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Monte Carlo Simulations of Natural Uranium Setups Irradiated With Relativistic Deuterons by Means of MCNPX Code

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Setup

Method

Results

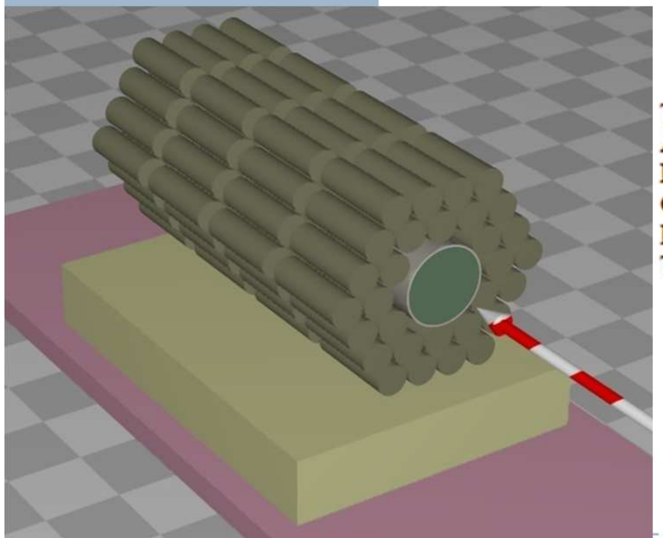
Beam monitors

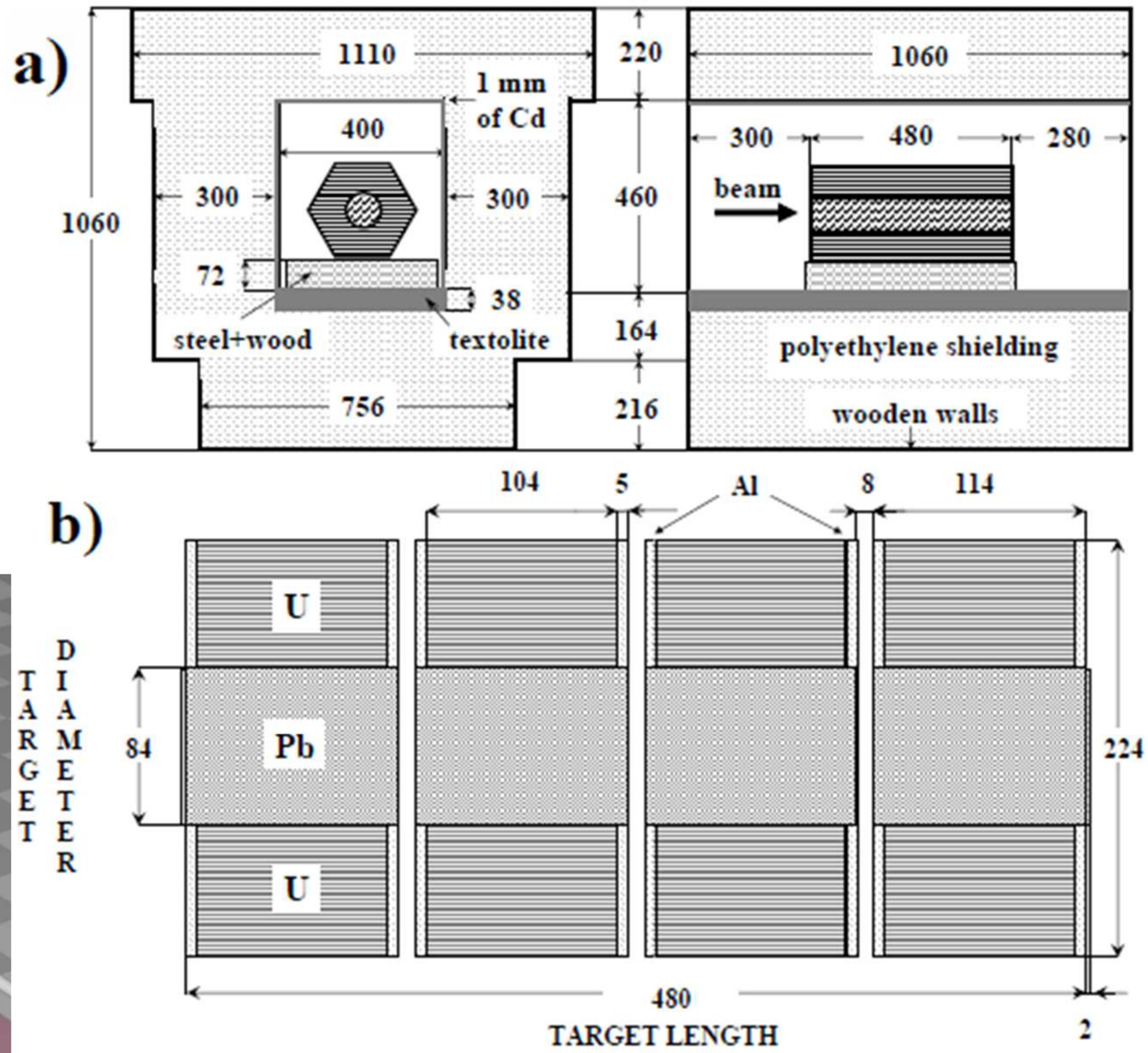
Conclusion

Outline

- Energy + Transmutation & Kvinta setup description
- Method and models used in MCNPX simulations
- Beam monitoring and input parameters
- Computation results
- Conclusion

Energy + Transmutation Setup





m natU = 206 kg

Kvinta 2010 and 2011 Setup

Setup
- *E+T setup*
- ***Kvinta setup***

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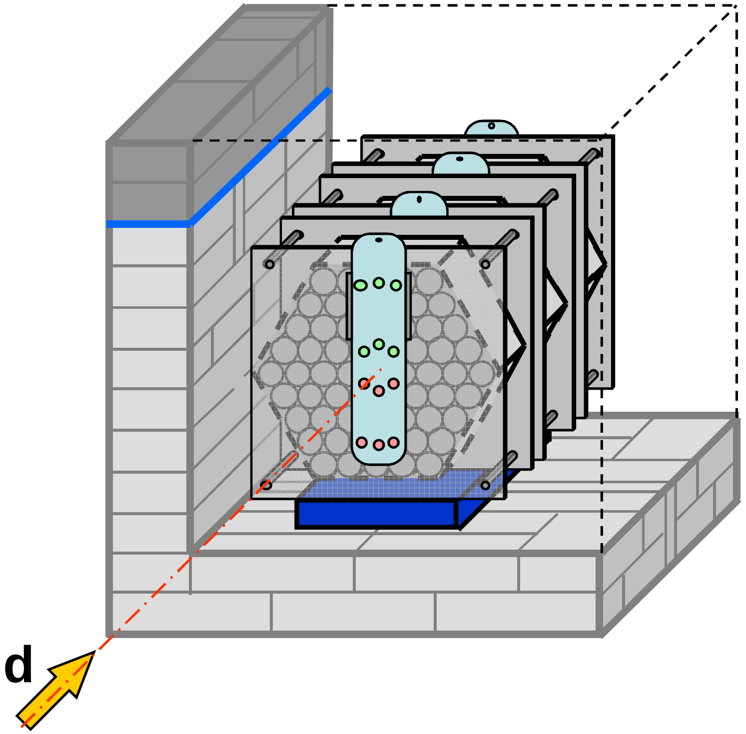
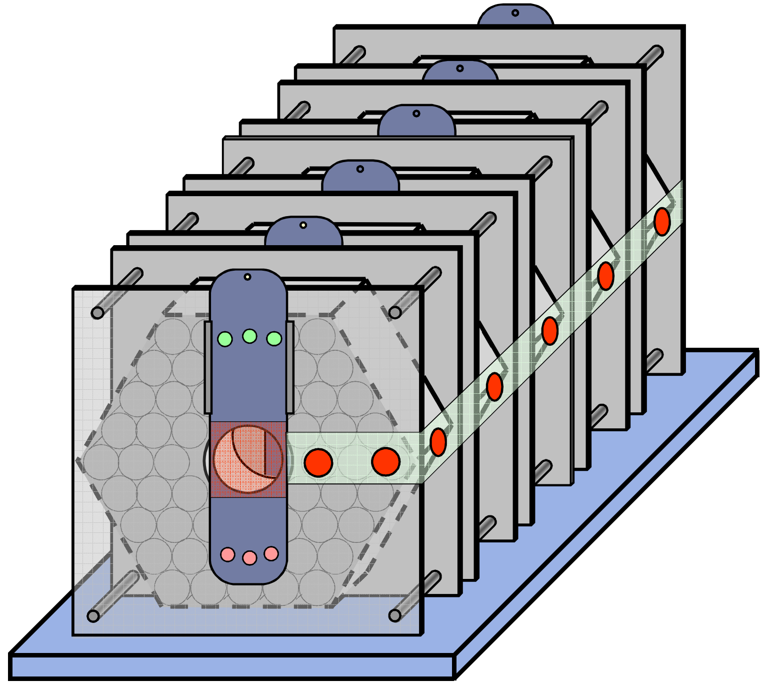
Kvinta 2010 setup



- 3 sections
- 4 detector plates
- Pb shielding

m natU = 315 kg

Kvinta 2011 setup



- 5 sections
- 6 detector plates
- no Pb shielding

m natU = 512 kg

Kvinta-M 2011 Setup

Setup
- *E+T setup*
- ***Kvinta setup***

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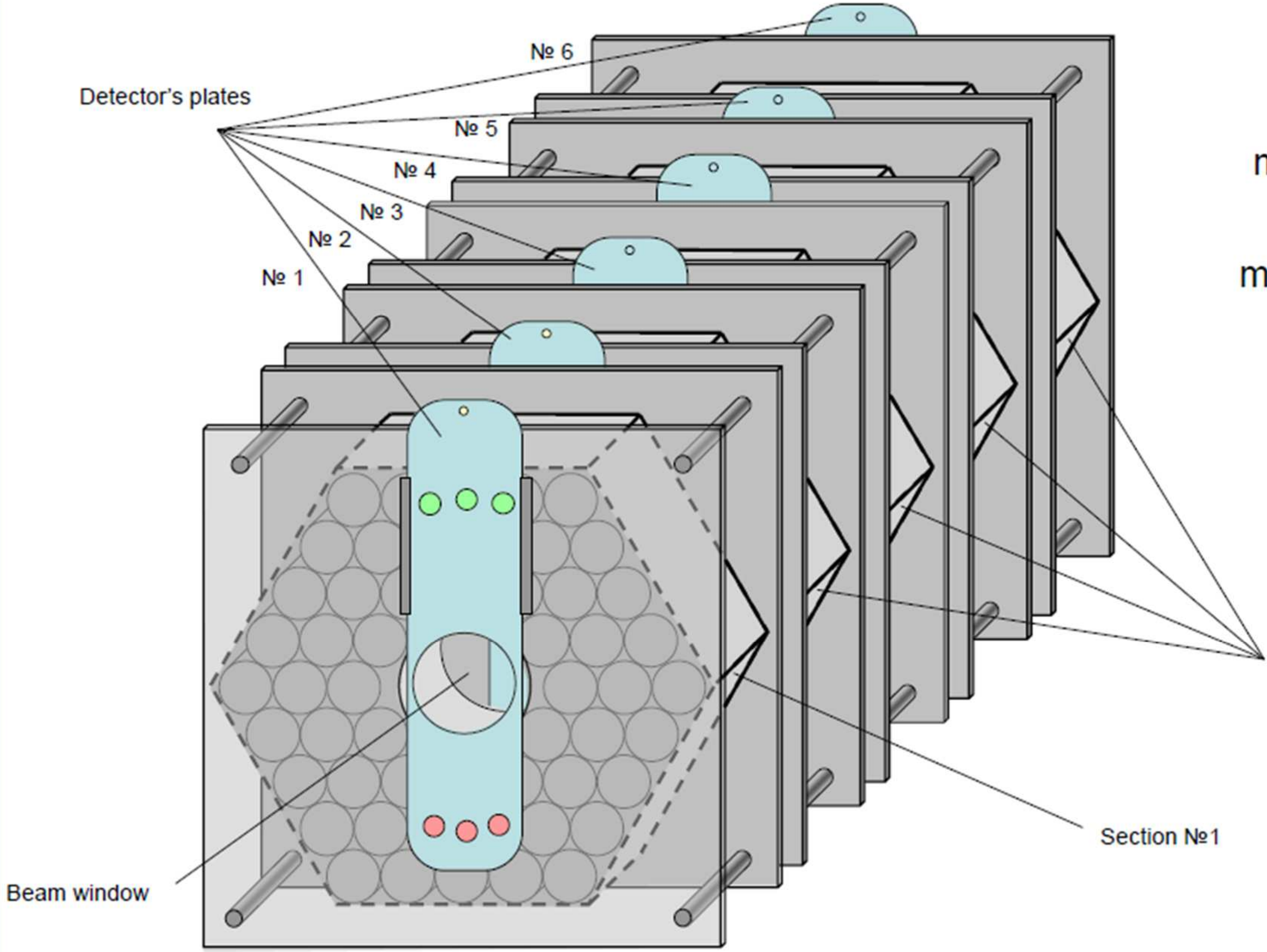

$m_U \approx 500$ kg

$m_{target} \approx 540$ kg

Setup

• *E+T setup*

• ***Kvinta setup***

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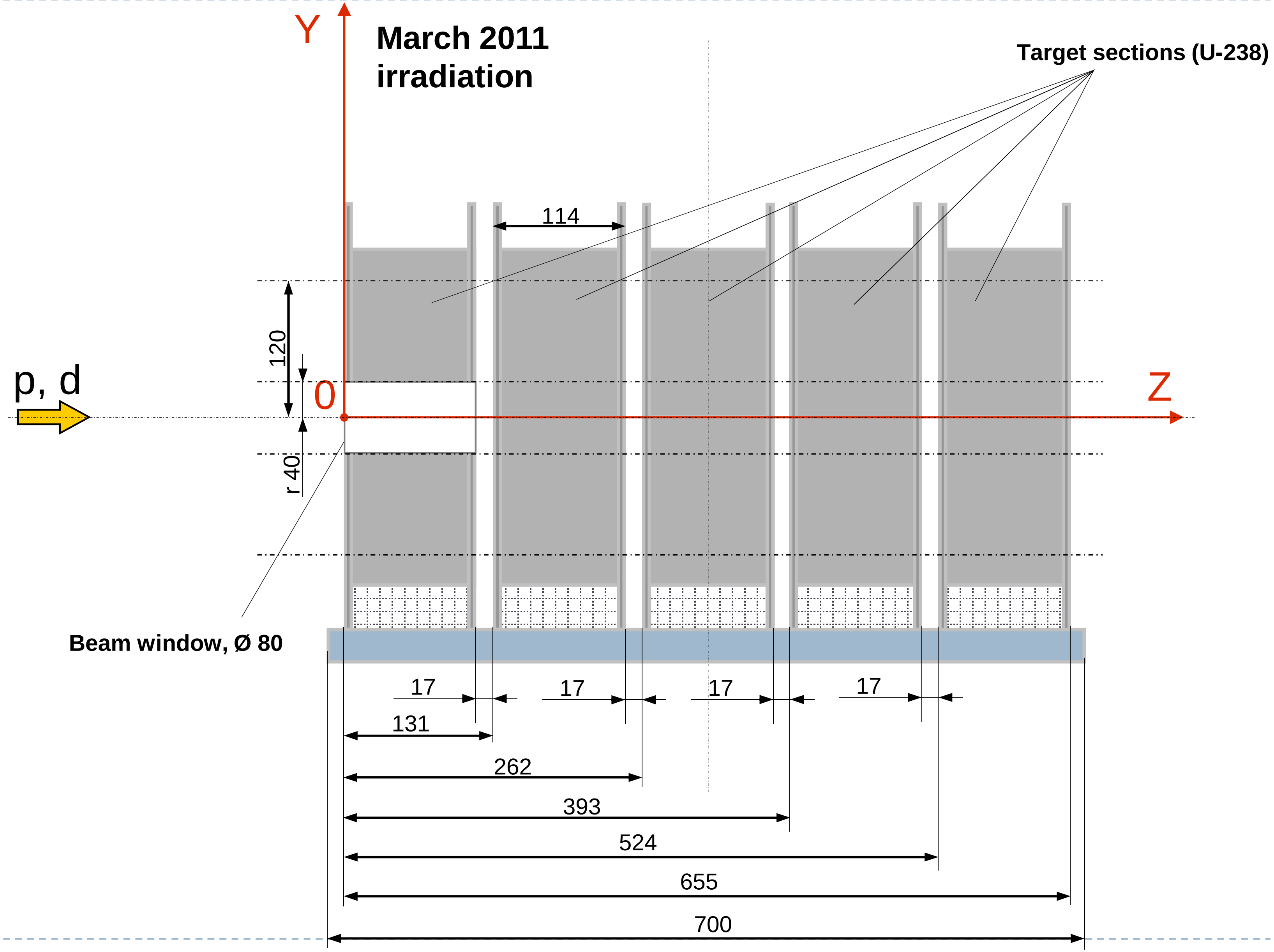
Kvinta-M 2011 Setup



