

LHCb status report



Nicola Neri
on behalf of the Milano LHCb group

University and INFN Milano

9 July 2021 - Milano

Outline

- ▶ LHCb experiment
 - Physics results
 - LHCb upgrade
 - Requests for 2022

LHCb physics

CKM and CP
violation

$\sin 2\beta$, γ , ϕ_s , $|V_{ub}/V_{cb}|$, CPV in B^0 , B_s^0 , D^0 , b-baryons, ...

Rare decays

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$, $b \rightarrow s \mu^+ \mu^-$, $b \rightarrow s e^+ e^-$,
 $\Sigma^+ \rightarrow p \mu^+ \mu^-$, ...

Spectroscopy

Tetraquarks, Pentaquarks, Ξ_{cc}^{++} ,
 Ω_c^* , Ξ_b^{-*} , ...

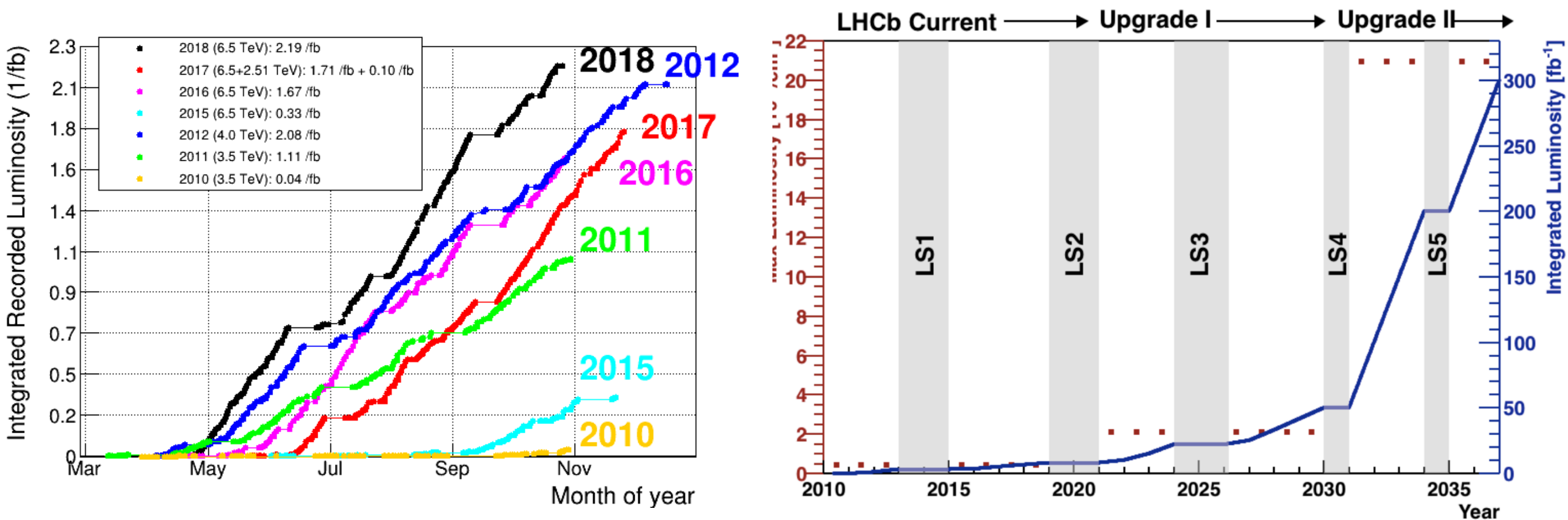
Electroweak
QCD, Exotica

Z^0 , W^+ , top, $H \rightarrow c\bar{c}$, Dark
photons, Long-lived particles, ..

Ion, Fixed-
target

Heavy ions, p-Gas, nuclear
effects, ...

LHCb data sample and plans



- ▶ Collected 9.23 fb⁻¹ (2010-2018). **Major detector upgrade during LS2** (Upgrade I). Aim at 50 fb⁻¹ before 2030
- ▶ First detector improvements in PID, tracking, and ECAL during LS3 (**Upgrade 1b** - 2025)
- ▶ Major detector upgrade during LS4 (**Upgrade II** - 2030). Aim at >300 fb⁻¹ after 2030 (FTDR in preparation)

Selection of recent results

Search for phenomena beyond SM in rare decays

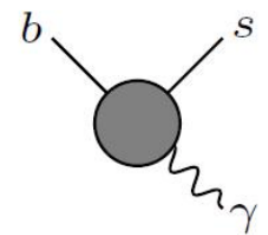
Theoretical framework

Effective hamiltonian for $b \rightarrow s$ transitions

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \left[\underbrace{C_i(\mu) O_i(\mu)}_{\text{left-handed part}} + \underbrace{C'_i(\mu) O'_i(\mu)}_{\text{right-handed part}} \right]$$

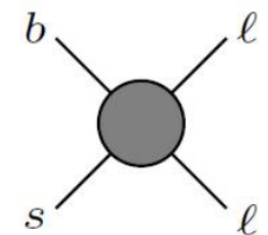
$i = 1, 2$	Tree
$i = 3 - 6, 8$	Gluon penguin
$i = 7$	Photon penguin
$i = 9, 10$	Electroweak penguin
$i = S$	Higgs (scalar) penguin
$i = P$	Pseudoscalar penguin

- ▶ **C_i Wilson coefficients:** short-distance physics (perturbative) couplings, μ =energy scale



- ▶ **O_i operators:** long-distance (non perturbative) matrix elements, e.g. from lattice QCD calculations

$i=7$ photon penguin



- ▶ New physics can modify C_i Wilson coefficients and/or add new operators

$i=9, 10, P, S$

Observation of $B_s \rightarrow \mu^+ \mu^-$ rare decay

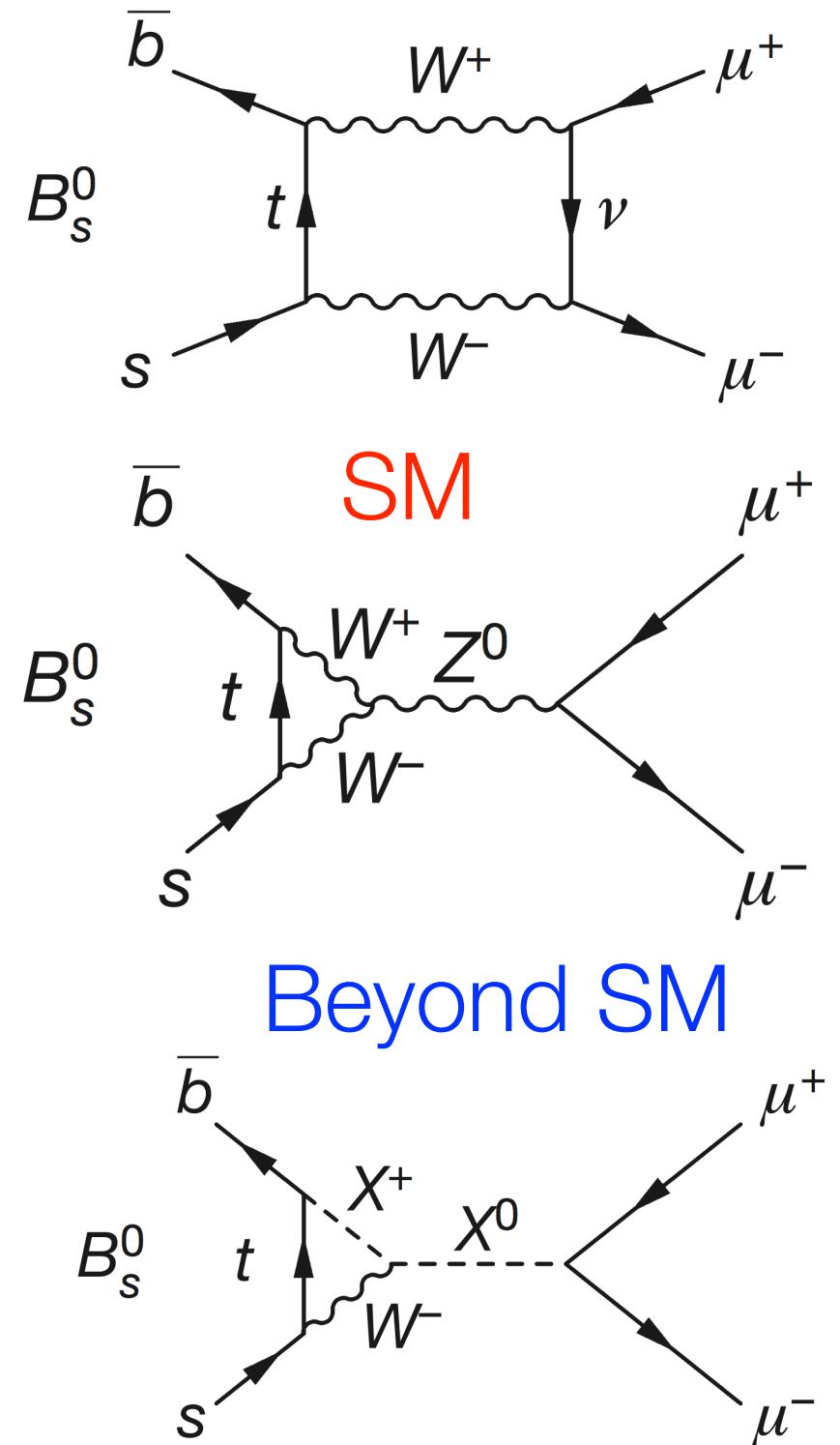
Rare FCNC decay

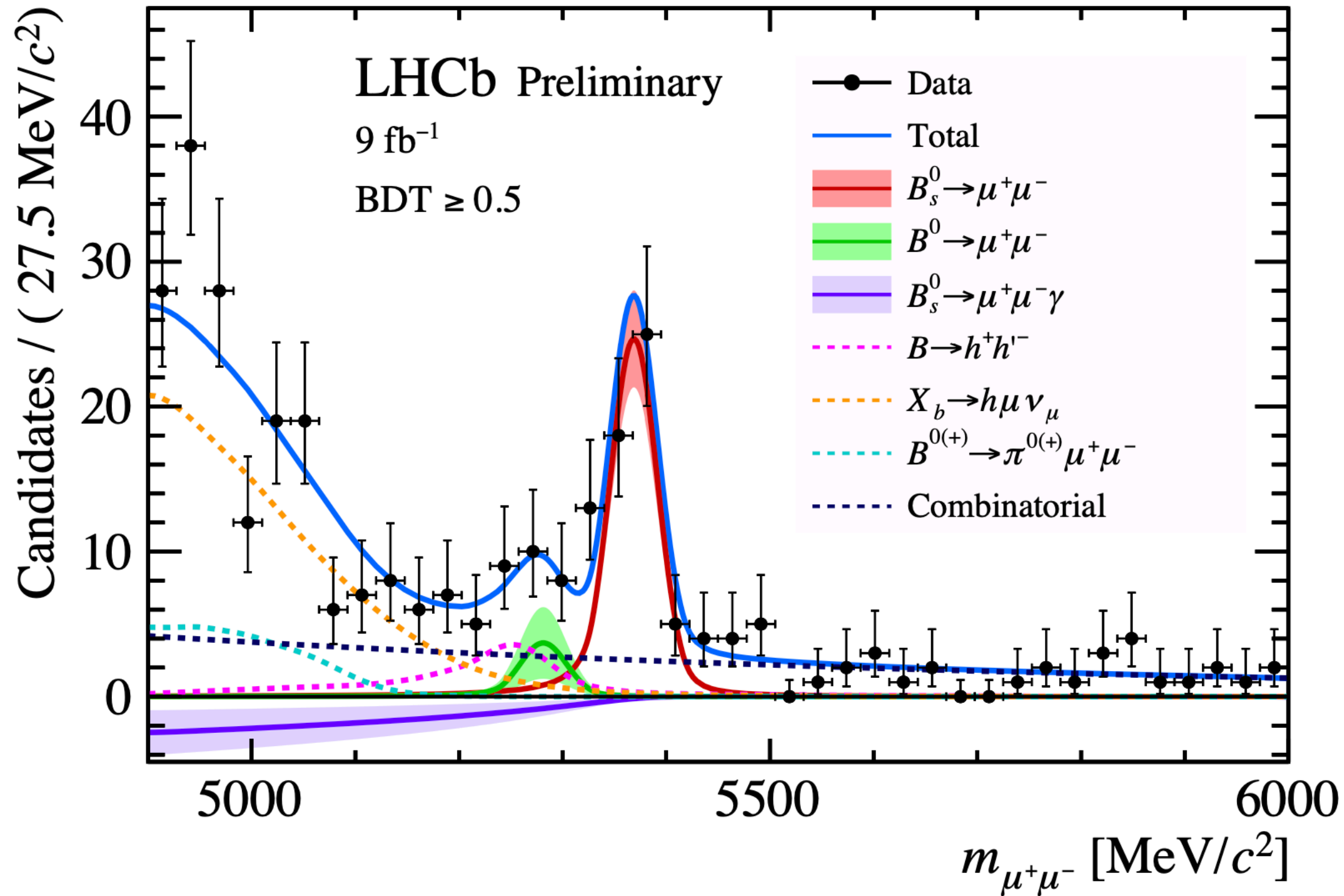
SM contributions from C_{10}
(dominant), C_S , C_P (negligible) only

$$\text{BR}_{\text{SM}}(B_s \rightarrow \mu^+ \mu^-) = (3.66 \pm 0.23) \times 10^{-9}$$
$$\text{BR}_{\text{SM}}(B^0 \rightarrow \mu^+ \mu^-) = (1.06 \pm 0.09) \times 10^{-10}$$

