

BEACH
BIRMINGHAM 2014

XI INTERNATIONAL CONFERENCE
ON HYPERONS, CHARM AND BEAUTY HADRONS
UNIVERSITY OF BIRMINGHAM, UK, 21-26 JULY 2014



A tribute to the Bards of BEACH 2014

Experiment Summary

Val Gibson
University of Cambridge

The Higgs Bard

The Higgs Bard

The Higgs Bard did not directly feature at this weeks performance...



The Higgs Bard

The Higgs Bard did not directly feature at this weeks performance...

.... many new and exciting experimental results did.

Apologies to

- Bards of BEACH for not mentioning all their results.
- Shakespeare for using his quotes in a most inappropriate manner



A stage with red curtains and a wooden floor. The curtains are a deep red color with a subtle sheen, featuring large, circular, ruffled valances at the top. The floor is made of light-colored wooden planks. The word "Prelude" is written in a white, serif font in the center of the stage.

Prelude

A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

“All the world's a stage, and all the
men and women merely players....”.

As you like it, Act II, Scene VII

A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

“All the world's a stage, and all the
physicists and experiments merely
players....”.

As you like it, Act II, Scene VII

Main players





QCD

A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

“When sorrows come, they come
not single spies, but in battalions”.

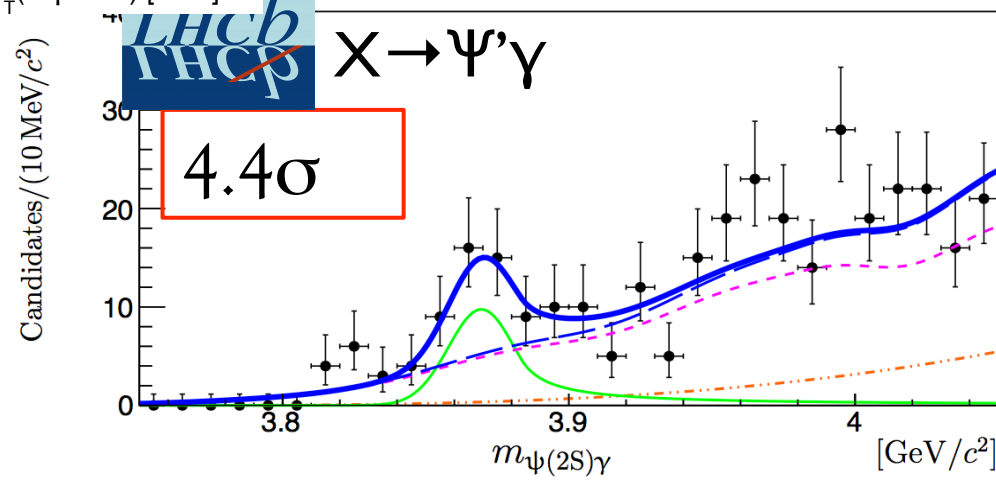
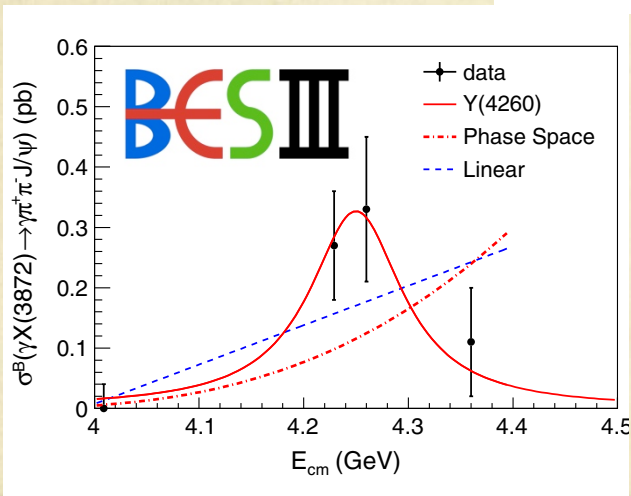
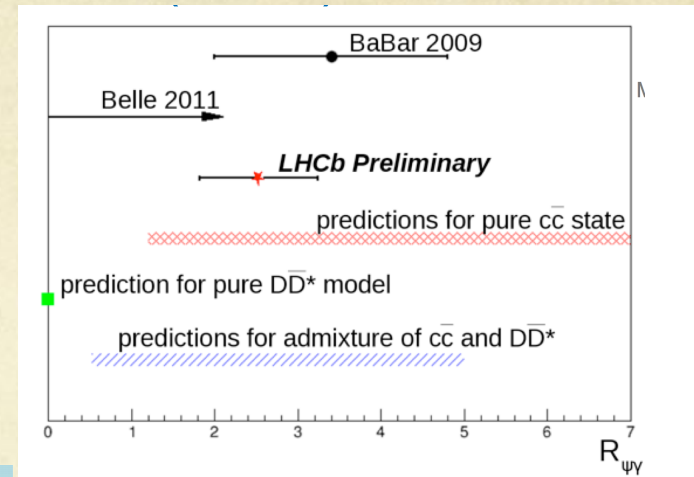
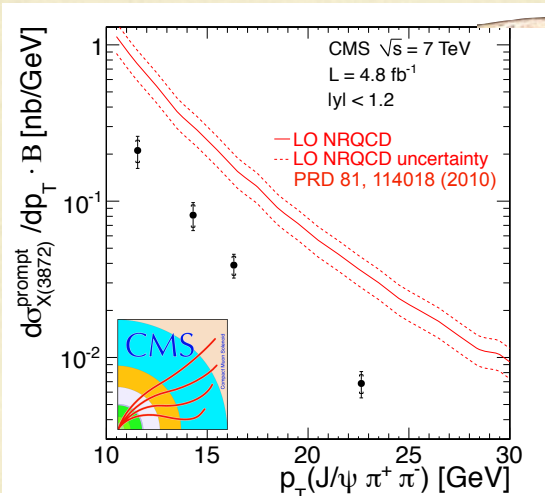
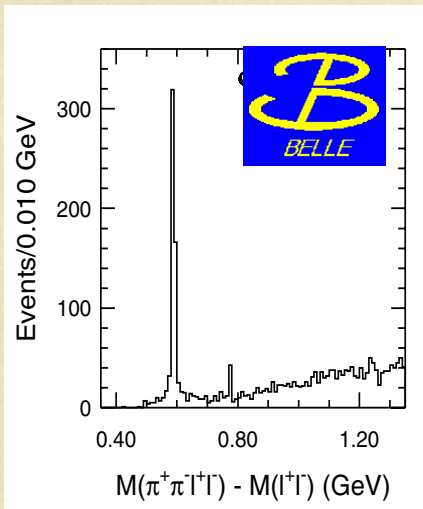
Hamlet Act IV, Scene V

A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

”When **exotics** come, they come not
single **states**, but in battalions”.

Hamlet Act IV, Scene V

X(3872)



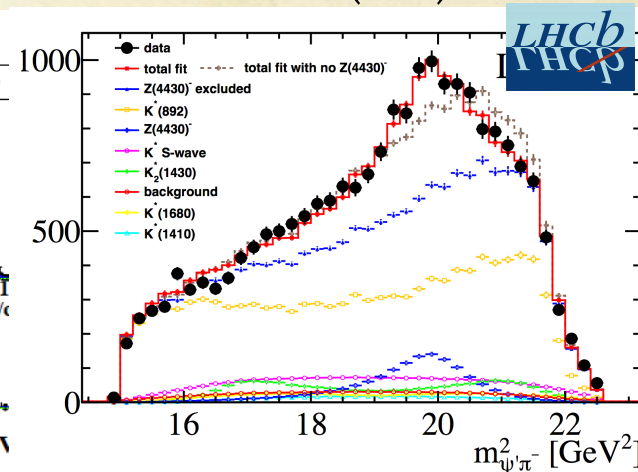
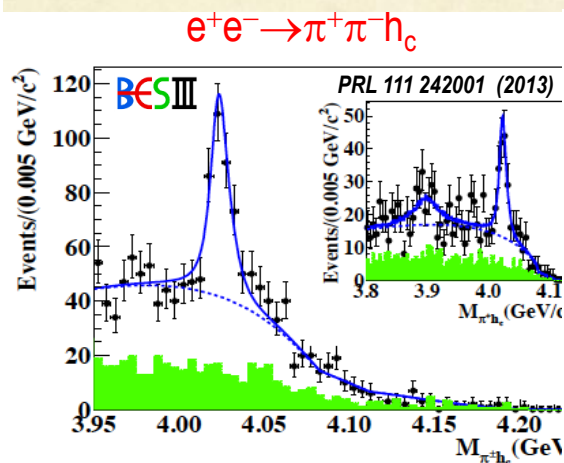
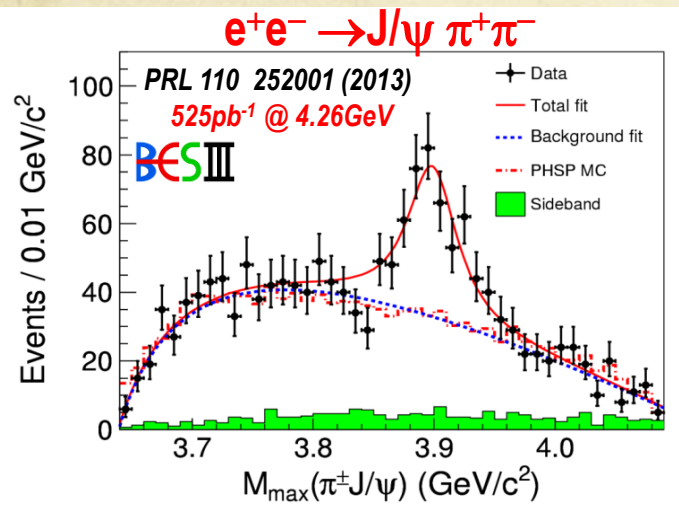
Most likely a mixture of DD^* molecule and a $\chi_{c1}(2^3P_{1++})$ charmonium state. Correlated to $Y(4260)$ & $Z_c(3900)$?

Z_c states

Charged exotic hadrons most promising way to search for exotic hadrons

$Z_c(3900)$, $Z_c(4020)$ and $Z_c(4430)$ states established

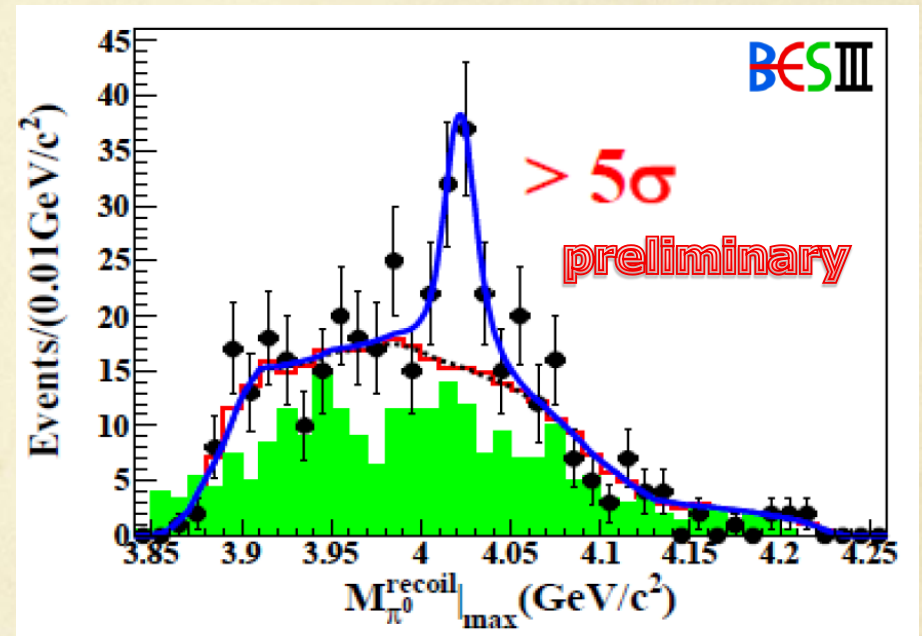
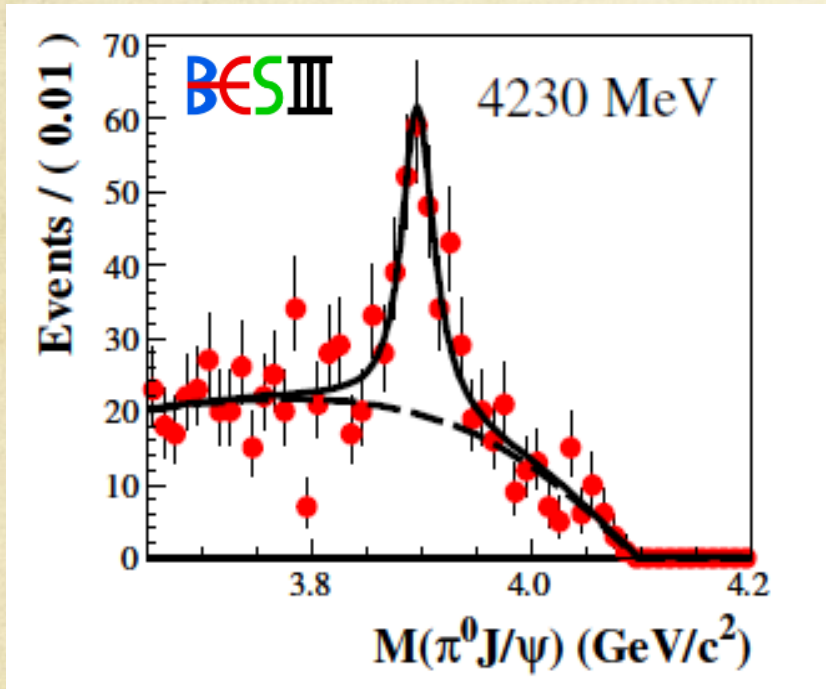
$$B^0 \rightarrow \psi(2S) \pi^- K^+$$



13.9 σ

Z_c states

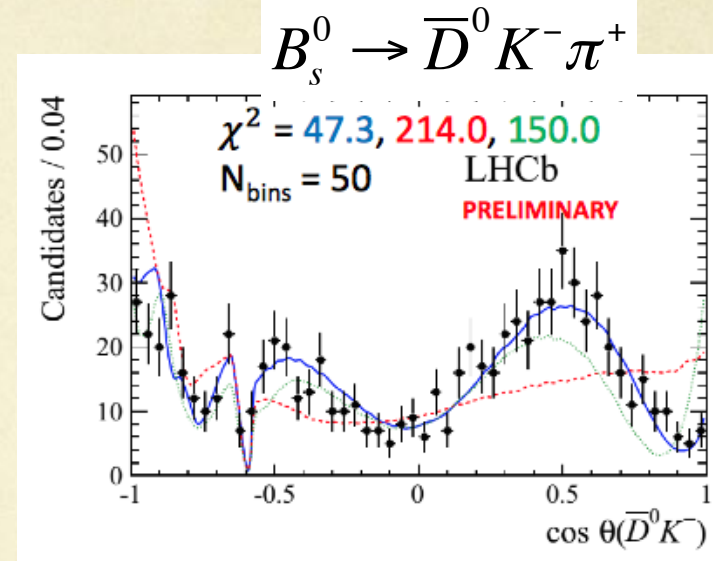
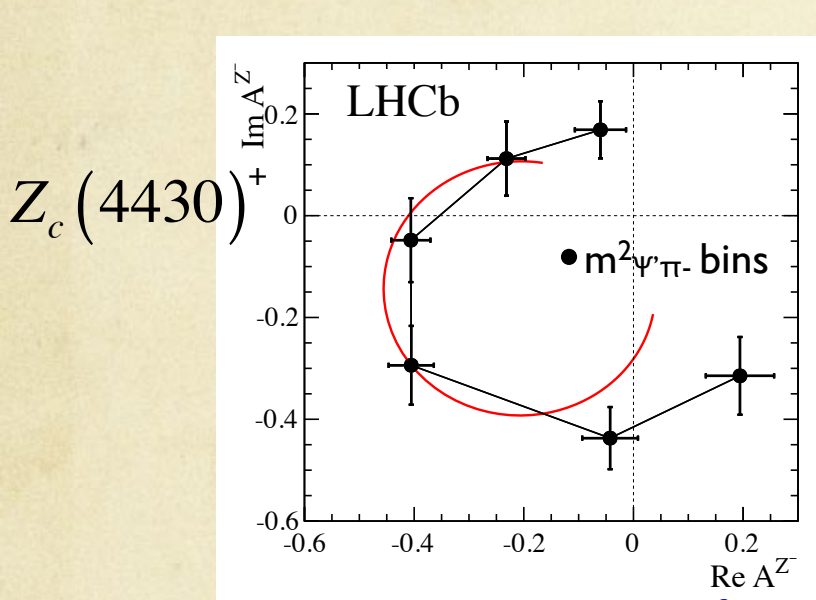
$Z_c(3090)$ and $Z_c(4020)$ isospin partners observed.



Is there an isospin partner of the $Z_c(4430)$?

Amplitude analyses

Amplitude analysis crucial in understanding new states



$D_{s1}^*(2860)^-$

$D_{s3}^*(2860)^-$

Resonance nature of $Z_c(4430)$ & first observation heavy-flavoured spin-3 state

Need to discover more states, explore transitions between them and decay modes.

Quarkonia production

“Common as gulls”: Kraetschmer



Quarkonia production

“Common as gulls”: Kraetzschmer

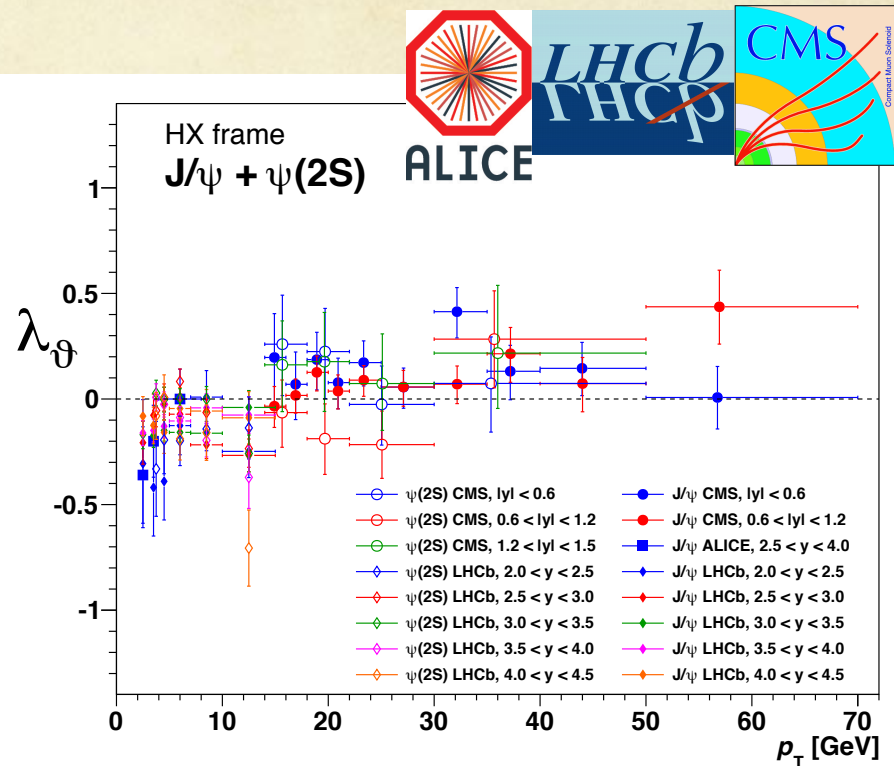
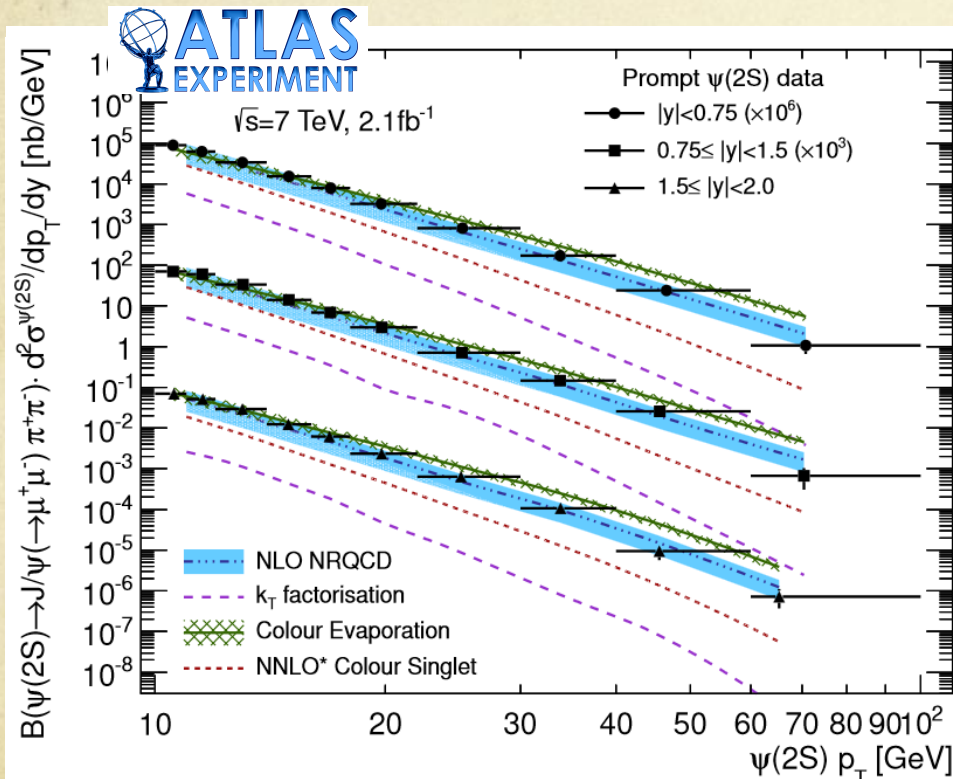


“Common as pigeons” in Birmingham



Quarkonia Production

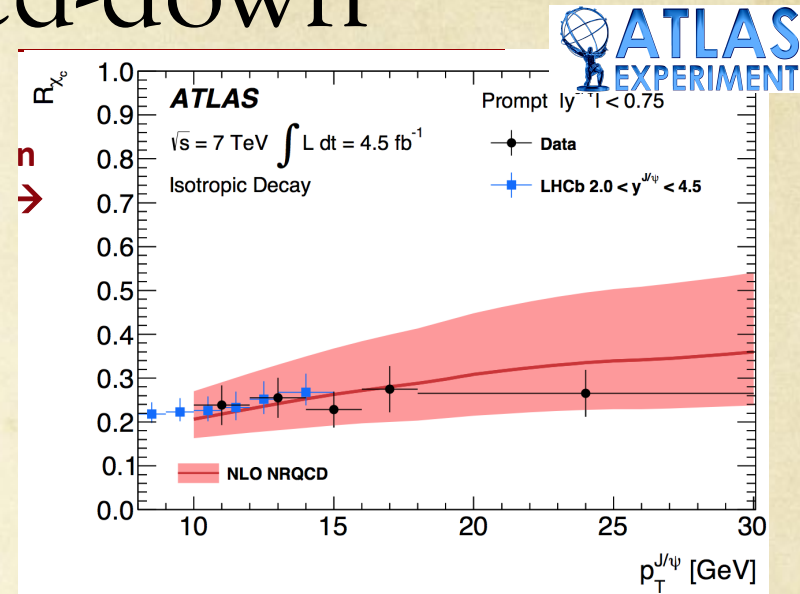
NRQCD describes quarkonia production but fails dismally at polarization.



Quarkonia feed-down

Understanding feed-down contributions very important

20-30% χ_c from J/ψ

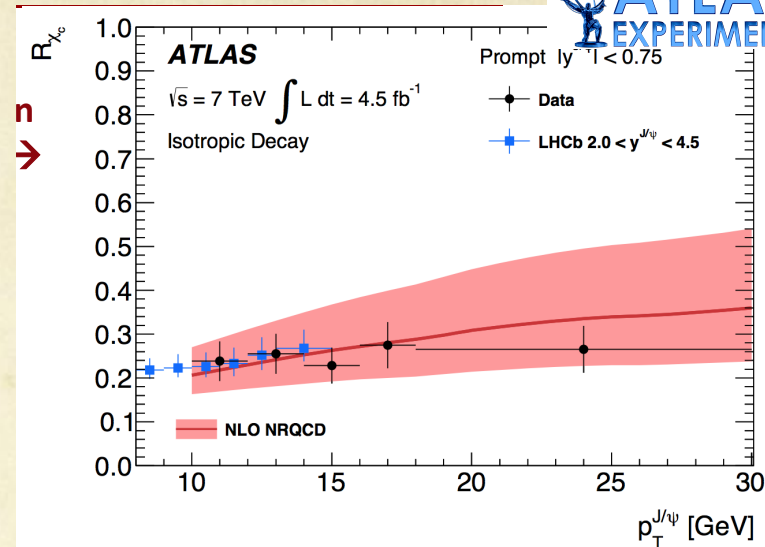


Quarkonia feed-down

Understanding feed-down contributions very important

20-30% χ_c from J/ψ

Following discovery of $\chi_b(3P)$..



BBC News Sport Weather iPlayer TV

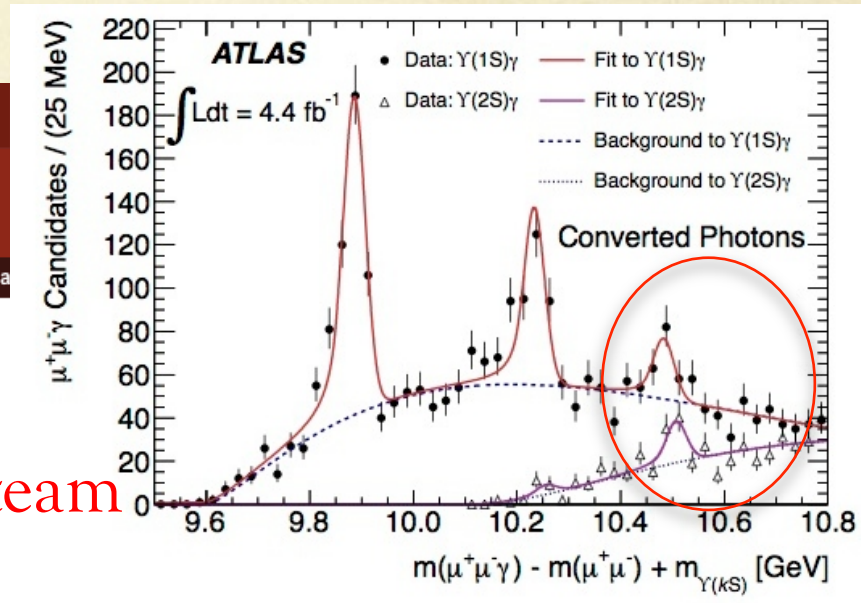
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22 December 2011 Last updated at 10:59

LHC reports discovery of its first new particle by Birmingham ATLAS team

By Jonathan Amos
Science correspondent, BBC News

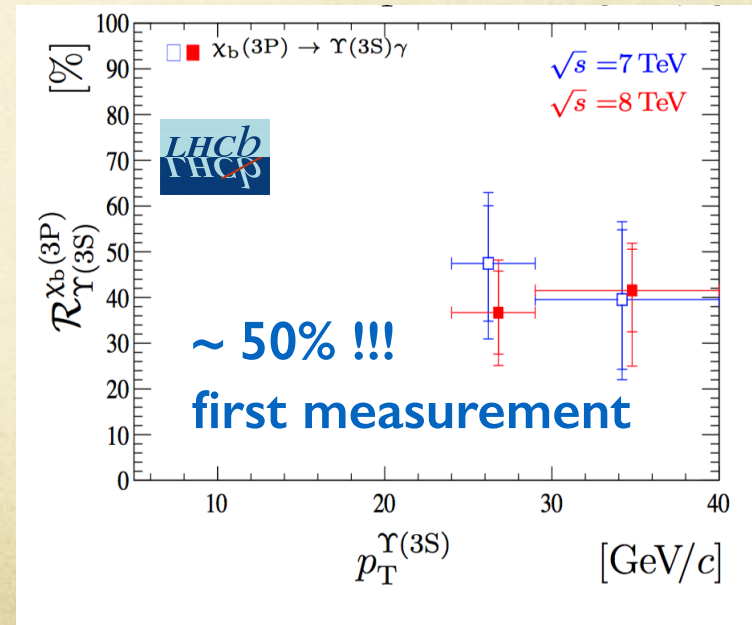
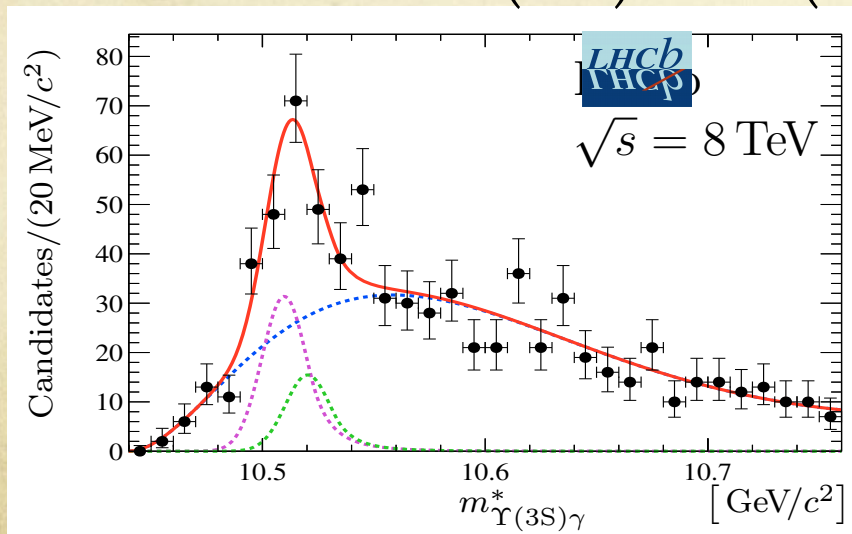
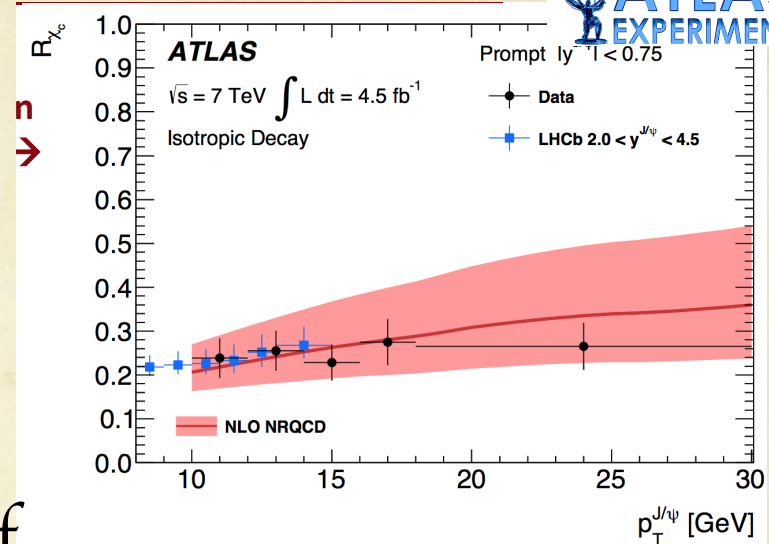


