XIX FRASCATI SPRING SCHOOL "BRUNO TOUSCHEK" in Nuclear, Subnuclear and Astroparticle Physics

Search for neutral long lived particles decaying to lepton-jet in ATLAS

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ATLAS EXPERIMENT

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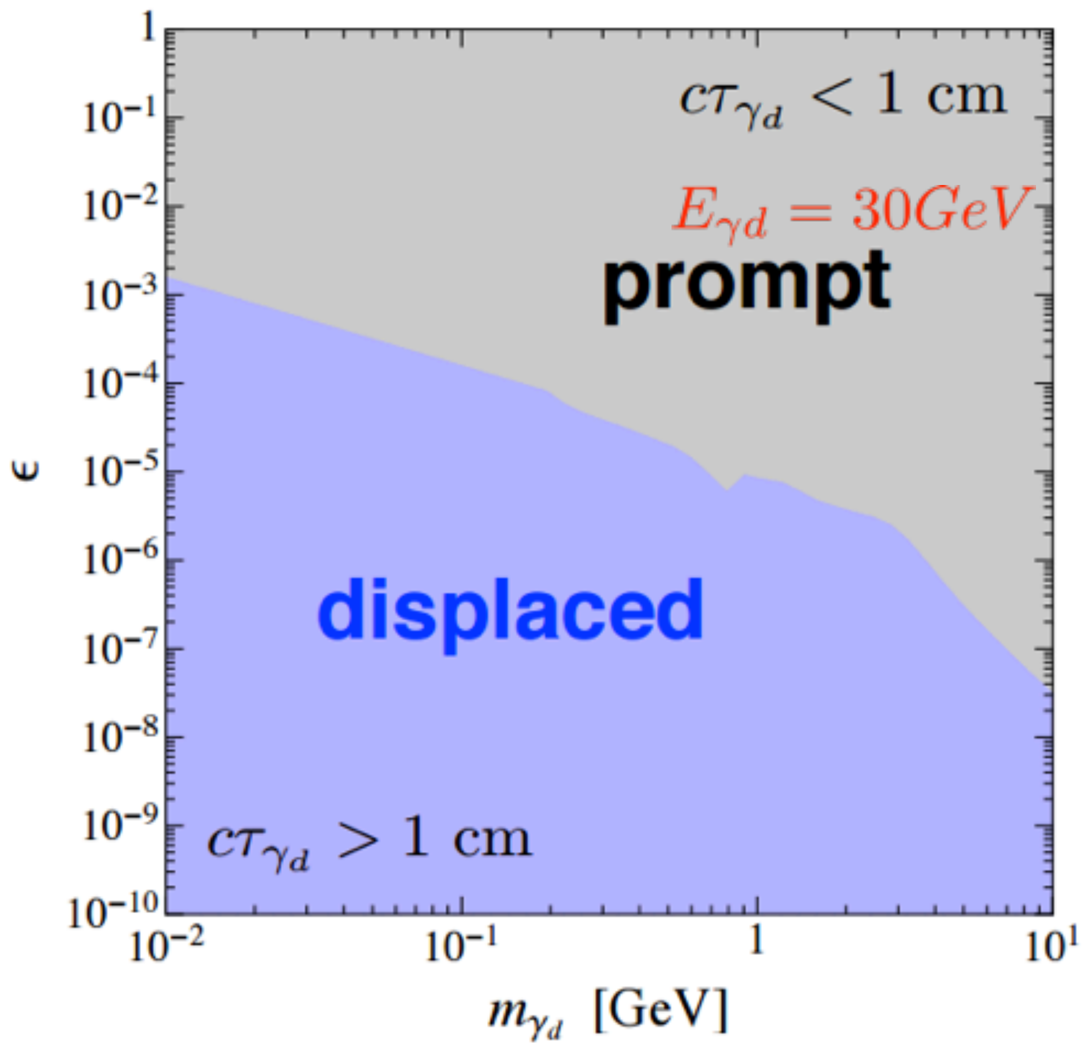
Long Lived Particles

- Many new physics models that extends the SM allows for (or requires) long-lived particles: solution to many problems like Dark Matter, naturalness ecc.
- Unique signature that can lead to an early discovery. Life-times can range form from fractions of micro-m to outside the ATLAS detector.
- Run2 much effort on LLP studies excluding a wide region of phase-space.
- Covering these regions opens an experimental challenge for the detector and analyses.
- Higgs portal production great place to search LLPs.
- Here we are working on <u>neutral</u> long lived particles.

