X-ray spectroscopy at HITRAP

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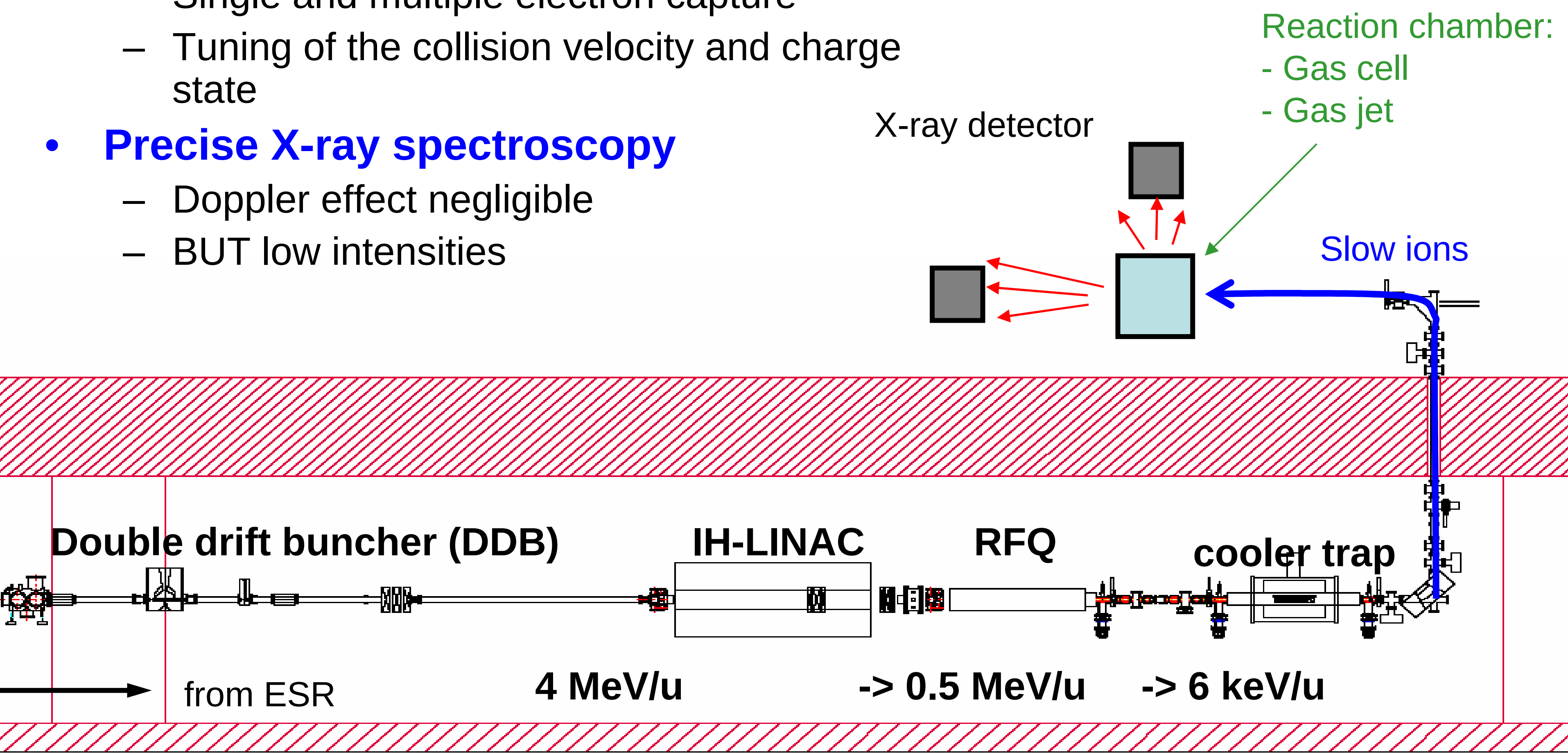
Summary

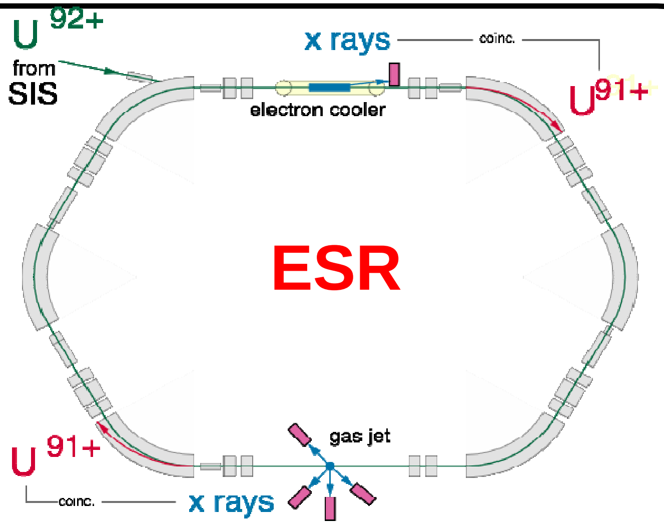
- X-ray spectroscopy at the ESR and HITRAP
- Charge exchange studies
- New large surface X-ray detectors
- Possible set-ups at HITRAP
- X-ray spectroscopy with microcalorimeters

