Dark photons: HPS & BDX

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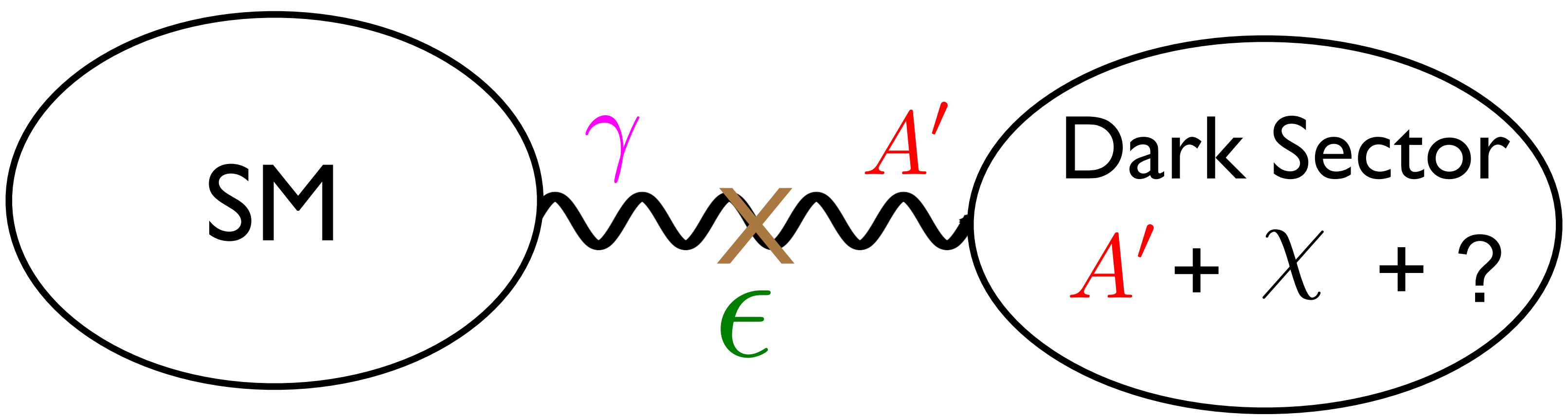
Dark Matter @ LPNHE

3 Novembre 2014

The dark photon sector

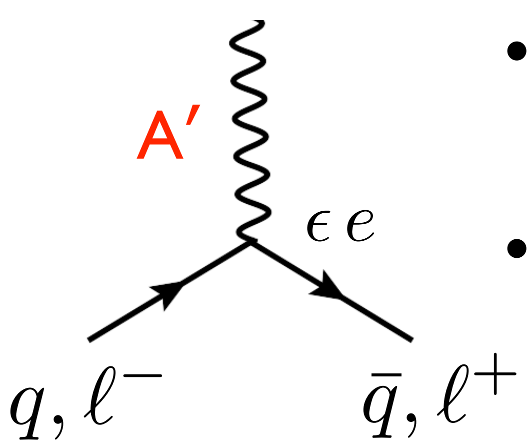
- the search for DM is dominated by the search for WIMPs of m~5-1000 GeV
- some physics models naturally predict non-WIMP DMs
- among them, models with a light (sub-GeV) dark sector communicating with SM particles through a light dark photon (additional gauge U(1)) which mixes with hypercharge



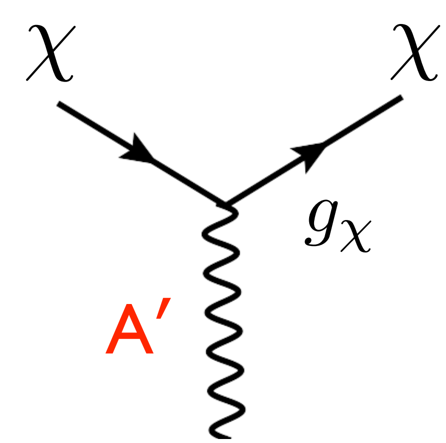
$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

4 parameters: $m_\chi, m_{A'}, \epsilon, g_\chi$

- this gives rise to diagrams like



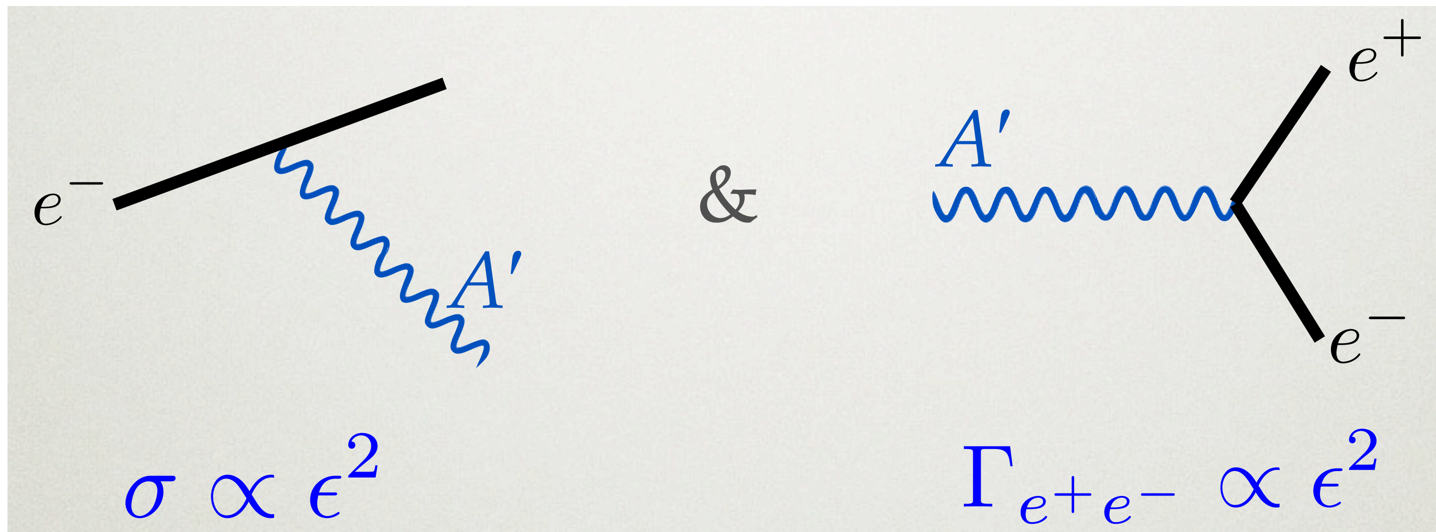
- **A' production in electron interactions with target** (bremsstrahlung)
- **A' decay to fermion pairs** (e^+e^-)



- **A' decay to X pairs**
- **X scattering on matter** (nucleons/e-)

HPS and BDX

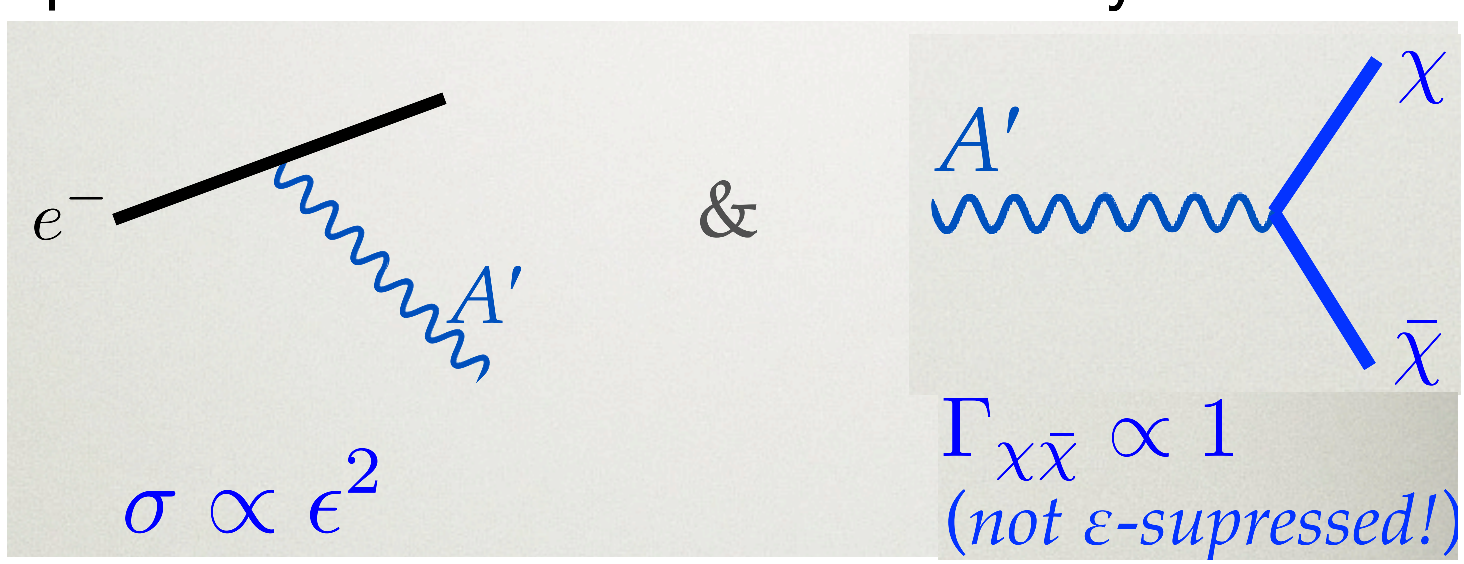
- Heavy Photon Search experiment @JLAB: search for visible decays to e^+e^-



