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Conference Summary

Many references not properly cited here. Apologies in advance.

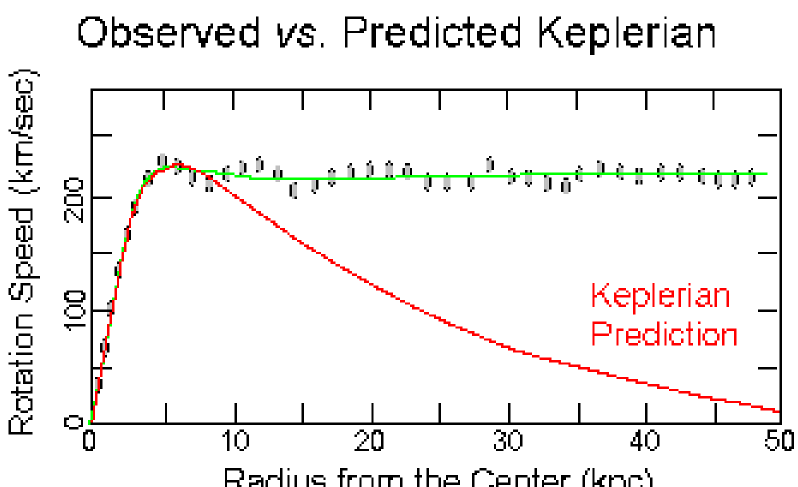
Far too much interesting Material to include in 45 min. Apologies in advance.

Physics Goals

- Discover, or help interpret, New Physics found elsewhere using b & c decays - There is New Physics out there: Standard Model is violated by the Baryon Asymmetry of Universe & by Dark Matter
- Measure Standard Model parameters, the "fundamental constants" revealed to us by studying Weak interactions
- Understand QCD; necessary to interpret CKM measurements.

Dark Matter

- 1933: Fritz Zwicky measured the motions of galaxies in the Coma cluster
  - Found velocities of 1000 km/sec relative to the cluster center.
  - This is greater than the escape velocity computed by adding up the light of the cluster galaxies.



Zwicky suggested that a component of "dark matter" adds extra gravity to hold the cluster together.

The Basics: Quark Mixing & the CKM Matrix

$$
V = \begin{array}{c} \\ u \\ c \\ t \end{array}
\begin{array}{c}
\begin{array}{ccc} \quad d \quad & \quad s \quad & \quad b \quad \end{array} \\
\begin{pmatrix}
1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3\left(\rho - i\eta\left(1-\frac{1}{2}\lambda^2\right)\right) \\
-\lambda & 1-\frac{1}{2}\lambda^2 - i\eta A^2\lambda^4 & A\lambda^2\left(1+i\eta\lambda^2\right) \\
A\lambda^3\left(1-\rho-i\eta\right) & -A\lambda^2 & 1
\end{pmatrix}
\end{array}
$$

$\longrightarrow$ mass

$\downarrow$ mass

- A, λ, ρ and η are in the Standard Model fundamental constants of nature like G, or α_{EM}
- η multiplies i and is responsible for CP violation
- We know λ=0.22 (V_{us}), A~0.8; constraints on ρ & η

All of The CKM Phases

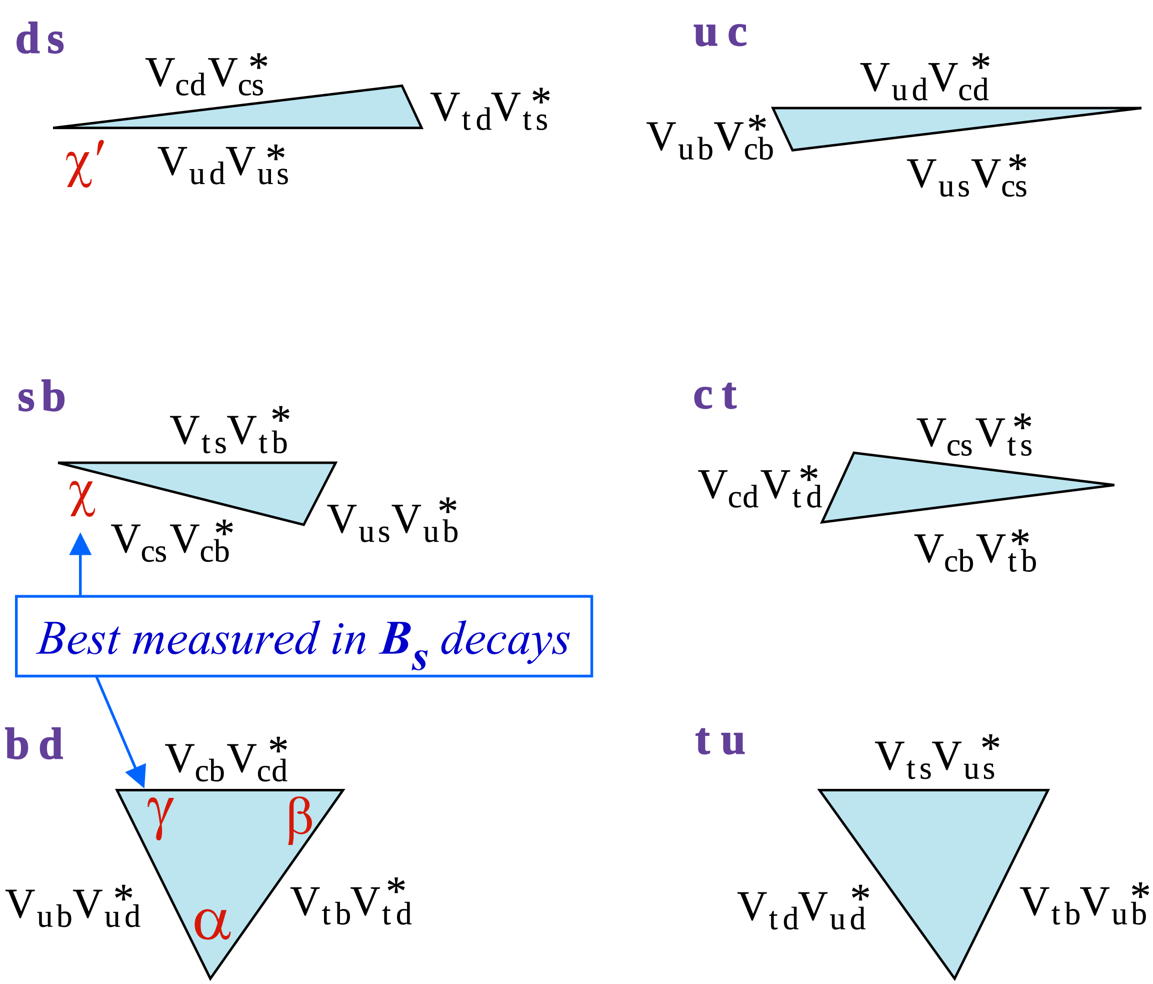
- The CKM matrix can be expressed in terms of 4 phases, rather than, for example λ, A, ρ, η:

$$\beta = \arg\left(-\frac{V_{tb}V_{td}^*}{V_{cb}V_{cd}^*}\right) \qquad \gamma = \arg\left(-\frac{V_{ub}^*V_{ud}}{V_{cb}^*V_{cd}}\right)$$

$$\chi = \arg\left(-\frac{V_{cs}^*V_{cb}}{V_{ts}^*V_{tb}}\right) \qquad \chi' = \arg\left(-\frac{V_{ud}^*V_{us}}{V_{cd}^*V_{cs}}\right)$$

- $\alpha = \pi-(\beta+\gamma)$, not independent
- α, β & γ probably large, χ small ~2^o, χ' smaller

The 6 CKM Triangles



- From Unitarity
- "ds" - indicates rows or columns used
- There are 4 independent phases: β, γ, χ, χ' (α can be substituted for γ or β, as $\alpha+\beta+\gamma=\pi$)

New Physics Tests

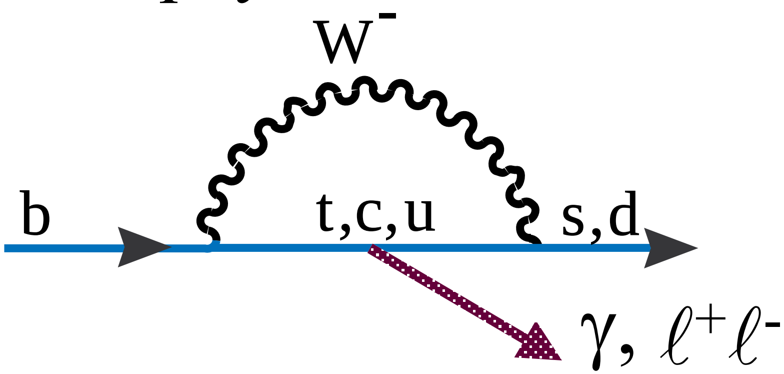
- We can use these CP violating or CP related variables to perform tests for New Physics, or to figure out what is the source of the new physics.
- There are also important methods using Rare Decays
- These tests can be either generic, where we test for inconsistencies in SM predictions independent of specific non-standard model, or model specific

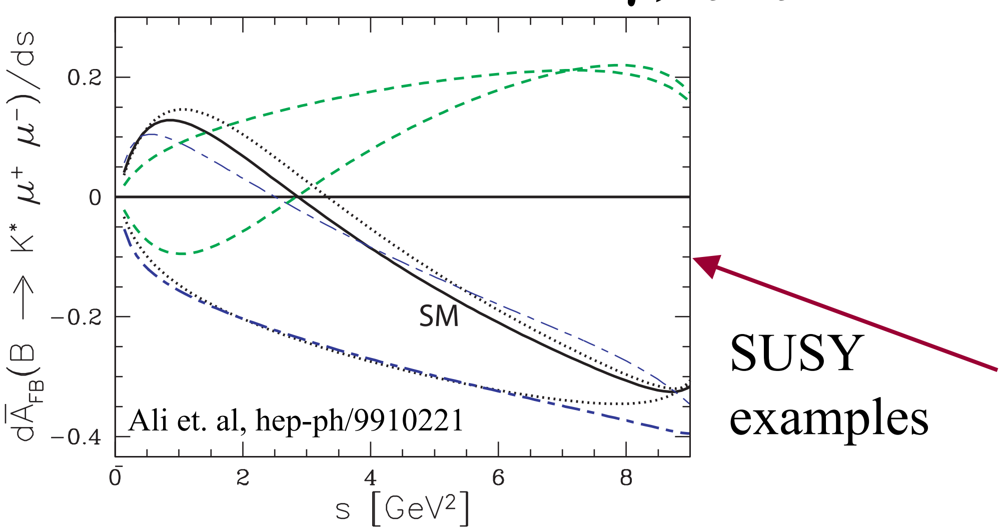
Generic Test: Critical Check using χ

- Silva & Wolfenstein (hep-ph/9610208), (Aleksan, Kayser & London), propose a test of the SM, that can reveal new physics; it relies on measuring the angle χ.
  - BTeV can use CP eigenstates to measure χ, for example $B_s \to J/\psi\eta^{(\prime)}$, $\eta \to \gamma\gamma$, $\eta' \to \rho\gamma$
  - Can also use $J/\psi\phi$, but need complicated angular analysis
  - The critical check is: $$\sin\chi = \lambda^2 \frac{\sin\beta\sin\gamma}{\sin(\beta+\gamma)}$$
  - Very sensitive since $\lambda = 0.2205 \pm 0.0018$
  - Since $\chi \sim 2^{o}$, need lots of data

