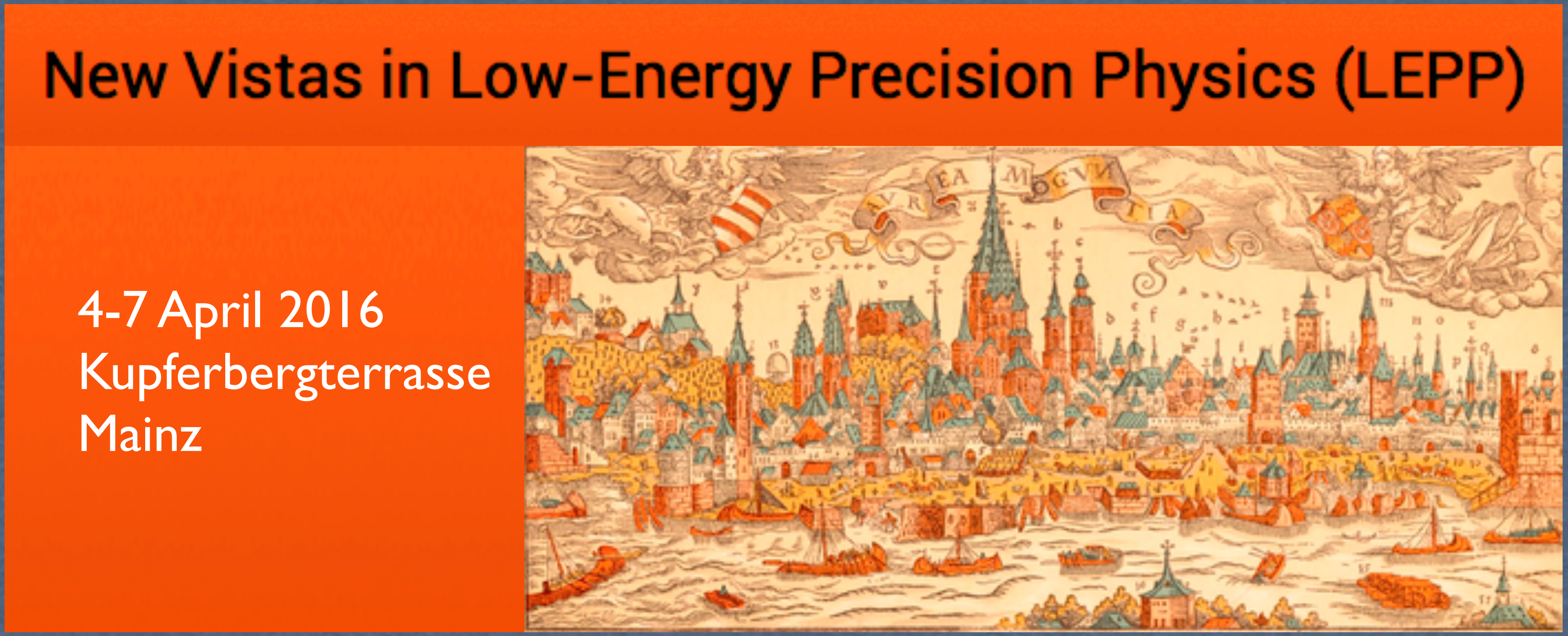


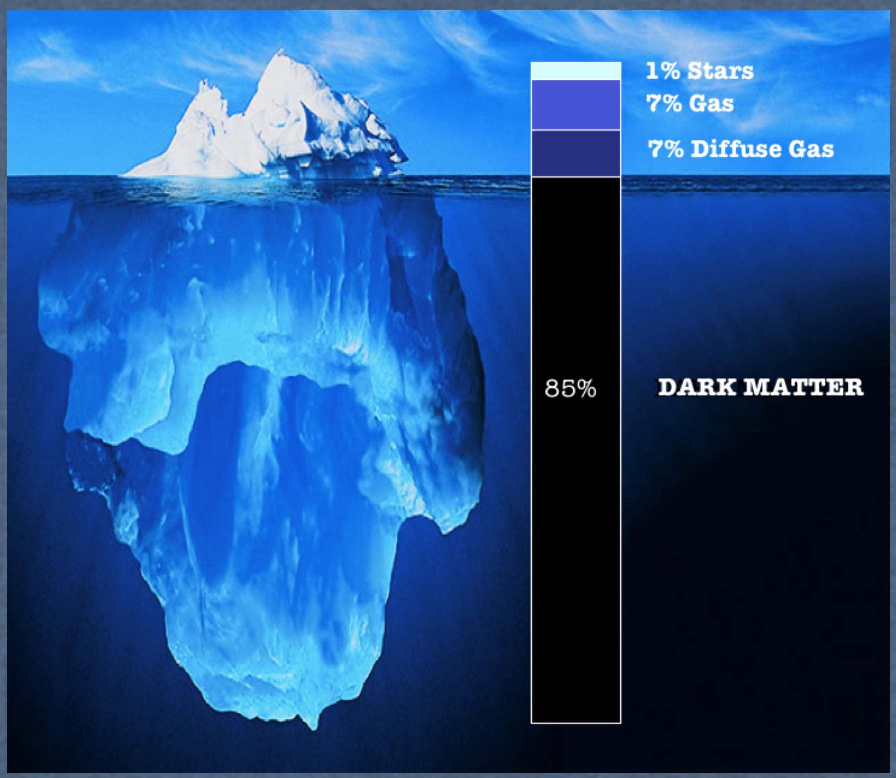
BDX
Light Dark Matter search in a Beam Dump eXperiment

M.Battaglieri
INFN-GE Italy

Dark Matter (DM) vs Baryonic Matter (BM)

Compelling astrophysical indications about DM existence

★ How much DM w.r.t. BM?



★ Does DM participate to non-gravitational interactions?
★ Is DM a new particle?

★ Constraint on DM mass and interactions

- should be '*dark*' (no em interaction)
- should weakly interact with SM particles
- should provide the correct relic abundance
- should be compatible with CMB power spectrum

… assuming that the gravity is not modified and DM undergoes to other interactions

★ We can use what we know about standard model particles to build a DM theory

Use the SM as an example: $SM = U(1)_{EM} \times SU(2)_{Weak} \times SU(3)_{Strong}$

Particles, interactions and symmetries

Known particles & new force-carriers

Particles:
quarks, leptons

Force-carriers:
gluons, γ, W, Z, graviton (?), Higgs, ...

Two options:

★ New matter interacting trough the same forces
★ New matter interacting through new forces

Any guess about the DM mass and interaction?

★ DM as thermal relic from the hot early Universe

Minimal DM abundance is left over to the present day

Correct DM density for an annihilation xsec:

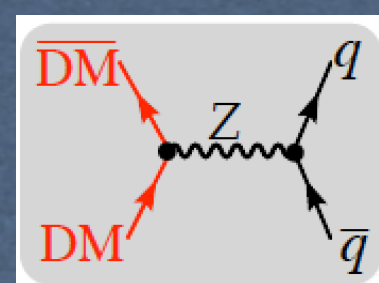
$\langle\sigma v\rangle \sim 3\text{x}10^{-26}\ \text{cm}^3/\text{s} \sim 1/(20\ \text{TeV})^2$

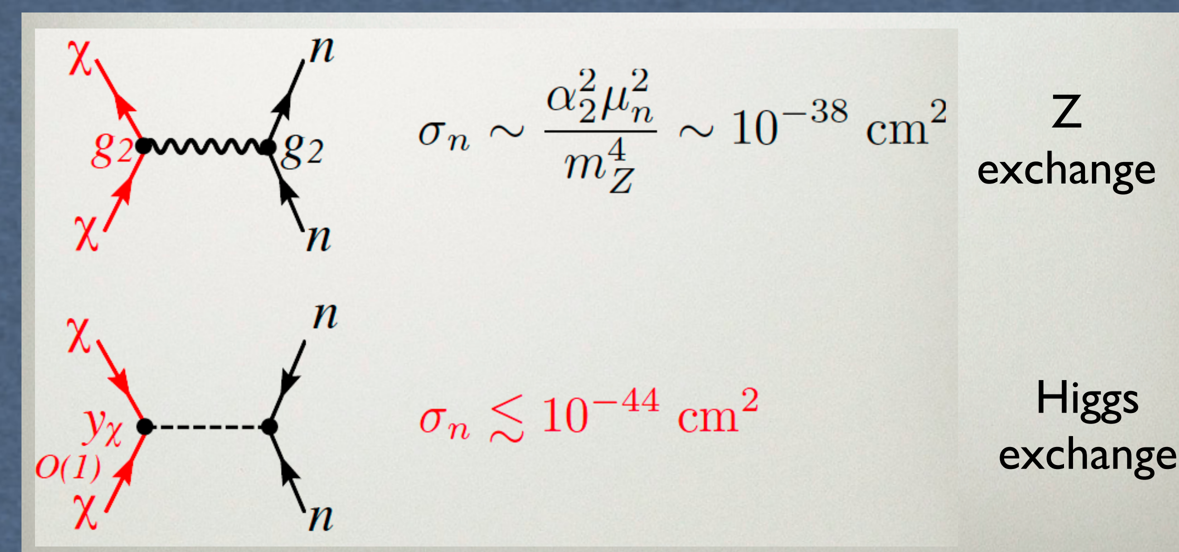
$\langle\sigma v\rangle \sim M^2_{DM}/M^4_{mediator}$

Thermal origin suggests DM interactions and mass in the vicinity of the weak-scale

★ WIMPs (Weakly Interacting Massive Particles)

- Massive DM with massive mediator
- For ~100 GeV DM mass, weak-scale mediators provide reasonable annihilation rate and range of DM-scattering rates





WIMPs paradigm is not the only option

Light Dark Matter

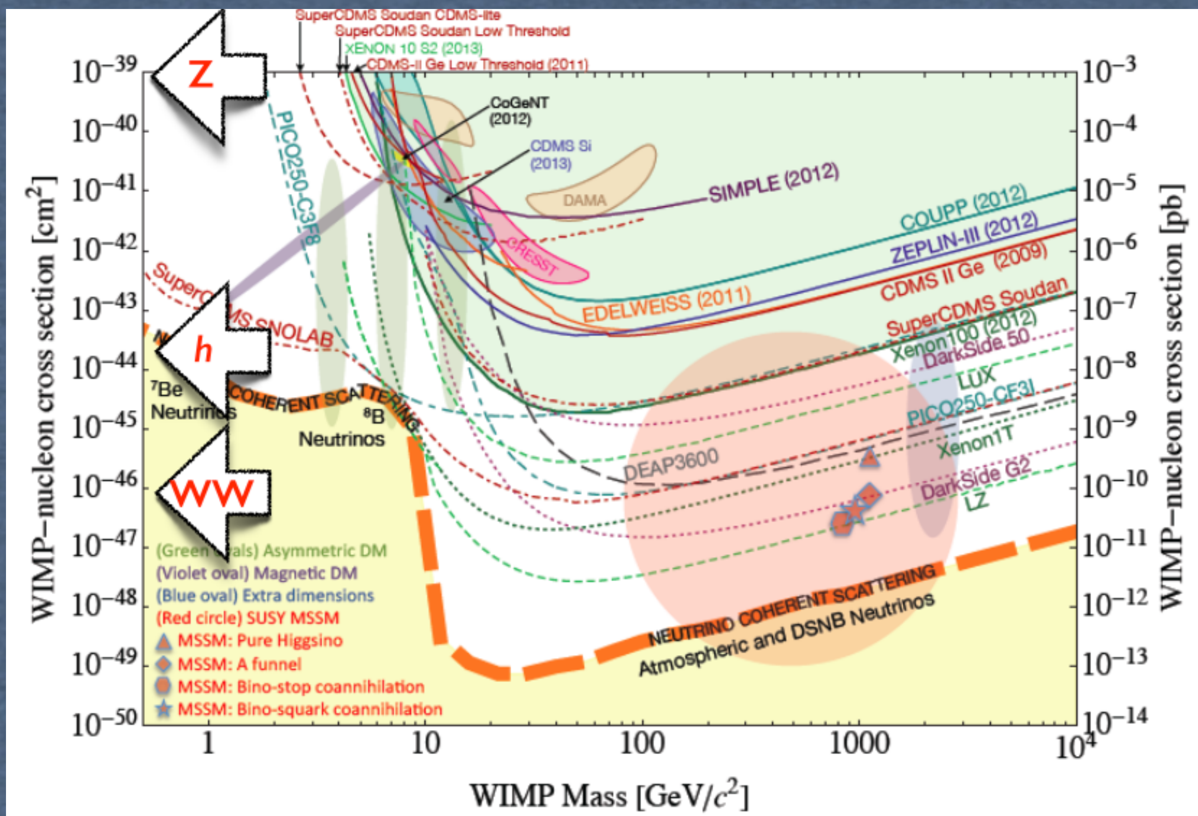
Light Dark Matter (<TeV) naturally introduces light mediators

what matter is: $\langle\sigma v\rangle$ x m^2

New interaction

Exploring the WIMP's option

★ Experimental limits



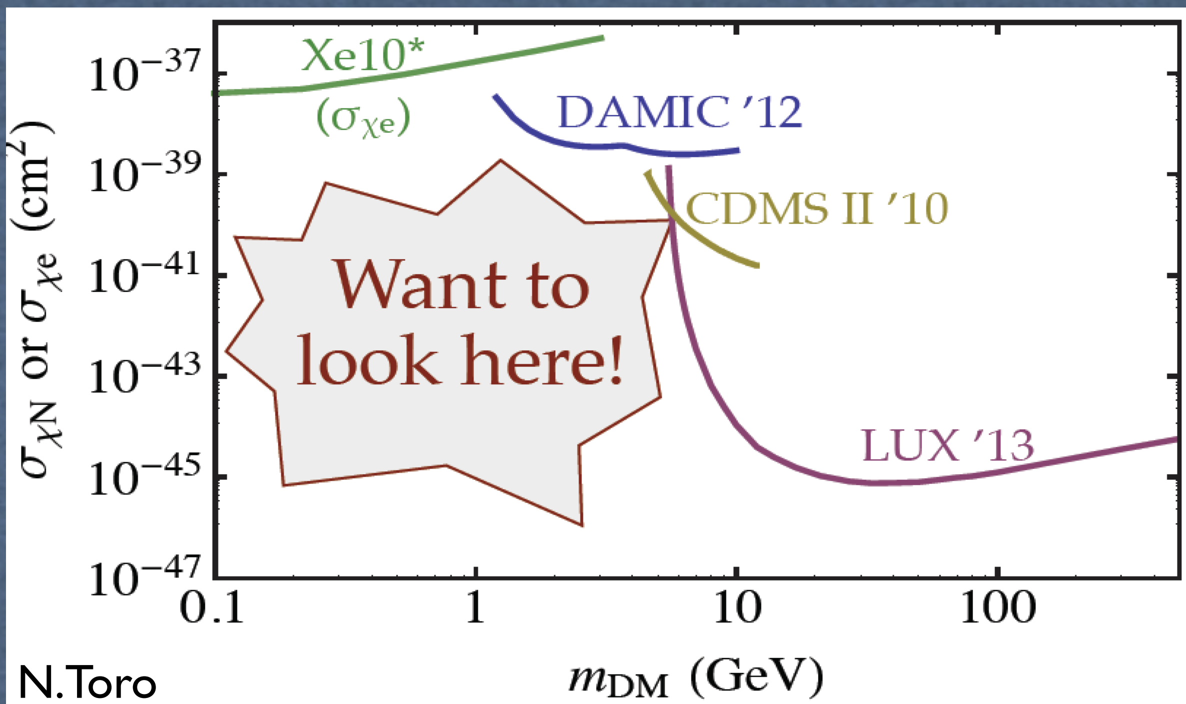
Slow-moving cosmological weakly interacting massive particles

- DM detection by measuring the (heavy)nucleus recoil
- Constraints on the interaction strength from the DM Direct Detection limits
  - Scattering through Z boson ($\sigma \sim 10^{-39}$cm^2): ruled out
  - Approaching limits for scattering through the Higgs ($\sigma \sim 10^{-45}$cm^2)
  - Close to irreducible neutrino background

No signal in direct detection → no sensitivity to light DM (<1 GeV)

What if ...

★ Experimental limits



Light Dark Matter with a (almost) weak interaction (new force!)

- Direct Detection is (almost) impossible
  - Low mass elastic scattering on heavy nuclei produces small recoil
  - eV-range recoil requires a different detection technology
  - Directionality may help to go behind existing limits at large masses

Accelerators-based DM search

covers an unexplored mass region extending the reach outside the classical DM hunting territory

- High intensity
- Moderate energy

Light Dark Matter | Direct Detection

1 MeV | 1 GeV | Mz | 10 TeV

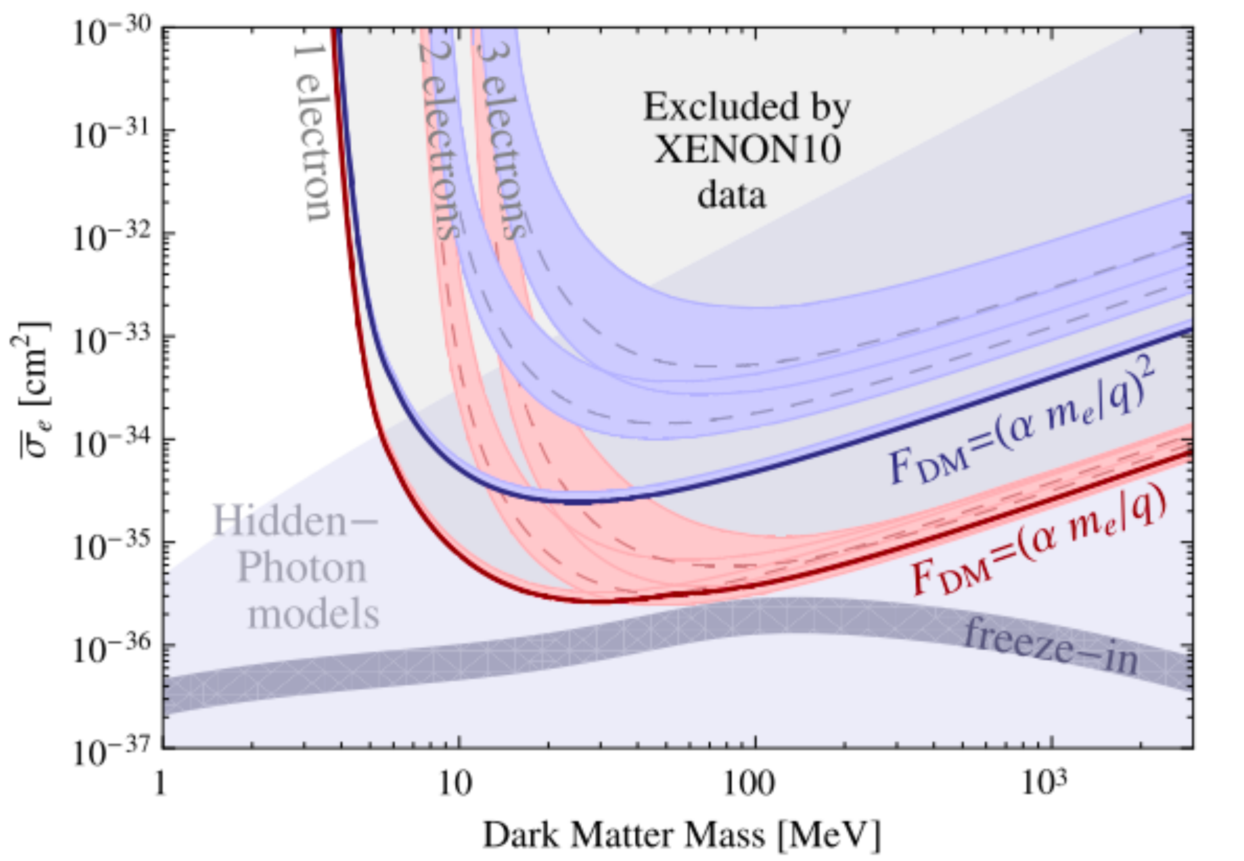
WIMPs

Dark Sector or Hidden Sector (DM not directly charged under SM interactions)

Can be explored at accelerators!

LDM - Direct Detection limits

Limits from XENON10



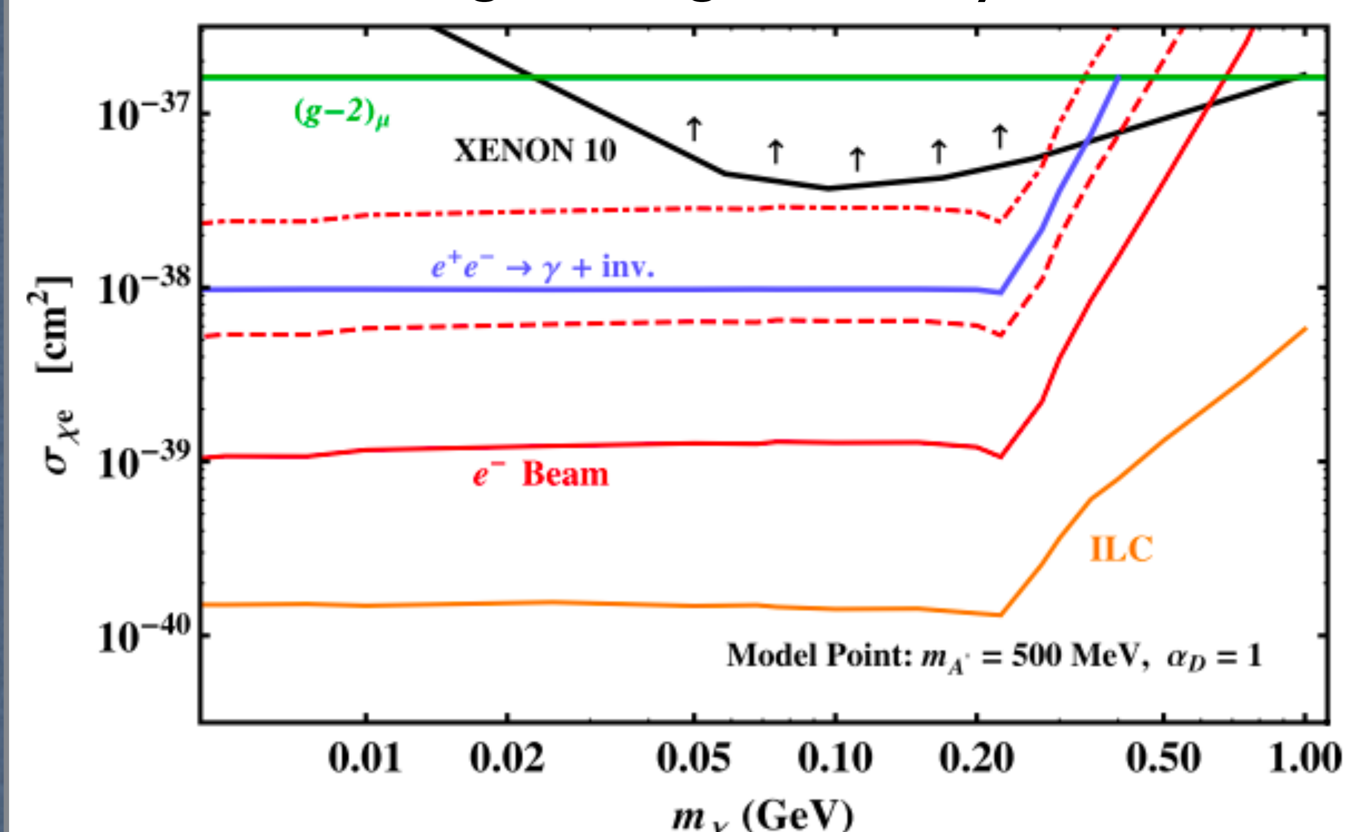
PhysRevLett. 109.021301 R.Essig, A.Manalaysay, J.Mardon, P.Sorensen, T.Volansky,

- Best limits on LDM interaction cross section obtained by direct DM detection (XENON10 and LUX)
  - χ_{cosmic}-e scattering
  - 1-electron ionization sensitivity
  - No FF for the scattering

- Fixed target electron beam experiments can be 10^3 - 10^4 more sensitive in the 1 MeV - 1 GeV mass range

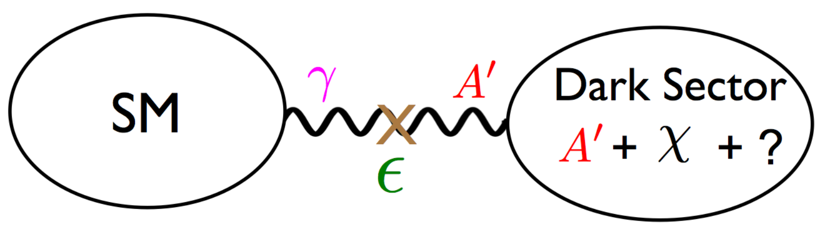
- No experiments were designed to measure LDM (all limits come from reinterpretation of old experiments)

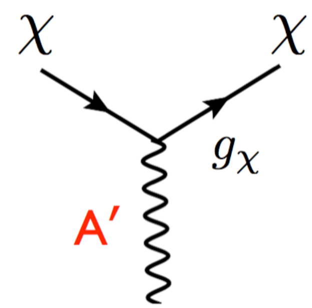
Fixed target & high intensity e$^-$ beam

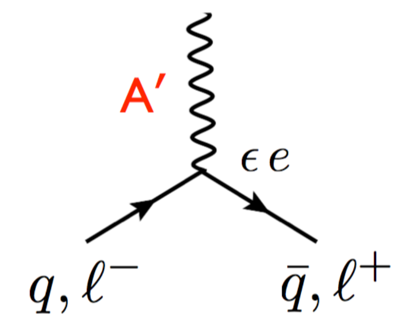


PhysRevD.88.114015 E.Izaguirre, G.Krnjaic, Gordan, P.Schuster, N.Toro

Dark forces and dark matter
(Light WIMPs - light mediators)



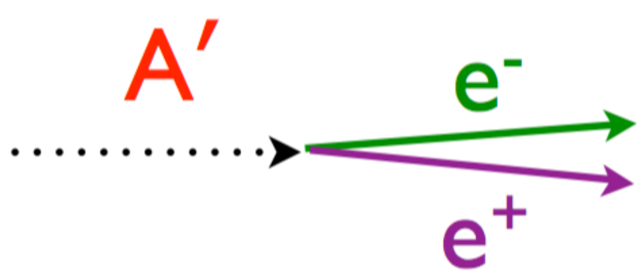




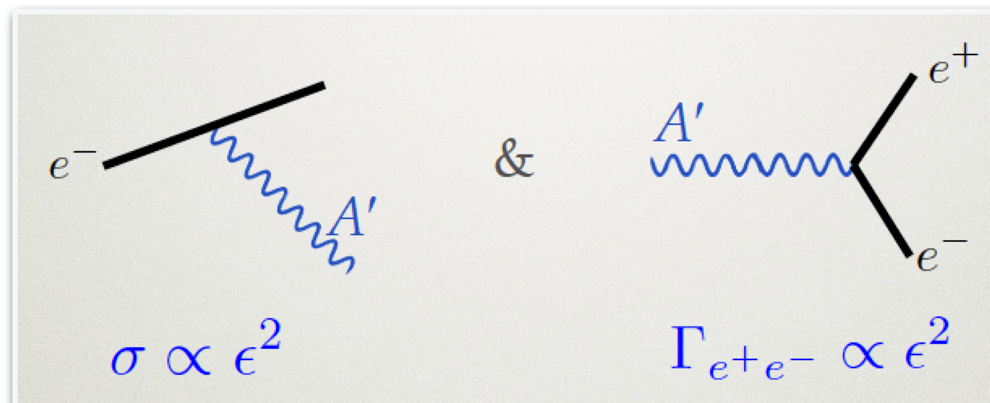
4 parameters: $m_\chi, m_{A'}, \epsilon, g_\chi$

