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
Heavy Flavors WG Program

- 4 sessions / 36 talks / interesting discussions
  - Top physics (joint with WG3)

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:00 - 14:24</td>
<td>Top quark cross section measurements with CMS</td>
</tr>
<tr>
<td>14:24 - 14:46</td>
<td>Top quark cross section measurements with ATLAS</td>
</tr>
<tr>
<td>14:48 - 15:12</td>
<td>Single top quark production with CMS</td>
</tr>
<tr>
<td>15:12 - 15:36</td>
<td>Single Top quark production cross section using the ATLAS detector at the LHC</td>
</tr>
<tr>
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<td>Uncertainties on Higgs and tbar predictions at the LHC from CTEQ-TEA Global Analysis</td>
</tr>
<tr>
<td>16:00 - 16:30</td>
<td>Coffee Break</td>
</tr>
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<td>17:39 - 18:02</td>
<td>Top quark pair properties - spin correlations, top quark pair asymmetry and complex final states using the ATLAS detector at the LHC</td>
</tr>
<tr>
<td>18:02 - 18:30</td>
<td>Top quark mass measurements with CMS</td>
</tr>
<tr>
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<td>Top quarks as a probe for heavy new physics</td>
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</tbody>
</table>
Heavy Flavors WG Program

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  - Top physics (joint with WG3)
  - Production

### Top quark cross section measurements with CMS
Javier FERNANDEZ MENEZED
Auditorium, BUW
14:00 - 14:24

### Heavy-flavour production in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC
Alessandro GRELLI
SKUBIC
14:24 - 14:46

### Measurement of D* photoproduction at three different centre-of-mass energies at HERA
Natalia ZAKHARCHUK
IOIO
14:46 - 15:12

### Combination of D* Differential Cross-Section Measurements in Deep Inelastic ep Scattering at HERA
Mykhailo LISOVYI
MONENI
15:12 - 15:36

### Diffractive production of open charm and bottom at the LHC
Harta LUSZCZAK
SCHEIDT
15:36 - 16:00

### Quarkonium production in pp, p-Pb and Pb-Pb collisions with the ALICE experiment at the LHC
Loic Henri Antoine MANCEAU
16:00 - 16:24

### Coffee break
16:24 - 16:48

### Charmonium production at HERA
Natella KOVALCHUK
F, BUW
16:48 - 17:12

### Running of the charm quark mass
Andrii GIZHKO
F, BUW
17:12 - 17:36

### Nuclear matter effects on J/ψ/ψ′ production in Cu+Au and $U+U$ collisions in PHENIX
Aneta IORDANOVA
17:36 - 18:00

### Top quarks as a probe for heavy new physics
Celine DEGRANDI
Auditorium, BUW
18:02 - 18:30
Heavy Flavors WG Program

- 4 sessions / 36 talks / interesting discussions
  - Top physics (joint with WG3)
  - Production
  - Decays

Top quark cross section measurements with CMS

Alessandro GRELLI

Heavy-flavour production in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC

A. Zupanc (JSI)

Theory overview of $B_{(s,d)} \to \mu^+ \mu^-$ decays
Rob KNEIEHNS

14:00 - 14:24

Perturbative contributions to rare B-meson decays
Mikolaj Krzysztof MISIAK

14:24 - 14:48

Rare Decays at LHCb
Jaroslaw Pawel WIECHCZYNSKI

14:48 - 15:12

Electroweak and radiative penguin processes in B decays at Belle
Luis PESANTEZ

15:12 - 15:36

Radiative B decays and new physics searches at BABAR
Liang SUN

15:36 - 16:00

Coffee break

F, BUN

16:00 - 16:30

Study of rare and suppressed processes in B meson decays with ATLAS
Vladimir NIKOLAENKO

16:30 - 16:54

Comprehensive Bayesian Analysis of Rare (Semi)leptonic and Radiative B Decays
Dr. Danny VAN DYK

16:54 - 17:18

Space for New Physics in Neutral B mixing observables
Mr. Gilberto TETLALMATZI-XOLONOTZI

