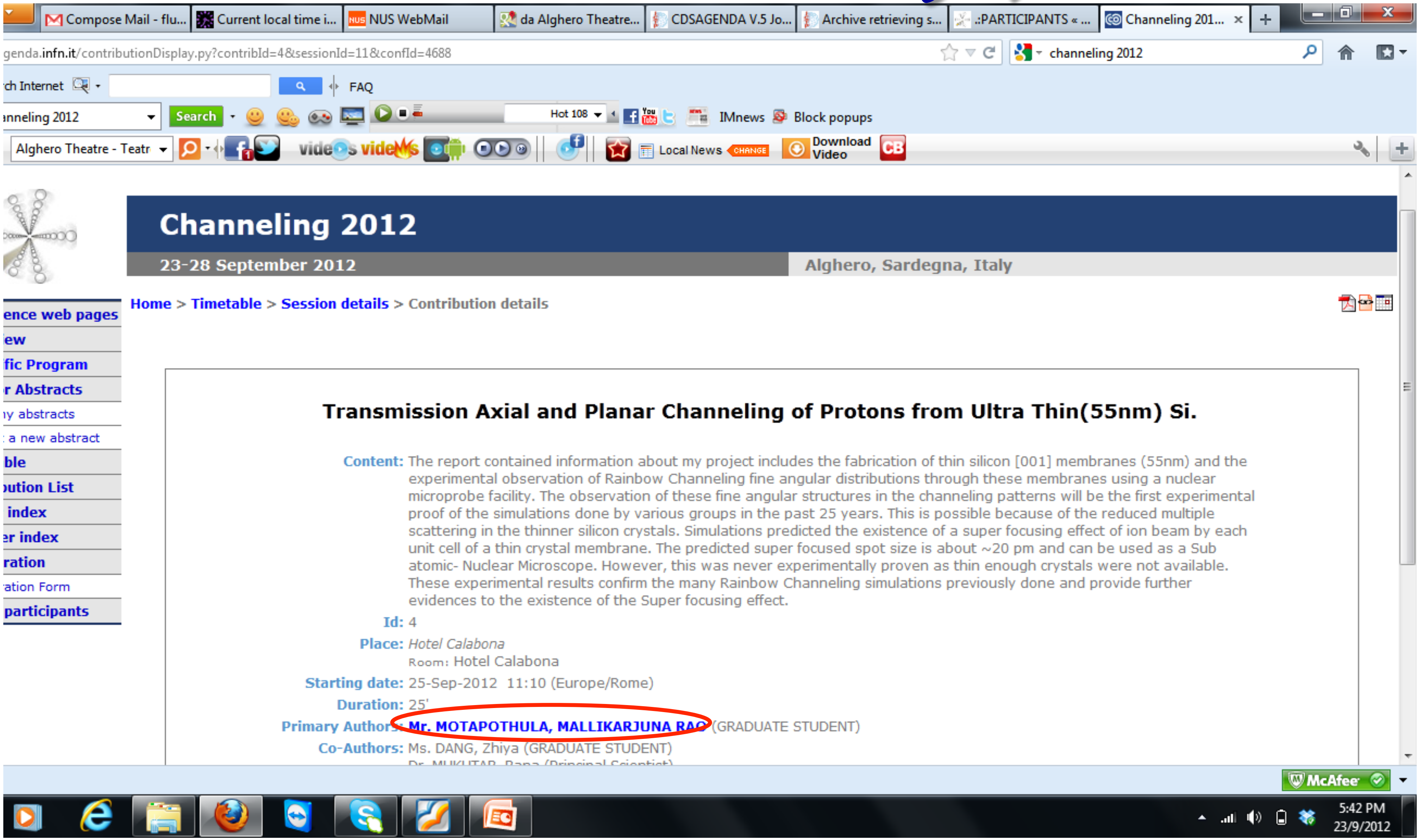
Thanks to all of you



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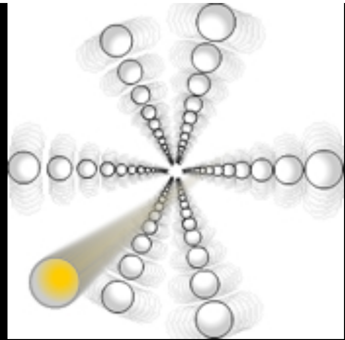

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ION CHANNELING IN CRYSTALS

MALLI

m@nus.edu.sg

NUS National University of Singapore

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I need to thank

M. A. RANA, A. OSMAN - FLUX SIMULATIONS

NESKOVIC, SRDJAN. PETROVIC - RAINBOW CODE SIMULATIONS

Z. Y. DANG - HELPED IN FABRICATING THIN MEMBRANES

T. VENKATESAN - FRUITFUL DISCUSSIONS

- Introduction, Motivation
- Experimental results
- Simulations
- Conclusions & Future plans

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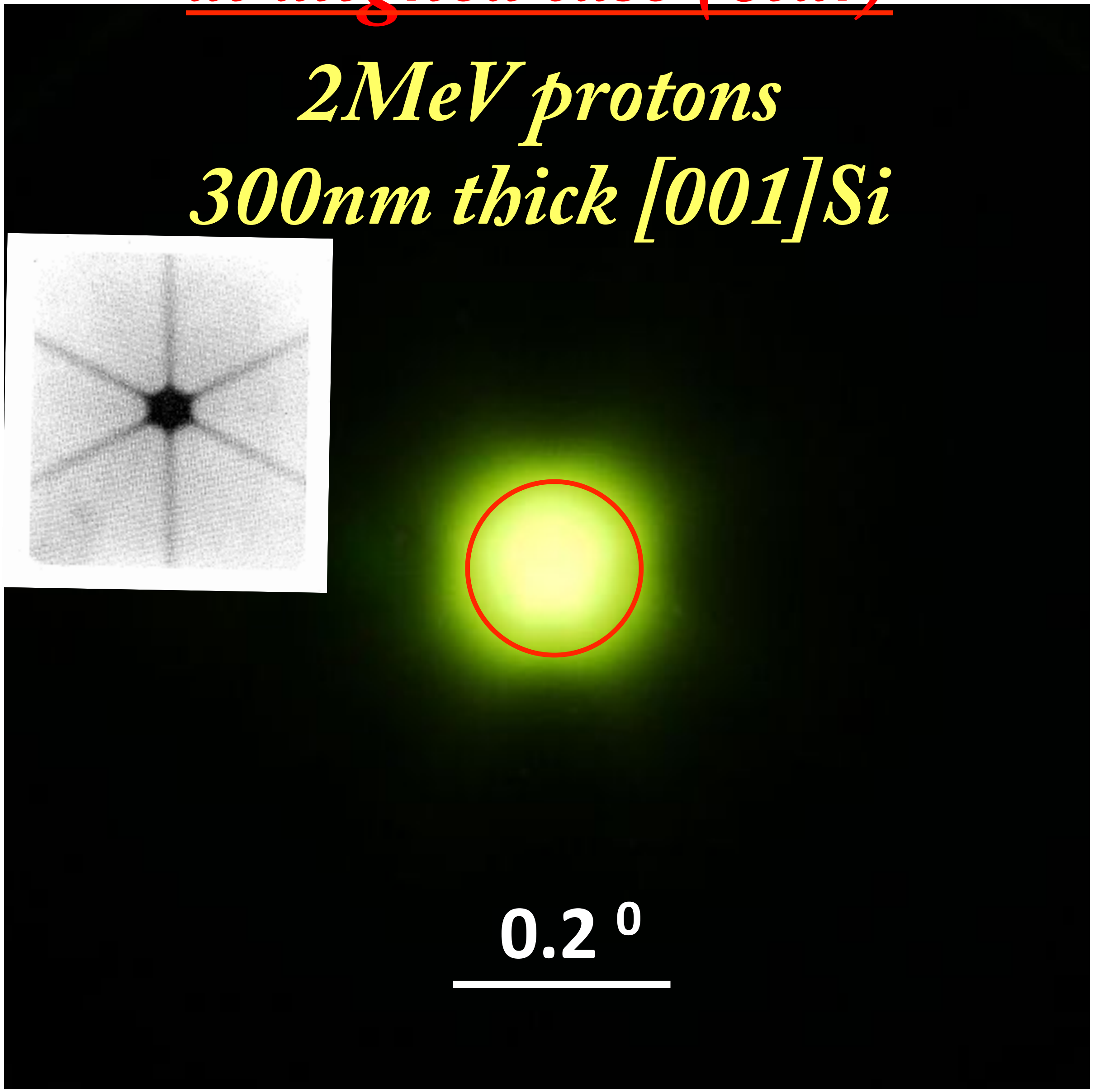
Introduction

Angular distribution at aligned case (Star)



high intense sharp focus beam

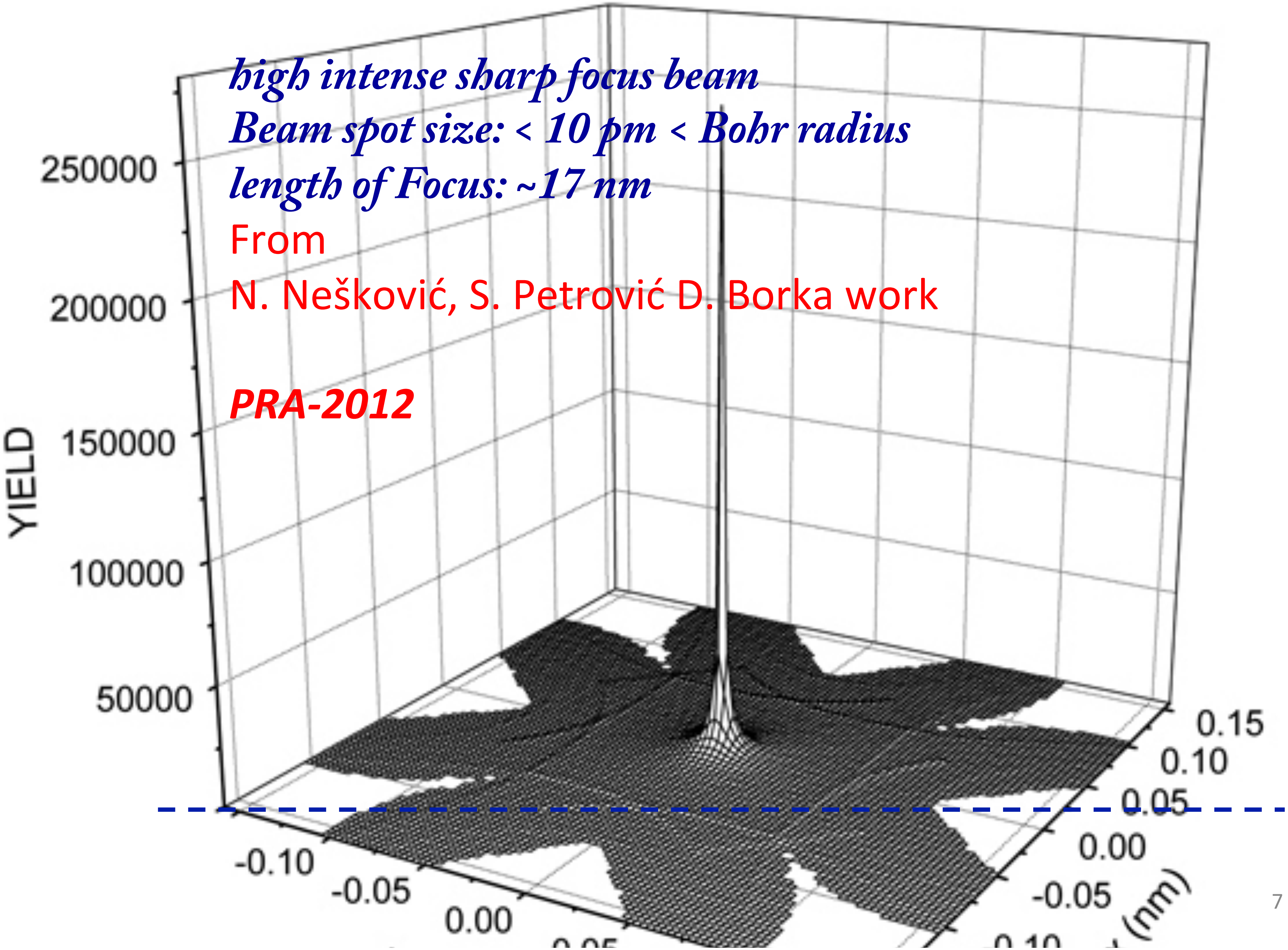
Beam spot size: < 10 pm < Bohr radius

length of Focus: ~17 nm

From

N. Nešković, S. Petrović D. Borka work

PRA-2012



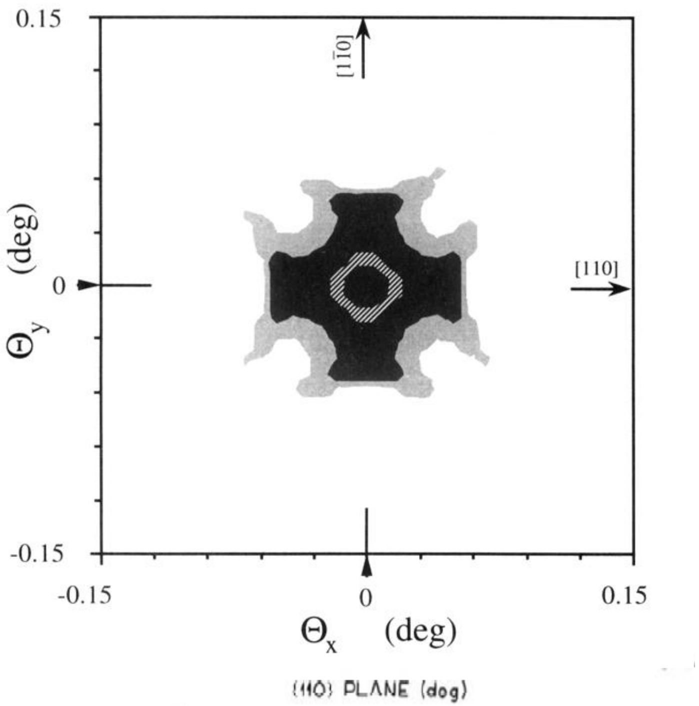
ions

4)

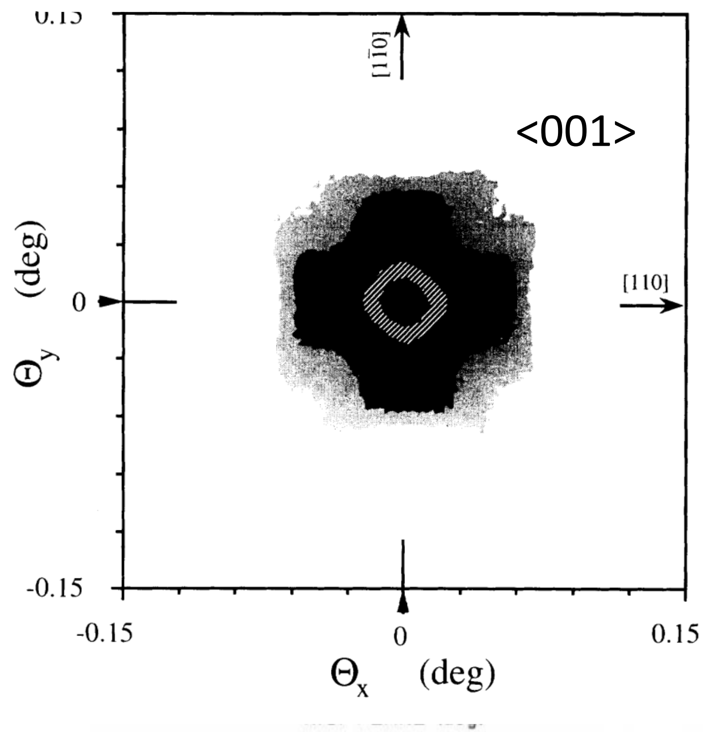
Literature

20 MeV, C^{6+}
180 nm Si

Simulation



Measured



Monte Carlo simulations(LAROSE)