  - if $m_{A'}<2m_\chi$, e^+e^- and other SM states are the only possible decay modes, Γ_{tot}~ε^2, BR(e^+e^-)~O(1): A' is narrow and HPS signal $\propto\varepsilon^2$

$$\gamma c\tau \approx 1 \text{ mm } (\gamma/10)\ (10^{-4}/\epsilon)^2\ (100\text{MeV}/m_{A'})$$

- Beam-Dump eXperiment: search for invisible decays to XX

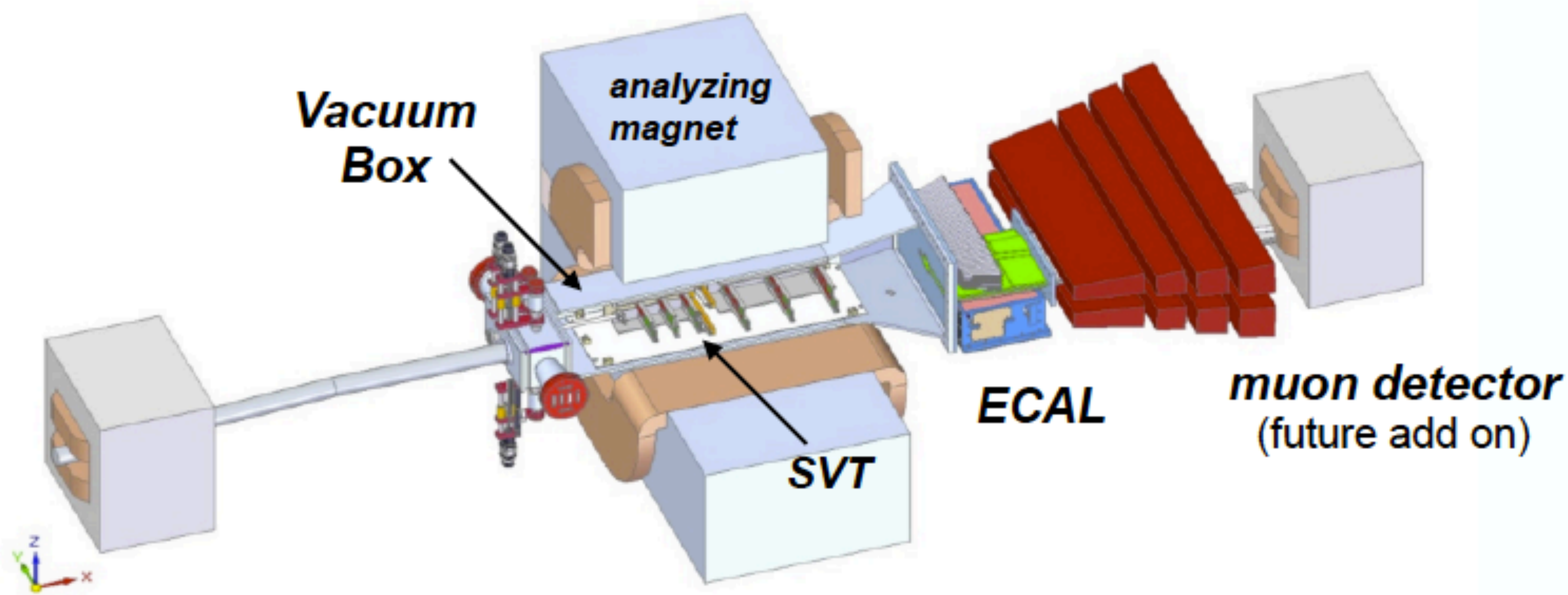


  - if $mA'>2m_\chi$, A' decays invisibly, HPS signal is further suppressed by ε^2

HPS @ JLAB (slide from Witek)

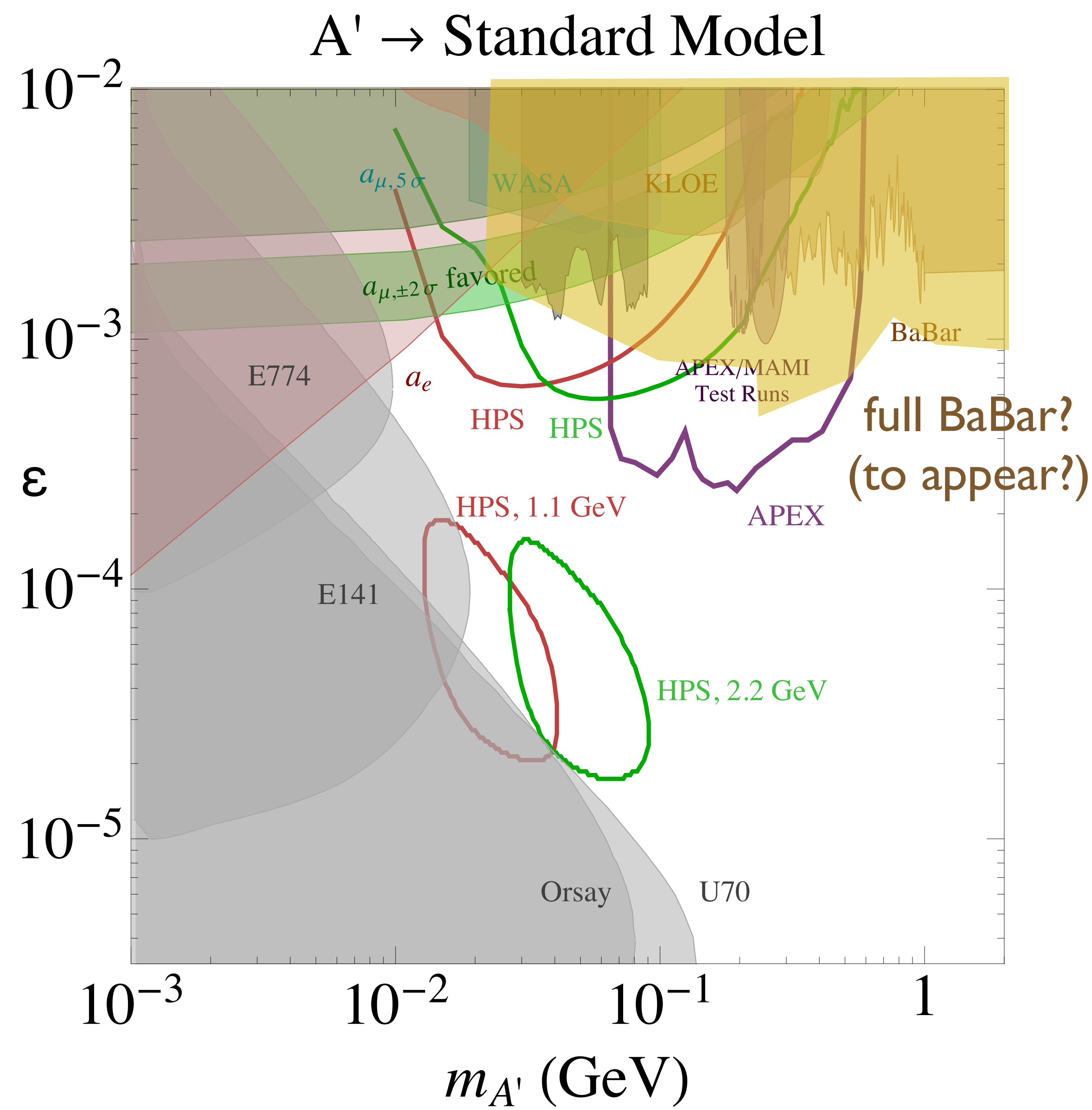
The **H**eavy **P**hoton **S**earch uses the lower current beam on a thin target with a high precision vertexing & tracking detector to search for displaced vertices

➡HALL B beam: <700 nA with 2 ns bunch spacing; $\sigma_{x,y}$ <50um
➡12-layer Si microstrip detector inside 0.5T magnet measures momentum & decay vertex
➡PbW crystal calorimeter w/APD readout used for triggering
➡decent mass resolution (~2-10%), decent acceptance (up to ~20%)
➡vertex resolution ~few mm; 10^{-6} rejection of prompt decays
➡mass resolution dominated by MS in tracker



HPS: physics perspectives, current status

- sensitive to regions not excluded by previous experiments
- experiment approved, installation almost complete (some delay with installation of tracker, probably in by end of 2014)
- accelerator in commissioning
- ~3.5 weeks of engineering run, + 4 weeks of data taking around April 2015
- further data-taking periods/ upgrades depend on schedule of other JLAB experiments and DOE funding