Quarkonia feed-down

Understanding feed-down contributions very important

20-30% χ_c from J/Ψ

... now have first observation of $\chi_b(3P) \rightarrow \Upsilon(3S)\gamma$

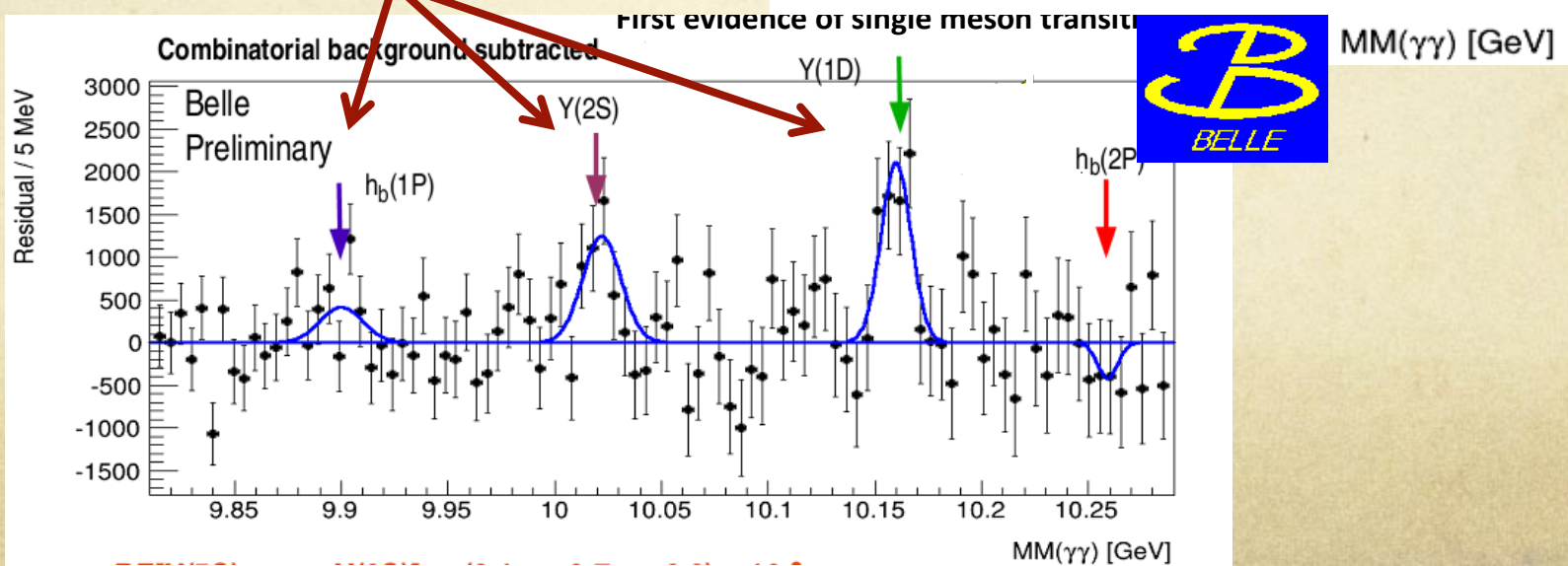
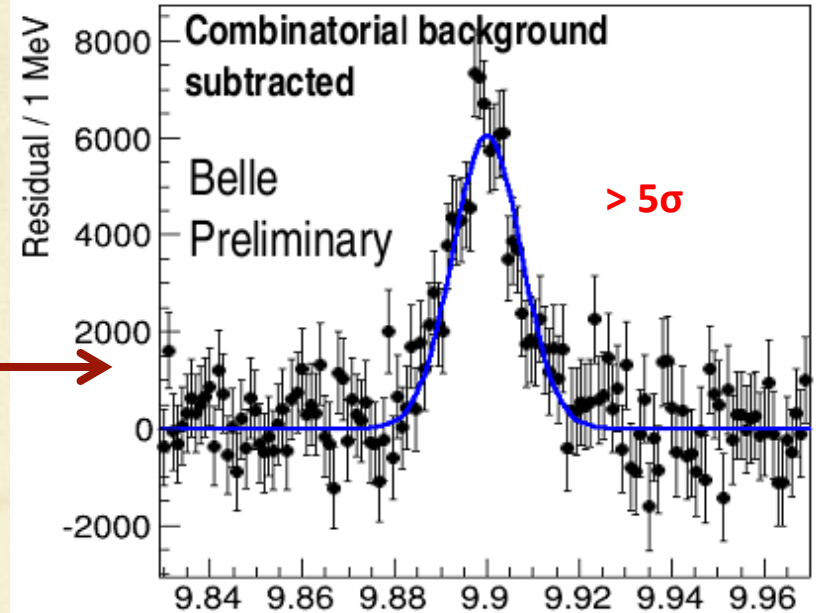


Bottomonium

New results on
bottomonium transitions,
in particular via η meson

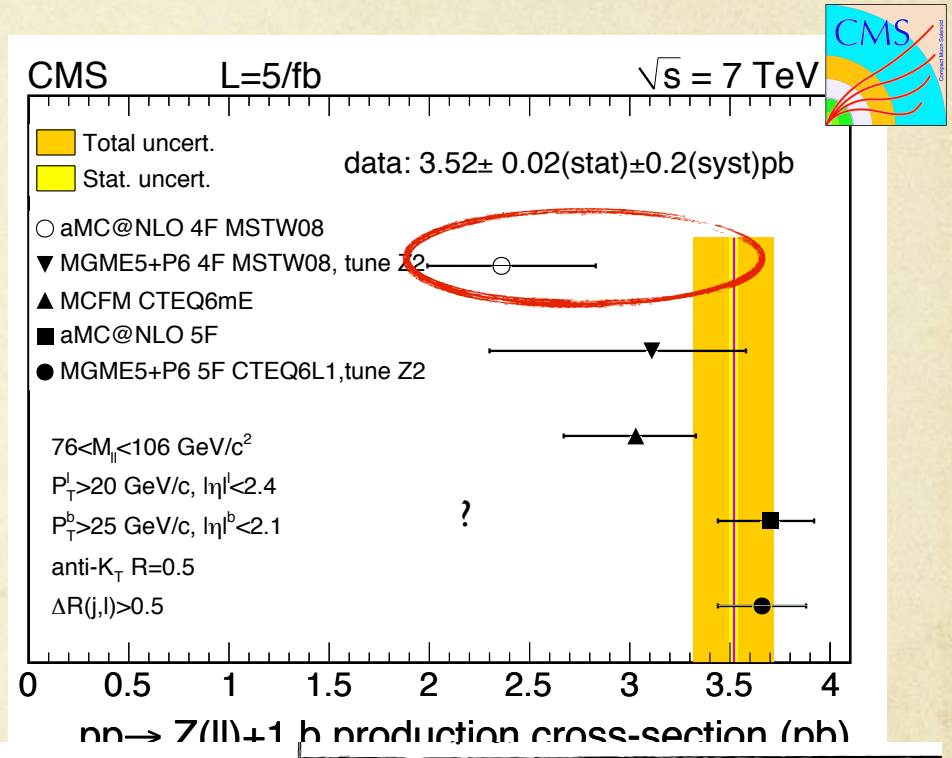
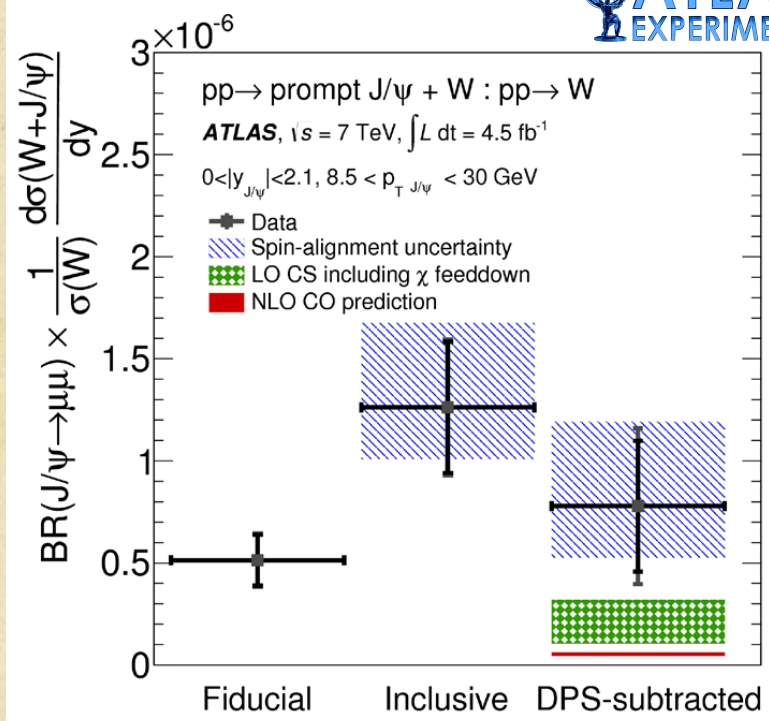
$$\Upsilon(4S) \rightarrow \eta h_b(1P)$$

$$\Upsilon(5S) \rightarrow \eta b\bar{b}$$



W+J/ψ

Z+b

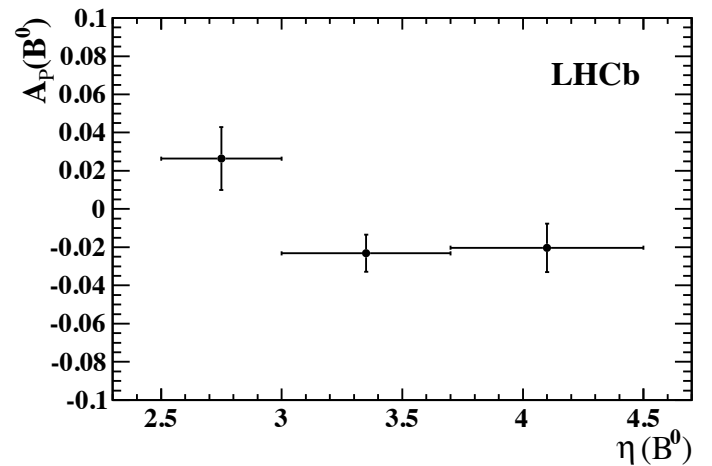
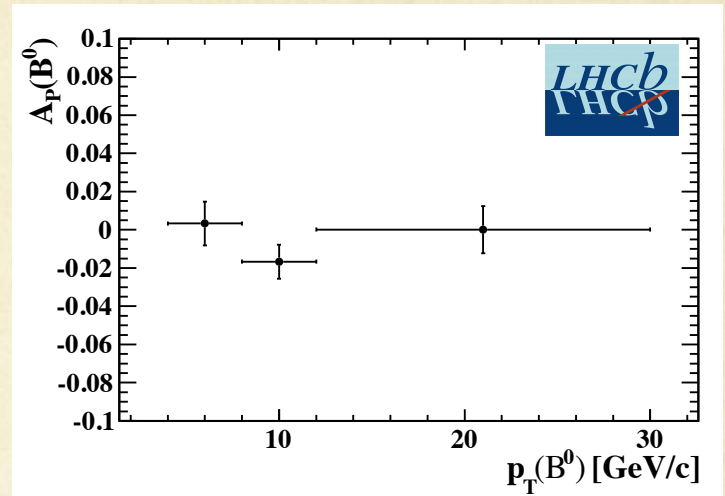
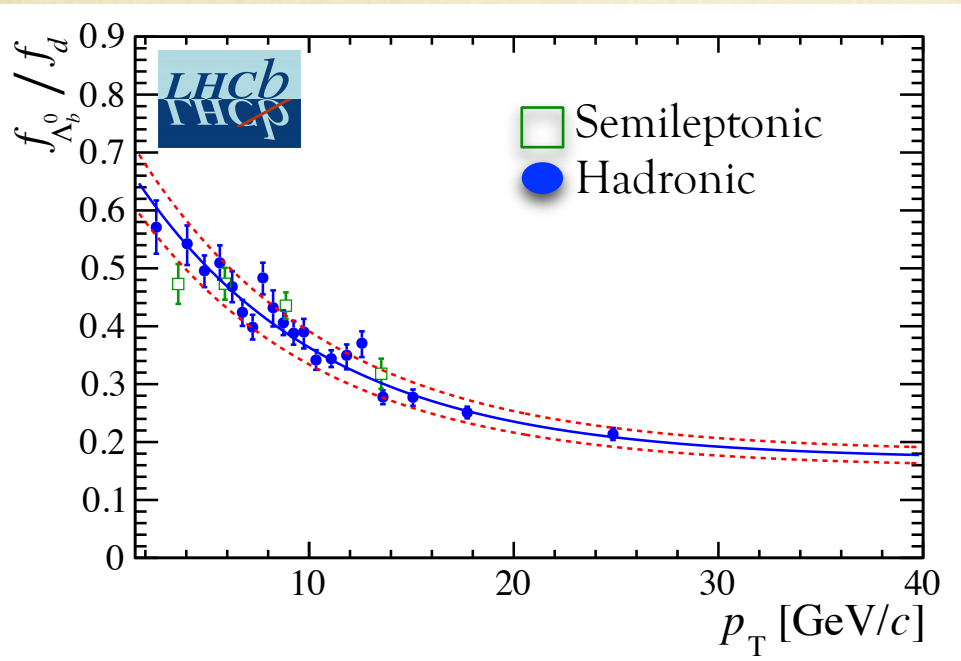


MadGraph 5F and aMC@NLO 5F
 good agreement
 aMC@NLO 4F and MCFM
 ~2σ away

B production

20-50% b hadrons are Λ_b 's

B production asymmetries
<few %



$$A_P(B^0) = -0.35 \pm 0.76^{(stat)} \pm 0.28^{(syst)} \%$$

$$\triangleright A_P(B_s^0) = 1.09 \pm 2.61^{(stat)} \pm 0.61^{(syst)} \%$$

B spectroscopy

Many world-leading mass and lifetimes measurements in many B decay channels. Most recently, b baryons and B_c .

$$\tau(\Lambda_b^0)/\tau(\bar{B}^0) = 0.974 \pm 0.006 \pm 0.004$$

$$\tau(\Lambda_b^0) = (1.479 \pm 0.009 \pm 0.010) \text{ ps}$$

WORLD'S BEST MEASUREMENT

$$\text{Theory: } \tau(\Lambda_b^0) = 1.41 \pm 0.08 \text{ ps}$$

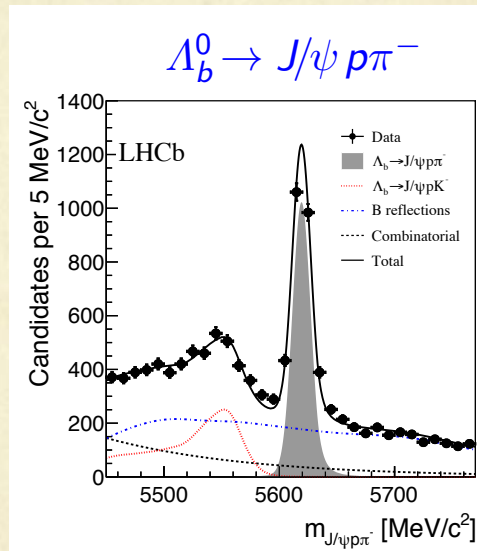
$$\Xi_b^- \rightarrow J/\psi \Xi^-$$

Signal candidates: 313 ± 20

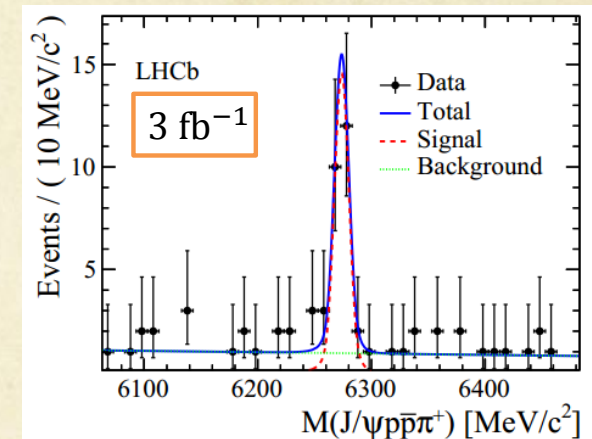
$$\tau(\Xi_b^-) = 1.55_{-0.09}^{+0.10} \pm 0.03 \text{ ps}$$

WORLD'S BEST MEASUREMENT

$$\text{Theory [Lenz'14]: } 1.56 \pm 0.10 \text{ ps}$$



$$B_c^+ \rightarrow J/\psi p \bar{p} \pi^+$$



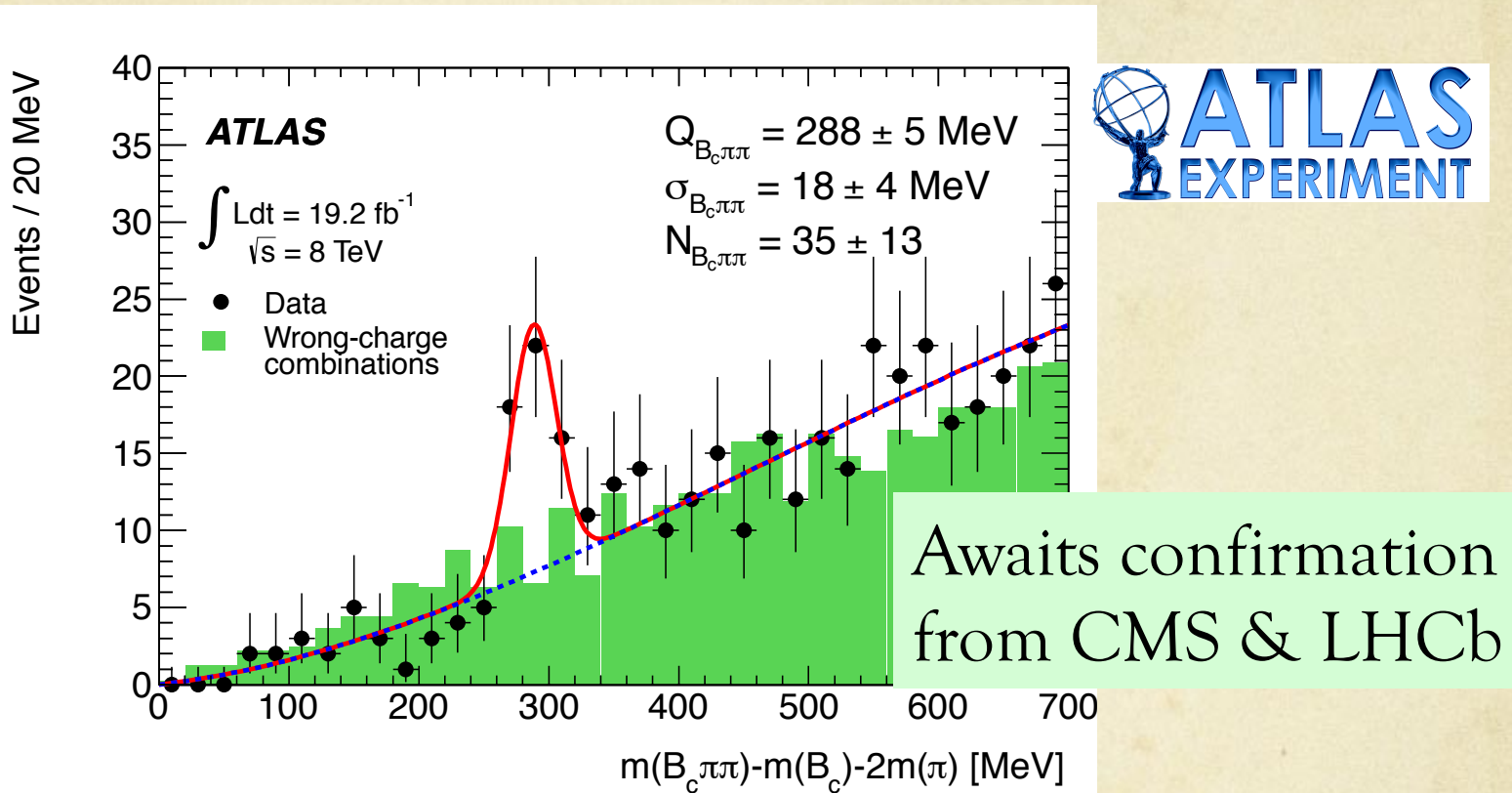
$$N_{\text{sig}} = 23.9 \pm 5.3 (7.3 \sigma)$$

HQE theory works

$$M(B_c^+) = 6274.7 \pm 0.9(\text{stat}) \pm 0.8(\text{syst}) \text{ MeV}/c^2$$

... and >50 new decay modes have been discovered in the last 2 years.

Discovery of $B_c(2S)$



A new state has been observed in the ATLAS detector with a mass

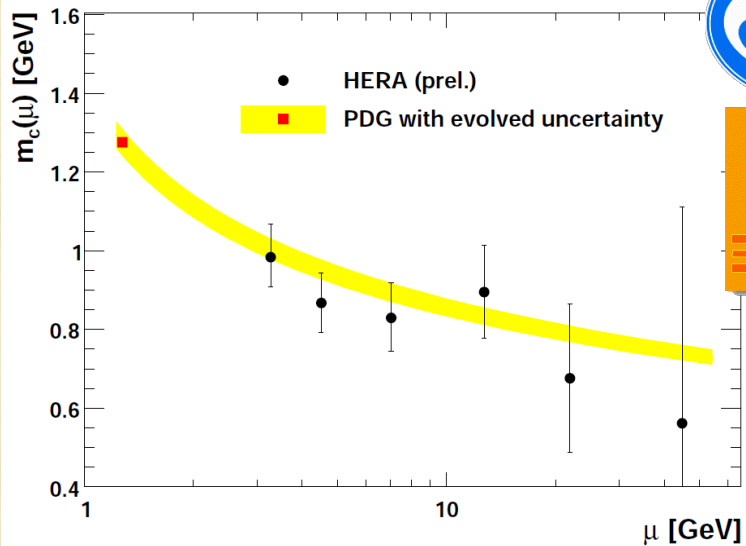
$$6841 \pm 4(\text{stat}) \pm 5(\text{syst}) \text{ MeV}$$

consistent with $B_c(2S)$ predicted as: $m_{B_c(2S)} \sim 6835 \div 6917 \text{ MeV}$

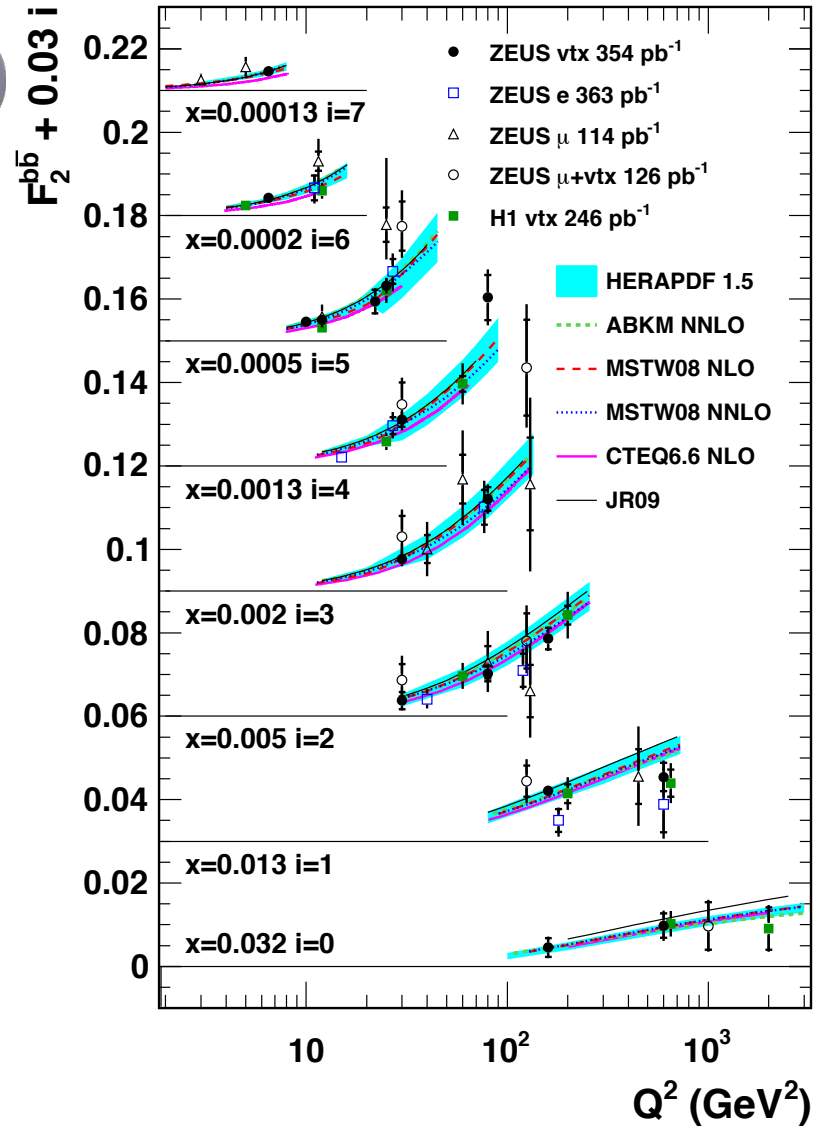
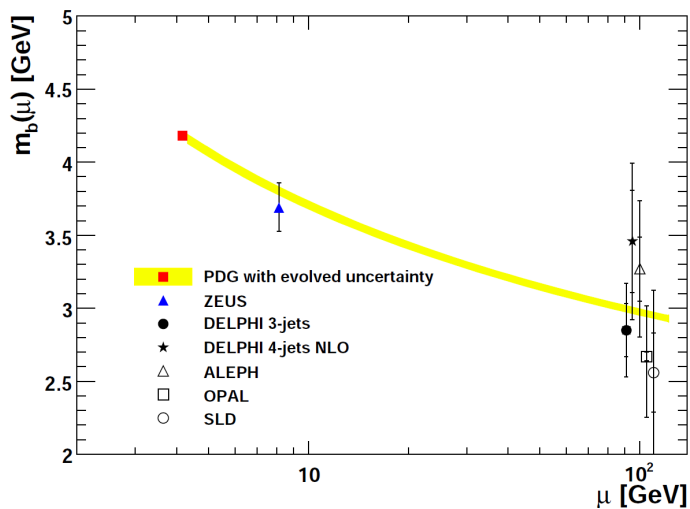
Heavy flavour at HERA



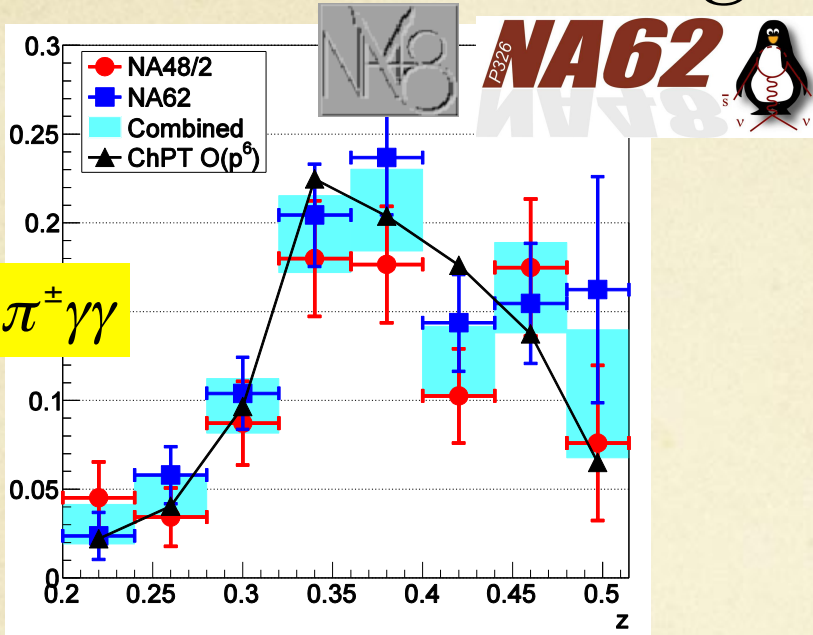
H1 and ZEUS preliminary



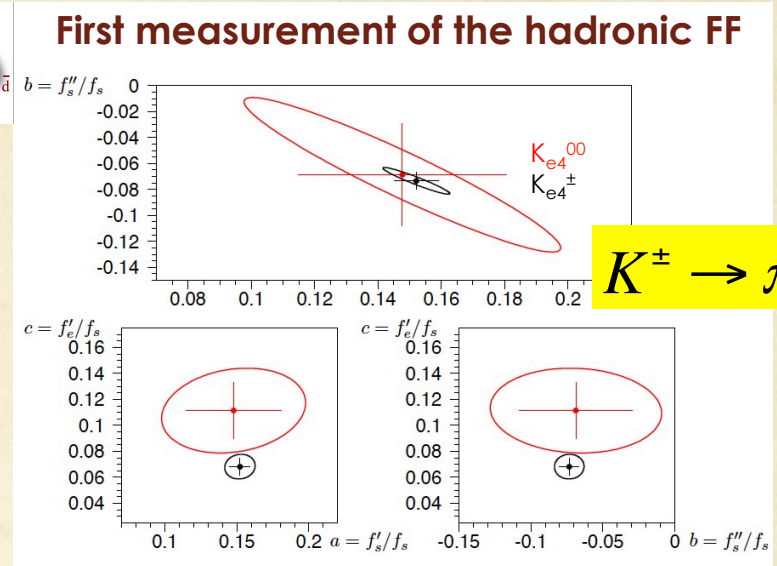
ZEUS



Strange QCD



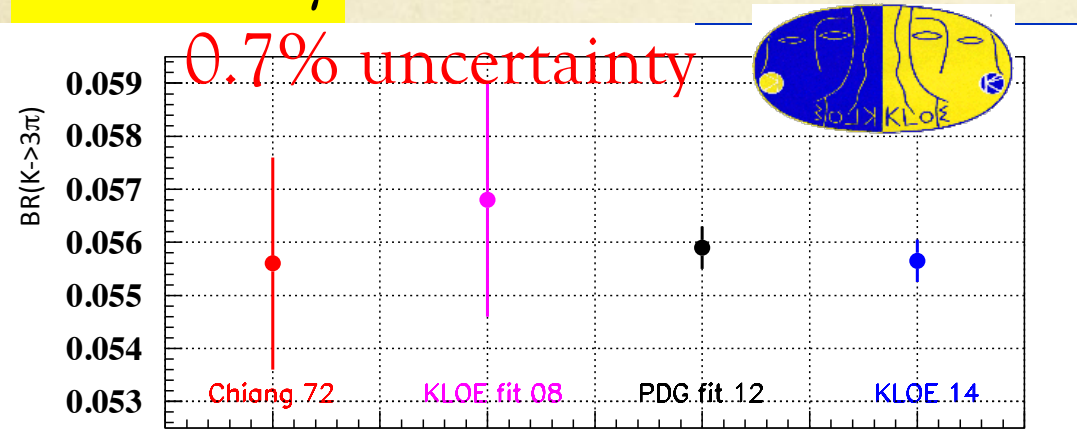
$K^\pm \rightarrow \pi^\pm \gamma \gamma$



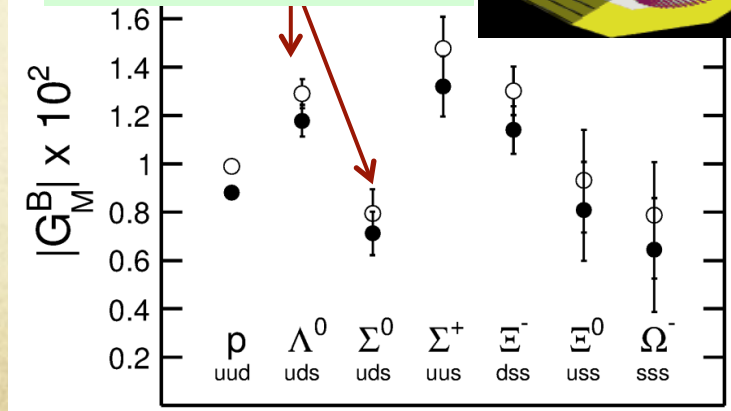
$K^\pm \rightarrow \pi\pi\ell\nu$

$K^+ \rightarrow \pi^+ \pi^+ \gamma$

0.7% uncertainty



Diquark spatial correlations?

