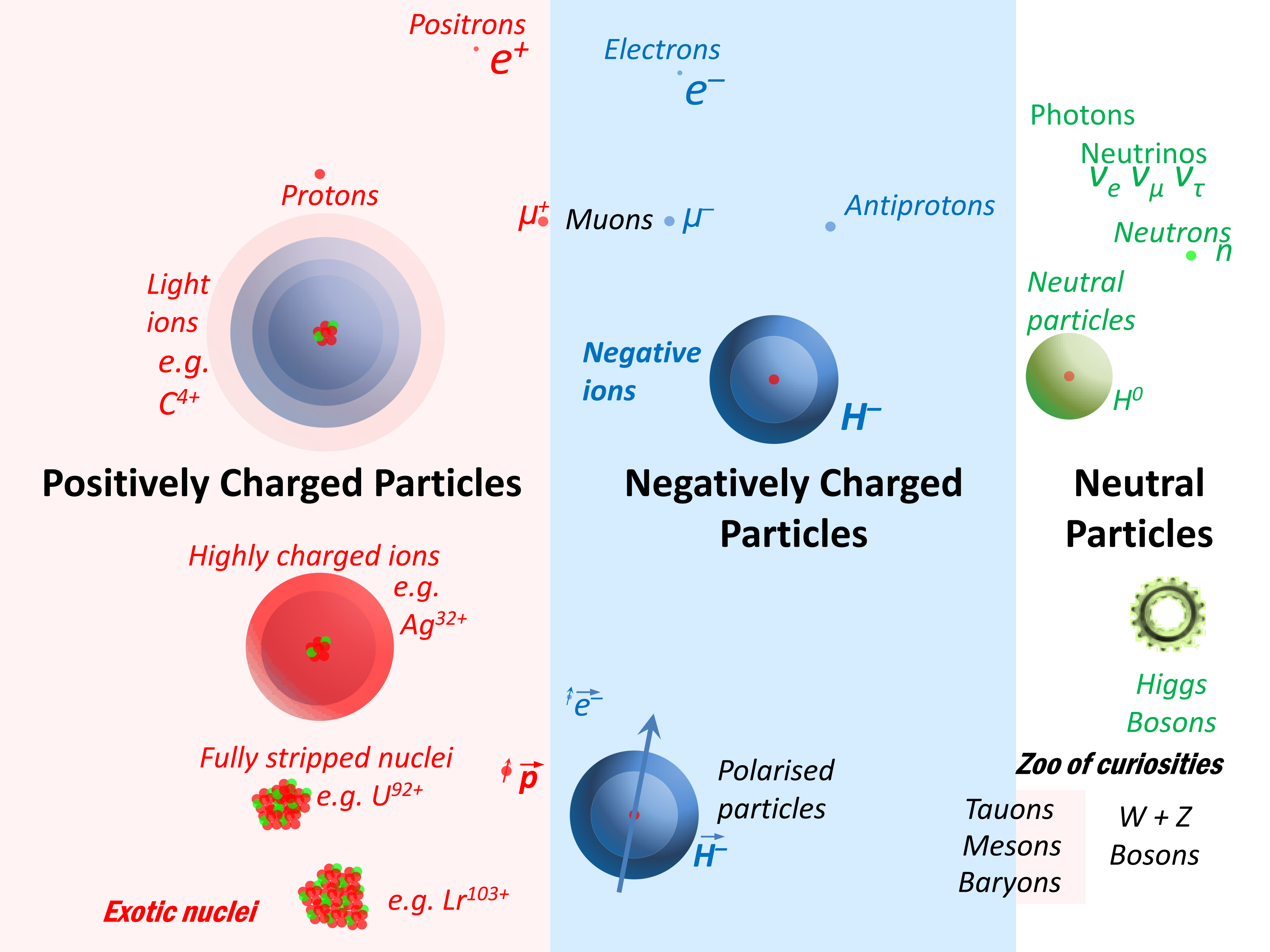
Particle Sources

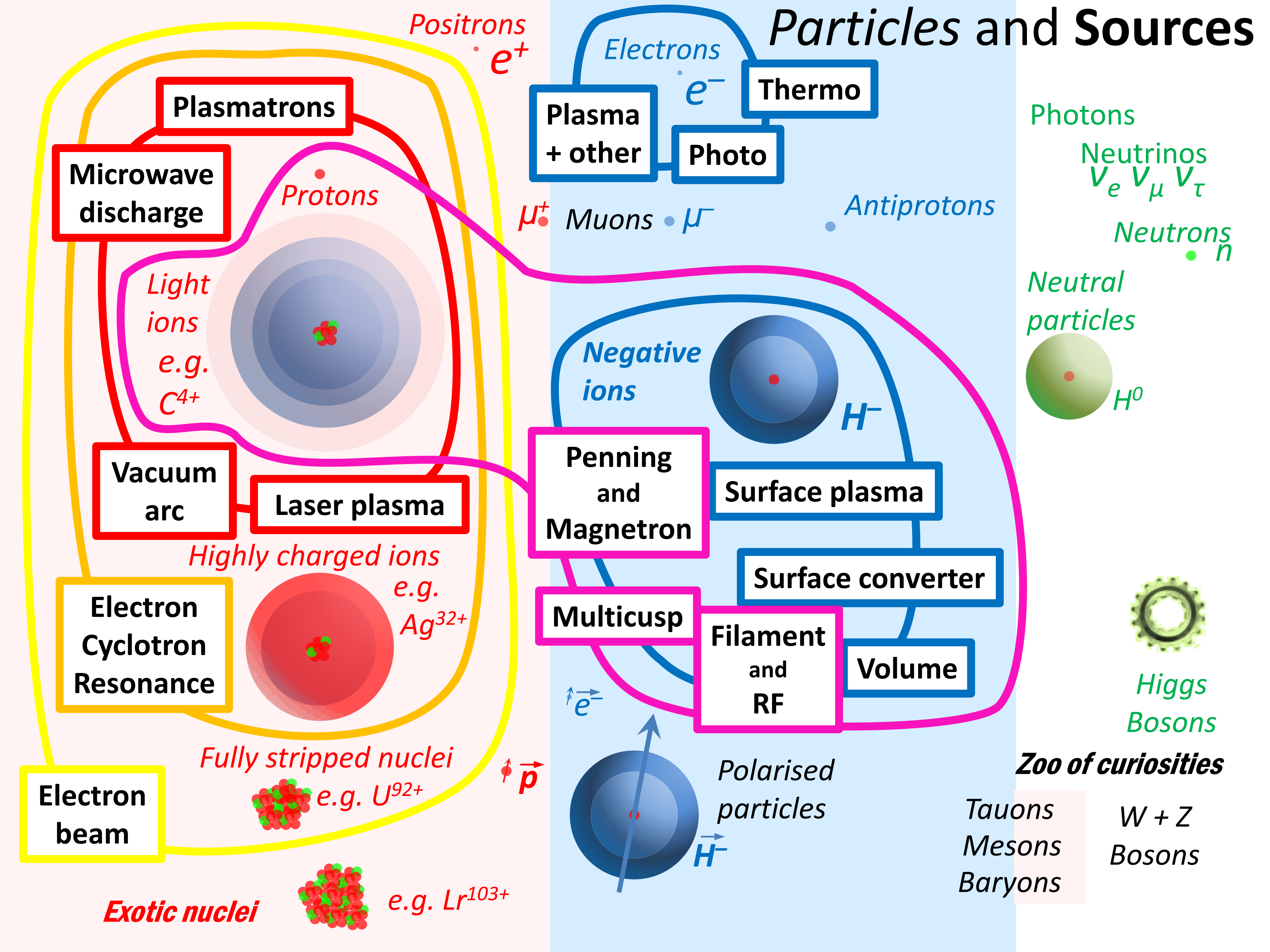
-The most important part of the whole machine

Dan Faircloth

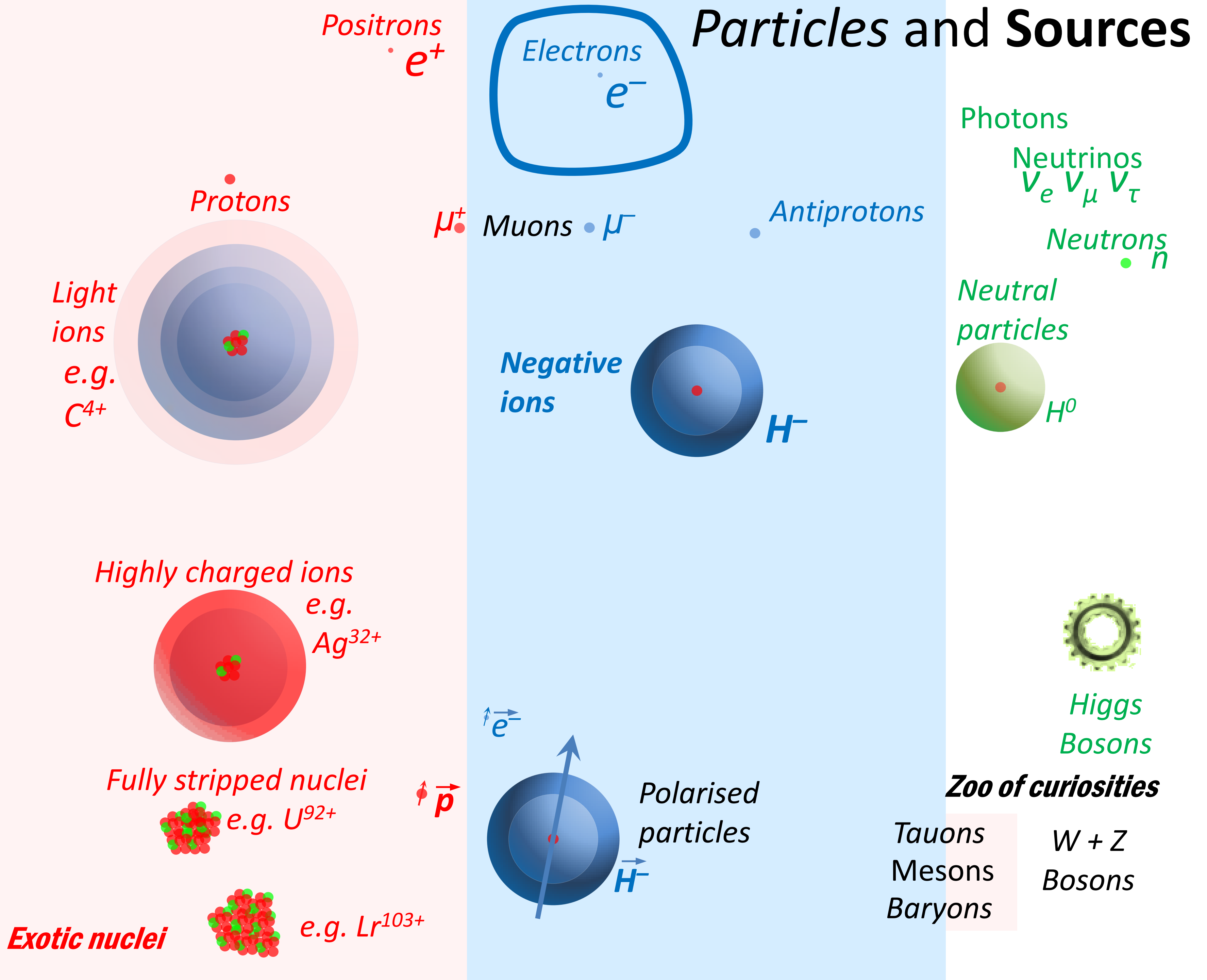
Rutherford Appleton Laboratory



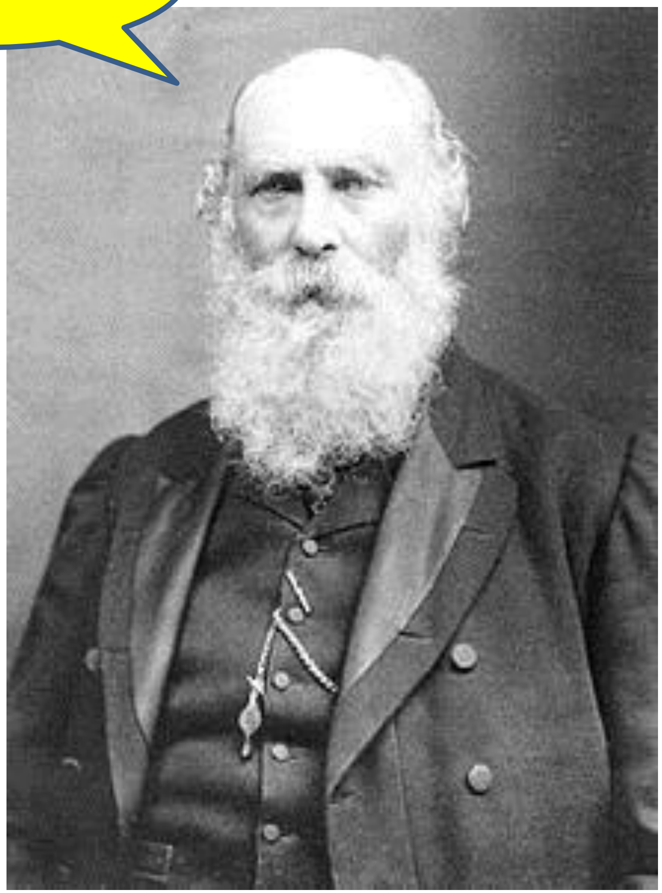
Positrons
e^+
Electrons
e^-
Photons
Neutrinos
ν_e ν_μ ν_τ
Protons
μ^+
Muons
μ^-
Antiprotons
Neutrons
n
Light ions e.g. C^{4+}
Negative ions
H^-
Neutral particles
H^0
Positively Charged Particles
Negatively Charged Particles
Neutral Particles
Highly charged ions e.g. Ag^{32+}
Fully stripped nuclei e.g. U^{92+}
$\vec{p}$
$\vec{e}^-$
Polarised particles
$\vec{H}^-$
Higgs Bosons
Zoo of curiosities
Tauons
Mesons
Baryons
W + Z Bosons
Exotic nuclei
e.g. Lr^{103+}


Particles and Sources
Positrons
e^+
Plasmatrons
Microwave discharge
Protons
Light ions e.g. C^{4+}
Vacuum arc
Laser plasma
Highly charged ions
e.g. Ag^{32+}
Electron Cyclotron Resonance
Fully stripped nuclei
e.g. U^{92+}
Electron beam
Exotic nuclei
e.g. Lr^{103+}
$\vec{p}$
Electrons
e^-
Plasma + other
Thermo
Photo
μ^+ Muons μ^-
Antiprotons
Negative ions
H^-
Penning and Magnetron
Surface plasma
Surface converter
Multicusp
Filament and RF
Volume
$\vec{e}^-$
Polarised particles
$\vec{H}^-$
Photons
Neutrinos
ν_e ν_μ ν_τ
Neutrons
n
Neutral particles
H^0
Higgs Bosons
Zoo of curiosities
Tauons
Mesons
Baryons
W + Z Bosons

Particles and **Sources**



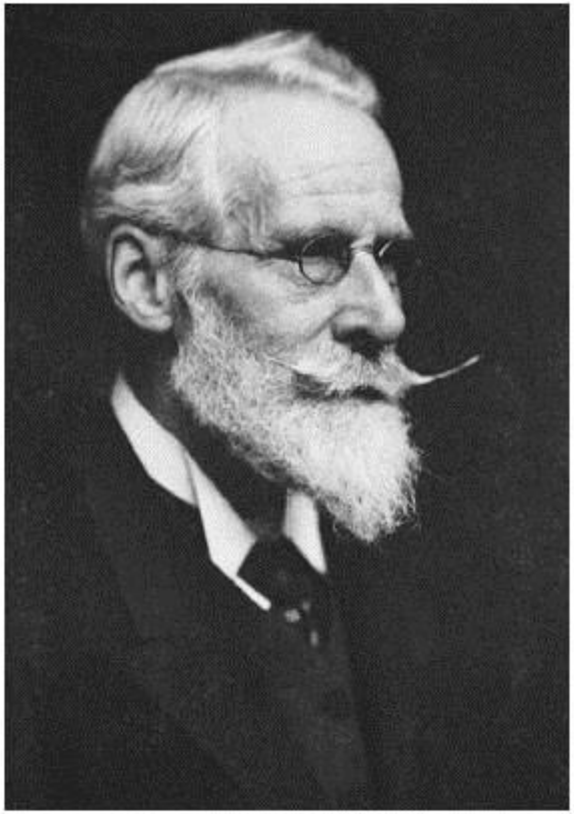
The Electron!

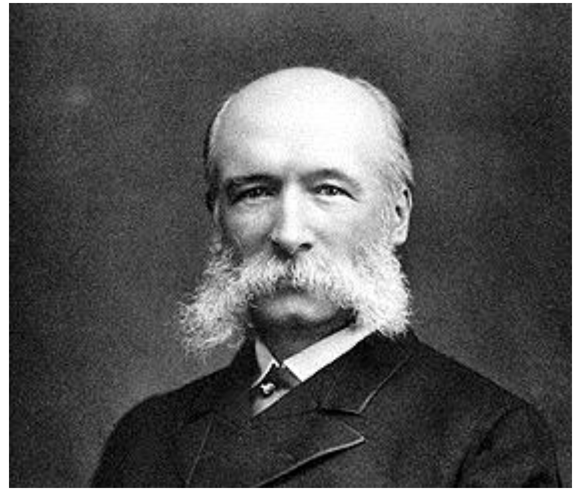


George Johnstone Stoney
1894

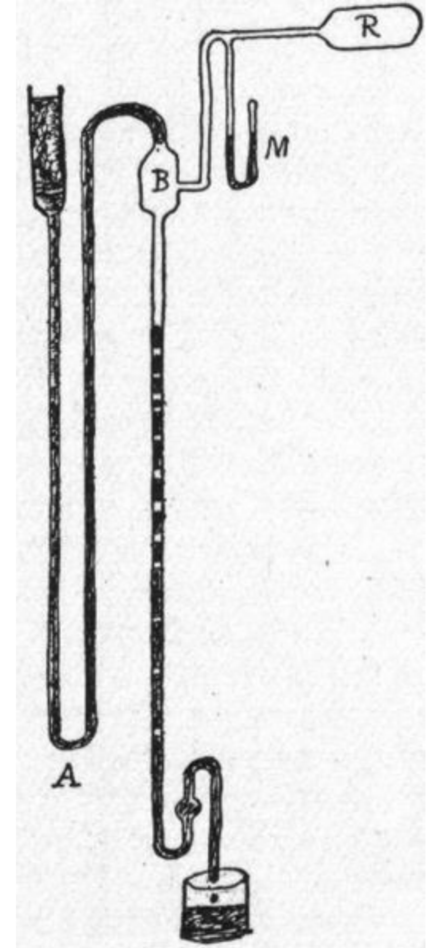
J. J. Thomson
1897

Early 1870's

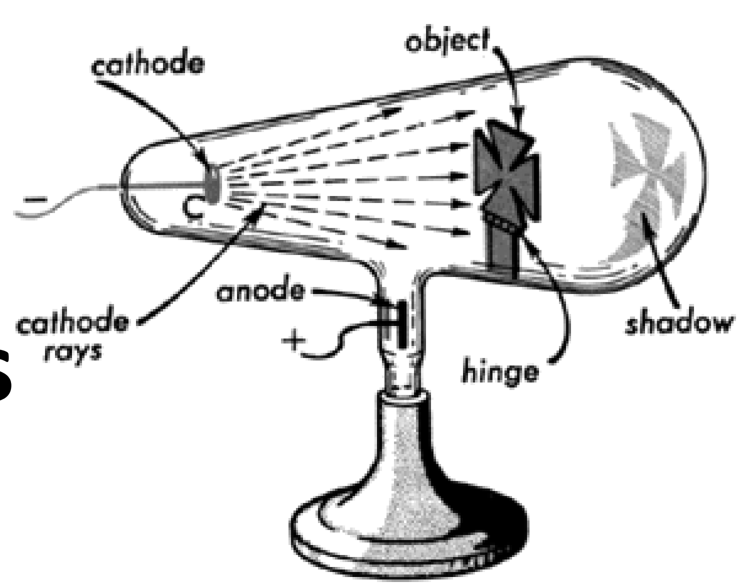




Hermann Sprengel



Improved
mercury pump
10^{-5} mBar



William Crookes

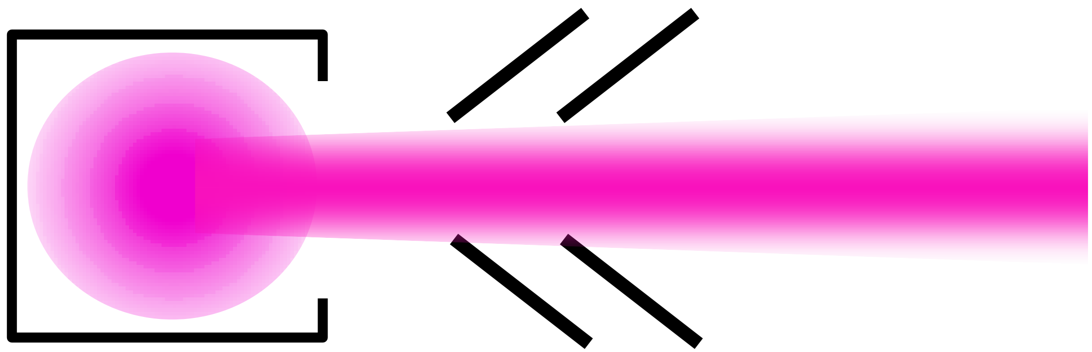
Electron Guns

Inferiority complex…

?

Ion Sources

Particle sources/guns consist of:

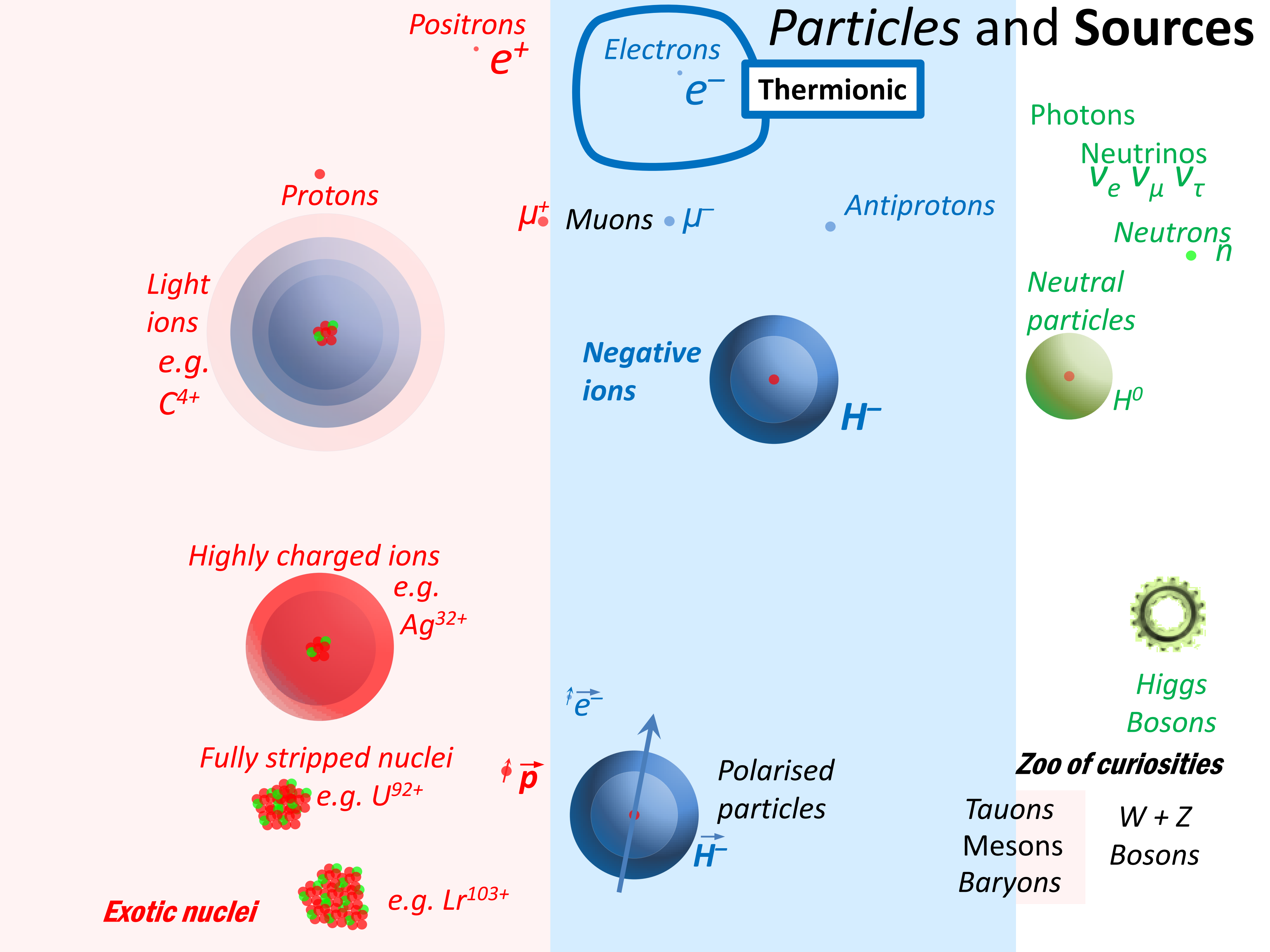


Something to make the particles

+

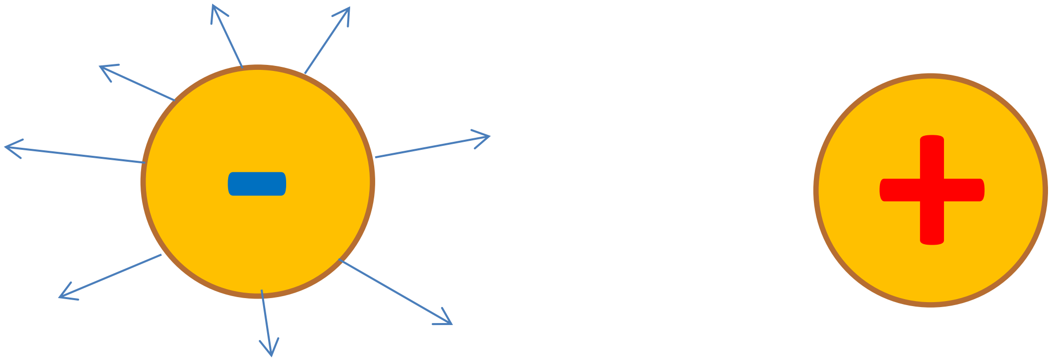
An extraction system to create and accelerate a beam

Particles and **Sources**



Fredrick Guthrie

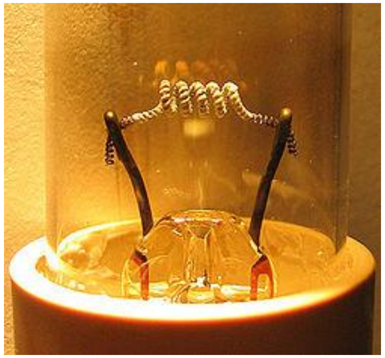
British scientific writer and professor



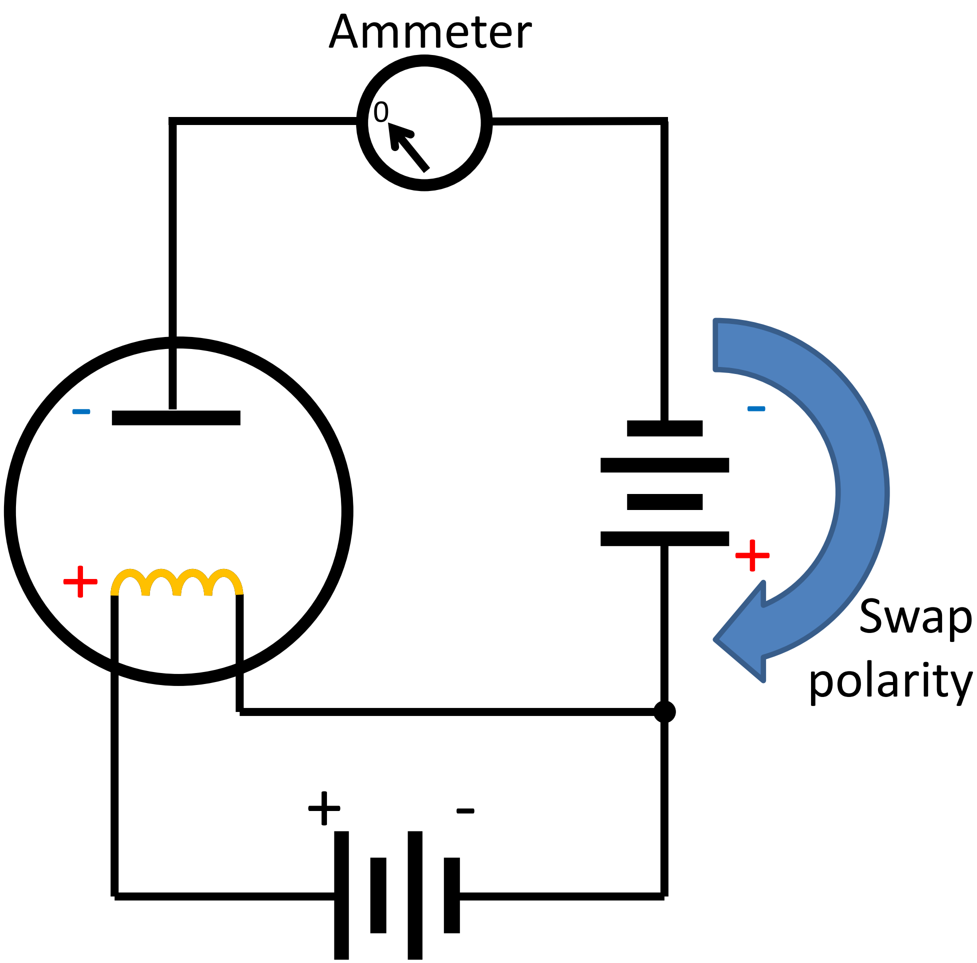
Elements of Heat in 1868

First experimental observation of thermionic emission

Thermionic Emission

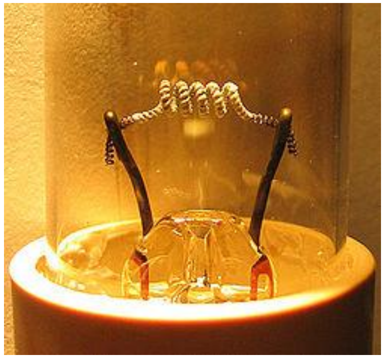


1880 Thomas Edison

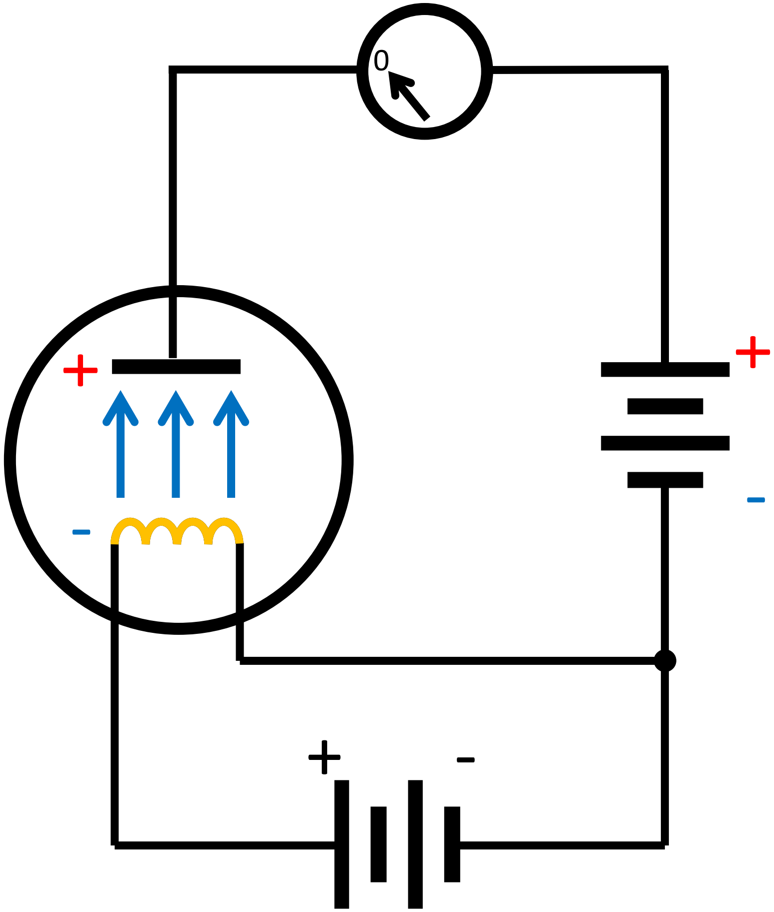


The "Edison effect"

Thermionic Emission



1880 Thomas Edison



The "Edison effect"

Thermionic Emission

J. J. Thomson
1897

1901 Owen Richardson

Cambridge University

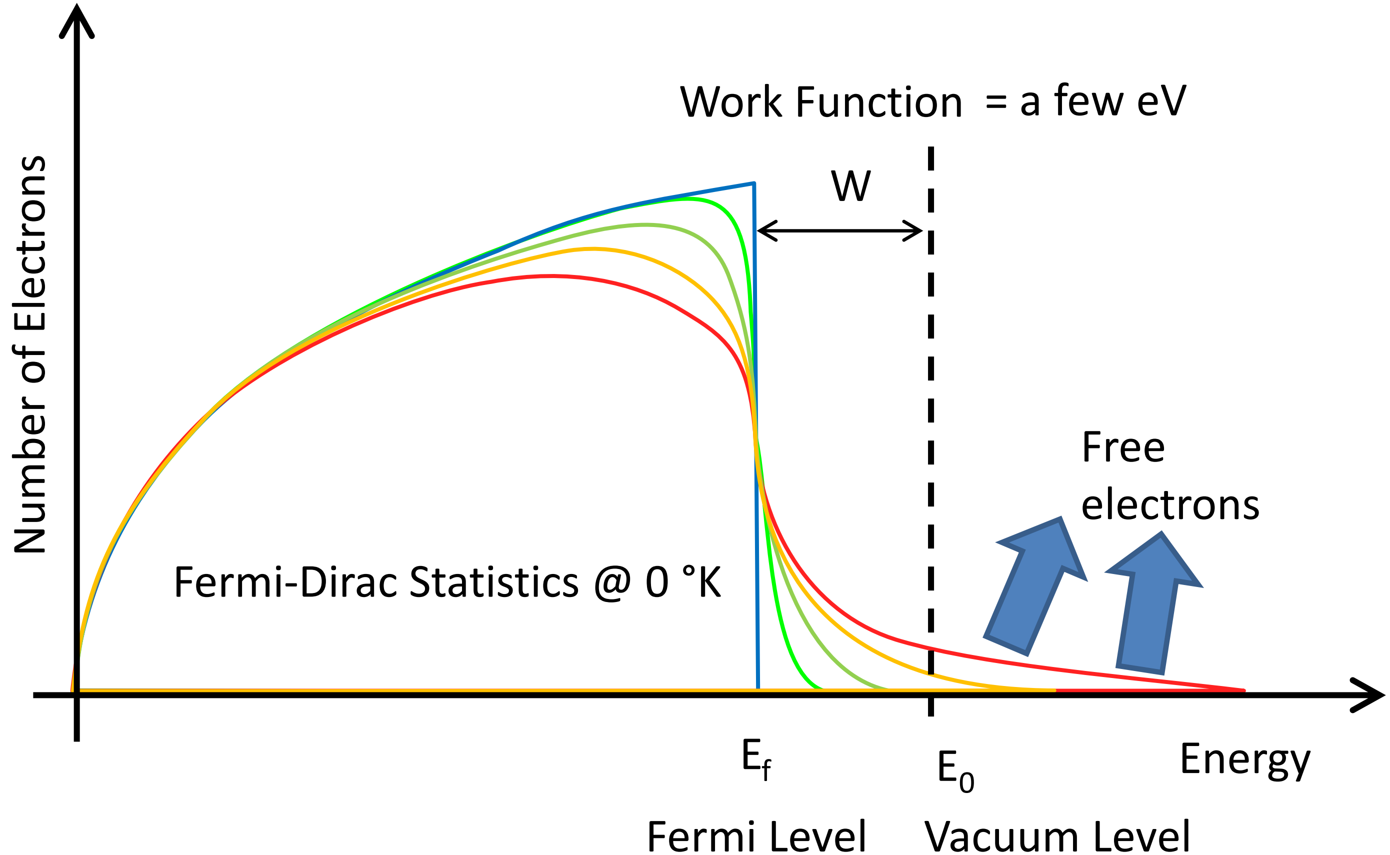
$$J = A_G T^2 e^{\frac{-W}{kT}}$$

Richardson's Law

Same form as the Arrhenius equation

Current increases exponentially with temperature

Thermionic Emission



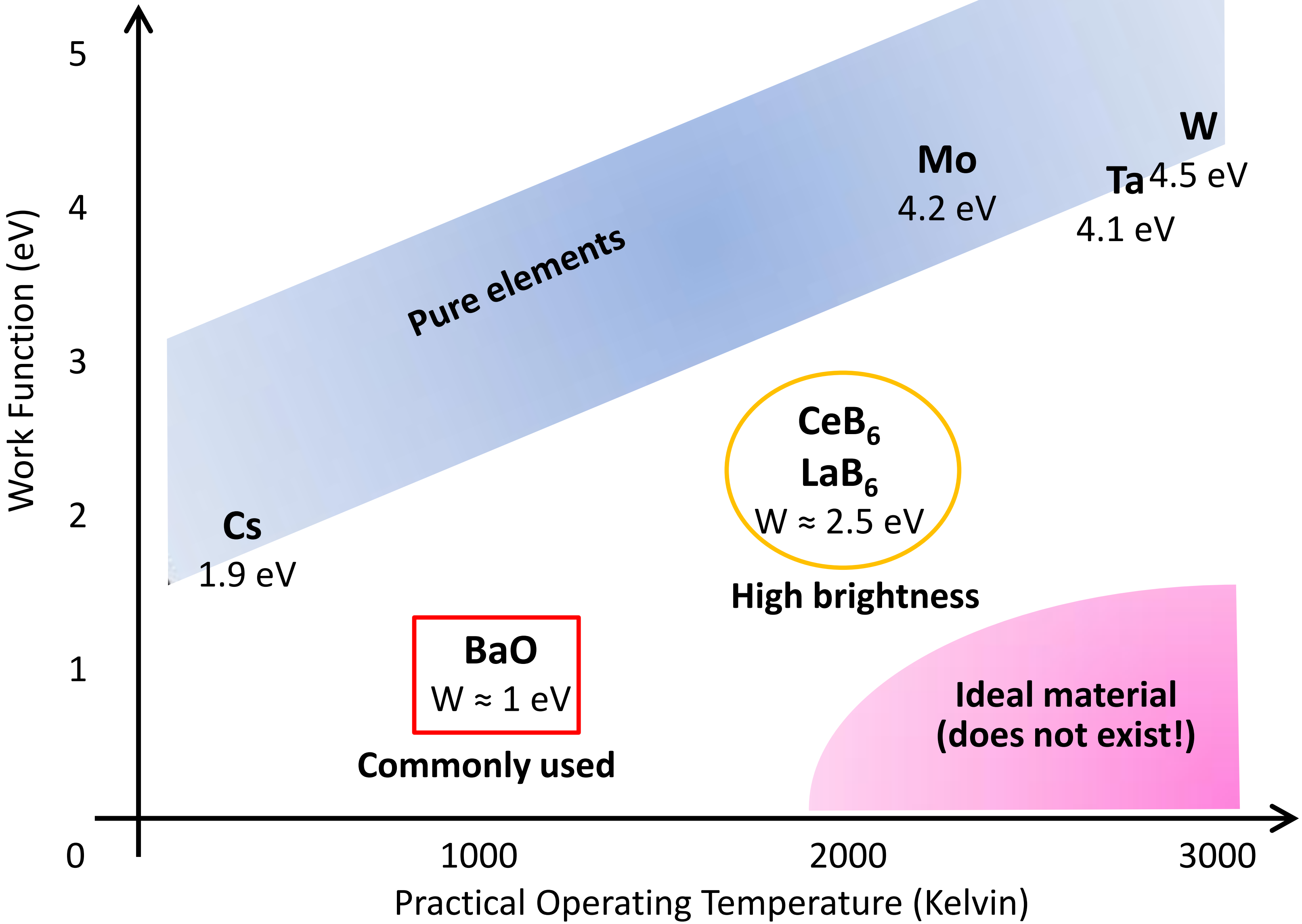
$$J = A_G T^2 e^{\frac{-W}{kT}}$$

For a good electron emitter you need:

Lowest possible work function

Highest possible temperature

Cathode Materials

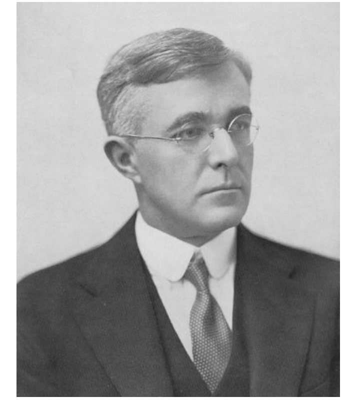


Child-Langmuir Law

(Space charge limited extraction)

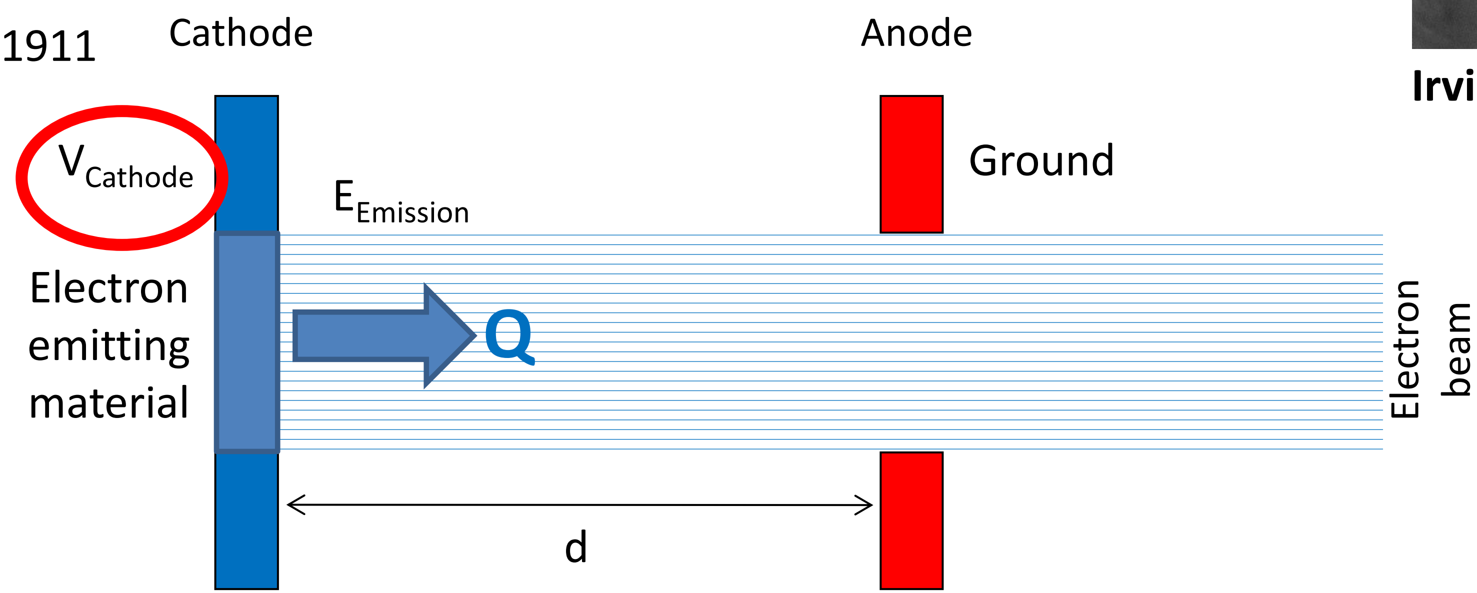
C.D Child

1911



Irving Langmuir

1913

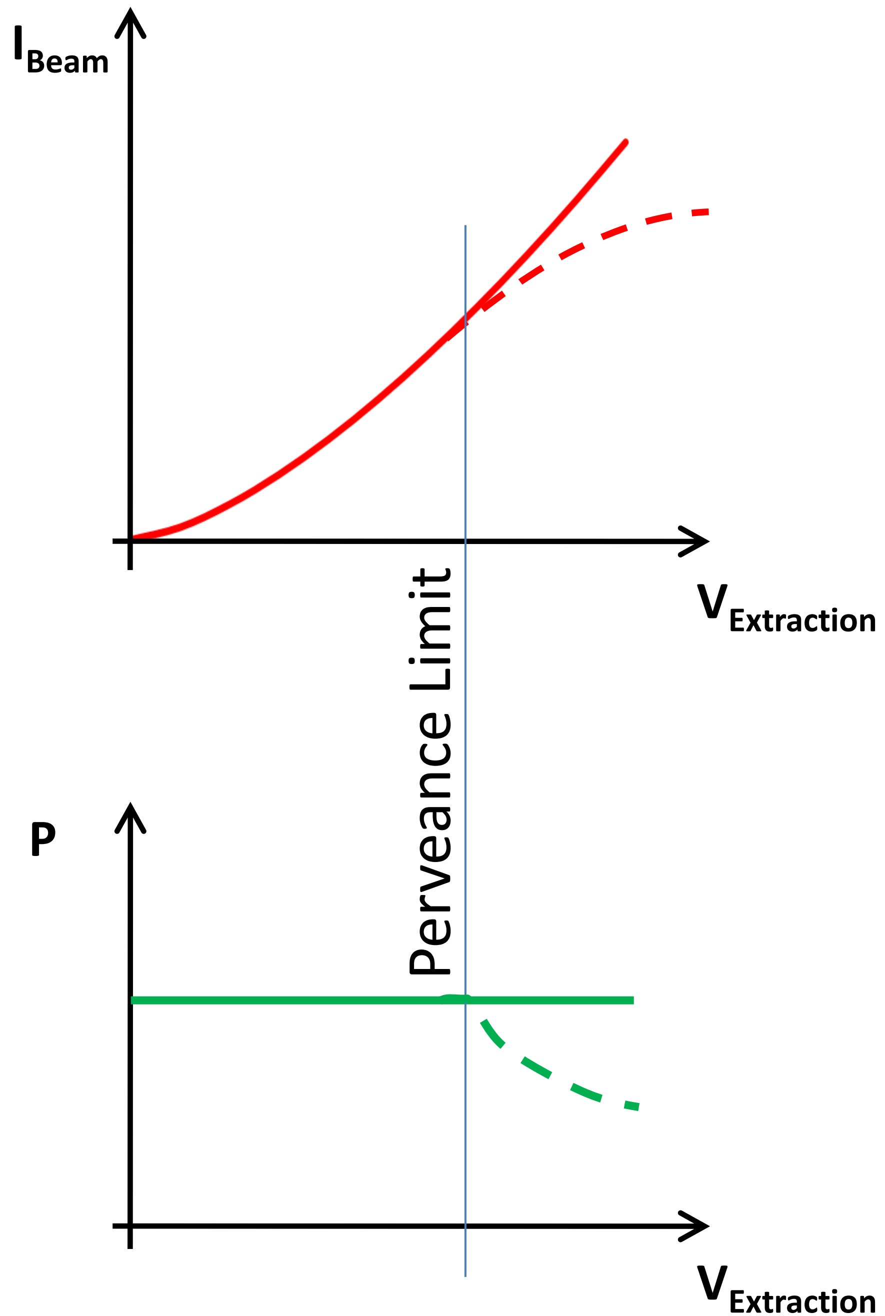


$$j = \frac{\frac{4}{9}\varepsilon_0\sqrt{\frac{2e}{m_e}}V^{\frac{3}{2}}}{d^2}$$

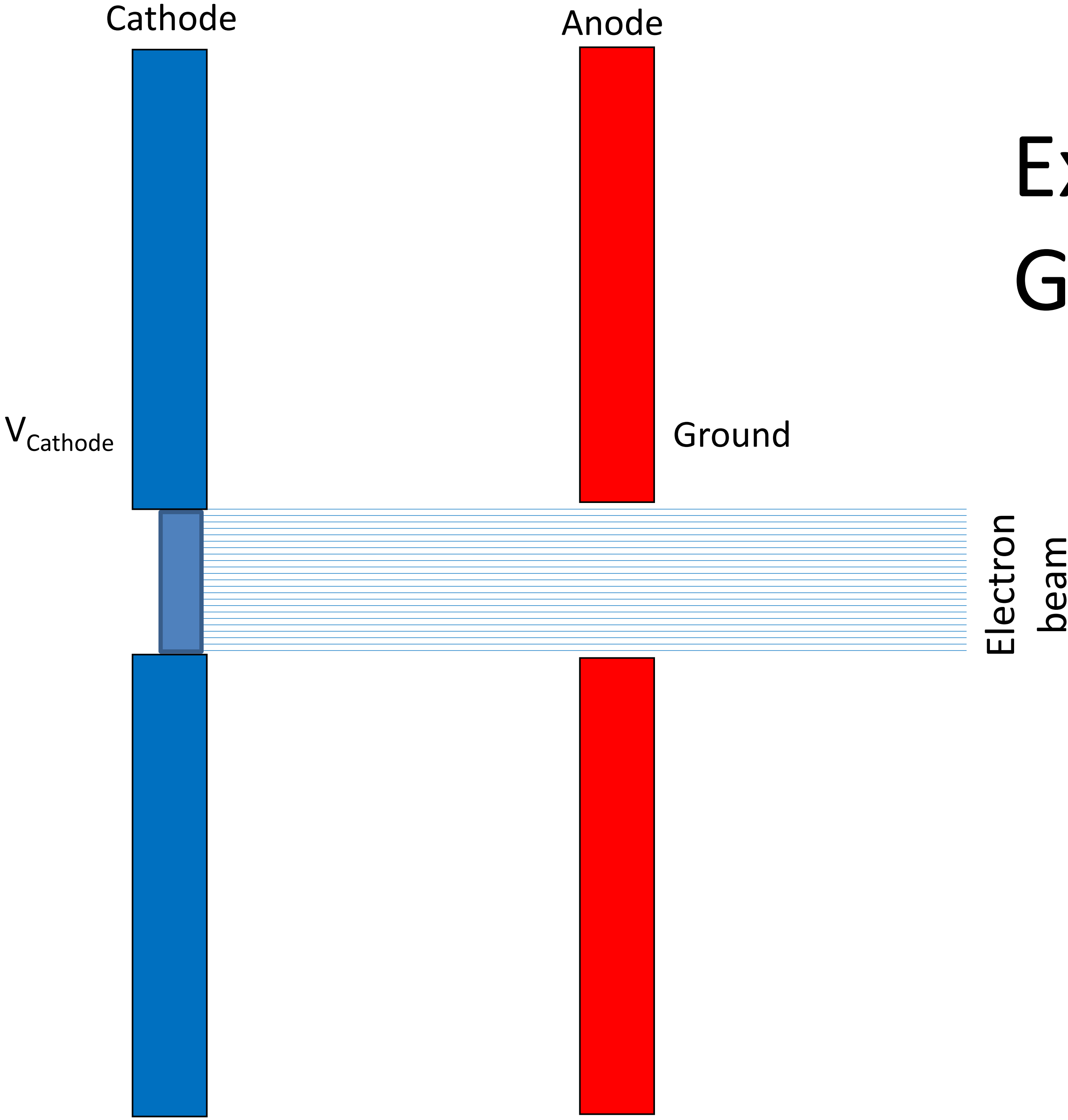
$$I \propto V^{\frac{3}{2}}$$

Perveance

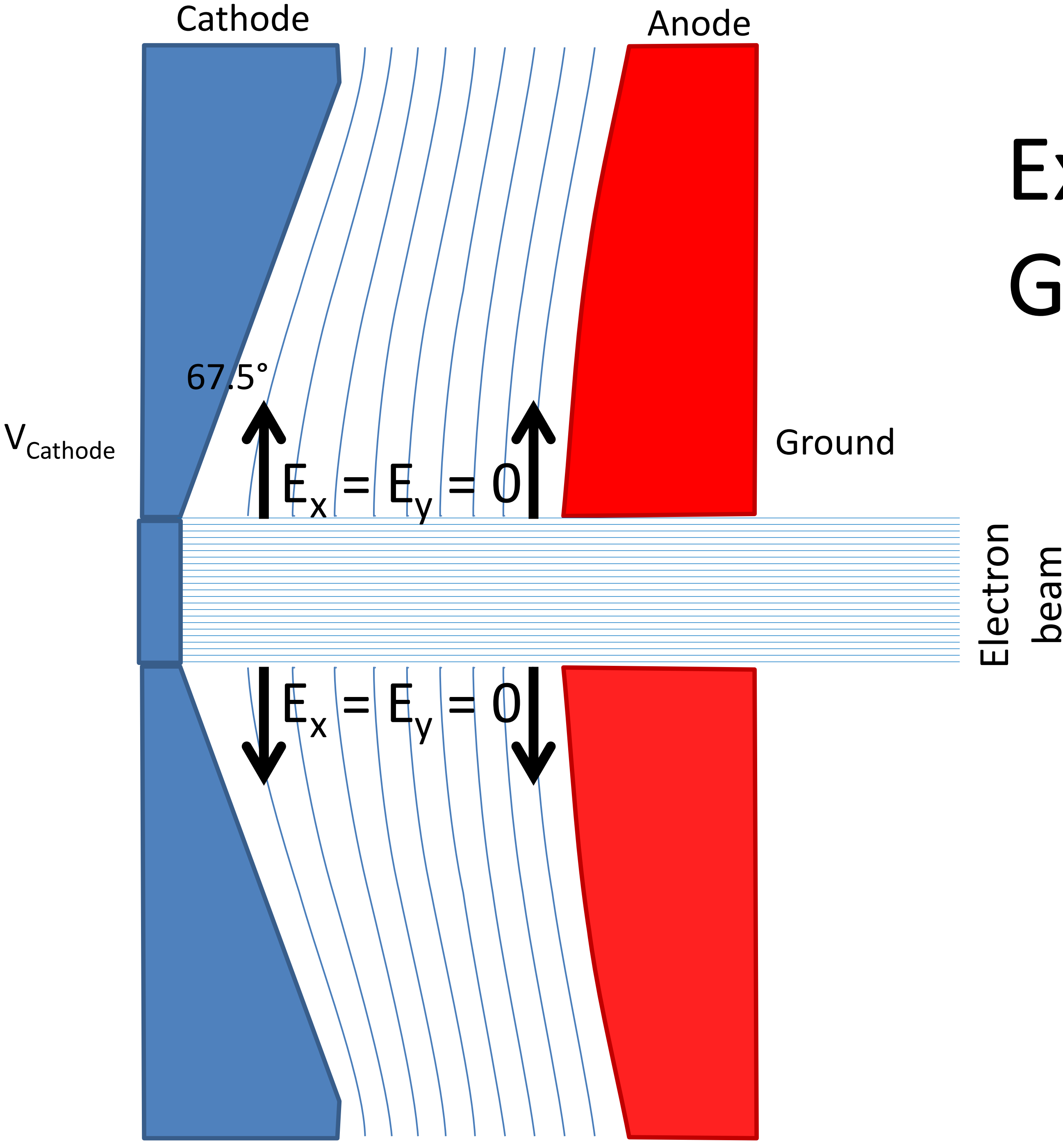
$$P = \frac{I}{V^{\frac{3}{2}}}$$



Pierce Extraction Geometry

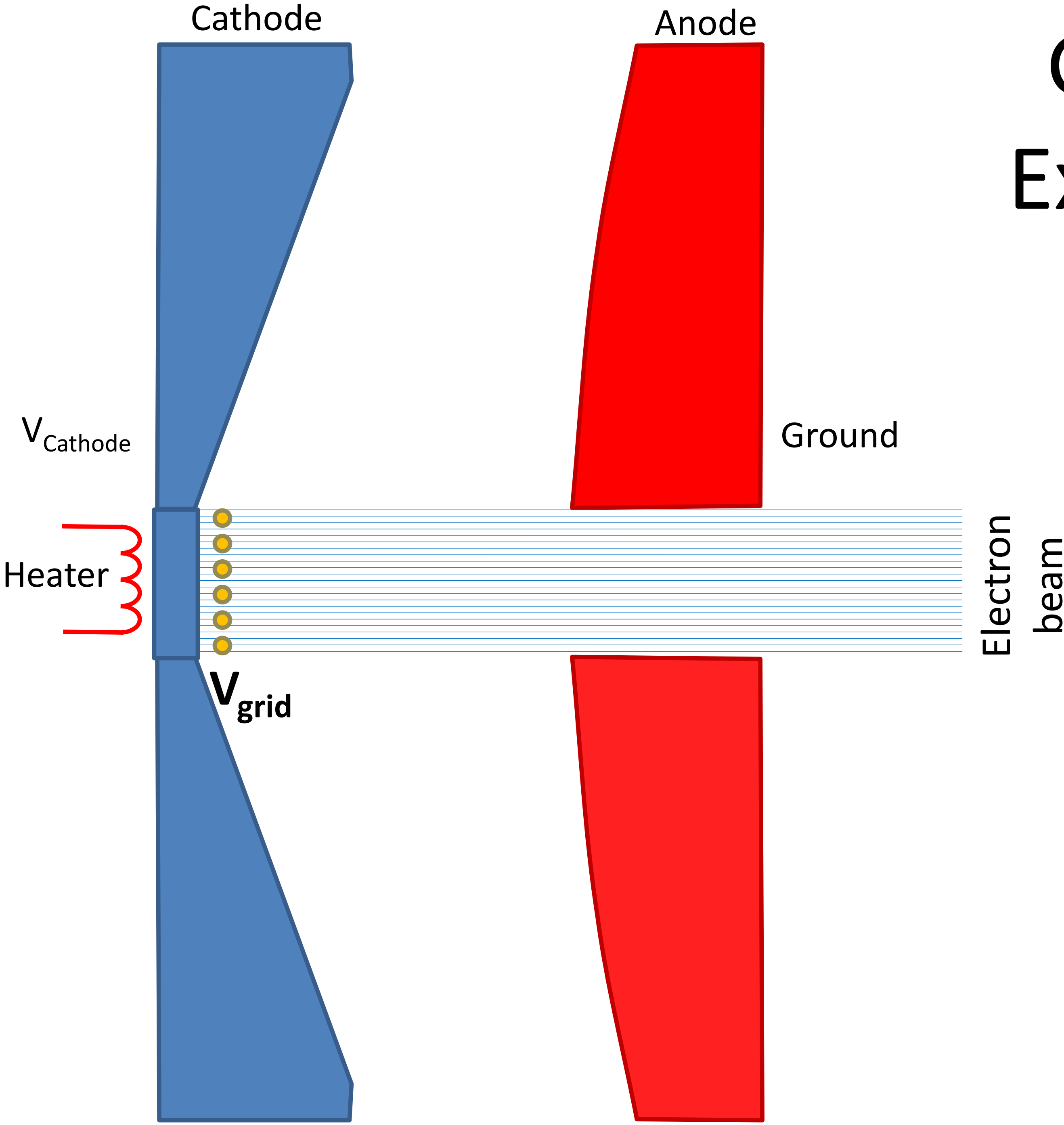


Pierce Extraction Geometry



Gridded Extraction

(A triode amplifier)