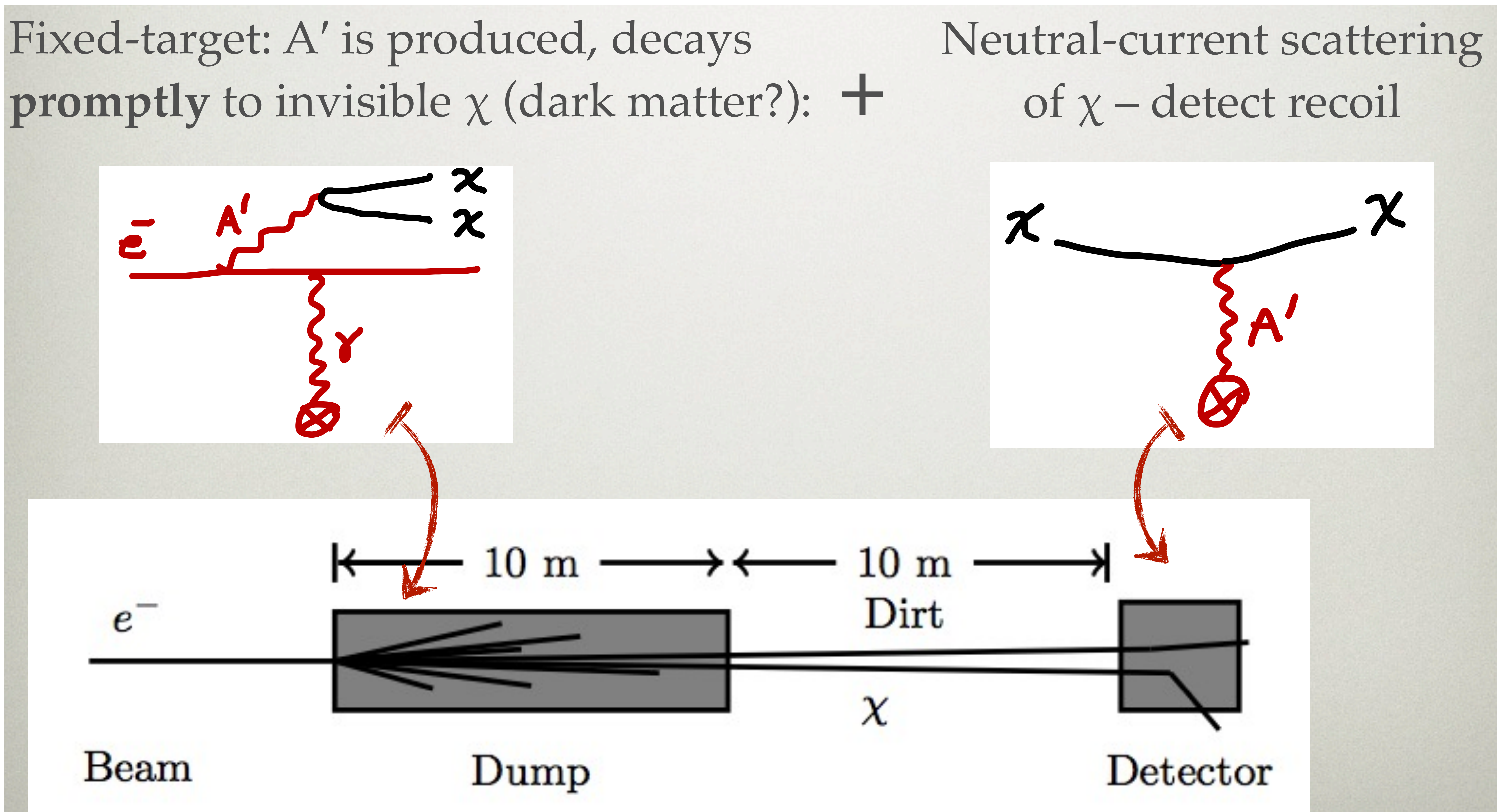
Note: if A' can also decay invisibly, visible signals should be rescaled by ε^2 and there's no limit below ε^2 ~1e-3..

HPS: possible contributions

- even though installation is almost complete, offline reconstruction and analysis software still requires some effort & manpower
- data taking soon, time to enter collaboration = now or never
- possible contributions:
  - coordination of ECAL reconstruction
  - ECAL calibration
  - SVT DB, timing, monitoring plots, ..
  - improvements to track reconstruction to increase sensitivity
  - data taking shifts
- one French group (IPNO) already in the Collaboration

BDX (LoI: arXiv:1406.3028)

- beam-dump experiment proposal based on theory paper "*New Electron Beam-Dump Experiments to Search for MeV to few-GeV Dark Matter*", PRD88,114015. Large overlap with HPS collaboration
  - search for signal from X pairs produced either in decay of on-shell A' or through mediation of off-shell A'



Why an electron beam?

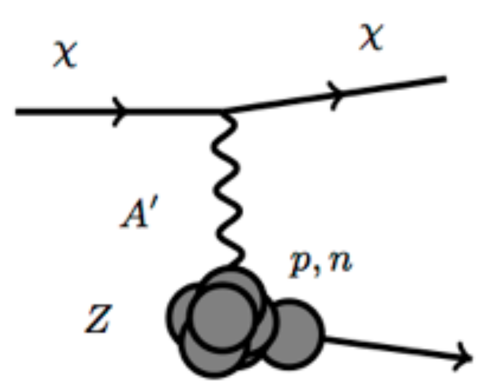
- similar searches can be done with fixed target experiments with proton beams (LSND, MiniBoone), typically (for low-mass A') from $\pi^0 \rightarrow \gamma\gamma \rightarrow \gamma A'$ decays, but
    - no sensitivity if $m_{A'} > m_\pi$ or $m_X > m_\pi/2$
    - large bkg from ν in beam
    - possibly leptophilic U-boson not produced in meson decay (kinetic mixing with universal coupling εq to all electric charges just the baseline; U-boson could couple to baryon number or to lepton number…)

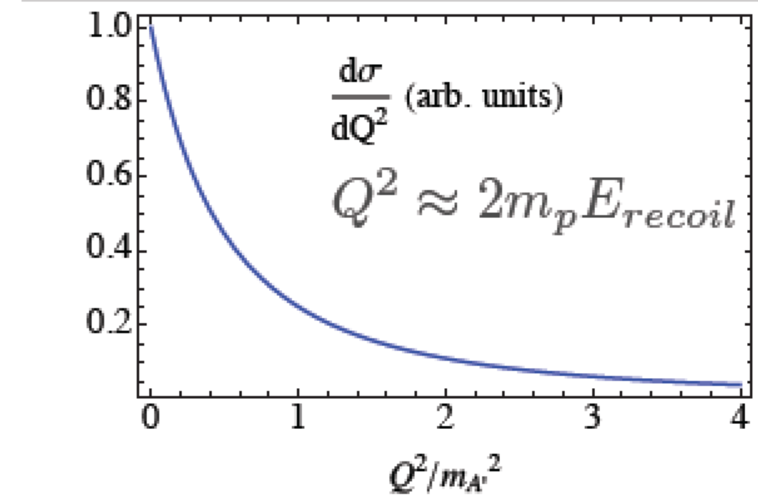
Signal cross sections for 2 benchmark scenarios

	S.I	S.II
M_χ	10 MeV	68 MeV
$M_{A'}$	50 MeV	150 MeV
ϵ	10^{-3}	10^{-3}
α_{Dark}	0.1	0.1
N_χ pairs produced per EOT	$3.4\ 10^{-10}$	$3.4\ 10^{-11}$
$\sigma_{\chi-p}$	1.4 nb	0.14 nb

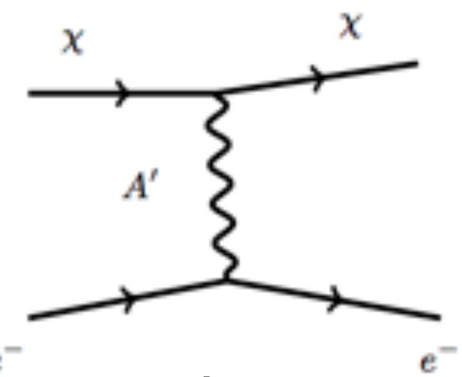
Signal properties

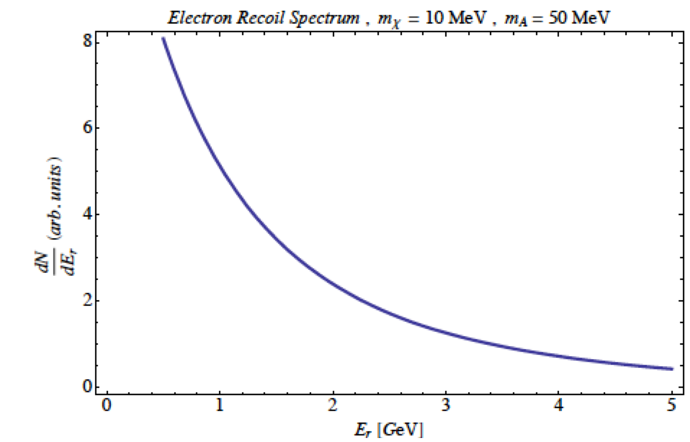
- A', X boosted forward ⇒ small ($1m^3$) detector enough for large acceptance
- 3 processes for potential detection
  - quasi-elastic nucleon scattering: main signal but large bkg, need low threshold ($E_{recoil} \sim m_{A'}^2/2m_N$ ~1-50 MeV)



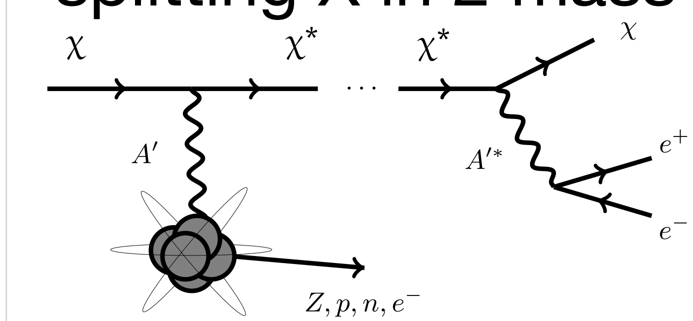


  - elastic electron scattering: small signal but virtually 0 bkg (e with > GeV energy)



