

FPCP 2012

Summary Talk on Experiments

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Hefei, China

Before Summarizing, Some Context

Particle Physics – The Study of Matter, Energy, Space,
and Time

What do we really want to know?

Matter

- Why is the universe so dominantly matter; why is there so little antimatter around?
- Why is matter made of quarks and leptons, antiquarks and antileptons?
- Why are these constituents spin $\frac{1}{2}$ particles?
- Why do quarks and leptons come in three generations? (and are there only three?)
- Why do the quark generations have such different masses?
- Why are neutrino masses so small; and why different by generation? Dirac or Majorana?
- Why do quarks come in three colors?

Energy

- Why is so little of the energy density in the universe composed of the mass that I just listed?
- What is the dark matter we claim is the rest of the matter?
- Why are the force carriers spin 1; not spin 0 for example? Why gravitons spin 2?
- Why are the strong and EW forces flavor independent?
- Why aren't all interactions flavor diagonal?

Space and Time

- Why are there three obvious dimensions?
Are there more?
- Why is the universe expansion accelerating?
Or, do we not understand gravity/space?

3x3 - Not the CKM or PNMS Matrices

Note the 3 threes in my list of questions.

In fact, a 3x3 matrix:

3 dimensions

3 generations

3 colors

Are all these trinities related?

Are any of them related?

Ideas About the Keys to Answering Some of These Questions

- Structure of quarks and leptons and generations from substructure?
- Higgs mechanism for EWS breaking – mass of W, Z – the same for quarks?
- Neutrino masses from a seesaw mechanism involving very massive right-handed partners?
- Matter/antimatter asymmetry – not the CKM matrix (inadequate by 8-10 orders of magnitude)? Seesaw mechanism in the neutrino sector?

Not all these ideas are directly testable. Those that are, we are working hard to test. We are doing it by going to higher energies at the LHC and by making more and more precise measurements in the flavor sector. The latter is the focus of our FPCP conferences, of course.

The Drunk and the Lamp Post

- I am reminded of the story of the drunk and the lamp post. Maybe this is only well known in the West, so indulge me if I tell it here.
- A drunk has lost his keys and is spending a long time looking for them under a lamp post. When asked why he is still looking there, he says that that is where there is enough light to see them!



"I'm searching for my keys."

The Drunk and the Lamp Post

- We need to be careful not to make the same mistake by only looking where theorists have suggested we look.
- Certainly, look where we think we may find the answers since we have good models to test.
- However, in parallel, probe as deeply as we can where we don't have such light to guide us.

Vast Data Sets – An Opportunity

- We have vast new data sets to use in testing our ideas
- But, also, we need to check for the unexpected.
- An example we have seen here: when looking for B, D decays to $h^{\pm} l^{\pm} l^{\pm}$, looked for $h^{\pm, \mp} l^{\pm} l^{\pm}$; etc.
- No matter what our theorist friends tell us about where the answer lies, we have already seen the preferred space of minimal SUSY disappear.
- The space for the Higgs to hide is also closing down.

Sorry, I am supposed to say that we are closing in on the Higgs at 125. GeV/c²!

Postcards from FPCP 2012

- This brings us to the beautiful results shown here at FPCP 2012 – very many of the results new since the last meeting, some shown here for the first time.
- As you look over the slides from the meeting, you will each have your favorites to use as souvenir post cards from this trip.
- Choosing post cards when you are on travel is a personal matter.
- I will show you some of my favorite postcards from FPCP 2012, those I have found especially pretty or revealing.
- I won't repeat all the excellent explanations of the results. I could not do as well as you have already heard from all the presenters themselves.

FPCP 2012 Picture Postcards



Flavor Physics & CP Violation

FPCP 2012 May 21-25, 2012, University of Science and Technology of China, Hefei

The aim of the conference is to discuss experimental and theoretical developments related to the physics of heavy flavors and CP violation. Among the topics included will be CP violation, rare decays, flavor beyond the standard model and at the energy frontier, spectroscopy, CKM elements, neutrino physics, and the potential for studies of heavy-flavor decays to help unravel any new physics seen directly at LHC.

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<http://hepg-work.ustc.edu.cn/fpcp2012/>



FPCP 2012 Picture Postcards



Chinese Opera Masks

Bao Gong Memorial Park



FPCP 2012 Physics Picture Postcards

There were lots of pretty plots with content.

Let me organize my souvenir postcards around some themes:

- Standard model confirmations
- Significant reductions in uncertainty
- New physics space ruled out
- New signals and structures
- Hints of new physics
- Tension with the standard model
- Looking beyond the lamp post
- Postcards of the future

Remember, these are just souvenirs, not a guide book.

FPCP 2012 Picture Postcards

Standard Model Confirmations - I

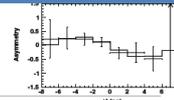
Superluminal ν_s

CONCLUSIONS

- No evidence for superluminal neutrinos
- **Strong** new constraints on neutrino Lorentz violation

$\delta < 10^{-12}$

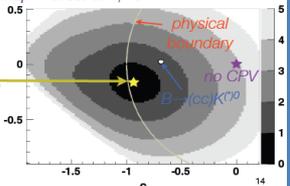
$B \rightarrow K_S K_S K_S$ time-dependent analysis



- CP=+1 eigenstate
- Include $K_S \rightarrow \pi^0 \pi^0$ (max 1) to increase statistics (eff: 3.1% wrt 6.7% for $3(\pi^+ \pi^-)$)
- Dalitz-plot information removed from fit (and veto χ_{cut}); replaced by proper time separation between B_{sig} and B_{tag} decays
- Signal time-dependent decay distribution:

$$P_{\text{sig}}^i(\Delta t, \sigma_{\Delta t}; q_{\text{tag}}, c) = \frac{e^{-|\Delta t|/\tau_{\text{sig}}}}{4\tau_{\text{sig}}} \left[1 + q_{\text{tag}} \frac{\Delta D_c}{2} + \left(q_{\text{tag}}(D_c) [S \sin(\Delta m_{\text{sig}} \Delta t) - C \cos(\Delta m_{\text{sig}} \Delta t)] \right) \otimes R_{\text{sig}}(\Delta t, \sigma_{\Delta t}) \right]$$
- Results:
 - $N_{\text{sig}} = 263 \pm 21$ ($P = 2.5\%$), B bkg-0
 - $S = -0.94 \pm 0.24 \pm 0.06$
 - $C = -0.17 \pm 0.18 \pm 0.04$

CPV at 3.8 σ
(first evidence of CPV in this channel)



Belle: $D_s \rightarrow \tau \nu$ Signal Yields

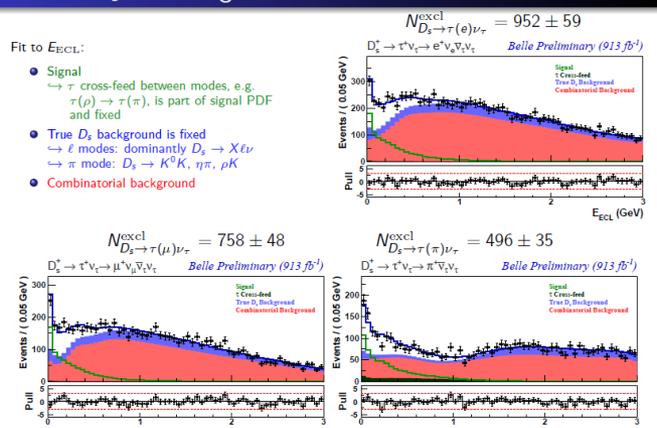
Fit to E_{BCL} :

- Signal $\rightarrow \tau$ cross-feed between modes, e.g. $\tau(\rho) \rightarrow \tau(\pi)$, is part of signal PDF and fixed
- True D_s background is fixed $\rightarrow \ell$ modes: dominantly $D_s \rightarrow X \ell \nu$ $\rightarrow \pi$ mode: $D_s \rightarrow K^0 K, \eta \pi, \rho K$
- Combinatorial background

$N_{D_s \rightarrow \tau(\pi)\nu_\tau}^{\text{excl}} = 952 \pm 59$
Belle Preliminary (913 fb $^{-1}$)

