High-resolution Measurements of Total Cross Section for Electron Scattering from Atoms and Molecules at Very-low-energy

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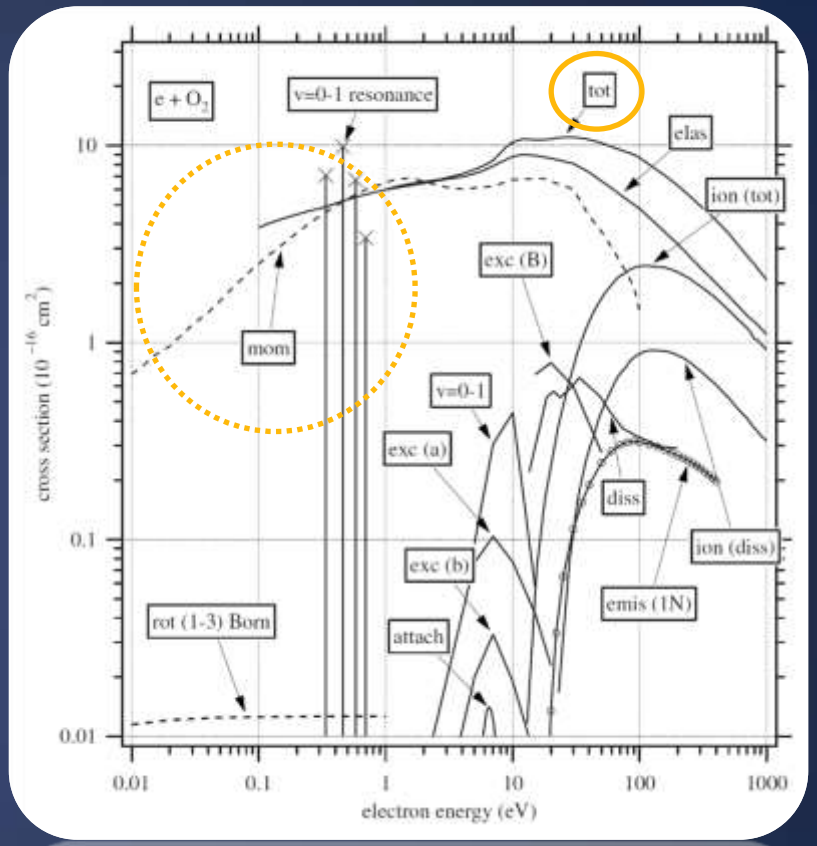
Present talk

- Our recent results for high-resolution measurements of the **grand total cross sections** for electron scattering from
  - Noble gas atoms; He, Ne, Ar, Kr, Xe
  - Small molecules; N_2, O_2, H_2 , D_2 (tentative)
- **Collision energy**; below 10 **meV** – 20 eV
- **Energy width** of the incident electron beam; 5 - 15 meV
- ***Total cross sections***
  - **Absolute values** are measurable accurately (No need of normalization)
  - Many **good** total cross section data have been reported
- High-resolution and very-low-energy (below a few hundred **meV**)

  - Long de-Broglie wave length of the electron
  - Nuclear motions may play important role in the scattering

Electron collision cross section data set of O_2

- Cross sections for
  - Elastic scattering
  - Inelastic scattering
    - Rotational excitation
    - Vibrational excitation
    - Electronic excitation
    - Ionization
    - Electron attachment
  - (Grand) Total Cross Sections
- Cross section data are still missing
  - Very-low energy region
  - Behavior around the resonances



High-resolution measurements provide deeper insight

Y. Itikawa, J. Phys. Chem. Ref. Data **38**, 1 (2009)

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Experimental techniques on total cross section measurements

- Beam experiments
  - Single collision condition
    - **Direct way to obtain cross sections**
  - Electron source; hot filament
    - Space charges, energy distributions, etc., prevents stable experiment below a few hundred meV.
  - Approaches to the lower energies and high-resolution
    - Time of Flight type apparatus

      J. Ferch *et al*., J. Phys. B **13**, 1481 (1980)

      S.J. Buckman and B. Lohmann, J. Phys. B **16**, 2547 (1986)
    - Photoelectrons using VUV emission lines of atoms

      V. Kumar *et al*. J. Phys. B **20** 2899 (1987)
  - Electron scattering experiment at very-low energy
    - Photoelectron source utilizing **Synchrotron Radiation**
      - Electron energy; below10 meV ~ 2 eV

      D. Field *et al*., Meas. Sci. Technol. **2**, 757 (1991)

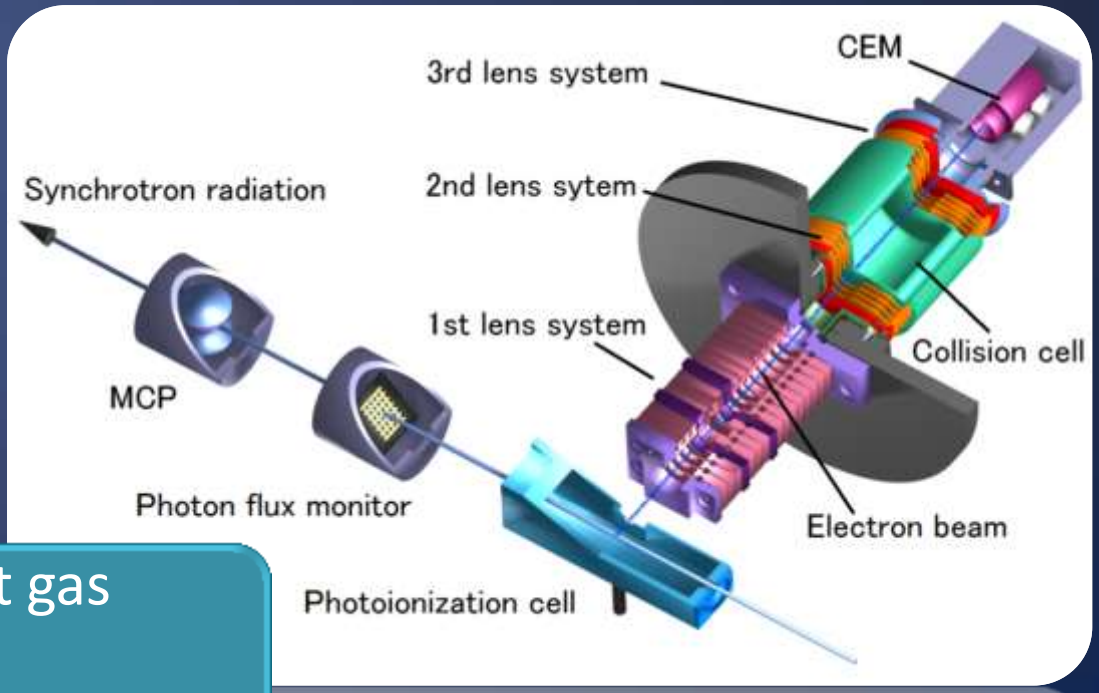
      S. V. Hoffman *et al*., Rev. Sci. Instrum. **73**, 4157 (2002)