Bobeth et al., PRL 112 (2014) 101801

- possible large BR enhancements in beyond SM models

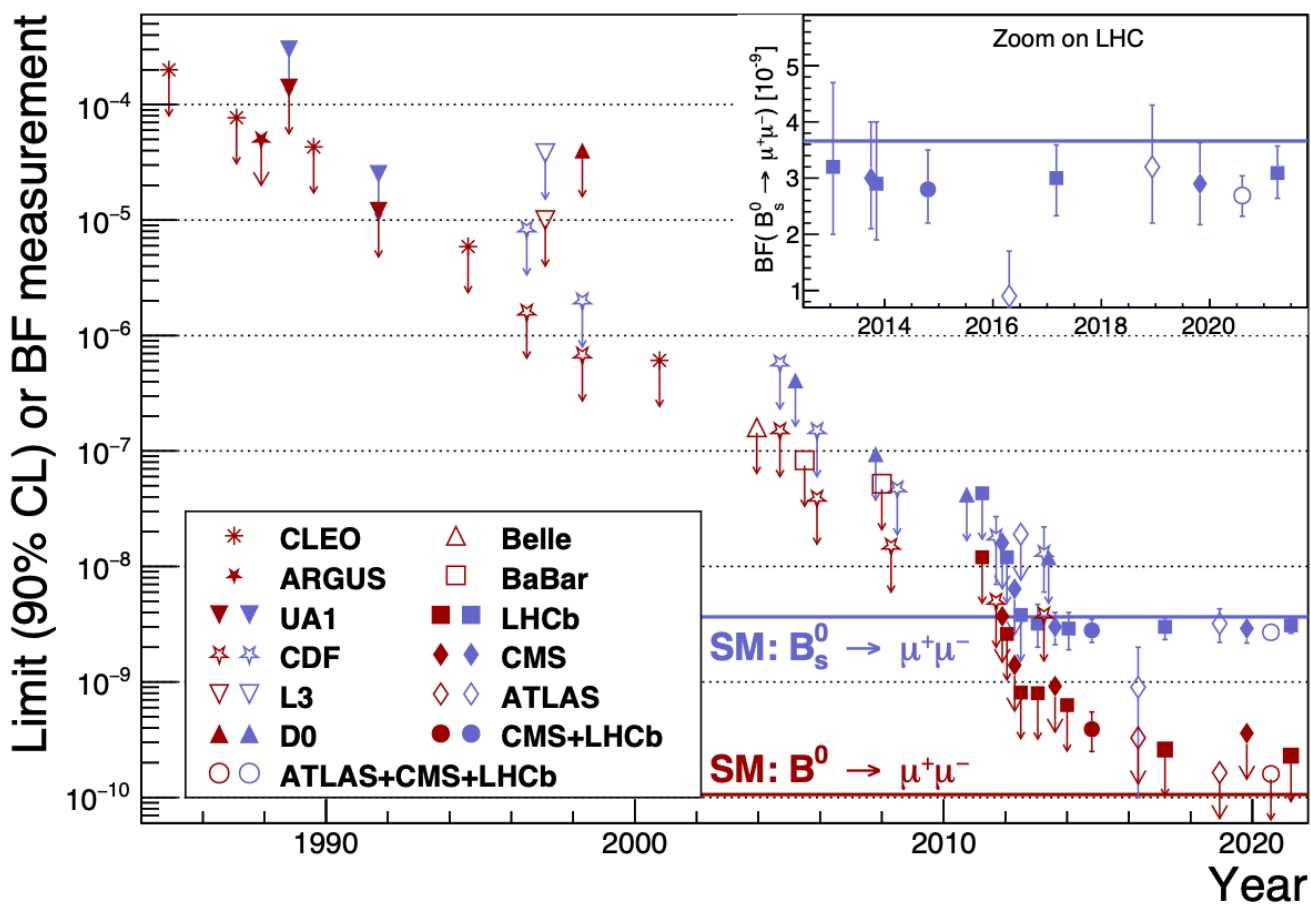




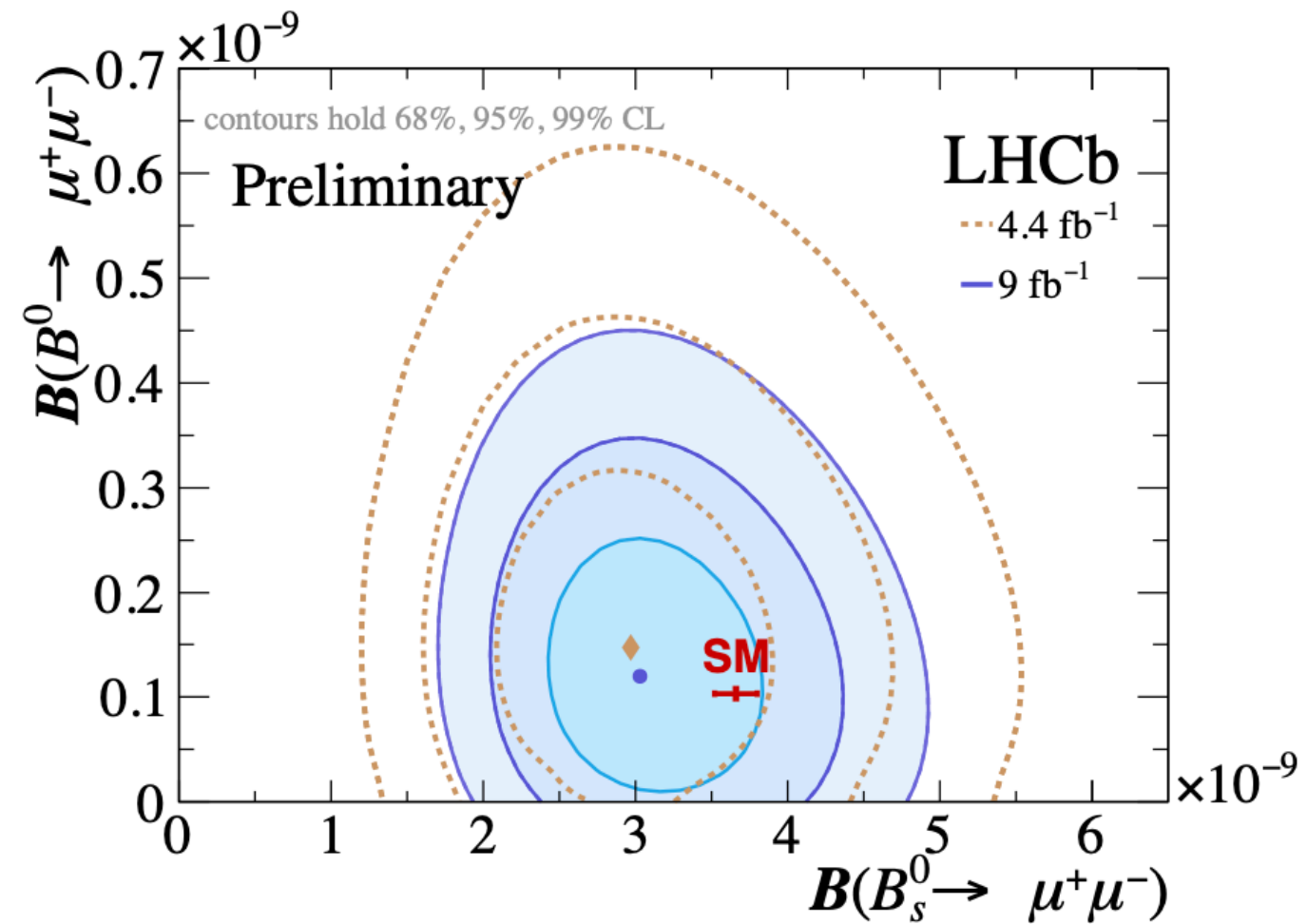
● $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = (3.09^{+0.46+0.15}_{-0.43-0.11}) \times 10^{-9} \quad (10.8\sigma)$

Branching fraction results and compatibility with the SM

30 years of investigation



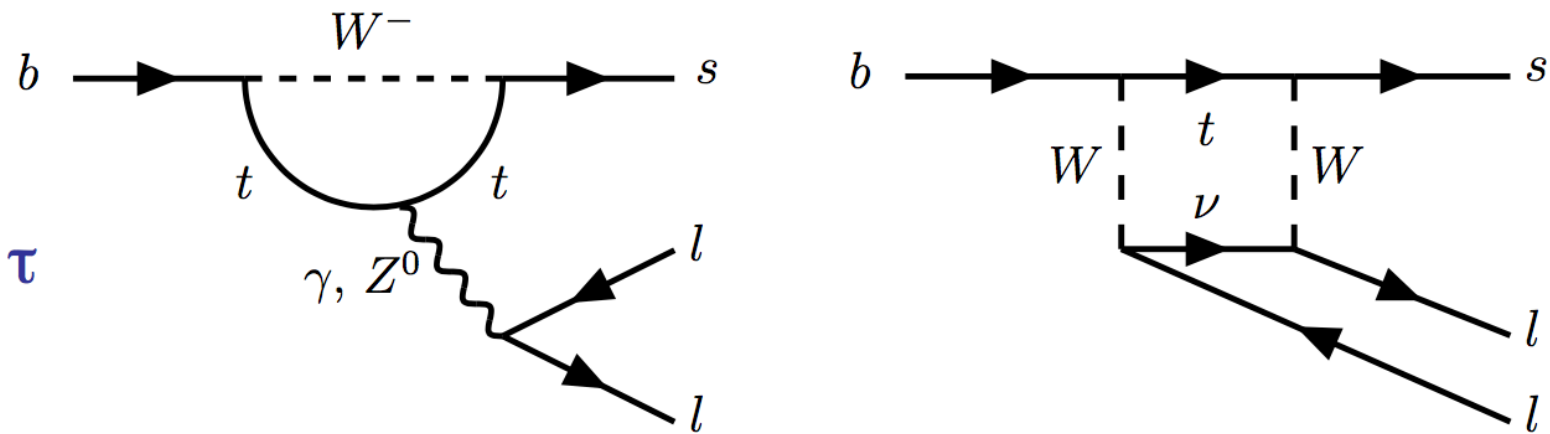
Results compatible with the SM



$B^0 \rightarrow K^{*0} \ell^+ \ell^-$ and lepton universality

Lepton Flavour Universality (LFU) in the SM:

— same EW couplings for $\ell = e, \mu, \tau$



In the SM couplings of gauge bosons to leptons are independent of lepton flavour
Theory clean observable to measure

$$R_{K^{(*)}} := \frac{\mathcal{B}(B \rightarrow K^{(*)} \mu^+ \mu^-)}{\mathcal{B}(B \rightarrow K^{(*)} e^+ e^-)} \stackrel{\text{SM}}{\cong} 1$$

