Accelerator facilities for dark sector/light dark matter searches

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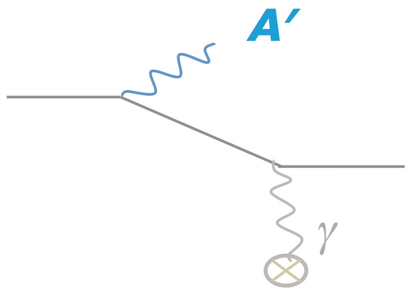
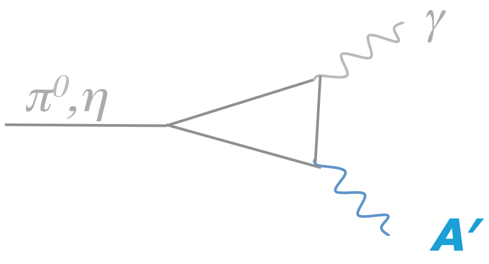
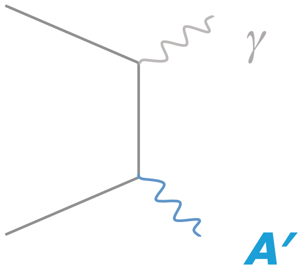
LDMA'17

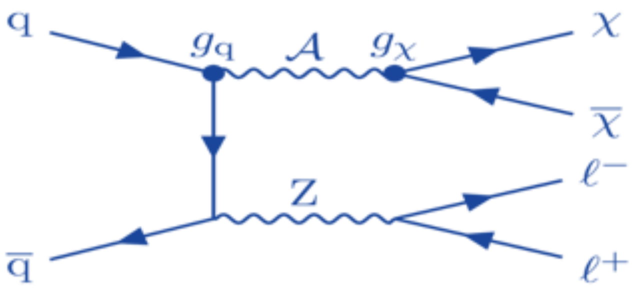
We use **electrons, positrons, protons** (and also **muons**) in **fixed target** experiments

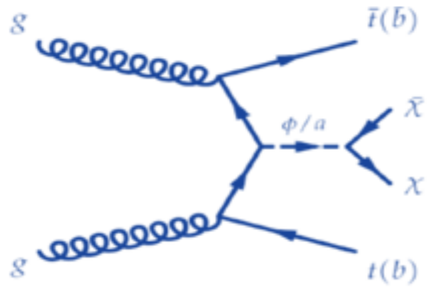






… as well as data from e^+e^- and pp **collisions**





…

Facilities for dark sector/LDM searches

Existing accelerators

- CEBAF & LERF@JLAB
- DAΦNE LINAC
- SPS extracted beams@CERN

- Colliders:

DAΦNE, LHC, SuperKEKB, BES-III

Approved new accelerators

- MESA@Mainz

Proposed accelerators **upgrades**

- DASEL@SLAC
- BDF@CERN (SHiP)
- Positrons from Synchrotron@Cornell
- VEPP-3 bypass
- Positrons from DAΦNE ring?

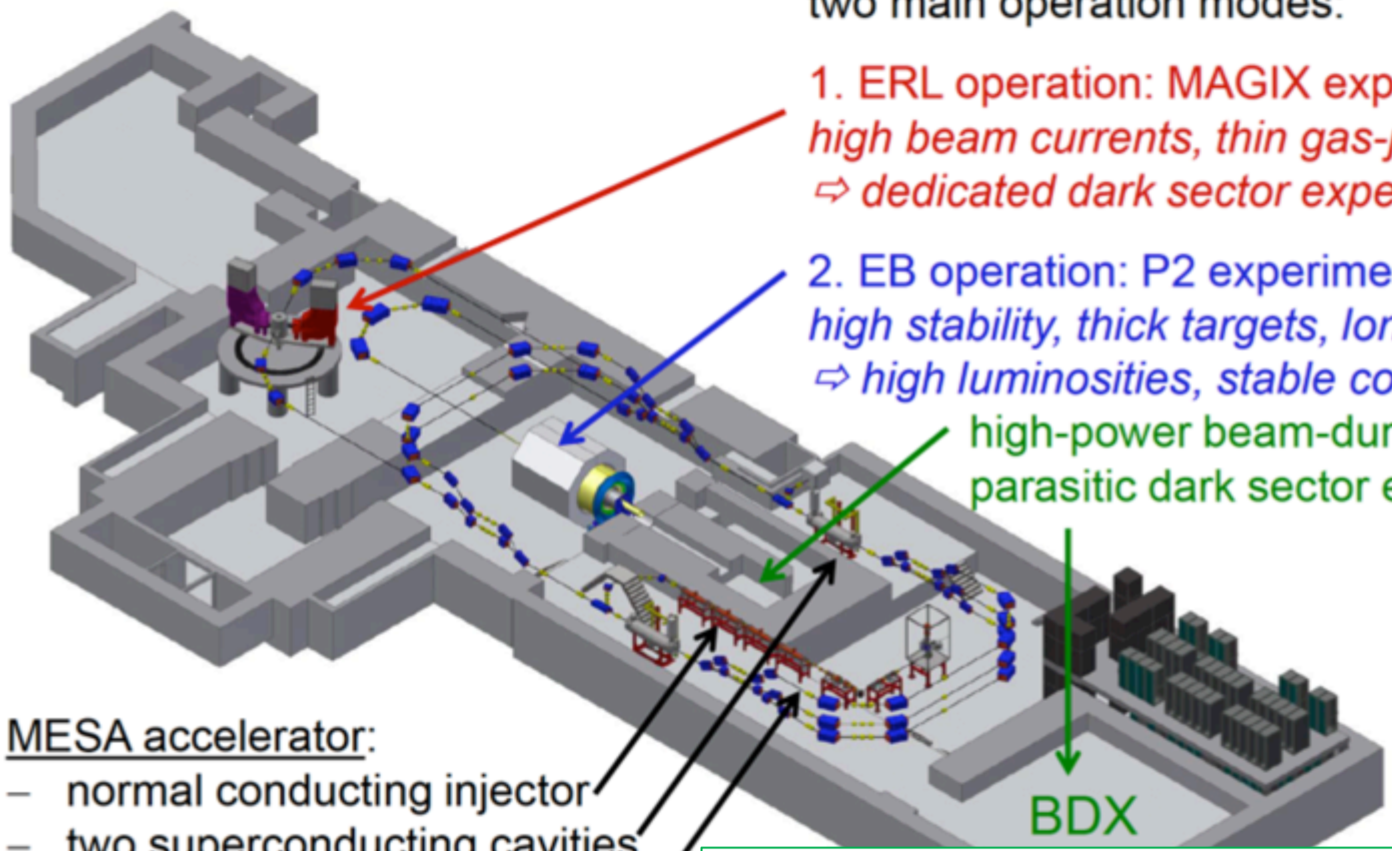
The MESA Facility

two main operation modes:

1. ERL operation: MAGIX experiment
high beam currents, thin gas-jet targets,
⇨ dedicated dark sector experiments

2. EB operation: P2 experiment
high stability, thick targets, long runs
⇨ high luminosities, stable conditions

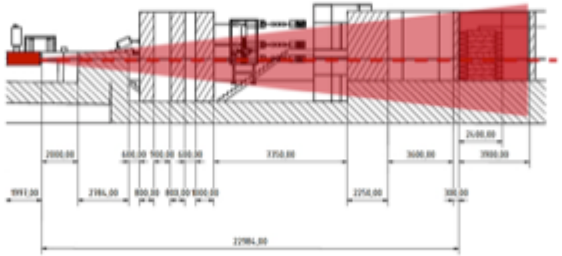
high-power beam-dump
parasitic dark sector experiment



MESA accelerator:
- normal conducting injector
- two superconducting cavities
- several recirculations
- 1.3 GHz c.w. electron beam

MAGIX on ERL
P2 on external beam
BDX behind dump?