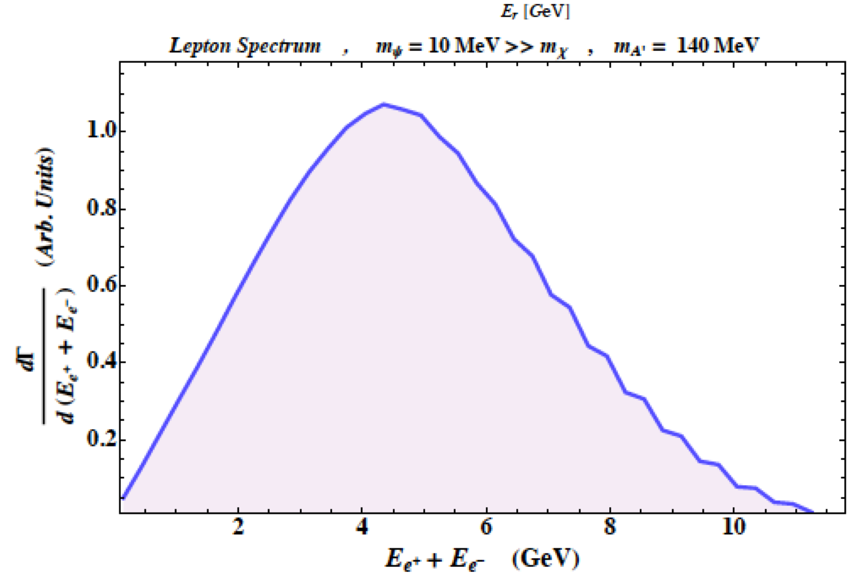


  - inelastic scattering (in case of Majorana mass term splitting X in 2 mass states with sufficient Δm):

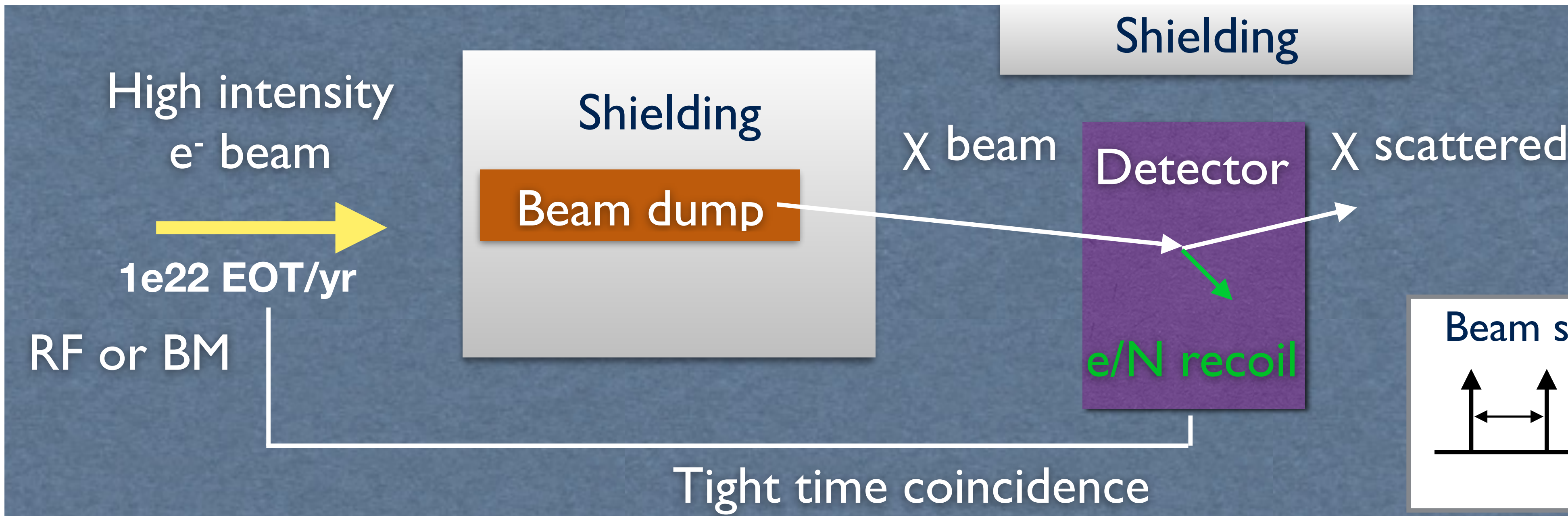


$$\text{energy} \sim \frac{\Delta m_\chi}{m_\chi} \times E_{beam}$$

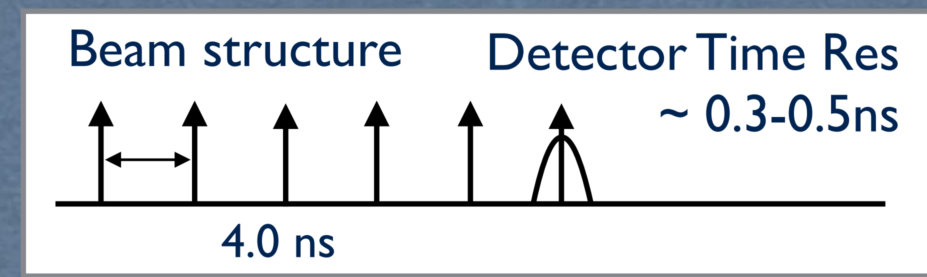
can be ≫ E_{recoil}

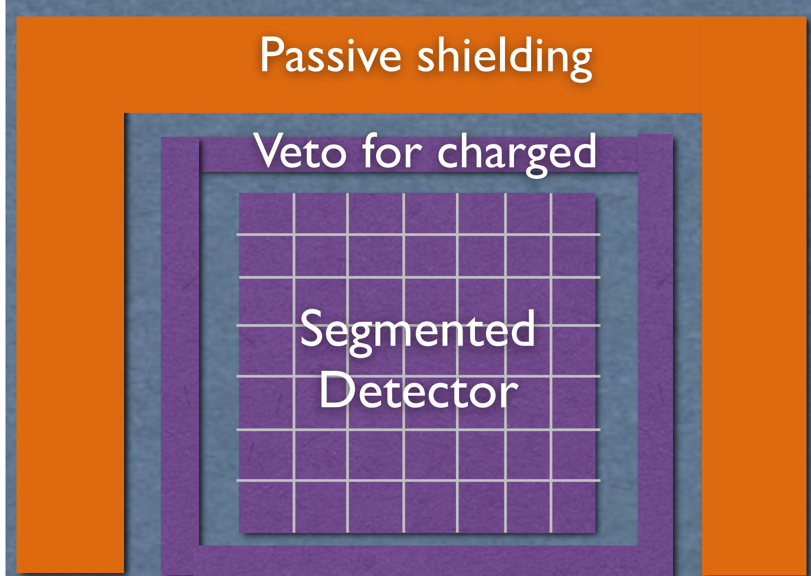


Detector concept and possible JLAB beam dumps



M.Battaglieri - INFN GE





Detector requirements

- Good time resolution to reject beam-uncorrelated background
- Segmentation for bg rejection
- Active veto
- Passive shielding **(1m iron + 5cm Pb)**
- Low threshold for nucleon recoil detection (~MeV)
- EM showers detection capability

~1 m^3 segmented plastic scintillator + lead foils

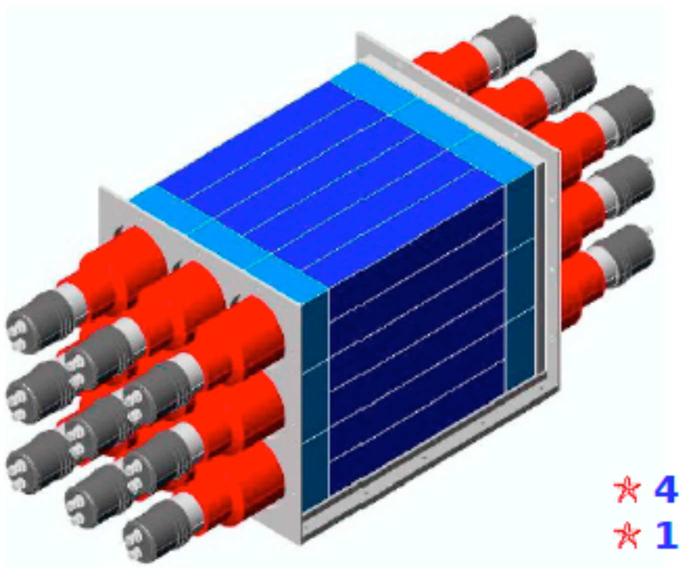
Hall-A/Hall-C

- E~11GeV
- high current (~100-200uA)
- Parasitic run
- No room behind the beam dump enclosure
- Ideal place for a full experiment

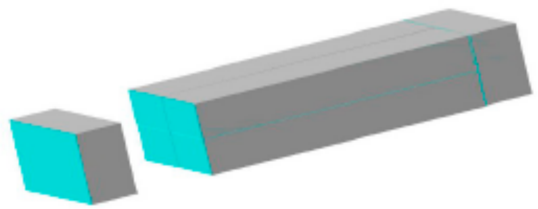
Hall-D

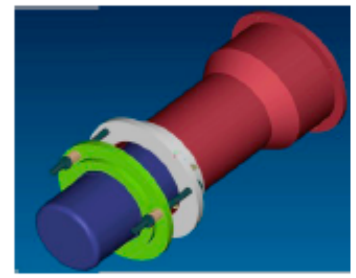
- E~12GeV
- moderate current ~200nA (may be increased up to 8 uA!)
- Over-the-ground beam dump
- Easy access to the back of the BD enclosure
- Simplified logistic: (shielded roof) hut, power, network, A/C