$m_\chi \sim m_{A'} \sim \mathrm{MeV} - 5\ \mathrm{GeV}$

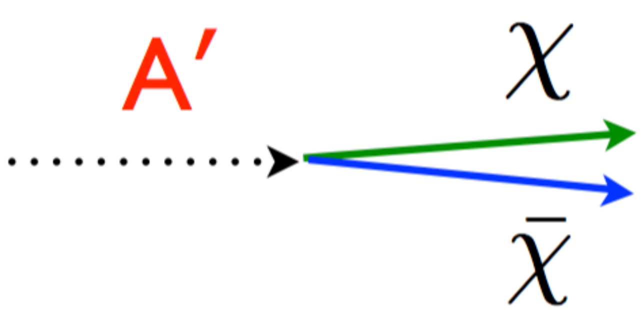
Visible



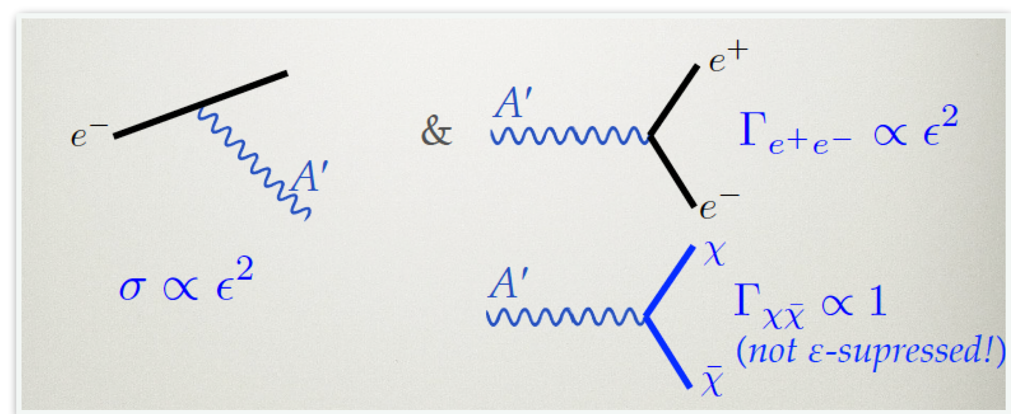
- *Minimal* decay
- Decay regulated by ε^2
- Independent of m_χ
- Requires $m_{A'} < 2m_\chi$



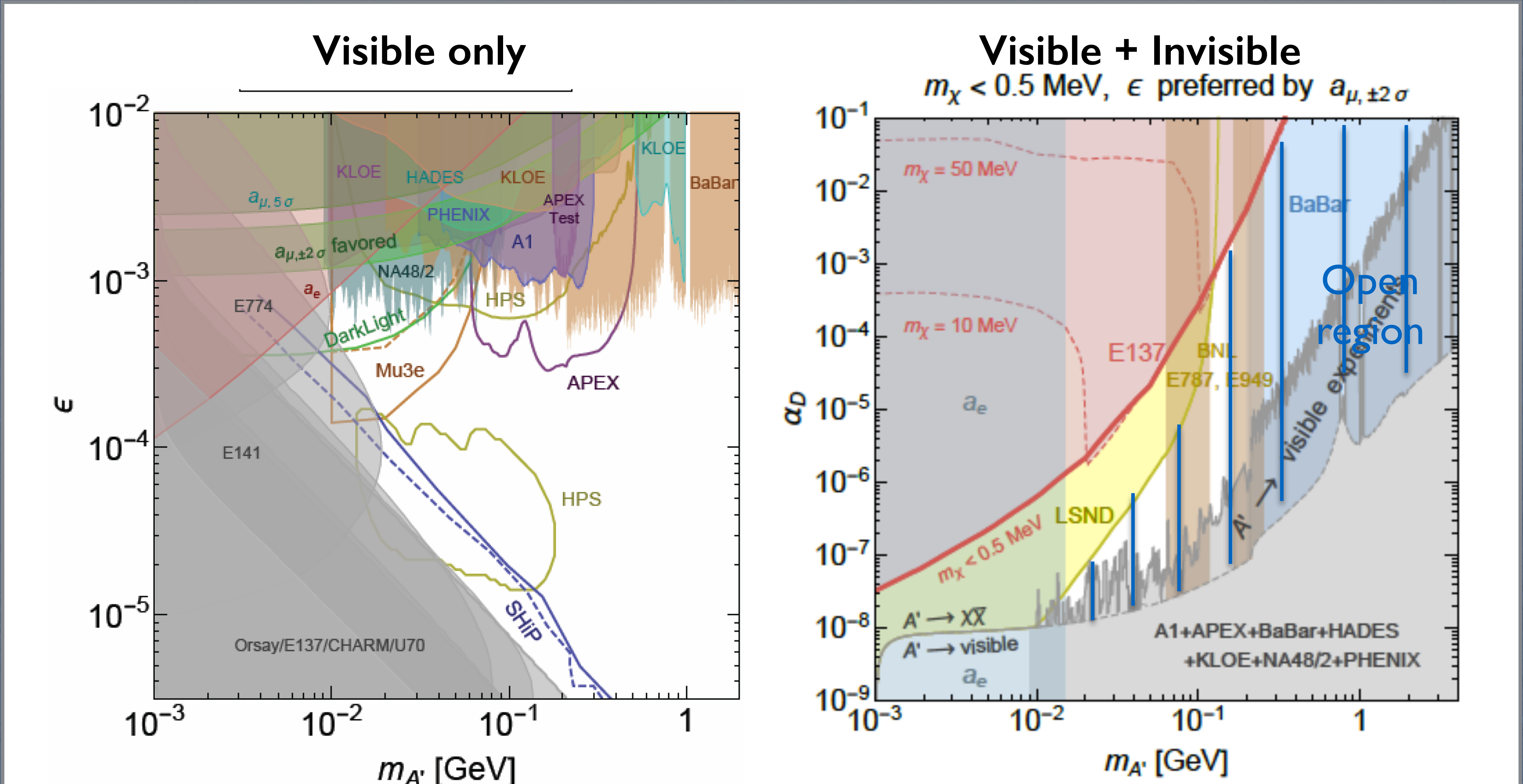
Invisible



- $m_\chi < 2m_{A'}$
- i) stable and invisible
- ii) decays to SM particles
- Independent of ε



Visible vs Invisible: complementarity
$(g-2)_\mu$



Strong Constraints on Sub-GeV Dark Matter from SLAC Beam Dump E137
PhysRevLett.113.171802 Brian Batell, Rouven Essig, Ze'ev Surujon

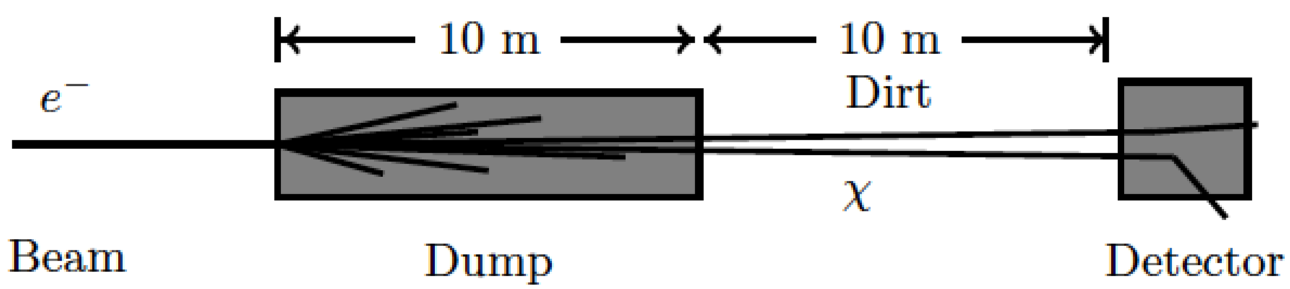
- *$(g-2)_\mu$* favoured region ruled out if DM ONLY decays to SM particles
- Exclusion limits are model dependent: if invisible decay is included limits do not hold!

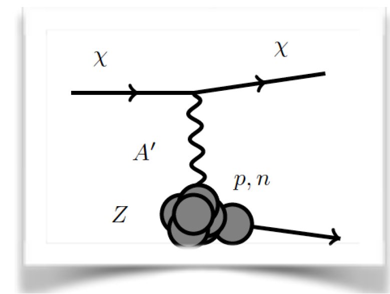
Fixed target DM production

Two steps process

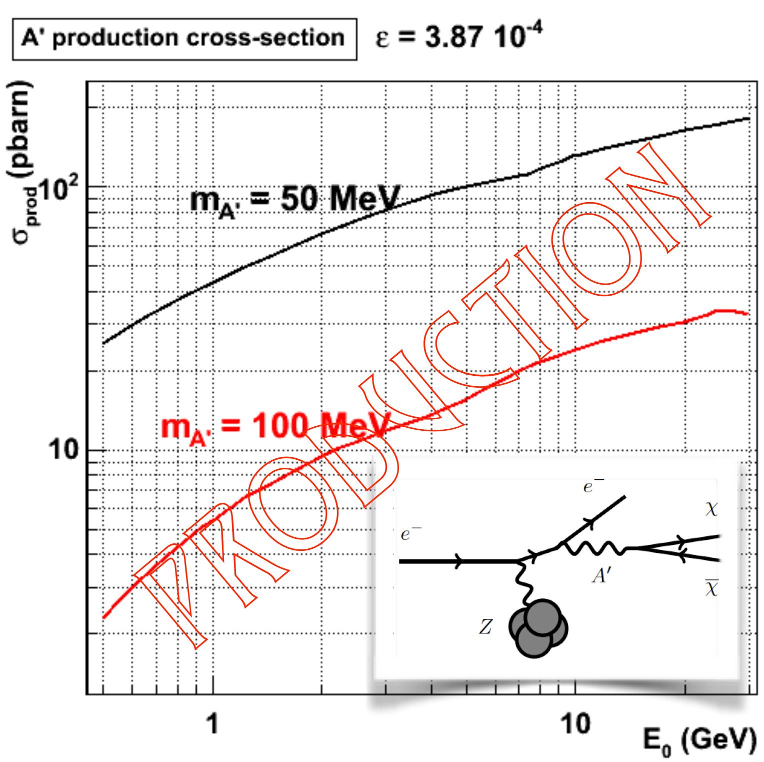
I) An electron radiates an A' and the A' promptly decays to a χ (DM) pair

II) The χ (in-)elastically scatters on a e⁻/nucleon in the detector producing a visible recoil (GeV/MeV)





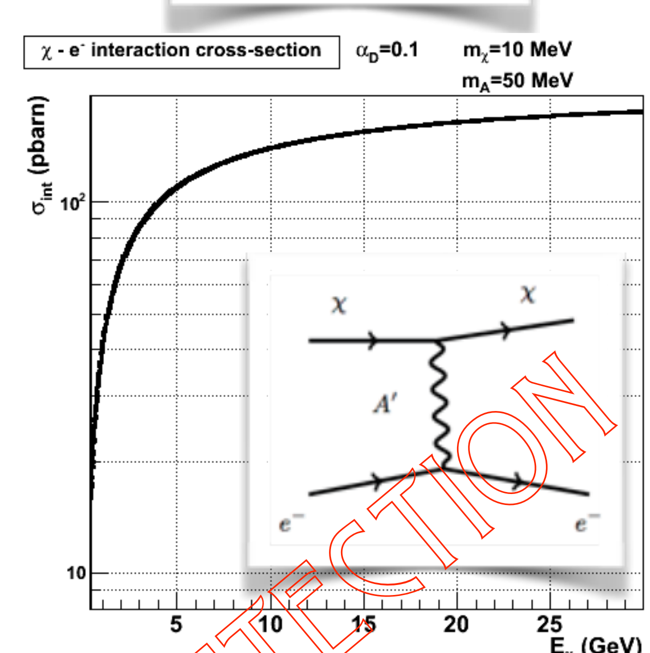
Elastic on nuclei



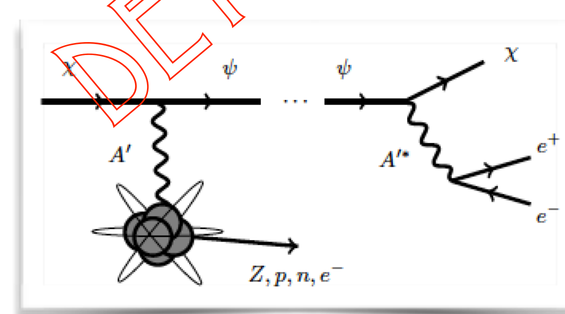
A' yield: $N_{A'} \propto \frac{\varepsilon^2}{m_{A'}^2}$

χ cross-section: $\sigma_{\chi e} \propto \frac{\alpha_D \varepsilon^2}{m_{A'}^2}$

Number of events: $N_\chi \propto \frac{\alpha_D \varepsilon^4}{m_{A'}^4}$



Elastic on electrons



Inelastic on nuclei

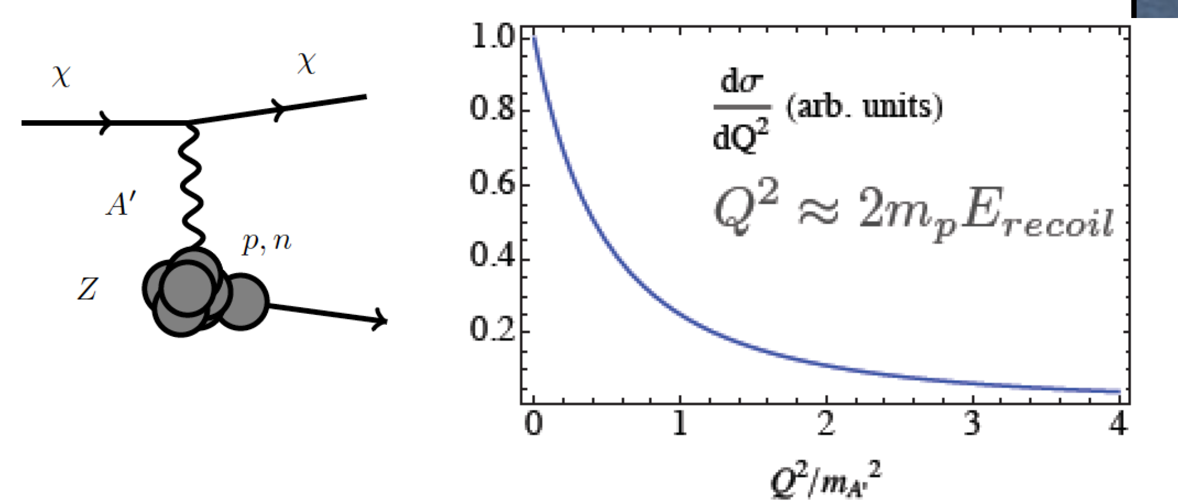
- Weak Xsections dependence on E_{beam} for E>few GeV
- At low energy detector acceptance can be an issue

PhysRevD.88.114015 E.Izaguirre,G.Krnjaic, P.Schuster, N.Toro

1) Elastic scattering on nucleon

2) Elastic scattering on electrons

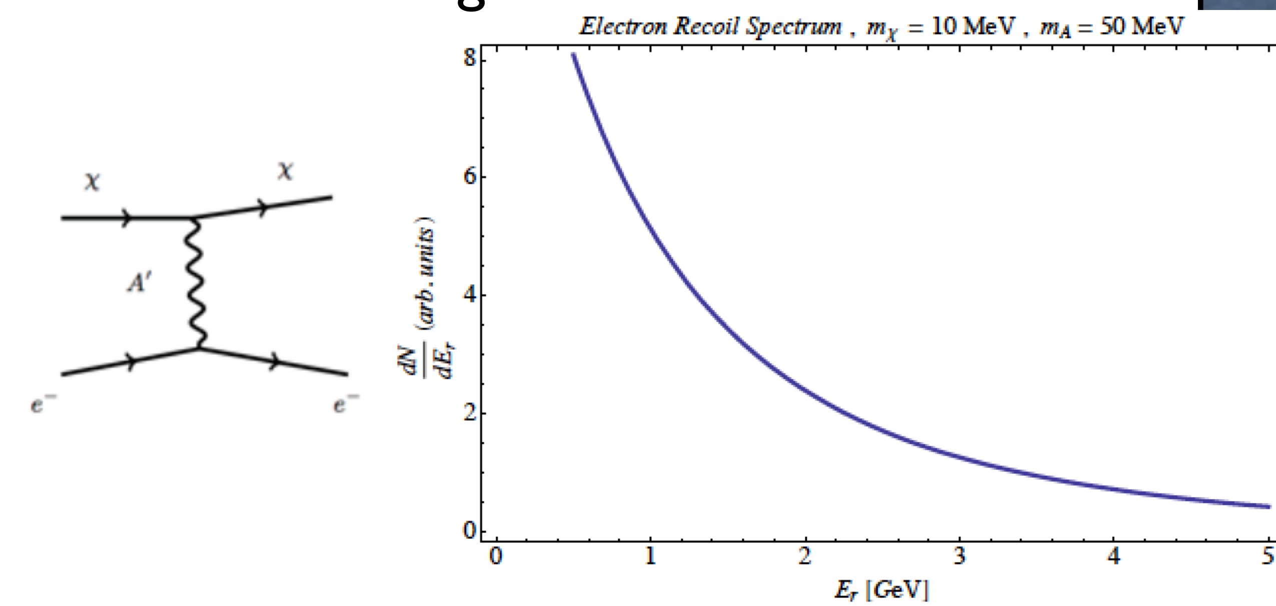
✳Elastic scattering on nucleon



Nucleon recoil: sizeable cross section for T_N>1-10 MeV

Low energy background rejection capability (~1 MeV)

✳Elastic scattering on electron



Electron recoil: em shower of few GeV

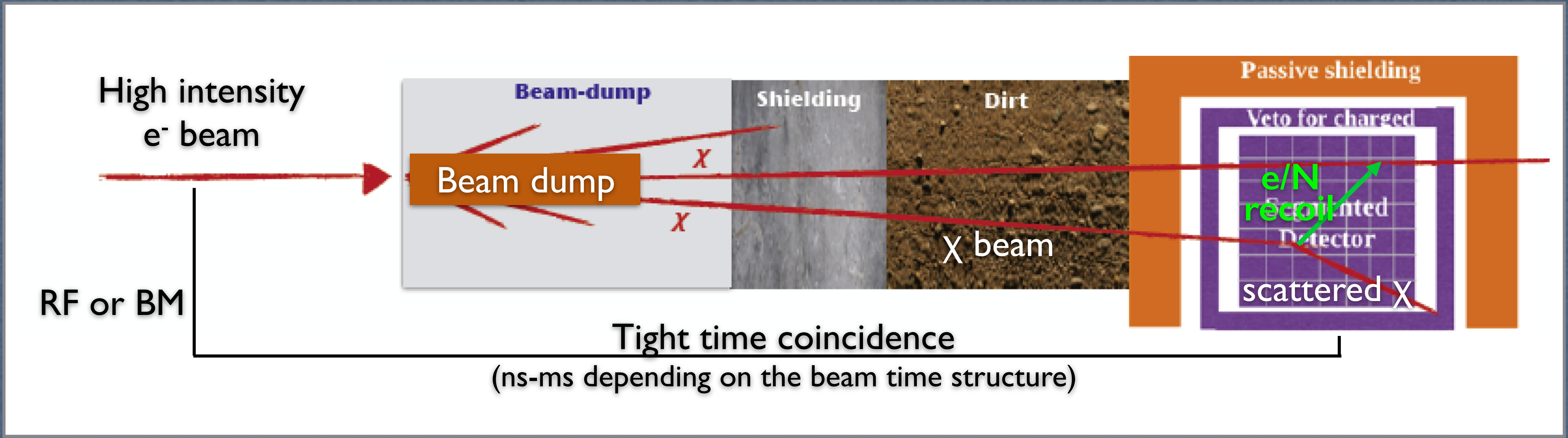
Bg is easier to beat

Experimental signature:

- proton → single hit of few MeV
- electron → em shower with ~GeV energy

The simultaneous measurement of e- and proton provides a strong evidence of LDM existence

Experimental setup



Producing and detecting LDM

- high intensity (~100-1000 $C_{on\text{-}target}$/year)
- moderate energy (~0.1-10 GeV) electron beam
- ~1 cubic meter (~1-5 tons) detector
- low energy thresholds
- EM showers detection

Reducing the background

- shielding and vetos
- directionality: segmented detector
- different technologies for systematic checks
- good time resolution

The BDX detector

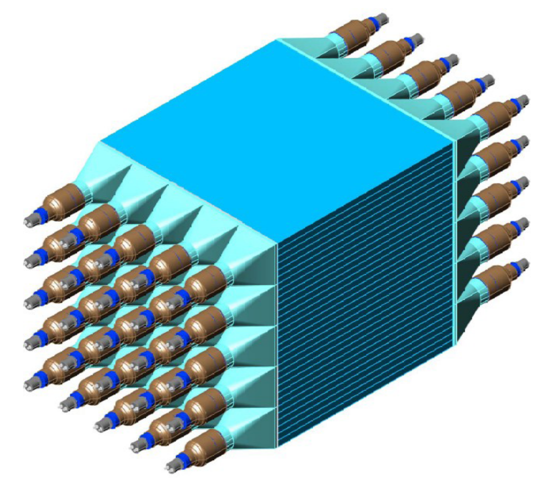
Requirements

- Good time resolution to reject beam-uncorrelated bg
- Low threshold for nucleon recoil detection (~MeV)
- EM showers detection capability
- Segmentation for bg rejection
- Active veto
- Passive shielding

Size: ~few tons detector

E.M. calorimeter

A **plastic scintillator** is the cheapest and easiest solution



- Fast and cheap
- Segmented and modular
- Plastic scintillator bars
- R/L PMT readout (~200)
- ~3mq = 0.3x0.30x10 m^3 (!)
- difficult logistics
- high veto/schielding costs

A **homogeneous crystal**-based detector provides unique advantages

Scintillator	Decay time (nsec)	Density (g/cm^3)	Radiation length (cm)	Light yield (relative)
$Bi_4Si_3O_{12}$ (BSO)	2.4/26/99*	6.80**	1.15**	0.25/0.5/3.4*
$Bi_4Ge_3O_{12}$ (BGO)	300	7.13	1.12	21
BaF_2	0.9/630	4.89	2.03	3.4/36
NaI:Tl	230	3.67	2.59	100
CsI:Tl	1300	4.51	1.86	165
CsI (pure)	6/35	4.51	1.86	1.1/3.6
$PbWO_4$ (PWO)	10/30	8.3	0.89	0.29/0.083
Lu_2SiO_5:Ce (LSO)	40	7.40	1.14	83
Gd_2SiO_5:Ce (GSO)	56/600	6.71	1.38	30/3

pros

★ Heavy crystals: density 5-8x wrt plastic (compact detector)
★ Easy EM shower detection
★ Similar LY and Timing as for plastic

cons

❖ Physics: is the χ scattering on a free N equivalent to a quasi free on heavy nuclei?
❖ Detection: light quenching?
❖ Minimum proton momentum detectable?
❖ Costs and timeline

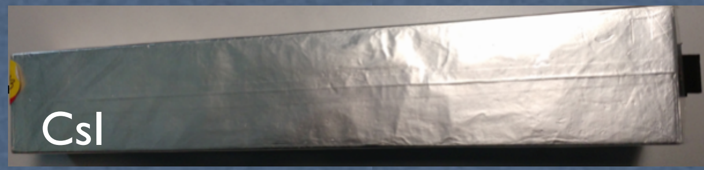
The BDX crystals

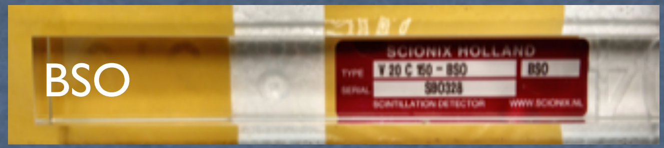
Requirements:

- Critical: high density
- Critical: high light yield
- Critical: cost-affordable for a ~ m^3 detector volume
- Desirable: Good timing

Possible options:

BaF2
CsI
BSO

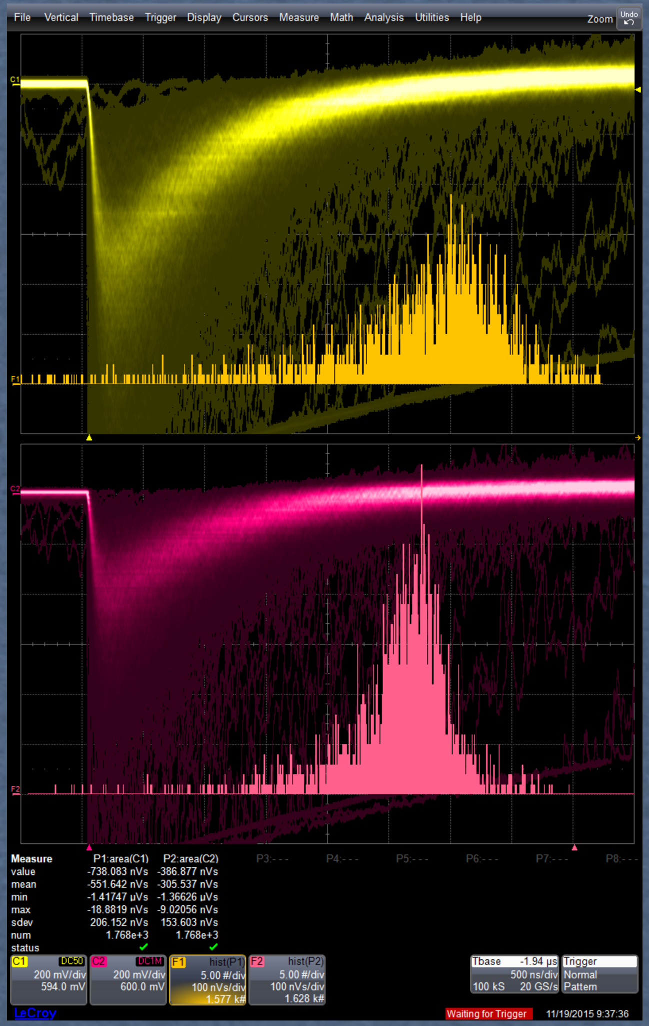




A dedicated measurement campaign to characterise the crystal properties

- Light yield (with SiPM readout!)
- Intrinsic decay time / time resolution

CsI (Tl)