- 20 Xo beam-dump, 70 Xo (~ 8 m) barite concrete
- total length of 23 m including several shielding walls
- practically no surviving neutrons at detector site
- practically free of beam-dump related background



- multiple scattering of electron in first radiation length of beam-dump: $\sqrt{\langle\theta^2\rangle}$ = Es/Eo ~ 10° ⇨ cone at detector site opens to ± 400 cm

ERL

polarized electrons
105 MeV
1 mA

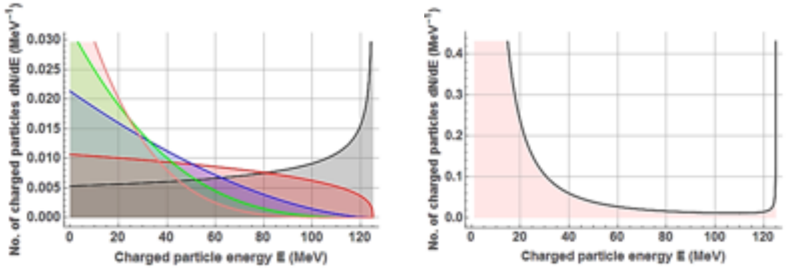
Beam to P2 target

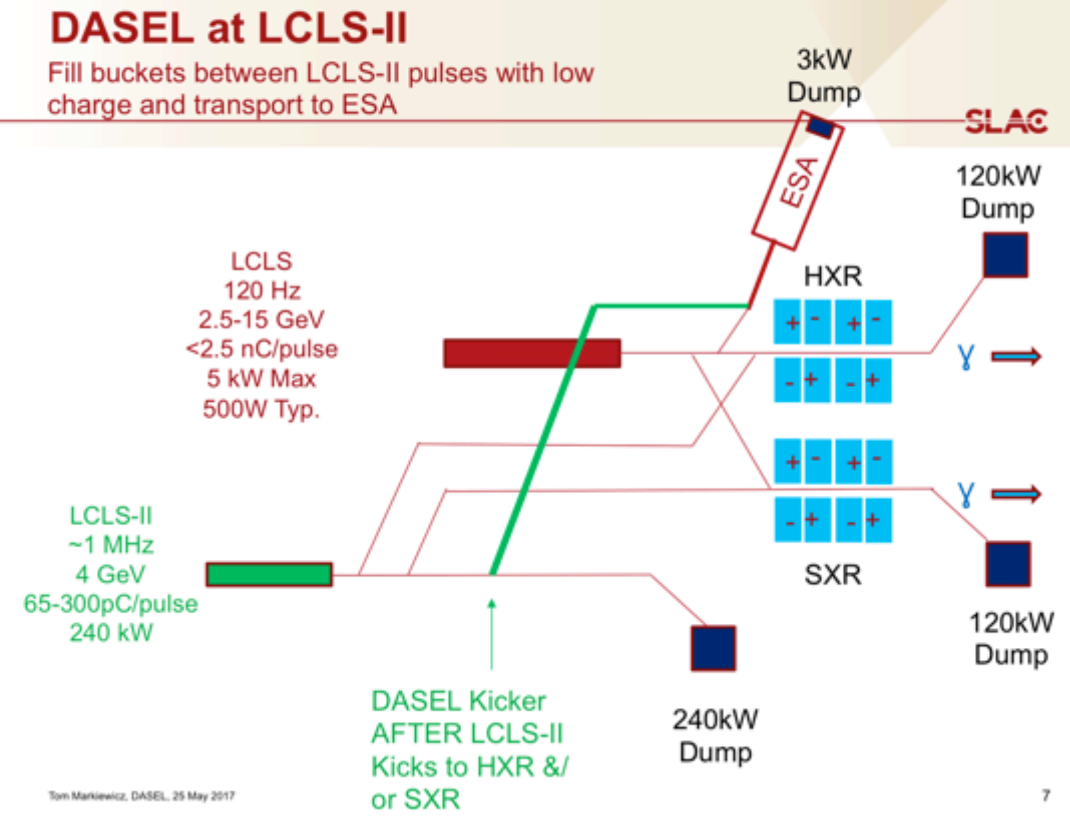
beam energy ~ 147-155 MeV
beam current ~ 150 µA

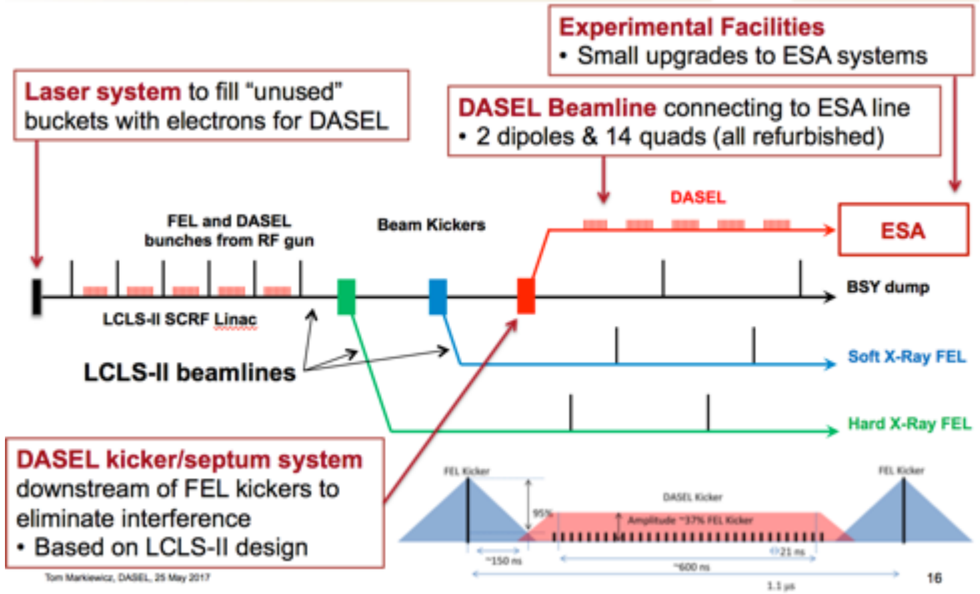
Beam to dump

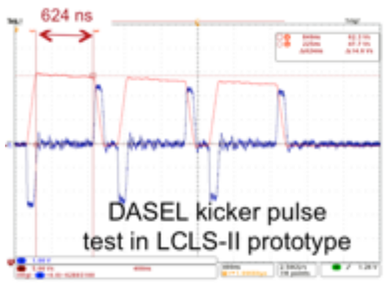
- beam energy ~ 130-138 MeV
- beam power ~ 20 kW
- lateral beam width ~ dump size
- main absorber material: 20 Xo Al
- in 10 000 h of operation:
  - ~ 3 x 10^{22} electrons
  - ~ 5400 C charge dumped

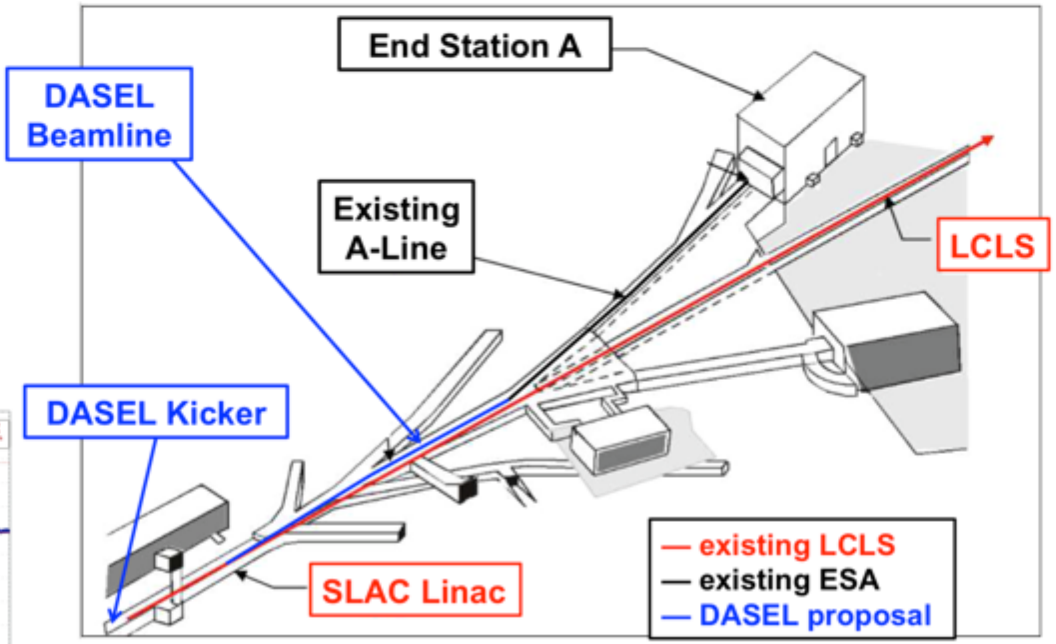
energy distribution at different shower depths: integral over complete shower:











- DASEL will operate with 10 nA beams at 46 MHz (21.5 ns period) using spare oscillator output: 50 DASEL pulses per LCLS-II cycle (phase I, ≈**2021**)
- Upgradable to ≈μA with bunches at 186 MHz (5.4 ns period) with new high frequency low power laser: 200 DASEL pulses per LCLS-II cycle (phase II, ≈**2025**)
- Can vary current at experiment using ESA spoiler/collimator from maximum current down to 1 e- per shot
- Collimators will be used to control IP spot sizes as well
- LOI written September 2016 and will be updated August 2017
- Plan a Preliminary Design Report in Fall 2017 with FDR in 2018
- Aggressive schedule has beam-line commissioning at end of 2020

Moreover:

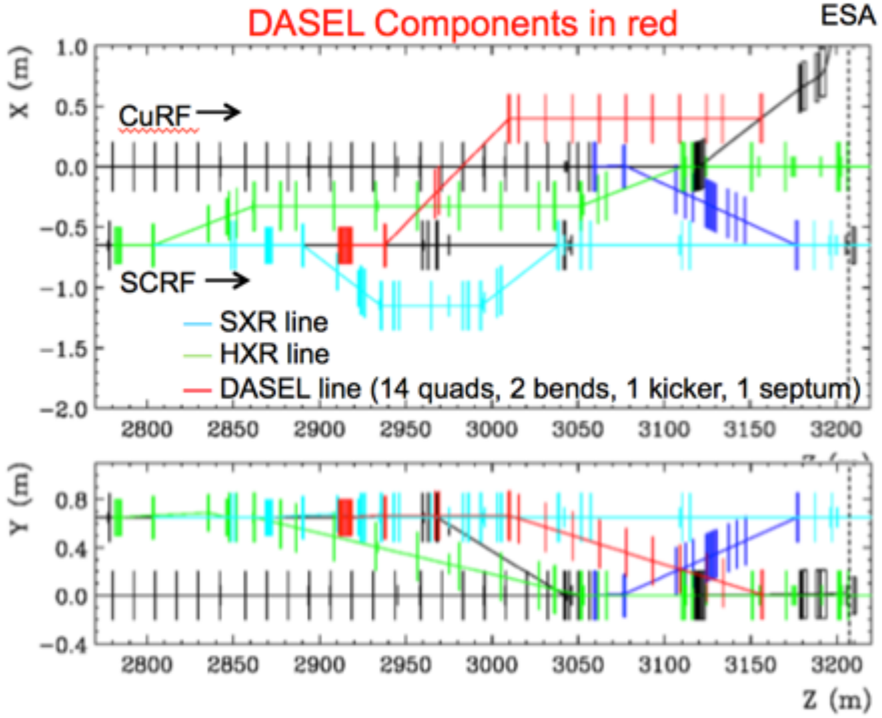
- Benefits from LCLS-II engineering & refurbished magnets (2 dipoles, 14 quadrupoles, 6 correctors) to minimize cost (<10 M) and schedule
- Capable of delivering **8 GeV** beam but would operate at **4 GeV** at start

LDMX experiment proposed at DASEL

DASEL Parameters

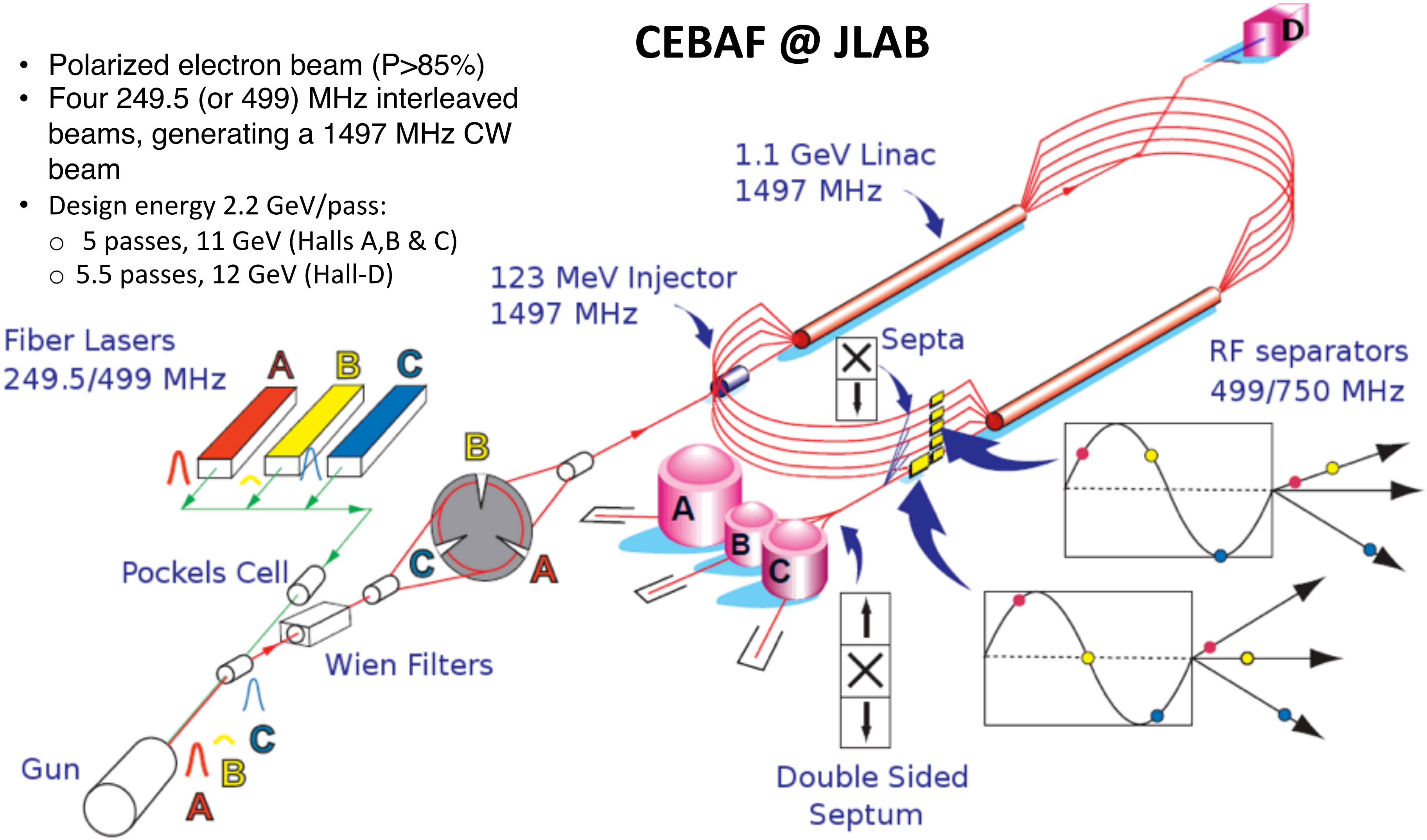
SLAC

Experiment Parameters	LDMX experiment (~2020)	Super-HPS-style upgrade (~2025)
Energy	4.0 GeV (possible to upgrade to 8.0 GeV)	4.0 GeV (possible to upgrade to 8.0 GeV)
Bunch spacing	21.5 ns	5.4 ns
Bunch charge	0.05 – 20 e-	70,000 e- (10 fC)
Macro pulse beam current	0.1 – 150 pA	2 uA
Duty cycle	55% (600 ns out of 1.1 us)	55% (600 ns out of 1.1 us)
Beam norm. emittance (rms)	~100 um; < 1000 um	~1 um
Bunch energy spread	<1%	<1%
IP spot size	4 cm x 4 cm (rastering at 40 MHz could be used)	<250 um including jitter
Max beam power	0.6 W	5 kW
ESA Spoiler Parameters		
Charge reduction	0 – 99.99%	N/A
Emittance increase	1 - 1000x	N/A
Max beam power	55 W	N/A
Spoiler thickness	0 – 0.5 r.l.	N/A
Accelerator Parameters		
Macro pulse beam current	0 – 25 nA	2 uA
Beam norm. emittance (rms)	~1um; < 25 um	~1um; < 25 um
Beam admittance (edge)	<50 nm; defined by LCLS-II collimators	<50 nm; defined by LCLS-II collimators
Bunch energy spread (FWHM)	<2% ; defined by LCLS-II collimators	<2%; defined by LCLS-II collimators
Bunch length (rms)	<1 cm	<1 cm
Max beam power	55 W	5 kW