Vector portal model: dark photon

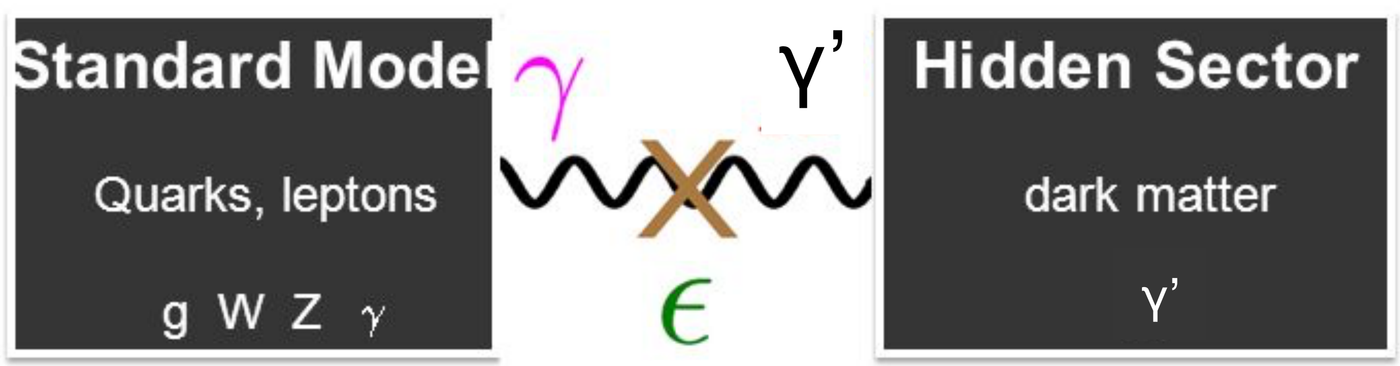
Exploring hidden portals searches for Dark Matter, Sterile Neutrinos and Dark Photons => long-lived particles (LLP)