Detector concept/prototype



CORMORAD prototype
CORMORINO
scale $(1:3)^3 \sim 3\%\ m^3$



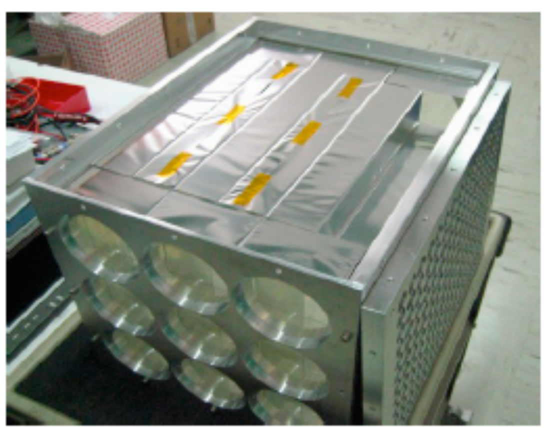


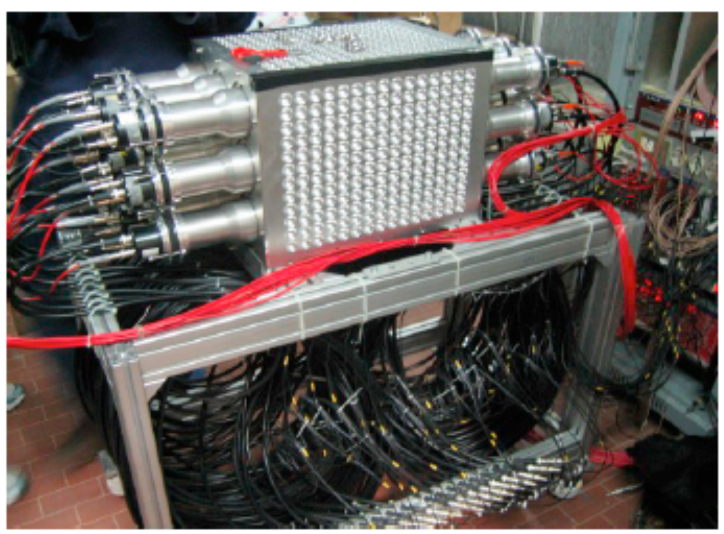
σ_T(MIP)~110 ps

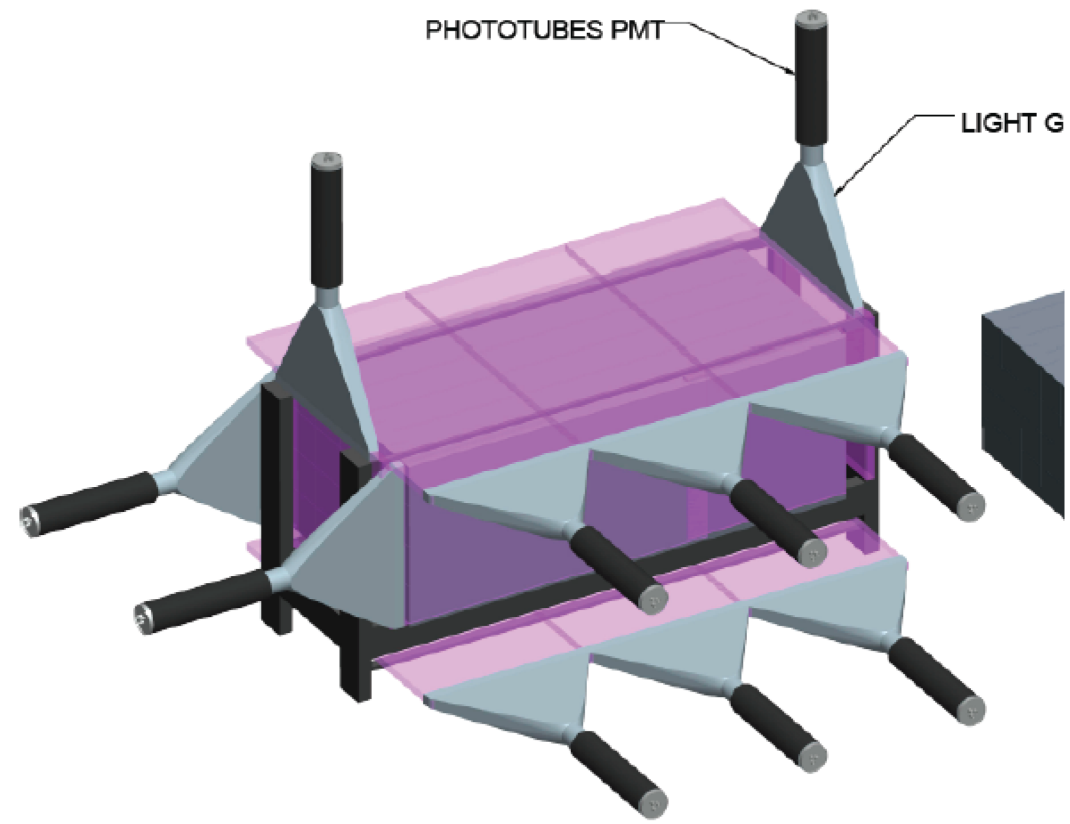
Prototype cell
- 4 30x5x5 cm^3 NE110 bars
- 1 5x10x10 cm^3 NE110 block
- 12.5 μm Gd foils wrapping

- Light read-out 18 Photonis XP2312 3" PMTs

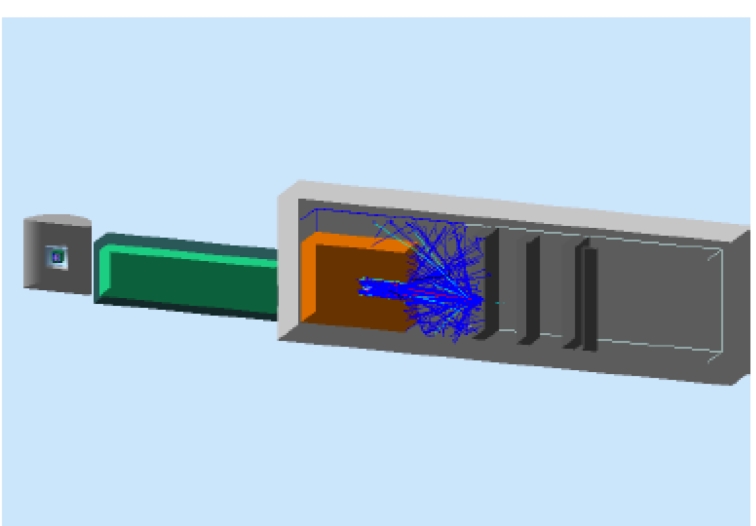
- Size: 40 x 30 x 30 cm^3

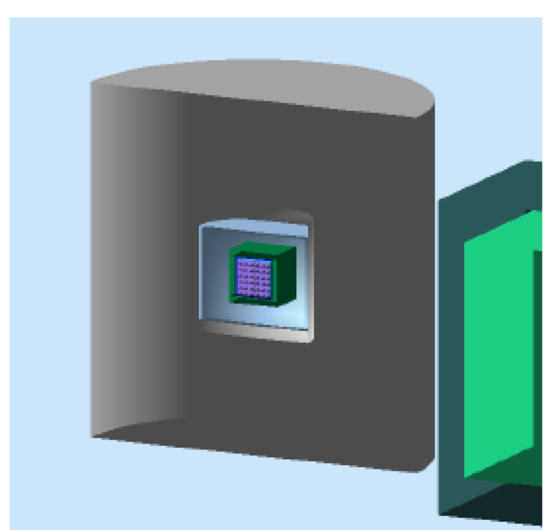






active veto (plastic scintillators paddles 2cm thick + single-side PMT readout)





- Implemented Geant4 simulation which includes attenuation length and light quenching effect
- Two detection thresholds studied: 1 MeV and 10 MeV

