Cryogenic GaAs cathodes development for improved lifetimes

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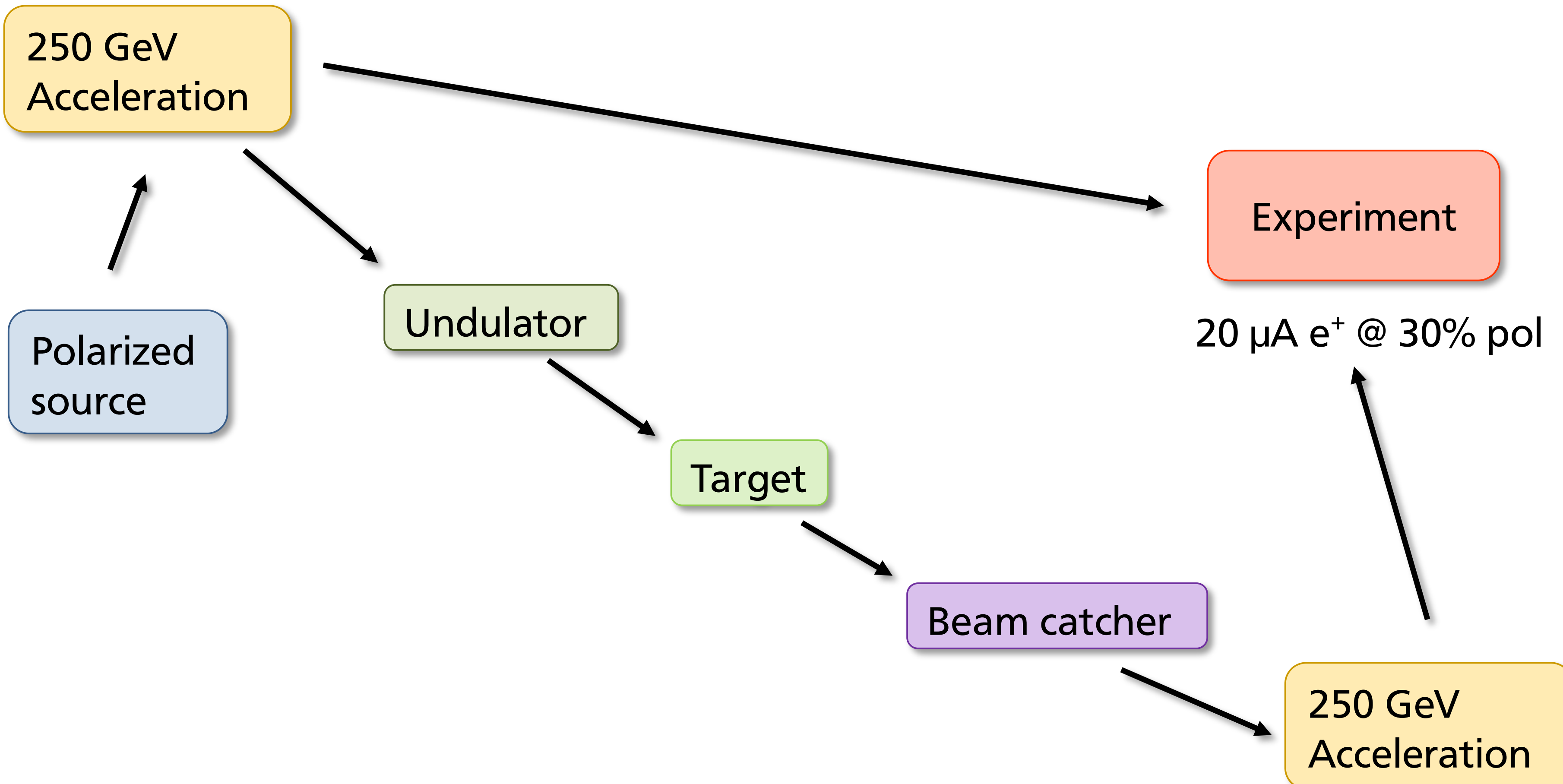
supported by DFG (GRK 2128) and BMBF (05H18RDRB1)

Motivation
ILC positron beam plan



- Need of very **expensive** undulator!

Motivation
ILC polarized positron source

50 MeV Acceleration

250 GeV Acceleration

Experiment

Polarized source

Target

Target

$20\ \mu A\ e^{+}$ @ > 50% pol

Beam catcher

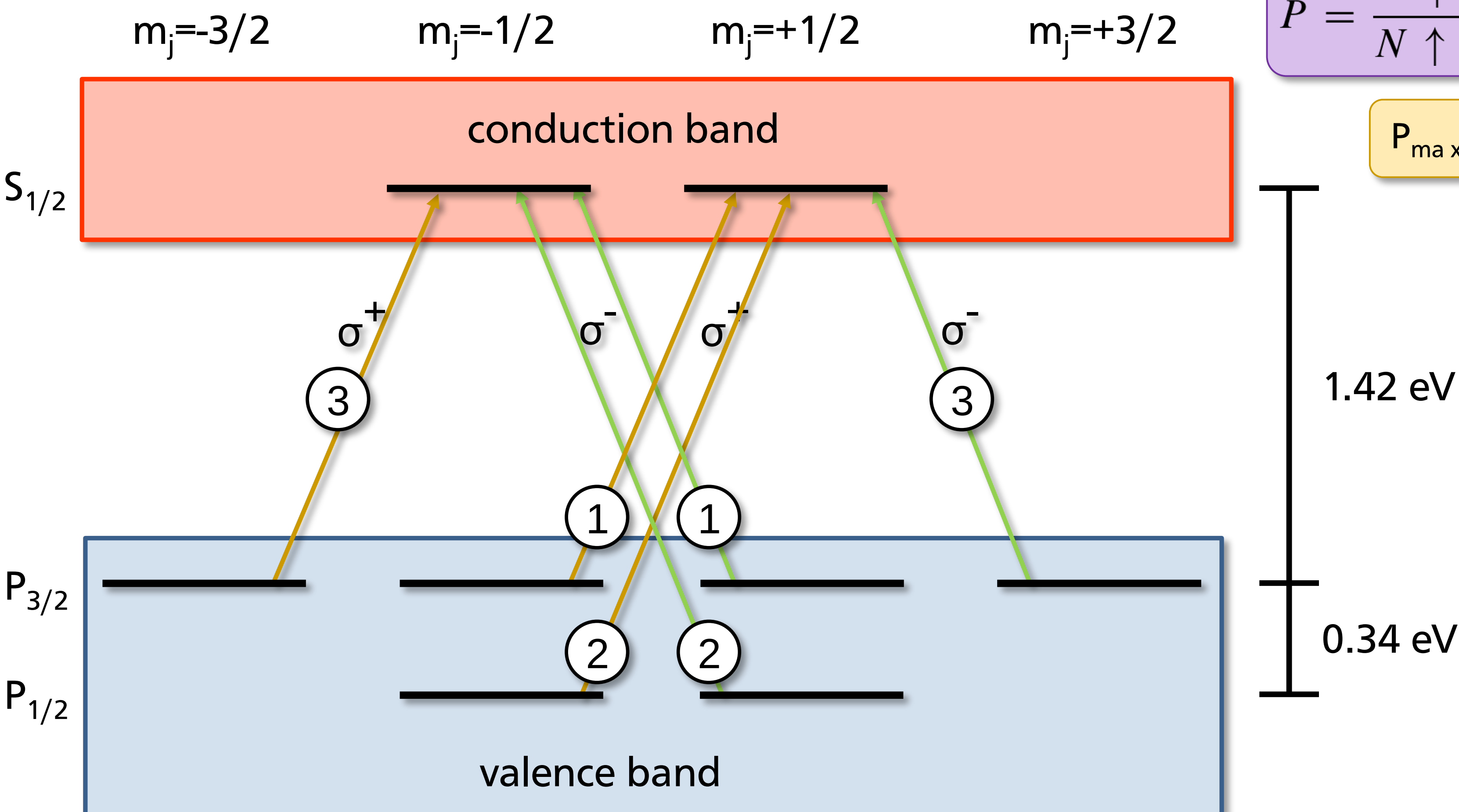
250 GeV Acceleration

- Cheap & compact setup
- Conversion Efficiency $<10^{-3}$
- Need of high power (20 mA) polarized electron beam
- Charge lifetime ~1 week → ≈ 10 000 C (Darmstadt: 10 C)

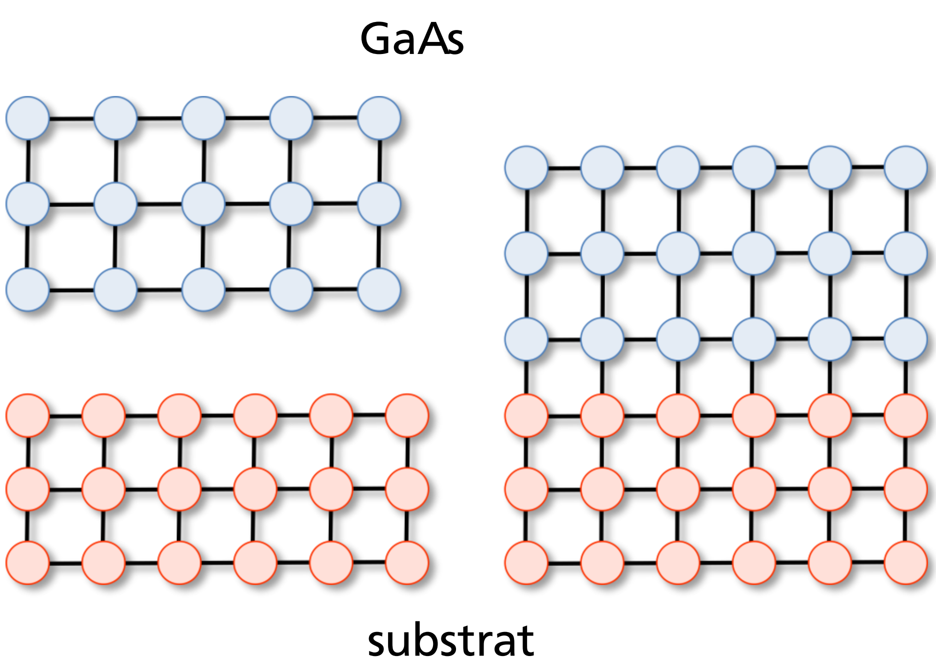
Principle of generating polarized electrons

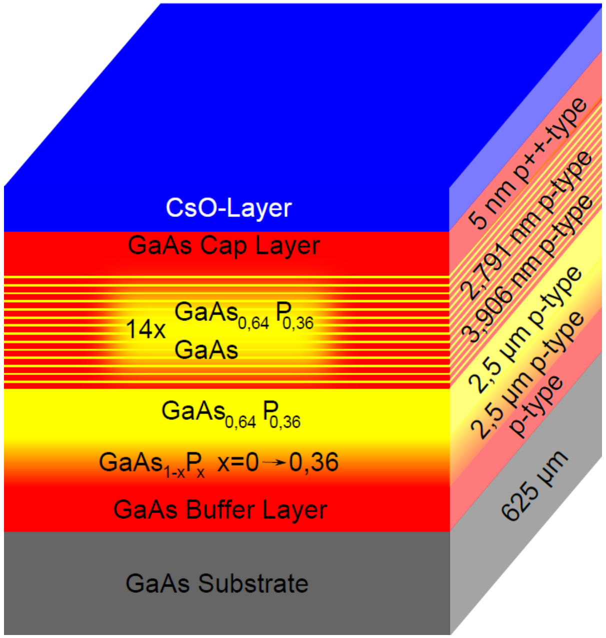
$$P = \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}$$

