History of Belle & some of its best results

Stephen Lars Olsen
Institute for Basic Science Daejeon KOREA

High Energy Physics and Quantum Field Theory
Samara, Russia  June 24 – July 1, 2015
History of Belle & some of its results not well known, but important

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Christenson-Cronin-Fitch-Turlay Experiment (1964)

Search for long-lived neutral kaon $\rightarrow \pi^+\pi^-$
Long-lived neutral $K \rightarrow \pi^+\pi^-$

($\sim 2$ parts in $10^3$)

J. H. Christenson et al.,
Long-lived neutral $K \rightarrow \pi^+ \pi^-$

($\sim 2$ parts in $10^3$)

Small CP violation ($2 \times 10^{-3}$) is seen

J. H. Christenson et al.,
1980 Nobel Prize

James Cronin

Val Fitch
Why the interest in CP violation?

- Critical for understanding the early Universe
  - Sakharov’s 1967 paper on the Baryon Asymmetry of the Universe

- Hard to incorporate into the Standard Model
  - Kobayashi & Maskawa’s 1972 paper on 6-quark flavor mixing

- Promising probe of New Physics
  - SM CPV is too small to be the mechanism behind Sakharov’s BAU; the BAU requires non-SM CPV mechanisms to explain it
Sakharov: CPV & the baryon asymmetry of the Universe (1967)

Out of S. Okubo's effect
At high temperature
A fur coat is sewed for the Universe
Shaped for its crooked figure.

Нарушение CP-инвариантности, C-асимметрия
и барионная асимметрия Вселенной

А.Д. Сахаров

Письма ЖЭТФ, Т. 5, № 5, 32–35 (1967)

Теория расширяющейся Вселенной, предполагающая сверхплотное начальное состояние вещества, по-видимому, исключает возможность макроскопического разделения вещества и антивещества; поэтому следует
Incorporating CPV into QM
CPV was big trouble for theorists!

Elementary Particles in 1964

only 3 quark flavors were known
1973 Kobayashi & Maskawa

Progress of Theoretical Physics, Vol. 49, No. 2, February 1973

**CP-Violation in the Renormalizable Theory of Weak Interaction**

Makoto KOBAYASHI and Toshihide MASKAWA

*Department of Physics, Kyoto University, Kyoto*

(Received September 1, 1972)

In a framework of the renormalizable theory of weak interaction, problems of CP-violation are studied. It is concluded that no realistic models of CP-violation exist in the quartet scheme.

“4 quark scheme”
“6 quark model”

Next we consider a 6-plet model, another interesting model of CP-violation.

\[
\begin{pmatrix}
    d
    \\
    s
    \\
    b
\end{pmatrix}
= \begin{pmatrix}
    c_{12} c_{13} & s_{12} c_{13} & s_{13} e^{-i\delta} \\
    -s_{12} c_{23} - c_{12} s_{23} s_{13} e^{i\delta} & c_{12} c_{23} - s_{12} s_{23} s_{13} e^{i\delta} & s_{23} c_{13} \\
    s_{12} s_{23} - c_{12} c_{23} s_{13} e^{i\delta} & -c_{12} s_{23} - s_{12} c_{23} s_{13} e^{i\delta} & c_{23} c_{13}
\end{pmatrix}
\begin{pmatrix}
    d
    \\
    s
    \\
    b
\end{pmatrix}
\]

3 Euler angles: $\theta_1$, $\theta_2$, & $\theta_3$, plus 1 CP-violating phase: $\delta$

Then, we have CP-violating effects through the interference among these different current components.

i.e., theory can accommodate CP violation, but only with 6 (or more) quarks
KM model predicts large differences between $B^0$ and $\bar{B}^0$ decays
Ashton Carter in 2015
CKM flavor-mixing matrix

The Kobayashi-Maskawa CPV complex phases are here

\[
\begin{pmatrix}
  d' \\
  s' \\
  b'
\end{pmatrix} = \begin{pmatrix}
  V_{ud} & V_{us} & V_{ub} \\
  V_{cd} & V_{cs} & V_{cb} \\
  V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\begin{pmatrix}
  d \\
  s \\
  b
\end{pmatrix}
\]
CKM flavor-mixing matrix