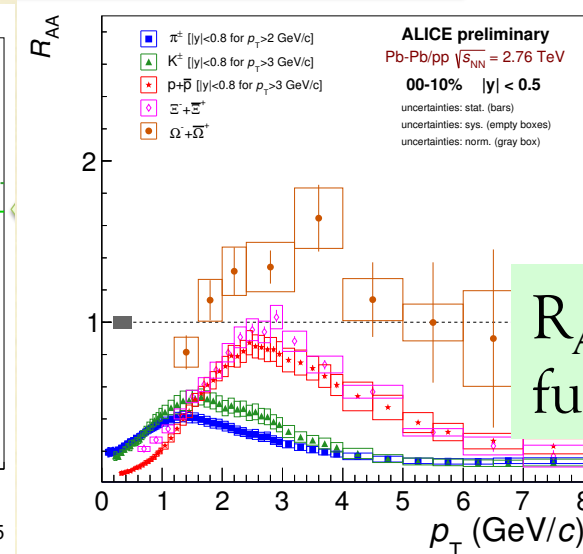
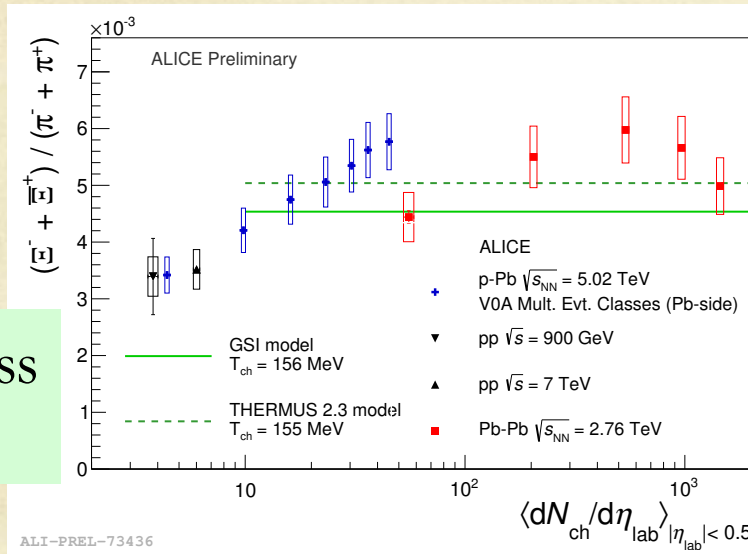


Strange & Charm in QGP



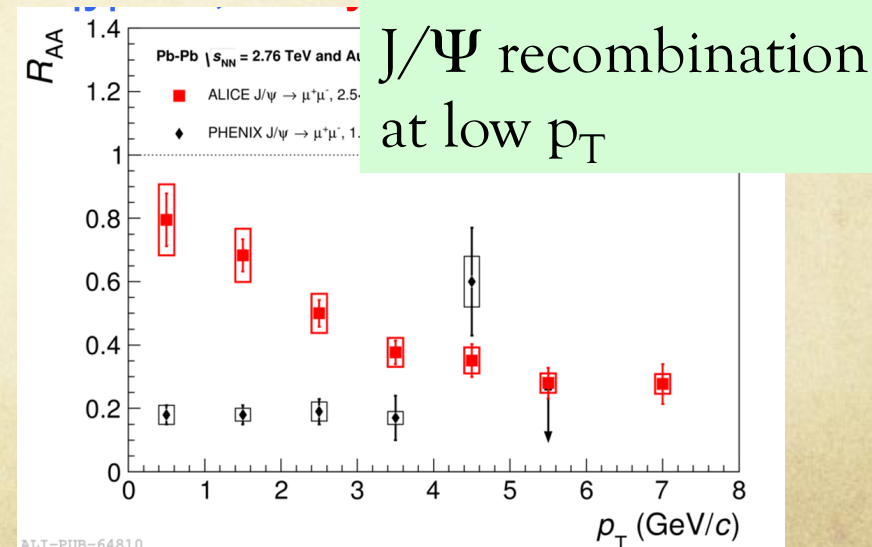
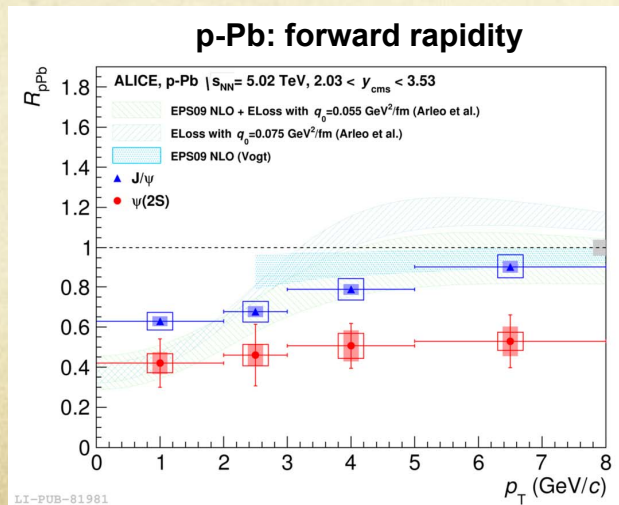
Strange

Strangeness enhanced



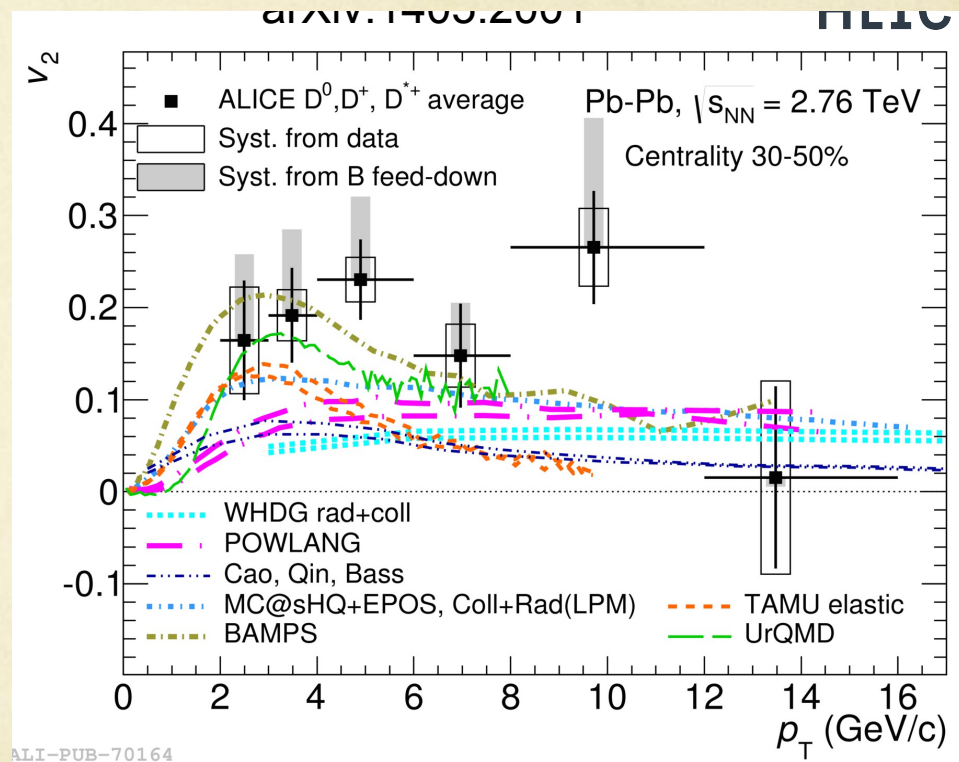
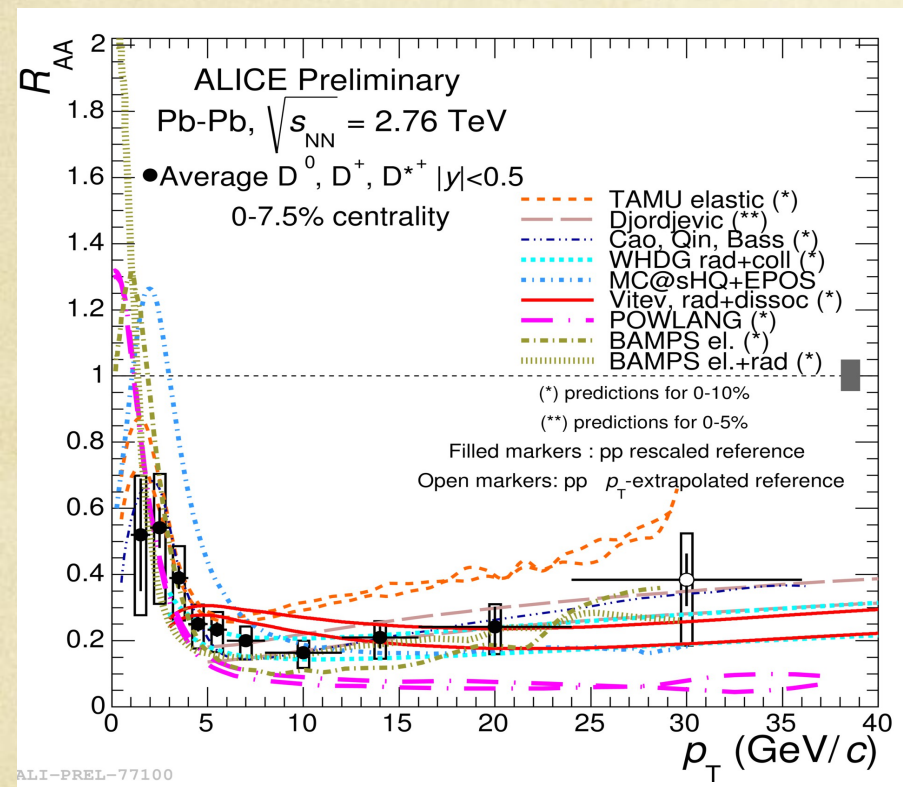
Quarkonia

Quarkonia suppressed



Strange & Charm in QGP

Open charm



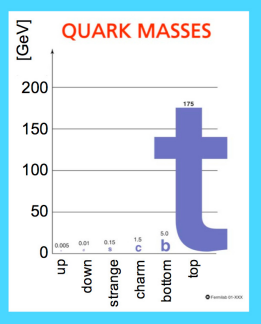
A stage with red curtains and a wooden floor. The word "Top" is written in white serif font in the center of the stage.

Top

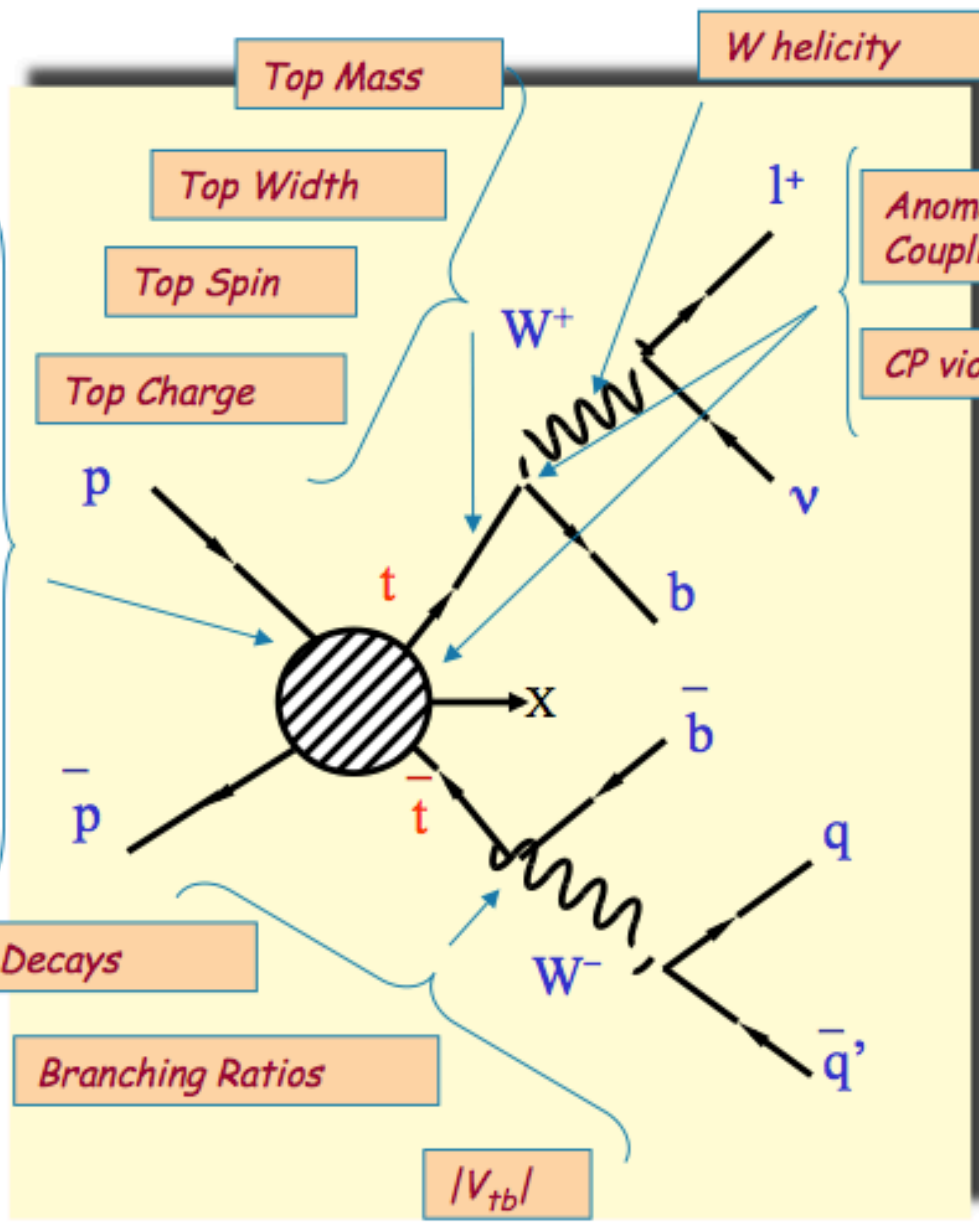
A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

” Both truth and beauty on my
love depends”.

Sonnets CI



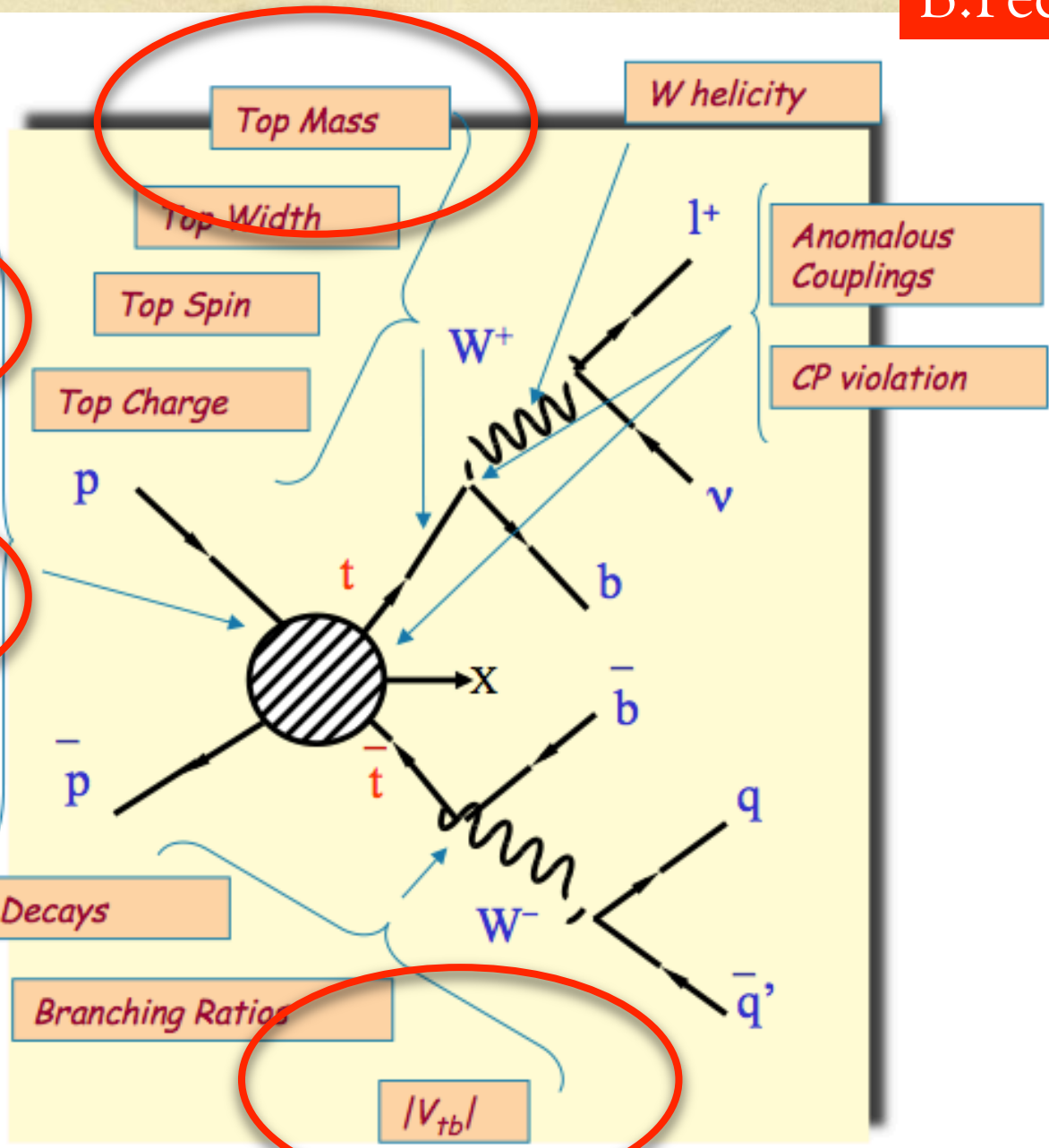
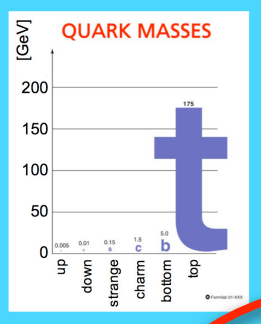
- Production cross-section
- Resonant production
- Production kinematics
- Top Spin Polarization



Rare/non SM Decays

Branching Ratios

$|V_{tb}|$



- Production cross-section
- Resonant production
- Production kinematics
- Top Spin Polarization

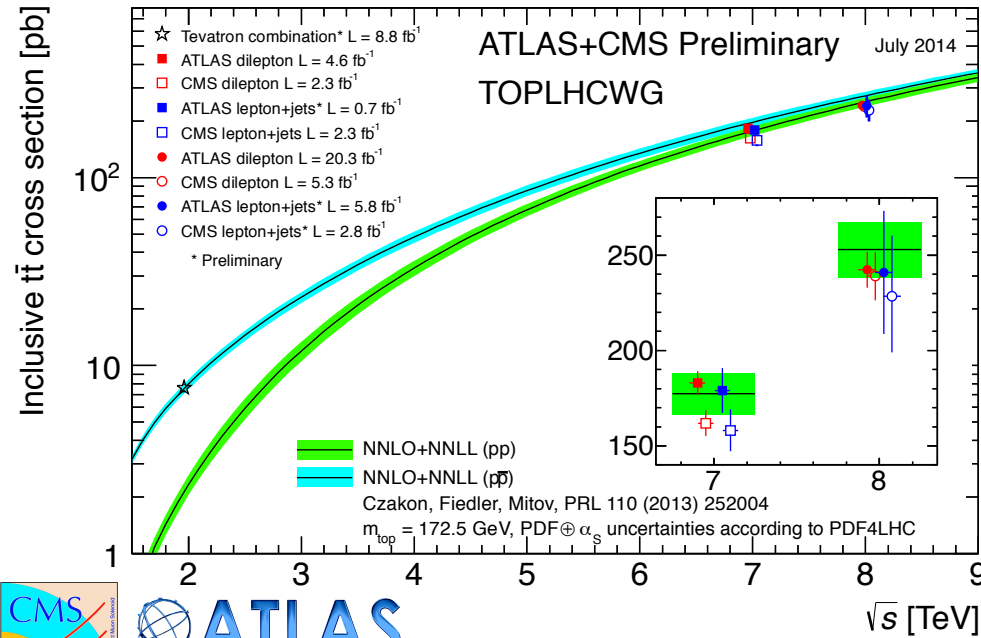
Precision era for top measurements

$|V_{tb}|$

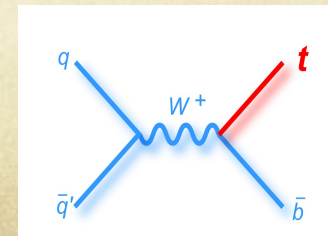
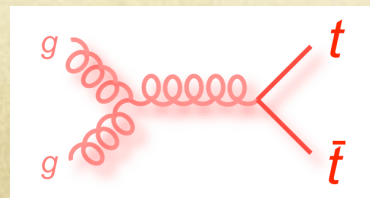
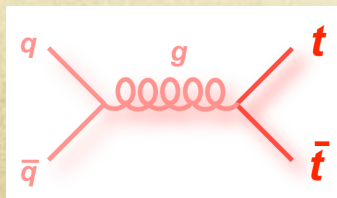
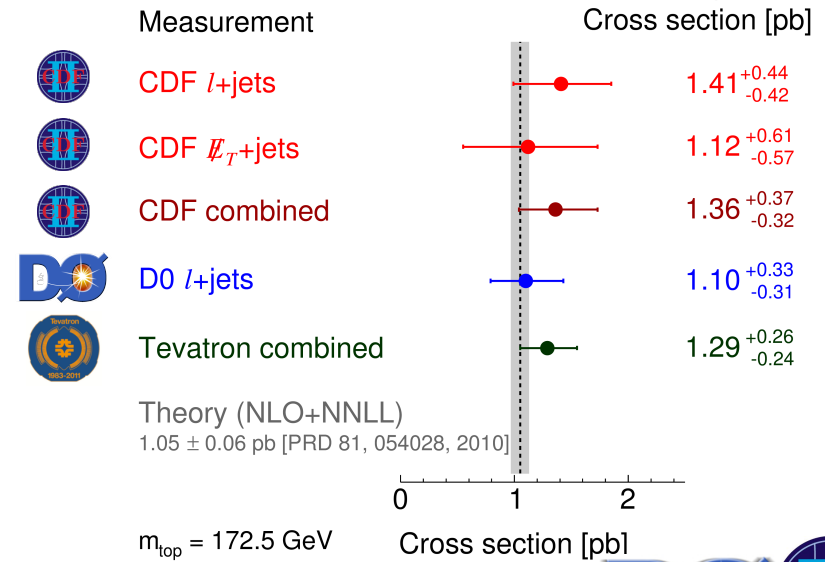
Top production

$\sigma_{t\bar{t}}$ Top pair
consistent with NNLO

σ_t s-channel single top
observed at 6.3σ



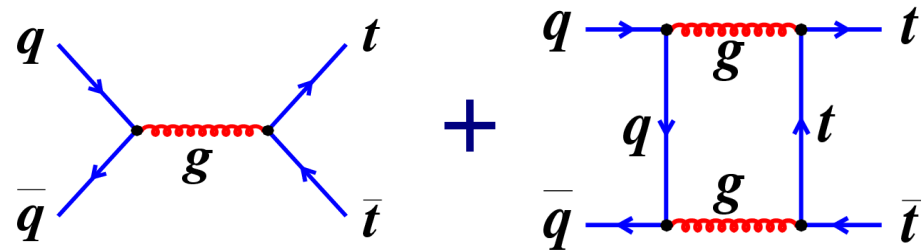
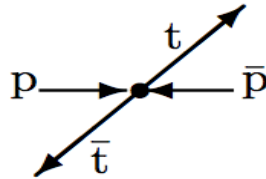
s-channel single top quark, Tevatron Run II, $L_{int} \leq 9.7$ fb⁻¹



$t\bar{t}$ asymmetries

- NLO QCD: Interference between $q\bar{q}$ diagrams \rightarrow causes $t\bar{t}$ asymmetry

- Top quarks more likely to go into direction of incoming quark

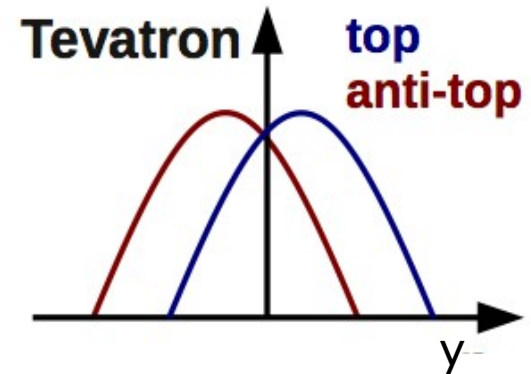


- Measurement of forward-backward asymmetry:

$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

- Also: study of lepton-based asymmetry

$$A_{FB}^l = \frac{N(q_l y_l > 0) - N(q_l y_l < 0)}{N(q_l y_l > 0) + N(q_l y_l < 0)}$$

