Low E e- driven e+ source for ILC

PosiPol09 at IPNL/Lyon

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Low E e- driven e+ source

- e- driven conventional e+ source is the only one method, which ever been operated, but some risks on the conversion and capture.
- Introducing advanced concepts and devices, the system performance can be improved.
- New risks are imported associated to the device, but it is concentrated and can be controlled by appropriate R&D.
  - **Example: Lithium lens improve capture efficiency; The drive beam intensity is less and potential target damage is less; Lithium lens is technically risky.**

Positron Yield study

- Positron generation is simulated by NRC-EGS4 with various electron energy (0.25 – 6.0 GeV) as a function of the target thickness (0.5 – 8.0 X_0).
- Beam spot : 2.5mm radius (rms)
- Capture optics: AMD (B_0=7.0, B_S=0.5T, L=220mm, μ=60.8 1/m)
- Positron acceptance is qualified by an analytical method by accounting
  - Transverse acceptance
    - Spiral motion
  - Longitudinal acceptance
    - Adiabatic condition
    - De-bunching: velocity, path-length

Transverse Acceptance

$$\left(\frac{B_0}{B_s}\right)\left(\frac{r_0}{a}\right)^2+\left(\frac{2\mathrm{p}_{r0}}{e\sqrt{B_0 B_s}\,a}\right)^2+\left(\frac{2\mathrm{p}_{\phi 0}}{eB_s a}\right)^2\left[\frac{B_0}{B_s}\left(\frac{a}{r_0}\right)^2-1\right]\leq 1$$

- ► B_0 :peak magnetic field of AMD, 7.0T
- ► B_s :solenoid field, 0.5 T
- ► r_0: e+ radial position at the target exit
- ► a: accelerator aperture (20mm)
- ► p_{r0}, $p_{\varphi 0}$: canonical momenta
- ► Acceptance is roughly (mm, MeV/c)

$$p_{r0}=\left(\frac{x_0}{r_0}\right)p_{x0}+\left(\frac{x_0}{r_0}\right)p_{y0}$$

$$p_{\phi 0}=\left(-y_0\,p_{x0}+x_0\,p_{y0}\right)+\frac{1}{2}e\,r_0^2 B_0$$

$$\left(\frac{x}{5.3}\right)^2+\left(\frac{p_x}{11}\right)^2\leq 1$$

Longitudinal Acceptance

- Adiabatic condition in AMD.

$$\epsilon_{AC}=\frac{\mu p_z}{eB_0}\leq 0.5$$

- De-bunching effects
  - **Velocity**
  - **Path in AMD**
  - **Path in accelerator**

$$\delta L_{vel}=\frac{1}{2}\int_0^L\left(\frac{1}{\gamma^2}-\frac{1}{\gamma_0^2}\right)$$

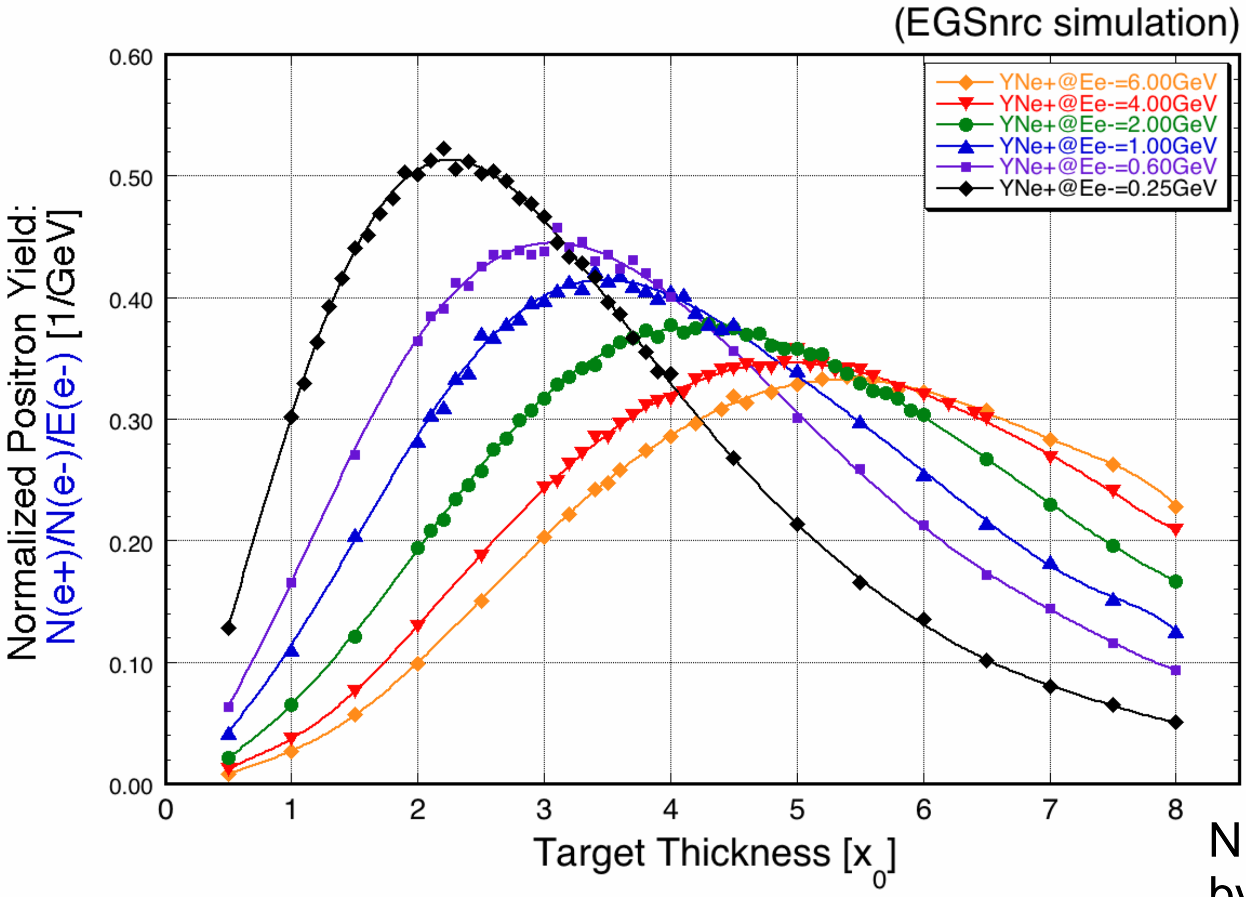
$$\delta L_{AMD}=\frac{1}{2\mu}\left(\frac{p_t}{p_z}\right)^2\ln\left(\frac{B_0}{B_s}\right)$$