$P_{max} = 50\%$



Principle of generating polarized electrons





Principle of generating polarized electrons

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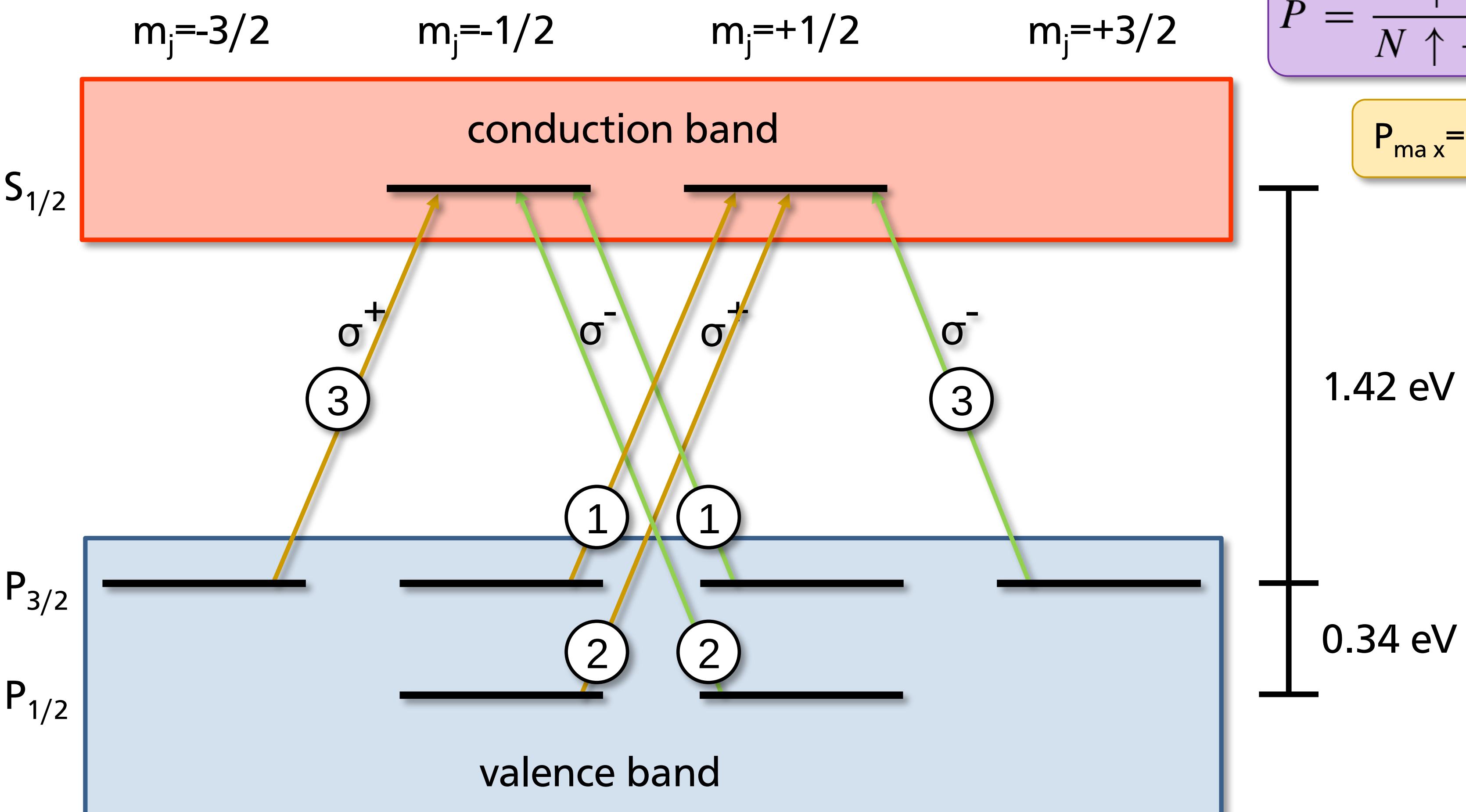
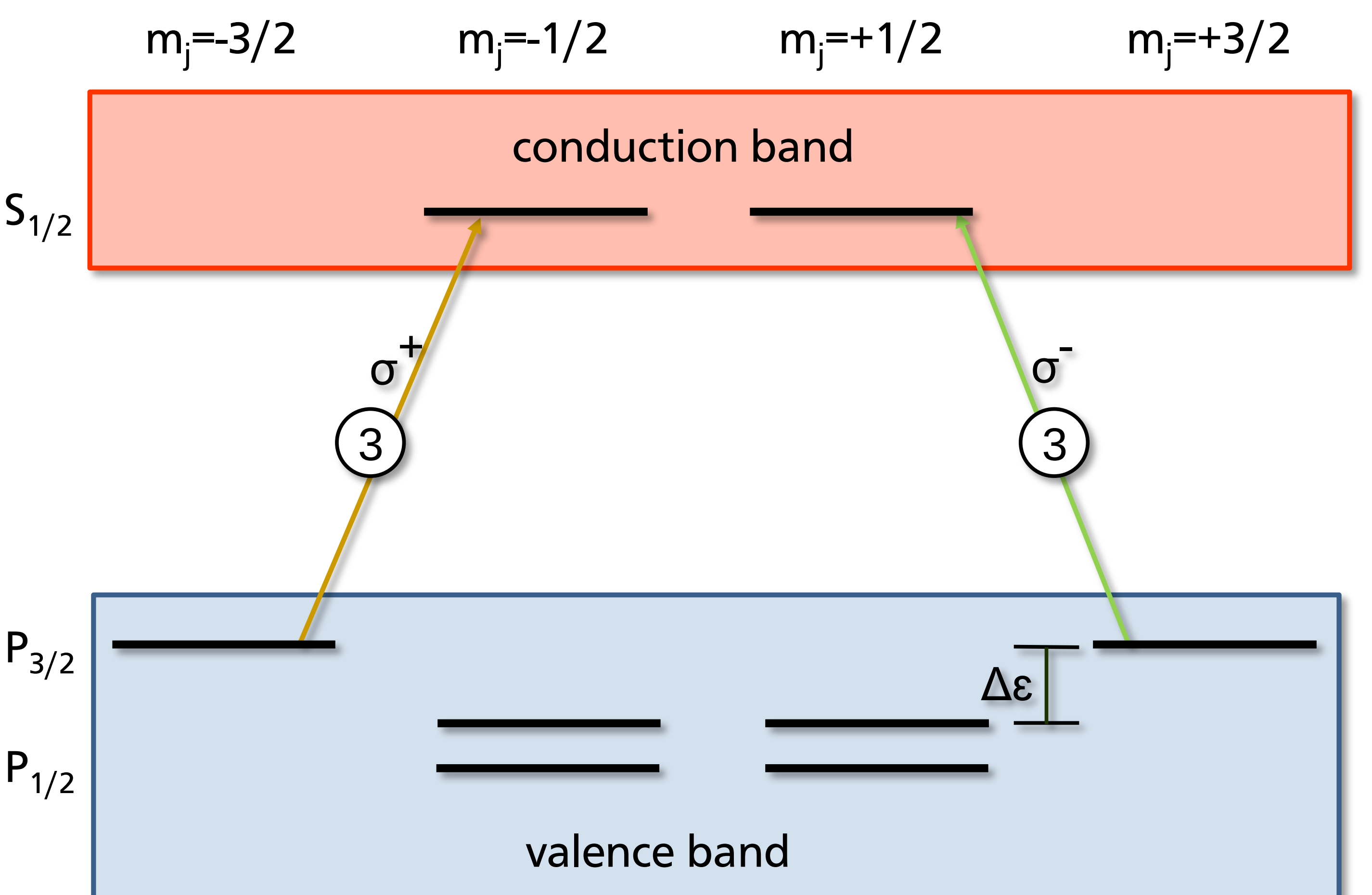


$$P = \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}$$

$P_{max} = 50\%$

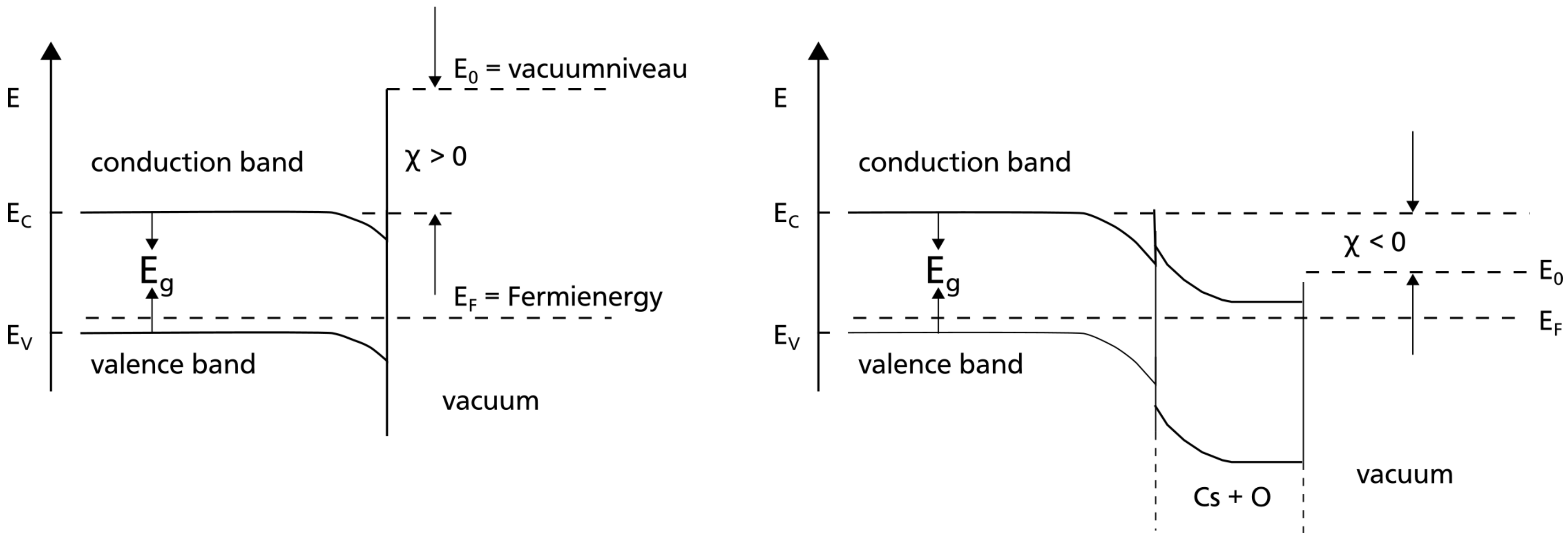
Principle of generating polarized electrons



$$P = \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}$$

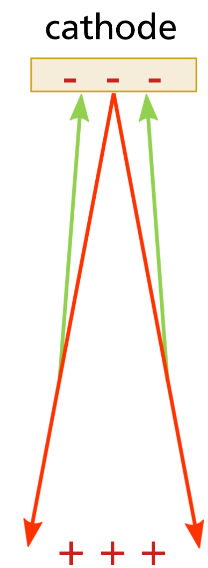
P_{max}= 100%

Negativ electron affinity



Cathode lifetime

$$\frac{1}{\tau} = \sum_i \frac{1}{\tau_i} = \overbrace{\frac{1}{\tau_{VAC}} + \frac{1}{\tau_{FE}}}^{\text{Charge-free lifetime}} + \overbrace{\frac{1}{\tau_{LOSS}} + \frac{1}{\tau_{IBB}}}^{\text{Charge lifetime}}$$