CEBAF @ JLAB

- Polarized electron beam (P>85%)
- Four 249.5 (or 499) MHz interleaved beams, generating a 1497 MHz CW beam
- Design energy 2.2 GeV/pass:
  - 5 passes, 11 GeV (Halls A,B & C)
  - 5.5 passes, 12 GeV (Hall-D)



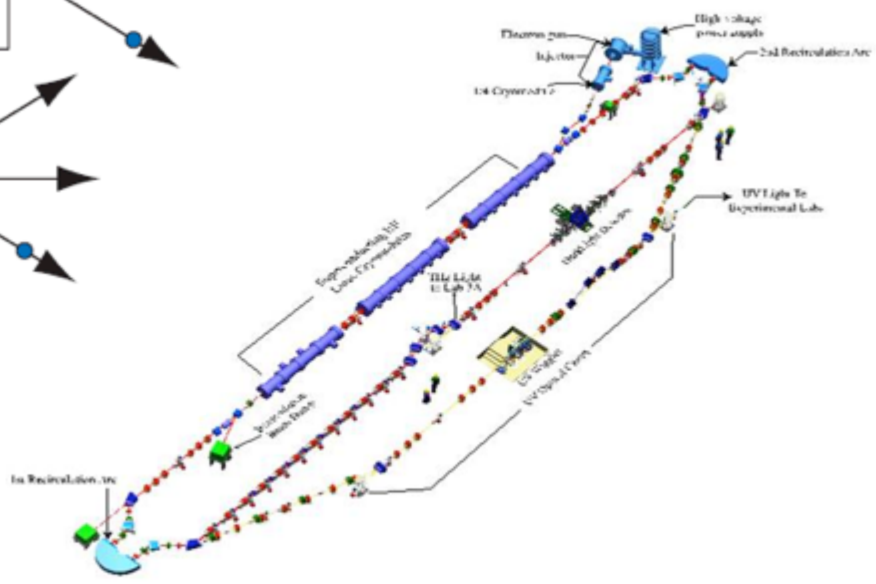
- Flexible extraction options for ABC, 1st…5th pass
- Hall A & C 1 MW high power dumps

Emittance < 10 (5) nm rad horizontal(vertical)
Energy spread <5 10^{-4}

APEX in Hall-A
HPS in Hall-B
BDX behind Hall-A dump

LERF @ JLAB

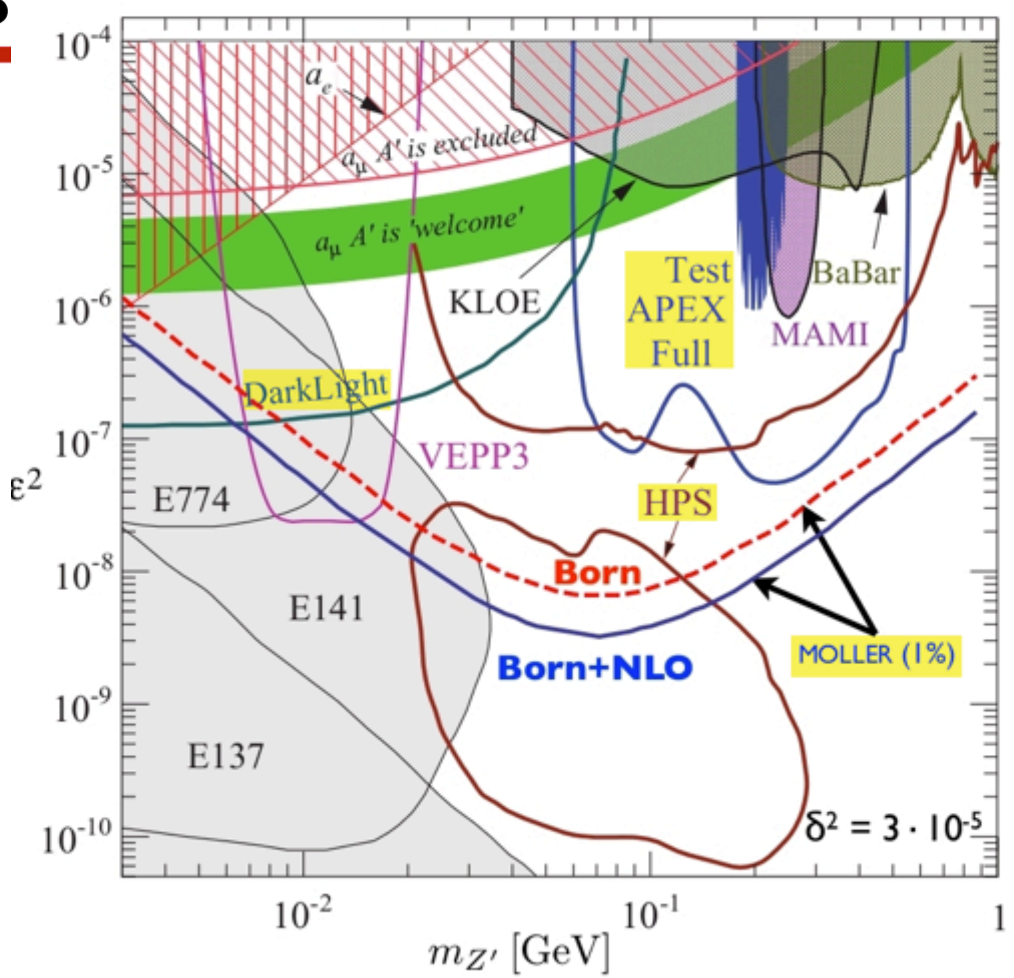
An energy-recovery superconducting linear accelerator of ~170 MeV



