# Accumulated indeterminacy : revision

MICHIGAN STATE UNIVERSITY LISE++

**_version 9.2.66_**

**Revised due to H.W.'s complain for unexpected very narrow spatial distribution**

***What is called by "accumulated indeterminacy" in LISE++ ?***

**Indeterminacy obtained in dispersive focal plane passing material due to:**

- **beam initial spot size (for one P exists dX!=0)**
- **beam initial momentum emittance (for one X exist dP!=0)**
- **energy loss straggling (for one X obtain dP!=0)**
- **material thickness defect (for one X obtain dP!=0)**
- **different incident angles (used only in MC LISE)**

***It is very important issue for very thick wedges & large dispersions ☹***

***In the previous versions all these contributions have summarized to a value "sigma_dPX" has been used coupling with global dispersion coefficient.
It is not correct assumption in the case of a separator from several selection stages.***

**This Important update has been done using DF4 distribution class.**



The code operates under MS Windows environment and provides a highly user-friendly interface.
It can be freely downloaded from the following internet addresses:
http://www.nscl.msu/edu/lise

# “DF4 distribution” class update

## See definition for the “DF4 distribution” class in v. 9.2.7 release

```
enum edistrFour {
    e4I,
    e4P,
    e4E,
    e4X,
    e4Y,
    e4AX,
    e4AY,
    e4Pd,
    e4Pu,
    e4Ed,
    e4Eu,
    e4dXd,
    e4dXu,
    e4dYd,
    e4dYu
};
```

Can be “Base”: e4P, e4E, e4X, e4Y, e4AX, e4AY

Implemented in version 9.2.7: e4AX, e4AY

Implemented now (version 9.2.66): e4dXd, e4dXu, e4dYd, e4dYu

**Distributions “e4Pd” & “e4Pu” are accumulated indeterminacies, Which have been used in the previous versions to obtain sigma_dPX & sigma_dPY.**

**Distributions “P” and “E” might be easily retransformed**

**e4P ↔ e4E**
**e4Pd ↔ e4Eu**
**e4Pu ↔ e4Eu**

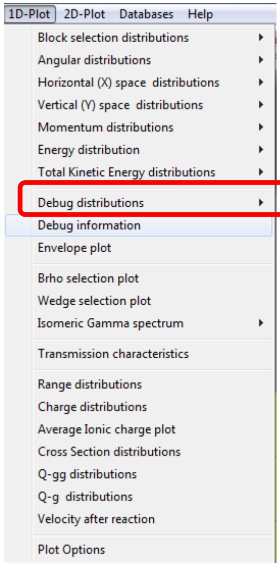
Distributions “E” are used just to have a possibility be by “Base” in the class.
For example for energy loss calculations.
All optical stuff is done with “P”-base

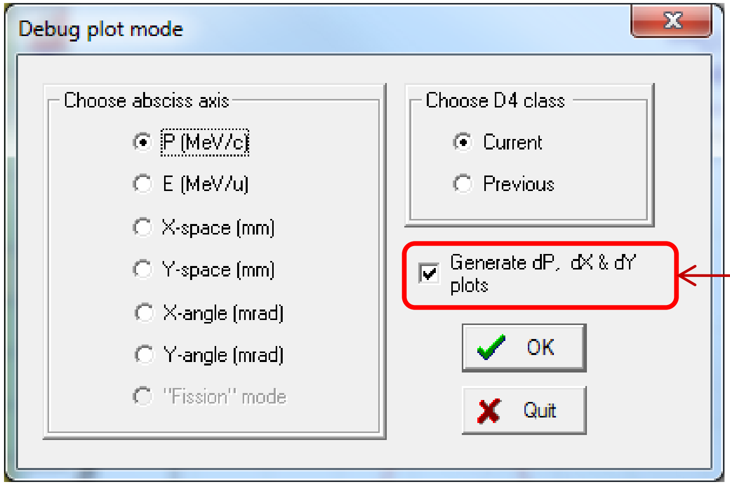
**New distributions *e4dXd, e4dXu, e4dYd, e4dYu* have been implemented to calculate spatial spots due to accumulated indeterminacies from block to block.**

$$e4dX^d_1 = e4dX^d_0 * (x/x)_{local} + e4P^d * (x/d)_{local}$$
$$e4dX^u_1 = e4dX^u_0 * (x/x)_{local} + e4P^u * (x/d)_{local}$$

$$e4dY^d_1 = e4dY^d_0 * (y/y)_{local} + e4P^d * (y/d)_{local}$$
$$e4dY^u_1 = e4dY^u_0 * (y/y)_{local} + e4P^u * (y/d)_{local}$$

