FLUKA Event Generator for Crystal Channeling: Advances and Benchmark against STF 45

P. Schoofs, F. Cerutti, A. Ferrari, G. Smirnov

Outline

- Introduction
- How does the code work ?
- Results
  - Illustration
  - Benchmarking (H8 experiment)
    - Crystal only
    - MCS in the telescope planes
  - MCS in the detector planes
  - Examples of other runs
- Conclusions

Introduction

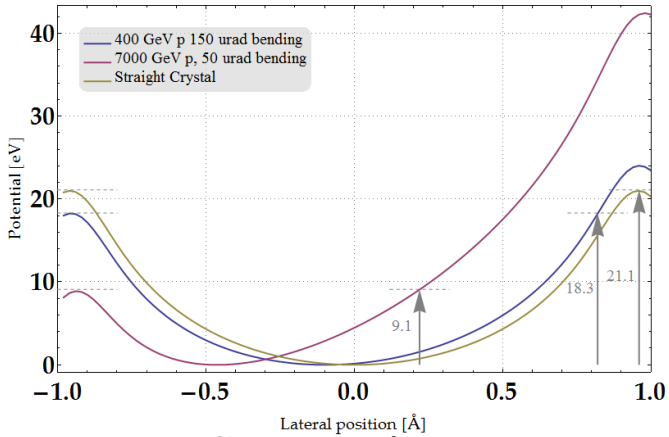
- **Why this model ?**
  - FLUKA used for all energy deposition studies at CERN
  - Make use of existing FLUKA interaction models
    - Coulomb Scattering, nuclear interactions,…
  - Extending FLUKA interactions capabilities
    - → Adding coherent interactions in crystals
  - Monte Carlo methods allow for fast execution
    - Of the order 0.1s/primary for 2mm-long crystal.
    - Code will be faster in the future
- **What cases ?**
  - Planar channeling of positively charged particles
  - Particles of any energies, benchmark to available data

(see https://cds.cern.ch/record/1950908)

How does the code work ?

- **Channeling :**
  - Moliere potential (w/ thermal motion)
  - Energy of transverse motion E_x > potential height

Moliere potential

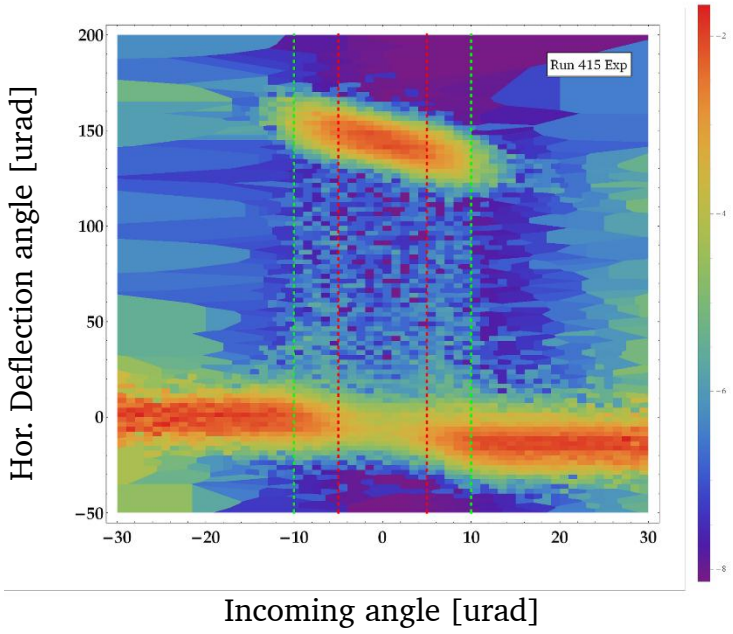


- **Dechanneling :**
  - Single Coulomb scattering
    - → modification of E_x
  - If E_x > barrier : dechanneling
- **Volume effects :**
  - Particles with trajectory tangent to planes can get reflected, (or captured if single-scattering make E_x < barrier)
- **Nuclear interactions :**
  - Relative reduction of nuclear density along oscillatory path of channeled particle inside the channel

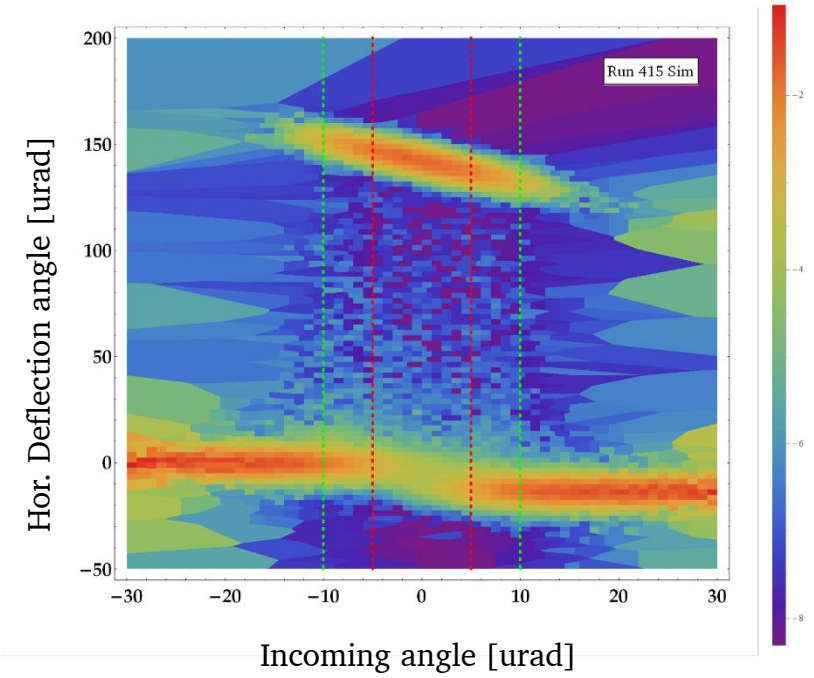
(P. Schoofs *et al.,* NIM B, **309** 115)

Results – 1. Introduction

- Run 415 population vs. deflection and Incoming angle



Experiment

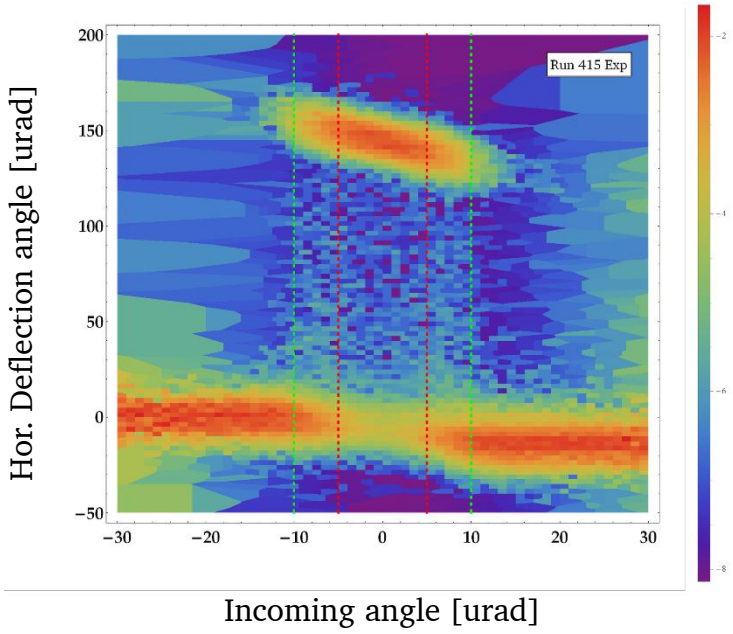


Simulation

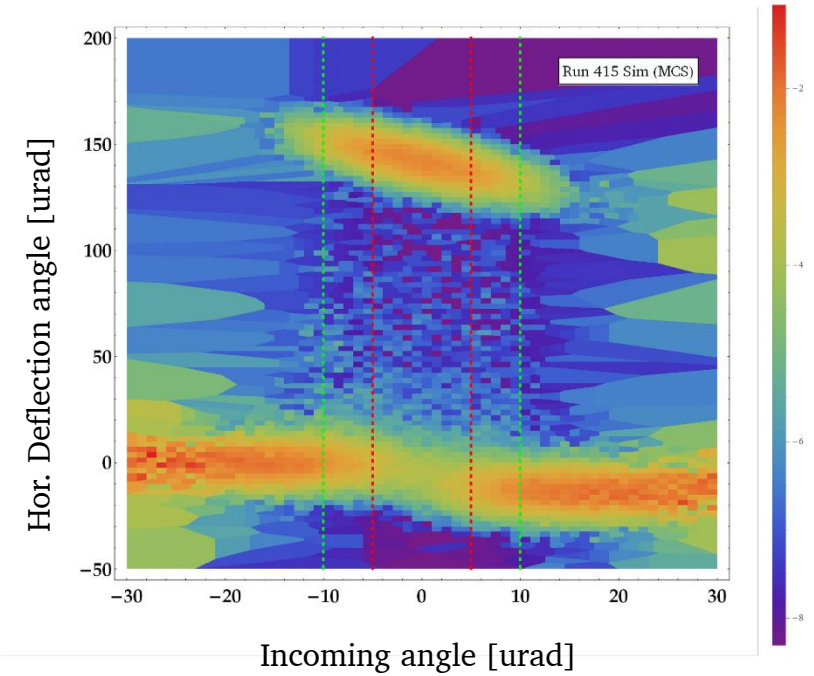
! No MCS from telescope !

Results – 1. Introduction

- Run 415 population vs. deflection and Incoming angle



Experiment



Simulation

MCS added to sim. results

Results – 1. Introduction

- Status :
  - Comprehensive benchmarking of 2010-2012 UA9-H8 runs was done in the past
    - Focus on the reproduction of entire runs with torsion
- Here :
  - Joint effort of the UA9 collaboration
    - Comparison campaign of simulation results
    - Against the reference case : STF 45 strip crystal from Ferrara
      - (Run 415 of the 2010 data taking campaign)
  - Analysis in the UA9 framework (see R. Rossi's, talk)
    - Filter in the incoming angle (5 or 10 urad)
    - Experimental data has torsion compensation

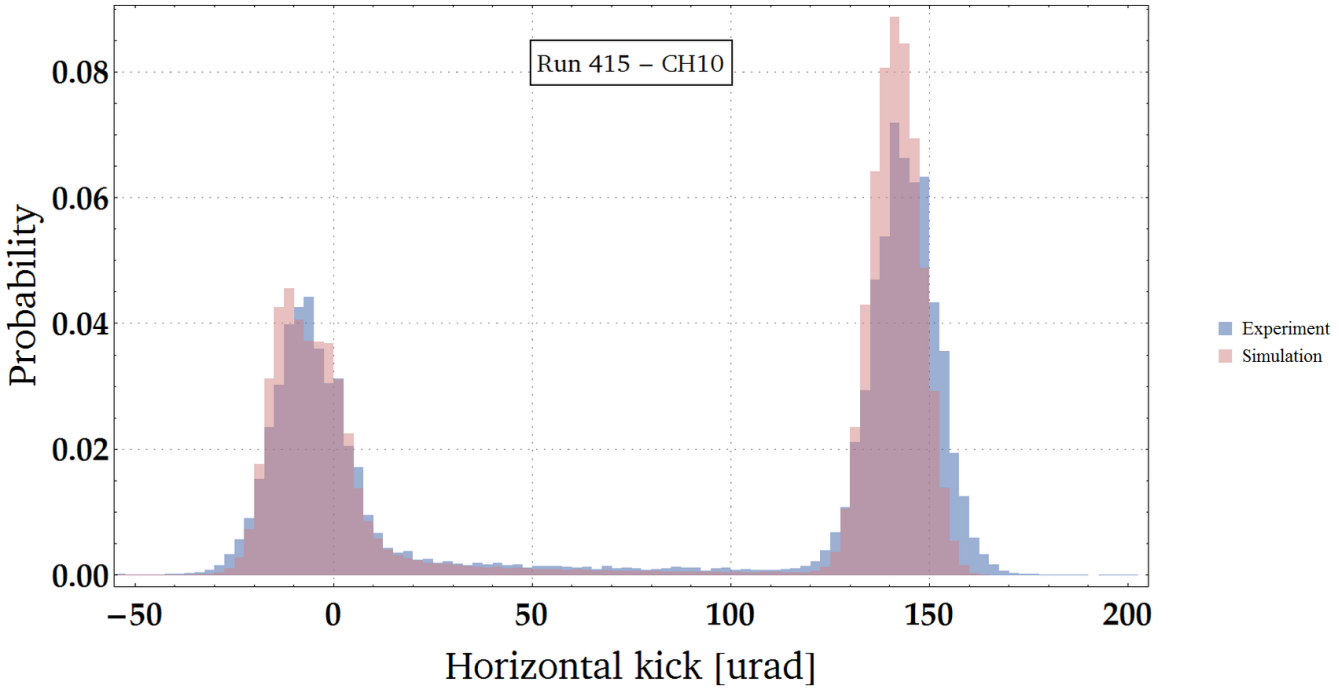
Results – 1. Introduction

- Crystal was in channeling orientation
- But : Beam Orientations :
  - VR : tail of the beam entirely in the VR region
  - CH5 : within 5 urad in both directions from the ideal channeling orientation
  - CH10 : same but within 10 urad
- RATES:
  - CH : within 3σ of the mean of the channeling peak
  - VC : outside of 3σ of the mean of the VR peak
  - DC : in between the peaks (boundary at 3σ)

Results – 2. Benchmarking (H8)

- Channeling (cut @ 10 urad)

! Simulation excluding MCS from telescope !

