# Light Dark Matter searches at accelerators

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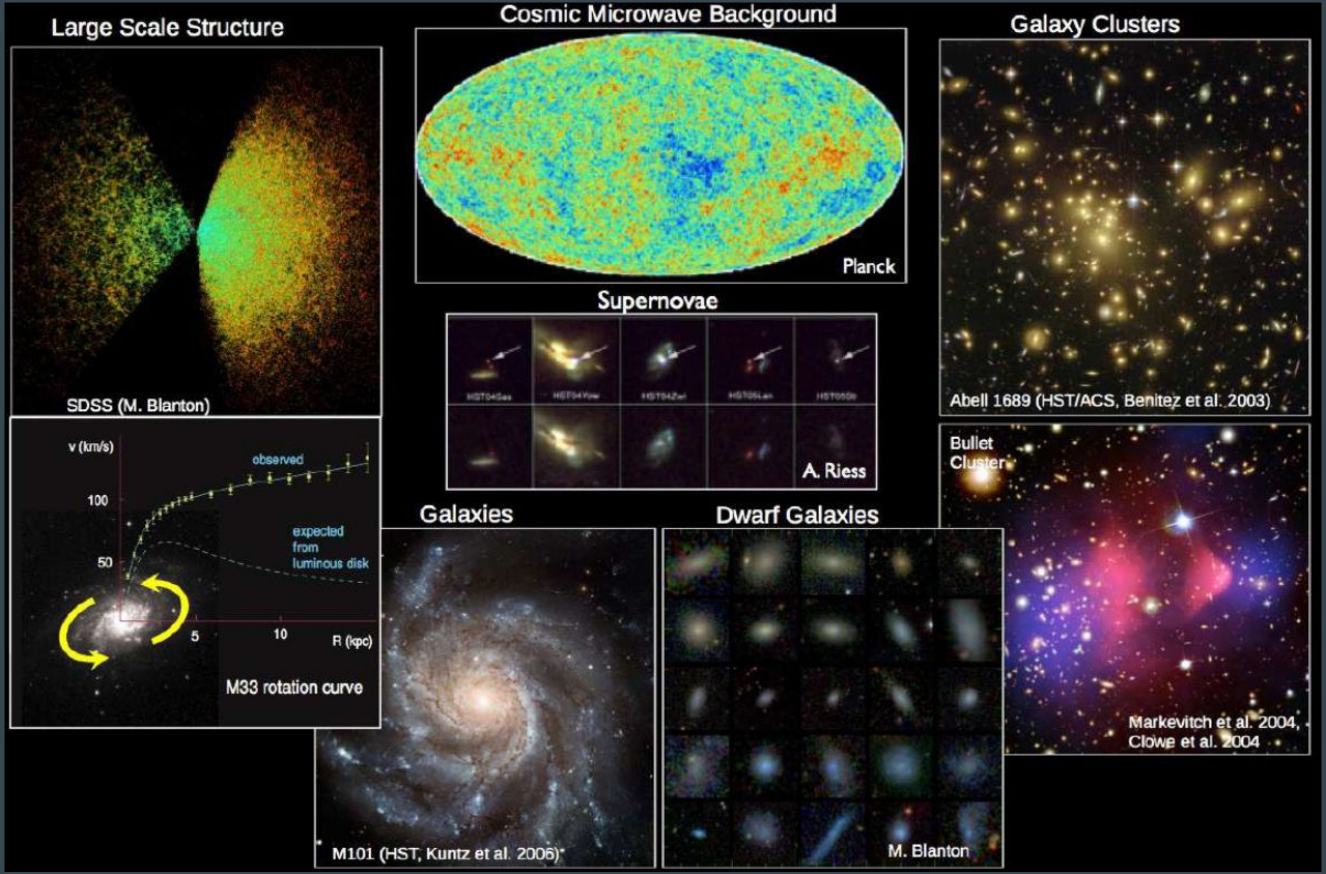
# Content of the lectures (tentative)

- Introduction: brief description of the Light Dark Matter model considered
- LDM Searches at colliders
  - focus on the LHCb searches for visible Dark Photon decays
- Fixed thin target experiments
  - the Heavy Photon Search at JLab
  - the X17 search at PADME
- Beam-dumps
  - the Beam Dump eXperiment (BDX)
  - SHIP@CERN
- Missing energy/momentum experiments
  - NA64-e
  - NA64-mu

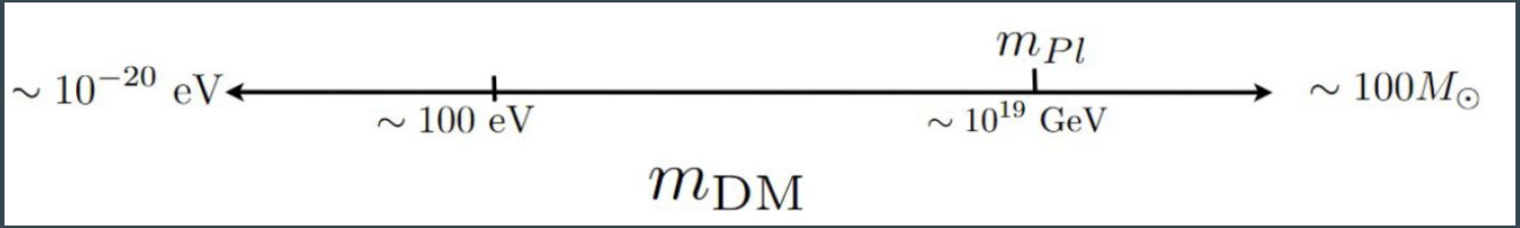
# DM: it is (most probably) there, but what it is made of?




see lectures by Graciela Gelmini

# DM: From particles to black holes

- All Dark Matter evidences come from the observation of its gravitational effects
- No hints on DM particle properties (mass, cross section) from particle physics experiment
- The viable DM mass window is dauntingly large:

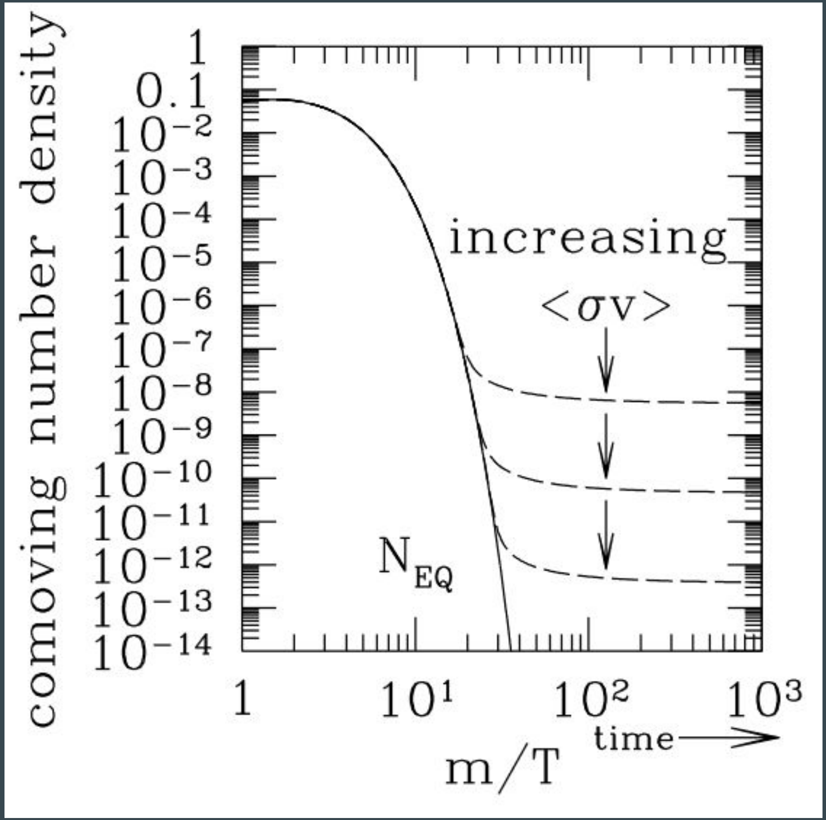



Theoretical guidance is needed to narrow the search window!

# Thermal DM Hypothesis

Cosmological Hypothesis: DM particles were in equilibrium with primordial thermal bath in early universe $\chi + \bar{\chi} \leftrightarrow f + f$

- Early universe: high-T, relativistic regime. Both reactions ($\leftarrow$ and $\rightarrow$ ) permitted
- As Universe expands and cools down below $\chi$ mass, only $\rightarrow$ reaction occurs. DM number density is exponentially suppressed: Boltzmann regime
- Eventually, DM number density is too low for $\chi$ to find each other $\rightarrow$ annihilation stops $\rightarrow$ Freeze Out

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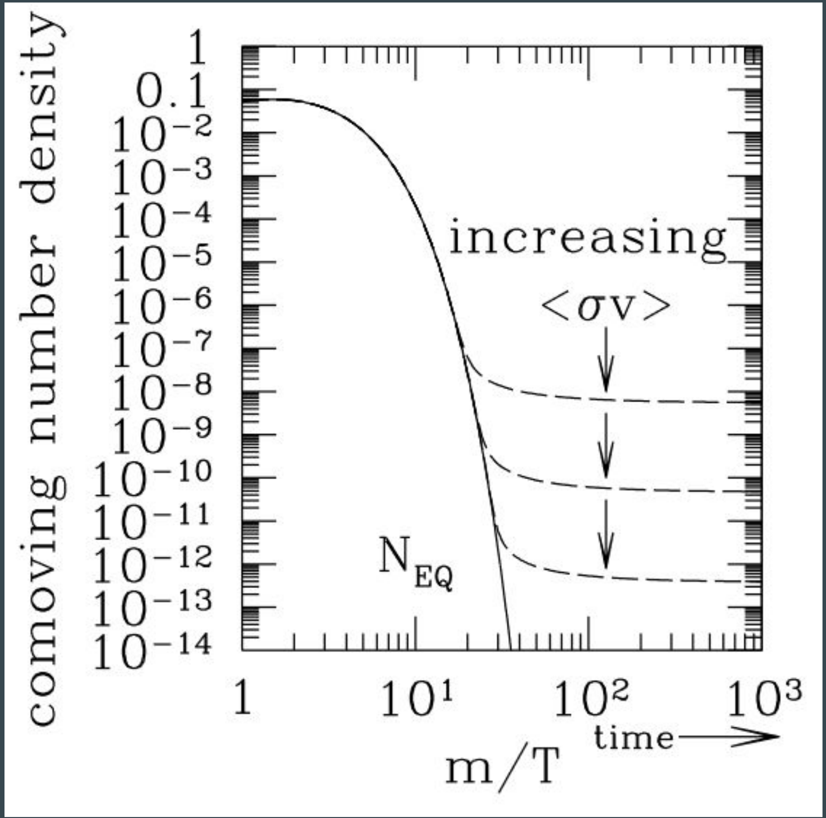
# Thermal DM Hypothesis

In the thermal DM scenario, DM density today can tell us about DM → SM model annihilation cross-section: $\chi + \bar{\chi} \leftrightarrow f + f$

- ❖ If annihilation-cross section is too high (small), DM particles would stay longer in equilibrium in the Boltzmann regime, resulting in a lower (higher) number density at present

- ❖ DM particle mass and annihilation cross-section are bound

- ❖ If $m_\chi \sim 100$GeV → typical weak Interaction cross section: WIMP Miracle

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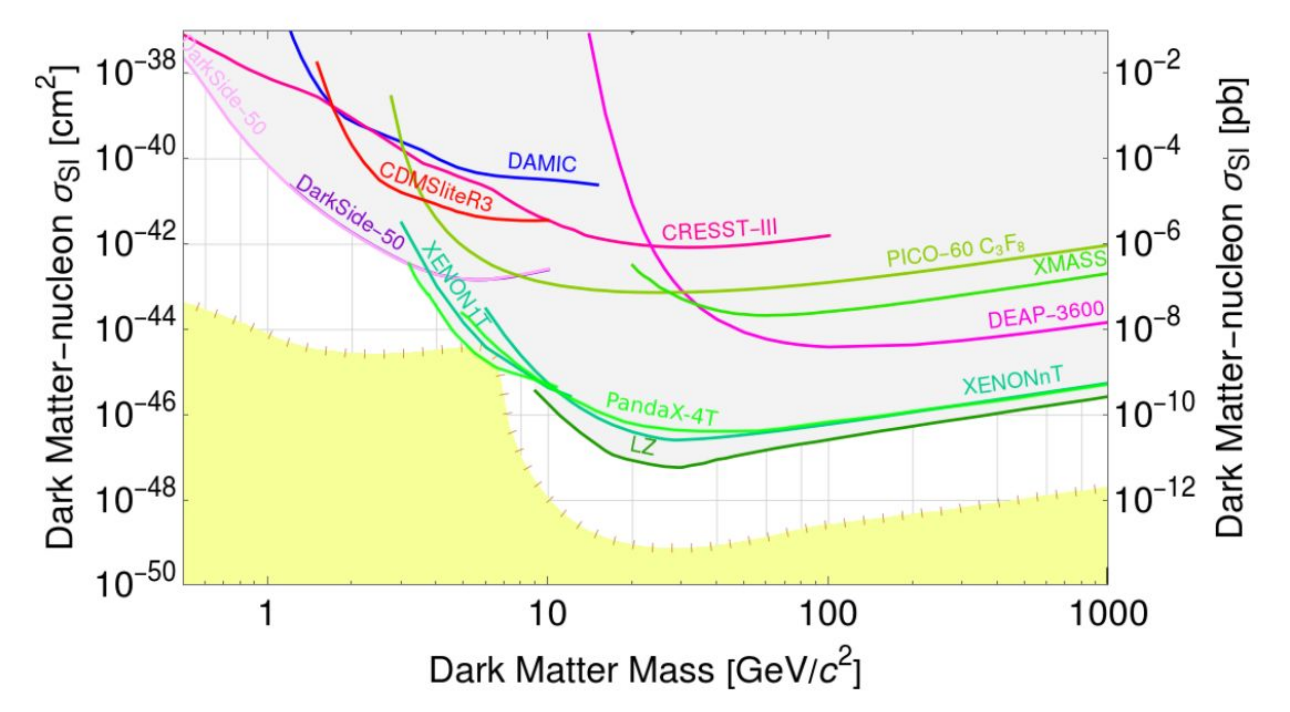
# Status of WIMP searches

- So far, no clear evidence for WIMP-like DM from direct search
- Experiment are reaching coherent neutrino floor
- Where to look next?

Direct detection program is crucial, only way to probe cosmogenic DM signals

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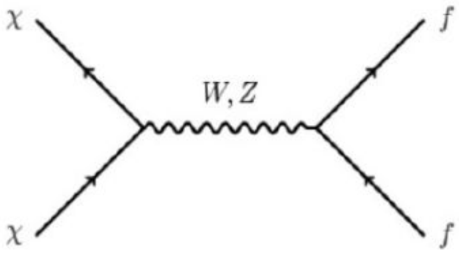
# A “light” WIMP?

A light WIMP does not reproduce correct relic abundance, in the thermal origin hypothesis



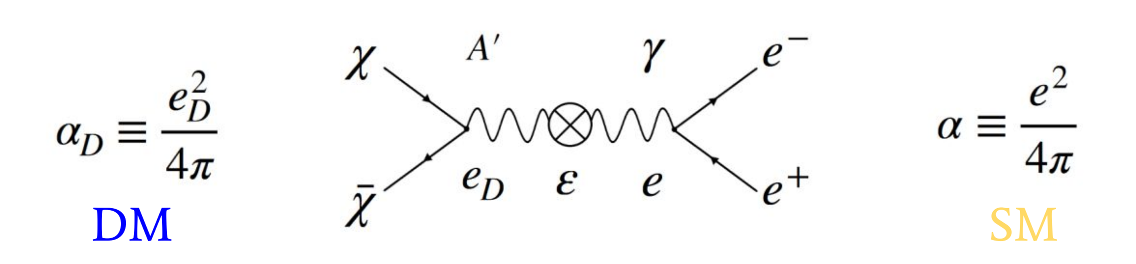

$$\langle \sigma v \rangle_{\rm WIMP} \sim 3 \times 10^{-26} {\rm cm}^3 {\rm s}^{-1} \left( \frac{\rm TeV}{m_\chi} \right)^2$$

If $m_\chi \sim 1GeV \, : \, \langle \sigma v \rangle \ll \langle \sigma v \rangle_{relic} \simeq 3 \times 10^{-26} \; cm^3 s^{-1}$

Need for a new interaction acting as a “portal” between DM and SM

# Vector Mediator: the Dark Photon

Simplest possibility: "vector-portal". DM-SM interaction through a new U(1) gauge-boson ("dark-photon") coupling to electric charge Dark QED




**DM charged under new mediator**
**Small A'-photon mixing $\varepsilon \ll 1$**

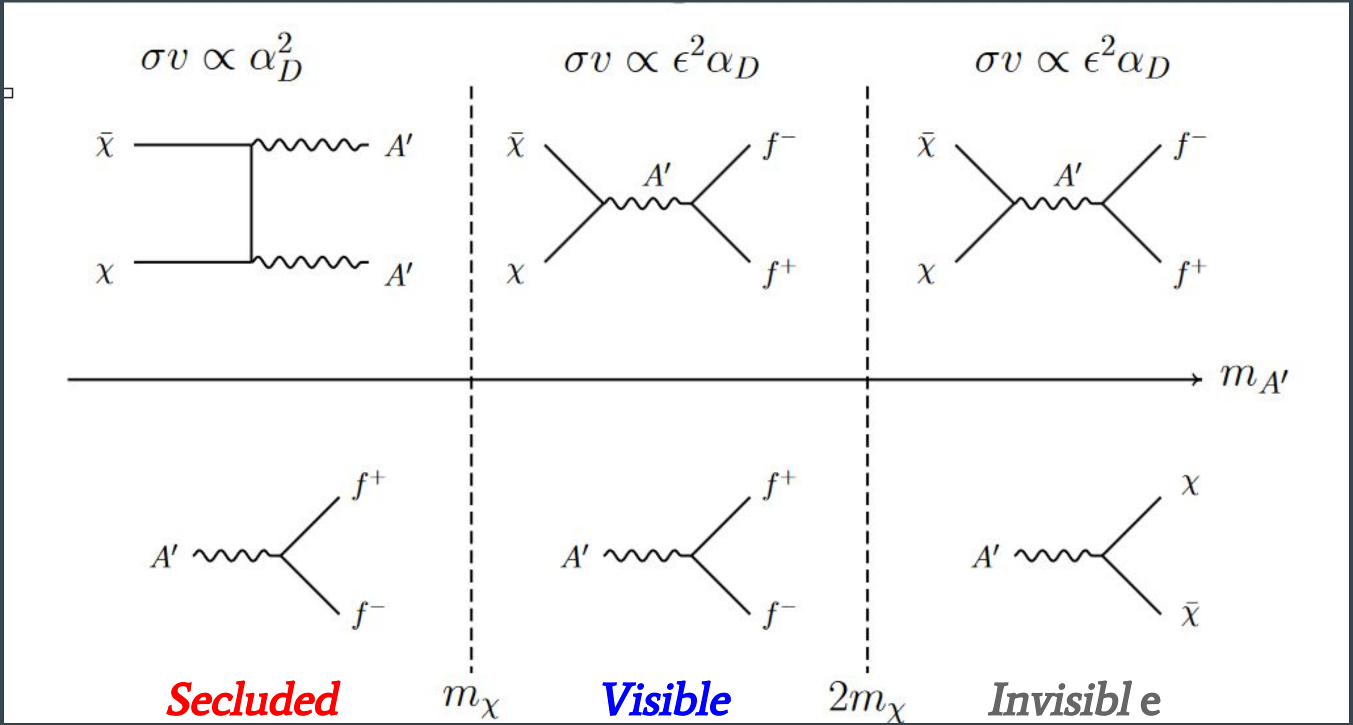
- By requiring that freeze-out mechanism reproduces today's relic abundance, a target in the parameters space can be derived:
- Define a new variable optimized for thermal targets:

$$\langle \sigma v \rangle \propto \frac{\varepsilon^2 \alpha_D m_\chi^2}{m_{A'}^4} = \alpha_D \varepsilon^2 \left( \frac{m_\chi}{m_{A'}} \right)^4 \frac{1}{m_\chi^2} = \frac{y}{m_\chi^2}$$

