WP11 – ANAC
Assessment of Novel Accelerator Concepts

M. Biagini, INFN-LNF, on behalf of the WP11 Task leaders:
C. Milardi, F. Zimmermann, R. Edgecook, V. Malka

EuCARD Final Meeting

CERN, June 10th, 2013

ANAC objectives

- This WP regroups important topics about novel accelerator concepts in three very different fields:
  - High luminosity colliders: a new collision scheme with an innovative correction of higher order optics aberrations combined with large angle and small beam sizes, to increase the luminosity in colliders
  - Technologies required by neutrino facilities: world's first non-scaling FFAG (Fixed Field Alternate Gradient) (EMMA, STFC) allows for a better knowledge of the beam dynamics, with possible application to neutrino facilities and medicine
  - Plasma wave accelerator techniques: the measurement of ultra-short electron beams is instrumental to the assessment of laser plasma acceleration (LPWA)
- Infrastructures involved:
  - DAΦNE e^+e^- storage ring, INFN, Frascati Nat. Labs, Italy
  - LHC collider, CERN
  - EMMA ns-FFAG Ring, STFC, Daresbury Laboratories, UK
  - LOA, CNRS, France
  - SPARC-LAB, INFN-LNF, Italy

WP11 - Tasks

- Task 11.1. ANAC Coordination and Communication
  (Coordinator M. Biagini, LNF - INFN)
  - Coordination and scheduling of the WP tasks
  - Monitoring the work, informing the project management and participants within the JRA
  - WP budget follow-up
- Task 11.2. Design of Interaction Regions for high luminosity colliders
  (Coordinator C. Milardi,INFN-LNF)
  - Design of a new IR based on the Crab Waist concept for the upgraded KLOE experiment at DAΦNE
  - Study the possible integration of the Crab Waist collision scheme into the LHC collider upgrade *(Coordinator F. Zimmermann, CERN)*
- Task 11.3. Upgrade of the EMMA FFAG Ring
  (Coordinator R. Edgecock, STFC)
  - Design, build and test the external diagnostics systems for EMMA ring
  - Commission EMMA using the diagnostics and perform the necessary experiments to evaluate non-scaling optics for a variety of applications
- Task 11.4. Instrumentations for novel accelerators
  (Coordinator V. Malka, LOA - CNRS)
  - Design, build and test of detectors for emittance measurements of electron beams delivered by laser plasma accelerators

Deliverables & Milestones

Deliverables of tasks	Description/title	Nature	Delivery month
11.1.1	ANAC web-site linked to the technical and administrative databases	O	M36
11.2.1	DAΦNE IR design for the upgraded KLOE detector	R	M24
11.2.2	Study of an IR design for LHC upgrade	R	M36
11.3.1	Results from the operation of EMMA using the new diagnostics	R	M36
11.4.1	Preliminary electron beam emittance measurement report	R	M36

Delayed to M48

Mile-stone	task	Description/title	Nature	De[illegible]	[illegible]ment
11.1.1	11.1	1st annual ANAC review meeting	[illegible]	[illegible]	
11.1.2	11.1	2nd annual ANAC review meetin[illegible]	[illegible]	[illegible]24	
11.1.3	11.1	3rd annual ANAC review m[illegible]	[illegible]	M36	
11.1.4	11.1	Final ANAC review r[illegible]	O	M48	
11.2.1	11.2	DAΦNE beam[illegible] definitio[illegible]	O	M12	Preparatory for IR study
11.2.2	11.2	Co[illegible] scheme	O	M18	Preparatory for IR study
11.3.1	11.3	[illegible]nts for electron beam [illegible]ostics	R	M2	
11.3.2	11.3	Construction of the electron beam diagnostics completed	R	M14	
11.3.3	11.3	Commissioning of EMMA completed	R	M20	
11.4.1	11.4	Electron beam emittance meter finished	P	M24	Alignment and pre test

All accomplished

Task 11.2: Large Piwinski Angle and Crab-Waist collision scheme

Coordinator C. Milardi, LNF - INFN

- Design of a new Interaction Region (IR) based on a new collision scheme for storage-ring colliders characterized by Large Piwinski Angle, low β* and Crab Waist (LPA & CW) for boosting the luminosity
- LPA & CW implementation at:
  - DAΦNE collider upgrade in view of the KLOE2 experiment data-taking
  - Possible upgrade for one of the LHC Interaction Regions
- Task Partners:
  - BINP, Russia *(beam-beam simulations, dynamic aperture optimization)*
  - CERN, Switzerland *(evaluation of LPA & CW implementation for an LHC IR)*
  - CNRS, France *(luminosity monitor design, beam measurements)*
  - INFN, Italy *(new IR design for the KLOE2 experiment)*

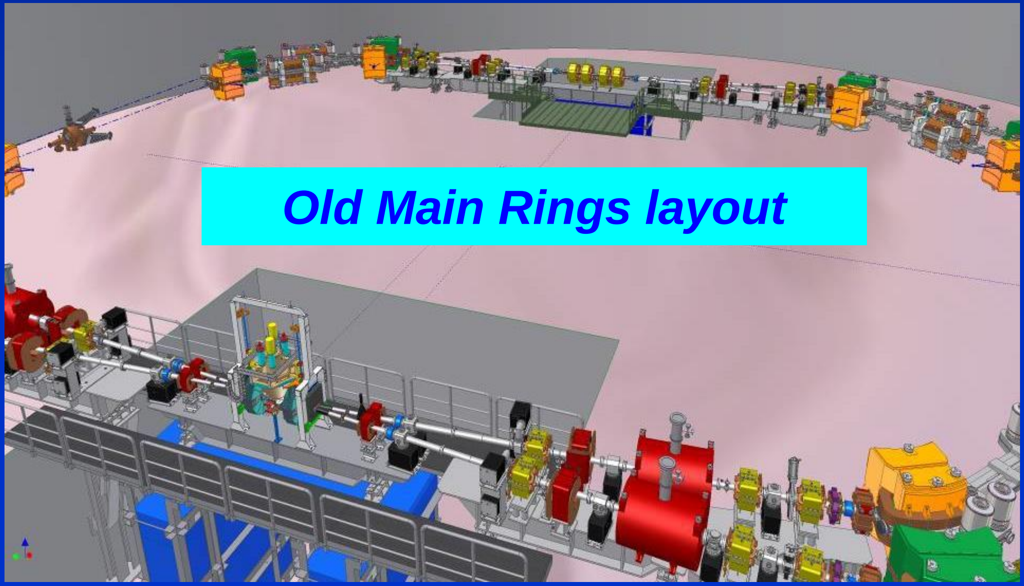
New DAΦNE IR for KLOE2

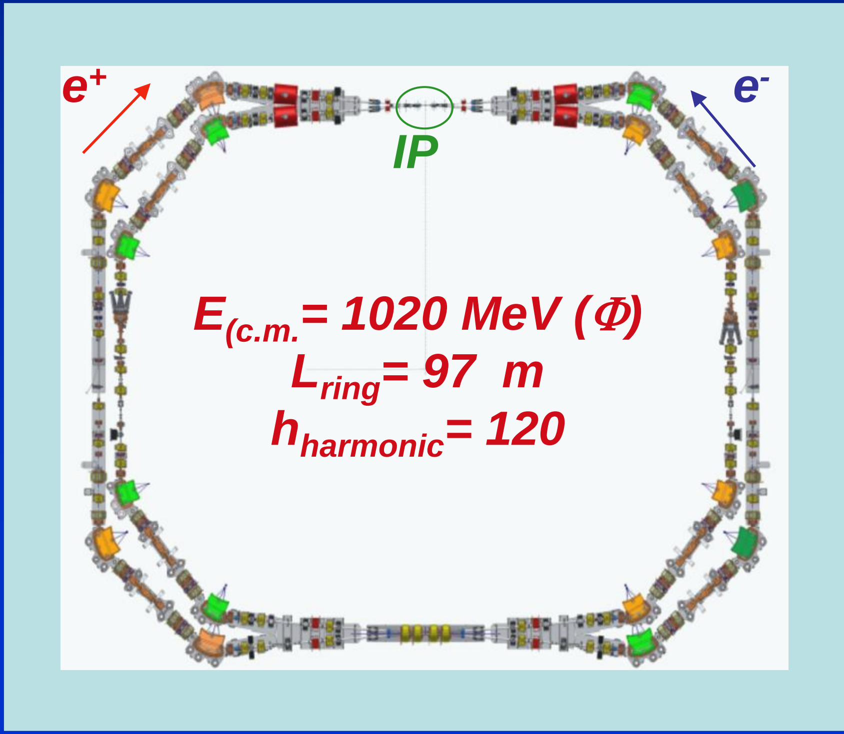
- The design has followed the LPA&CW principles already tested on the same ring for a different experiment (Siddharta, non magnetic detector), which has accomplished a boost of a factor of 3 in Luminosity
- The presence of a detector solenoid is an added complication for the x-y coupling introduced
- The final design and realization has involved not just the IR but all the rings, including simulations of collective effects and the introduction of diagnostics and devices to reduce beam instabilities

LPA & CW at DAΦNE

- Collider upgrade for new collision scheme:
  - new IR
  - new Ring Cross Region replacing former IR2
  - new injection kickers
  - new bellows
  - transverse and longitudinal feedback upgrade

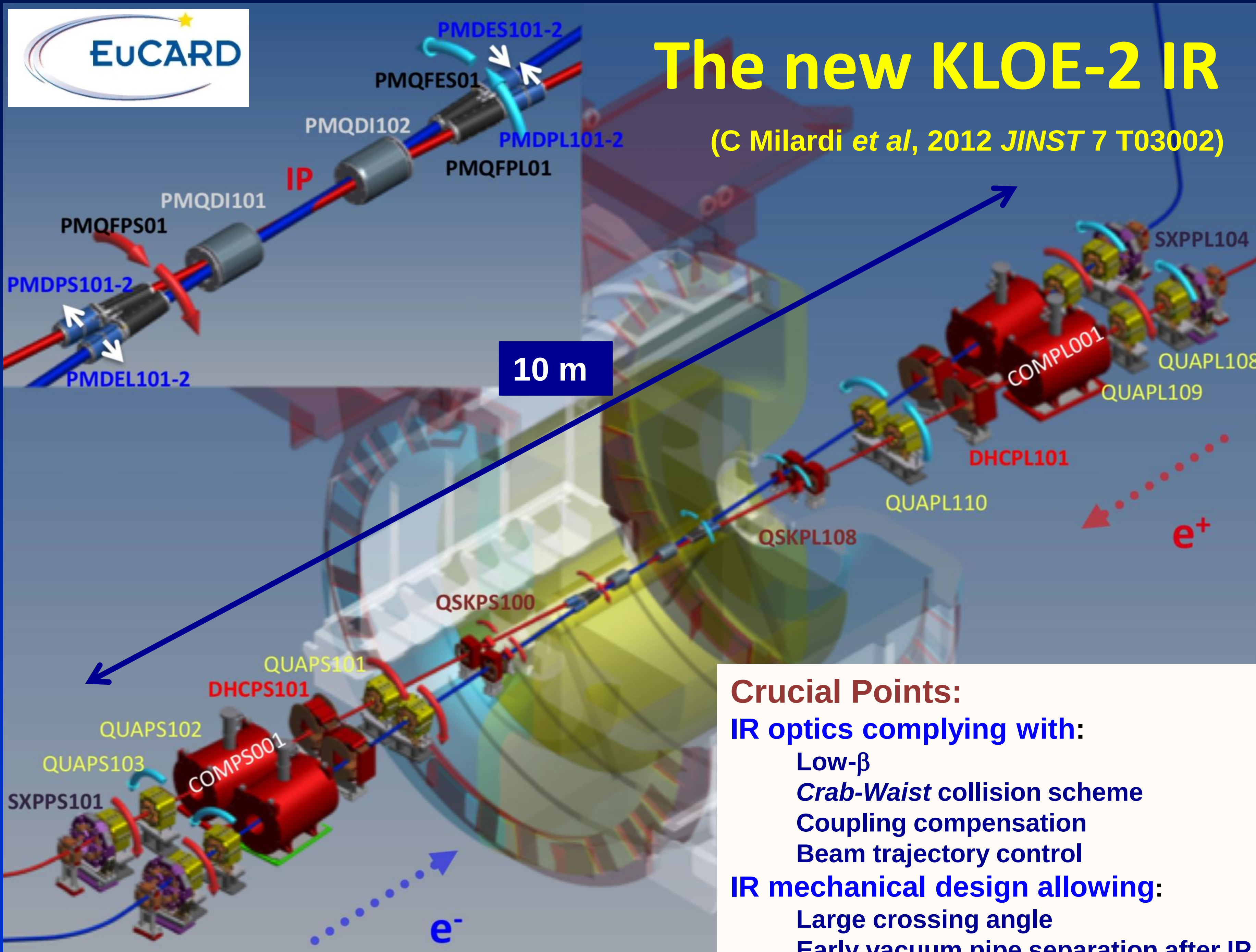
Much more than that was actually accomplished





The new KLOE-2 IR

(C Milardi *et al*, 2012 *JINST* 7 T03002)



Crucial Points:

IR optics complying with:

- Low-β
- *Crab-Waist* collision scheme
- Coupling compensation
- Beam trajectory control