- *Thermal vibration ignored*
- *multiple scattering ignored*
- *Lindhard potential*

- *Finer details faded ?*

H. F. Krause , Phys Rev B 33, 6036 ,1986. H. F. Krause , Phys Rev A 49, 283, 1994.

Simulated

Angular patterns [001] Si for any ion

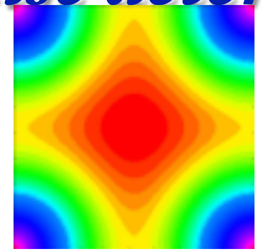
$$\Lambda = f(q, m_p)t/v$$

H. F. Krause , Phys Rev A 49, 283, 1994.

-

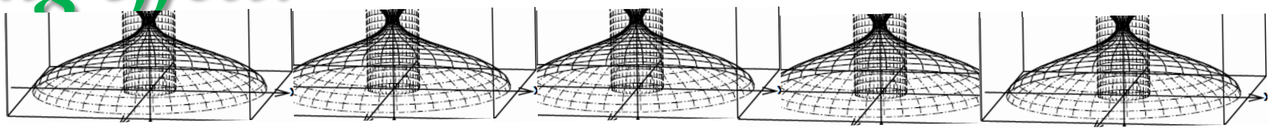
Motivation

- *Precise determination of ion channel potentials.*

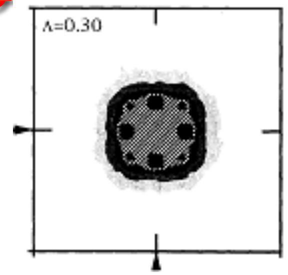


Si-H^+ (ZBL)

- *Experimental observation of Spatial-super focusing effect.*

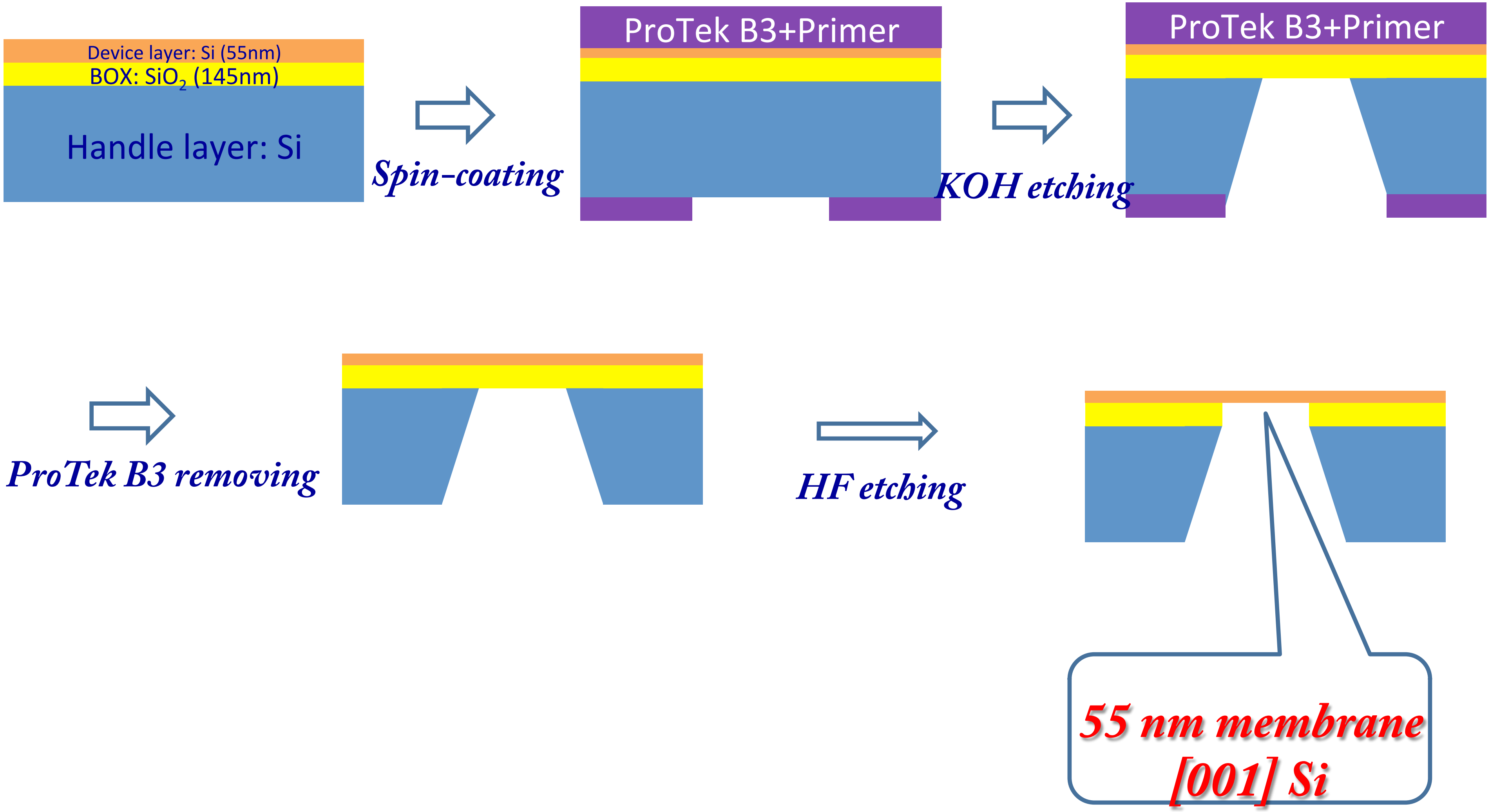


- *Capturing and understanding the fine features in the axial channeling patterns.*



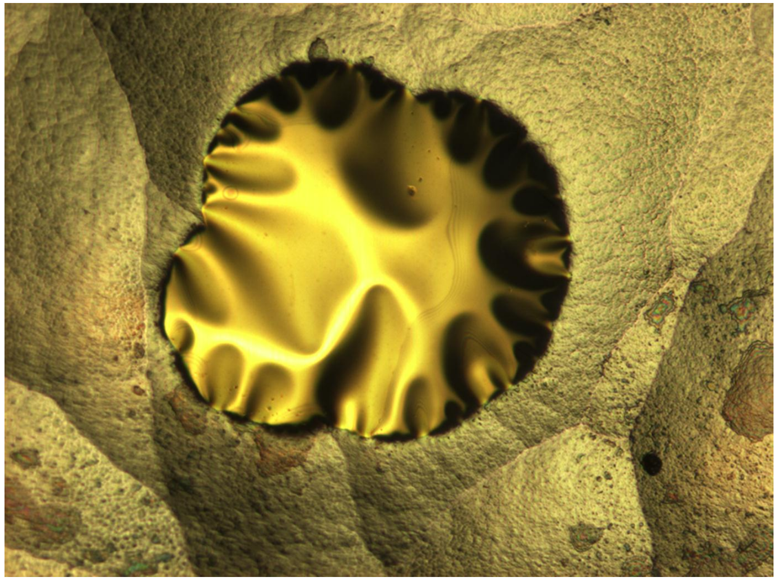
Experiments

Schematic of sample preparation



Optical Micrographs
55 nm thin Si membrane

145 nm SiO_2 on 55 nm Si



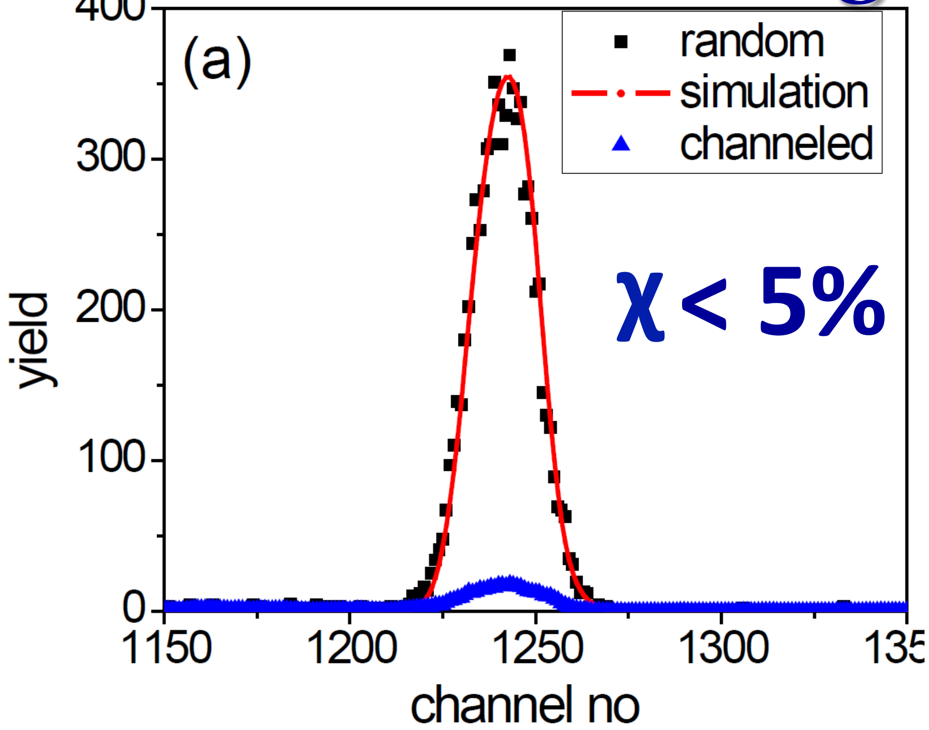
(500 µm)

- *Thin Si membrane is flat after removal of SiO_2*

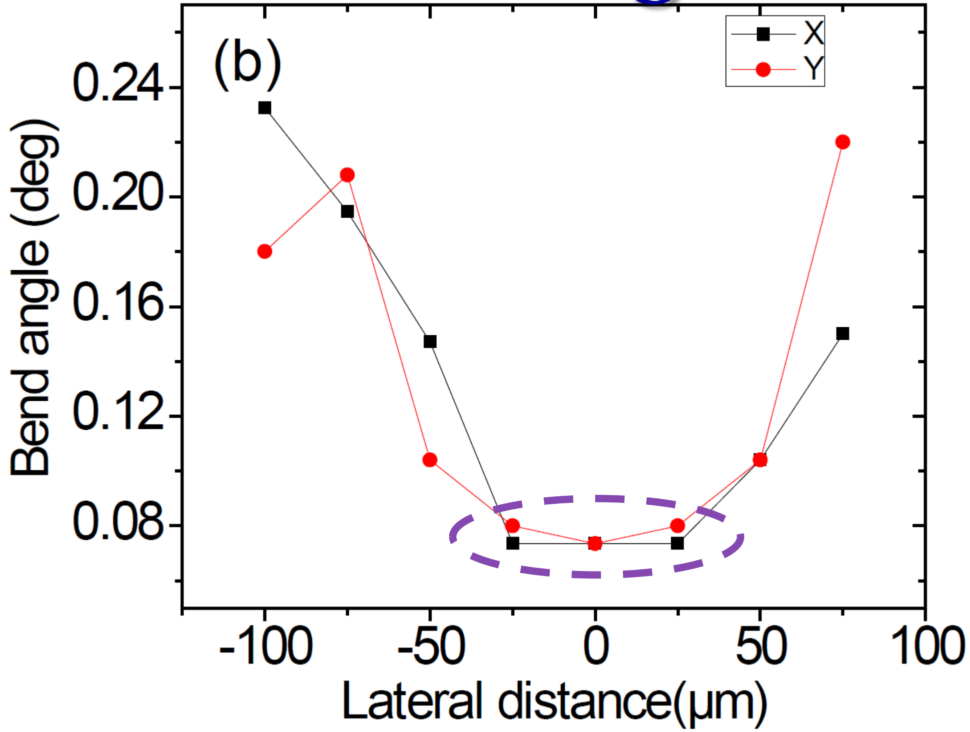
Dang et al., Appl. Phys. Lett. 99, 223105 (2011)

Sample Characterization

RBS-Channeling



Bend angle



Dang et al., Appl. Phys. Lett. 99, 223105 (2011)

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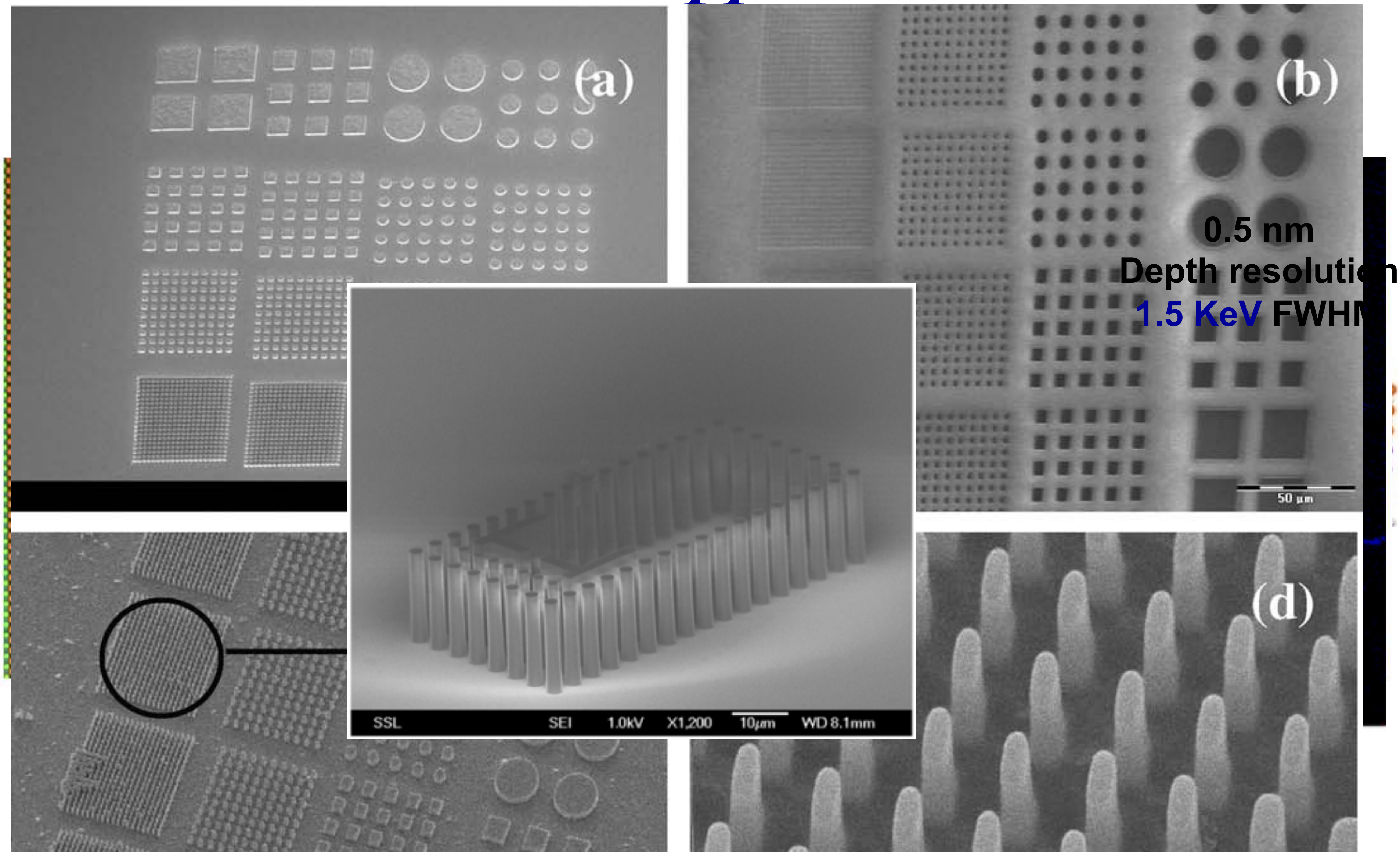
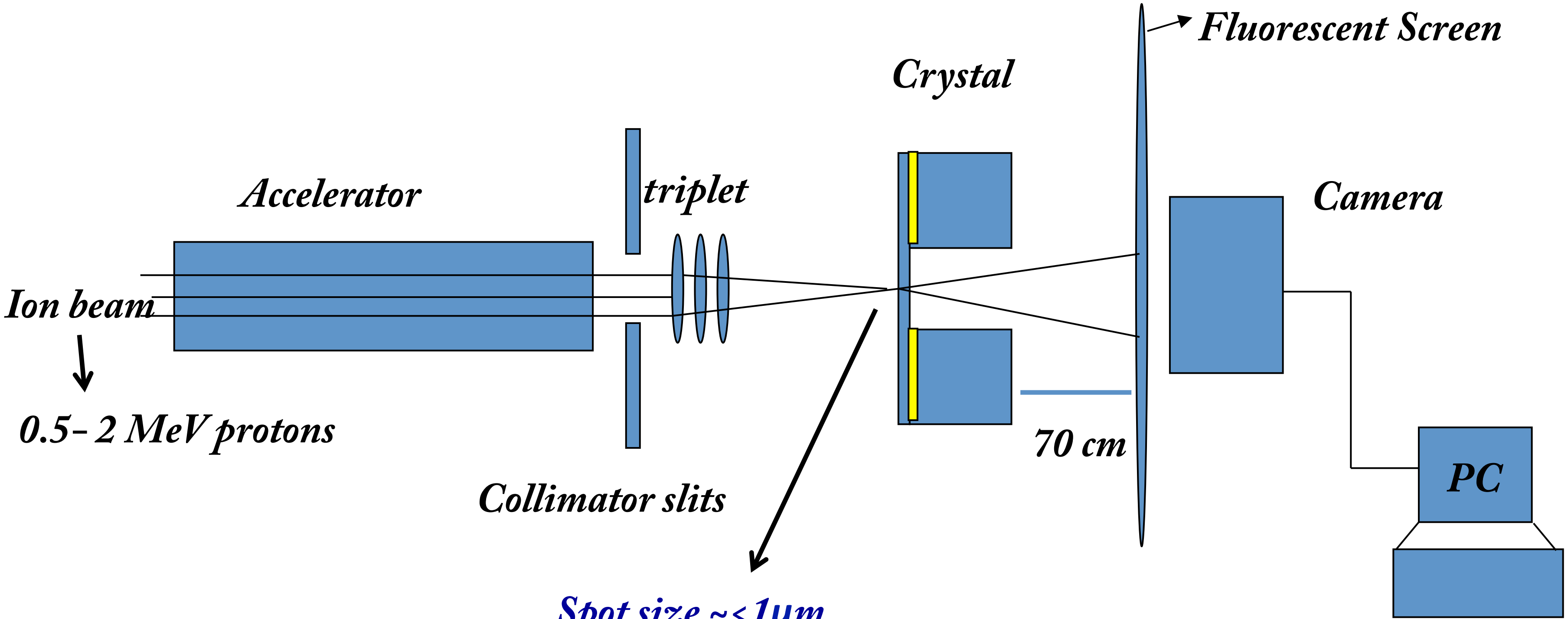