$N_{D_s \rightarrow \tau(\mu)\nu_\tau}^{\text{excl}} = 758 \pm 48$

$N_{D_s \rightarrow \tau(\pi)\nu_\tau}^{\text{excl}} = 496 \pm 35$
Belle Preliminary (913 fb $^{-1}$)

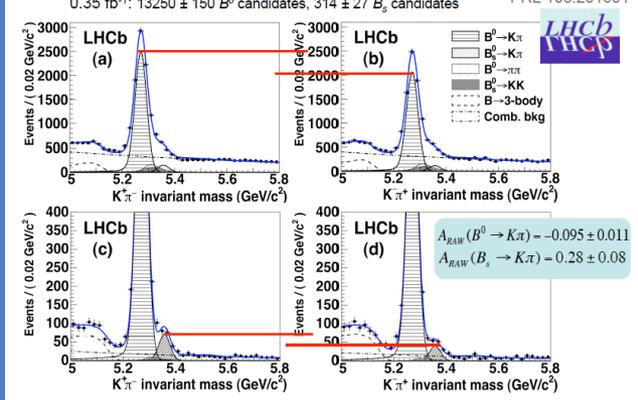


Andreas Borek for the Belle Collaboration © FPCP2012, Hefei, China Leptonic D_s and D decays 19

$B_{(d,s)} \rightarrow K \pi^+$ at LHCb

arXiv:1202.6251
PRL 108.201601

0.35 fb $^{-1}$: 13250 \pm 150 B^0 candidates, 314 \pm 27 B_s candidates



22 May 2012 FPCP 2012, Hadronic B decays, I. Nasteva 5

1 $^{\text{st}}$ 3 sigma evidence of CPV in Bs

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Standard Model Confirmations - II

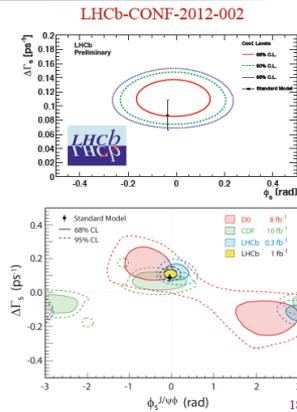
LHCb preliminary result

Parameter	Value	Stat.	Syst.
Γ_s [ps ⁻¹]	0.6580	0.0054	0.0066
$\Delta\Gamma_s$ [ps ⁻¹]	0.116	0.018	0.006
$ A_{\perp}(0) ^2$	0.246	0.010	0.013
$ A_0(0) ^2$	0.523	0.007	0.024
F_S	0.022	0.012	0.007
δ_{\perp} [rad]	2.90	0.36	0.07
δ_{\parallel} [rad]	[2.81, 3.47]		0.13
δ_s [rad]	2.90	0.36	0.08
ϕ_s [rad]	-0.001	0.101	0.027

Source of systematics on ϕ_s :

- direct CPV ignored in fit
- angular efficiency model
- background model

Improvement under investigation



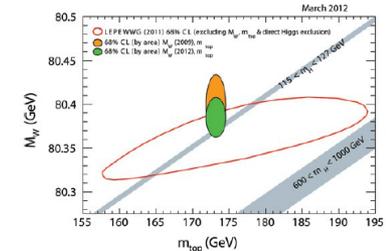
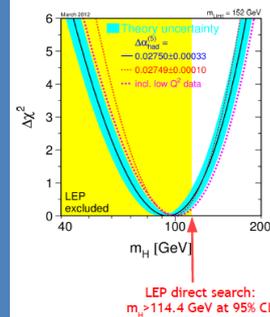
Heavier
Bs lives
longer.

Higgs?

Precision Electroweak Measurements

LEP, SLD, CDF/D0 and lower energy experiments

Sensitive to m_H via radiative corrections



New high-precision m_W measurements from CDF/D0

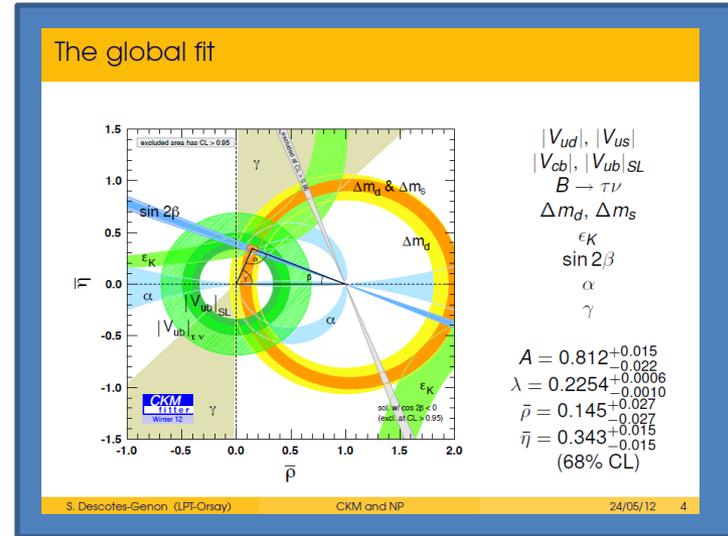
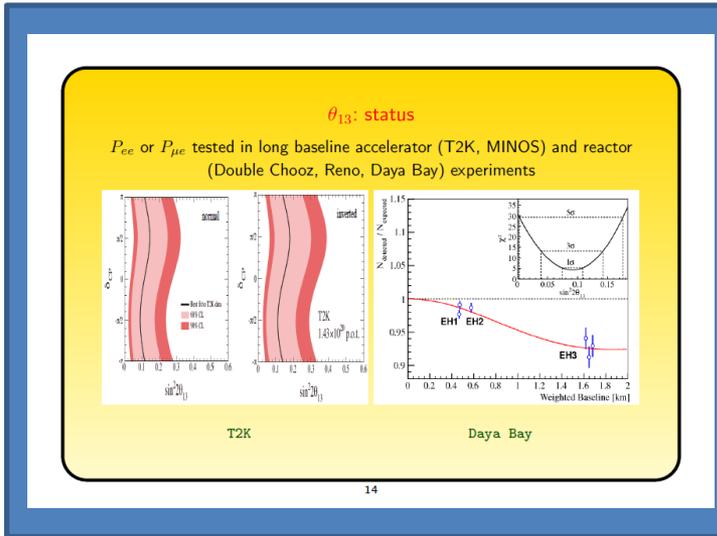
→ new world-average
 $m_W = 80.385 \pm 0.015$ GeV

SM prediction from precision EW fit suggests
 $m_H < 152$ GeV at 95% CL
relies on structure of SM radiative corrections

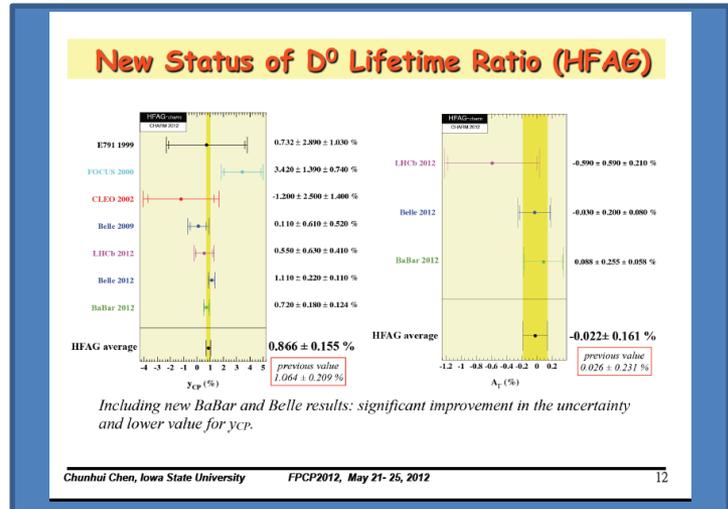
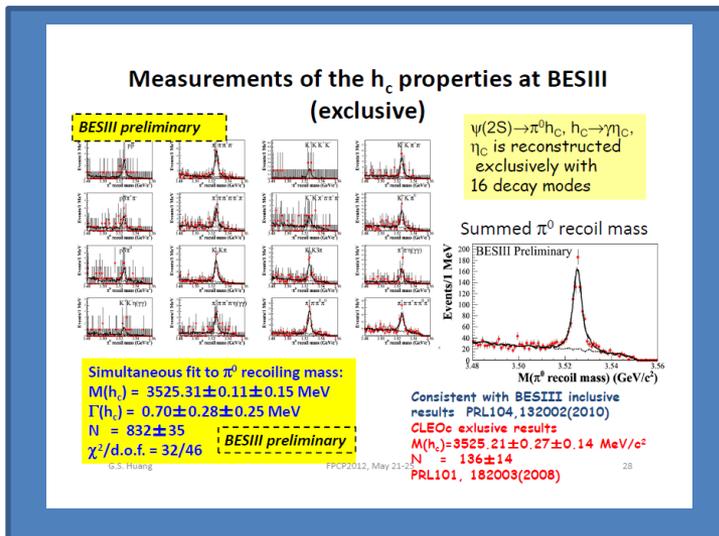
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Significant Reductions in Uncertainty - I