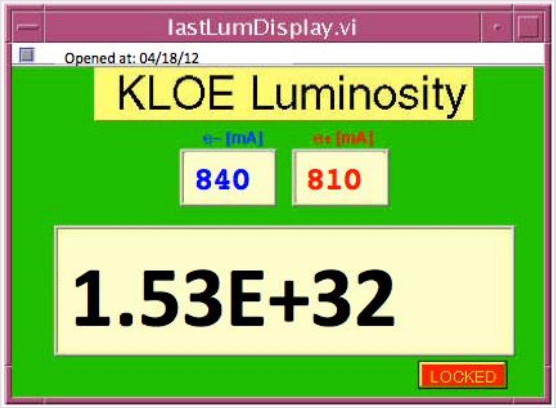
IR mechanical design allowing:

- Large crossing angle
- Early vacuum pipe separation after IP

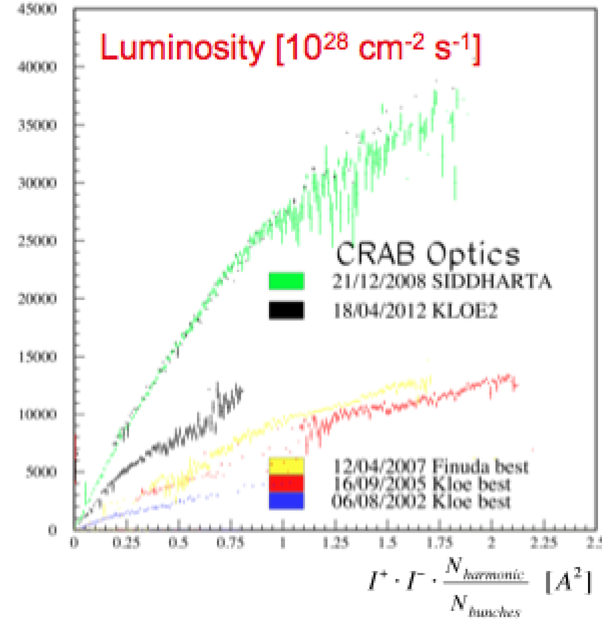
Achievements so far

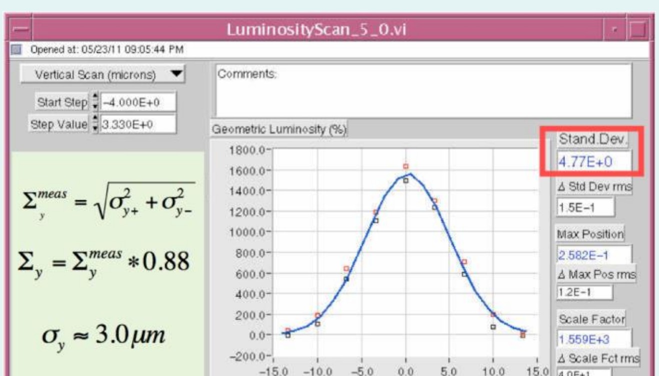
Last year DAΦNE activity: machine commissioning for KLOE2 and starting of detector data taking

Peak Luminosity (100 bunches)



Comparison of DAΦNE Best Runs with and without *Crab-Waist*

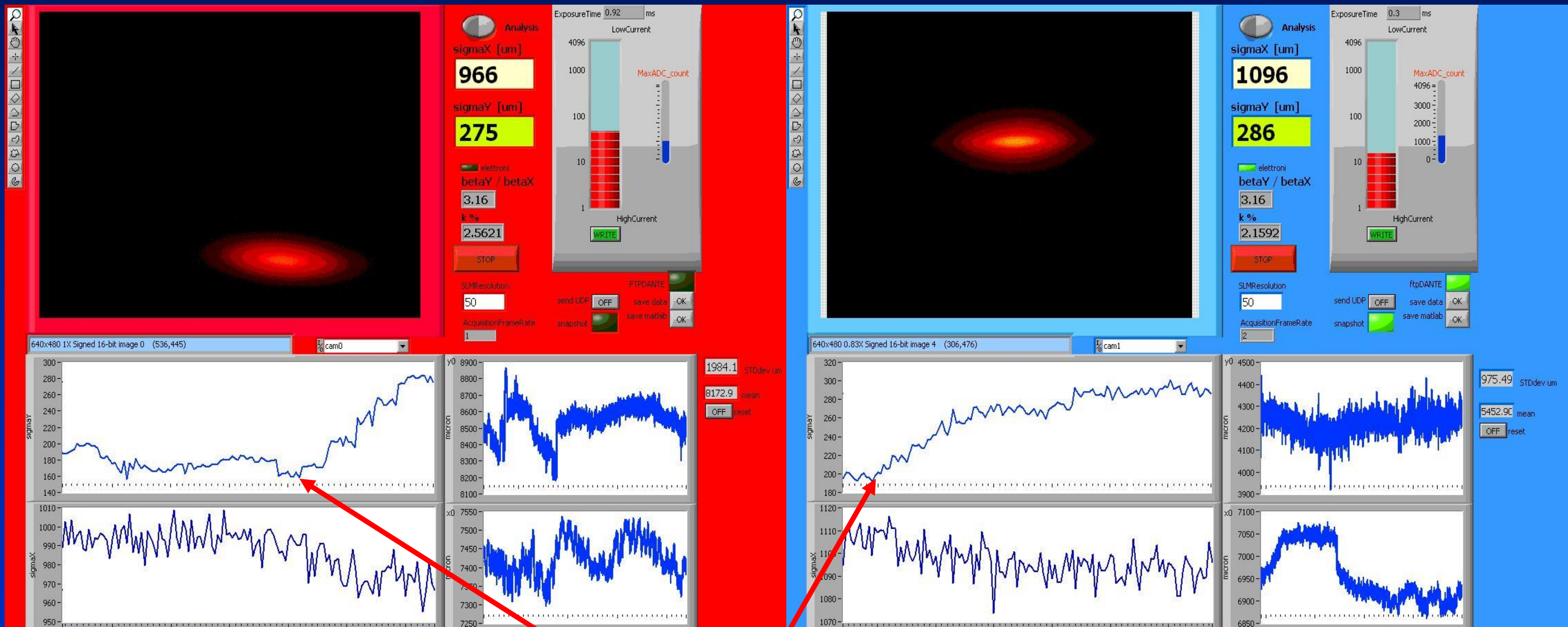




Vertical beam-beam scan

σ_y is ~15% lower than the best measured in the past

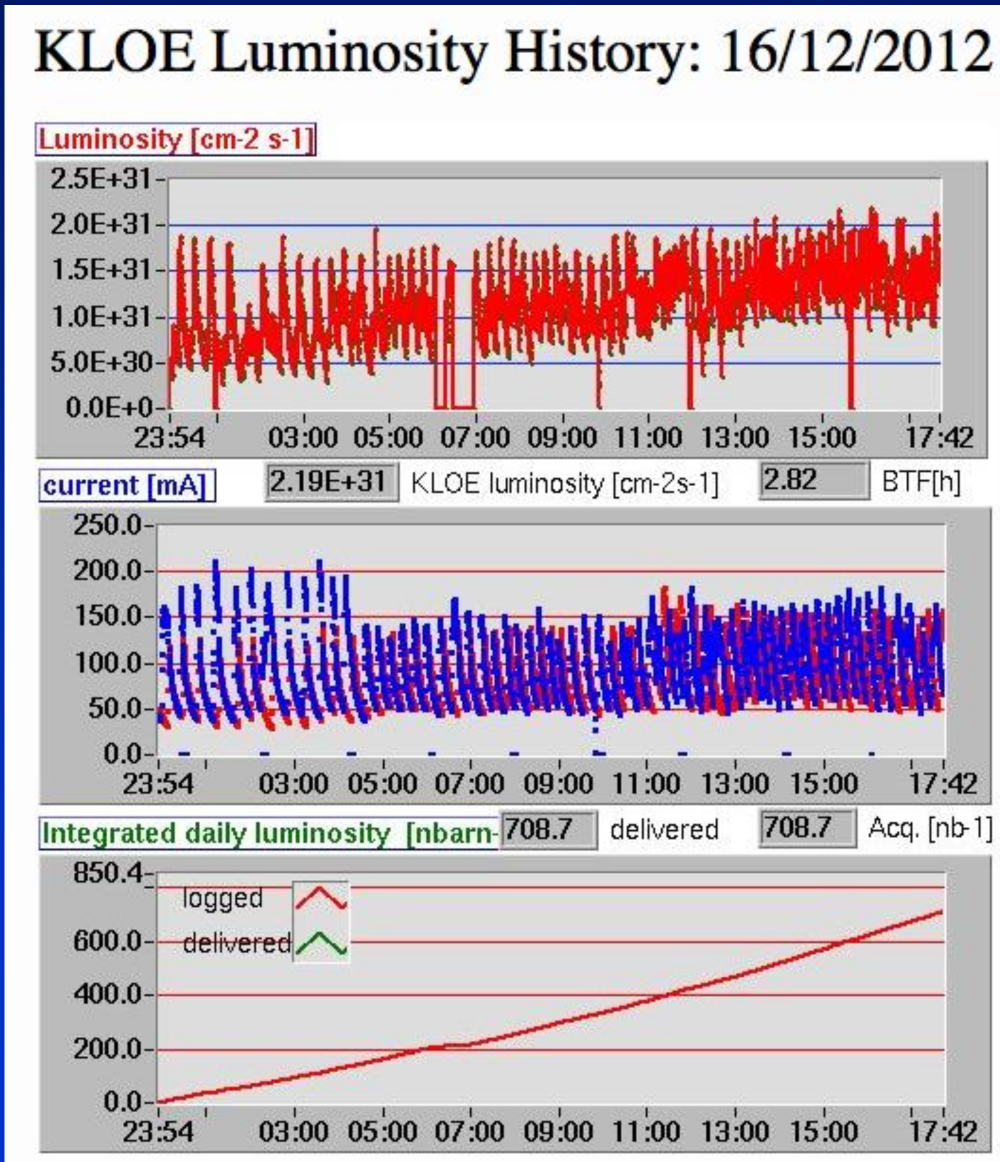
Crab Waist Sextupoles Test

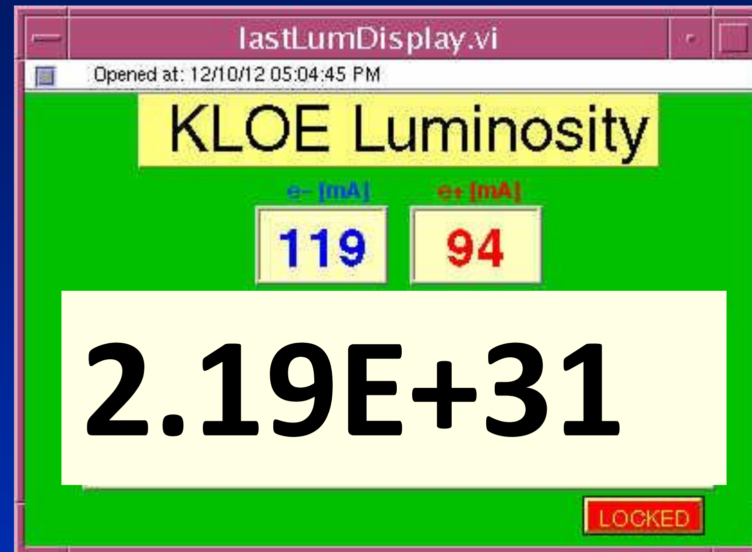


900 mA x 500 mA

Images from SLM when switching off the CW sextupoles in both rings: 200 A → 0 A

10 bunches collisions





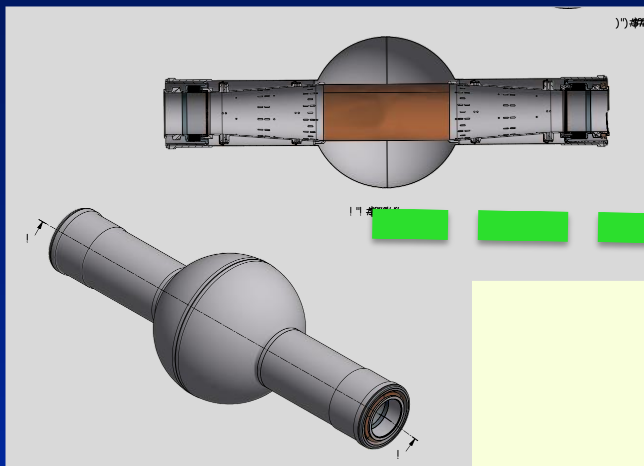
Projection:

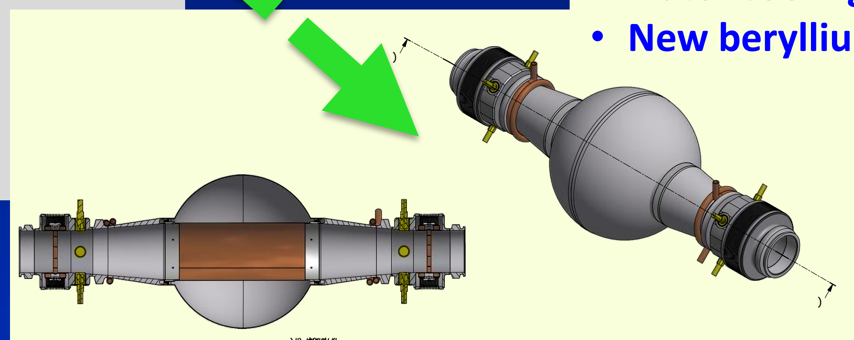
$L \approx 2.2 * 10^{32}\ cm^{-2}s^{-1}$

for 100 bunches

IR consolidation in 2013

Relying on beam measurements, operation experience and profiting from the shut down planned to complete the KLOE-2 detector upgrade



