Summary of WG5 – Heavy Flavors

- Conveners
  - Martin Gorbahn
  - Vanya Belyaev
  - Anze Zupanc

Role of Heavy Flavors

Study of top quark, beauty and charm hadrons to:

- *Test of QCD in (non-)perturbative regime*
  - Open flavor, Quarkonium production x-sections
  - Test Quark and exotic models via spectroscopy (masses, widths)
- *Determine fundamental parameters of the theory*
  - *Quark masses, couplings (CKM)*
- *Search for Physics Beyond the SM*
  - *In rare decays, meson mixing and CP violation*
- *Probe properties of hot and dense QCD matter*
  - *Heavy-Flavor production in Heavy Ion collisions*

Heavy Flavors WG Program

- *4 sessions / 36 talks / interesting discussions*

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  - *Top physics (joint with WG3)*

Top quark cross section measurements with CMS	*Javier FERNANDEZ MENENDEZ*	
Auditorium, BUW		14:00 - 14:24
Top quark cross section measurements with ATLAS	*Prof. Patrick SKUBIC*	
Auditorium, BUW		14:24 - 14:48
Single top quark production with CMS	*Alberto Orso Maria IORIO*	
Auditorium, BUW		14:48 - 15:12
Single Top quark production cross section using the ATLAS detector at the LHC	*Caterina MONINI*	
Auditorium, BUW		15:12 - 15:36
Uncertainties on Higgs and ttbar predictions at the LHC from CTEQ-TEA Global Analysis	*Carl SCHMIDT*	
Coffee Break		
Auditorium, BUW		16:00 - 16:30
Top quark pair properties - spin correlations, top quark pair asymmetry and complex final states using the ATLAS detector at the LHC	*Ralph SCHAFER*	
Associated production of heavy flavour final state and a vector boson and search for H->bb	*Roberto CASTELLO*	
Intrinsic top quark properties - top mass, charge and W helicity using the ATLAS detector at the LHC	*Riccardo DI SIPIO*	
Top quark mass measurements with CMS	*Elvire BOUVIER*	
Auditorium, BUW		17:39 - 18:02
Top quarks as a probe for heavy new physics	*Celine DEGRANDE*	
Auditorium, BUW		18:02 - 18:30

Heavy Flavors WG Program

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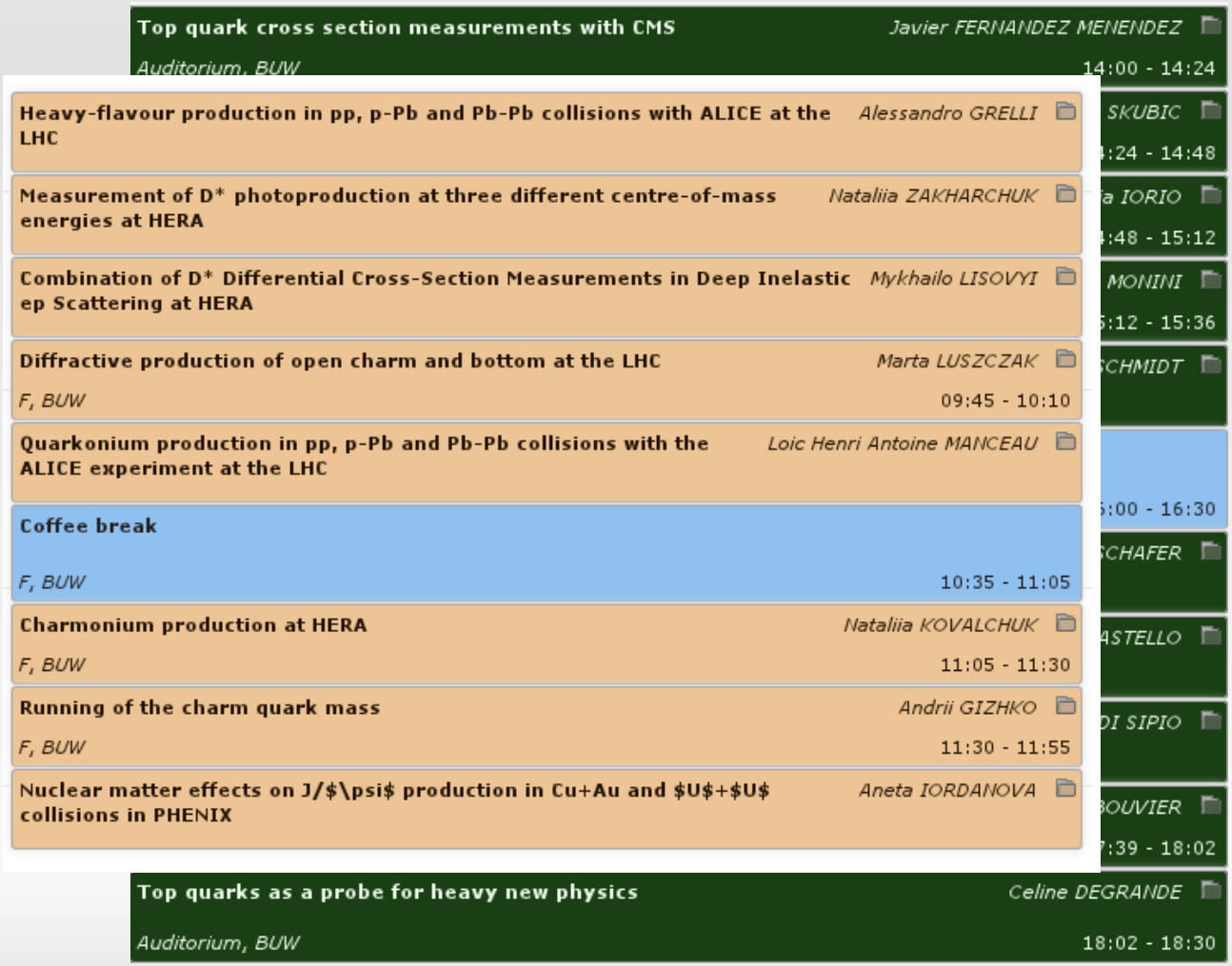
  - *Top physics (joint with WG3)*
  - *Production*



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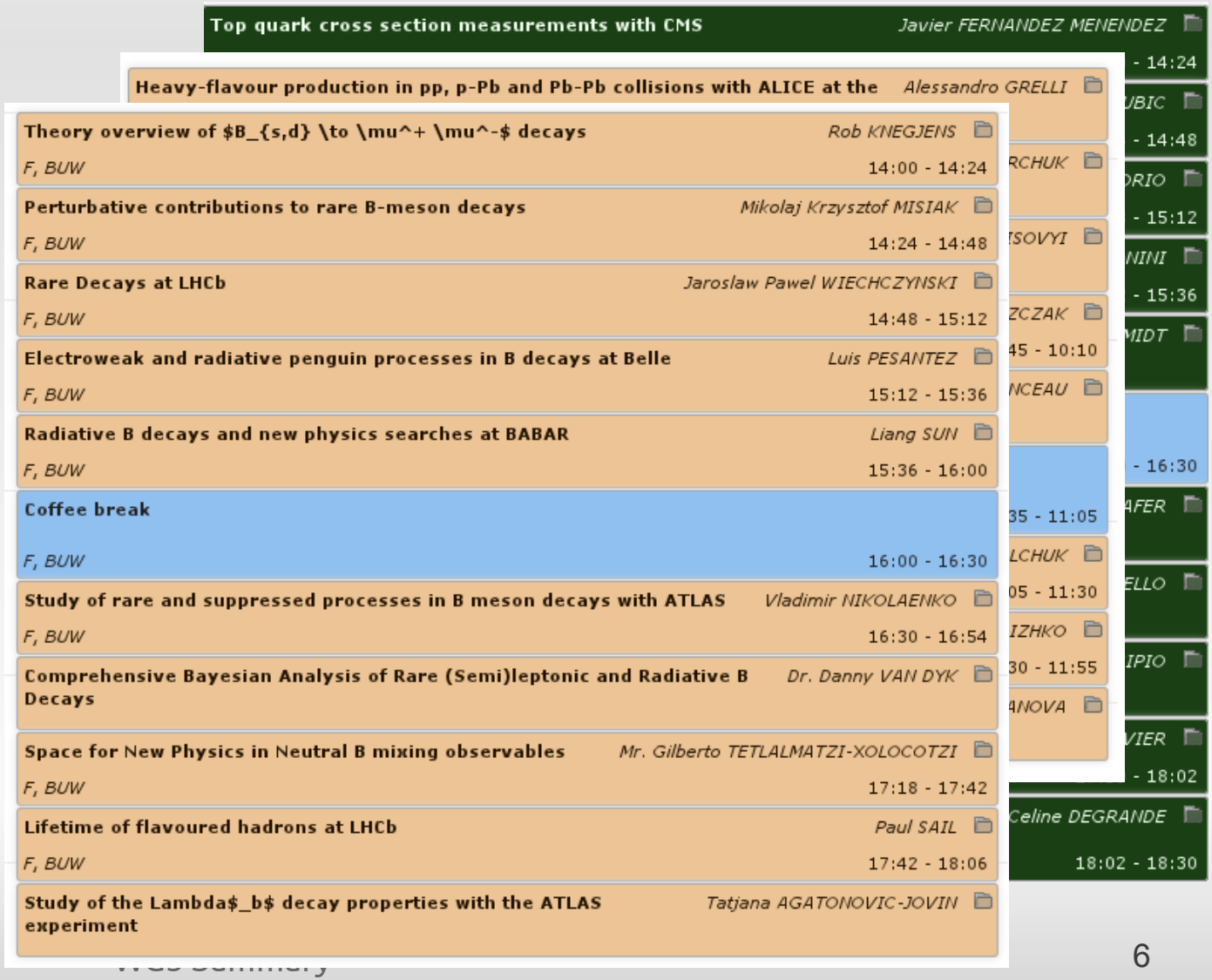

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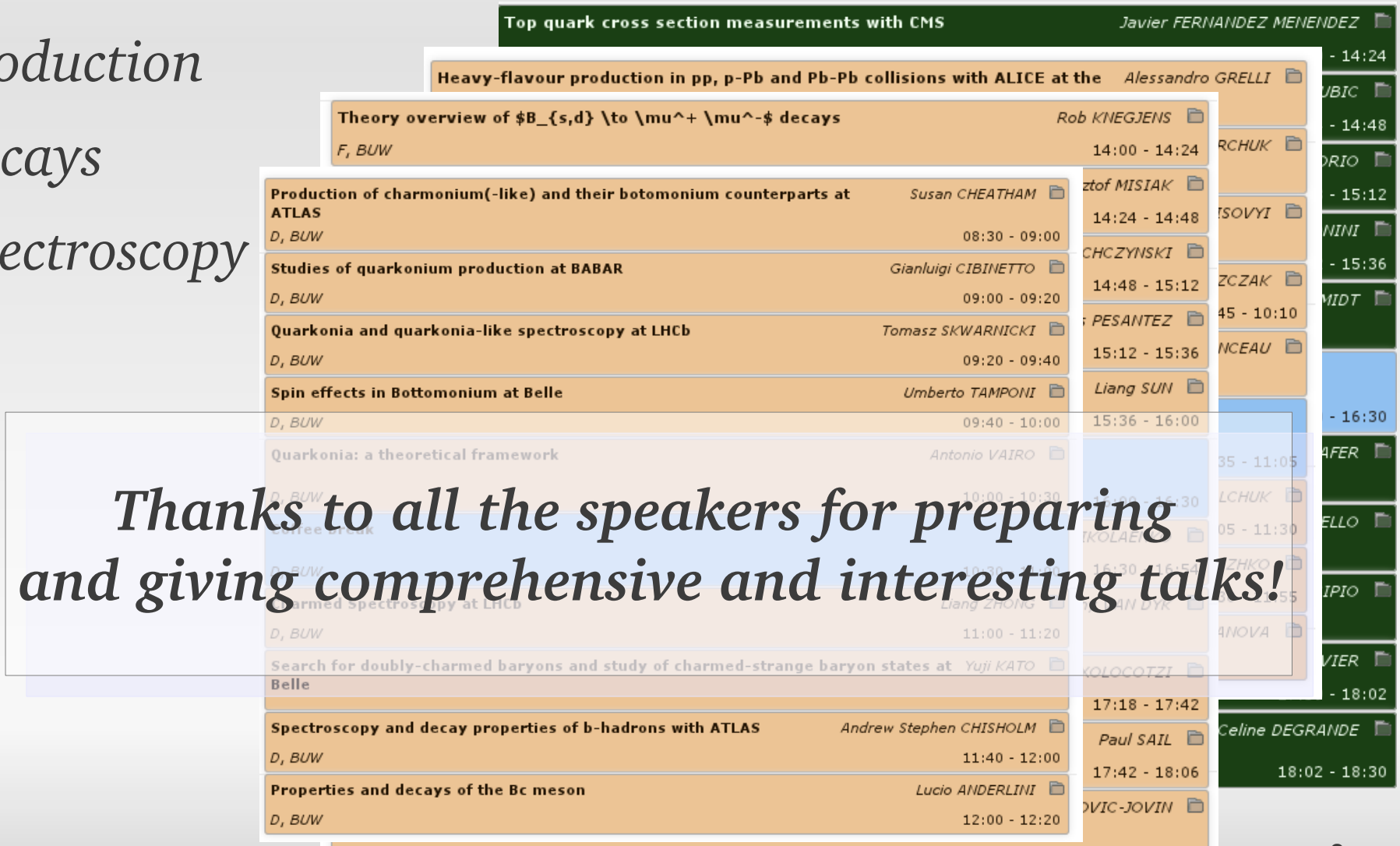


Thanks to all the speakers for preparing and giving comprehensive and interesting talks!

Disclaimer

- Impossible to give an overview of presentations

This is completely personal view and summary based on "freshness" of results, personal bias and mostly, on my capability of understanding the slides.

Apologies if your favorite topic is not covered.

Please refer to the parallel session talks for details as well as plenary talk on Heavy Flavors by A.Mischke on Monday.

Top physics

- The heaviest elementary particle

$$\frac{1}{m_t} < \frac{1}{\Gamma_t} < \frac{1}{\Lambda_{QCD}} < \frac{m_t}{\Lambda^2_{QCD}}$$

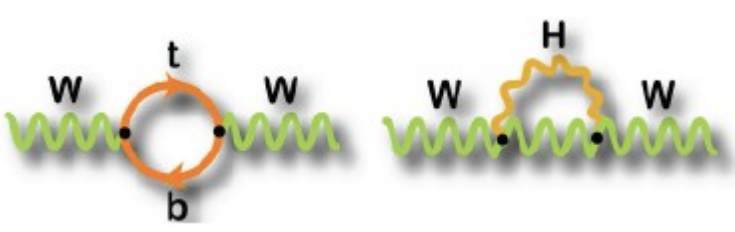
production time | lifetime | hadronization time | spin decorrelation time

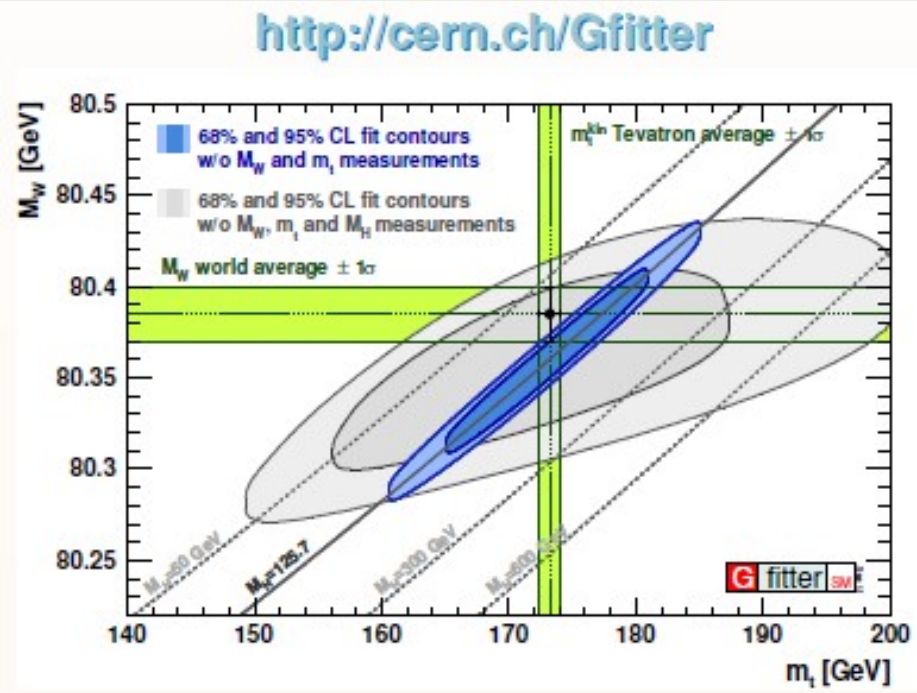
No hadronization!

