Эксперимент UA9 в CERN

Ю.М.Иванов, лаборатория мезоатомов

Кристаллическая коллимация: от У-70 к LHC

1997-2001 – первое применение коротких изогнутых кристаллов кремния для вывода и коллимации протонов с энергией 70 ГэВ на У-70 в ИФВЭ

2002-2006 – первое применение упругоквазимозаичных кристаллов кремния, наблюдение объемного отражения протонов с энергией 70 ГэВ в ИФВЭ и 1 ГэВ в ПИЯФ

2006-2009 – коллаборация H8-RD22 в CERN: исследование объемного отражения 400 ГэВ протонов, многократного объемного отражения, каналирования и объемного отражения отрицательных частиц, излучения при объемном отражении электронов и позитронов

2009-2014 – коллаборация UA9 в CERN: исследование кристаллической коллимации на протонном и ионном пучках SPS

2012-2016 – коллаборация LUA9 в CERN: исследование кристаллической коллимации на протонном и ионном пучках LHC

Letter of Intent for an experiment at LHC (CERN)

Letter of Intent for an experiment at LHC (CERN) June 1, 2011

LHC collimation with bent crystals - LUA9

A CERN - IHEP - Imperial College - INFN - JINR - LAL - PNPI - SLAC
LUA9 Collaboration
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G.Arduini (CERN), R. Assmann (CERN), R. Losito (CERN),
G. Cavoto (INFN), Yu.M. Ivanov (PNPI), G. Hall (Imperial College), T. Markiewicz (SLAC),
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Abstract

An experiment to demonstrate the feasibility of multi-stage collimation assisted by bent crystals in the Large Hadron Collider is proposed. Bent silicon crystals acting as primary collimators are expected to direct the beam halo promptly onto secondary absorbers thus ideally reducing outscattering, beam losses and the radiation load in critical regions of the ring. Extensive tests conducted by the UA9 Collaboration in the SPS and in H8 with proton and lead ion beams have shown that crystal-assisted collimation can improve the efficiency of a one-stage collimation system. The proposed experiment, called LUA9, has received full support from the CERN management, and expression of interest from three Russian Institutions (PNPI, IHEP, JINR), INFN, LAL-Orsay, Imperial College and SLAC (through the US LARP programme). This document reviews the scope, goals, organization, costs, manpower needed and the schedule of LUA9.

LoI представлено на LHCC 15 июня 2011

LHC COLLIMATION WITH BENT CRYSTALS:

PROPOSAL FOR AN EXPERIMENT AT LHC

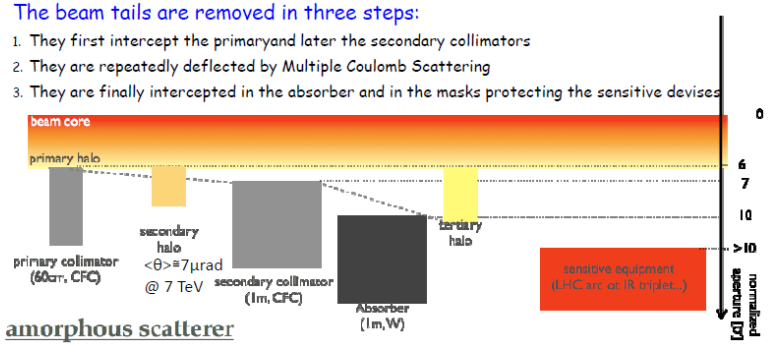
W. Scandale
for the LUA9 Collaboration

CERN - IHEP - Imperial College - INFN - JINR - LAL - PNPI - SLAC

Multi stage collimation in LHC

Multi-stage cleaning based on amorphous collimators.

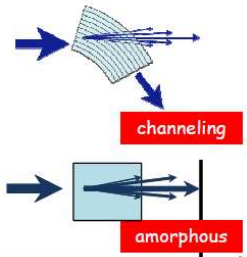
- The beam tails are removed in three steps:
  1. They first intercept the primaryand later the secondary collimators
  2. They are repeatedly deflected by Multiple Coulomb Scattering
  3. They are finally intercepted in the absorber and in the masks protecting the sensitive devises

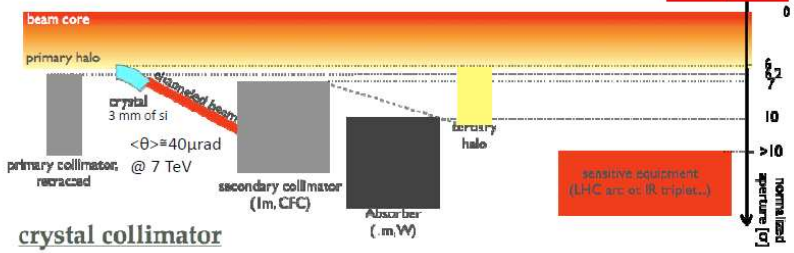


- Collimation efficiency in LHC > 99.99%
  - ✓ Probably not enough in view of a luminosity upgrade
  - ✓ The basic limitation of the amorphous collimation system
    - ✧ p: single diffractive scattering
    - ✧ ions: fragmentation and EM dissociation