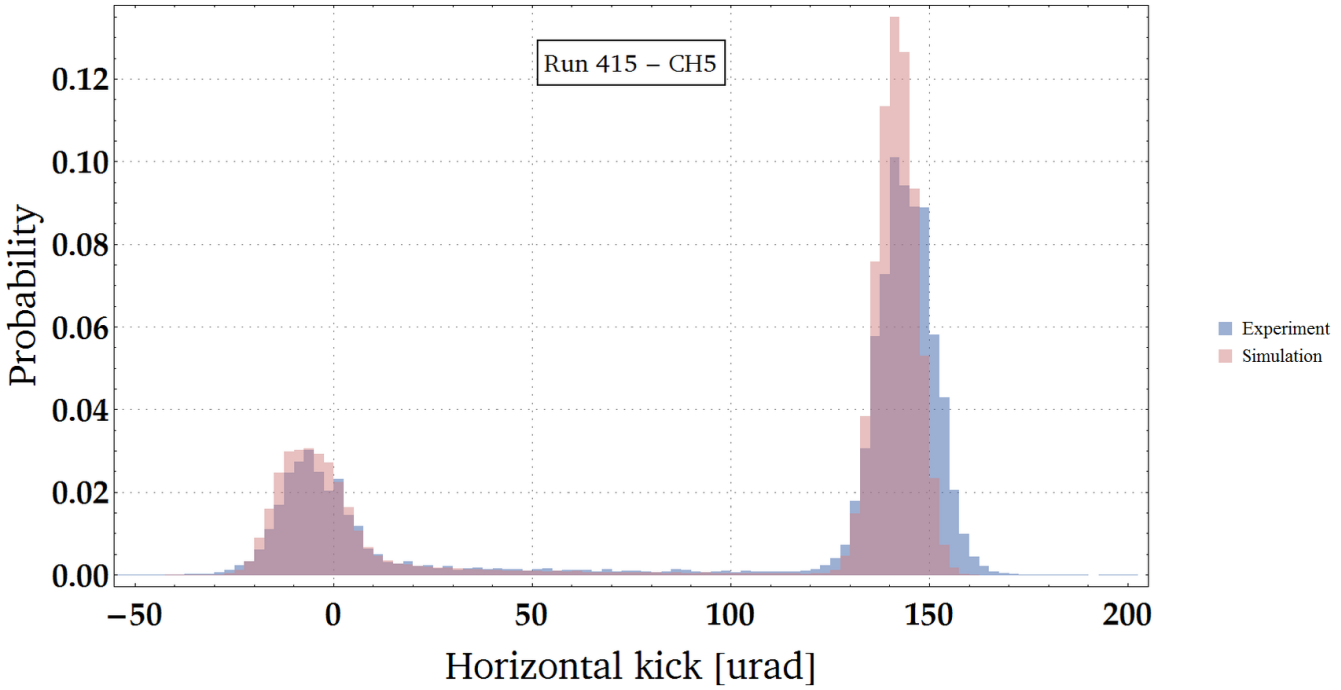


415	VR/AM peak	CH peak	CH rate	DC rate	L_D
	[urad]	[urad]	[%]	[%]	[mm]
Simulation	-6.3 σ 8.6	141.6 σ 6.1	56.90 ± 0.15	3.71 ± 0.06	0.845
Experiment	(-5.9 σ 9.5)	143.8 σ 8.2	54.0	(5.13 ± 0.18)	1.408

Results – 2. Benchmarking (H8)

- Channeling (cut @ 5 urad)

! Simulation excluding MCS from telescope !



415	VR/AM peak	CH peak	CH rate	DC rate	L_D
	[urad]	[urad]	[%]	[%]	[mm]
Simulation	-5.2 σ 8.6	141.8 σ 4.9	68.86 ± 0.19	3.71 ± 0.08	1.018
Experiment	(-4.5 σ 9.3)	144.0 σ 7.2	68.9	(4.76 ± 0.24)	1.228

Results – 2. Benchmarking (H8)

- Channeling (cut @ 5 urad)

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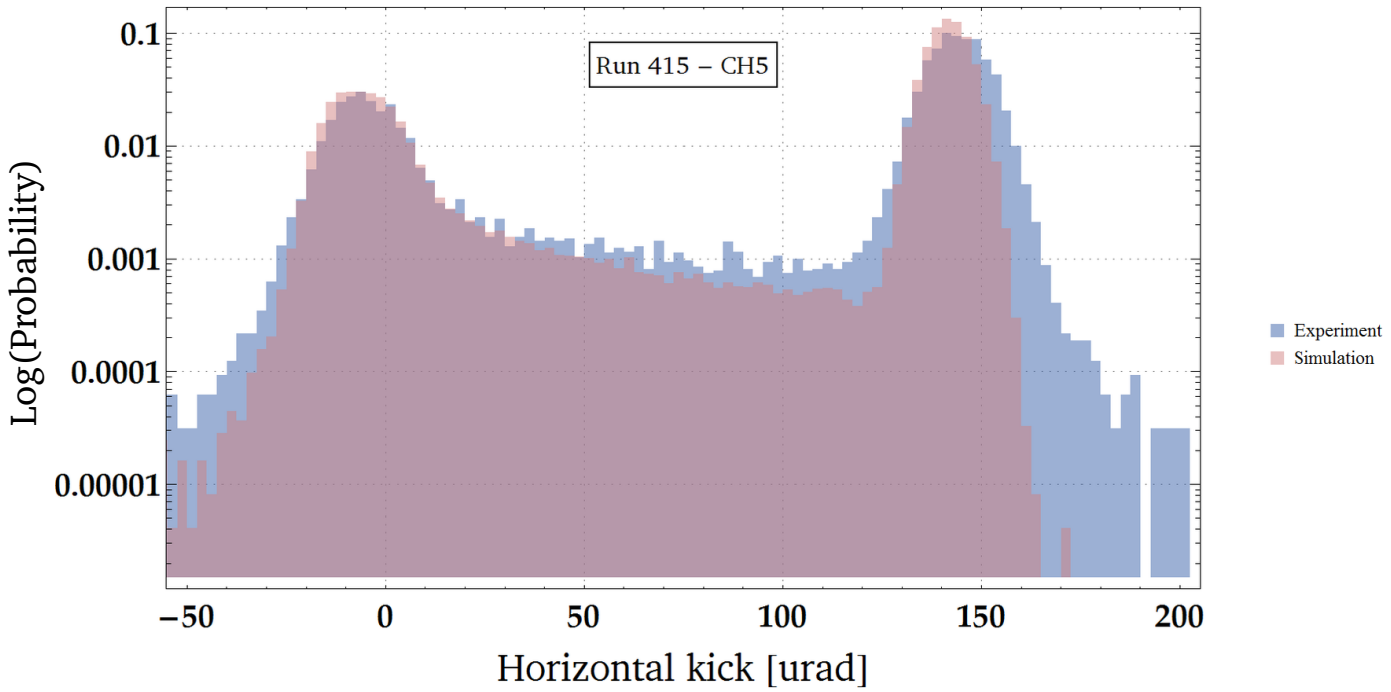

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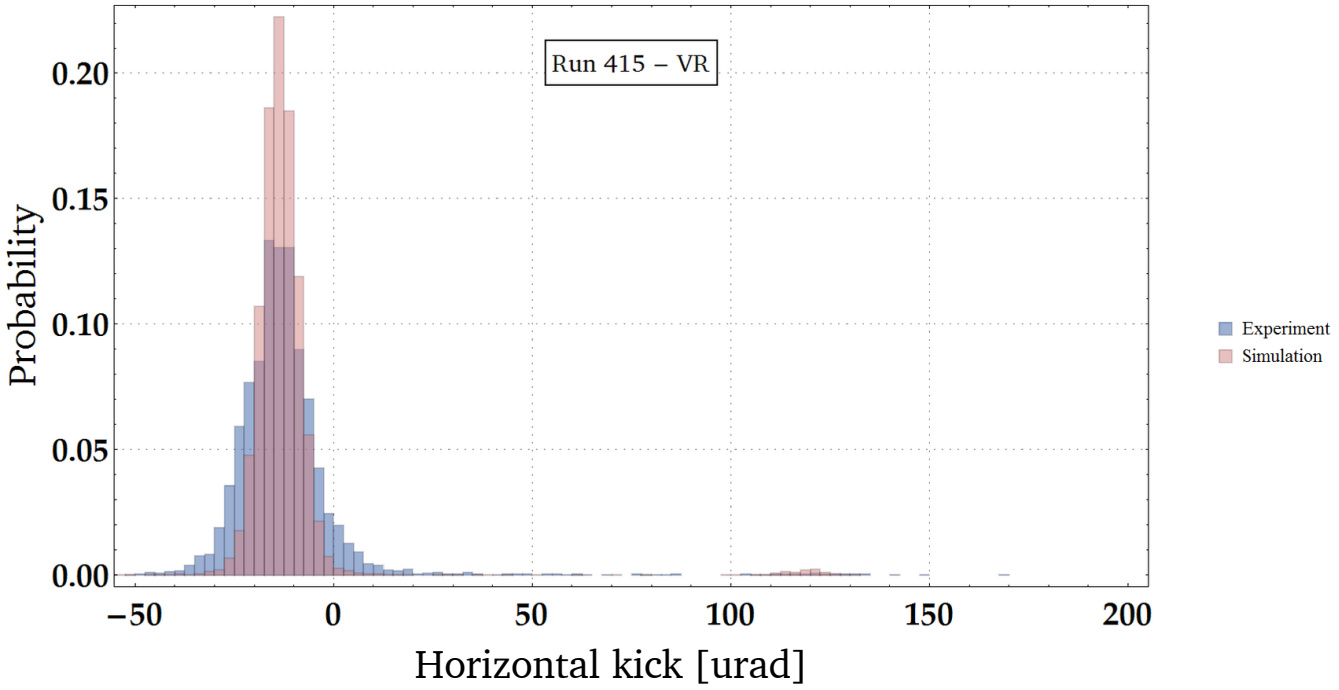
Results – 2. Benchmarking (H8)

- Volume reflection (low stat)

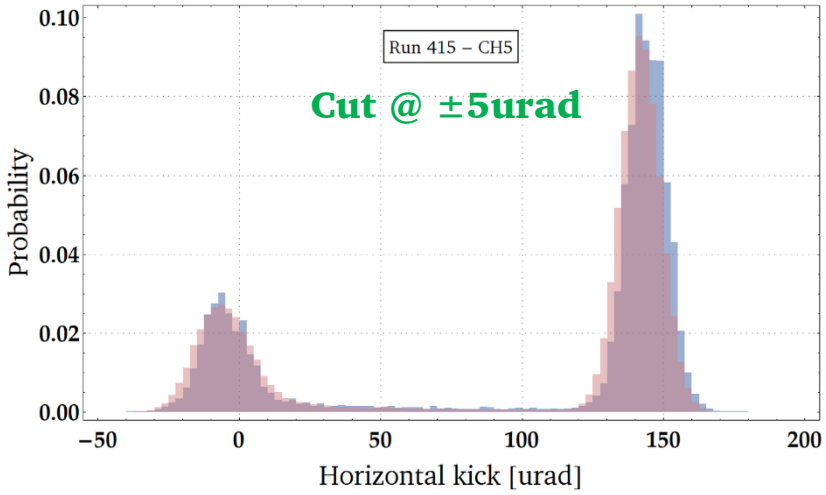
! Simulation excluding MCS from telescope !

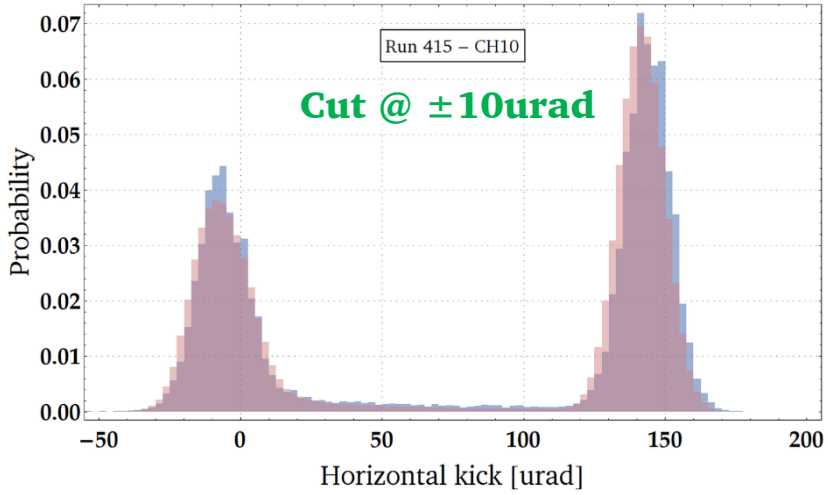


415	VR peak	VC rate
	[urad]	[%]
Simulation	-14.70 σ 7.82	1.1
Experiment	-14.03 σ 8.03	(1.7)

Results – 2. Benchmarking (H8)

- After correction of the MCS in the telescope
  - 5.2 urad sig

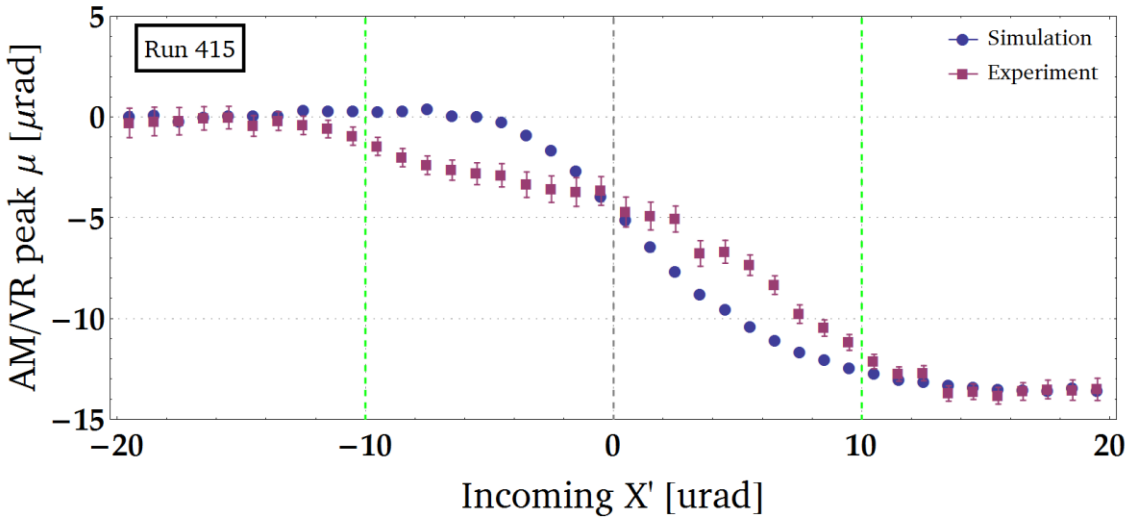


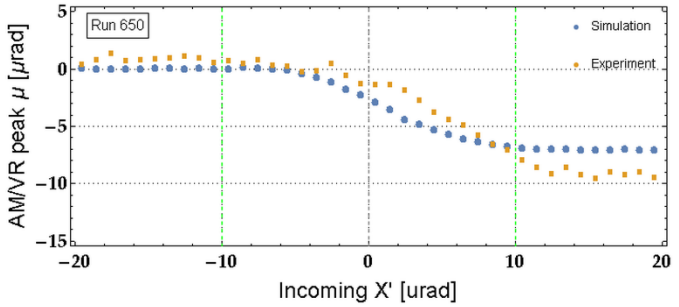


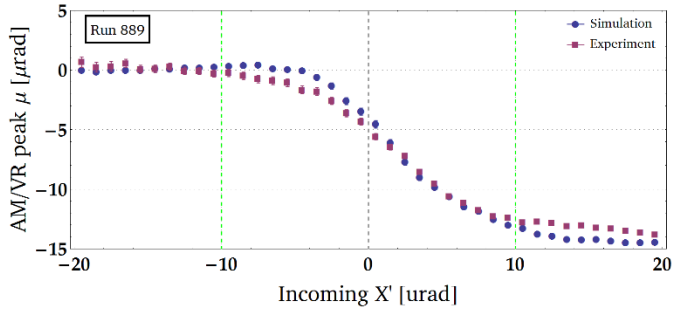
415	VR/AM	CH	CH rate	DC rate
	[urad]	[urad]	[%]	[%]
@5 Sim (MCS corr)	-4.9 σ 10.3	141.7 σ 7.1	68.92 ± 0.19	3.32 ± 0.07
@5 Experiment	(-4.5 σ 9.3)	144.0 σ 7.2	68.9	(4.76 ± 0.24)
@10 Sim (MCS corr)	-6.2 σ 10.2	141.6 σ 8.0	56.94 ± 0.15	3.37 ± 0.06
@10 Experiment	(-5.9 σ 9.5)	143.8 σ 8.2	54.0	(5.13 ± 0.18)

Results – 2. Benchmarking (H8 experiment)

- Low incoming angle, non-channeled particles







- Transition btw. volume reflection and amorphous mode
- Variable from crystal to crystal

Conclusions

- Presentation of a Monte Carlo model of crystal channeling
- For positively charged particles, at any high energy

- Good agreement with the UA9 experiment in H8
  - Channeling rates, description of the peaks
- Small underestimation of the dechanneling process

- **Next :**
  - Implementation in FLUKA
  - 7 TeV studies

THANK YOU FOR YOUR ATTENTION !

