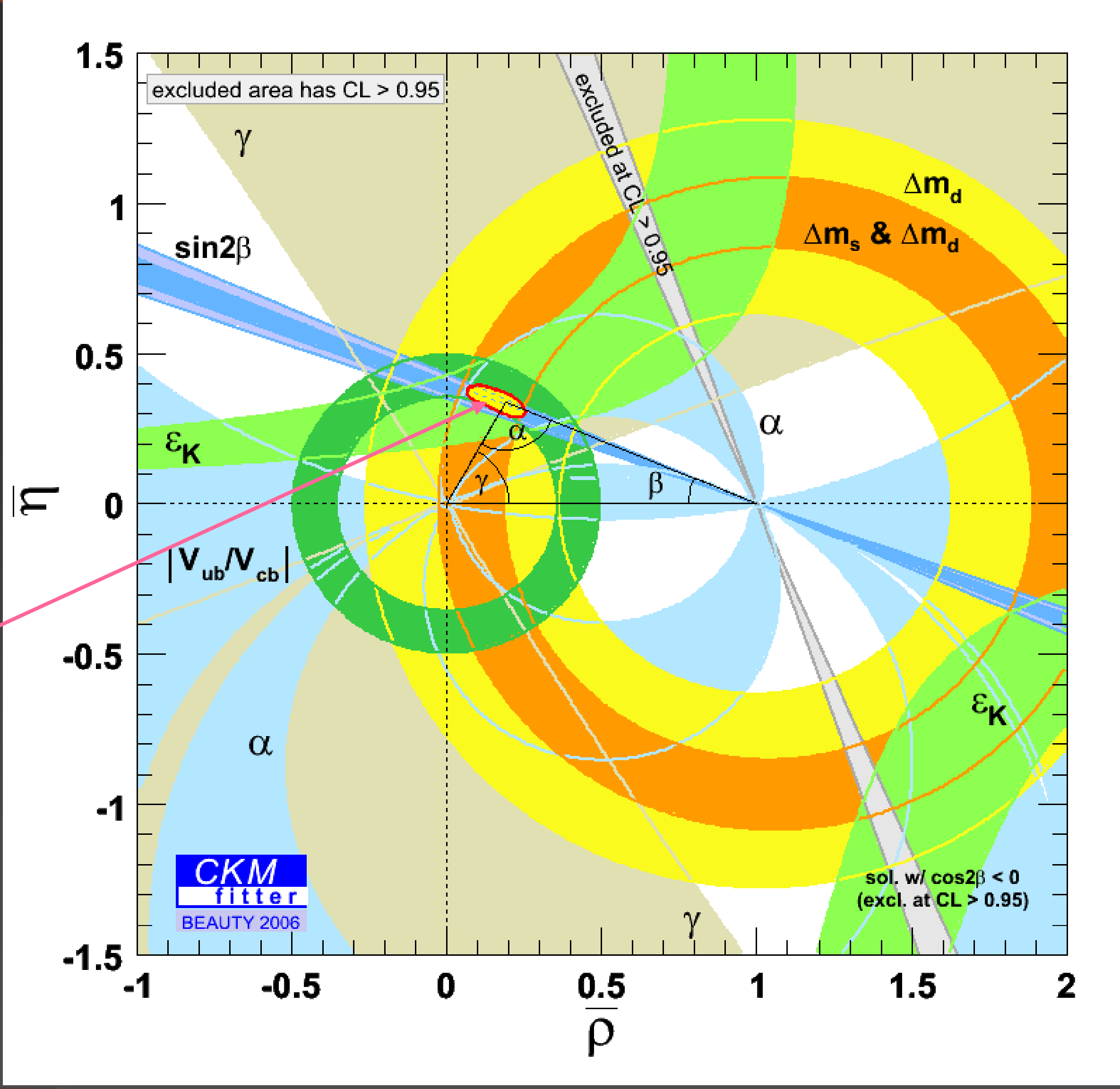
B Decays a Quick Introduction II

- CP violating decays measure interference between two diagrams where effects of new particles can more easily be evident.
  - Often one diagram used is the mixing diagram
  - New Gauge bosons could appear in association with the W^-



Current Status of CP & Other Measurements

- SM CKM parameters are: A~0.8, λ=0.22, ρ & η
- CKM Fitter results using CP violation in $J/\psi\ K_S$, $\rho^+\rho^-$, DK^-, K_L, & V_{ub}/V_{cb} & ΔM_S
- The overlap region excludes CL>95%
- Measurements "consistent"



Consistency?

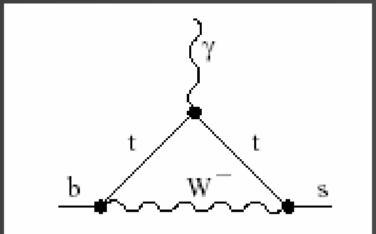
- It is often said that studies of b & c decays are all consistent with the Standard Model
  - Since all measurements are by their nature reflections of physics, i.e. SM + NP, what does this statement actually mean?
  - SM predictions are made using consistency of several measurements since there are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

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 ACD
- 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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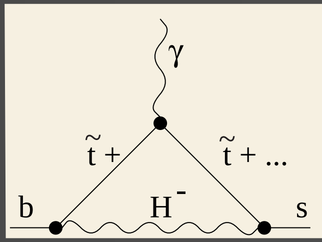
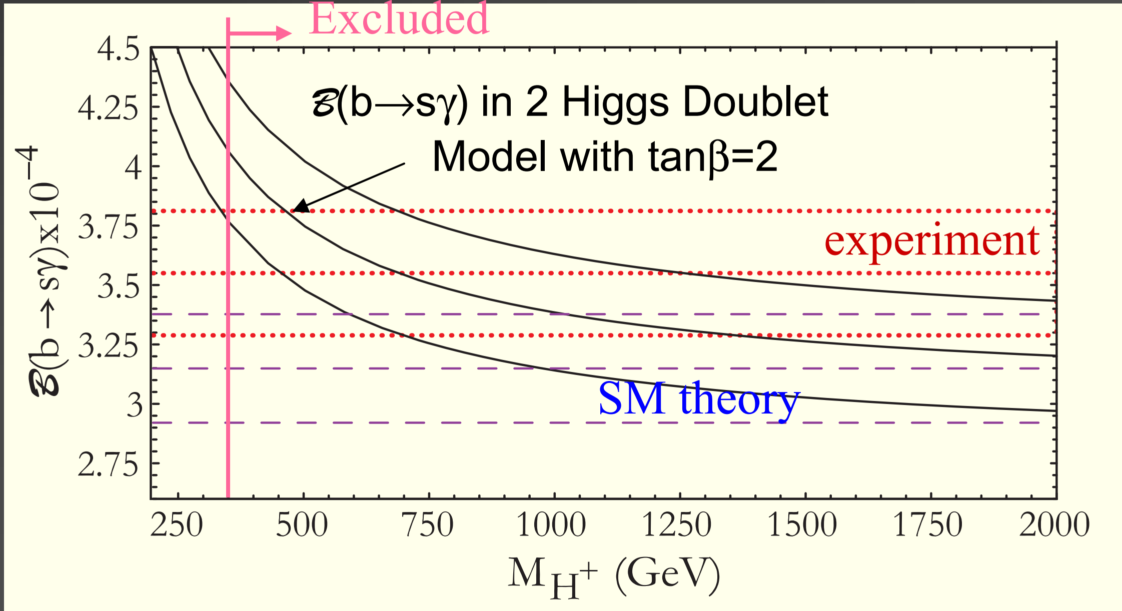


- Theory (Misiak et. al hep-ph/0609232):
  $\mathcal{B}(b \to s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$
- Limit on H^+ mass >295 GeV at 95% CL for tanβ>~2

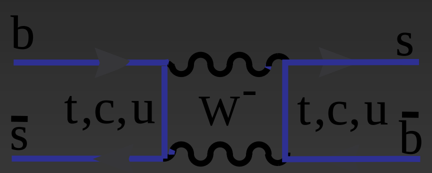
(plot shows central Values & ±1σ bands)