⬇

Intrinsic properties directly observed!

- top quark mass
  - correlation with W and H masses in EW
  - Stringent tests of SM

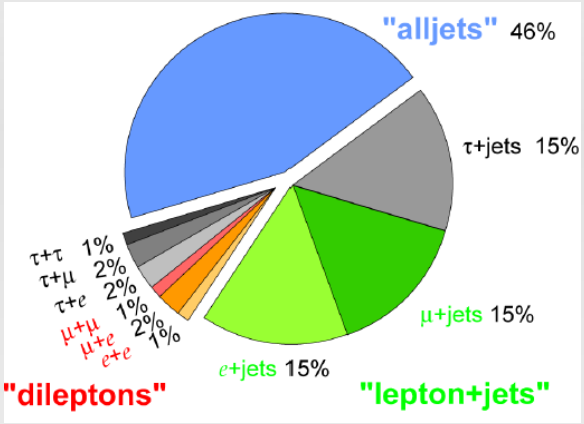




Top quark (pair) production

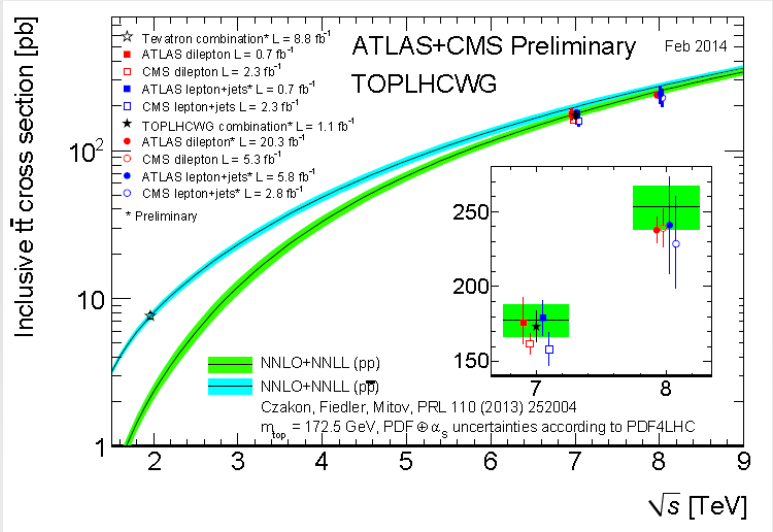
Dominant production mechanism at LHC

t → Wb (100%)



All final states being studied!

J. Fernandez (CMS) & P.Skubic (ATLAS)

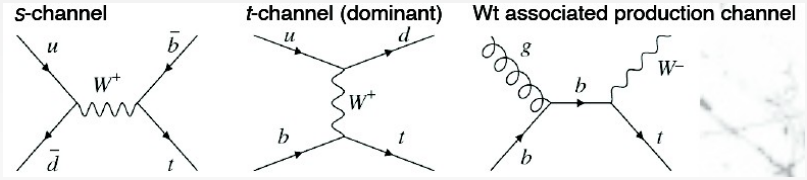


Top pair production measurements entered precision era:

σ(tt) uncertainty O(5%) at LHC compared to ~4% prediction uncertainty (NNLO+NNLL)

Single top production

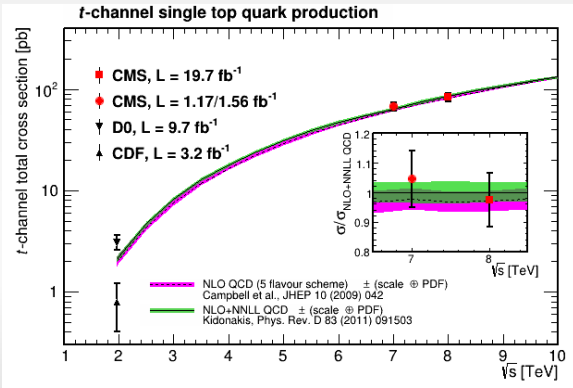
C.Monini(ATLAS) & A.Iorio (CMS)

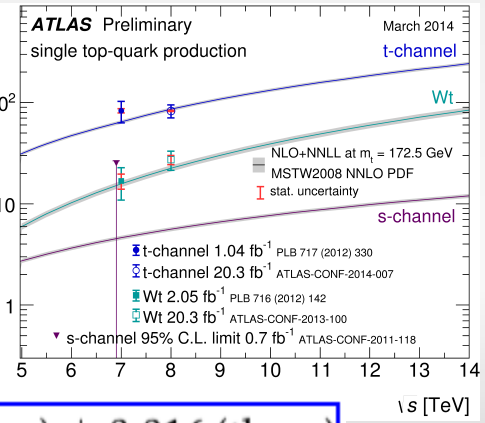


$$\sigma_s = 5.6 \pm 0.2 \text{ pb}$$

$$\sigma_t = 87.8^{+3.4}_{-1.9} \text{ pb}$$

$$\sigma_{Wt} = 22.4 \pm 1.5 \text{ pb}$$



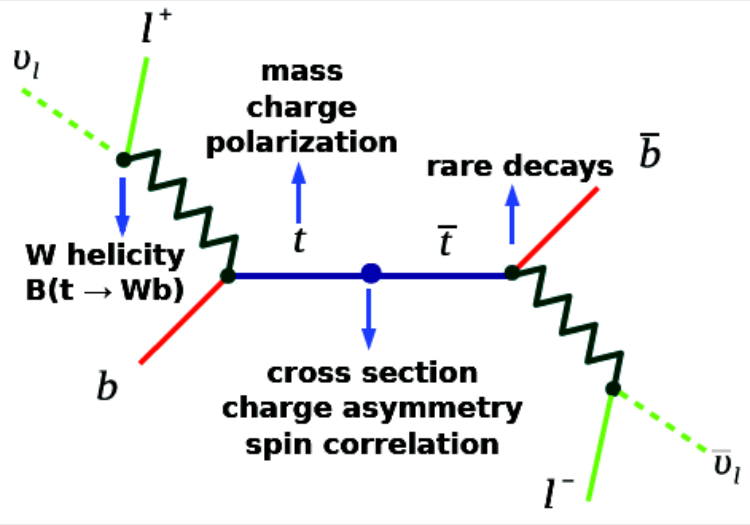


$$|V_{tb}| = 0.998 \pm 0.038\,(\text{exp.}) \pm 0.016\,(\text{theo.})$$

Top quark pair properties

Large $t\bar{t}$ samples → excellent laboratory for measurements of top properties

8 TeV analyses: ~5 10^6 ttbar pairs
7 TeV analyses: ~1 10^6 ttbar pairs



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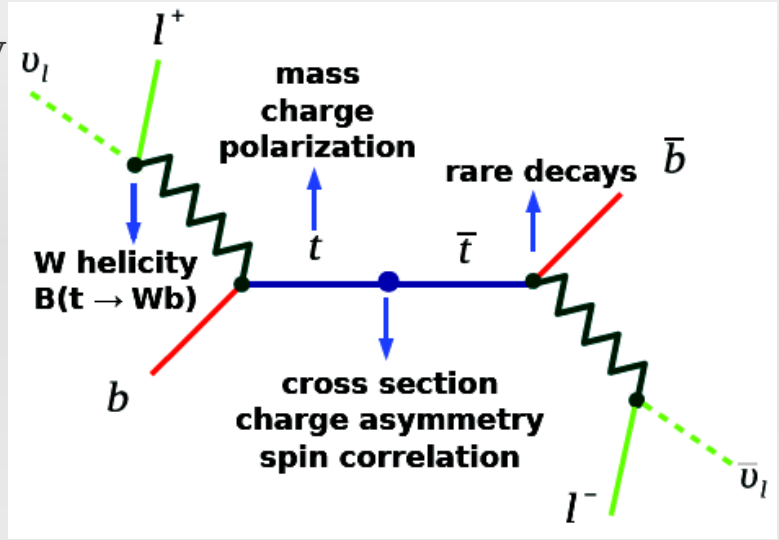
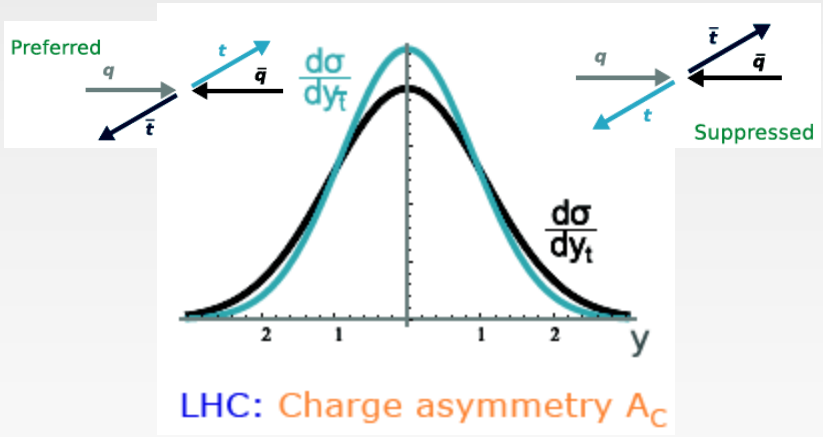


R.Schäfer (ATLAS): Charge Asymmetry

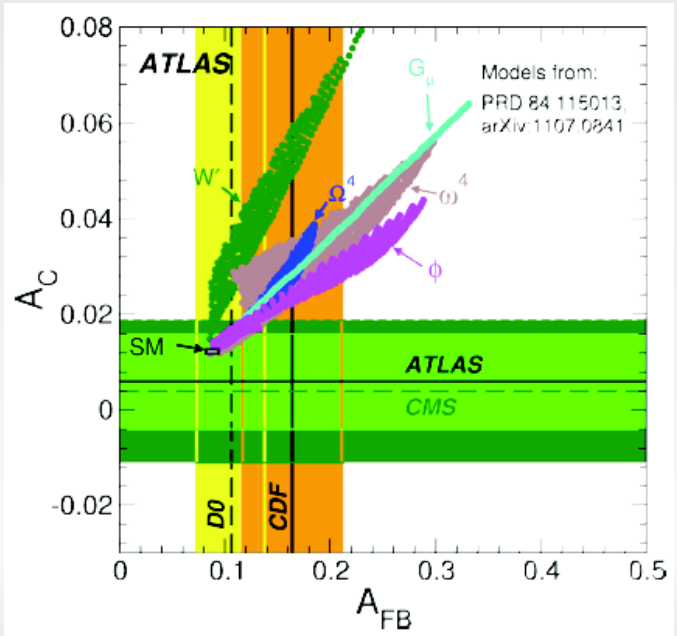
Test of tension between prediction and measurements of A_{FB} at Tevatron



$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

Experiment
0.6±1.0 % (stat+syst)

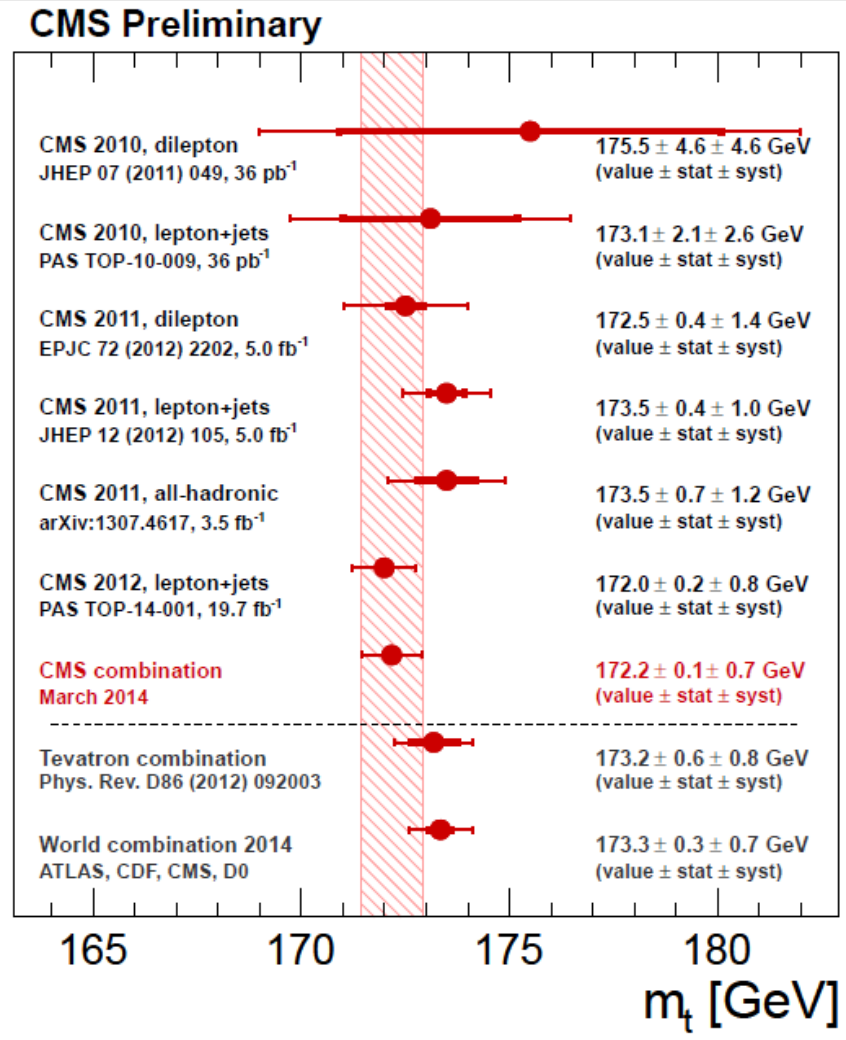
vs. SM prediction
1.23±0.05 %



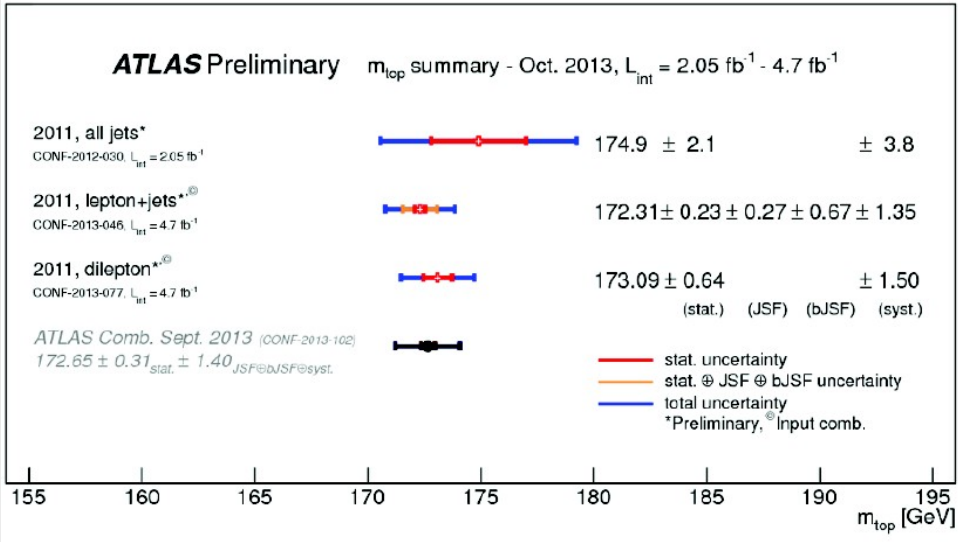
A_C @ LHC disfavours large fraction of parameter space for some models.