Rare b Decays

- A good place to find new physics

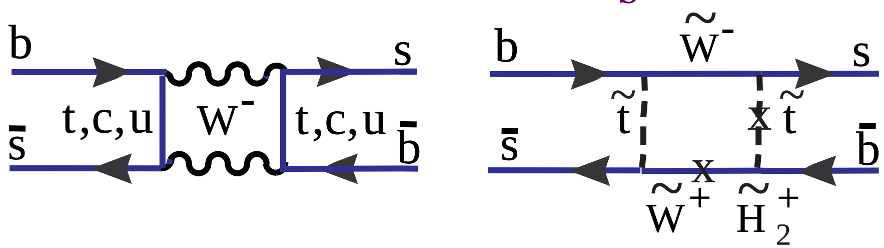




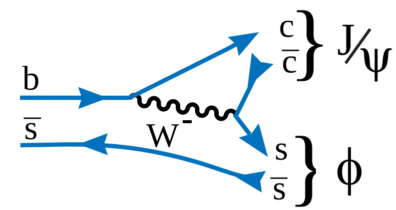
- New fermion like objects in addition to t, c or u, or new Gauge-like objects
- Inclusive Rare Decays such as inclusive $b \to s\gamma$, $b \to d\gamma$, $b \to s\ell^+\ell^-$
- Exclusive Rare Decays such as $B \to \rho\gamma$, $B \to K^*\ell^+\ell^-$: Dalitz plot & polarization

MSSM Measurements from Hinchcliff & Kersting (hep-ph/0003090)

- Contributions to B_s mixing



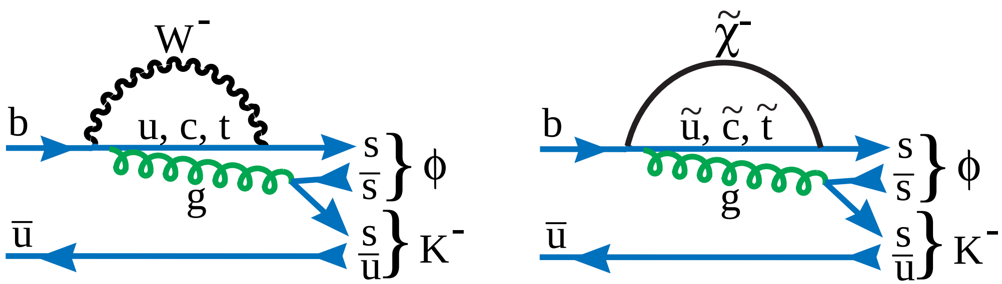
$B_s \to J/\psi\phi$



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

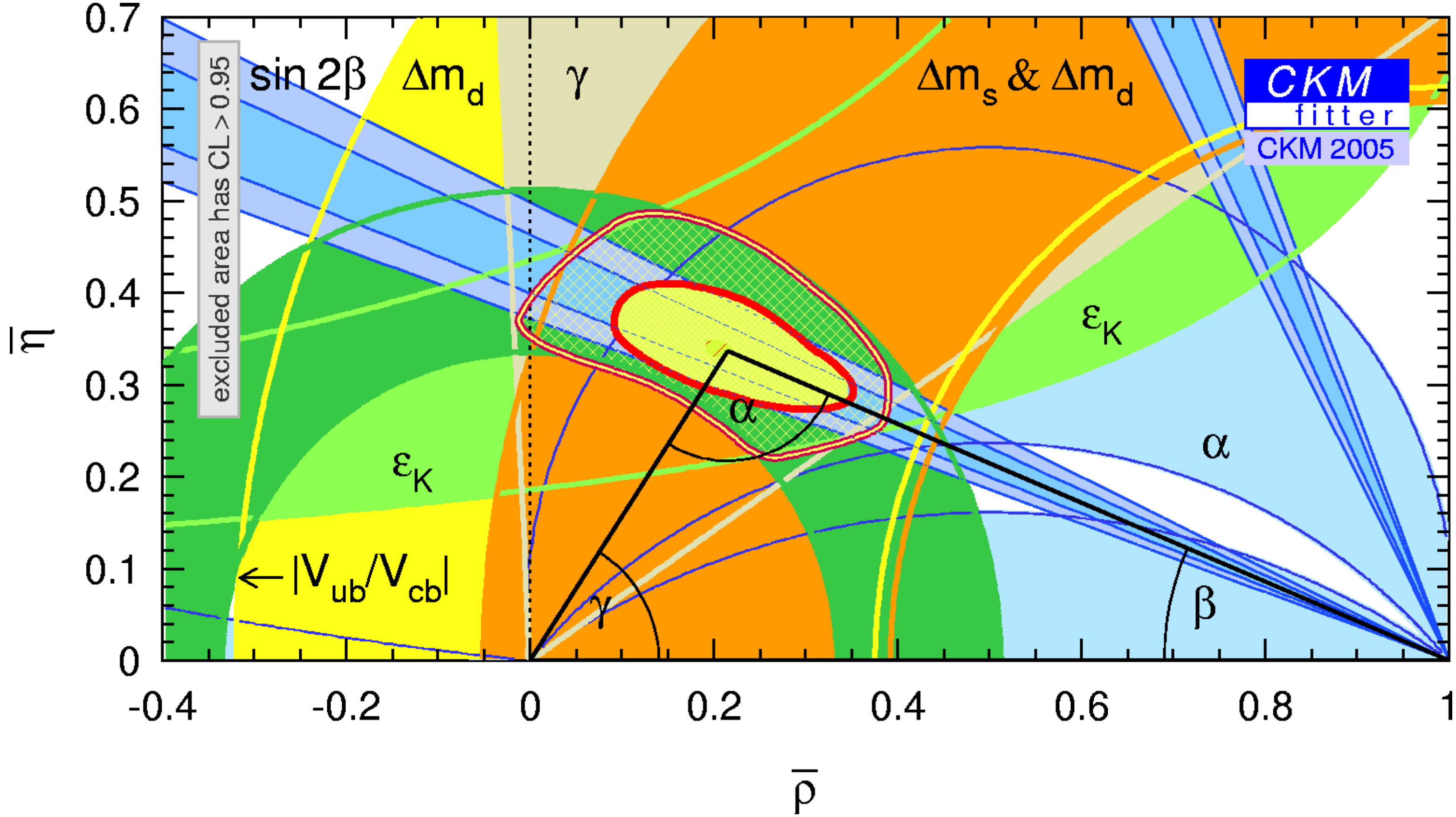
$B^- \to \phi K^-$



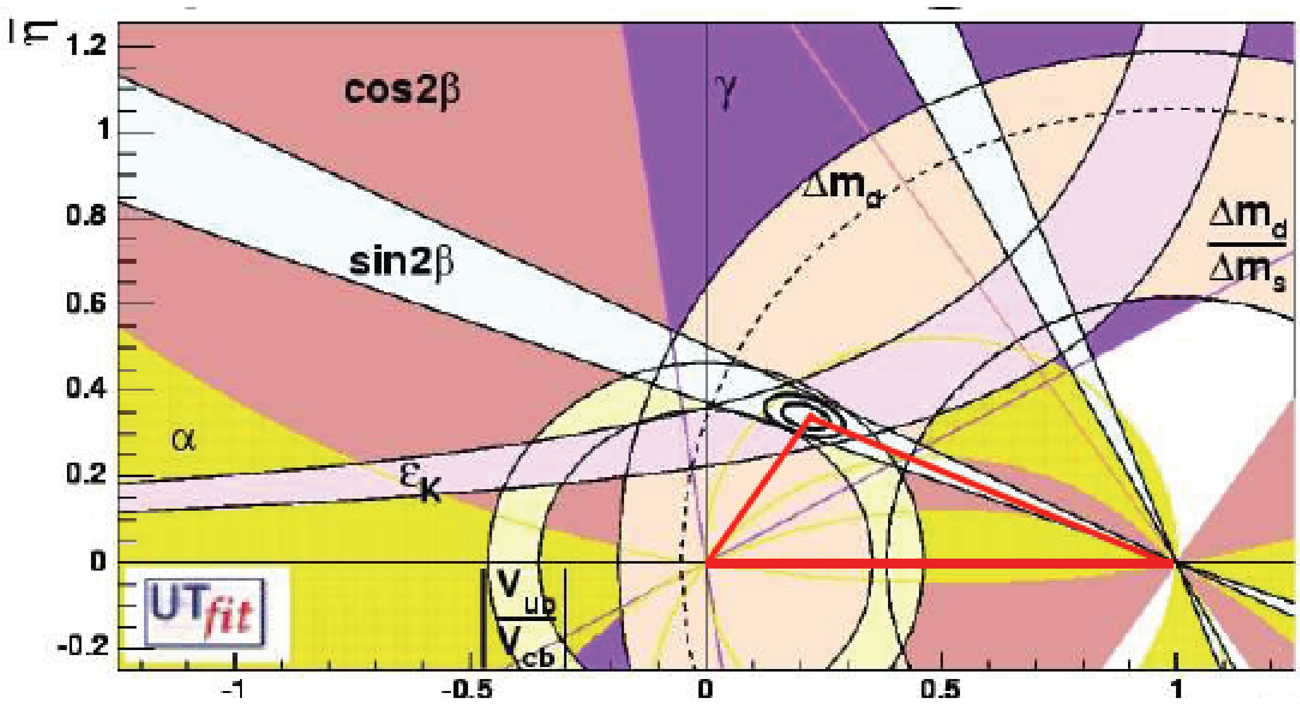
$\mathrm{Asym} = (M_W/m_{squark})^2\sin(\phi_\mu)$, ~0 in SM

What have we learned?