17:18 - 17:42

Lifetime of flavoured hadrons at LHCb
Paul SAIL

17:42 - 18:06

Study of the Lambda$\_b$ decay properties with the ATLAS experiment
Tatjana AGATONOVIC-JOVIN

18:02 - 18:30
Heavy Flavors WG Program

- 4 sessions / 36 talks / interesting discussions
  - Top physics (joint with WG3)
  - Production
  - Decays
  - Spectroscopy
Heavy Flavors WG Program

- 4 sessions / 36 talks / interesting discussions
  - Top physics (joint with WG3)
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  - Decays
  - Spectroscopy

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
  \[
  \frac{1}{m_t} < \frac{1}{\Gamma_t} < \frac{1}{\Lambda_{QCD}} < \frac{m_t}{\Lambda_{QCD}^2}
  \]
  - 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

A. Zupanc (JSI)
Top quark (pair) production

Top pair production measurements entered precision era:
\( \sigma(tt) \) uncertainty \( O(5\%) \) at LHC compared to \( \sim 4\% \) prediction uncertainty (NNLO+NNLL)

Single top production

\( \sigma_s = 5.6 \pm 0.2 \text{ pb} \)
\( \sigma_t = 87.8^{+3.4}_{-1.9} \text{ pb} \)
\( \sigma_{Wt} = 22.4 \pm 1.5 \text{ pb} \)
Top quark pair properties

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

8 TeV analyses: $\sim 5 \times 10^6$ t\bar{t} pairs
7 TeV analyses: $\sim 1 \times 10^6$ t\bar{t} pairs
Top quark pair properties

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

8 TeV analyses: $\sim 5 \times 10^6$ $t\bar{t}$ pairs
7 TeV analyses: $\sim 1 \times 10^6$ $t\bar{t}$ pairs

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 $0.6 \pm 1.0\%$ (stat+syst) vs. SM prediction $1.23 \pm 0.05\%$

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

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

\[ \mathcal{O}_{hG} = \bar{Q}\sigma_{\mu\nu} T^a t\phi G^{\mu\nu}_a \]

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

\[ \mathcal{O}_{Lv} = \bar{Q}\gamma_\mu T^a Q \sum_{u,d,s,c} \bar{q}\gamma^\mu T^a q \]
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 $\overline{\text{MS}}$ charm mass definition

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

$\overline{\text{MS}}$ charm mass:

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

PDG value:

$$m_c^{\overline{\text{MS}}}(m_c) = 1.275 \pm 0.025 \, \text{GeV}$$
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 $\chi_{c1}$ and $\chi_{c2}$ production
  - Test understanding of $\chi_c$ production at LHC
  - Get handle on feed-down contribution of J/$\psi$ from $\chi_c$ in J/$\psi$ cross-section measurements

NLO NRQCD predictions in good agreement with DATA:
  - (non-)prompt cross sections
  - Ratio of $\chi_{c2}/\chi_{c1}$
  - Prompt J/$\psi$ in $\chi_c$ feed-down

arXiv:1404.7035
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.

A few % of B mesons decay into $c\bar{c}$ and $K^{(*)}$

Easy to study.
Low background.
$J^{PC}$ using angular studies.

T. Skwarnicki (LHCb): $X(3872)$
- The most studied “new” state, but it's nature still not understood
- $J^{PC}=1^{++}$ ($\rightarrow DD^*$ molecule or charmonium)

Measure $R = \frac{B(X \rightarrow \psi(2S)\gamma)}{B(X \rightarrow J/\psi\gamma)}$

Molecule
loosely bound meson-antimeson “molecule”

Tetraquark
Tightly bound diquark & anti-diquark

Belle 2011
PRL 107 (2011) 091803
BaBar 2009
PRL 102 (2009) 132001

90% CL UL
predictions for pure $c\bar{c}$ state
prediction for pure $DD^*$ model
predictions for admixture of $c\bar{c}$ and $DD^*$
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

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 \( R = \frac{B(X \to \psi(2S)\gamma)}{B(X \to J/\psi\gamma)} \)

A. Zupanc (JSI)

WG5 Summary
Charged charmonium-like state $Z(4430)^-$

First observed by Belle in 2008 and confirmed recently by LHCb!
Charged charmonium-like state $Z(4430)^-$

Full 4D amplitude analysis performed!