Channeling experiment Setup



Spot size ~<1μm

Beam convergence ~ < 0.01^0

Beam currents ~ <1- 10 pA

Axial channels

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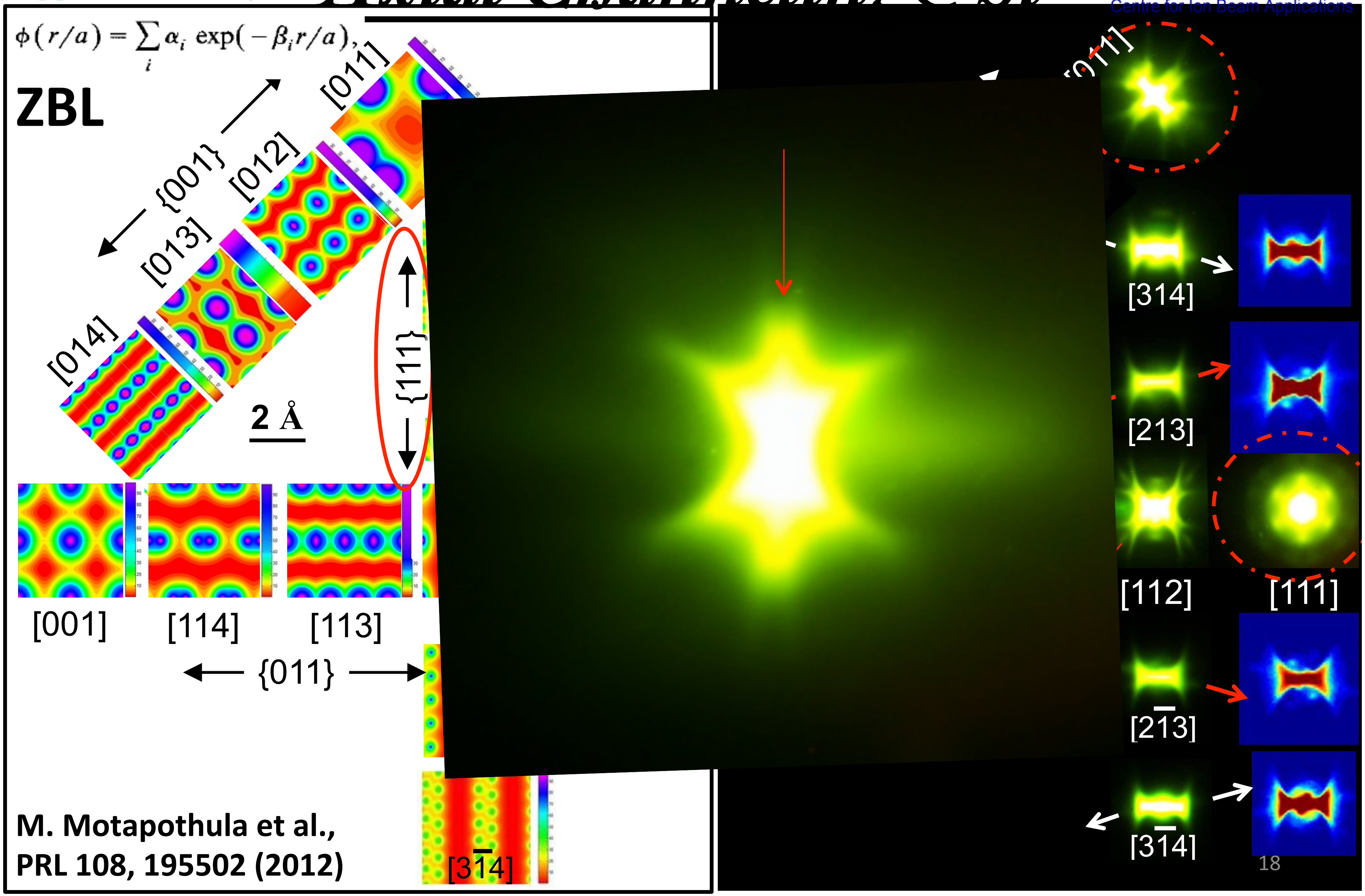
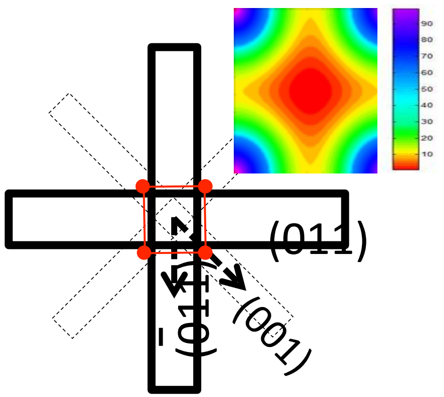
Axial Channeling@Si

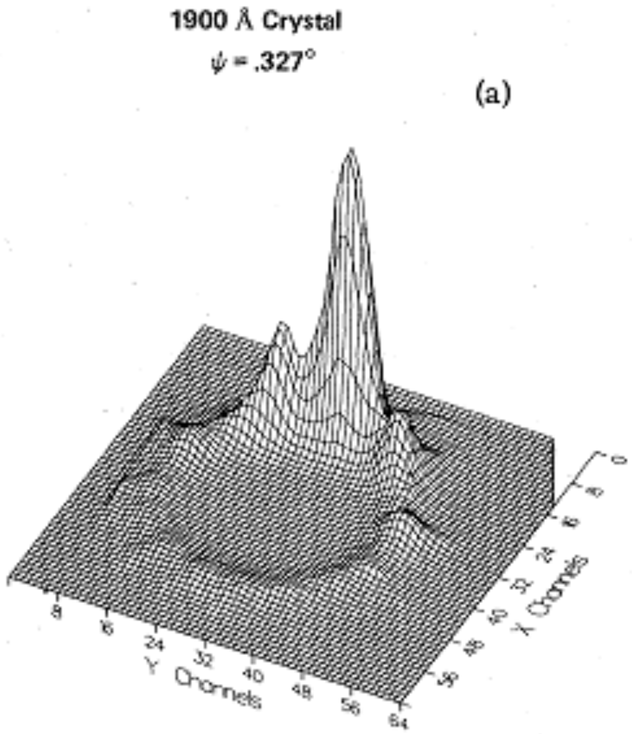


Doughnuts

- *Doughnuts show ring like shape distribution.*

$$E_T = E\varphi^2 + U(r)$$





J. S. Rosner et.al., PRB 18,1036, 1978

- *How they show at early stage of its evolution?*

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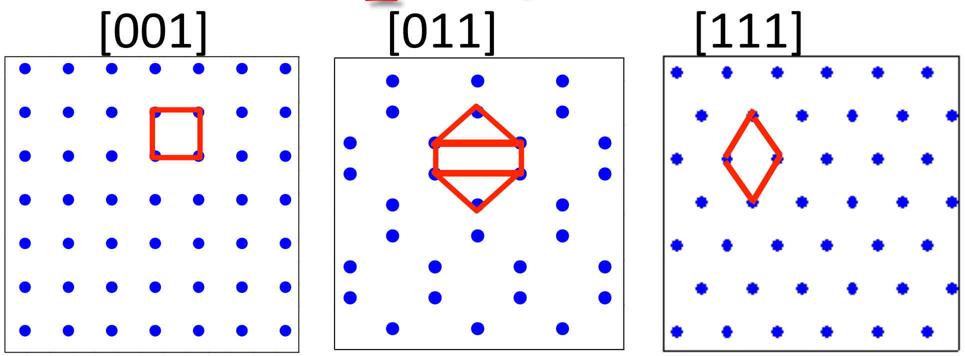
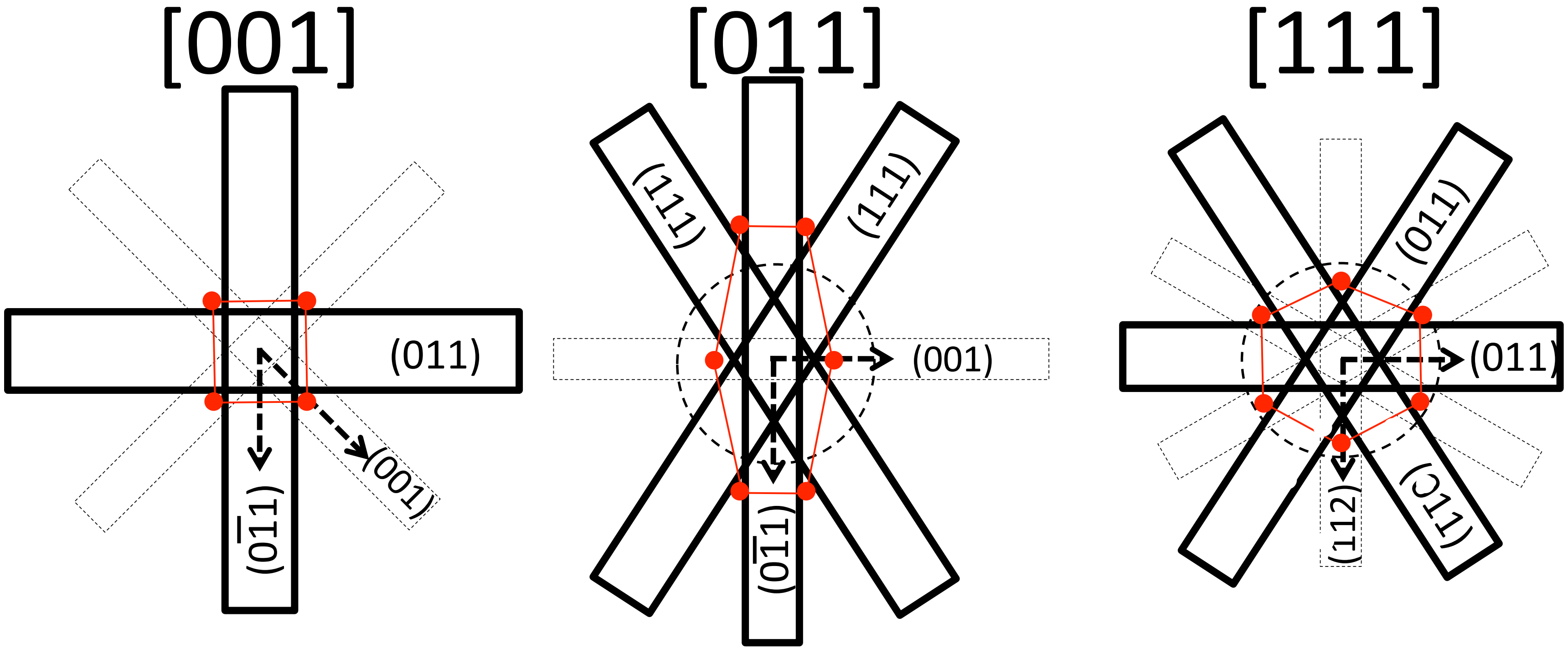
Axial projections

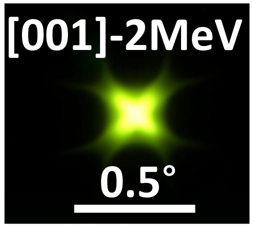




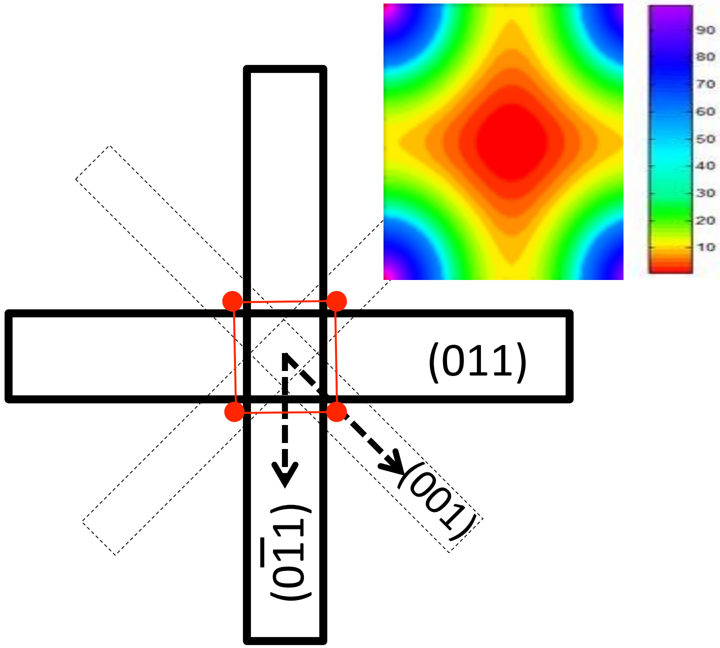
M. Motapothula et al., NIMB 283 (2012) 29–34

Channeling: tilted case

increasing axial tilt



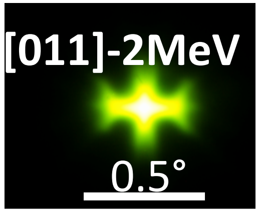
{001}



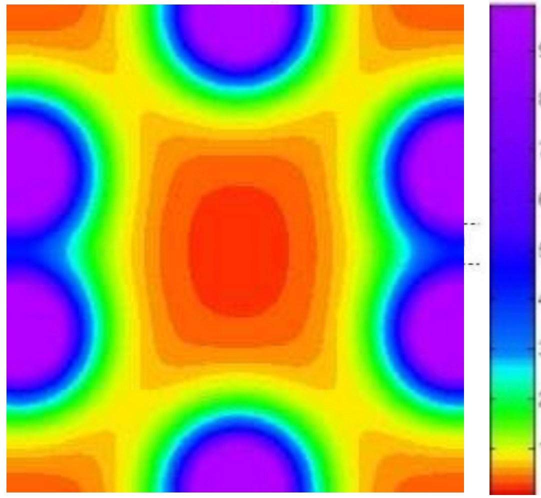
M. Motapothula et al., NIMB 283 (2012) 29–34