Kvinta-M 2011 Setup

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- *E+T setup*
- ***Kvinta setup***

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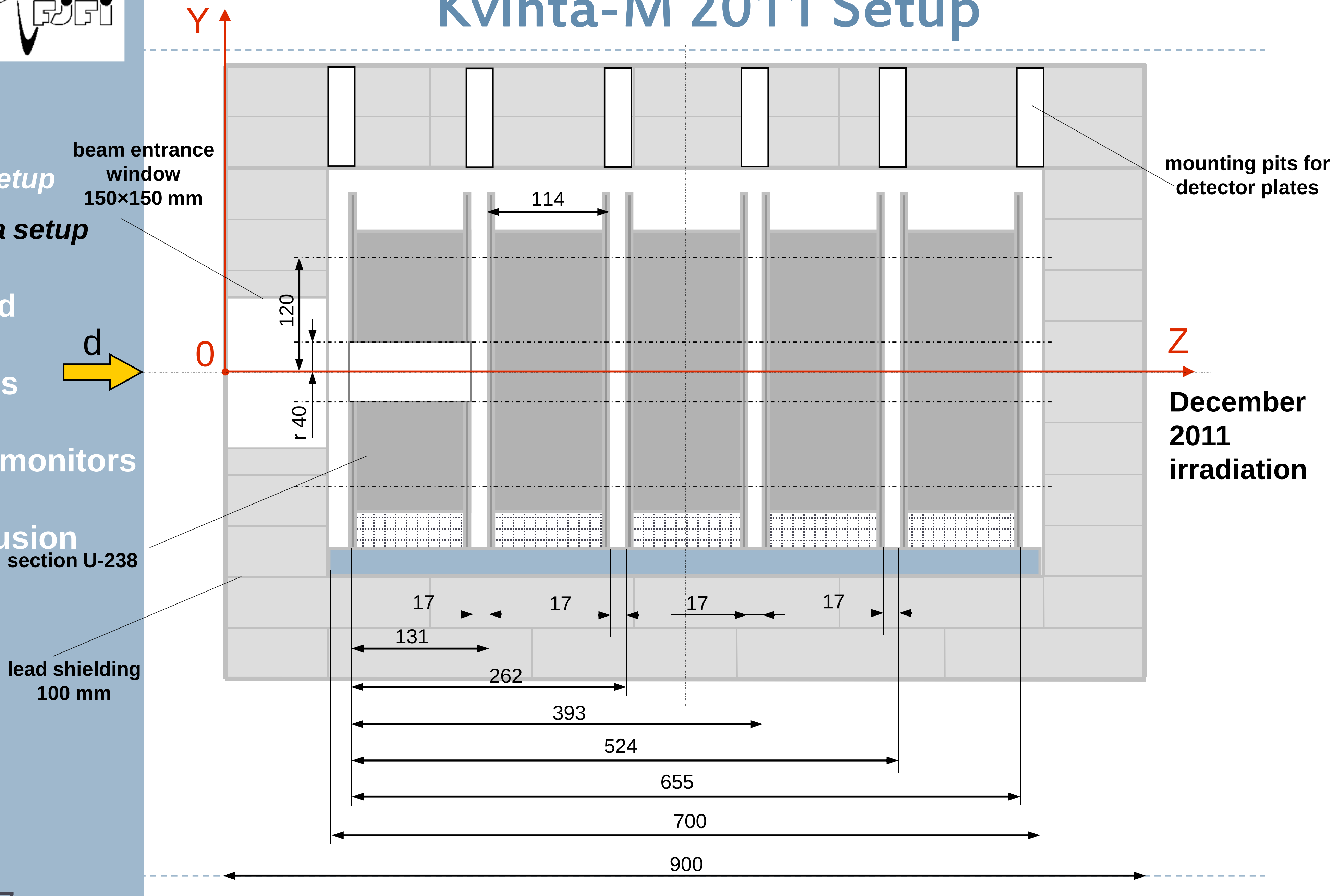
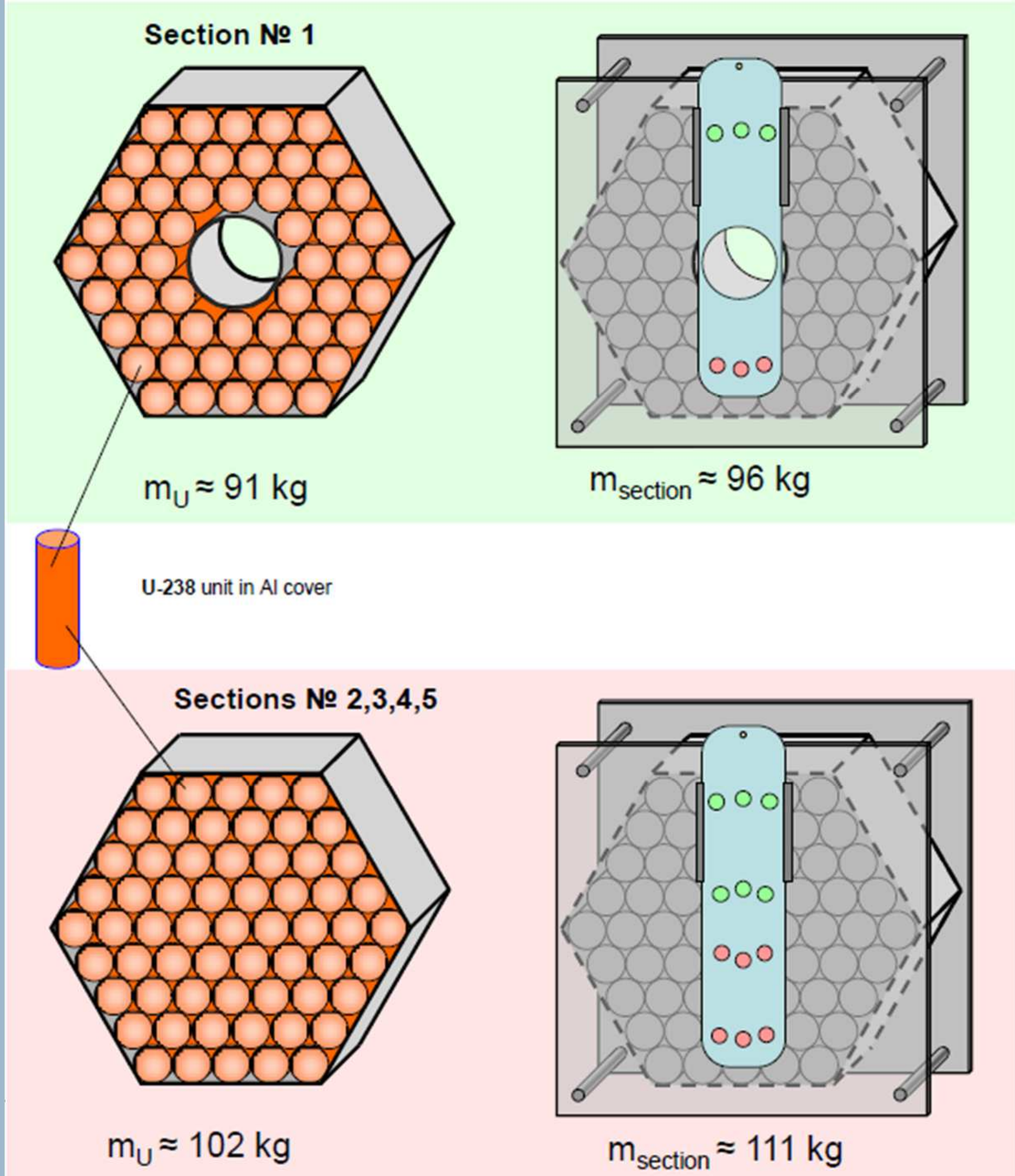
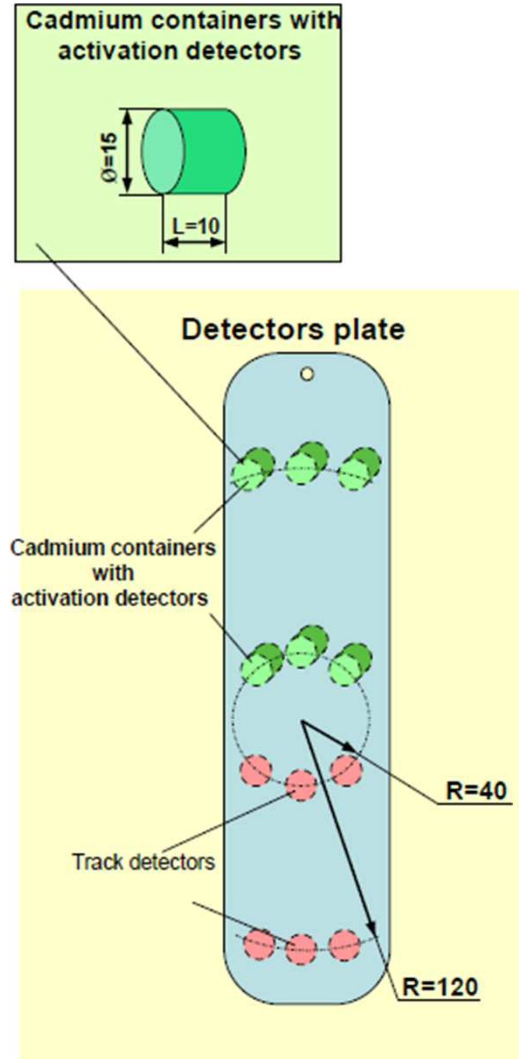


Kvinta-M 2011 Setup





Energy + Transmutation and Kvinta Irradiations

Energy + Transmutation set-up				
Beam energy [GeV]	Beam particles	Year	Irradiation time [h:m]	Integral beam flux [$x10^{13}$]
0.7	protons	2004	8:51	1.47
1.0		2003	6:03	3.40
1.5		2001	12:03	1.14
2.0		2003	7:43	1.25
1.6	deuterons	2006	8:00	2.45
2.52		2005	6:46	0.65
4.0		2009	17:48	1.99

Energy + Transmutation and Kvinta Irradiations

Setup
- *E+T setup*
- *Kvinta setup*
- ***Irradiations***

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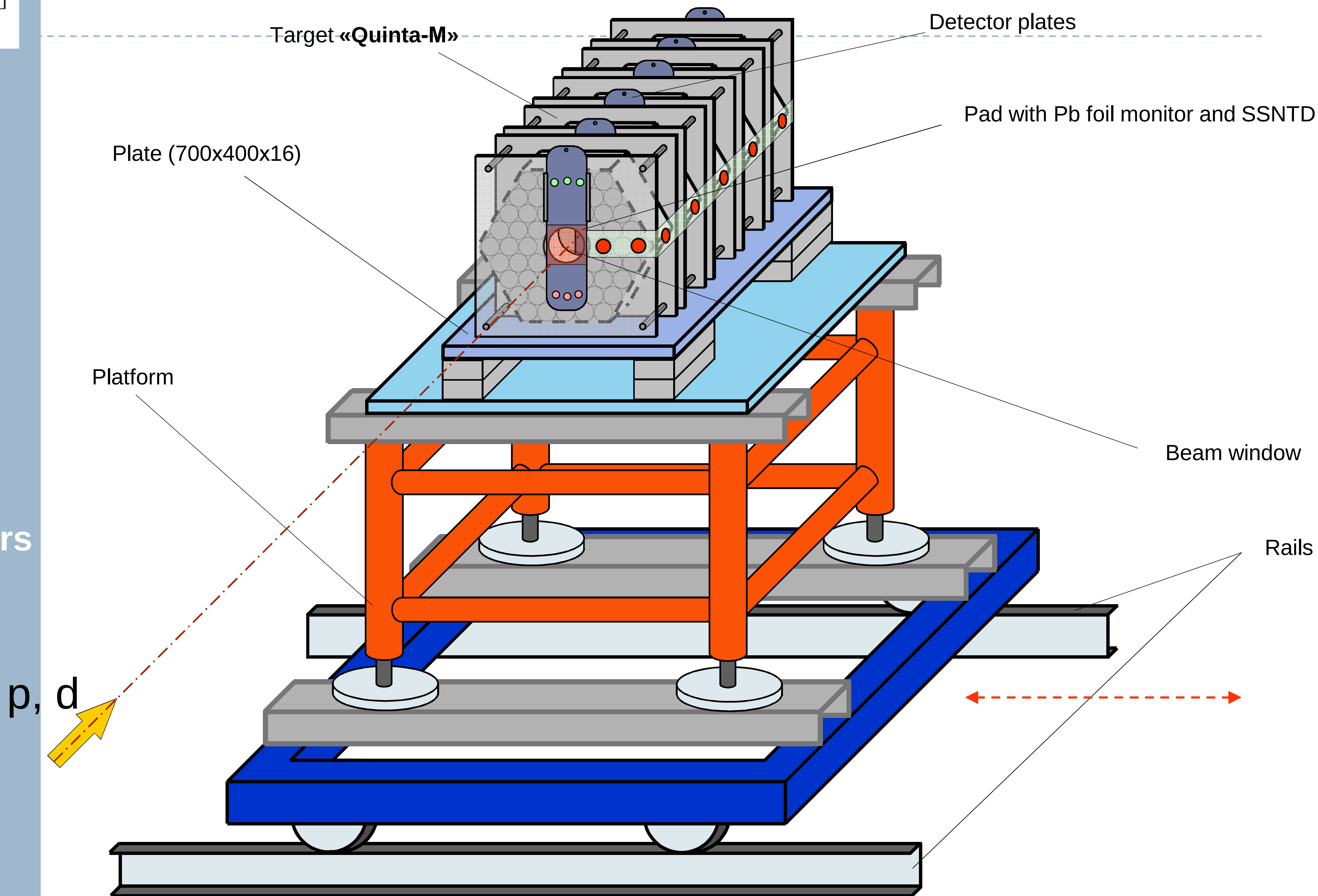
Kvinta set-up				
Beam energy [GeV]	Beam particles	Month Year	Irradiation time [h:m]	Integral beam flux [$x10^{13}$]
2.0	deuterons	March 2011	18:50	1.69
4.0			17:58	1.41
6.0			17:13	1.93
1.0	deuterons	Decem 2011	14:26	1.53
4.0			12:24	1.93
1.0	deuterons	March 2012	04:56	1.9
4.0			08:52	2.7
8.0			09:01	0.37

