

Activities of LHCb group



Nicola Neri
on behalf of the Milano LHCb group

INFN - Sezione di Milano

3 July 2019 - Milano

Outline

- ▶ LHCb experiment

- Physics results
- LHCb upgrade



- ▶ SELDOM ERC project

- Status update



- ▶ Timespot (in backup)

- R&D for fast timing pixel detector [Call CSN5]



LHCb physics program

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

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

Spectroscopy

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

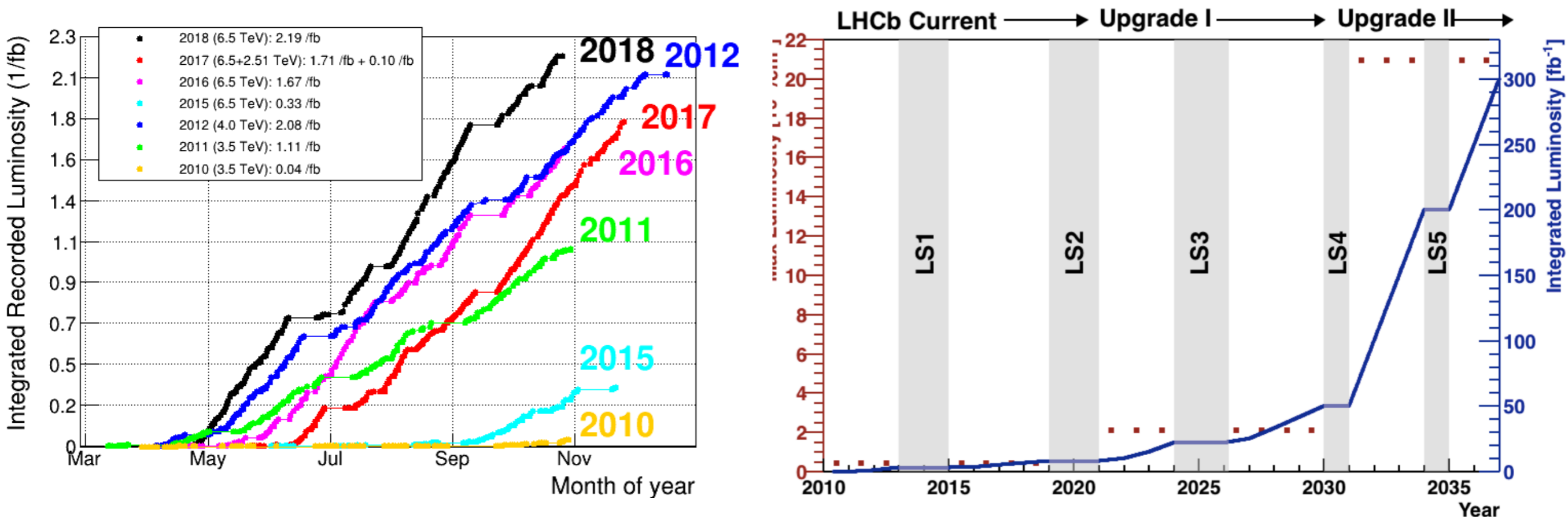
Electroweak
QCD, Exotica

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

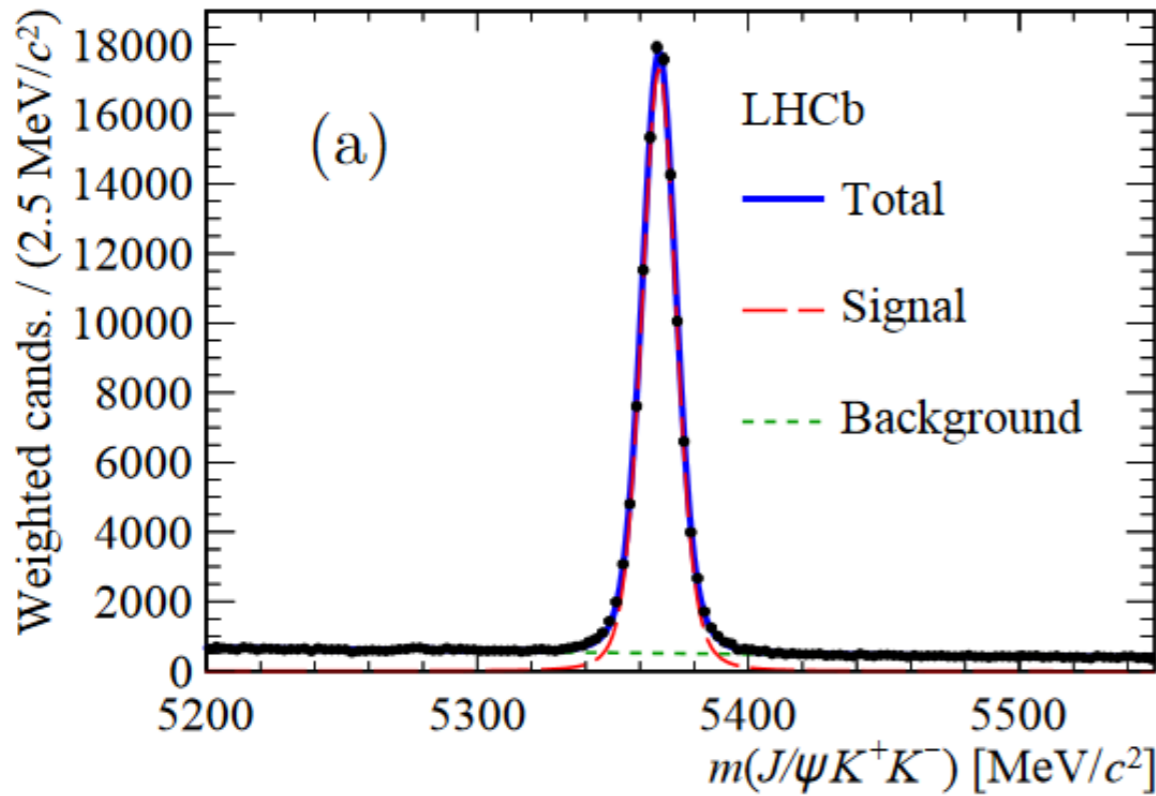


- ▶ Collected 9.23 fb⁻¹ (2010-2018). **Major detector upgrade during LS2** (Upgrade I- 2020). Aim at 50 fb⁻¹ before 2030
- ▶ First detector improvements in PID, tracking, and ECAL during LS3 (**Upgrade 1b** - 2025)
- ▶ Major detector upgrade during LS4 (**Upgrade II** - 2030). Aim at >300 fb⁻¹ after 2030

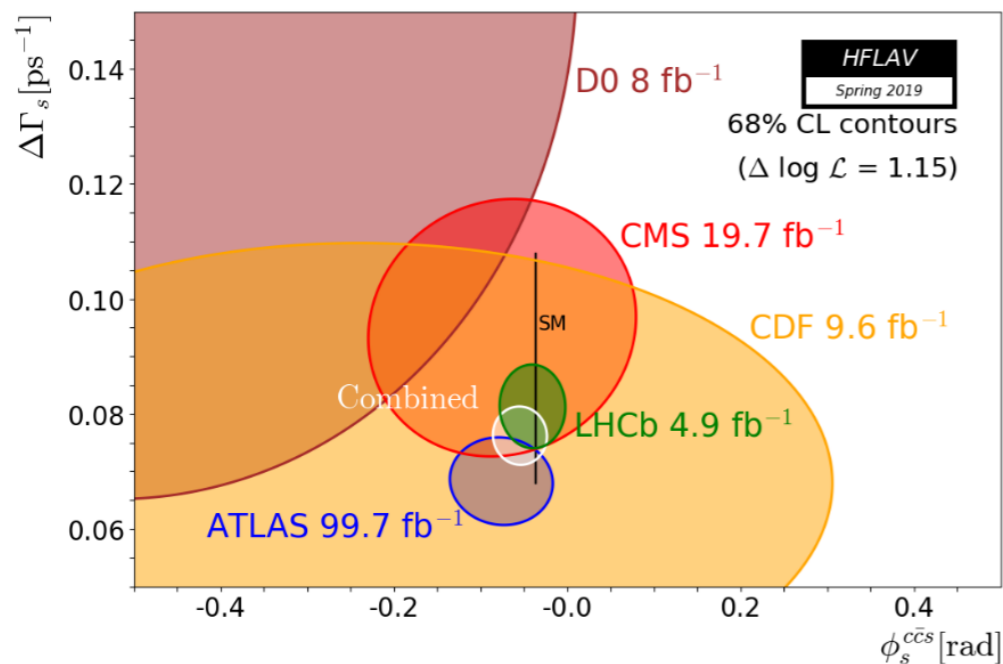
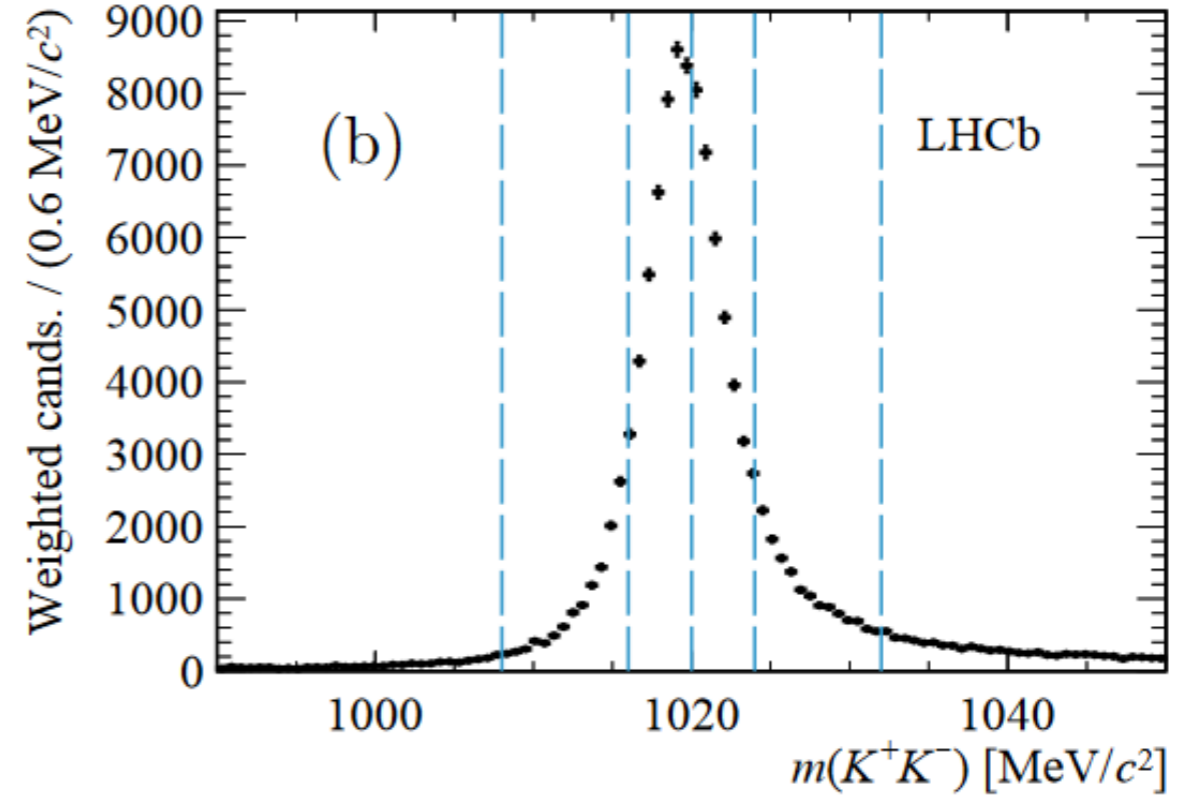
Recent results

