



# XXXII INTERNATIONAL SEMINAR of NUCLEAR and SUBNUCLEAR PHYSICS "Francesco Romano"

Search for an *invisible*  $Z'$  in  $\mu^+ \mu^-$  plus  
missing energy final states at Belle II.

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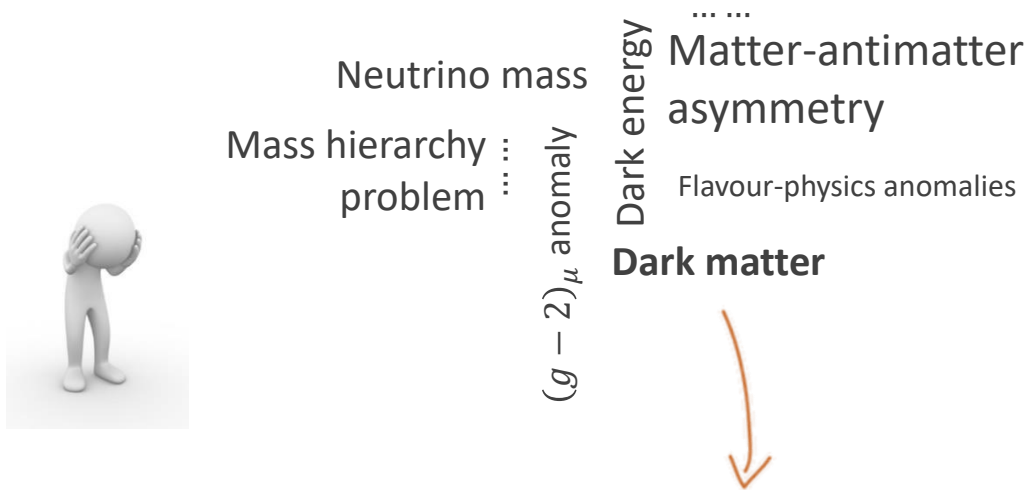


# Dark Sector searches

## Motivations & Models

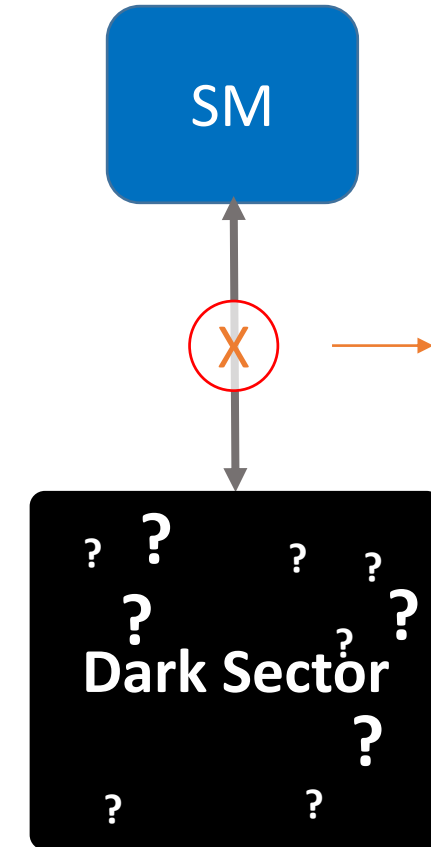
The Standard Model of particle physics may be not the ultimate theory

- Several missing pieces and tensions:



No evidences from DM direct detection experiments or LHC suggest a **possible MeV - GeV theoretical scenarios:**

- Light-DM feebly coupled to SM through new mediators.
- Dark Sector: light-DM and new dark forces;