Present Experimental Technique

- Threshold photoelectron source
  - Threshold photoelectrons
  - Penetrating field technique
    - **Synchrotron Radiation (SR)**
      - **Top-Up operation**

$$Ar + h\nu \rightarrow Ar^{+}(^{2}P_{3/2}) + e(E_{ex})$$
$$h\nu \cong IP_{Ar} \Rightarrow E_{ex} \cong 0$$

- Electron beam with narrow energy width
  - 5 ~ 15 meV
- Very low electron energy
  - Below 10 meV



Versatile to target gas

⇓

Precision measurements

M. Kurokawa *et al.*, Phys. Rev. A **82**, 062707 (2010)

Uncertainty in the present data

- Cross sections (attenuation method)

$$\sigma(E) = \frac{1}{nl} \ln\left(\frac{I_0(E)}{I_t(E)}\right)$$

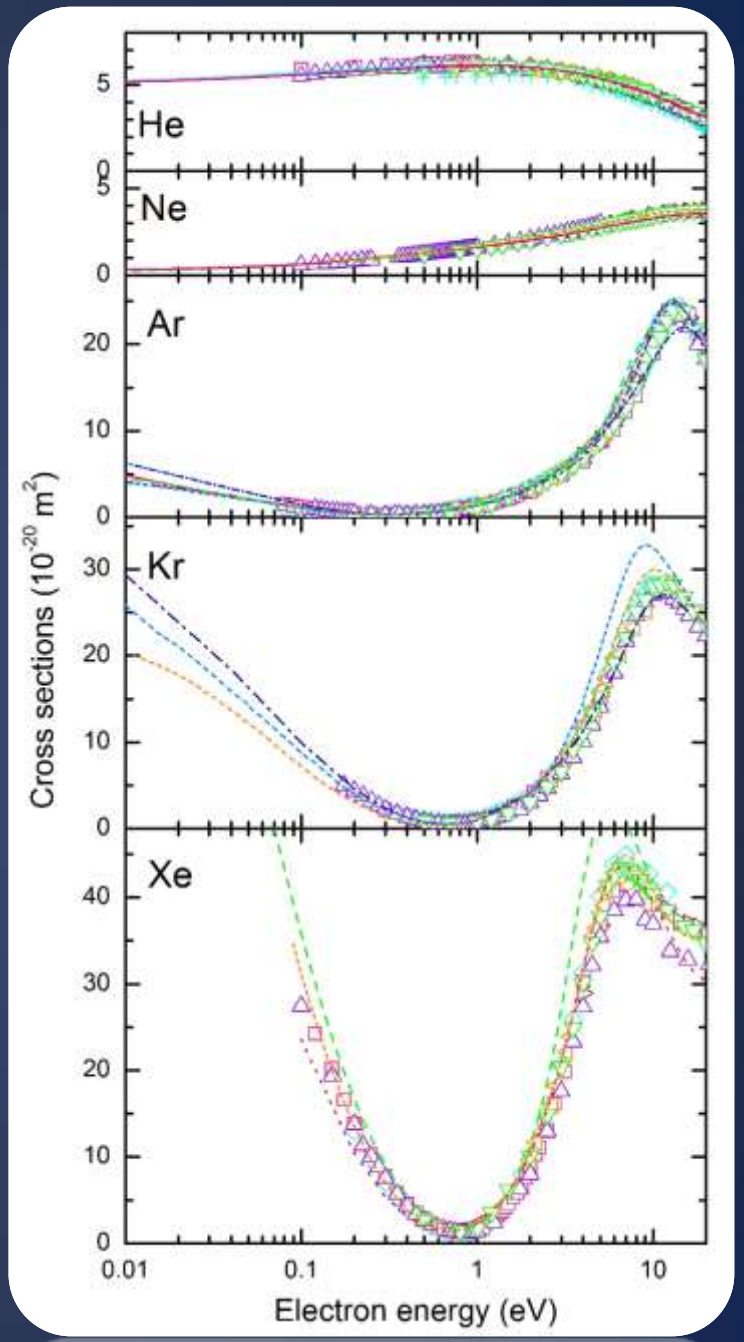
$\sigma(E)$	:	Total cross section
n	:	Number density
l	:	Collision Length
$I_0(E)$	:	Beam intensity without target
$I_t(E)$	:	Beam intensity with target

  - Systematic error ; n, l (less than 3 %) <Absolute scale>
  - Random error ; $I_0(E)$, $I_0(E)$ <Relative scale>
    - Statistical error of electron counts
    - Fluctuations of the electron beam intensity
      - Fluctuations of the SR light intensity distribution and wavelength
        - Instability of the SR ring and the SR beamline

