

# Thanks to all of you

The screenshot shows a web browser window with multiple tabs. The active tab is titled 'Channeling 2012' and displays a page from 'genda.infn.it'. The page header includes the event name 'Channeling 2012' and dates '23-28 September 2012' in Alghero, Italy. A navigation menu on the left lists various sections like 'Home', 'Timetable', and 'Session details'. The main content area features a session titled 'Transmission Axial and Planar Channeling of Protons from Ultra Thin(55nm) Si'. The session details include the content description, ID (4), location (Hotel Calabona), starting date (25-Sep-2012), duration (25'), and authors. The primary author, 'Mr. MOTAPOTHULA, MALLIKARJUNA RAO', is circled in red. The browser's taskbar at the bottom shows various application icons and the system clock indicating 5:42 PM on 23/9/2012.

genda.infn.it/contributionDisplay.py?contribId=4&sessionId=11&confId=4688

## Channeling 2012

23-28 September 2012 Alghero, Sardegna, Italy

Home > Timetable > Session details > Contribution details

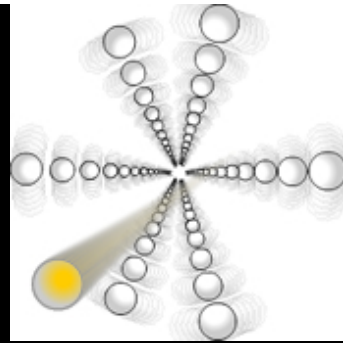
### Transmission Axial and Planar Channeling of Protons from Ultra Thin(55nm) Si.

**Content:** The report contained information about my project includes the fabrication of thin silicon [001] membranes (55nm) and the experimental observation of Rainbow Channeling fine angular distributions through these membranes using a nuclear microprobe facility. The observation of these fine angular structures in the channeling patterns will be the first experimental proof of the simulations done by various groups in the past 25 years. This is possible because of the reduced multiple scattering in the thinner silicon crystals. Simulations predicted the existence of a super focusing effect of ion beam by each unit cell of a thin crystal membrane. The predicted super focused spot size is about ~20 pm and can be used as a Sub atomic- Nuclear Microscope. However, this was never experimentally proven as thin enough crystals were not available. These experimental results confirm the many Rainbow Channeling simulations previously done and provide further evidences to the existence of the Super focusing effect.

**Id:** 4  
**Place:** Hotel Calabona  
Room: Hotel Calabona  
**Starting date:** 25-Sep-2012 11:10 (Europe/Rome)  
**Duration:** 25'  
**Primary Author:** **Mr. MOTAPOTHULA, MALLIKARJUNA RAO** (GRADUATE STUDENT)  
**Co-Authors:** Ms. DANG, Zhiya (GRADUATE STUDENT)  
Dr. MUKUTAR, Rana (Principal Scientist)



**NUS**  
National University  
of Singapore



**CIBA**

Centre for Ion Beam Applications

# ION CHANNELING IN CRYSTALS

**MALLI**

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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**

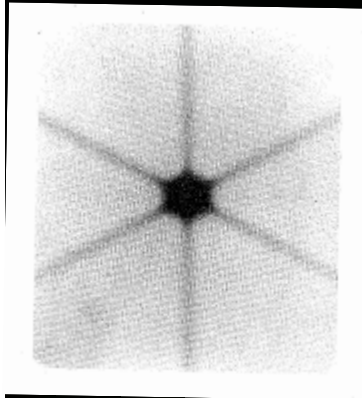
**Conclusions & Future plans**



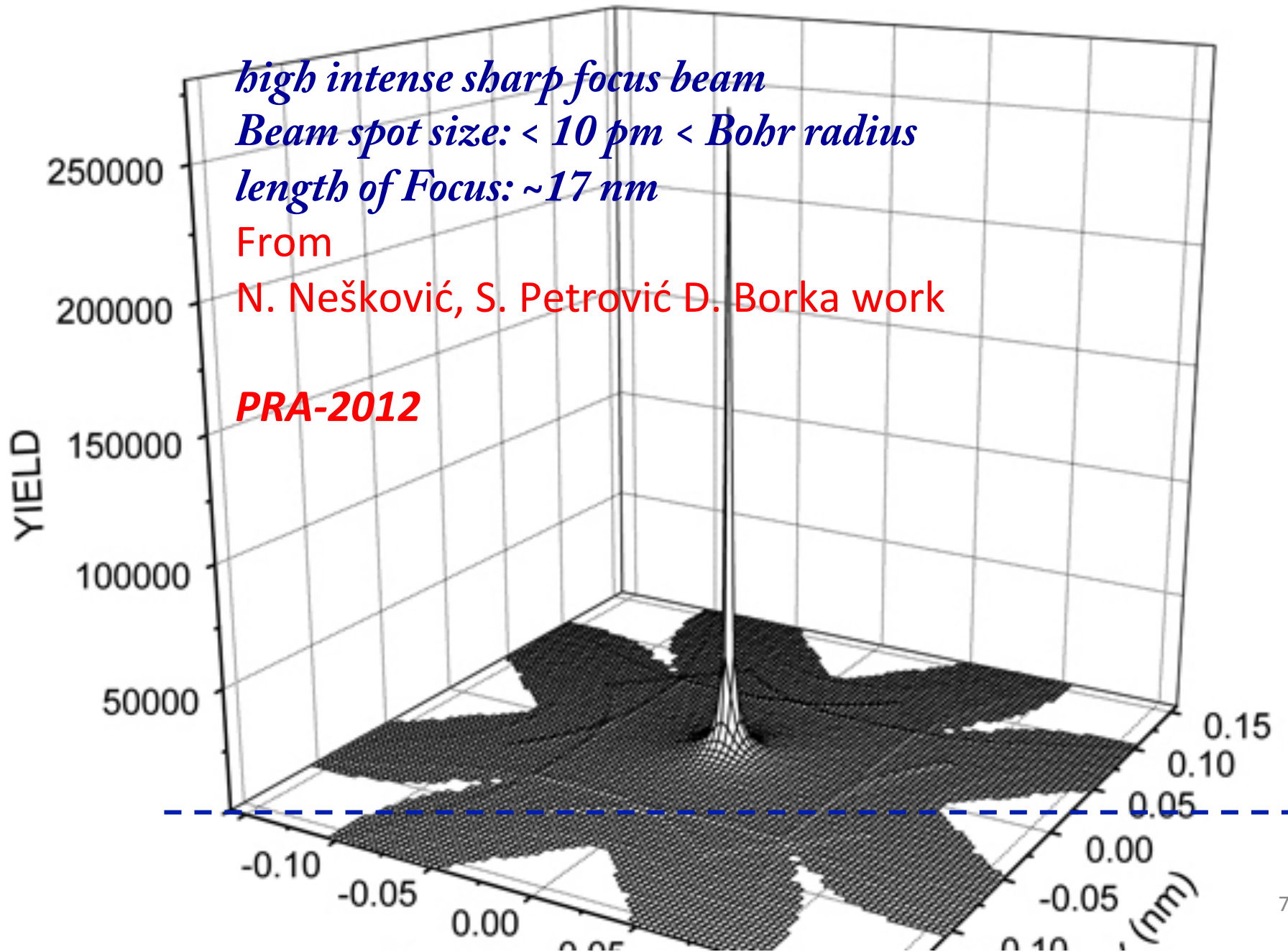
# *Introduction*

*Angular distribution*  
*at aligned case (Star)*

*2MeV protons*  
*300nm thick [001]Si*

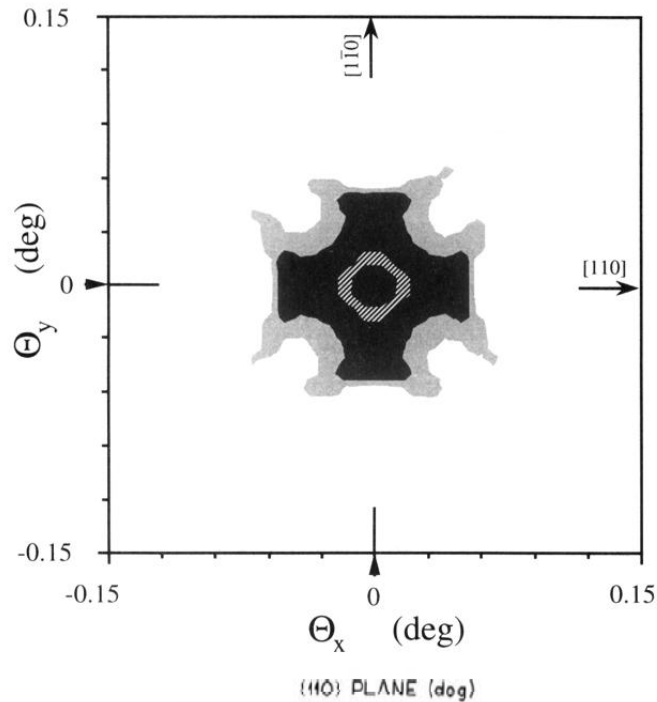


0.2°

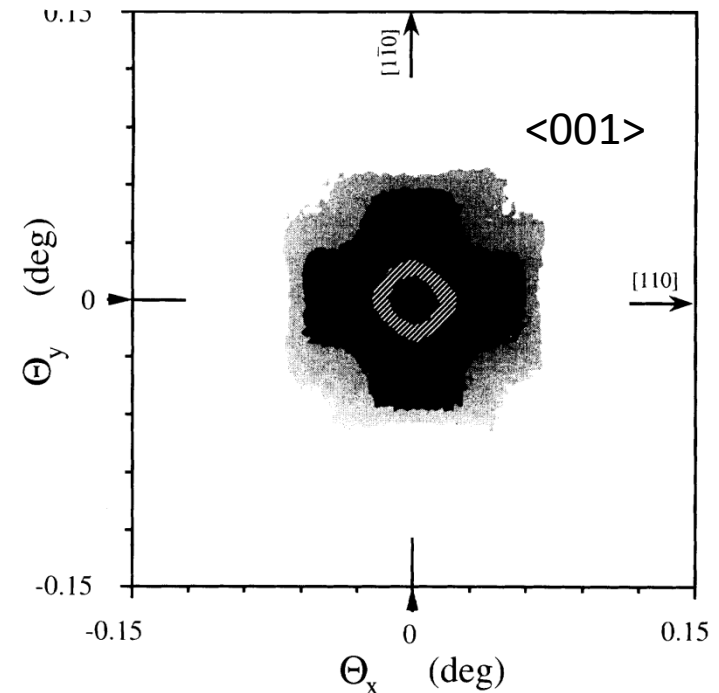


**20 MeV,  $10^{16}$ <sup>+</sup>  
188 nm Si**

*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.*



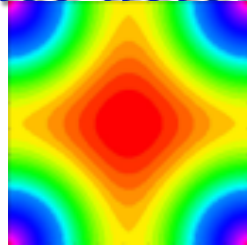
*Simulated*  
*Angular patterns [001] Si for any ion*

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

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

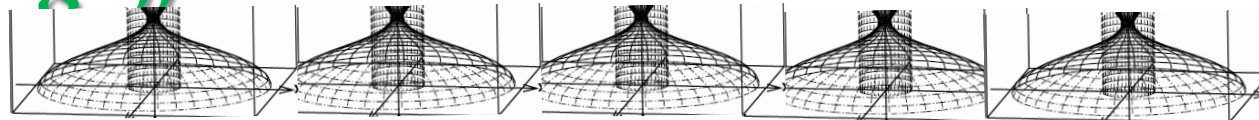
# Motivation

- *Precise determination of ion channel potentials.*

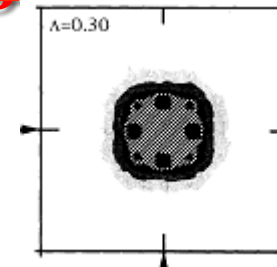


*Si-H<sup>+</sup> (ZBL)*

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

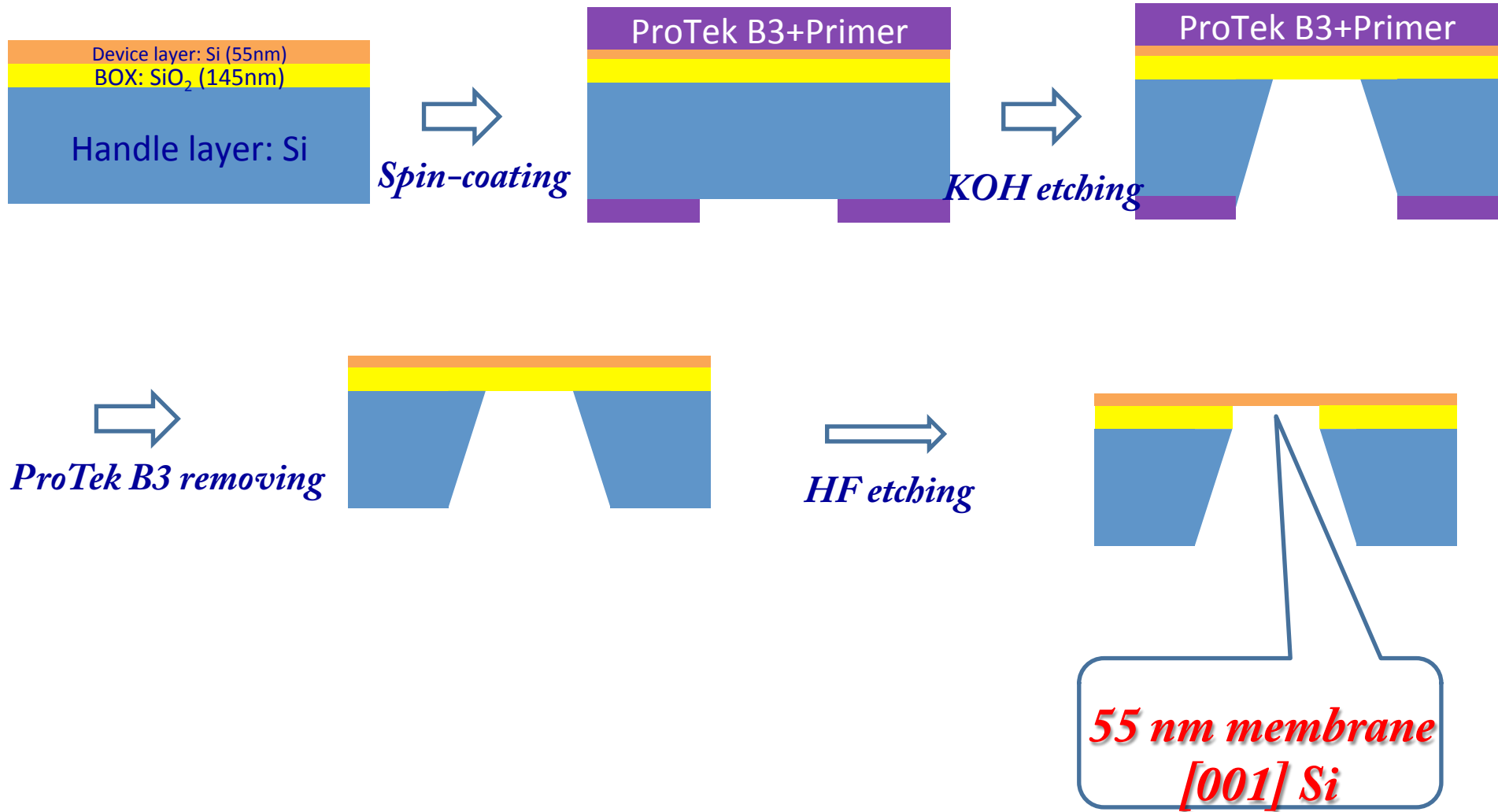


- Capturing and *understanding* the fine features in the axial channeling patterns.