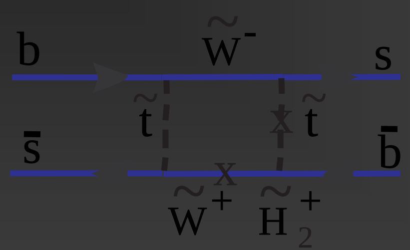
- By far best limit from any source



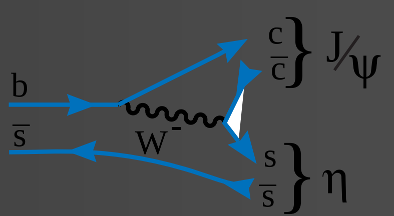
Another Example

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





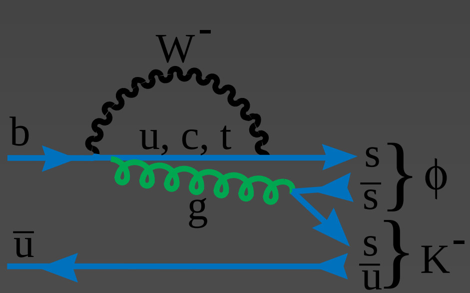
$B_s \to J/\psi\eta$

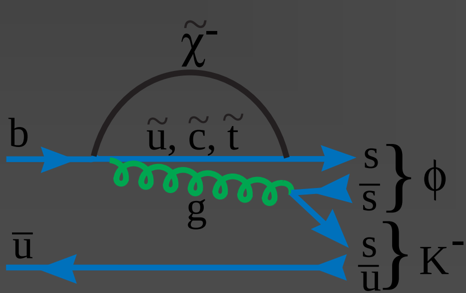


CP asymmetry $\approx 0.1\sin\phi_\mu\cos\phi_A\sin(\Delta m_s t)$, ~10 x SM

- Contributions to direct CP violating decay

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



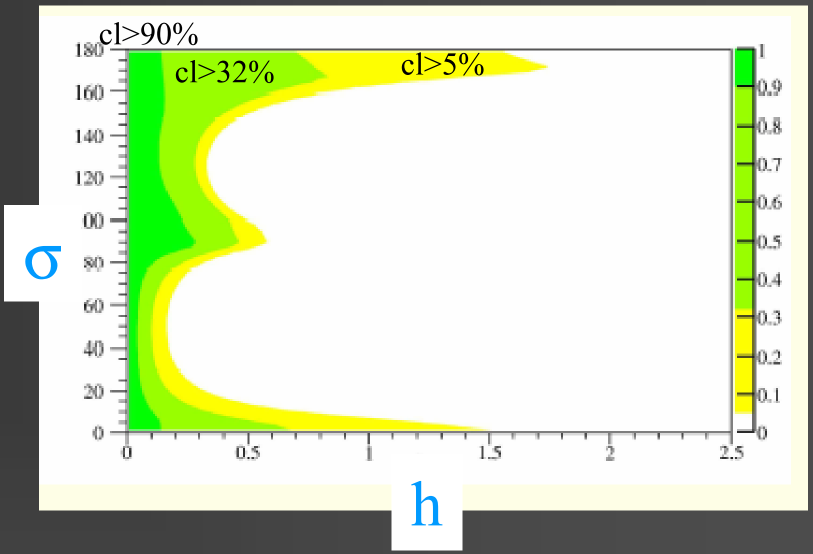


$Asym = (M_W/m_{squark})^2\sin(\phi_\mu)$, ~0 in SM

Limits on New Physics From B°

- 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}, $S_{\psi K}$, $S_{\rho\rho}$, Δm_d, A_{SL}
- Fit to η, ρ, h, σ

"Next to minimum flavor violation"

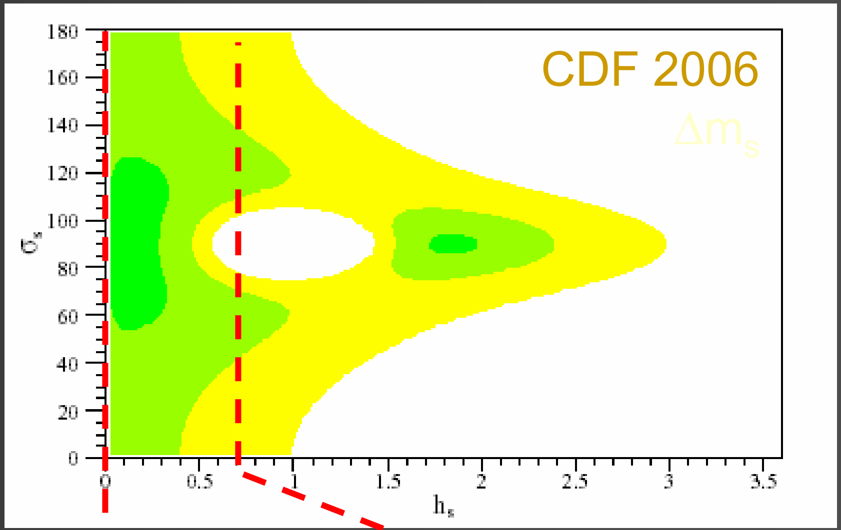


Agahse, Papucci, Perzez, Pirjol hep-ph/0509117

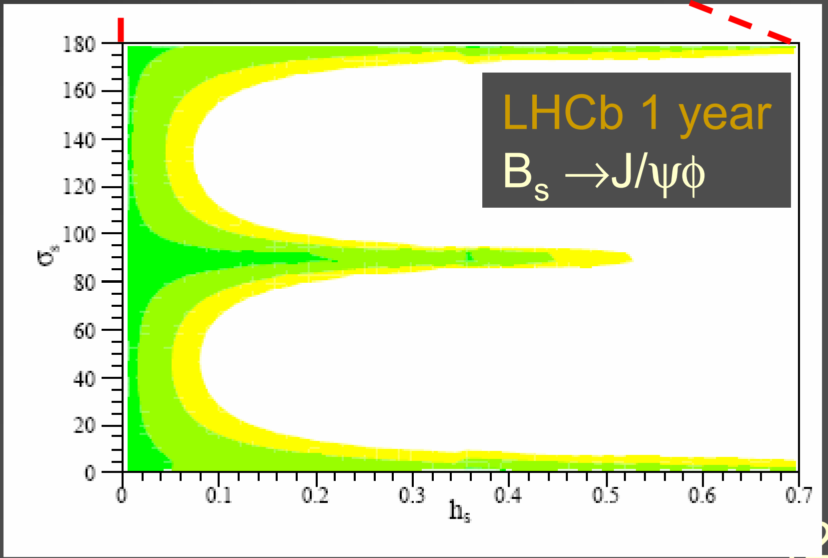
- For New Physics via B_d^o mixing, h is limited to ~<0.3 of SM except when σ_{Bd} is ~0° or ~180° of SM decays

Limits on New Physics From B_S

- Similar study for Bs decays including ΔM_S measurement from CDF
- Limits much weaker since phase in B_S mixing is yet to be measured



Ligeti, Paucci & Perez, hep-ph/0604112



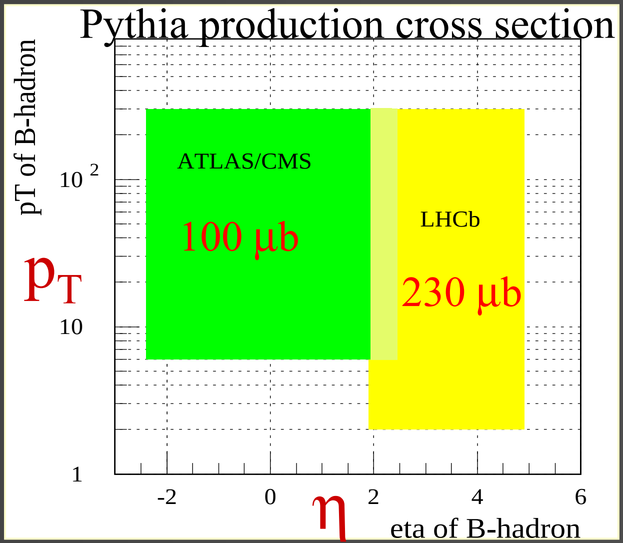
LHC Detectors & Issues

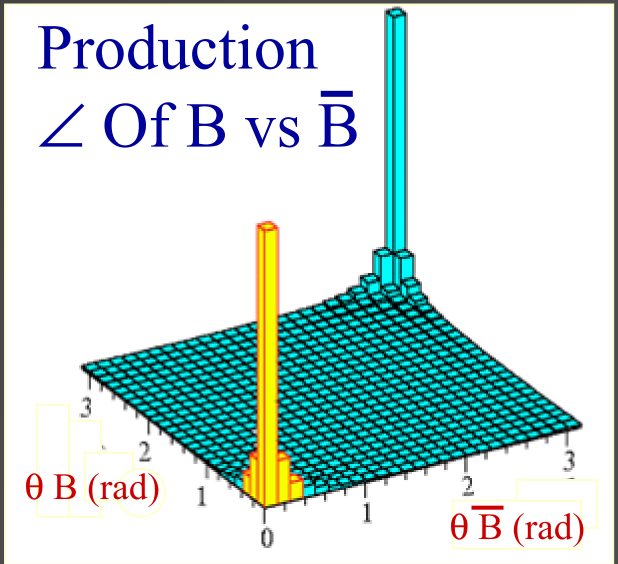
Detector Requirements - General

- 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 (Unique to LHCb)
  - Muon & electron identification because of the importance of semileptonic & leptonic final states including J/ψ decay
  - γ, π^o & η detection
  - Triggering, especially at hadronic colliders Different strategies, LHCb focuses on b's, read out 2 kHZ, 10x ATLAS & CMS. One of the largest "unknowns"
  - High speed DAQ coupled to large computing for data processing