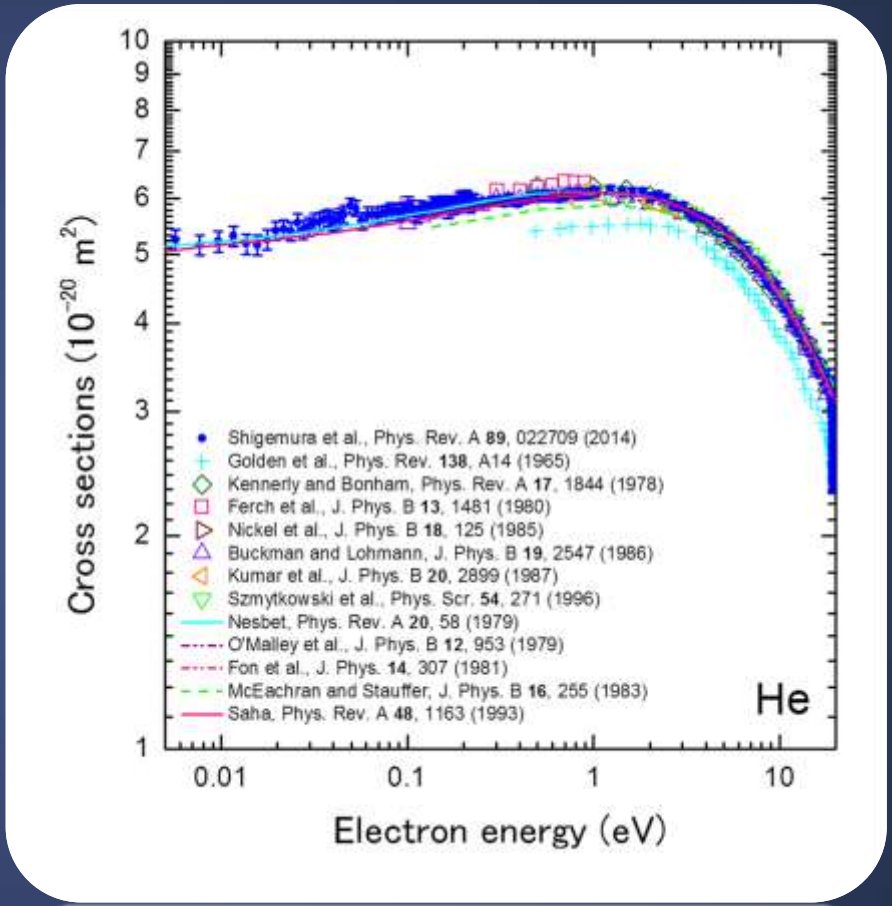
- Energy scale
  - Calibration of energy scale through resonances
    - Uncertainty 3 ~ 16 meV

Total cross sections for noble gases

- The total cross section curves of previous experiments agree reasonably well.
  - Characterized by a maximum at around 5–10 eV and the well-known Ramsauer-Townsend minimum below 1 eV for Ar, Kr, and Xe.
  - Experimental total cross sections obtained under the single collision condition has been limited to ~100 meV.
- Theoretical “standard cross sections” for He exists.

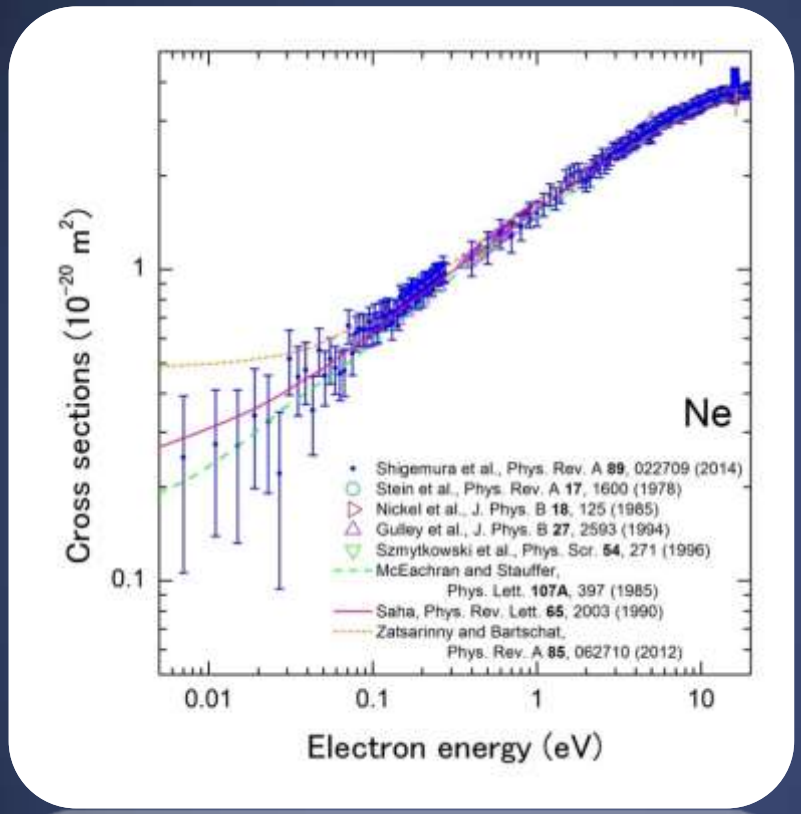


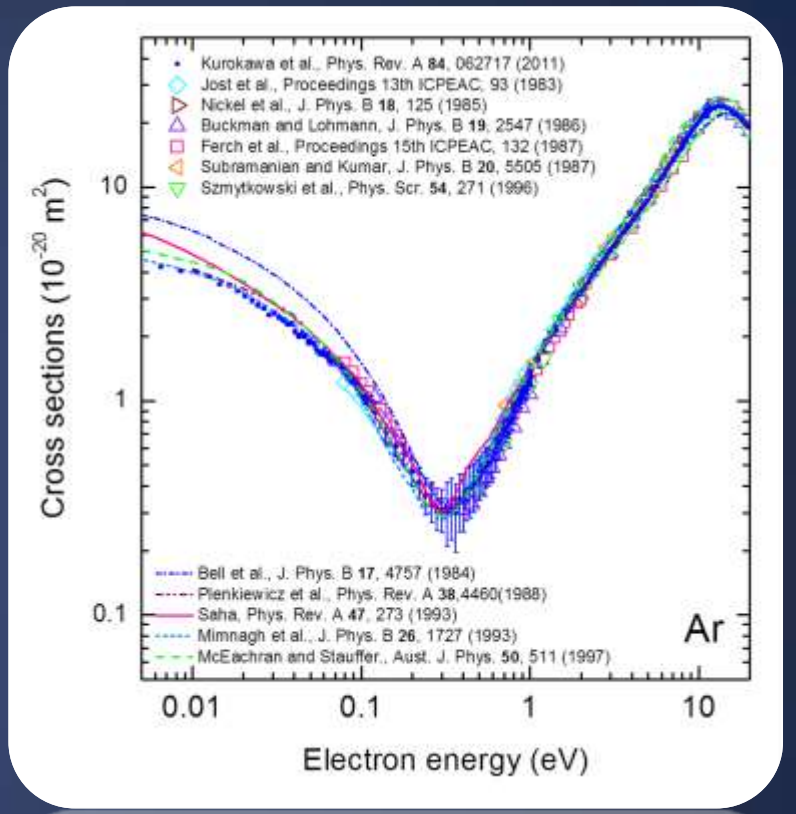
Total cross section of He



- Excellent agreement with the theoretical "standard" cross sections even below 100 meV