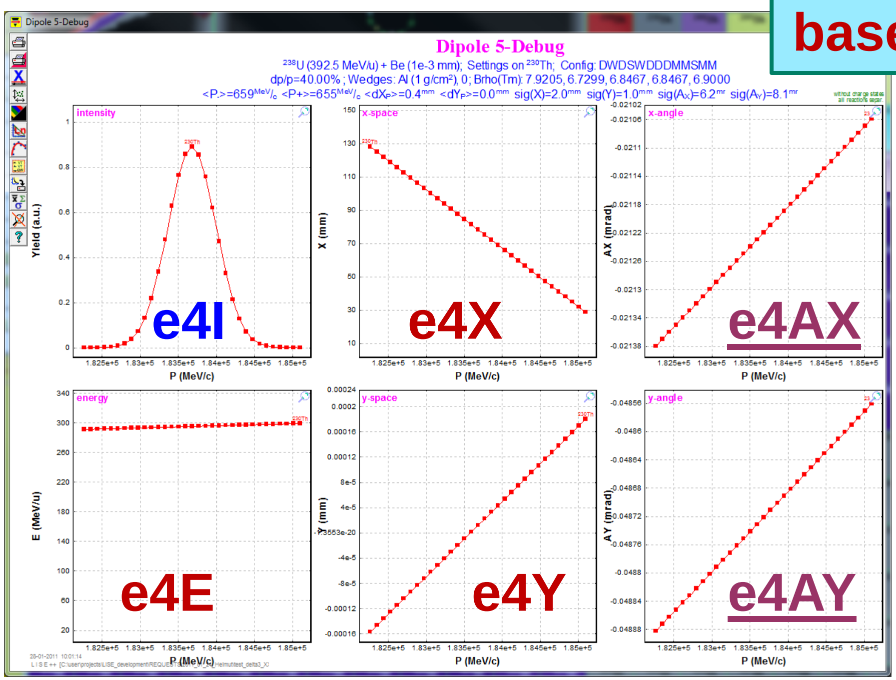
# Debug plots

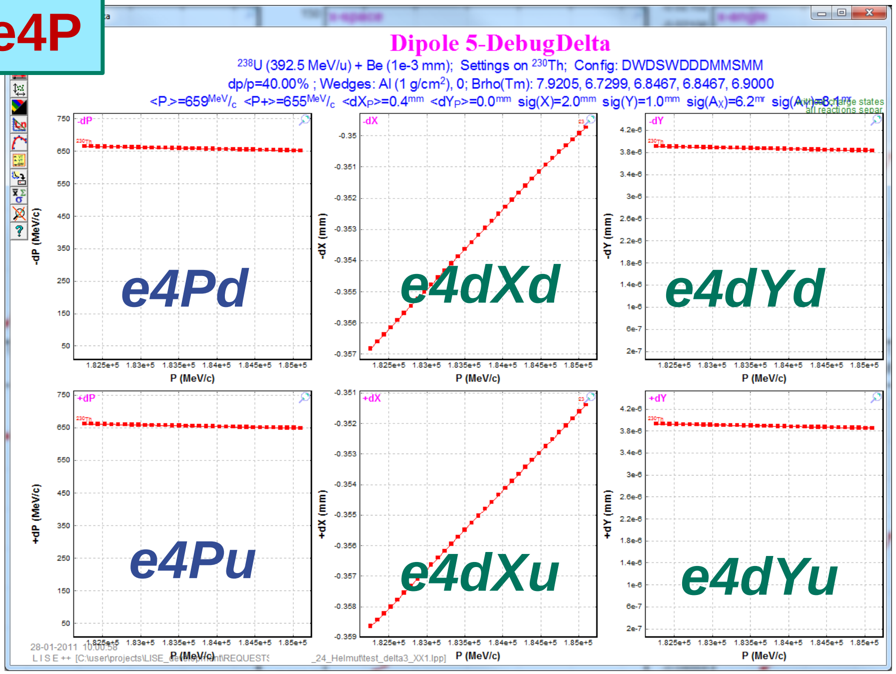


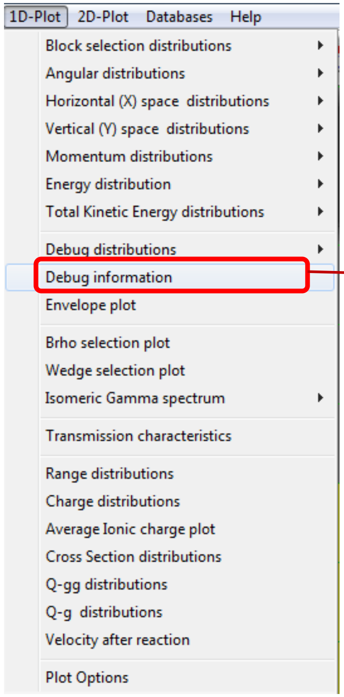

New update
(version 9.2.66)

base: e4P



# Debug Information




Debug Information (for last calculation)

Print · File Save

Debug distribution characteristics
(the data are shown after blocks)

| Block name | sPd(MeVc) | sPu(MeVc) | sX(mm) | sY(mm) | P-min | P-max | x-min | x-max | y-min | y-max | dX/dP | dY/dP | -deltaX(P) | +deltaX(P) | -deltaY(P) | +deltaY(P) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stripper | 0.00 | 0.00 | 1.00 | 2.00 | 214411 | 218165 | 0.0 | 0.0 | 0.00 | 0.00 | 8.52e-08 | 8.52e-08 | 0.00 | 0.00 | 0.00 | 0.00 |
| TA->PF2 | 0.00 | 0.00 | 1.71 | 4.07 | 214411 | 218165 | -22.4 | 22.4 | 0.00 | 0.00 | -1.19e-02 | -1.81e-07 | 0.00 | 0.00 | 0.00 | 0.00 |
| PF2-slit | 0.00 | 0.00 | 1.71 | 4.07 | 214411 | 218165 | -22.4 | 22.4 | 0.00 | 0.00 | -1.19e-02 | -1.81e-07 | 0.00 | 0.00 | 0.00 | 0.00 |
| Det. PF2 | 0.00 | 0.00 | 1.71 | 4.07 | 214411 | 218165 | -22.4 | 22.4 | 0.00 | 0.00 | -1.19e-02 | -1.81e-07 | 0.00 | 0.00 | 0.00 | 0.00 |
| PF2 degrader | 139.48 | 139.37 | 1.71 | 4.07 | 162817 | 165671 | -22.4 | 22.4 | 0.00 | 0.00 | -1.57e-02 | -2.37e-07 | 0.00 | 0.00 | 0.00 | 0.00 |
| PF2->PF4 | 139.46 | 139.36 | 1.98 | 3.23 | 162817 | 165671 | 0.0 | 0.1 | 0.00 | 0.00 | 4.16e-05 | 1.92e-07 | 2.54 | 2.54 | 0.00 | 0.00 |
| Det. PF4 | 139.46 | 139.36 | 1.98 | 3.23 | 162817 | 165671 | 0.0 | 0.1 | 0.00 | 0.00 | 4.16e-05 | 1.92e-07 | 2.54 | 2.54 | 0.00 | 0.00 |
| PF4 slit | 139.46 | 139.36 | 1.98 | 3.23 | 162817 | 165671 | 0.0 | 0.1 | 0.00 | 0.00 | 4.16e-05 | 1.92e-07 | 2.54 | 2.54 | 0.00 | 0.00 |
| PF4->MF1 | 139.45 | 139.35 | 4.18 | 3.91 | 162817 | 165671 | -56.3 | 56.4 | 0.00 | 0.00 | 3.95e-02 | -2.28e-07 | 0.15 | 0.15 | 0.00 | 0.00 |
| MF1 slit | 139.45 | 139.35 | 4.18 | 3.91 | 162817 | 165671 | -56.3 | 56.4 | 0.00 | 0.00 | 3.95e-02 | -2.28e-07 | 0.15 | 0.15 | 0.00 | 0.00 |
| MF1->MF2 | 139.45 | 139.35 | 1.91 | 3.94 | 162817 | 165671 | -51.6 | 51.4 | 0.00 | 0.00 | -3.61e-02 | 2.29e-07 | -2.59 | -2.59 | 0.00 | 0.00 |
| Det. MF2 | 139.45 | 139.35 | 1.91 | 3.94 | 162817 | 165671 | -51.6 | 51.4 | 0.00 | 0.00 | -3.61e-02 | 2.29e-07 | -2.59 | -2.59 | 0.00 | 0.00 |
| MF2 degrader | 226.75 | 226.26 | 1.91 | 3.94 | 124974 | 127168 | -51.6 | 51.4 | 0.00 | 0.00 | -4.70e-02 | 2.98e-07 | -2.59 | -2.59 | 0.00 | 0.00 |
| MF2 slits | 226.75 | 226.26 | 1.91 | 3.94 | 124974 | 127168 | -51.6 | 51.4 | 0.00 | 0.00 | -4.70e-02 | 3.06e-07 | -2.59 | -2.59 | 0.00 | 0.00 |
| MF2->MF3 | 226.75 | 226.26 | 4.18 | 3.17 | 124974 | 127168 | -56.5 | 56.0 | 0.00 | 0.00 | 5.13e-02 | -2.51e-07 | -6.00 | -6.02 | 0.00 | 0.00 |
| MF3 slit | 226.75 | 226.26 | 4.18 | 3.17 | 124974 | 127168 | -56.5 | 56.0 | 0.00 | 0.00 | 5.13e-02 | -2.51e-07 | -6.00 | -6.02 | 0.00 | 0.00 |
| MF3 -> MF9 | 226.75 | 226.26 | 1.98 | 1.95 | 124974 | 127168 | -0.5 | 0.0 | 0.00 | 0.00 | -2.07e-04 | -1.97e-07 | -8.36 | -8.38 | 0.00 | 0.00 |
| Det. MF9 | 303.64 | 302.59 | 1.98 | 1.95 | 108131 | 110902 | -0.5 | 0.0 | 0.00 | 0.00 | -1.64e-04 | -1.56e-07 | -8.36 | -8.38 | 0.00 | 0.00 |
| MF9 slit | 303.64 | 302.59 | 1.98 | 1.96 | 108131 | 110902 | -0.5 | 0.0 | 0.00 | 0.00 | -1.64e-04 | -1.56e-07 | -8.36 | -8.38 | 0.00 | 0.00 |

**e4dPd & e4dPu**

Weighted Average (by Intensity)

