Status of the MESA Project

Mainz **E**nergy recovering **S**uperconducting **A**ccelerator:

A small superconducting accelerator for particle and nuclear physics

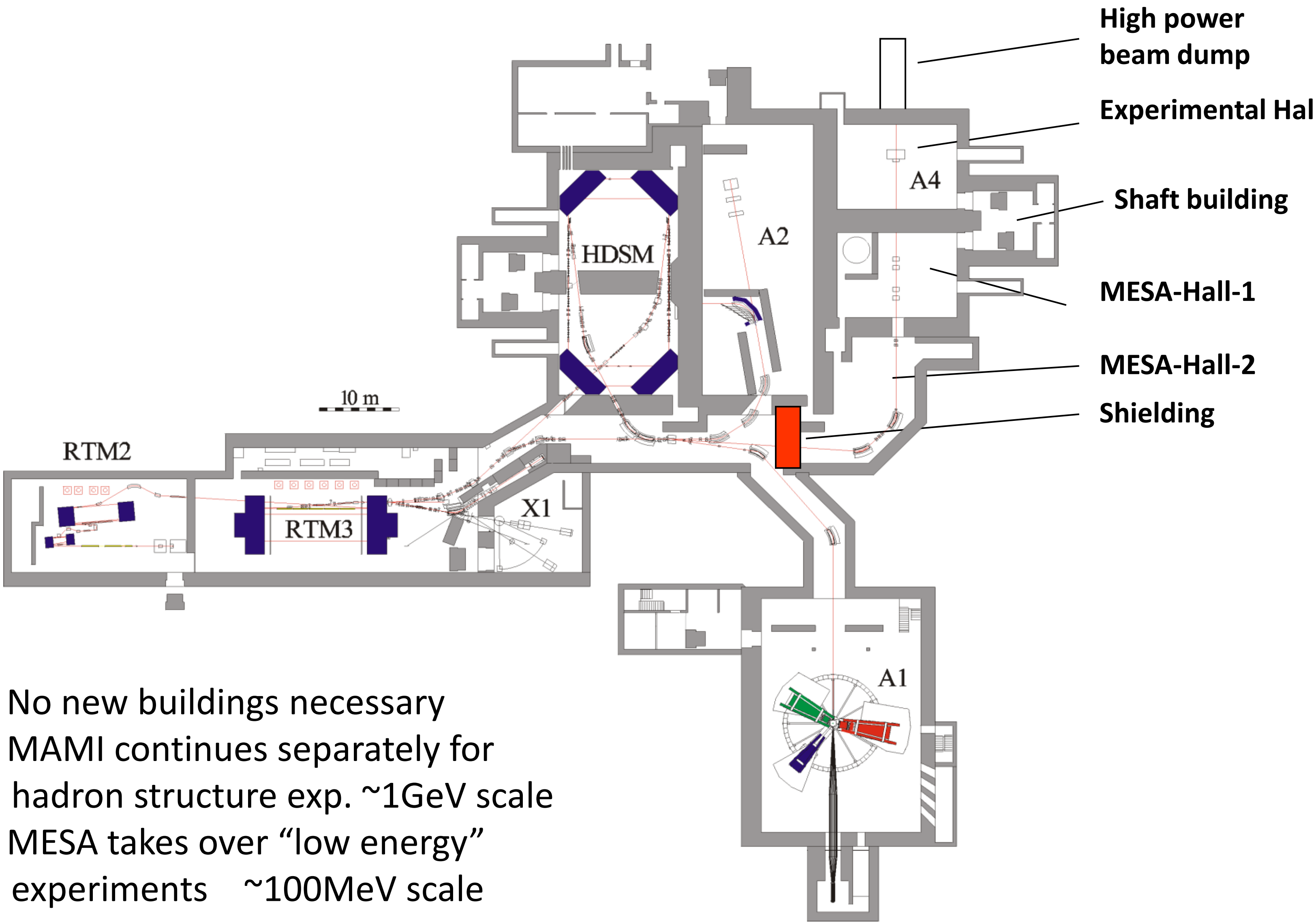
Kurt Aulenbacher
for the MESA-Project-team

Novosibirsk
September 9, 2013

Contents

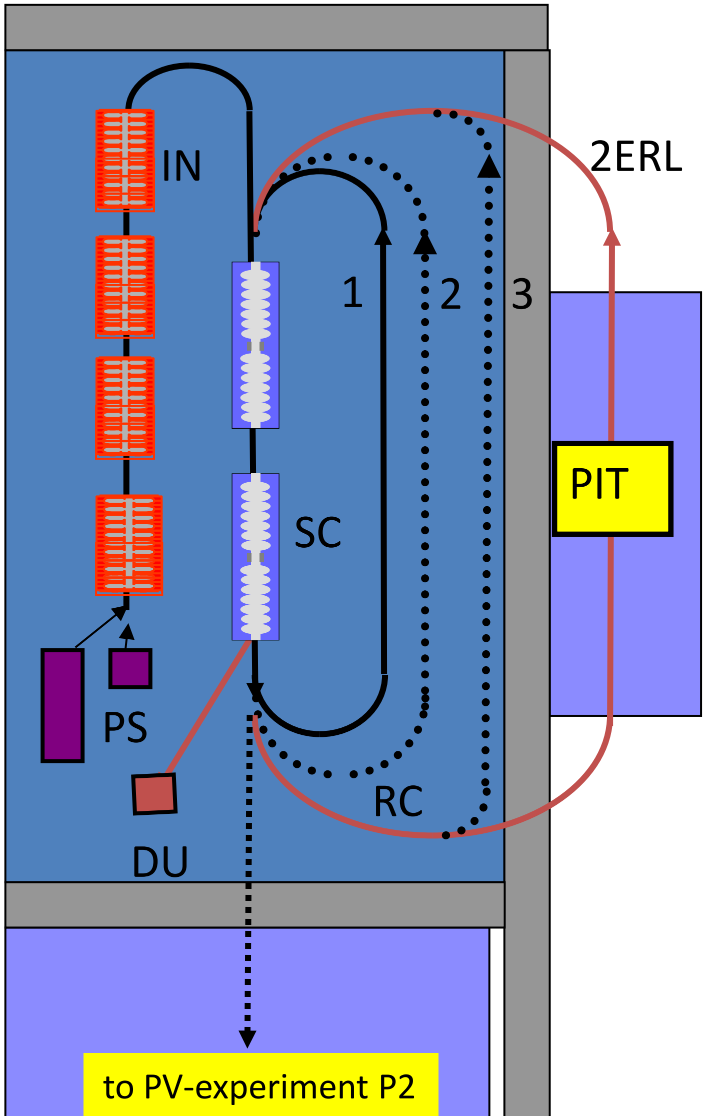
- Project objectives
- R&D issues: SRF
- R&D issues: Beamdynamics & Lattice

MESA: Real estate conditions



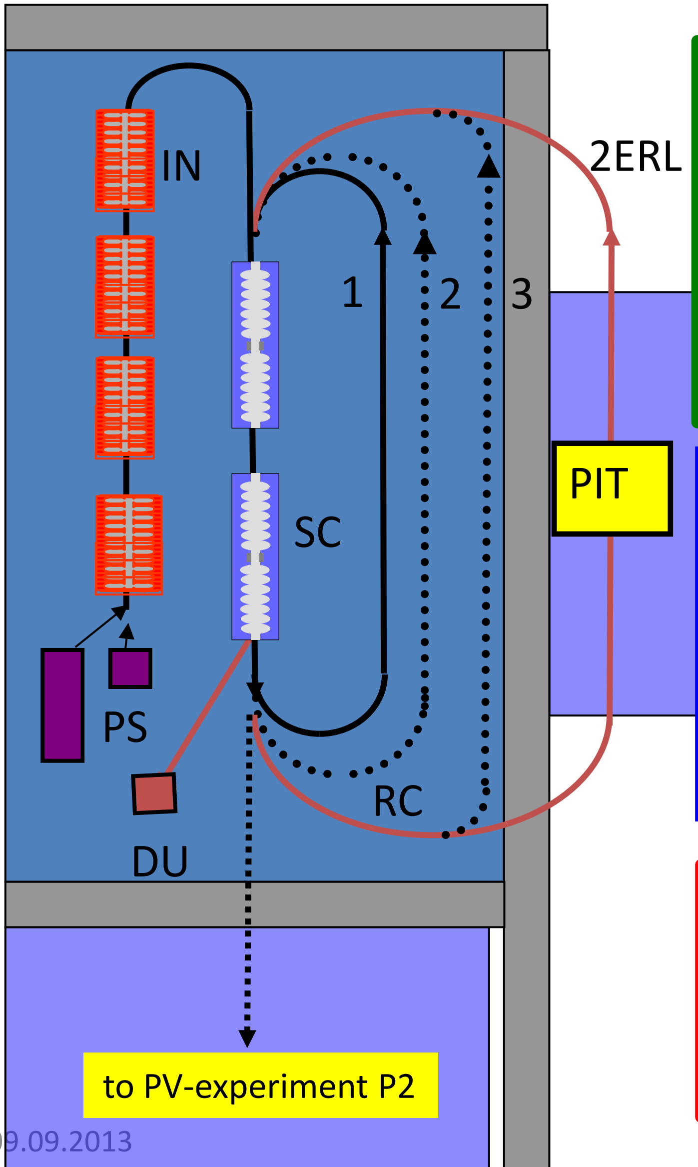
- No new buildings necessary
- MAMI continues separately for hadron structure exp. ~1GeV scale
- MESA takes over “low energy” experiments ~100MeV scale

MESA: A Concept and its history



- 3/2009 MAMI & beyond conference: A. Jankowiak and K. Aulenbacher present idea of ERL-Project „MESA“
- 2011: MESA accelerator „**stage-1**“ becomes major part of proposal for excellence cluster „PRISMA“, P2 experiment important part of proposal for SFB1044
- 11/2011 SFB 1044 proposal accepted
- 1/2012 Evaluation of PRISMA proposal & start of SFB1044
- 6/2012 PRISMA Excellence cluster accepted.
- 12/2012 PRISMA cluster starts, funding period **five years**

MESA and its Research fields



MESA‘s main objectives

1. **Accelerator physics: Multiturn, superconducting ERL**
2. **Particle Physics: Precision measurement of the weak mixing angle (P2-experiment)**
3. **New experimental technique for nuclear and particle physics: The PIT - high luminosity/low background at low energies**

MESA BEAM PARAMETERS:

c.w. beam

EB-mode: 150 μA, 200 MeV spin polarized beam (liquid Hydrogen target $L\sim10^{39}$)

ERL-mode: 10mA, 100 MeV unpolarized beam (Pseudo-Internal Hydrogen Gas target, PIT $L\sim10^{35}$)

During the application process it became evident, that not enough funding would be available to realize the envisaged Beam parameters – only a „stage-1“ was requested.

