Experimental summary

Angelo Di Canto
CHARM 2016 - Scientific Program

<table>
<thead>
<tr>
<th>Charm Physics with Heavy Ions</th>
<th>CP Violation, Mixing and nonleptonic decays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multibody Hadronic Decays</td>
<td>Open Charm Production and Spectroscopy</td>
</tr>
<tr>
<td>Leptonic, semi-leptonic and rare decays</td>
<td>Charm Baryons Decays</td>
</tr>
<tr>
<td>Charmonium and Exotics</td>
<td>Future experiments and facilities</td>
</tr>
<tr>
<td>Production and Spectroscopy</td>
<td>Summaries</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mon. 5/9</th>
<th>Tue. 6/9</th>
<th>Wed. 7/9</th>
<th>Thu. 8/9</th>
<th>Fri. 9/9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>Registration+ Welcome + Overview talks</td>
<td>Plenary</td>
<td>Parallel session</td>
<td>Plenary</td>
</tr>
<tr>
<td>Lunch</td>
<td>At the venue</td>
<td>At the venue</td>
<td>At the venue</td>
<td>At the venue</td>
</tr>
<tr>
<td>Afternoon</td>
<td>Plenary</td>
<td>Plenary and parallel session</td>
<td>Parallel session and Social activities</td>
<td>Plenary</td>
</tr>
<tr>
<td>Evening</td>
<td>Welcome drink (19:00)</td>
<td>Wine and posters (18:30)</td>
<td>Workshop Dinner (18:15)</td>
<td></td>
</tr>
</tbody>
</table>
Lunches and coffee breaks

- Coffee/tea breaks and lunches will take place in the cloister.

Restaurants

- Trattoria La Montanara (typical Bolognese)
- Trattoria Annamaria (typical Bolognese)
- Trattoria Da Pietro (typical Bolognese)
- Ristorante La Baita (typical Bolognese)
- Trattoria Manzoni (typical Bolognese)
- Trattoria da Pietro (typical Bolognese)
- Ristorante Donatello (typical Bolognese)
- Trattoria Caminetto d'Oro (typical Bolognese)
- Osteria dei Poeti (typical Bolognese, very small)
- Osteria Broccaindosso (typical Bolognese)
- Osteria dell'orsa (typical Bolognese)
- Pizzeria Bella Napoli (Pizza)
- Ristorante Michelemma (Pizza and Fish)
- Trattoria Pizzeria Belle Arti (Pizza)
- Ristorante La Cambusa (Fish)
Welcome drink

The welcome drink will be served on Monday evening at the venue, after the plenary session.

Social dinner

The social dinner will be held on Thursday evening at the Zuffa Winery, Imola (BO). The Zuffa farm and its winery were born at the beginning of the 19th century, when the first bottle was numbered. It is located in the area of Imola, at 50 km from Bologna. The Zuffa Winery has been selected as an Italian excellence to represent Emilia-Romagna, the region of Bologna, at Expo 2015. Augusto Zuffa, the winemaker, will guide us through his world of wine with a visit to the cellar. Dinner will be served at the farm accompanied with Zuffa’s wines and seasonal biological local foods. Bus service to the location, departing at 6:00 pm from San Domenico’s square, is foreseen.
Exactly like with food, where anyone has his/her own tastes, this summary does reflect my personal, limited and biased point of view
Charm(onia)
Production
Parton density functions (PDF)

- QCD evolution
- LHC
- Tevatron
- HERA
- Higgs
- top, jets,
- gluon

Parton densities from HERA and LHC data → cross sections at LHC, cosmic rays, ...

8.9.16

A. Geiser, Charm workshop
We (consider all measurements by using the theoretical sections at Pen Charm Prod and Spec at LHCb-PAPER-2016-042, New).
Charm(onia) Production in Heavy Ions Collisions
Prompt D-meson $R_{AA}$ in 2.76 TeV Pb-Pb

- Above 5 GeV/c strong suppression (factor 4-5) of D-meson yield in central Pb-Pb, compared to binary scaling from pp
- First $D_s^+$ measurement in heavy-ion collisions
- Expectation: enhancement of strange D-meson yield at intermediate $p_T$ if charm hadronises via recombination in the medium