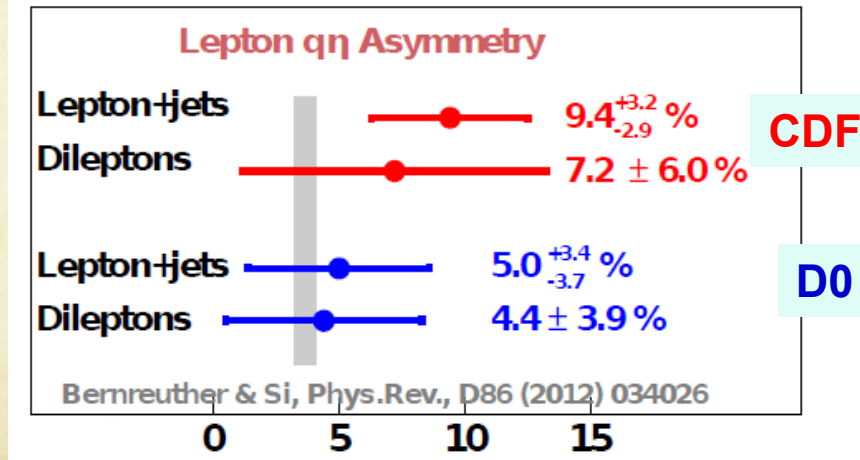
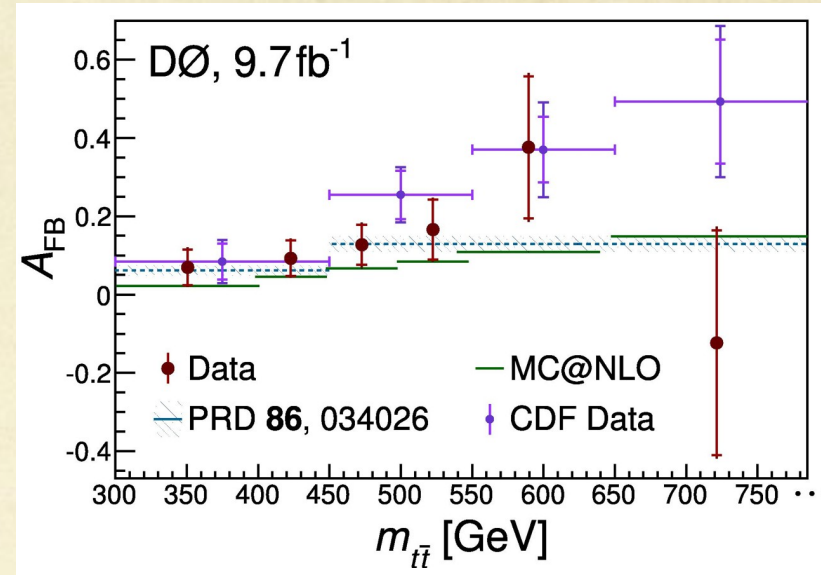
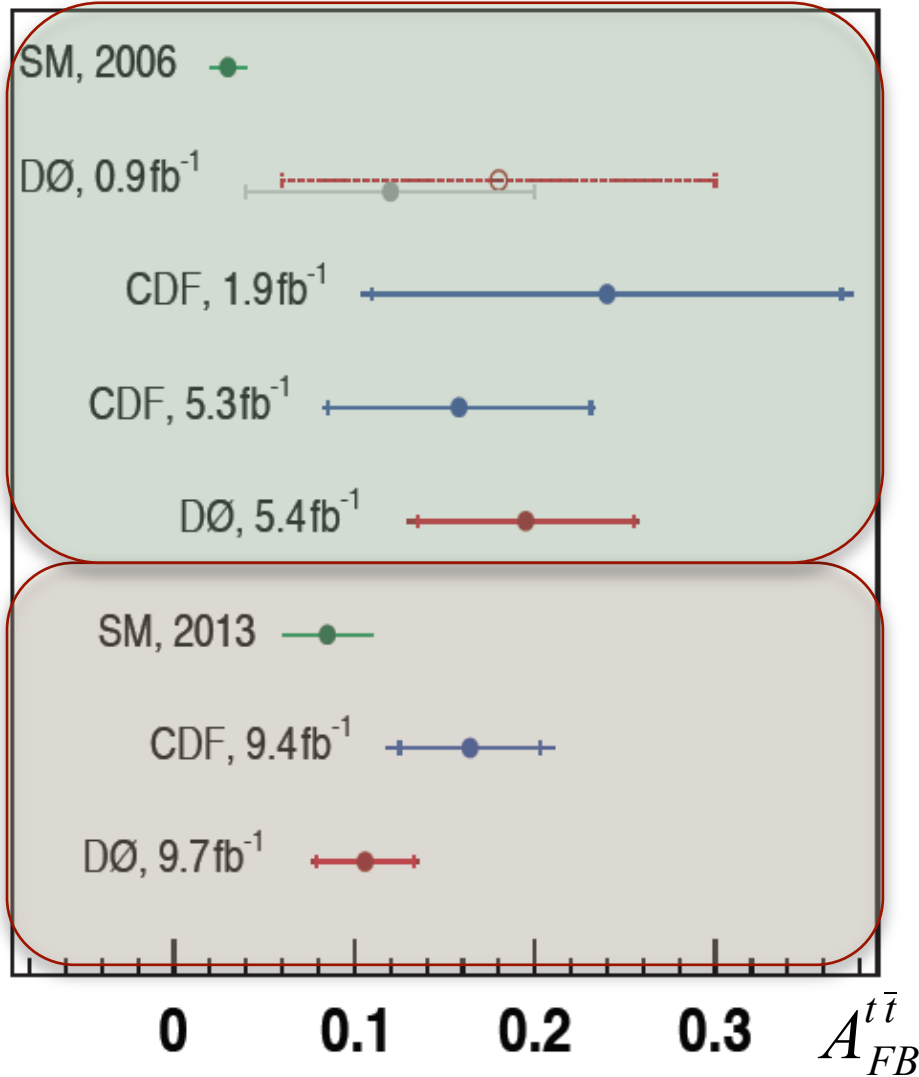


$$\Delta y = y_t - y_{\bar{t}}$$

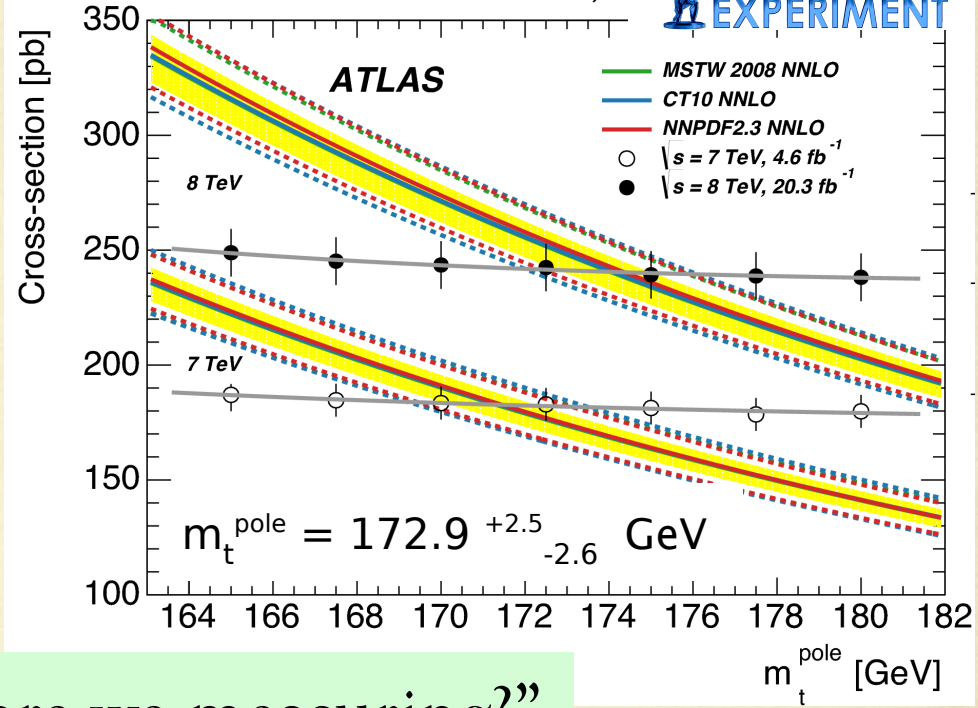
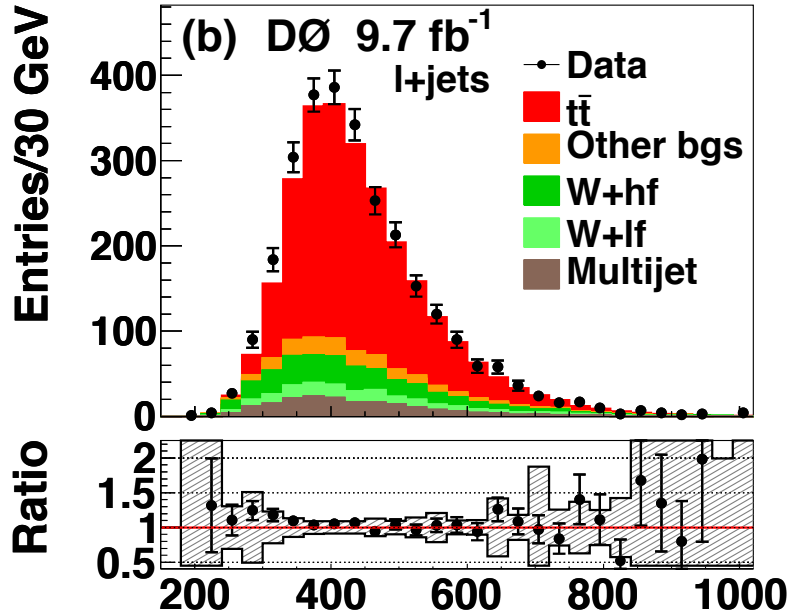
$$y = \frac{1}{2} \ln \left(\frac{E + p_z}{E - p_z} \right)$$



$t\bar{t}$ asymmetries

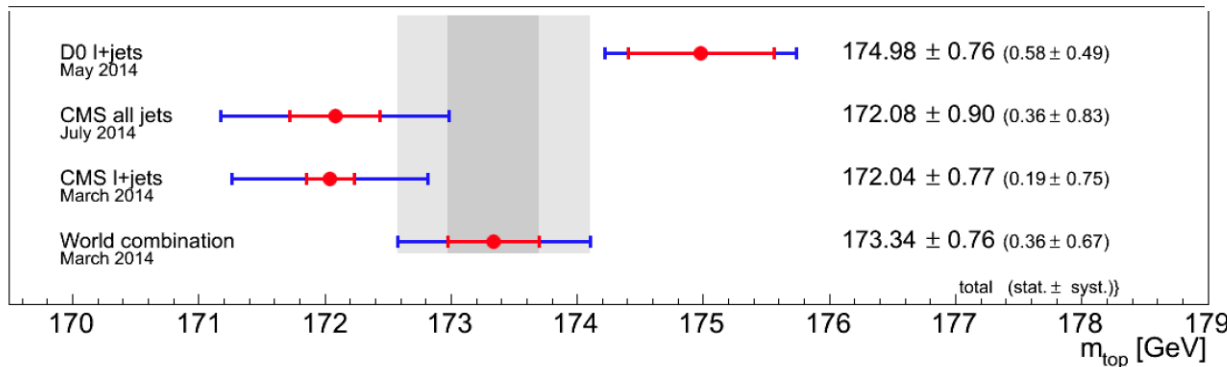


Top mass



“What top mass are we measuring?”

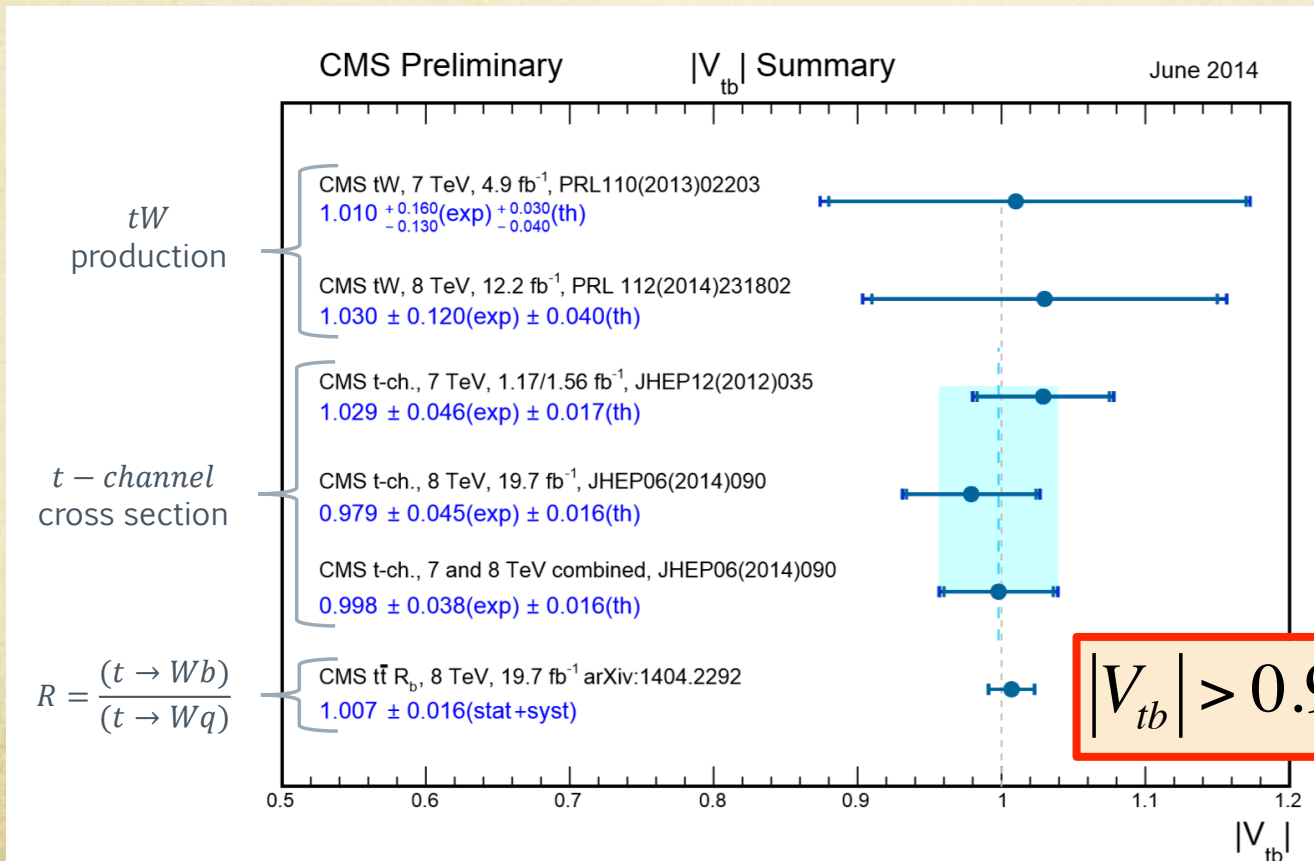
Status July



$$|V_{tb}|$$

Most precise value of $|V_{tb}|$ from measurement of $R = \frac{\mathcal{B}(t \rightarrow Wb)}{\mathcal{B}(t \rightarrow Wq)}$ from $t\bar{t}$ production with dilepton final state.

$$R = \frac{\mathcal{B}(t \rightarrow Wb)}{\mathcal{B}(t \rightarrow Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$



A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

Quark mixing and CP violation

A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

” To be, or not to be: that is
the question”.

Hamlet, Act III, Scene I

A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

” To **B**, or not to **B-bar**: that is
the question”.

Hamlet, Act III, Scene I

Discovery of CP violation

VOLUME 13, NUMBER 4

PHYSICAL REVIEW LETTERS

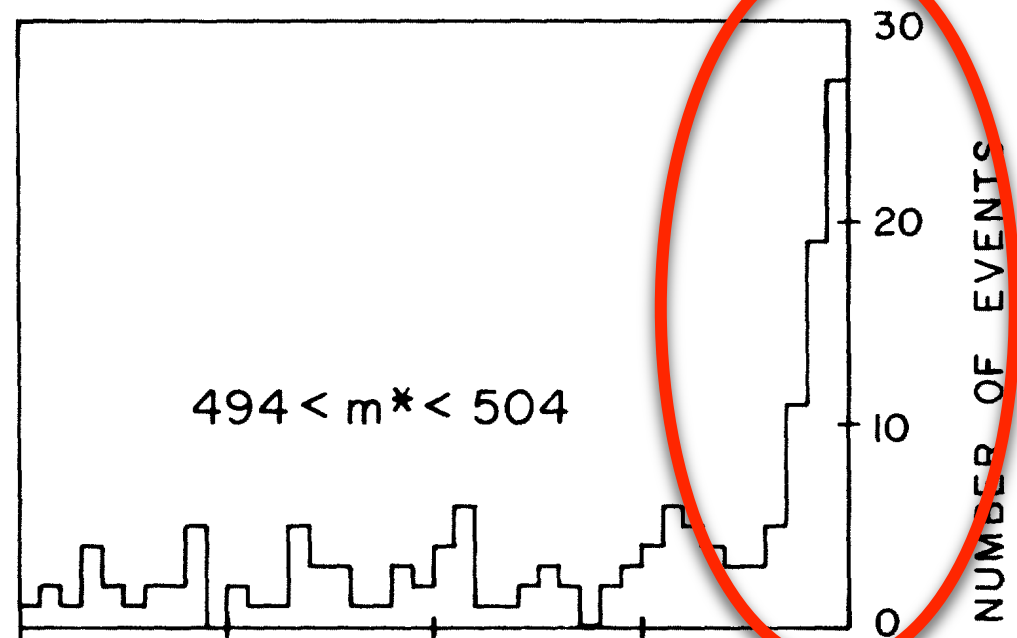
27 JULY 1964

EVIDENCE FOR THE 2π DECAY OF THE K_2^0 MESON*†

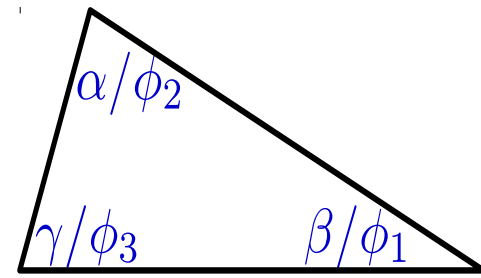
J. H. Christenson, J. W. Cronin,‡ V. L. Fitch,‡ and R. Turlay§

Princeton University, Princeton, New Jersey

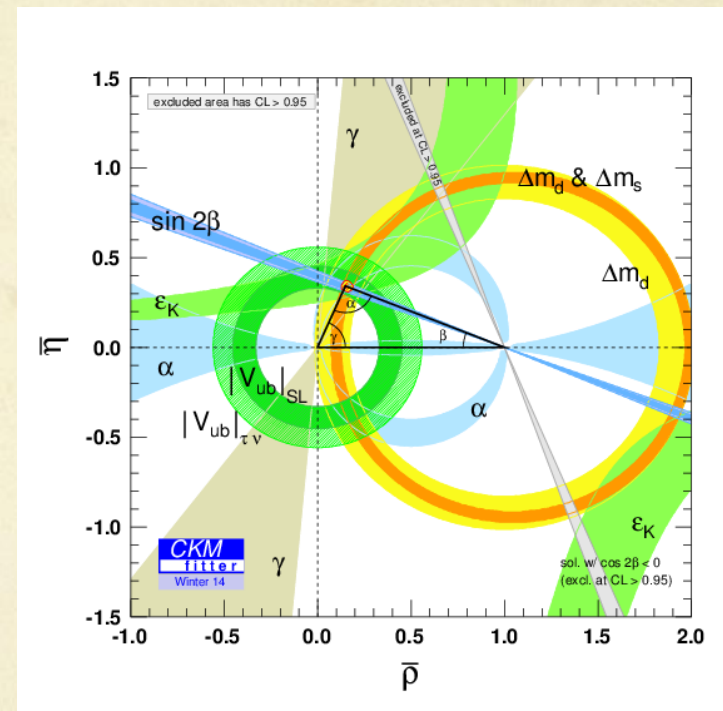
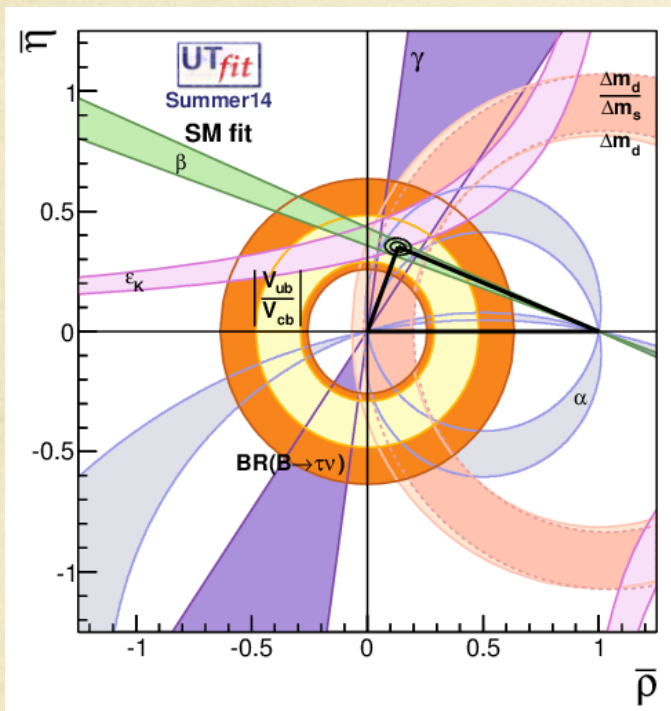
(Received 10 July 1964)



CKM picture 2014



SM picture of quark couplings is extremely successful



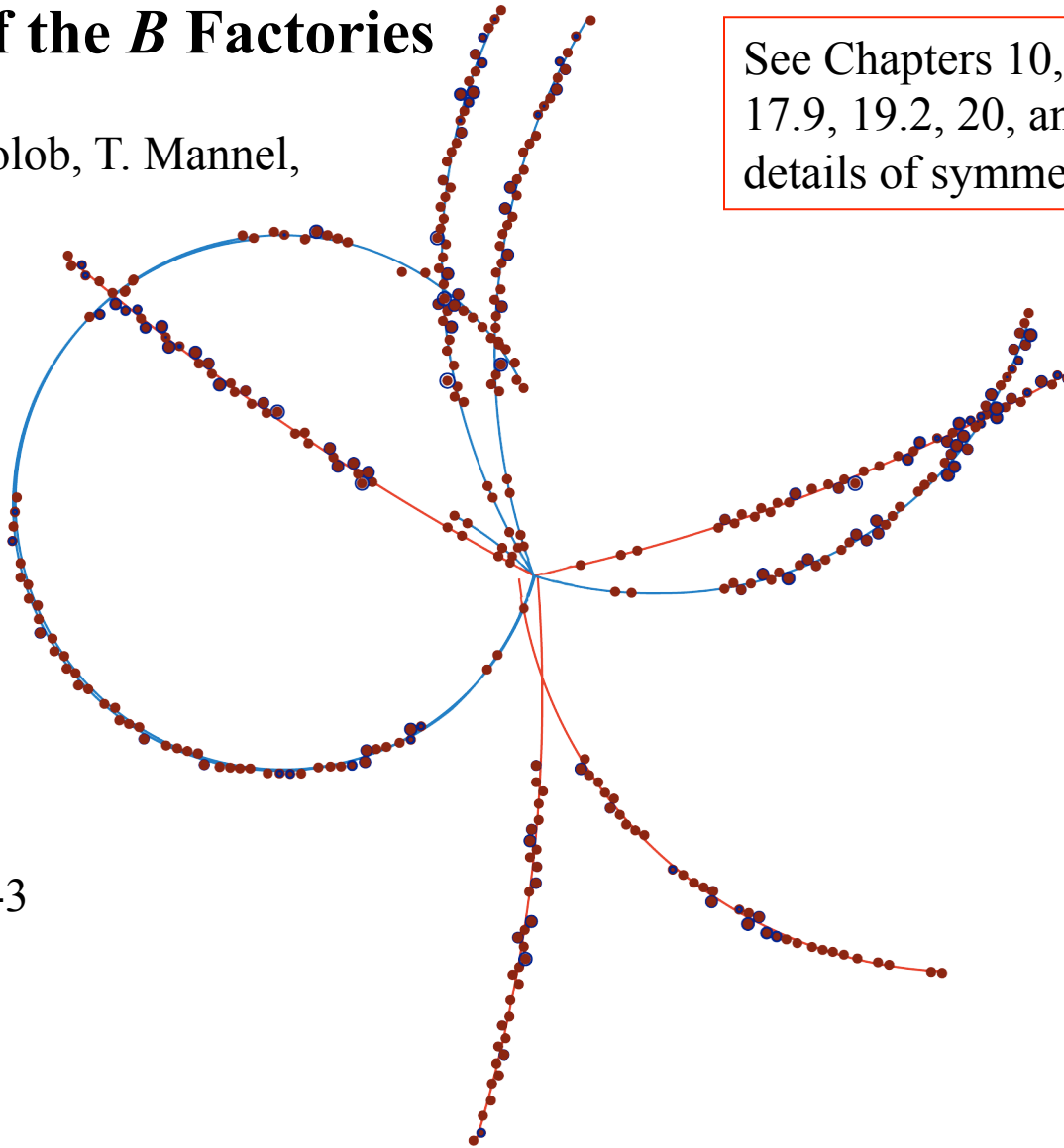
New physics contributions allowed at 10-20% level.

Read all about it...

The Physics of the B Factories

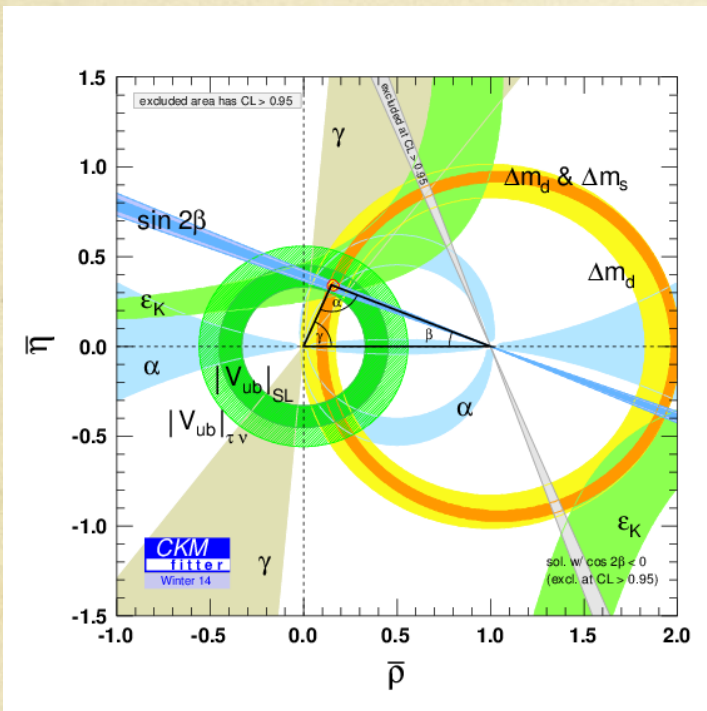
Ed. A. Bevan, B. Golob, T. Mannel,
S. Prell, B. Yabsley

See Chapters 10, 12, 15, 16, 17.4 –
17.9, 19.2, 20, and 25 for relevant
details of symmetry violation tests.