θ_{13}



CKM

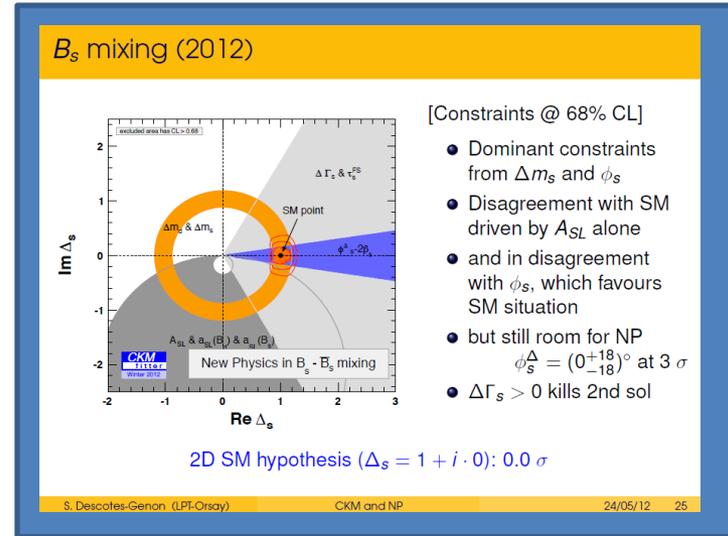
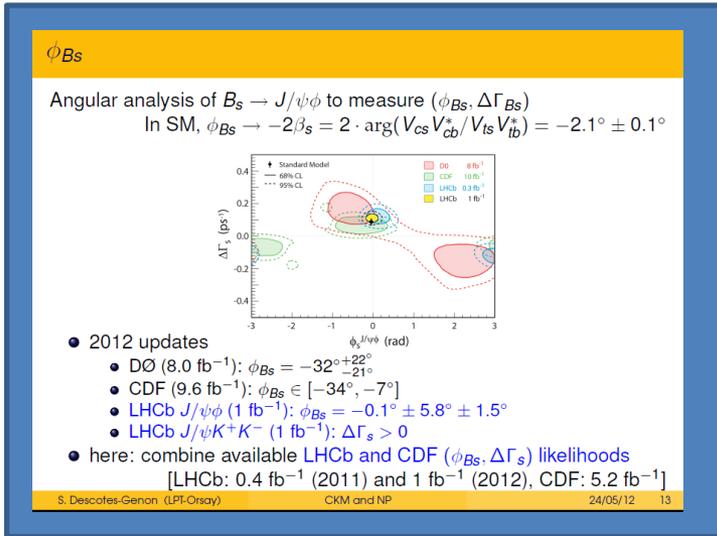


1st3 sigma evidence of CPV in Bs

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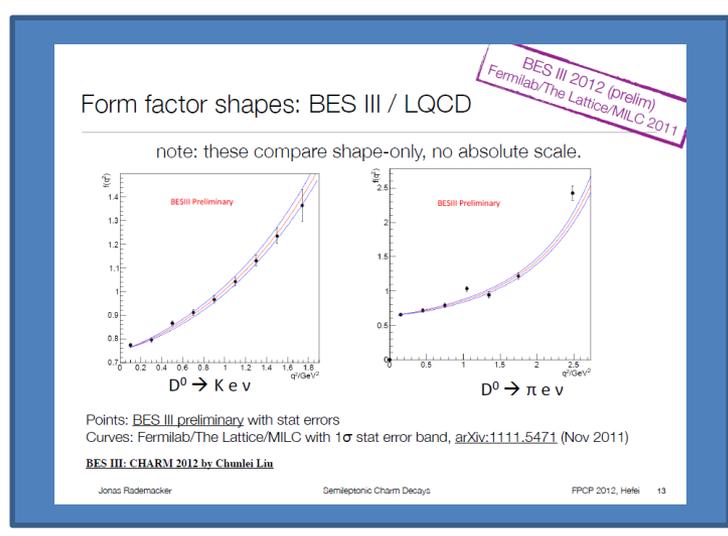
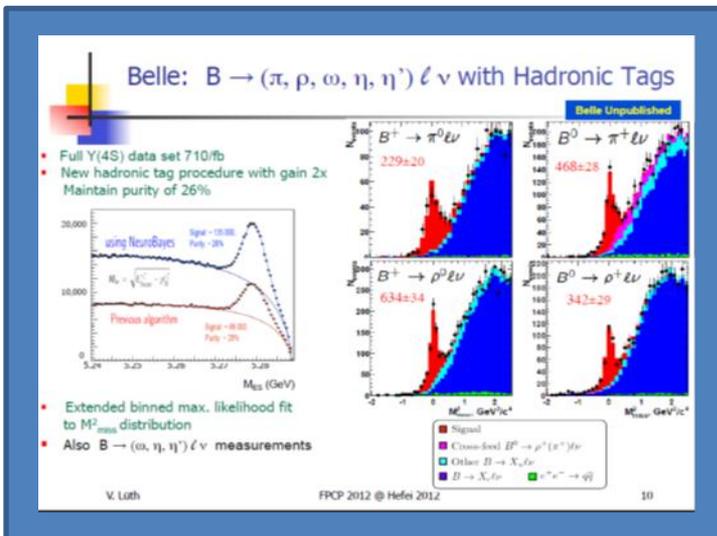
Significant Reductions in Uncertainty -II

ϕ_{Bs}



B_s Mixing

Incl/Ex
SL B
decays

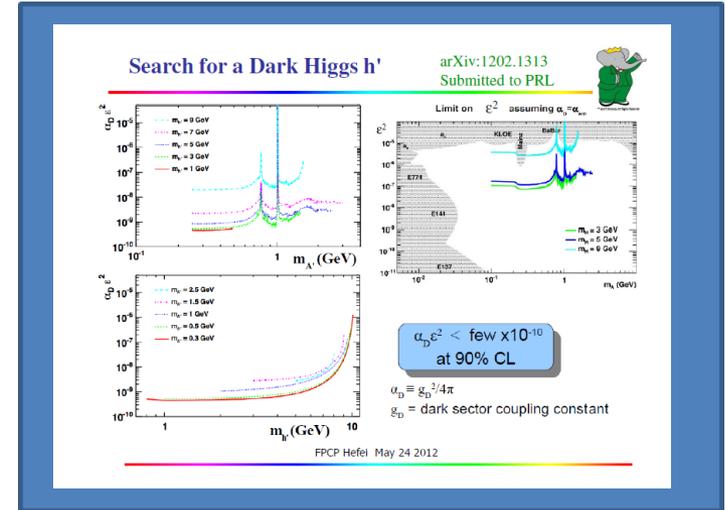
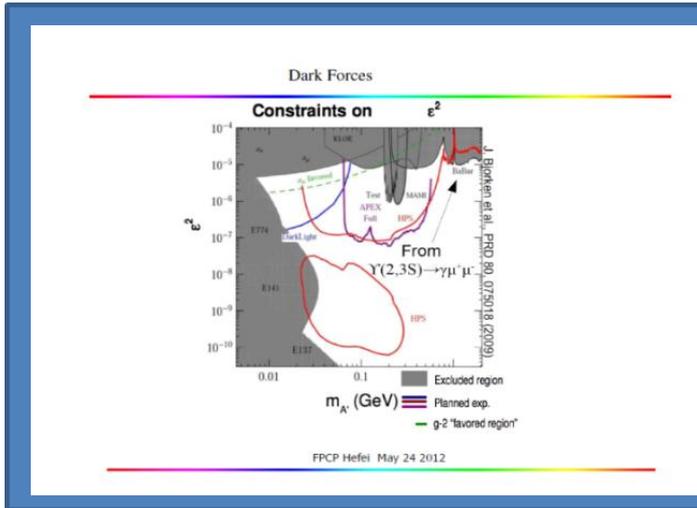