Any significant deviation is a signature of New Physics

R_K is measured as a double ratio to cancel out most systematic uncertainties

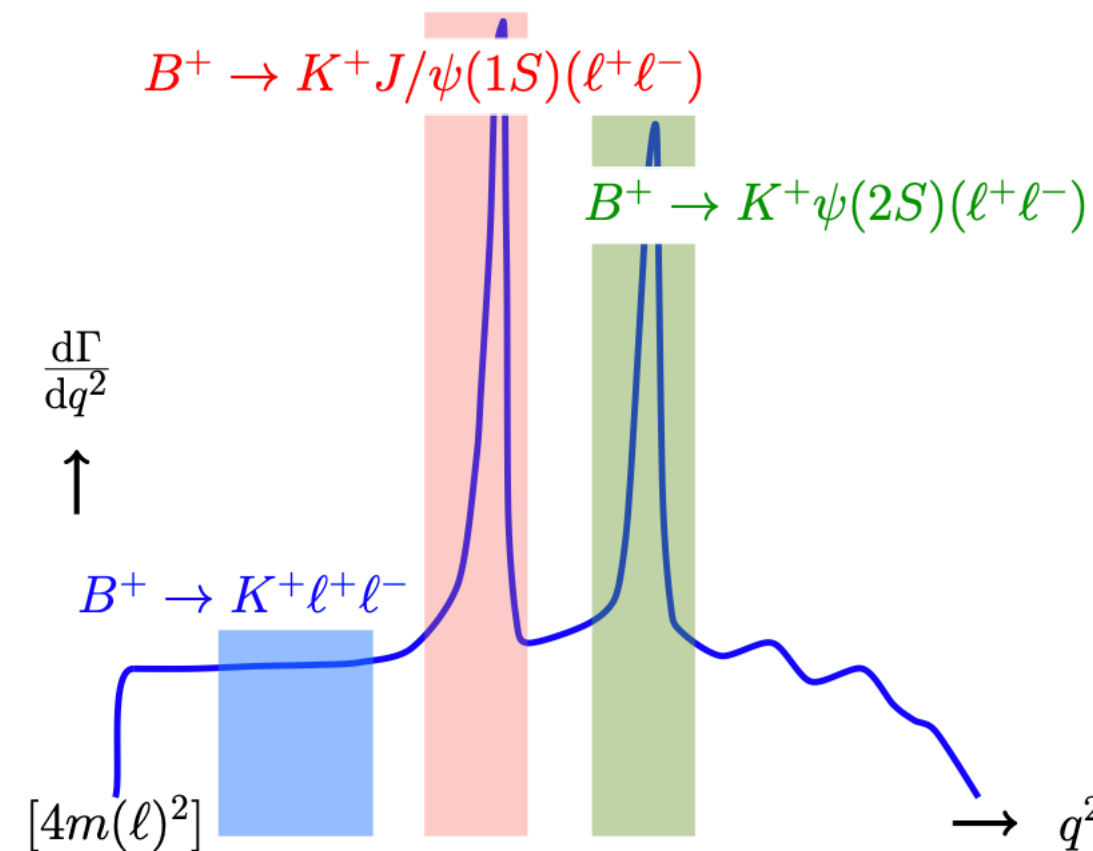
$$R_K = \frac{\mathcal{B}(B^+ \rightarrow K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \rightarrow K^+ J/\psi(\mu^+ \mu^-))} \bigg/ \frac{\mathcal{B}(B^+ \rightarrow K^+ e^+ e^-)}{\mathcal{B}(B^+ \rightarrow K^+ J/\psi(e^+ e^-))} = \frac{N_{\mu^+ \mu^-}^{\text{rare}} \varepsilon_{\mu^+ \mu^-}^{J/\psi}}{N_{\mu^+ \mu^-}^{J/\psi} \varepsilon_{\mu^+ \mu^-}^{\text{rare}}} \times \frac{N_{e^+ e^-}^{J/\psi} \varepsilon_{e^+ e^-}^{\text{rare}}}{N_{e^+ e^-}^{\text{rare}} \varepsilon_{e^+ e^-}^{J/\psi}}$$

As a test of the experimental technique, measure the ratio

$$r_{J/\psi} = \frac{\mathcal{B}(B^+ \rightarrow K^+ J/\psi(\mu^+ \mu^-))}{\mathcal{B}(B^+ \rightarrow K^+ J/\psi(e^+ e^-))} = 1$$

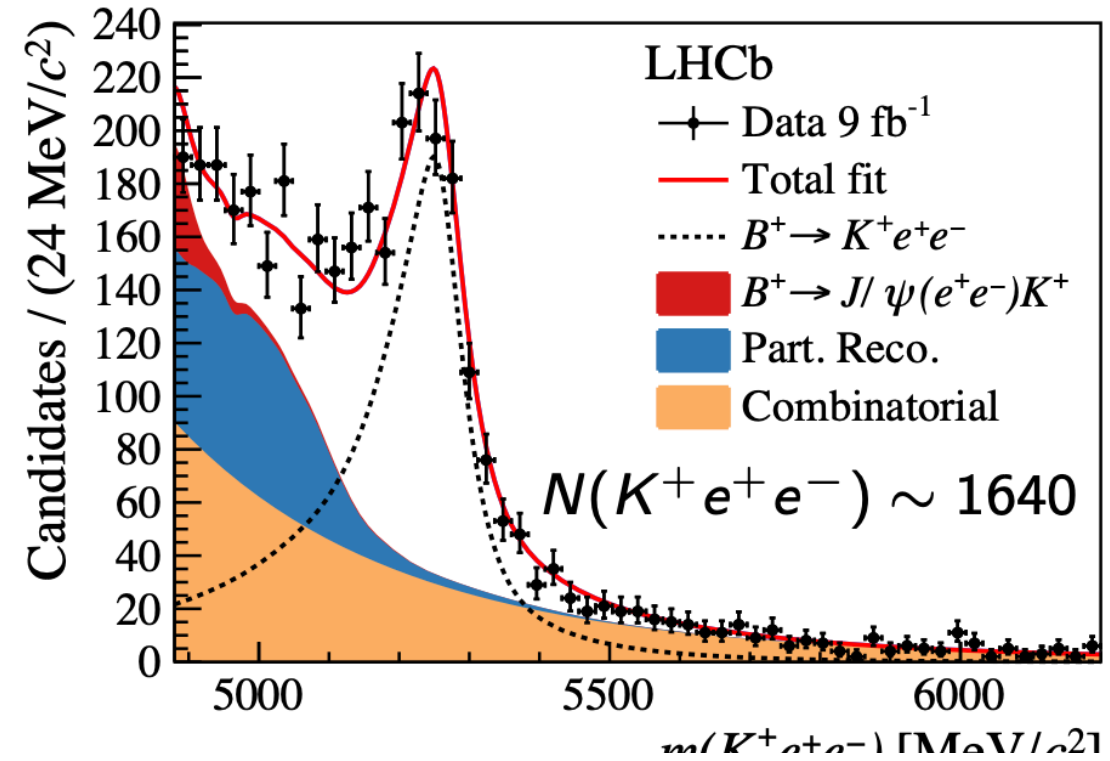
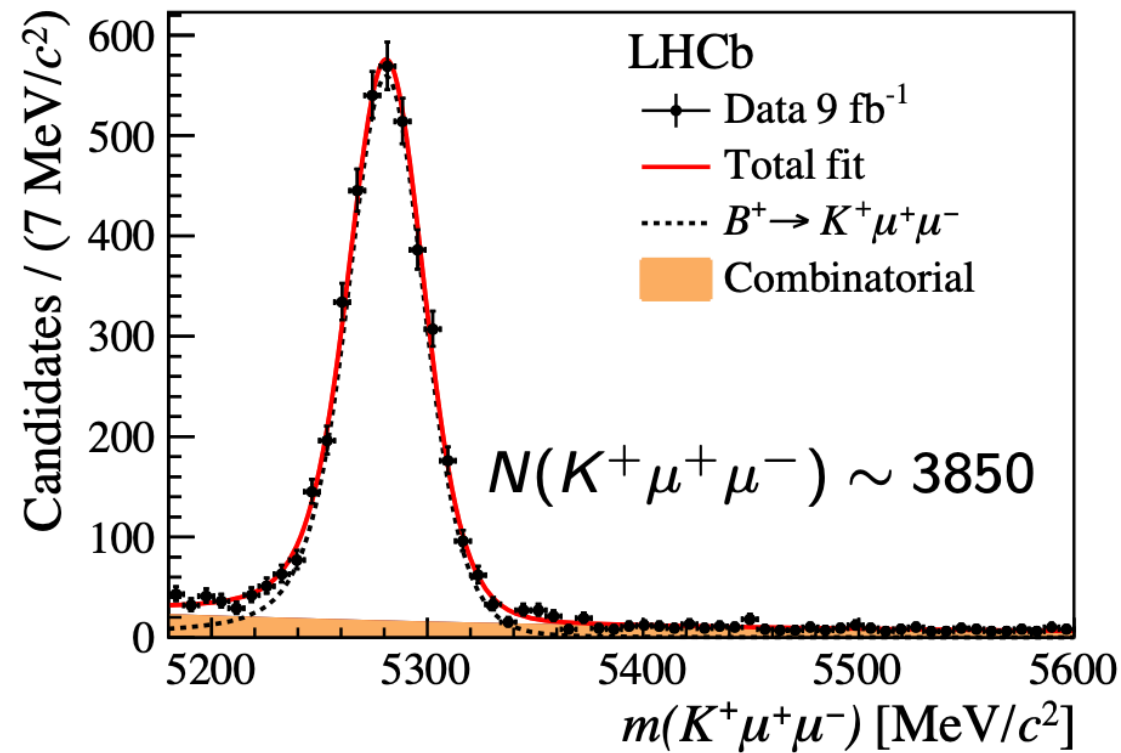
Results

