EuCARD-2 WP5 “XBEAM” Status and Highlights

G. Franchetti, F. Zimmermann

EuCARD-2 Annual Meeting, Glasgow

28 March 2017

many thanks to
K. Aulenbacher,
M. Biagini, and M. Eshraqi

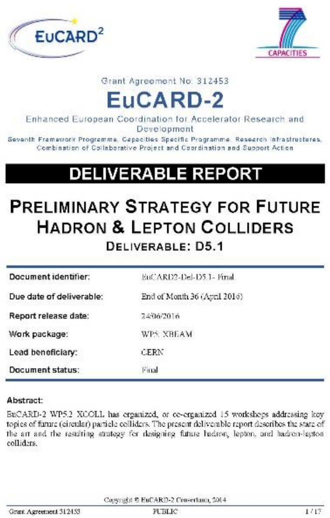
EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453

WP5 XBEAM topical strategies

four reports delivered in 2016

preliminary strategies

- for future hadron & lepton colliders
- for future high-performance hadron rings
- for future high-power high-current SC linacs
- for future polarized beams



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DELIVERABLE REPORT

PRELIMINARY STRATEGY FOR FUTURE HADRON & LEPTON COLLIDERS

DELIVERABLE: D5.1

Document identifier:	EuCARD2-Del-D5.1- Final
Due date of deliverable:	End of Month 36 (April 2016)
Report release date:	24/06/2016
Work package:	WP5: XBEAM
Lead beneficiary:	CERN
Document status:	Final

Abstract:

EuCARD-2 WP5.2 XCOLL has organized, or co-organized 15 workshops addressing key topics of future (circular) particle colliders. The present deliverable report describes the state of the art and the resulting strategy for designing future hadron, lepton, and hadron-lepton colliders.

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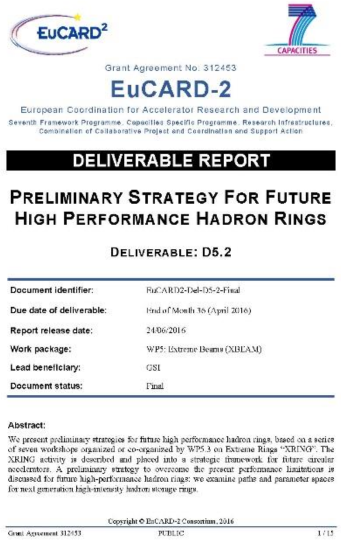

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DELIVERABLE REPORT

PRELIMINARY STRATEGY FOR FUTURE HIGH PERFORMANCE HADRON RINGS

DELIVERABLE: D5.2

Document identifier:	EuCARD2-Del-D5-2-Final
Due date of deliverable:	End of Month 36 (April 2016)
Report release date:	24/06/2016
Work package:	WP5: Extreme Beams (XBEAM)
Lead beneficiary:	GSI
Document status:	Final

Abstract:

We present preliminary strategies for future high performance hadron rings, based on a series of seven workshops organized or co-organized by WP5.3 on Extreme Rings "XRING". The XRING activity is described and placed into a strategic framework for future circular accelerators. A preliminary strategy to overcome the present performance limitations is discussed for future high-performance hadron rings: we examine paths and parameter spaces for next generation high-intensity hadron storage rings.

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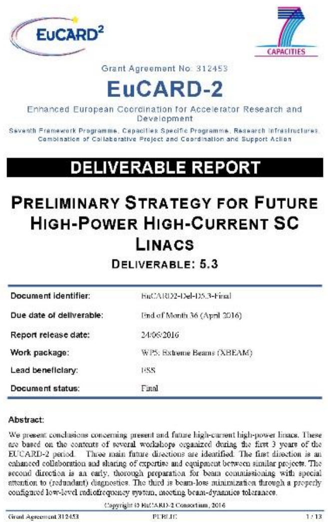

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DELIVERABLE REPORT

PRELIMINARY STRATEGY FOR FUTURE HIGH-POWER HIGH-CURRENT SC LINACS

DELIVERABLE: 5.3

Document identifier:	EuCARD2-Del-D5.3-Final
Due date of deliverable:	End of Month 36 (April 2016)
Report release date:	24/06/2016
Work package:	WP5: Extreme Beams (XBEAM)
Lead beneficiary:	ESS
Document status:	Final

Abstract:

We present conclusions concerning present and future high-current high-power linacs. These are based on the contents of several workshops organized during the first 3 years of the EUCARD-2 period. Three main future directions are identified. The first direction is an enhanced collaboration and sharing of expertise and equipment between similar projects. The second direction is an early, thorough preparation for beam commissioning with special attention to (redundant) diagnostics. The third is beam-loss minimization through a properly configured low-level radiofrequency system, meeting beam-dynamics tolerances.

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DELIVERABLE REPORT

PRELIMINARY STRATEGY FOR FUTURE POLARIZED BEAMS

DELIVERABLE: 5.4

Document identifier:	EuCARD2-Del-D5.4-Final
Due date of deliverable:	End of Month 36 (April 2016)
Report release date:	24/06/2016
Work package:	WP5: Extreme Beams (XBEAM)
Lead beneficiary:	JGU
Document status:	Final

Abstract:

We present conclusions concerning future accelerator research for spin polarized beams. These are based on the contents of several workshops organized during the first 3 years of the EUCARD-2 period. Two main future paths are identified. A first path is supporting future Terascale machines by spin polarized beam options. On the other hand small scale accelerators enable fundamental research by further improved control over the spin dynamics and by more accurate measurement of the degree of beam polarization.

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WP5 XBEAM global strategy

final deliverable report 2017

Grant Agreement No: 312453

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Enhanced European Coordination for Accelerator Research and Development

Seventh Framework Programme, Capacities Specific Programme, Research Infrastructures, Combination of Collaborative Project and Coordination and Support Action

DELIVERABLE REPORT

STRATEGY FOR FUTURE EXTREME BEAM FACILITIES

DELIVERABLE: D5.5

Document identifier:	EuCARD2-Del-D5.5- Draft
Due date of deliverable:	End of Month 46 (February 2017)
Report release date:	dd/mm/2017
Work package:	WP5: XBEAM
Lead beneficiary:	CERN
Document status:	Draft

Abstract:

Over a period of 4 years EuCARD-2 XBEAM has organized, or co-organized 35 workshops addressing key topics of future (circular) particle colliders, storage rings for intense beams, superconducting hadron linacs, and polarization challenges.

The present deliverable report summarizes the state of the art, discusses emerging new developments, and highlights a large number of upcoming and proposed projects, which will certainly push the existing boundaries. The report also underlines the important role played by the European accelerator networks, and it presents some tantalizing future perspectives, including large circular colliders, cold muon beams, crystals and nanotubes.

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10 WP5 XBEAM Workshops May 2016 – April 2017

- XRING “The Slow Extraction Workshop," Darmstadt (DE), 1-3 June 2016 (53 participants)
- XRING/XLINAC coorg. “HB2016,” Malmö (SE), 1-3 July 2016 (~150)
- XCOLL coorg. “Channelling 2016,” Sirmione (IT), 25-30 Sept. ‘16 (158)
- XCOLL “eeFACT2016,” Daresbury (UK), 24-27 October 2016 (75)
- XLINAC “Upgrading Existing High Power Proton Linacs,” Lund (SE), 8-9 November 2016 (22)
- XRING GSI-FZJ mini-workshop “Beam Dynamics and Control studies at COSY”, FZ Jülich (DE), 18 November, 2016 (~20)
- XPOL seminar “New Polarimeter Techniques for Symmetry Breaking Experiments at Accelerators,” Mainz (DE), 2 Dec. 2016 (5)
- XCOLL/EuroNNACc “Focus: Future Frontiers in Accelerator (F3iA) ”, Scharbeutz (DE), 5-9 December 2016 (25)
- XBEAM “Strategy Workshop”, Valencia (ES), 13-17 Feb. 2017 (17)
- XRING “Beam Dynamics meets Vacuum, Collimations, and Surfaces”, Karlsruhe (DE), 8-10 March 2017 (~60)