X-ray spectroscopy at HITRAP

- **Ion-atom collision studies**
  - Single and multiple electron capture
  - Tuning of the collision velocity and charge state
- **Precise X-ray spectroscopy**
  - Doppler effect negligible
  - BUT low intensities



Spectroscopy at the ESR and HITRAP



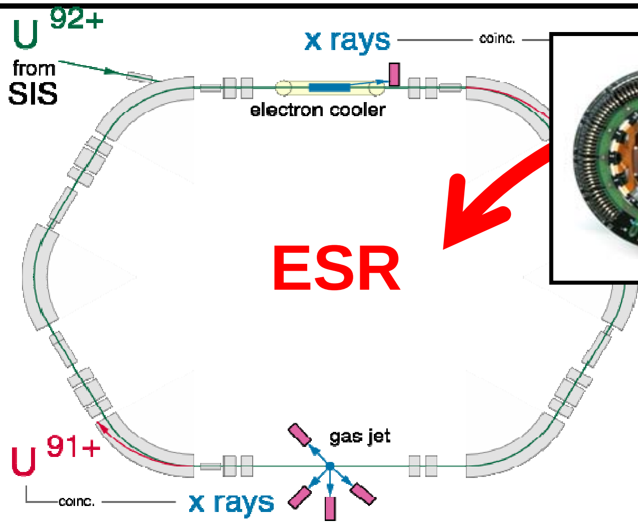
Ion energy: from 4 to 400 MeV/u
Revolution frequency: 2 MHz
Stored ions: ~10^8
=>"equivalent ion intensity" = 10^{14} ion/sec

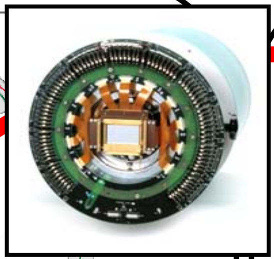
Ion energy: from few eV/u to ~20 keV/u
Ions intensity: ~10^4 ion/sec
Low Ion temperature

X-Ray Detection efficiency ~10^{-3}-10^{-8}

X-Ray Detection efficiency ~10^{-1}-10^{-7}

Spectroscopy at the ESR and HITRAP





Application of X-ray detection and coincidence techniques developed at the ESR !!!

First steps: simple experiments

=> large cross section

=> charge transfer processes

Ion-atom collisions at low velocity

Low charge ions

- Single and double capture studies
- UVH and X-ray spectroscopy
- Electron spectroscopy
- Coincidences with projectile and recoil ions

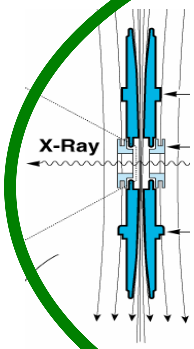
Highly charged ions (HCI)

- Ion-atom charge exchange in EBIT
- Few information for q > 50

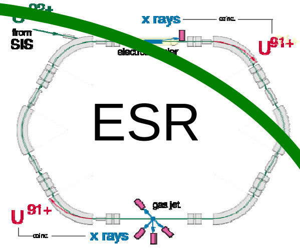
Discharge, hot cathode, ...

