Bent crystal extraction from leptons storage rings:

THE SHERPA EXPERIMENT

“Slow High-efficiency Extraction from Ring Positron Accelerator”

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HEP2023 Conference

10th January, 2023

Existing e^+ beams

Electron-positron colliders

- **Super KEKB and BEPC-II**
  - No extracted beam
- **DAΦNE**
  - Primary (< 500 MeV) and secondary (< 700 MeV) positrons.
    From LINAC, not extracted
- **VEPP**
  - Not an extracted beam, but by-pass in the VEPP-3 ring (510 MeV)

Secondary positrons

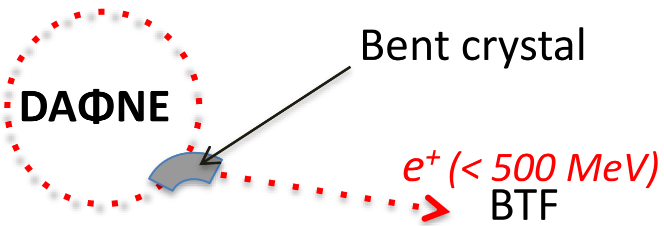
- **DESY-II**
  - 0.5 to 6 GeV/c positrons
- **CERN SPS North Area**
  - H4 “dedicated” beam-line, but production also possible in H2 and may be H6-H8
  - Up to 200 GeV with variable purity

There is no slow extraction of primary positron anywhere in the world !!!

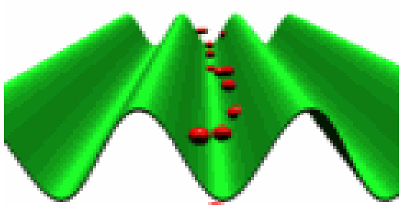
SHERPA

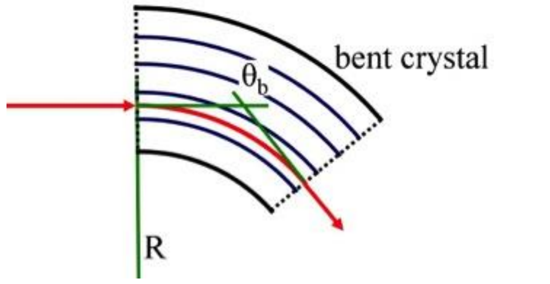
R&D study to extract a high-quality *e^+ (or e^-)* beam from one of the DAΦNE rings

The idea is to use coherent processes in a bent crystal to steer the positron beam



Channeling





Target spill parameters:

- Energy spread: $\Delta p/p < 10^{-3}$
- Emittance: $\varepsilon < 10^{-6}$ rad·m
- **Length: Δt ~ ms**

VS

Current BTF spill parameters:

- Energy spread: $\Delta p/p < 0.5 \times 10^{-2}$
- Emittance: $\varepsilon < 10^{-5}$ rad·m
- **Length: Δt ~ 300 ns**

Immediate application:

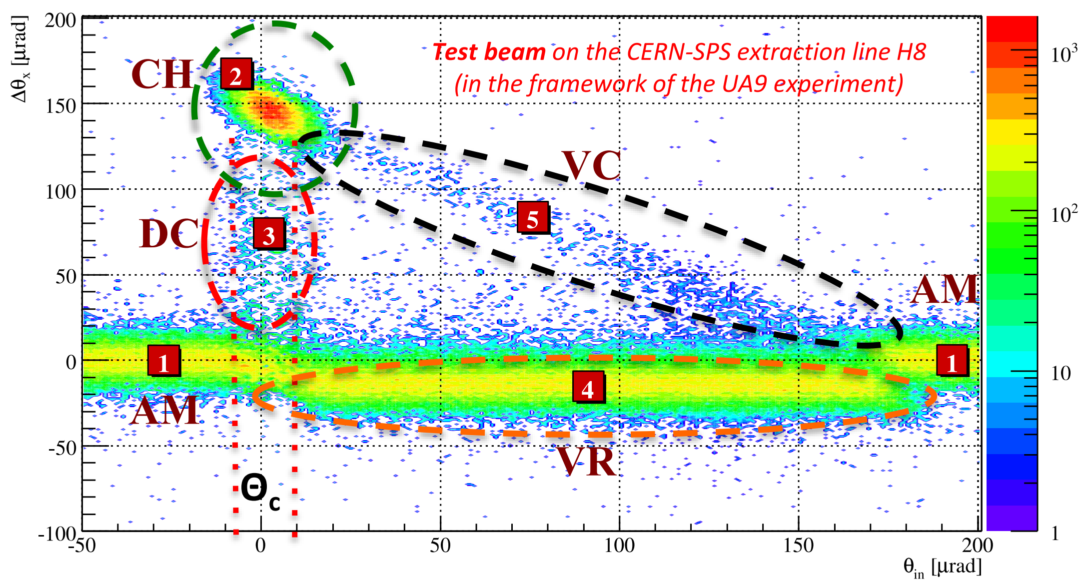
With the **SHERPA beam**, **PADME** ("**P**ositron **A**nnihilation into **D**ark **M**atter **E**xperiment") could increase the **statistics by a factor ~10^4** and its **sensitivity by a factor ~10^2**, largely extending the discovery potential. Now it is limited by VETO pile-up

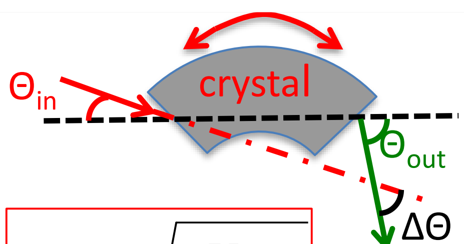
This technology can be used for all kind of lepton particles, positive and negative !!!

Coherent processes in bent crystals

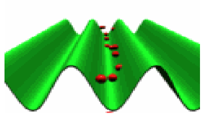
[1-2]

$$CH_{eff} = \frac{n_{e^+}(deflected)}{n_{e^+}(in\ \Theta_c)}$$

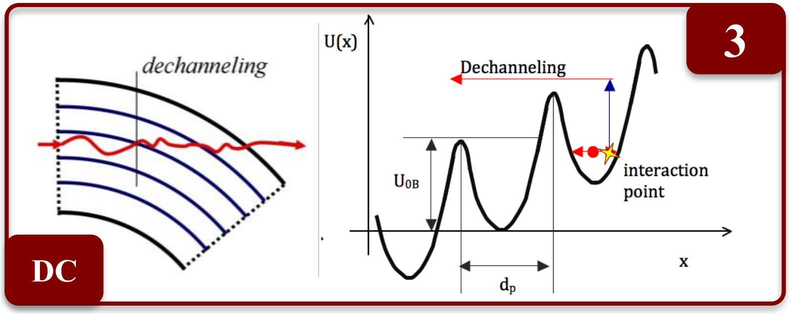




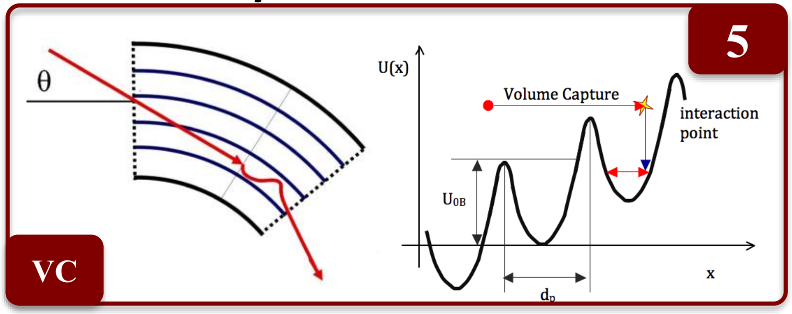
$$\theta_c = \sqrt{\frac{2U_{max}}{pv}}$$



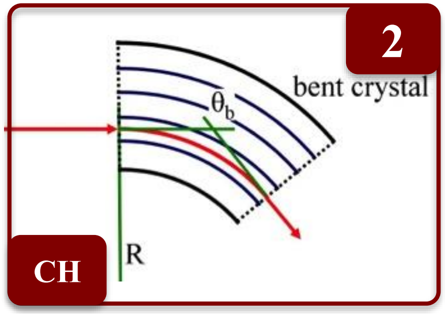
Dechanneling



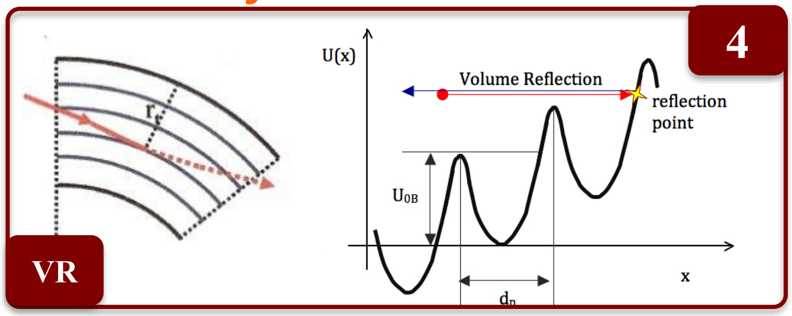
Volume capture



Channeling



Volume reflection



Crystal extraction history

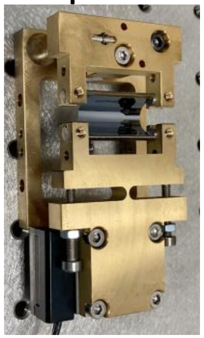
- (1990-95) - RD22 at the CERN-SPS as a test bed of beam extraction at LHC: crystal high-efficiency extraction of multi-GeV p^+ [3-4]
- (1993-98) - E853 at the FNAL-Tevatron as a test bed for the SSC: crystal high efficiency extraction of 900 GeV p^+
- (2001) - The CERN-INTAS programmes on crystal technology: crystal high efficiency extraction of 70 GeV p^+ by a short crystal (in IHEP U-70) [5]
- (2016) - UA9 at CERN-SPS: crystal assisted not-resonant & not-local slow extraction of 270 GeV p^+ in the TT20 north area extraction line [6,7]
- (2018) - UA9 at CERN-SPS: crystal "virtual" not-resonant local beam extraction of 270 GeV p^+ in channeling mode
- (2018) - UA9 at CERN-SPS: crystal shadowing of the ES-septum and assisted resonant slow extraction of 400 GeV p^+ [8,9]

Sub-GeV lepton crystal beam steering

In the depth of the crystal (z) the fraction of channeled particles decreases exponentially

$$\sim \exp(-z/L_\mathrm{D})$$

Sub-GeV Leptons



High-energy Hadrons

L_D is the dechanneling length, proportional to the particle energy
Particle and bent crystal dependent

In Silicon L_D is ~400 μm for ~500 MeV e^+ (~25 mm for 7 TeV p^+)

Very thin crystals (~20 μm) to reduce the dechanneling and increase the channeling efficiency
Challenging, but feasible

Moreover, a thin crystal will not affect so much the circulating beam

The crystal robustness is guaranteed by several test performed with multi-GeV hadrons [10,26], but must be considered and evaluated

Encouraging results already obtained with sub-Gev particles using thin crystals [11,12,13,14,15,16]

EXTRACTION FROM DAΦNE

The most common approach to extract slowly from a circular accelerator is Resonant multi-turn slow extraction technique [27]

Unstable region in the phase space acting on sextupoles → driving the tune towards the resonant value (e.g. 3rd order) → gradually eject particles driving them out of the stable region towards the separatrix. Septum is needed.

