Summary talk of the collider session

Walter M. Bonivento

INFN Cagliari

also on behalf of Eder Izaguirre who could not come to ther meeting but organised the session together with me!

11:00 - 13:00 II Colliders A

11:00 **Dark Sector Theory at LHC** *20'*
Speaker: Felix Yu (JGU Mainz)
Material: **Slides**

11:20 **Searches for Dark Matter at ATLAS and CMS** *20'*
Speaker: Ms. Rocio Vilar (Instituto de Fisica de Cantabria (CSIC-UC))
Material: **Slides**

11:40 **Low Mass Dark Sector Searches at ATLAS and at CMS** *20'*
Speaker: Monica Verducci (ROMA3)
Material: **Slides**

12:00 **ALPs at Colliders** *20'*
Speaker: Lou Hou Keong (University of California, Berkeley)
Material: **Slides**

17:45 - 19:00 IV Colliders B

17:45 **DM Theory at Neutrino Facilities** *20'*

Speaker: Dr. Claudia Frugiuele (Weizmann institute)

Material: **Slides**

18:05 **SHiP Dark Sector searches** *20'*

Speaker: Laura Fabbri (BO)

Material: **Slides**

18:25 **DM searches at Belle/Belle II** *20'*

Speaker: Enrico Graziani (ROMA3)

Material: **Slides**

18:45 **Discussion** *15'*

The dark sector, i.e. portals, and DM at accelerators, are relatively new research fields

Many experiments that were designed with other goals in mind (such as the LHC ones) are discovering now their physics potential for dark sector and DM particle searches

I do not personally believe (as sometimes is said by ourselves) that the dark sector would not be a strong enough physics case on its own

Indeed can we classify new physics ?? is a neutralino worth two axions or three? nobody knows where the truth is (especially now) and therefore we should keep an open mind and consider whatever theoretically allowed as viable for experiments (if we can afford them!) and leave no stones unturned

A different way to search for NP!

HS portals is yet another different way!

Dark sector particles can potentially solve many outstanding issues in particle physics such as

Dark Matter: WIMP-like particles, dark photons, axions, sterile neutrinos

Baryogenesis: Sterile neutrinos

Neutrinos masses: sterile neutrinos, see-saw

In this WG, we discussed dark sector particles searched with:

- pp collisions at LHC

- Pb-Pb collisions at LHC

- e+e- collisions at Belle2

- pp collisions in fixed target at SHiP

Apart from the last one, clearly pp and e+e- experiments are there and designed for other purposes, but are also providing and will provide for a long time very relevant information about dark sector particles (LHCb and Babar slipped into other sessions but they belong to the group!)

SHiP is indeed the first experiment at CERN designed for dark sector particle studies

Light Dark Matter 2017

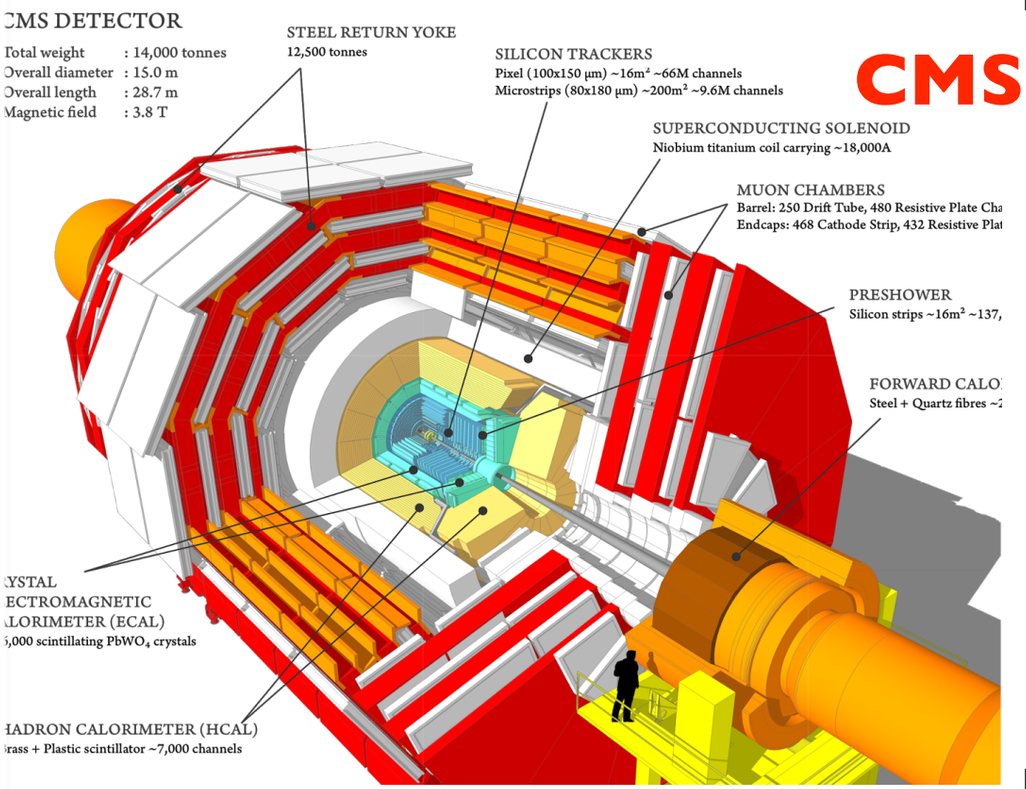
24-28 May 2017

La Biodola - Isola d'Elba

SEARCHES FOR DARK MATTER AT ATLAS AND CMS

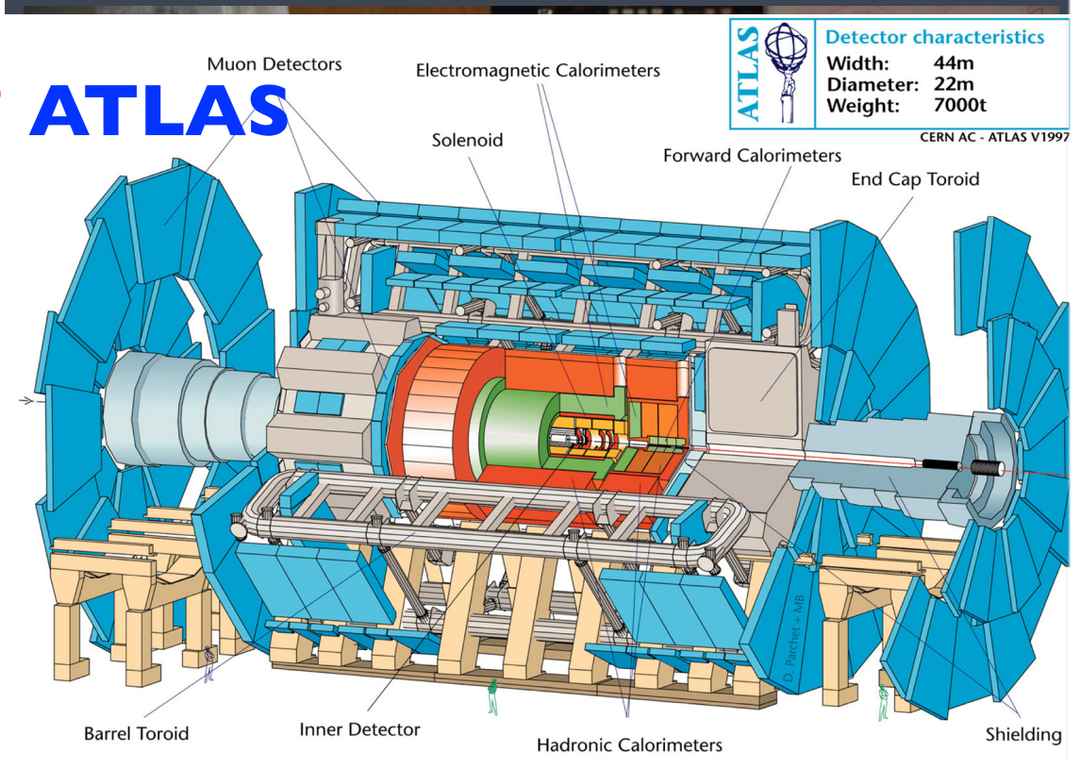
Rocío Vilar
(for Atlas and CMS collaboration)
Instituto de Física de Cantabria (IFCA)

