Bent Crystals for Mu2e

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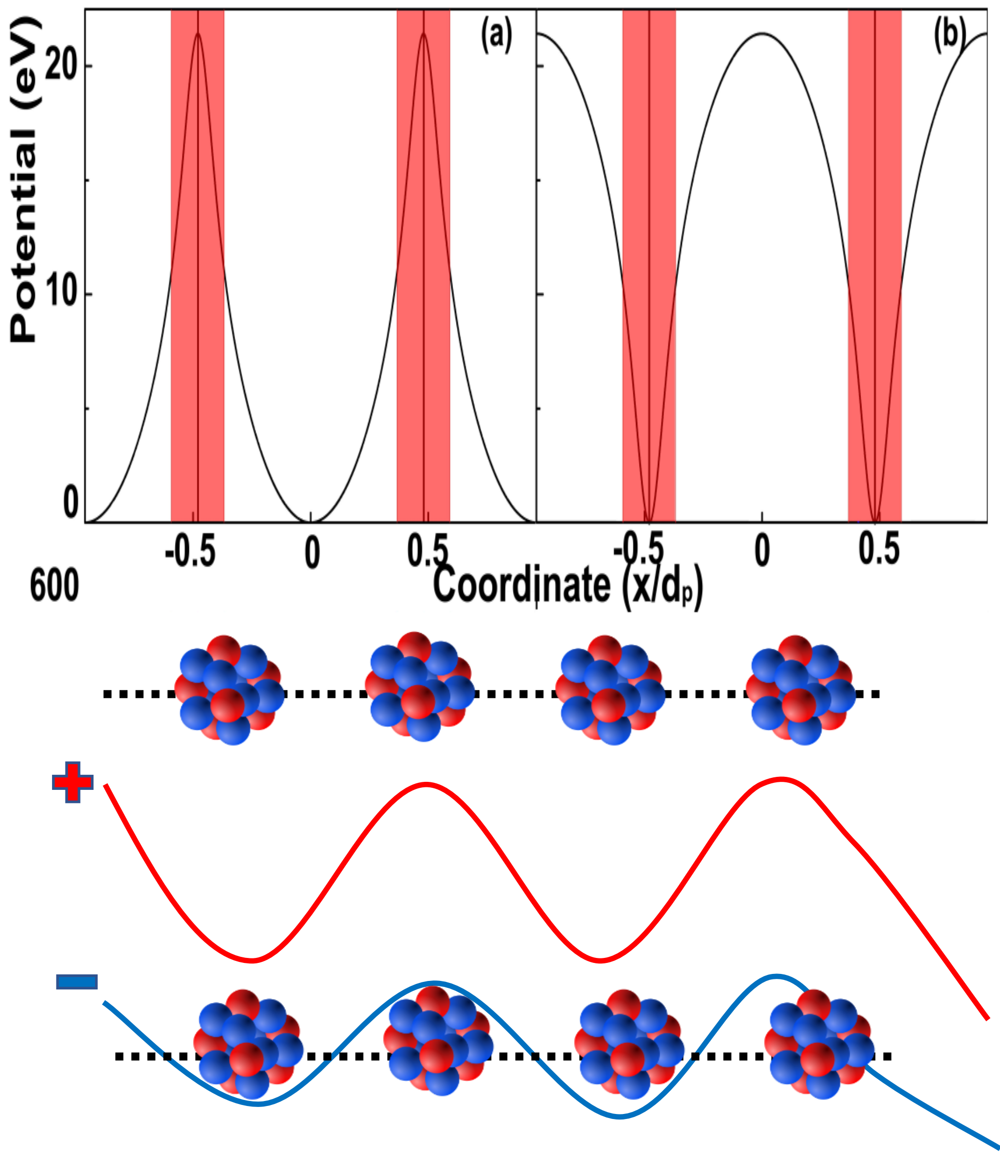
Channelling phenomenon

- Particles aligned with atomic planes perceive a continuous potential with wells and barriers
- Particles within a critic angle $\sqrt{(2U_0)/(pv)}$ can be bound to potential:
  - ⊕ Between adjacent planes if positively charged
  - ⊖ Into plane if negatively charged
- Scattering is strongly different in two cases:
  - ⊕ Reduction of inelastic collision with nuclei
  - ⊖ Increased inelastic collision with nuclei