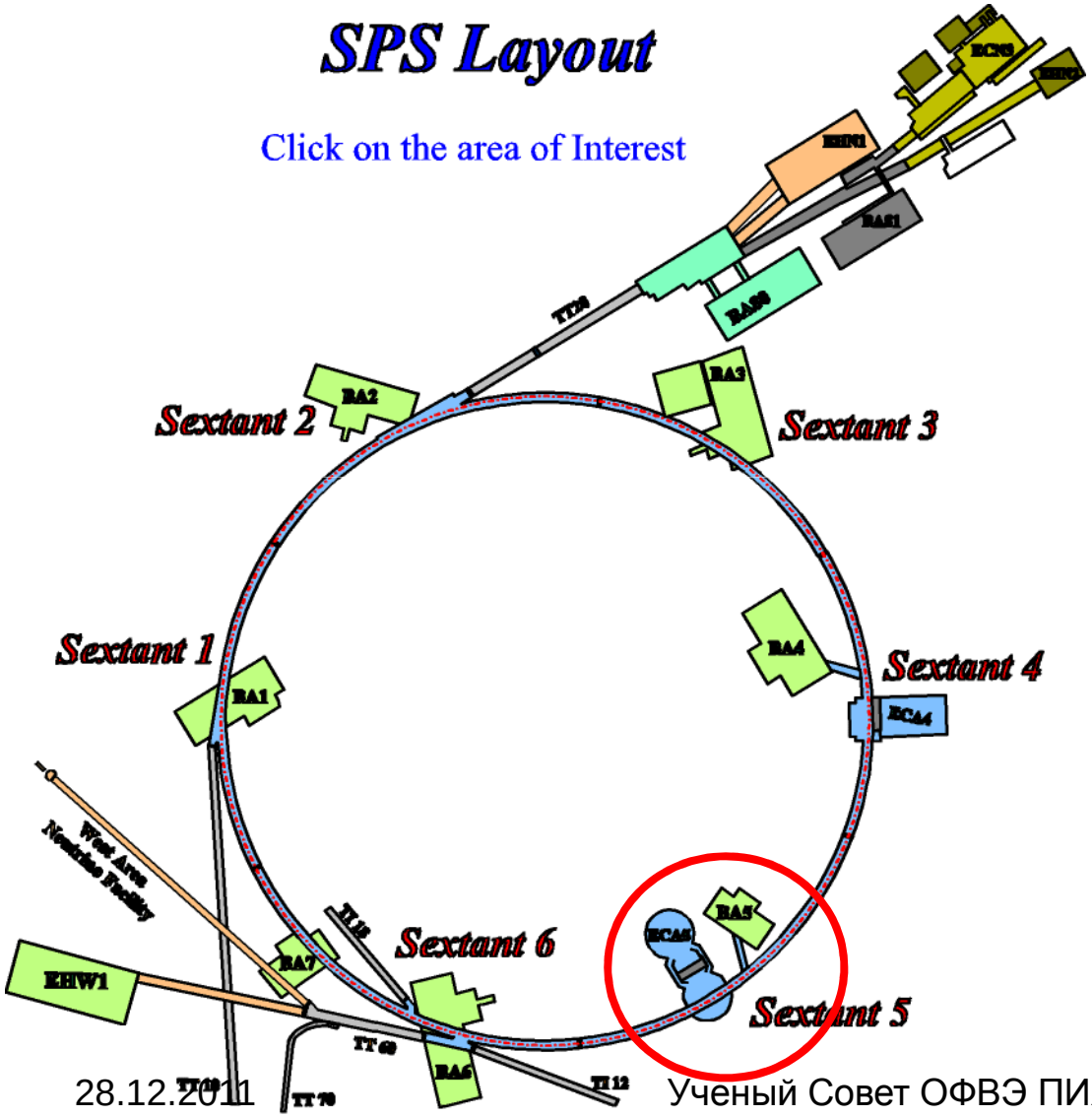
Crystal assisted collimation

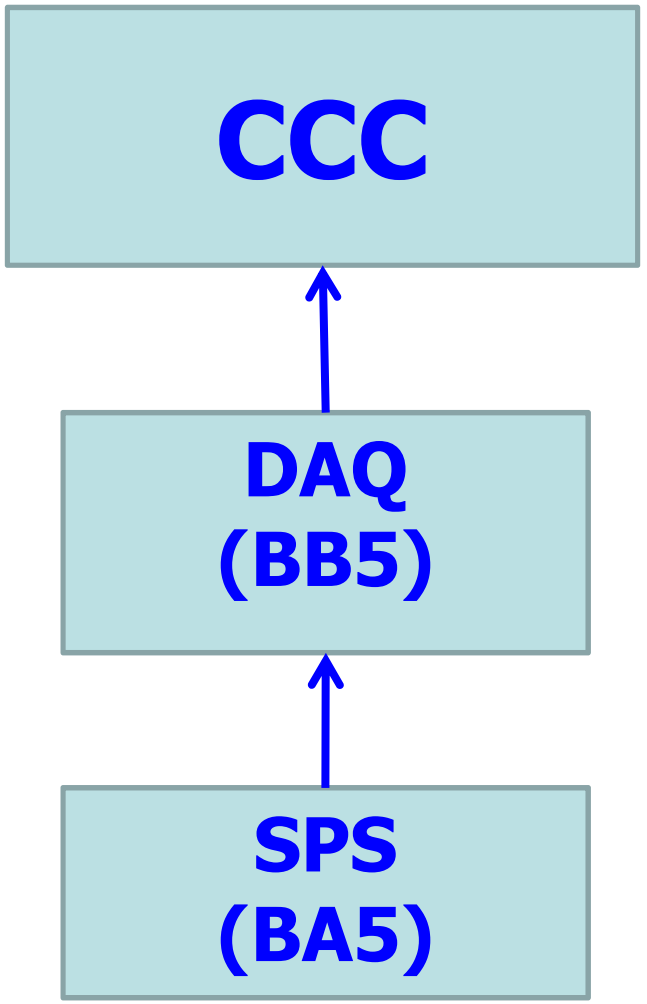
- Mechanically bent crystalswork as "smart deflectors" and increase the deflection angle
  - ✓ The primary collimator is either fully retraced
  - ✓ Or just retracted by 1-2 σ
- Coherent particle-crystal interactions should minimize the escaping particles and improve the collimation efficiency.