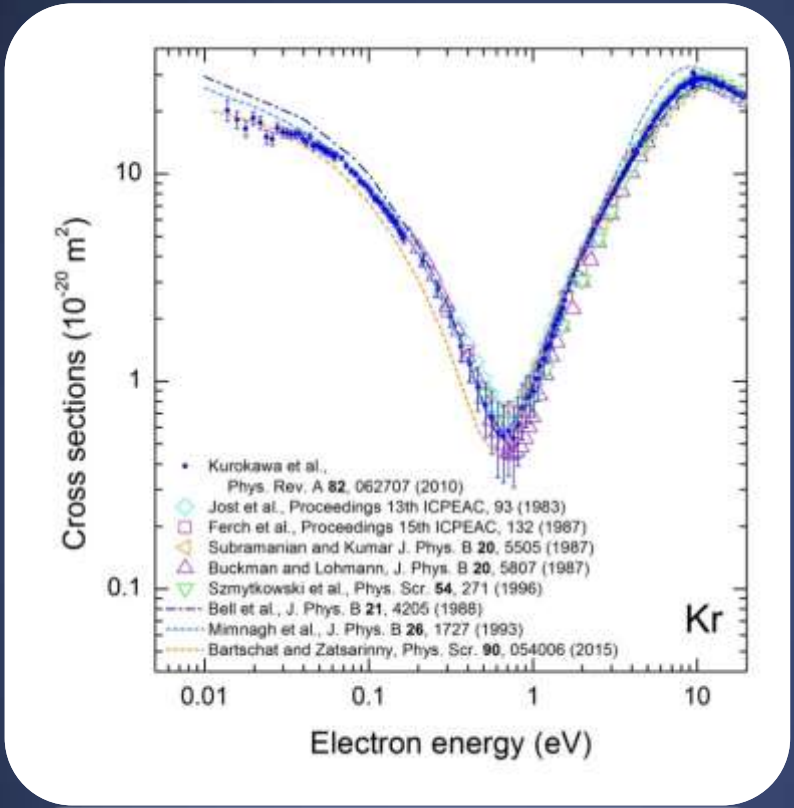
Total cross section of Ne and Ar

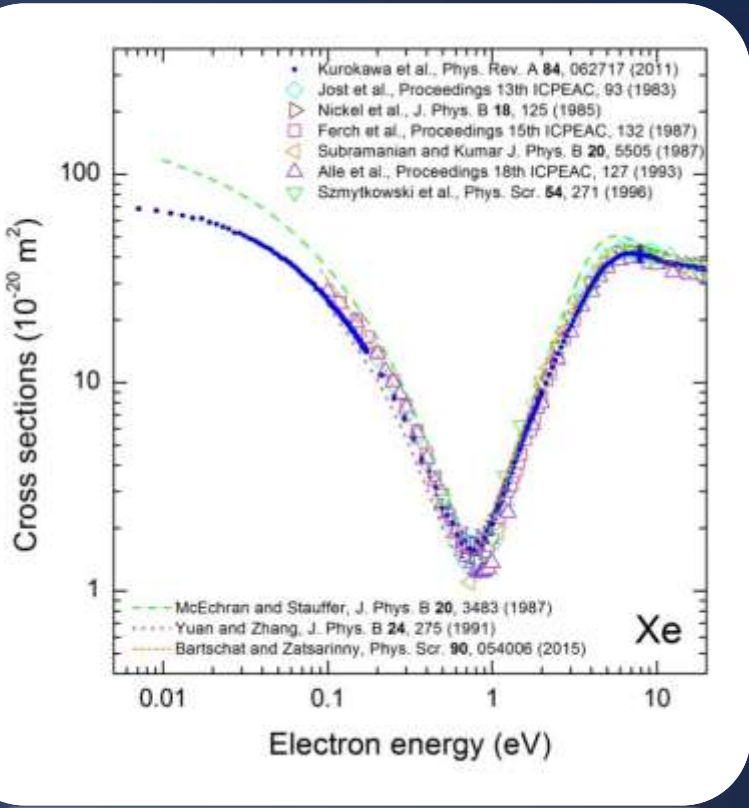




- Experimental cross sections agree with theoretical cross sections within the error bars at very low energies