EXPERIMENTAL SETUP



CMS

ATLAS

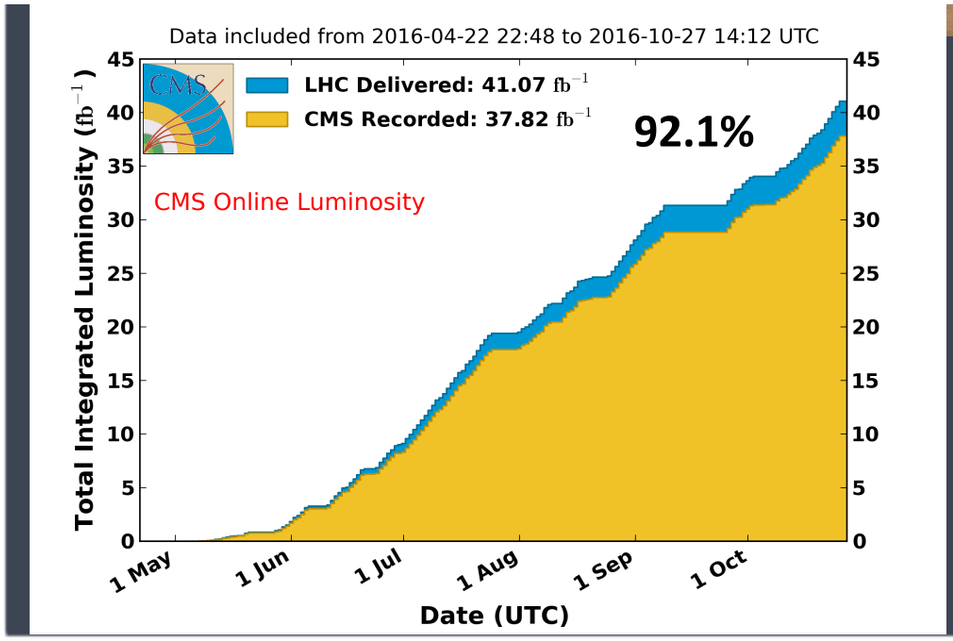


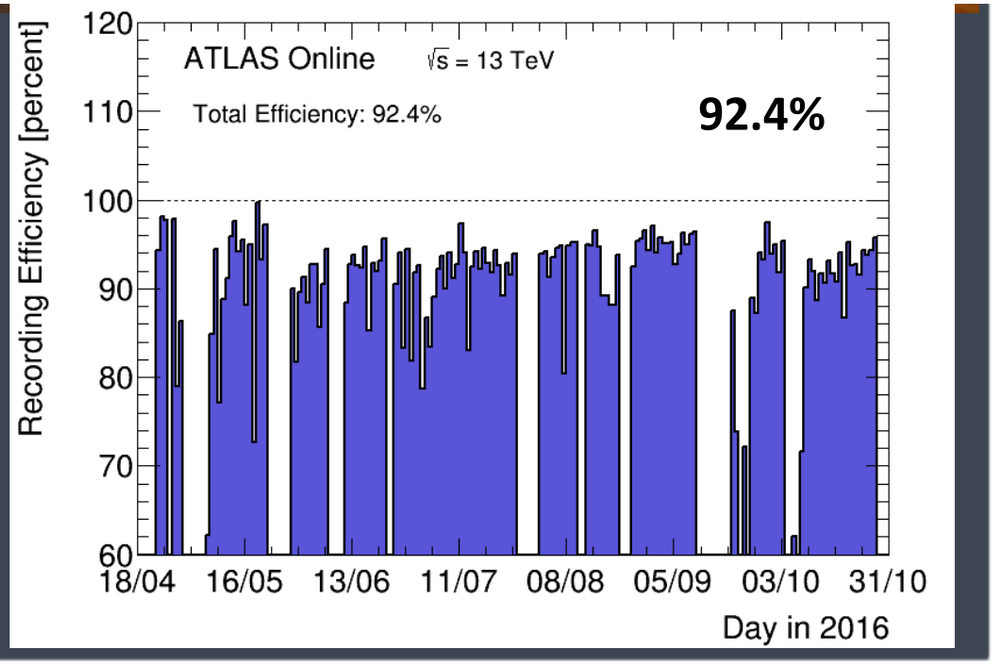
ATLAS

Detector characteristics

Width:	44m
Diameter:	22m
Weight:	7000t

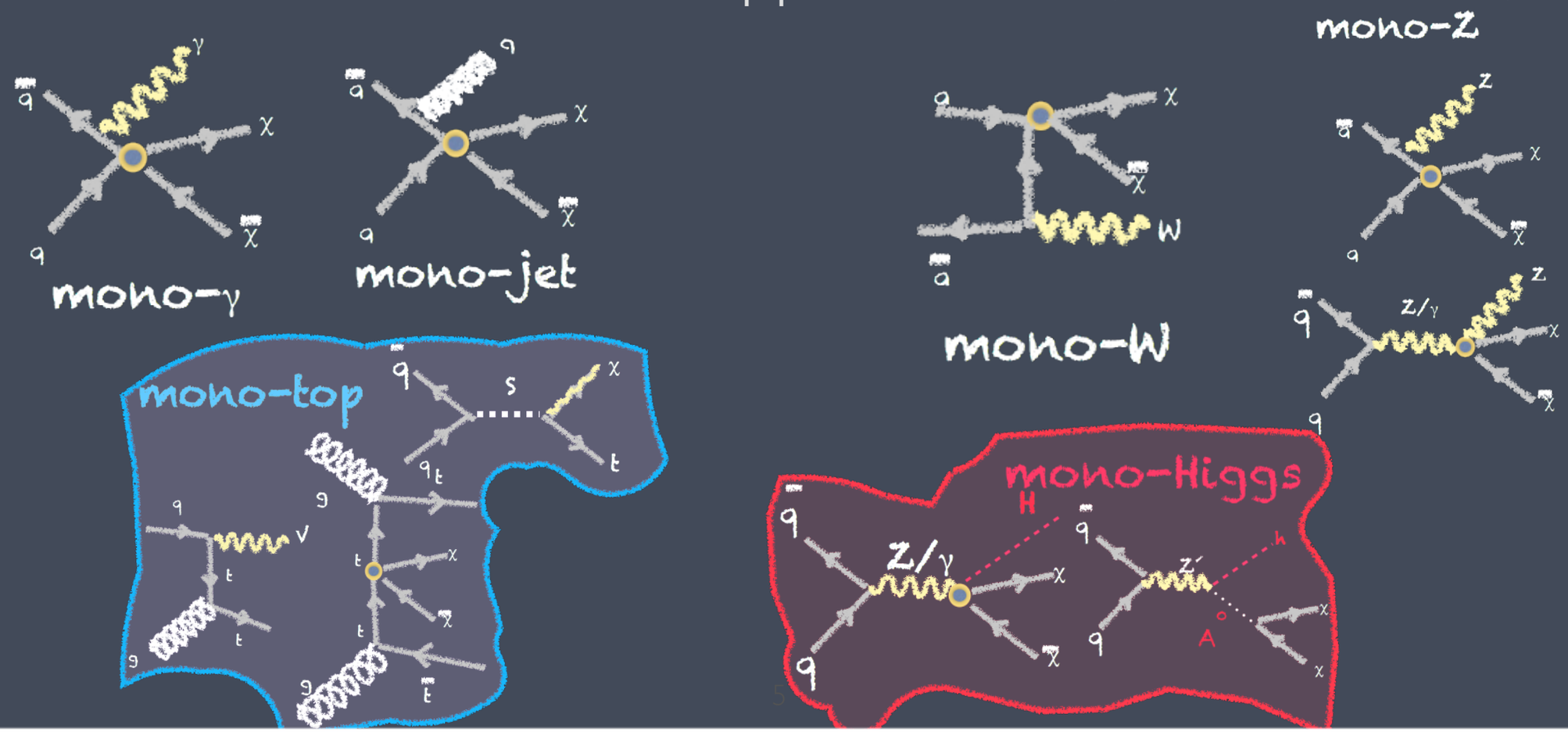
CERN AC - ATLAS V1997





INTRODUCTION

- Look everywhere, wide range and generic signatures
  - Dark Sector: dijets, dileptons, displaced, portals, etc (see M. Vertucci´s talk)
  - **Dark Matter candidates**: pp-> Met + X (**mono-X** search)



SEARCHES AT LHC

		ATLAS			CMS		
		ref.	data	L(fb^{-1})	ref	data	L(fb^{-1})
Mono-γ		arxiv 1704.03848 new	2015+2016	36.1	CMS-PAS-EXO-16-039	2016	12.9
Mono-V		Phys. Lett. B 763 (2016) 251	2015	3.2	CMS-PAS-EXO-16-048 new	2015+2016	35.9
Mono-jet		PRD 94 (2016) 032005	2015	3.2			
mono-Higgs	bb	ATLAS-CONF-2017-028 new	2015+2016	36.1	arXiv 1703.03 new	2015	2.3
	$\gamma\gamma$	ATLAS-CONF-2017-024 new	2015+2016	36.1	CMS-PAS-EXO-17-054	2015+2016	35.9
	ZZ	ATLAS-CONF-2015-059	2015	3.2			
mono-Z		ATLAS-CONF-2016-056	2015+2016	13.3	CMS-PAS-EXO-16-052 new	2016	35.9
mono-top					CMS-PAS-EXO-16-040	2015+2016	12.9
mono-tt	had	ATLAS-CONF-2016-077	2015+2016	13.3	CMS-PAS-EXO-16-005	2015	2.2
	semi-l	ATLAS-CONF-2016-050	2015+2016	13.2			
	lep	ATLAS-CONF-2016-076	2015+2016	13.3	CMS-PAS-EXO-16-028	2015	2.2
mono-bb		ATLAS-CONF-2016-086	2015+2016	13.3	CMS-PAS-B2G-15-007	2015	2.17

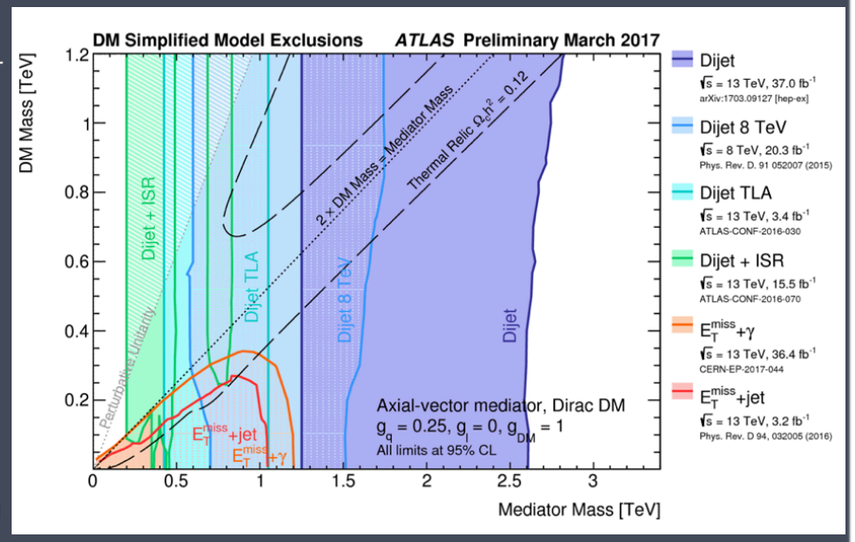
SUMMARY OF DM +X SEARCH

95% CL exclusion region in the mediator- DM mass plane for different MET+X searches for spin-1/0 mediators with couplings

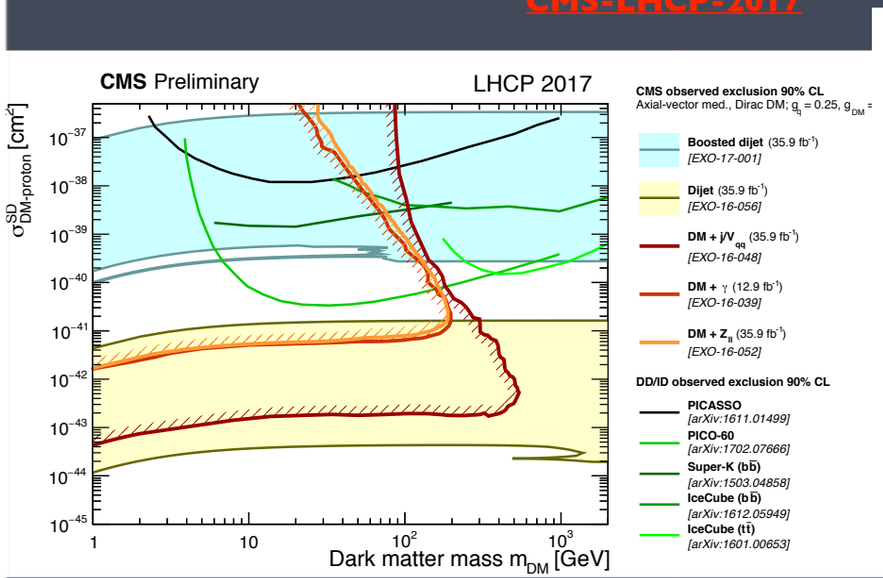
- g_q =0.25,g_l=0,g_{DM} =1 or g_q =0.1,g_l=0.1,g_{DM} =1