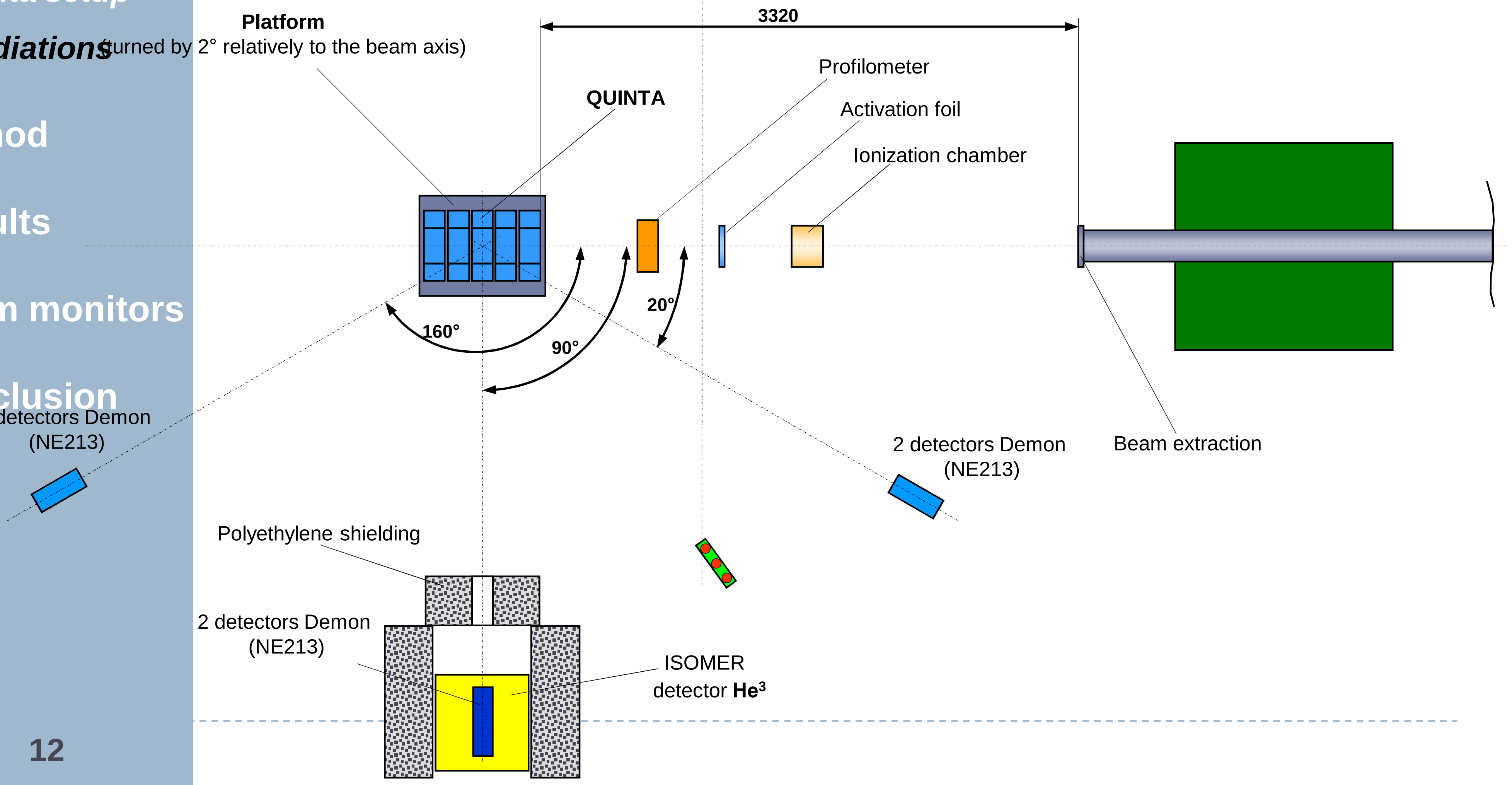
QUINTA-M setup layout at the irradiation position



SSNTD and AD positions on the QUINTA-M target surface

QUINTA setup and equipment layout during an experiment at F-3 focus (December 2011)

1) Activation detectors
2) Solid State Track detectors
3) NE213, Stilben neutron detectors
4) He-3 neutron detectors



Main Objectives of the Kvinta Setup

1) To have another set-up for benchmark studies of neutron production and transport simulation codes (e.g. MCNPX code)
2) To have systematic of deuteron beams with energies above 1 GeV
3) To obtain strong source of neutrons for transmutation tests
4) Measurement of neutrons and delayed neutrons during low intensity beam irradiation by scintillation detectors
5) Measurement of neutron field during high intensity beam irradiation by threshold activation and solid state track detectors
6) Measurement of fission yields in thorium and natural uranium samples in fast neutron spectra

Comparison of E+T and Kvinta Setup

Setup

Method
- ***Setup model***
- *MCNPX simulation*

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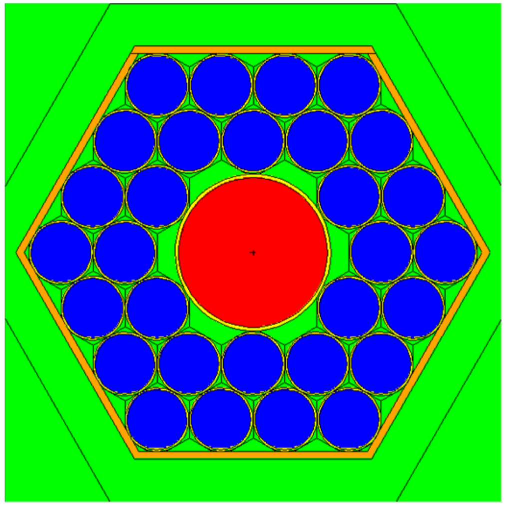
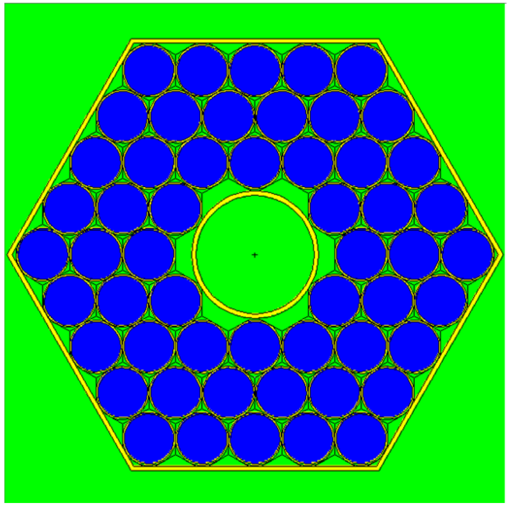
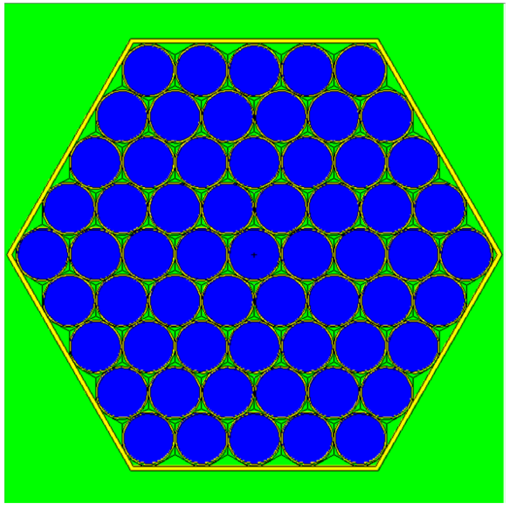
E + T setup model **Kvinta 2011 setup model**



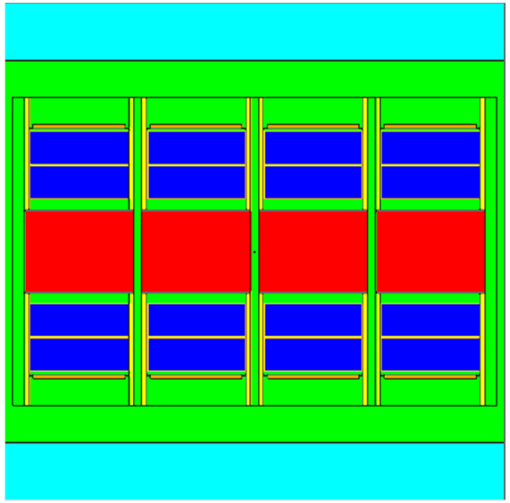
30 U rods

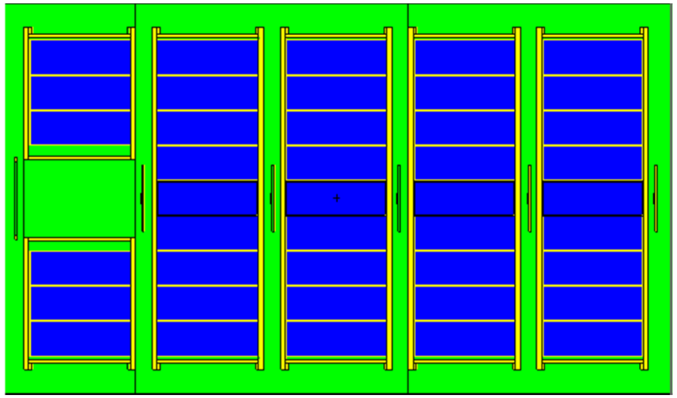


54 U rods



61 U rods





Kvinta Setup with Lead Shielding

Setup

Method
- ***Setup model***
- *MCNPX simulation*

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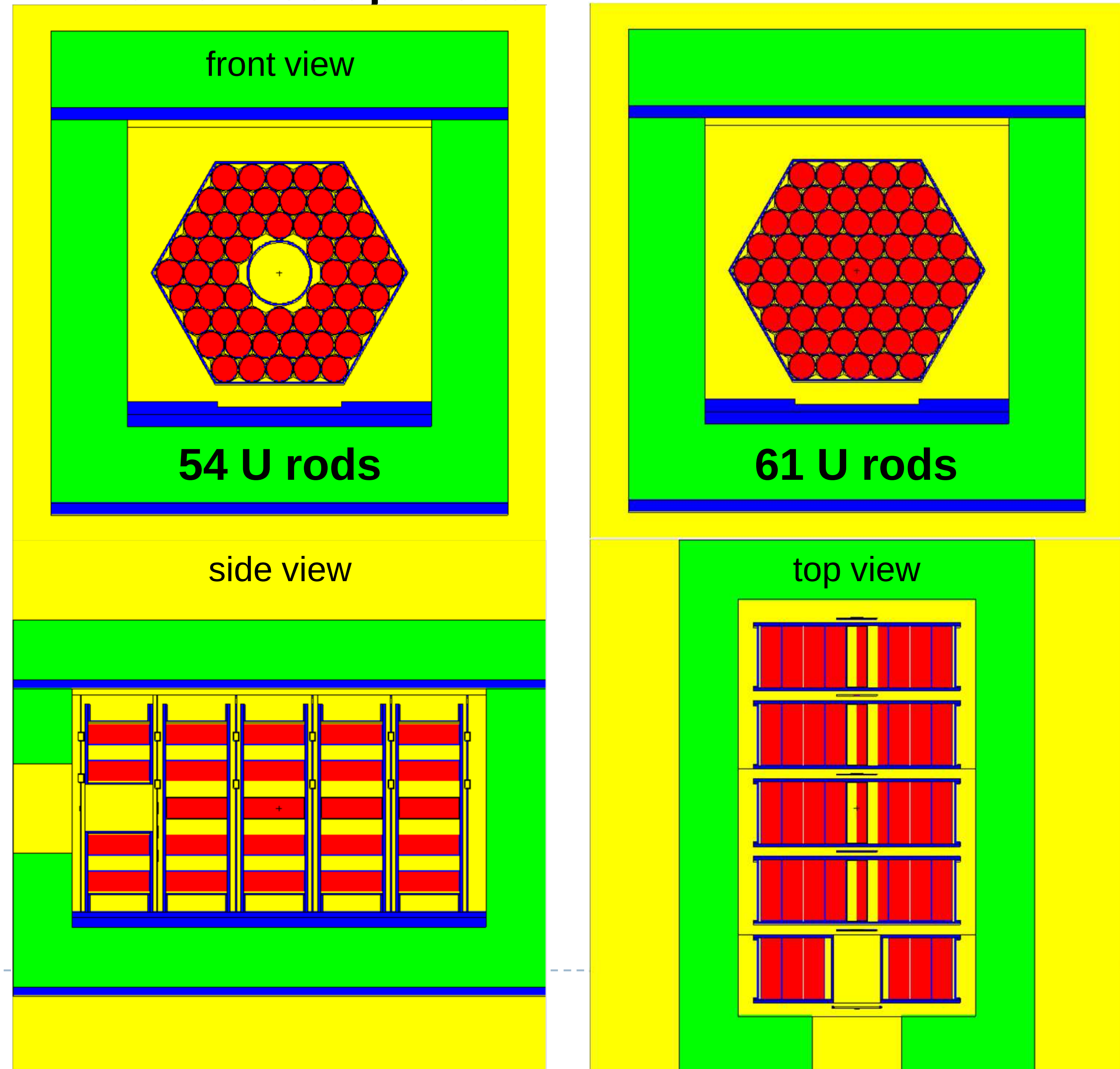
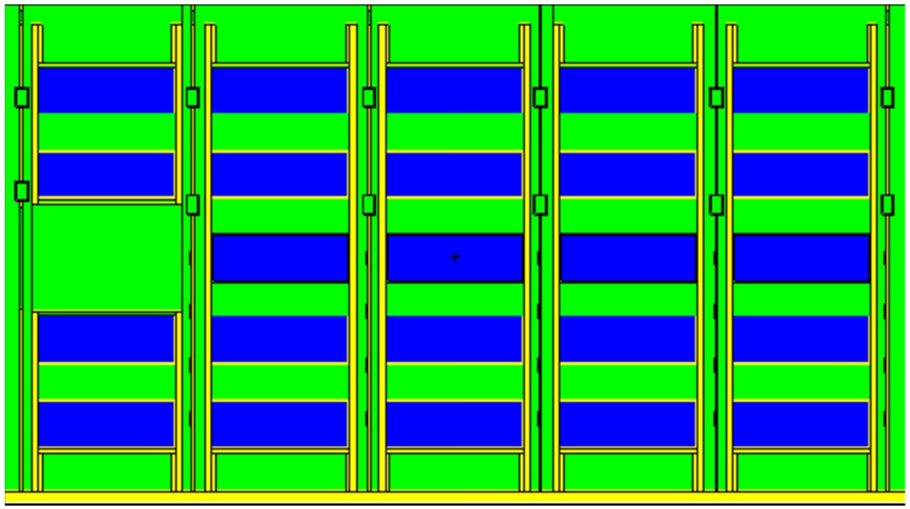
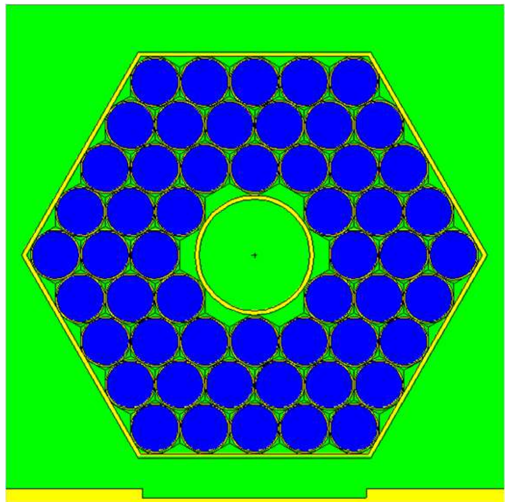
Kvinta 2012 setup model



MCNPX simulations

- Used version MCNPX 2.7a
- Used Los Alamos la150n neutron and la150h proton libraries
- All available physics models in the code tested
- Most preferred combination of models for spectra calculation – INCL-ABLA+FLUKA (time-consuming computation but provides the most reliable results)





Setup

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Beam Monitoring

- deuteron beam with energies of 1, 2, 4, 6 and 8 GeV
- common measurement of beam intensity using ionization chambers
- aluminium and copper foils + SSNTD for beam monitoring
- aluminium foil – integral number of deuterons determination, placed several meters away from the set-up
- copper foil – deuteron cross-section measurement, placed together with the aluminium foil
- copper foil cut into pieces – beam position and profile determination, placed directly on the beginning of the target
- copper foil – beam alignment with the target axis, placed on the back of the target (2, 4, 6 GeV experiments without Pb shielding)

Beam Monitors

Beam integral determination by Al foil

$$N_{yield} = \frac{S_p \cdot C_{abs}(E) \cdot B_a}{I_\gamma \cdot \varepsilon_P(E) \cdot C_g \cdot C_{area} \cdot Coi} \frac{t_{real}}{t_{live}} \frac{e^{(\lambda \cdot t_0)}}{1-e^{(-\lambda \cdot t_{real})}} \frac{\lambda \cdot t_{irr}}{1-e^{(-\lambda \cdot t_{irr})}}$$

- S_p – Peak area
- $C_{abs}(E)$ – Self-absorption correction
- B_a – Beam instability correction
- C_{area} – Square-emitter correction
- $\frac{e^{(\lambda \cdot t_0)}}{1-e^{(-\lambda \cdot t_{real})}}$ – Decay during cooling and measurement
- I_γ – γ line –intensity per decay
- $\varepsilon_P(E)$ – Detector efficiency
- C_g – Correction for geometry change
- Coi – Correction for Coincidences
- $\frac{t_{real}}{t_{live}}$ – Dead time correction
- $\frac{\lambda \cdot t_{irr}}{1-e^{(-\lambda \cdot t_{irr})}}$ – Decay during irradiation

λ – decay constant,
tirr – irradiation time,
treal – real measurement time,
tlive – live time of the detector,
t0 – cooling time.