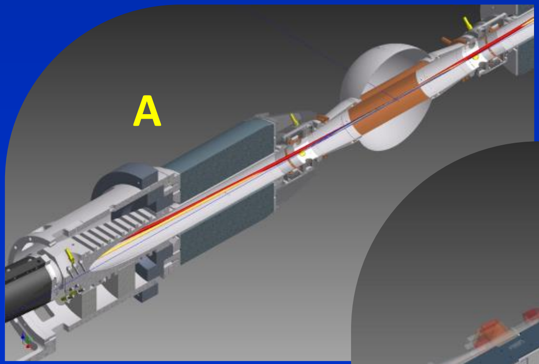


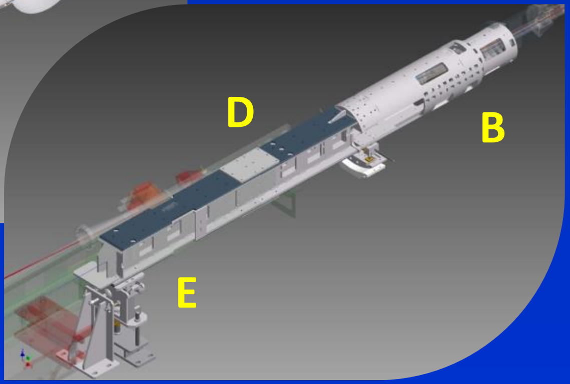
Spherical vacuum chamber evolution

- **Single vacuum chamber tapered**
- **New bellows with improved design**
- **2 BPMs around the IP**
- **water cooling added**
- **New beryllium screens**

Mechanical modification

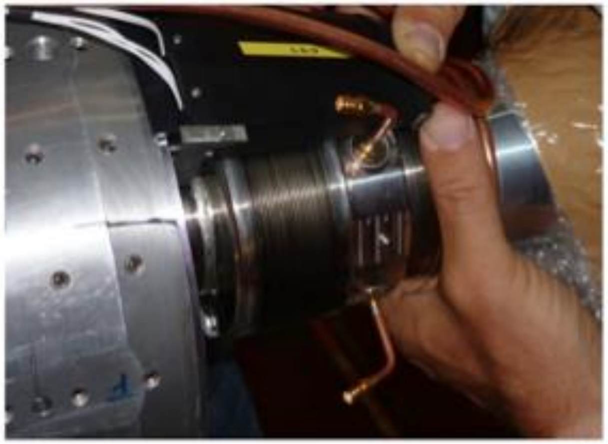
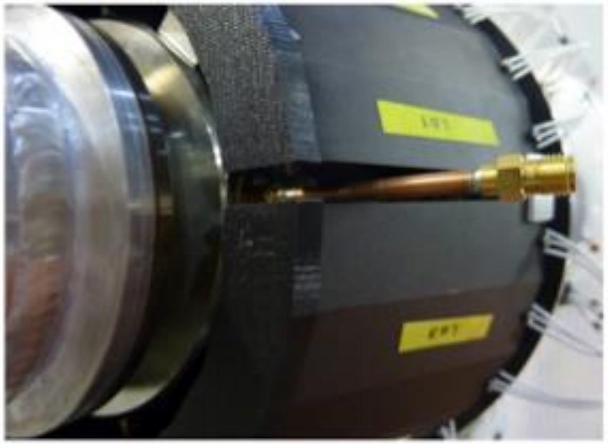
A. Lead toroidal shields added
B. New cylindrical vacuum chamber support
C. Improvements on alignment tools
D. H supports reinforced with plates
E. Modification of tail support of the girder
F. Temperature probes added
G. Carbon fiber composite additional supports





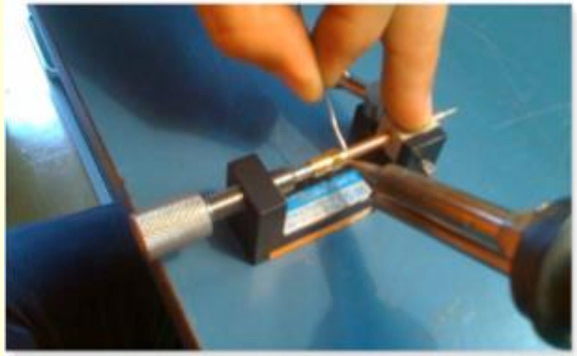
New Beam Position Monitors

Installation of the inner Beam Position Monitor


Lab preparation of the BPM feedthrough extension

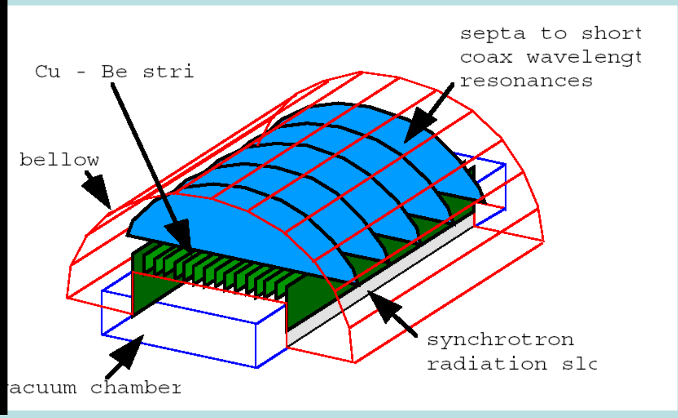
2 around the IP

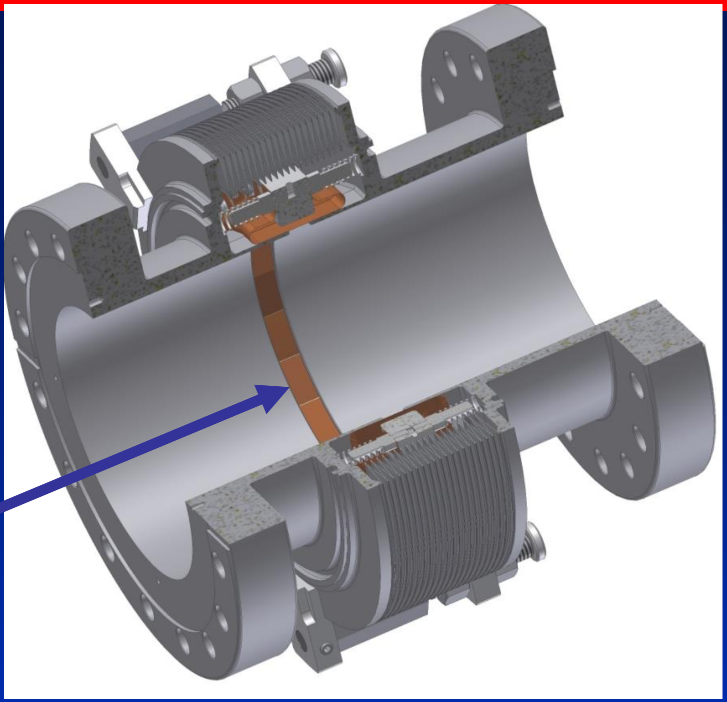



1 close by the injection septum **for each ring**

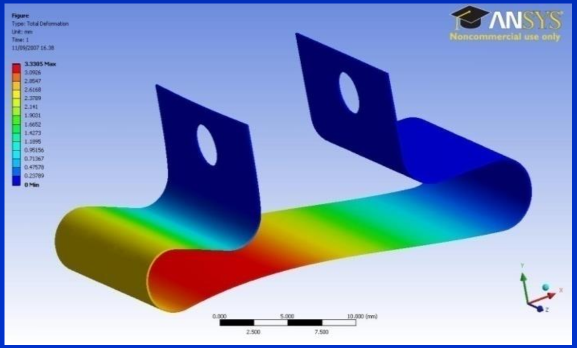
New Bellows

OLD BELLOW





- Shielding based on Be-Cu Ω strips 0.2 mm thick
- Lower impedance and improved mechanical specifications

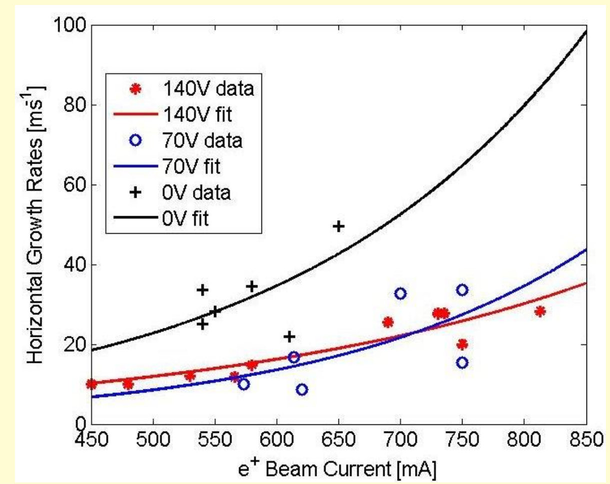


(courtesy of S. Tomassini)

Clearing electrodes for e-cloud suppression

- DAΦNE is the first collider operating routinely with long electrodes, for e-cloud mitigation
- Electrodes increase the instability threshold so that more positron current can be injected
- Measurements of e-cloud instabilities growth rate, transverse beam size variation, and tune shifts along the bunch train, demonstrate their effectiveness in mitigating e-cloud induced effects (D. Alesini et al, Phys. Rev. Lett. 110, 124801 (2013))

Horizontal instability Growth Rate measured using bunch-by-bunch feedback as a function of the electrode voltage

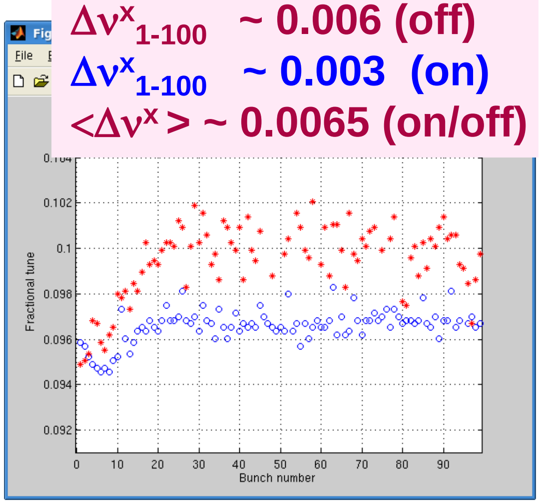


Tune Spread measurements

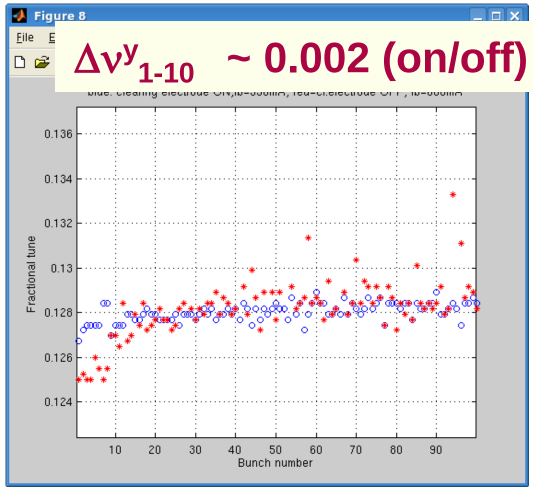
$\Delta\nu^x_{1-100}$ ~ 0.006 (off)

$\Delta\nu^x_{1-100}$ ~ 0.003 (on)

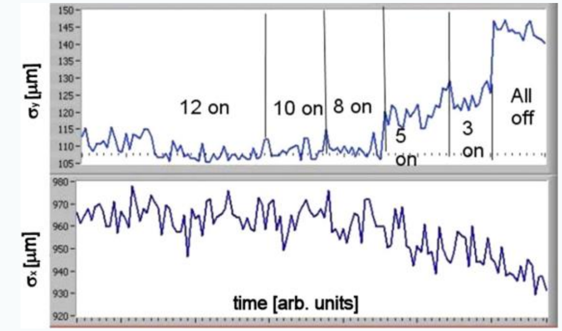
$<\Delta\nu^x>$ ~ 0.0065 (on/off)



$\Delta\nu^y_{1-10}$ ~ 0.002 (on/off)