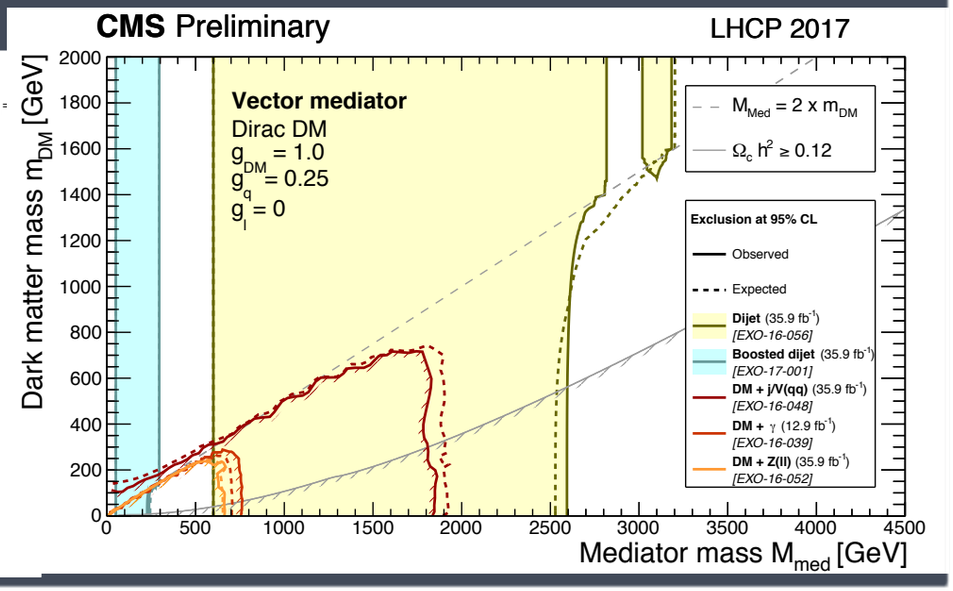
The mono-jet has better sensitivity with full 2016+2015 lumi.
Recast of MET+X analysis to set DM-nucleon limits:

- SD the strongest
- SI the strongest below 5.5 GeV
- this is only valid for the coupling and models chosen



CMS-LHCP-2017





the comparison with direct searches is model dependent —> important lesson: we need to pursue direct searches for low mass DM anyway!

Low Mass Dark Sector Searches at ATLAS and at CMS

Monica Verducci

INFN and University of Roma Tre

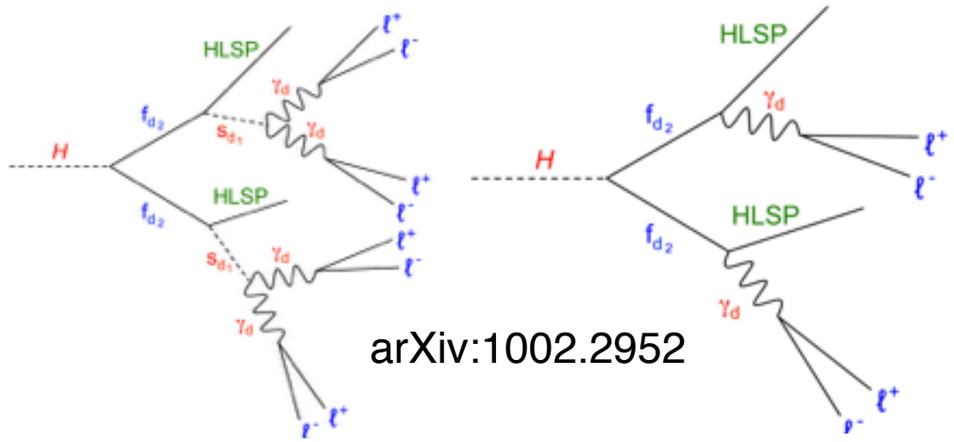
ATLAS-CONF-2016-042

Dark Photons in Lepton Jets (LJ)

Low-mass dark photons can be produced via cascade decays of heavier states

Benchmark models predicting Higgs boson or heavy scalar particle decays to neutral long-lived particles (dark photons $\gamma_d\gamma_d$ of 0.4 GeV Mass each), which in turn produce:

- **collimated jets of light leptons and mesons, so-called "lepton-jets"**



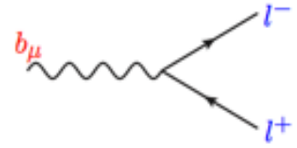
arXiv:1002.2952

The Low-mass of the Dark Photon produces:

—> large boost

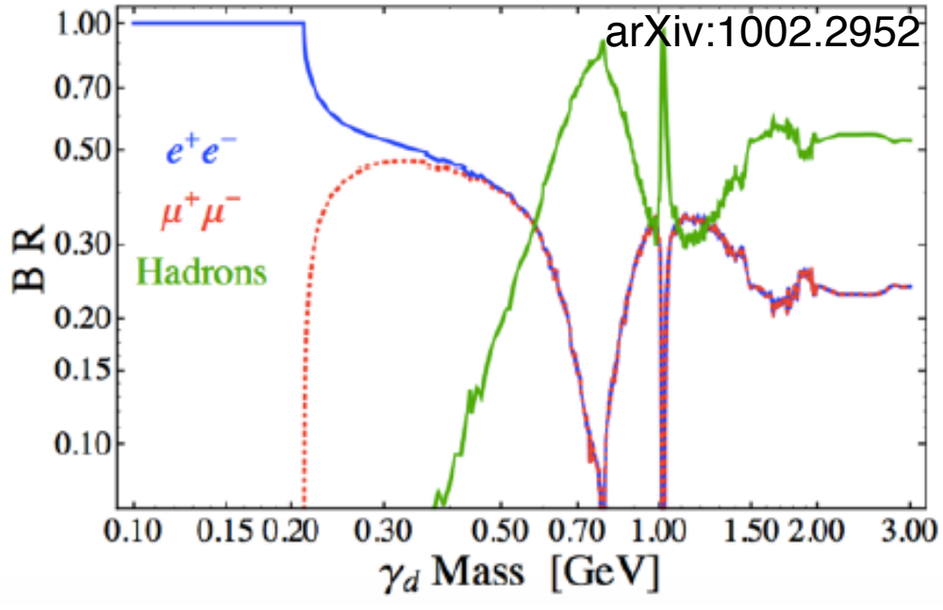
—> collimated decay products

$$\mathcal{L} \supset \frac{\epsilon}{2} F^{\mu\nu} b_{\mu\nu} + m^2_{\gamma_d} b^2$$



Dark photon lifetime depends on the size of kinetic mixing ε: small ε → displaced decays

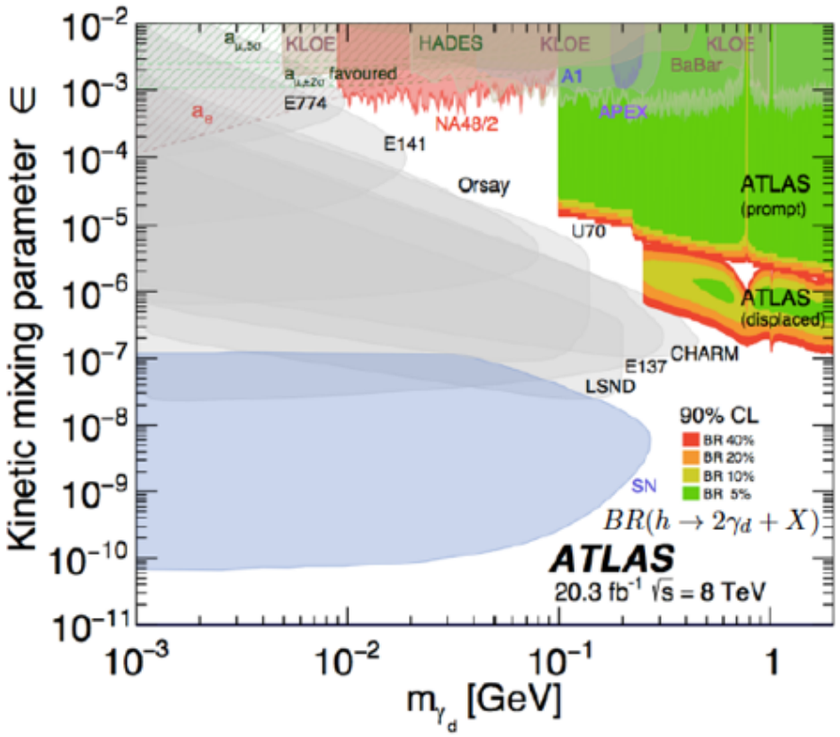
Leptonic decays prominent over wide (low) mass range. The dark photons and two LJs are expected to be produced back-to-back in the azimuthal plane.



ATLAS-CONF-2016-042

Dark Matter Interpretation

Run 1: JHEP 11 (2014) 088
JHEP 1602 (2016) 062



$$\mathcal{L} \supset \frac{\epsilon}{2} F^{\mu\nu} b_{\mu\nu} + m_{\gamma_d}^2 b^2$$

Key variables

Determine decay composition and lifetime

$$(\epsilon, m_{\gamma_d})$$

$$\Gamma = \frac{1}{3}\alpha\,\epsilon^2\, m_{\gamma_d} \sqrt{1 - \frac{4m_l^2}{m_{\gamma_d}^2}} \left(1 + \frac{2m_l^2}{m_{\gamma_d}}\right)$$

does it mean exclusion region? NB: here we add the additional assumptions on H decays

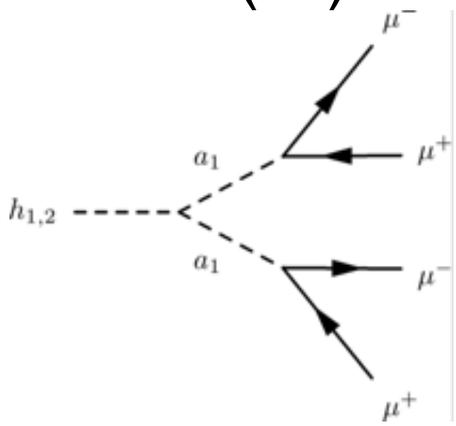
CMS-PAS-HIG-16-035

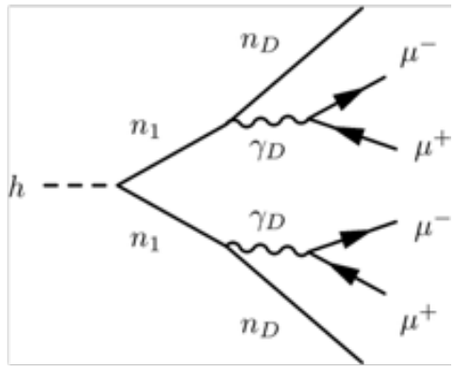
Light Bosons Decaying into Muon Pairs

- **This analysis searches for new light bosons with a mass in the range 0.25-8.5 GeV/c^2 decaying into muon pairs.**

- The results are interpreted in the context of two benchmark models, namely, the next-to-minimal supersymmetric standard model, and dark SUSY models including those predicting a non-negligible light boson lifetime.