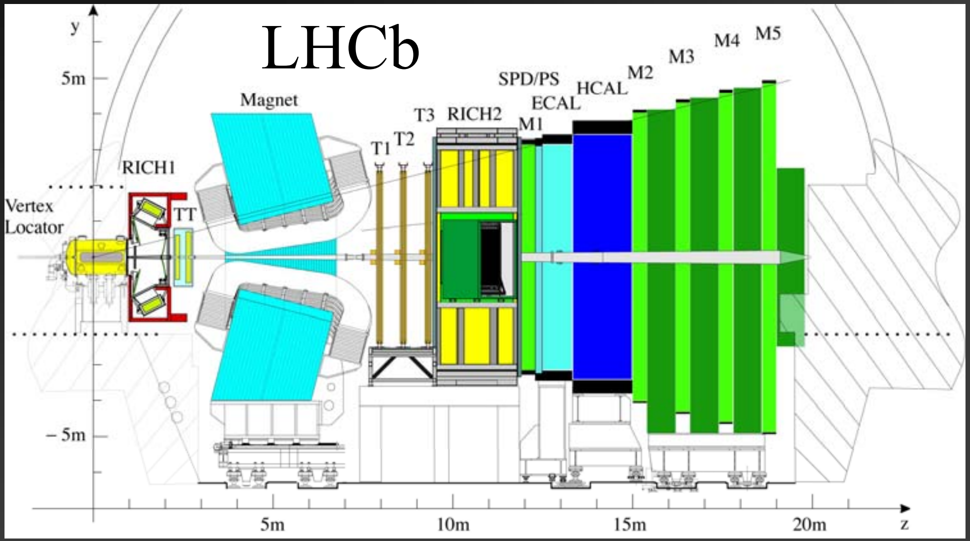
B Production at the LHC

- Predicted cross-sections in the approximate detector acceptances
- LHCb uses the forward region. Not only is the $b\bar{b}$ production σ large, but the hadrons containing the b & $\bar{b}$ quarks are both likely to be in the acceptance
- In the forward direction, 4.9 > η >1.9, the B's are moving with considerable momentum ~100 GeV, thus minimizing multiple scattering.
- ATLAS & CMS use the central region and make higher P_T cuts
- At $\mathcal{L}$=2x10^{32}/cm^2-s, LHCb gets 10^{12} B hadrons in 10^7 sec



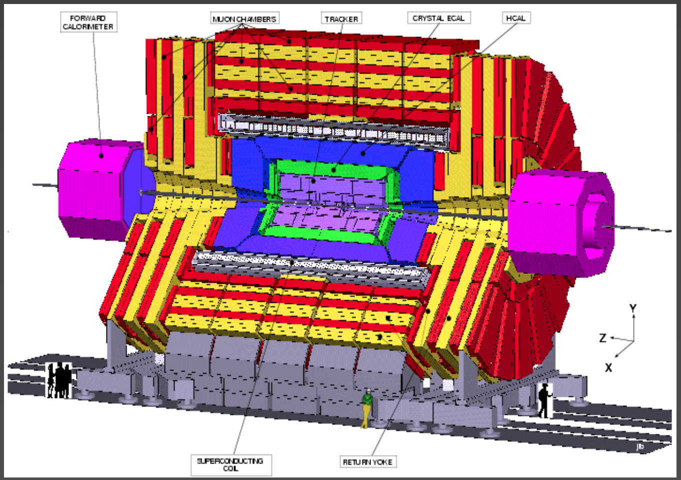


Future B experiments

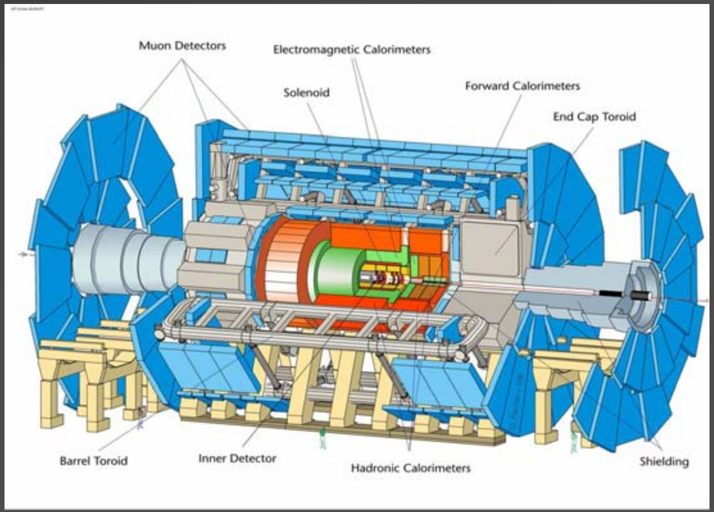


- LHCb: first dedicated b experiment at a hadron collider, the LHC
  - Excellent vertexing
  - Excellent particle id – UNIQUE feature

