TRIμP Facility at KVI

Stopping of ions in matter
Radio frequency buncher cooler

TRIµP – Trapped Radioactive Isotopes: µ-laboratories for fundamental Physics

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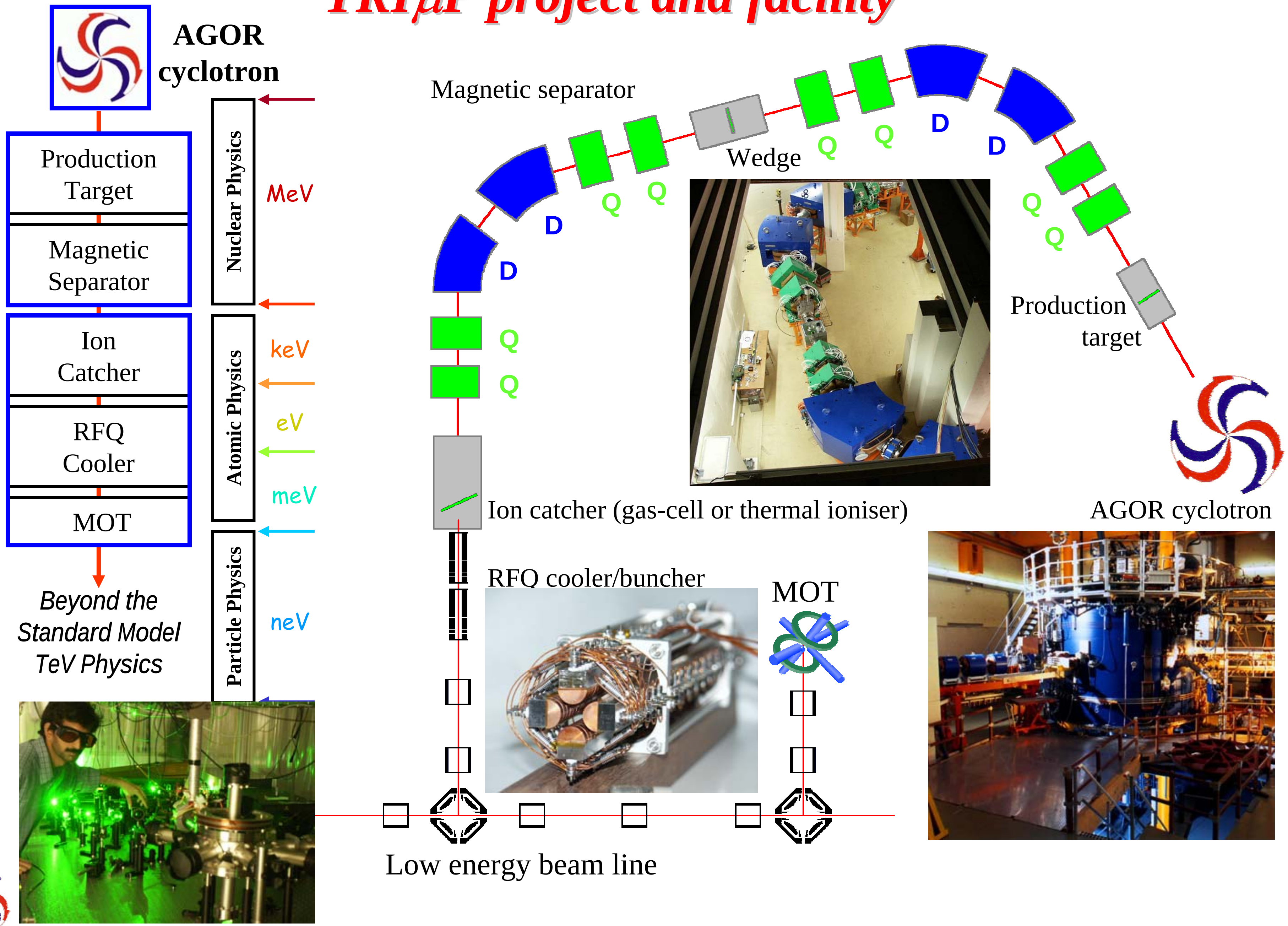
TRIμP project and facility

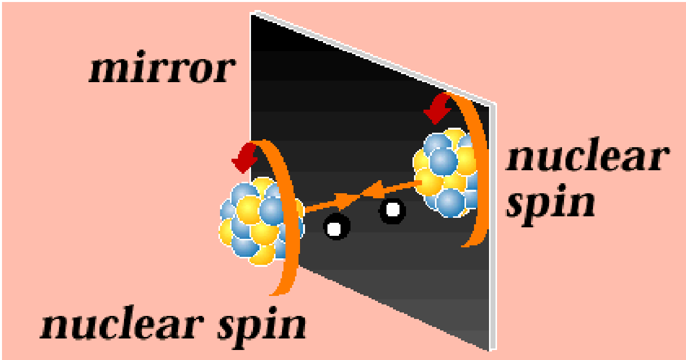


Trapped Radioactive Isotopes: μicro-laboratories for Fundamental Physics

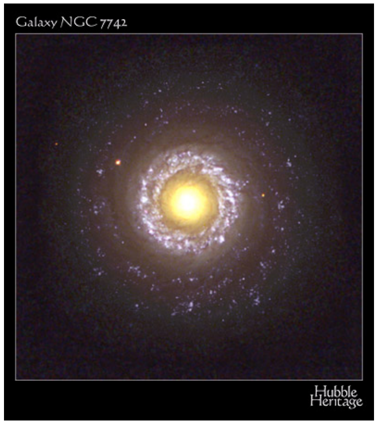
Experimental Program of TRIμP group

Investigating discrete symmetry violations C, P, and T.

- **Origin of Parity Violation**
  in Weak Interactions
- ⇒ details of β-decays
  Na, Ne isotopes



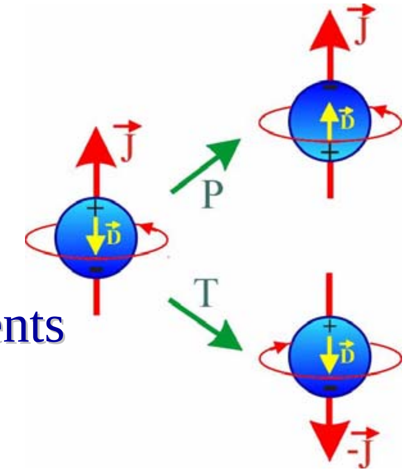
- **Dominance of Matter over Antimatter**



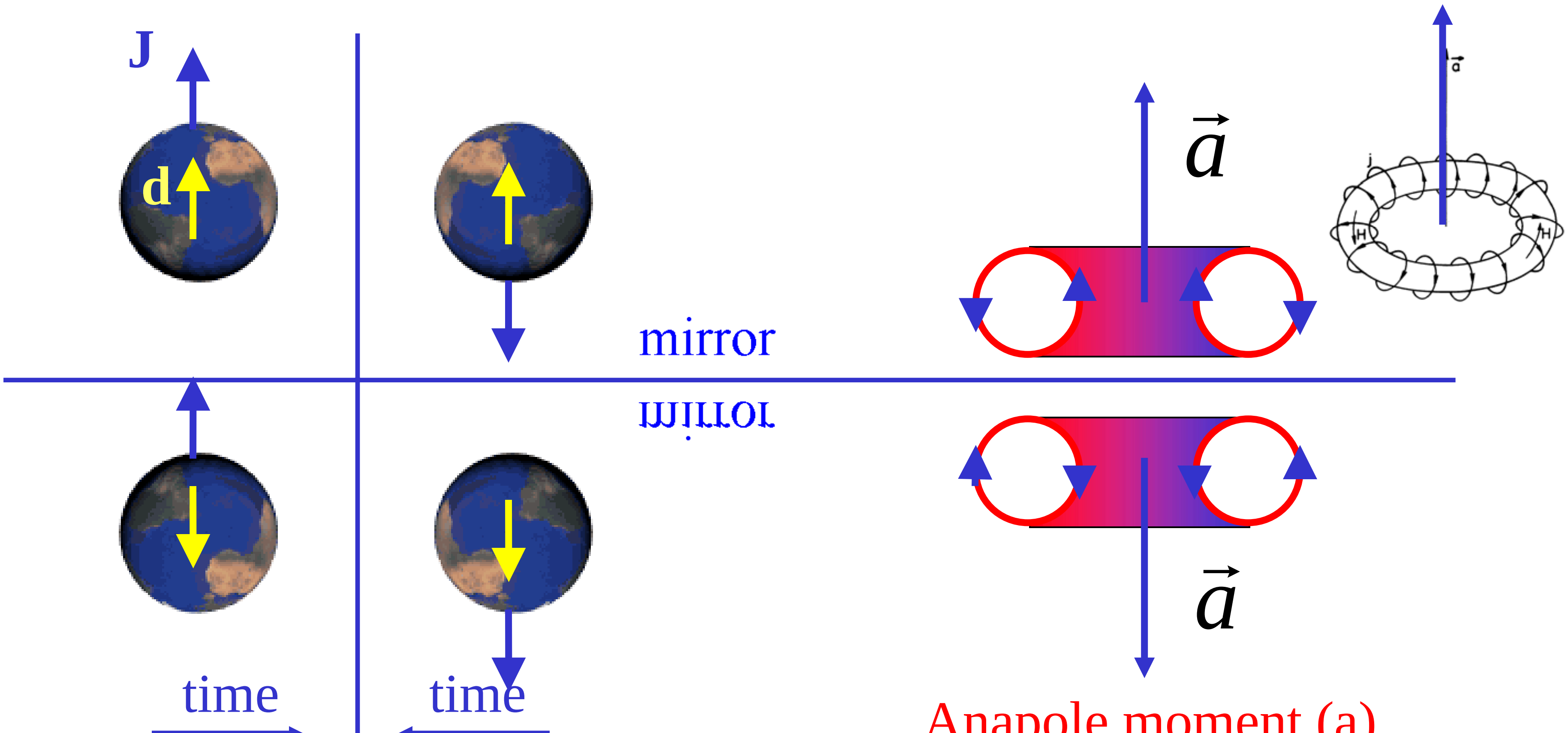
CP - Violation
Time Reversal Symmetry
Parity Violation