Местоположение UA9 на SPS

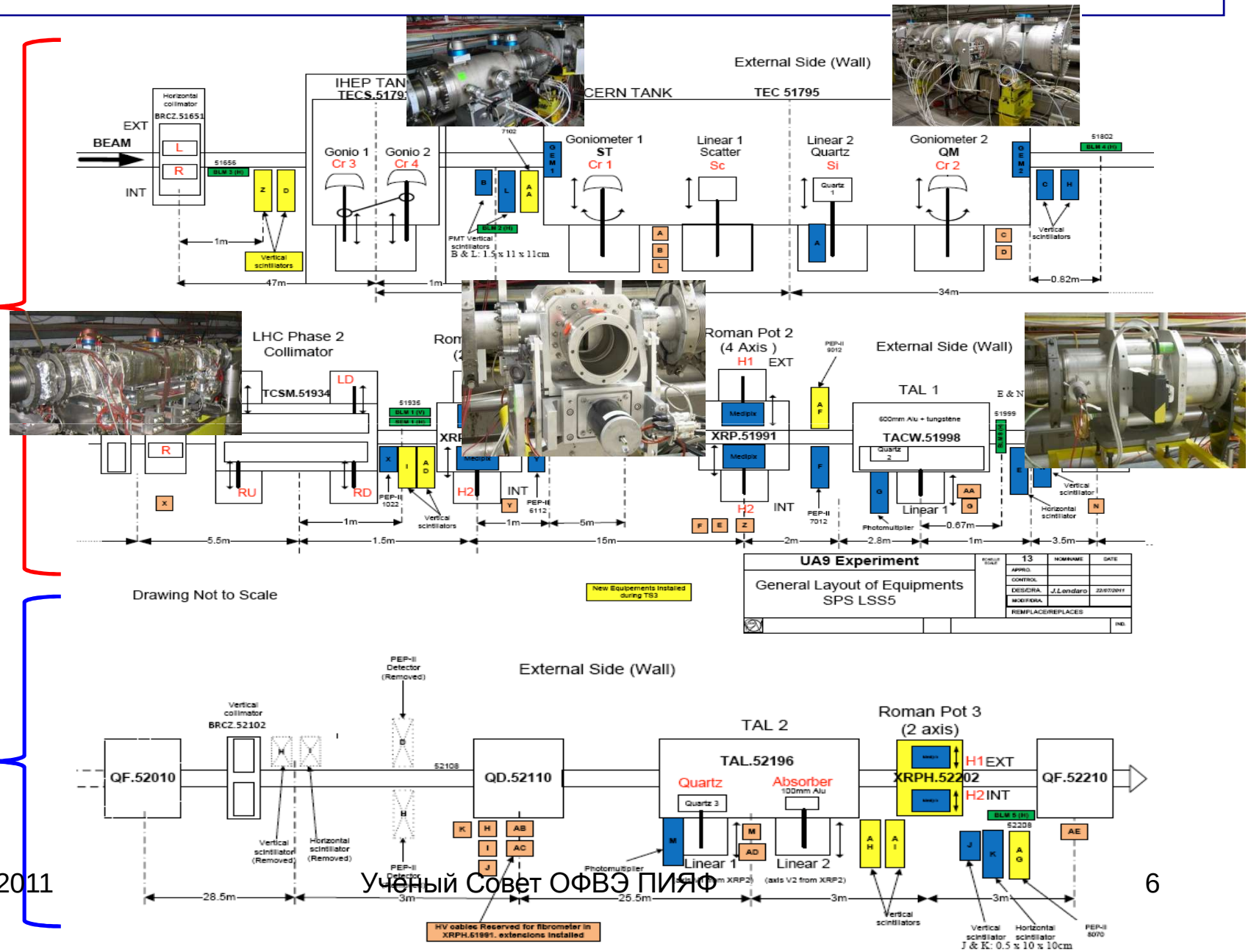




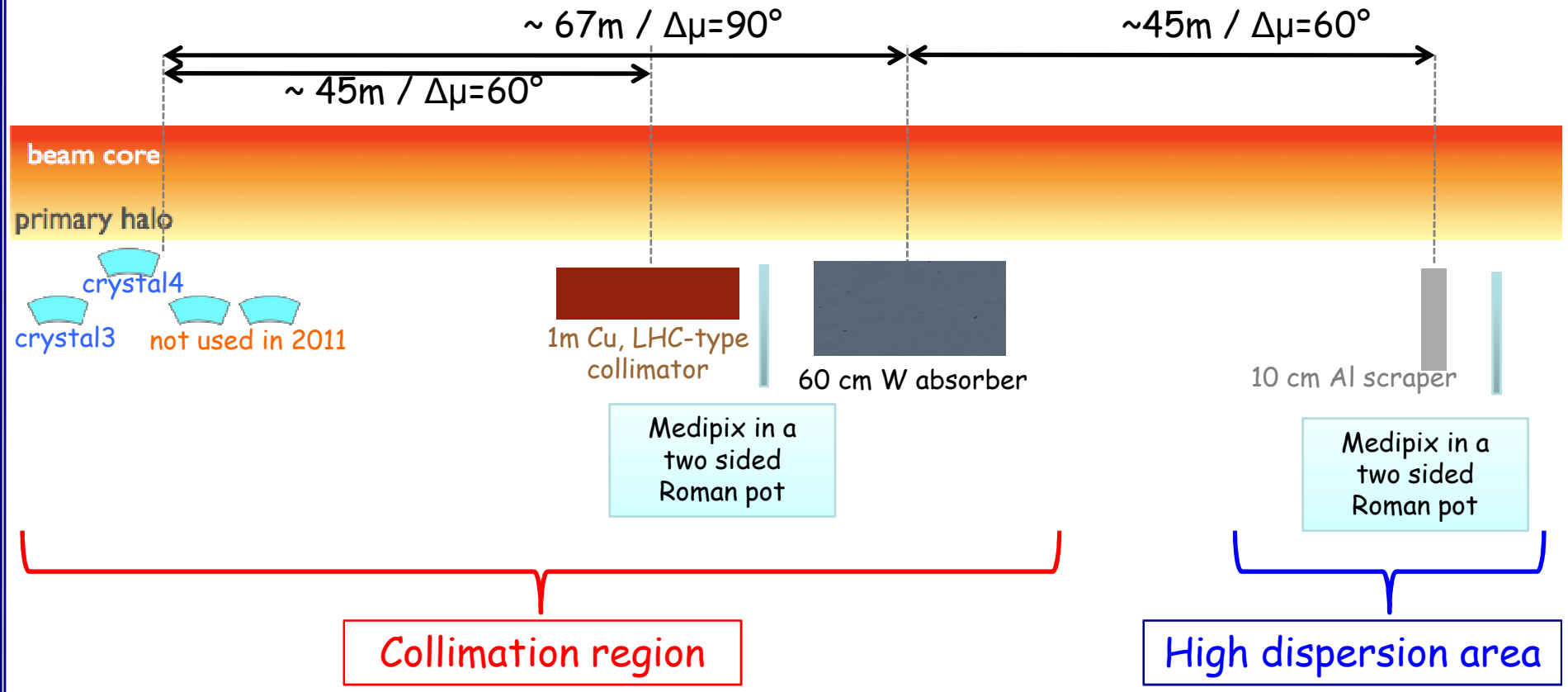
UA9 hardware in 2011

Collimation region

High dispersion area



UA9 basic layout



Observables in the collimation area:

- Intensity, profile and angle of the deflected beam
- Local rate of inelastic interactions
- Channeling efficiency (with multi-turn effect)

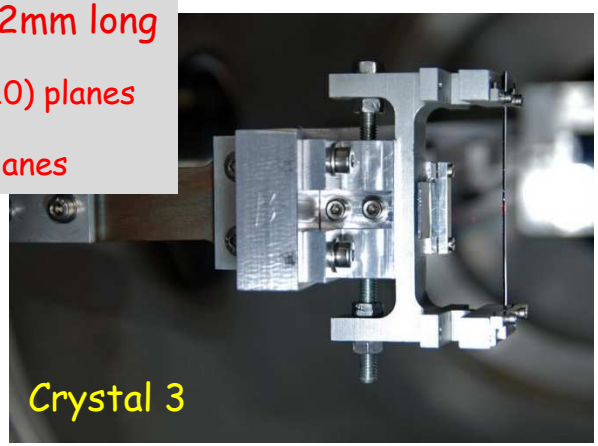
Observables in the high-D area:

- Off-momentum halo population escaping from collimation (with multi-turn effect)
- Off-momentum beam tails

Crystals

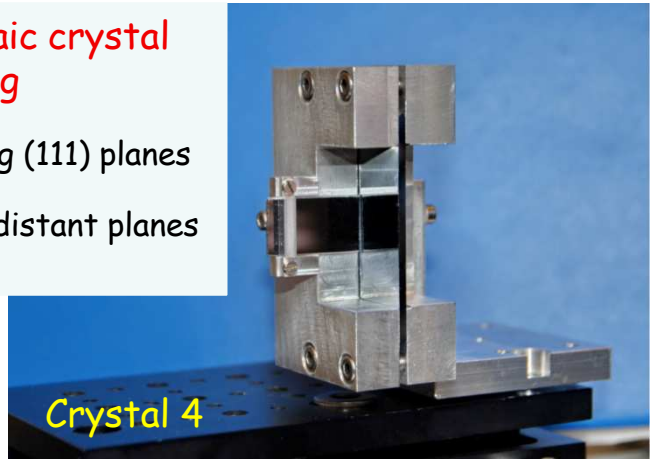
Strip crystal 2mm long

- Bent along (110) planes
- Equidistant planes



Quasimosaic crystal 1.9 mm long

- Bent along (111) planes
- Non-equidistant planes d1/d2 = 3



Residual imperfections:

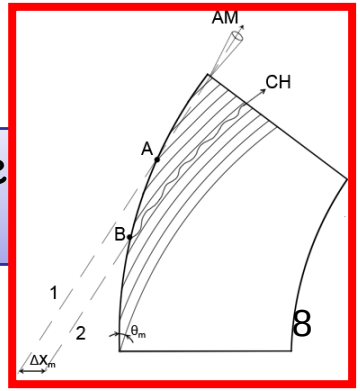
- ✓ Residual torsion ≈ 1 μrad/mm → different paths for different vertical hit points
- ✓ Amorphous layer size ≤ 1 μm
- ✓ Miscut ≈ 100 μrad

→ different paths at small impact parameter

Torsion is no longer an issue

- torsion over the beam size < critical angle
- full mitigation of the detrimental effects