DarkLight

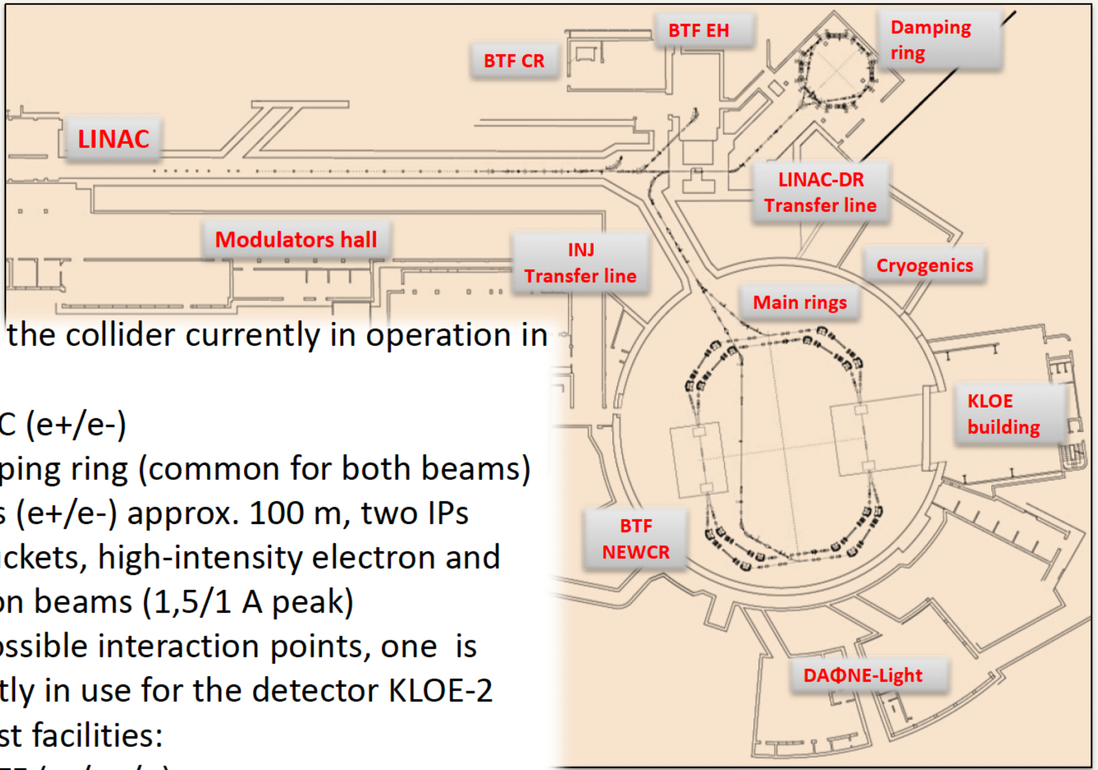
LERF and CEBAF Beam Parameters

	LERF	CEBAF
Max. Energy	170 MeV	11 GeV (ABC)
		12 GeV (D)
Duty Factor	CW	CW
Max. Beam Power	>1 MW	1 MW
Bunch Charge (Min-Max)	**60-135 pC**	0.004 fC – 1.3 pC
Repetition Rate on Target	4.68 - 74.85 MHz	31.2 – 499 MHz
Nominal Hall Repetition Rate	74.85 MHz	**249.5** MHz
Number of Exp. Halls	1	**4**
Max. Number of Passes	1	5.5
Emittance (geometric) at full energy	**50** nm-rad(X)/**30** nm-rad(Y) @ 135 pC	**3 nm-rad(X)/1 nm-rad(Y)**
Energy Spread at full energy	0.02%	**0.018%**
Polarization	None	>85%



The DAΦNE complex- LINAC

Laboratori Nazionali di Frascati (LNF)
Frascati (Rome, IT)



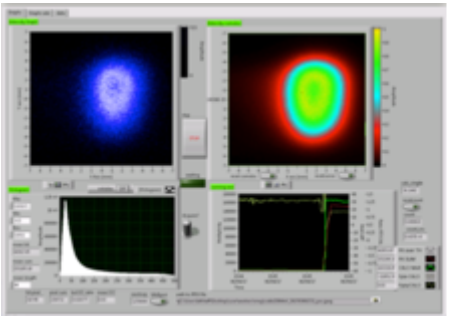
DAΦNE is the collider currently in operation in Frascati

- 1 LINAC (e+/e-)
- 1 Damping ring (common for both beams)
- 2 Rings (e+/e-) approx. 100 m, two IPs
- 120 buckets, high-intensity electron and positron beams (1,5/1 A peak)
- two possible interaction points, one is currently in use for the detector KLOE-2
- two test facilities:
  - BTF (e-/e+/n)
  - DAΦNE Light

Primary beams

	Design	Operational (top)
Electron beam final energy	800 MeV	510 MeV (750)
Positron conversion energy	250 MeV	220 MeV
Positron beam final energy	550 MeV	510 MeV (535)
RF frequency	2856 MHz	
Accelerating structure	SLAC-type, CG, 2π/3	
RF Amplifiers	4 x 45 MW sledded klystrons TH2128C	
Beam pulse rep. rate	1 to 50 Hz	1 to 50 Hz
Beam macropulse length	10 nsec	1.4 ns to 250 ns
Gun current for positron	8 A	8 A
Beam spot on positron converter	1 mm	1 mm
Normalized Emittance (mm mrad)	1 (electron) 10 (positron)	1 (electron) 10 (positron)
RMS Energy spread	0.5% (electron) 1.0% (positron)	0.5% (electron) 1.0% (positron)
Output electron current (510MeV)	>150 mA	180 mA (>500)
Electron current on positron converter	5 A	5.2 A
Output positron current (510MeV)	36 mA	50 mA (>85)
Transport efficiency from capture section to linac end	90%	90%