**StDef of X- and Y-distributions without momentum contribution**

**Boundaries of e4P, e4X, e4Y distributions**

**$\Delta X$ / $\Delta P$**
**Where**
**$\Delta X = X_{max} - X_{min}$**
**$\Delta P = P_{max} - P_{min}$**

See the next slide

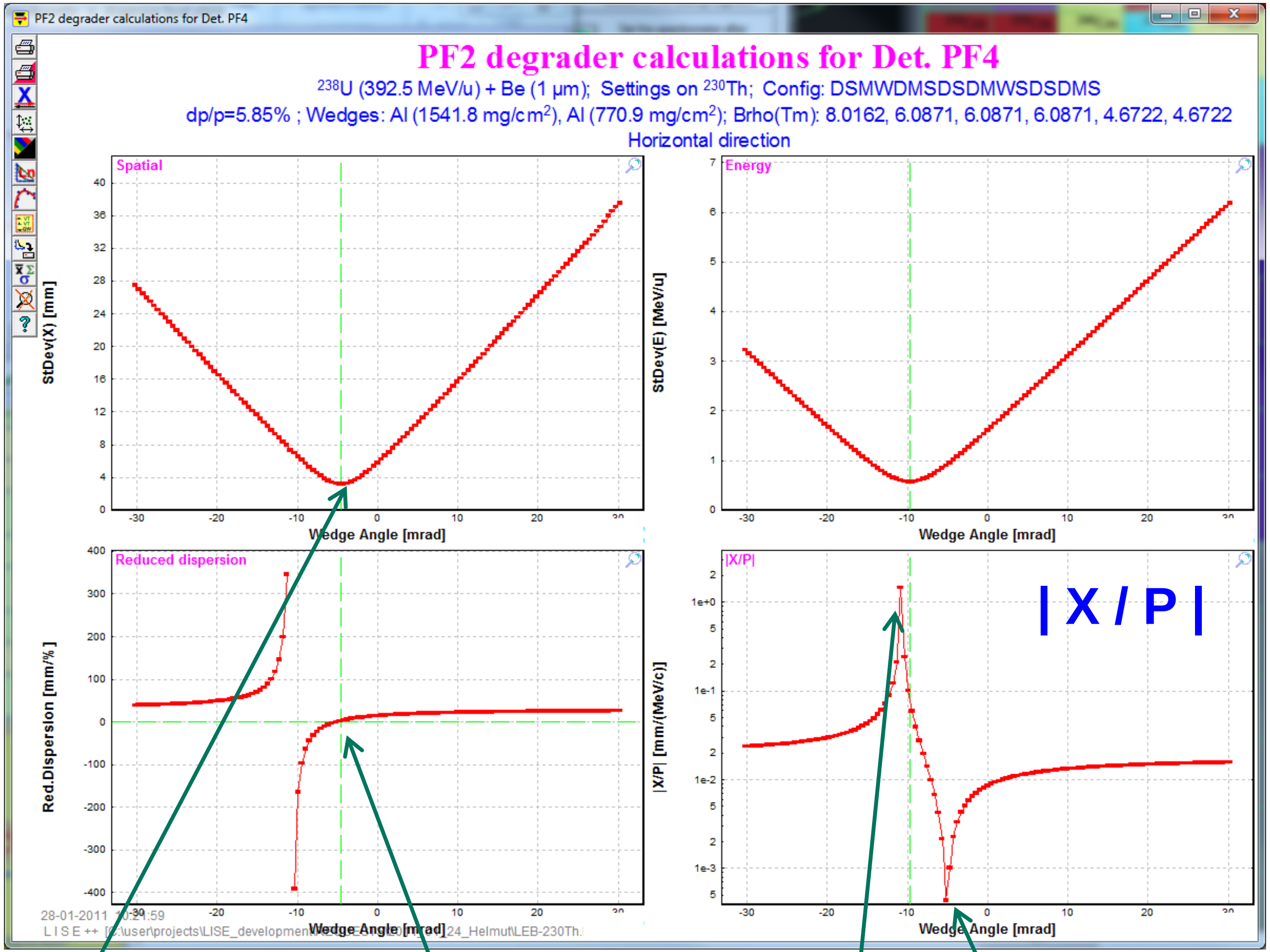
**e4dXd & e4dXu**

Weighted Average (by Intensity)

**e4dYd & e4dYu**

Weighted Average (by Intensity)

# Wedge angle calculations




"Reduced dispersion" (left bottom plot) is assumed in LISE++ as the **slope** of the **linear fit** of the D4F distribution **e4X** with **e4P** base [X=f(P)]

This is REAL achromatic mode, when the dispersion is equal to 0

But LISE++ assumes (that is not always correct), that the achromatic mode is correspond to a minimal spot

Corresponds to small ΔP

Corresponds to small ΔX

# Examples of Accumulated indeterminacy with Debug plots

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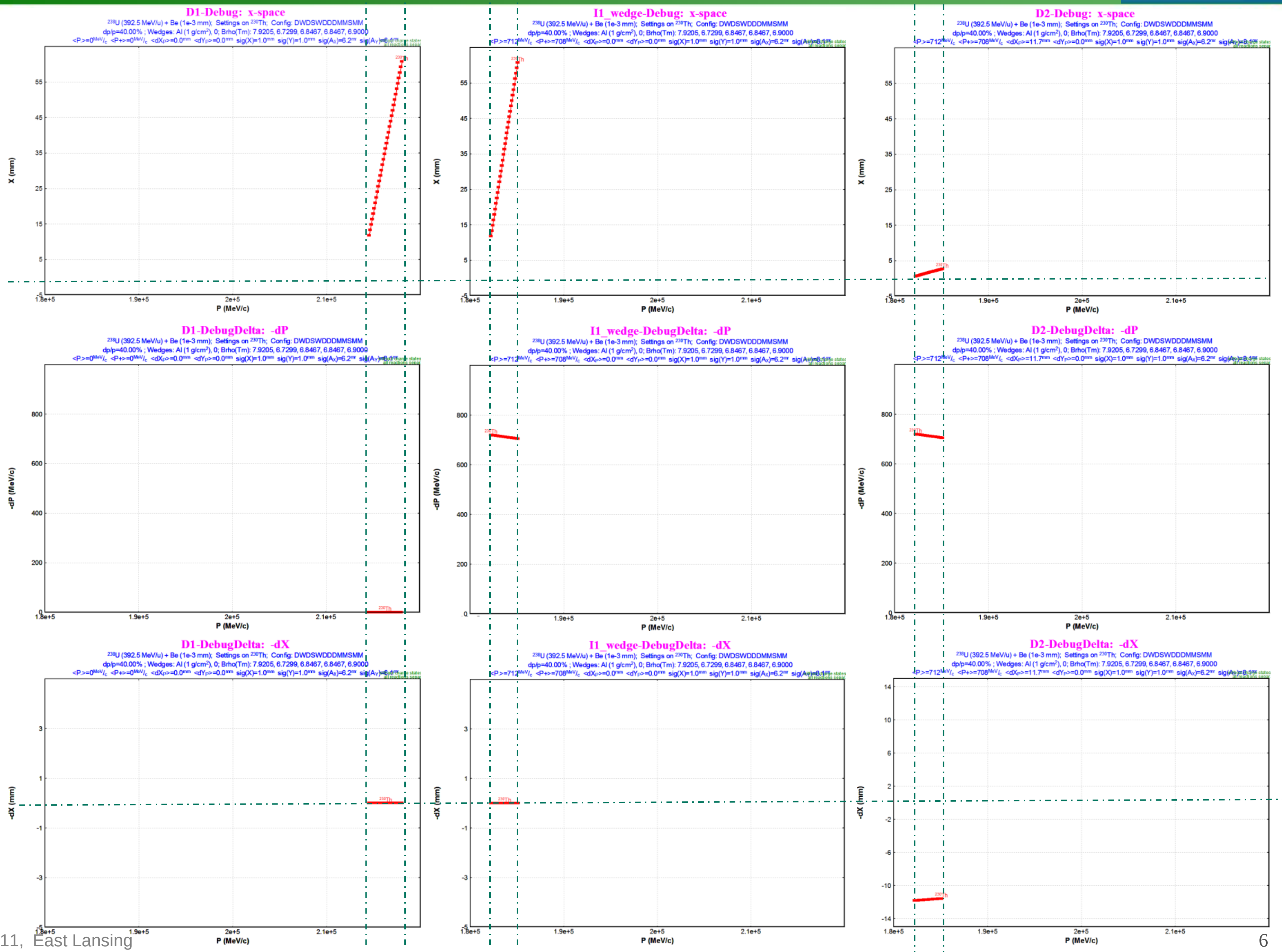
LISE++

file "1.lpp"
see envelopes on next slides

D1 – dispersive plane X/D=+30 mm/% X/X=1
I1 - Al-wedge (Achromatic for D2)
D2 – dipole X/D=-30 mm/% X/X=1



# Comparison of different versions to demonstrate the new update

Several files with multistage separation and several wedges from MP, MH and HW have been checked for the new update. But for comparison of different LISE++ versions and calculation methods in this manual it has been created a file to underline influence of Accumulated indeterminacy.

