JOHANNES GUTENBERG UNIVERSITÄT MAINZ

MAINZER MIKROTRON

Possibility of parity violation experiments at the **M**ainz **E**nergy recovering **S**uperconducting **A**ccelerator **(MESA)**

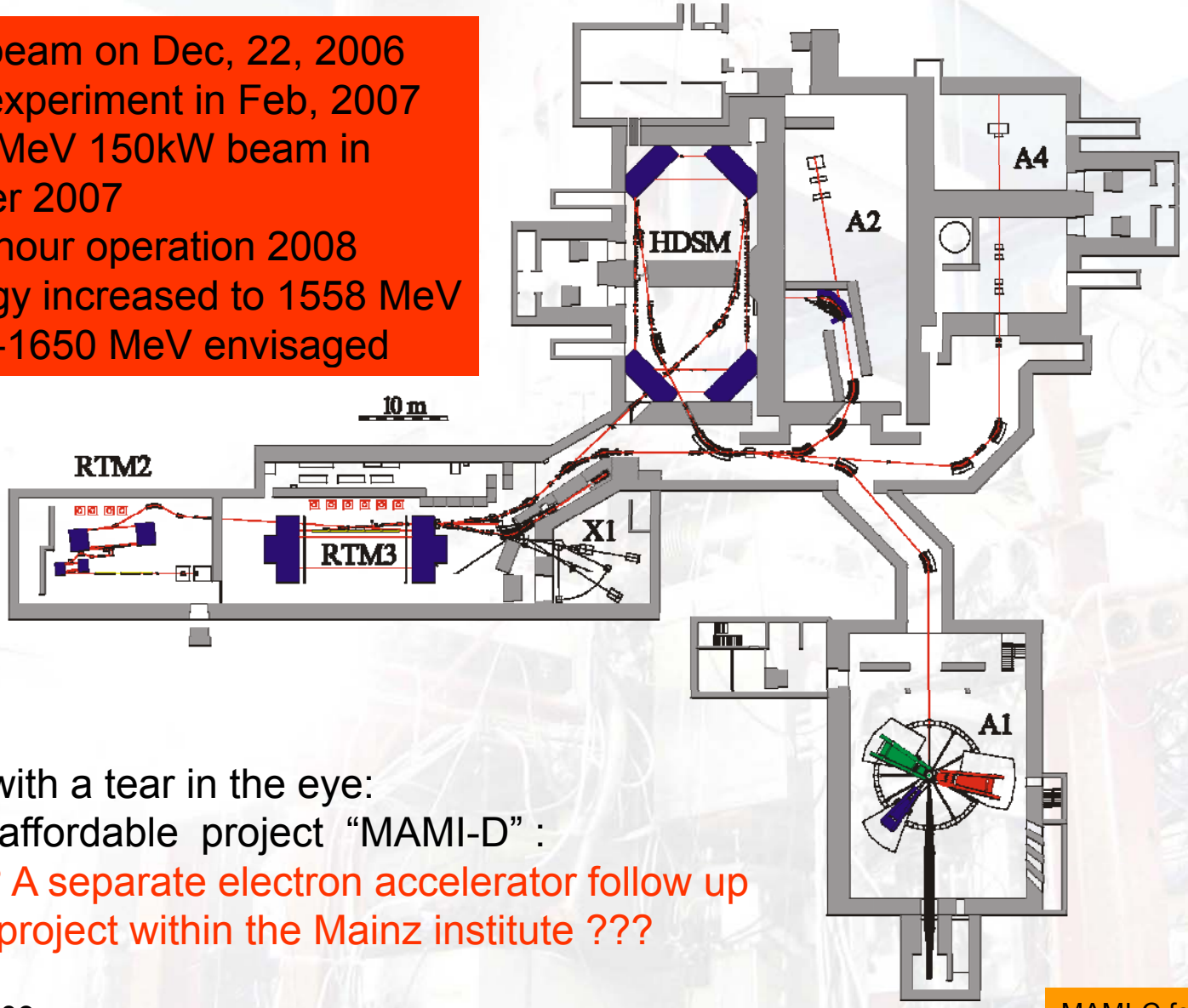
PAVI 2009
Bar Harbor
June, 24, 2009
Kurt Aulenbacher for the
B1,B2 and A4 collaborations

Outline

- What is MESA?
- Experiments at MESA
- Parity violation at MESA?

MAMI-C: A success story…

- First beam on Dec, 22, 2006
- First experiment in Feb, 2007
- 1508 MeV 150kW beam in October 2007
- 7000 hour operation 2008
- Energy increased to 1558 MeV
- 1600-1650 MeV envisaged



….with a tear in the eye:
No affordable project "MAMI-D" :
??? A separate electron accelerator follow up project within the Mainz institute ???

The challenge

Follow up project must take into account:

1. MAMI-C experiments have to go on without interference
2. Follow up must allow for first class innovative experiments
3. Has to be a lot cheaper than MAMI-C
4. Much smaller team (w.r.t. MAMI-C) available
5. Schedule must fit into the 'ENC-decade gap'

→ Think of a small c.w.-accelerator (100-200 MeV) ←

Whats NEW about that?