The Kobayashi-Maskawa CPV complex phases are here

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  V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\begin{pmatrix}
  d \\
  s \\
  b
\end{pmatrix}
\]

How can these phases be measured?
phase measurements require interference

Sanda, Bigi & Carter:

\[ B^0_d \rightarrow b V_{cb} \rightarrow c J/\psi \rightarrow c K_S \]

\[ B^0_b \rightarrow t V_{tb} \rightarrow b \overline{B^0}_d \rightarrow b J/\psi \rightarrow b K_S \]

\[ \propto V_{td}^* \]

(not \[ |V_{td}|^2 \])
Sanda-Carter-Bigi CPV asymmetry

\[ t \approx \Delta z/c \beta \gamma \]

\[ = (1-2w)\sin 2\phi_1 \]
Test of KM-mechanism for CPV require three miracles:

- 6 quark flavors
  - instead of 3 (or 4)

- Long B-meson lifetime & large $B \leftrightarrow \bar{B}$ mixing frequency
  \[ \tau_{B_d} \propto G_F^2 |V_{ub}|^2 \iff \text{small } V_{ub} \quad \Delta m_{B_d} \propto G_F^2 m_t^2 |V_{td}|^4 \iff \text{large } m_t \]

- huge improvements in accelerator & detector technology
  - Luminosity increases by $\sim 10^3$; asymmetric beam energies
  - High detection efficiency; excellent & efficient particle ID
  - Exquisite vertex resolution, especially along beam direction
Miracle 1: c-, b- & t-quark discovered

Elementary Particles
In 2000

6 quark flavors established
Miracle 2: $\tau_B$, $\Delta m_B$ & $m_t$ are “just right”

- ARGUS discovered $B \leftrightarrow \bar{B}$ mixing $\Delta m_B \approx 0.5$ ps$^{-1}$
- PEP exp’ts (HRS, MAC & MarkII) find $\tau_B \approx 1.5$ps ($\sim 3\tau_D$)
- CDF & D0: $m_t \approx 174$ GeV
Miracle 3: $e^+e^-$ luminosity $\sim 2^{(t/2.5\text{yr})}$
3 yrs of CLEO vs 3 years of Belle

Includes ~ 100X improvement in detector technology & reconstruction software
KEKB asymmetric $e^+e^-$ collider

- Two separate rings
  - $e^+$ (LER) : 3.5 GeV
  - $e^-$ (HER) : 8.0 GeV
- $E_{CM}$ : 10.58 GeV at Y(4S)
- Luminosity: Ultimately reached $2 \times 10^{34}$
  - Target: $10^{34} \text{ cm}^{-2}\text{s}^{-1}$
  - Achieved: $4 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
- $\pm 11$ mrad crossing angle
- Small beam sizes:
  - $\sigma_y \approx 3 \mu\text{m}$; $\sigma_x \approx 100 \mu\text{m}$
KEKB’s Special Features

- Small beam sizes ⇒ low beam currents
  - $4.5 \times 10^{33}$ with less than 1 Amp in each ring
- ± 11 mrad beam crossing angle
  - No bending magnets near the IR
  - Fewer spent particles into Belle
  - Synchrotron X-rays easily expelled
Belle special feature: Detect $K_L$s

1) $J/\psi \rightarrow l^+ l^- + K_L$

2) Assume $B \rightarrow J/\psi K_L$:
   compute $P_{KL}$

3) Remove reconstructed
   $B \rightarrow J/\psi K, J/\psi K^*, \ldots$

4) Cut on a likelihood
   based on kinematical
   and shape quantities

5) Plot $P_B^* = |P_{J/\psi} + P_{KL}|$

6) $B \rightarrow J/\psi K_L$ & $B \rightarrow J/\psi K_S$ have opposite CP & asymmetries
Belle results at LP-2001 Rome

Combine $q$, $\xi_f$ & $\Delta t$

- raw data
- more $B^0$s
- more $\bar{B}^0$s

July 23-28, 2001  LP01, Rome  The Belle Collaboration
Belle Results LP-2001 Rome

$\sin2\phi_1$ value that maximizes $\Pi_i L_i$

$\sin2\phi_1 = 0.99 \pm 0.14 \text{ (stat)} \pm 0.06 \text{ (sys)}$

weighted by CP sensitivity

curve from unbinned fit

July 23-28, 2001  LP01, Rome  The Belle Collaboration
Belle Results LP-2001 Rome

Compare CP –1 and CP+1

- mostly $J/\psi K_S$
- mostly $J/\psi K_L$

\[ \sin 2\phi_1 \]