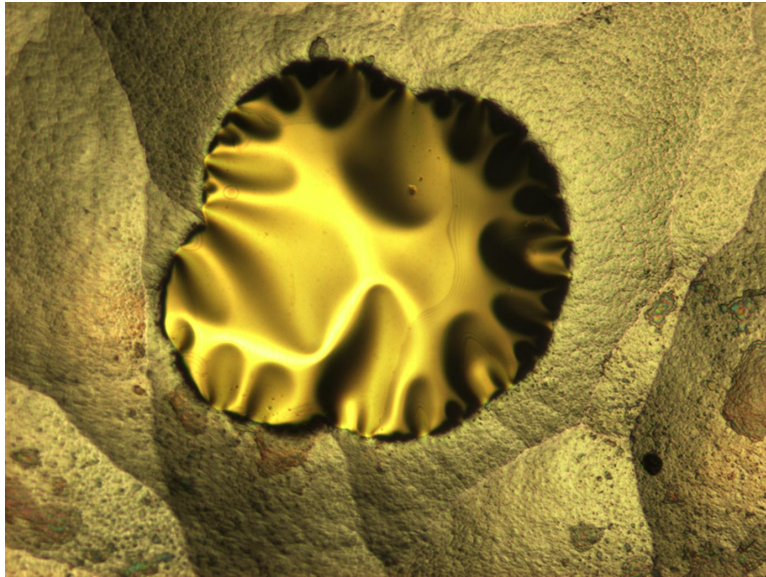
# *Experiments*

# Schematic of sample preparation



# *Optical Micrographs* *55 nm thin Si membrane*

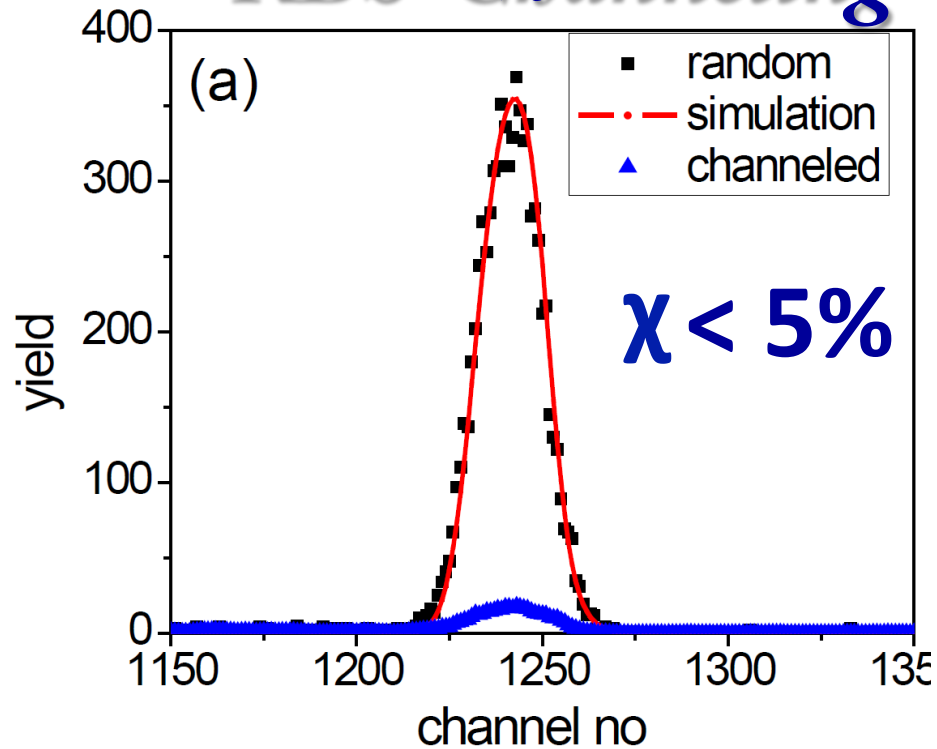
*145 nm SiO<sub>2</sub> on 55 nm Si*



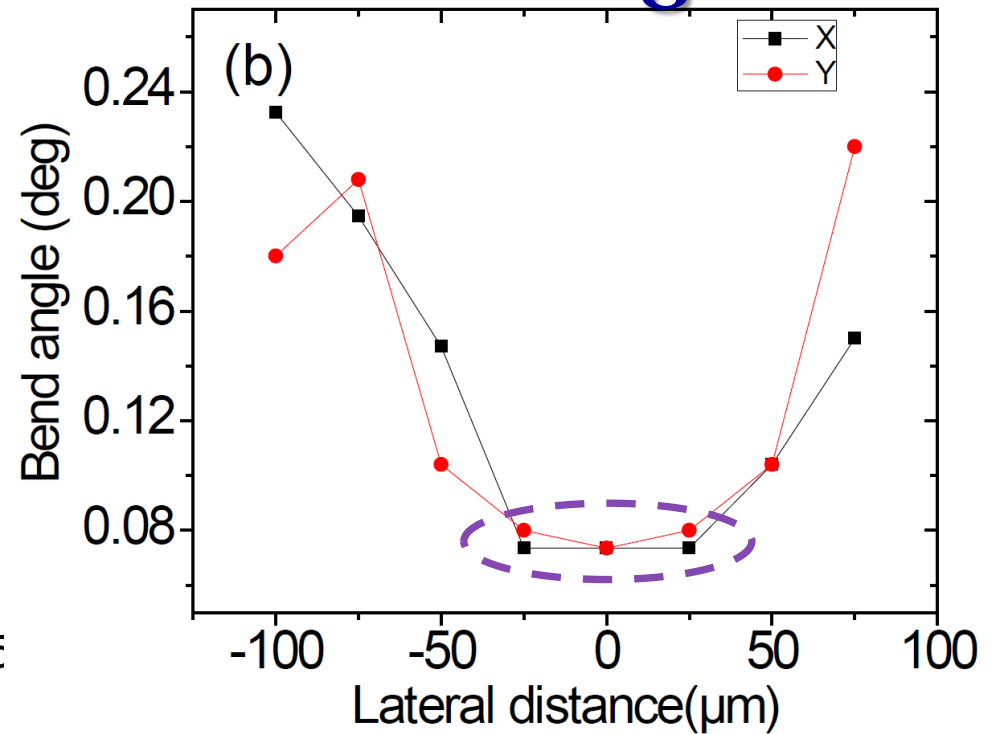
————— (500 μm)