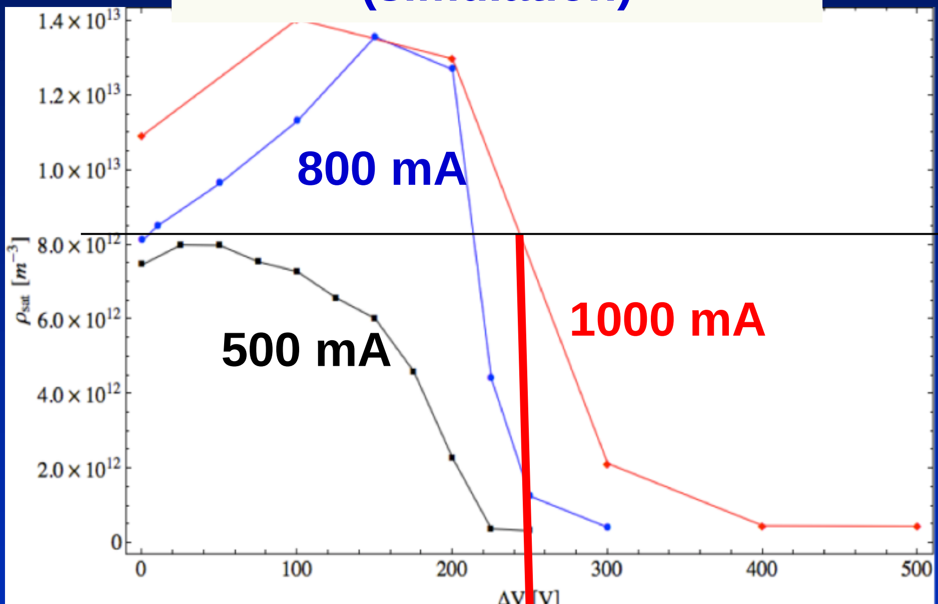


Beam Dimension



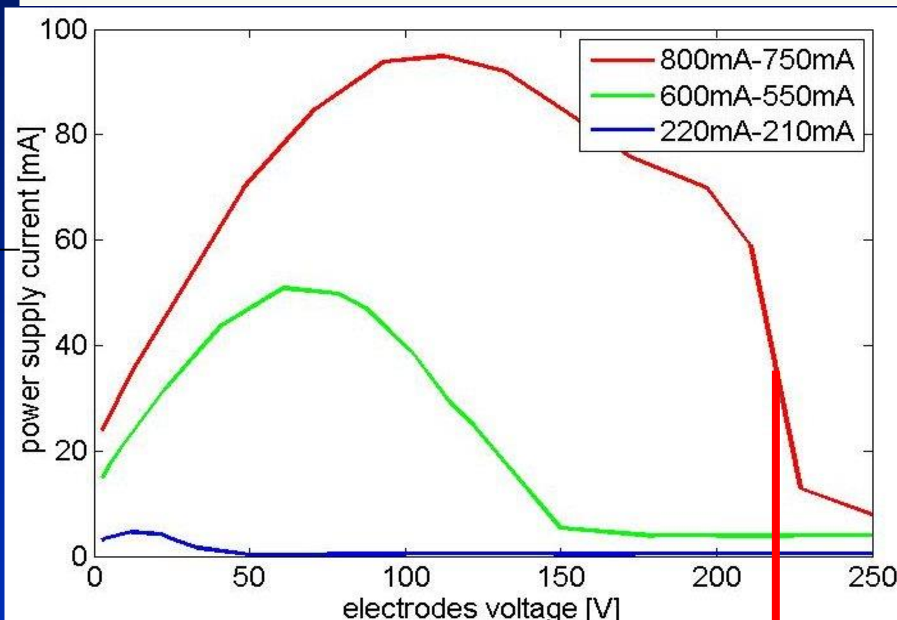
Effectiveness of Electron Cloud Clearing Electrodes

e-cloud density build-up (simulation)



(Courtesy of T. Demma)

Measured absorbed e-cloud current



With a maximum voltage of 250 V the electrodes are effective till a positron current of the order of 800-900 mA
For higher beam currents higher voltages are required → new higher voltage power supplies are being installed

What can be expected, at regime, from the DAΦNE consolidation?

- **Much lower fault rate -> uptime of the order of 80%**
- **Improved and faster injection due to:**
  - **better linac performances**
  - **enhanced diagnostic for Linac, TLs, A and MRs injection sections**
- **More stable operation**
  at low level due to:
  - **reliable low-level control**
  - **fast and exhaustive diagnostic and fault analysis of the interlocks coming from magnet power supplies and vacuum gages**
  - **no mechanical vibration in the IR**

  at higher level:
  - **new IP vacuum pipe**
  - **improved feedback system**
  - **orbit automatic control**
- **Higher positron current thanks to more efficient clearing electrodes**
- **More powerful diagnostics at the IP**
- **IR alignment from scratch**
- **Stable optics in the Main Rings**

C. Milardi, 46th LNF Sci. Comm., May 2013

Conclusions on SubTask 11.2.1

- A new IR, based on large crossing angle, Crab-Waist compensation of the beam-beam interaction and compatible with a large detector, has been designed and implemented on DAΦNE
- It satisfies the design requirements in terms of optics and betatron coupling compensation and beam-beam behaviour
- However the machine operation has been seriously slowed down by several technical problems and → radical consolidation program involving the whole accelerator complex needed
- Machine consolidation undertaken during 2013 shut-down (required to install the new layers of the KLOE-2 detector) is still in progress
- Electrodes for e-cloud mitigation are routinely used and showed to be effective in keeping under control e-cloud driven instabilities. Even better performances are expected with the new higher voltage power supplies

Publications for SubTask 11.2.1

- C Milardi et al, “The DAΦNE Interaction Region for the KLOE-2 run”, DAΦNE-TECHNICAL-NOTE-IR-14 (2009)
- C Milardi et al, “High Luminosity Interaction Region Design for Collisions with Detector Solenoid”, IPAC 2010
- C. Milardi, “DAΦNE & KLOE: a nice interaction”, http://eucard.web.cern.ch/EuCARD/news/newsletters/issue04/index.html
- A. Drago et al, “Mitigation and control of instabilities in DAΦNE positron ring”, arXiv:1204.5016 [physics.acc-ph]
- T. Demma, “Study of Electron Cloud Effects in the DAΦNE Φ-Factory for the KLOE-2 Run”, EuCARD-NOT-2011-002
- C Milardi et al,” DAΦNE tune-up for the KLOE-2 experiment”, IPAC 2011
- C Milardi et al, “High luminosity interaction region design for collisions inside high field detector solenoid”, 2012 JINST 7 T03002
- D. Alesini, et al, “Experimental Measurements of e-Cloud Mitigation using Clearing Electrodes in the DAΦNE Collider”, IPAC 2012
- S. Tomassini, “Measurement and Vibration Studies on the Final Focus Doublet at DAΦNE and new collider Implications”, IPAC 2013
- D. Alesini et al, “DAΦNE Operation with Electron-Cloud-Clearing Electrodes”, Phys. Rev. Lett. 110, 124801 (2013)

Subtask 11.2.2: Crab-waist collisions for LHC

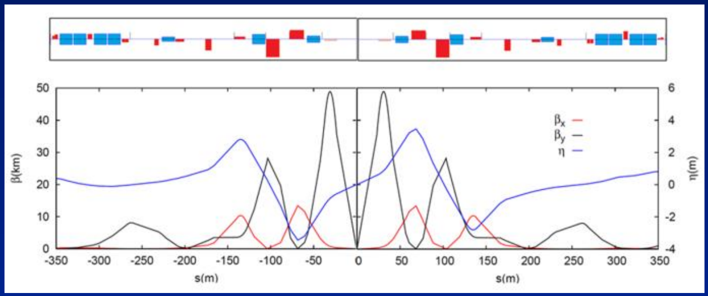
Coordinator F. Zimmermann, CERN

- Crab-waist collisions have been proved to effectively suppress resonances for σ_x/σ_y >10 (D. Shatilov et al) and were tested at DAΦNE
- However implementation of crab-waist collisions in **LHC**, if compared with **DAΦNE**, is not straightforward due to:
  - Same charge of the beams
  - Larger L* (23 m, 20.4 cm)
  - Larger Energy (7 TeV, 0.51 GeV)
  - Same emittance in the two planes ($\varepsilon_x/\varepsilon_y=1$, $\varepsilon_x/\varepsilon_y=200$)
- A new IR has been studied with :
  - Large Piwinski angle (reduces geometric luminosity but allows operation at much higher brightness and with significant β^*_y decrease through a reduction in the length of the collision area)
  - Flat beams
  - Symmetric optics
  - Chromatic correction in the IR
  - Crab-waist collisions (suppressing the X-Y betatron resonances excited by the beam-beam interaction)

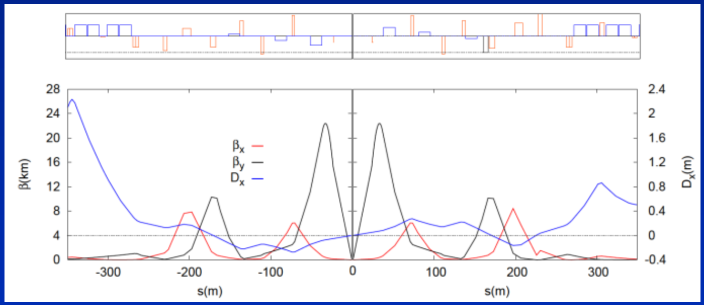
LHC IR design

Includes different lattice designs and a new Double-Half Quadrupole

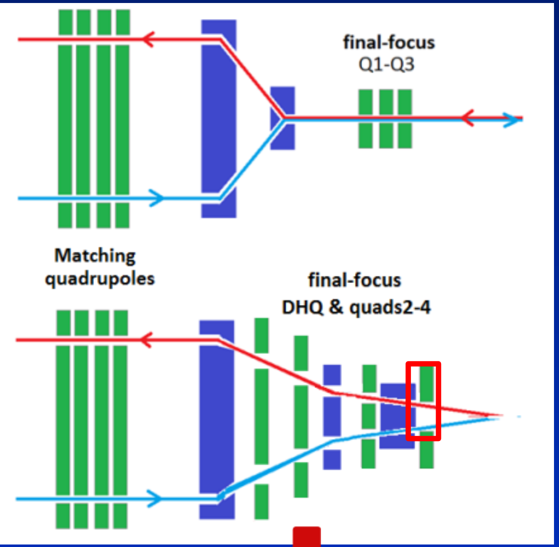
Schematic comparing the LHC crossing scheme and the proposed flat-beam scheme. The reference orbits for both beams are indicated. Bending magnets are shown in blue and quadrupoles in green



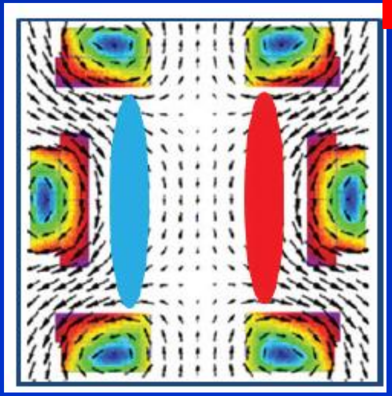
$\beta^*_{x,y}$	3.5 m, 3.5 cm
θ_c	2.6 mrad
ϵ_N	2.2 μm
$\sigma^*_{x,y}$	32.1, 3.2 μm
σ_z	7.55 cm
ϕ	3.1

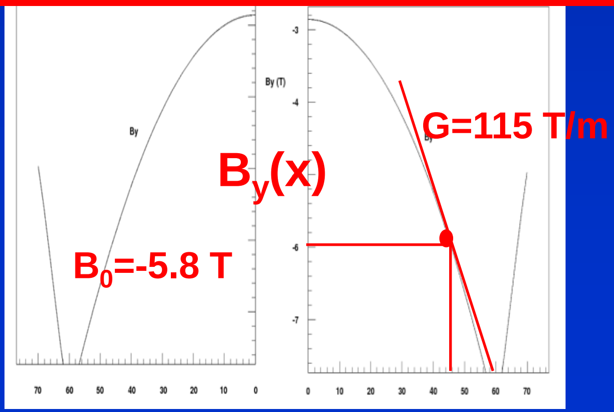


$\beta^*_{x,y}$	1.5 m, 1.5 cm
θ_c	4.0 mrad
ϵ_N	2.2–3.75 μm
$\sigma^*_{x,y}$	15.2–26.0, 2.0–3.5 μm
σ_z	7.55 cm
ϕ	9.9–5.8



Double-half quadrupole (DHQ)





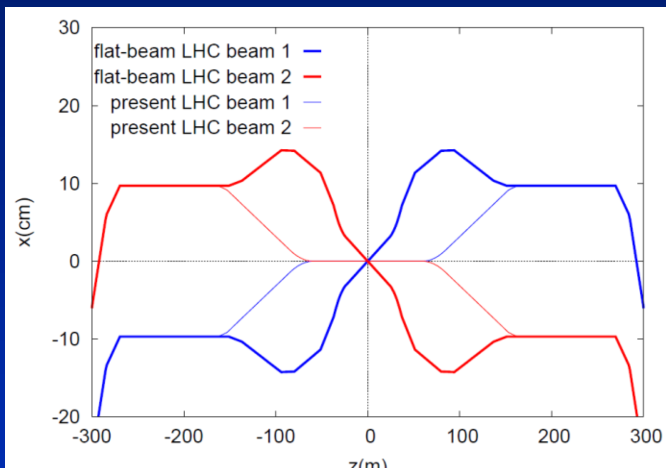
Sextupolar field can correct chromaticity locally by an appropriate value of the dispersion. Another sextupole in a zero dispersion region compensates for geometric aberrations