Updated measurement of CP violating phase φ_s

[arXiv:1906.08356](https://arxiv.org/abs/1906.08356)



data sample 1.9 fb⁻¹ (Run2 only)



CP violation in Bs system
 $\varphi_s = -0.037$ rad in SM

$$\varphi_s = -0.041 \pm 0.025 \text{ rad (LHCb)}$$

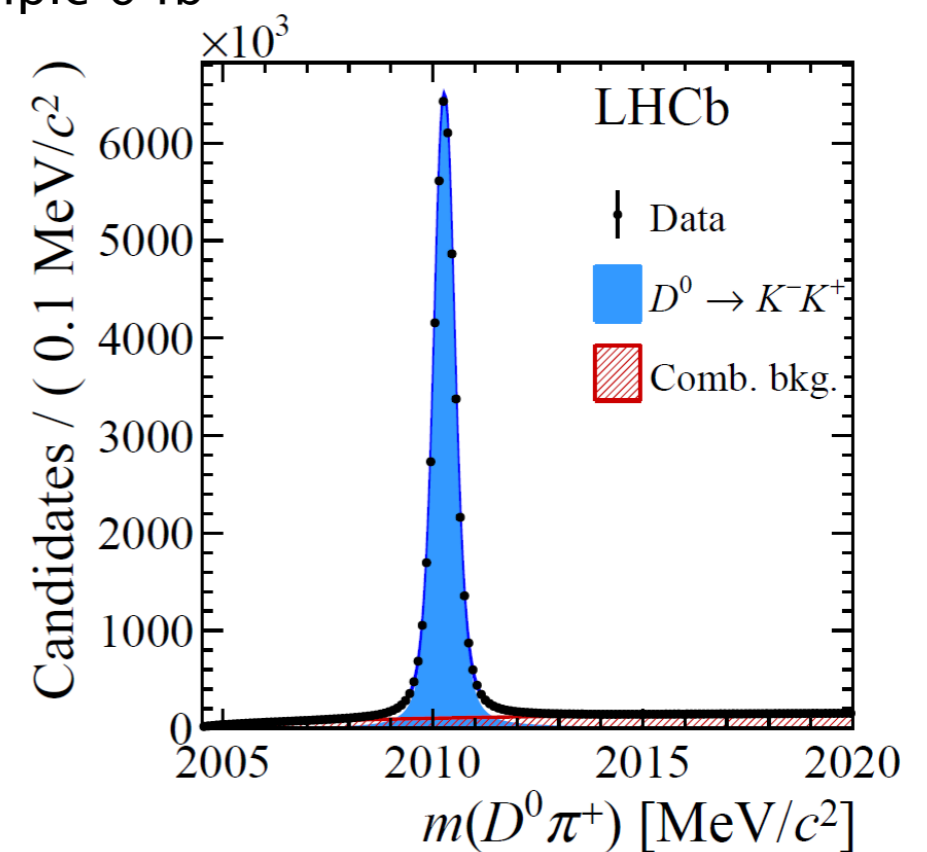
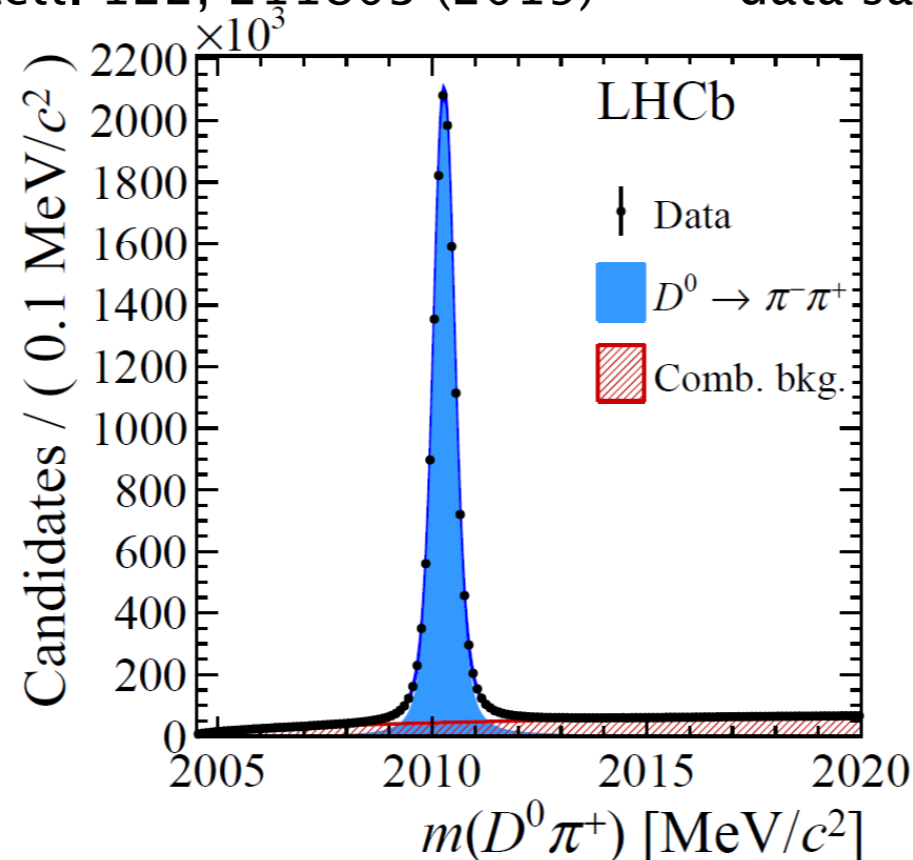
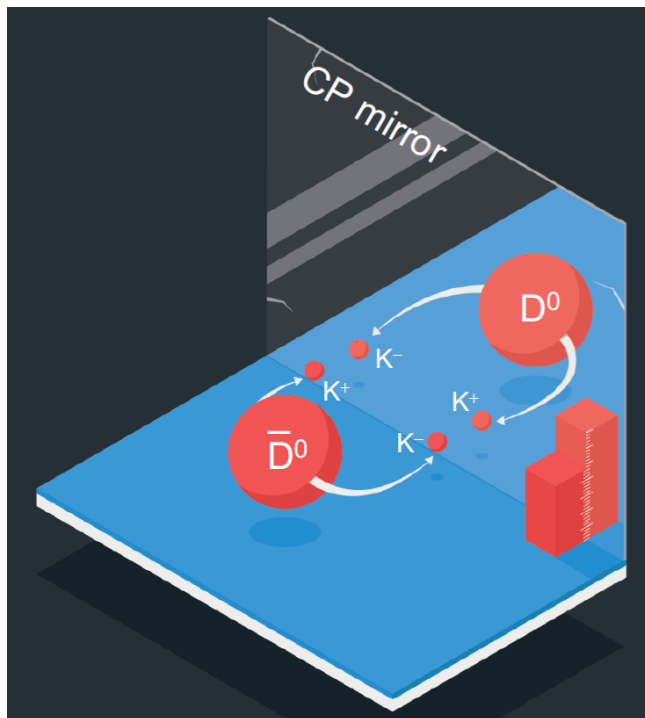
$$\varphi_s = -0.055 \pm 0.021 \text{ rad (World)}$$

Discovery of CP violation in charm particle decays

- ▶ An important milestone in the history of particle physics
- ▶ Difference of CP asymmetries between $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$ decays: $\Delta A_{CP} = (-0.154 \pm 0.029)\%$. SM predictions at 10^{-4} - 10^{-3} level
- ▶ Observed CPV at 5.3σ level