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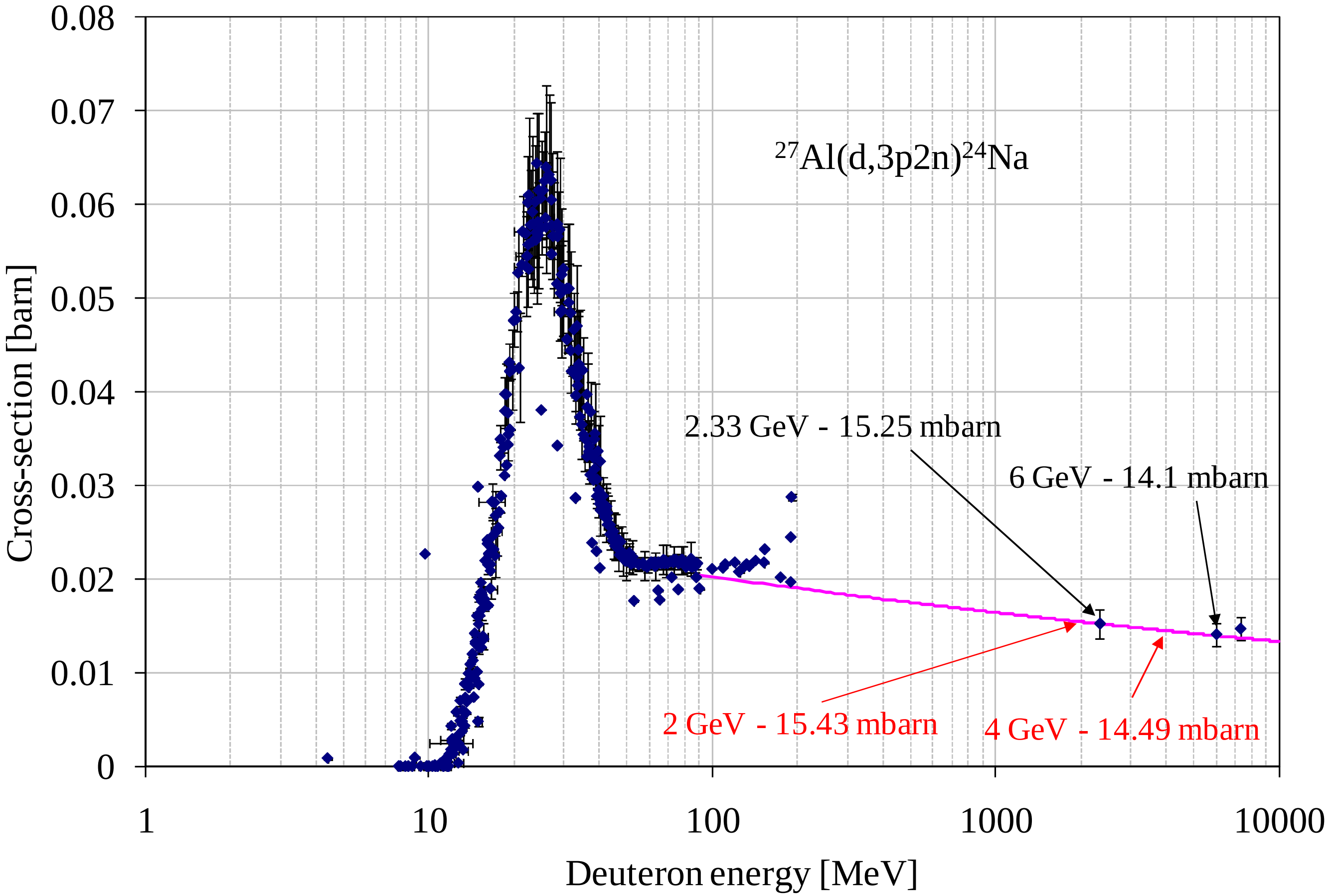
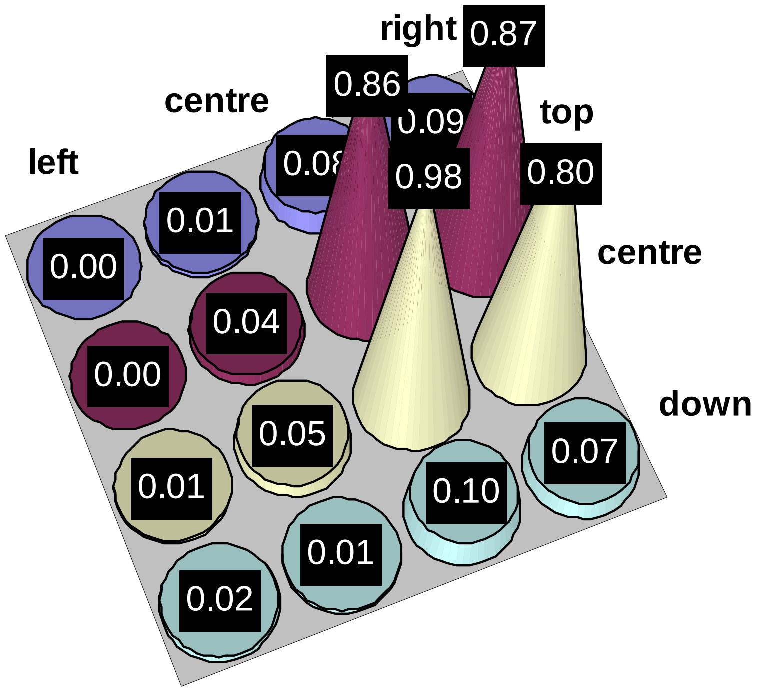
Beam Monitors



$$N_d = \frac{N_{yield} \cdot S \cdot A}{\sigma \cdot m \cdot N_A}$$

Nyield – total amount of produced 24Na nuclei,
A – molar weight,
σ - cross-section,
m – weight of the foil,
S – area of the foil,
N_A – Avogadro's number.

Beam Monitors

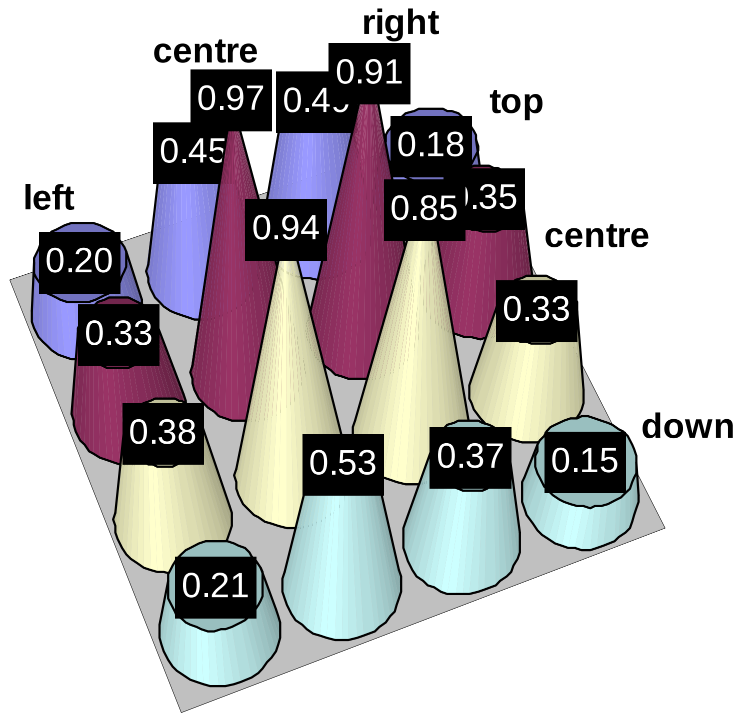


Cu foil cut into 16 pieces 2x2 cm

example of beam position and shape determination (6 GeV exp)

beam centre	beam FWHM
xc 1.42 ± 0.05 cm	xf 1.56 ± 0.05 cm
yc -0.18 ± 0.05 cm	yf 2.24 ± 0.05 cm

results from SSNTD (A. Potapenko)



4 most active foils cut again into 16 pieces 1x1 cm

beam centre	beam FWHM
xc 1.94 ± 0.10 cm	xf 2.39 ± 0.20 cm
yc 0.03 ± 0.10 cm	yf 2.83 ± 0.20 cm

results from activation foils (Řež group)

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- ***neutron flux***
- *neutron distribution*
- *MCNPX models*
- *Multiplicity in various models*

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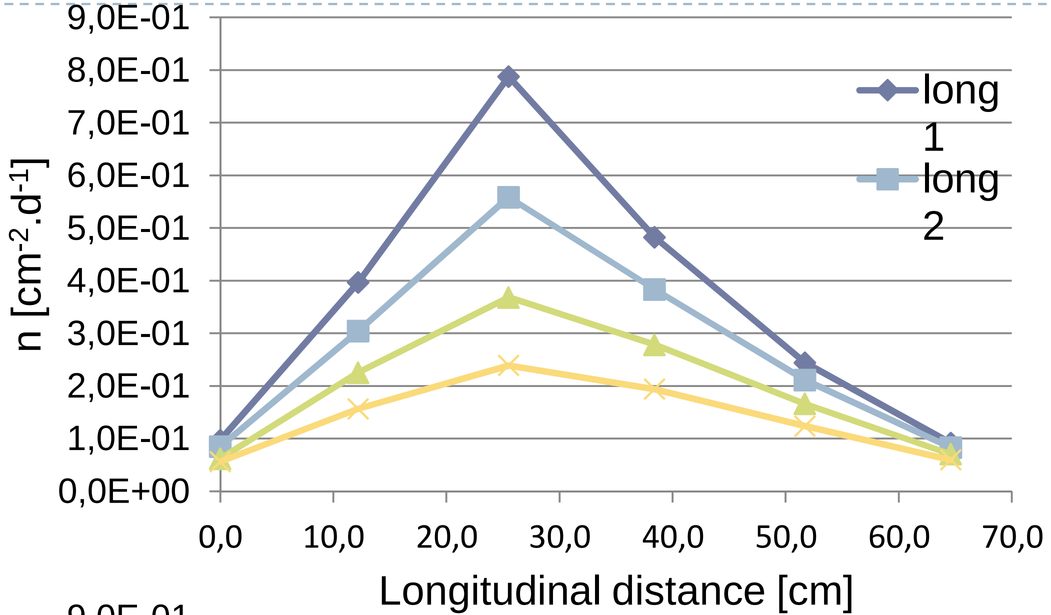
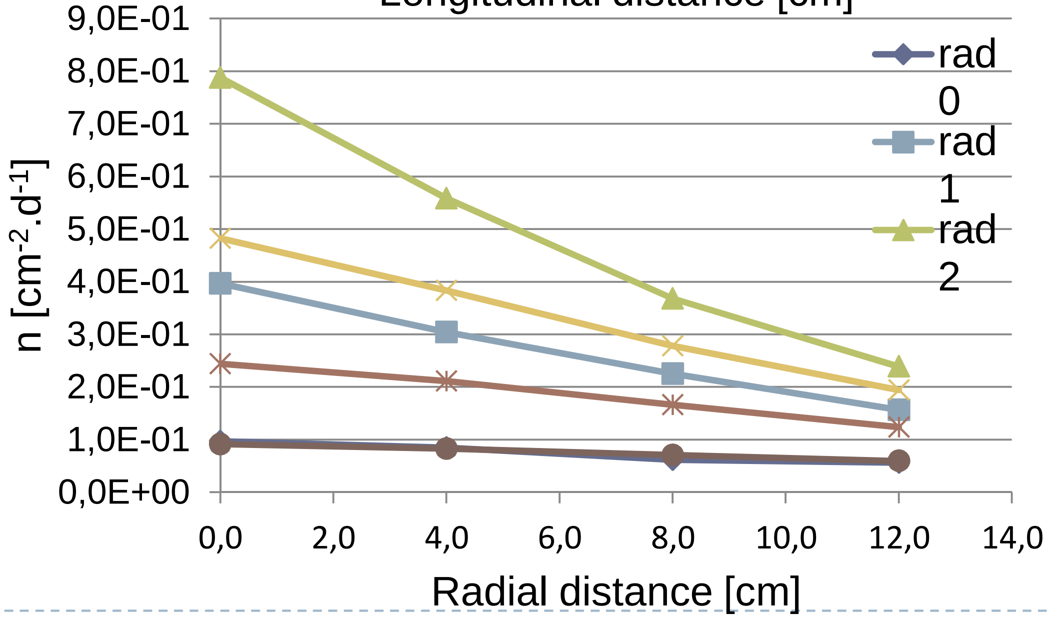
Kvinta neutron fluxes





Kvinta setup with Pb shielding simulated neutron flux in Al foils

Setup

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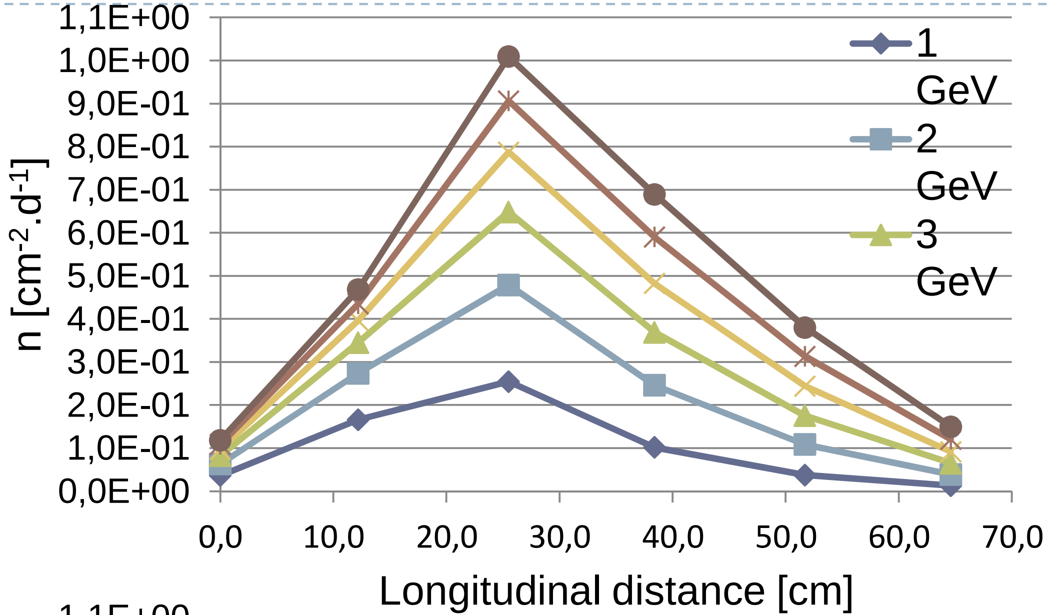
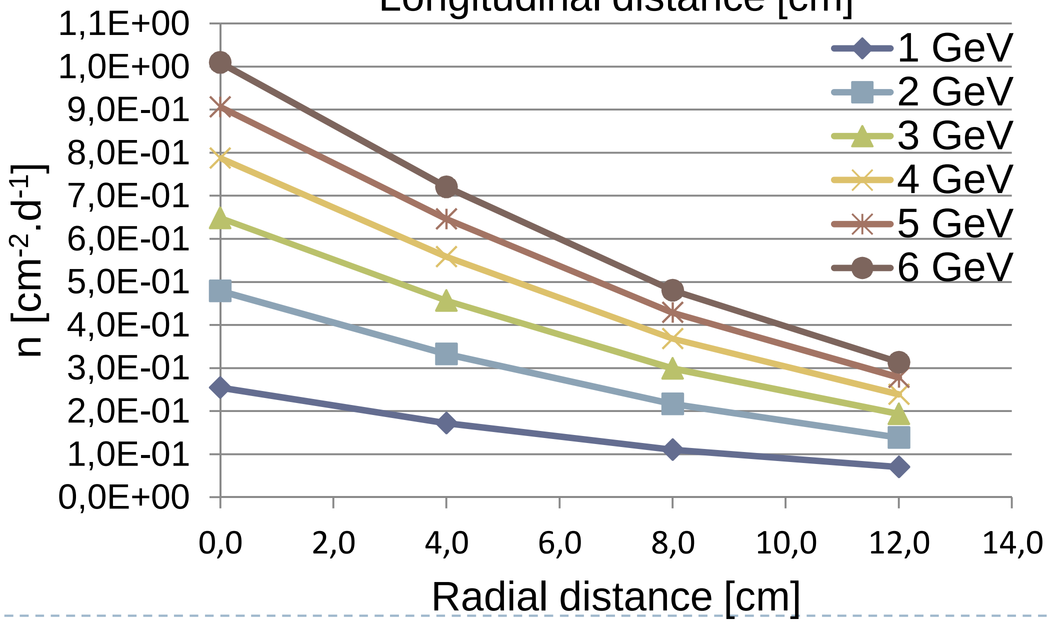
Kvinta neutron fluxes