MESA-Beam-parameters in stages 1 (2)

Beam Energy EB/ERL [MeV]	**155/105 (205/105)**
Operation mode	**c.w.**
Elektron-sources	**Stage-1 : NEA GaAsP/GaAs superlattice , 100keV Stage-2: additional unpolarised KCsSb, 200keV**
Bunch Charge EB/ERL [pC] 7.7pC=10mA@1300MHz	**0.12/0.77 (0.12/7.7)**
Norm. Emittance EB/ERL [μm]	**0.1/<1 (0.1/<1)**
Spin Polarisation (EB-mode only)	**> 0.85**
Recirculations	**2 (3)**
Beampower at Exp. EB/ERL [kW]	**22.5/100 (30/1050)**
R.f.-Power installed [kW]	**140 (180)**

Additional demands occur due to main external experiment....

EB-Experiment: "P2"

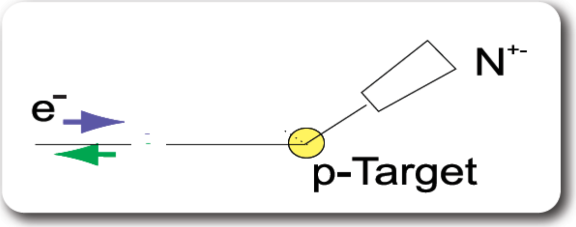
THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

PRISMA

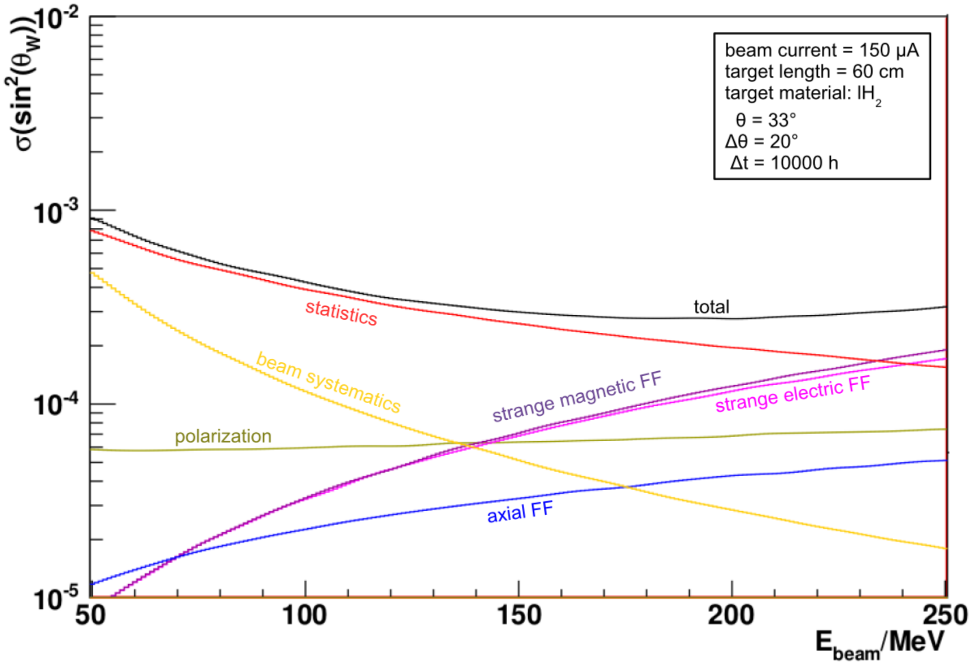
150 μA Beamcurrent , 60cm lq. H2, Beampol: 85%.
10000 h Data-taking (~13-15000 h Runtime)
High accuracy polarization measurement ($\Delta P/P$=0.5% **!!**)
Extremely high demands on control of HC-fluctuations!

→ **~4000h/Year Runtime**

→ **Accelerator must be optimized for reliability& stability**

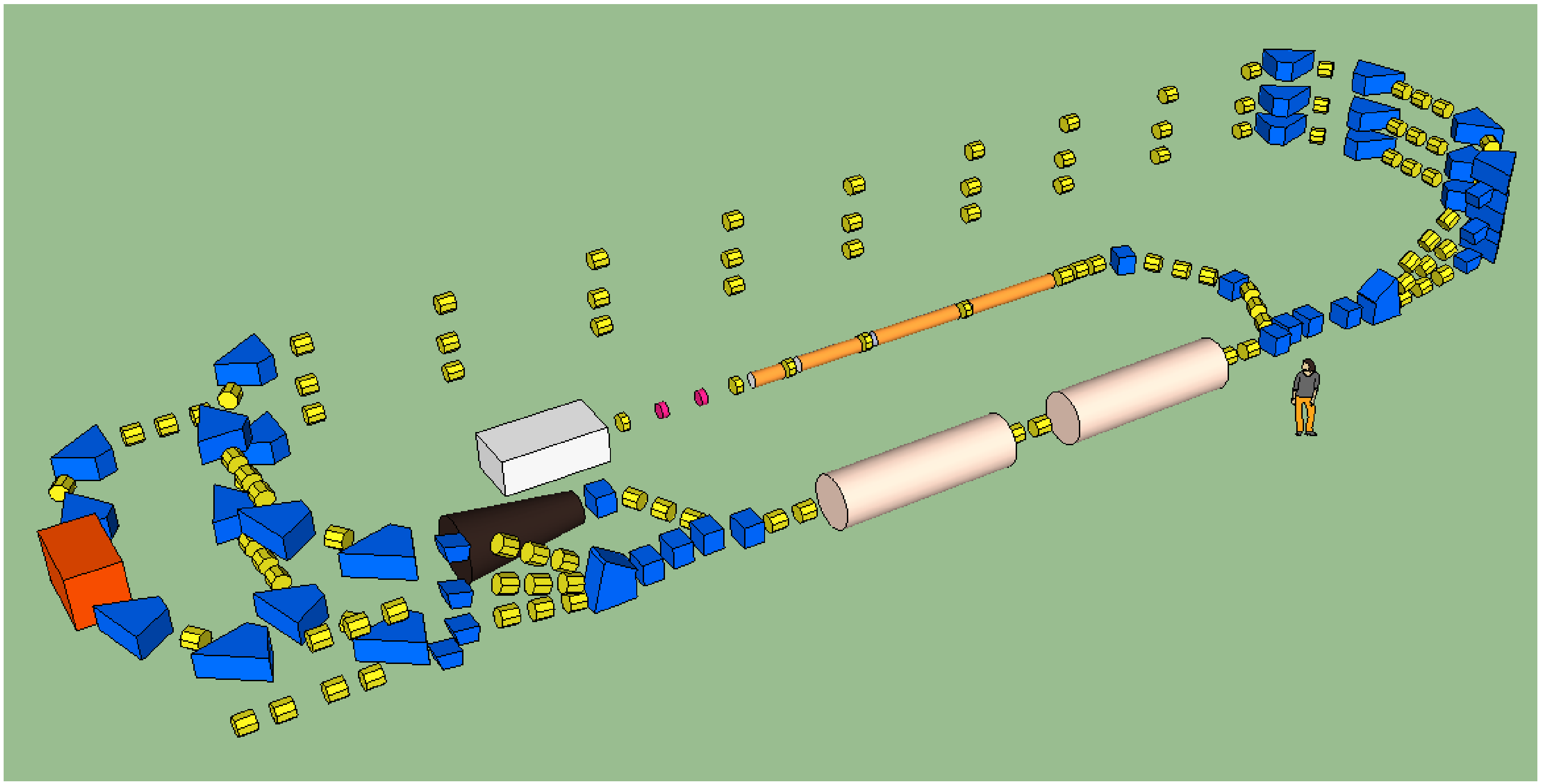


→ P2 is MESA-workhorse experiment ←



Good news:
Very flat minimum of total error allows to reduce beam energy to ~150 MeV

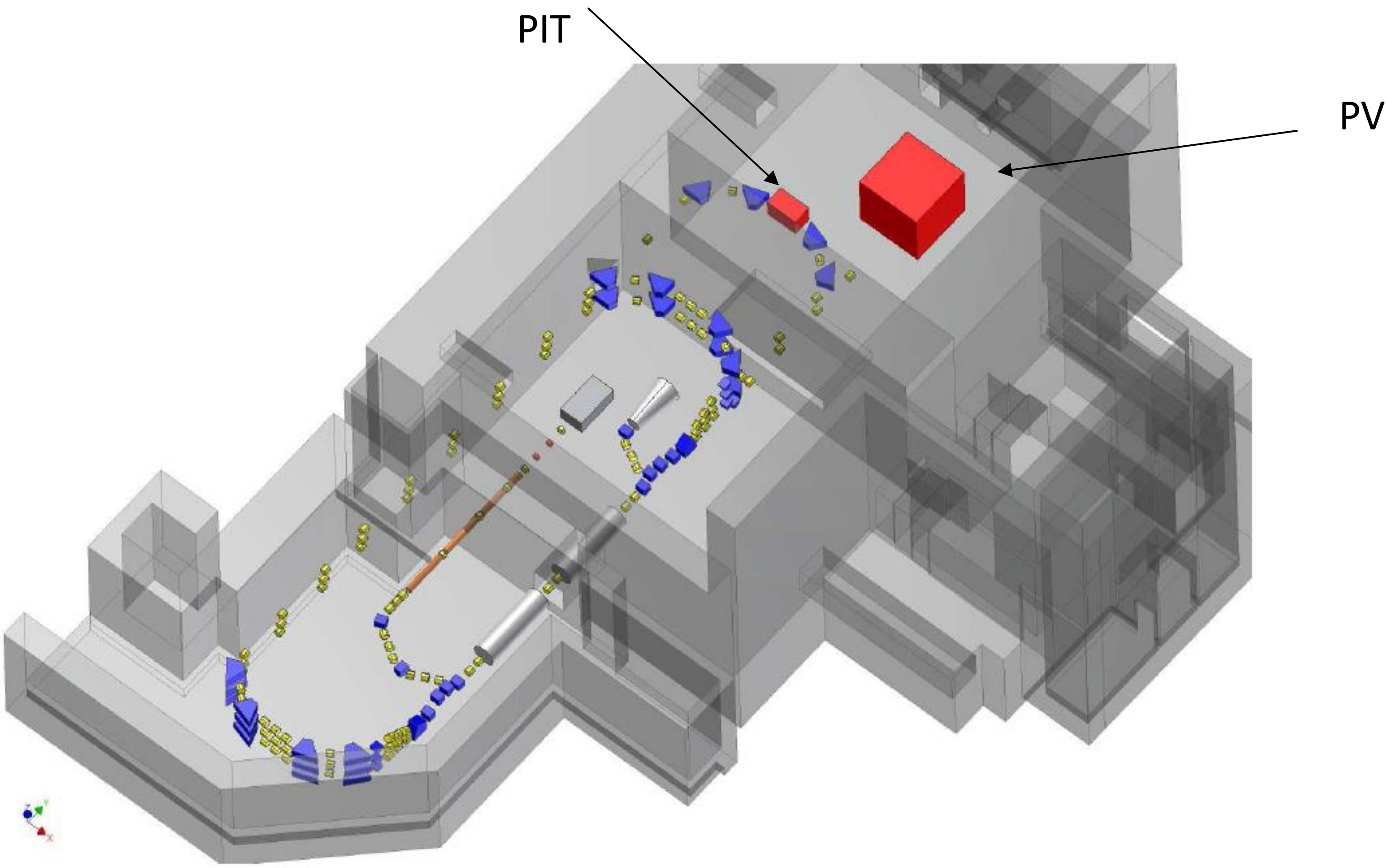
A possible accelerator layout



Ralf Eichhorn

Vertical stacking “a la CEBAF” keeps transverse footprint small
→ compatibility with building.

