Strategy for
Future Extreme Beam Facilities

compiled by G. Franchetti and F. Zimmermann, based on presentations at XBEAM Strategy Workshop, Valencia 13-17 February 2017

EuCARD²

XBEAM EXTREME

XBEAM COLL EXTREME

XBEAM RING EXTREME

XBEAM LINAC EXTREME

XBEAM POL EXTREME

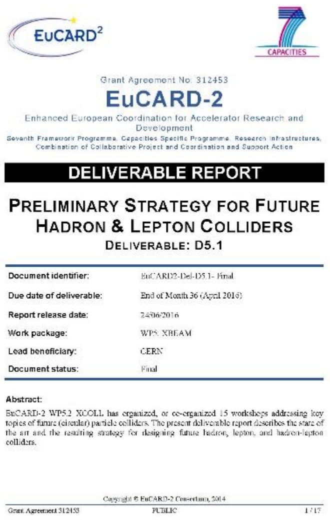
*Work supported by the **European Commission** under Capacities 7th Framework Programme project EuCARD-2, grant agreement 312453.*

EuCARD-2 WP5 XBEAM strategies

four strategy 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



Grant Agreement No: 312453

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

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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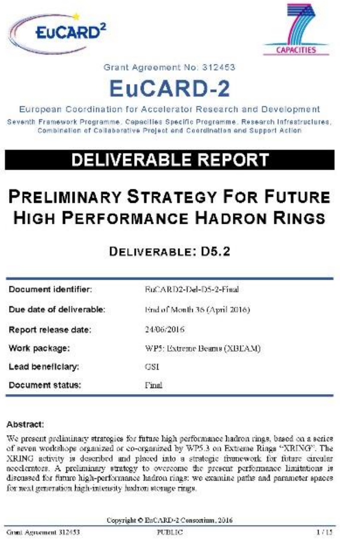

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DELIVERABLE REPORT

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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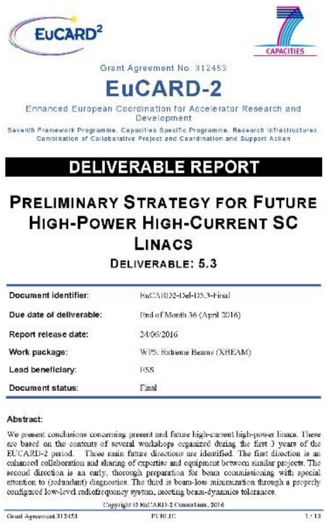

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DELIVERABLE REPORT

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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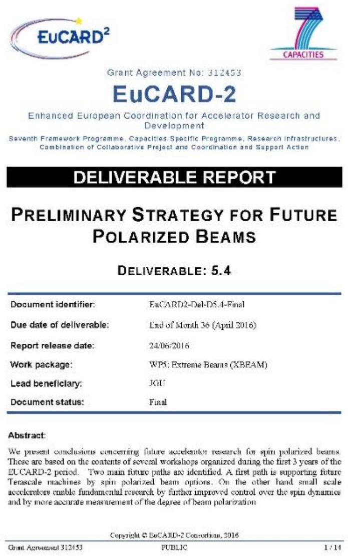

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DELIVERABLE REPORT

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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7 WP5 XBEAM Workshops May 2015 – April 2016

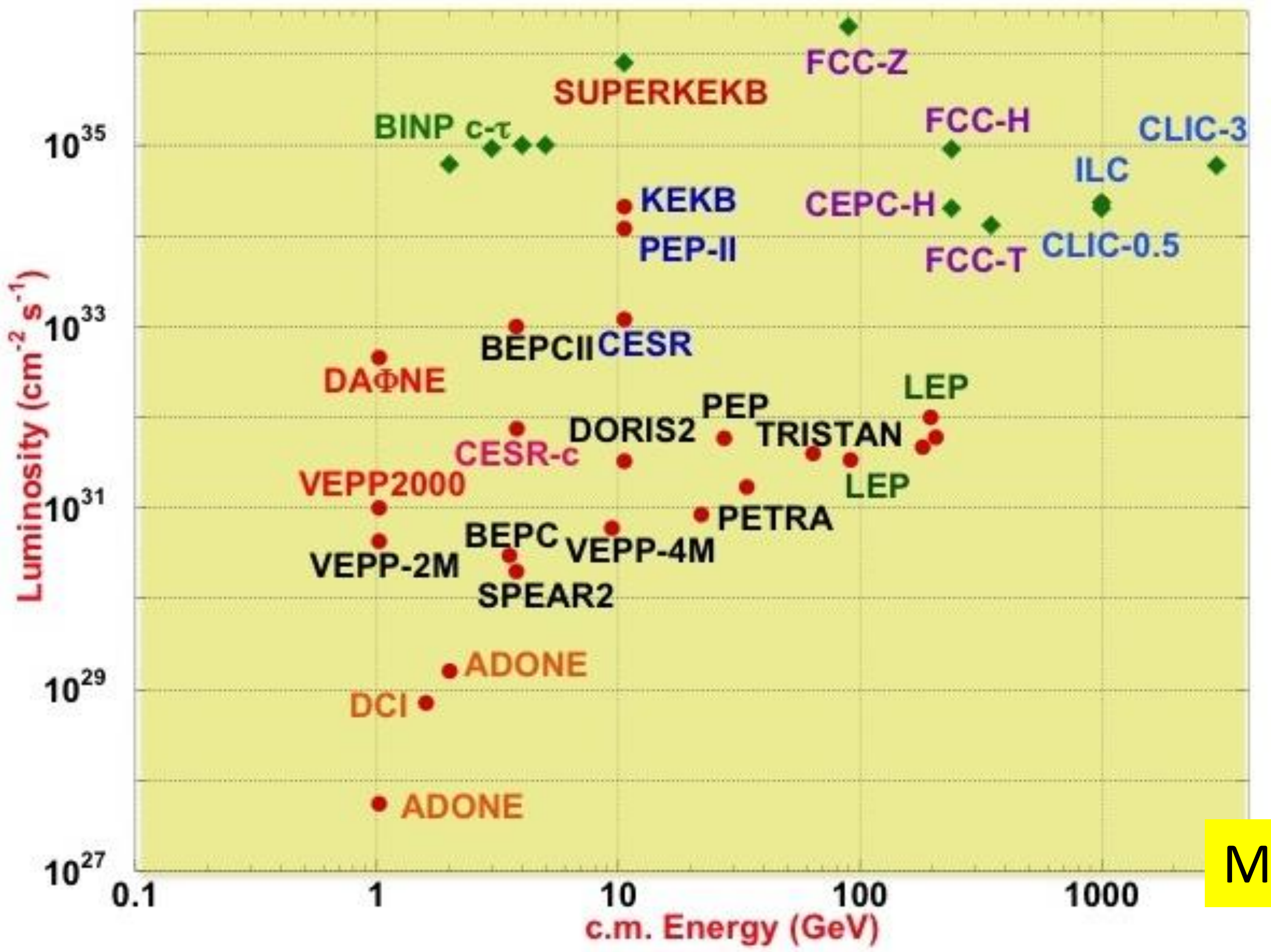
- XLINAC mini-workshop "LLRF and Beam Dynamics Mutual Needs in Hadron Linacs," Lund, 1-2 June 2015 (35 participants)
- XCOLL "Future electron–hadron colliders at CERN," CERN & Chavannes-de-Bogis, 24-26 June 2015 (120)
- XPOL workshop "Search for the Electron EDM in an Electrostatic Storage Ring," JGU Mainz, 10-11 September 2015 (28)
- XCOLL "Collimation Tracking Workshop," CERN, 30 Oct. 2015 (35)
- XRING/XLINAC workshop "Beam Dynamics meets Diagnostics," Firenze, 4-6 November 2015 (65)
- XCOLL co-org. workshop "FCC Week 2016", Rome, 11-15 April 2016 (468)
- XPOL workshop "Polarization Issues in Future High Energy Circular Colliders," Rome, 16 April 2016 (14)

9 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)
- XPOL “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”,

extreme colliders
1. lepton colliders

luminosity vs. c.m. energy for past, present and future e$^+$e$^-$ colliders



M. Biagini

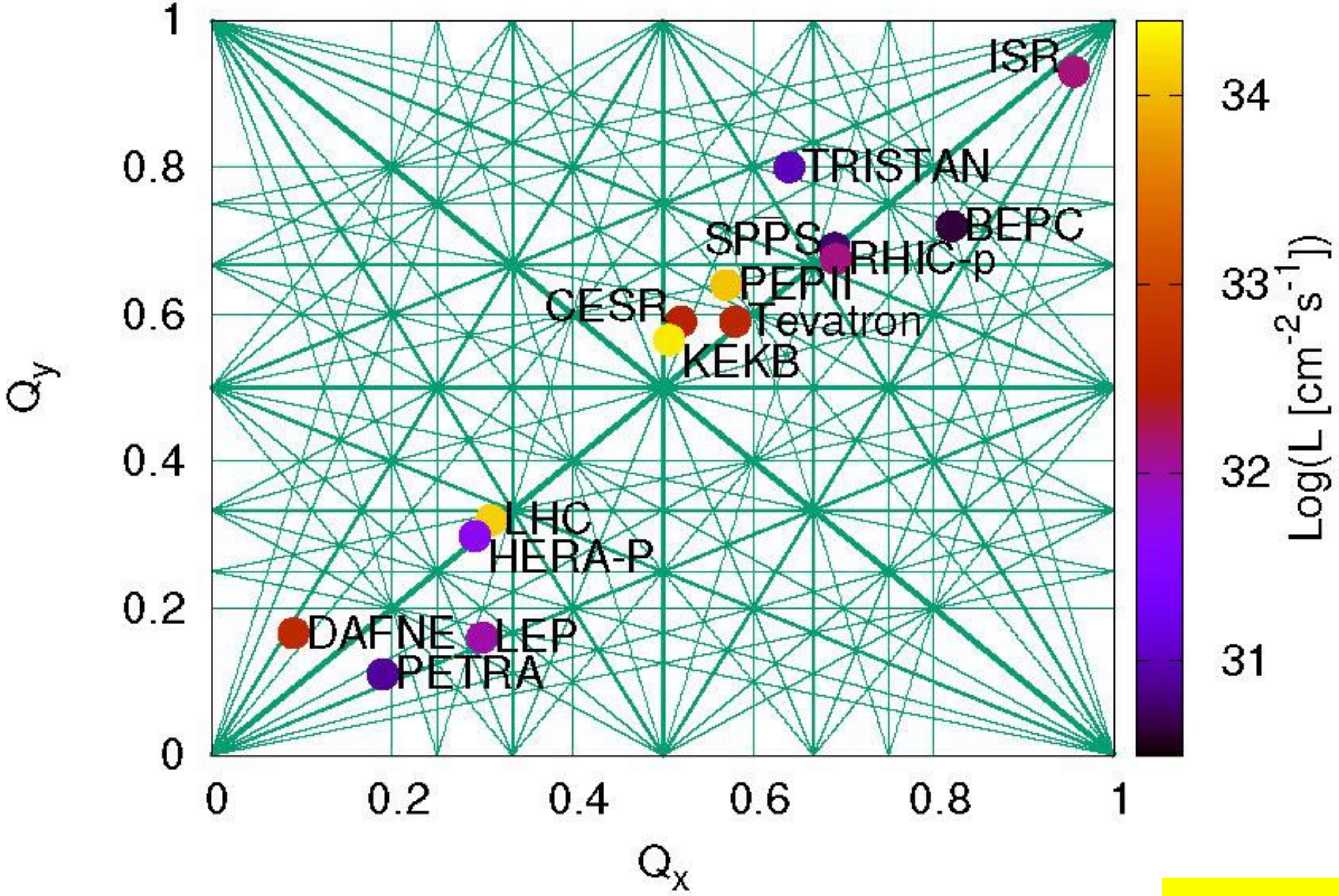
past [orange, black, green centre- right], present (2015) [red] and future e+e- colliders [blue, purple, green top-left] around the world

lessons learnt from past&present e^+e^- colliders

- high beam currents possible : control of HOMs & e-cloud
- crab waist works: special lattice
- top-up injection needed: reliable injection complex
- e-cloud mitigation possible: solenoids, low SEY, coating, clearing electrodes, grooves, NEG, scrubbing
- bunch-by-bunch feedbacks work well: upgrades
- backgrounds increase with I_{beam}, L and E: masking, shielding, beamstrahlung control
- emittance tuning essential: machine error minimization (girders), fast online procedures for orbit/beta /dispersion/ coupling correction
- IP orbit control needed: IP feedback
- nano-beams require vibrations control for FF quads

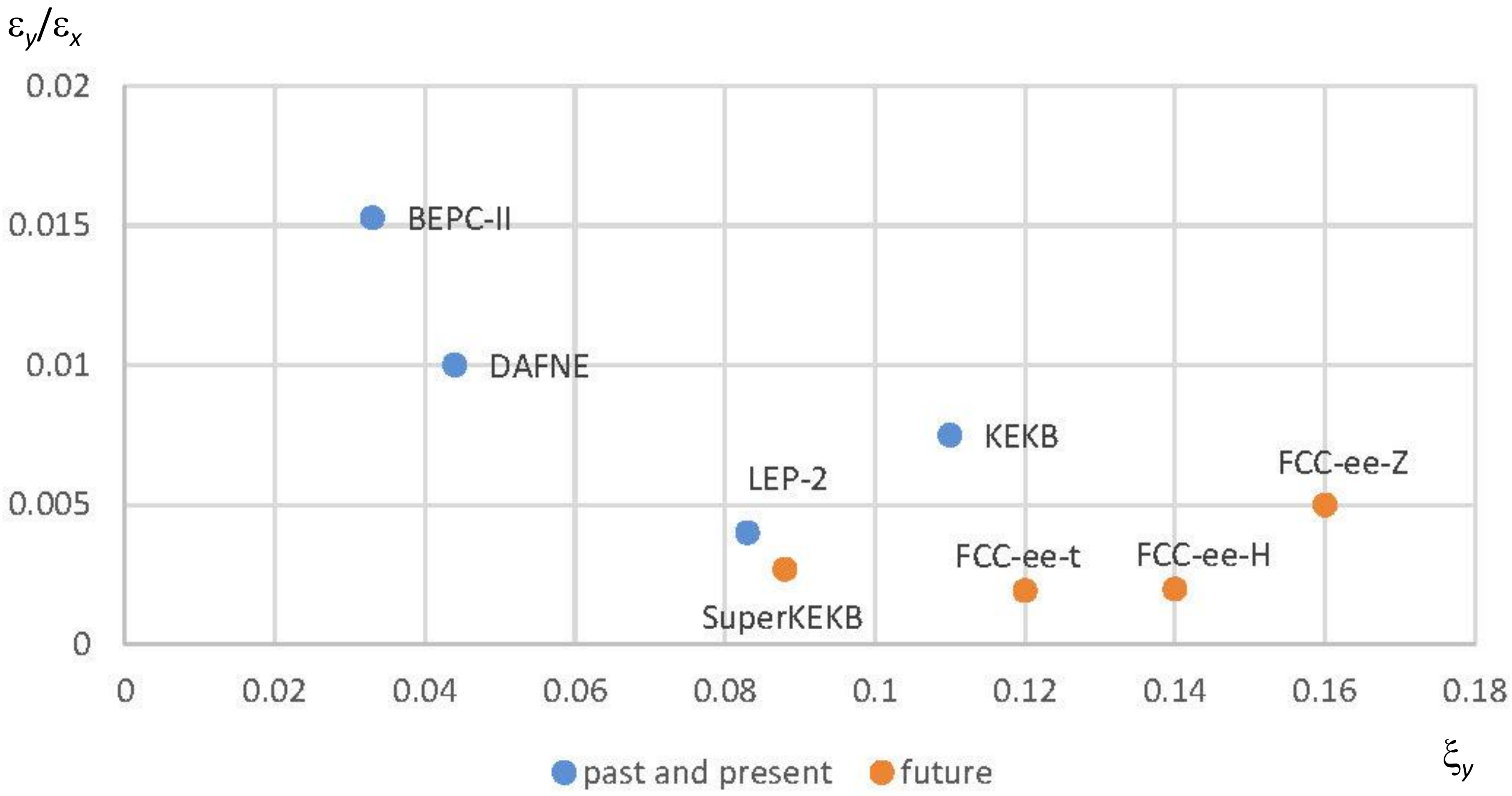
M. Biagini

collider operating points and performance



R. Tomas

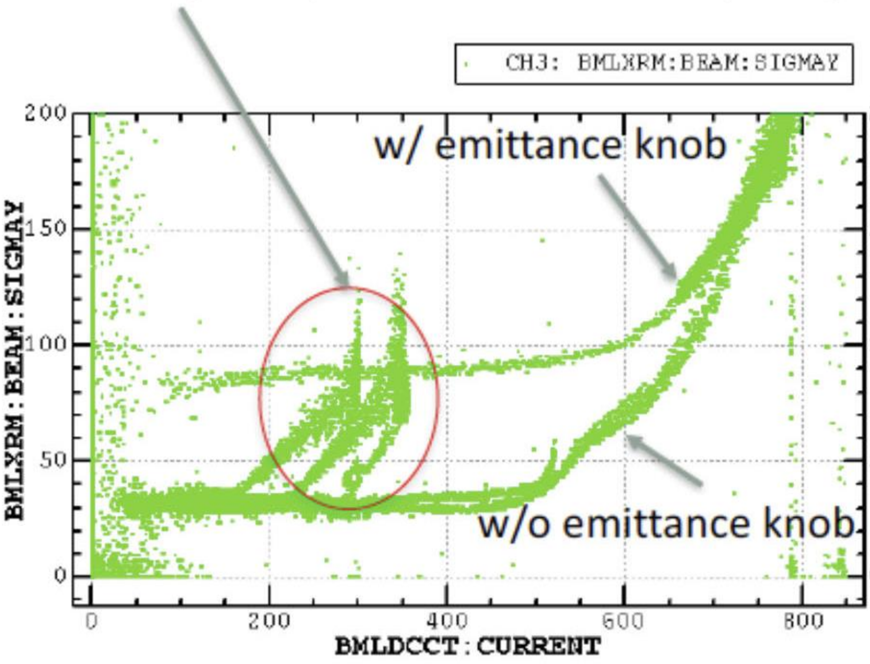
emittance ratio versus b-b tune shift



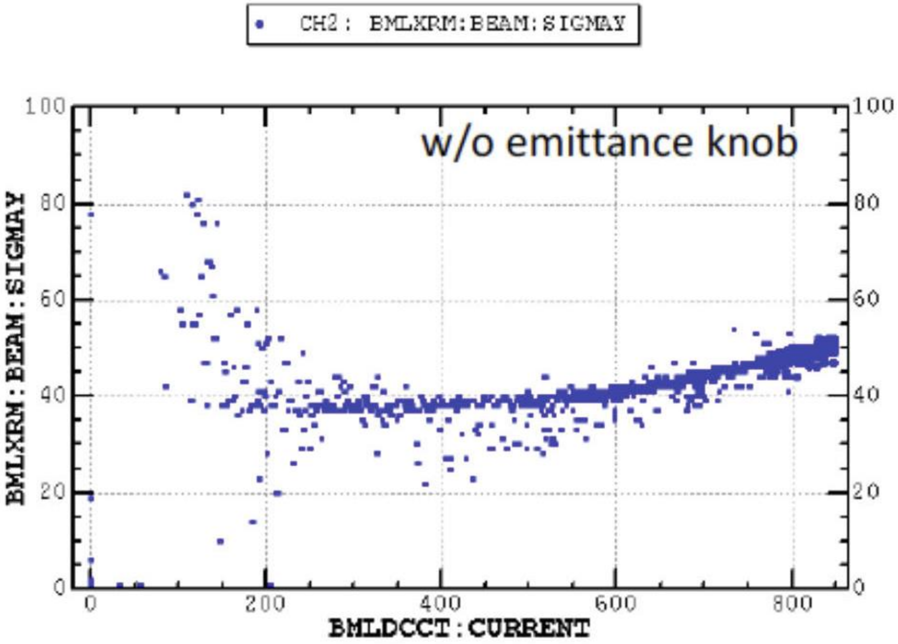
starting to learn from SuperKEKB: extremely low β_y^*, top-up injection, and-e-cloud mitigation