- CKM Fitter



UT Fits

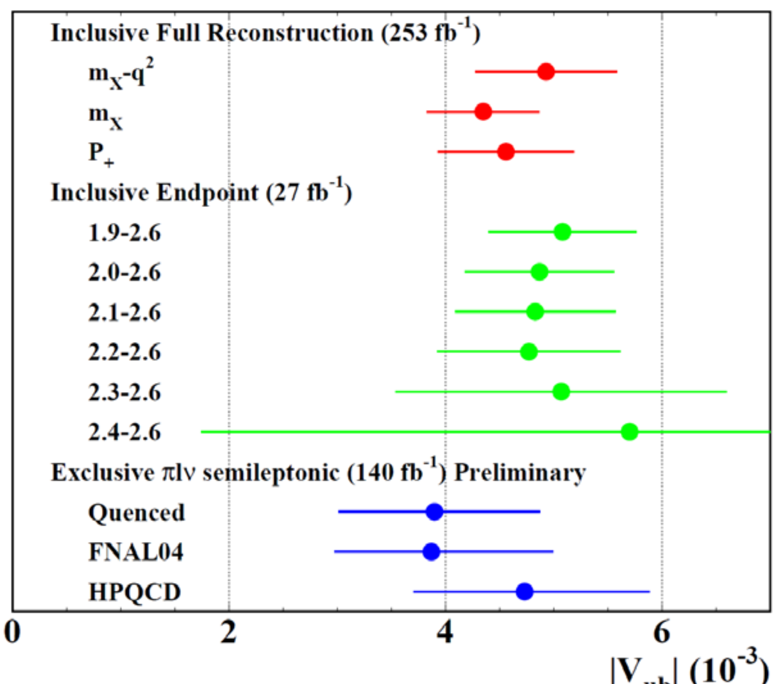


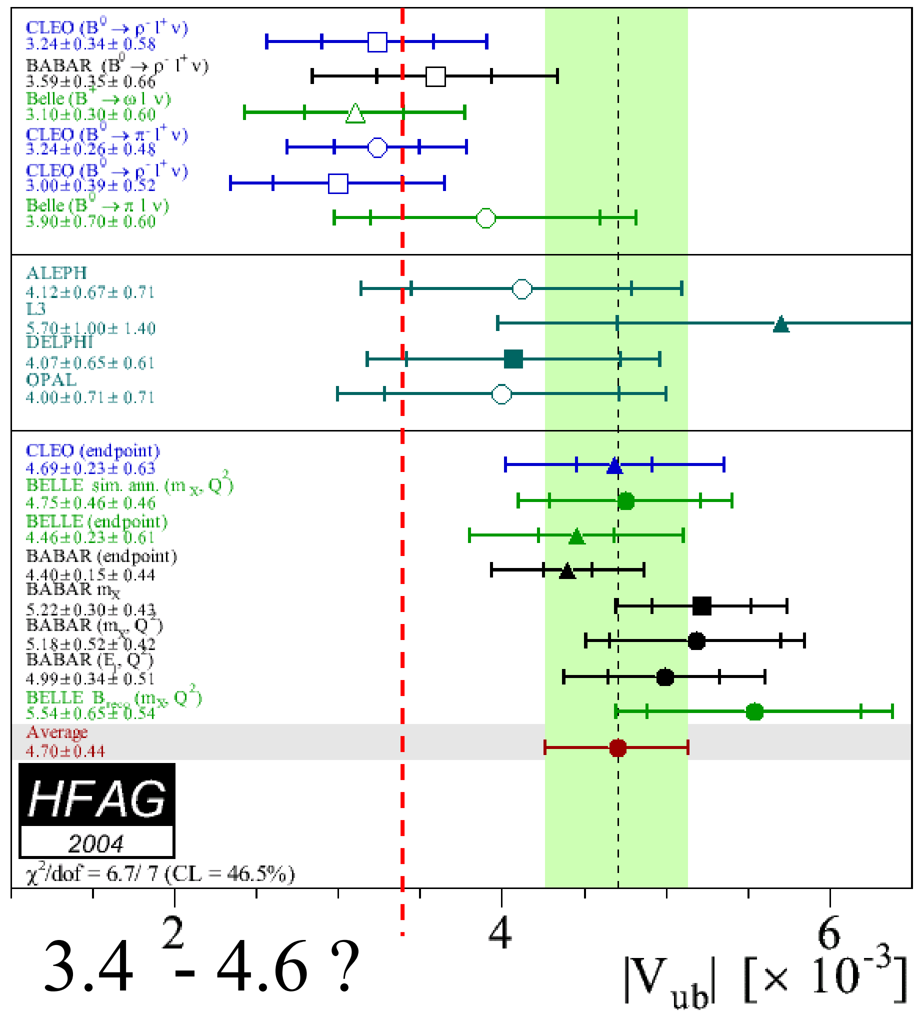
◆Not equivalent to CKM fitter: Much smaller input errors, e.g. V_{ub}. Bayesian statistics…

Example: V_{ub}

- Disagreement between exclusive & inclusive semileptonic V_{ub} determinations

New Belle Results



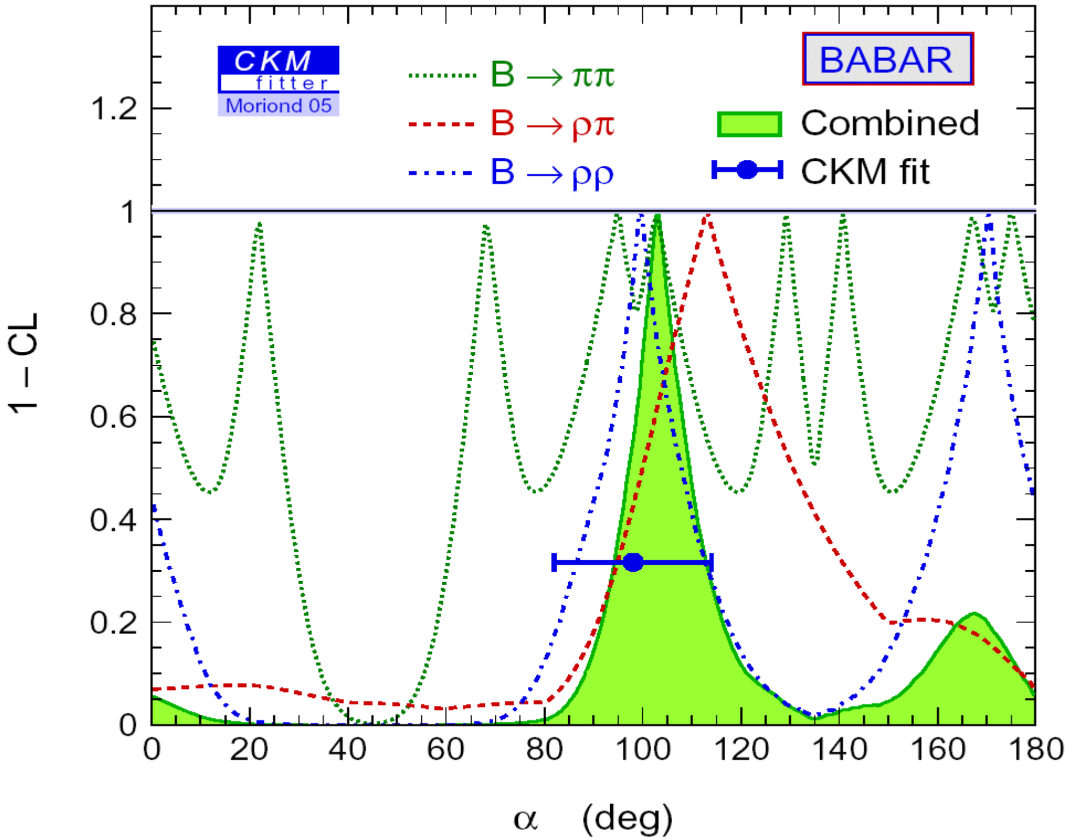


3.4 - 4.6 ?

What about WA?

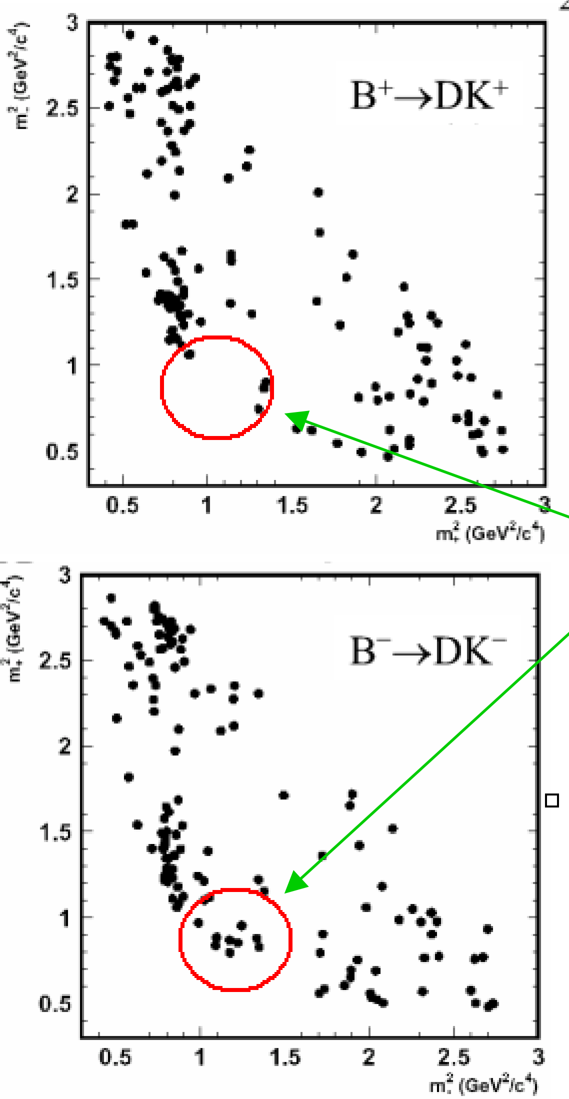
Important: α via B→ρρ (mostly)

- From Babar, similar results from Belle in excellent agreement
- Error dominated by upper limit on B→ρ°ρ° statistically limited, ideal for LHCb



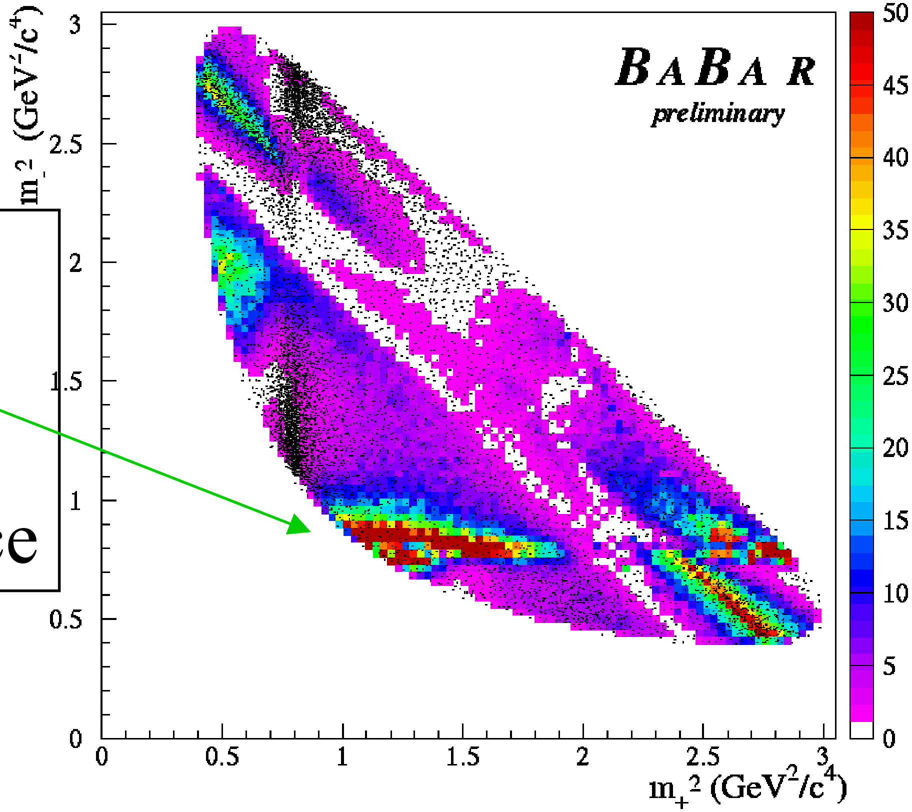
$$\alpha = (103^{+10}_{-\ 9})^{\circ}$$

Important: γ from $B \to D^o K^-$, $D^o \to K_s \pi^+ \pi^-$



Belle Sees Clear difference

$d^2 \ln L / d^2\gamma$ sensitivity



Are Babar & Belle compatible?

	Babar	Belle
DK :		
	$r_B = 0.118 \pm 0.079 \pm 0.034\ ^{+0.036}_{-0.034}$	$r_B = 0.21 \pm 0.08 \pm 0.03 \pm 0.04$
	$\delta_B = (\,104 \pm 45\ ^{+17}_{-21}\ ^{+16}_{-24}\,)°$	$\delta_B = (\,157 \pm 19 \pm 11 \pm 21\,)°$
*D*K :*	$r_B^* = 0.169 \pm 0.096\ ^{+0.030}_{-0.028}\ ^{+0.029}_{-0.026}$	$r_B^* = 0.12\ ^{+0.16}_{-0.11} \pm 0.02 \pm 0.04$
	$\delta_B^* = (\,296 \pm 41\ ^{+14}_{-12} \pm 15\,)°$	$\delta_B^* = (\,321 \pm 57 \pm 11 \pm 21\,)°$

Babar: $\gamma = (\,70 \pm \underbrace{31}_{\text{stat.}}\ \underbrace{^{+12}_{-10}}_{\text{syst.}}\ \underbrace{^{+14}_{-11}}_{\text{Dalitz}}\,)°$

Belle: $\gamma = (\,68\ \underbrace{^{+14}_{-15}}_{\text{stat.}} \pm \underbrace{13}_{\text{syst.}} \pm \underbrace{11}_{\text{Dalitz}}\,)°$

- Different r_B values generate very different errors. If r_B is fixed are results for g compatible?