Andre Mischke (Utrecht)
LHCb – a new actor in PbPb studies

- First PbPb data taking in 2015, result expected for peripheral and semiperipheral collisions

- LHCb SMOG project: p-A beam-gas collisions ($\sqrt{s_{NN}}=110$ GeV) Covers energy between SPS and RHIC

E. Scomparin, Charmonium physics with HI, experimental results, Bologna, September 2016
Decay properties and Spectroscopy
First observation of DCS charm baryon decay

After subtraction of the peaking background $\Lambda_c^+ \rightarrow \Lambda(p\pi^-)K^+$, we observed $3379 \pm 380 \pm 78$ DCS events with a significance $> 9\sigma$.

Residuals of the data with respect to fitted the combinatorial background

Absolute branching fraction

$\mathcal{B}(\Lambda_c^+ \rightarrow pK^+\pi^-) = (1.61 \pm 0.23^{+0.07}_{-0.08}) \times 10^{-4}$

(First observation)

- After subtracting the contribution $\Lambda^*(1520)$ and $\Delta$ isobar intermediates, which only contribute to CF decay, the revised ratio

$$\frac{\mathcal{B}(\Lambda_c^+ \rightarrow pK^+\pi^-)}{\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)} = (1.10 \pm 0.17) \tan^4 \theta_c$$

compatible with naïve expectation: no large $W$-exchange contribution in CF decay.
First observation of DCS charm baryon decay

After subtraction of the peaking background $\Lambda_c^+ \to \Lambda(p\pi^-)K^+$, we observed $3379 \pm 380 \pm 78$ DCS events with a significance $> 9\sigma$.

After subtracting the contribution of $\Lambda^*_{1520}$ and $\Delta$ isobar intermediates, which only contribute to CF decay, the revised ratio is compatible with naïve expectation: no large W-exchange contribution in CF decay.

$$\frac{B(\Lambda_c^+ \to pK^+\pi^-)}{B(\Lambda_c^+ \to pK^-\pi^-)} = \frac{2.35 \pm 0.29}{(0.82 \pm 0.14) \times 10^{-3}} = 1.10 \pm 0.17 \tan^4 \theta_c$$

Absolute branching fraction

$$(1.61 \pm 0.23^{+0.07}_{-0.08}) \times 10^{-4}$$
Several absolute BF measurements from BESIII

**Comparisons with Other Experiments in Some Modes**

- The results from BESIII are consistent with other measurements and have comparable precisions with the existing best measurements.
BESIII preliminary

78.7 ± 10.5 signals

Preliminary result:

\[ B[\Lambda_c^+ \rightarrow \Lambda \mu^+ \nu_\mu] = (3.49 \pm 0.46 \pm 0.26)\% \]

where the first error is statistical and the second systematic.

“other bkgrounds” stands for all possible background channels except the \( \Lambda_c^+ \rightarrow \Lambda \pi^+ \pi^0 \) channel. It is obtained based on MC simulation by removing the \( \Lambda_c^+ \rightarrow \Lambda \pi^+ \pi^0 \) channel when draw the \( U_{\text{miss}} \) distribution of backgrounds.
Everything started with the X(3872)

**X(3872)**

**PR** _L91_, _262001_ (_2003_)

\[ M(J/\psi\pi\pi) \sim 10 \sigma \]

M\(_X\) close to D\(_0^0\)D\(_*0^+\) threshold

\[ M = 3871.68 \pm 0.17 \text{ MeV} \]

not clear below or above:

\[ \Delta m = -0.11 \pm 0.22 \text{ MeV} \]

surprisingly narrow:

\[ \Gamma_{\text{tot}} < 1.2 \text{ MeV at } 90\% \text{ CL} \]

First observed by **Belle** in

**B**→**K** \( J/\psi\pi^+\pi^- \)

Confirmed:

**BaBar**, **LHCb**, **CMS**, **ATLAS**, **CDF**

**Hadronic collisions**: produced mostly promptly; only \( 0.263 \pm 0.023 \pm 0.016 \)

from **B**-decays (**CMS**)