Secondary beams

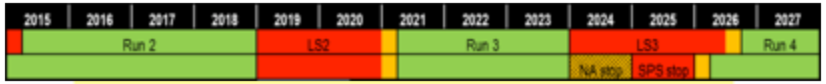


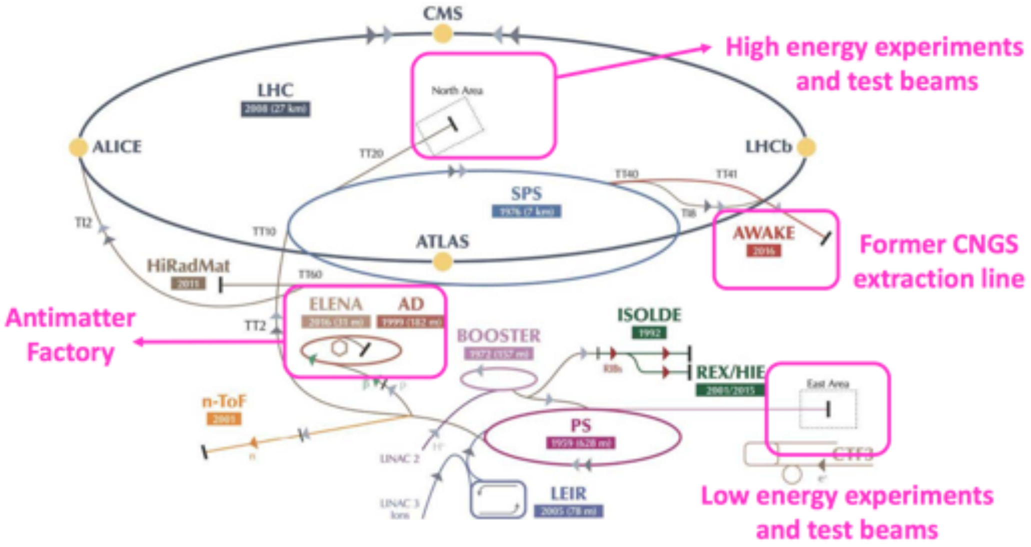
1.6 10^5 E=150 MeV electrons/10 ns

Aim at
10^4 E=550 MeV positrons/200 ns
for PADME

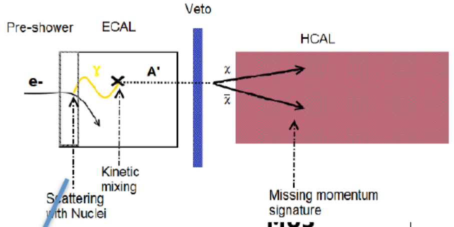
PADME ≈2018

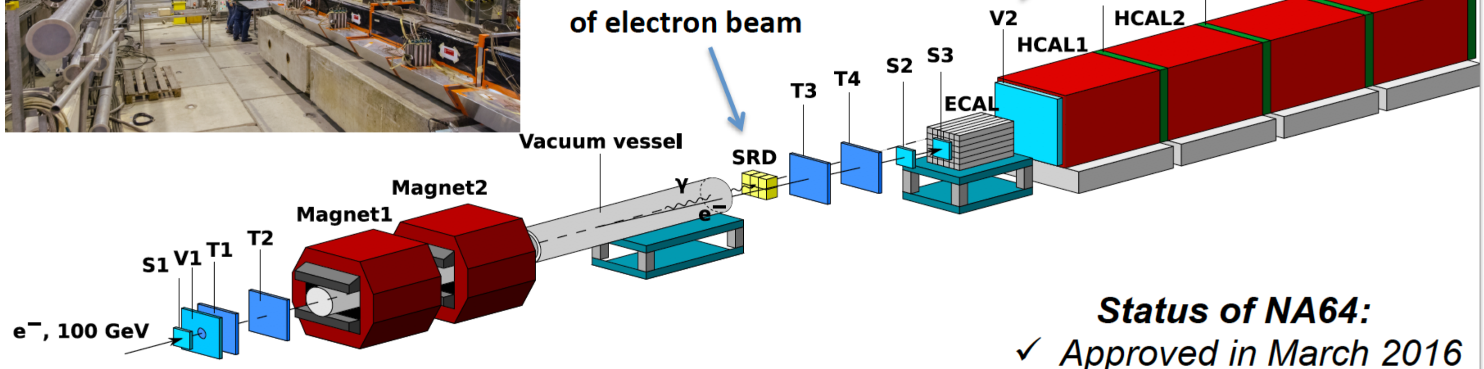
Parameter	Values			
Maximum average flux	3.125 10^{10} particles/s			
Spot size	1–25 mm (y) 1–55 mm (x)			
Divergence	1–2 mrad			
	Parasitic mode		Dedicated mode	
Pulse duration	10 ns		1.5–40 ns Selectable	
Repetition rate	Variable between 10 Hz and 49 Hz Depending on DAFNE mode		1–49 Hz Selectable	
	With target	Without target	With target	Without target
Particle species	e^+ or e^- Selectable by user	e^+ or e^- Depending on DAFNE mode	e^+ or e^- Selectable	
Energy	25–500 MeV	510 MeV	25–700 MeV (e^-) 25–500 MeV (e^+)	250–730 MeV (e^-) 250–530 MeV (e^+)
Energy spread	1% at 500 MeV	0.5%	0.5%	
Intensity (particles/bunch)	1–10^5	10^7–1.5 10^{10}	1–10^5	10^3–3 10^{10}





NA-64: search for HS at electron beam in events with missing energy



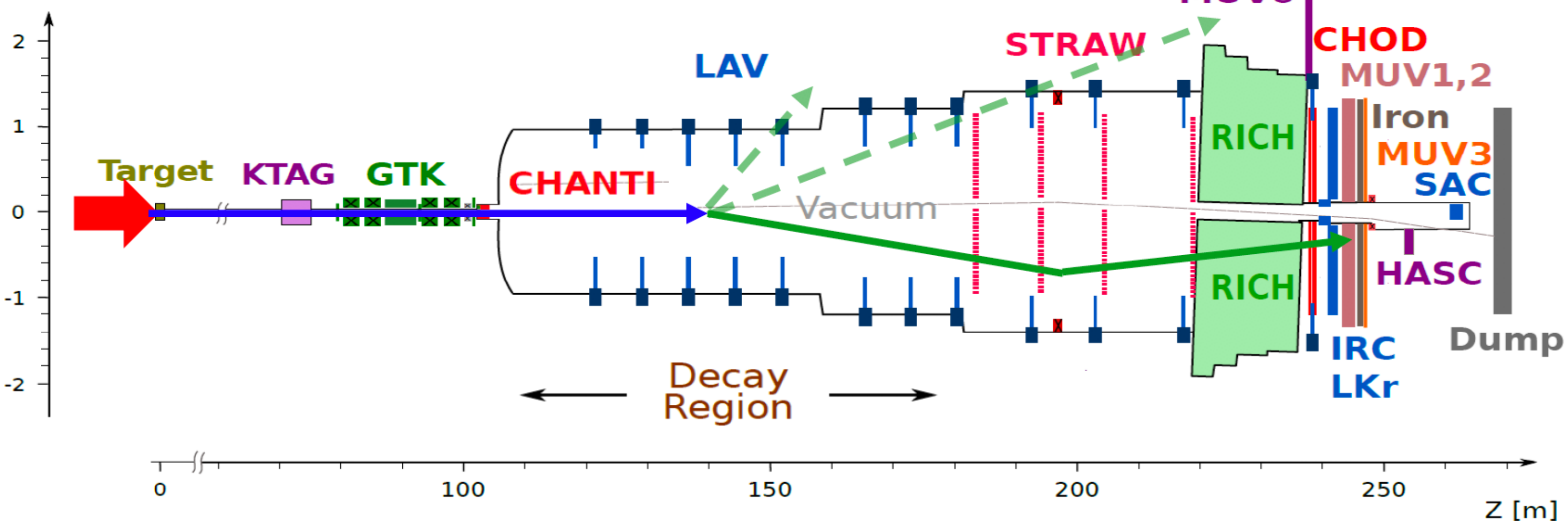


Status of NA64:

- ✓ *Approved in March 2016*
- ✓ *Two successful runs in 2016 with 4×10^{10} eot collected running at 5×10^{6} e^- / spill*
- ✓ *Plans for 2017:*
  Improve electron tagging
  Run at $(7\text{-}8)\times10^{6}$ e^- / spill
  to collect $(2\text{-}3)\times10^{11}$ eot

NA62 experiment

(Run 2 & proposal for Run 3)



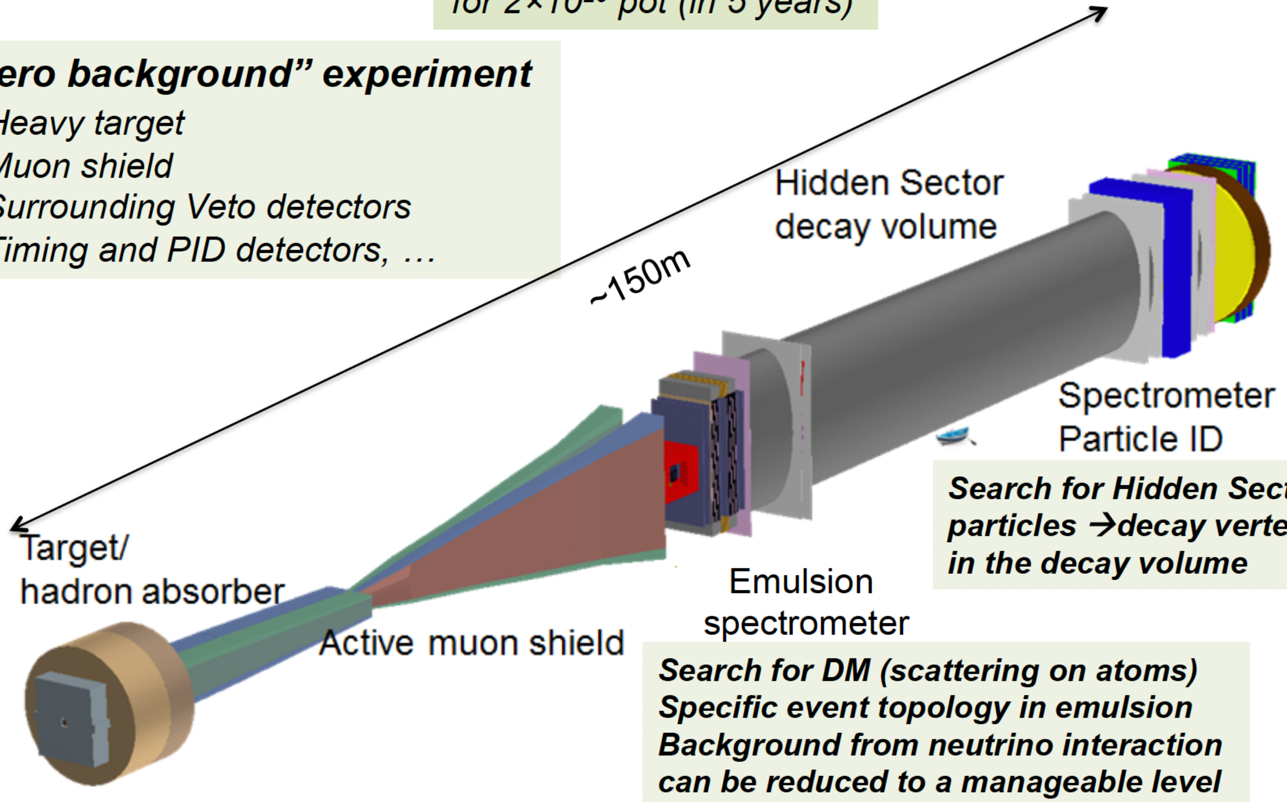
Secondary beams at CERN North Area: <200 GeV electrons in H4 and 75 GeV kaons (+pions) in K12