LY Results:

- 3x3 mm2 25 um SiPM: ~ 9.3 phe / MeV
- 3x3 mm2 50 um SiPM: ~ 12.3 phe / MeV

Signals at ~MeV level are detectable

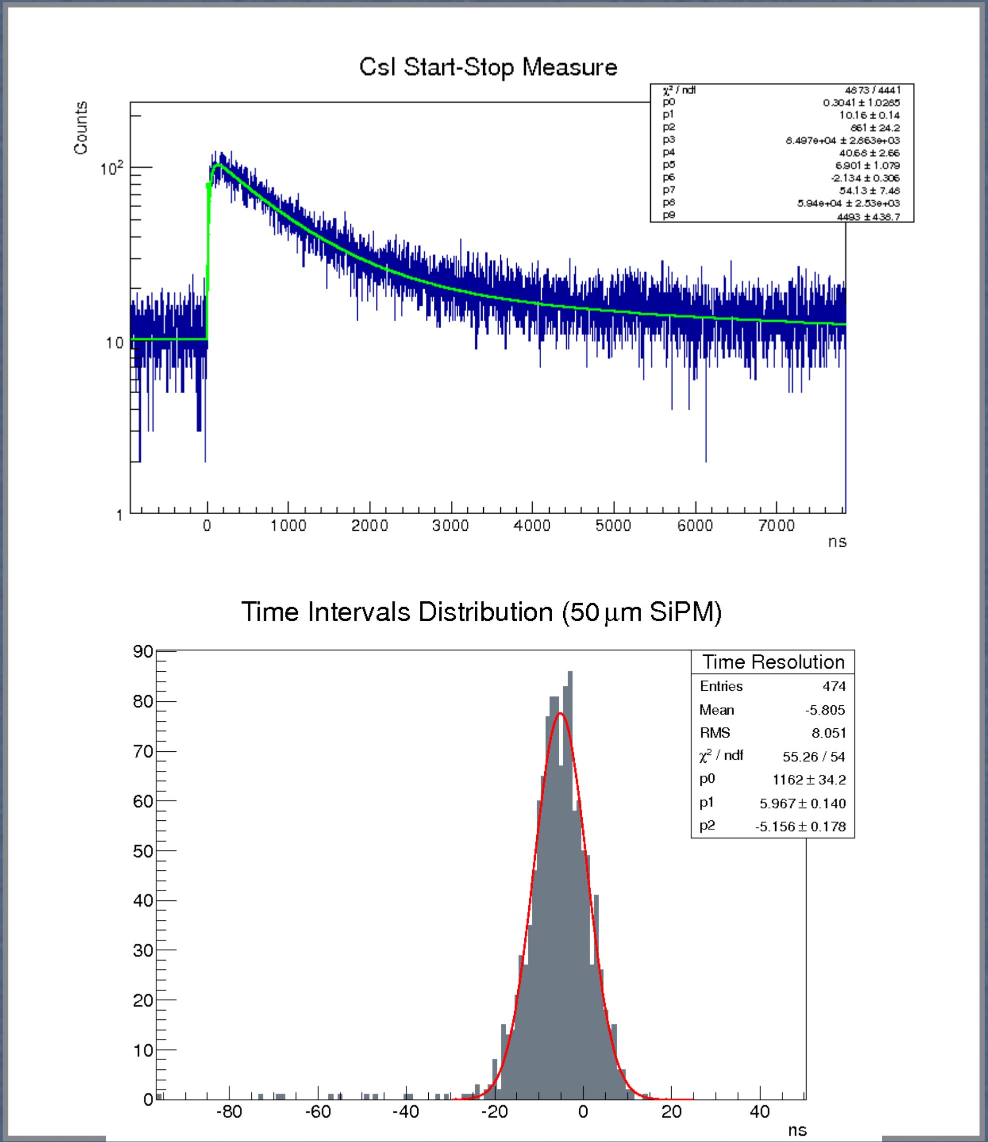
Scintillation decay time

- Fast ~ 900ns
- Slow: ~ 4000ns
- A Cerenkov fast component (~few ns) observed. Under investigation for fast timing

Time resolution:

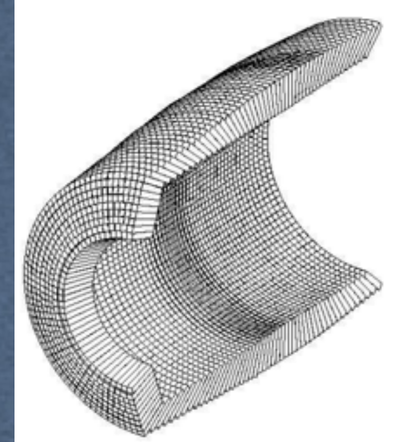
- 3x3 mm2 25 um SiPM: ~ 7ns
- 3x3 mm2 50 um SiPM: ~ 6ns

Despite a long scintillation time a few ns time coincidence is possible



A.Celentano, L.Marsicano

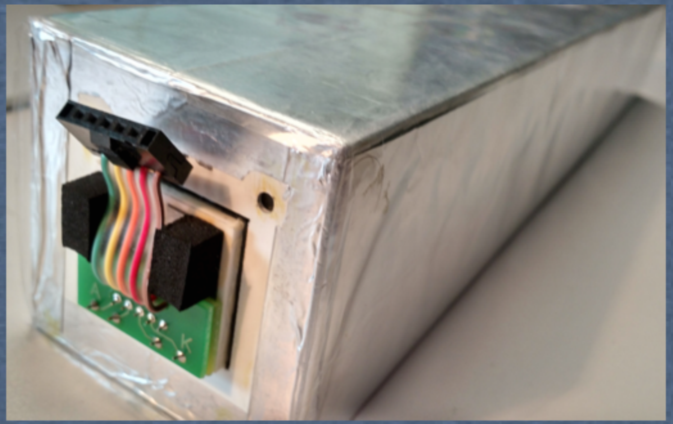
BaBar CsI(Tl)



Parameter	Values
Radiation length	1.85 cm
Molière radius	3.8 cm
Density	4.53 g/cm^3
Light yield	50,000 γ/MeV
Light yield temp. coeff.	0.28%/°C
Peak emission λ_{max}	565 nm
Refractive index (λ_{max})	1.80
Signal decay time	680 ns (64%)
	3.34 µs (36%)

BABAR em calorimeter

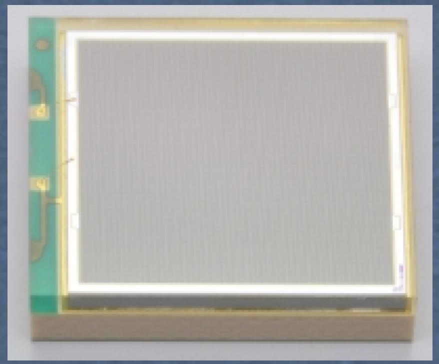
- ★ 6580 CsI(Tl) ~5(6)x5(6)x30cm^3 tapered geometry
- ★ 820 end cup + 5760 barrel
- ★ 2x Hamamatsu S2744-08 silicon diodes readout, thermalized
- ★ $\sim 3.9\,10^3$ pe/MeV (with reduced shaping time)



Trapezoidal cross-section

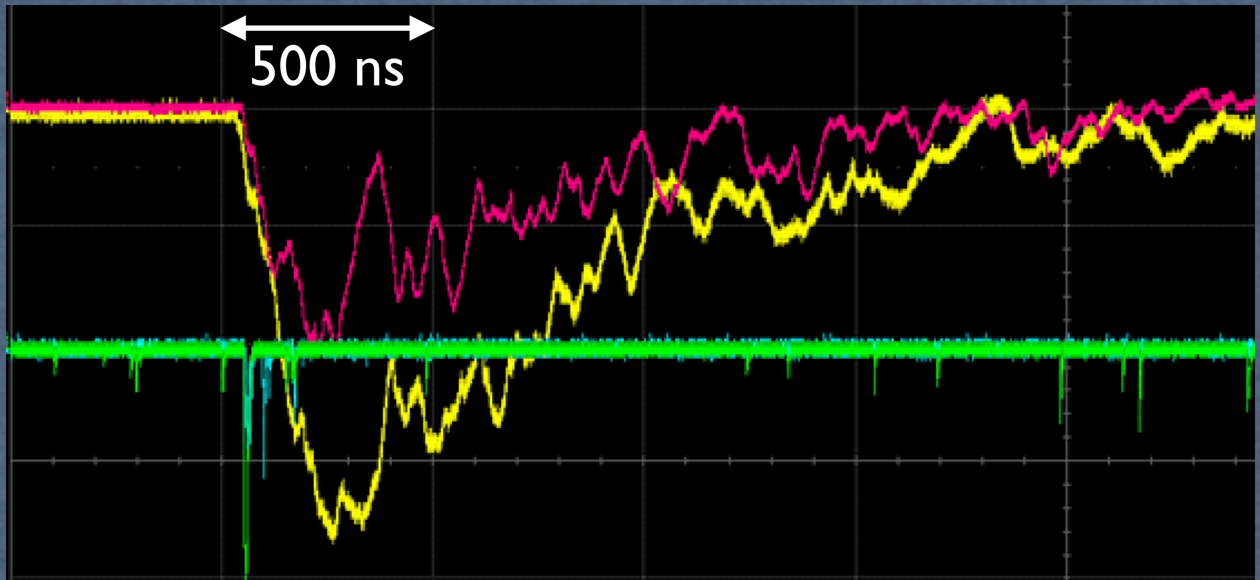
Front face : 4.7 x 4.7 cm^2
Back face : 6 x 6 cm^2

Crystal length (from Endcap): 30.5 cm/16.5 X_0 (80 crystals) and 32.4 cm/17.5 X_0



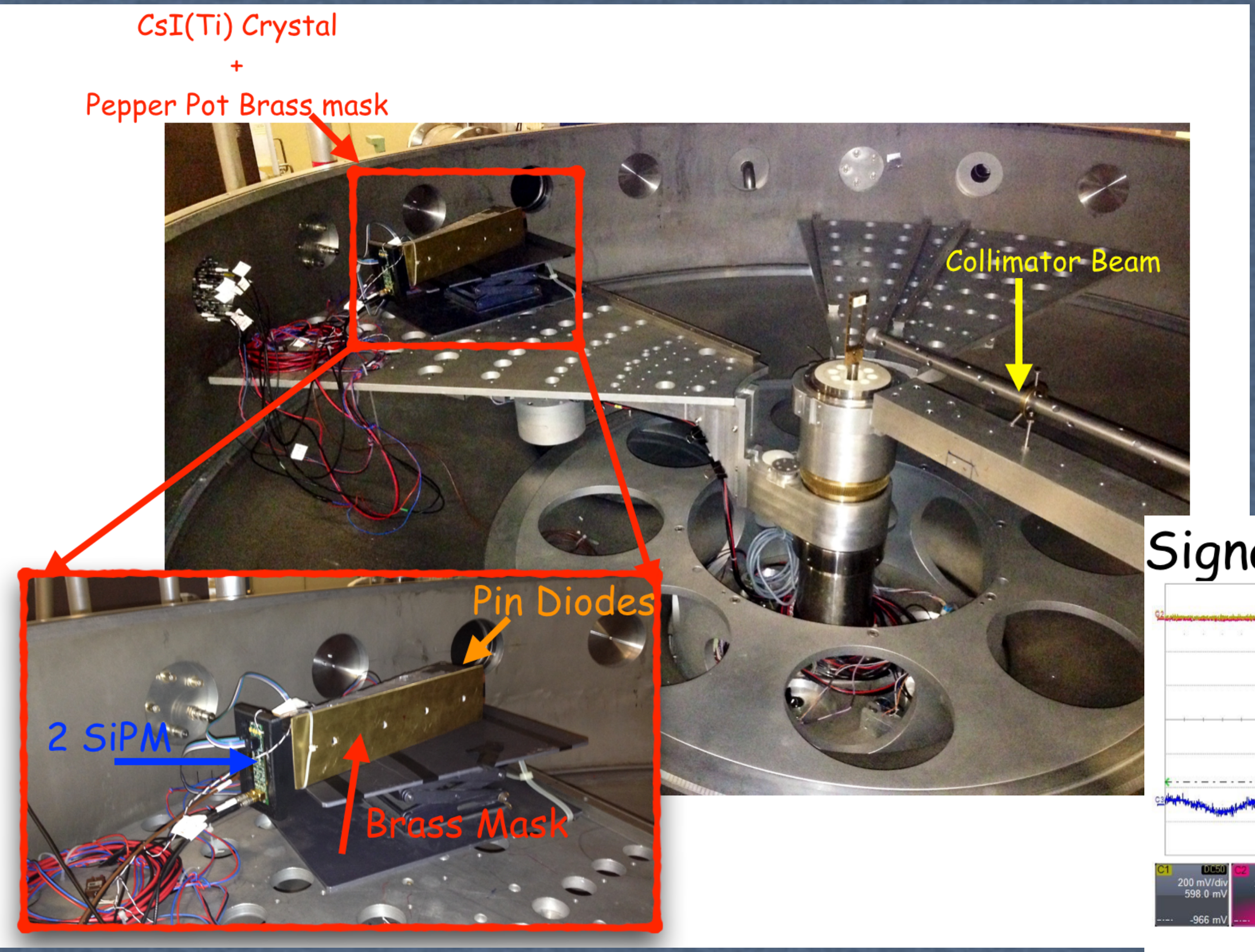
New SiPM readout

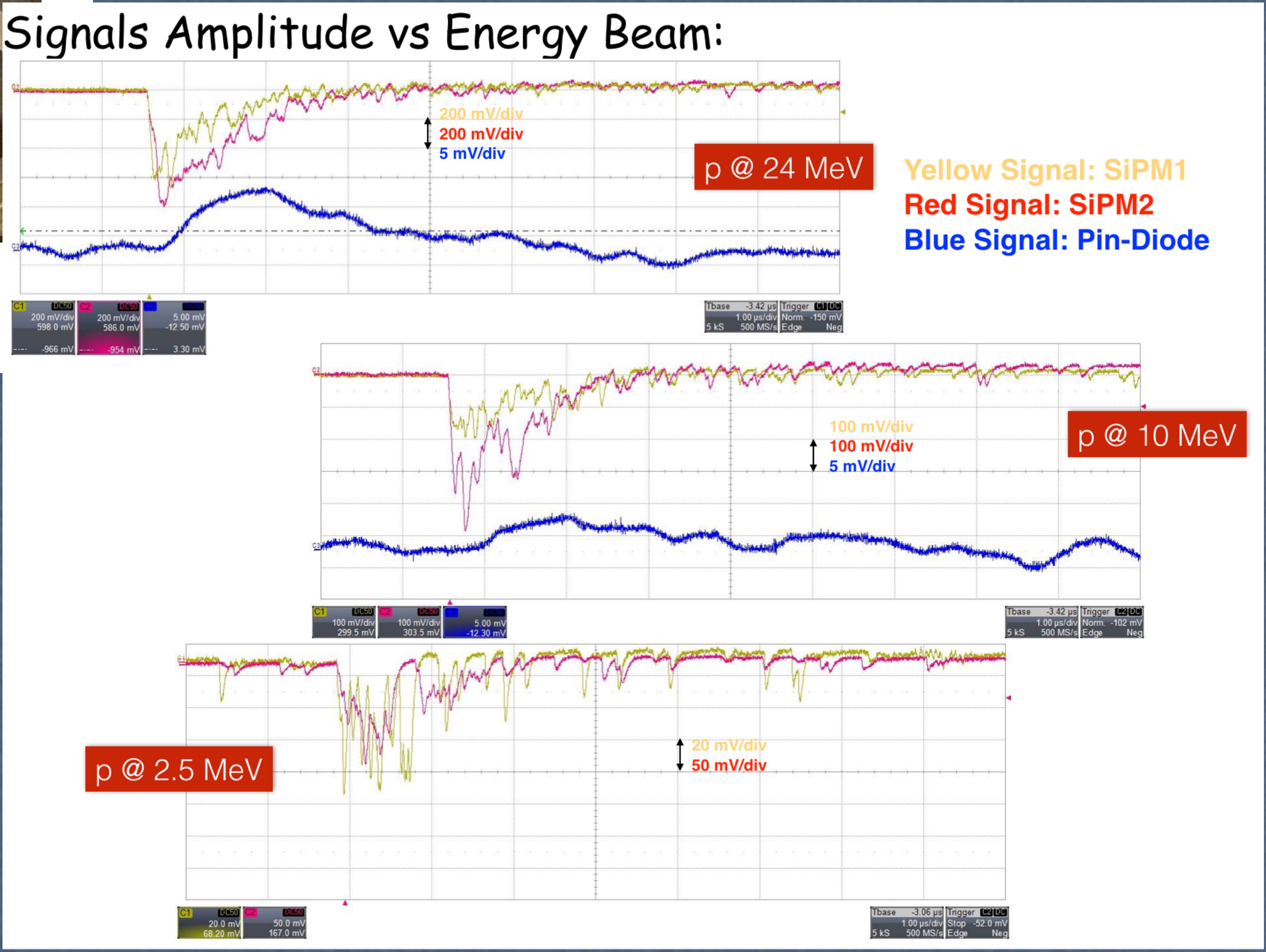
- ★ SPE capability
- ★ One (or two) 6x6 mm^2, 25um, 57.6k cells, trenched
- ★ CsI readout: ~40 pe/MeV
- ★ Detection threshold: ~5MeV



CsI BaBar crystal + 3x3 SiPM readout cosmic muon

Study of the BaBar CsI crystals response to monochromatic low energy protons



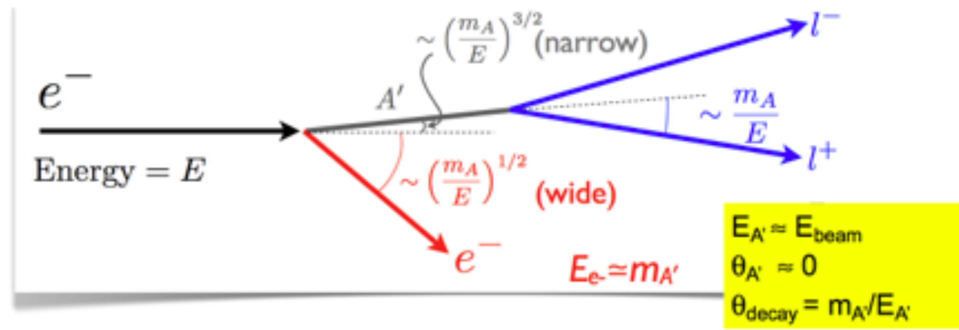


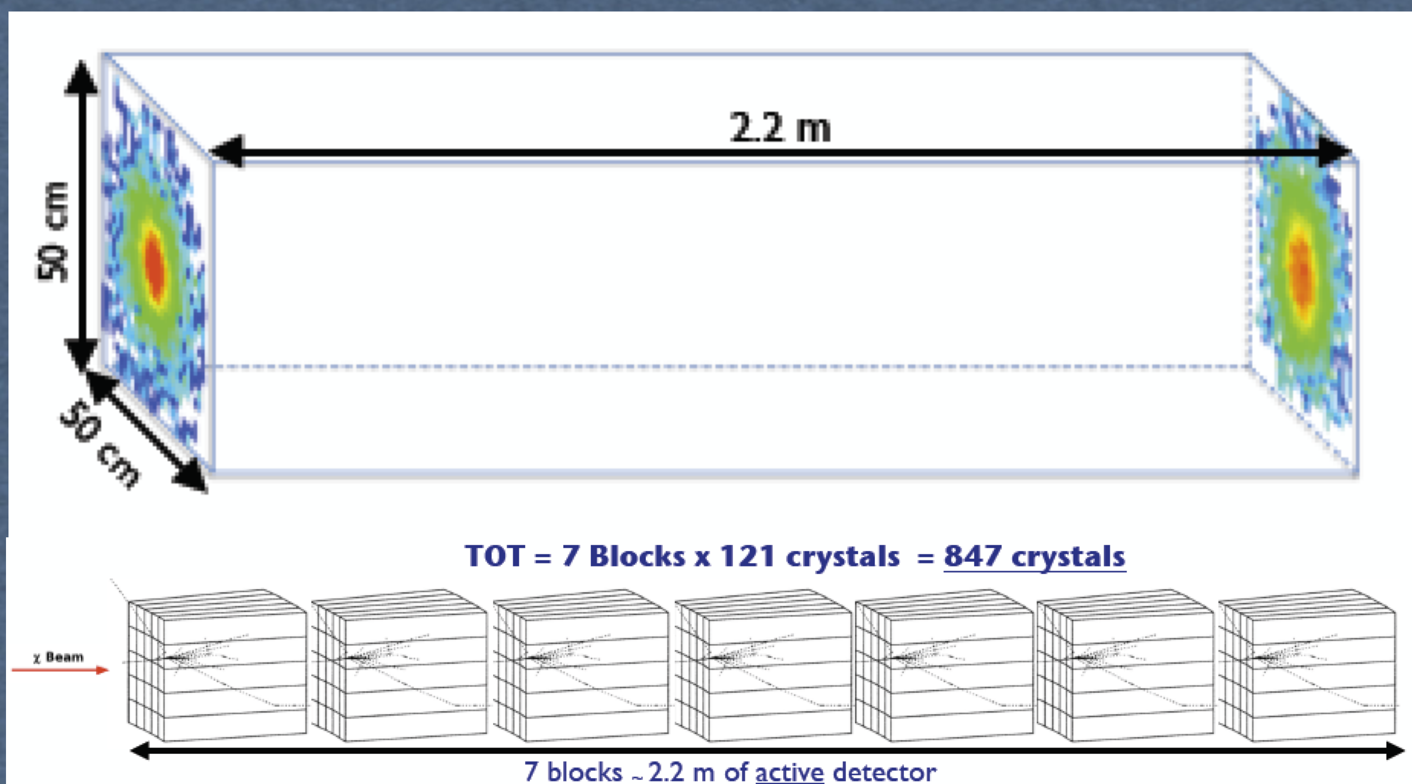
- ★ Low energy proton beam at LNS (24 MeV to 2.5 MeV)
- ★ CsI + 3x3 SiPM response
- ★ Dependence on the hit position

M.Bondi', M.DeNapoli, N.Randazzo, L.Marsicano

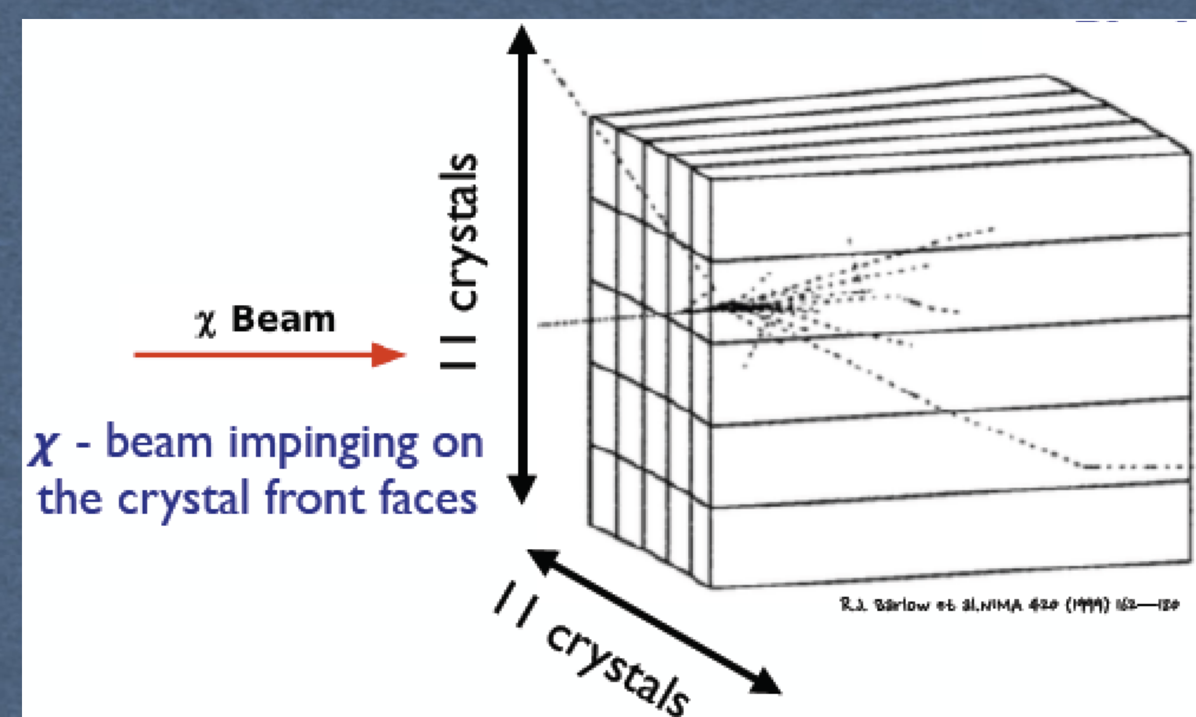
Calorimeter layout

Strongly forward peaked kinematics
focused χ-beam !