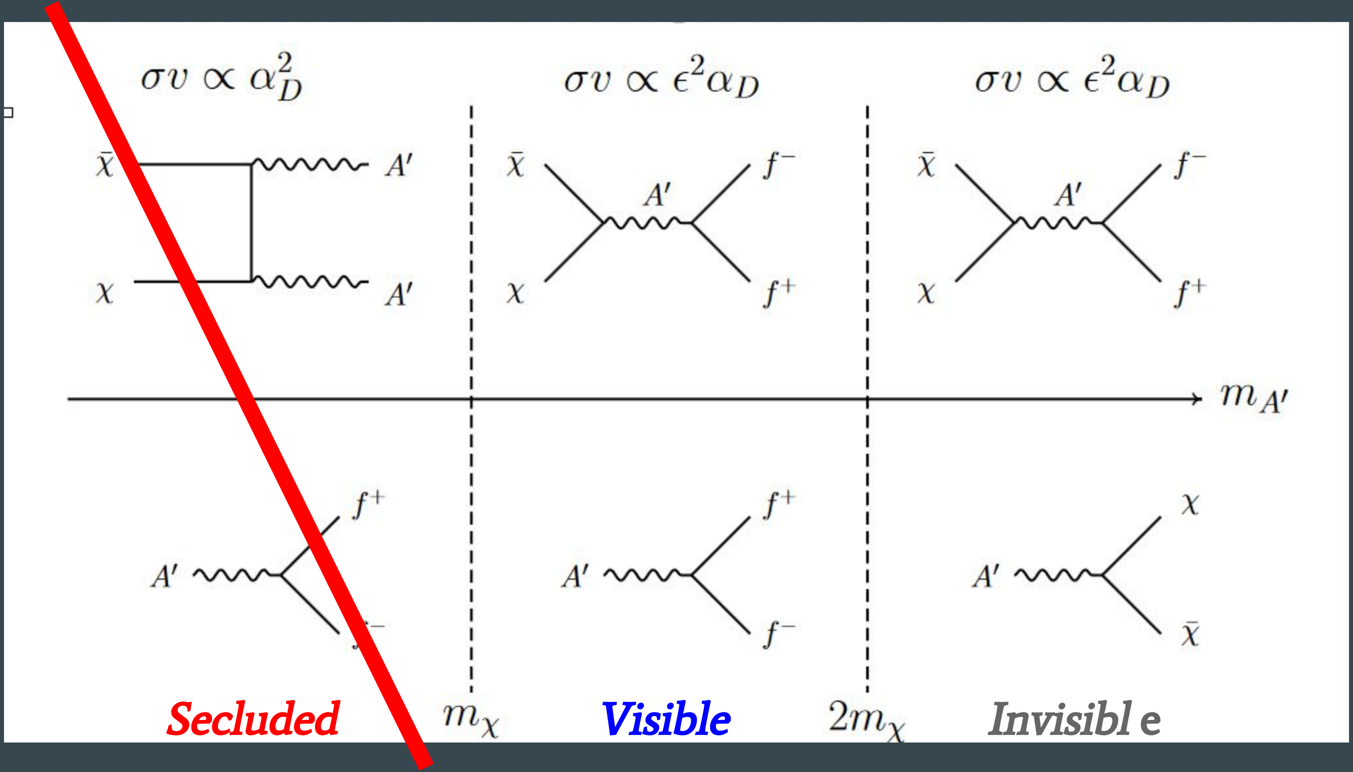
For a given value of $m_\chi$, thermal origin imposes one value of y

1707.04591, 2005.01515, 2011.02157

# LDM annihilation channels



# LDM annihilation channels



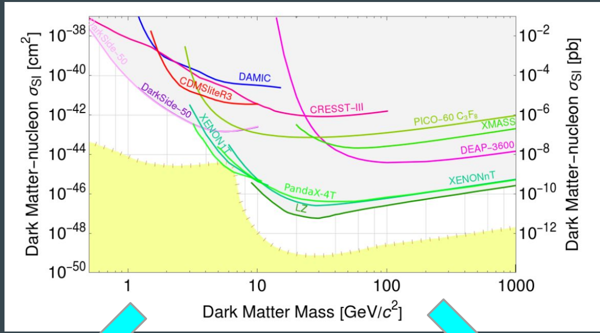

- Secluded scenario: provides no thermal target for accelerator-based experiments: any ε value is allowed

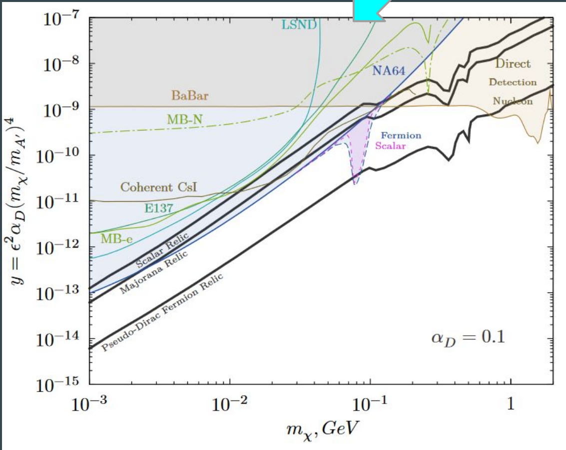
# Light DM - Direct Searches

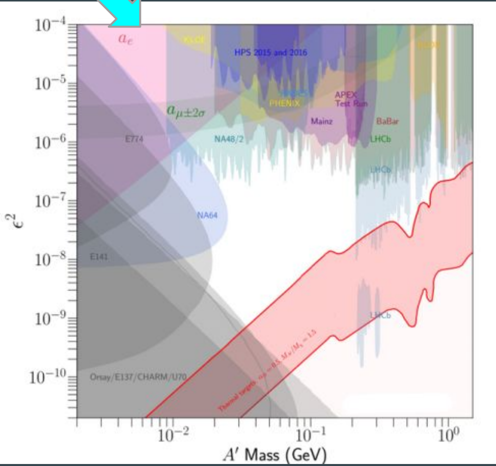
Dark Matter direct detection experiments, typically optimized for $m_\chi \geq 1$ GeV, have a limited sensitivity in the sub-GeV range

- $E_{rec} \propto \frac{m_\chi^2}{m_N}$
- Many ongoing efforts to overcome this limitation
- Given the mass range and expected couplings, collider and accelerator experiments are particularly well suited to search for LDM candidates

# Parameter spaces - from WIMPs to LDM



# Dark Photon phenomenology

- The mixing between the A’ and the SM photon results in a suppressed coupling to the EM current
  → A’ can decay both to SM hadrons and leptons (if kinematically admissible)

$$\mathcal{L}_{\gamma A'} \supset -\tfrac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + \tfrac{1}{2}m^2_{A'}A'^{\mu}A'_{\mu} + e\varepsilon j_{\mu}A'\mu$$

$$\Gamma_{A'} = \sum_l \Gamma_{A'\to l^+l^-} + \Gamma_{A'\to hadrons} + \Gamma_{A'\to invisible}$$

$$\tau_{A'} = \frac{\hbar}{\Gamma_{A'}}$$

# Dark Photon decay widths

Due to the considered values for ε and $\alpha_D$ the branching ratio to invisible states is dominant, provided that $m_{A'} > 2\ m_\chi$

$$\Gamma_{A' \to leptons} = \frac{\varepsilon^2 \alpha_{EM}}{3} m_{A'} \left(1 + 2\frac{m_l^2}{m_{A'}^2}\right) \sqrt{1 - 4\frac{m_l^2}{m_{A'}^2}}$$

$\varepsilon = 10^{-3} - 10^{-9}$

$$\Gamma_{A' \to \chi\bar{\chi}} = \frac{\alpha_D}{3} m_{A'} \left(1 + 2\frac{m_\chi^2}{m_{A'}^2}\right) \sqrt{1 - 4\frac{m_\chi 2}{m_{A'}^2}}$$

$\alpha_D = 0.1 - 0.5$

# Dark Photon decay widths

- Invisible scenario: negligible A' lifetime (prompt decay)
- Visible scenario: extremely varying lifetime depending on the considered region of the parameter space (from ~$10^{-10}$ *s* to ~100 *s*!)

$$\Gamma_{A' \to leptons} = \frac{\varepsilon^2 \alpha_{EM}}{3} m_{A'} \left(1 + 2\frac{m_l^2}{m_{A'}^2}\right) \sqrt{1 - 4\frac{m_l^2}{m_{A'}^2}}$$

$$\Gamma_{A' \to \chi\bar{\chi}} = \frac{\alpha_D}{3} m_{A'} \left(1 + 2\frac{m_\chi^2}{m_{A'}^2}\right) \sqrt{1 - 4\frac{m_\chi{}^2}{m_{A'}^2}}$$

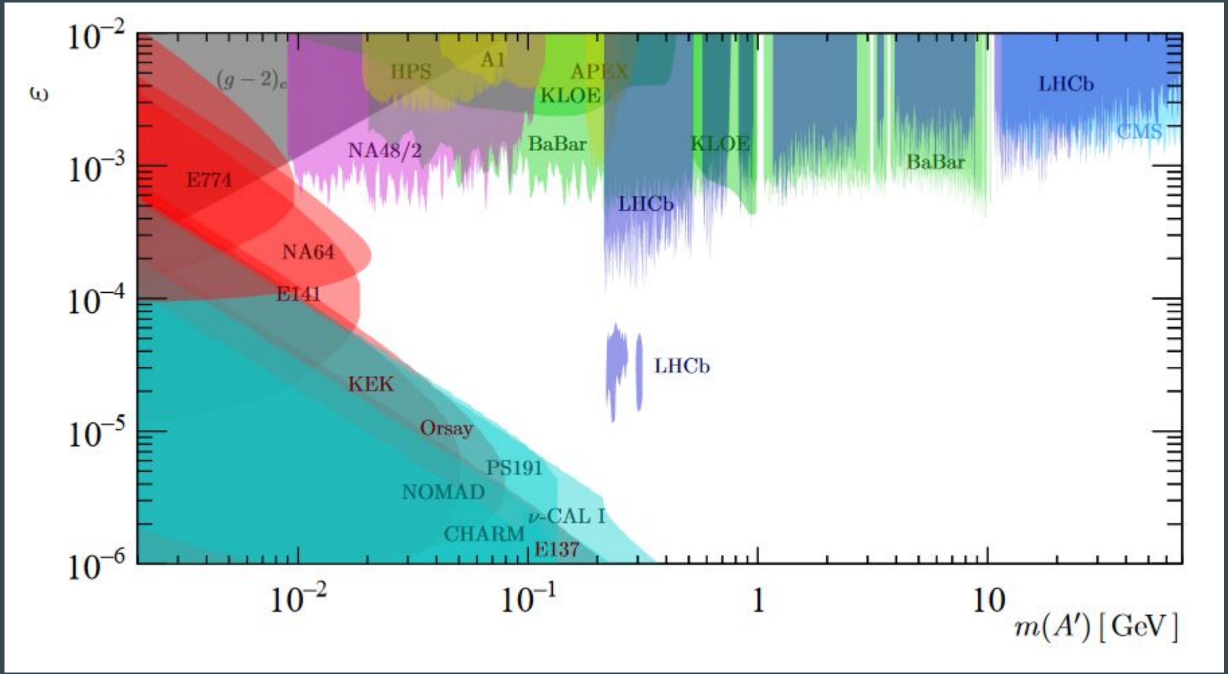
*"visible" scenario:*

$$m_{A'} < 2m_\chi$$

$$\Gamma_{A'} = \sum_l \Gamma_{A' \to l^+ l^-} + \Gamma_{A' \to hadrons} + \cancel{\Gamma_{A' \to invisible}}$$

# Visible scenario phenomenology

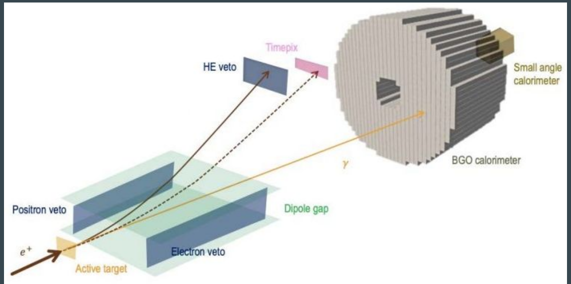
large cross-section

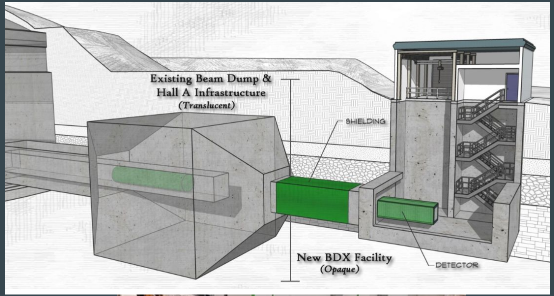


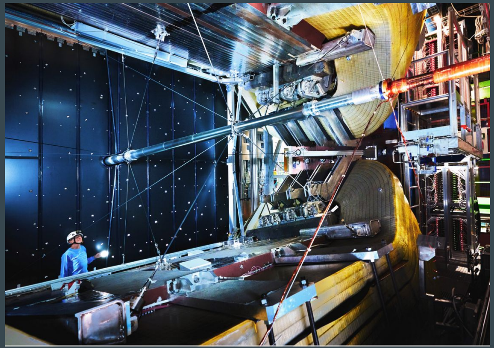

long-lived

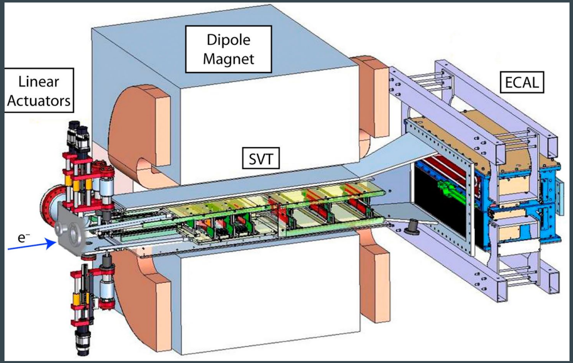
# Light DM searches at accelerators

- Many ongoing and future efforts: high energy/intensity colliders, beam-dumps, fixed targets



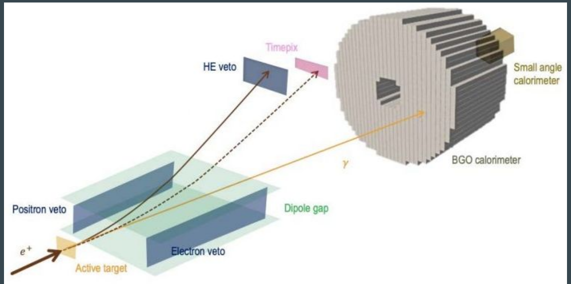



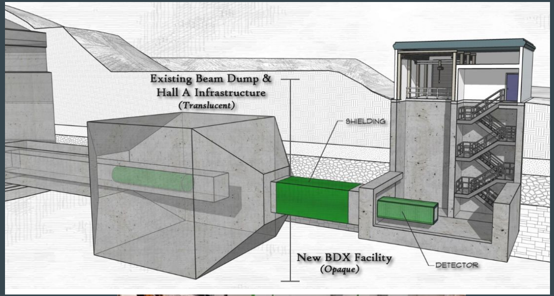


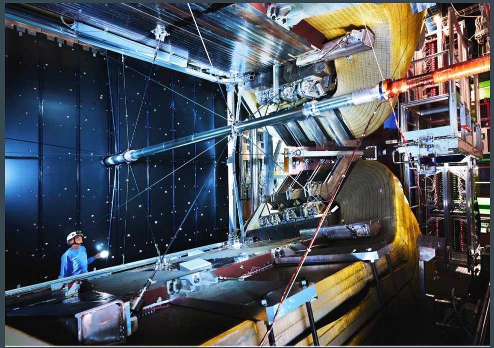

❖ dauntingly

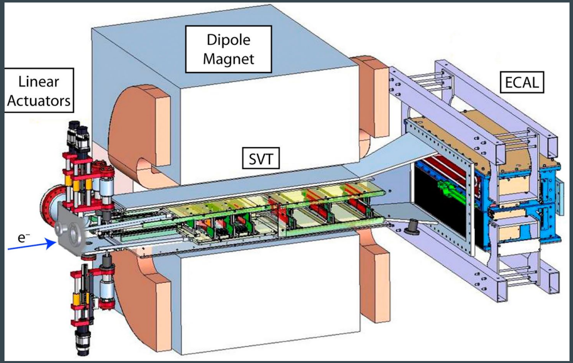
# Light DM searches at accelerators

❖ Many ongoing and future efforts: high energy/intensity colliders, beam-dumps, fixed targets