ECRIS

EBIT and EBIS



Super-EBIT

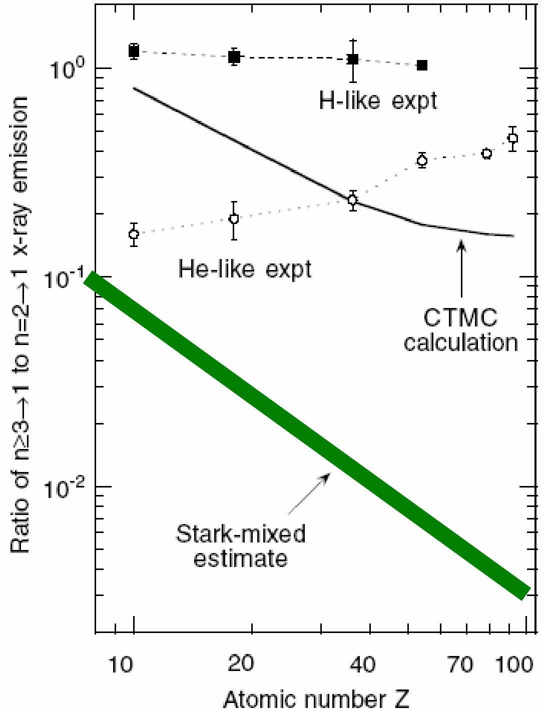


ESR

HITRAP

1+ 20+ 50+ 90+ q

Slow HCI-atom collisions



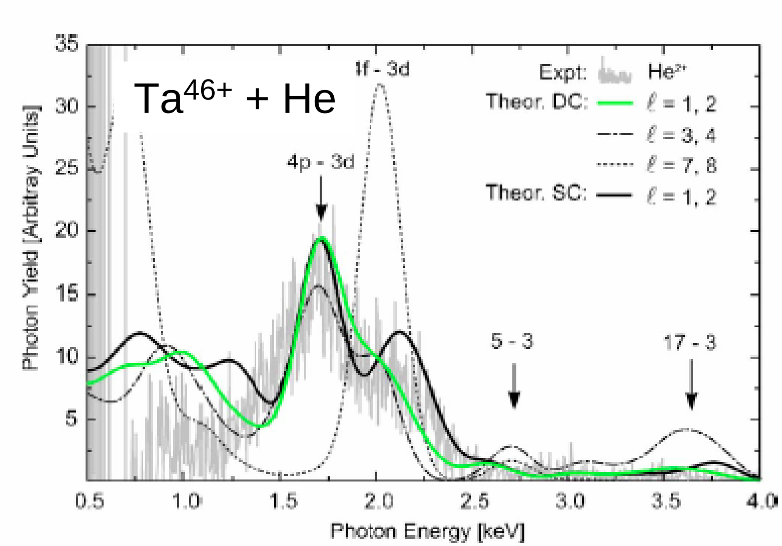
Super-EBIT [1]

- High charge state
- Velocity distribution
- No coincidences
- "Hot" ions
- Strong magnetic field

[1] Beiersdorfer et al., Phys. Rev.Lett. **85**, 5090 (2000).

EBIS [2]

- High-medium charge states
- Coincidence techniques
- "Hot" ions



[2] Madzunkov et al.Phys. Rev. A **73**, 032715-7 (2006).

Slow HCI-atom collisions at HITRAP

Low Ion temperature

Highly charged ions: up to q=92+

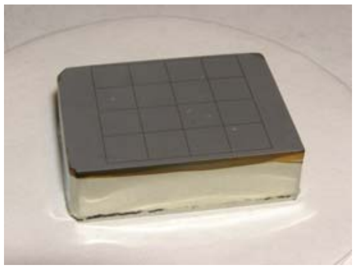
Selection of the ion charge state

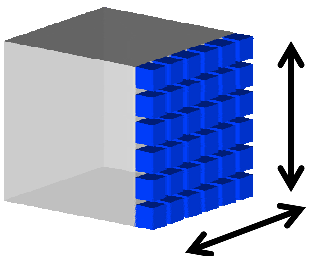
Selection of the ion velocity

Possible to apply coincidence techniques

New instruments: large position sensitive Ge detector

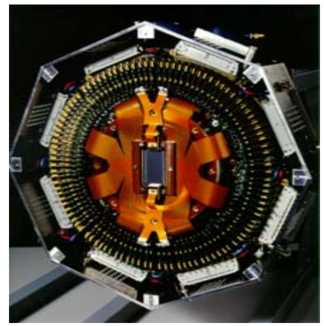
pixel detectors

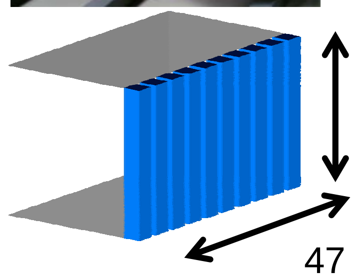




16 pixels

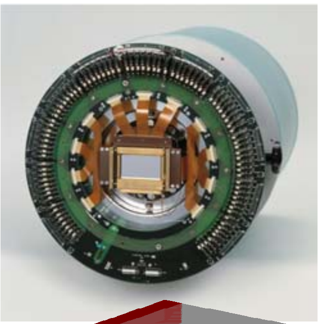
1D µ-strip detectors

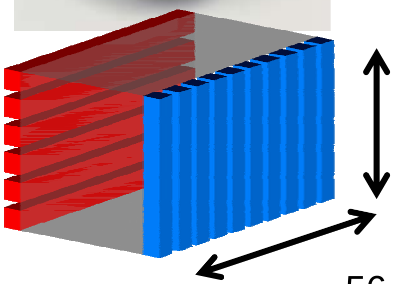




200 strips

2D µ-strip detectors





48 X 128 strips
equivalent to 6144 pixels

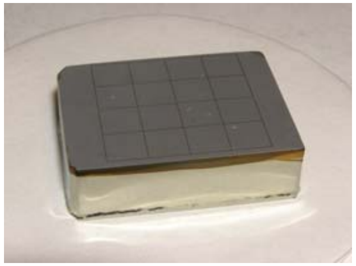
2D µSTRIP germanium detector

2D µ-strip Si(Li) detector arriving soon...