Top quark properties - Mass

E.Bouvier (CMS)



R.Di Sipio (ATLAS)



Top quark mass measured with ~0.5% precision:

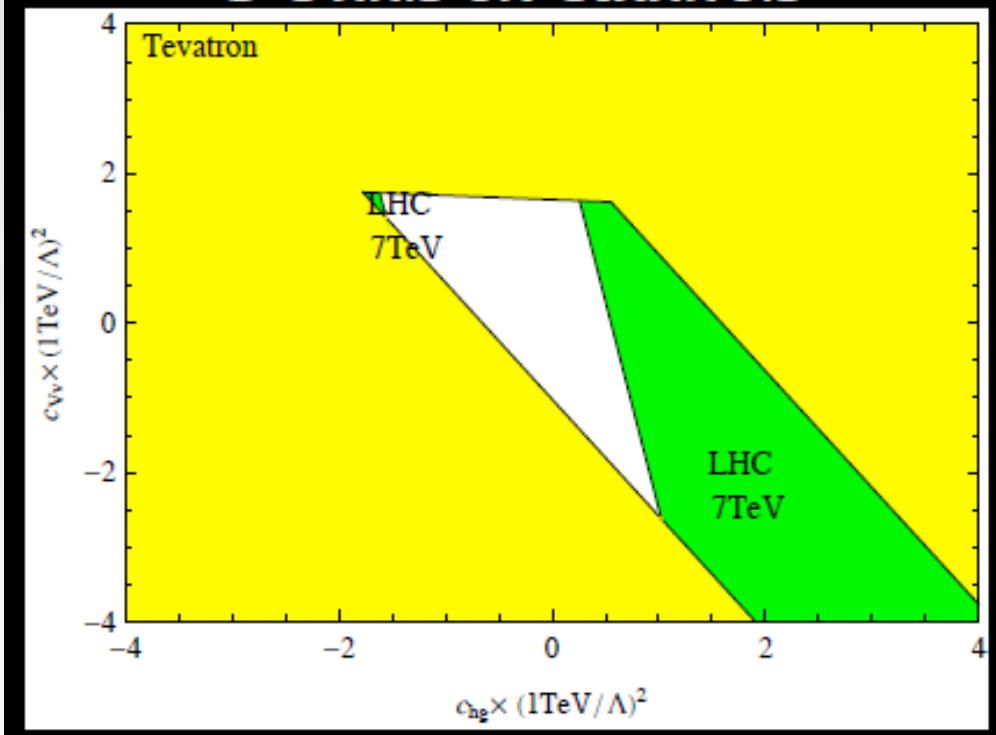
- Systematics dominated
  - b-JES, soft QCD, and more generally models expected to be better constrained by more data
- Alternative methods/measurements (uncorrelated syst!)
  - pole mass from $\sigma(tt)$
  - *kinematic endpoint*
  - *B hadron lifetime (L_{xy})*

Heavy new physics in top production and decay

Celine Degrande

Study the constraints on effective theory couplings from top decay, top pair production & same sign top pair production

Constraints



- Assumption : $E_{exp} << \Lambda$

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{C_i}{\Lambda^2}\mathcal{O}_i^6$$

$$\mathcal{O}_{hG} = \bar{Q}\sigma_{\mu\nu}T^a t\tilde{\phi}G_a^{\mu\nu}$$

$$\mathcal{O}_{Rv} = \bar{t}\gamma_\mu T^a t \sum_{u.d.s.c} \bar{q}\gamma^\mu T^a q$$

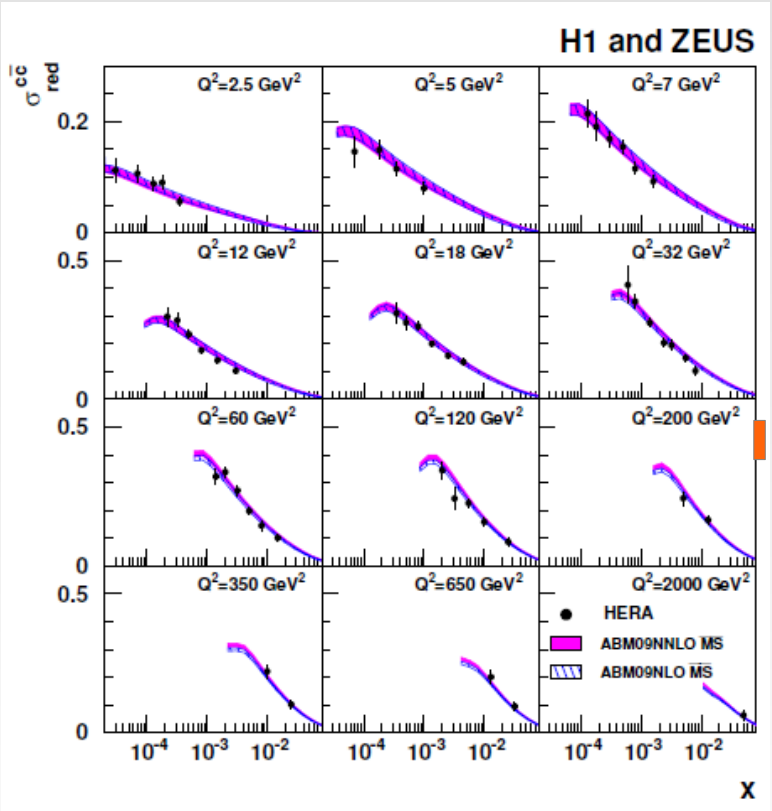
$$\mathcal{O}_{Lv} = \bar{Q}\gamma_\mu T^a Q \sum_{u,d,s,c} \bar{q}\gamma^\mu T^a q$$

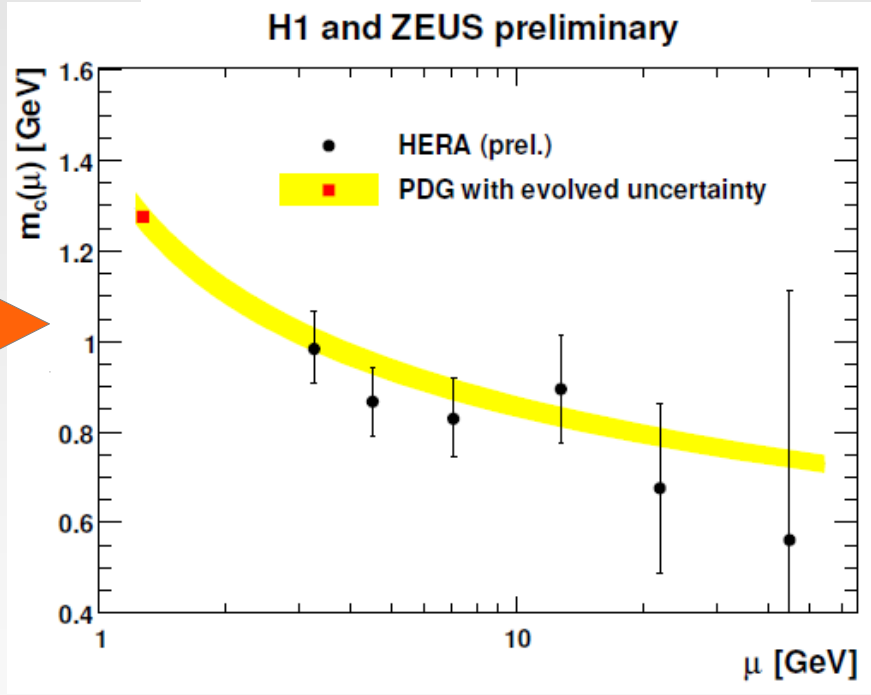
Running charm quark mass

- Use H1+ZEUS charm production in DIS data from different Q^2 regions to extract charm mass (m_c) at different scales
  - using FFNS and <u>MS</u> charm mass definition

A.Gizhko (H1+ZEUS)

$$m_c(\mu) = m_c(m_c)\frac{\left(\frac{\alpha_s(\mu)}{\pi}\right)^{\frac{1}{\beta_0}}}{\left(\frac{\alpha_s(m_c)}{\pi}\right)^{\frac{1}{\beta_0}}}$$



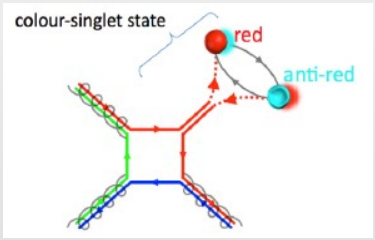


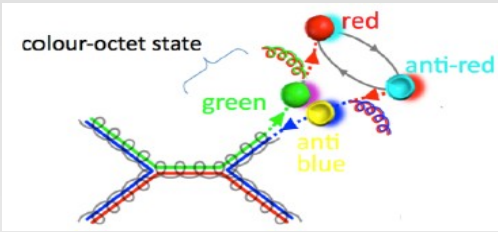
$$m_c^{\overline{MS}}(m_c) = 1.26 \pm 0.05_{exp} \pm 0.03_{mod} \pm 0.02_{param} \pm 0.02_{\alpha_s}\ \text{GeV}$$

PDG value : $m_c^{\overline{MS}}(m_c) = 1.275 \pm 0.025$ GeV

Charmonium Production in pp

- Study of non perturbative behavior of QCD
  - *Color Singlet mechanism failed to explain production of P-wave charmonium states observed at experiments*

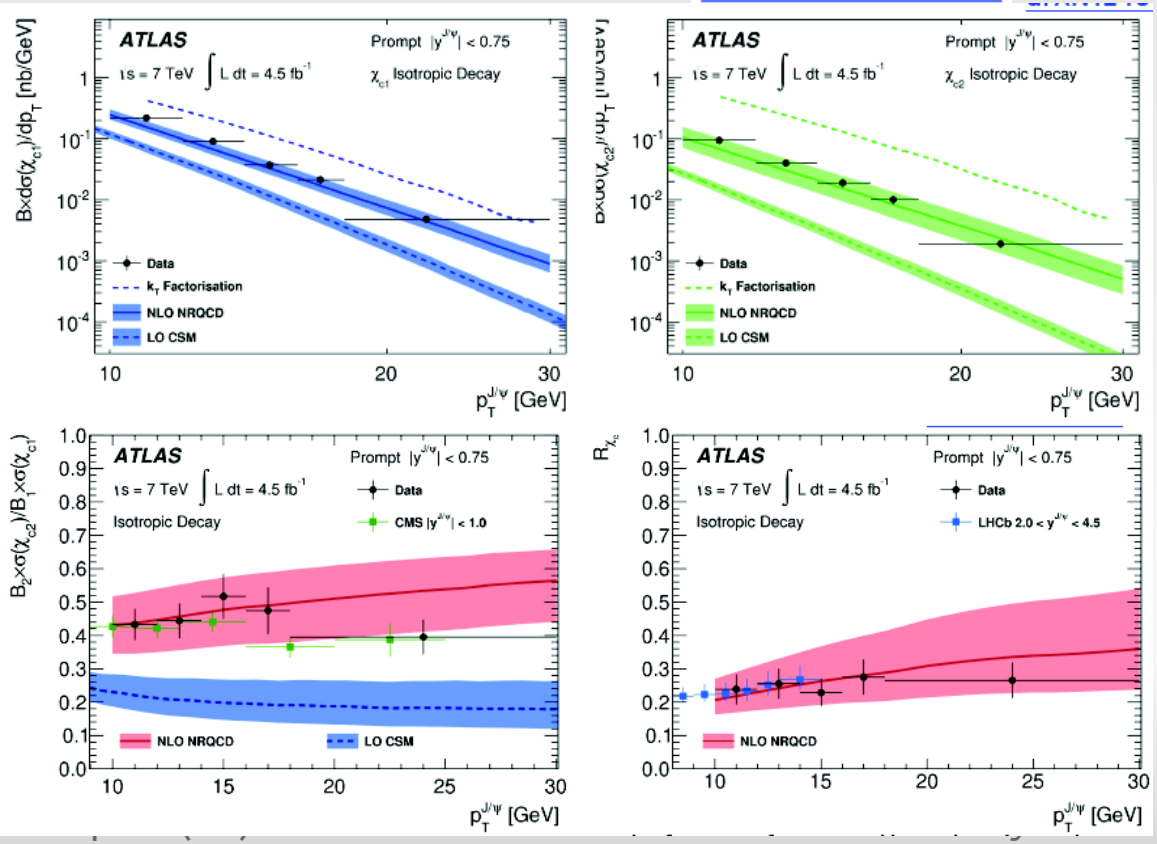




S.Cheatham(ATLAS):Measurement of the χc1 and χc2 production

- Test understanding of χc production at LHC
- Get handle on feed-down contribution of J/ψ from χc in J/ψ cross -section measurements

arXiv:1404.7035

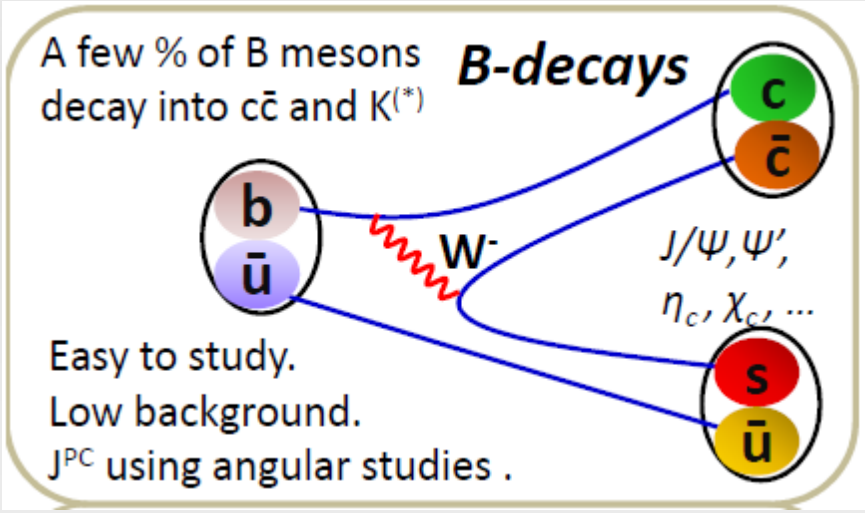


NLO NRQCD predictions in good agreement with DATA:

- (non-)prompt cross sections
- Ratio of χc2/χc1
- Prompt J/ψ in χc feed-down

Charmonium(-like) production in B decays

- B-decays are reach and clean source of charmonia

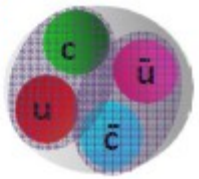


Last decade was full of discoveries of new particles that can not fit easily to any of the predicted states by the quark model.

Exotic alternatives (among meny):

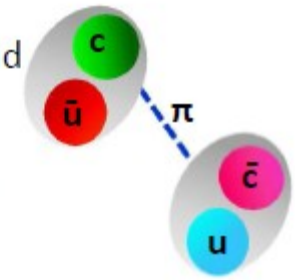
Tetraquark

Tightly bound diquark & anti-diquark



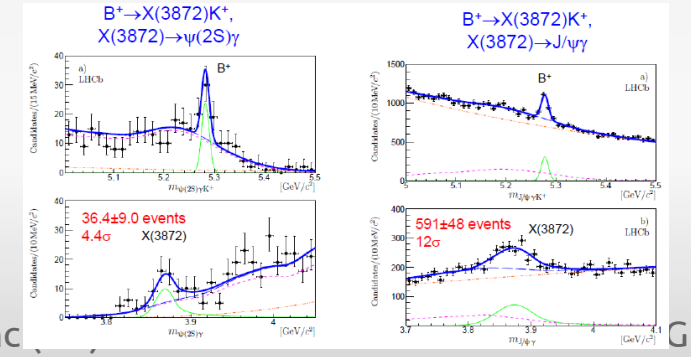
Molecule

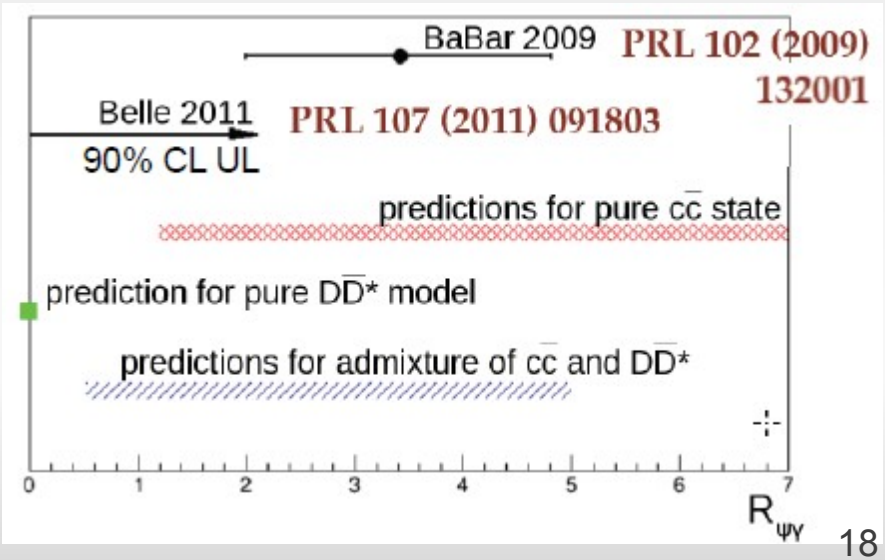
loosely bound meson-antimeson "molecule"



T.Skwarnicki(LHCb): X(3872)

- The most studied "new" state, but it's nature still not understood
- $J^{PC}=1^{++}$ (→ DD* molecule or charmonium)
  Measure R = B(X → ψ(2S)γ)/B(X → J/ψγ)