YU 171

Thermionic dispenser cathode with integrated heater and grid

Sinter of W and BaO

$1cm^2$
12 W heater

PAUL SCHERRER INSTITUT

PSI

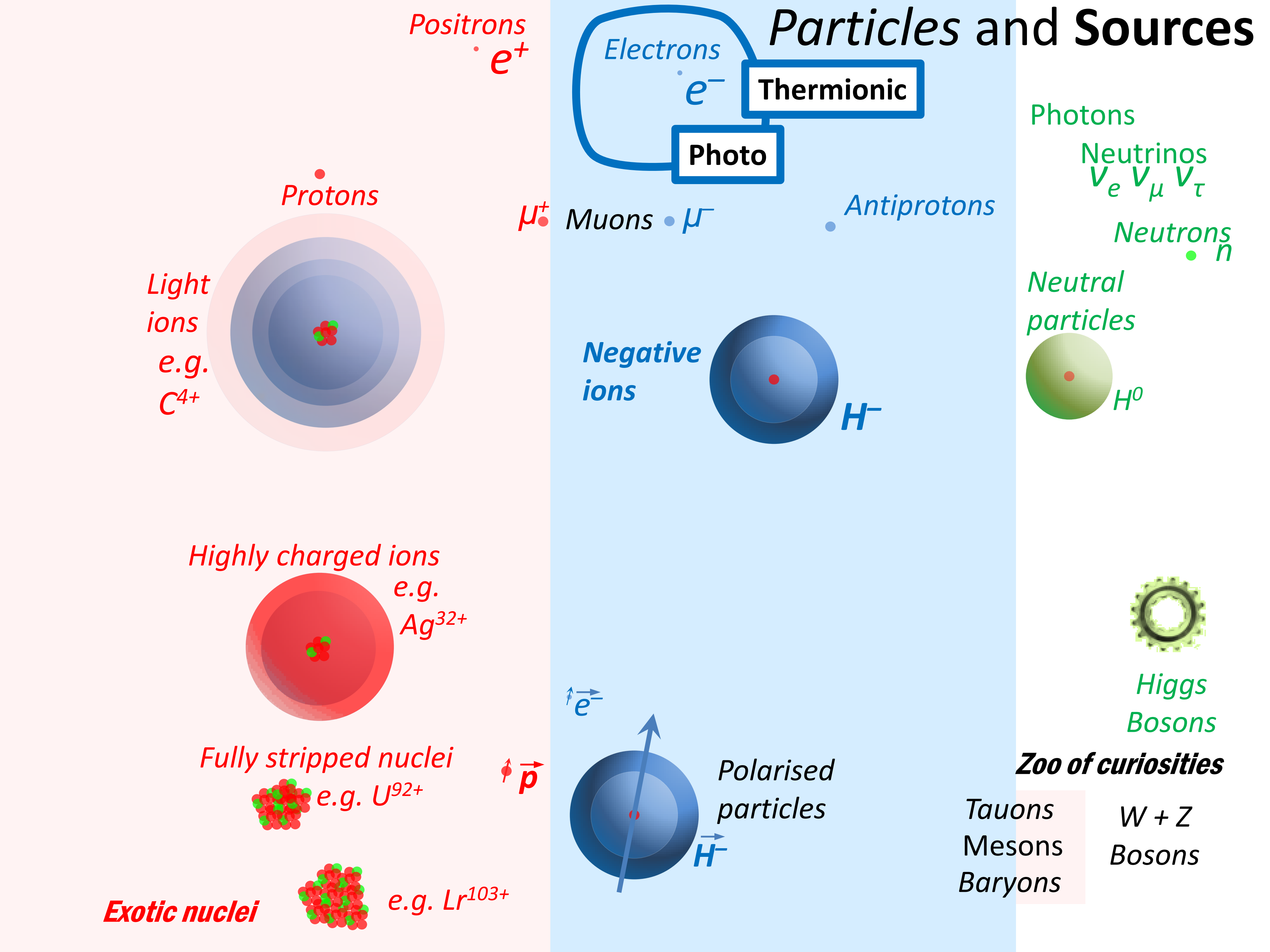
Swiss Light Source

diamond

90 kV triode gun with Pierce geometry

1000 ns, 3 nC long pulses
or
1 ns, 1.5 nC short pulses

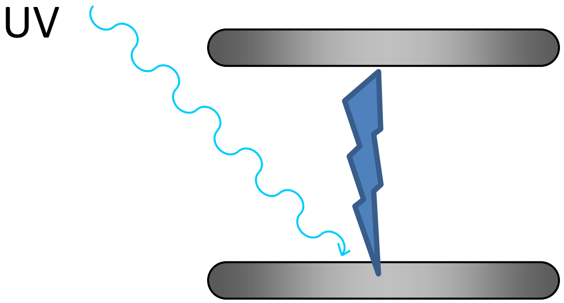
Lifetime =
several thousand hours



Particles and Sources
Positrons
e^+
Electrons
e^-
Thermionic
Photo
Photons
Neutrinos
$\nu_e \; \nu_\mu \; \nu_\tau$
Protons
μ^+
Muons
μ^-
Antiprotons
Neutrons
n
Light ions e.g. C^{4+}
Neutral particles
Negative ions
H^-
H^0
Highly charged ions
e.g. Ag^{32+}
Higgs Bosons
$\vec{e}^-$
Fully stripped nuclei
e.g. U^{92+}
$\vec{p}$
Polarised particles
$\vec{H}^-$
Zoo of curiosities
Tauons
Mesons
Baryons
W + Z Bosons
Exotic nuclei
e.g. Lr^{103+}

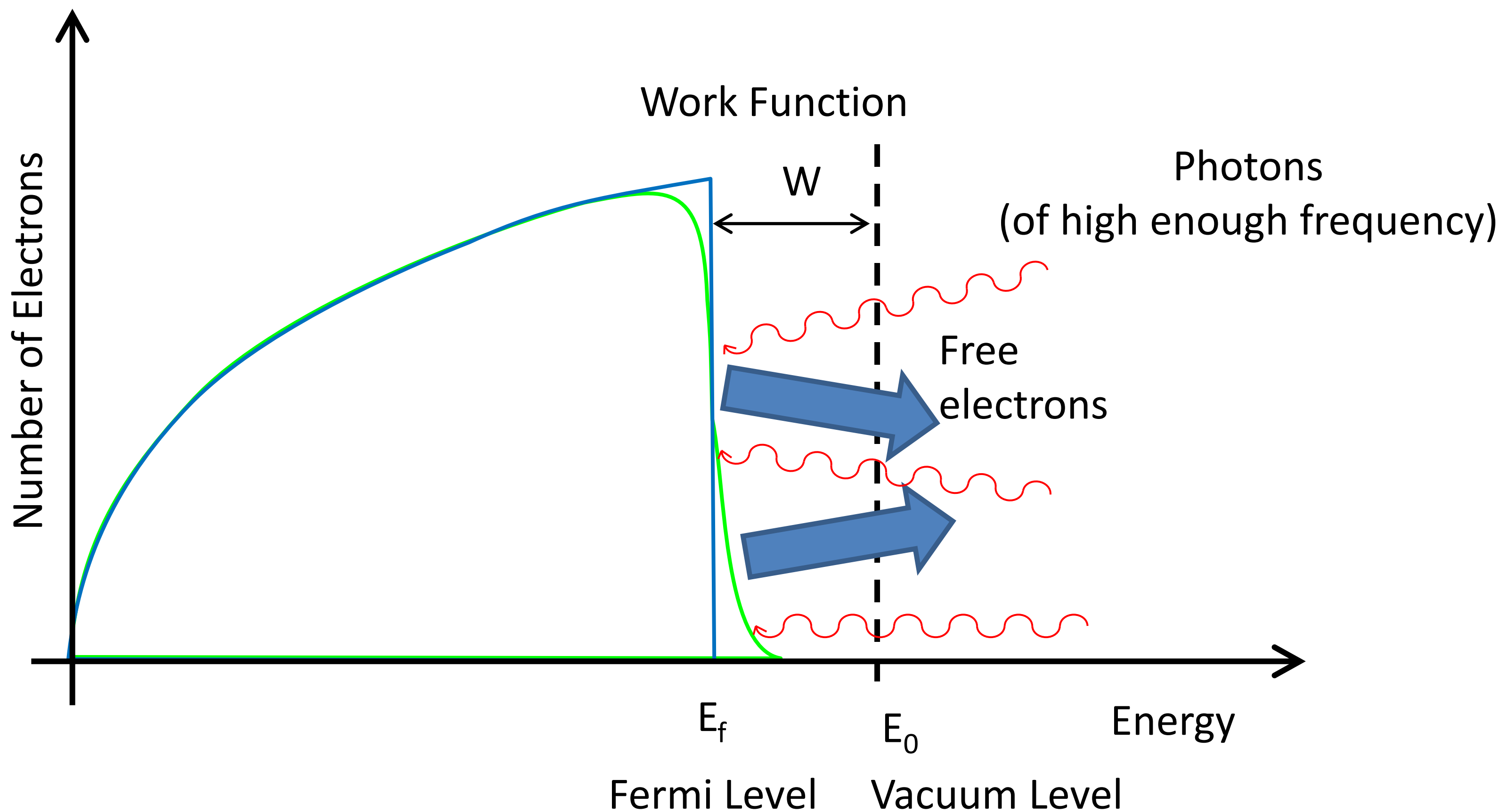
Photo Emission

First observed by Heinrich Hertz in 1887



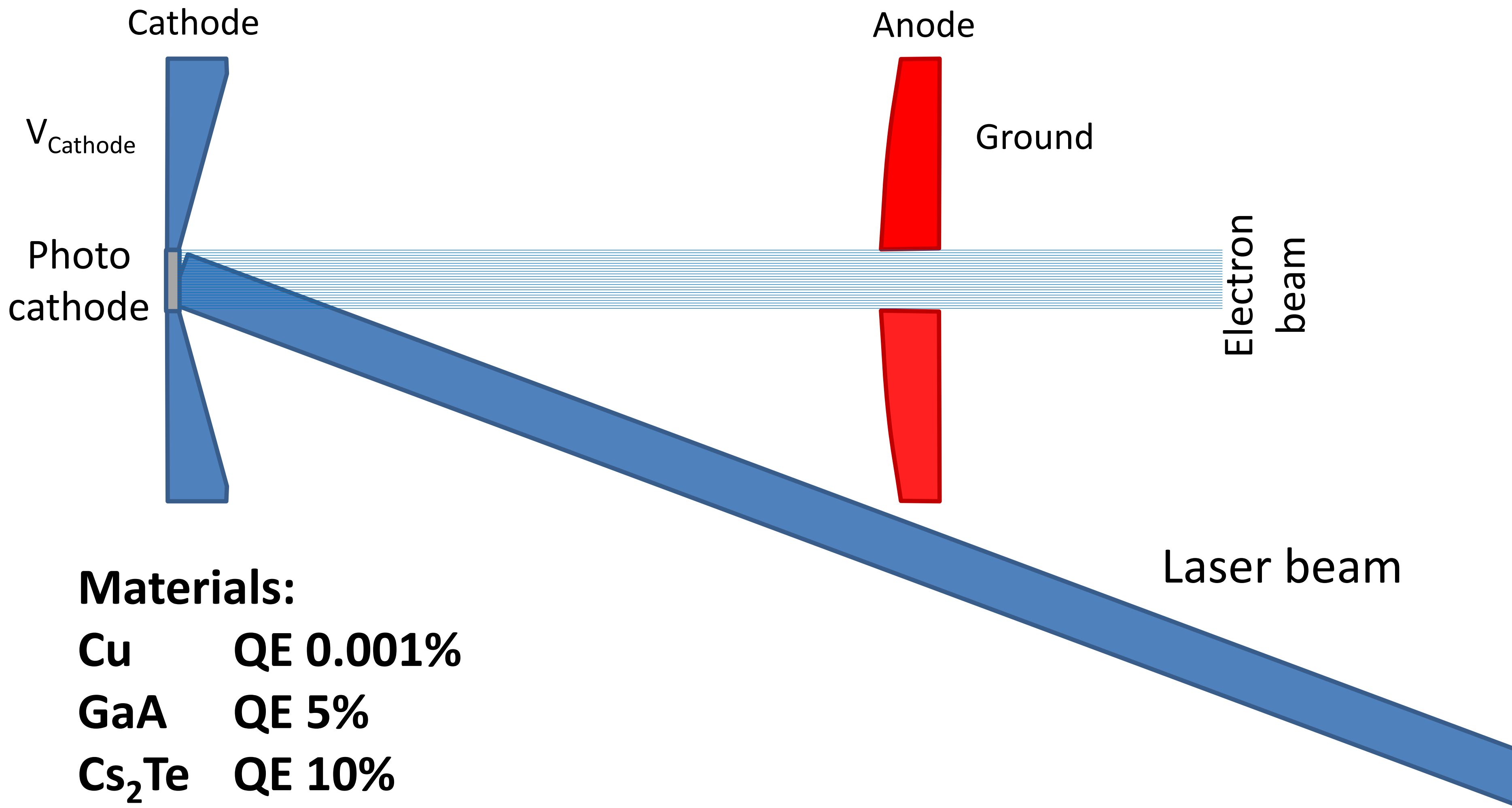
Theoretical explanation by Einstein in 1905

Photo electric emission



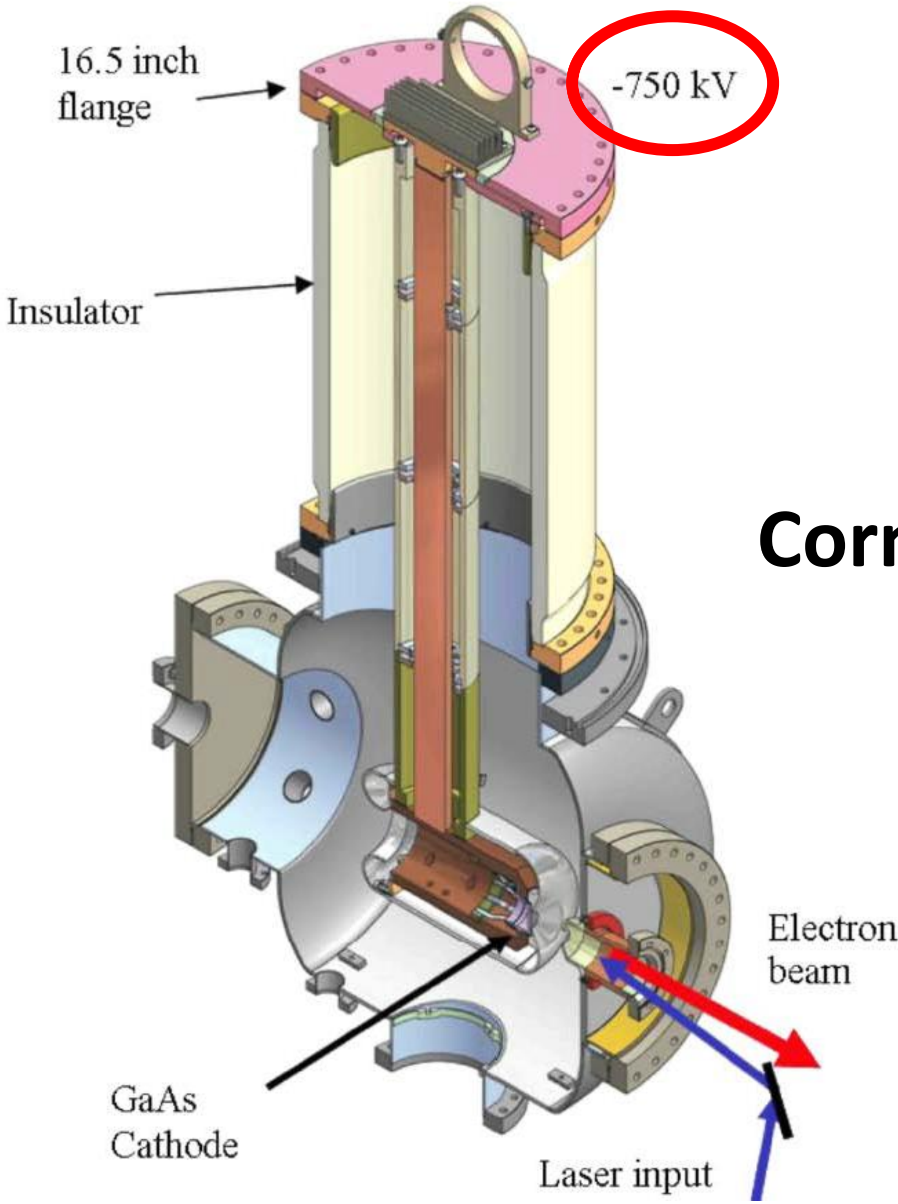
$$\text{Quantum efficiency (QE)} = \frac{\text{Number of electrons produced}}{\text{Number of incident photons}}$$

Photo Emission Gun



Materials:

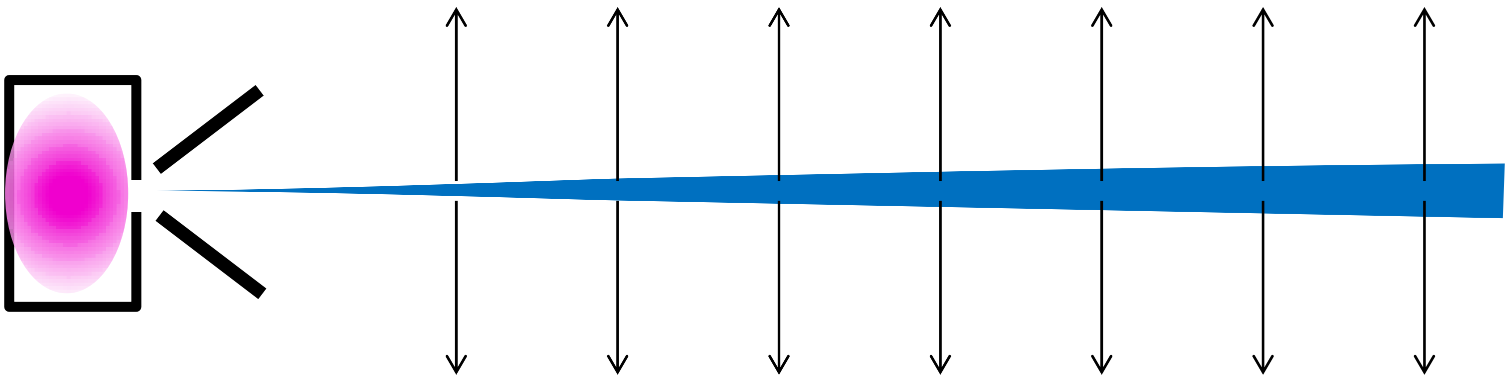
Cu	**QE 0.001%**
GaA	**QE 5%**
Cs_2Te	**QE 10%**



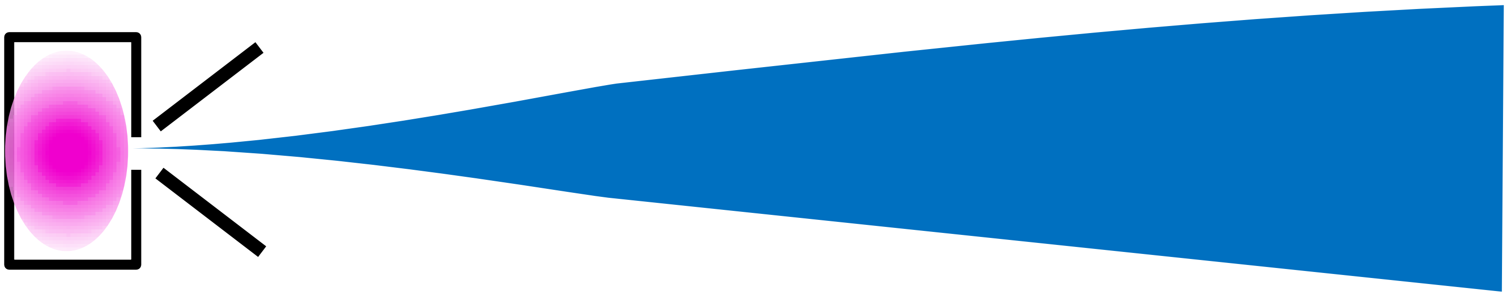
Cornell DC Photoemission gun

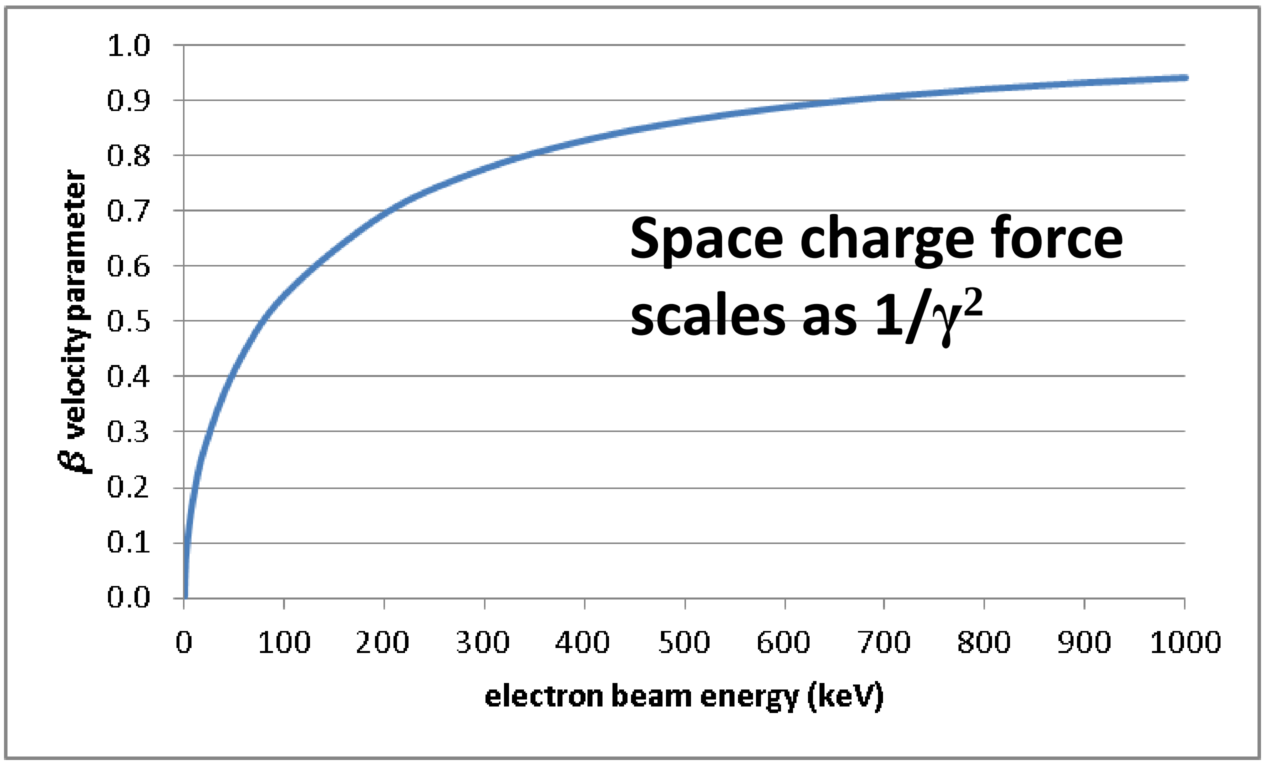
20 mA average current at 250kV

Space Charge



Space Charge





At 500 keV electron γ= 2

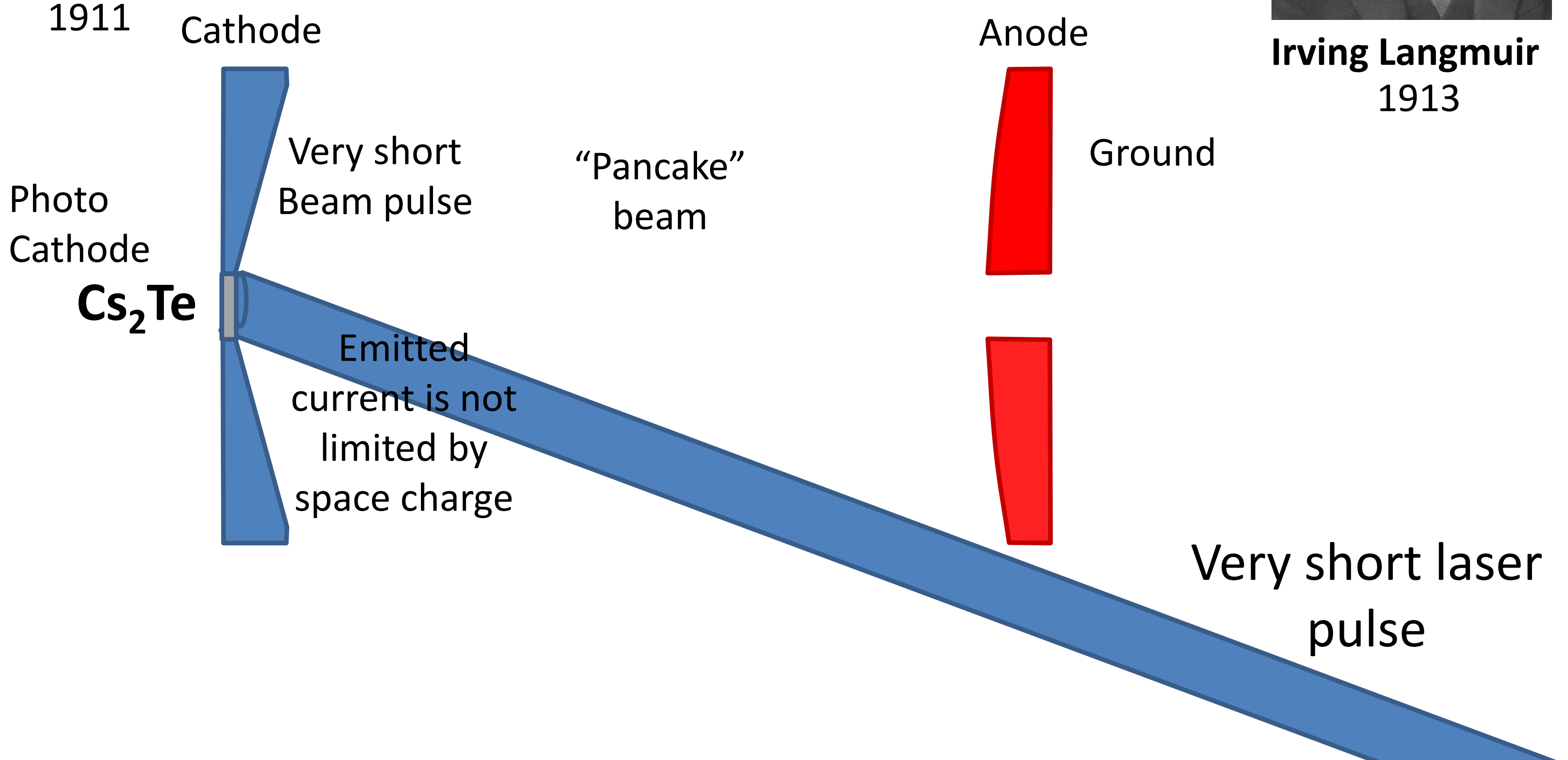
(940 MeV proton γ = 2)

Another reason to use lasers is…

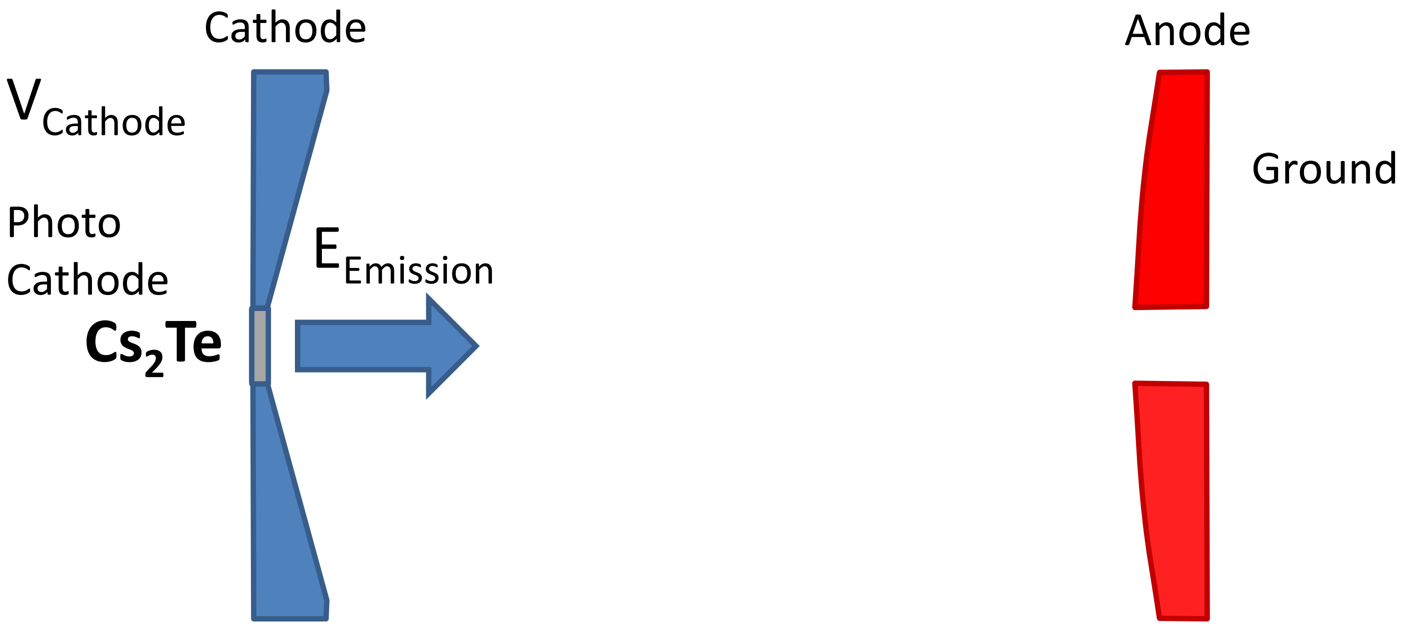
Child-Langmuir (to be fair,
gridded extr

C.D Child
1911

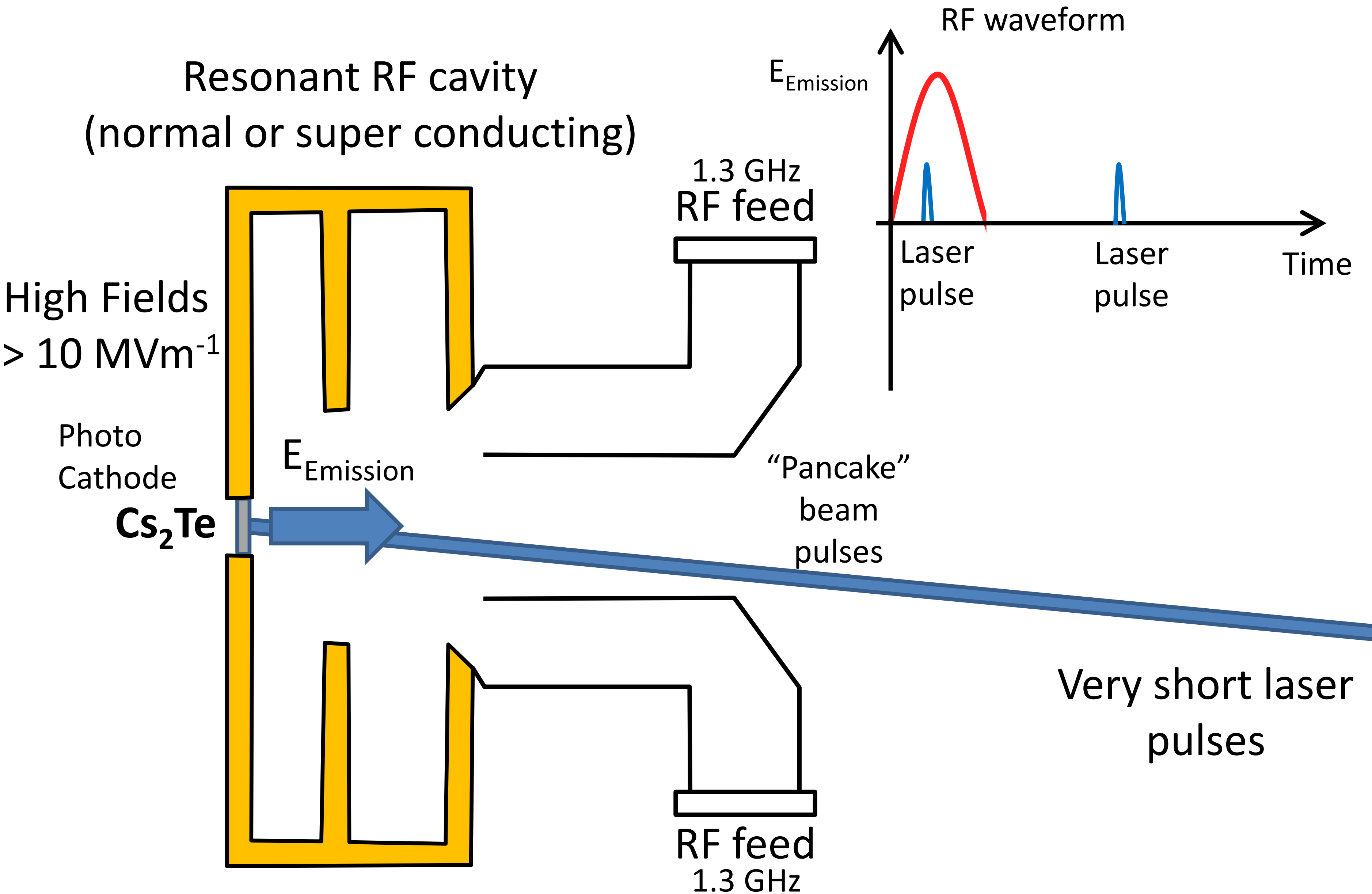
Irving Langmuir
1913



RF Photemission Source

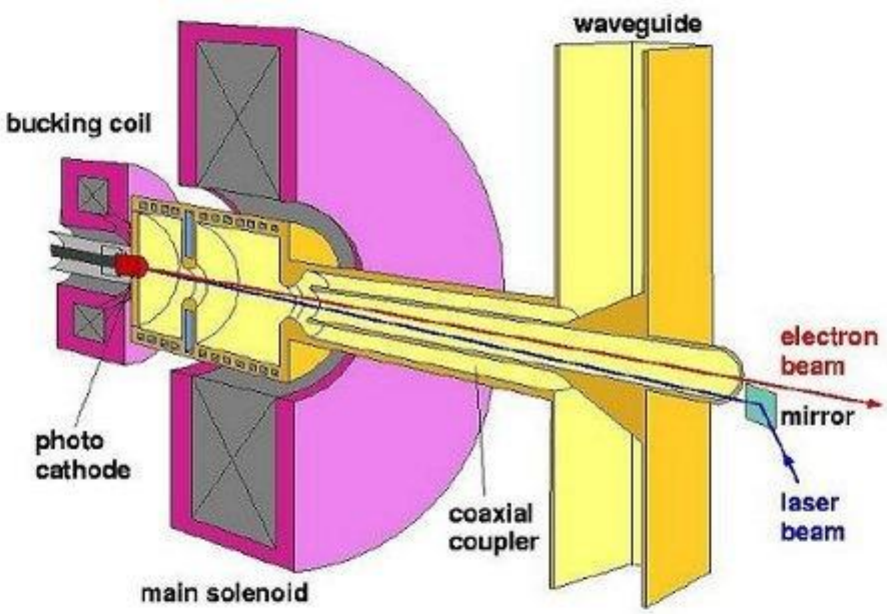


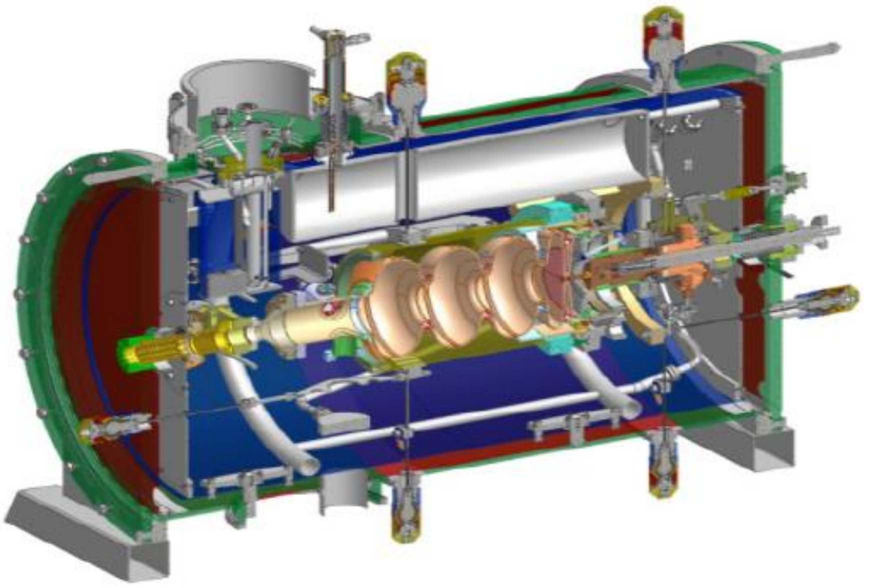
RF Photemission Source



Normally conducting

Super conducting



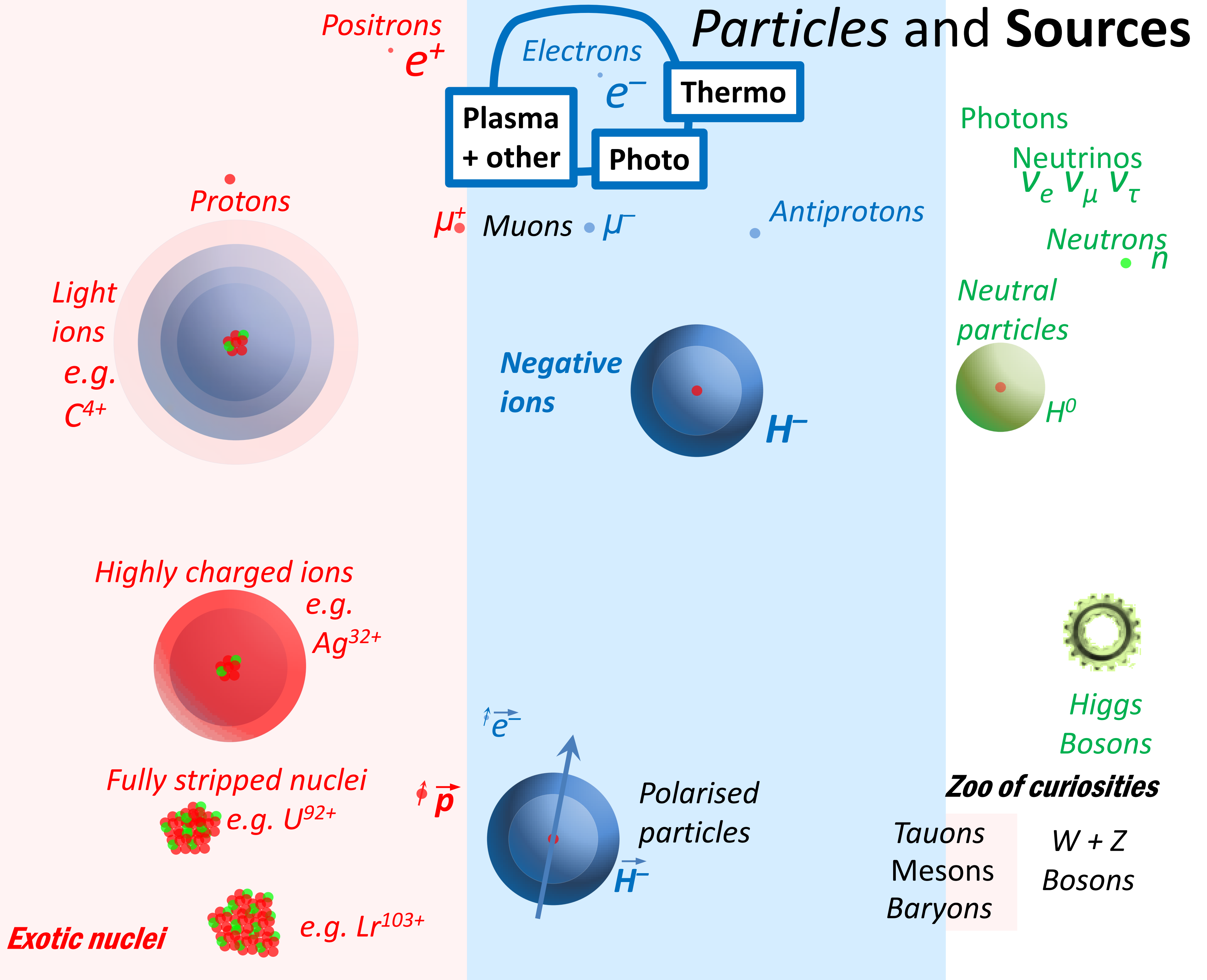


20 ps, 1 nC pulses
(50 A pulse)

15 ps, 1 nC pulses
(67 A pulse)

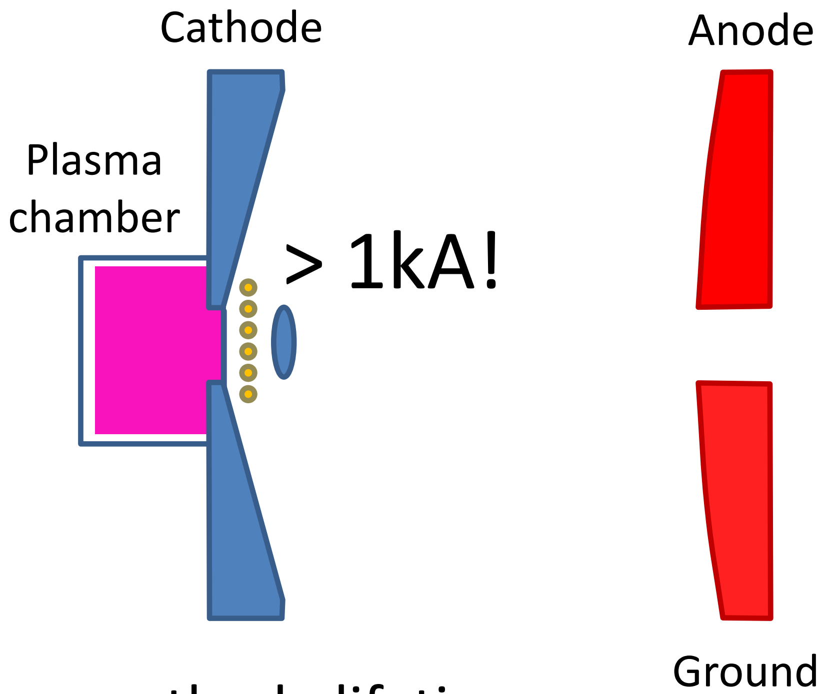
High brightness low emittance guns for FEL

Particles and **Sources**



Plasma Cathode

Very high electron currents can be extracted from plasma cathode electron sources



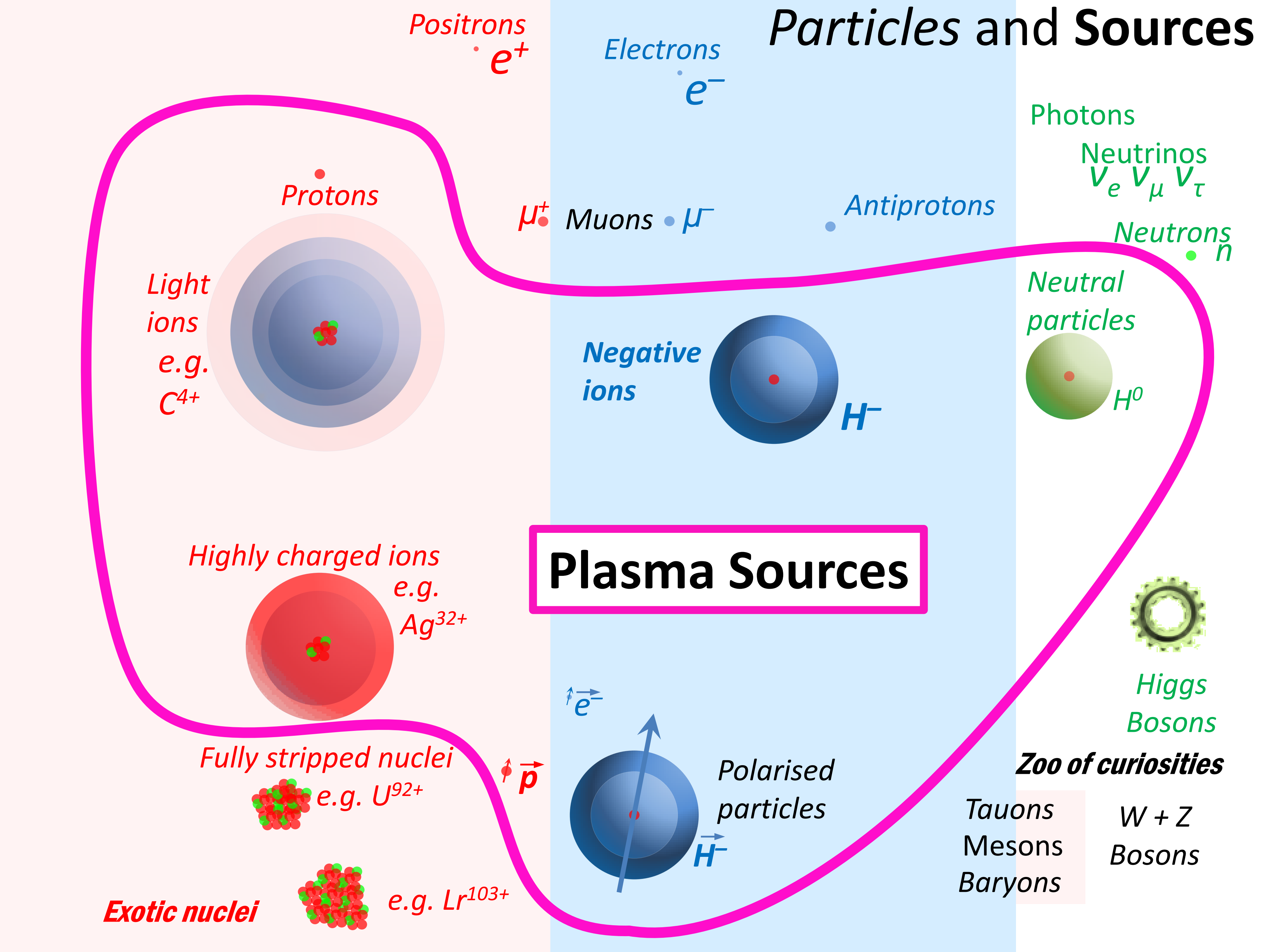
Long cathode lifetimes

Other electron sources:

Combinations of those already mentioned
e.g. photo-thermionic

Rarely used in accelerators:

Field emission from needle arrays
Diamond amplifiers
Etc...