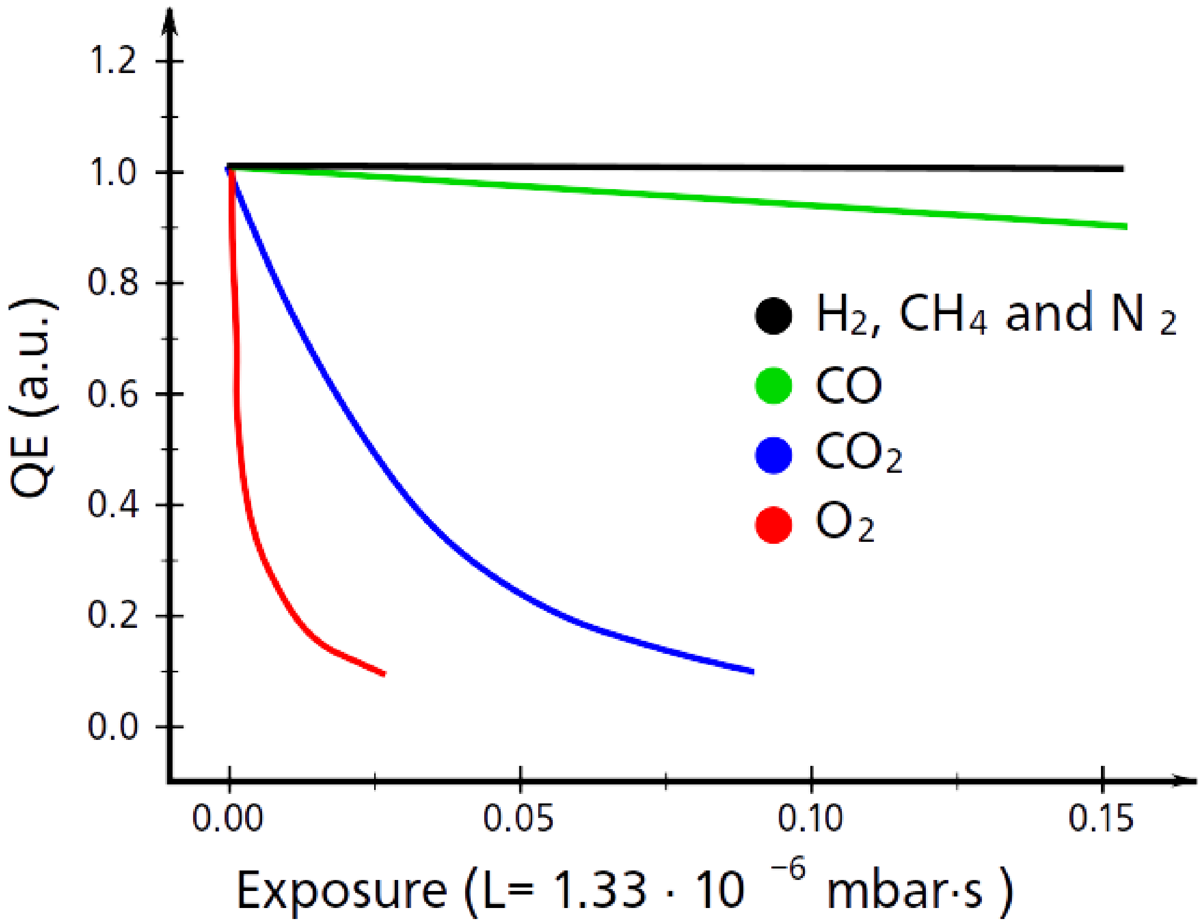
Vacuum lifetime: Better vacuum conditions

Field emission: Electrode design

Particle losses: Small emittance

Ion back bombardment: Better vacuum conditions

Cathode lifetime



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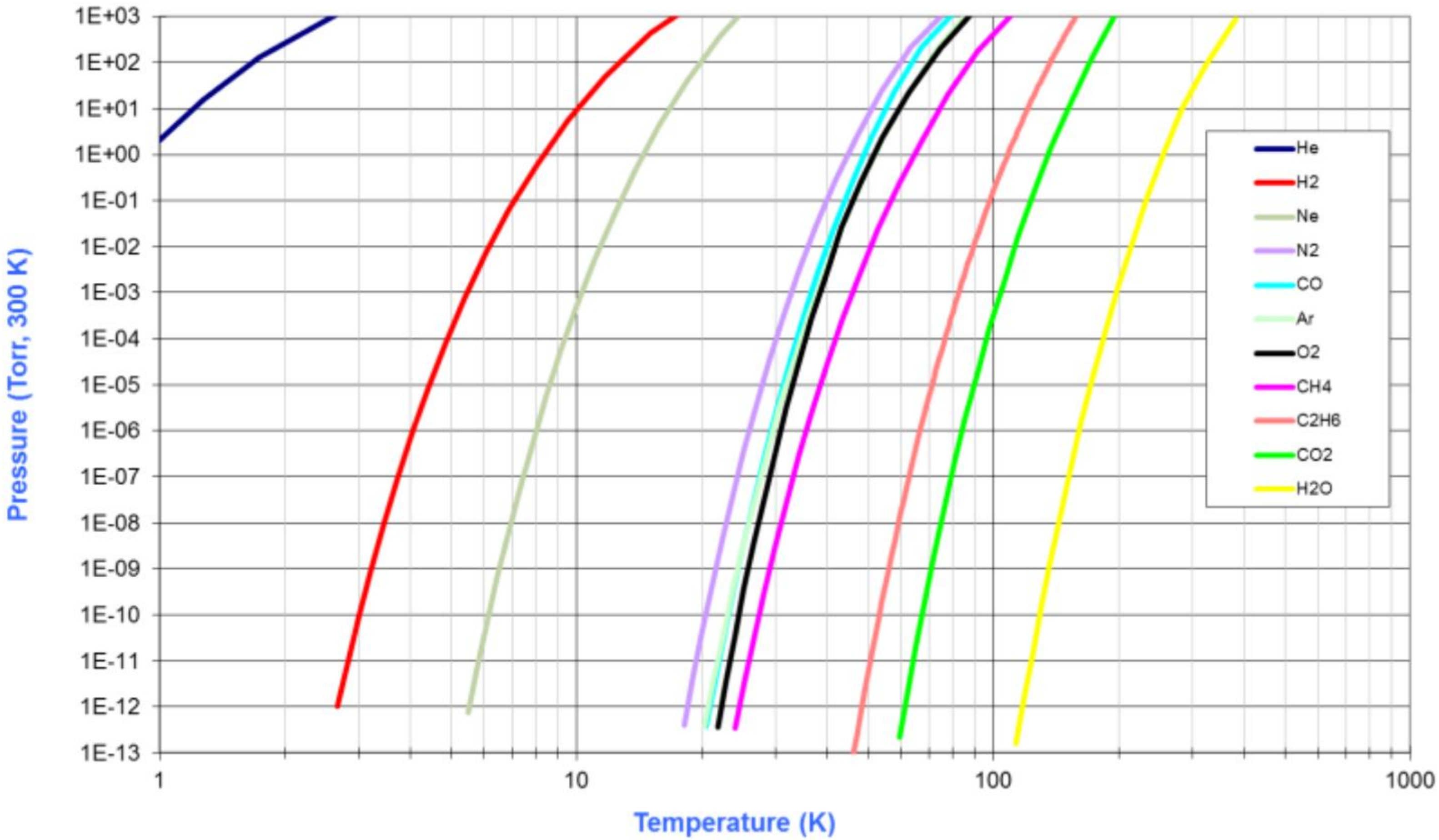
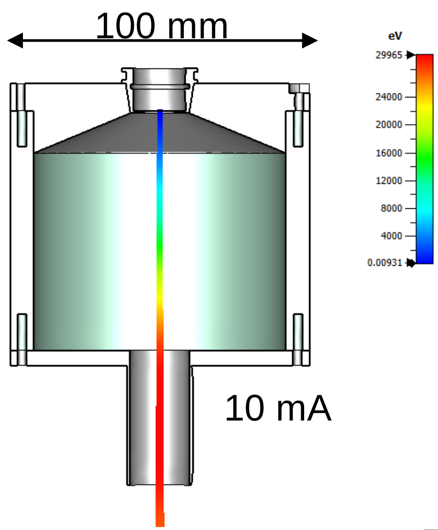
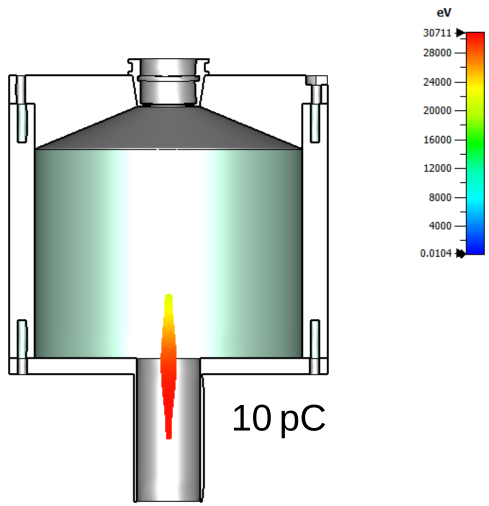
Better vacuum conditions with cryopumping

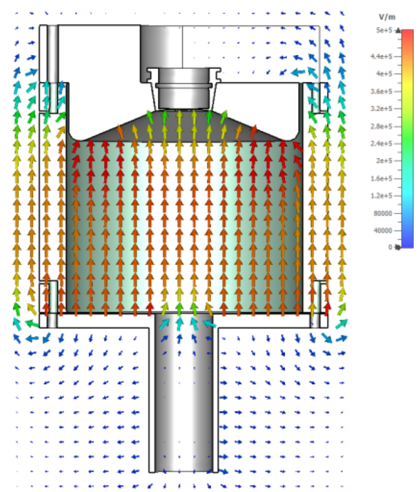


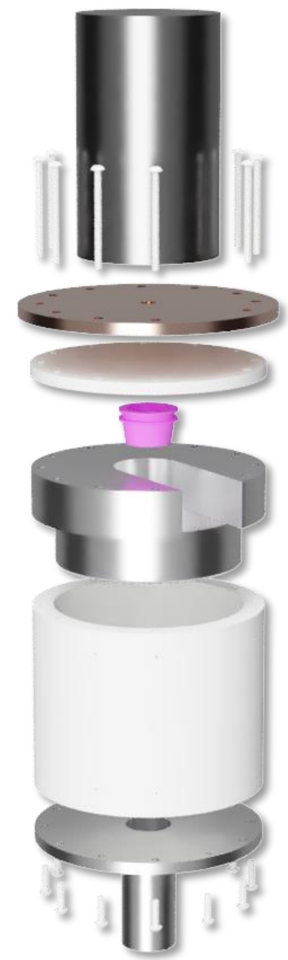
Honig, Hook, Vapor pressure data for some common gases

Source Design









CST

Expected vacuum conditions

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$$S = 1000c(T_{in})A\sqrt{\frac{8k_b T_{out}}{m\pi}}$$