LHC IR design

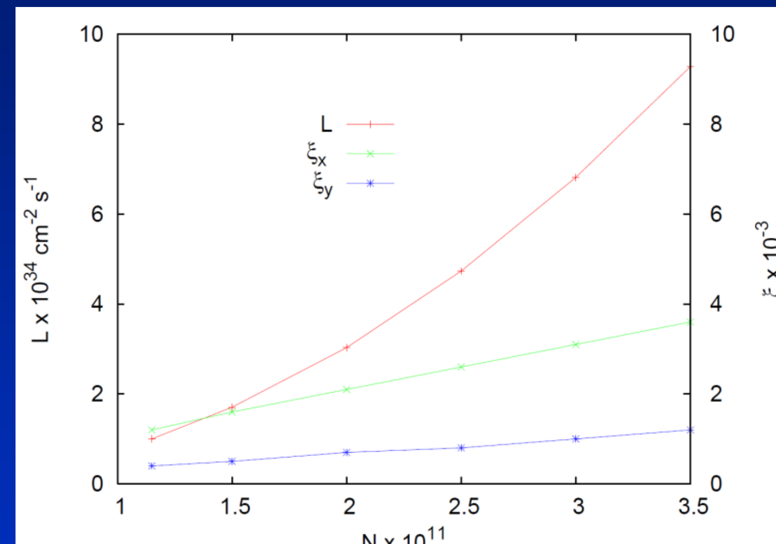
- The scheme requires a non-zero slope of dispersion at the IP and a new single-aperture final focusing element, which combines dipole and sextupolar field components
- The quadrupole feed down field focuses both beams in the vertical plane. The sextupole component together with the non-zero dispersion is used to correct the chromaticity locally
- Orbit, dispersion and beta functions were matched to the existing LHC arcs. Dynamic aperture is still a concern
- The geometric aberrations could be corrected perfectly by a second sextupole if the magnets were short, however the DHQ is quite long, with intrinsic octupolar aberrations difficult to compensate with a second sextupole. A segmentation of the final quadrupole, to confine the sextupole field to a shorter region, is proposed as mitigation

LHC IR design, orbit studies

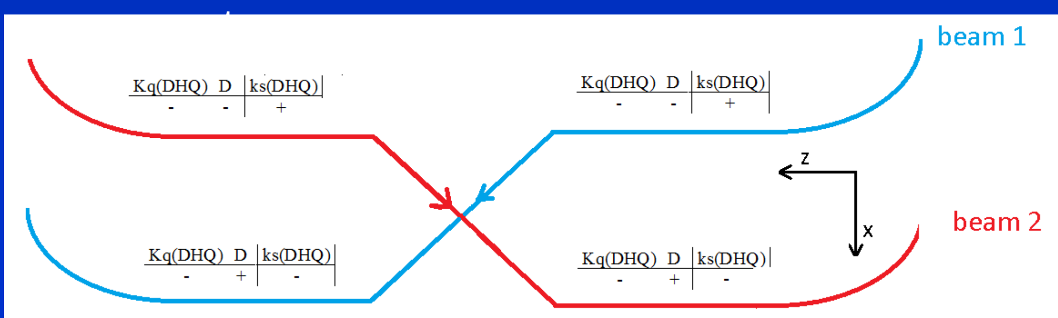
LHC reference orbits in the straight section for the new flat-beam optics, compared with the present LHC (inner)



Potential luminosity and beam-beam tune shifts at one IP for ε_N=2.2 μm as a function of bunch population. For the luminosity calculation, the total number of bunches is 2808

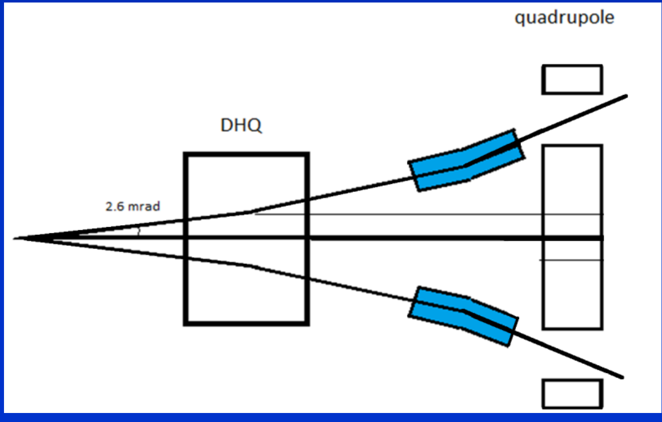


Schematic reference orbits of the two beams, together with signs of DHQ quadrupolar strength, of the dispersion, and of the DHQ sextupolar



Conclusions on SubTask 11.2.2

- An elegant conceptual optics solution for a future LHC luminosity upgrade, combining flat beams ($\beta_y^*/\beta_y^*=100$), local chromatic correction, large Piwinski angle and the option of crab-waist collisions was developed
- A similar final focus system, for a single beam was designed and qualified for the LHeC. Possible merits of, and parameters for, applying the described approach at the HE-LHC have also been investigated
- Proposed IR needs a big effort in terms of hardware: DHQ, dipoles in the IR, and new IR SC quadrupole magnets with opposite polarity
- Difficult also to match the IR optics (symmetric) to the arc (antisymmetric)
- There is a high ratio sextupolar/quadrupolar component in the DHQ. This element must be long to focalize the β^*_y and the sextupolar integrated field is very large → difficult to compensate for geometric aberrations
- A solution could be to split the final lens in a shorter DHQ and a SC quadrupole
- An experiment with quasi-flat beams was prepared for the LHC. It should be executed after resuming LHC beam operation in 2015



Publications for SubTask 11.2.2

D. Shatilov, et al, Application of frequency map analysis to beam-beam effects study in crab waist collision scheme. PRST-AB 14:014001 (2011).
J.L. Abelleira,et al, ”Design Status of LHeC Linac-Ring Interaction Region”, *Proc. of the 2011 International Particle Accelerator Conference, San Sebastian, Spain,* p. 2796 (2011).
J.L. Abelleira et al, “Final-Focus Optics for the LHeC Electron Beam Line”, *Proc. of the 2012 International Particle Accelerator Conference, New Orleans,USA,* p. 1861 (2012).
The LHeC study group, J L Abelleira *et al* 2012 *J. Phys. G: Nucl. Part. Phys.* 39 075001.
J.L. Abelleira, ”LHeC Final Focus System”, contribution to *2012 CERN-ECFA-NuPECC Workshop on the LHeC, 14-15 June 2012, Chavannes-de-Bogis, Switzerland.*
J.L. Abelleira et al. CERN-ATS-Note-2012-091. MD Large Piwinski angle
J.L. Abelleira,”Towards an extremely-flat beam optics with large crossing angle for the LHC”, contribution to EUCARD Annual Meeting, April 25-27, 2012, Warsaw, Poland.
J.L. Abelleira et al, “Local Chromatic Correction Scheme and Crab-Waist Collisions for an Ultra-Low Beta* at the LHC “, Proc. IPAC’12 New Orleans, U.S.A. p.118.
J.L. Abelleira, “Flat beam IR optics”, contribution to joint EuCARD-HiLumi-Snowmass Workshop on “Frontier Capabilities for Hadron Colliders.” February 22-23; 2013, CERN, Switzerland.
J.L. Abelleira et al, ”LHC Optics with Crab-Waist Collisions and Local Chromatic Correction”. Proc. IPAC’13 Shanghai, China.
J.L. Abelleira et al, ”Matching Antisymmetric Arc Optics to Symmetric Interaction Region”, Proc. IPAC’13 Shanghai, China.