T. Skwarnicki (LHCb)

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

Fit without $Z(4430)^-$

Fit with $Z(4430)^-$

Overall consistency with Belle results but with substantially improved errors.
Charged charmonium-like state $Z(4430)^-$

Including systematic variations:

<table>
<thead>
<tr>
<th>Disfavored $J^P$</th>
<th>Rejection level relative to $1^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>LHCb</strong></td>
</tr>
<tr>
<td>0$^-$</td>
<td>9.7σ</td>
</tr>
<tr>
<td>1$^-$</td>
<td>15.8σ</td>
</tr>
<tr>
<td>2$^+$</td>
<td>16.1σ</td>
</tr>
<tr>
<td>2$^-$</td>
<td>14.6σ</td>
</tr>
</tbody>
</table>

$J^P=1^+$ 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 $DD^*$ 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, ...).

\[ M \gg p \]
\[ M \gg \Lambda_{\text{QCD}} \]

This allows for a systematic non-relativistic and perturbative expansion

Many topics reviewed among them:

- Annihilation & production, width and decay ($\alpha_s$)
- Radiative transitions
- New quarkonium-like state below and above threshold
- Gluonic excitations
Charmonium hybrid states (grouped in spin multiplets): $H_1, H_2, H_4, \ldots$.

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.
Rare B-meson decays

- Flavor-Changing-Neutral-Current transitions $b \to s \gamma$, $b \to s \ell \ell$
  
  $B \to K^* \ell^+ \ell^-$  
  $B_s \to \mu^+ \mu^-$  
  $B \to K \ell^+ \ell^-$  
  $B \to K^* \gamma$  
  $B_s \to X_s \ell^+ \ell^-$  
  $B \to X_s \gamma$

- 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 $C_i$ from long-distance effects)

**New Physics may introduce new operators or modify existing Wilson coefficients**

$$\mathcal{H}_{\text{eff}} = -\frac{G_F}{\sqrt{2\pi}} V_{tb} V_{tq}^{*} \sum_{i} (C_i \mathcal{O}_i + C_i' \mathcal{O}_i')$$

Operators:

- $\mathcal{O}_{10} = (\bar{q} \gamma_{\mu} P_L b)(\bar{\mu} \gamma^{\mu} \gamma_5 \mu)$
- $\mathcal{O}_{S} = (\bar{q} P_R b)(\bar{\mu} \mu)$
- $\mathcal{O}_{P} = (\bar{q} P_R b)(\bar{\mu} \gamma_{5} \mu)$

Wilson coefficients

R. Knegjens
M. Misiak
D. van Dyk
Perturbative corrections for rare $B$-meson decays

Mikolaj Misiak

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

**NNLO QCD + NLO EW + LL QED:**

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


\[
\begin{align*}
\mathcal{B}_{s\mu} \times 10^9 &= (3.65 \pm 0.06) \times (3.65 \pm 0.23), \\
\mathcal{B}_{d\mu} \times 10^{10} &= (1.06 \pm 0.02) \times (1.06 \pm 0.09),
\end{align*}
\]

(LHCb & CMS : $2.9 \pm 0.7$)

(LHCb & CMS : $3.6^{+1.6}_{-1.4}$)