$$\delta L_{acc}=\frac{1}{2}\left(\frac{p_t}{p_z}\right)^2\left(1/\frac{dp}{dz}\right)\left(\frac{B_0}{B_s}\right)$$

  - **δL_{max}=15mm(50ps)**

$$\delta L_{vel}+\delta L_{AMD}+\delta L_{acc}<\delta L_{max}$$

Positron Yield



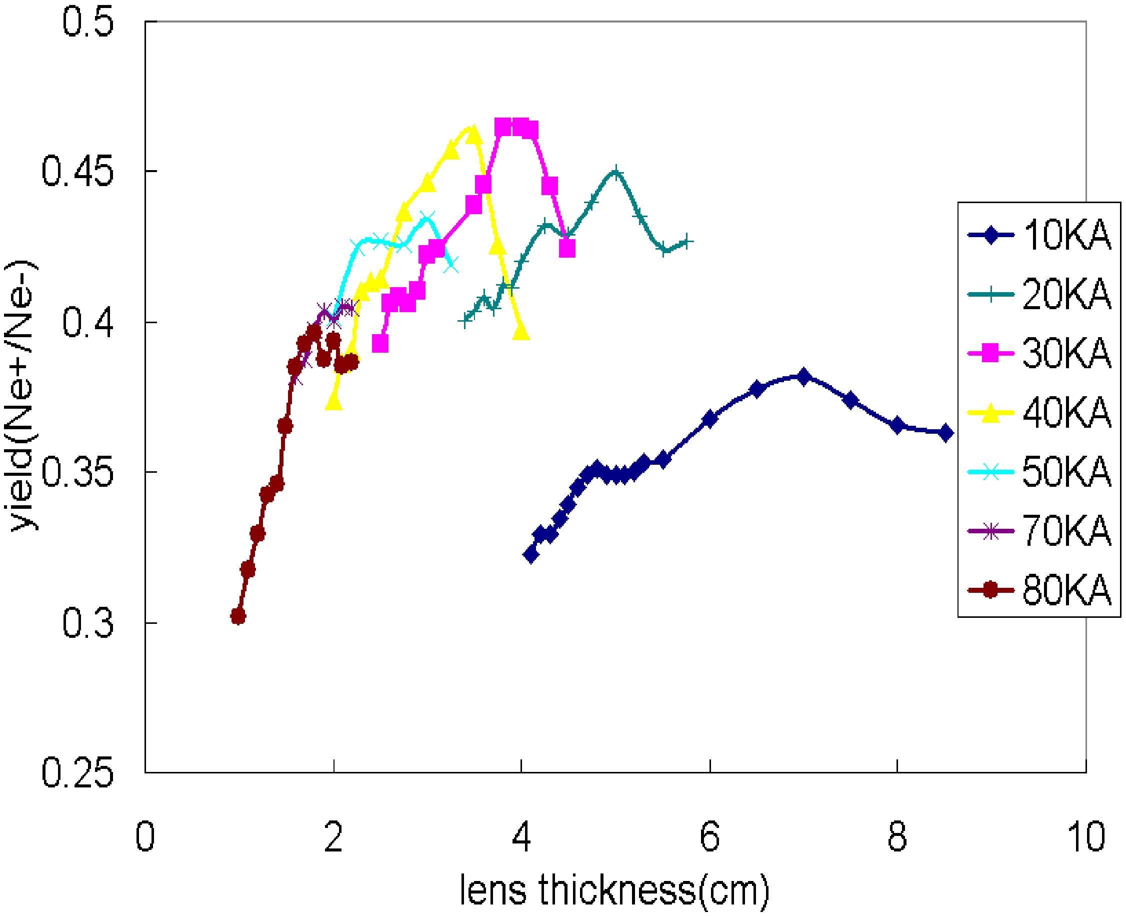
NRC EGS4
by T. Kamitani

- 0.44 Ne+/Ne-/E(GeV) for 0.6 GeV
- 0.42 Ne+/Ne-/E(GeV) for 1.0 GeV
- 0.37 Ne+/Ne-/E(GeV) for 2.0 GeV

Actual Yield

- ►Positron yield $\eta(N_{e+}/N_{e-})$ at 2.2 GeV : 0.37*2.2=0.81
- ►Positron acceptance in AMD case : 0.11 m.rad.
- ►DR acceptance is γJ<0.045 m.rad in both transverse planes.
- ►The actual acceptance is determined by DR (not capture device). Since DR acceptance corresponds to 1.5σ, the actual acceptance is 87% of 0.81 = 0.70.
- ►If we employ Lithium lens for capture device, some enhancement (30-40%) is expected.