THE SHERPA INNOVATION:

not-resonant multi-turn crystal ultra-slow extraction [5,6,7]

The beam halo population is steadily sustained switching off RF (e^+ loose energy by Synchrotron Radiation) properly tuned → A bent crystal, properly oriented, intercepts the diffusive halo and kicks it by coherent deflection through the inter-planar potential

It might provide a continuous multi-turn extraction with high-efficiency and a better spill quality in a simpler and cheaper way than resonant extraction

Better control of the extraction time and more collimated extracted beam

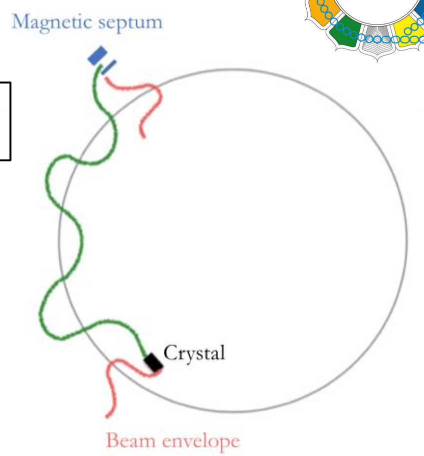
Minor ring modifications are necessary !!!

Crystals could also support the resonant approach strongly contributing to extract particles towards the extraction septum → crystal-resonant hybrid extraction

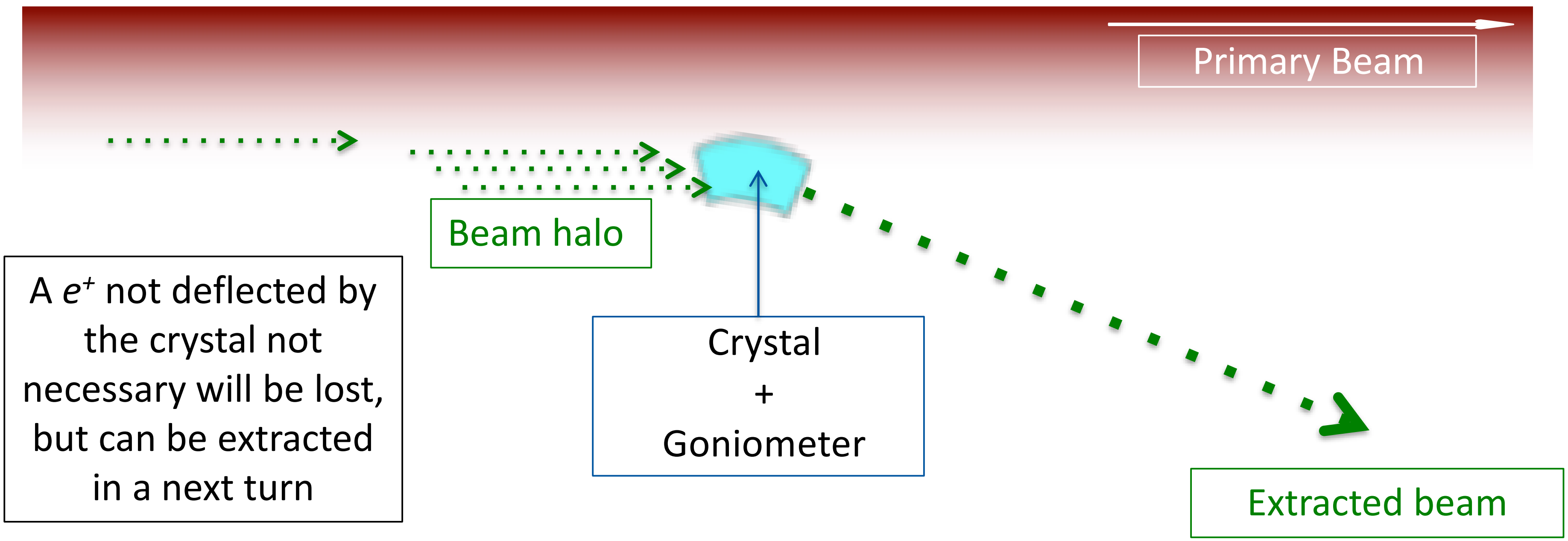
Multi-turn not resonant slow extraction

Energy loss by synchrotron radiation (RF off)

Not-local extraction

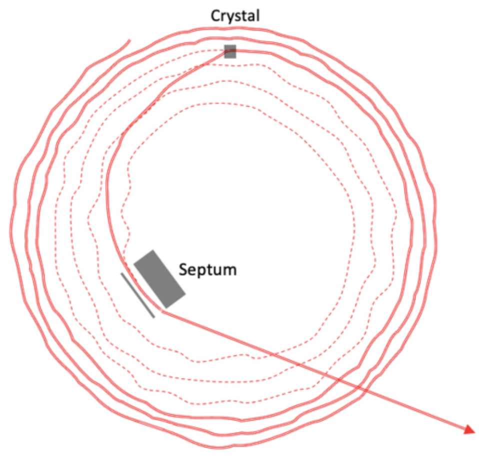


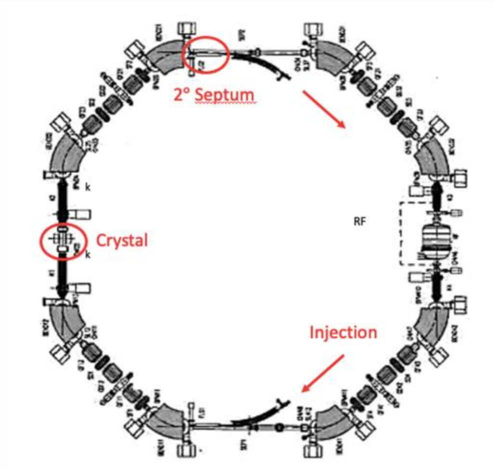
DAΦNE e^+ beam

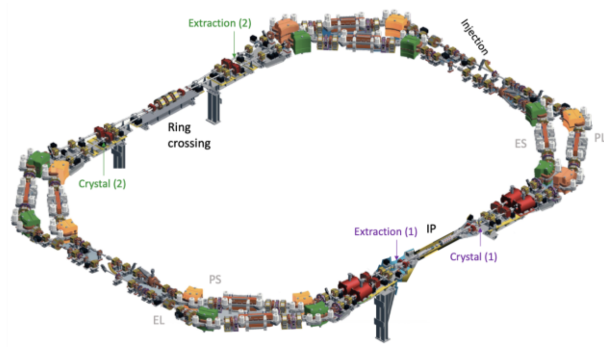


A e^+ not deflected by the crystal not necessary will be lost, but can be extracted in a next turn

SHERPA extraction simulations







Not local extraction

1. Injection of pulses ~ the ring length. **RF off**
2. Particles slowly lose energy (e.g. by Sync. Rad.) until pass through the crystal that gives a kick to circulating particles
3. The particles extracted in another point of the ring by septum

DAΦNE Accumulator solution

1. Same hardware of the actual accumulator (except for the crystal)
2. Some changes in the optics parameters
3. e^+ cross the crystal and are extracted by the same septum used to fill the main ring

DAΦNE Main ring solution

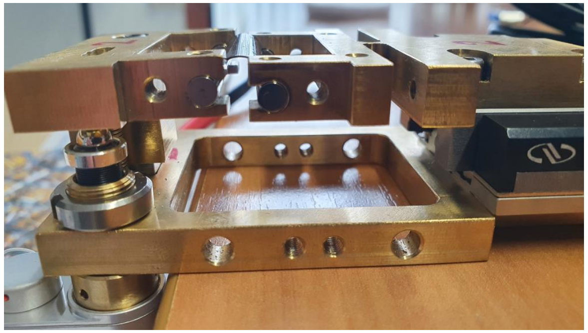
1. Actual configuration, except for the crystal and the extraction septum)
2. Some changes in the optics parameters
3. The beam cross the crystal and is extracted around the IP (2 different solutions)

Simulation studies (O. Blanco, S. Guiducci), without changing the layout of the rings (but only the currents), show that with a crystal deflection of 1 mrad it is possible to obtain **pulses of 0.1 ms (Accumulator ring) and up to 0.4 ms (Main ring)**

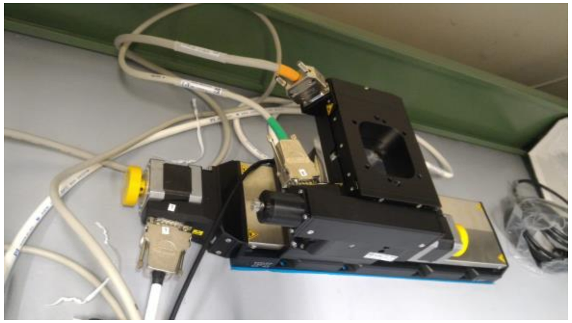
[29] M. Garattini et al., PRAB 25 (2022) 033501

SHERPA HARDWARE

Crystal bending holder by LNF (original design INFN-Fe/LNL)

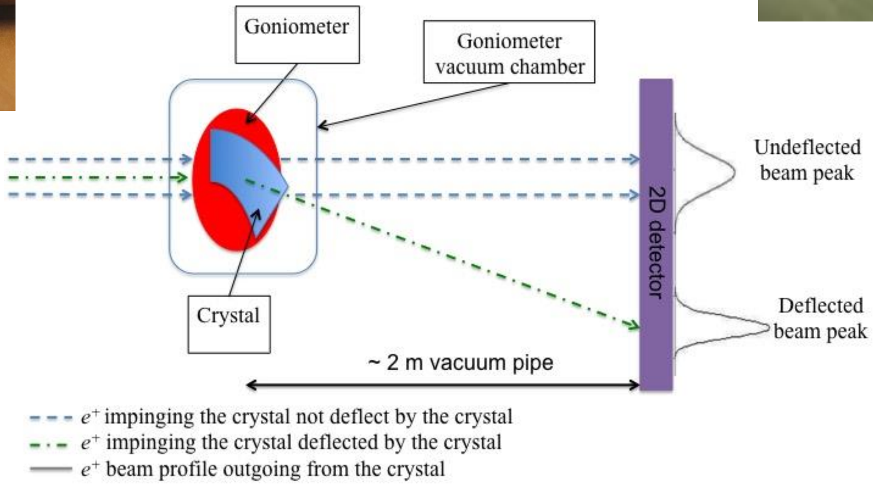


Crystal Goniometer (3axis)