❖ *Thin Si membrane is flat after removal of SiO<sub>2</sub>*

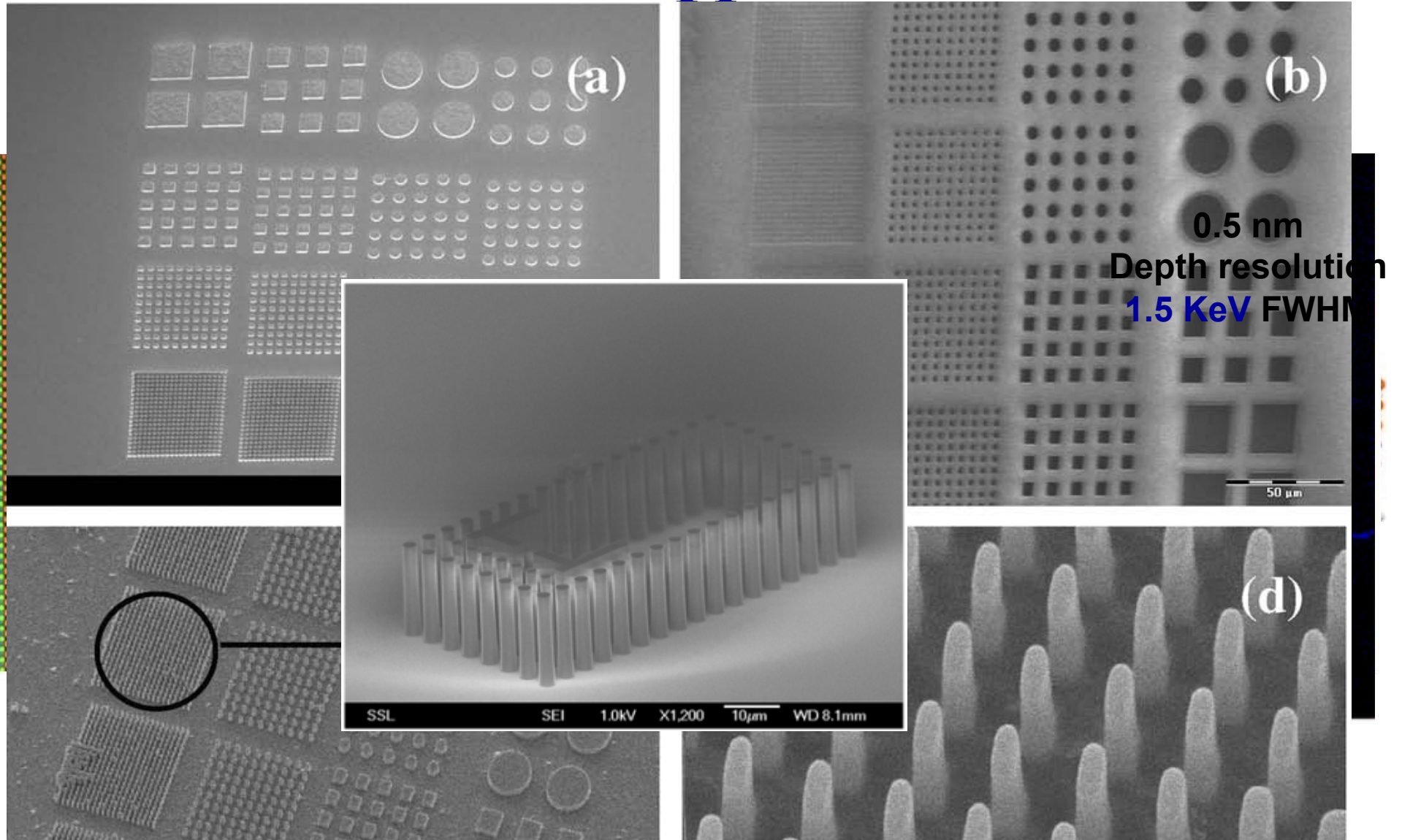
## RBS-Channeling



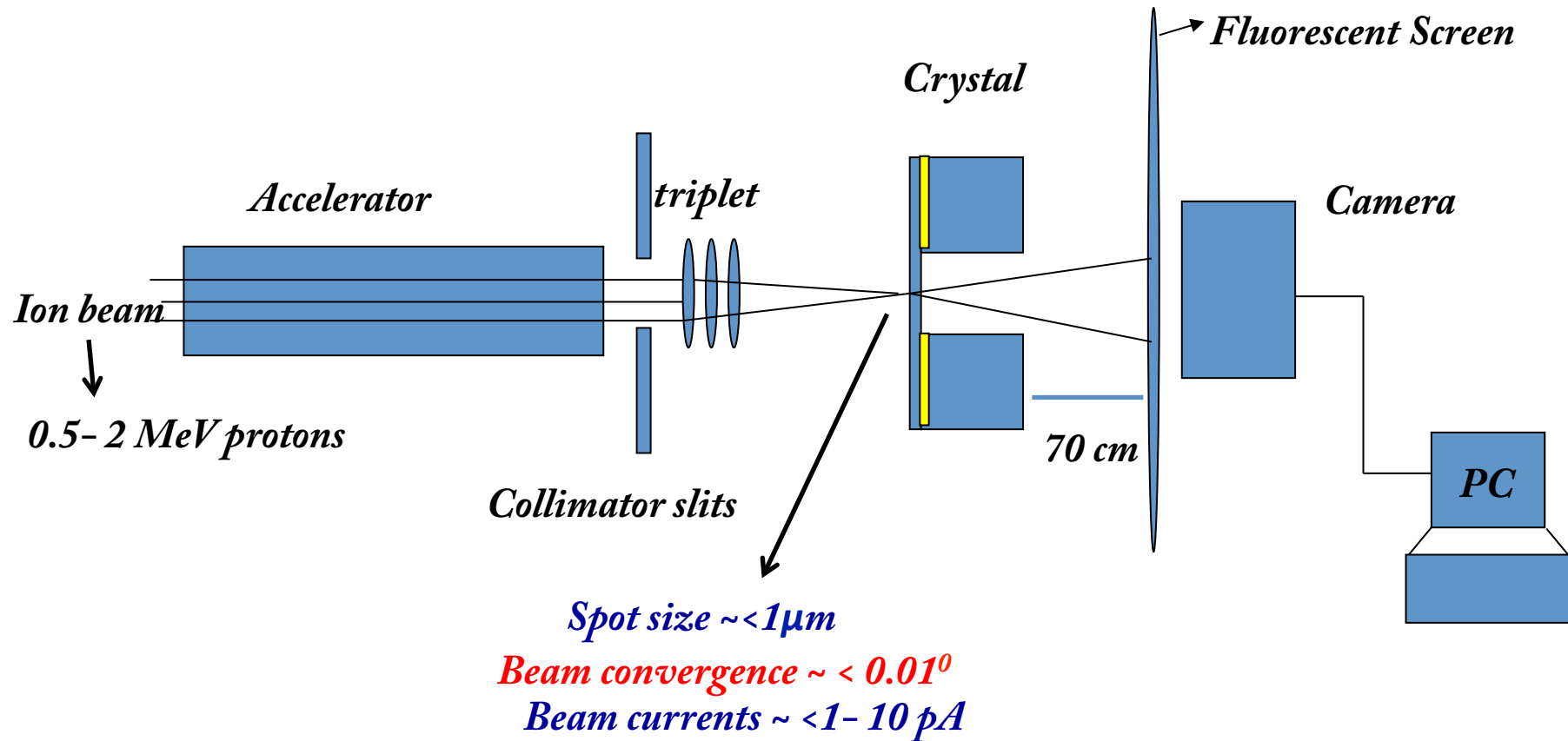
## Bend angle



# Centre for Ion beam applications



# Channeling experiment Setup



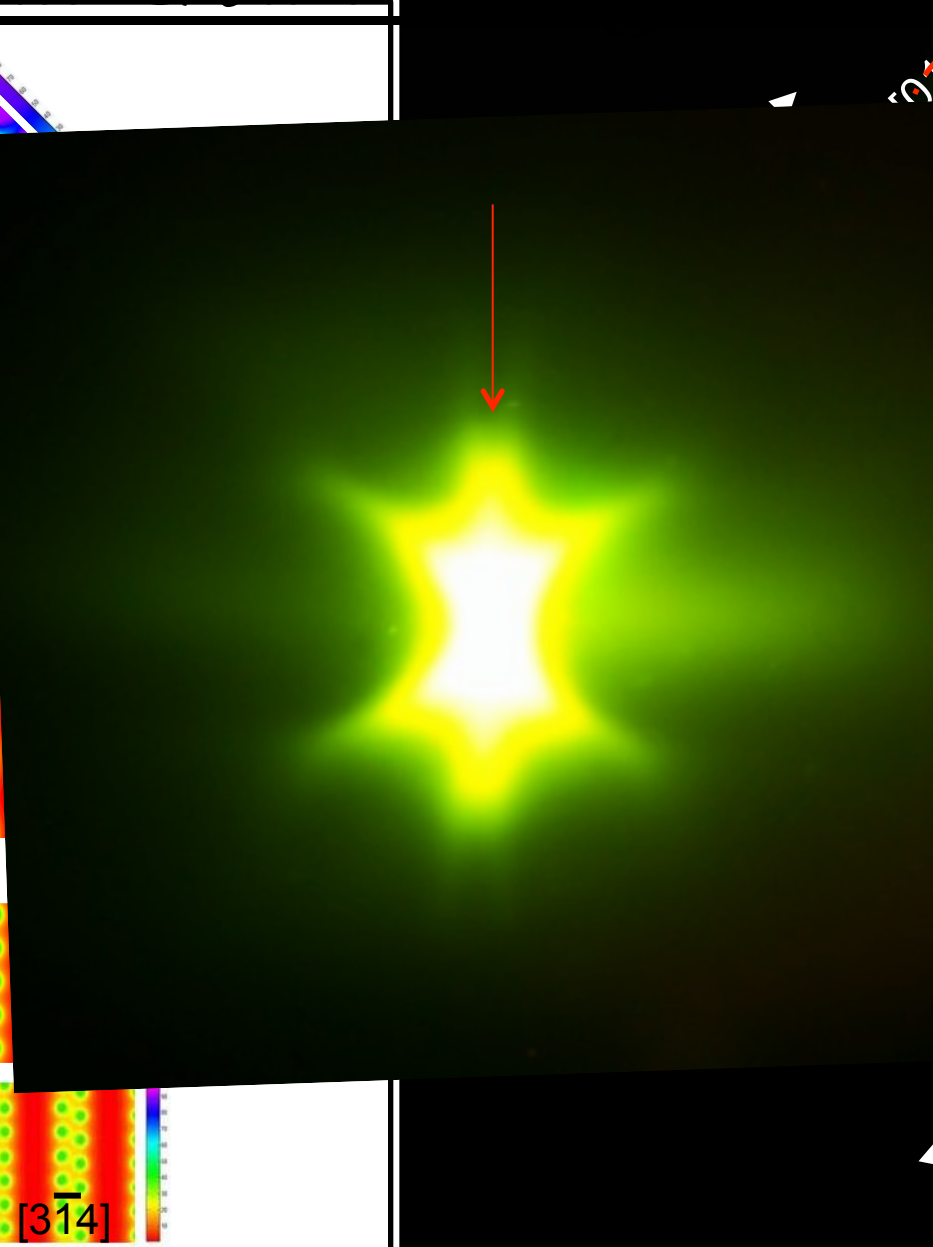
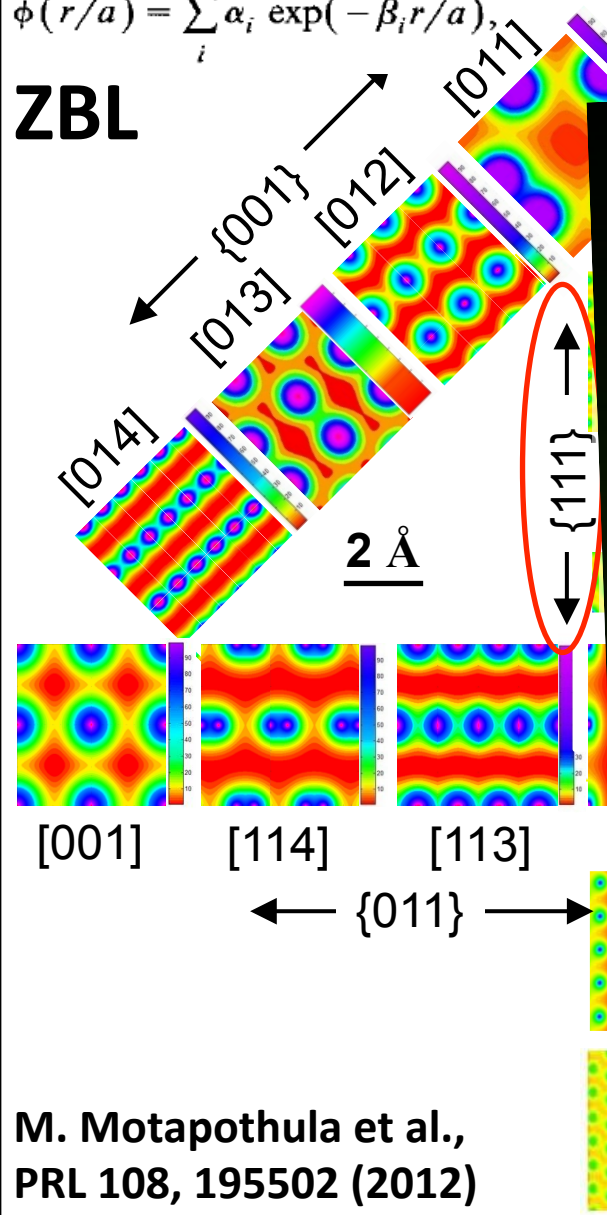


# *Axial channels*

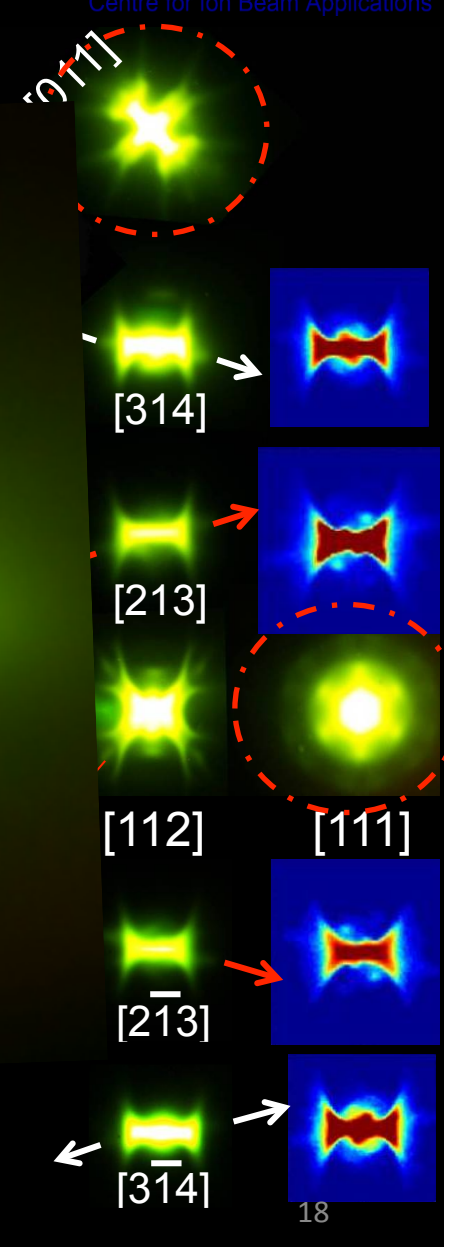
*Axial channels*

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

**ZBL**



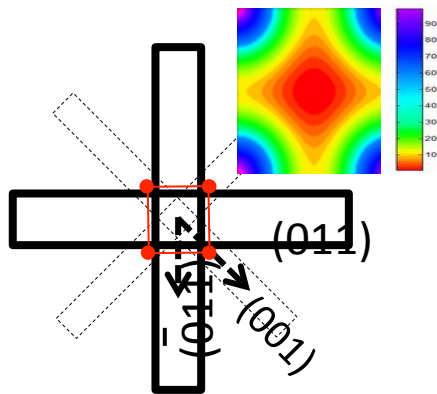
M. Motapothula et al.,  
PRL 108, 195502 (2012)



# Doughnuts

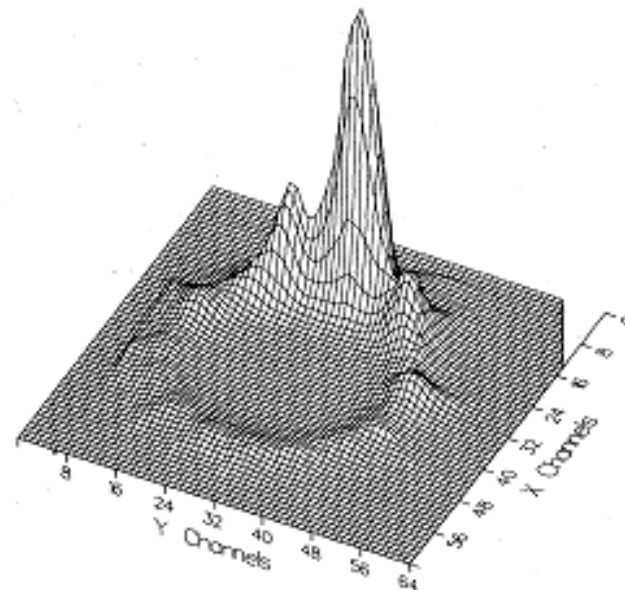
- *Doughnuts show **ring** like shape distribution.*

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



1900 Å Crystal  
 $\psi = .327^\circ$

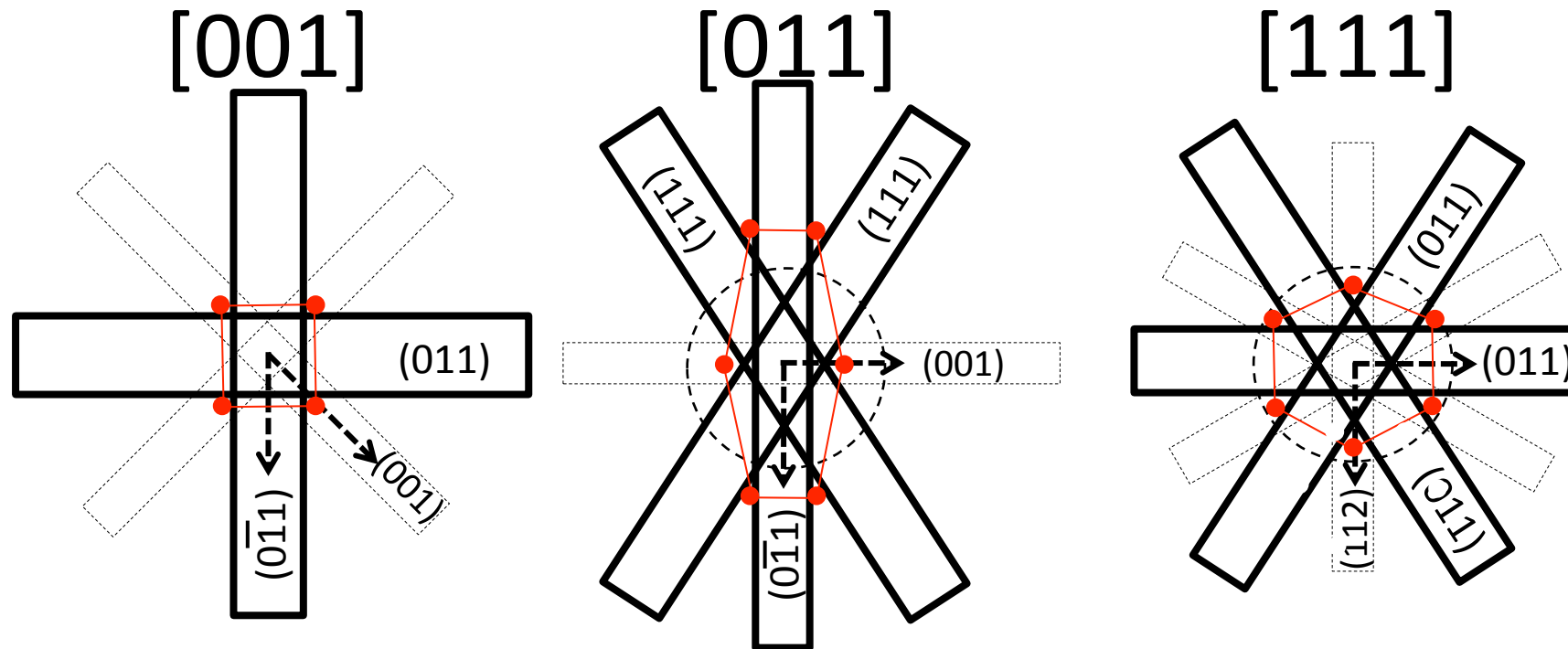
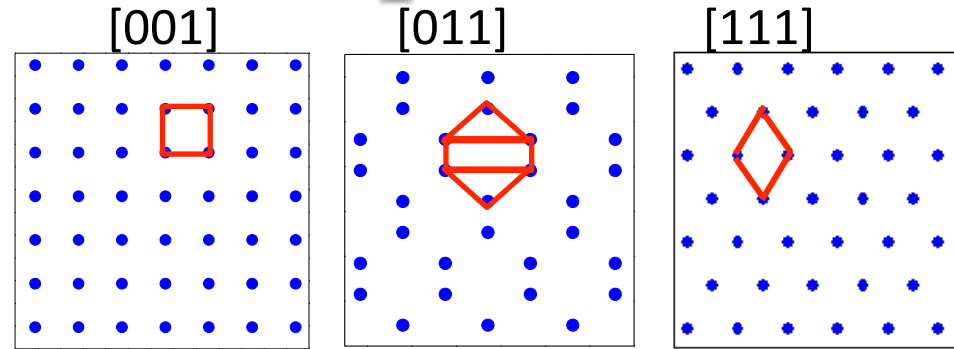
(a)