⇒ permanent electric dipole moments

Ra isotopes



Forbidden moments new/old physics

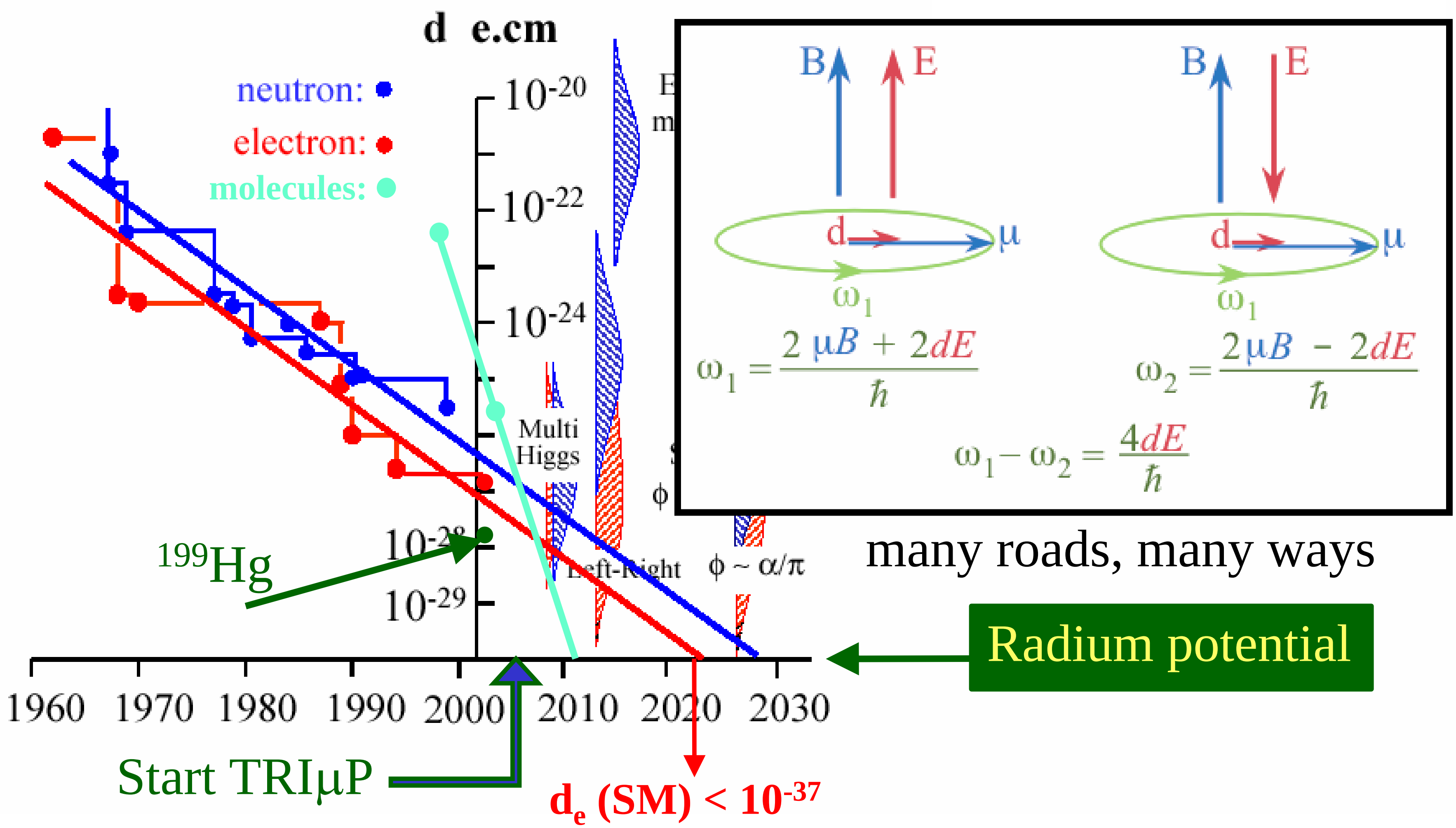


Anapole moment (a)
violates parity only
More objects with APV

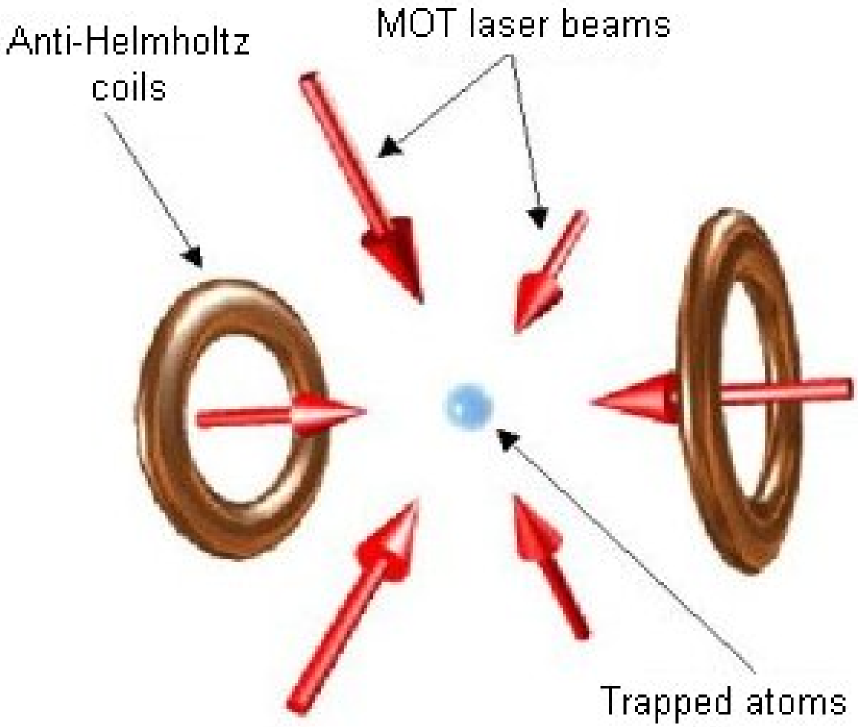
Electric dipole moment (EDM)
violates parity and time reversal

Need amplifiers to observe the effects:
near degenerate opposite parity states in atoms, nuclei and molecules

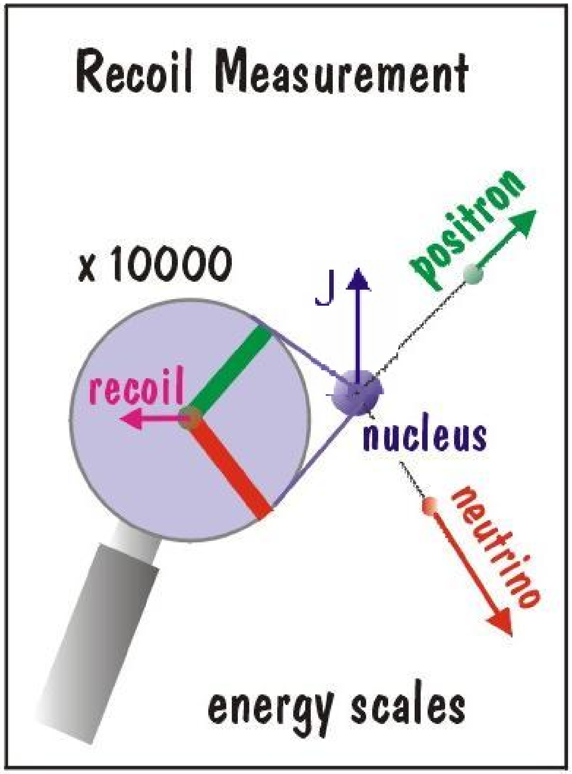
The race for a nonzero EDM…



Why do we need it cold?