MESA –"Integration"



V. Bechthold/R. Heine

Accelerator: R&D Issues

Constraints by Budget, Space and Schedule: Technology/Physics solutions must be compatible!

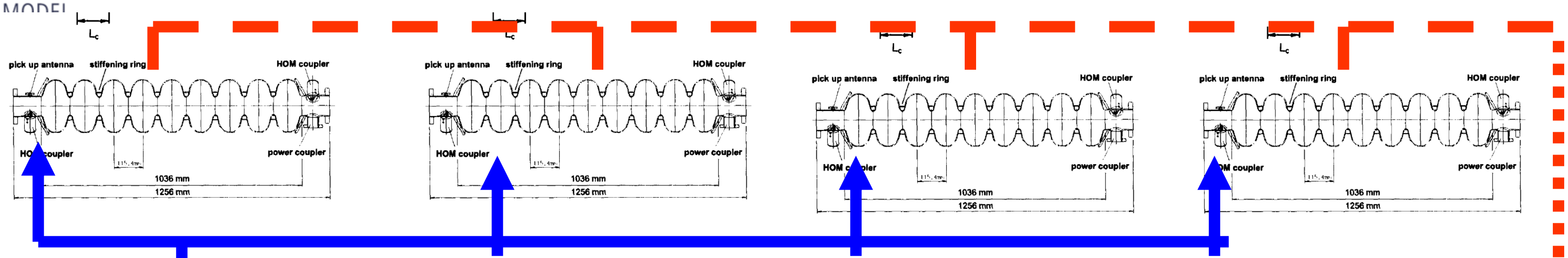
Technology:

- Cryogenics
- Cryomodule

Physics:

- Sources/Injector
- BBU Instability
- Rezirculator (Lattice) Design

Cryoplant-Constraint



200l /h, lq.
Helium

Available Power at 2K
≤100 Watt →
ΔE>50MeV from Linac
would be unrealistic

Injector-Linac (ILAC)

Motivation for normal Conducting -ILAC:

- Easy maintenance
- No cryogenic load,
- Established design (based on MAMI-ILAC, Th. Weis, H. Euteneuer 1984)

- Phase space shaping by „graded beta" structure
- ~100kW RF Power (50kW beam loading included)
- T=5MeV, $\Delta\psi_{100\%} < \pm 2.3°$ $\Delta E/E_{rms}=0.01\%$ length: 11,5 m

Detailed results published at IPAC 2013 (R. Heine et al.)

Cryomodules and BBU

„Two seater“ ELBE Cryomodule
With 2*9cell „TESLA“ cavities

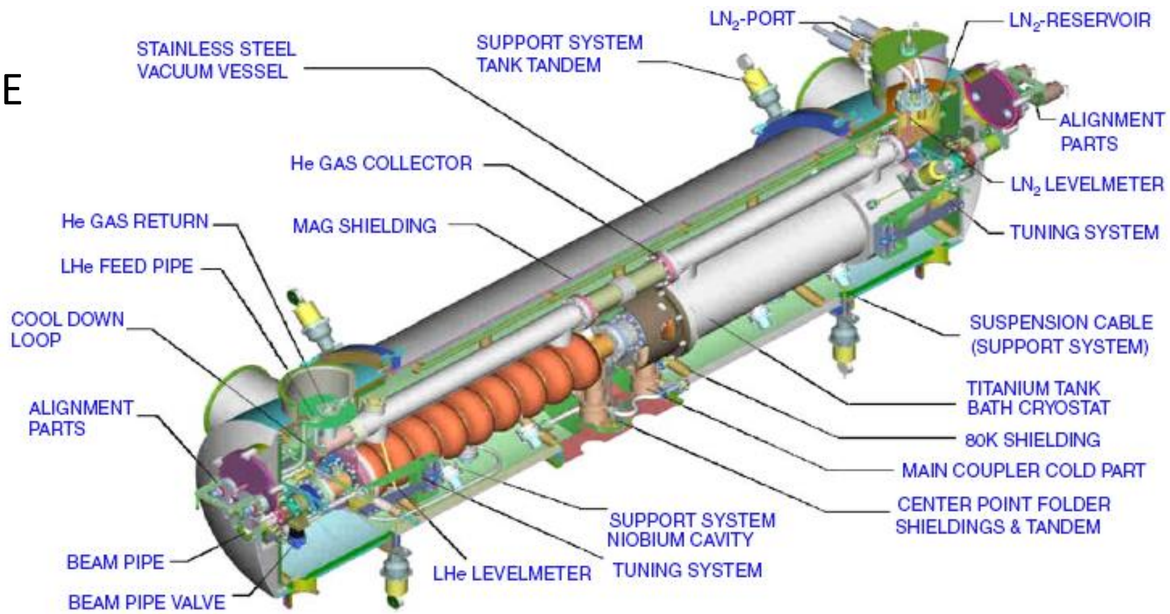
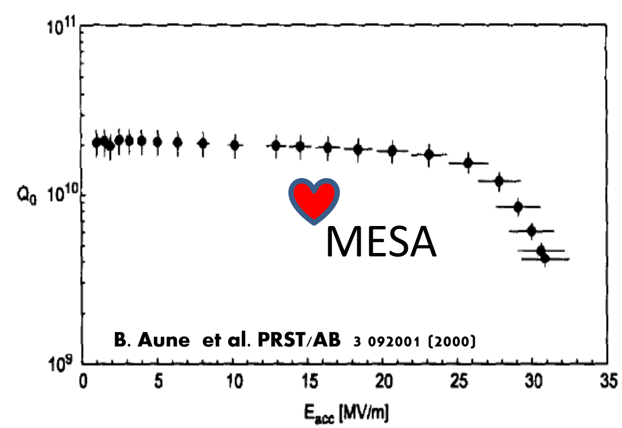


Fig. 1. Three-dimensional drawing of the ELBE cryomodule.

J. Teichert et al. NIMA 557 (2006) 239

- “ELBE” –Modules are suitable for high gradient c.w. op.
- Commercially available, no additional R&D
- Costs & Delivery time are (to some extent) predictable
- Limitation in Cryopower requires $Q_0=10^{10}$ at 14MeV/m (achieved at DESY/FLASH in operation with TESLA cavity)



Cryomodules and BBU

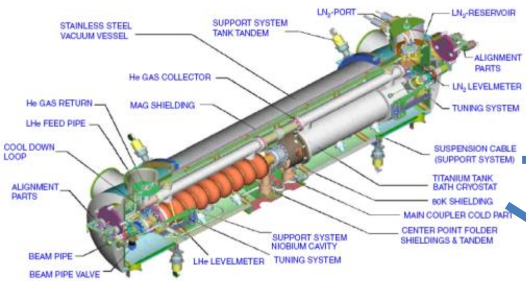
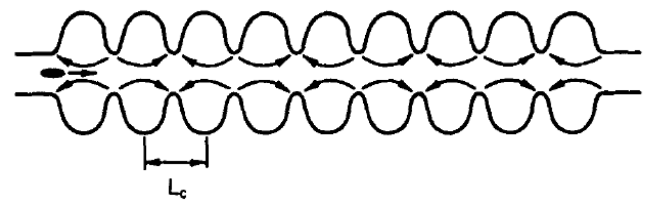
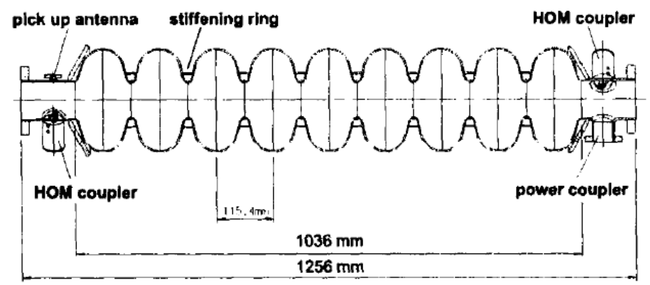


Fig. 1. Three-dimensional drawing of the ELBE cryomodule.

9 cell 'TESLA' π-mode Cavity:





Higher order modes (HOMs) with „bands“ of Eigenmodes e.g. TM11-like. →BBU- Instability for beamcurrent > I_T

In recirc. Linacs: Feedback-loop with instability threshold!

$$I_T = -\frac{2c^2}{e\left(R/Q\right)_{HOM} Q_{HOM}^{ext}\,\omega_{HOM}}\,\frac{1}{T_{12}\sin(\omega_{HOM} t_r)}$$

(simplified formula!)

T_{12} = Transformation from angle to position

t_r = Recirculation - time

General treatment for ERL's
G.H. Hoffstaetter, I. Bazarov: PRSTAB 7 054401 (2004)

Cryomodules und BBU

$$I_T = -\frac{2c^2}{e\left(R/Q\right)_{HOM} Q_{ext}\omega_{HOM}} \frac{1}{T_{12}\sin(\omega_{HOM}t_r)}$$

T_{12} = Horizontal Angle ⇒ Position

T_{34} = Vertical, T_{56} = Longitudinal (Energydeviation to phase)

„High current“ – Recirculators call for :

- Strong HOM damping (TESLA-Cavities are not optimzed!)
- Flexible Recirculation optics to adjust T_{12} , T_{34} but probably also T_{56}

Conclusions/conflicts:

1. „Non-Tesla Cryomodule“ for MESA → But: compatible with budget & schedule?
2. Second bullet calls for independent orbit recirculation

→ But: Polytronrecirculator is more compact , better inherent stability.