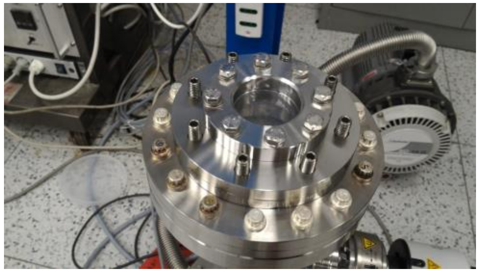


BTF-2 Detector (TimePix 3)

BTF apparatus scheme for crystal characterization



Ultra-thin (20 μm) Mylar windows



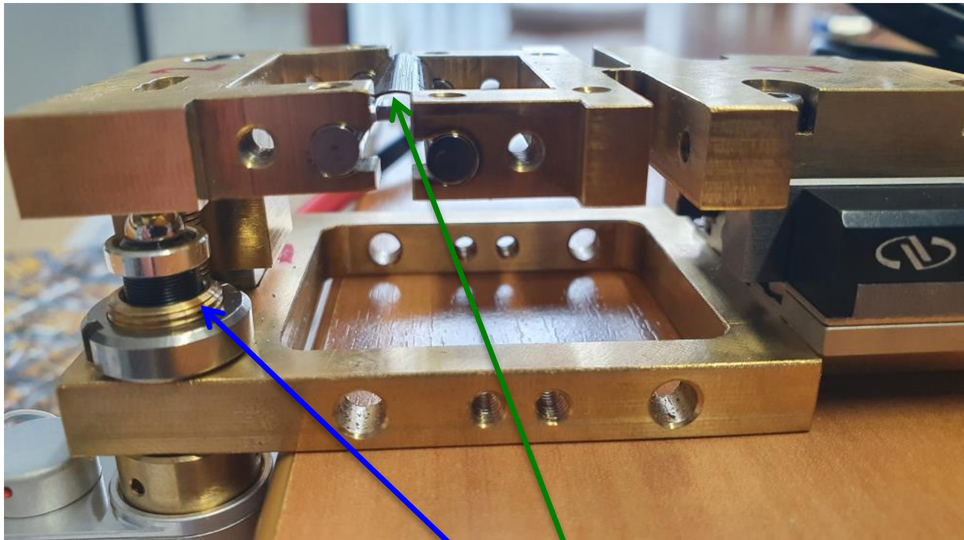
Crystal chamber

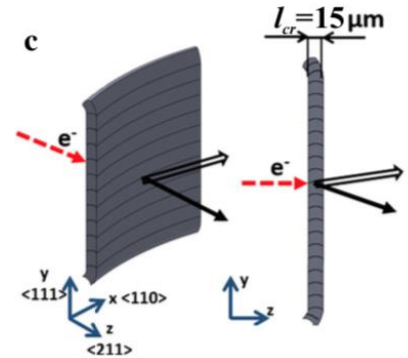
Ultra-thin Crystal at INFN-Fe

2 m pipe

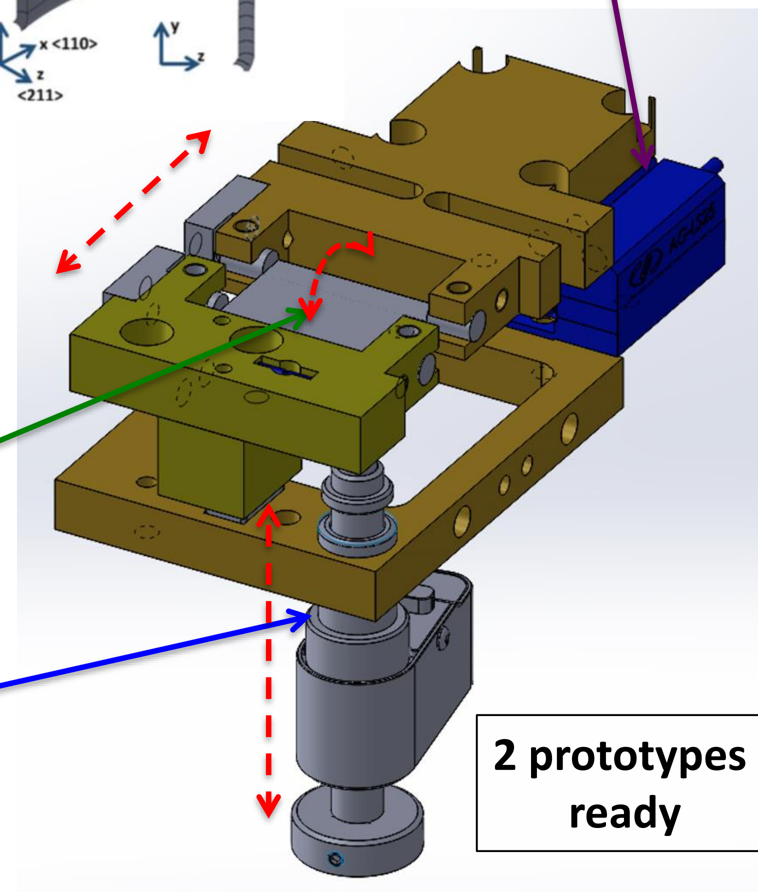
Piezo crystal bending holder

Crystal bending holder by LNF (design INFN-Fe/LNL)





Crystal bending by linear piezo-motor



~ 15 μm Crystal

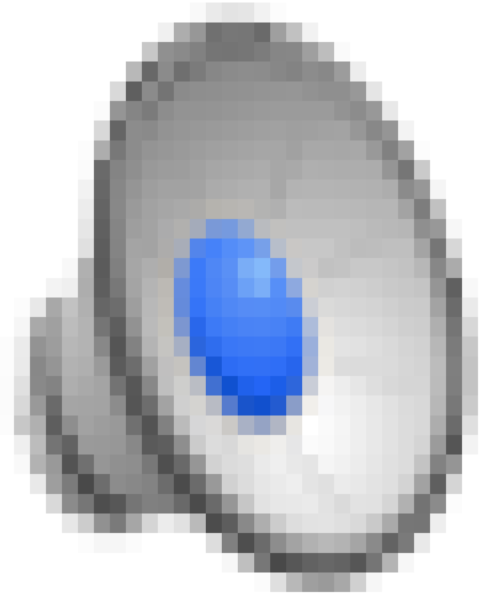
Innovation:

The crystal bending and its torsion can be controlled and corrected remotely and in real time !!!

Torsion correction by piezo-finger actuator

2 prototypes ready

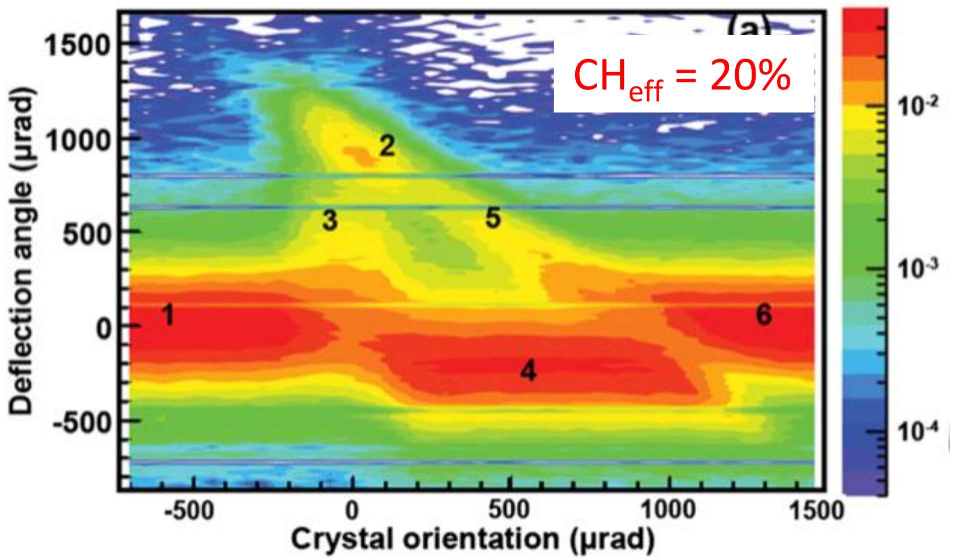
Bending of the SHERPA Crystal



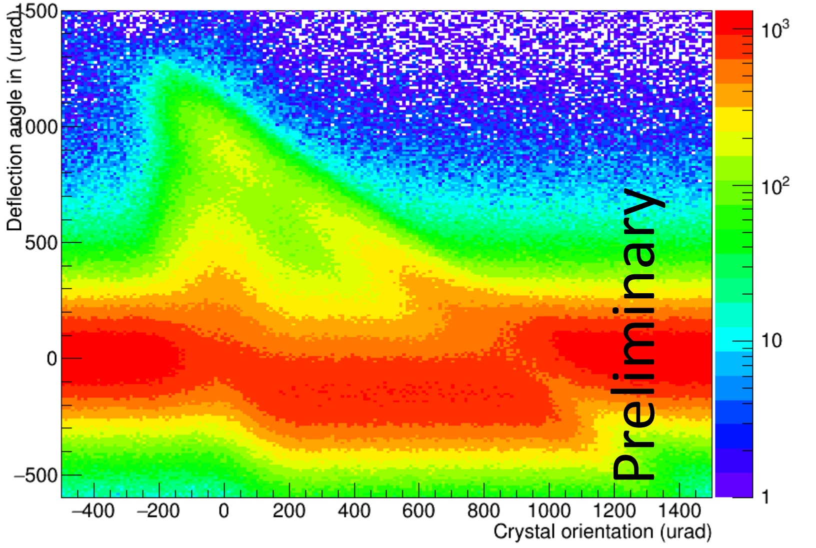
Crystal simulations (e^-)

We managed to well reproduce the angular scan of a "SHERPA like" crystal tested at the MAMI facility with 855 MeV e^- [PRL 112, 135503 (2014)]