The role of atom trapping



$$E_{recoil} = \frac{(\vec{p} + \vec{q})^2}{2M_{recoil}} < 100\,\mathrm{eV}$$

The trap sample:

- long storage times
- isotope (isomer) selective
- spin manipulation
- point source, no substrate
- recoil ion momentum spectrometry
- state preparation (for APNC,edm…)
- “low” EM fields (otherwise ion traps)

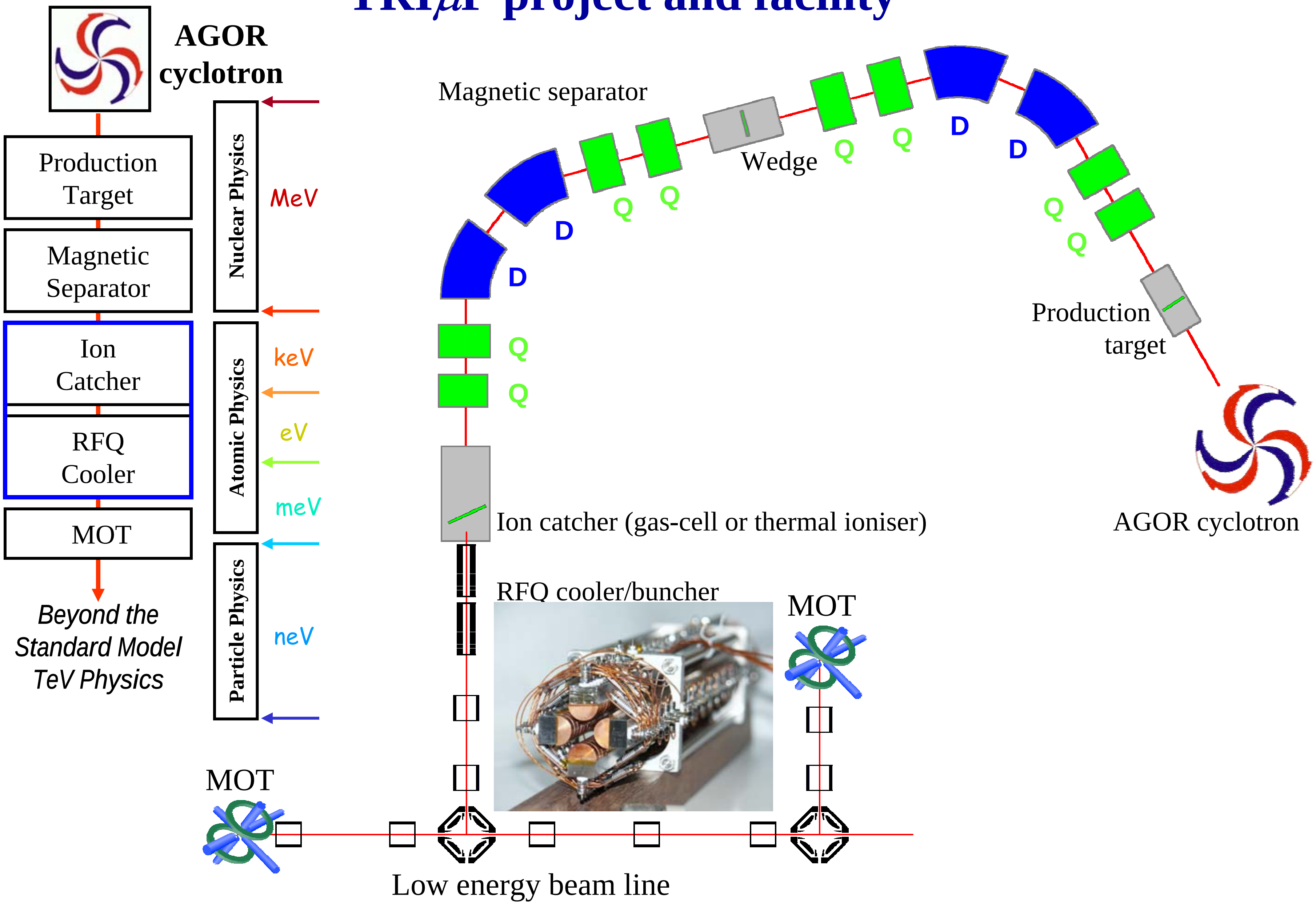
- Ideal environment for precision experiments

Laser Cooling and Trapping

Type	*Energies Scale*	
Slowing	1000 m/s	
Zeeman, white light, chirped laser, bichromatic force	100 meV	
MOT	100 m/s	inhomogeneous B-Field
Optical Molasses	10 m/s, 1 K	no B-Field
FORT	> 1 mK	no B-Field
Magnetic Trap	0.7 K/T/μ_B	inhomogeneous B-Field
Cryogenic Buffer Gas Loading	0.7 K/T/μ_B	inhomogeneous B-Field

Trap losses: background gas ~1 s @ 10^{-9} mbar
optical traps $\Rightarrow$ optical cycling losses

TRIμP project and facility



Trapped Radioactive Isotopes: μicro-laboratories for Fundamental Physics

Stopping Ions in gas
A general solution?

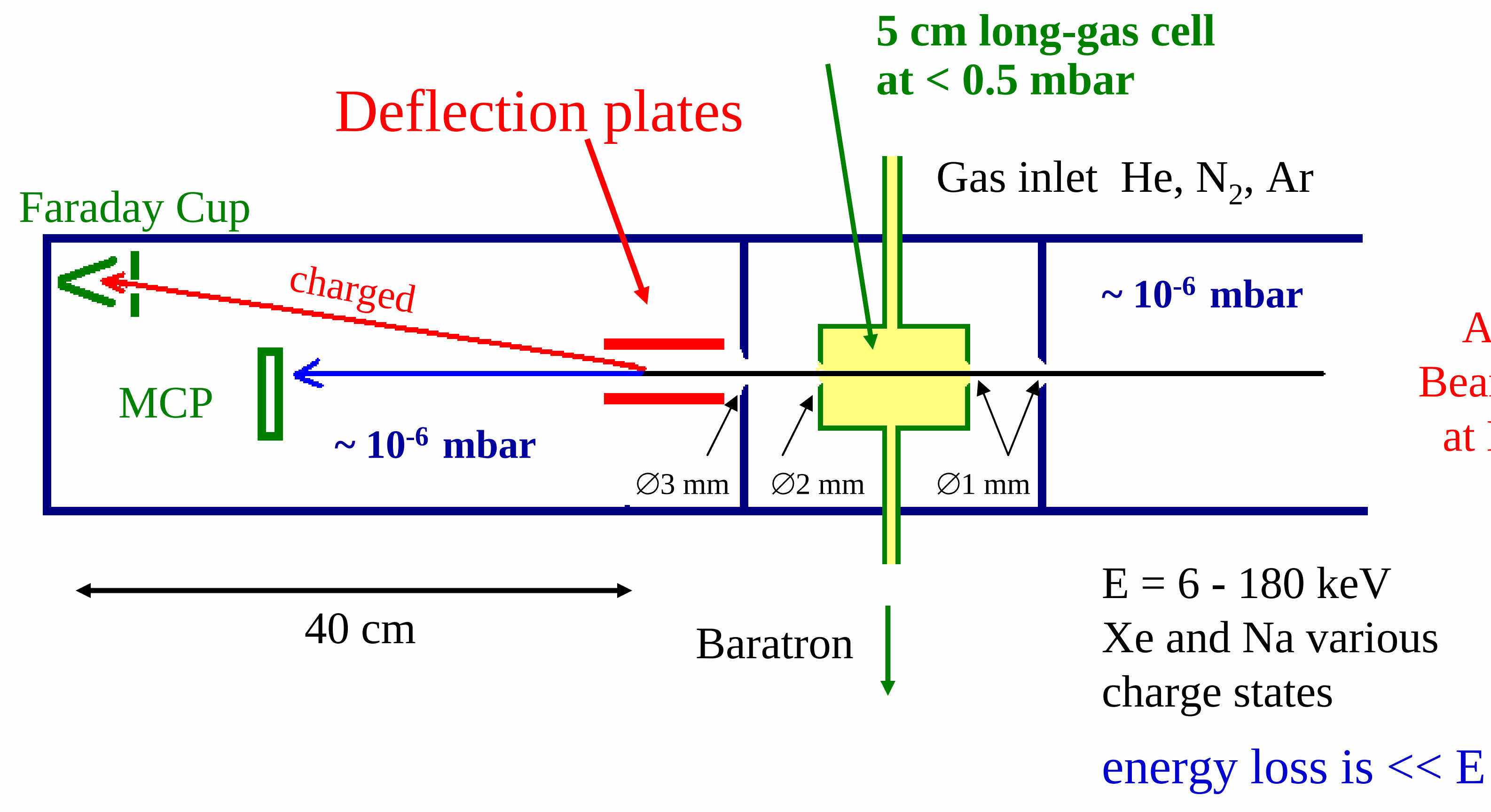
- What can theory tell us?
  - "Just need the charge exchange cross sections"
- Should it work?
  - Energy mismatch for ions at rest
- Does it work?
  - Existing devices
- How can we learn about the physics?
  - Cross sections and others