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

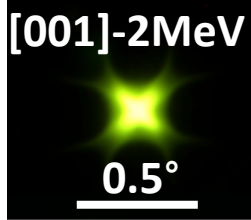
- *How they show at early stage of its evolution?*

# *Axial projections*

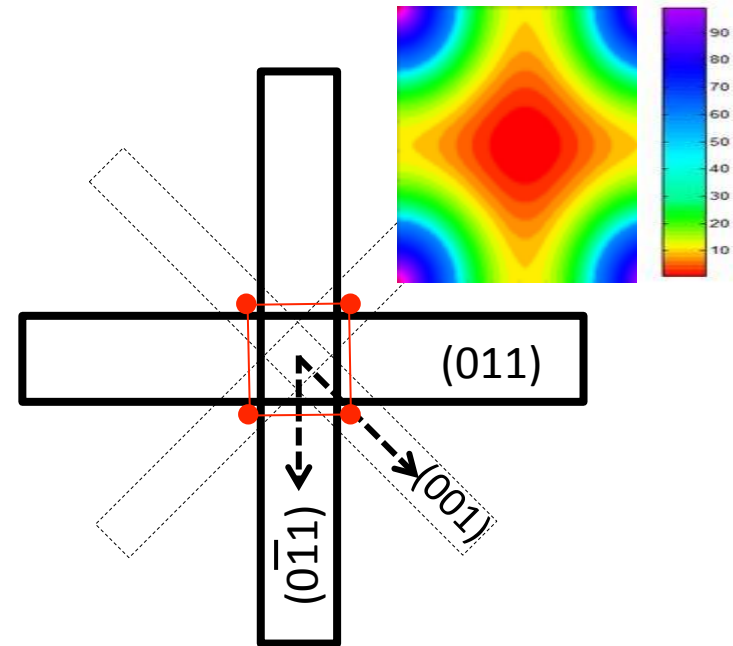


# Channeling: tilted case

increasing axial tilt



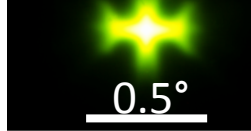
$\{001\}$



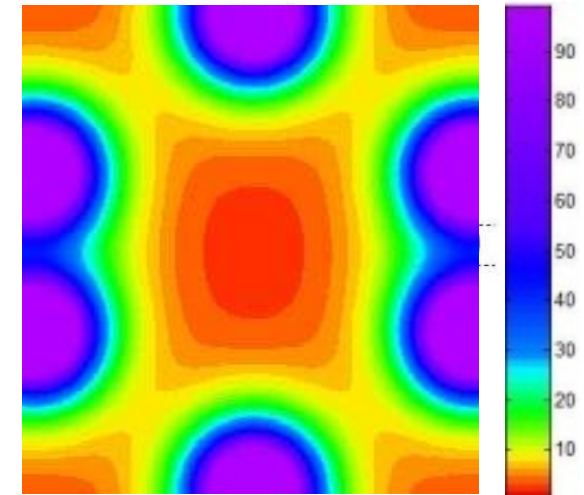
# *Channeling $\alpha$ -tilted case*

increasing axial tilt

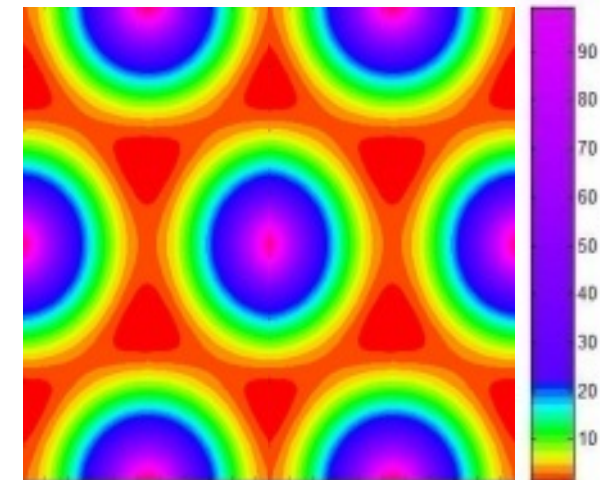
[011]-2MeV



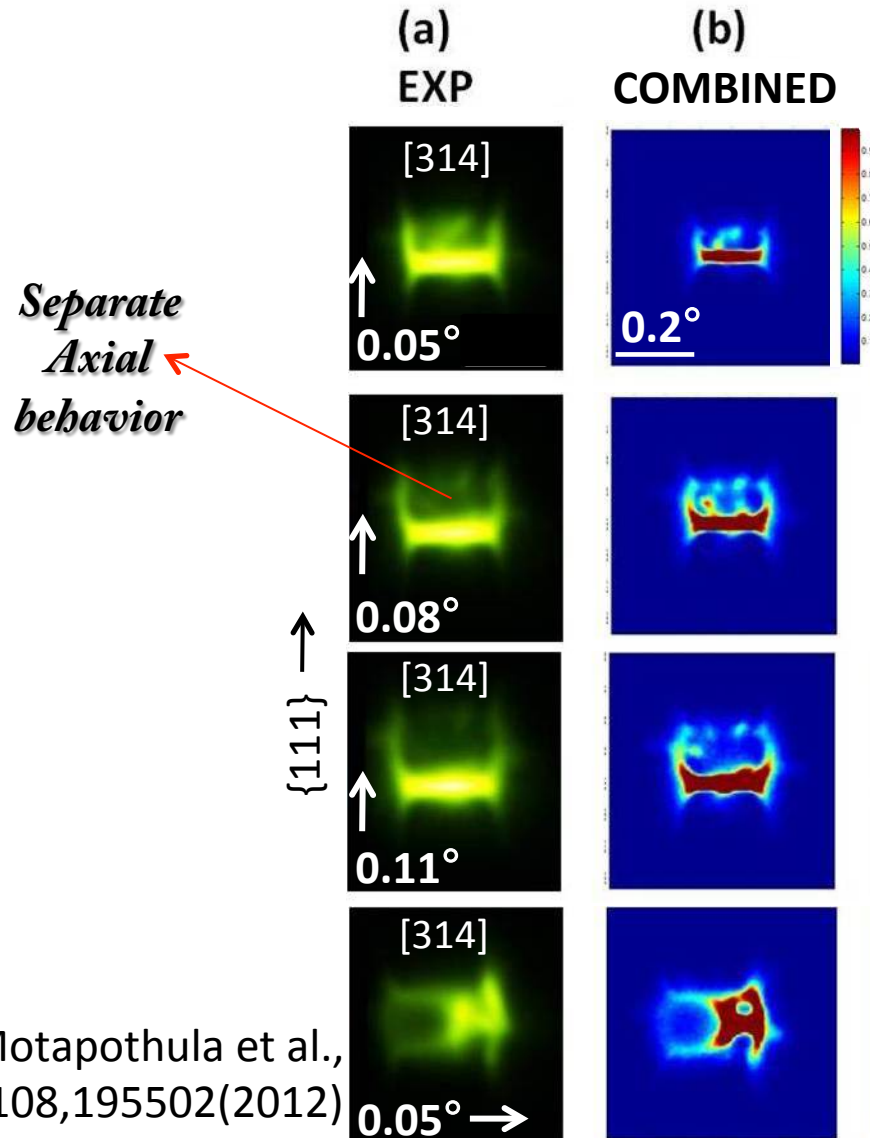
[011]



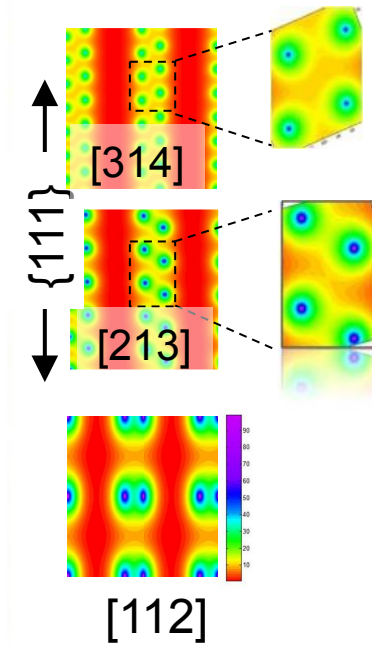
[111]



# *Axial doughnuts* *which contained {111}*



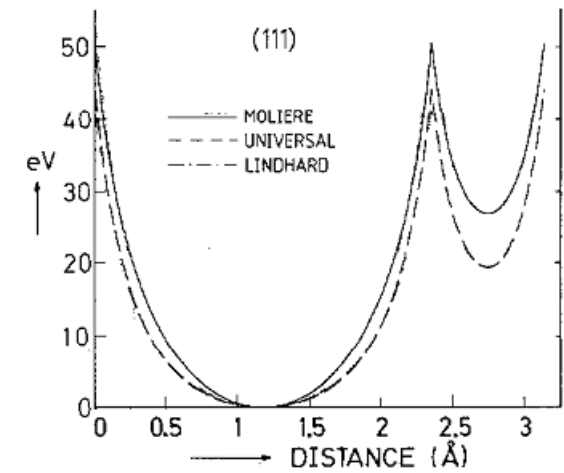
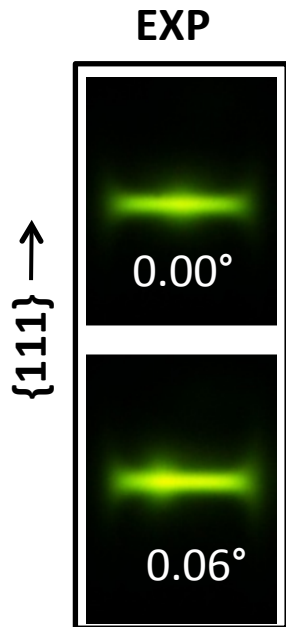
M. Motapohtula et al.,  
PRL 108,195502(2012)