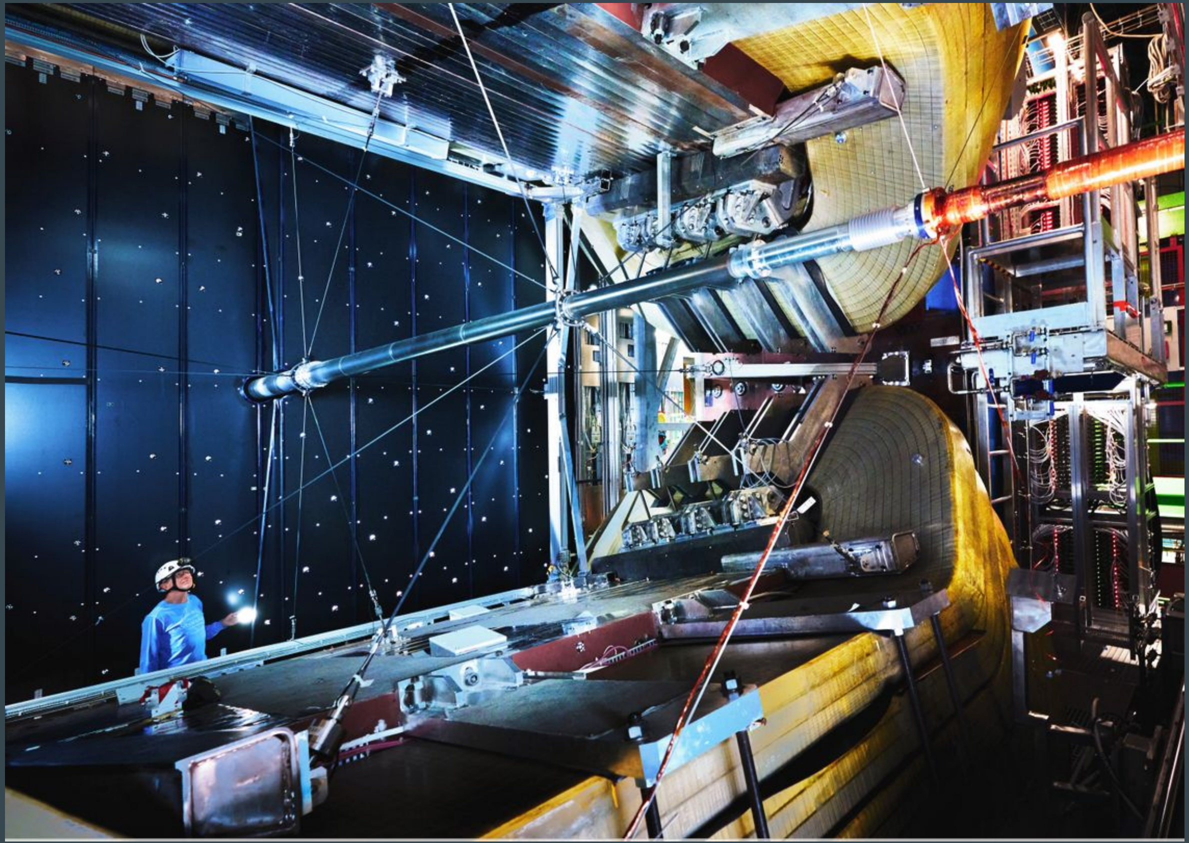





# Search for visible $A'$ decay at LHCb



# The Large Hadron Collider

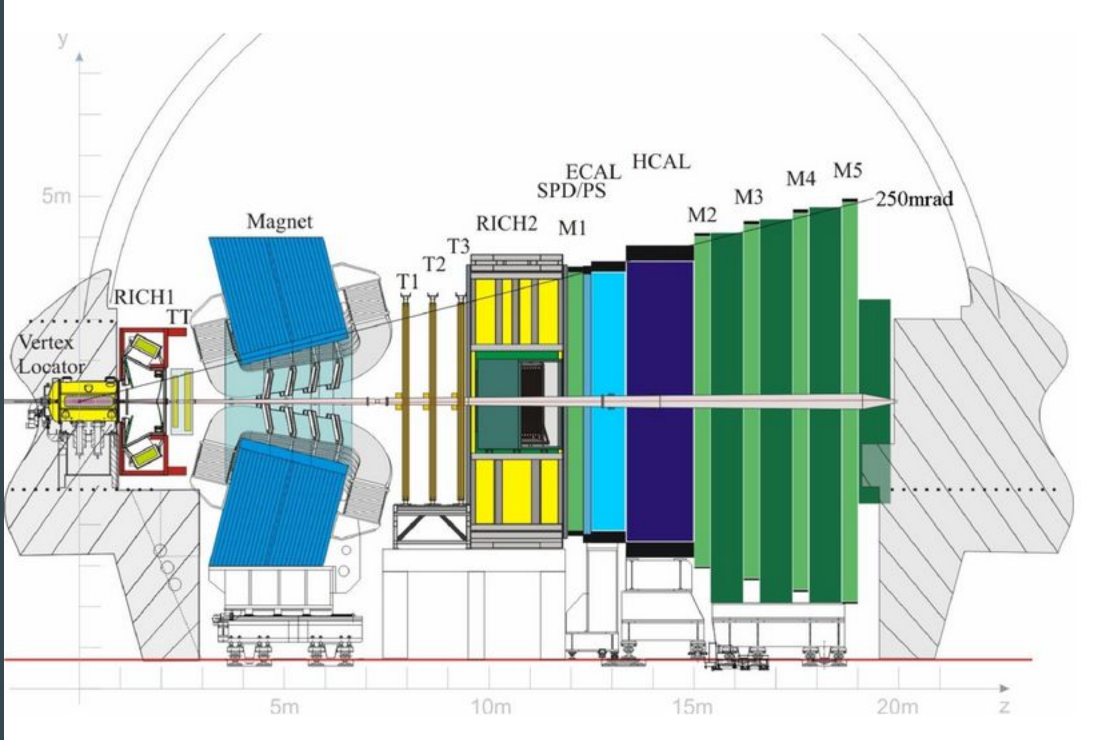
- LHC is the largest collider in the world:
  - ~27 km diameter, located at CERN (Geneva)
  - 1232 dipole magnets, (15-m long) for beam bending
  - 392 quadrupole magnets, (5–7 m- long) for beam focusing
  - pp collisions at $\sqrt{s}=13$ TeV

- Four main interactions points, where the ATLAS, CMS, ALICE and LHCb detectors are located

- Fundamental physics goals: investigate the origin of the baryon masses, Higgs physics (discovery in 2012), dark matter search, CP violation, supersymmetry...

# LHCb Experiment

- Single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$
- Designed for the study of particles containing *b* or **c** quarks
- 21 metres long, 10 metres high and 13 metres wide



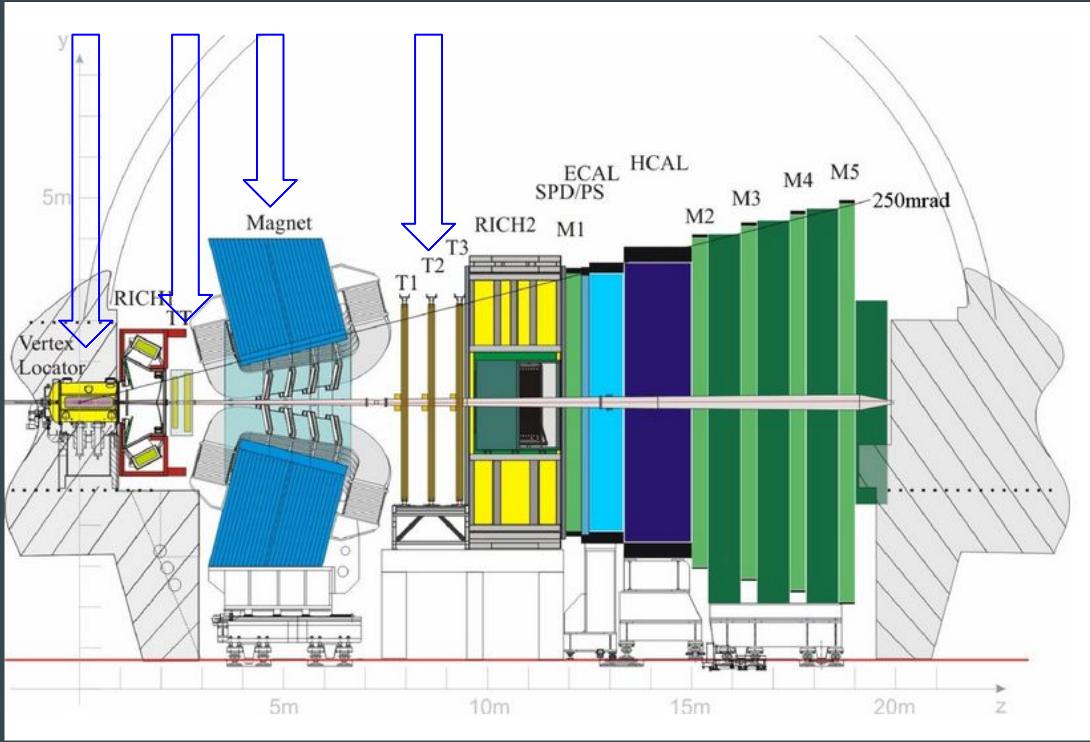

JINST 3 (2008) S08005, arXiv:1412.6352

# LHCb Tracking System

The tracking system of LHCb is composed of different elements:

- ❖ Inner vertex locator (VELO): silicon microstrips surrounding the pp interaction region
- ❖ Large-area silicon-strip detector
- ❖ Bending Magnet (bending power ~4 Tm)
- ❖ Three stations of silicon-strip detectors and straw drift tubes

Overall performance: $\Delta p/p = 1.0\%$ at 200 GeV/c. Impact parameter resolution: (15 + 29/ pT(GeV) ) µm

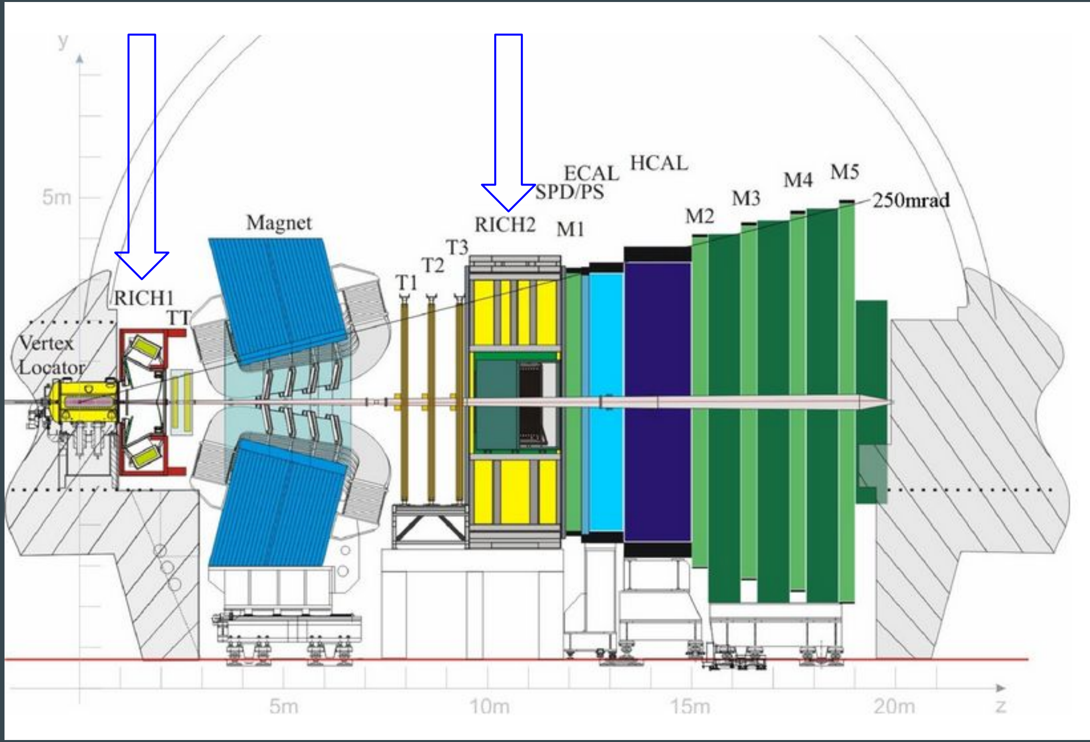



Aaij R et al. 2014 JINST 9 P09007, Arink R et al. 2014 JINST 9 P01002

# LHCb RICH detectors

The Ring Imaging Cherenkov detectors are crucial to identify different charged hadrons

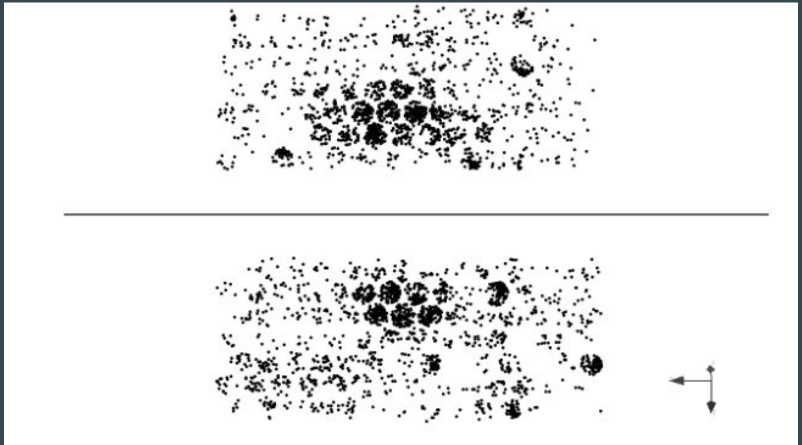
- RICH 1: Located at the exit of the the VELO detector. Momentum region covered 2 - 40 GeV/c (angular range 15–120 mrad). Material budget 8% $X_0$
- RICH 2: covering high momentum region: 15–100 GeV/c (angular range 15–120 mrad). Material budget 15% $X_0$
- Radiators: $C_4F_{10}$ (RICH 1 n=1.0014 ) and $CF_4$ (RICH 2 n= 1.0005 ) operated at 0 C, 101.325 kPa

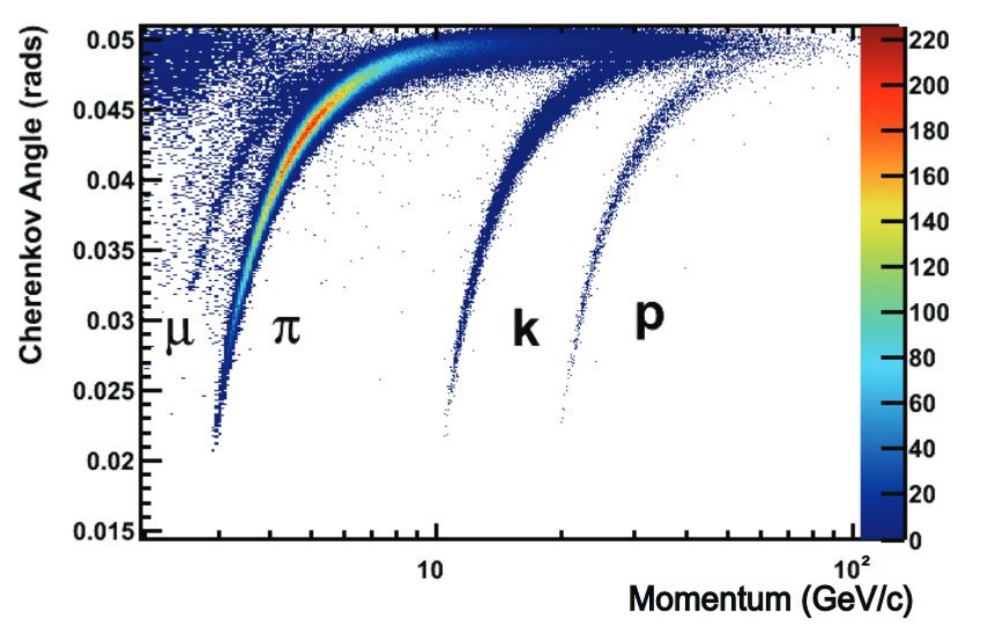



Adinolfi M et al. 2013 Eur. Phys. J. C73 2431

# LHCb RICH detectors - particles separation

Typical LHCb event seen in RICH 1





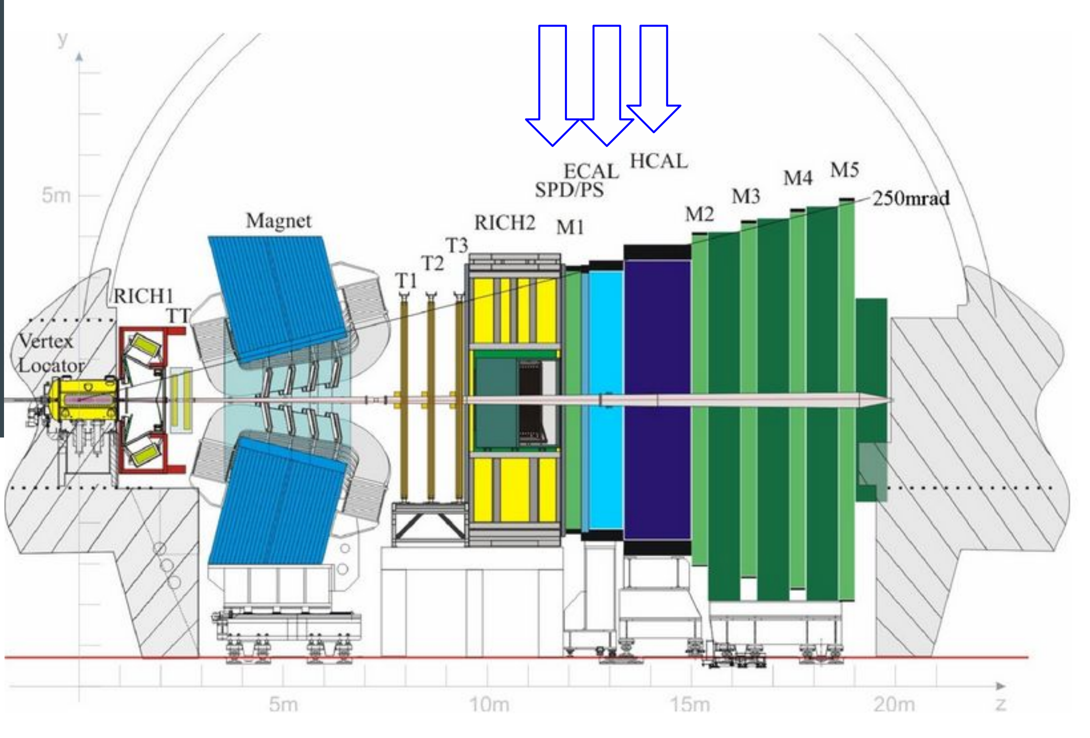

Adinolfi M et al. 2013 Eur. Phys. J. C73 2431

# LHCb Calorimeter system

Divided in 4 sub-detectors, all using the same technology (Pb/Fe plates + plastic scintillator fibers)

- ❖ Scintillator Pad Detector (SPD)
- ❖ PreShower (PS)
- ❖ Electromagnetic CALorimeter (ECAL)
- ❖ Hadronic CALorimeter (HCAL),

| sub-detector | SPD/PS | ECAL | HCAL |
|---|---|---|---|
| number of channels | 2×6016 | 6016 | 1488 |
| overall lateral dimension in x, y | 6.2 m × 7.6 m | 6.3 m × 7.8 m | 6.8 m × 8.4 m |
| cell size (mm) Inner | 39.7 (SPD), 39,8 (PS) | 40.4 | 131.3 |
| cell size (mm) Middle | 59.5 (SPD), 59.76 (PS) | 60.6 | |
| cell size (mm) Outer | 119 (SPD), 119.5 (PS) | 121.2 | 262.6 |
| depth in z | 180 mm, 2.5 $X_0$, 0.1 $\lambda_{int}$ | 835 mm, 25 $X_0$, 1.1 $\lambda_{int}$ | 1655 mm, 5.6 $\lambda_{int}$ |
| light yield | ~20 p.e./MIP | ~3000 p.e./GeV | ~105 p.e./GeV |
| dynamic range | 0 - 100 MIP 10 bits (PS), 1 bit (SPD) | 0 - 10 GeV $E_T$ 12 bits | 0 - 20 GeV $E_T$ 12 bits |

