ELSA: slow extracting stretcher ring at BONN University

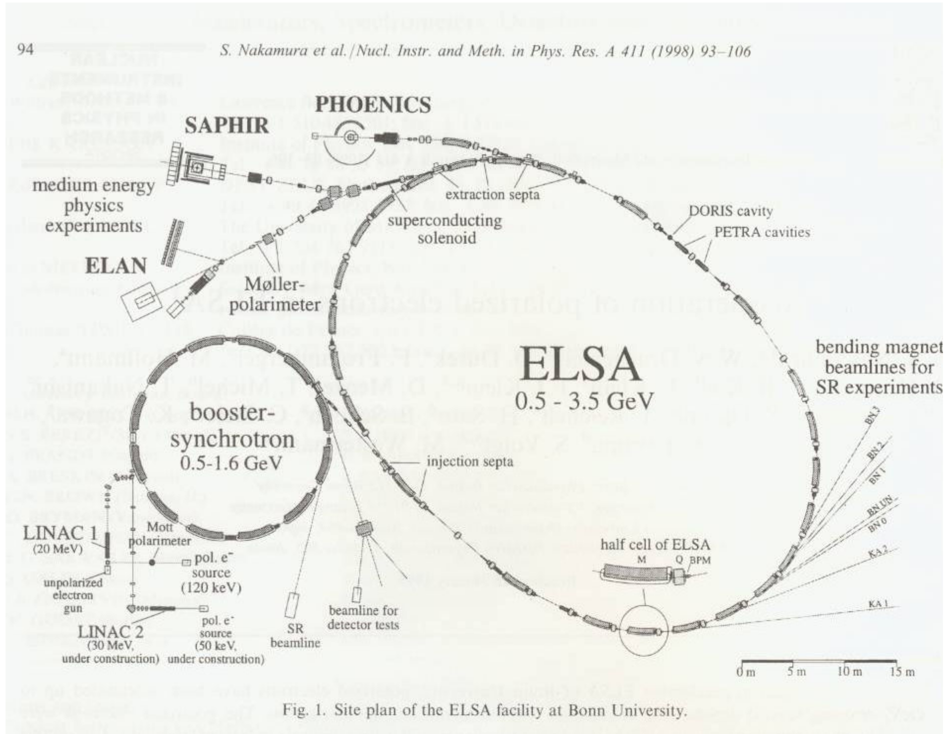
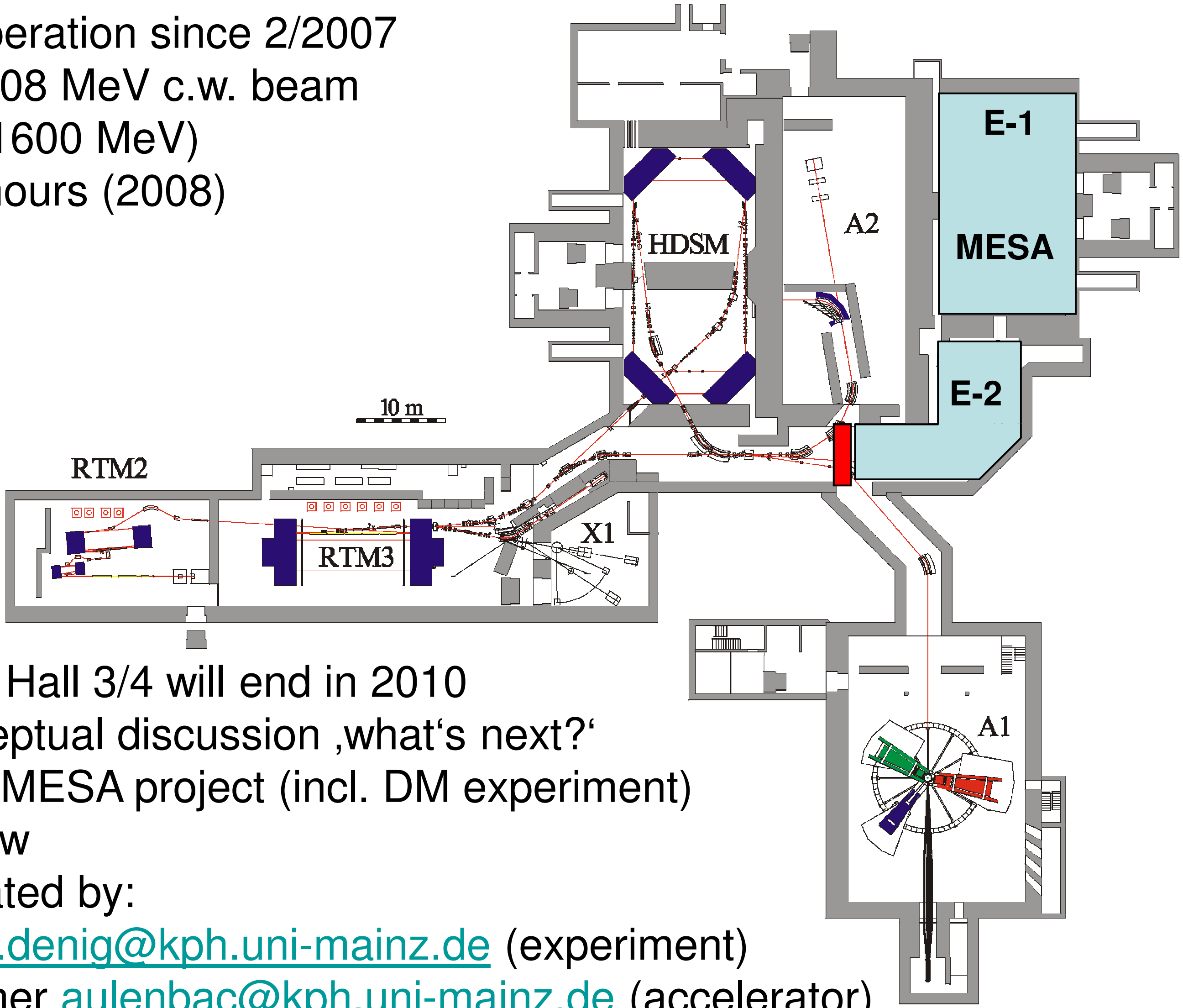


Fig. 1. Site plan of the ELSA facility at Bonn University.

Energy 0.5--3.5 GeV
external beam current a few nA (--100na?)
Contact: Wolfgang Hillert w.hillert@ikp.uni-bonn.de (accelerator)

MAMI-C @ Mainz University

- MAMI-C: In Operation since 2/2007
- 100μA, 180-1508 MeV c.w. beam
  (increased to 1600 MeV)
- op-time:7000 hours (2008)



- Experiments in Hall 3/4 will end in 2010
- Currently conceptual discussion ‚what‘s next?‘
- One possibility MESA project (incl. DM experiment)
  → talk tomorrow
- efforts coordinated by:
  Achim Denig a.denig@kph.uni-mainz.de (experiment)
  Kurt Aulenbacher aulenbac@kph.uni-mainz.de (accelerator)

The Paradigma

MESA must allow to perform electron scattering experiments which are:

- not feasible at MAMI-C
- have an important physics impact
- are competetive to any other such experiment at any other place

In short, those experiments must be **‚unique‘**
….but must be realized within the given constraints
→ ‚precision‘ frontier→new experimental regime

21th centuries innovations for c.w. electron accelerators

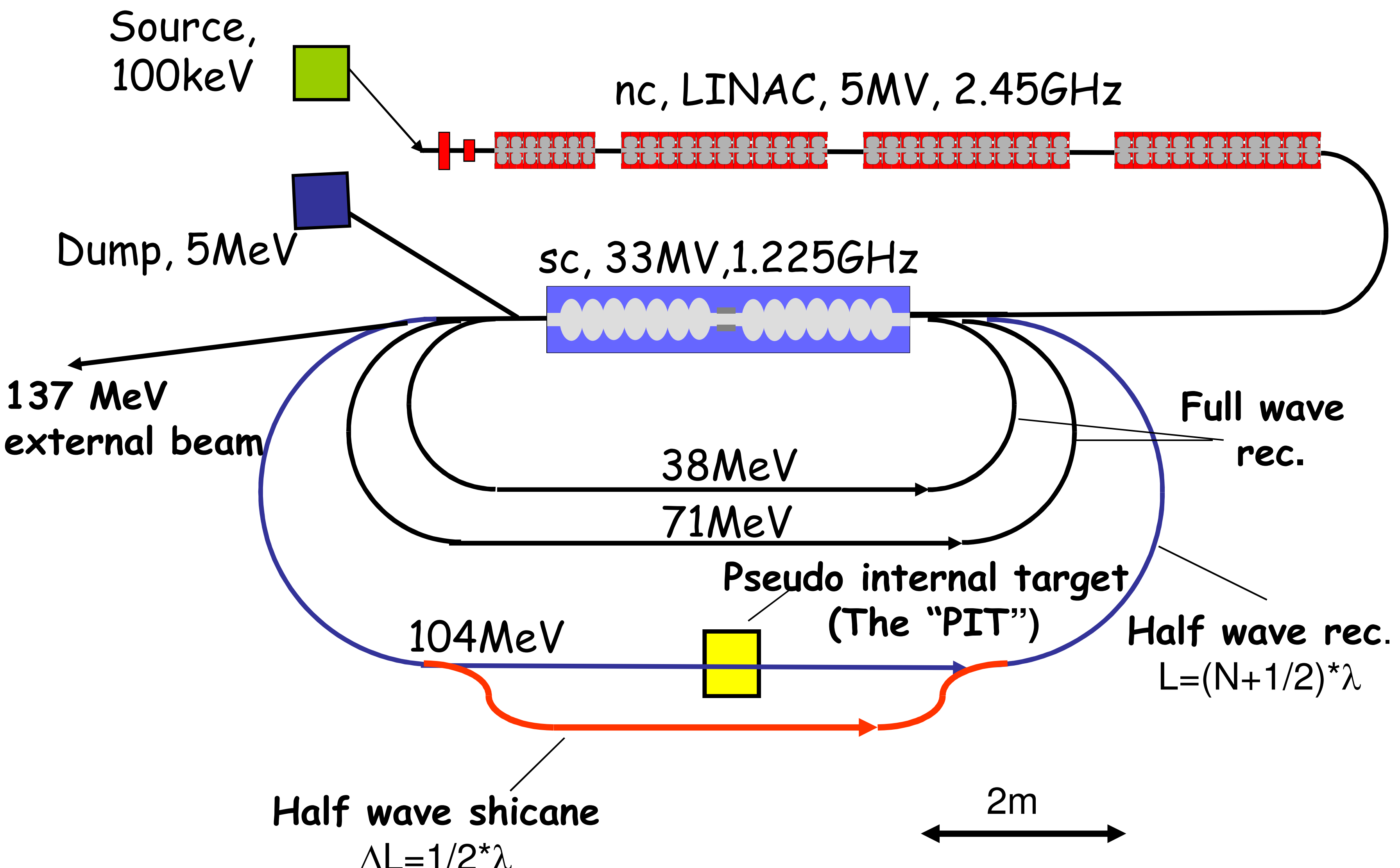
1. Energy recovery linac (ERL)
 (5mA c.w. beamcurrent, JLAB-ERL, 2004)
2. Improvements on high gradient-SC-c.w. op:
 (e.g. 20 MeV/m BESSY 2007)