“Slow extraction workshop” – Darmstadt, 1-3 June 2016

spill comparison- result from Darmstadt

Name, Institution	spill duration	particles in spill	original bin length	Particles Per Bin, av. (orig.) (PPB_{av})	$\frac{\Delta PPB_{rms}}{PPB_{av}}$	Particles Per Bin, av. (1 ms) (PPB_{av})	$\frac{\Delta PPB_{rms}}{PPB_{av}}$ (1 ms)
M. Fraser, CERN	4.0 s	$4.0 \cdot 10^{13}$	0.4 ms	$4.0 \cdot 10^{9}$	0.158	10^{10}	0.157
C. Krantz, MIT	8.0 s	$2.7 \cdot 10^{8}$	0.05 ms	1700	0.25	34000	0.17
K. Brown, BNL (*)	2.4 s	$7.6 \cdot 10^{13}$	0.04 ms	$1.3 \cdot 10^{9}$	0.21	$3.2 \cdot 10^{10}$	0.19
C. Schömers, HIT	5.0 s	$1.5 \cdot 10^{8}$	0.05 ms	1500	0.31	30000	0.21
H. Stockhorst, FZJ (+)	3.5 s	$1.3 \cdot 10^{7}$	1.0 ms	3700	0.28	3700	0.28
S. Ivanov, IHEP	1.3 s	$(2 - 10) \cdot 10^{12}$	0.04 ms	$(6.0 - 30.0) \cdot 10^{8}$	0.45	$(1.5 - 7.5) \cdot 10^{9}$	0.329
P. Forck, GSI (x)	1.5 s	$1.4 \cdot 10^{6}$	0.02 ms	18	0.58	900	0.334
A. Wastl, MedAustron	5.0 s	$1.8 \cdot 10^{10}$	0.02 ms	72000	0.90	$3.6 \cdot 10^{6}$	0.54
K. Brown, BNL (**)	1.6 s	$6.2 \cdot 10^{13}$	0.04 ms	$1.5 \cdot 10^{9}$	0.87	$3.0 \cdot 10^{10}$	0.57
M. Tomizawa, J-PARC	2.1 s	$4.8 \cdot 10^{13}$	0.01 ms	$2.3 \cdot 10^{8}$	0.91	$2.3 \cdot 10^{10}$	0.637
P. Forck, GSI (xx)	2.0 s	$1.1 \cdot 10^{6}$	0.02 ms	11	0.81	550	0.642
P. Forck, GSI (xxx)	2.1 s	$2.1 \cdot 10^{6}$	0.02 ms	20	1.4	1000	0.73
H. Stockhorst, FZJ (++)	3.0 s	$4.3 \cdot 10^{6}$	1.0 ms	1400	1.1	1400	1.1

K. Brown (*) – empty 93 MHz bucket
K. Brown (**) – no empty bucket filtering
H. Stockhorst (+) – stochastic extraction
H. Stockhorst (++) – quadrupole driven extraction
P. Forck (x) – bunched beam, KO extraction
P. Forck (xx) – bunched beam, quadrupole driven extraction
P. Forck (xxx) – unbunched beam, quadrupole driven extraction

1st time laboratories compare experimental data on slow extraction spill performance

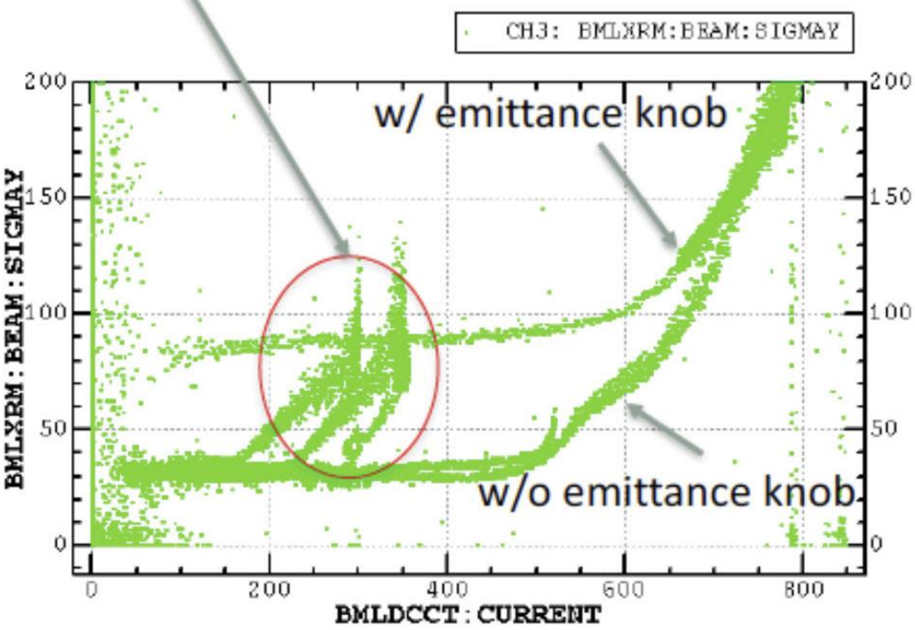
"eeFACT2016" – Daresbury, 24-27 October 2016

about 75 experts from Europe, US and Asia -
reviewing and documenting state of the art in e^-e^+ factory design,
preparing the **commissioning of the SuperKEKB collider** and advancing contributions to the **FCC-ee, CEPC & tau-charm design efforts**,
fostering **synergies and new collaborations** across communities,
jointly developing **novel solutions** to outstanding problems

starting to learn from SuperKEKB: extremely low β_y^*, top-up injection, and-e-cloud mitigation

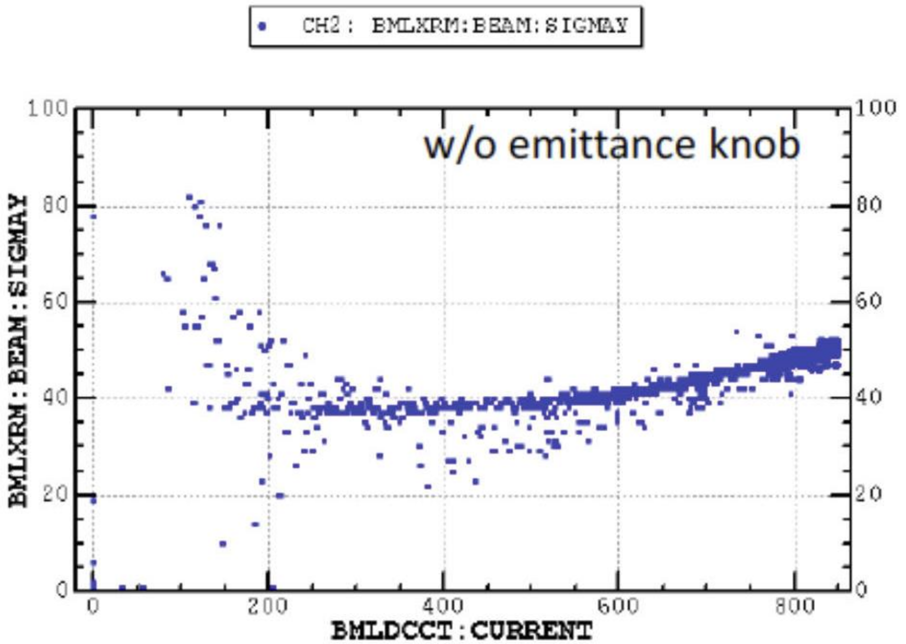
Measured at SuperKEKB Phase I

Blowup study with shorter bunch spacing



3.06 spacing (1576 bunches)

June 1st (before installation of solenoids at bellows chambers)



3.06 spacing (1576 bunches)

June 6th (after installation of solenoids at bellows chambers)

Before Phase 2, we will install solenoids at ante-chambers with TiN coating.