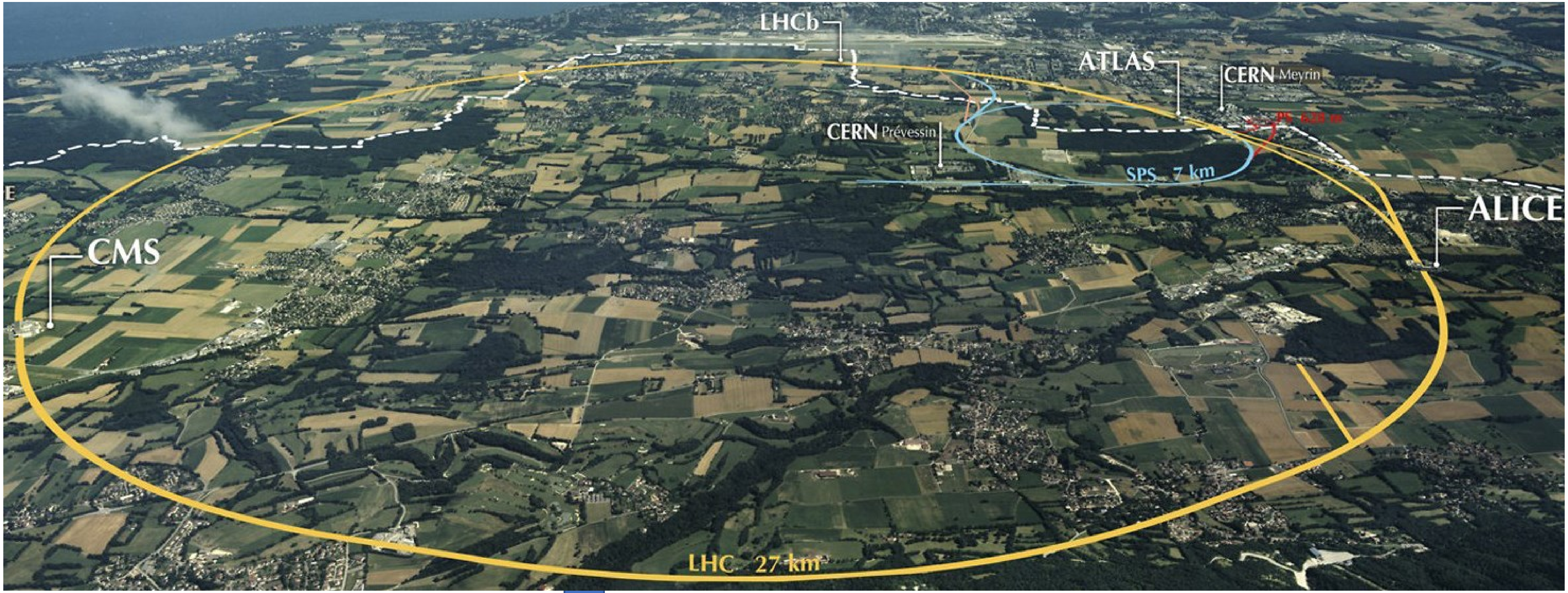


Channeling in bent crystals

- Channeled particle <u>follows the curvature</u> of the lattice plane
- A bent crystal can act as a sort of <u>waveguide</u> for channeled particle, steering them at angle depending on its geometry
- Large steering power can be obtained in few millimeters of crystal, equivalent to that of <u>hundreds of Tesla</u> magnetic dipole

Energy (GeV)	Deflection	Size (mm)	Equivalent dipole
6500	50	4	276 T
0.855	1500	0.015	285 T
20.53	400	0.06	456 T
2000	14000	70	1134 T

To visualize the difference…



Large Hadron Collider (Fr/Ch):

- circumference 27km
- Dipole max field 8.3 T

WOULD FIT INTO

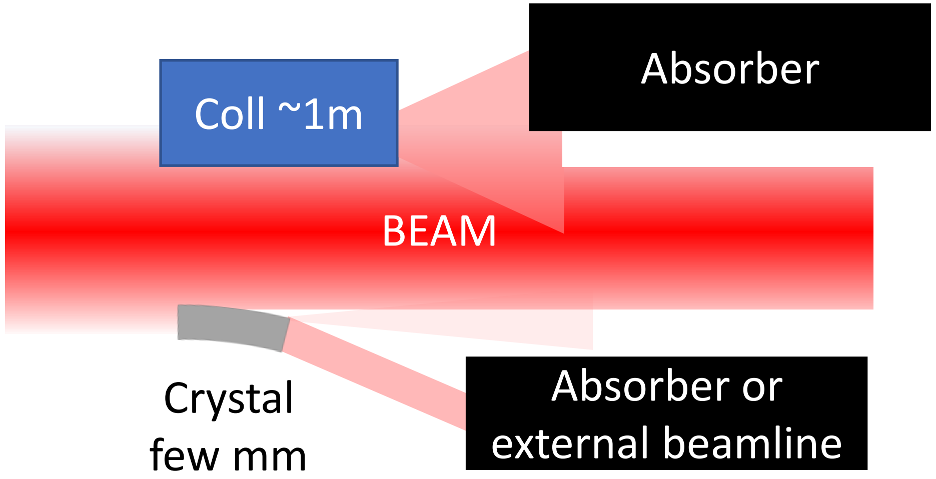
Advanced Photon Source (USA):

- circumference 1.1 km
- With magnets strong as crystals

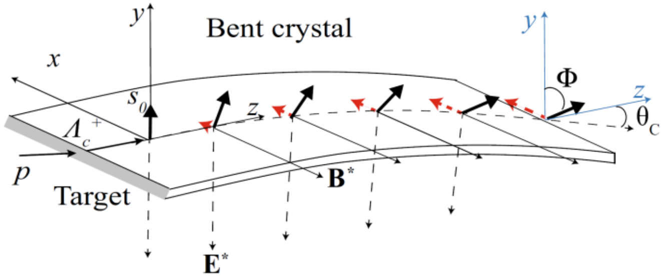
Ferrara experience in bent crystal applications

:Beam collimation

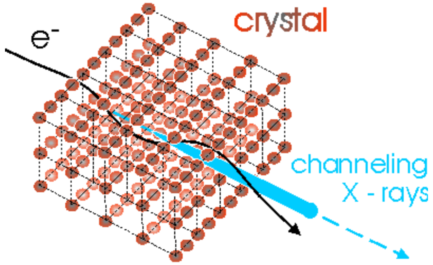
:Beam halo extraction



:Charmed baryons spin precession



:Novel radiation sources



Energy range of previous experiments

Experiments with several types of particles : protons, electrons, positrons, pions and ions