DK :*

$r_B(K^*) = 0.25\ ^{+0.17}_{-0.18} \pm 0.09 \pm 0.04 \pm 0.08$

$\delta_B(K^*) = (\,353 \pm 35 \pm 8 \pm 21 \pm 49\,)°$

$\gamma = (\,112 \pm 35 \pm 9 \pm 11 \pm 8)°$

Limits on New Physics via B_d mixing

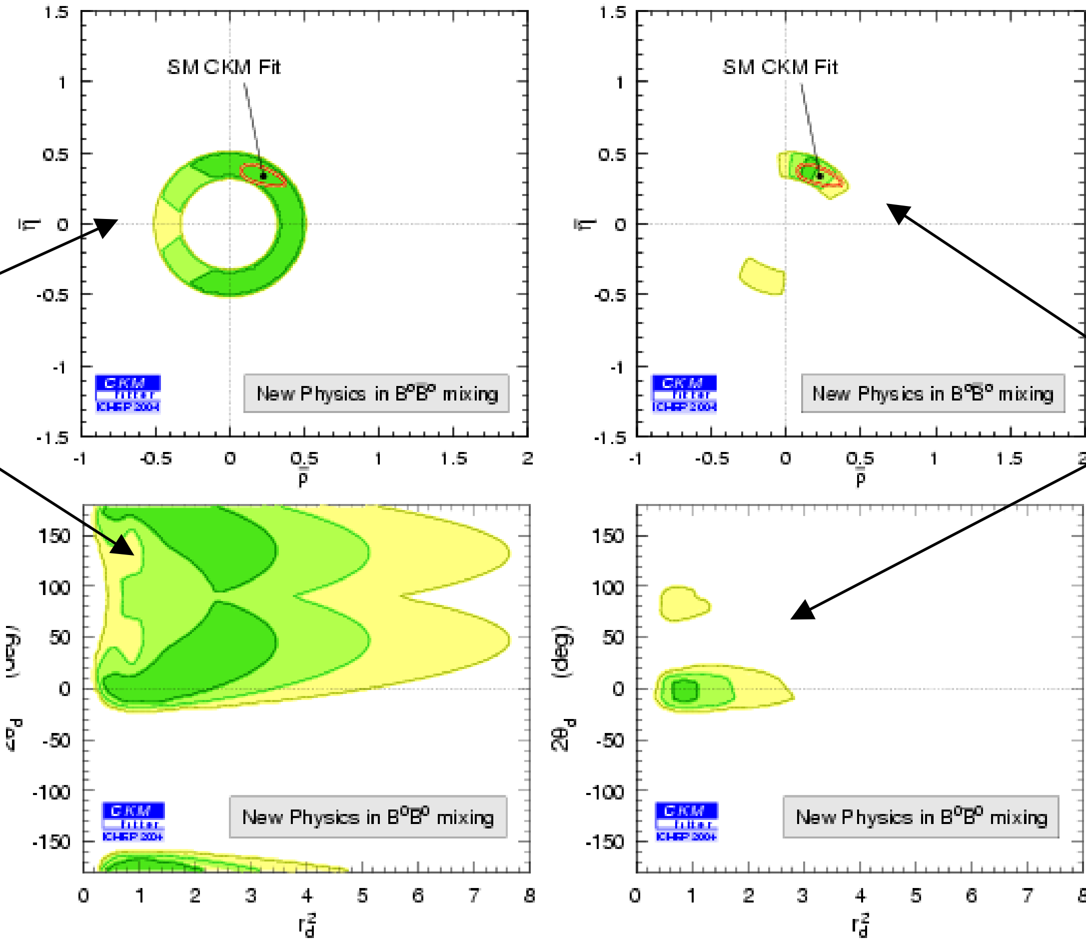
- Many ways to do this
- Ligeti Beijing 2004
  - Take V_{ub}/V_{cb} and γ from $B \rightarrow DK^-$ as tree level processes not affected by new physics
  - Take $\Delta m_b = r_d^2 \Delta m_b(SM)$, ($r_d$ magnitude of NP)
  - Take $S_{\psi Ks} = \sin(2\beta + 2\theta_d)$, $S_{\rho+\rho-} = \sin(2\alpha - 2\theta_d)$, ($\theta_d$ phase of NP)
- Silvestrini – UT triangle fits

Constraints on New Physics

From Ligeti

Without α, γ

With α, γ



gure 8. Allowed regions in the $\rho-\eta$ plane (top) and the $r_d^2 - 2\theta_d$ plane (bottom) in the presence of new ıysics in $B-\overline{B}$ mixing. The left [right] plots are the allowed regions without [with] the new constraints on α, cos 2β, and $2\beta+\gamma$. The dark, medium, and light shaded areas have CL $>$ 0.90, 0.32, and 0.05, respectively.

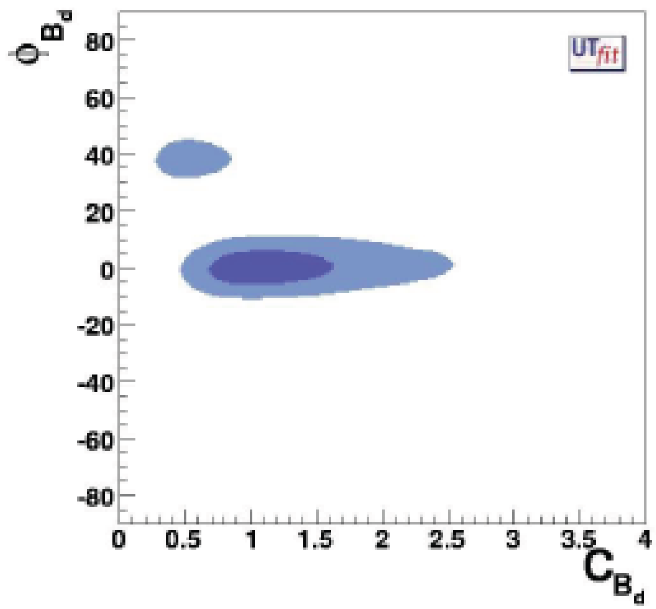
UT Constraints on NP

- Generally same answer as Ligeti, though one can argue with the precision
- ϕ_{Bd} is probably close to ϕ_{SM} and NP can be large wrt to SM for close to equal phases
- Physics via B_s mixing (angle χ is unconstrained)

Using:

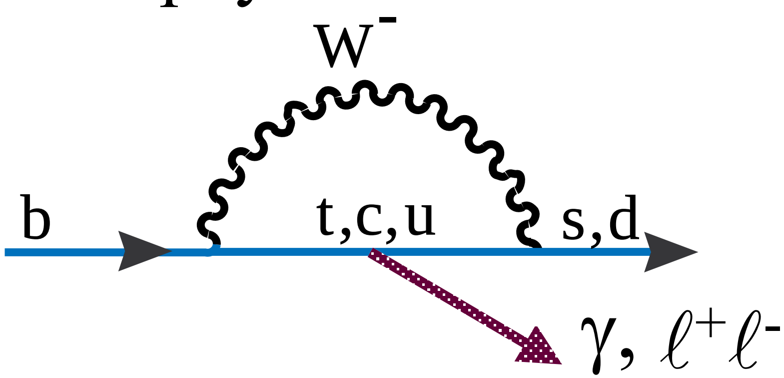
- ε, Δm_d, sin 2β
- α, cos 2β & A_{SL}

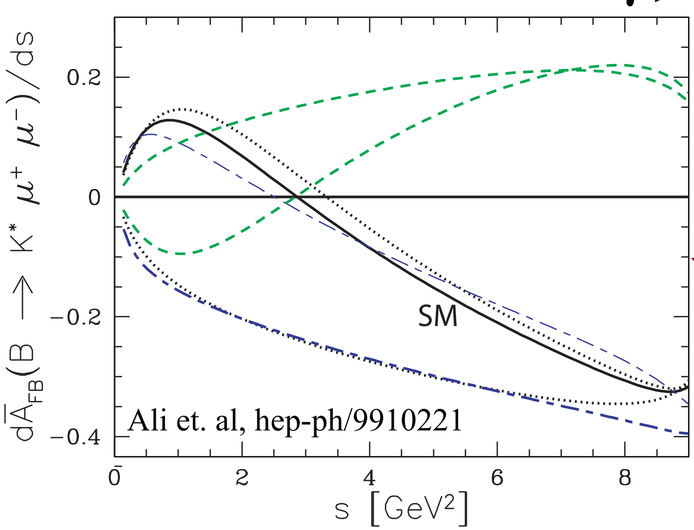
$C_{Bd}=r_d^2$



Rare b Decays

- A good place to find new physics



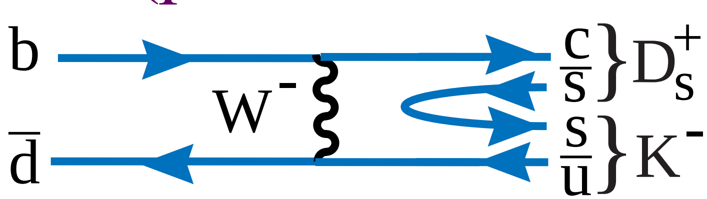


SUSY examples

- New fermion like objects in addition to t, c or u, or new Gauge-like objects
- Inclusive Rare Decays such as inclusive $b \to s\gamma$, $b \to d\gamma$, $b \to s\ell^+\ell^-$
- Exclusive Rare Decays such as $B \to \rho\gamma$, $B \to K^*\ell^+\ell^-$: Dalitz plot & polarization

Hadronic B Decays: Phase shifts can be large

- Known to be large in D decays
- $B^o \rightarrow D^o\pi^o$ observed by CLEO & Belle & BaBar; construct isospin triangle with $B^o \rightarrow D^+\pi^-$ & $B^- \rightarrow D^o\pi^-$, find strong phase shift between 16.5° - 38.1°
- $B^o \rightarrow D_s^- K^+$ observed by Belle & BaBar at $4\text{x}10^{-5}$ level, evidence for W exchange diagram? or is it rescattering from $D^+\pi^-$? (phase shifts & rescattering go hand-in-hand)

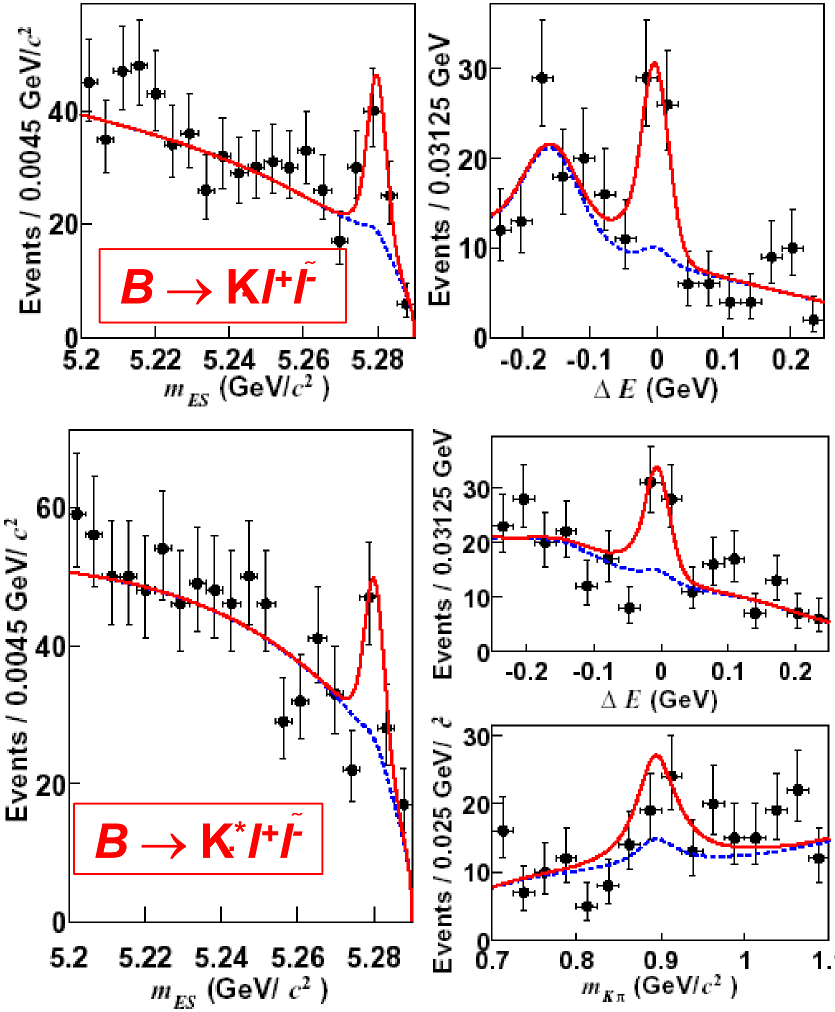


- Final state rescattering plays a role in interpreting the fundamental CP violating angles from charmless two-body decays