Schematic view of the residual miscut angle

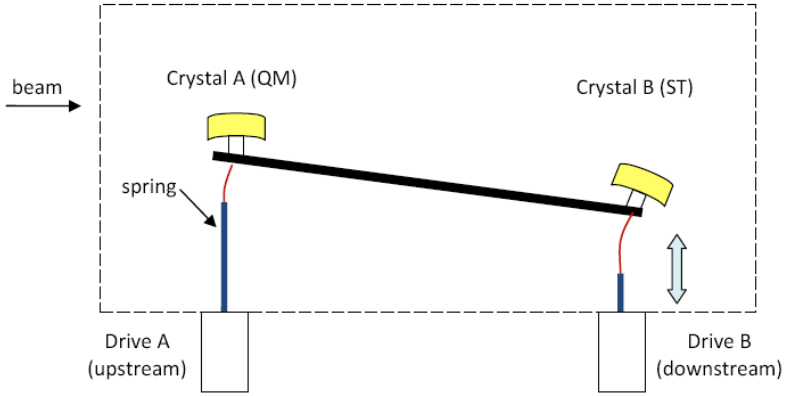


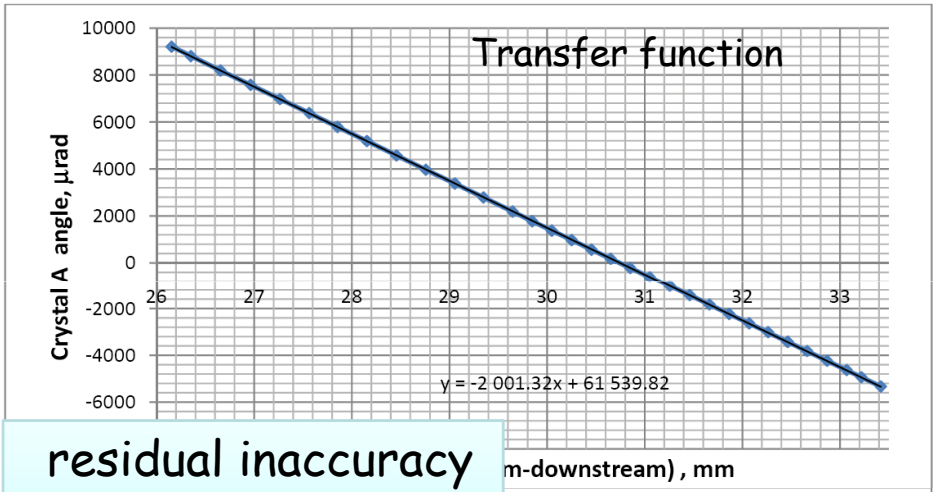
Goniometer

The critical angle governs the acceptance for crystal channeling

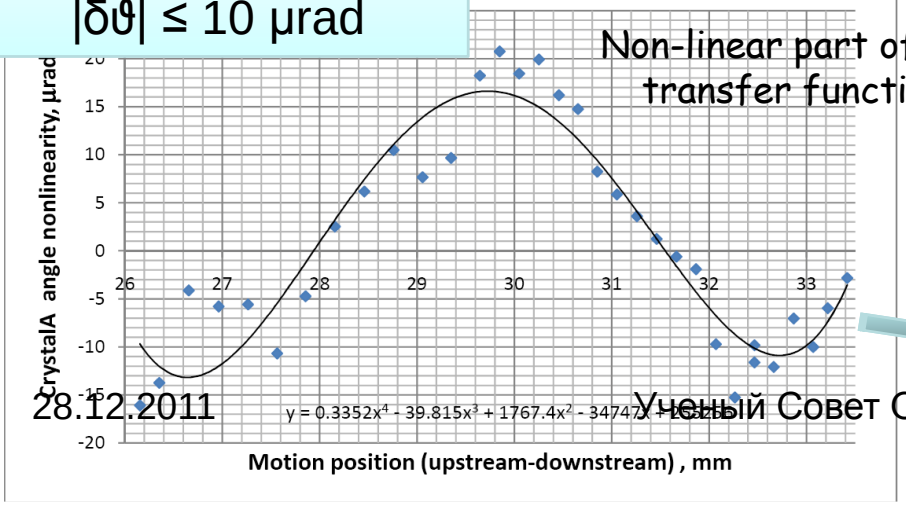
- 120 GeV➔θ_c = 20 μrad
- 270 GeV➔θ_c = 13.3 μrad