D SL
FF

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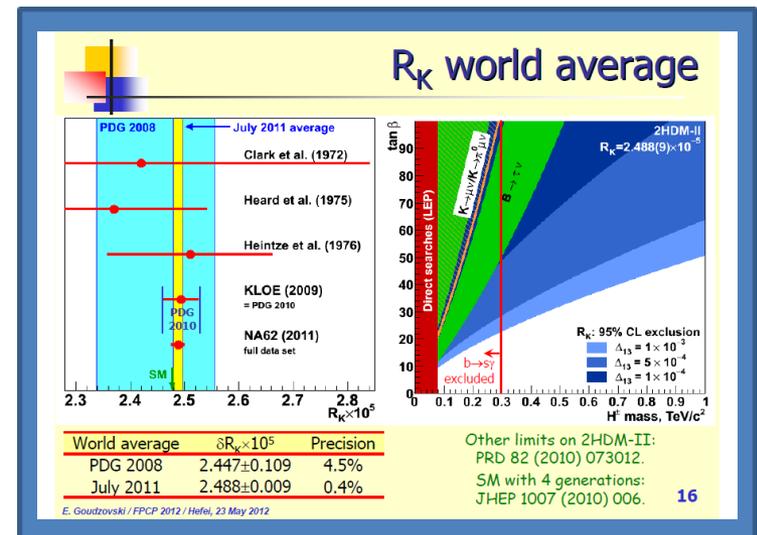
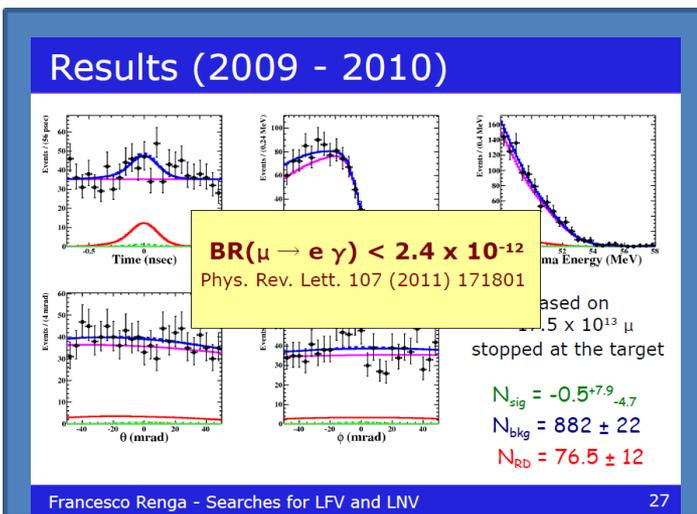
New Physics Space Ruled Out - I