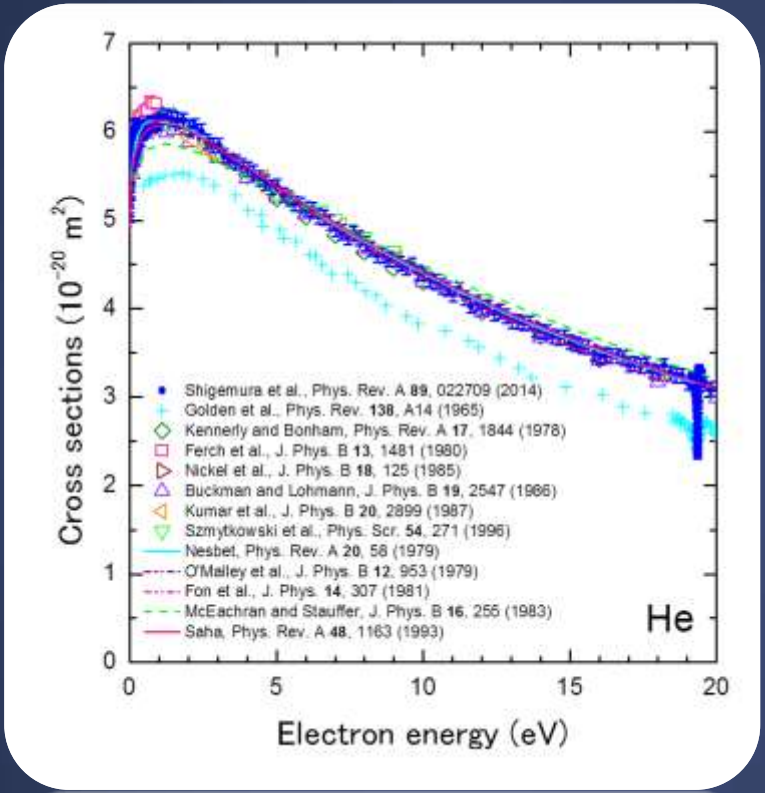
Total cross section of Kr and Xe

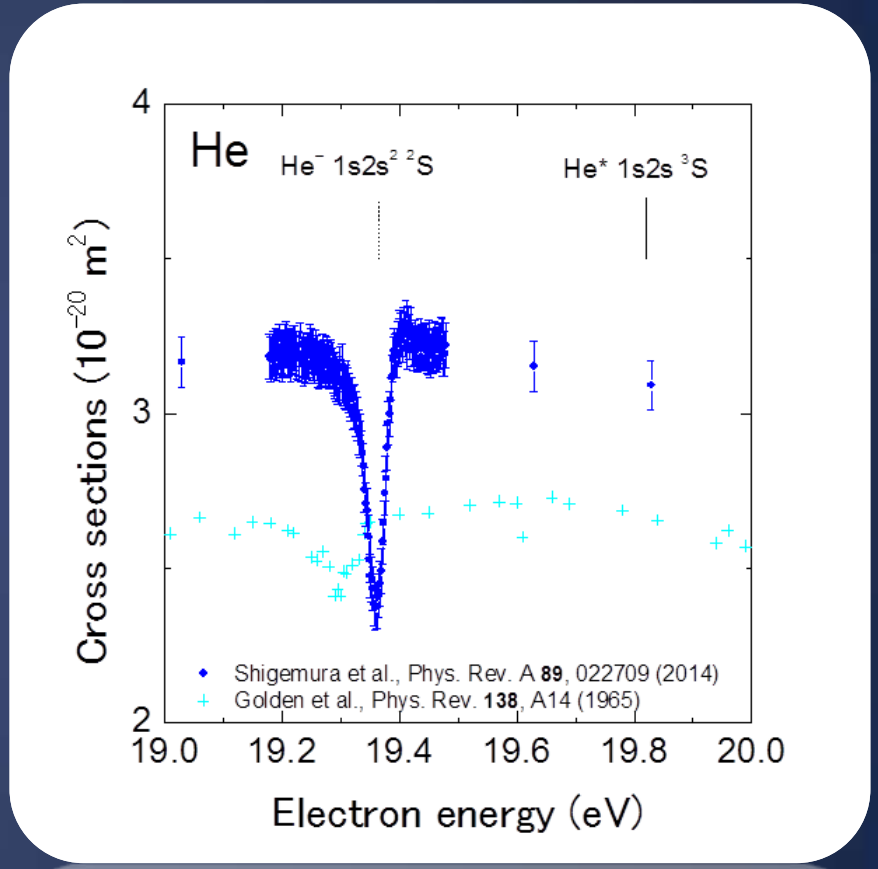




- Smaller cross sections compared to the theoretical cross sections at very low energies for Xe

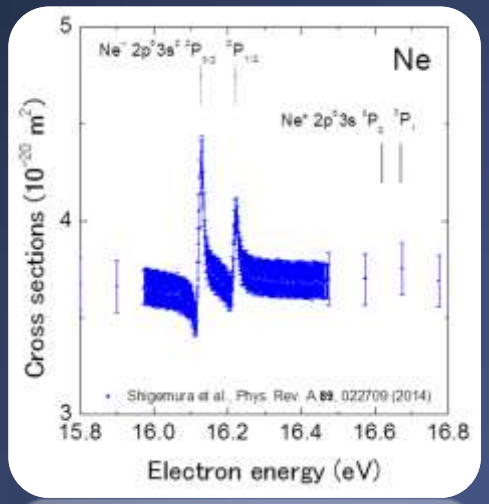
Total cross section of Feshbach resonance; He