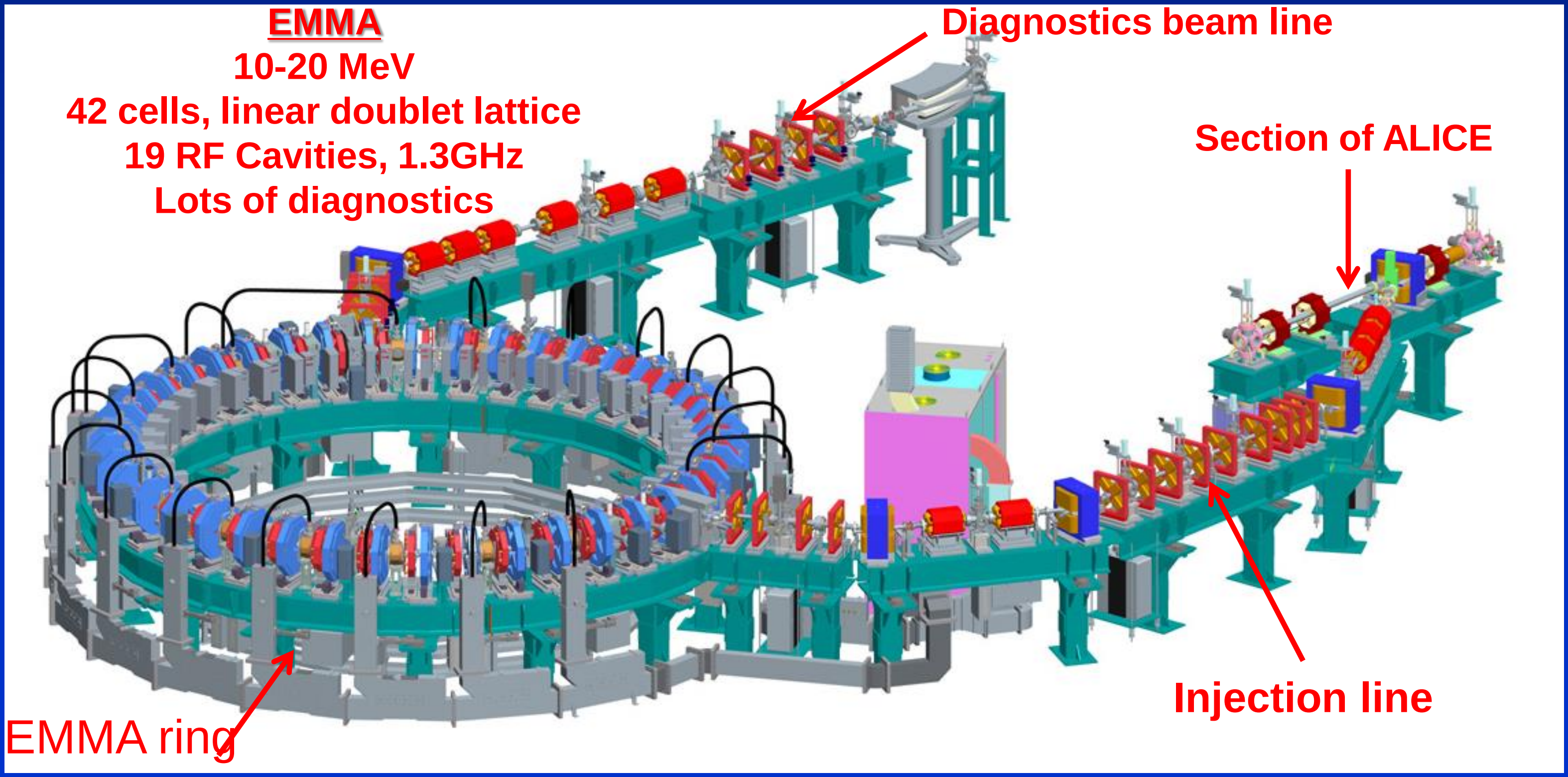
Task 11.3: Non-scaling FFAG

Coordinator T.R. Edgecock, STFC

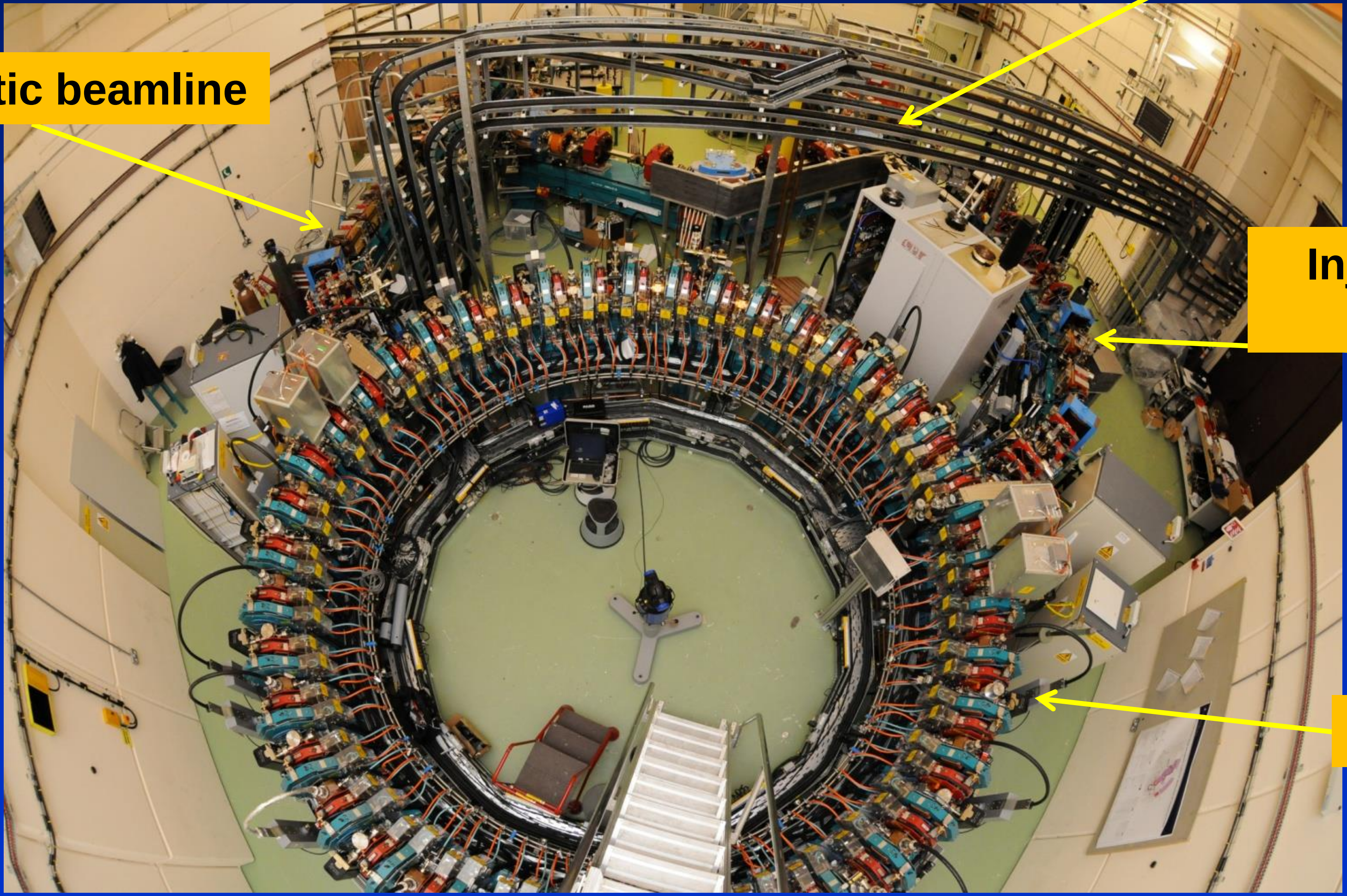
- Non-scaling FFAGs can be used for:
  - muon acceleration in a Neutrino Factory
  - proton & ion acceleration for cancer therapy
  - muon production for μSR
  - spallation neutron production and ADSR
- So far, only scaling FFAGs built
- EMMA → proof of principle ns-FFAG
  - built at Daresbury Laboratory
  - electron acceleration from 10-20 MeV
  - uses ALICE (energy recovery linac prototype) as injector
  - diagnostics is very important

Within ANAC

- External diagnostics design, construction and testing
- Installation in the beam-lines
- Commissioning and experimental running
- Task Partners:
  - STFC, UK
  - CNRS, France (later substituted by Huddersfield University, UK)



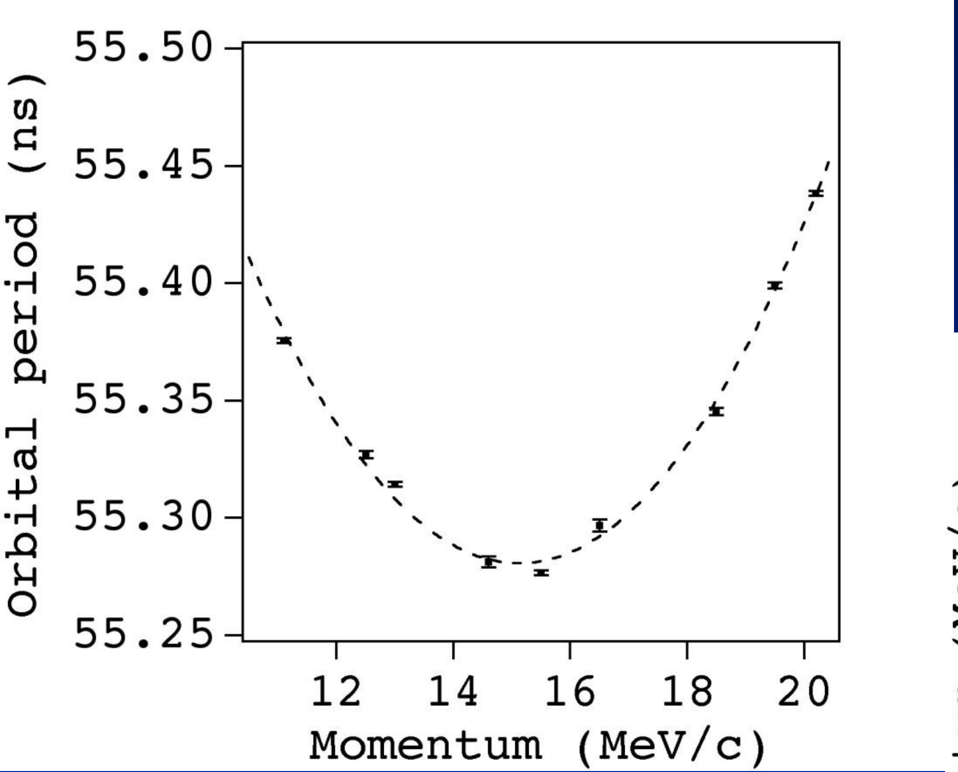
EMMA



EMMA Status

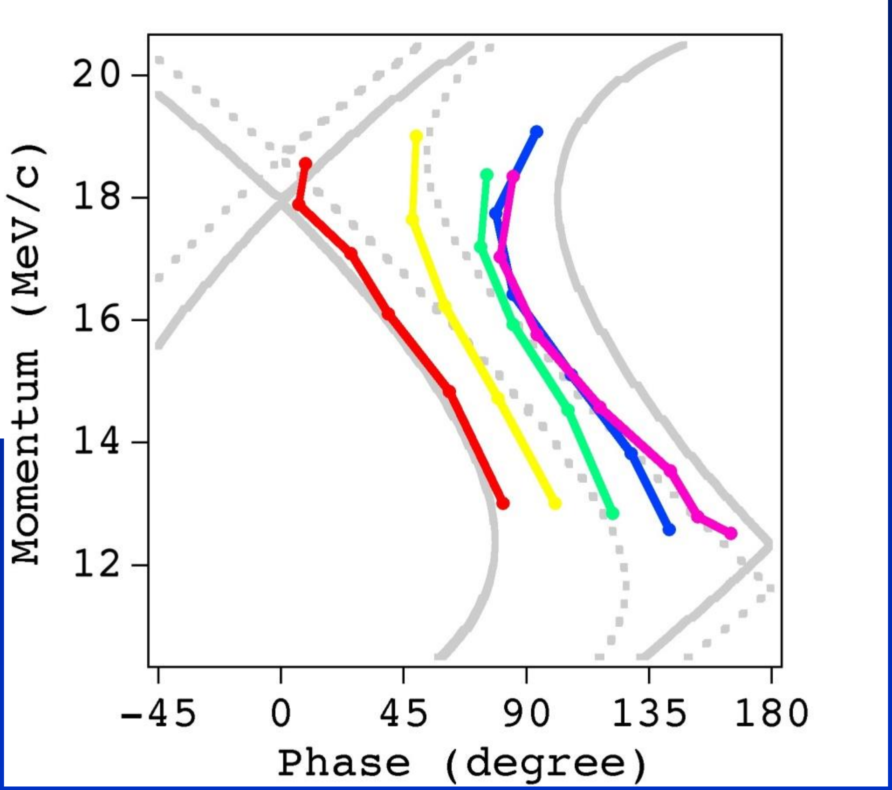
- EMMA construction completed at start of 2011
- Commissioning completed in April 2011
- Most goals achieved:
  - linear non-scaling FFAGs work!
  - first ever demonstration of serpentine acceleration
  - parabolic time of flight as expected
  - tune variation as expected
  - multi-integer resonances crossed without beam quality degradation
- Results published:

Machida et al., Nature Physics 8, 243 (2012)

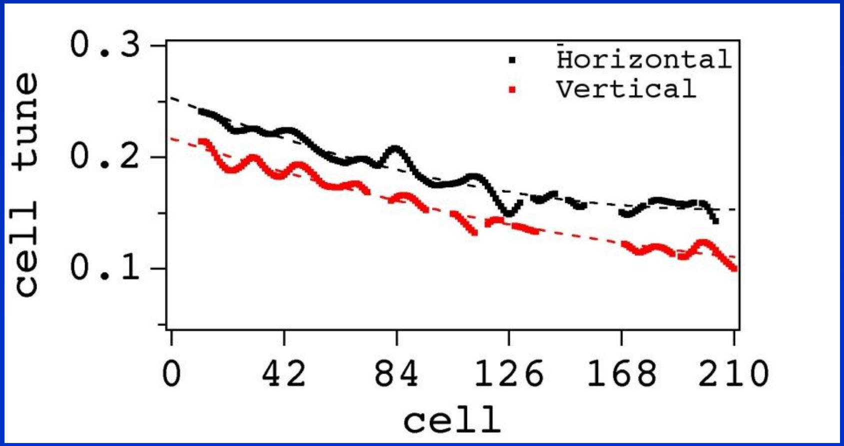


Results from EMMA commissioning spring 2011

Time of flight



Longitudinal phase = serpentine acceleration



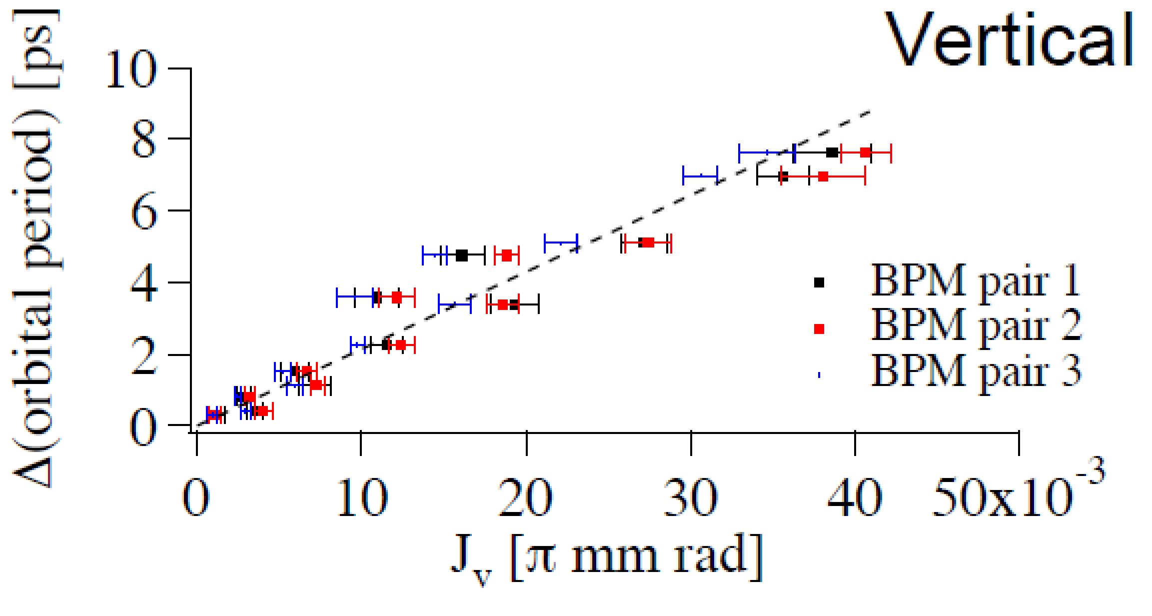
Tunes

Since then…

- Study remaining muon acceleration issues:
  - Acceptance
  - Amplitude dependent time of flight
- Understand closed orbit errors
- More general studies:
  - Experiment for PRISM demonstration
  - Tune crossing experiment – still on-going