Backgrounds

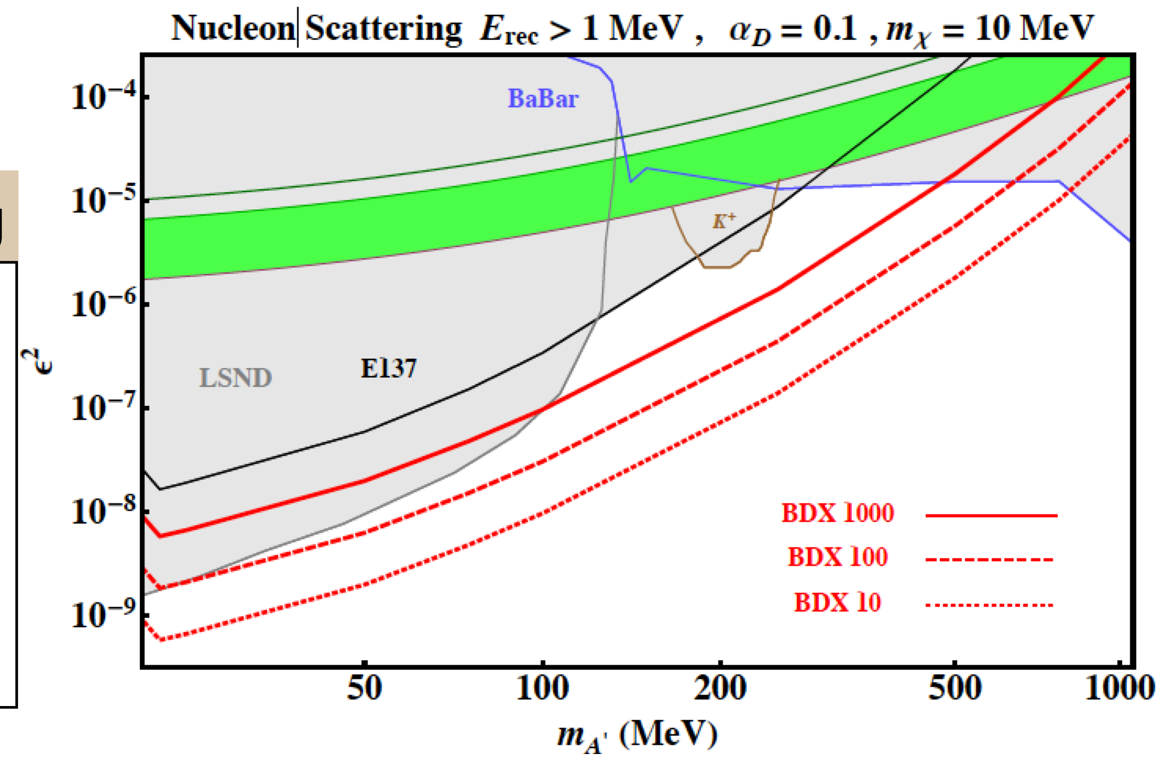
- beam-related: only neutrinos are expected to exit from the beam-dump (confirmed by simulation with 1.6e9 EOT so far)
  - negligible compared to beam-unrelated

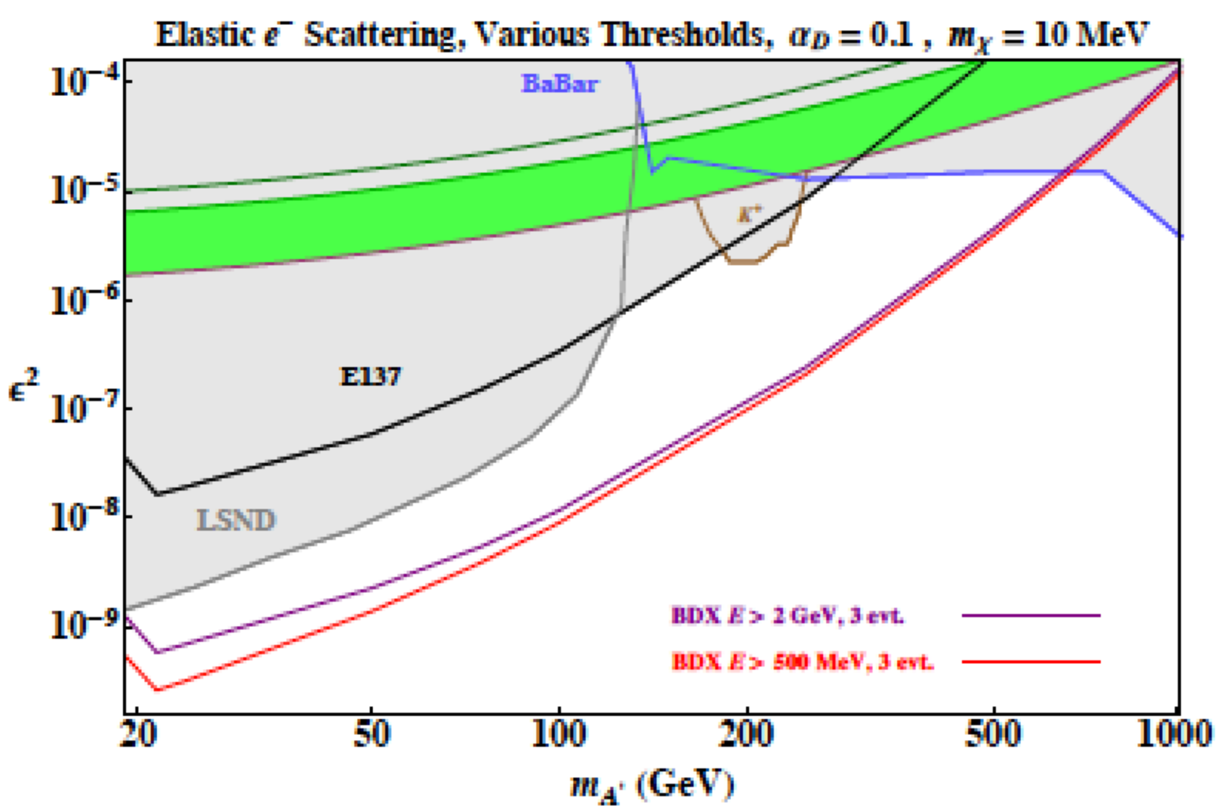
- beam-unrelated:
  - cosmic ν: negligible considering flux, xsec and threshold
  - cosmic n: sizeable (small probability to interact with plastic of veto)
    - 1m iron shield + detection energy threshold introduce a neutron energy cutoff (detection efficiency = 0 for $T_N < 50$ (100) MeV)
  - cosmic mu: sizeable
    - crossing: $\propto$ veto inefficiency (5%)^2 x probability(single hit)
    - decaying: $\propto$ veto inefficiency x probability(single hit)
  - estimated with MC, to be validated by real measurements

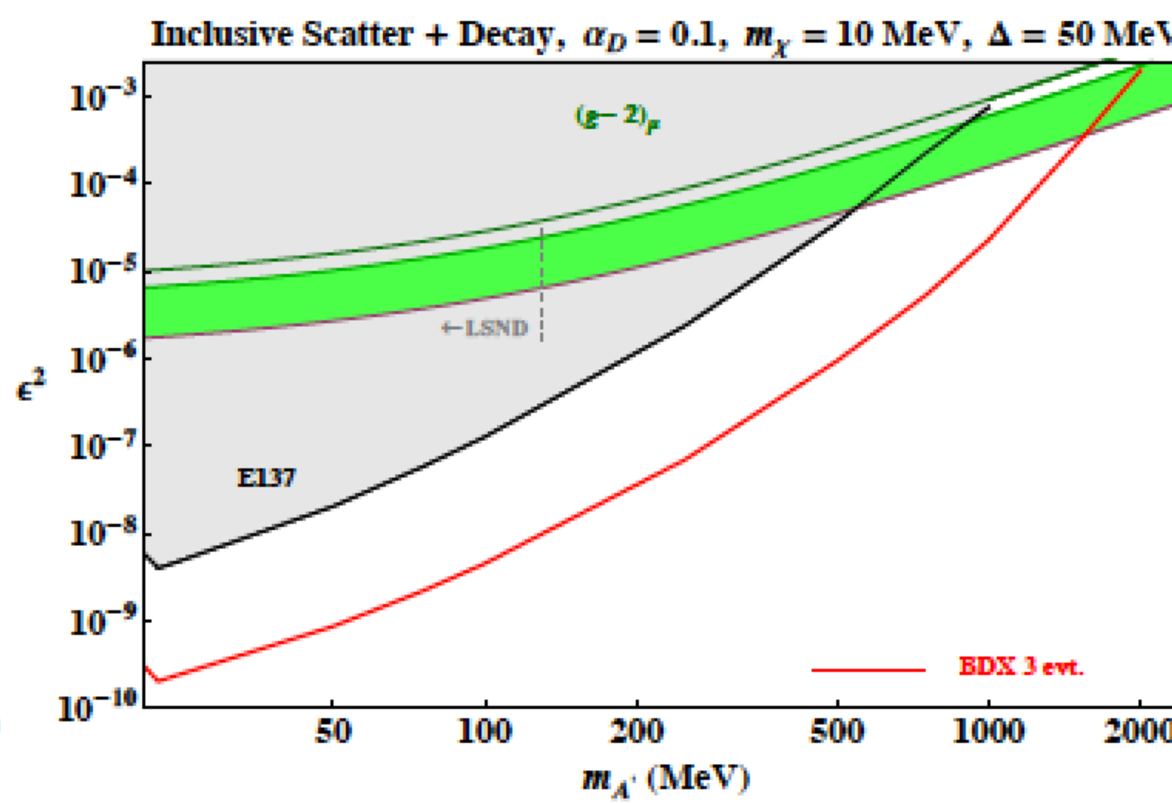
BDX expectations

- baseline detector = 30x Cormorino interleaved with 1mm lead foils to increase X/X_0
- assume time coincidence giving non-beam rejection factor $R=3\sigma_T/4ns=5$ (conservative)

	nucleon scattering		e scattering
	Counts $_{Thr=1MeV}$	Counts $_{Thr=10MeV}$	EM shower Thr=150 MeV
χ detection - S.I	$0.5\ 10^6 \pm 700$	$5.7\ 10^4 \pm 240$	
χ detection - S.II	$1.0\ 10^4 \pm 100$	$3.3\ 10^3 \pm 60$	
Beam-rel bg	100 ± 10	10 ± 3	~0 (<3)
Beam-unrel bg	$1.6\ 10^6 \pm 1300$	$1.4\ 10^6 \pm 1200$	~0 (<3)