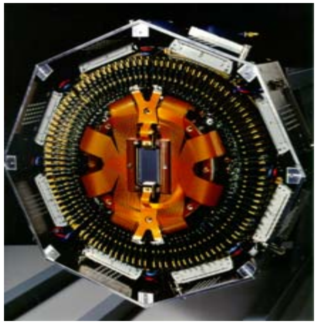
SPARC Stored Particles Atomic Physics Research Collaboration

New instruments:
large position sensitive Ge detector

pixel detectors

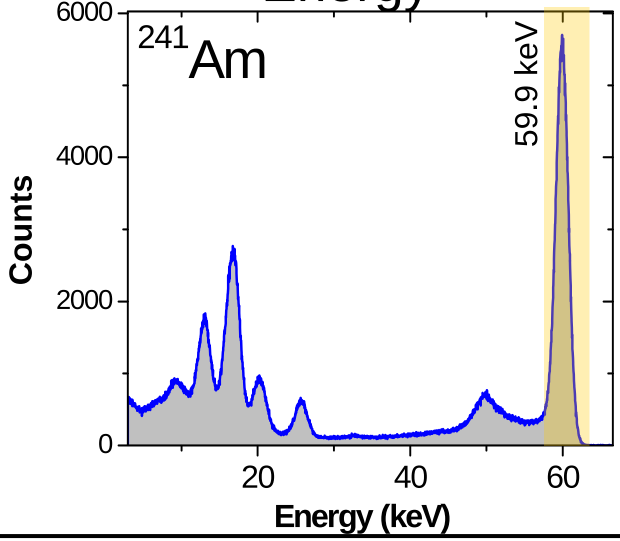


1D μ-strip detectors

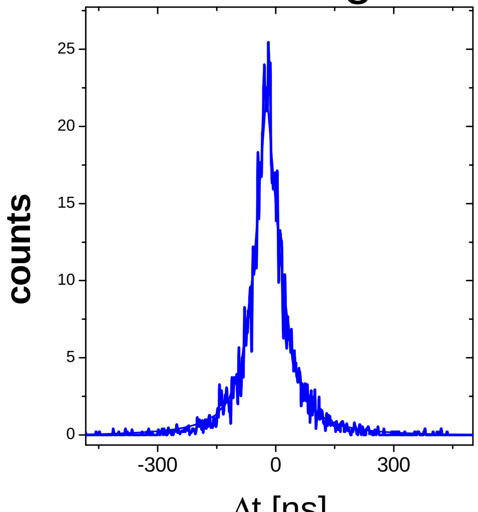


2D μ-strip detectors

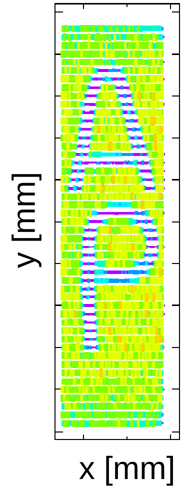
Energy



Timing

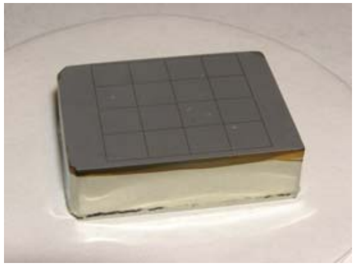


Position

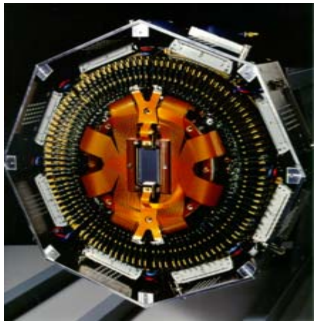


New instruments: large position sensitive Ge detector

pixel detectors [1,2]



1D μ-strip detectors [3]



2D μ-strip detectors [4,5]

Angular distribution measurement

Polarization detection (via Compton scattering)