Ions in gasses: different applications

- rfq cooler, buffer gas cooling in ion traps, mass spectrometry
- creation of neutral atom beams, resonant charge exchange
- Muonium (μ^+e^-) formation in gasses (Ar, Kr, Xe)

Gas	Muonium fraction	Energy mismatch
Ar	0.65(5)	2.22eV
Kr	0.80(10)	0.46eV
Xe	1	-1.46eV

Charge Exchange Cell



charge states

=> Determine mean charge as function of exchange gas pressure

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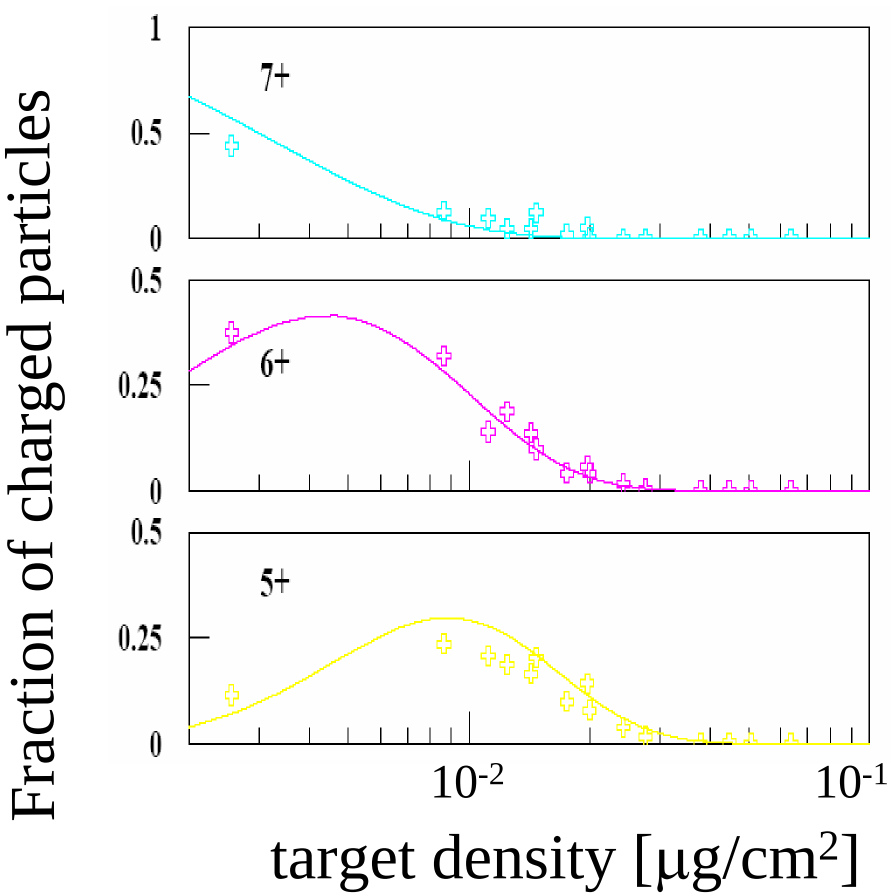
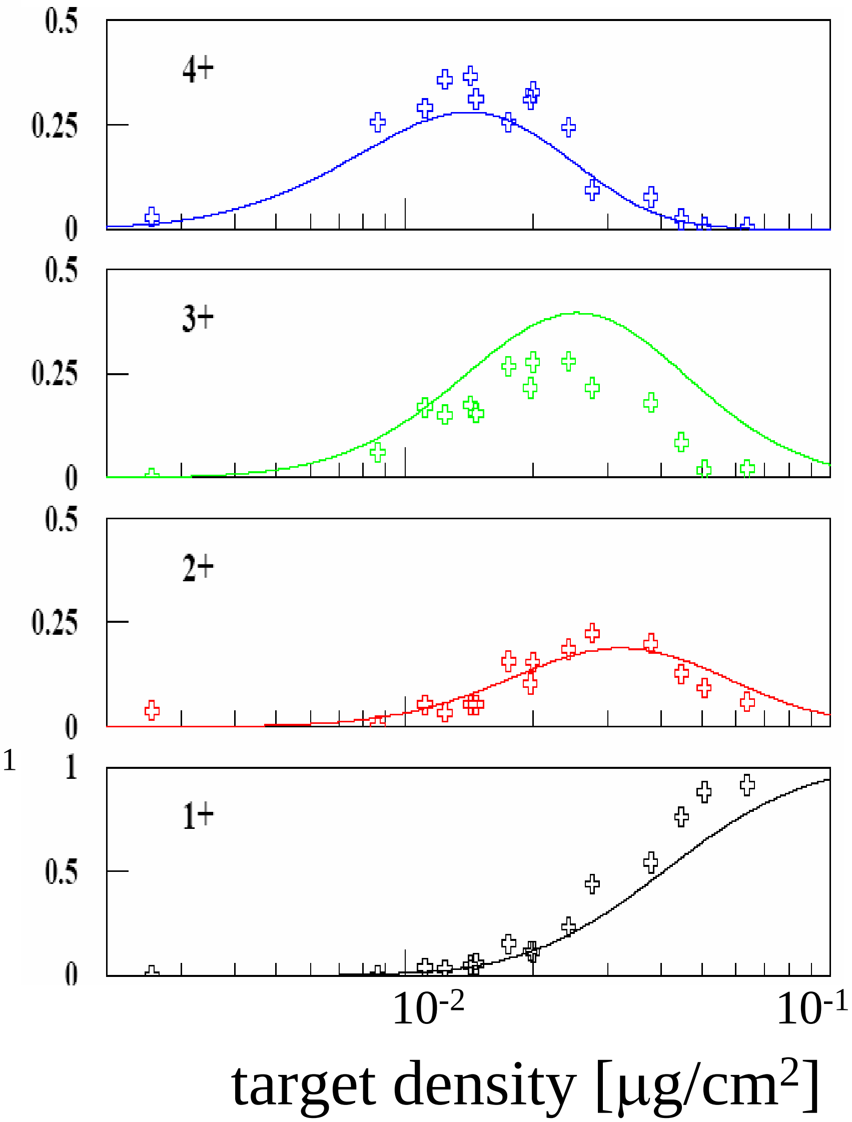
56keV O^{q+} in He