Kvinta setup with Pb shielding simulated neutron flux in Al foils

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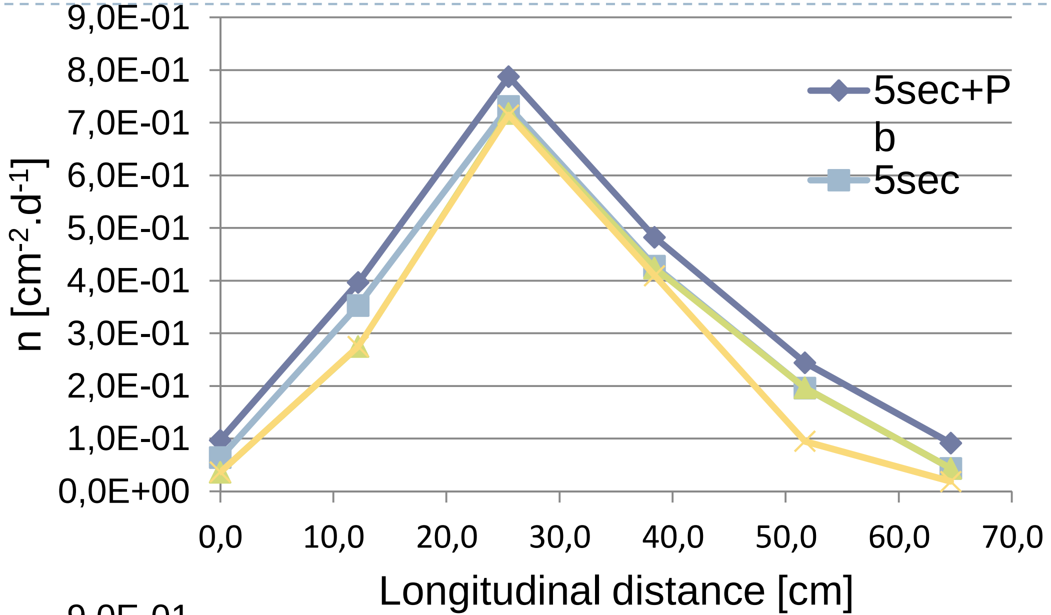

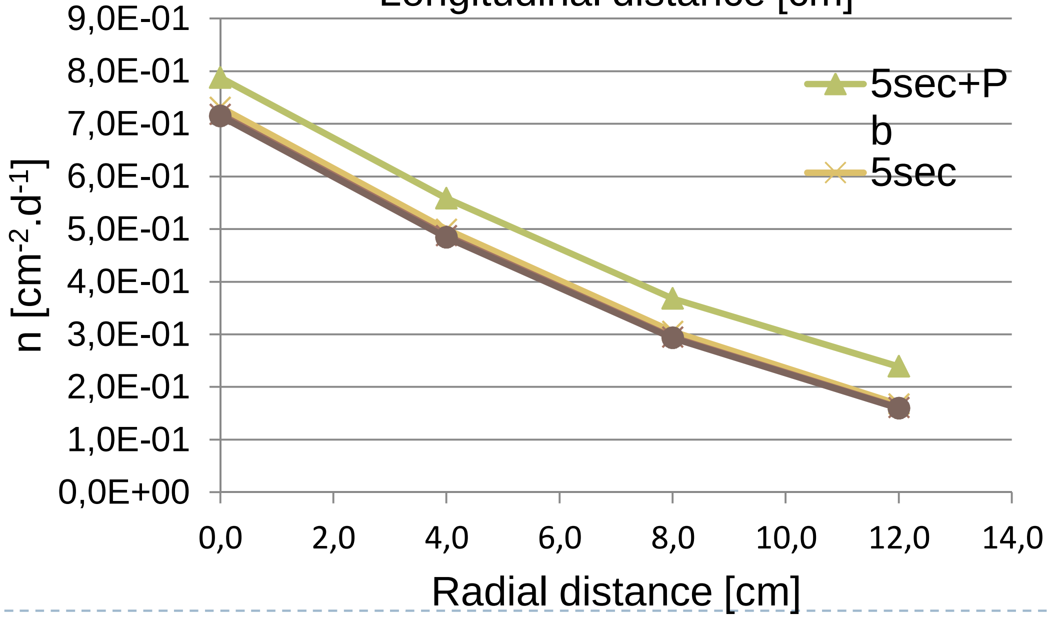

Different types of Kvinta setups simulated neutron flux in Al foils

Kvinta neutron spectra

Setup

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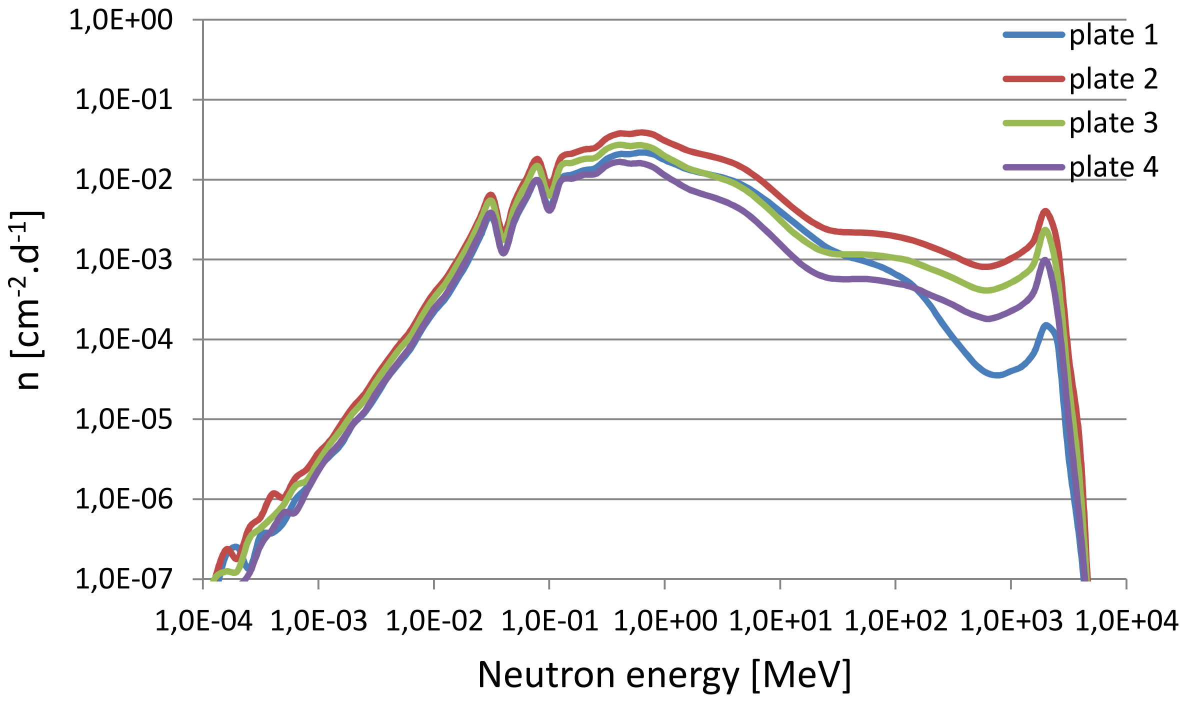
Kvinta setup with Pb shielding simulated neutron spectra in Al foil



$$N_{yield} = \sum_{n,p,d,\pi} \int \Phi(E)\sigma(E)dE$$

Convolution of cross-sections calculated by TALYS+MCNPX with spectral fluences calculated by MCNPX for neutrons, protons, deuterons and pions

Kvinta neutron distribution

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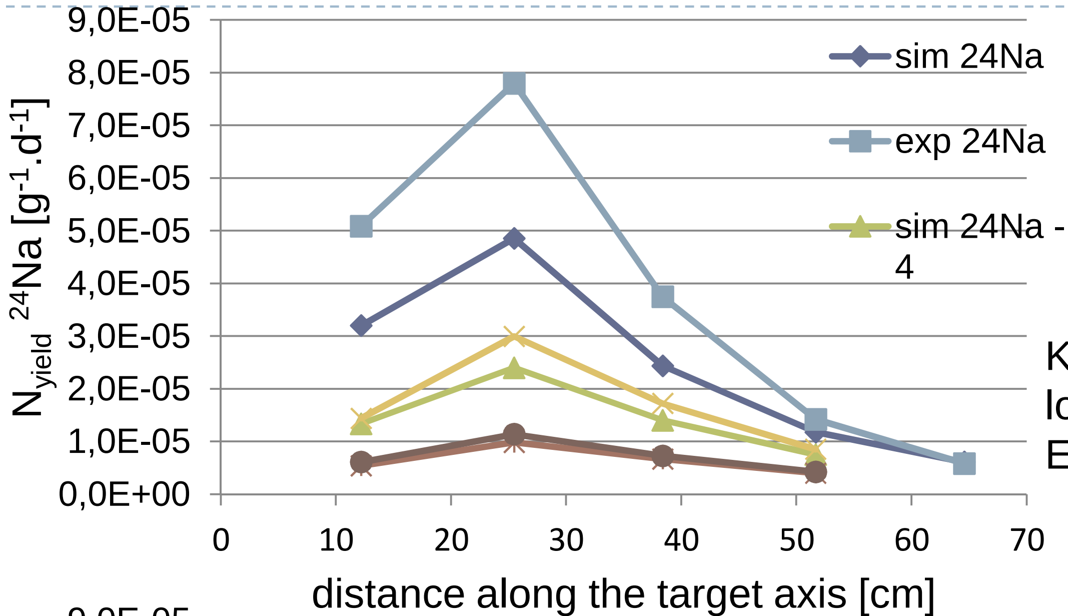
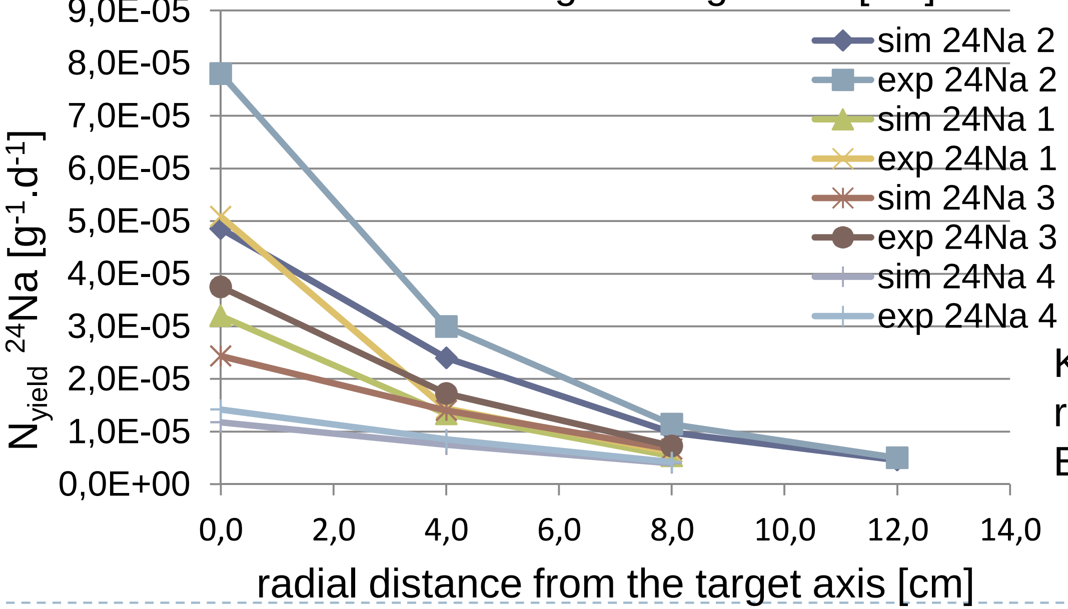


Kvinta setup with Pb shielding
longitudinal neutron distribution
Experiment 4 GeV December 2011



Kvinta setup with Pb shielding
radial neutron distribution
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Kvinta neutron distribution

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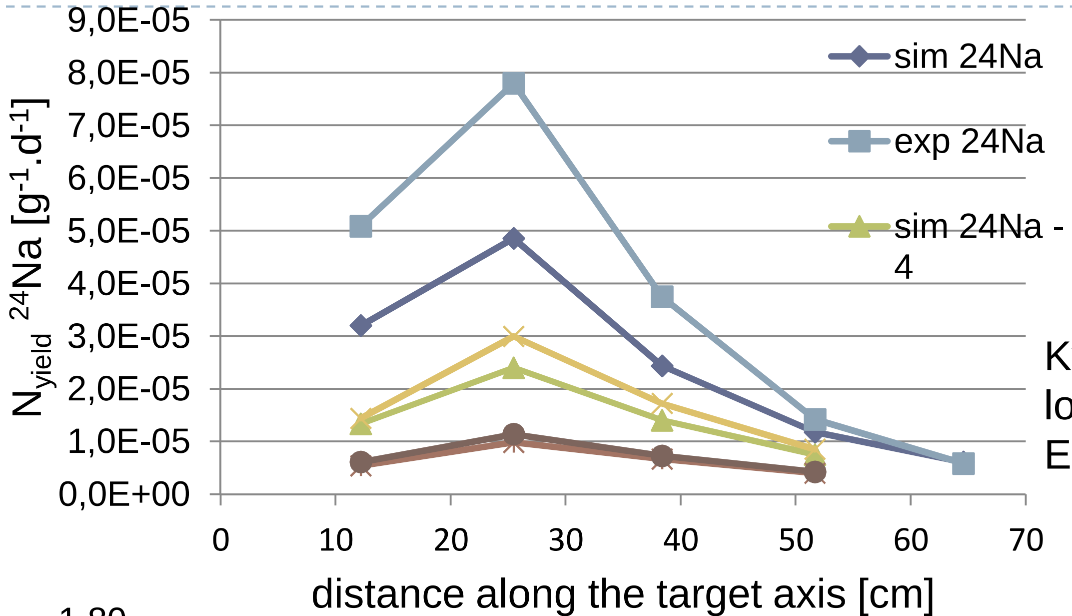