Measured at SuperKEKB Phase I

Blowup study with shorter bunch spacing



3.06 spacing (1576 bunches)



3.06 spacing (1576 bunches)

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

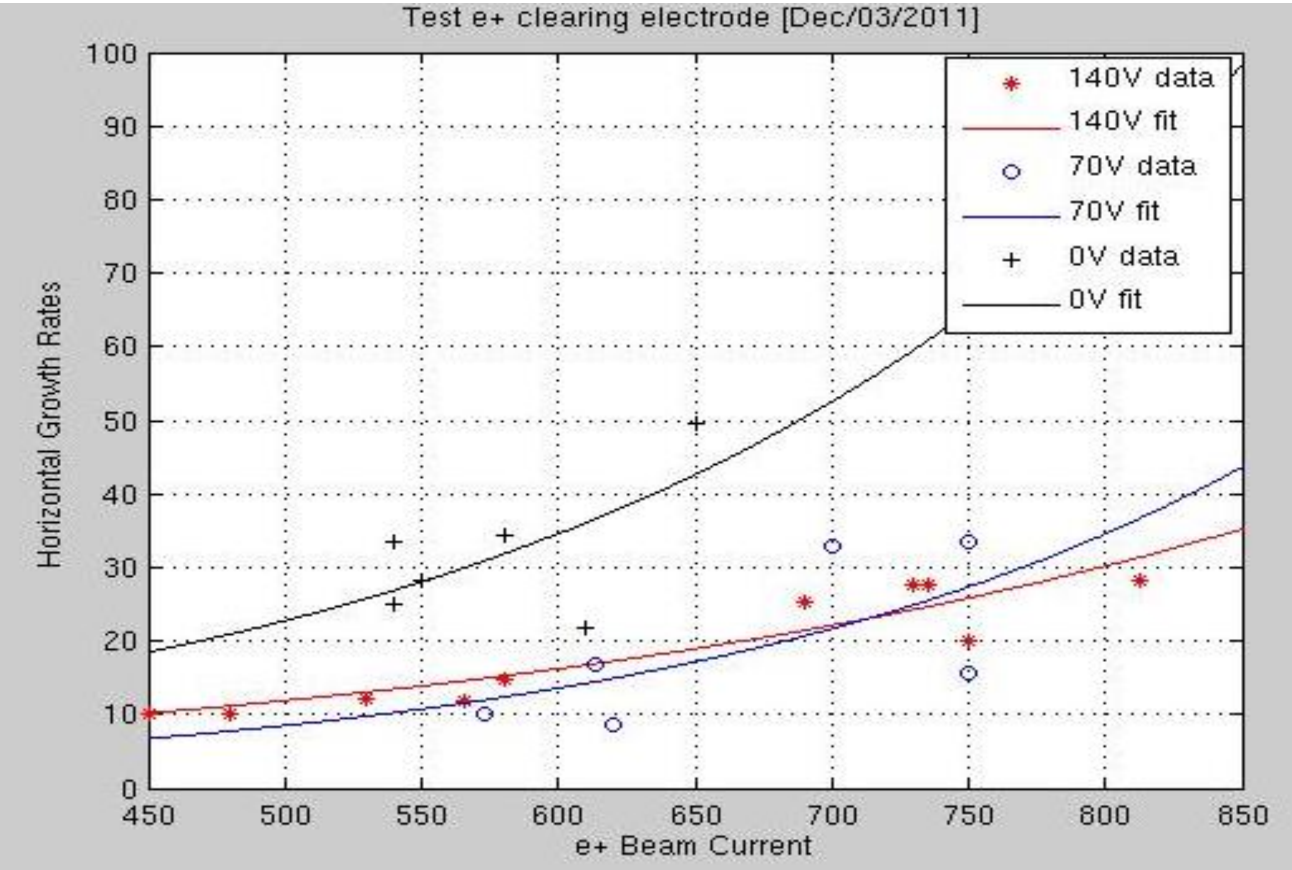
June 6th (after installation of solenoids at bellows chambers)

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

M. Biagini

e-cloud clearing-electrodes at DAFNE

- smaller vertical dimensions, less transverse tune spread and slower growth rates clearly indicate a positive effect



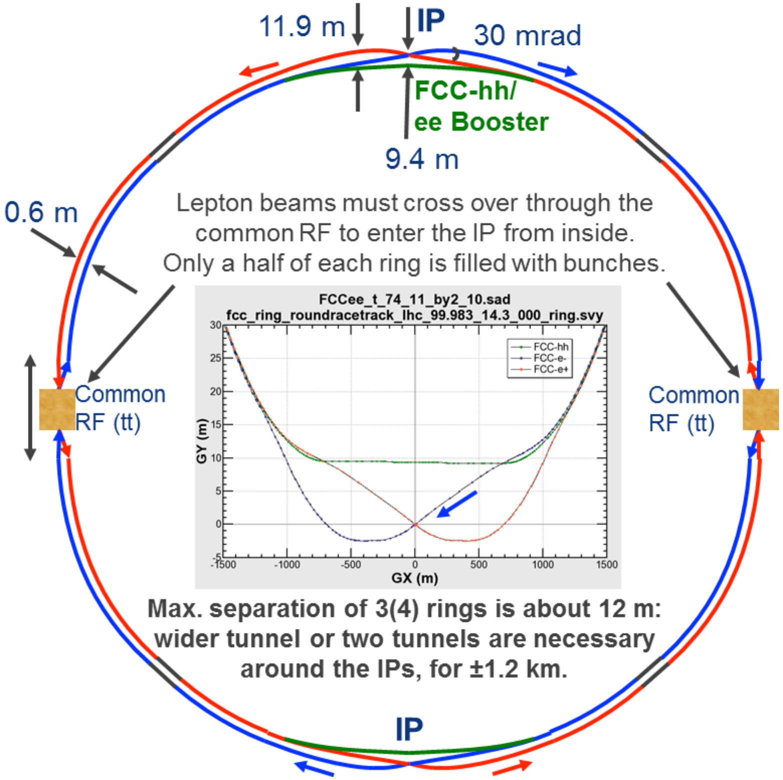
- after 5 years 10/12 electrodes grounded (destruction of shapal insulators or damage of copper? check in 2018)

A. Drago

designs for future e+e- colliders are converging

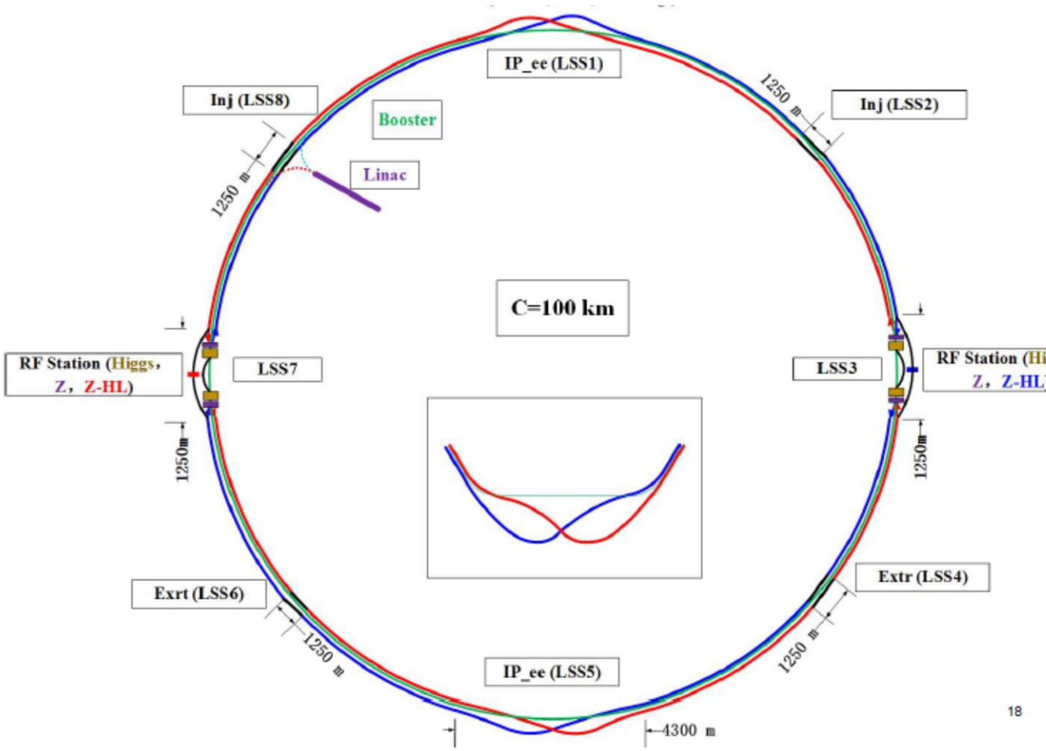
FCC-ee design, K. Oide, 2015

CEPC design, J. Gao, 2017



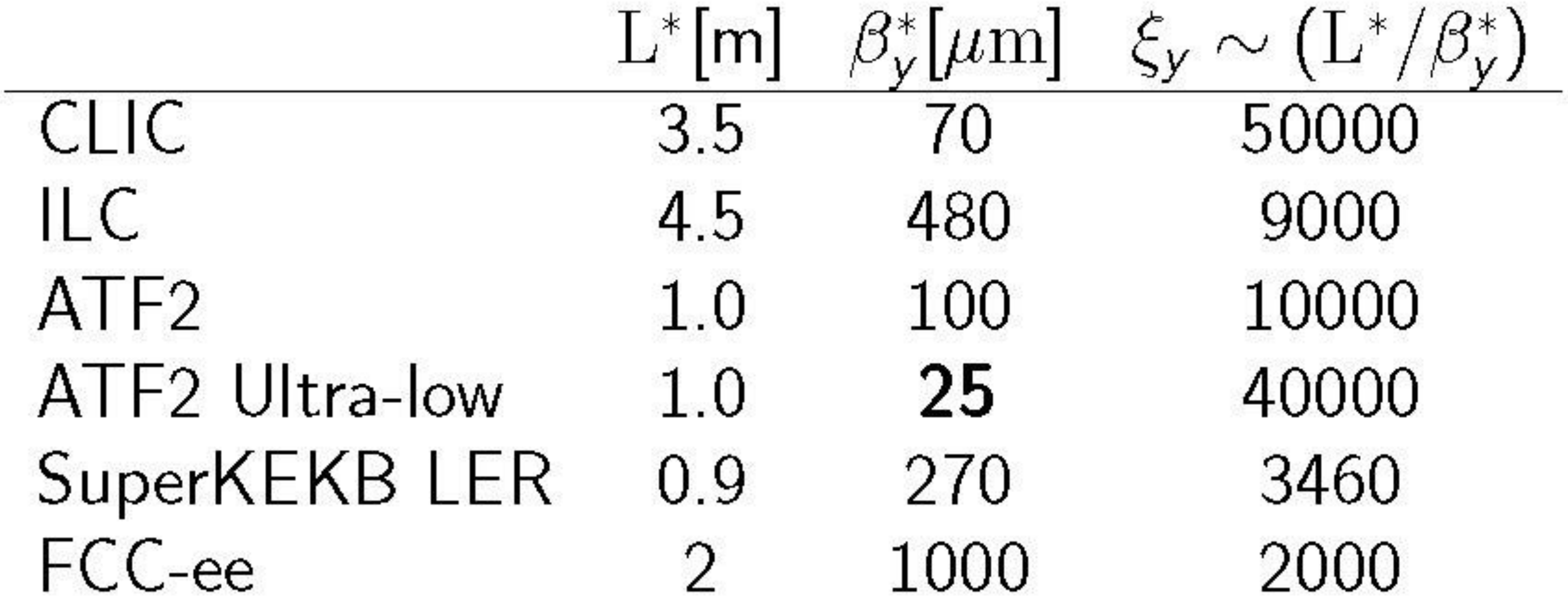
Lepton beams must cross over through the common RF to enter the IP from inside.
Only a half of each ring is filled with bunches.

Max. separation of 3(4) rings is about 12 m: wider tunnel or two tunnels are necessary around the IPs, for ±1.2 km.



F. Zimmermann

final-focus systems of lepton colliders



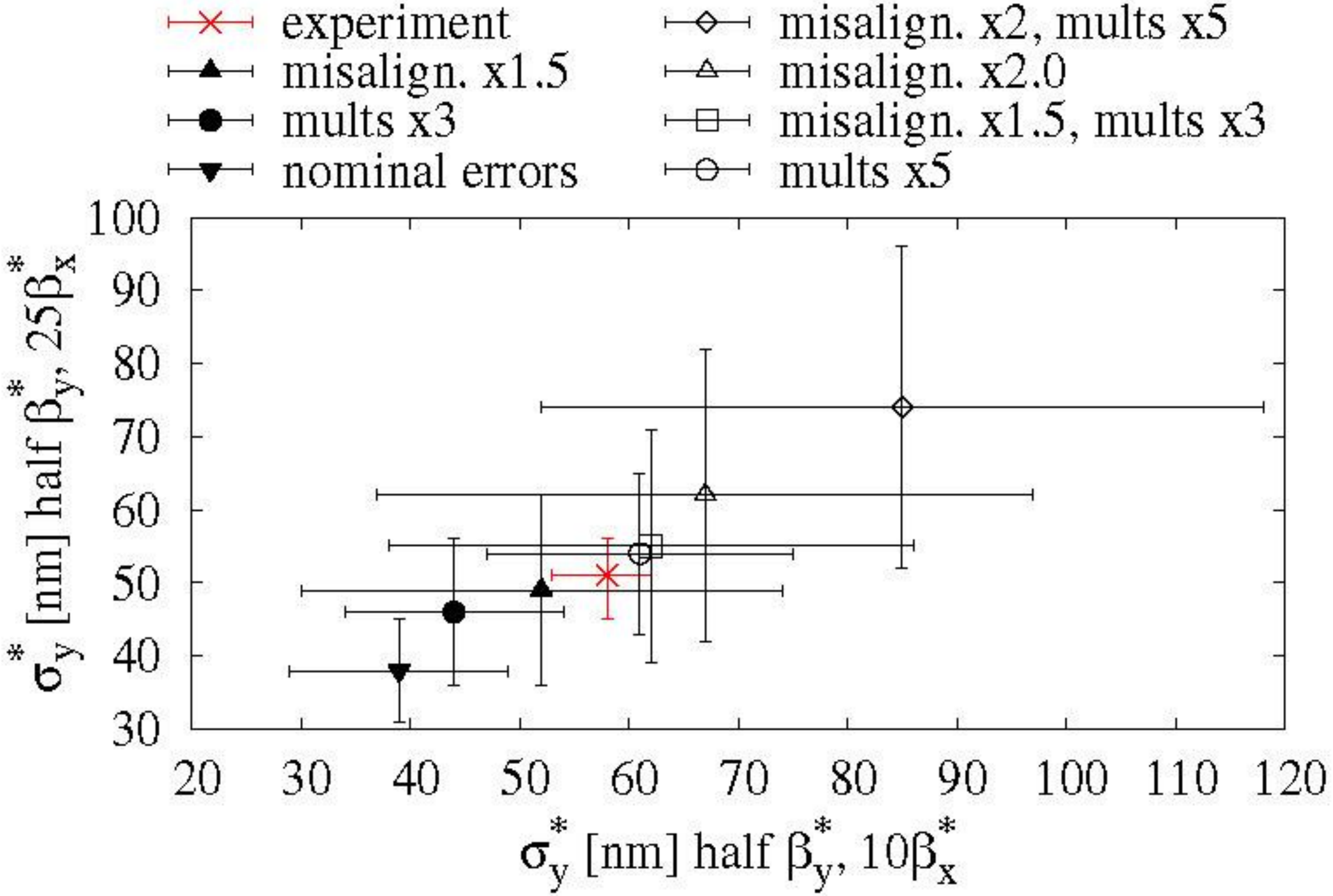
	L^* [m]	β_y^* [μm]	$\xi_y \sim (L^*/\beta_y^*)$
CLIC	3.5	70	50000
ILC	4.5	480	9000
ATF2	1.0	100	10000
ATF2 Ultra-low	1.0	**25**	40000
SuperKEKB LER	0.9	270	3460
FCC-ee	2	1000	2000

SuperKEKB = proof-of-principle for FCC-ee

LC final foci extremely challenging

R. Tomas

linear collider final foci – ATF2 tests



M. Patecki et al, Phys. Rev. Accel. Beams **19**, 101001

predictions were/are too optimistic (reminiscent of SLC, but for ATF2 even at low intensity)

R. Tomas

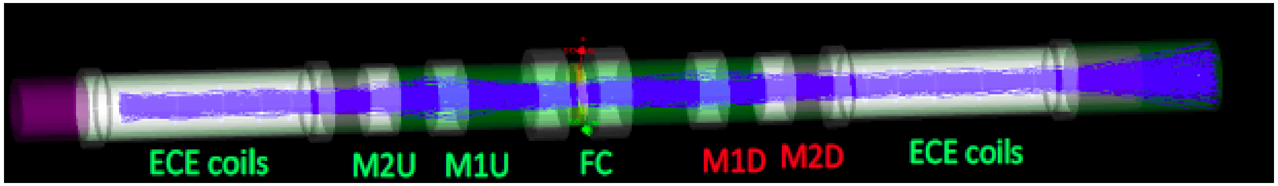
comparison of proposed future e+e- colliders

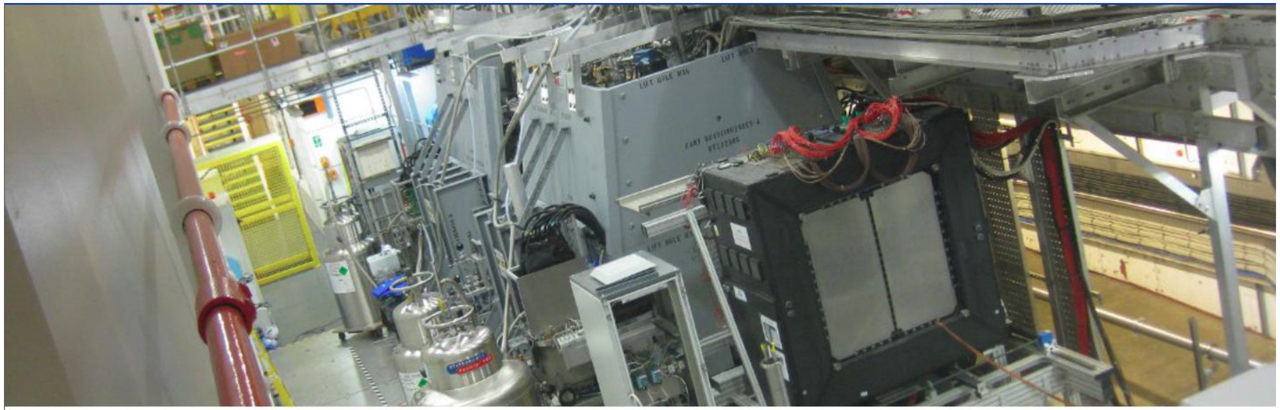
	Unit	**ILC - TDR**			**CLIC – CDR+**		**FCC-ee**		
Technology		Linear SRF, Klystron driven			Linear NRF, 2-beam driven		Circular (2 IPs)		
Energy	GeV	250	**500**	1,000	380	3,000	91	**240**	**350**
Acc. Length	km	~21	31	50	11	48	100		
Tot Lumin.	$10^{34}\ \mathrm{cm^{-2}s^{-1}}$	**0.82**	**1.8**	**3.6**	**1.5**	**5.9**	**200 - 400**	**10**	**2.6**
Acc. Gradient	MV/m	31.5	31.5	31.5/45	72	100	7	10	10
Res. Frequency	GHz	1.3	1.3	1.3	12	12	0.4		
IR, v. beam-size	nm	7.7	5.9	2.7	2.9	1	32	49	70
Beam Power (/IP)	MW (2-beams)	2 x 2.9	2 x 5.2	2 x 10.6	2x2.8	2 x 14	2x66000	2x3600	2x1160
SR loss	MW	4	4	4	3	2	100		
AC Power	MW	**129**	**163**	**300**	**252**	**589**	**275**	308	**364**
L / AC	Relative	0.64	1.1	1.2	0.60	1.0	72 - 145	3.2	0.71