**D1**

| | Block matrix | | | | | | Global matrix | | | | | | | Beam (sig) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. X | 1 | 0 | 0 | 0 | 0 | 30 | 1 | 0 | 0 | 0 | 0 | 30 | [mm] | 2.3259 |
| 2. T | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | [mrad] | 6 |
| 3. Y | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | [mm] | 1 |
| 4. F | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | [mrad] | 8 |
| 5. L | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | [mm] | 0 |
| 6. D | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | [%] | 0.07 |

**D2**

| | Block matrix | | | | | | Global matrix | | | | | | | Beam (sig) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. X | 1 | 0 | 0 | 0 | 0 | -30 | 1 | 0 | 0 | 0 | 0 | 0 | [mm] | 1 |
| 2. T | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | [mrad] | 6 |
| 3. Y | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | [mm] | 1 |
| 4. F | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | [mrad] | 8 |
| 5. L | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | [mm] | 0 |
| 6. D | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | [%] | 0.07 |

**D3**

| | Block matrix | | | | | | Global matrix | | | | | | | Beam (sig) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. X | -1 | 0 | 0 | 0 | 0 | -30 | -1 | 0 | 0 | 0 | 0 | -30.00001 | [mm] | 2.3259 |
| 2. T | 0 | -1 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 | [mrad] | 6 |
| 3. Y | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0.00001 | [mm] | 1 |
| 4. F | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | [mrad] | 8 |
| 5. L | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | [mm] | 0 |
| 6. D | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | [%] | 0.07 |

**D4**

| | Block matrix | | | | | | Global matrix | | | | | | | Beam (sig) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. X | -4 | 0 | 0 | 0 | 0 | -1.15e+2 | 4 | 0 | 0 | 0 | 0 | 5.00004 | [mm] | 4.0153 |
| 2. T | 0 | -0.25 | 0 | 0 | 0 | 0 | 0 | 0.25 | 0 | 0 | 0 | 0 | [mrad] | 1.5 |
| 3. Y | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0.00001 | [mm] | 1 |
| 4. F | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | [mrad] | 8 |
| 5. L | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | [mm] | 0 |
| 6. D | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | [%] | 0.07 |

**D5**

| | Block matrix | | | | | | Global matrix | | | | | | | Beam (sig) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. X | -0.5 | 0 | 0 | 0 | 0 | -60 | -2 | 0 | 0 | 0 | 0 | -62.50002 | [mm] | 4.8105 |
| 2. T | 0 | -2 | 0 | 0 | 0 | 0 | 0 | -0.5 | 0 | 0 | 0 | 0 | [mrad] | 3 |
| 3. Y | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0.00001 | [mm] | 1 |
| 4. F | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | [mrad] | 8 |
| 5. L | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | [mm] | 0 |
| 6. D | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | [%] | 0.07 |