2 MeV

300→855 MeV

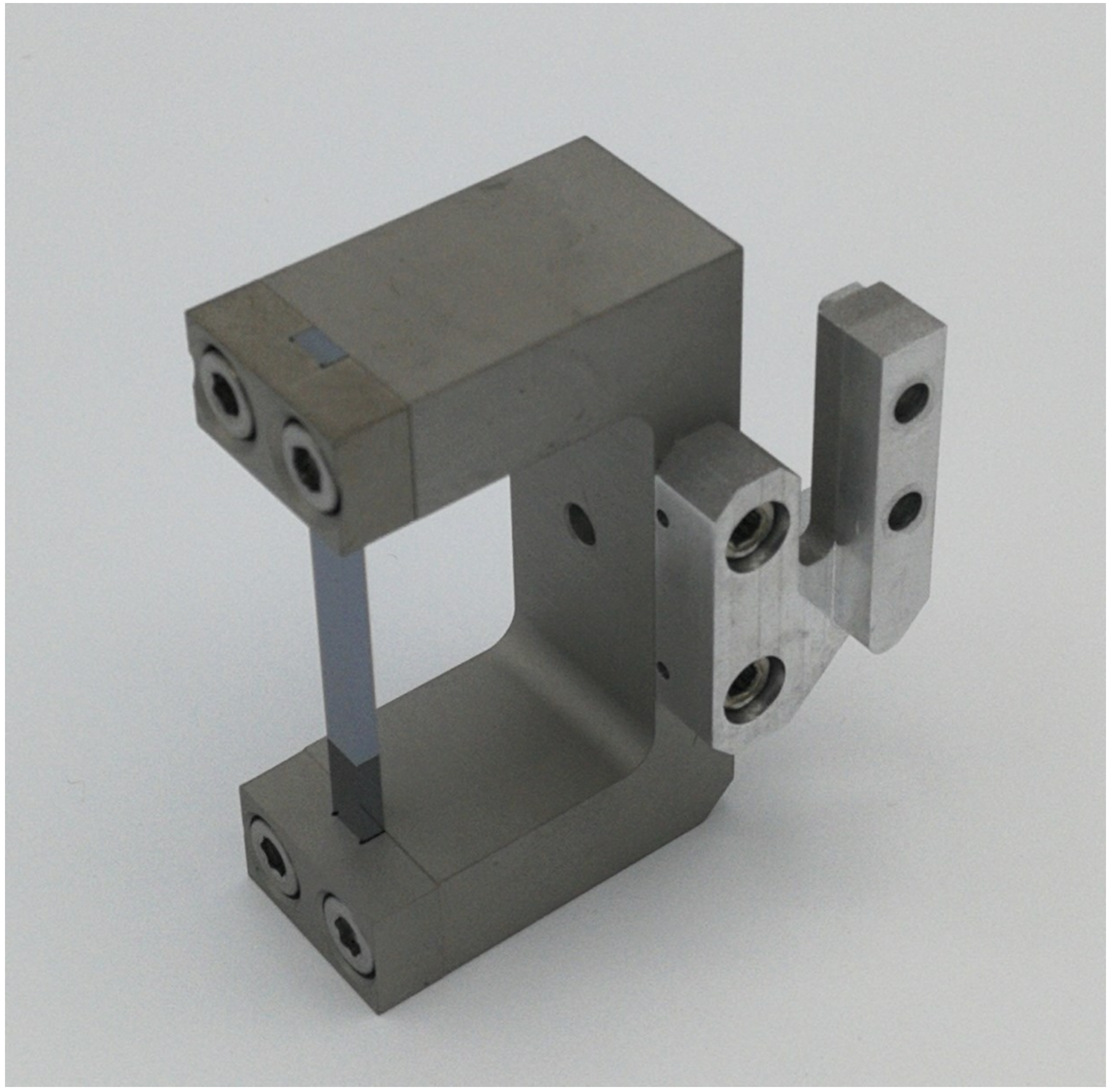
5.6 GeV

9→20.5 GeV

30→**6500 GeV**

6 orders of magnitude in energy

Latest result



- LHC started investigating ion beam crystal assisted collimation in preparation for High Luminosity upgrade
- 6 bent crystals have been provided to CERN by INFN-Ferrara under *INFN KE4350/EN/HL-LHC* agreement