# *Planar channeling*

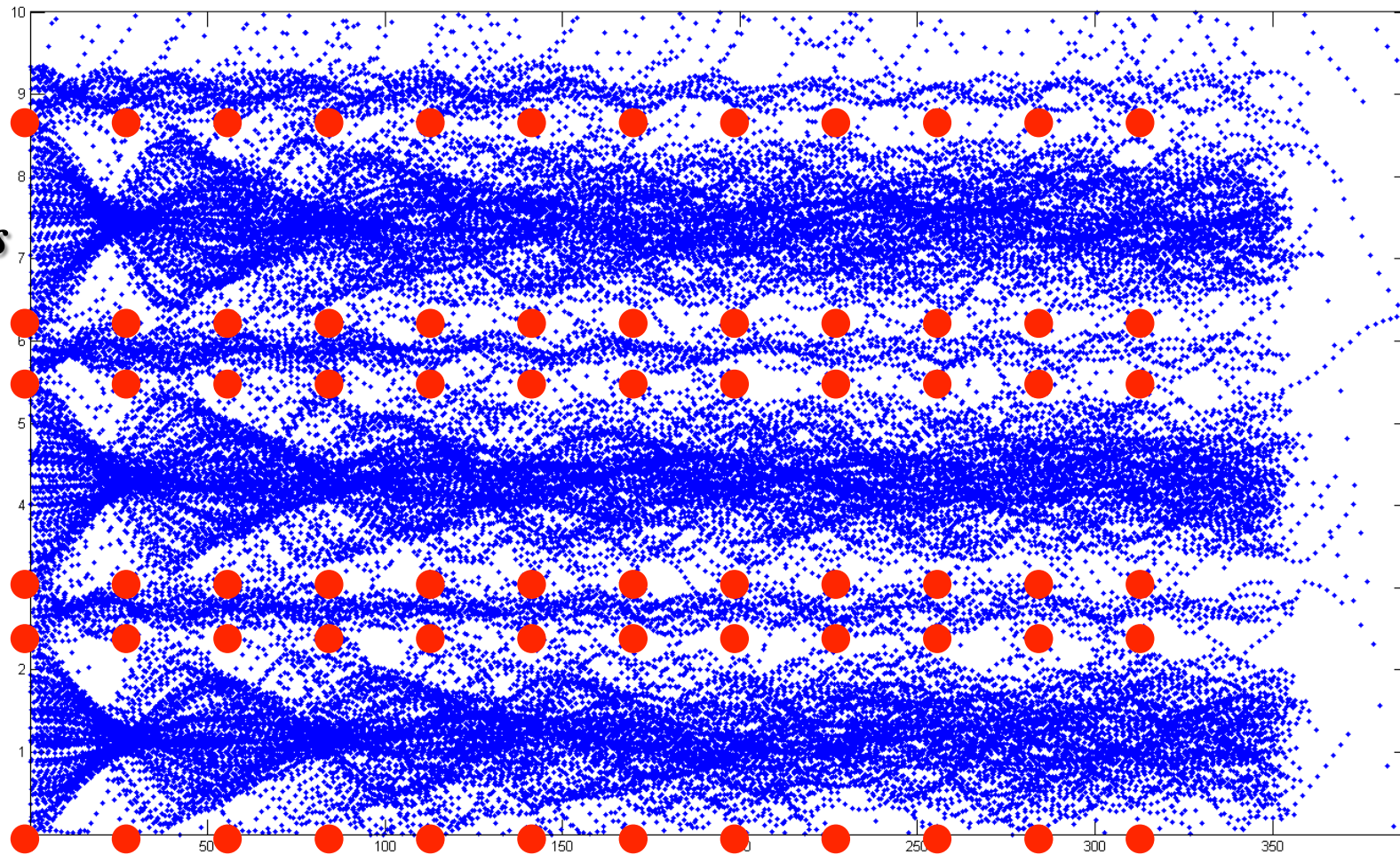


# Simulations comparison



# *{111} Planar channeling*

*2MeV  
Protons  
Silicon*

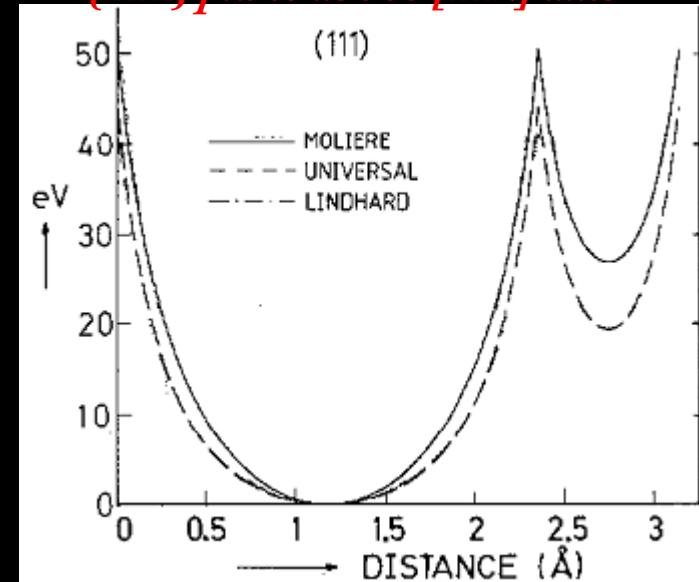


*Depth (1 $\mu$ m)* <sup>26</sup>

# *{111} Planar channeling*

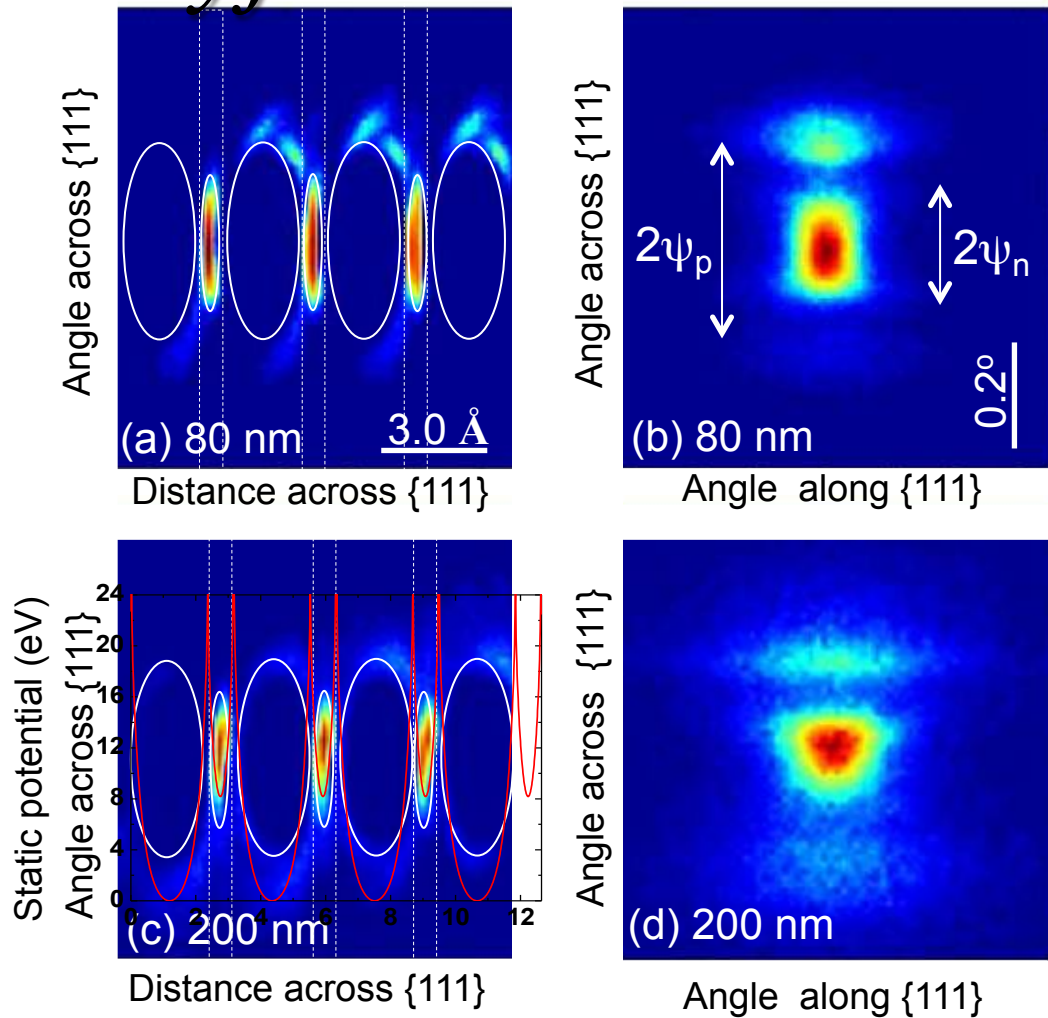
*2MeV Protons; 55nm thick [001] Silicon*

*{111} plane above [112] axis*



# Phase space analysis

*Data is only from: Ions incident on Narrow planes*



Captured  
Early stage  
axial  
channeling

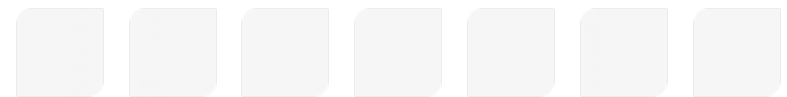
Doughnuts  
Squares  
&  
Hexagons

{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*.



# *Future plans*

# 55nm thick [001] Silicon

2.0 MeV H+

1.5 MeV

1.0 MeV

0.95 MeV

0.5°

0.90 MeV

0.85 MeV

0.75 MeV

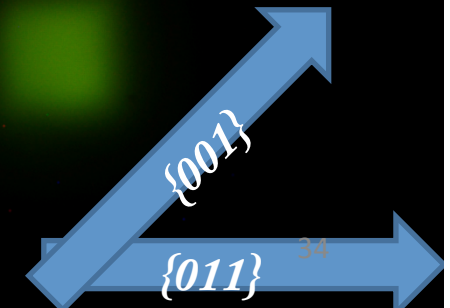
0.7 MeV

0.65 MeV

0.60 MeV

0.55 MeV

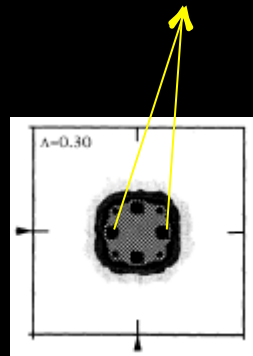
0.5 MeV



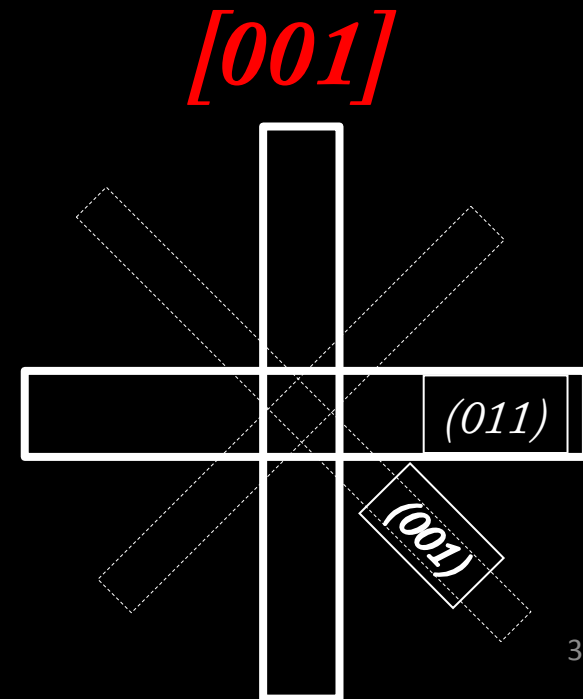
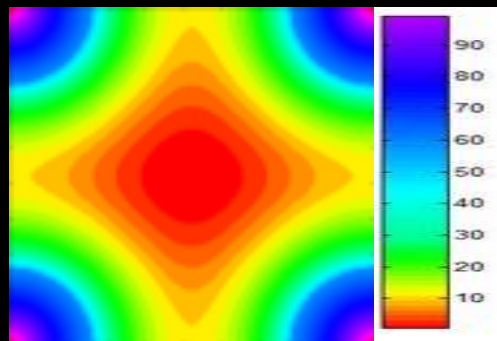
# $\{011\}$ planar tilt at $[001]$ 700 KeV $H^+$

*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).*



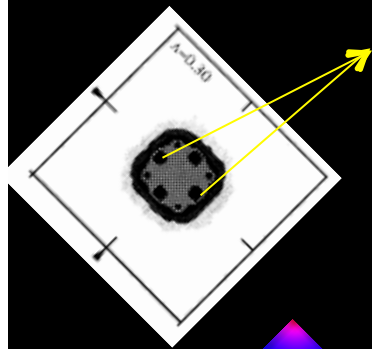
*Only 2 middle central bright dots are moving first when tilted*



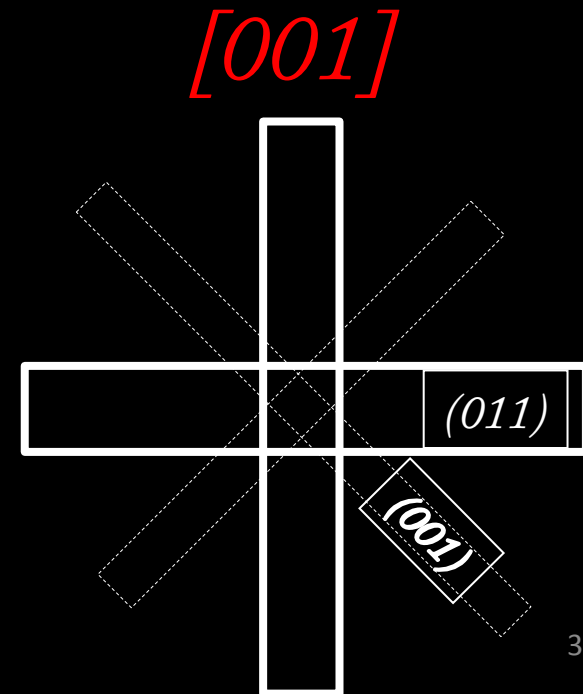
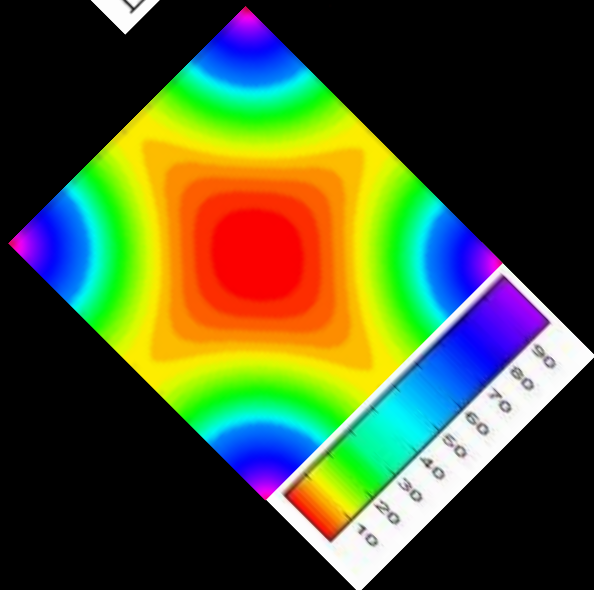
# $\{001\}$ planar tilt at $[001]$ 700 KeV $H^+$

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).



All the 4 central bright dots are moving together when tilted



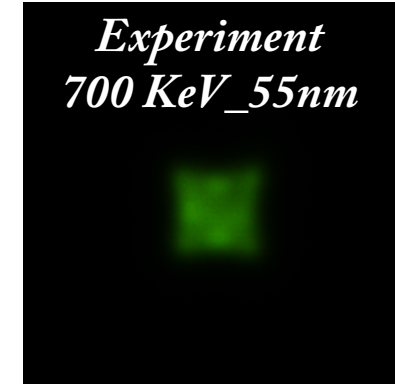
$$= \frac{Z_1 Z_2 e^2}{r} [0.35 \exp(-br) + 0.55 \exp(-4br) + 0.10 \exp(-20br)] ,$$

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

$$\alpha(i) = \{0.1818, 0.5099, 0.2802, 0.02817\},$$

$$\beta_i = \{2, 0.9423, 0.4029, 0.2106\},$$

$$a = 0.8853 a_0 / (Z_1^{1.25} + Z_2^{1.25}).$$

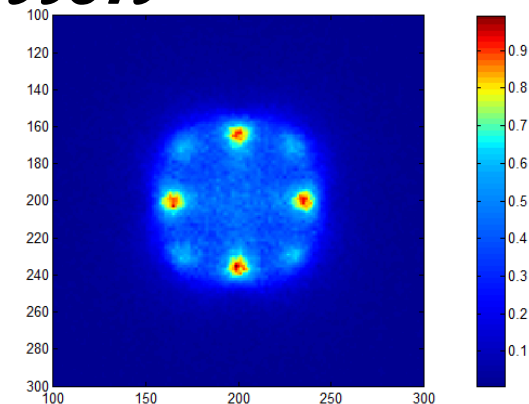
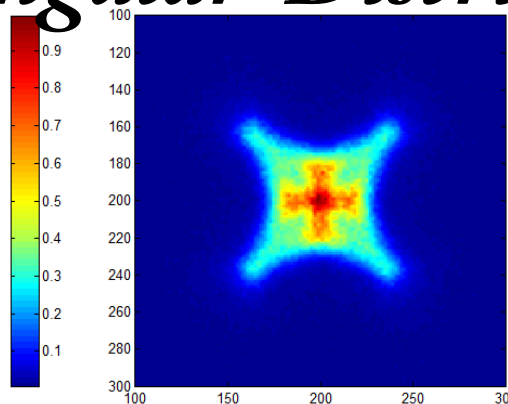
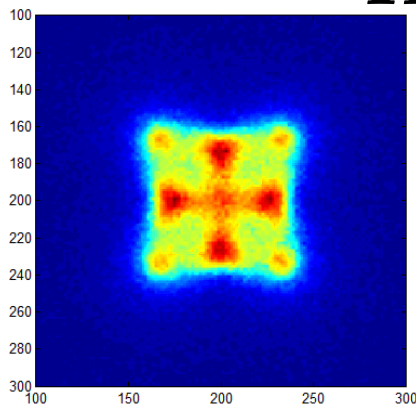