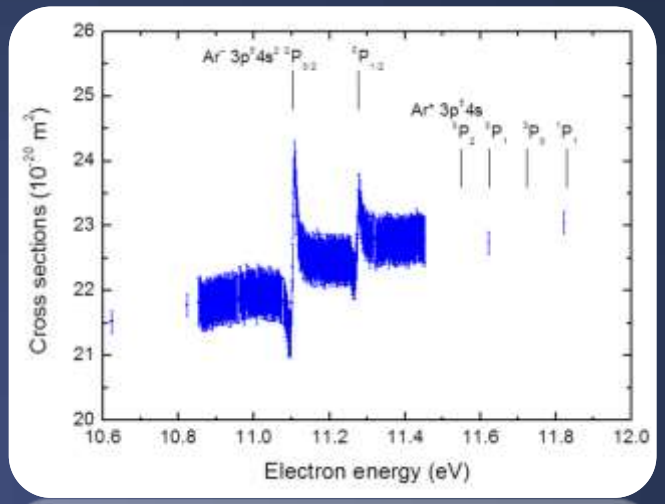


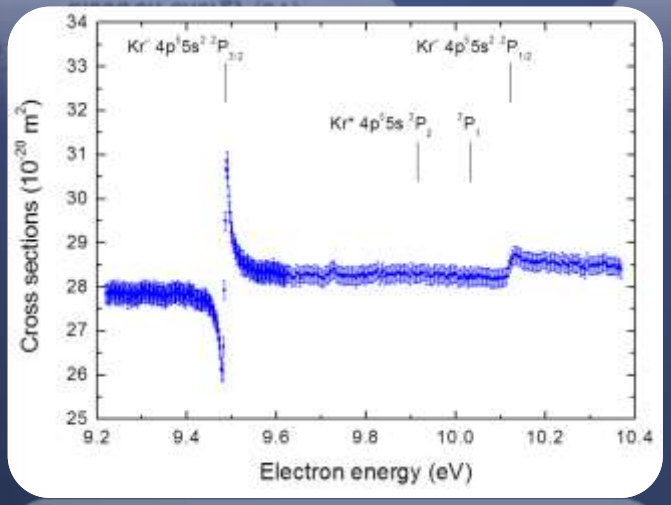


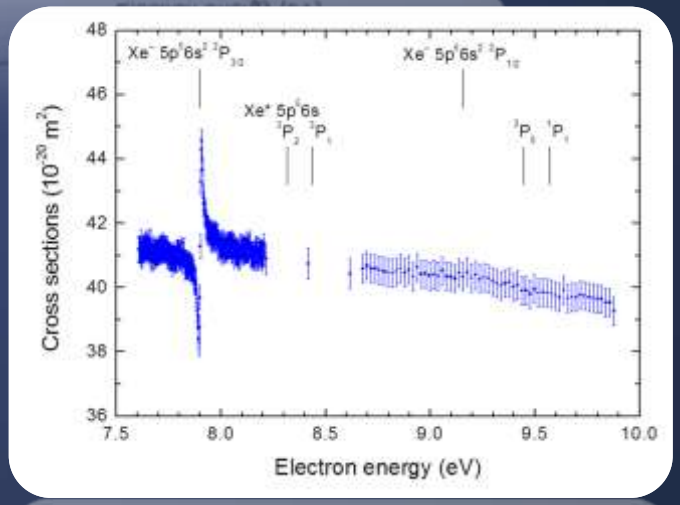
- Feshbach resonance (Γ = 9.2 meV)

Total cross section of Feshbach resonance; Ne, Ar, Kr and Xe









Ne; $\Gamma_{3/2,\,1/2}$ = 1.17±0.07 meV, Ar; $\Gamma_{3/2}$ = 2.3±0.2, $\Gamma_{1/2}$ = 2.4±0.4 meV

Kr; $\Gamma_{3/2}$ = 3.2±0.1 meV, Xe; $\Gamma_{3/2}$ = 4.1±0.2 meV

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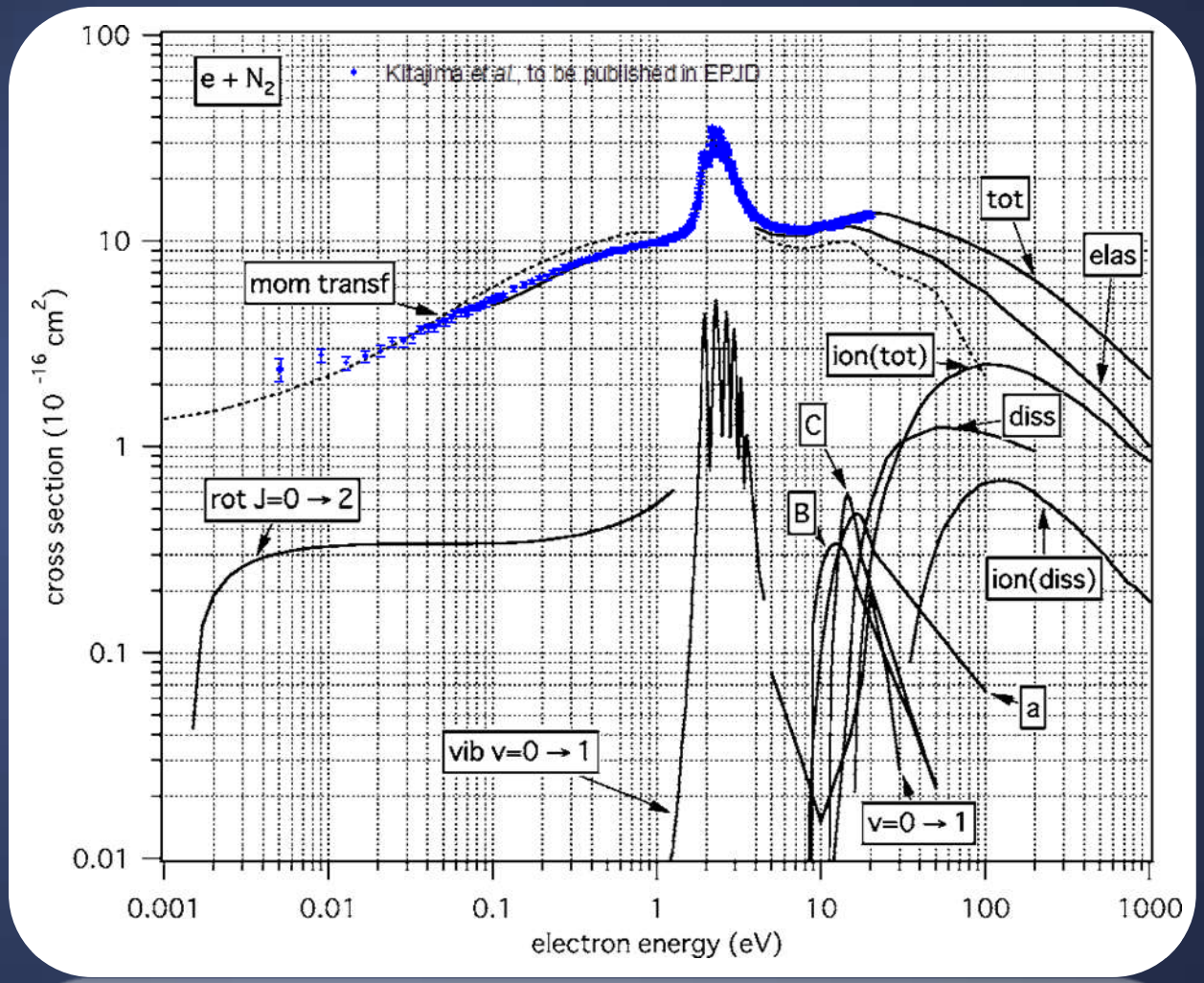
Total cross sections for small molecules

- N_2, O_2, H_2, and D_2
  - (Tentative results)