Channeling: tilted case

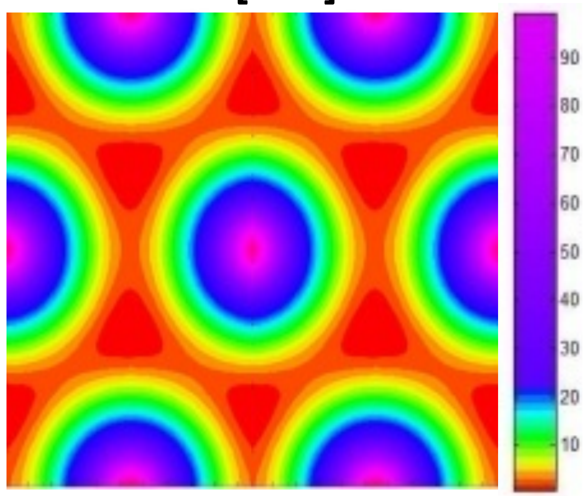
increasing axial tilt



[011]



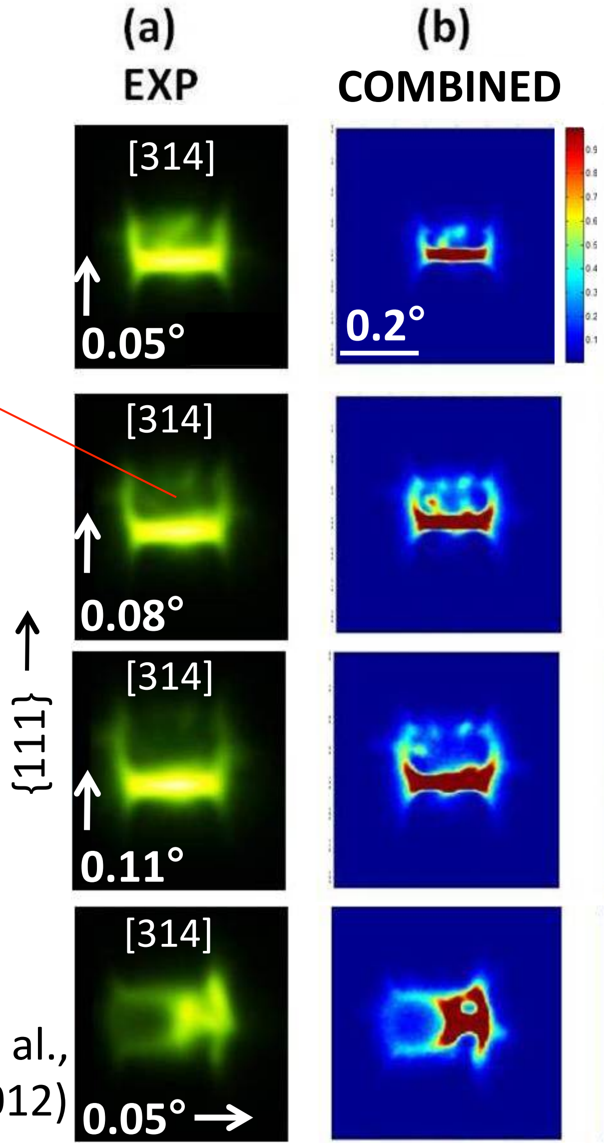
[111]

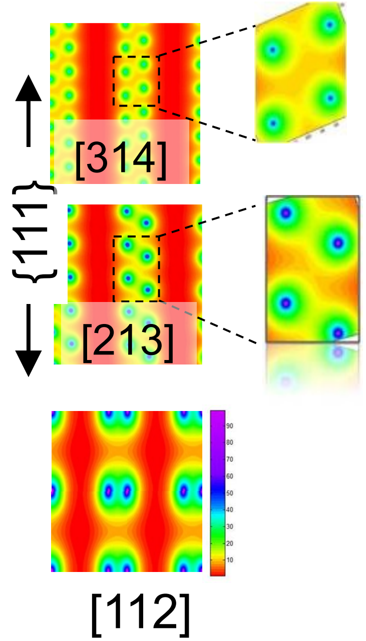


M. Motapothula et al., NIMB 283 (2012) 29–34

Axial doughnuts which contained {111}

Separate Axial behavior

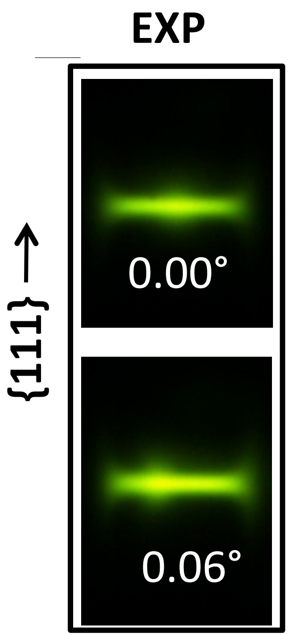


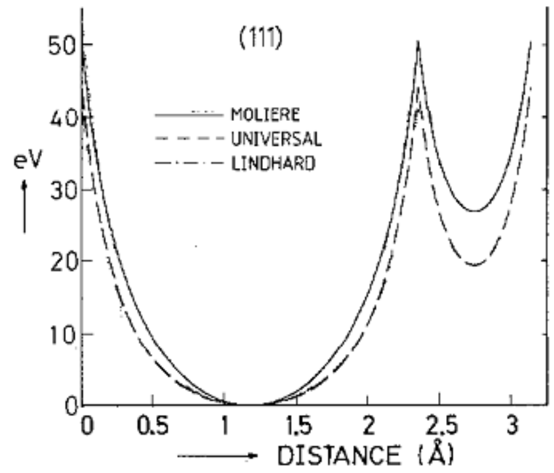


M. Motapothula et al., PRL 108,195502(2012)

Planar channeling

Simulations comparison

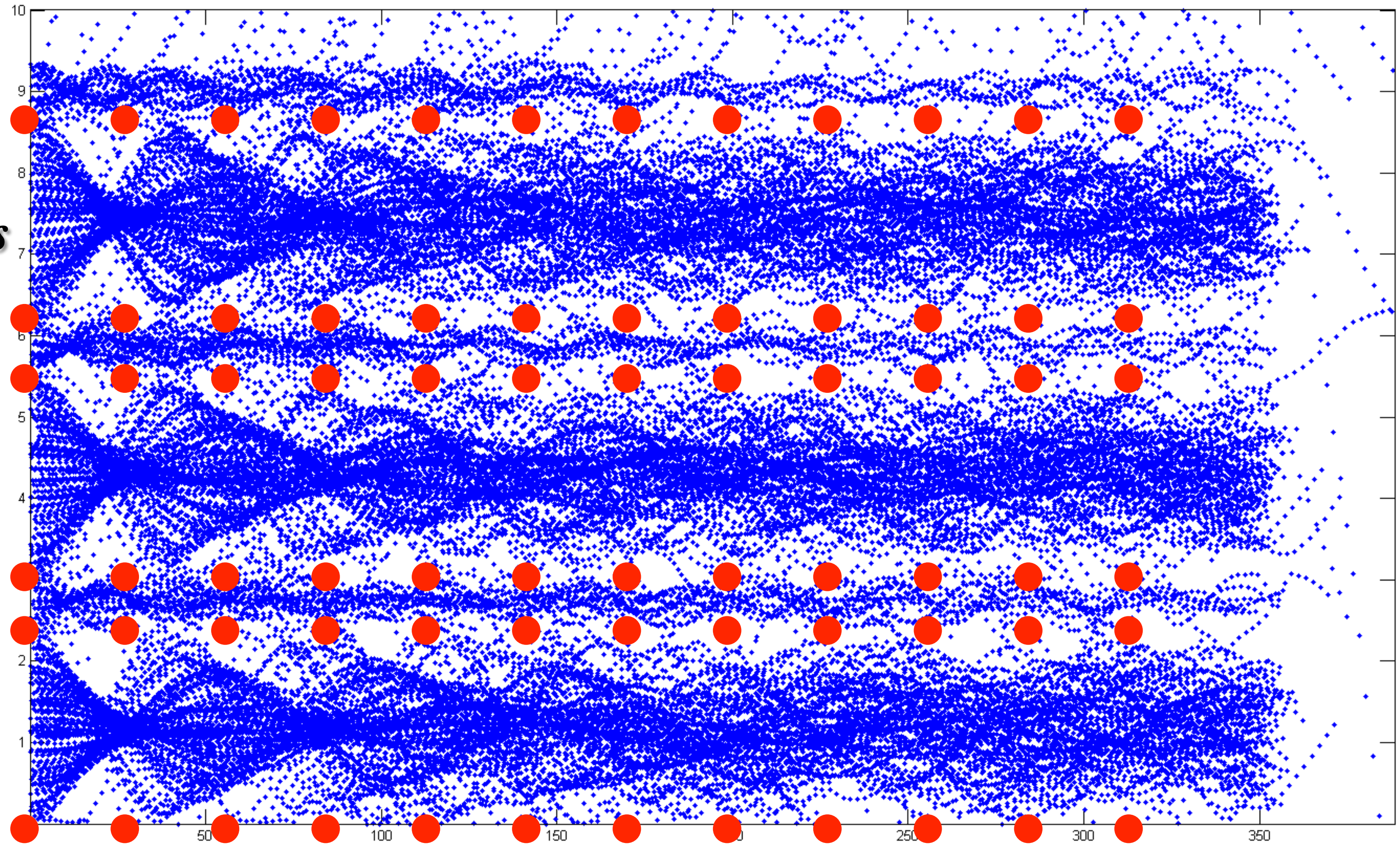




M. Motapothula et al., PRL 108, 195502 (2012)

{111} Planar channeling

2MeV Protons Silicon

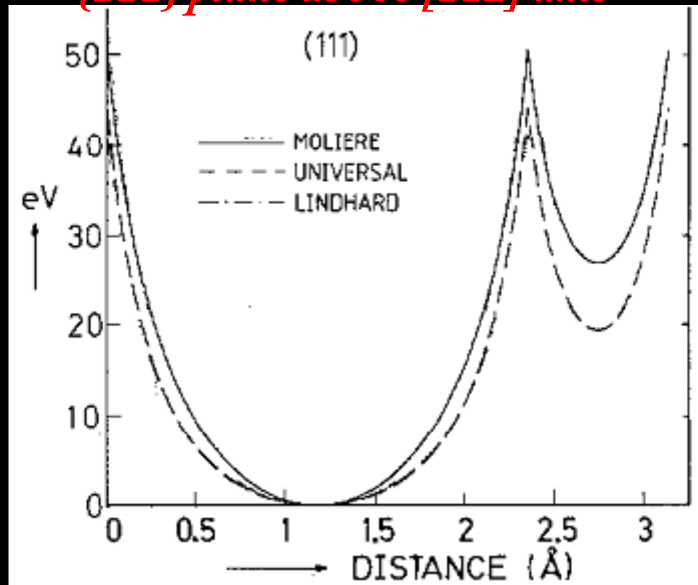


Depth (1µm)

{111} Planar channeling

2MeV Protons; 55nm thick [001] Silicon

{111} plane above [112] axis



Phase space analysis

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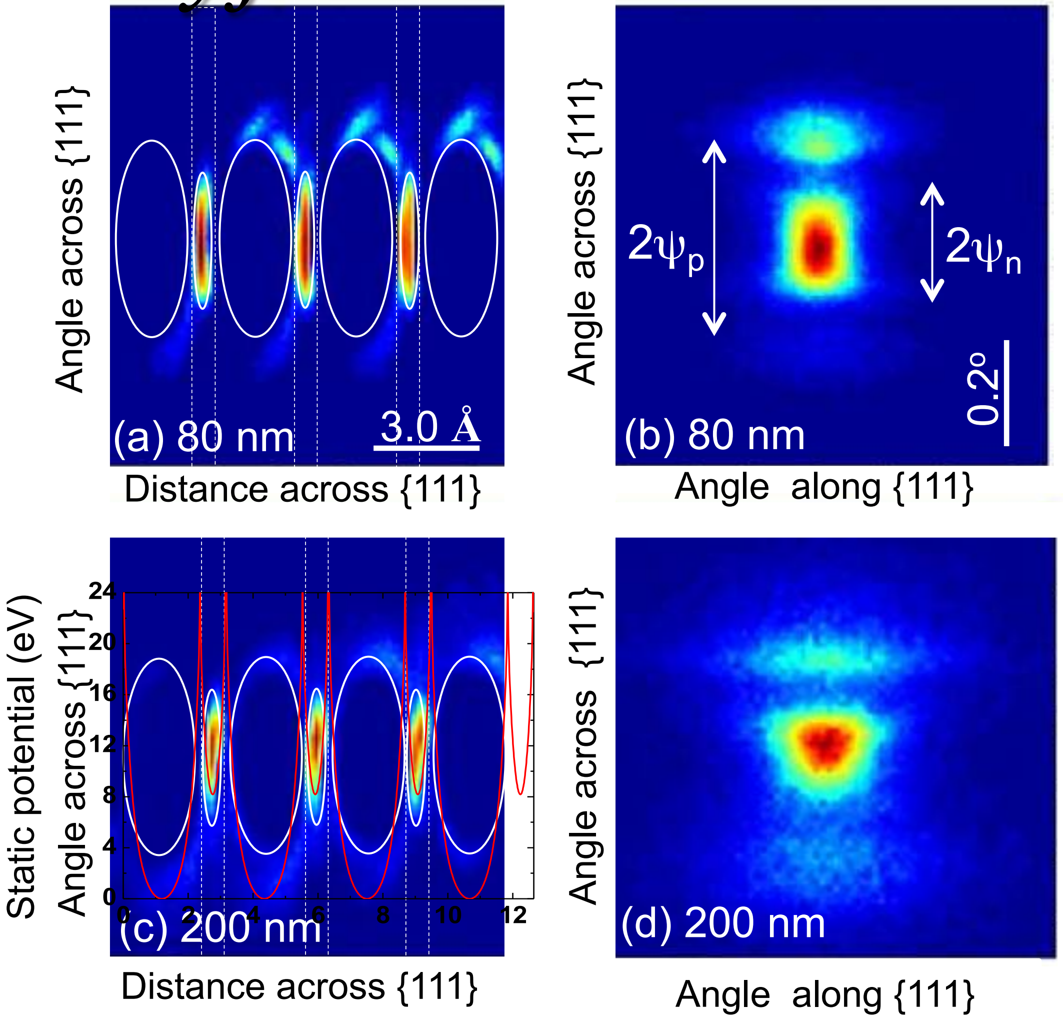
Data is only from: Ions incident on Narrow planes



Captured
Early stage
axial
channeling

Doughnuts
Squares
&
Hexagons

{111} plane
Showed
It’s impact
In planes/axes

Thanks

A

Lot

Whole CIBA Photo

Conclusions

- *Captured the best Axial channeling features coming from the early stage of its evolution.*
- *Observed the minor axial-channeling patterns for the first time.*
- *Doughnuts are squares, hexagons etc…*

  but not rings at every axis.
- *Understood narrow {111} planar channeling.*
- *Observed the separate axial like behaviour at axes which contain narrow {111} plane.*