- ★ ~800 BaBar EndCup crystals
- ★ Simplified assembly mechanics
- ★ Modular detector
- ★ A possible arrangement:
  - 11x11crystals (front face ~50x50 cm2)
  - 7 modules (active/total length: 210/250 cm)

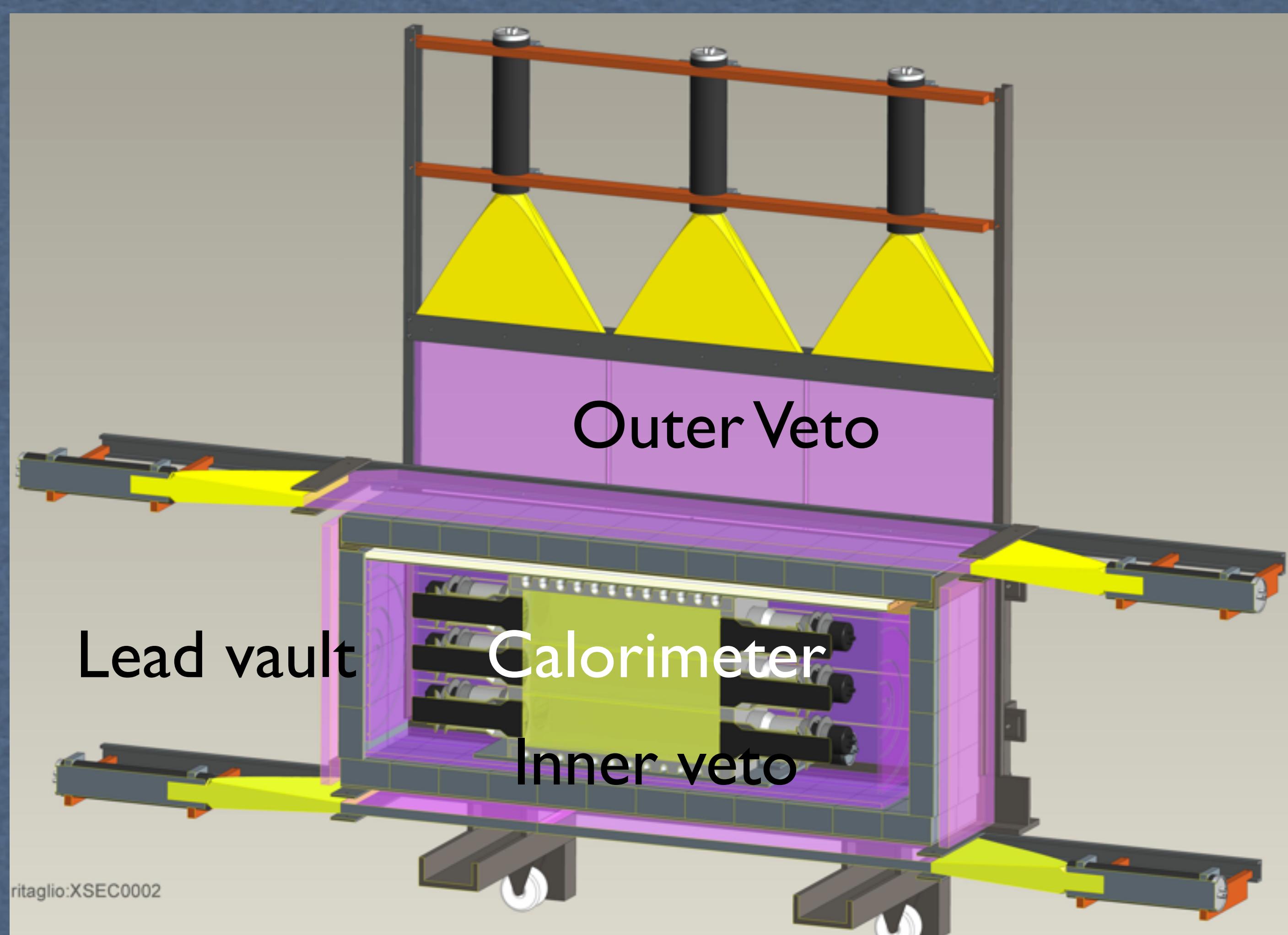


- ★ Each module is made by an array of 11x11 (front face ~50x50 cm2) or 9x9 (front face ~40x40 cm2) crystals matrix
- ★ Each crystal is read separately

Beating the background

Active and passive requirements

- High efficiency (>99%) to MIPs
- Fast (~ns) for time coincidence with the calorimeter
- Segmentation for bg rejection
- Multi-layer layout
- Heavy material (lead) vault between active layers to shield from low energy gamma
- Overburden (concrete, iron, dirt, …)



Active veto

Plastic scintillator with different readout (light guide +PMT and WLS + SiPM) cheap

- easy to assemble
- trustable technology
- high efficiency

Passive veto

Lead vault made of bricks

Background(s)

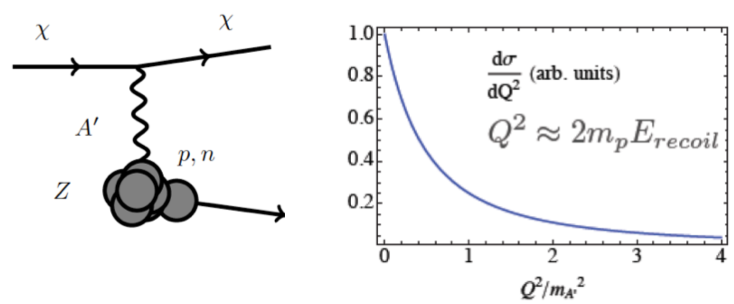
I) Backgrounds associated to the beam (beam-related)

- every prompt particles detected is interpreted as a 'signal'
- Easy to shield charged, more difficult neutrals
- fortunately low energy particles produce weak signals
- detection thresholds define the bg level

• II) Cosmic background (beam-unrelated)

- it can be measured (beam off) and-subtracted
- acc location usually prevents deep underground installation
- Few meters of concrete at most
- Time uncorrelated bg
- Requires a dedicated measurement to evaluate cosmic and terrestrial bg

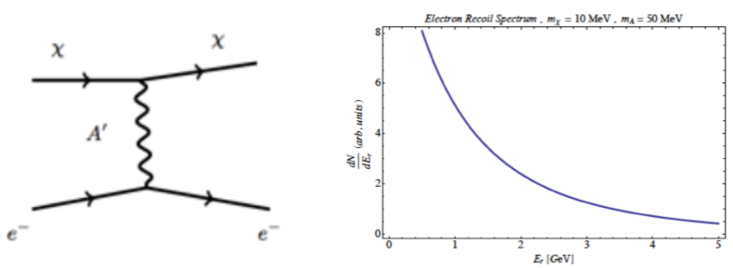
✳Elastic scattering on nucleon



Nucleon recoil: sizeable cross section for T_N>1-10 MeV

Low energy background rejection capability (~1 MeV)

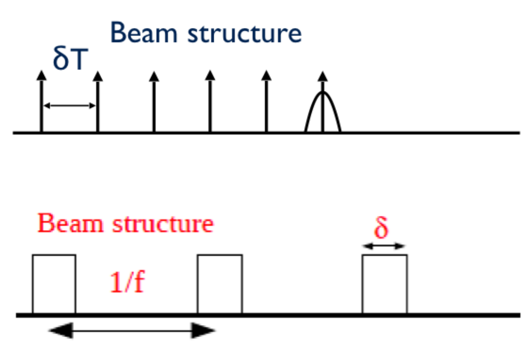
✳Elastic scattering on electron



Electron recoil: em shower of few GeV

Bg is easier to beat

A tight time coincidence reduces cosmic and delayed bg but it does not work for a CW beam! (it'd require δT~10ps)



- **CW beam**: requires good detector time resolution

Background rejection factor $R \simeq \frac{\delta T}{3\sigma} <\simeq 100$ σ = Detector Time Resolution (~ 0.1-1.0ns)

- **Pulsed beam**: less critical (if better than bunch size)

Background rejection factor $R = \frac{1}{f \cdot \delta} = 2 \cdot 10^5 \text{ @ } 50\,Hz, 100\,ns$

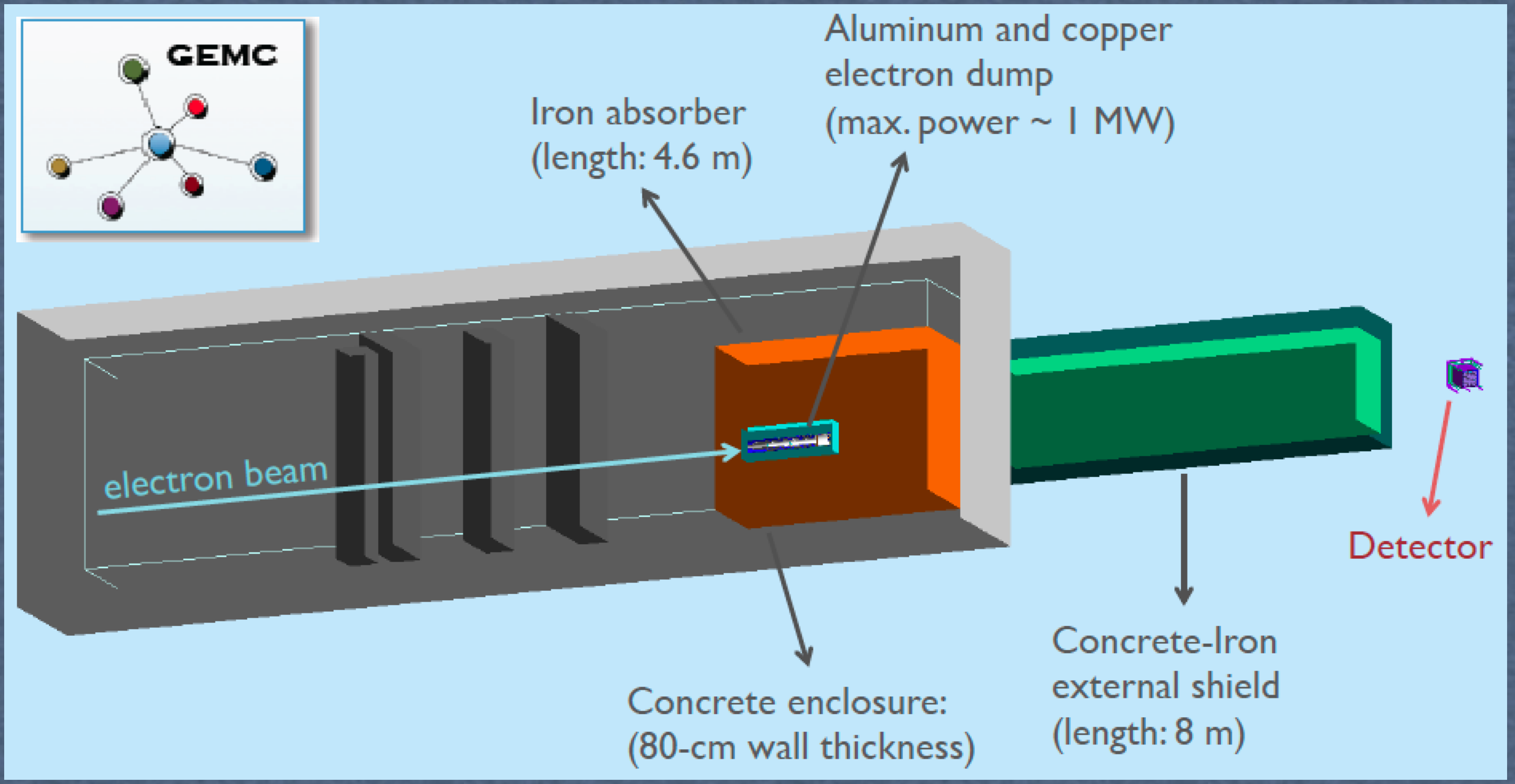
Passive shielding and active veto(s) are important components of the detector

Backgrounds I: beam-related

- Backgrounds created by beam interaction with the dump is estimated via MC simulations

BDX run conditions:

- Electron energy in the GeV range
- 10^{22} electrons on target (EOT)
- 100 uA electron beam on dump for 6 months running



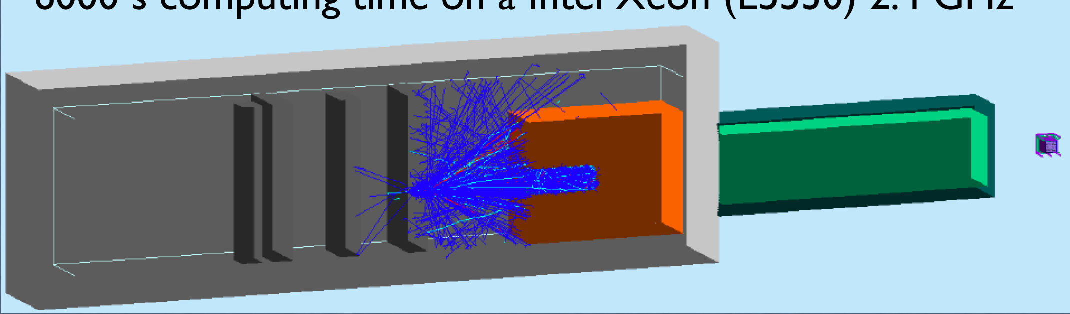
Challenges and Issues:

- Computing limitations: high EOT and energy
- Physics issues: modelling GeV to eV, low energy nuclear reactions, neutron transport

Brute force approach:

- Model beam dump geometry and materials
- Use Geant4 (GEMC)
- high precision physics lists: QGSP_BERT_HP + EM_HP
- Determine fluxes of particles exiting from the dump and reaching the detector locations

10000 EOT (12 GeV) ⇔ 16 ps of beam on target at 100 uA
~6000 s computing time on a Intel Xeon (E5530) 2.4 GHz

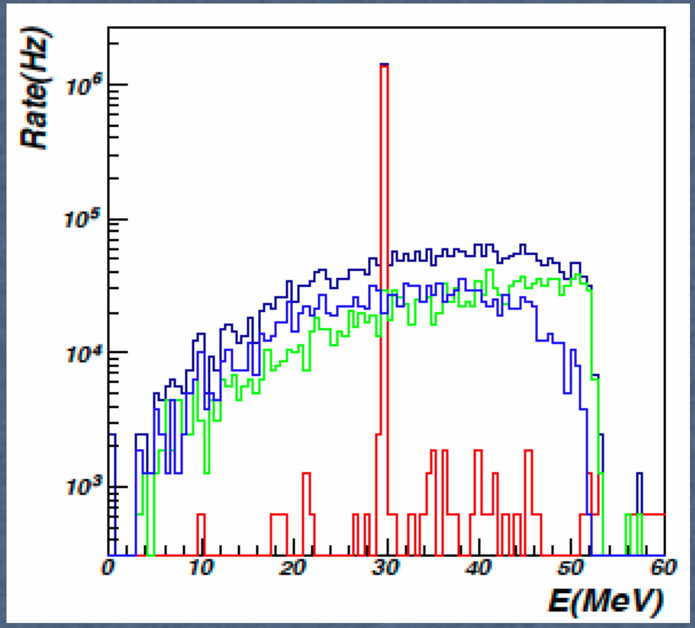


Results based on:

- 1 month of simulations on a 200 cores farm (~3600 HepSpec2006)
- equivalent to 2×10^9 EOT (3.2 us of beam on target at 100 uA)
- Results would need to be extrapolated by more then 12-13 orders of magnitude to reach the desired experiment luminosity

R.De Vita

Backgrounds I: beam-related



Neutrinos at the detector location

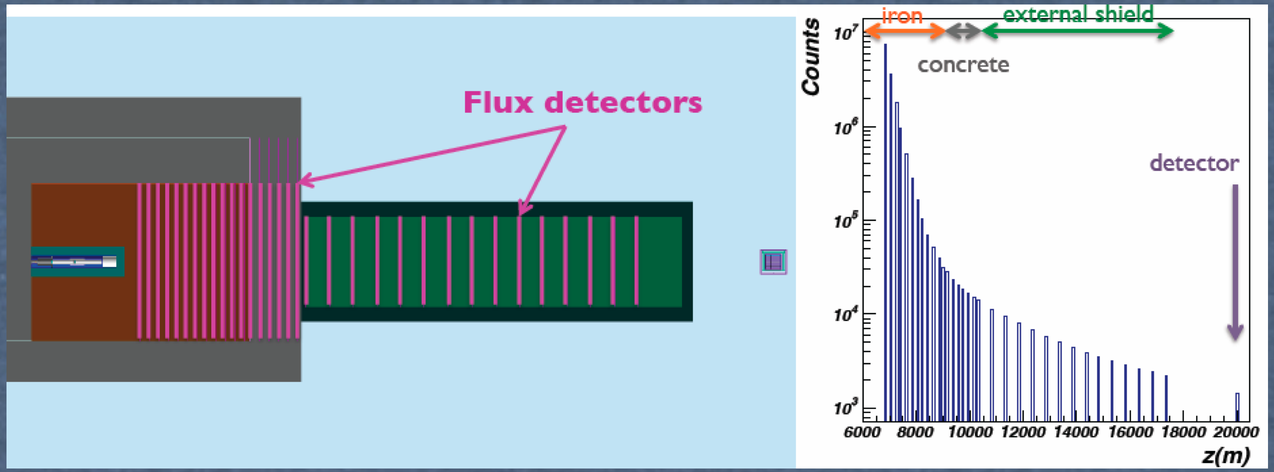
- Only neutrinos and low energy gamma (<eV)
- $\pi^+ \rightarrow \mu^+ \nu_\mu$ (π^- are mainly captured by nuclei)
- $\mu^+ \rightarrow e^+ \nu_\mu \nu_e$
- Energy limited to 60 MeV
- Flux scales with primary beam energy and square of dump-detector distance

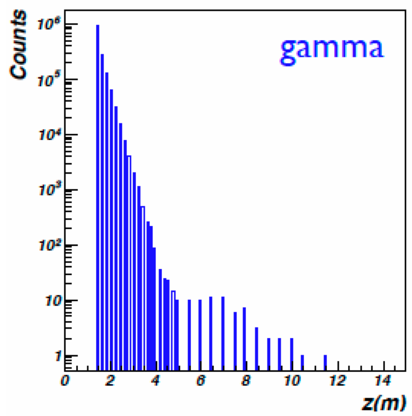
negligible

A different approach

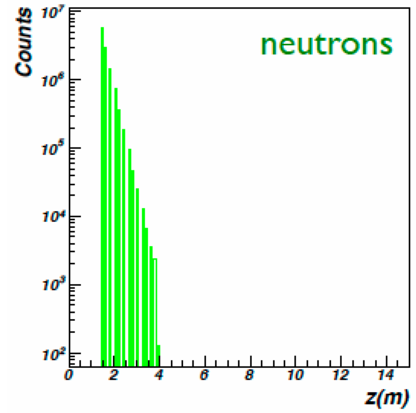
- Neutrino flux can be extrapolated to the full luminosity but zero rate for n and γ only allows setting an upper limit
- Reasonable cpu time (1y, 2000 cores): 10^{11}-10^{12} EOT (expected 10^{22}!). Extrapolation over 10-12 order of magnitudes!

- GEANT4 for treatment of high energy (GeV to MeV) interactions
  I) Sample particle fluxes at different depths within the dump: non-zero flux used to extrapolate at full luminosity





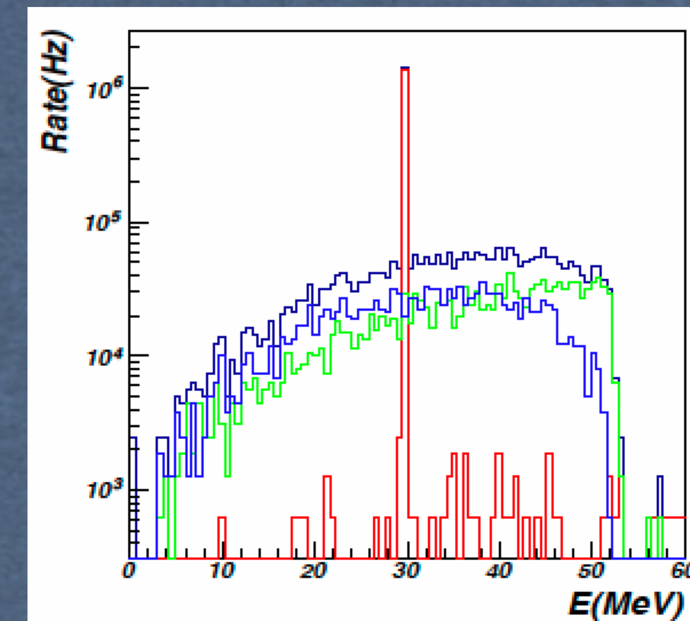
Gamma:
- Flux reduction :3600 in 2.2 m of iron
- γ detected after the iron absorber < keV
- Further reduction by time correlation cut



Neutrons:
- Attenuation x1700 in 2.2 m iron
- Attenuation x4.3 in 10 cm of concrete
- <1 neutron @10^{22} EOT ~3.5 m of concrete
- Attenuation depends on energy
- Spectrum: further studies in progress

R.De Vita

Backgrounds I: beam-related



Neutrinos at the detector location

- Only neutrinos and low energy gamma (<eV)
- $\pi^+ \rightarrow \mu^+ \nu_\mu$ (π^- are mainly captured by nuclei)
- $\mu^+ \rightarrow e^+ \nu_\mu \nu_e$
- Energy limited to 60 MeV
- Flux scales with primary beam energy and square of dump-detector distance

negligible

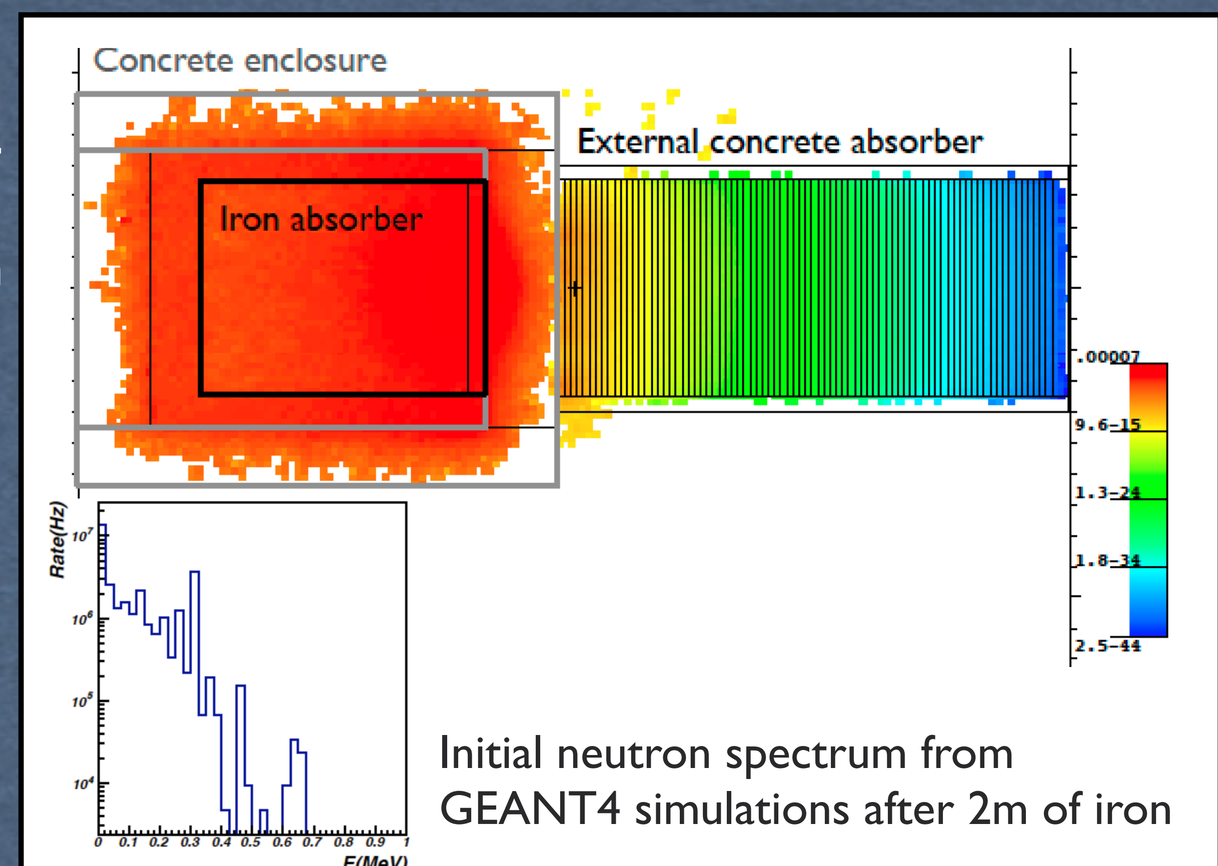
A different approach

- Neutrino flux can be extrapolated to the full luminosity but zero rate for n and γ only allows setting an upper limit
- Reasonable cpu time (1y, 2000 cores): 10^{11}-10^{12} EOT (expected 10^{22}!). Extrapolation over 10-12 order of magnitudes!