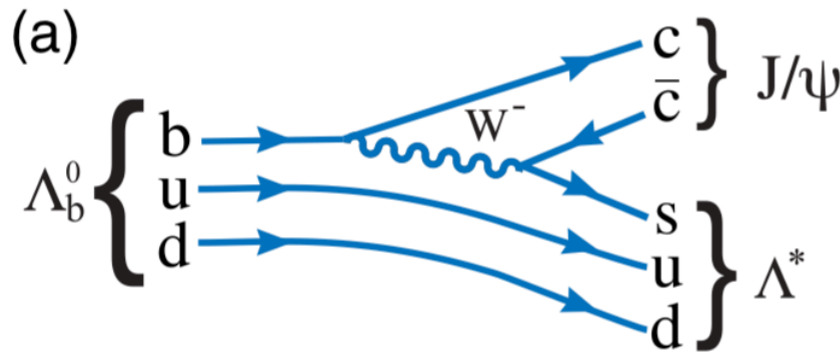
Phys. Rev. Lett. 122, 211803 (2019)

data sample 6 fb^{-1}

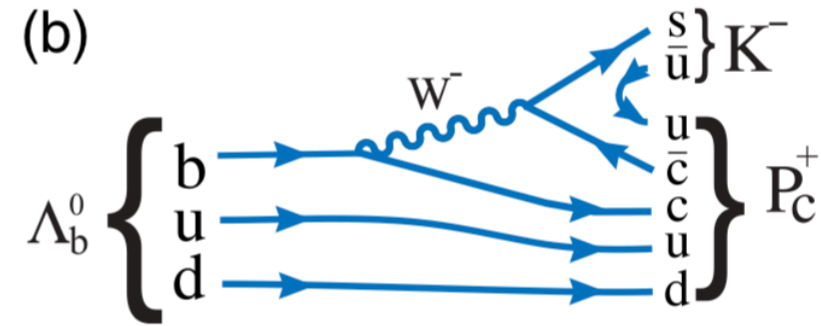


Pentaquark discovery in 2015

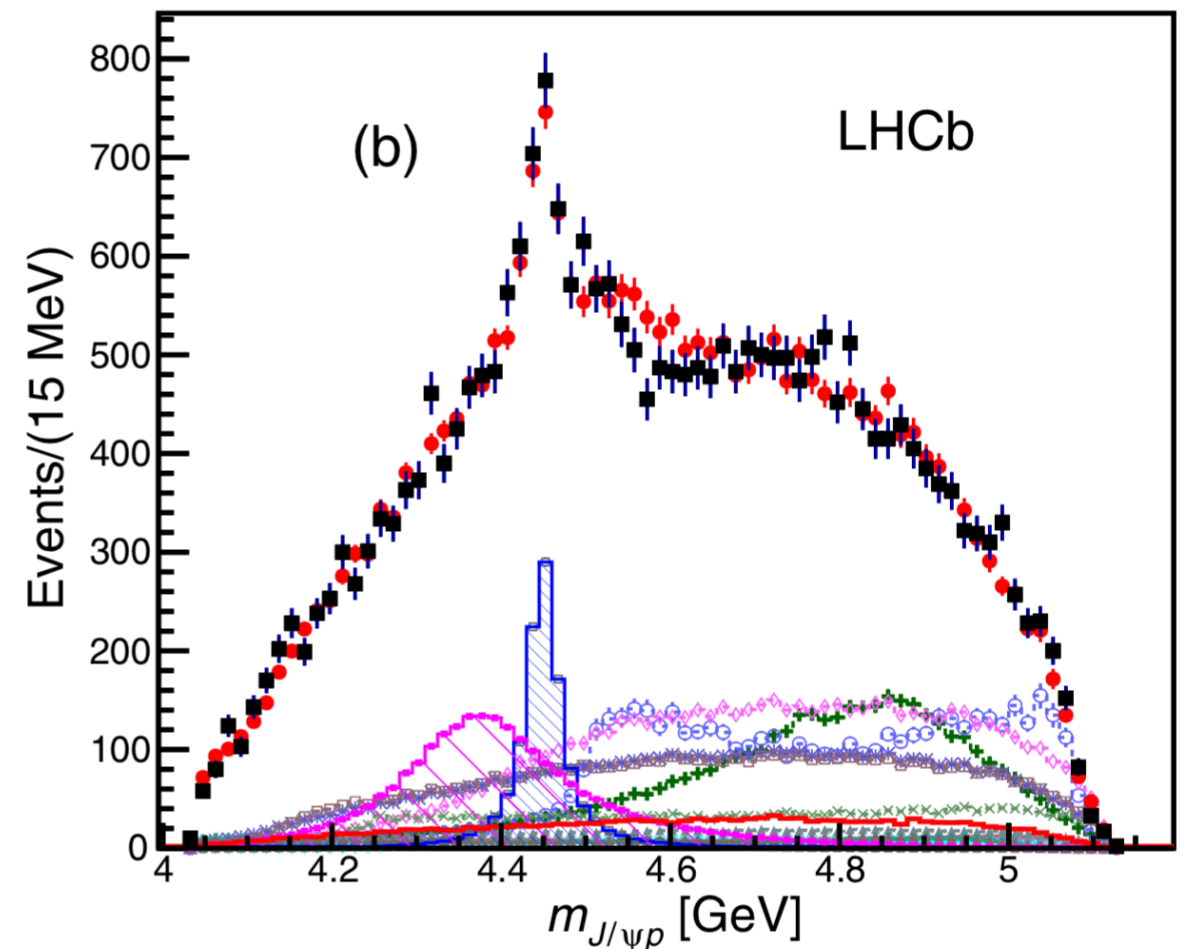
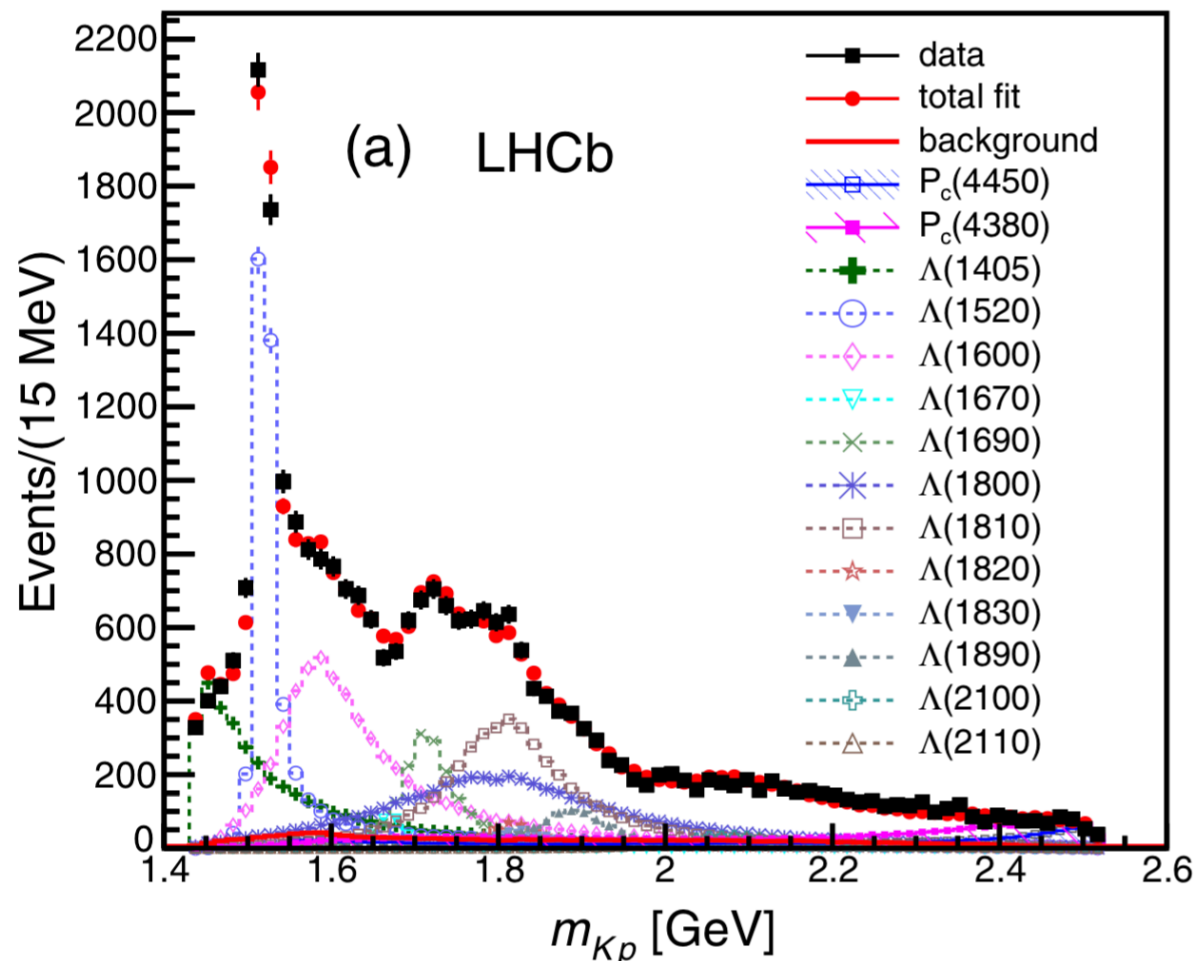
- ▶ Observation of $J/\psi p$ resonances consistent with Pentaquark states: $P_c(4450)^+$, $P_c(4380)^+$