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

Sources of uncertainties

<table>
<thead>
<tr>
<th>$f_{B_q}$</th>
<th>CKM</th>
<th>$\tau_H^{s}$</th>
<th>$M_t$</th>
<th>$\alpha_s$</th>
<th>other parametric</th>
<th>non-parametric</th>
<th>$\sum$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{B}_{s\ell}$</td>
<td>4.0%</td>
<td>4.3%</td>
<td>1.3%</td>
<td>1.6%</td>
<td>0.1%</td>
<td>&lt; 0.1%</td>
<td>1.5%</td>
</tr>
<tr>
<td>$\mathcal{B}_{d\ell}$</td>
<td>4.5%</td>
<td>6.9%</td>
<td>0.5%</td>
<td>1.6%</td>
<td>0.1%</td>
<td>&lt; 0.1%</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

In the case of $\mathcal{B}_{s\ell}$, 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].
$B_{(s)} \rightarrow \mu^+ \mu^-$

J. Wiechczynski (LHCb) & R. Knegjens

Consistent with SM!

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

$$\frac{\Gamma(B_{s,1} \rightarrow f) - \Gamma(B_{s,2} \rightarrow f)}{\Gamma(B_{s,1} \rightarrow f) + \Gamma(B_{s,2} \rightarrow f)}$$

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

In SM:

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

K. Bruyn, R. Fleischer, RK, P. Koppenburg, M. Merk, A. Pellegrino, N.
(Angular) Observables in $B \rightarrow K^* \ell^+ \ell^-$

- 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. $A_{FB}, F_L, P'_{4,5,6}, \ldots$

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

Definitions

\[
\Gamma \sim 3J_{1c} + 6J_{1s} - J_{2c} - 2J_{2s} \quad A_{FB} \sim \frac{J_{6s}}{\Gamma} \quad F_L \sim \frac{3J_{1c} - J_{2c}}{\Gamma}
\]

\[
P'_4 \sim \frac{+J_4}{\sqrt{-J_{2s}J_{2c}}} \quad P'_5 \sim \frac{+J_5}{2\sqrt{-J_{2s}J_{2c}}} \quad P'_6 \sim \frac{-J_7}{2\sqrt{-J_{2s}J_{2c}}}
\]
J. Wiechczynski (LHCb)

Consistent with SM!
$\textbf{B} \rightarrow \textbf{K}^* \mu^+ \mu^-$

J. Wiechczynski (LHCb)

However, some surprises...

See $3.7\sigma$ local tension in $P_5$ → $0.5\%$ global p-value
Comprehensive Bayesian Analysis of Rare (Semi)leptonic and Radiative B Decays

Danny van Dyk

The $B \rightarrow K^* \ell^+ \ell^-$ "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
  $\langle P_5' \rangle_{[1,6]} = -0.34^{+0.09}_{-0.08}$ (BBvD, nominal priors)
  $\langle P_5' \rangle_{[1,6]} = -0.32^{+0.18}_{-0.10}$ (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 $B \rightarrow X_{s(+d)} \gamma$

- **Inclusive (Belle)**
  
  - $\gamma$
  
  - $B \rightarrow \gamma(4S) \rightarrow \bar{B} \rightarrow X_{s+d} \gamma$

  - **L.Sun (BaBar) & L.Pesantez (Belle)**
  
  - + reduced model uncertainty
  
  - - lower signal purity

- **Sum-of-exclusive (BaBar)**

<table>
<thead>
<tr>
<th>Charged Modes:</th>
<th>Neutral Modes:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_S^0 \pi^+ \gamma$</td>
<td>$K^+ \pi^- \gamma$</td>
</tr>
<tr>
<td>$K^+ \pi^0 \gamma$</td>
<td>$K^+ \pi^- \pi^0 \gamma$</td>
</tr>
<tr>
<td>$K^+ \pi^+ \pi^- \pi^- \gamma$</td>
<td>$K^+ \pi^- \pi^- \pi^- \gamma$</td>
</tr>
</tbody>
</table>
  
<table>
<thead>
<tr>
<th>Channel</th>
<th>$A_{CP} (SM)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \rightarrow X_s \gamma$</td>
<td>[-0.6%, +2.8%]</td>
</tr>
<tr>
<td>$B \rightarrow X_d \gamma$</td>
<td>[-62%, +14%]</td>
</tr>
<tr>
<td>$B \rightarrow X_{s+d} \gamma$</td>
<td>0</td>
</tr>
</tbody>
</table>

- Cancellation due to unitarity, negligible theory error!