$$c\tau = \frac{1}{\Gamma_{tot}} \propto \frac{1}{\epsilon^2}$$

for small epsilon very displaced decays

Hidden sector weakly coupled with the SM

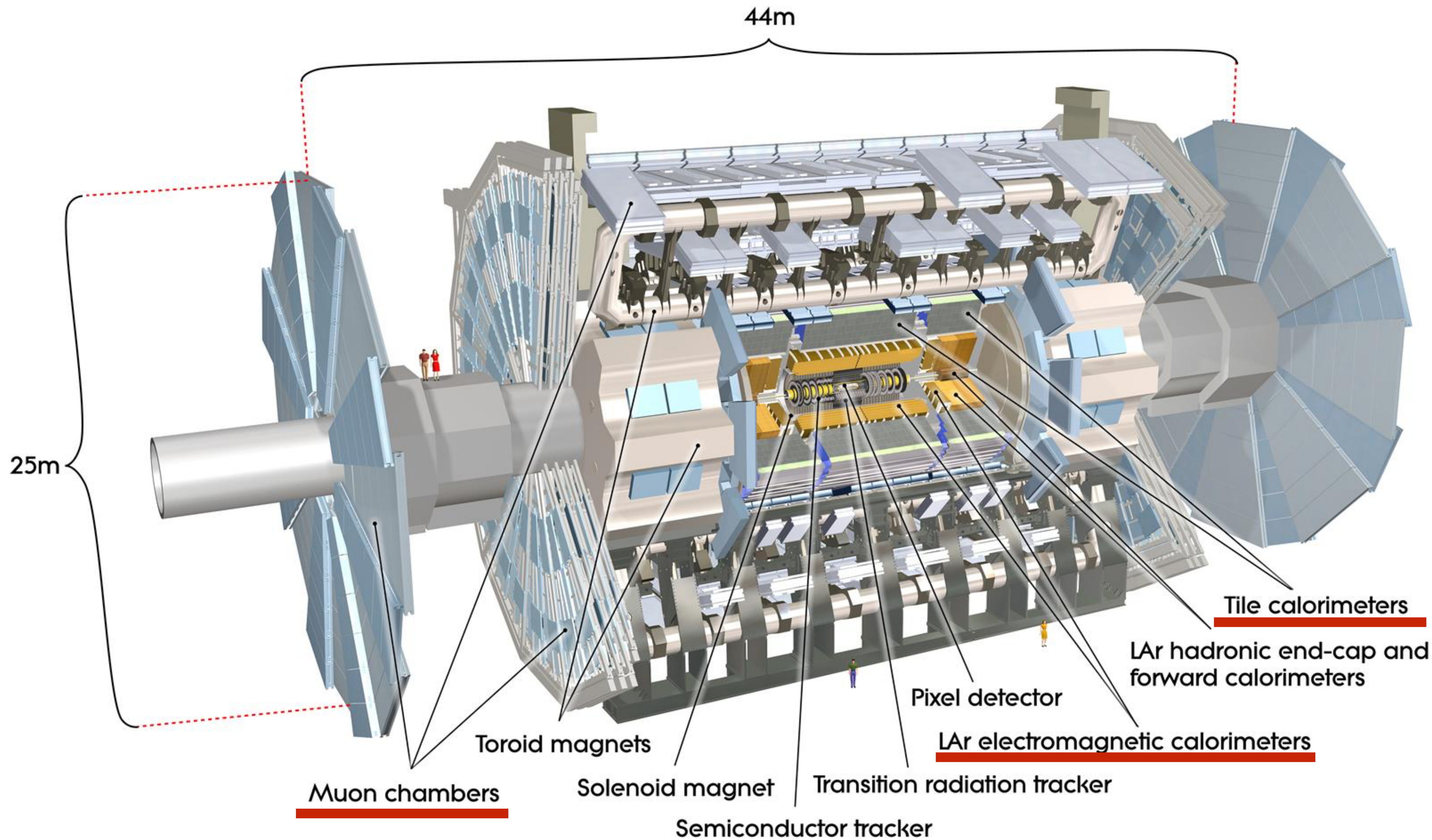


Minimal model:

- **No direct coupling**
- **New U(1) gauge invariance**
- **Kinetic mixing with only one parameter epsilon (interaction strength)**

Dark-QED U(1): $\mathcal{L} \propto \varepsilon e \gamma_d^{\mu} J_{\mu}^{em}$

ATLAS detector @LHC



This search will exploit the Muon Spectrometer (MS), the electromagnetic (ECAL) and hadronic calorimeter (HCAL)

Dark photon: Lepton-jet analysis

Dark photon is reconstructed as a lepton-jet, collimated pair of particles (leptons or light hadrons)