Phys. Rev. Lett. 115, 072001 (2015)



data sample 3 fb⁻¹

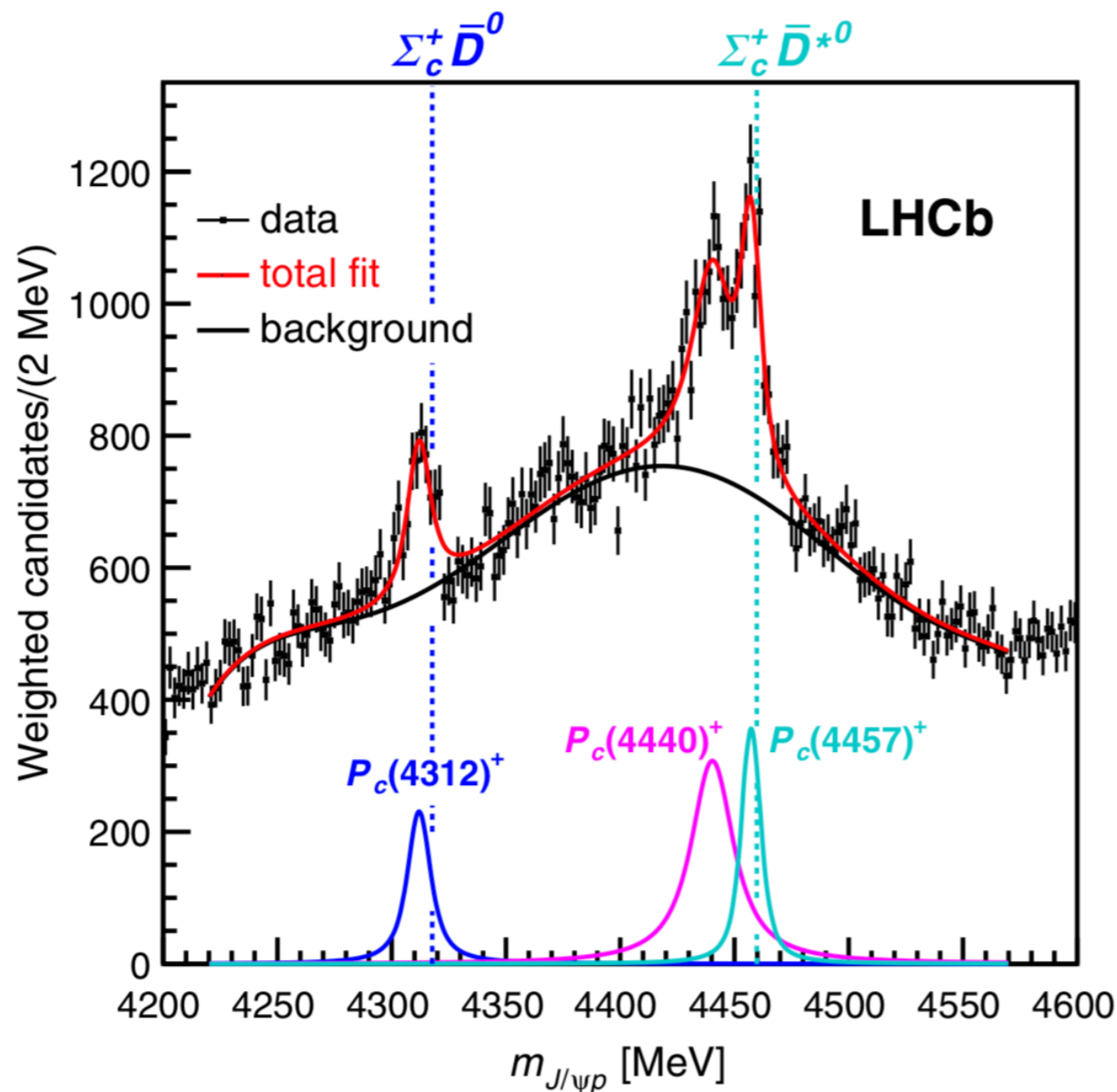


New pentaquark candidates in 2019

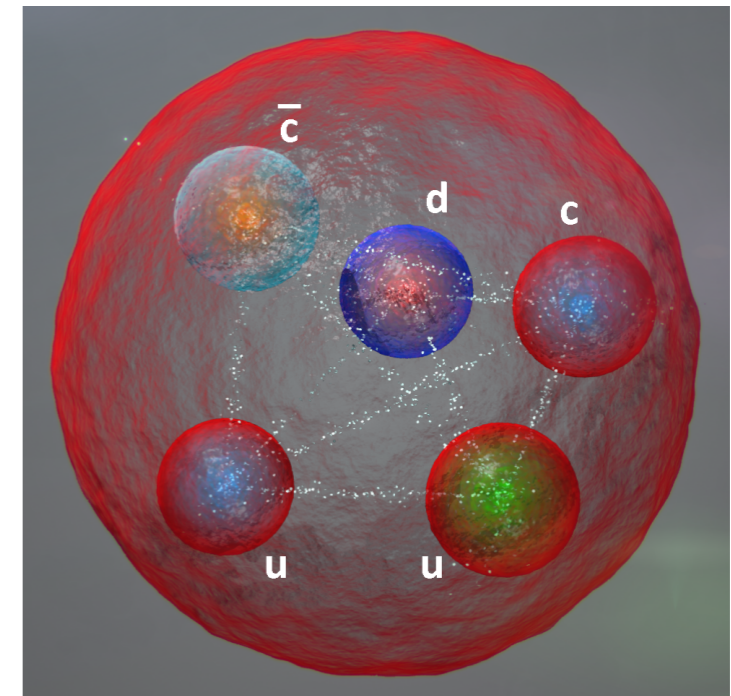
- ▶ New narrow resonances consistent with Pentaquark candidates observed in 2015

Phys. Rev. Lett. 122, 222001 (2019)

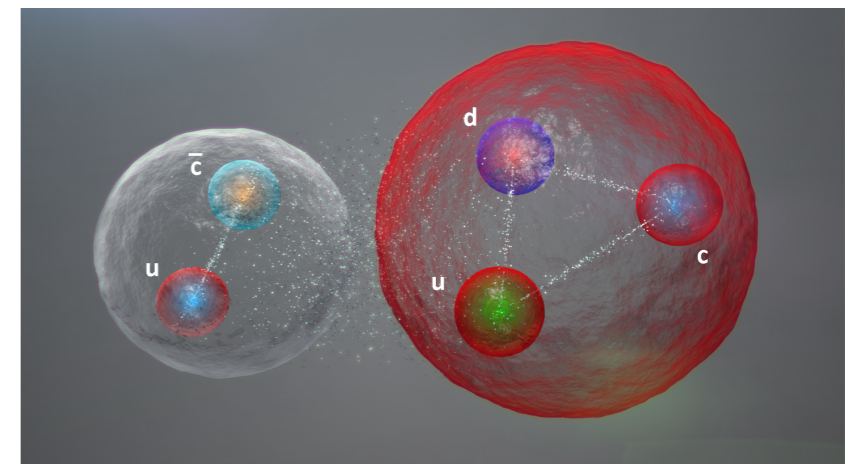
data sample 9 fb⁻¹



Pentaquark



Meson-Baryon Molecule



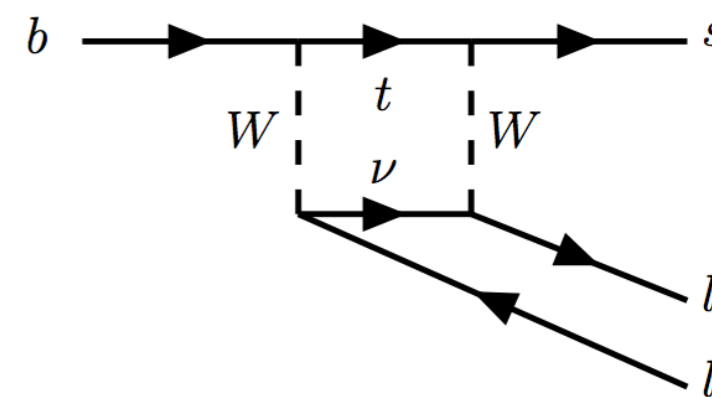
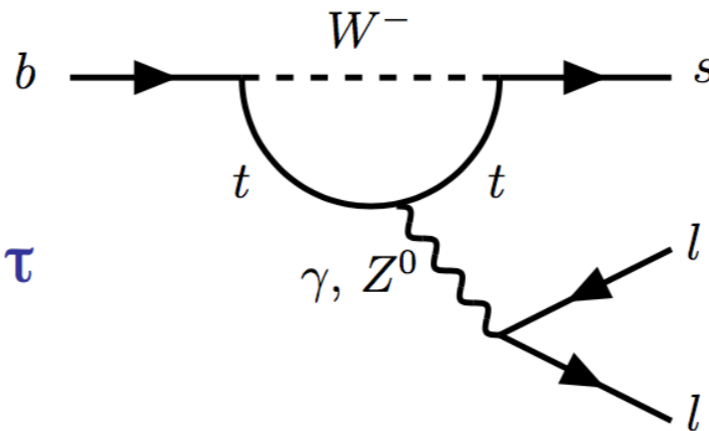
B → Kℓ⁺ℓ⁻ and lepton universality

Lepton Flavour Universality (LFU) in the SM:

— same EW couplings for ℓ = e, μ, τ

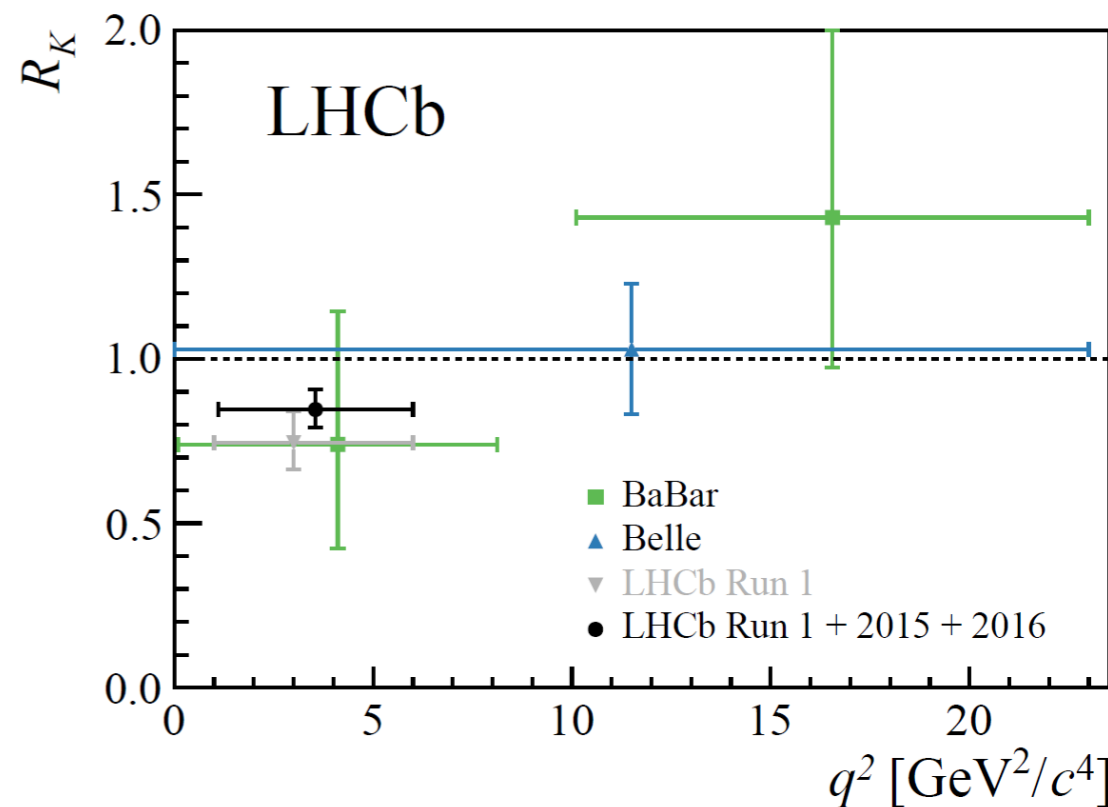
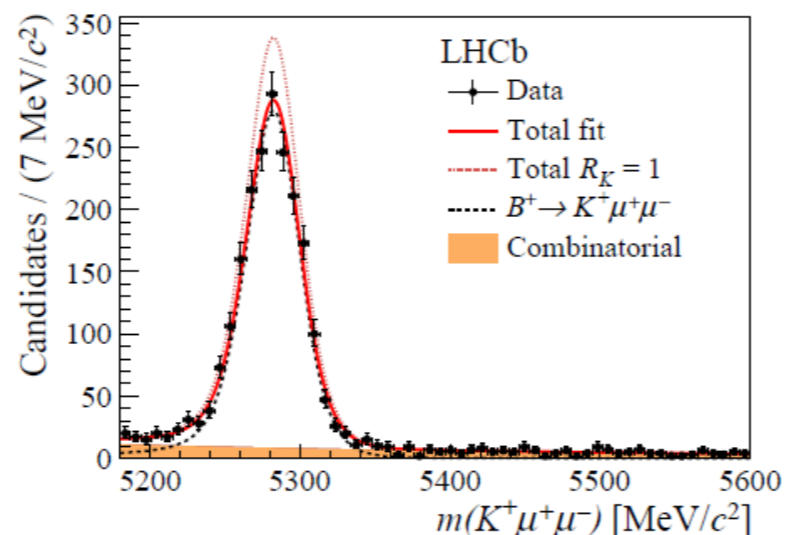
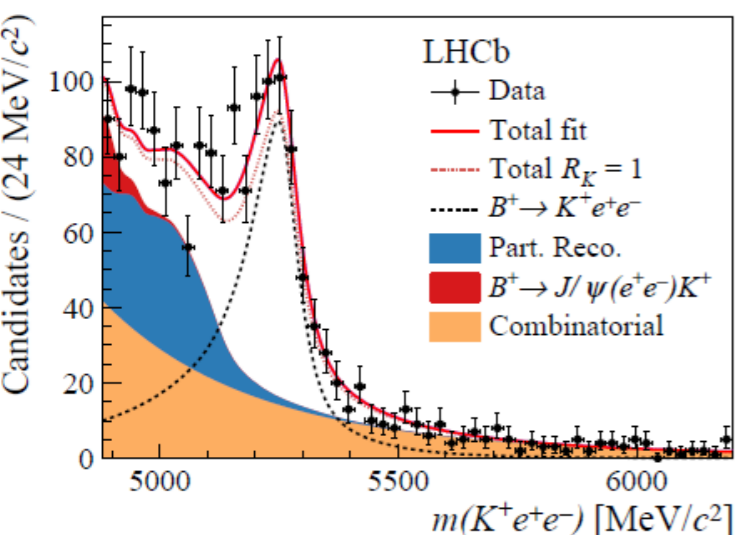
LHCb:

— electron reconstruction challenging,



Phys. Rev. Lett. 122, 191801 (2019)

data sample 5.0 fb⁻¹



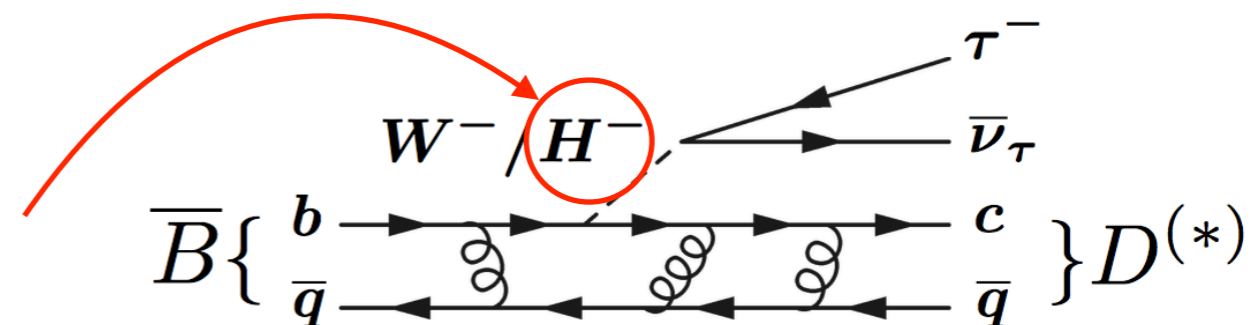
$$R_K = \frac{BR(B^+ \rightarrow K^+ \mu^+ \mu^-)}{BR(B^+ \rightarrow K^+ e^+ e^-)} = 0.846^{+0.060}_{-0.054} {}^{+0.016}_{-0.014}$$

2.5σ from the SM

Test of lepton flavour universality

LFU test with $B \rightarrow D^{(*)} \ell \nu$

tree level decay, sensitive to possible H^+ contribution



$R(D)$ and $R(D^*)$ definition

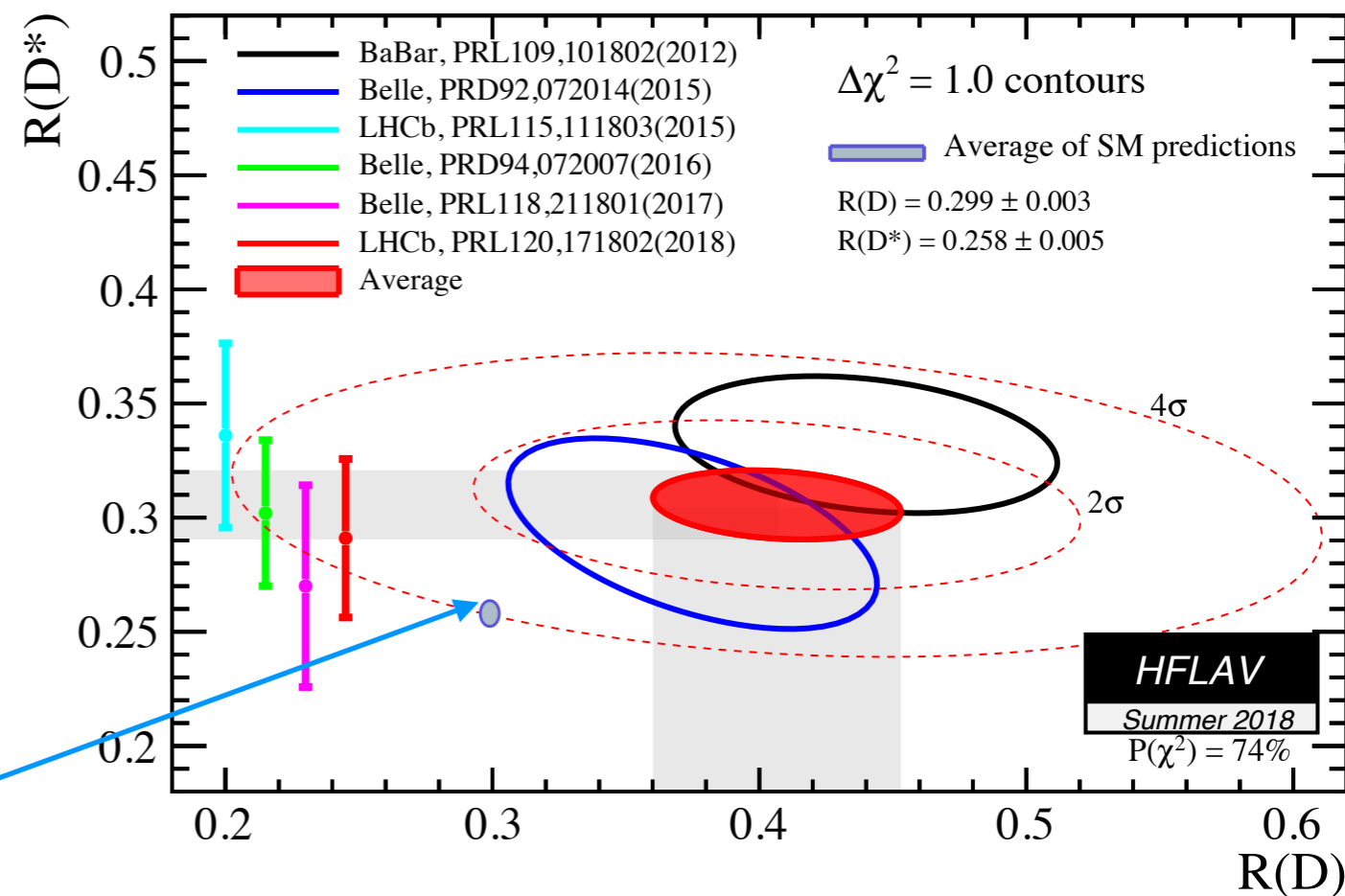
$$R(D^{(*)}) = \frac{B^0 \rightarrow D^{(*)-} \tau^+ \nu_\tau}{B^0 \rightarrow D^{(*)-} \ell^+ \nu_\tau}$$