M. Biagini, F. Zimmermann

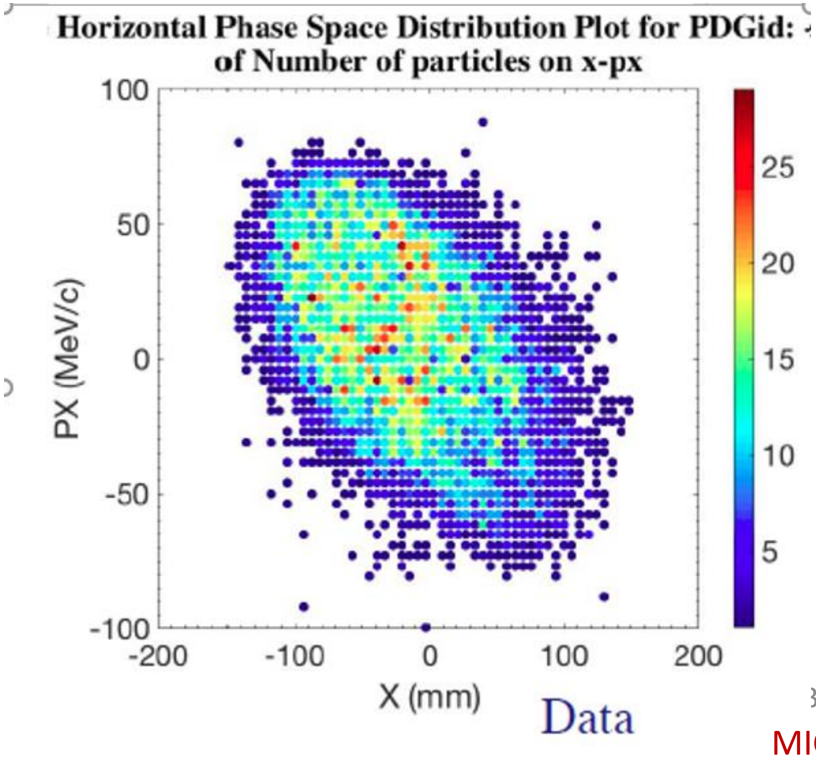
MICE success

- at RAL
- 10M muon tracks
- 8% cooling observed
  - w/o RF yet
- re-accel'n in 2018

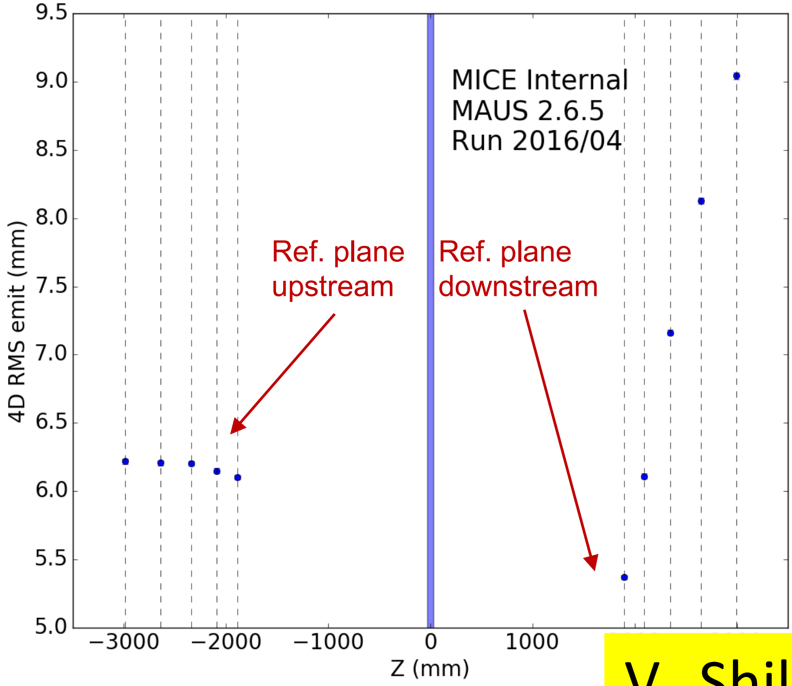




MICE Operation and Demonstration of Muon Ionization Cooling



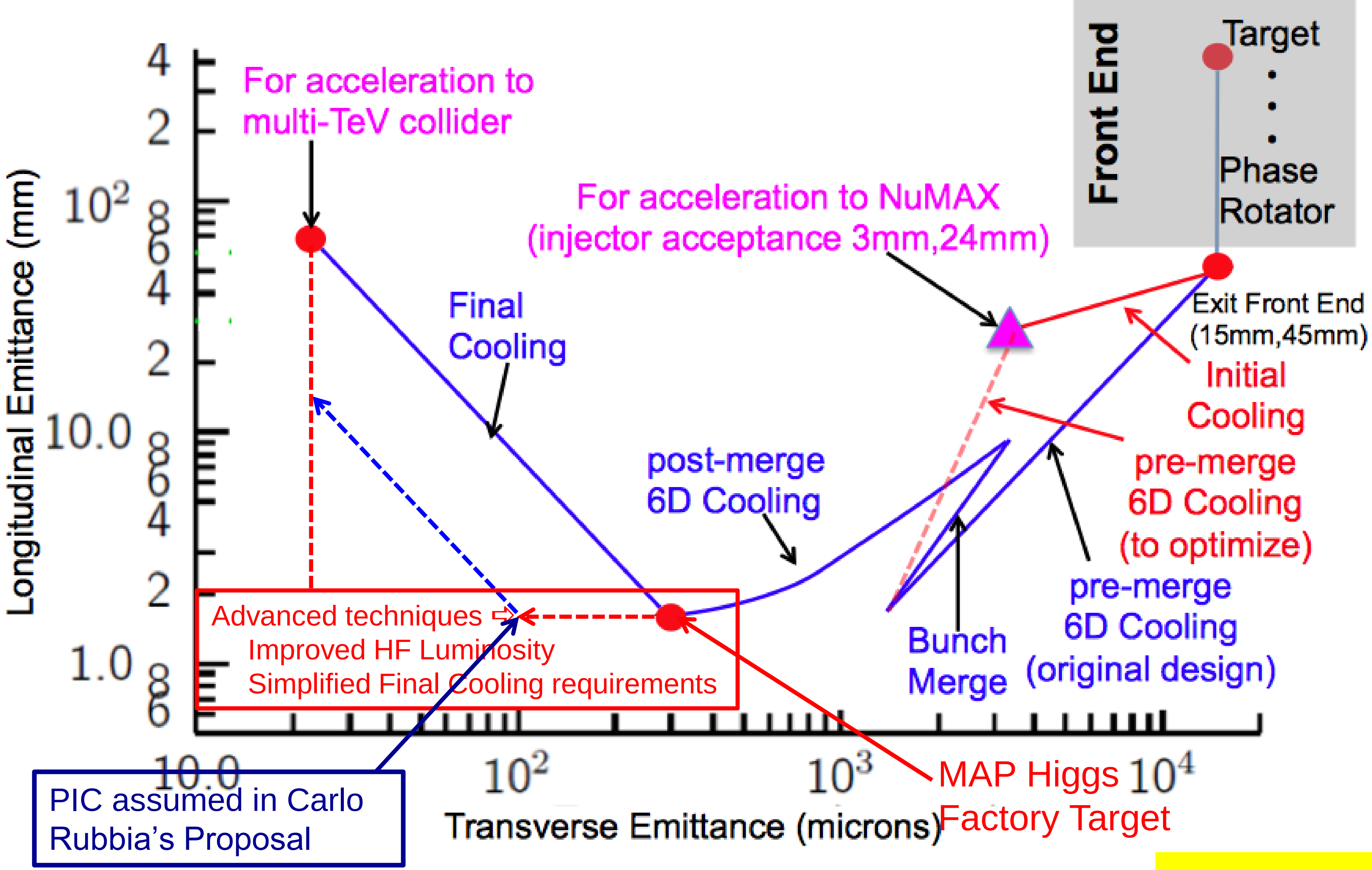
EAM 201



MICE (very) preliminary A.Bross, A.Liu, F.Drielsma

V. Shiltsev

two novel approaches boosting muon collider
no. 1: parametric res. ionization cooling (PIC)



Advanced techniques ⇨
Improved HF Luminosity
Simplified Final Cooling requirements

PIC assumed in Carlo Rubbia’s Proposal

M. Boscolo

two novel approaches boosting muon collider: no. 2: direct muon pair production $e^+e^- \rightarrow \mu^+\mu^-$

M. Boscolo

advantages:

1. **Low emittance**
2. **Low background**
3. Reduced losses from decay
4. Reduced **energy spread**

disadvantage (key challenge!):

rate: much smaller cross section wrt protons

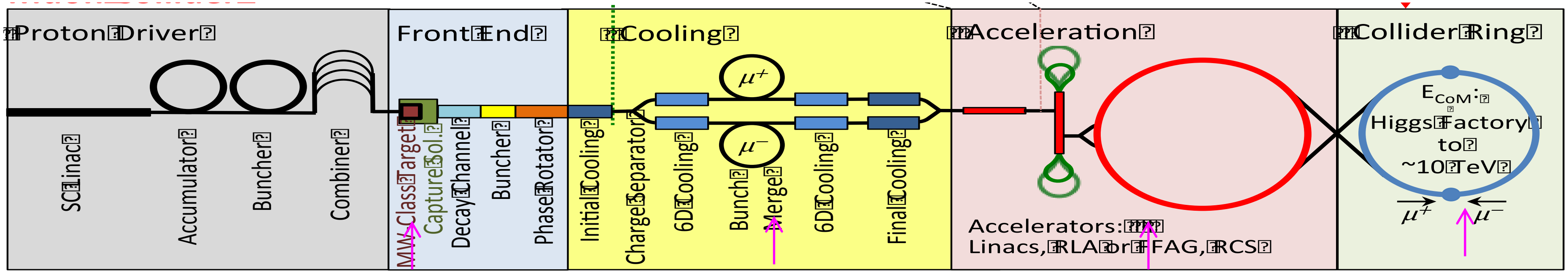
$\sigma(e^+e \rightarrow \mu^+\mu^-) \sim 1\ \mu b$ at most

i.e. Luminosity(e+e-)= $10^{40}\ cm^{-2}\ s^{-1}$ → gives μ rates 10^{10} Hz

use e+ ring to reduce request on positron source

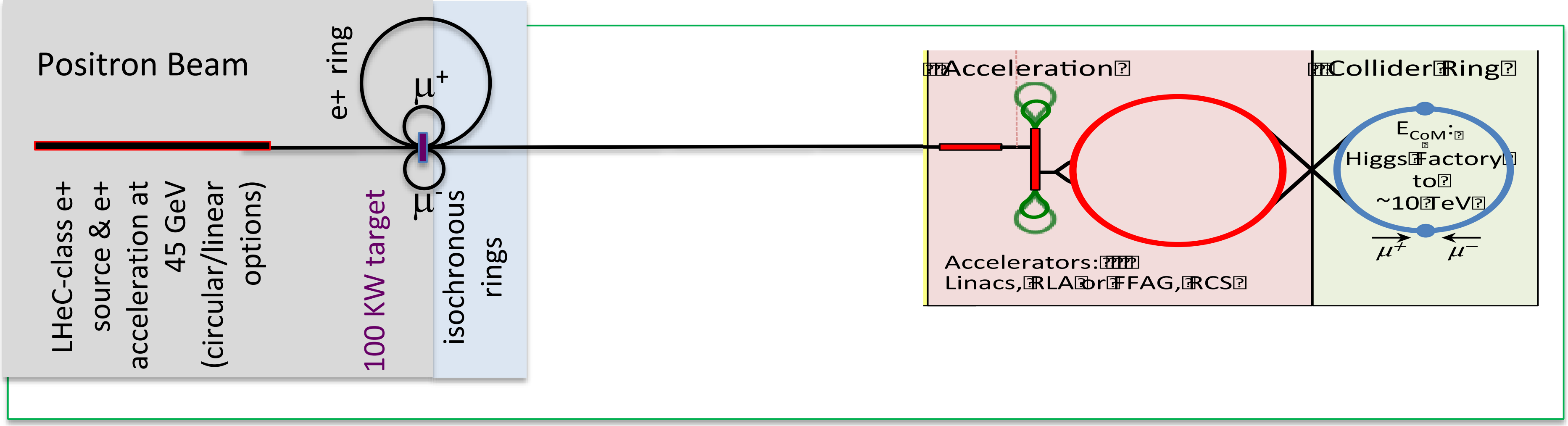
→ *we should compare cross sections of competing processes*

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



Key Challenges

- ~10^{13}-10^{14} μ / sec
Tertiary particle
p→π→μ:
- 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-→*μ+μ−*

Key R&D

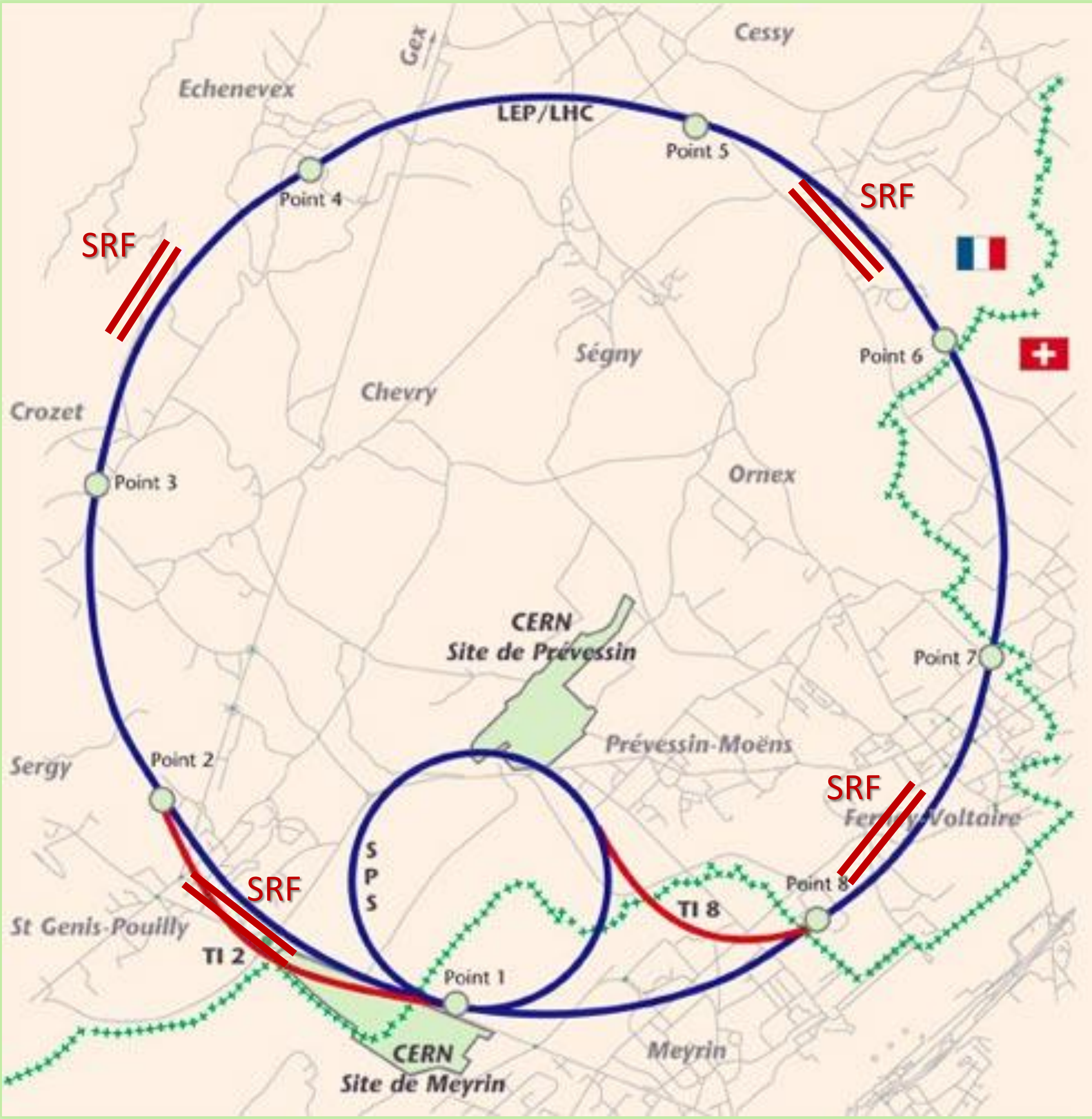
10^{15} e+/sec, 100 kW class target, NON distructive process in e+ ring