Particles and Sources
Positrons
e^+
Electrons
e^-
Photons
Neutrinos
ν_e ν_μ ν_τ
Protons
μ^+
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μ^-
Antiprotons
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n
Light ions e.g. C^{4+}
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Plasma Sources
Higgs Bosons
$\vec{e}^-$
Fully stripped nuclei
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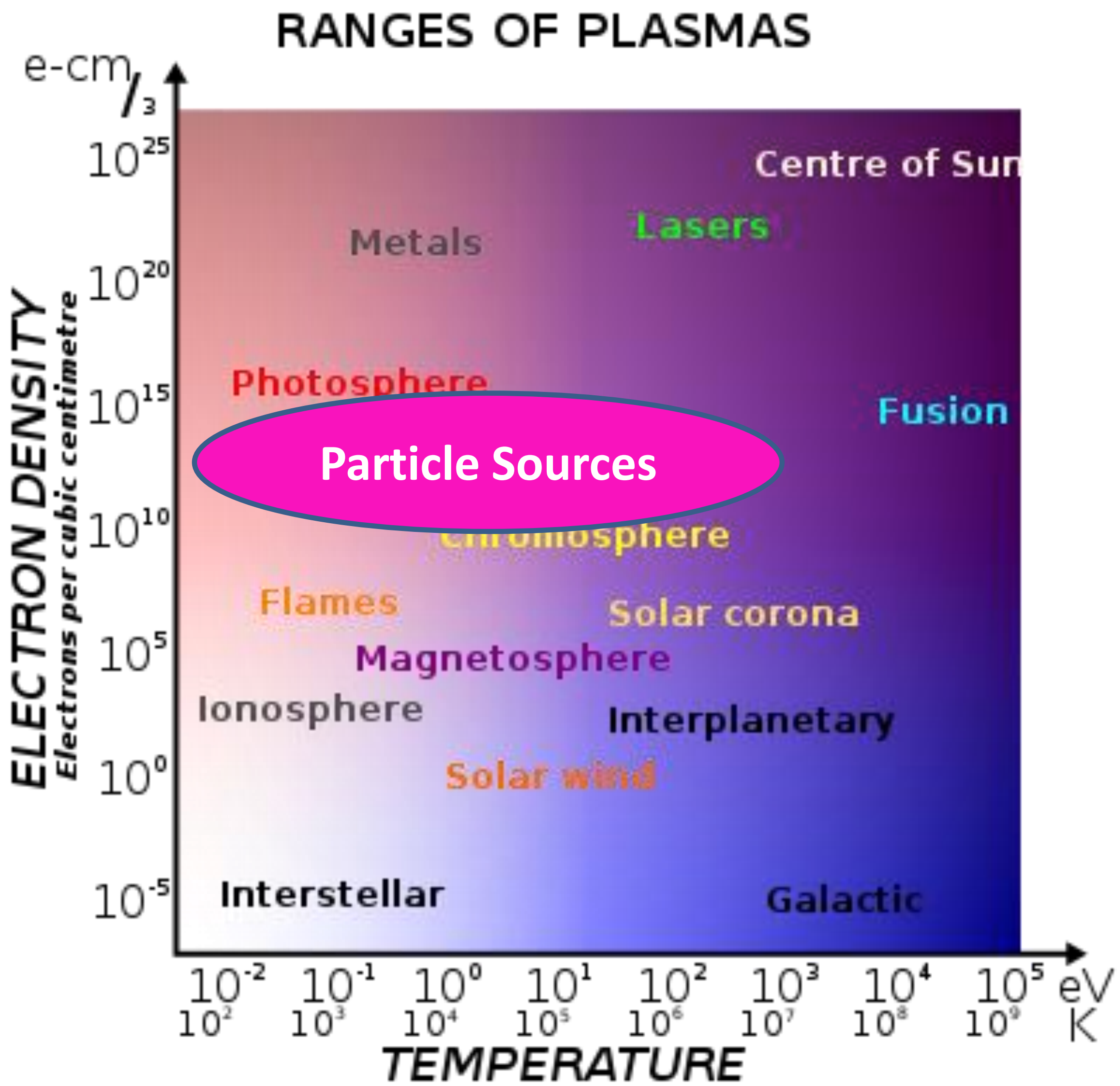
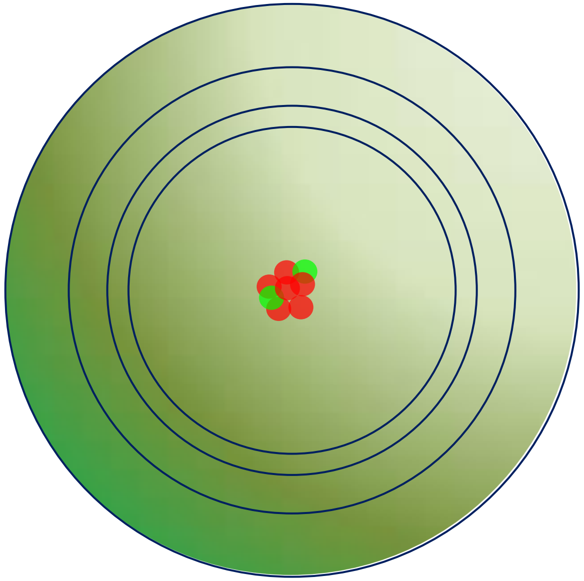
e.g. Lr^{103+}


RANGES OF PLASMAS
e-cm/3
ELECTRON DENSITY
Electrons per cubic centimetre
10^25
10^20
10^15
10^10
10^5
10^0
10^-5
Centre of Sun
Lasers
Metals
Photosphere
Fusion
Particle Sources
Chromosphere
Flames
Solar corona
Magnetosphere
Ionosphere
Interplanetary
Solar wind
Interstellar
Galactic
10^-2 10^-1 10^0 10^1 10^2 10^3 10^4 10^5 eV
10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 K
TEMPERATURE

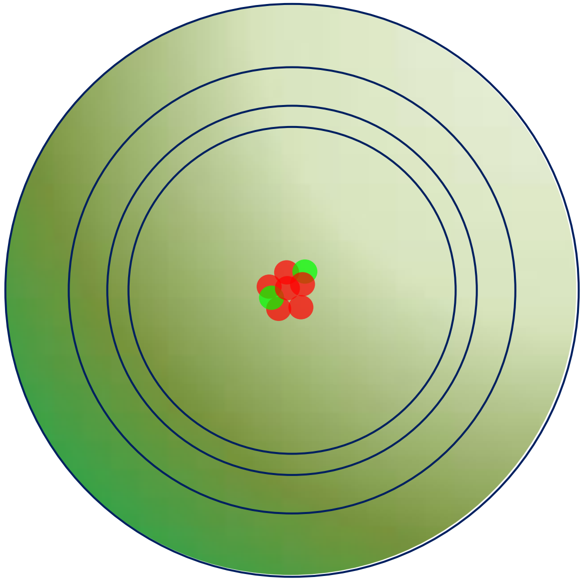
Ionisation



Neutral Atom

Most sources rely on electron impact ionisation

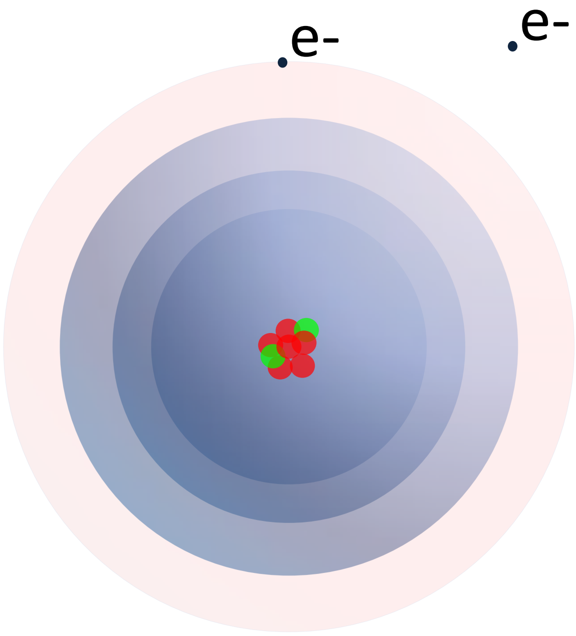
Ionisation



Neutral Atom

Most sources rely on electron impact ionisation

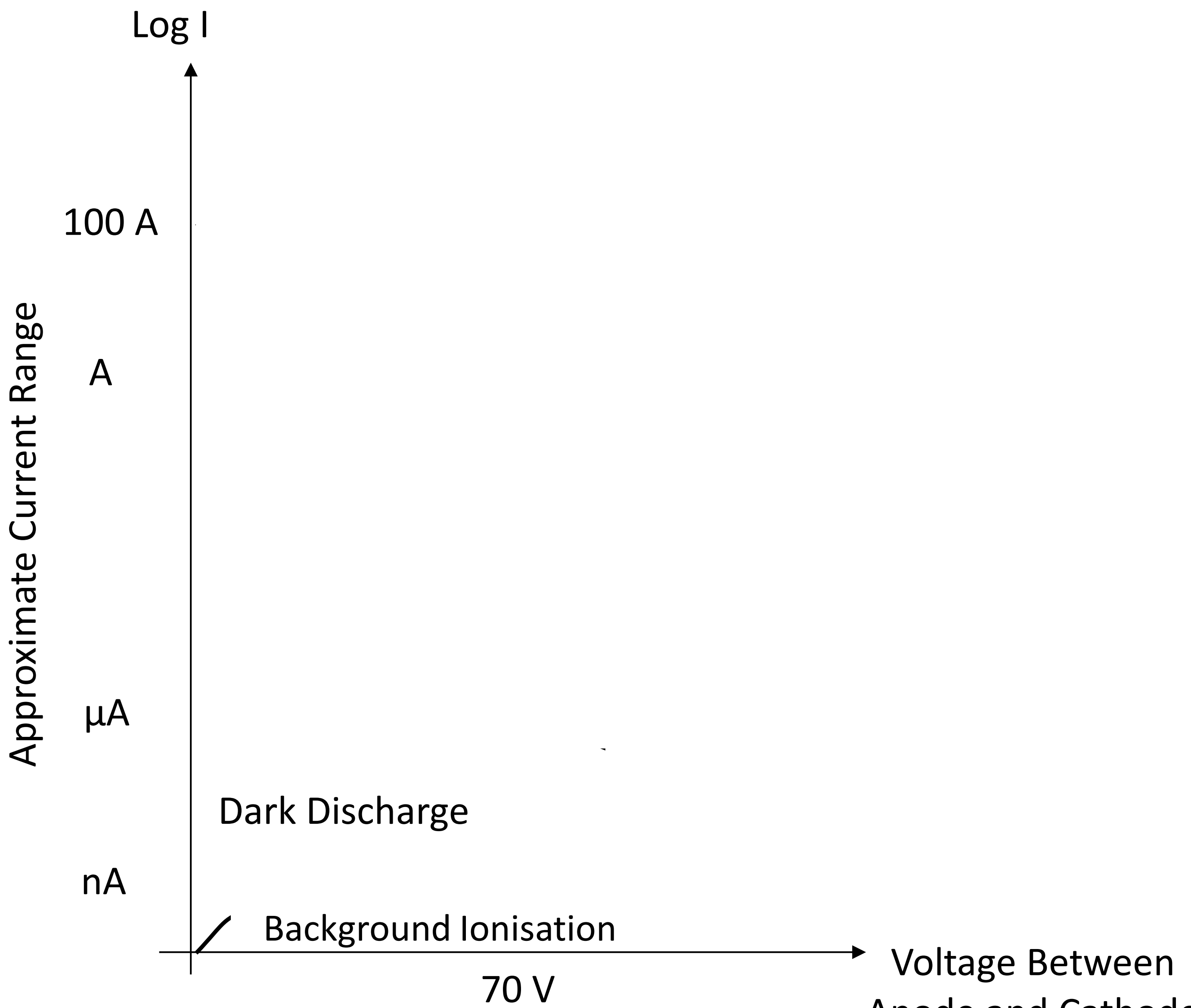
Ionisation

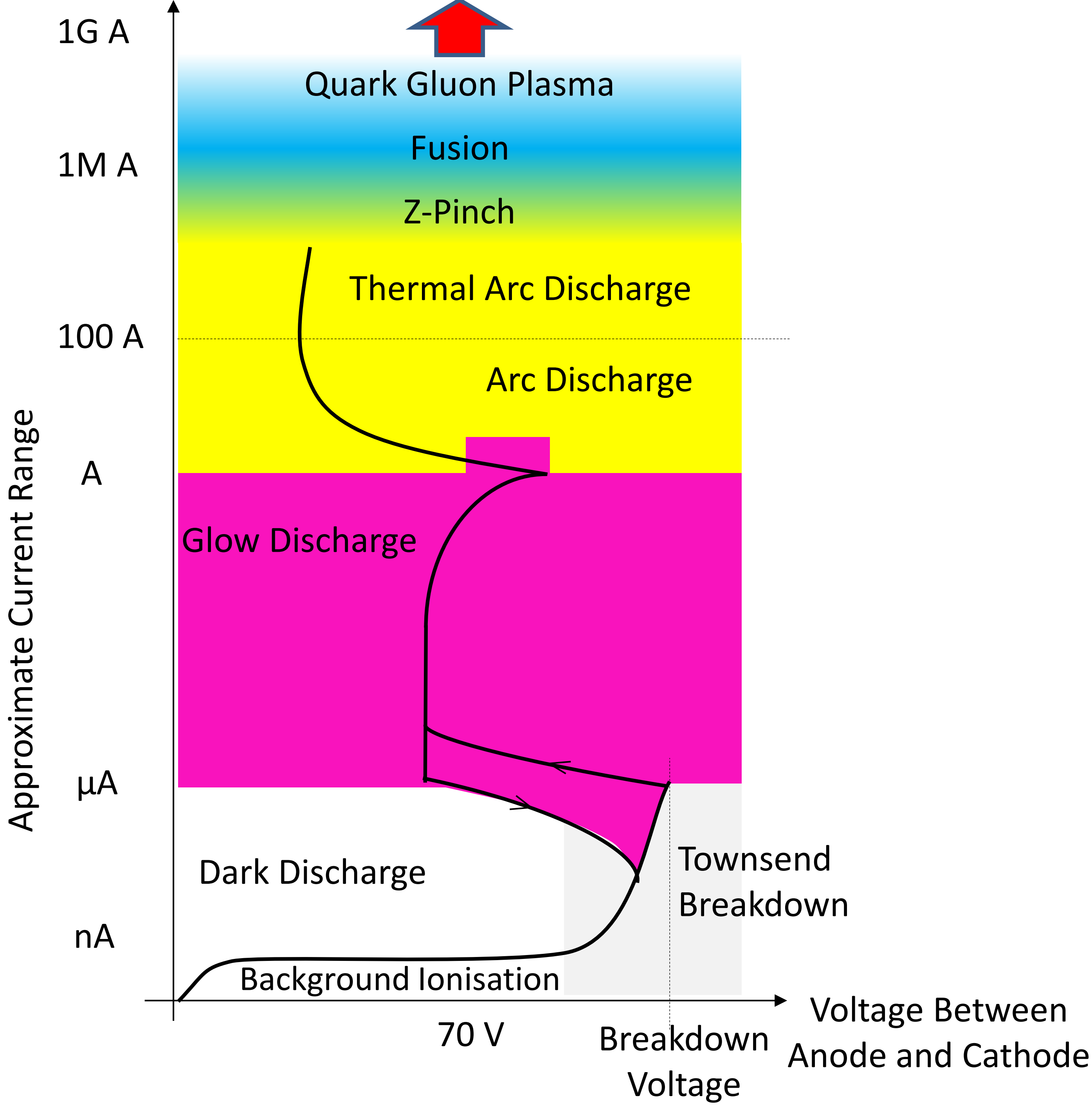


Positive Ion

Most sources rely on electron impact ionisation

Electrical Discharges




1G A
1M A
100 A
A
µA
nA
Approximate Current Range
Quark Gluon Plasma
Fusion
Z-Pinch
Thermal Arc Discharge
Arc Discharge
Glow Discharge
Dark Discharge
Townsend Breakdown
Background Ionisation
70 V
Breakdown Voltage
Voltage Between Anode and Cathode

Basic Plasma Properties

Density, *n* (per cm^3)

n_e = density of electrons

n_i = density of ions

n_n = density of neutrals

Charge State, *q*

H^+ $\longrightarrow$ $q = +1$

Pb^{3+} $\longrightarrow$ $q = +3$

H^- $\longrightarrow$ $q = -1$

Temperature, *T* (eV)

T_e = temperature of electrons

T_i = temperature of ions

T_n = temperature of neutrals

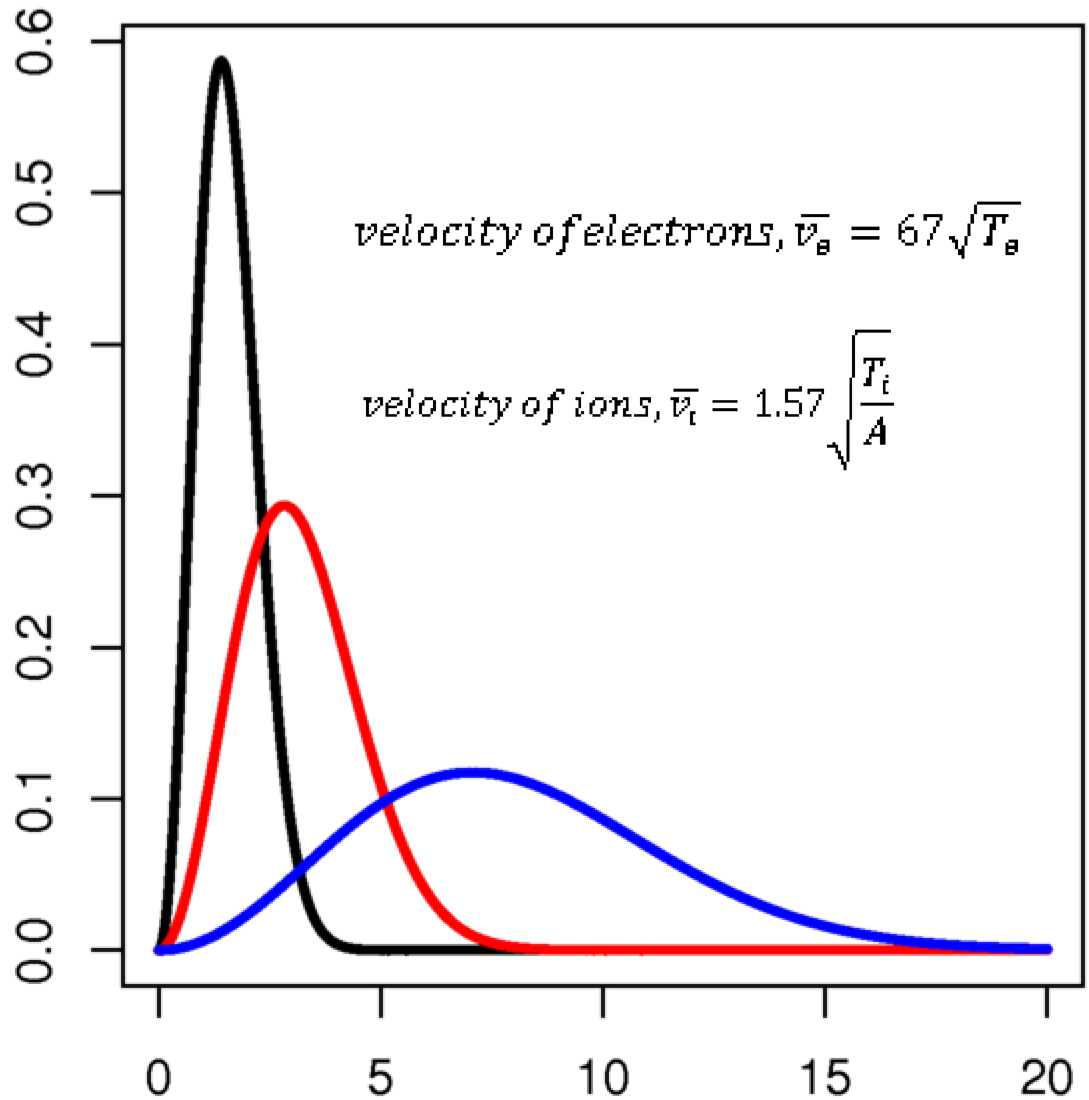
11600°K = 1 eV

Temperature Distribution

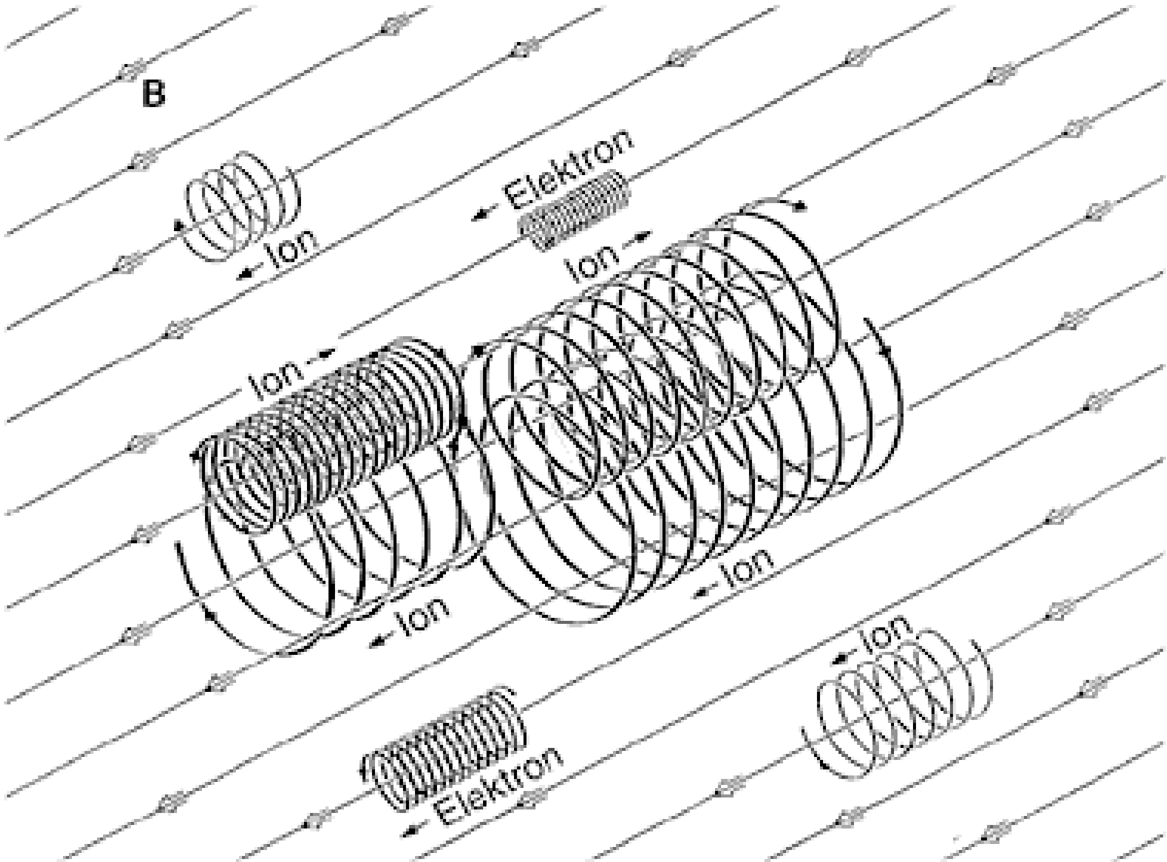
If thermalised velocity distributions should follow Maxwell Boltzmann statistics

However, in magnetic fields:

$$v_x \neq v_y \neq v_z$$

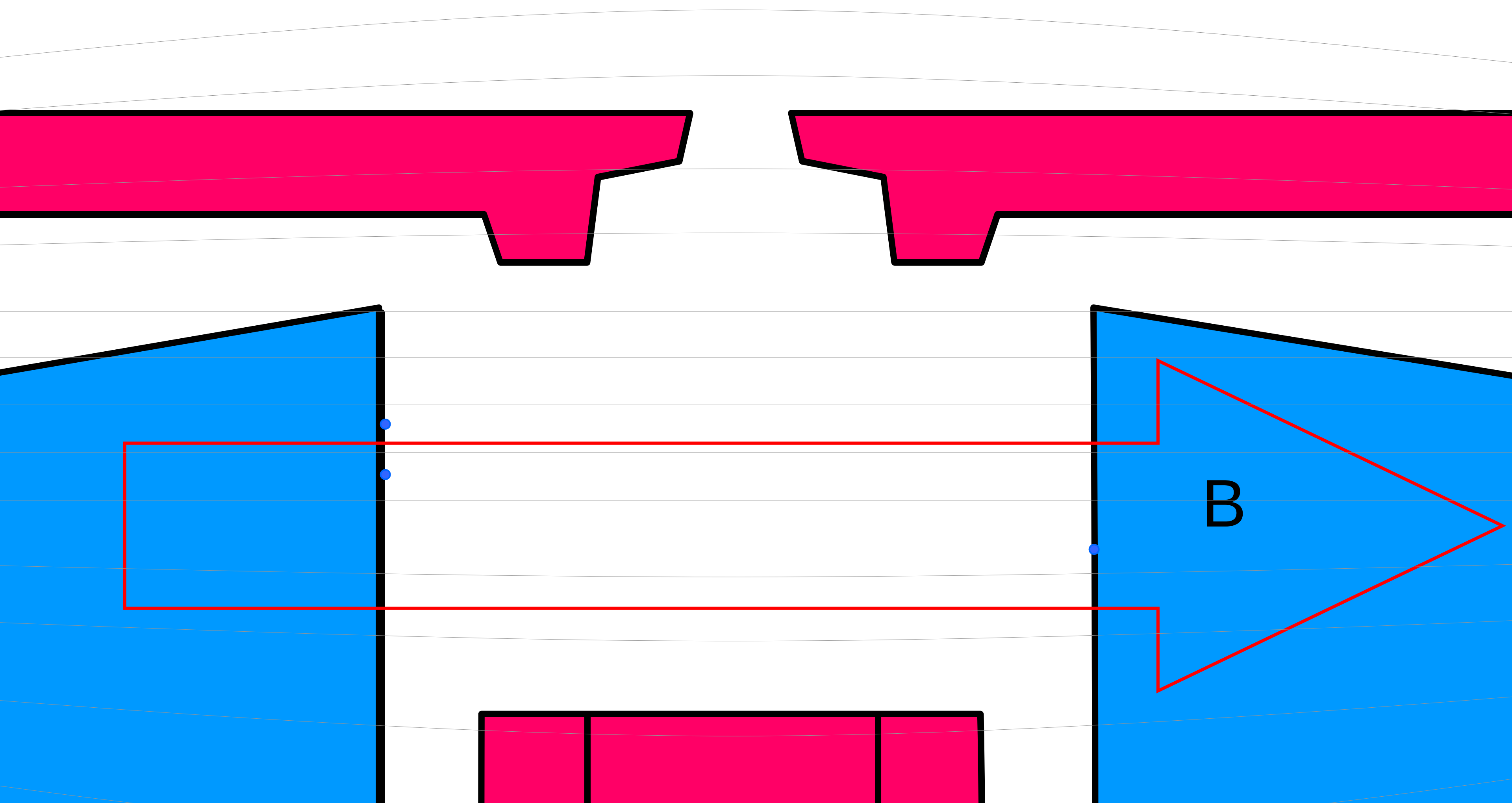


Magnetic Confinement

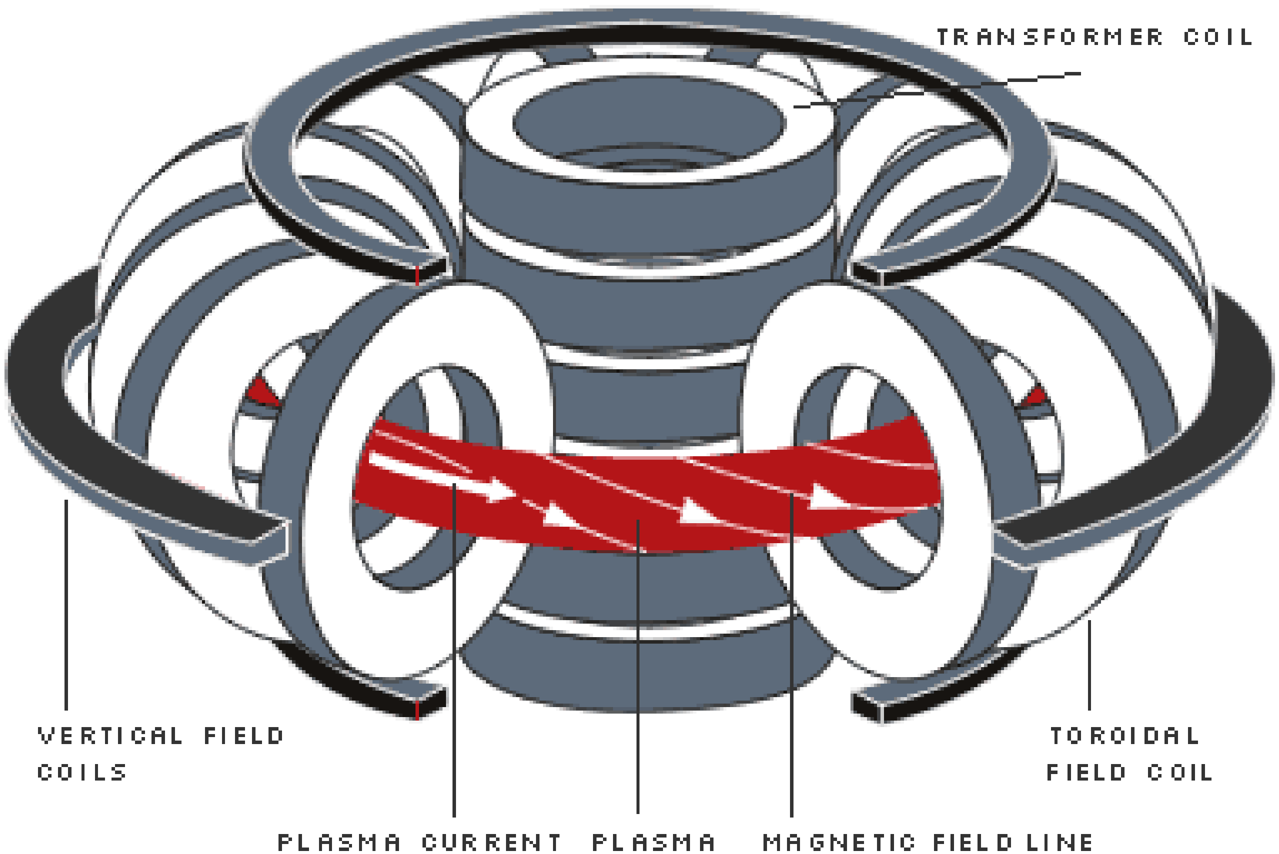


Particles spiral along magnetic field lines

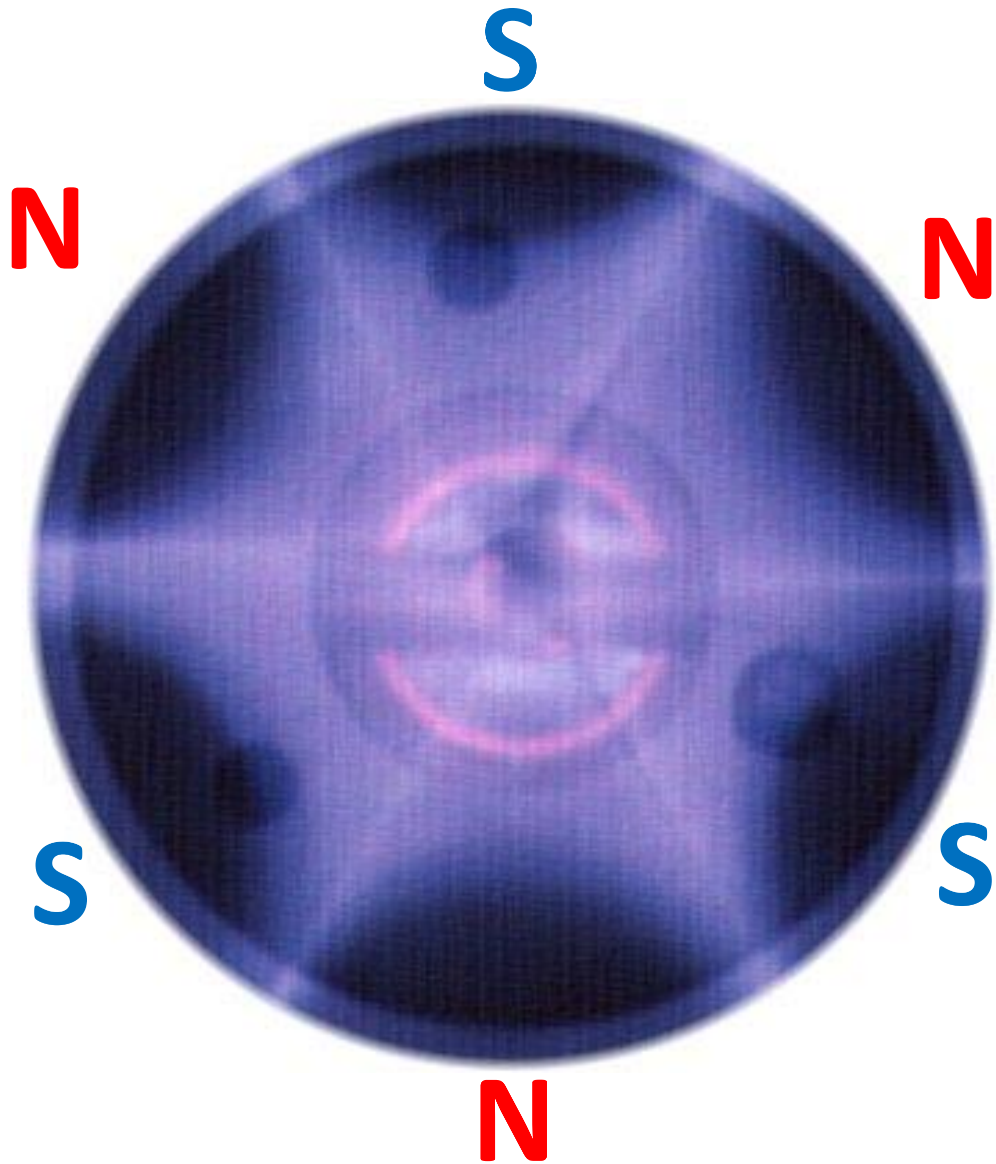
Dipole field



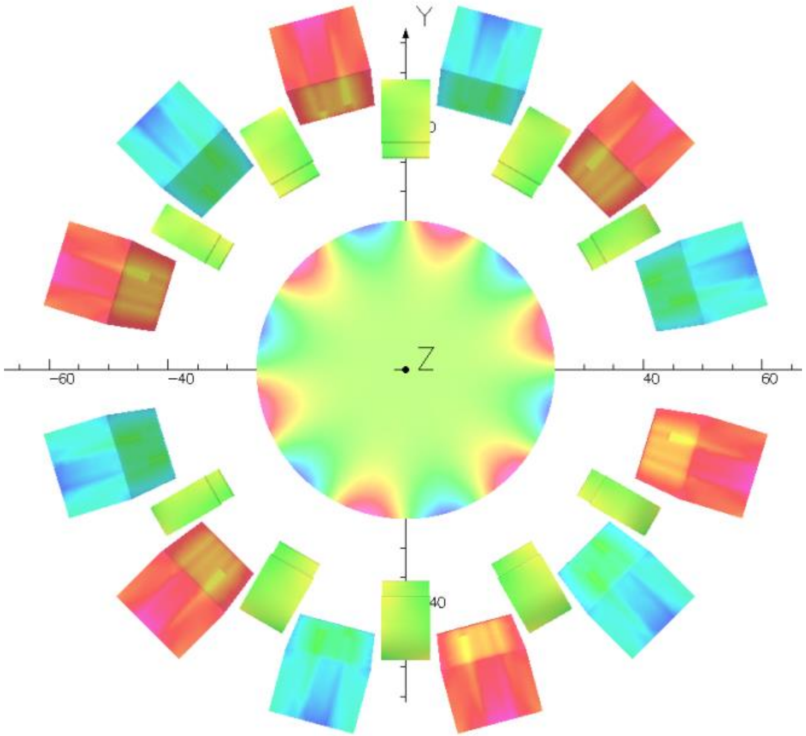
Solenoid field

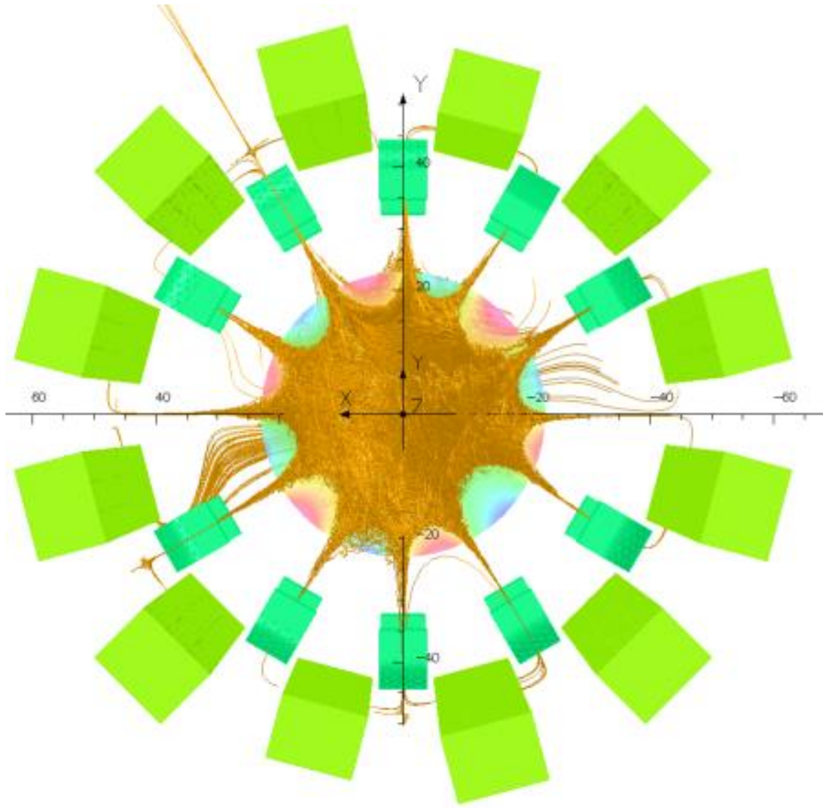


Hexapole



Multicusp Confinement

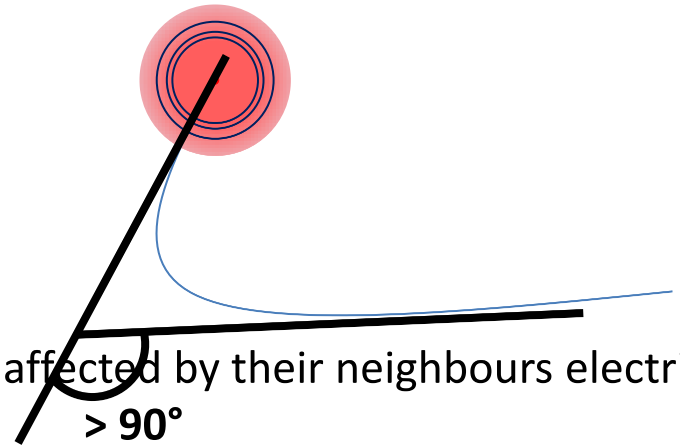




Collisions

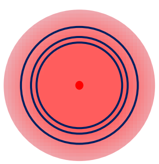
e-

Concept of mean free path does not work in a plasma



The average time it takes for a particle to be deflected by 90 °

Charged particle trajectories are constantly affected by their neighbours electric fields



e-

Relaxation time = 90° deflection time

Percentage Ionisation

$$\frac{n_i}{n_i + n_n}$$

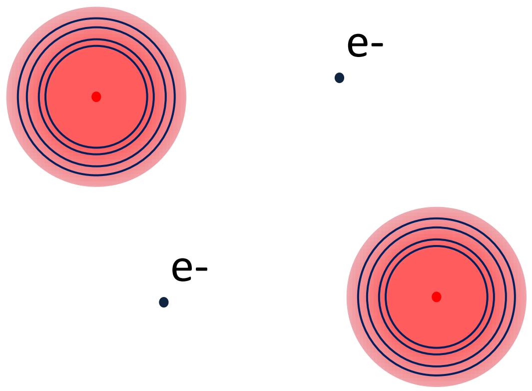
> 10 % → Highly ionised

< 1 % → Weakly ionised

Quasi Neutrality

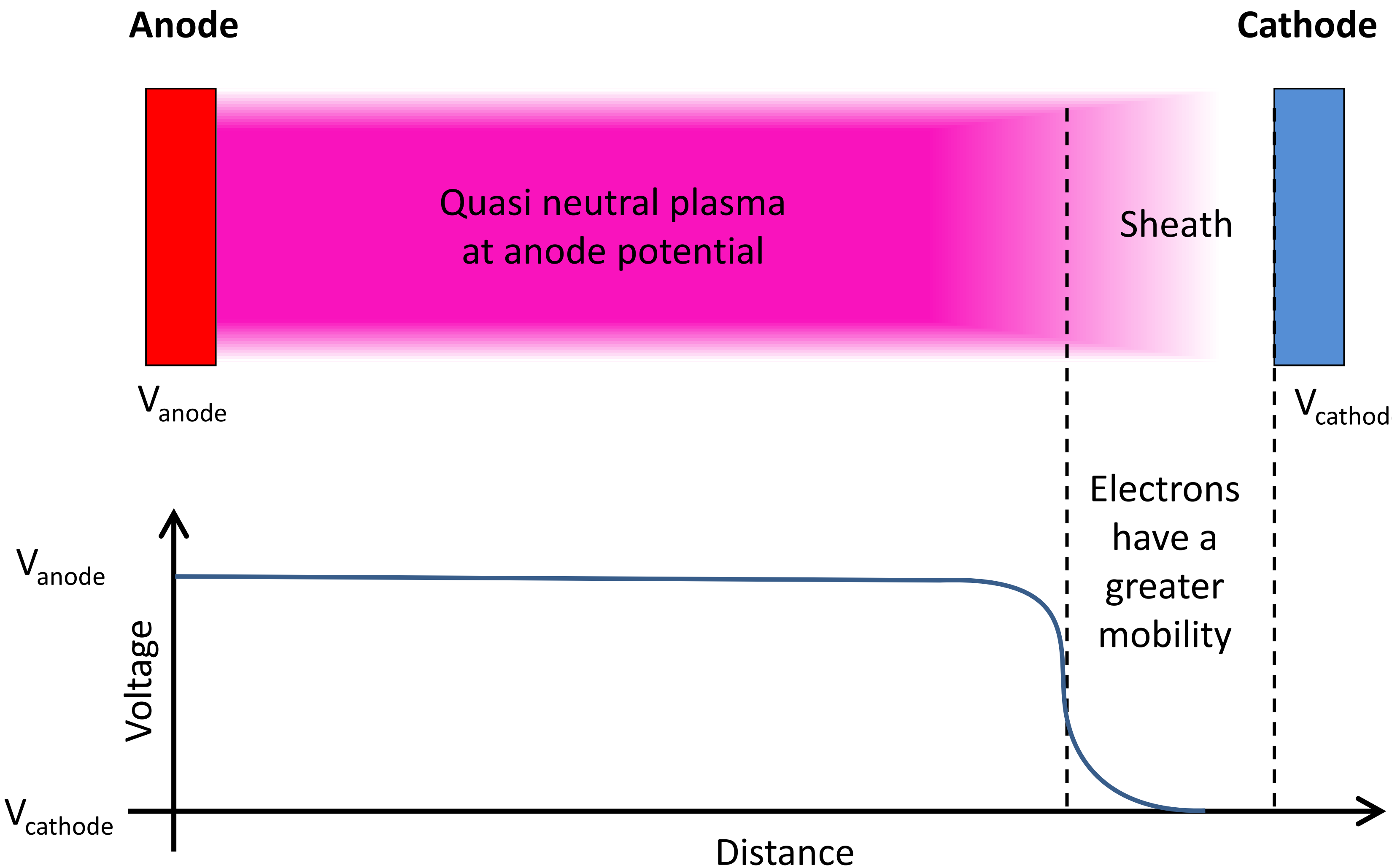
$$\Sigma\, q_i\, n_i = n_e$$

Debye Length

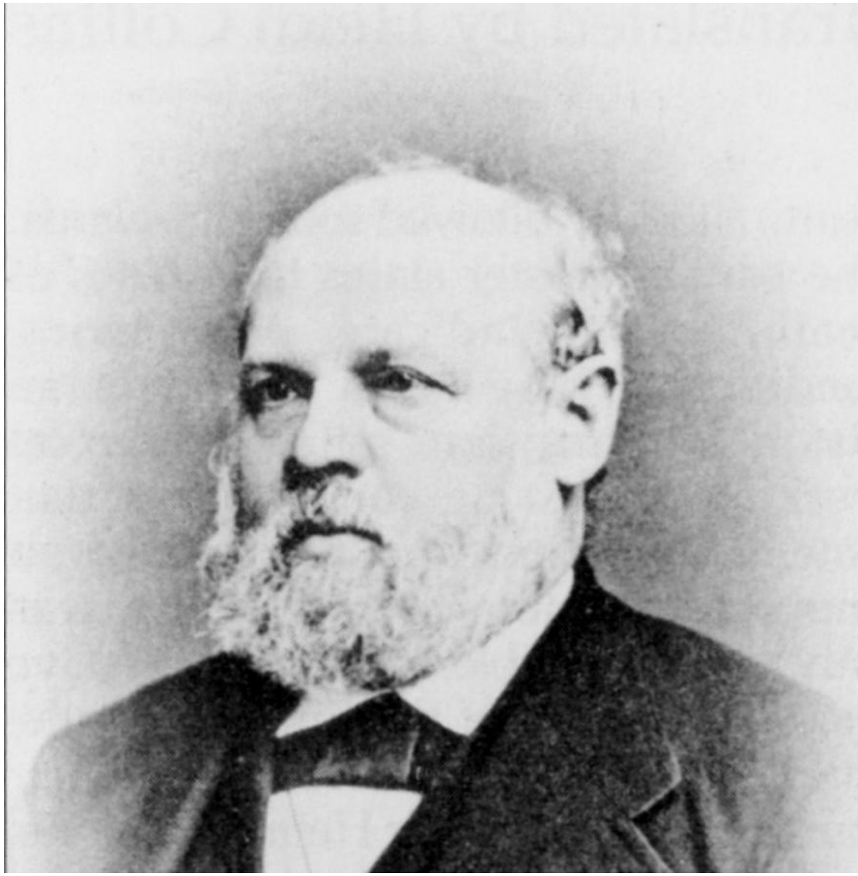


$$\lambda_D = \sqrt{\frac{\epsilon_0 k T_e}{n_e {q_e}^2}}$$

Plasma Sheath



Plasma Pioneers



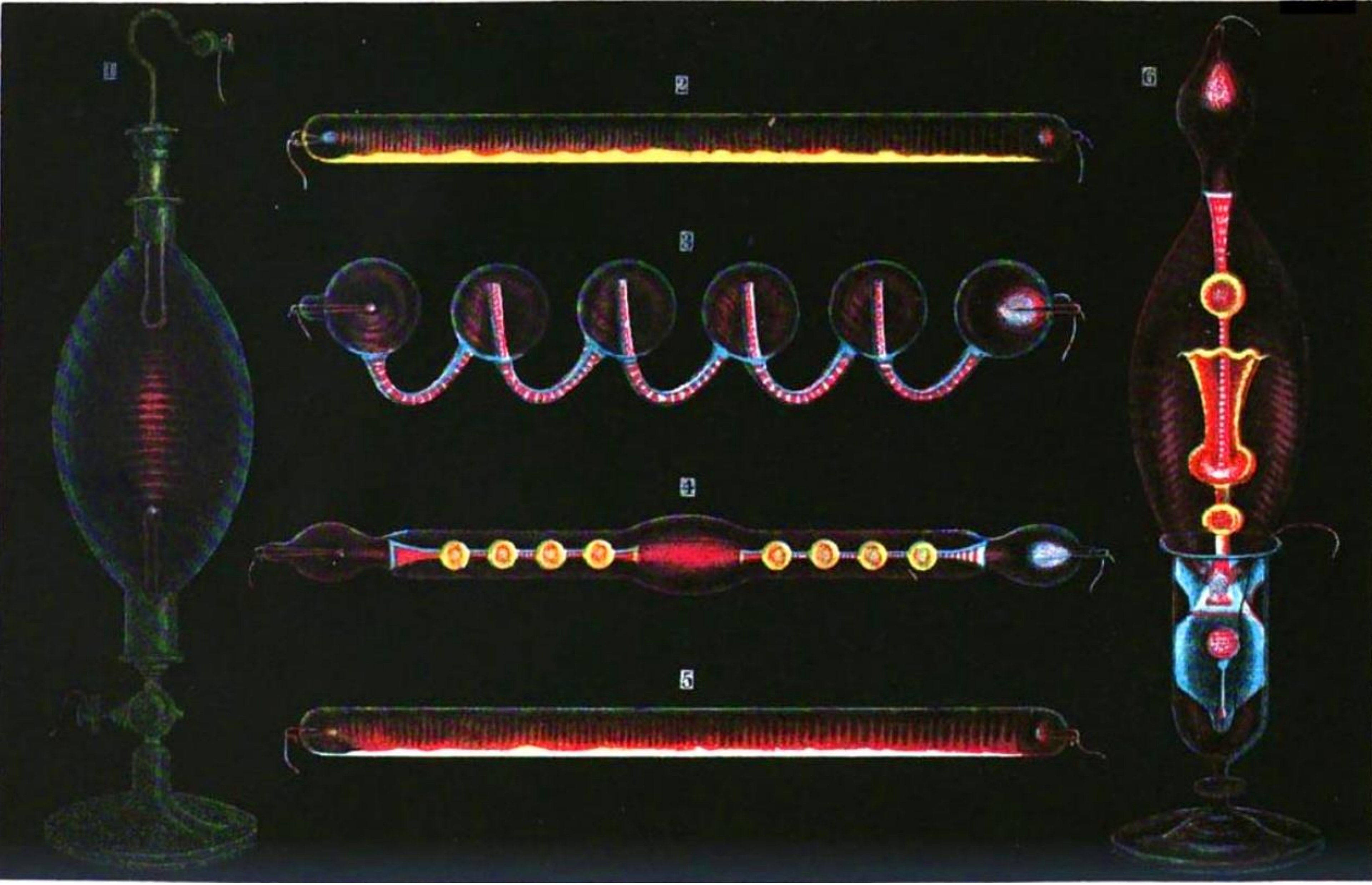
Heinrich Geißler

Julius Plücker

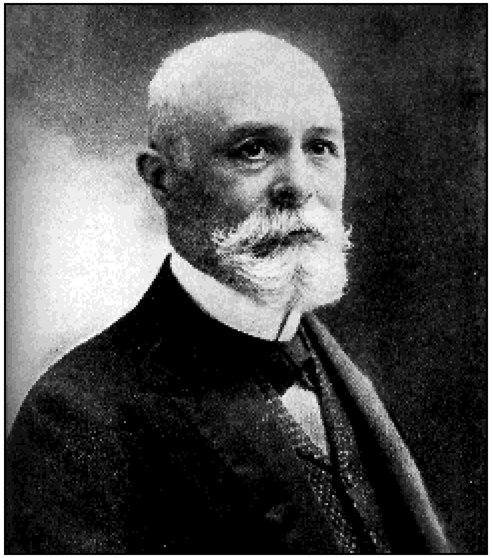
Gas discharge tube and mercury displacement pump just less than 1 mBar