- CP-1: $0.84 \pm 0.17$
- CP+1: $1.31 \pm 0.23$

(statistical errors only)
BaBar/Belle comparison (LP2001)

<table>
<thead>
<tr>
<th></th>
<th>BaBar</th>
<th>Belle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Luminosity</td>
<td>23fb⁻¹</td>
<td>33fb⁻¹</td>
</tr>
<tr>
<td>$K_2(\pi+\pi^-)$ $J/\psi$ events (purity)</td>
<td>316(96%)</td>
<td>457 (97%)</td>
</tr>
<tr>
<td>$K_L$ $J/\psi$ events (purity)</td>
<td>273(51%)</td>
<td>569 (61%)</td>
</tr>
<tr>
<td>Other CP modes</td>
<td>214</td>
<td>366</td>
</tr>
<tr>
<td>Effective tagging effic (w)</td>
<td>26%</td>
<td>27%</td>
</tr>
<tr>
<td>$\sin^2\phi_1$</td>
<td>0.59±0.14±0.05</td>
<td>0.99±0.14±0.06</td>
</tr>
</tbody>
</table>
Unitary Triangle: then

Unitary Triangle: & now

CKM fitter 2015
The Nobel committee considered these to be Belle’s best results

Unitary Triangle: & now

CKM fitter 2015
Stockholm, December 2008
Not just B mesons

pioneering work in areas other than CPV & B physics

-- results with 100's of citations that non-specialists don’t know about --

▪ Discovery of anomalous $e^+e^- \rightarrow \bar{c}c\bar{c}c$ annihilations
  - challenge to NRQCD

▪ Clarifying the nature of the light Scalar mesons
  - $\Gamma(f_0(980)\rightarrow\gamma\gamma)$ measurement

▪ Collins Spin Fragmentation Function
  - spin analyzer for quark jets

▪ Is the “$\Upsilon(5S)$” the $\Upsilon(5S)$?
Pre-Belle: NRQCD predictions for $e^+e^- \rightarrow J/\psi + X$

- **Strong signal expected near** $p_{J/\psi}^* = \text{max}$

- **Total**
  - $\sigma(J/\psi + X) = (0.8\sim 1.7) \text{pb}$
  - $\sigma(J/\psi + (c\bar{c})) \approx 0.07 \text{pb}$

- **$e^+e^- \rightarrow J/\psi + gg$** expected to dominate

- **$e^+e^- \rightarrow J/\psi + c\bar{c}$**
2002 Belle measurements of $e^+e^- \rightarrow J/\psi + X$

$\sigma(e^+e^- \rightarrow J/\psi + X) = 1.47 \pm 0.16$ pb

Pakhlov et al. Belle PRD 88, 052001

No significant signal for $p^*_{J/\psi} > 4.5$ GeV

This is where color-octet $e^+e^- \rightarrow (J/\psi)c^+g$ would show up – if, in fact, it occurred.
2005 Belle study of $e^+e^- \rightarrow J/\psi + X$

3 discoveries in one plot!

i) no $e^+e^- \rightarrow J/\psi + gg$ signal for $M(gg)<3.0$ GeV

ii) $\sigma(e^+e^- \rightarrow J/\psi \eta_c) > 10x$ NRQCD prediction

iii) New XYZ particle

$\sigma(e^+e^- \rightarrow J/\psi \eta_c) \approx 25.6 \pm 4.4 \text{ pb} \Rightarrow > 2\text{chg}$

NRQCD < 2 fb
NRQCD vs Belle data

\[ \sigma(e^+e^- \rightarrow J/\psi + cc) \leq 0.1 \]
\[ \sigma(e^+e^- \rightarrow J/\psi + gg) = 1.72 \pm 0.14 \]

\[ e^+e^- \rightarrow J/\psi + gg \text{ strong for } p^* \approx 4.5 \]
\[ e^+e^- \rightarrow J/\psi + gg \approx 0 \text{ for } p^* \approx 4.5 \]
\[ \sigma(e^+e^- \rightarrow J/\psi \eta_c) \approx 2 \text{ pb} \]
\[ \sigma(e^+e^- \rightarrow J/\psi \eta_c) \approx 25.6 \pm 4.4 \text{ pb} \]