Dark Matter



Dark Higgs

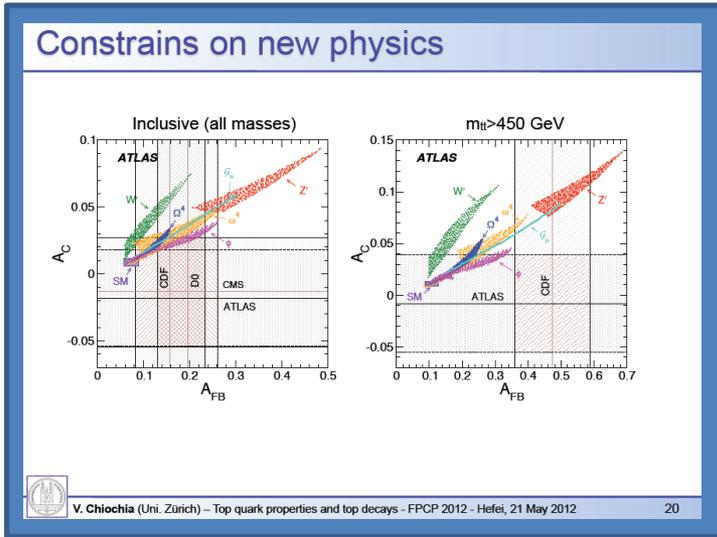
μ to $e \gamma$



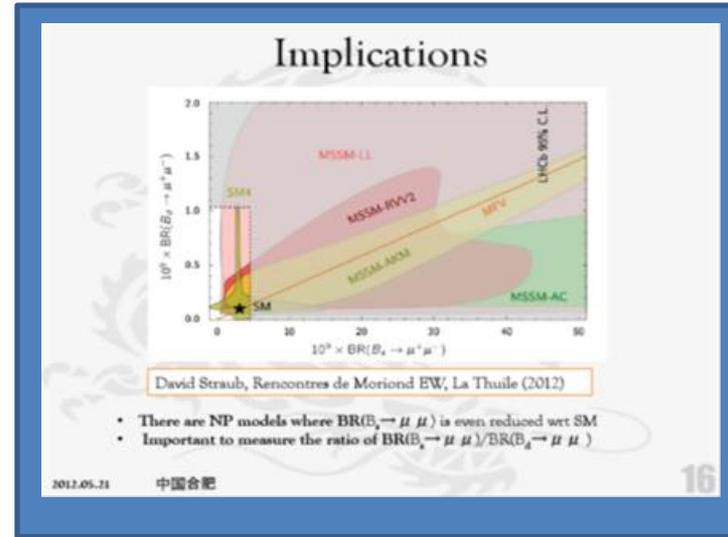
FPCP 2012 Picture Postcards

New Physics Space Ruled Out - II

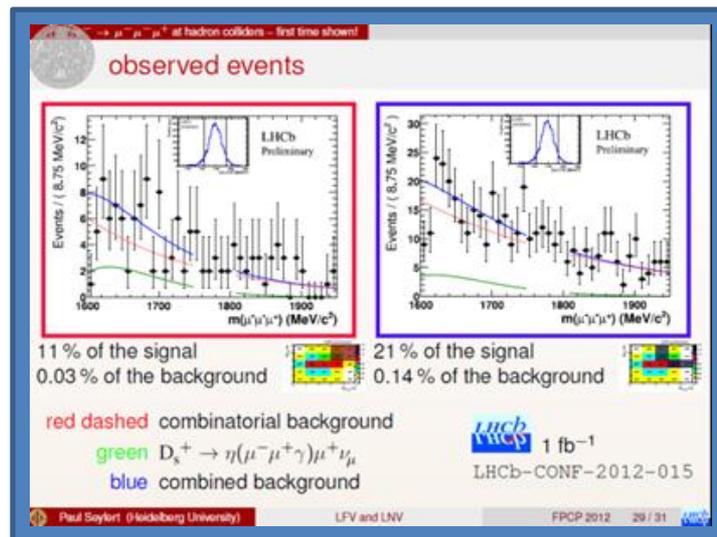
top
quark



B_s to $\mu\mu$

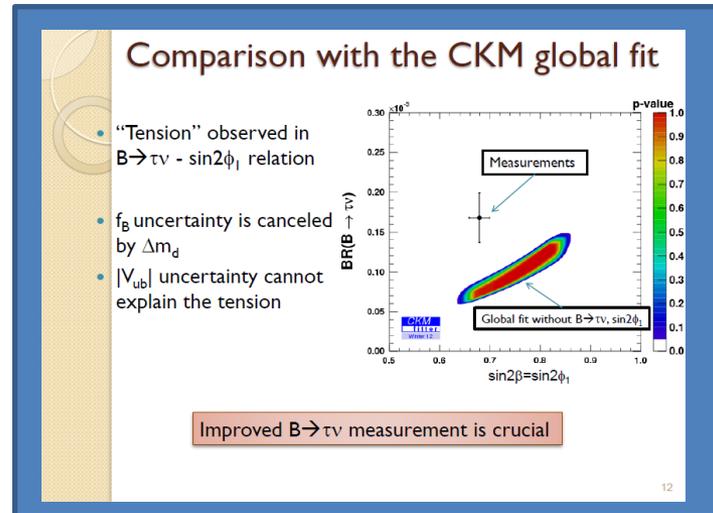
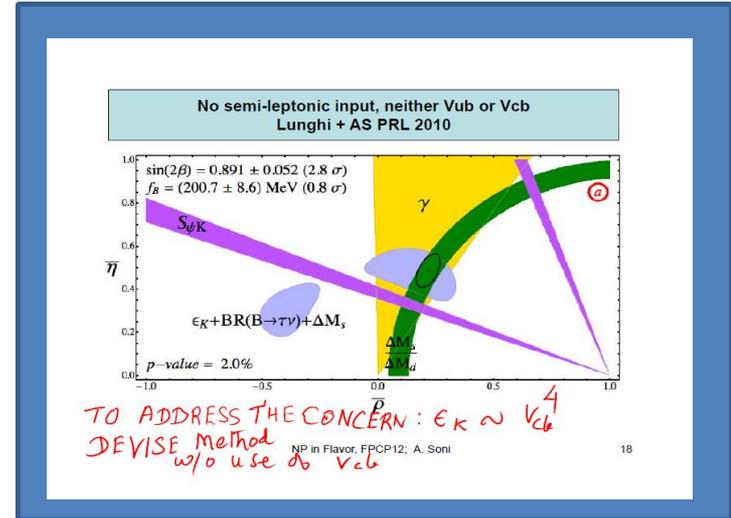
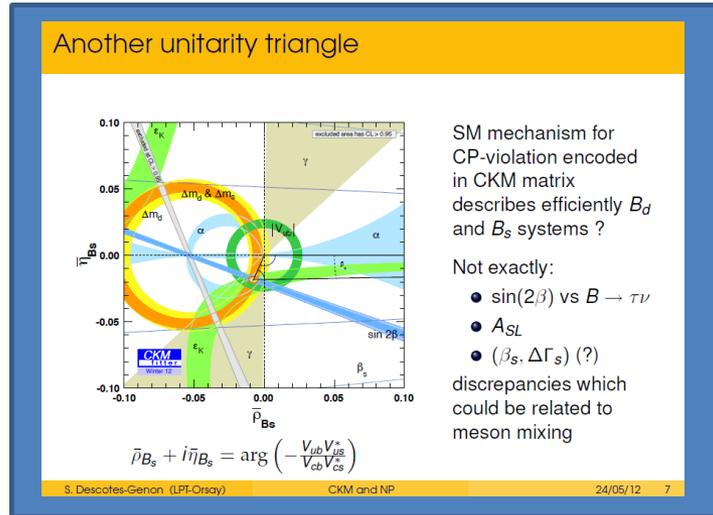


τ to
 3μ



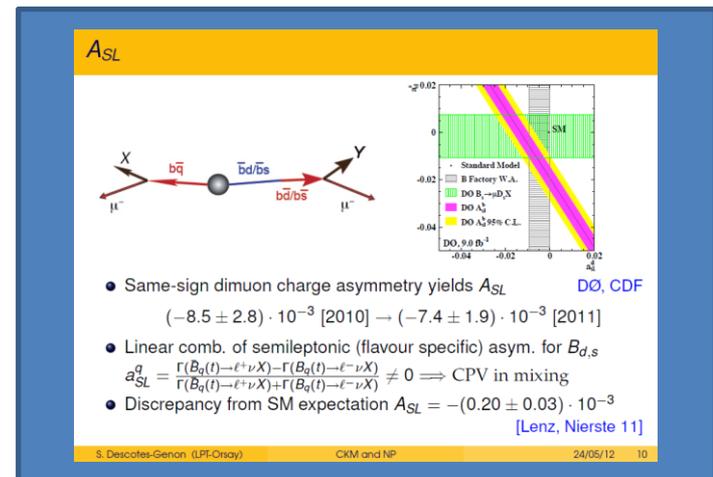
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Tension with the Standard Model - I



B to $\tau\nu$ and $\sin(2\beta)$

CKM w Selected Inputs



A_{SL}

$A_{\mu\mu}$ and ϕ_s

FPCP 2012 Picture Postcards

Tension with the Standard Mode - II

Summary of R(D) and R(D*) Measurement

to be submitted to PRL

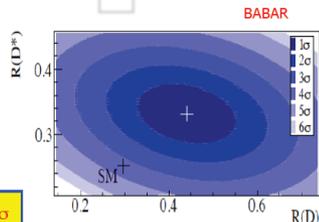
Decay	N_{sig}	N_{norm}	$R(D^{(*)})$	$\mathcal{B}(B \rightarrow D^{(*)}\tau\nu)$ (%)	$\Sigma_{tot}(\sigma)$
$D^0 \tau^- \bar{\nu}_\tau$	314 ± 60	1995 ± 55	0.429 ± 0.082 ± 0.052	0.99 ± 0.19 ± 0.13	4.7
$D^{*0} \tau^- \bar{\nu}_\tau$	639 ± 62	8766 ± 104	0.322 ± 0.032 ± 0.022	1.71 ± 0.17 ± 0.13	9.4
$D^+ \tau^- \bar{\nu}_\tau$	177 ± 31	986 ± 35	0.469 ± 0.084 ± 0.053	1.01 ± 0.18 ± 0.12	5.2
$D^{*+} \tau^- \bar{\nu}_\tau$	245 ± 27	3186 ± 61	0.355 ± 0.039 ± 0.021	1.74 ± 0.19 ± 0.12	10.4
$D \tau^- \bar{\nu}_\tau$	489 ± 63	2981 ± 65	0.440 ± 0.058 ± 0.042	1.02 ± 0.13 ± 0.11	6.8
$D^* \tau^- \bar{\nu}_\tau$	888 ± 63	11953 ± 122	0.332 ± 0.024 ± 0.018	1.76 ± 0.13 ± 0.12	13.2

Comparison with SM calculation:

	R(D)	R(D*)
BABAR	0.440 ± 0.071	0.332 ± 0.029
SM	0.297 ± 0.017	0.252 ± 0.003
Difference	2.0 σ	2.7 σ

The combination of the two measurements (-0.27 correlation) yields $\chi^2/NDF=14.6/2$, i.e. Prob. = $6.9 \times 10^{-4}!!$

Thus the SM prediction is excluded at 3.4 σ



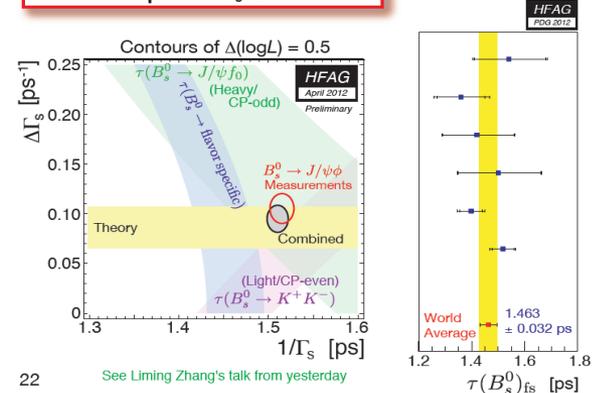
V. Luth

FPCP 2012 @ Hefei 2012

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B to D $\tau\nu$
B to D* $\tau\nu$
3.4 σ

Flavor-Specific B_s^0 Lifetime



Flavor Specific Bs Lifetime

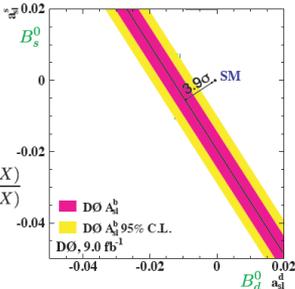
Relation to B_s^0 Semileptonic Decays?

- Asymmetry is a linear combination of semileptonic charge asymmetries of B_d^0 and B_s^0 :

$$A_{sl}^b = C_d a_{sl}^d + C_s a_{sl}^s$$

$$a_{sl}^q = \frac{\Gamma(\bar{B}_q \rightarrow \mu^+ X) - \Gamma(B_q \rightarrow \mu^- X)}{\Gamma(\bar{B}_q \rightarrow \mu^+ X) + \Gamma(B_q \rightarrow \mu^- X)}$$

$$= \frac{1 - |q/p|^4}{1 + |q/p|^4}$$



Pointing to a new source of CP violation?