Excellent agreement with
published cross section data

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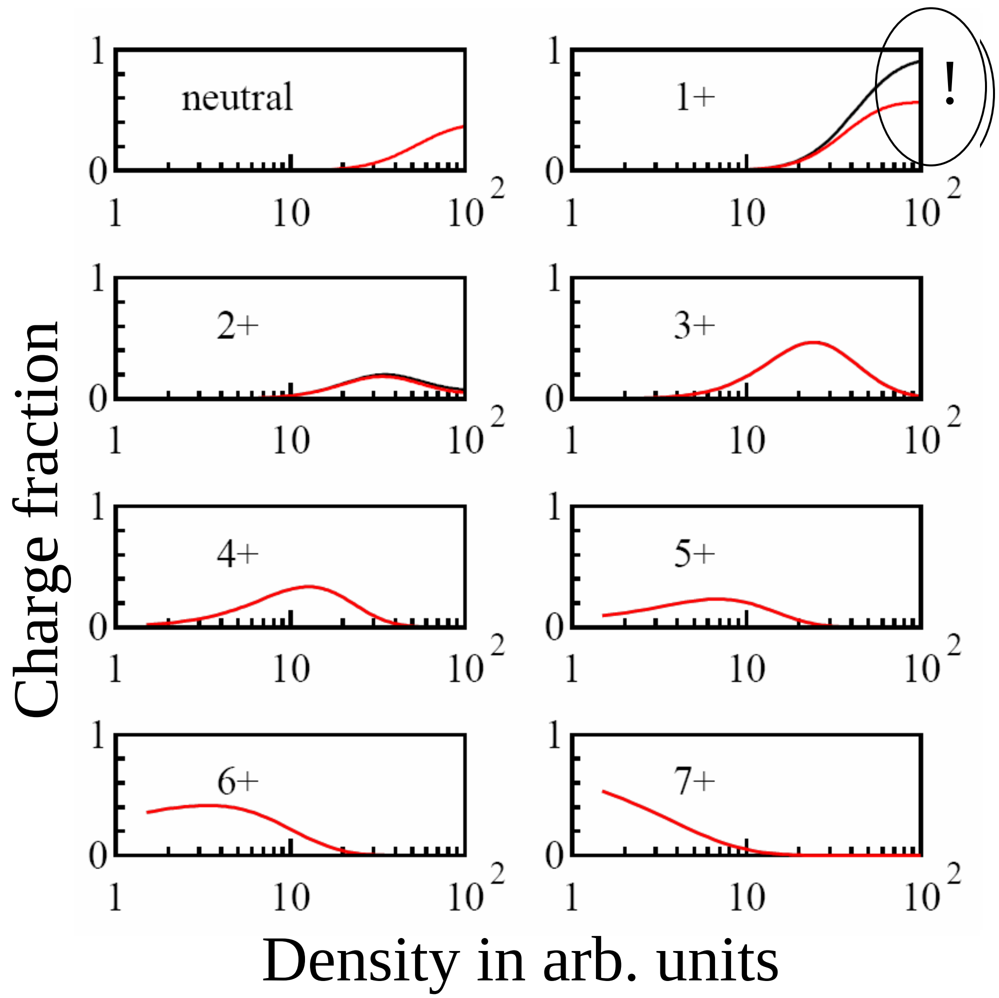
Charge fraction O^{q+} in He



$$F_q = \frac{I_q}{\sum_{q'>0} I_{q'}}$$

σ_{10} & σ_{01} important for 1^+ & 0 fractions

Charged State fractions

cross sections are energy dependent

$$\frac{dI^-}{dx} = -nQ_{\bar{1}0}I^- + nQ_{0\bar{1}}I^0$$

$$\frac{dI^0}{dx} = -nQ_{01}I^0 + nQ_{\bar{1}0}I^- + nQ_{10}I^+$$

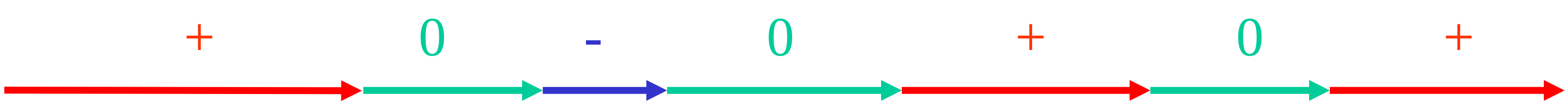
$$\frac{dI^+}{dx} = -nQ_{10}I^+ + nQ_{01}I^0$$

} = 0 at any position if $n_{coll} >> 1$

Definitions:

- I^i=fraction with q=i
- Q_{ij} cross section for H charge change from q=i to q=j
- n = number atoms/volume

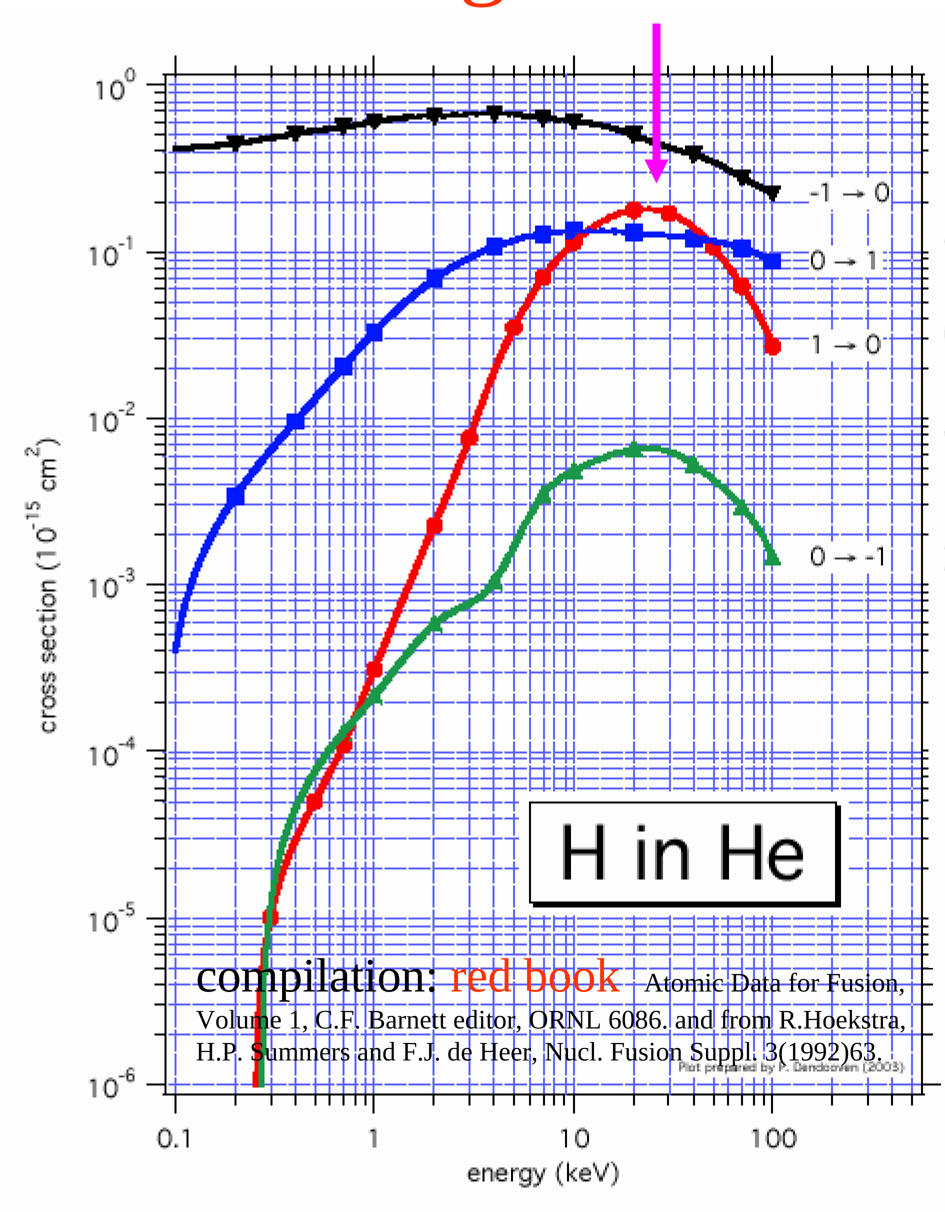
ignoring + ↔ - (double charge transfer)