$c(T_{in})$:	sticking-factor
A:	area
T_{out}:	gas temperature
m:	gas mass

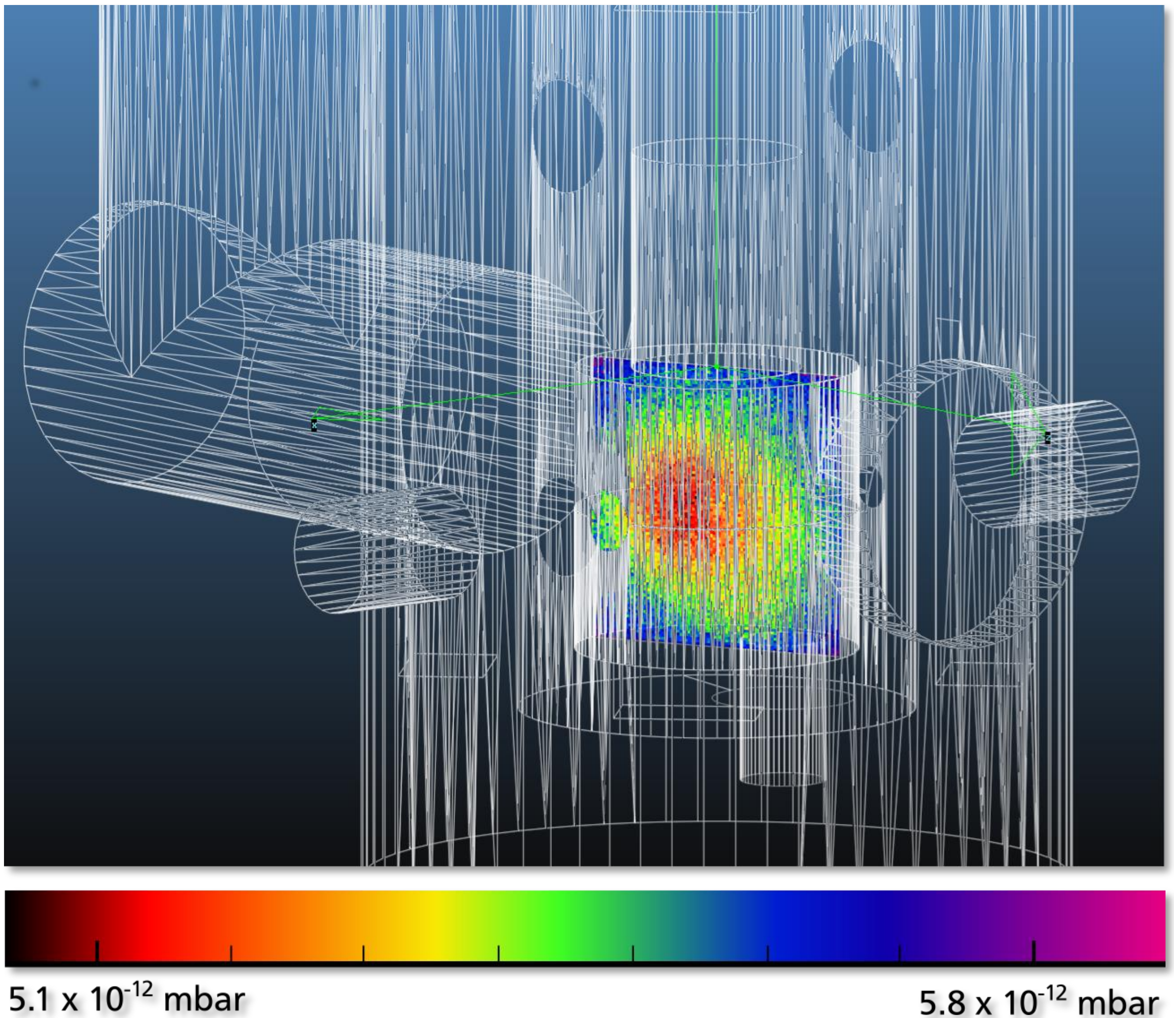
5 K: > 18000 l/s
7 K: > 15000 l/s
12 K: > 8900 l/s
for Hydrogen

$$Q = 1000\frac{\pi d^3}{12l}\sqrt{\frac{8k_b T_{out}}{m\pi}}$$

$$\frac{p_{in}}{p_{out}} = \frac{Q}{S}$$

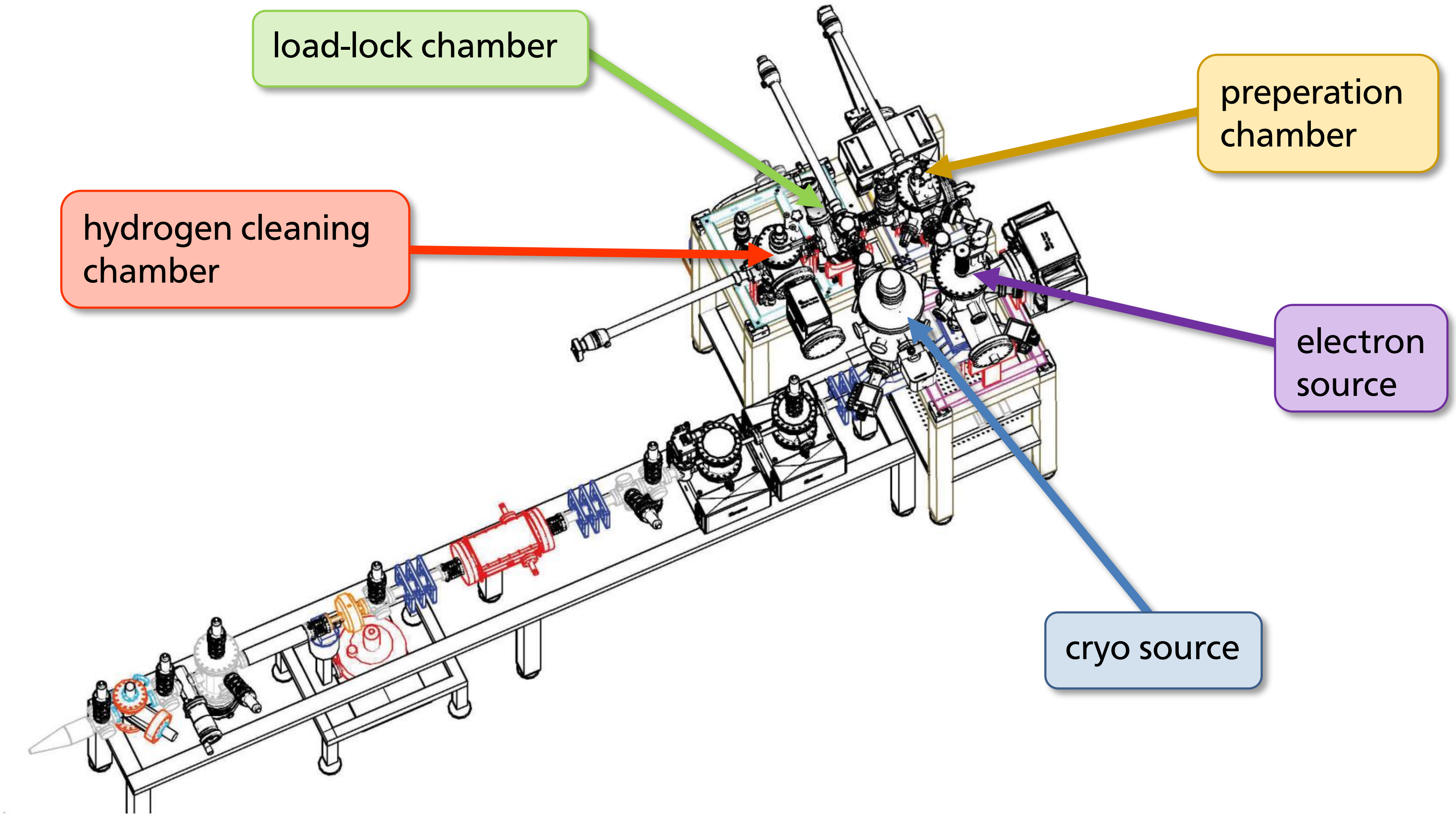
5 K: > 5.1 x 10^{-4}
7 K: > 6.2 x 10^{-4}
12 K: > 1.0 x 10^{-3}

Prevacuum Simulations



5 K:	2.5×10^{-15} mbar
7 K:	3×10^{-15} mbar
12 K:	5×10^{-15} mbar

Experimental setup at Photo-CATCH in Darmstadt



Current state and outlook

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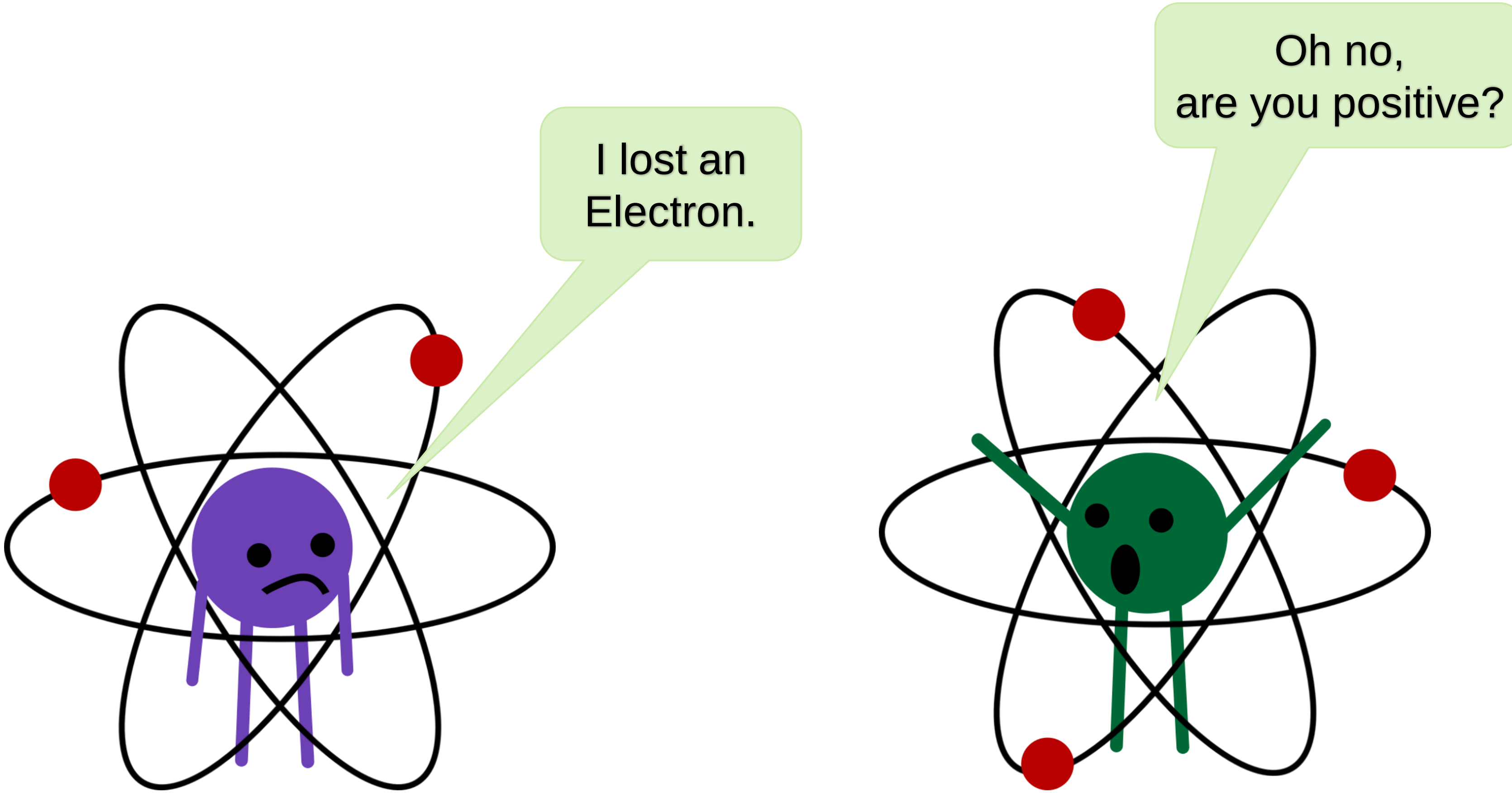
Done