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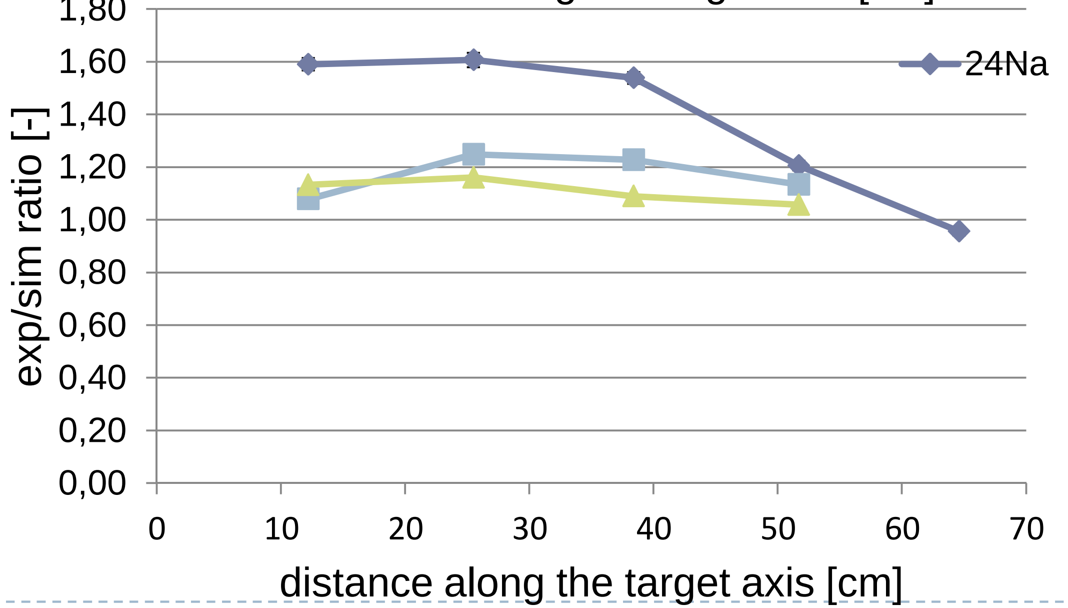

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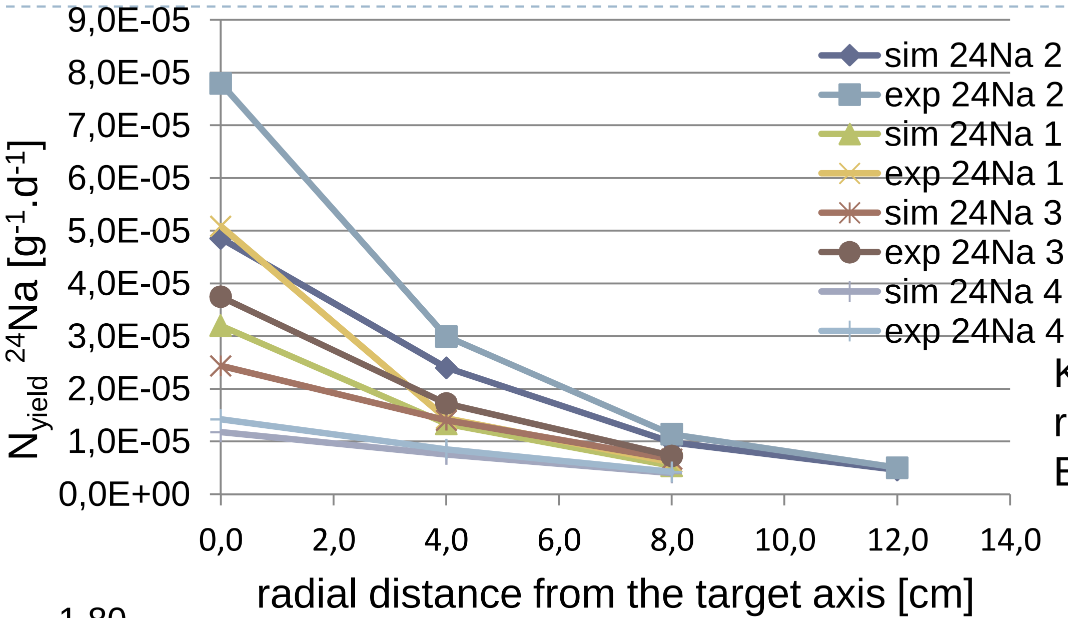
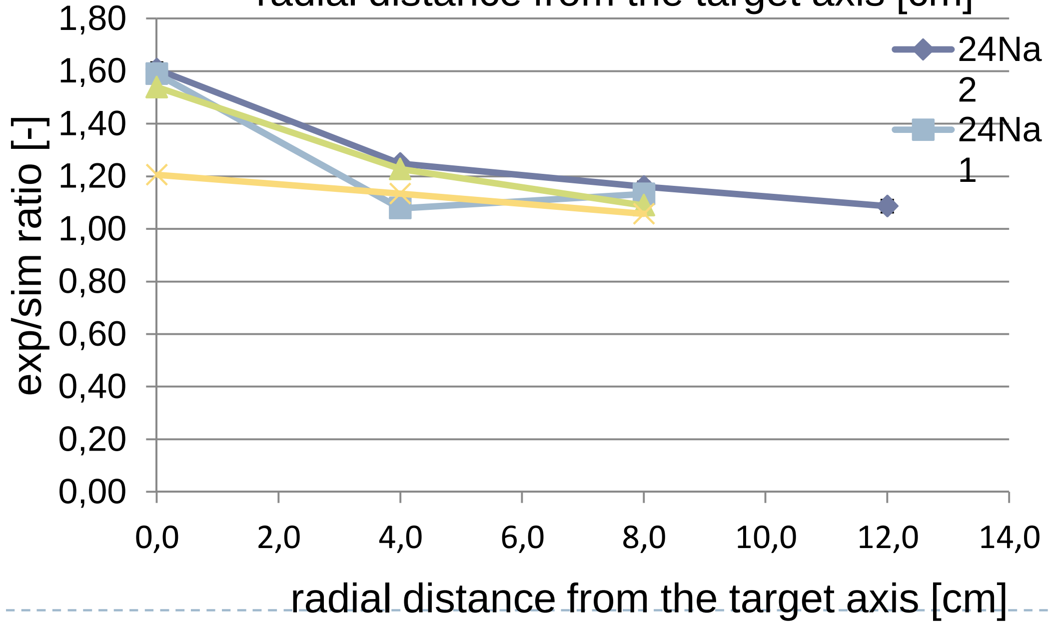


Kvinta setup with Pb shielding radial neutron distribution Experiment 4 GeV December 2011



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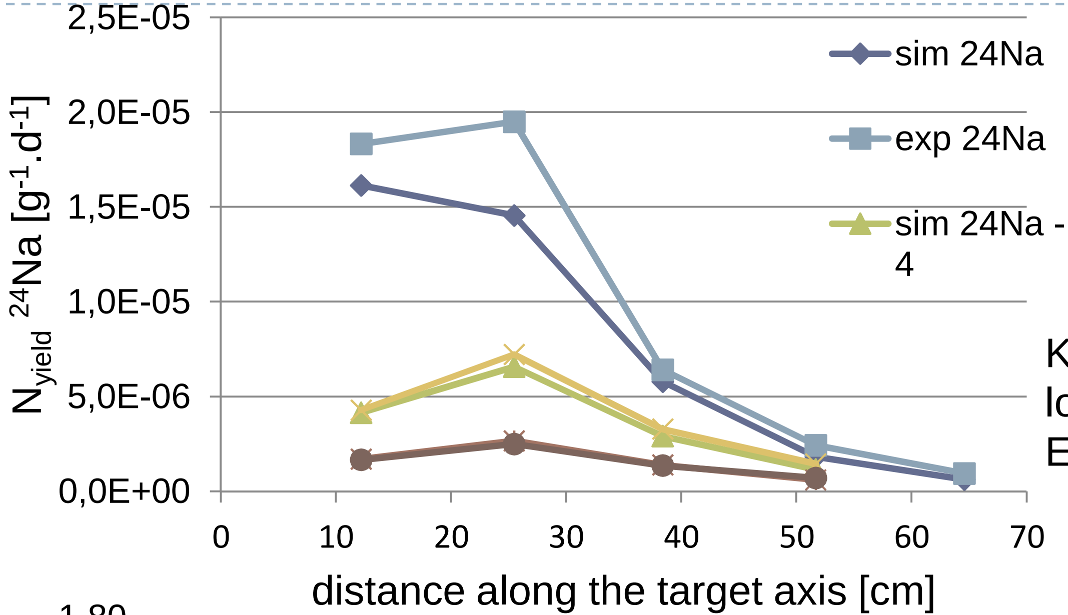
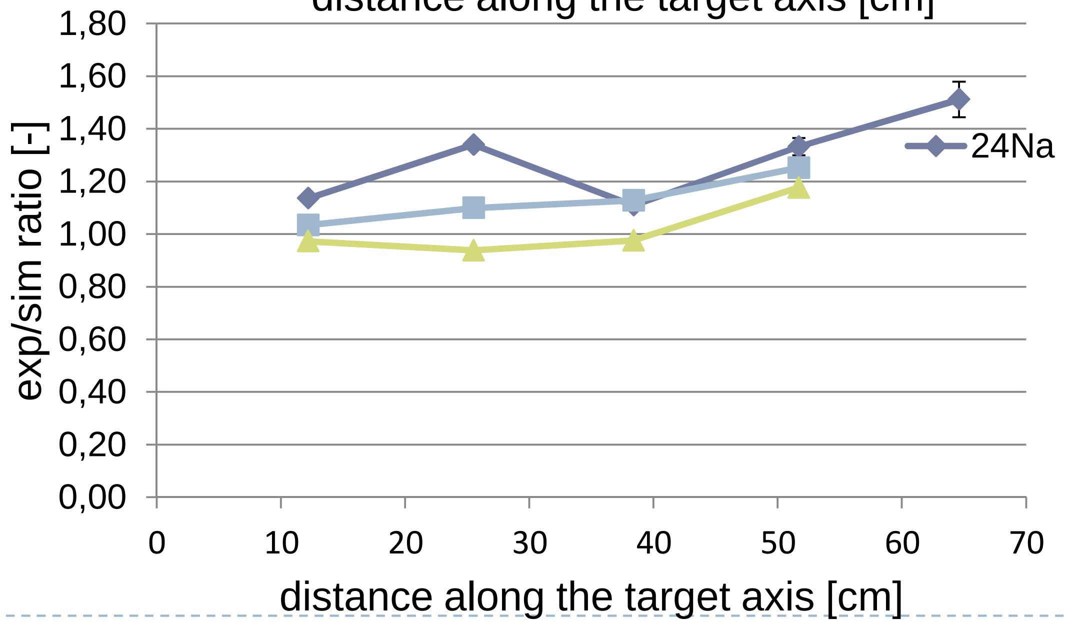


Kvinta setup with Pb shielding longitudinal neutron distribution Experiment 1 GeV March 2012



Kvinta neutron distribution

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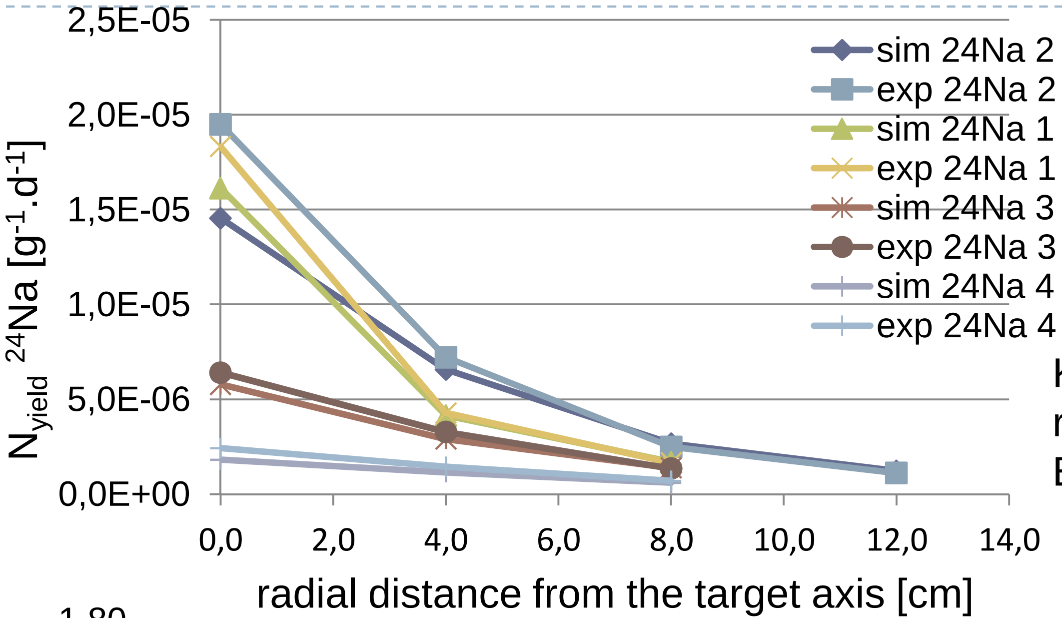
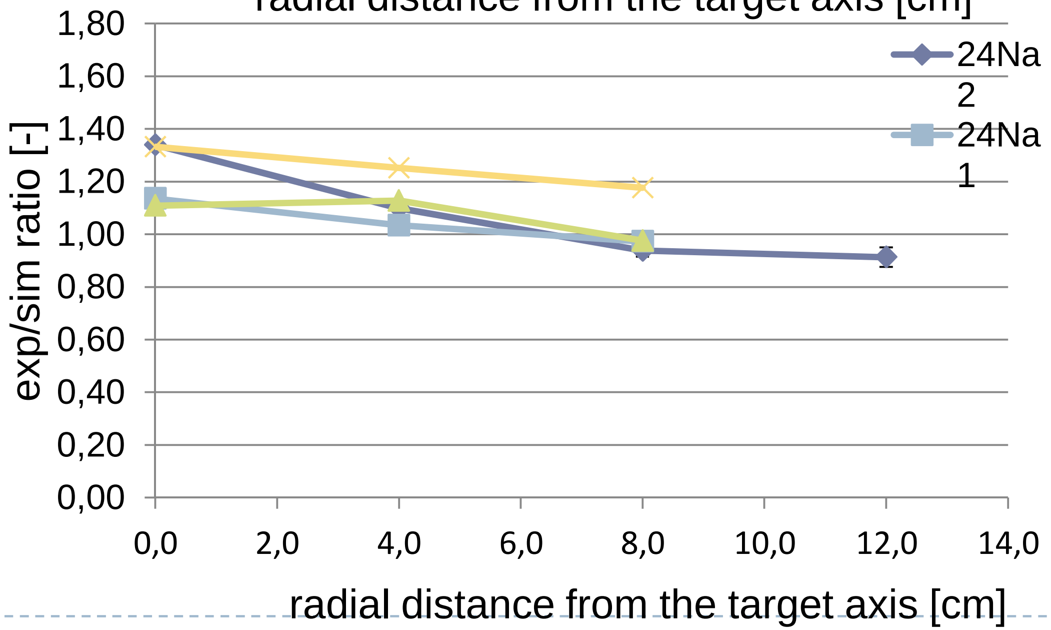


Kvinta setup with Pb shielding radial neutron distribution Experiment 1 GeV March 2012



Kvinta neutron distribution

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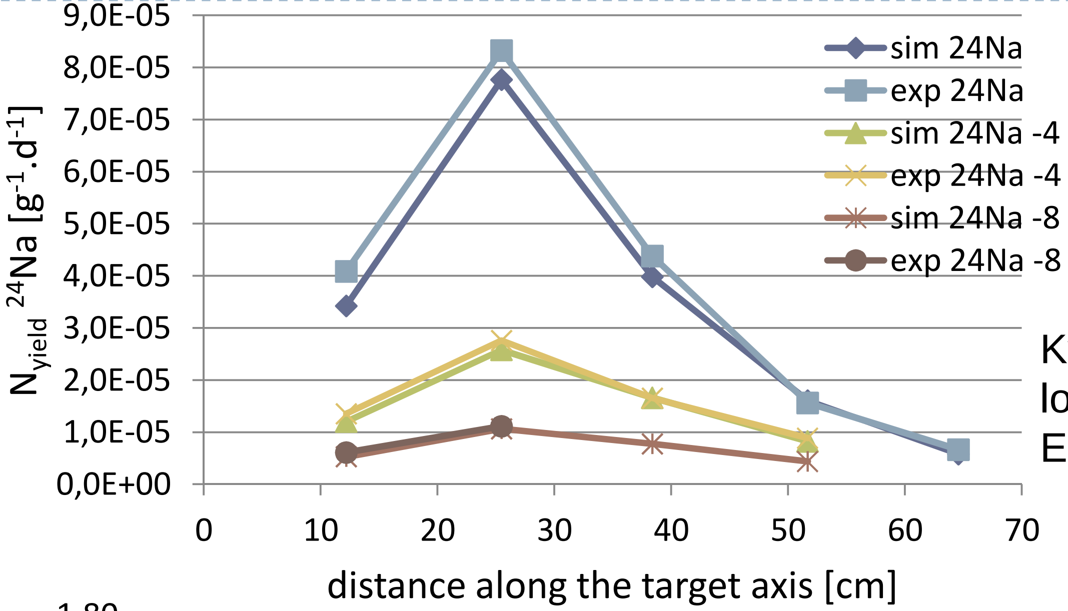