Status

- $\mathcal{B}(B \to K \ell^+ \ell^-) = (3.4 \pm 0.7 \pm 0.3) \times 10^{-7}$
- $\mathcal{B}(B \to K^* \ell^+ \ell^-) = (7.8 \pm 1.8 \pm 1.2) \times 10^{-7}$
- Based on 229 M BB’s
- Almost nothing yet on polarization

Babar here (also Belle)

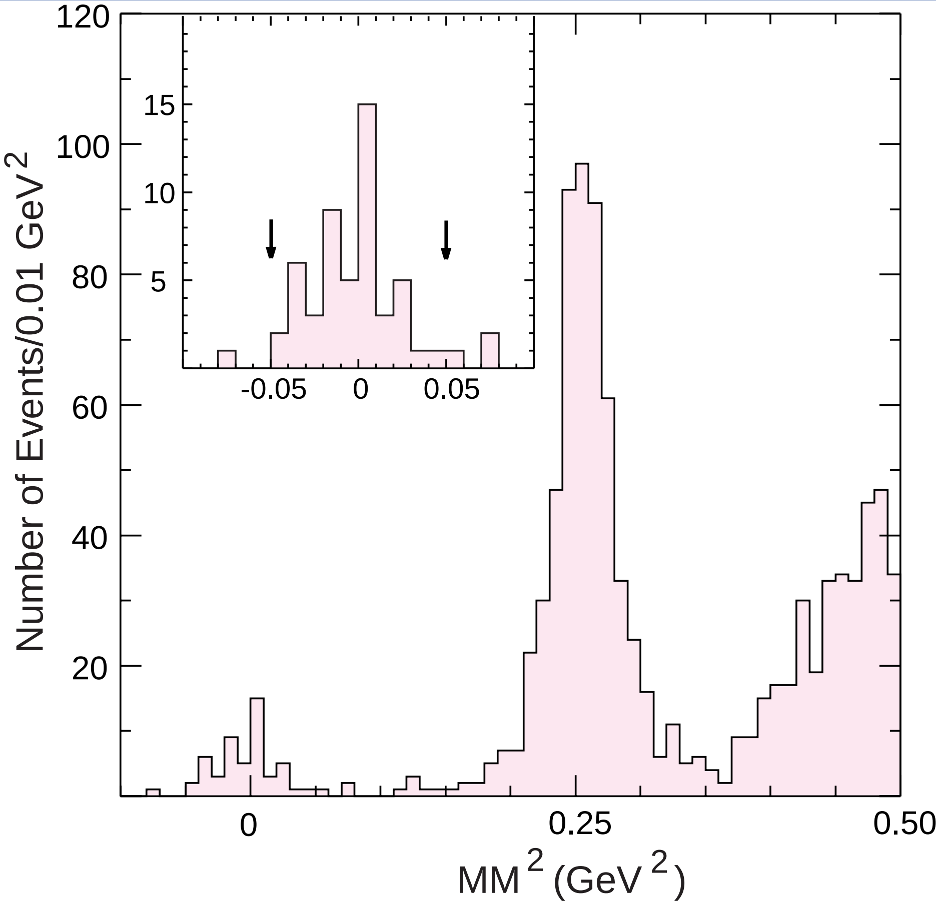


Thus Beware of Theory

- Example: BBNS a real theory in QCD but failed to get the right two-body branching ratios for $B \to \pi^o \pi^o$ and $B \to K\pi$ (M. Beneke, G. Buchalla, M. Neubert & C.T. Sachrajda, Nucl.Phys. B606 (2001) 245-321)
- Best to test a theory in one place and then use it in another.
- Examples
  - Unquenched Lattice QCD. Check with f_D measurements and ratio f_{D^+}/f_{Ds}

f_{D^+} From CLEO-c

- New value will be announced at Lepton-Photon conference in Artuso's talk. Error will be $\pm 16^{+9}_{-7}$ MeV
- New Unquenched Lattice result to also appear
- Thus we will have an interesting comparison



Combining Semileptonics & Leptonics

- Decay rate:

$$\frac{d\Gamma\left(D \to Pe\nu\right)}{dq^2} = \frac{\left|V_{cq}\right|^2 P_P^3}{24\pi^3}\left|f_+(q^2)\right|^2$$

- Test of models in D decays: predictions of shapes of form factors (for D→Vector $\ell^+\nu$ there are 3 form-factors)
- Note that this ratio depends only on QCD:

$$\frac{1}{\Gamma\left(D^+ \to \ell\nu\right)}\frac{d\Gamma\left(D^+ \to \pi e\nu\right)}{dq^2} \,\alpha\, \frac{P_\pi^3\left|f_+(q^2)\right|^2}{f_{D^+}^2}$$

New Particles

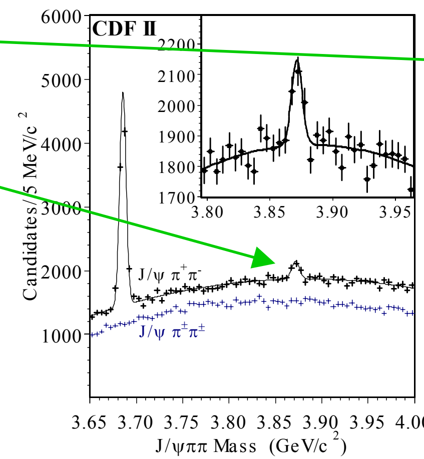
- This teaches us about QCD & is also lots of fun
- X(3870) found in $B^- \to K^- \pi^+\pi^- J/\psi$, in $\pi^+\pi^- J/\psi$ mass spectrum by Belle

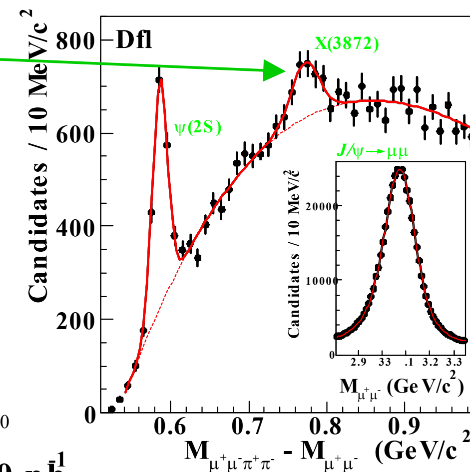
  M_x = (3871.9 ± 0.5) MeV is within error equal to the D^oD^{o*} threshold (3871.3 ± 1) MeV $\to$ Speculation: X might be a molecule - like bound state

- $\pi^+\pi^-$ mass prefers J^{PC} 1^{++}
- Belle observes $X \to \gamma J/\psi$ (~14% of $\pi\pi J/\psi$ rate) $\Rightarrow C=+1$
- They also see $X \to \pi^+\pi^-\pi^o J/\psi$ (ω below threshold)

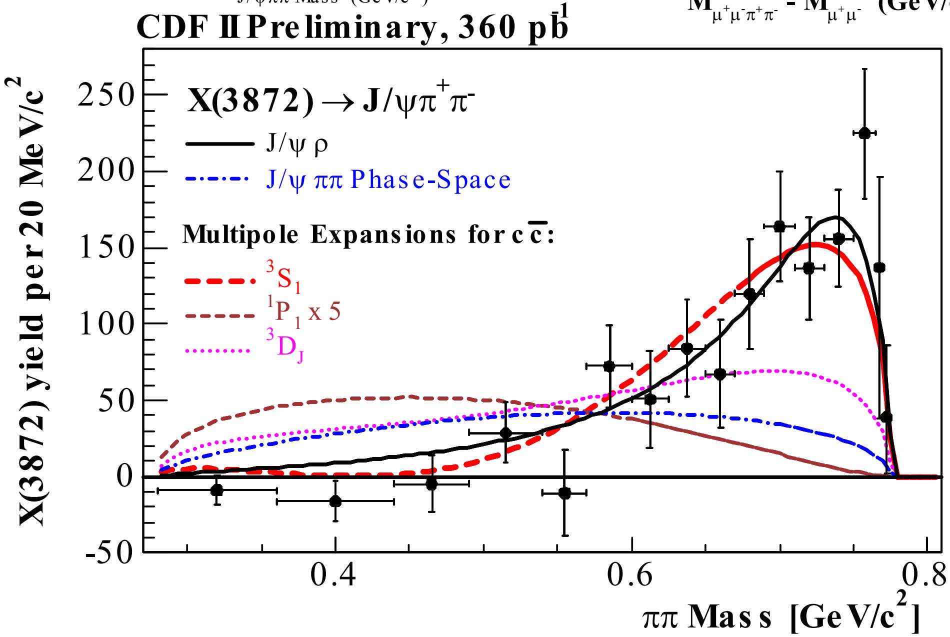
CDF & D0 confirmation

Mass Peaks





- $m(\pi^+\pi^-)$ favours high end of mass spectrum, compatible with intermediate ρ^0 ! $\pi^+ \pi^-$ resonance
- also $^3S_1$ multipole-expansion for charmonium possible
  - no charmonium candidate at that mass
  - $^3S_1$ also has $J^{PC} = 1^{-}$) non-observation by BES



$\psi'' \to \gamma\, \chi_{C1}$

- CLEO measures $\psi'' \to \gamma\, \psi /\ \psi'' \to \pi^+\pi^-\, \psi = 1.8 \pm 0.4 \pm 0.2$
- The ψ'' is primarily a 1^3D_1 state, expect a 2-3X larger rate for a 1^3D_2 state
- $\Rightarrow$ X(3870) is not a 1^3D_2 state

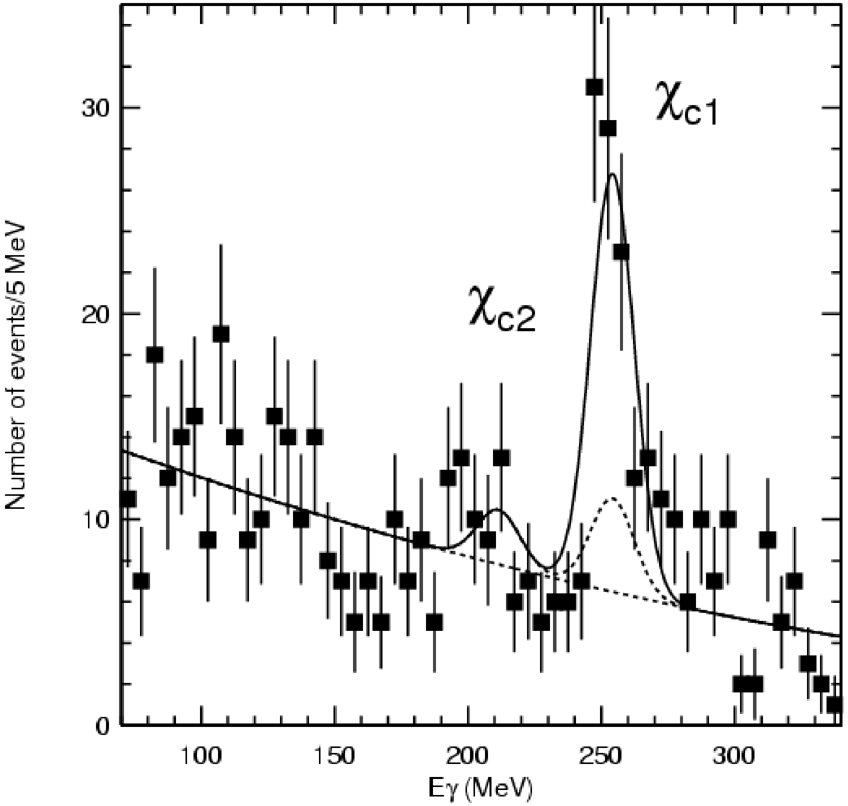
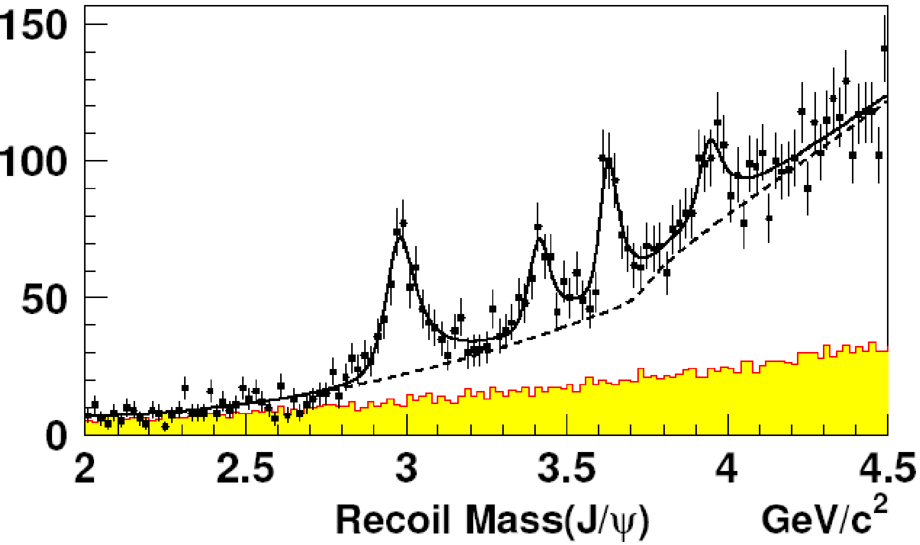