M. Biagini

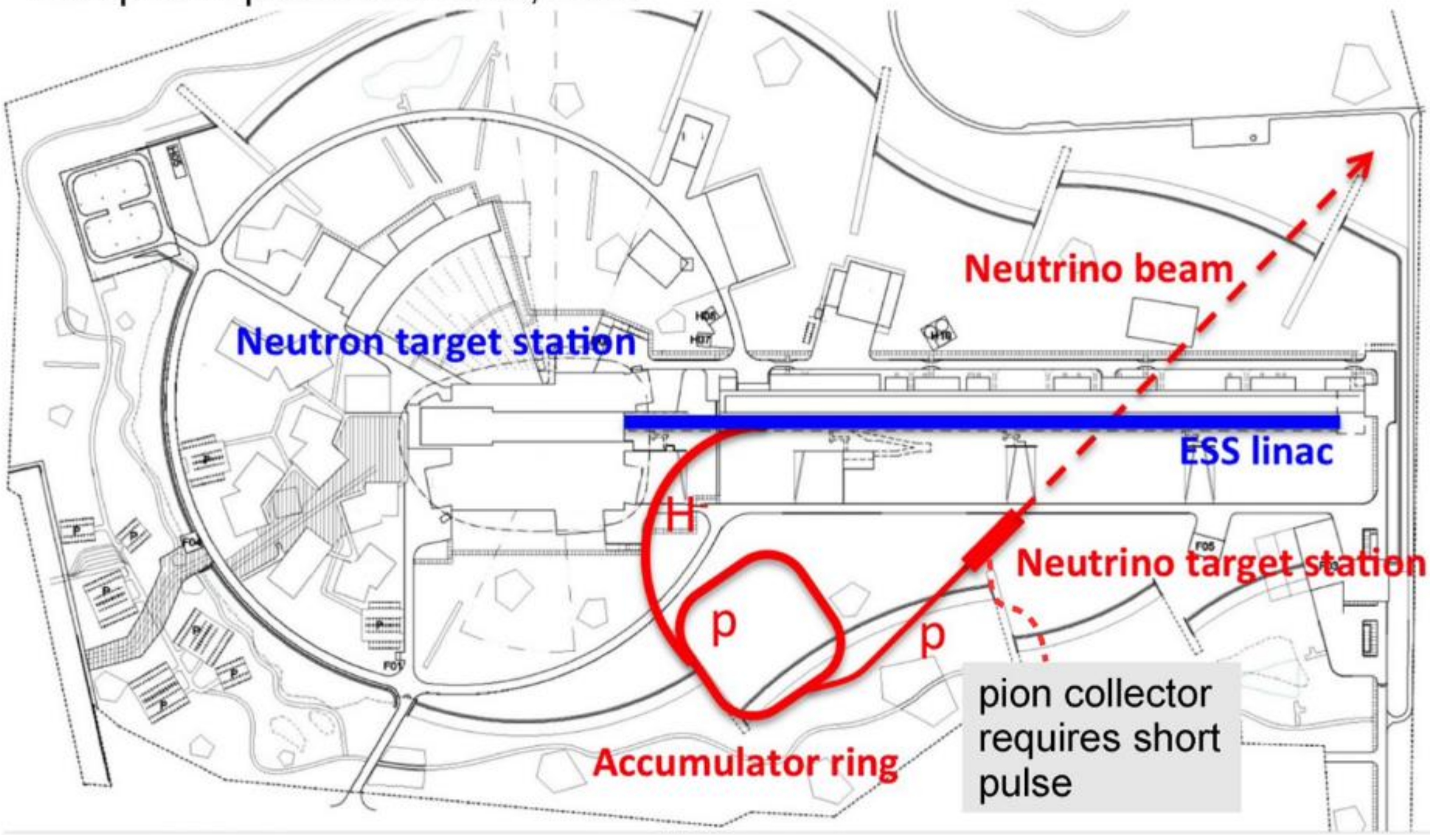
extreme superconducting linear accelerators

	Particle	Duty factor	Energy/Nucleon resp. energy per e- [MeV]	(Pulse) Current [mA]	Av.power [kW]
ATLAS at ANL	ions	up to CW	10 to 20	0.0002-0.06	2
ELBE	e	CW	40	1	40
SNS	H-	8%	1000	38	1400
SPIRAL-2	p, d, ions	up to CW	8 to 33	1 to 6	200
CEBAF Upgr.	e	CW	12000	0.1	1000
ESS	P	4%	2000	62.5	5000
FRIB	ions	up to CW	200 to 320	0.65	400
LCLS-II	e	CW	4000	0.06-0.3	300-1200
Europ. XFEL	e	0.7%	17500	5	900
Chinese ADS	p	CW	1500	10	15000
MESA Mainz	e	CW	105-155	1-10	1600
MYRRHA	P	CW	600	4	2400
eRHIC (ERL)	e	CW	20000	50	1000,000
LHeC (ERL)	e	CW	60000	6.6	400,000
SPL at CERN	p	4%	5000	20 (40)	4000
ESS+ESSnuSB	p	~9%	2000	62.5	10000
ILC	e	0.4%	250	5.8	2x5200

linacs in operation (blue), under construction (green), or being proposed (red)

“Upgrading Existing High Power Proton Linacs” – Lund, 8-9 Nov, ‘17

European Spallation Source, Lund



Proposed upgrade from ESS (blue) to ESSnuSB (red)

5 MW proton beam
3 ms pulses
1e15 protons/pulse

5 MW H-/proton beam
<2 μs pulses

P. M. Olvegard, Uppsala

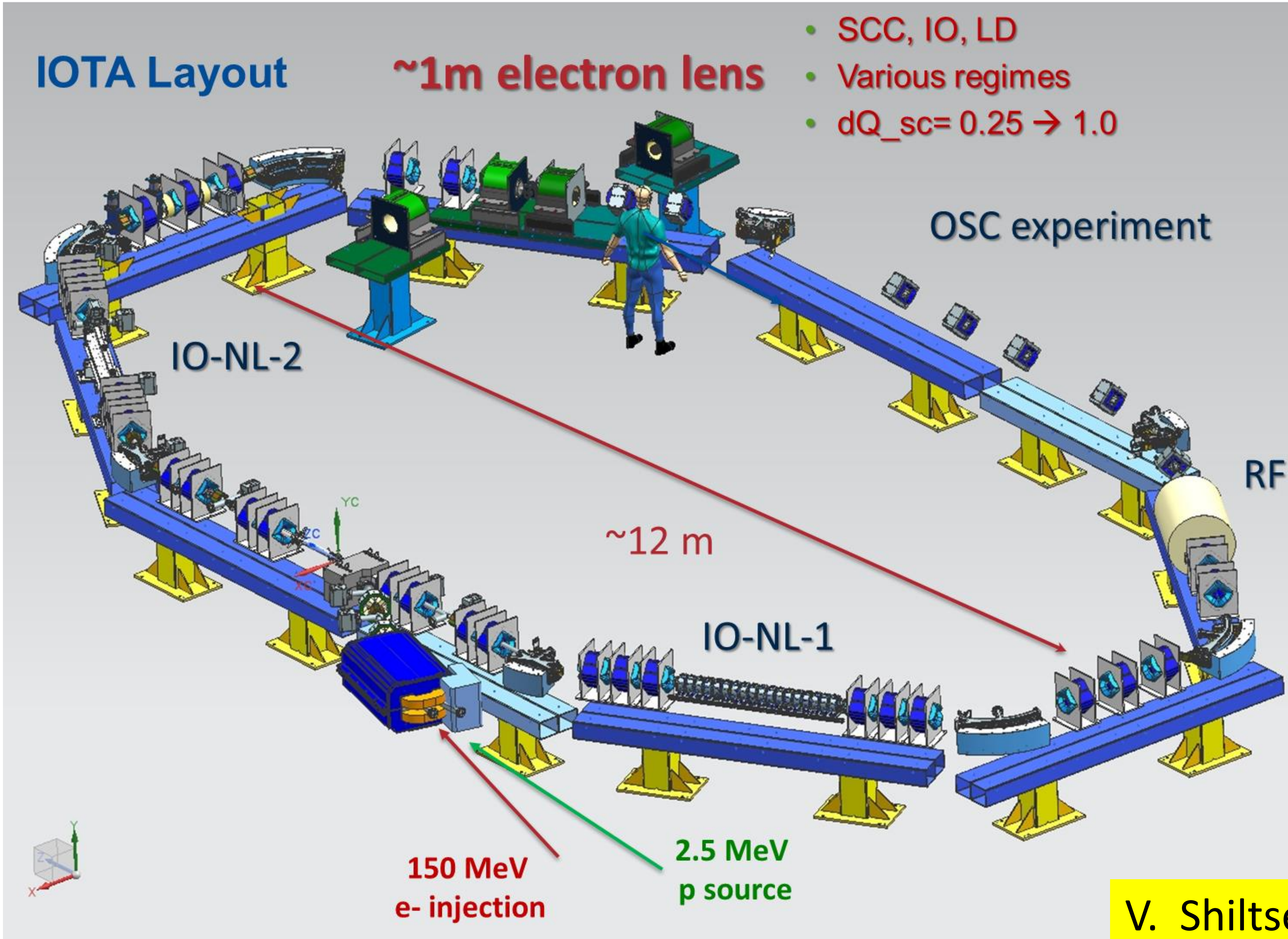
GSI-FZJ mini-workshop, Jülich, 18 November 2016

about 20 participants from FZJ, GSU and TU Darmstadt

addressing topics of common interest for SIS18 and COSY:

1) **optics** problems and optimization
2) experiences and issues in **slow extraction**
3) **instabilities and resonances**
4) **electron cooling**
5) advanced **beam measurement techniques**
6) **electron lenses for space charge mitigation**

beam test facility IOTA at FAST turns on soon



V. Shiltsev

EuCARD^2

"Beam Dynamics meets Vacuum, Collimation & Surfaces"

- Karlsruhe, 8-10 March 2017

66 specialists, workshop co-sponsored by several industrial companies

vacuum stability with heavy-ion beam loss in FAIR machines,
mitigating cloud in LHC and HL-LHC,
handling synchrotron radiation in FCC-hh and HE-LHC,
collimation, surface science,...
pioneering legal agreement for industrial exhibition

XPOL: polarization in future experiments

low-energy "small" accelerators (EDM JEDI, MESA)

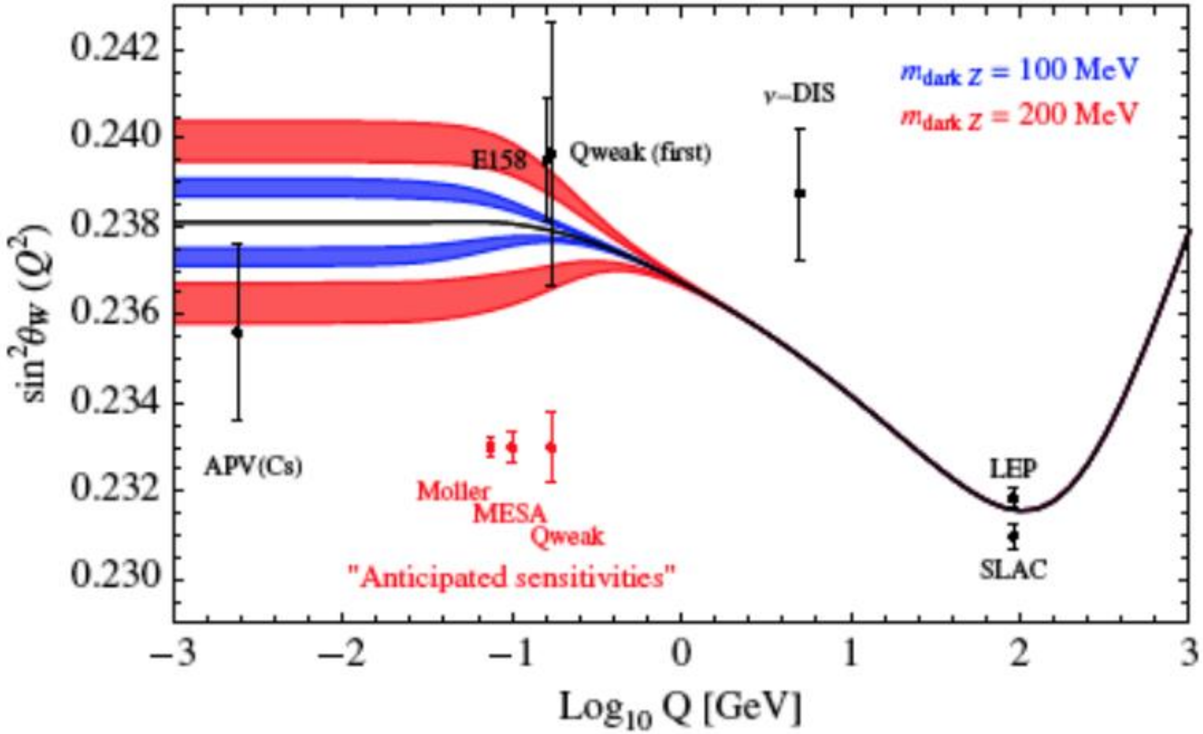
- **discovery** (strong CP and T violation)
- **precision experiments** (weak P violation)

high-energy "big" accelerators:

- precision measurements at the **ILC**
  - pol e+ source technologically challenging
  - polarization measurement via Compton backscattering promising ($\Delta P/P \sim 0.1\%$)
- precision beam parameters at the **FCC-ee**
  - absolute energy calibration (by resonant dep.) $\Delta E/E \sim 10^{-6}$
- high energy polarized proton beam at the **FCC-hh**
  - not completely impossible
- fixed target polarization is possible at **LHC** or **FCC-hh**
- **LHeC** feasible with polarized e- beam

K. Aulenbacher

electro weak mixing angle „$\sin^2\theta_W$" at MESA



influence of „dark Z boson" which also contributes to muon anomalous magnetic moment...

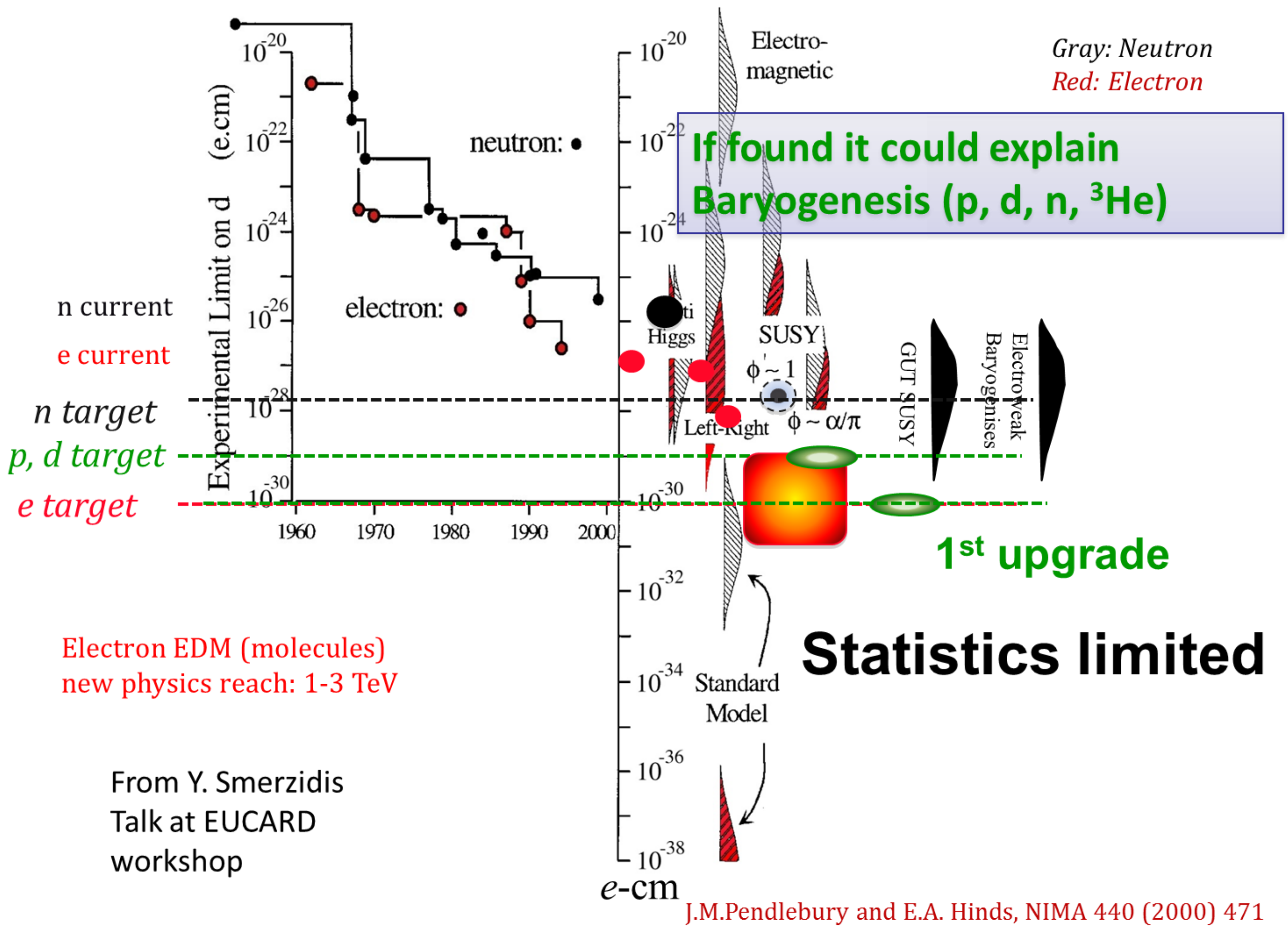
elastic electron scattering on proton measures $1\text{-}4\sin^2\Theta_W$