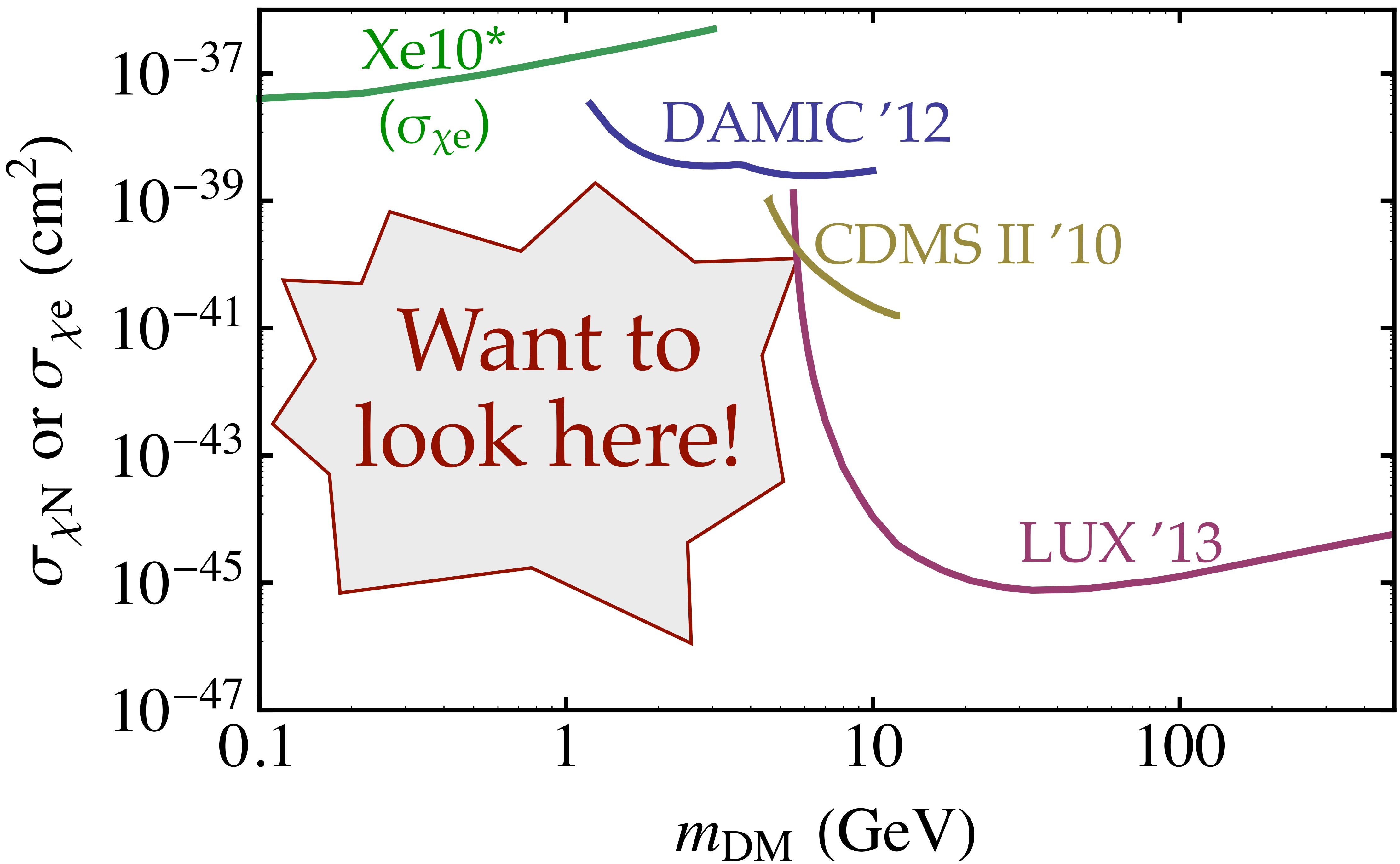
Activities foreseen

- Measurement of cosmogenic bkg
- Define full detector design, try to
    - improve electron/proton discrimination
    - directionality to correlate hits with beam
    - optimise cost (PMTs, # of instrumented channels)
- Prepare full simulations
- Reconstruction
- Financing/construction/installation..

Conclusion

- low-mass DM and dark photons a possible alternative to the WIMP paradigm
- HPS: visible decays of the dark photon: short-term perspectives, requiring no R&D effort
  - possible contributions to software, data-taking and analysis in 2015 and 2016 (further data-taking depending on JLAB schedule and DOE funds)
  - data taking in 2015, join now or never
- BDX: complementary search for invisible decays, more medium term, contribution to design phase possible
  - important overlap with HPS Collaboration
- partial contributions from people already involved at larger FTEs in other projects possible
- small initial investment needed for an activity that is complementary to the WIMP searches in which other LPNHE members are getting involved

Current landscape



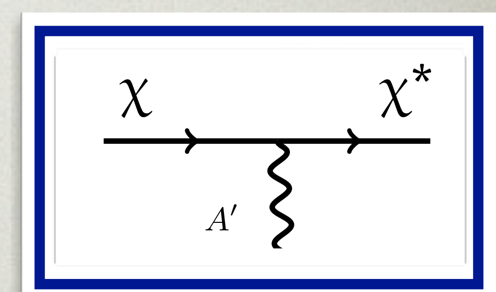
Some unknowns

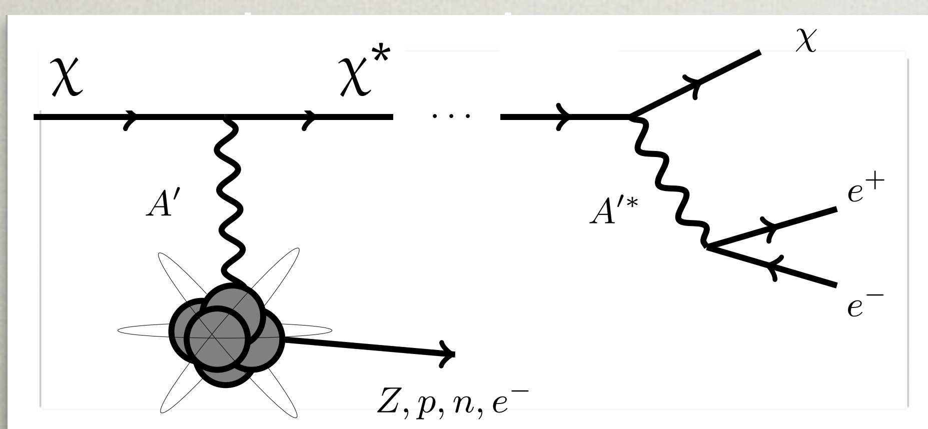
Matter couplings

- Baseline model: A′ kinetic mixing (coupling εq to **all** electric charges)
- But U-boson could couple to baryon number, or to lepton numbers
  - ⇒ some beams/scattering reactions insensitive
  - ⇒ indirect constraints (e.g. modified e–ν scattering from $U(1)_L$)

Dark Matter Structure

- Generic possibility: χ splits into two Majorana/real states of different mass (χ and χ*). **A′ coupling is off-diagonal.**





⇒ kinematic threshold for up-scattering **shuts off** direct detection $E_\chi > m_{\chi^*} + \frac{\Delta m_\chi^2}{2m_e}$