MAMI measurements [15]



GEANT4 Monte Carlo simulations [28]



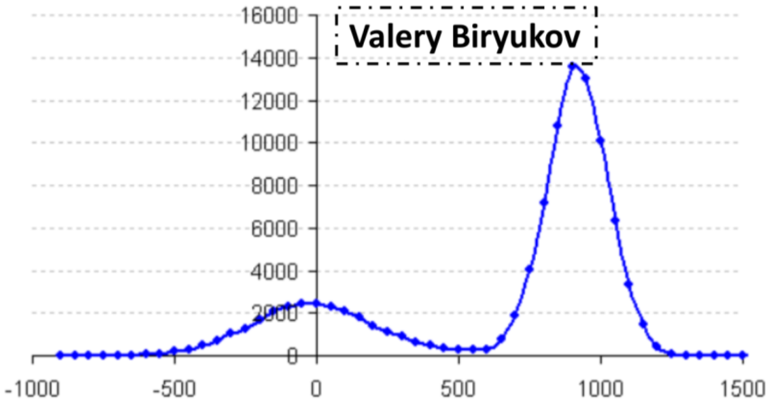
The difference in channeling efficiency (~ 10%) is probably due to the "rechanneling process", not yet implemented…

The CH_{eff} for negative particles is always lower w.r.t. positive particles

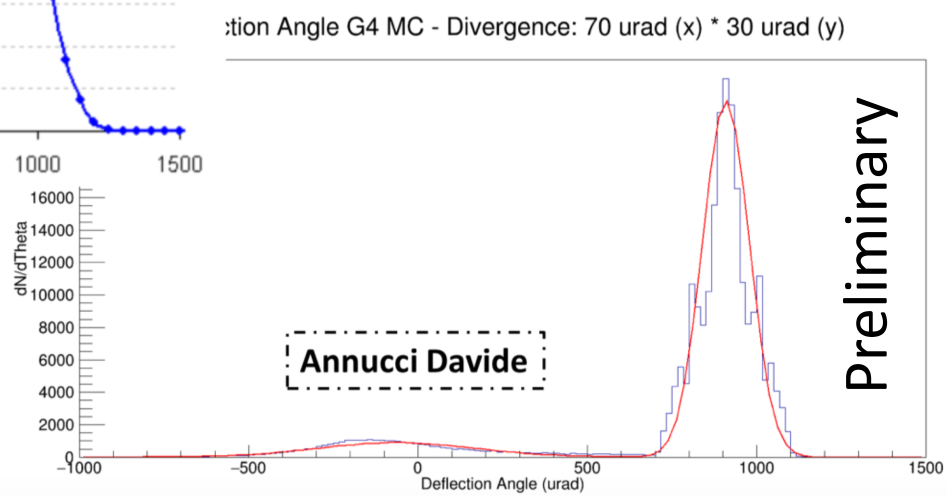
Crystal simulations (e^+)

We did also a comparison between GEANT4 Monte Carlo simulations and Analytical one of a "SHERPA like" bent crystal for 855 MeV e^+

Analytical simulations



GEANT4 Monte Carlo simulations [28]



Analytical: $CH_{eff} \cong 80\%$

GEANT4: $CH_{eff} \cong 88\%$

The difference from Analytical and Monte Carlo simulations is probably due to lack of the data benchmark

Measurements and data analysis are in progress to improve simulations…

Scientific and technological impact

Long high quality positron pulses will be useful not only for **PADME**…

4) e^+ extraction, collimation, etc…, will be crucial for the new generation of leptons colliders like FCC-ee.

2) High quality photon production using e^+ channeled in crystal lattices [23]

1) Asymmetric e^+ (high energy) e^- (low energy) colliders for dark matter studies [22]

6) The same is valid for every kind of leptons, negative included

7) The same is valid for higher energies leptons

3) μ production in the future μ^+/μ^- colliders. e^+ beams on low density target e^- can produce μ with very low emittance and energy spread, reducing cooling procedures [24,25]

5) Crystals are innovative, effective and cheap, and can also be applied in medical and industrial accelerators, with a strong social-economic impact in the near future

CONCLUSIONS

- **SHERPA** aims to study and implement a system to slowly extract a high-quality *e^+ (or e^-)* beam from one of the DAΦNE accelerator rings using a bent crystal
- Hadron and lepton crystal beam steering is already well known and the crystal extraction has been proved with hadrons several times and in different conditions
- The proposal is based on multi-turn not-resonant extraction, but crystals could also support the resonant approach
- **SHERPA**'s studies demonstrated the crystal non-resonant slow extraction feasibility both on the Accumulator and Main DAΦNE rings
- The **PADME** experiment might be the first user of the **SHERPA** beam, obtaining enormous advantages in terms of duty cycle and sensitivity
- In addition to providing an extracted beam with unprecedented features, this project is scientifically interesting per se: indeed no crystal-assisted extraction of positrons has been used so far. Moreover, high-quality positron beams are quite rare.
- **SHERPA can provide an important scientific and technological impact on lepton beams manipulations**

References

[1] M. Biryukov, Y. A. Chesnokov, and V. I. Kotov, "Crystal channeling and its application at high-energy accelerators". Springer Science & Business Media, 2013

[2] W. Scandale *et al,* PRL 98, 154801 (2007)

[3] F. Ferroni for the RD22 Collaboration, Nuclear Instruments and Methods in Physics Research A 351 (1994) 183-187

[4] The RD22 Collaboration, Phys. Lett. B 357 (1995) 671-677

[5] A. G. Afonin *et al.*, Phys. Rev. Lett. 87.9 (2001): 094802

[6] Fraser, M. A., *et al*. "Experimental results of crystal-assisted slow extraction at the SPS."(*arXiv preprint arXiv:1707.05151)* (2017)

[7] F. Addesa *et al.,* "The SE-CpFM Detector for the Crystal-Assisted Extraction at CERN-SPS", IBIC'17, MI, USA, 20-24 August

[8] F. M. Velotti et al., Phys. Rev. Accel. Beams, 22.9: 093502 (2019)

[9] F.M. Velotti et al., IPAC2019, Melbourne, Australia (doi:10.18429/JACoW-IPAC2019-THXXPLM2) (2019)

[10] W. Scandale, M. Garattini et al., European Physical Journal C, EPJC-19-09-144.R1 (2019)

[11] S. Bellucci *et al.*, Nucl. Instrum. Meth. Phys. Res. B 252 (2006) 3–6

[12] S. Bellucci *et al.*, JETP Lett. 2013, Vol. 98, No. 11, pp. 649–651

[13] Guidi V. et al., Phys. Rev. Lett. 108.1 (2012): 014801

[14] W. scandale et al., Physics Letters B 734 (2014) 1–6

[15] A. Mazzolari *et al.*, Phys. Rev. Lett. 112 (2014) 135503

[16] Y. Takabayashi *et al.*, Phys. Lett. B 751 (2015) 453

[17] J. Baudot *et al.,* IEEE Nuclear Science Symposium Conference Record (2009), N22-6

[18] M. Campbell *et al*., Nucl. Instrum. Meth. A 633 (2011) S1-S10

[19] A. Natochii et al., JINST 14 P03018 (2019)

[20] G. Alglieri Rinella *et al.,* Nucl. Instrum. Meth. A 845 (2017) 583-587

[21] M. Raggi, EPJ Web Conf. 142 (2017) 01026

[22] B. Wojtsekhowski *et al.*, arXiv:1705.00051 [physics.acc-ph]

[23] U.I. Uggerhøj, Nucl. Instrum. Meth. B355 (2015) 35

[24] G. S. Sushko *et al.*, J. Phys.: Conf. Ser. 438 (2013) 012018

[25] M. Antonelli *et al*., Nucl. Instrum. Meth. in Phys. Res. A 807 (2016) 101–107

[26] W. Scandale, M. Garattini et al., JINST_061P_0621 (2021)

[27] S. Guiducci *et al*., IPAC2018, Vancouver, BC Canada

[28] E. Bagli et al., Eur. Phys. J. C (2014) 74:2996

[29] M. Garattini et al., Phys. Rev. Accel. Beams 25 (2022) 033501

Thank you for your attention !

And thank you very much to the whole SHERPA team !!!

LNF: P. Gianotti, S. Guiducci, O. R. Blanco-Garcia, T. Napolitano, A. Liedl
INFN-Roma1: P. Valente, M. Raggi, D. Annucci
INFN-Fe: V. Guidi, A. Mazzolari, L. Bandiera, M. Romagnoni, M. Soldani

SPARE

Proposed high-energy positron beams

Electron-positron colliders

- **DAΦNE**
  - Proposal for resonant and not-resonant extraction of primary positrons at 510 MeV
  - Proposal for LINAC modifications for bunch extension < 300 MeV

- **CESR**
  - Proposal for $n + 1/3$ resonant extraction of primary positrons at 6 GeV not approved

LINAC-based

- **CEBAF at Jefferson Lab**
  - Proposal for 11 GeV primary positron source (JPOS), not yet approved, ≈5 years of construction
  - Possibility of secondary positron beams, ???