Mid 1850's University of Bonn

magnetism could move the glow discharge

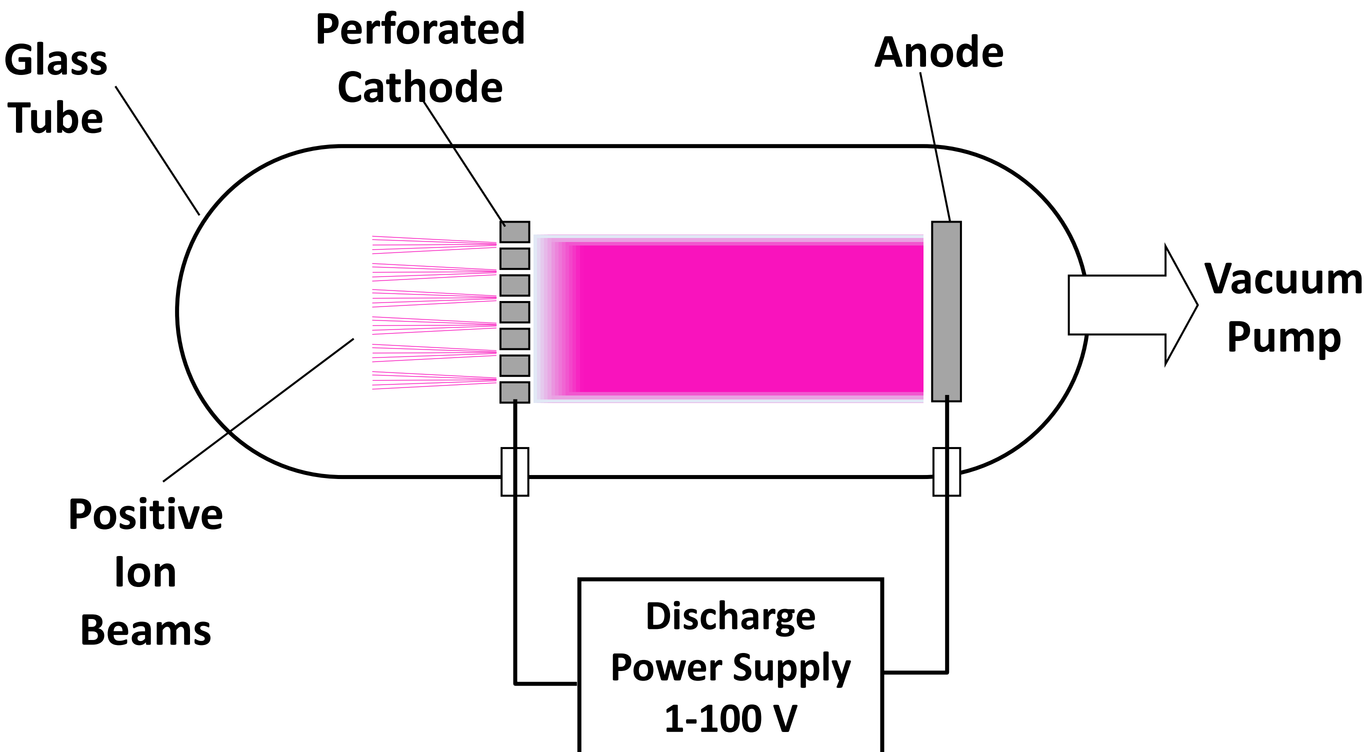


Drawing of Geissler tubes from 1860’s French physics book

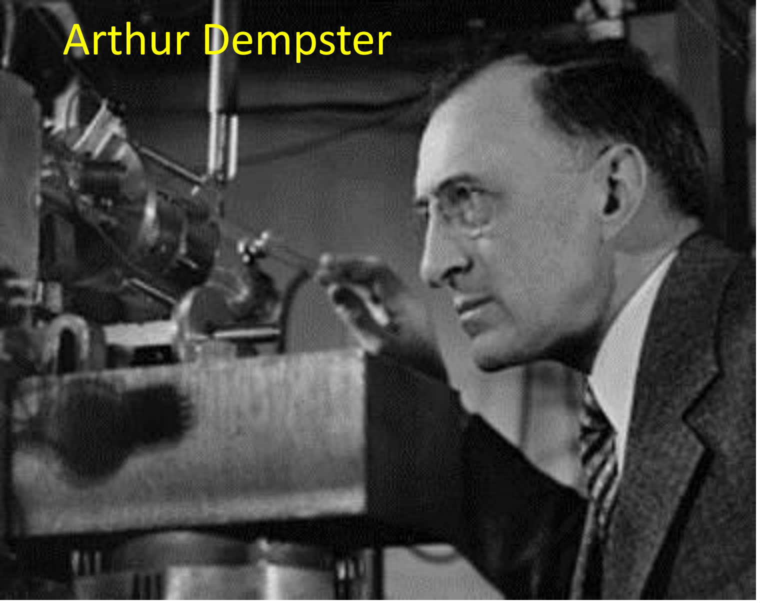


Canal Ray Source

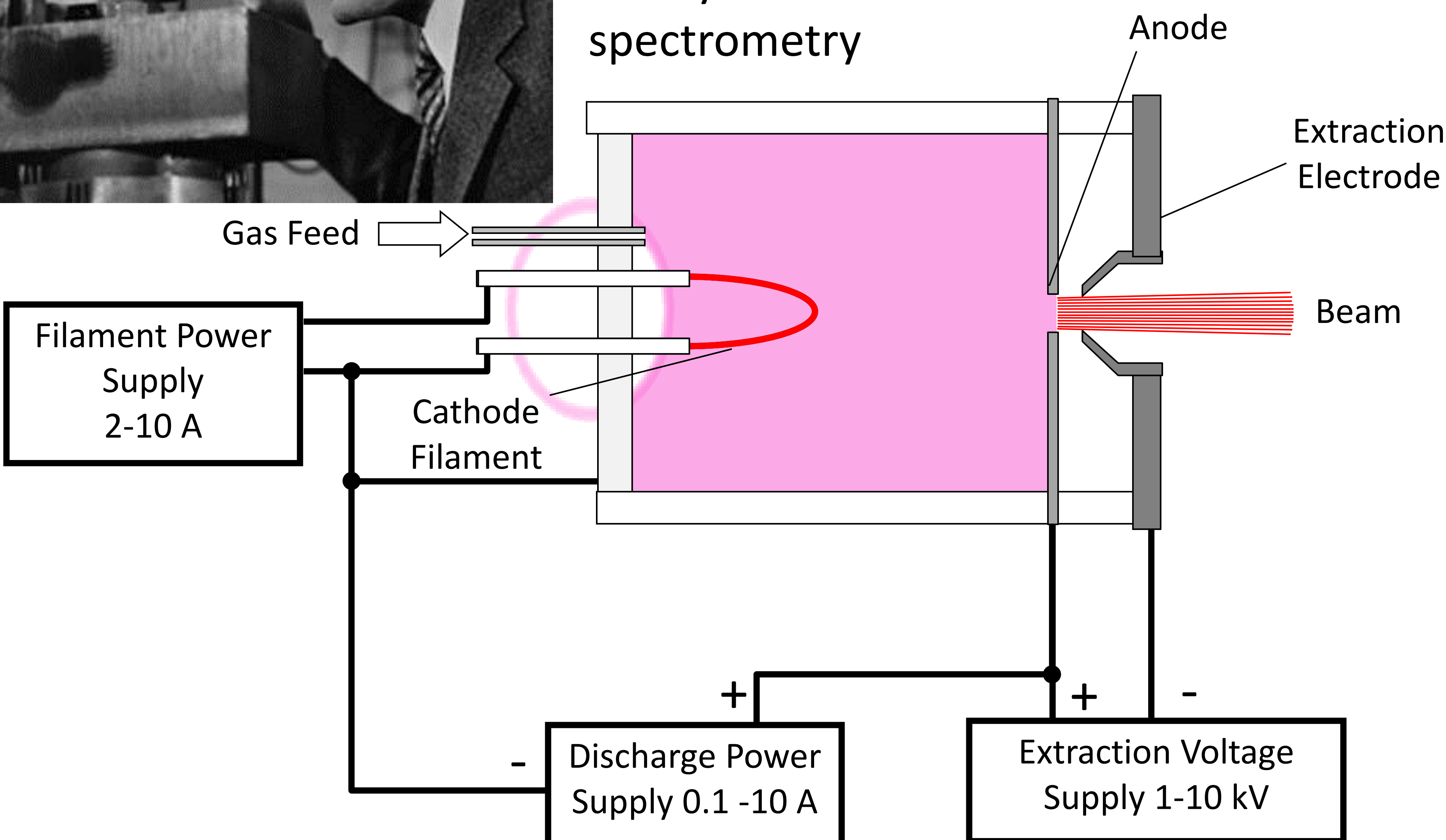
In 1886 Eugen Goldstein discovered canal rays

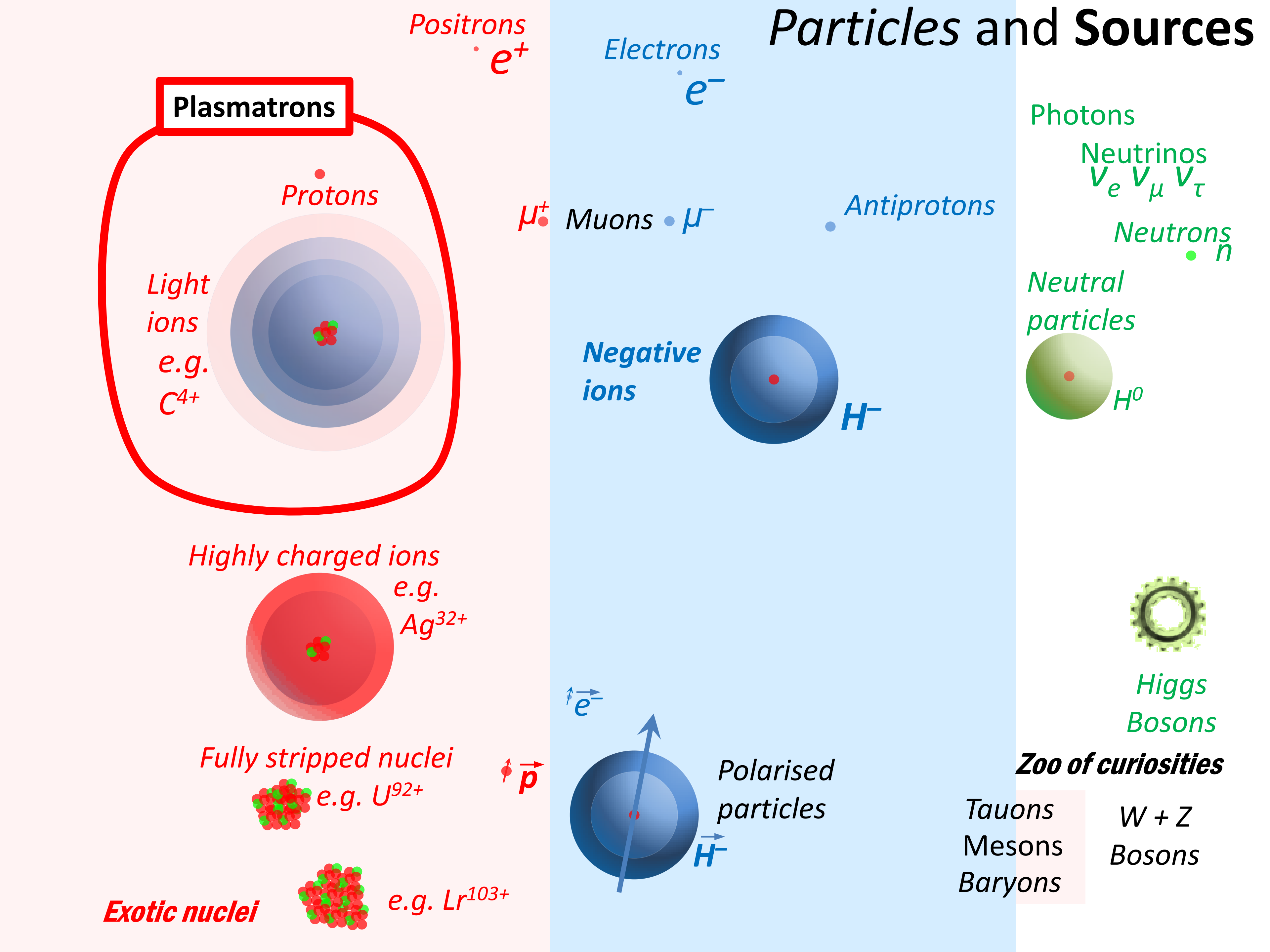


Electron Bombardment Source (1916)



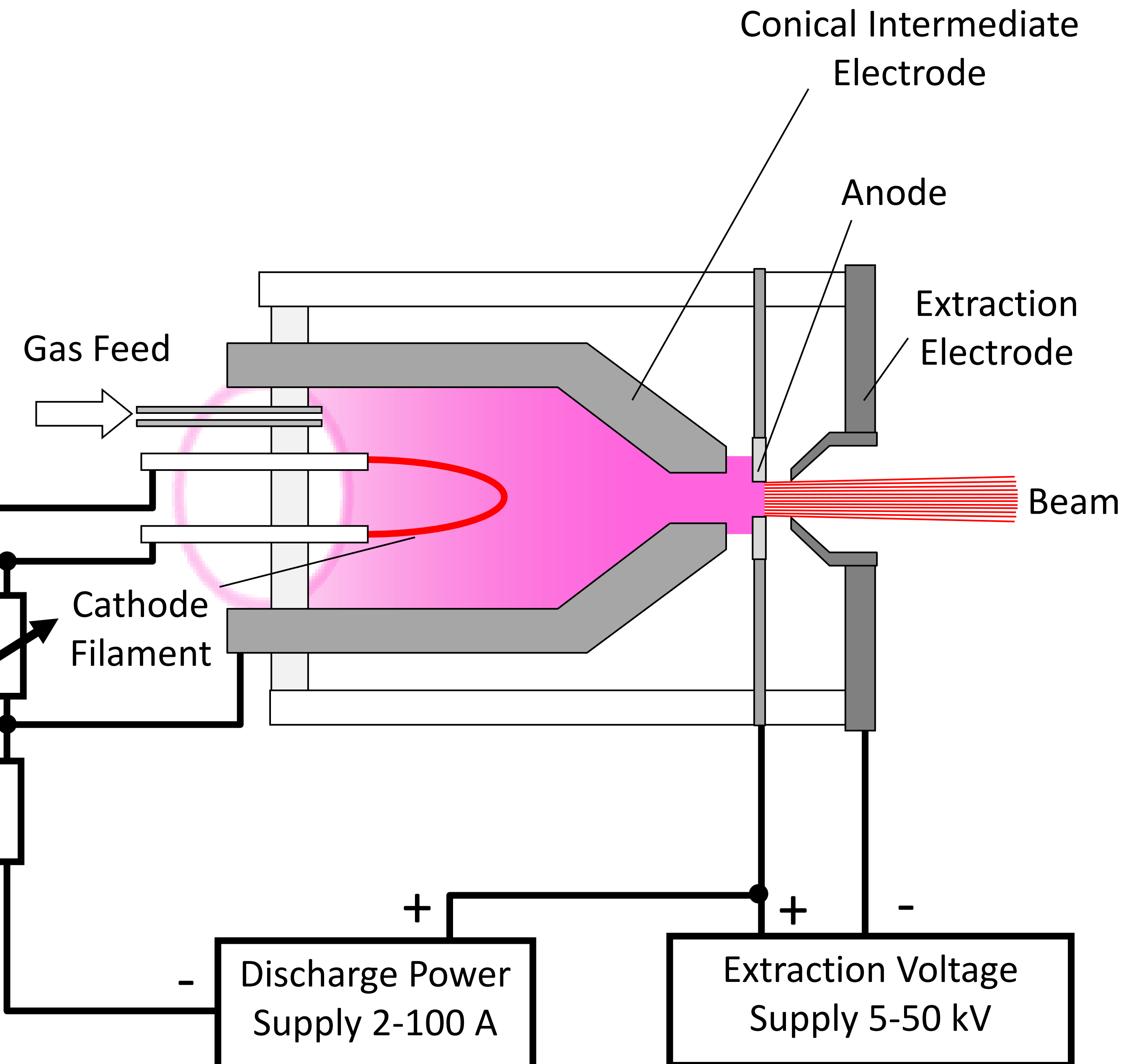
Early mass spectrometry



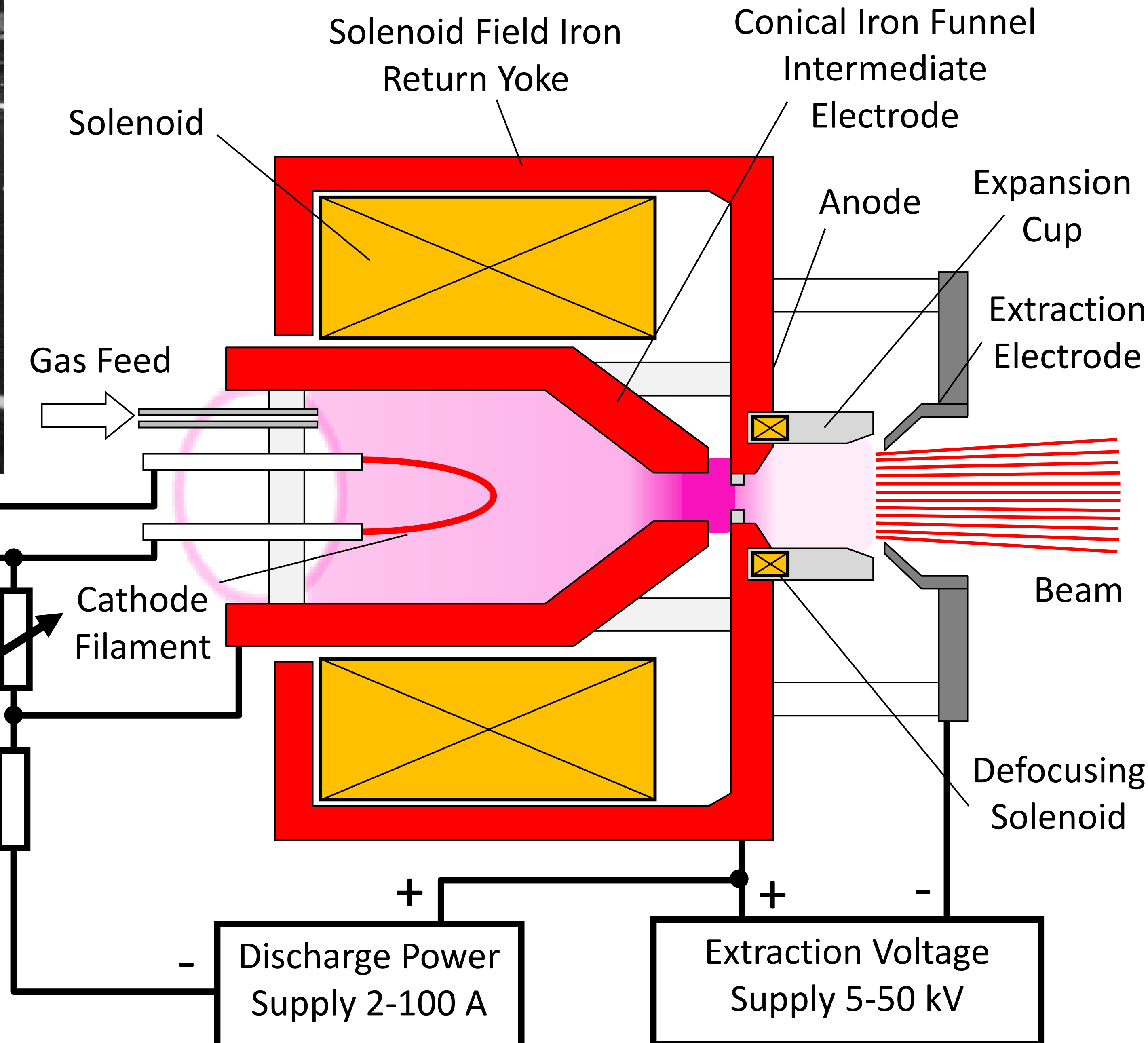


Particles and Sources
Positrons
e^{+}
Electrons
e^{-}
Plasmatrons
Protons
Light ions e.g. C^{4+}
μ^{+}
Muons
μ^{-}
Antiprotons
Photons
Neutrinos
ν_e ν_μ ν_τ
Neutrons
n
Neutral particles
H^0
Negative ions
H^{-}
Highly charged ions
e.g. Ag^{32+}
Fully stripped nuclei
e.g. U^{92+}
$\vec{p}$
$\vec{e}^{-}$
Polarised particles
$\vec{H}^{-}$
Higgs Bosons
Zoo of curiosities
Tauons
Mesons
Baryons
W + Z Bosons
Exotic nuclei
e.g. Lr^{103+}

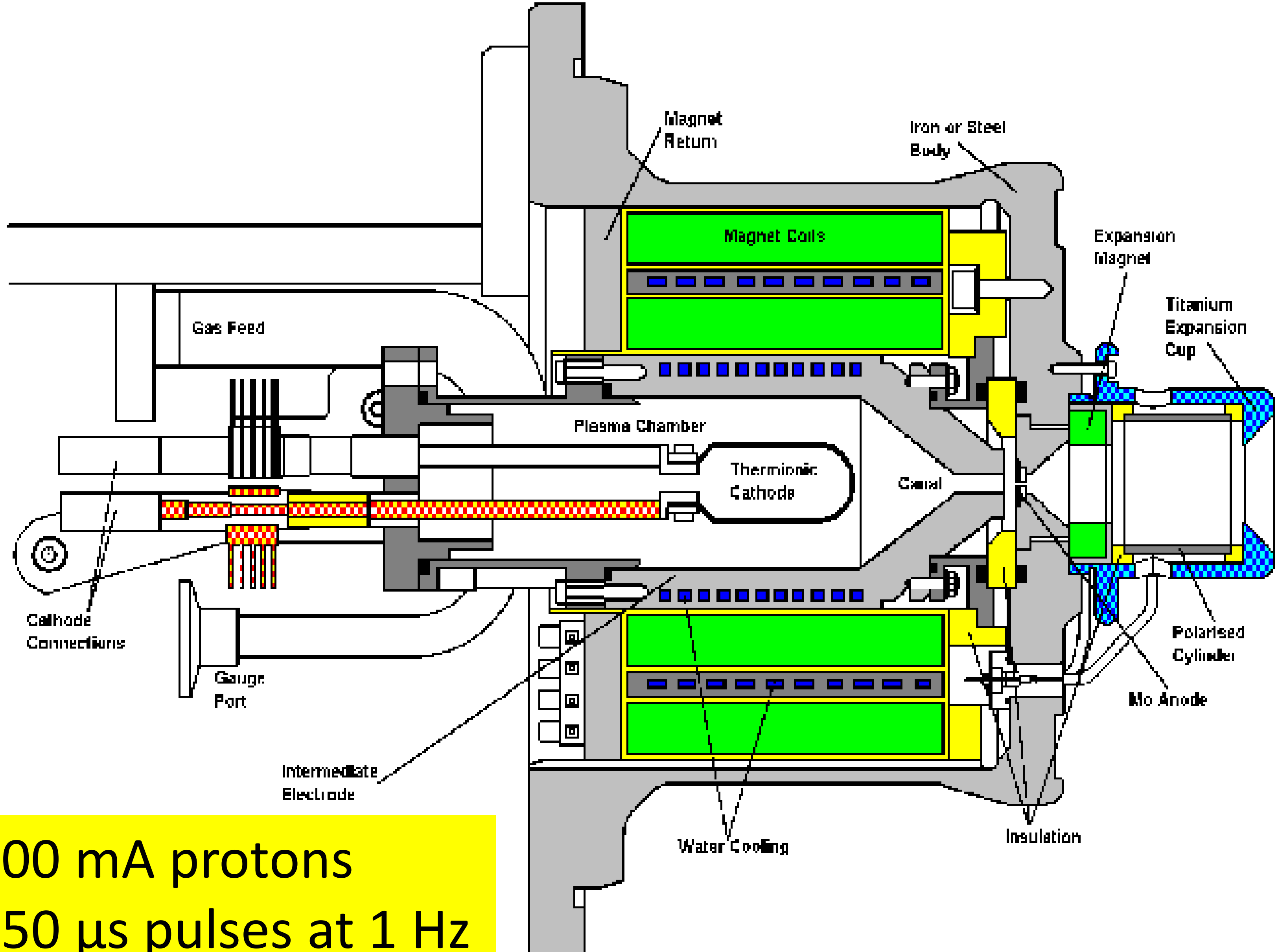
Plasmatron (late 1940s)



Duoplasmatron (1956)

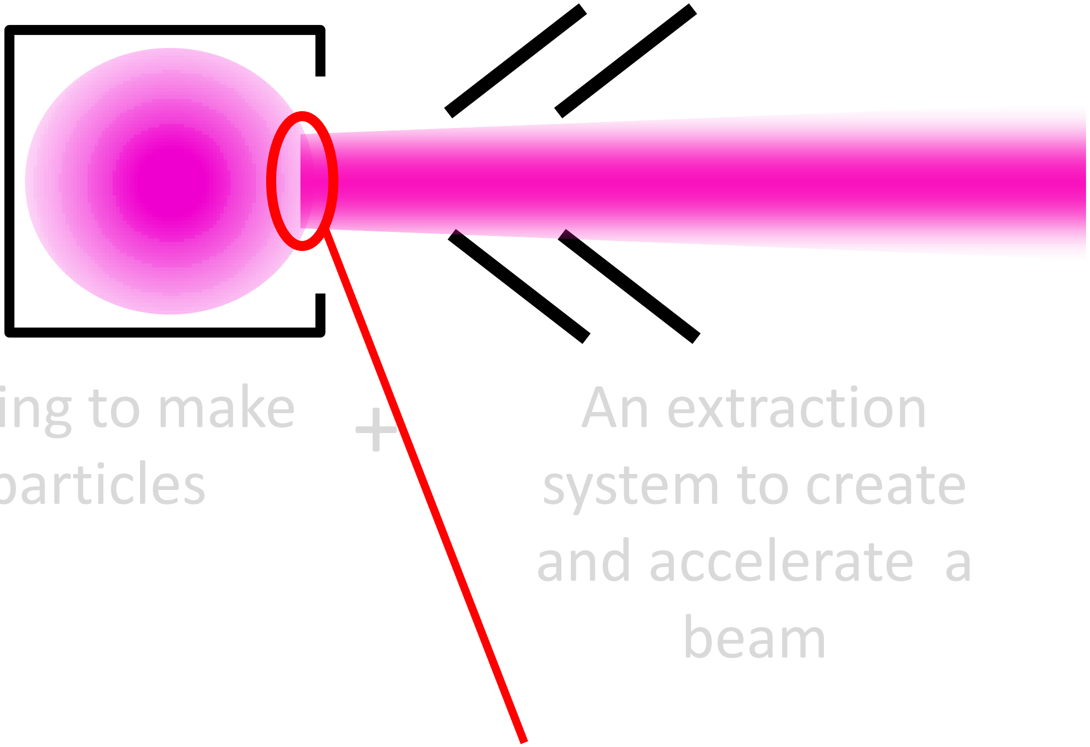


CERN Duoplasmatron



300 mA protons
150 µs pulses at 1 Hz

Particle sources/guns consist of:



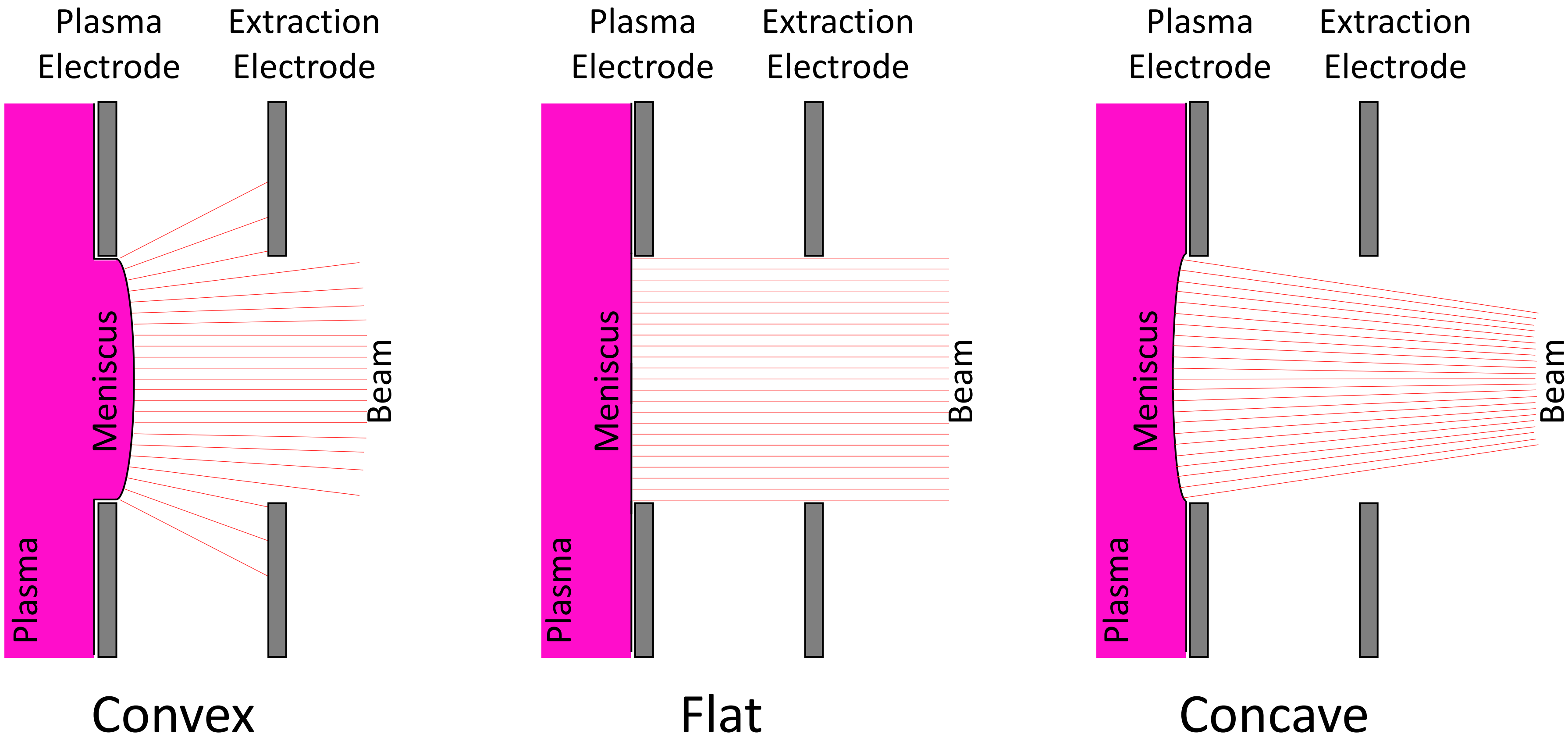
Something to make the particles

+

An extraction system to create and accelerate a beam

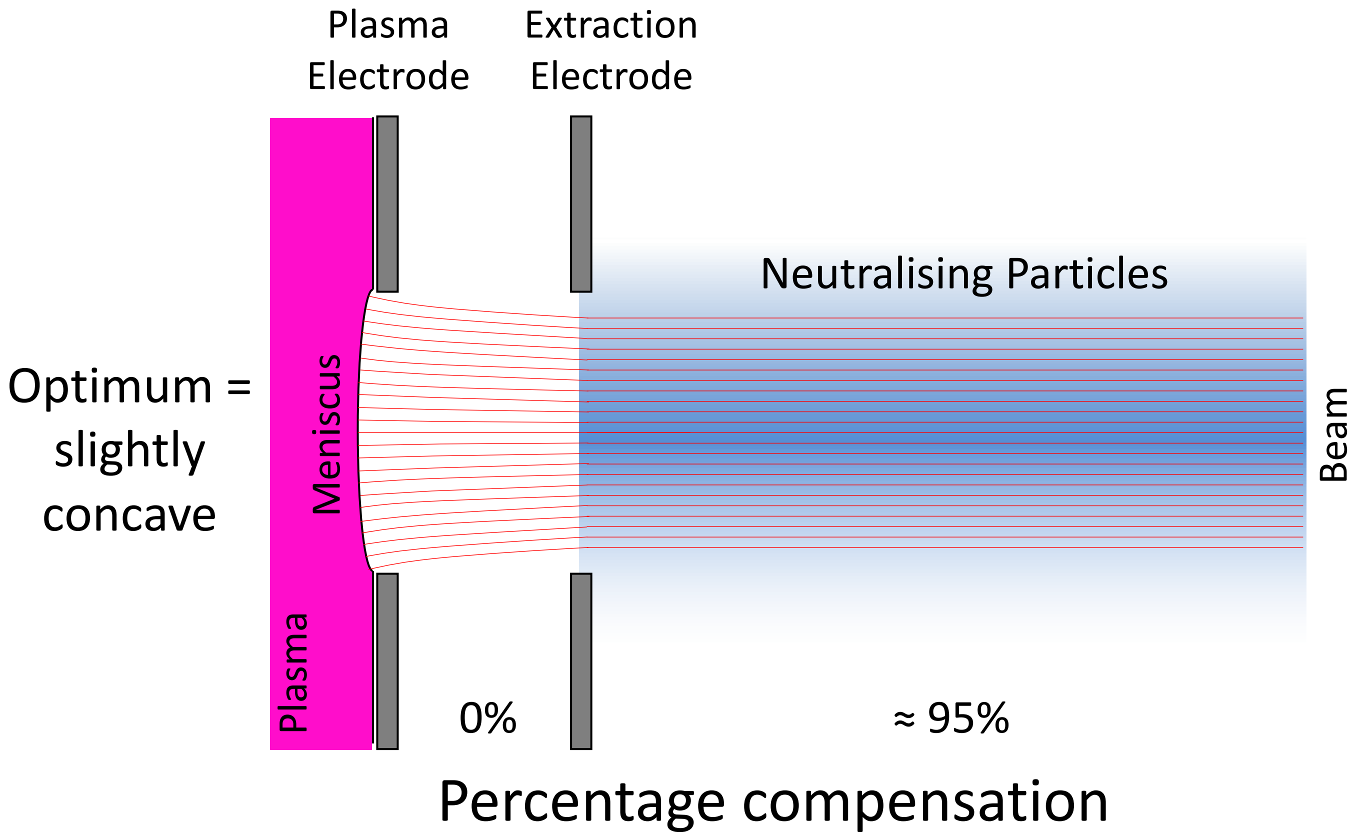
The emission surface is critical to the quality of the beam

Plasma Mencius

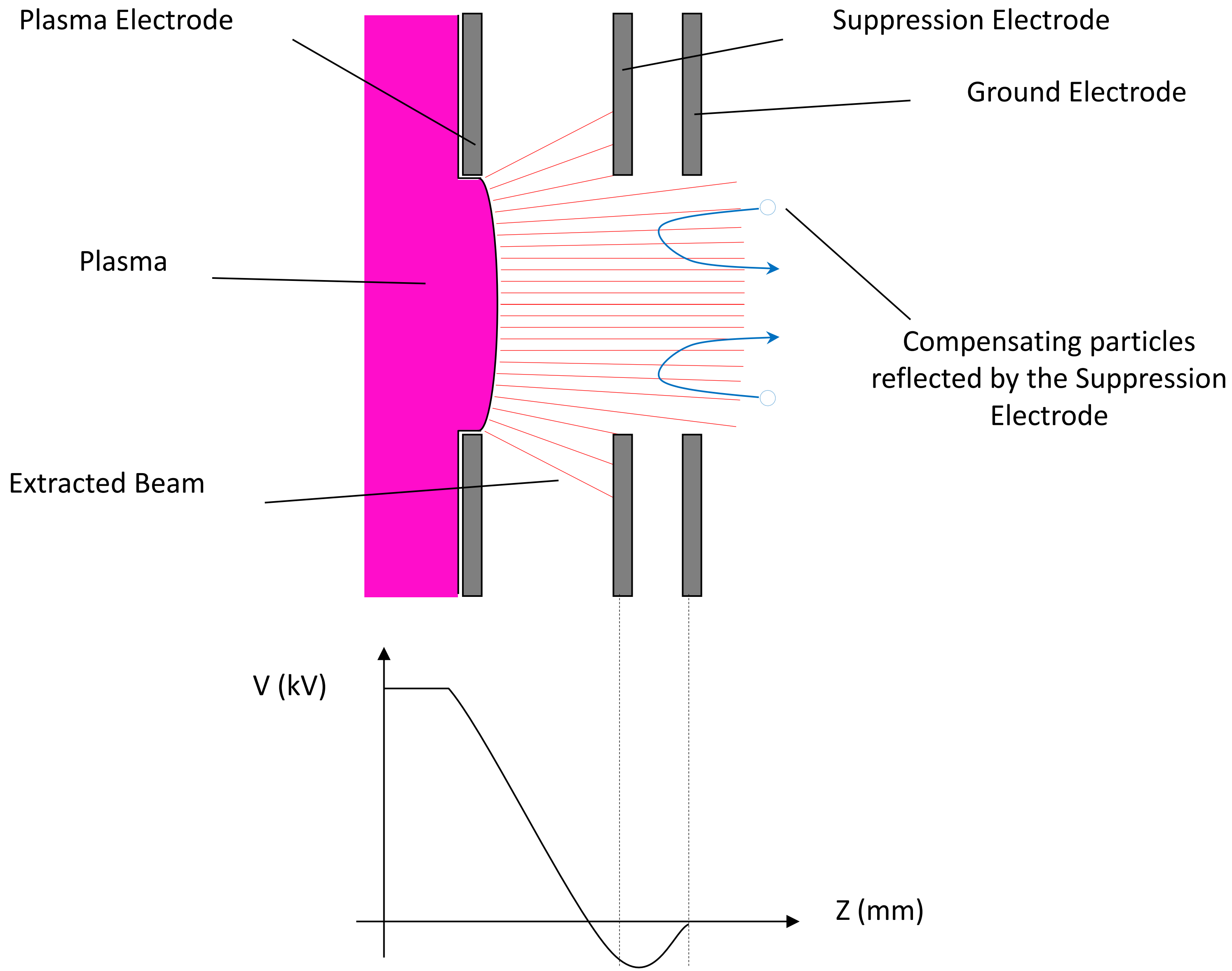


Not including space charge effects

Space Charge



Suppressor Electrode

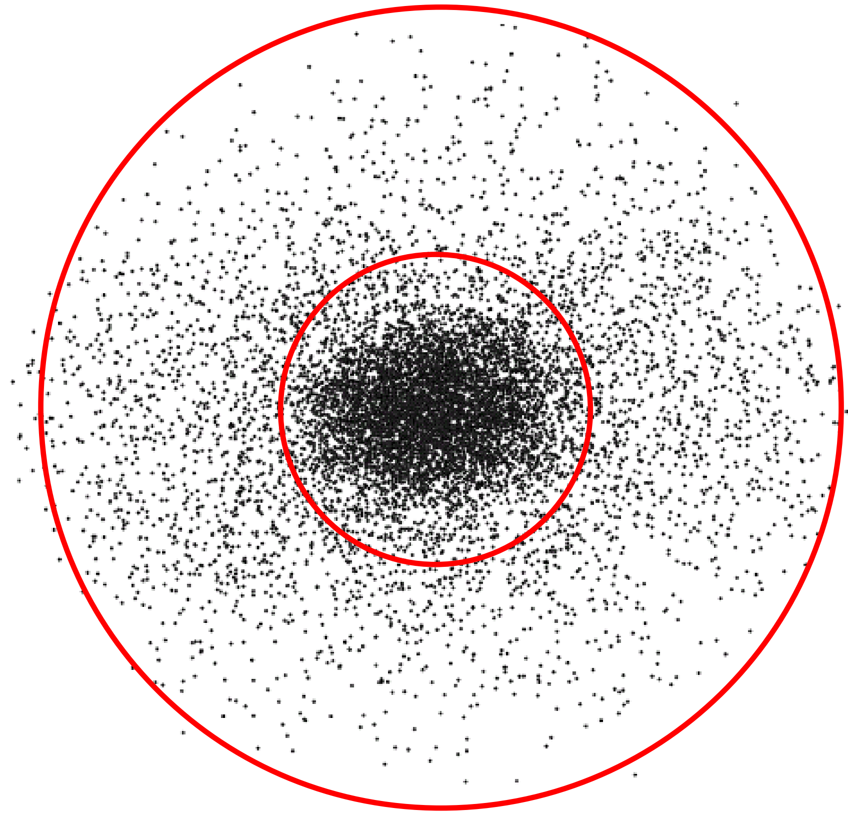


Emittance of Real Beams

Halo Effect

- Plasma boundary
- Fringe fields

How big is this beam?



95% emittance

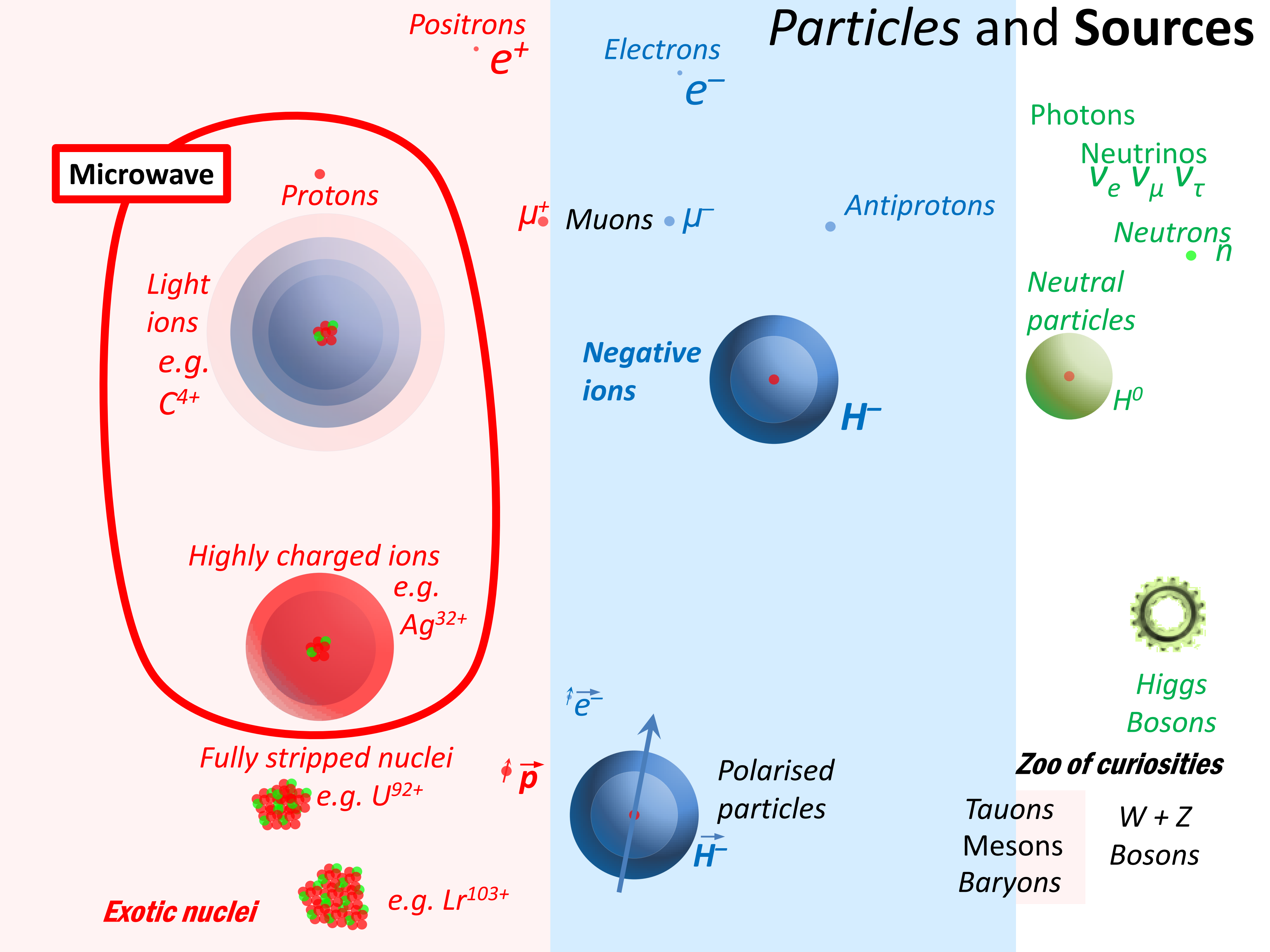
rms emittance

Brightness

$$B = \frac{I}{\varepsilon_x \varepsilon_y}$$

Be careful- Some definitions include factors of 2, 8 and π
Are the emittances normalised?