$Q_{\bar{1}0} >> Q_{0\bar{1}}$

equilibrium: $I^+/I^0 = Q_{01}/Q_{10}$

Charge Fractions and cross sections



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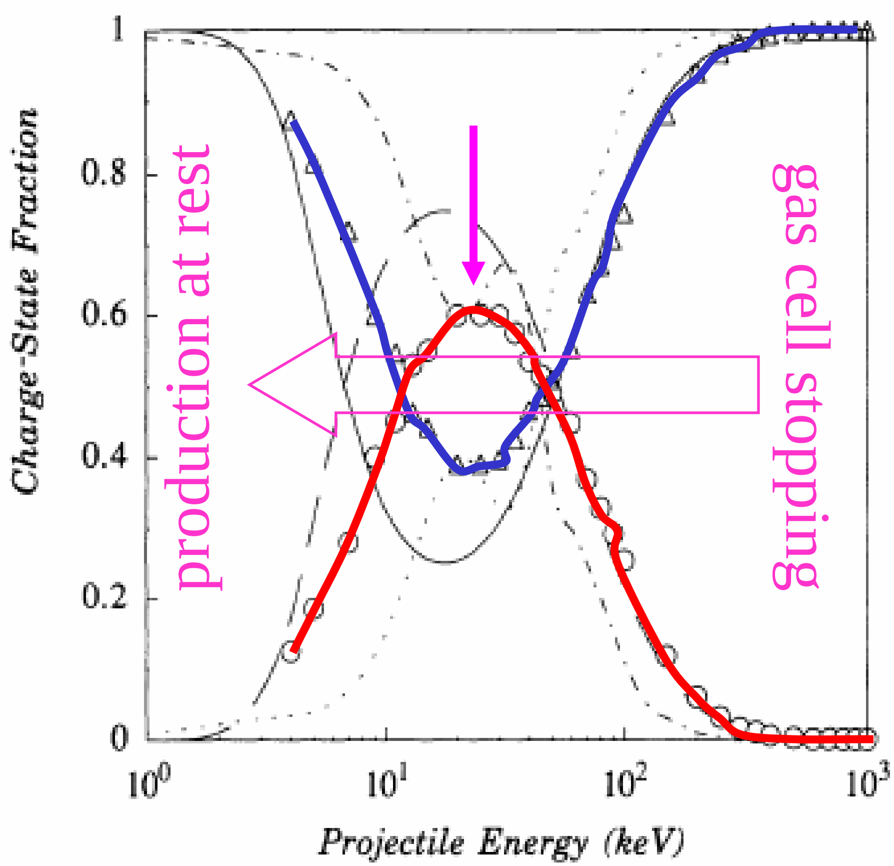
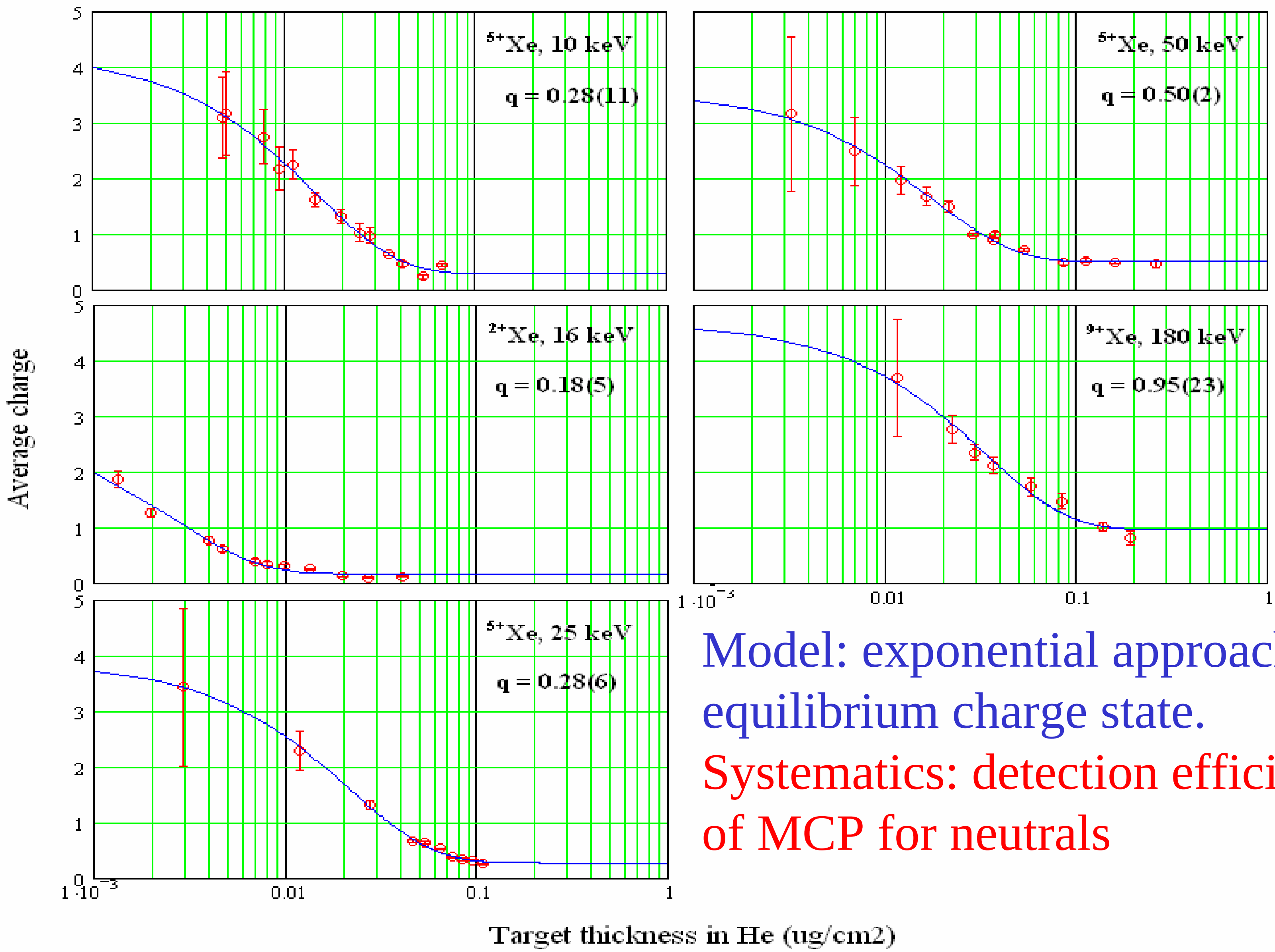


H neutralizes and ionizes while stopping

Average charge of Xe in He



Model: exponential approach to equilibrium charge state.

Systematics: detection efficiency of MCP for neutrals

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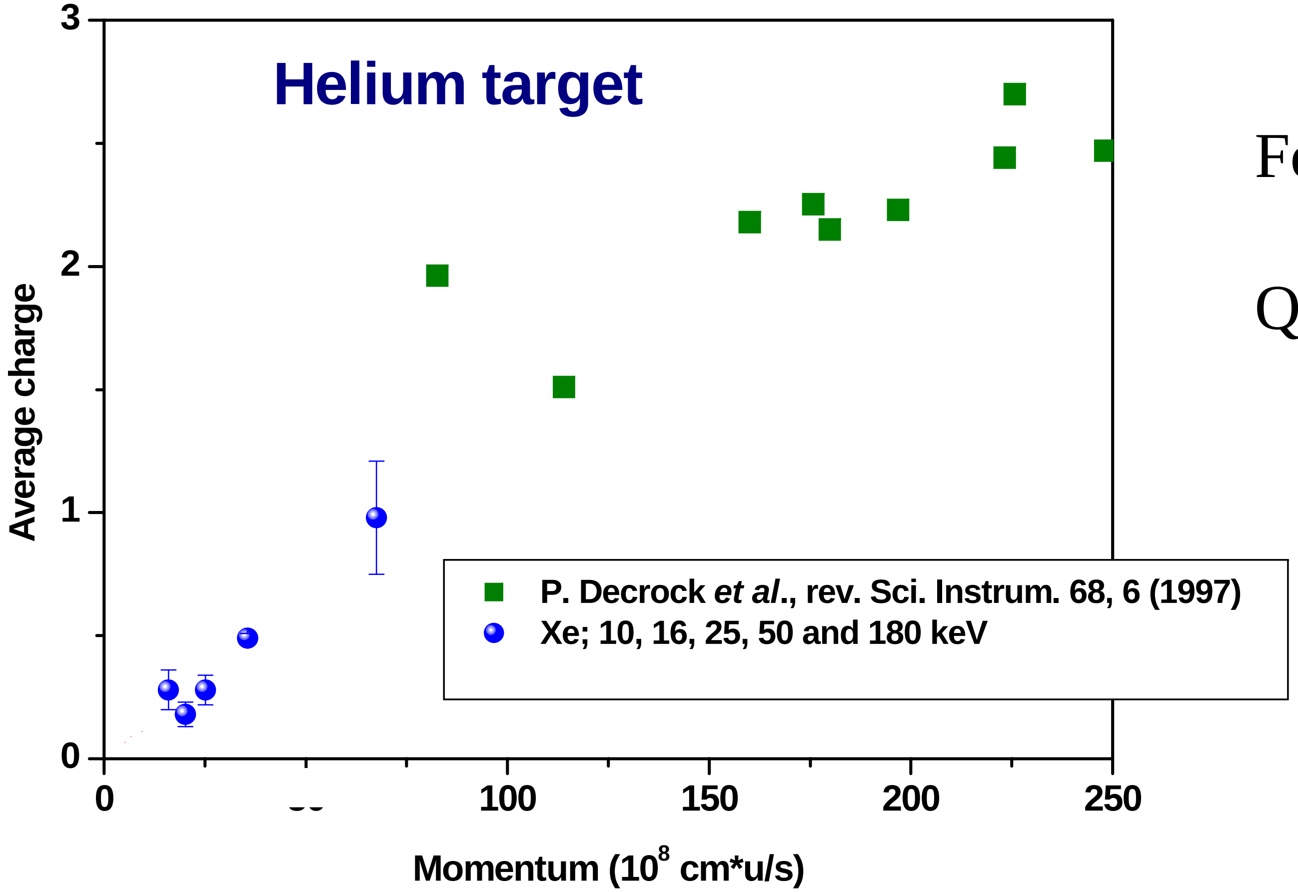