Inventions were prompted by desire for FEL's or other light sources

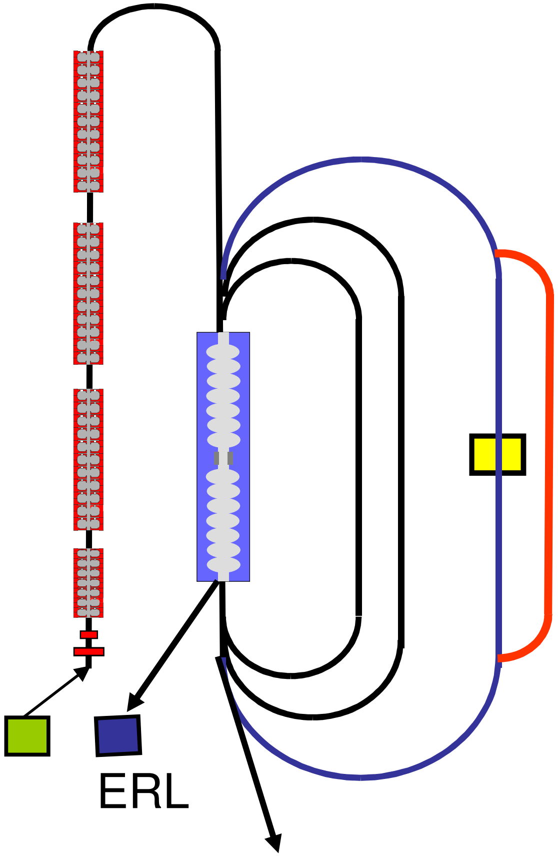
Our plan:

- Combine both achievements,
- use accelerator for hadron or particle physics (no light source!)
- make use of existing technology & know how
- take advantage from lower demands towards source brightness

MESA-Layout


Source,
100keV
nc, LINAC, 5MV, 2.45GHz
Dump, 5MeV
sc, 33MV,1.225GHz
137 MeV
external beam
Full wave
rec.
38MeV
71MeV
Pseudo internal target
(The "PIT")
104MeV
Half wave rec.
L=(N+1/2)*λ
Half wave shicane
ΔL=1/2*λ
2m

MESA-Opmodes:



Beam Time Structure:

1.2245 GHZ, c.w.

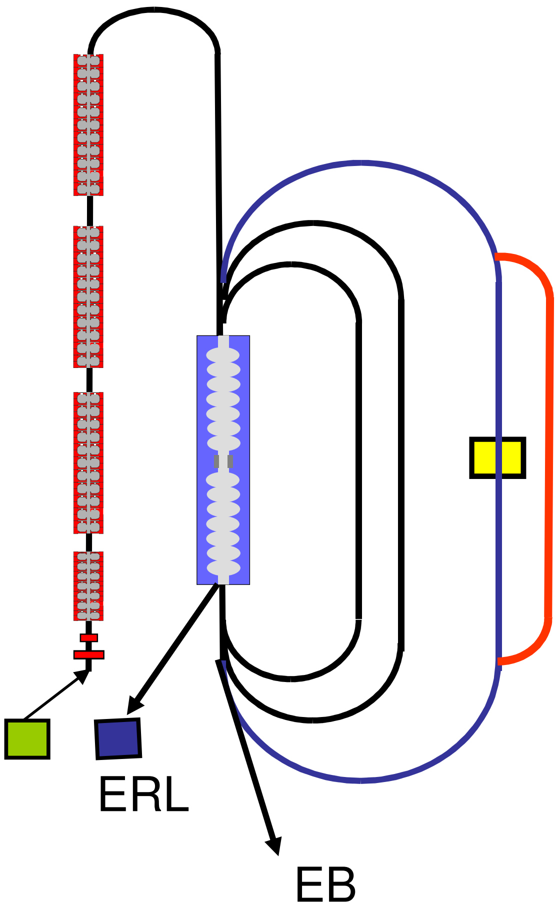
Beam operation modes:

Energy recovery (ERL): 10mA, 104 MeV, unpolarized

Ext. Beam (EB): 0.15mA, 137 MeV, polarized, P=0.85

Investment Cost of machine: ~10 M$
\+ Investment for experiments

MESA: Main experiments



ERL-Mode:

1 ‘dark matter’ e(p,)e’,p
(Particle physics)

EB-modus:

2 PV: weak charge
3 PV: strange magnetic form factor
(hadron physics)

} ‘workhorse experiment’

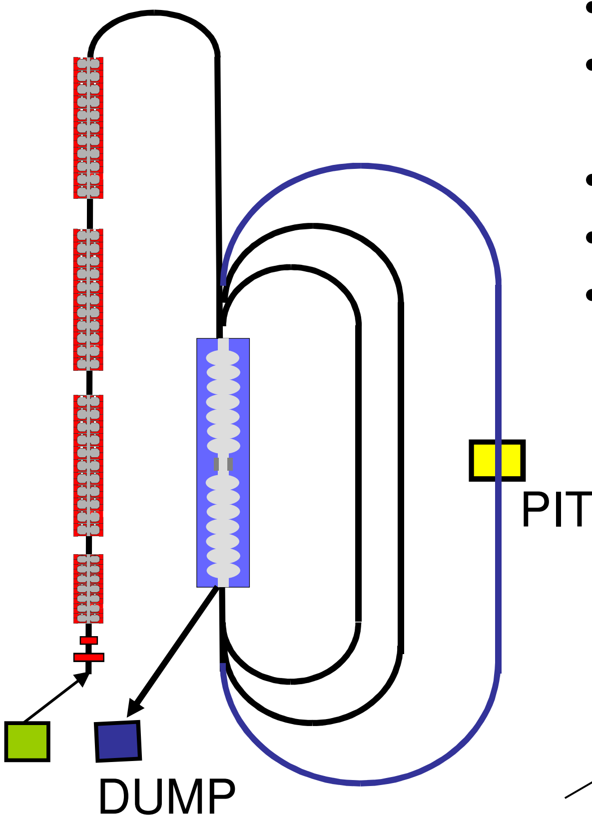
Other, interesting experiments/applications

4 (ERL-mode) e(16O, 12C) e’, α
(Nuclear-stellar-astrophysics)

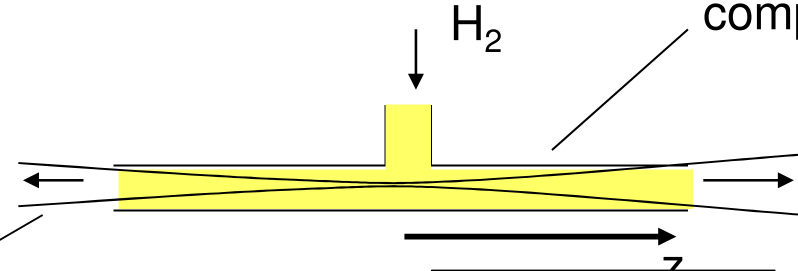
5 (EB-mode) polarized cold positrons to MAMI: channelling radiation

6 (ERL-mode, parasitic) Nanodiamonds (medical, spintronics, …)

MESA-ERL as ultra low background electron scattering machine



- windowless gas target
- low target density compensated by high (10mA) beam current: L~10^35 cm-2 s-1
- High beampower (1MW) feasible due to energy recovery
- Electron energy at dump 5MV→ minimized background
- < 50nm beam emittance allows for > 10 σ beam clearance in target



Beam envelope:

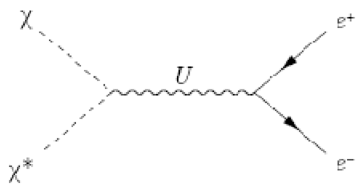
$$r_{\max} = \sqrt{\varepsilon\beta(z)} = \sqrt{\varepsilon(\beta(0) + z^2 / \beta(0))}$$

$$\text{Parameters}: \ \beta(0) \sim 1\text{m}; \quad z_{\max} = 1\text{m}; \ \varepsilon = 10^{-7}\ m$$

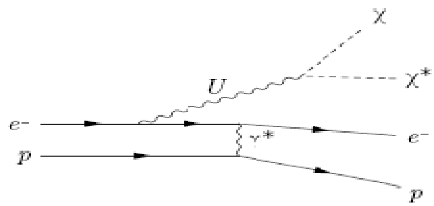
$$r_{\max} = 0.44mm$$

Dark matter signature: in e,p 'elastic'

Hypothetical WIMPS "χ,χ^*" and "U-Boson",
may explain 511 keV γ-flux from galactic center
(C. Boehm et al.:Nucl. Phys. B683 (2004) 219)



e.g. Heinemeyer et al: arXiv:0705.4056v2 (2007)
Proposes to test hypothesis at accelerator
by detecting U-Boson-radiation in e,p-scattering

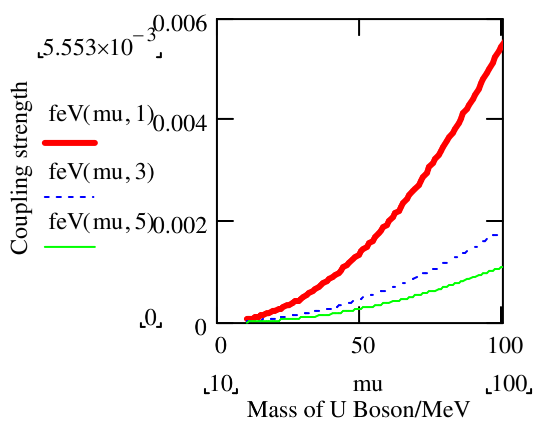


Production rate depends on several unknown parameters
P. Fayet, arXiv:hep-ph/0607094

$$C_\chi \sqrt{(f^2_{e,V} + f^2_{e,A})} \approx 10^{-6} \frac{\left| m_U^2 - 4m_\chi^2 \right|}{1.8 MeV \cdot m_\chi} \sqrt{B^{ee}_{ann}}$$

Example: C_χ=1, $f_{e.A}$=0, m_u=10…100, m_χ=5, B=1

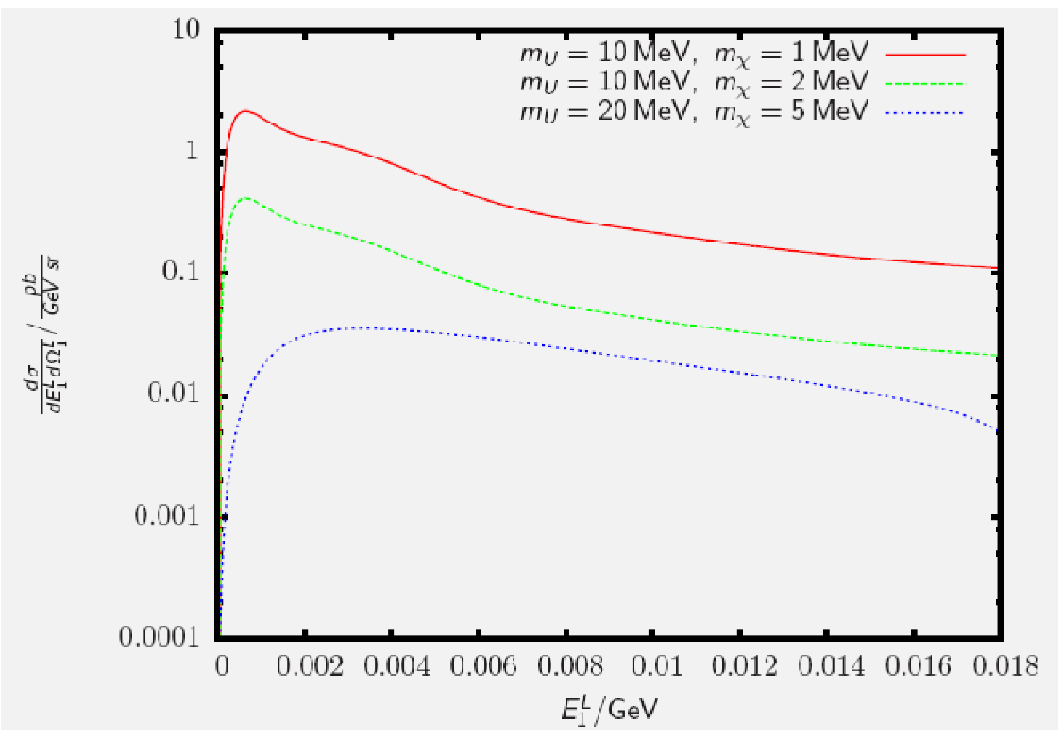
Fayet: Limit to $f_{e,V}$ from g_e-2: < $1.3 \cdot 10^{-4}$*mu[MeV]



Calculation of cross section

First estimations by: Heinemeyer et al: arXiv:0705.4056v2 (2007)

New calculations by T. Beranek (Mainz): C_χ=1, 40 MeV beam energy, 90 degree lab scattering angle: 10-1000 fb/(sr*GeV)

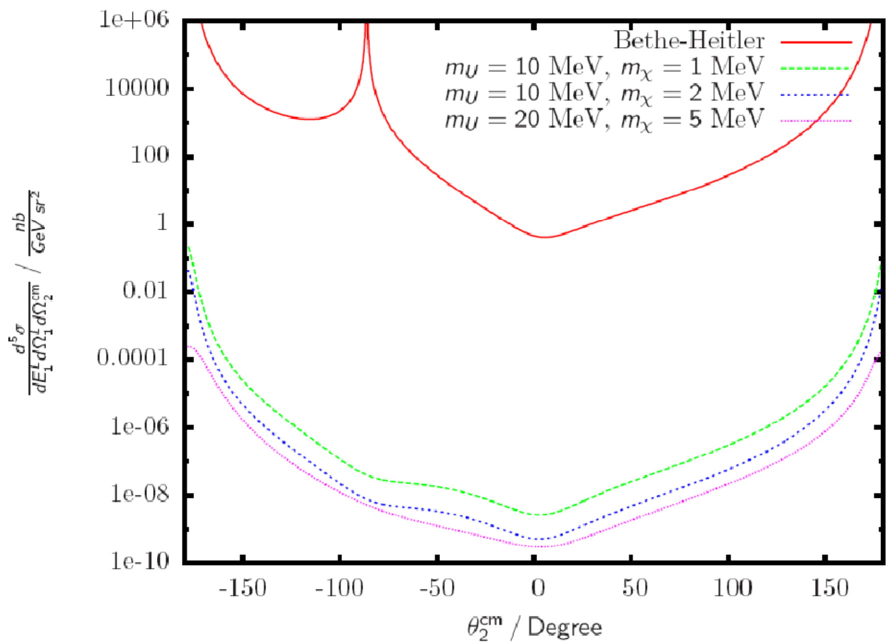


Estimation of max: Signalrate:

500msr Elektron Detektor
5-15 MeV bin with average cross section 0.4pb/(sr*GeV)
→2femtoBarn at L=10^{35}
yields 17 events per day.

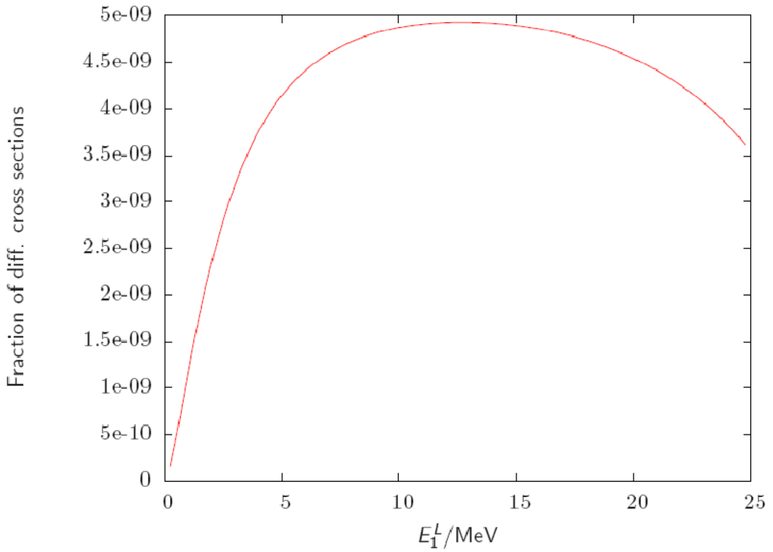
Background cross sections

Bethe Heitler Background
(5 times differential cross section)