Schematic picture of the LJ classification according to the decay final state

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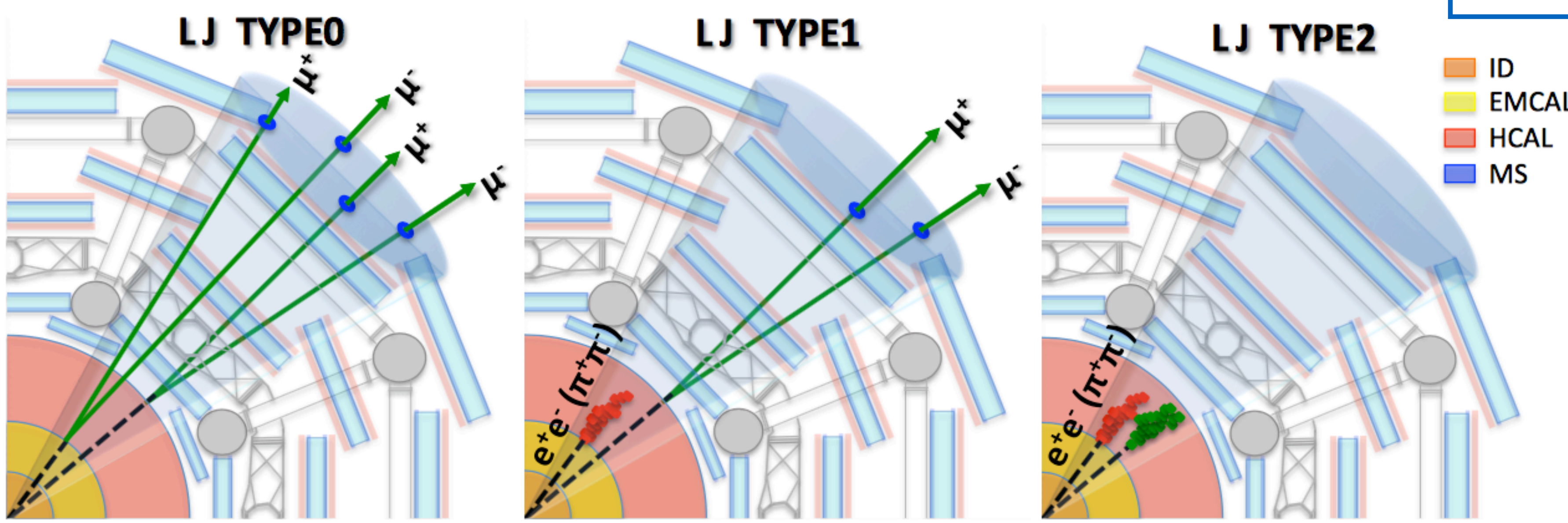
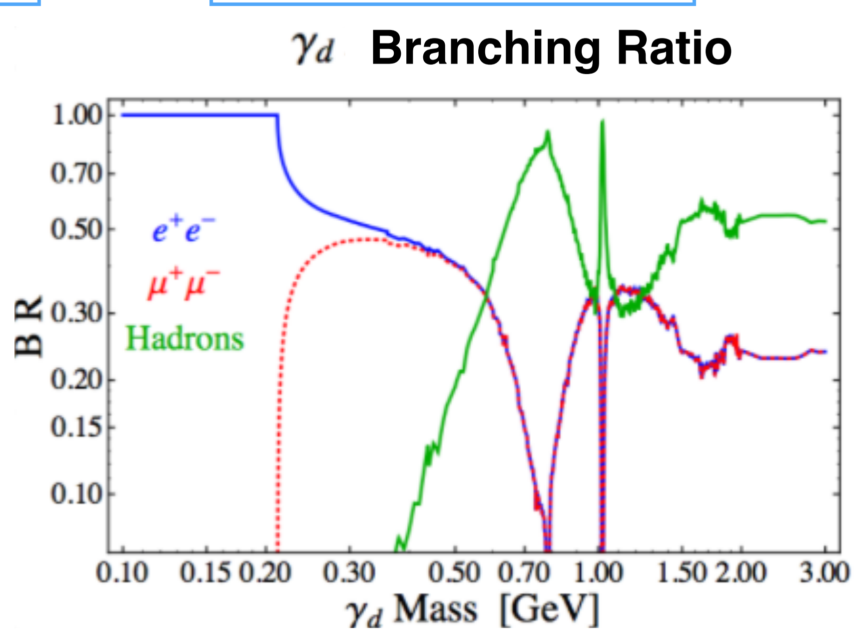
ATLAS-CONF-2016-042 (2016)