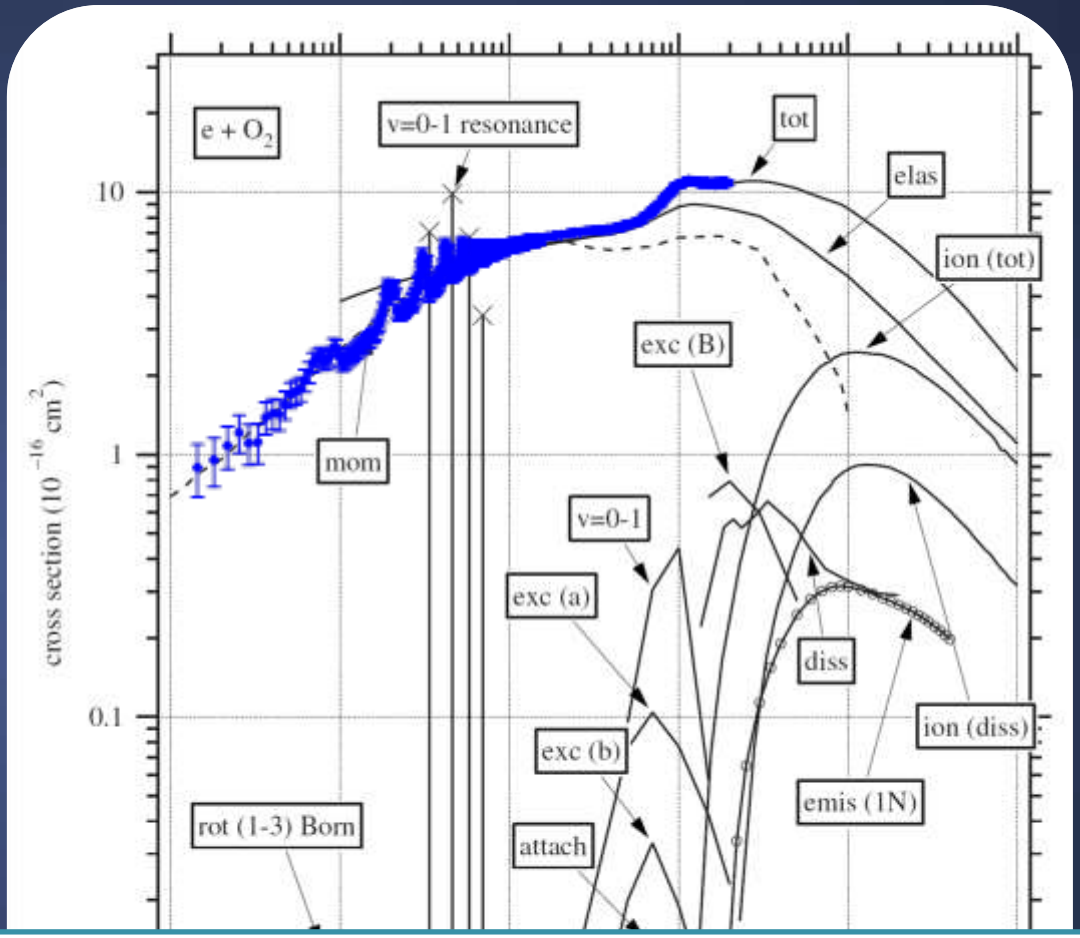
  - Measured with threshold photoelectron sources
    - Extending down the energy range
    - Resonance feature (Shape resonance, Feshbach resonance)
  - Comparison with cross section data sets