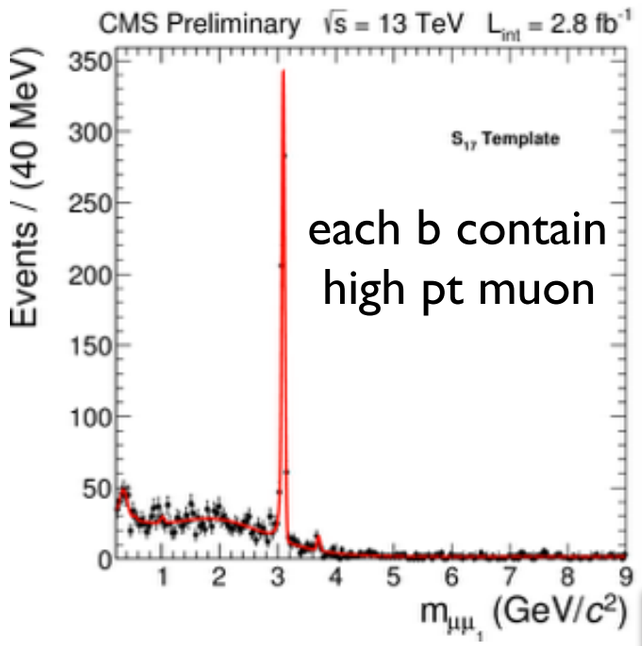
H ->aa(ss)-> 4SM (or 2SM+X)

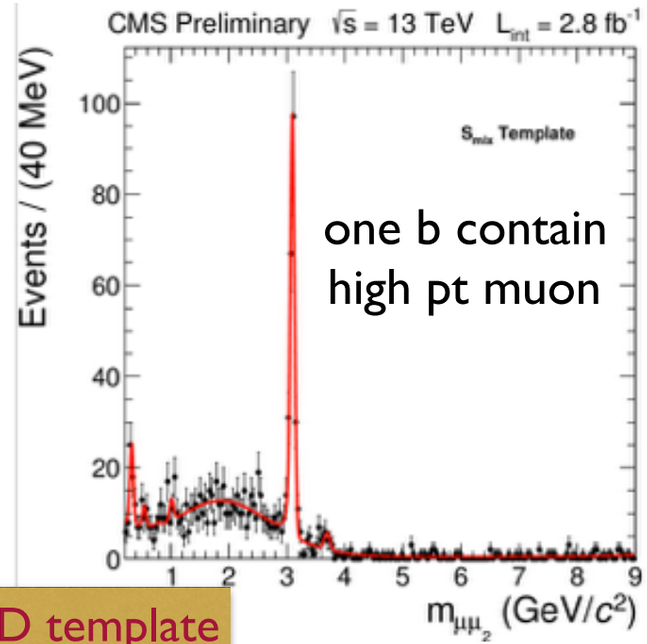




Event Identification:

main background is bb events. Background is modelled as a two dimensional (2D) template bb (m1, m2) in the plane of the invariant masses of the two di-muons in the selected events, where (1) always refers to the dimuon containing a muon with pT > 17 GeV/c and |η| < 0.9.



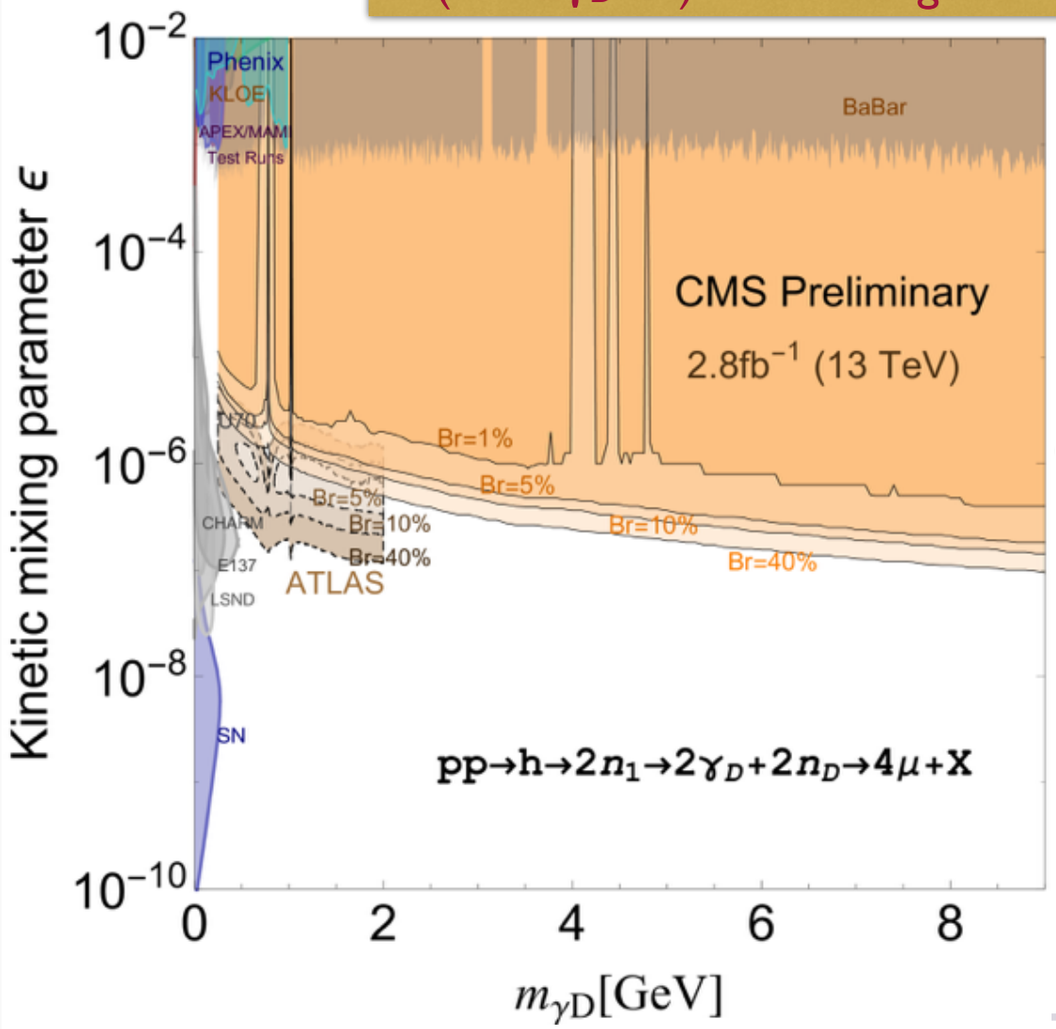


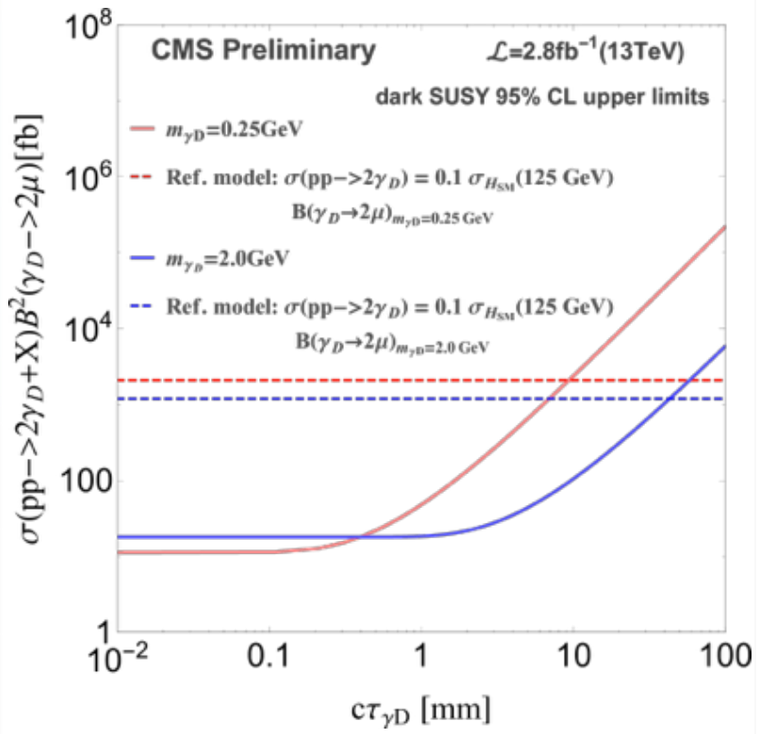
1D template

CMS-PAS-HIG-16-035

Multi-Muons Limits

BR(H→2γ$_D$+X) in the range 1-40%.