- GEANT4 for treatment of high energy (GeV to MeV) interactions
  I) Sample particle fluxes at different depths within the dump: non-zero flux used to extrapolate at full luminosity
  II) Validate results for low energy n/γ with different simulation tools (MCNP) and using variance reduction techniques

Neutron flux in iron or concrete absorbers with MCNP

- Initial neutron spectrum from GEANT4 simulations
- Large attenuation of neutron flux in concrete is confirmed
- Actual value strongly depends on neutron energy
- Final flux reaching the detector may be dominated by gaps in the dump structure: realistic geometry is needed



Initial neutron spectrum from GEANT4 simulations after 2m of iron

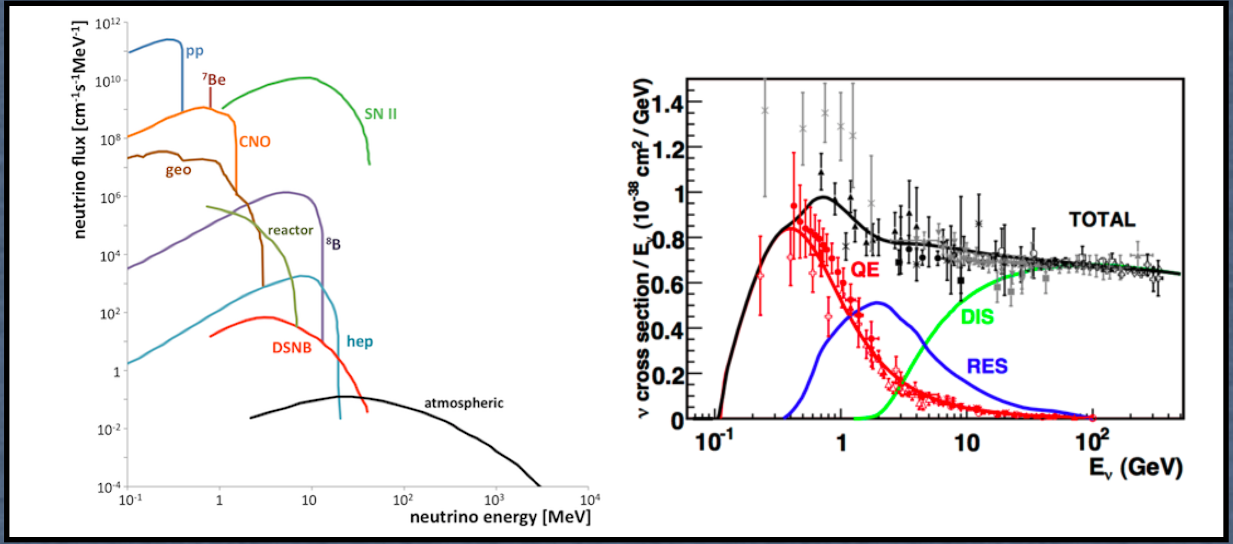
R.De Vita

Backgrounds II: cosmogenic

I) Neutrinos

- Considering flux, interaction cross sections and 1MeV (10 MeV) detection threshold the number of detected cosmic neutrinos is negligible

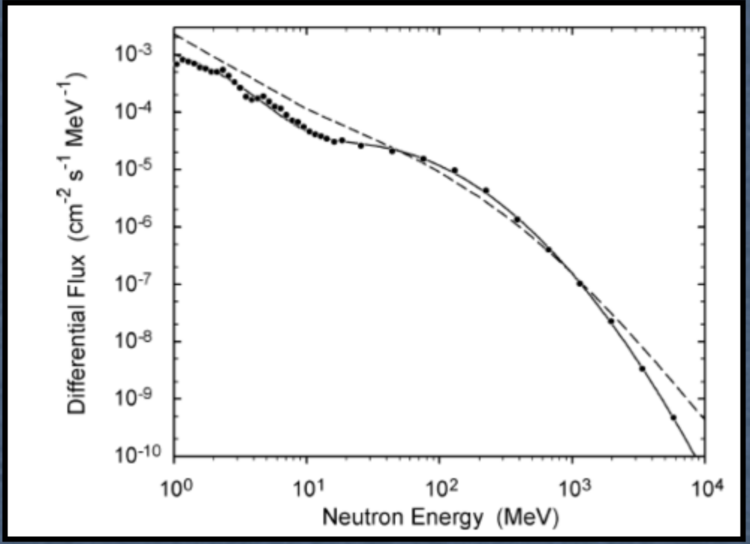
negligible



II) Neutrons

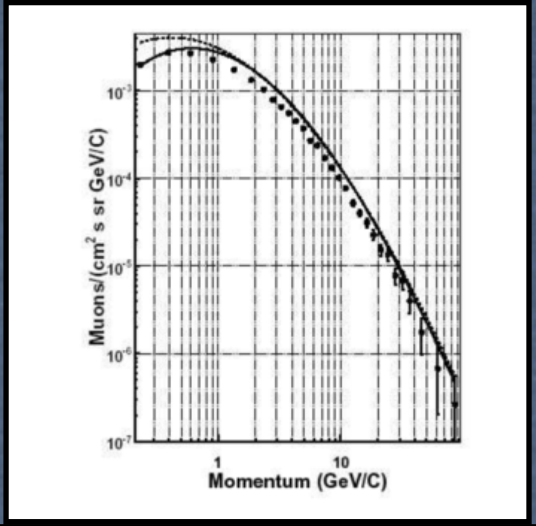
- A high energy neutron can penetrate the shielding and interact inside the detector mimicking a χ-N interaction
- 1m iron shield + detection energy threshold introduce a neutron energy cutoff (detection efficiency = 0 for $T_N < 50$ (100) MeV)

sizeable



III) Muons

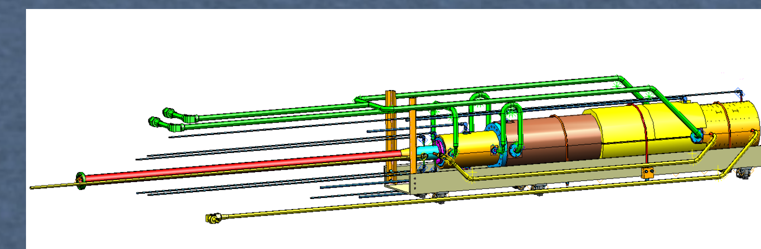
- Crossing muons are rejected by the veto
- Crossing muons can produce a fake signal for veto inefficiency (~ 1% per layer) **sizeable**
- Muons decaying inside the detector not rejected for veto inefficiency **sizeable**
- Muons decaying inside the lead shielding not rejected for veto inefficiency **sizeable**
- Muons decaying between iron and veto **negligible**
  - for the standard decay $\mu^+ \rightarrow e^+ \nu_\mu \nu_e$ e+ is detected by the veto
  - for the rare decay $\mu^- \rightarrow e^- \nu_\mu \nu_e \gamma$ (Br~1.5%) the 10-100 MeV photon could by-pass the veto and interact in the detector but the rate is negligible



BDX@JLab

Hall-D

- E~12GeV
- moderate current (~200nA, up to 7-8 uA))
- Over-the-ground beam dump
- Easy access to the back of the BD enclosure
- Simplified logistic: hat, power, network, A/C

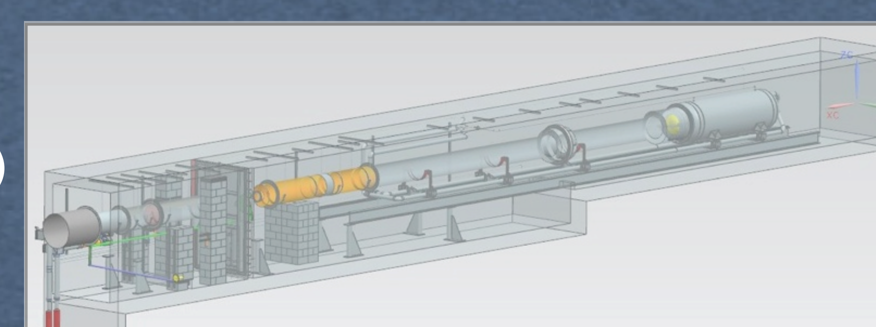


Hall-B

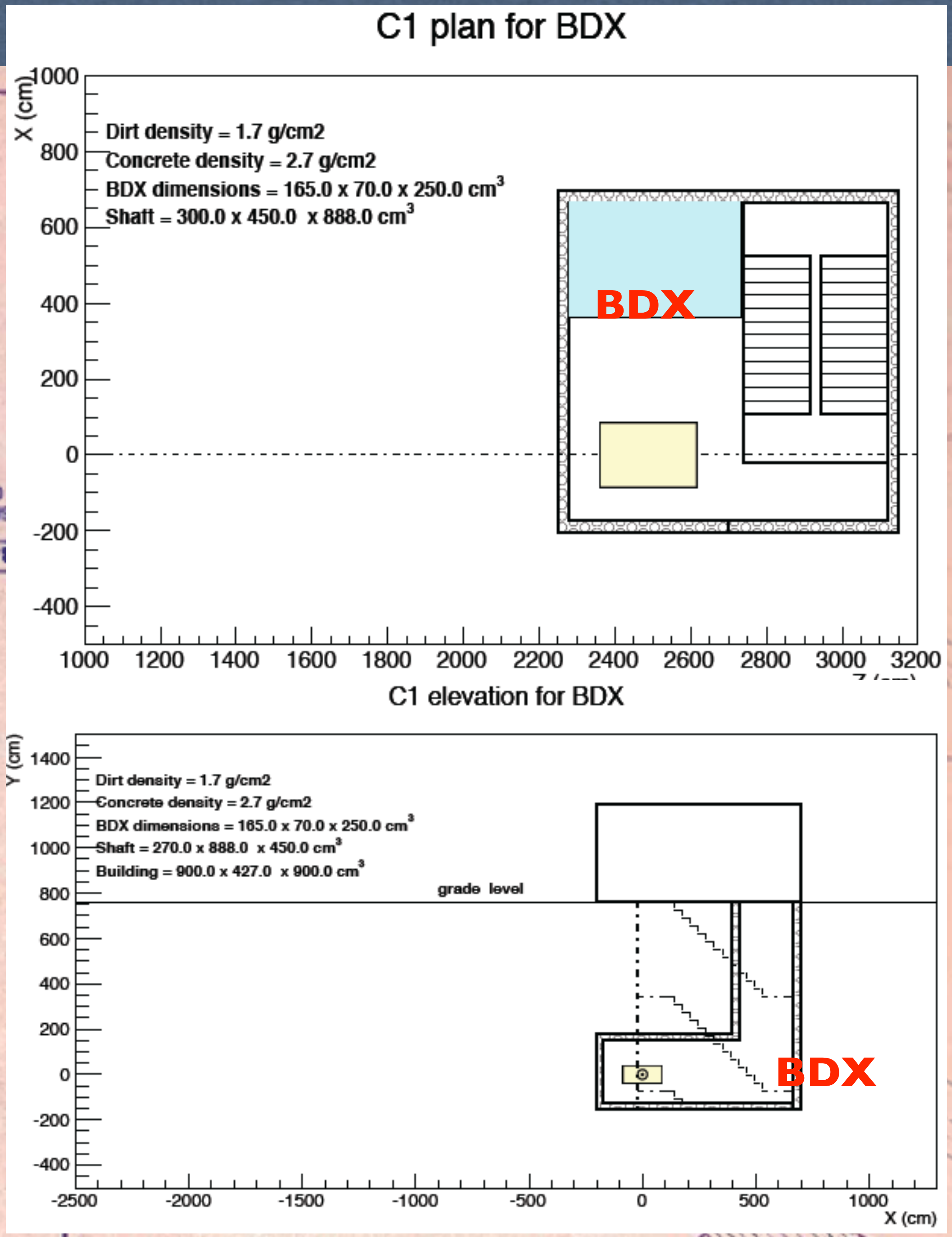
- E~11GeV
- moderate current (~200nA)
- 5kW beam dump
- Same area as HPS setup
- >20m behind the Faraday cup

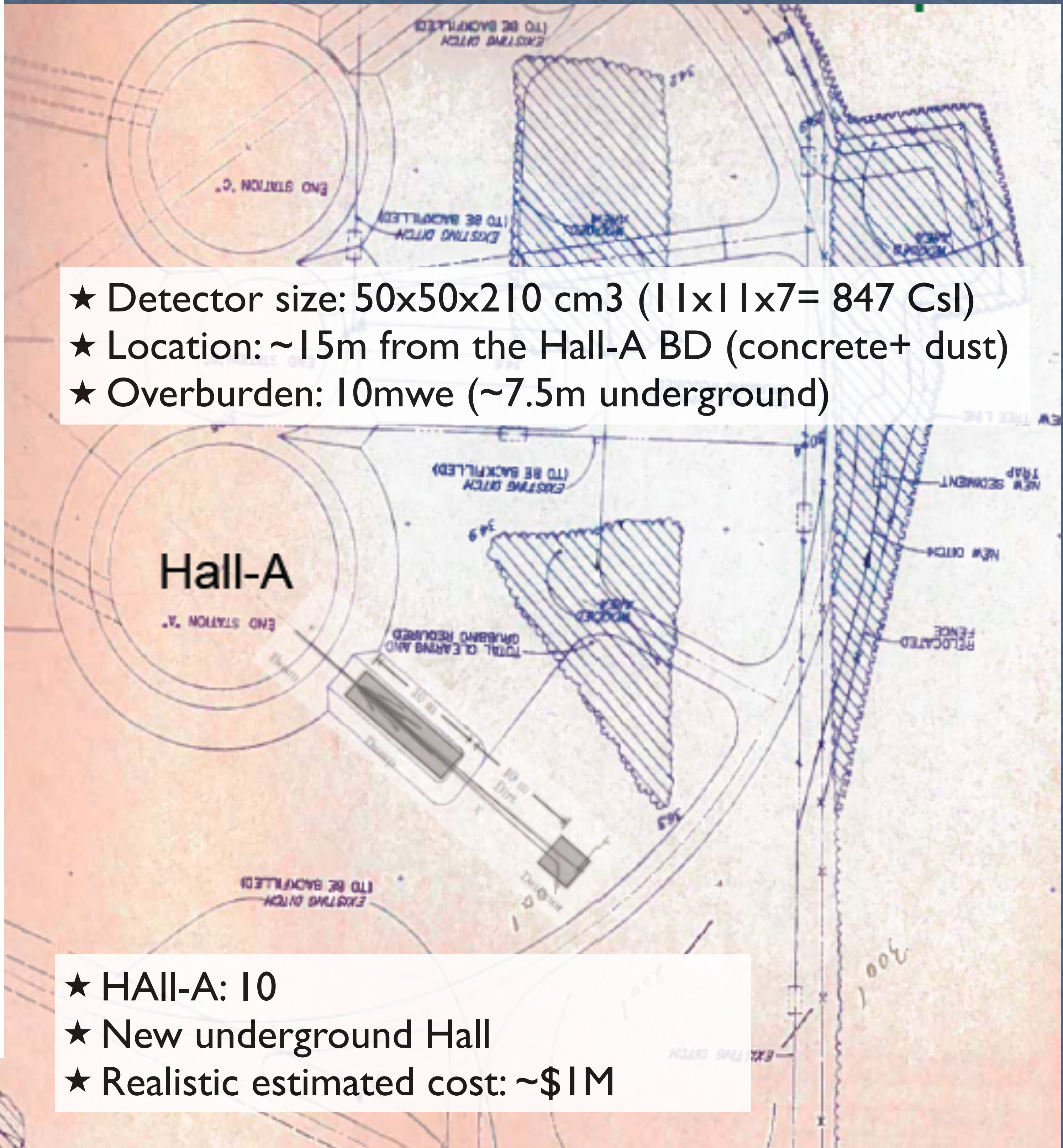
Hall-A/Hall-C

- E~11GeV
- high current (~50-100uA)
- Parasitic run
- 900 kW beam dump



BDX @ Hall-A



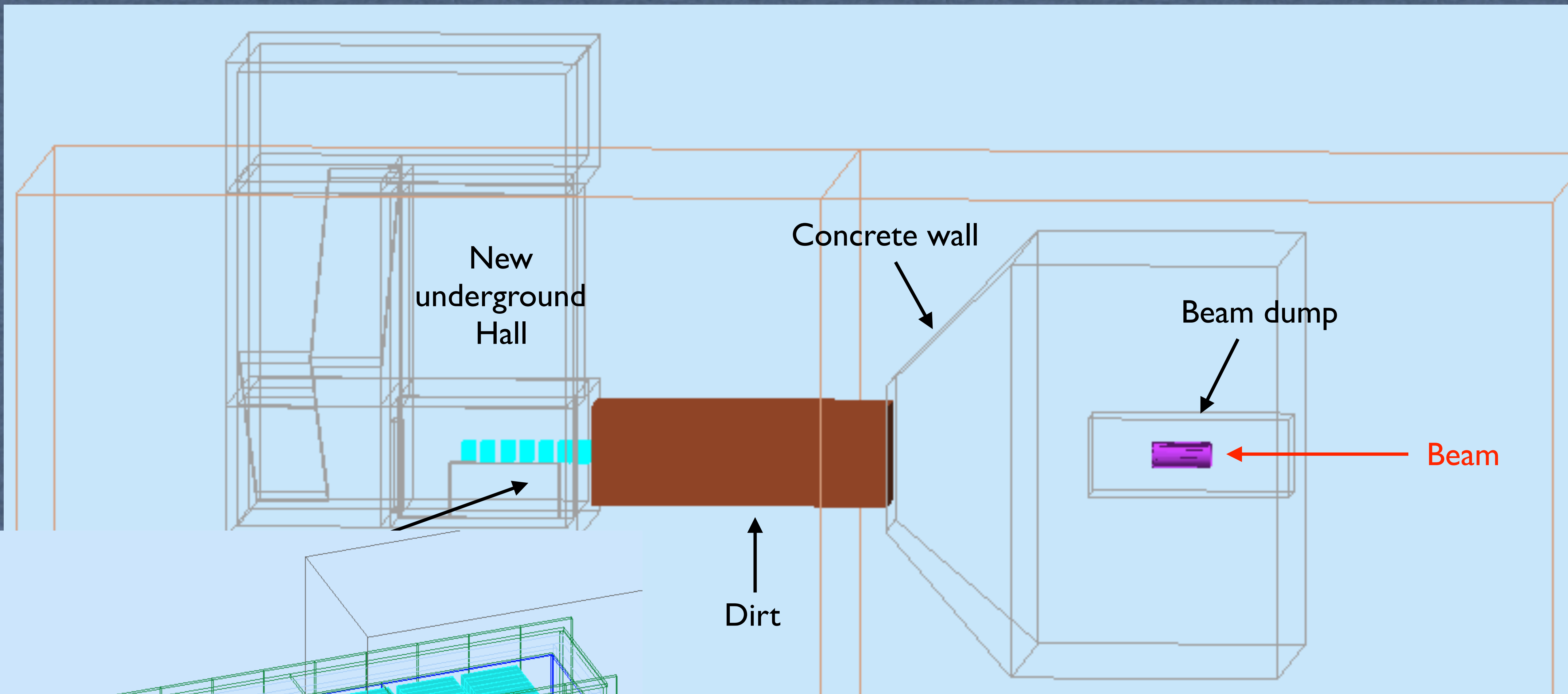


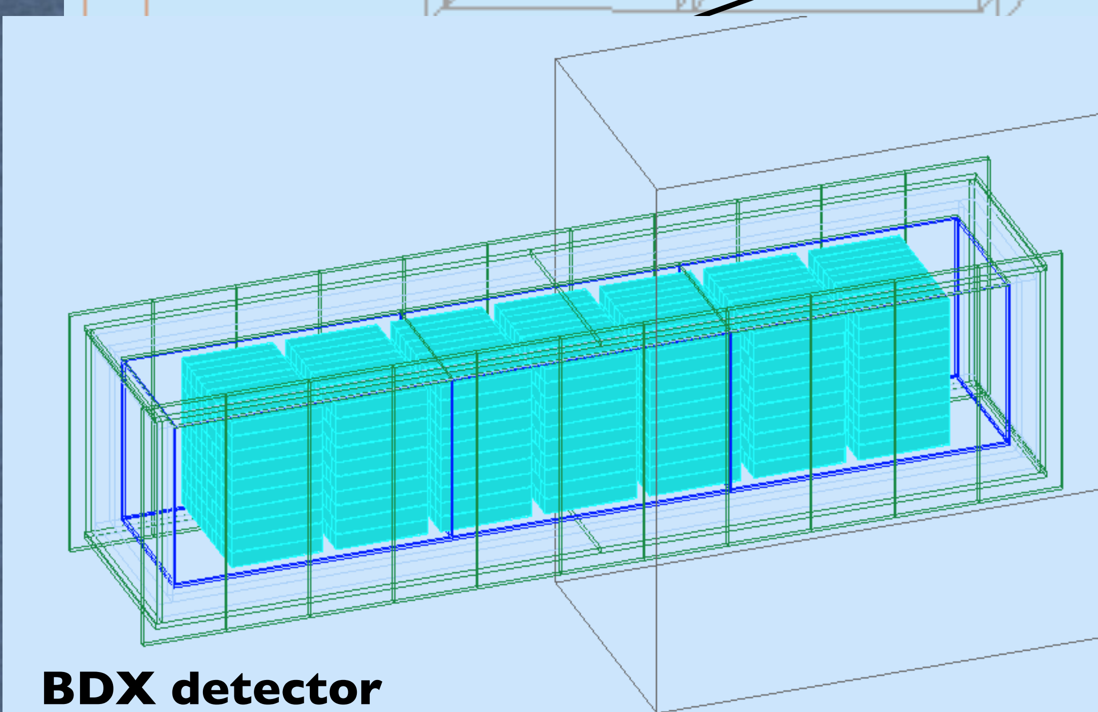
- ★ Detector size: 50x50x210 cm3 (11x11x7= 847 CsI)
- ★ Location: ~15m from the Hall-A BD (concrete+ dust)
- ★ Overburden: 10mwe (~7.5m underground)

E.S. Smith and T. Whitlatch

- ★ HAll-A: 10
- ★ New underground Hall
- ★ Realistic estimated cost: ~$1M

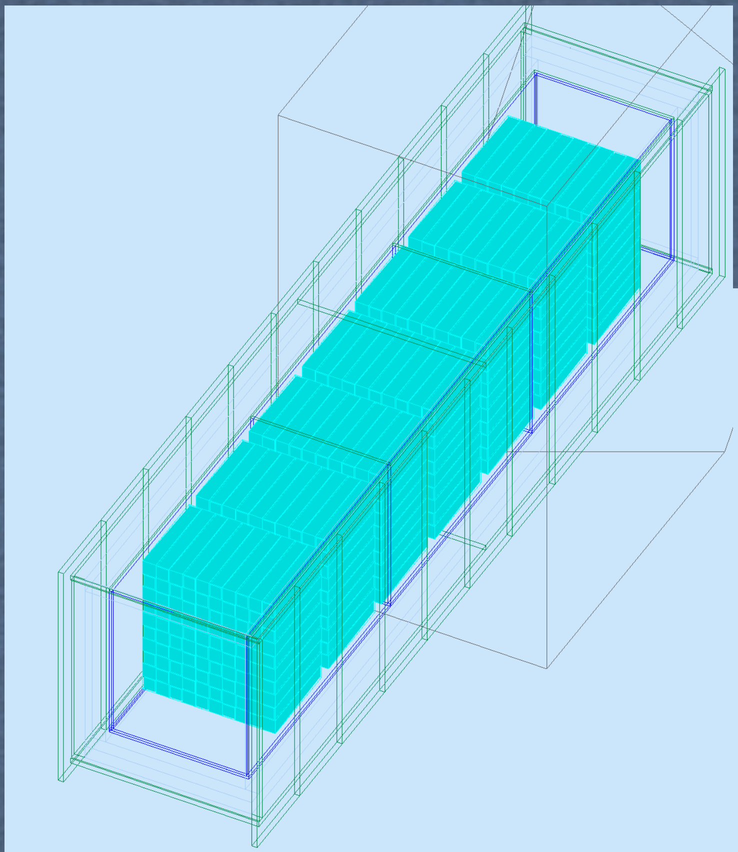
BDX Geant4 optimization (GEMC)





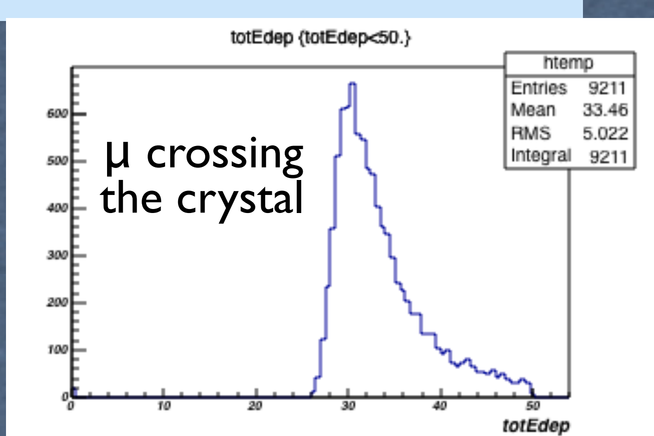
- Realistic description of the beam dump area and detector location
- Measured Crystal+SiPM response implemented
- Measured Vetos response implemented
- Shielding optimization underway
- Detector optimization underway

An example of BDX set-up (GEMC)



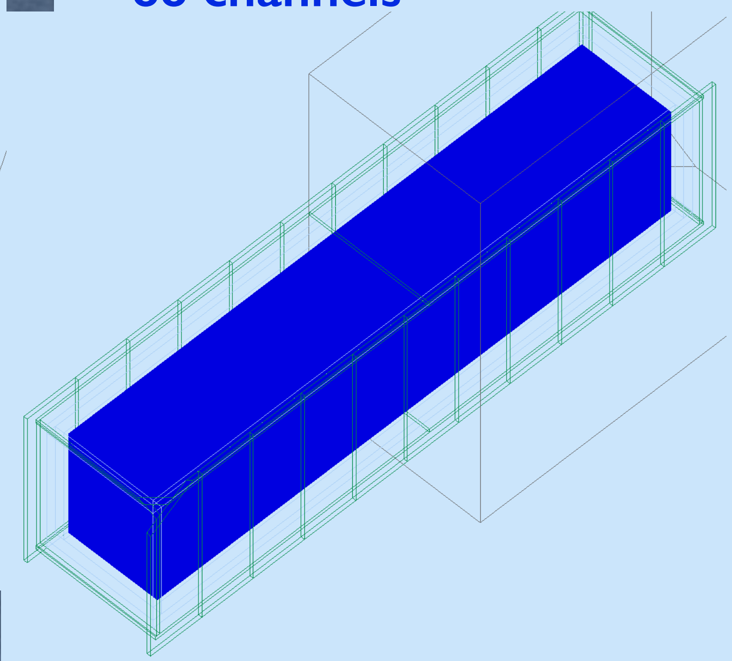
Crystal matrix:

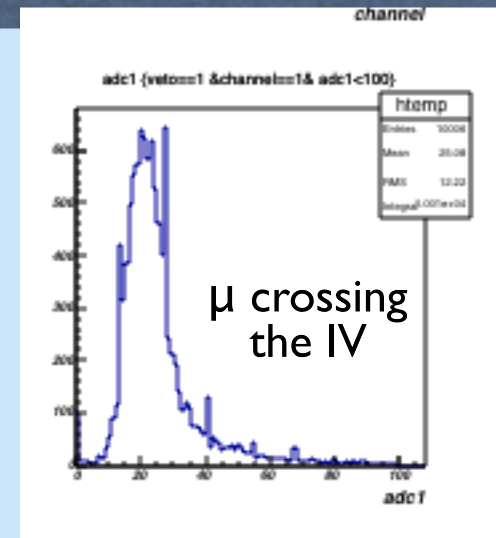
- 10x10 x 7modules
- 700 crystals
- 99 x 111 x 258 cm^3
- 700 6x6 Hamamatsu SiPM

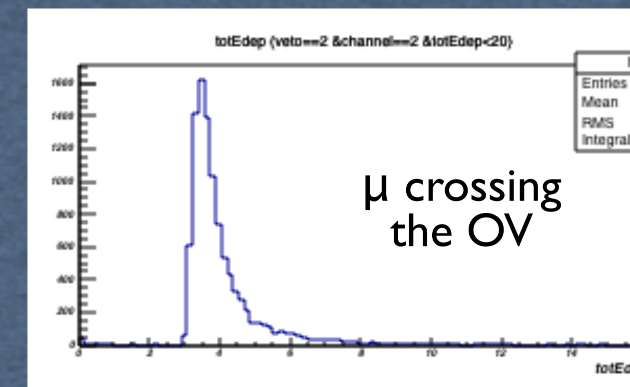


Inner Veto:

- Plastic scintillator+WLS fibers
- SiPM readout
- 88 channels

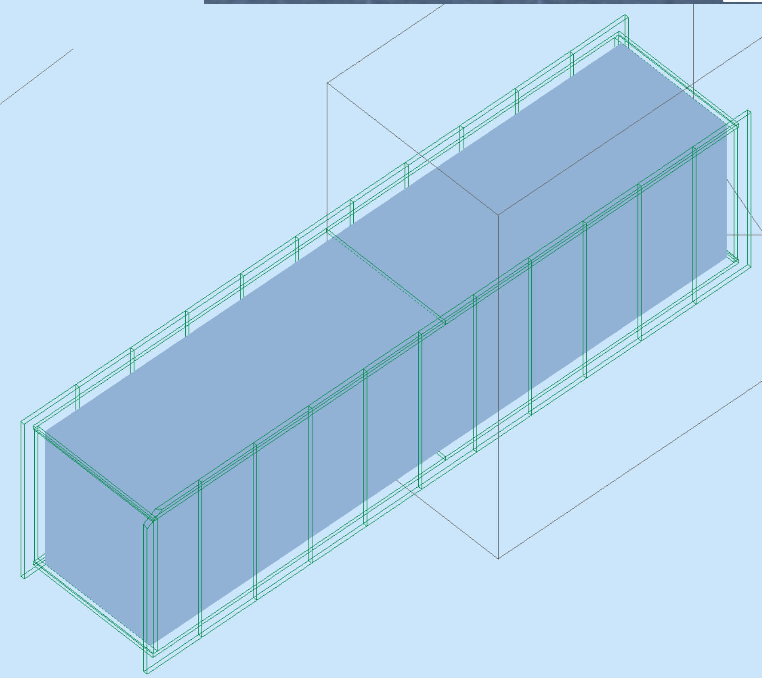






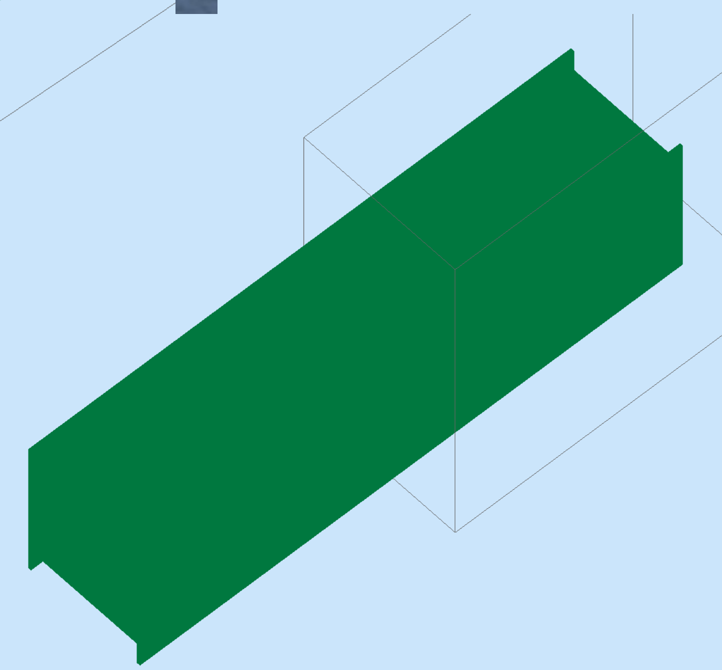
Outer Veto:

- Plastic scintillator +light guides
- PMT readout
- 28 channels

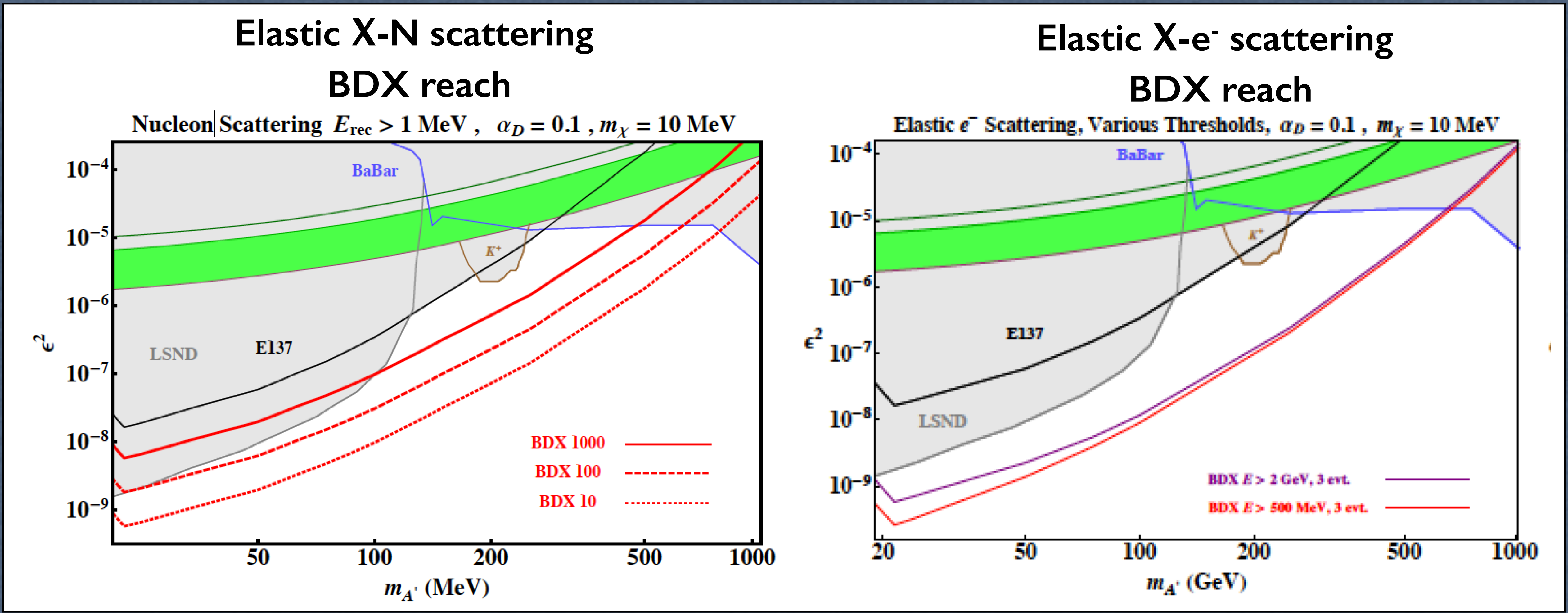


Lead vault:

- 5cm thick lead bricks
- 5 ton



BDX - Dark matter search in a Beam Dump eXperiment



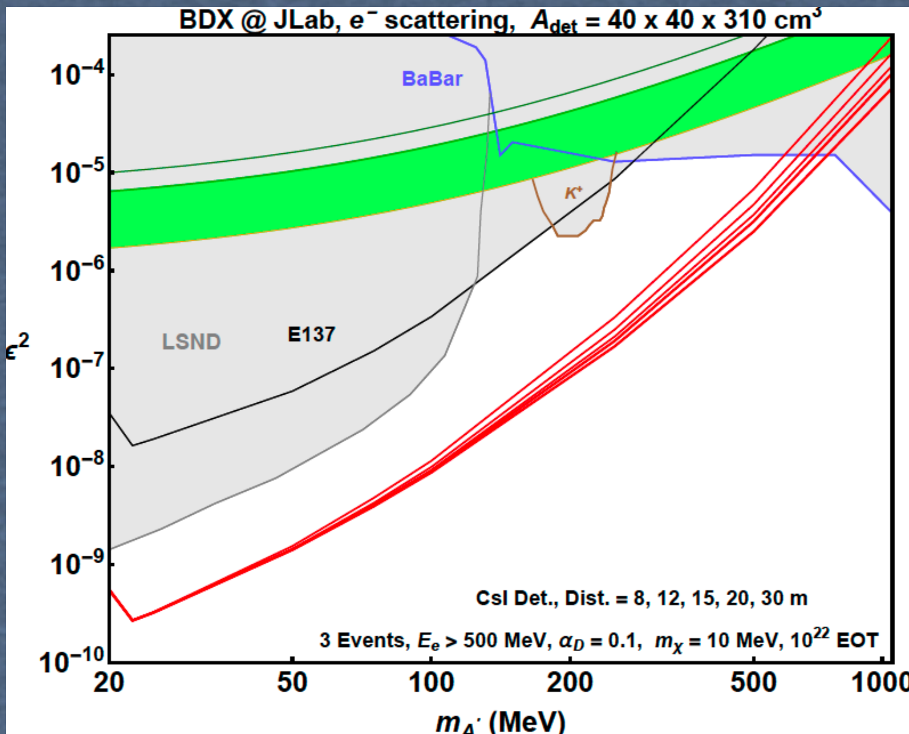
BDX@JLab reach

- CsI calorimeter (~800 crystal, 2.2m long)
- 10^{22} EOT (100 uA for 6 months)
- BDX is full parasitic: data tacking with Hall-A running or not
- realistic estimates of cosmogenic and beam-related background

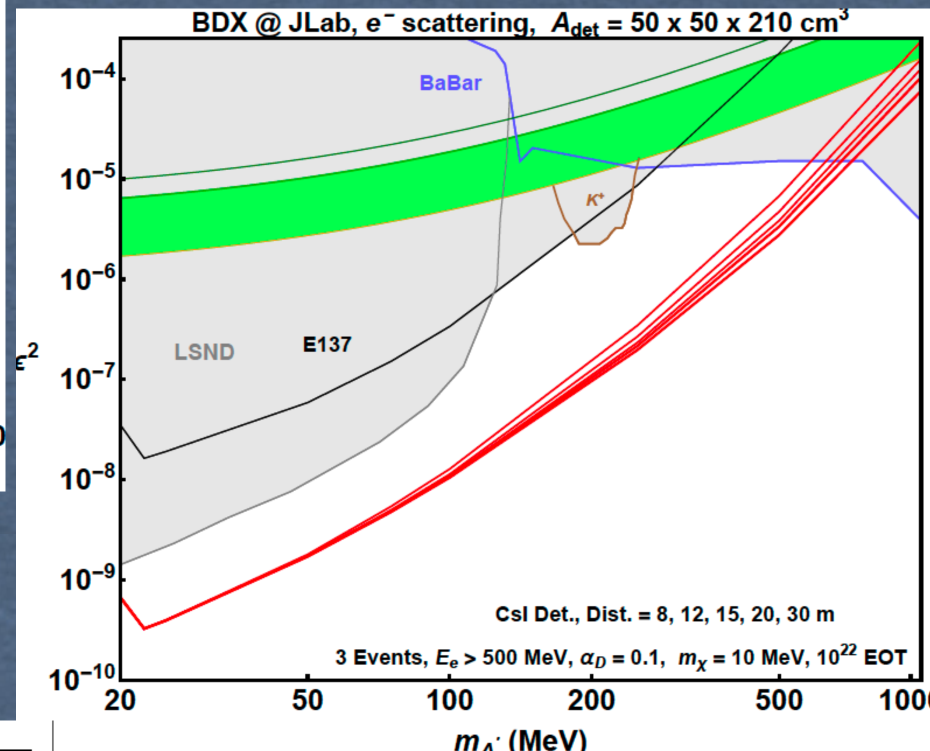
At least, two orders of magnitudes better than any previous experiments

- BDX LOI submitted to JLAB PAC42 - August 2014 (http://arxiv.org/abs/1406.3028)
- Positive feedback: the BDX Collaboration is planning to present a full proposal to PAC44 (June 2016)

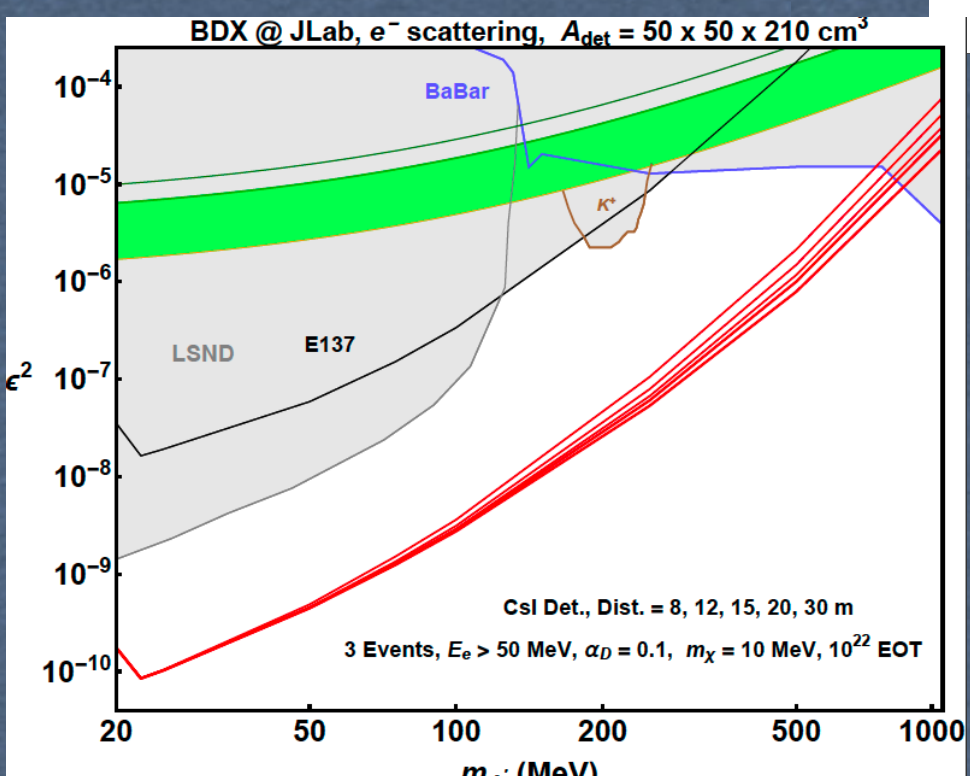
Set-up optimization (in progress)



- ✓ Weak dependence on the BD/detector distance 8,12,15,20,30 m

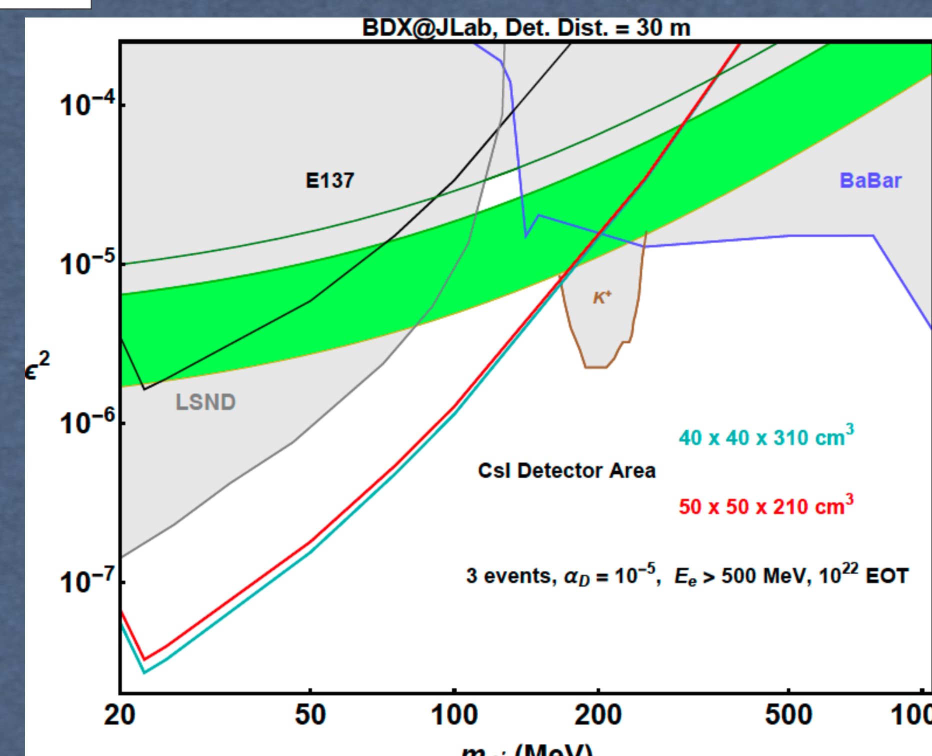


- ✓ No sizeable effect by varying the detector footprint with fixed volume (40x40x310) vs. (50x50x210)



- ✓ No sizeable effect by varying the electron energy threshold 500MeV vs 50 MeV

- ✓ Significant reach even considering a reduced dark sector coupling $\alpha_D=10^{-5}$ vs $\alpha_D=10^{-1}$



R&D, prototyping, tests

BDX prototype
- crystal array
- ext-veto
- int-veto
- lead shielding

★ BDX - Cosmic Run

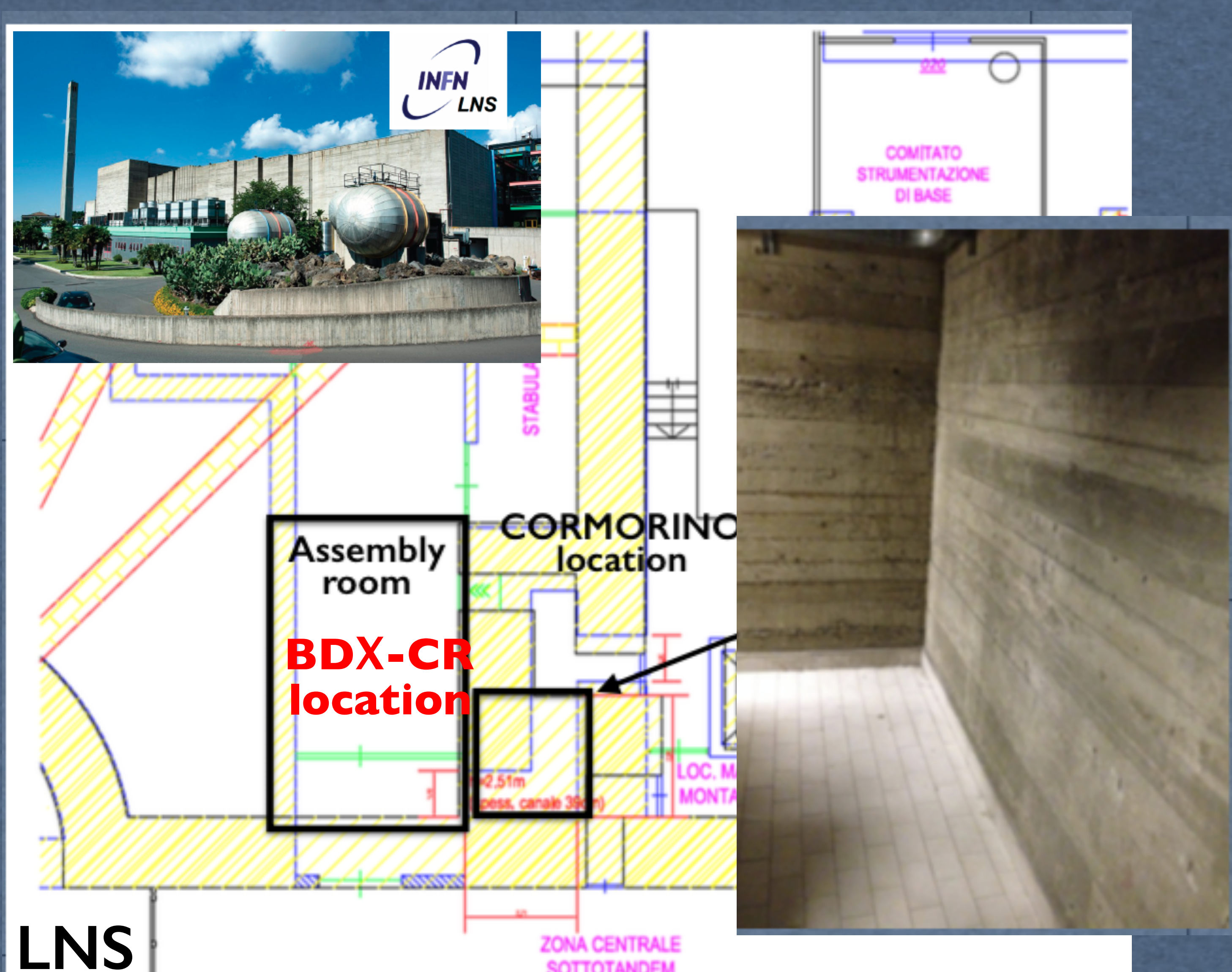
@ Laboratori Nazionali del Sud (LNS - Catania)

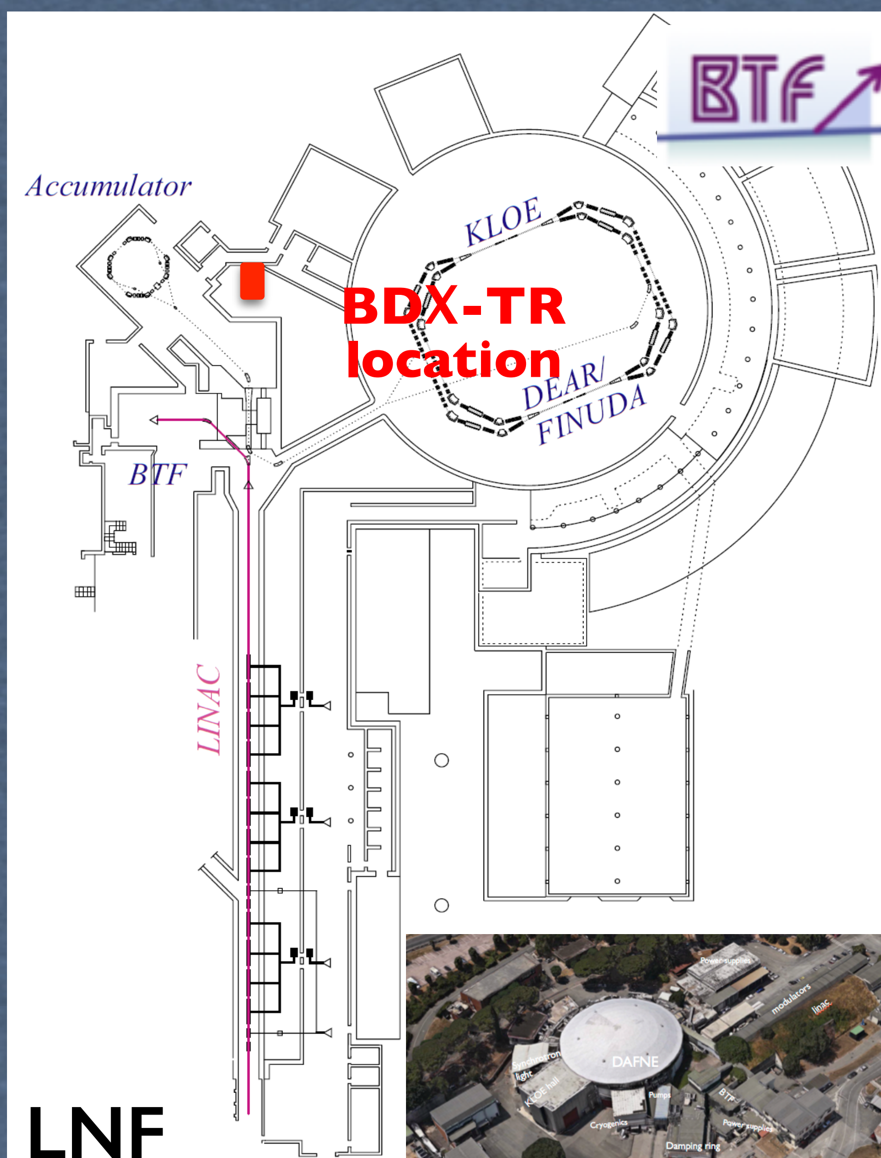
★ BDX - Test Run

@ Laboratori Nazionali di Frascati (LNF - Frascati)

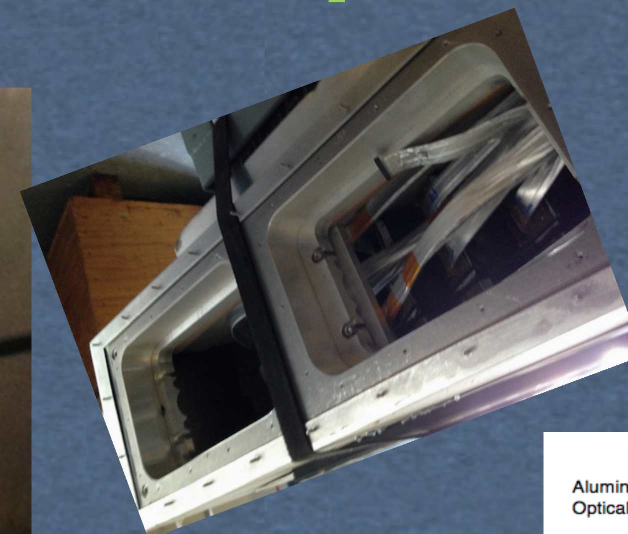
- Test of different veto options
- Veto inefficiency
- Shielding optimization (cosmic/beam)

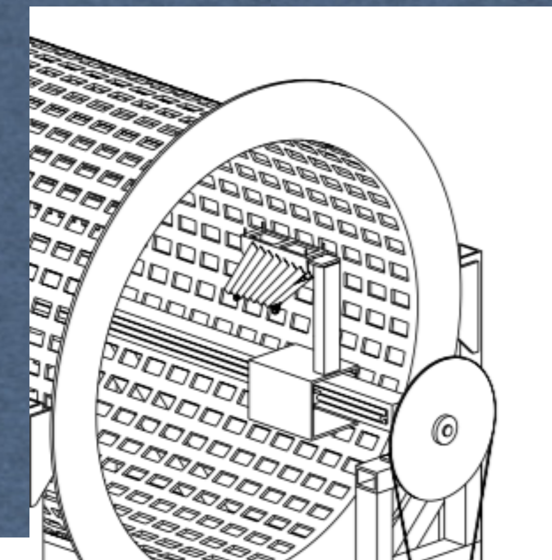
- Validate MC results
- Test of different crystals
- Quantify background rates vs energy thresholds