SPARE SLIDES

SPARE SLIDES

- Run 1197 QMP29 (low bending angle, QM)
- Run 650 STF49(high bending angle, strip)
- Run 889 STF50(high bending angle, strip)

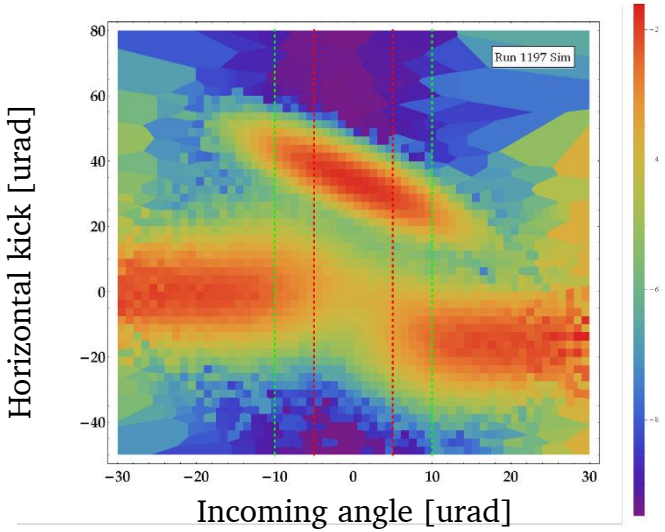
- FOR EACH
  - Run maps
  - Kick distribution at 5 and 10 urad filters & in VR
    - Logscale at 5
  - Same for MCS-corrected sim
  - Transition region

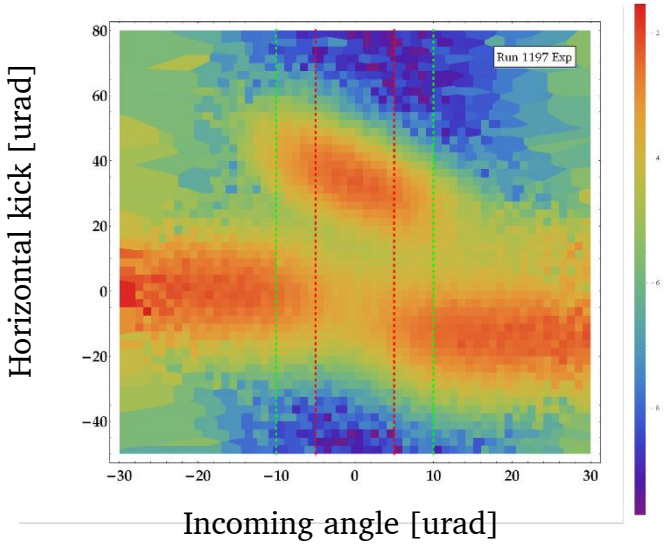
- OTHER CRYSTALS

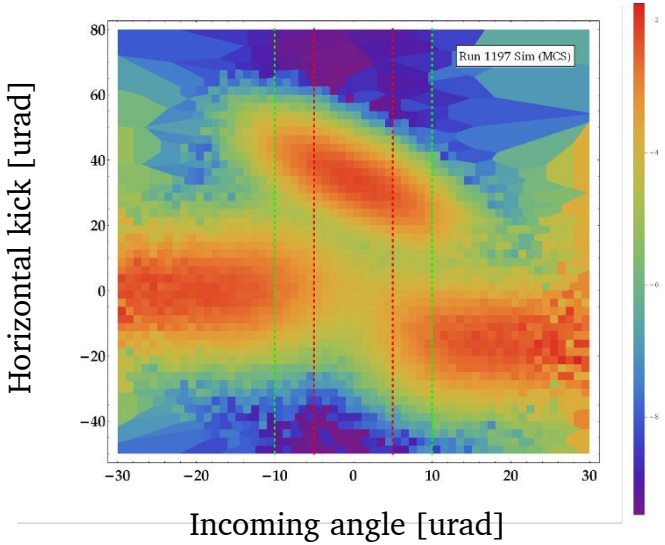
- 1197

Spare slides – 1. 1197 with QMP29

- Run maps
  - Simulation, sim w/ MCS
  - Experiment



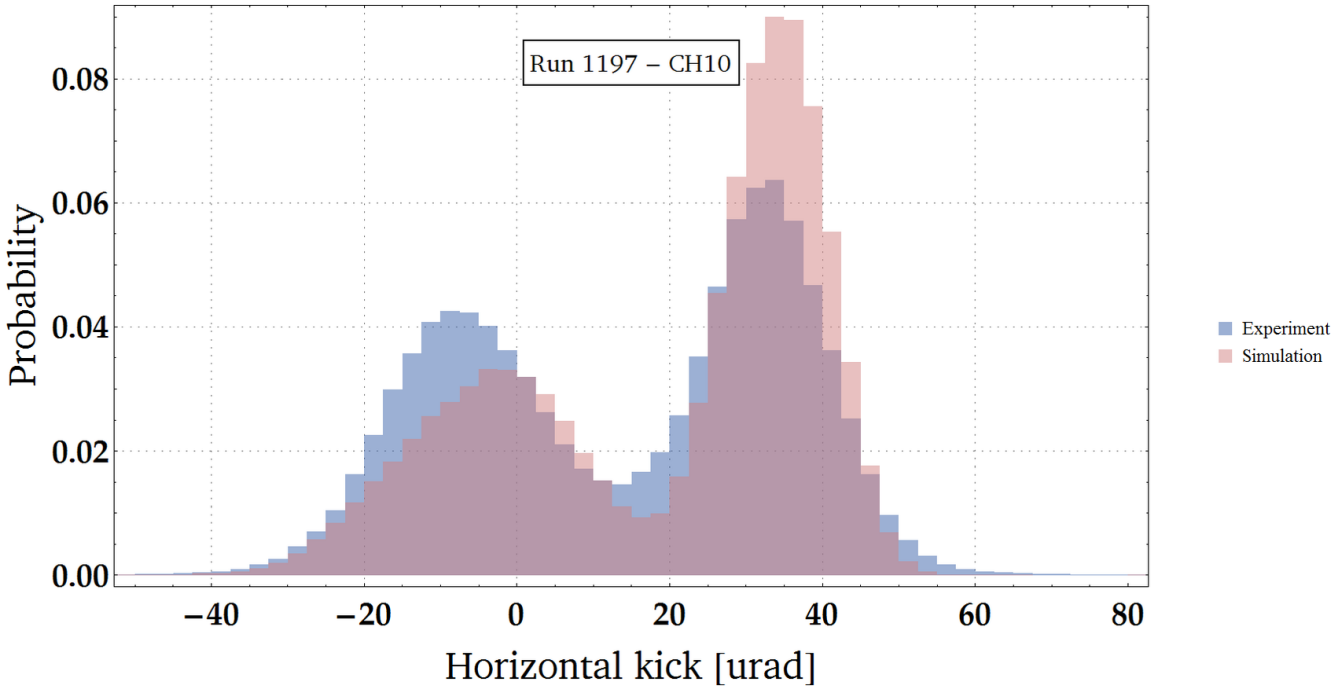




Spare slides – 1. 1197 with QMP29

- Channeling (cut @ 10 urad)

! Simulation excluding MCS from telescope !



1197	VR/AM peak	CH peak	CH rate	DC rate	L_D
	[urad]	[urad]	[%]	[%]	[mm]
Simulation					
Experiment					

Spare slides – 1. 1197 with QMP29

- Channeling (cut @ 5 urad)

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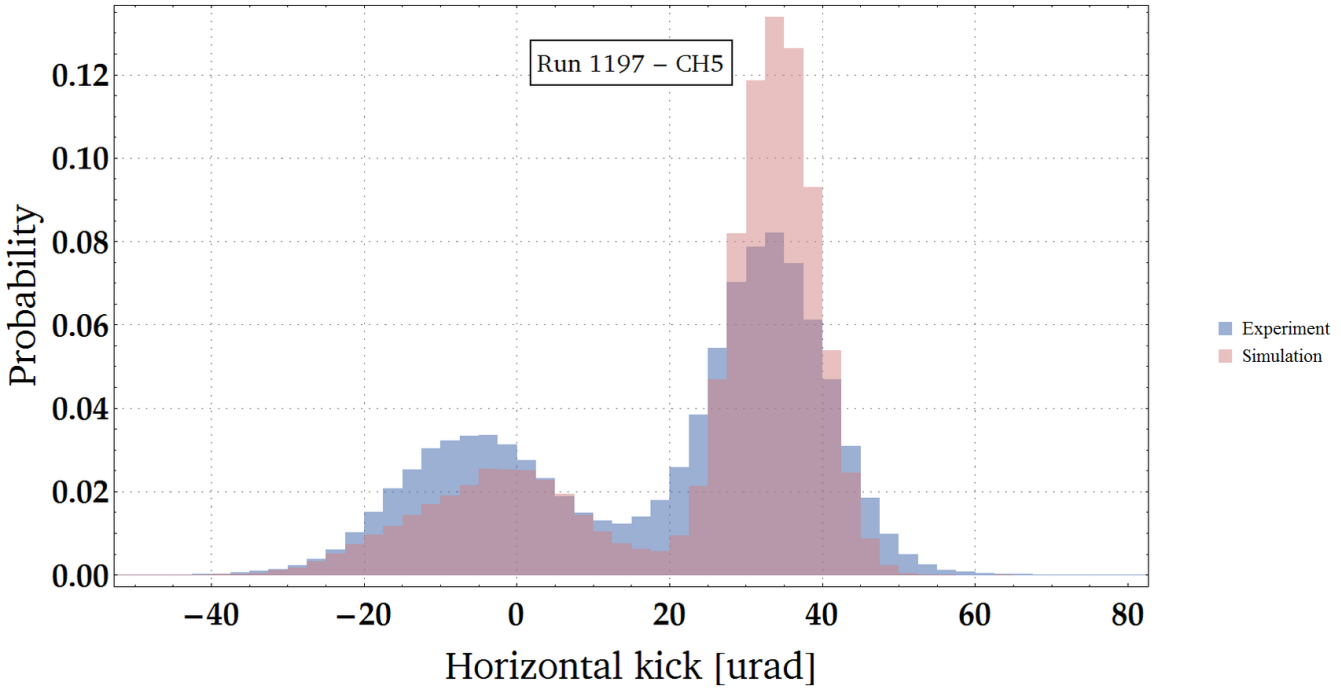

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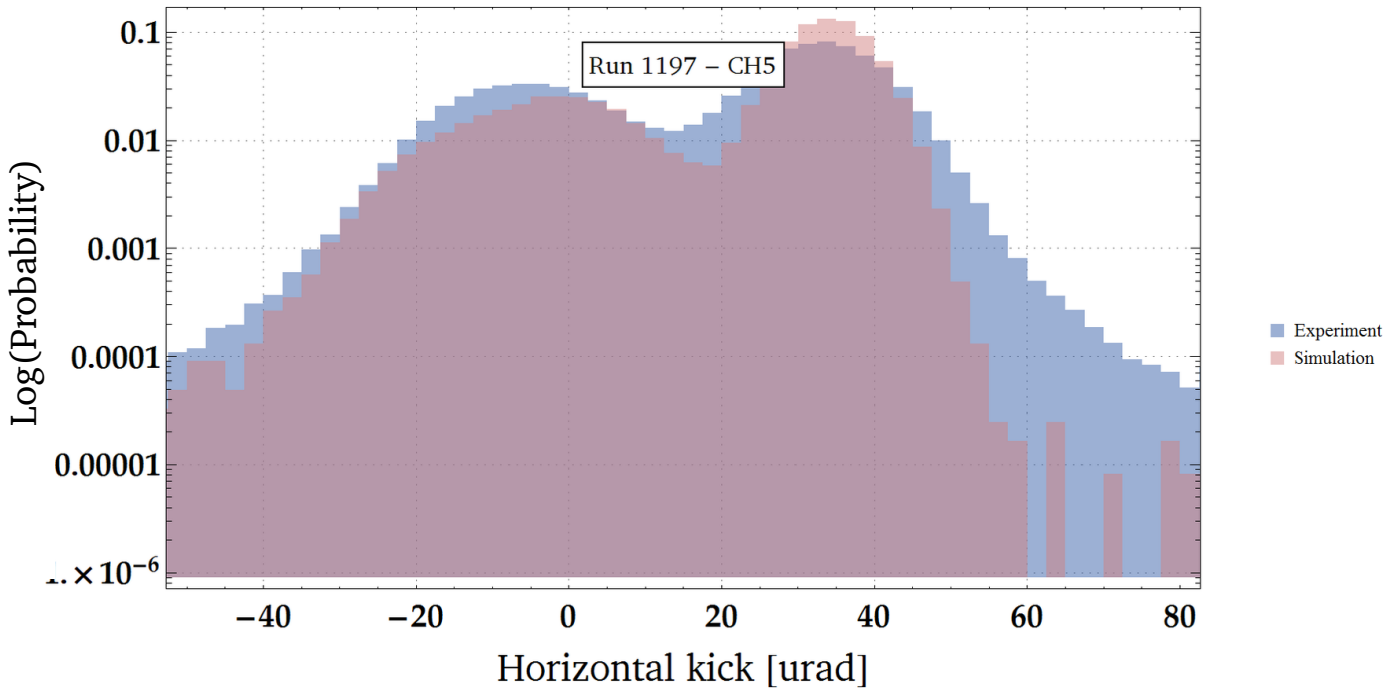

Spare slides – 1. 1197 with QMP29

- Volume reflection (low stat)