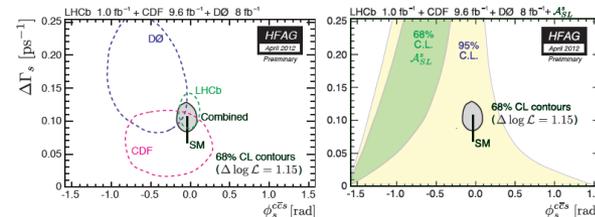
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$B_s a_{sl}$

Consistency with Other CP Measurements in B_s^0 System?

$$a_{sl}^s = \frac{|\Gamma_s^{12}|}{|M_s^{12}|} \sin \phi_s = \frac{\Delta \Gamma_s}{\Delta M_s} \tan \phi_s \quad \phi_s = \phi_s^{SM} + \phi_s^{NP}$$

(0.0042 ± 0.0014) (modulo penguin pollution, Lenz, arXiv:1205.1444)



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

(-0.036 ± 0.002)

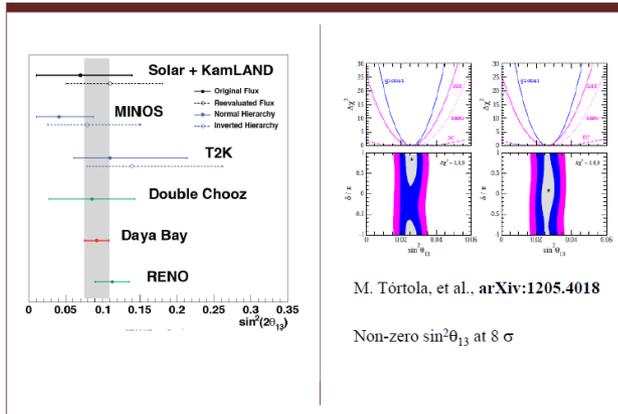
If new physics in mixing, same new phase angle in $B_s^0 \rightarrow J/\psi \phi$

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New Signals and Structures - I

Summary of All Existing θ_{13} Measurements

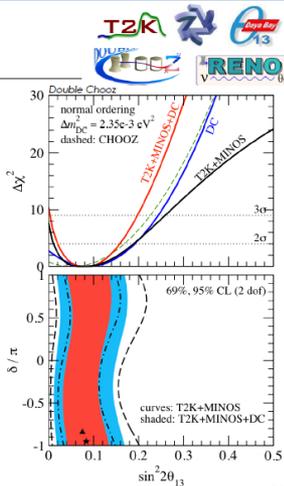


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Our new knowledge

In under a year θ_{13} has gone from unknown to well measured.

- At the top of expected range.
- Focus is rapidly shifting to CP phase and mass-hierarchy.
 - Need precision on $|U_{e3}|^2$, but also $|U_{\mu 3}|^2$ and Δm_{atm}^2

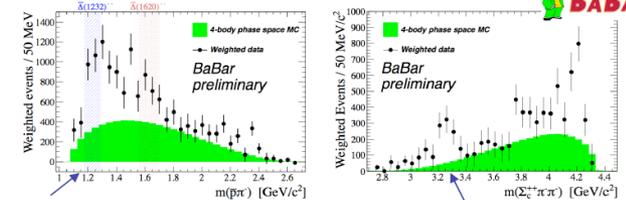


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Baryonic B decays at BaBar

Preliminary
O. Grunberg
Moriond 2012

- $B^- \rightarrow \Sigma_c^{++} \bar{p} \pi^- \pi^-$
- Background-subtracted and efficiency-corrected data.



Excess in range $1.2 < m(\bar{p}\pi^-) < 1.7 \text{ GeV}/c^2$ may be due to resonances $\Delta(1232)^{--}, \Delta(1600)^{--}, \Delta(1620)^{--}$

Unexplained structures around $3.250 \text{ GeV}/c^2$ and $4.200 \text{ GeV}/c^2$

- Search for $\bar{B}^0 \rightarrow \Lambda_c^+ \bar{p} p \bar{p}$
- 2 events in data.

Conservative upper limit on BR: $B(\bar{B}^0 \rightarrow \Lambda_c^+ \bar{p} p \bar{p}) \cdot \frac{B(\Lambda_c^+ \rightarrow p K^- \pi^+)}{5\%} < 6.2 \cdot 10^{-6} @ CL = 90\%$

↑
PDG value

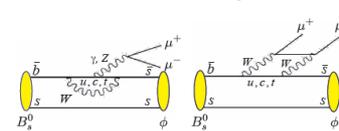
22 May 2012

FPCP 2012, Hadronic B decays, I. Nasteva

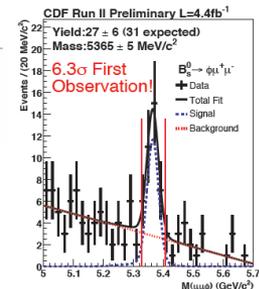
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Semi-rare B_s^0 Penguin Decays

CDF PRL 106, 161801 (2011),
 4.4 fb^{-1} , reconstructs $B_s^0 \rightarrow \phi \mu^+ \mu^-$



$$B(B_s^0 \rightarrow \phi \mu^+ \mu^-) = (1.44 \pm 0.33 \pm 0.46) \times 10^{-6}$$



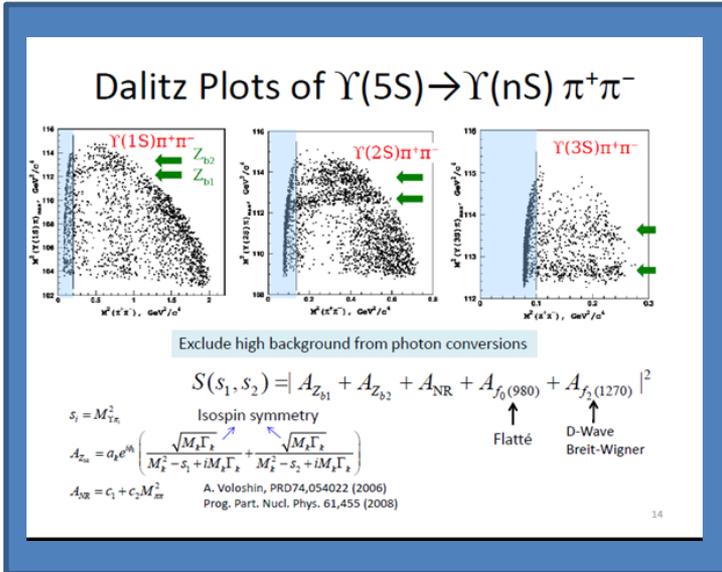
...but not enough stats to get angular distributions of decay products (like $B_d^0 \rightarrow K^* \mu^+ \mu^-$) to better probe for new physics

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Bs to
 $\phi \mu \mu$

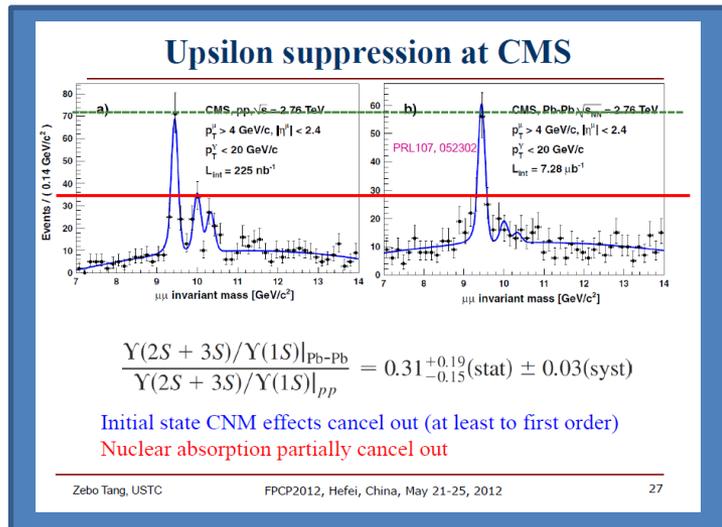
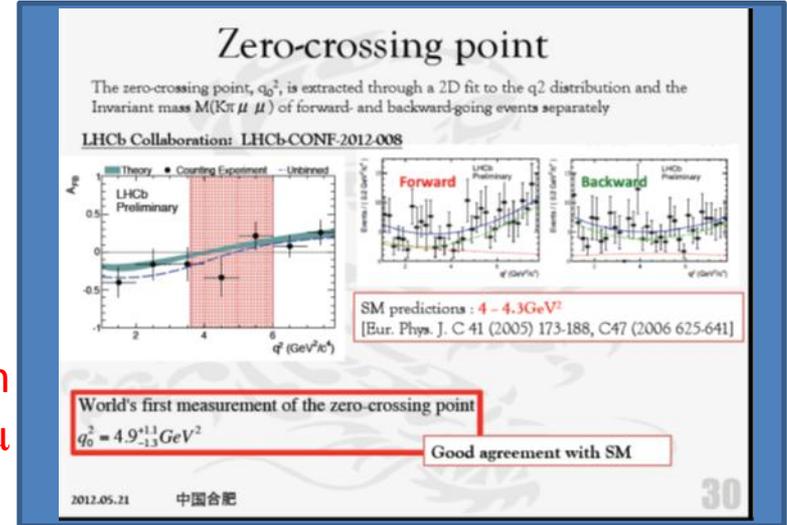
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New Signals and Structures - II