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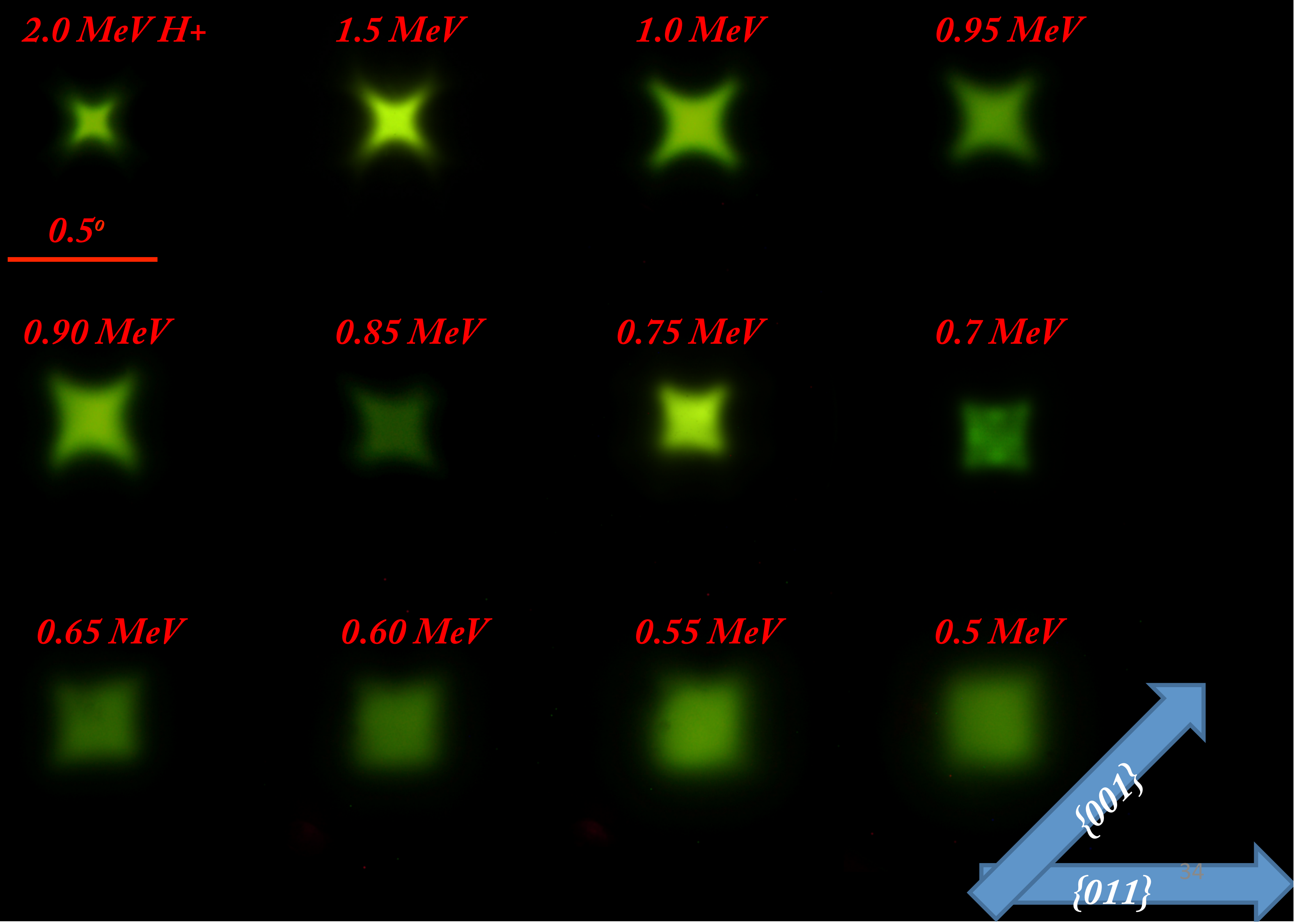
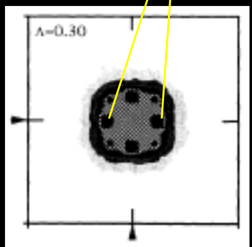
Future plans

55nm thick [001] Silicon

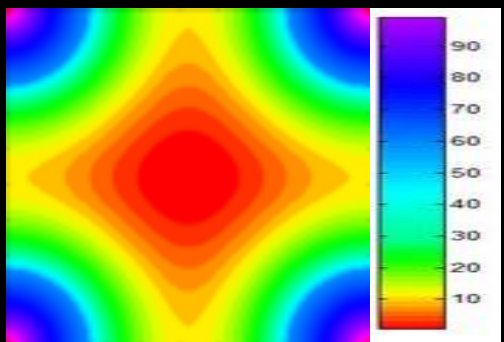


{011} planar tilt at [001] 700 KeV H+

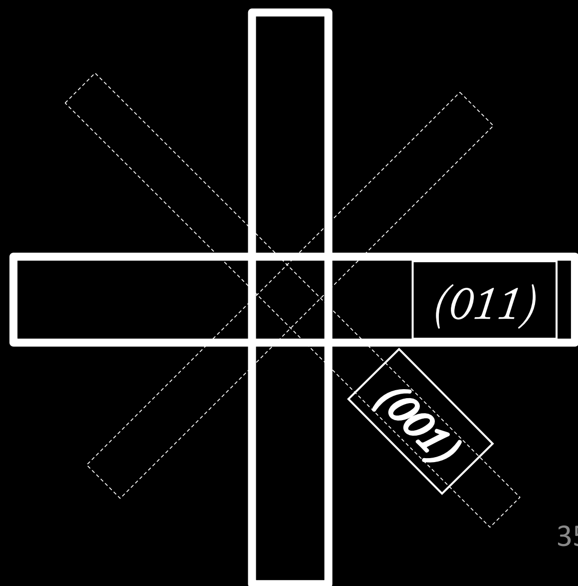
Short movie:
The central bright dots are only moving and merging with the side bright regions by tilting away
The large bright dots are coming from the side-middle of the unit cell where the potential is not lowest (moderate).



Only 2 middle central bright dots are moving first when tilted



[001]



{001} planar tilt at [001] 700 KeV H+

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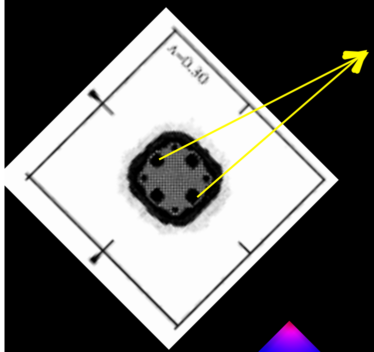
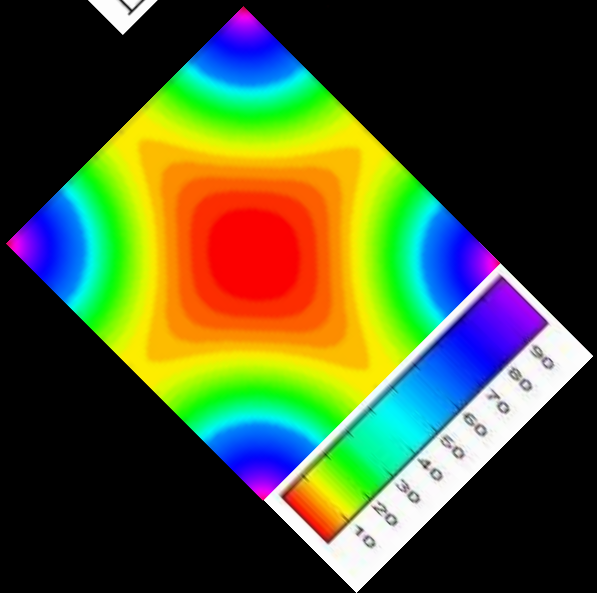
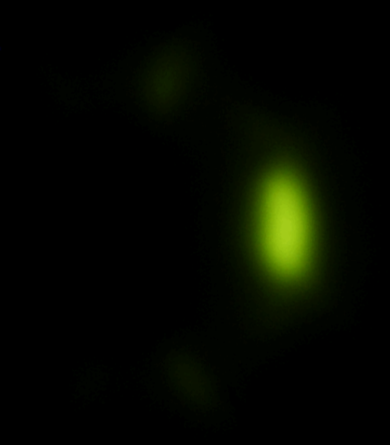
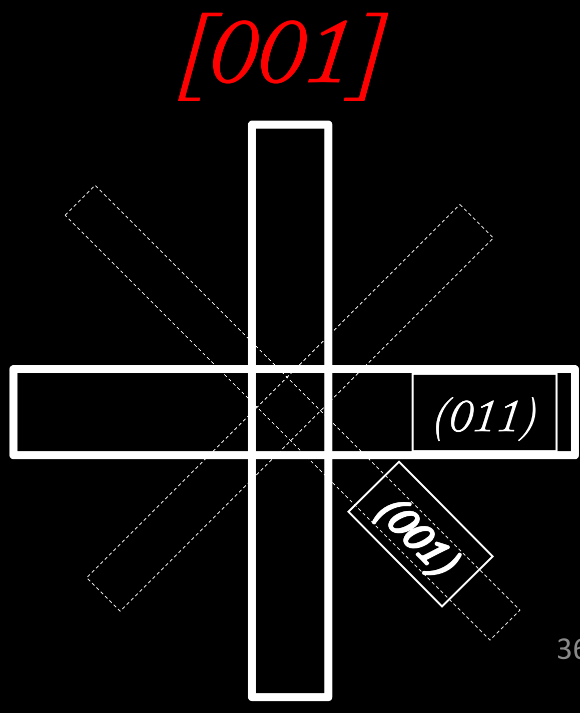


All the 4 central bright dots are moving together when tilted





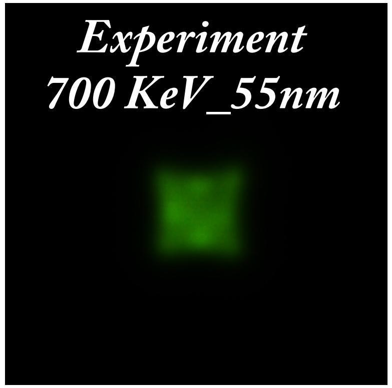


mparison of main 3 potenti

$$= \frac{Z_1 Z_2 e^2}{r}[0.35\exp(-br)+0.55\exp(-4br)+0.10\exp(-20br)],$$

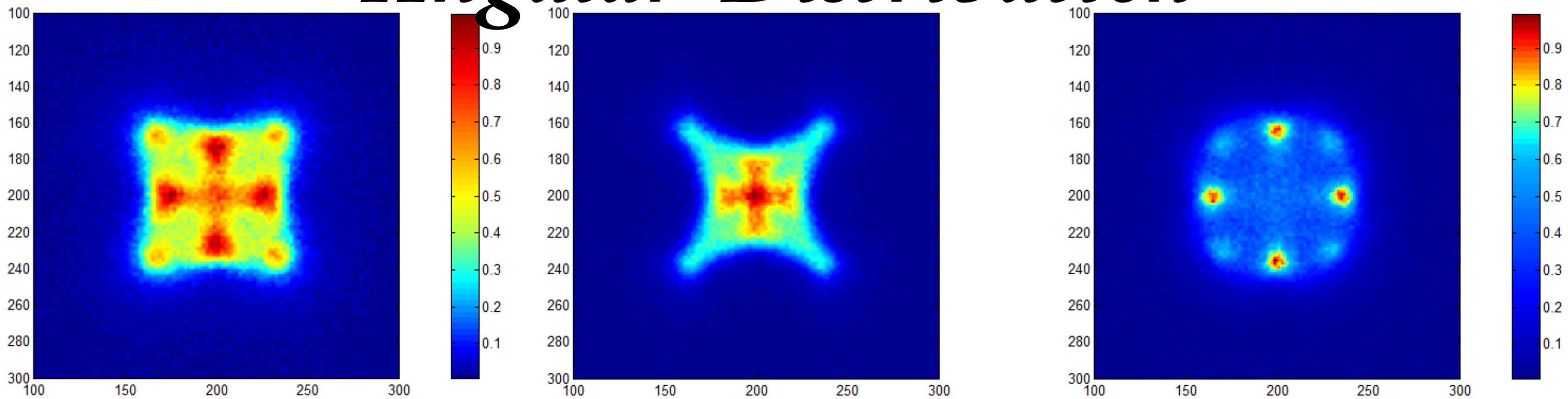
$$\varphi\left(\frac{r}{a}\right) = \sum_i a(i)\exp\left(-\frac{\beta_i r}{a}\right)$$

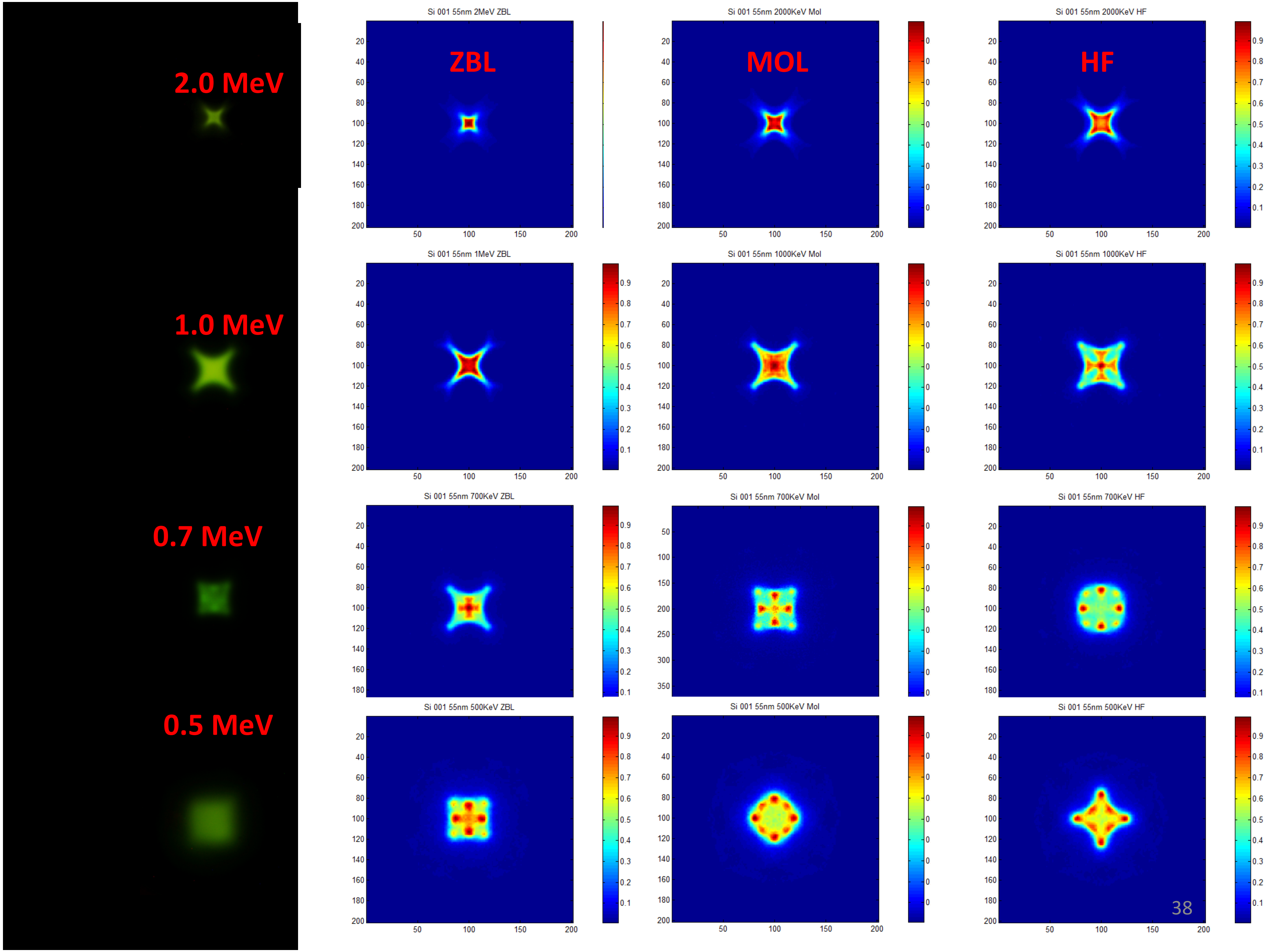
$$a(i) = \{0.1818, 0.5099, 0.2802, 0.02817\},$$
$$\beta_i = \{2, 0.9423, 0.4029, 0.2106\},$$
$$a = 0.8853 a_0/(Z_1^{0.23} + Z_2^{0.23}).$$