⇒ new signal: decay e⁺e⁻ pair

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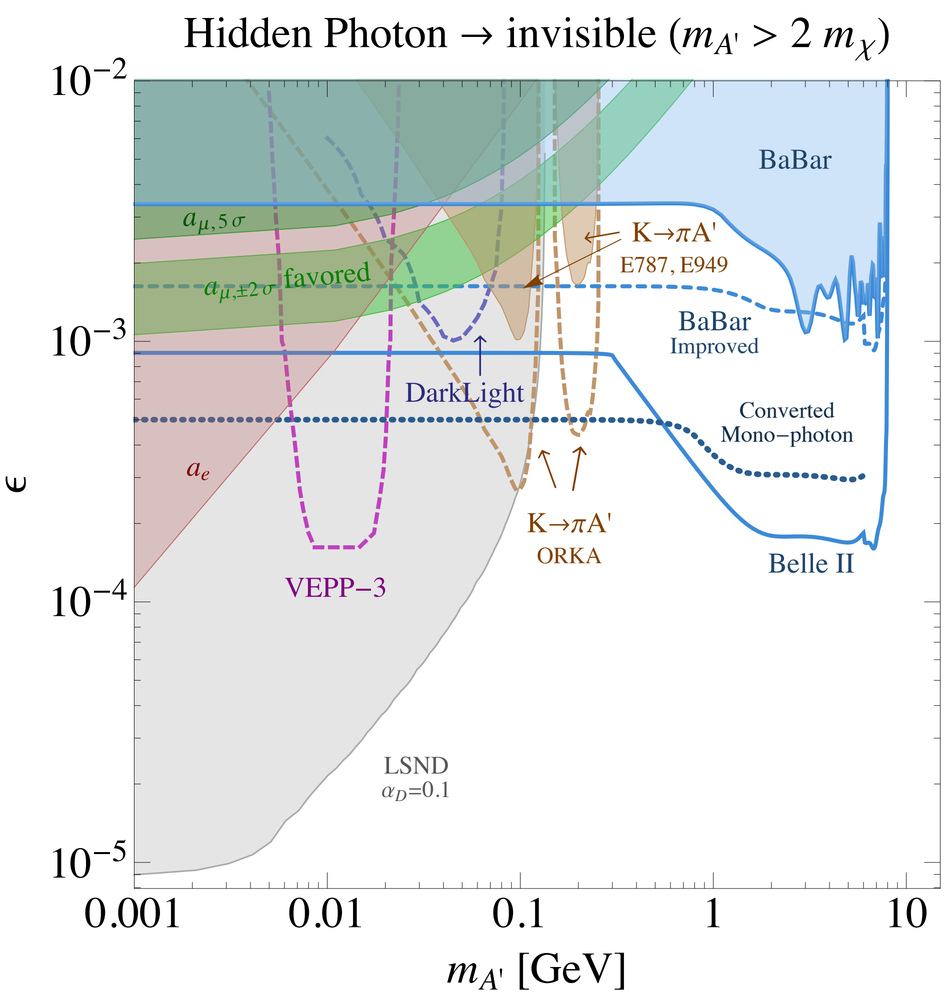
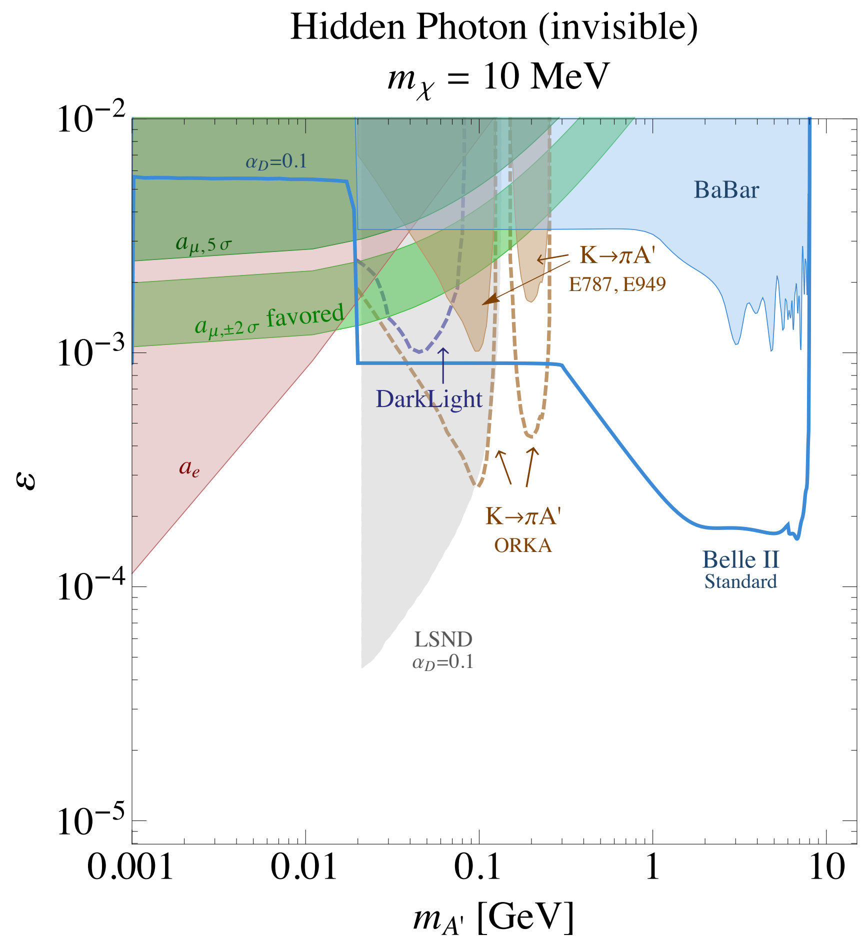
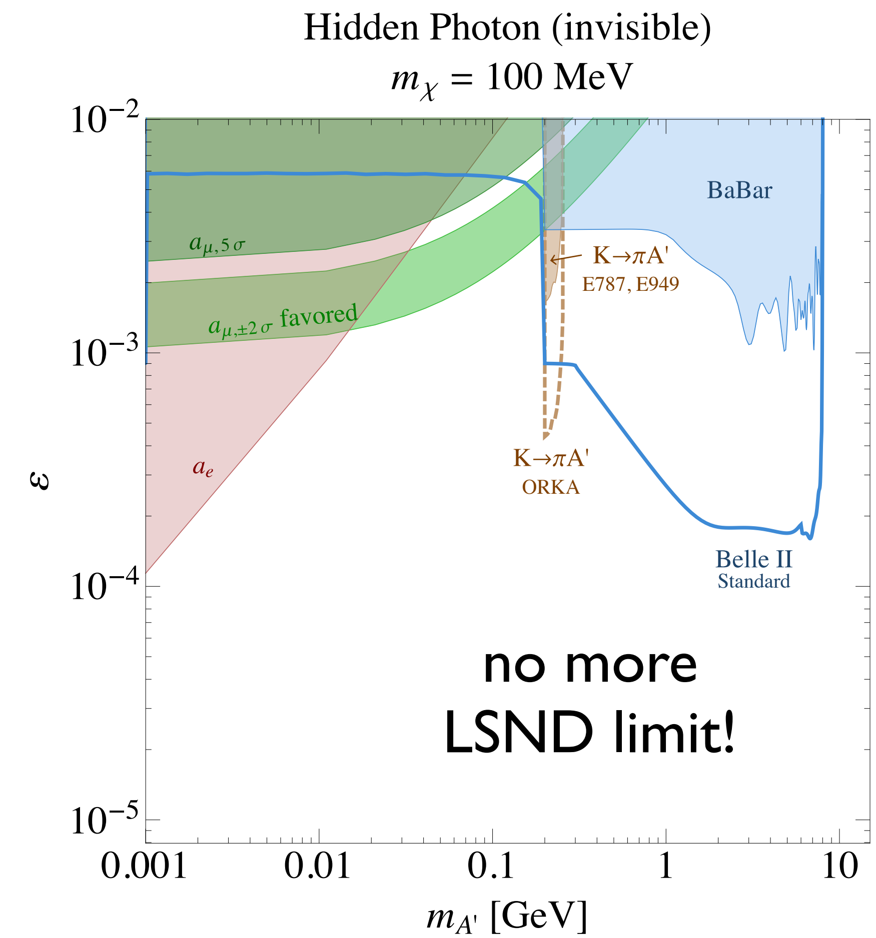
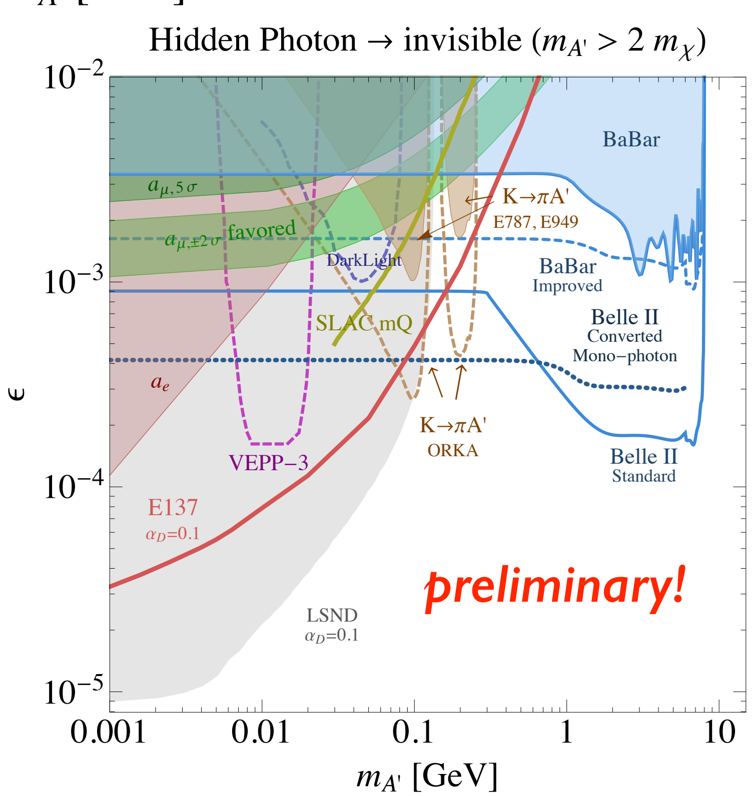
Current limits









Important caveat

There is a danger in comparing constraints/prospects from different experiments “blindly”. They are correct in the “simplest” kinetic mixing model, w/o mass splitting among DM states, etc., but simple model building can change things drastically

Expected backgrounds in Cormorino prototype

	Rate $_{Thr=1\text{MeV}}$ (Hz/μA))	Rate $_{Thr=10\text{MeV}}$ (Hz/μA))
χ detection - S.I	$1.0\ 10^{-5}$	$1.2\ 10^{-6}$
χ detection - S.II	$2.0\ 10^{-7}$	$0.7\ 10^{-7}$
B-rel ν	$2.0\ 10^{-9}$	$2.0\ 10^{-10}$
B-rel neutron	0	0
	Rate $_{Thr=1\text{MeV}}$ (Hz)	Rate $_{Thr=10\text{MeV}}$ (Hz)
B-unrel ν	$2.0\ 10^{-6}$	$2.0\ 10^{-7}$
B-unrel neutron	$2.7\ 10^{-3}$	$0.6\ 10^{-3}$
Crossing muons	$3.3\ 10^{-3}$	$3.5\ 10^{-3}$
Captured μ^+	$1.4\ 10^{-3}$	$2.4\ 10^{-3}$
Decaying μ^- (CORM)	$2.9\ 10^{-3}$	$4.8\ 10^{-3}$
Stopped μ in lead	$7.0\ 10^{-3}$	$4.3\ 10^{-3}$
μ^- rare decay	$2.0\ 10^{-5}$	$8.0\ 10^{-6}$
Total Beam-unrelated bg	$1.7\ 10^{-2}$	$1.5\ 10^{-2}$

- with baseline granularity and no use of timing information
- beam-related bkg does not seem to be an issue
- cosmogenic bkg to be validated by real measurements