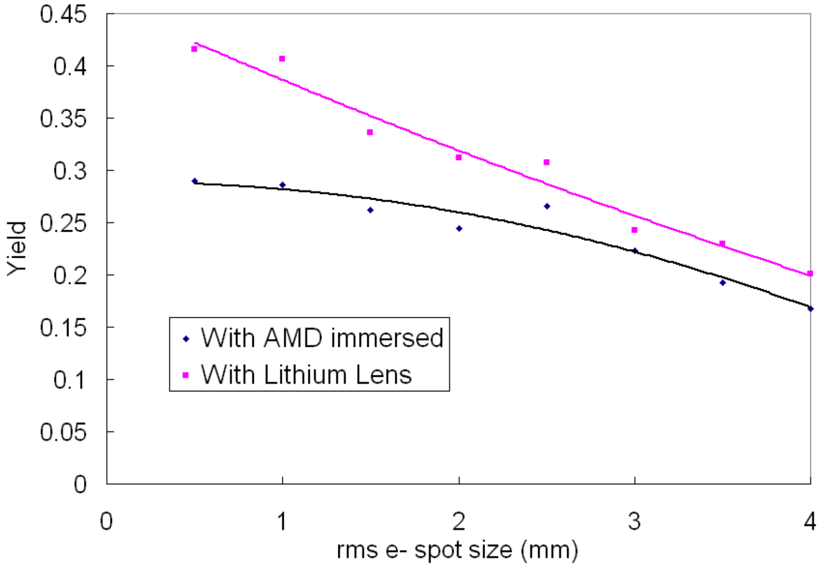
Lithium lens, 700MeV, $3X_0$ liquid Pb (ANL)



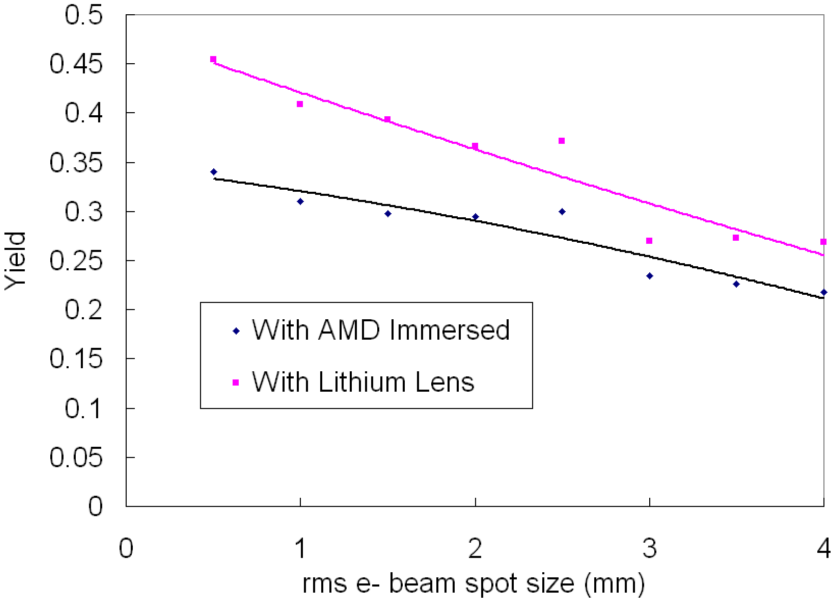
As showing in this figure, the maximum yield is about 0.46 when lithium lens is about 4cm thick and driven by 30KA current.

Comparing with yield of~0.33 achieved by using AMD and immersed liquid lead target, using lithium lens only enhanced the capture by ~40%.

e+ Yield for different rms spot size of drive e- beam (ANL)



600MeV e- drive beam



700MeV e- drive beam

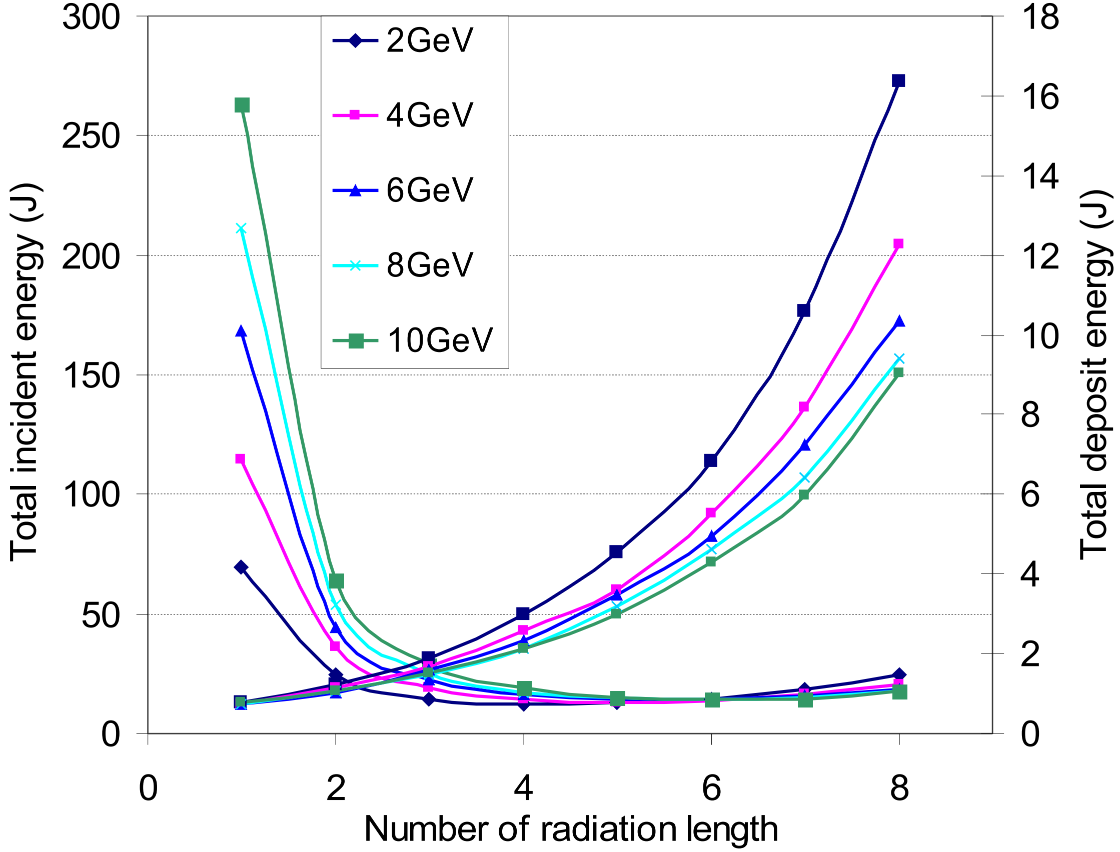
AMD is 6T to 0.5 T in 14 cm for all data points.
Lithium lens parameters are optimized for each case. We optimized both the thickness and the driving current density. The current is assumed to be uniform in the lens.