→ small asymmetry , high sensitivity

- supressing hadronic contributions favours low momentum transfer and low beam energy

K. Aulenbacher

Jülich Electric Dipole Moment Investigation „JEDI“



From Y. Smerzidis
Talk at EUCARD
workshop

- aiming at discovery in„electrostatic storage ring“

K. Aulenbacher

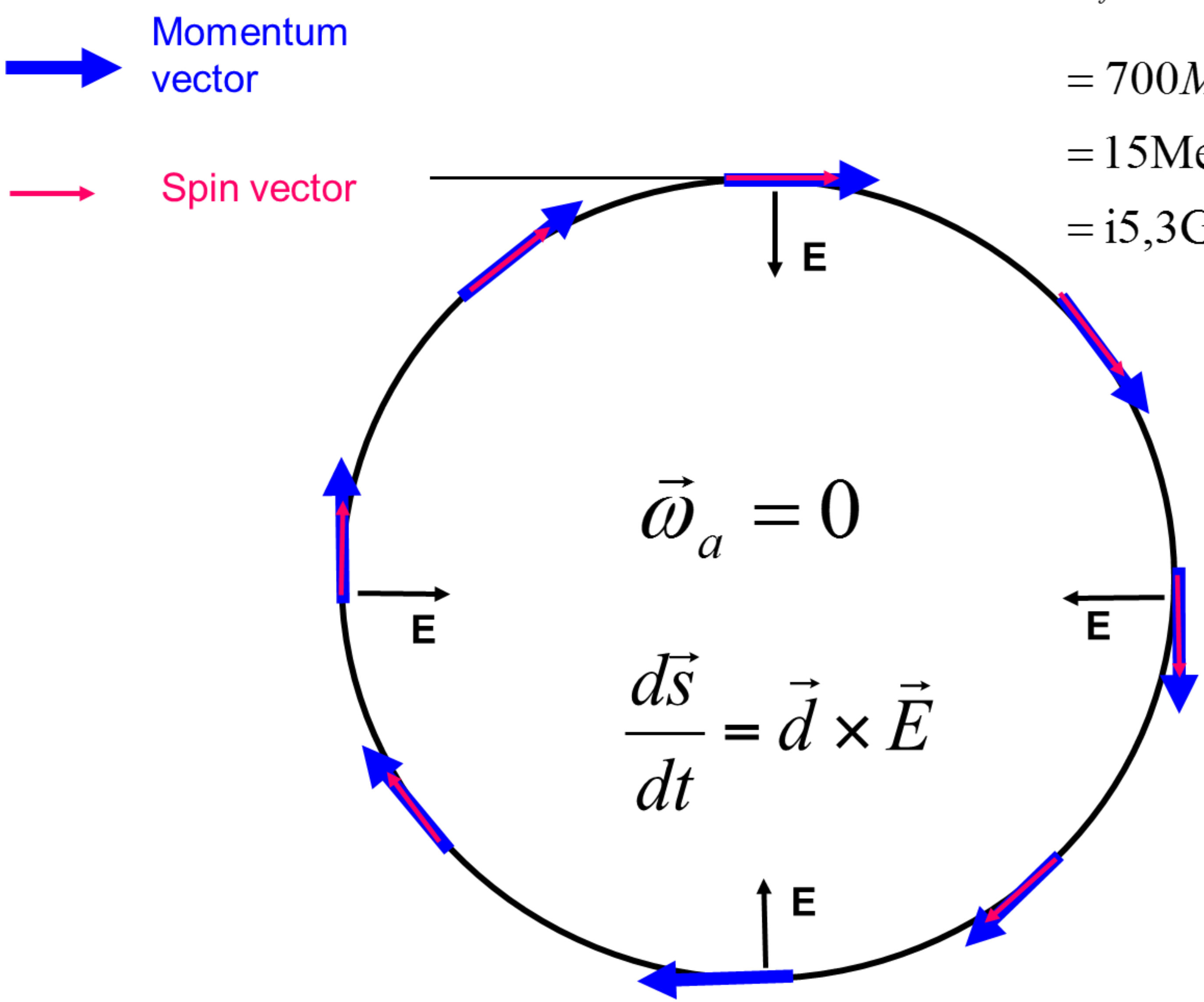
Jülich Electric Dipole Moment Investigation „JEDI“

$$p_{freeze} = \frac{m}{\sqrt{G}}$$

$= 700 MeV/c$ (Proton)

$= 15 MeV/c$ (Elektron)

$=$ i5,3GeV/c (Deuteron)



$$\vec{\omega}_a = 0$$

$$\frac{d\vec{s}}{dt} = \vec{d} \times \vec{E}$$

now considered at CERN

K. Aulenbacher

XBEAM XCOLL & EuroNNAc Joint Workshop

25 selected accelerator experts from Europe, Asia and the U.S.

discussing future accelerator concepts and technologies,
brainstorming on new ideas

Chairs
R. Aβmann and F. Zimmermann

Photo
courtesy M. Biagini

nuclear photonics & quantum FEL - Scharbeutz

Future Trends for FELs in Nuclear Physics and Nuclear Photonics

Luca Serafini (INFN-Milan) and Reinhard Brinkmann (DESY)

Present X-ray FELs in operation or under commissioning achieve maximum photon energies in the range 10-20 keV. It has been debated whether a scientific case exists for FELs towards photon energy entering the Nuclear Photonics domain, which starts at around 1 MeV and extends up to several MeVs. Despite the large costs inherent in the development of Linac based FELs with electron beam in the range 20-50 GeV, a strong scientific case could justify a design study within the frame of a Linear Collider scenario, i.e. conceiving a parasitic use for a nuclear oriented FEL of a separate beam line at a TeV-class Linac based collider. We consider here in the following FEL-type machines, but we would like to briefly add that in principle very large synchrotron radiation storage rings with ultra-low emittance could also make MeV photon beams accessible with very high brilliance.