FIG. 1: Energy of the lower energy photon for the selected $e^+e^- \to \gamma\gamma J/\psi$, $J/\psi \to l^+l^-$ events at the $\psi(3770)$ resonance. The solid line shows the fit. The dashed lines show the smooth background and the expected background peaks from radiatively produced tail of the $\psi(2S)$ resonance (see the text). The latter saturates the χ_{c2} contribution. The excess of data over the χ_{c1} peak indicated with the dashed line represents the evidence for $\psi(3770) \to \gamma\chi_{c1}$ transitions.

Other new particles



Belle $e^+e^- \to J/\psi\ X$

Fit yields:

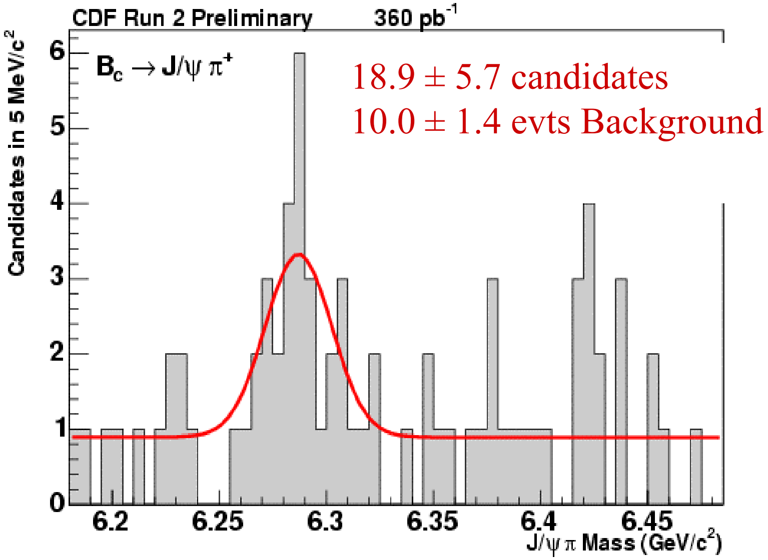
	N	M [GeV/c^2]	σ
η_c	471 ± 40	2.969 ± 0.006	∞
χ_{c0}	232 ± 37	3.406 ± 0.007	large
η_c'	350 ± 17	3.626 ± 0.006	HUGE
X	236 ± 71	3.937 ± 0.012	5.0

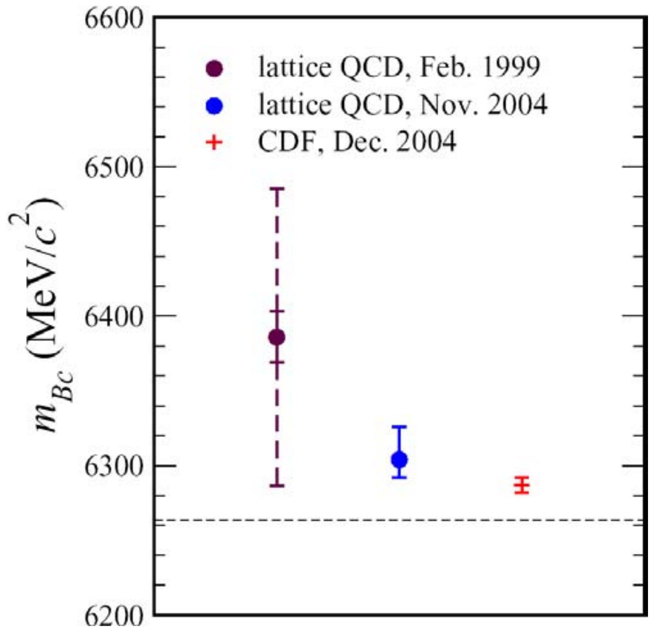
$\Gamma_X = 27 \pm 21$ MeV; $<$ 95 MeV at 90% CL

- Babar – NO PENTAQUARKS!

B_c

- Not new but now much better mass determination





Mass = 6287.0 ± 4.8(stat.) ± 1.1(syst.) MeV

Also confirmation from both CDF & D0 in $J/\psi\ \ell\ \nu$

Technology

- Necessary elements for a first class heavy flavor experiment
  - Excellent vertex detection – time resolution of ~40 fs desired for B_s physics & to reduce bkgrds
  - Particle identification usually via some form of RICH technique
  - γ, π^o & η detection
  - At hadron colliders – selective and efficient b triggers
  - Efficient charged particle tracking
- Sufficient computing resources, include code for alignment, monitoring, calibration & analysis

Trigger Comparison

- B factories trigger on all hadronic events
- CMS & ATLAS: Single muons above a relatively high p_t threshold & dimuons above a somewhat lower threshold or at high luminosity plus other triggers (see next slide)
- Problem: p_t of the b's peaks at $\sim M_b$
- LHCb: Triggers on intermediate p_t hadrons, electrons or muons then looks for evidence of a detached vertex
- BTeV: Looked for detached vertex in lowest trigger level

ATLAS Trigger Summary

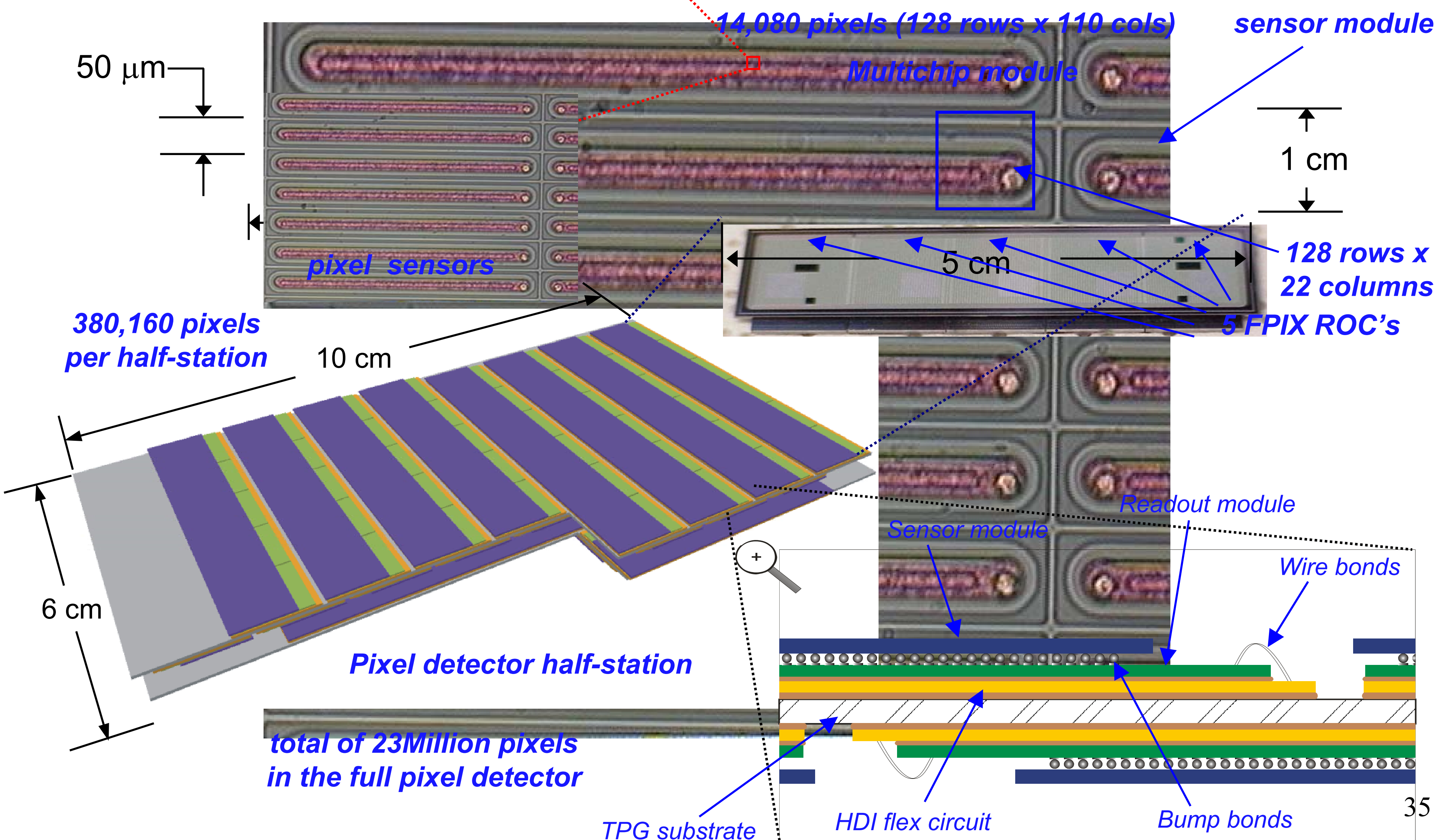
Trigger	LVL1	LVL2 & event filter	Example channels
Di-muon L @ 2.10^{33} ($L \approx 10^{34}$)	2 muons $p_T > 6$ GeV (barrel) 3 GeV (end-caps)	Confirm muons Refit tracks in ID Decay vertex reconstr. Select decays using mass/decay length cuts	$B_d \rightarrow J/\psi(\mu\mu)K^0_s$ $B_s \rightarrow J/\psi(\mu\mu)\varphi$ $B \rightarrow \mu\mu$ $B \rightarrow K^{0*}\mu\mu$ $B \rightarrow \phi\mu\mu$ $\Lambda_b \rightarrow \Lambda^0 J/\psi(\mu\mu)$ $\Lambda_b \rightarrow \Lambda^0 \mu\mu$
EM+μ $L < 2.10^{33}$	1 muon $p_T > 6$ GeV 1 EM cluster $E_T > 2$GeV	Confirm muons & EMC Decay vertex reconstr. Refit tracks Selections	$B_d \rightarrow J/\psi(\mu\mu)K^0_s + b \rightarrow eX$ $B_d \rightarrow J/\psi(ee)K^0_s + b \rightarrow \mu X$ $B_d \rightarrow K^{0*}\gamma$ $B_s \rightarrow \phi\gamma + b \rightarrow \mu X$
Hadronic $L < 2.10^{33}$	1 muon $p_T > 6$ GeV 1 jet cluster $E_T > 5$GeV	Confirm muons & j.c. Decay vertex reconstr. Refit tracks Selections	$B_s \rightarrow D_s(\varphi(KK))\pi$ $B_s \rightarrow D_s(\varphi(KK))a_1(\rho^0\pi^+)$ $B^+ \rightarrow K^+K^+\pi^-$ $B_d \rightarrow \pi^+\pi^-$ $(+ b \rightarrow \mu X)$