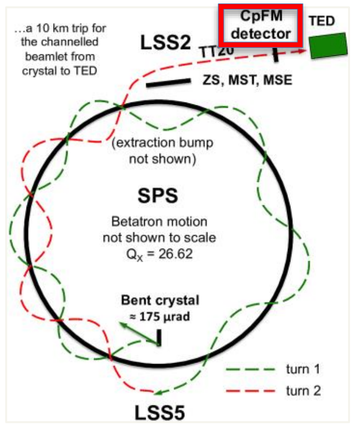
- **FACET-II at SLAC**
  - Proposal for 10 GeV primary positrons (produced from extracted electrons, damped and re-accelerated)
  - Approved but staged to Phase-2, > 2022

CERN SPS crystal extraction (UA9)

Joint activity with TE/ABT and EN/STI

2016 - slow not-local extraction of 270 GeV p^+ in channeling mode [6,7(M.G.)] beam into the TT20 extraction line towards the North Experimental Area of the SPS was demonstrated using the extraction septa and a bent crystal

Extraction in 2 turns



UA9 CpFM
("Cherenkov for proton Flux Measurements") detector for SPS and LHC has seen the extracted beam

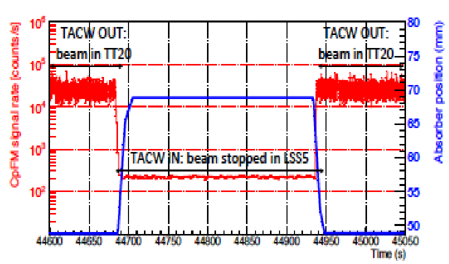
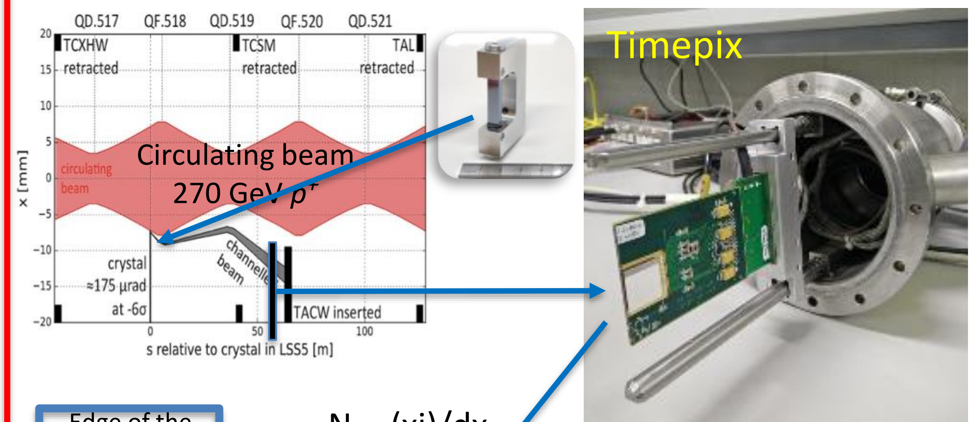
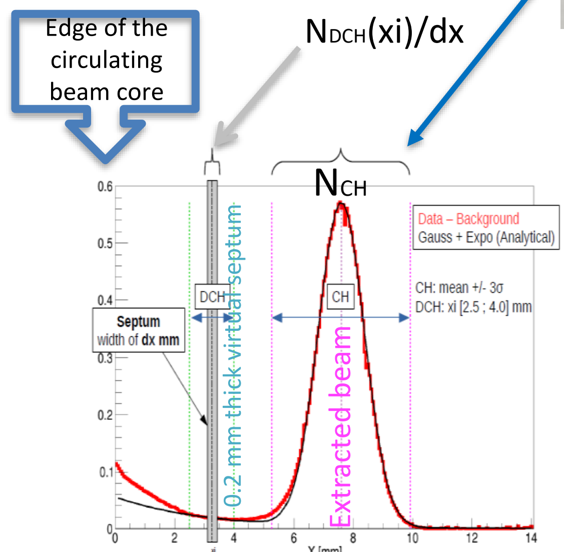


Figure 4: TT20 CpFM signal rate (red) vs. TACW position (blue) [19].

2018 - "Virtual" not-resonant local beam extraction of 270 GeV p^+ in channeling mode





Halo density in channeling mode along the horizontal axis
(self-normalized to the total No of impinging particles)

loss ratio R ≈ N_{DCH} / N_{CH} = ~6 ‰

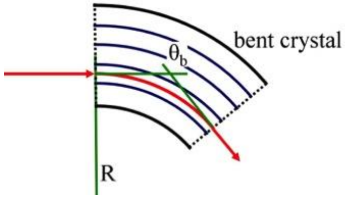
Sub-GeV crystal beam steering: e^+ & p^+

The idea is to use the solid expertise developed to scale crystal extraction from multi-GeV hadron beam to < 1 GeV positron beam

- **Sub-GeV *e^+* crystal beam steering** in two different configuration at the BTF (Beam Test Facility, INFN-LNF):

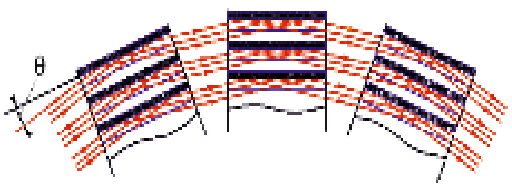
2006 – Channeling of 480 MeV *e^+* [11]

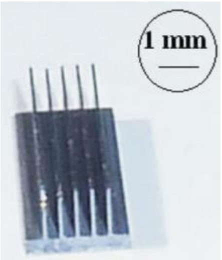
- 1 mm thick silicon crystal
- ~10 mrad with ~10% of efficiency



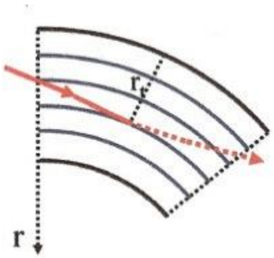
2013 – Multi volume reflection of 100 MeV *e^+* [12]

- 5 bent silicon crystals in a raw
- 5 x ~100 µm thick silicon crystal
- 5 mrad with ~30 % of efficiency

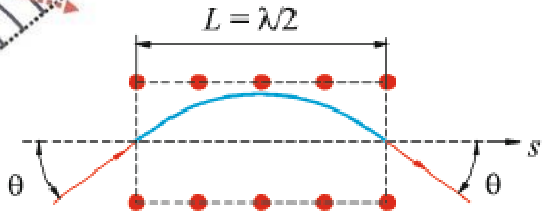




- **Ultra-thin crystal mirroring**
- **2012 – Mirroring and Volume-reflection of 2 MeV *p^+*** [13] (nanometric crystal!!!)
- ultrathin silicon crystal (100 nm, half wavelength of the planar channeling oscillation)
- Deflection: ~ 5 mrad (CH), ~1 mrad (VR)
- Efficiency: 58% (CH), 42% (VR)



- **UA9 in 2014 – Mirroring of 400 GeV *p^+*** [14]
- 26,5 µm thick silicon crystal
- Deflection: ~ 10 µrad (CH)
- Efficiency: 80% (CH)



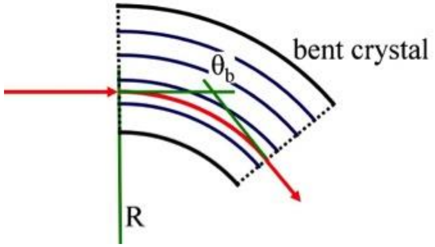
Sub-GeV crystal beam steering: e^-

Also e^- crystal beam steering has been performed in different conditions, giving useful references for leptons coherent effects in bent crystals and for thin crystal technology

Negative particle deflection is always less efficient then for positive ones

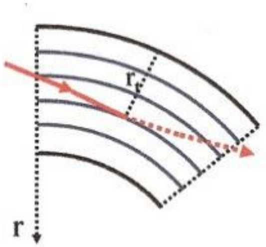
2014 – (MAMI) Channeling of 855 MeV e^- [15]

- 30 μm Silicon crystal (111),
- Deflection: 910 μrad
- Efficiency: 20%



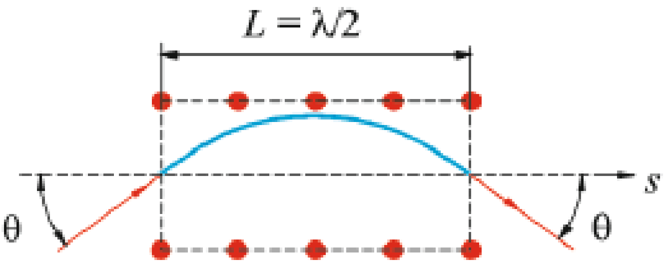
2014 – (MAMI) Volume reflection of 855 MeV e^- [15]

- 30 μm Silicon crystal (111),
- Deflection:191 μrad
- Efficiency: 77%



2016 – (SAGA-LS) mirroring of 255 MeV e^- [16]

- ultrathin silicon crystal (0.74 μm, half wavelength of the planar channeling oscillation), deflection
- Deflection: 450 μrad
- Efficiency: 29%

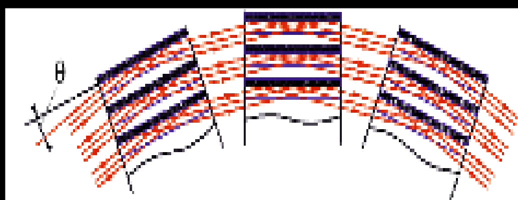
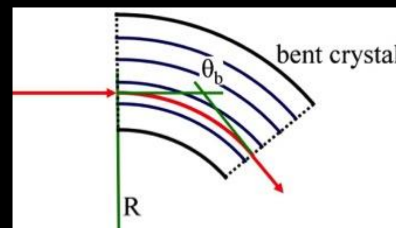
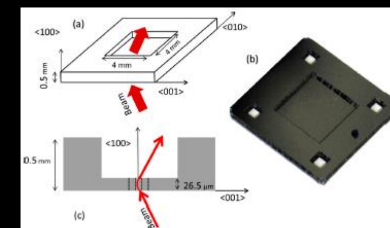