Particles and **Sources**



Microwave Ion Sources

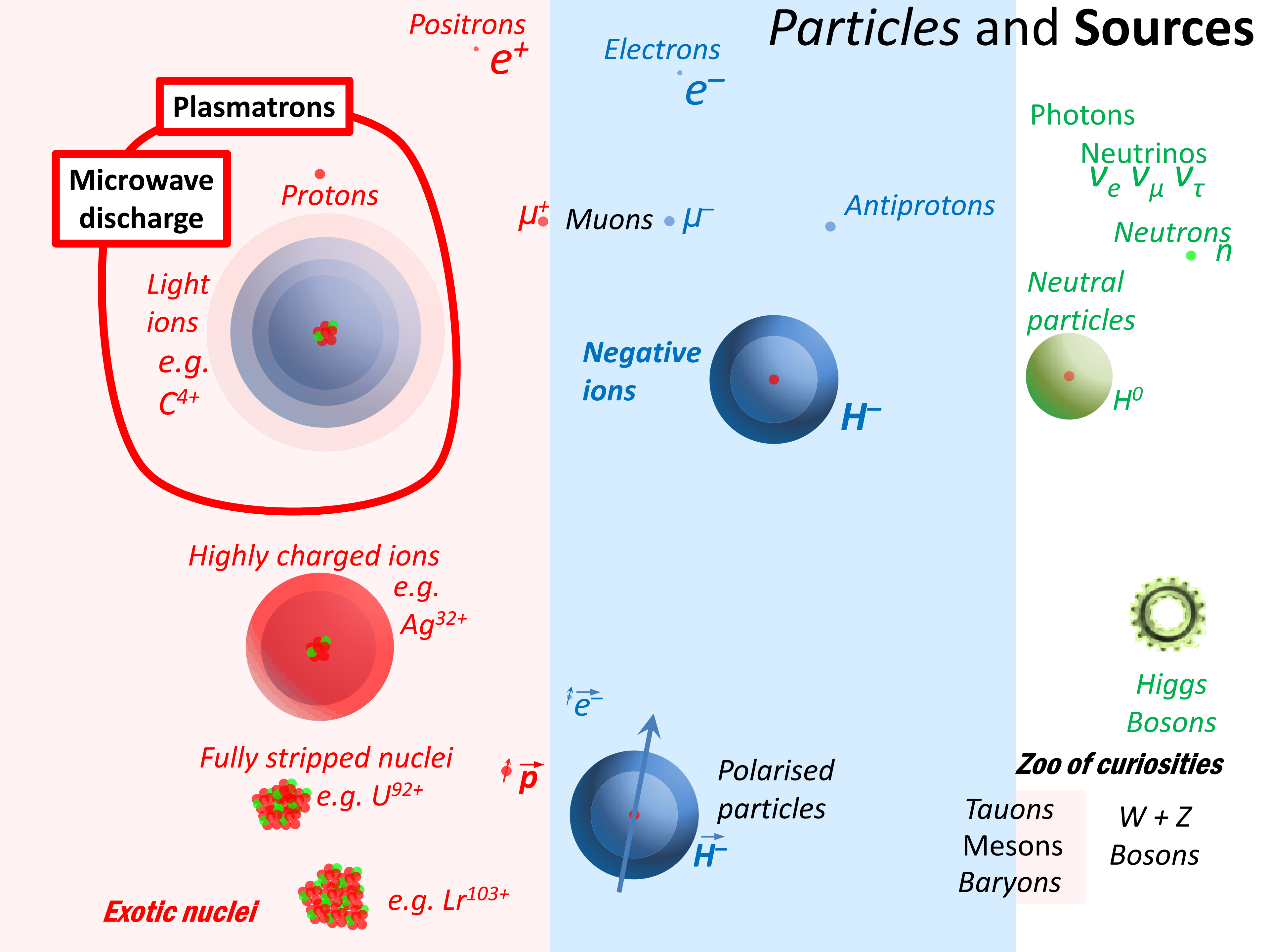
Off resonance

= Microwave discharge ion sources

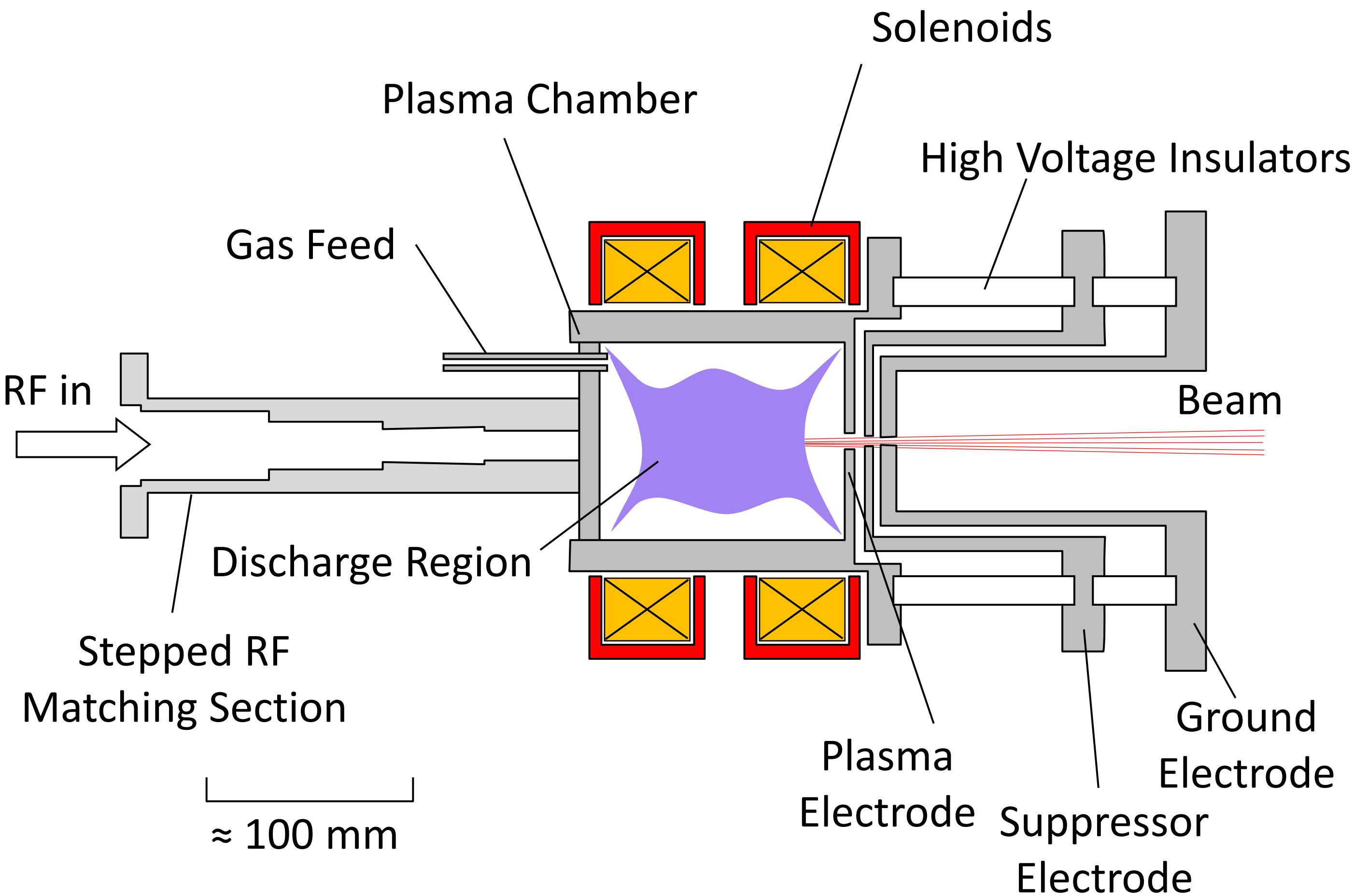
On resonance

= Electron Cyclotron Resonance (ECR) sources

Particles and **Sources**

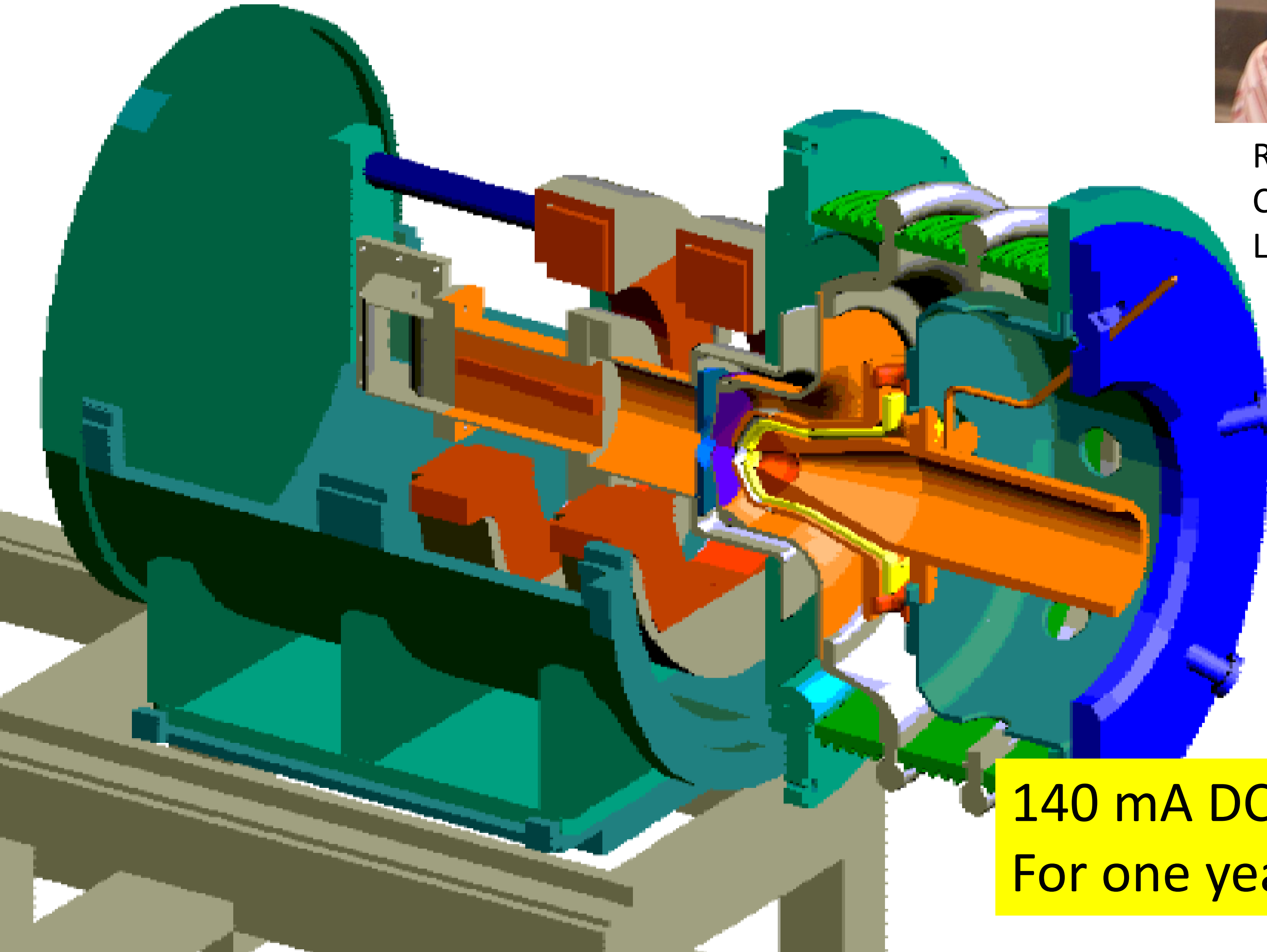


Microwave Discharge Ion Source



2.45 GHz commonly used

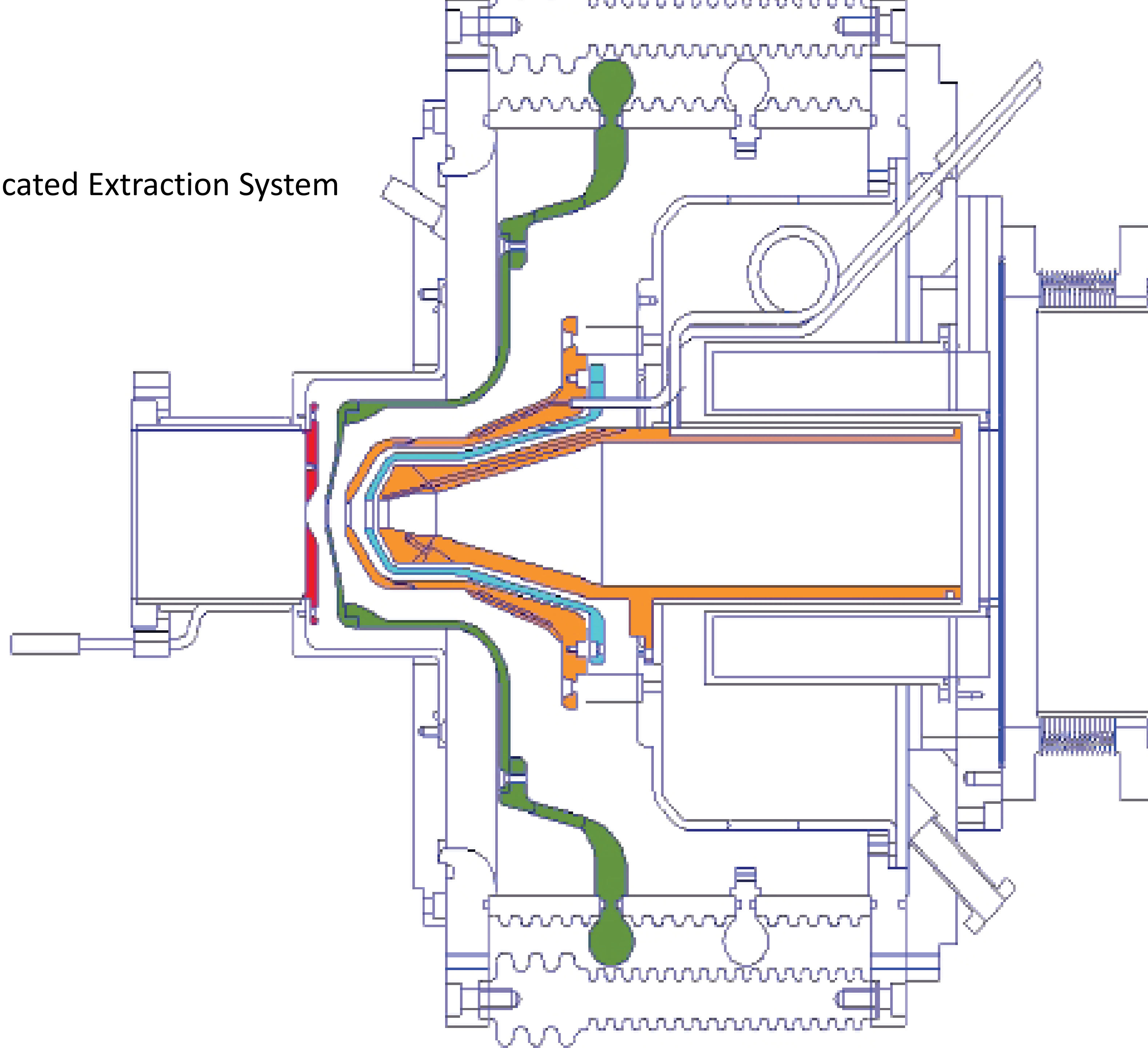
SILHI Microwave Source



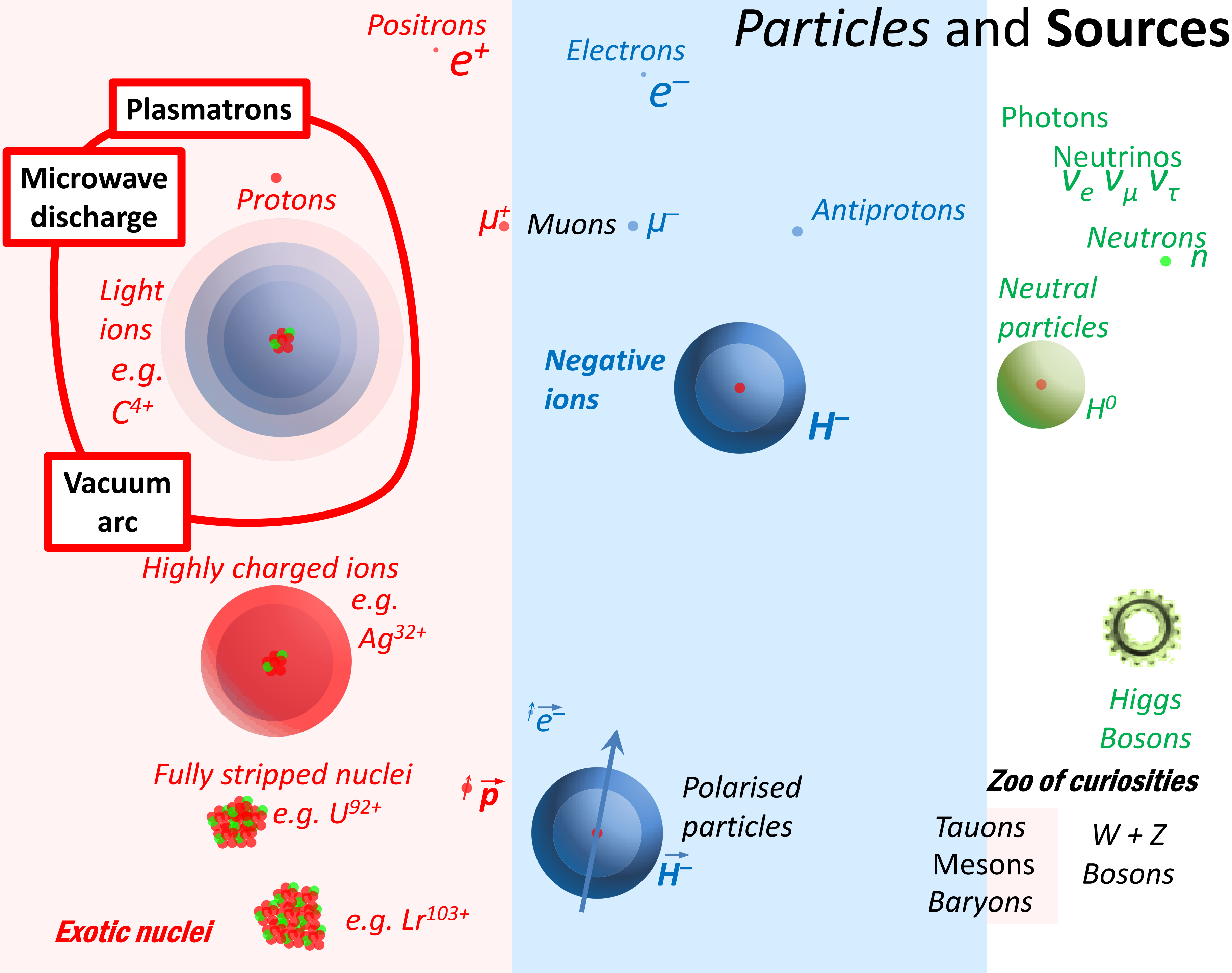
Rafael Gobin
CEA Saclay
Late 1990s

140 mA DC protons
For one year!

Sophisticated Extraction System

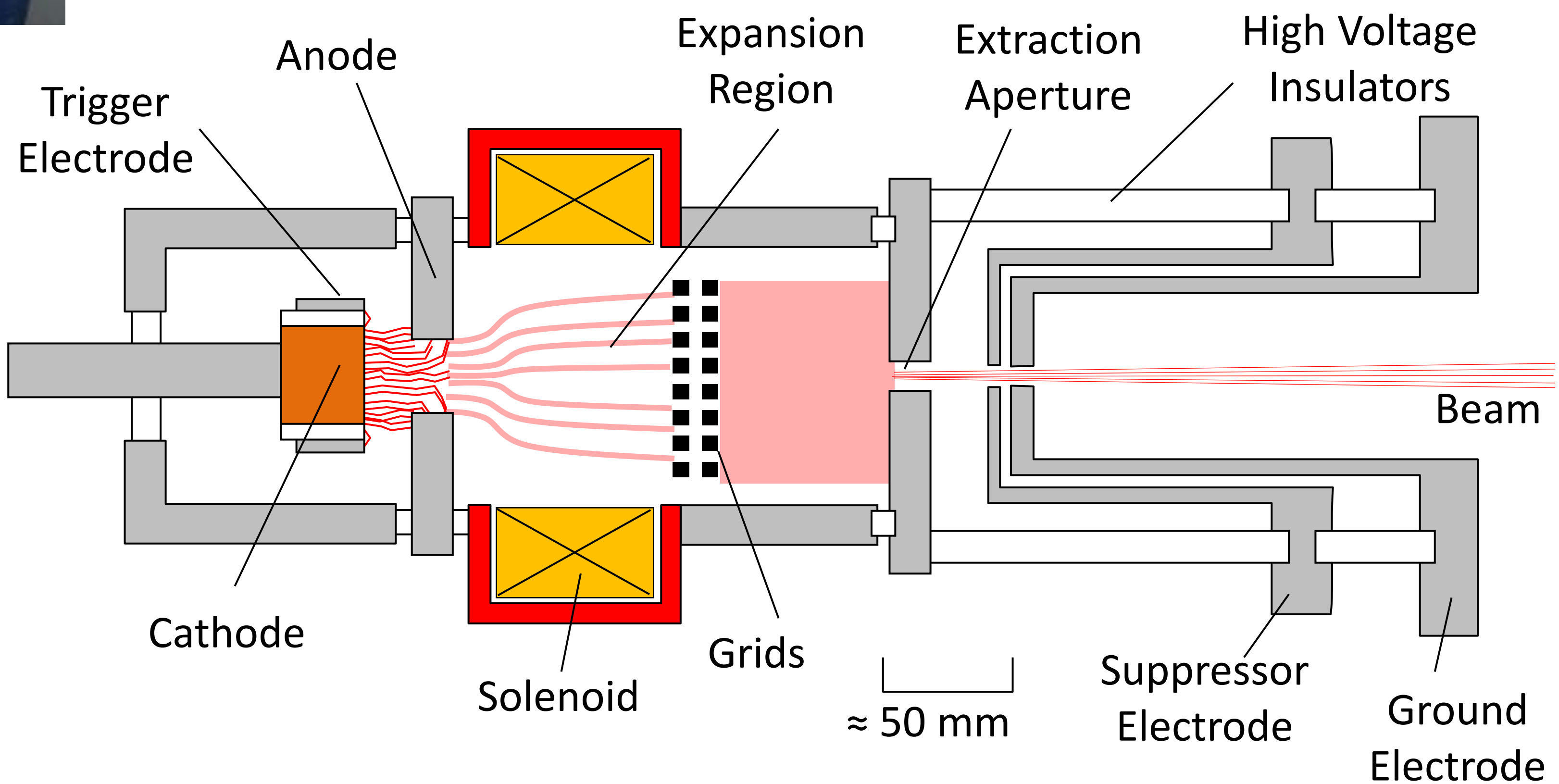


Particles and **Sources**



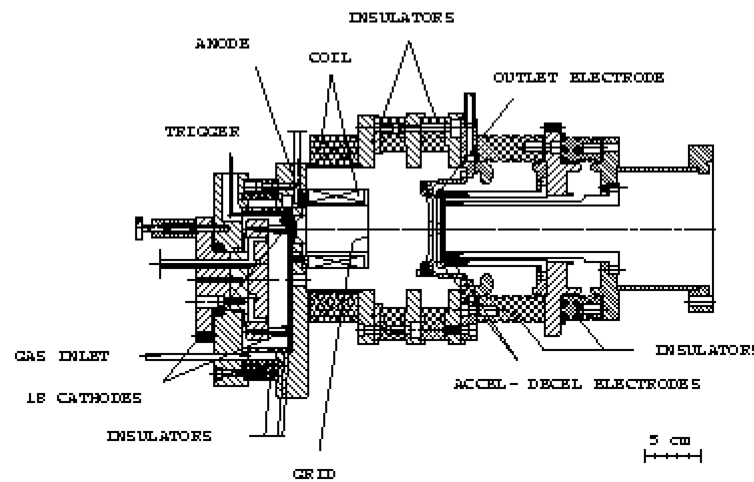
Vacuum Arc Ion Sources

1980s - Ian Brown and others



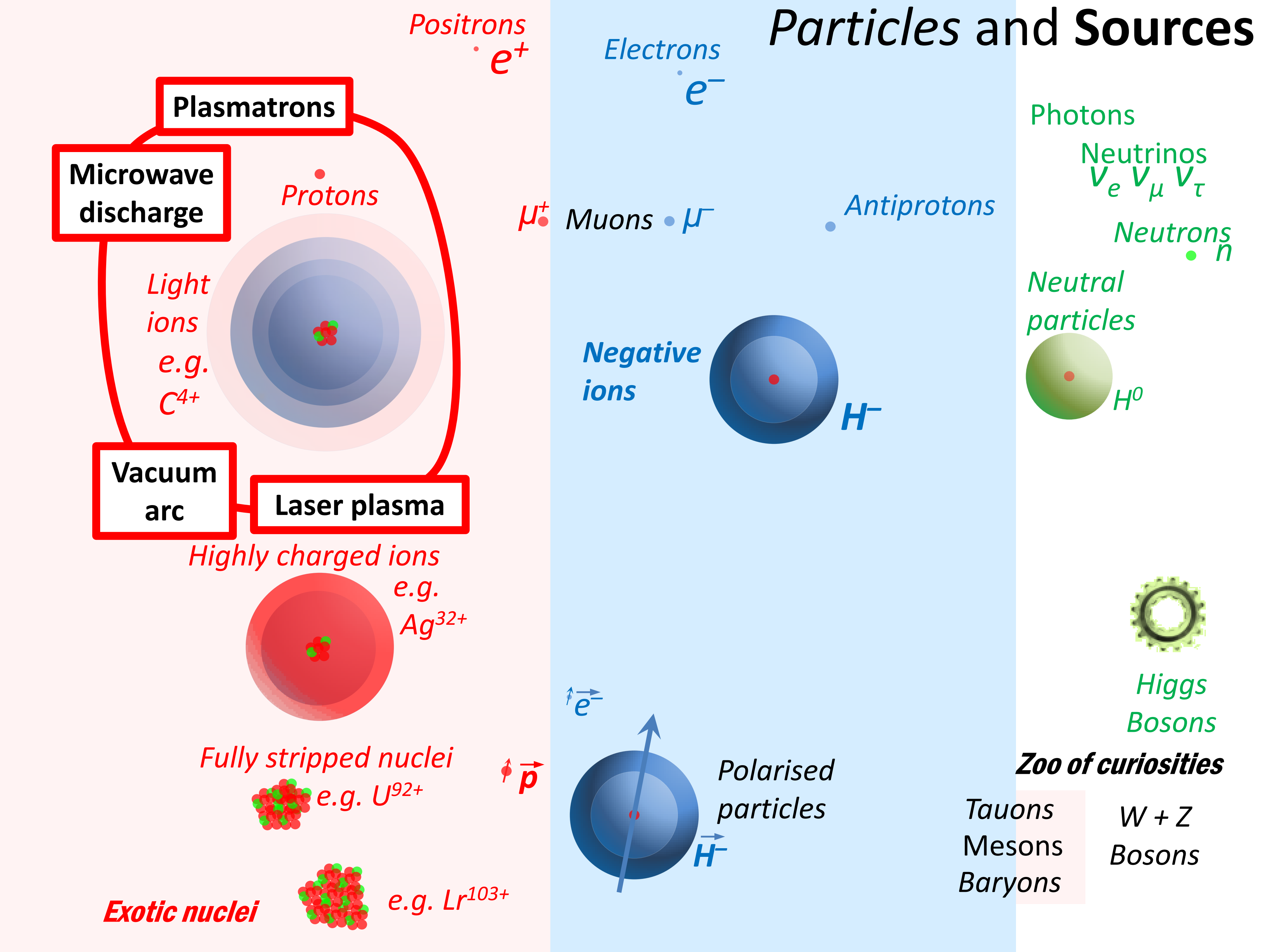
Lawrence Berkley Lab
MEVVA

GSI MEVVA

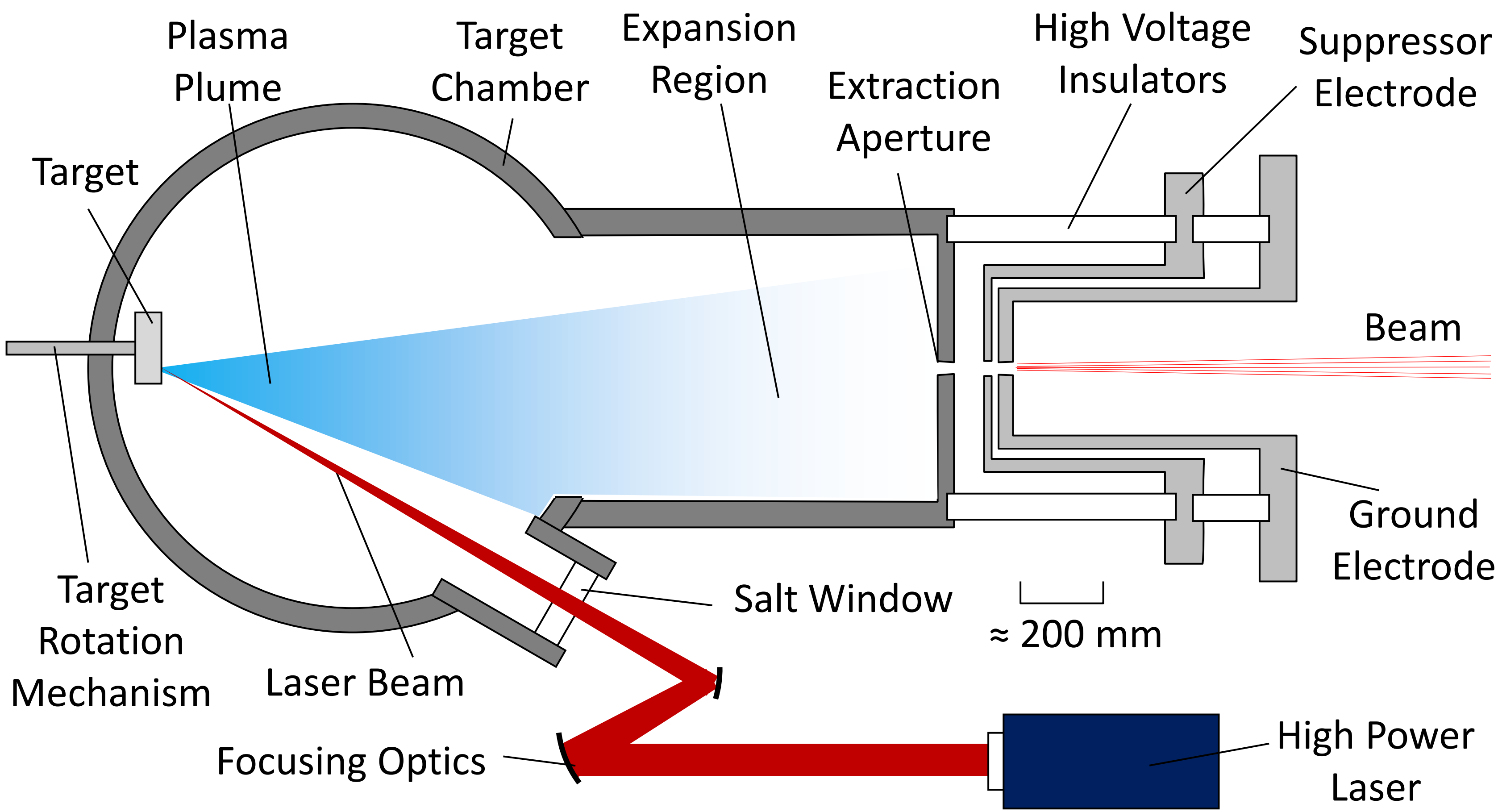


15 mA of U^{4+} ions

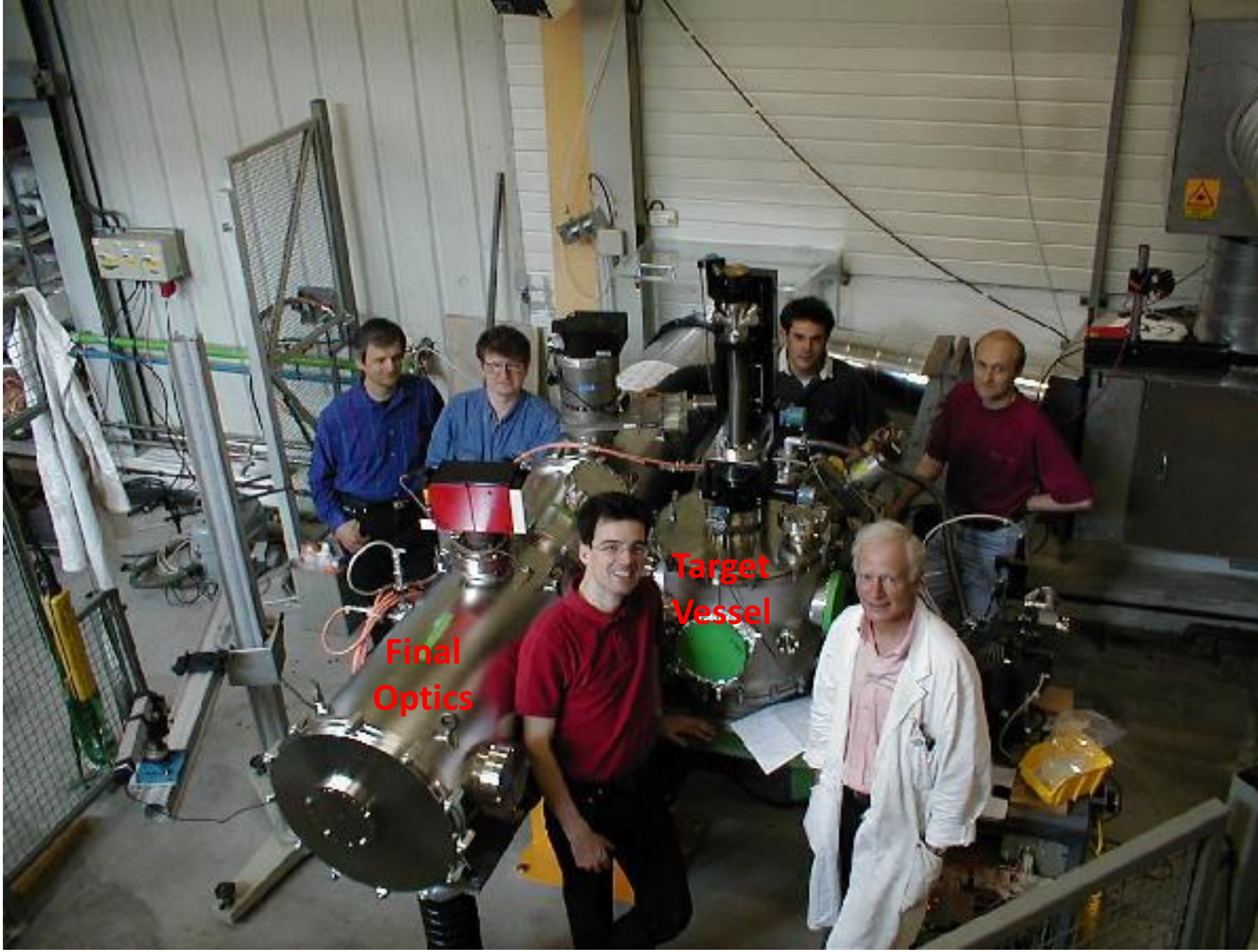
Particles and **Sources**



Laser Plasma Ion Sources



1 -100 Joules per pulse!



ITEP Laser source at CERN

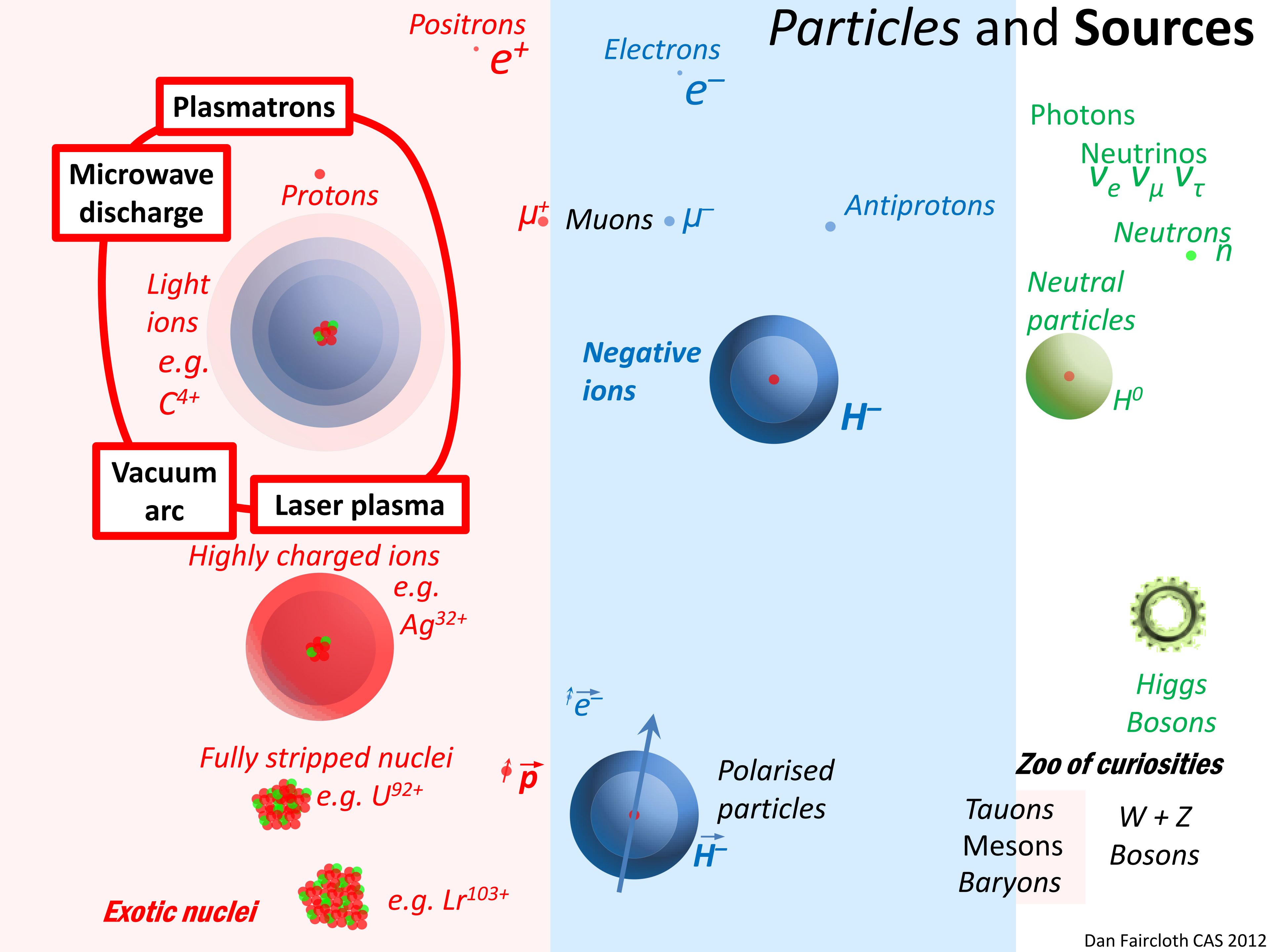
ITEP Laser source at CERN

TWAC at ITEP Moscow

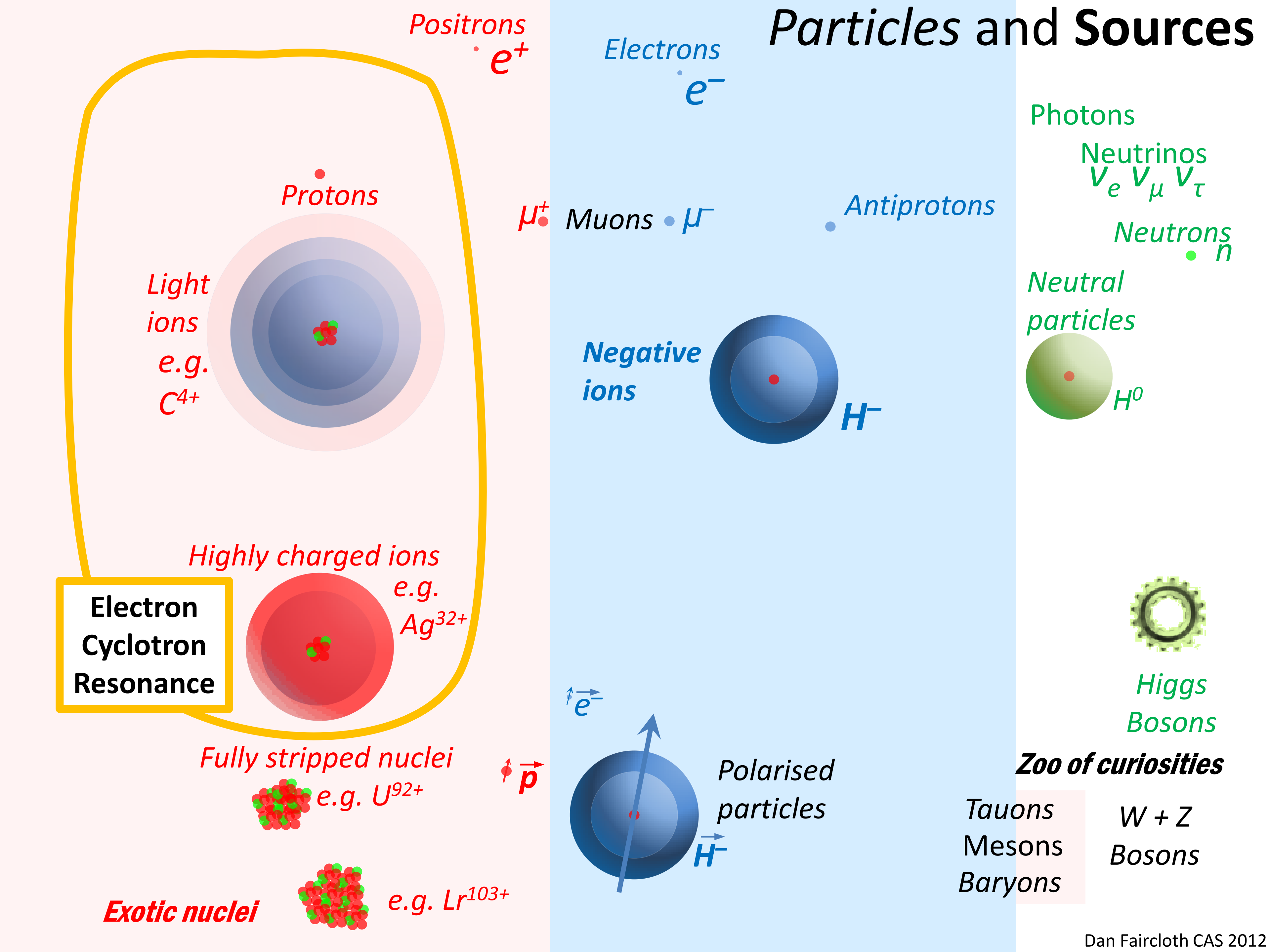
7 mA, 10 μs pulses of C^{4+}

BNL and RIKEN

Masahiro Okamura has demonstrated Direct Plasma Injection into an RFQ



Particles and Sources
Positrons
e^+
Electrons
e^-
Photons
Neutrinos
$\nu_e \; \nu_\mu \; \nu_\tau$
Plasmatrons
Microwave discharge
Protons
μ^+
Muons
μ^-
Antiprotons
Neutrons
n
Light ions e.g. C^{4+}
Neutral particles
Negative ions
H^-
H^0
Vacuum arc
Laser plasma
Highly charged ions
e.g. Ag^{32+}
$\vec{e}^-$
Higgs Bosons
Fully stripped nuclei
e.g. U^{92+}
$\vec{p}$
Polarised particles
Zoo of curiosities
Tauons
Mesons
Baryons
W + Z Bosons
$\vec{H}^-$
Exotic nuclei
e.g. Lr^{103+}
Dan Faircloth CAS 2012



Particles and Sources
Positrons
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Electrons
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Photons
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$\nu_e \; \nu_\mu \; \nu_\tau$
Protons
μ^+
Muons
μ^-
Antiprotons
Neutrons
n
Light ions e.g. C^{4+}
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H^0
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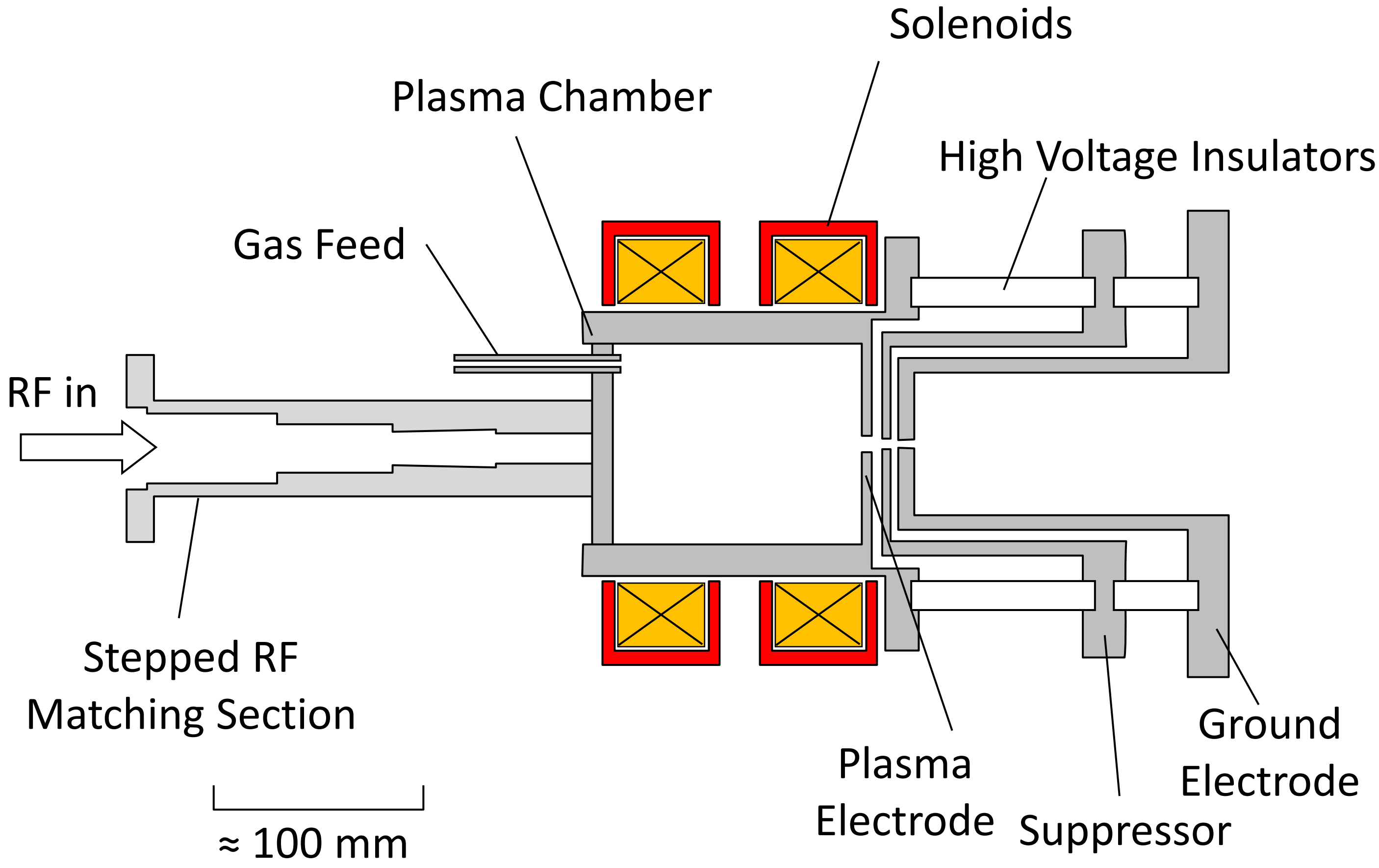
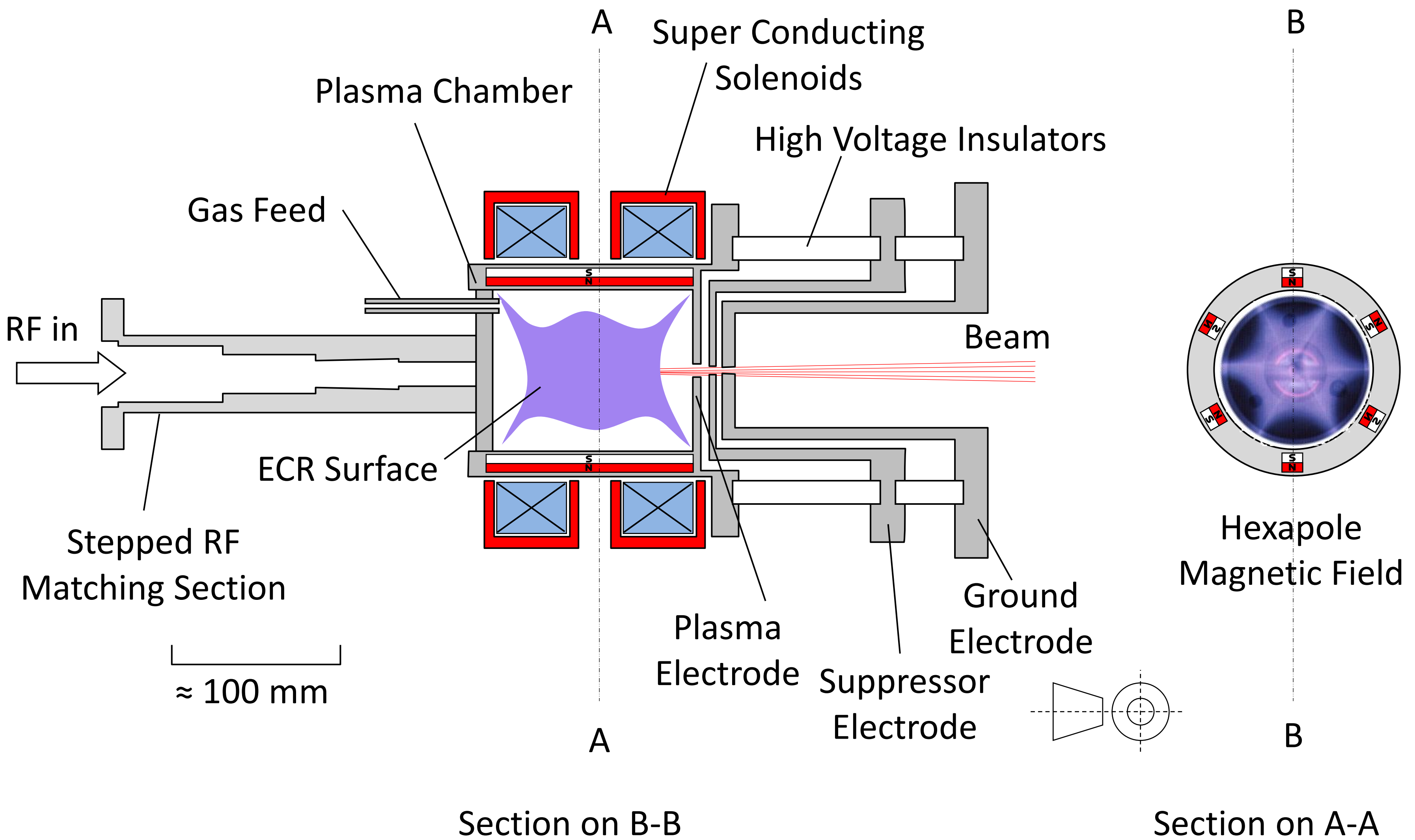
$\vec{H}^-$
Exotic nuclei
e.g. Lr^{103+}
Dan Faircloth CAS 2012

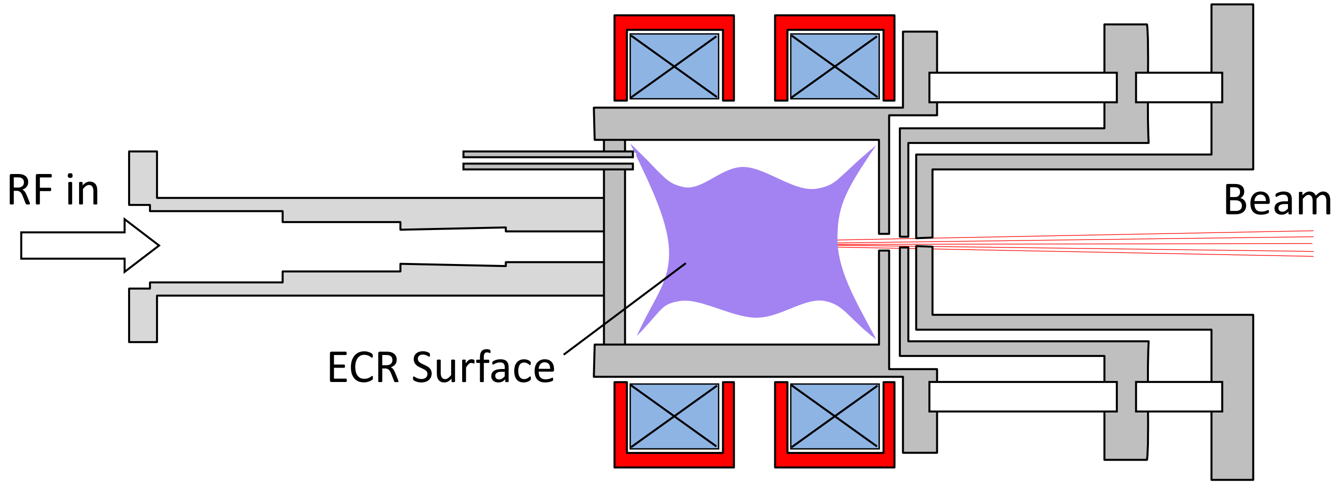
Microwave Discharge Ion Source



ECR Ion Source



ECR Surface



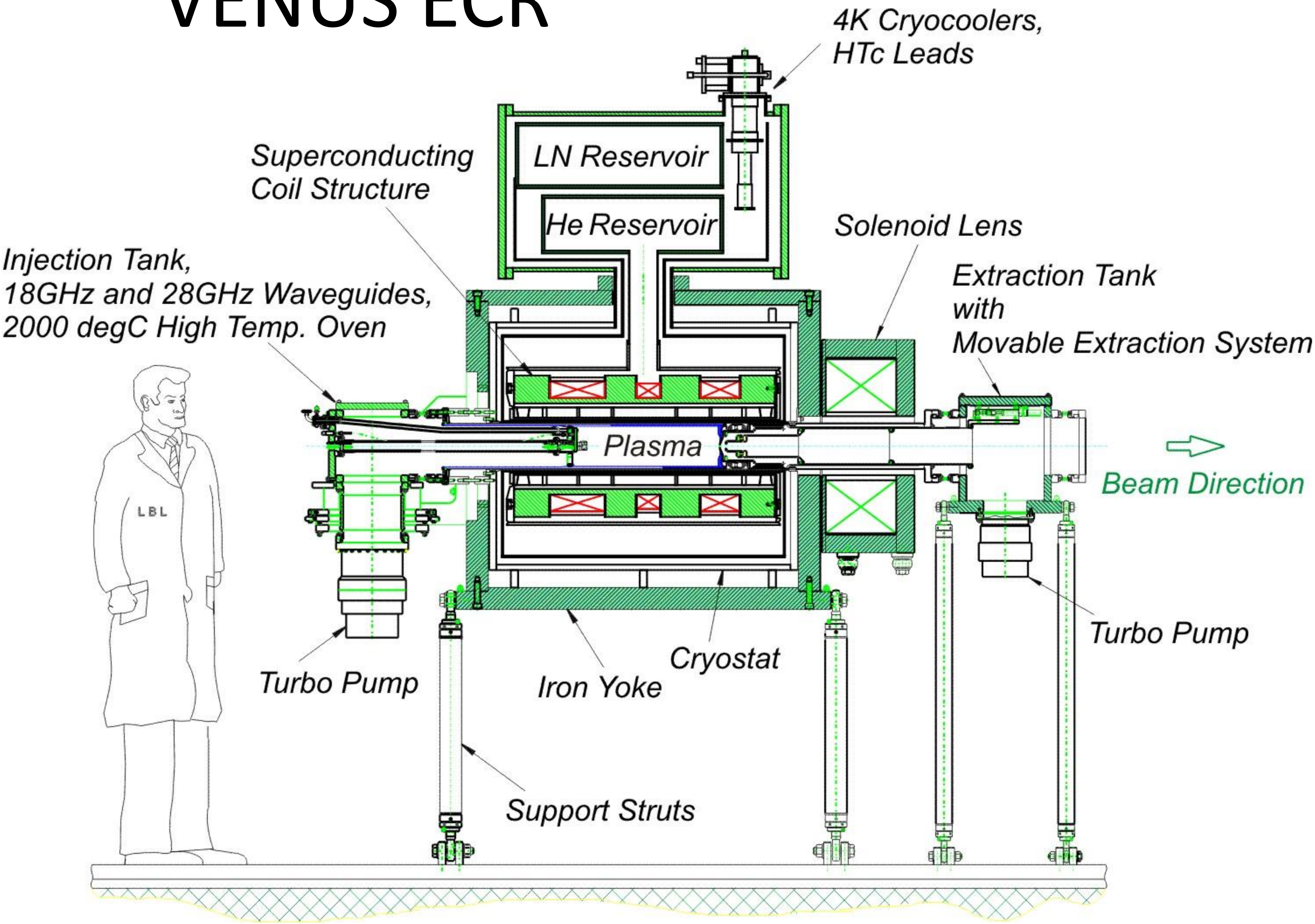
$$\omega_{ECR} = 2\pi f_{ECR} = \frac{eB}{m}$$