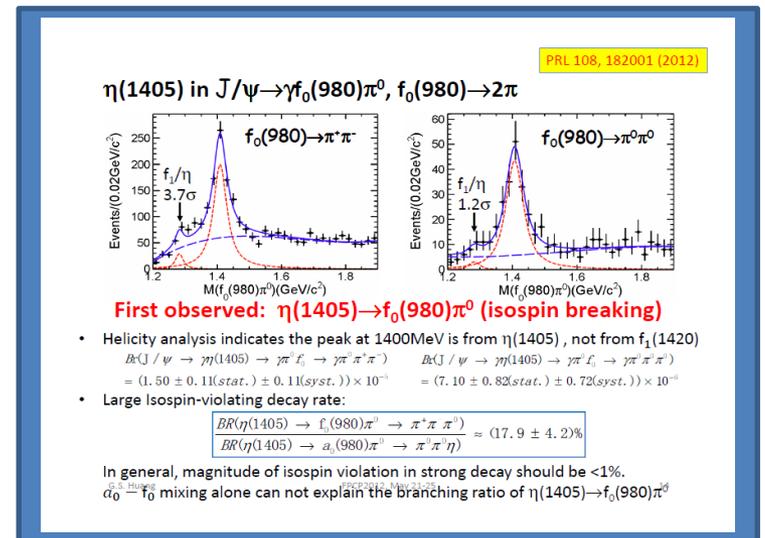


$Z_{1,2}$ to $h_b(1,2) \pi$

A_{FB} in
B to $K^* \mu \mu$



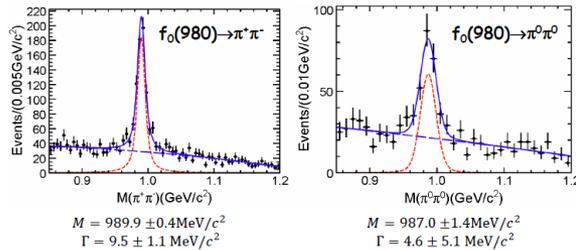
Υ
suppression
in HI col



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New Signals and Structures - III

Anomalous Lineshape of $f_0(980)$ in $J/\psi \rightarrow \gamma f_0(980) \pi^0$



Surprising result:

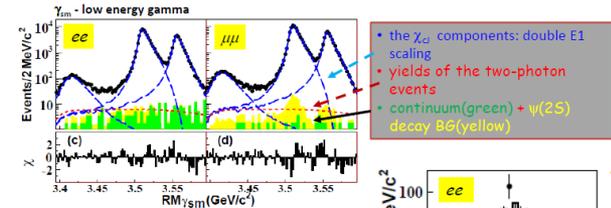
very narrow $f_0(980)$ width: $< 11.8 \text{ MeV}/c^2$ @90% C.L.
 much narrower than the world average (PDG 2010: 40-100 MeV/c^2)

G.S. HA possible explanation is KK^* loops, Triangle Singularity (TS) (J.J. Wu et al, PRL 100, 081801(2012))

First evidence of $\psi(2S) \rightarrow \gamma\gamma J/\psi$

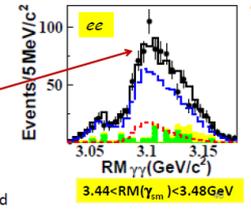
arXiv: 1204.0246 Submitted to PRL

- Select $\psi(2S) \rightarrow \gamma\gamma J/\psi$, $J/\psi \rightarrow e^+e^-$ and $\mu^+\mu^-$ events



- the χ_{ci} components: double E1 scaling
- yields of the two-photon events
- continuum (green) + $\psi(2S)$ decay BG (yellow)

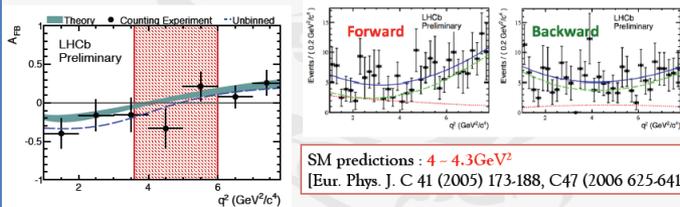
- Global fit of the two-photon process and cascade χ_{ci} processes
- See **clear excess** over BG + continuum
- $Br(\psi(2S) \rightarrow \gamma\gamma J/\psi) = (3.3 \pm 0.6^{+0.8}_{-1.1}) \times 10^{-4}$ (both ee and $\mu\mu$)
- Significance : 3.8 σ including systematics**
- $Br(\psi(2S) \rightarrow \gamma\chi_{ci}\chi_{ci} \rightarrow \gamma J/\psi)$ are also measured



Zero-crossing point

The zero-crossing point, q_0^2 , is extracted through a 2D fit to the q^2 distribution and the Invariant mass $M(K\pi \mu \mu)$ of forward- and backward-going events separately

LHCb Collaboration: LHCb-CONF-2012-008



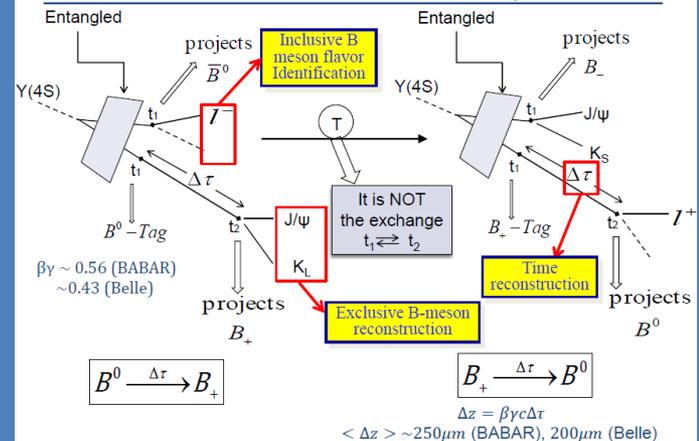
SM predictions : 4 - 4.3 GeV^2
 [Eur. Phys. J. C 41 (2005) 173-188, C47 (2006) 625-641]