$$r_{J/\psi} = 0.981 \pm 0.020 \text{ (stat + syst)}$$



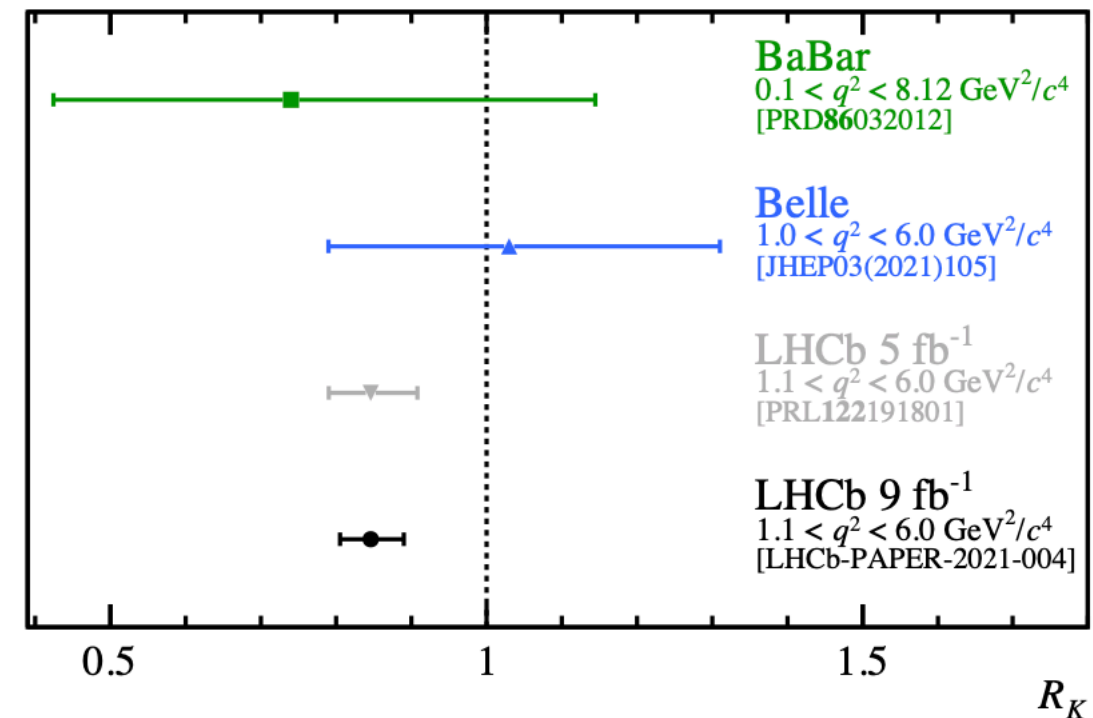
R_K measurement

LHCb-PAPER-2021-004



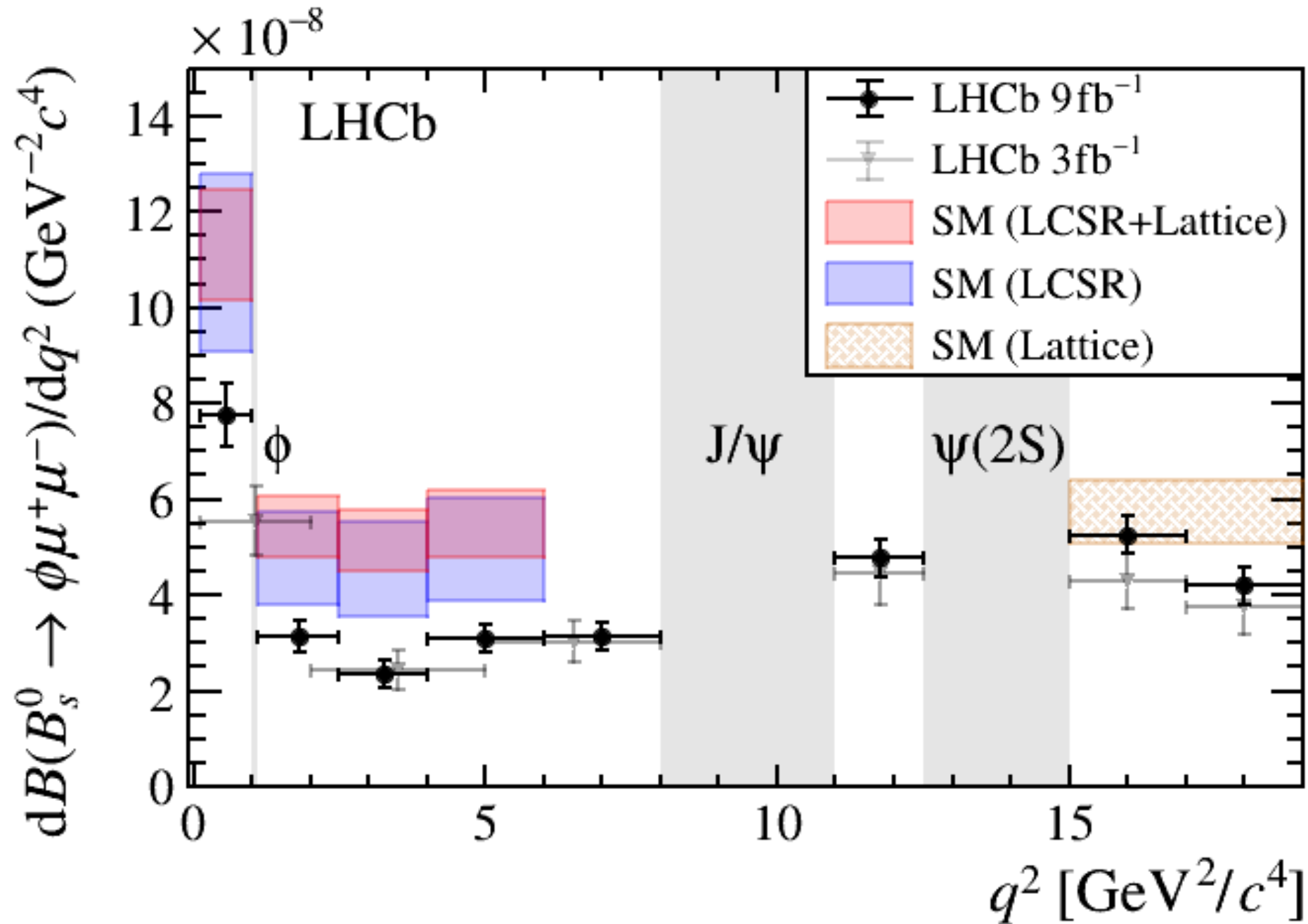
$$R_K = 0.846^{+0.042}_{-0.039} (\text{stat})^{+0.013}_{-0.012} (\text{syst})$$

Evidence of LFU violation at 3.1σ



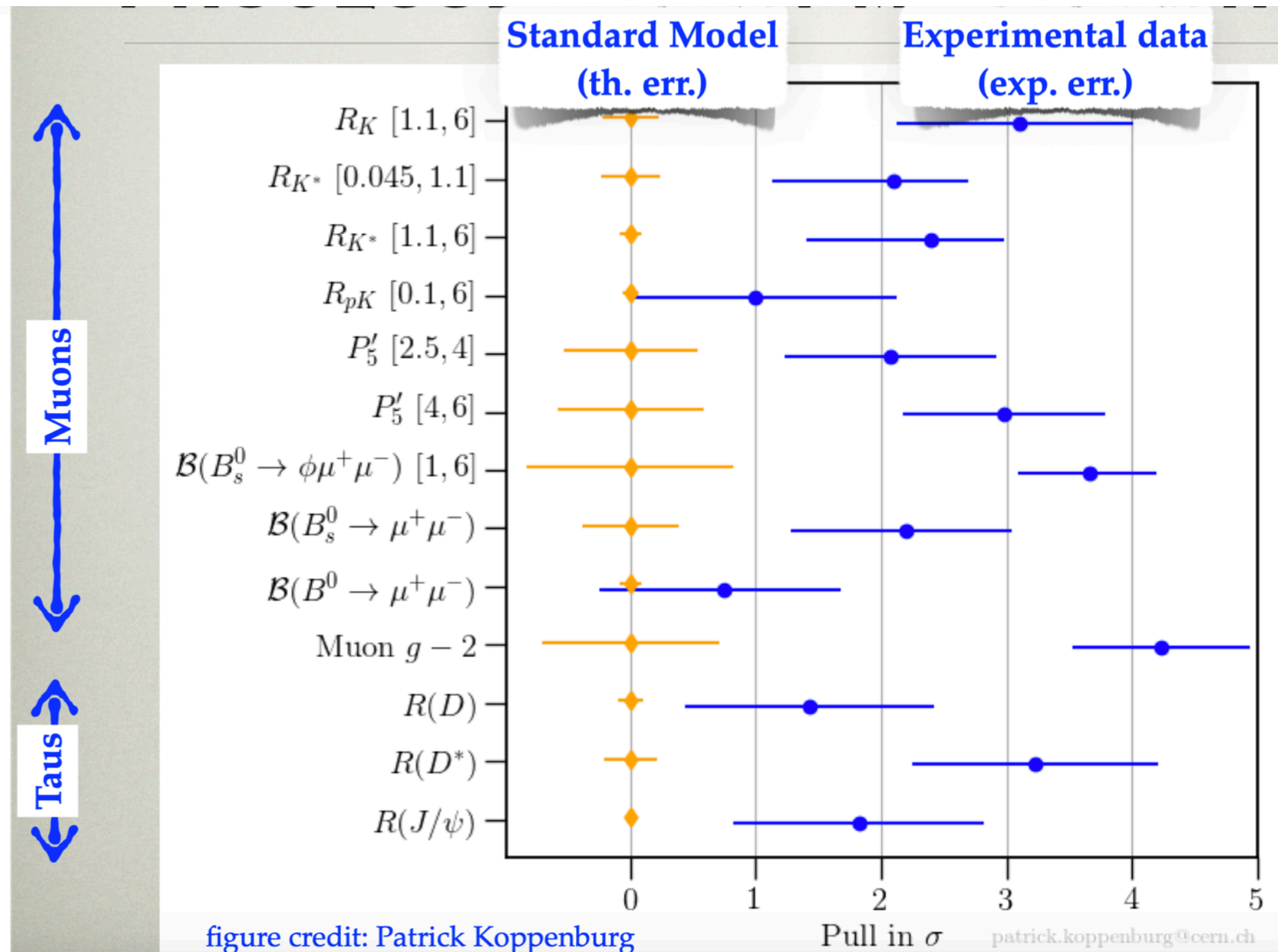
Results for $\mathcal{B}(B_s^0 \rightarrow \phi \mu^+ \mu^-)$

LHCb-PAPER-2021-014



Tension with SM at 3.6σ

“Flavour anomalies”

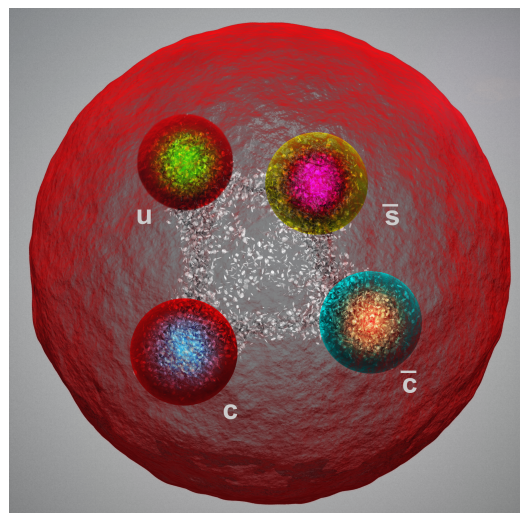


If true, this result...

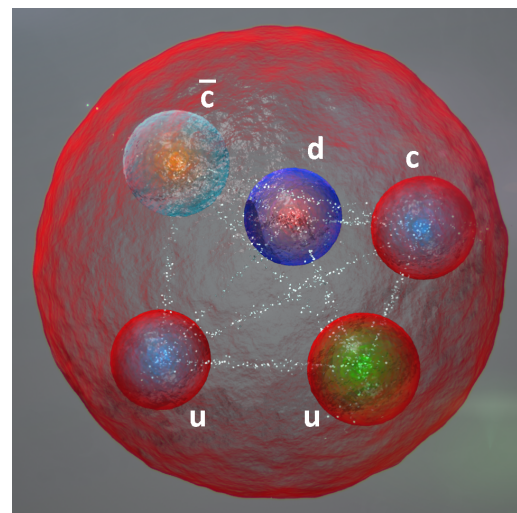
- would be the most revolutionary surprise in fundamental physics since the discovery that the Universe is expanding at an accelerating rate.
- would break apart the flavour structure of the Standard Model and the symmetries on which it rests.
- would radically change our future perspective: a boost for the flavour, precision, and high-energy programmes.