Laboratories and instruments in Ferrara

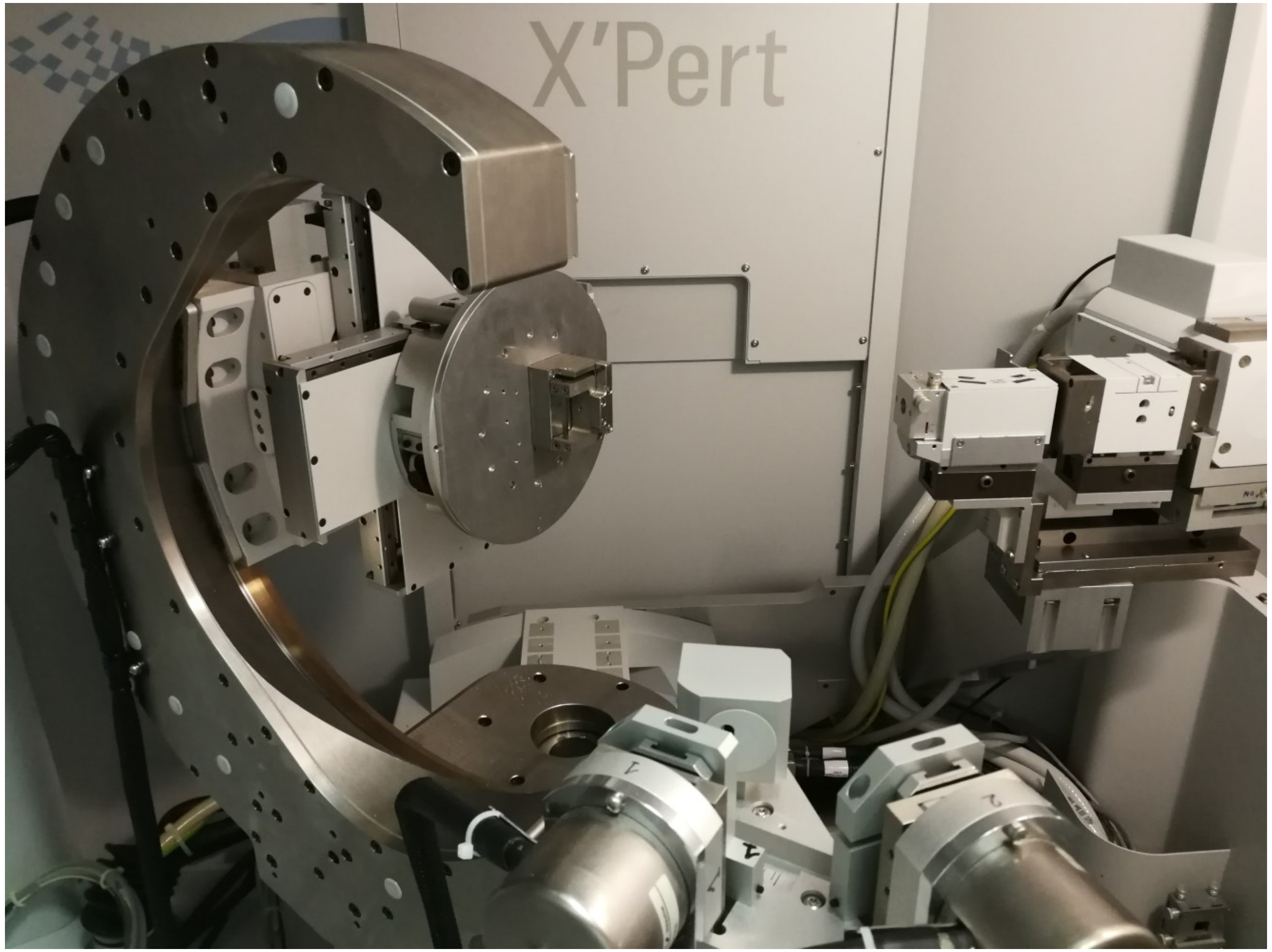
- Clean rooms facilities
- X-rays structural characterizations
- Interferometetric morphological characterizations
- Vacuum oven for thermal stability tests
- Crystal shaping technologies

Clean rooms facility

- 3 clean rooms for dust-free handling of samples (220m^2 total area)
- Station for wet chemical etching procedure on silicon
- Sample cleaning with mega-sound bath
- «dark- room» for lithography procedures

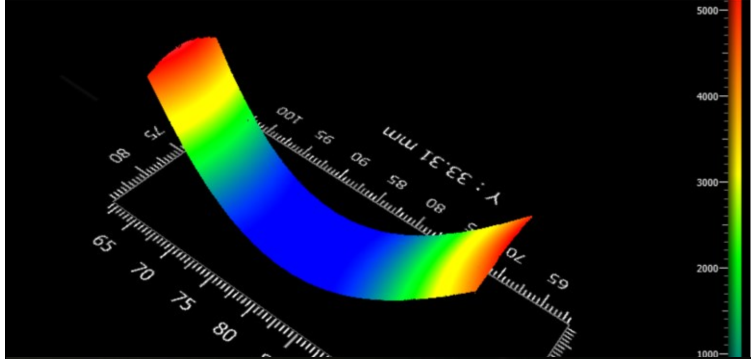
X-Ray structural characterization

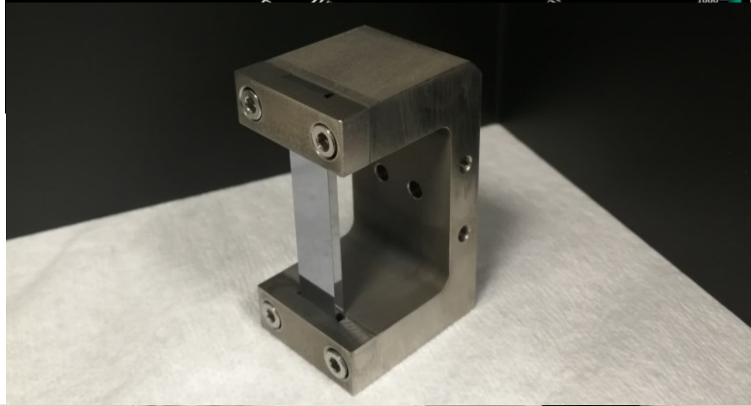
- HR-XRD with monochromatic 8.14 KeV beam (Cu Kα_1)
- 7 axis handling.
- Goniometer with high angular resolution 1.7 μrad