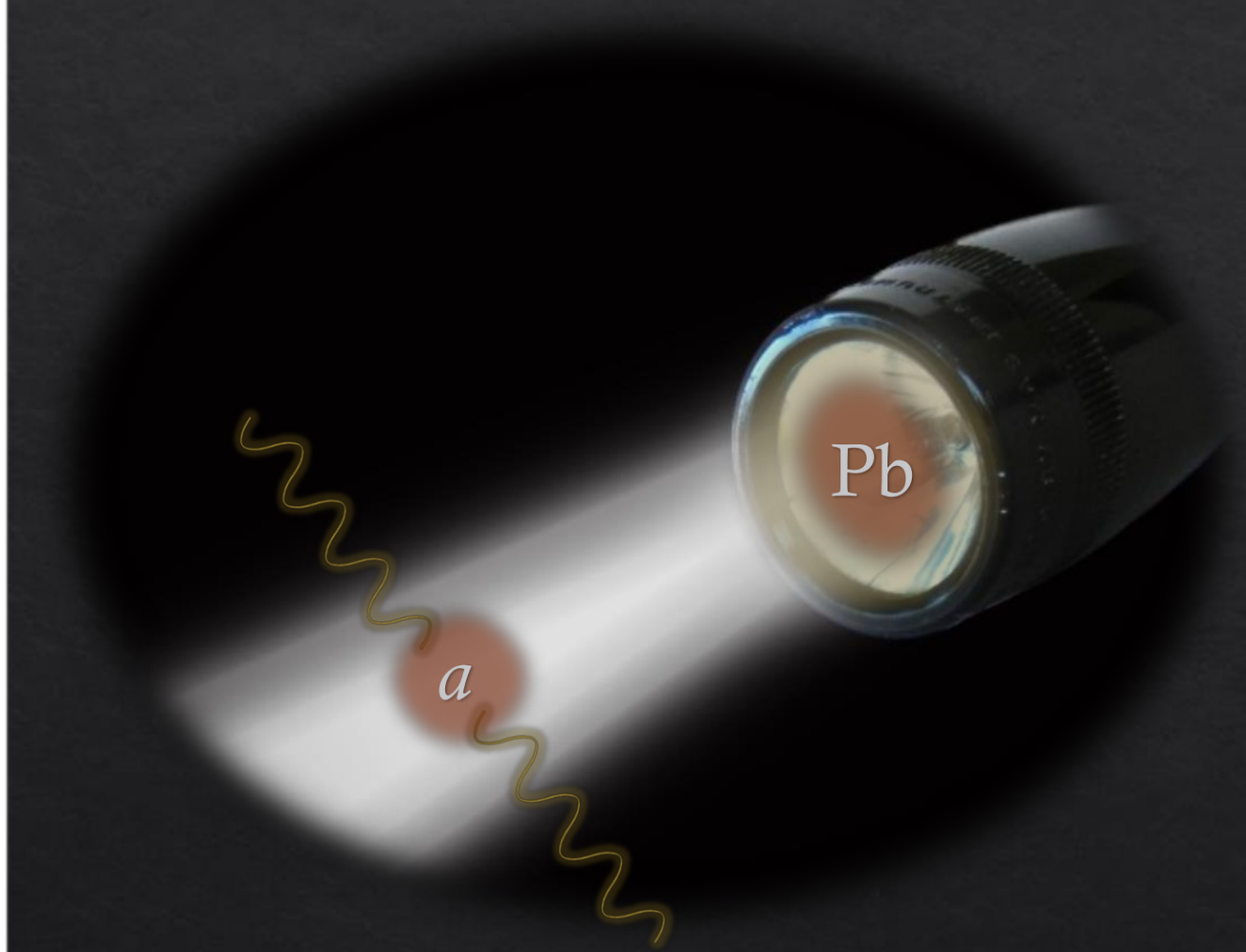




LDMA 2017 Monica Verducci 11

does it mean exclusion region? model dependent but shows that it would be in a region that is not already excluded

Light Dark Matter 2017



Searching for Axion-like particles with heavy-ions

Hou Keong (Tim) Lou,

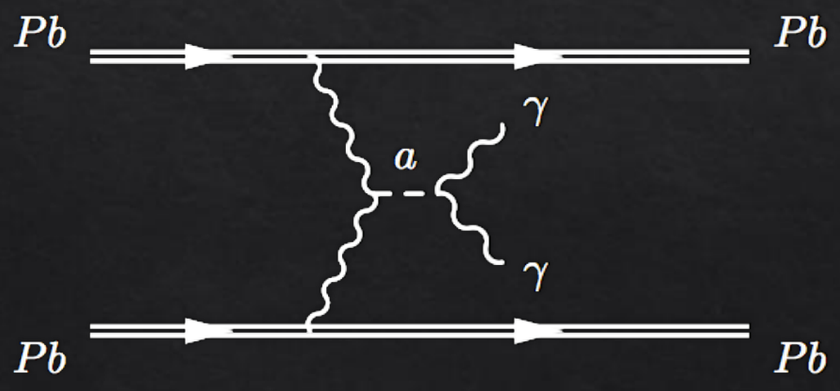
Simon Knapen, Tongyan Lin and Tom Melia

PhysRevLett.118.171801

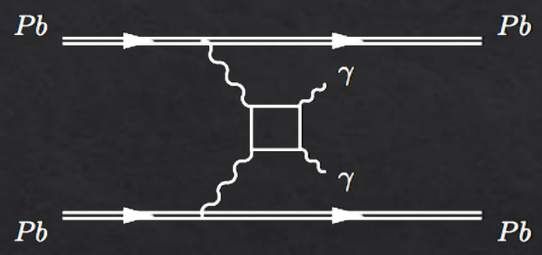
*Disclaimer: Not Dark Matter! Sorry!

Heavy-ion as a γ source

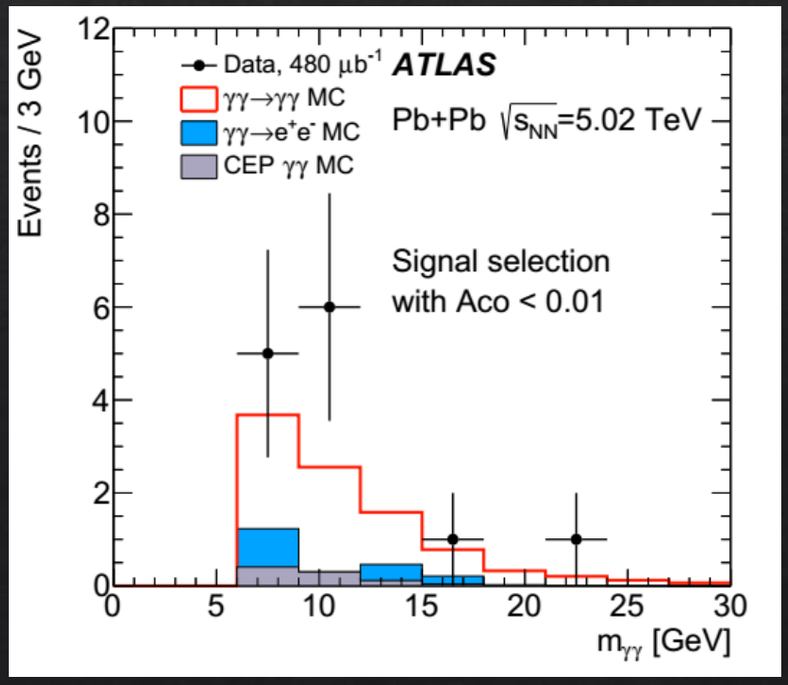
- Old idea A. Balantekin et.al. 1985, M. Greiner et.al. 1993…
- Enhanced production at Heavy-ion collisions (~GeV)
- QED is strongly coupled!
- $Z^4 \sim 50 \times 10^6$ enhancement



- Can observe LBL scattering!



D. d'Enterria et.al. 1305.7142



ATLAS 1702.01625

Signal & Background

Signal

- Intact Pb-Pb ions, no tracks, very little calorimeter activity
- Veto on tracks
- Two ~GeV back to back photons (cut on $\Delta\phi_{\gamma\gamma}$)
  - Otherwise ions will likely breakup
- Intact ions may be tagged
- Prominent mass peak!

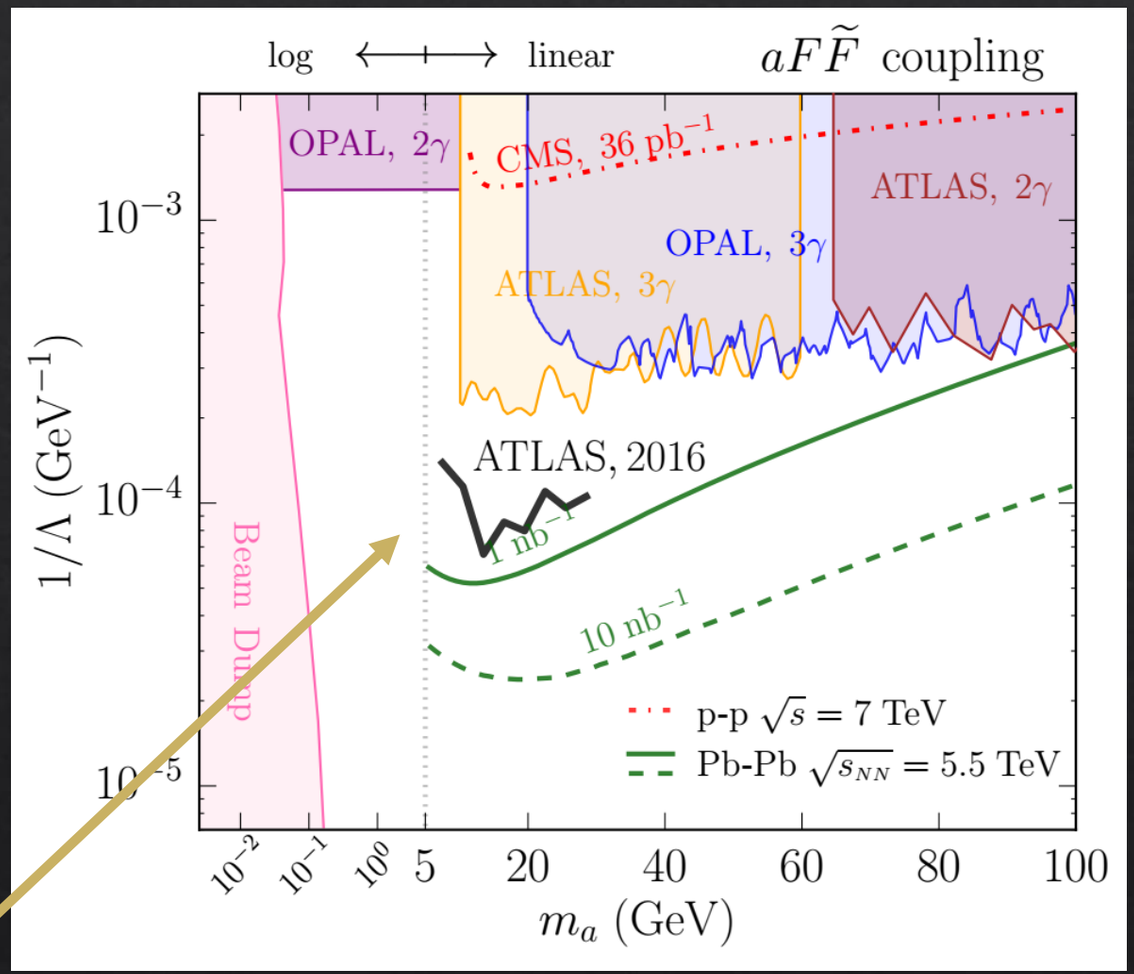
Background

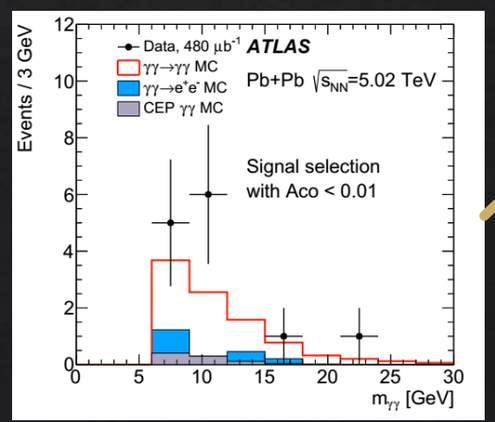
- LBL scattering
  - Irreducible
  - Has been measured! Can be calculated reliably
- Electrons fakes/brem or CEP (photons from QCD)
  - Photons not back to back
- All background smoothly falling in $m_{\gamma\gamma}$!