SLAC-PUB-15968,
KEK Preprint 2014-3
submitted to EPJC
arXiv:1406:6311

CKM picture 2014



Direct measurements

$$\alpha = (88.8^{+4.5}_{-4.3})^\circ$$

$$\beta = (21.5^{+0.8}_{-0.7})^\circ$$

$$\gamma = (70^{+7.7}_{-9.0})^\circ$$

$$-2\beta_s = +0.00 \pm 0.07$$

HFAG

CKM fit


$$(93.6^{+3.2}_{-2.9})^\circ$$

$$(25.38^{+0.80}_{-1.57})^\circ$$

$$(66.4^{+1.2}_{-3.3})^\circ$$

$$-0.0363^{+0.0014}_{-0.0012}$$

CKM fitter

- $\sin 2\beta$ tension (driven by $B \rightarrow \tau^+ \tau^-$) eased
 $\sin 2\beta = 0.682 \pm 0.019$ (*meas*) $0.774^{+0.017}_{-0.036}$ (*fit*) ($< 2.3\sigma$)
- $|V_{ub}|$ & $|V_{cb}|$ excl. vs incl. results still don't agree (3σ)
- New $B^0 \rightarrow \pi^0 \pi^0$ analysis from  may change value of α

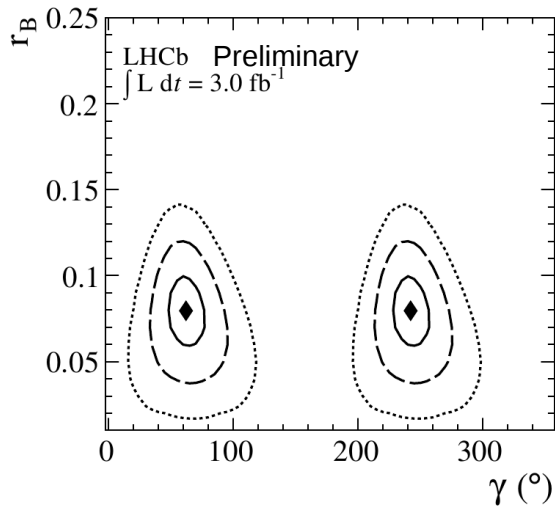
see talks by Drásal, Sibidanov



UT angle γ

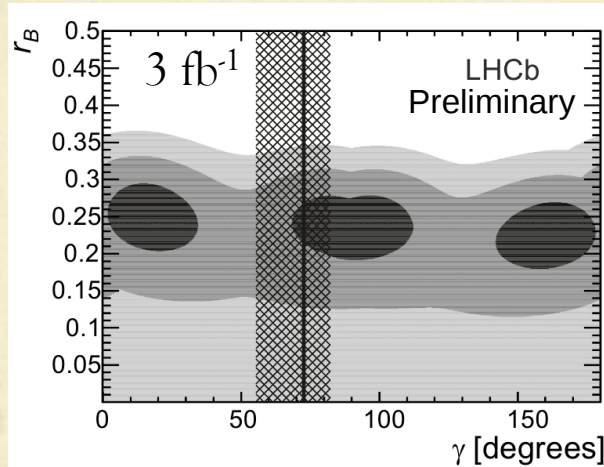
GGSZ (MI & MD)

$$B^{\pm} \rightarrow D(K_s^0 h^+ h^-) K^{\pm}$$



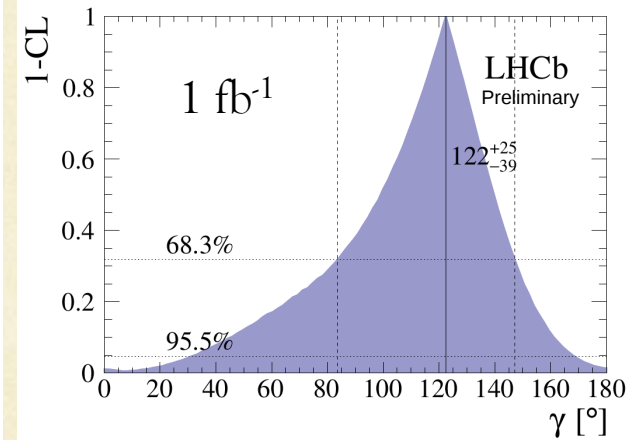
GLW/ADS

$$B^0 \rightarrow D(h^+ h^-) K^{*0}$$



Time-dependent

$$B_s \rightarrow D_s K$$



$$r_B = 0.080^{+0.019}_{-0.021}$$

$$\gamma = (62^{+15}_{-14})^\circ$$

$$\delta_B = (134^{+14}_{-15})^\circ$$

Preliminary

$$r_B = 0.240^{+0.055}_{-0.048}$$

Preliminary

$$\gamma = (115^{+28}_{-43})^\circ,$$

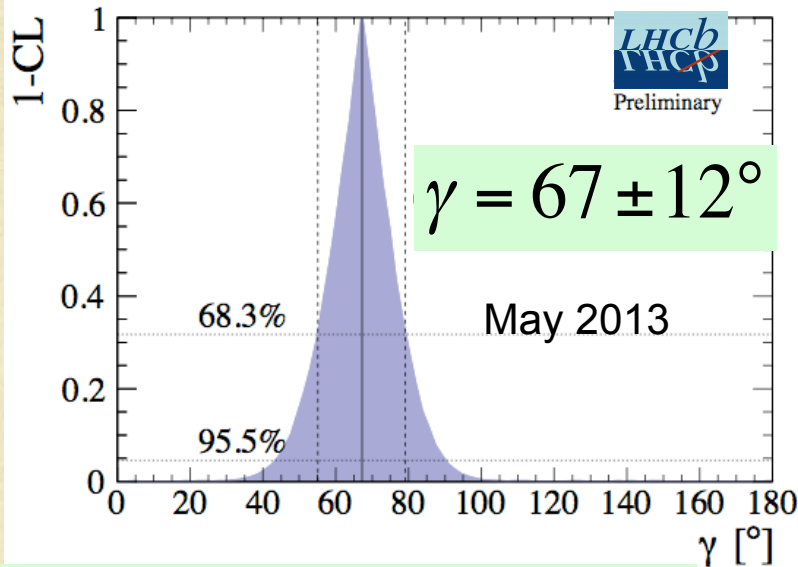
$$\delta = (3^{+19}_{-20})^\circ,$$

$$r_{D_s K} = 0.53^{+0.17}_{-0.16},$$

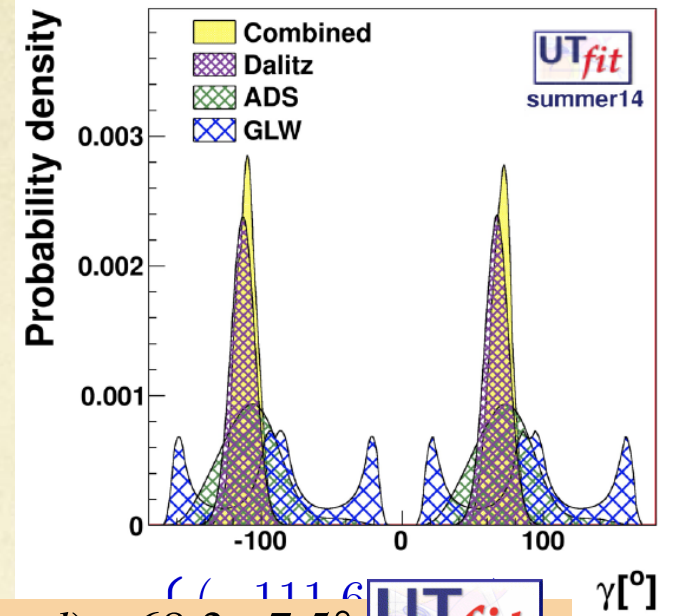
Preliminary

UT angle γ

Current LHCb combination



New combination CKM 2014



$$\gamma(\text{combined}) = 68.3 \pm 7.5^\circ$$

$$\gamma(\text{combined}) = 70.0^{+7.7^\circ}_{-9.0}$$

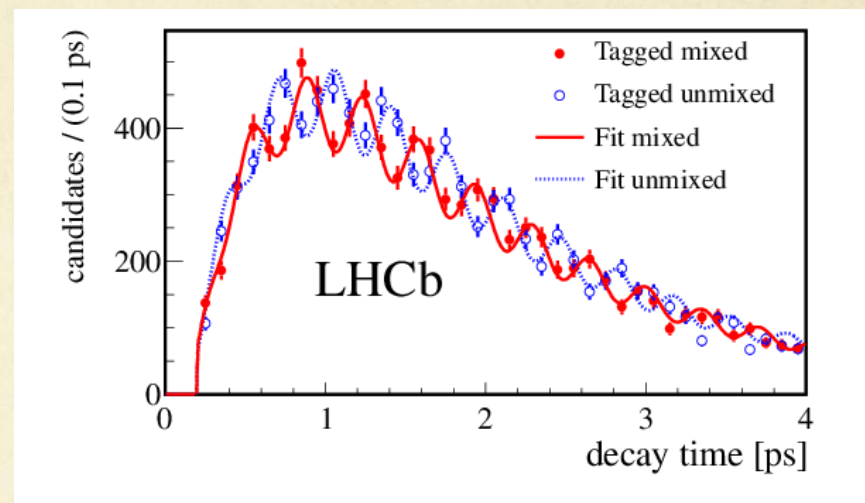
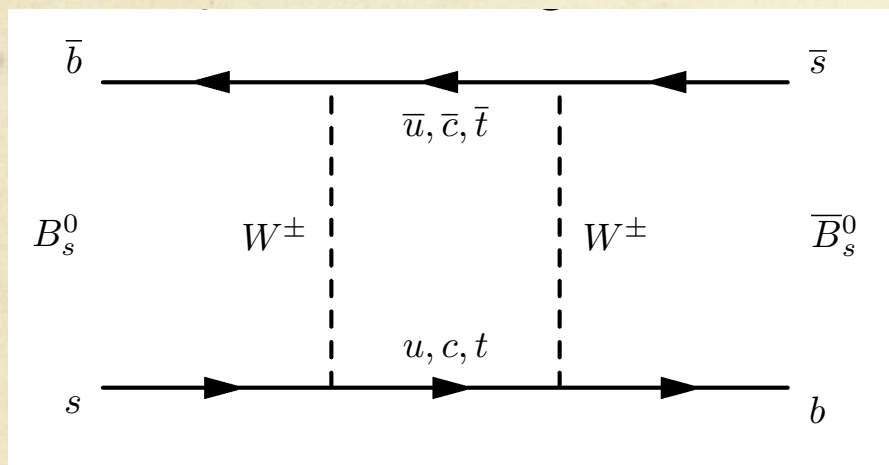
UTfit
CKM
fitter

Precision on direct γ measurements will improve.

Compare to indirect measurements e.g. $B \rightarrow h^+h^-$ and Gronau-London & Fleischer method to reduce U-spin breaking effects.

B_s^0 system

The B_s^0 system has come of age and is moving swiftly towards the precision era.

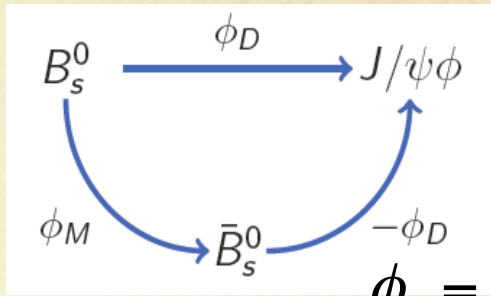
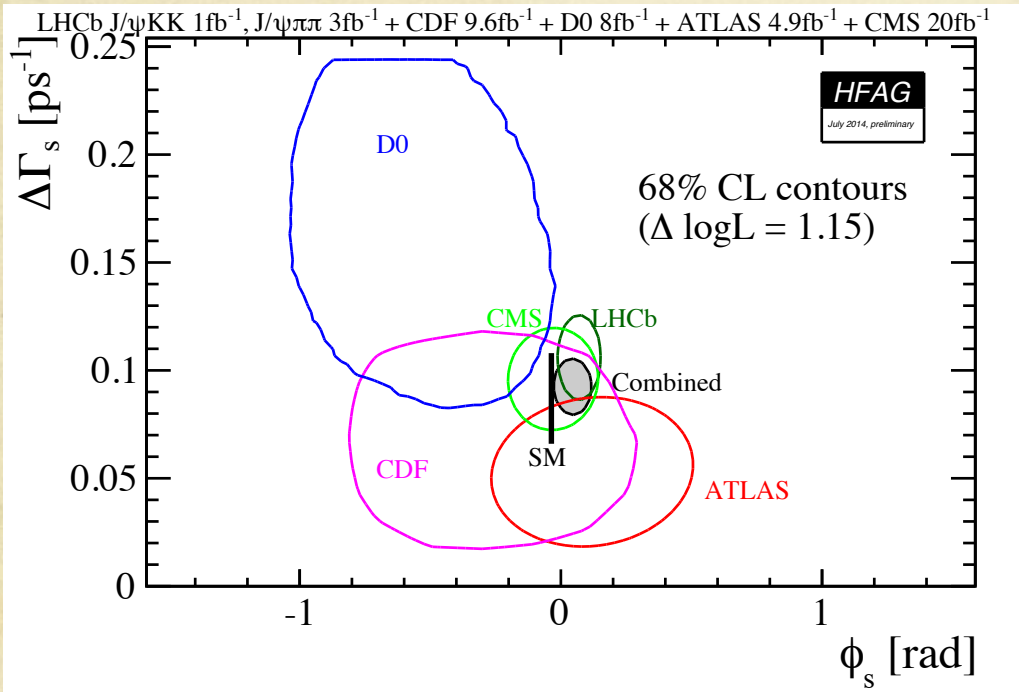


3 main observables

$$\Delta m_s \approx 2|M_{12}|, \quad \Delta\Gamma_s \approx 2|\Gamma_{12}|\cos\phi_{12}, \quad a_{sl} = \left| \frac{\Gamma_{12}}{M_{12}} \right| \sin\phi_{12}$$

$$\Delta m_s = 17.768 \pm 0.023^{(stat)} \pm 0.006^{(syst)} \text{ ps}^{-1}$$

B_s^0 CP phase (ϕ_s)



$$\phi_s = \phi_M + 2\phi_D$$

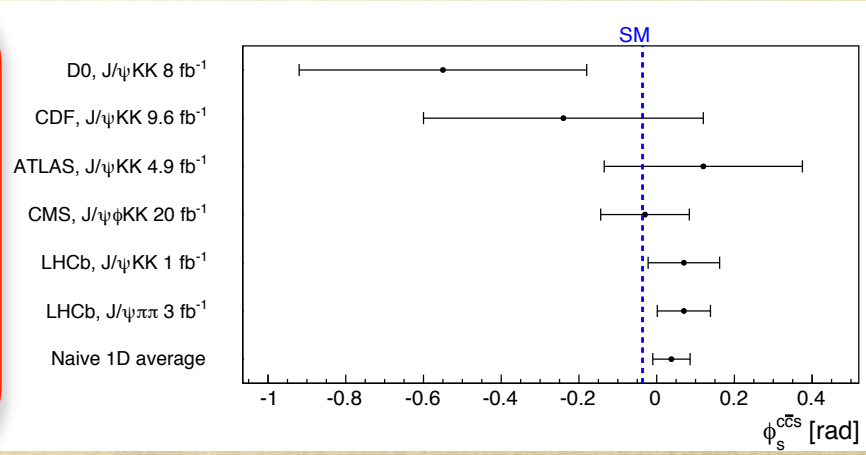
HFAG

$\phi_s = 0.00 \pm 0.07$ rad

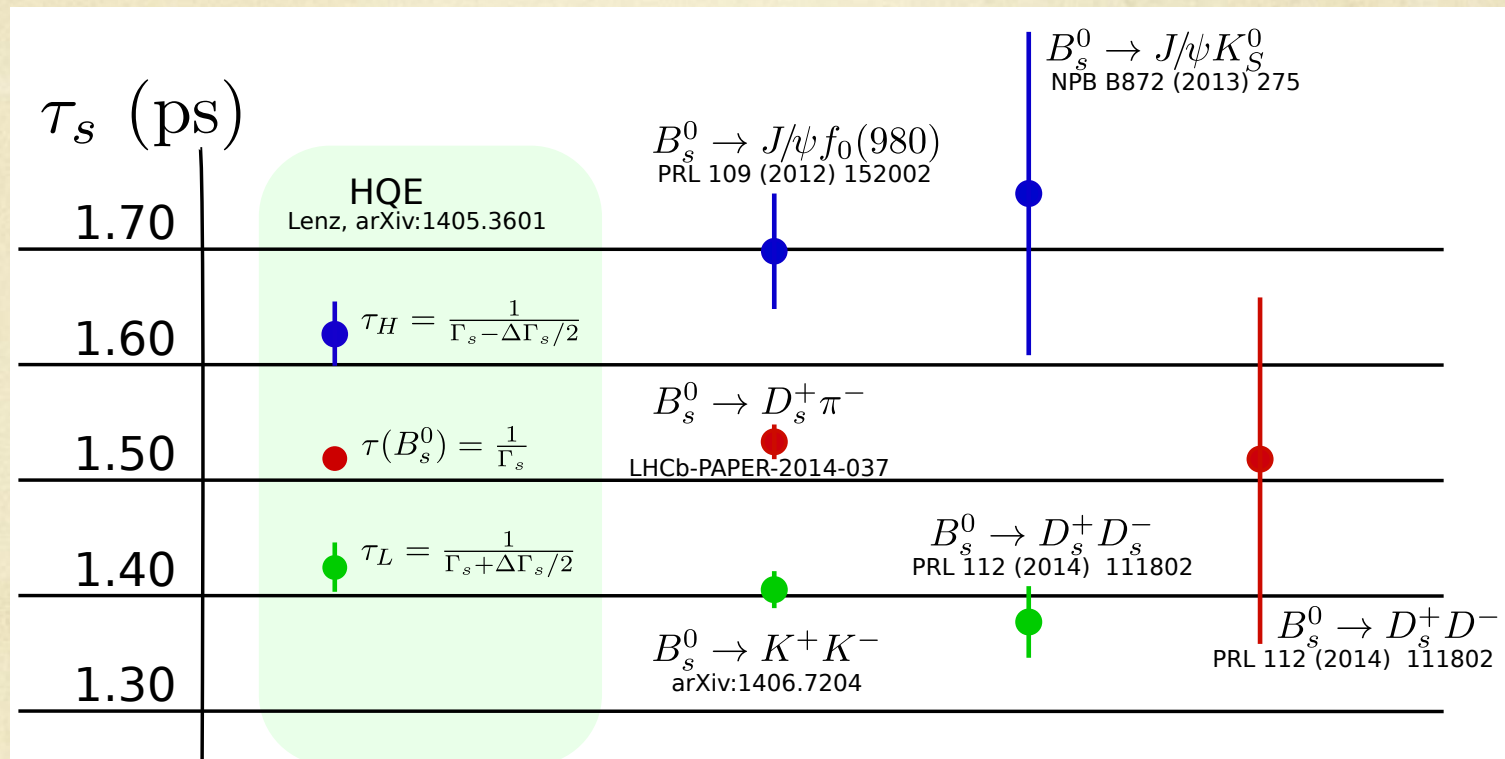
$\Gamma_s = 0.6615 \pm 0.0032$ ps^{-1}


$\Delta\Gamma_s = +0.091 \pm 0.008$ ps^{-1}

Latest results from
 LHCb ($3\text{fb}^{-1} B_s \rightarrow J/\psi\pi\pi$),
 CMS ($20\text{fb}^{-1} B_s \rightarrow J/\psi\phi$) and
 ATLAS ($4.9\text{fb}^{-1} B_s \rightarrow J/\psi\phi$ tagged)
 consistent with SM.



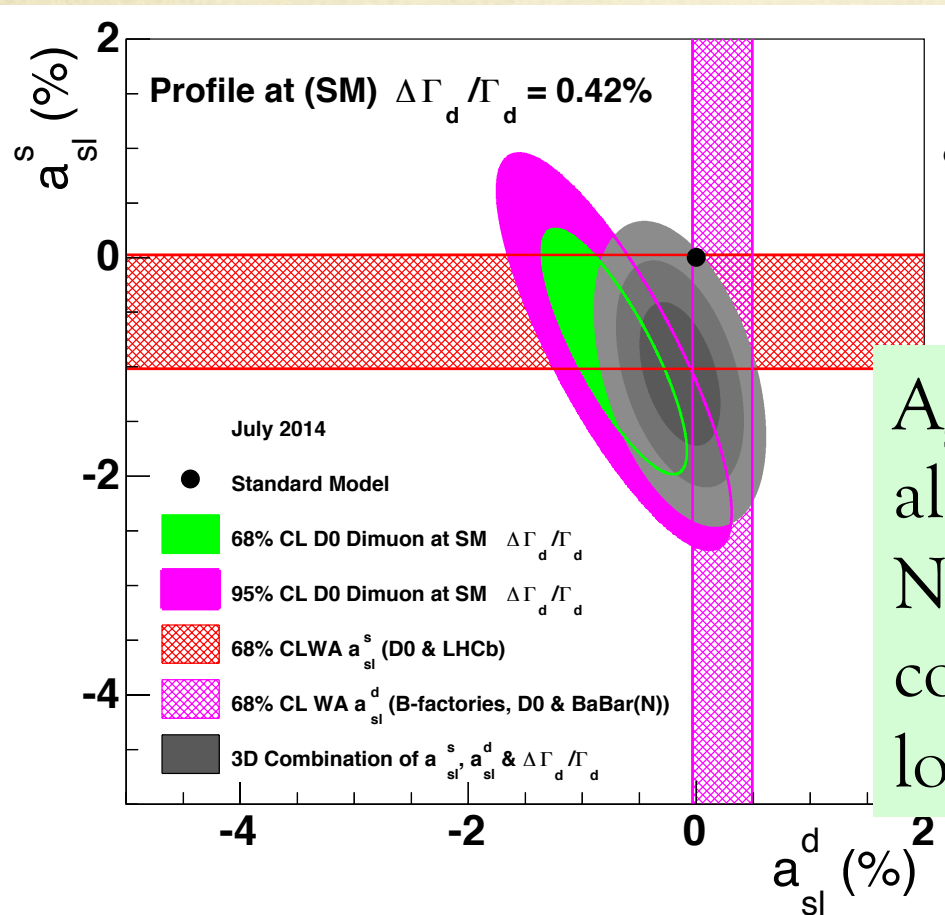
B_s^0 lifetime



B_s^0 system internally consistent & with SM, no evidence for CPV, except for the  dimuon asymmetry...

Semileptonic asymmetry A_{sl}^s

“It would be funny if this was SUSY!” I. Bertram




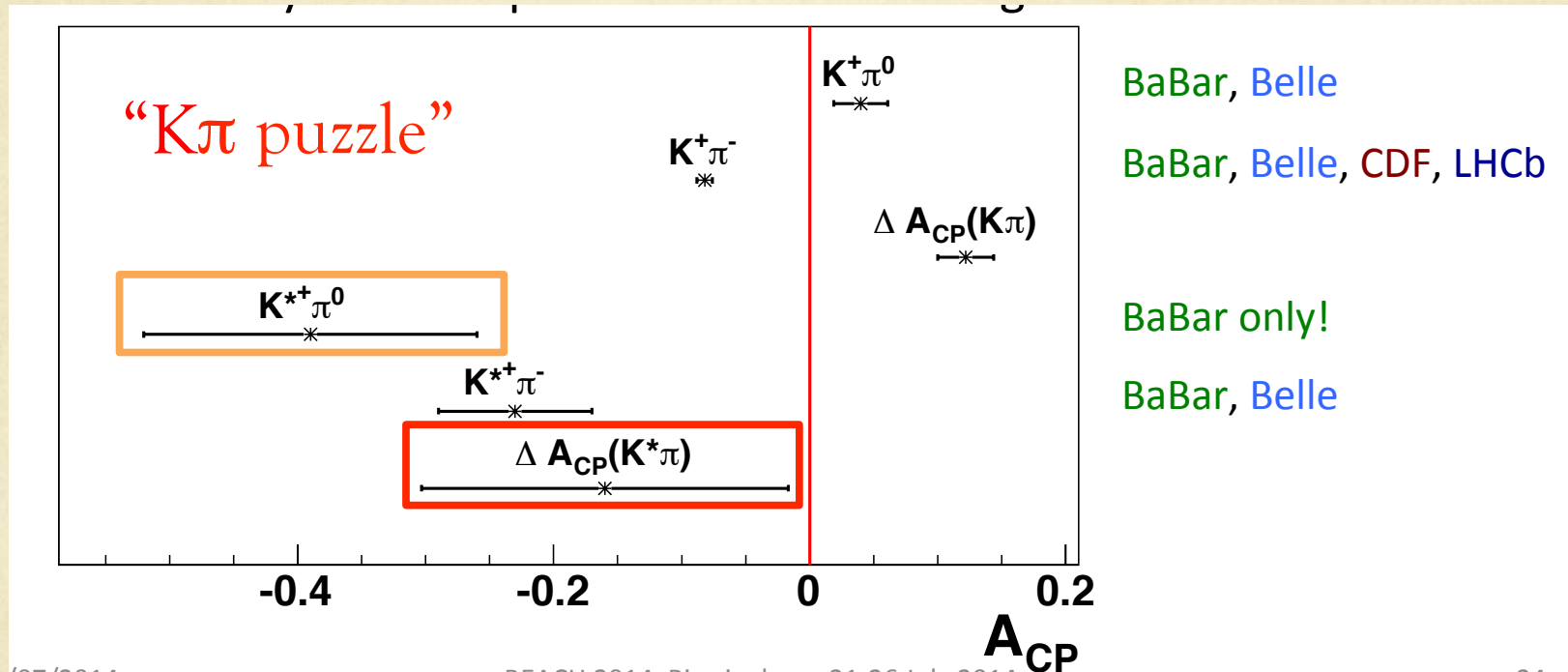
$$A_{sl}^b(D0) = C_d a_{sl}^d + C_s a_{sl}^s + C \frac{\Delta\Gamma_d}{\Gamma_d}$$


A_{sl}^s remains at 2.8σ from SM, allowing for $\Delta\Gamma_d/\Gamma_d$
Need to understand non-B contributions, particularly at low i.p.

Assuming all from B decays

The $B \rightarrow K\pi$ puzzle

First evidence of direct CP violation in $B^+ \rightarrow K^{*0}\pi^+$ by  adds to knowledge of $K\pi$ puzzle:



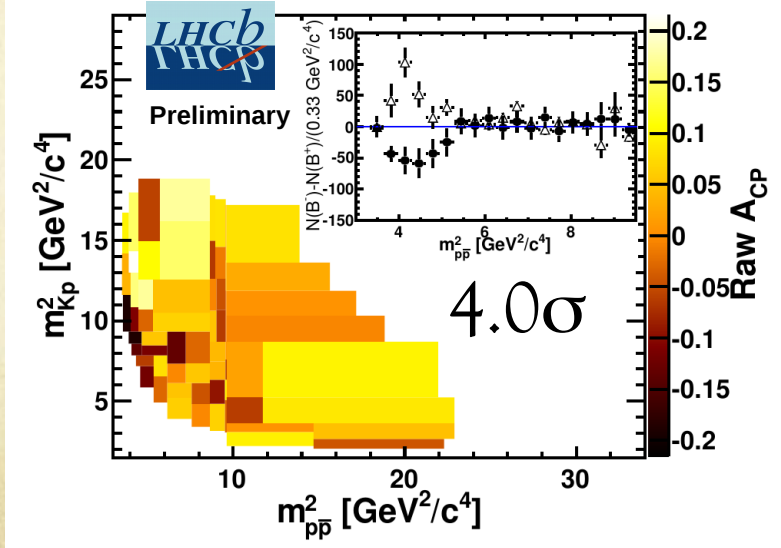
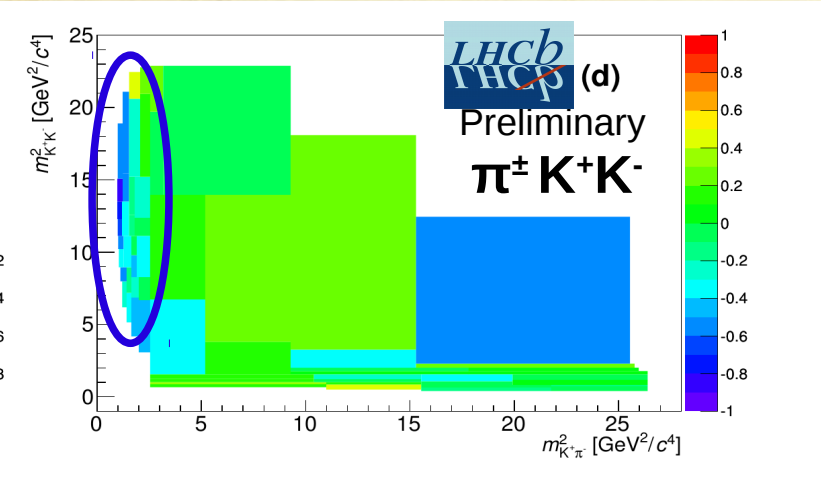
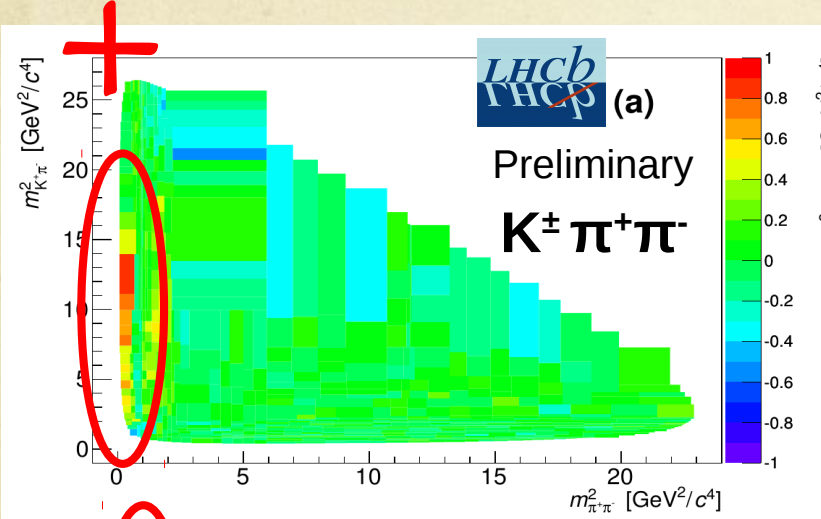
First observation of $B_s^0 \rightarrow K^{*+}K^-$ and evidence for $B_s^0 \rightarrow K^{*0}\pi^+$ by  will add to picture.