→ highlight talk by Luca Serafini

two possible figures-of-merit for the efficiency

1. beam power at collision point(s) divided by total electrical power of the facility
2. luminosity per electrical input power

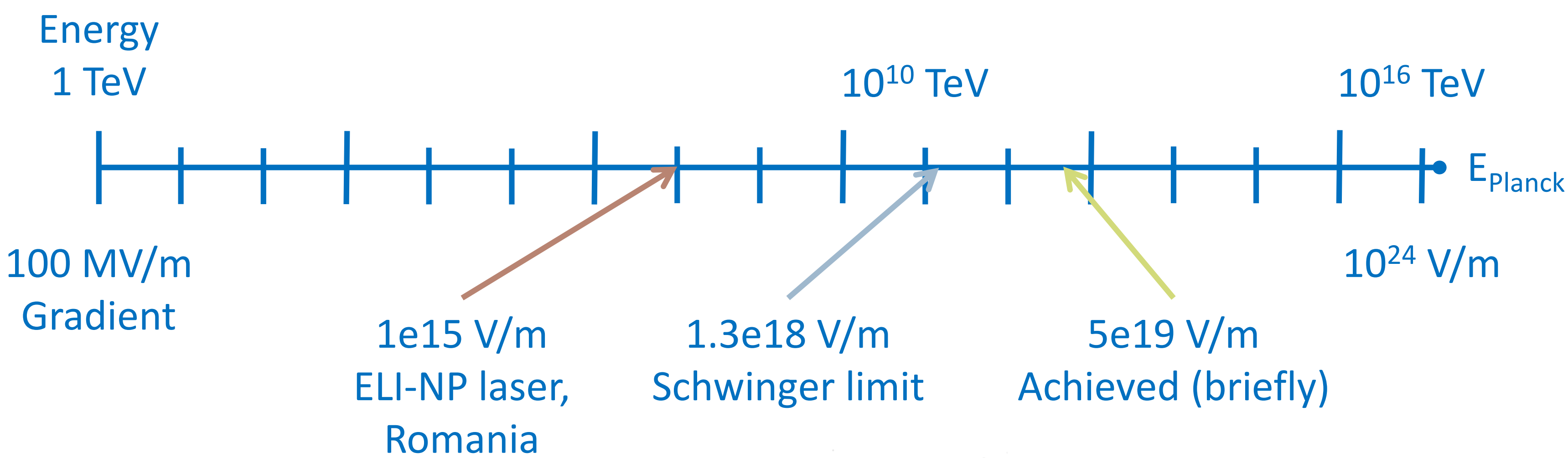
F. Zimmermann

collider	c.m. energy [TeV]	P_{el}: tot. el. power [MW]	P_b: IP beam power [GW]	luminosity L [$nb^{-1}s^{-1}$]	P_b/P_{el}	L/P_{el} (/IP) [$nb^{-1}s^{-1}$/MW]
CEPC	0.24	~500	4.0	20	**8000**	**0.04**
FCC-ee	0.091	276	132	2000	**500000**	**7.2**
FCC-ee	0.24	308	7.2	50	**23000**	**0.16**
FCC-ee	0.35	364	2.3	13	**6300**	**0.04**
LHeC	1.3	75 (e- only)	0.4 (e- only)	1	**5**	**0.01**
LHeC-HF	1.3	100 (e- only)	1.5	16	**15**	**0.16**
ILC	0.25	122	0.0059	7.5	**0.05**	**0.06**
ILC	0.5	163	0.0105	18	**0.06**	**0.11**
CLIC	0.5	271	0.009	23	**0.03**	**0.08**
CLIC	3.0	582	0.028	59	**0.05**	**0.10**
laser-plasma	3.0	282	0.045	100**	**0.05??**	**??**
LHC	13.0	~150	8000	10	**50000**	**0.07**
FCC-hh	100.0	500 (target)	50000	300 (phase 2)	**100000**	**0.6**
SPPC	70.2	600 (guess)	53000	100	**90000**	**0.2**

FCC-ee & FCC-hh = most efficient machines

→ highlight talk by Michael Benedikt

gradients in 2x10 km facility – Scharbeutz



- "Throw particles at each other"

On a Diffuse Reflection of the α-Particles.

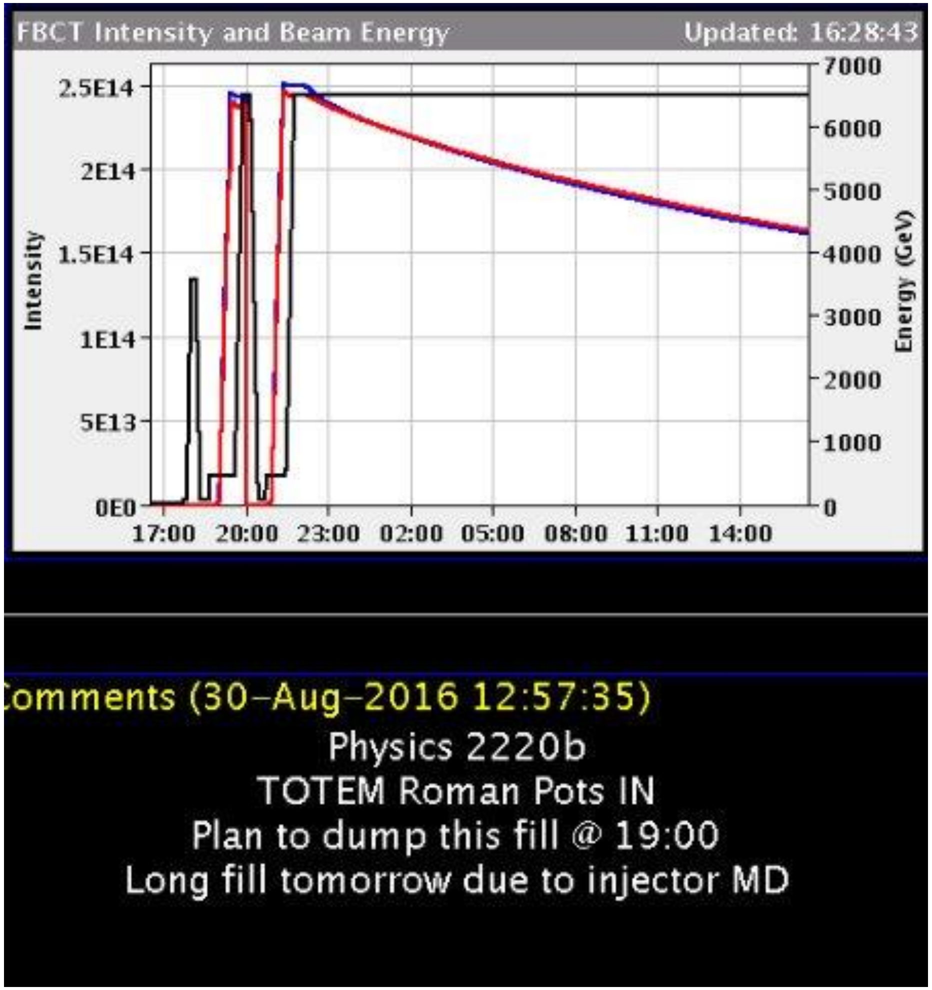
By H. Geiger, Ph.D., John Harling Fellow, and E. Marsden, Hatfield Scholar, University of Manchester.

(Communicated by Prof. E. Rutherford, F.R.S. Received May 19,—Read June 17, 1909.)

- Still not quite at the Planck energy, what can we do about that? In 10 km.

S. Brooks

the case for optimism - Scharbeutz



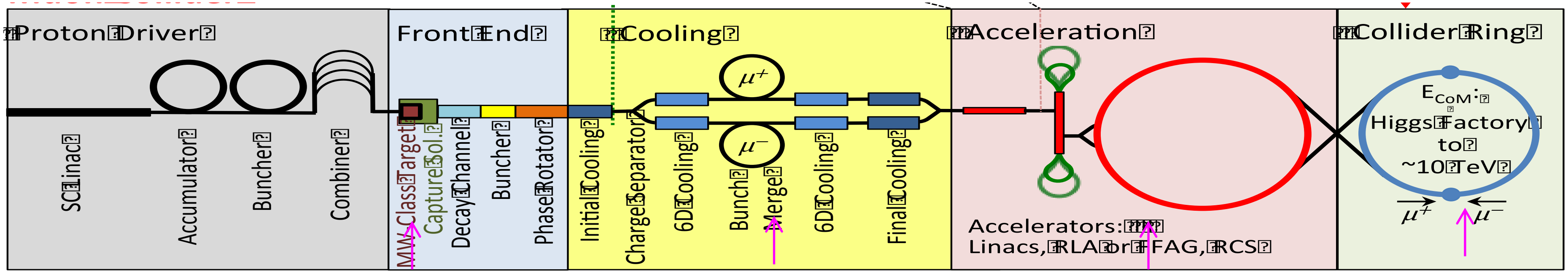
@JoshMcFayden (UCL/ATLAS) via Twitter

- 2 * 2.5e14 * 6500 GeV
- = 521 MJ
- = 0.266 E_{Planck}
- **total energy is OK but it's in too many particles**

S. Brooks

final XBEAM strategy workshop – Valencia, 13-17 Feb. 2017

from US-MAP (2015) to Italian μ-collider (2017)