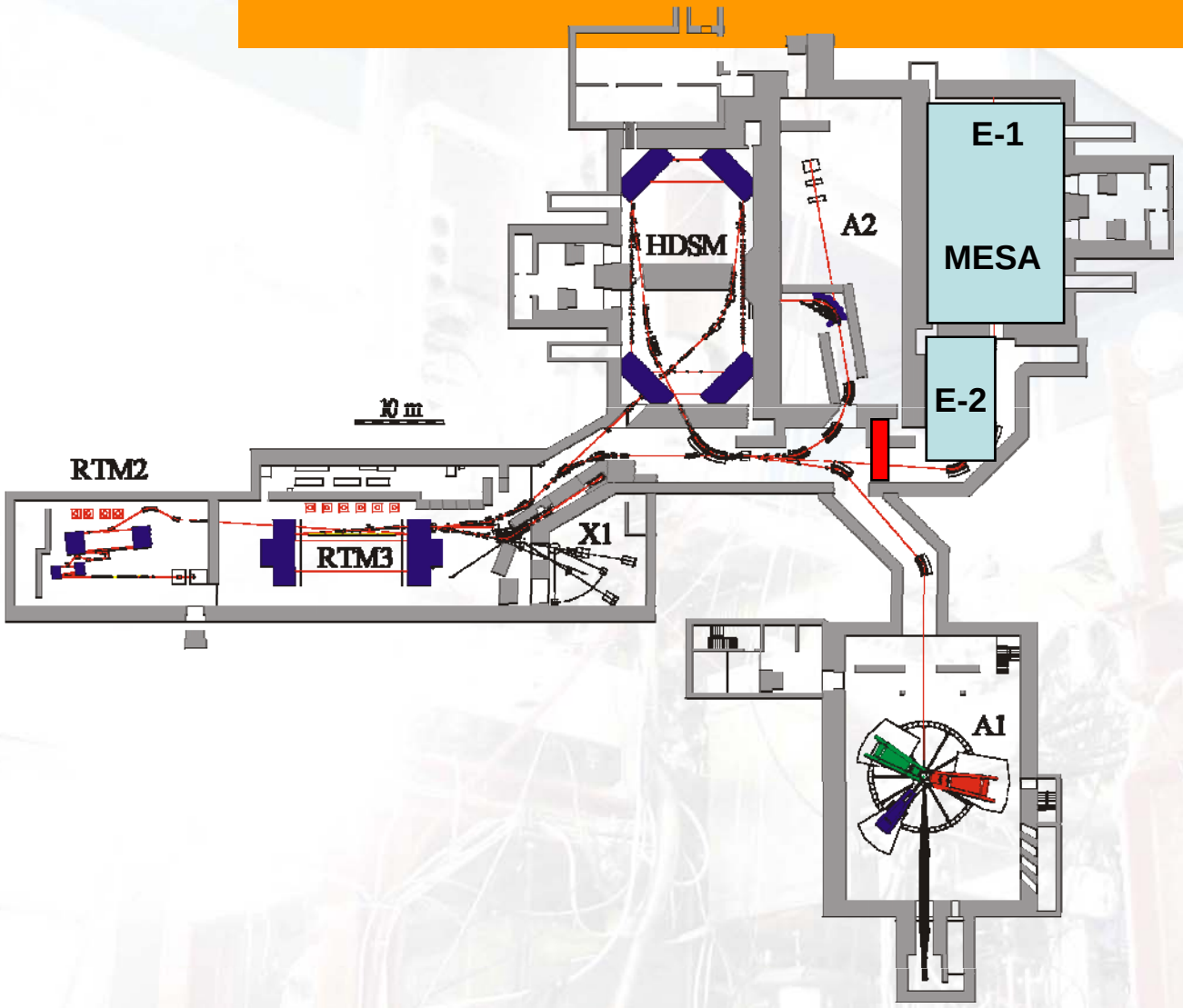
21th centuries innovations for c.w. electron accelerators