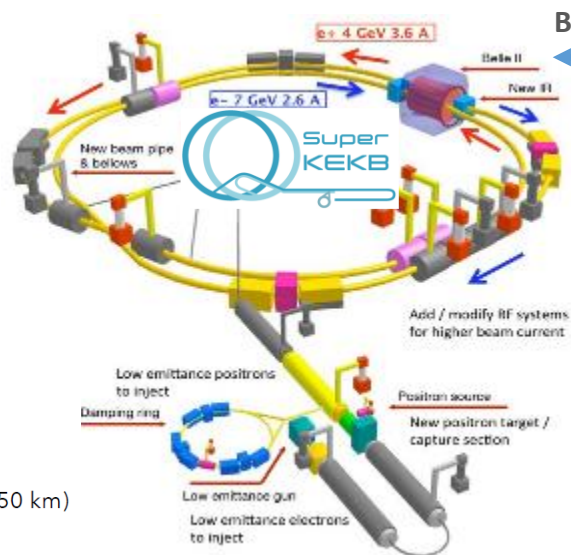
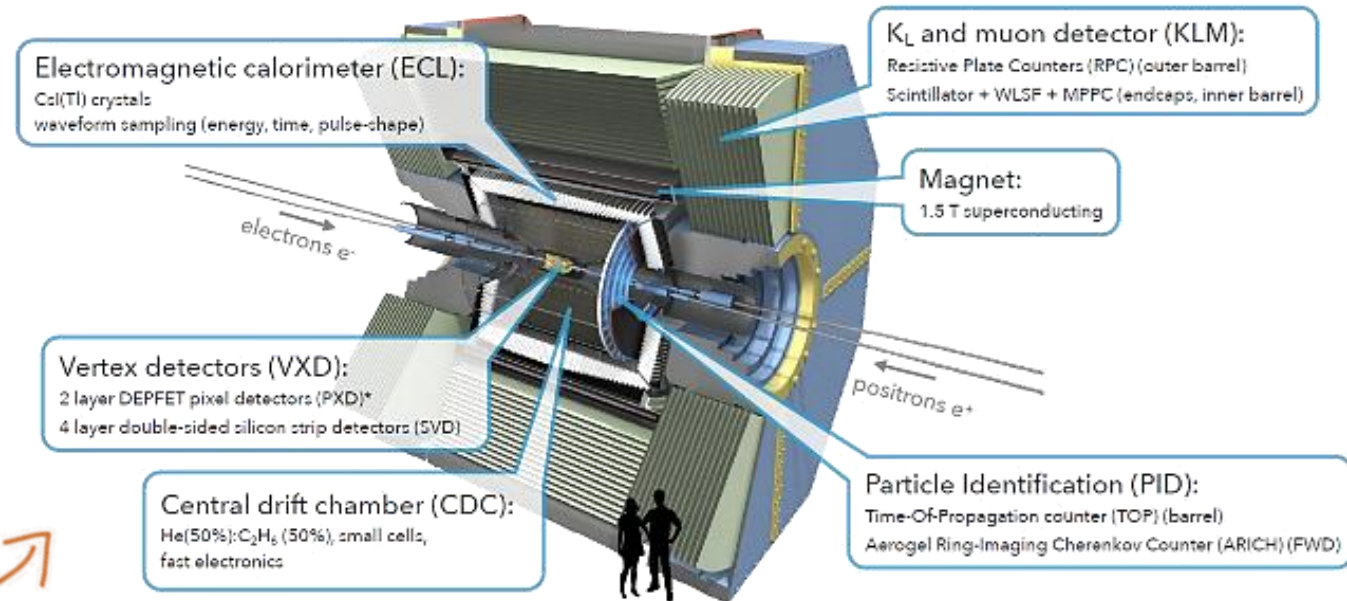
e.g. dark photon, Z', dark higgs, etc.

**Low energy  $e^+e^-$  colliders: perfect places to explore Dark Sector Physics in the MeV - GeV range.**

# The Belle II Experiment

## A look at the detector

- Located at IP of  $e^+e^-$  collider SuperKEKB in Tsukuba, (JP);
- Operated at  $\sqrt{s} = 10.58 \text{ GeV}$  ( $= M_{Y(4s)}$ );
- Design luminosity:  $L = 6.5 \cdot 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ ,
- Rich physics program: B, D and tau physics and **low mass dark sector**,



## Data taking time schedule

### 2018

#### Phase 2 (pilot run)

- First physics data ( $500 \text{ pb}^{-1}$ ).
- Incomplete detector (1/8 VXD)
- Commissioning data.


### 2019 to date

#### Phase 3

- Belle II routinely integrates more than  $1 \text{ fb}^{-1}/\text{day}$ .
- Up to now  $\sim 150 \text{ fb}^{-1}$  collected

### ~2030

#### Goal

- Integrate up to  $50 \text{ ab}^{-1}$  
- X50 dataset of its predecessor (Belle)

# Z' to invisible

## Overview

A new light gauge boson  $Z'$  coupling only to the 2<sup>nd</sup> and 3<sup>rd</sup> generation of leptons.