Time of flight dependence on beam amplitude

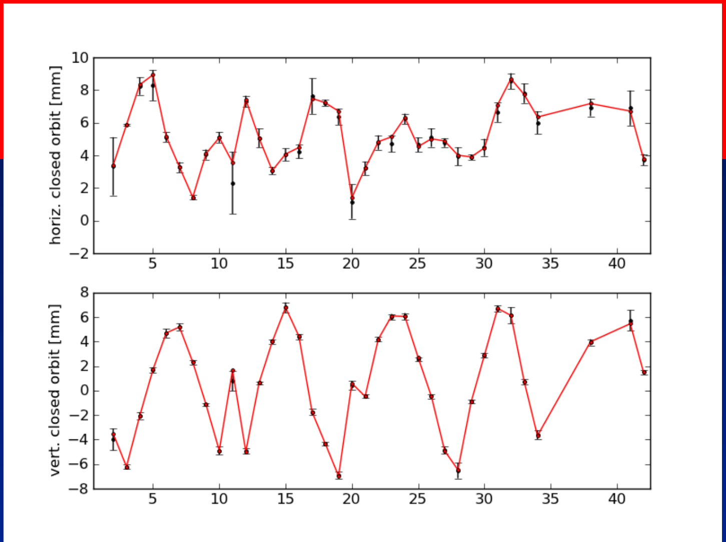
Vertical measurement at 16.15 MeV/c

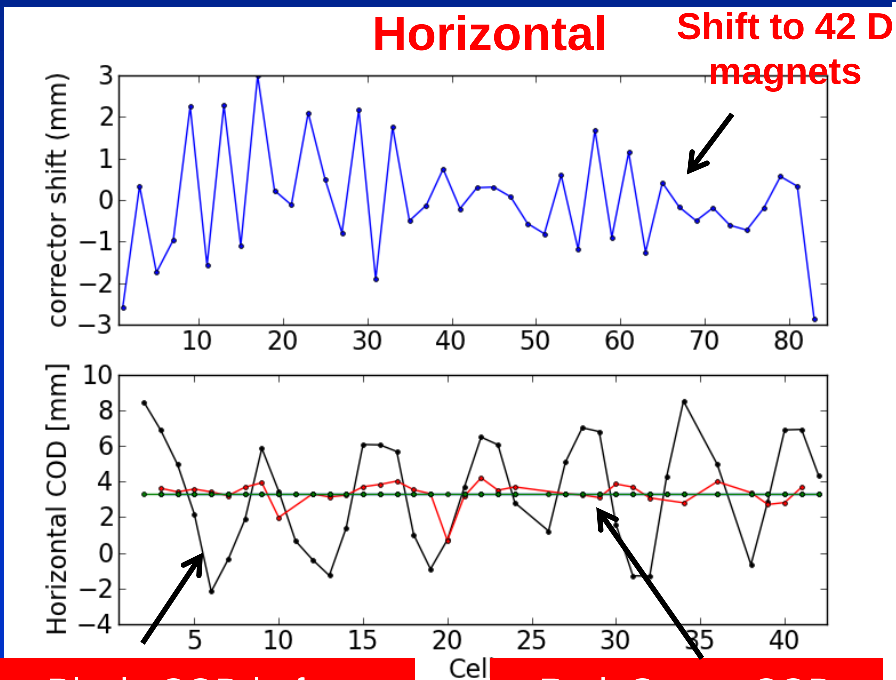


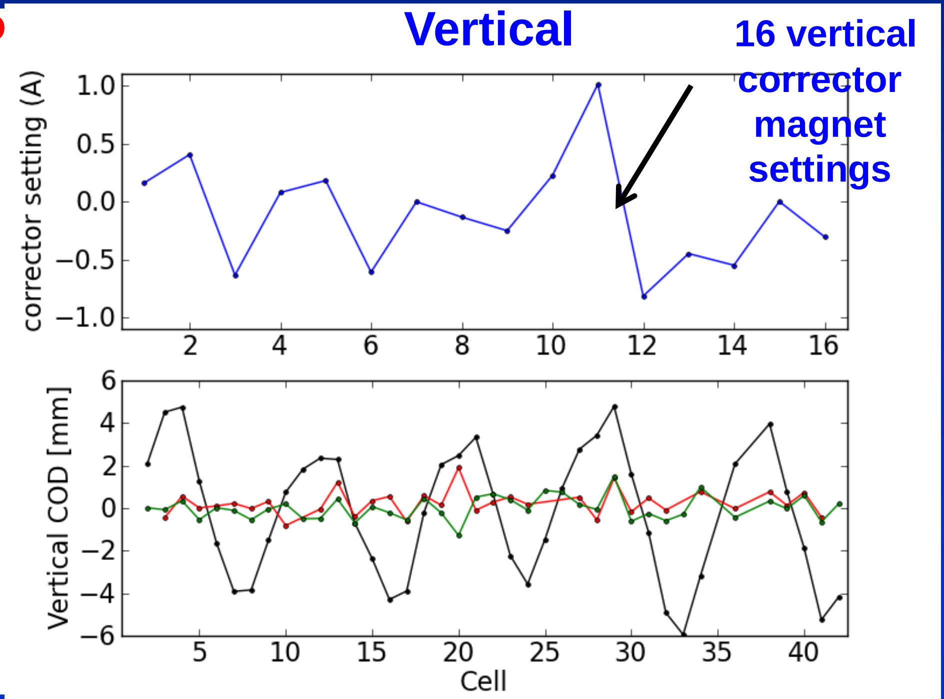
- As expected in Berg, NIMA 570 15 (2007)
- Measured EMMA acceptance: ~1 π mm rad

COD correction

- "Large" closed orbit errors:
  - horizontal: due to septum stray field
  - vertical: origin unclear
- COD correction at single momentum 17.9 MeV/c







Black: COD before correction

Red, Green: COD after correction using 2 different methods

Same correction performed at all momenta

Publications for Task 11.3

- R. Edgecock, C. Beard, J. A. Clarke, et al, “The EMMA non-scaling FFAG”, Proc. IPAC2010, Kyoto, May 2010
- R. Edgecock, “Commissioning of the EMMA non-scaling FFAG”, Proc. IPAC2010, Kyoto, May 2010
- R.Barlow et al, "EMMA - The world's first non-scaling FFAG", Nucl Instrum Meth A 624 (1) 1-19 (2010)
- R. Edgecock, “The EMMA FFAG”, Int.J.Mod.Phys. A26 (2011) 1736-1743, April 2011
- S.Machida et al, "Acceleration in the linear non-scaling fixed-field alternating-gradient accelerator EMMA, Electron Model for Many Applications", Nature Physics 8 243-247 (2012)
- K.Marinov et al, "Design, tests and commissioning of the EMMA injection septum", Nucl Instrum Meth A 701 164-170 (2013)
- Eight further journal papers are in various stages of preparation
- 63 EMMA papers have been published in the proceedings of the PAC-like conferences since 2009

Conclusions on Task 11.3

- EMMA is first (and only) linear non-scaling FFAG
- It has been used to study FFAG feasibility for a Neutrino Factory
- Work is still on-going
- Future directions:
  - Investigate whether linear ns-FFAGs can be used for proton acceleration with moderate RF:
    - high power proton applications
    - compact machines for medical applications
  - Investigate whether linear ns-FFAGs can be used as a muon accelerator for a muon collider
- Studies of non-linear FFAGs for proton/ion applications under way: see EuCARD2 WP4 meeting on Friday

Task 11.4: Emittance measurements of laser-plasma accelerator

Coordinator V. Malka, CNRS

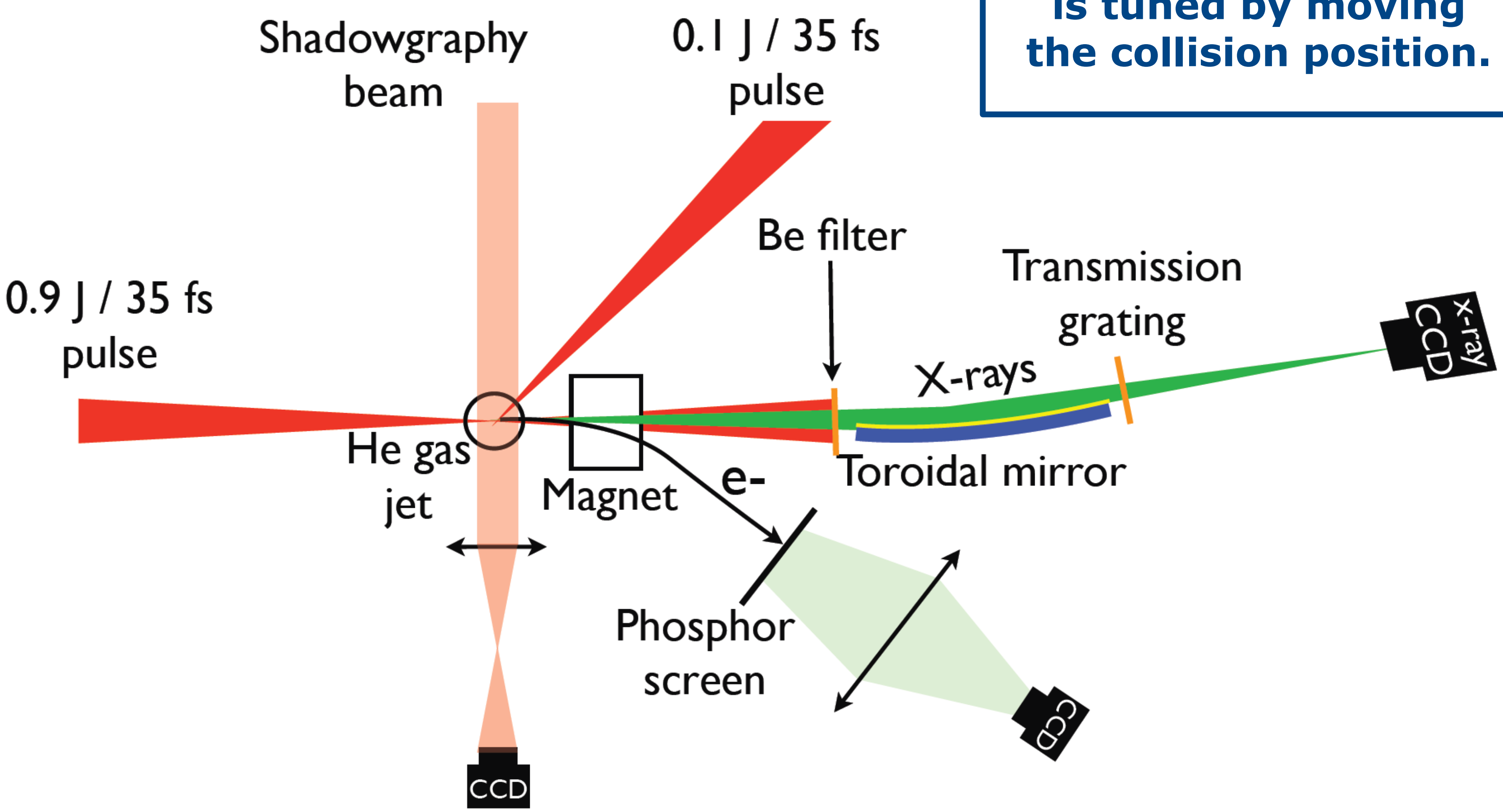
- The development of ultra short electron beams with low emittance, using RF or laser based accelerators, is crucial for the development of a two stage laser plasma accelerator, which should permit to reduce notably the relative energy spread of the electron beam

- An experimental methodology is needed to investigate the electron beam parameters, such as emittance or relative energy spread, since they are not today produced with a very high shot to shot reproducibility as those produced using RF cavity based accelerators

- This Task aimed at studying the different approaches for measuring emittance, expected to be in the mm x mrad range, of these electron beam by using the X-ray emission produced in a laser-plasma accelerator

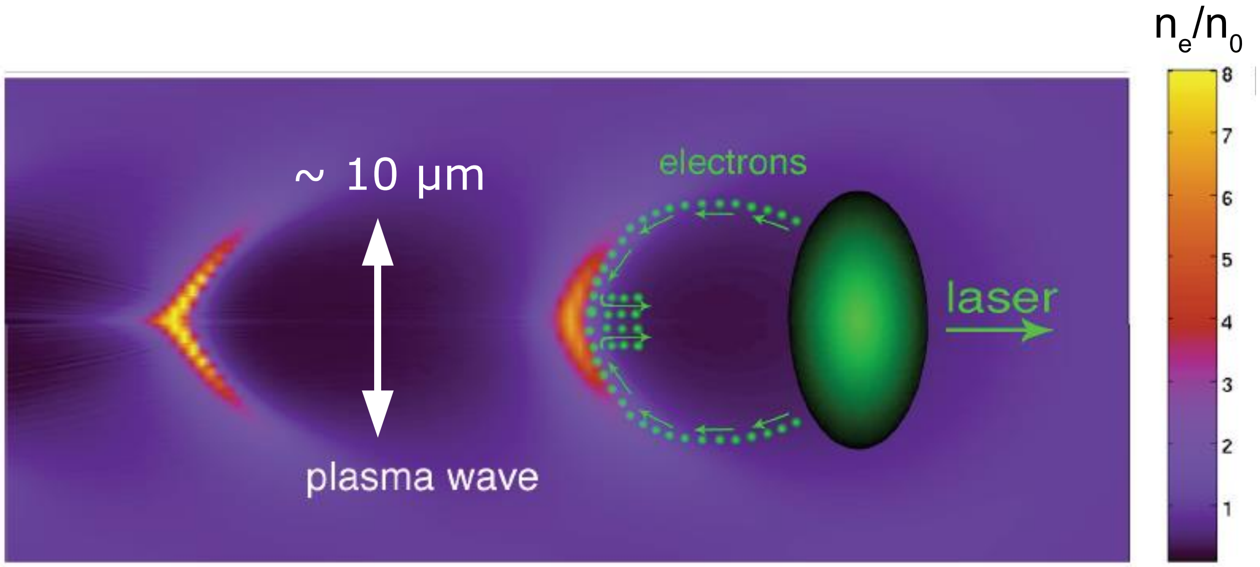
Experimental setup @ LOA

The acceleration length is tuned by moving the collision position.



S. Corde *et al.* Phys. Rev. Lett. **107**, 255003 (2011)

Laser-plasma acceleration



Main properties :

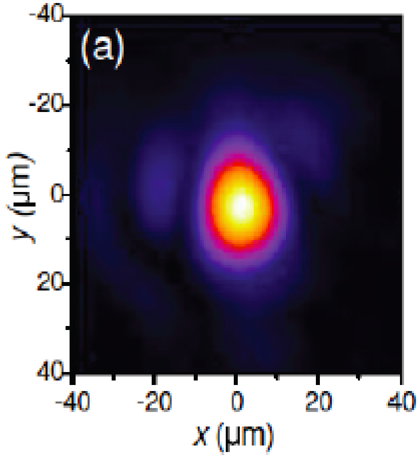
- Up to 1 GeV electron energy.
- ~ 10-100 pC charge, fs duration, ΔE/E ~ 1-10%.
- Transverse size ~ µm, divergence ~ mrad
  ➡ ε_N ~ π.mm.mrad.