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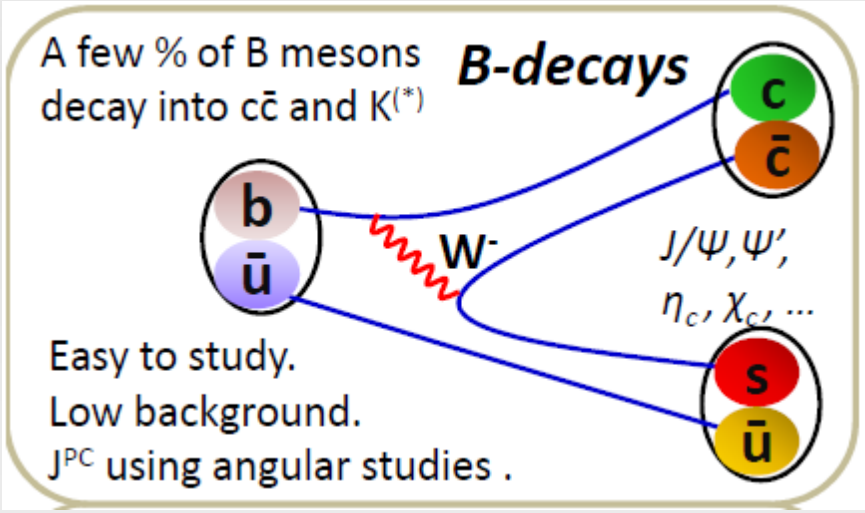

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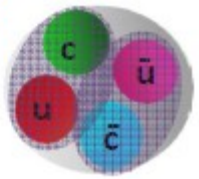

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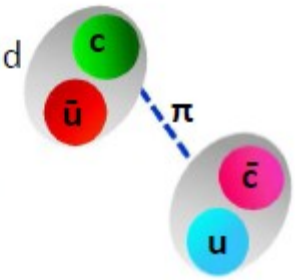
loosely bound meson-antimeson "molecule"



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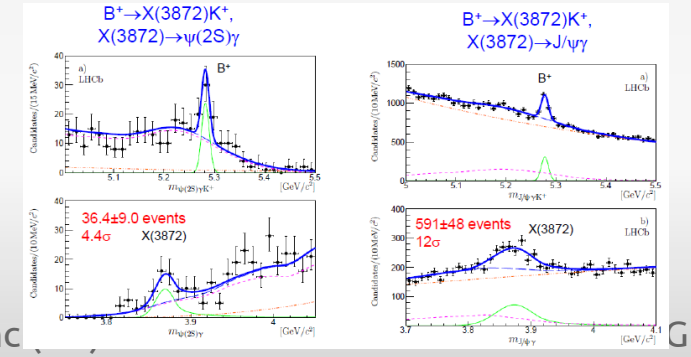
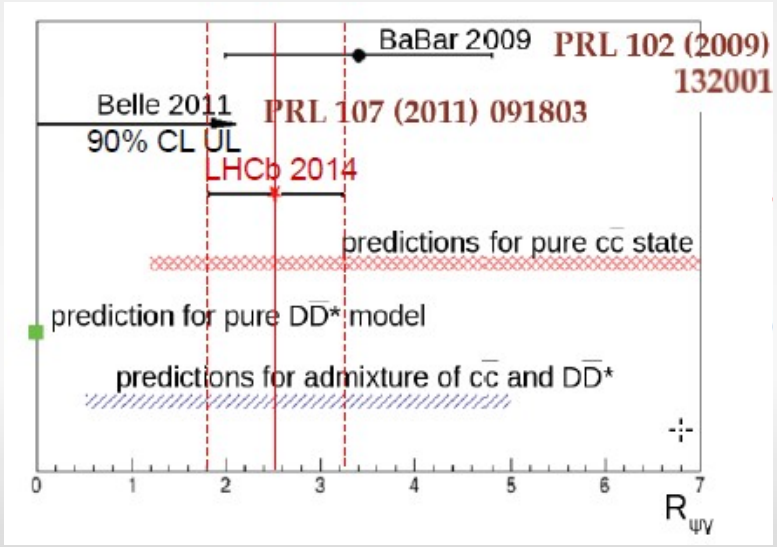
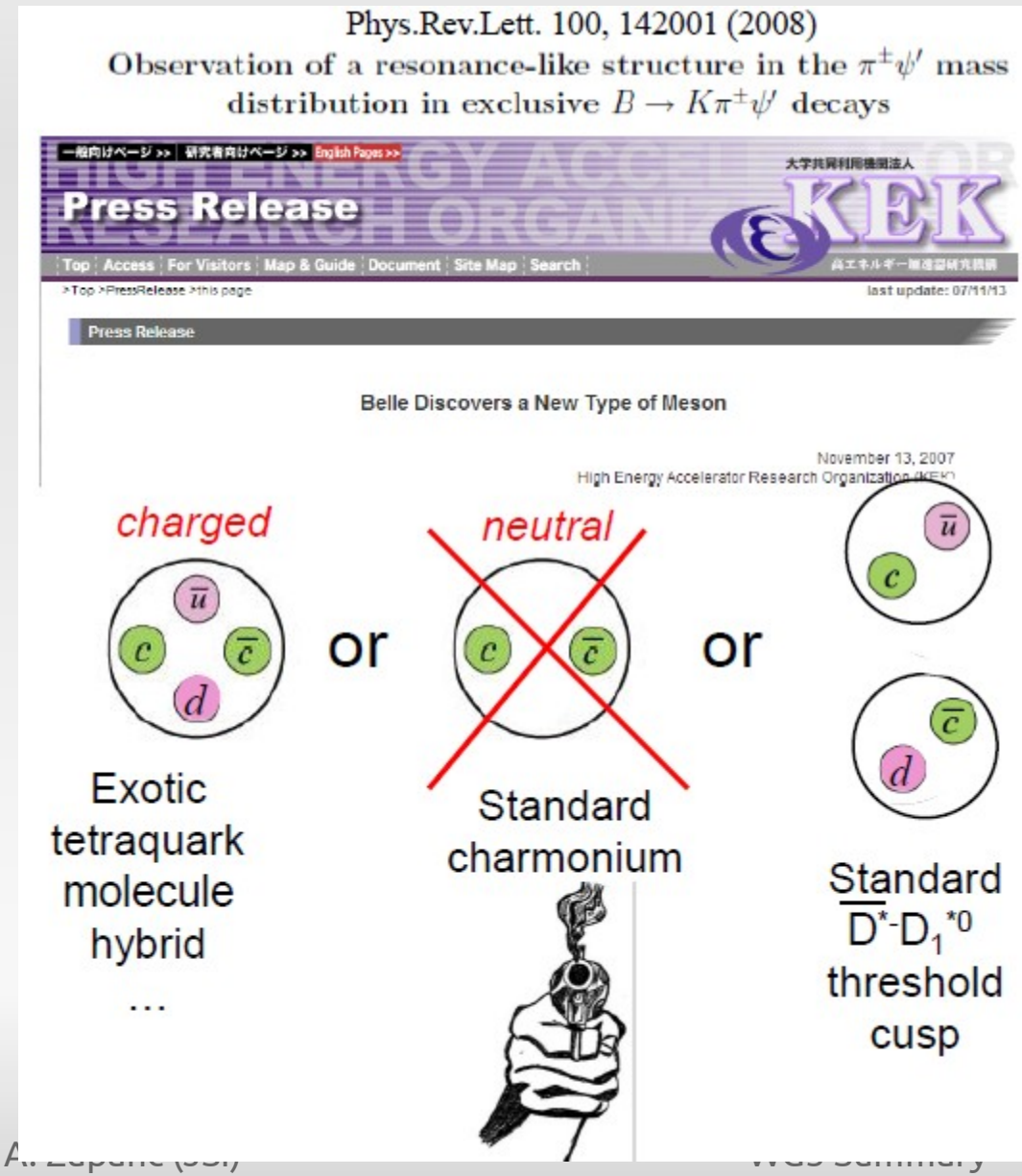




Charged charmonium-like state $Z(4430)^-$

First observed by Belle in 2008 and confirmed recently by LHCb!



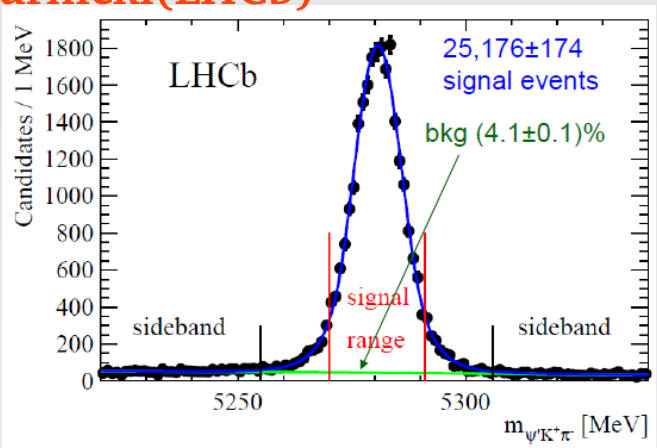
T.Skwarnicki(LHCb)

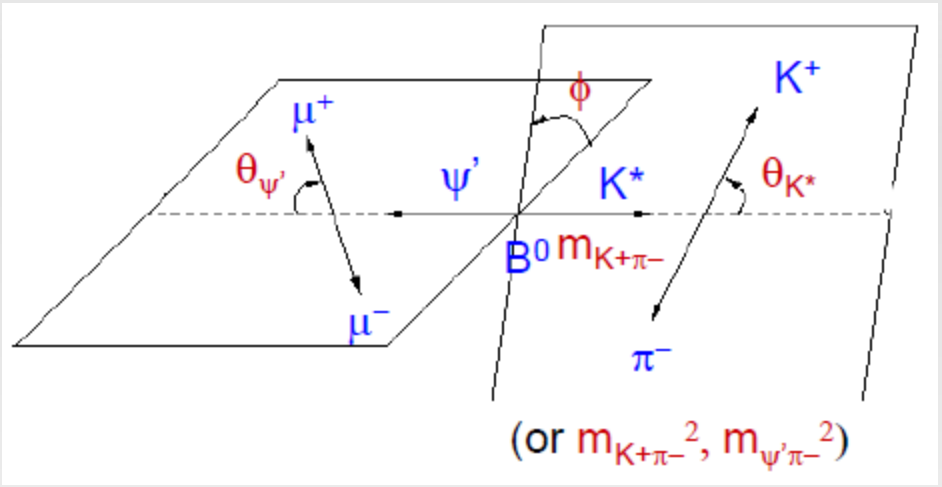
Charged charmonium-like state $Z(4430)^-$

Full 4D amplitude analysis performed!

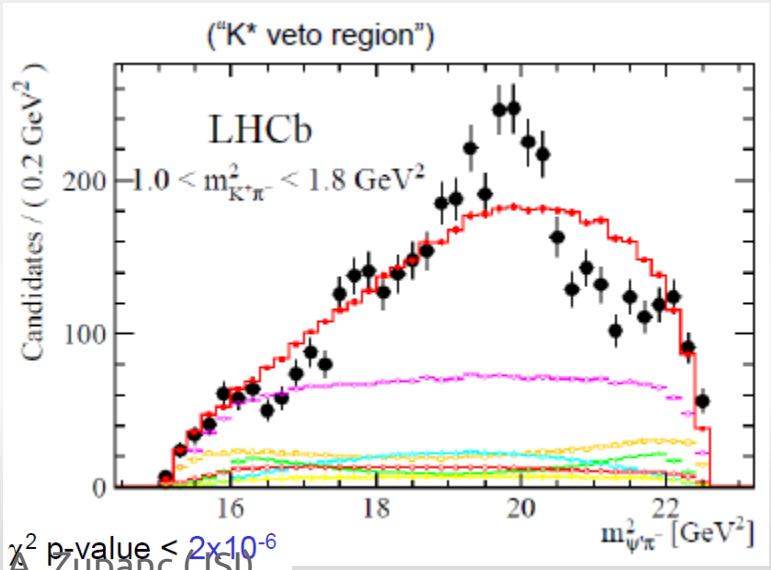
T.Skwarnicki(LHCb)

$B^0 \to \psi' K^+ \pi^-$, $\psi' \to \mu^+ \mu^-$ (3 fb^{-1})



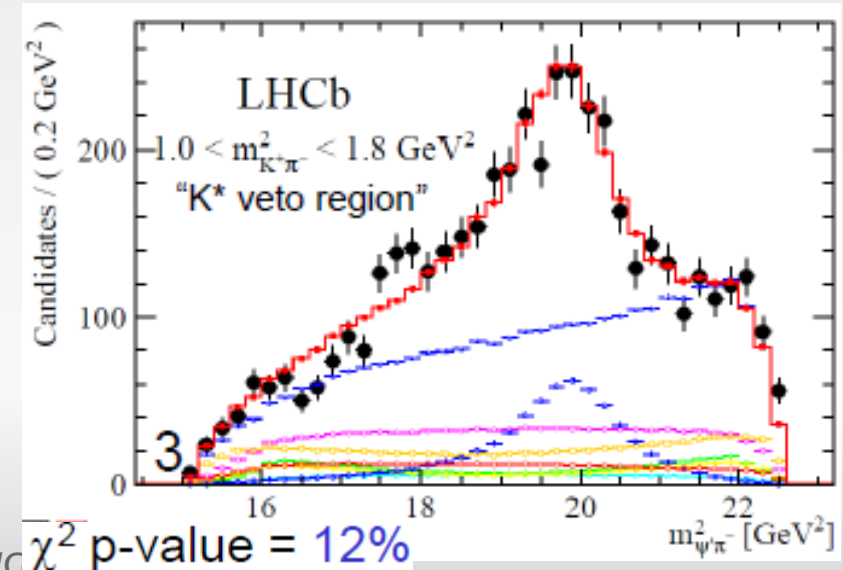


Fit without $Z(4430)^-$



χ^2 p-value < 2×10^{-6}

Fit with $Z(4430)^-$

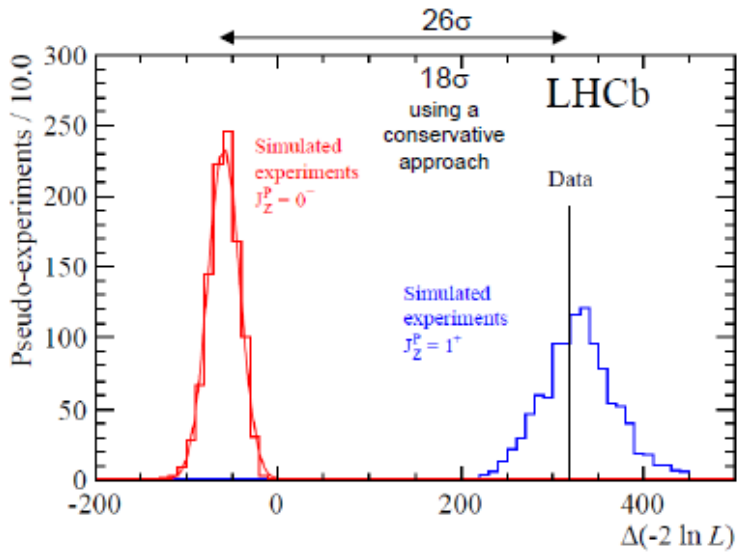


χ^2 p-value = 12%

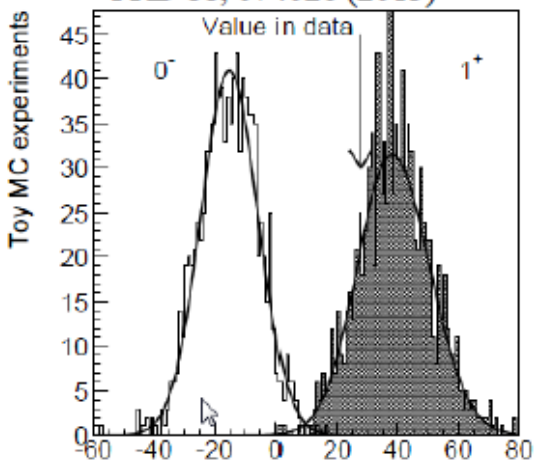
Overall consistency with Belle results but with substantially improved errors.