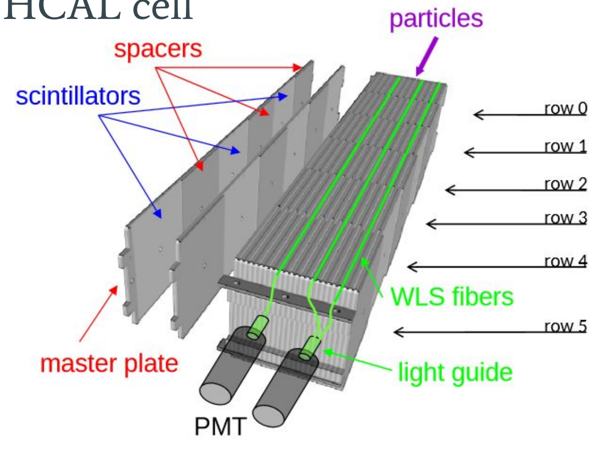



arXiv:2008.11556

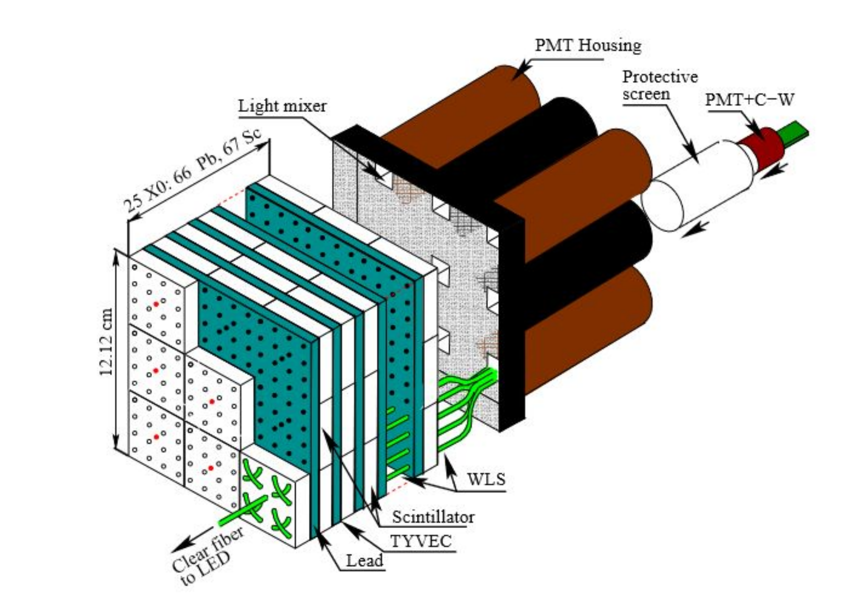
# LHCb Calorimeter system

## SPD cell

## HCAL cell



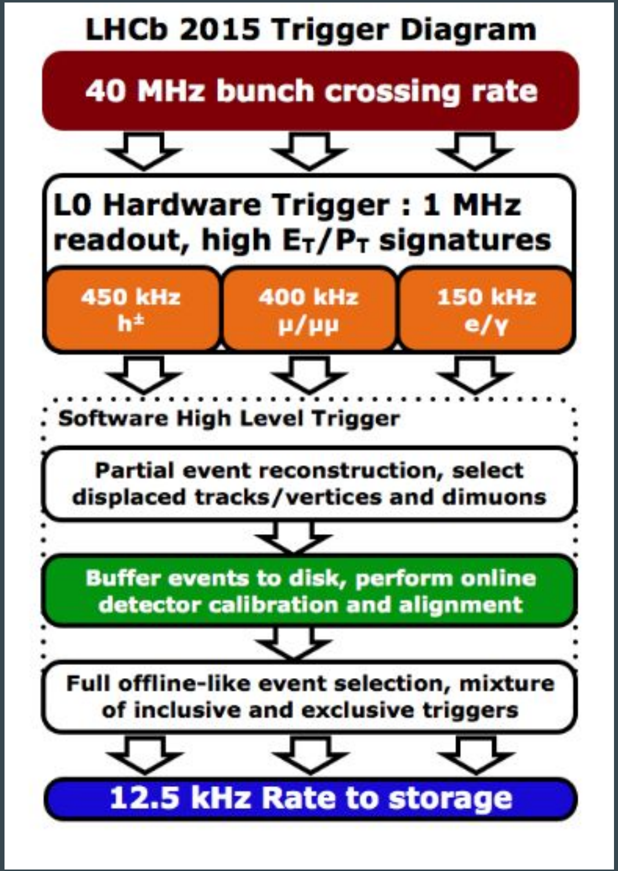

## ECAL cell




arXiv:2008.11556

# LHCb Detector - Trigger

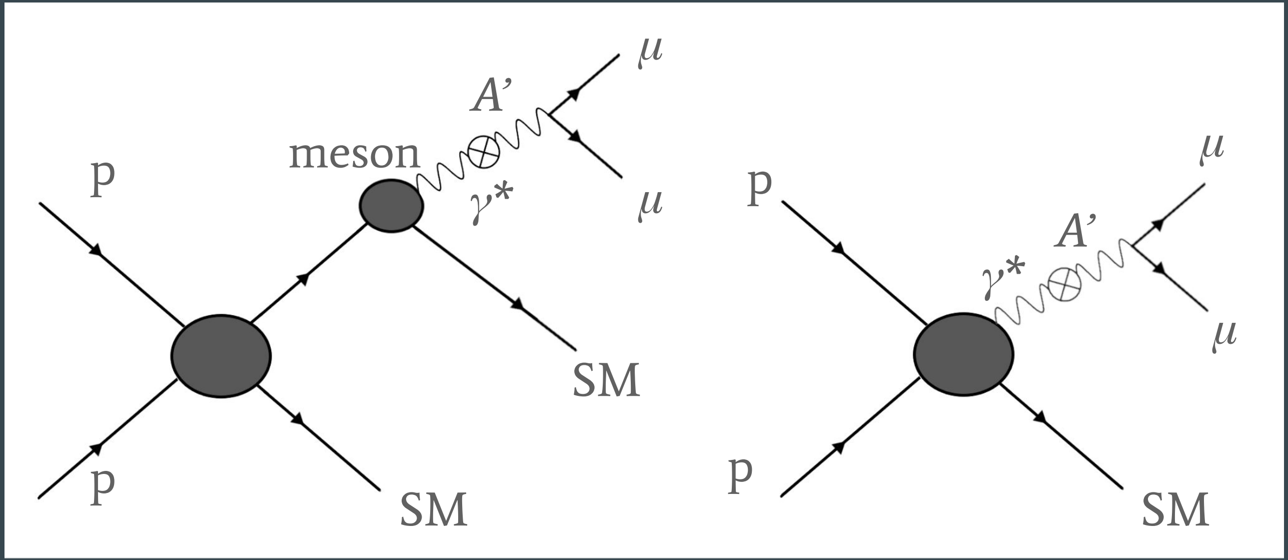
- Need to cope with very large events rate (**40 MHz** crossing rate during Run 2)
- Typical event dimension order of **~200 kB**
- Critical to select events online to reduce the data stream to save to disk
- Multi-level trigger and online calibration procedure of the sub-detectors
  - L0: hardware level - information from calorimeters and muon systems
  - HLT1 & HLT2: high level software trigger: include tracking and RICH information to event selection




Aaij R et al. 2013 JINST 8 P04022
J. Phys. Conf. Ser. 664 (2015) 082010

# Dark Photon Production in pp collisions

- Dark Photon production through different processes: meson decays (M(A')<1 GeV) Drell-Yan (M(A')> 1 GeV)
- In the visible decay scenario, A decay dominantly to SM leptons
- If $m_{A'} > 2\,m_{\mu}$ dominant decay to muons → *clear signature at LHCb*



# LHCb Dark Photon search

*A'* search in a data sample corresponding to an integrated luminosity of 1.6 $fb^{-1}$, collected with the LHCb detector in 2016 (LHC Run 2).

- *A'* inherits the production mode from the "original" $\gamma^*$
- the $A' \to \mu^+\mu^-$ yield can be normalised to $\gamma^* \to \mu^+\mu^-$
- Fully data-driven analysis

expected $\gamma^* \to \mu^+\mu^-$ yield

$A'/\gamma^*$ detection efficiency ratio

$$n_{\rm ex}^{A'}[m(A'),\varepsilon^2] = \varepsilon^2 \left[\frac{n_{\rm ob}^{\gamma^*}[m(A')]}{2\Delta m}\right] \mathcal{F}[m(A')]\, \epsilon_{\gamma^*}^{A'}[m(A'),\tau(A')]$$

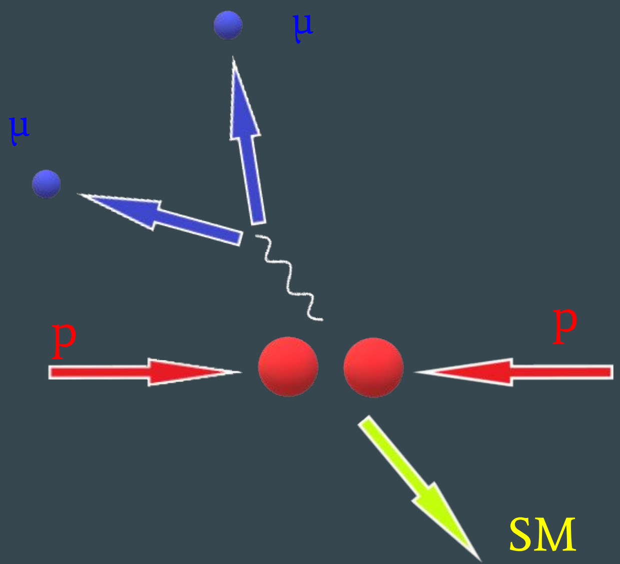
expected $A' \to \mu^+\mu^-$ yield

phase-space (known)

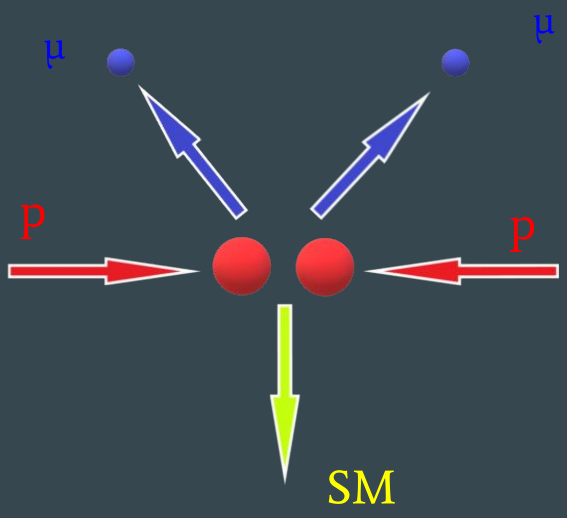
# Data sample split: prompt VS long lived

Distinct signatures depending on the addressed region of the *A'* parameter space: if $c\tau_{A'}$ is larger than the detector vertex resolution, search for displaced vertex
→ Divide the data sample in two sub-sets, depending if the reconstructed vertex is consistent with primary vertex

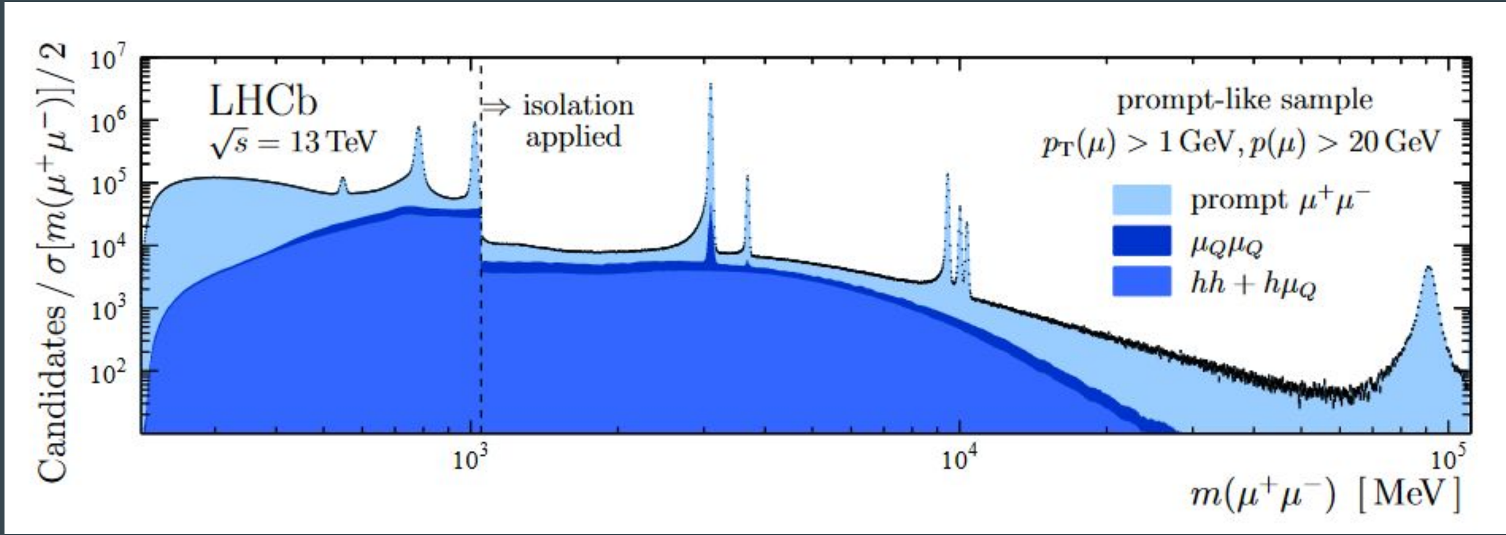
*Displaced vertex*




*Prompt*



# Prompt Muon Spectrum



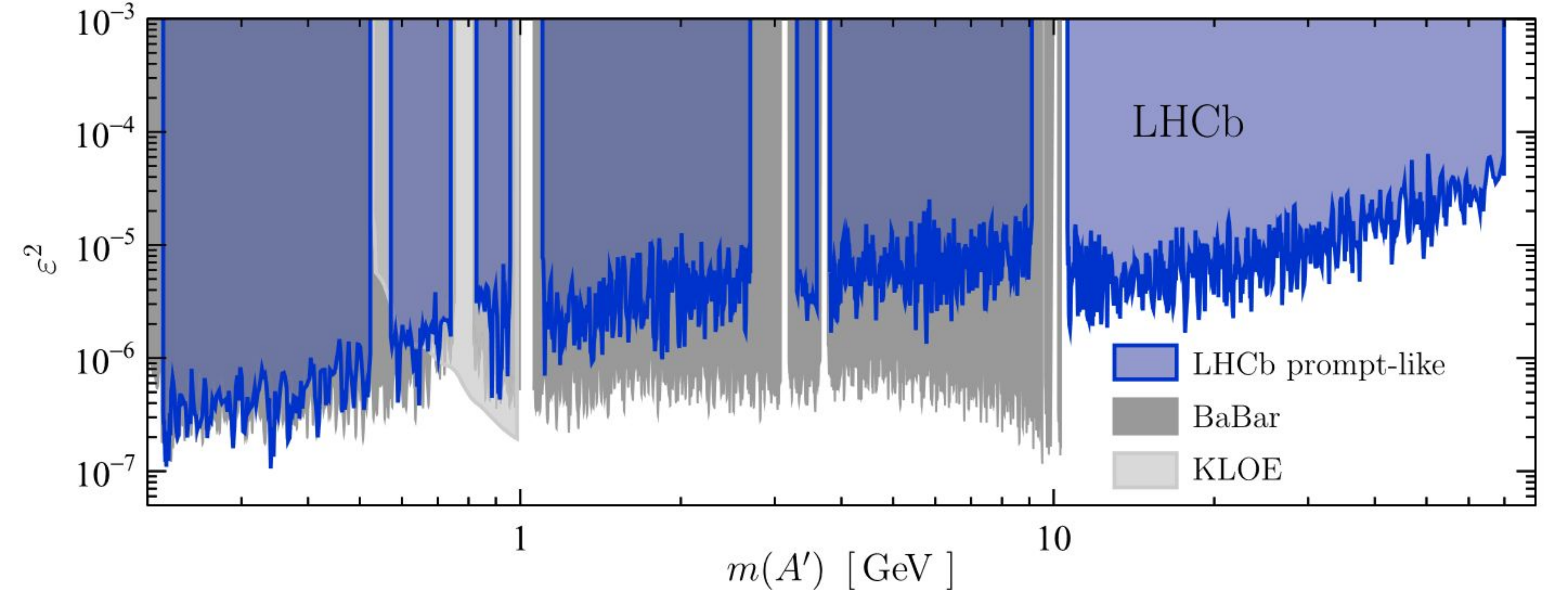

**Main backgrounds for the prompt analysis:**

- $\mu_Q\mu_Q$: 2 muons produced in a decay of a hadron containing a heavy-flavor quark, Q.
- *hh*: double misidentification of prompt hadrons as muons
- $h\mu_Q$: misidentified prompt hadron + muon produced in a decay of a hadron containing a heavy-flavor quark, Q.
- prompt $\gamma^* \to \mu^+\mu^-$ production
- hadron resonant decays to $\mu^+\mu^-$

# Search for Dark Photon - Prompt

Mass spectrum scanned in steps of $\sigma[m(\mu^+\mu^-)]/2$ searching for $A' \rightarrow \mu^+\mu^-$ contributions. At each mass, a binned extended maximum likelihood fit is performed using all prompt-like candidates in a $\pm 12.5\sigma[m(\mu^+\mu^-)]$ window around $m(A')$.