$\ell = \mu, e$

Experimental challenge

- tau reconstruction, missing neutrinos

▶ **3.6 σ** from **SM**



Recent results of Milano group

Search for CPV in $\Lambda_b^0 \rightarrow pK^-K^+K^-$, $pK^-\pi^+\pi^-$ and $\Xi_b^0 \rightarrow pK^-K^-\pi^+$

[JHEP 1808 \(2018\) 039](#) [Fu](#), [Merli](#), [Neri](#)

Observation of baryonic resonances in $\Lambda_b^0\pi^\pm$ systems

[Phys. Rev. Lett. 122, 012001 \(2019\)](#) [Gandini](#) [[CERN courier article link](#)]

Observation of $B_{(s)}^0 \rightarrow J/\psi p\bar{p}$ decays and precision measurement of $B_{(s)}^0$ masses

[Phys. Rev. Lett. 122, 191804 \(2019\)](#) [Spadaro](#), [Fu](#), [Neri](#)

Search for CPV in $\Lambda_b^0 \rightarrow p\pi^-\pi^+\pi^-$ in review [Merli](#), [Fu](#), [Neri](#)

Update of analysis published on Nature Physics reporting first hint of CPV in heavy baryon decays

Observation of new baryonic resonances in review [Gandini](#)

Ongoing analyses in Milano

Amplitude analysis of charm baryon decays from semileptonic production [ongoing Marangotto, Neri](#)

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

Λ polarisation measurement in $\Xi_c^0 \rightarrow \Lambda K^- \pi^+$ decays [ongoing Fu](#)

Amplitude analysis of $B_{(s)}^0 \rightarrow J/\psi p \bar{p}$ decays for exotic state searches [ongoing Spadaro, Fu, Neri](#)

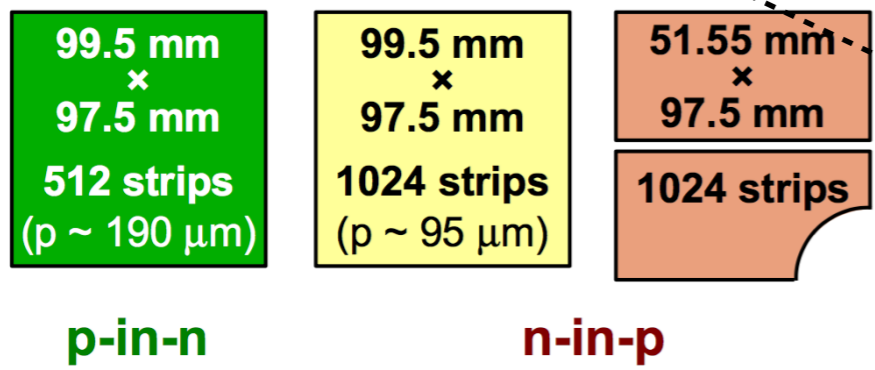
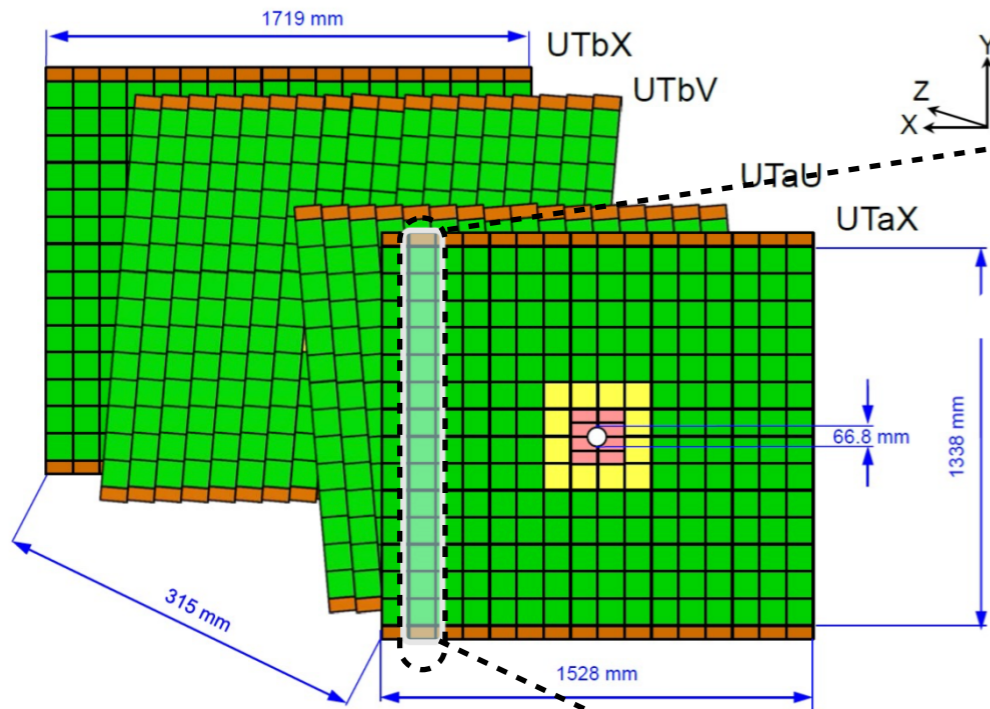
LHCb upgrade