Charged charmonium-like state $Z(4430)^-$

$Z(4430)^-$ spin-parity analysis



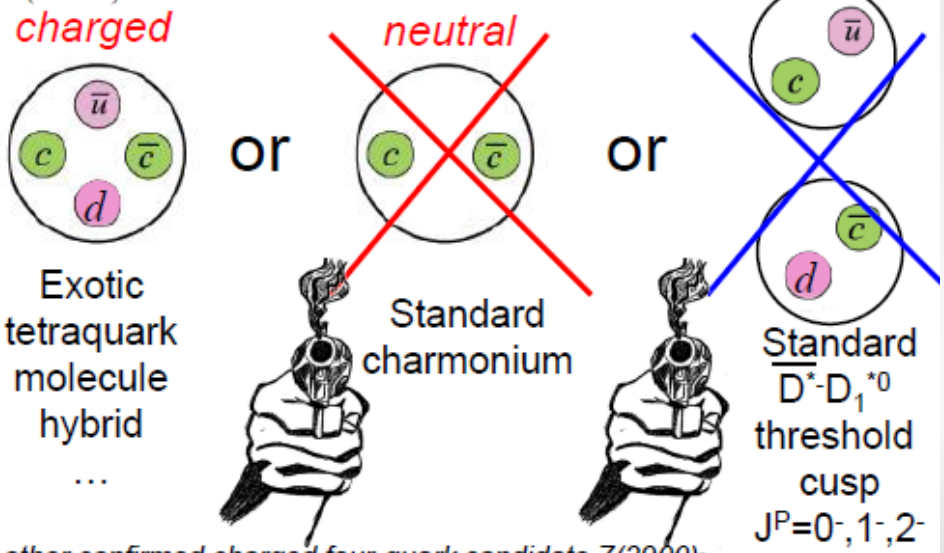
Belle
PRD 88, 074026 (2013)



Including systematic variations:

	Rejection level relative to 1^+	
Disfavored J^P	LHCb	Belle
0-	9.7σ	3.4σ
1-	15.8σ	3.7σ
2+	16.1σ	5.1σ
2-	14.6σ	4.7σ

$J^P=1^+$ now established beyond any doubt



The only other confirmed charged four-quark candidate Z(3900)⁻ observed by BES-III and Belle in 2013 could be a $\overline{D}D^*$ threshold effect

Quarkonia: A Theoretical Framework

Antonio Vairo

Quarkonia are systems where low energy QCD may be studied in a systematic way (e.g. large order perturbation theory, non-perturbative matrix elements, QCD vacuum, exotica, confinement, deconfinement, ...).

$M \gg p$

$M \gg \Lambda_{\rm QCD}$

This allows for a systematic non-relativistic and perturbative expansion

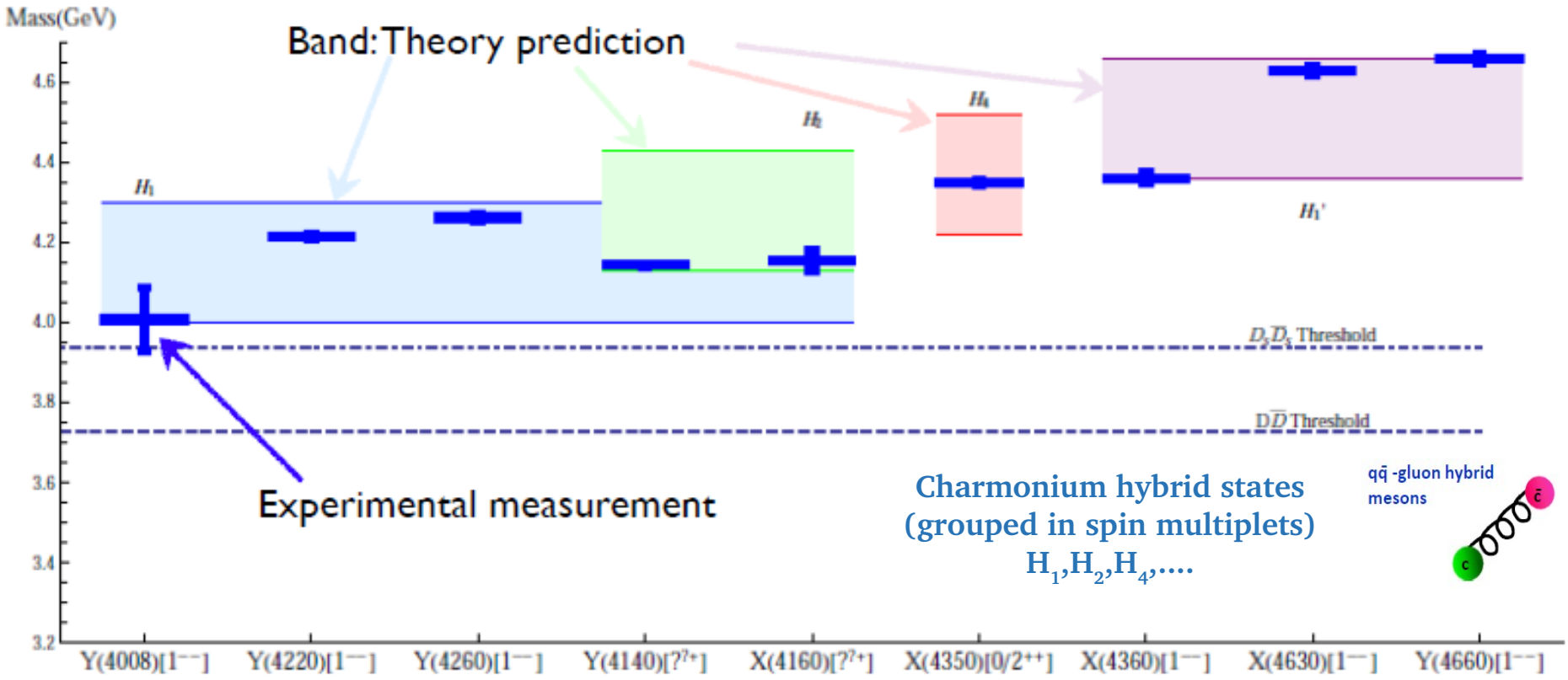
Many topics reviewed among them:

- Annihilation & production, width and decay (α_s)
- Radiative transitions
- New quarkonium-like state below and above threshold
- Gluonic excitations

Quarkonia: A Theoretical Framework

Antonio Vairo

- Charmonium states (BELLE, CDF, BESIII, BABAR):



- Bottomonium states: $Y_b(10890)[1^{--}]$, $M_{Y_b} = (10.8884 \pm 3.0)$ GeV (BELLE). Possible H1 candidate, $M_{H1} = (10.79 \pm 0.15)$ GeV.

Berwein Brambilla Tarrus Castellà Vairo in preparation (2014)

Rare B-meson decays

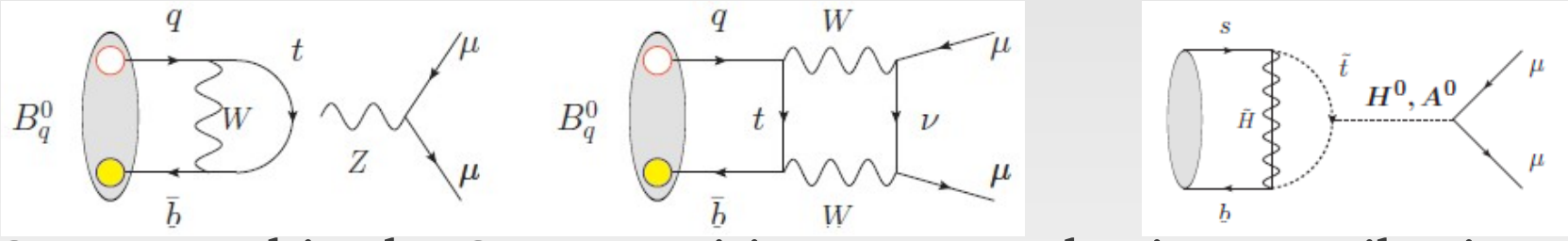
- Flavor-Changing-Neutral-Current transitions b → sγ, b → s l l

$B \to K^* \ell^+ \ell^-$ $\quad B_s \to \mu^+ \mu^-$ $\quad B \to K \ell^+ \ell^-$

$B \to K^* \gamma$ $\quad B \to X_s \ell^+ \ell^-$ $\quad B \to X_s \gamma$

R.Knegjens
M.Misiak
D.van Dyk

  - forbidden at tree level in SM, proceed via loop and box diagrams



  - Suppressed in the SM / sensitive to New Physics contributions
  - Effective theory description (factorizes short-distance Wilson coefficients Ci from long-distance effects)

New Physics may introduce new operators or modify existing Wilson coefficients

$$\mathcal{H}_{\text{eff}} = -\frac{G_F\,\alpha}{\sqrt{2}\pi} V_{tb} V_{tq}^* \sum_i^{\{10,S,P\}} \left(C_i\,\mathcal{O}_i + C_i'\,\mathcal{O}_i' \right)$$

Wilson coefficients

Operators:

$$\mathcal{O}_{10} = (\bar{q}\gamma_\mu P_L b)(\bar{\mu}\gamma^\mu\gamma_5\mu)$$
$$\mathcal{O}_S = (\bar{q} P_R b)(\bar{\mu}\mu)$$
$$\mathcal{O}_P = (\bar{q} P_R b)(\bar{\mu}\gamma_5\mu)$$

Perturbative corrections for rare B-meson decays

Mikolaj Misiak

Status of $\overline{B} \to X_s \gamma$, $b \to s l^- l^+$, $B_{s,d} \to l^- l^+$

NNLO QCD + NLO EW + LL QED:

SM predictions for all the branching ratios $\overline{\mathcal{B}}_{q\ell} \equiv \overline{\mathcal{B}}(B_q \to \ell^+\ell^-)$

[C. Bobeth, M. Gorbahn, T. Hermann, MM, E. Stamou, M. Steinhauser, PRL 112 (2014) 101801]

$$\overline{\mathcal{B}}_{s\mu} \times 10^9 = (3.65 \pm 0.06)\, R_{t\alpha}\, R_s = 3.65 \pm 0.23, \qquad \text{(LHCb \& CMS : } 2.9 \pm 0.7\text{)}$$

$$\overline{\mathcal{B}}_{d\mu} \times 10^{10} = (1.06 \pm 0.02)\, R_{t\alpha}\, R_d = 1.06 \pm 0.09, \qquad \text{(LHCb \& CMS : } 3.6^{+1.6}_{-1.4}\text{)}$$

$$R_{t\alpha} = \left(\frac{M_t}{173.1\ \text{GeV}}\right)^{3.06} \left(\frac{\alpha_s(M_Z)}{0.1184}\right)^{-0.18} \qquad R_s = \left(\frac{f_{B_s}[\text{MeV}]}{227.7}\right)^2 \left(\frac{|V_{cb}|}{0.0424}\right)^2 \left(\frac{|V_{tb}^\star V_{ts}/V_{cb}|}{0.980}\right)^2 \frac{\tau_H^s\,[\text{ps}]}{1.615}$$

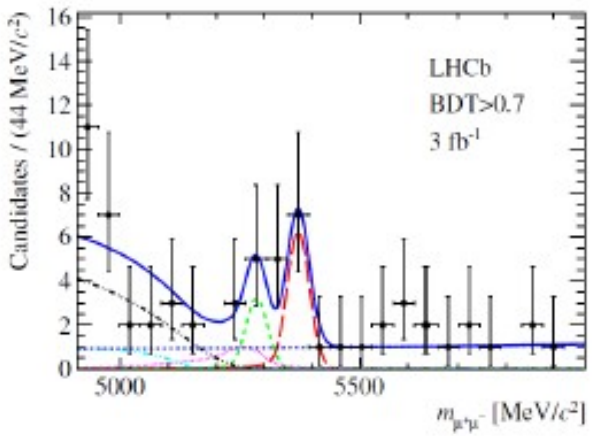
Sources of uncertainties	f_{B_q}	CKM	τ_H^q	M_t	α_s	other parametric	non-parametric	$\sum$
$\overline{\mathcal{B}}_{s\ell}$	4.0%	4.3%	1.3%	1.6%	0.1%	$< 0.1\%$	1.5%	6.4%
$\overline{\mathcal{B}}_{d\ell}$	4.5%	6.9%	0.5%	1.6%	0.1%	$< 0.1\%$	1.5%	8.5%

$\longrightarrow$ 4.7% (?)

In the case of $\overline{\mathcal{B}}_{s\ell}$, the main uncertainty (4.2%) originates from $|V_{cb}| = 0.0424(9)$ that comes from a recent fit to the inclusive semileptonic data [P. Gambino and C. Schwanda, arXiv:1307.4551].

$B_{(s)} \to \mu^+ \mu^-$

J.Wiechczynski (LHCb) & R.Knegjens



LHCb + CMS combined: 1307.5024, 1307.5025

$$\overline{\mathrm{BR}}(B_s \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9} \quad (> 5\sigma)$$

$$\overline{\mathrm{BR}}(B_d \to \mu^+\mu^-) = (3.6^{+1.6}_{-1.4}) \times 10^{-10} \quad (< 3\sigma)$$

Consistent with SM!

In future probe New Physics with new (complementary) observables:

$$\overline{R} = \frac{(1 + y_s\, \mathcal{A}^{\mu\mu}_{\Delta\Gamma})}{1 + y_s} \left(|\boldsymbol{P}|^2 + |\boldsymbol{S}|^2\right)$$

$$\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = \frac{|\boldsymbol{P}|^2 \cos\left(2\varphi_{\boldsymbol{P}} - \phi_s^{\mathrm{NP}}\right) - |\boldsymbol{S}|^2 \cos\left(2\varphi_{\boldsymbol{S}} - \phi_s^{\mathrm{NP}}\right)}{|\boldsymbol{P}|^2 + |\boldsymbol{S}|^2}$$

K. Bruyn, R. Fleischer, RK, P. Koppenburg, M. Merk, A. Pellegrino, N. Tuning, Phys.Rev.Lett 109 (2012)

$$\mathcal{A}^{f}_{\Delta\Gamma} = \frac{\Gamma(B_{s,\mathrm{H}} \to f) - \Gamma(B_{s,\mathrm{L}} \to f)}{\Gamma(B_{s,\mathrm{H}} \to f) + \Gamma(B_{s,\mathrm{L}} \to f)}$$

In SM:

$$\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = +1$$

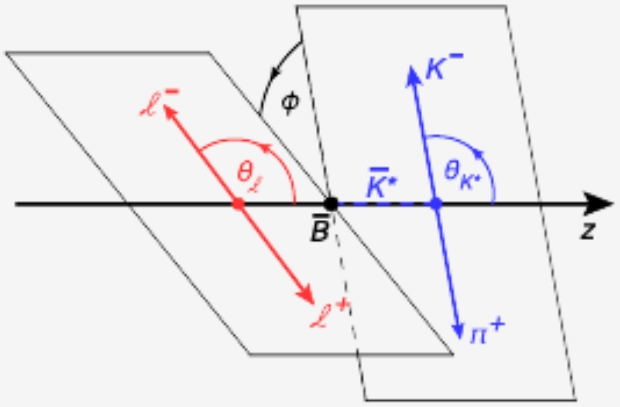
Can be measured via “effective lifetime”, however large statistics required.

Comprehensive Bayesian Analysis of Rare (Semi)leptonic and Radiative B Decays

Danny van Dyk

(Angular) Observables in $B \to K^* \ell^+ \ell^-$

- kinematics
  - dilepton mass squared q^2
  - three angles
- complicated diff. decay width
  - 12(+) angular observables J_n
  - express all observables through J_n
  - compose observ. from J_n with specific benefits, e.g. $A_{\rm FB}$, F_L, $P'_{4,5,6}$, ...