Pakhlov et al. Belle PRD 88, 052001

no color octet
NRQCD vs Belle data

The NRQCD community considers these to be Belle's best results:

- $\sigma(e^+e^- \rightarrow J/\psi + gg) \approx 2$ pb
  - Strong for $p^* \approx 4.5$
- $\sigma(e^+e^- \rightarrow J/\psi + cc) \approx 25.6 \pm 4.4$ pb
  - $\sigma(e^+e^- \rightarrow J/\psi + gg) \approx 1.72 \pm 0.14$

Pakhlov et al. Belle PRD 88, 052001

No color octet – – –
low-mass scalar meson puzzle
-- a 40 year-old puzzle in hadron physics --

the “light” scalar-meson nonet

\[ J^P=0^+ \]

\[ \begin{align*}
\pi^0 &\quad \kappa^0 &\quad \kappa^+ \\
800 &\quad 800 &\quad 800 \\
S &= +1 \\
\sigma &\quad f_0 &\quad a_0 \\
980 &\quad 980 &\quad 980 \\
S &= 0 \\
a_0^- &\quad a_0^+ &\quad \kappa^0 \\
800 &\quad 800 &\quad 800 \\
S &= -1 \\
Q &= -1 \quad L = 1 \\
Q &= +1 \\
\bar{S} &= -1
\end{align*} \]
In \( q\bar{q} \) meson octets, the \( I=1 \) state (here the \( a_0(980) \)) has no \( s \)-quarks, and is the lightest. Here, the \( a_0(980) \) Isospin triplet is the most massive.

- \( m(f_0(980)) \approx m(a_0(980)) \) implies “ideal” mixing & \textit{small} \( s \)-quark content in \( f_0(980) \).
- strong \( a_0(980) \) & \( f_0(980) \) couplings to \( K\bar{K} \) indicate strong OZI-rule violations.
\( \gamma\gamma \rightarrow \pi^+\pi^- \) as a probe \( f_0(980) \) structure

\[
\sigma(\gamma\gamma \rightarrow R \rightarrow \pi^+\pi^-) \propto \Gamma(R \rightarrow \gamma\gamma) \times Bf(R \rightarrow \pi^+\pi^-)
\]
World’s data on $\gamma\gamma \rightarrow \pi^+\pi^-$

Mori et al. Belle PRD 85, 051101

$\gamma\gamma \rightarrow \pi^+\pi^-$

$f_0(980)$?
World’s data on $\gamma\gamma \rightarrow \pi^+\pi^-$

Belle data: ~2 orders of mag. improvement
World’s data on $\gamma \gamma \rightarrow \pi^+ \pi^-$

Belle data only

Belle data: ~2 orders of mag. improvement
Results

PredicGons from different models

<table>
<thead>
<tr>
<th>Model</th>
<th>$\Gamma_{\gamma\gamma}$ [eV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$uubar, dbar$</td>
<td>$1300 – 1800$</td>
</tr>
<tr>
<td>$ssbar$</td>
<td>$300 – 500$</td>
</tr>
<tr>
<td>$KKbar molecule$</td>
<td>$200 – 600$</td>
</tr>
<tr>
<td>Four-quark</td>
<td>$270$</td>
</tr>
</tbody>
</table>

Probably a QM mixture of these with very little $uubar$ & $ddbar$
Similar improvements on other channels, mass ranges

<table>
<thead>
<tr>
<th>Process</th>
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<tr>
<td>$\pi^+\pi^-$</td>
<td>PLB 615, 39 (2005)</td>
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<tr>
<td></td>
<td>PRD 75, 051101(R) (2007)</td>
</tr>
<tr>
<td></td>
<td>PLB 615, 39 (2005)</td>
</tr>
<tr>
<td>$\pi^0\pi^0$</td>
<td>PRD 78, 052004 (2008)</td>
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<tr>
<td></td>
<td>PRD 79, 052009 (2009)</td>
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<tr>
<td>$K^0_SK^0_S$</td>
<td>PLB 651, 15 (2007)</td>
</tr>
<tr>
<td></td>
<td>PTEP 2013, 123C01 (2013)</td>
</tr>
<tr>
<td>$\eta\pi^0$</td>
<td>PRD 80, 032001 (2009)</td>
</tr>
<tr>
<td>$\eta\eta$</td>
<td>PRD 82, 114031 (2010)</td>
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Similar improvements on other channels, mass ranges