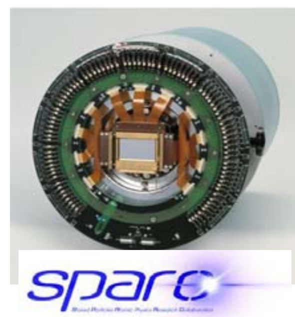
Lifetime measurement

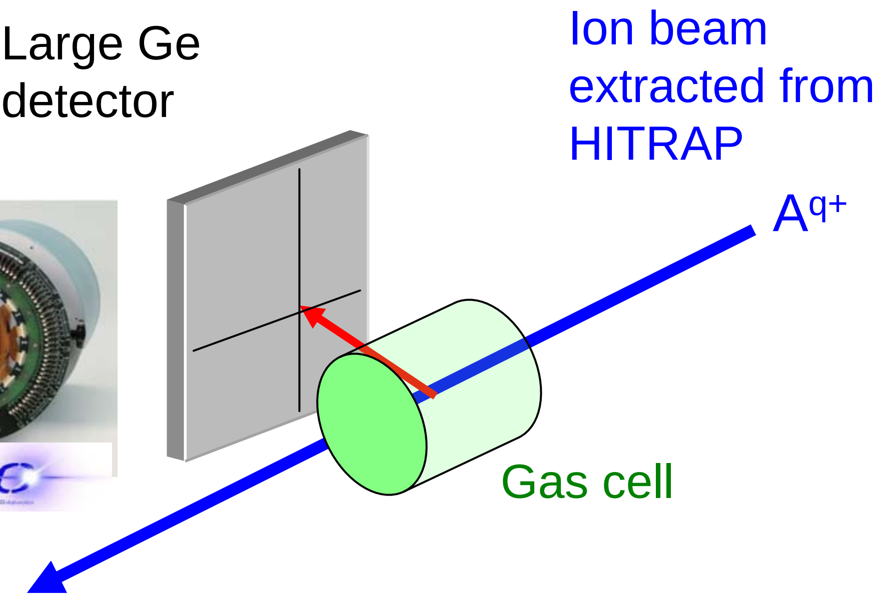
[1] S. Tashenov *et al.*, Physical Review Letters submitted (2006)
[2] S. Tashenov Ph.D. Thesis, University of Frankfurt, 2005
[3] D. Protic *et al.*, IEEE Transactions on Nuclear Science **48**, 1048-1052 (2001).
[4] D. Protic *et al.*, IEEE Transactions on Nuclear Science **52**, 3194-3198 (2005)
[5] U. Spillmann Ph.D. Thesis, University of Frankfurt, 2006 (to be finished)

New instruments + new facility =...

- **X-ray spectroscopy**

for nl -> 1s and Balmer transitions

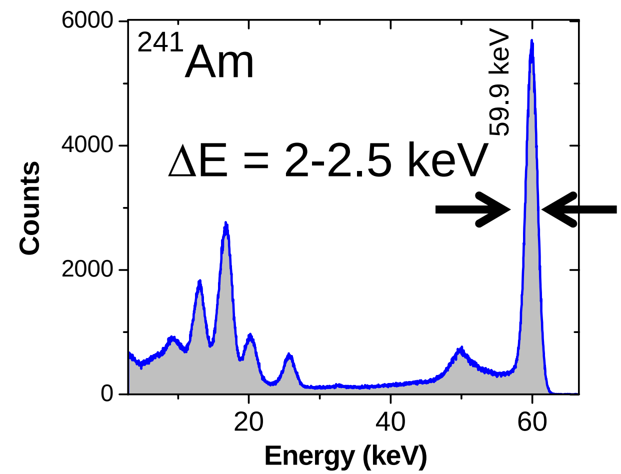




- Large solid angle: $\Omega/4\pi$ ~ 10-30%

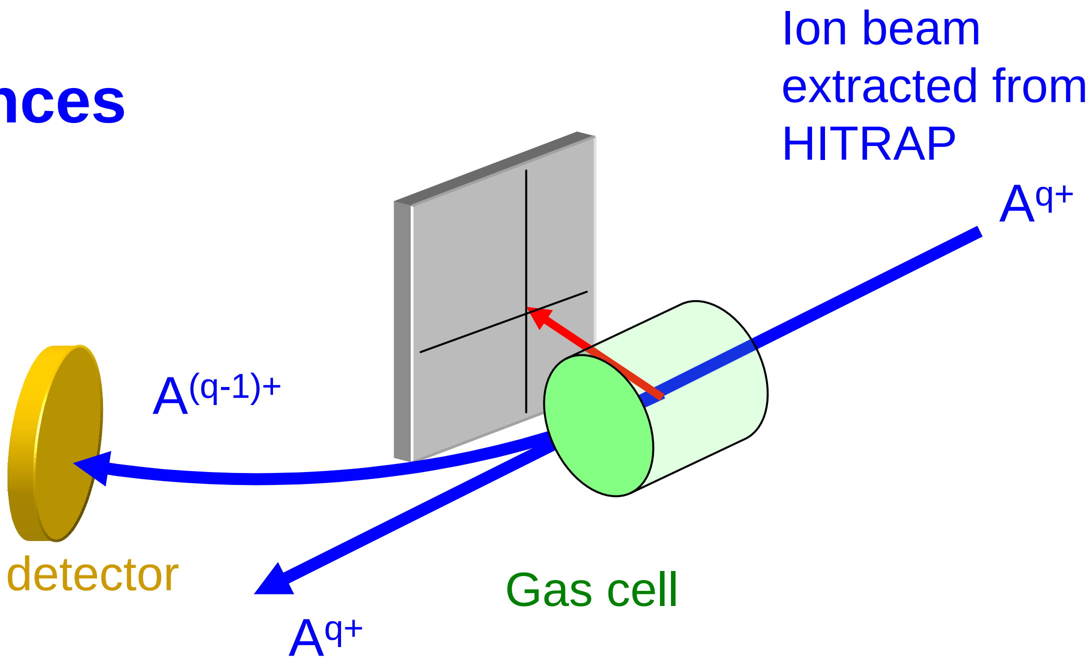
- Good energy resolution for 50-100 KeV photons