Kvinta setup with Pb shielding
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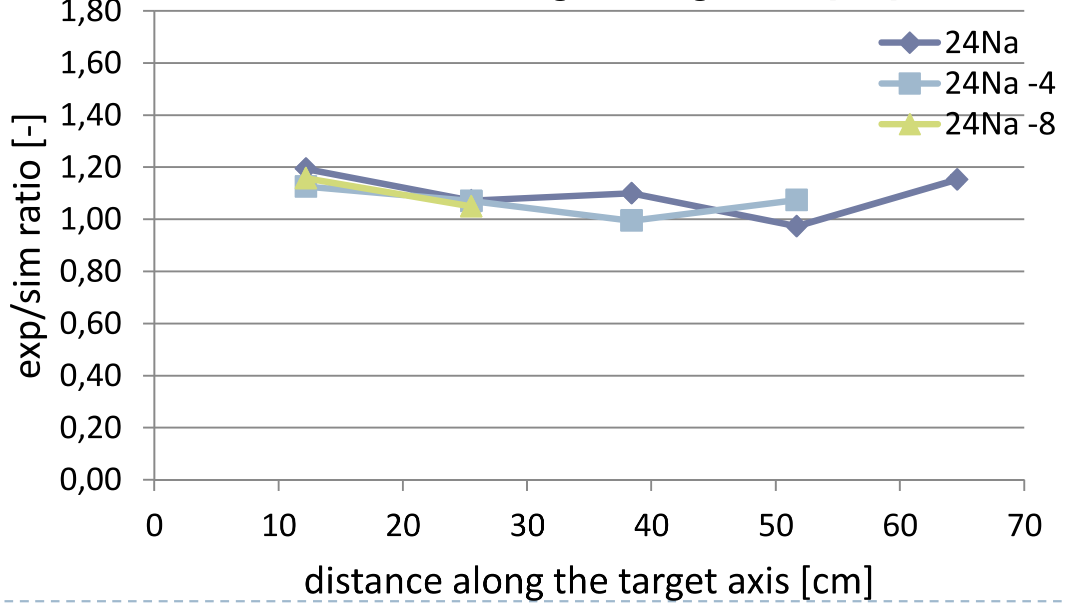
Experiment 4 GeV March 2012



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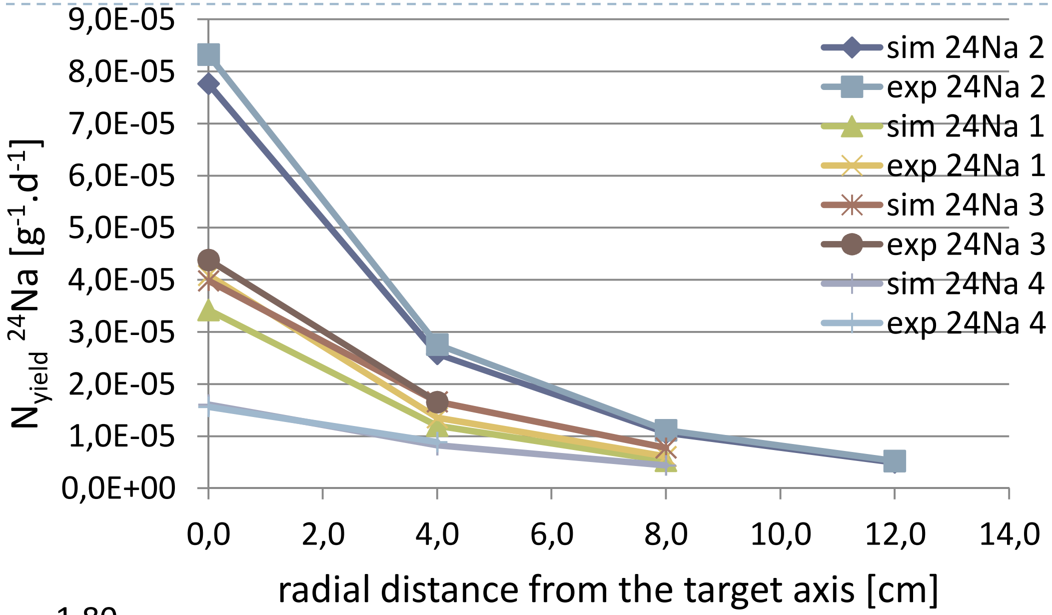
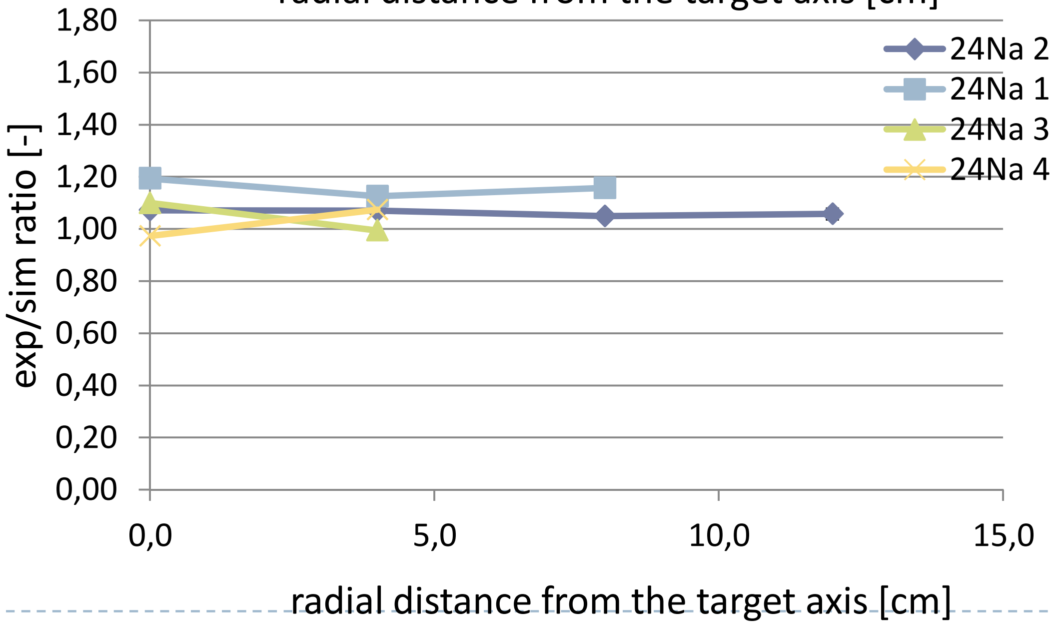


Kvinta setup with Pb shielding radial neutron distribution Experiment 4 GeV March 2012



Simulated multiplicity – various models

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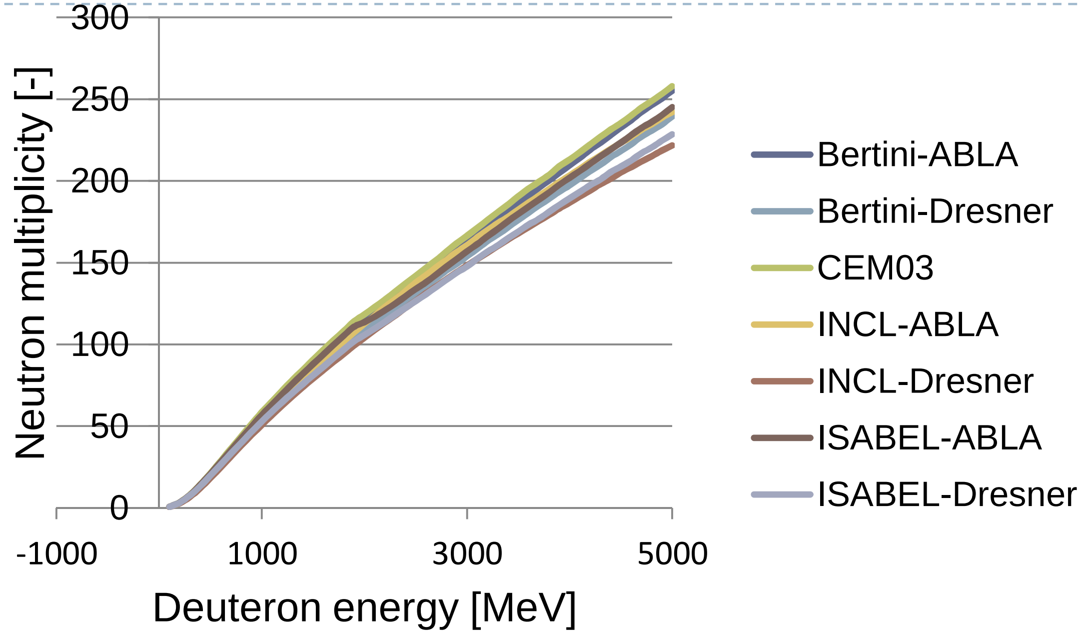
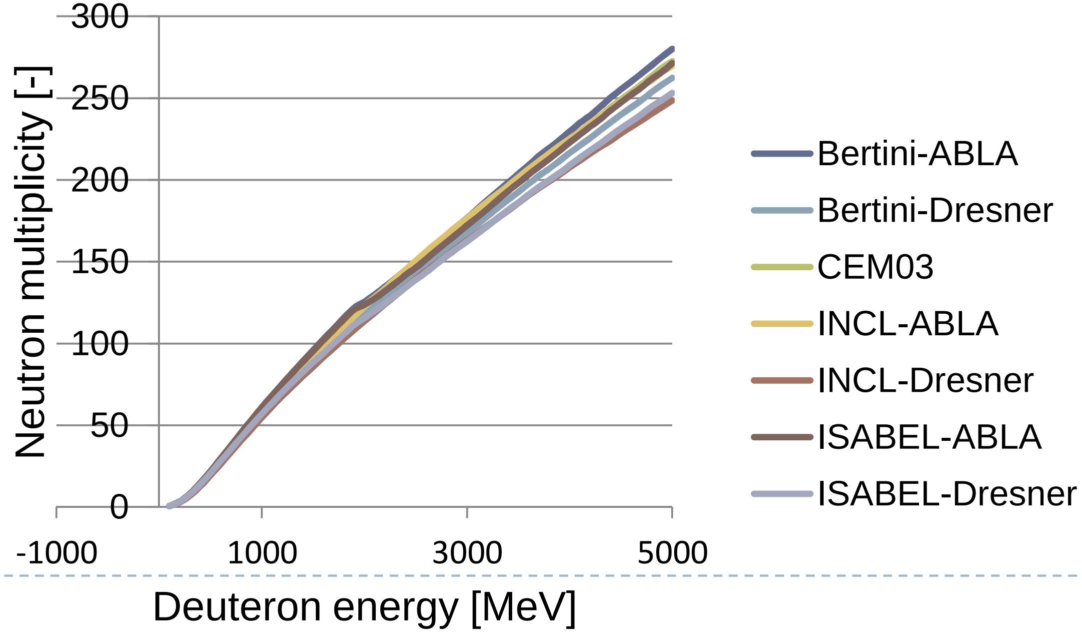


Kvinta 5 sections setup neutron multiplicity



Kvinta 5 sections setup with Pb shielding neutron multiplicity

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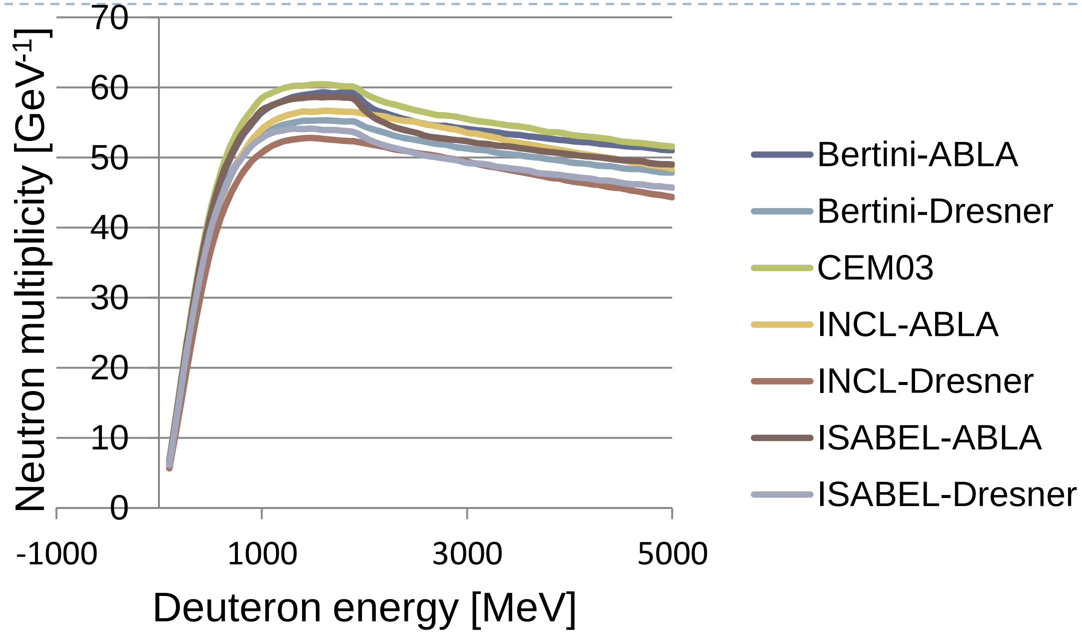
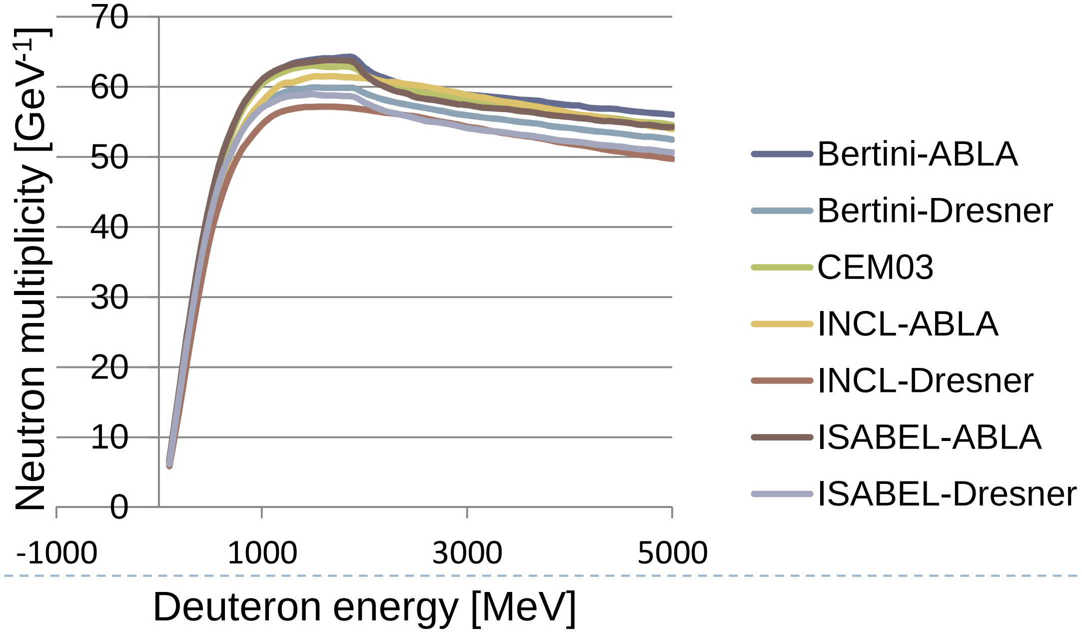
Simulated multiplicity – various models