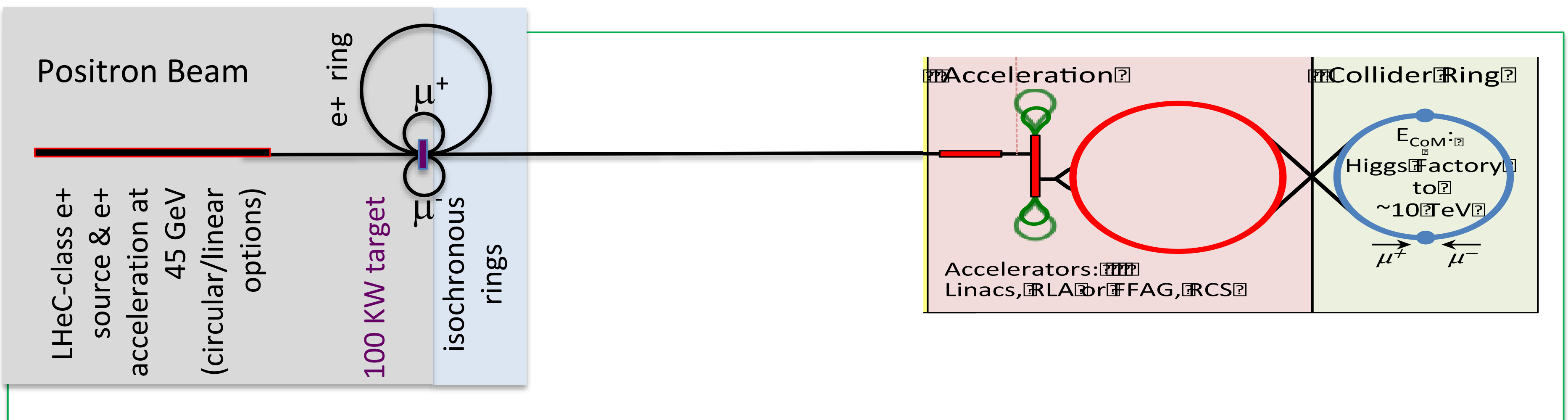
Key Challenges

~10^{13}-10^{14} μ / sec
Tertiary particle
$p \rightarrow \pi \rightarrow \mu$:

Fast cooling
(τ=2μs)
by 10^6 (6D)

Fast acceleration
mitigating μ decay

Background
by μ decay



Key Challenges

~10^{11} μ / sec from $e+e- \rightarrow \mu+\mu-$

Key R&D

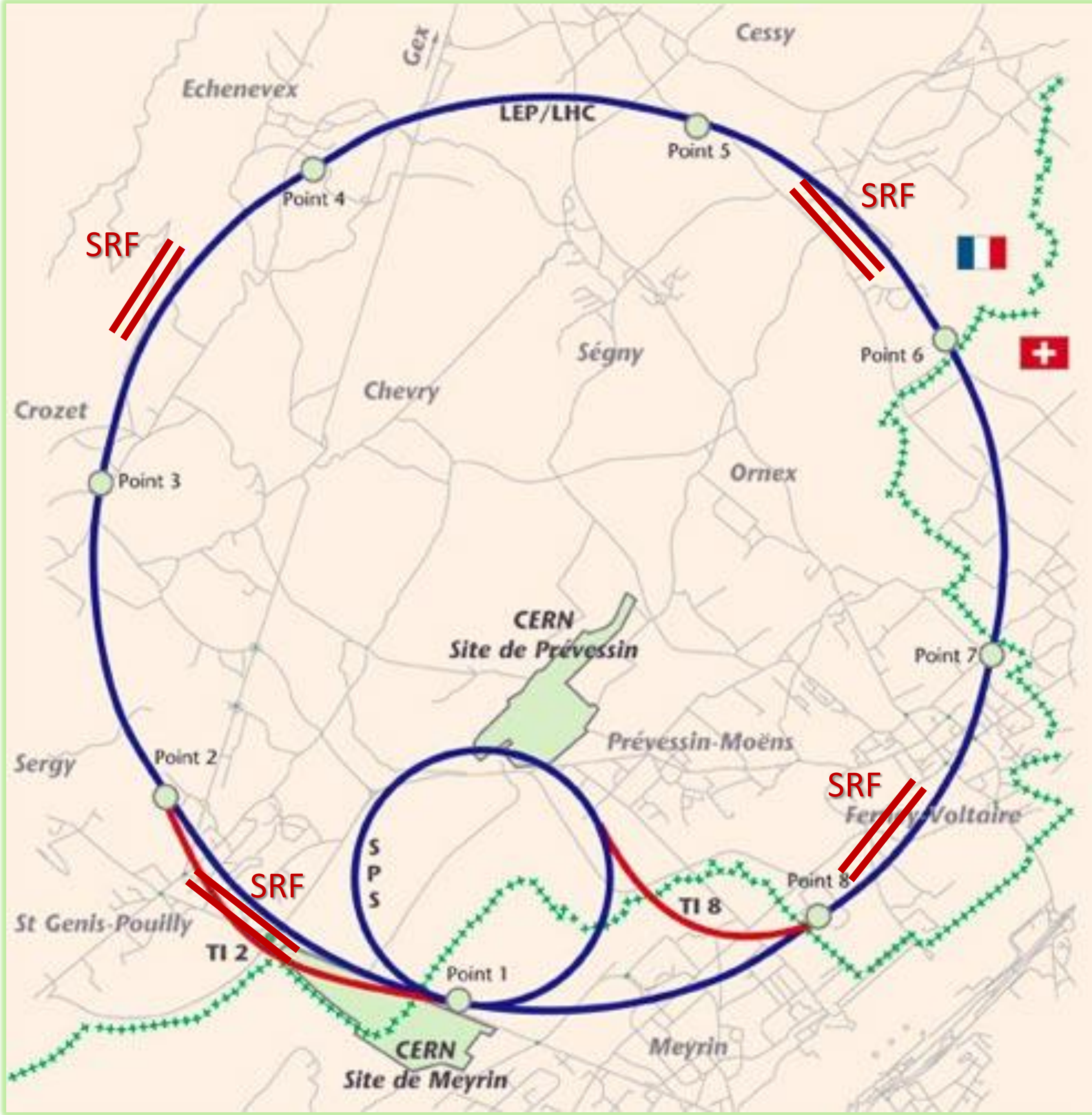
10^{15} e+/sec, 100 kW class target, NON-destructive process in e+ ring

M. Boscolo

CMC

CERN Muon Collider

- *14 TeV cm*
- *LHC tunnel*
- *SPS tunnel and mb PS*
- *~7GeV SRF*
- *pulsed magnets*
- ***cost ~LHC***