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

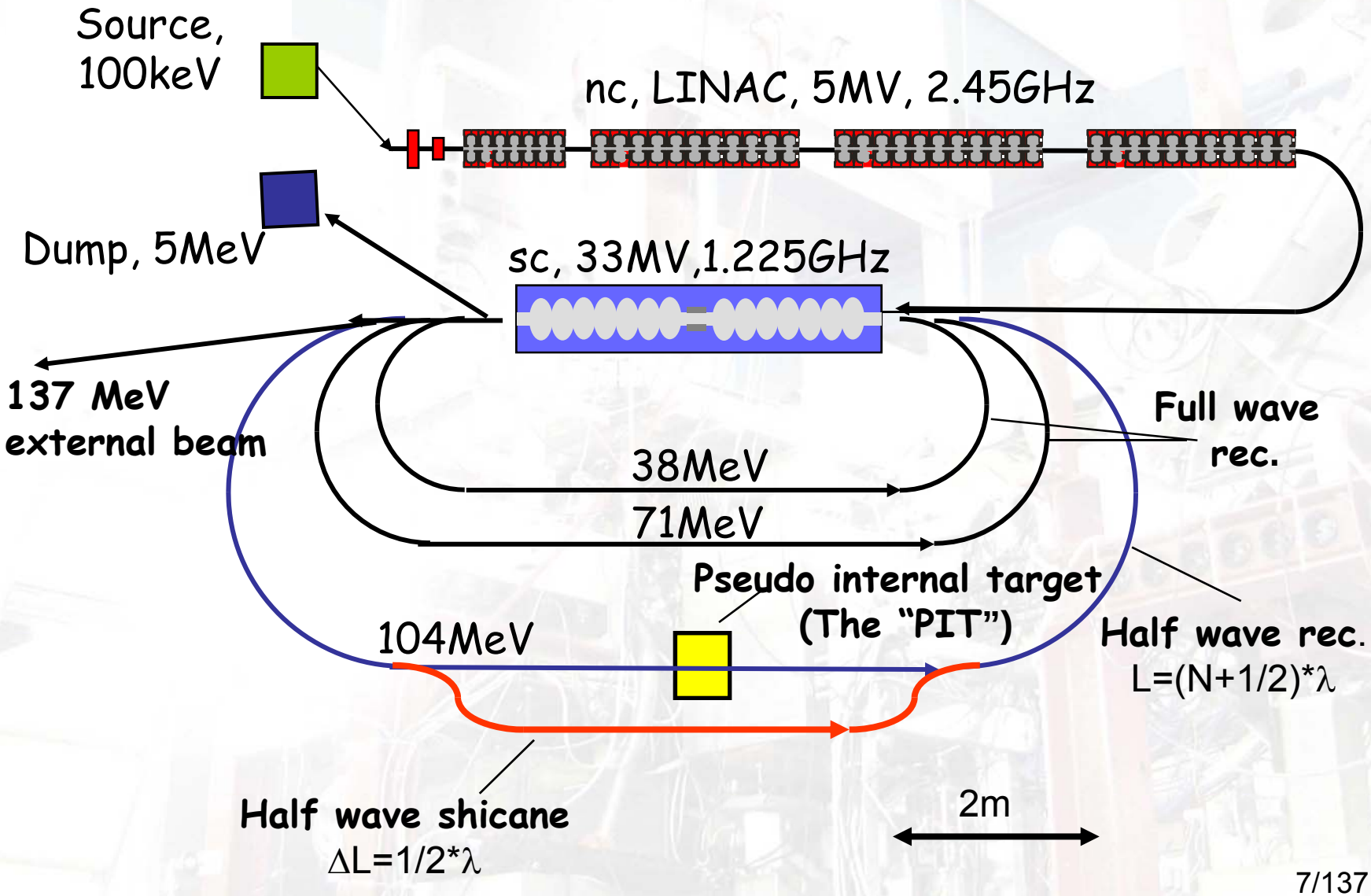
Inventions where prompted by desire for
FEL's or 4GLS

Our plan to build "MESA": Mainz Energy Recovering SC-Accelerator
- Combine both innovations
- use accelerator for electron scattering experiments (no light source!)
- make use of existing technology & know how
- take advantage from lower demands towards source brightness (w.r.t. FEL)

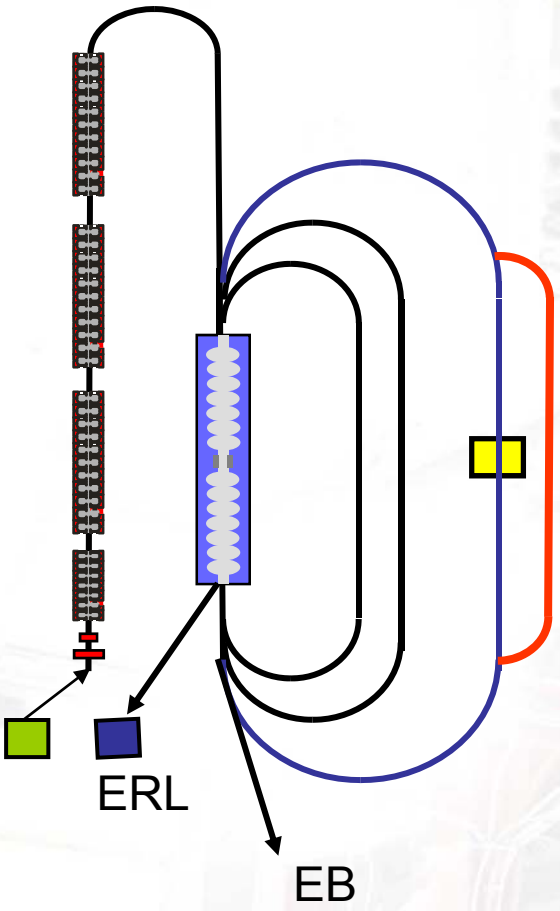
MESA: Possible site



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-Parameters: Beam &Source



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

Source:

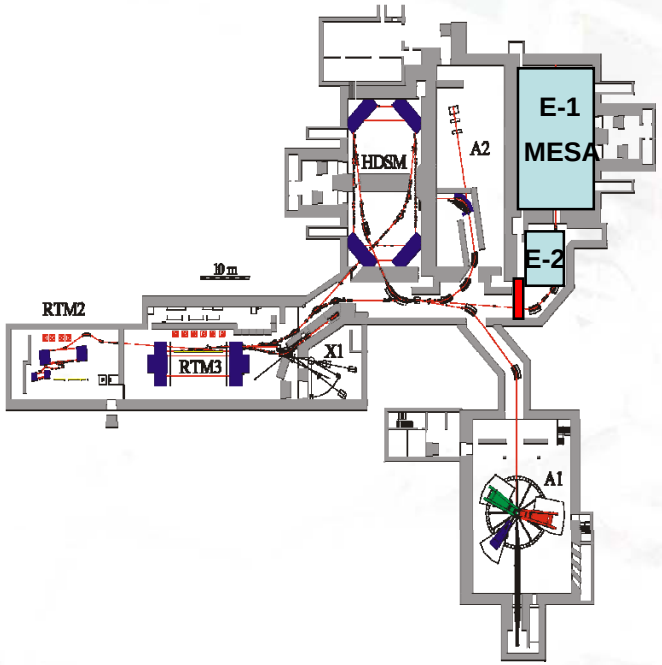
100keV, Photosource
(available 'upgraded' MAMI-standard)
Norm. emittance: ERL:ε=10μm, EB: ε=0.2μm
bunchlength: 150ps