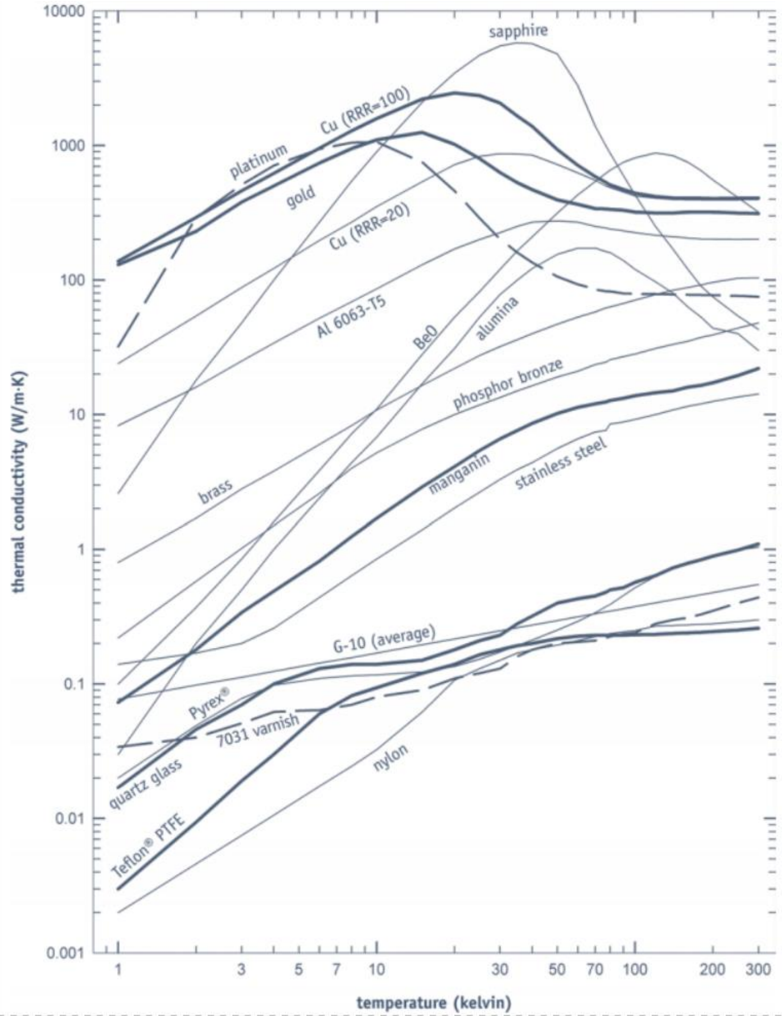
- Cryocooler
- Design of inner chamber
- Ordered inner chamber
- Test stand for setup is available

To DO

- Design outer chamber
- Modification of Photo-CATCH
- Commissioning of the source

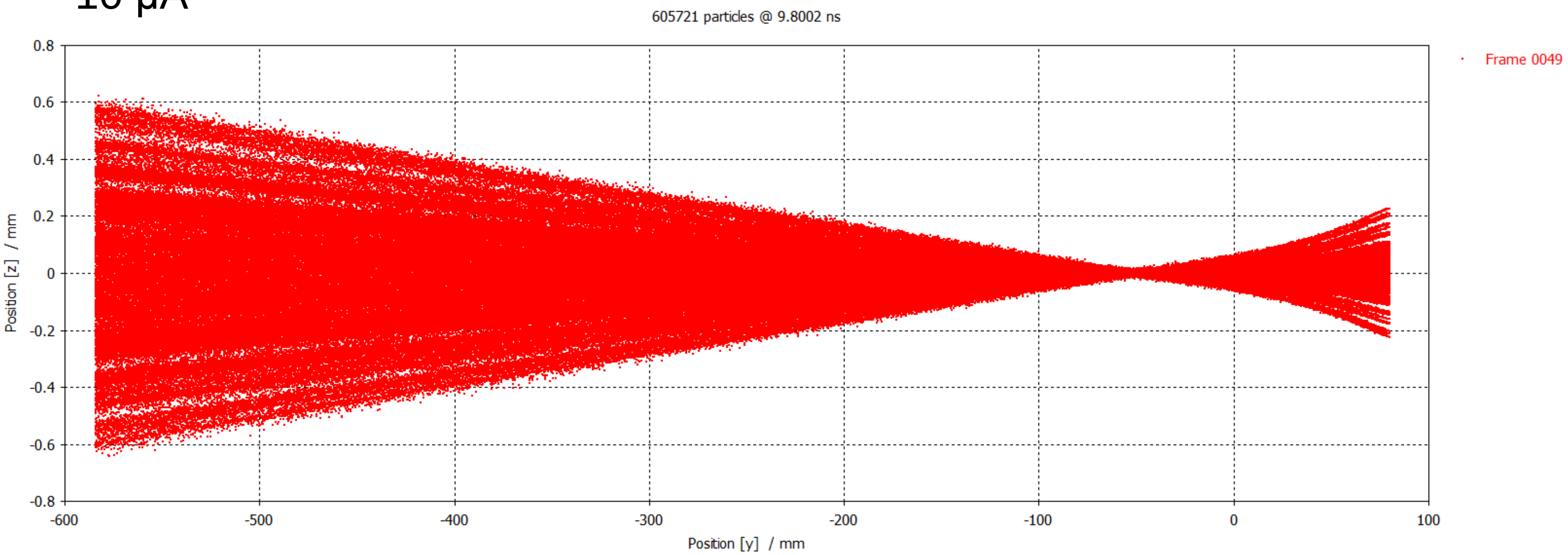
Thank you for your attention



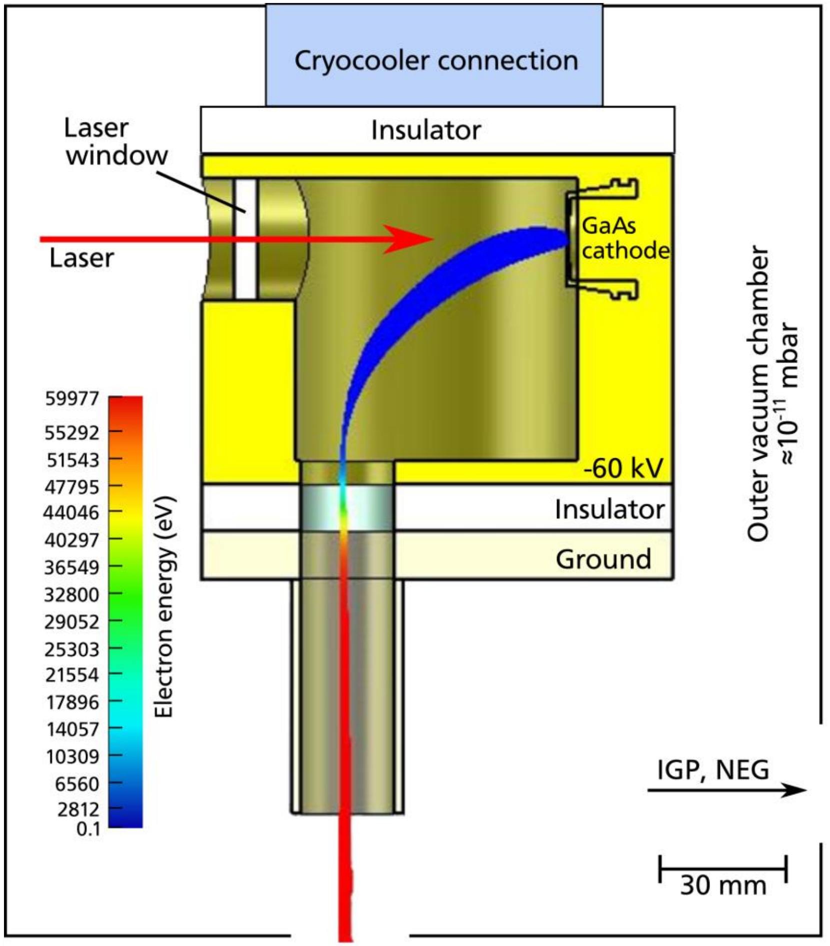


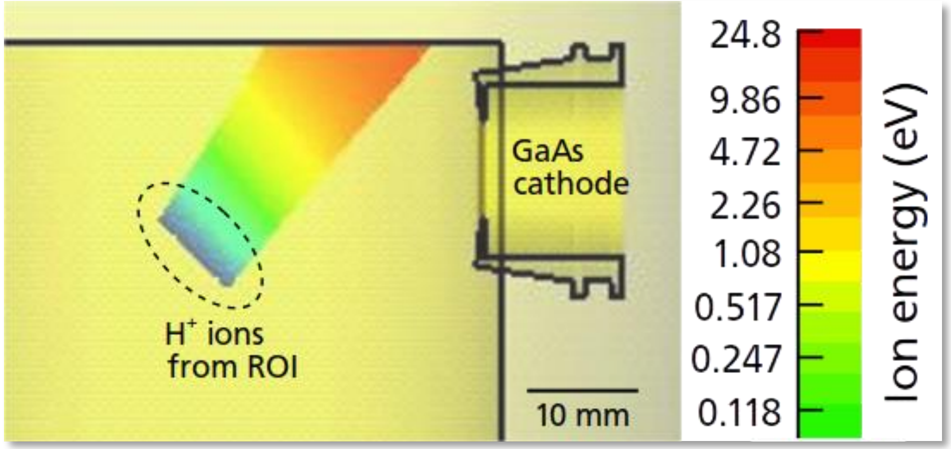
sapphire
Cu (RRR=100)
platinum
gold
Cu (RRR=20)
Al 6063-T5
BeO
alumina
phosphor bronze
brass
manganin
stainless steel
G-10 (average)
Pyrex®
7031 varnish
quartz glass
nylon
Teflon® PTFE
thermal conductivity (W/m·K)
temperature (kelvin)
10000
1000
100
10
1
0.1
0.01
0.001
1
3
5
7
10
30
50
70
100
200
300