- High charge state -> high relative accuracy



New instruments + new facility =

- X-ray spectroscopy
- **Projectile-ion coincidences**

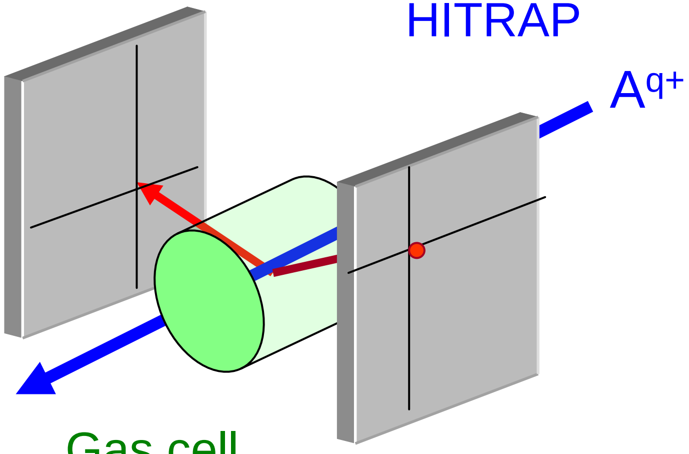


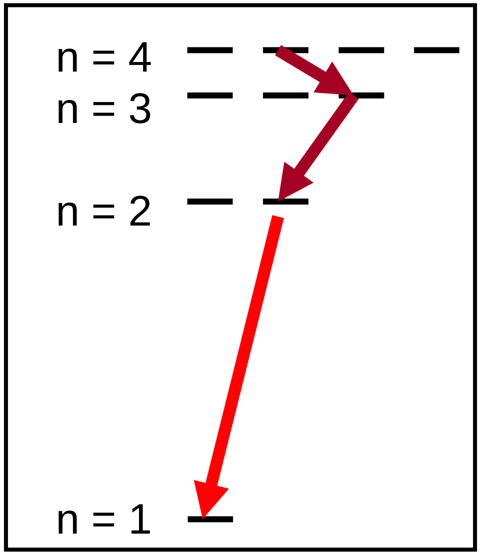
Selection of the capture process:

- single capture
- double capture
- ....