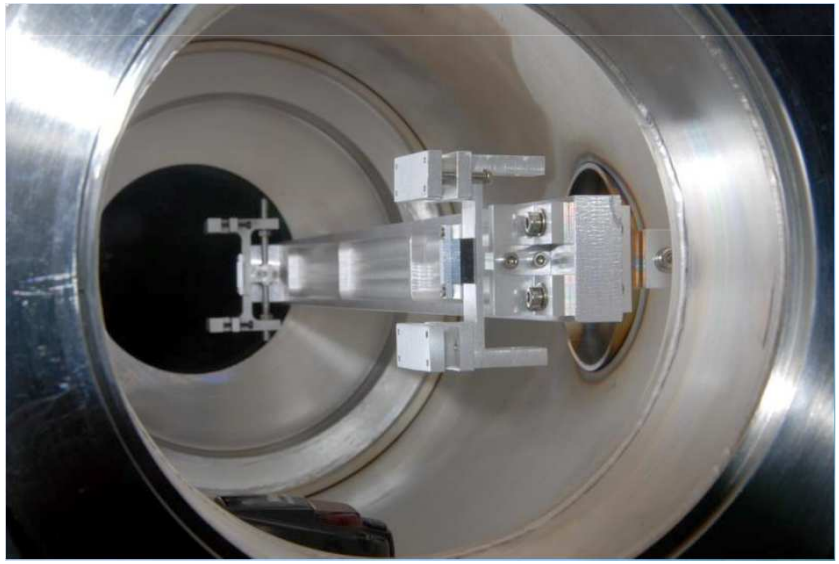
$$\theta_c = \sqrt{\frac{2U_0}{E}}$$





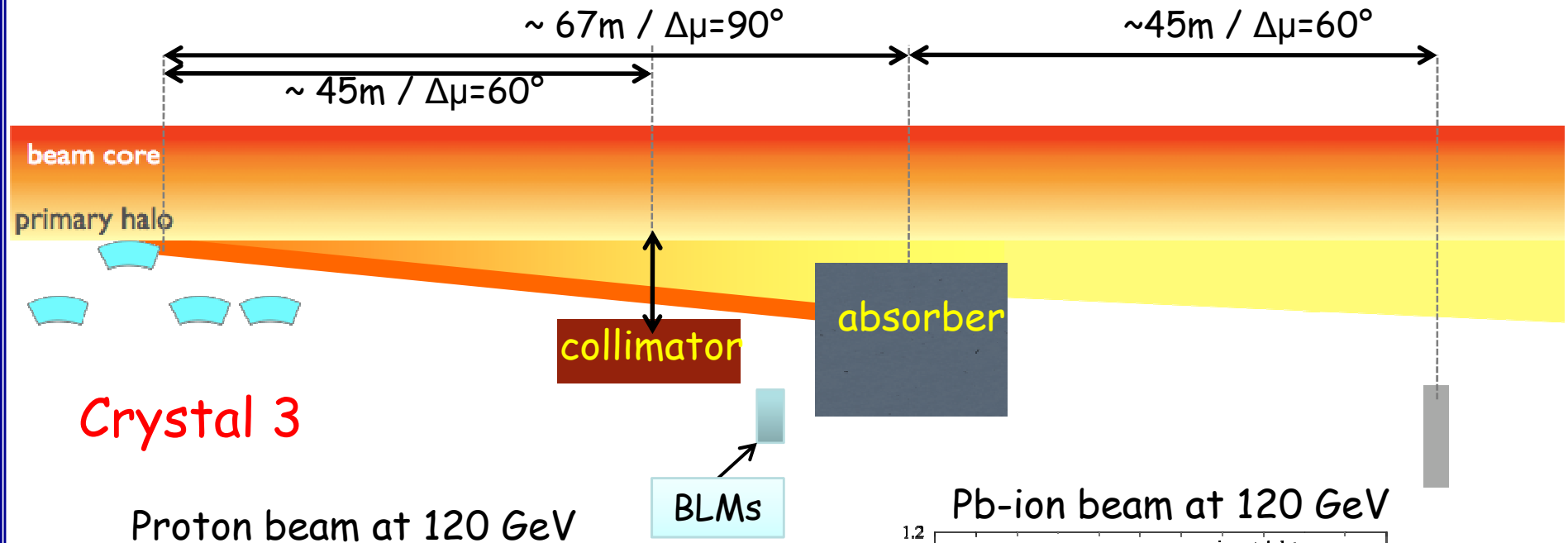
residual inaccuracy
|δϑ| ≤ 10 μrad





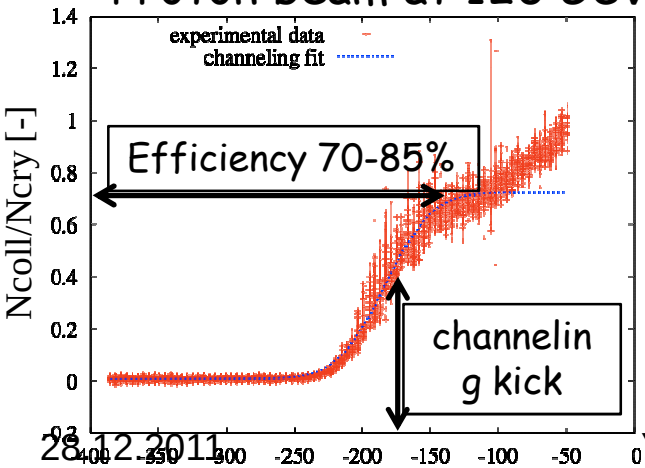
in a full angular scan
the drive position changes by 300 μm
around the initial value in the plotted range