Interferometric morphological characterization

- Optical interferometry can achieve **sub-nanometric** vertical resolution
- Curvature can be calculated from surface shape
- Laser interferometer Zygo Verifire HDX: large field of view (150 ø mm), max lateral resolution 0.044mm



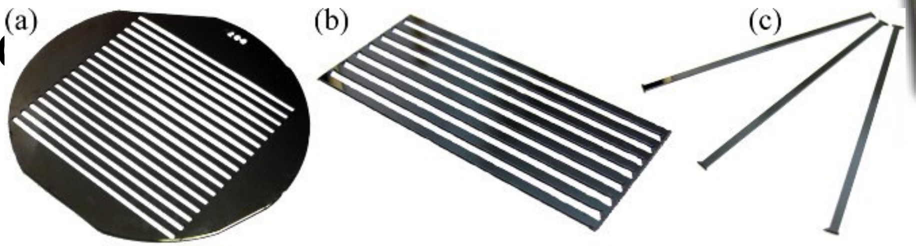


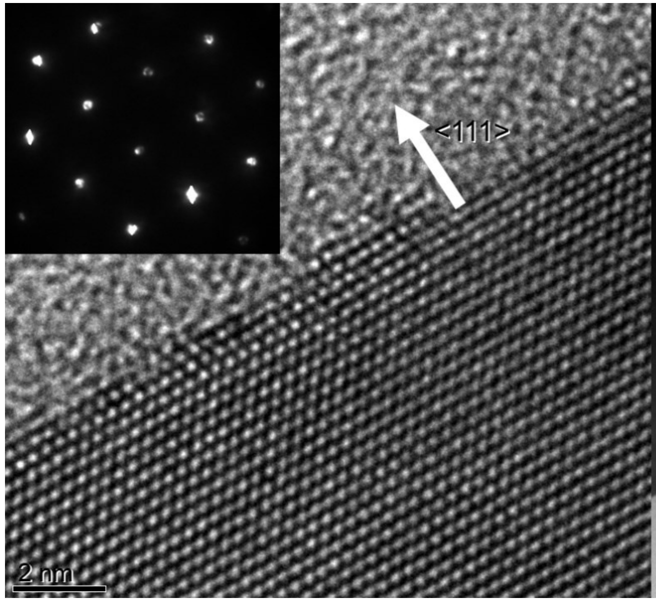
Crystal fabrication

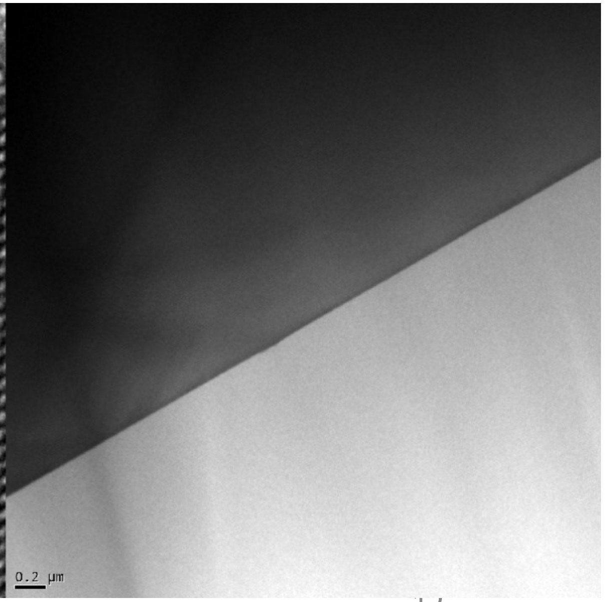
Silicon wafer of highest available lattice perfection are prime material

Shaping of crystal sample can be achieved
- Via mechanical cut with automatic dicing saw (0.001 mm lateral resolution and 0.01° angular resolution)
- Via anisotropic wet chemical etching

In case of mechanical cut, crystal quality is restored via chemical etching or polishing