Cathodes:

ERL-mode: bulk GaAs (later: CsK_2Sb)
EB-mode: GaAs/GaAsP-superlattice,
cont. op.: ERL:20-50h (CsK_2Sb: 1000), EB 200-500h

Investment Cost of machine: ≈ 8 M€

MESA: possible experiments

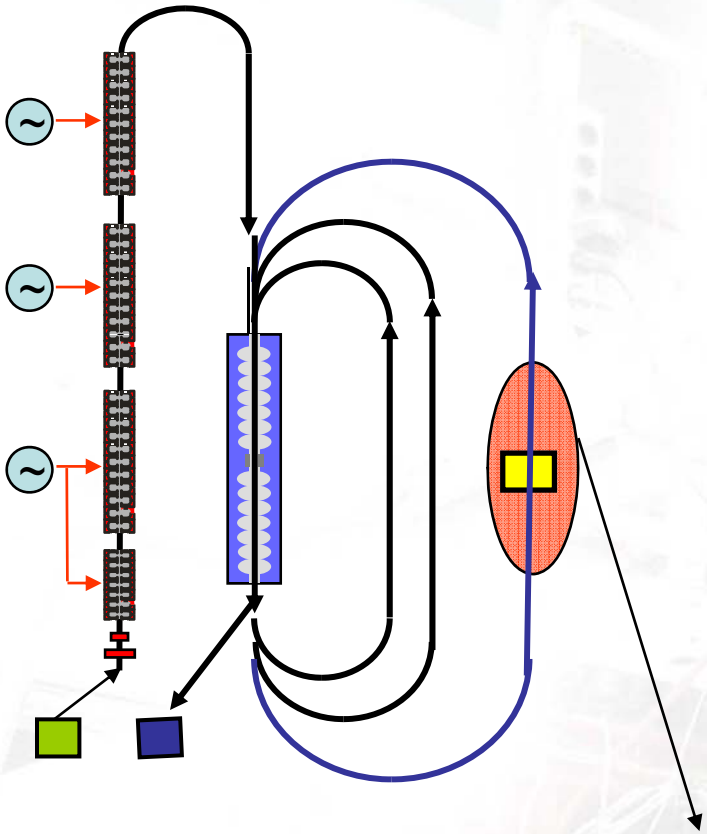


ERL-Mode:
ERL-1: ‘dark matter’ e+p→e’+p’+U
(Particle physics)
ERL-2: e+16O→e’+12C+α
(Nuclear-stellar-astrophysics)

EB-modus:
EB-1: PV: weak charge
EB-2: PV: strange magnetic form factor

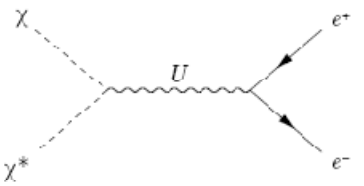
Injektor or ERL-parasitical:
NV-Nanodiamonds (medical, spintronics, …)
pol. cold positrons (materials research, → MAMI?)

MESA- ERL: Possible Experiment 'Dark matter'

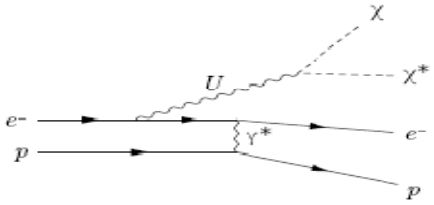


Hypothetical WIMPS "χ,χ^*" and "U-Boson", may explain 511 keV γ-flux from galactic center

(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

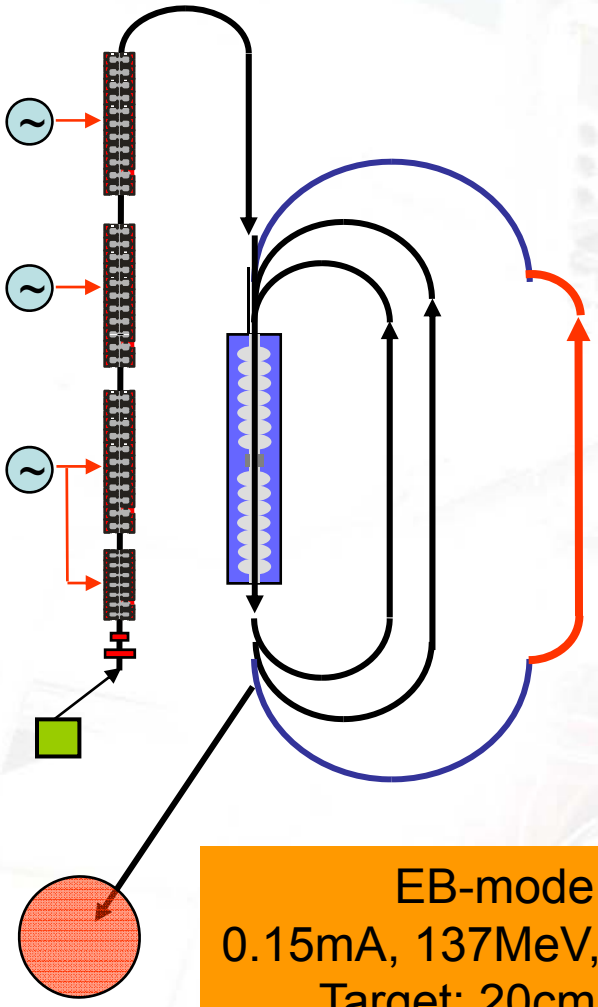


Rate: $<10^{-9}$*elastic

ERL-mode,
10mA, 104MeV, unpol

- Emittance dilution negligible (Gas Target)
- LUMI ~10^{33} - 10^{34} $cm^{-2}s^{-1}$
- minimum 'diffusive' background

PV @ MESA ??