*Moliere*

*ZBL*

*Hartree-Fock*

## FLUX Monte Carlo Simulations Angular Distribution

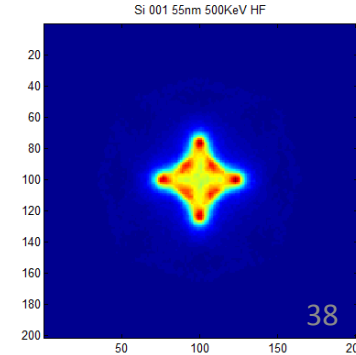
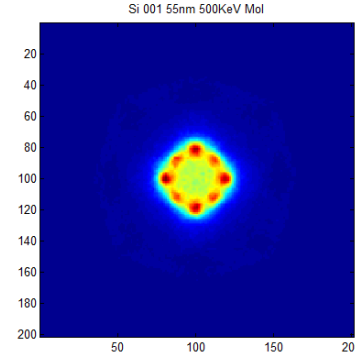
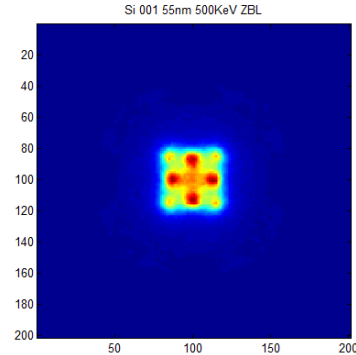
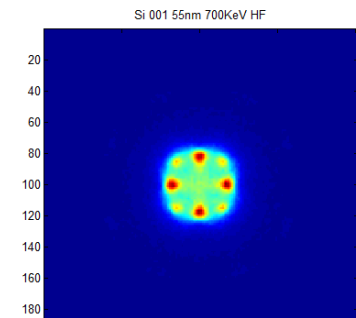
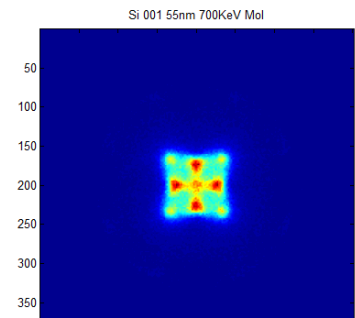
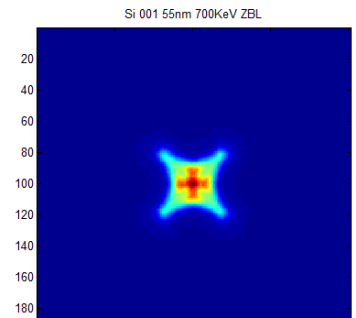
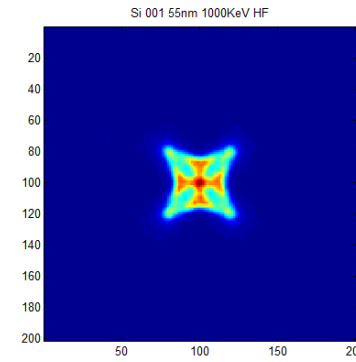
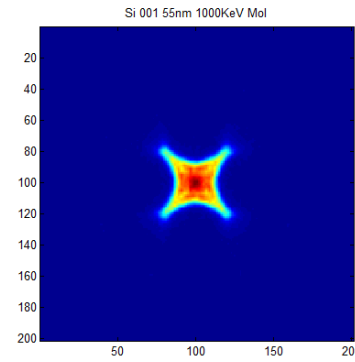
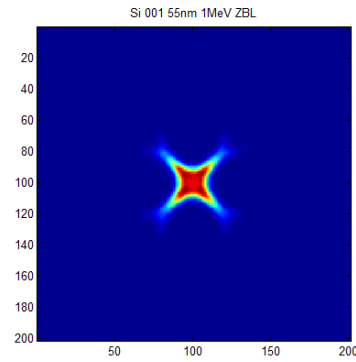
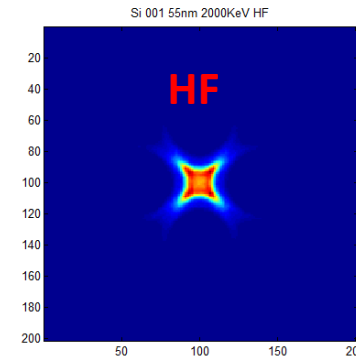
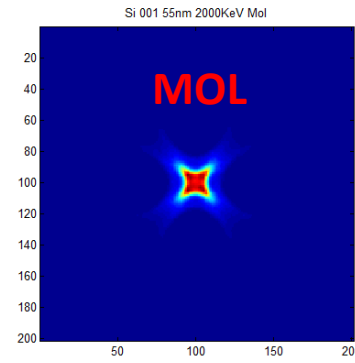
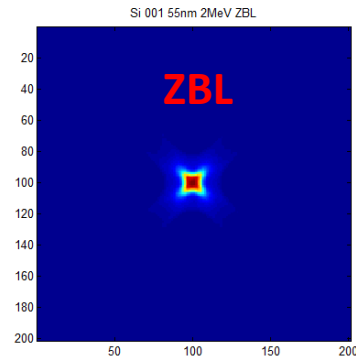


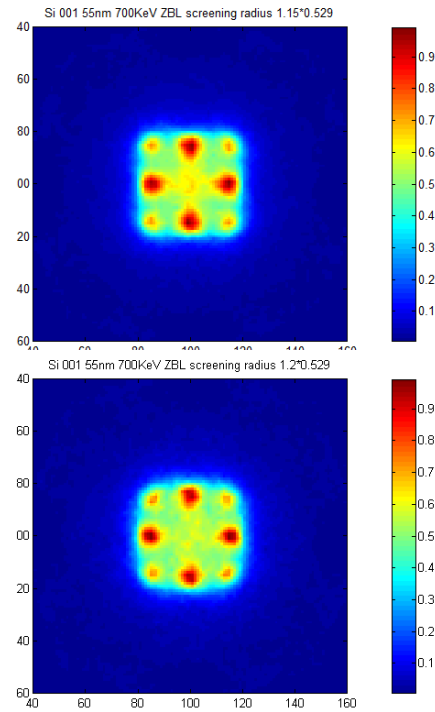
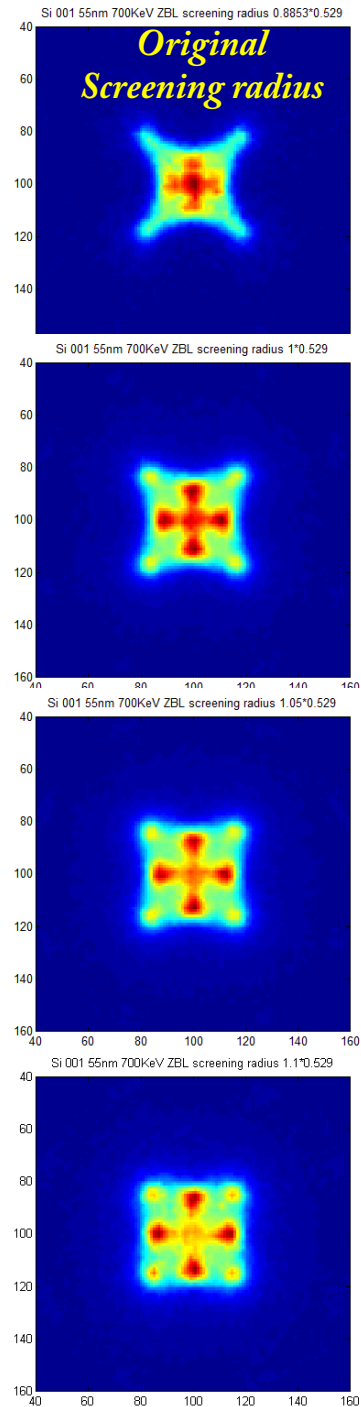
2.0 MeV

1.0 MeV

0.7 MeV

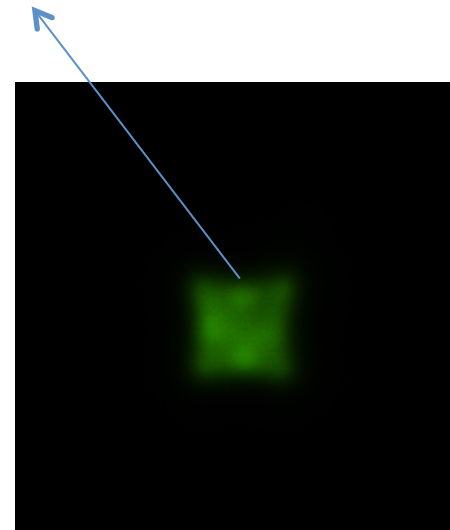
0.5 MeV





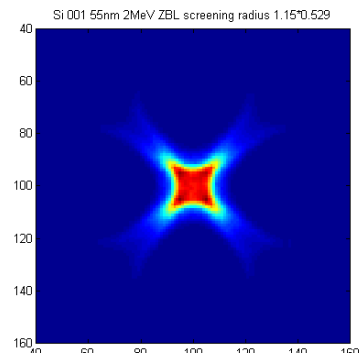
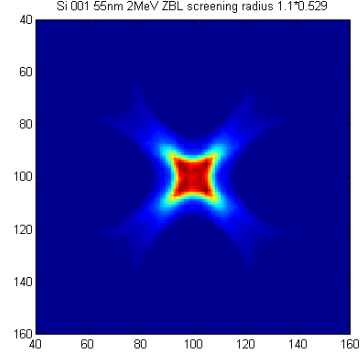
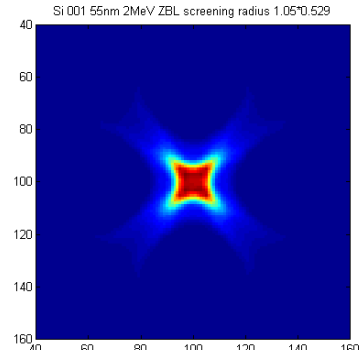
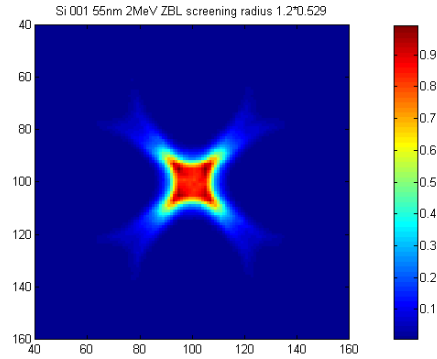
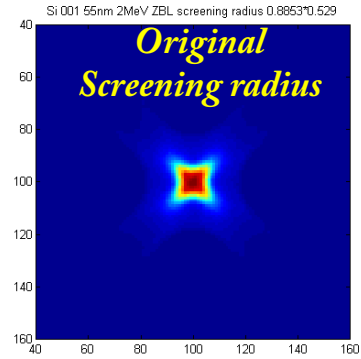
# FLUX ZBL

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



*Increasing the screening radius*

The screenshot shows the ImageJ interface. The main window displays a ZBL image with a line profile drawn across it. A 'Plot of 2 MeV\_115\_09-09-20110100\_cr' window is open, showing a graph of Gray Value versus Distance (pixels). The graph shows a peak at approximately 45 pixels.

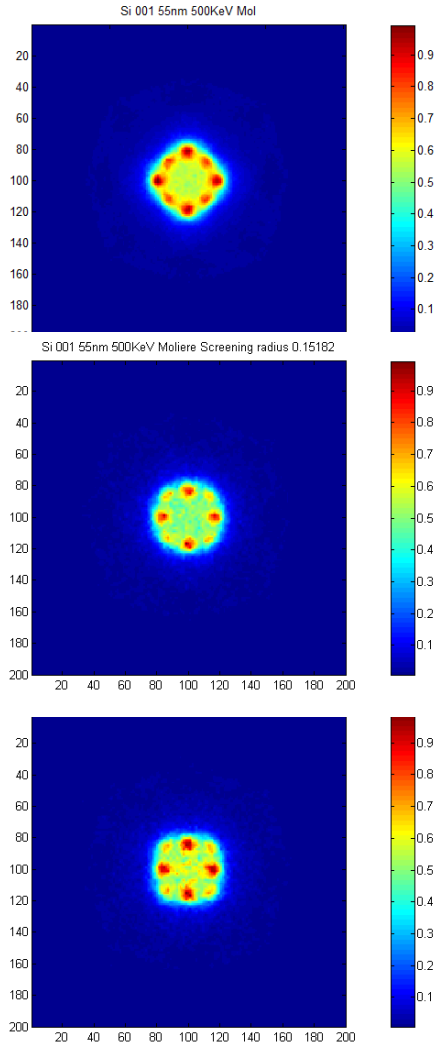
Distance (pixels)	Gray Value
0	20
10	60
20	80
30	65
40	85
45	90
50	85
60	40
70	20
80	10
90	5