10 μA

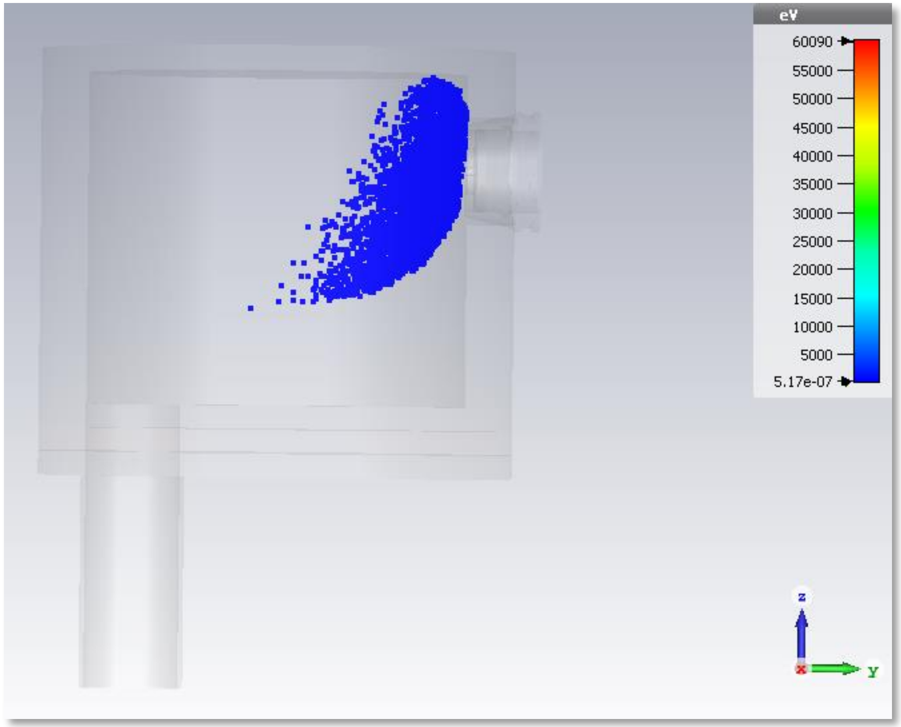

605721 particles @ 9.8002 ns
Frame 0049
Position [z] / mm
Position [y] / mm
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-600
-500
-400
-300
-200
-100
0
100