$C\chi$=1;
E_{out}(electron)=1MeV
θ_{lab}(elektron)=π/2

S/B Ratio Signal
for given kinematics



$C\chi$=1;
θ_{CM}(Proton)=π/4
θ_{lab}(Electron)=π/2

MESA summary

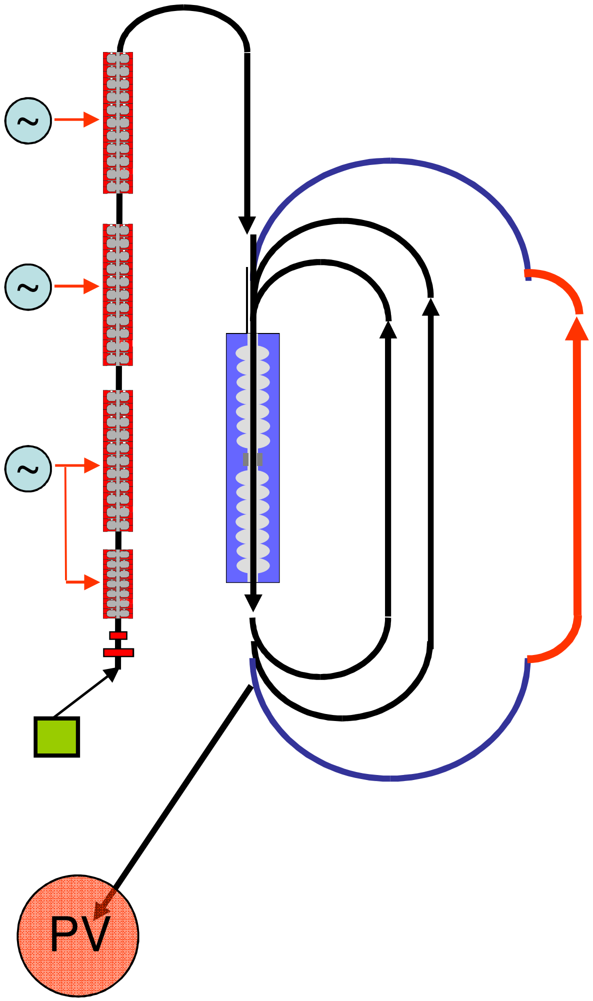
Whats next:

- Extensive Scan of parameterspace for optimum conditions
- Investigate other experimental observables to suppress BH background
- Determine limits to background suppression in a realistic set-up
- → feasibility study

- MESA is a small scale machine, affordable for U Mainz
- innovative, explorative Experiments (‘dark matter’) require feasibility study
- Parity violation a possible ‘workhorse’ experiment
- several other options in applied science,
- high potential for effective education of post graduate students in accelerator physics + other fields!

follow: MESA-backups

PV @ MESA

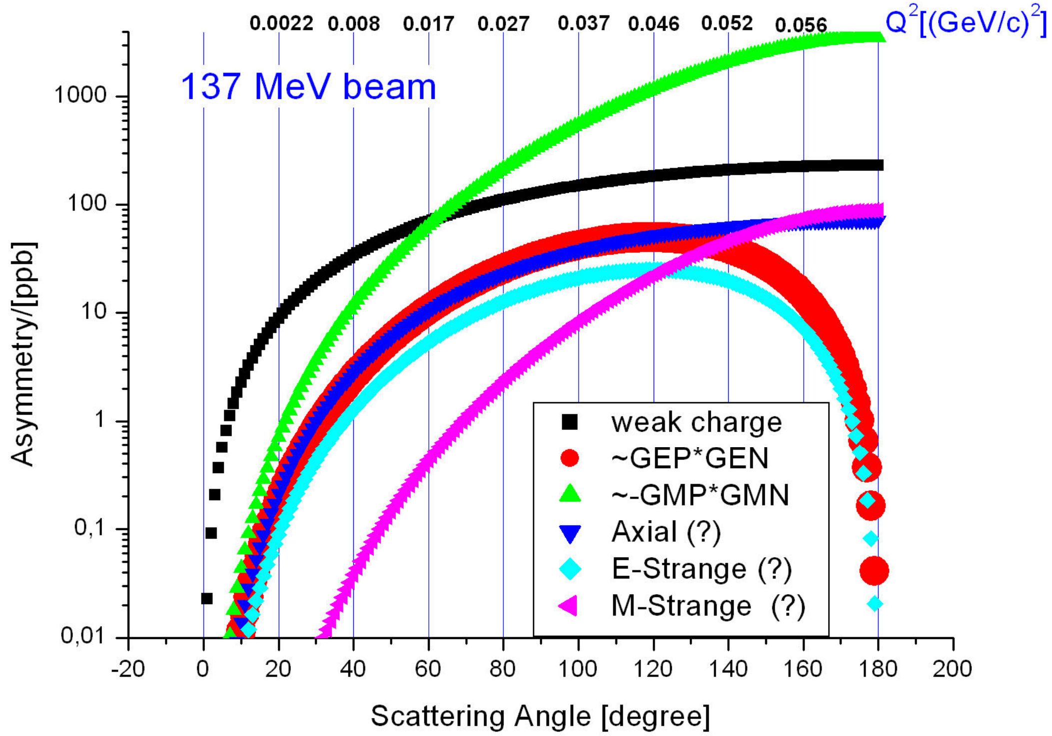


EB-mode,
0.15mA, 137MeV, P=0.85
Target: 20cm lq. H2
$L=10^{39}\ cm^{-2}s^{-1}$

Exp: Only small momentum transfer available!
For given Q^2
large $\Delta\Omega$ Detektor must
compensate for ~ E^2/Q^4
cross section behavior in
ep elastic

Experimental challenges for the source

Black und magenta curve contain interesting observables, others are t.s.e. 'background'



- High statistics→ extreme Luminosity+ extended runtime (several thousand hours)
- Control of false Asymmetries at the few ppb level
- 1% absolute beam polarization measurement

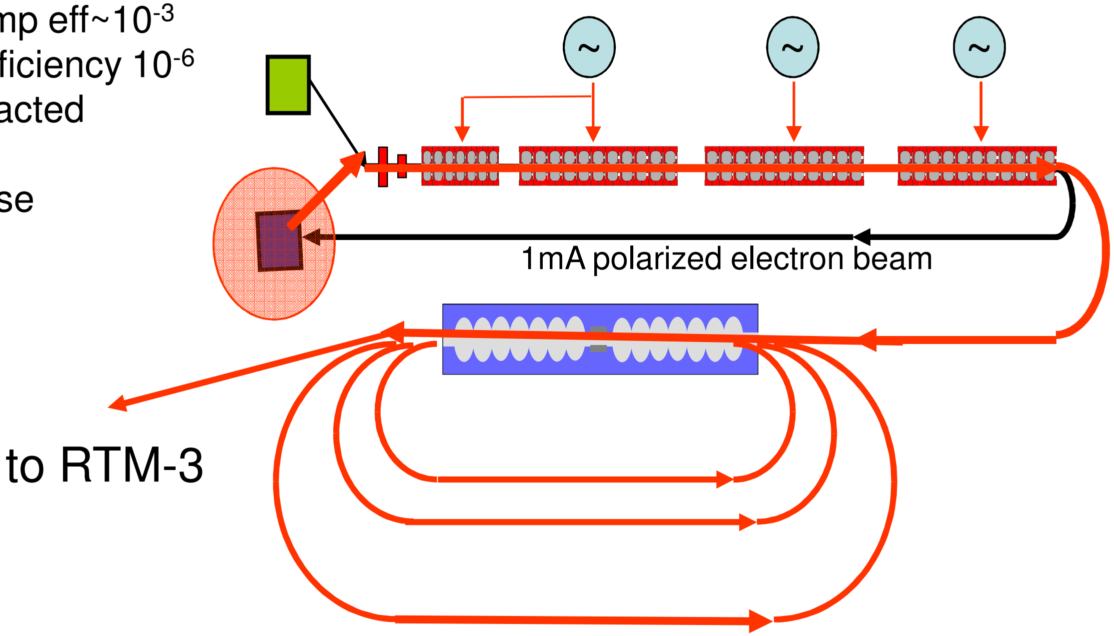
Advantages of MESA approach for PV-experiment

…..with respect to competing experiments:

- Weak radiative corrections much smaller than at GeV energy
- Backgrounds reduced since operating below pion threshold
- First Accelerator with "Parity integrated design": optimized for HCA-control, stability, diagnostic & feedback equipment.
- More economic approach
- Exclusive access to machine for at least 4000h/year.