Spectroscopy and search for new hadronic particles

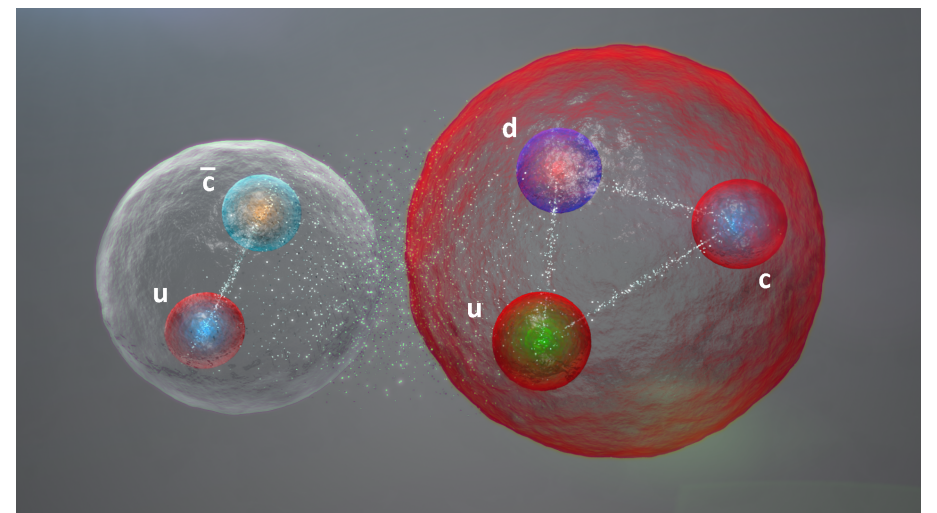
Tetraquark



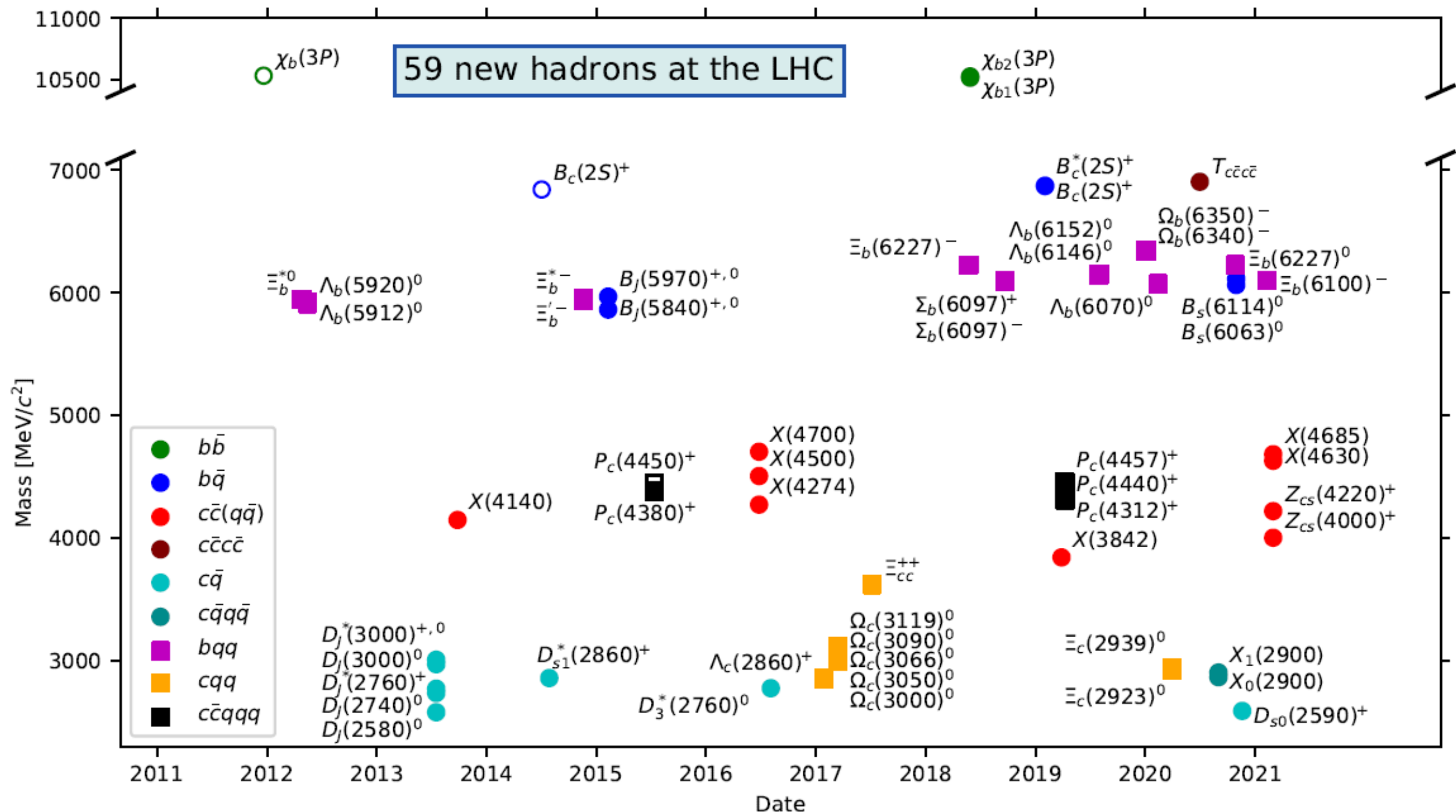
Pentaquark



Meson-Baryon Molecule



LHC is a Large Hadron Discovery Factory



- ▶ 52 new hadrons observed at LHCb
- ▶ Significant contribution of INFN Milano (P. Gandini)

Evidence of a new pentaquark

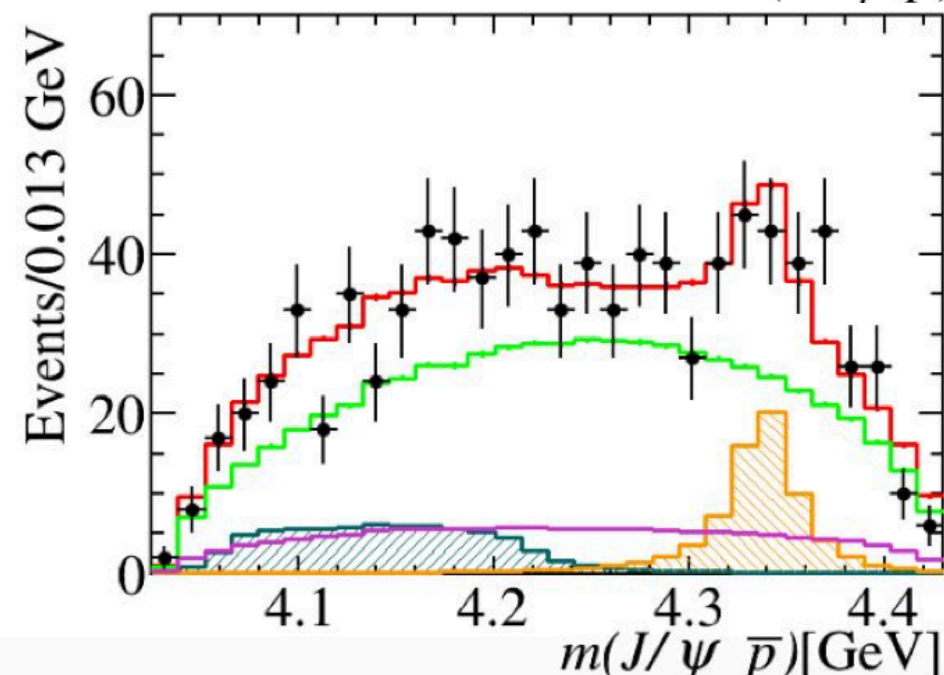
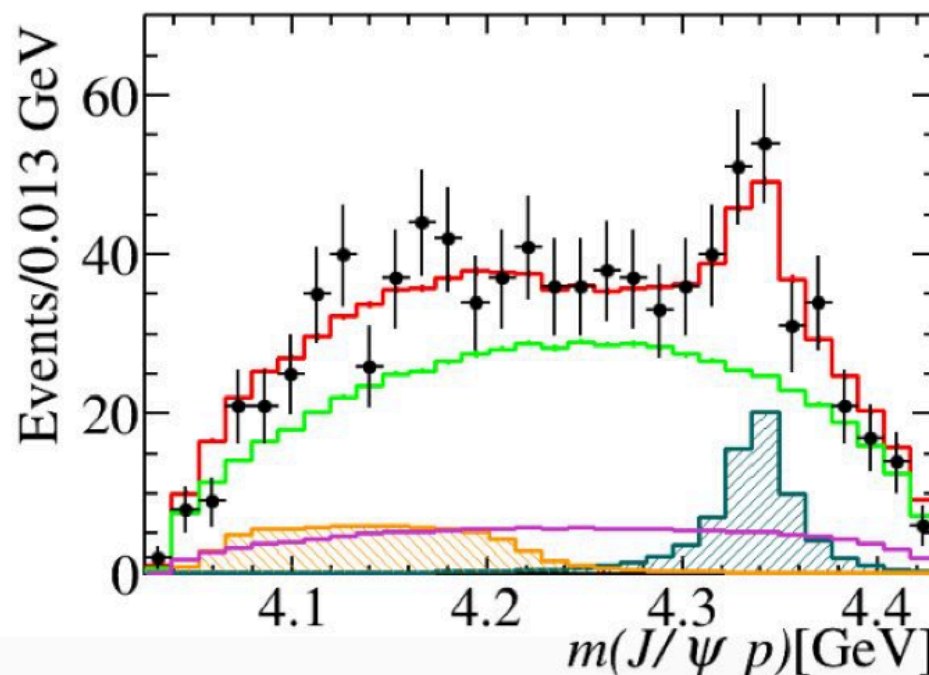
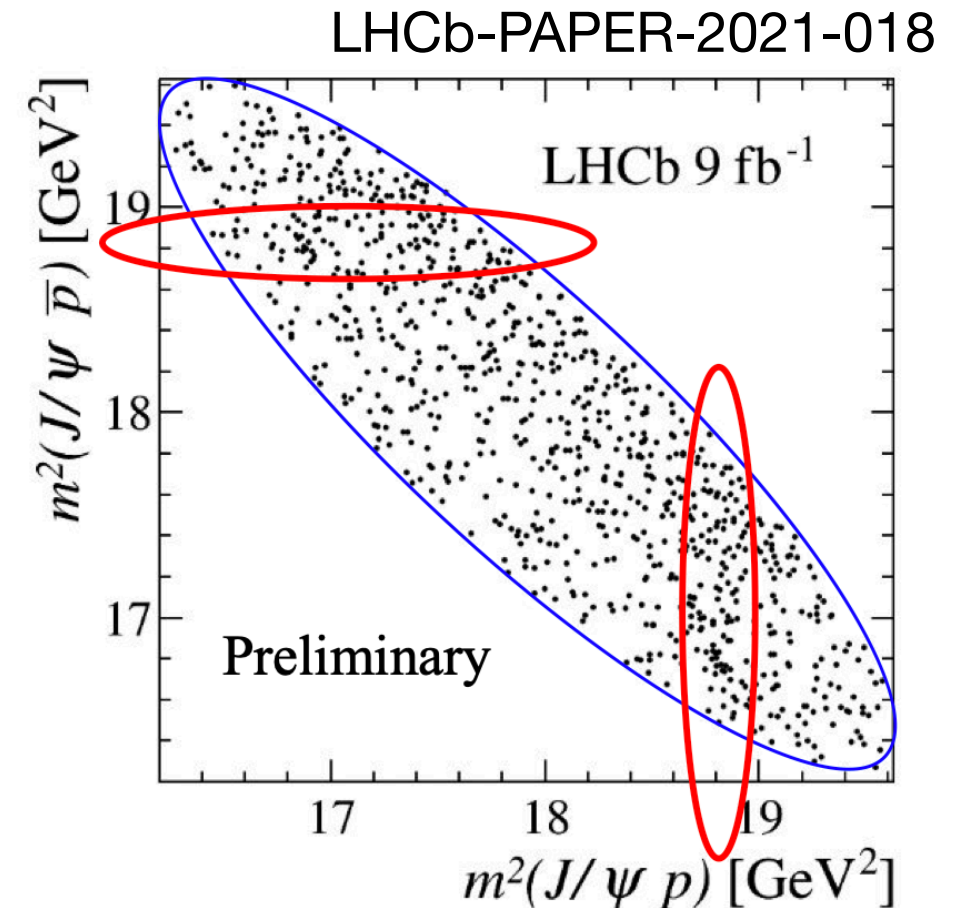
- From the full amplitude analysis of $B_s \rightarrow J/\psi pp$ decays

E. Spadaro Norella CERN-THESIS-2021-040

New pentaquark-like state (uud cc-bar) with significance between **3.1 - 3.7 σ**

$$M_{P_c} = 4337_{-4}^{+7}(\text{stat}) \pm 2(\text{sys})\text{MeV},$$

$$\Gamma_{P_c} = 29_{-12}^{+26}(\text{stat}) \pm 14(\text{sys})\text{ MeV}$$



Ongoing analyses in Milano

Amplitude analysis of charm baryon decays from semileptonic production [D. Marangotto PhD Thesis](#) (in review)

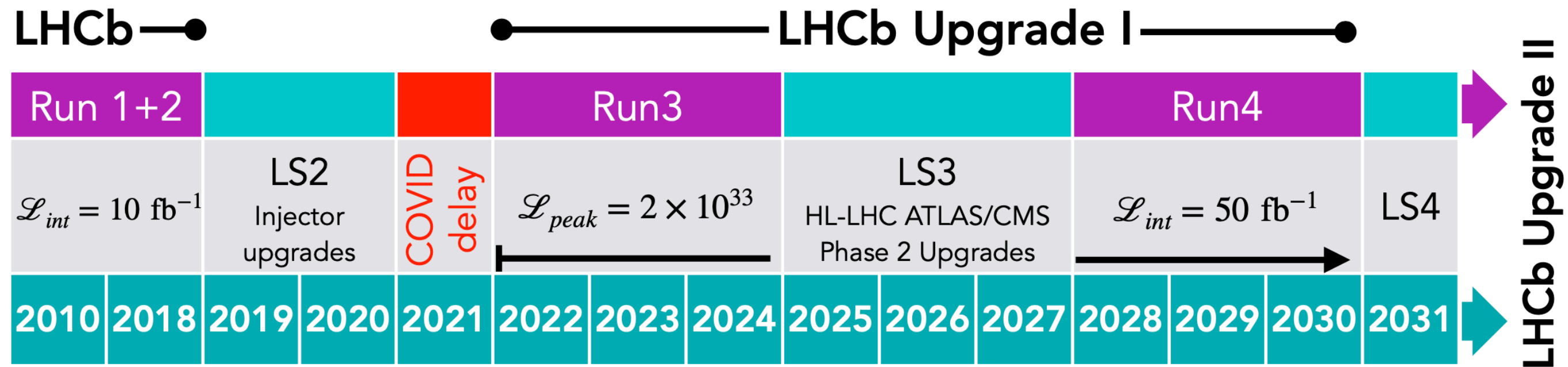
Λ_c^+ polarisation measurement in p-Ne collisions at $\sqrt{s}=68$ GeV [Merli](#) (ongoing)

Λ polarisation measurement in $\Xi_c^0 \rightarrow \Lambda K^- \pi^+$ decays [Tonani Master thesis](#), [Merli](#), N. N.