Cross section data set of N_2



Y. Itikawa, J. Phys. Chem. Ref. Data **35**, 31 (2005)

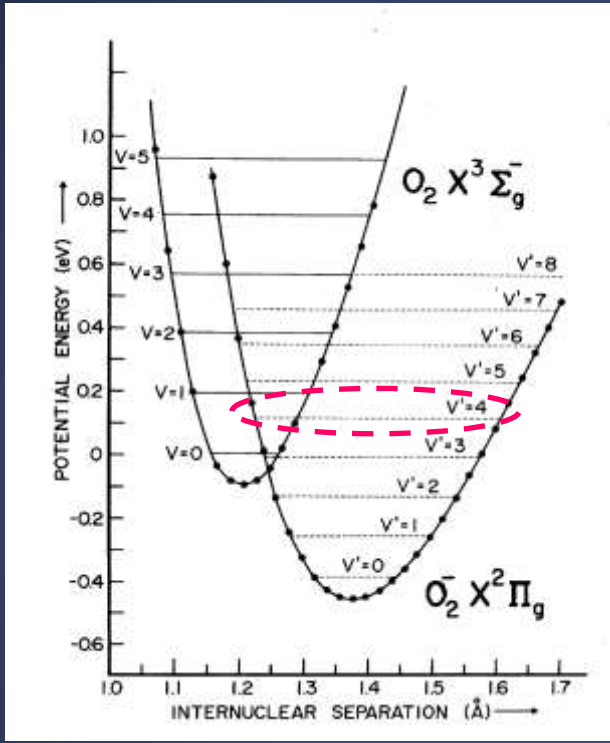
Cross section data set of O_2

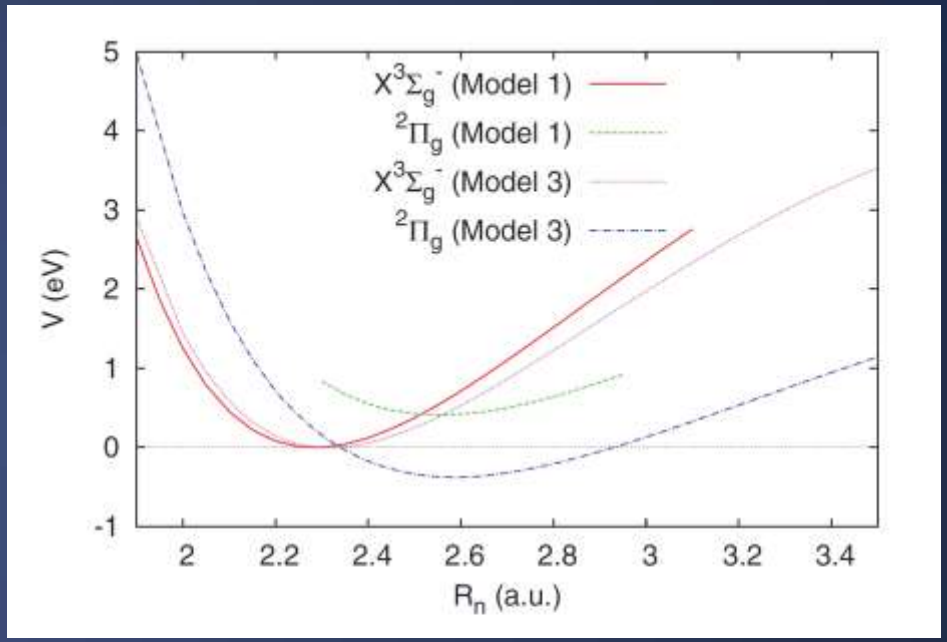


- Very large enhancement of the shape resonance
- Smaller value compared to recommended cross sections at lower energies

Y. Itikawa, J. Phys. Chem. Ref. Data **38**, 1 (2009)

Shape resonance of O_2



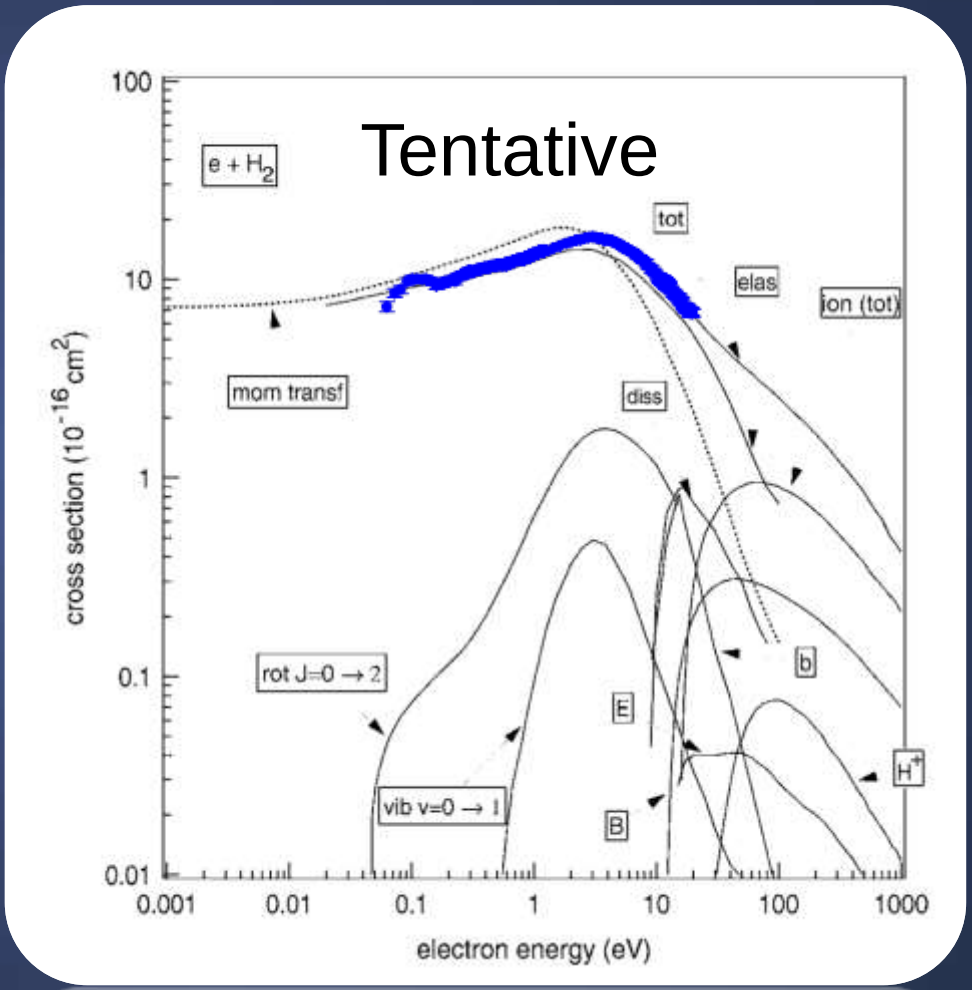


- Shape resonance with long life time
  - Temporary negative ion is formed

G. J. Schulz, Rev. Mod. Phys. **45**, 423 (1973)

M. Tarana and C. H. Greene, Phys. Rev. A **87**, 022710 (2013)

Cross section data set of H_2



Jung-Sik Yoon *et al*., J. Phys. Chem. Ref. Data **37**, 913 (2008)

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Summary

- Threshold photoelectron source
  - High-resolution measurements at very-low energy
    - Energy width of the electron beam 5 ~ 15 meV
    - Uncertainty for the energy scale 3 ~ 16 meV
  - Also capable for precision cross section measurements
    - Free from target gas effect around the electron source
    - Uncertainty of the cross section data are easier to be estimated
- Total cross section for scattering from He, Ne, Ar, Kr, and Xe
  - Theoretical cross sections for He known as the 'standard' also agree well with the experimental results at very-low energies
- Total cross section for scattering from O_2, N_2, H_2 and D_2
  - Rich resonance features, threshold cusps, …
  - Some of the recommended cross section should be modified for very-low energy region

Collaborators

- Tokyo Tech.
  - Keisuke Shigemura
  - Naomasa Kobayashi
  - Atsushi Sayama
  - Yuma Mori
  - Takuma Okumura
  - Atsushi Kondo
  - Manabu Kurokawa
  - Akira Sato
  - Kaiji Toyoshima
  - Takaya Kishino
  - Yuichiro Hirano
  - Koichi Hosaka
  - Noriyuki Kouchi
- Sophia Univ.
  - Hidetoshi Kato
  - Hirotomo Kawahara
  - Daisuke Suzuki
  - Kazutoshi Anzai
  - Atsushi Suga
  - Masamitsu Hoshino
  - Hiroshi Tanaka
  - Takeshi Odagiri
- KEK-PF
  - Kenji Ito

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		2016G521