CMS

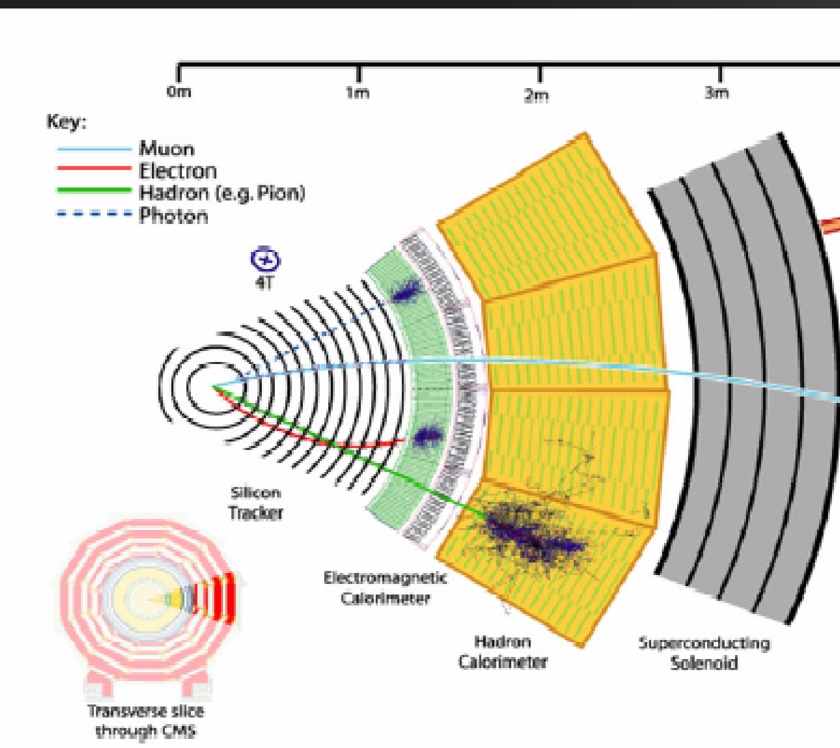


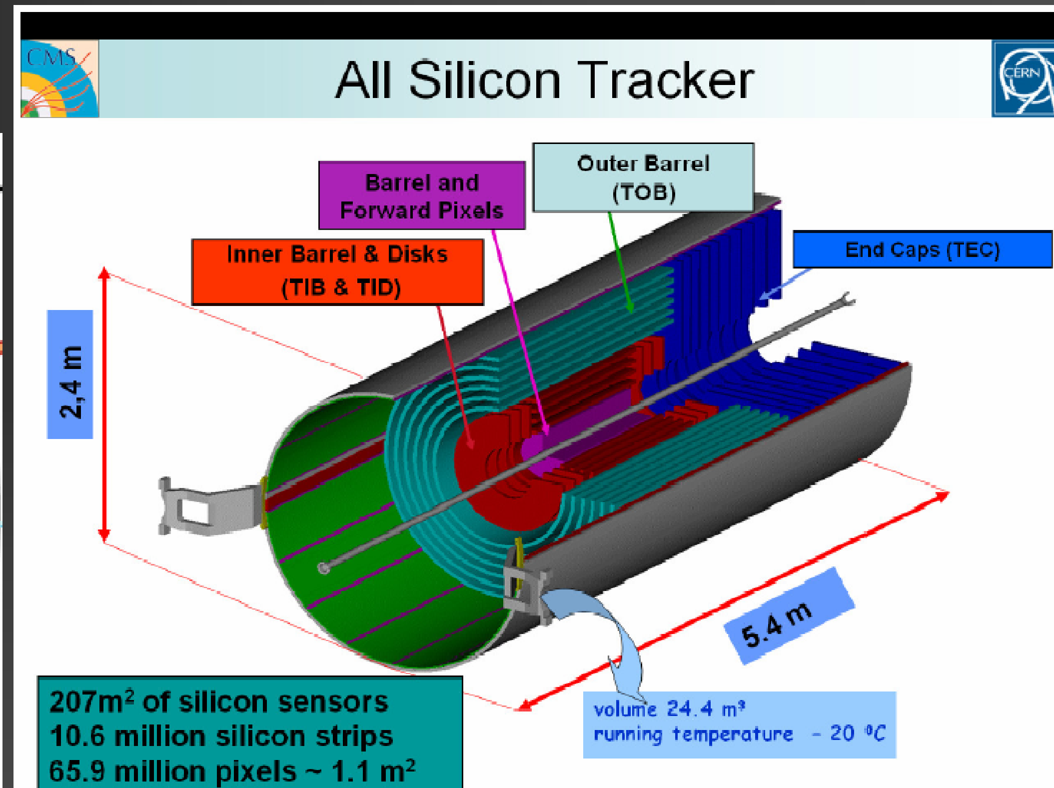
ATLAS



Vertex Detector Region - CMS

- Transverse slice

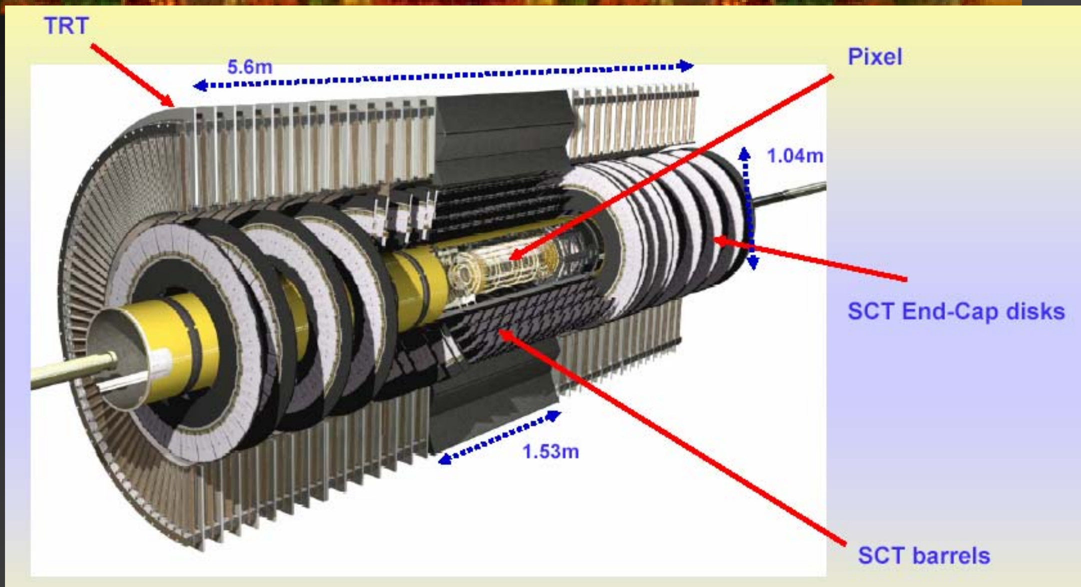




Pixels:
100 μm x 150μm
rϕ and z resolution: ~15 μm

1st pixel layer 4 cm from the beam

Vertex Detector Region ATLAS

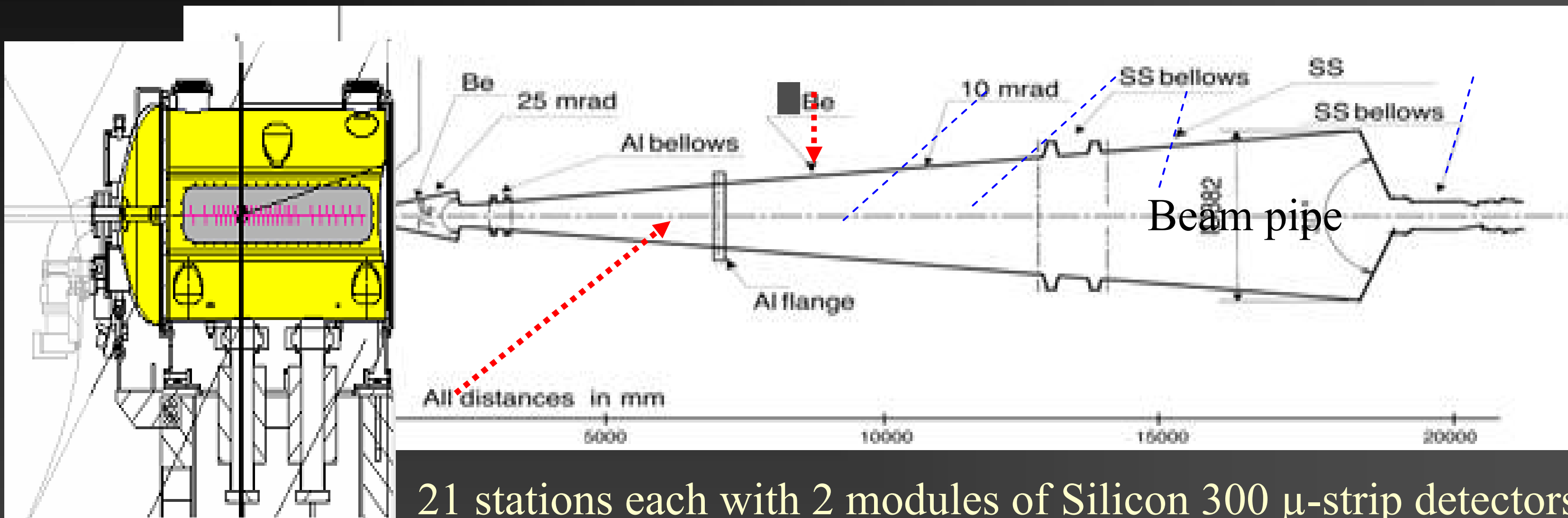


1^{st} pixel layer 5 cm from the beam

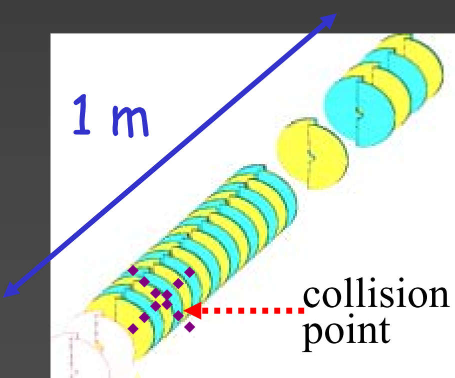
80,000,000 pixels a 50 x 400 micron
Resolution 14 x 115 microns
Total area 1,8 m^2

3 barrels at r = 5.0, 8.5, and 14.5 cm
3 disks (r = 11 - 20 cm) at each side

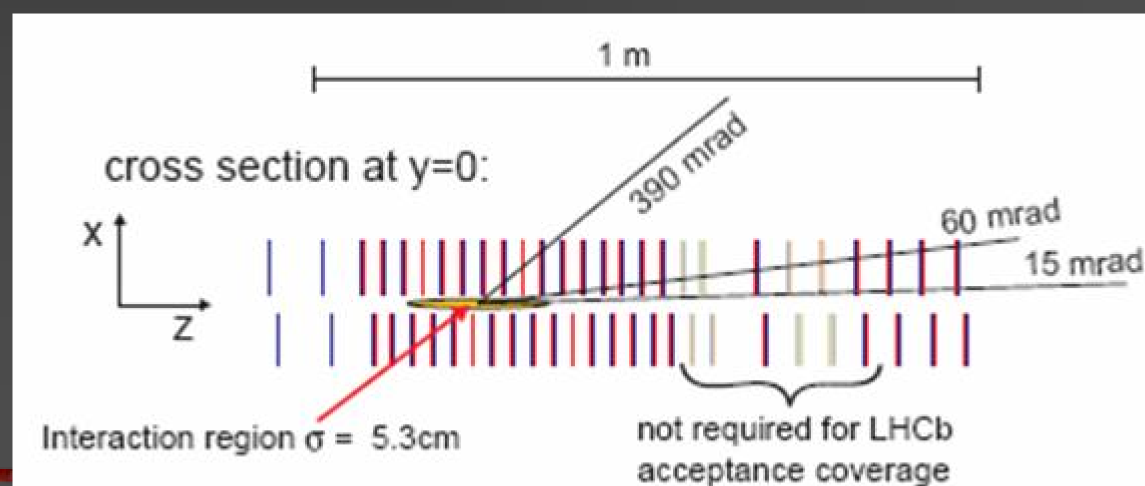
Vertex Detector Region LHCb



21 stations each with 2 modules of Silicon 300 μ-strip detectors that partially overlap, and move as close as 8 mm from the beam (retractable, 172K channels)



r-φgeometry variable pitch
[r (40-102μ);φ(36-97μ)]



Basics For Sensitivities

- # of b's into detector acceptance
- Triggering
- Flavor tagging
- Background reduction
  - Good mass resolution
  - Good decay time resolution: vertexing essential for reducing backgrounds at hadron colliders
  - Particle Identification

Detector Issues: Triggering

- ATLAS & CMS have a total bandwidth of ~200 Hz with limited bandwidth for b's ~15 Hz
- ATLAS
  - High luminosity (>2×10^{33} $cm^{-2}s^{-1}$): generally require 2 muons each with p_t> 6 GeV/c
  - Low luminosity: Add single muon trigger p_t> 6 GeV/c & use additional info in higher trigger levels
- CMS
  - High luminosity (>2×10^{33} $cm^{-2}s^{-1}$): generally require 2 muons each with p_t> 3 GeV/c
  - Low luminosity: Add single muon trigger p_t> 14 GeV/c & use additional info in higher trigger levels

Detector Issues: Triggering II

- LHCb uses multilevel scheme: 1st level Hardware trigger on "moderate" p_T μ, di-muons, e, γ & hadrons, e.g. p_T μ >1.3 GeV/c; veto on multiple interactions in a crossing except for muon triggers.
- Higher Level software triggers that require detached vertices
- Total of 2 kHz readout rate devoted to b's