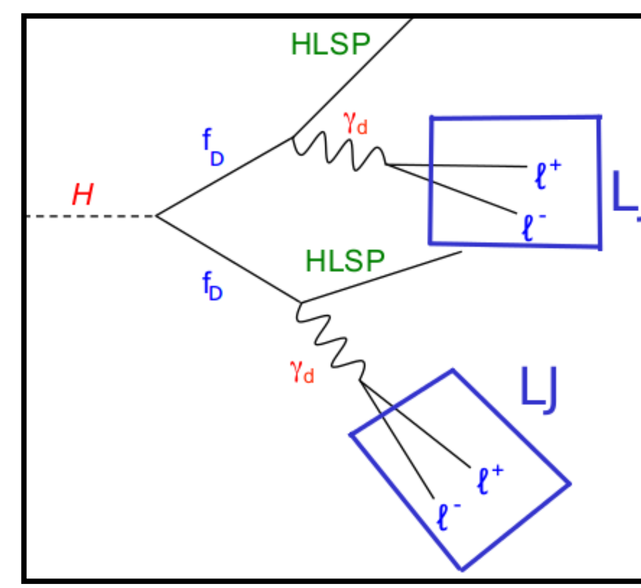


Only muons | muons and jets | Only jets

Falkowsky, Ruderman, Volansky, Zupan [FRVZ] arXiv:1002.2952

$$\Delta\Phi \simeq \frac{m_{\gamma d}}{E_{\gamma d}} << 1$$





The main sources of background to the LJ signal are QCD multi-jet production, beam halo muons (BIB), and cosmic-ray muons that cross the detector in time coincidence with a bunch-crossing interaction.

Strategy

- Analysis based on 13 TeV collected data in 2015+2016: search for **two back-to-back Lepton-Jets** (LJ) from heavy particle decay
  - benchmark models: FRVZ models with m_H=125 to 800 GeV, dark-photon masses 0.4 to 10 GeV
  - Higgs produced by gluon fusion (ggf) mechanism
- dedicated and standard triggers
- 2 LJs per event
- cuts on each LJ of the pair (according to LJ type)
- final discriminants (variables at event level): isolation in the inner detector (SumPt) and deltaPhi between the 2 LJs
- use simultaneous ABCD method to estimate dominant QCD background in the signal region
- final yield

Discriminant variables and backgrounds

Signal selection requires a logical OR of these ATLAS High Level Triggers:

Narrow-scan: 2 *MSonly* tracks (p_T > 20 GeV, p_T > 6 GeV) in a ΔR=0.5 cone

Tri-muon: 3 *MSonly* tracks with p_T > 6 GeV

- for muon-LJs reconstructed as Msonly tracks

CaloRatio: jet with p_T > 30 GeV and low EM fraction

- for e/π-LJs reconstructed as narrow, low EMF jets and no ID tracks

Source of background

- Cosmic-ray muon energy deposits in calorimeters mis-reconstructed as jets
- Cosmic muon bundles, mainly concentrated in barrel, reconstructed as muon-LJs
- Beam-induced background, high-energy muon longitudinally crossing detector with bremsstrahlung in hadronic calorimeter, reconstructed as e/π-LJs
- QCD multi-jet

Cuts defined to optimize signal significance:

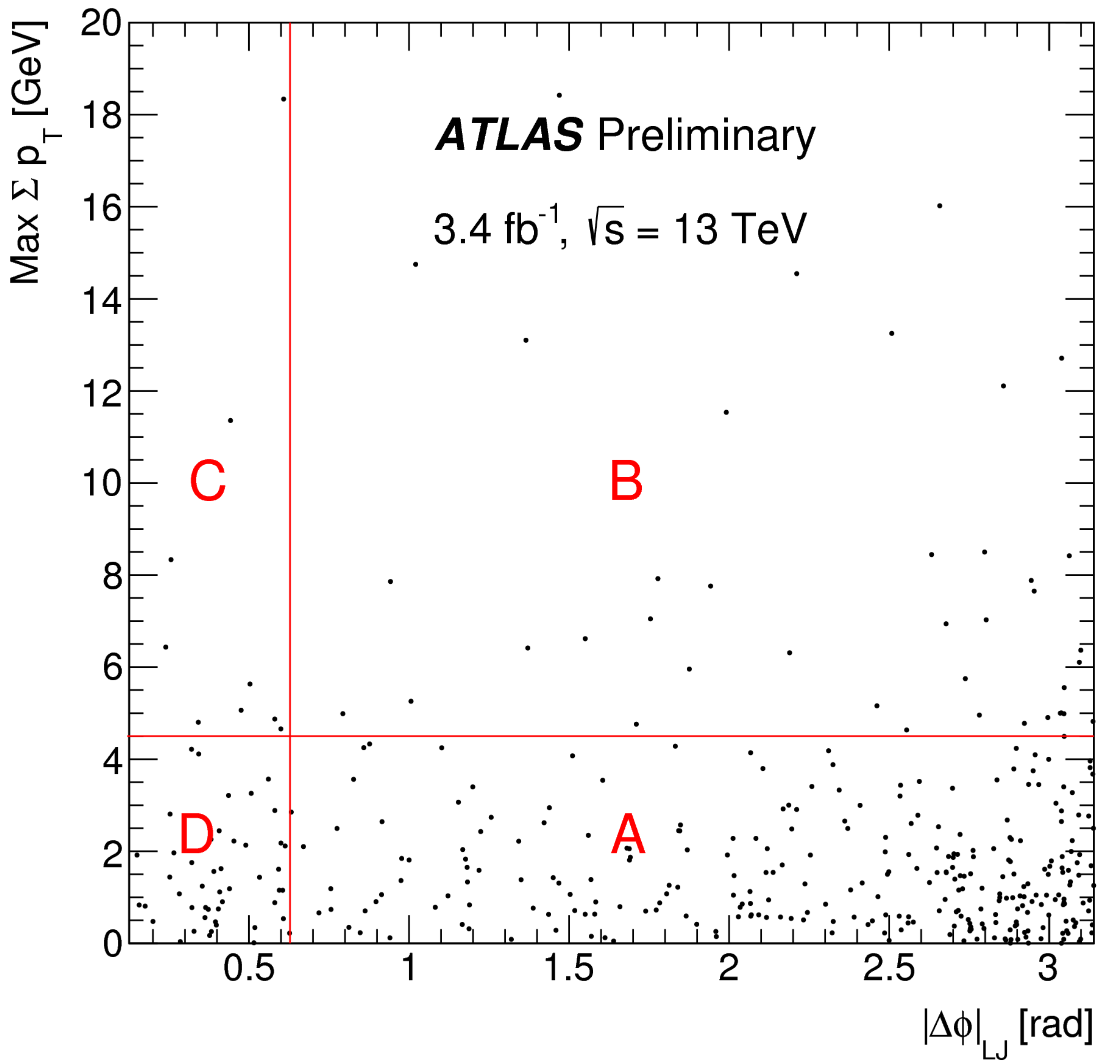
- **LJ isolation** ($\sum p_T$ of ID tracks belonging to primary vertex in ΔR=0.5 cone around LJ center, with p_T>0.5 GeV)
- **BIB tagging** (Rejects BIB jets accompanied by φ–matched muons parallel to beam pipe)
- **Jet timing** (rejects mis-reconstructed cosmics and BIB)
- **Muon impact parameter**: (rejects cosmic muons)
- **Jet width** (rejects QCD)
- **Jet EM fraction** (Rejects QCD)

ABCD method

The data-driven method used to estimate the QCD multi-jet contribution in region A, is the **simplified matrix method ABCD**, assuming that:

- The multi-jet background is factorizable in 2D plane formed by $\sum p_T$ and $|\Delta\phi|$
- In the FRVZ models, LJs have high $|\Delta\phi|$ and low $\sum p_T$

The multi-jet background estimation is given by $N_A=N_D x N_B/N_C$.



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Main systematic uncertainties:

- ➤ Narrow scan trigger efficiency
- ➤ 3mu6 trigger efficiency
- ➤ CaloRatio trigger efficiency
- ➤ Reconstruction efficiency for single dark-photon
- ➤ Overall normalisation of integrated luminosity
- ➤ Effect of pile-up on ΣpT
- ➤ **ABCD background estimation**

Run1 analysis results

σ×BR limits interpreted ad exclusion regions in the (ε,mγd) plane in the context of the Vector portal model as a function of BR (h→ dark sector)