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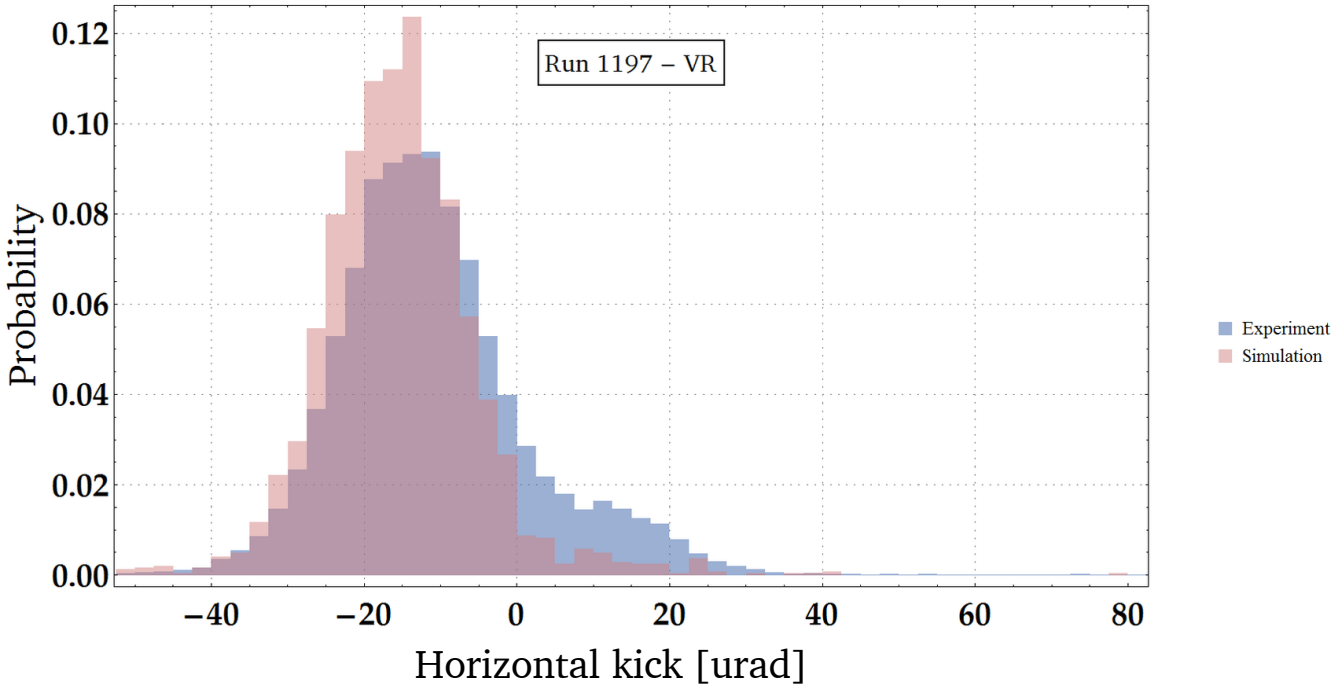

1197	VR peak	VC rate
	[urad]	[%]
Simulation		
Experiment		

Spare slides – 1. 1197 with QMP29

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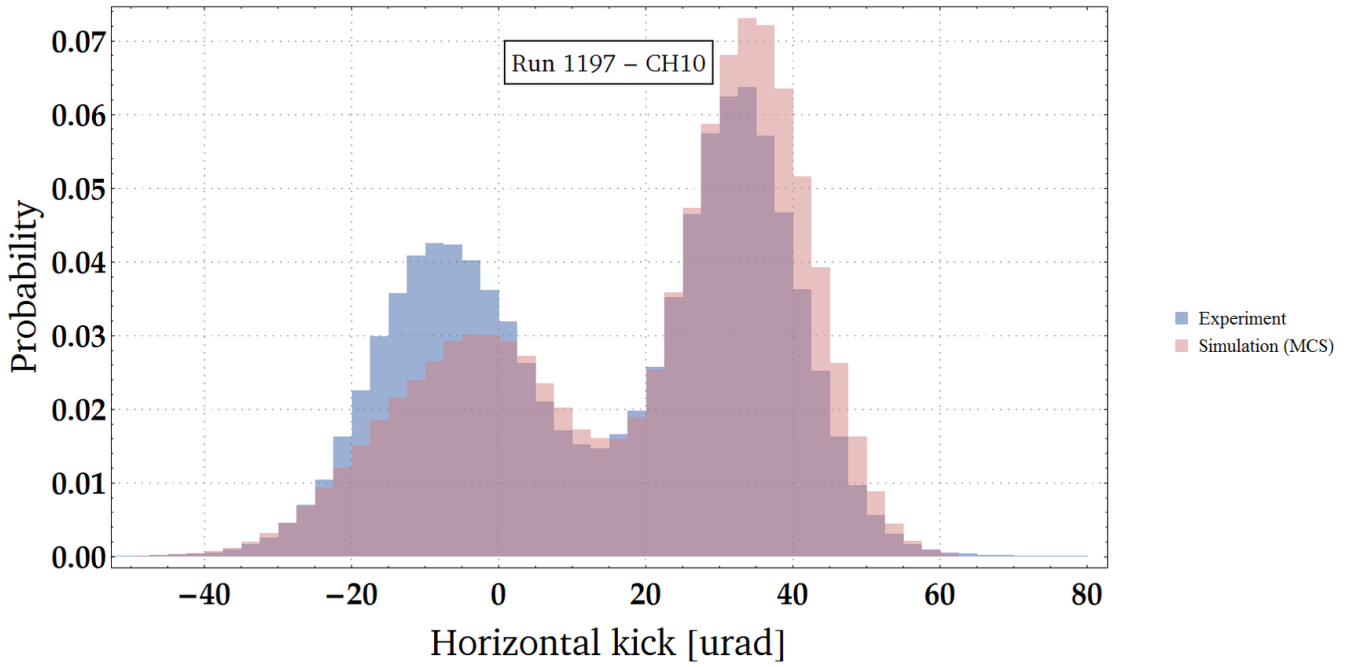

1197	VR/AM peak	CH peak	CH rate	DC rate	L_D
	[urad]	[urad]	[%]	[%]	[mm]
Simulation (MCS)					
Experiment					

Spare slides – 1. 1197 with QMP29

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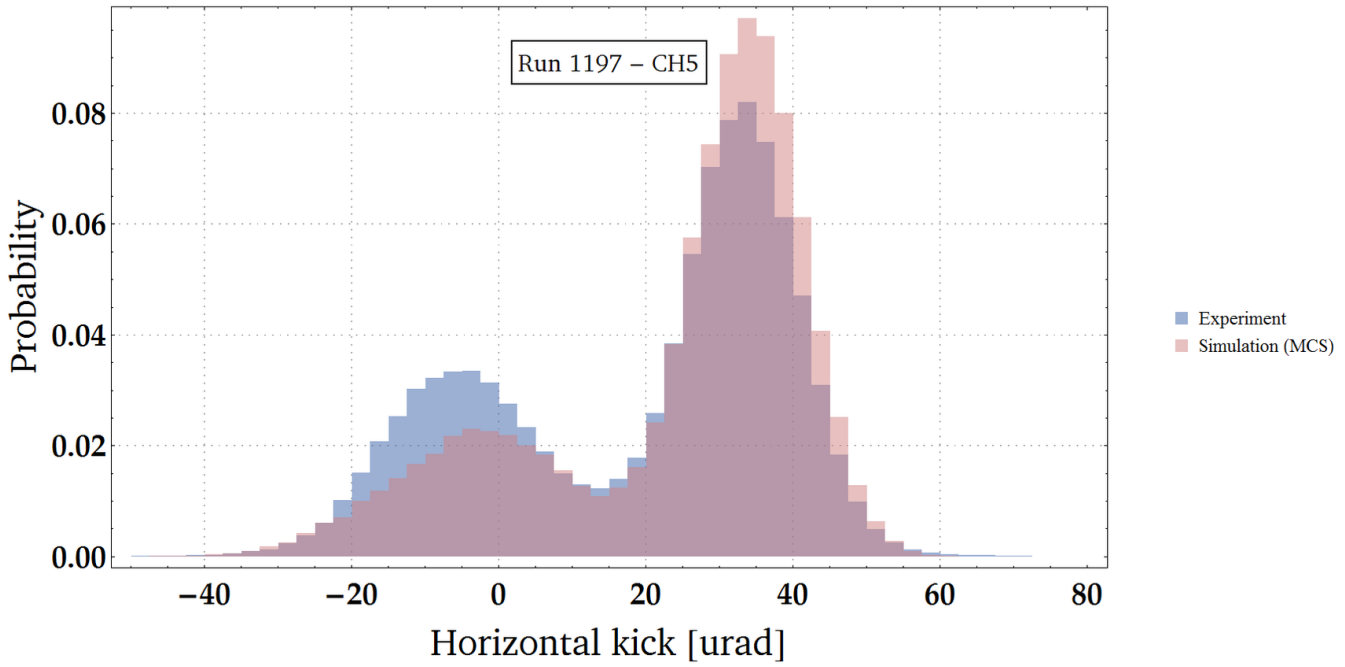

1197	VR/AM peak	CH peak	CH rate	DC rate	L_D
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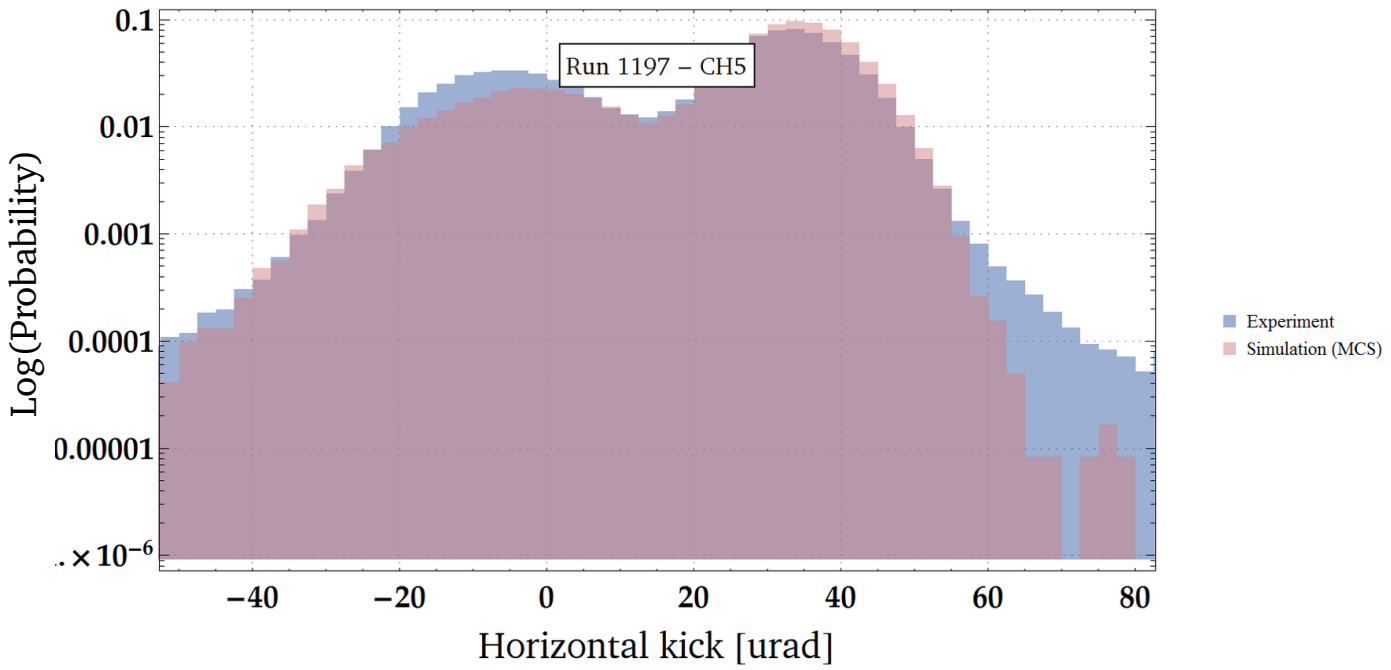

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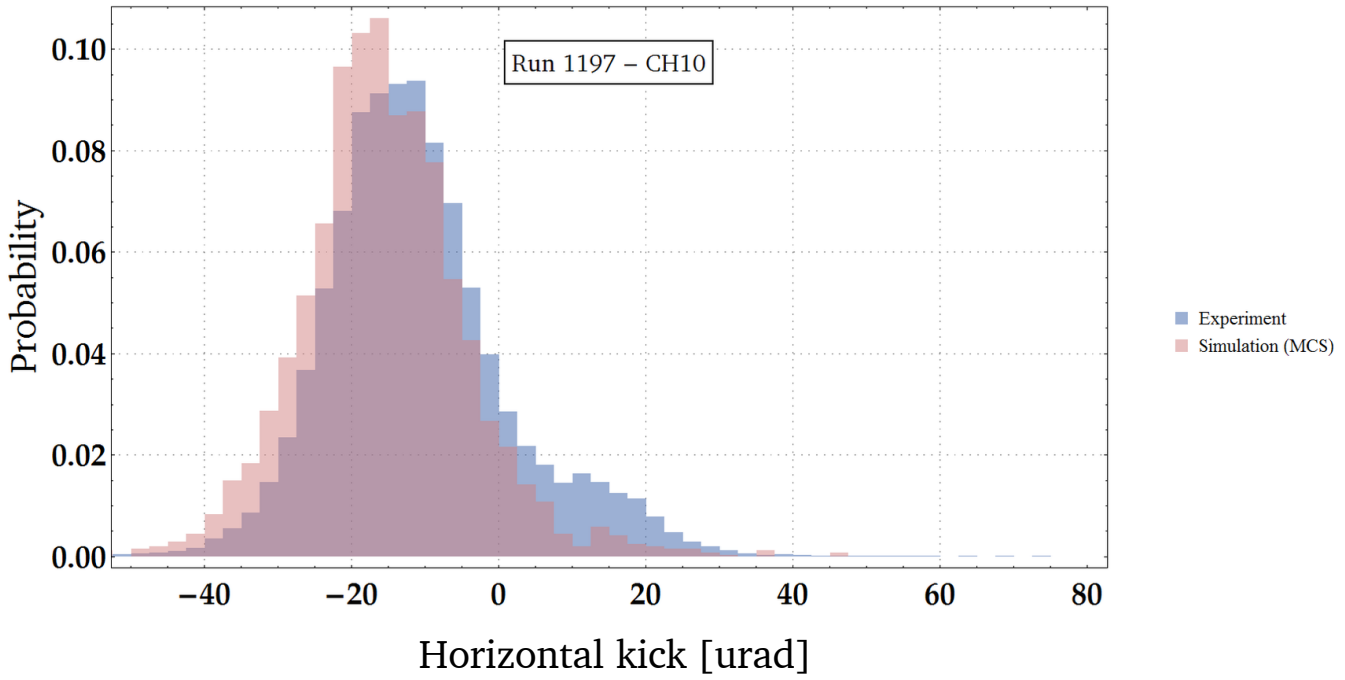
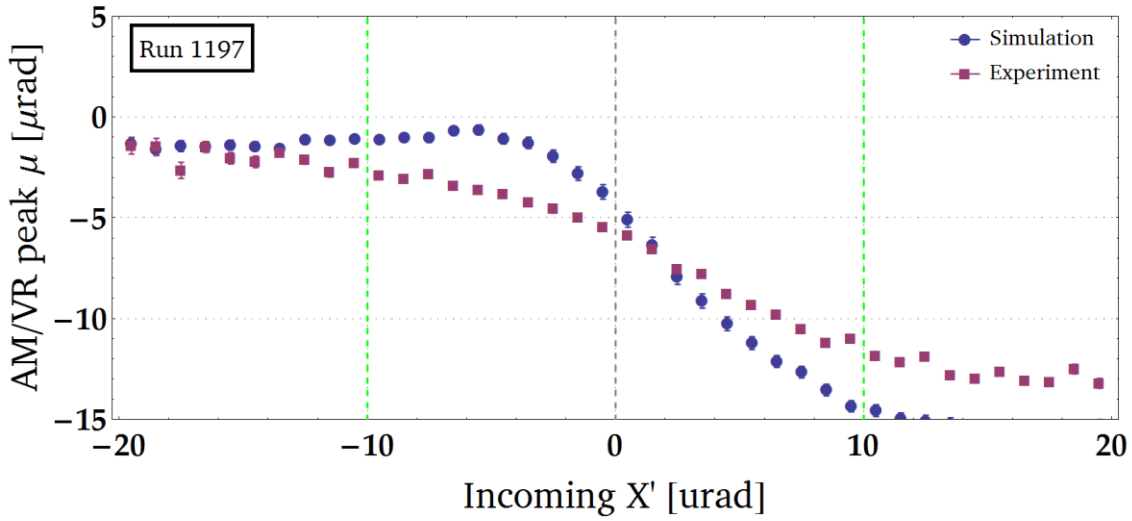