Some of observables motivated by minimization of theoretical uncertainty (and have no physical meaning)

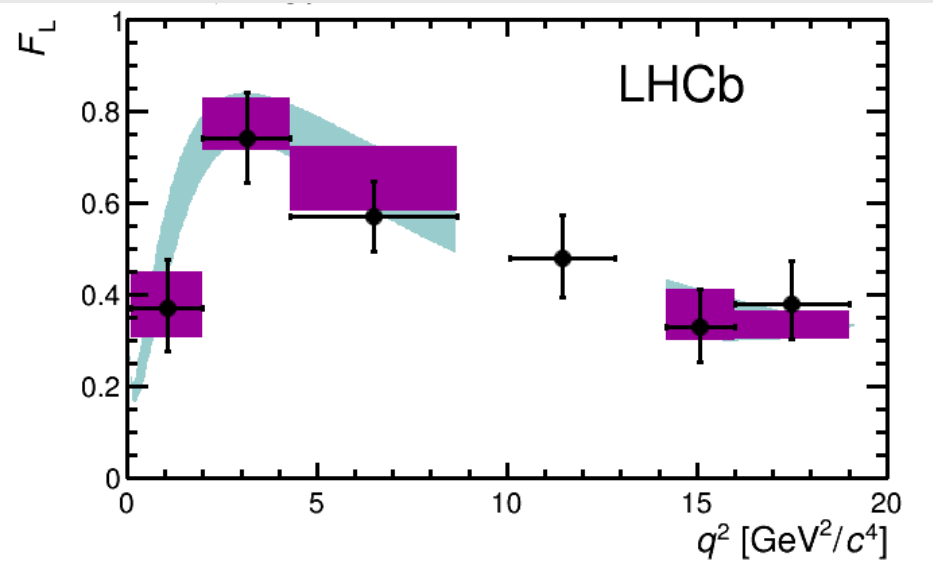
Definitions

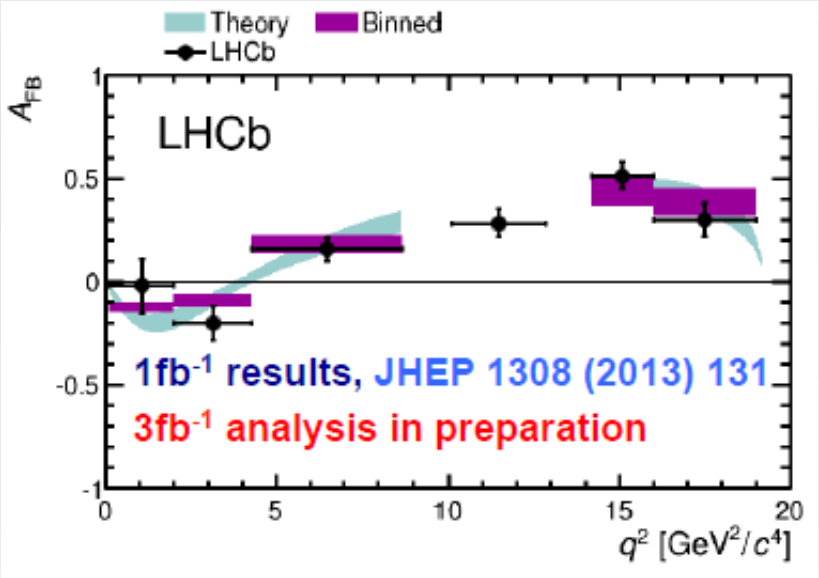
$$\Gamma \sim 3J_{1c} + 6J_{1s} - J_{2c} - 2J_{2s} \qquad A_{\rm FB} \sim \frac{J_{6s}}{\Gamma} \qquad F_L \sim \frac{3J_{1c} - J_{2c}}{\Gamma}$$

$$P'_4 \sim \frac{+J_4}{\sqrt{-J_{2s}J_{2c}}} \qquad P'_5 \sim \frac{+J_5}{2\sqrt{-J_{2s}J_{2c}}} \qquad P'_6 \sim \frac{-J_7}{2\sqrt{-J_{2s}J_{2c}}}$$

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

J.Wiechczynski (LHCb)

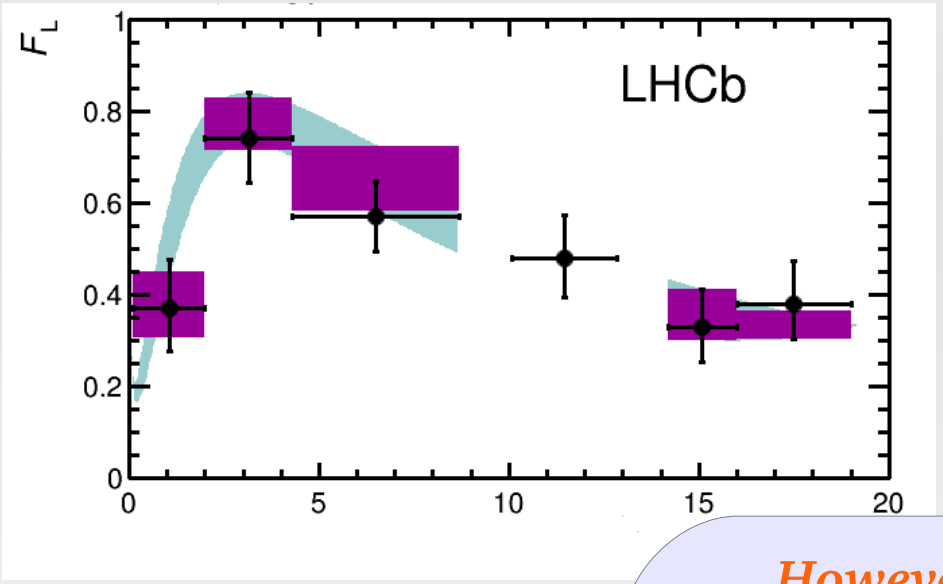


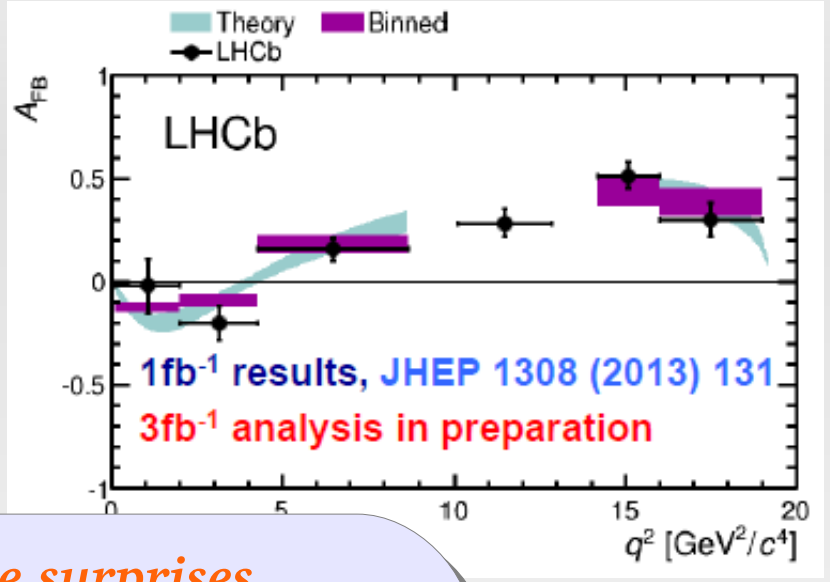


Consistent with SM!

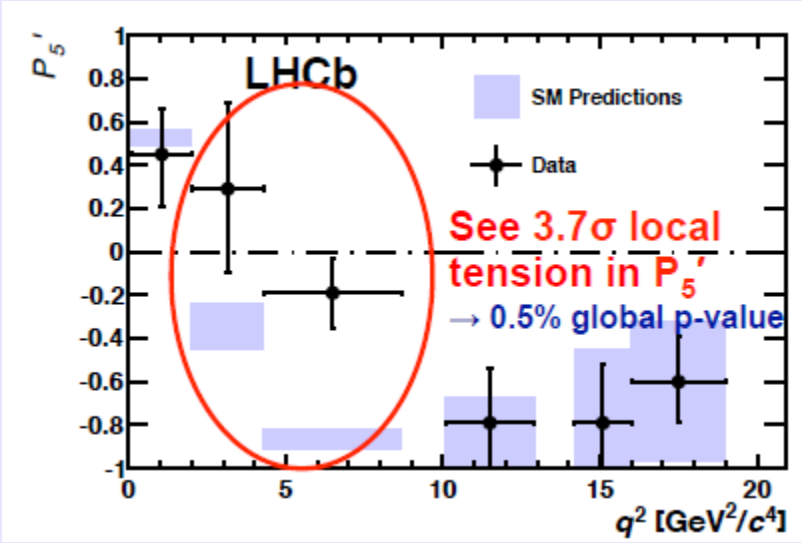
$B \rightarrow K^* \mu^+ \mu^-$

J.Wiechczynski (LHCb)





However, some surprises...



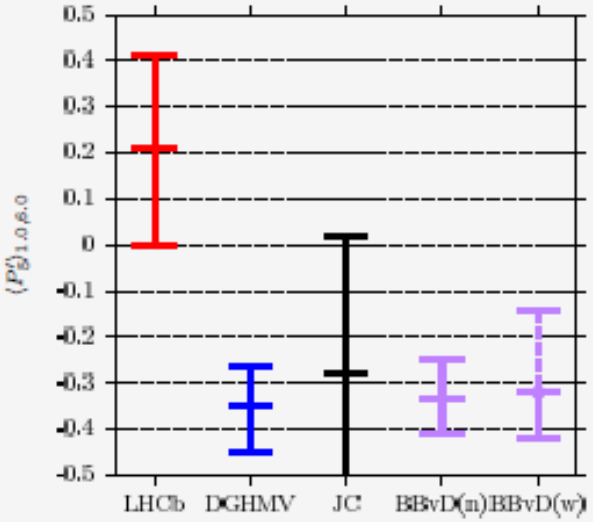
Comprehensive Bayesian Analysis of Rare (Semi)leptonic and Radiative B Decays

Danny van Dyk

The $B \to K^* \ell^+ \ell^-$ "Anomaly"

- **LHCb** measurement [1308.1707]
  - deviation from SM prediction in form factor-free obs. $\langle P_5' \rangle_{[1,6]}$
  - LHCb uses one SM prediction (**DGHMV**)

    [Descotes-Genon/Hurth/Matias/Virto 1303.5794]



- however: further SM prediction exist, much larger uncertainty (**JC**)

  [Jäger/Camalich 1212.2263]
- our take on SM prediction

$$\langle P_5' \rangle_{[1,6]} = -0.34^{+0.09}_{-0.08} \text{ (BBvD, nominal priors)}$$
$$\langle P_5' \rangle_{[1,6]} = -0.32^{+0.18}_{-0.10} \text{ (BBvD, wide priors)}$$

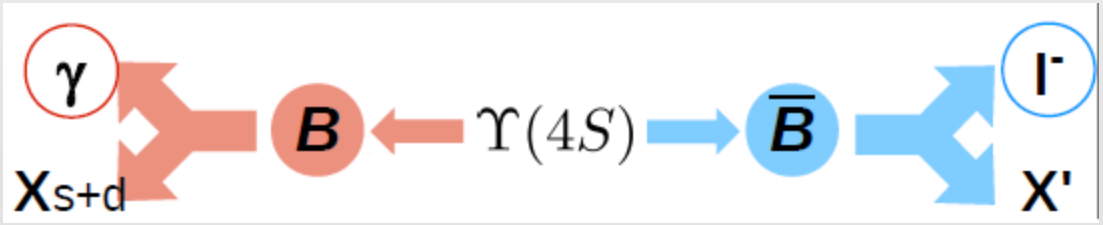
see also backups for $P_{4,6}'$ and $[2, 4.3]$ bins

difference: treatment of unknown power corrections
(form factor corrections, $\bar{c}c$ resonances)

CP Asymmetry in $B \to X_{s(+d)}\gamma$

- Inclusive (Belle)

L.Sun (BaBar) & L.Pesantez (Belle)



+ reduced model uncertainty
- lower signal purity

- Sum-of-exclusive (BaBar)

Charged Modes:

$K_S^0\,\pi^+\,\gamma$
$K^+\,\pi^0\,\gamma$
$K^+\,\pi^+\,\pi^-\,\gamma$
$K_S^0\,\pi^+\,\pi^0\,\gamma$
$K^+\,\pi^0\,\pi^0\,\gamma$
$K_S^0\,\pi^+\,\pi^-\,\pi^+\,\gamma$
$K^+\,\pi^+\,\pi^-\,\pi^0\,\gamma$
$K_S^0\,\pi^+\,\pi^0\,\pi^0\,\gamma$
$K^+\,\eta\,\gamma$
$K^+\,K^-\,K^+\,\gamma$

Neutral Modes:

$K^+\,\pi^-\,\gamma$
$K^+\,\pi^-\,\pi^0\,\gamma$
$K^+\,\pi^+\,\pi^-\,\pi^-\,\gamma$
$K^+\,\pi^-\,\pi^0\,\pi^0\,\gamma$
$K^+\,\eta\,\pi^-\,\gamma$
$K^+\,K^-\,K^+\,\pi^-\,\gamma$

Channel	A_{CP}(SM)
$B \to X_s\gamma$	[-0.6% , +2.8%]
$B \to X_d\gamma$	[-62% ,+14%]
$B \to X_{s+d}\gamma$	0

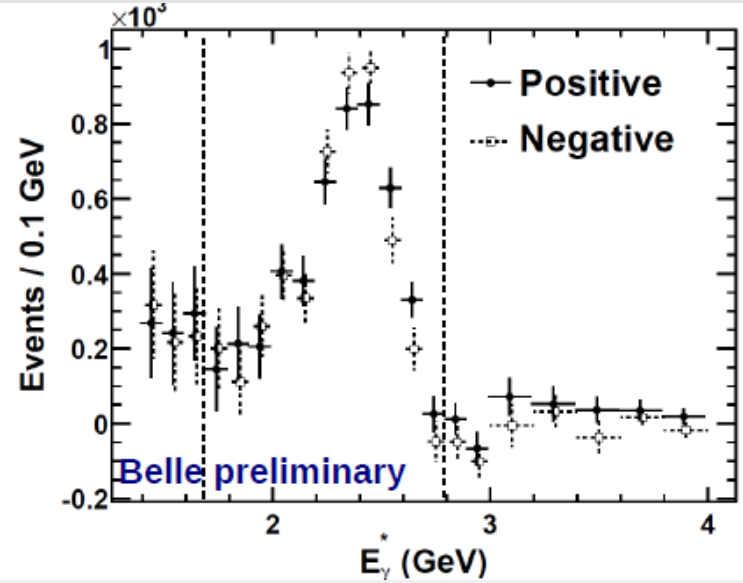
PRL 106, 141801 (2011)

Cancellation due to unitarity, negligible theory error!

+ better signal purity
- mode uncertainty, lower efficiency

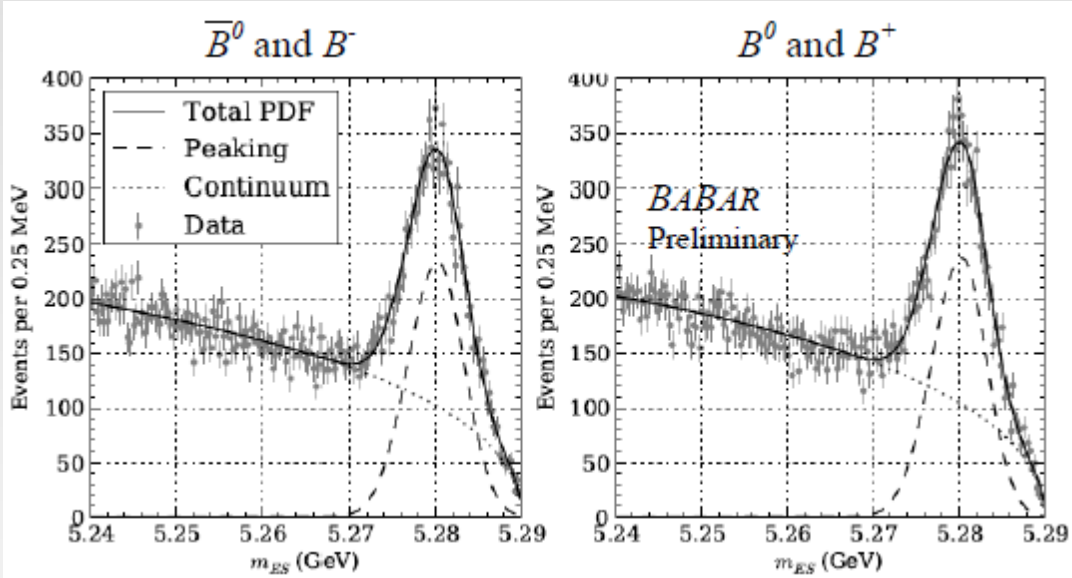
CP Asymmetry in $B \to X_{s(+d)}\gamma$

- Inclusive $B \to X_{s+d}\gamma$ (Belle)



$A_{CP} = 2.2 \pm 4.0 \pm 0.8\ \%$

- Sum-of-exclusive $B \to X_s\gamma$ (BaBar)



$A_{CP} = +(1.7 \pm 1.9_{stat} \pm 1.0_{syst})\%$

$\Delta A_{X_s\gamma} = A_{B^\pm \to X_s\gamma} - A_{B^0/\overline{B}^0 \to X_s\gamma}$

$\Delta A_{Xs\gamma} = +(5.0 \pm 3.9_{stat} \pm 1.5_{syst})\%$

$\Delta A_{Xs\gamma} = 0$ in SM

Measurements consistent with SM expectations!

L.Sun (BaBar) & L.Pesantez (Belle)

Summary

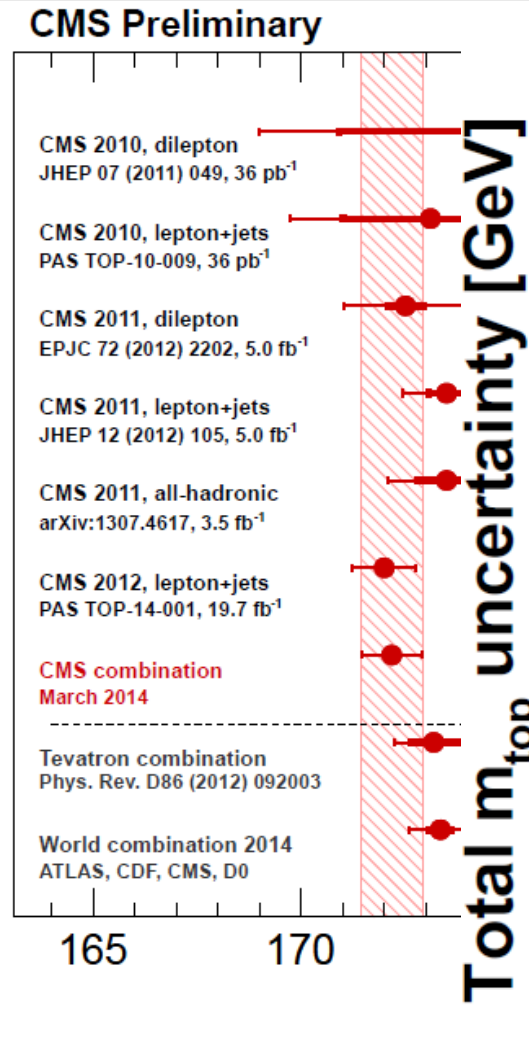
- Heavy Flavour production is a powerful tool to study QCD and searches of New Physics
- A lots of interesting new results presented

"One never notices what has been done; one can only see what remains to be done."