As luminosity drops during the fill, more triggers are turned on

Event Environment

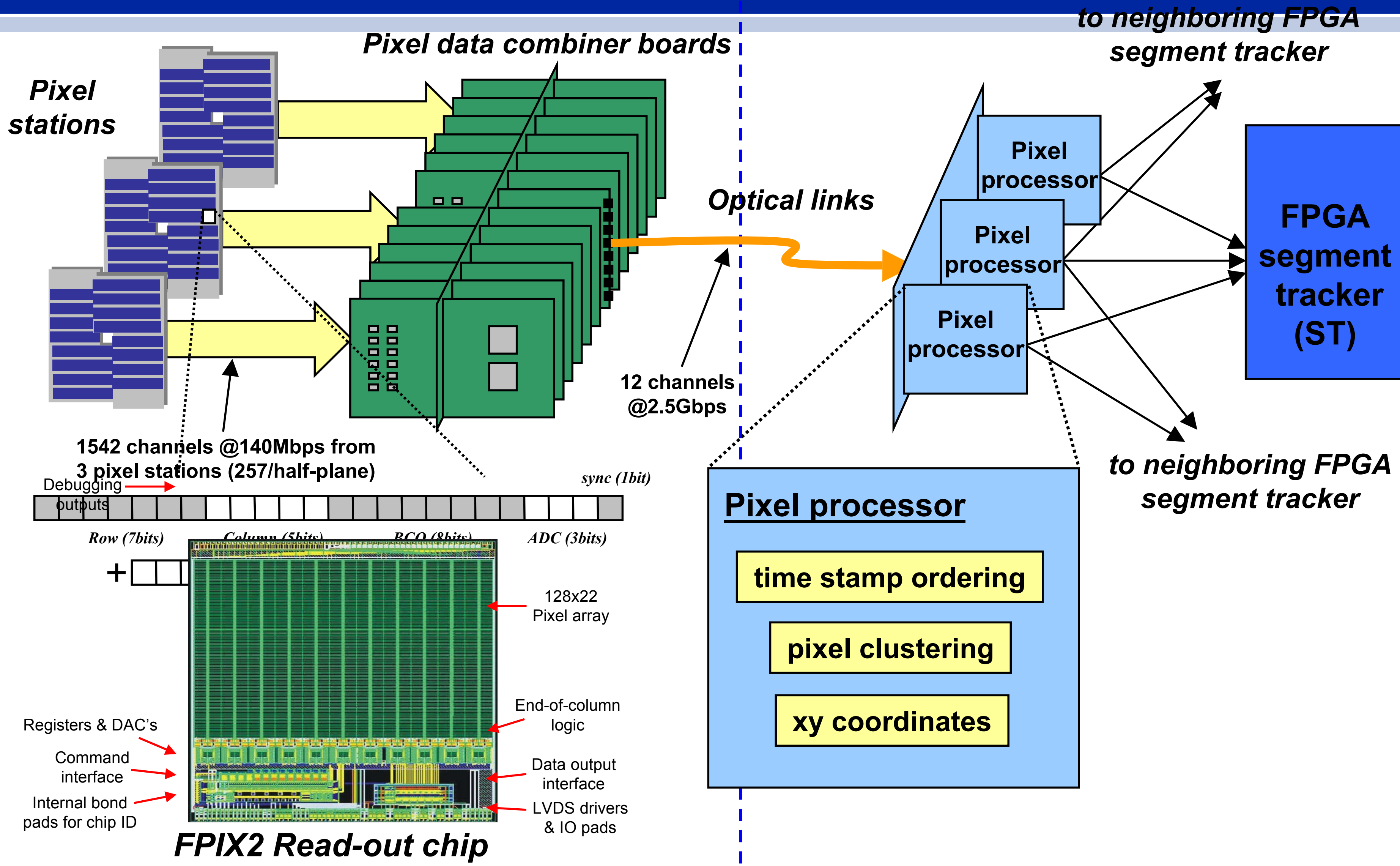
- e^+e^- one interaction per crossing
- LHCb ~<1 interaction per crossing, running at $2x10^{32}/cm^2s$
- ATLAS & CMS low luminosity ($2x10^{33}/cm^2s$) ~7 int/crossing (initial period ~200 days giving 30 fb^{-1})
- ATLAS & CMS high luminosity ($10^{34}/cm^2s$) ~35 int/crossing – B physics a real challenge
- BTeV was ~7 int/crossing

BTeV Silicon Pixel Detector



Pixel Data Readout & 1st Part of L1 Trigger

Collision Hall | Counting Room



Differences due to Trigger

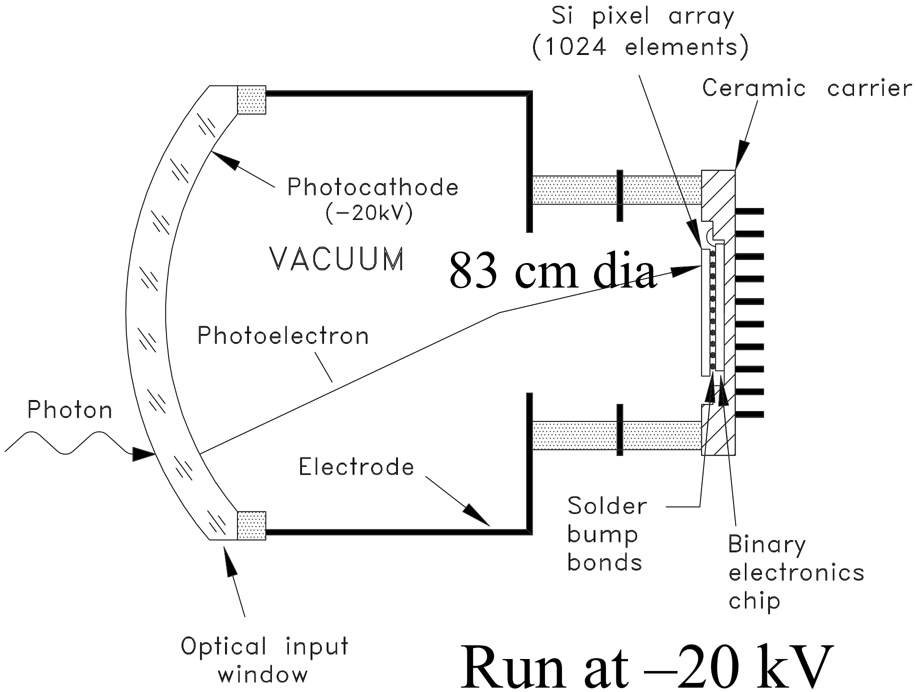
- CMS ATLAS do relatively well on $B \rightarrow \mu^+\mu^-$, $B \rightarrow K \mu^+\mu^-$, & $B \rightarrow J/\psi X$, but its harder for them to get purely hadronic decays. Much is from the other B for when they trigger on a single muon, from which they also get a muon flavor tag
- However muon flavor tag is not that good $\varepsilon D^2 \sim 1\%$ as demonstrated by CDF & D0
- LHCb triggers directly on all "interesting" final states but restricts itself to ~1 interaction per crossing

Differences in Particle ID

- LHCb has (& BTeV had) excellent kaon/pion identification using Ring Imaging Cherenkov detection
- LHCb has effectively 3 systems: one for high momentum in its own tank using CF_4 & two for lower momentum using C_4F_{10} gas & separately using aerogel
  - CDF & D0 have demonstrated that pid is necessary to get reasonable ~5% εD^2
  - LHCb will be able to measure B_s mixing quickly if CDF/D0 don't do it and will also be able to measure CP violation in $B_s \rightarrow D_s K^-$ (γ)
- B factories have good particle id as well

LHCb RICH

- Uses HPD's, basically a phototube with a pixel readout chip



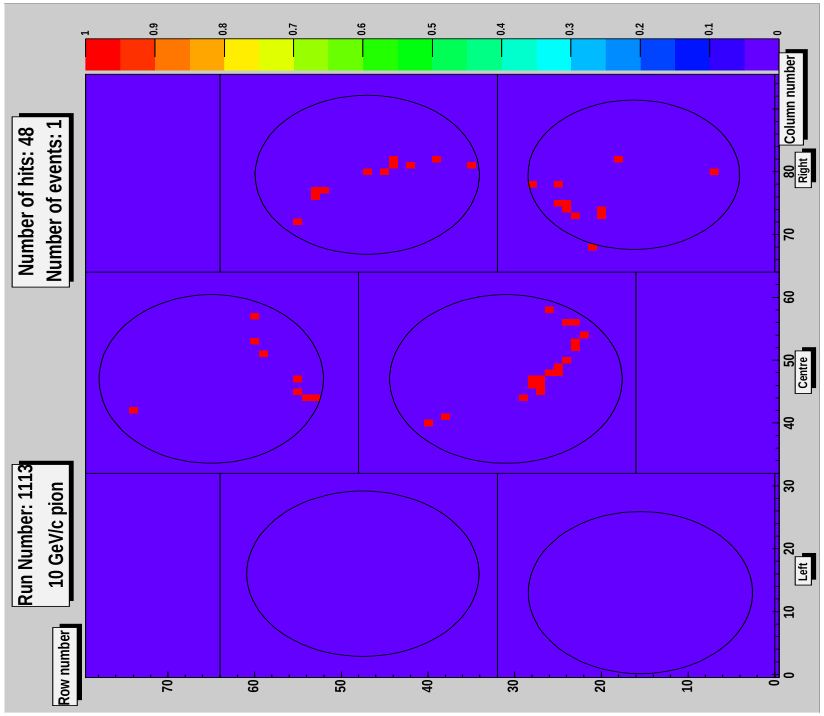
Run at –20 kV

Effective pixel size is $2.5 \mathrm{x} 2.5\ \mathrm{mm}^2$ at the front glass

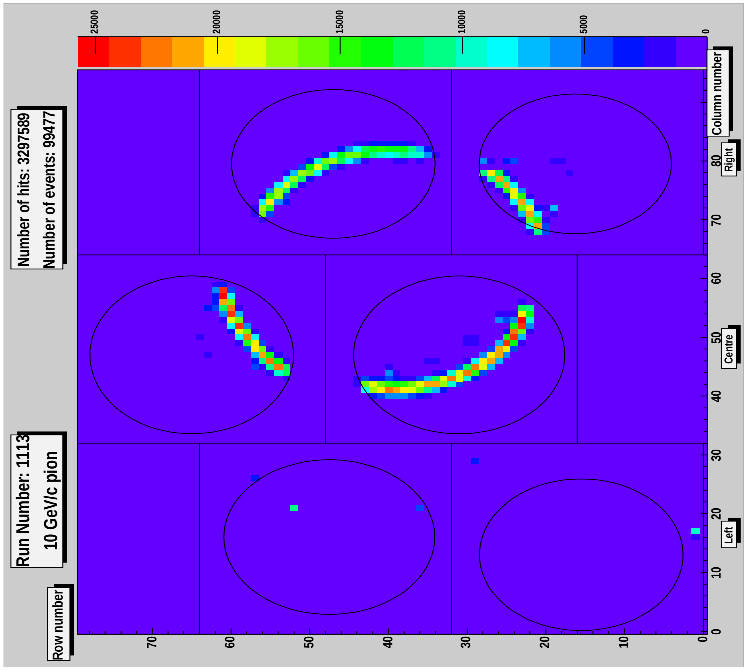
LHCb beam test

C_4F_{10} run, ring on four HPDs.