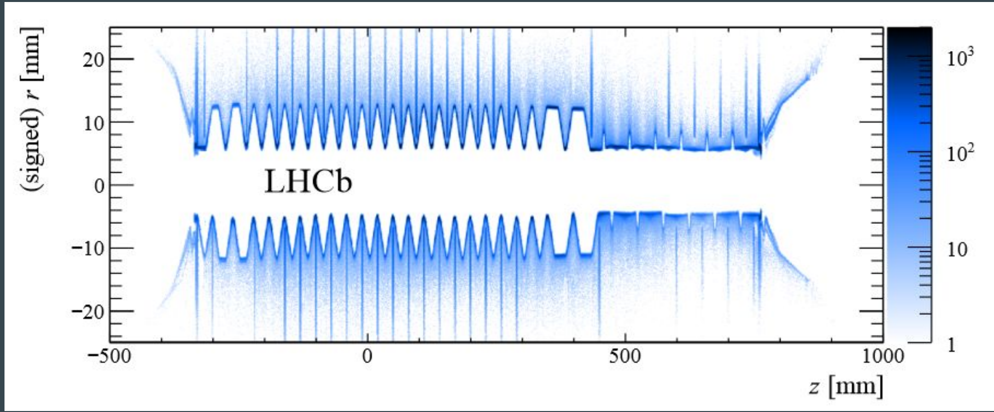
No significant excess found - exclusion regions at 90% C.L.




arXiv:1710.02867v2

# Background for the long-lived *A'* search

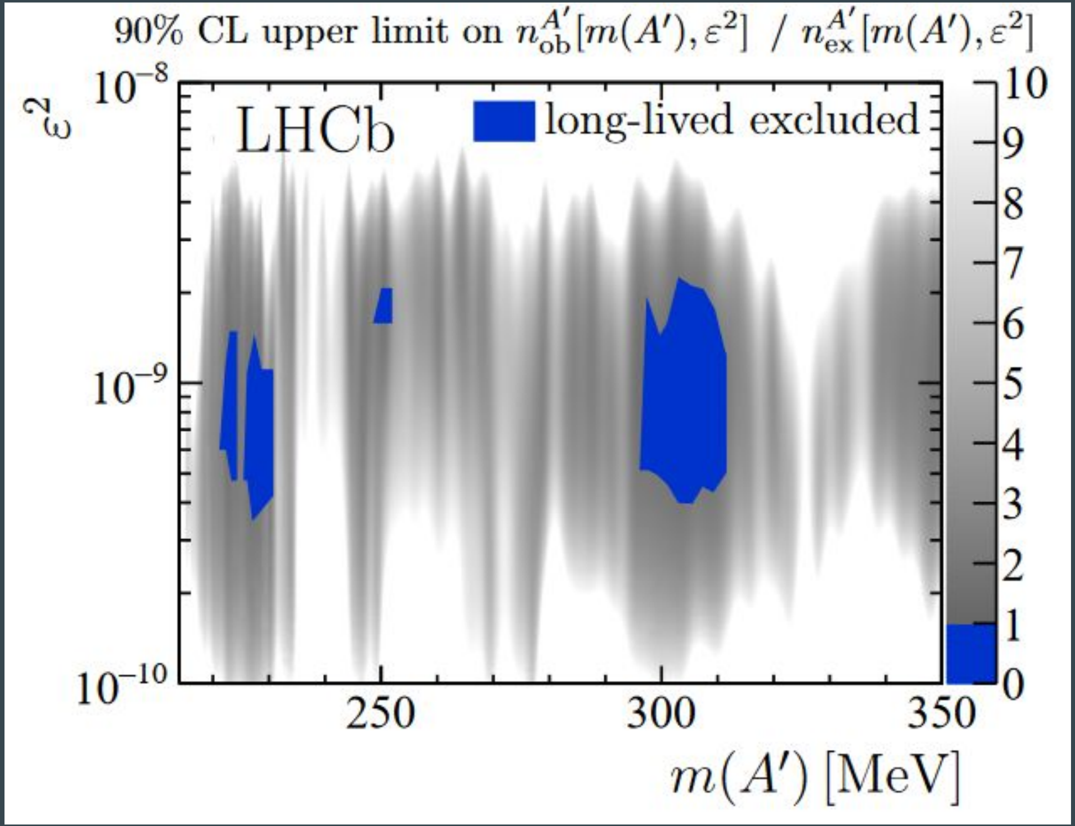
- Background dominated by photon conversion to a muon pair in the VELO detector material budget
- A high-precision three-dimensional material map was produced from a data sample of secondary hadron interactions
- A p-value is assigned to the photon-conversion hypothesis for each long-lived $A' \to \mu^+\mu^-$ candidate. A mass-dependent requirement is applied to the p-values, reducing the expected photon-conversion yields to a negligible level




arXiv:1803.07466

# Search for Dark Photon - long lived

- Long-lived *A'* search limited to the 214-350 MeV mass range
- Loose requirements on the event selection w.r.t. the prompt analysis → larger efficiency
- Negligible contamination from prompt $\gamma^* \to \mu^+\mu^-$
- Fit in bins of mass and lifetime
- Extract p-values and confidence intervals from the fit
- No significant excess observed → set limits in a small region of the parameter space

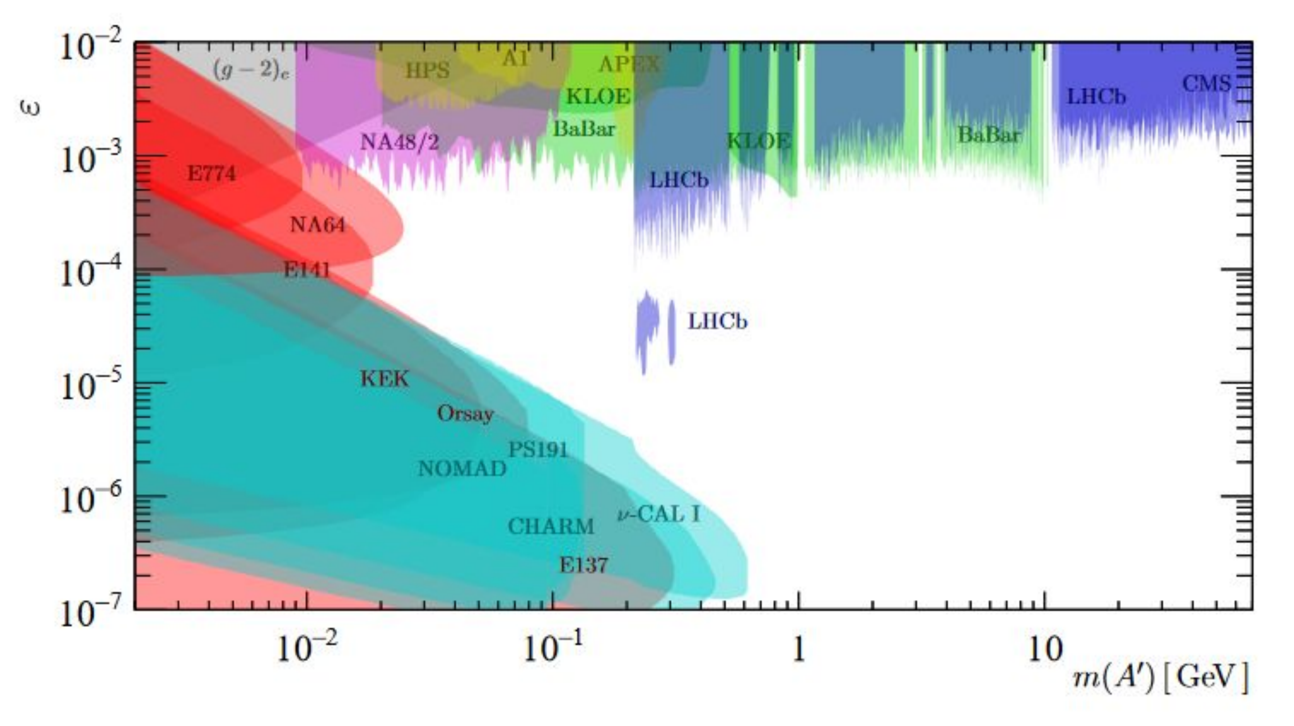



arXiv:1710.02867v2

# Other visible *A'* searches at colliders

Other relevant results in the *A'* visible decay search from the BaBar and CMS experiments.

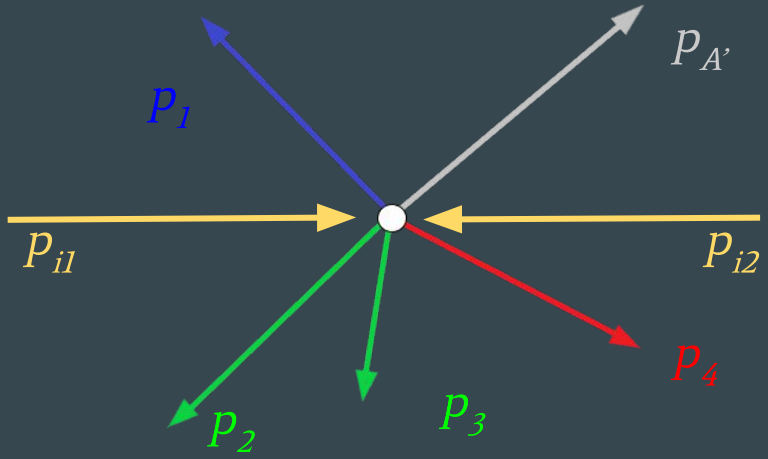
- BaBar: $e^+e^-$ collider, search for $e^+e^- \rightarrow \gamma A'$, $A' \rightarrow e+e-$
- CMS: search for $A' \rightarrow \mu+\mu-$ resonance



# How to search for A' invisible decays at colliders?

- If $m_{A'} > 2\, m_\chi$ no visible final state
- possible strategy: search for peak in *missing momentum* distribution
- challenging technique: mandatory to detect all the SM particle produced in the collision to correctly reconstruct the missing momentum

$$M_{A'}^2 = \left(p_{i1} + p_{i2} - \sum_{j=1}^{4} p_j\right)$$

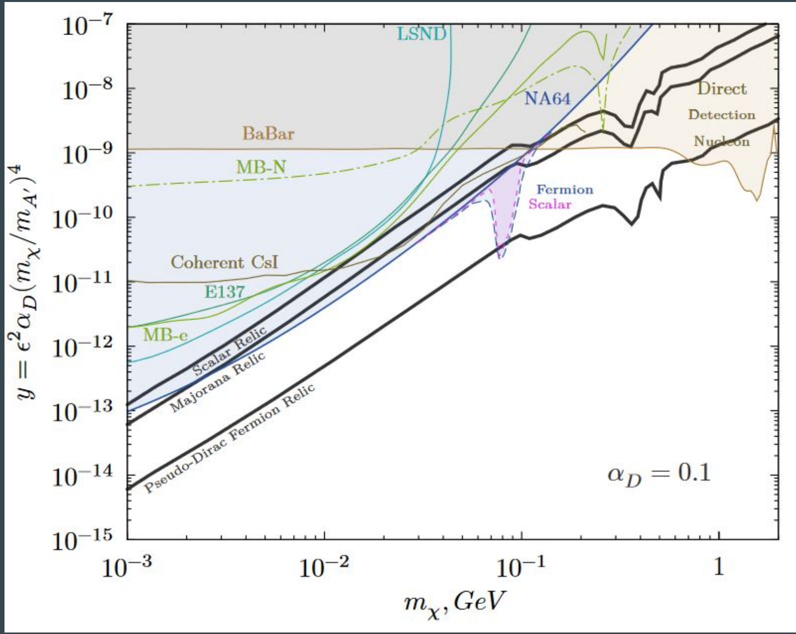


# The missing mass search at BaBar

- Multi-layer detector: silicon vertex tracker + drift chambers + CsI(Tl) electromagnetic calorimeter in solenoidal magnet
- Operating at PEP II e+e- asymmetric collider (SLAC): CM energy ~ $\Upsilon(2S)$, $\Upsilon(3S)$ and $\Upsilon(4S)$ resonances
- Search for A' peak in MM distribution from $e^+e^- \to \gamma A'$, $A' \to invisible$


Analysis based on 53 $fb^{-1}$ integrated luminosity

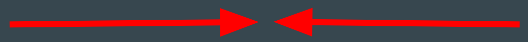
- no significant excess observed



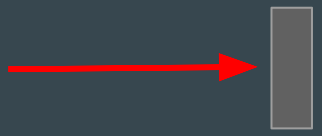

arXiv:1702.03327v2

# From colliders to fixed target experiments

- Experiments at colliders are particularly well suited to explore the “heavier” part of the LDM parameter space
- For lighter candidates (~O(100 MeV)) searches at colliders are generally affected by larger backgrounds and reduced signal efficiency
- The large $\sqrt{s}$ values achievable at colliders are not necessary for LDM search below few hundreds of MeV
- Small-scale fixed-target experiments at the ***intensity frontier*** can overcome the colliders’ limitations in specific regions of the LDM parameter space

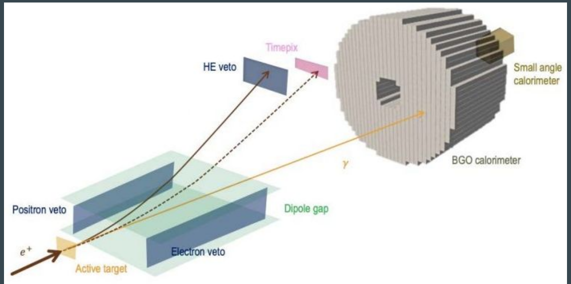


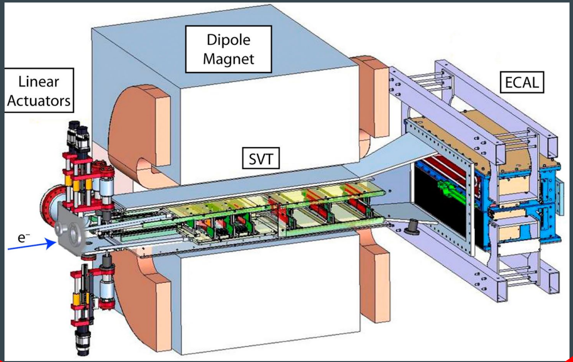
$$\sqrt{s} = 2E_{beam}$$

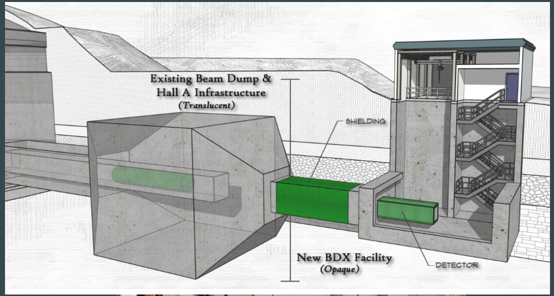


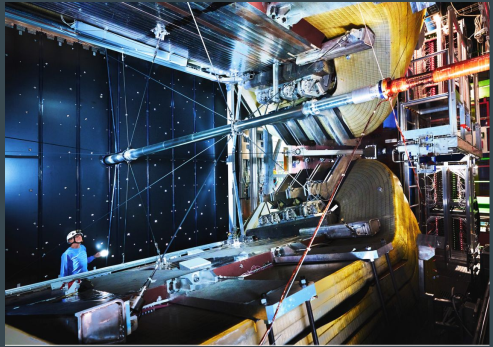
$$\sqrt{s} =\propto \sqrt{E_{beam}}$$

# Light DM searches at accelerators - thin targets



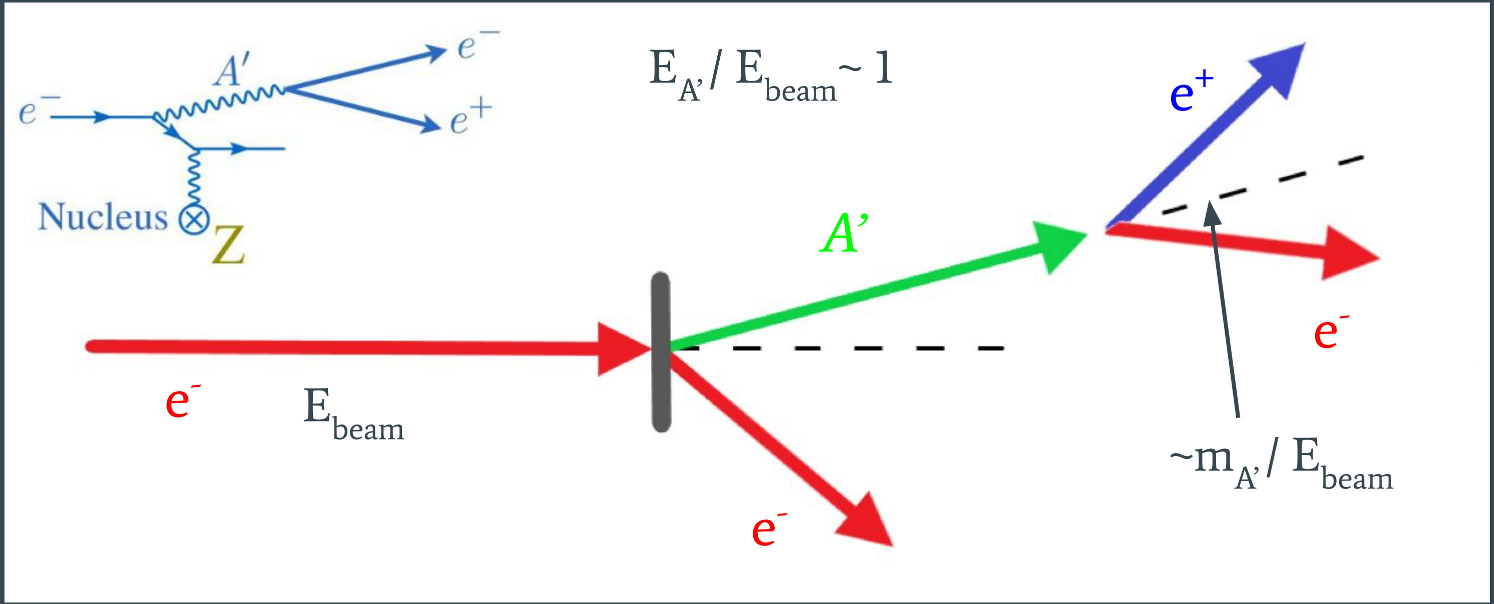



# Thin target experiment - visible scenario:

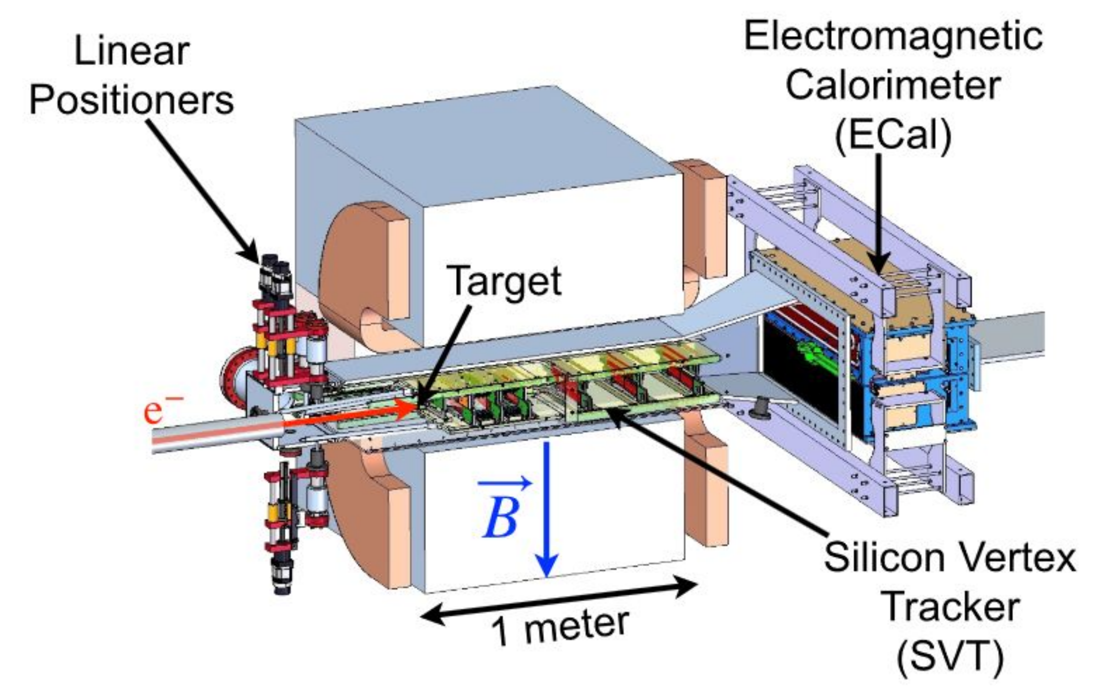
**General concept:**

- A' production via radiative process "A'-strahulung" from a O(GeV) electron beam
- Detection of the decay products: search for peak in invariant mass spectrum
- Search for detached vertices



# The Heavy Photon Search (HPS) Experiment@JLab

- Continuous ~2-4 GeV electron beam impinging on thin W target (~$10^{-3}$ $X_0$)
- A' produced by radiative process (*A'-strahlung*) in the target
- Search for the A' →e+e- both with a silicon tracker (SVT) and a fast $PbWO_4$ calorimeter
- Search for displaced vertices and peaks in the e+e- invariant mass

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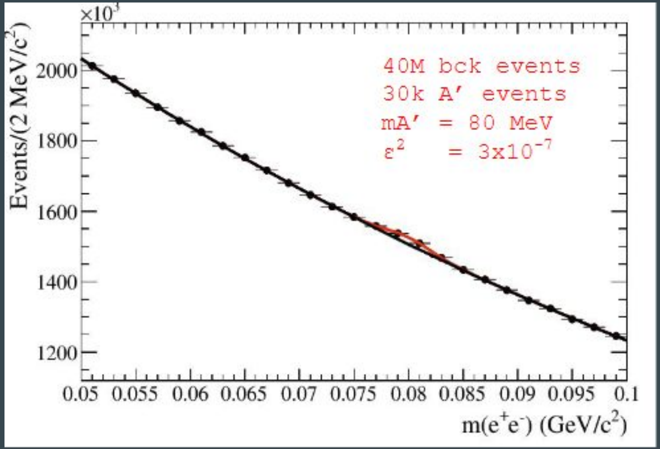
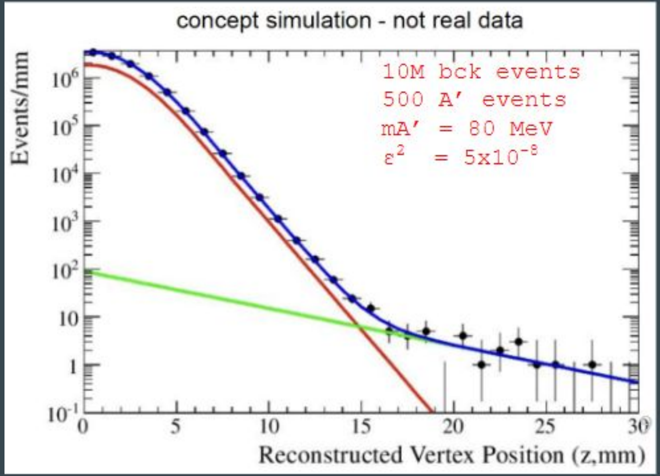
# Two complementary searches

- **Resonance search (aka "bump-hunt")**
  - At large ε, A' decays promptly in the target. Measure the e +e - invariant mass and search for a peak on top of the smooth QED background.
  - Difficult to reach lower values of ε: need very large luminosity and careful control of systematics.