World's first measurement of the zero-crossing point

$$q_0^2 = 4.9^{+11}_{-13} \text{ GeV}^2$$

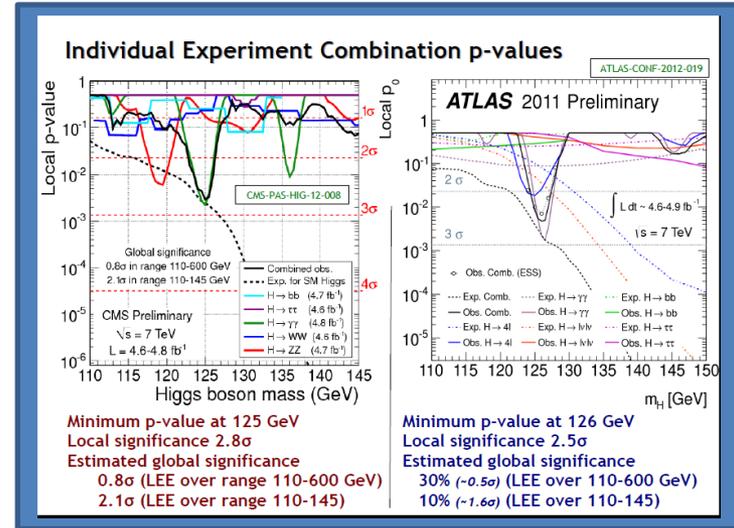
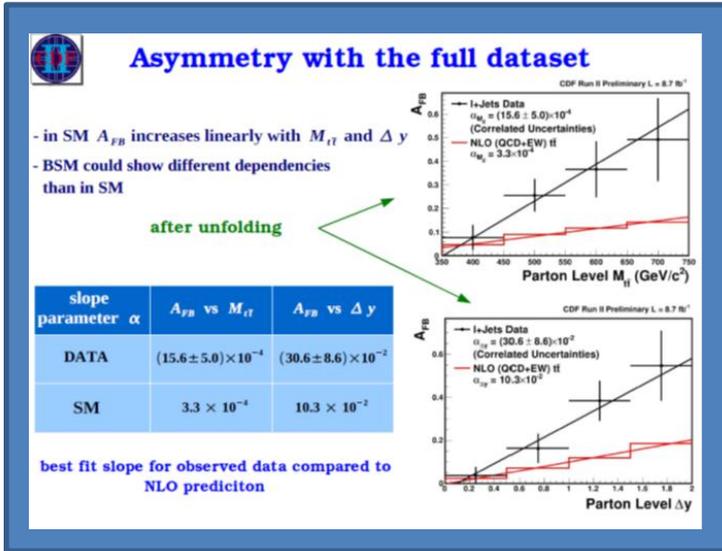
Good agreement with SM

Foundations of the analysis

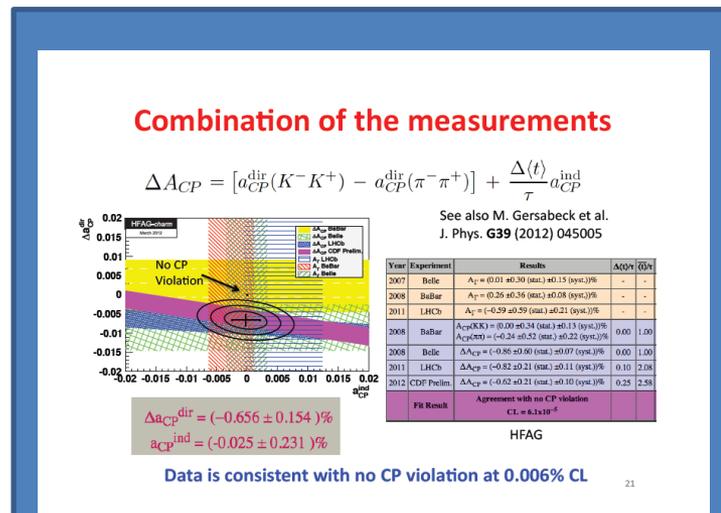


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Hints of New Physics



125/126 GeV Higgs?



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New Techniques & Looking Beyond the Lamp Post

NIKHEF
multibody final states

two main ideas

- ADS/GLW style analyses: choose channel with large r_B , so more sensitive e.g. [arXiv:hep-ph/0211282] e.g. $B^- \rightarrow D(K^- \pi^+) K^- \pi^+ \pi^-$
- exploit variation of hadronic parameters over final state phase space (similar to GGSZ/Dalitz method)
 - e.g. $B^0 \rightarrow D\pi^- K^+$ [arXiv:0810.2706v3, arXiv:0909.1495v2]
 - e.g. $\Lambda_b^0 \rightarrow Dph$ ($h = K, \pi$) [LHCb-CONF-2011-036]

Manuel Schiller (Nikhef/VU A/dam) FPCP 2012, Hefei, China May 22th, 2012 23 / 29

Tevatron H Search

Tevatron Higgs searches are well established, major improvements vs time have been delivered

For new 2012 results:

- Very high performance, optimised, b taggers
- b-jet specific energy scale corrections (CDF updated)
- Tuned and improved lepton ID, missing- E_T algorithms
- Multivariate discriminant analyses

New CDF b-tagger gives 25-40% improvement in relative efficiency at same fake rate

CDF/DOC/CDF/PUBLIC/10803

New Methods

$B^+ \rightarrow D^- \ell^+ \ell^+$ upper limits

D meson is reconstructed through $D \rightarrow K^+ \pi \pi$

90% C.L. upper limits (UL) on the BFs in different modes:

Mode	ϵ [%]	N_{obs}	$N_{\text{exp}}^{\text{bkg}}$	U.L. [10^{-9}]
$B^+ \rightarrow D^- e^+ e^+$	1.2	0	0.18 ± 0.13	<2.6
$B^+ \rightarrow D^- e^+ \mu^+$	1.3	0	0.83 ± 0.29	<1.8
$B^+ \rightarrow D^- \mu^+ \mu^+$	1.9	0	1.10 ± 0.33	<1.1

$M_{\text{Dic}} = \sqrt{E_{\text{beam}}^2 - p_B^2}$

$\Delta E = E_D^* - E_{\text{beam}}$

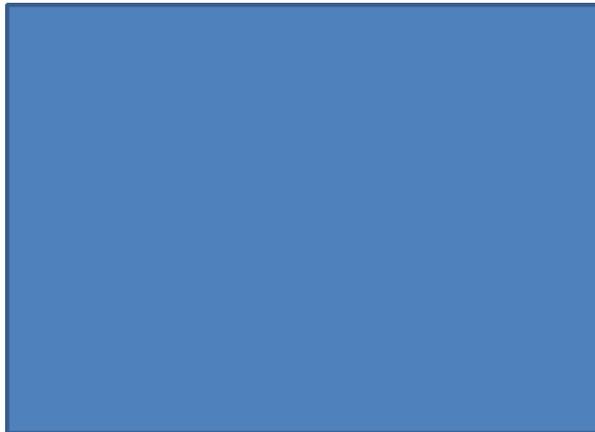
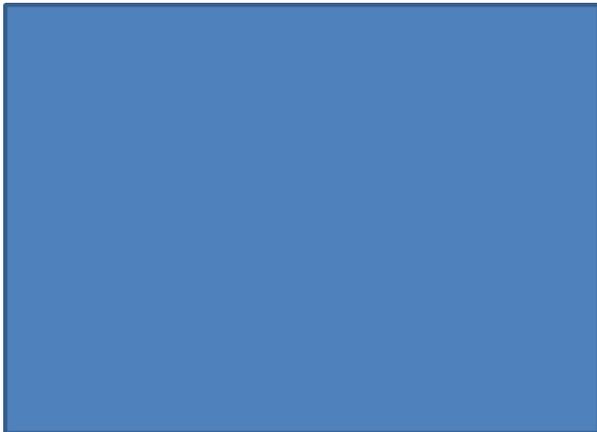
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Analysis Improvements

The Unexpected

FPCP 2012 Picture Postcards

Postcards of the Future



The Previous Slide

I was going to reserve the last slide for postcard images of the morning's new facilities.

However, I decided to focus on the physics we expect most.

The fact is, I am less certain what to expect than for many years.

FPCP 2012 Experiment Summary

As we flipped through the picture post cards, we have seen a wonderfully rich panoply of new results.

There were over 40 experiment talks!

- Standard model confirmations
- Significant reductions in uncertainty
- New physics space ruled out
- New signals and structures
- Hints of new physics
- Tension with the standard model
- Looking beyond the lamp post

FPCP 2012 Experiment Summary

- Perhaps fewer outstanding experimental issues, less tension with the Standard Model this year
- Growing disquiet over not seeing directions for the answers to the questions listed at the start about
Matter, Energy, Space, and Time
- No certainty about the direction of the needed New Physics
- Bright new idea could be the lamp post to light our way
- Hard to predict what the post cards will look like next year at Buzios
- Data sets collected and anticipated are reason for hope!

谢谢

Thank you.

Thanks, too, to all the presenters and especially to the organizers of this very enjoyable and interesting meeting.

May you all have a safe journey home, whether near or far...