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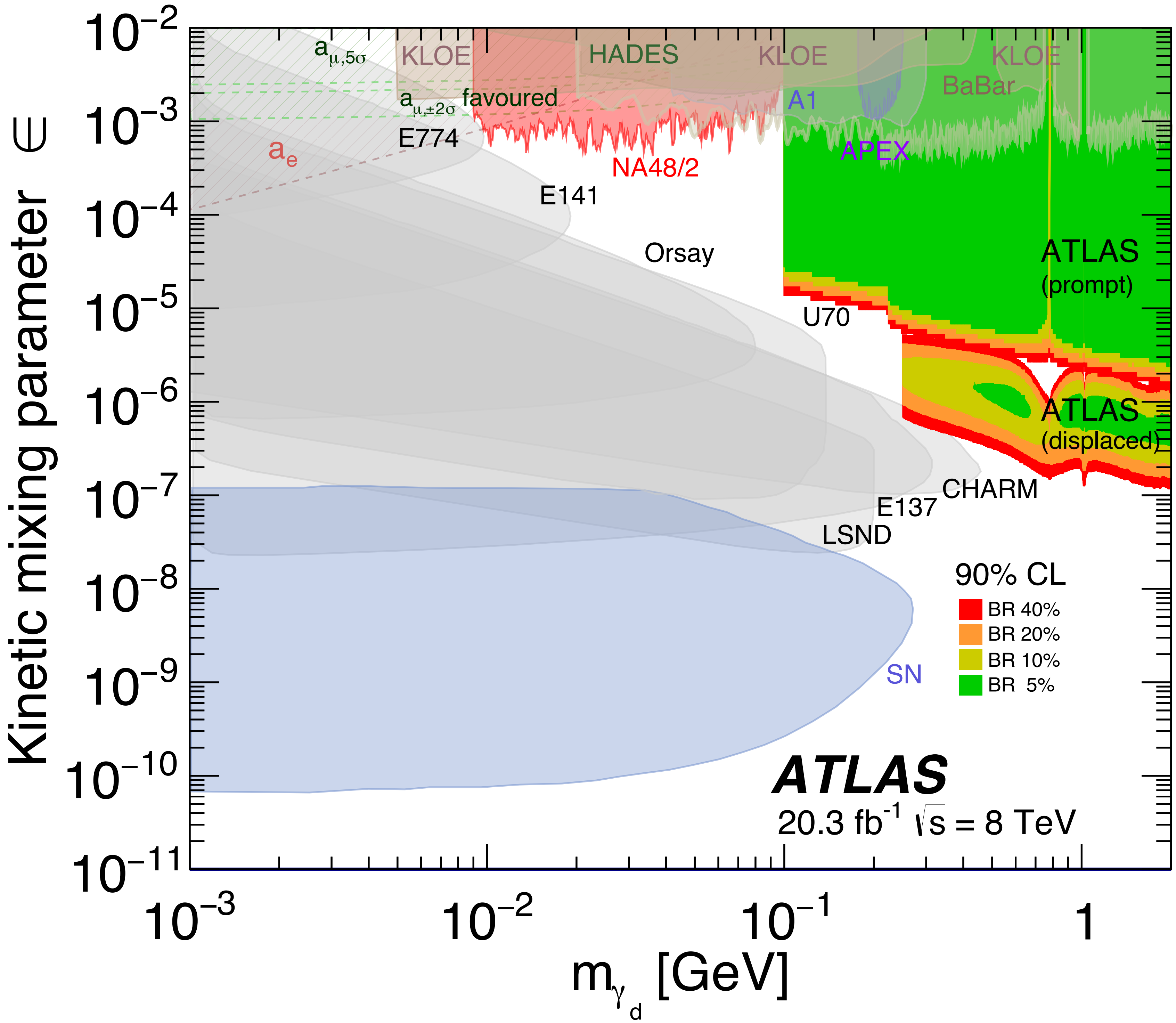