For E $\Rightarrow$ 0

$$Q_{avg=} \frac{\sigma_{10}}{\sigma_{11}}$$

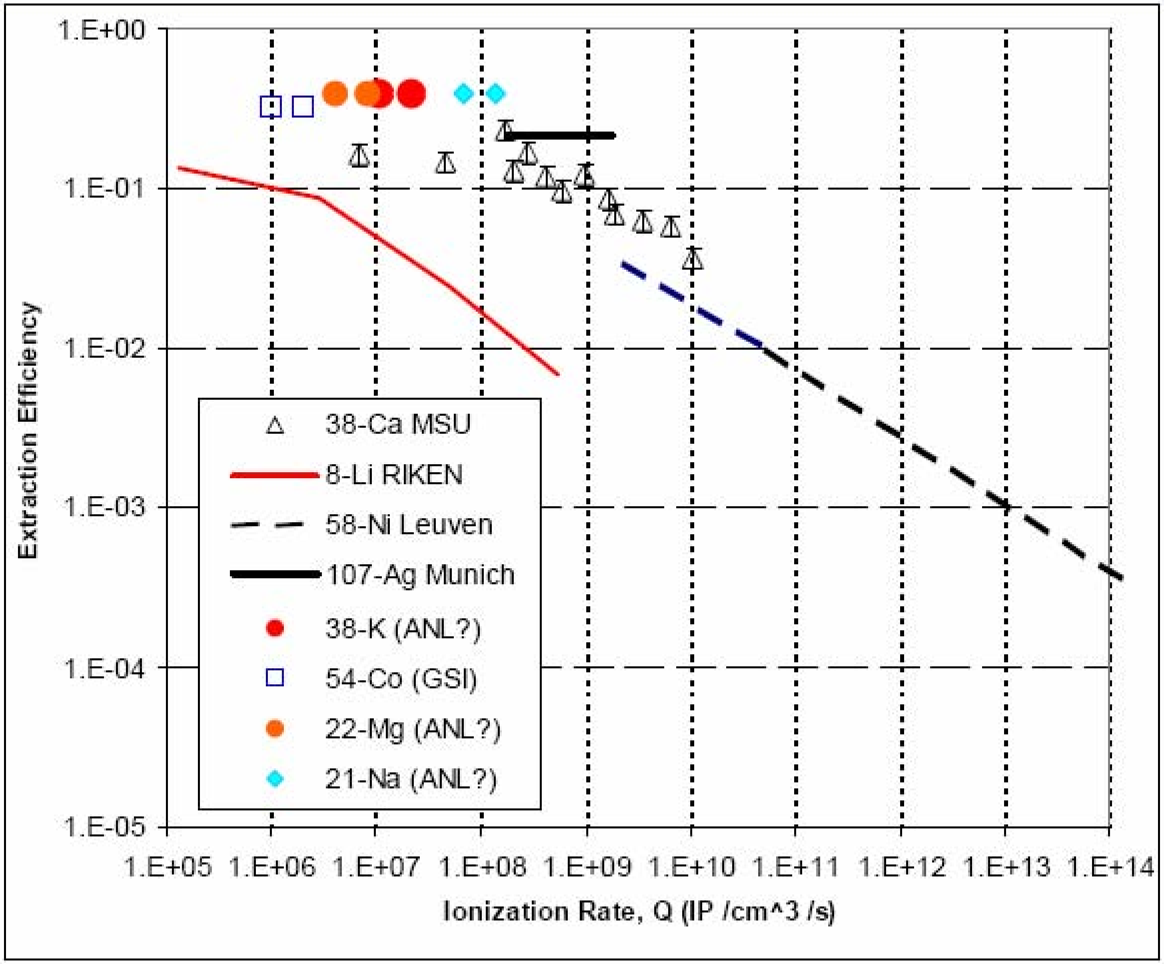
Indication of large neutral fraction.

How does it continue toward lower energies?