New instruments + new facility =

- X-ray spectroscopy
- Projectile-ion coincidences
- **X-X coincidences**



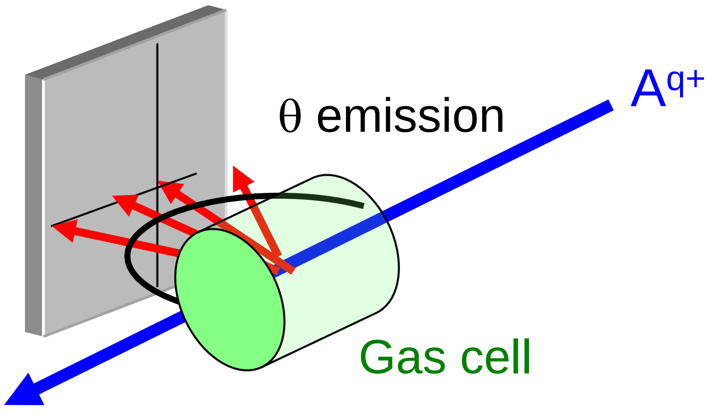


- Investigation of the cascade process

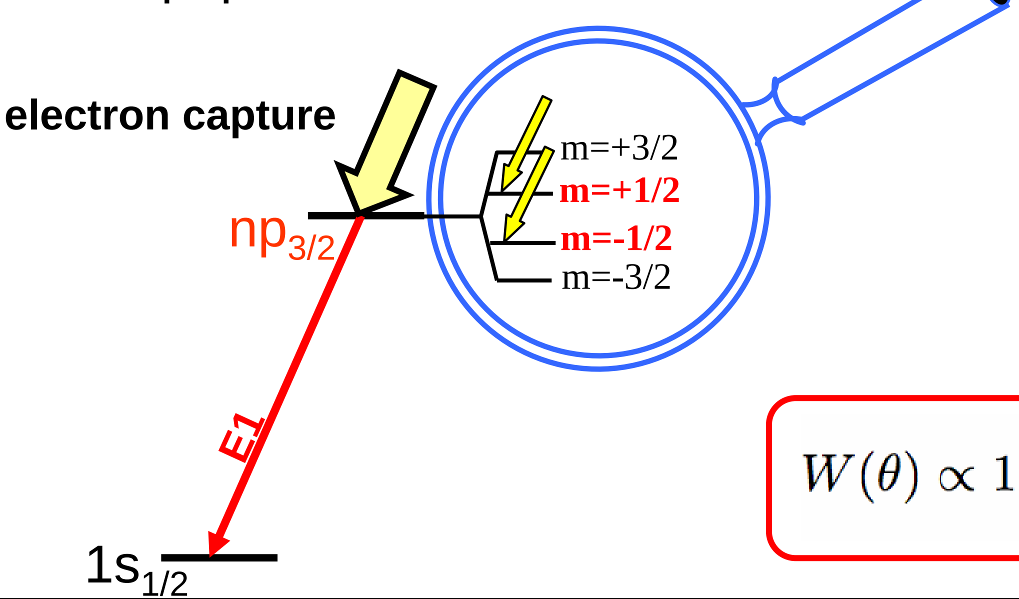
- Angular correlation measurement

New instruments + new facility =

- X-ray spectroscopy
- Projectile-ion coincidences
- X-X coincidences
- **Angular distribution**



Possibility to measure the alignment of the level population and distribution of <L>



Alignment Parameter

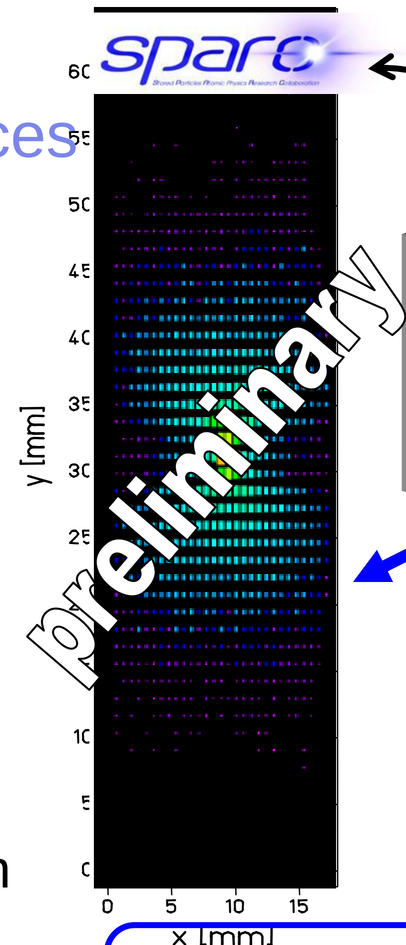
$$\beta_A = \frac{1}{2}\,\frac{\sigma\left(\frac{3}{2}\,\frac{3}{2}\right) - \sigma\left(\frac{3}{2}\,\frac{1}{2}\right)}{\sigma\left(\frac{3}{2}\,\frac{3}{2}\right) + \sigma\left(\frac{3}{2}\,\frac{1}{2}\right)}$$