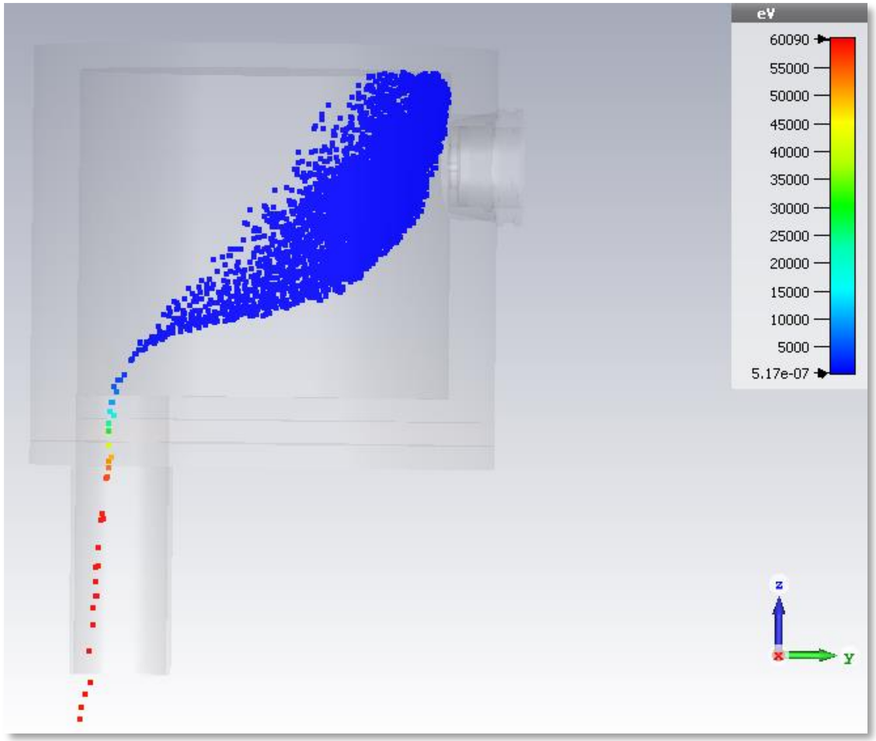
Original Design



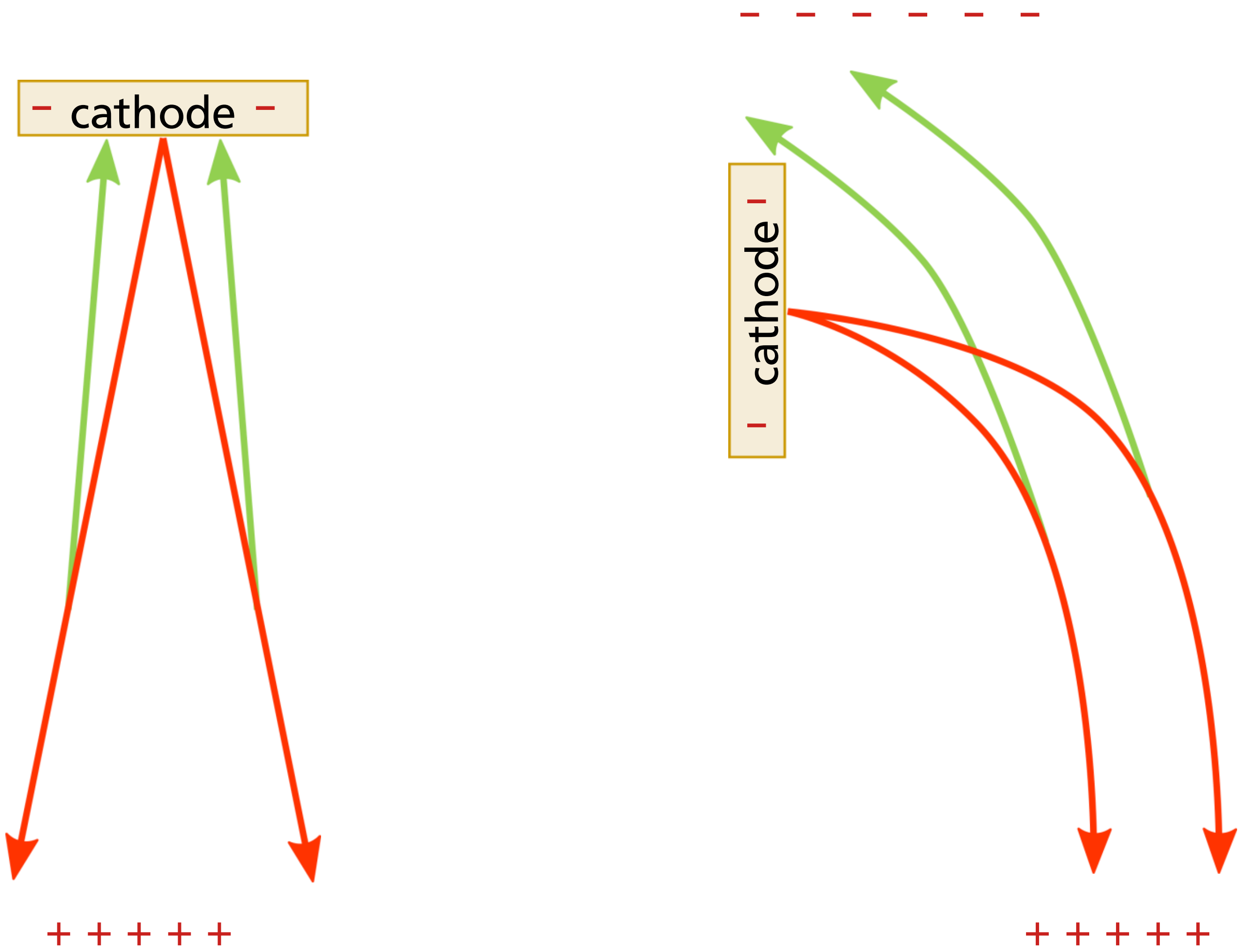


Original Design

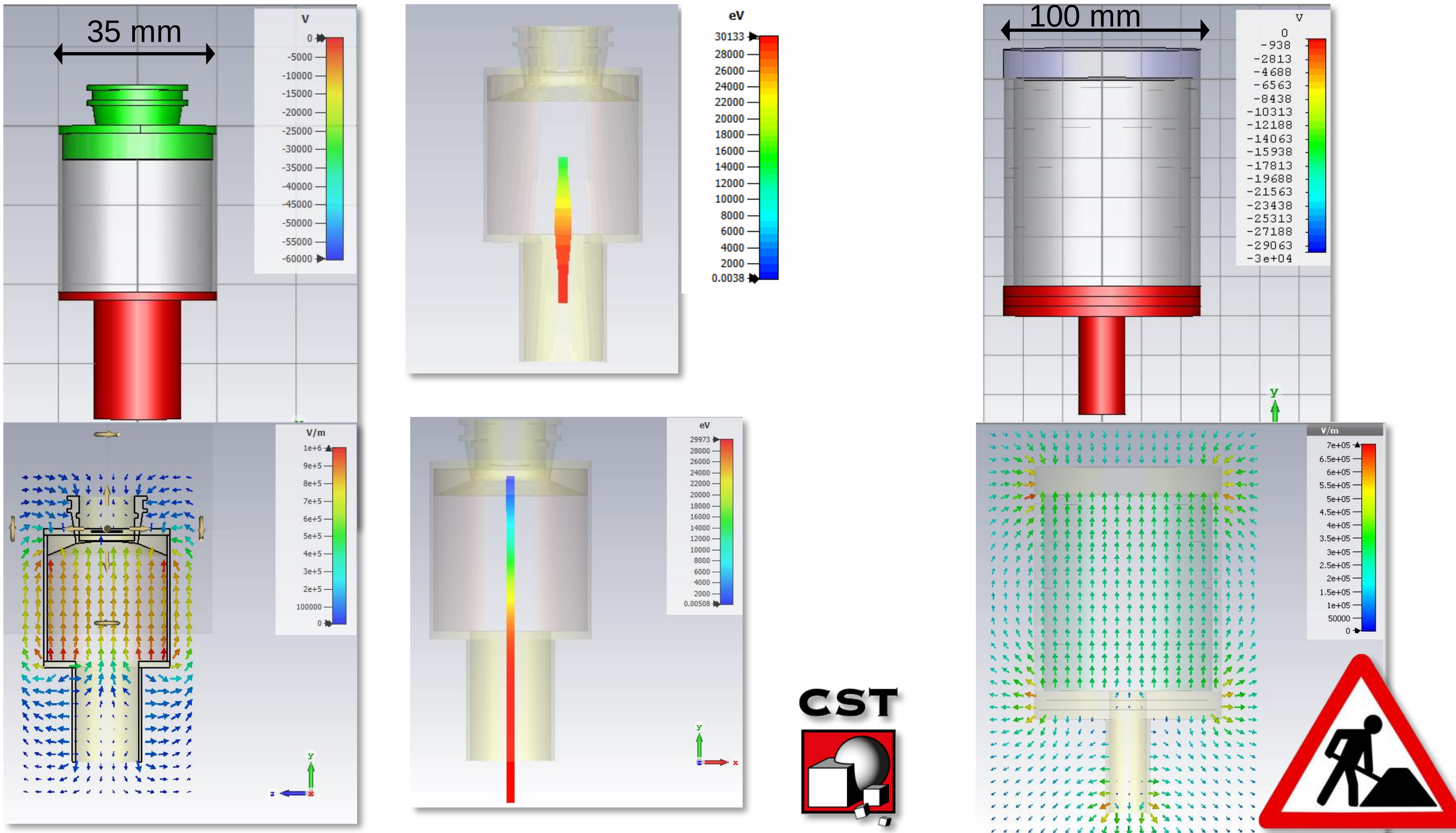




Ion back bombardment



Ongoing Design Studies



Beam Simulation Parameters

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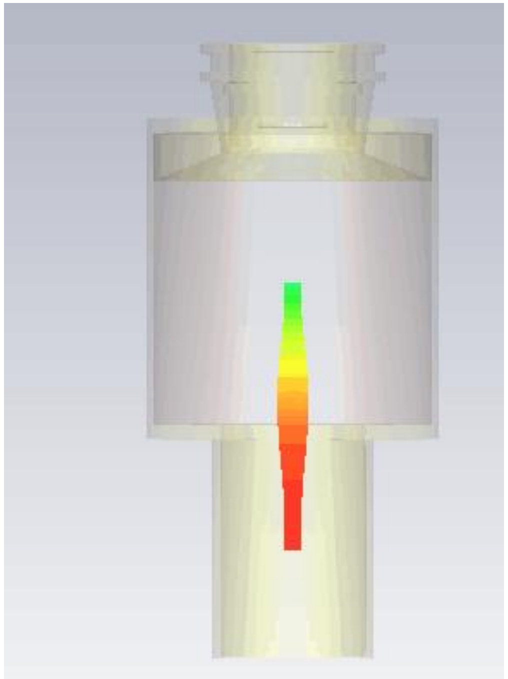
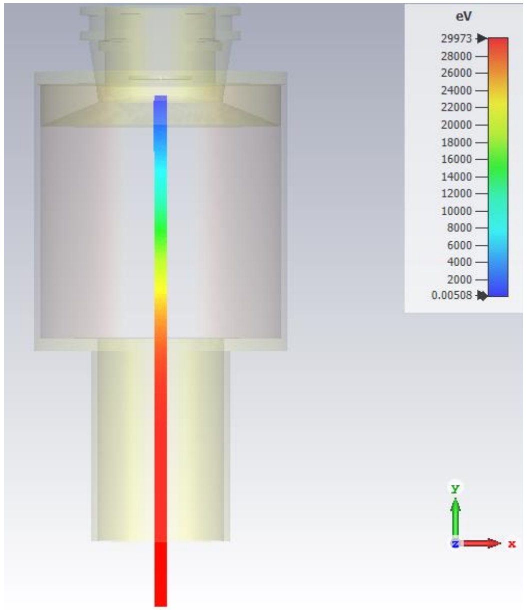
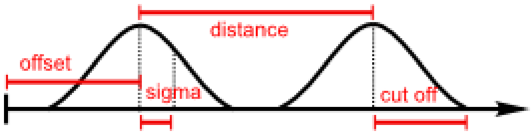
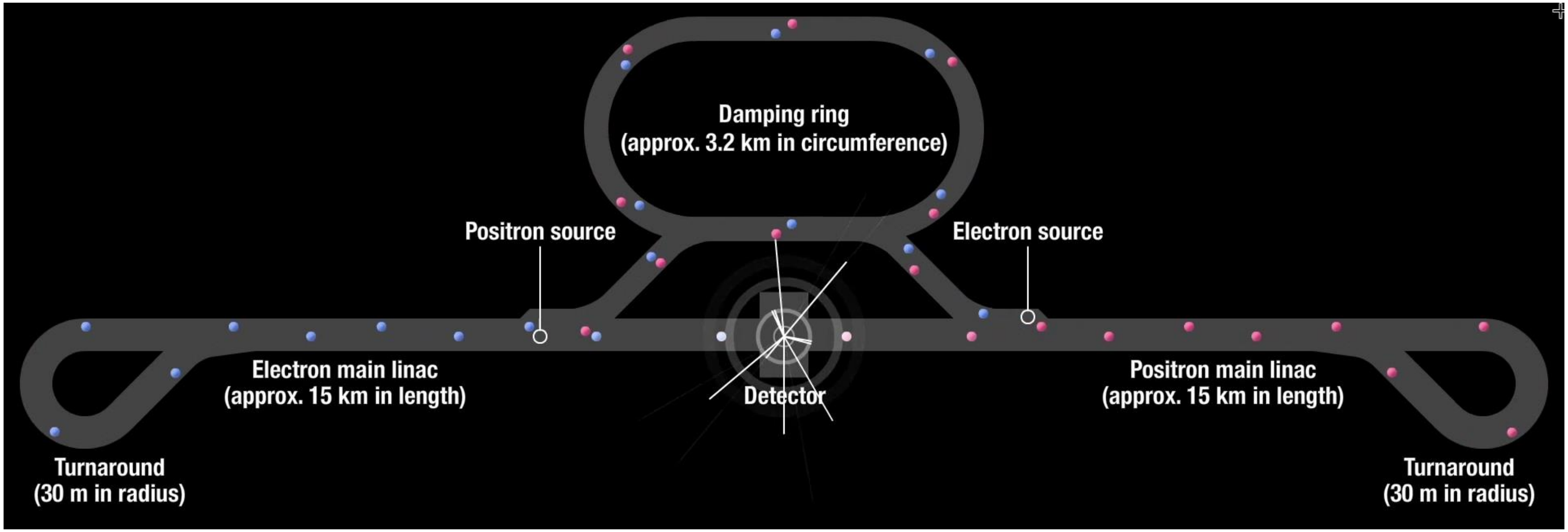


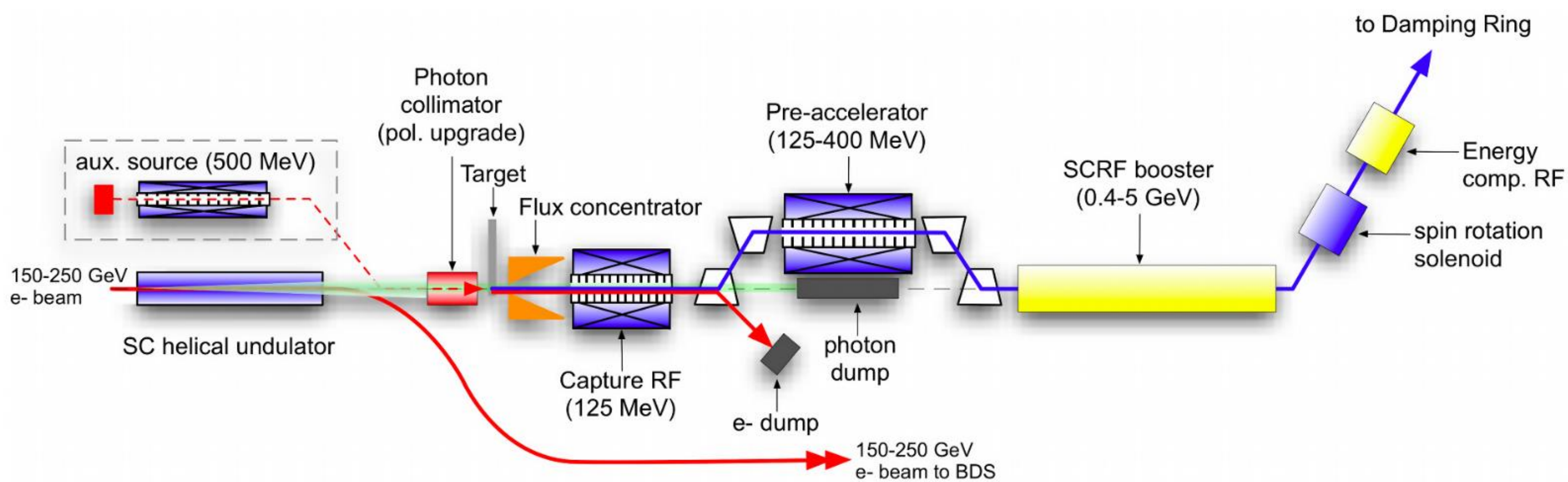


Current: 1 mA

Charge: $1 \cdot 10^{-11}$ C
Sigma: 0.05 ns
Cutoff length: 0.2 ns
Offset: 0.2 ns
Distance: 1ns




Damping ring
(approx. 3.2 km in circumference)
Positron source
Electron source
Electron main linac
(approx. 15 km in length)
Detector
Positron main linac
(approx. 15 km in length)
Turnaround
(30 m in radius)
Turnaround
(30 m in radius)

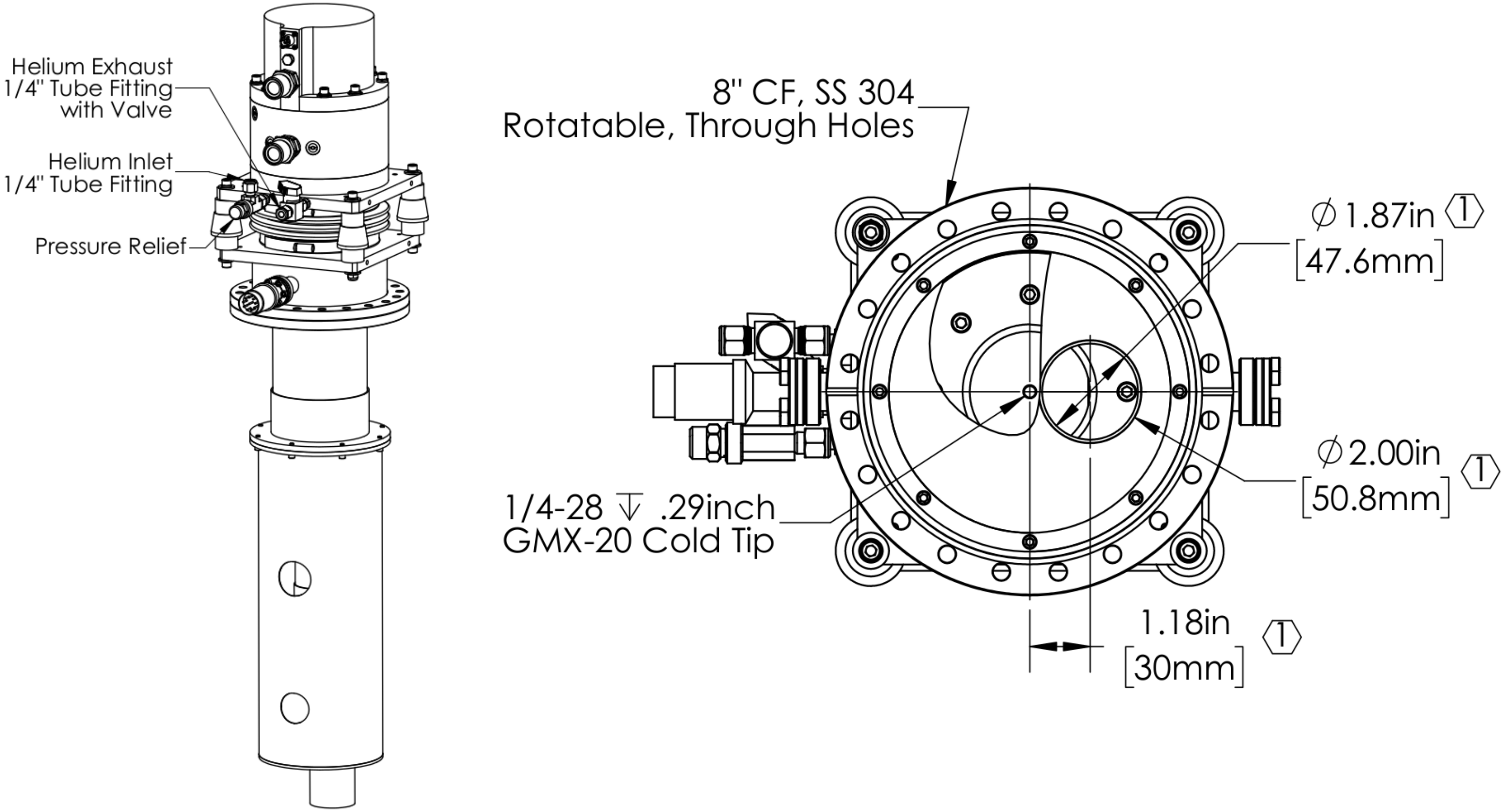

to Damping Ring
Photon
collimator
(pol. upgrade)
Pre-accelerator
(125-400 MeV)
Energy
comp. RF
aux. source (500 MeV)
Target
Flux concentrator
SCRF booster
(0.4-5 GeV)
spin rotation
solenoid
150-250 GeV
e- beam
SC helical undulator
photon
dump
Capture RF
(125 MeV)
e- dump
150-250 GeV
e- beam to BDS