It gauge the  $L_\mu - L_\tau$  accidental symmetry of the SM:  $\mathcal{L} = \sum_{\mu, \tau, \nu_{\mu, L}, \nu_{\tau, L}} \theta g' \bar{\ell} \gamma^\mu Z'_\mu \ell$

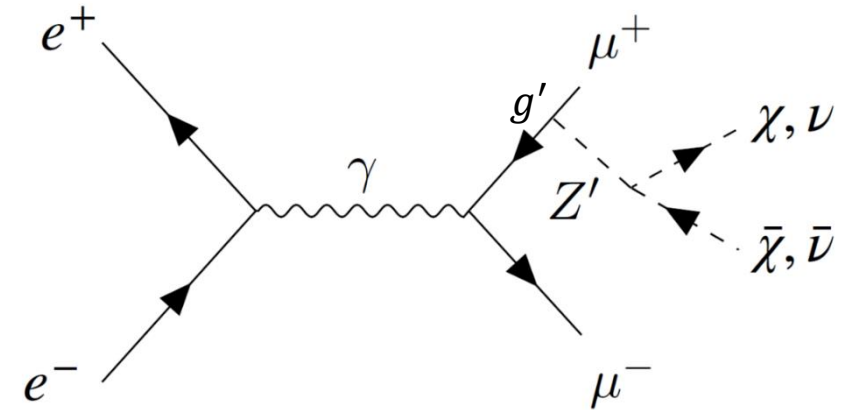
This model may explain [1,2]:

- DM puzzle;
- $(g-2)_\mu$  anomaly;
- B-physics anomalies;

## Several experimental signatures:

- Visible decay into a muon/tau pair (constrained by BaBar and CMS [3,4]);
- @ Belle II looking for the invisible decay: SM neutrinos or DM if kinematically accessible (never explored before).

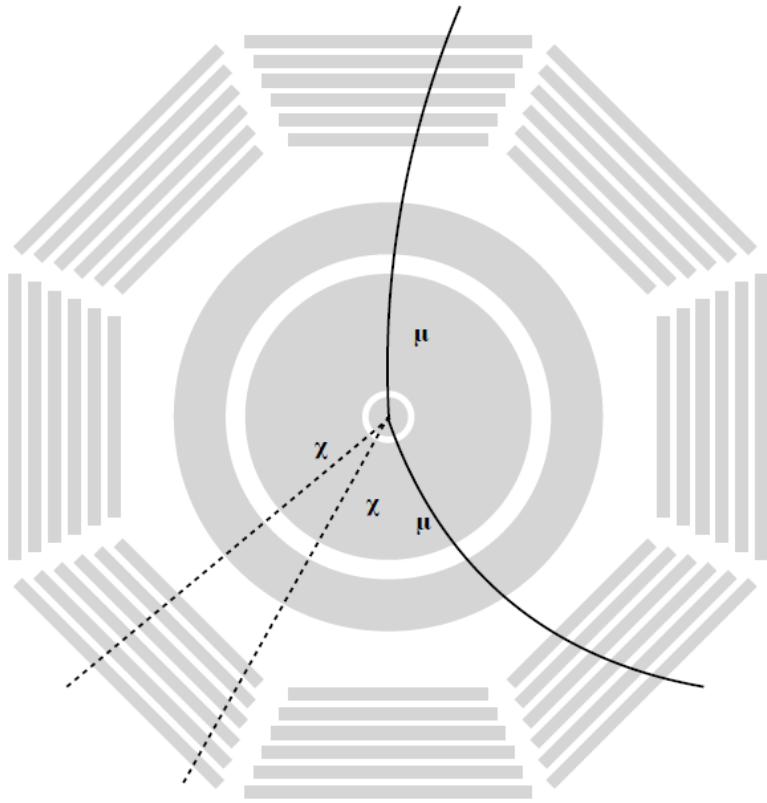
- [1] [Shuve et al. \(2014\)](#)
- [2] [Altmannshofer et al. \(2016\)](#)
- [3] [Lees et al. \(2016\)](#)
- [4] [CMS collaboration \(2019\)](#)



$$e^+e^- \rightarrow \mu^+\mu^- Z' \rightarrow \text{invisible}$$

# Z' to invisible

## Experimental signature



**Just two muons plus missing energy final state.**

- Looking for a peak in the mass distribution of the recoiling system against  $\mu\mu$  pair:

$$M_{rec}^2 = s + m_{\mu\mu}^2 - 2E_{\mu\mu}^* \sqrt{s}$$

- Background sources: everything with 2 particles identified as muons and missing momentum. Mainly from:

$$\mu^+\mu^-(\gamma); \quad \tau^+\tau^-(\gamma); \quad \mu^+\mu^-e^+e^-;$$

- Event selection in short:
  - Two muon tracks;
  - Almost nothing in the rest of the event;
  - tau suppression cut on muon and recoil momenta;