*2 MeV  
55 nm  
[001]*





# FLUX MOL

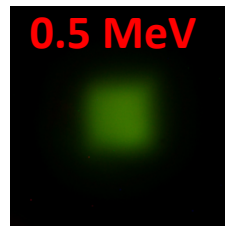


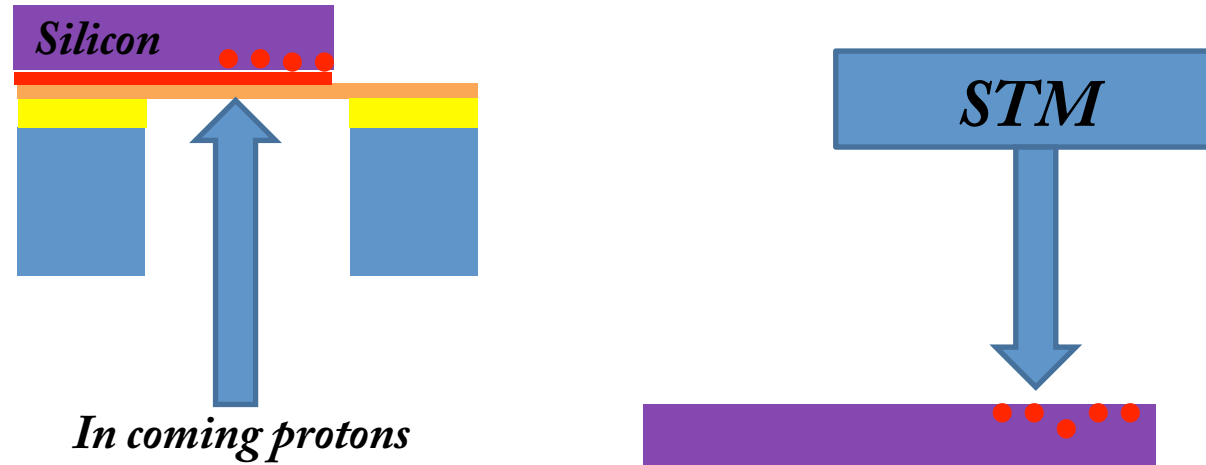
↓ *Decreasing the screening radius*

*500 KeV*

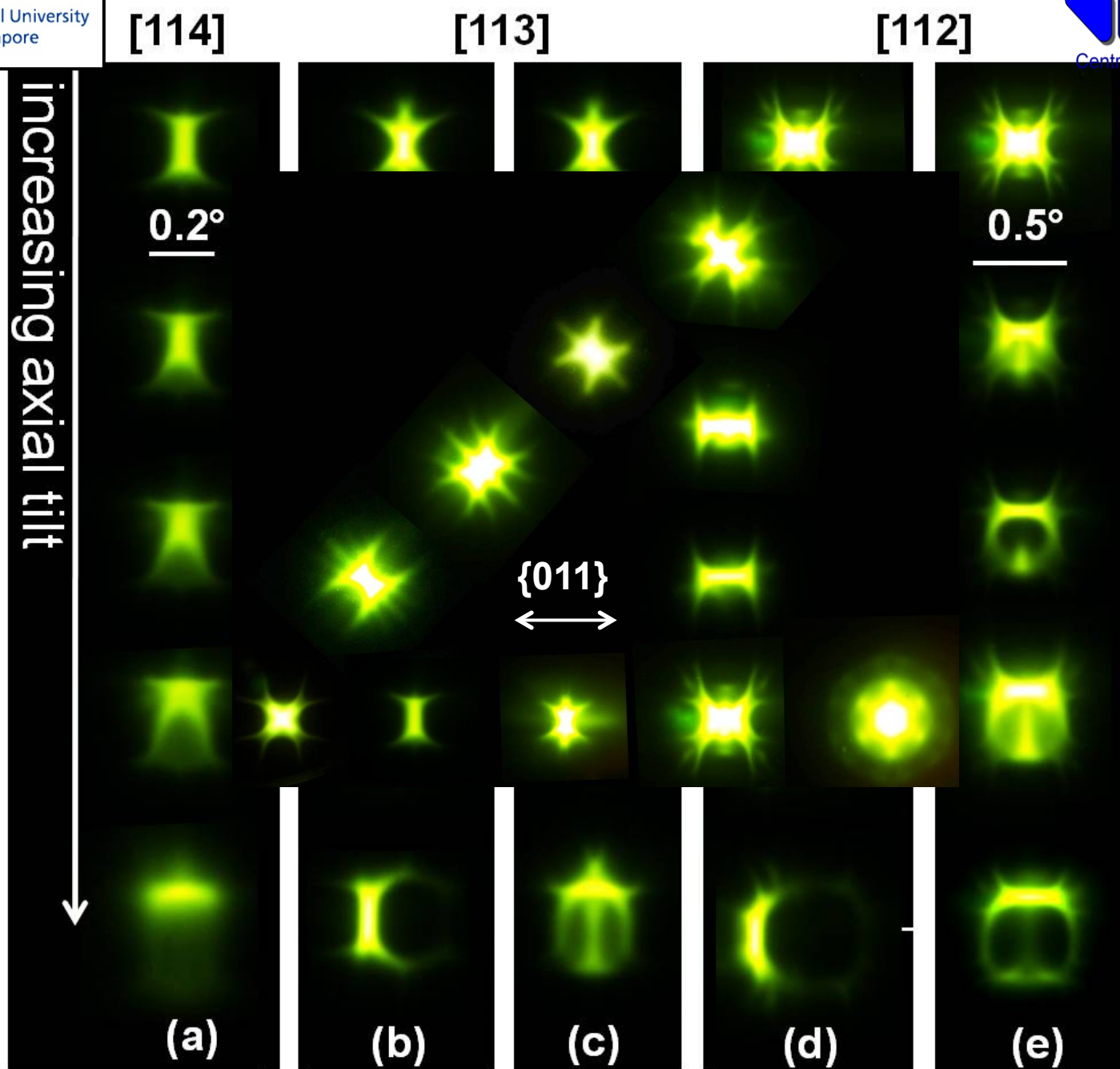
*55 nm*

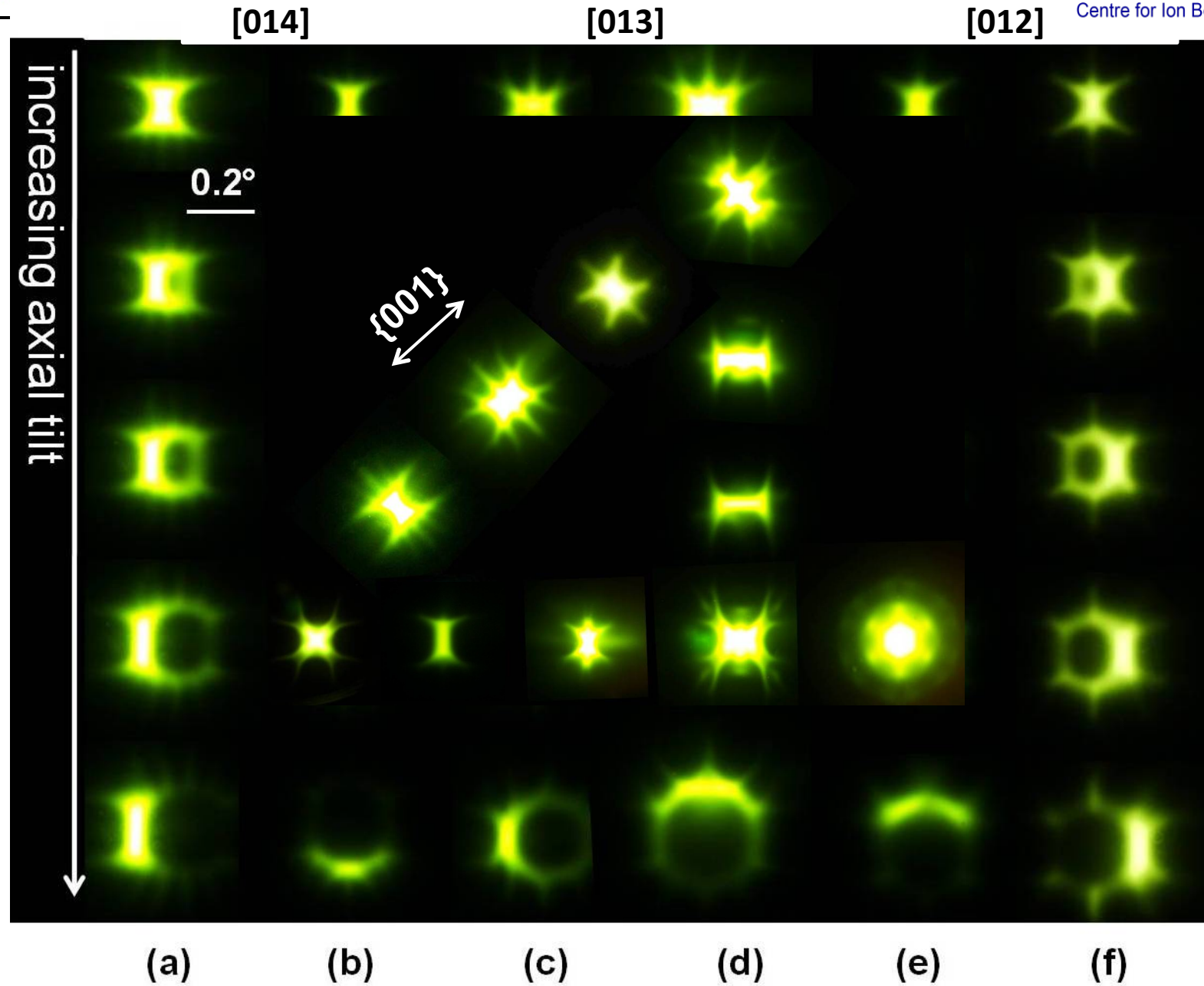
*[001]*



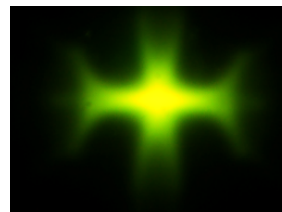
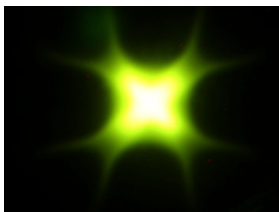
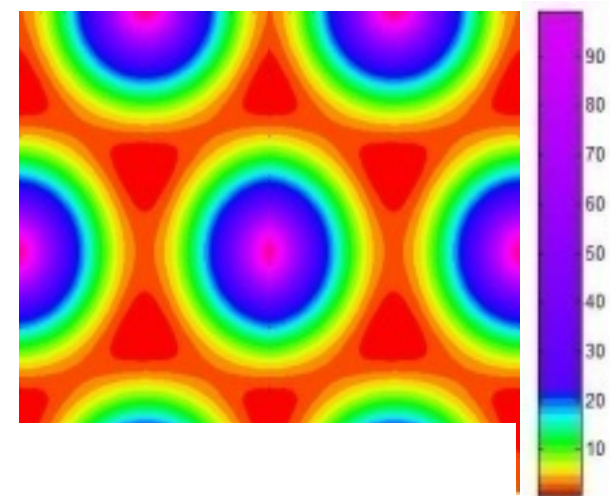
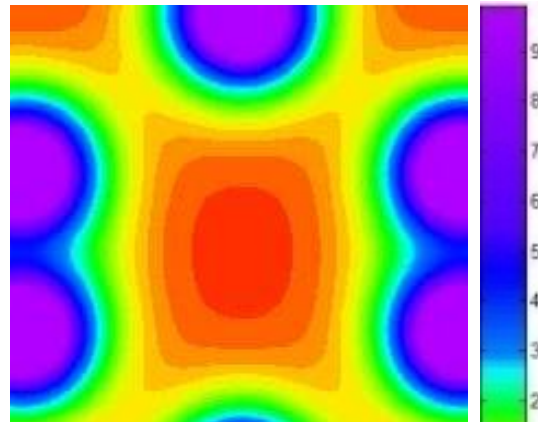
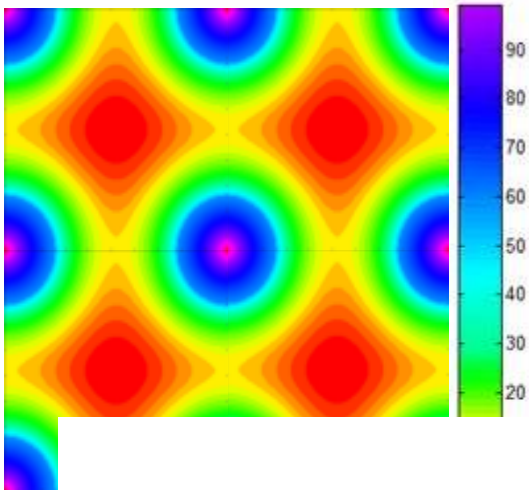
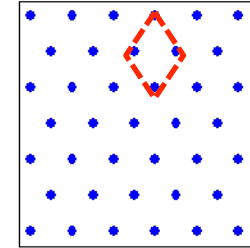
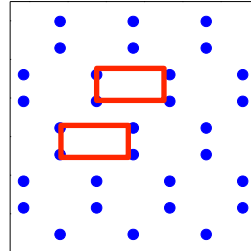
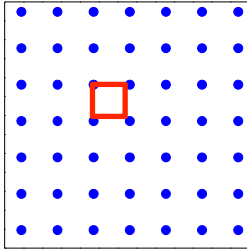


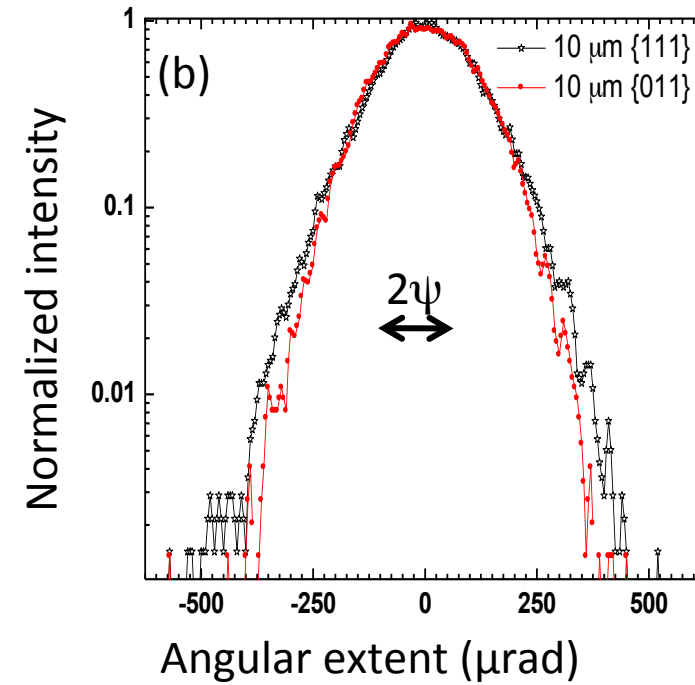
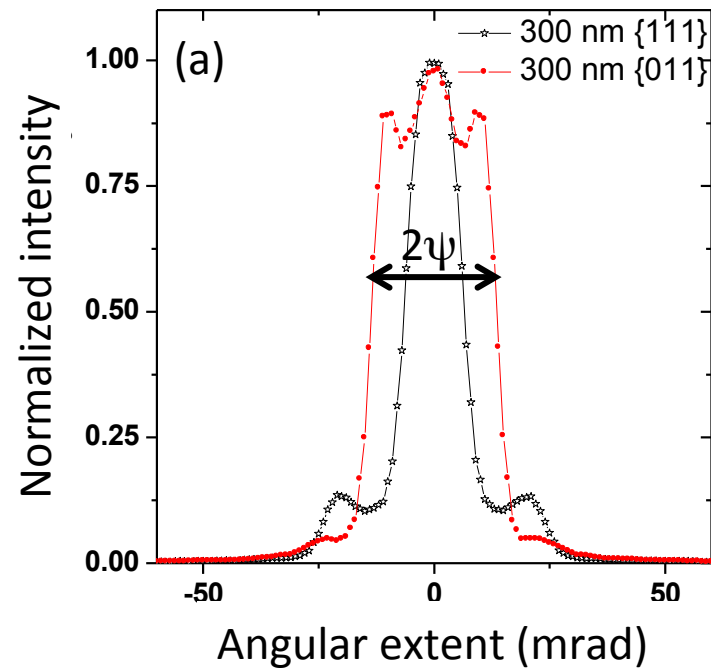
- 1. Deposit a monolayer of metallic film on membrane and clamp a substrate on top.*
- 2. The super focused channeled protons recoil the metal atoms into the Si substrate.*
- 3. Observing these Recoiled metal atoms by STM can prove the Super focusing effect.*