  + better signal purity
  
  - mode uncertainty, lower efficiency
CP Asymmetry in $B \rightarrow X_{s(+d)}\gamma$

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

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

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

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 lot 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 mass measured with ~1 GeV precision:

- Systematics dominated by b-JES, soft QCD, and more generally models expected to be better constrained by more data
- Alternative methods/measurements (uncorrelated syst!)

CMS preliminary projection

CMS-PAS-FTR-13-017
New Physics (NP) effects in $\Delta \Gamma_s$ are strongly constrained in comparison with $\Delta \Gamma_d$ because:

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

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

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

$\implies$ 100% enhancement on $\Gamma(b \rightarrow c\bar{c}d)$ 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.

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

Uncertainties on $H$ and $ttbar$ Predictions at the LHC
Carl Schmidt [CTEQ-TEA]

**Uncertainties in $gg\rightarrow ttbar$**

- Same analyses applied to $gg\rightarrow ttbar$
- HERA combined data (T2) constrains low values of cross section
- But T2 less important for combined PDF+$\alpha_s$
- 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>
<thead>
<tr>
<th>Acceptance</th>
<th>Mode</th>
<th>Integrated cross sections, $\mu$b</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2.0 &lt; y &lt; 4.5$</td>
<td>$D^0 + \overline{D^0}$</td>
<td>$2.19$</td>
</tr>
<tr>
<td>$2.0 &lt; y &lt; 4.0$</td>
<td>$D^0\overline{D^0}$</td>
<td>$0.009$</td>
</tr>
</tbody>
</table>
Charm(-onium) production at HERA

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

N. Kovalchuk

$\frac{\sigma(\psi(2S))/\sigma(J/\psi(1S))}{\sigma(J/\psi(1S))}$
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, ...)

\[
R_{SS}(\pi\pi, \eta) = \frac{BF(Y(nS) \rightarrow \eta \ Y(mS))}{BF(Y(nS) \rightarrow \pi\pi \ Y(mS))} \ll 1
\]

\[
R_{SP}(\pi\pi, \eta) = \frac{BF(Y(nS) \rightarrow \eta h_b(mP))}{BF(Y(nS) \rightarrow \pi\pi h_b(mP))} \geq 1
\]

**Experimental status**

<table>
<thead>
<tr>
<th></th>
<th>Y(2S) →</th>
<th>Y(3S) →</th>
<th>Y(4S) →</th>
<th>Y(5S) →</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y(1S)</td>
<td>~ 2 x 10^{-3}</td>
<td>&lt; 2 x 10^{-3}</td>
<td>2.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Y(2S)</td>
<td></td>
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<td>0.4</td>
</tr>
<tr>
<td>Y(3S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y(4S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Almost OK

Not a Zb effect. Other coupled channel effects?

\[\text{No measurements, until now!} \quad \text{U. Tamponi (Belle)}\]
Hadronic transitions in quarkonia

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

Y(4S) sample

Y(5S) sample

First test of QCDME with $\eta h_b(1P)$ transitions

U. Tamponi (Belle)

<table>
<thead>
<tr>
<th></th>
<th>Y(4S) →</th>
<th>Y(5S) →</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_b(1P)$</td>
<td>&gt; 2.0</td>
<td>&lt; 0.9</td>
</tr>
<tr>
<td>$h_b(2P)$</td>
<td></td>
<td>&lt; 0.6</td>
</tr>
</tbody>
</table>

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)
  - Deconfinement 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

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

A. Grelli
Probing hot QCD matter

- **Cold** Nuclear Matter Effects (p+A)
  - Shadowing, Color Glass Condensate, Coherent Energy Loss
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\]

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

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

A. Iordanova
Probing hot QCD matter

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

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

**Hints of strong regeneration of J/ψ at LHC energies**