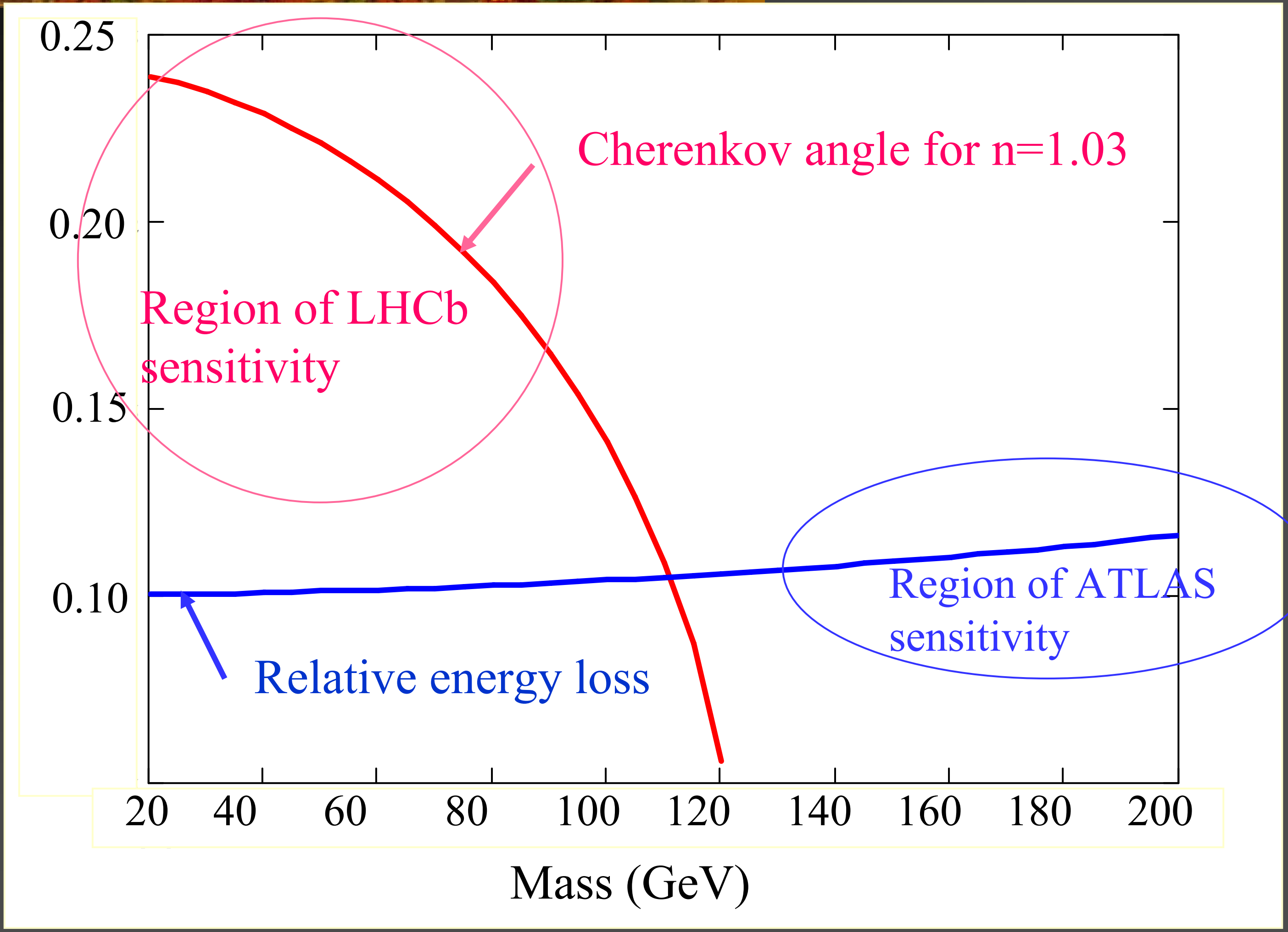
Detector Issues

- Multiple interactions/crossing
  - At full luminosity 1 for LHCb
  - At full luminosity ATLAS/CMS have 23
  - At low luminosity ATLAS/CMS have ~5
  - Multiple int/xing can cause confusion among production and decay vertices

Particle Identification

- In LHCb
  - 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 π, K, p over "entire" momentum range (2-100 GeV/c)
  - $\therefore$ a heavy charged particle will not radiate but anything normal, i.e. e, π, K, p, will in all 3 radiators. Thus we will know that we have new massive particle. Tracks also will deposit energy in calorimeters & muon detector, so some idea of energy and good measurement of its momentum
- ATLAS can measure dE/dx in TRT ~$(p/E)^2$

Cherenkov angle vs. dE/dx



- For stable particle p=500 GeV/c

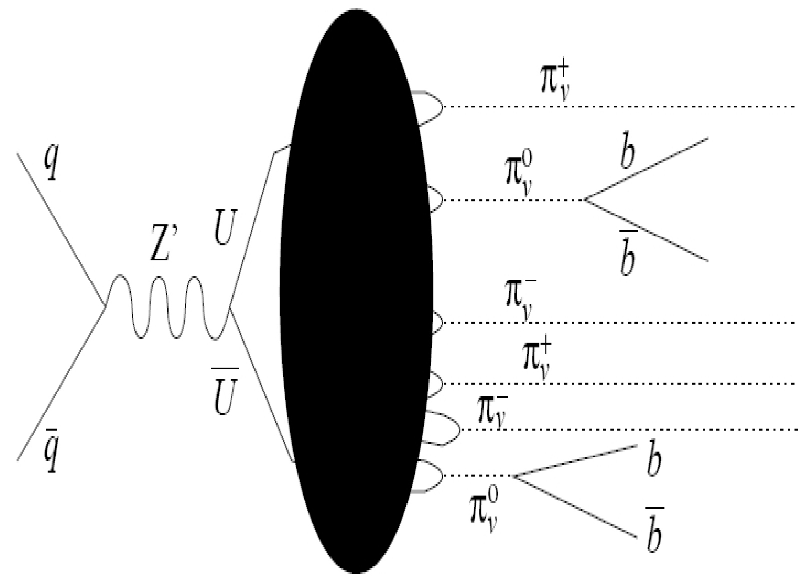
Most Currently Desirable Modes

- B_S mixing using $B_S \rightarrow D_S^+ \pi^-$
- High Statistics Measurement of forward-backward asymmetry in $B \rightarrow K^* \mu^+ \mu^-$
- Precision measurements of CP $\angle$'s
  - CP violating phase in B_S mixing using $B_S \rightarrow J/\psi \phi$
  - γ (or ϕ_3) Using $B^- \rightarrow D^o K^-$ tree level decays
  - γ using $B_S \rightarrow D_S^+ K^-$ time dependent analysis
  - α especially measurements of $B^o \rightarrow \rho\pi$ & $B^o \rightarrow \rho^o \rho^o$
  - β at high accuracy to pin down other physics
- CPV in various rare decay modes
- $B_{(S)} \rightarrow \mu^+ \mu^-$
- Important: Other modes, not currently in vogue

Possibilities of Detecting "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 Electroweak Baryogenesis
  - 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 $Z' \rightarrow U\,\overline{U}$, fragmentation causes lots of particle production, with some particles containing new U_1 & U_2 with v=0. These scalar particles $\pi_v^o \rightarrow b\overline{b}$ preferentially due to helicity conservation if $2m_B < m(\pi_v) < m_{WW}$

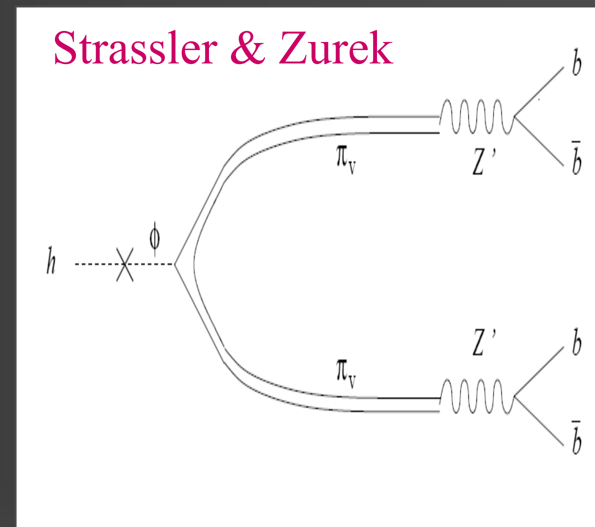
Strassler & Zurek



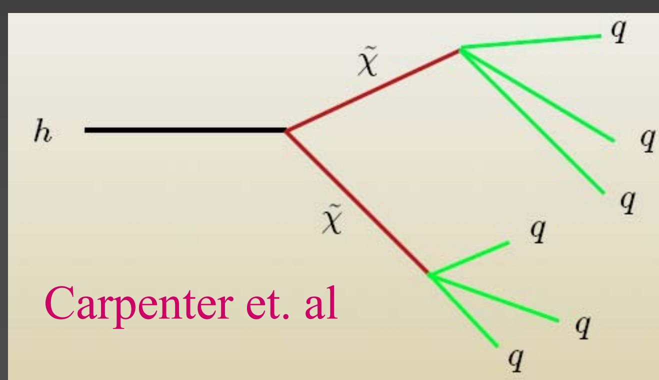
Higgs decays

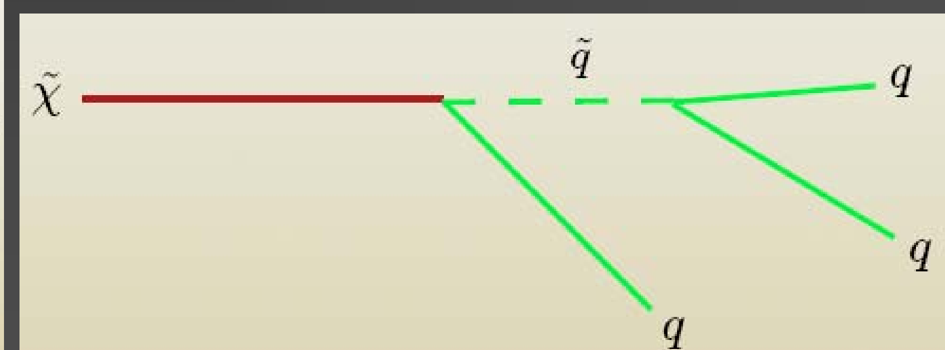
- π_v lifetime can be large or small
- Can also have