The MESA PHYSICS repertory: Polarized Positrons

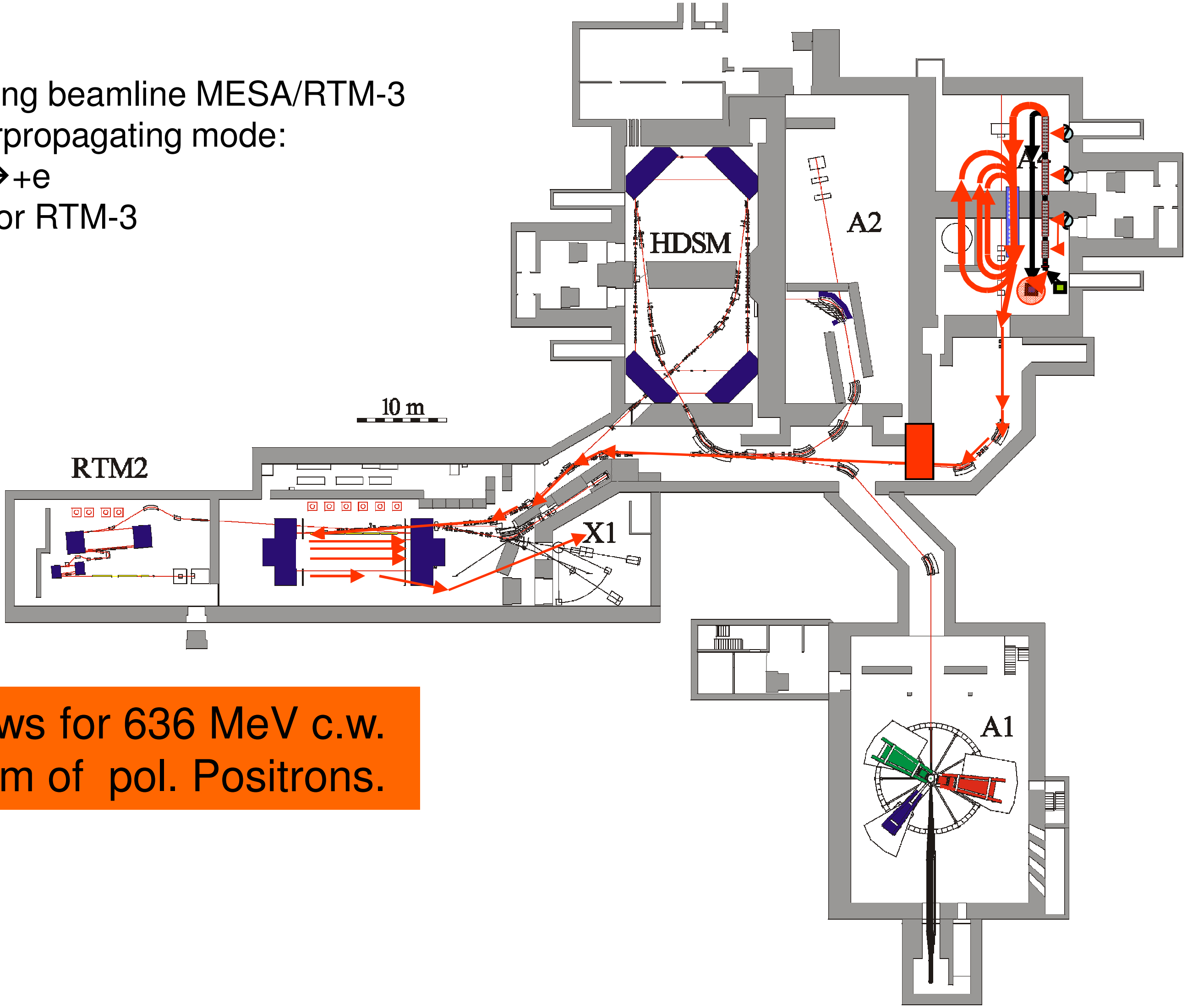
1. Polarized Positron generation in beamdump eff~10^{-3}
2. Moderation of positrons: eff~10^{-3}→total efficiency 10^{-6}
3. Cold polarized positrons (P>0.5) are extracted
4. Norm emittance of positrons <30µm.
5. Co-Acceleration in ILAC on 180 deg. Phase
6. separation of e+/e- after ILAC,
7. (Accelerate with rev. Recirculator polarity)



Creates a third mode of operation:
EB-e^+: 1nA, Pol≥0.5, E=137MeV,
(100nA unpol.)

The MESA PHYSICS repertory: Polarized Positrons (cont.)

Use existing beamline MESA/RTM-3 in counterpropagating mode:
v→-v, -e→+e
…Same for RTM-3

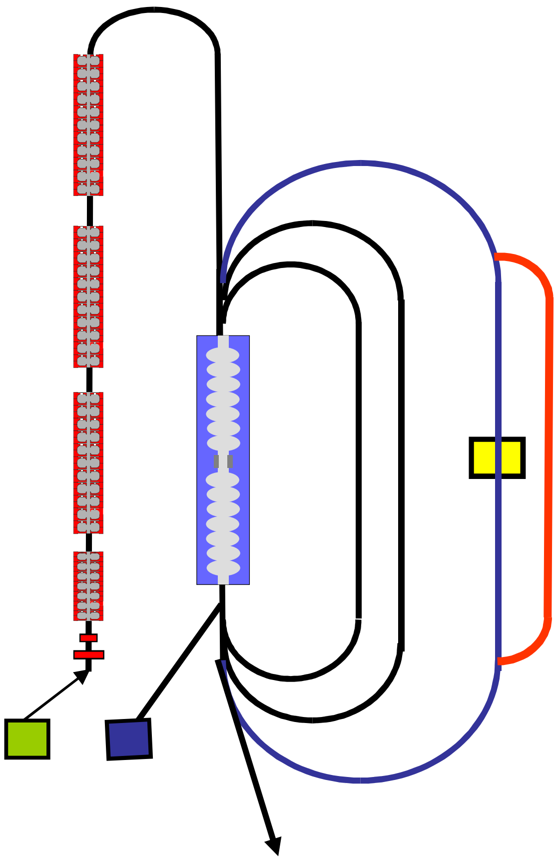


allows for 636 MeV c.w. beam of pol. Positrons.

MESA summary

- MESA is a small scale machine, affordable for U Mainz
- innovative, explorative Experiments (‘dark matter’) possible
- Parity violation a possible ‘workhorse’ experiment
- several other options in applied science,
- high potential for effective education of post graduate students in accelerator physics + other fields!

Injector:Using existing technology for predictable behaviour



Beam operation modes:

ERL: 10mA 104 MeV, unpolarized
External Beam (EB): 0.15mA, 137 MeV, polarized

Source:

100keV, Photosource (MAMI-standard)
Norm. emittance, ERL mode:ε=10μm EB: ε=0.2
bunchlength: 150ps

Cathodes:

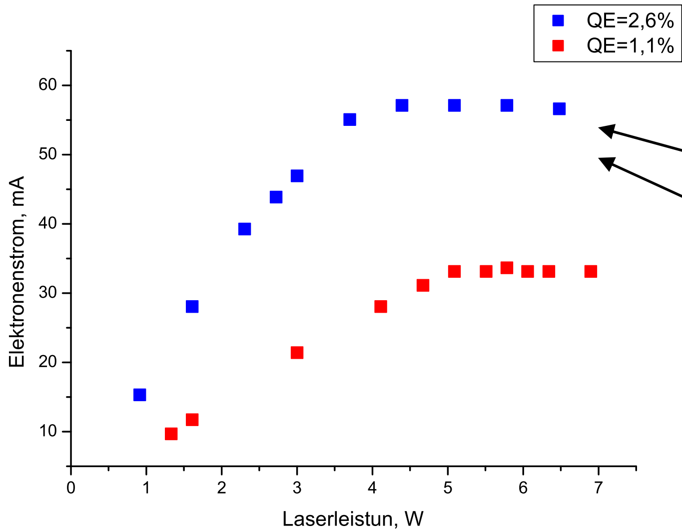
ERL-mode: bulk GaAs (later: CsK2Sb)
EB-mode: GaAs/GaAsP-superlattice

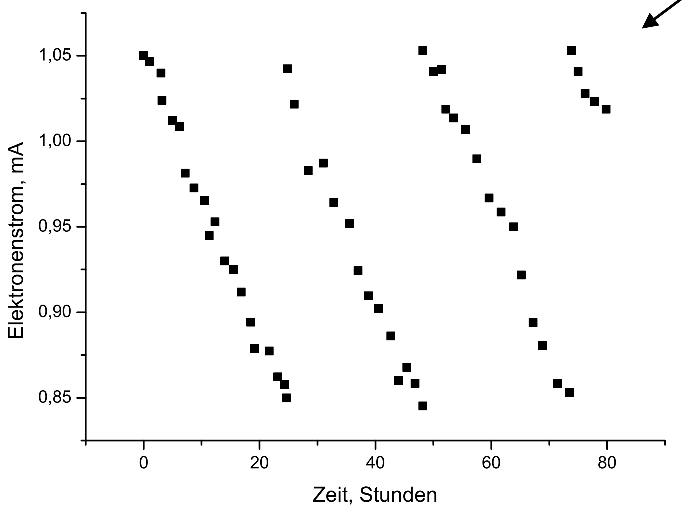
Lasers:

2 Frequency doubled Fiber-Synchro-MOPAs (775nm/530nm),
P_{av}=1 Watt.

Green Laser will allow for average current of 70mA from bulk GaAs,
IR-Laser for 2mA highly polarized beam

Beam &Source: Achieved results





GaAs-Photocathode

- •50mA current possible from 2 mm diameter cathode emission site
- Beam transport over 3 Meter demonstrated
- 300 Coulomb lifetime

→~10 hours operation at 20mA possible

→GaAs cathode is a good starting point for unpolarized ERL-mode

→ ….but commisioning of more stable cathode (CsKSb) is desirable!