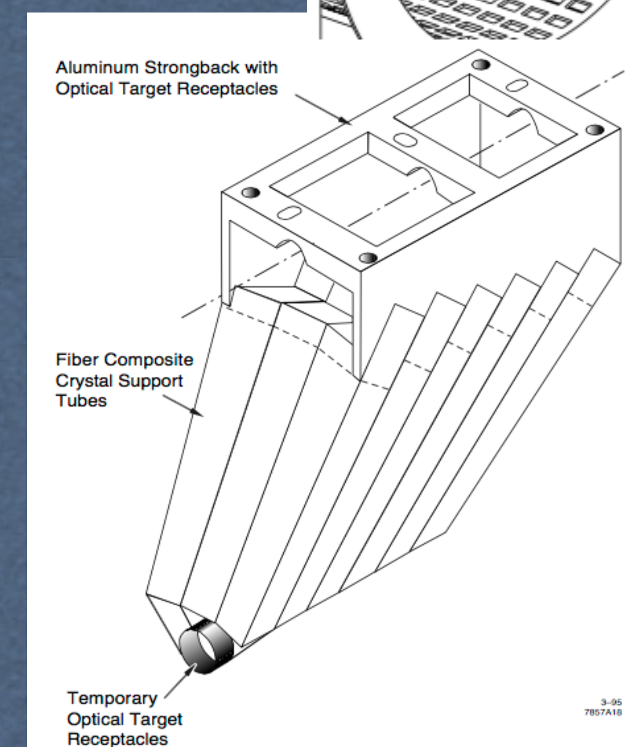




Reuse of BaBar crystals - BDX proto

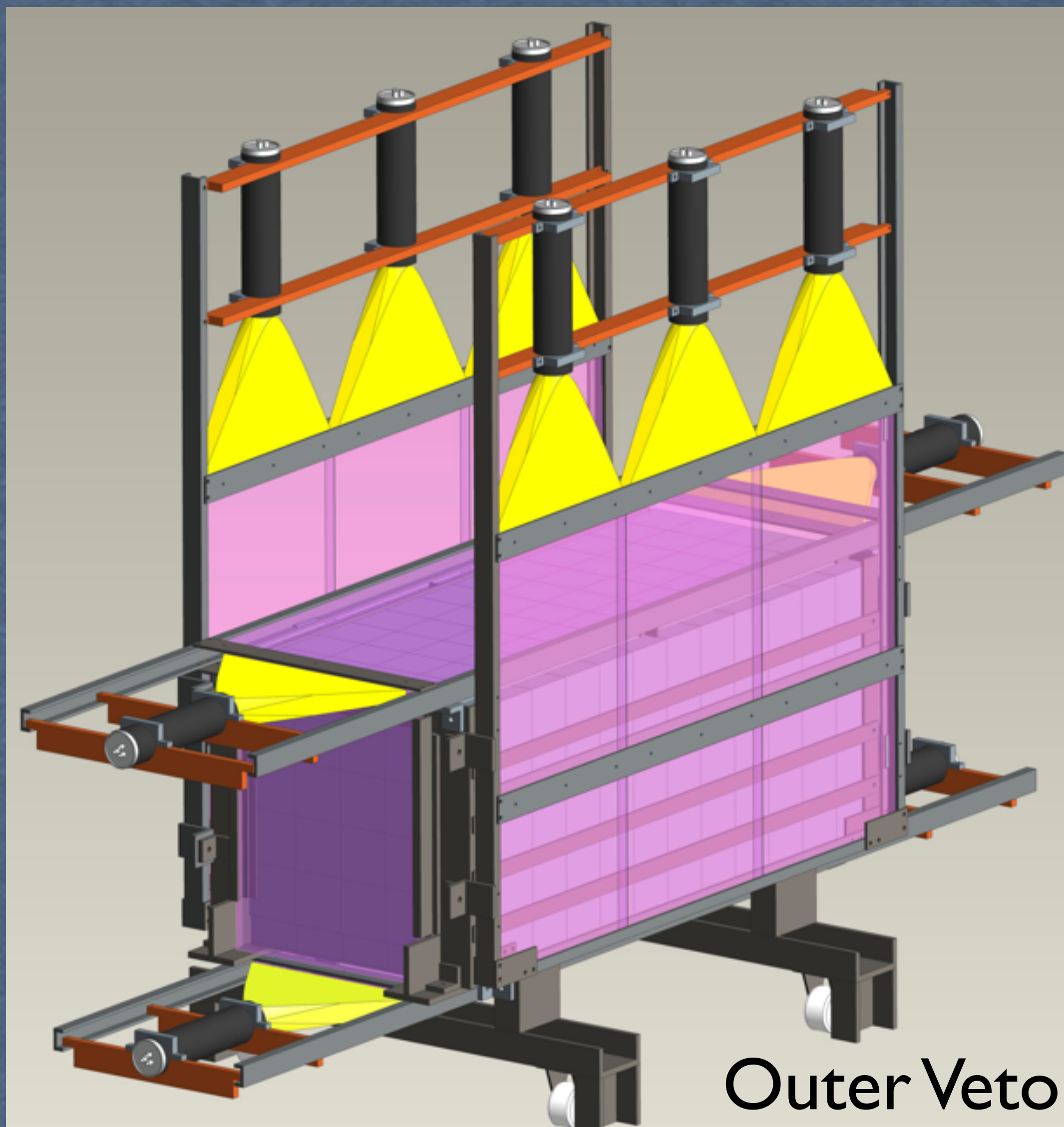






- ★ Crystals from a test module of BaBar ECal could be used as a BDX prototype
- ★ Negotiation with SLAC management already started
- ★ Barrel module, ~50cmx100cm, 3x7=21 crystals

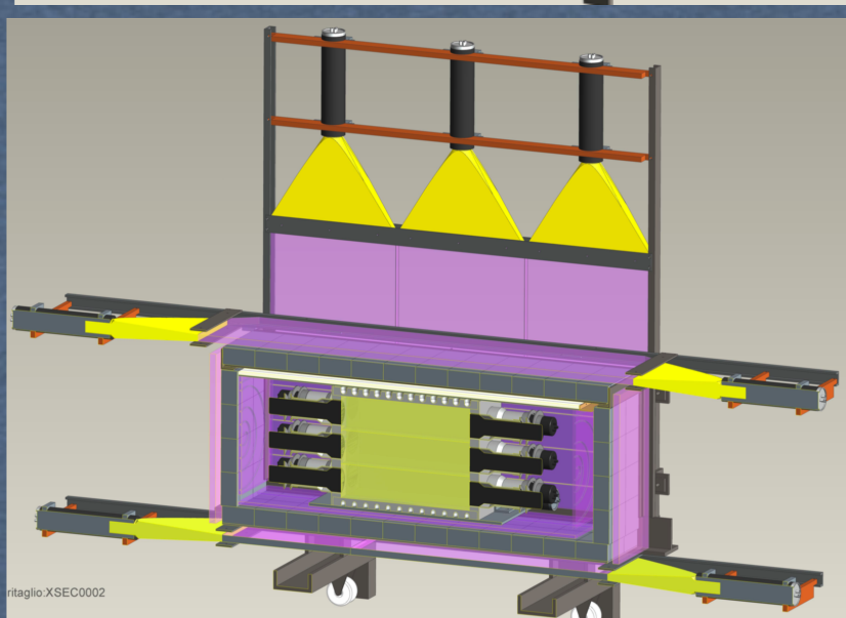
BDX - Proto
Inner and outer Veto

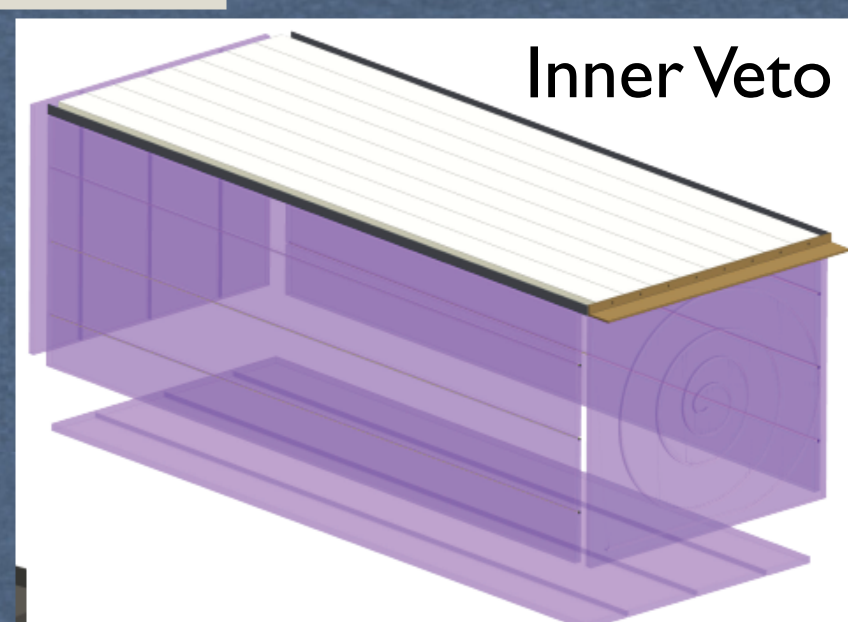


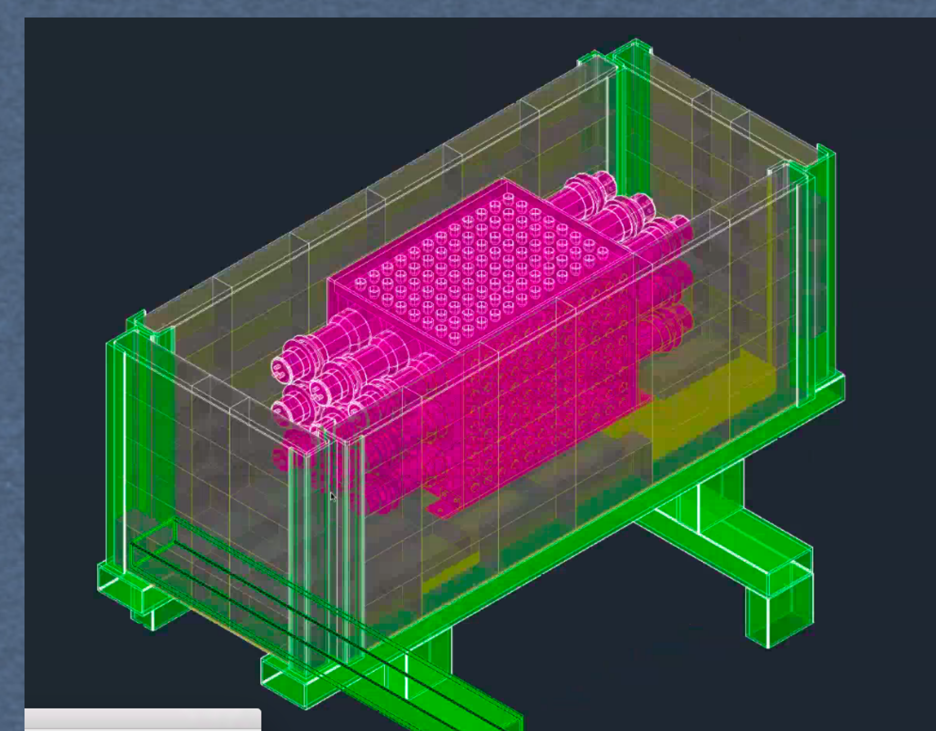
Inner Veto
- Clear/extruded plastic scintillator + WLS
- SiPM readout
- multiple sipm per side
- Individual paddle efficiency > 99.5% (Not true for extruded)

Outer Veto
- 80x40x2 cm^3 paddles
- PMT readout
- 12 channels
- Individual paddle efficiency > 99.5%

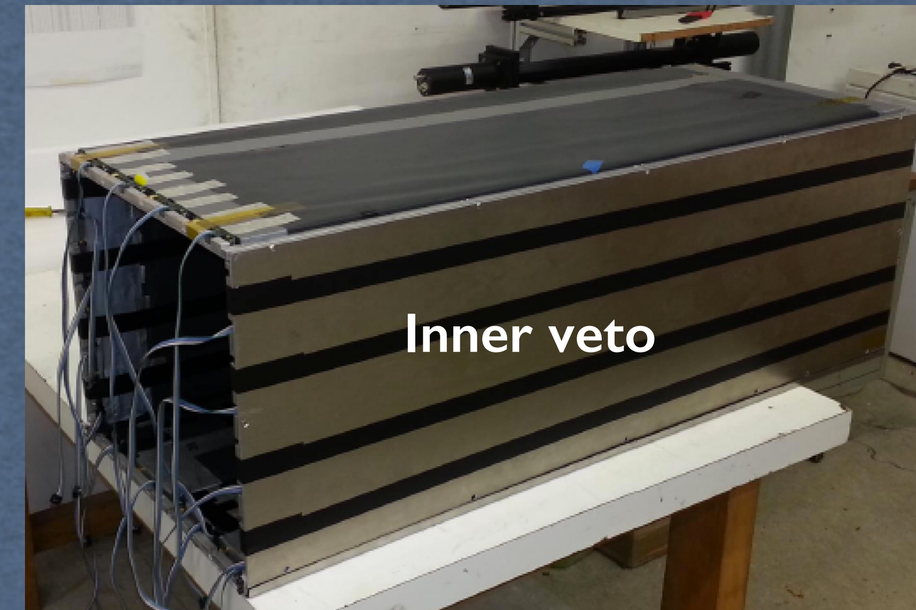
Lead vault
- ~150 10x20x5 cm3 lead bricks
- Total weight ~1ton

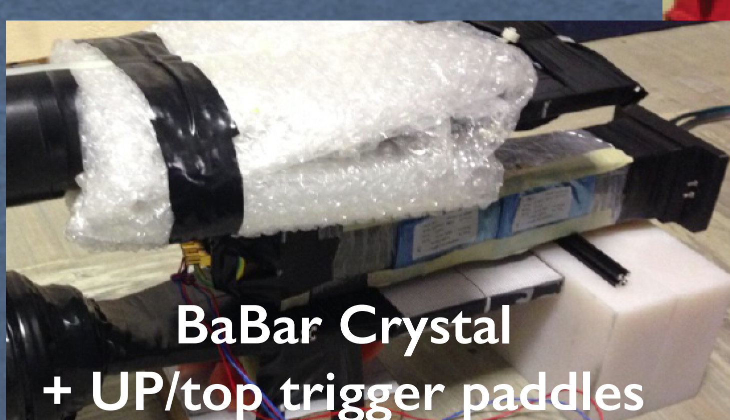






BDX-proto





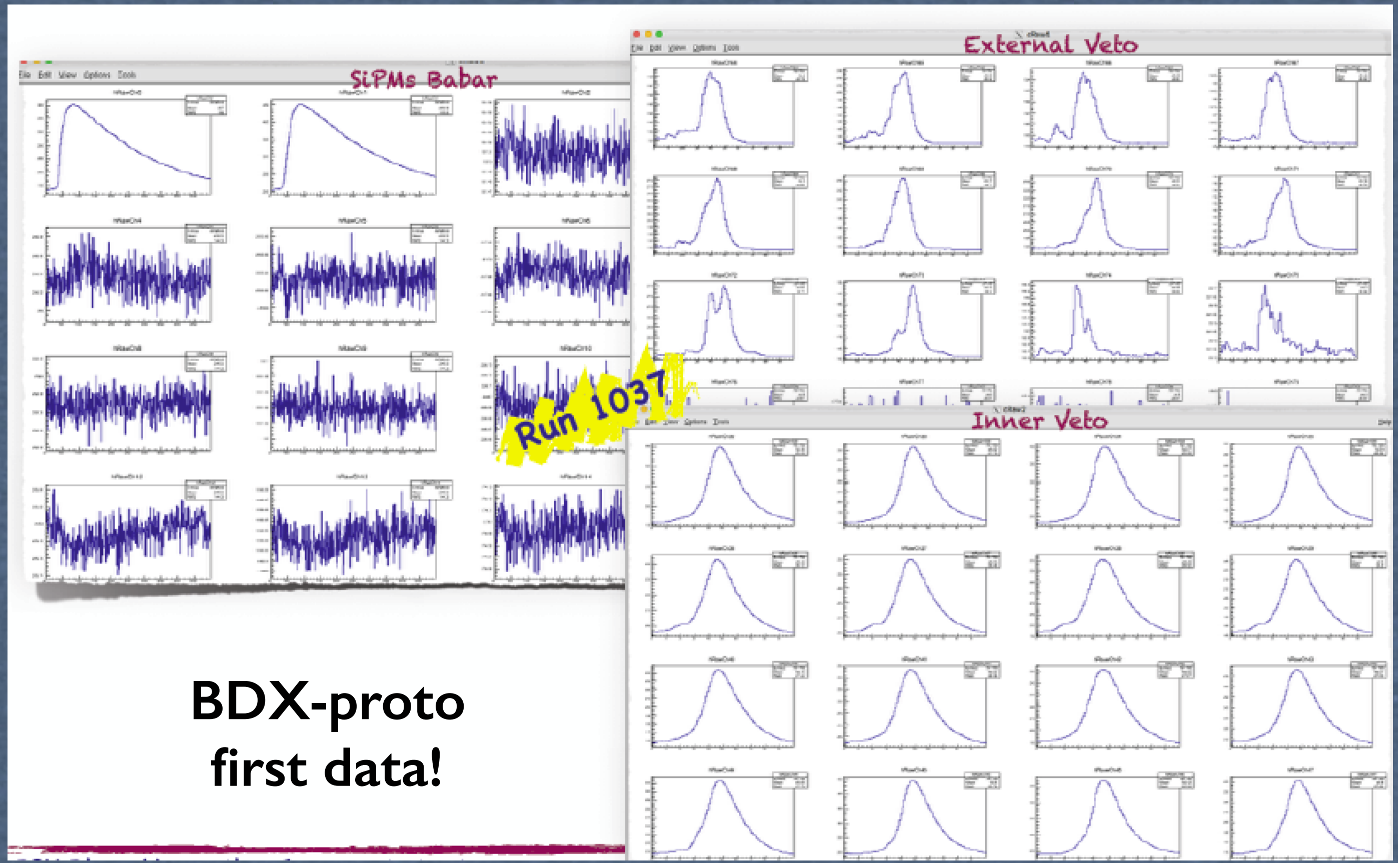
BDX-proto

- Outer Veto
- Lead vault
- Inner Veto

now	~ few months
1 CsI crystal 2x 3x3 sipm + pin-diode	20 CsI crystals

BDX-proto

BDX-proto currently running at LNS (CT-Italy)

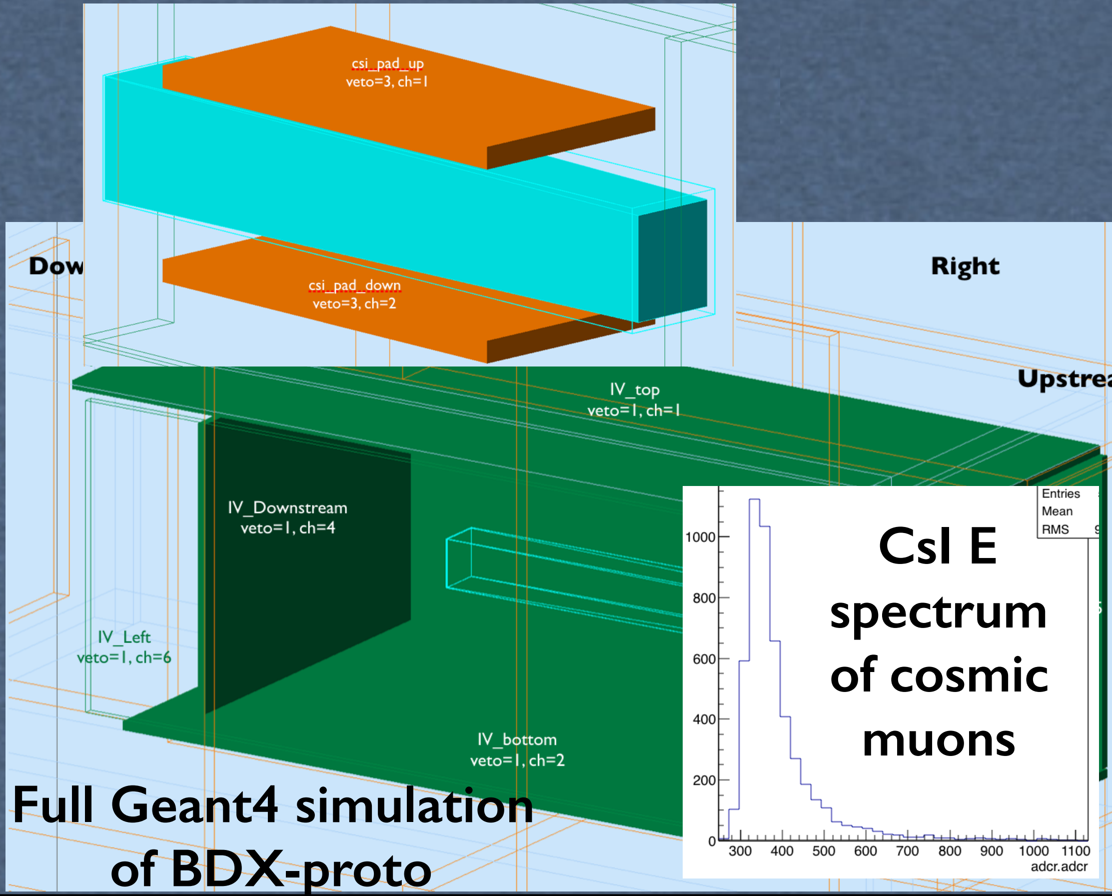


BDX-proto first data!

Thresholds

- Babar Sipm1/Sipm2: 100 mV (few MeV equivalent)
- Paddle_up/Paddle_down: 120mV (MIPs ~200 mV)
- Inner Veto: 40 mV (MIPs ~100mV)
- Outer Veto:100-150mV (MIPs ~300-400 mV)

Triggers	Rates
• Trigger 1: Babar_Sipm1 .OR.Babar_Sipm2	~ 13 Hz
• Trigger 2: Paddle_up .AND. Paddle_down	~ 0.5 Hz
• Trigger 3: at least 2 of any Inner Veto	~ 1 kHz
• Trigger 4: at least 2 Outer Veto	~ 0.1 kHz



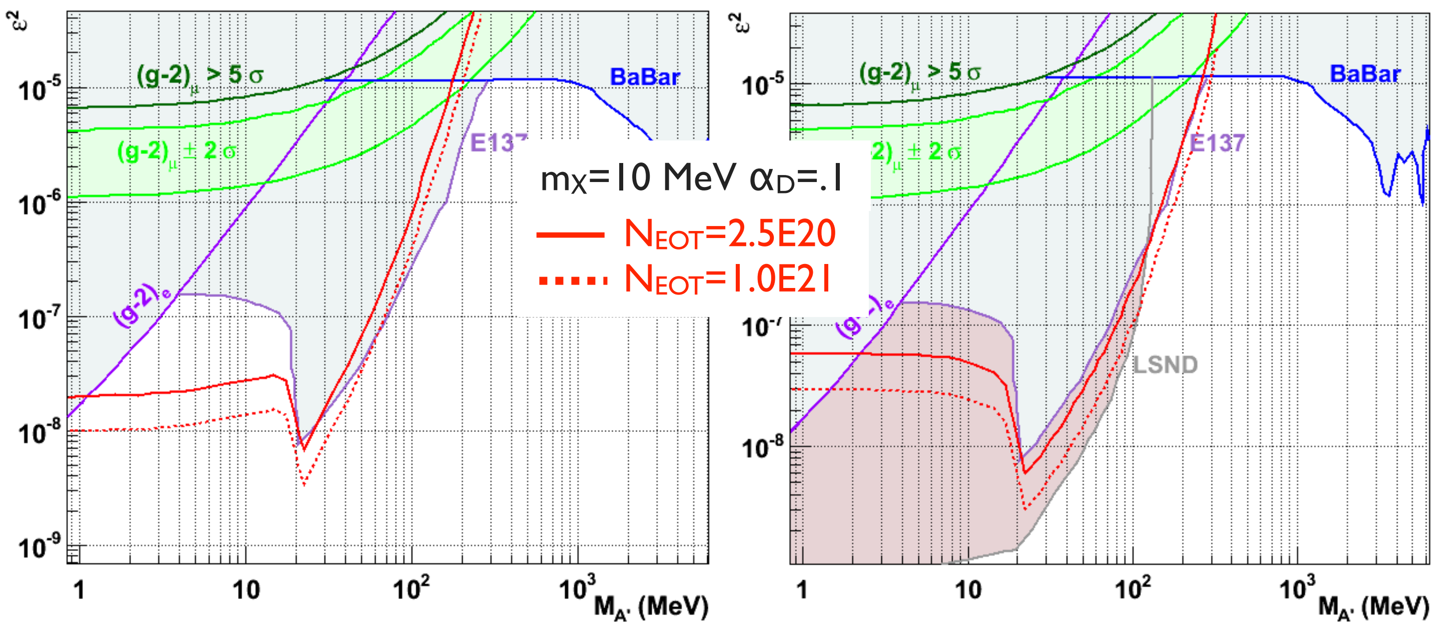
Full Geant4 simulation of BDX-proto

Data analysis underway

- Full wave forms stored for offline analysis
- Anti-coincidence with veto's
- Rate as a function of the threshold (off-line)
- MC comparison and validation

Competition with other facilities

El scattering on electrons | El scattering on nucleon



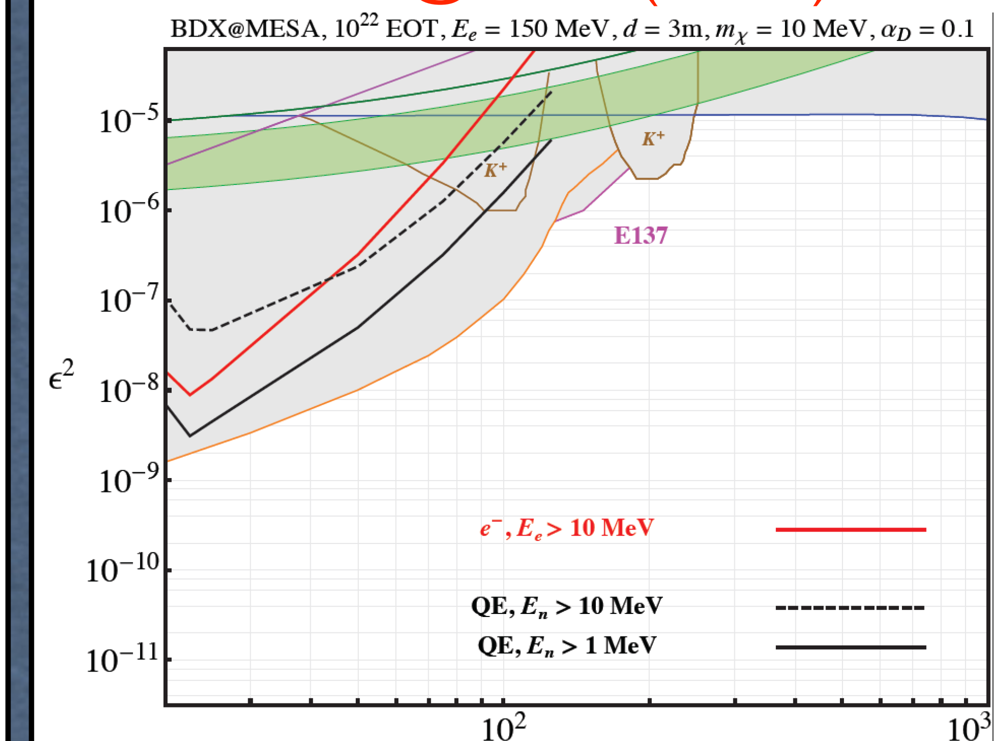
BDX @ LNF

- E_{e-} = 1.250 GeV (now 0.75GeV)
- EOT ~ 10^{20}-10^{21} year^{-1} (now 10^{19})
- Pulsed beam 50Hz
- Minimal infrastructure costs

- Re-use of BaBar crystals (~1080)
- Detector: 60x60x225 cm3 at 5m from the dump
- 1y run (within PADME Experiment)
- 2-3y from now

P.Valente

BDX@Mainz (MESA)



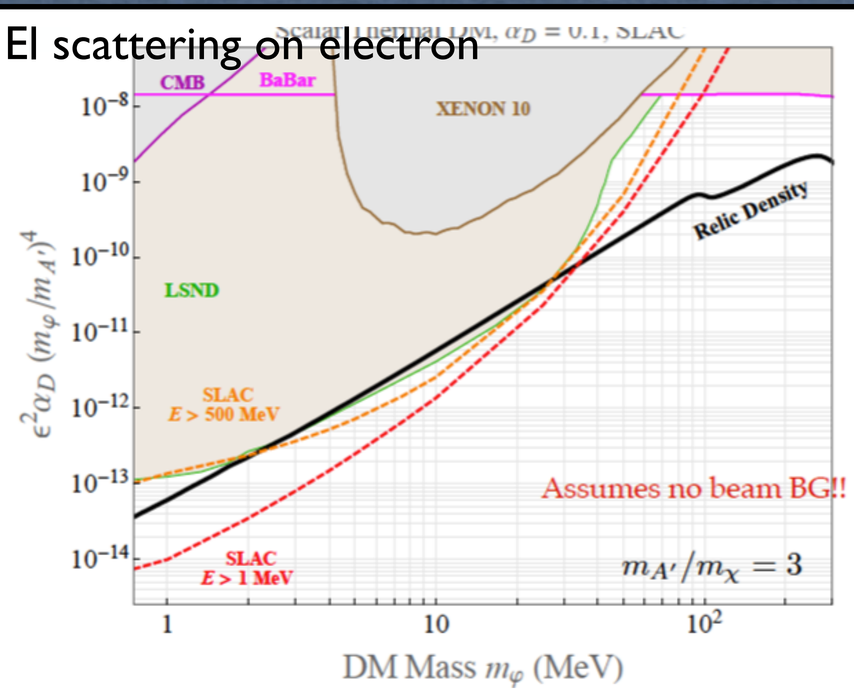
- E_{e-} = 150 MeV
- EOT ~ 10^{22}
- CW beam (3ns)
- Infrastructure costs limited
- Time line ?