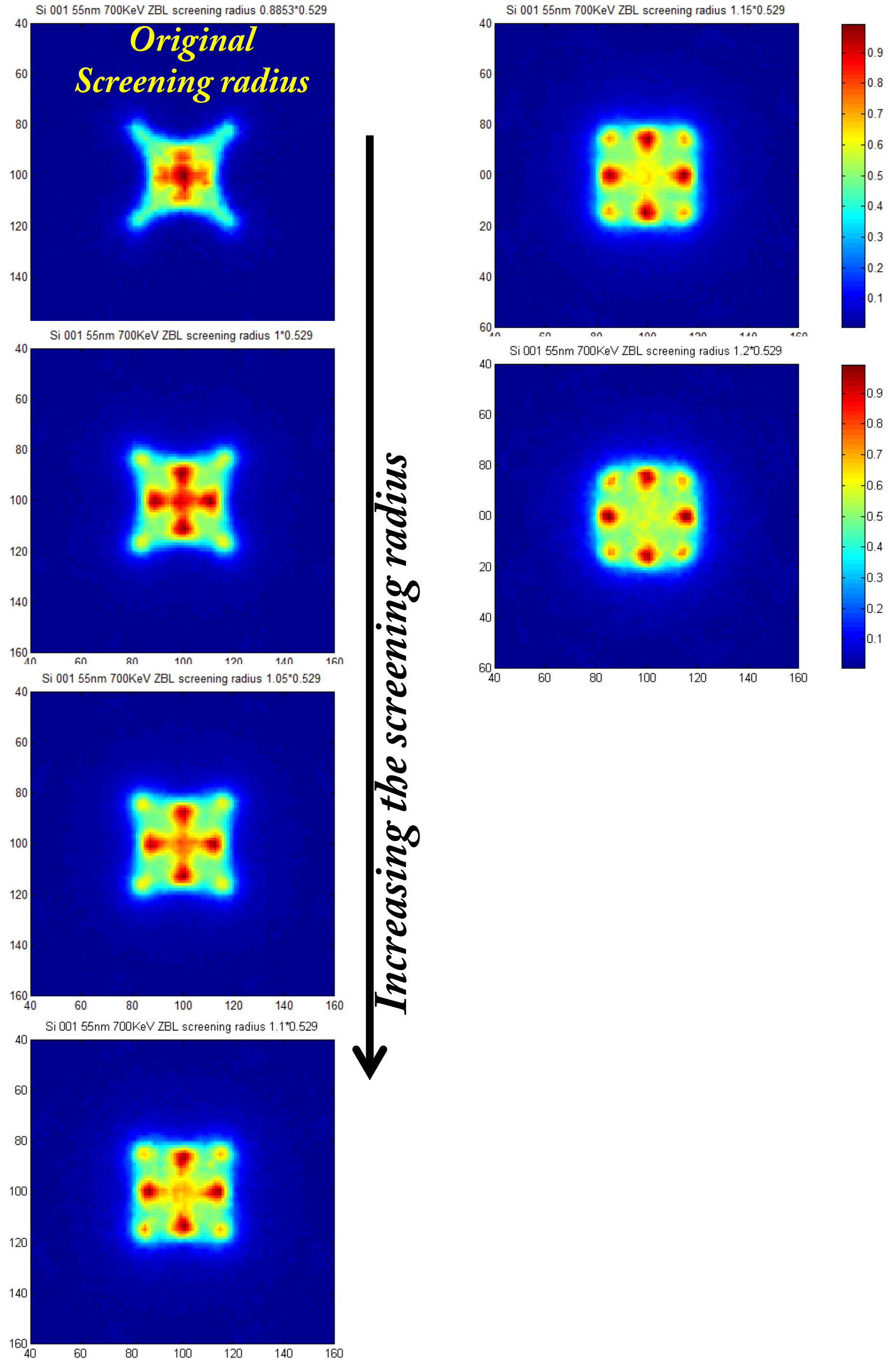
Moliere *ZBL* *Hartree-Fock*

FLUX Monte Carlo Simulations
Angular Distribution



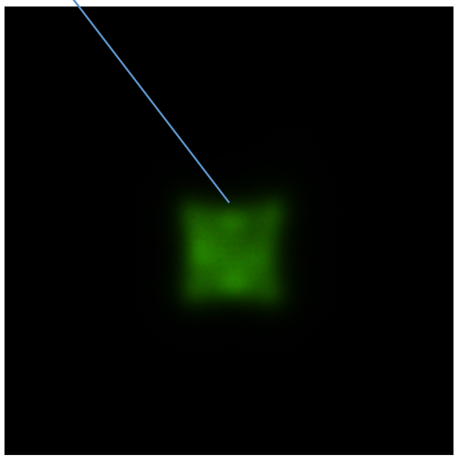


2.0 MeV
1.0 MeV
0.7 MeV
0.5 MeV
Si 001 55nm 2MeV ZBL
ZBL
Si 001 55nm 2000KeV Mol
MOL
Si 001 55nm 2000KeV HF
HF
Si 001 55nm 1MeV ZBL
Si 001 55nm 1000KeV Mol
Si 001 55nm 1000KeV HF
Si 001 55nm 700KeV ZBL
Si 001 55nm 700KeV Mol
Si 001 55nm 700KeV HF
Si 001 55nm 500KeV ZBL
Si 001 55nm 500KeV Mol
Si 001 55nm 500KeV HF



FLUX ZBL

1. *The dot is at side edge (not inside)*
2. *There should be a curvature*
3. *No center bright intensity distribution*

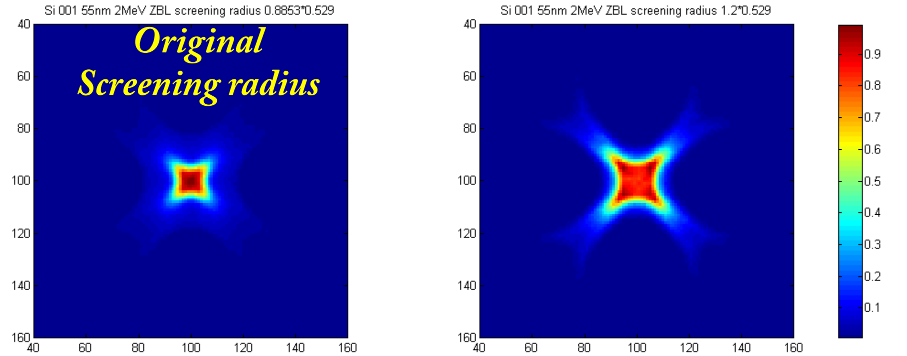


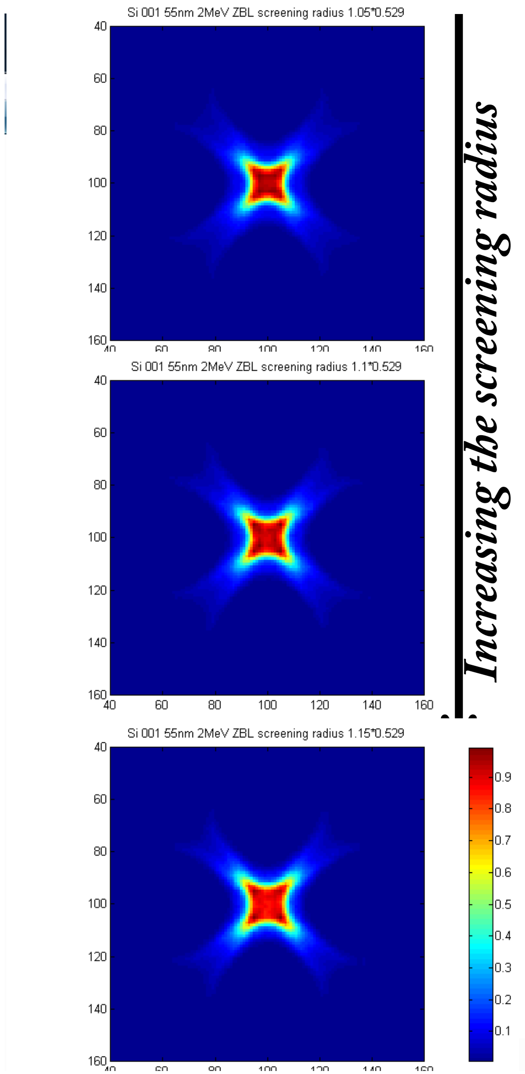
700 KeV

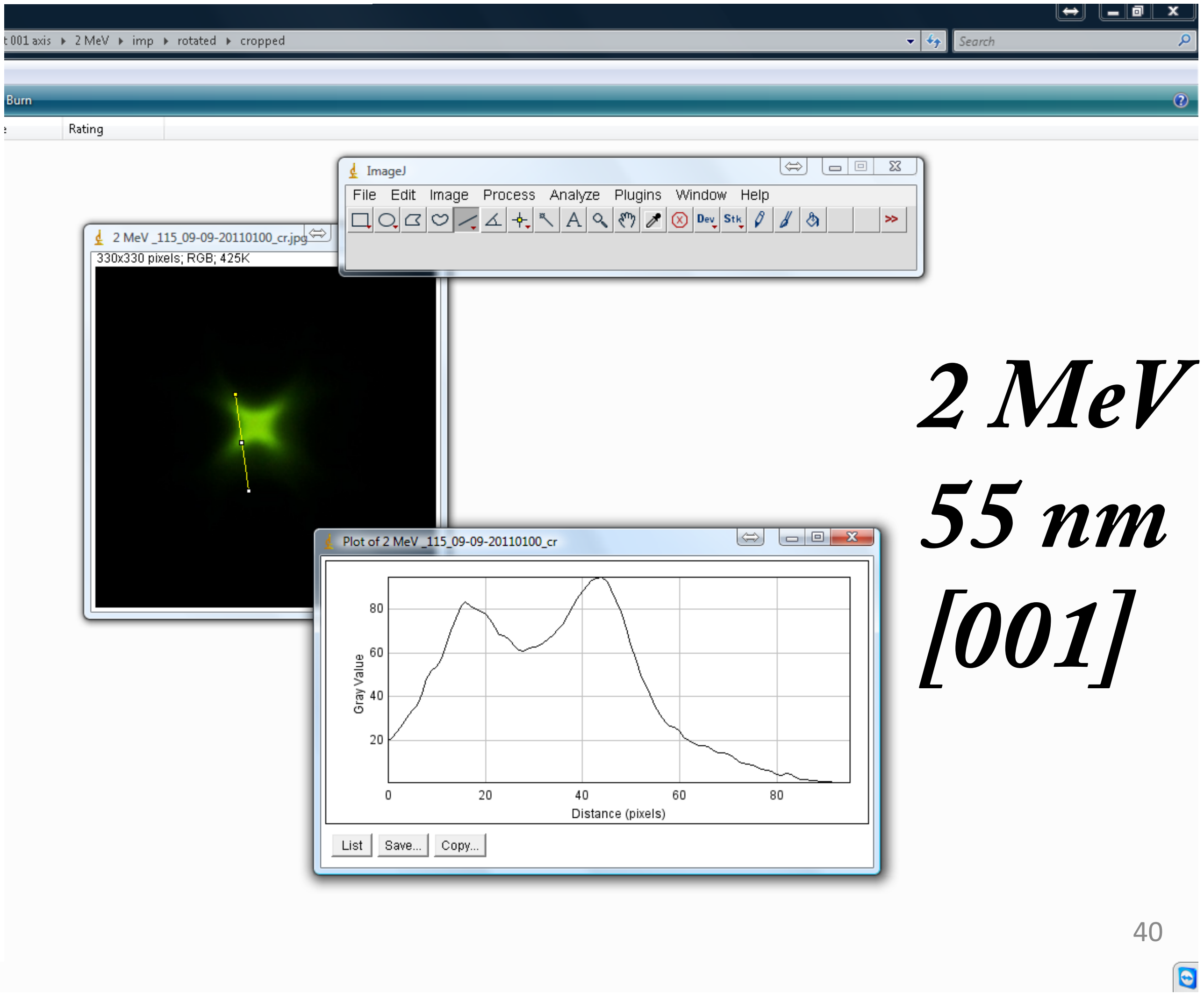
55 nm

[001]

FLUX ZBL





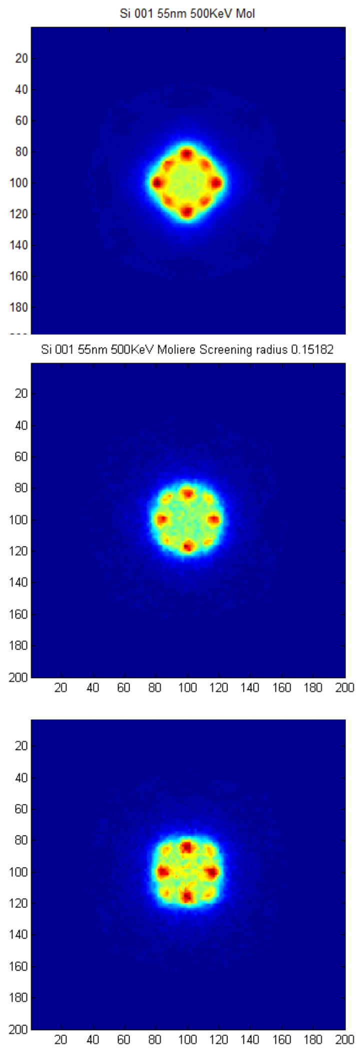


2 MeV

55 nm

[001]

FLUX MOL

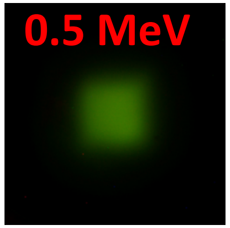


Decreasing the screening radius

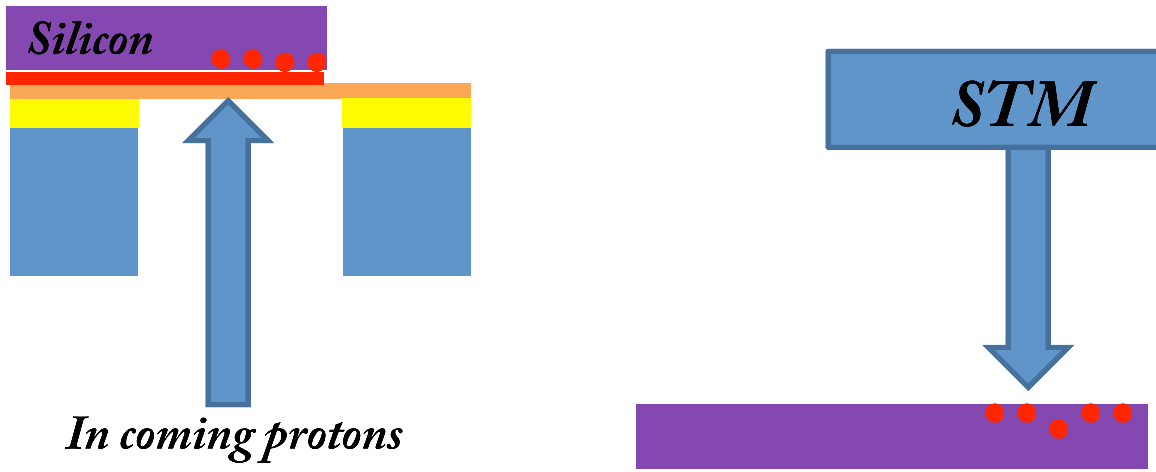
500 KeV

55 nm

[001]