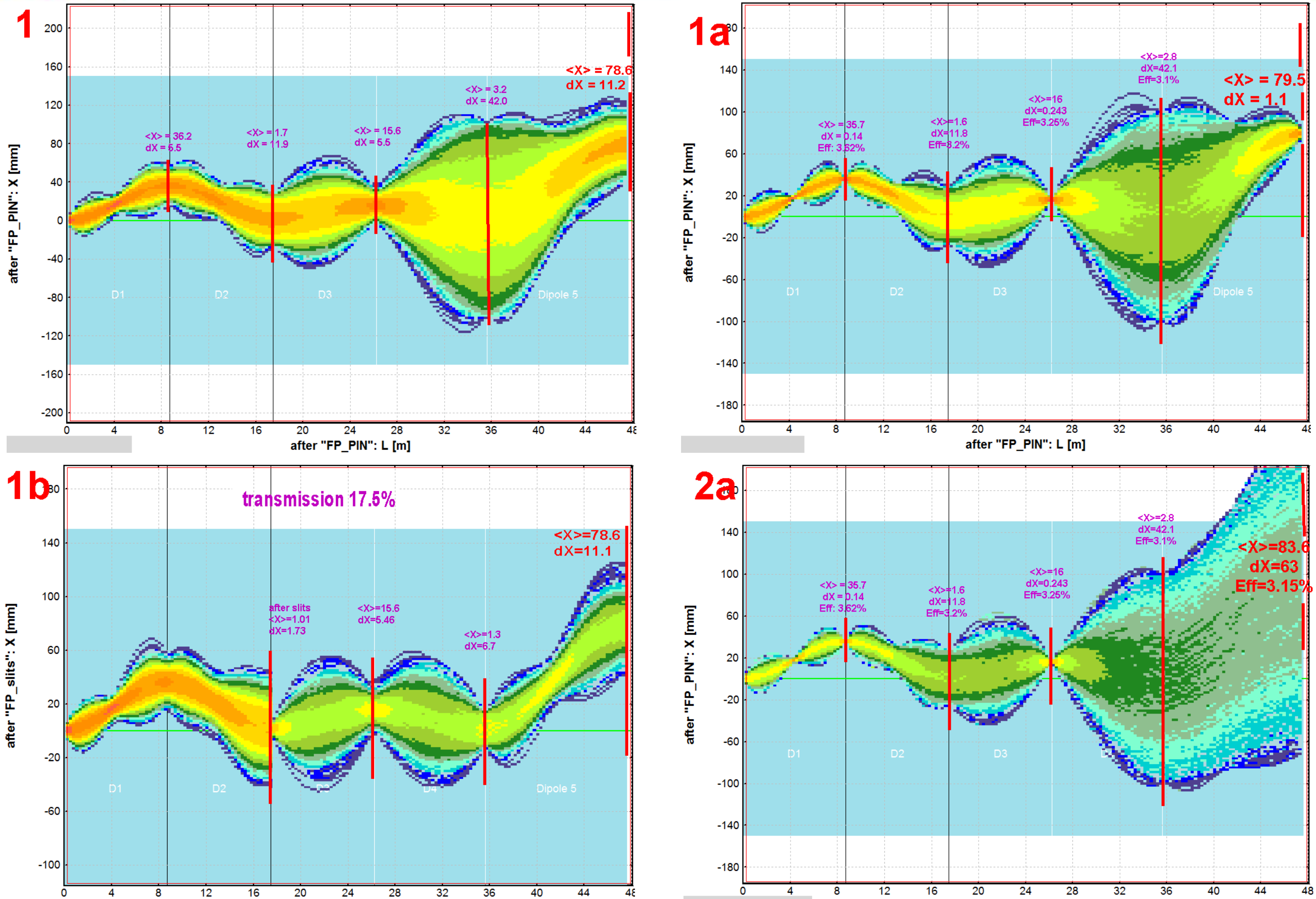
**I1_wedge is "achromatic after D2"**

***Base is "1.lpp":***

**D1 + I1_wedge + D2 + I2_slits + D3 + D4 + D5**

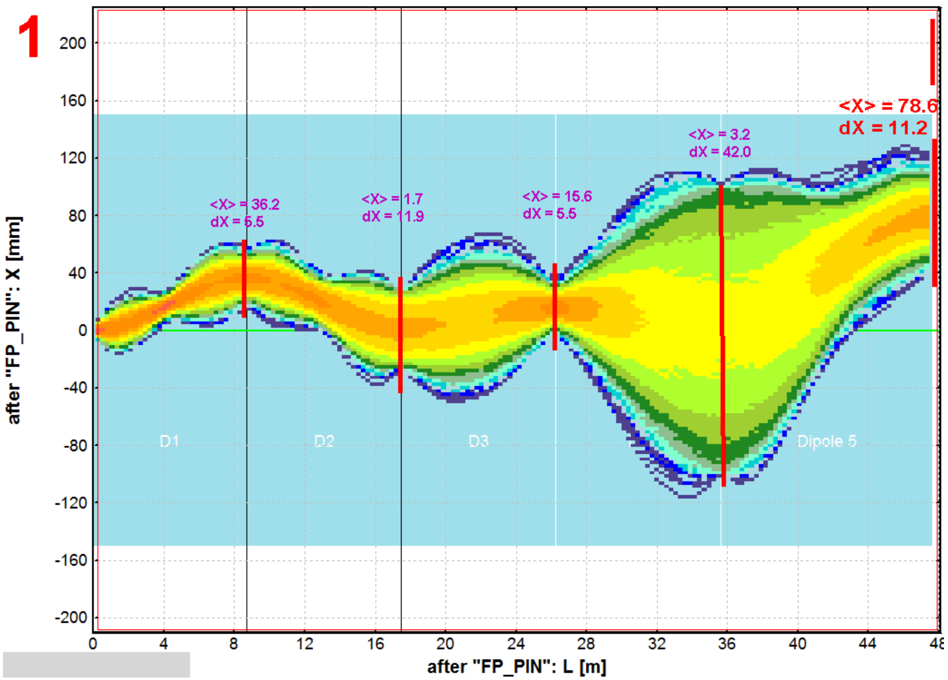
| *File* | *base* | *Changes from base* |
|---|---|---|
| 1.lpp | | |
| 1a.lpp | 1.lpp | D1-slits +35.5 ÷ +36.0 |
| 1b.lpp | 1.lpp | D2-slits -2 ÷ +4 |
| 2a.lpp | 1a.lpp | $(X/X)_{D5}$ = 1.0 instead -0.5 |