# $Z'$ to invisible

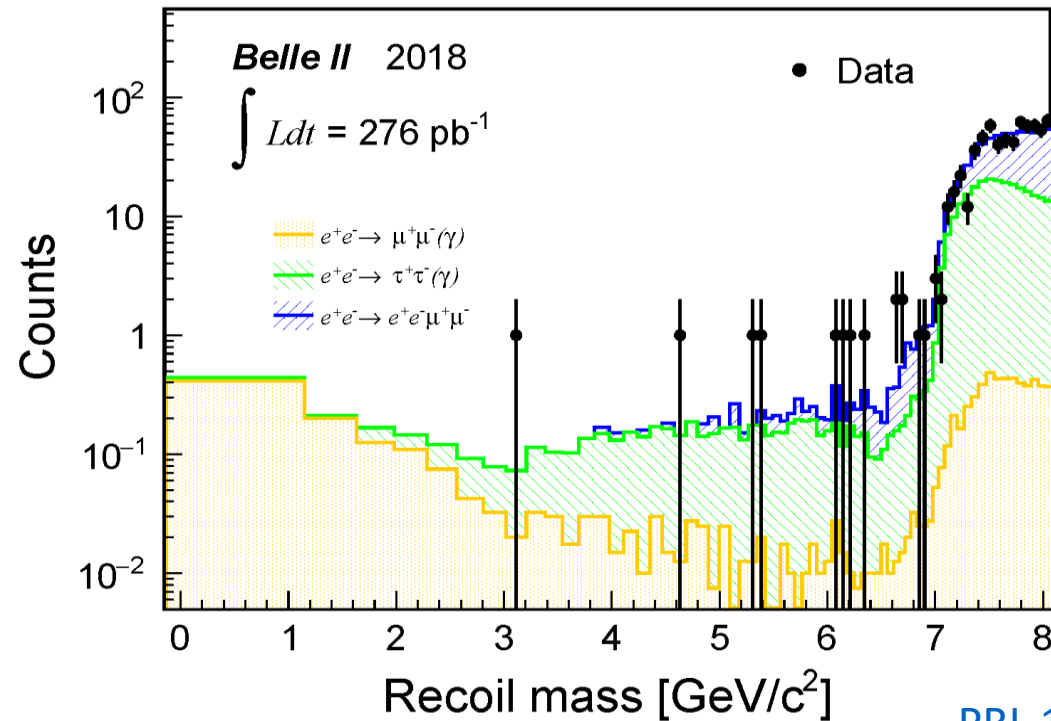
## Results

Measurement performed with 2018 pilot run data (276 pb<sup>-1</sup>).

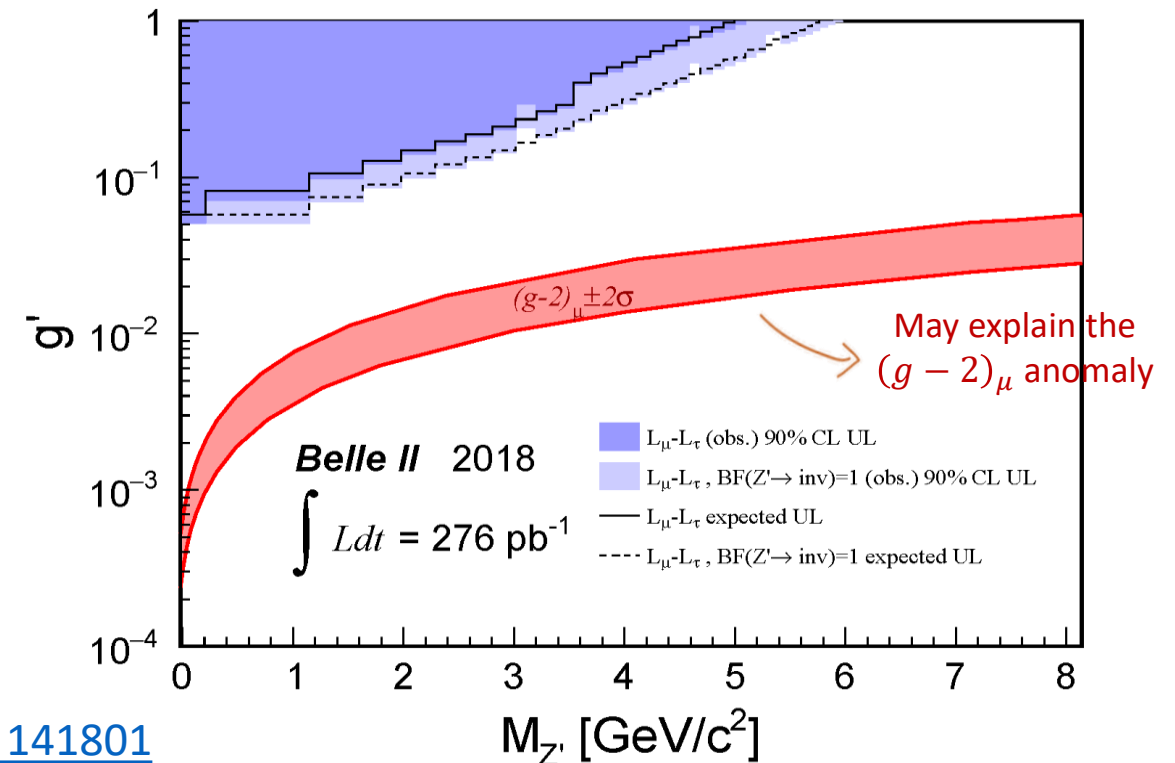
- No anomalies observed in data. U.L. on the coupling constant  $g'$ .