Crystal extraction solutions

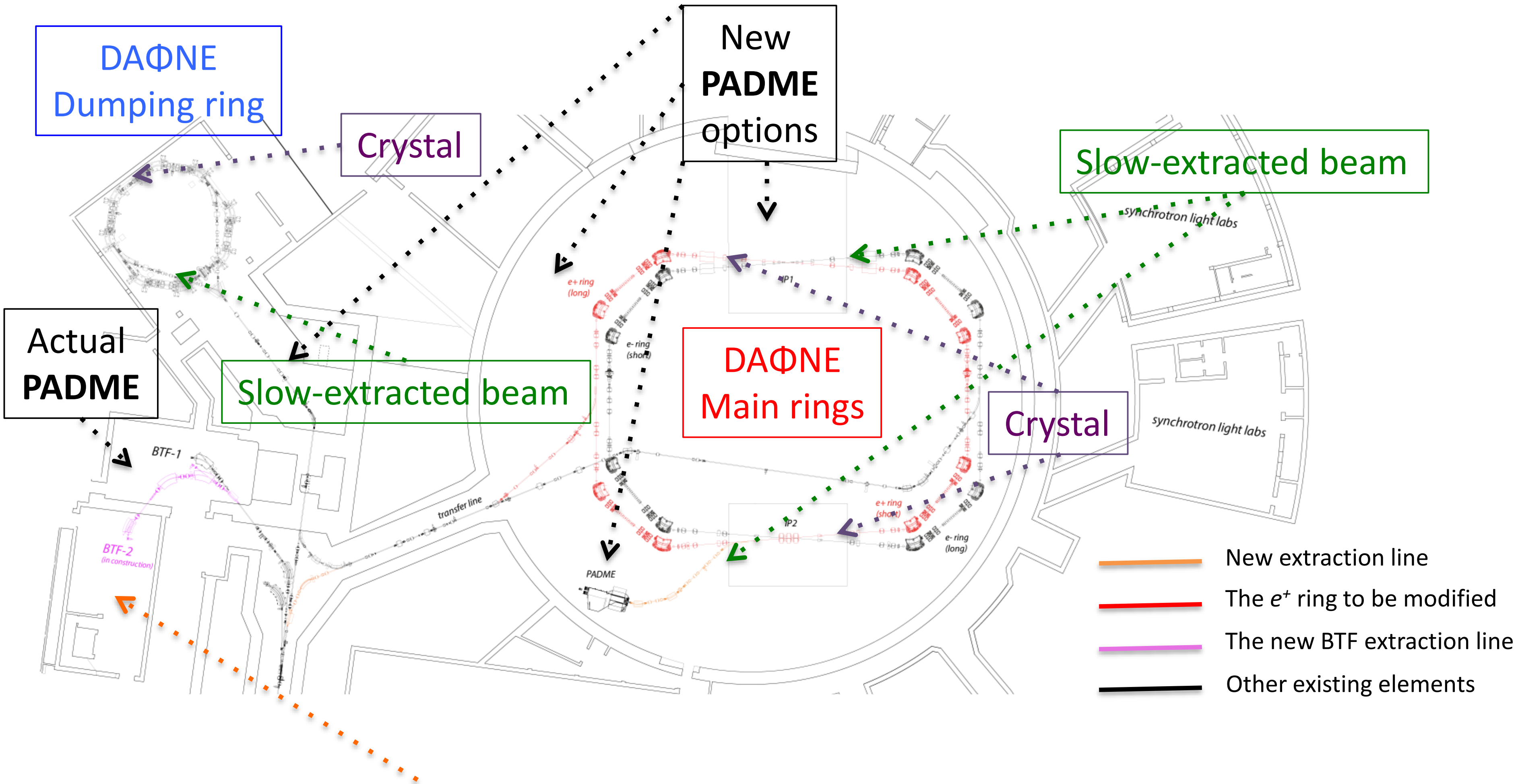
Crystal general parameters

Material: silicon (or Germanium)
Thickness: 1 – 100 µm

Angle: ~mrad
Critical angle (0.5 GeV): ~300µrad

	Muti-Volume Reflection	Planar Channeling	Mirroring
			
Pro	**- Larger angular acceptance** **- Higher efficiency** - More standard crystal technology	**- Larger deflection angle** **- Multi-turn extraction** **- Less beam-crystal interactions** - Simpler crystal system	**- Multi-turn extraction** **- No bending needed** - Simpler operation procedure??? (T.b.i.)
Cons	**- Smaller deflection angle** **- Higher beam-crystal interactions** - More complex crystal system	**- Lower efficiency** **- Thin crystal technology (<100 µm)** - Smaller angular acceptance	**- Smaller angular acceptance** **- Extreme thin crystal technology (~1 µm)**
	Basic solution	**Upgraded solution**	**Exotic but appealing**

DAΦNE crystal slow-extraction layouts

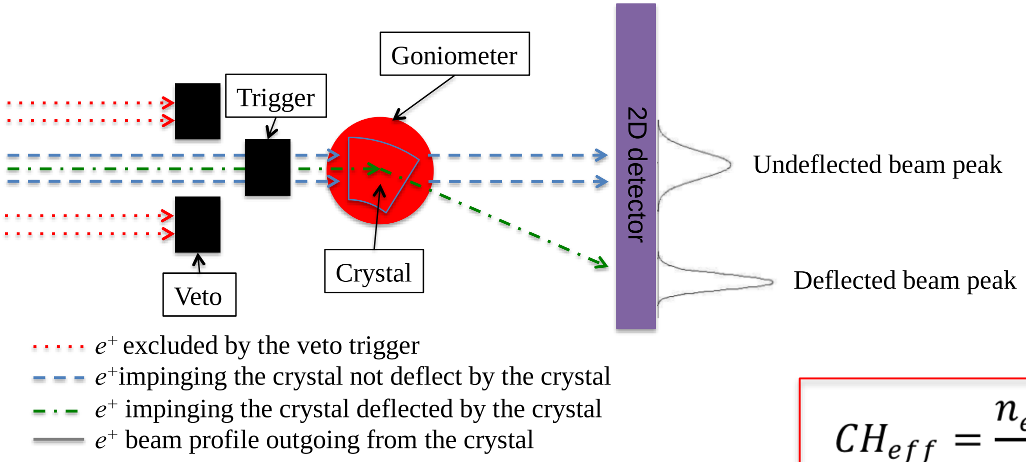


Crystal characterization apparatus (BTF-2) → MAMI (Mainz) and CERN PS East Area are two possible alternatives

The BTF experimental apparatus

The BTF is obviously the perfect place for crystal characterization

If $X'_{e+} < \Theta_c$ of the crystal (~300 μrad at 500 GeV)



Apparatus 1.0

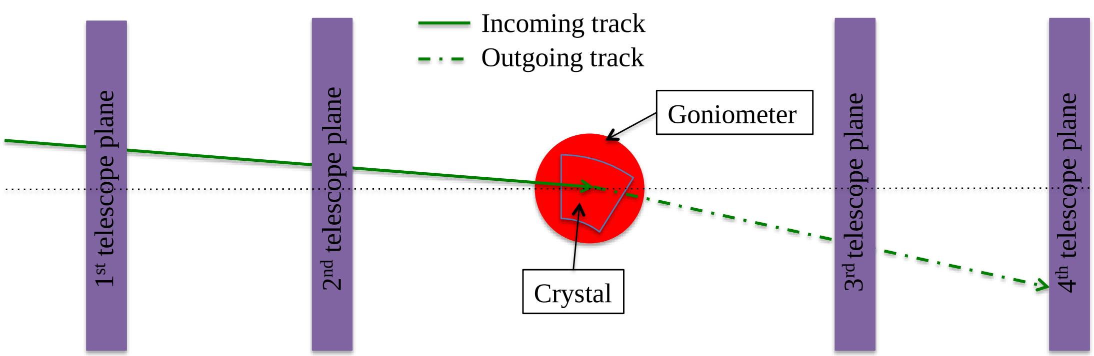
First estimation of the crystal performances

- Deflection angle
- Deflection efficiency

$$CH_{eff} = \frac{n_{e^+}(deflected)}{n_{e^+}(in\ \Theta_c)}$$

If $X'_{e+} > \Theta_c$ of the crystal (~300 μrad at 500 GeV)

(Same type of apparatus used by UA9 at CERN)



Apparatus 2.0

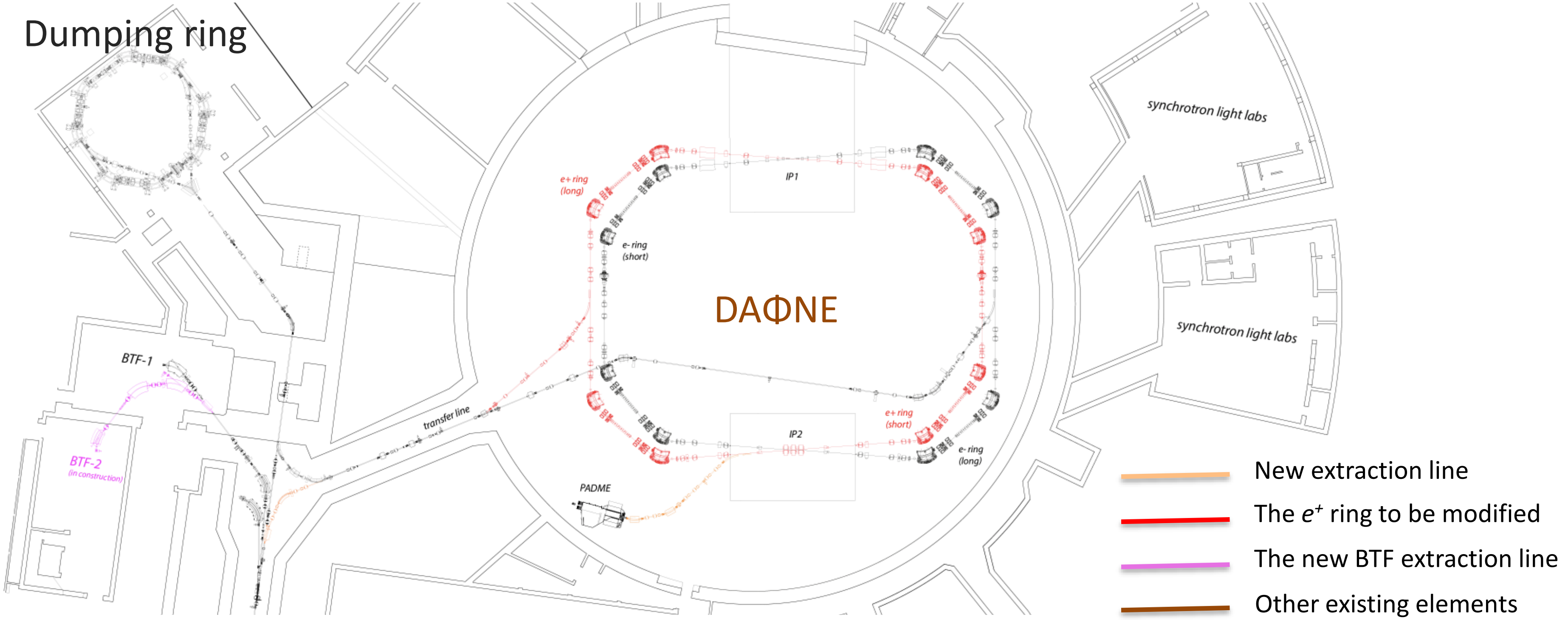
Very precise reconstruction of each *e+* tracks before and after the crystal

- Deflection angle
- Deflection efficiency

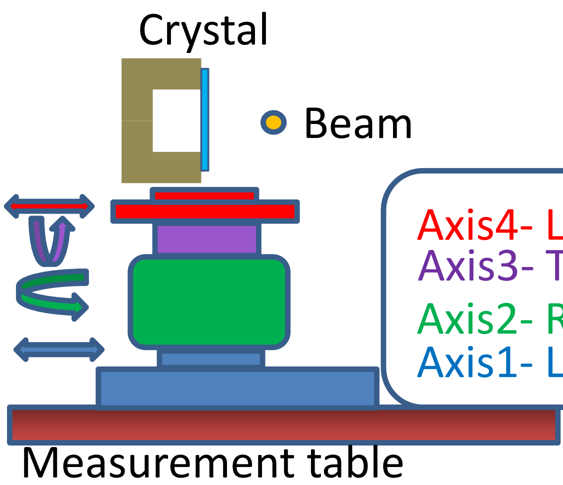
SHERPA 2.0: *what else to extract from DAΦNE*