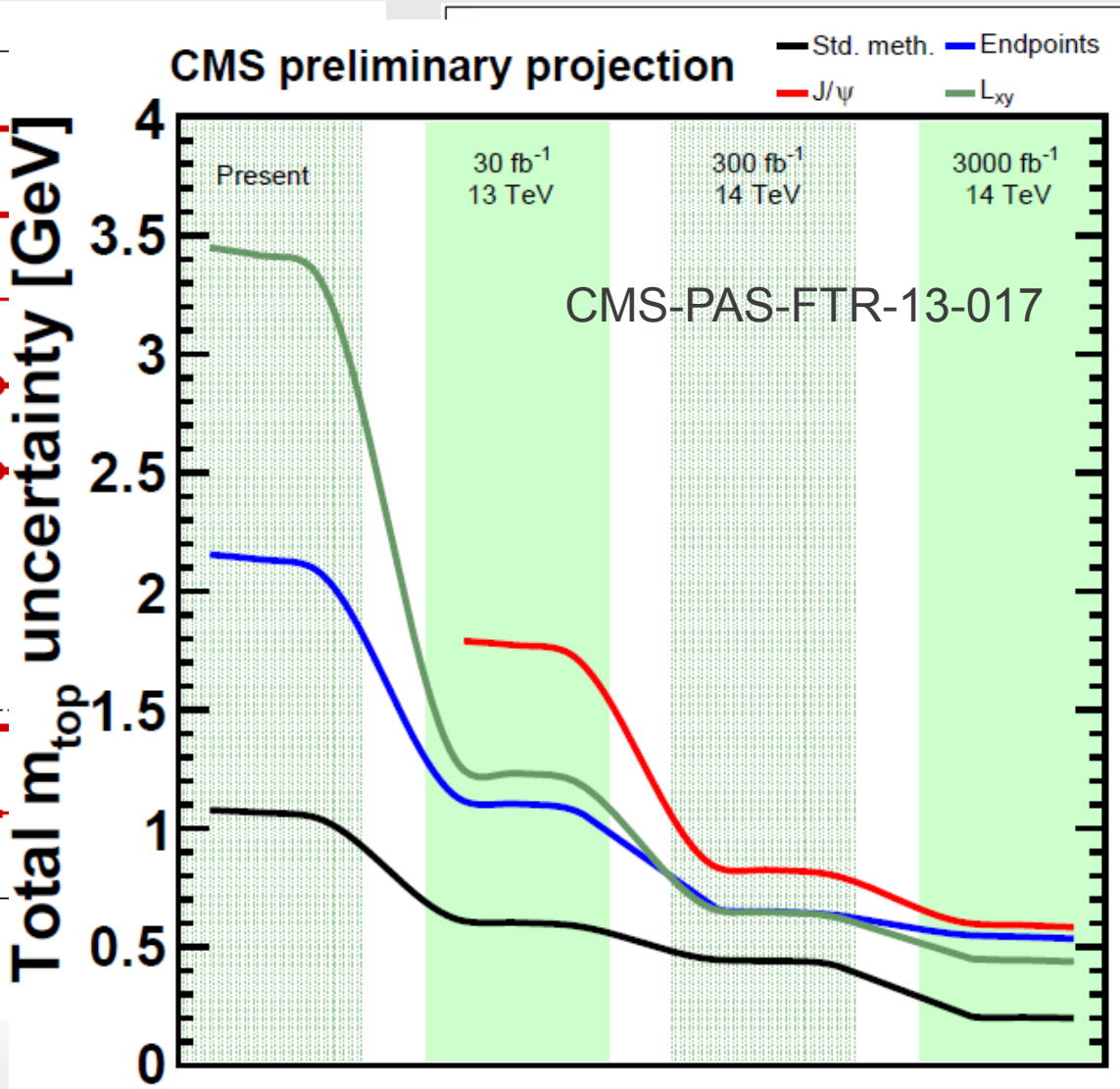
Marie Skłodowska-Curie

Top quark properties - Mass

E.Bouvier (CMS)



R.Di Sipio (ATLAS)



-1 GeV precision:

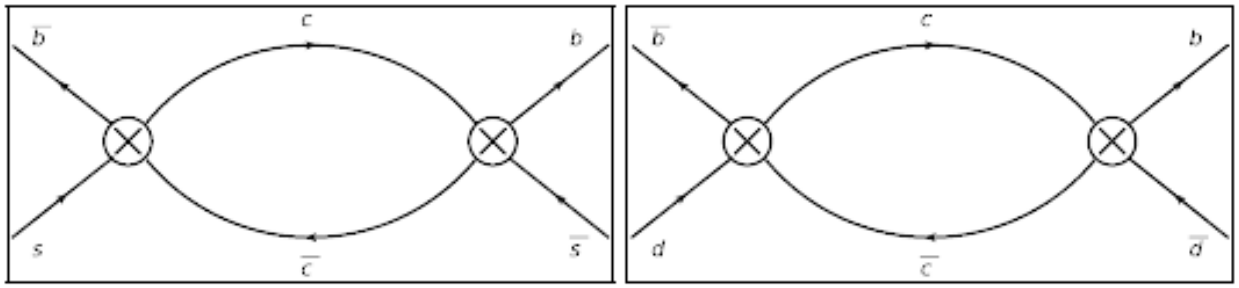
models expected to be

correlated syst!)

Space for New Physics in Neutral B mixing observables

Gilberto Tetlalmatzi

New Physics (NP) effects in $\Delta\Gamma_s$ are strongly constrained in comparison with $\Delta\Gamma_d$ because:



$\Delta\Gamma_s$ triggered by $b \to c\bar{c}s$ $\Delta\Gamma_d$ triggered by $b \to c\bar{c}d$

$$Br(b \to c\bar{c}s) = (23.7 \pm 1.3)\% \;||\; Br(b \to c\bar{c}d) = (1.31 \pm 0.07)\%$$

$\Longrightarrow$ 100% enhancement on $\Gamma(b \to c\bar{c}s)$ leads to sizable effect on Γ_{tot}

$\Longrightarrow$ 100% enhancement on $\Gamma(b \to c\bar{c}d)$ hidden in the hadronic uncertainties.

Enhancements in $\Delta\Gamma_d$ arise from:

- CKM Unitarity violations.
- New Physics at SM tree level decays.
- $(\bar{d}b)(\bar{\tau}\tau)$ operators.

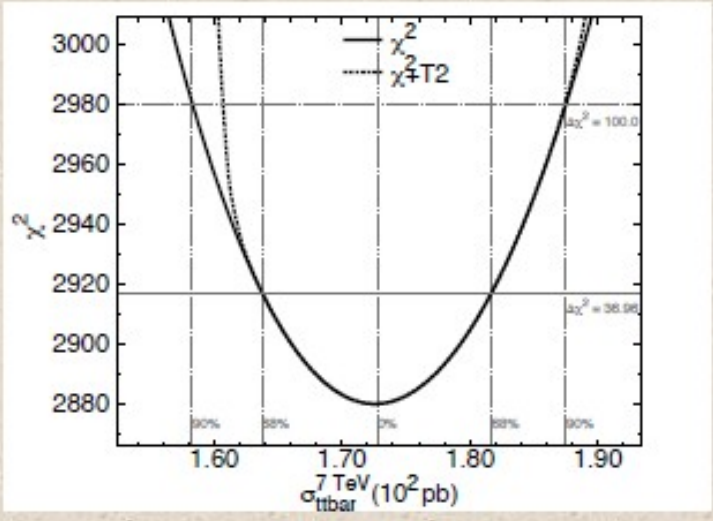
$$\frac{\Delta\Gamma_d}{\Delta\Gamma_d^{SM}} \leq \begin{cases} 4 & \text{CKM unitarity violations.} \\ 16 & \text{Current-current operators.} \\ 3.7 & (bd)(\tau\tau) \text{ operators.} \end{cases}$$

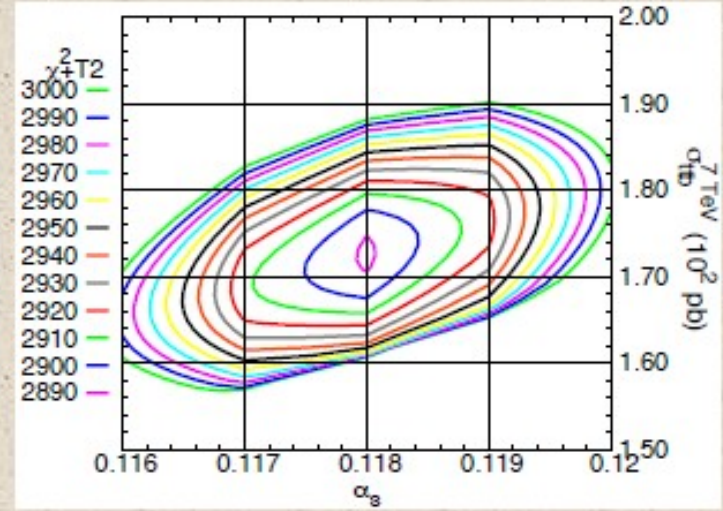
Bobeth, Haisch, Lenz, Pecjak and Tetlalmatzi-Xolocotzi, arXiv:1404.2531.

Uncertainties on H and ttbar Predictions at the LHC

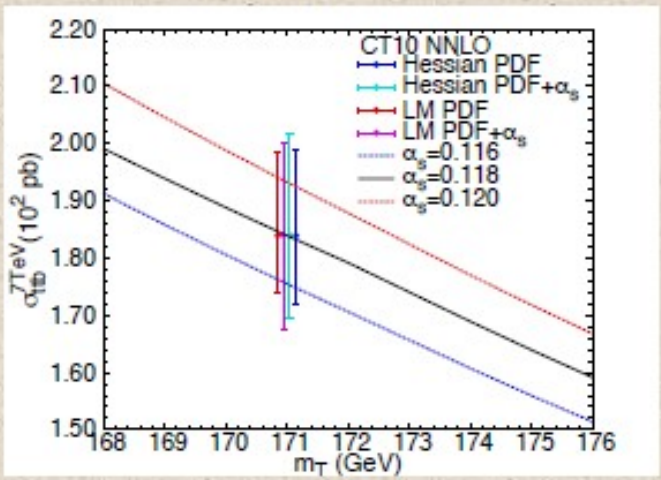
Carl Schmidt [CTEQ-TEA]

Uncertainties in gg→ttbar



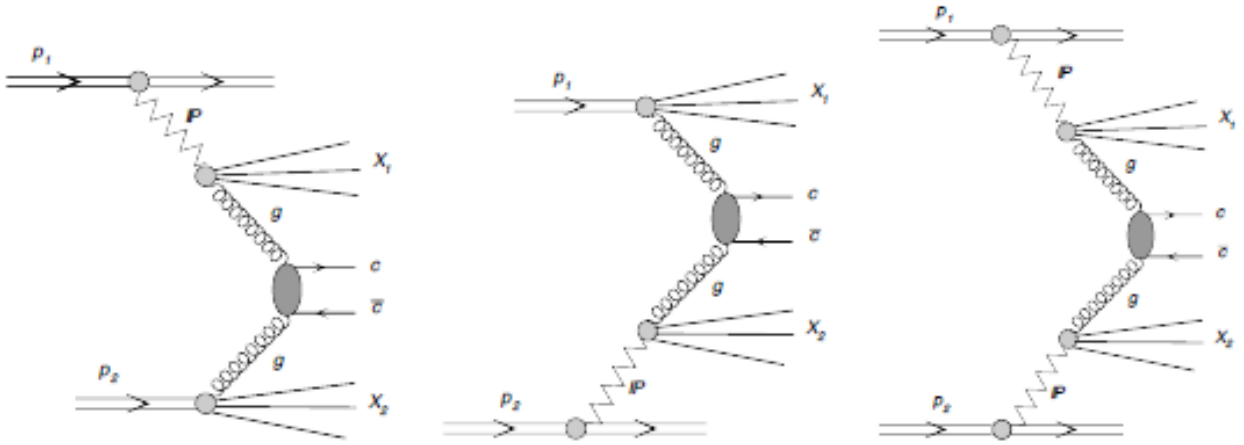


- Same analyses applied to *gg*→ttbar
- HERA combined data (T2) constrains low values of cross section
- But T2 less important for combined PDF+α_S
- Hessian and LM consistent



Diffractive production of open charm and bottom at the LHC

Marta Łuszczak



Łuszczak, Maciula, Szczurek, PRD84(2011)4018

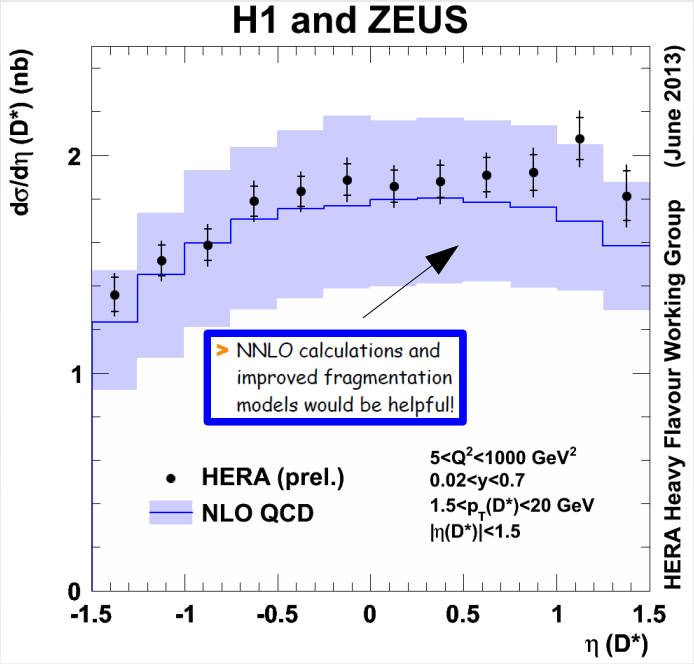
- Cross sections for single and central diffractive production of $c\bar{c}$ and $b\bar{b}$ have been calculated.
- Large and measurable cross section for charm single diffractive production.
- Cross sections for D^0 and $B^{\pm}$ mesons have been calculated for different experiments (cuts).

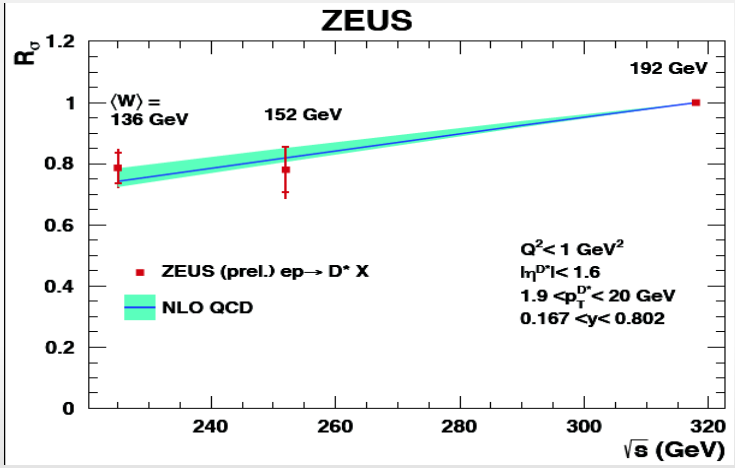
TABLE I: Total cross sections for charmed meson-antimeson pair production for the LHCb detector.