<table>
<thead>
<tr>
<th>Known decays</th>
<th>BR relative to ( J/\psi\rho ) mode</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>( J/\psi\rho )</td>
<td>1</td>
<td>isospin violation</td>
</tr>
<tr>
<td>( J/\psi\omega )</td>
<td>( 0.8 \pm 0.3 )</td>
<td>isospin violation</td>
</tr>
<tr>
<td>( J/\psi\gamma )</td>
<td>( 0.21 \pm 0.06 )</td>
<td>Belle&amp;<strong>Babar</strong> good agreement</td>
</tr>
<tr>
<td>( \psi(2S)\gamma )</td>
<td>( 0.50 \pm 0.15 )</td>
<td>Belle&amp;<strong>Babar</strong> disagreement <strong>LHCb</strong> confirms <strong>BaBar</strong></td>
</tr>
<tr>
<td>( D^0D\ _{*0} )</td>
<td>( \sim 10 )</td>
<td>dominant mode</td>
</tr>
</tbody>
</table>
X(4140) and friends

Search for structures in the J/ψ spectrum at LHCb

Fit with conventional plus exotic contributions

Only X contributions lead to significant improvements in the description of the data.

The model contains seven K→+ states, four X states and K and J/ψ nonresonant components.

\[
\begin{align*}
K^+ & \rightarrow X(4140) + K^- \\
K^+ & \rightarrow X(4274) + K^- \\
K^+ & \rightarrow X(4500) + K^- \\
K^+ & \rightarrow X(4700) + K^- \\
\end{align*}
\]

Candidate/(30 MeV)

Data
Total fit
Background
K+φ
NR
1
K
1
K'
1
K'
2
K
2
K
1
K
2
K
0
K
(4140)
X
1
(4274)
X
1
(4500)
X
0
(4700)
X
0
φ
ψ
J/
NR
0
LHCb

Also seen by D0 (in B decays and promptly produced)
Various Y and Z states

\[ e^+e^- \rightarrow \pi^+\pi^0 J/\psi \] using ISR at BaBar

PRD 86, 051102 (2012)

\[ e^+e^- \rightarrow \pi^+\pi^0 J/\psi \] using ISR at Belle

PRL 110, 252002 (2013)

Asymmetric shape?
Low-mass Y(4008)?

The cross section is inconsistent with a single peak for the Y(4260)!
Two peaks are favored over one peak by $> 7\sigma$

Peak 1:

Peak 2:

Confirmed by LHCb

Some seen also by Belle
Pentaquark candidates

\[ \Lambda_b \rightarrow J/\psi pK^- \]

\[ \Lambda_b \rightarrow J/\psi p\pi^- \]
Mixing and CPV
New results for time-integrated CPV

\[ A_{CP}^{comb}(KK) = [0.04 \pm 0.12 \pm 0.10] \%
\]
\[ A_{CP}^{comb}(\pi\pi) = [0.07 \pm 0.14 \pm 0.11] \%
\]

Belle

\[ \mathcal{A}_{CP}(D^0 \rightarrow K_s K_s) = (-0.002 \pm 0.15 \pm 0.17) \%
\]
\[ \mathcal{A}_{CP}(D^0 \rightarrow \phi \gamma) = (-0.094 \pm 0.066 \pm 0.001) \%
\]
\[ \mathcal{A}_{CP}(D^0 \rightarrow K^{*0} \gamma) = (-0.003 \pm 0.020 \pm 0.000) \%
\]
\[ \mathcal{A}_{CP}(D^0 \rightarrow \rho^0 \gamma) = 0.056 \pm 0.151 \pm 0.006
\]

LHCb

\[ \mathcal{A}_{CP}(D^\pm \rightarrow \eta' \pi^\pm) = (-0.61 \pm 0.72 \pm 0.55 \pm 0.12) \%
\]
\[ \mathcal{A}_{CP}(D_s^\pm \rightarrow \eta' \pi^\pm) = (-0.82 \pm 0.36 \pm 0.24 \pm 0.27) \%
\]

BESIII

<table>
<thead>
<tr>
<th>Mode</th>
<th>( A_{CP} ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K^0_S K^\pm )</td>
<td>-1.5 \pm 2.8 \pm 1.6</td>
</tr>
<tr>
<td>( K^0_S K^\pm \pi^0)</td>
<td>1.4 \pm 4.0 \pm 2.4</td>
</tr>
<tr>
<td>( K^0_L K^\pm )</td>
<td>-3.0 \pm 3.2 \pm 1.2</td>
</tr>
<tr>
<td>( K^0_L K^\pm \pi^0)</td>
<td>-0.9 \pm 4.1 \pm 1.6</td>
</tr>
</tbody>
</table>
New results for time-dependent CPV