Observables in PV-ep-elastic:

$$A_{PV} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \frac{A_V + A_A + A_S}{\varepsilon(GE^p)^2 + \tau(GM^P)}$$

$$Q^2 < 0.0577 \ (GeV^2/c^2)$$

$$\tau = \frac{Q^2}{4M_p}$$

$$\varepsilon = \left[(1 + (1+\tau)(\tan(\theta/2))^2)\right]^{-1}$$

$$A_V = \underbrace{1 - 4\sin^2("\theta_W")}_{"\text{weak charge}"\sim 0.0448}(\varepsilon(GE^p)^2 + \tau(GM^P)) - \varepsilon GE^p GE^n + \tau GM^n GM^P$$

$$A_A = 1 - 4\sin^2("\theta_W")\sqrt{(1-\varepsilon^2)}\sqrt{\tau(1+\tau)}GM^P GA^{p,weak}$$

$$A_S = \varepsilon GE^p GSE \ + \tau GM^p GM^s$$

FF's in our momentum transfer range :

$$GE^P \approx 1; \quad GM^P \approx 2.79; \quad GM^n \approx -1.91$$

$$GE^n \approx 0.4Q^2; \quad GM^s \approx 0.7Q^2$$

assumption on exotic FF :

$$GE^s \approx 0 \quad GM^s \approx 0.04 \quad GA^{p,s} = 1.$$

Weak charge Term is dominant for forward scattering,

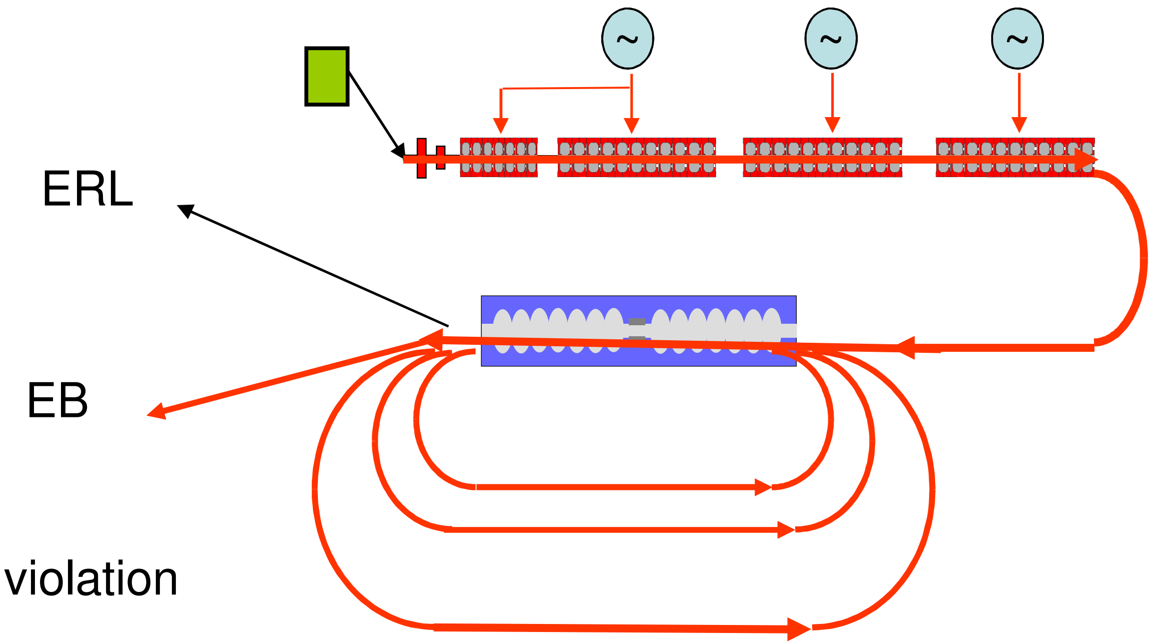
Magnetic Term is dominant for backward scattering

Backward Strange magnetic Term contribution few percent.

Important issues for feasibility study of the MESA-ACcelerator project

A) ERL-Beam dynamics

1.) Injector: source(s), space charge,....
2.) Recuperator Beam dynamics
3.) Photosource with robust cathode for ERL operation (+related issues)



B) Integrated Design for Parity violation

4.) Optimized HCA-compensation +diagnostic set-up
5.) Polarimetry: “self calibrating” polarimeter + Möller Polarimeter
6.) Optimization of accelerator/beam transport lattice with respect to beam parameter stability

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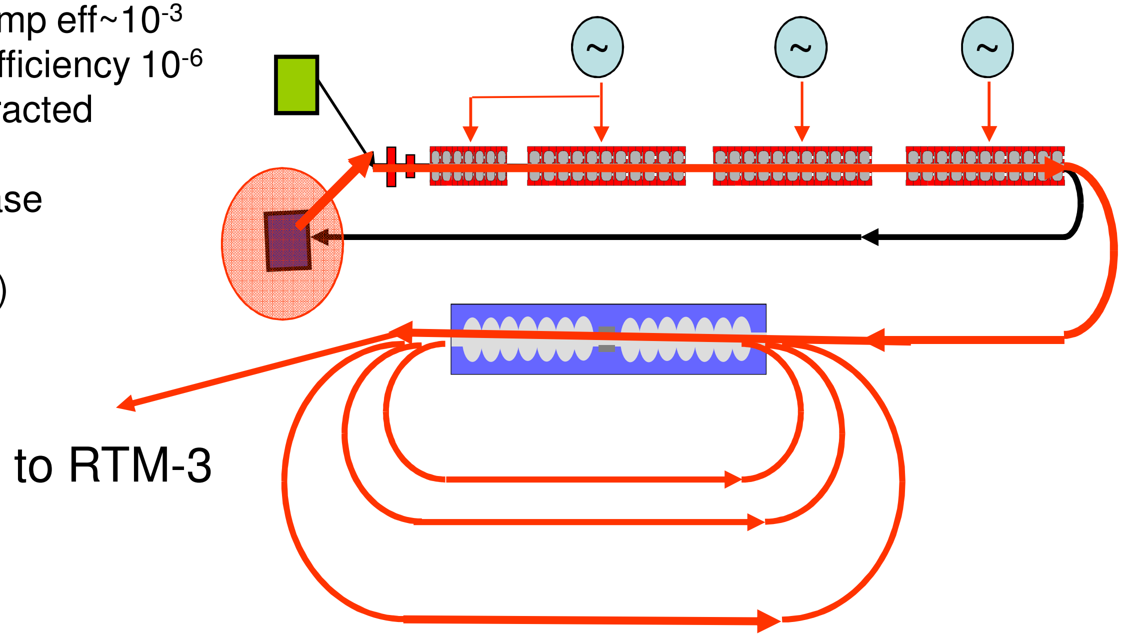

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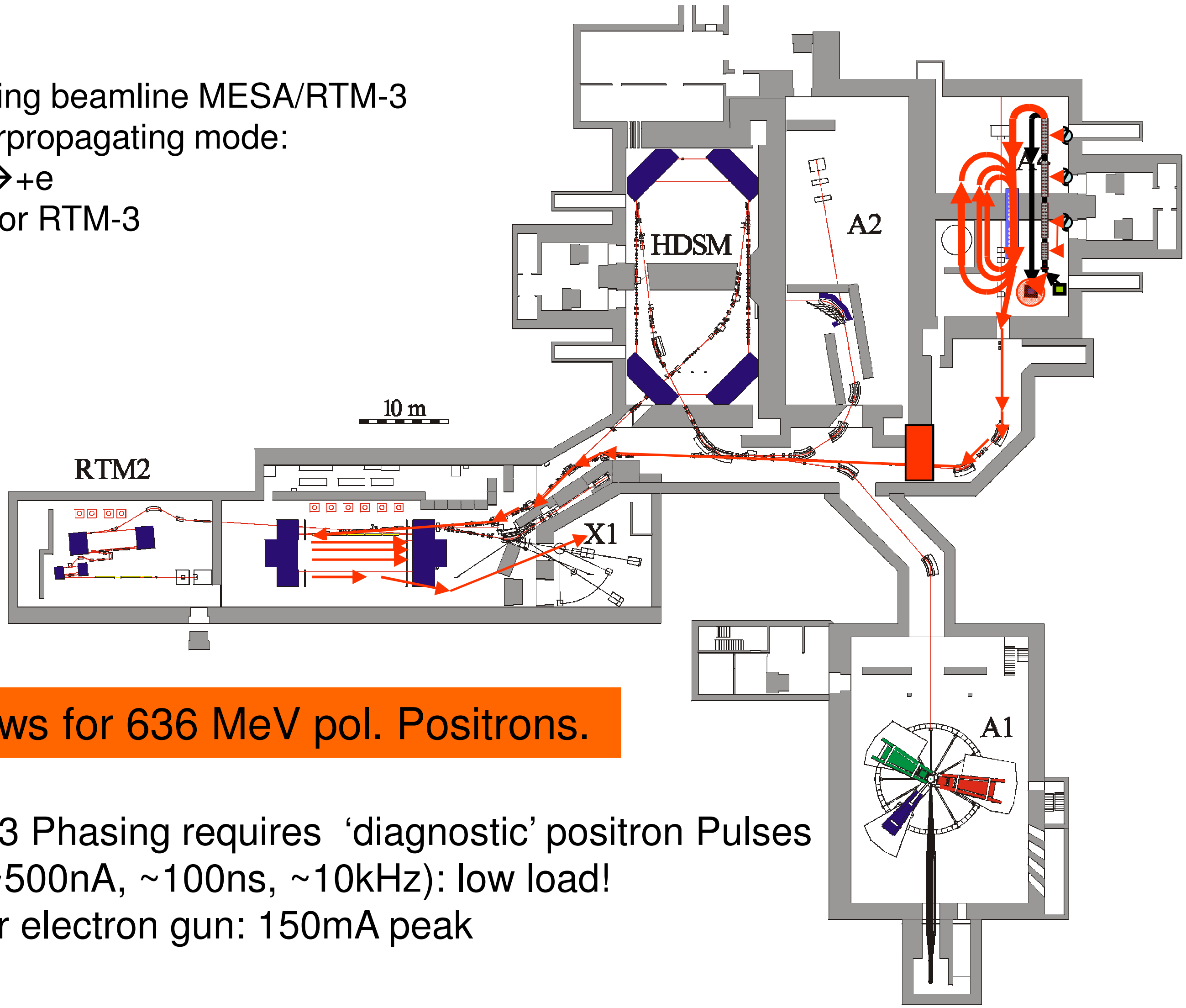


allows for 636 MeV pol. Positrons.