Initial-Plan: Use TESLA/Rossendorf Module („Stage-1“ with limited current)

Cryomodule alternative-1

Discussions with JLAB :
Fabrication of one further „C-100“ cryomodule , identical To the ones used for CEBAF Energy doubling

$$P_{Loss} \propto N_{Cav} E_{Cav}^2$$

$$\Delta U = N_{Cav} E_{Cav} l_{Cav} \Rightarrow P_{Loss} \propto \frac{\Delta U^2}{N_{Cav} l_{Cav}^2}$$

for given Linac energy gain and cavity length more cavities are advantageous to reduce cryo-load

JLAB „8-seater“ C-100 Cryomodule at 1500 MHZ
+ better HOM damping than TESLA
+ several buildt and tested
+ MESA energy doubling possible with investment in cryoplant

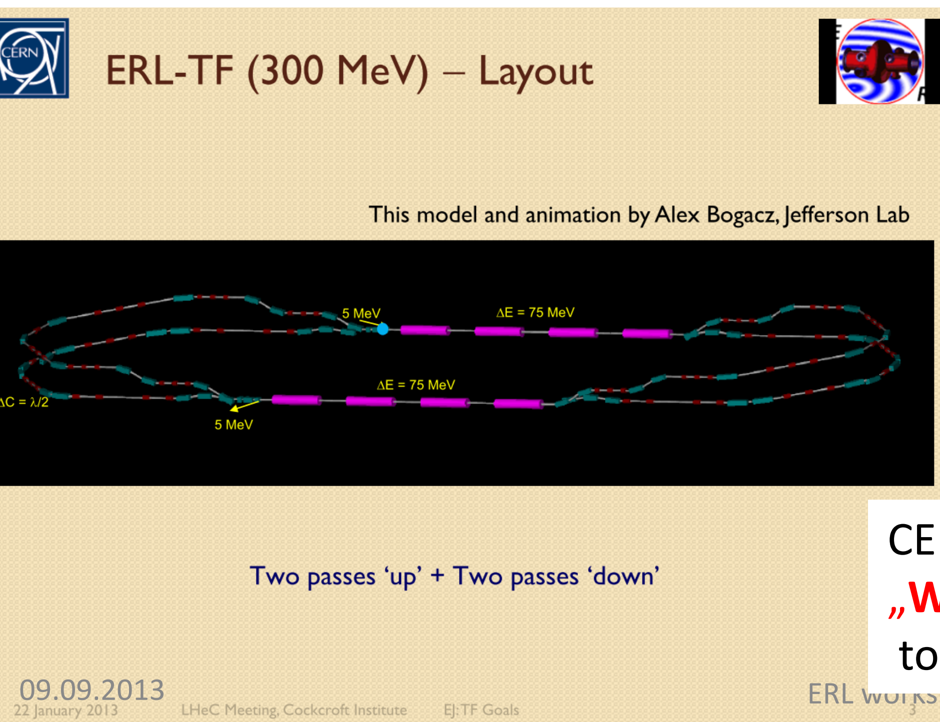
- Module too long for exisiting shaft

Source: JLAB

Cryomodule alternative-2

Contacts with CERN LHC/LHeC group (O. Bruning, E. Jensen, M. Klein):

- LHEC needs cryomodule with frequency as an integer multiple of LHC RF (40.079MHz) (802 MHz is almost RF-frequency for **SPS,** the LHC injector)
- CERN group plans to build ERL test facility with, e.g., 802 MHz cryomodule
- Indications for a support of Testfacility+cryomodule project by CERN-management (final decision end of September 13)
- Common objectives, complementary competences, similar timescale:
  → **This may be a great oppurtunity!**



E. Jensen, Talk at Daresbury LHeC meeting January, 2013

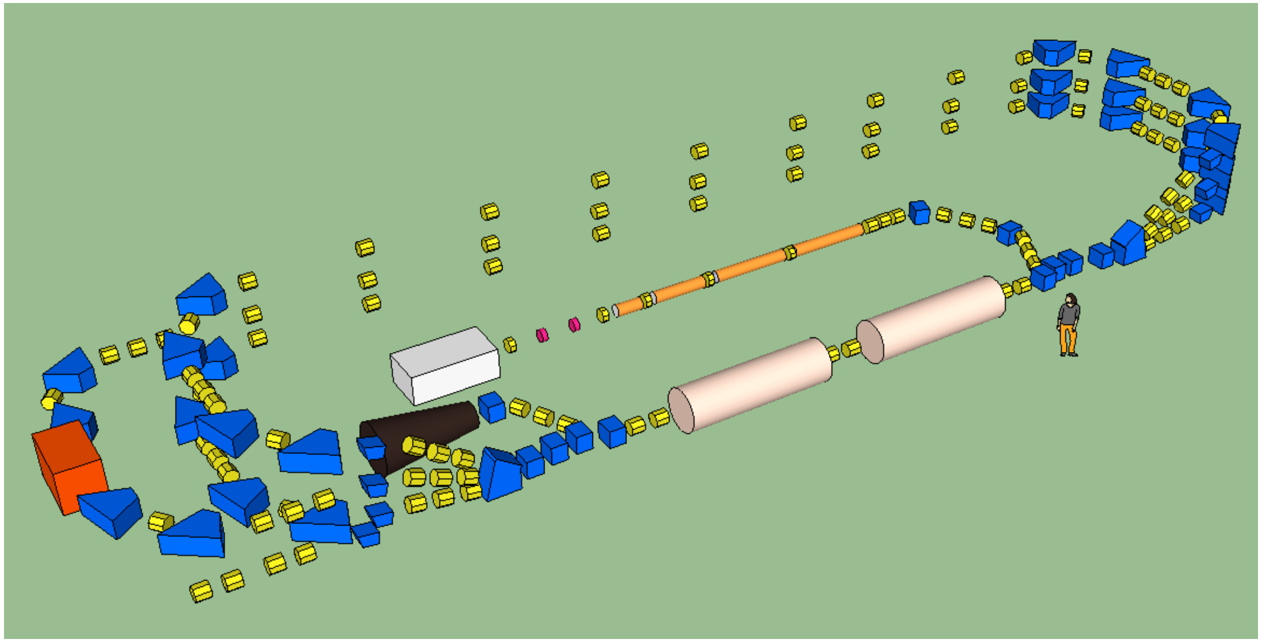
CERN/MESA Consultations to define a concrete plan
„What it takes to achieve a new cryomodule"
took place in August

Beam-dynamics: Recirculator-Lattices

Beam-dynamics: Recirculator-Lattices

THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

PRISMA



„CEBAF“ inspired

Design: Ralph Eichhorn

Advantage:

- Identical horizontal deflections and magnets
- High symmetry

Problem: Vertikal stacking under very constrained long orbit axis

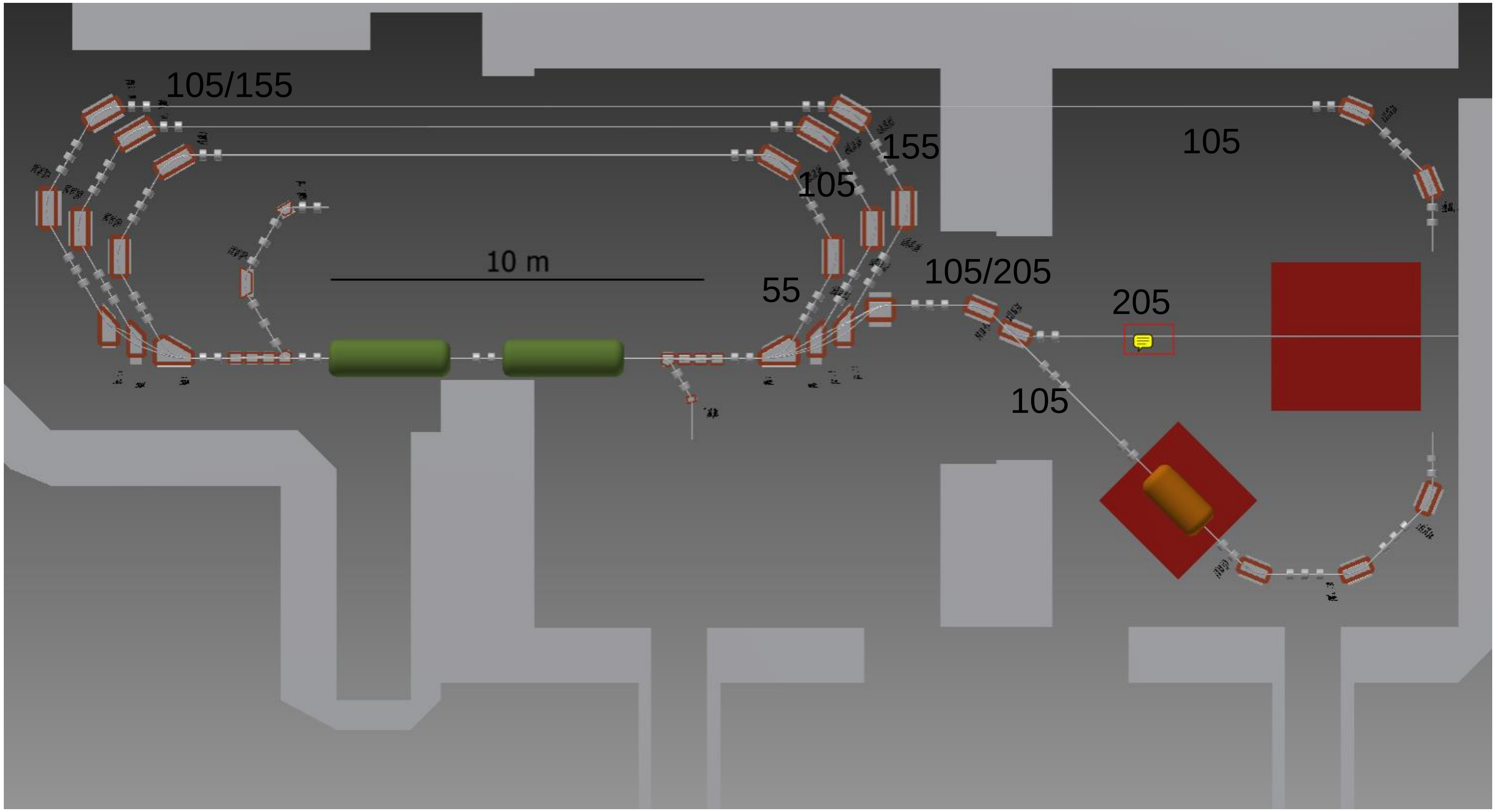
- Large vertical deflection angles
- Small space for compensation quads.

→ Vertical dispersion probably difficult to control

We presently investigate also two types of „flat“ lattices

Horizontal lattices: "Conventional recirculator"

„S-DALINAC" inspired



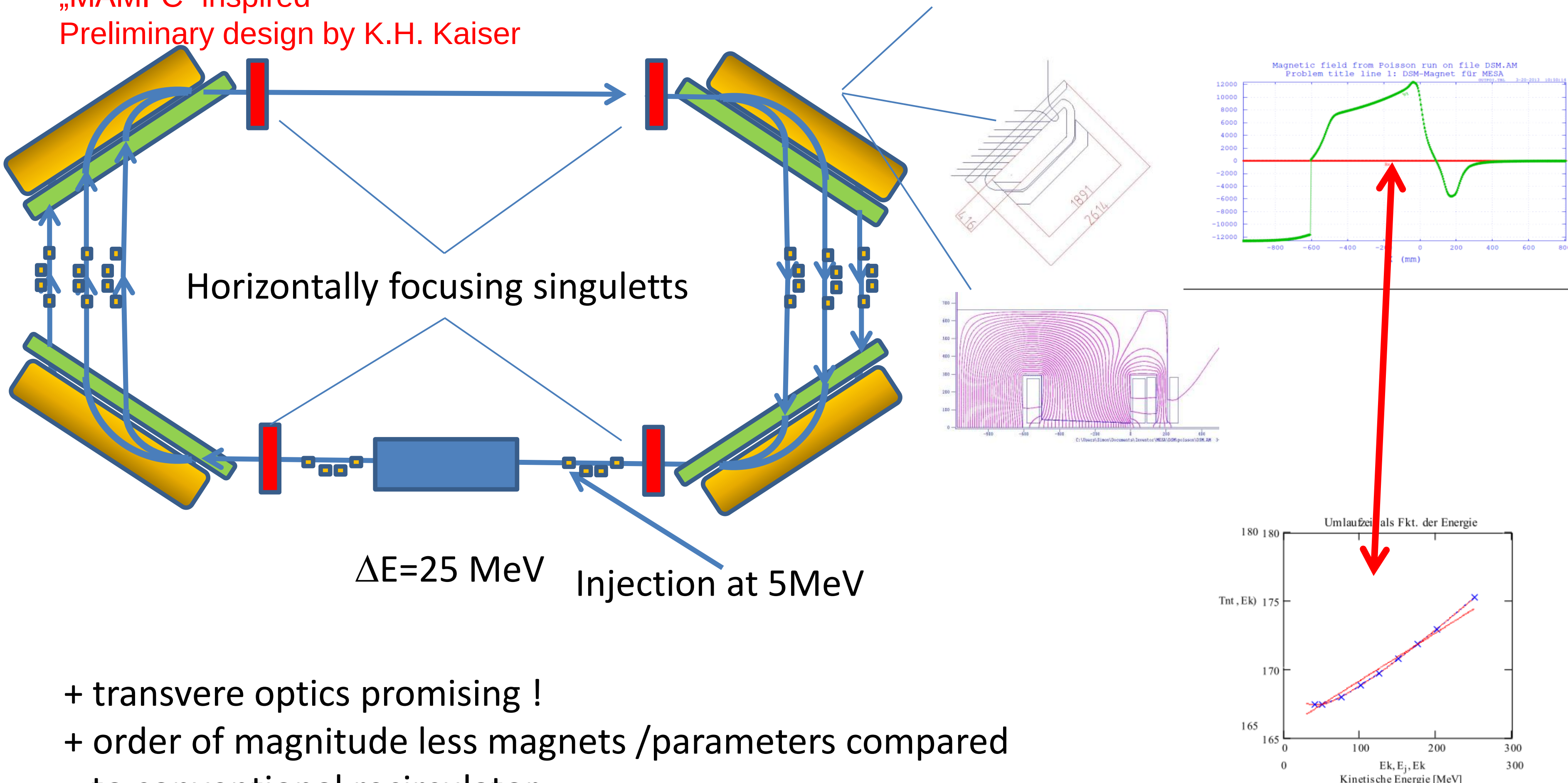
Daniel Simon, Diploma thesis: Sketch of flat lattice with realistic dipole dimensions