M. Boscolo

CMC

CERN Muon Collider

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

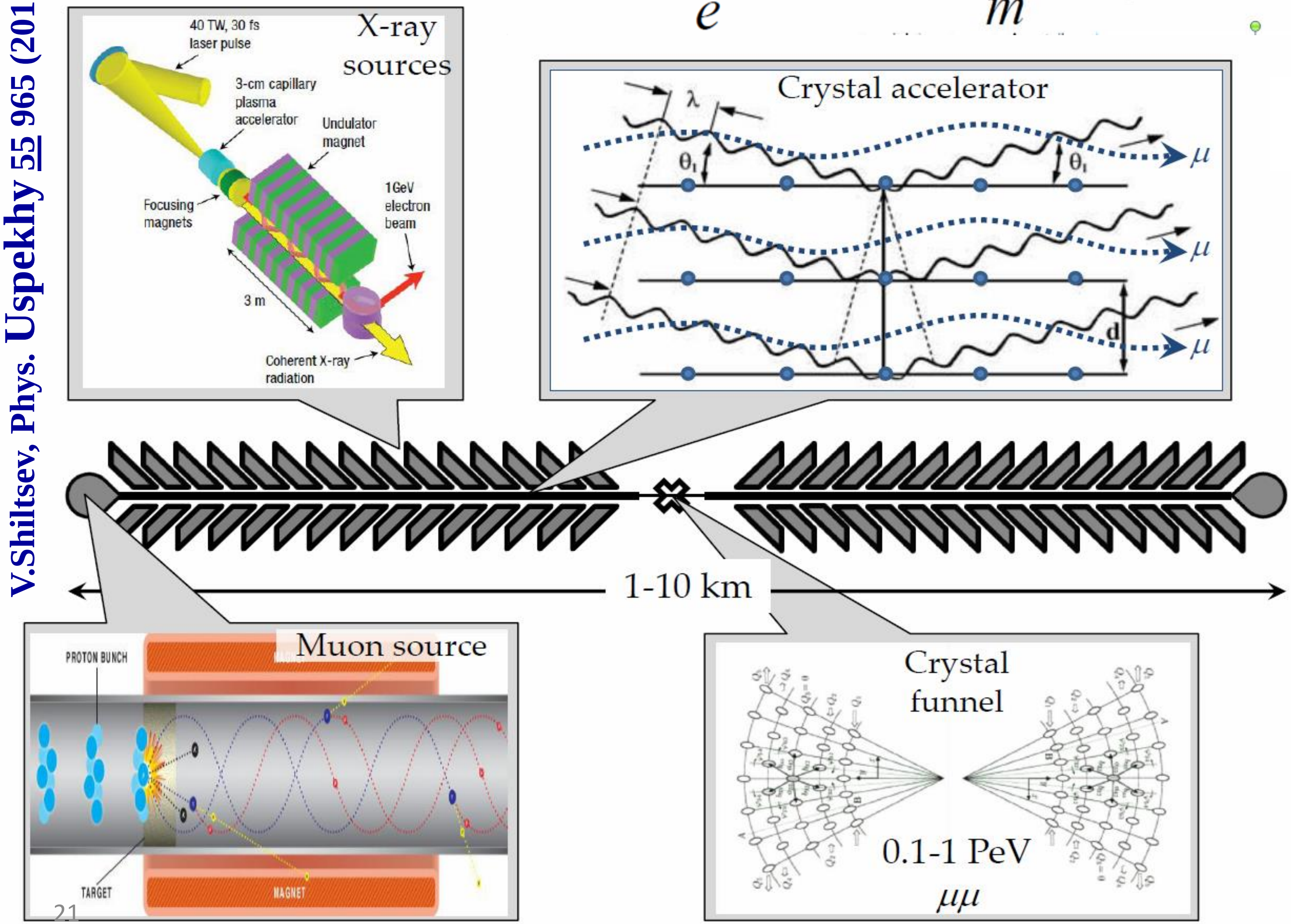


V. Shiltsev

“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

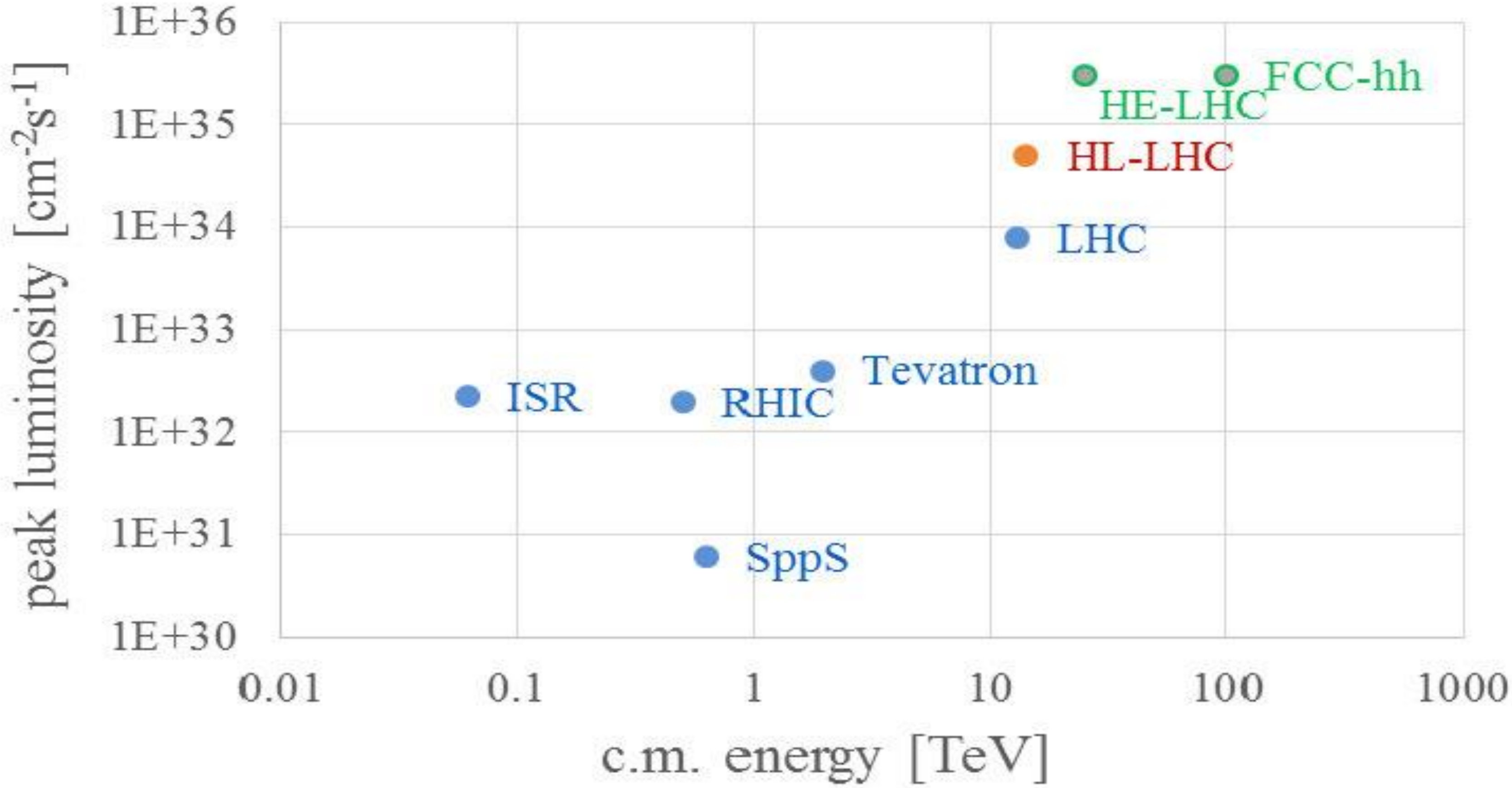
f_{rep} ~10^6

L ~10^{30-32}

V. Shiltsev

extreme colliders
2. hadron colliders

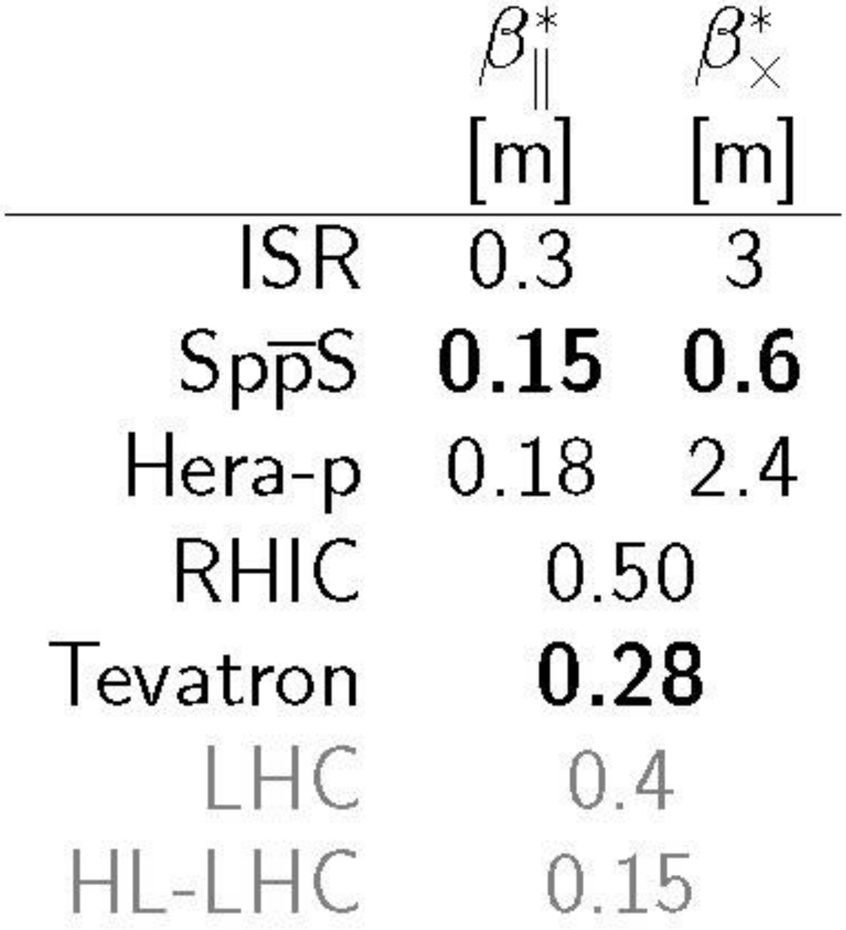
luminosity vs. c.m. energy for past, present and future hadron colliders



past and present [blue], upcoming [red], and longer-term future hadron (pp or p-pbar) colliders [green] around the world

F. Zimmermann

beta* of hadron colliders



	$\beta^*_{\parallel}$ [m]	$\beta^*_{\times}$ [m]
ISR	0.3	3
Sp$\overline{\text{p}}$S	**0.15**	**0.6**
Hera-p	0.18	2.4
RHIC	0.50	
Tevatron	**0.28**	
LHC	0.4	
HL-LHC	0.15	

pushing FCC-hh β* down to 5 cm ?
R. Martin et al., submitted to PRAB

R. Tomas

hadron-beam instabilities & cures (LHC)

- beam instabilities observed for different LHC beam processes

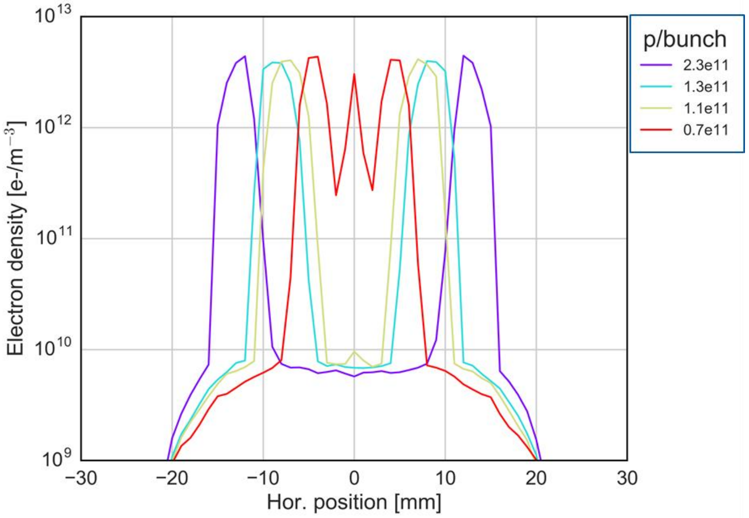
- some lesson learnt:
  - narrow range of machine settings to keep beam stable along the cycle
  - instabilities occur if coupling exceeds a certain threshold (at different stages)
  - chromaticity settings are crucial along the cycle and can’t be relaxed
  - octupole settings have to be adapted according to beam emittance
  - transverse damper indispensable to preserve beam stability all along the cycle

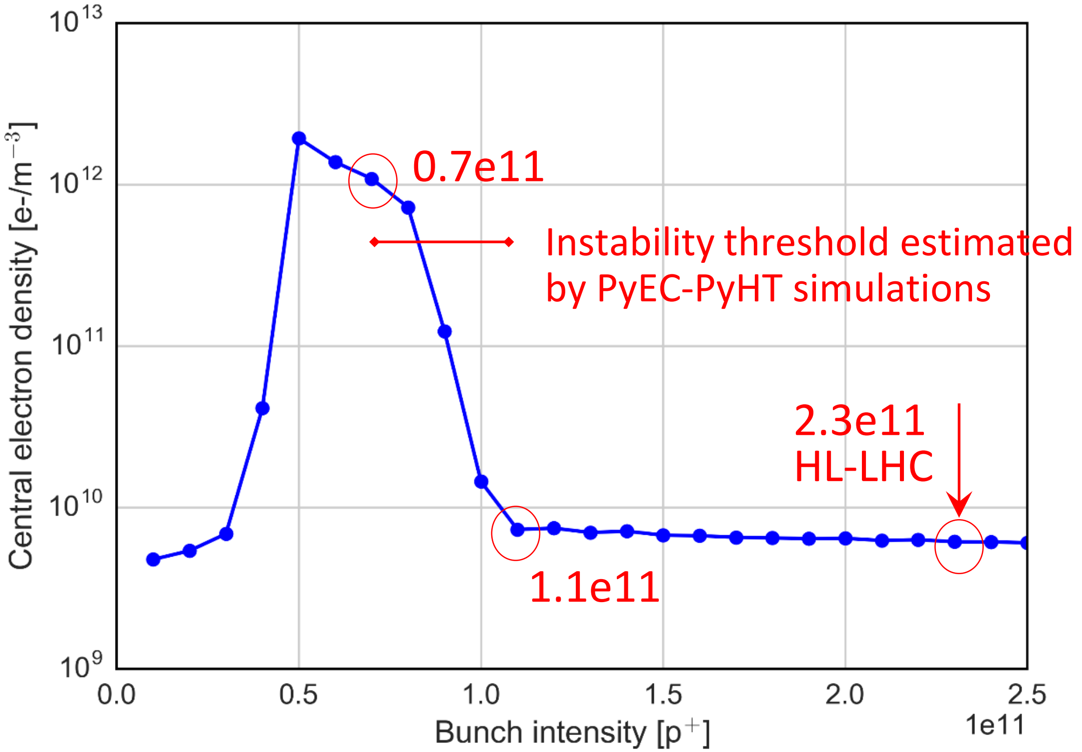
- sources of instability
  - electron cloud (with 25 ns beams) → tends to become better with scrubbing
  - machine impedance and loss of Landau damping

G. Rumolo

e-cloud causes coherent instability in collision

- coherent instabilities in stable beams → simulations
  - electron cloud in the dipoles tends to form a central stripe for lower bunch intensities
  - the central density threshold (5e11 m^{-3}) is crossed when the bunch intensity decreases with Q'=15
  - the threshold becomes much higher for Q'>20
- explanation also consistent with the disappearance of this phenomenon (due to scrubbing)





0.7e11

Instability threshold estimated by PyEC-PyHT simulations

2.3e11
HL-LHC

1.1e11

G. Rumolo

extreme colliders
3. efficiency & cost

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

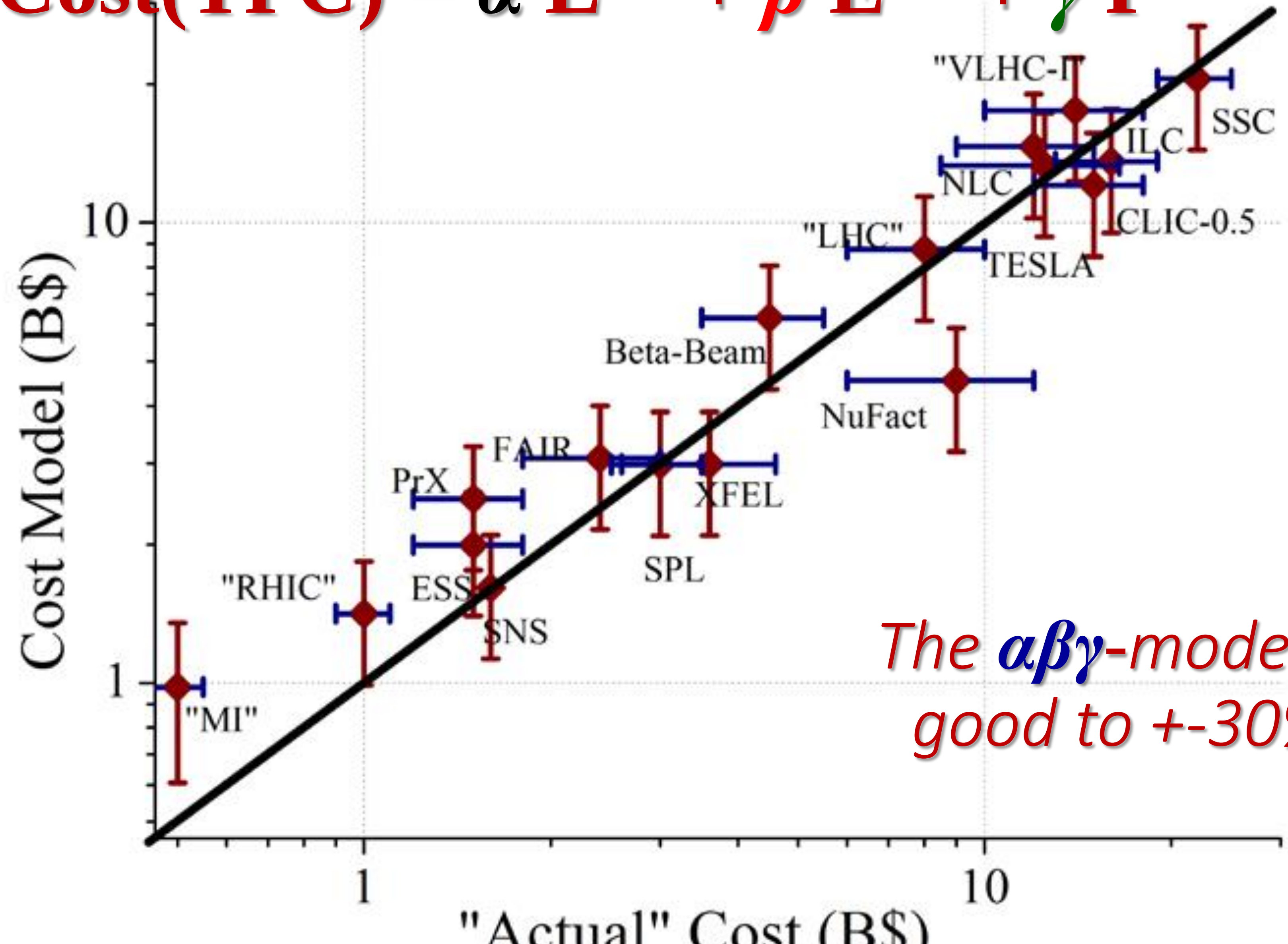
collider	c.m. energy [TeV]	P_{el}: tot. el. power [MW]	P_b: IP beam power [GW]	luminosity L [nb^{-1}s^{-1}]	P_b/P_{el}	L/P_{el} (/IP) [nb^{-1}s^{-1}/MW]
CEPC	0.24	~500	4.0	20	**8000**	**0.04**
FCC-ee	0.091	276	132	2000	**500000**	**7.2**
FCC-ee	0.24	308	7.2	50	**23000**	**0.16**
FCC-ee	0.35	364	2.3	13	**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**

some efficiency lessons

- linear colliders must operate with much smaller IP spot sizes to compete in luminosity
- ERLs do not (yet) reach the efficiency of circular machines
- future circular lepton and hadron colliders offer outstanding luminosities / input power
- figures of merit for plasma linear colliders highly uncertain

project costs fitted by αβγ model

$$\mathrm{Cost(TPC)} = \alpha\, L^{1/2} + \beta\, E^{1/2} + \gamma\, P^{1/2}$$



*The **αβγ**-model is good to +-30%*

technology cost drivers

"SRF is the most expensive technology ever invented"

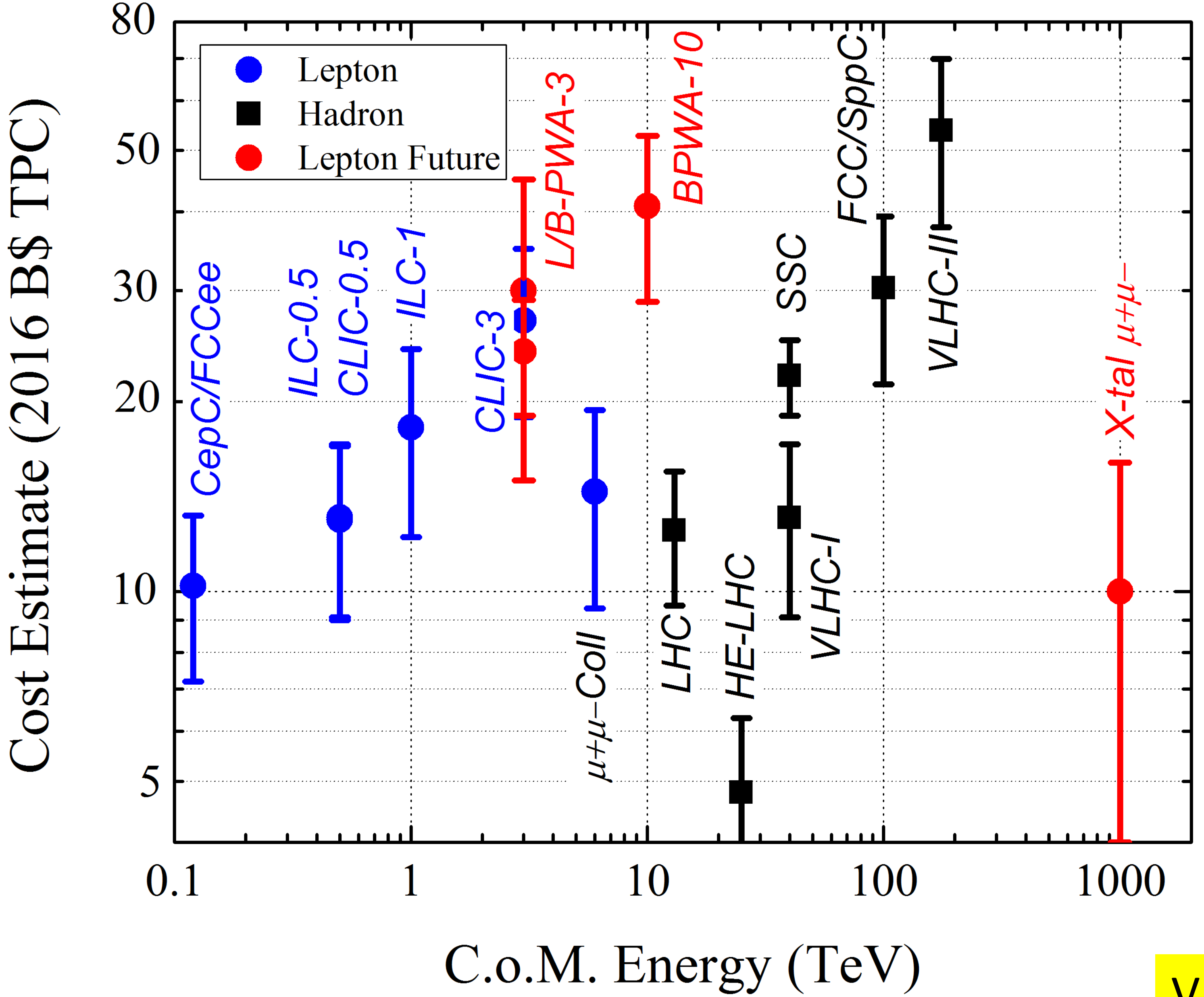
$\beta \approx$ **10B$/sqrt(*E*/TeV)**

"only plasma acceleration is even more expensive"