Channeling efficiency bycoll. scans

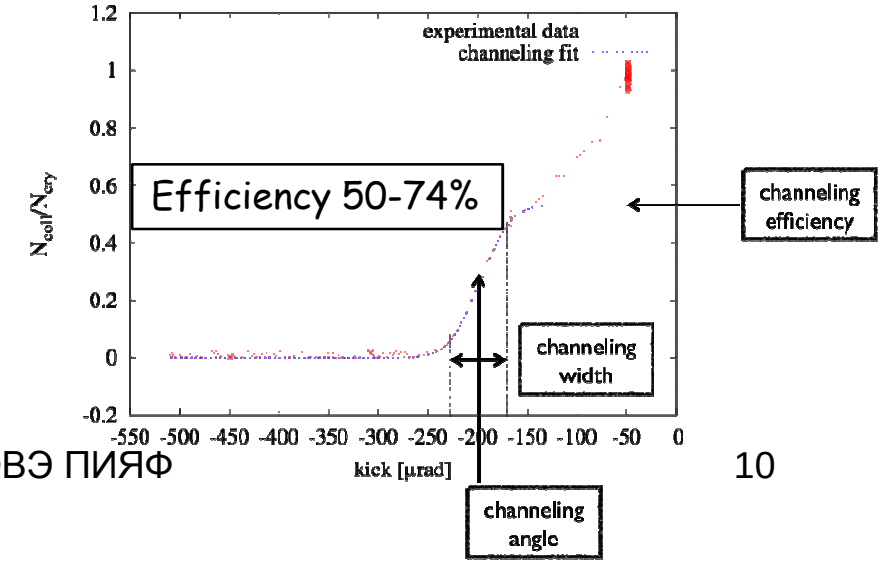


Crystal 3

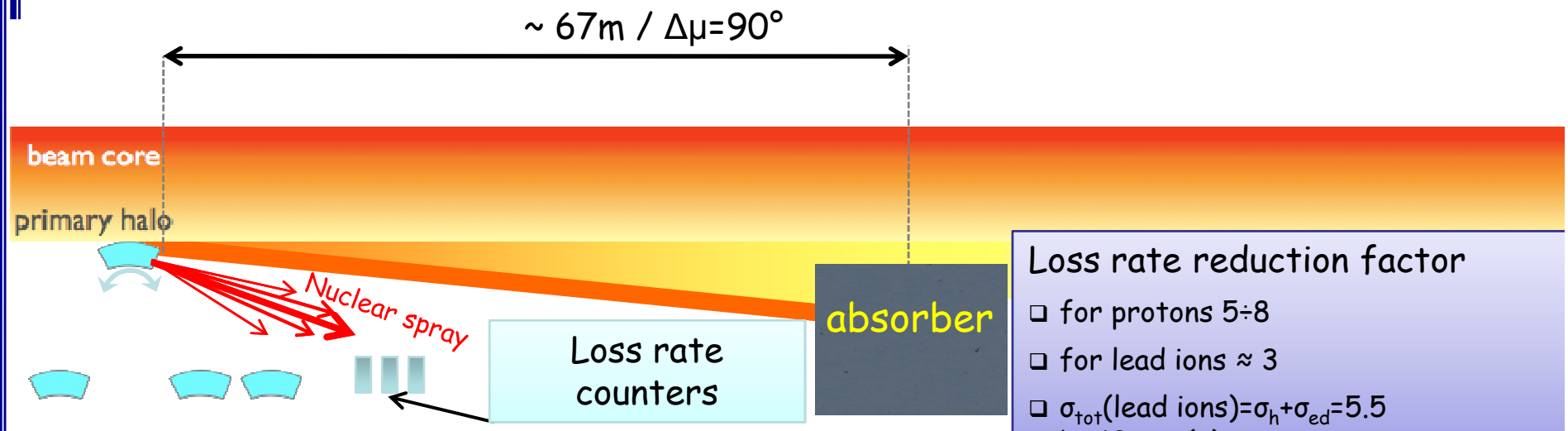
Proton beam at 120 GeV



Pb-ion beam at 120 GeV

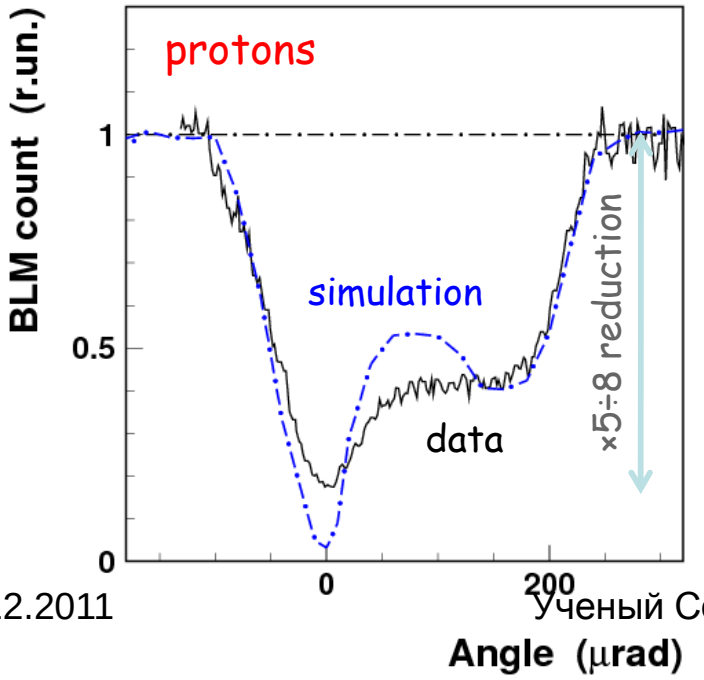


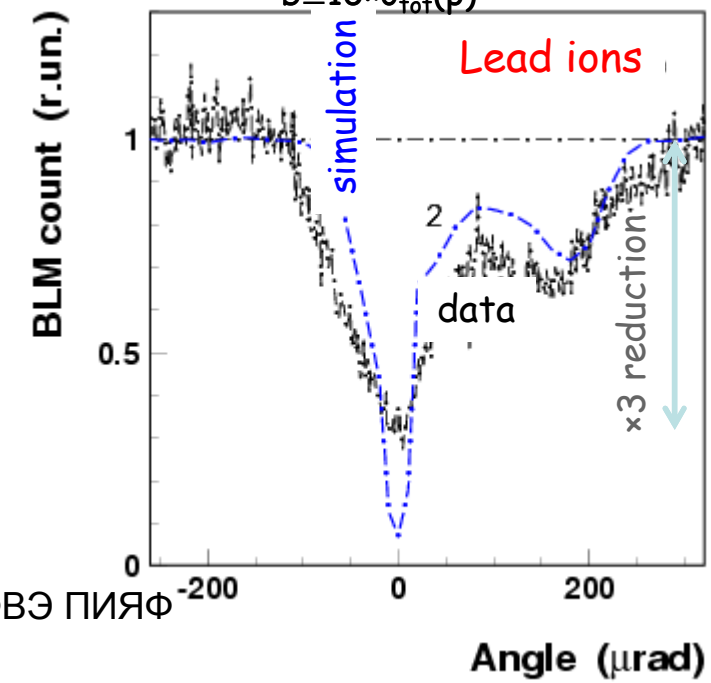
Loss rate reduction at the crystal



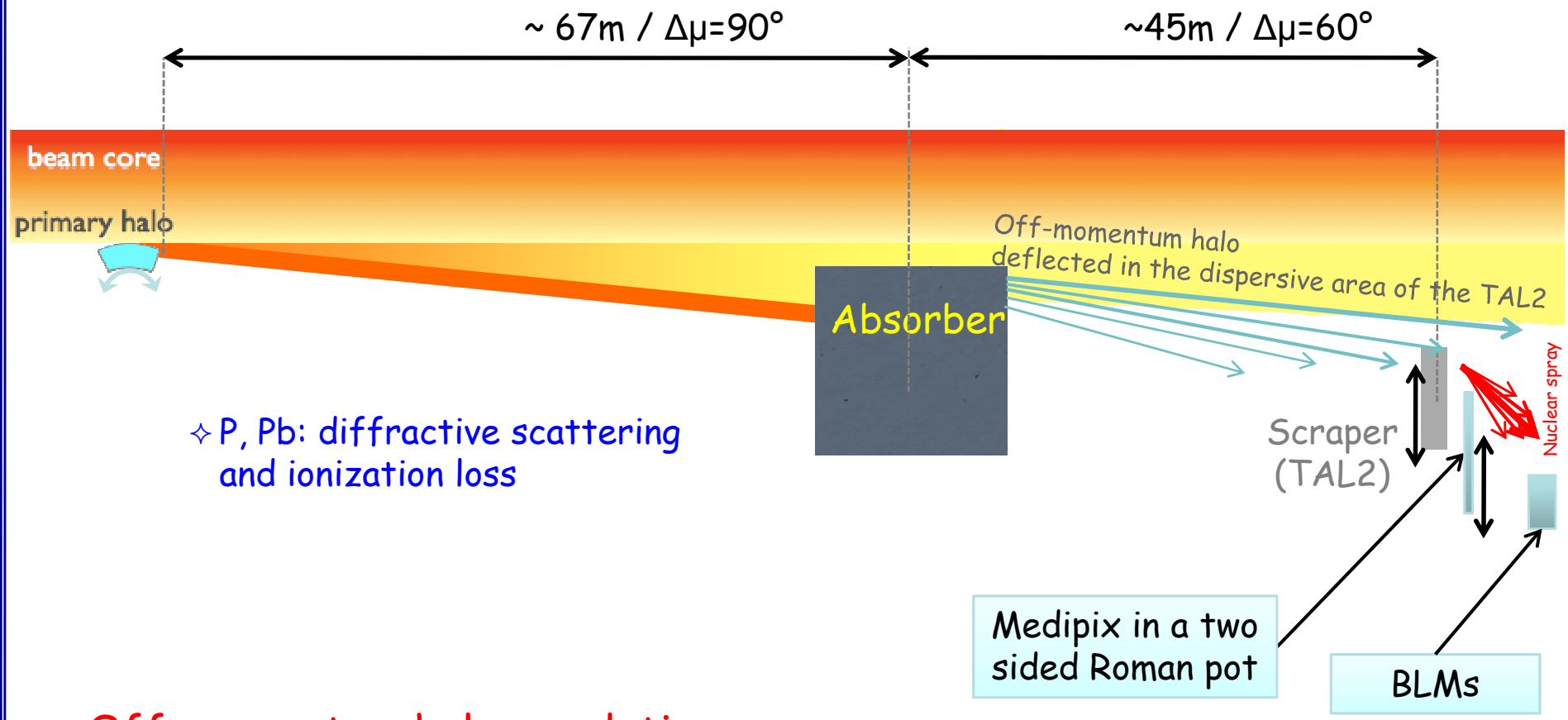
Loss rate reduction factor

- for protons 5÷8
- for lead ions ≈ 3
- σ_{tot}(lead ions)=σ_h+σ_{ed}=5.5 b≅10×σ_{tot}(p)