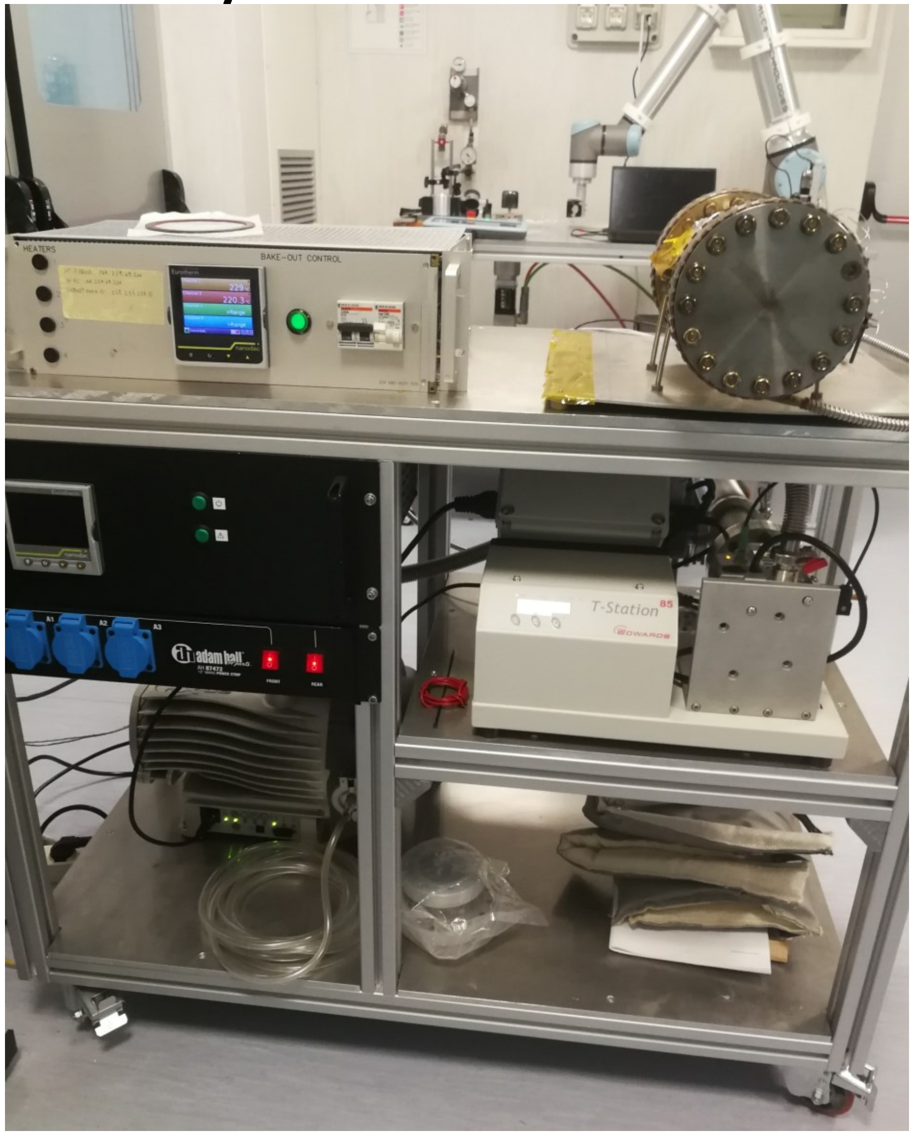






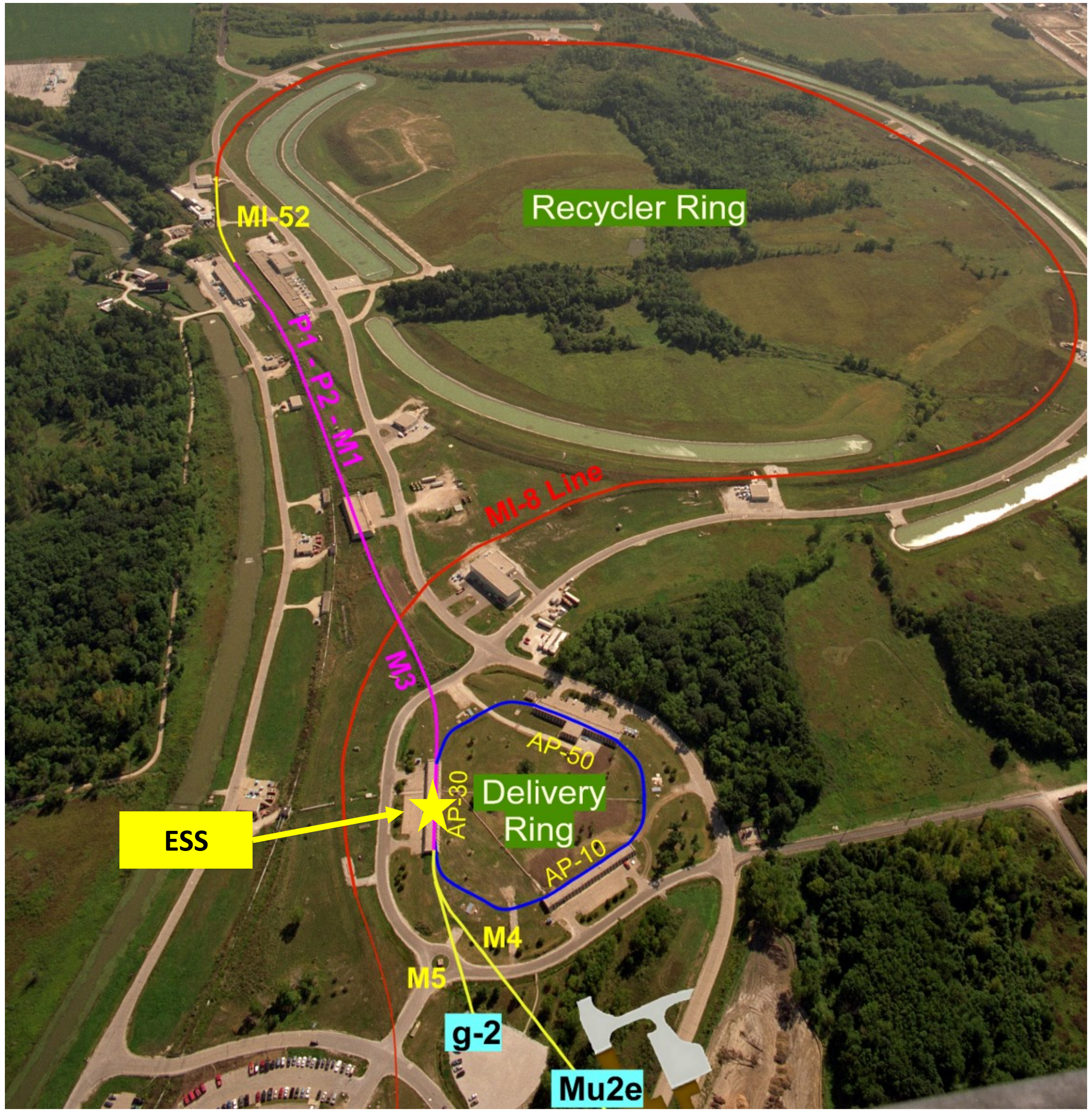
Vacuum oven for thermal stability test

- Chamber volume 120 Ø x 300 mm
- Max temperature 350°C
- Vacuum <10^{-6}mbar



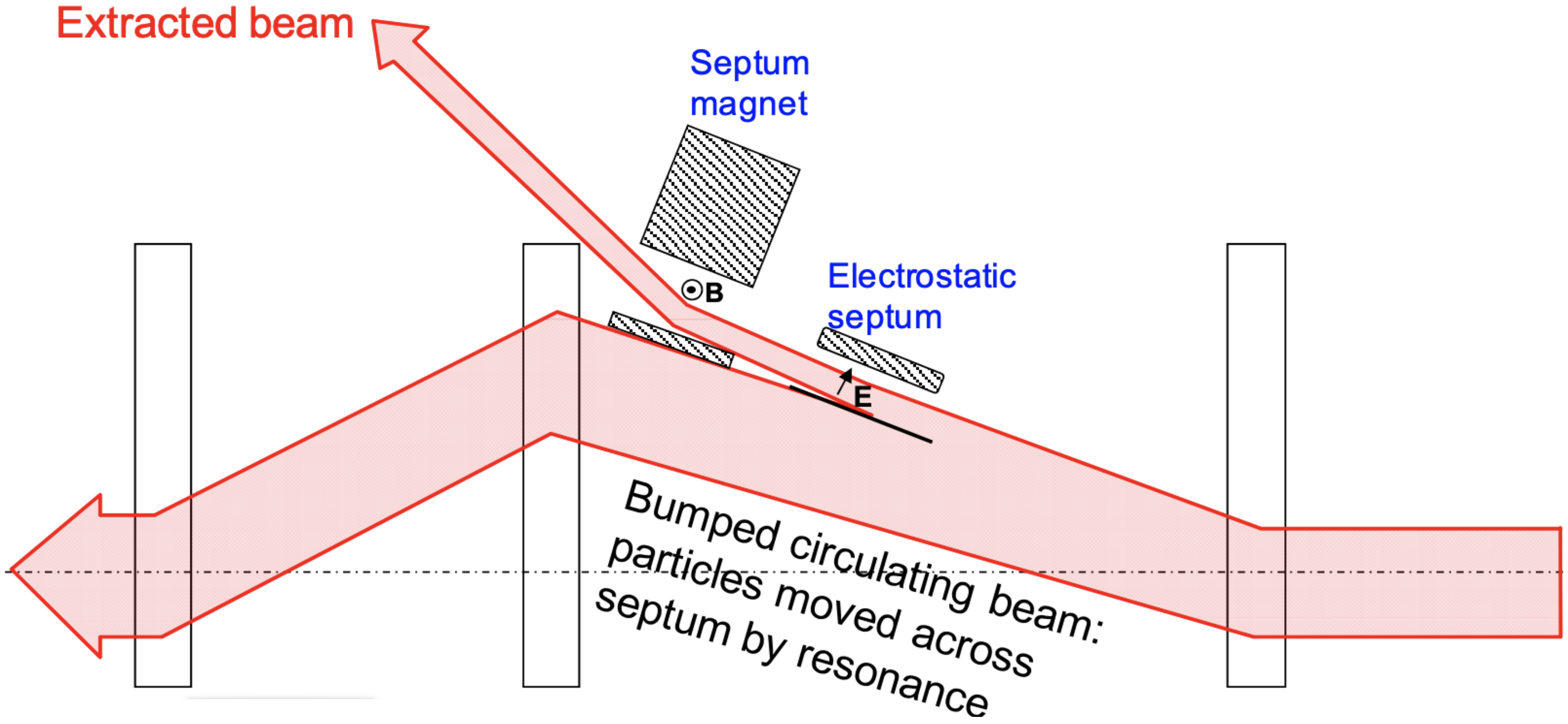
General information about the Mu2e

Aerial view to the Accelerator beam lines



Septum magnet for slow resonant extraction

- Resonance is driven by sextupoles
- Largest oscillating particles are captured by the septum magnet yielding extraction