- By-pass of the dumping ring
- The e^+ & e^- rings has to be separated at the interaction points
- Adjust the DAΦNE ring optics to fit with the crystal system
- Mount the crystal system (gonio, crystal & monitoring)
- An extraction line

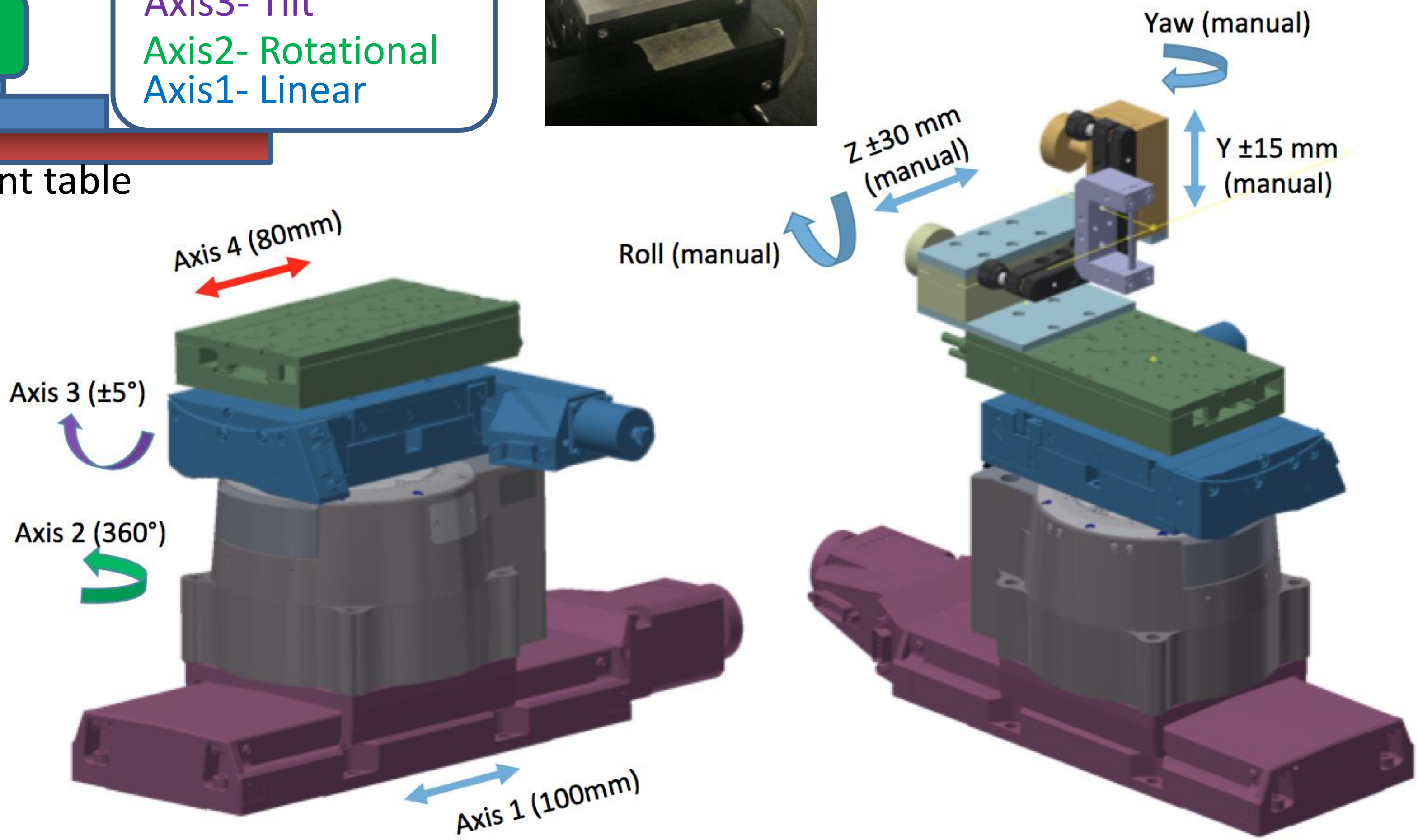
Not included in the project presented here…



The crystal/goniometer assembly



Axis4- Linear
Axis3- Tilt
Axis2- Rotational
Axis1- Linear



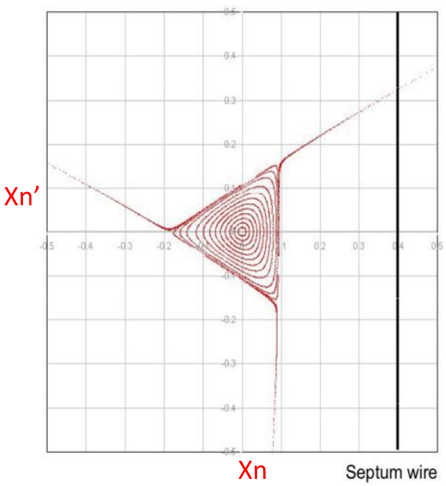
Crystal simulations

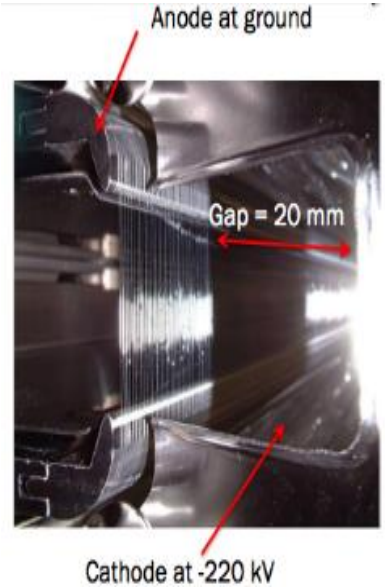
- To simulate coherent processes in crystals exist several crystal simulation routine, both full analytical and Monte Carlo
- They are mainly focused and optimized to high energy hadrons particles, benchmarked with a large amount of data available in literature
- At the moment in SHERPA we are developing two Monte Carlo routines, adapting them to sub Gev leptons (e^- and e^+): GEANT4 [28] and FLUKA, ideal to simulate crystal behavior integrated in an accelerator context
- The GEANT4 routine shows nice performance for sub-GeV e^-, and now we are developing the sub-GeV e^+ version (CH_{eff} for e^+ is higher w.r.t. e^-)
- The FLUKA one is developing in collaboration with the FLUKA team at CERN
- SHERPA data with sub-GeV e- and e+ will be extremely useful also for simulation benchmark in the next future

Shadowing of the ES-septum with a bent crystal

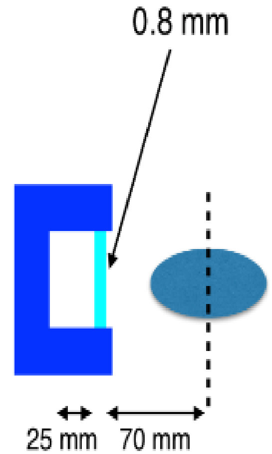
Joint activity with TE/ABT and EN/STI

Phase space during resonant extraction

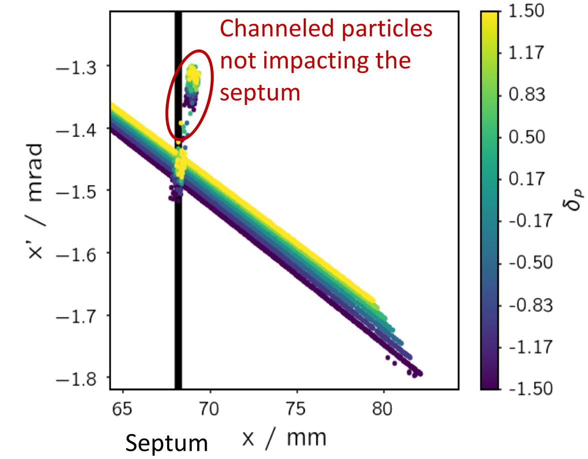


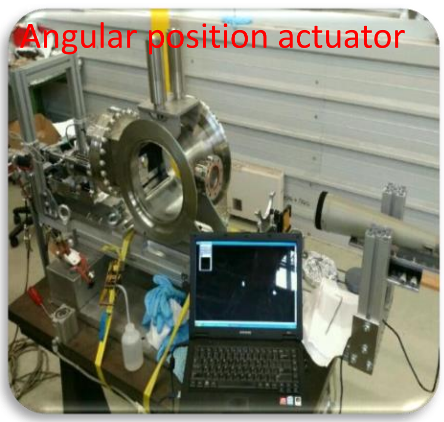


Schematic crystal shape for shadowing

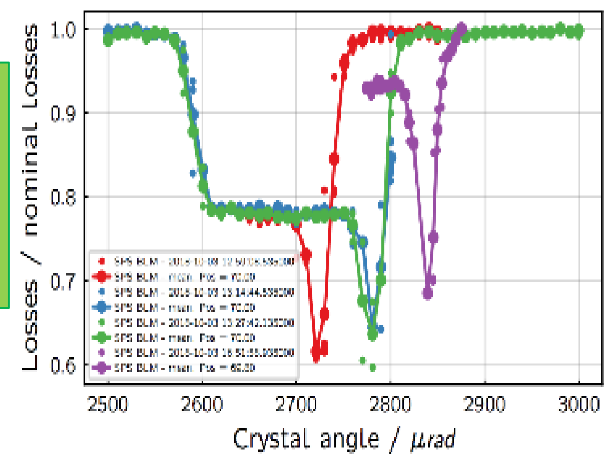


Protons are deflected 5m upstream of the ES, to avoid loss with the anode wires





A loss reduction at the ZS of 40%
was recorded on 1-second 400 GeV spill

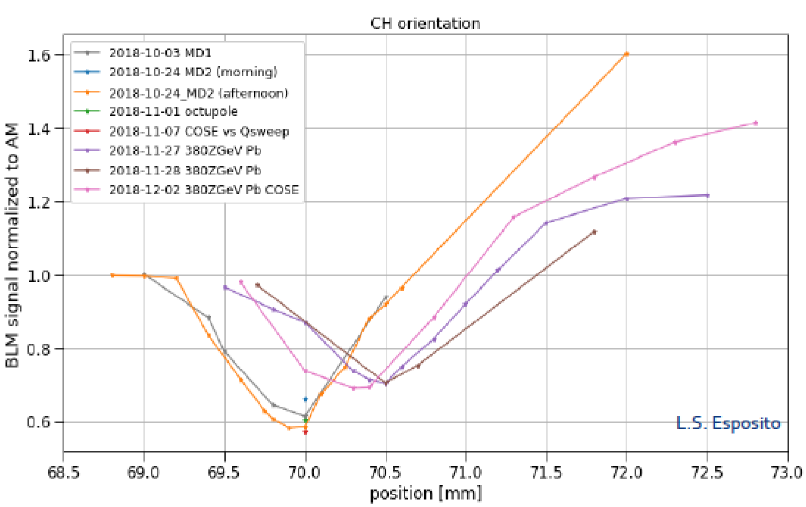


SPS slow extraction with crystal shadowing

- This technique is developed to reduce the number of particles on the SPS extraction septum (ZS wires) and consequently the extraction losses