off-momentum halo population

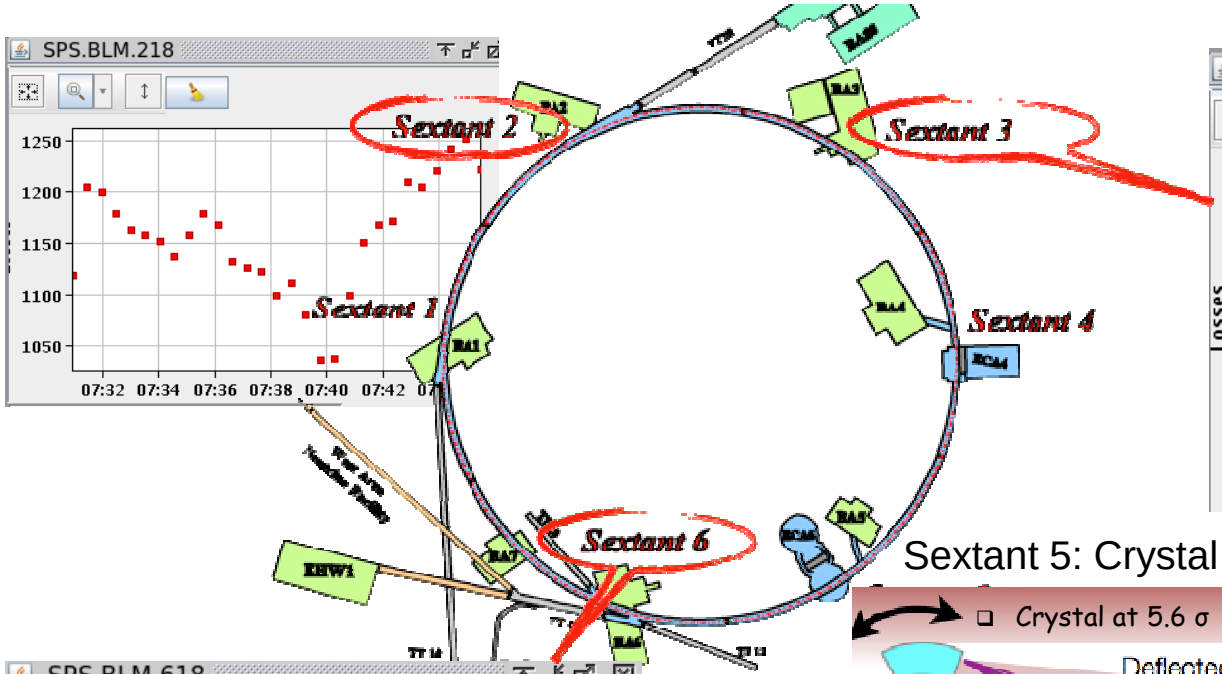


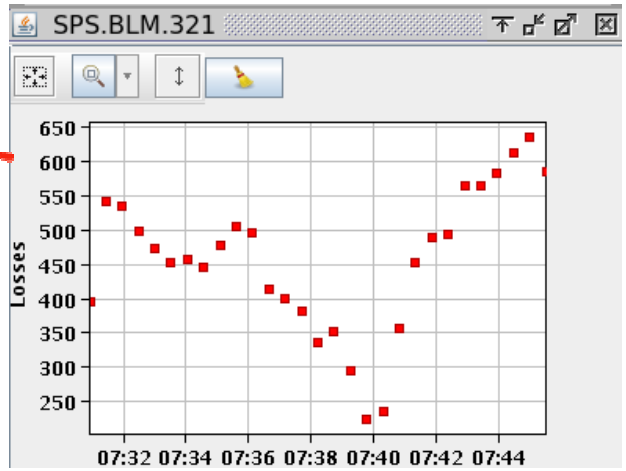
✧ P, Pb: diffractive scattering and ionization loss

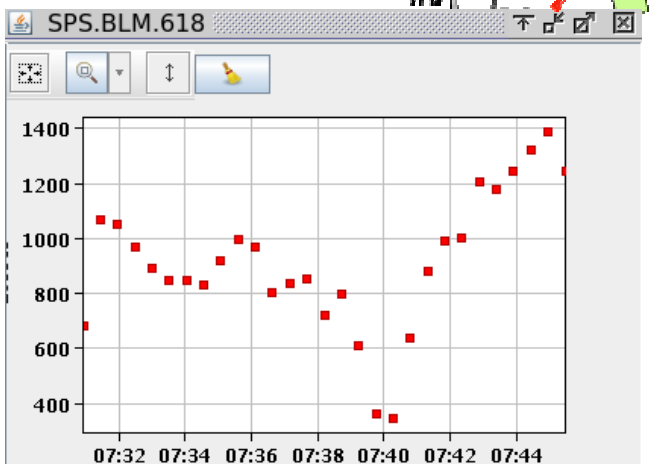
Off-momentum halo population

1. Linear scan made by the TAL2 (or Medipix) with the crystal in fixed orientation
2. angular scan of the crystal with the TAL2 (or the Roman pot) in fixed position in the shadow of the absorber

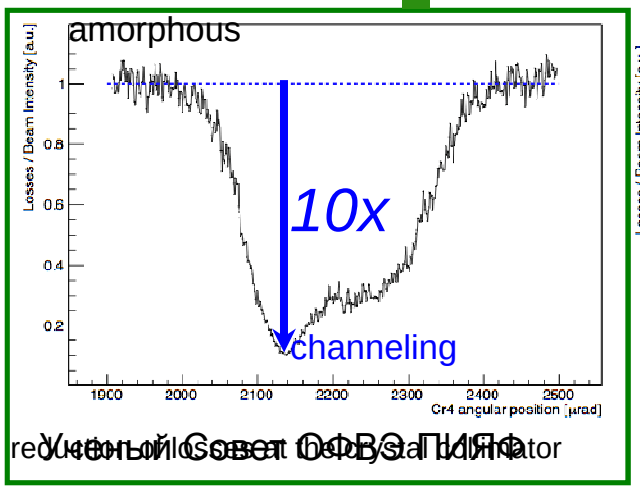
Main result from UA9 in 2011: with high beam intensity the loss reduction at the collimation insertion reproduced in all the sextants !

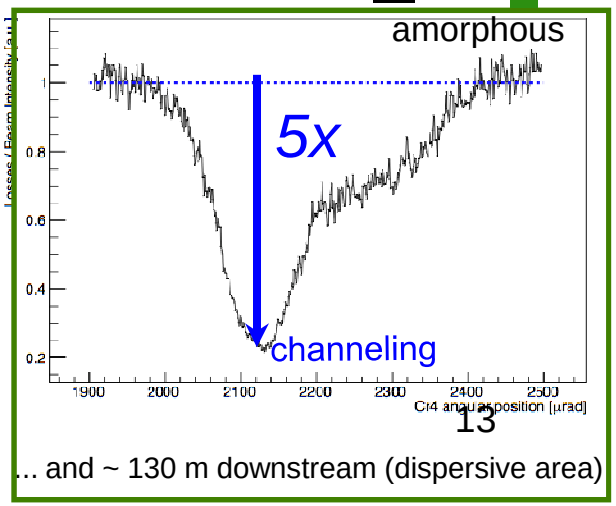






Sextant 5: Crystal collimation insertion





reduction of losses at the crystal collimator

... and ~ 130 m downstream (dispersive area)

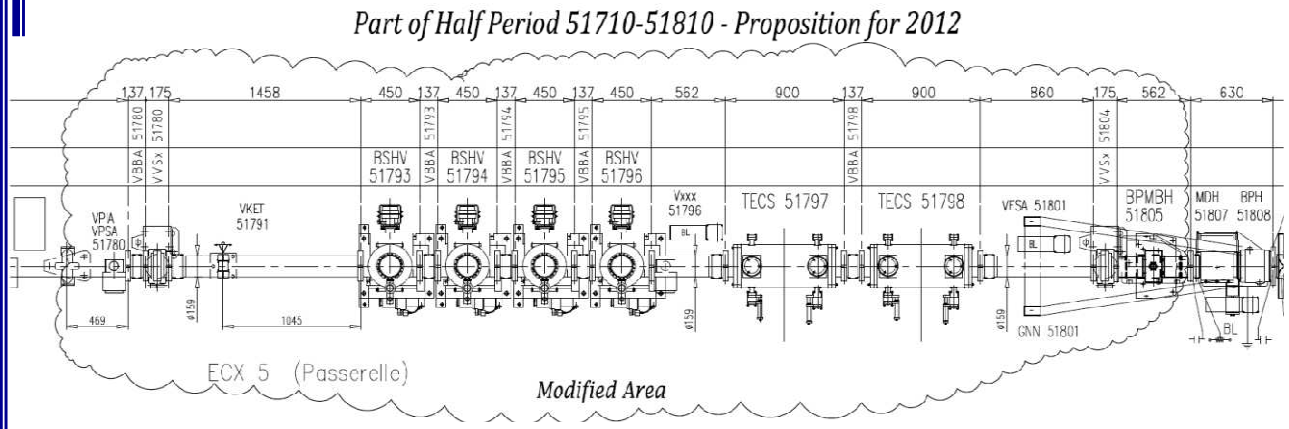
Perspective for 2012

- The extension of UA9 to LHC is seen favorably by LHCC and by the accelerator directorate (to be announced soon)
  - ✓ time allocation in LHC to be shared in between the machine and the experiments (however very limited)
  - ✓ dedicated run time to avoid conflicts with the high-luminosity operation.
- UA9 in the North Area and in the SPS
  - ✓ The main goal will be to validate scenarios, detectors and hardware for LHC
  - ✓ Upgrade of the SPS experimental setup required