Amplitude analysis of B decays for exotic state searches [Spadaro](#), [Fu](#), N. N. (in review)

Studies of excited b baryons [Gandini](#) (ongoing)

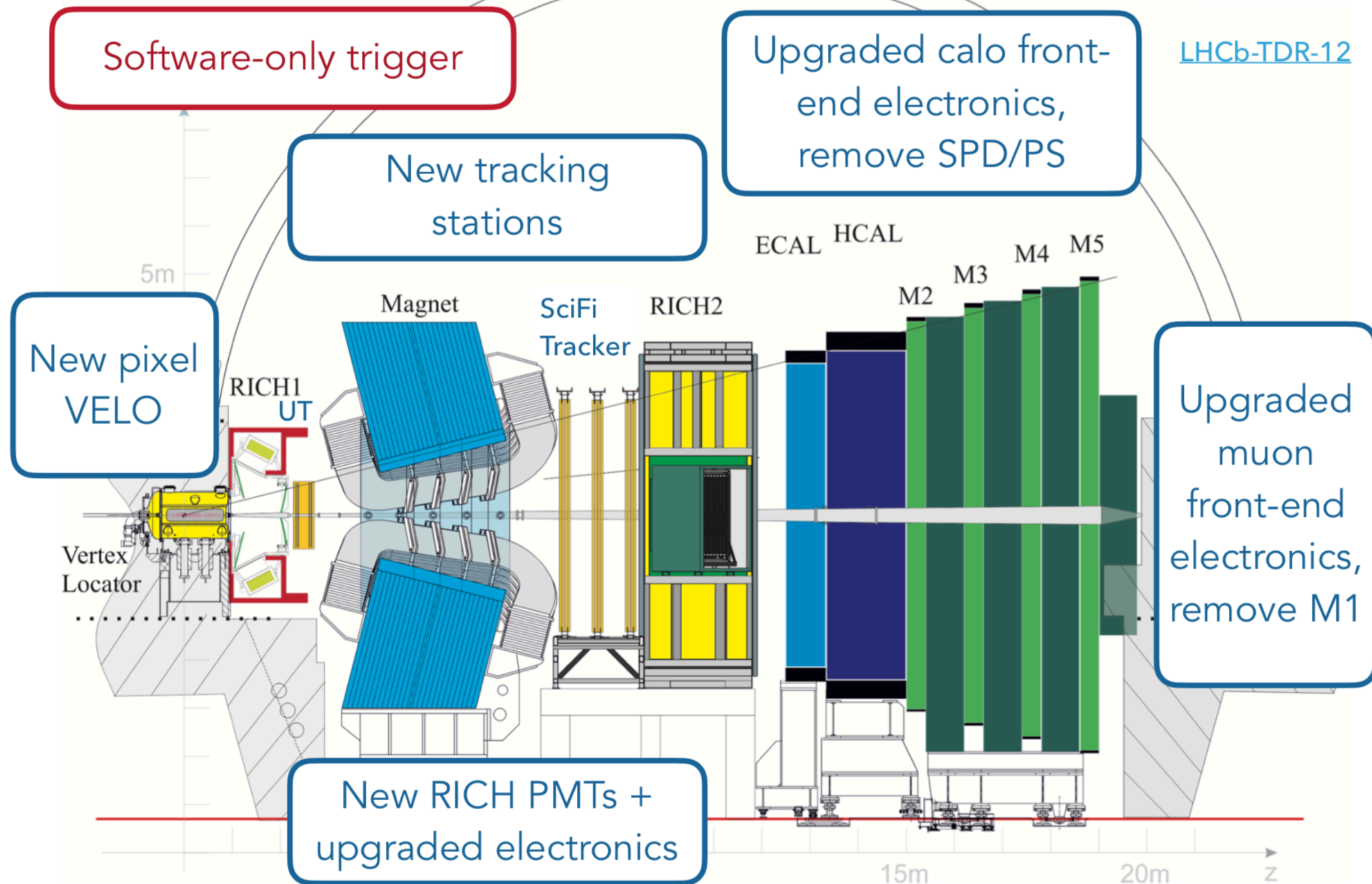
LHCb upgrade



Full software based trigger
Removed L0 bottle neck

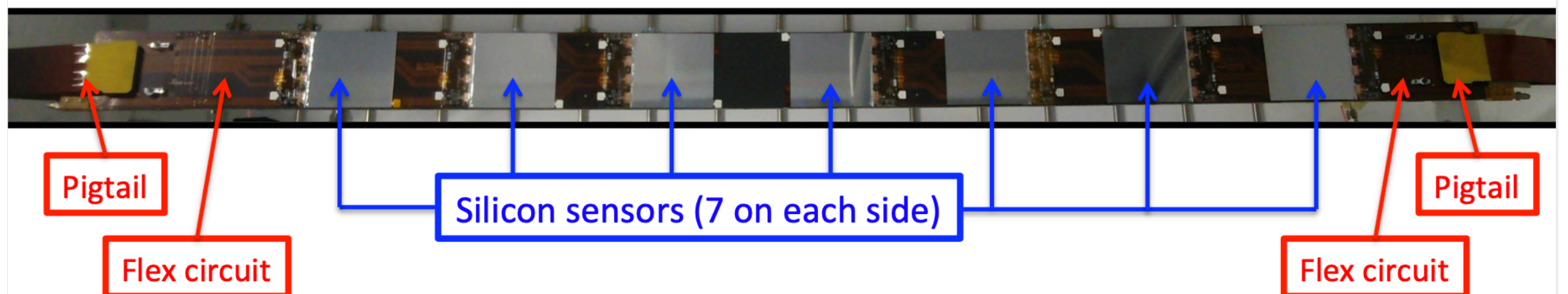
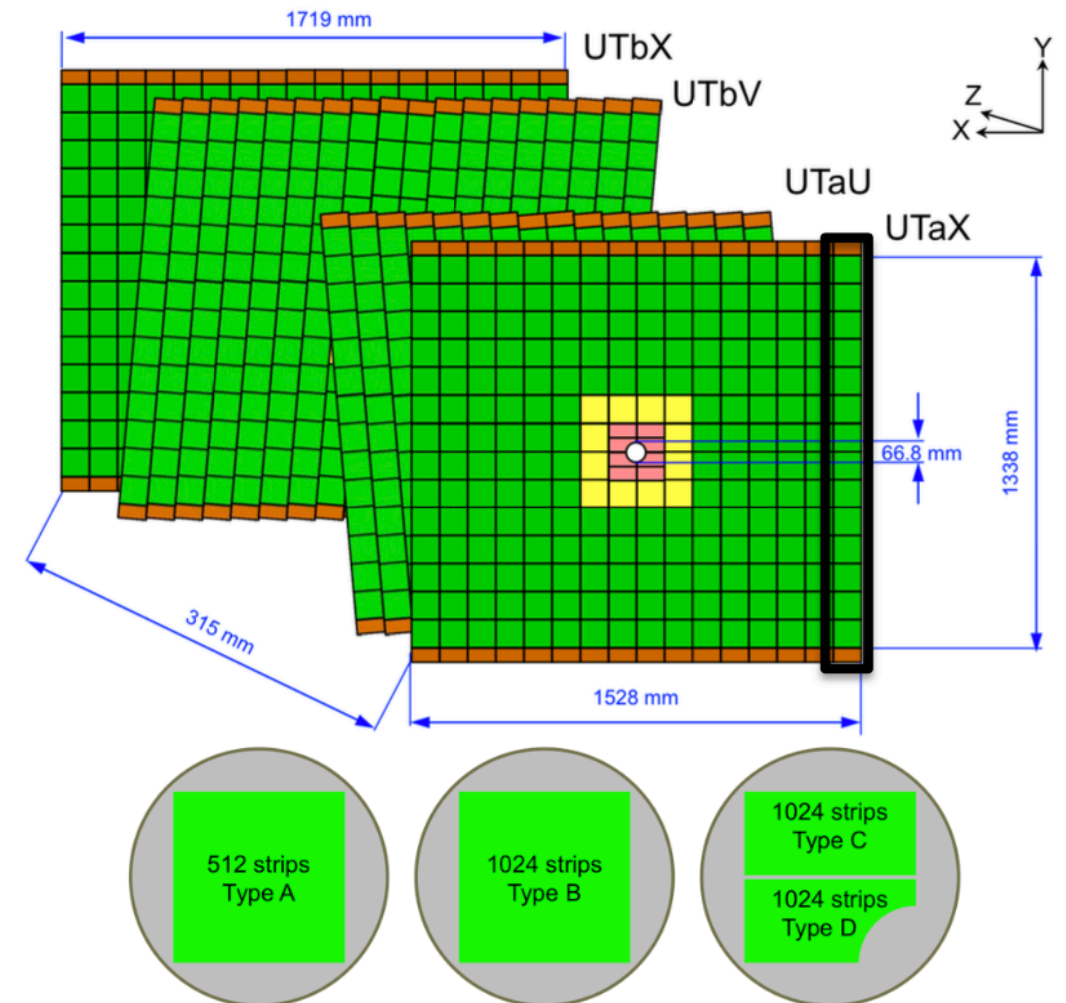
increased instantaneous luminosity x5 wrt Run2