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

Parametrisation of Asymmetry in ep-elastic:

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

$$A_V=\underbrace{1-4\sin^2(\text{"}\theta_W\text{"})}_{\text{"schwache Ladung"}}-\varepsilon GE^pGE^n+\tau GM^nGM^p$$

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

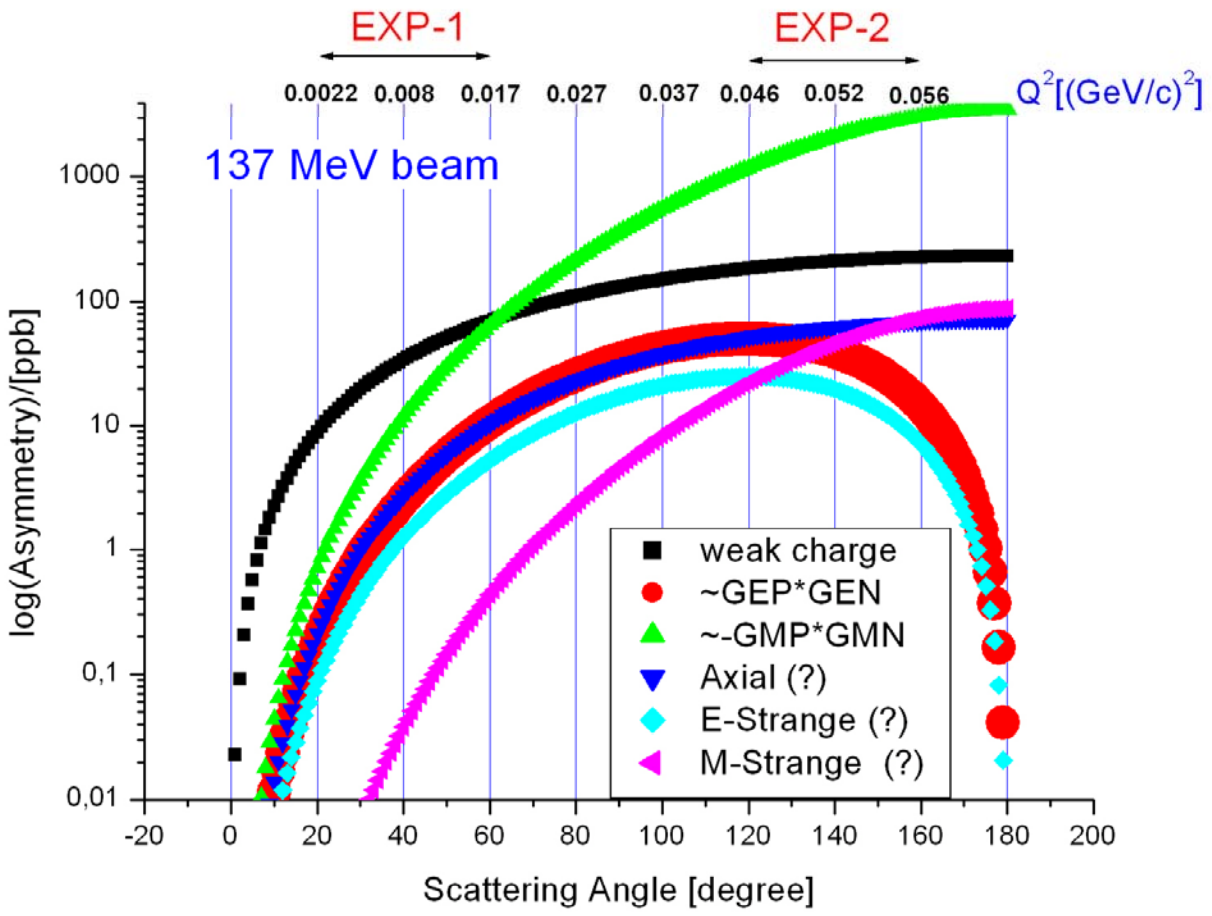
$$A_S=\varepsilon GE^pGSE+\tau GM^pGSM$$

Compared to a higher energy machine, large detector solid angle must compensate for lower cross section at given Q^2

PV@ MESA ??

$$\sin^2(\theta_W) \approx 0.0238 \rightarrow$$
$$\underbrace{1-4\sin^2("\theta_W")}_{\text{"schwacheLadung"}} = 0.048$$