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<tr>
<td>$\pi^0\pi^0$</td>
<td>PRD 78, 052003 (2008)</td>
</tr>
<tr>
<td>$K^0_sK^0_s$</td>
<td>PRD 80, 032001 (2009)</td>
</tr>
<tr>
<td>$K^0_sK^0_s$</td>
<td>JPC 123C01 (2013)</td>
</tr>
</tbody>
</table>

The scalar-meson community considers these to be Belle's best results.
Analyzing the spin of quarks

Theorists deal with quarks & gluons

Experimenters deal with jets

Relating partons to hadrons is a critical issue
quark fragmentation functions

Unpolarized quarks:

\[ D^h_q (z, P_{h\perp}) \]

Density of finding a hadron h with energy fraction \( z = P^h / P^q \) and \( |P_{h\perp}| \) in a jet produced by a parton q

Belle has done a lot of work on these
Collins spin fragmentation functions

Polarized quarks:

Asymmetries like this are seen seen in Hermes and Compass

\[ D_{q^\uparrow}^h(z, P_{h\perp}) = D_{1,q}^h(z, P_{h\perp}^2) + H_{1,q}^{\perp h}(z, P_{h\perp}^2) \frac{(\hat{k} \times P_{h\perp}) \cdot S_q}{z M_h} \]


To measure \( H \), a source of quarks with known polarization is needed 😞
Use spin correlations in $e^+e^- \rightarrow q\bar{q}$

\[
\frac{d\sigma(e^+e^- \rightarrow h_1h_2X)}{d\Omega dz_1dz_2d^2q_T} = \cdots B(y)\cos(\varphi_1 + \varphi_2)H_1^{\perp[1]}(z_1)\overline{H}_1^{\perp[1]}(z_2)
\]

\[
B(y) = y(1-y)^{cm} = \frac{1}{4} \sin^2\Theta
\]

Net (anti-)alignment of transverse quark spins

1st observation of a Collins-type $\cos(\phi_1 + \phi_2)$ asymmetry
Results

\[ A_{12}(z_1, z_2) \propto H(z_1) \overline{H}(z_2) \]

5% \( A_{12} \) asymm \( \rightarrow \) 22% \( H(z) \) asymm
The spin-physics community considers these to be Belle's best results.

$$A_{12}(z_1, z_2) \propto H(z_1) \overline{H}(z_2)$$

5% $A_{12}$ asymm $\Rightarrow$ 22% $H(z)$ asymm
Is the “\(\Upsilon(5S)\)” the \(\Upsilon(5S)\)

\[\Upsilon(4S)\]

“\(\Upsilon(5S)\)” “\(\Upsilon(6S)\)”
\[ \Upsilon(4S) \rightarrow \pi^+\pi^- \Upsilon(1S) ? \]

2M_b = 10358.7 MeV

Spin and Orbital Angular Momentum

Mass (GeV)

\[ \Upsilon(5S) \]

\[ \Upsilon(4S) \]

\[ \eta_b(3S) \Upsilon(3S) \]

\[ \eta_b(2S) \Upsilon(2S) \]

\[ \eta_b(1S) \Upsilon(1S) \]

\[ \eta_b(2P) \Upsilon_b(2P) \]

\[ \eta_b(1P) \Upsilon_b(1P) \]

Open Beauty Threshold

CLEO 85

\[ \Upsilon(4S) \]
Belle: $\Gamma_{\Upsilon(4S) \rightarrow \pi^+\pi^-\Upsilon(1S)}$