THE UPGRADE DETECTOR



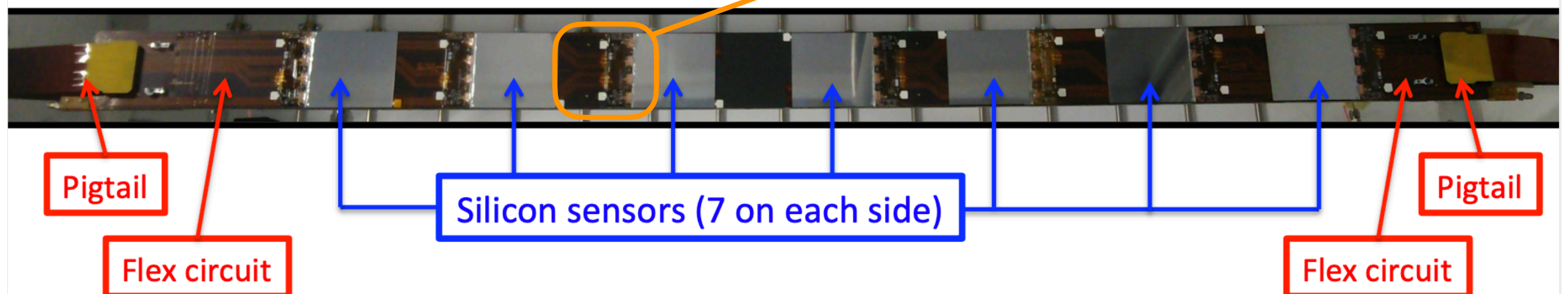
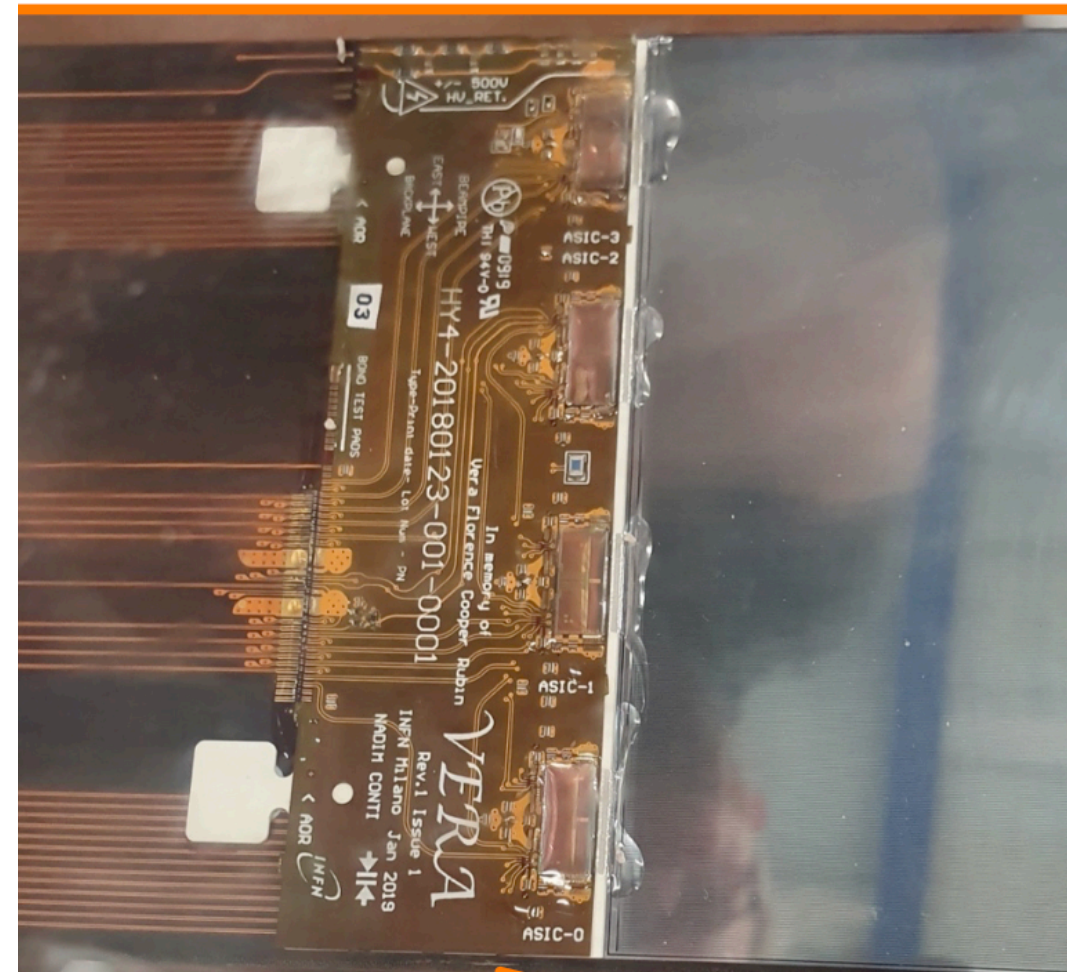
UT detector

- ▶ Silicon micro-strip detector
 - ▶ 4 layers (x, u, v, x) upstream of magnet
- ▶ 4 types of sensors
 - ▶ 968 sensors of type A, B, C, D: 888, 48, 16, 16
 - ▶ n- and p-type with 512 or 1024 strips
 - ▶ 320/250 μm thick; 187.5/93.5 μm pitch
- ▶ **Modules** mounted on double-sided **staves**
 - ▶ 68 staves / 968 modules
 - ▶ CO₂ cooling pipe integrated in stave
- ▶ **ASIC (SALT) and hybrid circuits**
 - ▶ 128 channels with 6-bit ADC.
 - ▶ 4192 ASICs mounted on hybrid circuits
 - ▶ 888 4-chip hybrids; 80 8-chip hybrids
- ▶ Read-out electronics mounted on detector frame



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Activities in Milano

- ▶ Milano responsibilities in UT project:
 - ▶ **Flex cables**. Production and test completed ✓
 - ▶ **Hybrid circuits**. Production by ARTEL completed ✓
 - ▶ **Integration** of hybrid and SALT chip: glueing, bonding, burn-in ✓
 - ▶ **CO₂ distribution system** ✓ to be installed in LHCb
- ▶ Milano coordination roles in UT project:
 - ▶ Deputy project leader: Nicola Neri
 - ▶ Sensor and hybrid WG co-convener: Mauro Citterio
 - ▶ Mechanics and cooling WG co-convener: Simone Coelli
 - ▶ Hybrid production coordinator: Paolo Gandini

Flex cables

- Production at CERN workshop > 300 pieces completed ✓

Short cables

Medium cables

Long cables

- Tested, delivered for stave assembly ✓

Visual inspection, electrical tests

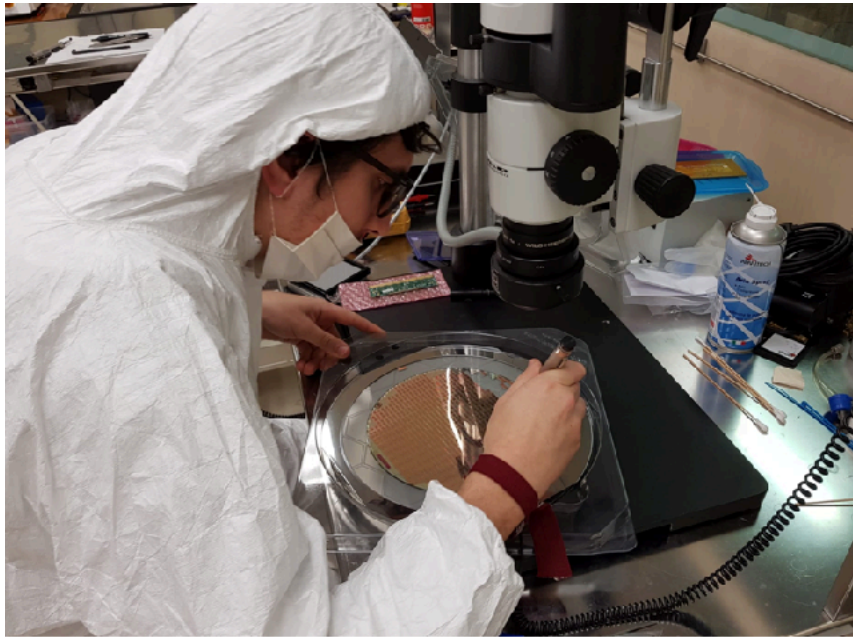
Automatic test for shorts or opens, measurement of impedance