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

V. Shiltsev

predicting costs by αβγ model



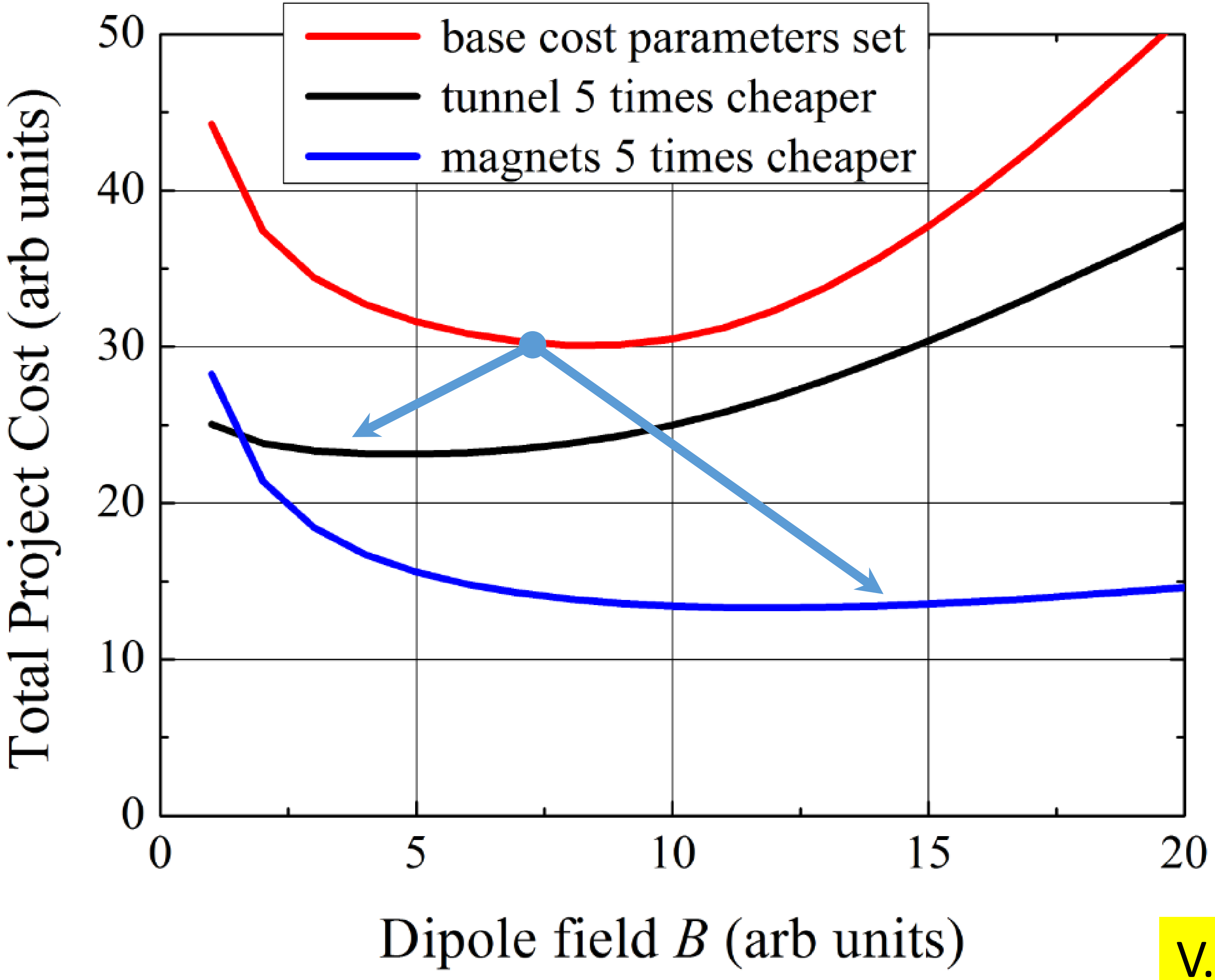
V. Shiltsev

3 steps to lower the cost of future 100 TeV pp collider

- build on site with existing injector complex
- consider staging (e^+e^- 1st, *pp* 2nd)
- reduce SC/magnet cost

develop technology to lower the cost

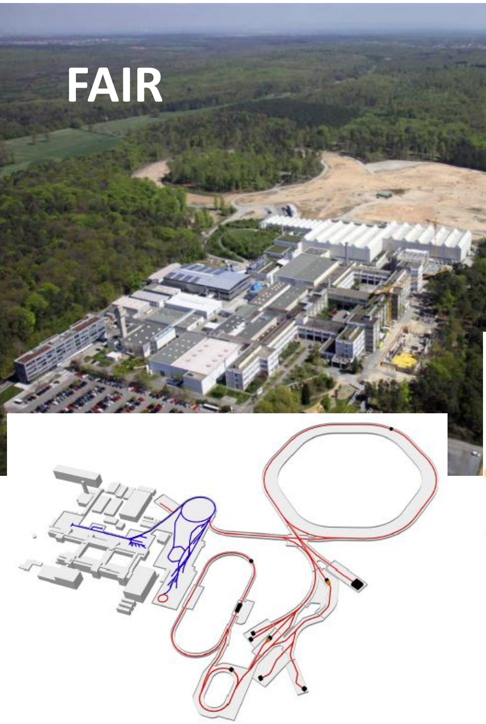
100 TeV *pp* : Qualitative Cost Dependencies



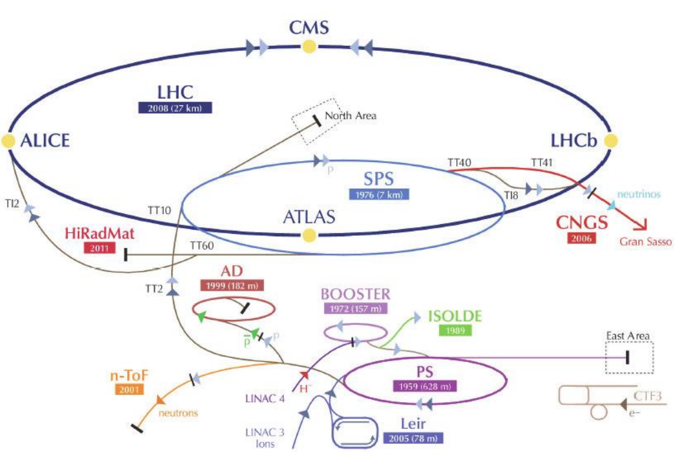
V. Shiltsev

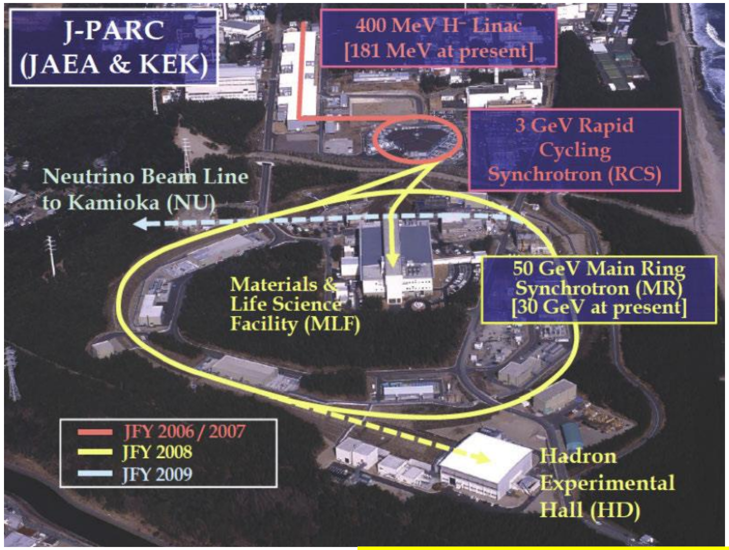
extreme rings

more hadron rings & becoming more powerful



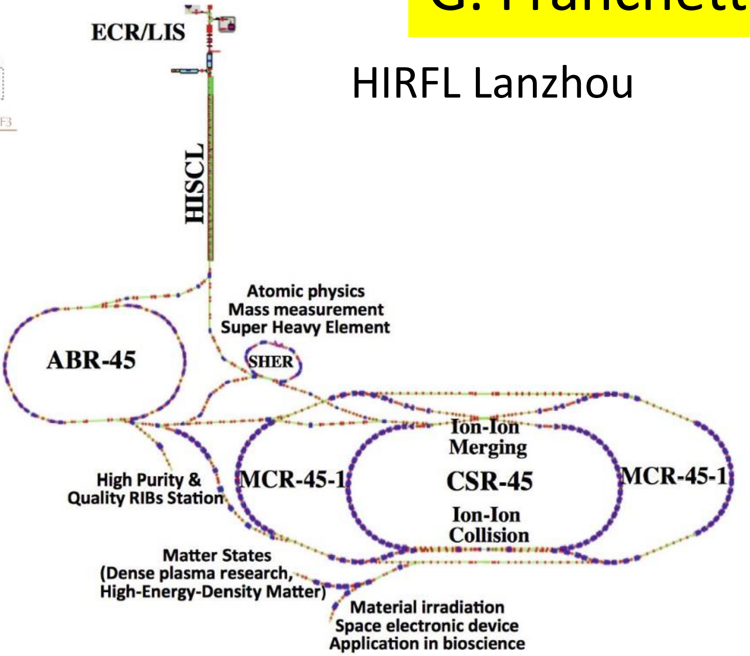
LIU/HL-LHC



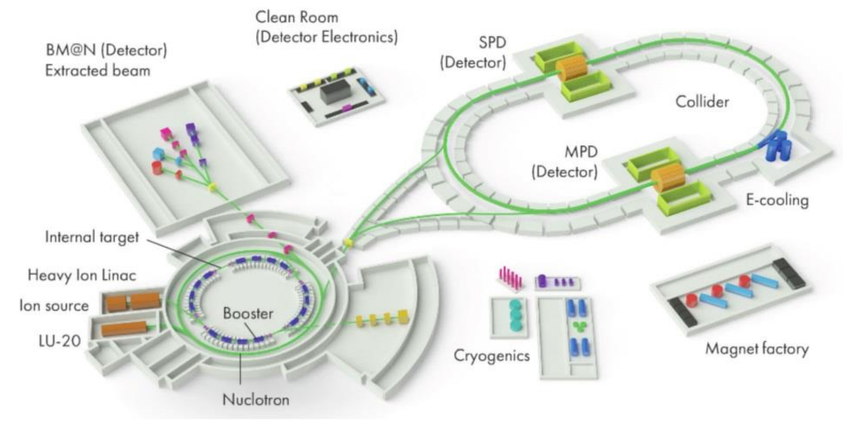


G. Franchetti

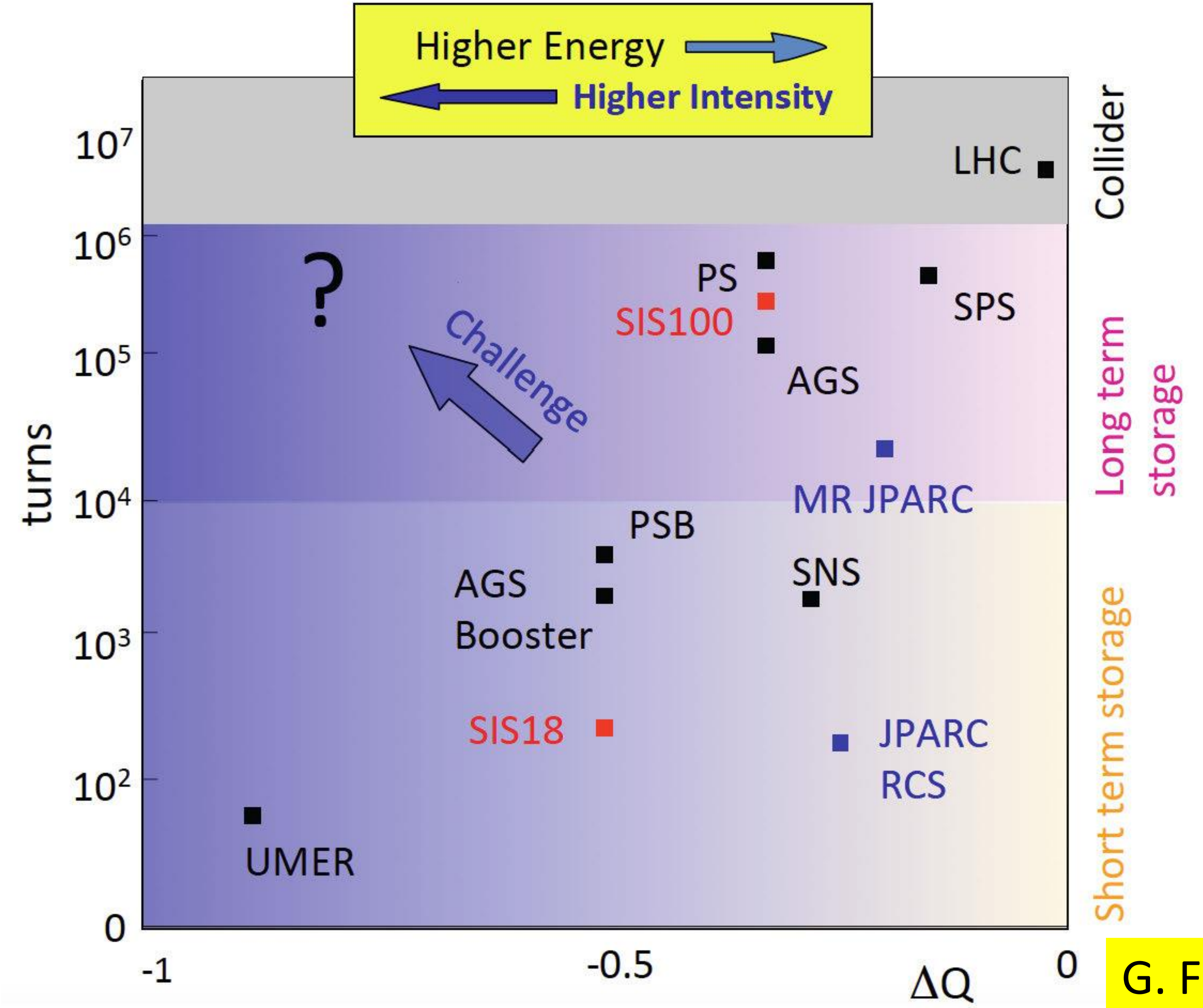
HIRFL Lanzhou



NICA Complex Dubna



hadron rings becoming more extreme

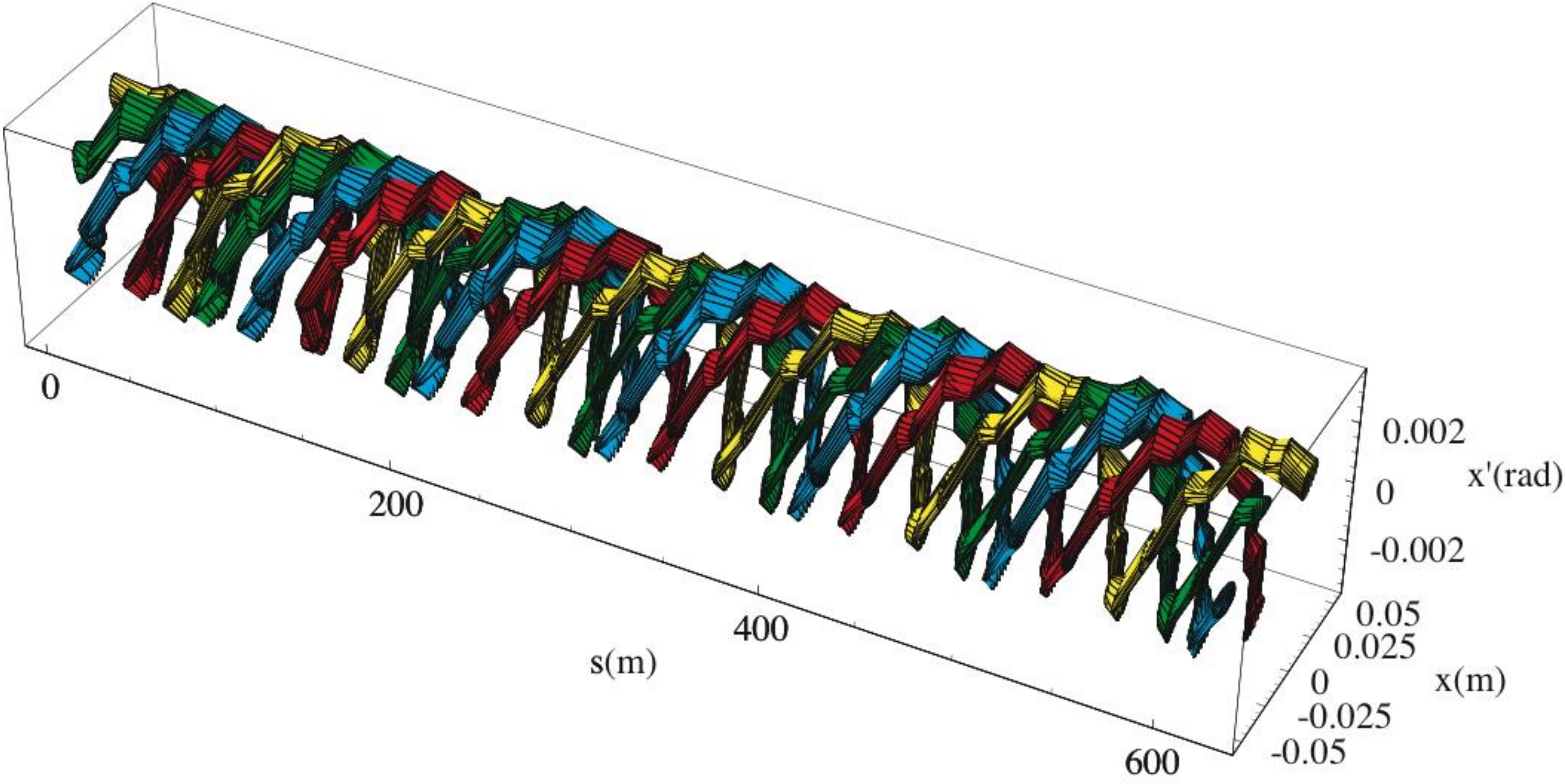


G. Franchetti

key topics and trends for extreme rings

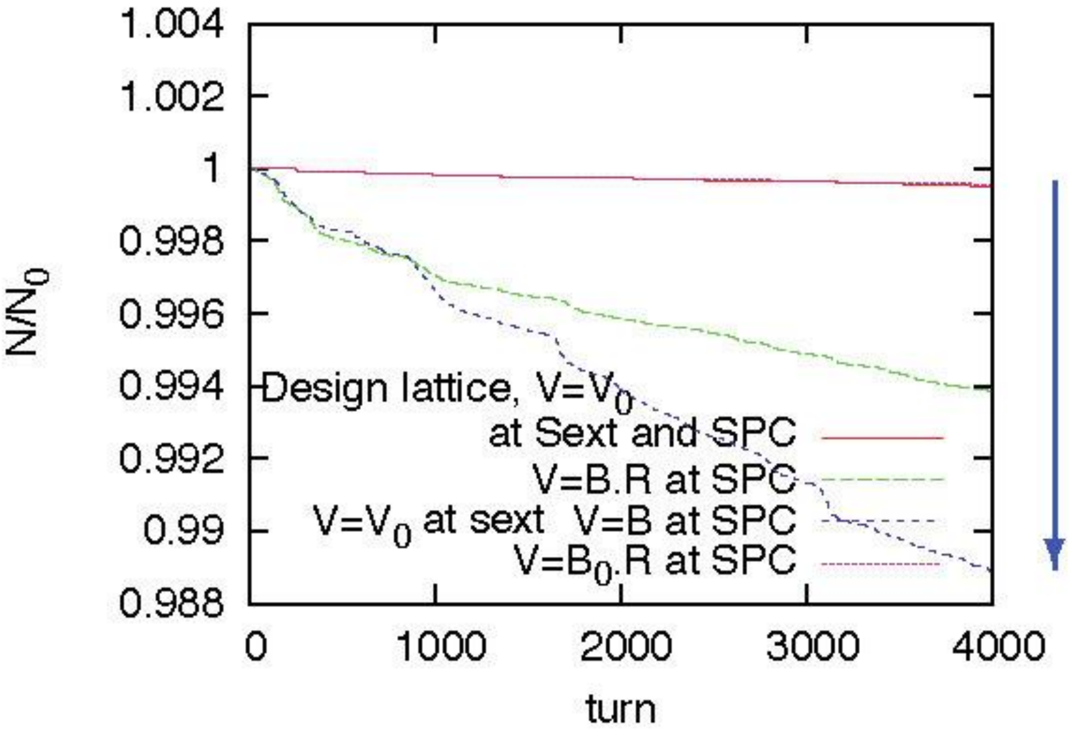
- **space charge limit & mitigations** (resonance compensation, improved optics control, e-lenses …)
- magnet alignment & more accurate **field models**
- **dynamic vacuum pressure & ion beam lifetime**
- **multi-turn injection and extraction** (novel loss-free or septum less schemes based on resonance islands)
- **slow extraction** with reduced micro-spill structure (spill feedback)
- electron **cooling**, stochastic cooling, laser cooling, advanced schemes (opt. stoch. cooling, coh. el. cooling) – beam tests and developments at FNAL and BNL
- "**making beams great [=stable] again**" (e-lenses for Landau damping, integrable systems – IOTA)
- isochronous operation mode
- **transition crossing** (jump, optics change, islands)

sextupoles and octupoles can generate stable islands in phase space -
- used at SPS, multiple advanced applications



M. Giovannozzi

optics control needs for extreme rings



Beam loss due to introducing measured $\frac{\Delta\beta}{\beta}$=5% in simulations

K. Ohmi et al.: "Estimation of errors of accelerator elements is inevitable to study beam loss."

space-charge limited rings would benefit from sub-% optics control ;
new diagnostics: AC ORM? other?