Because of the large divergence, conventional emittance measurement techniques are not suitable.

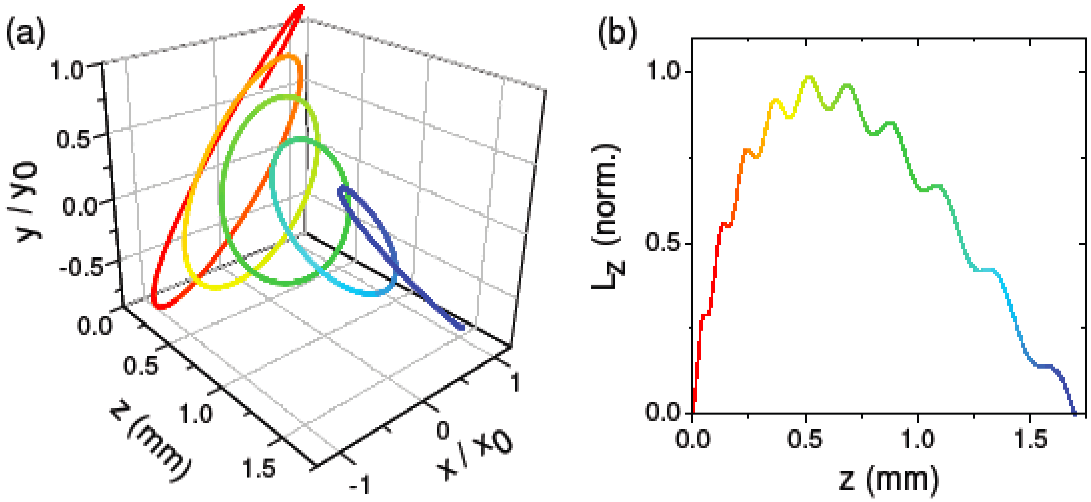
Measurements & Simulations

- The measurement of the emittance was more complex than expected, due to poor stability and control over the acceleration and to the large electron beam divergence
- It was observed that electrons carry some non zero angular momentum, and that the X-ray properties depend on this angular momentum. Since electrons are injected with a zero angular momentum, the increase could be due to the elliptic plasma cavity (elliptical laser pulse)
- Test-particle simulations were carried out to test this explanation
- They show indeed that, in an elliptical cavity, the angular momentum varies in time because the transverse focusing forces are different along x and y

EUCARD[I]: Angular momentum growth in a LPWA



Asymmetric laser pulse
- asymmetric plasma cavity
- angular momentum grows

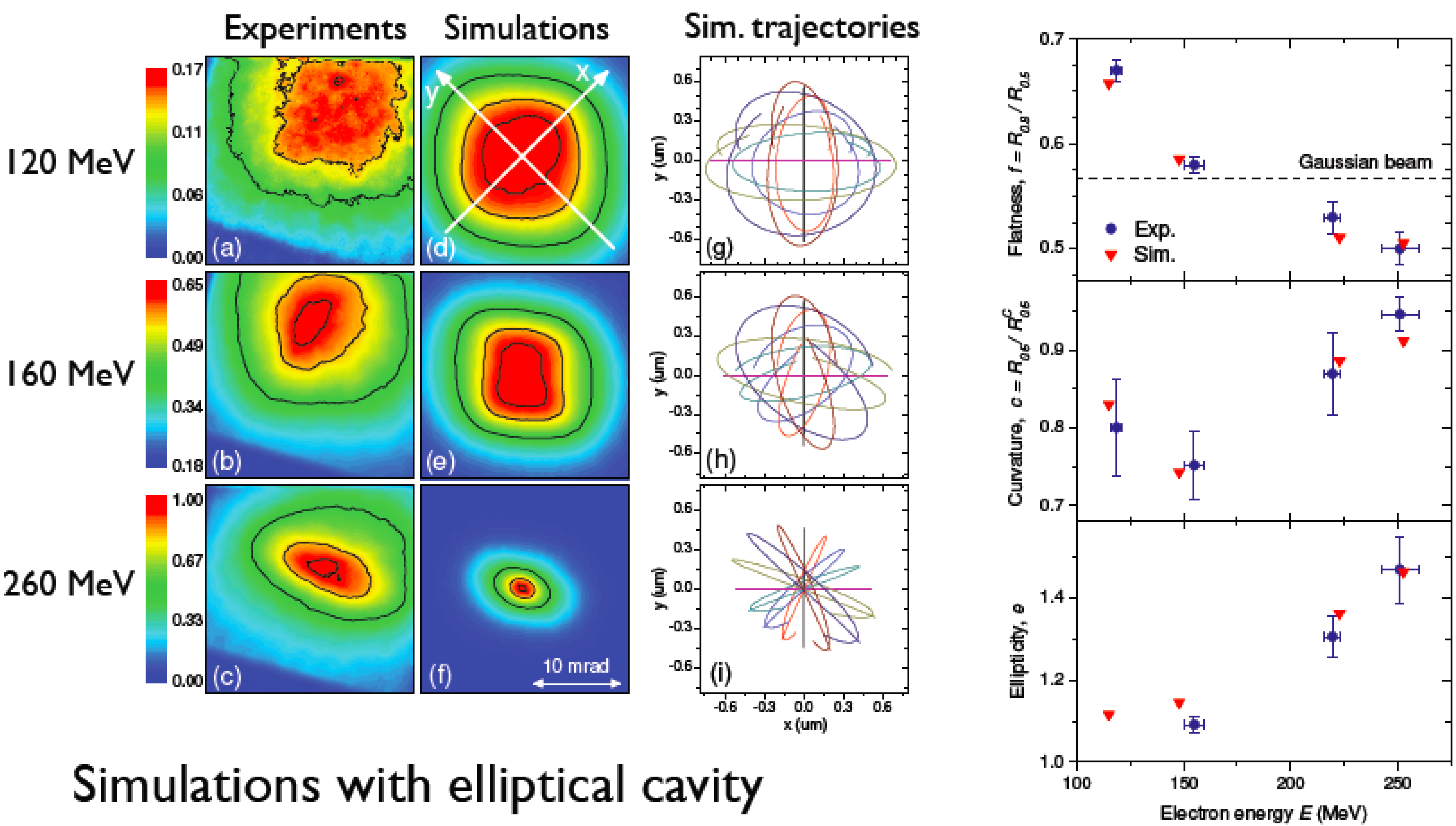


Laser focal spot, which drives an elliptical plasma cavity. The curves were obtained from a test-particle simulation

Measurements & Simulations

- Simulations have then been compared to experimental results and showed good agreement, so the results of the simulations can be used to estimate the emittance to about 1 $\pi \times mm \times mrad$
- Further studies and experiments showed that electrons can be trapped either via longitudinal or transverse self-injection, having very different features. Transverse injection is well suited for applications that require a high charge, but have little stability, large energy spread and mediocre emittance. Longitudinal injection is instead ideal for applications in which a good stability and a low emittance are essential
- See Malka's talk on Wednesday

EUCARD[I]: Angular momentum growth in a LPWA



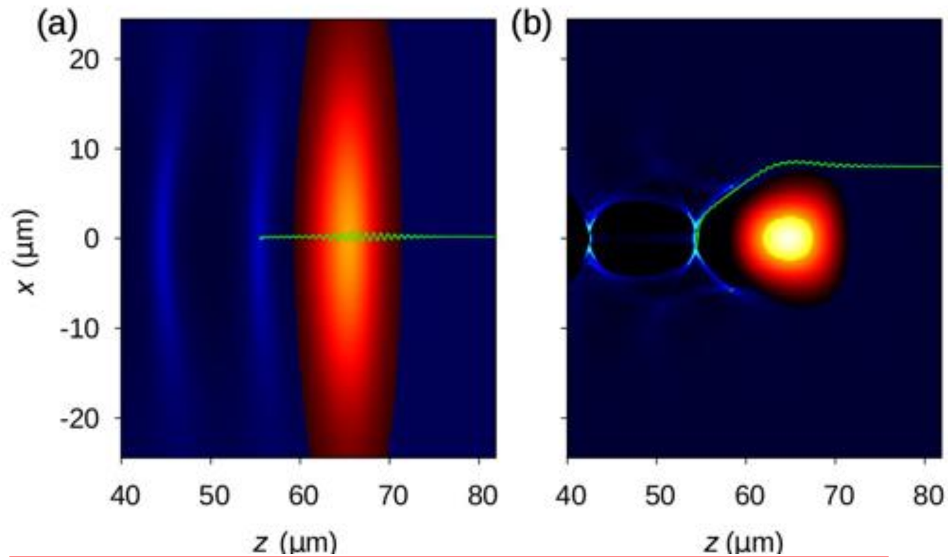
Simulations with elliptical cavity

➡ normalized emittance of 1 π mm. mrad

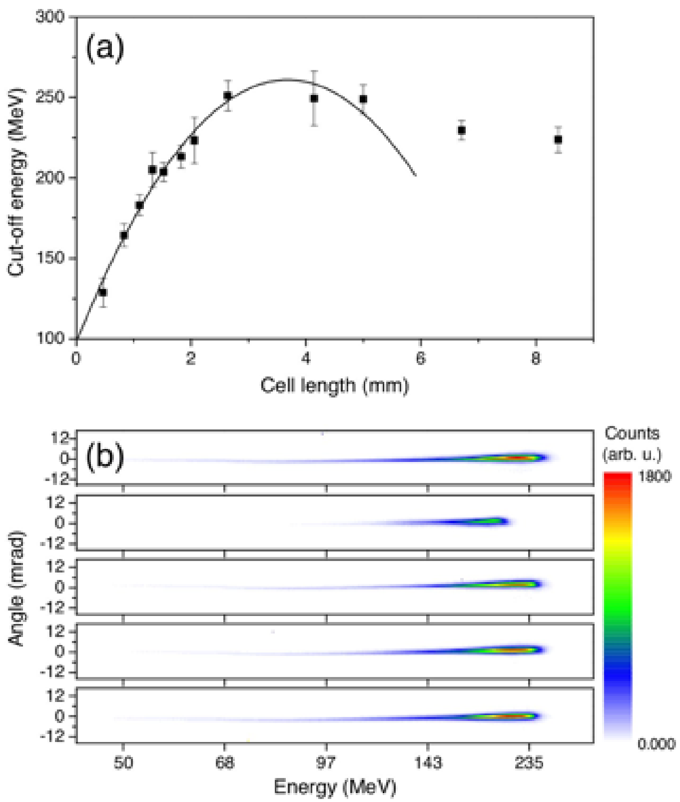
Simulations compared to experimental results

2013 Longitudinal injection

Two different self-injection mechanisms take place :



- At lower plasma density transverse injection is prevented
- Only one bunch is injected (longitudinal injection)



longitudinal injection improves
- the stability of the electron beam
and
- reduces the divergence of the electron beam

S. Corde *et al.*, Nature Communications (2013)

Publications for Task 11.4

- A. Rossi, “Emittance evolution of a tightly focused electron bunch with high energy spread”, EuCARD-NOT-2011-003
- S. Corde, C. Thaury, A. Lifschitz, G. Lambert, K. Ta Phuoc, X. Davoine, R. Lehe, D. Douillet, A. Rousse, V. Malka, “Observation of longitudinal and transverse self-injections in laser-plasma accelerators”, Nature Communications DOI:10.1038/ncomms2528
- S. Corde, K. Ta Phuoc, R. Fitour, J. Faure, A. Tafzi, J. P. Goddet, V. Malka, and A. Rousse , “Controlled Betatron X-Ray Radiation from Tunable Optically Injected Electrons“, PRL 107, 255003 (2011)
- S. Corde, C. Thaury, A. Lifschitz, G. Lambert, K. Ta Phuoc, X. Davoine, R. Lehe, D. Douillet, A. Rousse, V. Malka, “Self-Injection and Stability in Laser-Plasma Accelerators”, Nature Communications, 4, 1501 (2013)

Conclusions on Task 11.4

- Emittance measurement of electron beams from Laser Plasma Wave Acceleration turned out to be more difficult than expected
- However a methodology was found through the use of the “betatronic radiation” emitted during acceleration. Study of the origin of the large e- beam divergence and simulations to reproduce measurements were performed
- Study of the properties of longitudinal self-injection have shown that it improves the beam stability and reduces the e- beam divergence
- Work is continuing to better understand LPWA mechanism and performances

Conclusions on WP11

- WP11 milestones and deliverables were accomplished in due time (1 year delay just for Subtask on LHC IR due to fellow recruitment difficulties)
- All Tasks have reached their goals, but work is continuing to get better performances and comprehension
- EuCARD has provided within WP11 the opportunity to:
  - design, build and commission a new IR for the DAΦNE collider
  - design a new option for one LHC Interaction Region
  - complete and commission the first non-scaling FFAG ring EMMA
  - perform measurements of electron beam emittance in LPWA experiments

Thanks to all for the amazing work !

Thanks to Jean-Pierre, Svet and Merethe for their hard work, their support and… their patience!