The SHiP experiment at SPS
(to search for HS particles with O(10 GeV) masses)

SHiP Technical Proposal: 1504.04956

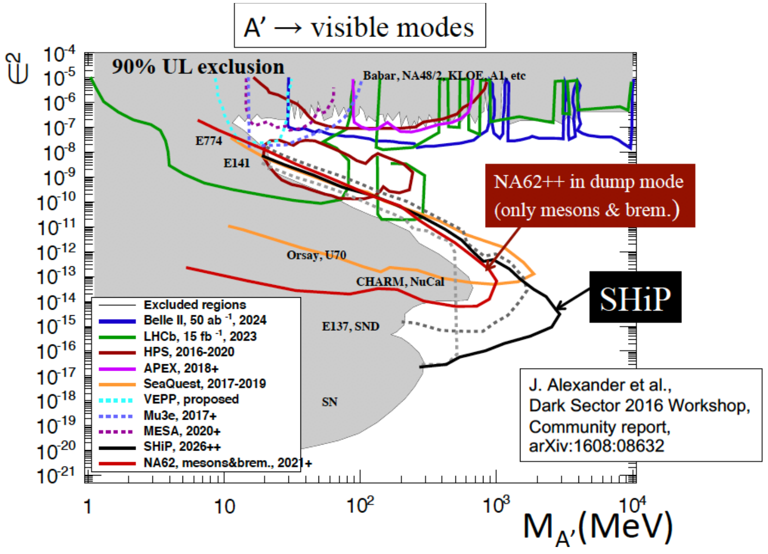
$>10^{18}$ D, $>10^{16}$ τ, $>10^{20}$ γ for 2×10^{20} pot (in 5 years)

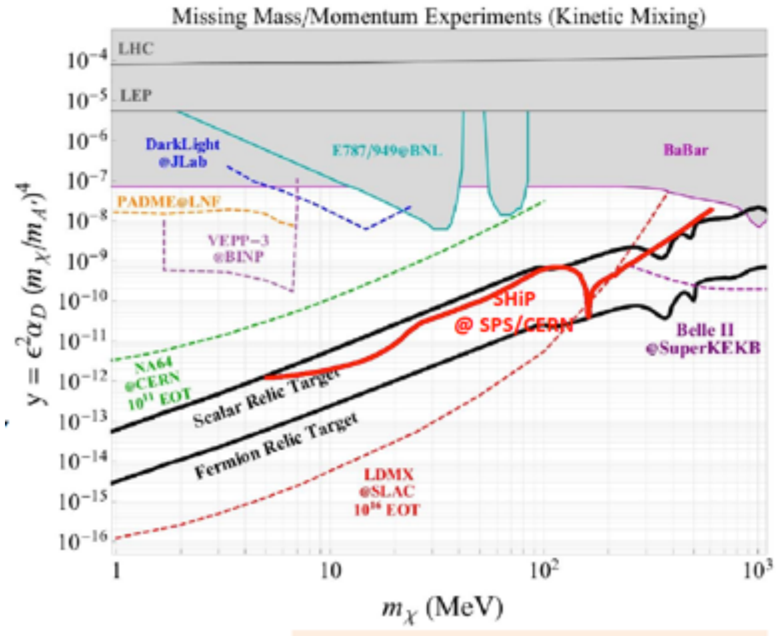
"Zero background" experiment
- *Heavy target*
- *Muon shield*
- *Surrounding Veto detectors*
- *Timing and PID detectors, …*



Search for Hidden Sector particles → decay vertex in the decay volume

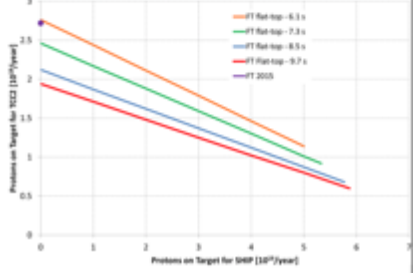
Search for DM (scattering on atoms)
Specific event topology in emulsion
Background from neutrino interaction can be reduced to a manageable level



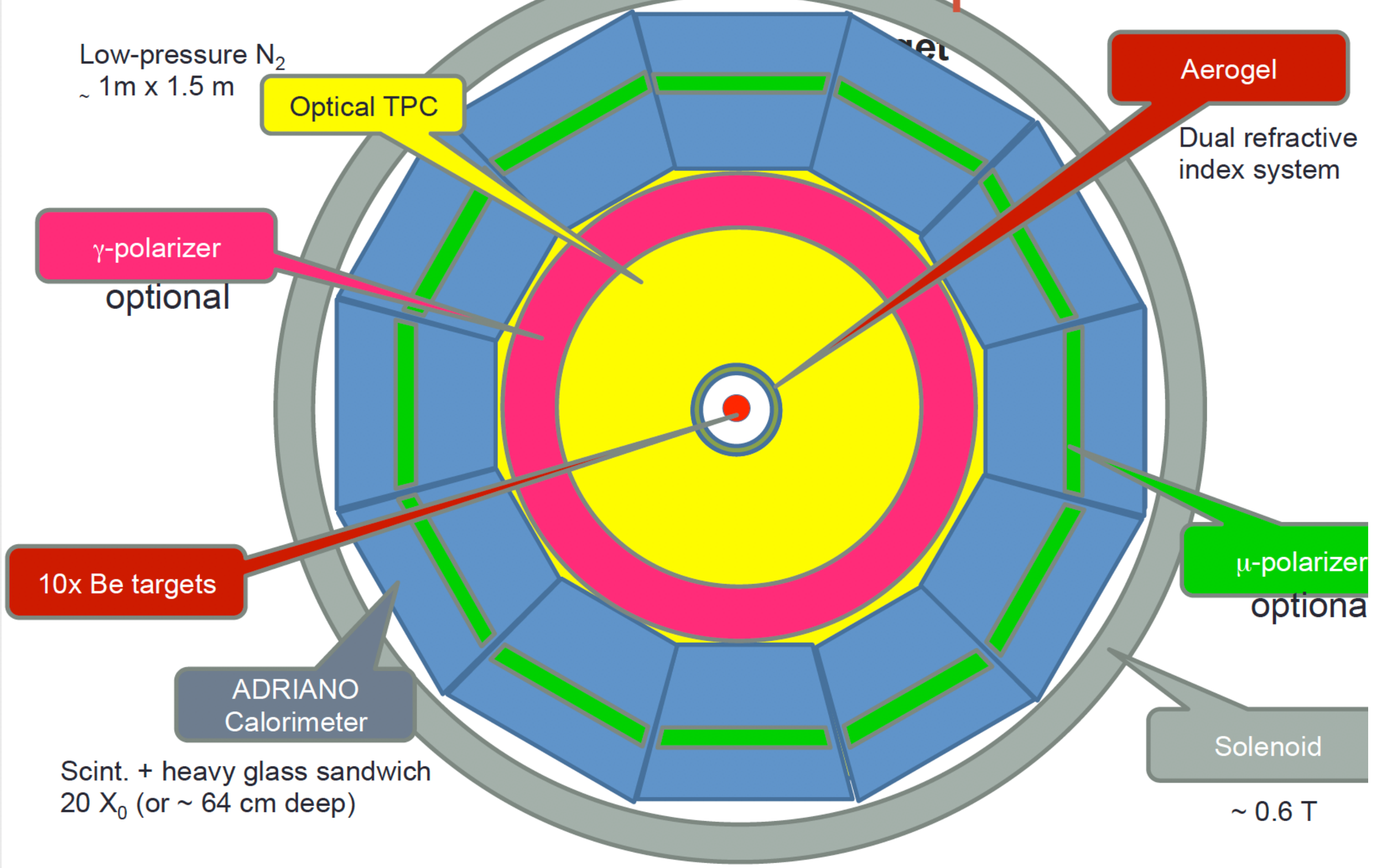


Proposed **Beam Dump Facility @CERN North Area**
- 450 GeV maximum SPS energy
- Start with **Run 4 ≈2027**

