A new algorithm for positron source parameter optimisation

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Abstract

In this report, we proposed a new simple and efficient algorithm for positron source parameter optimisation, which is based on iterations of scan of free parameters in the simulation. The new algorithm is fast, simple and convincing since the results can be visually drawn and flexibly tuned and it has an advantage that it can easily handle realistic parametric problems with more than one objective quantities to optimise. The optimisation of the main parameters of the CLIC positron source at the 380 GeV stage is presented as an example to demonstrate how the algorithm works.

Introduction

- Optimisation of positron source helps to reduce energy deposition and cost
- Conventional algorithms usually have disadvantages, e.g. Nelder-Mead simplex algorithm:
  - only works for single quantity problem
  - easily falls into a local solution instead of global one (Fig. 1)
  - Compromise with alternative solutions not allowed
  - Bad at non-smooth / discontinuous functions
  - Many unnecessary iterations around the solution, etc.
- The new algorithm does not have such disadvantages
- The new algorithm theoretically can be much faster allowing for simultaneous / distributed computations

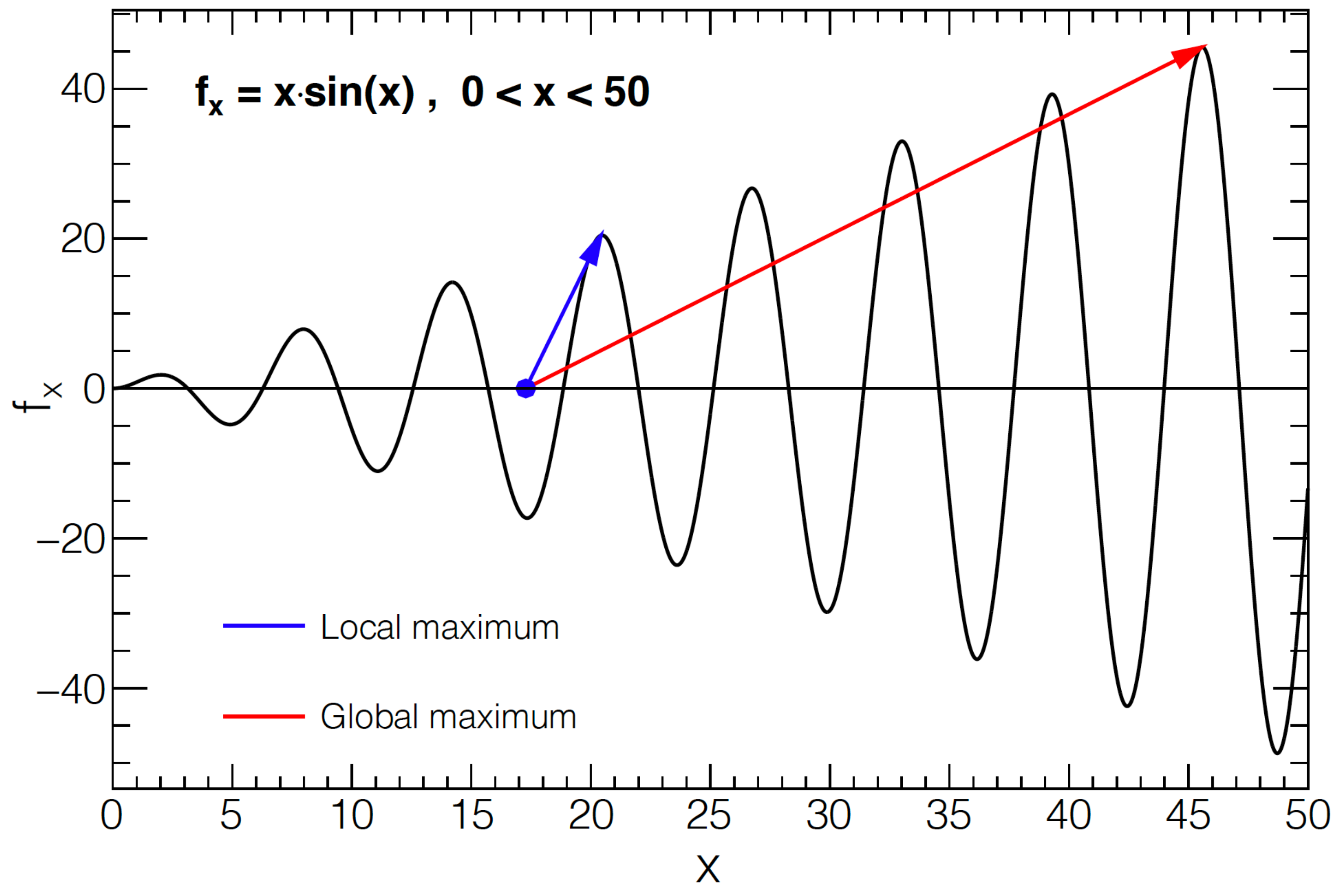


Fig. 1: local v.s. global solutions

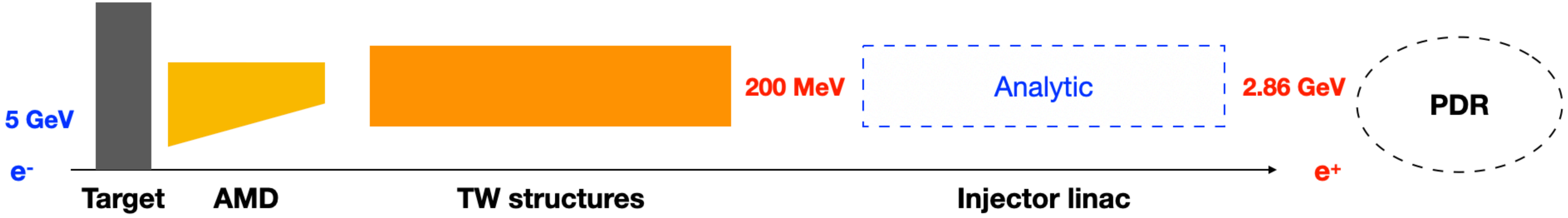
The new algorithm

1. Define the default parameters to start with
2. Scan the parameters separately but simultaneously
   - Scan only one parameter at a time, with other parameters fixed to the default
   - Parameters can be scanned at the same time since the scans are independent
3. Choose new default parameters giving best results. And repeat the scan iteratively until all parameters are optimised and stable (plateaued in the scan)

Example: CLIC positron source optimisation (at 380 GeV)

- Aimed at maximum positron yield accepted by PDR
- Peak energy deposition density (PEDD) in tungsten target < 35 J/g