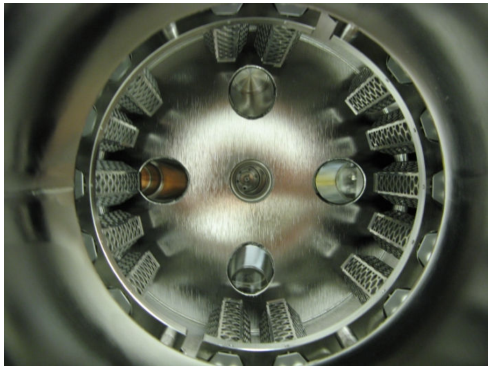
RTM-3 Phasing requires ‘diagnostic’ positron Pulses (I_{peak}~500nA, ~100ns, ~10kHz): low load!
driver electron gun: 150mA peak

Summary

- MESA is a possible follow-up project to MAMI-C
- only negligible interference with MAMI-C ‘harvest time’.
- highly flexible beam conditions for electrons and positrons
- … for a large variety of experiments
- many ‘lab scale’ projects→ large “educational potential”

Was kann man von vorhandener GaAs-Quelle erwarten?

1. GaAs ist leicht beschaffbar, preiswert, extrem effizient (S≥70mA/Watt) @500nm
2. Synchro-Laser bei 1.3GHz einige 10 Watt bei 500nm demonstriert (Cornell)
3. bis 12mA d.c. (65mA Langpuls 100μs) polarisiert erprobt, ε~5-20μm. (norm)
4. 2mA Demo 500nm: >4*Stabiler als IR→300Coulomb pro τ aus d=2,5 mm
5. Skalierung auf Fläche erwartet (J. Grames et al. Proc. PAC 2005, 2875 (??))
6. Erwartete Standzeit bei 10mA entspricht 1000C pro τ: $1*10^5$ s (>1 Tag).



7. Neue Quellenkammer (in Betrieb seit 1/2009) mit 10* besserem S/O Verhältnis
8. Cs:KSb3 > 50*stabiler (D.H. Dowell et al. , NIM A 356 167 (1995)) : CAVEAT!!→Tests
9. 2 Isolatorkonzept überdimensioniert: Vorteil: 150kV Betrieb denkbar→Tests

Was kann man von d.c.-GaAs-Quelle NICHT erwarten?

Emittanzskalierung:

$$\varepsilon_{x,y,norm} = \sigma_{x,y}\sqrt{\frac{kT_{eff}}{mc^2}}$$

0.25µm pro mm radius ?
T_{eff} GaAs ~300-400K (IR)
~ 1200K (Blau)
I.V. Bazarov et al. Proc PAC 2007 1221

Brillanzskalierung:

$$\frac{I}{\varepsilon^2} \propto B \xrightarrow{\sigma\to 0} \infty \quad ???$$

$$B_{\max} \propto \frac{E_{Kath}}{kT_{eff}}$$

Kurzpulslimit: $(q/A)_{max} = \varepsilon_0 E_{kath}$

Favorisiert eine R.f.-quelle

Ionenbackbombardment: -R.f-Hochbrillanzquelle schwieriger. wg. $\sigma \sim 1$mm
+CsTe dafür toleranter (GaAs/IR *1000 ??)+Vakuumgain
+Ionenbombardment nur bis einige keV
(BNL, E. Pozdeyev, Proc. PESP2008)
+keine Cs-Verdampfung
- Sputtering !?

→Experimentelles Programm an MESA mit d.c. Quelle starten,
und H.f.-Quellenentwicklung abwarten.

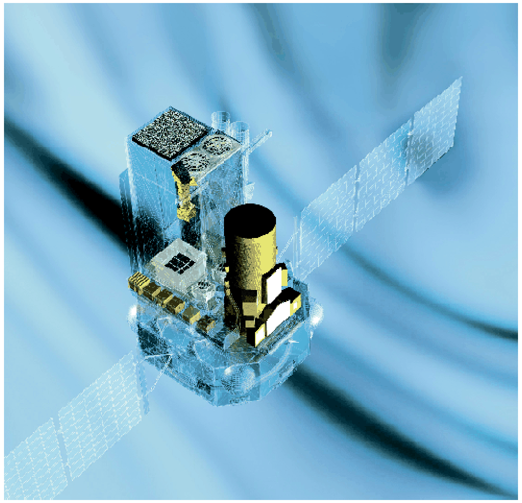
‘Dunkle Materie’ im Elektronenbeschleuniger

> azimuthally symmetric galactic bulge of ~9° typical *FWHM*, yet the uncertainties on the width are still rather large (6°–18°, 2σ). The bulge seems centred on the galactic centre, yet a marginal displacement towards positive latitudes and negative longitudes may be indicated. Obviously, this displacement clearly needs confirmation by the analysis of a much larger set of data.

J. Knödelseder et al.
Astron, Astrophys.
411 (2003) L457

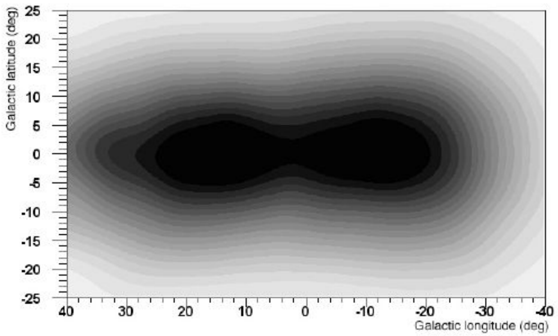
Dunkle Materie suchen ist spekulativ und das Thema kann leicht von heute auf morgen obsolet werden. → MESA braucht ‘Arbeitspferde’

MESA-PHYSIK ‘Dunkle Materie’:



“INTEGRAL”-Satellit:
γ-Beobachtung des Himmels

J. Knödelseder et al.
Astron. Astrophys.
411 (2003) L457

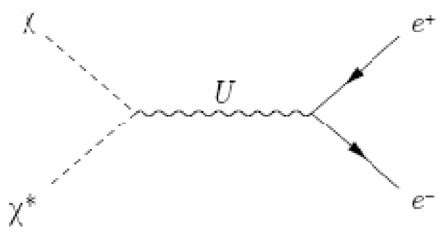


Intensität der 511keV-γ Linie
(Positronenvernichtung)
im galaktischen Zentrum

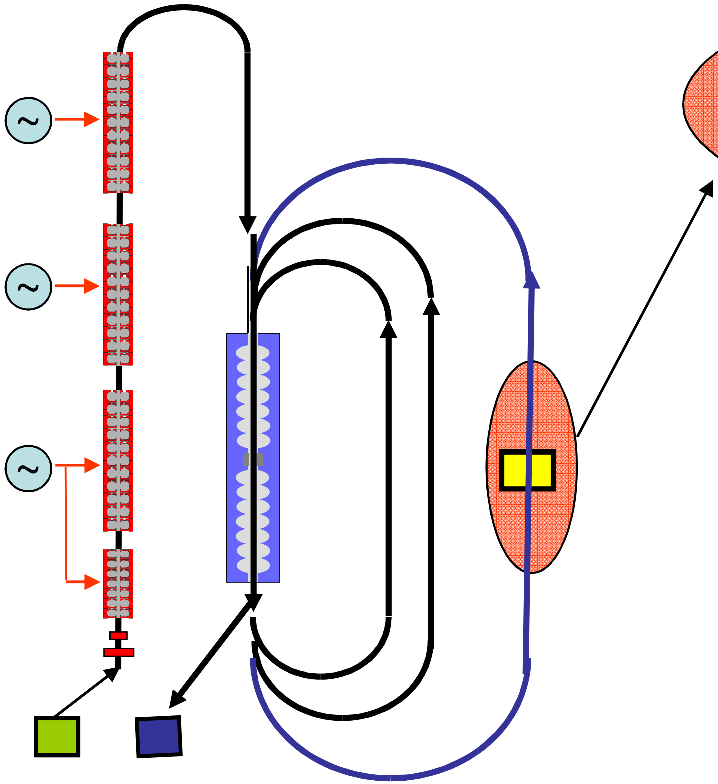
Erklärung des Signals mit konventionellen Quellen (z.B. radioaktive Substanzen aus Supernovae) schwierig.