- A crystal is used upstream to shadow the ZS wires deflecting the particles that would hit him

- In 2018, a feasibility test has been performed and a reduction of 40 % of losses with protons and 30 % with lead ions was observed



PHYSICAL REVIEW ACCELERATORS AND BEAMS **22,** 093502 (2019)

Septum shadowing by means of a bent crystal to reduce slow extraction beam loss

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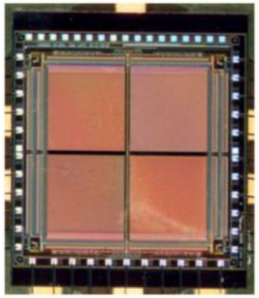
(Received 21 May 2019; published 27 September 2019)

The flux of high-energy protons slow-extracted from the CERN Super Proton Synchrotron (SPS) is limited by the induced radioactivity caused by the beam loss intrinsic to the extraction process. Methods to substantially increase the efficiency of the extraction process are of great interest to fulfill requests for an increasing flux of 400 GeV protons to the present experiments, located in the North Area of the SPS, and also for potential future experiments with very high demanded protons on target. A crystal shadowing technique to significantly reduce the beam scattered and lost on the electrostatic extraction septum during the third-integer resonant slow extraction process has been developed and a prototype system tested with beam. The technique is based on the use of a thin, bent silicon crystal to coherently channel or volume reflect the portion of beam that would otherwise impinge the wire array of the electrostatic septum and instead eject it into the transfer line toward the production targets of the experiments. In this paper, the concept is described and applied to the SPS machine in order to specify the requirements of the prototype crystal shadowing system. Beam dynamics simulations of the prototype system are compared and benchmarked to the results obtained through beam tests, before being exploited to understand the characteristics of the present system and the potential performance reach of an optimized, future operational configuration. The remaining challenges faced to bring the system into operation, the optimization possibilities and other potential applications are discussed.

DOI: 10.1103/PhysRevAccelBeams.22.093502

The telescope sensors

MIMOSA [17]



- ✓ Performance fit with SHERPA needs
- ✓ Already used and developed for the **PADME** experiment at the BTF
- ✓ Well known integration and data management
- ✓ First sensors for free

TIMEPIX [18,19]

- ✓ Performance fit with SHERPA needs
- ✓ Already used and developed for crystal applications at CERN
- ✓ Well known integration and data management
- ✓ First sensors for free at the BTF

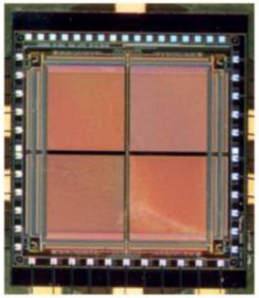
ALPIDE (spare solution) [20]

- ✓ Performance fit with SHERPA needs
- ✓ To be studied and adapted for crystal characterization
- ✓ No sensors available at the BTF

The telescope sensors

MIMOSA [17]

- Sensible area = 13.7 x 21.5 mm^2 (576 x 1152 pixels)
- Pitch: 18.4 µm
- Thickness: 50 µm silicon
- Detection eff. 99.5 % (10^{-4} fake it probability)
- Maximum hit rate = 1 Mhits/s/cm^2



TIMEPIX [18,19]

- Sensible area= 15 x 15 mm^2 (256x256 pixels)
- TOA resolution = 1.56 ns
- Maximum hit rate = 40 Mhits/s/cm^2
- Thickness = 300 µm

ALPIDE (spare solution) [20]

- Sensible area: 15x30 mm^2 (512x1024 pixels)
- Detection eff.: 99% (10^{-5} fake it probability)
- Spatial resolution: ~ 5 µm
- Thickness = 50 µm silicon + 100 µm polyammide + 50 µm Al

SHERPA APPLICATIONS

Resuming the main goals

Spill features pursued:
- Energy spread: $\Delta p/p < 10^{-3}$
- Emittance: $\varepsilon < 10^{-6}$ rad·m
- **Length: ms < Δt < s**

VS

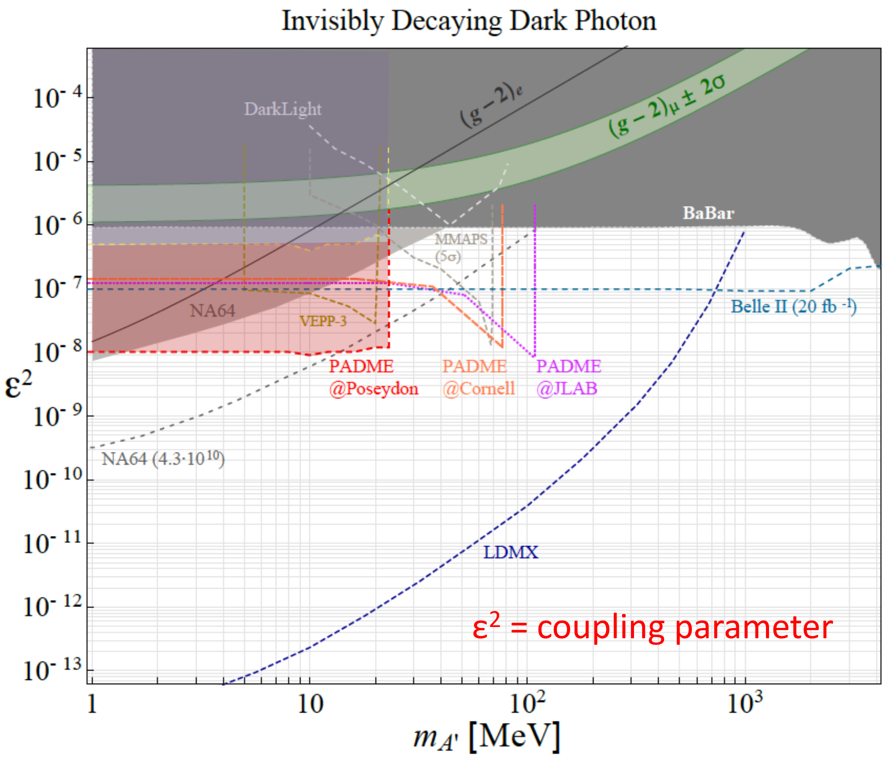
Current spill features from LINAC:
- Energy spread: $\Delta p/p \sim 10^{-3}$
- Emittance: $\varepsilon < 10^{-5}$ rad·m
- **Length: $\Delta t \sim 200$ ns**

- The most immediate application of such beam is **PADME** [21], already running at the BTF, but currently strongly limited by the duty cycle
- With the e^+ beam from the LINAC, the maximum rate on the target is $<10^2$ e^+/ns, keeping the event pile-up and the background at an acceptable level
- Using the **SHERPA** extraction, **PADME** could increase the statistics by a factor 10^4 and its sensitivity by a factor 10^2, obtaining a cutting-edge discovery potential
- Even an unrealistic very bad extraction efficiency of 5%, with the worst-case scenario of a beam pulse length of 100 μs, **SHERPA** still improves by a factor 50–100 the **PADME** sensitivity with respect to the plain LINAC beam
- A beam with such characteristics is interesting for any kind of fixed target experiment

Quasi c.w. positron beam applications

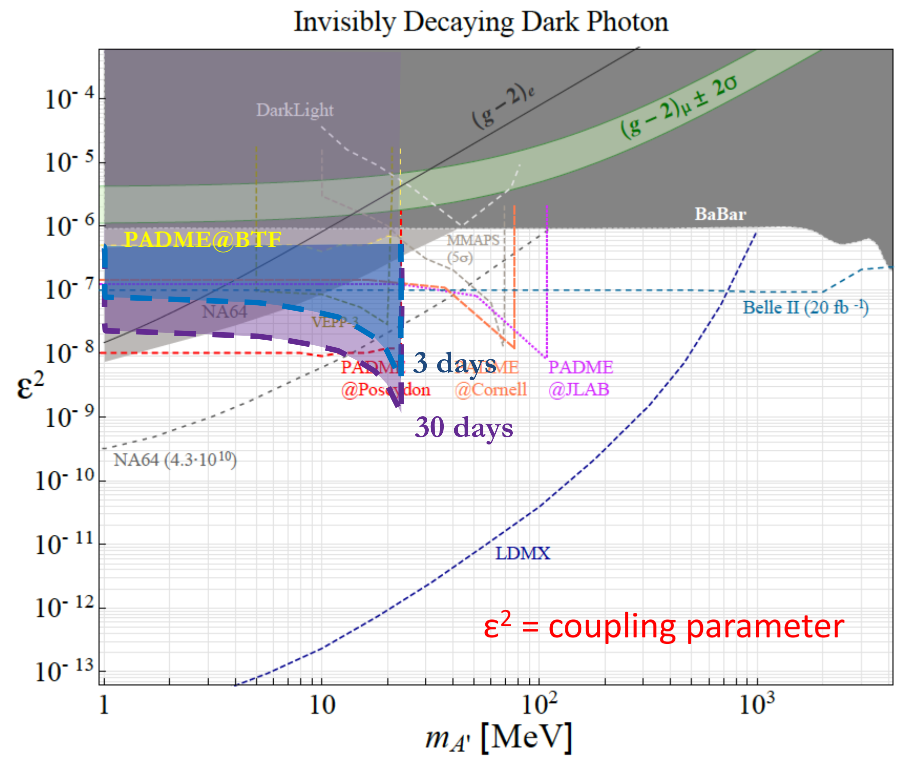
PADME is searching for invisible decays of a dark photon *A'* eventually produced in the annihilation: ***$e^+ e^- \rightarrow A' \gamma$ (e^+ beam on fixed target e^-)***

PADME dark photon sensitivity (invisible decays)



6 months of data-taking at DAΦNE using resonant estraction, 0.4 ms spills (optimistic)

PADME dark photon sensitivity (invisible decays)



~1 month of data-taking at DAΦNE using ultra-slow extraction, (10^{-4} extraction efficiency)

(P. Valente, Ferrara workshop on crystal applications, 13 Apr. 2019: https://agenda.infn.it/event/15101/)