1197	VR peak	VC rate
	[urad]	[%]
Simulation		
Experiment		

Spare slides – 1. 1197 with QMP29

- Low incoming angle, non-channeled particles



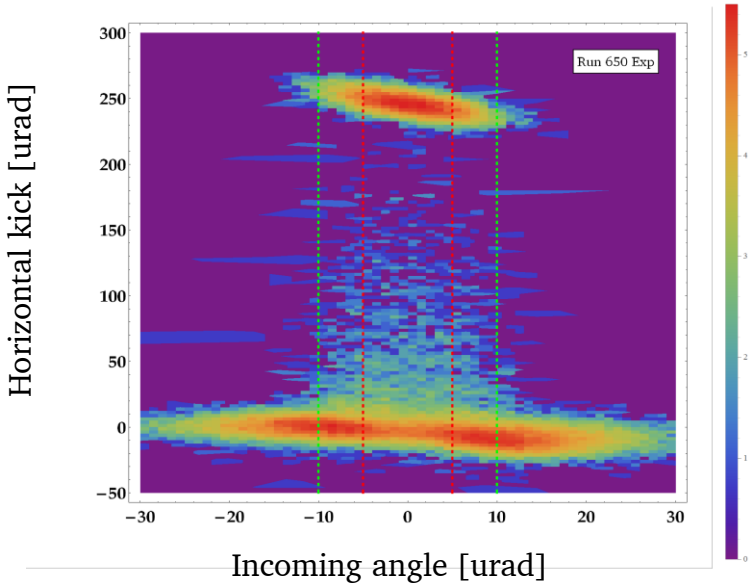
- Transition btw. volume reflection and amorphous mode
- Variable from crystal to crystal

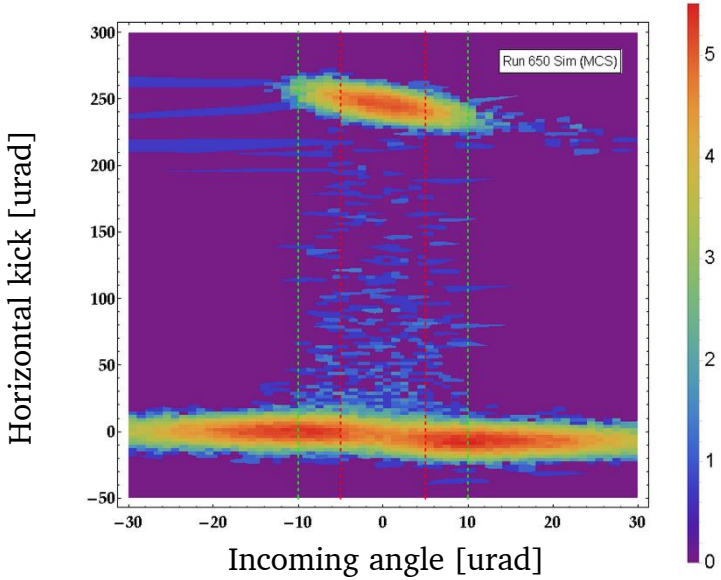
- OTHER CRYSTALS

- 650 STF 49

SPARE SLIDES – 2. 650 WITH STF49

- RUN MAPS
  - Simulation, sim w/ MCS
  - Experiment

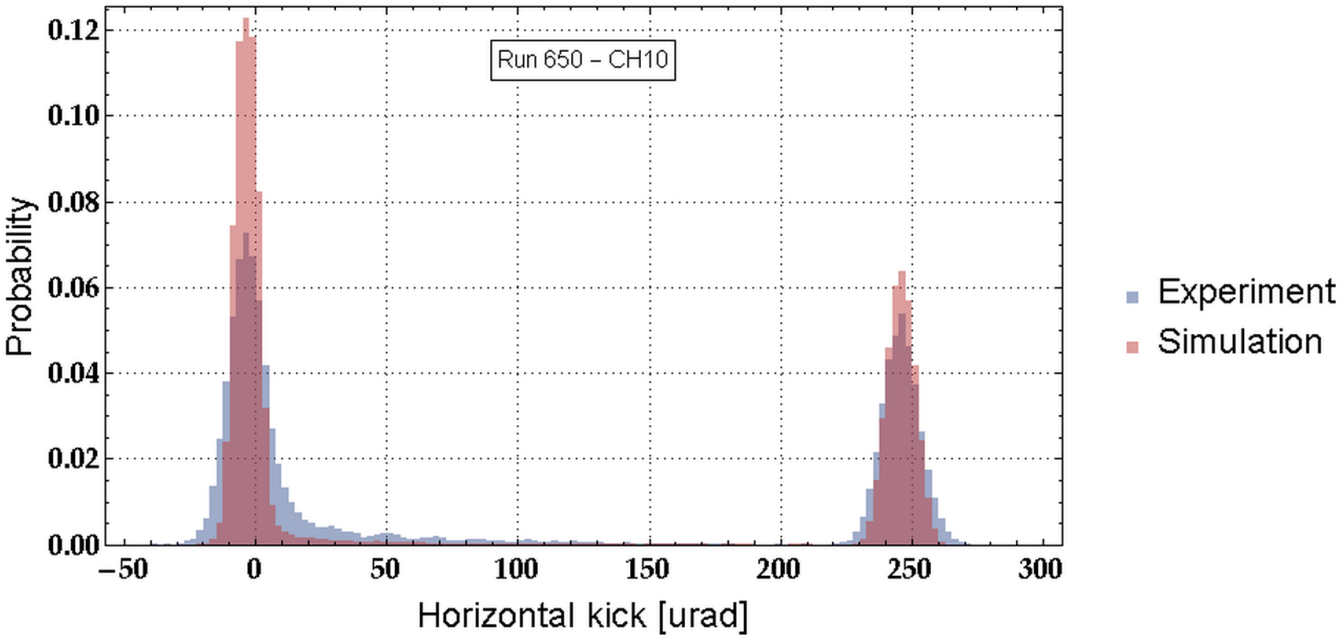




SPARE SLIDES – 2. 650 WITH STF49

- CHANNELING (CUT @ 10 URAD)

! Simulation excluding MCS from telescope !



1197	VR/AM peak	CH peak	CH rate	DC rate	L_D
	[urad]	[urad]	[%]	[%]	[mm]
Simulation					
Experiment					

SPARE SLIDES – 2. 650 WITH STF49

- CHANNELING (CUT @ 5 URAD)

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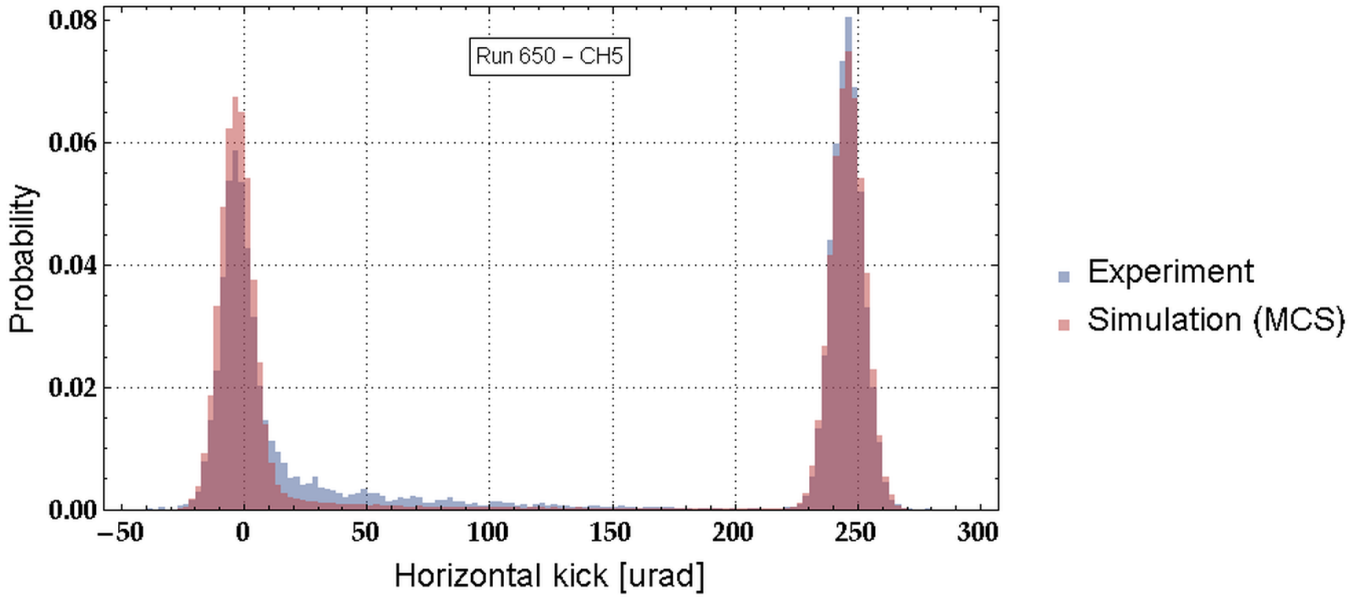

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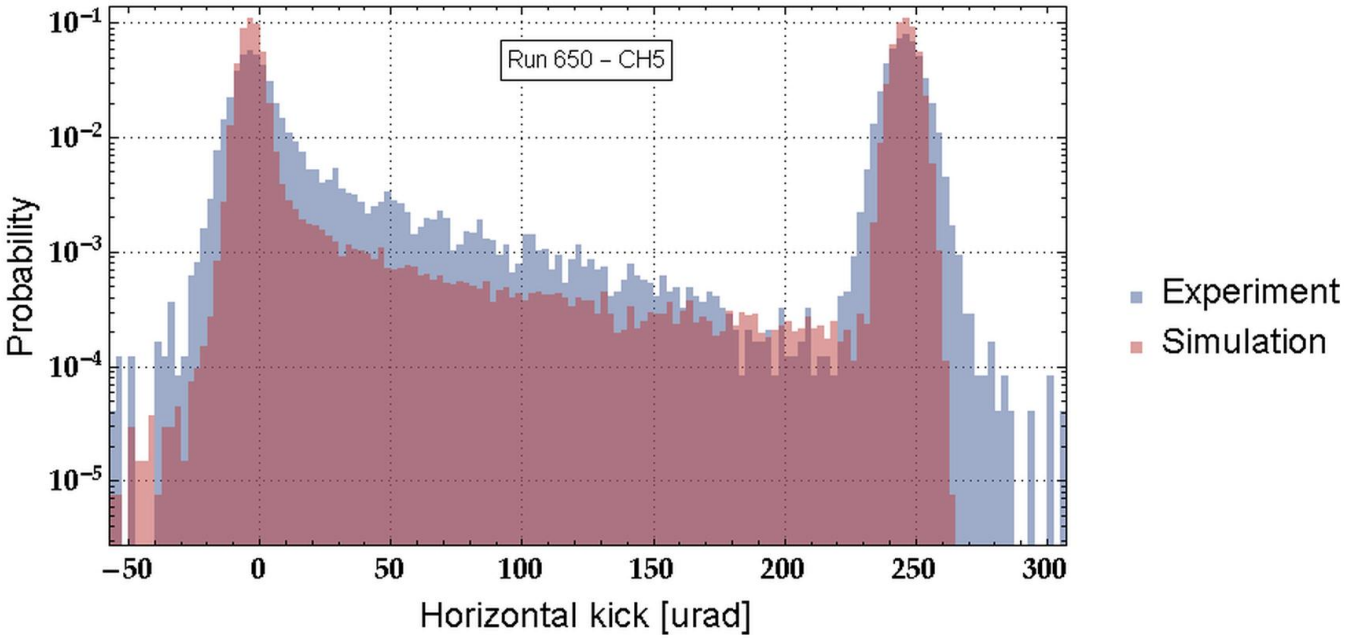
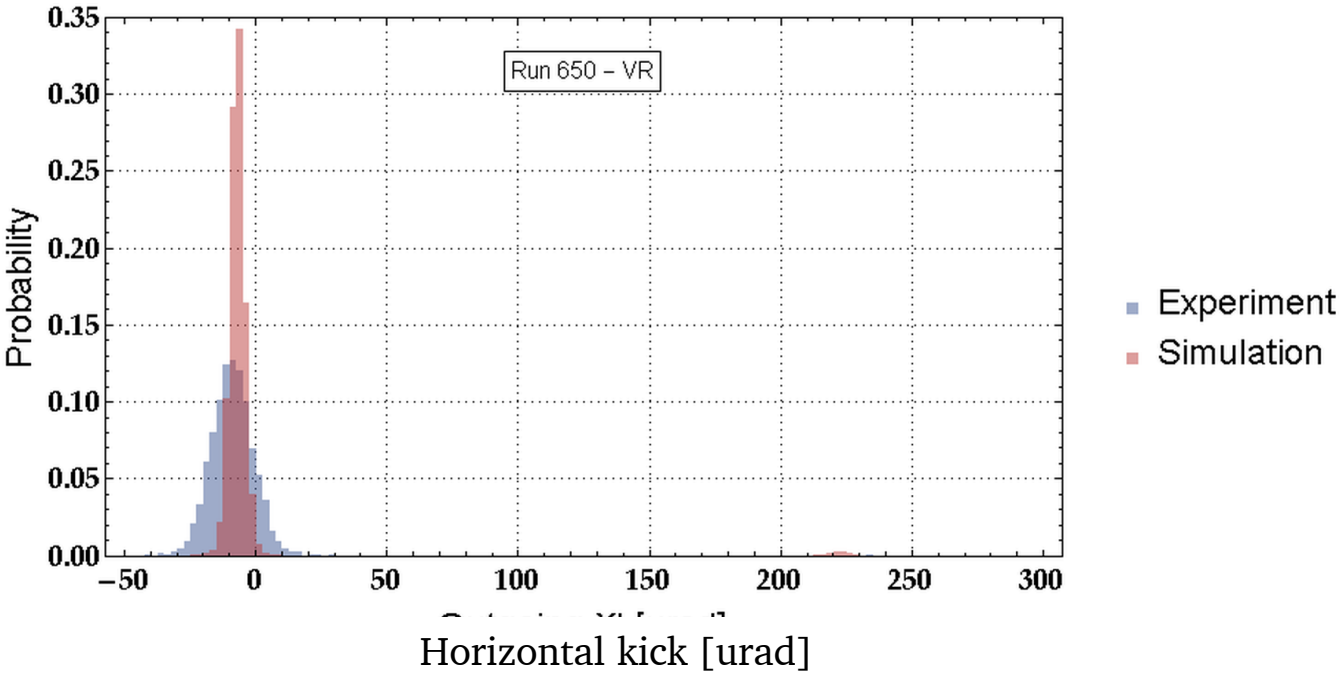