Charmless $B \rightarrow 3h$ decays

Observe large local CPV effects

Important to pin-down mechanism and perform full amplitude analysis

First evidence of CPV in baryonic B decays

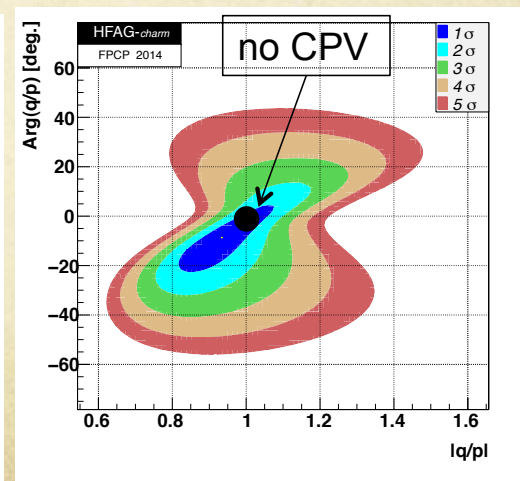
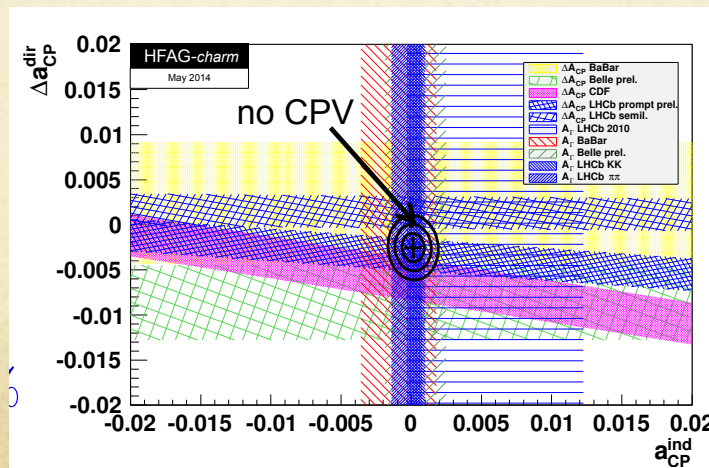
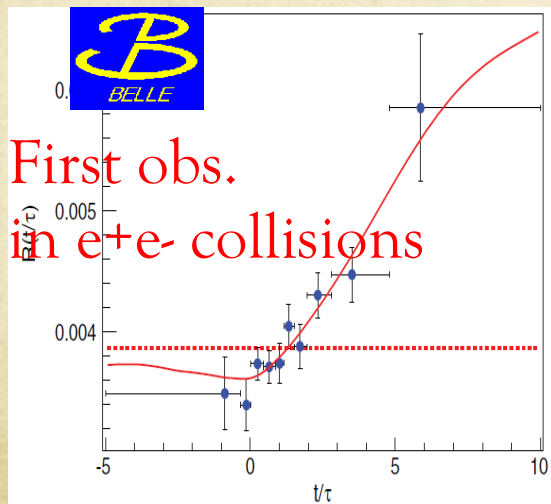
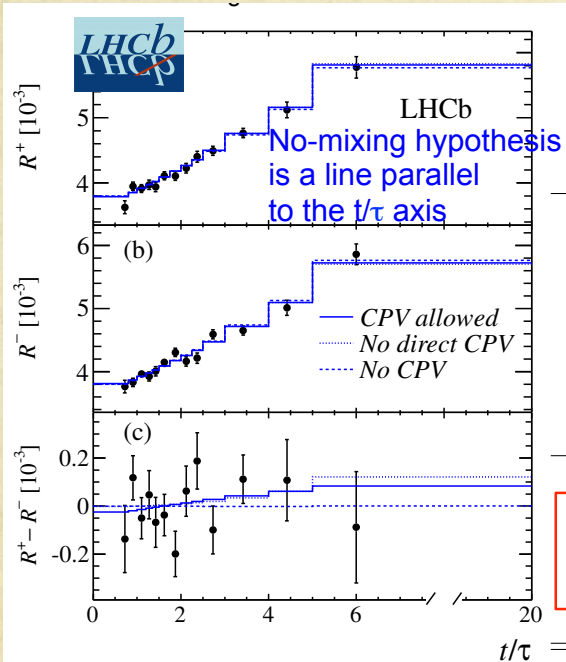


Charm mixing & CPV

Many searches for CPV in charm decays $D^0 \rightarrow h^+ h^-$ (ΔA_{CP} & A_{Γ}), $D_{(s)}^+ \rightarrow K_s h^+$, multi-body.

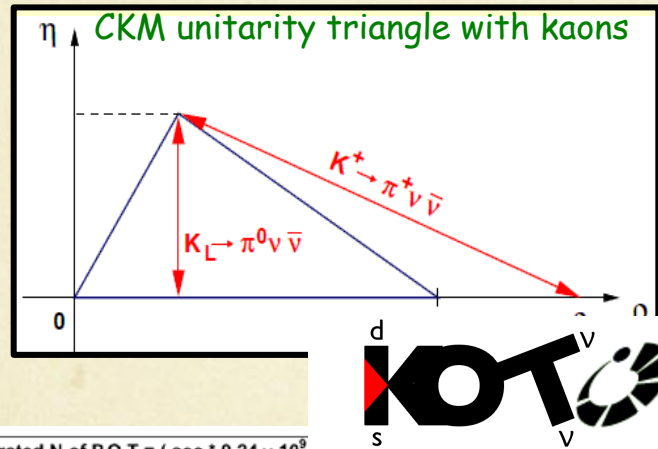
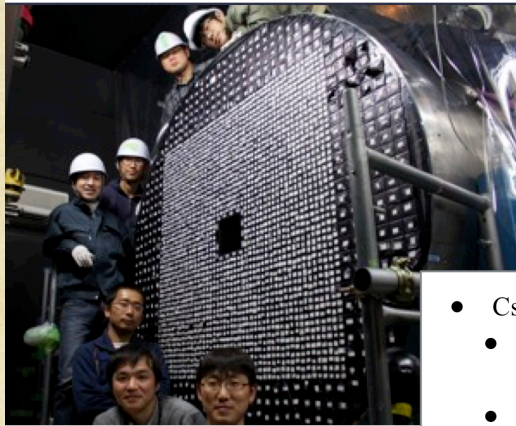
All consistent with no CPV at 10^{-3} level (SM $< 10^{-3}$)

Still room for NP effects in charm mixing

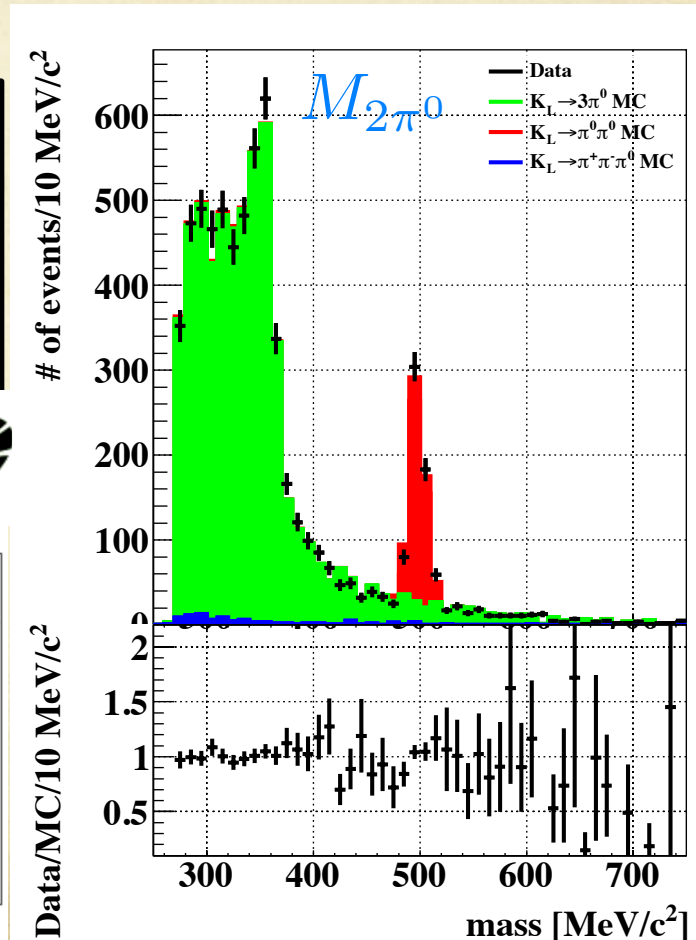
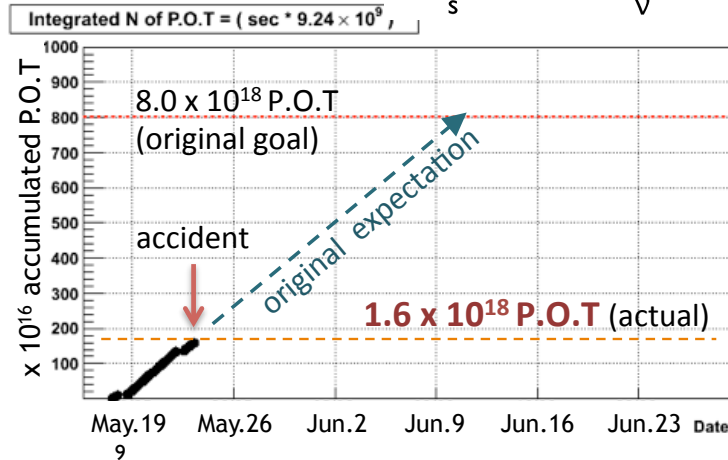


$$K \rightarrow \pi \nu \bar{\nu}$$

KOTO (JPARC) and NA62 (CERN) will make stringent tests of the SM by measuring the ultra rare $K^0_L \rightarrow \pi^0 \nu \nu$ decays and $K^+ \rightarrow \pi^+ \nu \nu$ decays, resp.

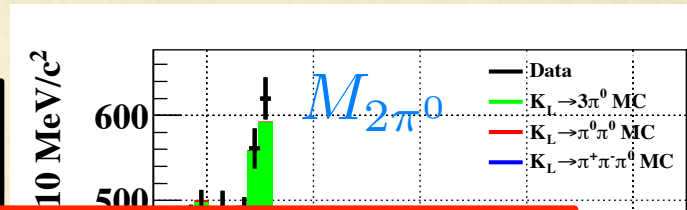
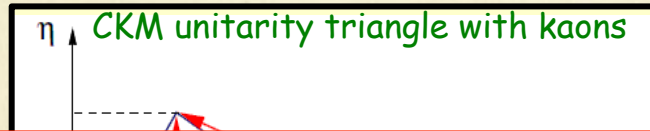



- May : Physics run
- 20 kW x 1 day + 24 kW x 4 days (~100 hours)




$$K \rightarrow \pi \nu \bar{\nu}$$

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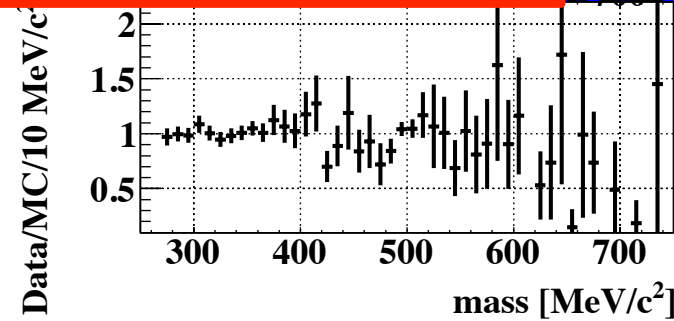
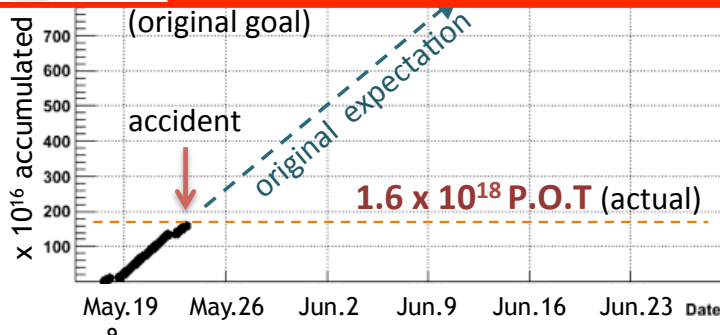


We look forward to first results from the 100 hour and 2015 runs.



Good luck for October!!

- May : Physics run
- 20 kW x 1 day + 24 kW x 4 days (~100 hours)



A stage with red curtains and a wooden floor. The curtains are a deep red color with a subtle sheen, featuring large, circular, ruffled valances at the top. The floor is made of light-colored wooden planks. The text "Rare Decays" is centered on the stage in a white, serif font.

Rare Decays

A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

” O Romeo, Romeo!
Wherefore art thou Romeo?”.

Romeo and Juliet, Act II, Scene II

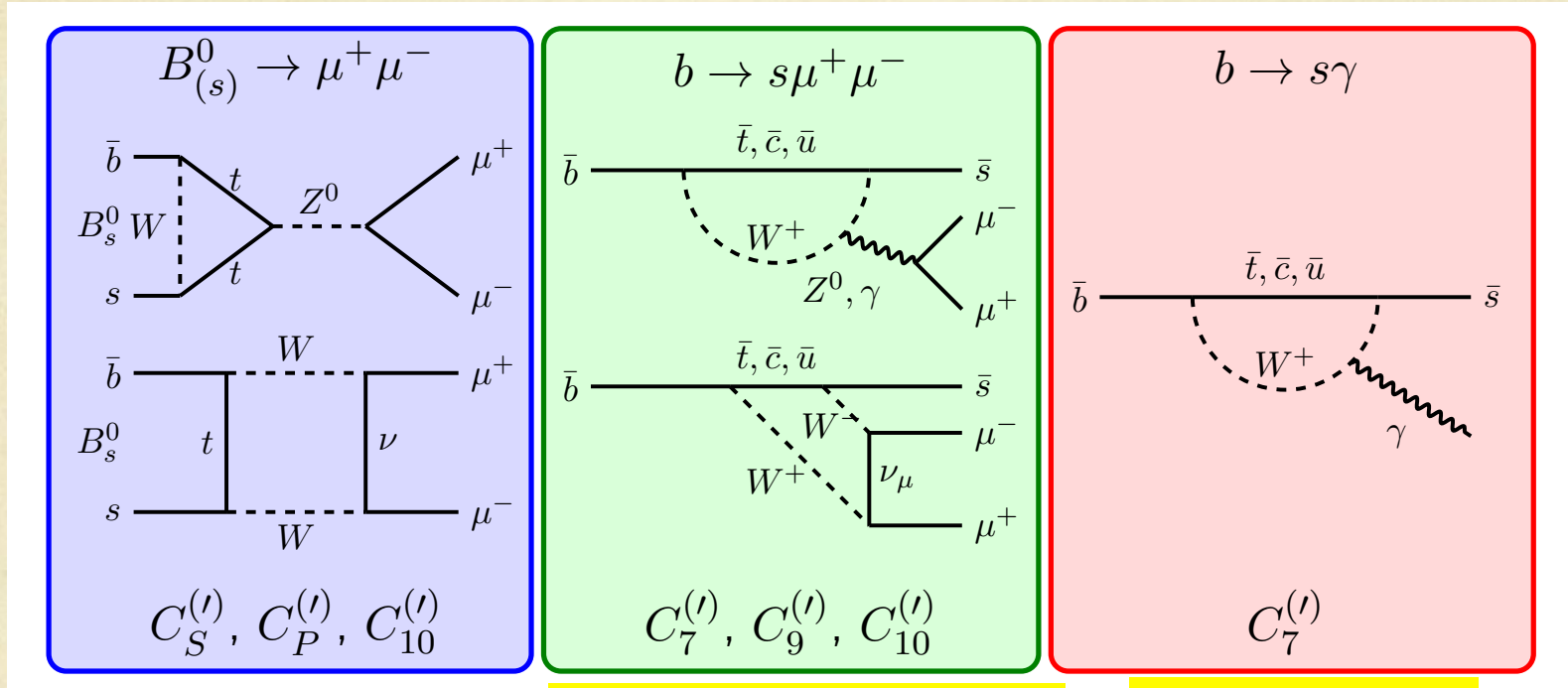
A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

” O **Signal, Signal!** Wherefore
art thou **Signal?**”.

Romeo and Juliet, Act II, Scene II

Rare B decays

Sensitive to new physics via non-standard couplings



Branching ratio

angular distributions

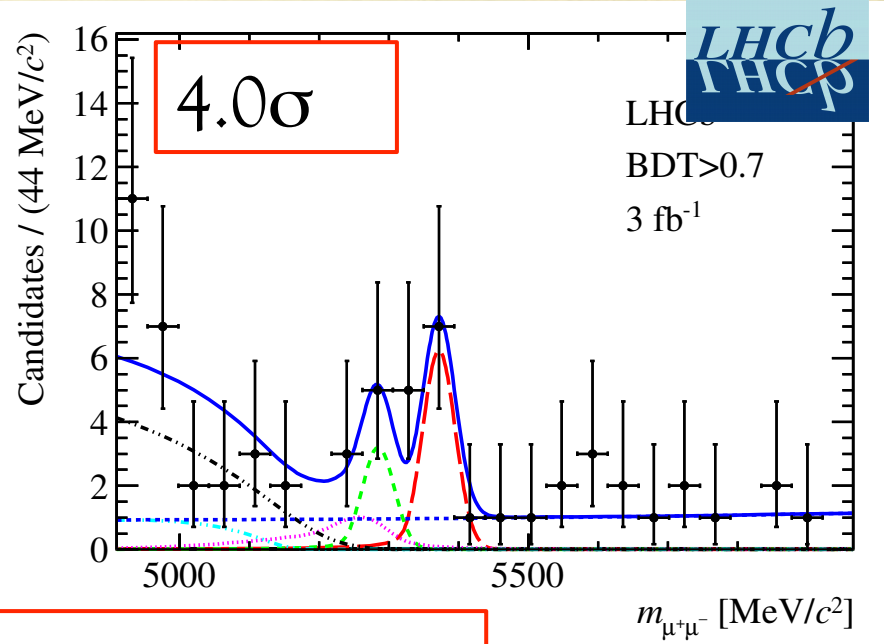
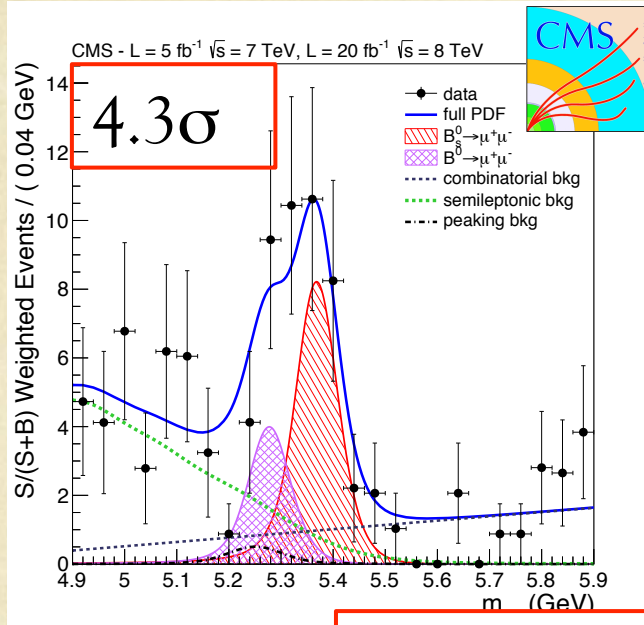
γ polarization

$$H_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \left[\underbrace{C_i(\mu) O_i(\mu)}_{\text{left-handed part}} + \underbrace{C'_i(\mu) O'_i(\mu)}_{\text{right-handed part suppressed in SM}} \right]$$

- $i = 1, 2$ Tree
- $i = 3 - 6, 8$ Gluon penguin
- $i = 7$ Photon penguin
- $i = 9, 10$ Electroweak penguin
- $i = S$ Higgs (scalar) penguin
- $i = P$ Pseudoscalar penguin

$B \rightarrow \mu^+ \mu^-$

CMS PRL 111 (2013) 101804



LHCb PRL 111 (2013) 101805

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (2.9 \pm 0.7) \times 10^{-9}$$

$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) = (3.6^{+1.6}_{-1.4}) \times 10^{-10}$$

Preliminary

Full combination of likelihoods coming soon ... followed by
 Search for $B_d \rightarrow \mu^+ \mu^-$ and measure $\mathcal{B}(B_d \rightarrow \mu^+ \mu^-) / \mathcal{B}(B_d \rightarrow \mu^+ \mu^-)$
 Measure B_s effective lifetime
 Search for other decays (e.g. $B_s \rightarrow \tau^+ \tau^-$)

$$B^0 \rightarrow K^* \mu^+ \mu^-$$



$$B^0 \rightarrow K^* \mu^+ \mu^-$$

” Is this a dagger which I see before me?”.
Macbeth, Act II, Scene I



$$B^0 \rightarrow K^* \mu^+ \mu^-$$

” Is this a Z^1 which I see before me?”.

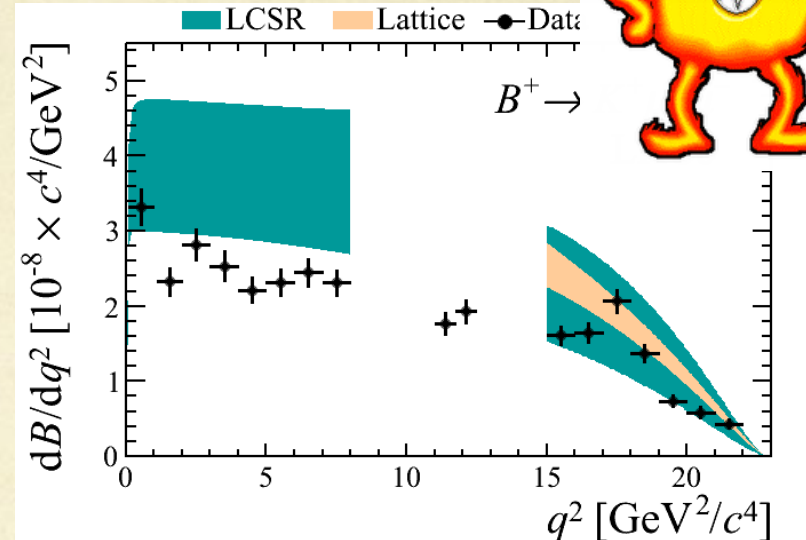
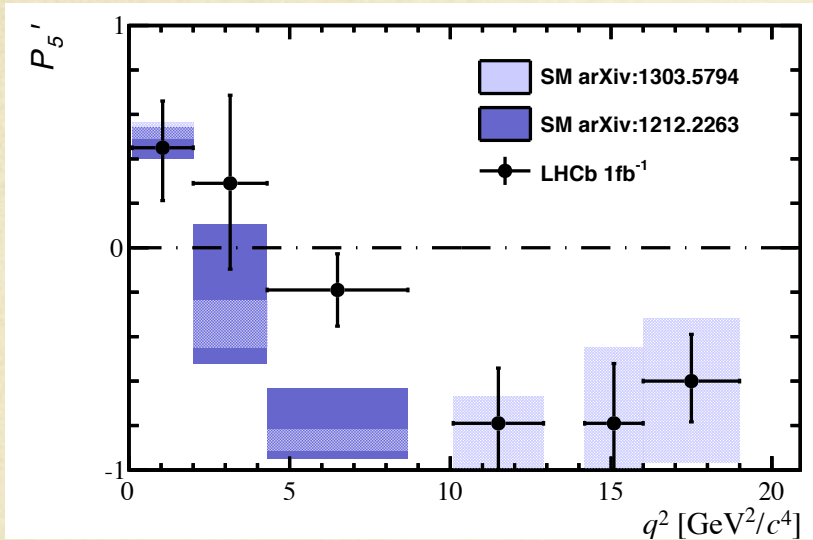
P. Owen



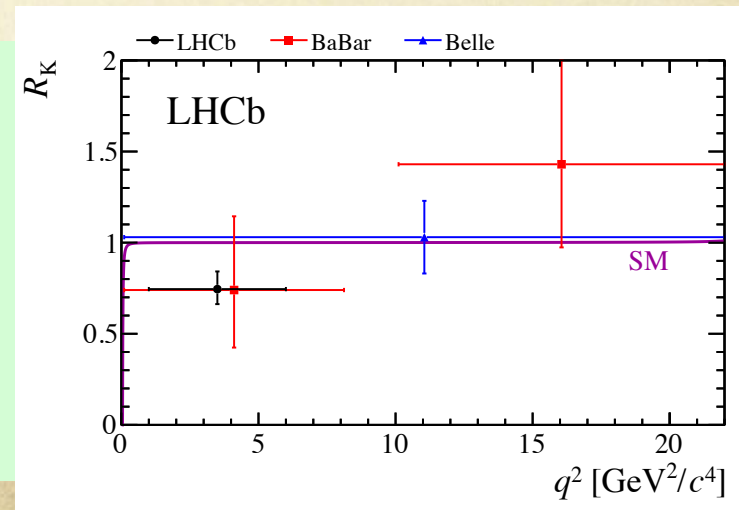
$$B^0 \rightarrow K^* \mu^+ \mu^-$$



” Is this a Z' which I see before me?”.

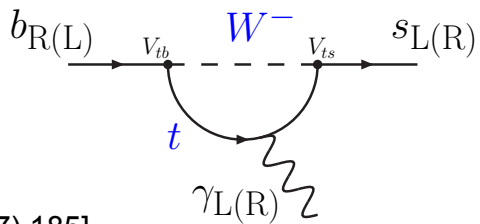


A hot topic of discussion within community. Reduced QCD uncertainties. Improved theory & more measurements needed. Watch this space....





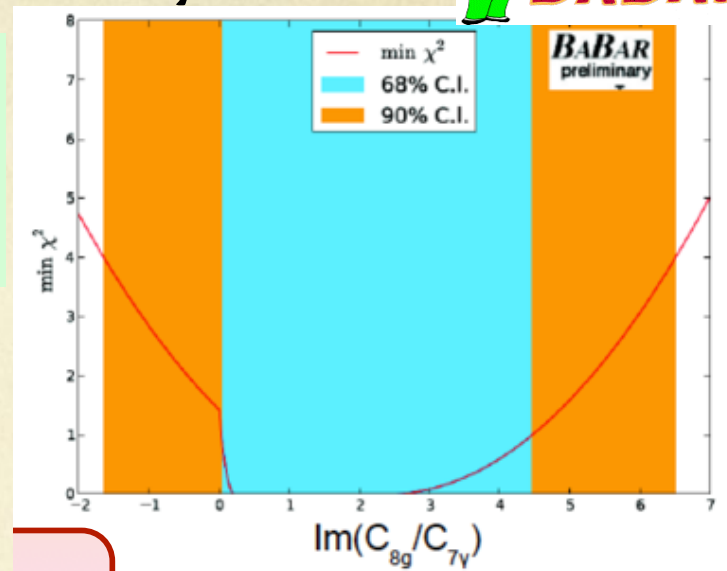
Radiative B decays



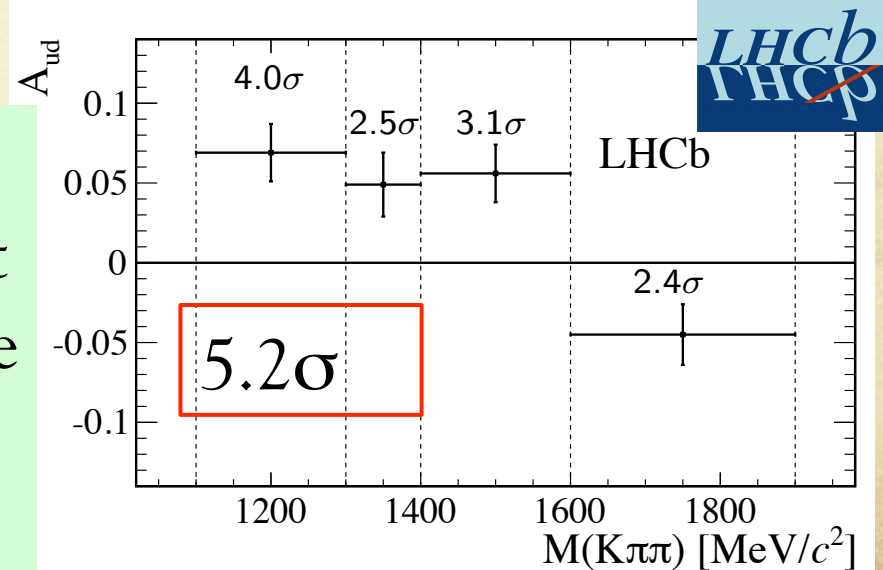
First constraint on C_8 from isospin difference of CP asymmetries

$$\Delta A_{CP} = A_{CP}(B^\pm) - A_{CP}(B^0 / \overline{B}^0) \propto \text{Im} \frac{C_8}{C_7}$$

$$\Delta A_{CP} = +(5.0 \pm 3.9 \pm 1.5)\%$$



First observation of photon polarisation in $b \rightarrow s \gamma$ decay - but this measurement doesn't tell the sign and the magnitude of the polarization.



A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text "Lepton Sector" is centered on the stage.

Lepton Sector

A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

” When shall we three meet again
in thunder, lightning or in rain?”.

Macbeth, Act I, Scene I

A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

” When shall we three meet again
in oscillation, violation or in $0\nu\beta\beta$
decay?”.