- Re-use of BaBar crystals (~1080)
- Detector: 60x60x225 cm3 at 3m from the dump
- 3y run (parasitic to PV exp)

- Proposal accepted

A.Denig

El scattering on electron



BDX@SLAC LCLSII

- E_{e-} = 4 (8) GeV
- EOT ~ 3 10^{21}
- Pulsed beam ~1MHz
- Reduced cosmogenic bg
- Beam dump area clear
- Infrastructure costs limited
- May be some bg from the X-ray line
- Time line: 2020

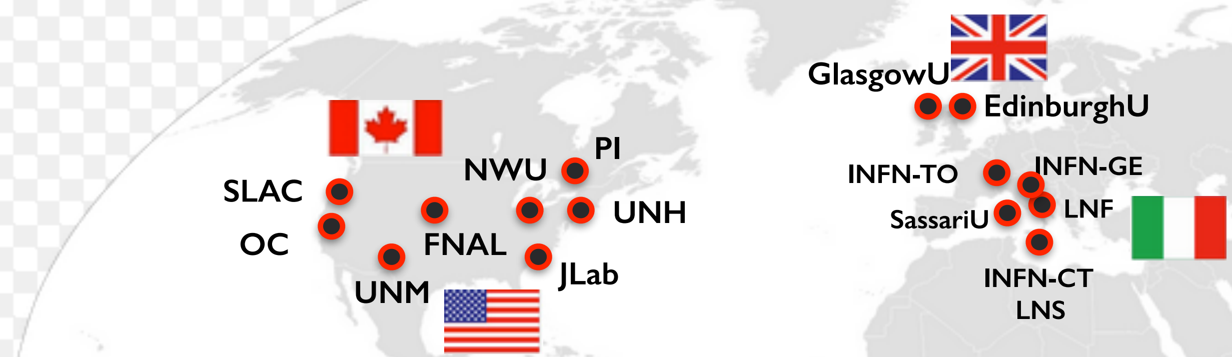
G.Krnjaic

BDX@Cornell

- E_{e-} = 200 MeV
- EOT ~ 2.5 10^{22}
- Energy Recovery machine with extracted beam
- Some interest for a BDX-like experiment
- Time line: 2019

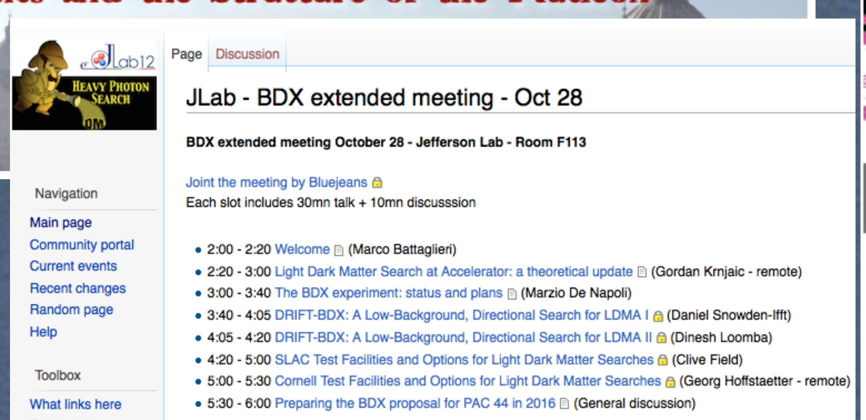
J.Alexander

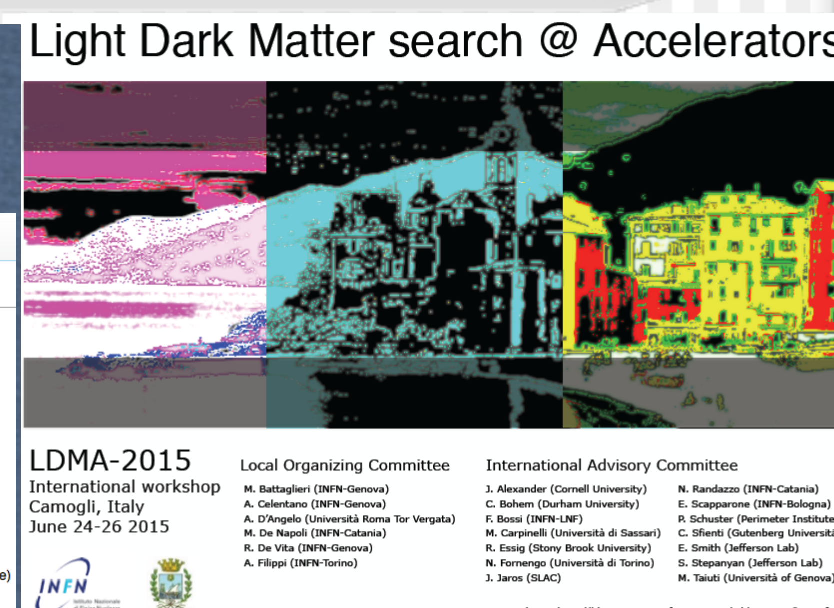
The BDX Collaboration

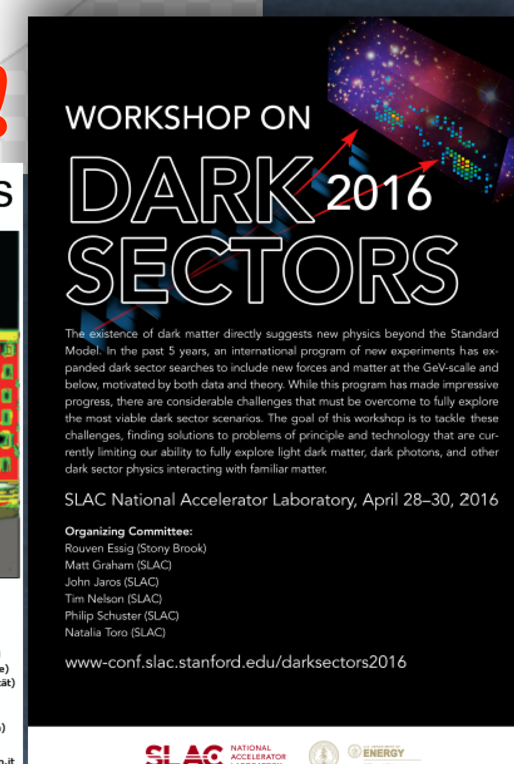


- More than 80 researchers signed the LOI presented to PAC 42
- More expected for the PAC44 proposal
- Connection with groups involved in similar projects at SLAC, CERN, Mainz and LNF
- Core group working on different aspects: physics, detector, simulations
- Weekly meeting to check progresses and share information
- Wiki page to store documents and meetings minutes
- Organisation of dedicated workshops and satellite meetings at major venues
- R&D funds from INFN and grant requests submitted to NSF (BDX-DRIFT) and Italian PRIN (LightDAMS)

New collaborators are welcome!







Conclusions

- Existence of Dark Matter is a compelling reason to investigate new forces and matter over a broad range of mass

- Accelerator-based (Light)DM search provides unique feature of distinguish DM signal from any other cosmic anomalies or effects

- Extensive experimental plans at high intensity e-facility: JLab, LNF, Cornell, Mainz, SLAC (+ p beam at FNAL and CERN)

- A detector based on CsI crystals + InnerVeto + Outer Veto running parasitically downstream of JLab Hall-A beam dump in 1y would set 10-100 times better limits

- A BDX prototype is currently tacking cosmic data and results will be used to validate MC simulations and cosmic bg estimates

- A detailed infrastructure cost has been performed

- Discovery or decisive tests of simplest scenarios will possible in the next ~5-8 years!

Backup

Candidates for BDX calorimeter

	PbWO	BGO Bi4Ge3O122	BSO Bi4Si3O12	LuAG:Ce	BaF2	CsI:Tl0.1%	Plastic
density (g/cm^3)	8.3	7.1	6.8	6.7	4.9	4.5	1
LY (N_γ/MeV)	120 (0.3 %NaI)	6 10^3 (15%NaI)	100/200/1.4 10^3 (0.25/0.5/3.4 %NaI)	8 10^3 (20 %NaI)	1.4 10^3/15 10^3 (3.4/36 %NaI)	75 10^3 (105/60 %NaI)	
Decay time (ns)	10	300	2.4/26/99	70	0.9/630	680/3340	1.8
Radiation length (cm)	0.9	1.12	1.15	1.4	2.03	1.85	42.5
Emission peak (nm)	420	480	480	530	220/300	565	410
Light Quenching (T_p=10MeV)		0.5	0.5			0.5	0.5
cost ($) 30x30x40$cm^2$	750k 450x (2x2x20)	crystals from L3	600k 600x (2x2x15)		540k 120x (10x10x20)	crystals from BaBar	9k 36x (5x5x30)
cost ($) 30x30x1000eq	2.25M L=1.2m	0.3M L=1.5m	2.4M L=1.5m		2.75M L=2m	0.3M L=2.25m *	0.3M L=10m
Full cost (cal+veto+shield)	2.5M	0.5M	2.6M		2.85M	0.5M	2.0M

* Reuse of 810 CsI(Tl) crystals from BaBar the instrumented volume would be 60x45x225 cm3

The BDX crystals

Requirements:

- Critical: high density
- Critical: high light yield
- Critical: cost-affordable for a ~ m^3 detector volume
- Desirable: Good timing

3 possible options

- BaF2
- CsI
- BSO

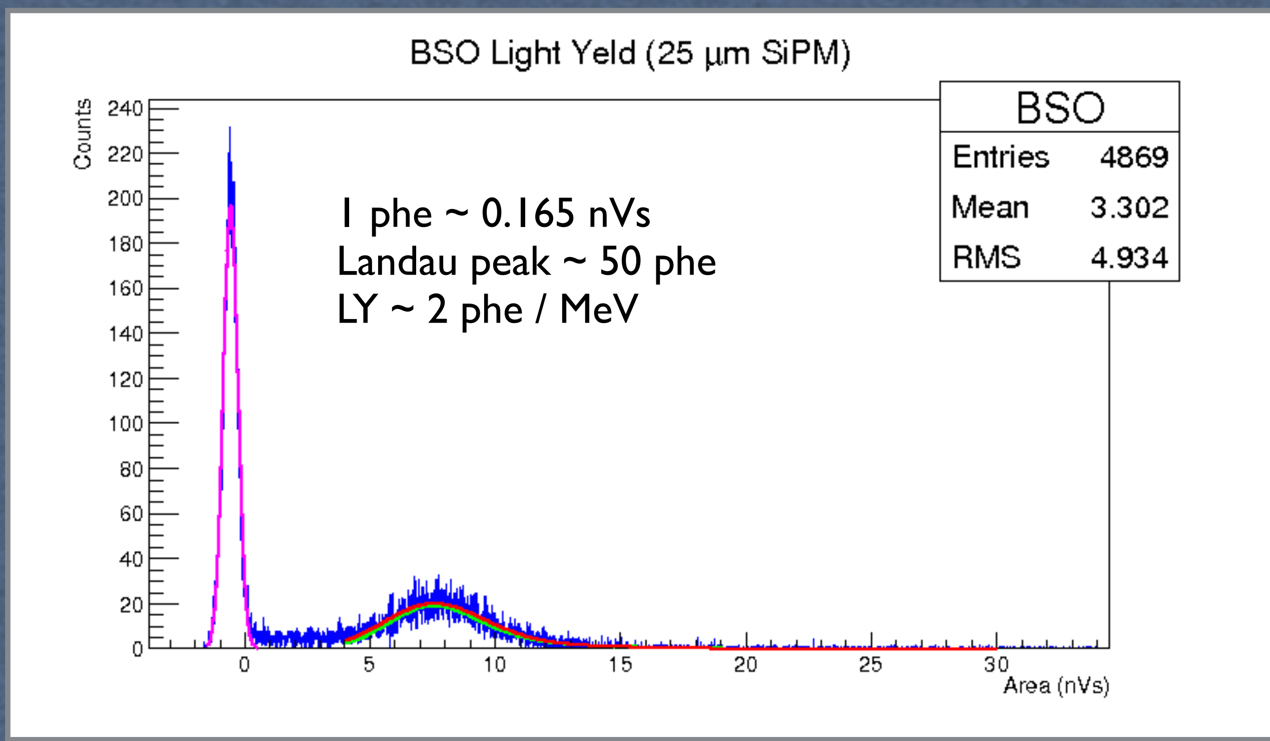
A dedicated measurement campaign to characterise the crystal properties

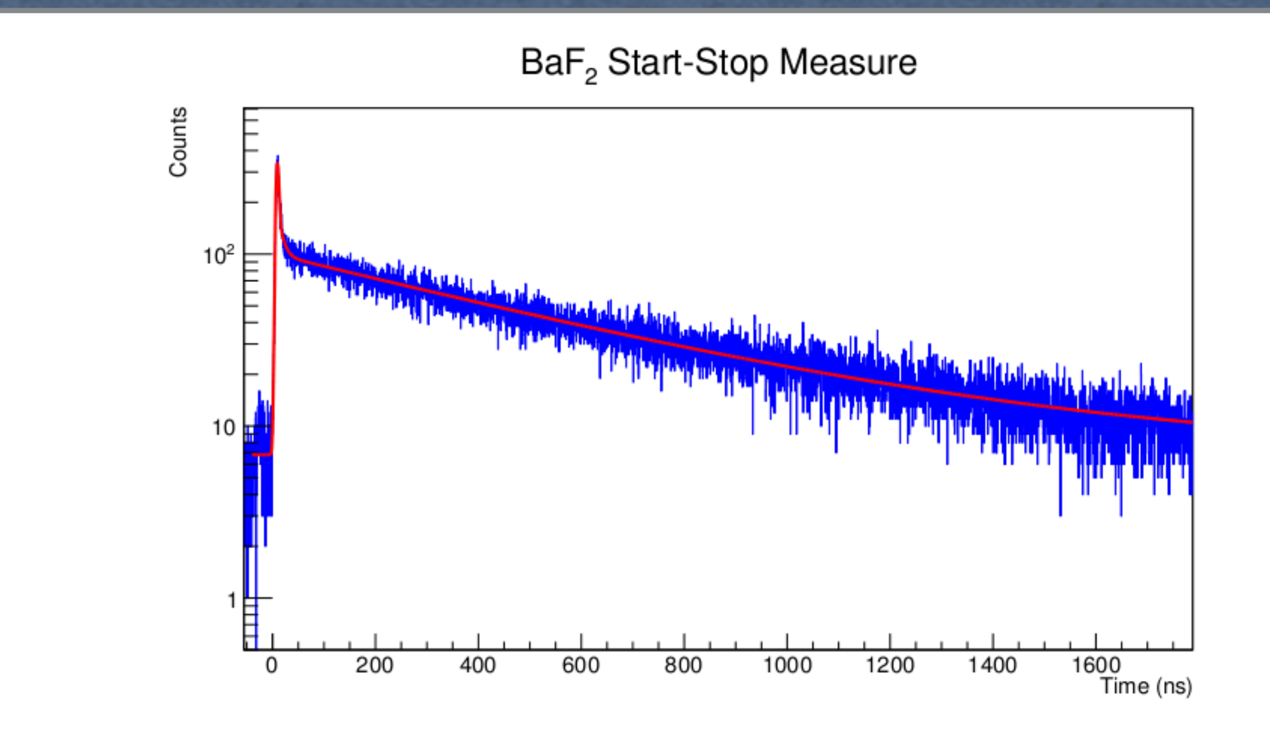
- Light yield (with SiPM readout!)
- Intrinsic decay time / time resolution

BSO & BaF_2

LY Results:

- Light yield measured with SiPM is ~ few phe/MeV for both crystals
- Measured decay time is compatible with literature results
- BaF2 shows an intense Cerenkov component in the START-STOP measurement (different crystal geometry)





A.Celentano, L.Marsicano

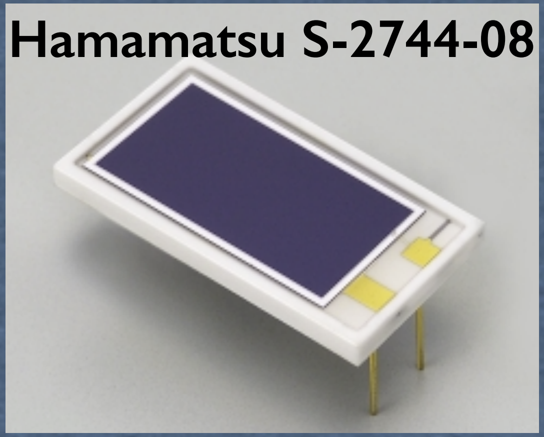
Reuse of BaBar crystals - Crystal redout

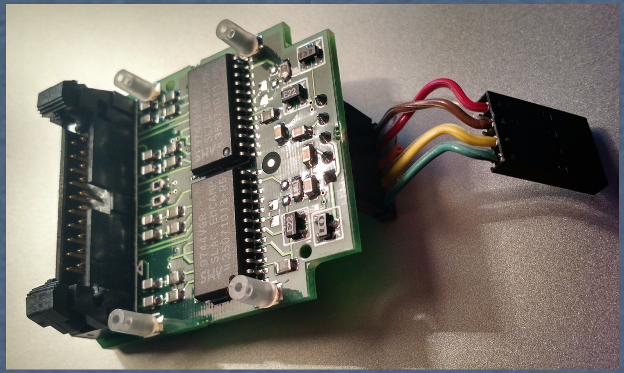
Different options under investigation:

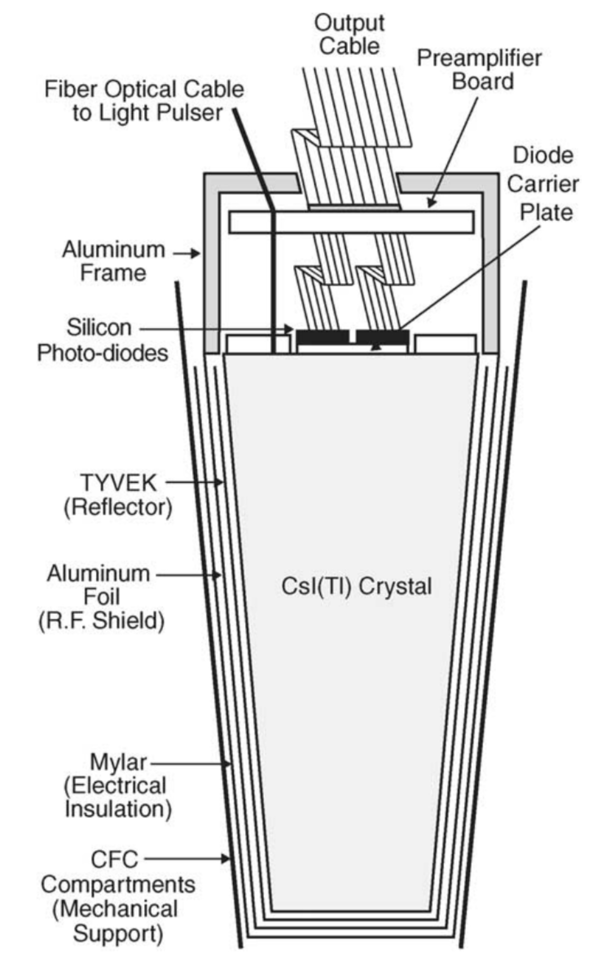
I) Use the existing pin-diodes + old BaBar FE electronics

PIN silicon photodiodes

- Photosensitive area 2 x 1 cm2
- 85% quantum efficiency at the peak light emission for CsI(Tl) of 565 nm
- Operational voltage : 50 V
- Dark current and capacitance of 4 nA and 85 pF at 70 V
- Light yield crystal+diode 7300 γ/MeV (1.836 MeV 88Y source - 2μs gaussian shaping time)



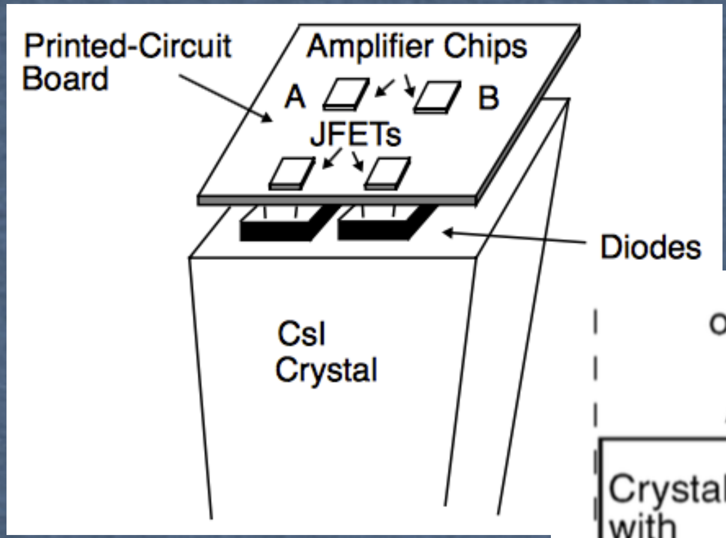


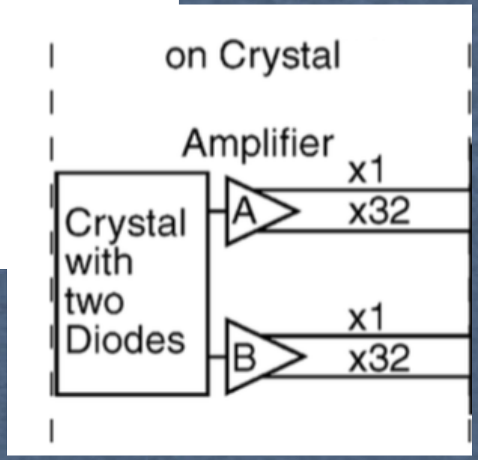


Two identical photodiodes installed on each crystal
Diodes glued to a transparent 1.2 mm polystyrene substrate
The remaining area is covered by a plastic plate coated with white reflective paint

Custom amplifier integrated circuit

- Custom amp asic + HV biasing resistors and filters
- Low-noise Q sensitive preamp + band-pass filter for high and low-freq noise
- Shaping time <1 μsec
- Two independent chans for each crystal
- Each out (A,B) amps x1 and x32

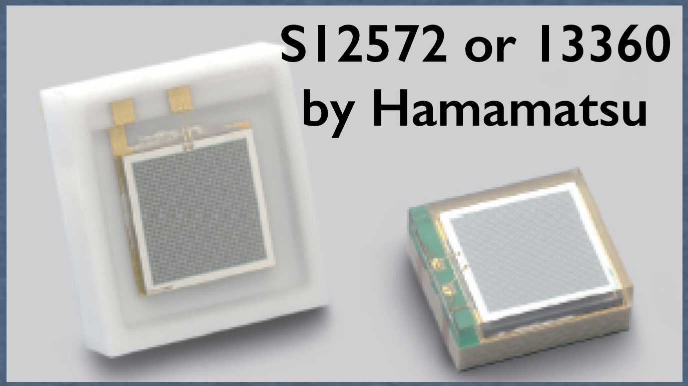


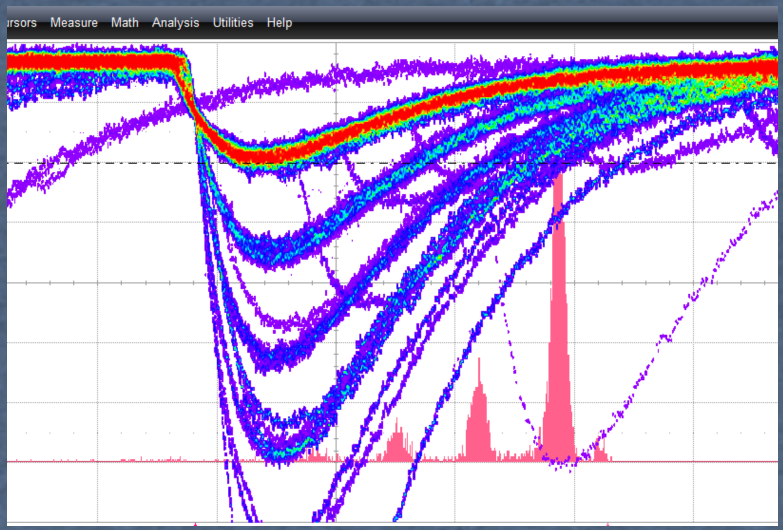


Reuse of BaBar crystals - Crystal redout

II) By-pass diodes by gluing new silicon PMs

Requirements
- SPE capability for efficient calibration
- Detection threshold: ~5MeV
  - Spectroscopy: integrated signal over ~0.5us
  - Trigger/Timing: Amplitude > 10mV





Tests performed with cosmic muons crossing one BaBar CsI crystal with a single 0.3x0.3cm2 S12572 on the front face + CLAS12-FT-Hodo preamp (based on CLAS-IC designed by E.Rauly -Orsay trans-impedance preamp)

SiPM: S12572-0100
- Pixel size: 100um
- Pixel N: 900
- G(1.4V OV)~3 10^6

Preamp: FT-H-redG
- G~15
- Q_{SPE}~0.6 nVs
- A_{SPE}~10mV

- Crossing muons~35 MeV
- Int-time=1us (65% LY)
- Area: 300 nVs (~6 nC)
- Peak: 550 mV

Measured ~10-15 pe/MeV

Expected: ~16 pe/MeV

pe (MeV)= Nγ Side s/S PDE FFF IT
Nγ = CsI LY = 50k/MeV
Side = 0.5 half in one dir x1.2 reflection=0.6
s/S = 0.09 cm2 / 25 cm2=3.6 10^{-3}
PDE= Photon Detection Efficiency=30%
FF=geometrical Filling Factor=78%
IT= IntegrTime 1us=65% tot

SIPM
- Area 3x3mm = 0.09 cm2
- Pixel size = 15um
- Pixel N=40k
- Linearity: 1-20k
- G (4V OV)~3 10^5
- PDE~25%
- FF~50%
- An overall 1/20 wrt 100um

Preamp
- G~30 (2x)
- Q_{SPE}~0.1 nVs
- A_{SPE}~2mV

Expected
- Npe/MeV = 1-1.2
- $Q_{Threshold}$ (5MeV)= 5pe
- $A_{Threshold}$ (5MeV)= 10 mV
- A_{Max}(Amp sat 2.0V) → 1000 pe (1GeV)