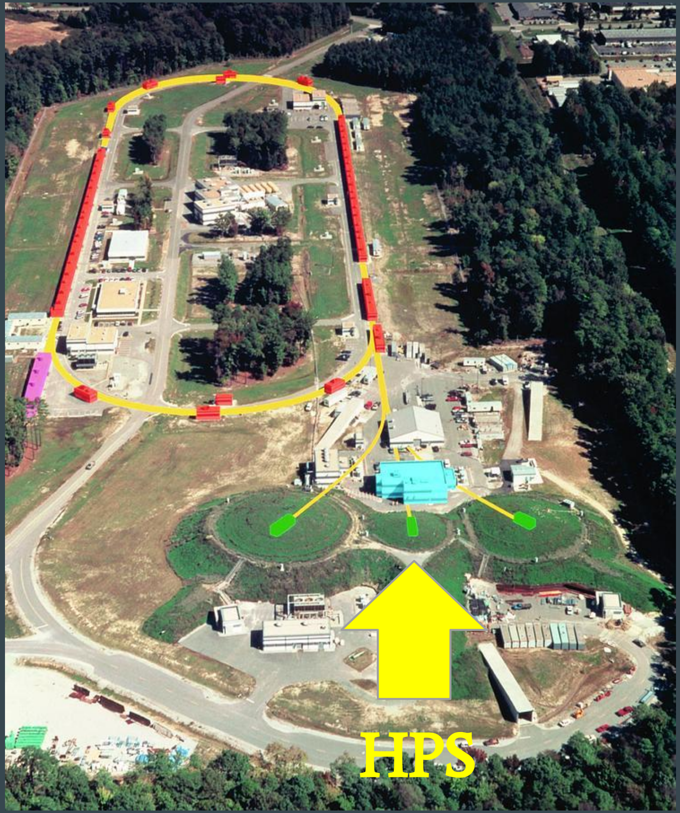
- **Detached vertex search**
  - At small ε, A' decays promptly in the target. Search for two tracks showing a common production vertex downstream the target, and with P e+ + P e- pointing toward the beam-spot.



# The Thomas Jefferson National Laboratory

- Medium-size nuclear physics lab in Virginia, USA
- Host of CEBAF (Continuous Electron Beam Accelerator Facility)
- Accelerated particles make multiple passes of the linacs — gaining 2.2 GeV per pass for up to 5.5 passes
- Serving simultaneously the different experimental halls
- Unique beam characteristics:
  - continuous beam (HPS operating at 100 nA)
  - small beamspot (<50 μm vertically) with vanishing low halo rate (.10−6 outside
  - the gaussian core)
  - excellent beam stability (<30 μm vertical variation).

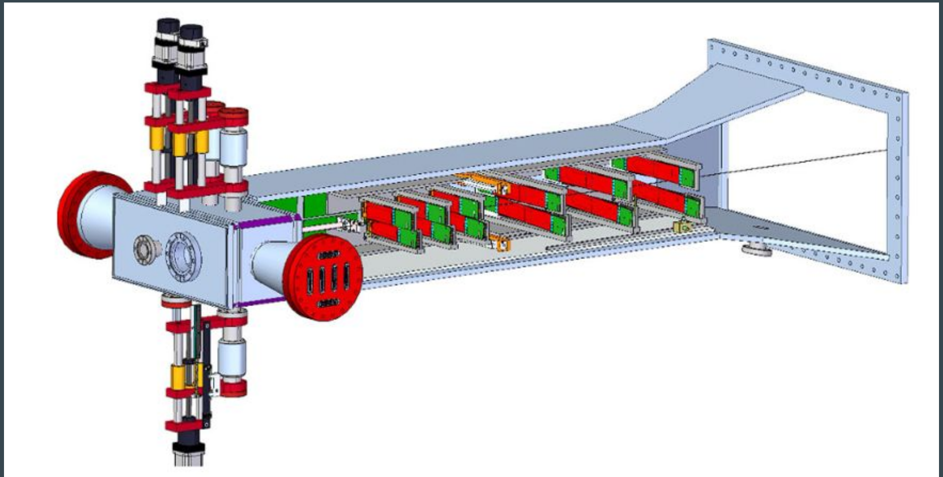


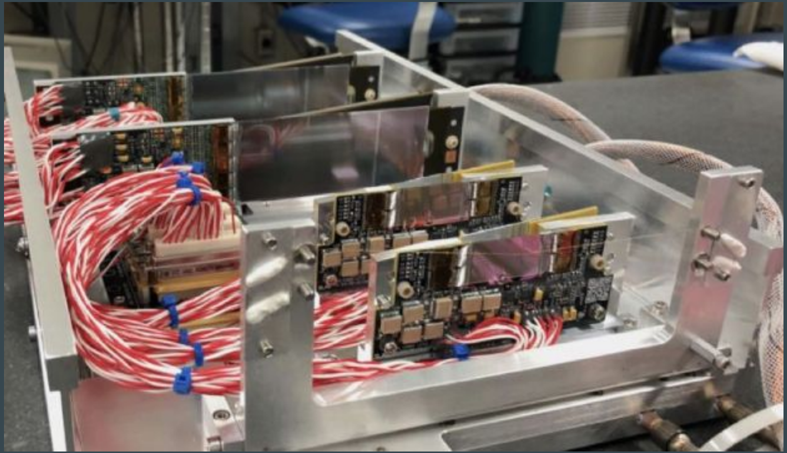
# The HPS Tracker

## Original SVT design:

- 6 layers of Si modules
- Detector (vertical) acceptance down to +/- 15 mrad (which means L1 of SVT is 0.5 mm from beam axis!).
- Two modules with top/bottom splitting. Operates in vacuum.
- Spatial resolution of each layer is 6 um in the vertical plane

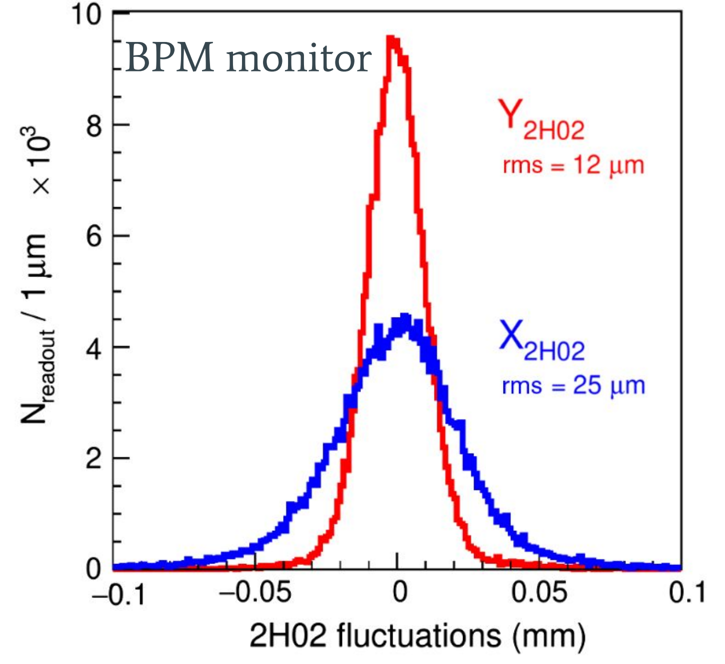
**Precision Movers:** position layers 1-3 close to the beam, do wire scans, and insert targets as needed.

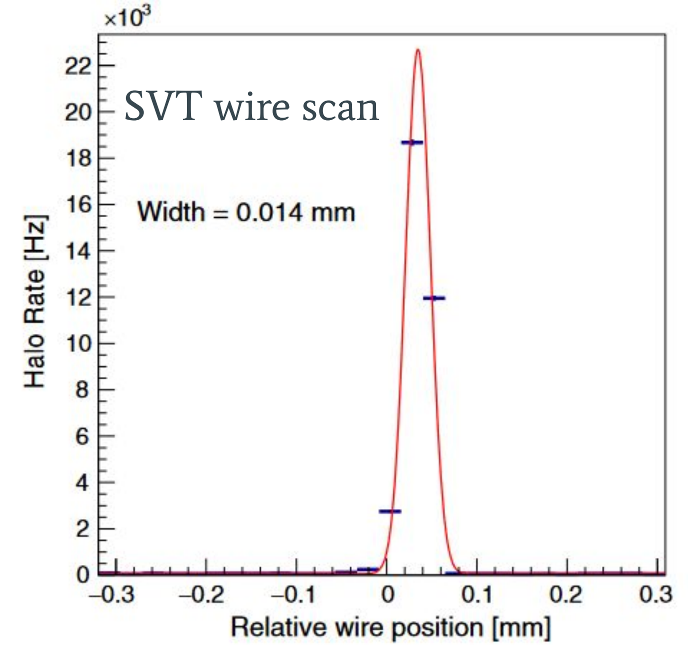




# Beam Monitoring

Beam position monitors (BPMs) are used to continuously monitor the transverse position of the beam at multiple locations during data taking and are tied to machine controls to ensure the stability of the beam.



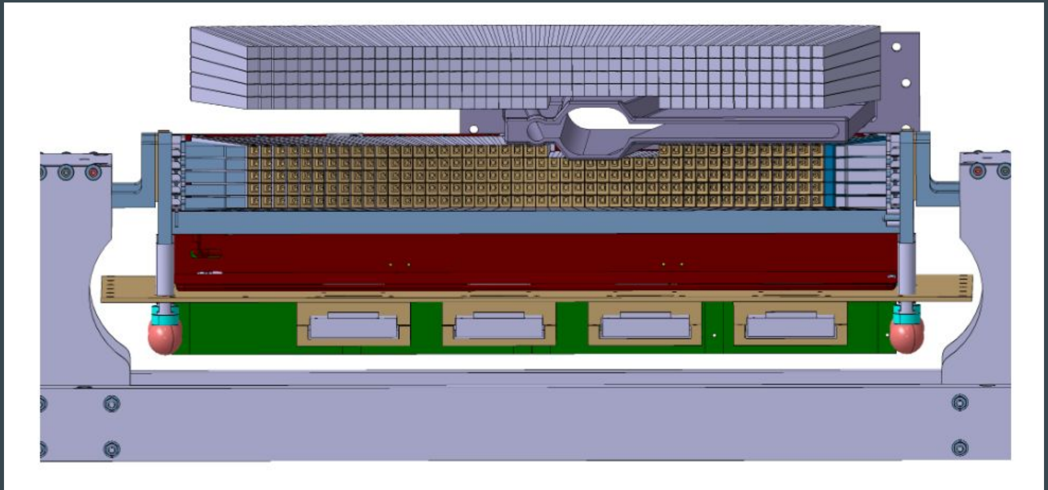



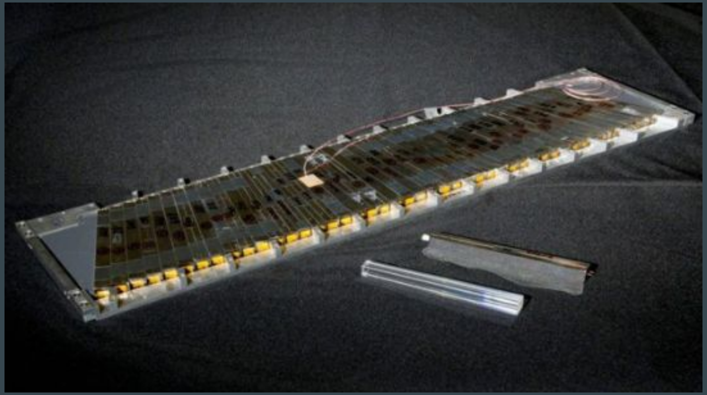
# The HPS Electromagnetic Calorimeter

**Main goals: e+e- energy measurement for bump-hunt search; fast trigger**

**Detector design:**

- ❖ $PbWO_0$ crystals with LA-APD readout
- ❖ 5 vertical layers per module, 442 crystals in total (13x13 $mm^2$ 160 mm-long -- 18 $X_0$)
- ❖ DAQ: 250 MHz, 12 bit FADC
- ❖ Custom LED monitoring system
- ❖ Cooling system, $\Delta T < 0.1$ C.

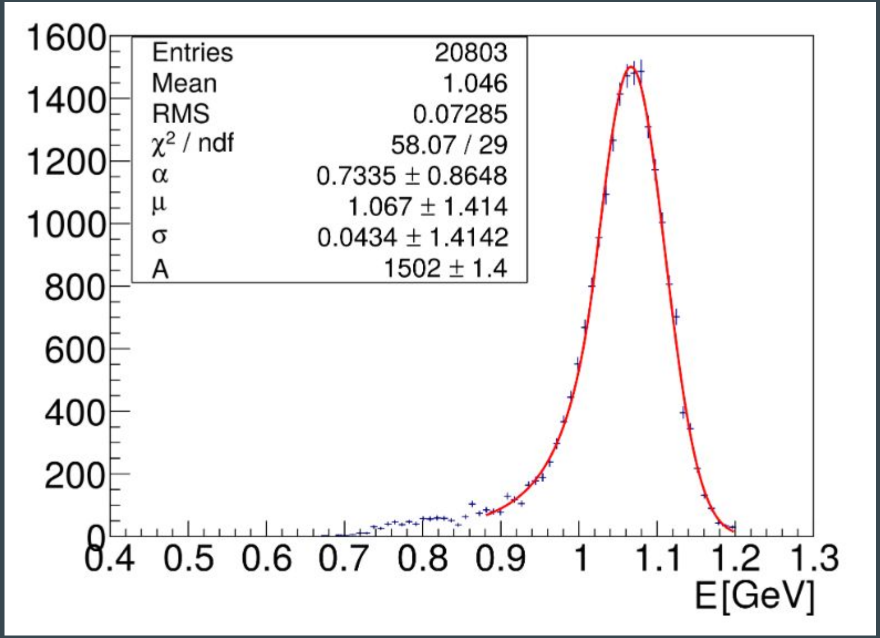




arXiv:1610.04319v3

# The ECAL performance

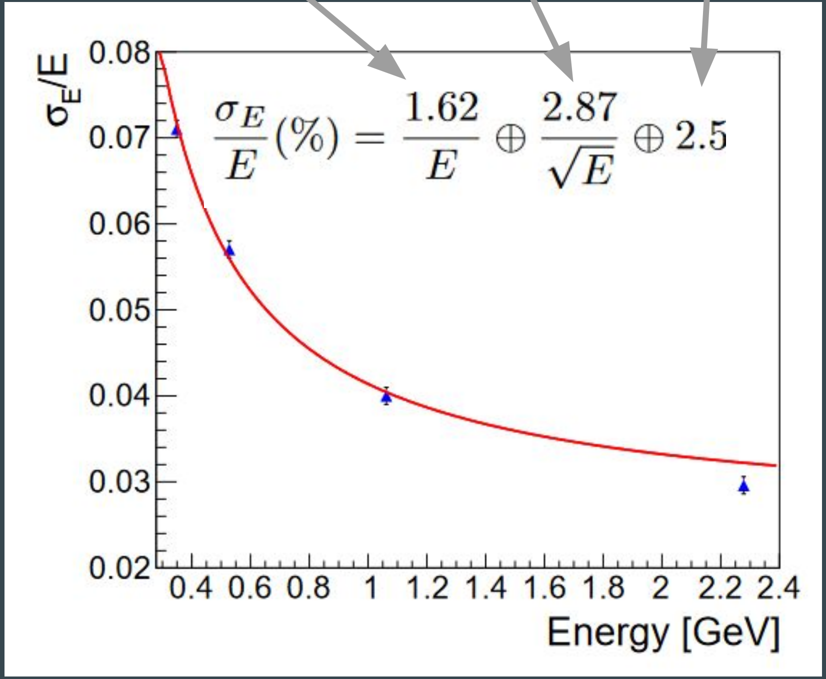
ECAL energy resolution measured with elastically scattered electrons of the beam