Lattice design is ongoing!!

Second option for flat lattice:
Polytron recirculator?

Asymmetric Polytron of second order (AP2)
(A low budget lattice for up to 8 recirculations)

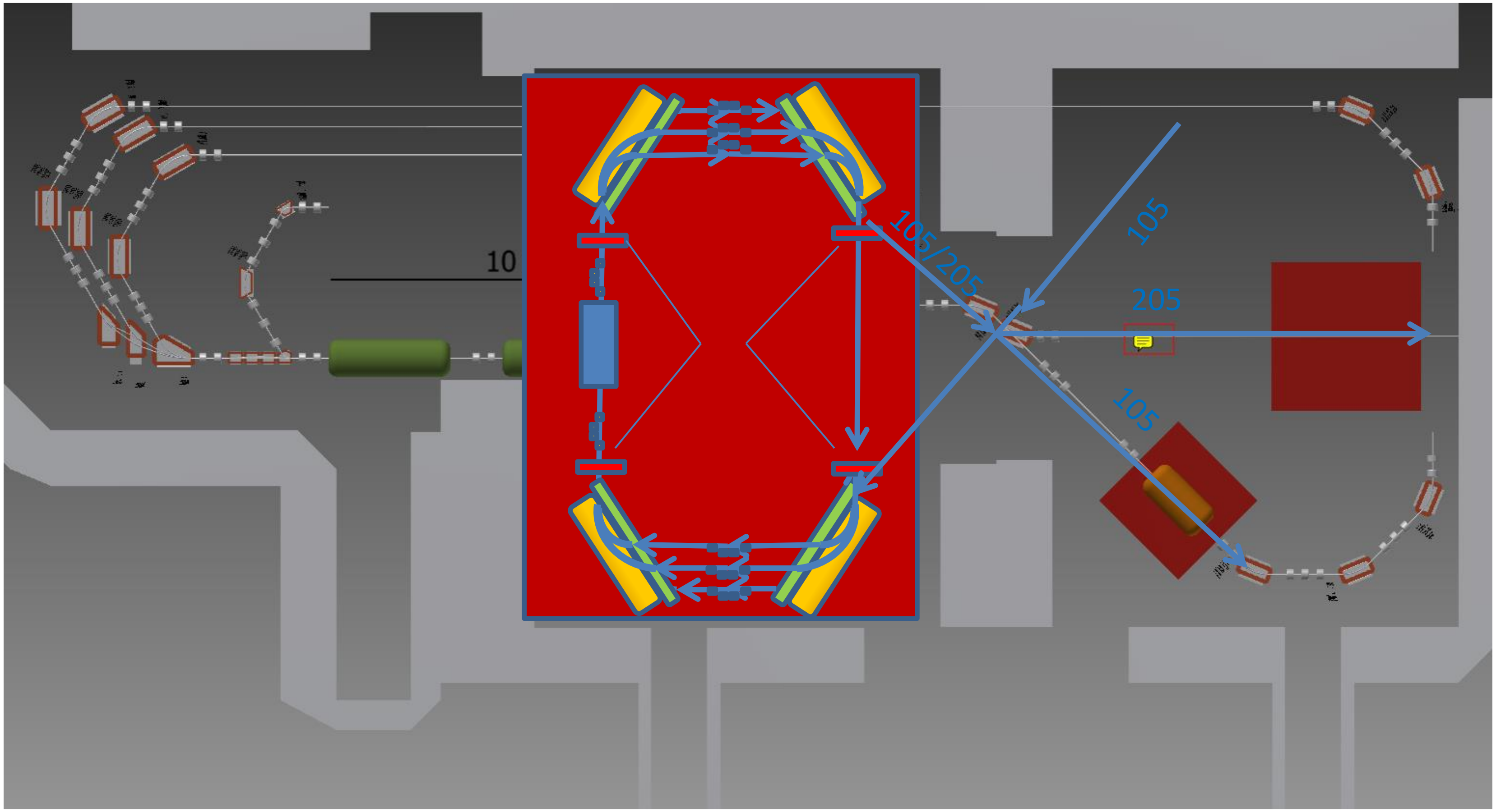
„MAMI-C“ inspired
Preliminary design by K.H. Kaiser



+ transvere optics promising !
+ order of magnitude less magnets /parameters compared
  to conventional recirculator

- Very large turn by turn phase shifts must be compensated
by shicanes in several (not all) turns.

AP2 –advantages wrt other lattices



- 50% reduction of cryoload
- Significant reduction of invest for cryomodules
- Much less space required
- Energy stability/stabilization as in MAMI due to large R_{56}, long bunches allowed

AP2 is kind of a temptation…

The AP2 –temptation: vade retro?!

Detail from:
Hyronimus Bosch:
Temptation of St. Anthony
(15th century)

The AP2 –temptation: vade retro?!

Possible disadvantages and/or showstoppers

- Fixed optics&larger number of recirculations
  → (too) low BBU threshold?
- Shicanes mandatory
- Complex magnets with small bending radius
  (first turn critical)
- 25 MeV req. 4 turn ERL (8mA in Linac at stage-1) ??
- Upgrade to 80mA (stage-2)????

Important decisions & Project timeline

- End 2013 Decision Cryomodule
- Spring 2014   Decision Lattice
- Summer 2014 Infrastructure modifications start (Building, 2K System,..)

Acknowledgments

MESA-Project-team:
I. Alexander, K. Aulenbacher, V. Bechthold, Ma.Dehn, Mo.Dehn, J. Diefenbach, F. Fichtner, S. Heidrich, R. Heine, K.H. Kaiser, E. Kirsch, H.J.-Kreidel, Ch. Matejcek, U. Ludwig-Mertin, F. Schlander, V.Schmitt, D. Simon

WE ARE HIRING!

- ERL beam dynamics
- Kryogenics

Contact:
aulenbac@kph.uni-mainz.de

MESA is supported by :

- State of Rhineland Palatinate
- German university excellence initiative: PRISMA-Cluster of excellence
- German Science foundation (DFG): SFB 1044
- German Ministry of science & ed. (BMBF):
  -PCHB- Consortium (Photocathodes for high brillance beams)
  -HOPE- Consortium (Hochbrillante Photoelektronenquellen)

Thank you

THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

Spares

MESA-Collaborations

- Collaboration between HZB & KPH
- Consortia within BMBF: HOPE (High brillance sources) KPH/HZDR/HZB and PCHB (Photocathodes for high brillance beams, many partners)
- Contacts related to ERL problems with: CERN/Daresbury/BNL/Daresbury
  → Cryomodule Collaboration??

MESA-Staffing

MESA is PRISMA „Project E“. Project leaders: Kurt Aulenbacher & Frank Maas

Task	In charge	Support
General Design, „beam dynamics“	NN, Jun.-Prof. (Tenure track W2!) (call 8/2013)	J. Diefenbach, Post-Doc (stabilizations) Ma. Dehn (50%) staff scientist PhD student (NN(*))
Sources	K. Aulenbacher	PhD student (I. Alexander) PhD student (Mo. Dehn) PhD student (NN(*))
RF, Injector	R. Heine (80%), staff scientist	F. Fichtner (engineer) 80% PhD student (NN(*))
SRF Module/Cryogenics	F. Schlander, Post-Doc	PhD student (NN(*)) technician (NN (**))
Control-system	H.J. Kreidel, staff scientist (20%),	P. Schwalbach (technician) 30%
Radiation protection , room temperature systems (magnets, etc.)	NN, staff scientist (80%) Call 7/2013	U. Ludwig-Mertin (staff scientist) 25% U. Reiss (engineer, rad. Prot.) 30% M. Goebel (technician, rad prot.) 30%

Black: PRISMA-personel/Blue: KPH-staff, Percentage: work fraction devoted to MESA/Green: BMBF-personel
(*) : Large reservoir of Master/diploma students! (**) Technician will be integrated in TBV.

- Accelerator workshop „TBB“ (6 workers&technicians):
  Contributes strongly to MESA infrastructure (has also to support MAMI and its experiments!)
- Electronics (TBE), mechanical workshops (TBM), vacuum&cryogenics (TBV):
  Contribute to MESA within their capacities! (on average ~6 workers/techicians/engineers in each unit)
- Further MAMI staff (technicians, engineers, operators) are, as a rule, required for MAMI operation, but may deliver support if capacity allows.

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

Possible CERN/MAINZ/+X Collaboration

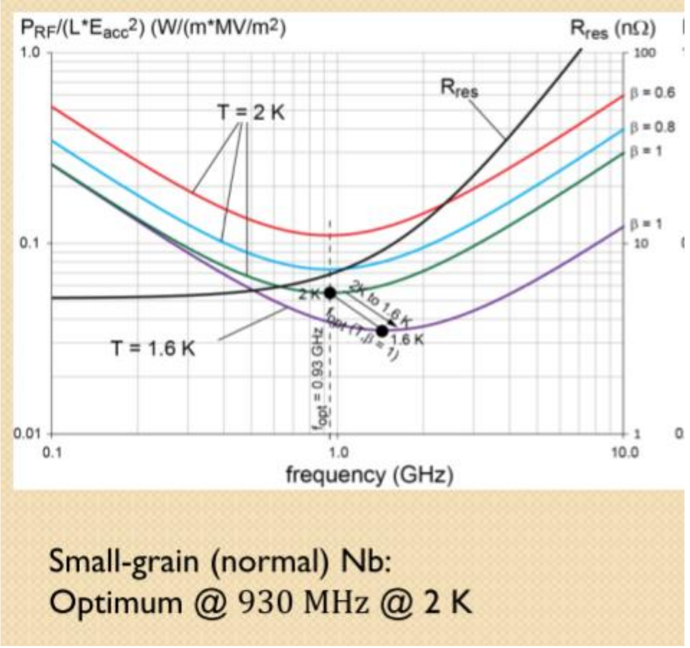
PRISMA

Fabrication of a dedicated 802MHz cryomodule:
What may we contribute?