UT detector upgrade

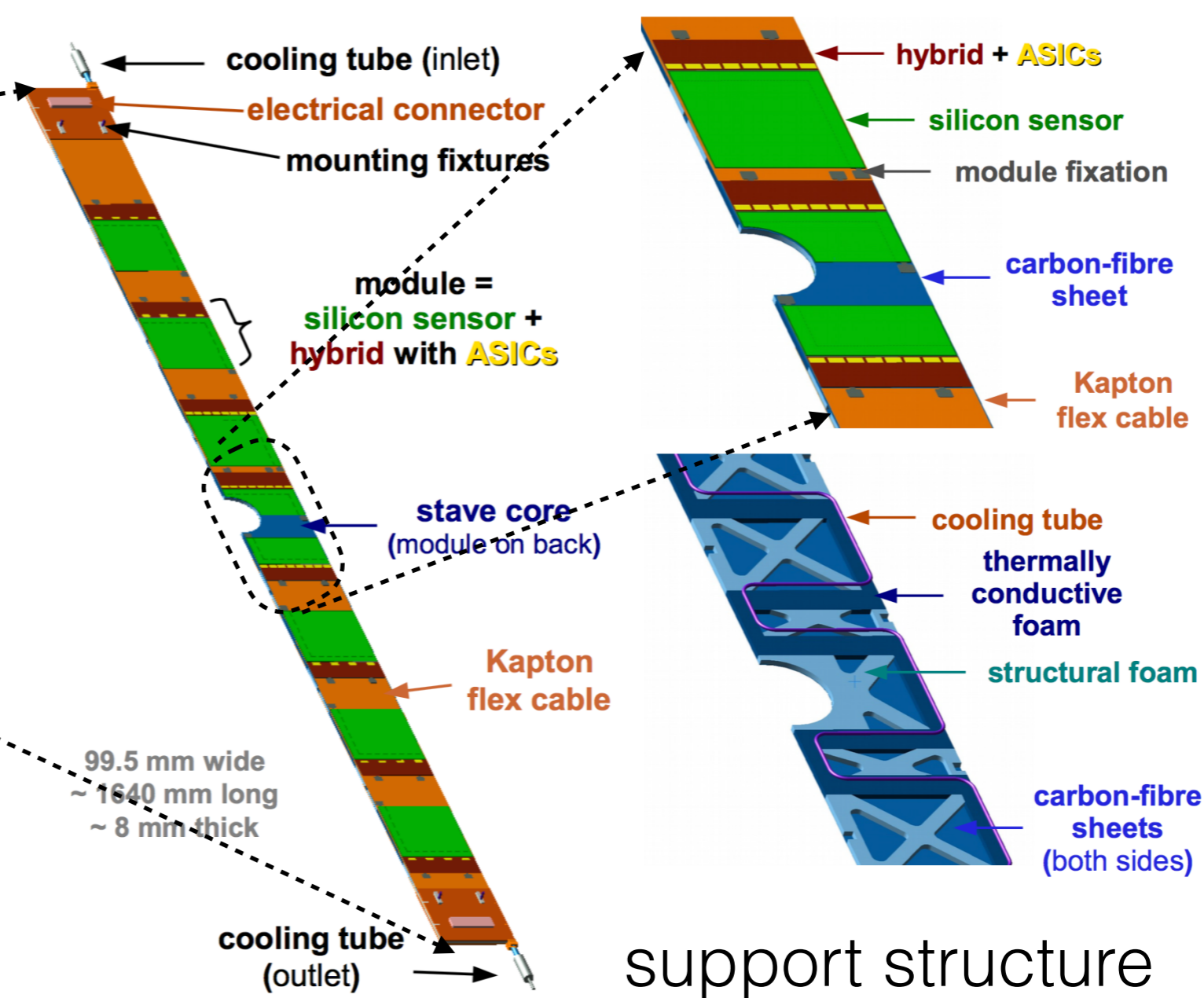
4 detection layers

stave design

module design



3 silicon sensor geometries



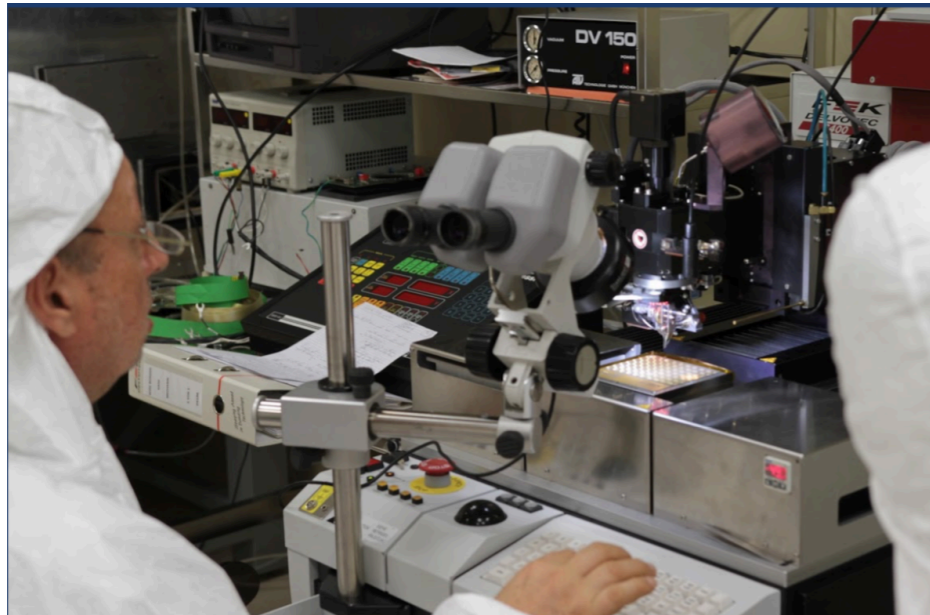
support structure
CO₂ cooling tube

Activities in Milano

- ▶ Production phase to be completed in 2019, installation in 2020
- ▶ Milano responsibilities in UT project:
 - ▶ **Flex cables**. Production and test (in progress at CERN)
 - ▶ **Hybrid circuit for ASIC**. Production by ARTEL in progress
 - ▶ **Integration** of hybrid and SALT chip: glueing, bonding, burn-in (started in Milano)
 - ▶ **CO₂ distribution system** in production
- ▶ 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