11

ATLAS recast

- $\sqrt{s_{NN}} = 5.02$ TeV
- $\int Ldt = 480\ \mu b^{-1}$
- Current best limit on ALPs with EM coupling!
- First time heavy-ion yields best limit on BSM physics





Light Dark Matter 2017

24-28 May 2017 **La Biodola** - Isola d'Elba

SHiP Dark Sector searches

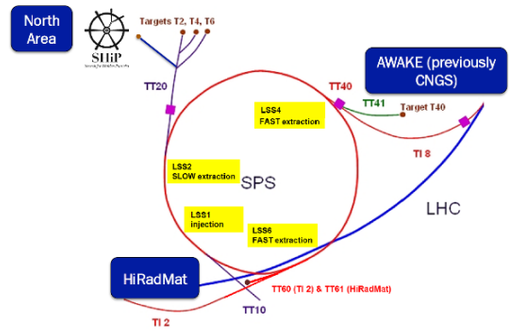
Laura Fabbri
on behalf of the SHiP Collaboration

SHiP
Search for Hidden Particles

The SHiP Experiment

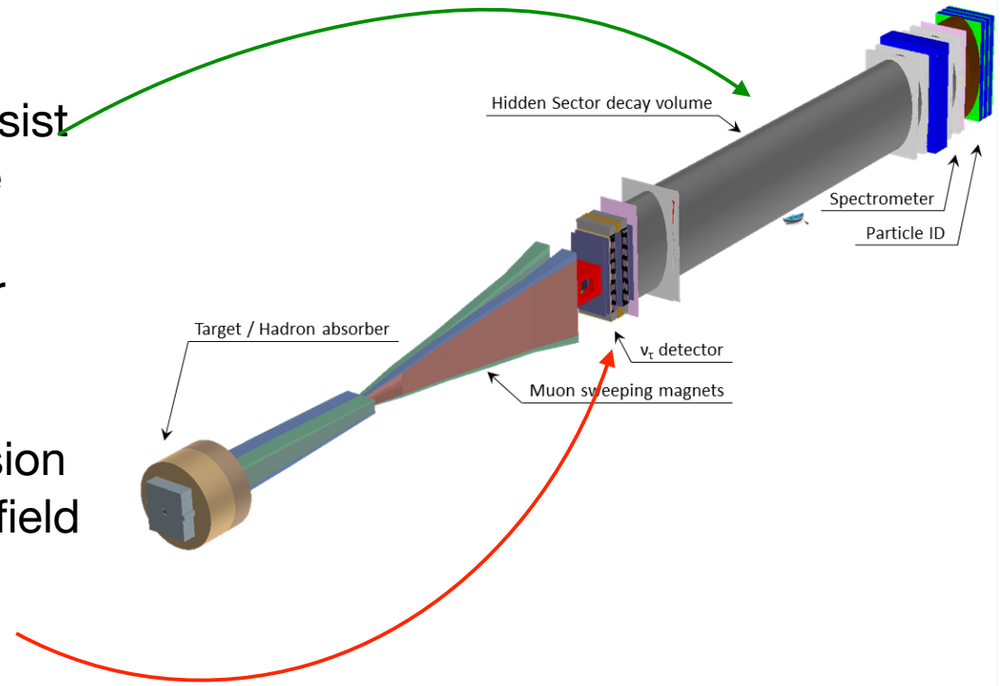
- The SHiP (**S**earch for **Hi**dden **P**articles) experiment is a proposed fixed target experiment at the CERN SPS

5×10^{13} protons per spill @ 400 GeV
→ 2×10^{20} collisions in 5 years



- **Hidden particle detector** will consist of a long evacuated decay volume with a magnetic spectrometer, calorimeters, and a muon detector located on the far end

- **Neutrino detector** consists emulsion target with tracking in a magnetic field followed by a muon spectrometer
$N\nu_\tau \sim 10^4$

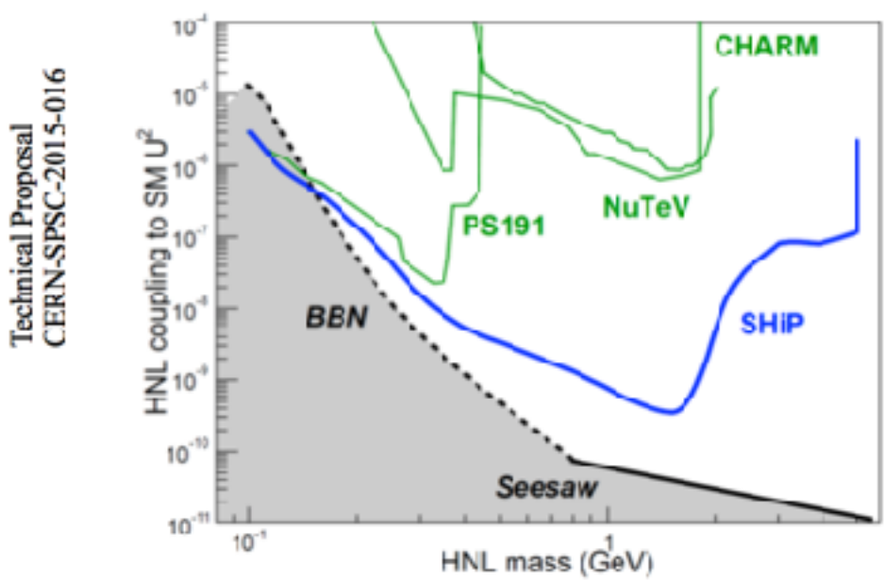


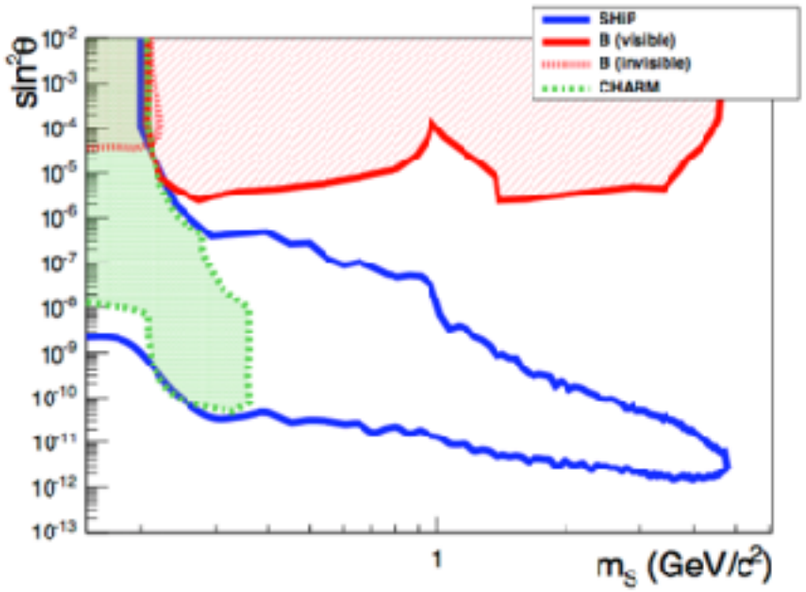
this experiment is designed to detect dark sector particles (it is not the only case as we learned also in this conference)

SHiP Experimental prospects

- **Primary Physics goals**

1. Exploring hidden portals and extensions of the SM:
   - searches for Dark Matter, Sterile Neutrinos and Dark Photons => long-lived and very weakly interacting particles through their decays to SM particles

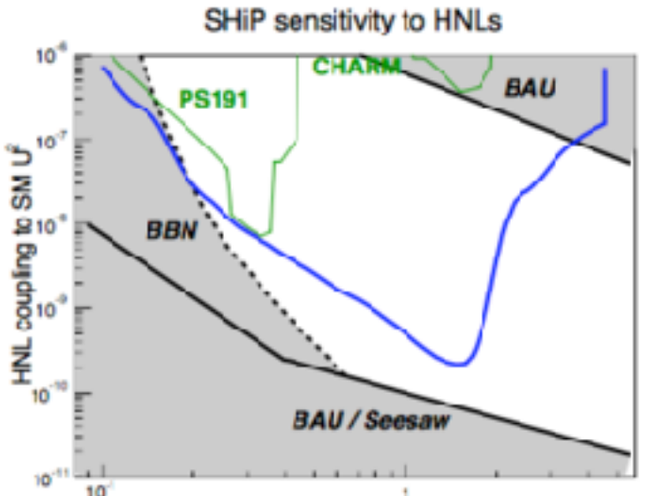




2. Explore the physics of τ-neutrino:
   - first observation of $\bar{\nu}_\tau$
   - independent measurement of σ_{ν_τ} and $\sigma_{\bar{\nu}_\tau}$