477 fb$^{-1}$

<table>
<thead>
<tr>
<th>$N(\Upsilon_{4S})$</th>
<th>$N(\pi^+\pi^-\Upsilon_{1S})$</th>
<th>$B(\Upsilon_{4S} \rightarrow \pi\pi\Upsilon_{1S})$</th>
<th>$\Gamma(\Upsilon_{4S} \rightarrow \pi\pi\Upsilon_{1S})$</th>
<th>$\Gamma_{\text{theory}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$535 \times 10^6$</td>
<td>$52 \pm 10$</td>
<td>$9 \pm 2 \times 10^{-5}$</td>
<td>$1.75 \pm 0.35$ keV</td>
<td>$1.47 \pm 0.03$ keV</td>
</tr>
</tbody>
</table>

Belle: PRD 75 071103
“ϒ(5S)” → π⁺π⁻ ϒ (1S)?
Belle: $\Gamma \ "\gamma(5S)" \rightarrow \pi^+\pi^- \gamma(1S)$

$\sim 1/20^{th}$ the data $23.6 \text{ fb}^{-1}$ vs $477 \text{ fb}^{-1}$

$\sim 1/5^{th}$ the cross-section

325±20 evts!

Chen et al (Belle) PRL 100, 112001
$$\Gamma \Gamma^{(5S)} \rightarrow \pi^+\pi^- \Gamma (1S) \approx 300 \times \Gamma \Gamma^{(4S)} \rightarrow \pi^+\pi^- \Gamma (1S)$$

<table>
<thead>
<tr>
<th>state</th>
<th>N($\gamma_{ns}$)</th>
<th>N_{evts}</th>
<th>$\Gamma (\gamma_{4s} \rightarrow \pi\pi\gamma_{1s})$</th>
<th>$\Gamma_{theory}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_{4s}$</td>
<td>535M</td>
<td>52±10</td>
<td>1.8±0.4 keV</td>
<td>1.5 keV</td>
</tr>
<tr>
<td>“$\gamma_{5s}$”</td>
<td>4.4M</td>
<td>325±20</td>
<td>590±80 keV</td>
<td>&lt;1.5 keV</td>
</tr>
</tbody>
</table>

~300x too large!!
Something anomalous near “ϒ(5S)”

\[ M = (10,882 \pm 2) \text{ MeV} \]

\[ M = (10,891 \pm 3) \text{ MeV} \]

\[ \delta M = (9 \pm 3) \text{ MeV} \]

-- two different, nearly overlapping states?

-- new dynamics at the \( \Upsilon(5S) \)?

-- influence of b-sector XYZ states?

Belle Santel et al. (Belle) arXiv:1501.01137

Bonder et al. (Belle) PRL, 108, 122001
Something anomalous near “ϒ(5S)”

M = (10,882 ± 2) MeV

M = (10,891 ± 3) MeV

δM = (9 ± 3) MeV

Belle

Santel et al. (Belle)  arXiv:1501.01137

Bonder et al. (Belle)  PRL, 108, 122001

π⁺π⁻ϒ(1S)

π⁺π⁻ϒ(2S)

π⁺π⁻ϒ(3S)

A work in progress
# Belle citation summary

<table>
<thead>
<tr>
<th>Citation summary results</th>
<th>Citeable papers</th>
<th>Published only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of papers analyzed:</td>
<td>1,371</td>
<td>602</td>
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<tr>
<td>Total number of citations:</td>
<td>33,539</td>
<td>28,901</td>
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<tr>
<td>Average citations per paper:</td>
<td>24.5</td>
<td>48.0</td>
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<tr>
<td>Breakdown of papers by citations:</td>
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<td></td>
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<tr>
<td>Renowned papers (500+)</td>
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<tr>
<td>Famous papers (250-499)</td>
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<td>14</td>
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<td>Very well-known papers (100-249)</td>
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<td>Well-known papers (50-99)</td>
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<td>Less known papers (1-9)</td>
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<tr>
<td>Unknown papers (0)</td>
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<tr>
<td>$h_{\text{HEP}}$ index [2]</td>
<td>91</td>
<td>89</td>
</tr>
</tbody>
</table>
Summary

- Belle was successful
- It answered a number of questions
- And raised a number of new ones
Summary

- Belle was successful.
- It answered a number of questions and raised a number of new ones.

We are looking for to BelleII, -- and the next talk--
Thank You

Спасибо

감사합니다

どううありがとうございます