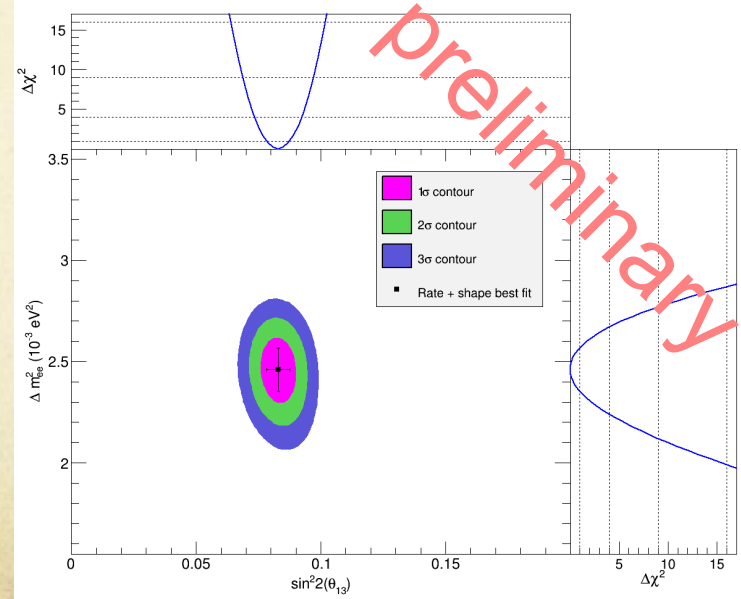
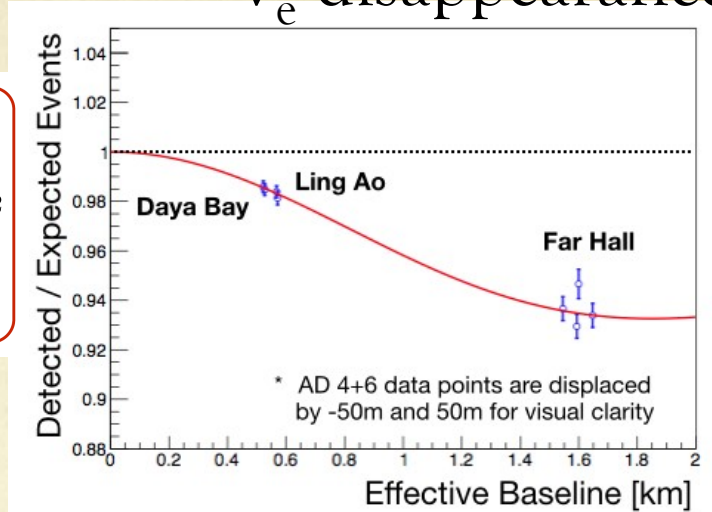
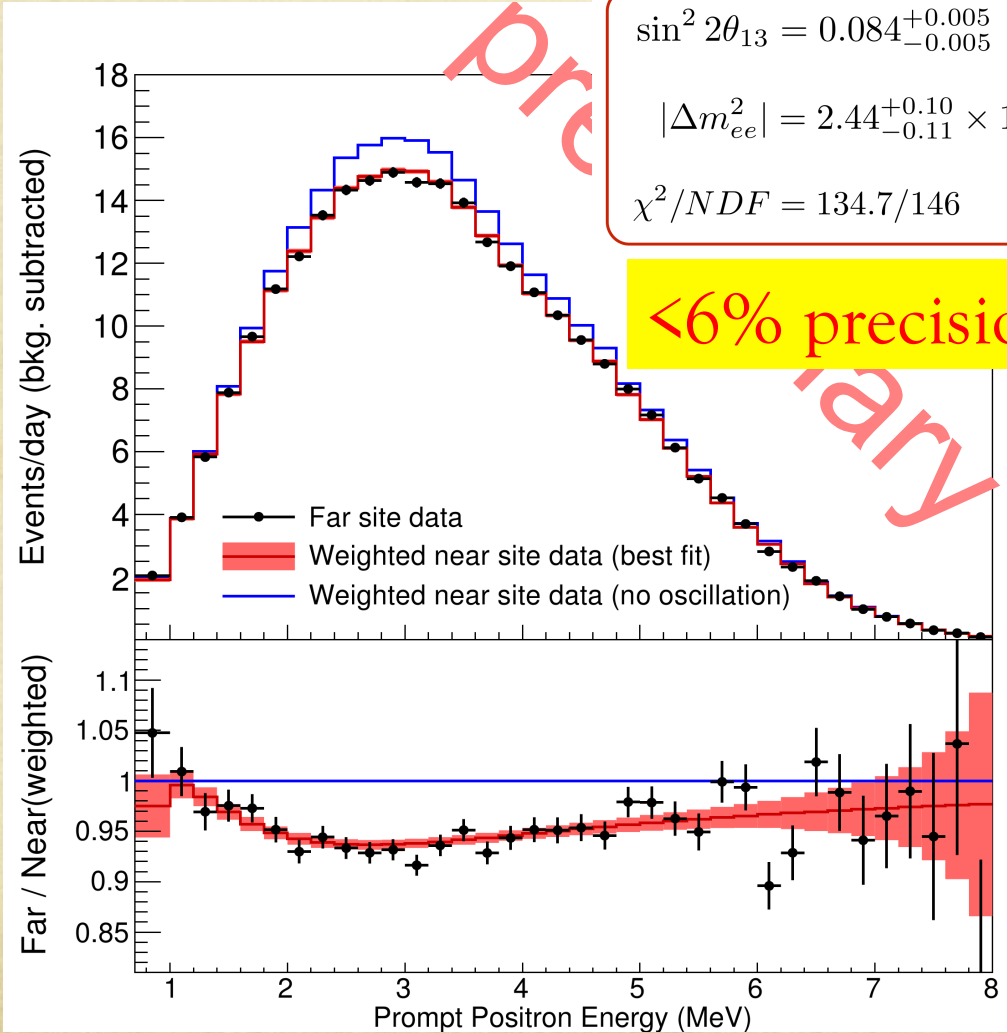
Macbeth, Act I, Scene I



Neutrino oscillations

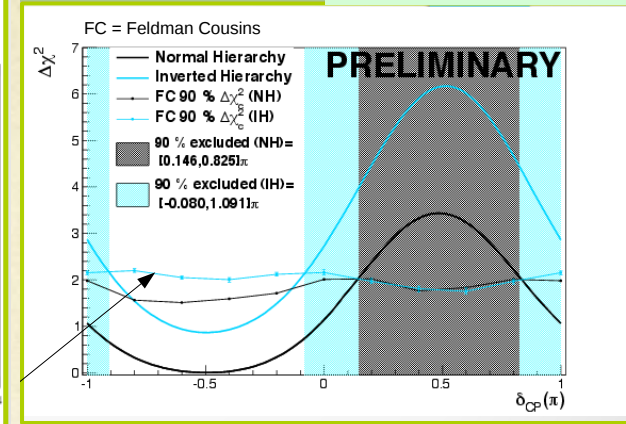
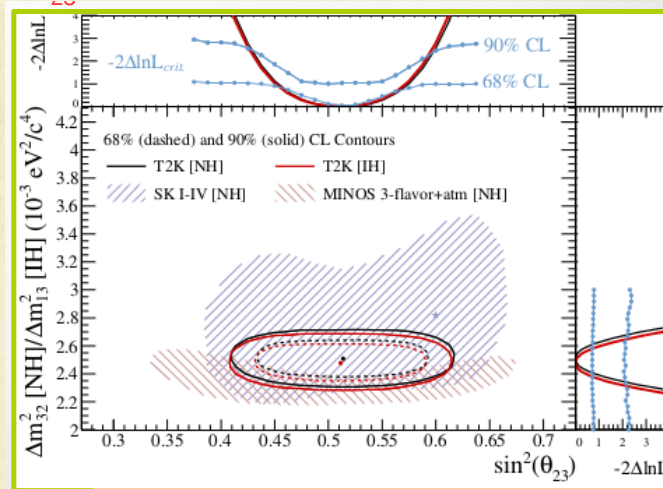
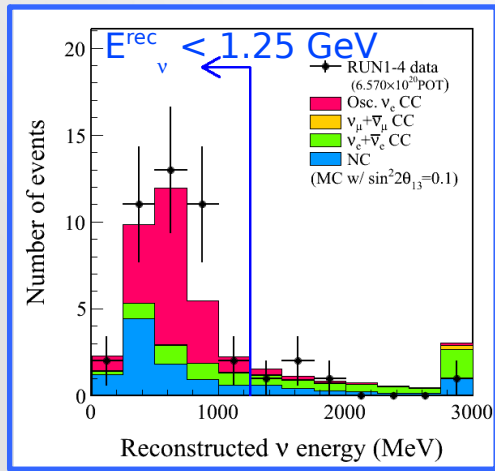
$\bar{\nu}_e$ disappearance

Short baseline reactor



Neutrino oscillations

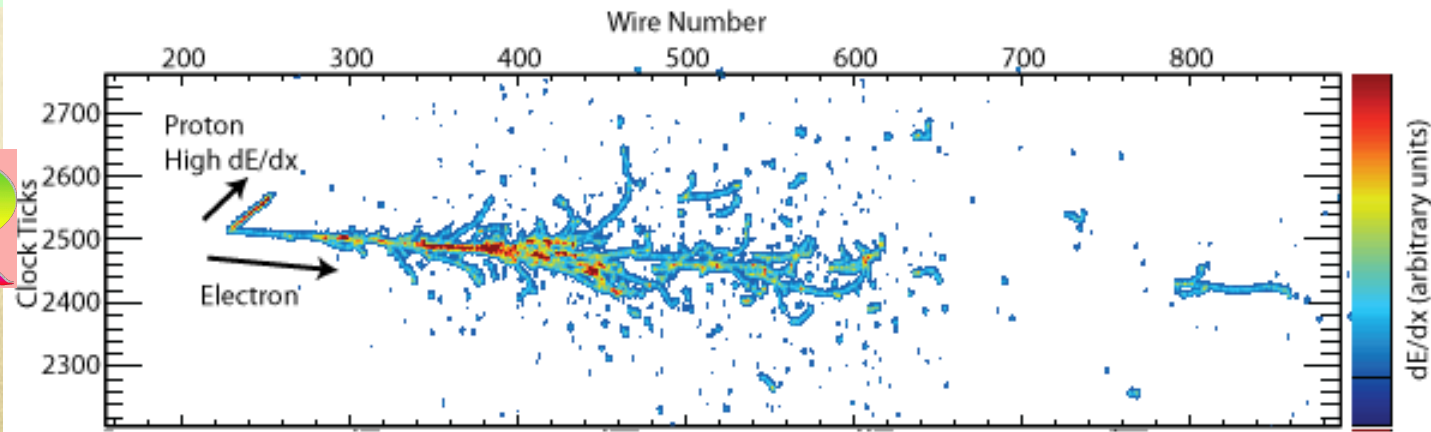
Long baseline accelerators



7.3 σ observation
 ν_e appearance

World-best $\sin^2\theta_{23}$
 ν_μ disappearance

Hint of $\delta_{CP} = -\pi/2$



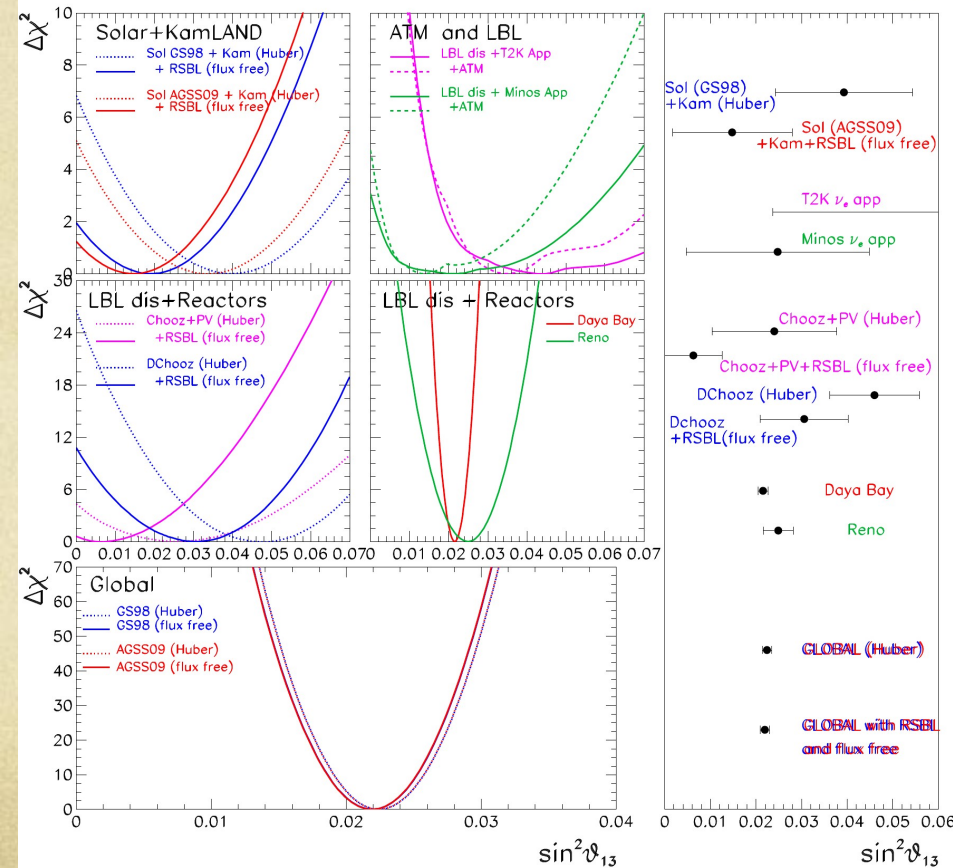
Neutrino oscillations



Latest fit results (post Neutrino 2014)

$\sin^2 2\theta_{13}$

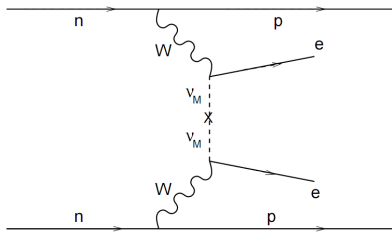
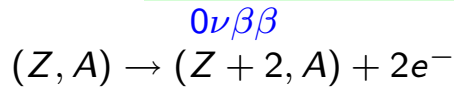
NuFIT 1.3 (2014)



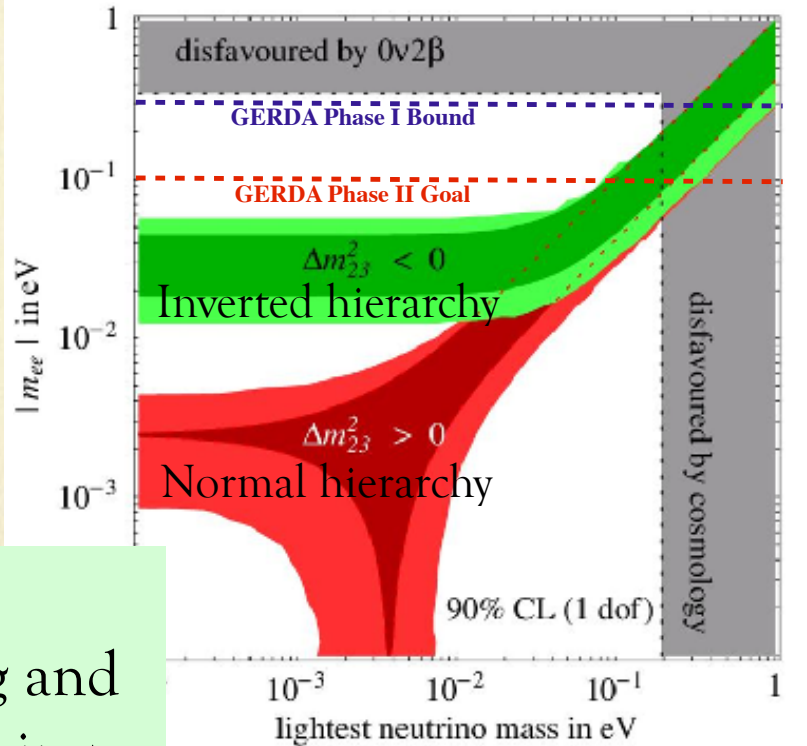
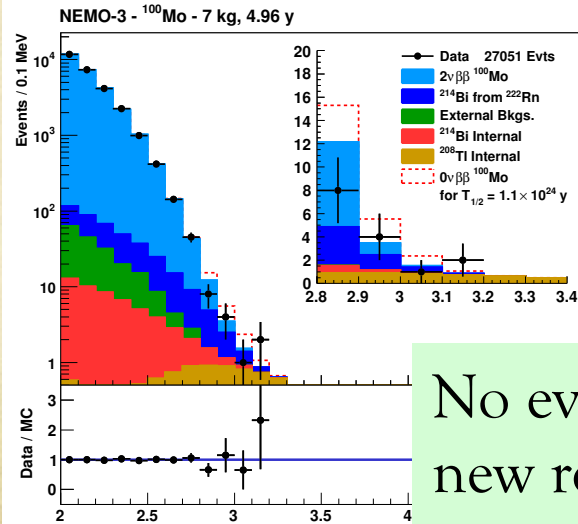
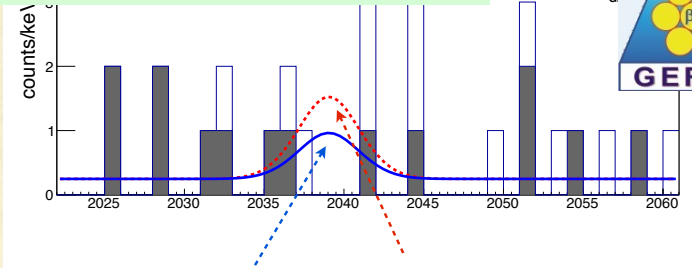
$\sin^2 \theta_{12}$	$0.304^{+0.012}_{-0.012}$
$\theta_{12}/^\circ$	$33.48^{+0.77}_{-0.74}$
$\sin^2 \theta_{23}$	$[0.451^{+0.001}_{-0.001}] \oplus 0.577^{+0.027}_{-0.035}$
$\theta_{23}/^\circ$	$[42.2^{+0.1}_{-0.1}] \oplus 49.4^{+1.6}_{-2.0}$
$\sin^2 \theta_{13}$	$0.0219^{+0.0010}_{-0.0011}$
$\theta_{13}/^\circ$	$8.52^{+0.20}_{-0.21}$
$\delta_{CP}/^\circ$	251^{+67}_{-59}
$\frac{\Delta m_{21}^2}{10^{-5} \text{ eV}^2}$	$7.50^{+0.19}_{-0.17}$
$\frac{\Delta m_{31}^2}{10^{-3} \text{ eV}^2}$ (N)	$[+2.458^{+0.002}_{-0.002}]$
$\frac{\Delta m_{32}^2}{10^{-3} \text{ eV}^2}$ (I)	$-2.448^{+0.047}_{-0.047}$

Are neutrinos Majorana?

See talk by Ramackers for current status of field



$\Delta L = 2 \implies$ Prohibited by SM (no RH ν)
 $Q = M_i - M_f - 2m_e$
 Light Majorana neutrino exchange?



No evidence as yet...
 new results appearing and
 new experiments coming...

g-2

$$a_\mu^{5\ell(QED)} =$$

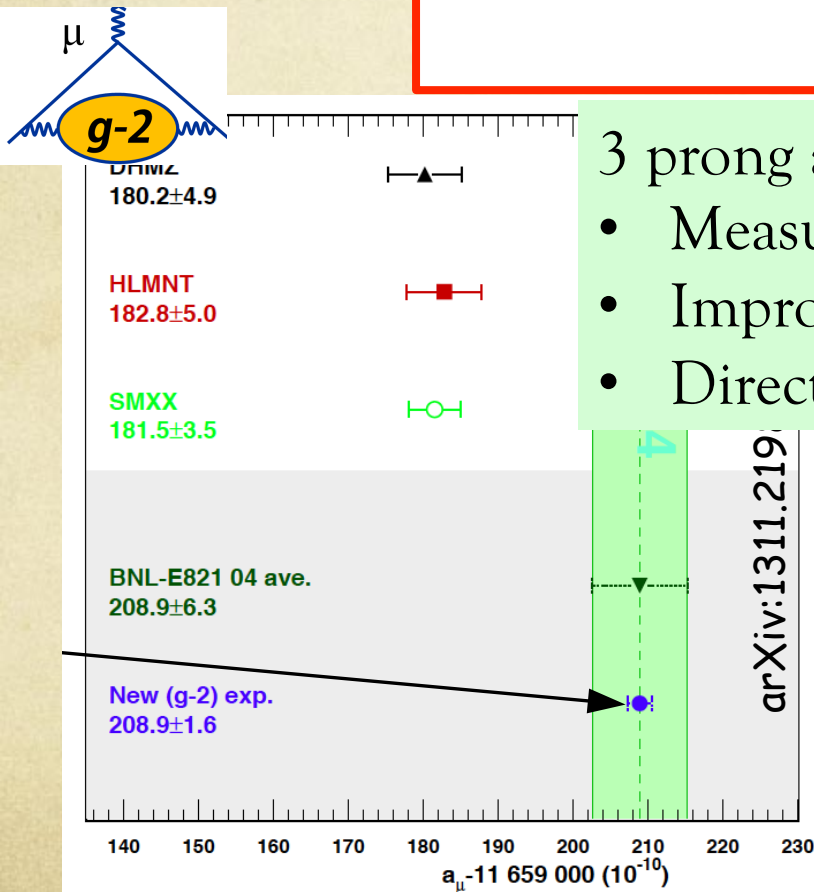
Aoyama, Hayakawa, Kihoshita & Nio

$$(116584718.951 \pm 0.077 \pm 0.019 \pm 0.009 \pm 0.007) \times 10^{-11}$$

$$\Delta a_\mu(E821 - SM) = (287 \pm 80) \times 10^{-11}$$

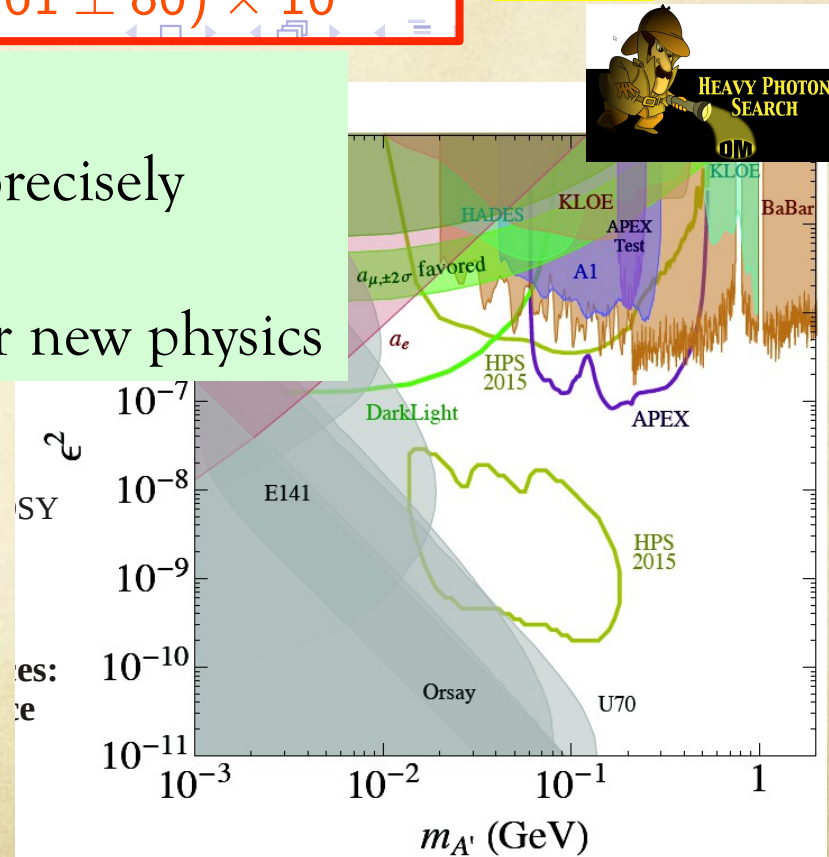
$$= (261 \pm 80) \times 10^{-11}$$

>3σ

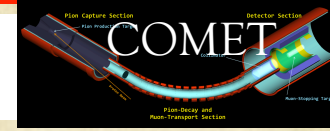


3 prong approach:

- Measure more precisely
- Improve theory
- Direct search for new physics



cLFV



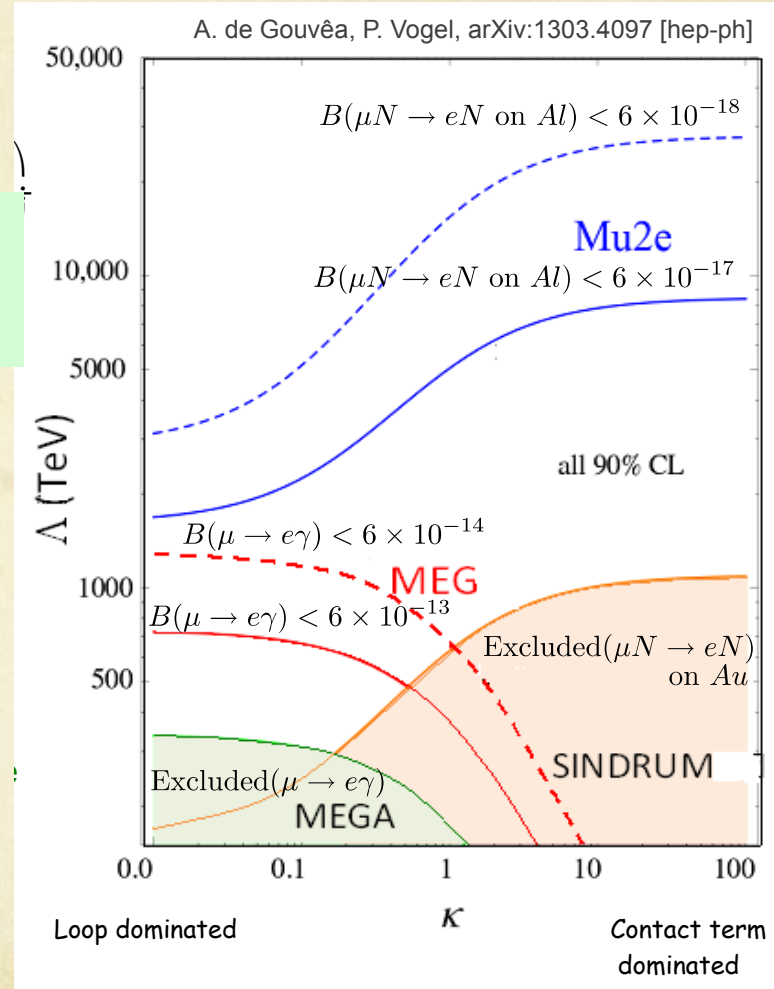
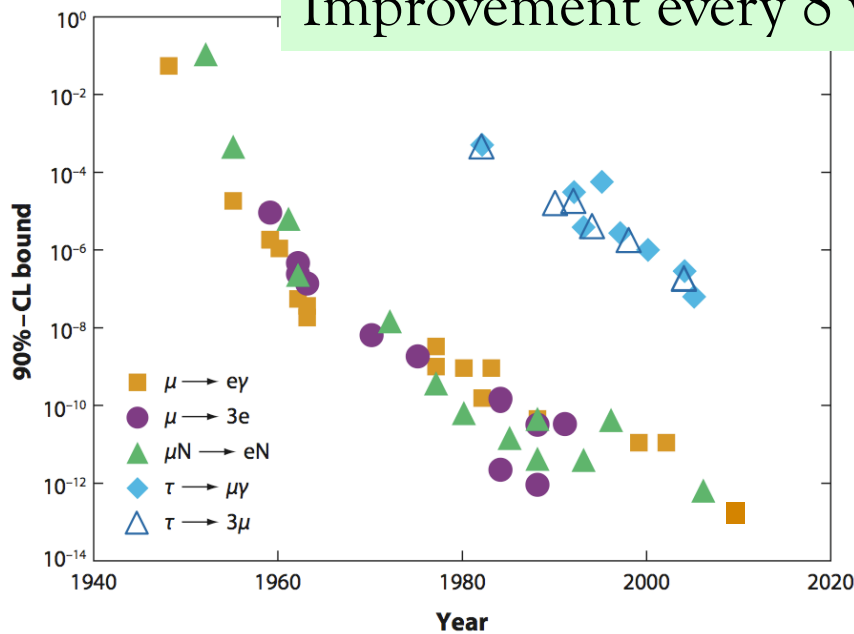
$B(\mu^+ \rightarrow e^+ \gamma) \approx 10^{-54}$ SM

SM

$10^{-14} < B(\mu^+ \rightarrow e^+ \gamma) < 10^{-11}$ BSM

BSM

Order of magnitude
Improvement every 8 years



$B(\mu^+ \rightarrow e^+ \gamma) < 5.7 \times 10^{-13}$ (all combined data)



A stage with red curtains and a wooden floor. The word "Future" is written in white serif font in the center of the stage.

Future

A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

” We are such stuff as dreams are
made on, rounded with a little sleep”.

The Tempest

A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The text is centered on the stage.

” We are such **experiments** as dreams
are made on, rounded with **the
prospect for new discoveries**”.

The Tempest

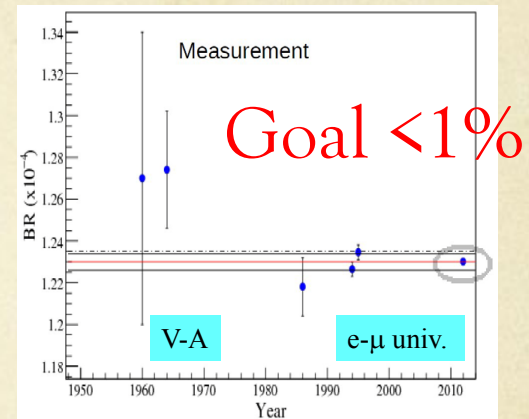
BEACH 2016



First results from



$$R_{e/\mu}^{\text{th}} = \frac{\Gamma(\pi \rightarrow e\nu + \pi \rightarrow e\nu\gamma)}{\Gamma(\pi \rightarrow \mu\nu + \pi \rightarrow \mu\nu\gamma)}$$



$$K_L^0 \rightarrow \pi^0 \nu \nu$$



Broad program incl. $K^+ \rightarrow \pi^+ \nu \nu$ & exotics



See talk by Duk




Neutrino oscillations, HPS, MEG

and...T2K, LHC 13 TeV!!

BEACH 2018

Somewhere in Europe?