electronic noise

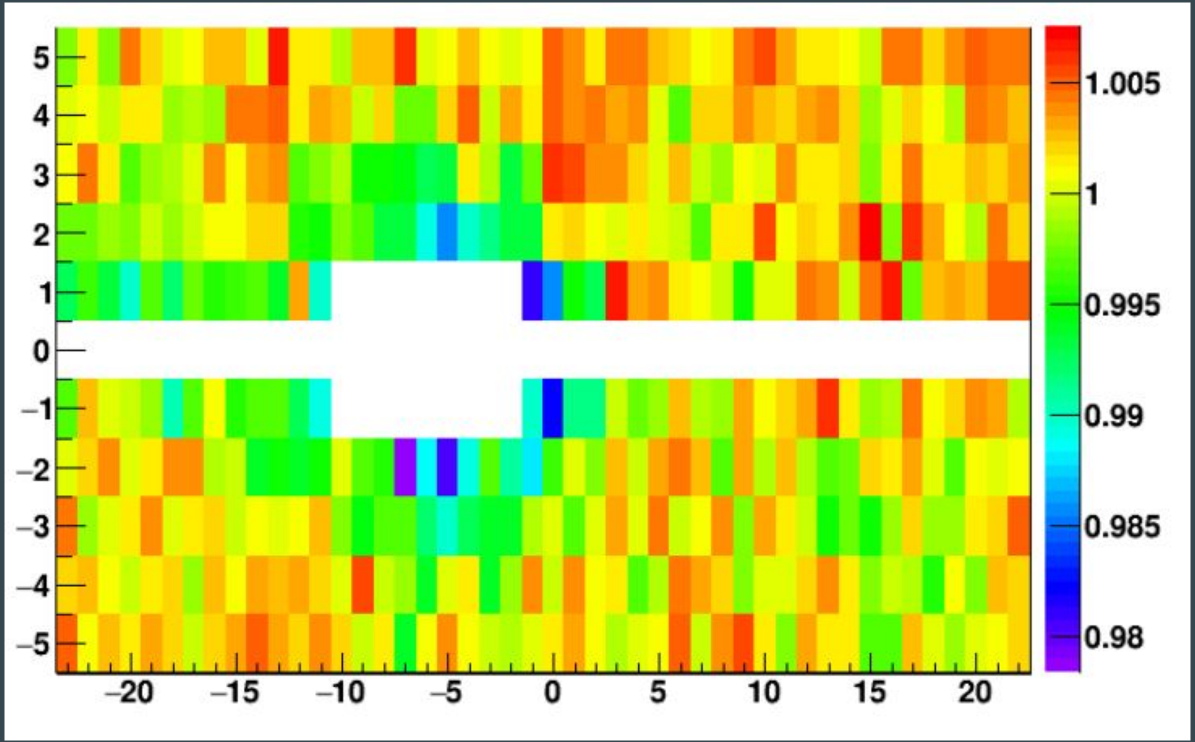
shower/light statistical fluctuations

leakage



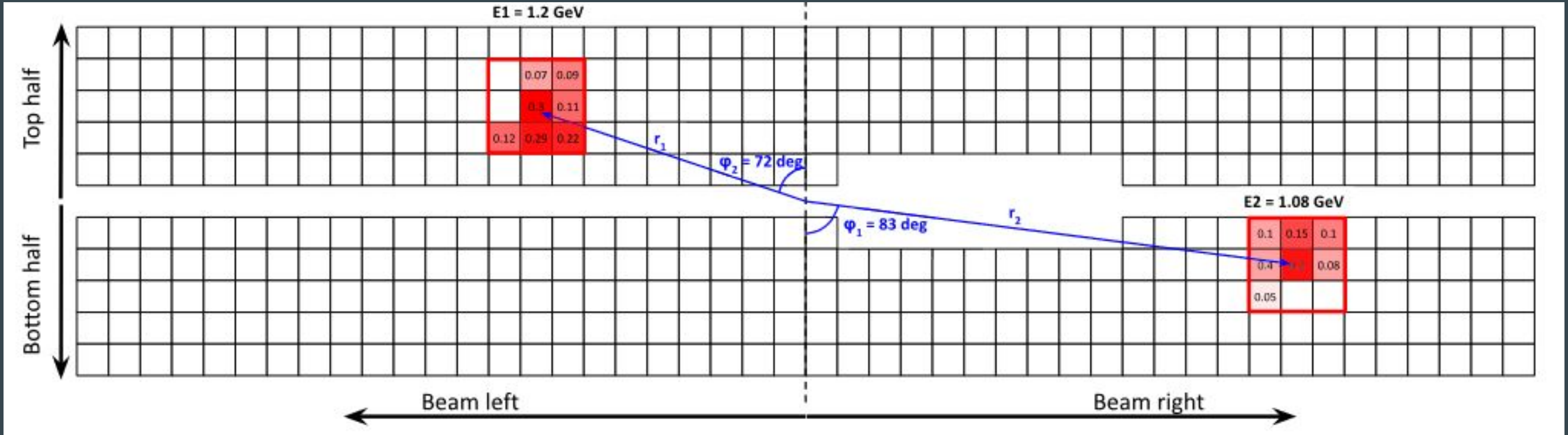
# ECAL radiation damage

LED signal ratio after ~70 hours of beam exposure at nominal intensity:



# HPS Trigger

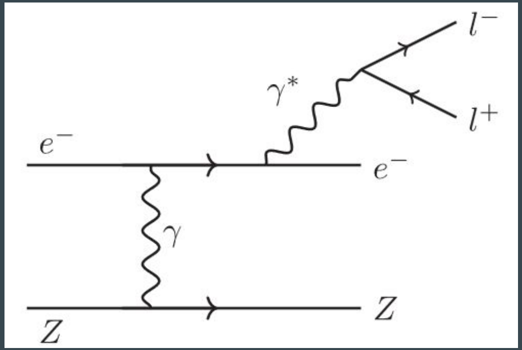
- Trigger condition requires energetic clusters in both ECAL halves (top and bottom), with the two clusters displaced horizontally in opposite directions from the centerline according to their energies, since lower-energy particles will curve more in the magnetic field.



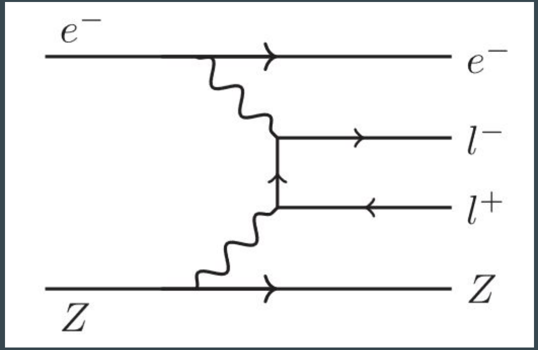
# Expected Backgrounds

**Main background processes:**

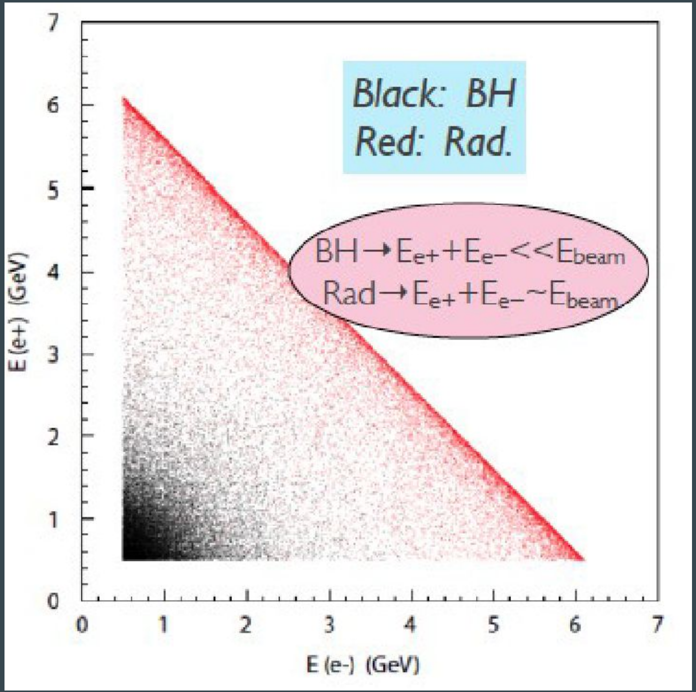
- ❖ Radiative e+ e- emission (irreducible, $P_{e+} + P_{e-} \sim E_0$)
- ❖ Bethe-Heitler processes (different kinematics: final state leptons with lower momentum)




"Radiative"

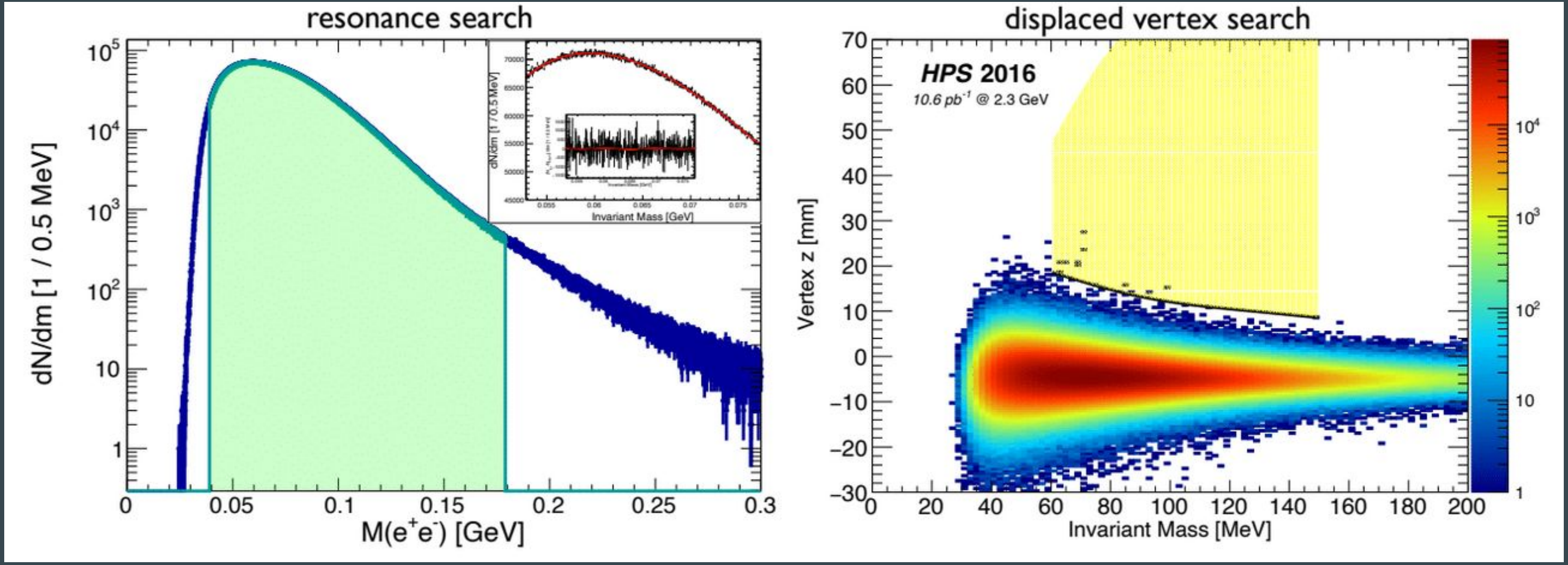



"Bethe-Heitler"



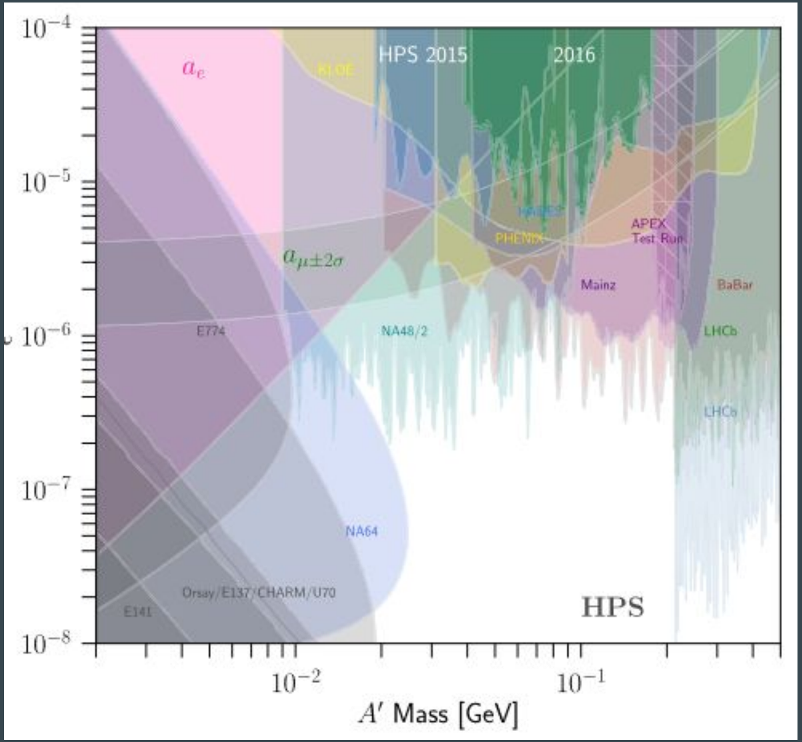
# First HPS results from 2016 engineering run

Final engineering run performed in 2016 (10608 nb–1); first (non competitive) limits cast with the bump hunt search

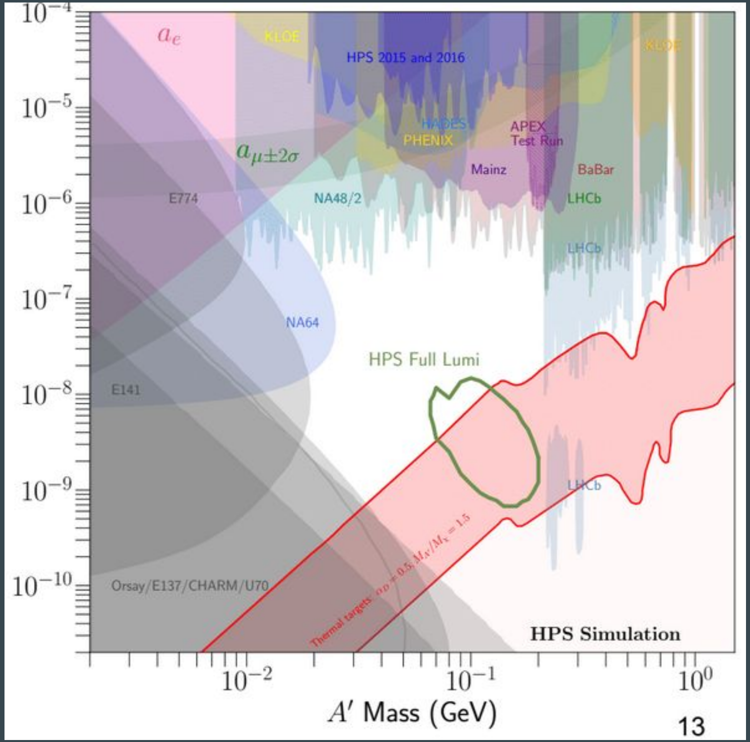


# HPS Projected Sensitivity

Engineering Run




Full Lumi

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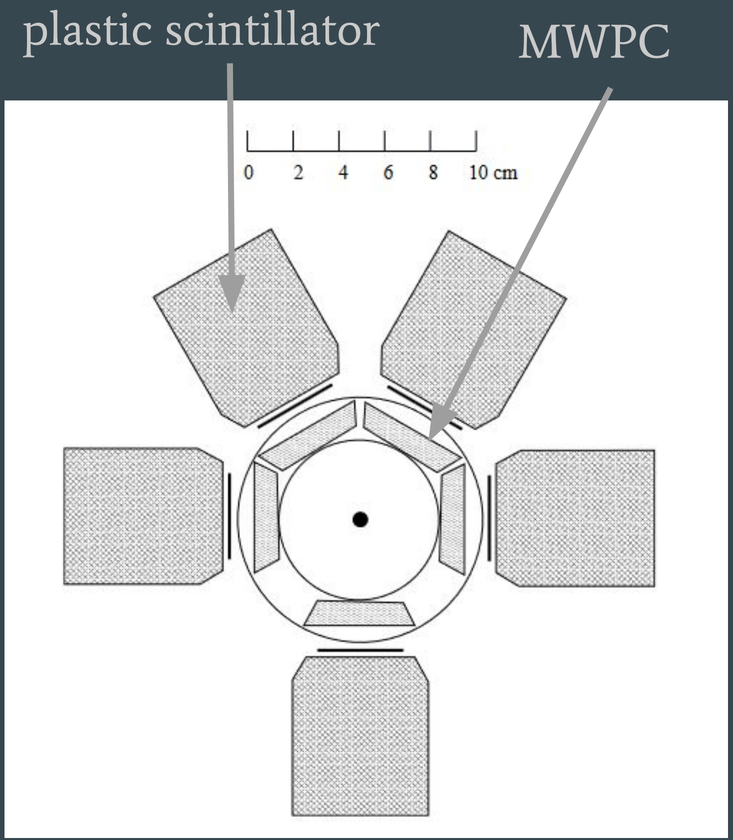
# Parenthesis: the ATOMKI experiment

- ATOMKI experiment: measurement of the angular correlation between e+e- pairs produced by *internal pair conversion* in the de-excitation of $^{8}Be^{*}$ nuclei

- $^{8}Be^{*}$ nuclei produced hitting a $^{7}Li$ target with a ~1 MeV proton beam

- Pair spectrometer detector composed of “telescopes”: Multi Wire Proportional Chambers (MWPC) for impinging position definition and plastic scintillator for energy measurement



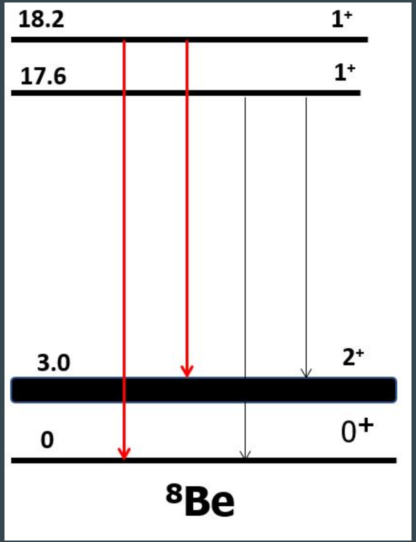

arXiv:1504.01527v1

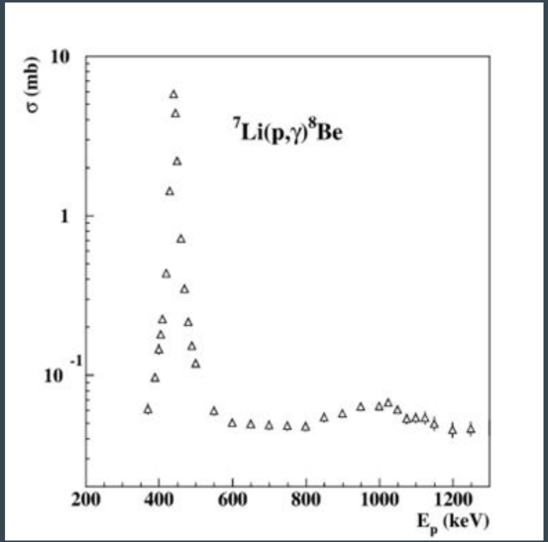
# $^{8}$Be* transitions

ATOMKI: study of the M1 transitions from excited $^{8}$Be* states

Internal pair conversion: the photon emitted due to the de-excitation converts in a e+e- pair in the nucleus

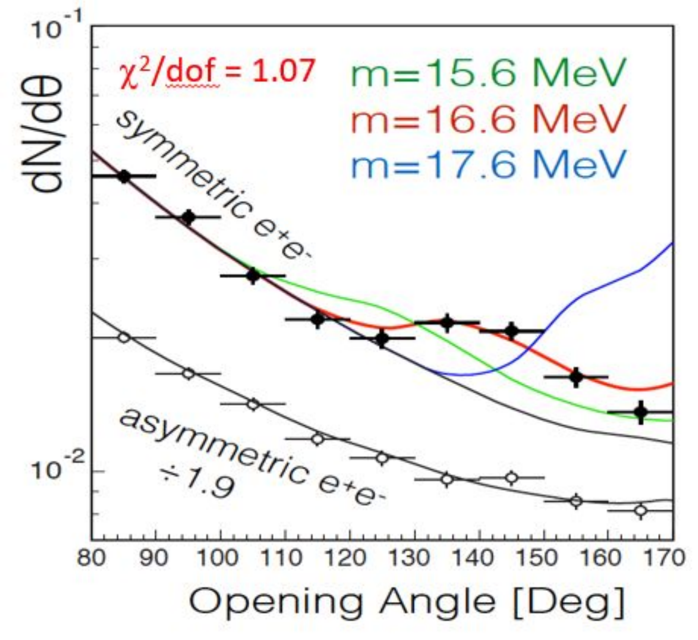
Excited states (18.2 MeV, 17.6 MeV) obtained with 1030 keV and 441 keV proton beams



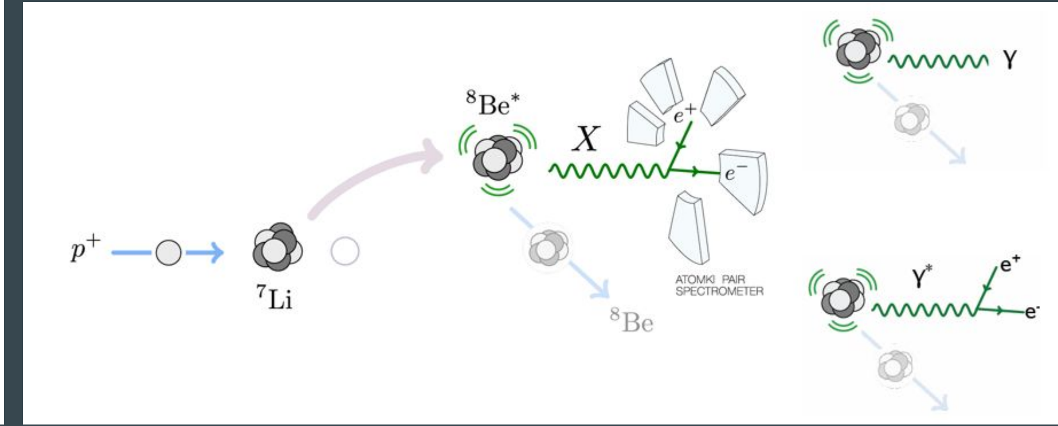



# New physics hints?

- ATOMKI anomaly: observed unexpected peak in the e+e- opening angle distribution!