SPARE SLIDES – 2. 650 WITH STF49

- VOLUME REFLECTION (LOW STAT)

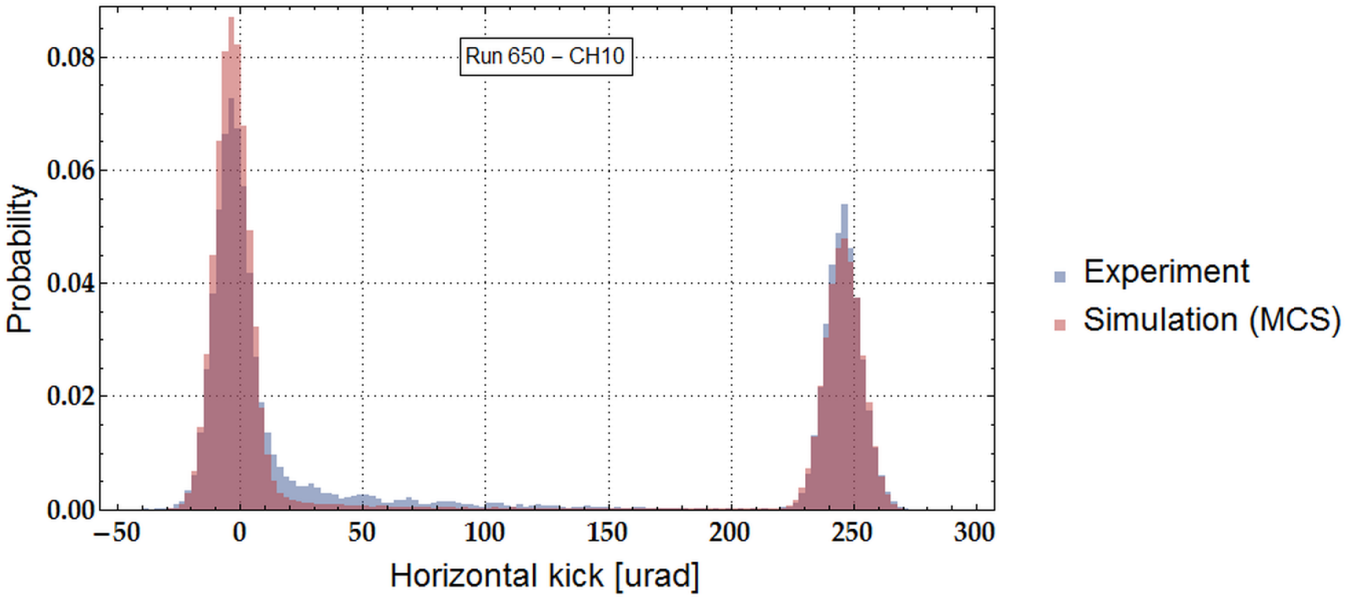
! Simulation excluding MCS from telescope !



1197	VR peak	VC rate
	[urad]	[%]
Simulation		
Experiment		

SPARE SLIDES – 2. 650 WITH STF49

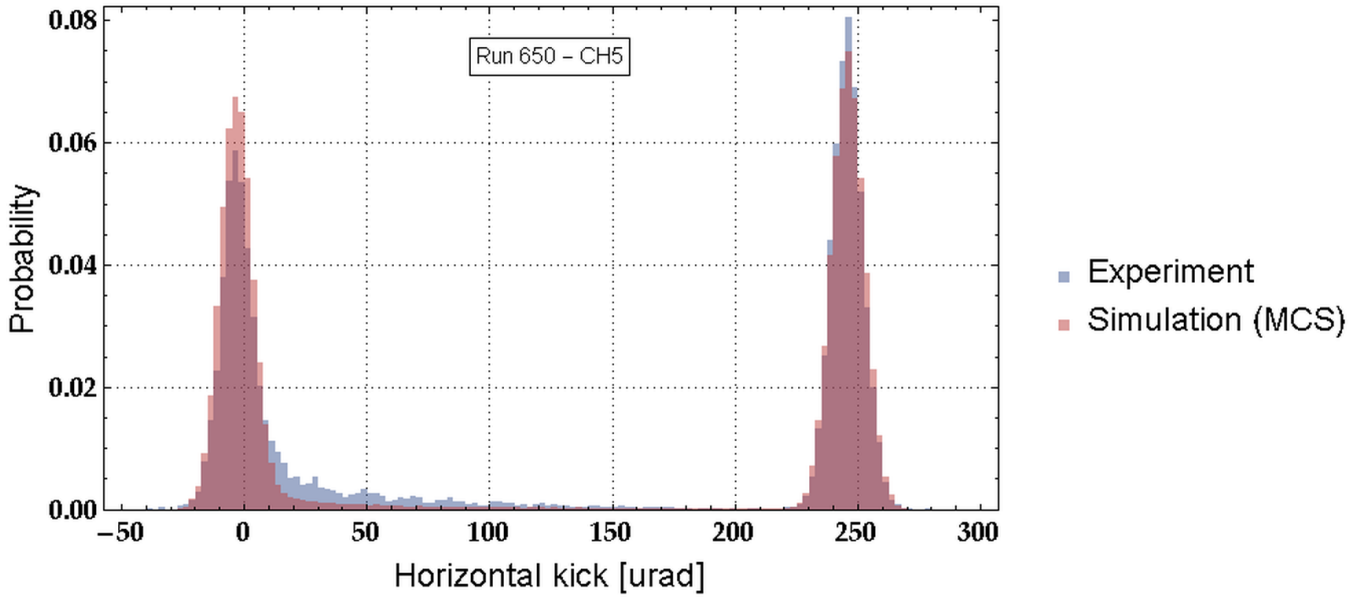
- CHANNELING (CUT @ 10 URAD)



1197	VR/AM peak	CH peak	CH rate	DC rate	L_D
	[urad]	[urad]	[%]	[%]	[mm]
Simulation (MCS)					
Experiment					

SPARE SLIDES – 2. 650 WITH STF49

- CHANNELING (CUT @ 5 URAD)



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Simulation					
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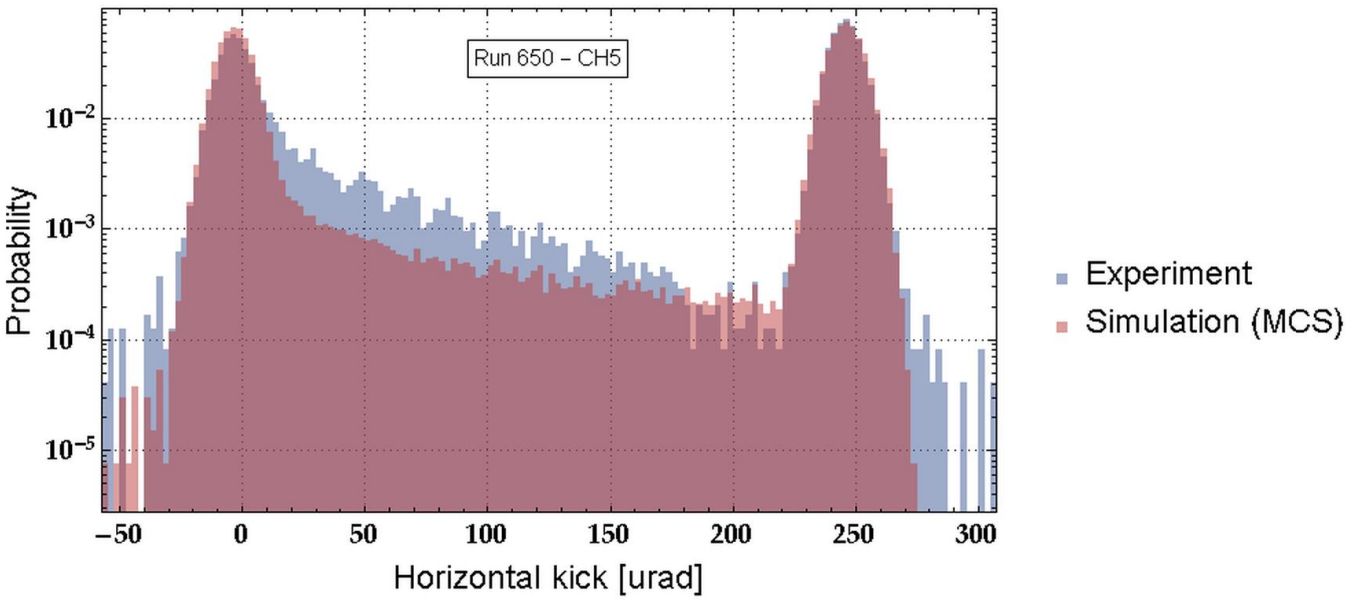
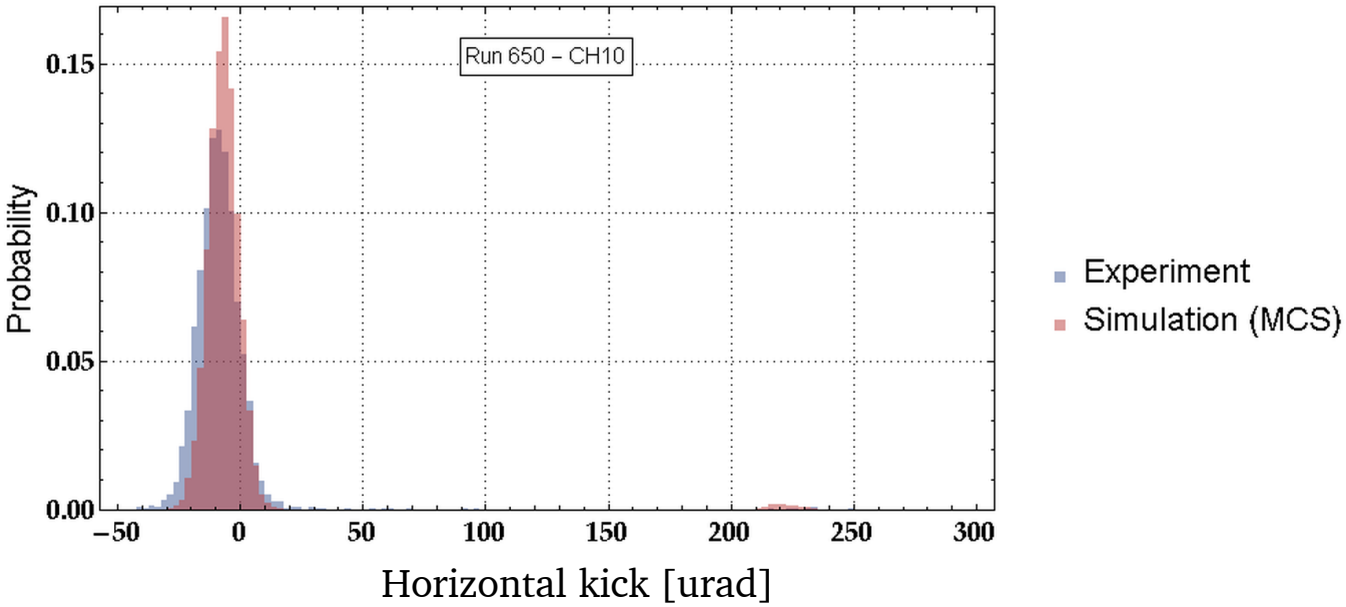


SPARE SLIDES – 2. 650 WITH STF49

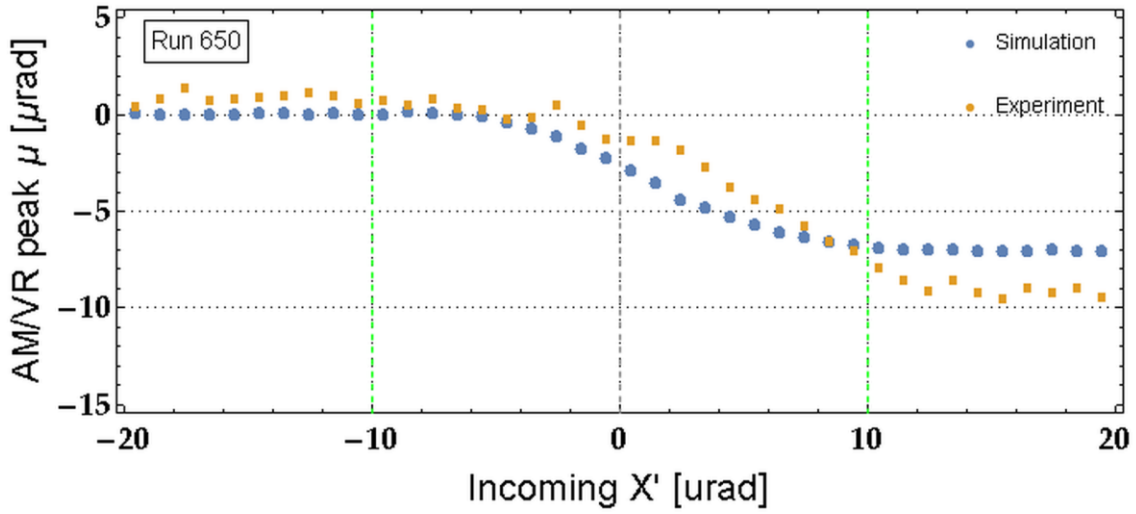
- VOLUME REFLECTION (LOW STAT)



1197	VR peak	VC rate
	[urad]	[%]
Simulation		
Experiment		

SPARE SLIDES – 2. 650 WITH STF49

- LOW INCOMING ANGLE, NON-CHANNELED PARTICLES



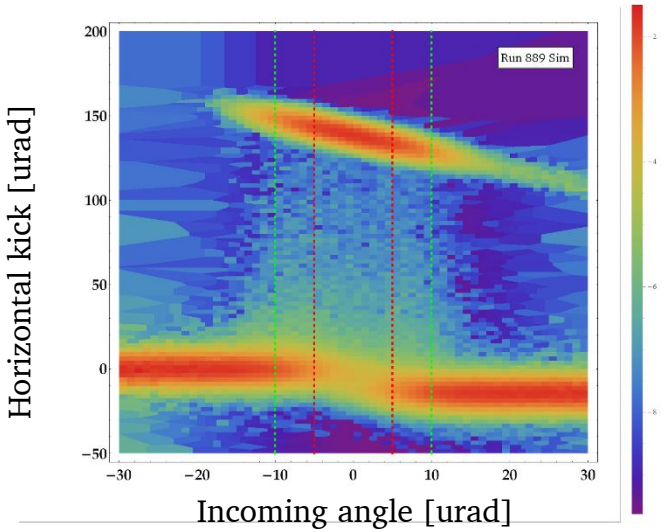
- Transition btw. volume reflection and amorphous mode
- Variable from crystal to crystal