- Manpower (Post-Docs, PhD students)
- Invest (same amount as for commercial acquisition)
- Infrastructure in **HIM building** (cleanroom, horizontal test stand/bunker)
- **But:** Only very limited number of engineers, designers, etc…..!

Fabrication of a dedicated 802 MHz cryomodule:
Where we need support from collaborators

- Cryomodule design
- Resonator, HOM damping, etc design
- Additional invest ???
- Project coordination, management, administration???
- …..

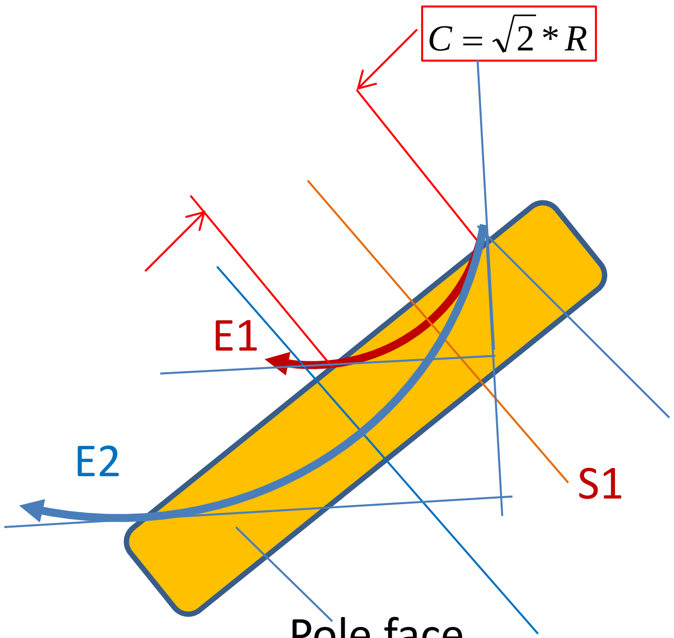


F. Marhauser ,

CERN/MESA Consultations to define a concrete plan
„What it takes to achieve a new cryomodule“
will begin in the first week of August.

Horizontal lattices: Segment Magnet Recirculator

90 degree Segment



Segment- or „Polytron"- magnet:
Each Orbit enters and exits at **THE SAME** Pole edge
Orbit is **SYMMETRIC** around normal to pole edge:
→ Deflection angle 2*pol face inclination

- Deflection angle is **independent** of energy
- Very convenient transv. Optics (Apart from fringe fields)
- Dispersion **cancels** after each two deflections
- Circular orbits achieved after N*2 Segments

  N=1 Microtron (not suitable for MESA)
  N=2 Double sided Microtron (Two dispersion free sections
  N=3 Hexatron

We investigate an Asymmetric Polytron of second order (AP2)
(Not: „single sided DSM")

"Low budget " Lattice Alternative: Segment (Polytron-)Magnet Recirculator: Asymmetric Polytron of second order (AP2)

SFB 1044 — THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

PRISMA

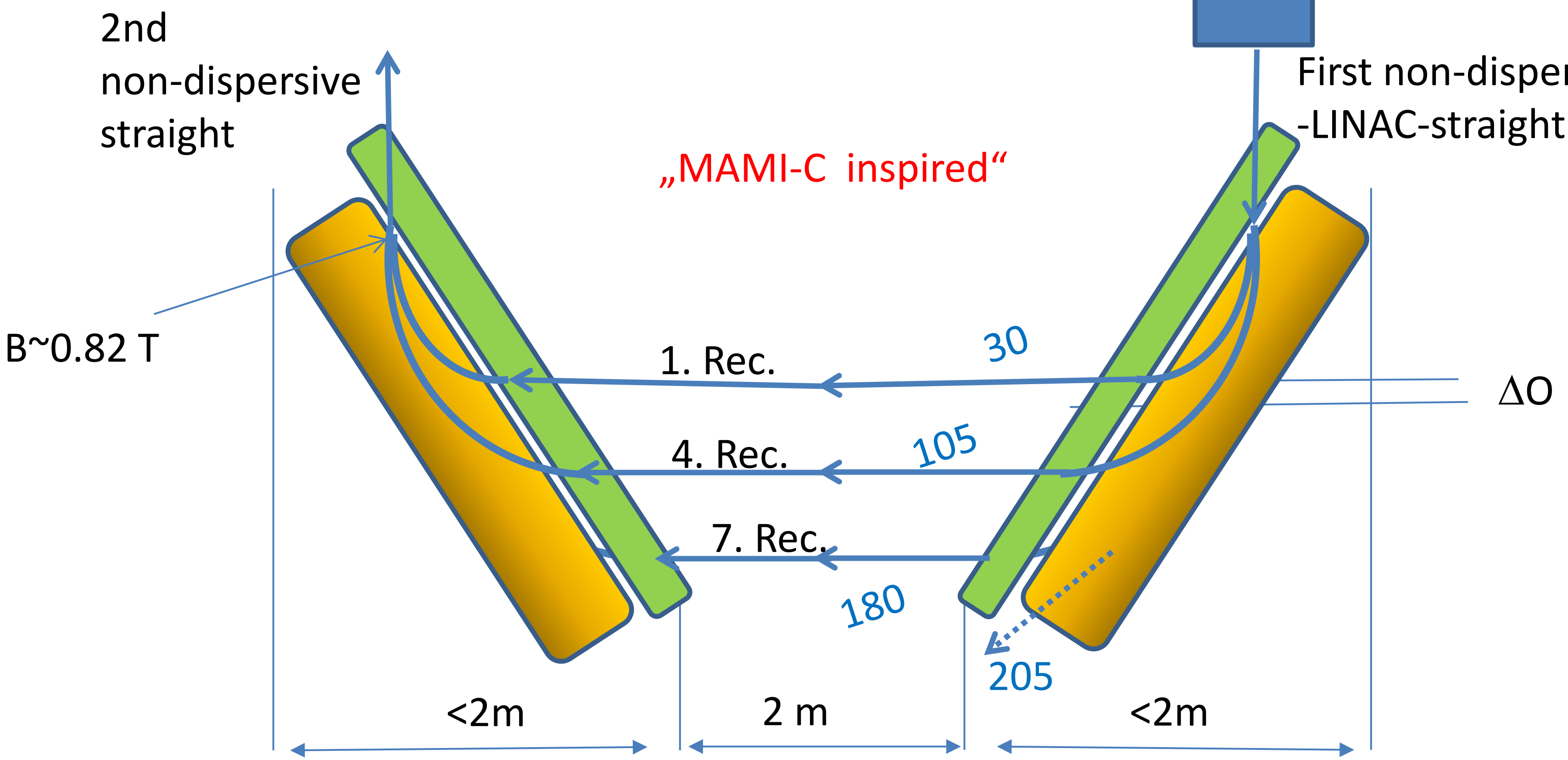
Injection at 5MeV

Single Cryomodule ΔE=25MeV

AP2-Coherence Condition: $\Delta E = \frac{\lambda e c B}{2(\pi - 2)}$

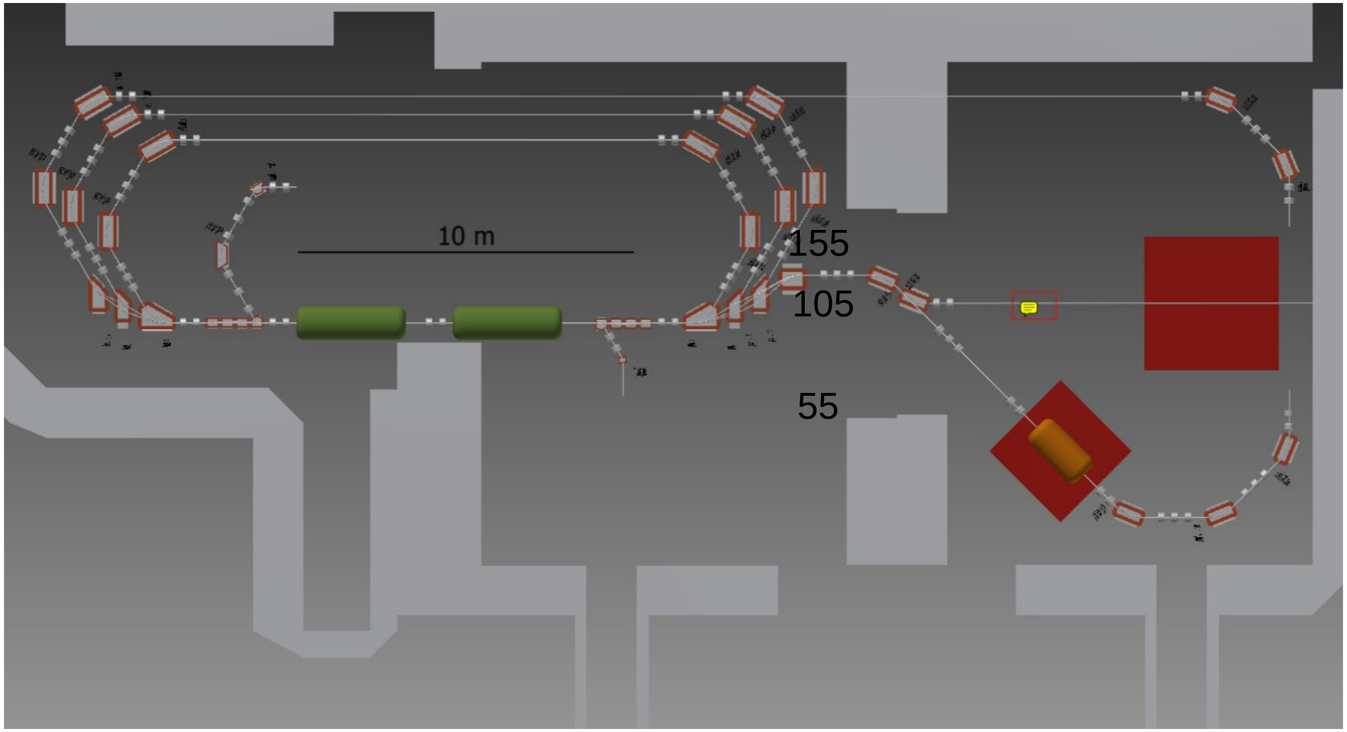
Distance between adjacent orbits: $\Delta O_{i,i+1} = \frac{\lambda}{2(\pi - 2)} = 10.01 cm$

(numerical value for 1300MHz)