$$\text{yield}_{e+} = \frac{n_{e+}^{\text{produced}}}{n_{e-}^{\text{primary}}}$$



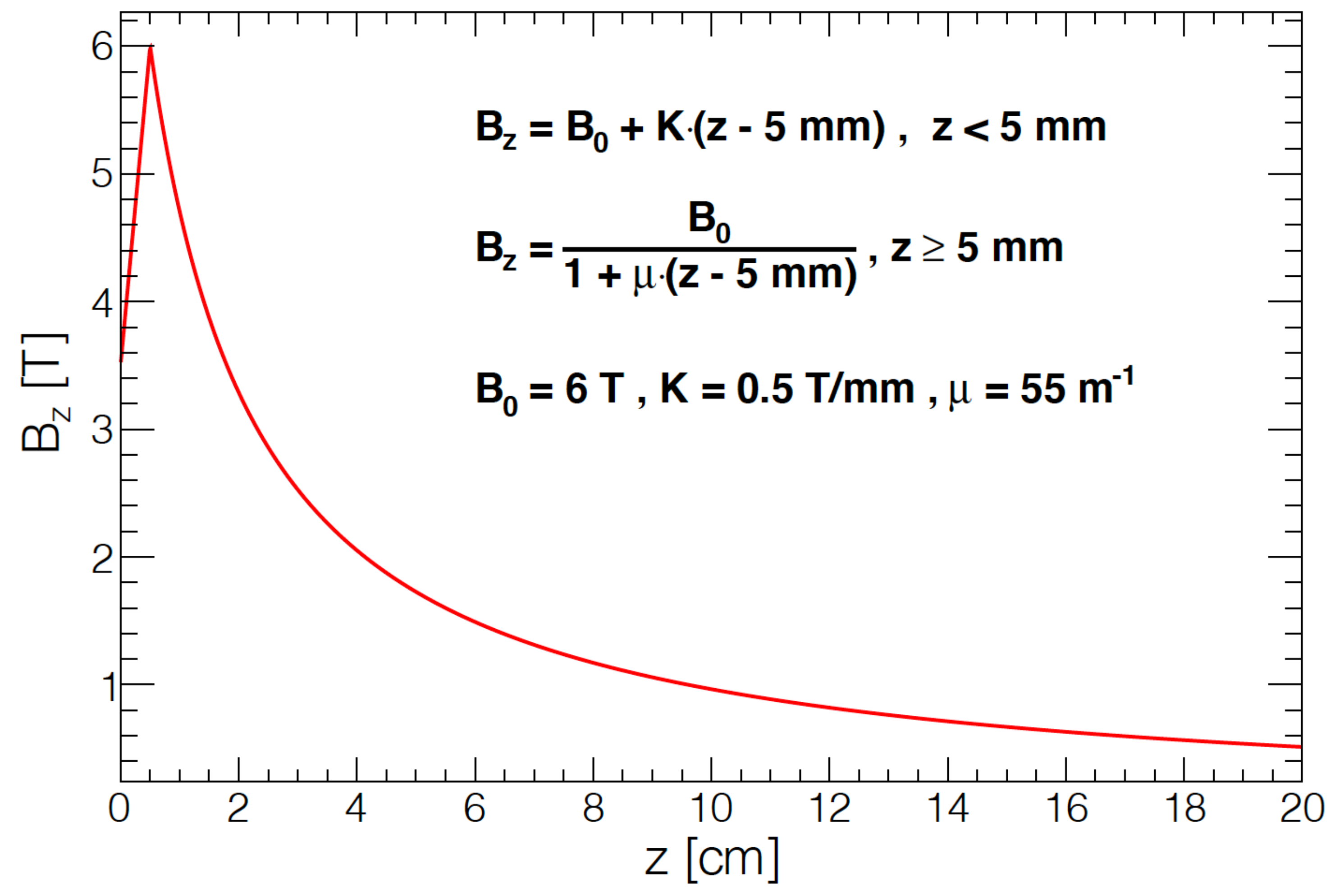
- **Fixed beam parameters:**
  - e^- parameters

Parameter	Value	Unit
Energy	5	GeV
Energy spread (RMS)	0.1	%
Normalised RMS emittance	80	mm·mrad
Bunch length (RMS)	1	mm
Number of bunches per pulse	352	
Repetition rate	50	Hz

  - e^+ parameters at the entrance of PDR

Parameter	Value	Unit
Energy	2.86	GeV
Energy acceptance (±)	1.2	%
Time window (total)	20	mm/c
Bunch charge	5.2 x 10^9	e^+
Bunch charge safety margin	20	%

- **Analytic Adiabatic Matching Device (AMD) field profile**



- **Travelling wave (TW) structures**
  - L-band, 2π/3 mode, 2 GHz, aperture: 20 mm (R)
  - No. of RF structures: 1 dec. + 10 acc.
  - NC solenoid: 0.5 T

- **Analytic injector linac energy gain**

$$\Delta E = (2.86\,\text{GeV} - E_{\text{ref}}) \cdot \cos[\omega \cdot (t - t_{\text{ref}})]$$