Target and capture

- The positron yield is basically calculated by assuming AMD.
- In Lithium lens case, the yield is evaluated to be 1.3 times of that by AMD.
- The radiation length (thickness of the target) is optimized by considering ratio of yield and energy deposition instead of only yield.

Total incident energy and deposit energy (ANL)

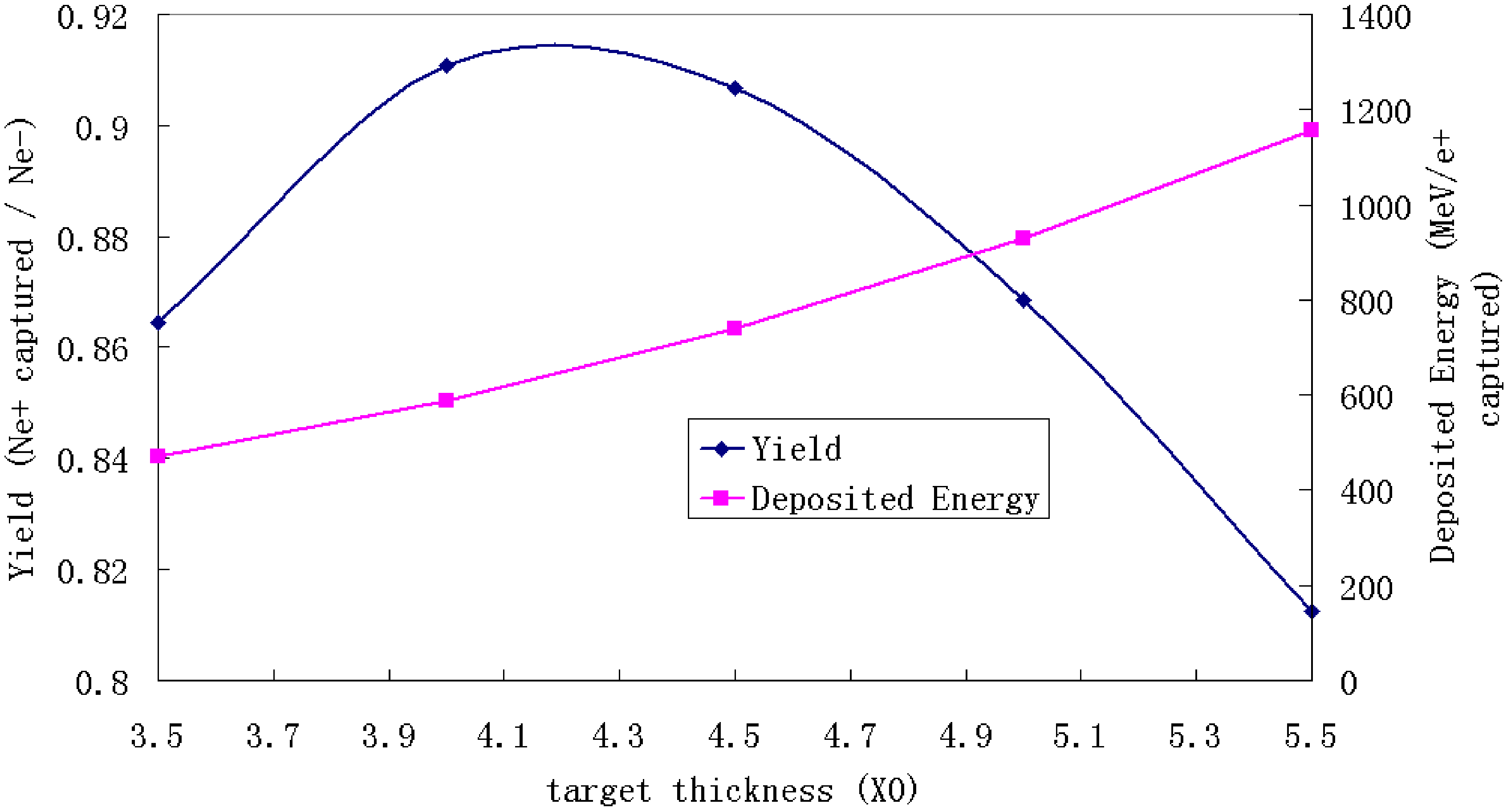
Assuming 3nC e+ are captured



This figure from our previous conventional e+ source study shows that lower drive beam energy will result in a higher energy deposition in target.

Energy deposition per captured e+ does not have any strong dependence on the energy. It increases simply by X_0.
(Comment by MK)

2200MeV drive beam, Yield and energy deposition (ANL)



Optimization (1)

- ►The positron yield as a function of X_0 has an optimum point, but the dependence is not strong.
- ►On the other hand, the energy deposition per captured positron is simply increased as a function of X_0.
- ►By considering both facts, another optimum is lower side of the maximum of the yield.
- ►Yield/Energy deposition is maximized around $3X_0$ for 2.0GeV drive beam.