Design: K.H. Kaiser

Infrastructure issues

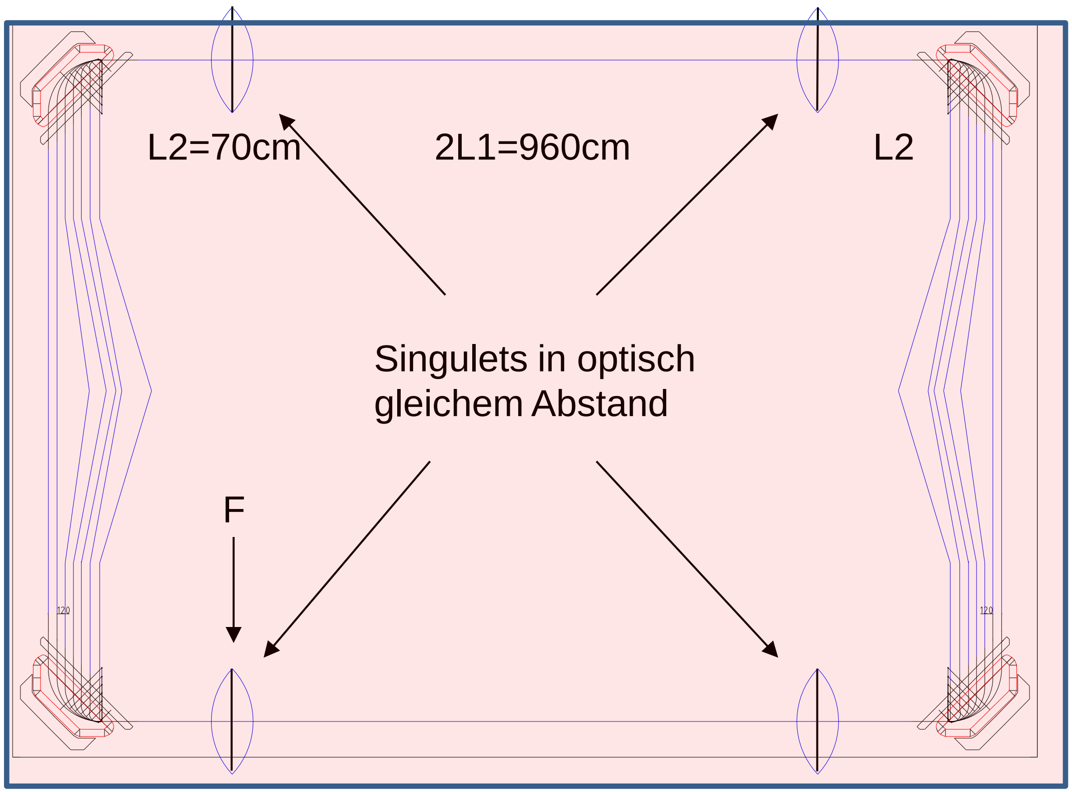


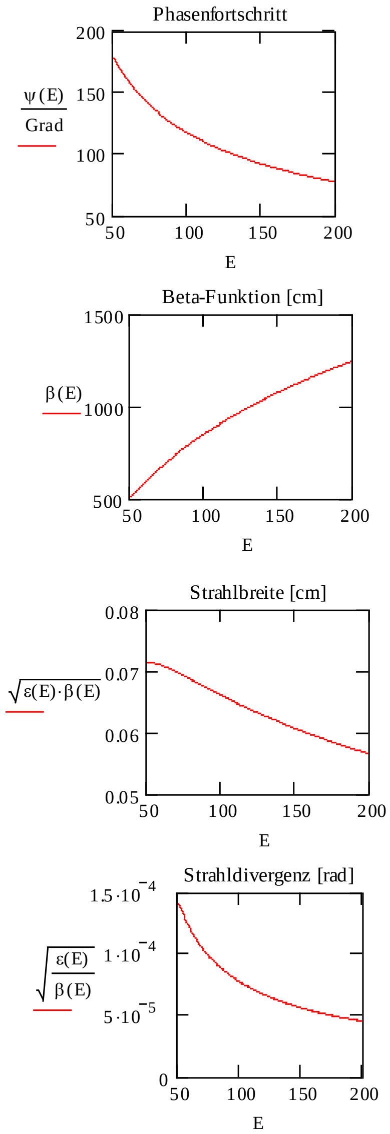
Building& real estate Propriator is „LBB“

LBB=
Landesbetrieb
Liegenschaften
und
Bau
Betreuung

- Building has thick walls which have to be cut/drilled (at apropriate places): Building integrety, fire protection by LBB & external companies
- Sufficient electrical & cooling power is available, but machine cooling water hydraulic layout &temperature stabilization by LBB & external companies,
- Option for managing other installation work by in house staff, in particular: lq. Helium distribution/2K booster, Radiation Protection Application

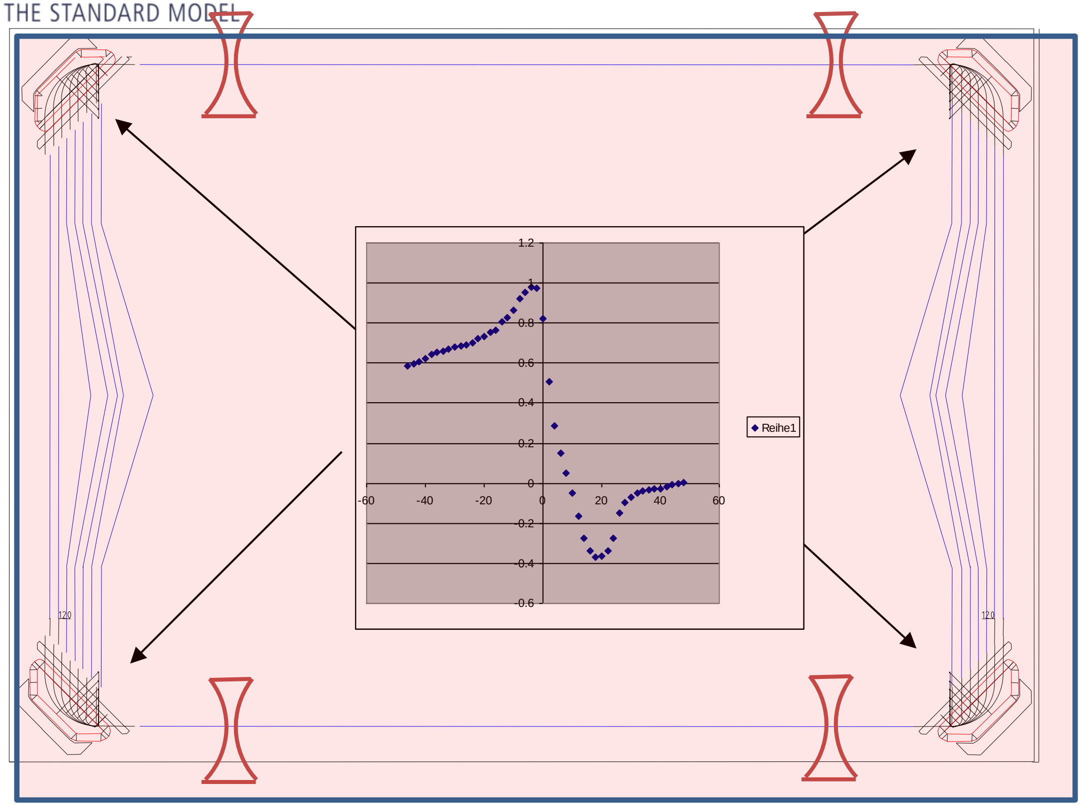
Horizontal Optics

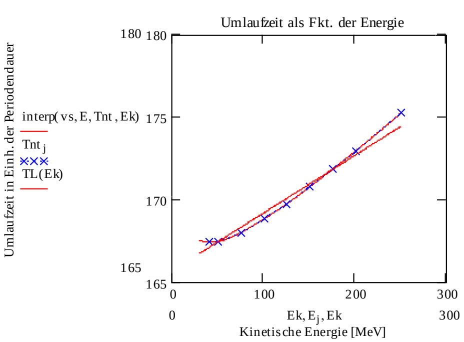




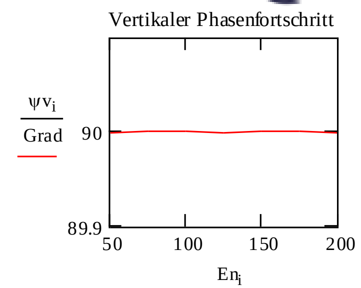
09.09.2013

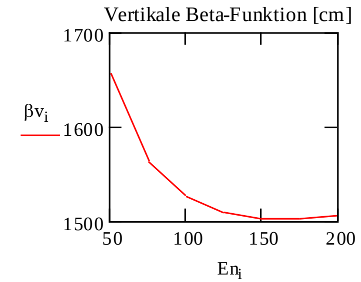
Vertical Optics

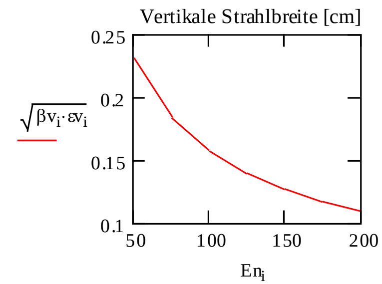




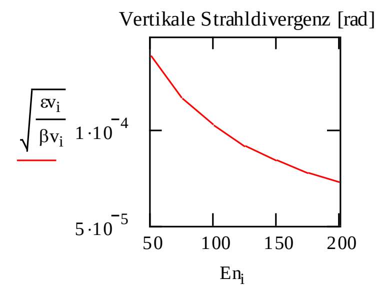
Counter-field & gradient lead to strong longitudinal Phase shifts!





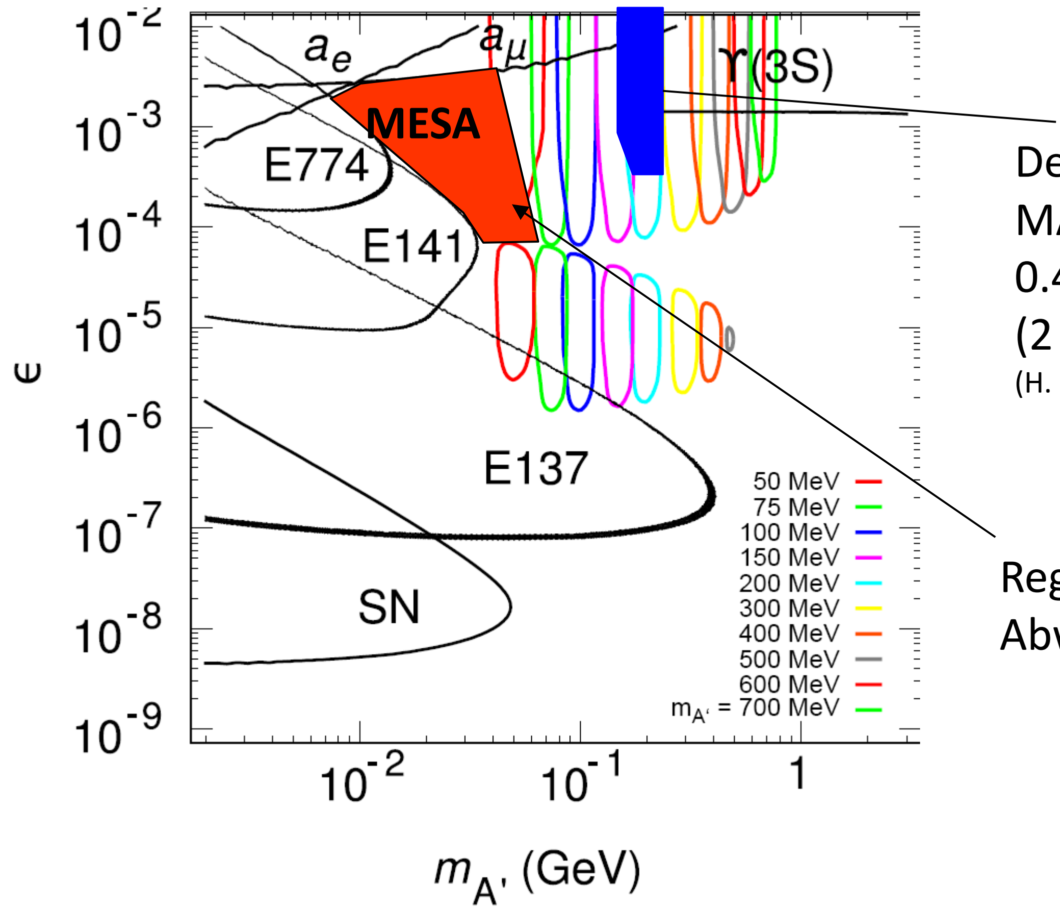


*1/3



Suche nach dunklen Photonen an MAMI/MESA

"Bump-hunt" Experimente können (M_{A}'> 100MeV) sofort begonnen werden: MAMI/A-1 und JLAB/Aspect