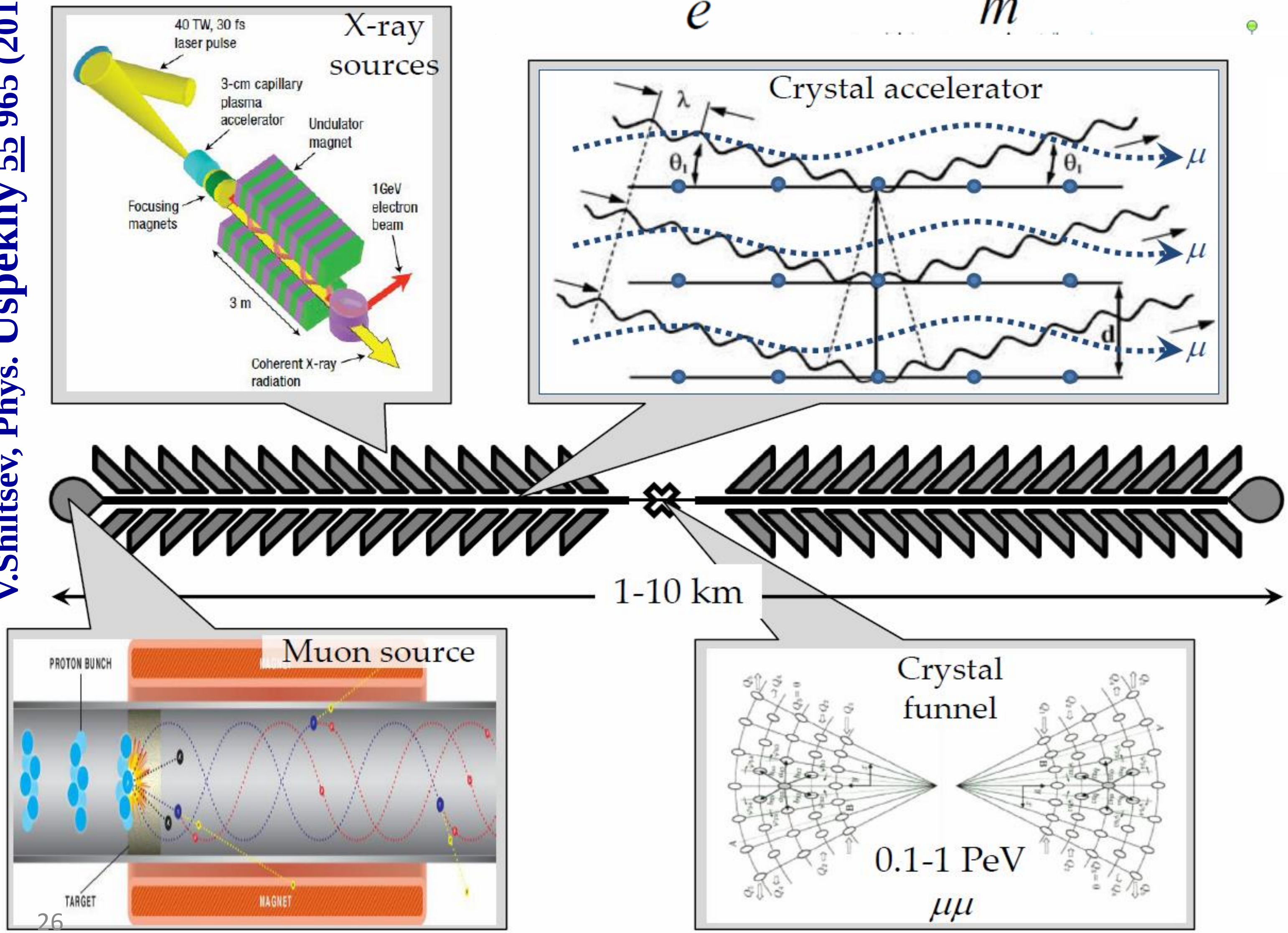


V. Shiltsev

"dream" collider = muon crystal acceleration

$$E_0 = \frac{m_e c \omega_p}{e} \approx 100[\frac{GeV}{m}] \cdot \sqrt{n_0[10^{18} cm^{-3}]}$$

V.Shiltsev, Phys. Uspekhy 55 965 (2012)



n~10^{22} cm^{-3},
10 TeV/m →

1 PeV =
1000 TeV

n_μ ~1000
n_B ~100
f_{rep} ~10^6
L ~$10^{30\text{-}32}$

V. Shiltsev

technology cost drivers

"RF is the most expensive technology ever invented"

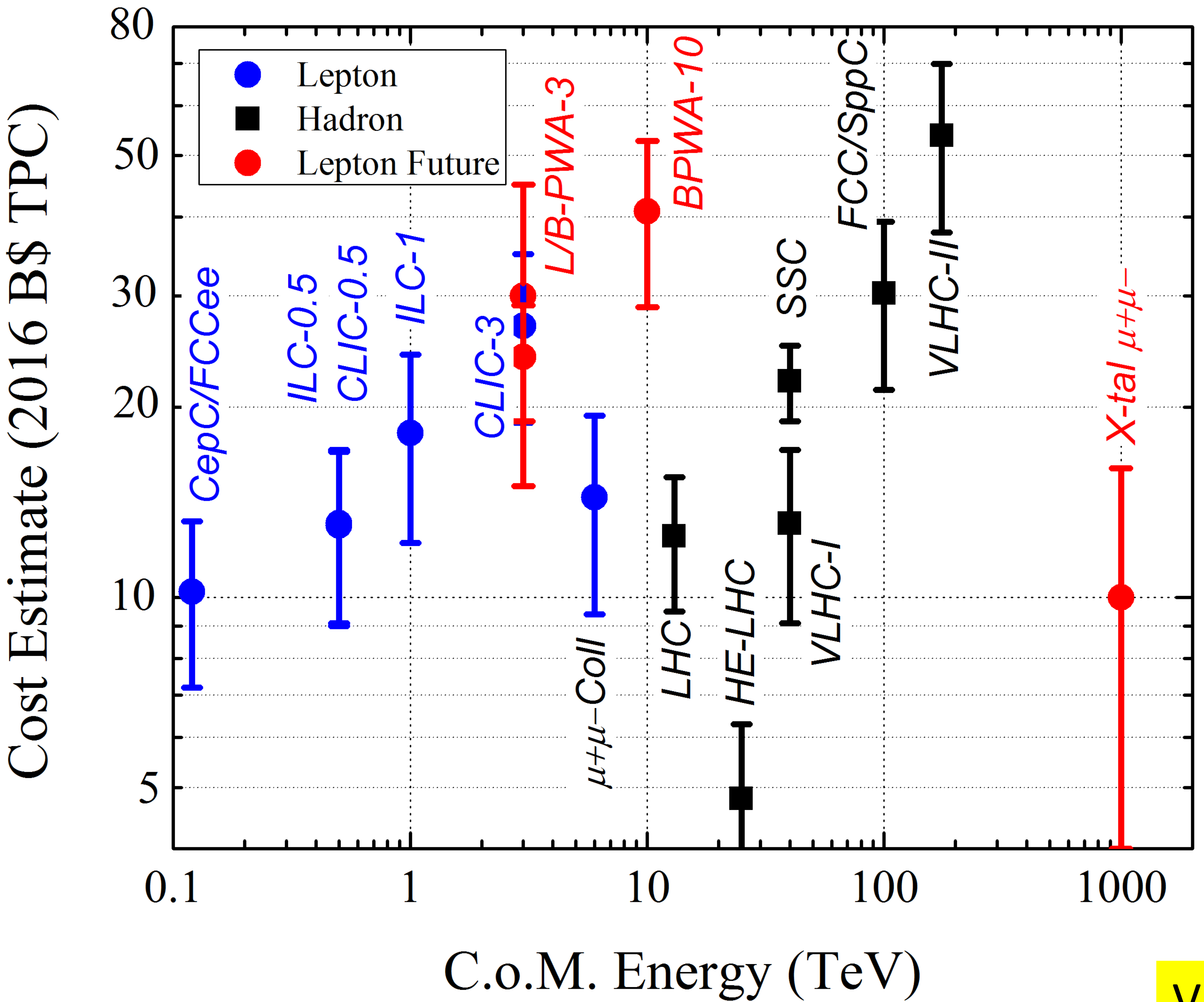
$\beta \approx$ **10 B$/sqrt(*E*/TeV)**

"only plasma acceleration is even more expensive"

$\beta \approx$ **20 B$/sqrt(*E*/TeV)**

V. Shiltsev

collider costs from αβγ model



V. Shiltsev

XBEAM concluding thoughts

- **circular colliders and storage rings work well and advance further thanks to new concepts** (crab waist, top up, monochromatization,…) and tools (e-lenses, e-cloud mitigation, cooling,…)
- **one route forward: e+e- → hadrons →muons**
- **technology cost** to be reduced
- **crystal and nanotubes concepts** to be explored
- **beam power of rings and linacs** is increasing
- **polarization** offers additional handle for discovery and precision studies at lower energy
- **SuperKEKB, IOTA, ESS, HEPS, NICA, MESA coming**, will teach us new lessons
- **ESSnuSB, JEDI, FCC, CEPC, … proposed**

seen in Tokyo Ueno …
but where is the European guy?

EuCARD²

… building no walls, but bridges between communities

Beam dynamics meets magnets I+II

Beam dynamics meets diagnostics

Universities meet laboratories I+II

Beam dynamics meets vacuum,
collimation … surfaces

Slow Extra… …nities

Sp… …unities

…connected

many thanks, Giuliano

a fantastic 4 years!

The end of EuCARD-2 XBEAM …

… becomes the start of ARIES APEC