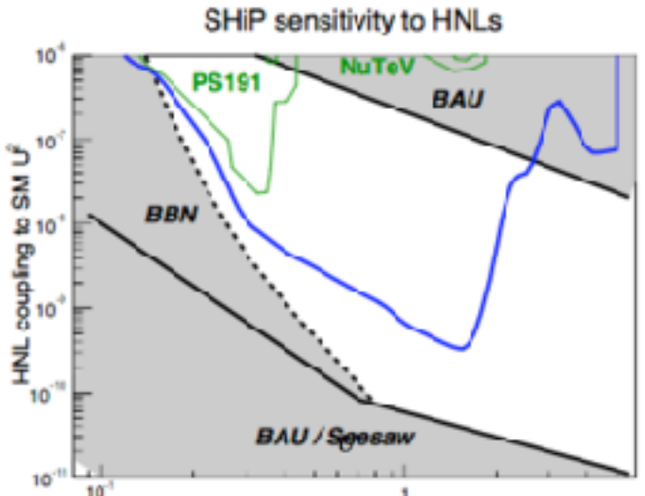
Sensitivity to Hidden Sector

INVERTED HIERARCHY SCENARIO



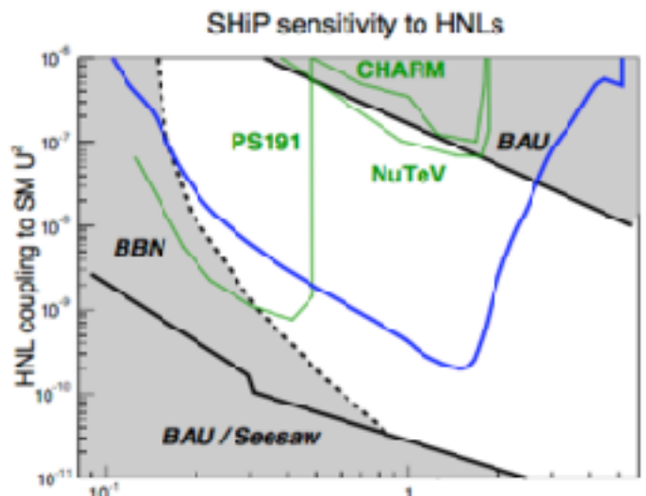
$U_e^2 : U_\mu^2 : U_\tau^2 = 52 : 1 : 1$

BENCHMARK SCENARIO

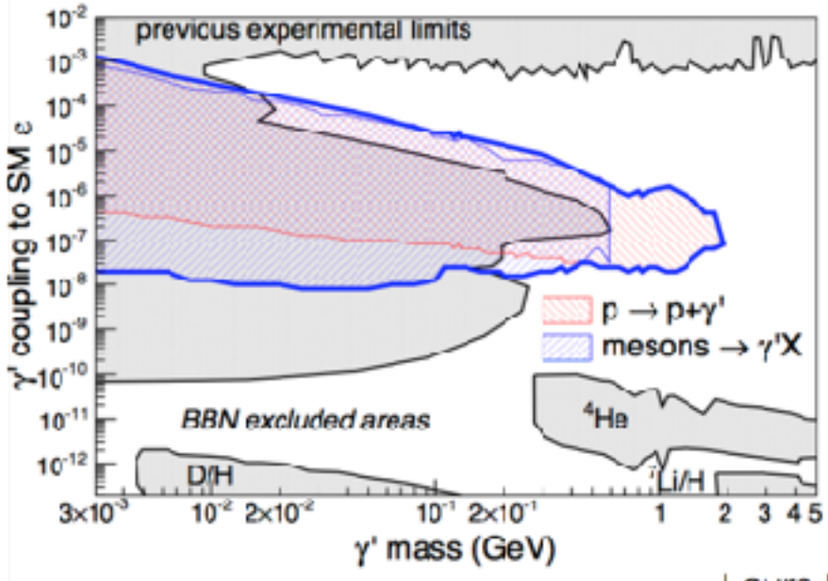


$U_e^2 : U_\mu^2 : U_\tau^2 = 1 : 16 : 3.8$

SCENARIO SENSITIVE TO BARYOGENESIS



$U_e^2 : U_\mu^2 : U_\tau^2 = 48 : 1 : 1$



Sensitivity to dark photon as a function of the mixing with the SM photon and the dark photon mass

Technical Proposal CERN-SPSC-2015-016

Dark Matter Search at Belle/Belle2

Enrico Graziani

INFN – Roma 3

on behalf of the Belle II Collaboration

OUTLINE OF THE TALK

- **Belle II and SuperKEKB**
- **Search of the dark photon invisible decay in Phase 2**
- **Alternative LDMA searches**
- **Search of ALP**
- **Summary**

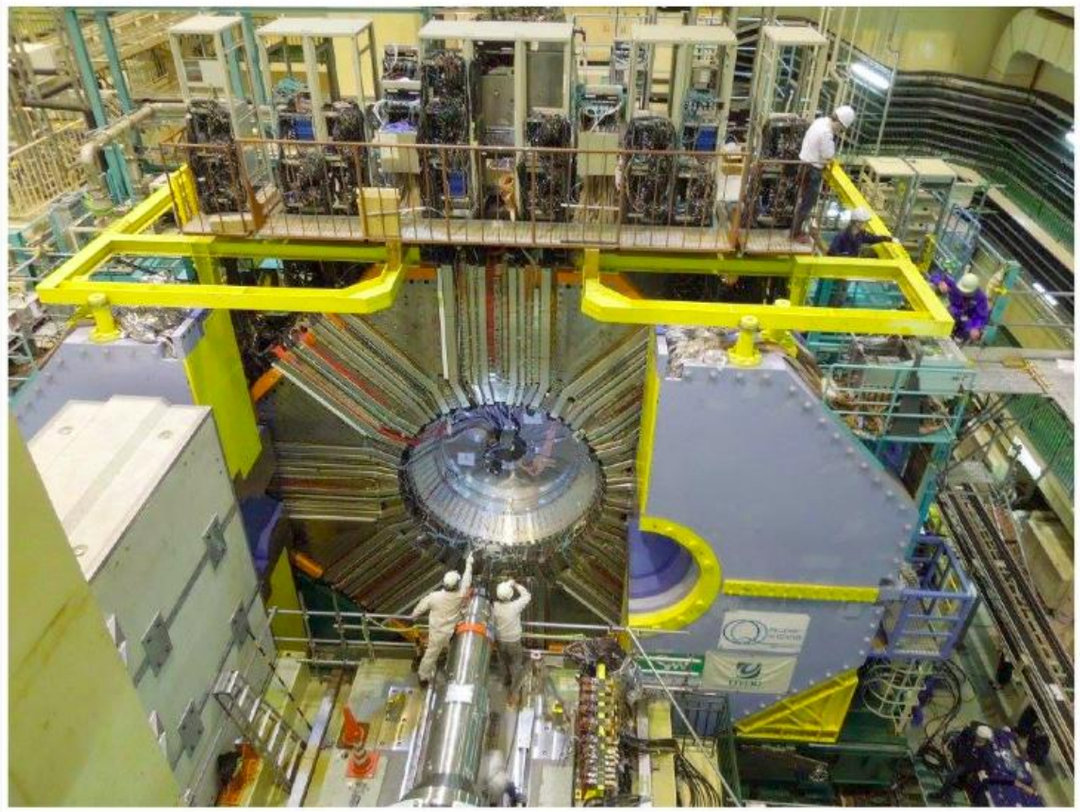
Light Dark Matter 2017

La Biodola – Isola d'Elba, 24-28 May 2017

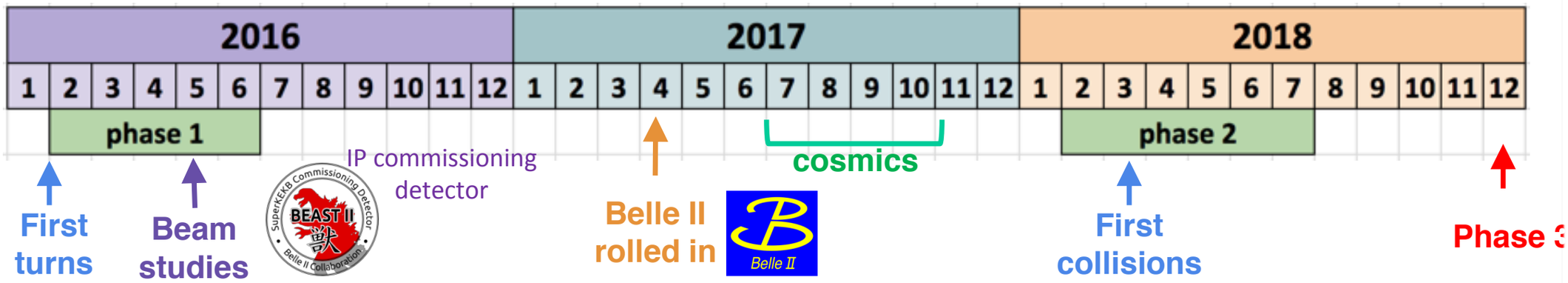
Breaking news

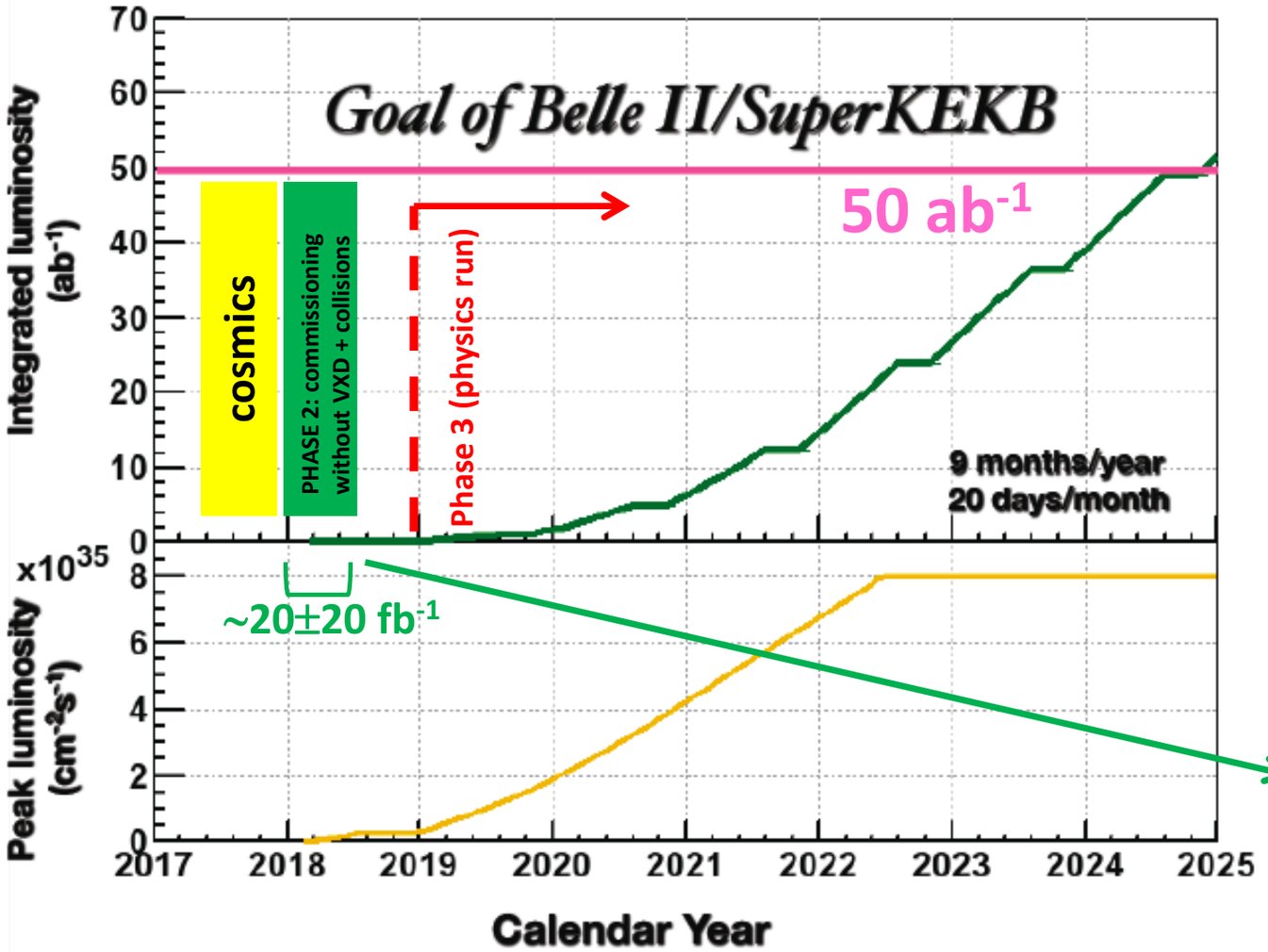
Belle II succesfully rolled in on April 11th

perfectly in time with plans (and sakura)