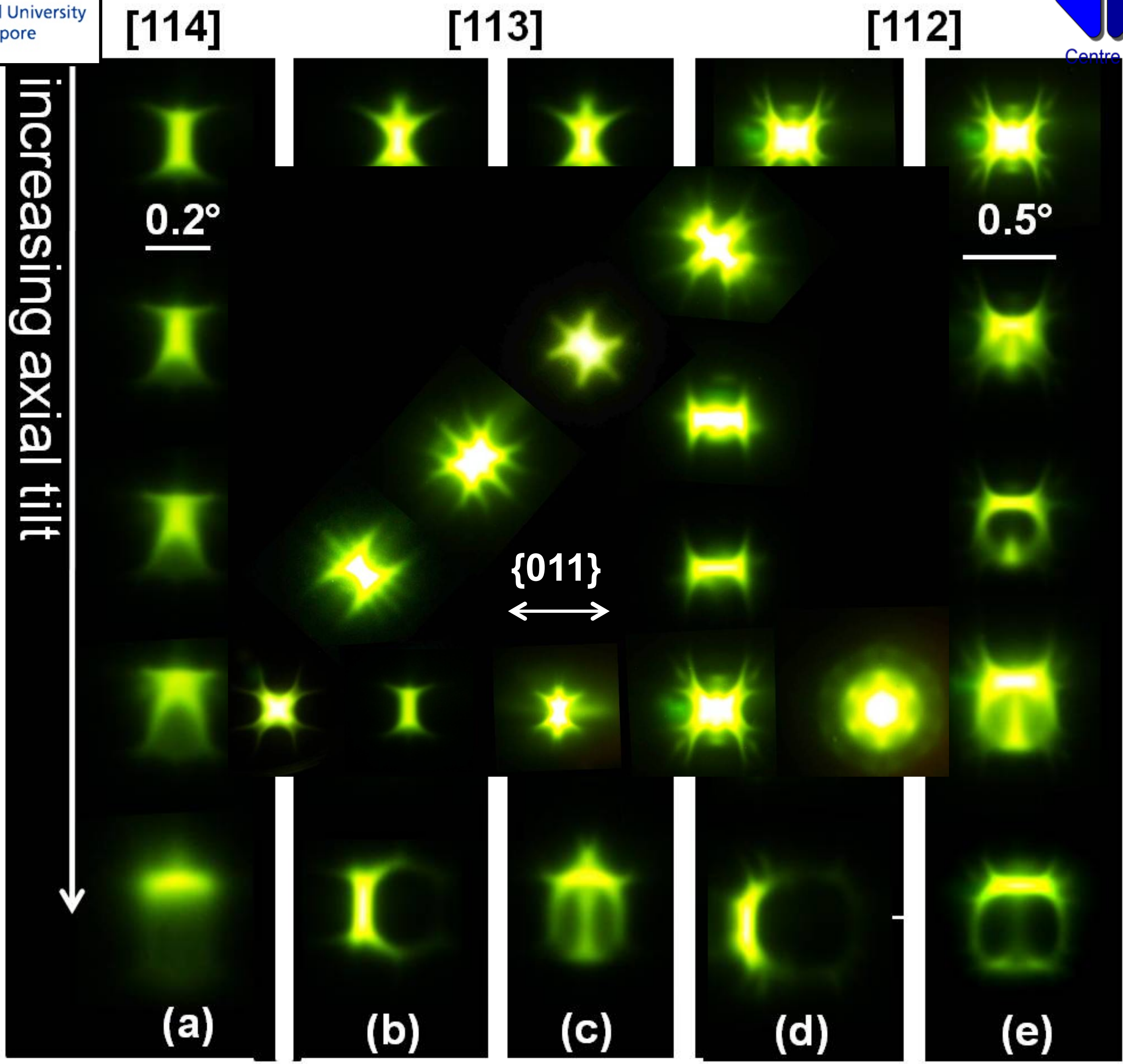
Verifying Super focusing effect

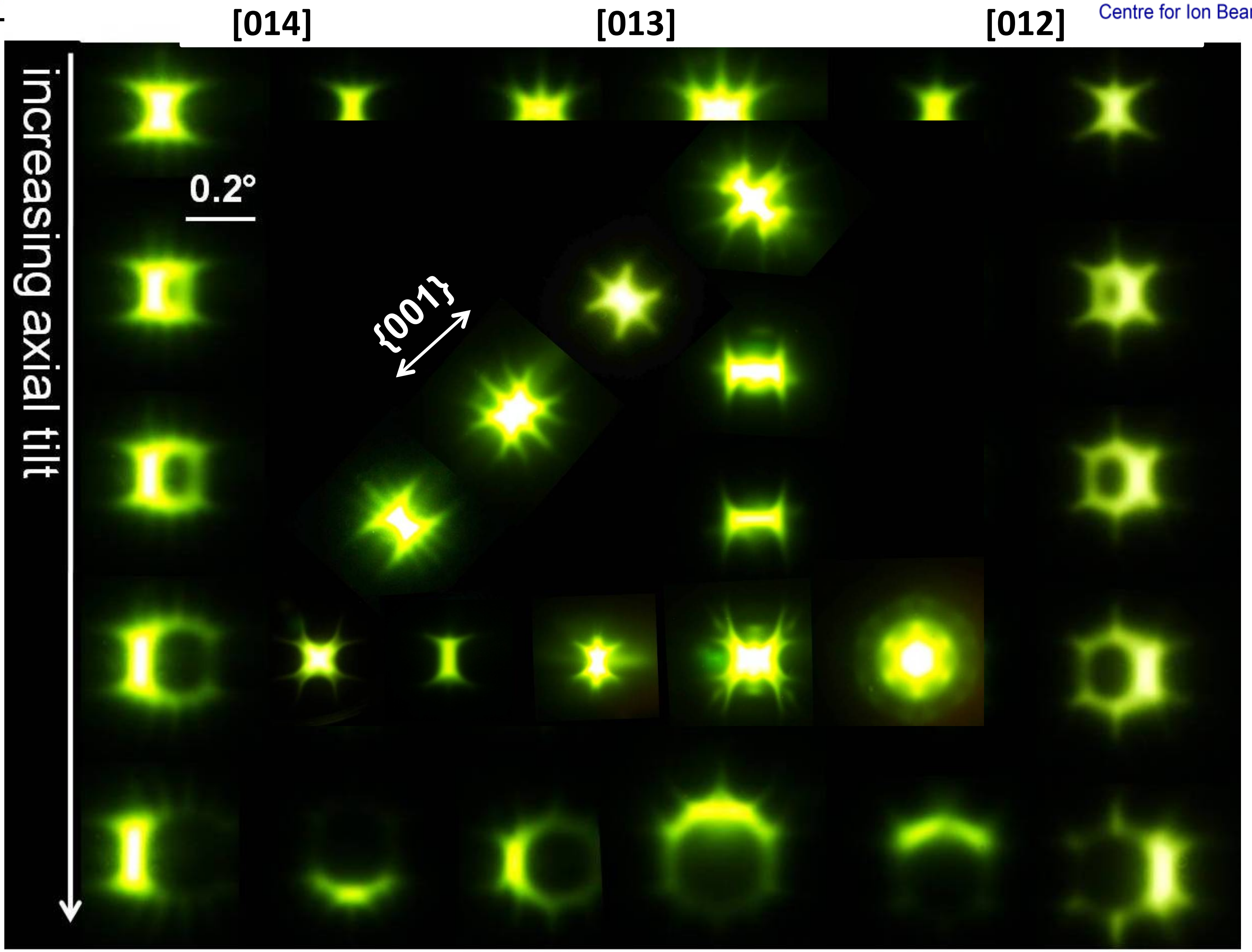


1. Deposit a monolayer of metallic film on membrane and clamp a substrate on top.

2. The super focused channeled protons recoil the metal atoms into the Si substrate.

3. Observing these Recoiled metal atoms by STM can prove the Super focusing effect.


[114]
[113]
[112]
increasing axial tilt
0.2°
0.5°
{011}
(a)
(b)
(c)
(d)
(e)



(a) (b) (c) (d) (e) (f)

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Axial projections

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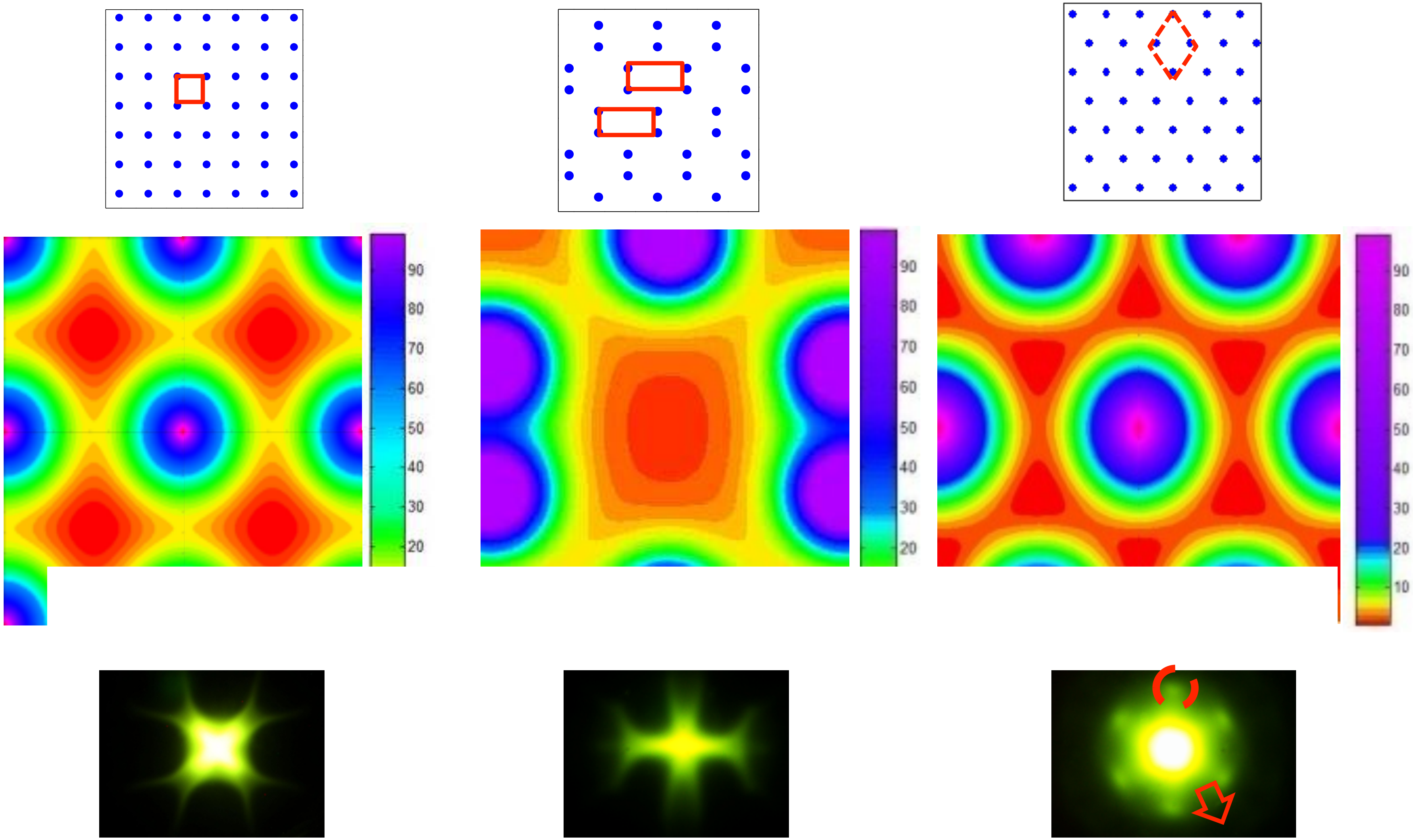
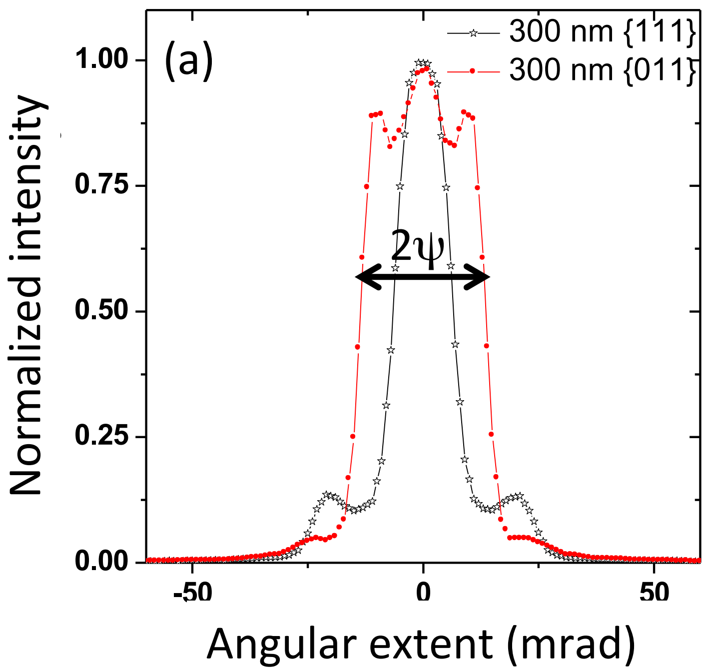
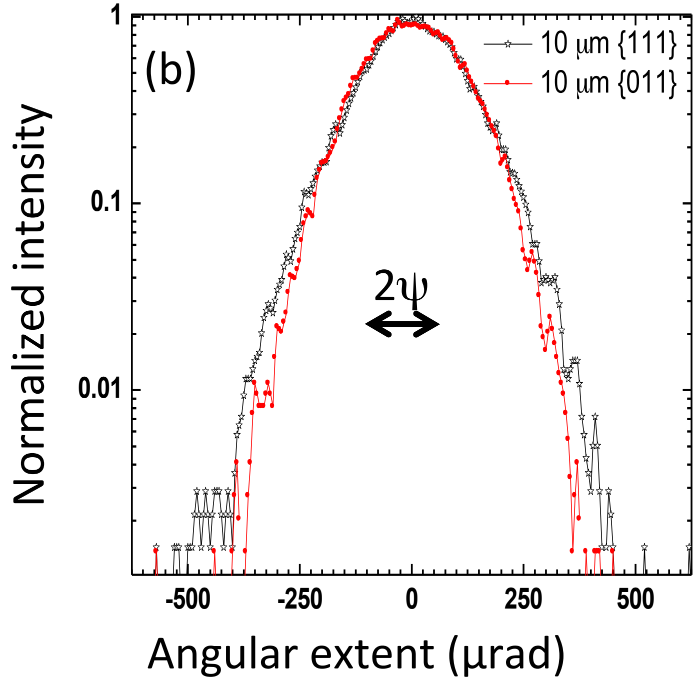