28 GHz superconducting VENUS ECR

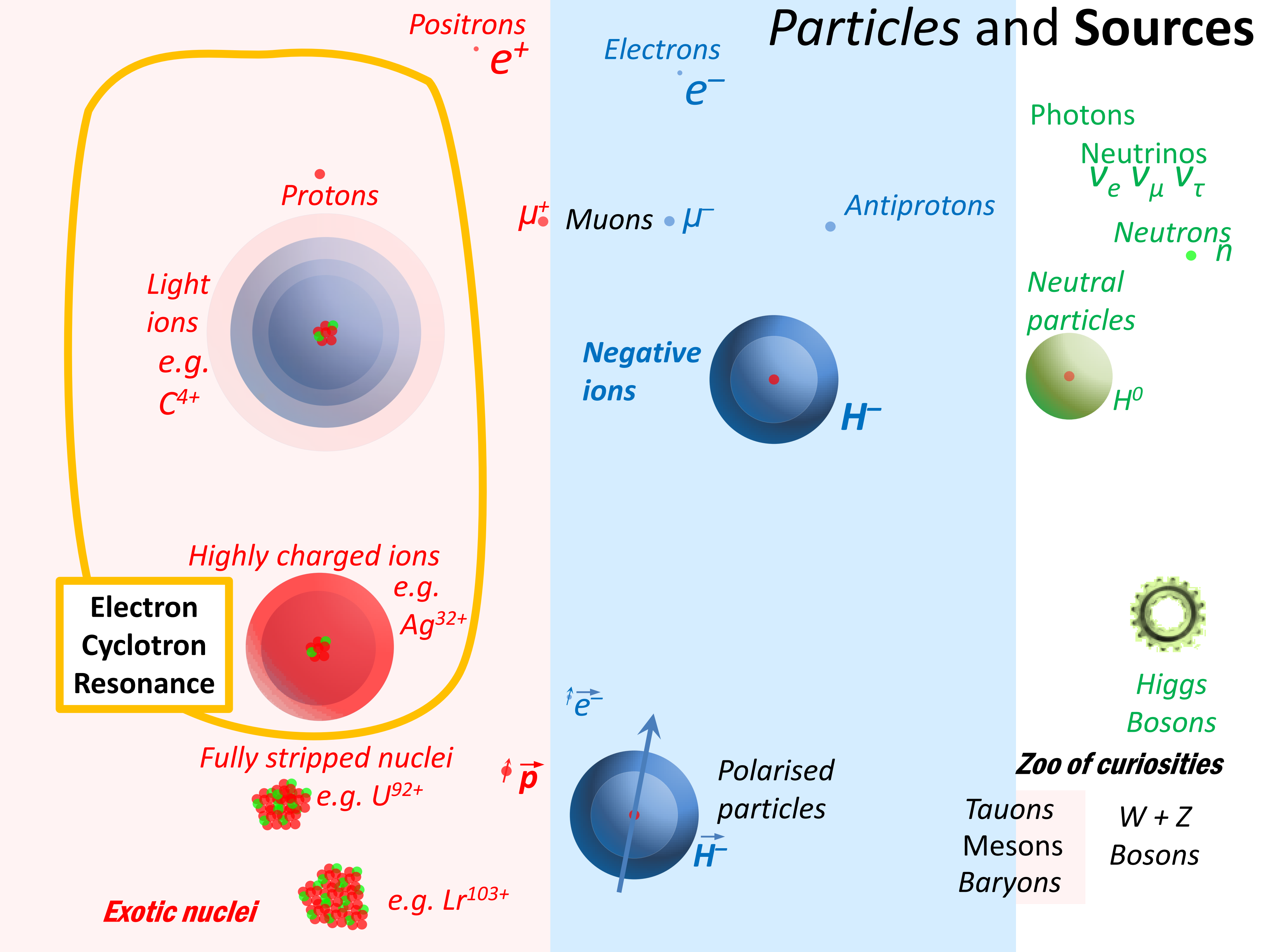
Daniela Leitner
LBNL
Late 2000s

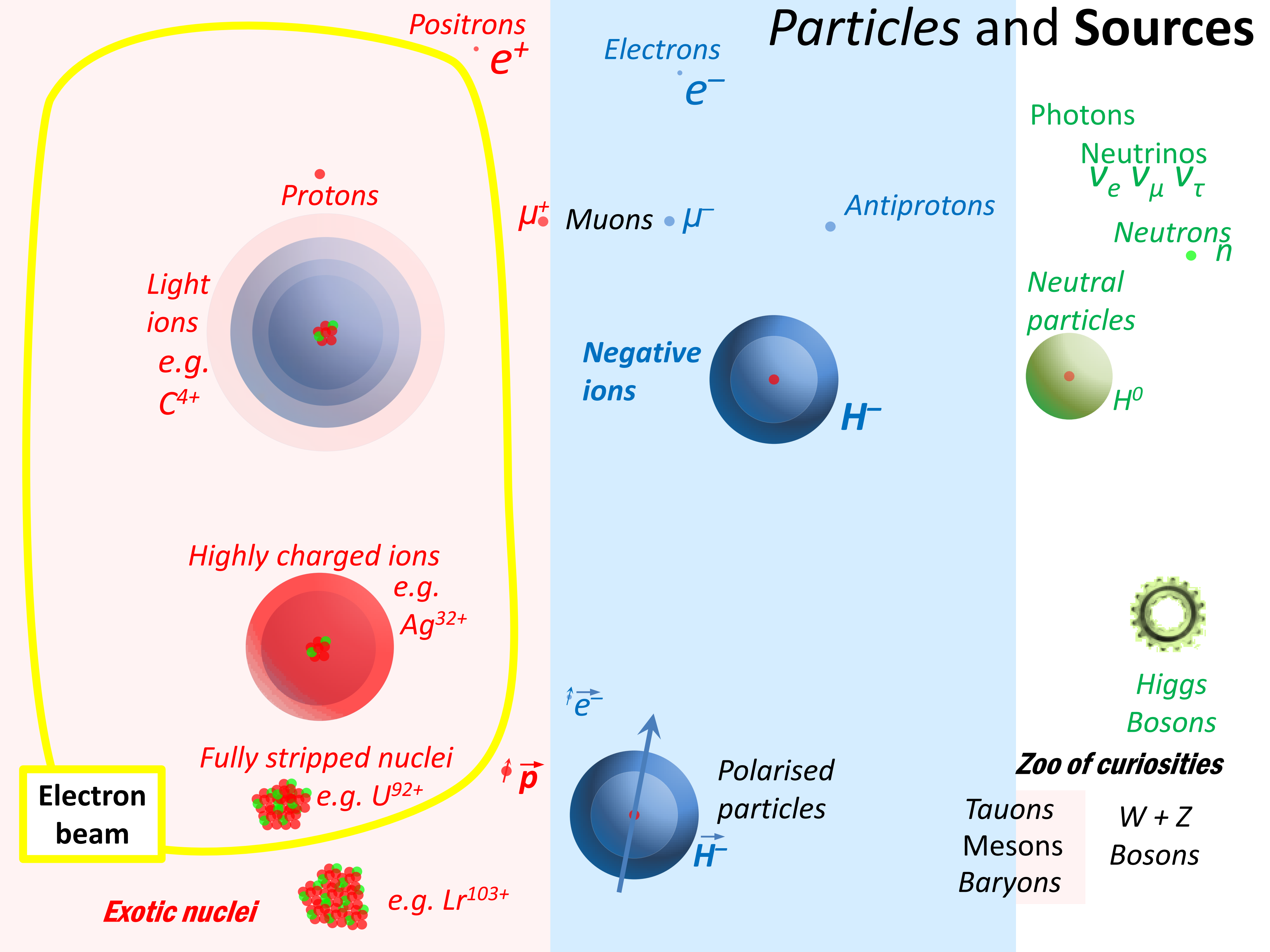
200 eμA U^{34+} ions
4.9 eμA U^{47+} ions

VENUS ECR


4K Cryocoolers,
HTc Leads
Superconducting
Coil Structure
LN Reservoir
He Reservoir
Solenoid Lens
Injection Tank,
18GHz and 28GHz Waveguides,
2000 degC High Temp. Oven
Extraction Tank
with
Movable Extraction System
LBL
Plasma
Beam Direction
Turbo Pump
Turbo Pump
Cryostat
Iron Yoke
Support Struts

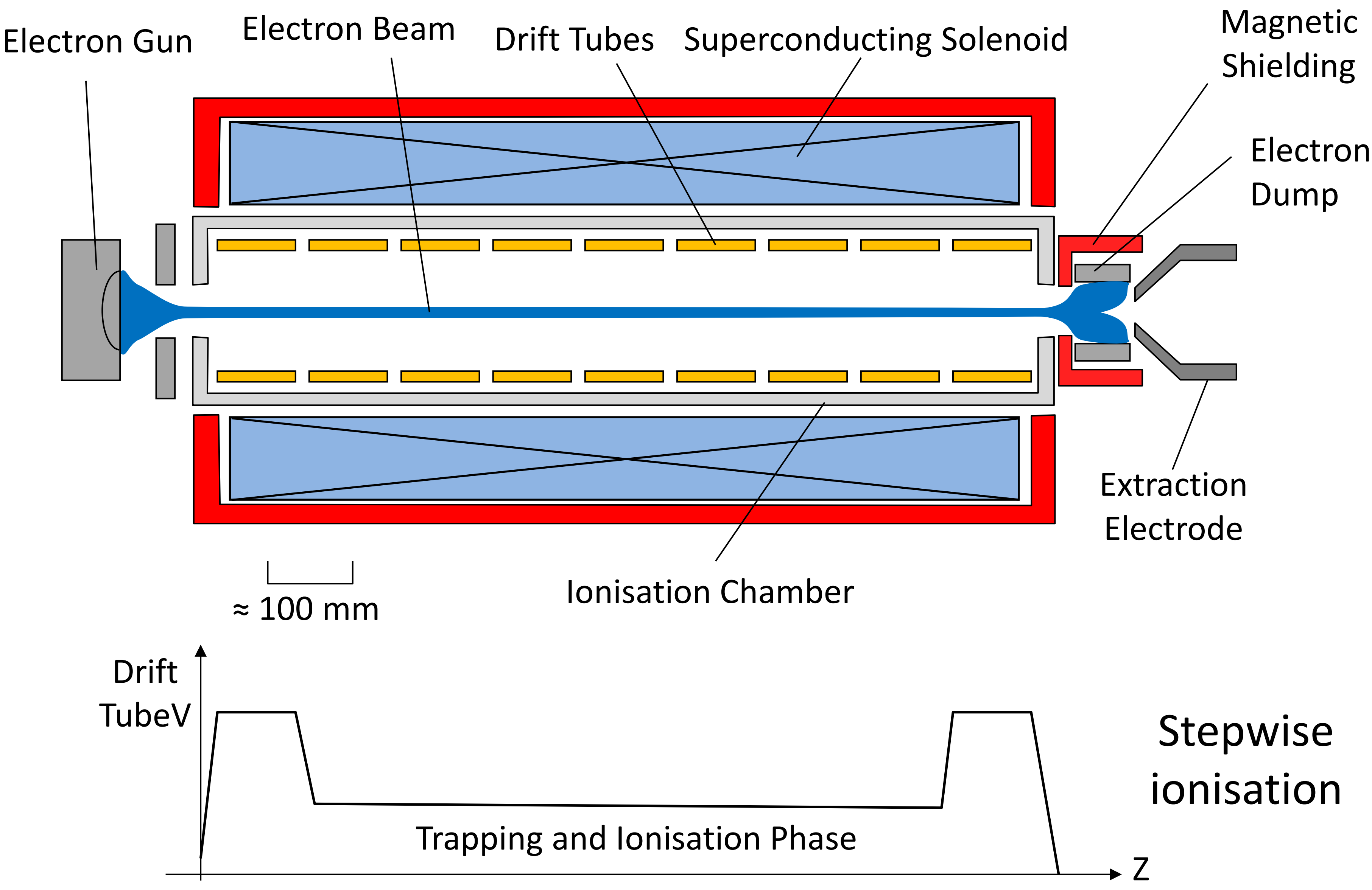
Particles and **Sources**



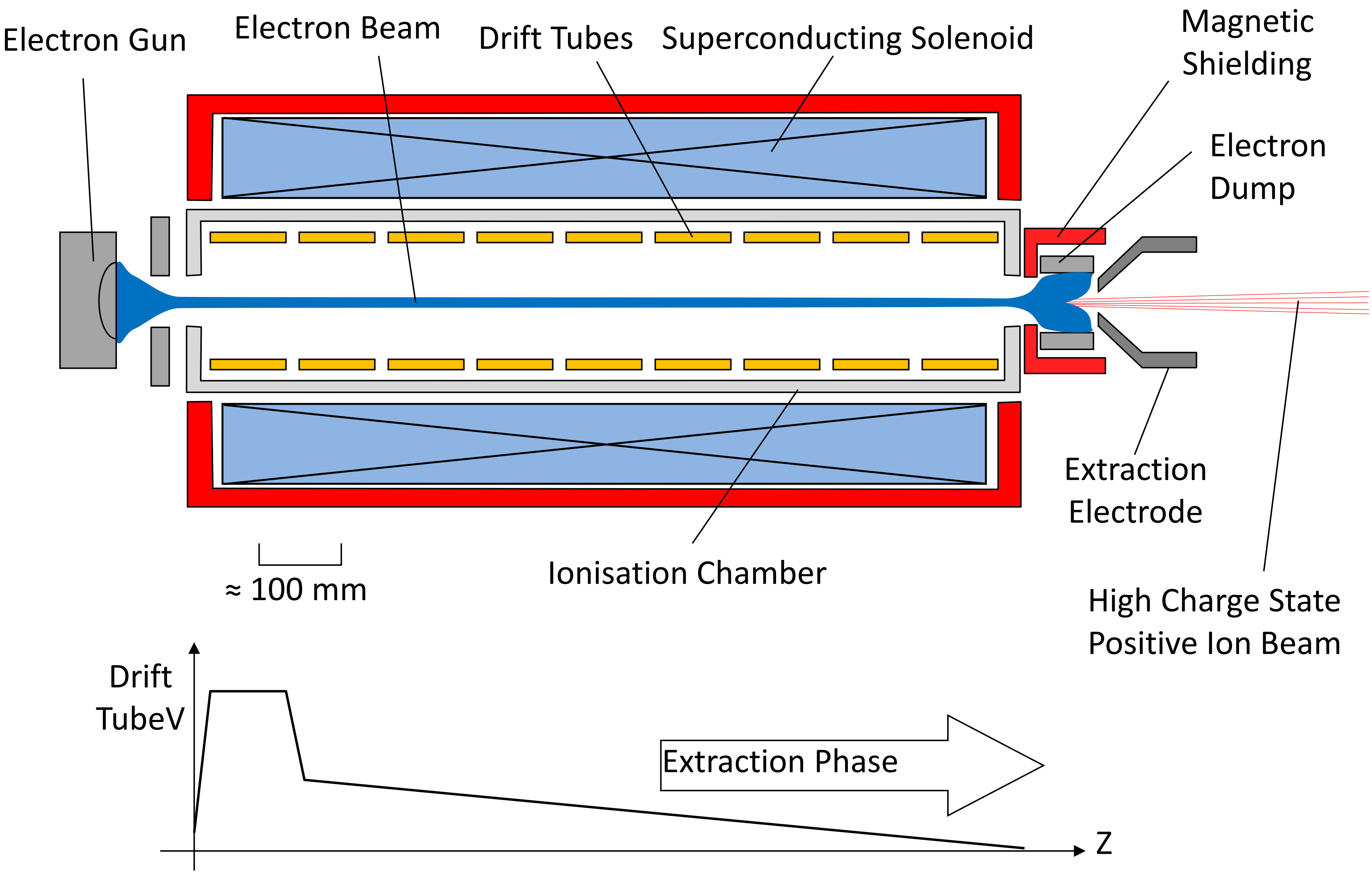


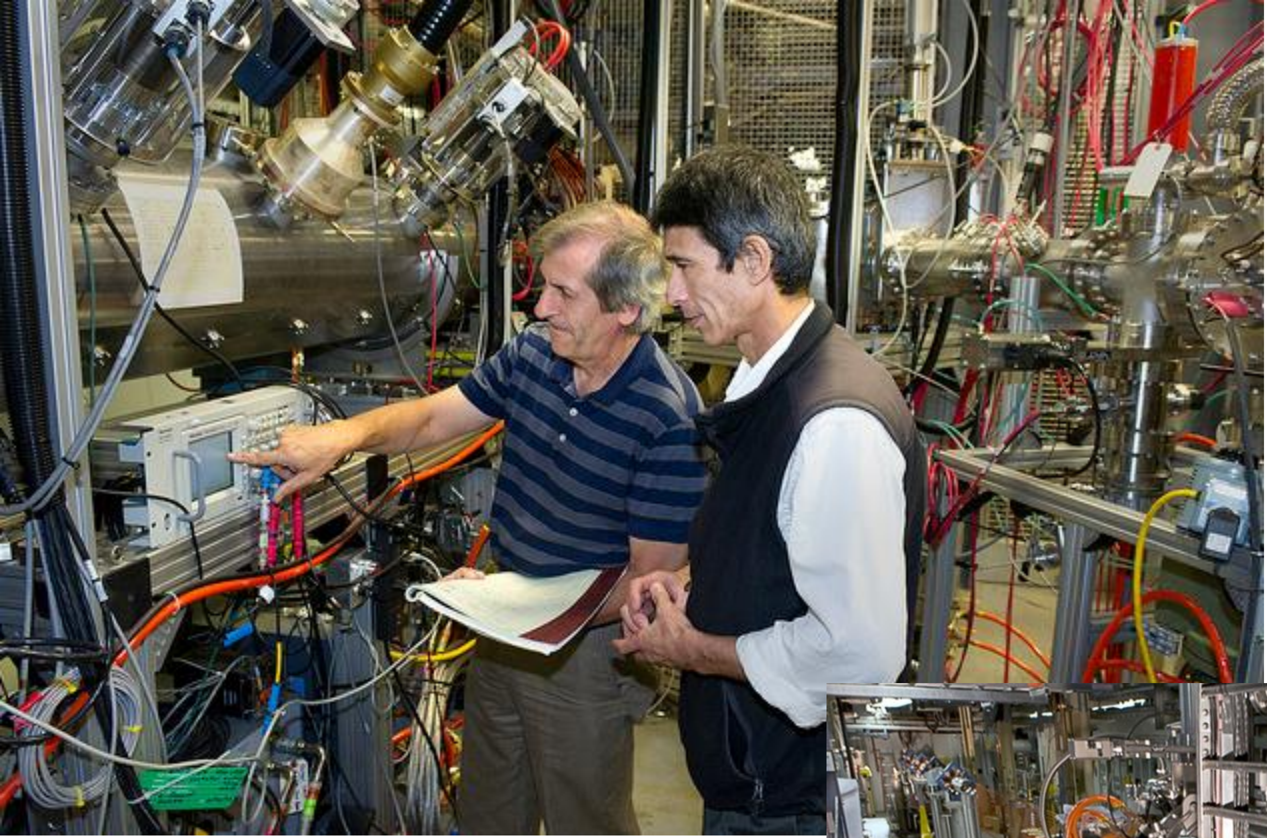
Particles and Sources
Positrons
e+
Electrons
e−
Photons
Neutrinos
νe νμ ντ
Protons
μ+
Muons
μ−
Antiprotons
Neutrons
n
Light ions e.g. C4+
Negative ions
H−
Neutral particles
H0
Highly charged ions
e.g. Ag32+
Higgs Bosons
Fully stripped nuclei
e.g. U92+
p
e−
Polarised particles
H−
Zoo of curiosities
Tauons
Mesons
Baryons
W + Z Bosons
Electron beam
Exotic nuclei
e.g. Lr103+

Electron Beam Ion Sources

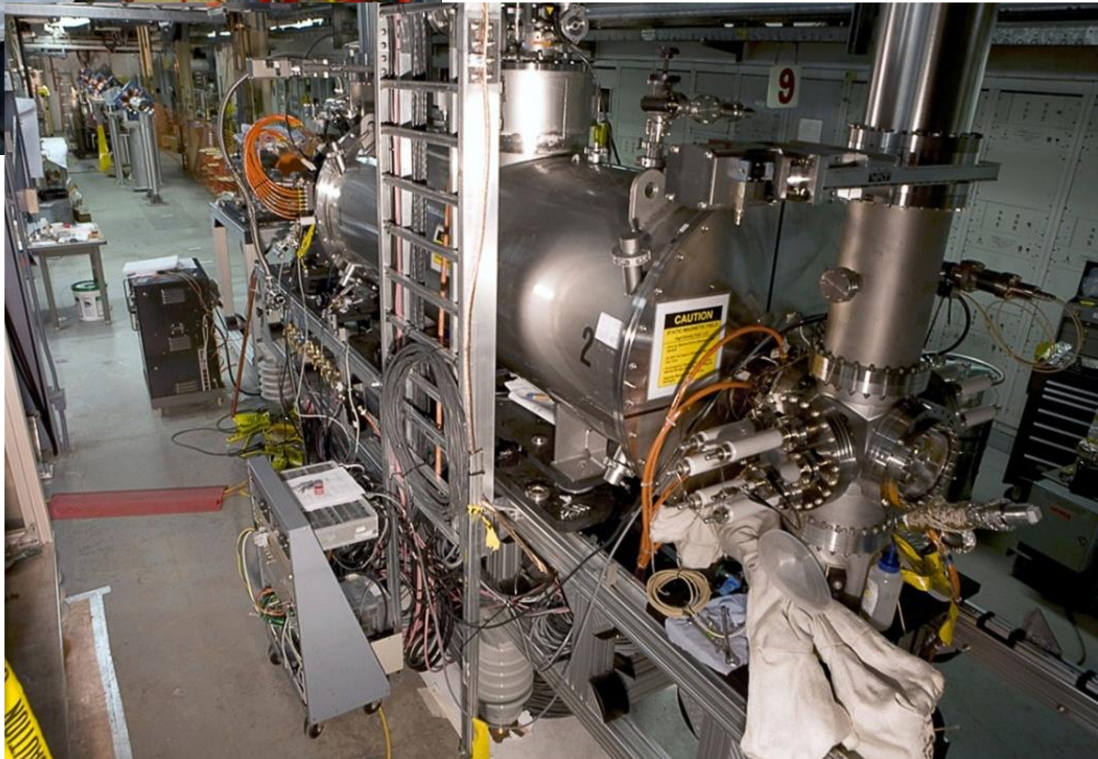


Electron Beam Ion Sources





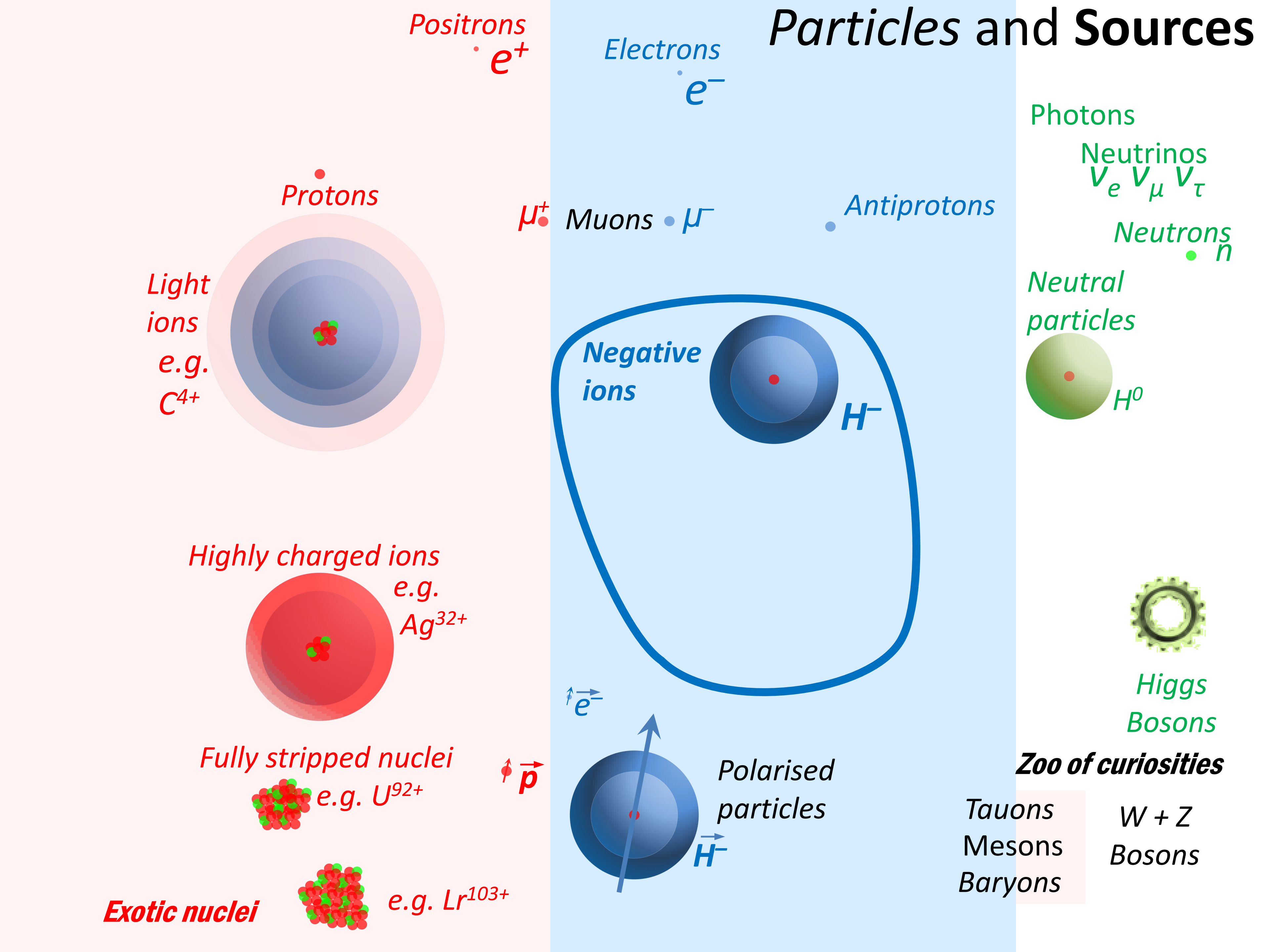
Jim Alessi
BNL



1.7 emA, 10 μs, 5 Hz
Ag^{32+} ions

Fully stripped nuclei can be obtained in EBIT mode

Particles and **Sources**



Negative Ion Sources

Ripping electrons off is easy!

- It is much harder to add them on….

Not all elements will even make negative ions

Hydrogen has an electron affinity of 0.7542 eV

H^- has a much larger cross section than H^0

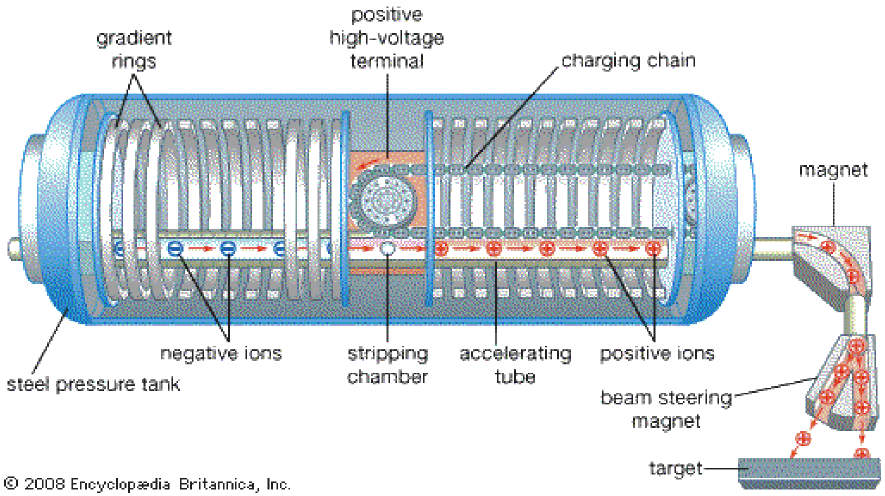
30 times for e^- collisions

100 times for H^+ collisions

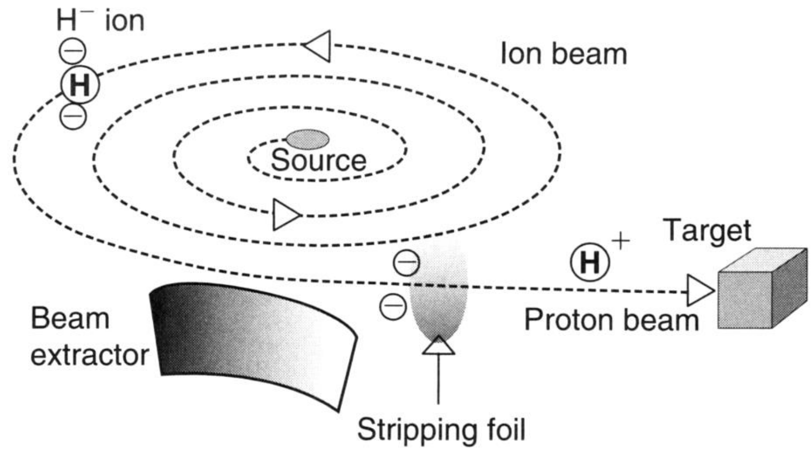
H^- are very fragile!

Applications

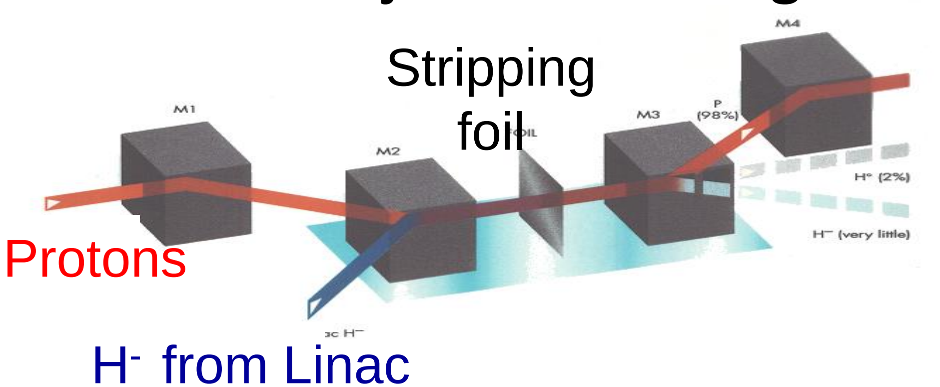
Tandem accelerators



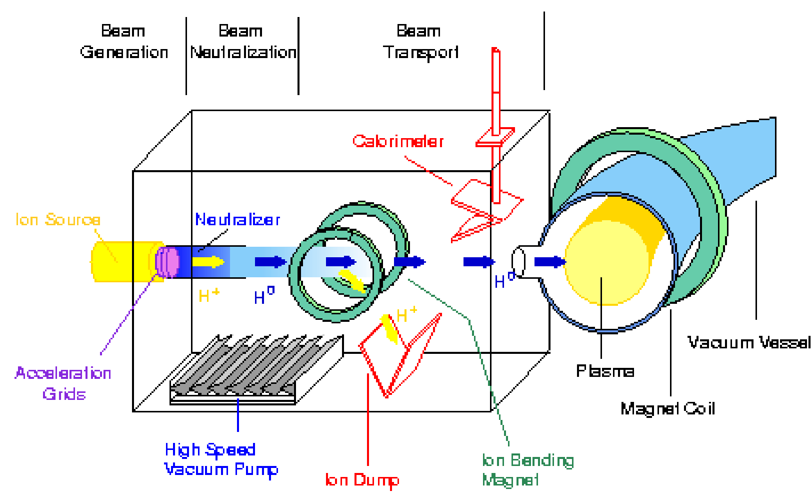
Cyclotron extraction



Multi-turn injection into rings



Neutral Beams

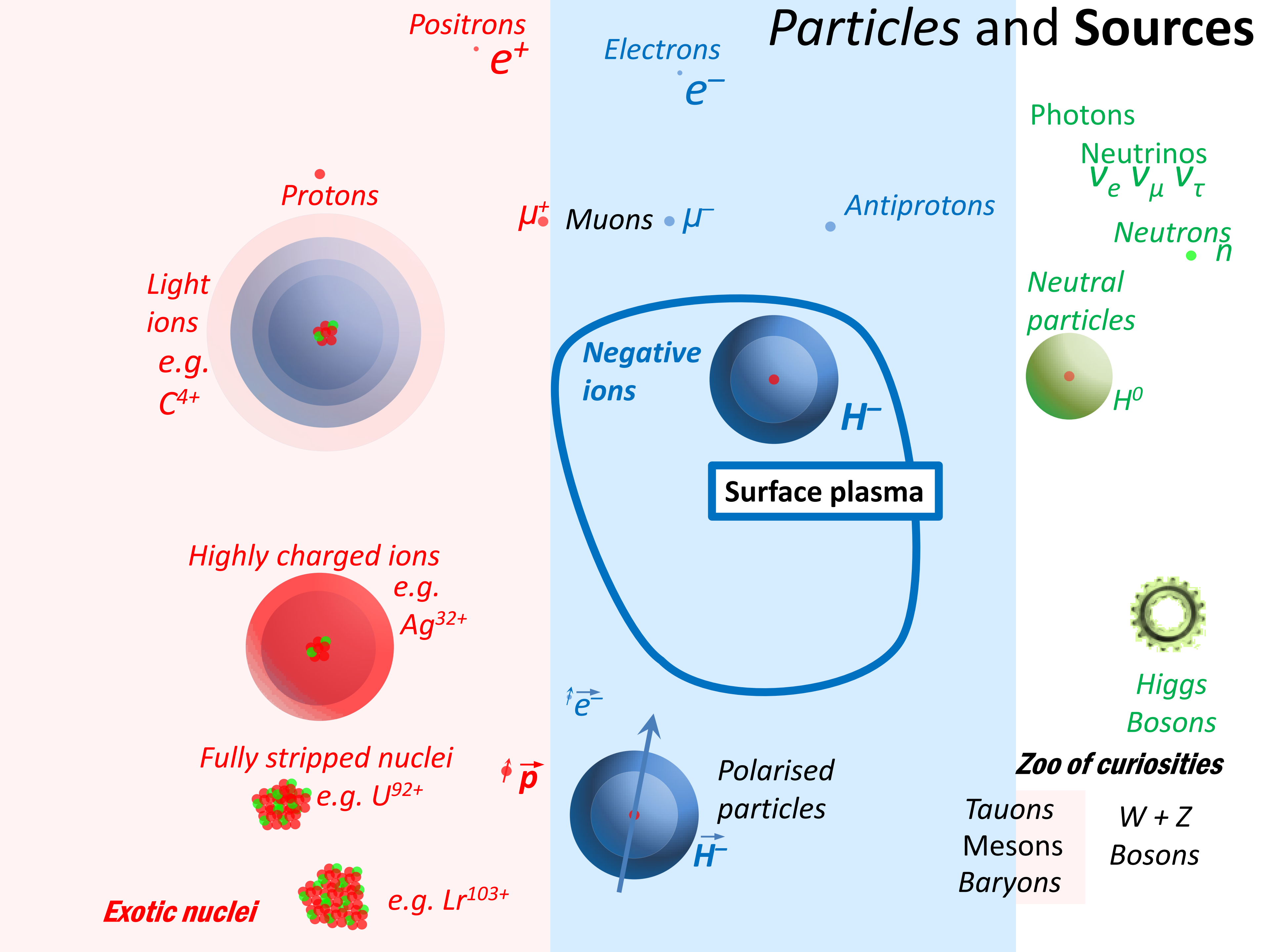


Early attempts at producing negative ion beams:

1. Charge exchange of positive beams in gas cells
   - very inefficient

2. Extraction from existing ion sources

Particles and **Sources**



Early 1970s Budker Institute of Nuclear Physics
Novosibirsk

Production of H^- ions by surface ionisation with the addition of ceasium

Surface Plasma Sources (SPS)

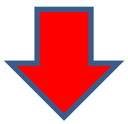
Gennady Dimov

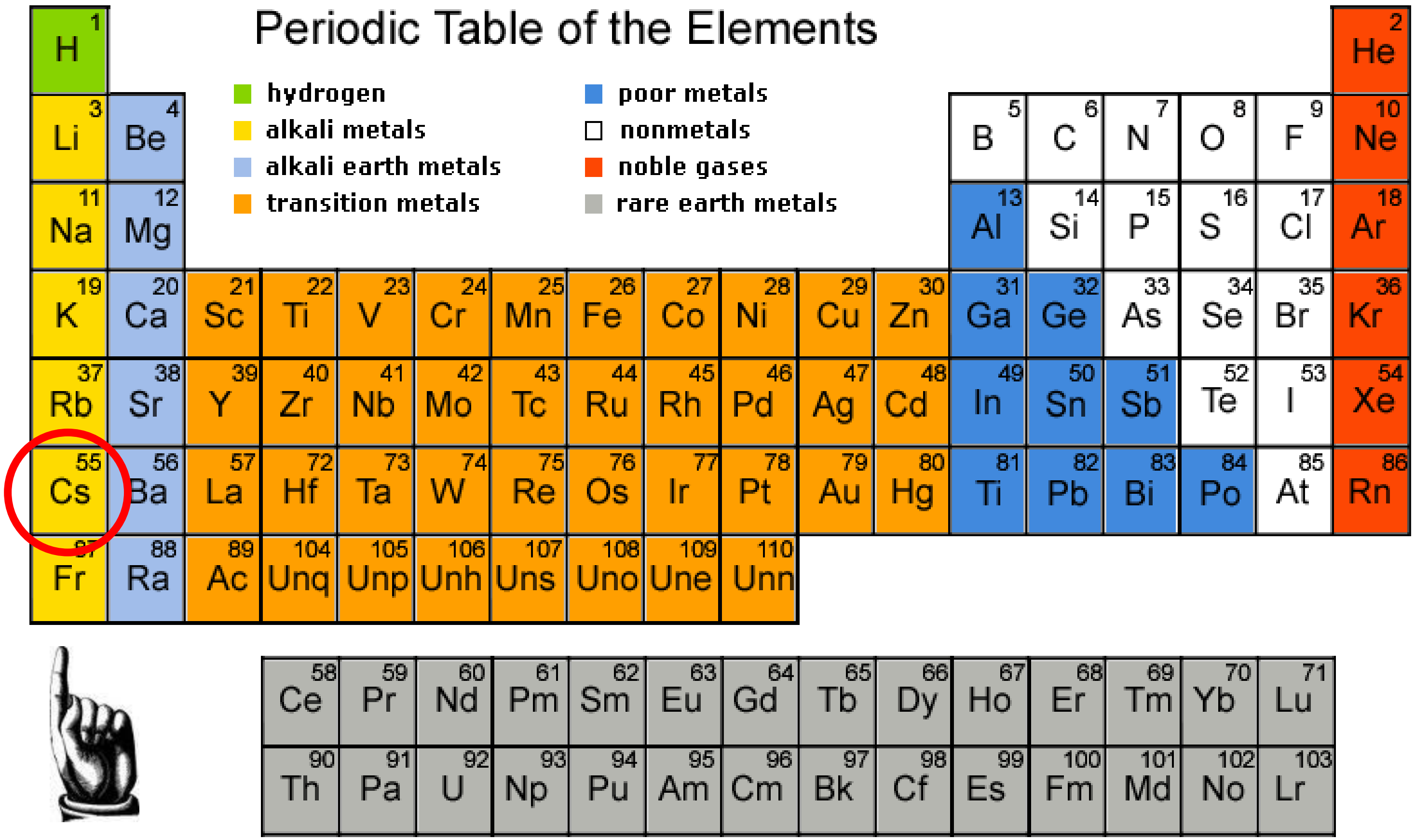
Yuri Belchenko

Vadim Dudnikov

Caesium! – The magic elixir

More reactive



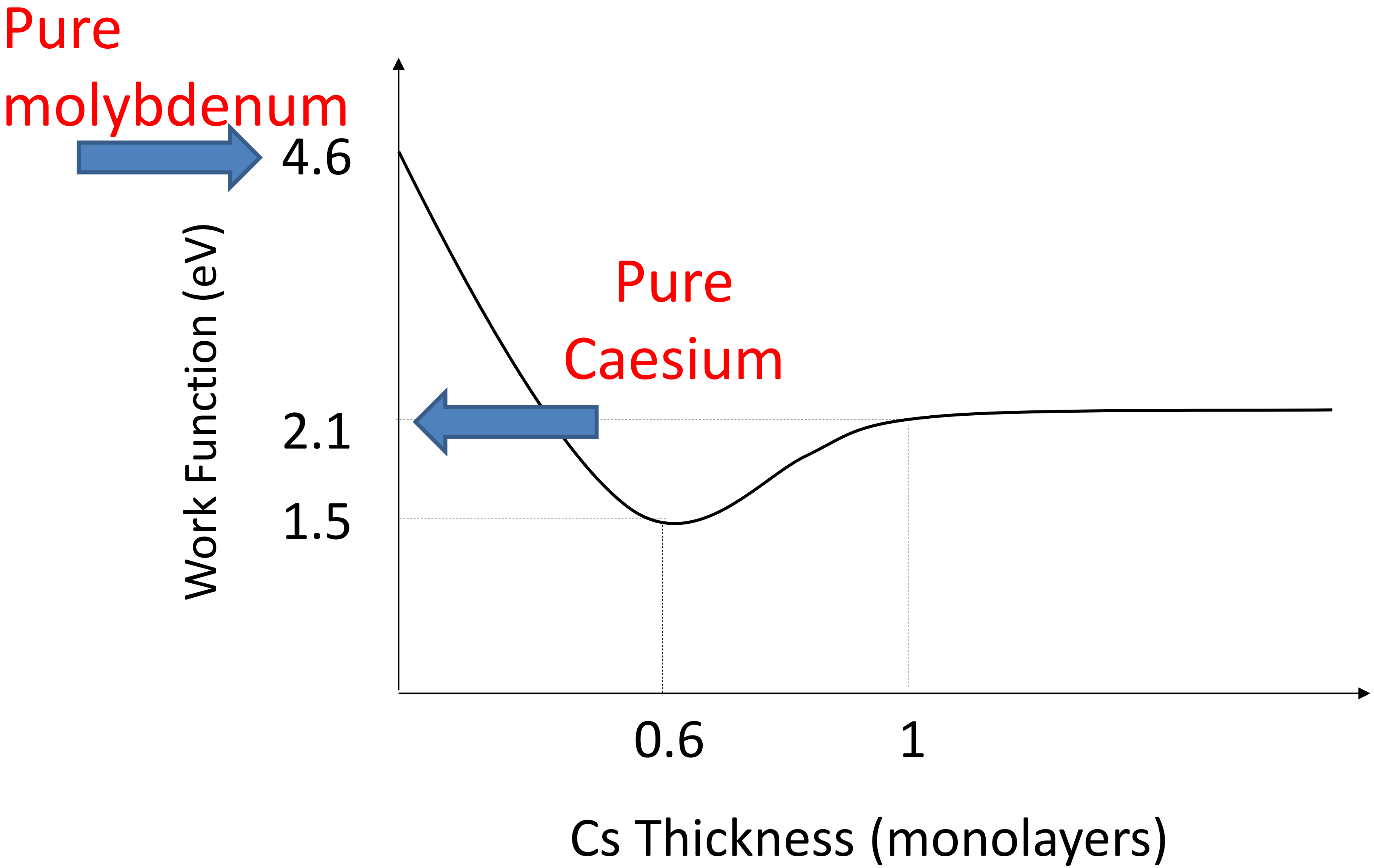


1 electron in the outer orbital

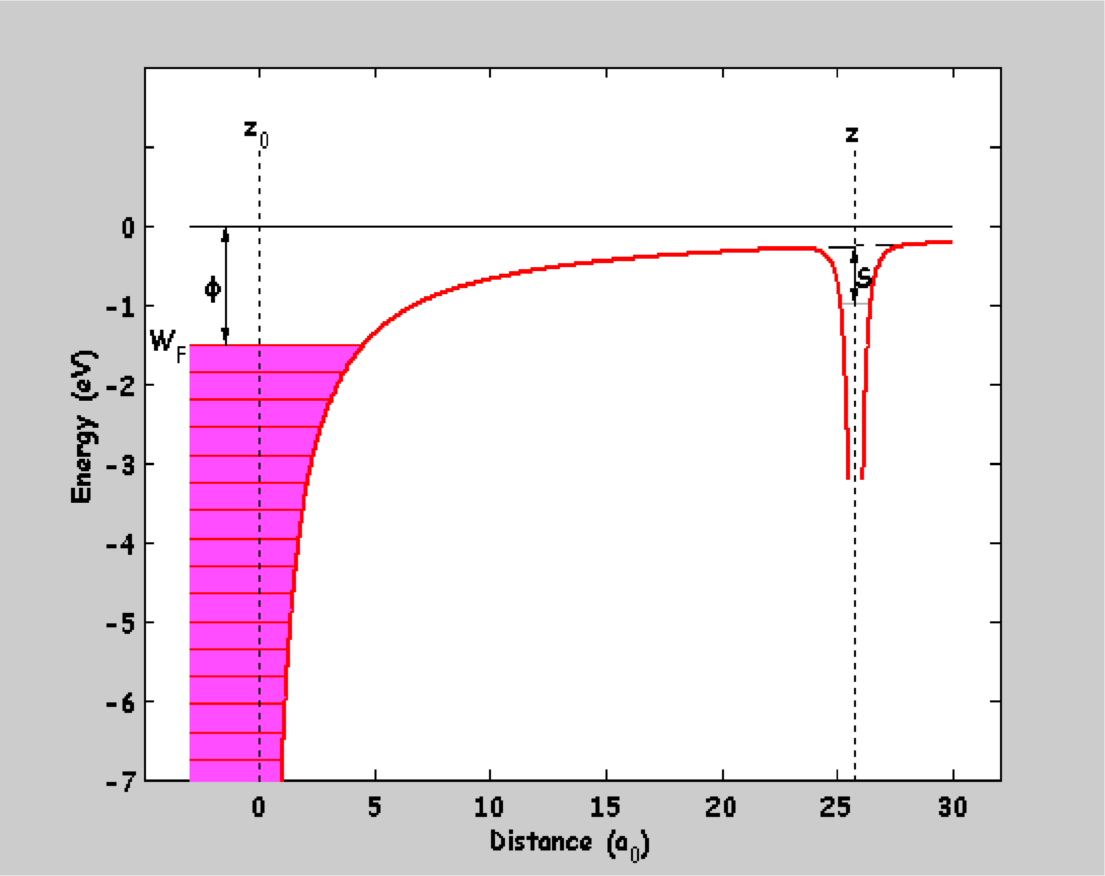
An amazing donor of electrons
= great for making negative ions