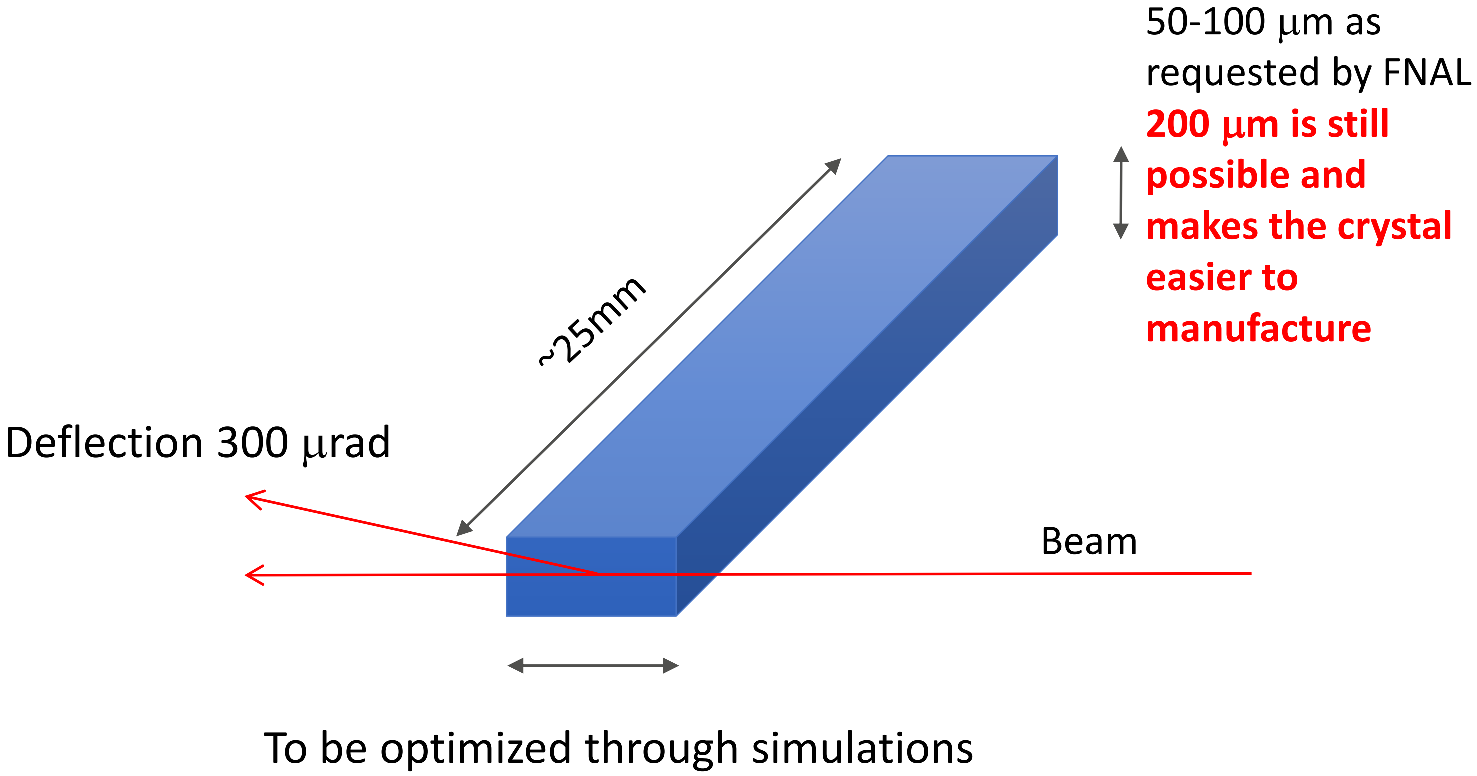


A fraction of the particle beam interact with the matter in the septum and generates losses

Shadowing deflector location options

A way to reduce the beam losses at Slow Extraction: Diffuse the beam away from the septum plane (shadow)

- Use diffuser
- Use the bending crystal



Ferrara assignments in Mu2e

- Simulation to optimize crystal geometry
- Fabrication of crystal
- Design and fabrication of bending holder
- Assembling of crystal and holder
- Bending characterization
- Installation at FNAL

Funding requests

Capitolo	Descrizione	Parziali (k€)	Parziali SJ (k€)	Totale/Cap (k€)	Totale/Cap SJ (k€)
apparati	60 keuro SJ per costruzione cristallo e holder a valere come MOF spese e servizi"	0	60	0	60
interno	1 keuro per riunioni di collaborazione, 11 keuro per missioni a FNAL di cui 5.5 keuro sub judice	6.5	5.5	12	11
	1+1 Muomo per A. Saputi come L3 per istallazione calorimetro	5.5	5.5		
			Totale:	**12**	**71**

Thank you for your attention

X-Ray characterization validations

SAMPLE id	X-ray measure	Observed beam steering	Consistency
STF47	33±2	35±2	YES
STF48	144±2	142±2	YES
STF49	247±3	246±2	YES
STF50	142±5	143±2	YES
STF51	33±2	33±2	YES
STF70	56±2	55±2	YES
STF71	60±5	62±2	YES
STF99	119±3	120±2	YES
STF100	67±6	63±2	YES
STF101	170±6	165±2	YES
STF102	45±3	42±2	YES
STF103	52±5	54±2	YES
STF104	95±5	91±3	YES
STF105	49±3	50±2	YES
STF106	42±2	42±2	YES
STF107	56±2	56±2	YES
STF110	52±3	54±2	YES
STF110	56±10	62±2	YES
STF112	64±3	63±2	YES
STF113	46±3	45±1	YES
STF114	52±3	52±1	YES
STF117	53±3	50±1	YES
STF118	52±3	53±1	YES
STF119	54±3	52±1	YES
STF120	54±3	52±1	YES
STF121	48±3	48±1	YES
STF122	50±3	46±1	YES
SFT123	52±3	52±1	YES