For 2.0 GeV drive beam

X0	Yield (Ne+/Ne-/GeV)	Energy Deposit per e+ (J/3nC)	Yield/Energy deposition
2	0.2	1.54	0.13
3	0.32	1.88	0.17
4	0.37	3	0.12
5	0.35	4.52	0.08

Optimization(2)

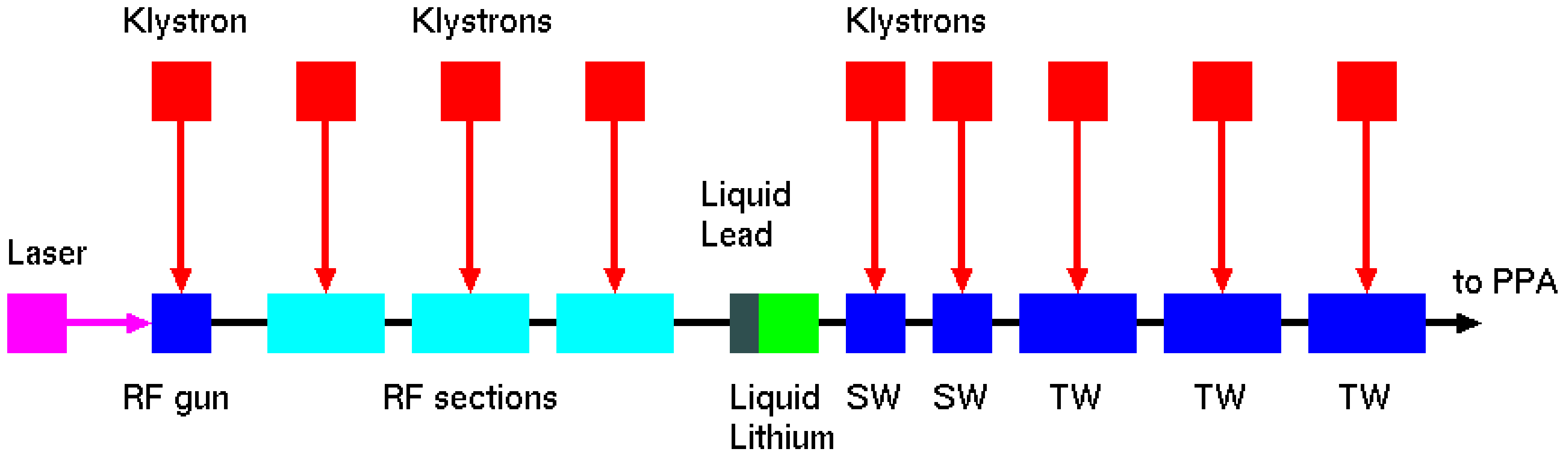
- Assume 3 X_0 for 2.2GeV drive beam, where the ratio is maximized.
- The positron yield (N_{e+}/N_{e-}) for 2.2GeV drive beam is 0.32x2.2=0.70.
- Taking account the DR acceptance and enhancement by lithium lens (30%), the yield becomes 0.70x0.87x1.3=0.80.
- The drive beam intensity giving 3.2nC e+ bunch is 3.2/0.8=4.0nC.

For 2.0 GeV drive beam

X0	Yield (Ne+/Ne-/GeV)	Expected Yield (2.2GeV)	Drive beam intensity (nC)
2	0.2	0.5	6.43
3	0.32	0.8	4.02
4	0.37	0.92	3.48
5	0.35	0.87	3.67

ILC e+ source

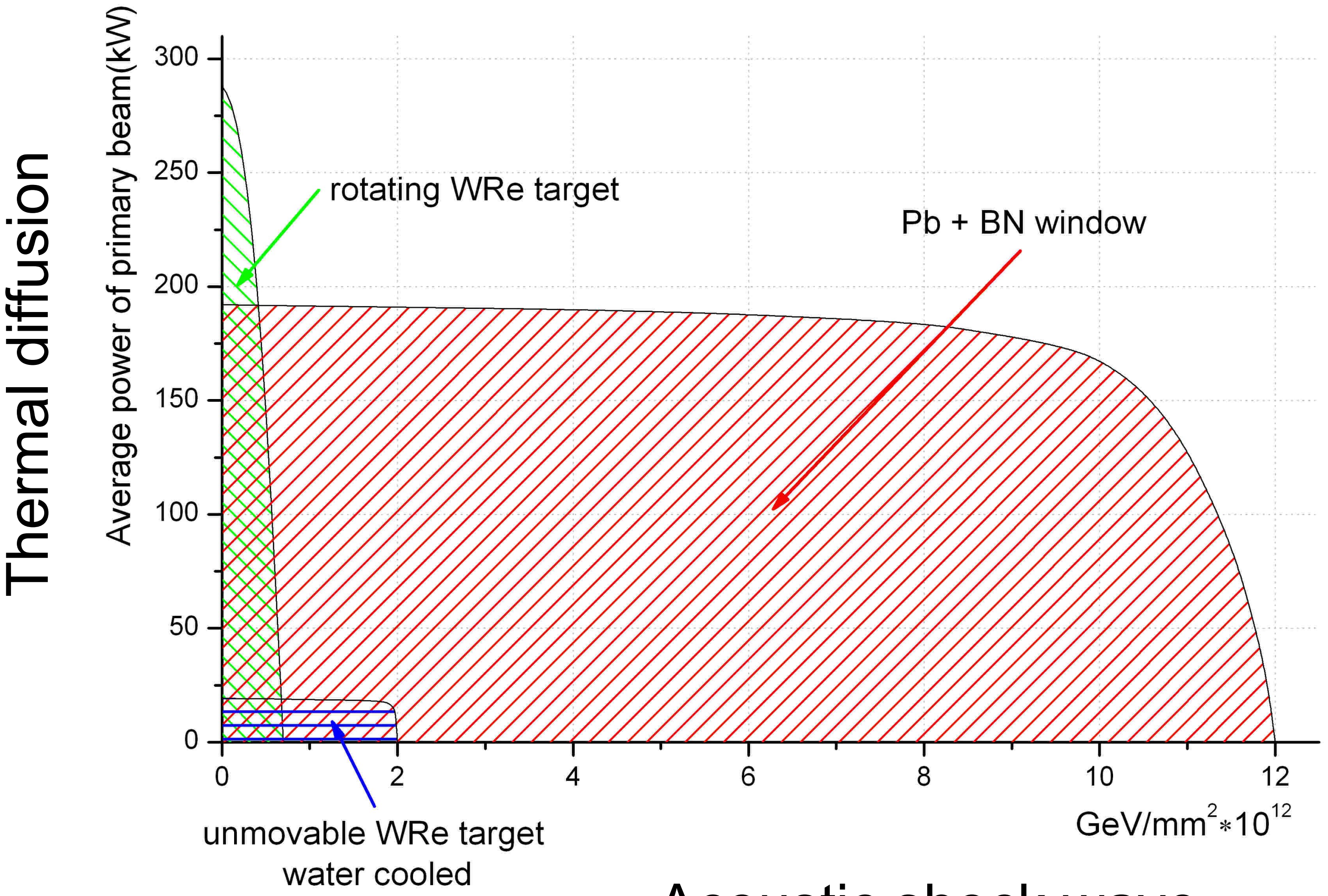
- L-band RF gun (FLASH type) generates ILC format beam with 4.0nC bunch intensity.
- Three RF sections (2 klystron + 3 cryomodules, 24 cavities) accelerate it up to 2.2 GeV.
- Liquid lead target + Liquid Lithium lens.