# Different configurations with the MC method

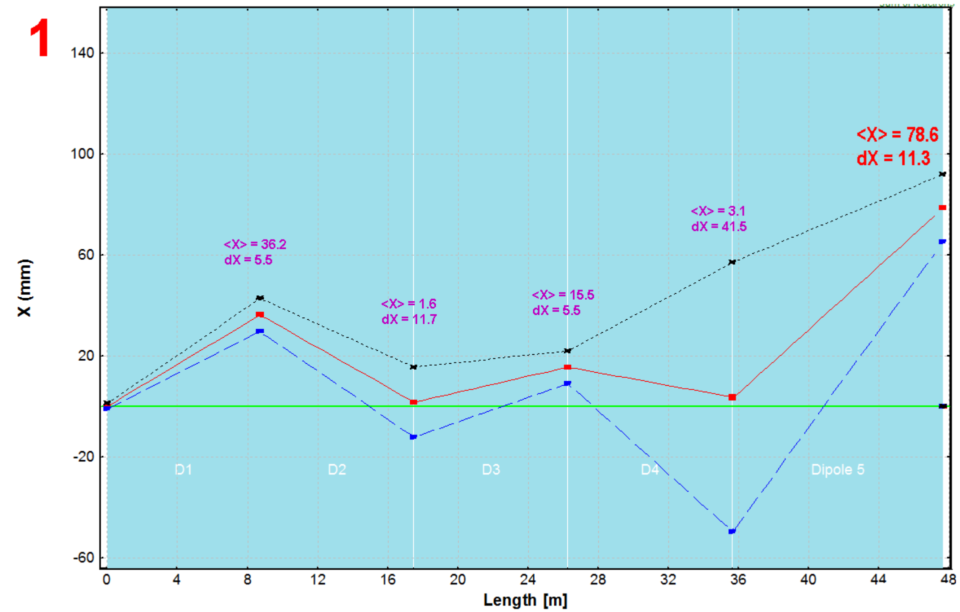


# Comparison (1) : Monte Carlo & Distribution (new & old) methods

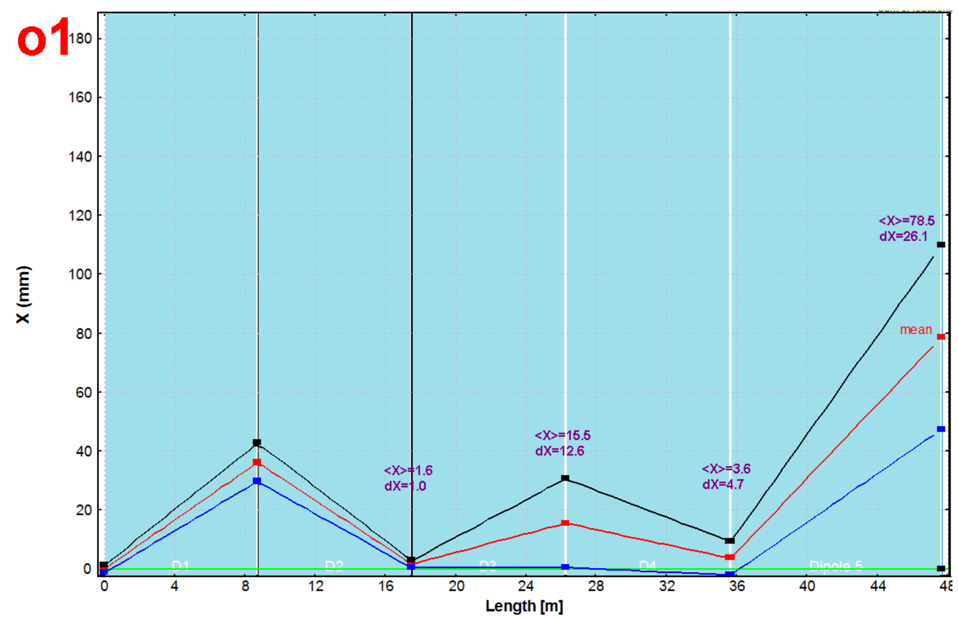
1



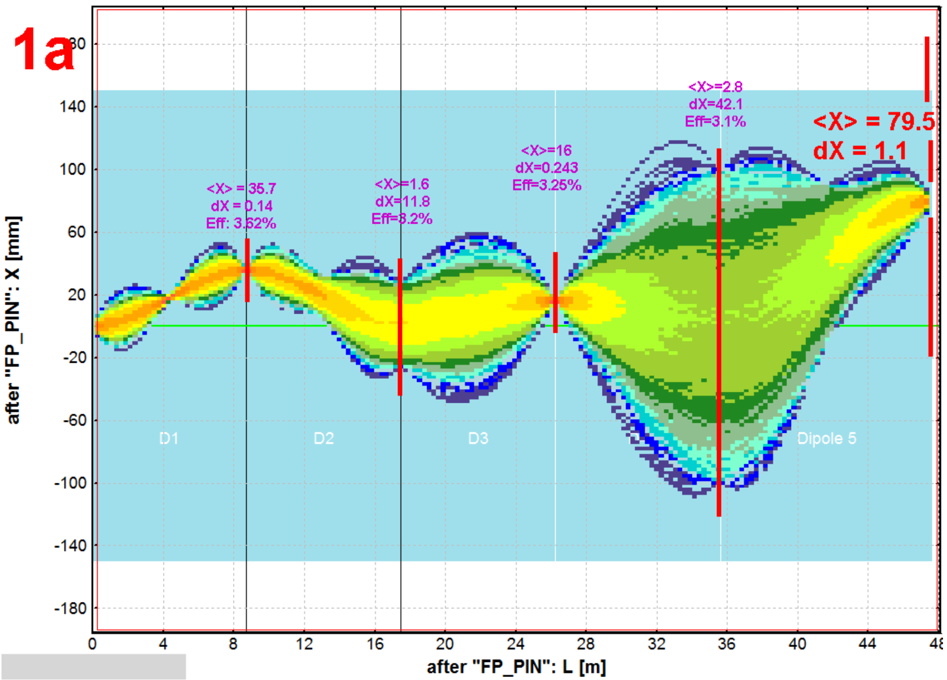

1

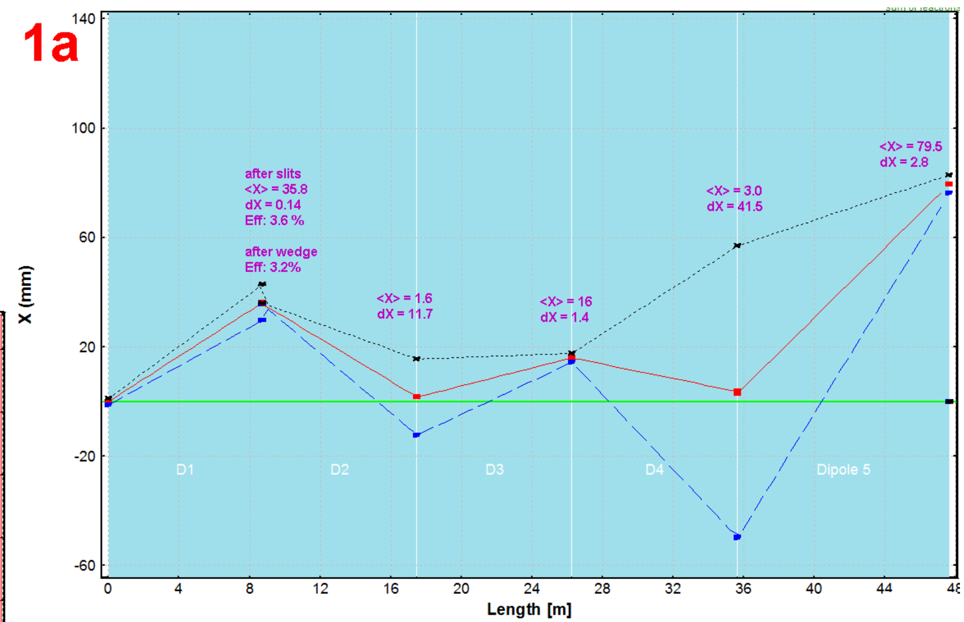


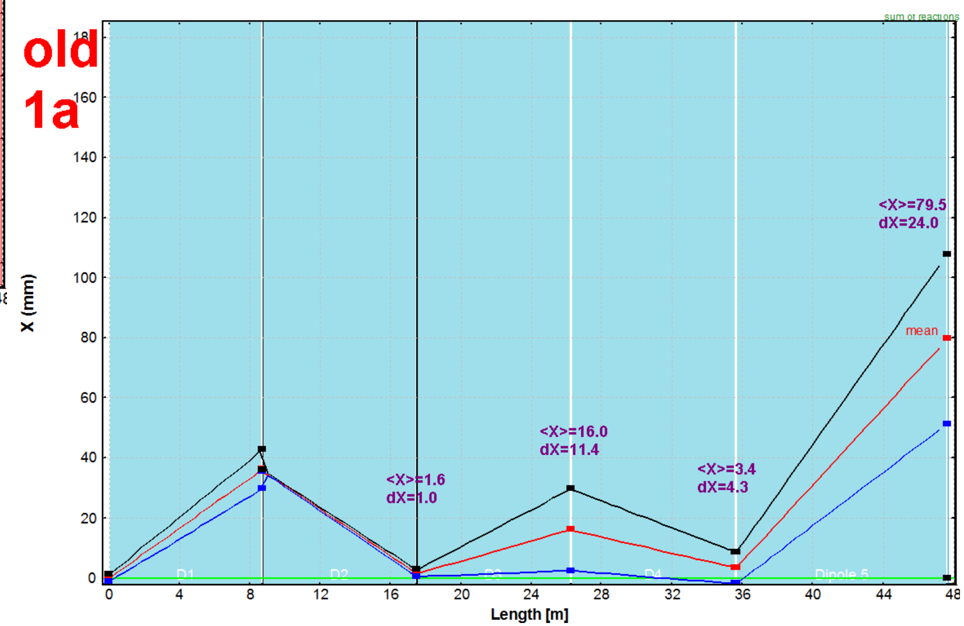