Reference particle with energy around 200 MeV

Results

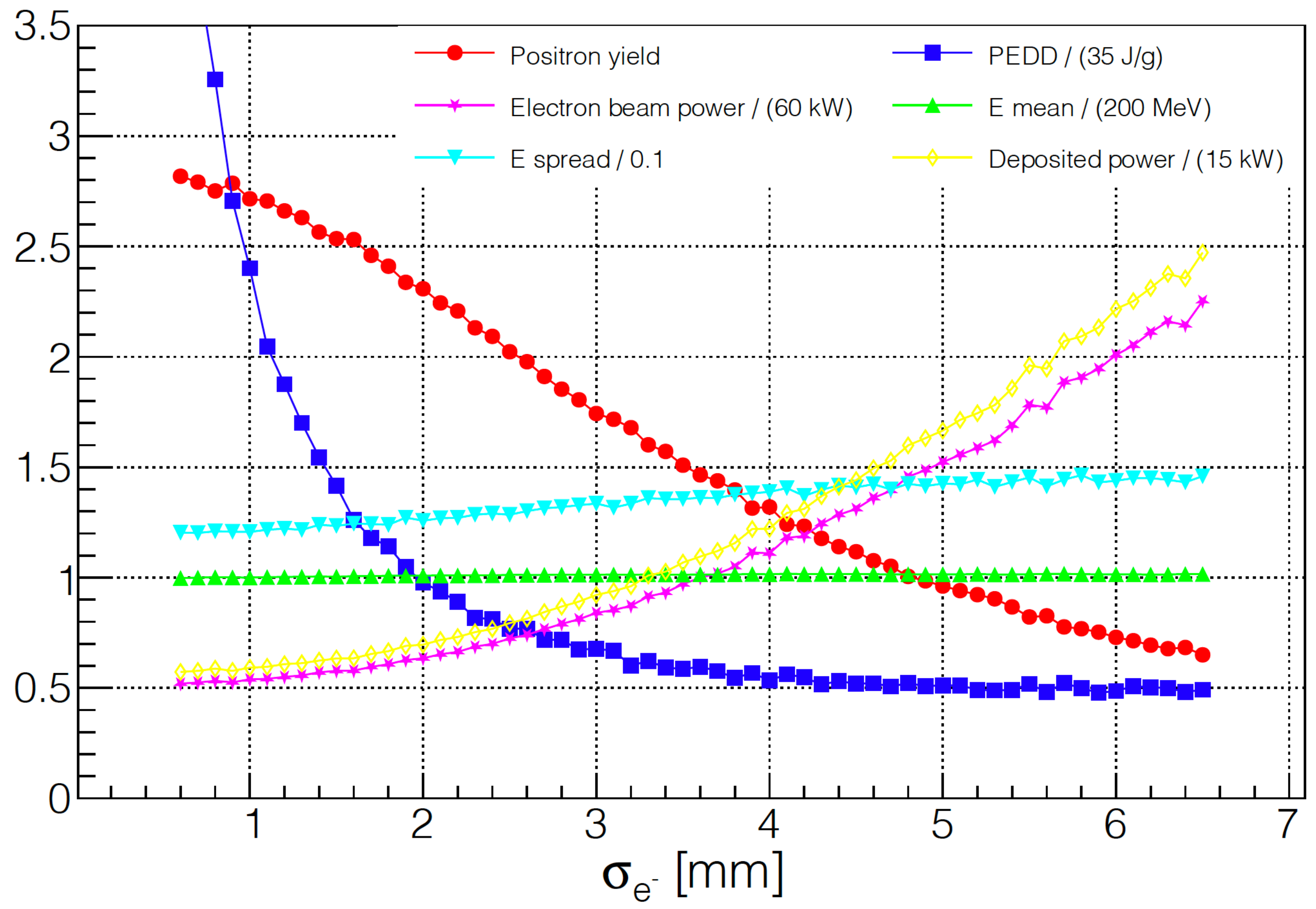
- **Free parameters to optimise (default values)**

Parameter	Symbol	Value
Electron spot size (RMS)	σ_{e^-}	5 mm
Amorphous target thickness	δ_{amor}	12 mm
AMD peak on-axis field	B_0	5 T
AMD length	L_{amd}	10 cm
AMD upstream aperture (radius)	R_{amd}	4 mm
TW decelerating phase	ϕ_{dec}	120 °
TW accelerating phase	ϕ_{acc}	120 °
TW decelerating gradient (average)	E_{dec}	16 MV/m
TW accelerating gradient (average)	E_{acc}	16 MV/m
Accepted positron yield	η_{e^+}	0.12
Target PEDD (normalised)	PEDD	98.6 J/g