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

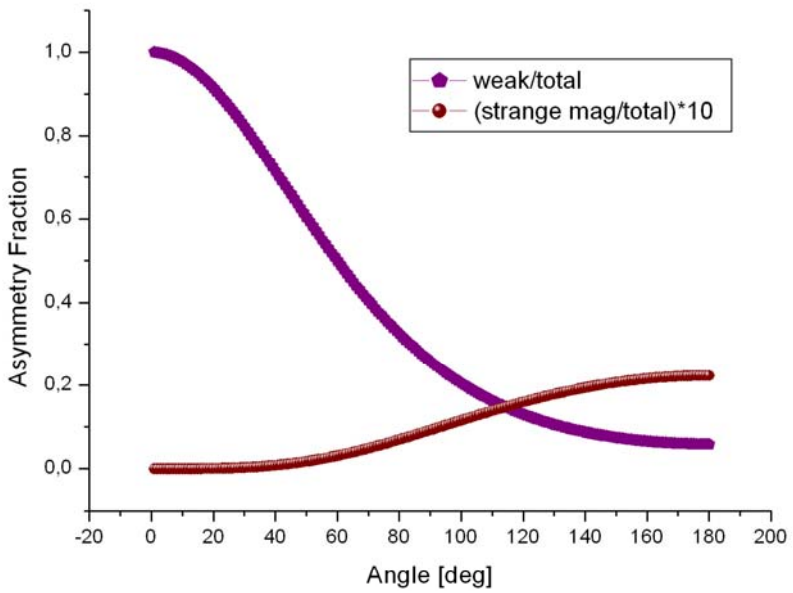


assumed: GES=0.02*Q²/0.1; GMS=0.07*Q²/0.1

PV @ MESA ??

$$\sin^2(\theta_W) \approx 0.0238 \rightarrow$$
$$\underbrace{1 - 4\sin^2("\theta_W")}_{"schwacheLadung"} = 0.048$$

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;
→370 days runtime for ΔA_{stat}=6ppb

Challenges:
HCA control
uncorr. Noise

Exp-2: 120-160 degree
~130 MHz;
time for ΔA_{stat}=20ppb → ~260 days

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

Note: Low inelastic background.
Detectorsystem could be very simple.
measure Q_W, GMS simultaneously

PV@MESA
Pro's and Con's

Problematic Aspects:

- W.r.t. A4: Order of magnitude increased demands on accelerator performance (correlated and uncorrelated signals, luminosity)
- New detectorsystem required
- Is a recirculator really the best solution for PV?
- Relaunch of A4 collaboration!

Advantageous Aspects:

- "Greenfield design"→ may be optimized for PV
- Quasi exclusive machine access for PV: single user @ 2/3 of av. beamtime
- low operating costs
- Background conditions

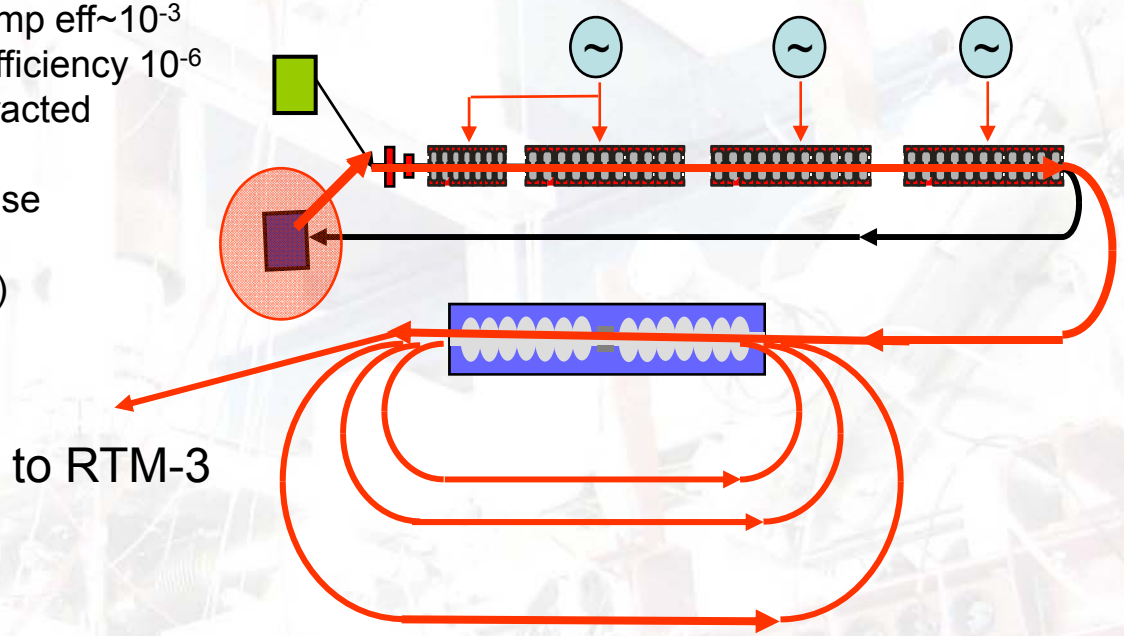
MESA summary

- innovative & speculative Experiments (‘dark matter’)
- for “reasonable” investment
- Parity violation a possible ‘workhorse’ experiment
- other options in applied science,
- high potential for effective education of post graduate students in accelerator physics (+ other fields!)