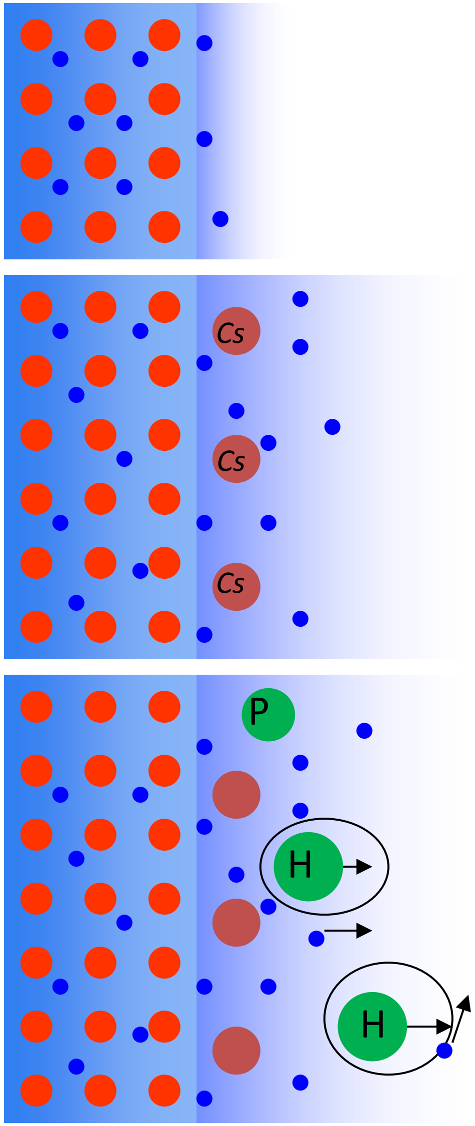

5 g Caesium
Ampoule

Caesium coverage and work function

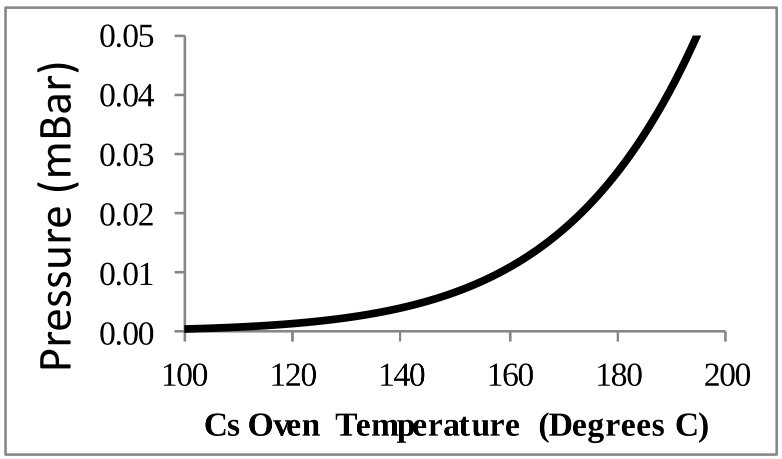


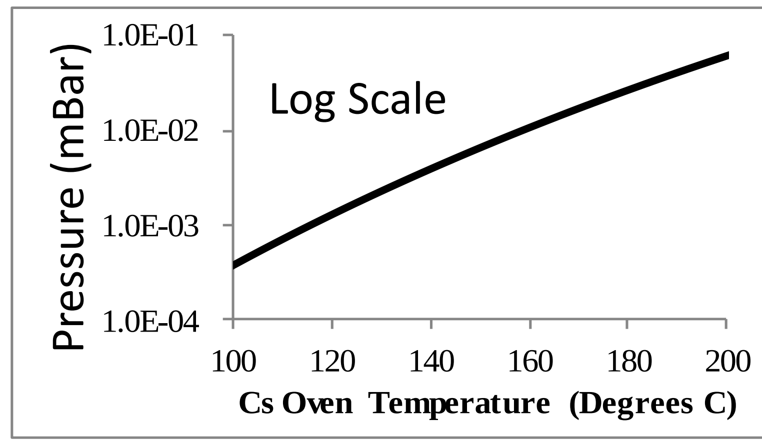
Fermilevels



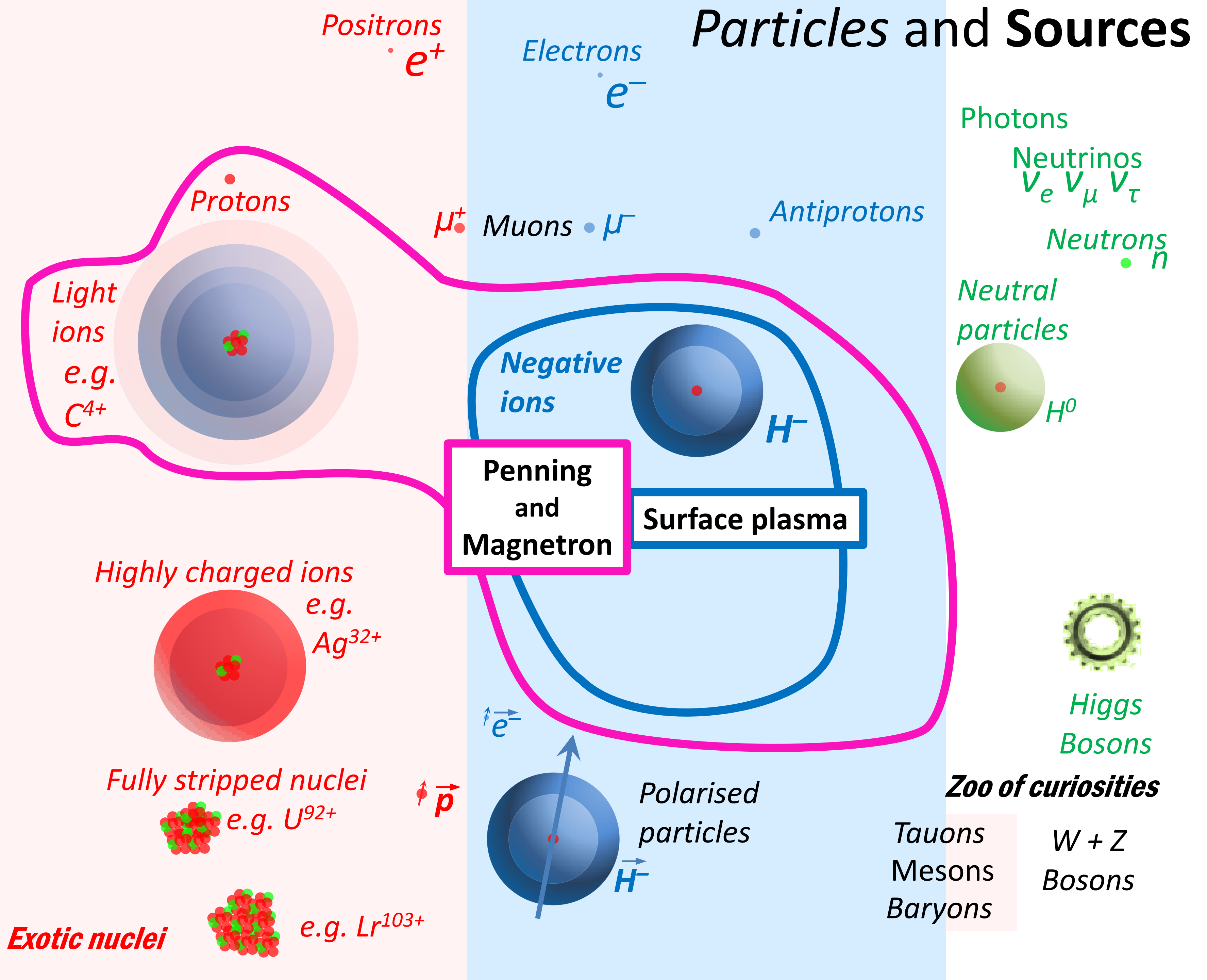


Caesium oven temperature → Caesium vapor pressure → Control caesium coverage

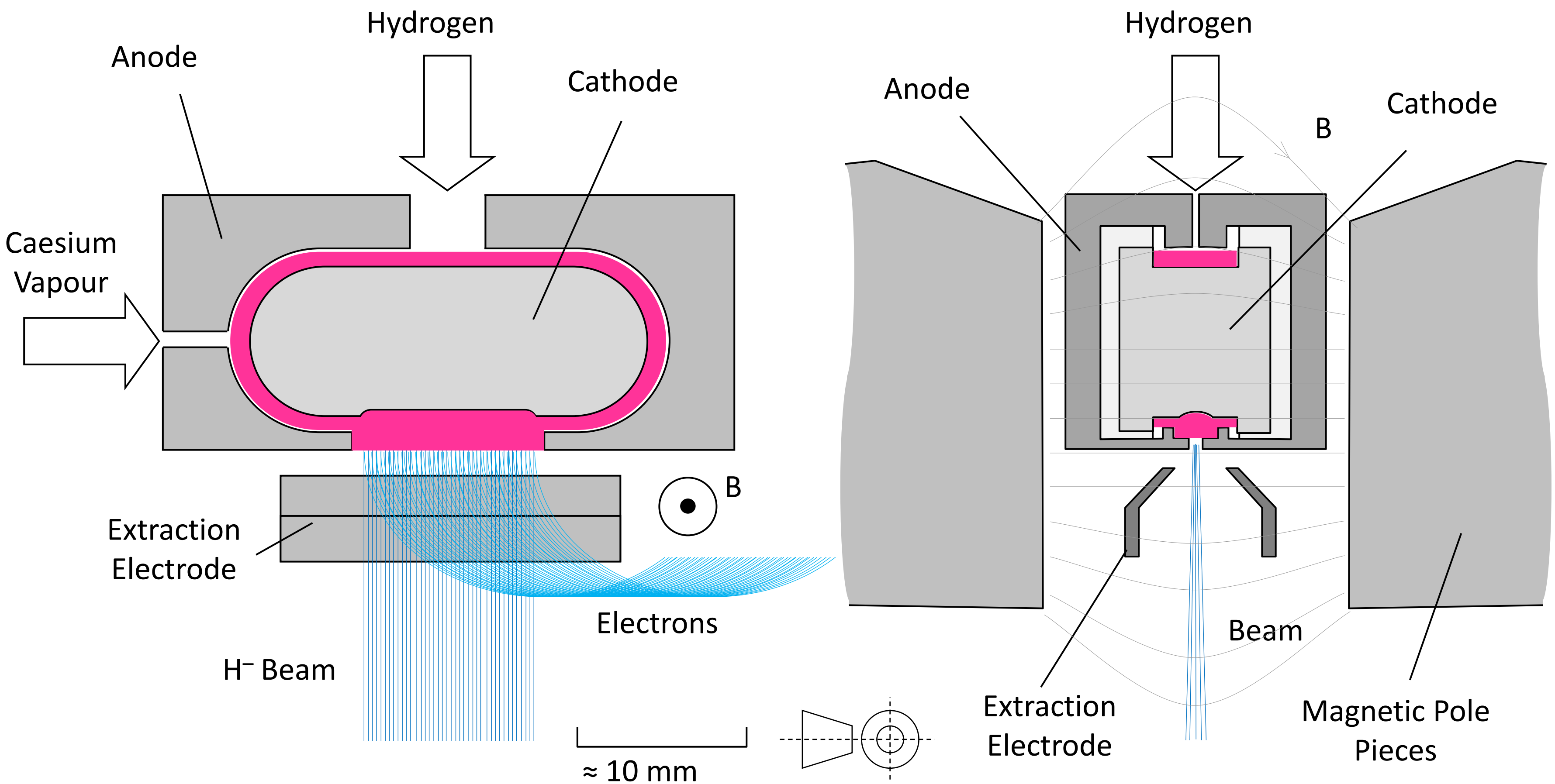




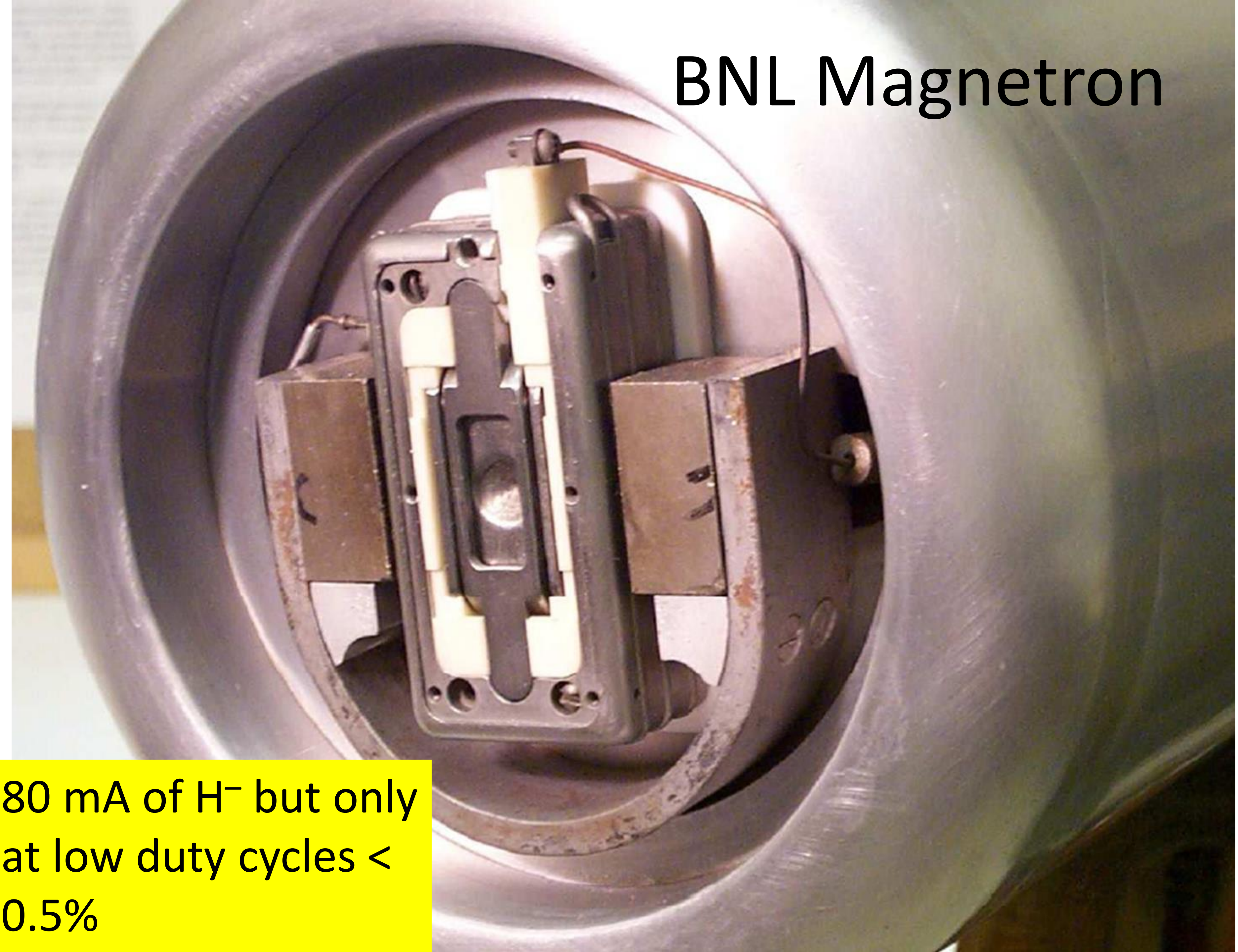
Particles and **Sources**



Magnetron SPS



BNL Magnetron

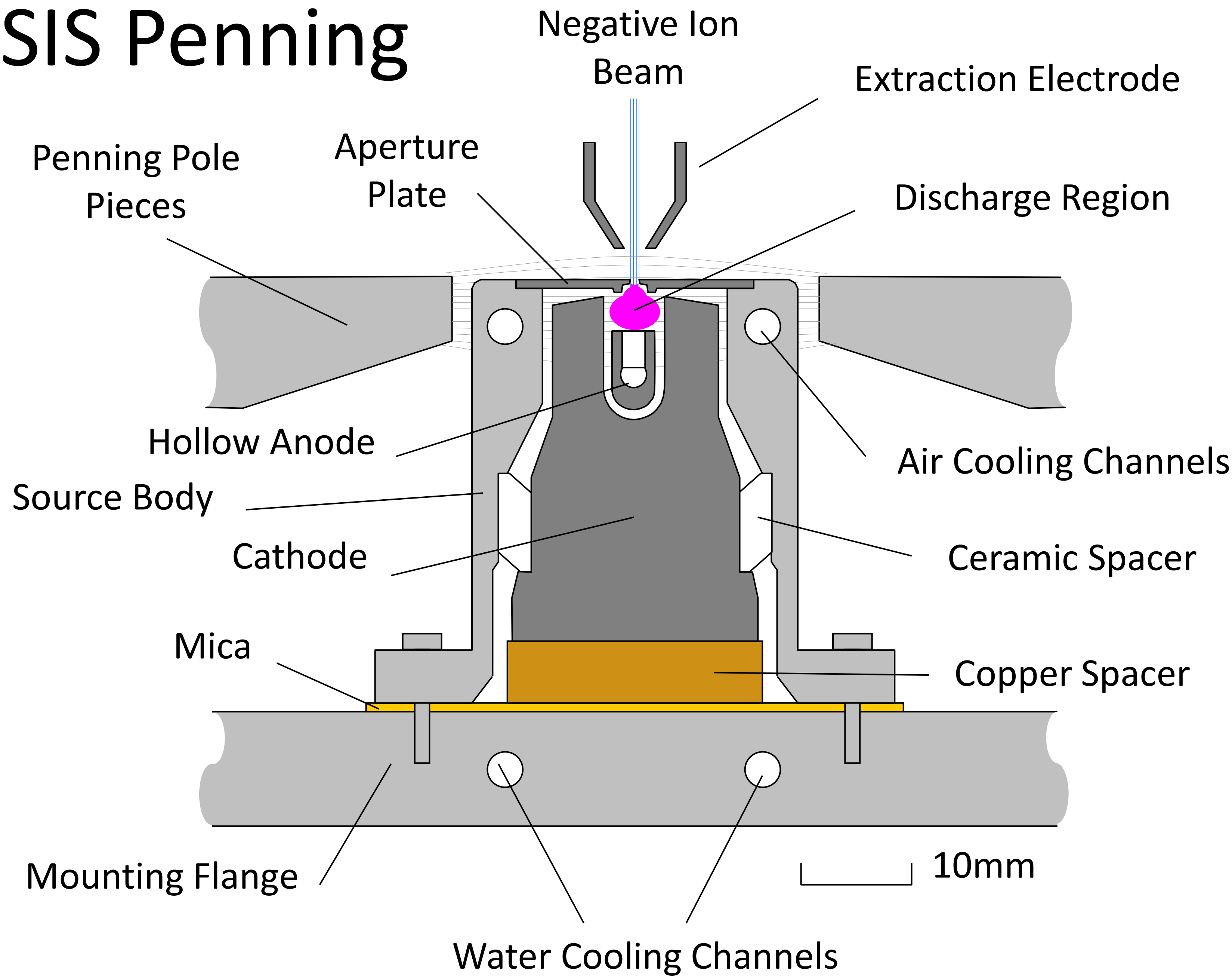


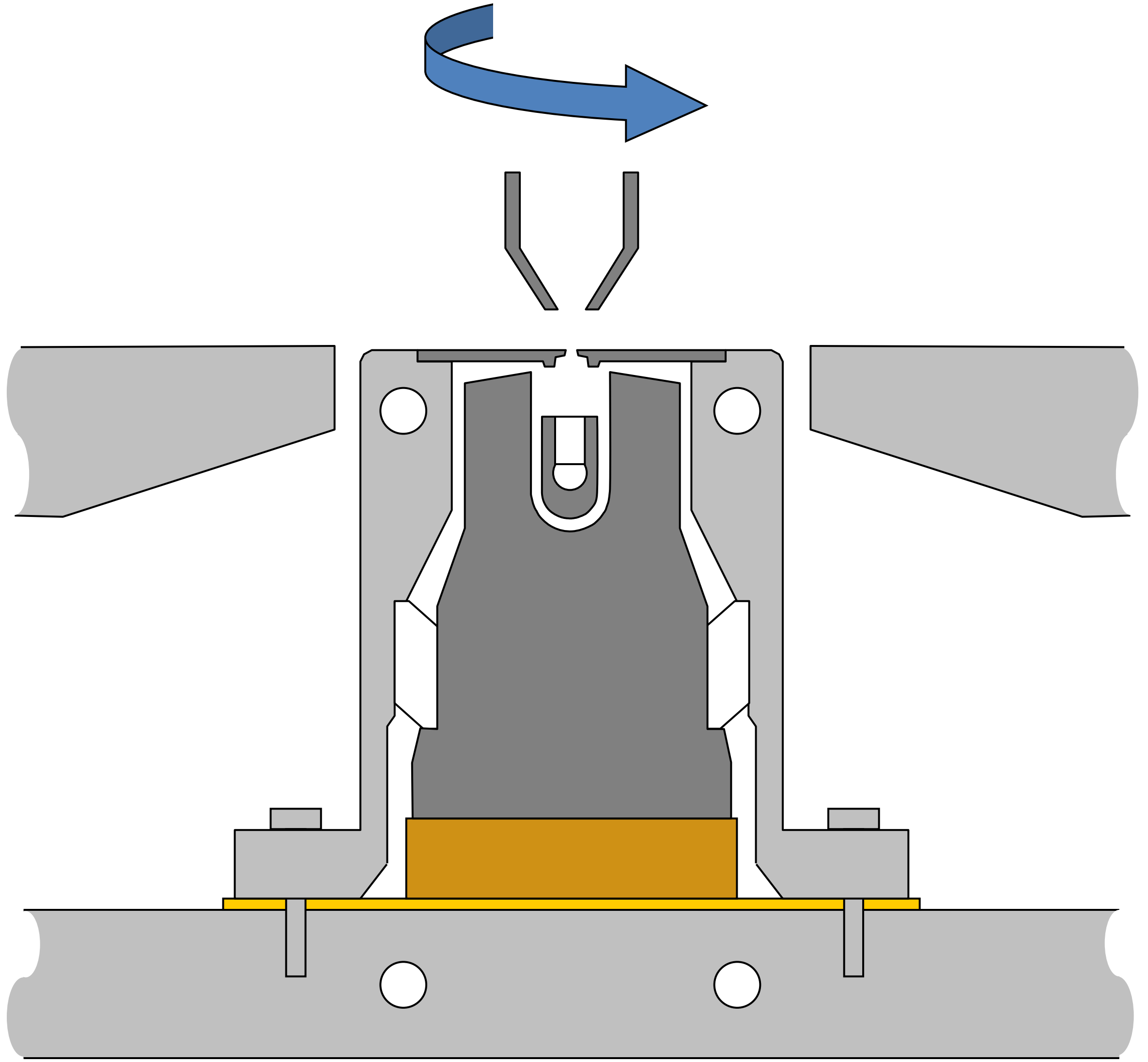
80 mA of H^- but only at low duty cycles < 0.5%

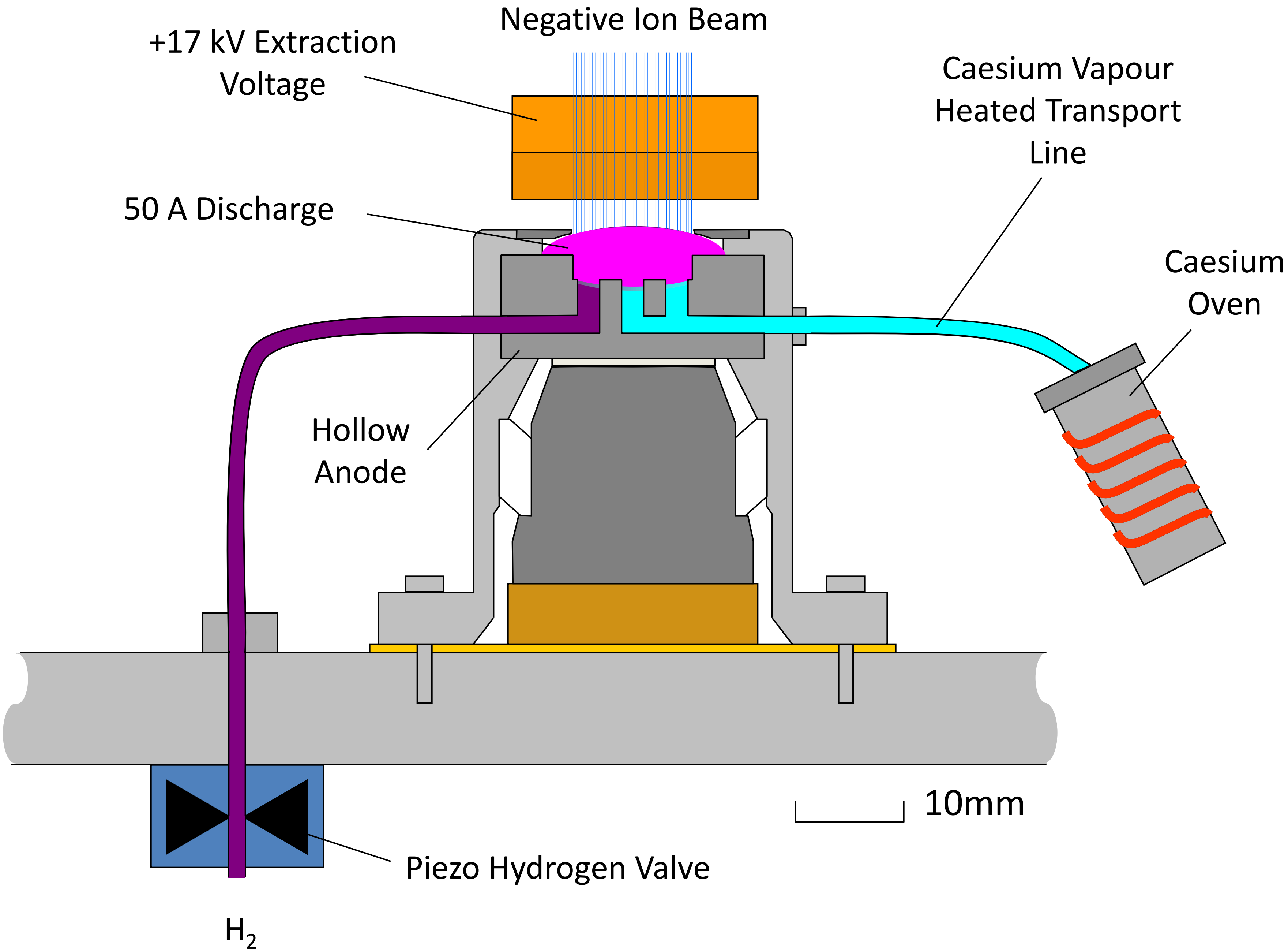
Penning SPS

- Invented by Dudnikov in the 1970's
- Very high current density > 1 Acm^{-2}
- Low noise
- Does not work without ceasium

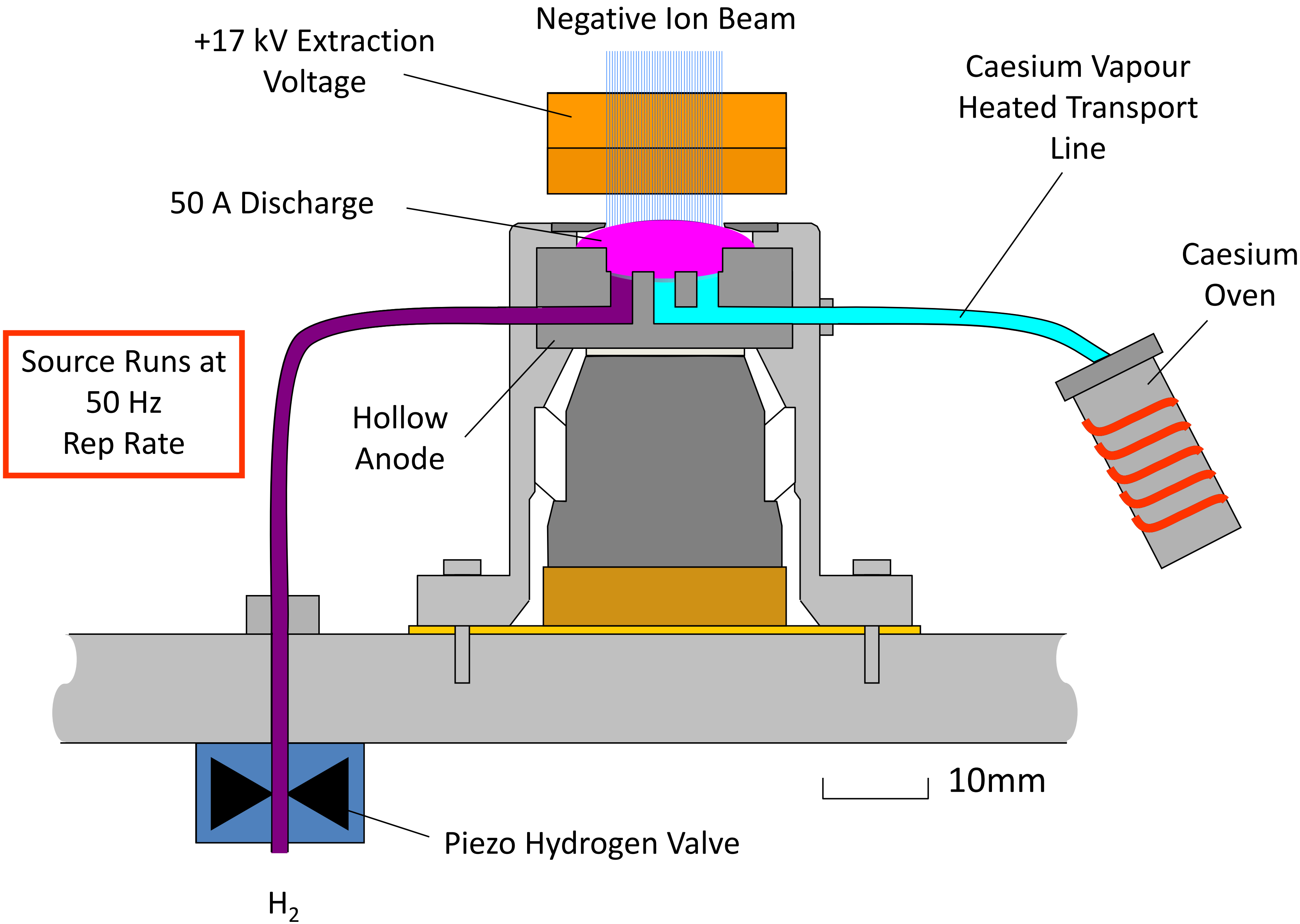
ISIS Penning

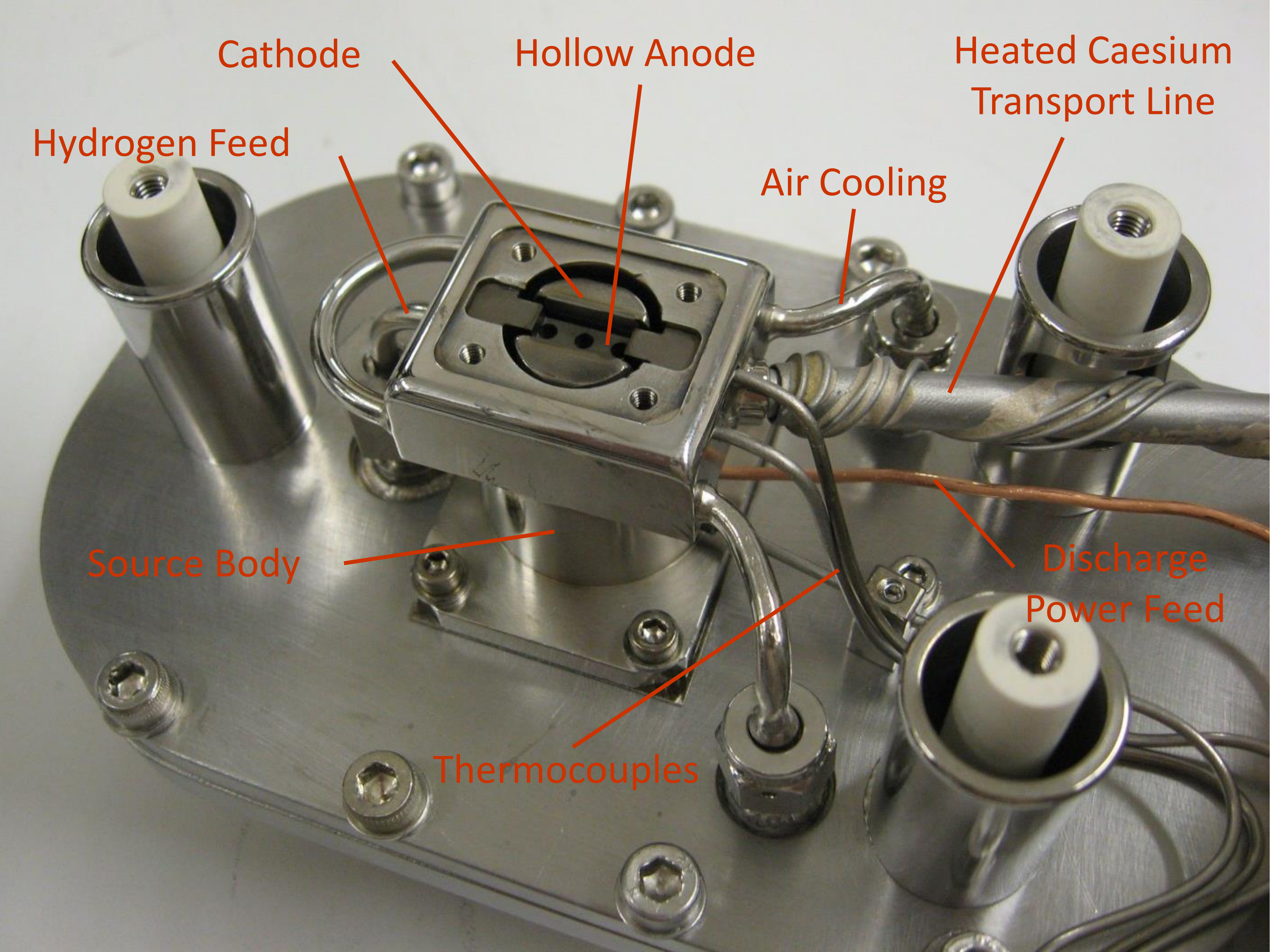


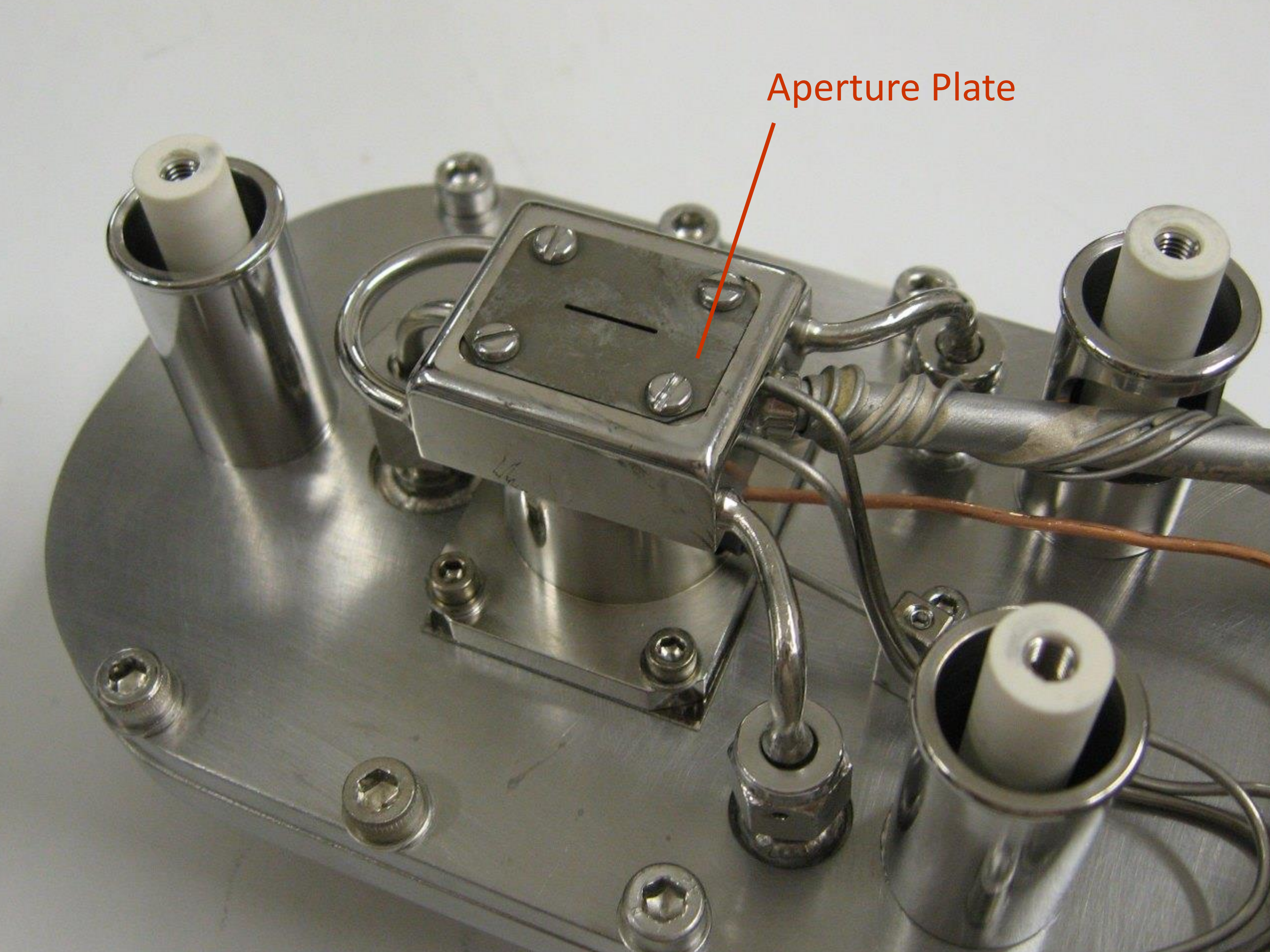


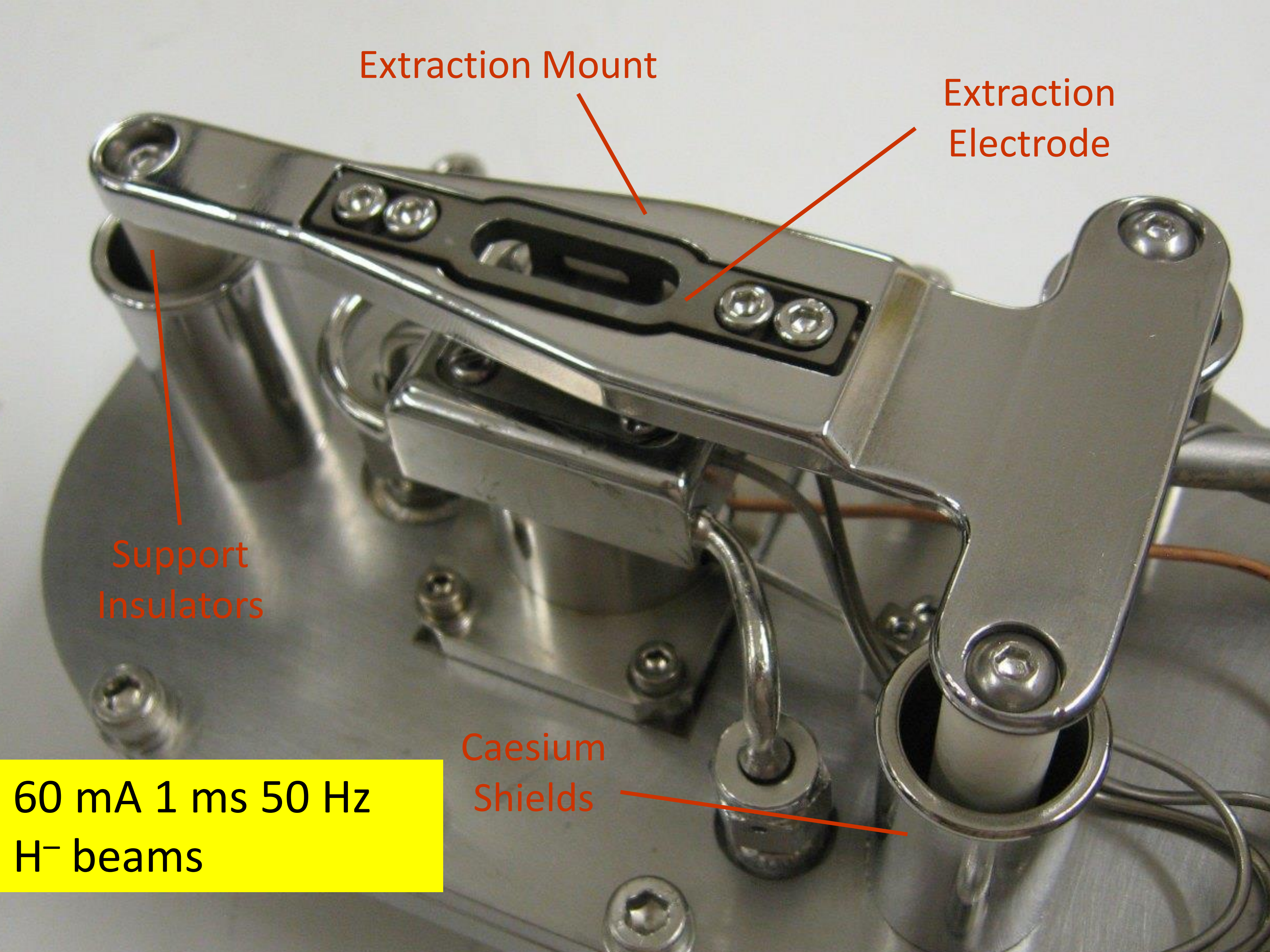


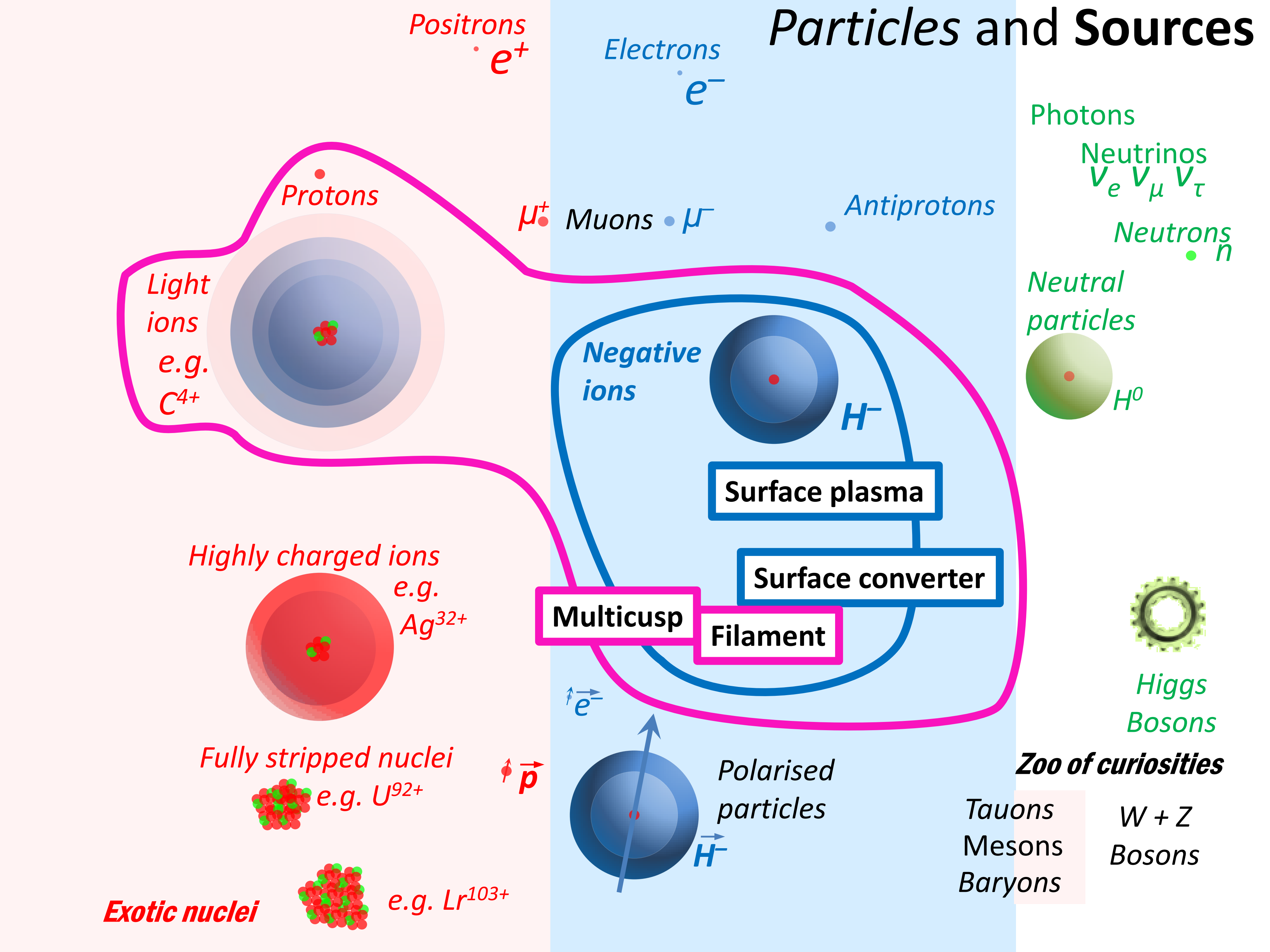
Negative Ion Beam
+17 kV Extraction Voltage
Caesium Vapour Heated Transport Line
50 A Discharge
Caesium Oven
Hollow Anode
10mm
Piezo Hydrogen Valve
H_2


Negative Ion Beam
+17 kV Extraction Voltage
Caesium Vapour Heated Transport Line
50 A Discharge
Caesium Oven
Source Runs at 50 Hz Rep Rate
Hollow Anode
10mm
Piezo Hydrogen Valve
H2

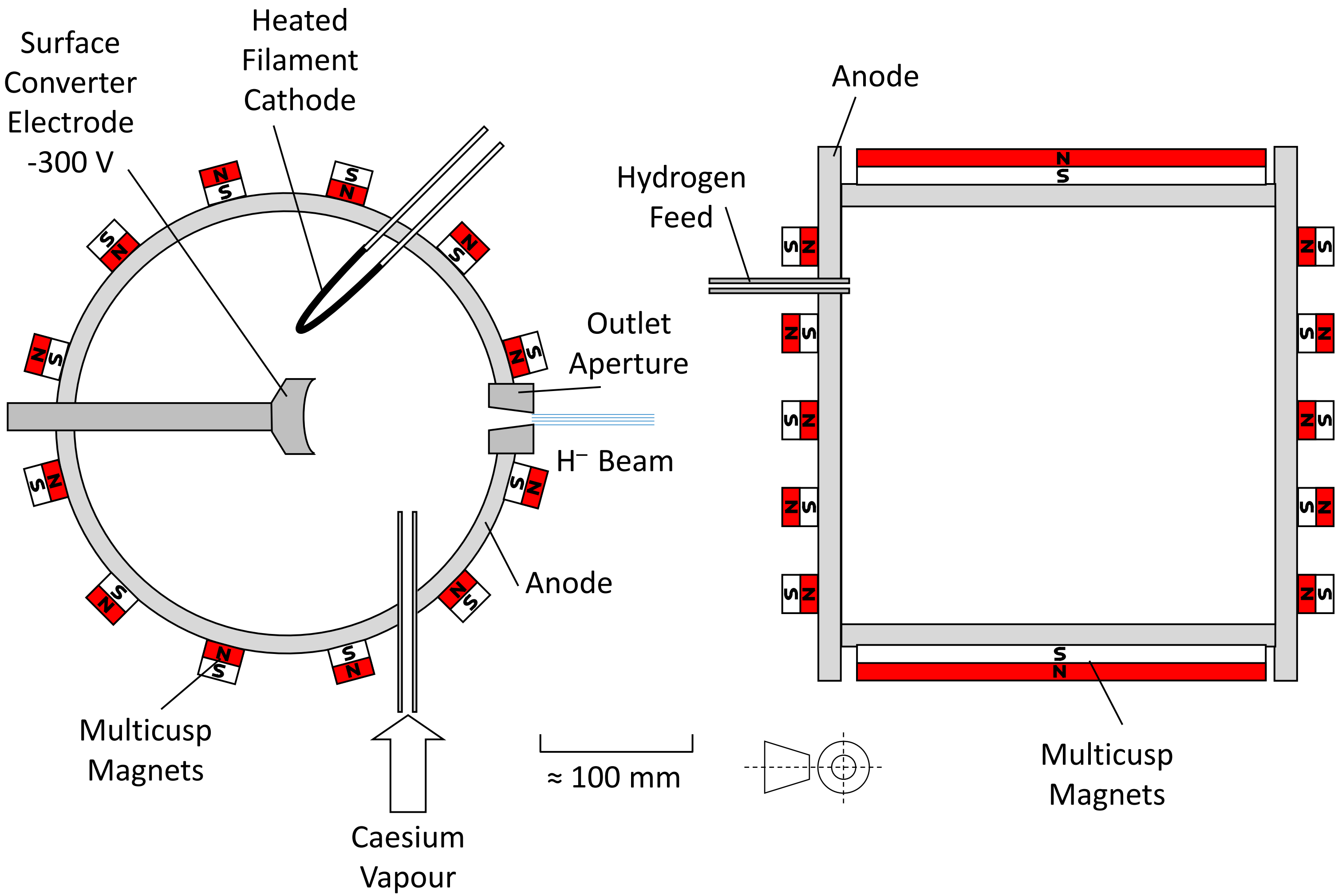

Cathode
Hollow Anode
Heated Caesium
Transport Line
Hydrogen Feed
Air Cooling
Source Body
Discharge
Power Feed
Thermocouples

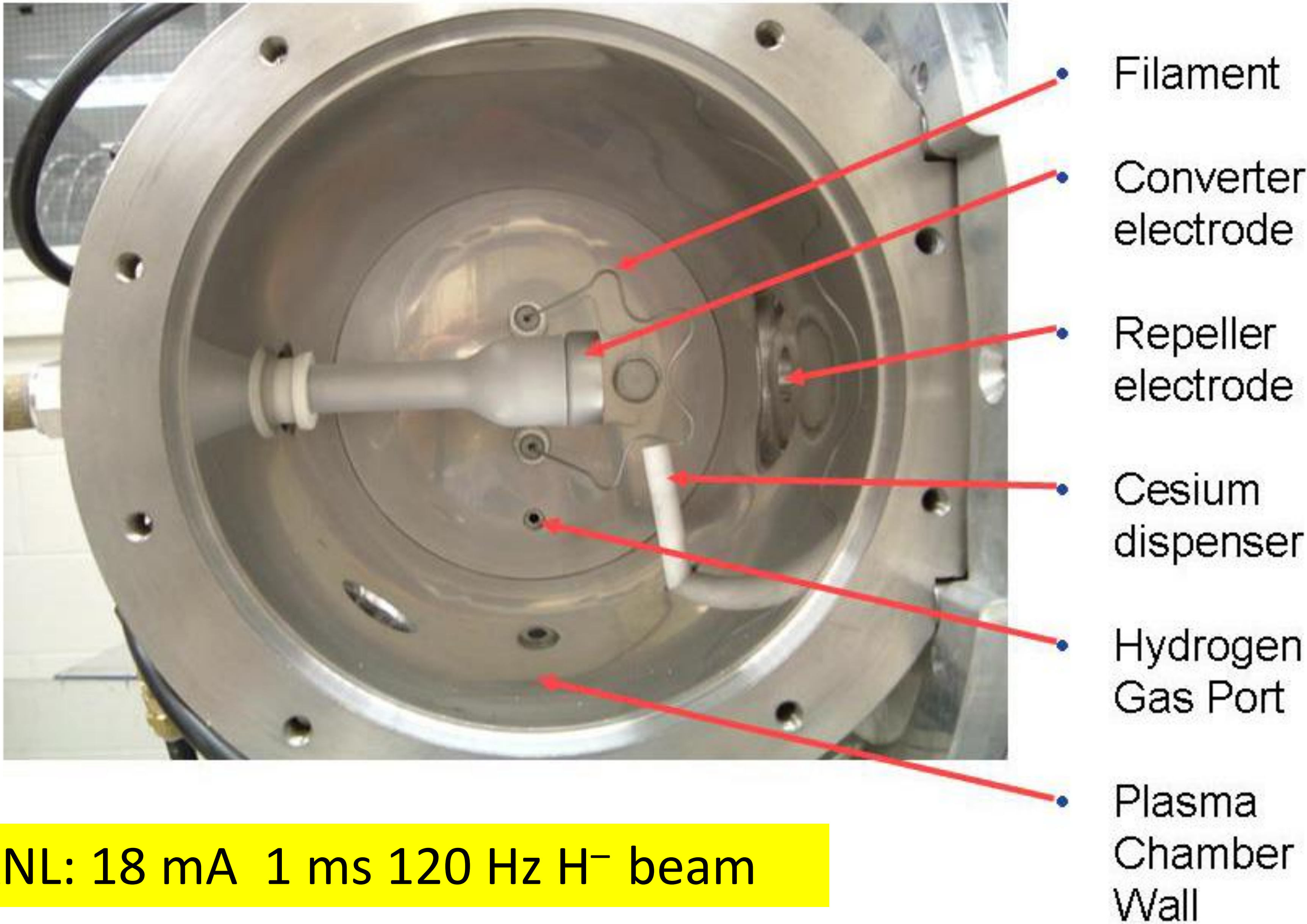

Aperture Plate


Extraction Mount
Extraction
Electrode
Support
Insulators
Caesium
Shields
60 mA 1 ms 50 Hz
H^- beams


Particles and Sources
Positrons
e^+
Electrons
e^-
Photons
Neutrinos
ν_e ν_μ ν_τ
Protons
μ^+
Muons
μ^-
Antiprotons
Neutrons
n
Light ions e.g. C^{4+}
Neutral particles
Negative ions
H^-
H^0
Surface plasma
Surface converter
Multicusp
Filament
Highly charged ions
e.g. Ag^{32+}
Higgs Bosons
$\vec{e}^-$
Fully stripped nuclei
e.g. U^{92+}
$\vec{p}$
Polarised particles
$\vec{H}^-$
Zoo of curiosities
Tauons
Mesons
Baryons
W + Z Bosons
Exotic nuclei
e.g. Lr^{103+}