Goals for Run2 analysis

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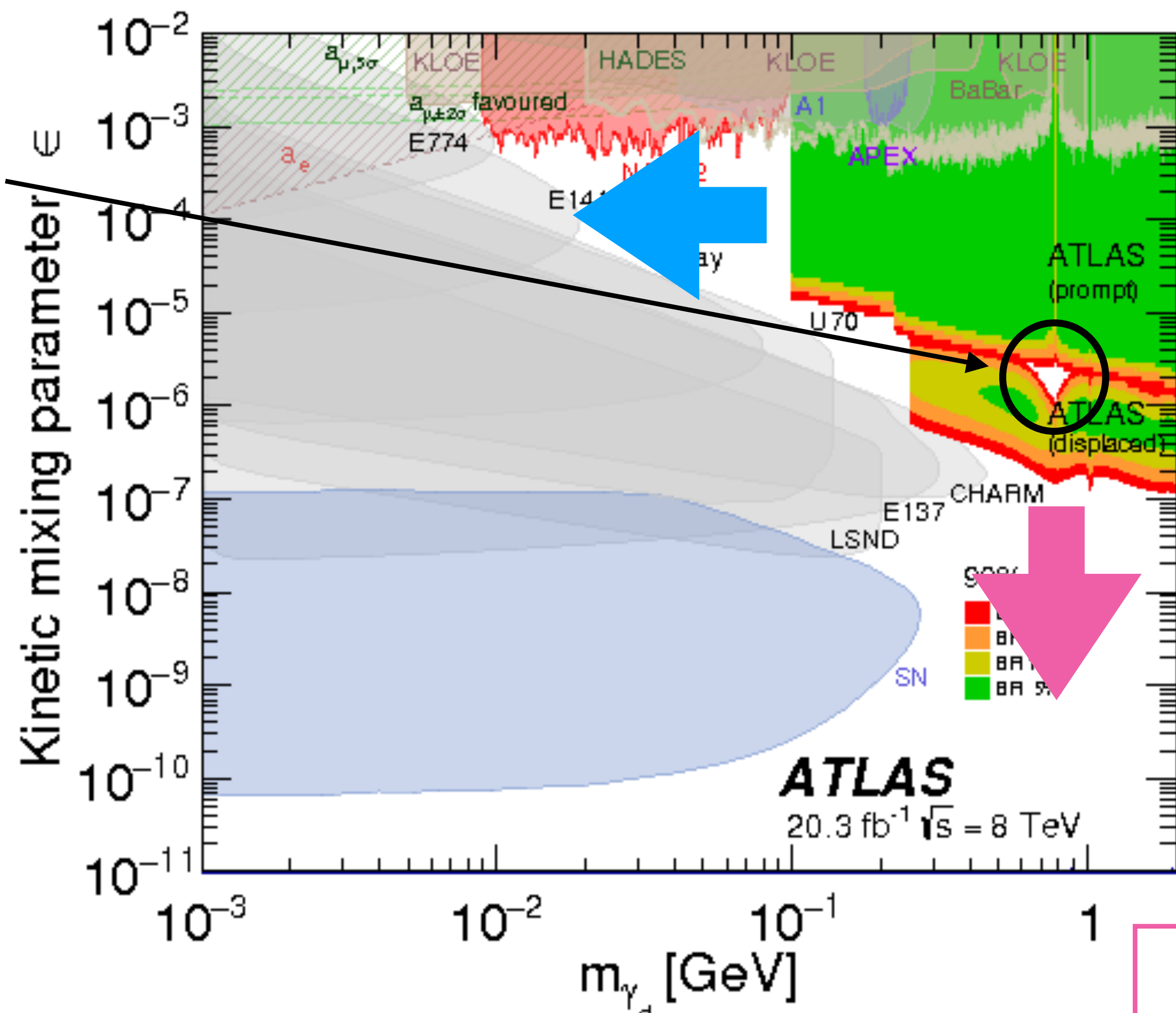
A two-dimensional exclusion plot in the dark-photon mass mγd and the kinetic mixing ϵ parameter space

Small gap: Improve analysis in the hadronic channel, with higher background reduction and larger statistics.



Extend mass region (from few MeV to ~10 GeV): Develop new analysis and dedicated triggers.

Look at different production and decay modes:
W/Z + h
Drell-Yan

Very displaced region: new topological studies with mono-LJ, jet+LJ and mono-jet