Kvinta 5 sections setup neutron multiplicity per GeV



Kvinta 5 sections setup with Pb shielding neutron multiplicity per GeV

Simulated multiplicity – various models

Setup

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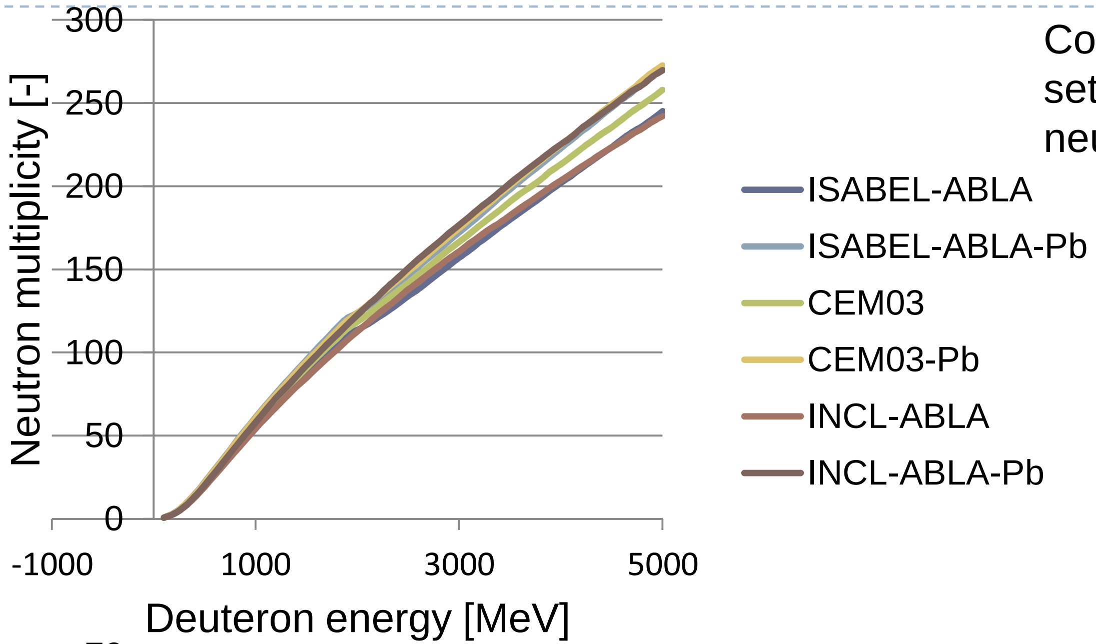
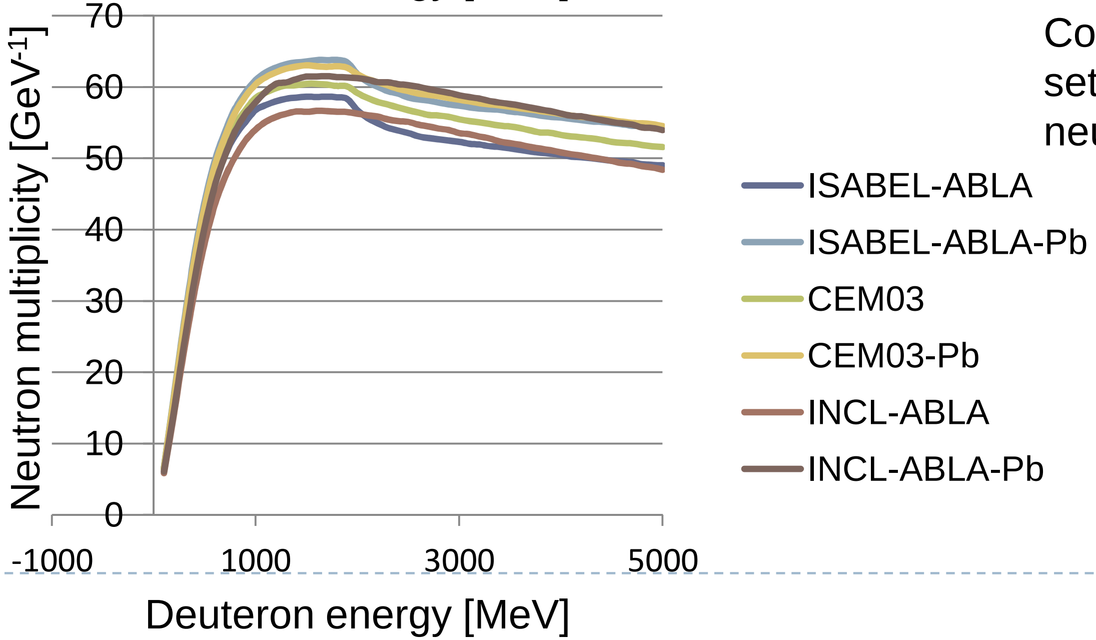
Conclusion

Comparison of Kvinta 5 sections setup with and without Pb shielding neutron multiplicity



Comparison of Kvinta 5 sections setup with and without Pb shielding neutron multiplicity per GeV



Neutron multiplicity from various models

Setup

Method

Results

- *neutron spectra*
- *neutron distribution*
- *MCNPX models*
- ***Multiplicity in various models***

Beam monitors

Conclusion

Kvinta	5 sections		4 sections		3 sections + Pb	
Model	2 GeV	4 GeV	2 GeV	4 GeV	2 GeV	4 GeV
Bertini-ABLA	115.7	209.6	112.5	204.1	116.2	208.0
Bertini-Dresner	108.9	197.3	106.1	192.4	109.7	196.4
CEM03	118.3	213.1	115.2	207.7	114.7	204.7
INCL-ABLA	112.6	203.3	108.4	197.2	113.8	205.2
INCL-Dresner	104.1	186.6	100.6	181.6	105.8	189.4
ISABEL-ABLA	113.6	201.9	110.3	196.2	114.5	201.3
ISABEL-Dresner	105.8	189.3	102.7	183.9	106.7	189.3

Neutron multiplicity from various models

Setup

Method

Results
- *neutron spectra*
- *neutron distribution*
- *MCNPX models*
- ***Multiplicity in various models***

Beam monitors

Conclusion

Kvinta	5 sections			5 sections + Pb		
Model	1 GeV	2 GeV	4 GeV	1 GeV	2 GeV	4 GeV
Bertini-ABLA	56.4	115.7	209.6	60.7	125.5	229.6
Bertini-Dresner	53.4	108.9	197.3	57.4	118.2	216.5
CEM03	58.5	118.3	213.1	60.4	123.6	224.9
INCL-ABLA	54.0	112.6	203.3	57.8	122.5	225.2
INCL-Dresner	50.7	104.1	186.6	54.6	113.5	207.6
ISABEL-ABLA	56.8	113.6	201.9	61.0	123.7	222.9
ISABEL-Dresner	52.8	105.8	189.3	57.0	115.5	209.0

Simulated multiplicity – various models

Setup

Method

Results

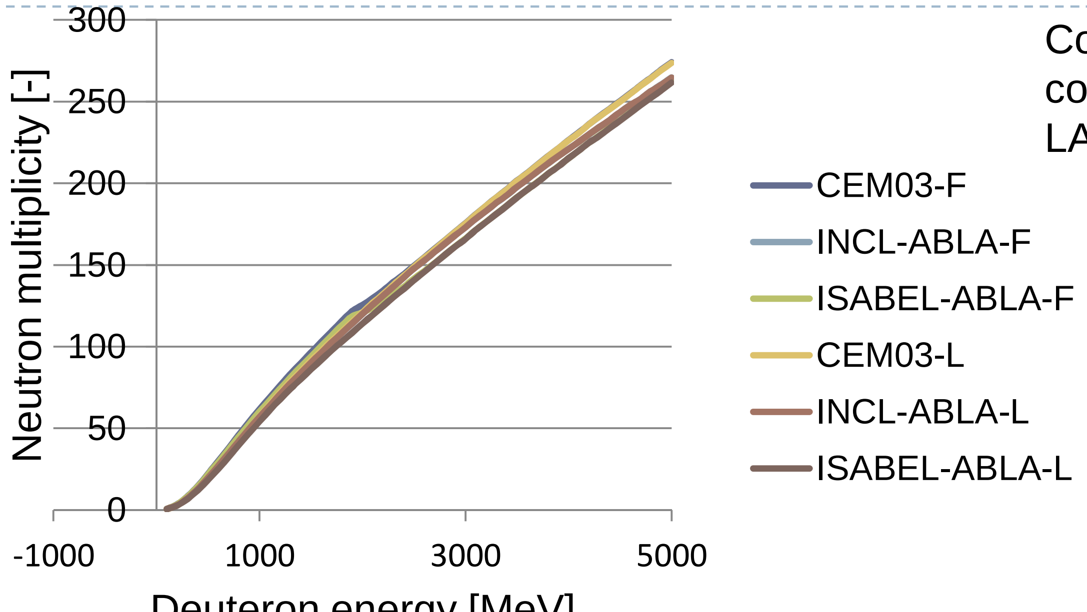
- *neutron spectra*
- *neutron distribution*

•MCNPX models

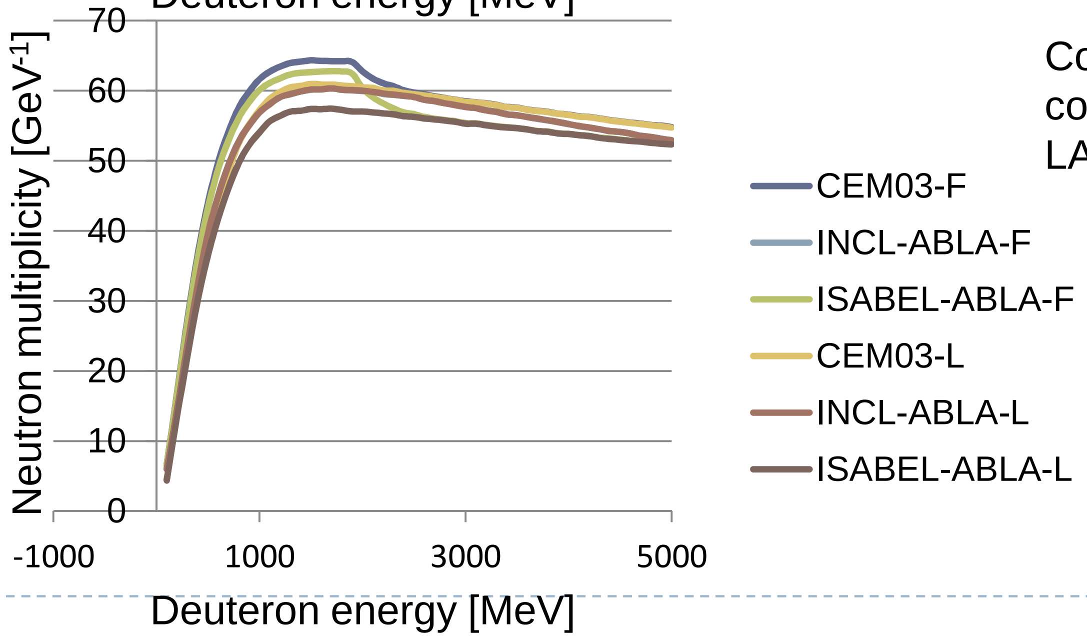
- *Multiplicity in various models*

Beam monitors

Conclusion



Comparison of models in combination with FLUKA or LAQGSM - neutron multiplicity



Comparison of models in combination with FLUKA or LAQGSM - neutron multiplicity/GeV

Simulated multiplicity – various models

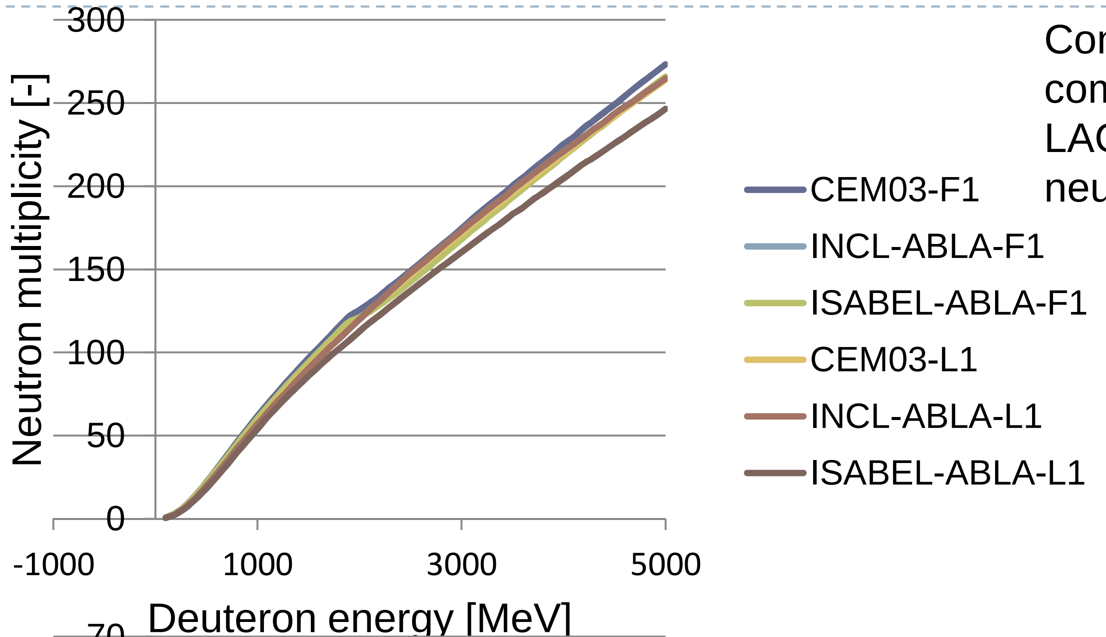
Setup

Method

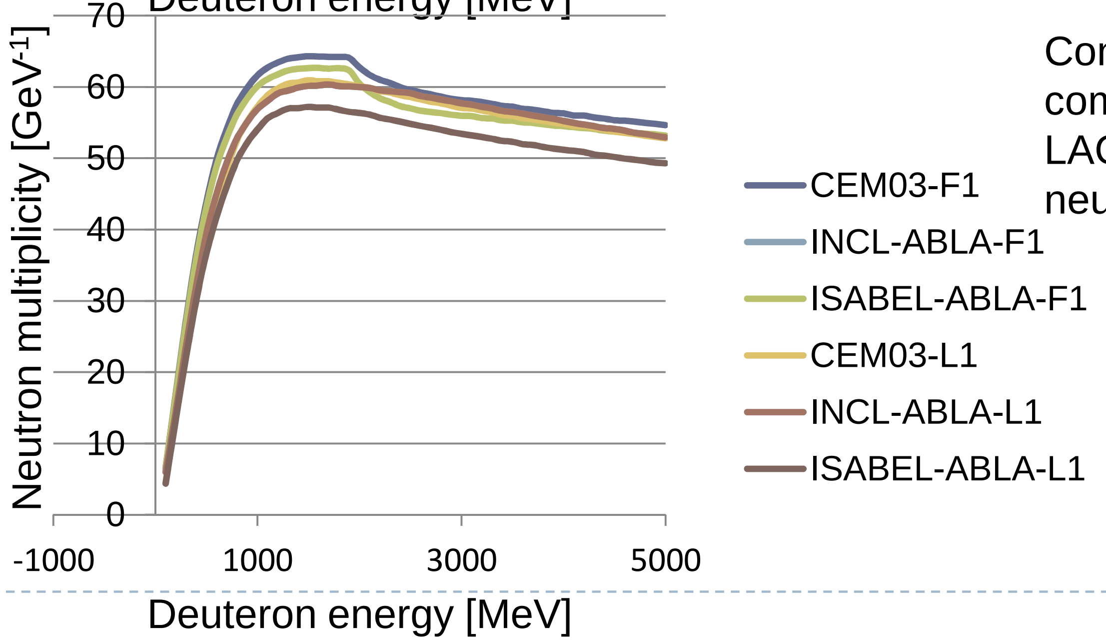
Results
- *neutron spectra*
- *neutron distribution*
- ***MCNPX models***
- *Multiplicity in various models*

Beam monitors

Conclusion



Comparison of models in combination with FLUKA or LAQGSM above 1 GeV - neutron multiplicity



Comparison of models in combination with FLUKA or LAQGSM above 1 GeV - neutron multiplicity/GeV

Conclusion

- made detailed model of the new Kvinta setup consisting of uranium target and blanket
- calculated neutron multiplicity of several modifications of the new Kvinta setup
- performed beam integral, position, shape and alignment monitoring using aluminium and copper foils
- beam characteristics used as input parameters for simulations
- simulated neutron fluxes and spectra in diverse positions in the new Kvinta setup and obtained experiment/simulation yield ratios
- studied dependency on various physics models included in MCNPX

Thank you for your attention