First results ever for the  $Z'$  to invisible decay  
First physics paper by Belle II



[PRL 124 \(2020\) 141801](#)

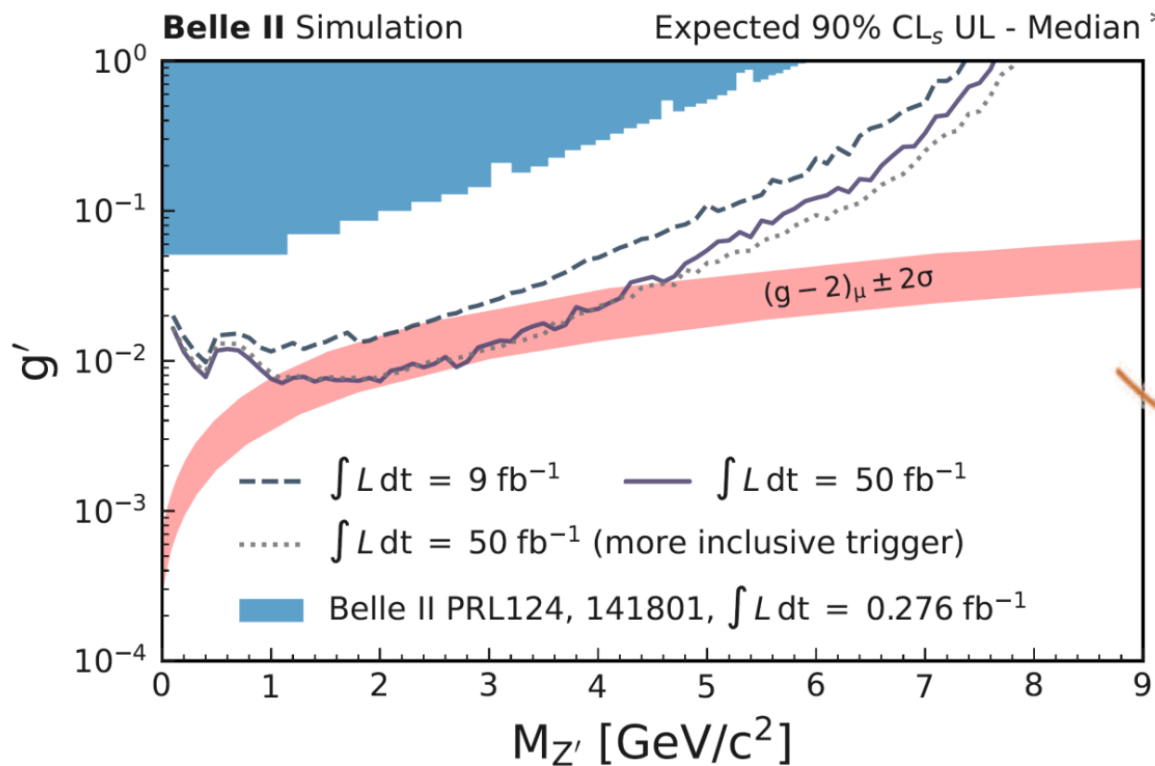




# Z' to invisible

## Short term projection

Several improvements foreseen in a short term.