Citterio, Conti, Sabatini

Hybrid production operations

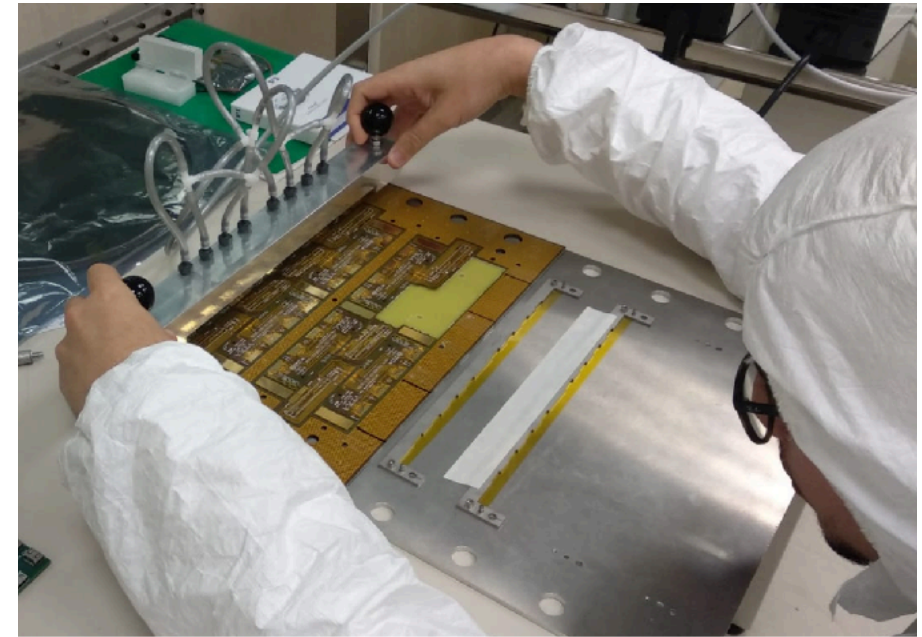
Chip sorting



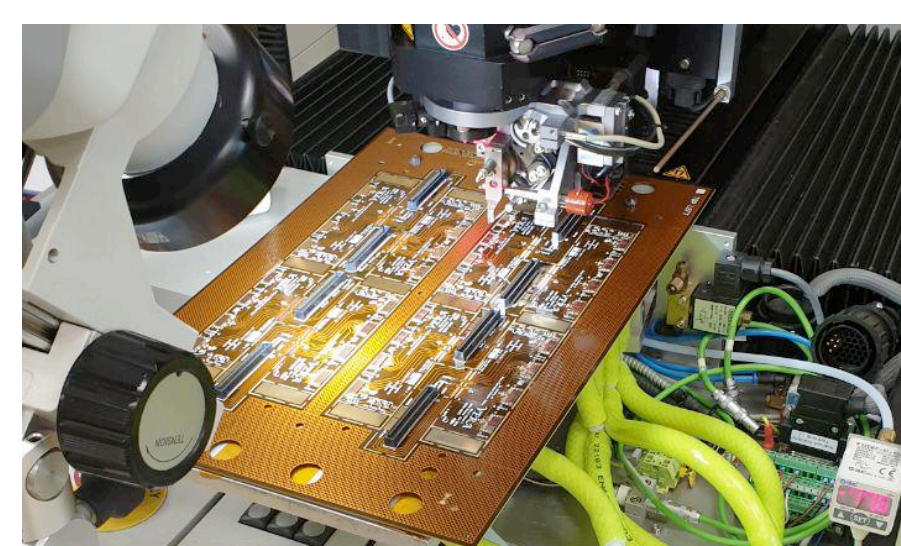
Gluing



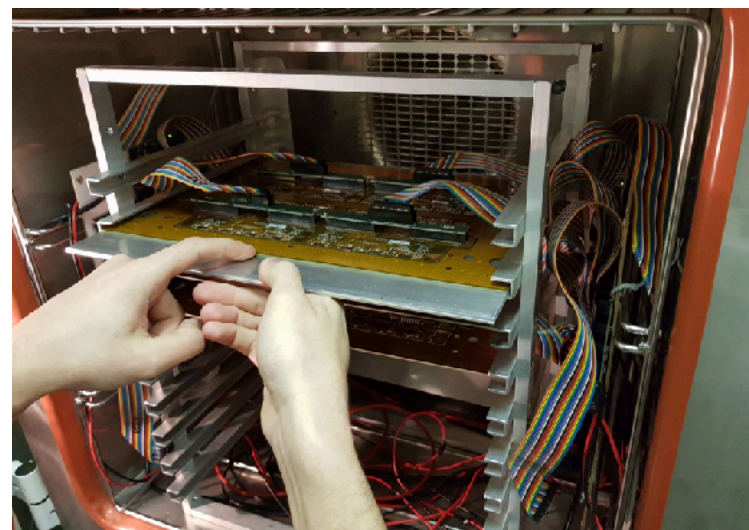
Pickup and positioning



Bonding



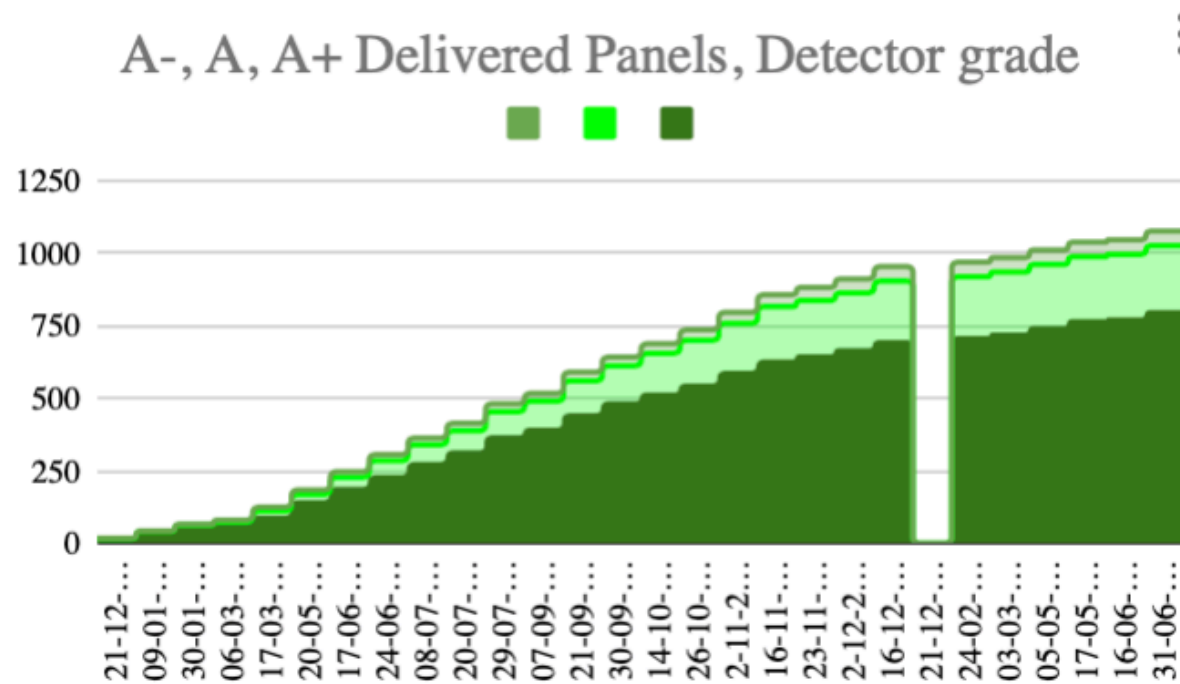
Burnin



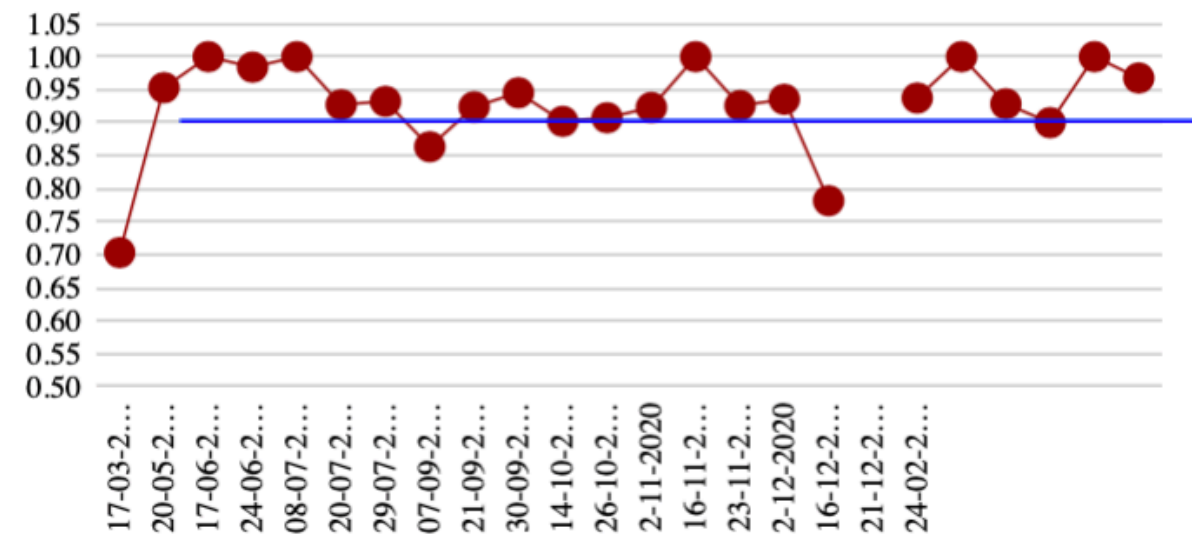
Testing



Hybrid production statistics



Production yield by manufacturing in Milano. Yield includes the B grades (ch do non depend on us)



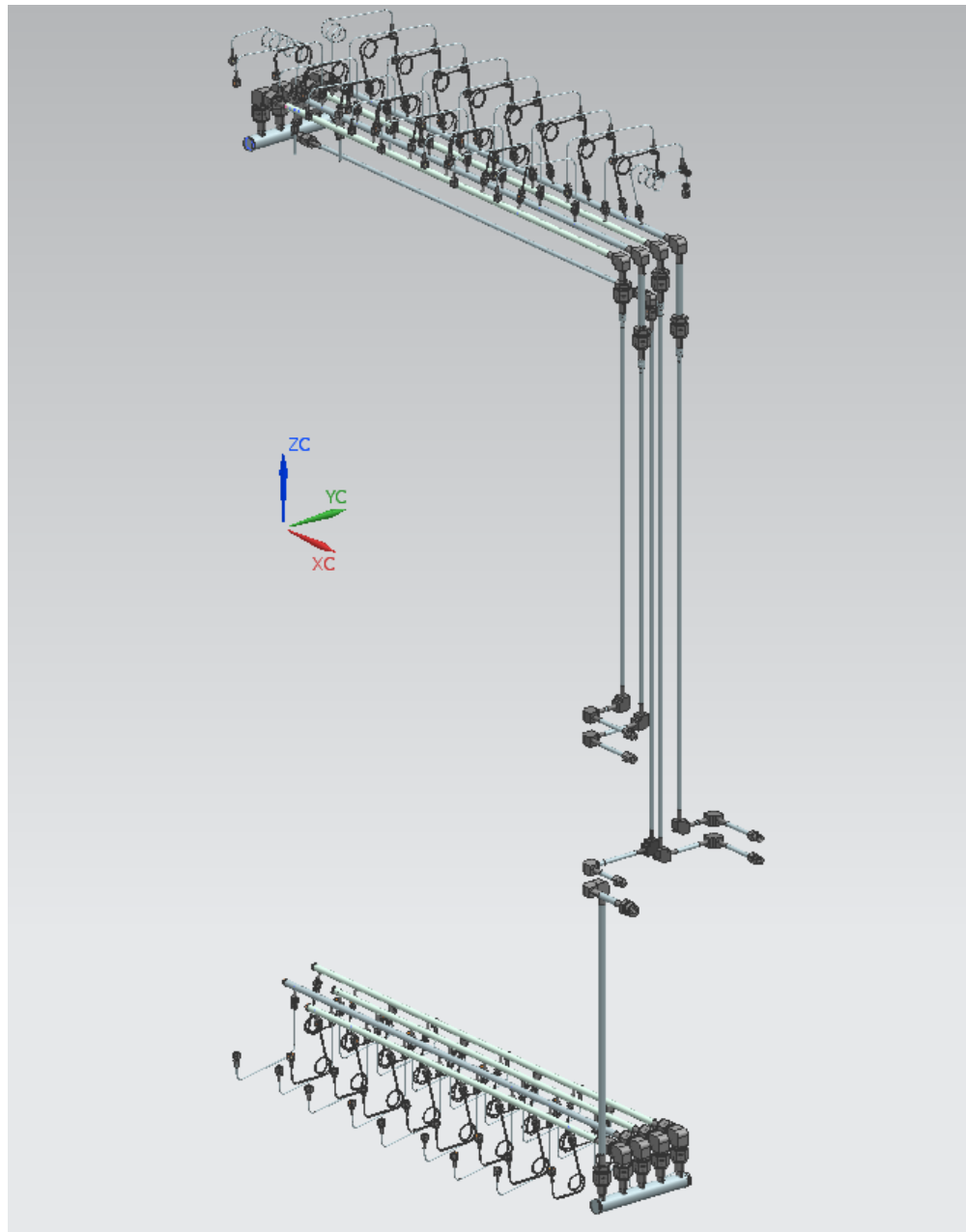
- ▶ Completed 4-chip hybrids (1076) and 8-chip hybrids (106) for detector construction ✓
- ▶ Big effort of a small group of dedicated people 🙌
- ▶ Many difficulties $\Rightarrow$ many lessons learned

Andreani, Carbone,
Citterio, Conti, De
Benedetti, Gandini,
Manca, Merli, Petruzzo,
Spadaro Norella

UT CO₂ distribution system

Designed, assembled and tested in Milano ✓

C side ready to be installed in LHCb at P8 ✓ A side in September



Capsoni, Coelli, Monti,
Gesmundo, Trotta, Viganò,
Viscione

Conference contributions

- 1) "Design, Production, Burn-in and Tests of the hybrid circuits of the Upstream Tracker at the LHCb detector", 20-24 September 2021. F. De Benedetti
- 2) "Progress towards the charm baryon dipole moments with bent crystals" at workshop FTE@LHC a Parigi, 4th June 2021. A. Merli
- 3) "Tetra- and pentaquark spectroscopy", 9th Conference of Large Hadron Collider Physics (LHCP 2021), Paris, France, (remote-only due to Covid-19), 7-12th June 2021. E. Spadaro Norella
- 4) Fixed Target and Proton-Ion results at LHCb, International Conference on Flavour Physics and CP Violation (FPCP 2020), A Toxa, Spain (remote-only due to COVID-19), 8-12 June 2020. D. Marangotto
- 5) "The Upstream Tracker: the silicon strip detector for the LHCb upgrade", 16th (Virtual) "Trento" Workshop on Advanced Silicon Radiation Detectors FBK, Trento, 16-18 February 2021. M. Petruzzo
- 6) "A 4D fast tracking detector for the high-luminosity LHC", International Conference on Technology and Instrumentation in Particle Physics, TIPP 2021, Online format (virtual) 24-28 May 2021. M. Petruzzo

Thesis in LHCb

1. Study of Λ baryon polarization in $\Xi_c^0 \rightarrow \Lambda K^- \pi^+$ decays, 6 luglio 2021, Magistrale. G. Tonani
2. Search for pentaquark candidates with an amplitude analysis of $B^0 \rightarrow J/\psi p \bar{p}$ decays at LHCb, 25 marzo 2021, Dottorato. E. Spadaro Norella
3. Selezione di decadimenti di barioni pesanti con quark b per analisi di spettroscopia, 16 dicembre 2020, Triennale. A. Sala
4. Studio di decadimenti di barioni Λ in preparazione alla misura dei momenti di dipolo elettromagnetici a LHCb, 8 ottobre 2020, Triennale. L. Pessina

Composizione gruppo di ricerca

Personale	FTE	LHCb (FTE)	SELDOM (FTE)	Inquadramento
Citterio	0,1	0,1		Dirigente Tecnologo
Coelli	0,3	0,2	0,1	Tecnologo
De Benedetti	1,0	0,0	1,0	AR INFN (UE)
Frontini	0,35	0,35		AR Unimi
Gandini	1,0	1,0		Ricercatore
Liberali	0,3	0,3		PA
Marangotto	1,0	0,0	1,0	AR Unimi (UE)
Merli	1,0	0,0	1,0	AR Unimi (UE)
Neri	1,0	0,4	0,6	PA
Petruzzo	1,0	0,0	1,0	AR INFN
Riboldi	0,2	0,2		RU
Stabile	0,2	0,2		
Spadaro	1,0	1,0	0,0	AR Unimi
Mancuso	1,0	1,0		Dottorando Paris-Milan
TBD	1,0	0,0	1,0	Dottorando (UE)
Tot. (FTE)	10,45	4,75	5,7	

- ▶ LHCb 3.9 FTE in 2021 → 4.75 FTE in 2022
- ▶ SELDOM 5.7 FTE in 2021 → 5.7 FTE in 2022

Richieste servizi di sezione

- ▶ Completamento spare hybrids (versione 8 chip)
- ▶ Installazione e messa a punto del sistema di cooling a CO₂
- ▶ Development and test of front-end chip for Upgrade II
- ▶ Richieste:
 - ▶ 10% FTE Mauro Citterio (6 m.u. servizio elettronico)
 - ▶ 20% FTE Simone Coelli (6 m.u. servizio officina e progettazione meccanica)
 - ▶ **Occorre uno spazio di laboratorio per le attività del gruppo LHCb (richiesta già presentata da diversi anni)**