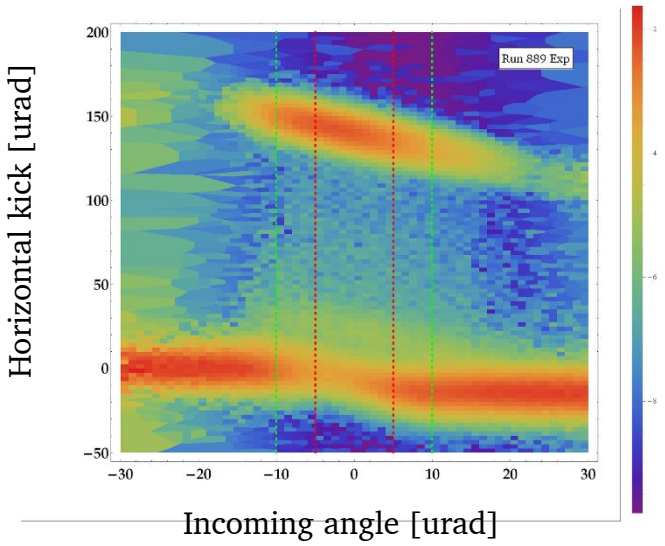
- OTHER CRYSTALS

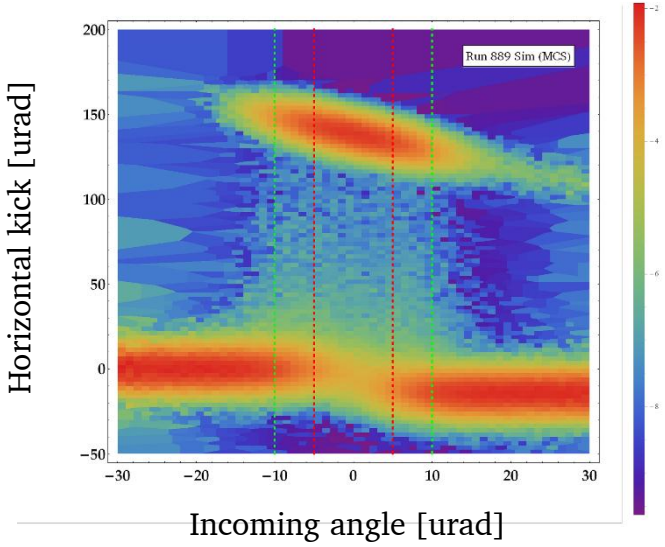
- 889 STF 50

Spare slides – 3. 889 with STF50

- Run maps
  - Simulation, sim w/ MCS
  - Experiment



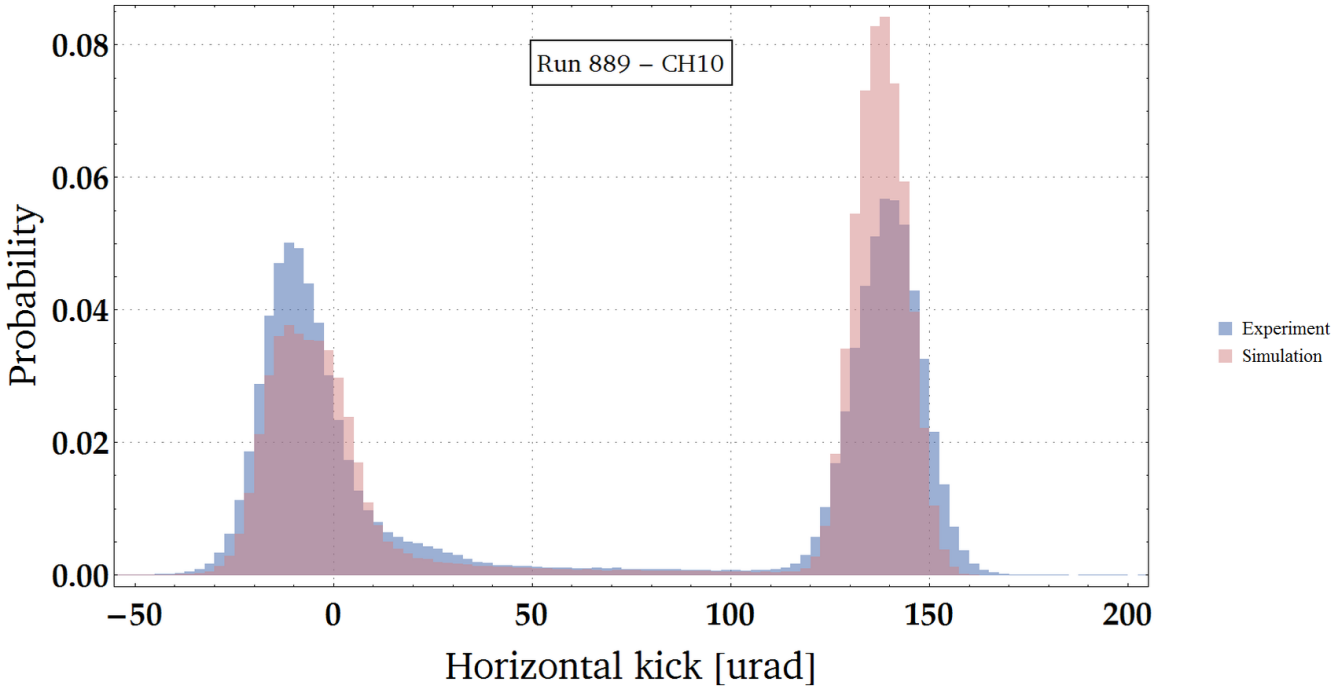




SPARE SLIDES – 3. 889 WITH STF50

- CHANNELING (CUT @ 10 URAD)

! Simulation excluding MCS from telescope !

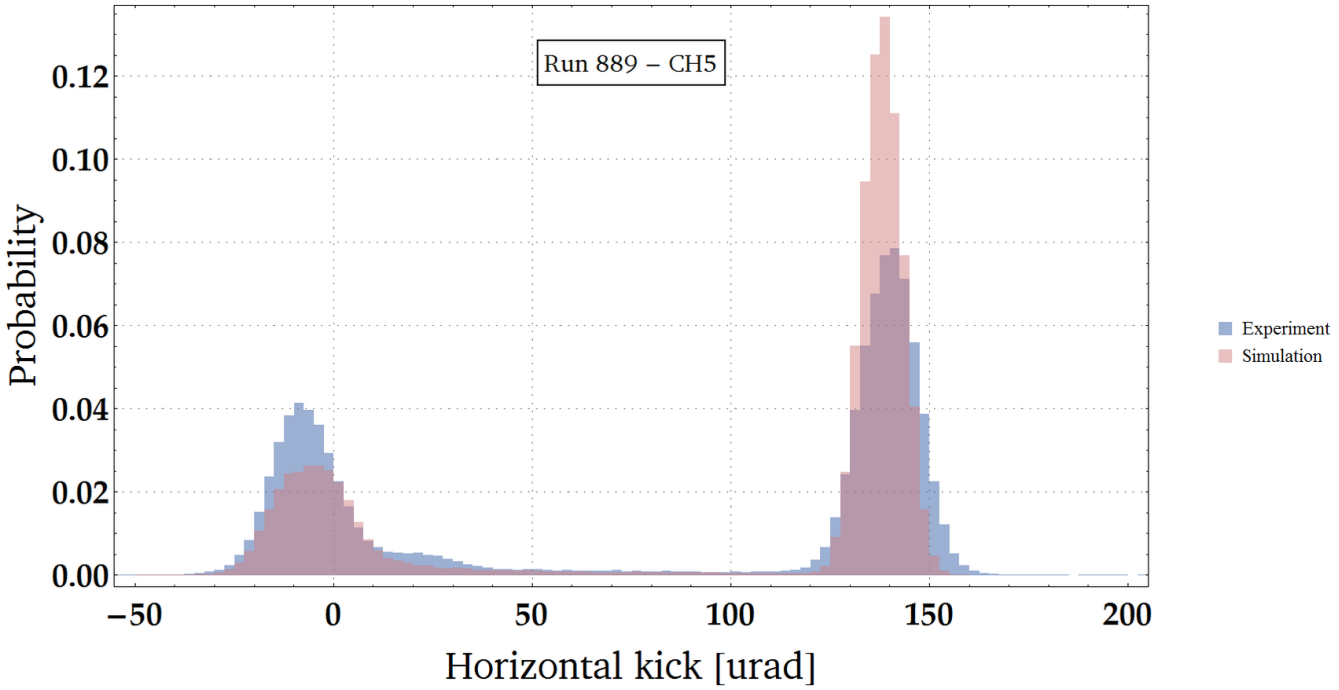


1197	VR/AM peak	CH peak	CH rate	DC rate	L_D
	[urad]	[urad]	[%]	[%]	[mm]
Simulation					
Experiment					

SPARE SLIDES – 3. 889 WITH STF50

- CHANNELING (CUT @ 5 URAD)

! Simulation excluding MCS from telescope !

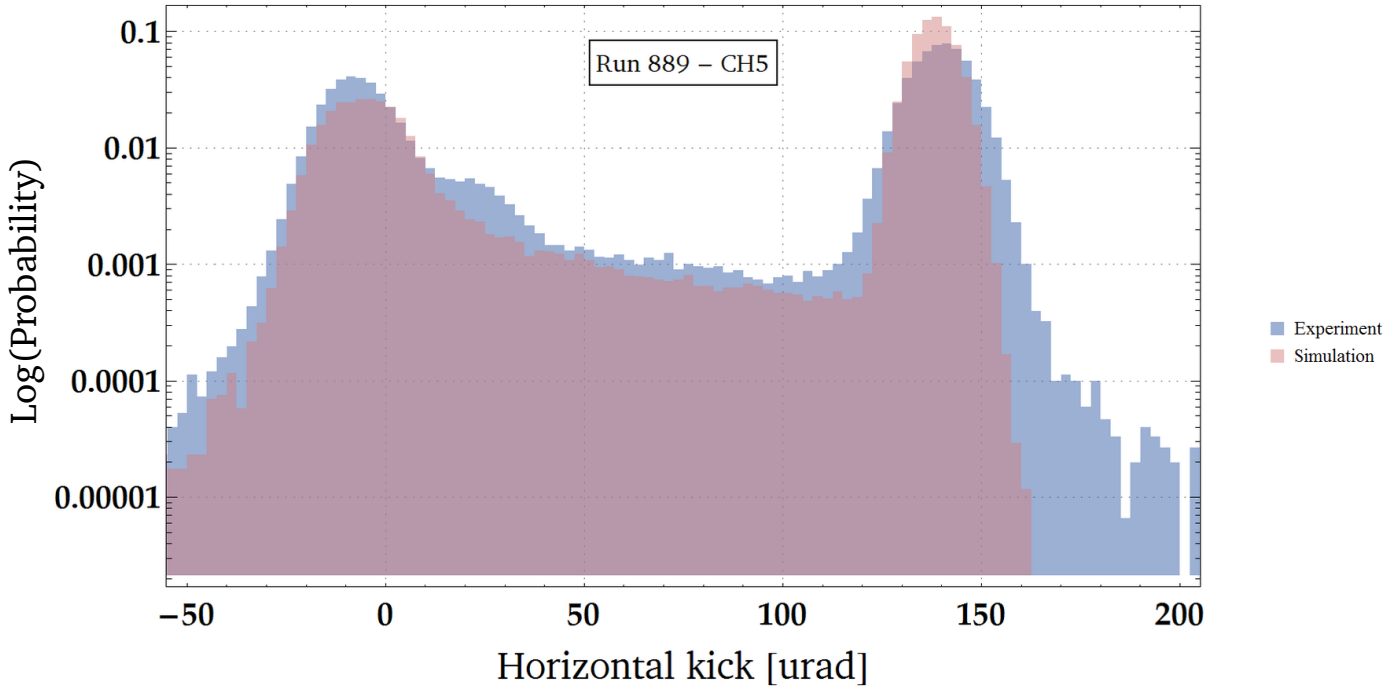


1197	VR/AM peak	CH peak	CH rate	DC rate	L_D
	[urad]	[urad]	[%]	[%]	[mm]
Simulation					
Experiment					

Spare slides – 3. 889 with STF50

- Channeling (cut @ 5 urad)

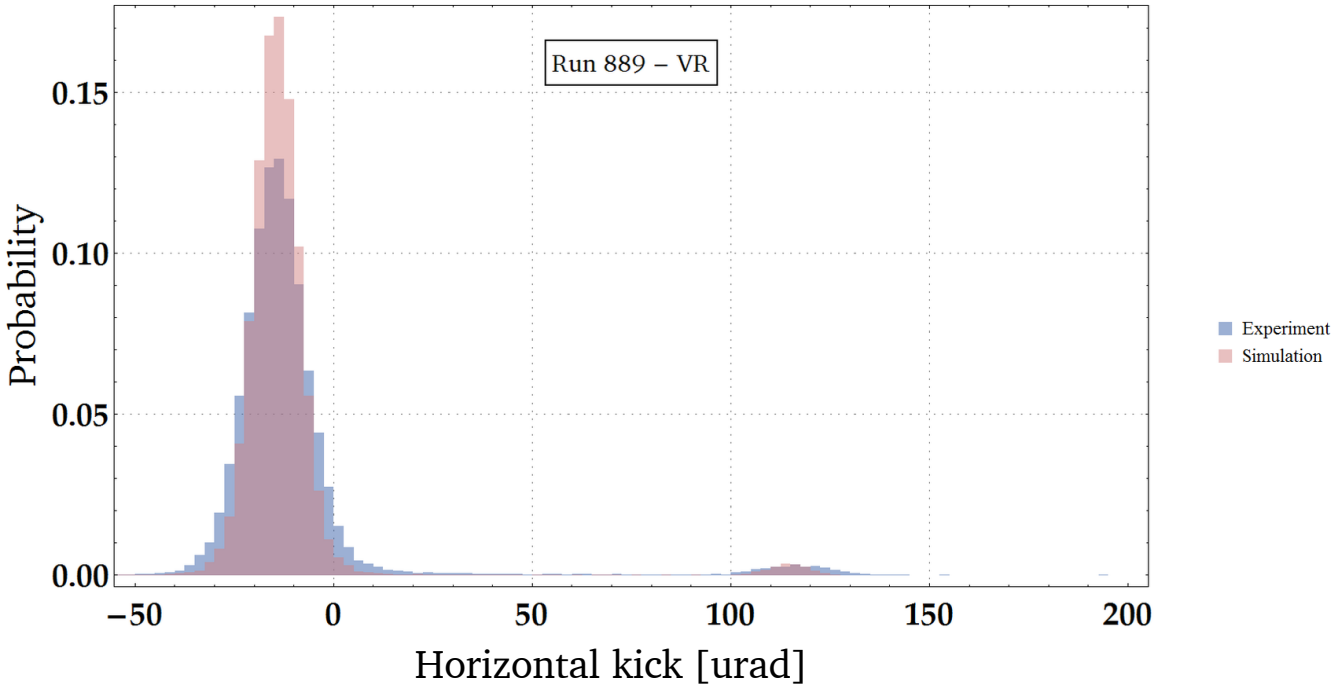
! Simulation excluding MCS from telescope !