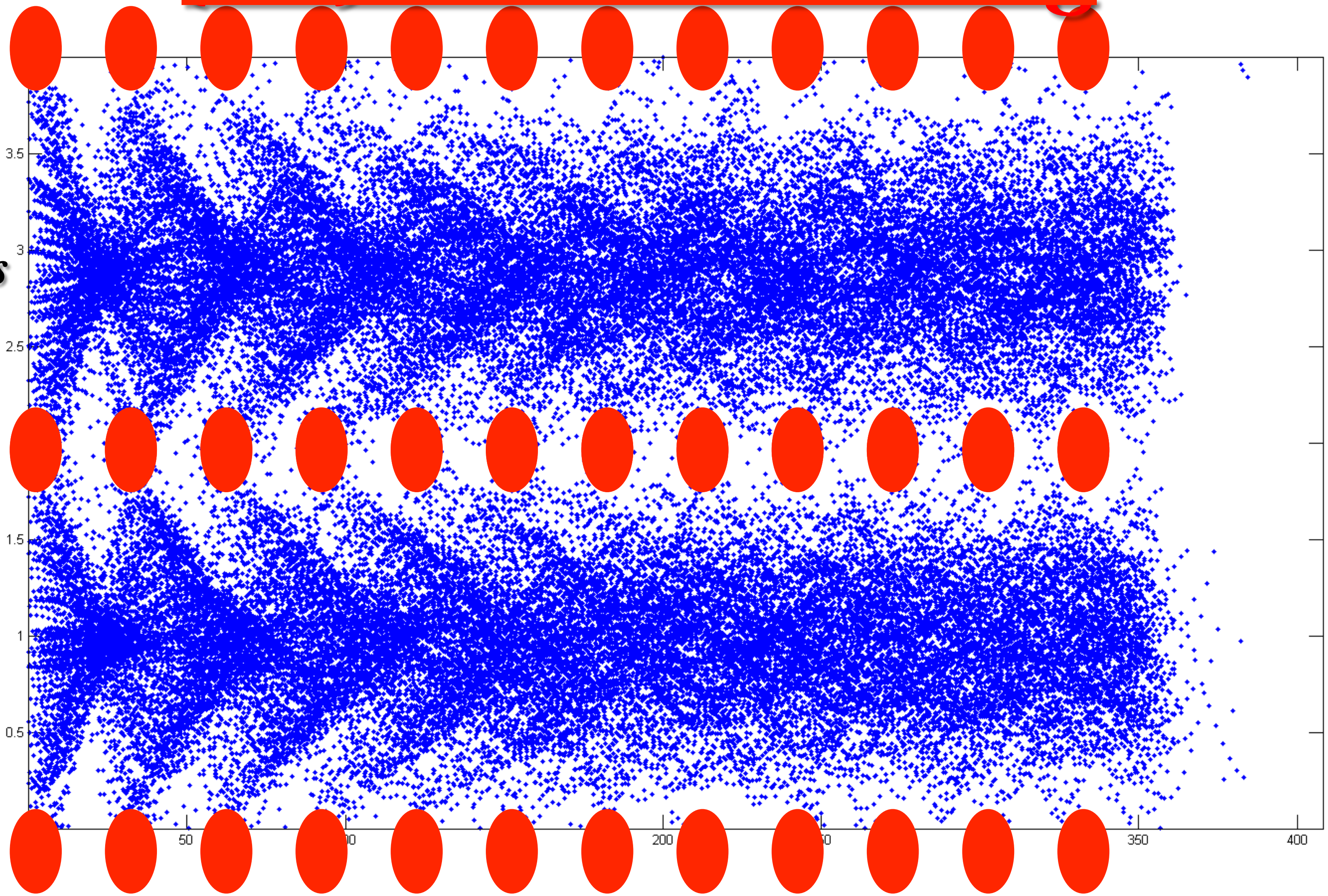
M. Motapothula et al., NIMB 283 (2012) 29–34


(a)
300 nm {111}
300 nm {011}
2ψ
Normalized intensity
1.00
0.75
0.50
0.25
0.00
-50
0
50
Angular extent (mrad)


(b)
10 μm {111}
10 μm {011}
2ψ
Normalized intensity
1
0.1
0.01
-500
-250
0
250
500
Angular extent (μrad)

{110} Planar channeling

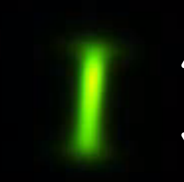
2MeV
Protons
Silicon



Depth (1μm)

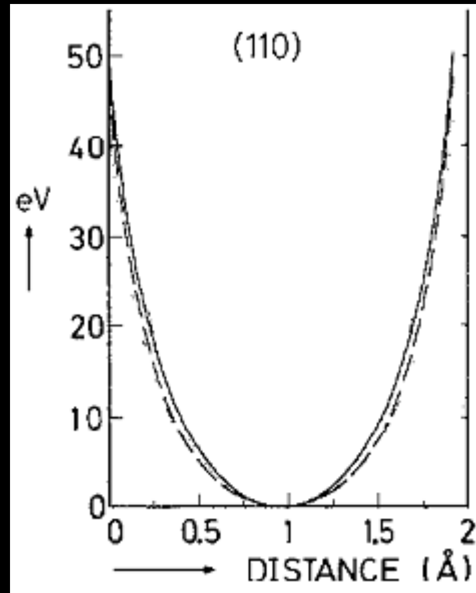
{110} Planar channeling

2MeV Protons; 55nm thick [001] Silicon



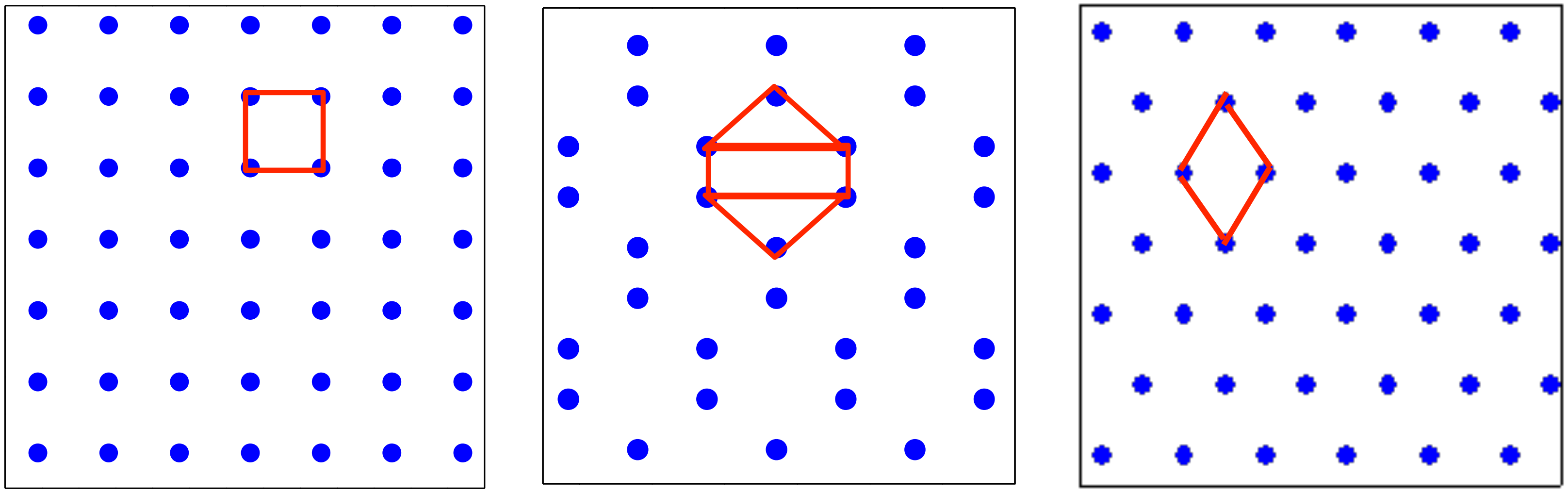
$2\psi_p$

{110} plane near [112] axis



Axial projections

[001] [011] [111]



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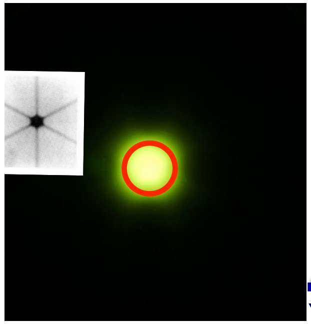
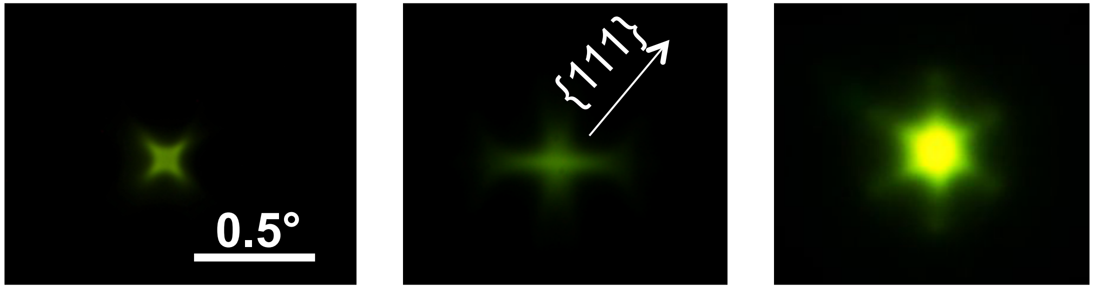
Axial channeling



T=55nm	T≈78nm	T≈84nm
[001]	[011]	[111]



Incident Ions: 2MeV H+

Increasing exposure time

We can See Minor plane Intersections With axes

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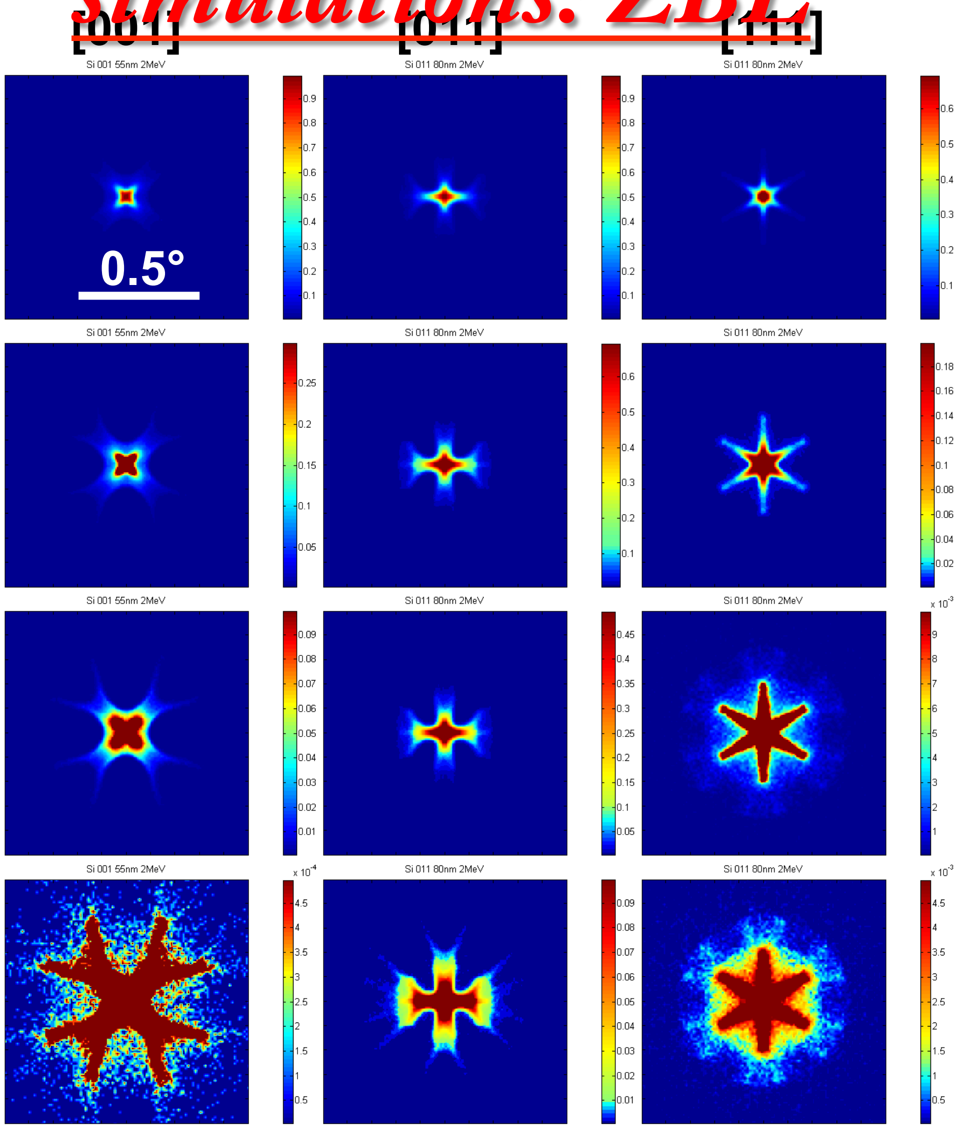
Monte Carlo FLUX simulations: ZBL

$$\Delta p_{\perp}(b) = \int_0^{\infty} F_{\perp}\, dt$$
$$\simeq \frac{1}{v}\int_{-\infty}^{\infty} F_{\perp}\, dz$$
$$= \frac{-1}{v}\frac{\partial}{\partial b}\int_{-\infty}^{\infty} V(\sqrt{z^2+b^2})\, dz,$$

$$V(r) = \frac{Z_1 Z_2 e^2}{r}\phi(r/a).$$

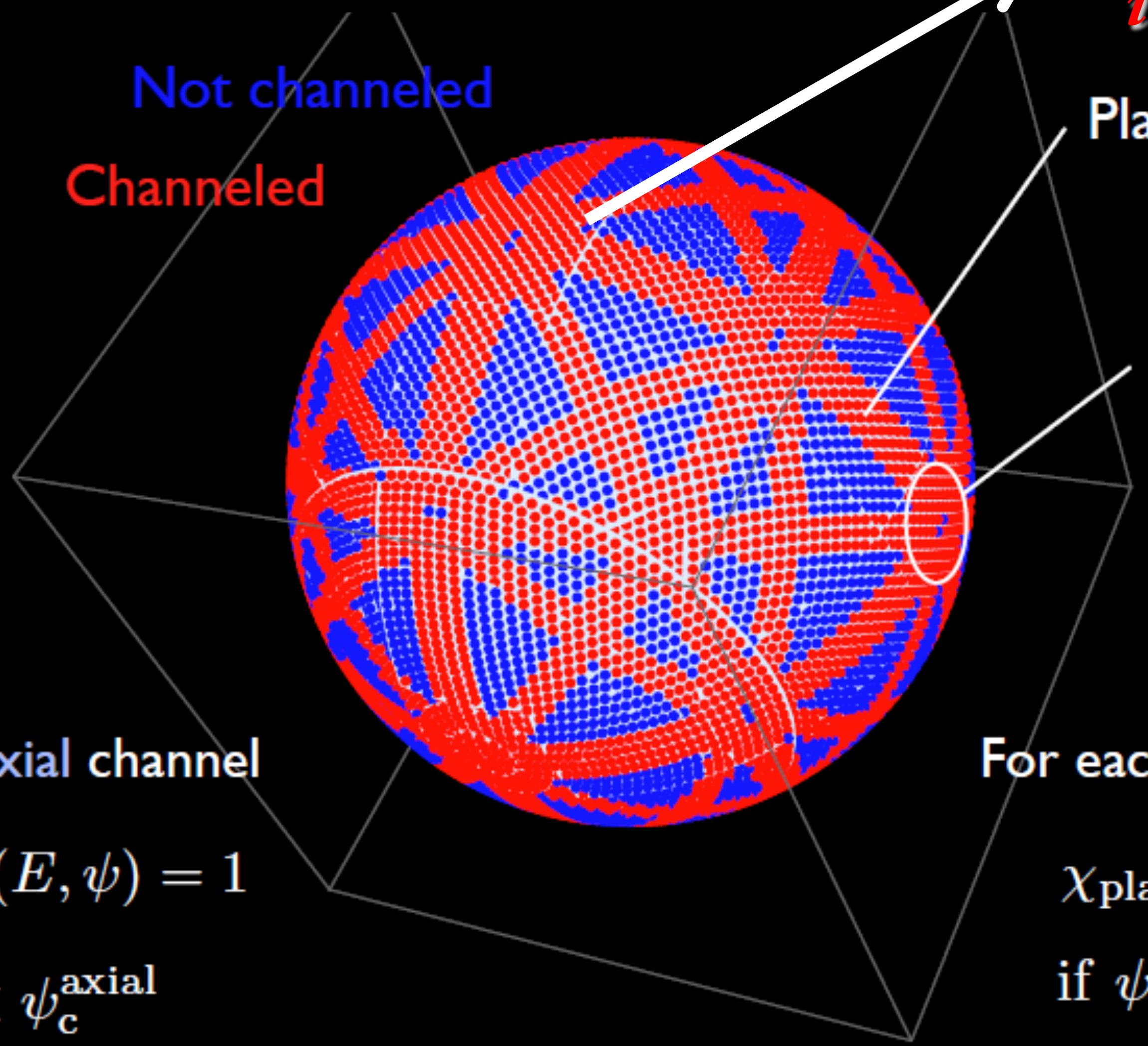
$$\phi(r/a) = \sum_i \alpha_i \exp(-\beta_i r/a),$$



Which uses Binary collision Model

Stereographic projection Si

Boundaries are important



For each axial channel

$$\chi_{\mathrm{axial}}(E, \psi) = 1$$

if $\psi < \psi_{\mathrm{c}}^{\mathrm{axial}}$

For each planar channel

$$\chi_{\mathrm{planar}}(E, \psi) = 1$$

if $\psi < \psi_{\mathrm{c}}^{\mathrm{planar}}$