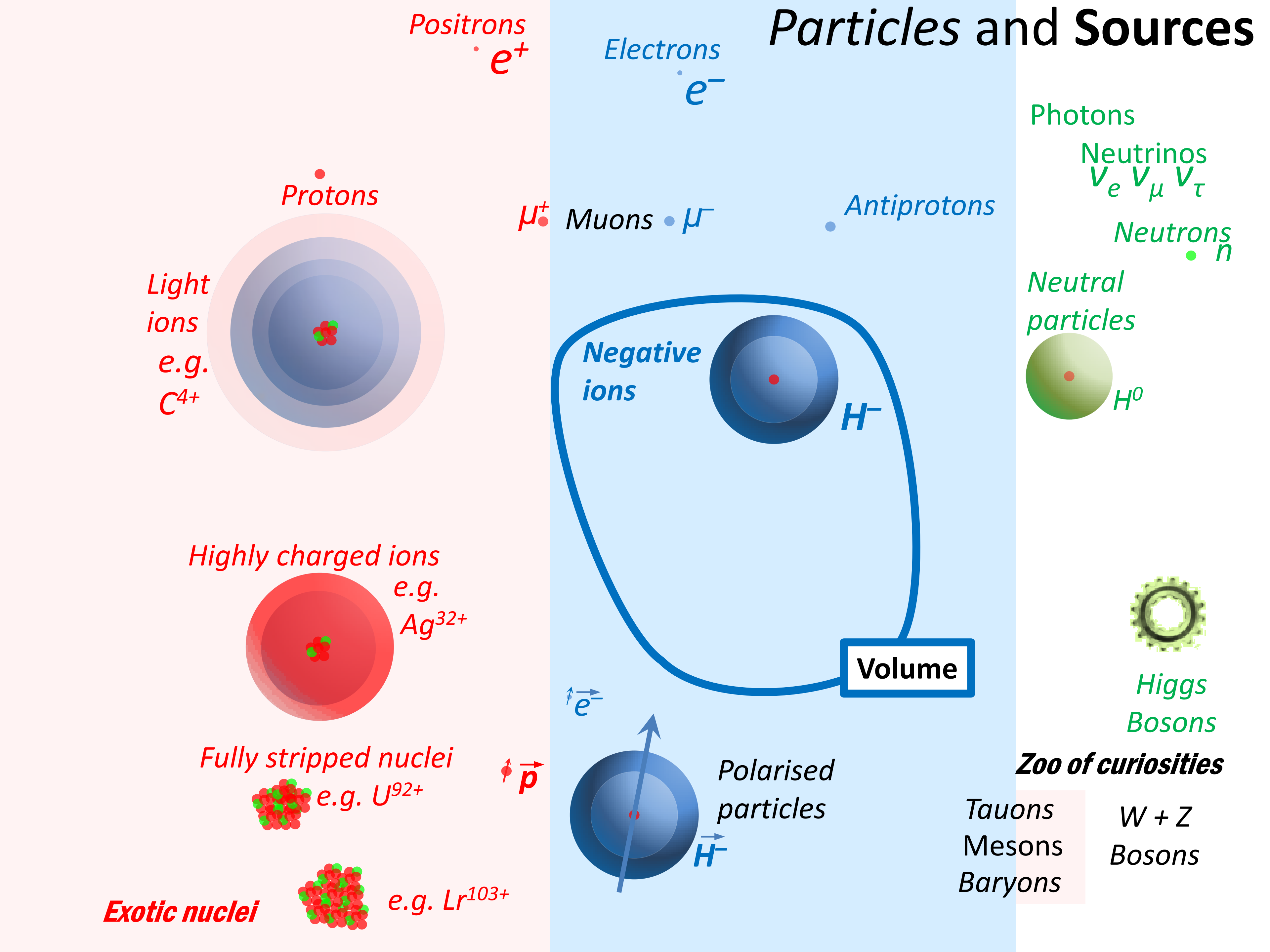
Filament Cathode Multicusp Surface Converter Source





LANL: 18 mA 1 ms 120 Hz H^- beam

Particles and **Sources**



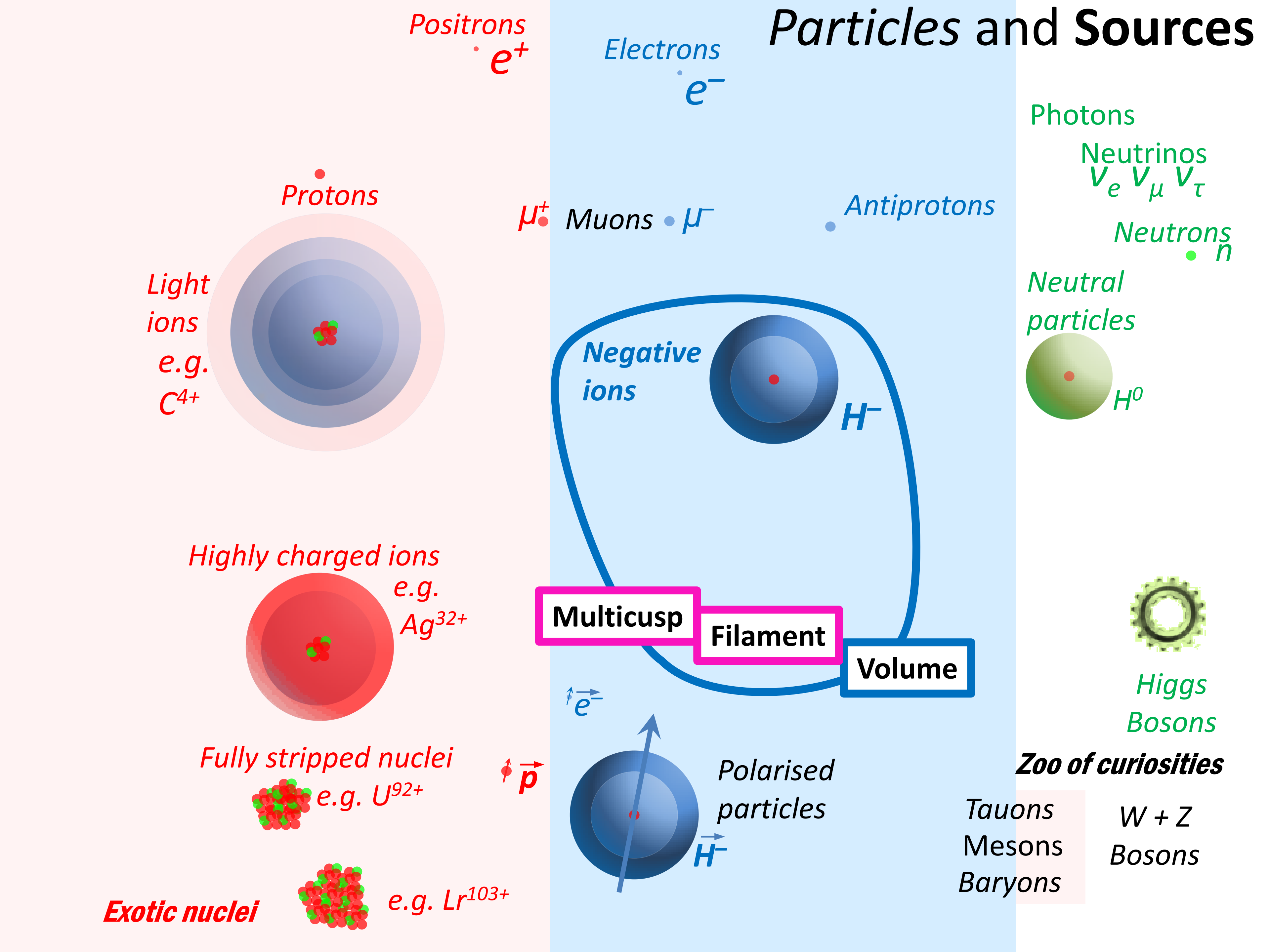
Marthe Bacal
Ecole Polytechnique
mid 1970's

Volume Production

$$H_2^* + e\ (\leq 1\ \text{eV}) \rightarrow H^- + H^0$$

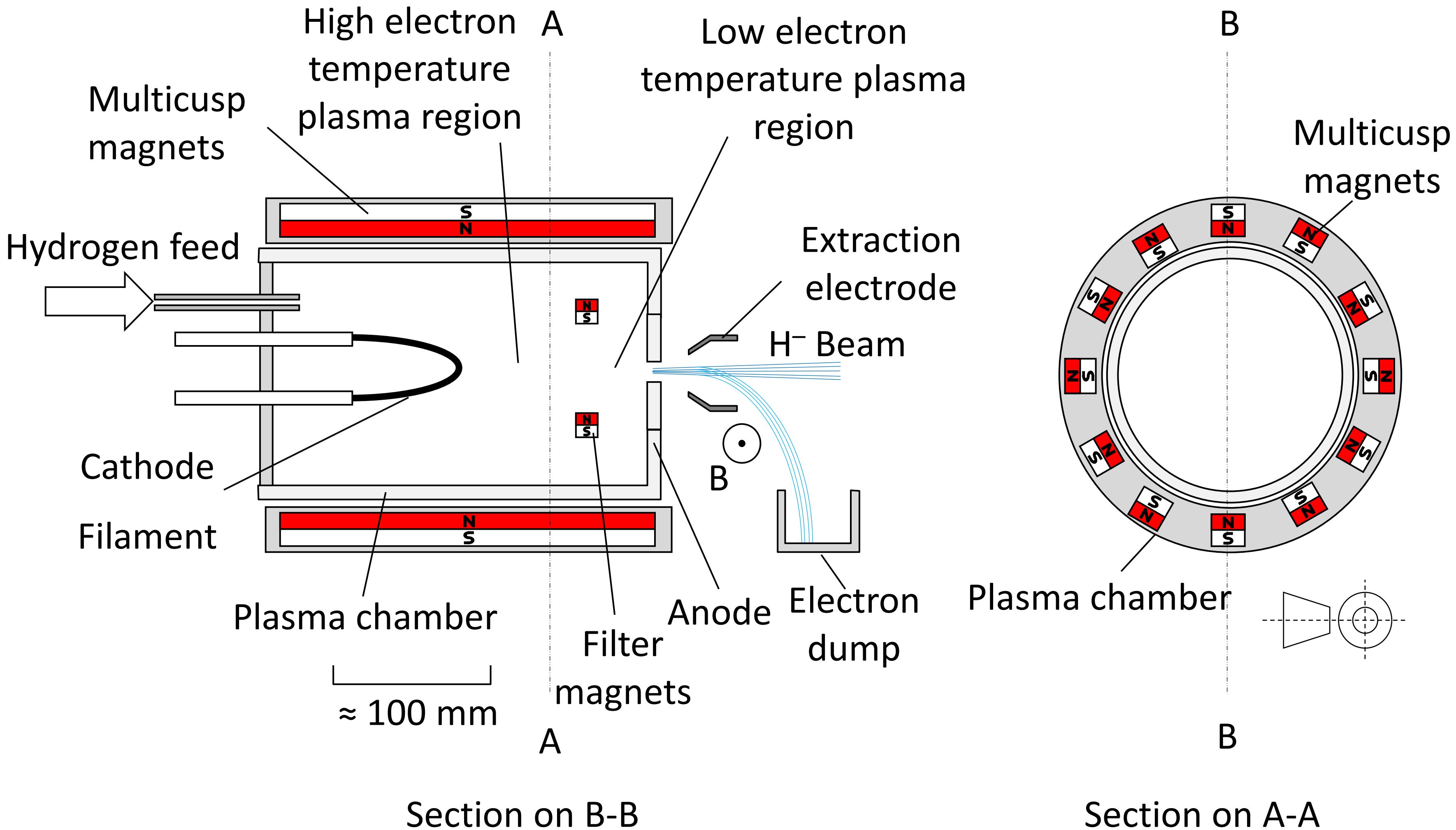
Dissociative attachment
of low energy electrons
to rovibrationally excited
H_2 molecules

Developed by Ehlers + Leung at LBNL



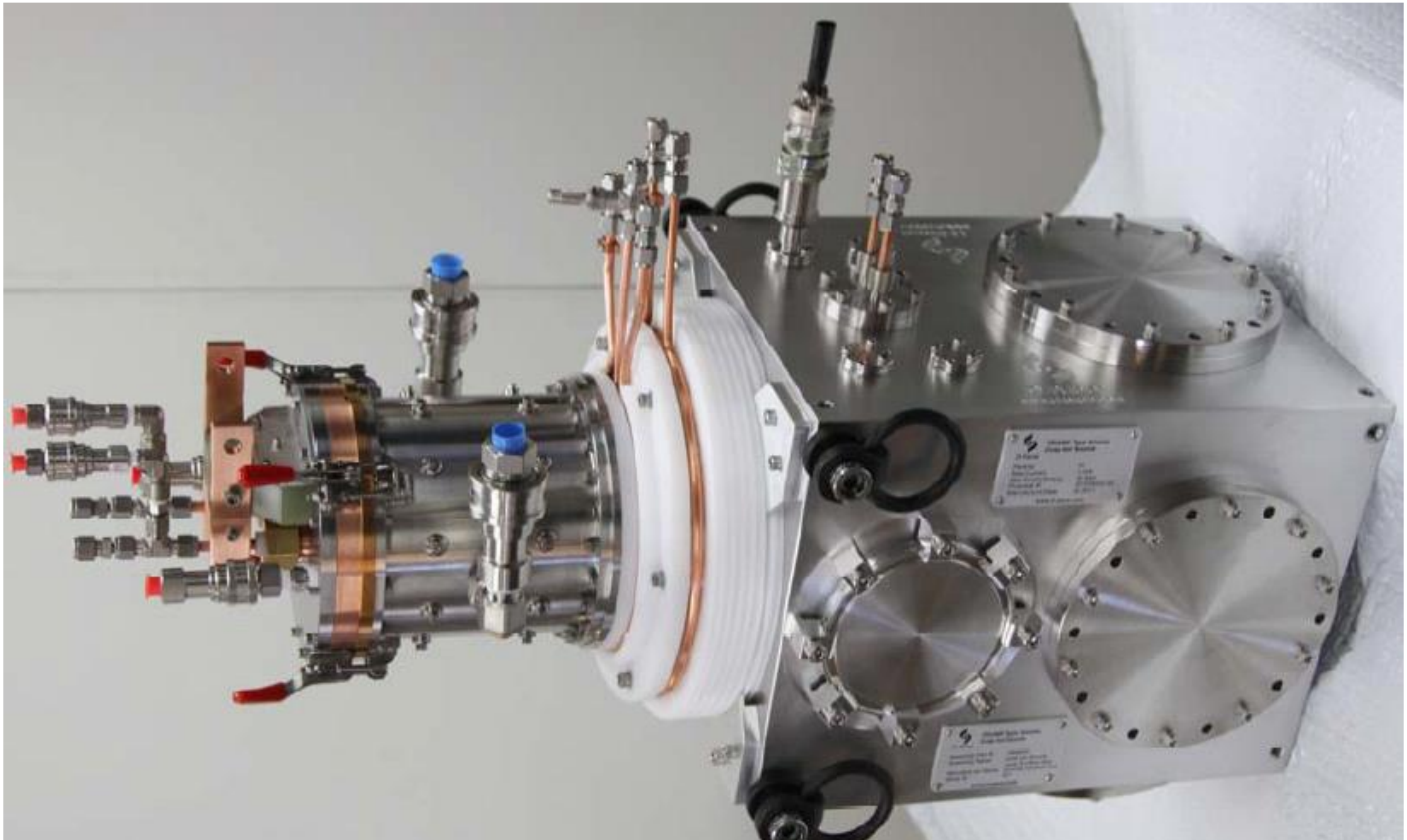
Particles and Sources
Positrons
e+
Electrons
e−
Photons
Neutrinos
νe νμ ντ
Protons
μ+
Muons
μ−
Antiprotons
Neutrons
n
Neutral particles
H0
Light ions e.g. C4+
Negative ions
H−
Highly charged ions
e.g. Ag32+
Multicusp
Filament
Volume
e−
Higgs Bosons
Fully stripped nuclei
e.g. U92+
p
Polarised particles
H−
Zoo of curiosities
Tauons
Mesons
Baryons
W + Z Bosons
Exotic nuclei
e.g. Lr103+

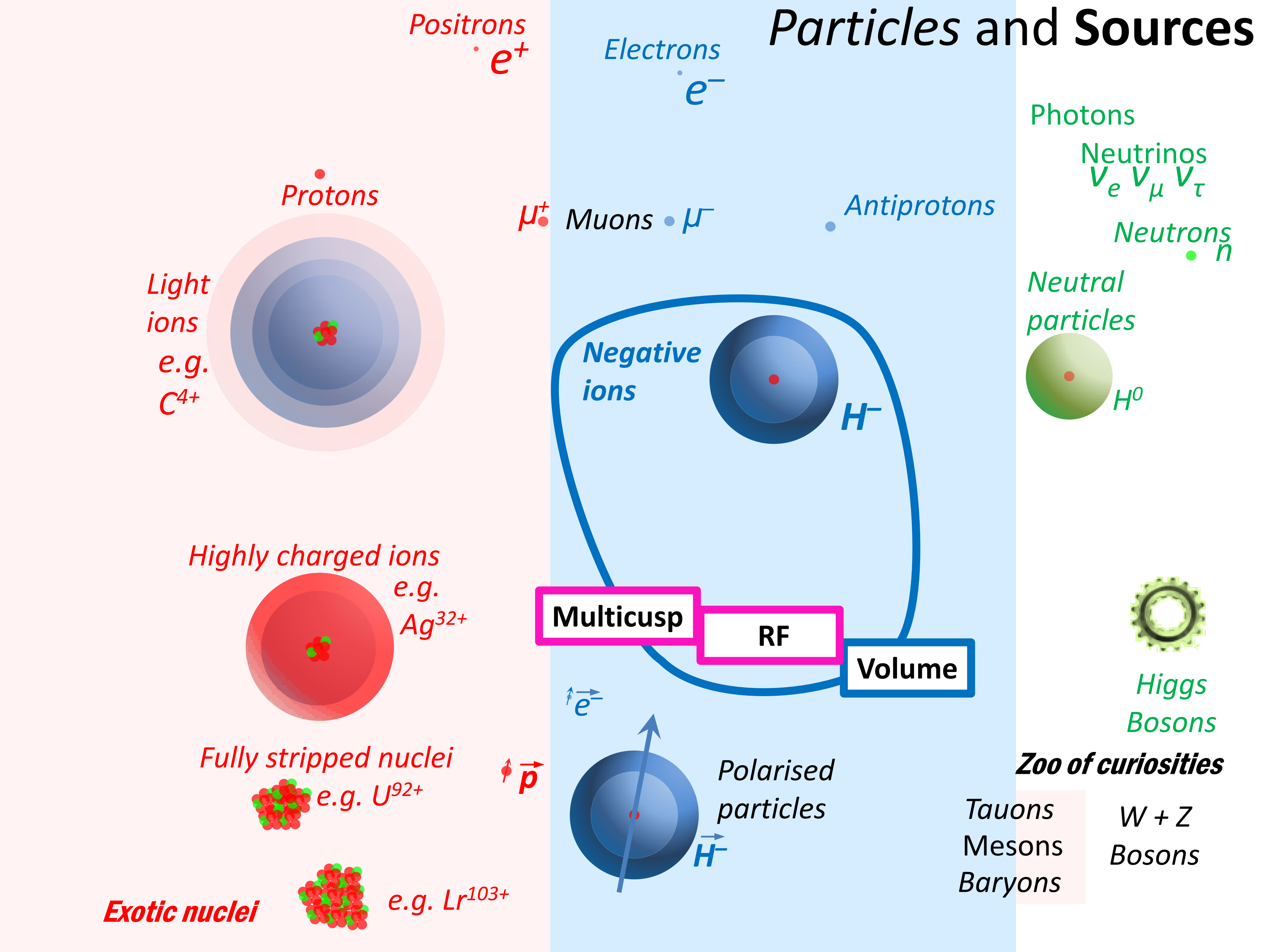
Multicusp Filament Volume Source



Many Variations: e.g. JPARC use a LaB_6 cathode

D-Pace 15 mA DC H^- Multicusp Volume Source





Particles and Sources
Positrons
e+
Electrons
e−
Photons
Neutrinos
νe νμ ντ
Protons
μ+
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μ−
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Neutrons
n
Light
ions
e.g.
C4+
Negative
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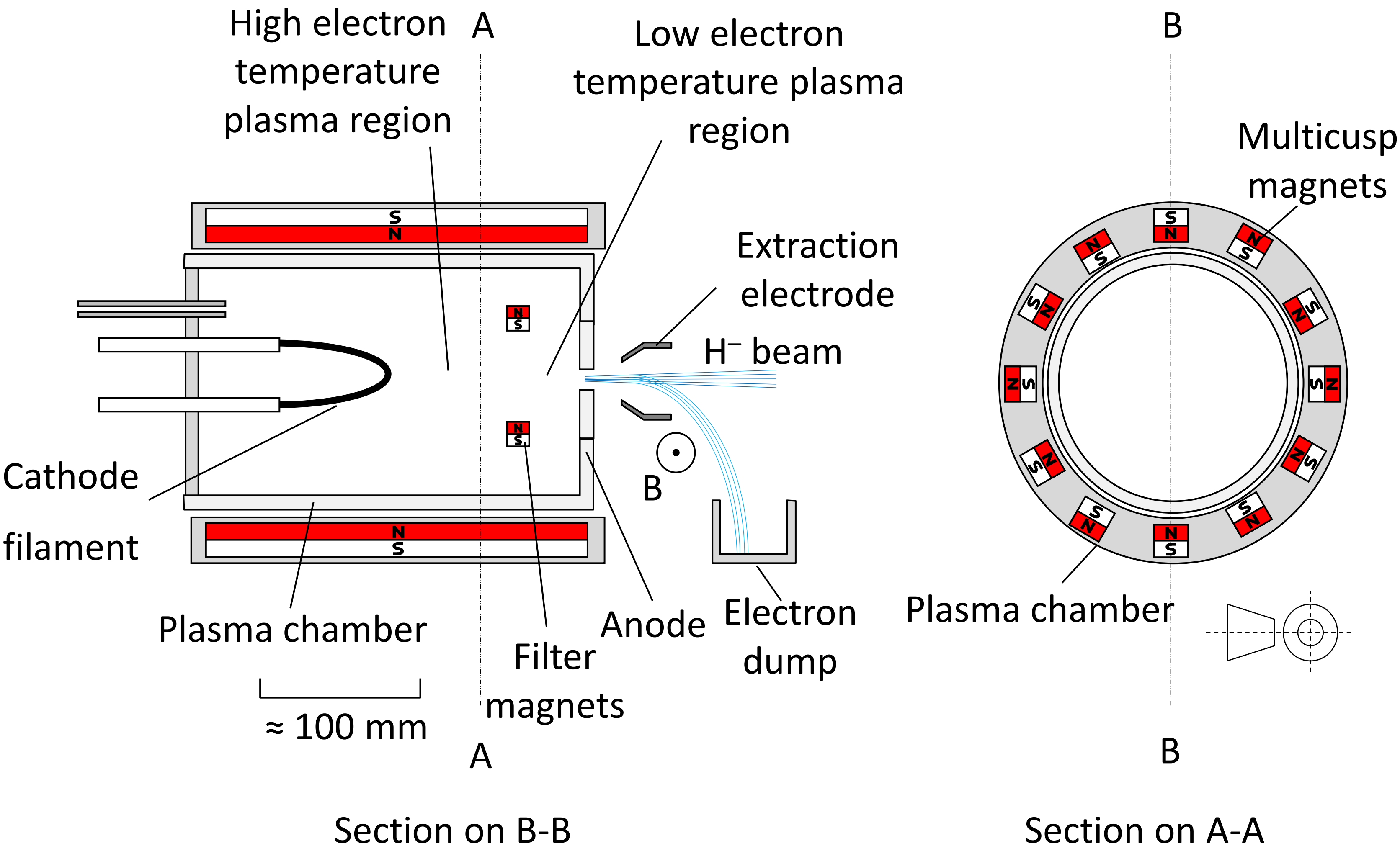
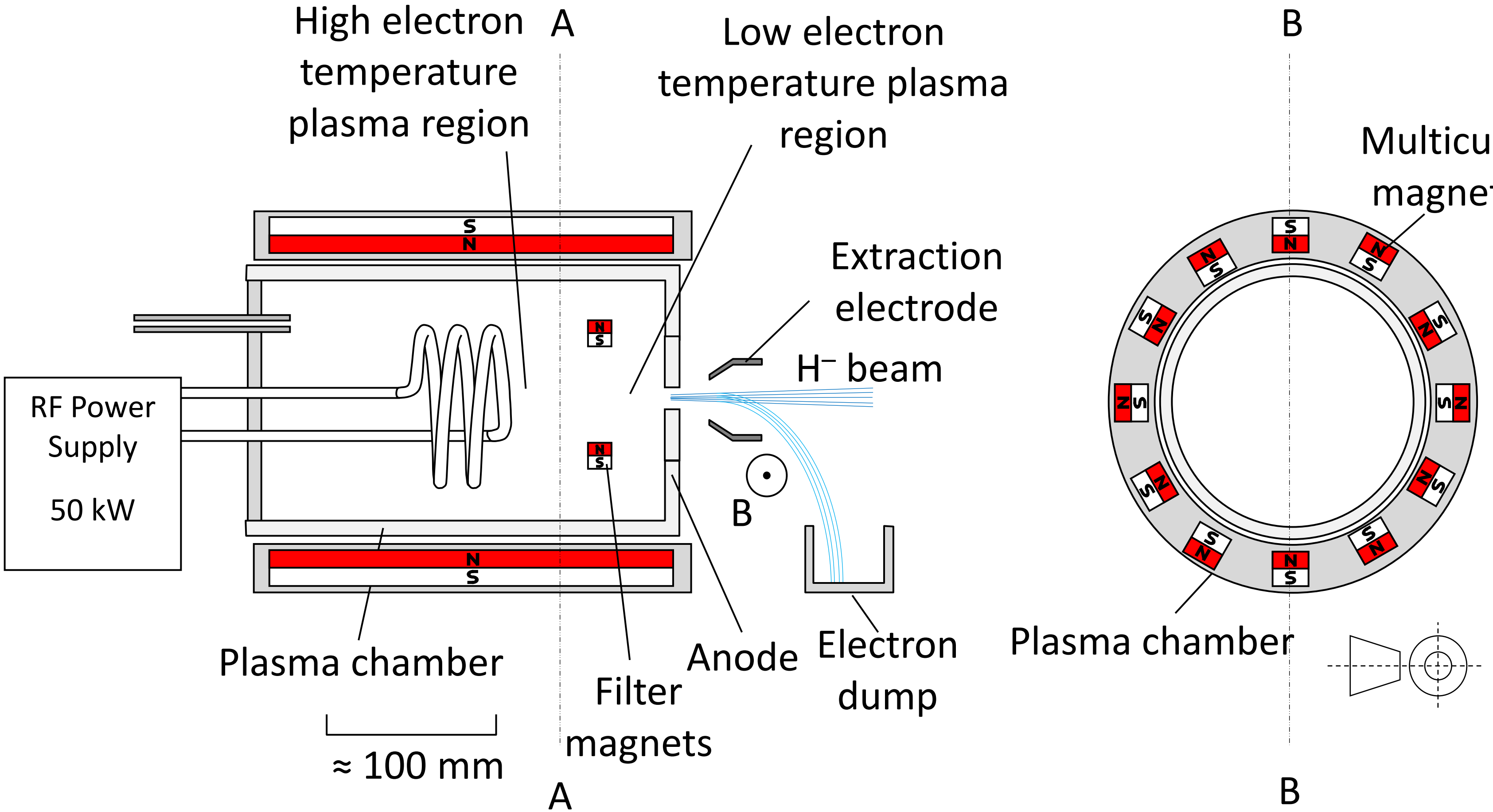
H−
Neutral
particles
H0
Highly charged ions
e.g.
Ag32+
Multicusp
RF
Volume
e−
Higgs
Bosons
Fully stripped nuclei
e.g. U92+
p
Polarised
particles
H−
Zoo of curiosities
Tauons
Mesons
Baryons
W + Z
Bosons
Exotic nuclei
e.g. Lr103+



High electron temperature plasma region
A
Low electron temperature plasma region
B
Multicusp magnets
Extraction electrode
H⁻ beam
S
N
Cathode filament
B
Plasma chamber
Filter magnets
Anode
Electron dump
Plasma chamber
≈ 100 mm
A
B
Section on B-B
Section on A-A

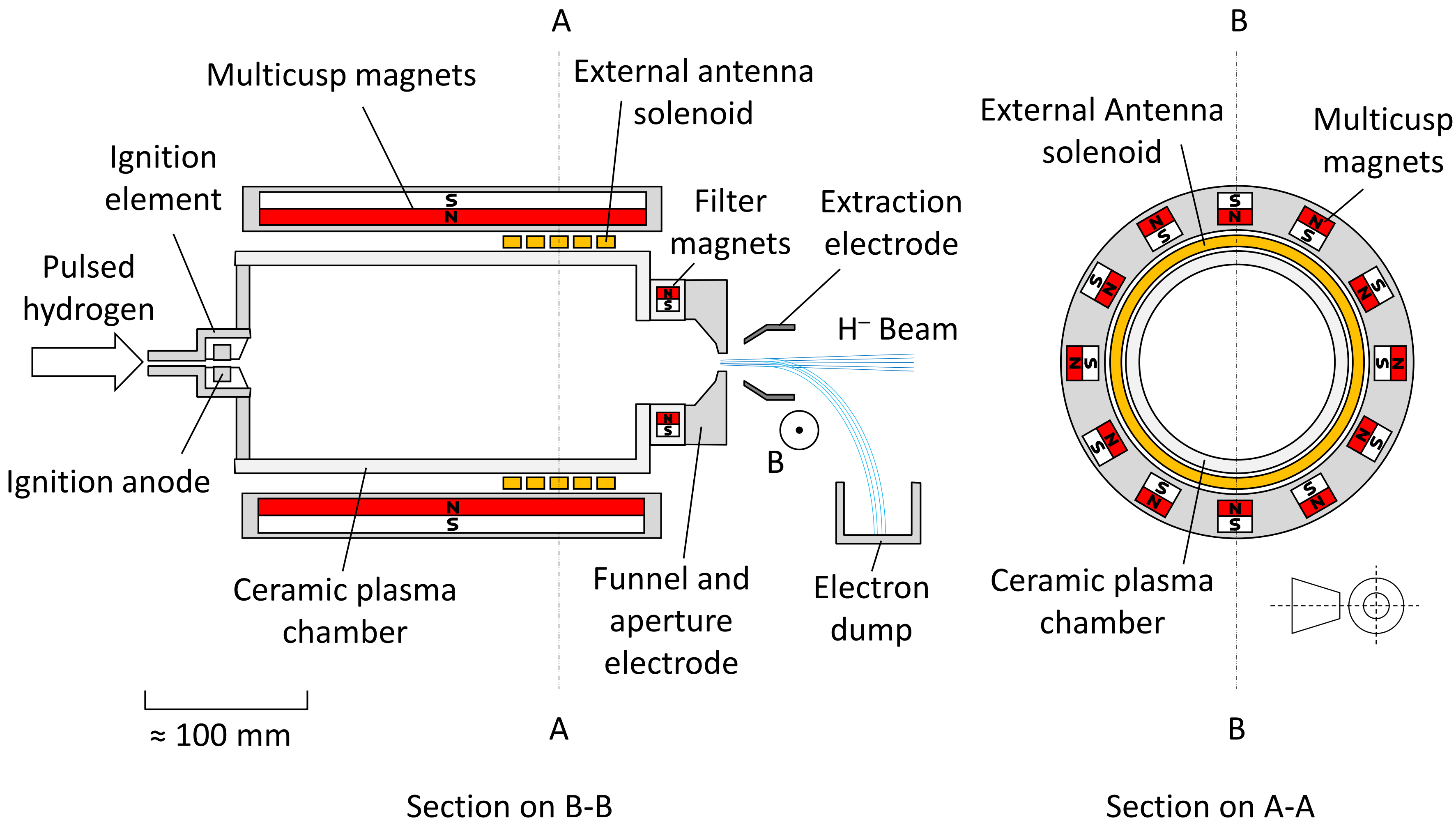
Internal RF Solenoid Antenna Volume Source



Section on B-B

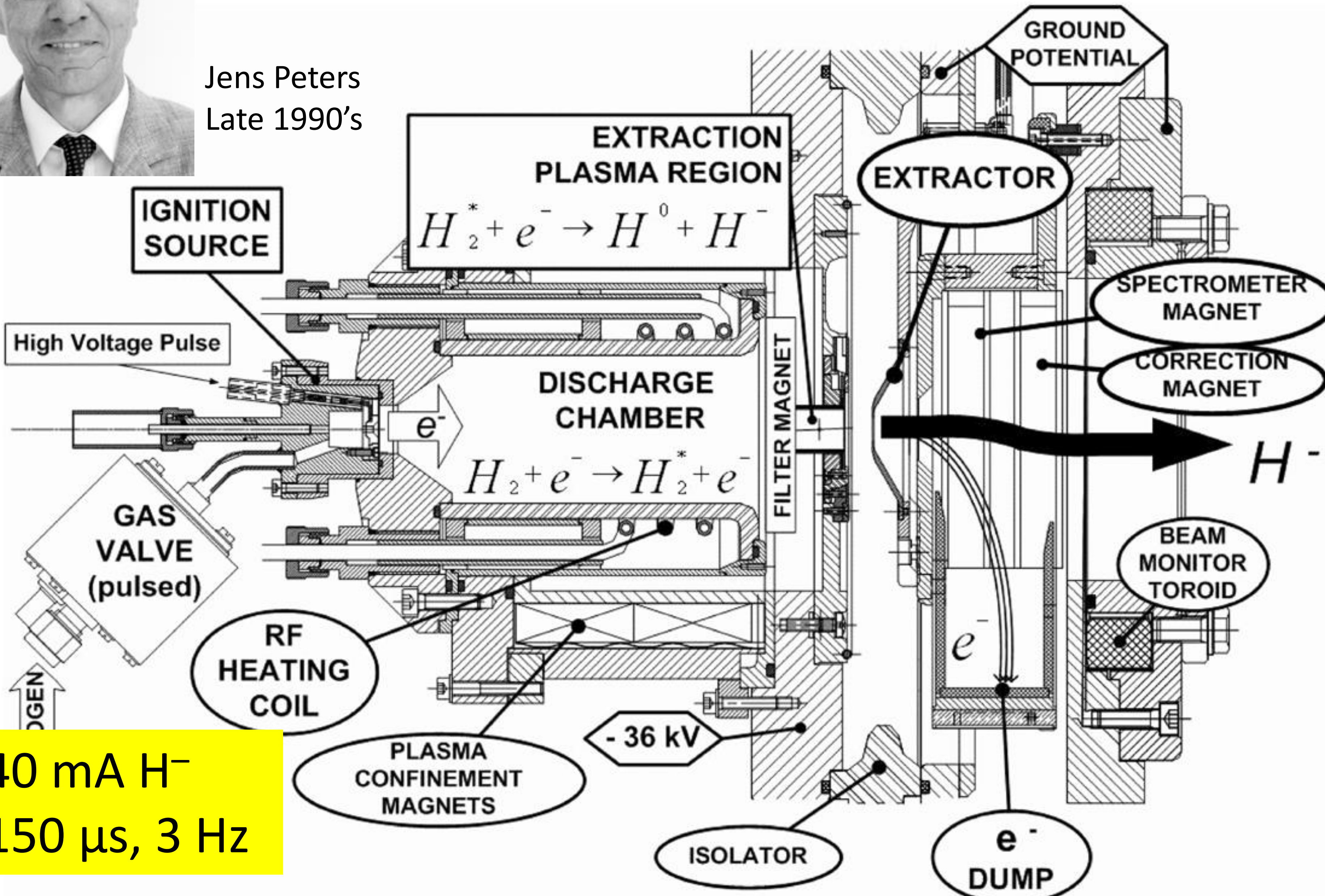
Section on A-A

External RF Antenna Multicusp Source

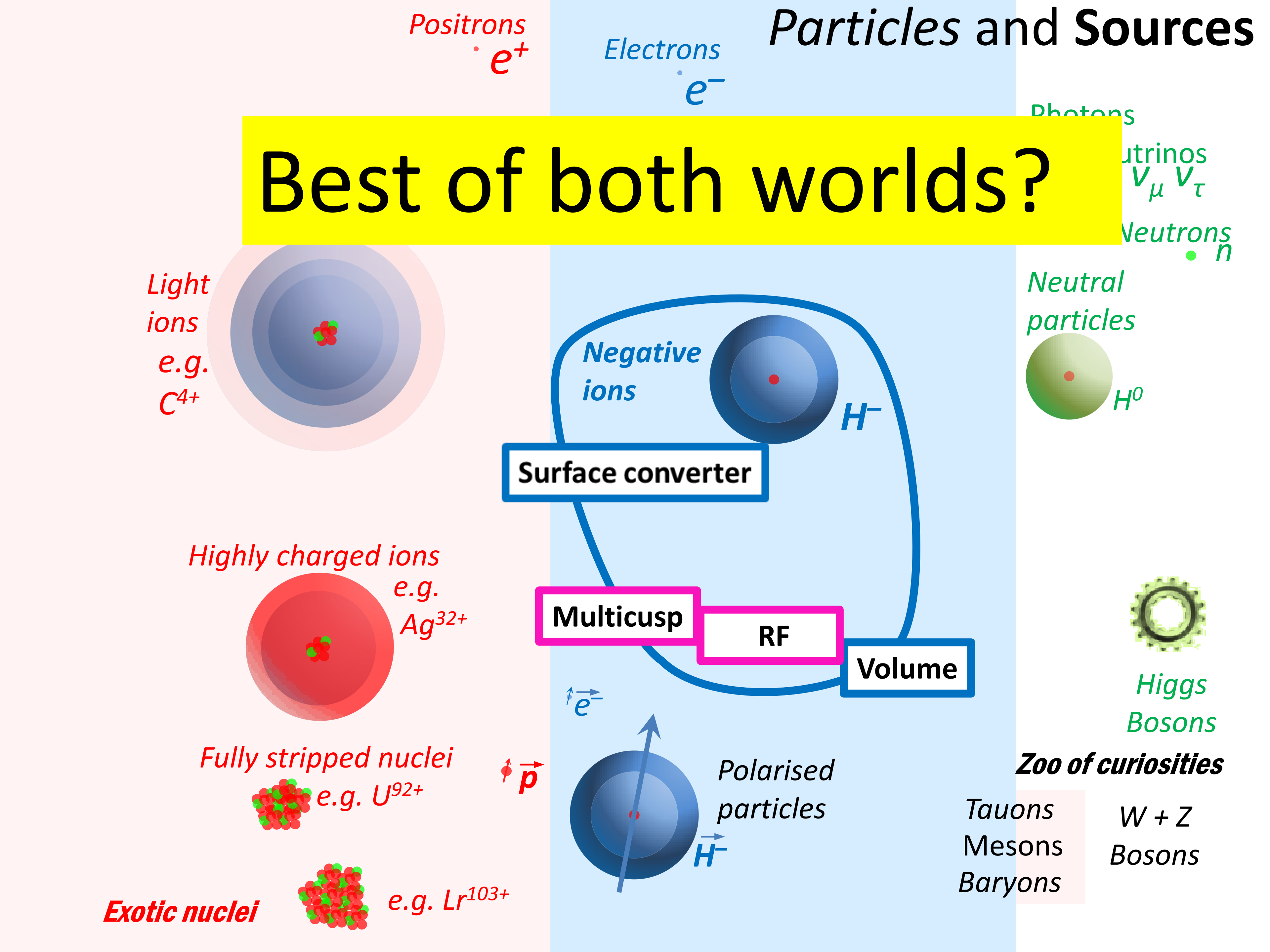


DESY Source

Jens Peters
Late 1990's



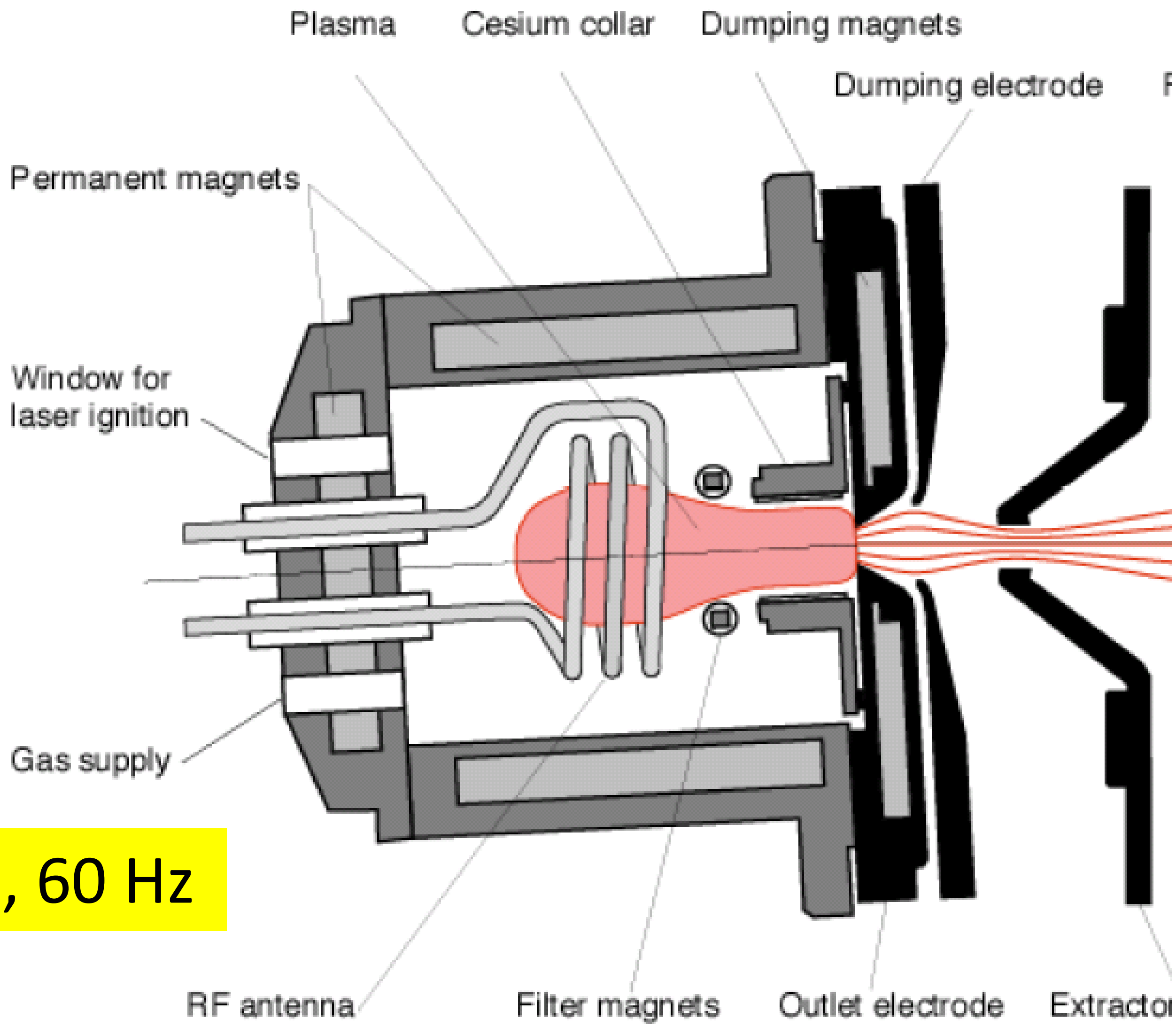
40 mA H^-
150 µs, 3 Hz



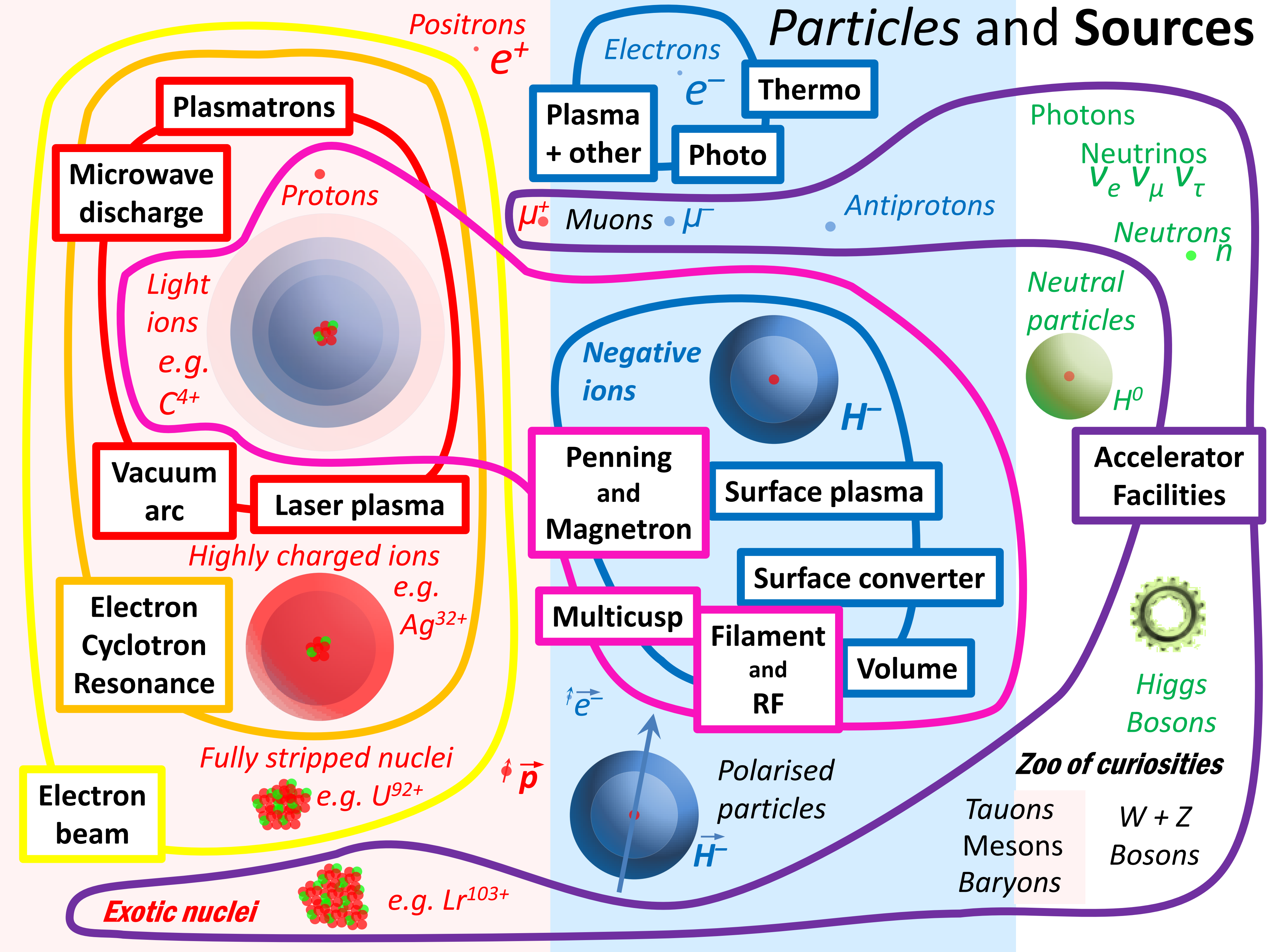
Particles and Sources
Best of both worlds?
Positrons
e^+
Electrons
e^-
Photons
utrinos
ν_μ ν_τ
Neutrons
n
Light ions e.g. C^{4+}
Negative ions
H^-
Neutral particles
H^0
Surface converter
Highly charged ions
e.g. Ag^{32+}
Multicusp
RF
Volume
$\vec{e}^-$
Higgs Bosons
Fully stripped nuclei
e.g. U^{92+}
$\vec{p}$
Polarised particles
$\vec{H}^-$
Zoo of curiosities
Tauons
Mesons
Baryons
W + Z Bosons
Exotic nuclei
e.g. Lr^{103+}

CERN are developing a ceasiated external antenna source for LINAC4

SNS ion source



38 mA H^- 1 ms, 60 Hz



Particles and Sources
Positrons
e+
Electrons
e−
Thermo
Plasma + other
Photo
Plasmatrons
Microwave discharge
Protons
Light ions e.g. C4+
μ+
Muons
μ−
Antiprotons
Photons
Neutrinos
νe νμ ντ
Neutrons
n
Neutral particles
H0
Negative ions
H−
Penning and Magnetron
Surface plasma
Accelerator Facilities
Vacuum arc
Laser plasma
Highly charged ions
e.g. Ag32+
Surface converter
Multicusp
Filament and RF
Volume
Electron Cyclotron Resonance
e−
Higgs Bosons
Fully stripped nuclei
e.g. U92+
p
Polarised particles
Zoo of curiosities
Electron beam
H−
Tauons
Mesons
Baryons
W + Z Bosons
Exotic nuclei
e.g. Lr103+

Which Source?

- Type of particle
- Current, duty cycle, emittance
- Lifetime
- Expertise available
- Money available
- Space available

Reliability – is King!

- Operational sources should deliver >98% availability
- Lifetime compatible with operating schedule
- Ideally quick and easy to change
- Short start-up/set-up time

cryogenic systems

timing systems

machine interlocks

communication systems

Reliability also depends on:

low voltage power supplies

Everything Else!

cooling water

hydrogen

human error

vacuum systems

compressed air supplies

temperature controllers

high voltage power supplies

control systems

mains power

laser systems

personnel interlocks

material purity

Developing Sources

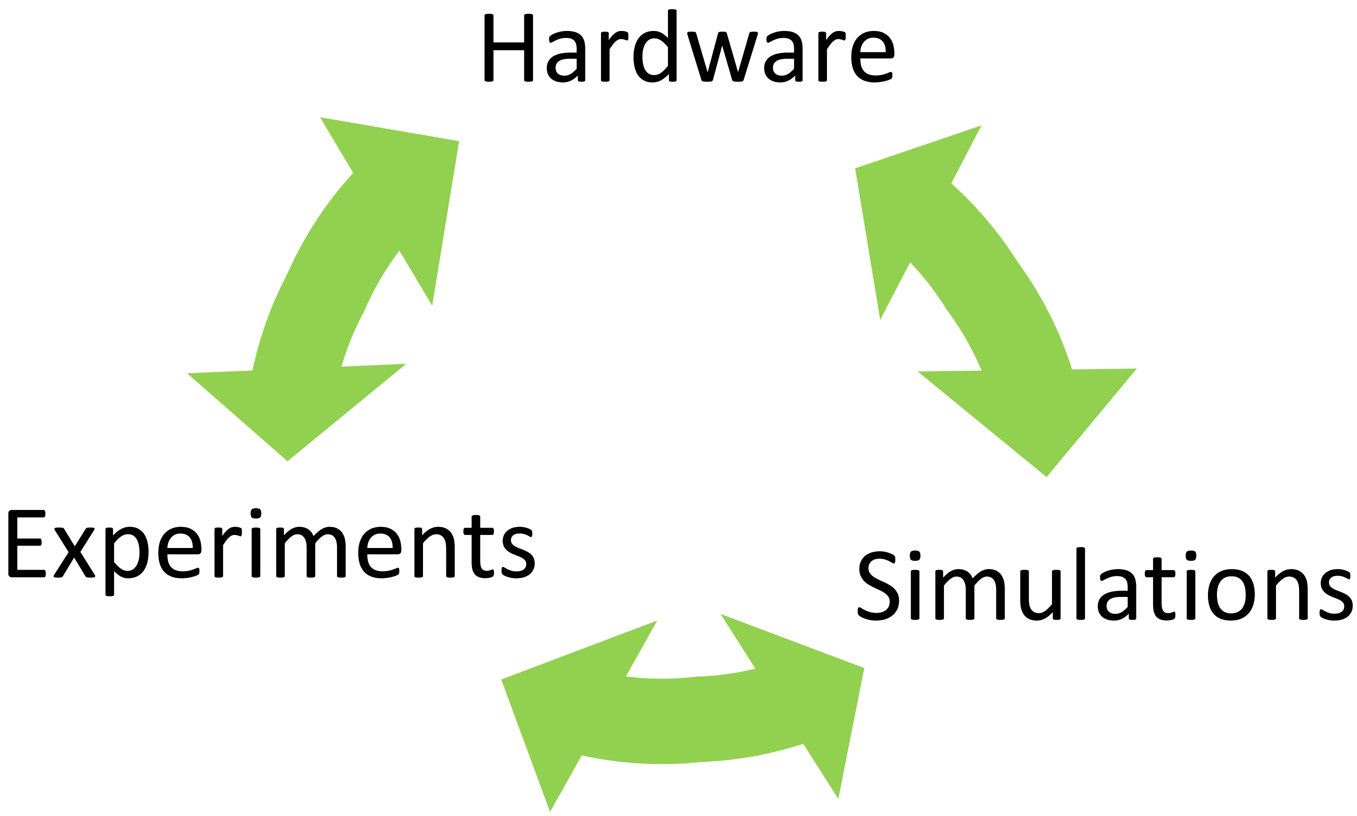
Driven by demand for

- Increases in current, duty cycle and lifetime
- Improvements in beam quality

Development strategy

- Simulations
- Test stands
- Diagnostics

The Development Cycle



Summary

- Particle sources are a huge interesting subject
- A perfect mixture of engineering and physics
- We have only scratched the surface

Thank you for listening