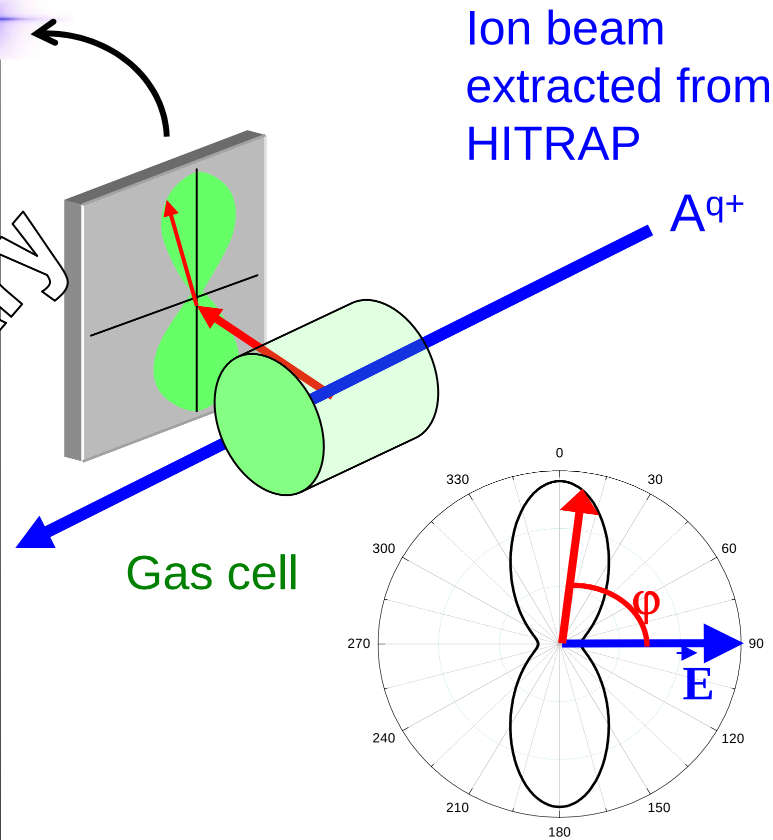
$$W(\theta) \propto 1 + \beta_A \left(1 - \frac{3}{2}\sin^2\theta\right)$$

New instruments + new facility =

- X-ray spectroscopy
- Projectile-ion coincidences
- X-X coincidences
- Angular distribution
- **Polarization**

Via Compton scattering





Possibility to measure the alignment of the level population and distribution of <L>

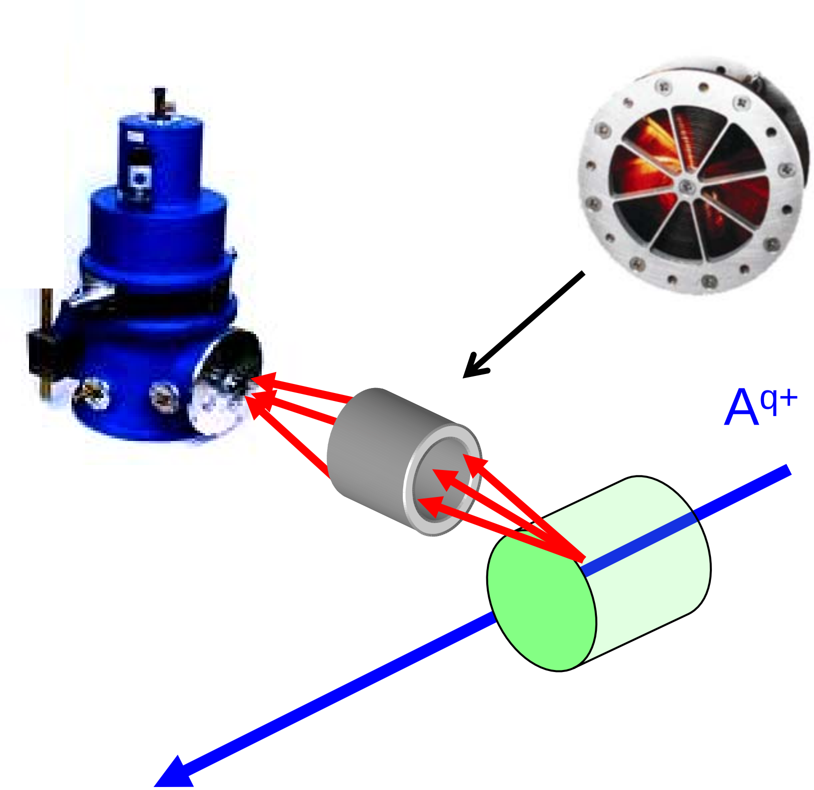
Klein-Nishina equation

$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_0^2 \left(\frac{\hbar\omega'}{\hbar\omega}\right) \left(\frac{\hbar\omega'}{\hbar\omega} + \frac{\hbar\omega'}{\hbar\omega} - \sin^2\theta \cos^2\varphi\right)$$

Micro-calorimeters at HITRAP

E. Silver et al., Harvard Smithsonian

- 4 X 4 bolometers (0.1 X 0.1 mm^2)
- Energy range: 3-50 keV
- High resolution: around 3 eV at 6 keV
- Low efficiency



Grazing incidences X-ray lenses

Increase of efficiency up to a factor 6-8

High accuracy spectroscopy starts to be possible

Conclusions and outlooks

- HITRAP: unique tool
- Possible first experiments: low velocity collision studies
- Coincidences techniques
- State alignment measurement

- Energy resolution improvement with bolometers and x-ray optics
- Precise X-ray spectroscopy
- QED tests in HCI
- ...

Thanks

GSI Collaborator:

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…and thank to you