Parameter	Symbol	Value	Units
Positrons per bunch at IP	n_b	2×10^{10}	number
Bunches per pulse	N_b	1312	number
Pulse Repetition Rate	f_{rep}	5	Hz
Positron Energy (DR injection)	E_0	5	GeV
DR Dynamic Aperture	$\gamma(A_x + A_y)$	<0.07	m rad
DR Energy Acceptance	Δ	0.75	%
DR Longitudinal Acceptance	A_l	3.4 x 37.5	cm-MeV
Electron Drive Beam Energy[a]	E_e	150/175/250	GeV
Undulator Period	λ	1.15	cm
Undulator Strength[b]	K	0.92/0.75/0.45	-
Undulator Type	-	Helical	-
Undulator Length	L_u	147	m
Photon Energy (1st harm cutoff)	E_{c10}	10.1/16.2/42.8	MeV
Photon Beam Power	P_γ	63.1/54.7/41.7	kW
Target Material	-	Ti-6%Al-4%V	-
Target Thickness	L_t	0.4 / 1.4	r.l. / cm
Target Absorption	-	7	%
Incident Spot Size on Target	σ_i	1.4/1.2/0.8	mm, rms
Positron Polarisation	P	31/30/29	%

[a] For centre-of-mass energy below 300 GeV, the machine operates in 10 Hz mode where a 5 Hz 150 GeV beam with parameters as shown in the table is a dedicated drive beam positron source.

[b] K is lowered for beam energies above 150 GeV to bring the polarisation back to 30 % without adding a photon collimator before the target.

≈ 20 mA average current


Helium Exhaust
1/4" Tube Fitting
with Valve
Helium Inlet
1/4" Tube Fitting
Pressure Relief
8" CF, SS 304
Rotatable, Through Holes
⌀ 1.87in ⟨1⟩
[47.6mm]
⌀ 2.00in ⟨1⟩
[50.8mm]
1/4-28 ↧ .29inch
GMX-20 Cold Tip
1.18in ⟨1⟩
[30mm]

Cryopumping

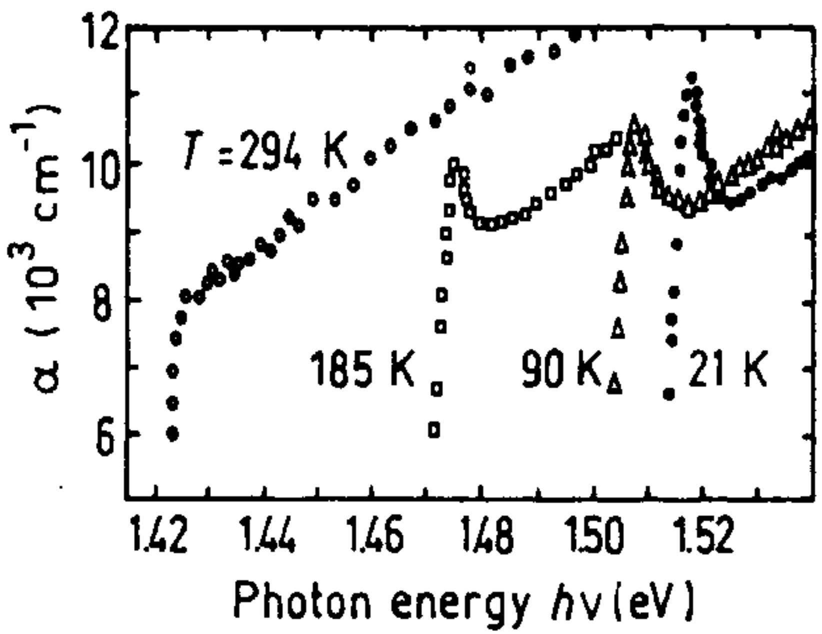
Adavantages

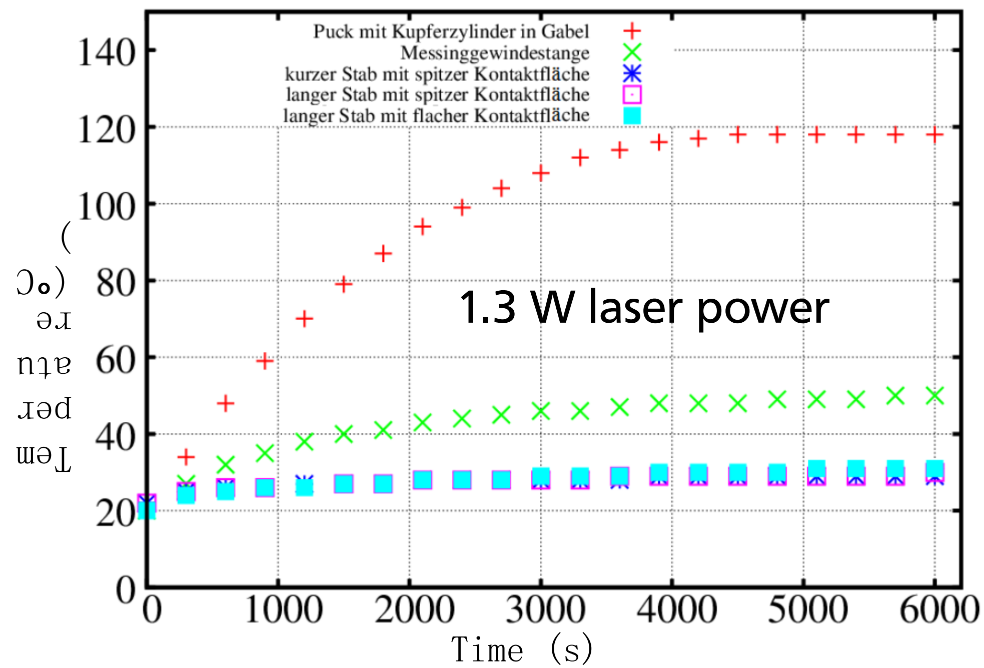
- nearly infinite pumping speed for all gases except H_2 and He
- H_2 pumping speed > 10 000 l/s He pumping speed > 1000 l/s

Disadavantages

- Expensive
- No constant pumping speed
- If surface is full with sorbed material no pumping effect
  → use $<10^{-11}$ mbar "prevacuum"
- Even at $p < 10^{-12}$ mbar, outgassing of surrounding walls results in particles inside the chamber
- Particles need time to "find" a pump
  → Let the chamber be the pump

Thermal behavior of GaAs





Sturge, M. D., Phys. Rev. 127, 3 (1962) 768.

Philipp Herrmann, Optimierung der Wärmeleitung von Photokathoden für die Hochstrom-Elektronenquelle von MESA,Diplomarbeit, Johannes Gutenberg-Universität Mainz

ILC Specifications

Beam Parameters	Collision Energy	500 giga-electron-volts (500 GeV = 250 GeV + 250 GeV)
	Luminosity	2×10^{34} cm^{-2} s^{-1}
	Bunch population	2 x 1010
	Number of bunches	1312
	Bunch spacing	554 ns
	Number of collision	6560 s^{-1}
	Number of beam acceleration	5 s^{-1}
	Acceleration gradient	31.5 MV/m
	Beam size at collision point Number of acceleration cavity unit	Width 474 nm Thickness 5.9 nm
Accelerator unit	Number of cryomodules	14742
	Number of klystrons in distributed klystron system	1701 378
	Size of cryomodule	1m diameter, 12m length
Cryomodule	Cryomodule type	
	Type 1 Type 2 Frequency of pulsed RF	9 units of 9-cell acceleration cavities 8 units of 9-cell acceleration cavities + 1 unit of superconducting quadrupole magnet 1.3 GHz
Operation	Power of pulsed RF	190 kW/cavity
	Operation temperature of acceleration cavity	2 K
Size of accelerator	Circumference of Damping ring	3.2 km
	Length of main linac	11 km (electron linac) + 11 km (positron linac)
Collision experiment	Number of Detectors	2 (push-pull alternation)

Ionisation cross section

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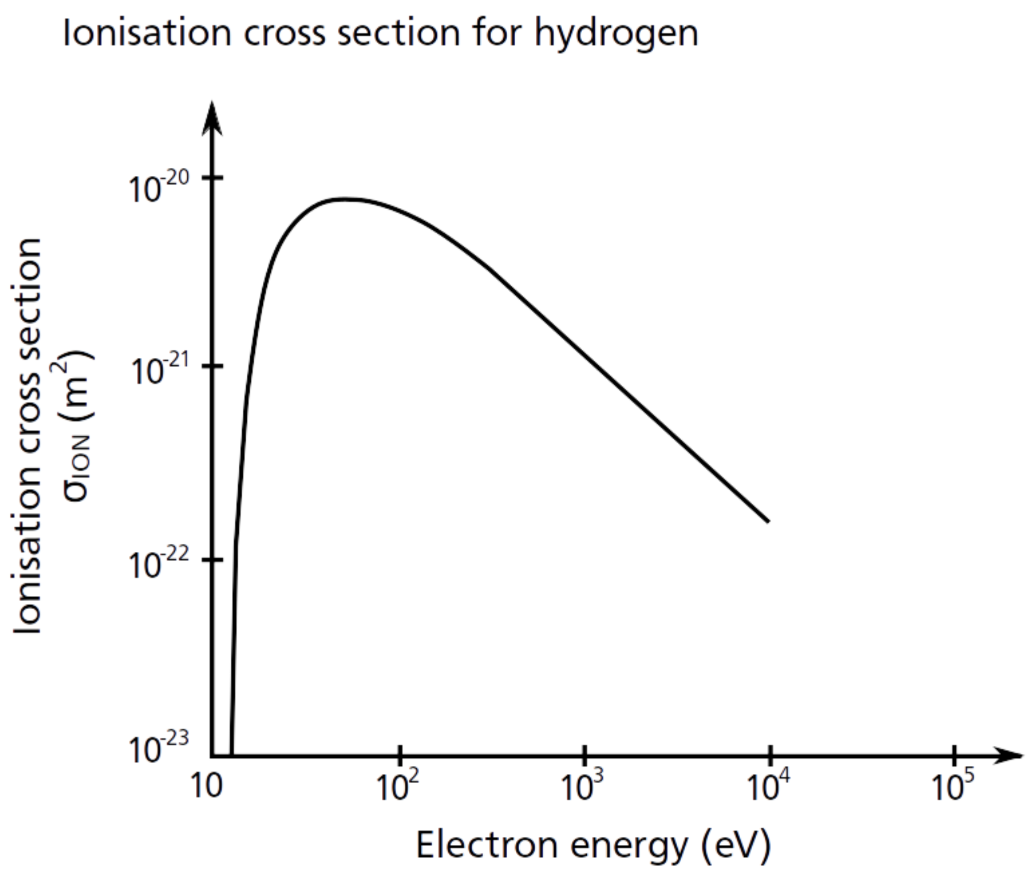

PMS.IITK.ERNET.IN, Collisional processes in plasmas