SPARE SLIDES – 3. 889 WITH STF50

- VOLUME REFLECTION (LOW STAT)

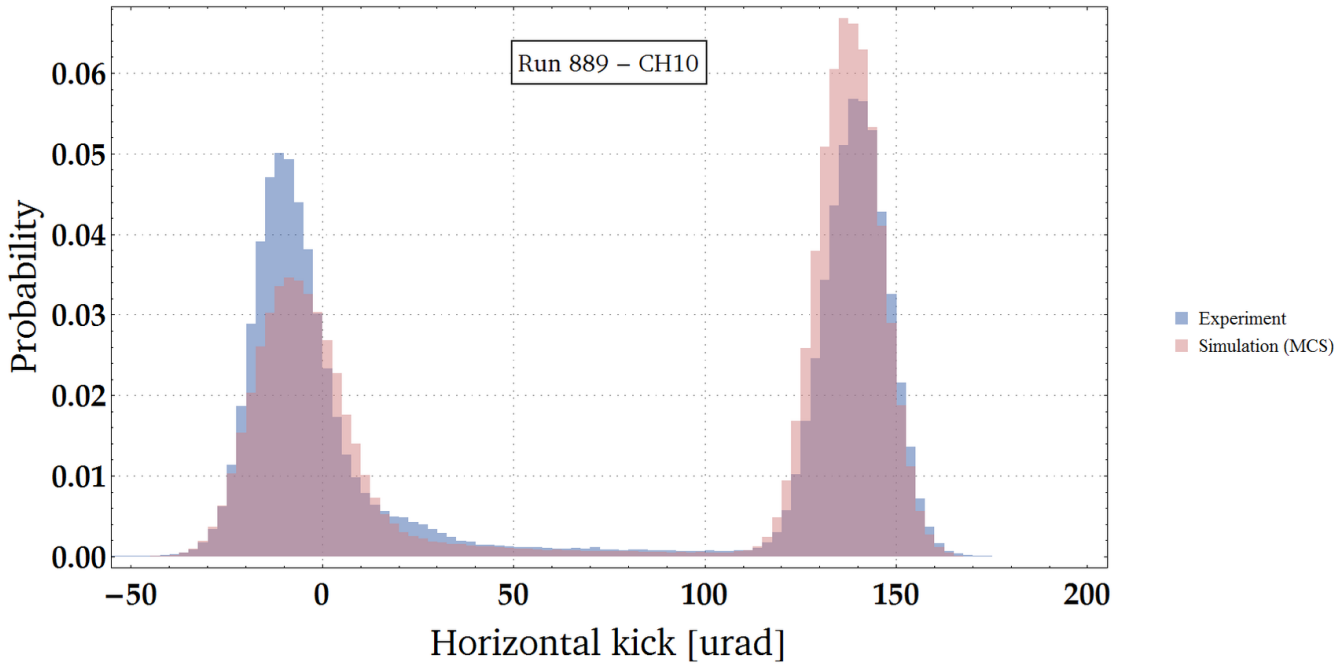
! Simulation excluding MCS from telescope !



1197	VR peak	VC rate
	[urad]	[%]
Simulation		
Experiment		

Spare slides – 3. 889 with STF50

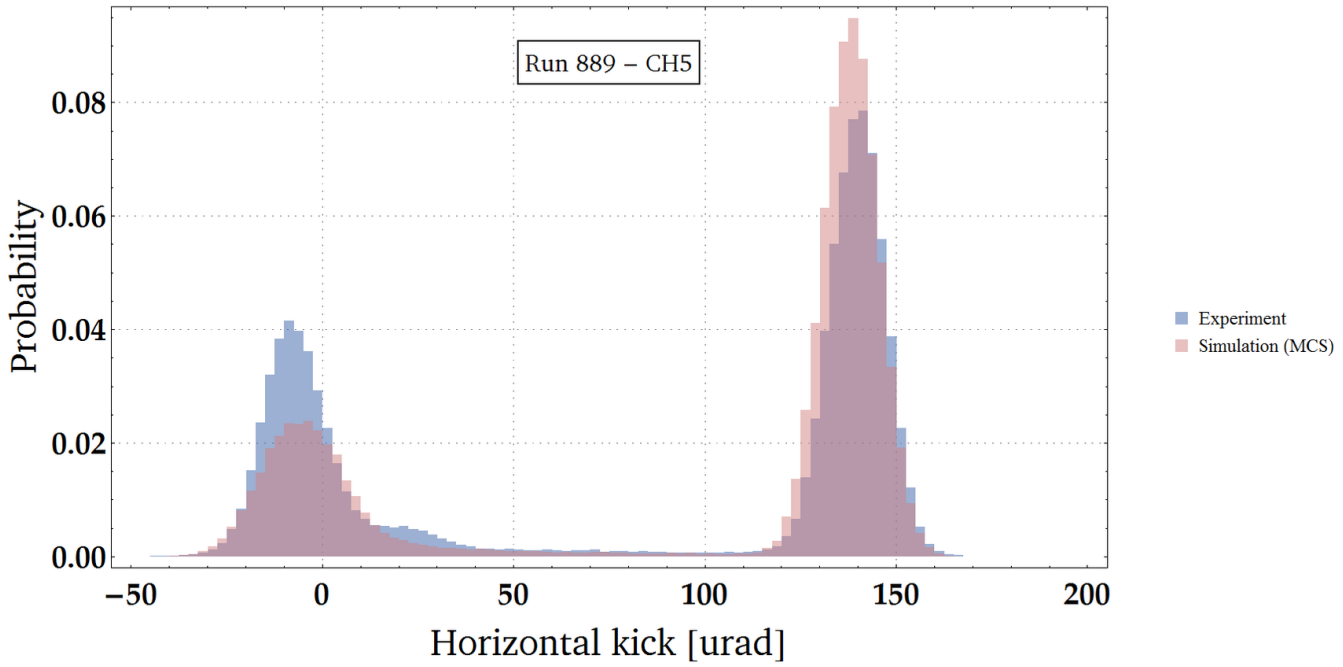
- Channeling (cut @ 10 urad)



1197	VR/AM peak	CH peak	CH rate	DC rate	L_D
	[urad]	[urad]	[%]	[%]	[mm]
Simulation (MCS)					
Experiment					

Spare slides – 3. 889 with STF50

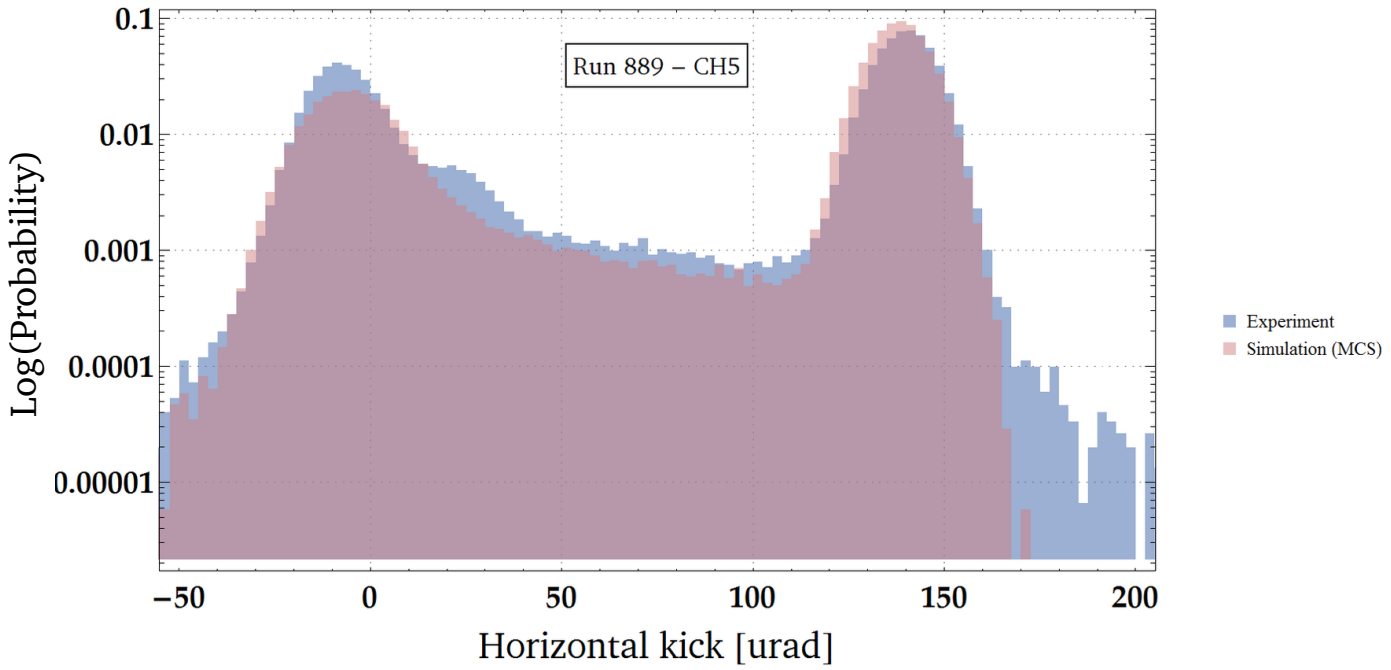
- Channeling (cut @ 5 urad)



1197	VR/AM peak	CH peak	CH rate	DC rate	L_D
	[urad]	[urad]	[%]	[%]	[mm]
Simulation					
Experiment					

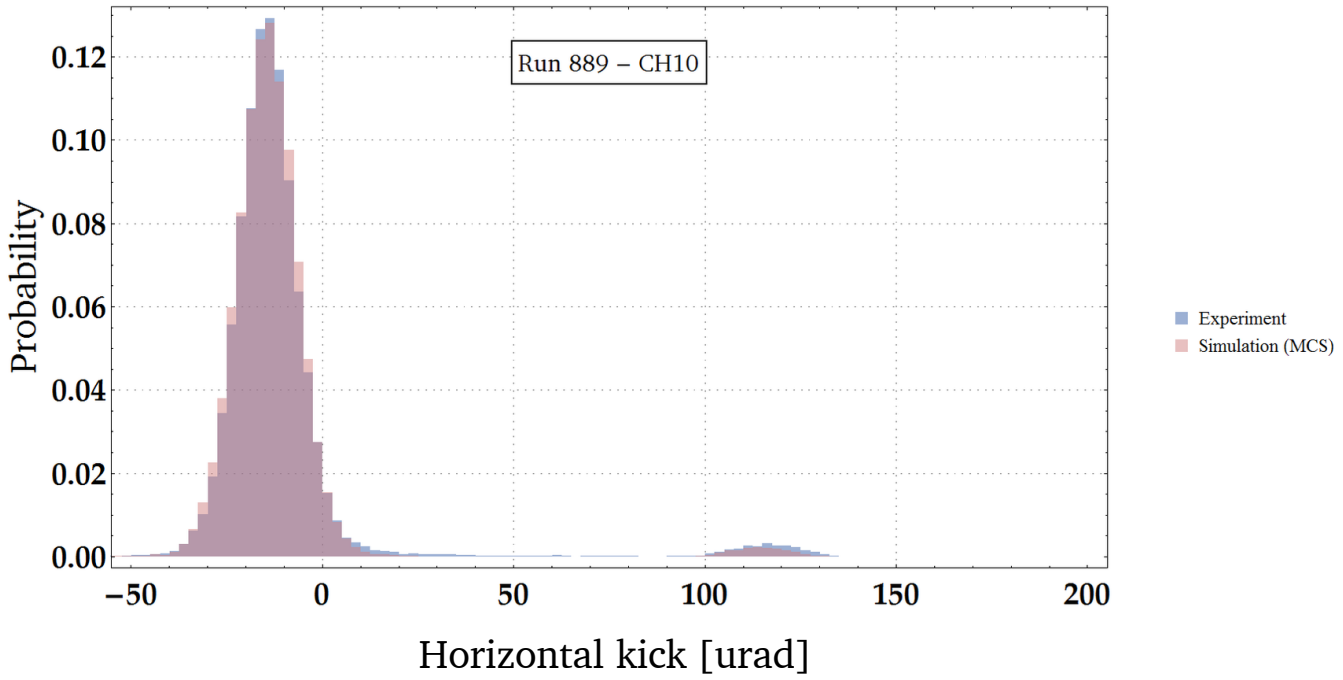
SPARE SLIDES – 3. 889 WITH STF50

- CHANNELING (CUT @ 5 URAD)



SPARE SLIDES – 3. 889 WITH STF50

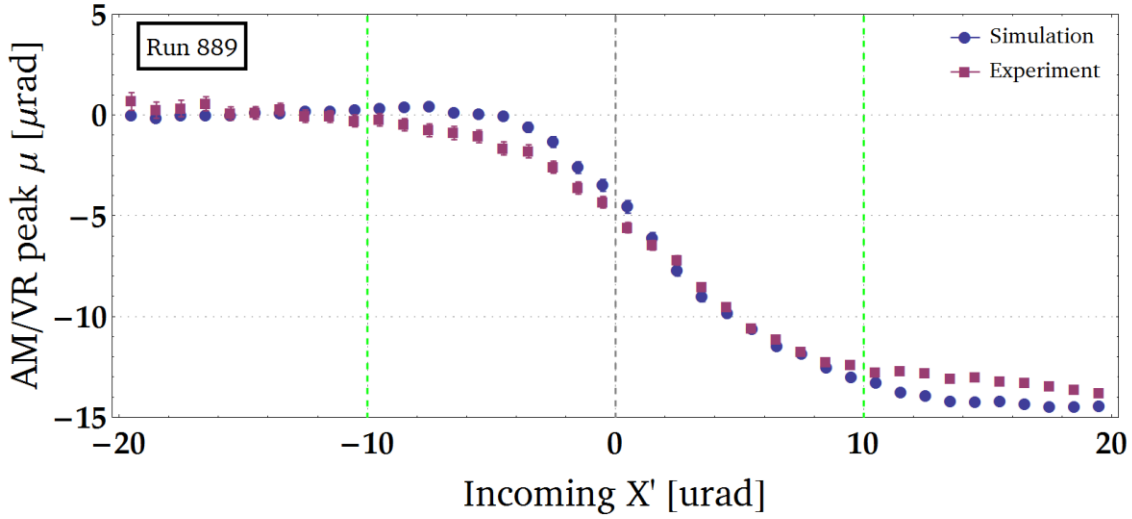
- VOLUME REFLECTION (LOW STAT)



1197	VR peak	VC rate
	[urad]	[%]
Simulation		
Experiment		

SPARE SLIDES – 3. 889 WITH STF50

- LOW INCOMING ANGLE, NON-CHANNELED PARTICLES



- Transition btw. volume reflection and amorphous mode
- Variable from crystal to crystal

SPARE SLIDES – 2222. 650 WITH STF49

- RUN MAPS
  - Simulation, sim w/ MCS
  - Experiment