follow: MESA-backups

The MESA PHYSICS repertory: Polarized Positrons

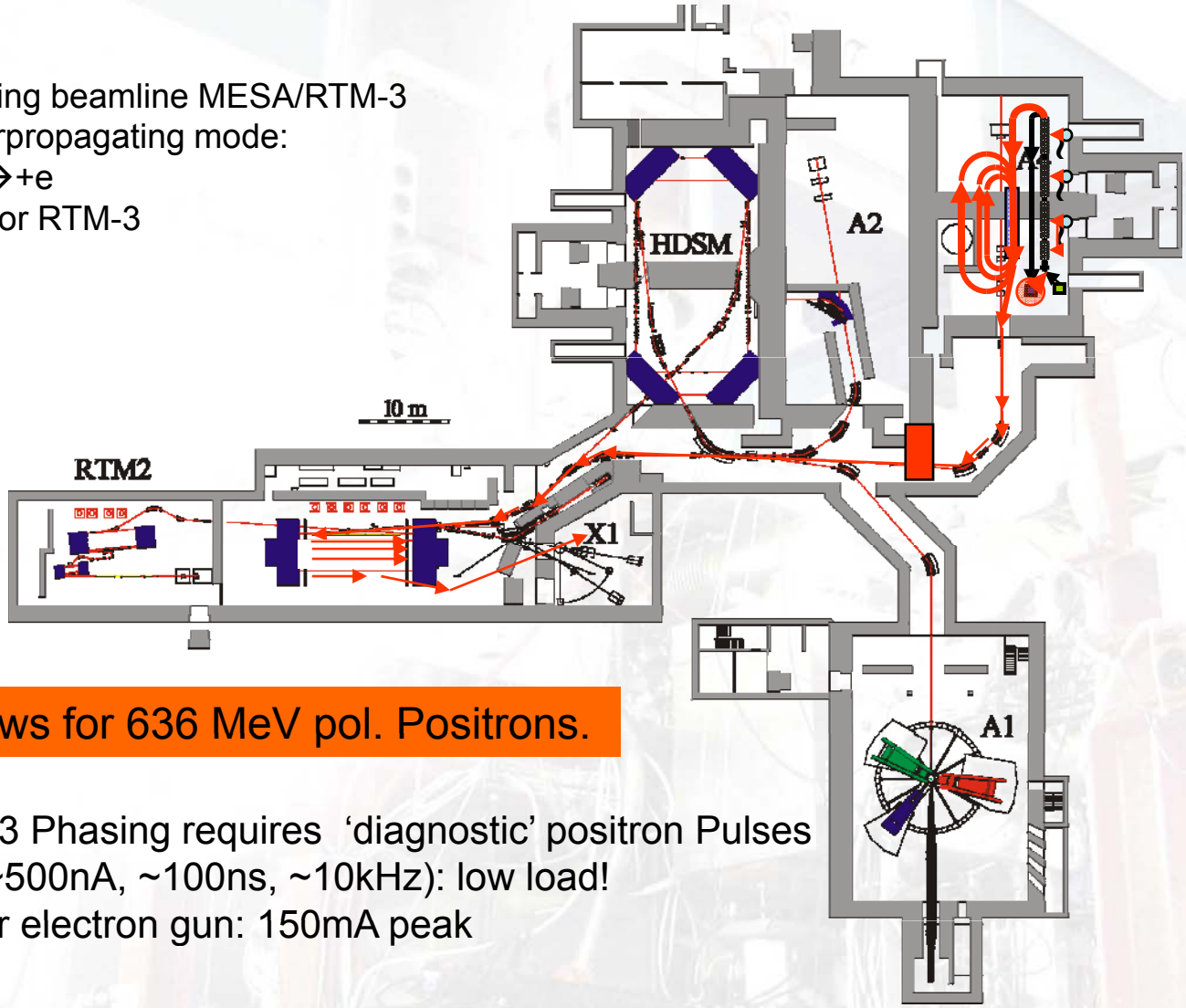
1. Polarized Positron generation in beamdump eff~10^{-3}
2. Moderation of positrons: eff~10^{-3}→total efficiency 10^{-6}
3. Cold polarized positrons (P>0.5) are extracted
4. Norm emittance of positrons <30μm.
5. Co-Acceleration in ILAC on 180 deg. Phase
6. separation of e+/e- after ILAC,
7. (Accelerate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

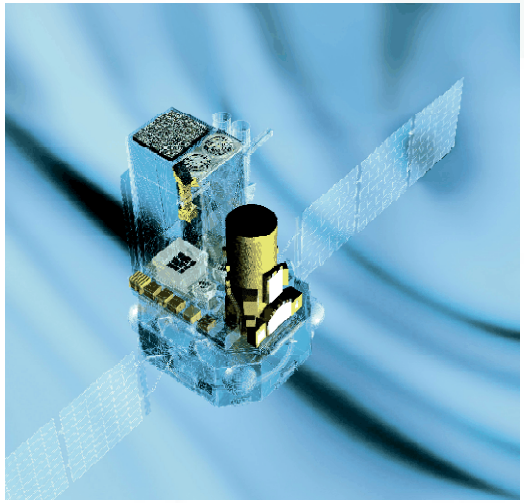
‘Dunkle Materie’ im Elektronenbeschleuniger

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.
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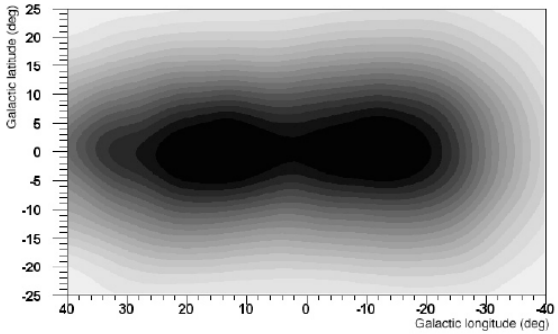
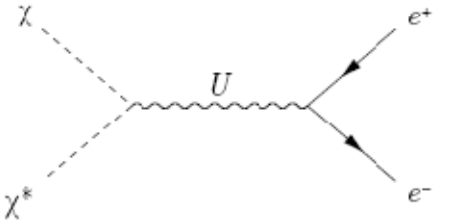