R. Tomas

SC compensation with e-lenses: FNAL booster

simulations for FNAL Booster (Yu. Alexahin & V. Kapin, 2007)

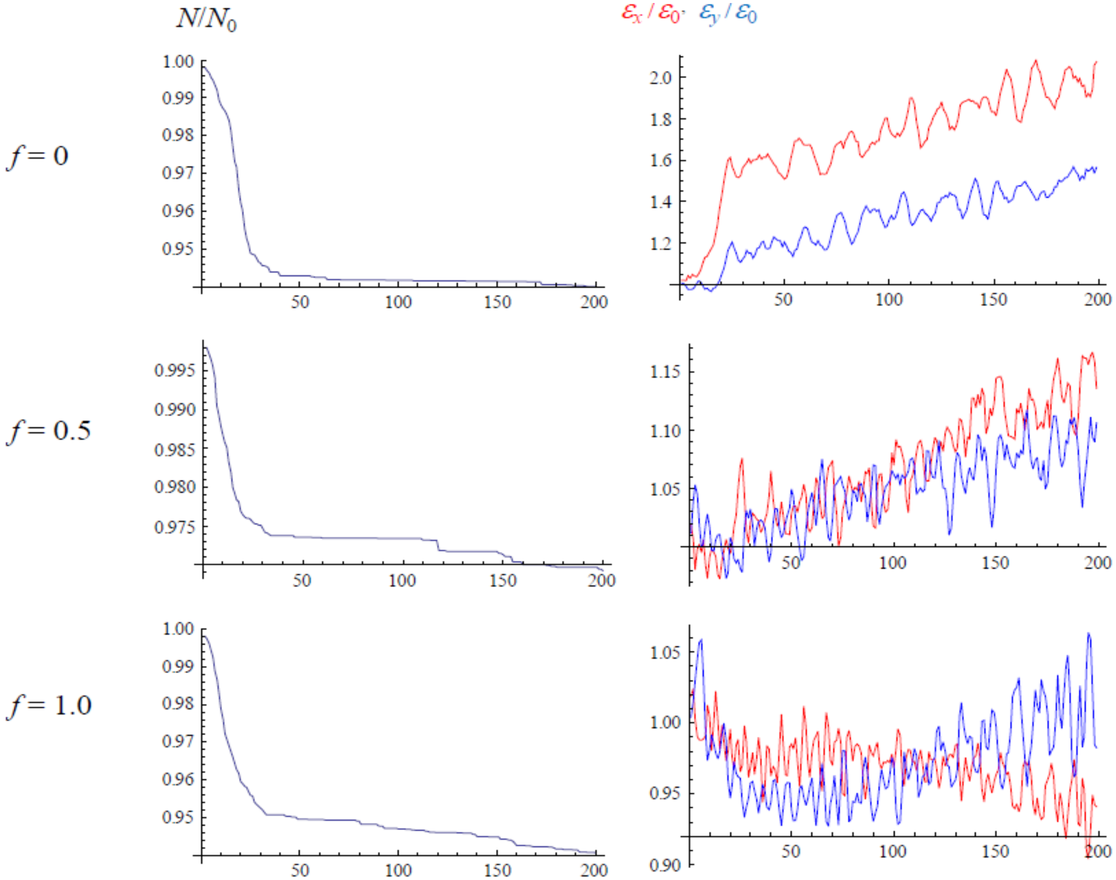
Booster:

400 MeV, 474 m

P=24

N_p~4.5e12

dQ_sc=-0.3



- “space charge compensation with e-lenses works”
- the more compensators the better (24→12→3 minimum)

V. Shiltsev

SC compensation with e-lenses: KEK PS

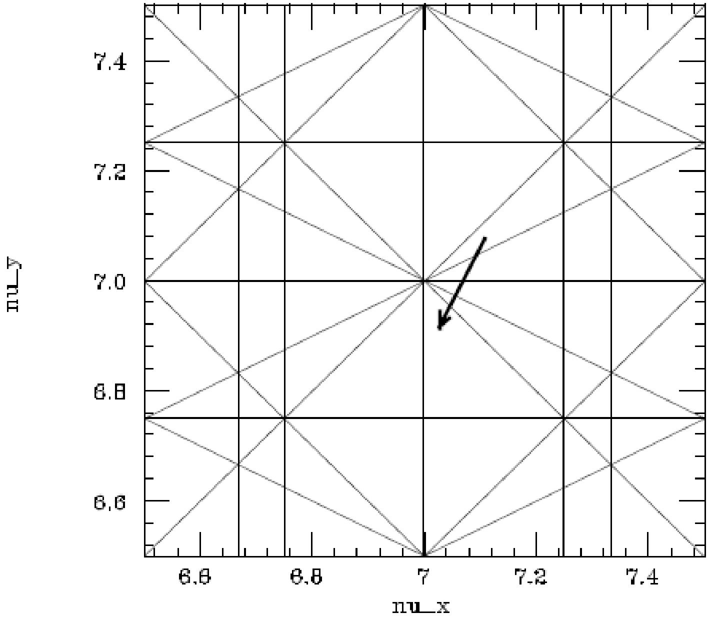
simulations for KEK PS (S. Machida, 2001)

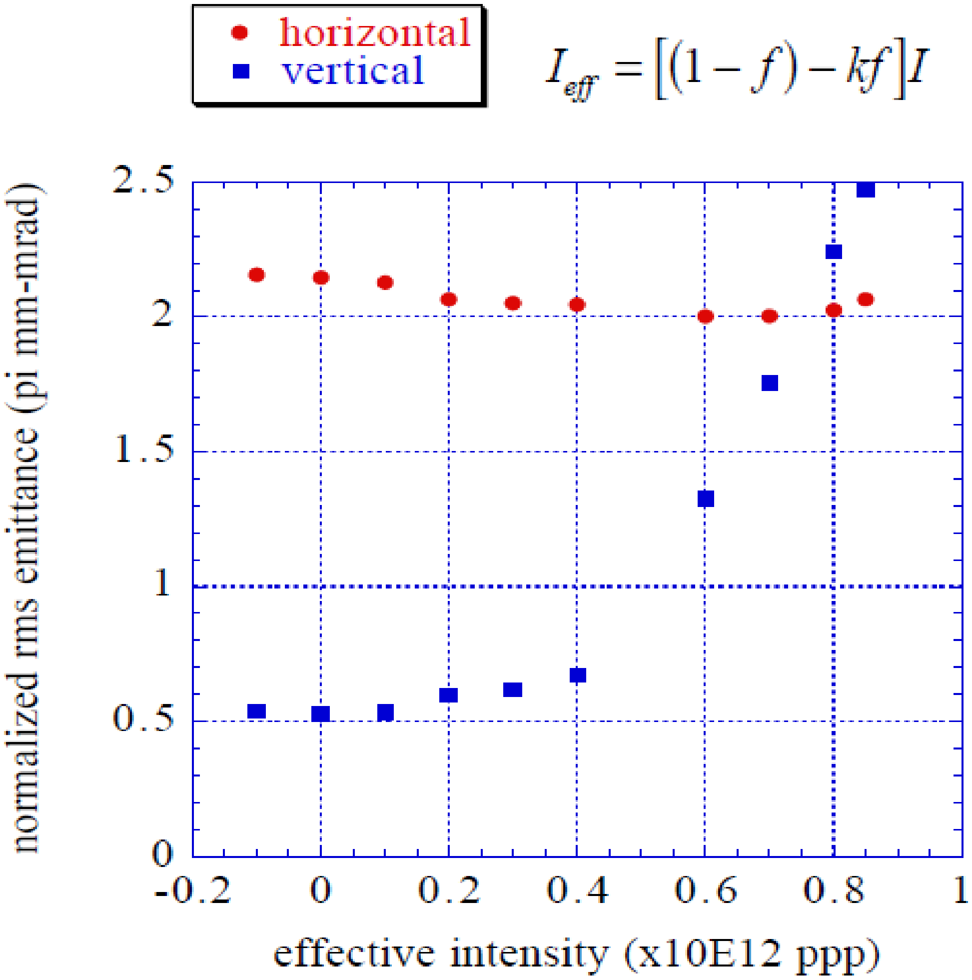
KEK PS:

500 MeV, 340 m

N_p~1e12

dQ_sc=-0.2





$$I_{eff} = [(1-f) - kf]I$$

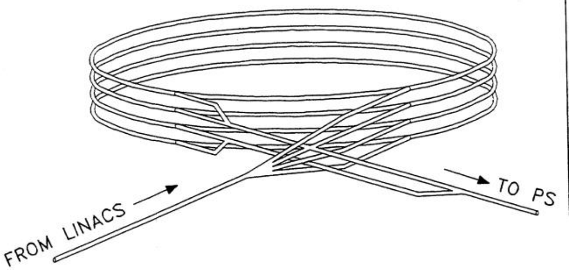
- “space charge compensation with e-lenses works
- +0.1-0.2 sigma e-p displacement tolerable

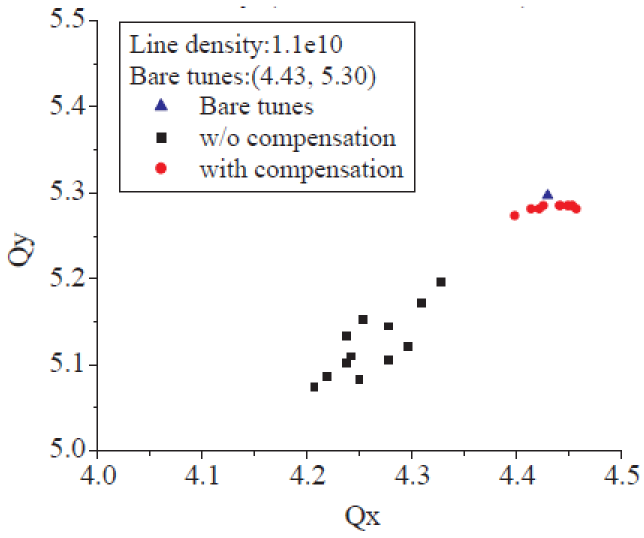
V. Shiltsev

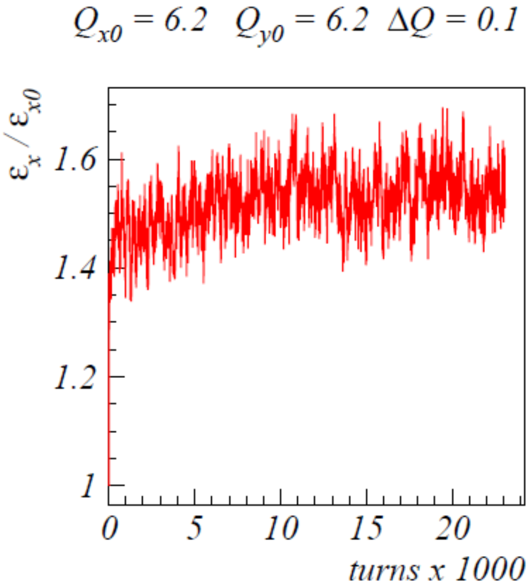
SC compensation with e-lenses: CERN PS-B

simulations for CERN PS-B (M. Aiba et al.,2007)

Proceedings of PAC07, Albuquerque, New Mexico, USA







PS Booster:

50 MeV, 157 m

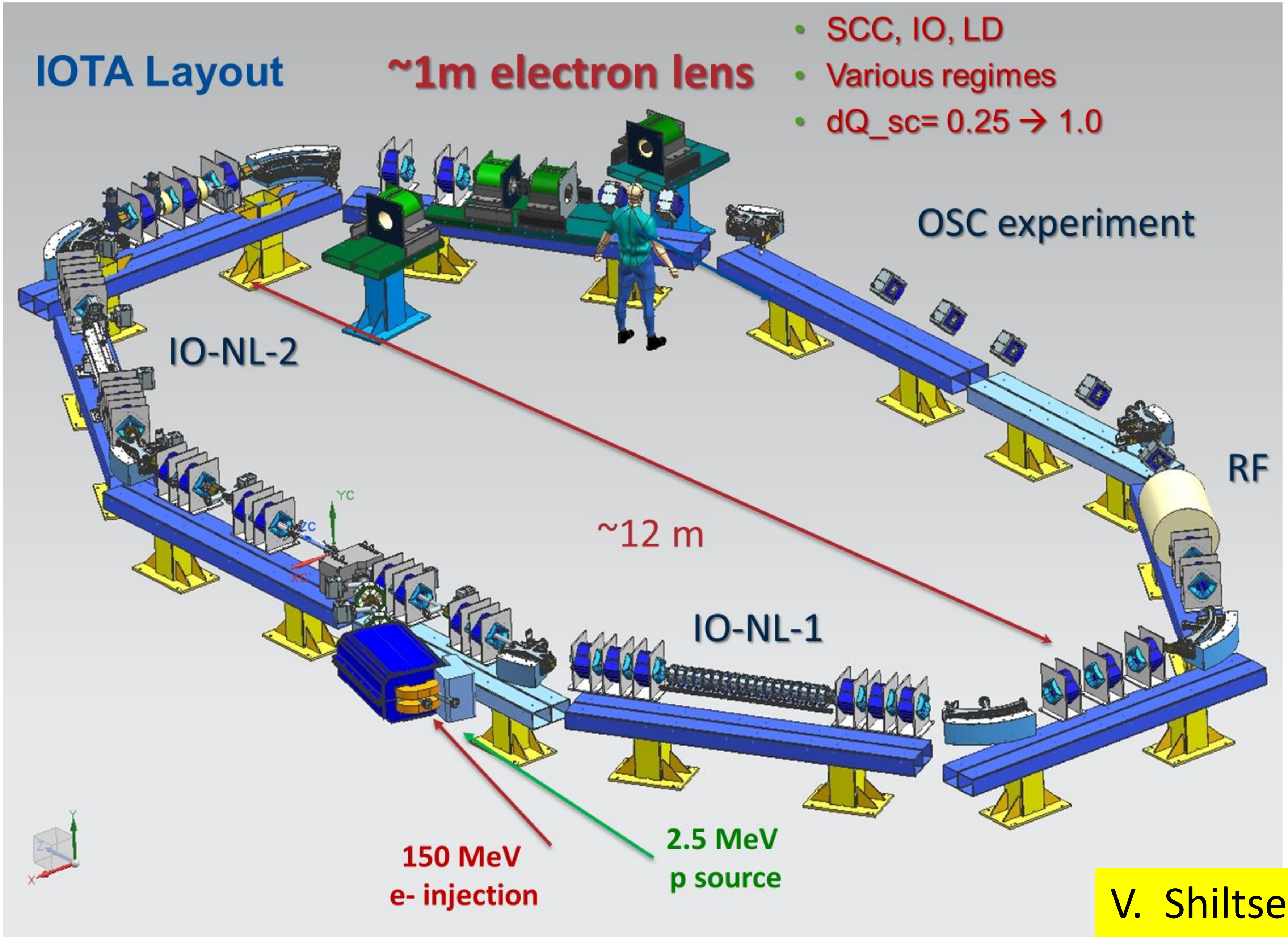
P=16

dQ_sc ~ -0.5

- "space charge compensation with e-lenses works in principle… deserves further studies"
- no evidence for coherent modes limitation in PSB and PS
- concern of overcompensation in the head and tail
- the more compensators the better (8 better than 4)

V. Shiltsev

beam test facility IOTA at FAST turns on soon



V. Shiltsev

IOTA construction status, beam in 2018?