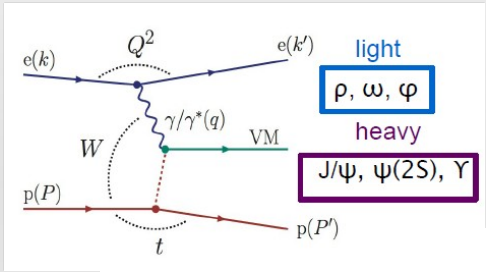
Acceptance	Mode	Integrated cross sections, μb			
		CD ($I\!P$ - $I\!P$)	SD1 (d0) ($I\!P$ - gluon)	SD2 (0d) (gluon - $I\!P$)	non-diffractive LHCb data
$2.0 < y < 4.5$ $p_\perp < 8$ GeV	$D^0 + \overline{D^0}$	2.19	33.78	26.71	1488.0
$2.0 < y < 4.0$ $3 < p_\perp < 12$ GeV	$D^0\overline{D^0}$	0.009	0.121	0.135	6.23

Charm(-onium) production at HERA

M. Lisovyi: Combined diff. D* x-sect

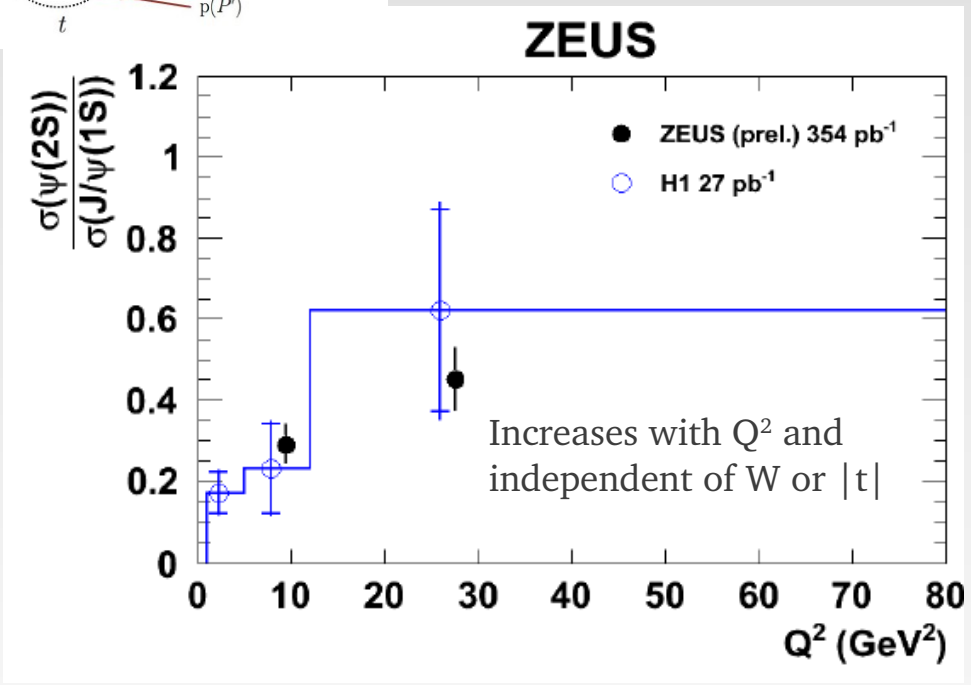






N. Kovalchuk

σ(ψ(2S))/σ(J/ψ(1S)) in exclusive DIS



N.Zakharchuk:
Energy dependence of D* Photo-production

Good agreement with NLO QCD predictions

Hadronic transitions in quarkonia

- Described by QCD multipole expansion
  - Chromoelectric terms (E1 , E2, …)
  - Chromomagnetic terms (M1 , M2 …)

E1E1 transition

$\Upsilon(nS) \rightarrow \pi\,\pi\ \Upsilon(mS)$

$b\bar{b}$ — NO Spin flip — $b\bar{b}$

E1M2 transition

$\Upsilon(nS) \rightarrow \eta,\ \pi^0\ \Upsilon(mS)$

$b\bar{b}$ — Spin flip — $b\bar{b}$

$$R^{SS}(\pi\pi,\eta) = \frac{BF(\Upsilon(nS) \rightarrow \eta\ \Upsilon(mS))}{BF(\Upsilon(nS) \rightarrow \pi\pi\ \Upsilon(mS))} \ll 1$$

$R^{SS}(\pi\pi,\eta)$ Experimental status

	Υ(2S) →	Υ(3S) →	Υ(4S) →	Υ(5S) →
Υ(1S)	~ 2 x10^{-3}	< 2 x10^{-3}	2.4	0.1
Υ(2S)				0.4
Υ(3S)				
Υ(4S)				

Almost OK

Not a Zb effect.
Other coupled channel effects?

~2 -3 order of magnitude above th. expectations

$$R^{SP}(\pi\pi,\eta) = \frac{BF(\Upsilon(nS) \rightarrow \eta\, h_b(mP))}{BF(\Upsilon(nS) \rightarrow \pi\pi\, h_b(mP))} >= 1$$

$R^{SP}(\pi\pi,\eta)$ Experimental status

	Υ(4S) →	Υ(5S) →
hb(1P)	?	?
hb(2P)		?

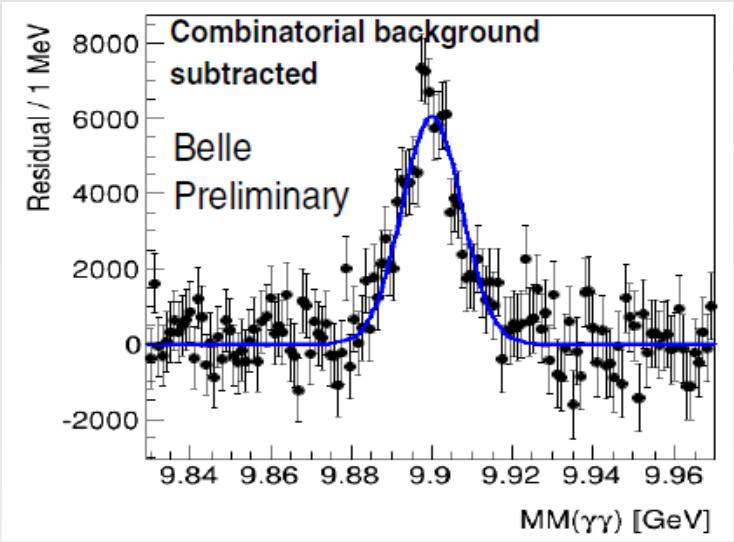
No measurements, until now!

U.Tamponi (Belle)

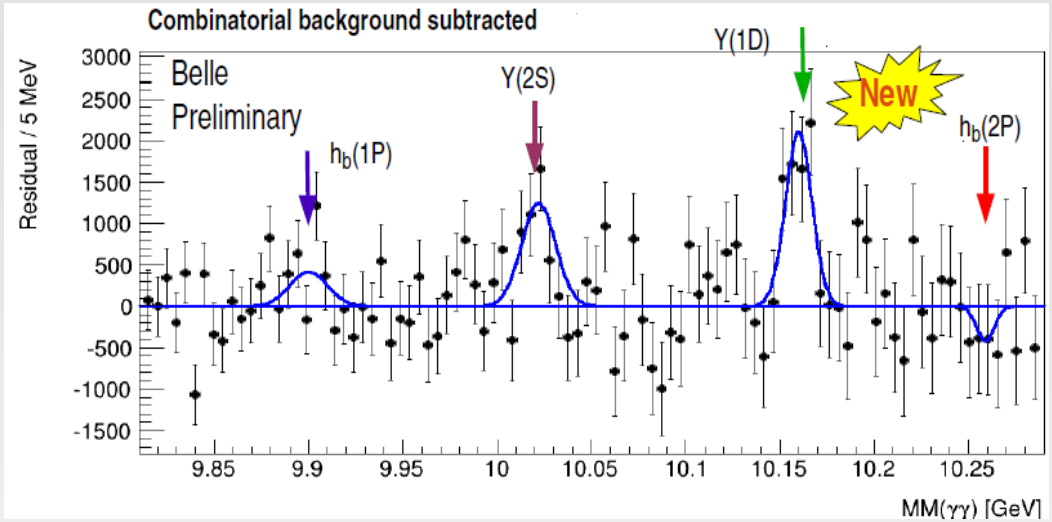
Hadronic transitions in quarkonia

Search for h_b recoiling eta against in $e^+e^- \rightarrow \Upsilon(4S/5S) \rightarrow$ eta h_b

Y(4S) sample



Y(5S) sample



$$R^{SP}(\pi\pi,\eta) = \frac{BF(\Upsilon(nS) \rightarrow \eta h_b(mP))}{BF(\Upsilon(nS) \rightarrow \pi\pi h_b(mP))} \quad >= 1$$

First test of QCDME with η h_b(1P) transitions

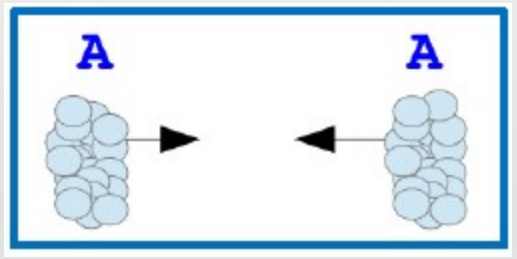
U.Tamponi (Belle)

	Y(4S) →	Y(5S) →
hb(1P)	> 2.0	< 0.9
hb(2P)		< 0.6

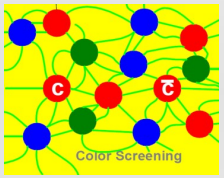
OK

Y(5S) anomalous behavior due to Zb intermediate states

Probing hot QCD matter



- **Cold** Nuclear Matter Effects (p+A)
  - Shadowing, Color Glass Condensate, Coherent Energy Loss
- **Hot** Nuclear Matter Effects (A+A)
  - Deconfinment of quarks and gluons
    - Quarkonium suppression by color screening



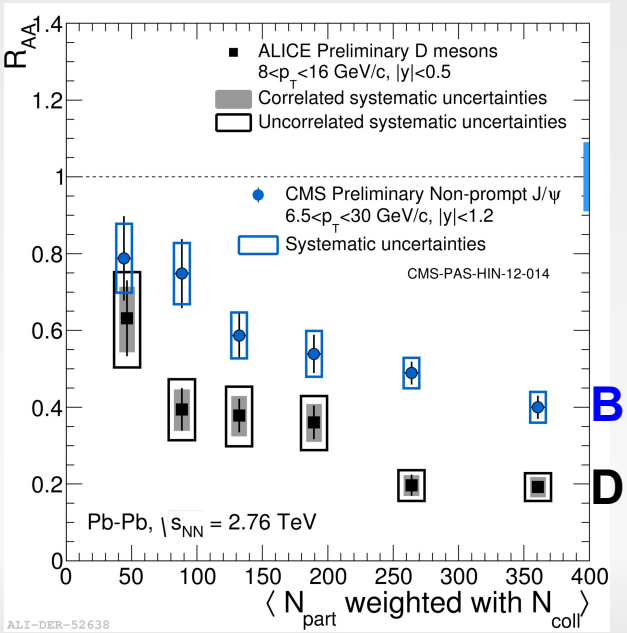
Strategy: Measure (then parametrize) CNM effects in p+A to "remove" them in A+A collisions and be able to study HNM effects in Quark Gluon Plasma

Nuclear Modification Factor

$$R_{AA}^{D}(p_T) = \frac{dN_{AA}^{D}/dp_T}{\langle T_{AA} \rangle \times d\sigma_{pp}^{D}/dp_T}$$

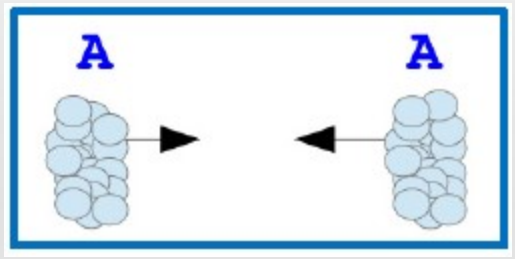
Relative particle production in AA(pA) with respect to pp collisions

A. Grelli



First indication of 'heavy-quark mass' dependence of the energy loss.

Probing hot QCD matter



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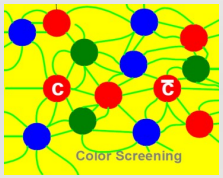

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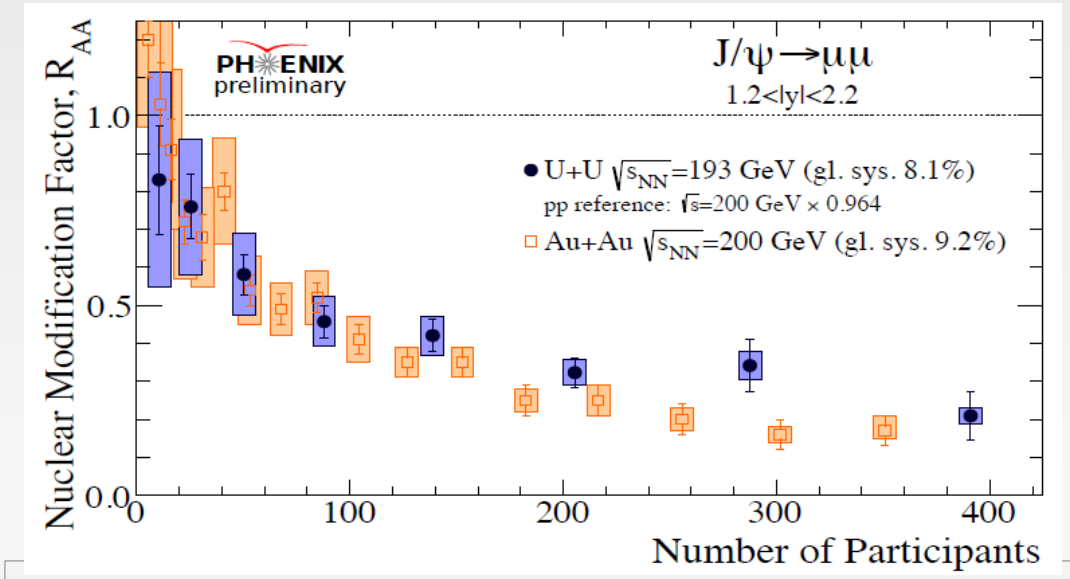
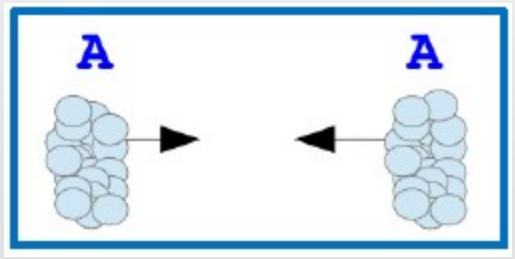
Relative particle production in AA(pA) with respect to pp collisions

A. Iordanova



Weaker suppression in central collisions in U+U?
Higher coalescence?

Probing hot QCD matter



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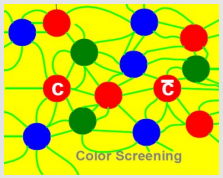

Strategy: Measure (then parametrize) CNM effects in p+A to "remove" them in A+A collisions and be able to study HNM effects in Quark Gluon Plasma

L. Manceau

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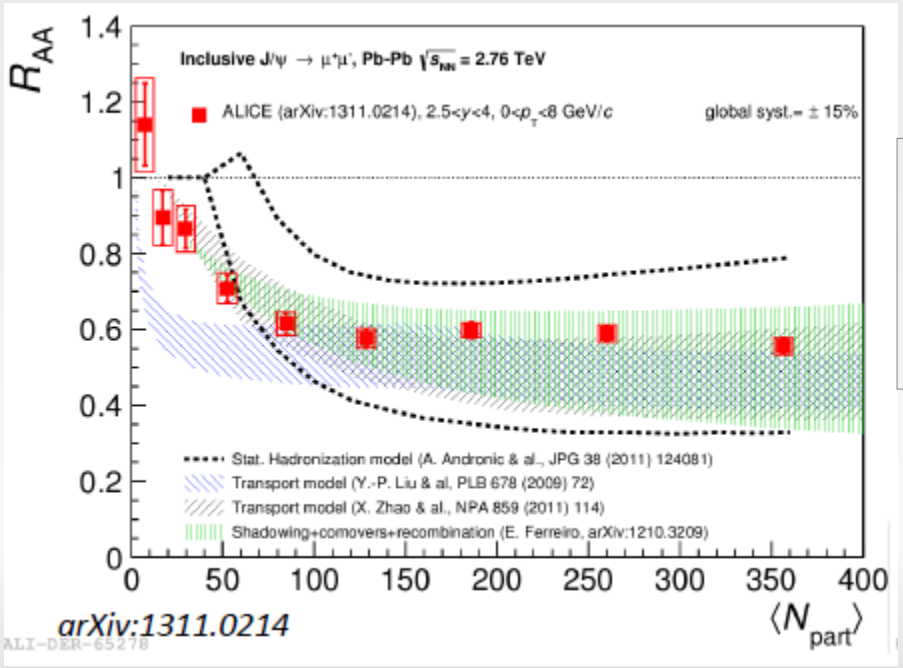
Relative particle production in AA(pA) with respect to pp collisions



Hints of strong regeneration of J/ψ at LHC energies