**Unbinned Results** (8 TeV only):

\[
A_r(K^+K^-) = (-0.03 \pm 0.46 \pm 0.10) \times 10^{-3} \\
A_r(\pi^+\pi^-) = (+0.03 \pm 0.79 \pm 0.16) \times 10^{-3}
\]

Combine with published 7 TeV result to determine Run 1 average (KK + ππ):

\[
A_r = (-0.07 \pm 0.34) \times 10^{-3}
\]

**Binned Results** (7+8 TeV):

\[
A_r(K^+K^-) = (-0.30 \pm 0.32 \pm 0.14) \times 10^{-3} \\
A_r(\pi^+\pi^-) = (+0.46 \pm 0.58 \pm 0.16) \times 10^{-3}
\]

Run 1 KK+ππ average:

\[
A_r = (-0.12 \pm 0.30) \times 10^{-3}
\]
LHCb squeezing the most out of the data

**Combined fit** using two independent data samples
- Double-tagged (DT) sample
- Prompt sample *PRL 111, 251801 (2013)*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DT+prompt combination</th>
<th>Prompt alone</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R_D[10^{-3}])</td>
<td>3.533 ± 0.054</td>
<td>3.568 ± 0.067</td>
</tr>
<tr>
<td>(x^2[10^{-5}])</td>
<td>3.6 ± 4.3</td>
<td>5.5 ± 4.9</td>
</tr>
<tr>
<td>(y'[10^{-3}])</td>
<td>5.23 ± 0.84</td>
<td>4.80 ± 0.94</td>
</tr>
<tr>
<td>(\chi^2/NDF)</td>
<td>96.594/111</td>
<td></td>
</tr>
</tbody>
</table>

Precision improves by 10-20% when adding DT data (2.5% of signal)
Gain from complementary decay-time coverage, and higher signal purity.

**LHCb-PAPER-2016-033** in preparation
Parallel session slides from P. Marino
(Outdated) Averages

- $y$ well determined, $x$ still uncertain
- $|q/p|$ is well compatible with 1
- phases are all compatible with 0

NO EVIDENCE FOR CPV
...YET...

Bayesian Fit
Floated parameters:

$x, y, \left| \frac{q}{p} \right|, R_{K\pi}, \delta_{K\pi}, \delta_{K\pi\pi}$
Need multibody decays...

\[ D^0 \rightarrow \pi^+ \pi^- \pi^0 \]

\[ x = (1.5 \pm 1.2 \pm 0.6)\% \]
\[ y = (0.2 \pm 0.9 \pm 0.5)\% \]
\[ \tau(D^0) = 410.2 \pm 3.8\text{ fs} \]
...and more measurements at threshold

<table>
<thead>
<tr>
<th>Bins</th>
<th>BES-III $c_i$</th>
<th>CLEO-c $c_i$</th>
<th>BES-III $s_i$</th>
<th>CLEO-c $s_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.066 ± 0.066</td>
<td>-0.009 ± 0.088</td>
<td>-0.843 ± 0.119</td>
<td>-0.438 ± 0.184</td>
</tr>
<tr>
<td>2</td>
<td>0.796 ± 0.061</td>
<td>0.900 ± 0.106</td>
<td>-0.357 ± 0.148</td>
<td>-0.490 ± 0.295</td>
</tr>
<tr>
<td>3</td>
<td>0.361 ± 0.125</td>
<td>0.292 ± 0.168</td>
<td>-0.962 ± 0.258</td>
<td>-1.243 ± 0.341</td>
</tr>
<tr>
<td>4</td>
<td>-0.985 ± 0.017</td>
<td>-0.890 ± 0.041</td>
<td>-0.090 ± 0.093</td>
<td>-0.119 ± 0.141</td>
</tr>
<tr>
<td>5</td>
<td>-0.278 ± 0.056</td>
<td>-0.208 ± 0.085</td>
<td>0.778 ± 0.092</td>
<td>0.853 ± 0.123</td>
</tr>
<tr>
<td>6</td>
<td>0.267 ± 0.119</td>
<td>0.258 ± 0.155</td>
<td>0.635 ± 0.293</td>
<td>0.984 ± 0.357</td>
</tr>
<tr>
<td>7</td>
<td>0.902 ± 0.017</td>
<td>0.869 ± 0.034</td>
<td>-0.018 ± 0.103</td>
<td>-0.041 ± 0.132</td>
</tr>
<tr>
<td>8</td>
<td>0.888 ± 0.036</td>
<td>0.798 ± 0.070</td>
<td>-0.301 ± 0.140</td>
<td>-0.107 ± 0.240</td>
</tr>
</tbody>
</table>