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



  - Or





  - Again lifetime (decay length) is unknown

Generalized Search

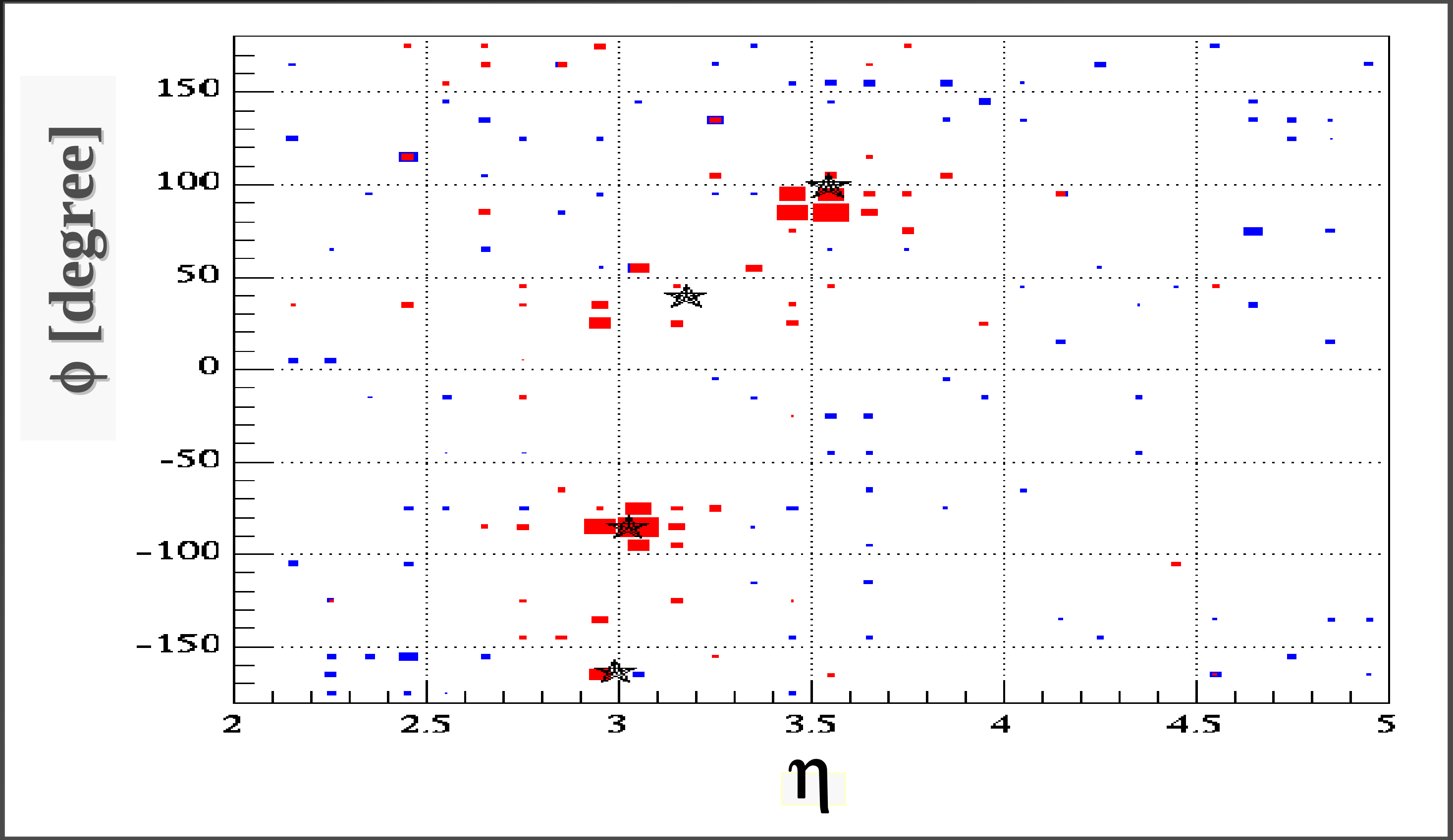
- Many models, many possibilities (see S. Kraml et al hep-ph/0608079)
- We need to search for anything new that decays to $b\bar{b}$
  - Need to do this as a function of lifetime and mass
  - We don't know branching ratio for Higgs decay or production cross-section for hidden valleys so we start with 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 Λ_v in the interval 35-120 GeV
- τ_v in the interval 0.1ps-100ps & infinity
- Use "acceptance" cuts:
  - At least 3 b-quarks in LHCb acceptance

E_t Flow Example for Higgs

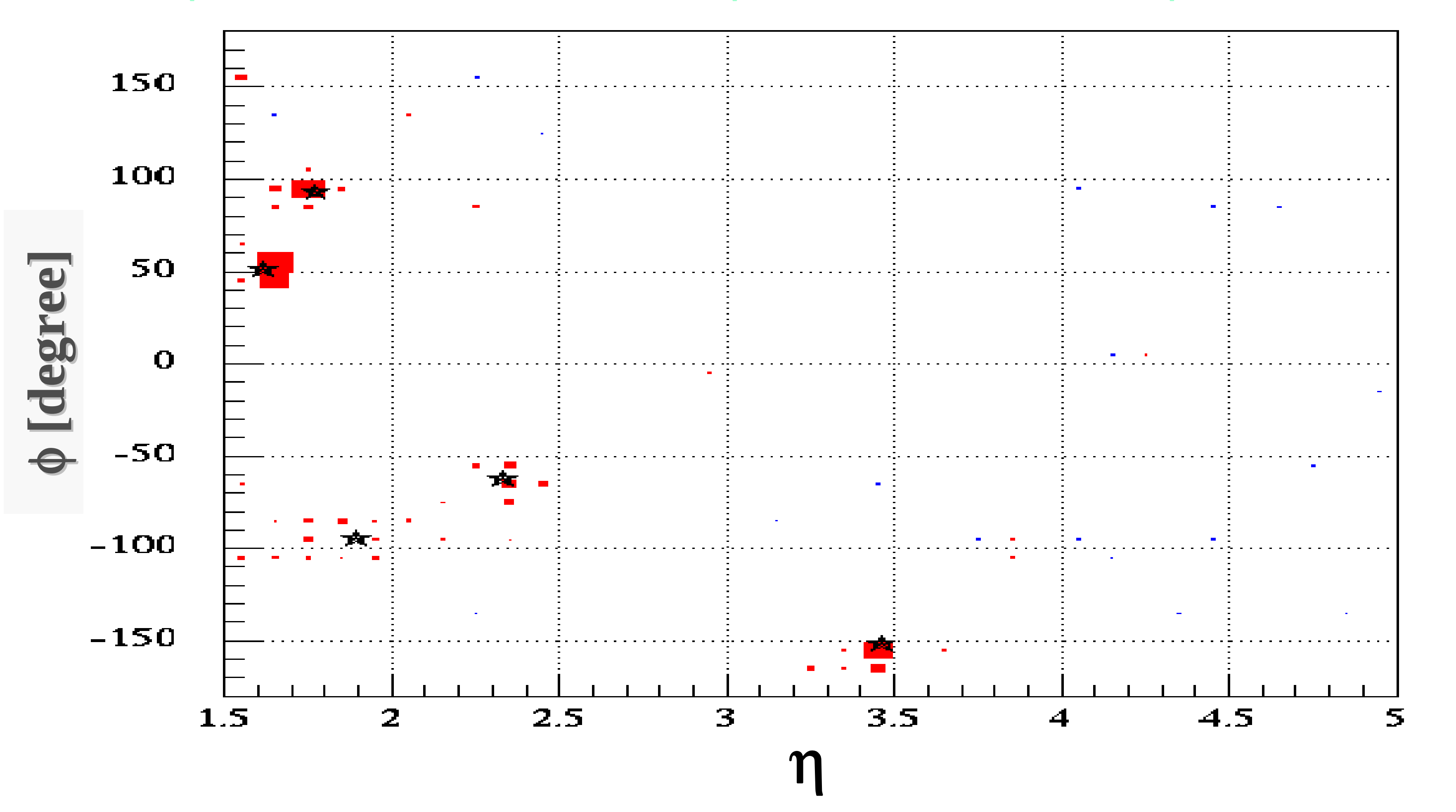
$M(H^0)$=120 GeV, $m(\pi_v^o)$=35 GeV, $\tau(\pi_v^o)$=1 ps