Liquid Pb target

- Liquid Pb-Sn
- Melting point :~ 600K.
- Boiling point (Pb) : 2200K
- BINP studies
  - **Circulated by Cog-wheel pump.**
  - **Circulation system test bench: 2E+4 h operation without any difficulties. Window-less.**
  - **A target prototype is manufactured. 10m/s flow speed is assumed. Brazing test was done with BN window.**
  - **Practical limit is given by the BN isolation window.**

Operable parameter



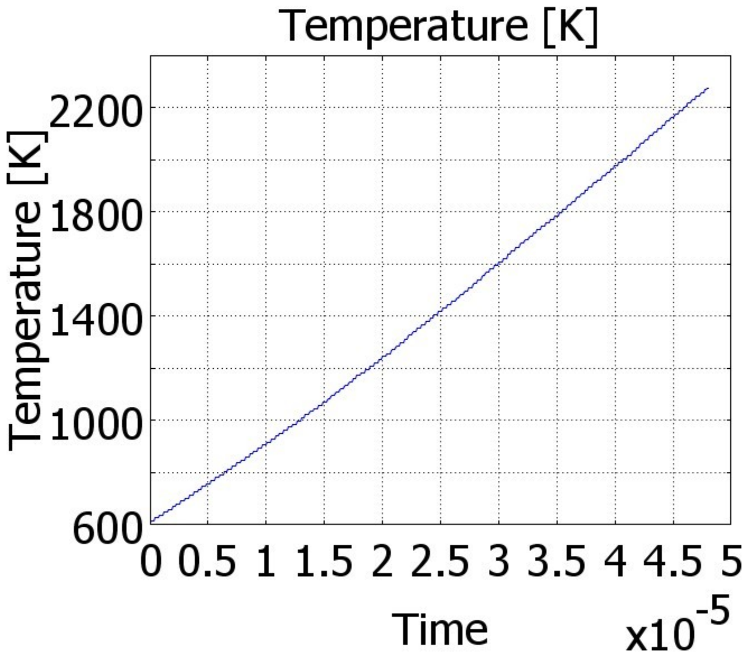
Acoustic shock wave

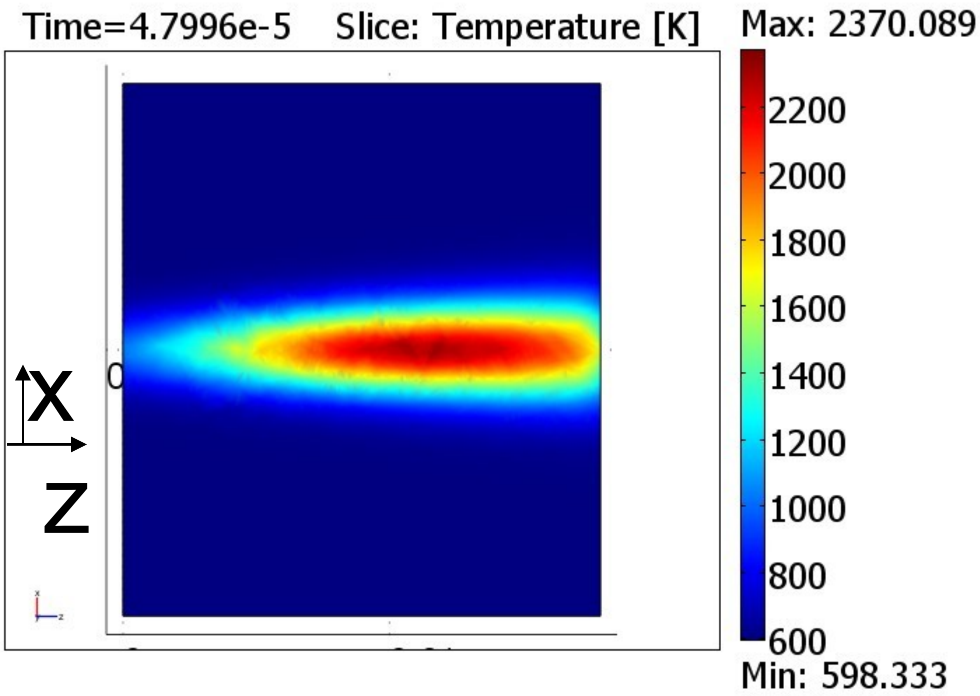
P. Logachev

Target vitality

- Actual limit on the liquid Pb target is given is by BN isolation window.
  - **$10x10^{12}$ GeV/mm^2 in 100ns duration (may be longer).**
  - **180kW average power.**
- 2.2GeV, 4.0nC bunch with 369ns spacing, 2625 bunches, 5Hz
  - **$2.8x10^9$ GeV/mm^2 (spot size 20mm^2): much safer**
  - **2.2x4.5x2625x5=120kW : below the limit**
- ANL group pointed out that Pb boiling is a potential problem.