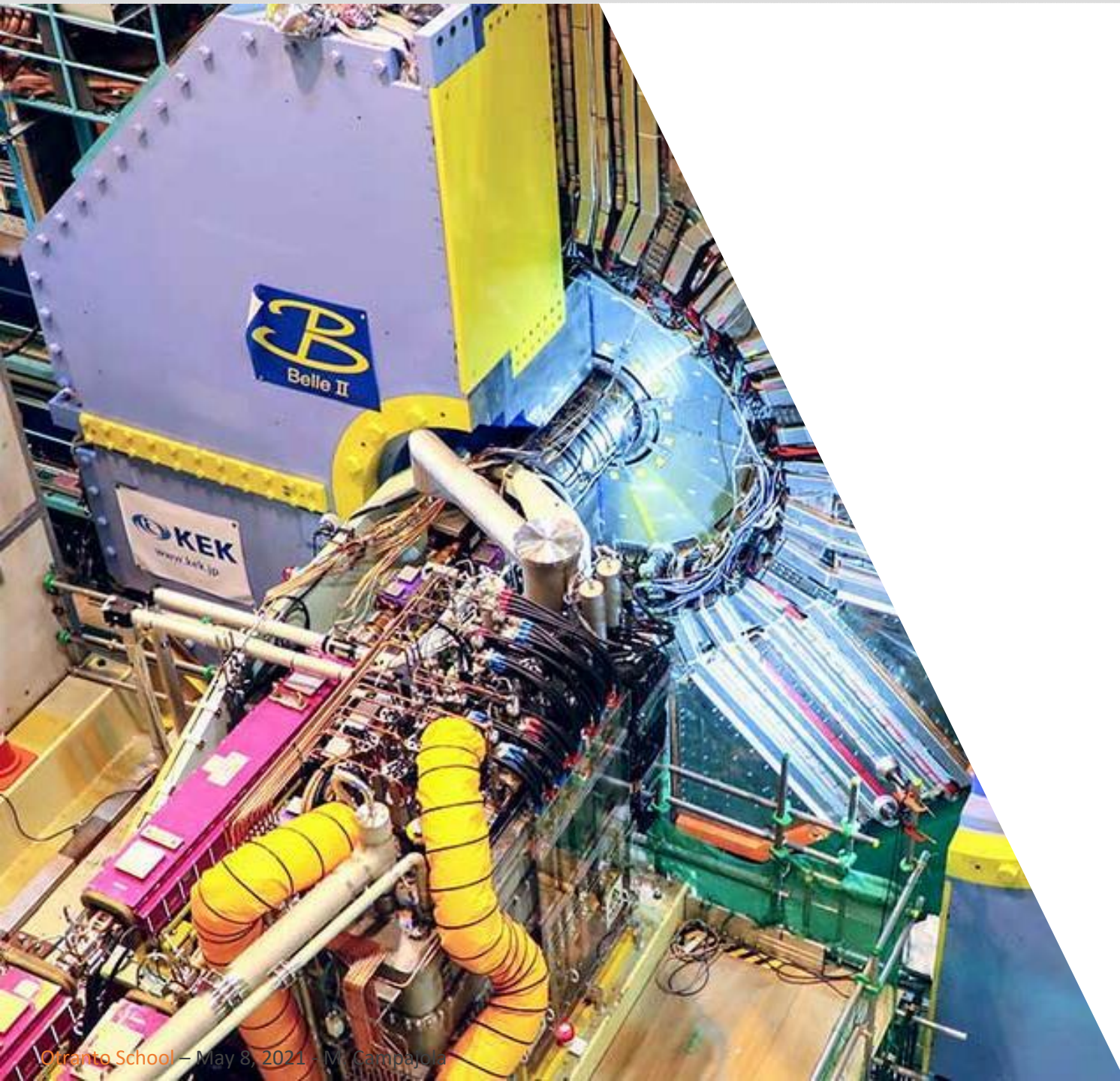


\* Preliminary (conservative) systematics estimate

- Much higher integrated luminosity (already on tape).
- Analysis improvements.
  - KLM  $\mu$ ID
  - MVA selection
- New triggers.

**Starting to probe the  $(g-2)_\mu$  band with 50 fb<sup>-1</sup> !!**

**Stay tuned. This and many other results are coming soon....**



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