- **Evolution of optimised parameters**

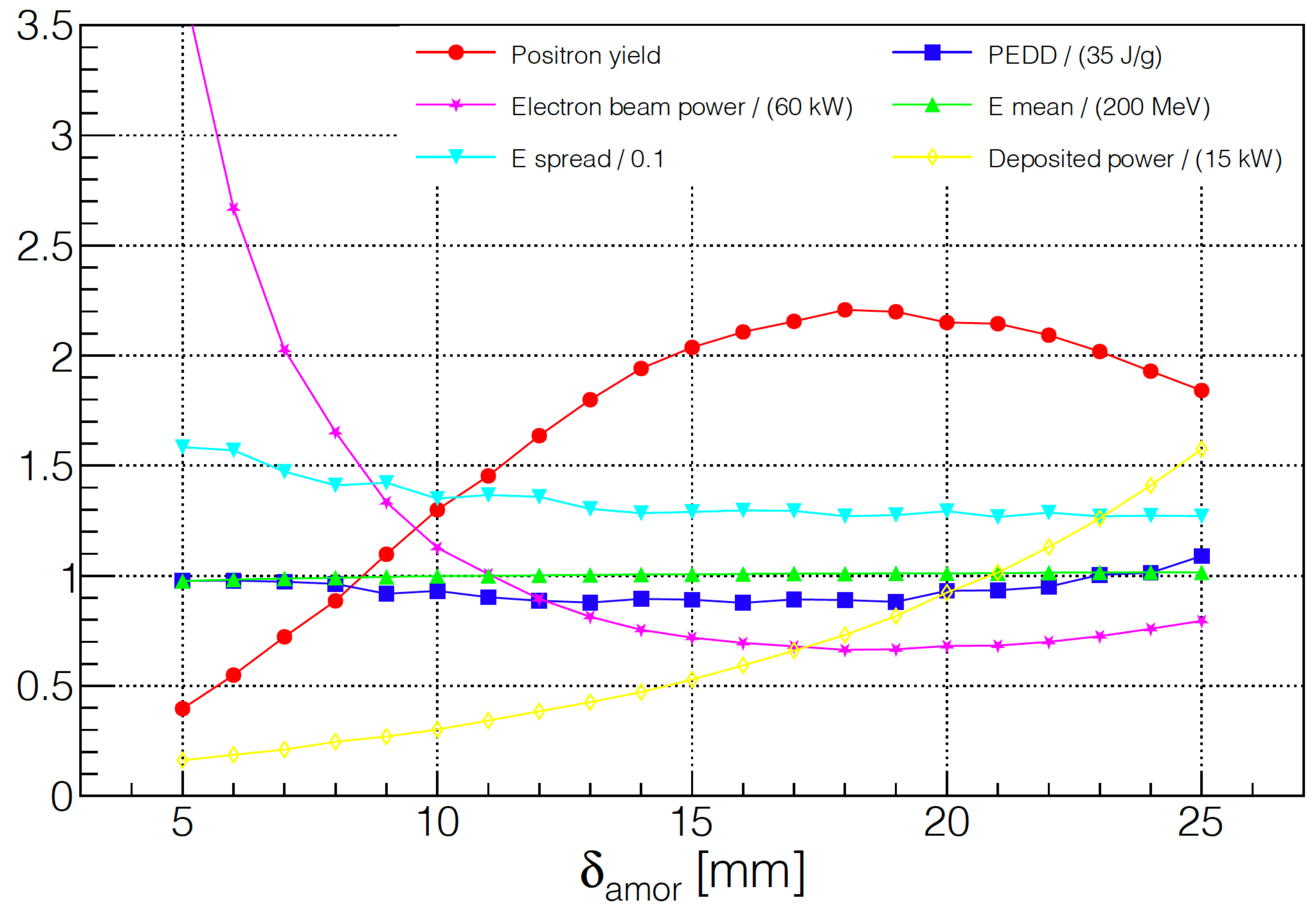
Iteration	σ_{e^-}	δ_{amor}	B_0	L_{amd}	R_{amd}	ϕ_{dec}	ϕ_{acc}	E_{dec}	E_{acc}	η_{e^+}	PEDD
1	5.0	12	5.0	10	4	120	120	16	16	0.12	98.6
2	5.0	17	5.5	10	8	150	150	15	15	0.68	24.1
3	3.2	16	4.5	20	8	150	150	12	15	1.35	25.2
4	2.5	17	6.0	22	8	155	150	13	15	1.86	29.3
5	2.2	18	6.0	22	8	155	155	11	16	2.08	33.3
6	2.2	18	6.0	22	8	160	155	13	17	2.15	32.2

- **Scan plots from final iteration look like:**



Optimised:

2.2 mm



Optimised:

18 mm

Summary

- Proposed a new simple and efficient algorithm based on iterations of scan for positron source optimisation
- Many advantages compared with conventional algorithms, such as Nelder-Mead algorithm
- New algorithm can also be dozens of times faster, benefiting from simultaneous and distributed computations
- An application example demonstrated with an simplified optimisation the CLIC positron source at 380 GeV