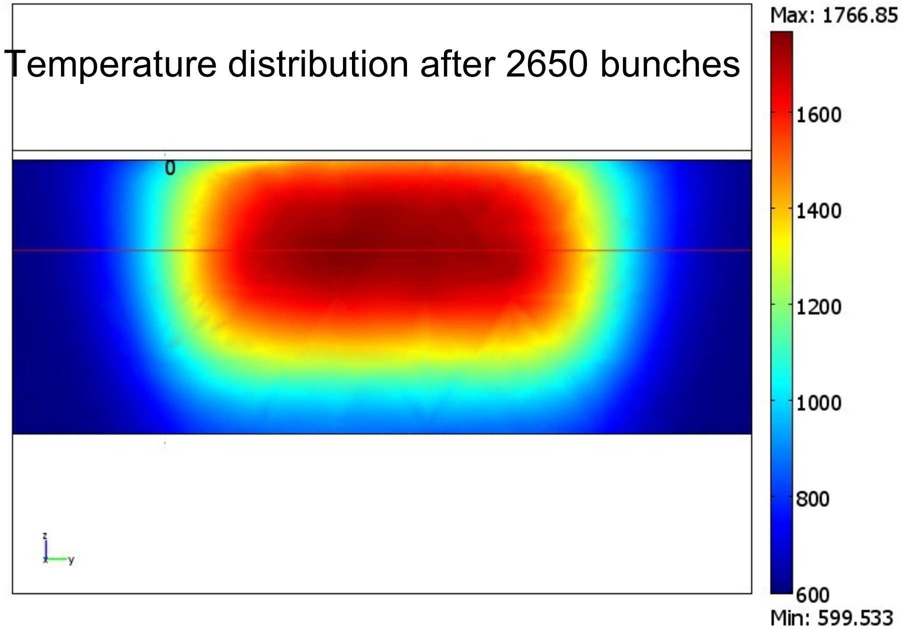
Heat transfer simulation up to 130 bunches, 700MeV drive beam, 1mm spot size, AMD immersed target (ANL)

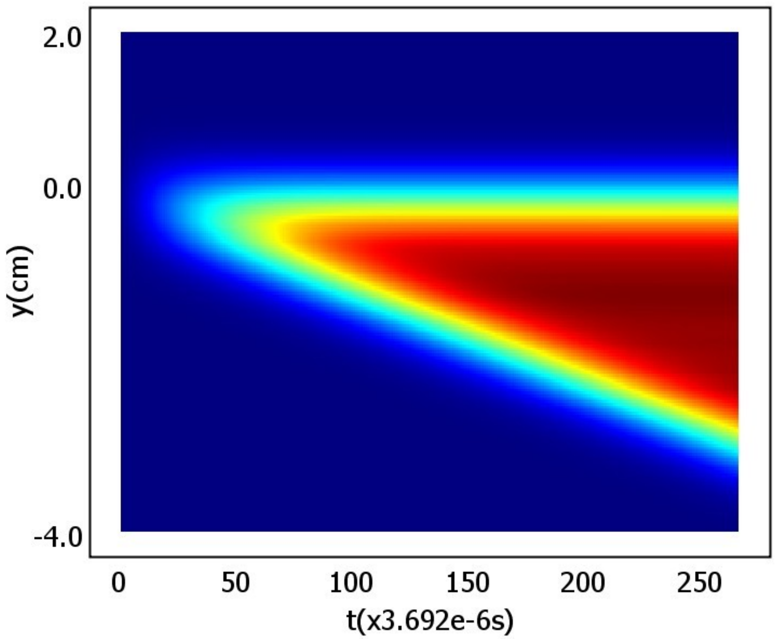


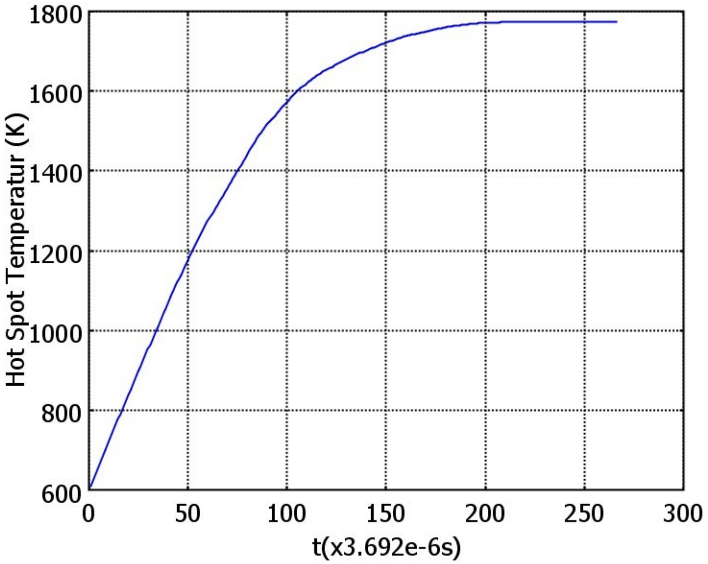


The difference between 700MeV and 600MeV drive e- is very small at this point.