single event

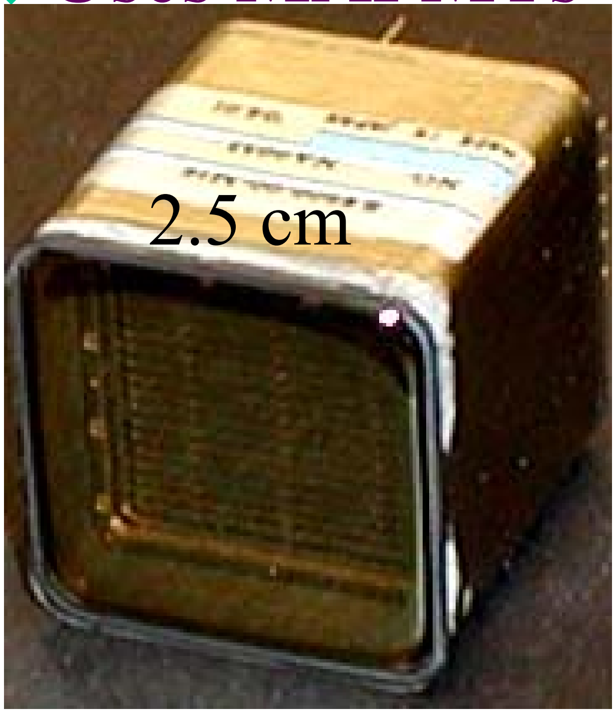


accumulated rings

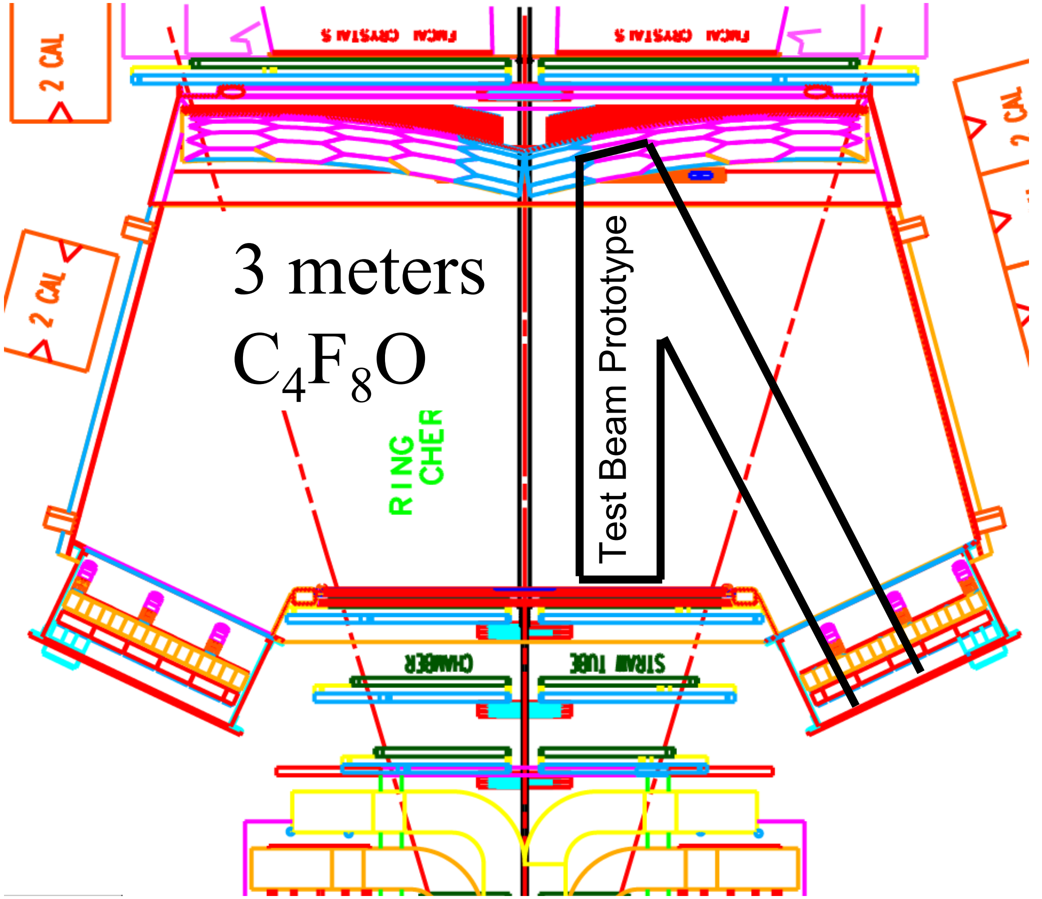


BTeV RICH Test

- 120 GeV proton beam at Fermilab
- Uses MAPMTs



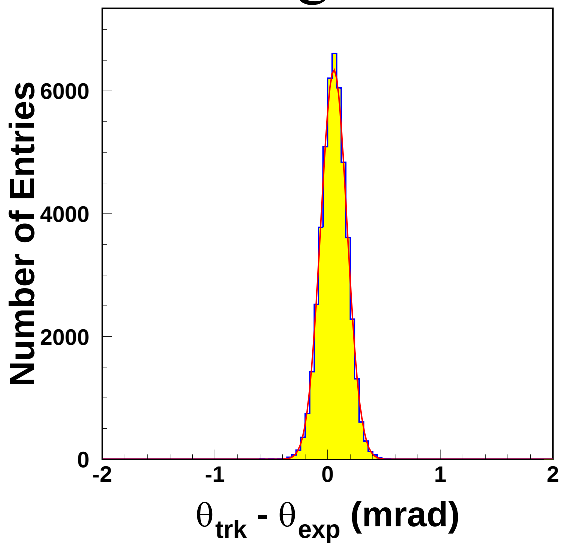
Hamamatsu R8900-M16



BTeV RICH Results

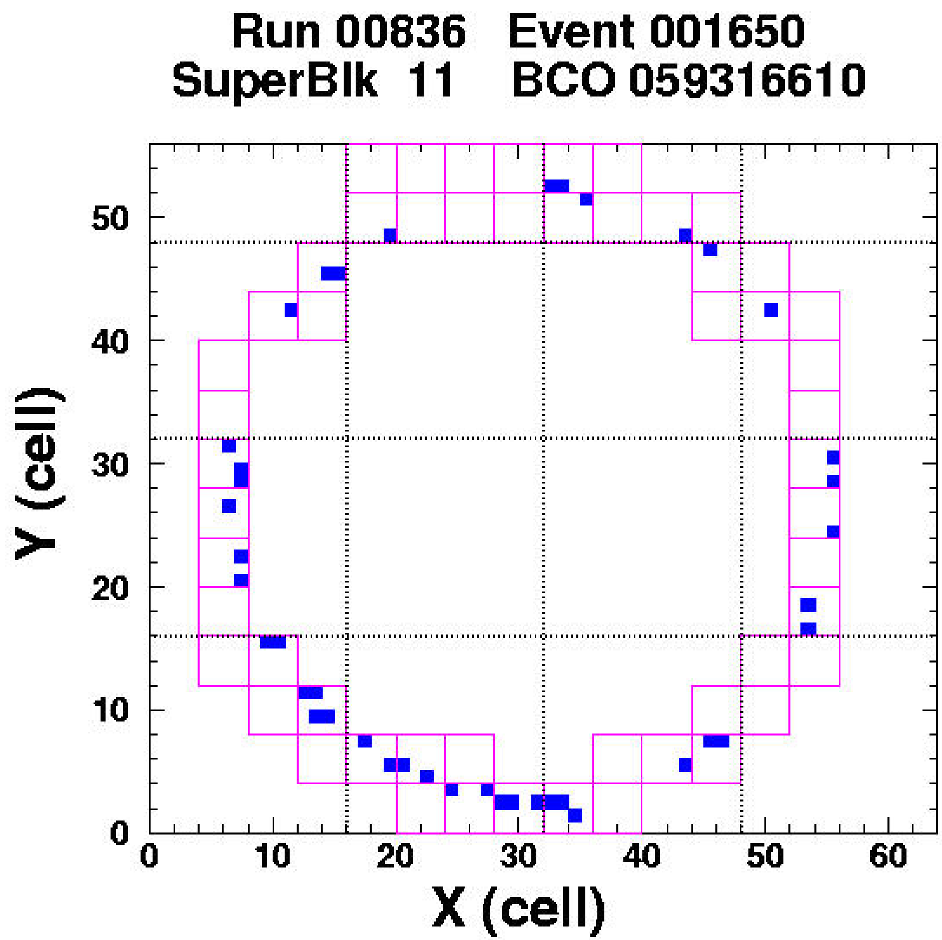
Ng is 43.1 (data), 40.5 MC, excess due to some cross-talk

Cherenkov angle resolution



$\sigma_{Data} = 0.1164$ mrad

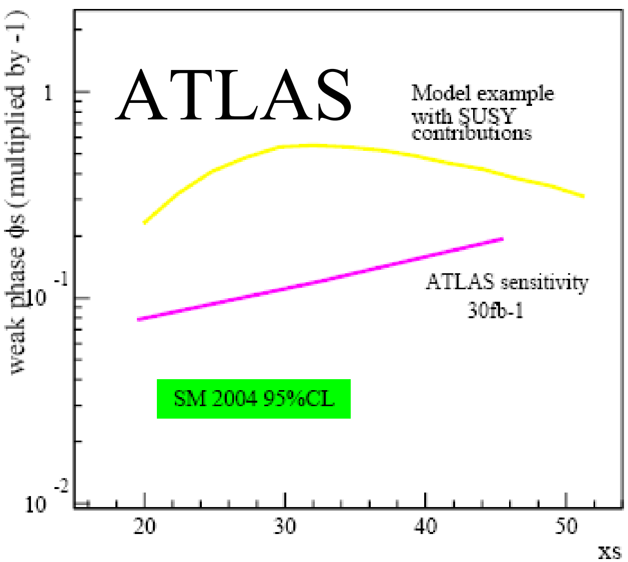
$\sigma_{MC} = 0.112$ mrad



5σ separation up to 70 GeV

One Physics Reach Comparison: χ or ϕ_s

- Use $B_s \rightarrow J/\psi\ \phi$, take one year of data for ATLAS 30 fb^{-1}, for LHCb 2 fb^{-1}



LHCb

Sensitivity (1 year)	$\sigma(\Delta\Gamma_s/\Gamma_s)$	$\sigma(\phi_s)$ [rad]	Annual yield	B/S
$B^0_s \rightarrow J/\psi\ \phi$	0.018	0.06	100k	< 0.3
$B^0_s \rightarrow J/\psi\ \eta$	~0.025	~0.1	7k	< 5.1
$B^0_s \rightarrow \eta_c \phi$	~0.025	~0.1	3.2k	< 1.4
Combined ϕ_s sensitivity		~0.05		

=> 5 years sensitivity $\sigma(\varphi_s)$~0.02

- Although ATLAS gets 15x the data and is using a favored dimuon mode, LHCb does better, result of a dedicated trigger, particle identification, geometry…

Differences in Physics Reach

- Good to do what you can, but also need to realize what needs to get done to complete the physics studies

B_s at e^+e^-

$B \rightarrow \tau\nu$ at hadron colliders

$B \rightarrow \rho\rho$ at ATLAS & CMS

Combination of LHCb & Super-B would address all these issues

The Future

- Unfortunately we will lose CLEO, Babar, CDF, & D0 by ~2009
- LHCb, & Belle are dedicated to heavy flavor physics and will have much to do
- ATLAS & CMS will be able to make a few measurements better
- We will need these data to interpret the new physics found directly at the LHC

Thanks to the Organizers

Beauty 2005

- Without Giancarlo Mantovani and
  Maurizio Biasini, Patrizia Cenci, Riccardo Faccini, Orlando Panella, Attilio Santocchi, Leonello Servoli
- There would not have been this wonderful meeting
- We all thank you very much!
- Thanks to the speakers who after all provide the intellectual input!