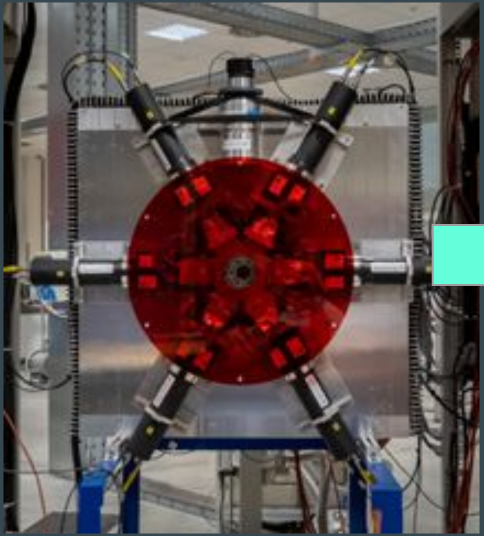


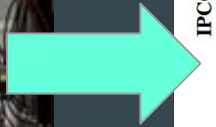

Possible explanation: new short lived particle with mass ~17 MeV (X17) decaying to e+e- pairs

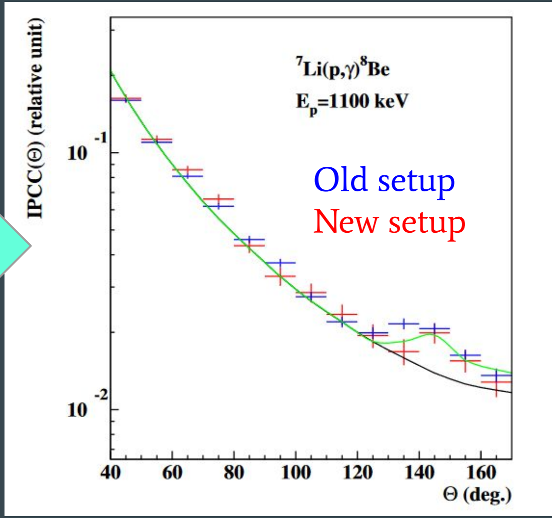


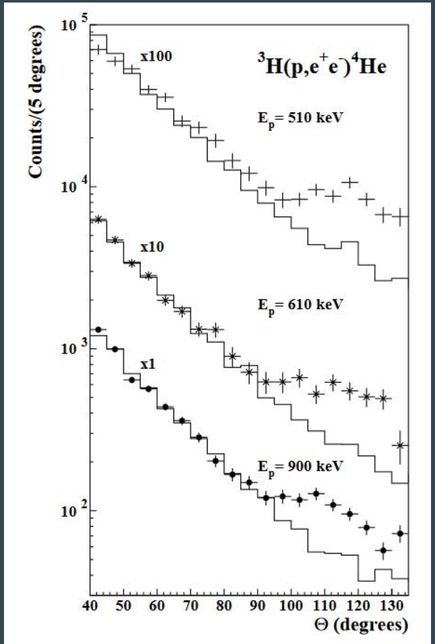
# Additional studies:

❖ Same anomaly observed with a new experimental setup and on excited He nuclei





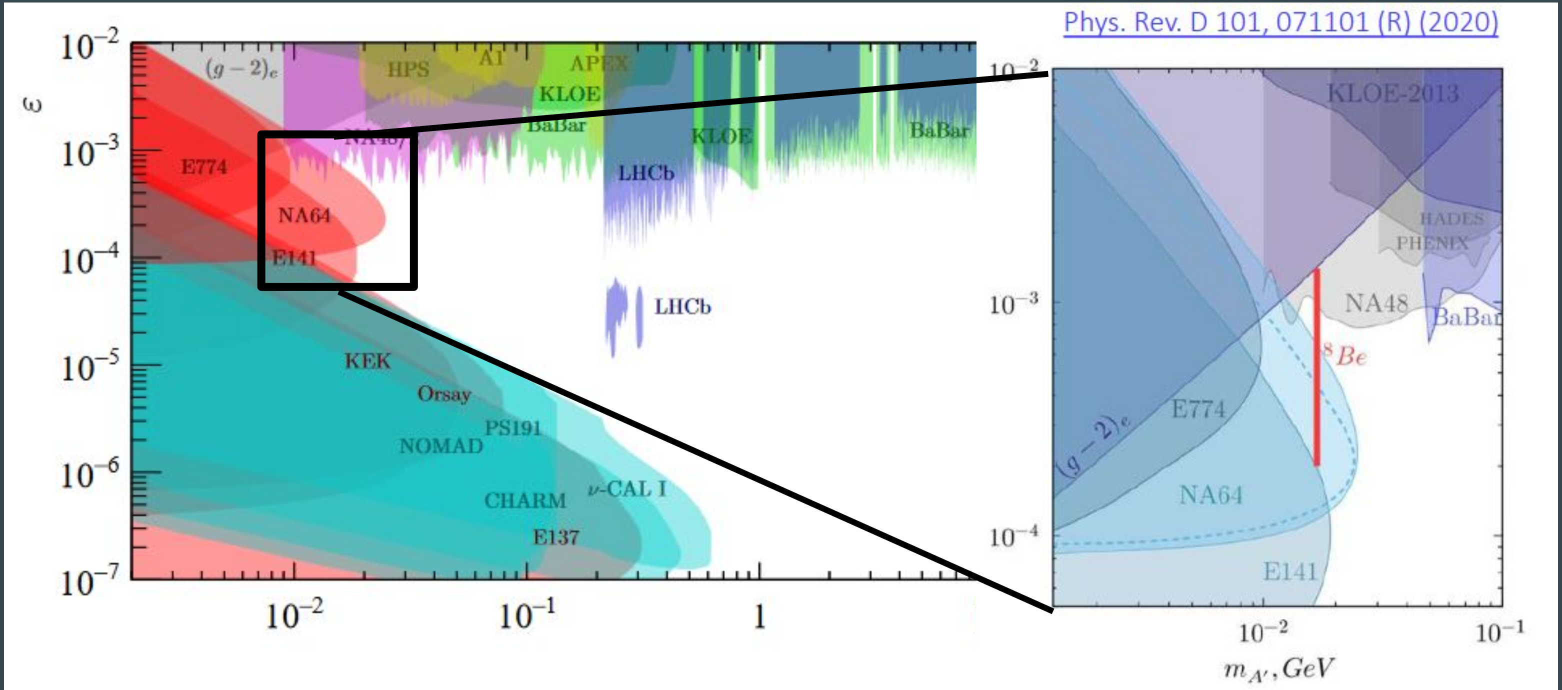


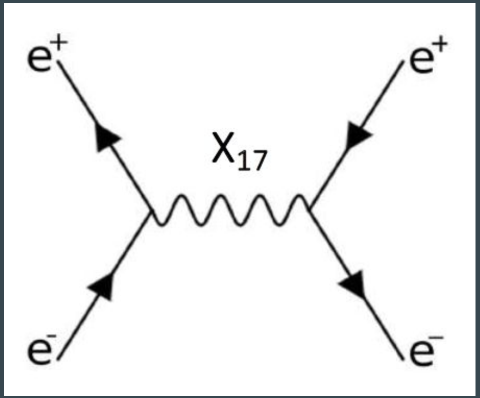

arXiv:2104.10075v1, J. Phys.: Conf. Ser. 1056 012028

# May it be a dark photon??

- There is still some free parameter space compatible with a Dark Photon explanation of the ATOMKI anomaly

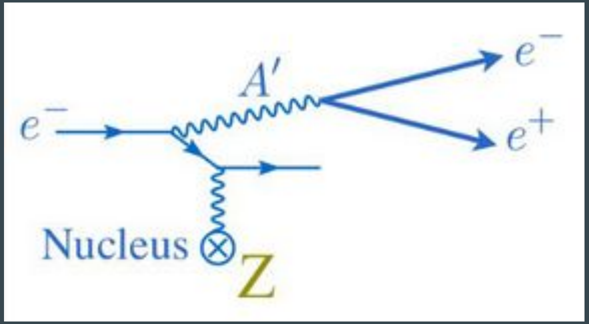


# Resonant A’ production




- Idea: X17 production via e+e- **resonant annihilation** on thin target at the exact beam energy such that:

$$\sqrt{s} = \sqrt{2m_e E_{beam}} = m_{X17} = 17\ MeV$$



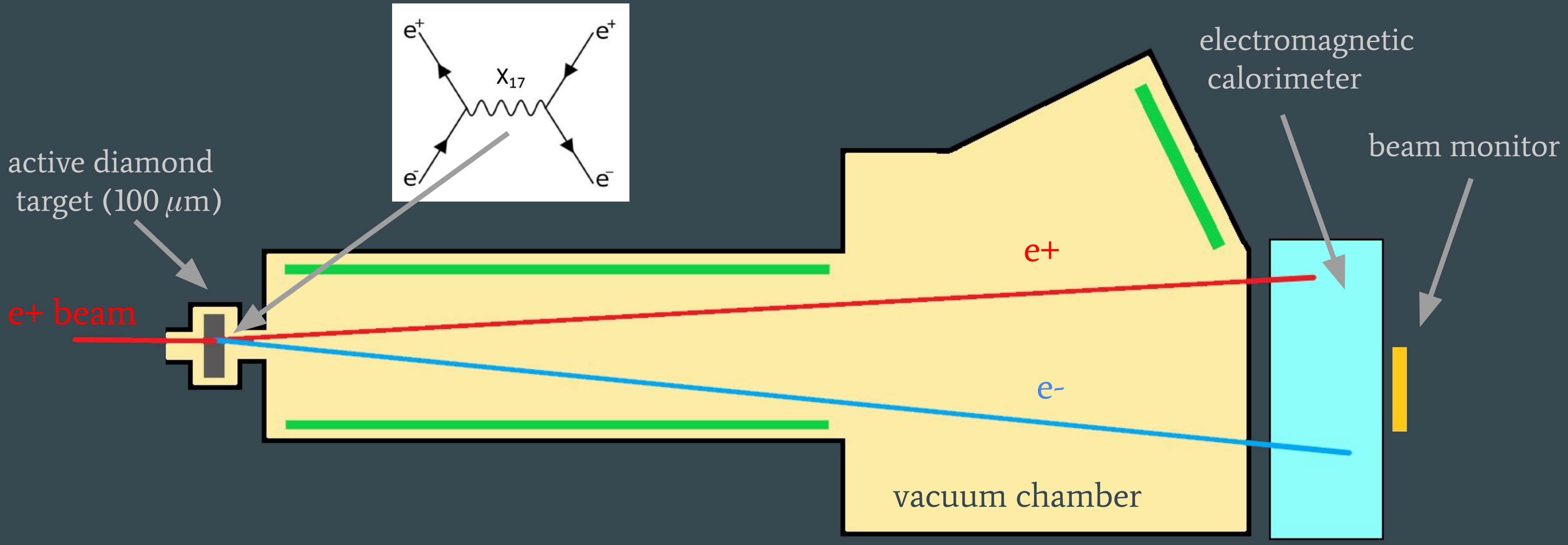

- **Resonant annihilation:**
  - Better $\alpha_{EM}$ scaling than the A’-strahlung
  - Large cross section in a very narrow range of sqrt(s)
  - Ideal to search for a candidate with known mass!

$$\sigma_r = \sigma_{\text{peak}} \frac{\Gamma_{A'}^2/4}{(\sqrt{s}-m_{A'})^2 + \Gamma_{A'}^2/4}\,, \quad \sigma_{\text{peak}} = 12\pi/m_{A'}^2$$

Need a positron beam with energy: $E_{resonant} = \frac{m_{X17}^2}{2m_e} \simeq 390\ MeV$

# The PADME experiment at LNS

- PADME: search for X17 via resonant annihilation, performing a “scan” in beam energy around the resonance value




arXiv:2209.09261v2

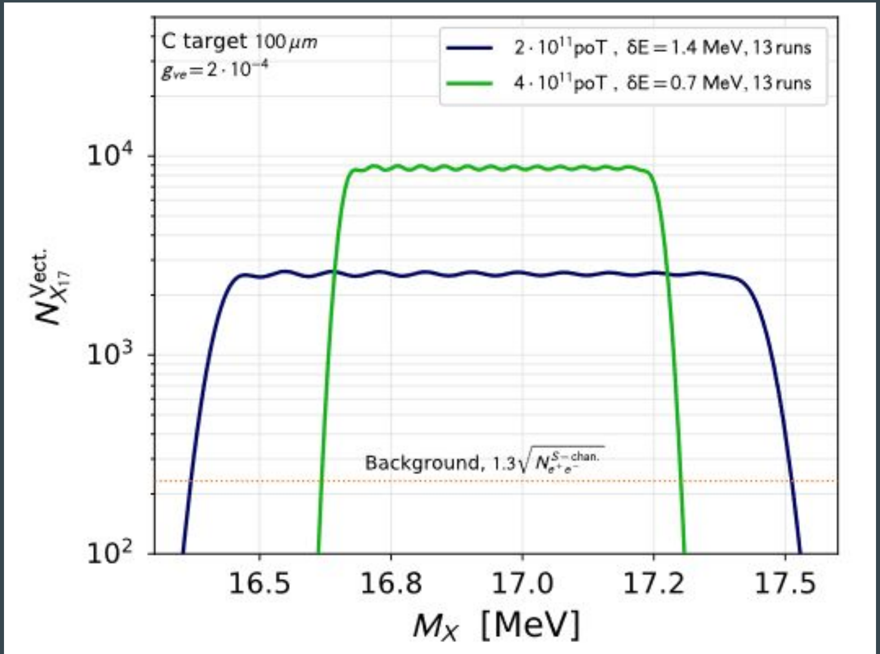
# The PADME detector


arXiv:2405.07203

# The Heavy Photon Search (HPS) Experiment

❖ Given the narrow width of the X17/*A'*, the resonant production yield depends critically on the beam energy

→ by performing several measurements varying the energy of the beam in small steps, it is possible to observe the rate increase of the e+e- pairs impinging on the ECAL, when the beam energy comes close to the resonance




❖ The overall increase in e+e- rate at the resonance is of order ~1% or less

➢ It is critical to monitor the stability of the beam

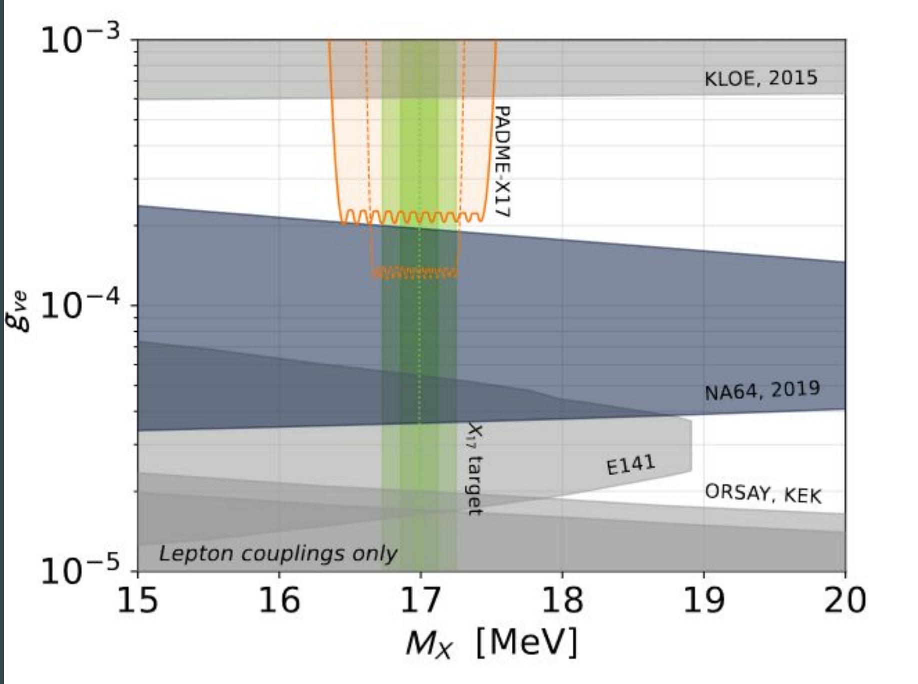
arXiv:2209.09261v2

# PADME projected sensitivity

❖ Two scenarios considered:

*Conservative:* $2 \cdot 10^{11}$ total PoT, a 0.5% beam spread, a broad energy range [265, 297] MeV, an energy scan with 12 bins

*Aggressive:* $4 \times 10^{11}$ total PoT on target, a 0.25% beam spread, a narrow energy range [273, 291] MeV, and an energy scan with 14 bins.




arXiv:2209.09261v2