Intensität der 511keV-γ Linie
(Positronenvernichtung)
im galaktischen Zentrum

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

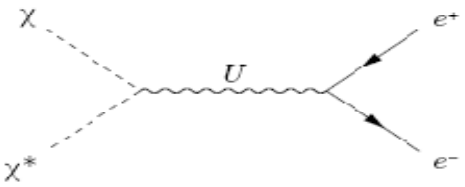
Unkonventionelle Erklärung:
Leichte Teilchen $\chi,\chi*$, die nur schwach Wechselwirken (WIMPS,→ Dunkle Materie)
C. Boehm, P. Fayet
Nucl. Phys. B683 (2004) 219

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

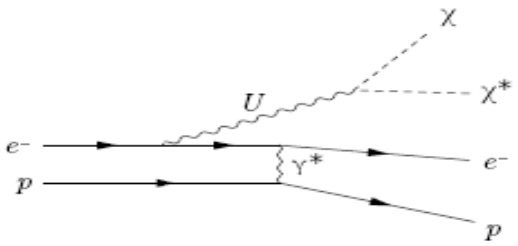


‘Dunkle Materie’ im Elektronenbeschleuniger

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



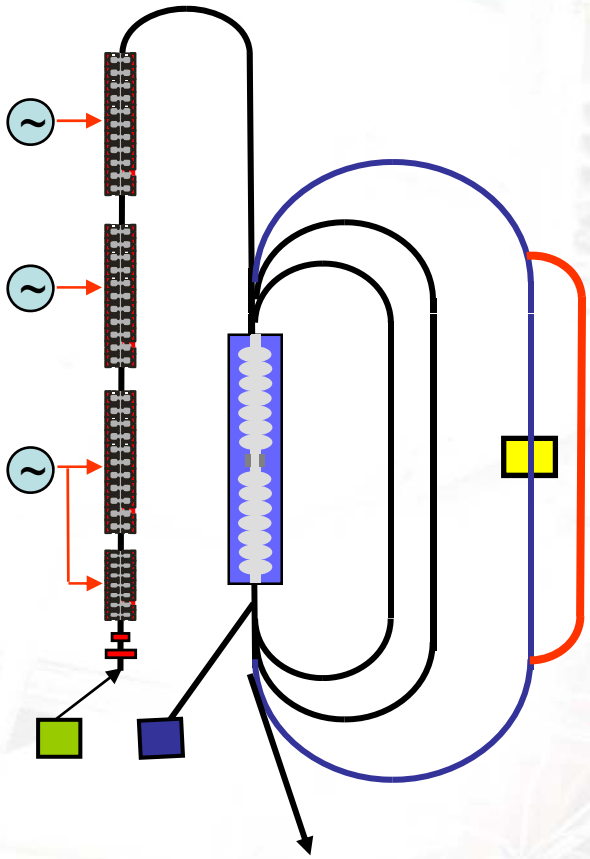
Wenn dieser Prozess im Zentrum der Galaxis geschieht..



..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.:

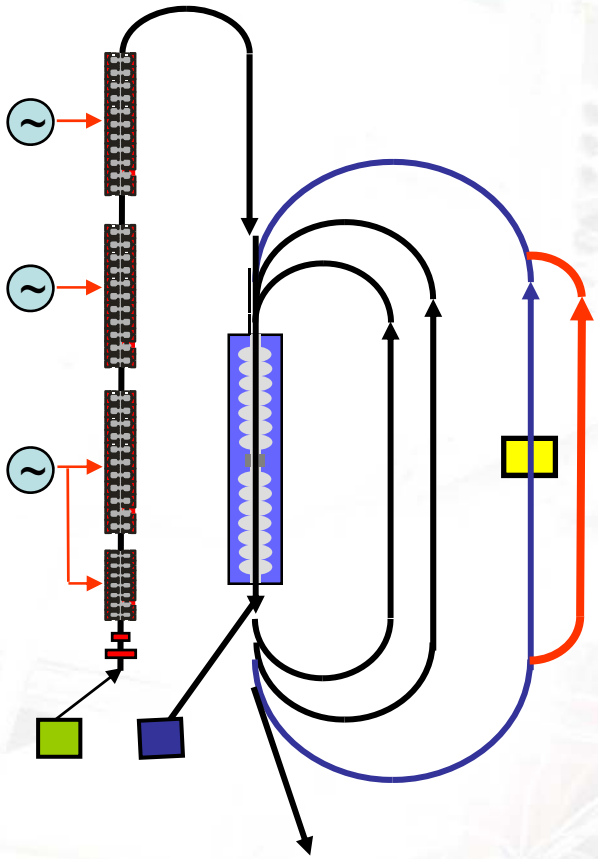
2.449 GHz, c.w., normal conducting
harmonic buncher
graded-β section (0.1-0.55 MeV)
discrete-β section (0.55-2 MeV)
2*β=1 section (2-5 MeV)

typ. Gradient 0.75MV/m

Rf-transmitters:

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

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**