Girders aligned, RF cavity installed, magnets ready, injection magnets and cable trays installed, etc etc

V. Shiltsev

IOTA beam tests of electron lens applications

new applications of e-lenses include:

- electron lenses for space-charge compensation
- electron lenses for integrable optics
- electron lenses for Landau damping

V. Shiltsev

extreme linacs

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)

issues for extreme linacs

- cost reduction
- more efficient production of SC cavities (large grain, hydroforming)
- beam halo and losses
- HOM couplers
- pushing 1-MW limit of fundamental power couplers

M. Eshraqi

the ESS linac

Design Drivers:

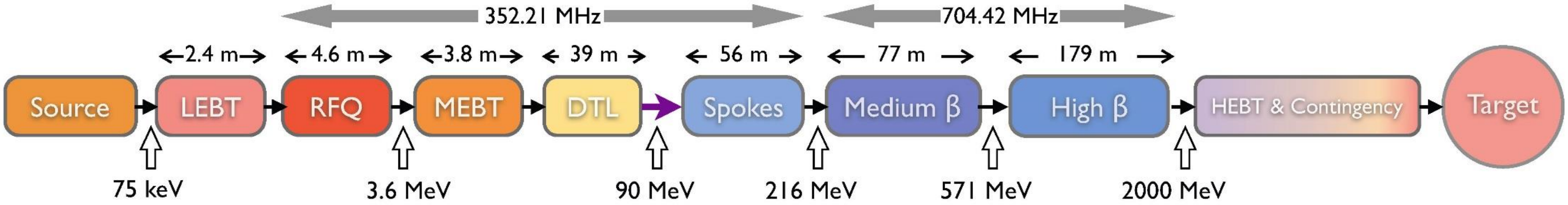
High average beam power	5MW
High peak beam power	125 MW
High availability	>95 %

Key Linac parameters:

Energy	2.0 GeV
Current	62.5 mA
Repetition rate	14 Hz
Pulse length	2.86 ms
Losses	<1W/m
Ions	p

Flexible/Upgradable design

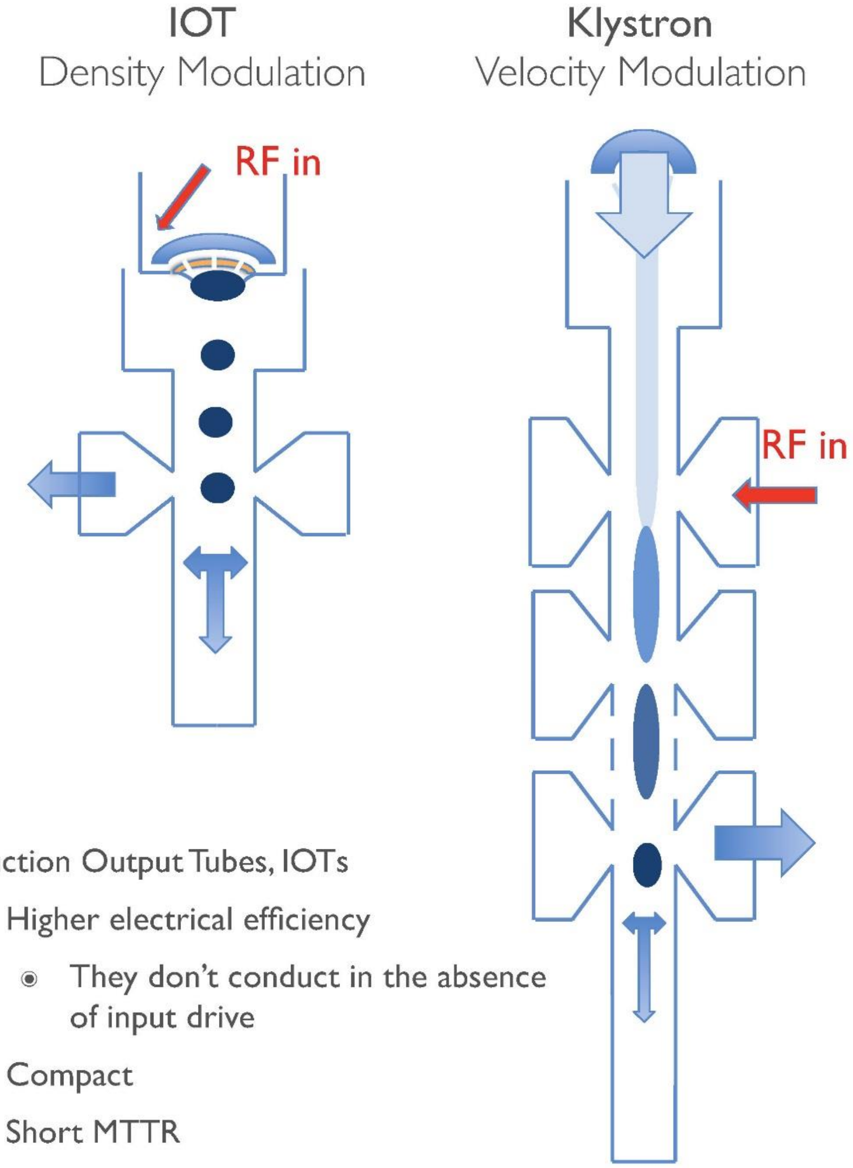
Minimize energy consumption



First beam at 571 MeV ready in June 2019,
Full energy/full power planned for 2023

M. Eshraqi

are IOTs more efficient than klystrons?



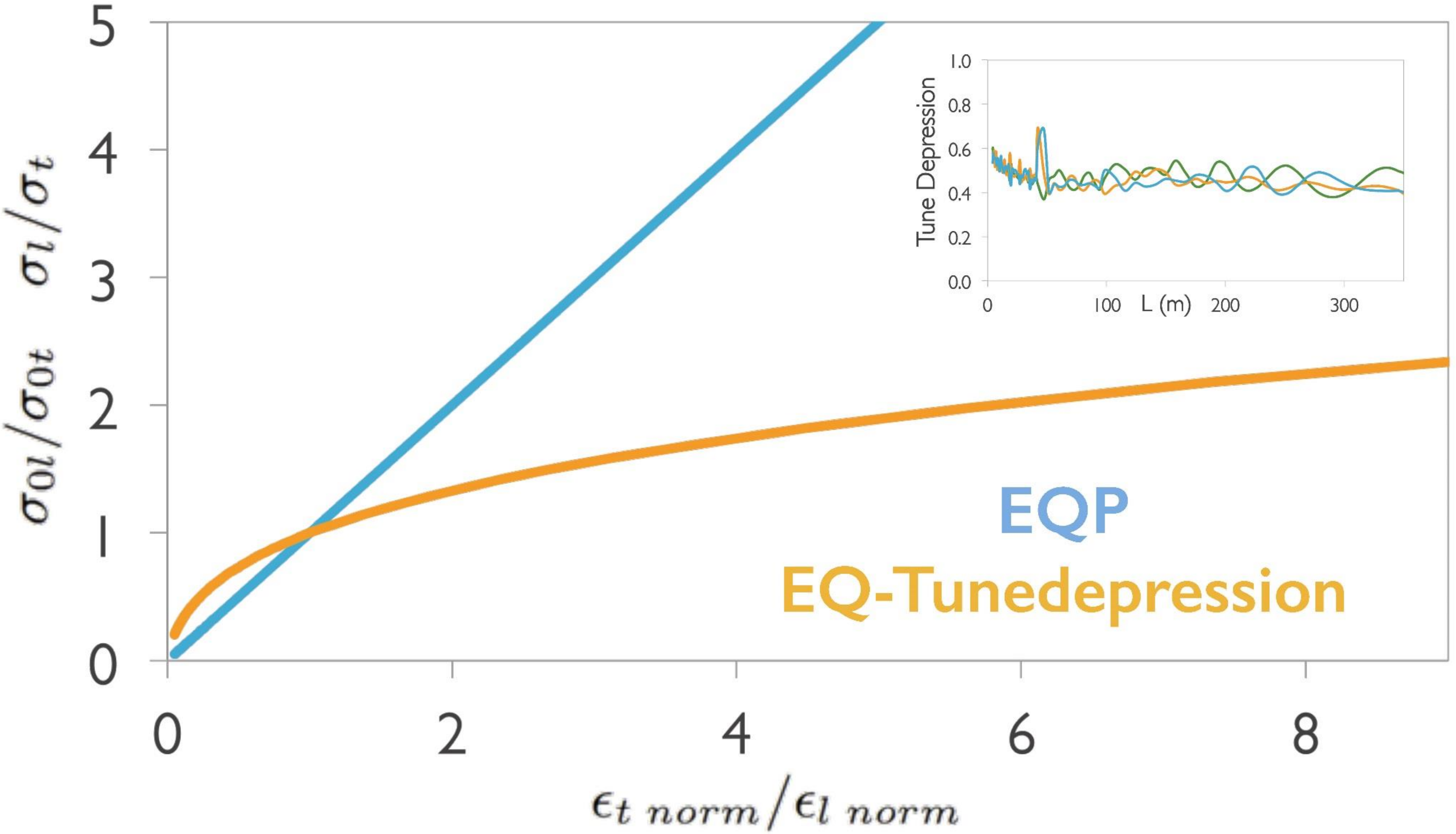
Induction Output Tubes, IOTs

- Higher electrical efficiency
  - They don’t conduct in the absence of input drive
- Compact
- Short MTTR
- Cheaper modulator (No high voltage switching)

Courtesy: Morten Jensen

M. Eshraqi

optimized beam physics



equipartition versus equal tune depression

M. Eshraqi

diagnostics for high-power proton linacs

3 B’s (BCT, BLM, BPM, + BPhaseM)
- controlling beam loss
- trigger fast abort in case of failure

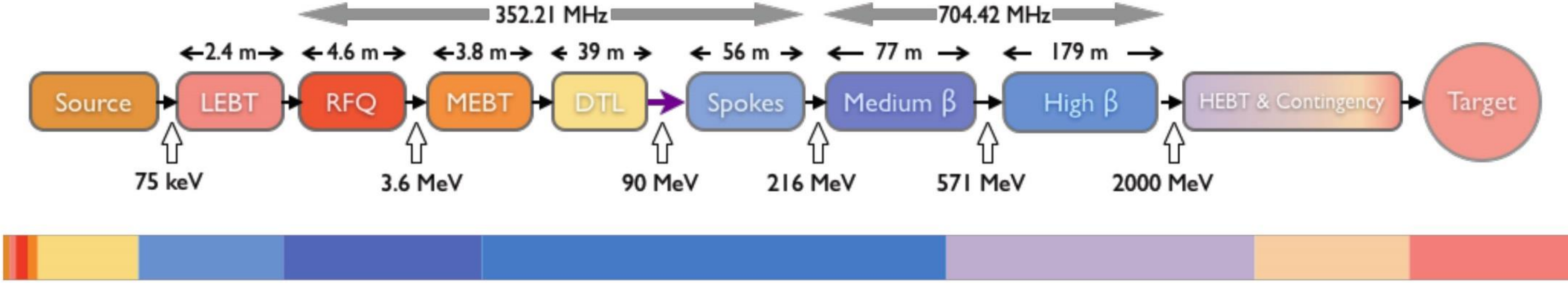
profile measurements
- minimally invasive diagnostics
- wire scanner, ionization, BIF (w. pump laser?)

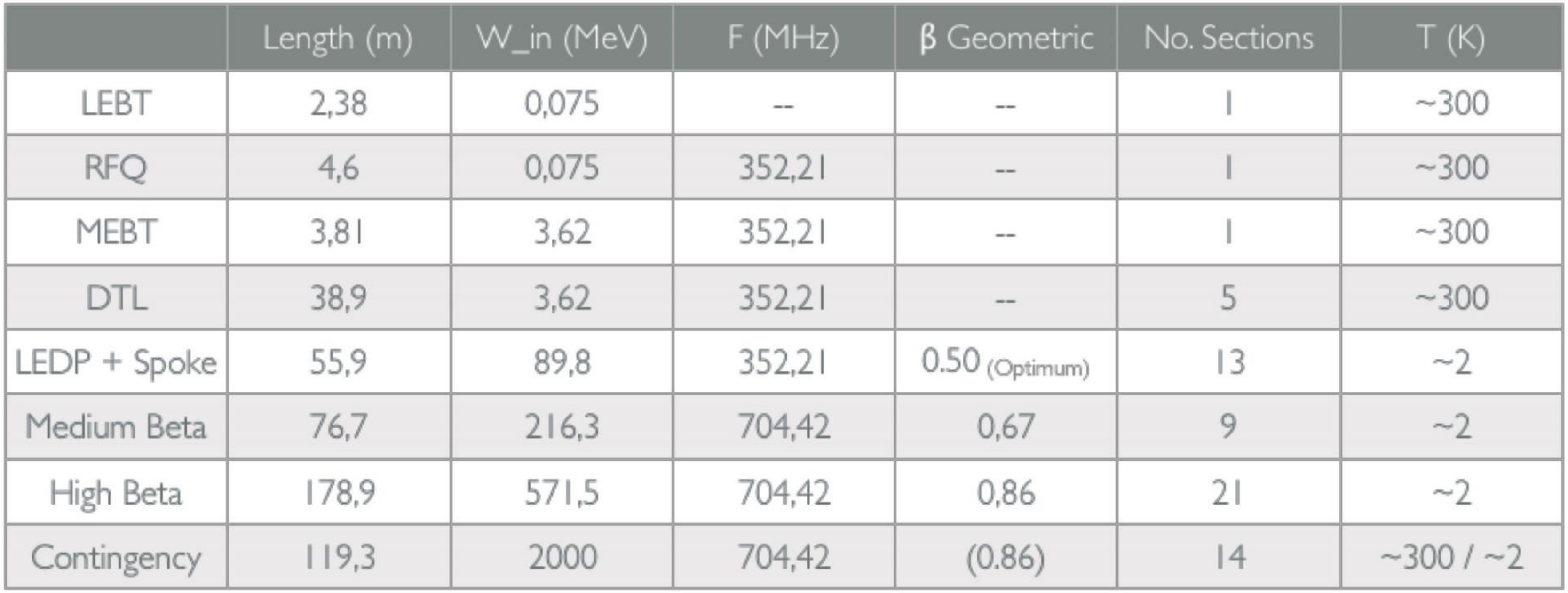
advanced beam instrumentation
- fast neutron monitor
- differential BCM, bunch shape monitor
- gas jets, e-beam scanner, 6D emittance

advanced use of 3B instrumentation
- “Shishlo method” BPM sum & cavity scan

A. Jansson

the ESS linac & its diagnostics


352.21 MHz
704.42 MHz
2.4 m
4.6 m
3.8 m
39 m
56 m
77 m
179 m
Source
LEBT
RFQ
MEBT
DTL
Spokes
Medium β
High β
HEBT & Contingency
Target
75 keV
3.6 MeV
90 MeV
216 MeV
571 MeV
2000 MeV



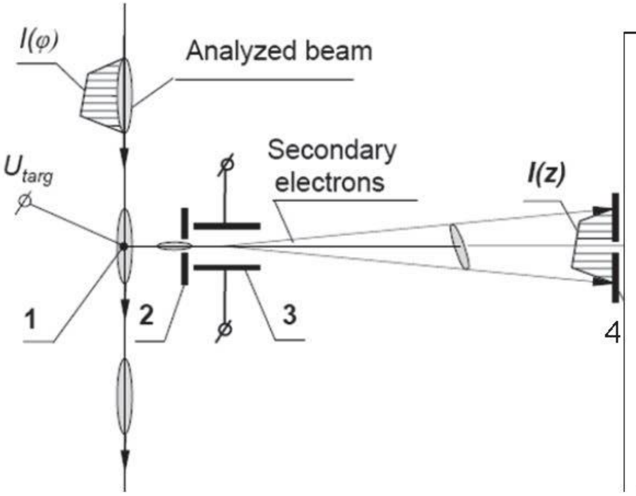
	Length (m)	W_in (MeV)	F (MHz)	β Geometric	No. Sections	T (K)
LEBT	2,38	0,075	--	--	1	~300
RFQ	4,6	0,075	352,21	--	1	~300
MEBT	3,81	3,62	352,21	--	1	~300
DTL	38,9	3,62	352,21	--	5	~300
LEDP + Spoke	55,9	89,8	352,21	0.50 (Optimum)	13	~2
Medium Beta	76,7	216,3	704,42	0,67	9	~2
High Beta	178,9	571,5	704,42	0,86	21	~2
Contingency	119,3	2000	704,42	(0.86)	14	~300 / ~2

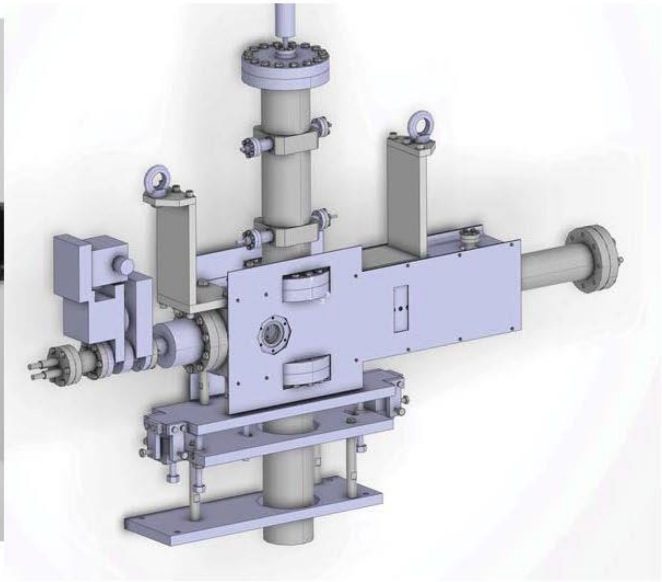
About 500 diagnostics systems (mostly BLM & BPM) of about 20 different types

A. Jansson

longitudinal bunch shape monitor

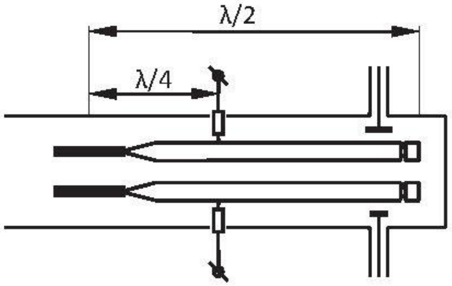
A. Feschenko,, INR

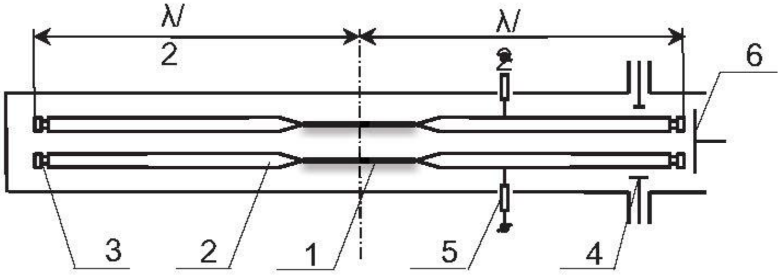


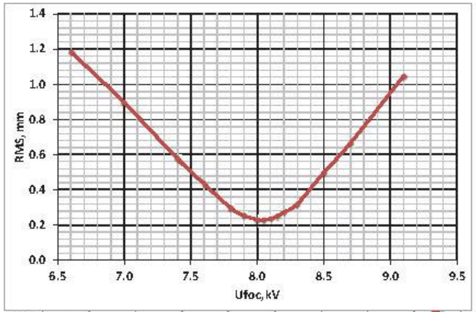


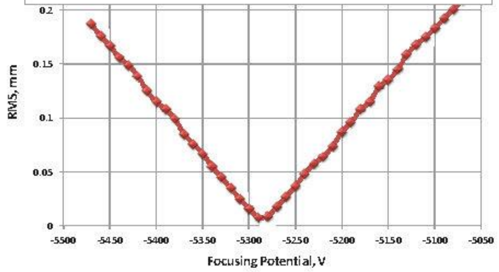
With new symmetric deflector, expect resolution limited by electron time dispersion, which is very small (but of unknown magnitude)