Heat transfer simulation up to 2650 bunches, 600MeV, 3mm rms spot size, 30m/s pumping speed, Lithium lens


Temperature distribution after 2650 bunches

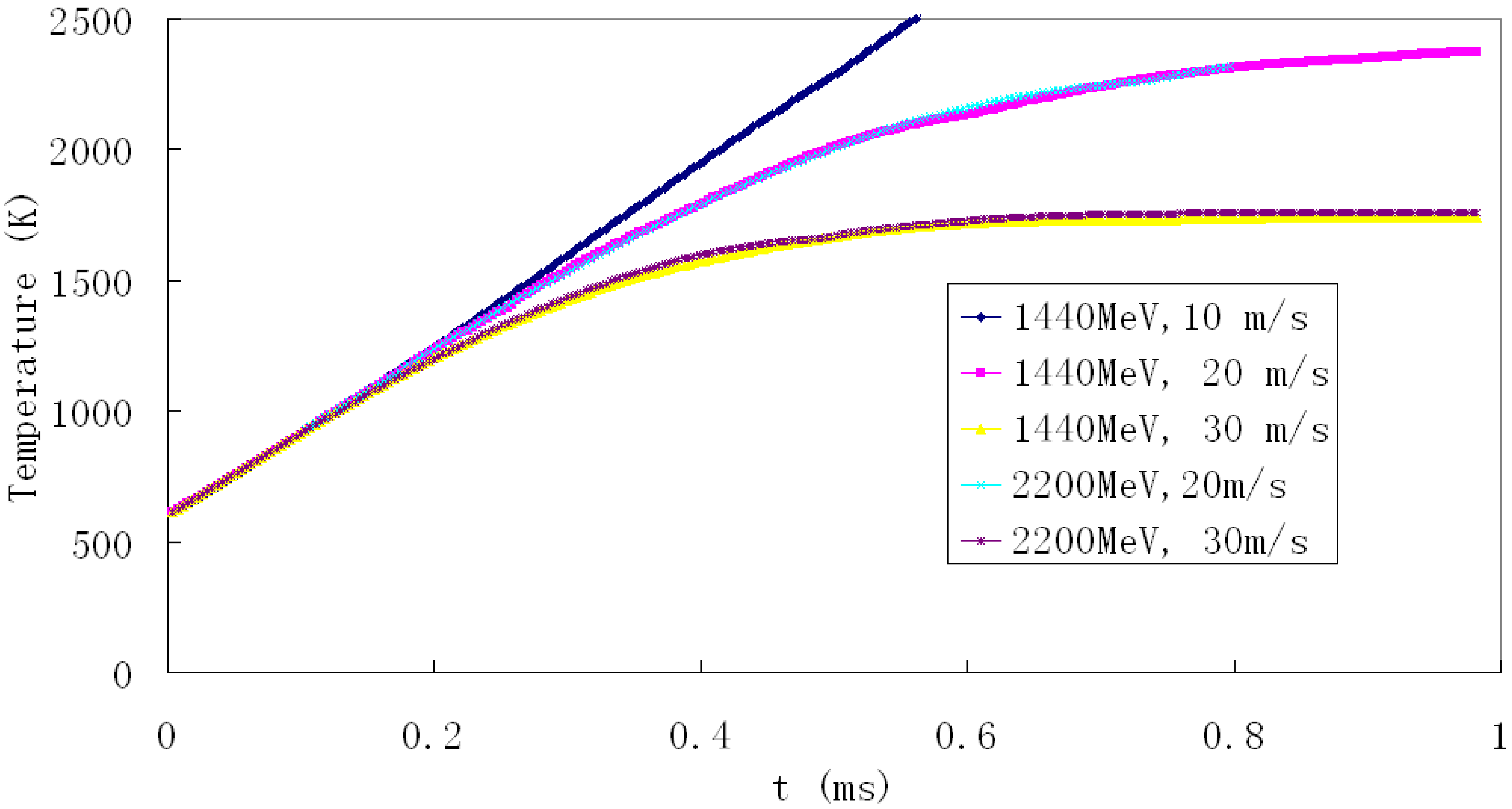




With 30m/s pumping speed and 3mm rms drive beam spot size, using lithium lens, the temperature of hot spot in liquid lead target saturated at near 1800 K bellow the boiling point.

Since the yield with 3mm rms spot size with lithium lens is about 0.26 and the yield with 1mm rms spot size with AMD immersed target is about 0.285. Taking this difference into consider, the saturated temperature will be about 1973 which is very closed to the boiling point

Evolution of Temperature(ANL)



Drive beam spot size: rms 3mm for both 1440MeV and 2200MeV.
Target thickness: 3X0 for 1440MeV, 3.5X0 for 2200MeV

Pb boiling extrapolation

- ANL's Pb boiling study was made with 2.30 J energy deposition per bunch. 2.2GeV, 4.0nC drive beam gives 1.65 J energy deposition per bunch.
- Results of ANL are scaled by this energy deposition per bunch.
- Boiling can be avoided with larger spot size and higher flow rate.

Name	e- (GeV)	Spot (mm)	Pb flow (m/s)	Yield e+/e-	Ne- (nC)	Comment
MK1	2.2	1.0	10	0.80	4.00	Boiling at 250 bunches
MK2	2.2	3.0	10	0.80	4.00	Boiling at 1670 bunches
MK3	2.2	3.0	30	0.80	4.00	Saturated at 1590K
MK4	2.2	4.0	30	0.80	4.00	Saturated at 1300K

Summary

- ►A solution of ILC e+ source based on conventional positron generation is considered.
- ►By employing the lower energy drive beam, relatively higher yield is obtained.
- ►The target thickness is optimized yield/energy deposition instead of yield, to minimized the load to the target.
- ►2.0GeV, 4.0nC drive beam can generate ILC e+ beam.
- ►Issues: Pb boiling, technical implementations for the target and capture devices.