Not accessible with this method

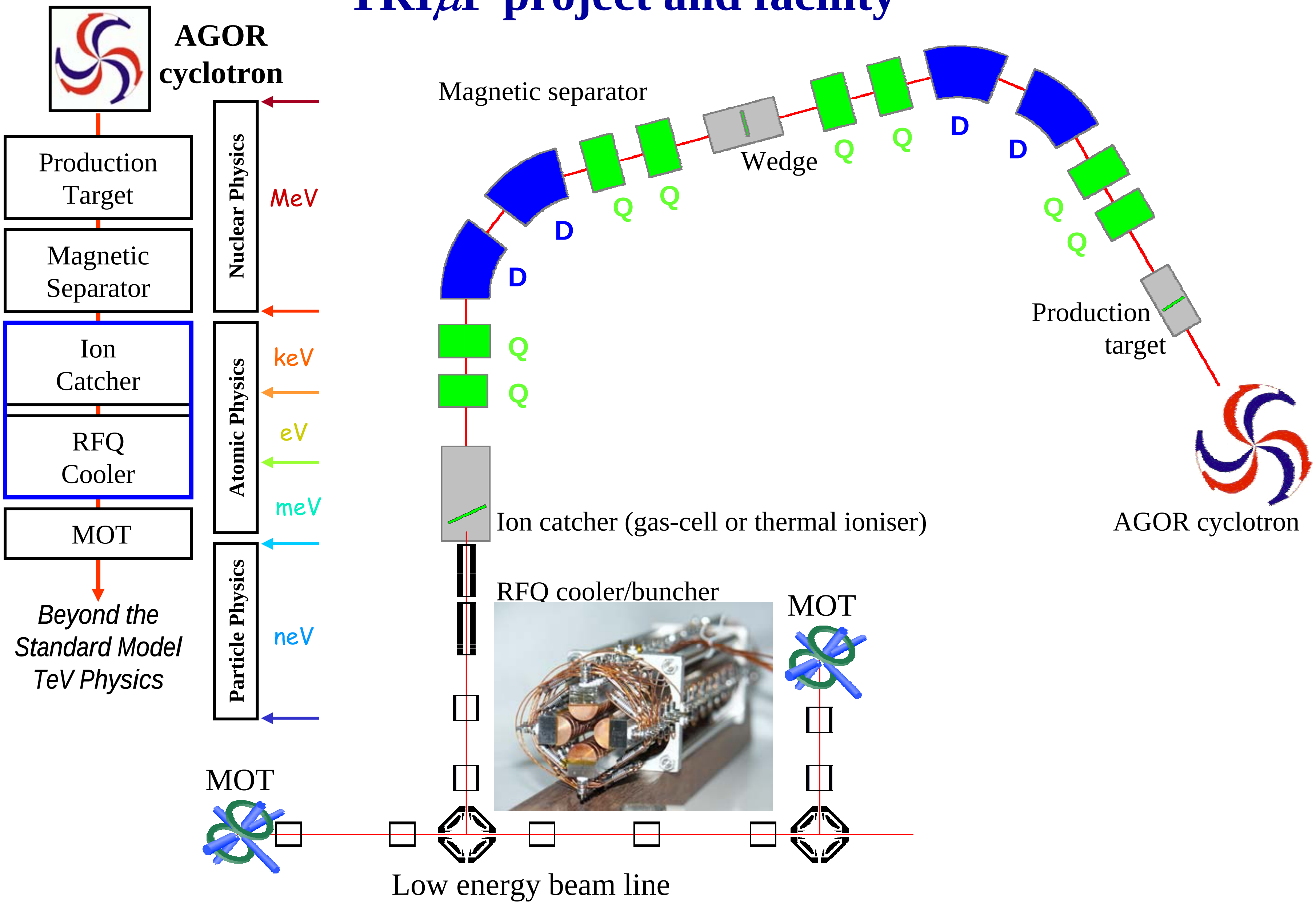
Survival of ions after stopping in He

Extraction efficiency, summary figure



Complilation by D. Morrissey, MSU

TRIμP project and facility



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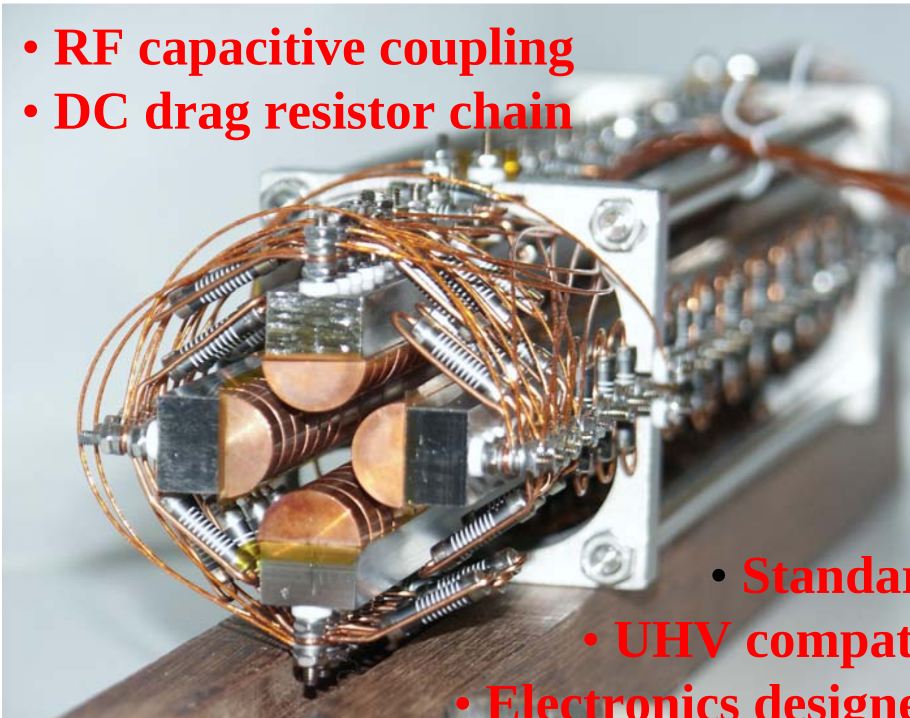
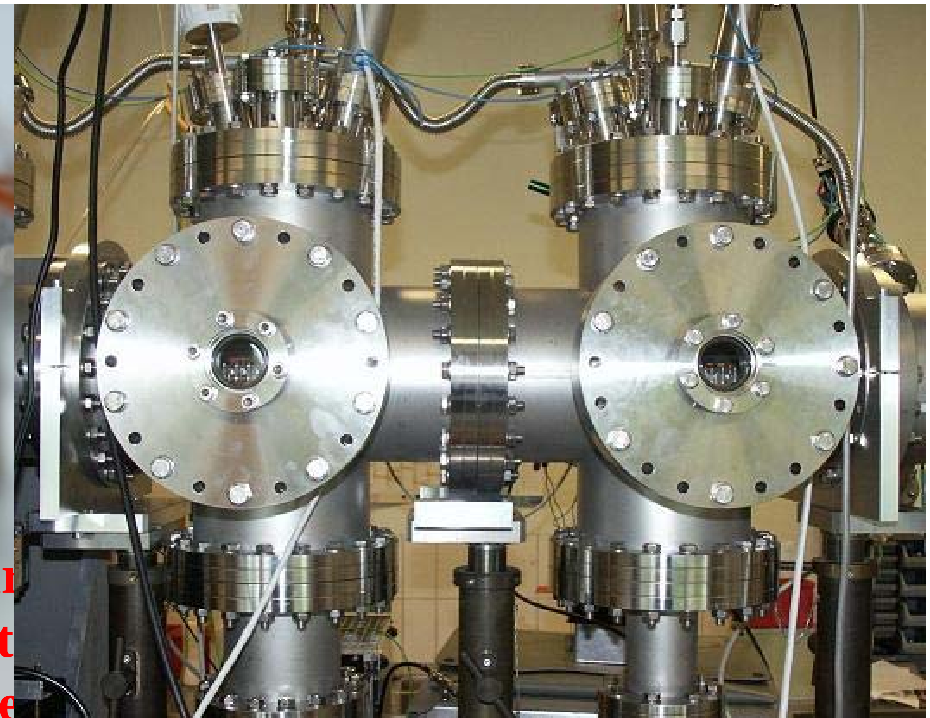
Our RFQ cooler/buncher concept



- RF capacitive coupling
- DC drag resistor chain
- Standar
- UHV compat
- Electronics designe

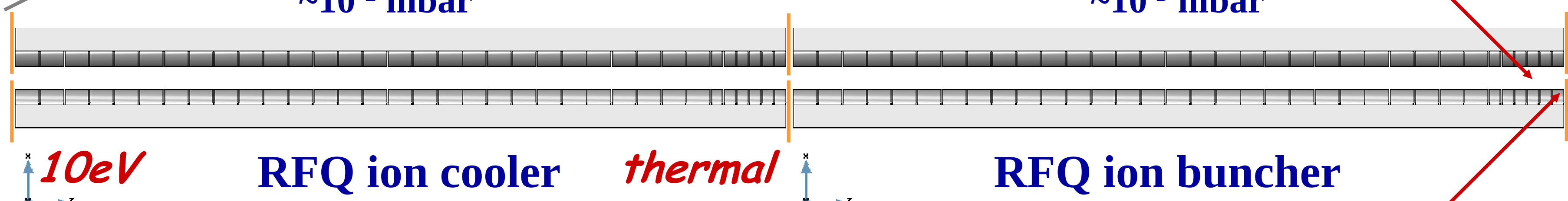


Buffer gas pressure (He):

~10^{-1} mbar

~10^{-3} mbar

Trap position



10eV RFQ ion cooler *thermal*

RFQ ion buncher

Switching on end electrodes

Preliminary results for RFQ cooler buncher

- Storage time several seconds
  -> purity of buffer gas
  with production rate fill trap in about 1s
- Drift tube accelerator -> no high voltage platform
- Efficiency for MCP detector for different ion energies
- Good transmission > 80% of RFQ
- Short (200ns) ion pulses

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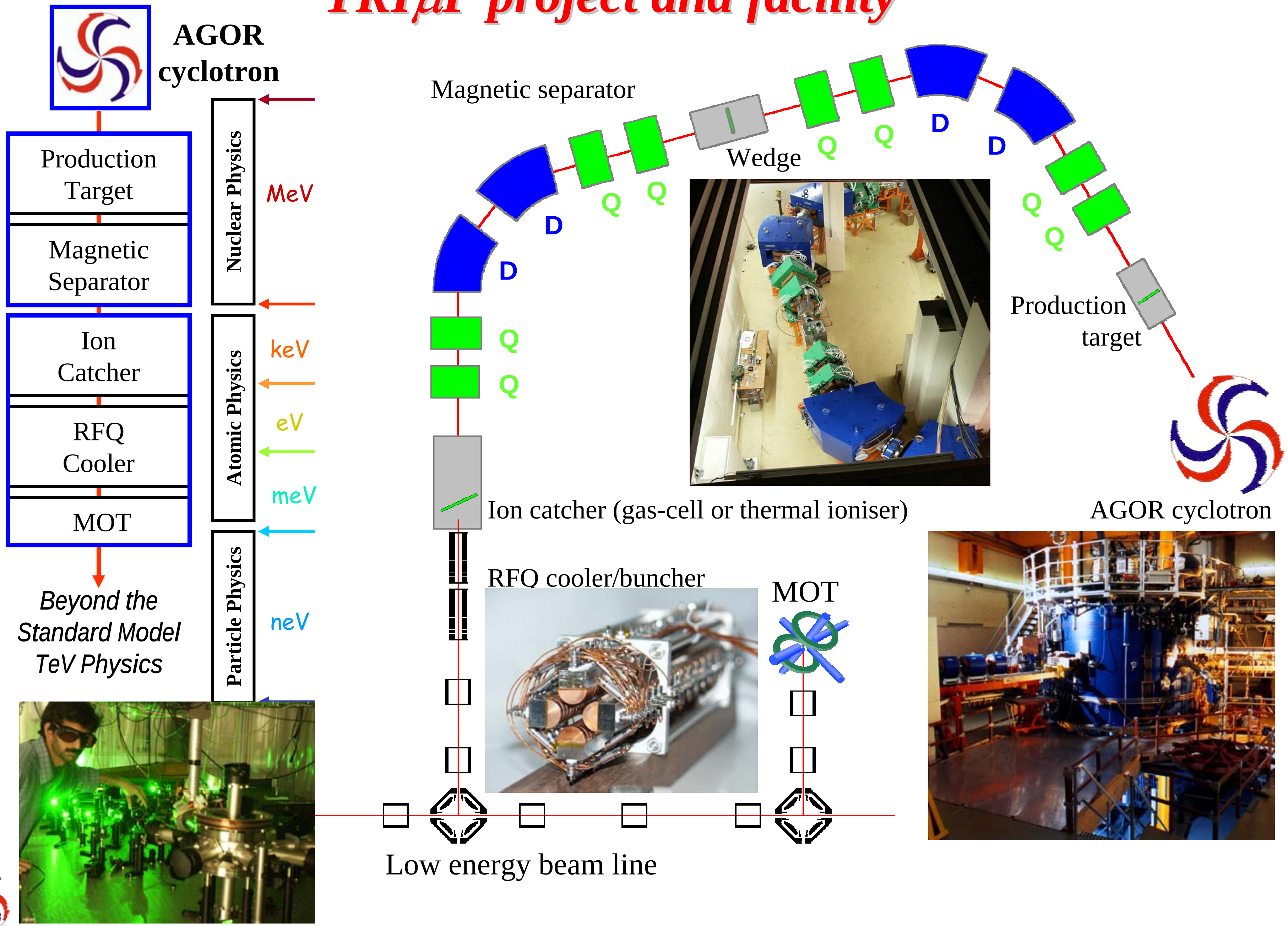

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