UA9 request to the SPSC	
	❑ 5 days in the SPS (4 with protons and 1 with Pb-ions)
	❑ 5 weeks in H8 (3 with protons and 2 with Pb-ions)

- crystal collimation scheme for the high-intensity SPS operation.
  - ✓ Preliminary investigations based on UA9 experimental setup
  - ✓ Later an ad-hoc setup is required.
  - ✓ The collimation is requested at high-energy in pulsed mode
    - Very demanding constraints on crystal acceptance and on goniometer stability

New hardware and priorities for 2012

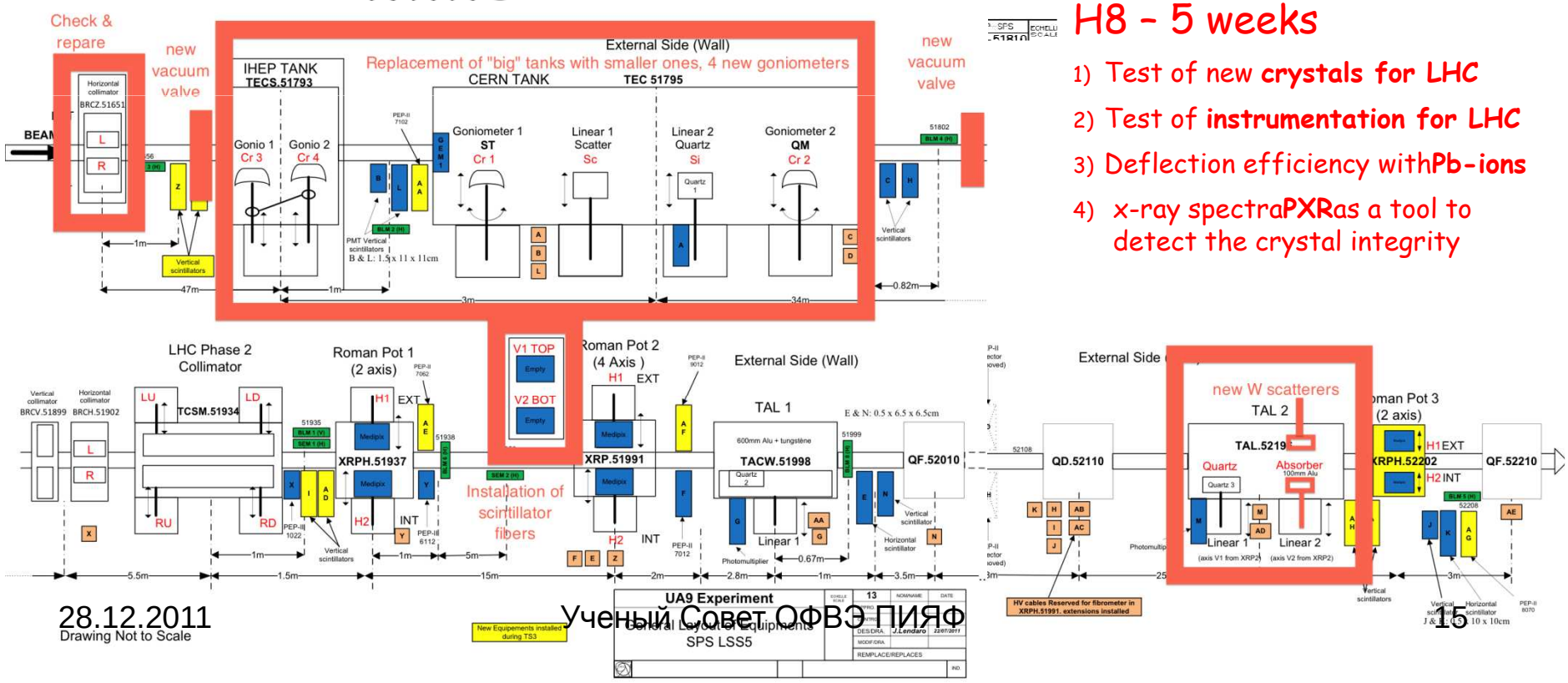


SPS – 5 full days

1) High intensity, high flux operation for **loss maps** along the SPS
2) Operation with **Pb-ions**
3) Hardware test for LHC (**crystals and goniometer**)
4) Collimation efficiency of **multi-strip crystals**

H8 – 5 weeks

1) Test of new **crystals for LHC**
2) Test of **instrumentation for LHC**
3) Deflection efficiency with **Pb-ions**
4) x-ray spectra **PXR** as a tool to detect the crystal integrity



Публикации 2009

- *Experimental study of the radiation emitted by 180-GeV/c electrons and positrons volume-reflected in a bent crystal,* Physical Review A 79, 012903 (2009)
- *Observation of Multiple Volume Reflection of Ultrarelativistic Protons by a Sequence of Several Bent Silicon Crystals,* Physical Review Letters 102, 084801 (2009)
- *Observation of nuclear dechanneling for high-energy protons in crystals,* Physics Letters B 680 (2009) 129–132
- *High-efficiency deflection of high-energy negative particles through axial channeling in a bent crystal,* Physics Letters B 680 (2009) 301–304
- *Observation of channeling and volume reflection in bent crystals for high-energy negative particles,* Physics Letters B 681 (2009) 233–236
- *First observation of multiple volume reflection by different planes in one bent silicon crystal for high-energy protons,* Physics Letters B 682 (2009) 274–277

Публикации 2010

- ***Multiple volume reflections of high-energy protons in a sequence of bent silicon crystals assisted by volume capture,*** **Physics Letters B 688 (2010) 284–288**
- ***Deflection of high-energy negative particles in a bent crystal through axial channeling and multiple volume reflection stimulated by doughnut scattering,*** **Physics Letters B 693 (2010) 545–550**
- ***Probability of inelastic nuclear interactions of high-energy protons in a bent crystal,*** **Nuclear Instruments and Methods in Physics Research B 268 (2010) 2655–2659**
- ***First results on the SPS beam collimation with bent crystals,*** **Physics Letters B 692 (2010) 78–82**

Публикации 2011

- ***Observation of multiple volume reflection by different planes in one bent silicon crystal for high-energy negative particles,*** **EuroPhysics Letters , 93 (2011) 56002**
- ***Observation of parametric X-rays produced by 400 GeV/c protons in bent crystals,*** **Physics Letters B 701 (2011) 180–185**
- ***Comparative results on collimation of the SPS beam of protons and Pb ions with bent crystals,*** **Physics Letters B 703 (2011) 547–551**
- ***The UA9 experimental layout,*** **JINST 6 T10002 (2011)**