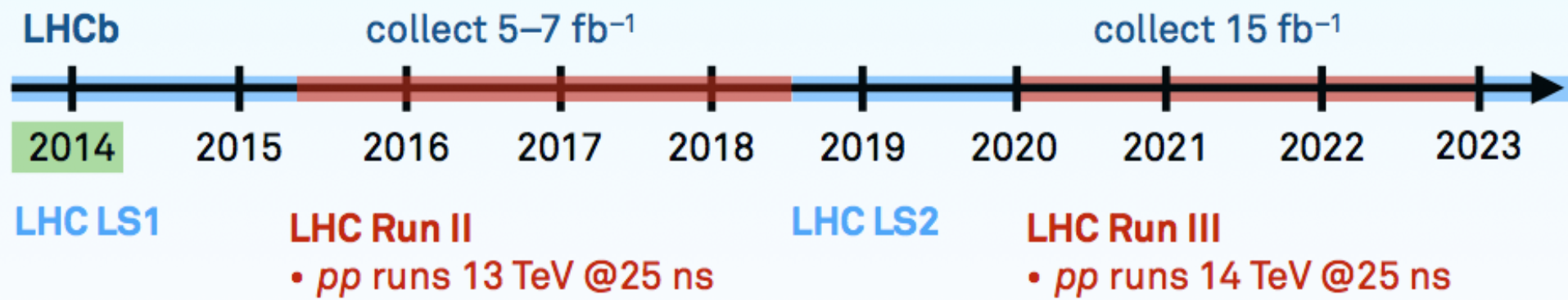
First results from
SIDDHARTA2 - Kaonic D, He, charged kaon mass

KLOE-2  goal is x2 statistics to 5fb^{-1} in 2-3 yrs

Belle II



See talks by Akar, Casarosa





BEACH 2020

Somewhere in the US?

First results from



Hyperon spin $\frac{1}{2}$ & $\frac{3}{2}$ observables

Many LHC (& upgrades) results.... &

2022 JUNO neutrino reactor

>2025 HyperK, LBNE

BEACH physics has a very rich future...

A stage with red curtains and a wooden floor. The curtains are pulled back, revealing a wooden floor. The word "Finale..." is written in white text in the center of the stage.

Finale....

Sonnet 18

"Shall I compare thee to a summer's day?
Thou art more lovely and more temperate:
Rough winds do shake the darling buds of May,
And summer's lease hath all too short a date".

Sonnet BEACH 2014

Sonnet BEACH 2014

"Shall I compare **Birmingham** to a summer's day?

Sonnet BEACH 2014

"Shall I compare **Birmingham** to a summer's day?
Thou art more **cultured** and more **populated**:

Sonnet BEACH 2014

"Shall I compare **Birmingham** to a summer's day?
Thou art more **cultured** and more **populated**:
Rough winds do shake the darling buds **from Curry,**

Sonnet BEACH 2014

"Shall I compare **Birmingham** to a summer's day?
Thou art more **cultured** and more **populated**:
Rough winds do shake the darling buds **from Curry**,
And summer's **conference** hath all too short a date".

Backstage crew

Many thanks for a wonderful BEACH 2014 conference

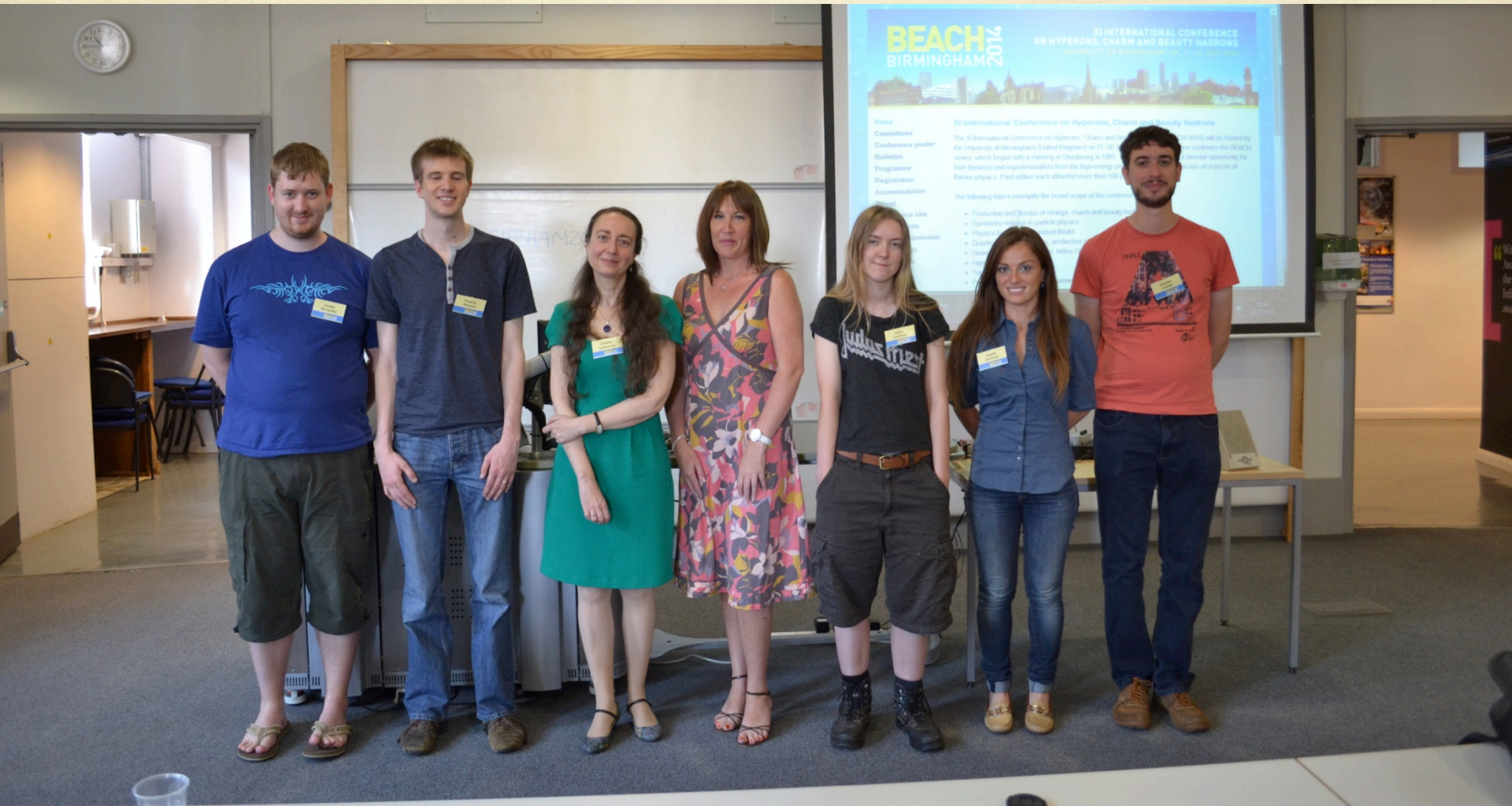
Backstage crew

Many thanks for a wonderful BEACH 2014 conference



Backstage crew

Many thanks for a wonderful BEACH 2014 conference



"The Lady doth protest
too much, methinks".

Hamlet, Act III, Scene II



"The Lady doth **say**
too much, methinks".

Hamlet, Act III, Scene II



"The Lady doth **say**
too much, methinks".

Hamlet, Act III, Scene II

Thank you

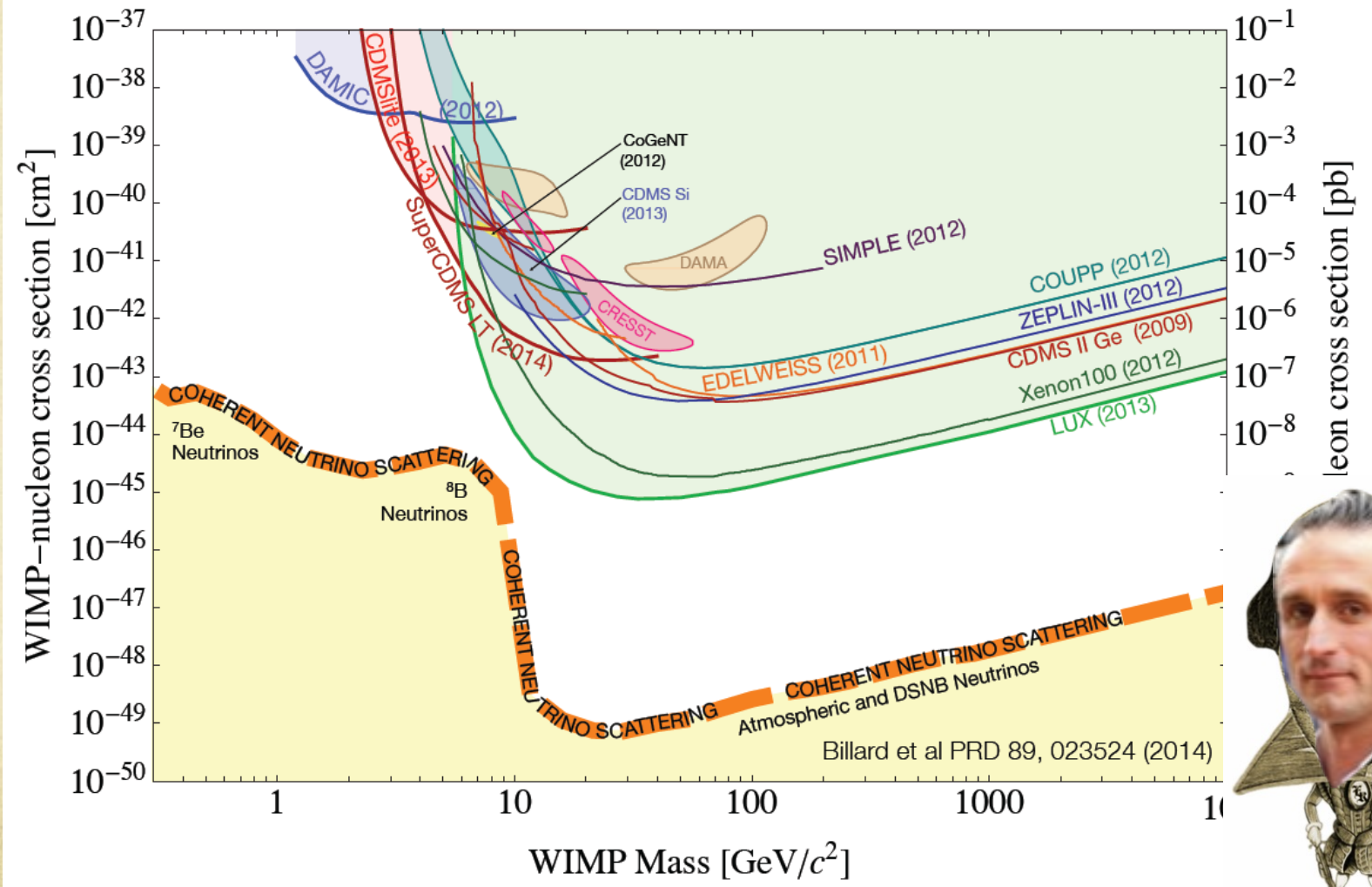


A stage with red curtains and a wooden floor. The curtains are a deep red color with a subtle sheen and are drawn back to reveal a light-colored wooden floor. The word "Backstage" is written in a white, serif font in the center of the image.

Backstage

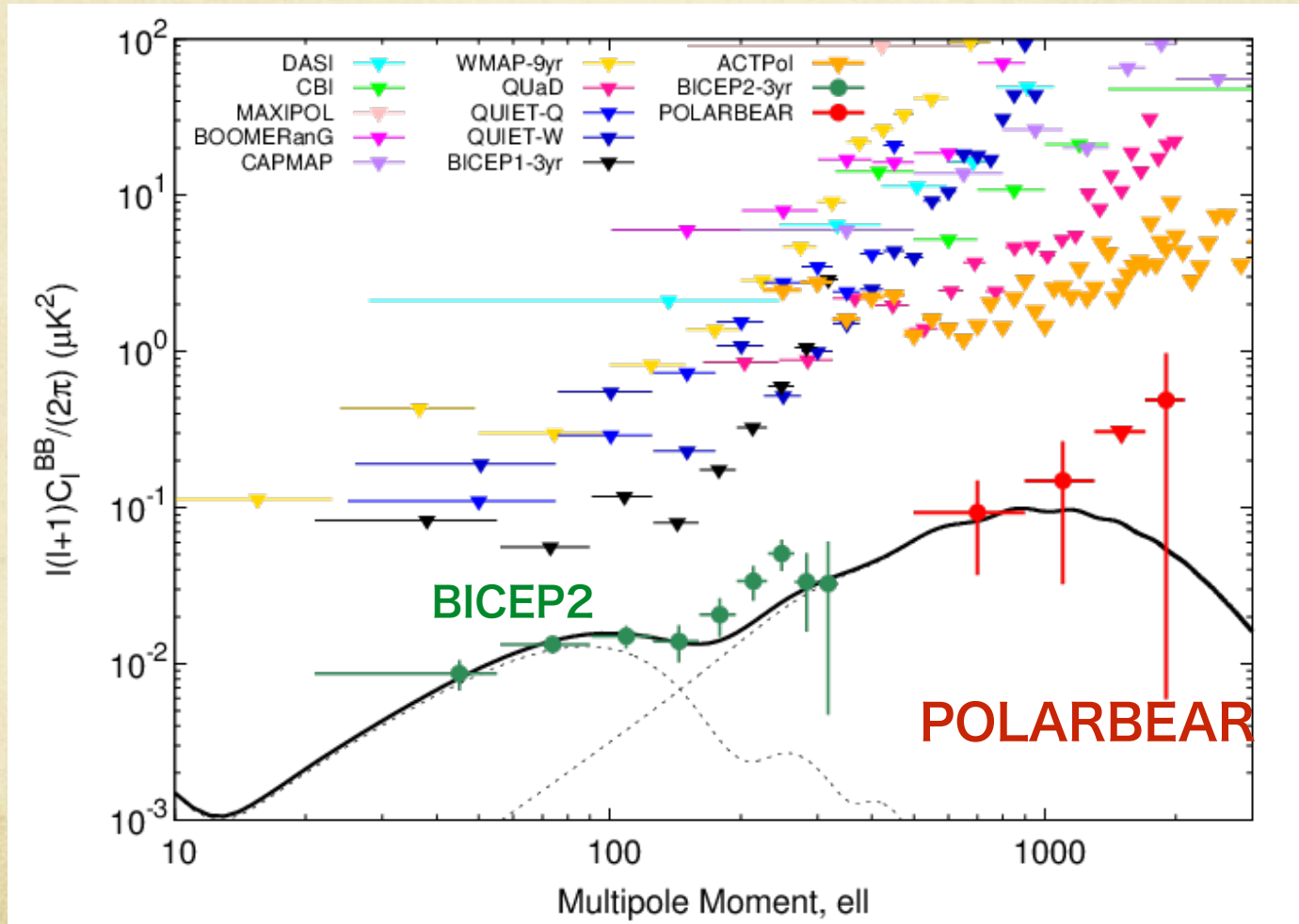
Dark Matter

30 years of direct searches for 96% of the Universe



Gravitational Waves

Discovery of CMB B-mode polarization



QCD Hadron Model



HAPPY BIRTHDAY

Volume 8, number 3

PHYSICS LETTERS

1 February 1964

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN

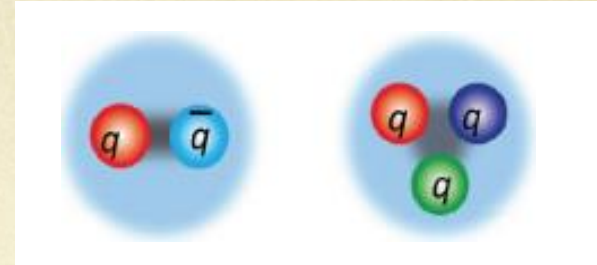
California Institute of Technology, Pasadena, California

Received 4 January 1964

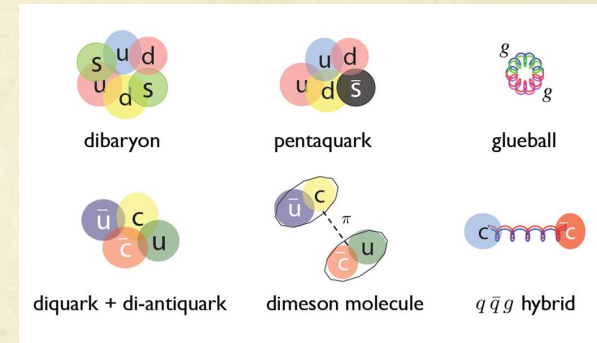
anti-triplet as anti-quarks \bar{q} . Baryons can now be constructed from quarks by using the combinations (qqq) , $(qqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. It is assumed that the lowest baryon configuration (qqq) gives just the representations 1, 8, and 10 that have been observed, while the lowest meson configuration $(q\bar{q})$ similarly gives just 1 and 8.

Exotic QCD

QCD describes hadrons composed of 2 (meson) or 3 (baryon) quarks.



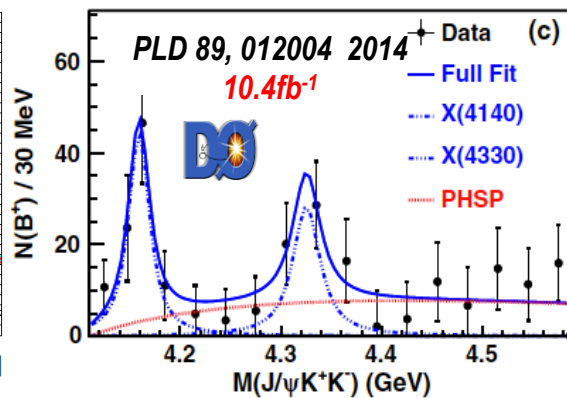
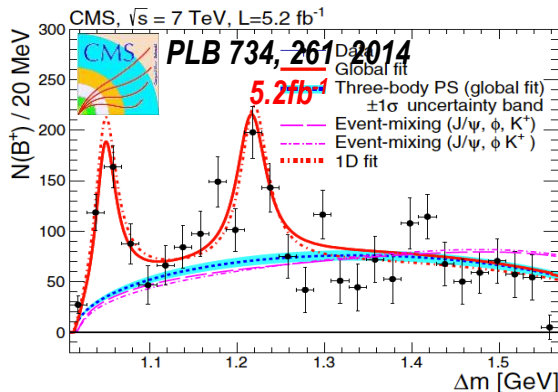
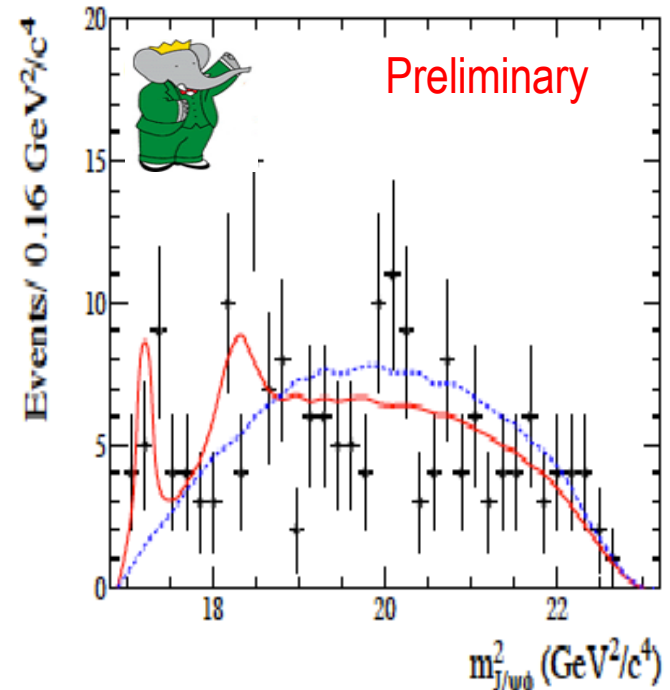
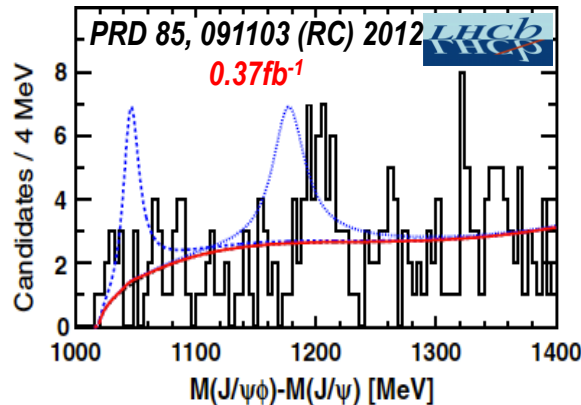
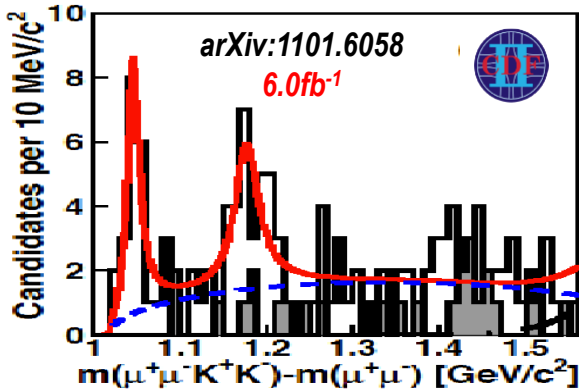
QCD suggests multi (>2) quark states (& hybrids and glueballs).



Since 2003 many new charmonium and bottomonium-like states observed at/above threshold

Are the exotic hadrons beginning to show their nature?

X(4140) a.k.a. Y(4140)



$f(4140) = (7.3 \pm 2.5 \pm 3.8)\%$, UL @ 90% C.L. = 12.1 %
 $f(4270) = (7.7 \pm 3.7 \pm 5.2)\%$, UL @ 90% C.L. = 16.4 %

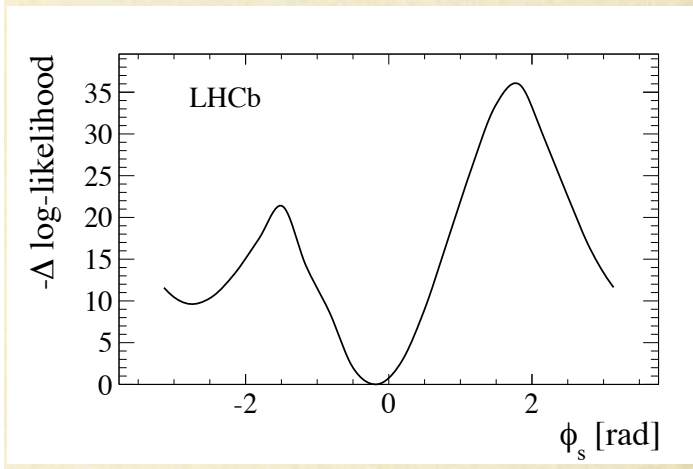
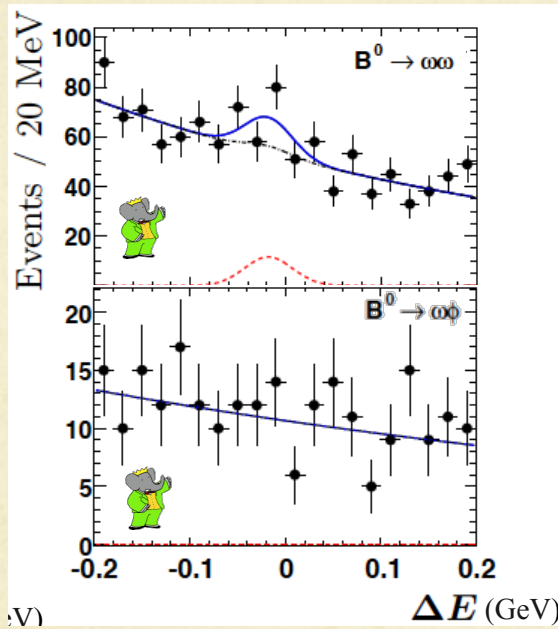
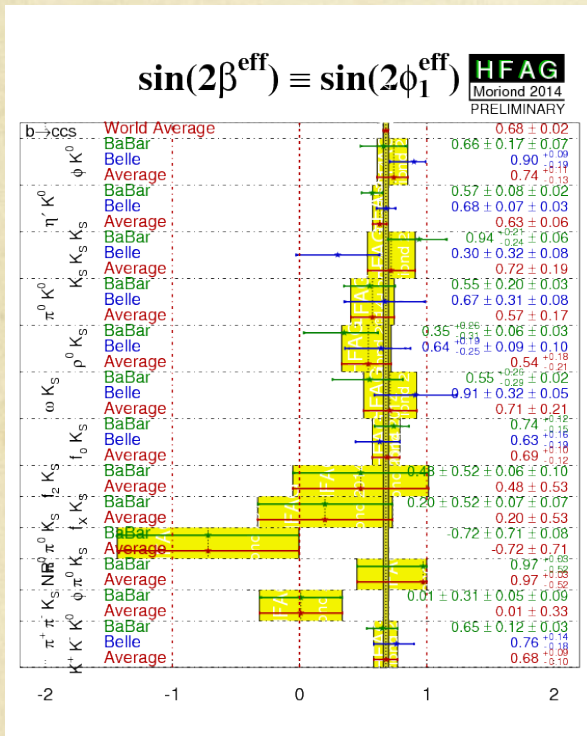
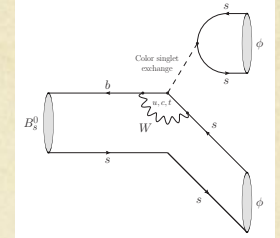
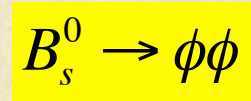
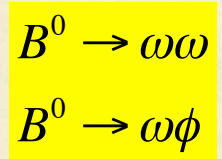
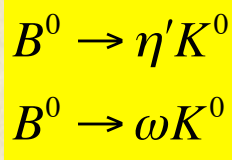
- Y(4140) and Y(4274) was first observed by CDF in $B^+ \rightarrow J/\psi \phi K^+$
- LHCb did not observed the two resonances
- CMS confirmed the results
- D0 showed hints for the two Y resonances

Can not access the present of resonance behavior

Higher statistics and a full Dalitz plot analysis is need

See Valentina Santoro's talks on last Thursday

Penguin dominated B^0 decays



$\phi_s = -0.17 \pm 0.15 \pm 0.03 \text{ rad}$
 $|\lambda| = 1.04 \pm 0.07 \pm 0.03$

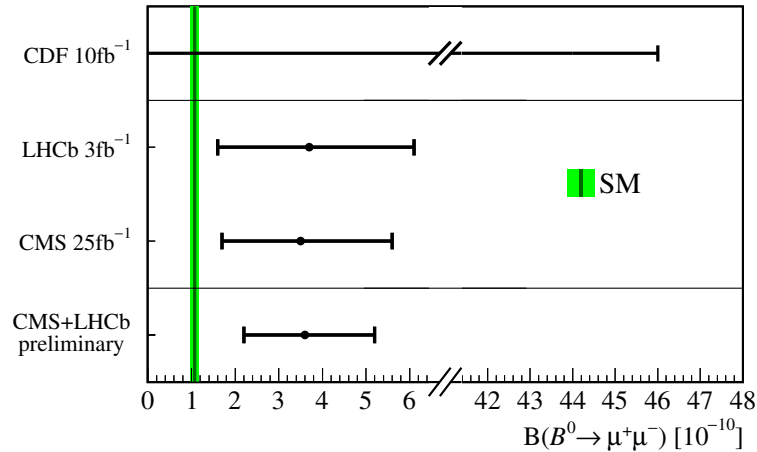
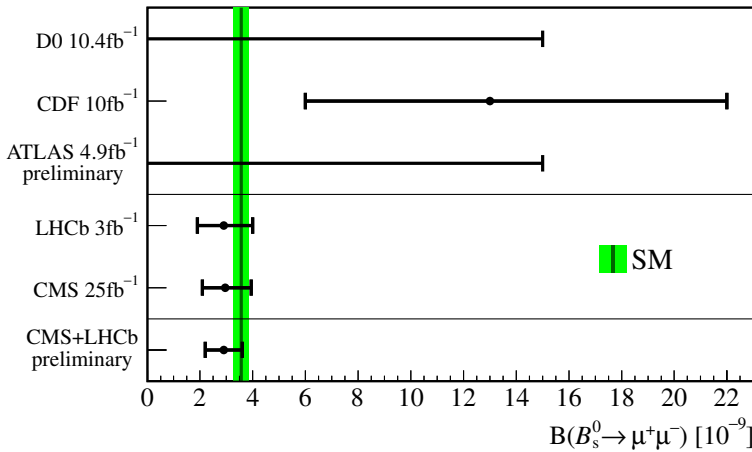
$S_{\eta' K^0} = +0.68 \pm 0.07 \pm 0.03$

$S_{\omega K_S^0} = +0.91 \pm 0.32 \pm 0.05$

$B(B^0 \rightarrow \omega\omega) = (1.2 \pm 0.3_{-0.2}^{+0.3}) \times 10^{-6}$

$B(B^0 \rightarrow \omega\phi) < 0.7 \times 10^{-6} \text{ 90\% c.l.}$

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$ combined



D0:
PRD87(2013)072006
CDF:
PRD87(2013)072003
ATLAS:
ATLAS-CONF-2013-076
LHCb:
PRL 111 (2013) 101805
CMS:
PRL 111 (2013) 101804

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (2.9 \pm 0.7) \times 10^{-9}$$

$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) = (3.6^{+1.6}_{-1.4}) \times 10^{-10}$$

Full combination of likelihoods coming soon followed by
 Search for $B_d \rightarrow \mu^+ \mu^-$ and measure $\mathcal{B}(B_d \rightarrow \mu^+ \mu^-)/\mathcal{B}(B_d \rightarrow \mu^+ \mu^-)$
 Measure B_s effective lifetime
 Search for other decays (e.g. $B_s \rightarrow \tau^+ \tau^-$)

Further in the future

Monday

Tuesday

Wednesday

Thursday

Friday