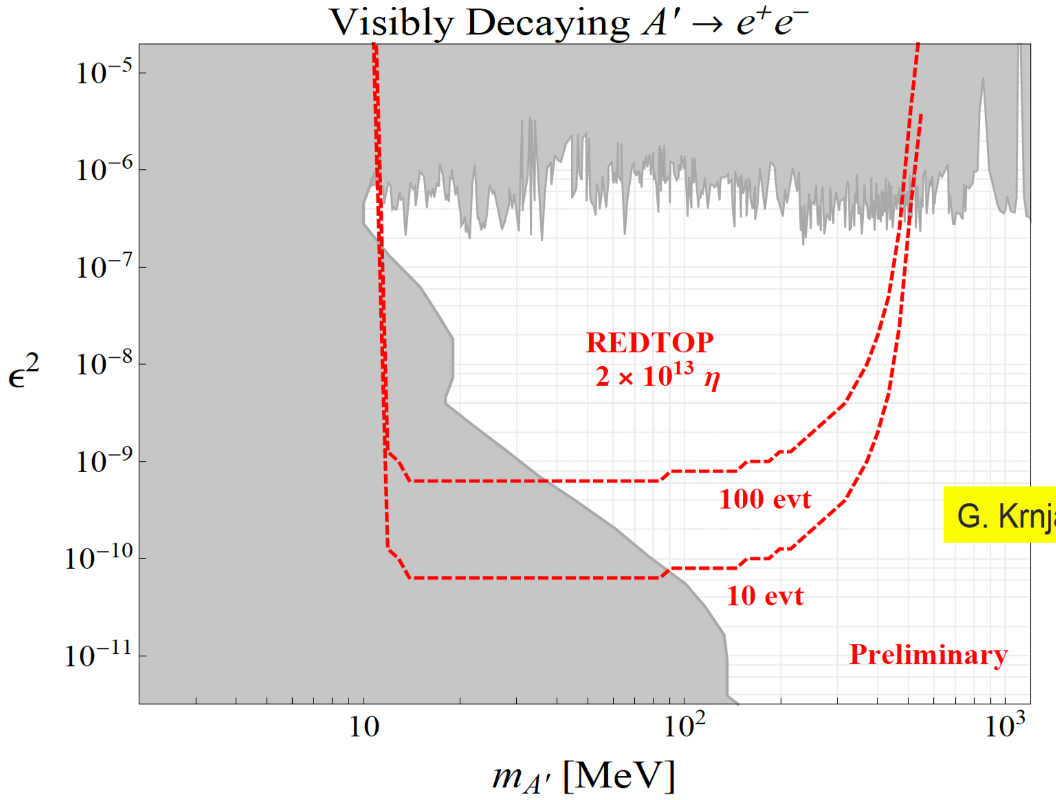
Sharing of pot between current fixed target exp. and planned Beam Dump Facility (BDF)



REDTOP Detector Concept



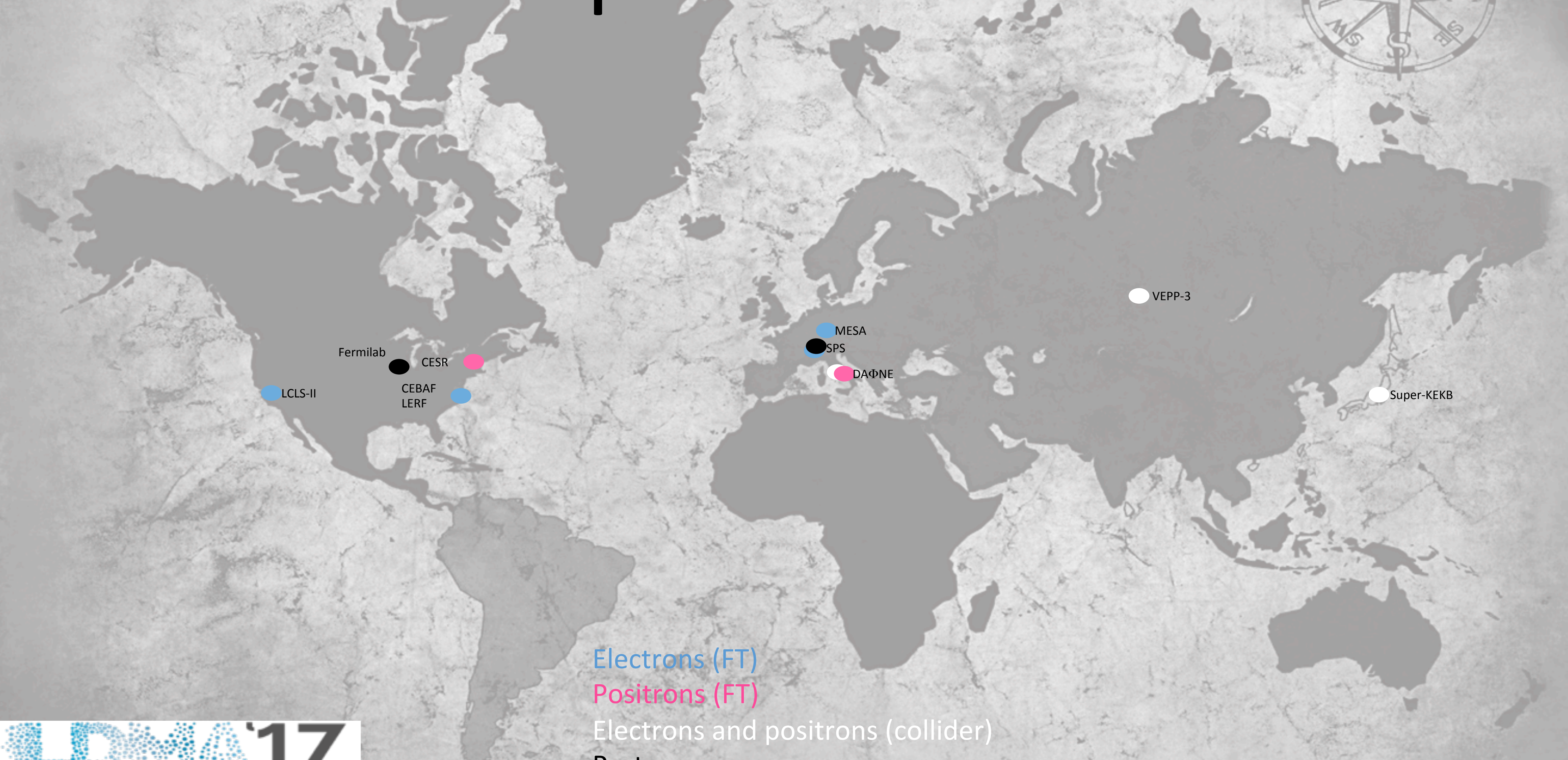
- Incident proton energy of ~ 1.8 – 1.9 GeV
- Intensity > 1×10^{11} POT/sec
- Corresponds to beam power of ~ 30 W
- Impinges on a sparse target
  - 10 x 0.1 mm Nb or 10 x 0.33 mm Be spaced 10 cm apart
  - better vertex resol. w/ Nb but more primary hadrons
- Large beam spot (~1 cm) with small divergence (< 1°)
- Inelastic interaction every 100 nsec per target



G. Krnjaic

- Yield of 2×10^{13} η mesons per year (total inelatic x-section is 10 – 20 mbar in the 2 GeV beam energy region)
- Can also serve as a η' factory
- 4π (almost) detector which can be used with beams of different energies and particle species

Map of facilities



Electrons (FT)
Positrons (FT)
Electrons and positrons (collider)
Protons

Time of facilities