o1



# Comparison (1a) : Monte Carlo & Distribution (new & old) methods

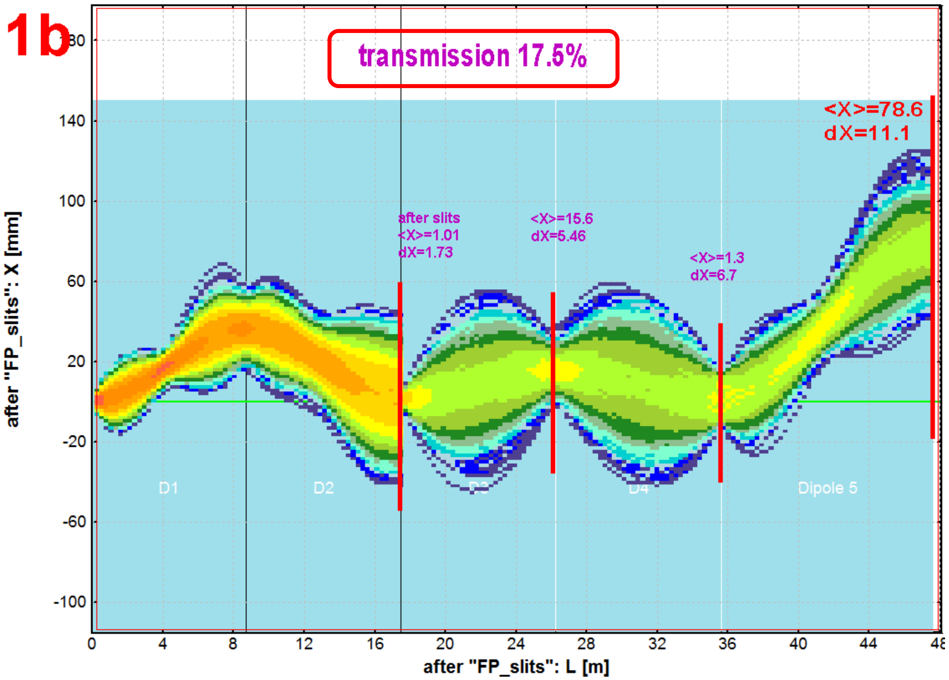


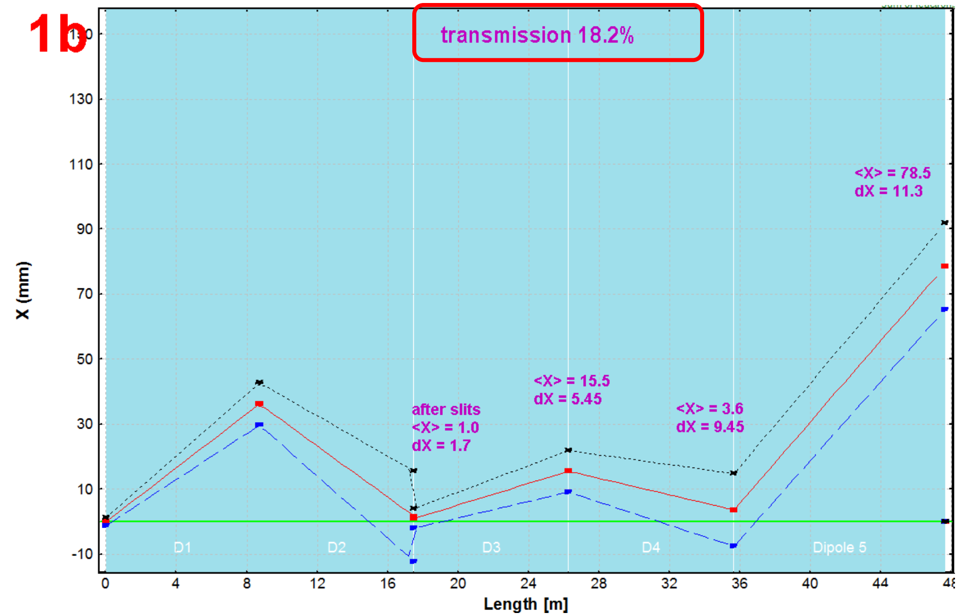



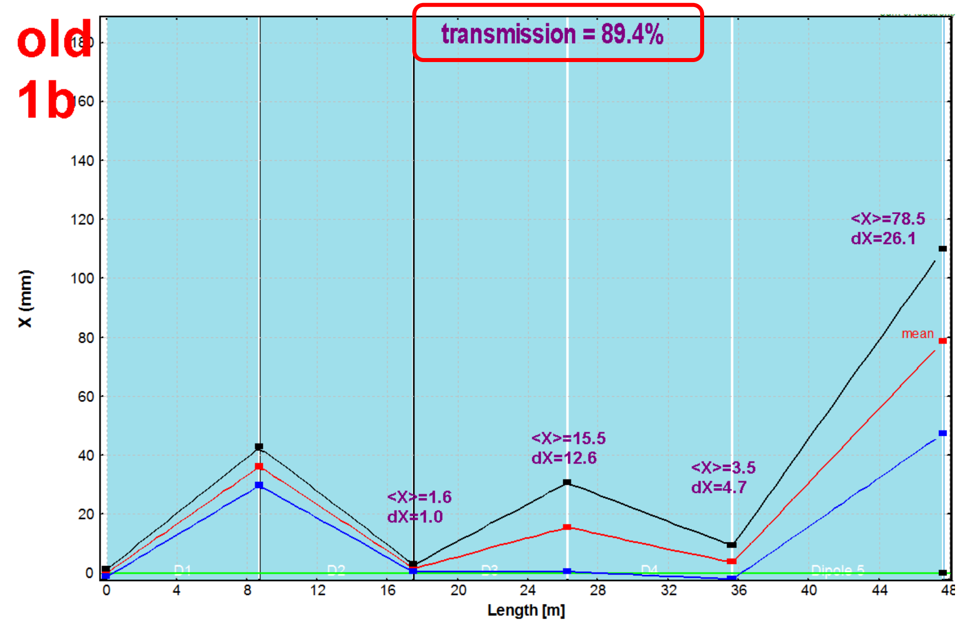




| *File* | *base* | *Changes from base* |
|---|---|---|
| 1a.lpp | 1.lpp | D1-slits +35.5 ÷ +36.0 |