$D^0 \rightarrow K_S \pi^+ \pi^-$
Multibody Hadronic Decays
**D^0 → π⁺π⁻π⁺π⁻**  
(P. d’Argent)

\[ \text{Amplitude fit} \]

18 amplitudes selected

\[ \sigma / \nu = 1.33 \]

\[ \pm (\text{GeV}) \]

\[ π⁻π⁻π⁻π⁻ / \text{π⁺π⁺π⁺π⁻} \]

Events (norm.)

D^0 → π⁻ a_1(1260)⁺  
5.0 ± 3.2

D^0 → π⁺ a_1(1260)⁻  
6.8 ± 13.2

D^0 → π⁻ π(1300)⁺  
−7.4 ± 8.0

D^0 → π⁺ π(1300)⁻  
−9.6 ± 16.5

D^0 → π⁻ a_1(1640)⁺  
7.8 ± 12.5

D^0 → π⁻ π_2(1670)⁺  
6.7 ± 14.0

D^0 → σ f_0(1370)  
−8.7 ± 4.5

D^0 → σ ρ(770)  
26.3 ± 15.2

D^0 → ρ(770) ρ(770)  
−46.7 ± 34.0

D^0[P] → ρ(770) ρ(770)  
−9.1 ± 7.9

D^0[D] → ρ(770) ρ(770)  
−7.9 ± 8.3

D^0 → f_2(1270) f_2(1270)  
−28.7 ± 20.7

D^0 → π⁺π⁻π⁺π⁻  
−5.5 ± 3.3

\[ X^2 / \text{ndf} = 1.128 \]

\[ \text{CLEO} \]

\[ \text{BESIII Preliminary} \]
Very challenging at LHCb

**D^{+} → K^{+}K^{-}K^{+}**

~100k (DCS) decays with 91% purity

Three different S-wave parameterisations:

1. Non-resonant (i.e. flat) + \( f_{0}(980) \).
2. \( f_{0}(X) \) (single Breit-Wigner with floating mass and width) + \( f_{0}(980) \).
3. \( a_{0}(1450) + f_{0}(980) \).

All models additionally include a \( \phi(1020) \) component.

For \( f_{0}(x) \):

\[
\begin{align*}
    m_{0} &= 1430 \pm 19 \text{ MeV}/c^{2}, \\
    \Gamma_{0} &= 348 \pm 49 \text{ MeV}/c^{2}.
\end{align*}
\]

<table>
<thead>
<tr>
<th>Model</th>
<th>( \chi^{2}/\text{dof} )</th>
<th>( \sum \text{FF} ) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>844.49/495 = 1.71</td>
<td>93.6 ± 8.0</td>
</tr>
<tr>
<td>2</td>
<td>635.66/493 = 1.29</td>
<td>55 ± 13</td>
</tr>
<tr>
<td>3</td>
<td>652.15/495 = 1.32</td>
<td>55.9 ± 2.2</td>
</tr>
</tbody>
</table>
Rare Decays
Just a little tasty bite...

BR(D^0 → γγ) < 8.5 x 10^{-7} @ 90 CL
Future prospects
LHCb + Upgrade + Infinity&Beyond  
(C. Parkes)

BESIII  
(X. Shen)

Belle II  
(A. Schwartz)

PANDA  
(G. Boca)
Looking forward to CHARM 2018

• Keep exploiting a rich experimental program

• Many more results from the data already available and much more data to come

• Increase sensitivity to new physics, but also build a better understanding of QCD

• In parallel a theory community will work hard on improving predictions
Many thanks to the organisers (especially to Angelo) for the invitation and the organisation of this great event