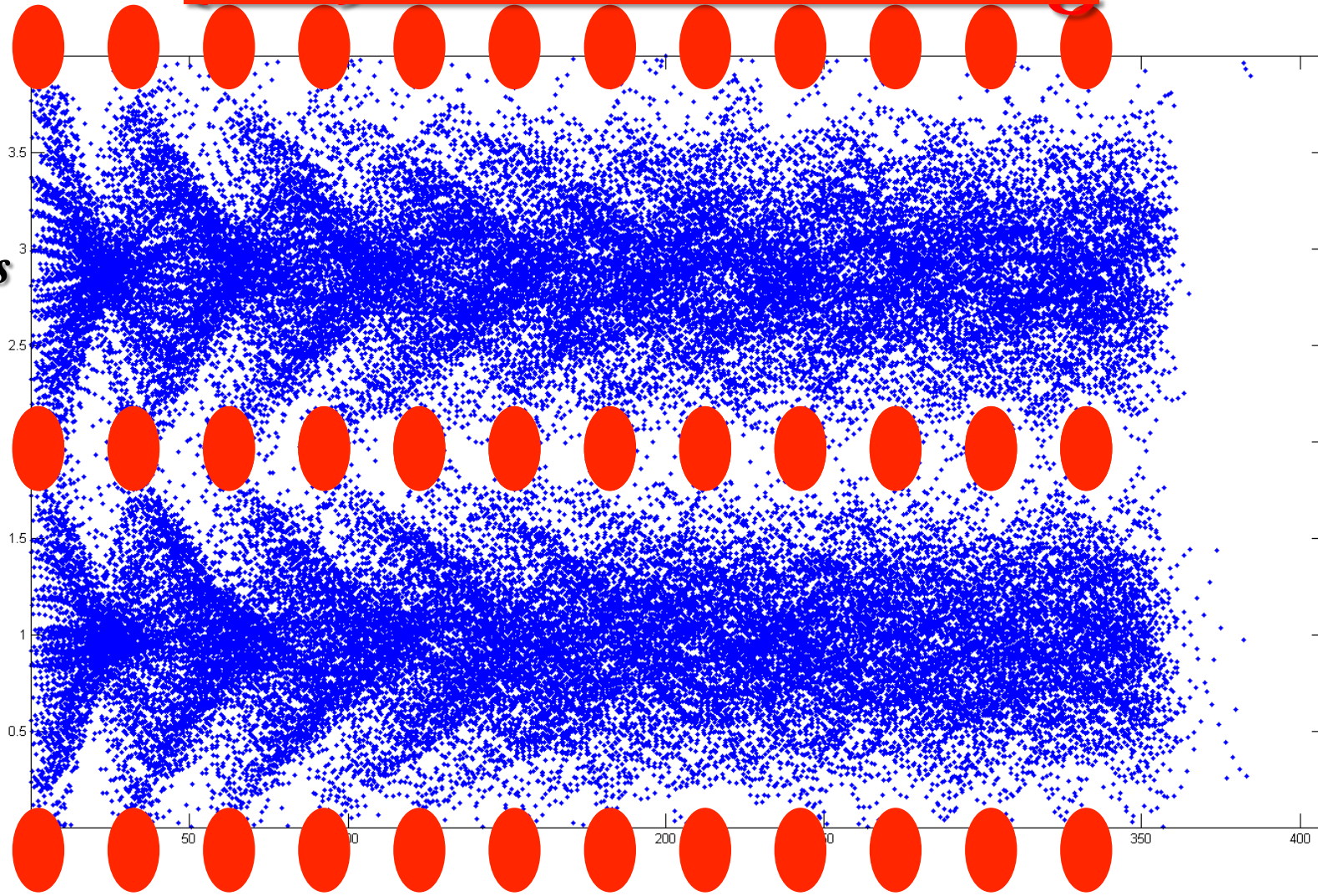
# *Axial projections*





# *{110} Planar channeling*

*2MeV  
Protons  
Silicon*

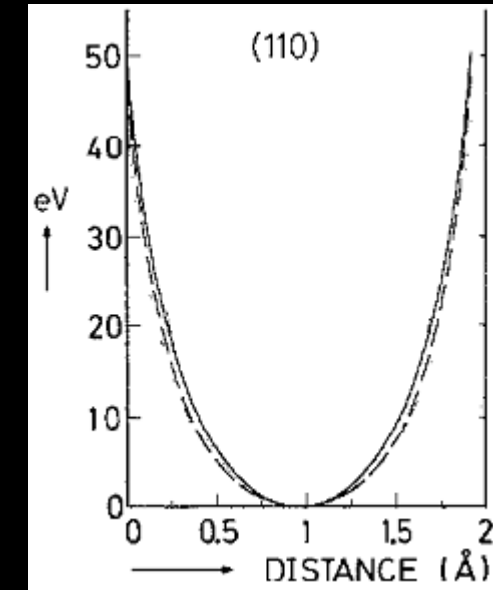


*Depth (1μm)* <sup>47</sup>

# *{110} Planar channeling*

2MeV Protons; 55nm thick [001] Silicon

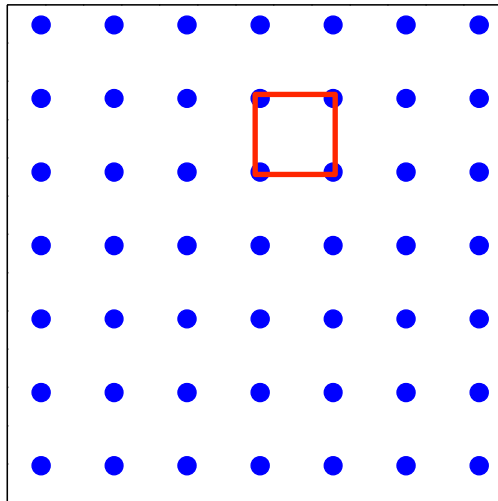
{110} plane near [112] axis



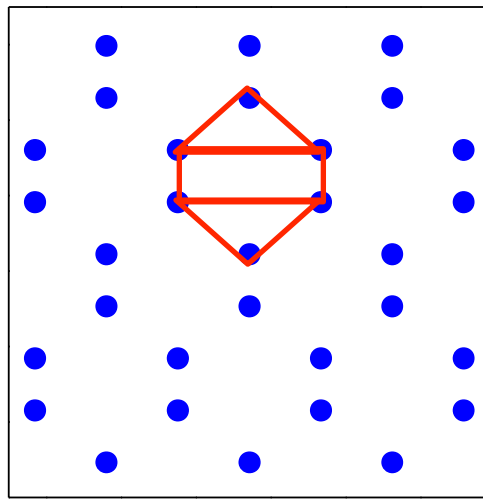


# *Axial projections*

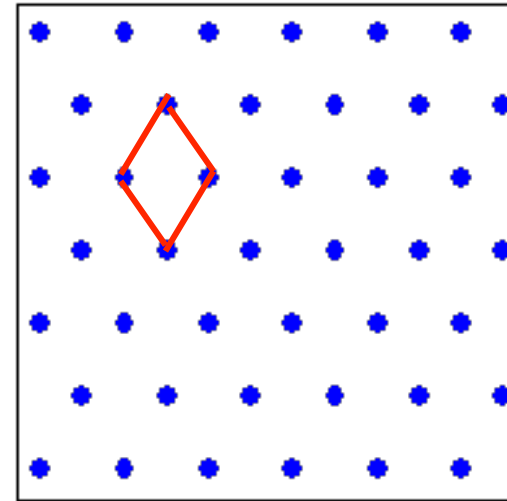
[001]



[011]

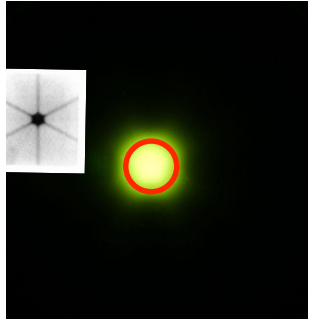


[111]

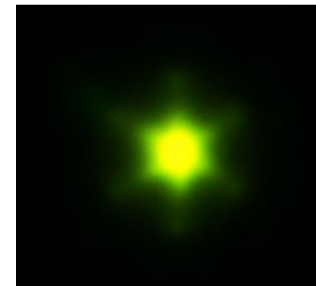
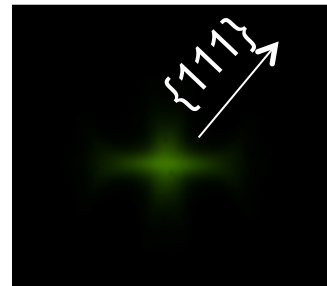
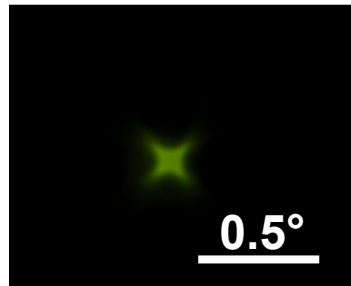


# *Axial channeling*

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



Increasing exposure time



*Incident  
Ions:  
2MeV H+*

We can See  
Minor plane  
Intersections  
With axes

# Monte Carlo FLUX

## simulations: ZBL

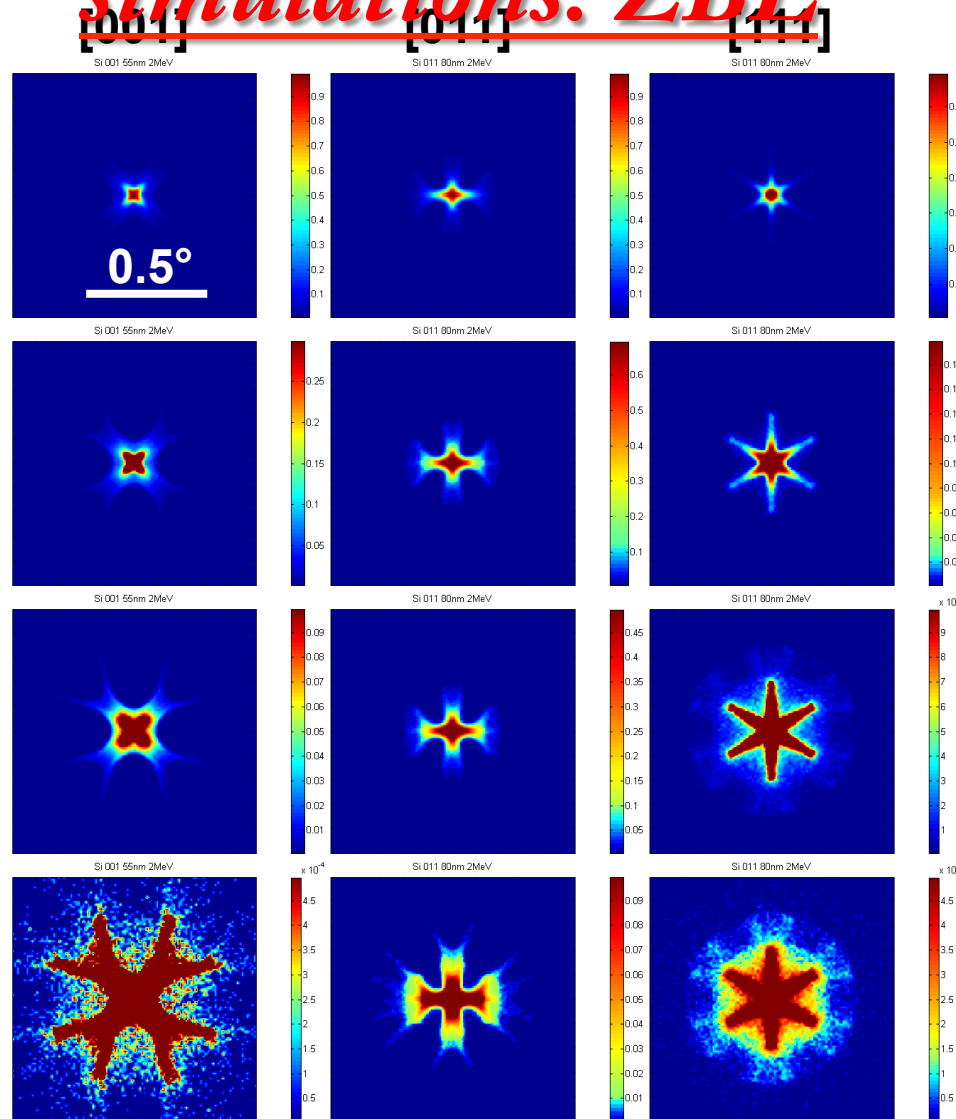
$$\Delta p_{\perp}(b) = \int_0^{\infty} F_{\perp} dt$$

$$\approx \frac{1}{v} \int_{-\infty}^{\infty} F_{\perp} dz$$

$$= -\frac{1}{v} \frac{\partial}{\partial b} \int_{-\infty}^{\infty} V(\sqrt{z^2 + b^2}) dz,$$

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

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



Which uses  
Binary collision  
Model

# Stereographic projection Si

*Boundaries are  
important*