# Comparison (1b) : Monte Carlo & Distribution (new & old) methods



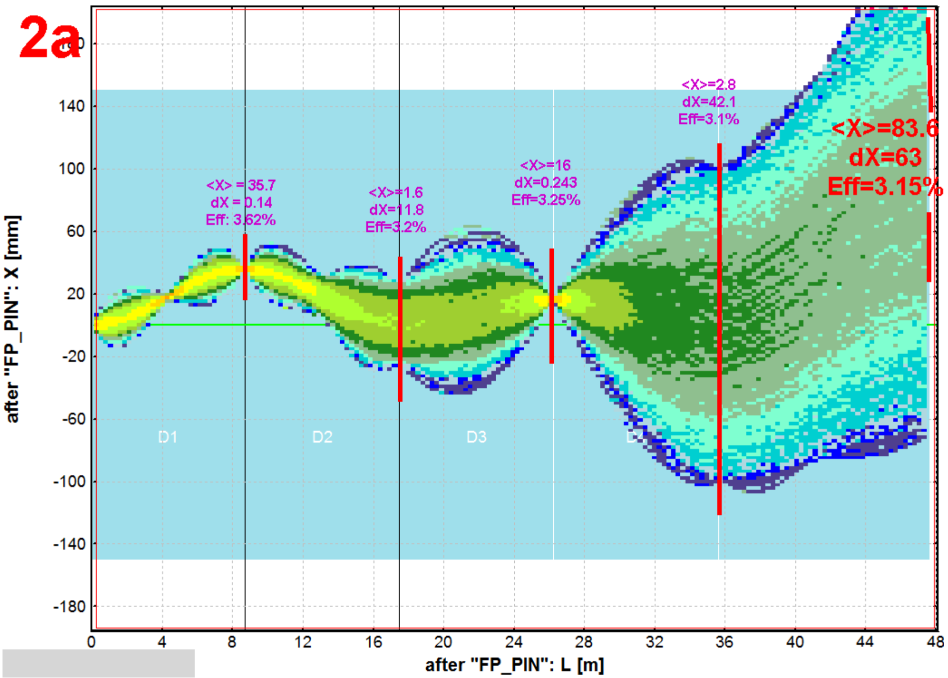



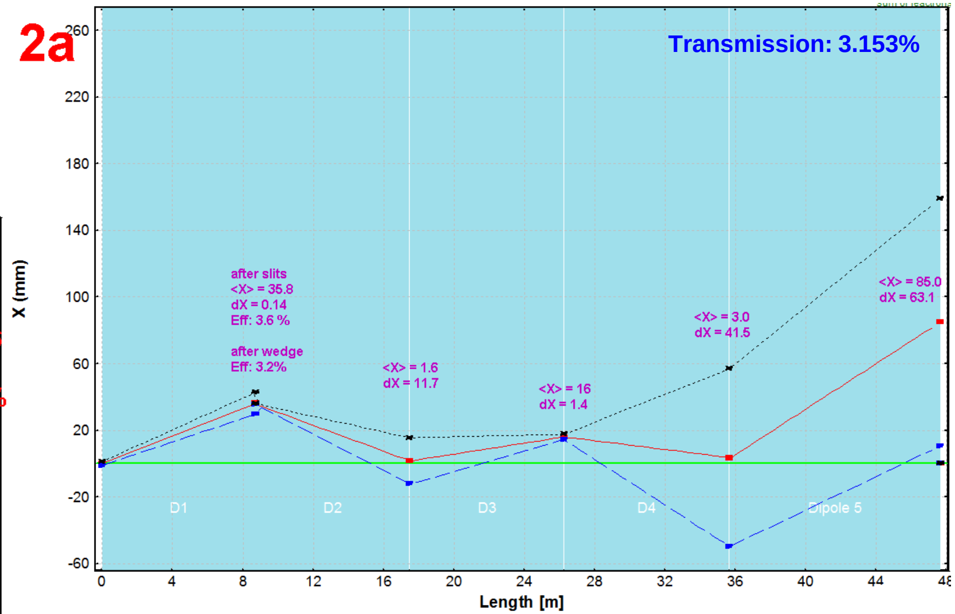



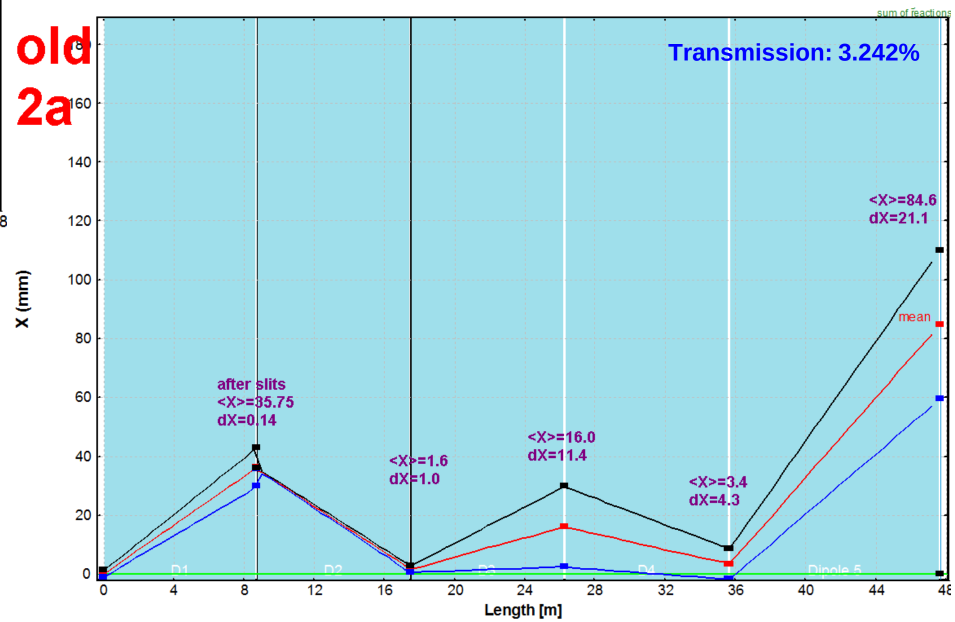

| *File* | *base* | *Changes from base* |
|---|---|---|
| [1b.lpp]() | 1.lpp | D2-slits -2 ÷ +4 |

# Comparison (2a) : Monte Carlo & Distribution (new & old) methods






| *File* | *base* | *Changes from base* |
|---|---|---|
| 2a.lpp | 1a.lpp | $(X/X)_{D5}$ = 1.0 instead -0.5 |

# H.W.'s request analysis

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | Monte Carlo | | | | | Distribution method | | | |
| 2 | **Angular Straggling** | **Energy Straggling** | **Thickness target** | **Detector resolution** | **dX emittance** | **dP emttiance** | **Sigma** | **MC sum** | **shape** | **Trans-mission, % (OLD)** | **Trans-mission, % (NEW)** | **Sigma (OLD)** | **Sigma (NEW)** | **Trans-mission, % (OLD)** | **Trans-mission, % (NEW)** |
| 3 | REGULAR | DGM | REGULAR | REGULAR | 1 | 0.1 | 10.7 | 5.00E+04 | | | | | | | |
| 4 | REGULAR | ATIMA | REGULAR | REGULAR | 1 | 0.1 | 9.06 | 3.60E+04 | | 83% | 63% | 1.97 | 8.6 | 62% | 62% |
| 5 | REGULAR | no | REGULAR | REGULAR | 1 | 0.1 | 7.37 | 5.09E+04 | | | | | | | |
| 6 | no | no | REGULAR | REGULAR | 1 | 0.1 | 7.39 | 3.57E+04 | | | | | | | |
| 7 | no | no | no | REGULAR | 1 | 0.1 | 7.4 | 5.23E+04 | | **See the next slide** | 66% | 1.97 | 5.8 | | 64% |
| 8 | no | no | no | no | 1 | 0.1 | 7.4 | 4.40E+04 | | | | | | | |
| 9 | no | no | no | no | 0 | 0.1 | 0.057 | 5.36E+04 | Assimetric! | | | | | | |
| 10 | no | no | no | no | 0 | 0 | 0.053 | 4.30E+04 | Assimetric! | | | | 0.052 | | |
| 11 | REGULAR | no | no | REGULAR | 0 | 0 | 0.055 | 6.48E+04 | Assimetric! | | | | | | |
| 12 | REGULAR | no | REGULAR | REGULAR | 0 | 0 | 0.060 | 4.55E+04 | Assimetric! | | | 0.04 | | | |
| 13 | REGULAR | no | REGULAR | REGULAR | 0 | 0.1 | 0.065 | 5.98E+04 | Assimetric! | | | 0.05 | | | |
| 14 | REGULAR | ATIMA | REGULAR | REGULAR | 0 | 0.1 | 5.17 | 6.66E+04 | | | 64% | 0.05 | 6.378 | | 61% |
| 15 | REGULAR | ATIMA | REGULAR | REGULAR | 1 | 0 | 9.04 | 2.10E+04 | | | | | | | |
| 16 | | | | | | | | | | | | | | | |
| 17 | | | | | | =+SQRT(SUMSQ(G14,G7))= | 9.03 | | | | | =+SQRT(SUMSQ(N14,N7))= | 8.62 | | |

# Corrections in MC transmission calculation

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LISE++

☑ Take into account losses due to reactions in materials

**The new version expands block transmission coefficients in the MC mode**

Monte Carlo transmission statistics by blocks

230Th : Monte Carlo Transmission Plot

238U (392.5 MeV/u) + Be (10 µm); Transmitt
dp/p=0.39% ; Wedges: Al (1541.8 mg/cm2); Br
"PF4 slit" - last block for MC calculation;
Number of passed ions 975

| | |
|---|---|
| Global Transmission | 1.02% |
| Target | 10.94% |
| NoReacted | 99.95% |
| Q-state | 10.95% |
| TA->PF2 | 25.38% |
| Angular acceptance | 58.31% |
| Slits | 43.53% |
| Det. PF2 | 100.0% |
| PF2 degrader | 36.60% |
| NoReacted | 85.17% |
| Q-state | 42.97% |
| PF2->PF4 | 100.0% |
| Det. PF4 | 100.0% |
| PF4 slit | 100.0% |

**OLD**

Monte Carlo transmission statistics by blocks

230Th : Monte Carlo Transmission Plot

238U (392.5 MeV/u) + Be
dp/p=5.85% ; Wedges: Al
"MF9 slit" - last block
Number of passed ions 0

| | |
|---|---|
| Global Transmission | 83.31% |
| Target | 100.0% |
| TA->PF2 | 100.0% |
| PF2-slit | 100.0% |
| Det. PF2 | 100.0% |
| PF2 degrader | 100.0% |
| PF2->PF4 | 100.0% |
| Det. PF4 | 100.0% |
| PF4 slit | 100.0% |
| PF4->MF1 | 99.92% |
| Angular acceptance | 99.92% |
| MF1 slit | 100.0% |
| MF1->MF2 | 100.0% |
| Det. MF2 | 100.0% |
| MF2 degrader | 100.0% |
| MF2 slits | 100.0% |
| MF2->MF3 | 98.42% |
| Angular acceptance | 98.42% |
| MF3 slit | 100.0% |
| MF3 -> MF9 | 84.71% |
| Angular acceptance | 84.71% |
| Det. MF9 | 100.0% |
| MF9 slit | 100.0% |

**NEW**

Monte Carlo transmission statistics by blocks

230Th : Monte Carlo Transmission Plot

238U (392.5 MeV/u) +
dp/p=5.85% ; Wedges:
"MF9 slit" - last blo
Number of passed ions

| | |
|---|---|
| Global Transmission | 63.80% |
| Target | 100.0% |
| TA->PF2 | 100.0% |
| PF2-slit | 100.0% |
| Det. PF2 | 100.0% |
| PF2 degrader | 85.41% |
| NoReacted | 85.41% |
| PF2->PF4 | 100.0% |
| Det. PF4 | 100.0% |
| PF4 slit | 100.0% |
| PF4->MF1 | 99.85% |
| Angular acceptance | 99.85% |
| MF1 slit | 100.0% |
| MF1->MF2 | 100.0% |
| Det. MF2 | 100.0% |
| MF2 degrader | 92.56% |
| NoReacted | 92.56% |
| MF2 slits | 100.0% |
| MF2->MF3 | 98.28% |
| Angular acceptance | 98.28% |
| MF3 slit | 100.0% |
| MF3 -> MF9 | 84.14% |
| Angular acceptance | 84.14% |
| Det. MF9 | 97.74% |
| NoReacted | 97.74% |
| MF9 slit | 100.0% |