Calorimeter energies much larger than underlying event

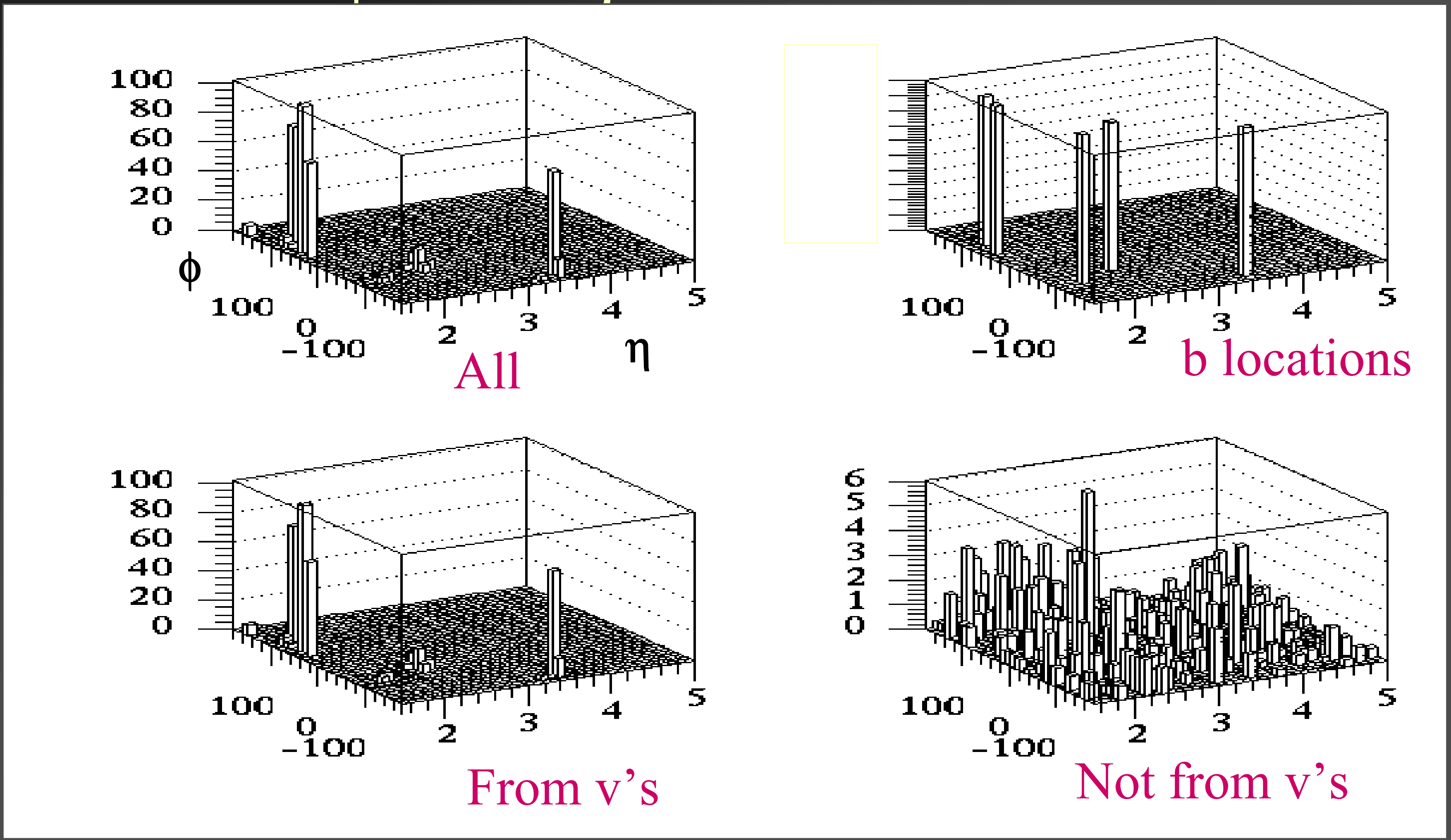
E_t Flow Example for Hidden Valley

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



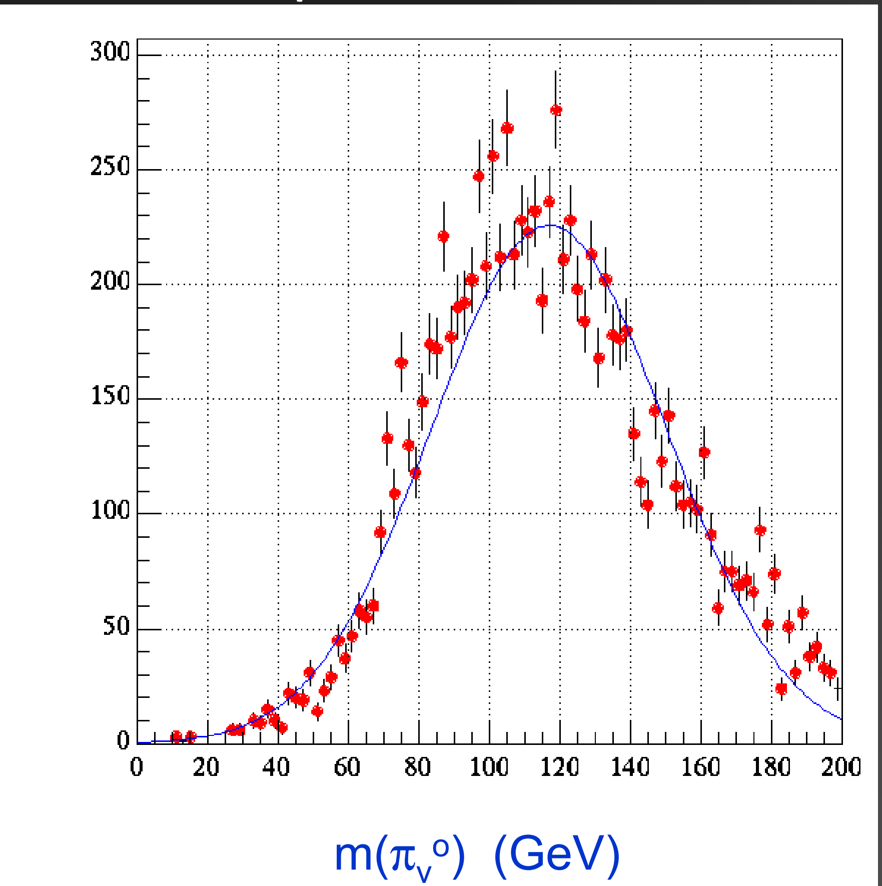
E_t versus ϕ & η

- Most of E_t is in b jets

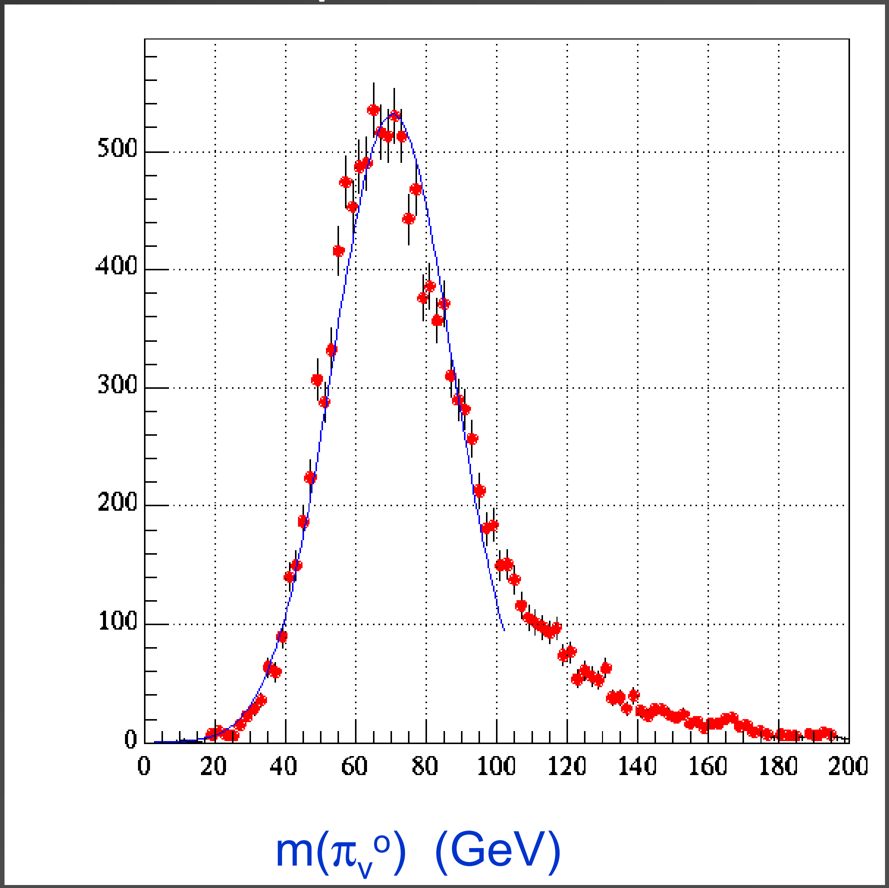


Dijet Invariant Mass

- $m(\pi_v^o)$= 120 GeV



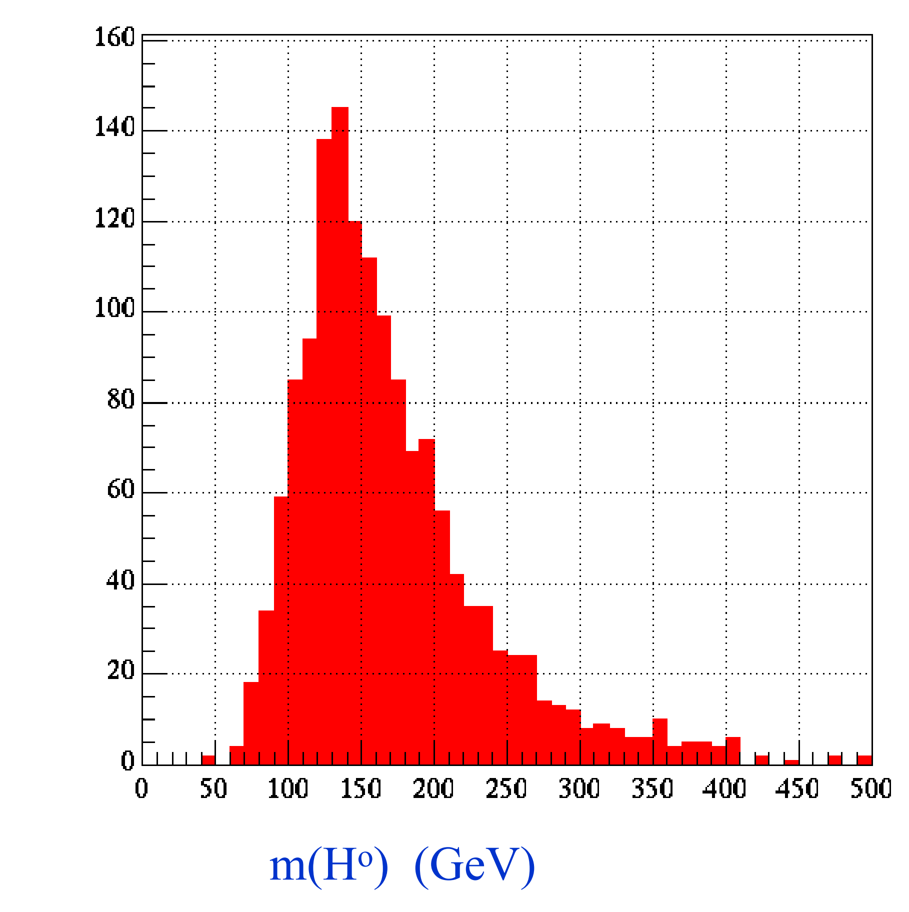
$m(\pi_v^o)$= 70 GeV



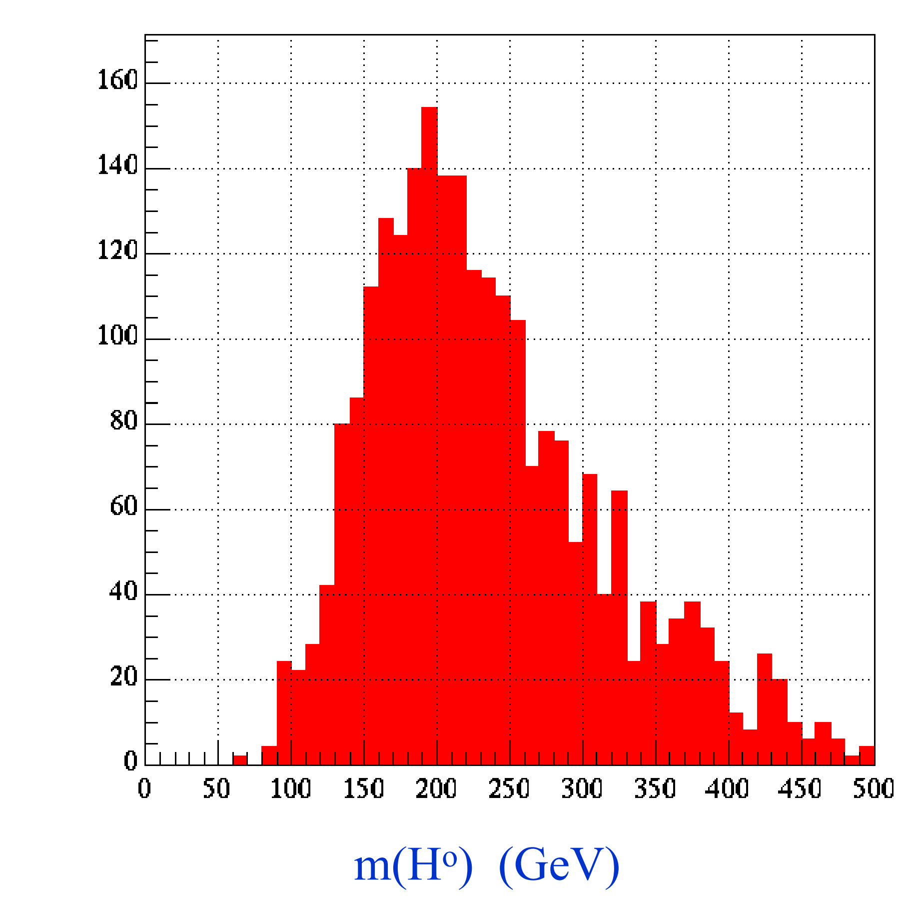
A first look, improvements possible

Higgs Masses: 4 jet masses

M_H=120 GeV



M_H=180 GeV

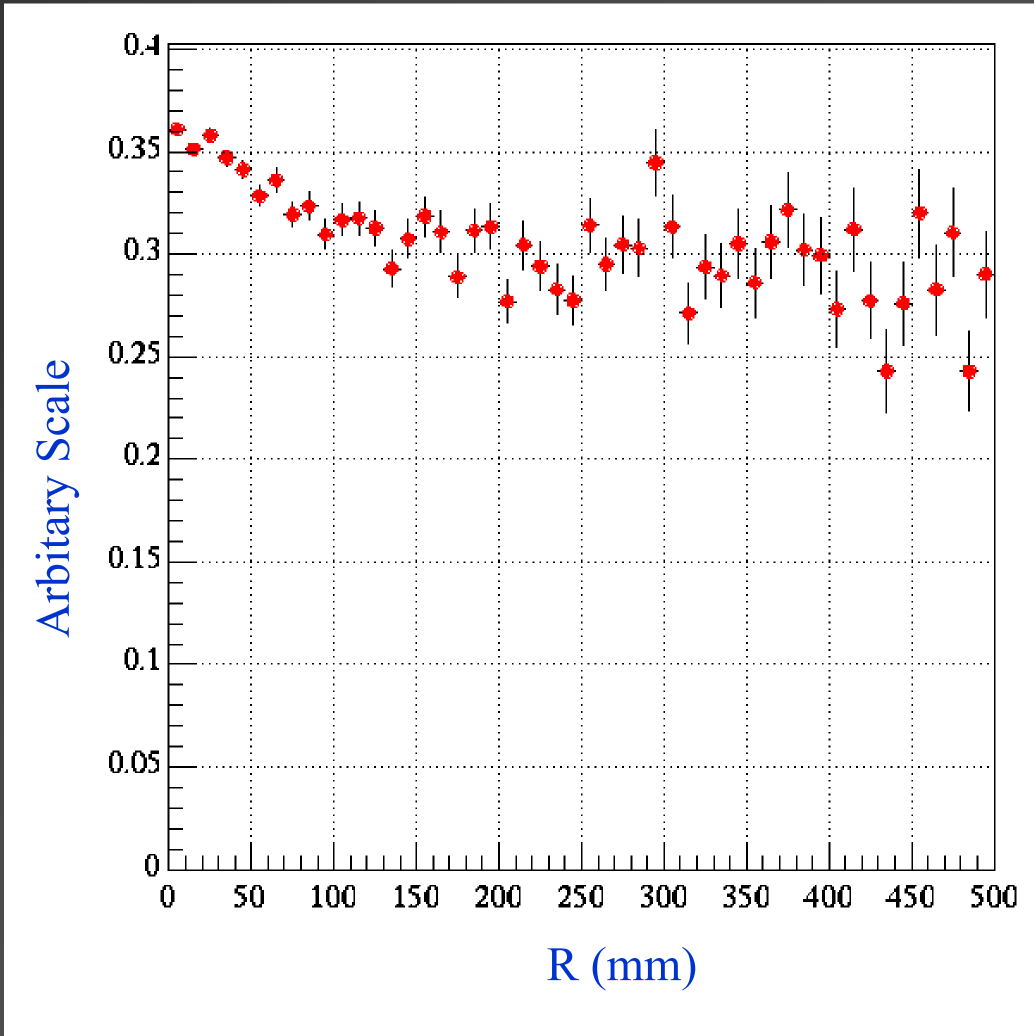


A first look, many improvements possible

Efficiencies

- 1st 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



Backgrounds

- These have not been yet considered
- Worried about $gg \to b\bar{b}b\bar{b}$, yet these b's are at relatively soft E_t
- Other Potential backgrounds are $b\bar{b}jj$ with two fake b jets (see Stelzer et al hep-ph/0611242), but excellent B tagging will help
- Long v lifetime would really distinguish events

Conclusions

- b & c decays essential to restrict models of New Physics seen at LHC/Tevatron
- Possibilities exist of seeing NP effects
  - in b or c decays
  - in new particles $\rightarrow b\bar{b}$
- Experiments at the LHC are well equipped to exploit heavy flavor decays
- LHCb is planning a higher luminosity upgrade

LHCb Ski Outing
March 2007

The End

A Hidden Valley?