Unkonventionelle Erklärung:
Leichte Teilchen $\chi,\chi*$, die nur schwach Wechselwirken (WIMPS,→ Dunkle Materie)
C. Boehm, P. Fayet
Nucl. Phys. B683 (2004) 219

Die Fermionen χ,χ^* erzeugen Electron Positron Paare,
→die so entstandenen Positronen erzeugen das das Signal des INTEGRALsatelliten
→ die Masse der $\chi,\chi*$ wäre etwa 3-20 MeV, die Masse des U-Bosons <100MeV



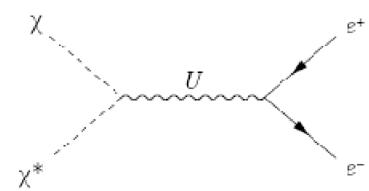
MESA- ERL:
Possible Experiment ‘Dark matter’



- Emittance dilution negligible (Gas Target)
- LUMI ~10^{34} $cm^{-2}s^{-1}$
- minimum ‘diffusive’ background

Hypothetical WIMPS “χ,χ^*” and “U-Boson”, may explain 511 keV γ-flux from galactic center

(C. Boehm et al.:Nucl. Phys. B683 (2004) 219)



e.g. Heinemeyer et al: arXiv:0705.4056v2 (2007)
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ERL-mode,
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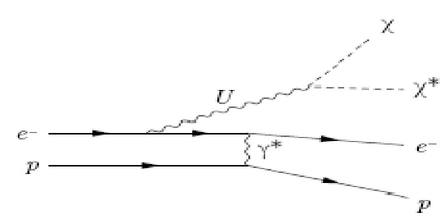
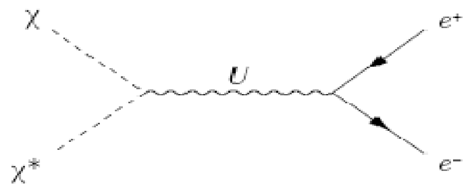


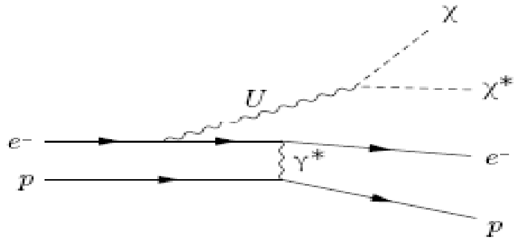
Rate: <10^{-9}*elastic

‘Dunkle Materie’ im Elektronenbeschleuniger

Idee von Heinemeyer et al. arXiv:0705.4056v2 (2007)



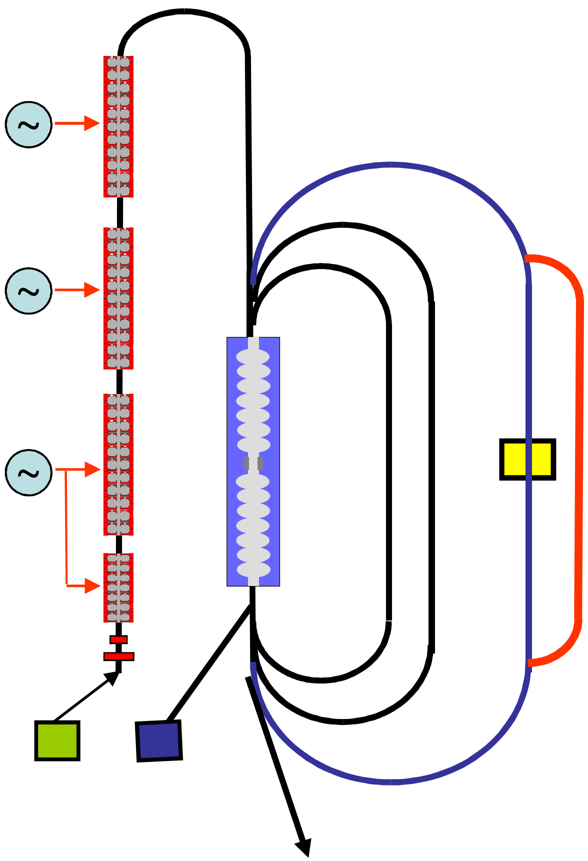
Wenn dieser Prozess im Zentrum der Galaxis geschieht..



..Ist dieser Prozess in der Elektronenstreuung möglich. → Die dunkle Materie kann im Beschleunigerexperiment hergestellt und (indirekt) nachgewiesen werden.

Ein Elektron verliert bei Streuung um Winkel θ Energie, die ‘spurlos’ verschwindet
Modellgegebene Signalrate : bis zu 10^{-9} der elastischen Streuung
phys. Untergrund: (i) Bremsstrahlung (beherrschbar: u.a. Koinzidenzmessung)
(ii) Kernreaktionen, Pionen (beherrschbar: H-target, E<141 MeV)
exp. Untergrund: Vielfachstreuung von ‘dicken’ Targets aller Art
(beherrschbar: Gastarget)
→Akzeptables S/U Verhältnis im MESA-ERL-Modus (10mA, 50kW r.f. power)
→ auch mit konventioneller Maschine, aber: 1MW Hochfrequenzleistung

MESA-Parameters:
ILAC



ILAC-R.f.:

2.449 GHz, c.w., normal conducting
harmonic buncher
graded-β section (0.1-0.55 MeV)
discrete-β section (0.55-2 MeV)
2*β=1 section (2-5 MeV)

typ. Gradient 0.75MV/m

Rf-transmitters:

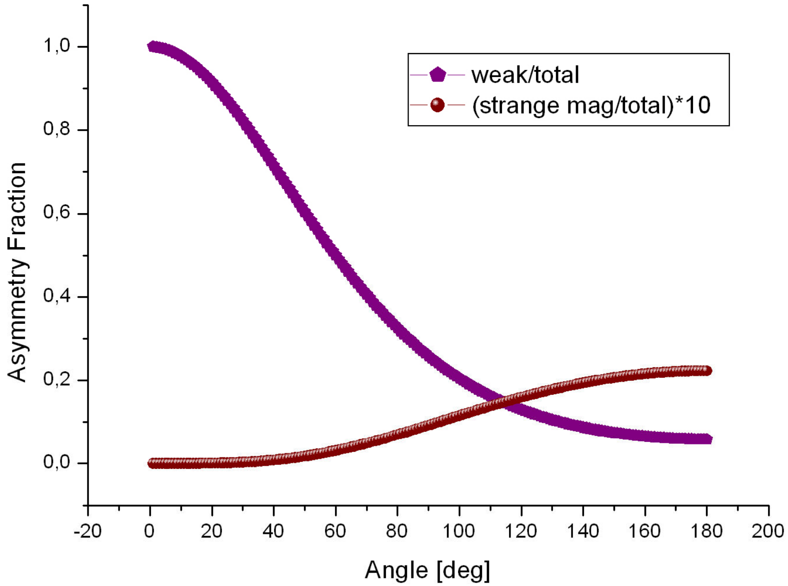
3* Thales TH2155, 50kW each
beam power/rf power 1/3

PV @ MESA ??

$\sin^2(\theta_W) \approx 0.0238 \rightarrow$

$\underbrace{1-4\sin^2("\theta_W")}_{"schwache Ladung"} = 0.048$

A_{PV} is very sensitive to changes in θ_w (motivation of E-158, Qweak ,etc…)



Exp-1: 70-80 degree $\Delta\Omega$=1sr Q^2=0.014
R ~1.2 GHz; av. A =P*148ppb
→370 days runtime for ΔA_{stat}=6ppb

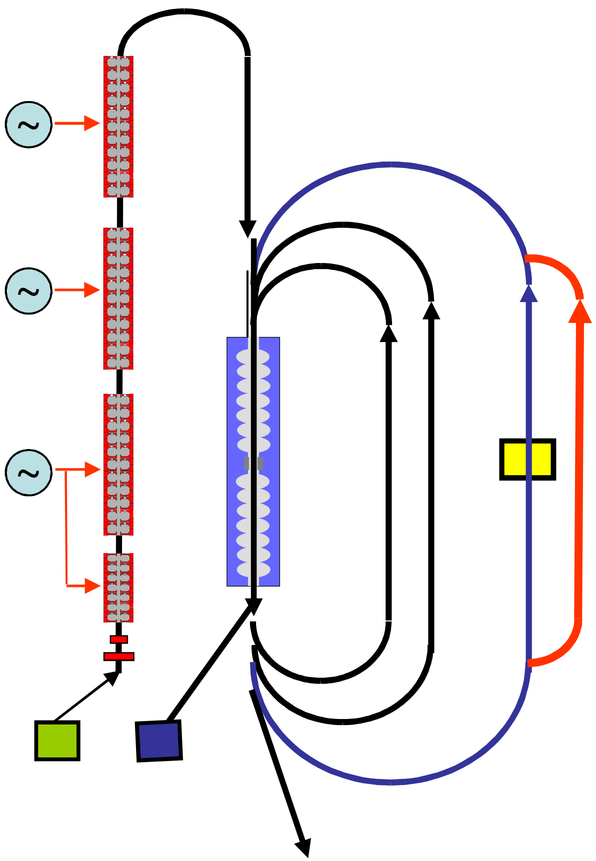
Challenges:
HCA control
uncorr. Noise

Exp-2: 120-160 degree
~130 MHz; av. A=P* 2200 ppb
time for ΔA_{stat}=20ppb (stat) → ~260 days

Challenges:
Polarisation measurement <1%
Axial separation (Deuterium ?)

Note: Low inelastic background:
Detectorsystem could be very simple.

MESA-Parameters:
s.c. accellerating module



R.f.:

1.2245 GHz c.w.
2*7 cell module
Gradient: 20MV/m
Beam loading <0.01 kW (ERL) 19.8 kW (EB)
Energy gain: 33MeV per pass.
Transmitter: 2*IOT + Combiner

Kryogenics:

T=1.8K
total Losses (dynamic+static): 80 Watt

Recirculation:

2* Full wave, (38, 71 MeV)
1* Full wave (EB) / Half wave(ERL) (137 MeV/5MeV)

Energy recovery to:

5MeV (50kW load to beam dump, ERL-Mode)

MESA-COST in k€

He liquifier, 4K (140l/h with N_2 precooling)	1550
1.8K booster, cooling cap. 80 watt	1100
1 high. grad module (2 x 7cell, 1.2245GHz) (HoBiCat like)	1600
rf-station (30kW, 1.2245GHz)	500
Laser+ncILAC ,chopper/buncher, solenoids, graded-β, disc. β, klystron HVPS, vacuum, diagnostics...)	1100
Isochronous recirc. (dipoles, quads, sexts, vacuum, diagnostics, shicane...)	1300
infra-structure (He-distrib., cooling, construction)	800
misc. (control, beam dump, safety system)	300
Total:	**8250**