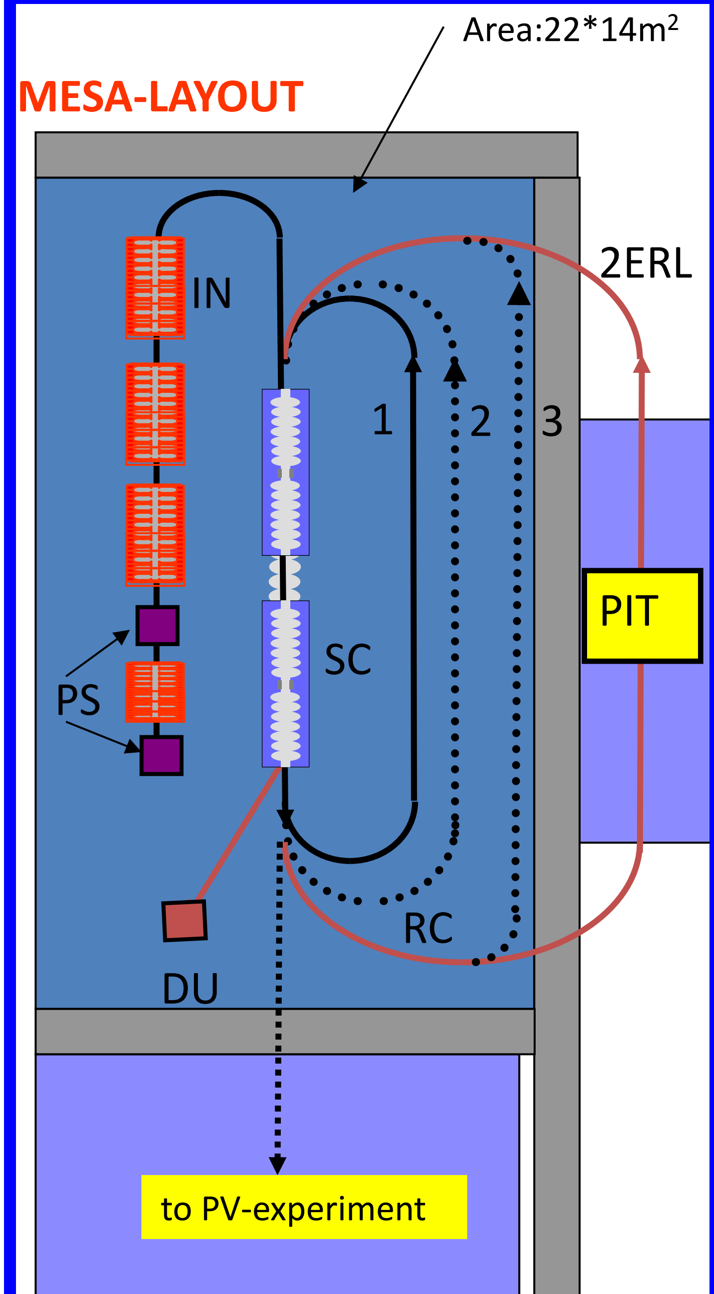


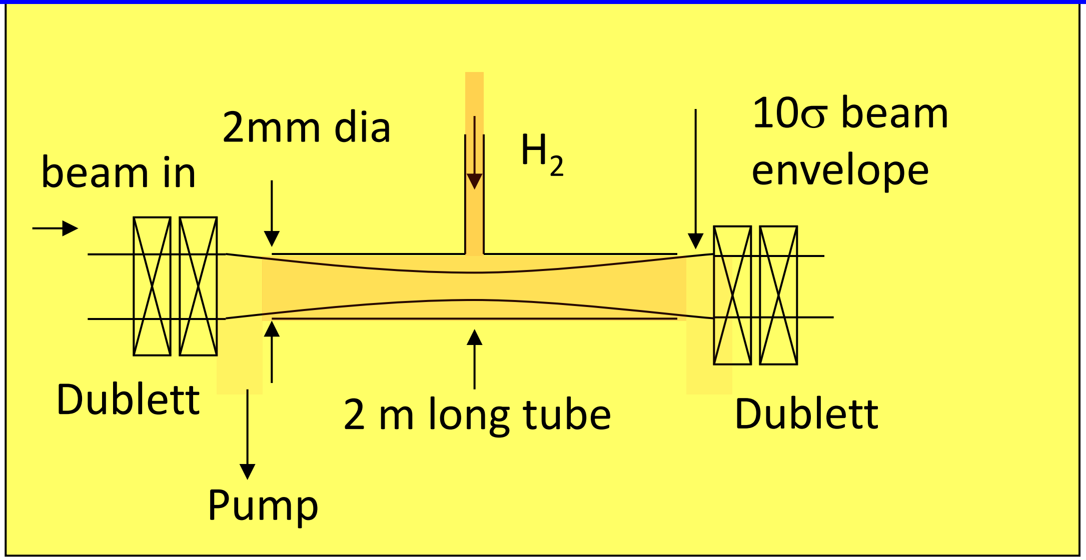
Demonstrationsexperiment an MAMI: 100µA/855MeV auf 0.4% rad. length Tantal (2 Wochen Laufzeit)

(H. Merkel et al. PRL **106** 251802 (2011))

Region interessant wg. $(g-2)_\mu$ Abweichung

ERL/PIT: Ein neues Regime bei E<1GeV





Target dichte N=$2*10^{18}$ atoms/cm^{-2} (3.2 μg/cm^2, $5*10^{-8}$ X_0)

→ $I_0=10^{-2}$ A: L= $1.2*10^{35}$ $cm^{-2}s^{-1}$

→(mittlerer) Enereverlust (Ionisation): ~ 17eV

→ RMS Streuwinkel (Vielfachstreuung): 10μrad

→ Single pass Strahlverschlechterung ist akzeptabel

Bei Bunchladung 7.7pC (10mA): $\varepsilon_{norm} \approx 1\mu m$

Strahldurchmesser prop. der strahloptischen Funktion β:

$$r^2_{beam}(z) = \varepsilon_{Geo} * \beta(z)$$

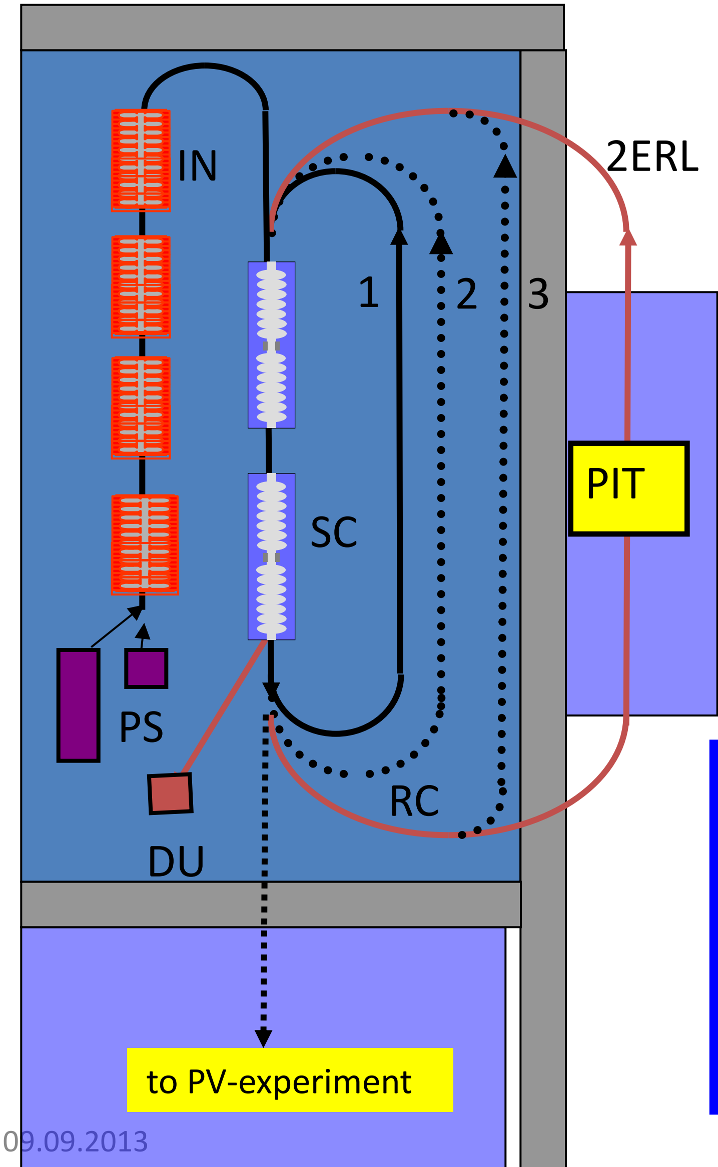
$$\text{mit } \varepsilon_{Geo} = \frac{\varepsilon_{Norm}}{\sqrt{\gamma^2 - 1}} \Rightarrow \varepsilon_{Geo}(100\text{MeV}) \sim 5\text{nm}.$$

In der feldfreien Region um den Punkt $z^* = 0$

$$\beta(z) = \beta(z^*) + \frac{z^2}{\beta(z^*)} = \beta^*(1 + (z/\beta^*)^2) \text{ wähle: } \beta^* = 1m$$

$\Rightarrow$ Maximaler Strahldurchmesser ≤ 0.2mm ($z = \pm 1$m)

MESA: Concept and its history



BEAM PARAMETERS:
1.3 GHz c.w.
EB-mode: 150 µA, 200 MeV polarized beam
(liquid Hydrogen target L~10^{39})
ERL-mode: 10mA, 100 MeV unpolarized beam
(Pseudo-Internal Hydrogen Gas target, PIT L~10^{35})