Expect 0.2-0.5°





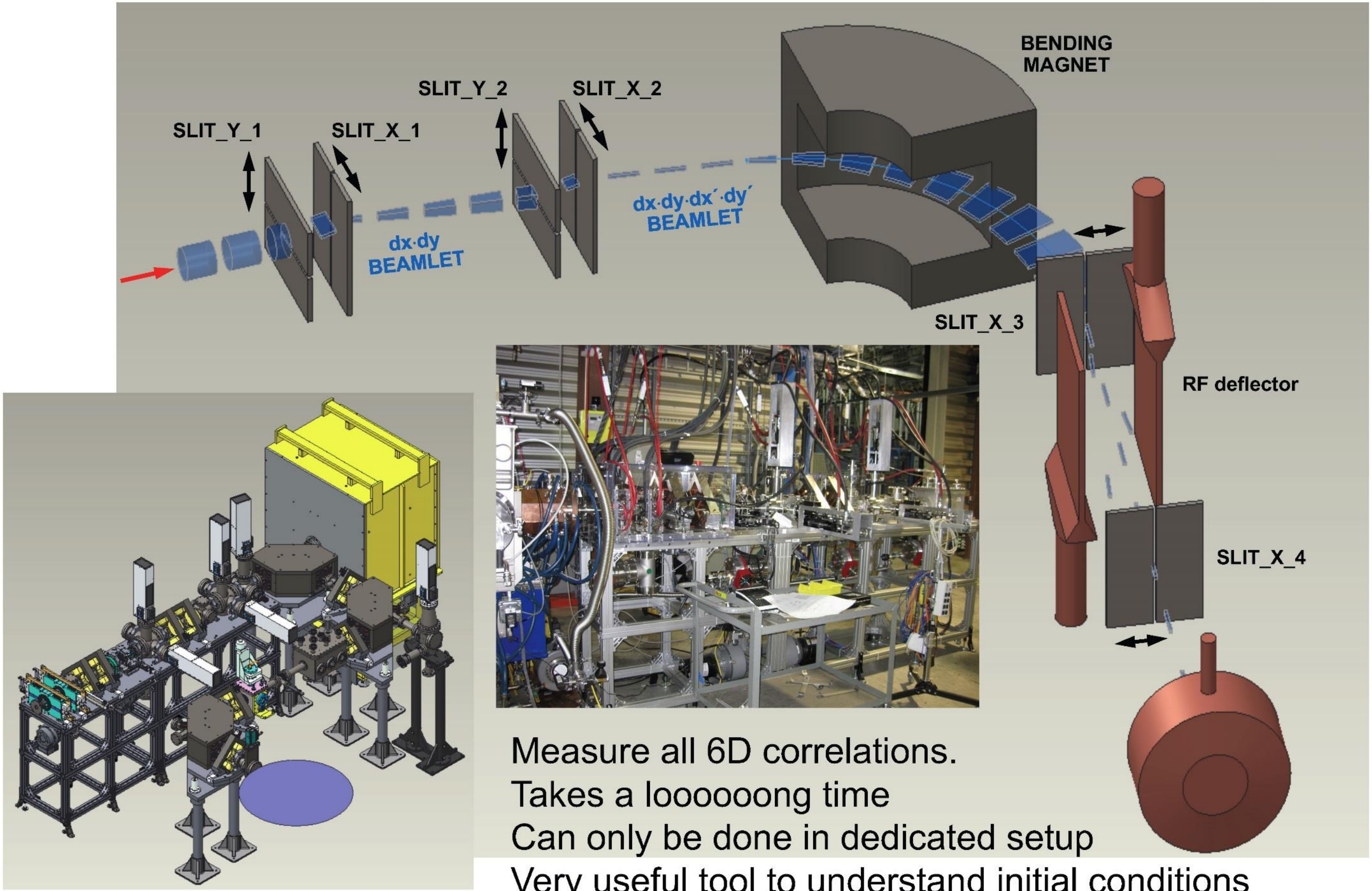




A. Jansson

6D emittance measurement

A. Aleksandrov, SNS

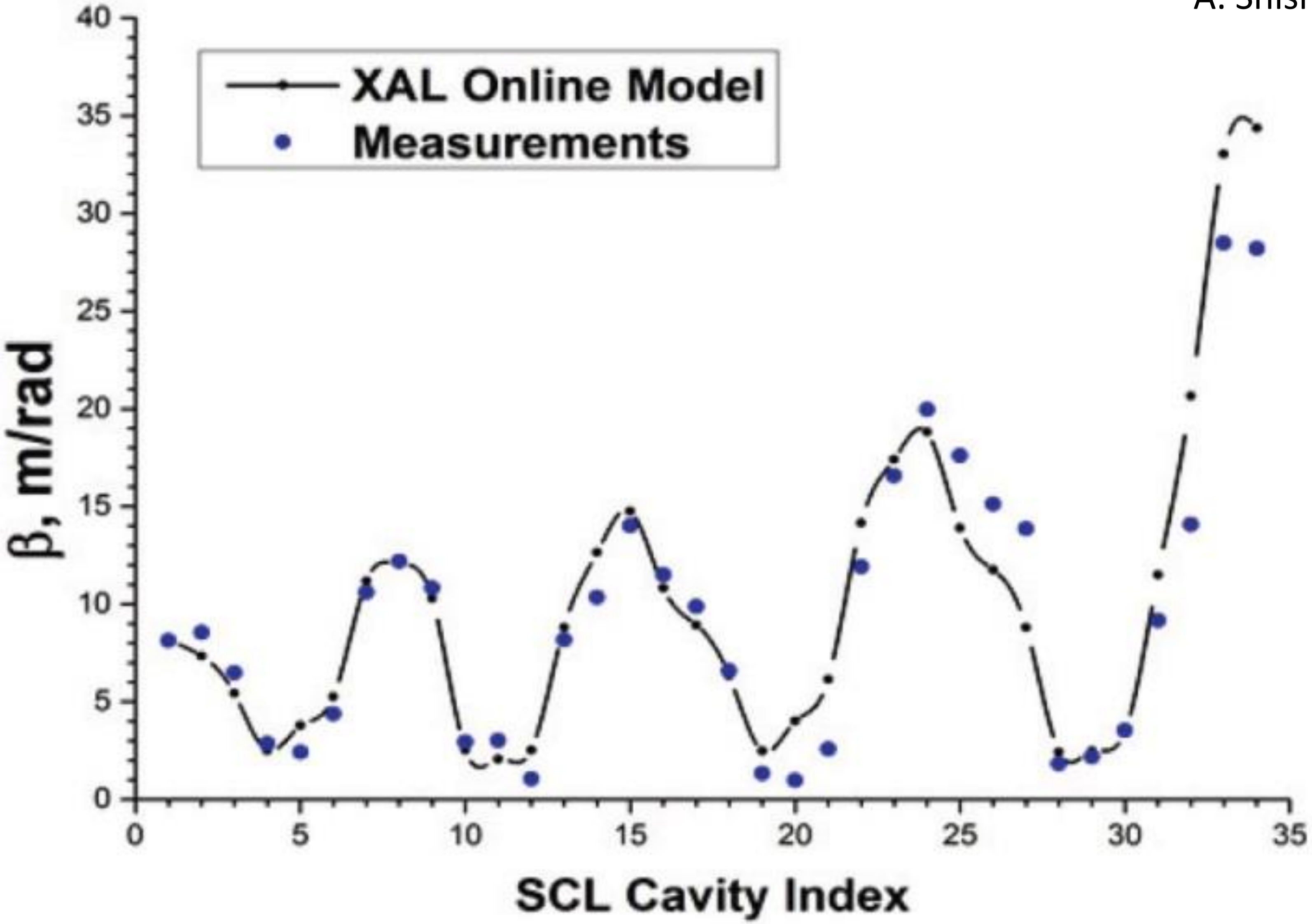


Measure all 6D correlations.
Takes a loooooong time
Can only be done in dedicated setup
Very useful tool to understand initial conditions

A. Jansson

“Shishlo method” –longitudinal optics

A. Shishlo, SNS

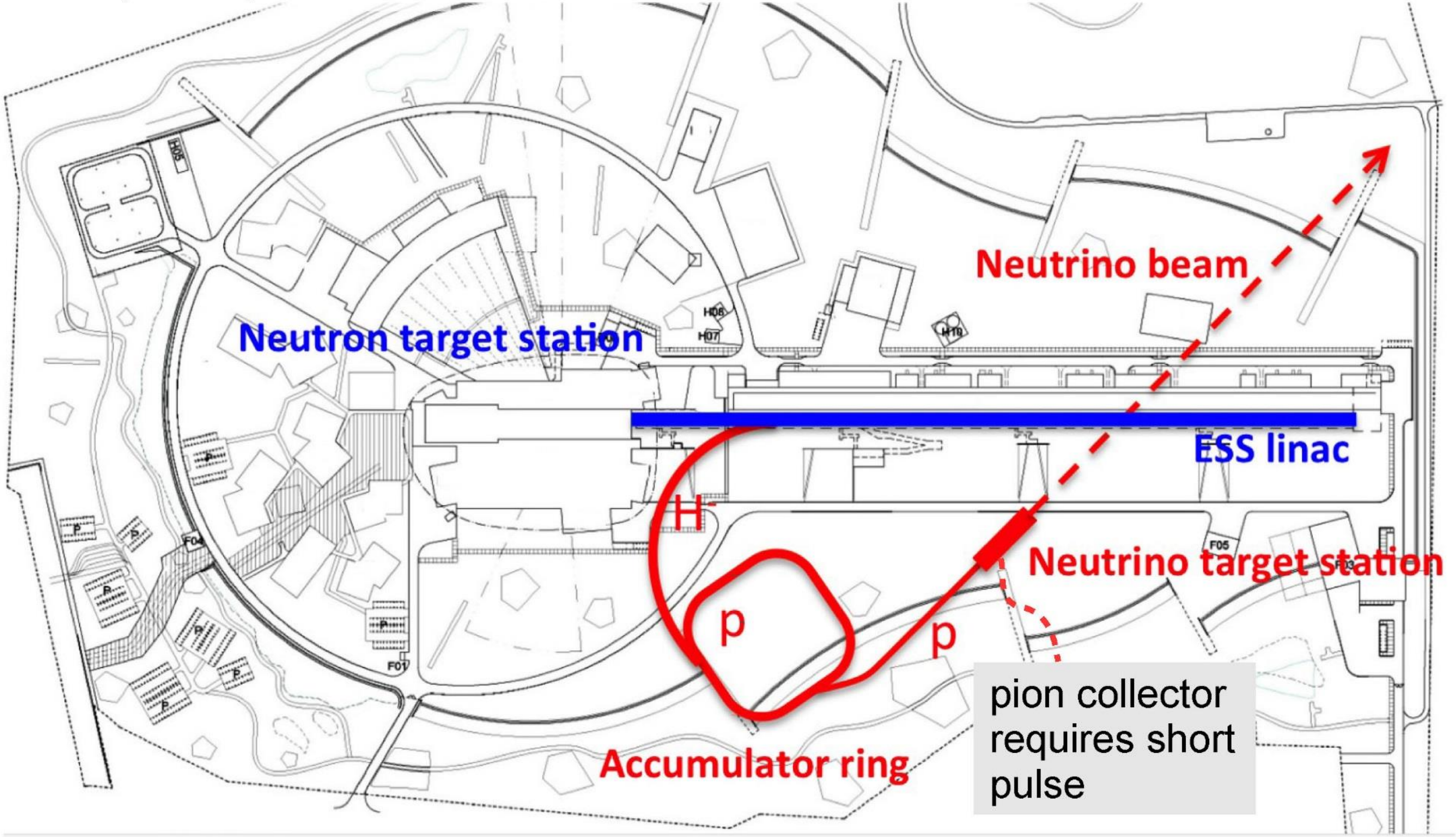


A. Jansson

ESSnuSB proposal

M. Olvegard,
Uppsala

European Spallation Source, Lund



pion collector requires short pulse

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

5 MW H-/proton beam
<2 µs pulses

M. Eshraqi

extreme polarization

lessons from EuCARD-2 XPOL

- polarization in upcoming accelerator projects
- the role of polarization measurement
- electric dipole moments
- advances in polarimetry

K. Aulenbacher

polarization in future experiments

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

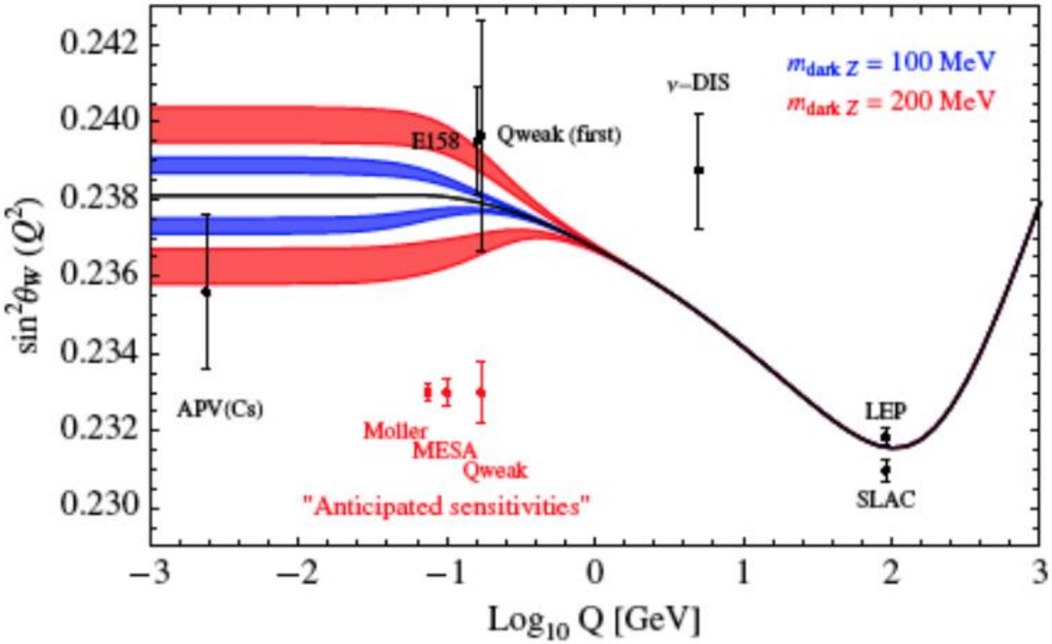
- **discovery** (strong CP and T violation)
- **precision experiments** (weak P violation)

high-energy "big" accelerators:

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

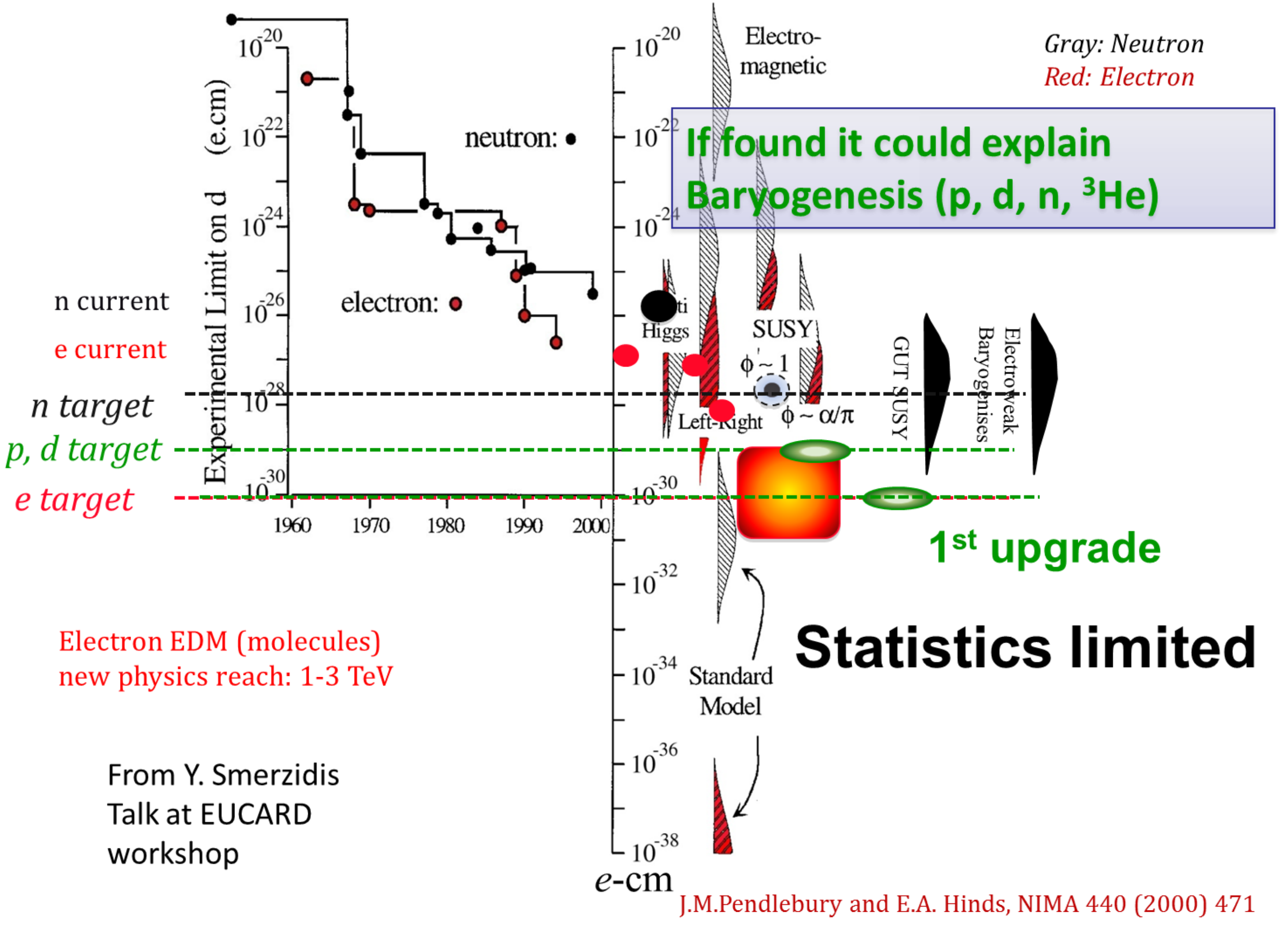
„Elastic electron scattering on proton measures $1-4\sin^2\Theta_W$

→ small asymmetry , high sensitivity

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

K. Aulenbacher

Jülich Electric Dipole Moment Investigation „JEDI“



J.M.Pendlebury and E.A. Hinds, NIMA 440 (2000) 471

If found it could explain Baryogenesis (p, d, n, ^{3}He)

1st upgrade

Statistics limited

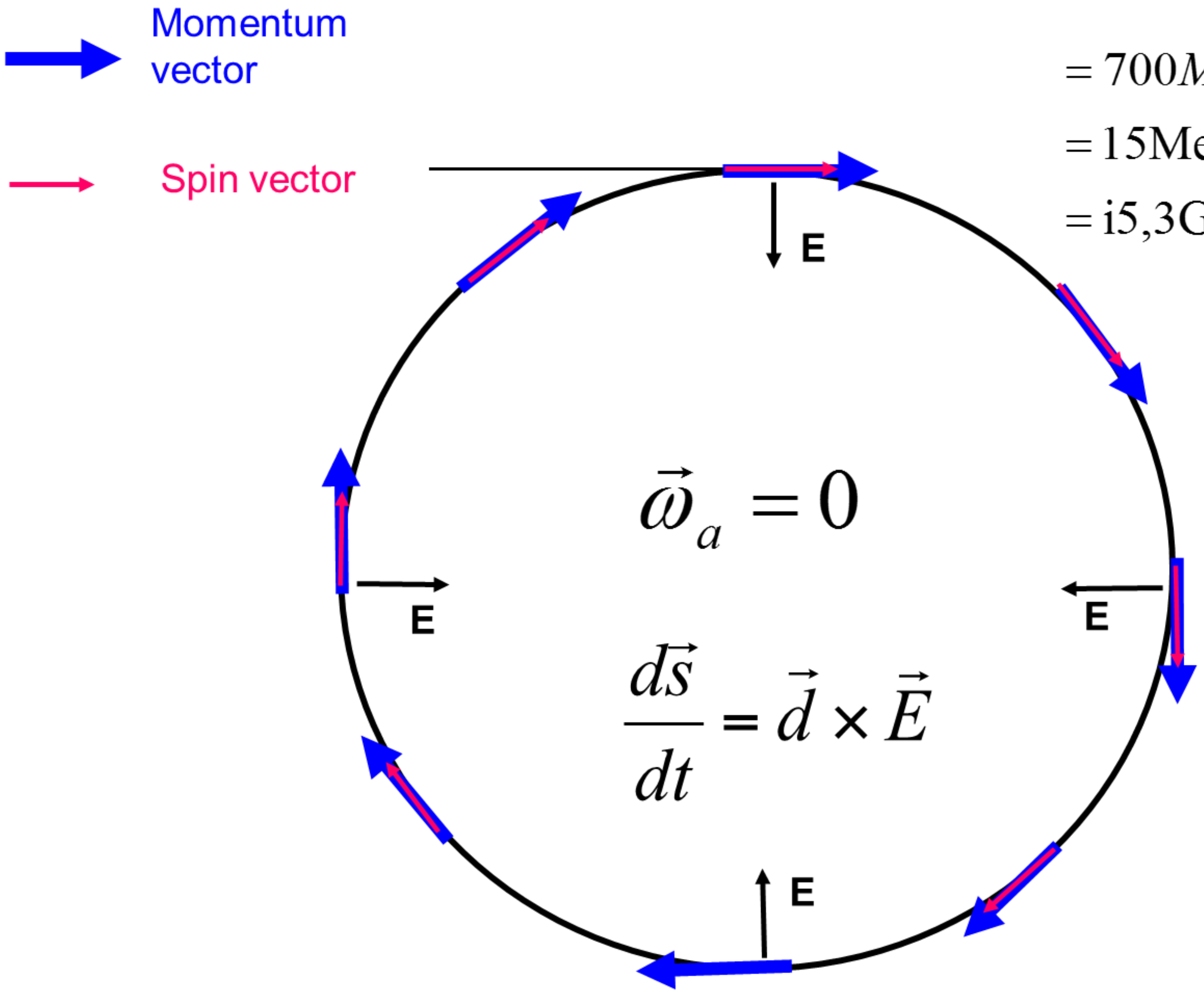
Electron EDM (molecules)
new physics reach: 1-3 TeV

From Y. Smerzidis
Talk at EUCARD
workshop

- aiming at discovery in„electrostatic storage ring“

K. Aulenbacher

Jülich Electric Dipole Moment Investigation „JEDI“



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

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

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

$$= 700 MeV/c \quad \text{(Proton)}$$

$$= 15 \text{MeV/c} \quad \text{(Elektron)}$$

$$= i5{,}3 \text{GeV/c} \quad \text{(Deuteron)}$$

K. Aulenbacher

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, and MESA upcoming,** will teach us new lessons
- **ESSnuSB, JEDI, FCC, CEPC, … proposed**

The end of EuCARD-2 XBEAM …

… becomes the start of ARIES APEC