Belle II + SuperKEKB schedule





- **phase-1 (done)**
  - Beam commissioning
- **phase-2 (Jan. 2018)**
  - Beam BG measurement
  - Belle II detector with partial vertex sensors
- **phase-3 (Dec. 2018)**
  - Physics running
  - Full Belle II detector

20±20 fb^{-1} for physics analysis without VXD

Single photon trigger(s)

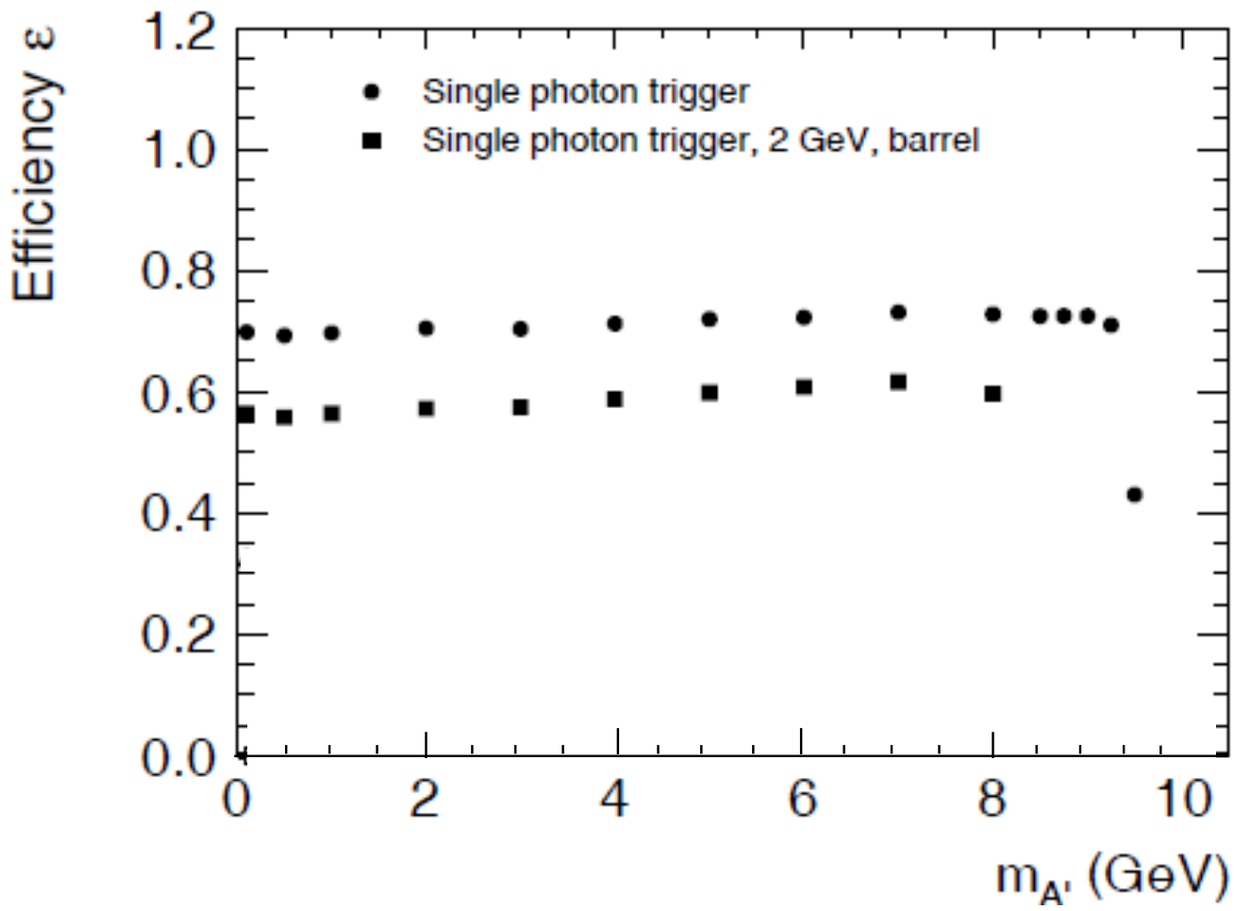
Two level 1 single photon triggers, both excluding the innermost ECL crystal towers

- $E_{\gamma 1}^{CMS} > 1$ GeV, with the second cluster energy $E_{\gamma 2}^{CMS} < 0.2$ GeV → ~4 nb
- $E_{\gamma 1}^{CMS} > 2$ GeV ∩ Bhabha veto ∩ $e^+e^- \to \gamma\gamma$ veto → ~2.5 nb

↓

mostly $e^+e^- \to e^+e^-\gamma$

to be compared with ~ 10 nb hadronic+leptonic cross section
⇒ ~10 kHz at 8×10^{35} $cm^{-2}s^{-1}$

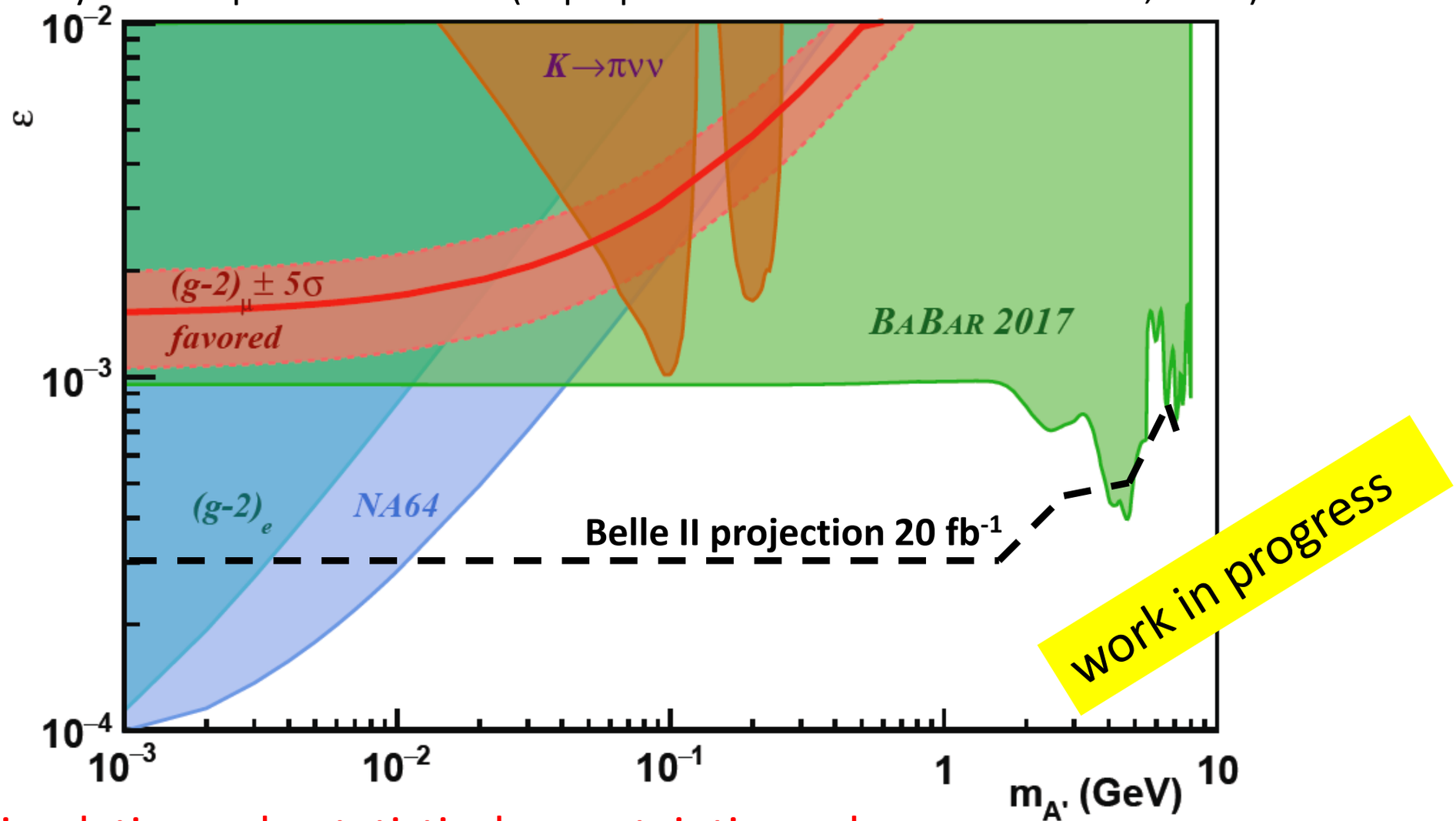


Trigger efficiency is expected to be high and mostly limited by acceptance (up to 95% within angular acceptance)

Very preliminary simulation studies

Belle II projection (simulation)

B2TiP: The Physics Prospects for Belle II (in preparation for submission to PTEP, 2017)



Simulation only, statistical uncertainties only

It would be tempting to extrapolate beyond Phase 2 (up to 50 ab^{-1}), but the sustainability of the single photon trigger rate at higher luminosities must be checked

very exciting times ahead of us!