Equipment in Milano

Bonding machine from CERN
Delvotec FEK6400



Dry cabinet



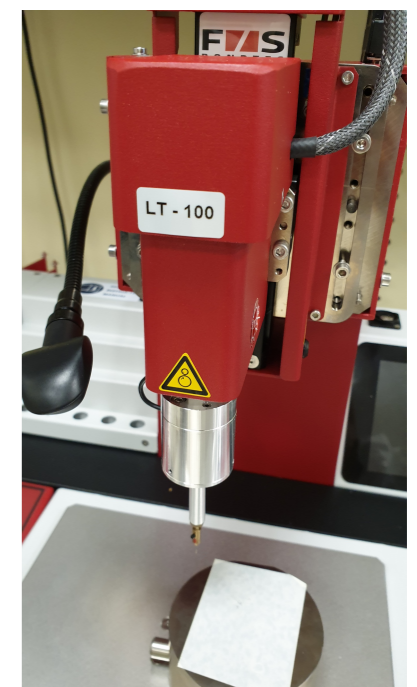
Glue dispenser



TRACI CO₂ cooling system

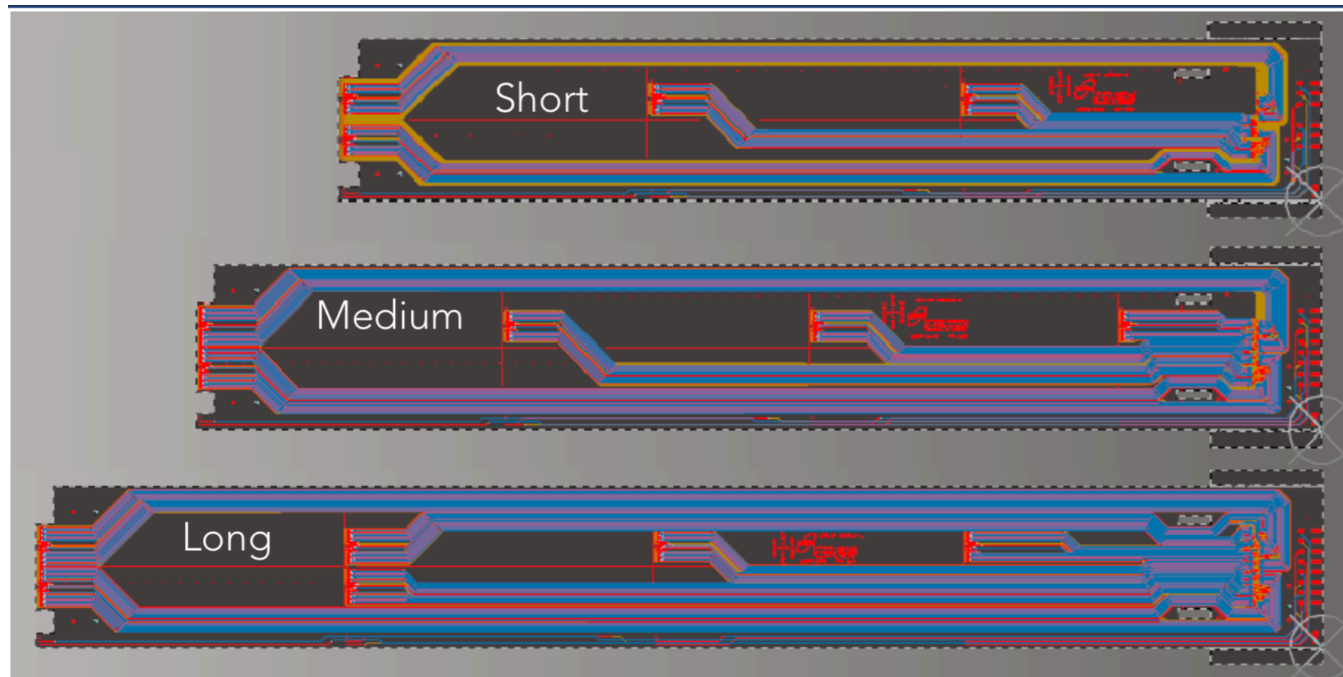


Pull tester



Flex cable production and test

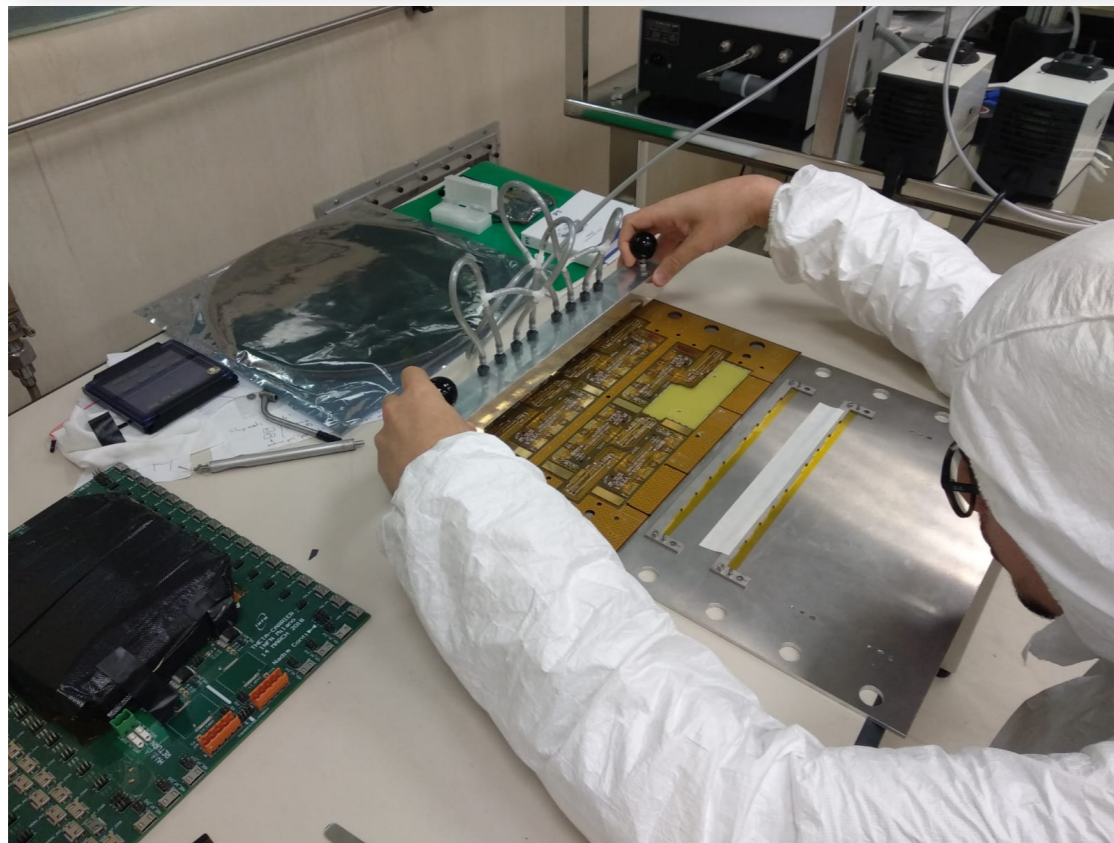
Citterio, Conti



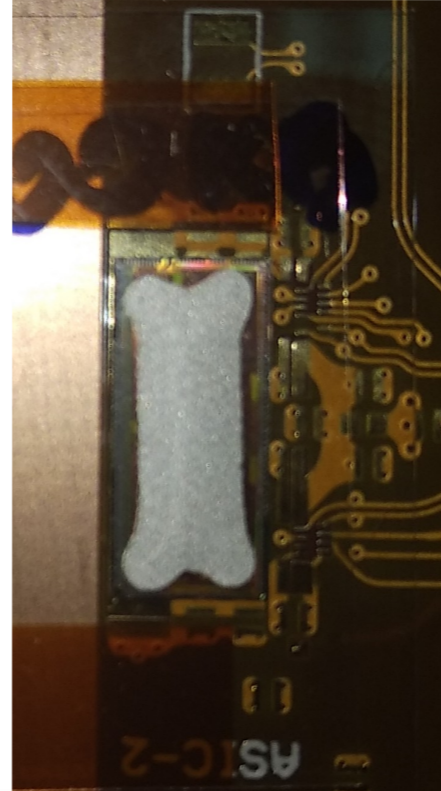
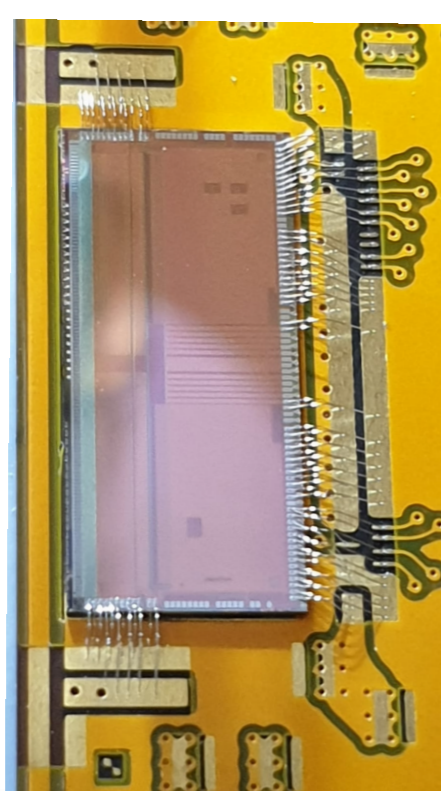
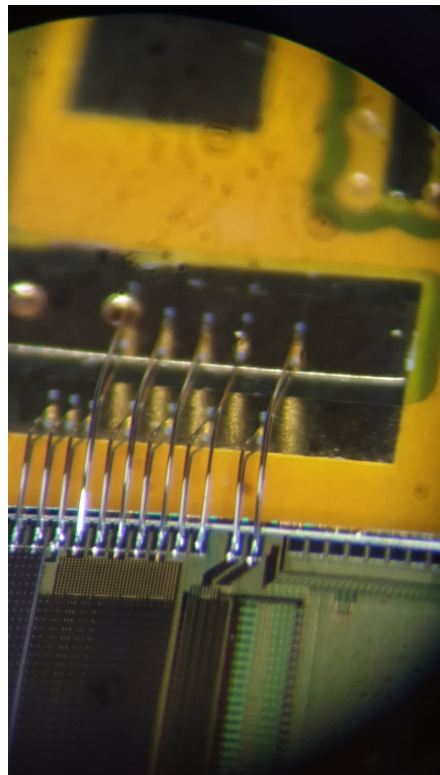
- ▶ Flex cable production of 300 cables takes 6 months
- ▶ Tender with QFLEX cancelled
- ▶ Production started at CERN

- ▶ Flex cable test at CERN (30 cables per week)
- ▶ Test automatico di 16 linee differenziali con TDR, attraverso scheda custom Jocelyn

Hybrid construction



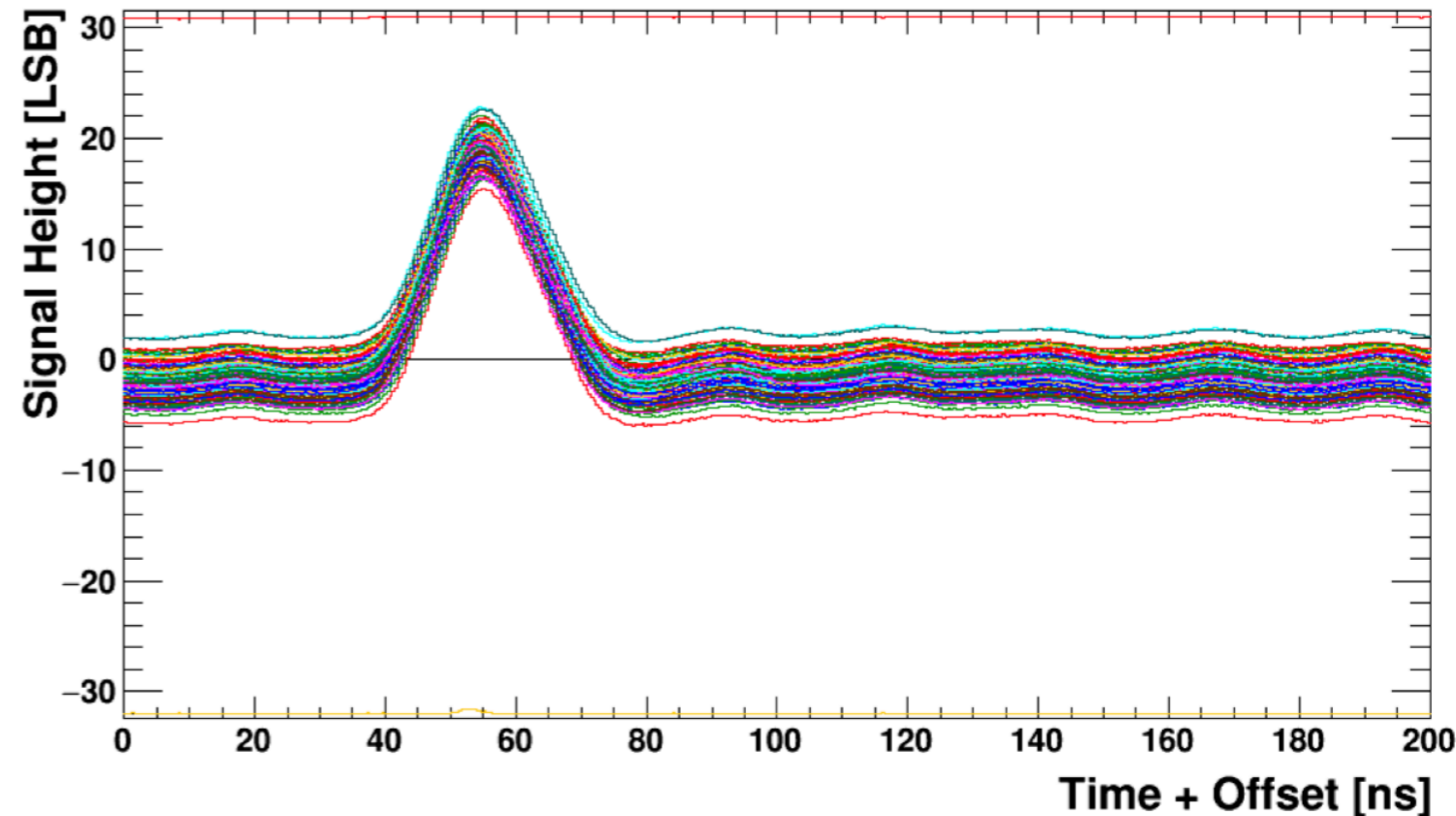
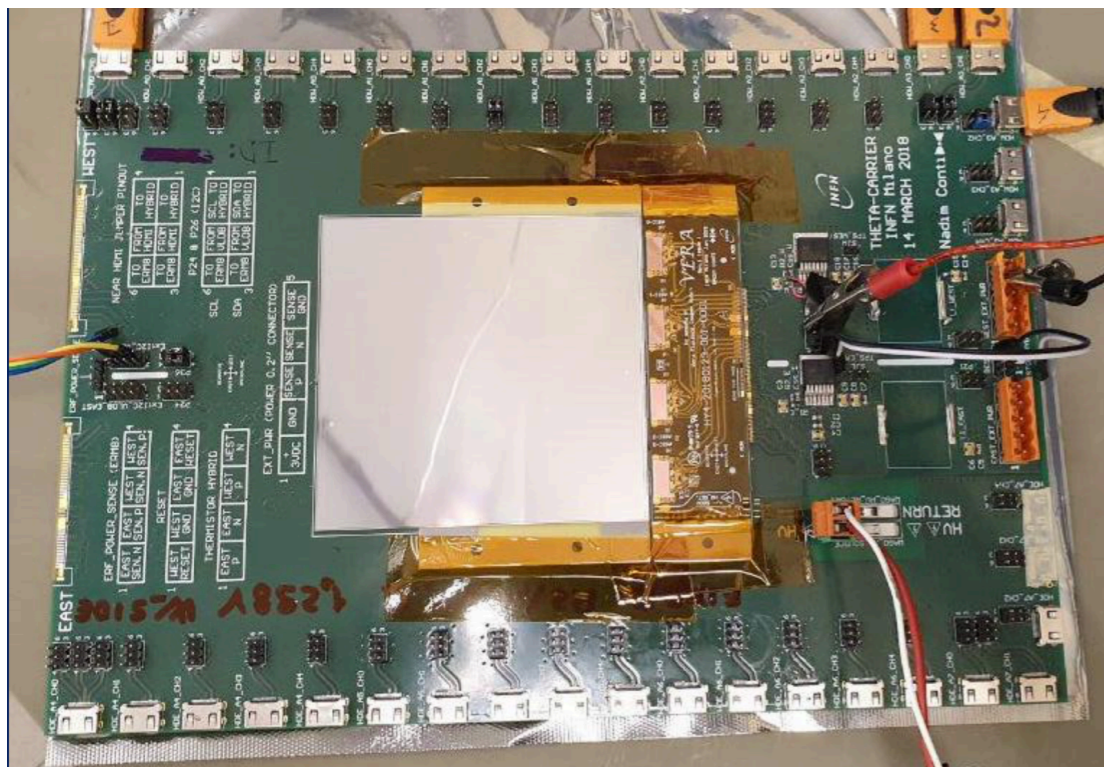
- ▶ 8 Hybrids per panel to facilitate shipment, testing, module construction
- ▶ Integration with ASIC, gluing, bonding, burn in test in Milano
- ▶ 1200 hybrids to construct and test, i.e. 4800 chips to glue and bond



Andreani, Carbone, Citterio,
Conti, De Benedetti,
Gandini, Manca, Petruzzo

Hybrid test

- ▶ SALT chip, hybrid, sensor: test and characterisation of prototypes
- ▶ Burn-in test to qualify hybrid production

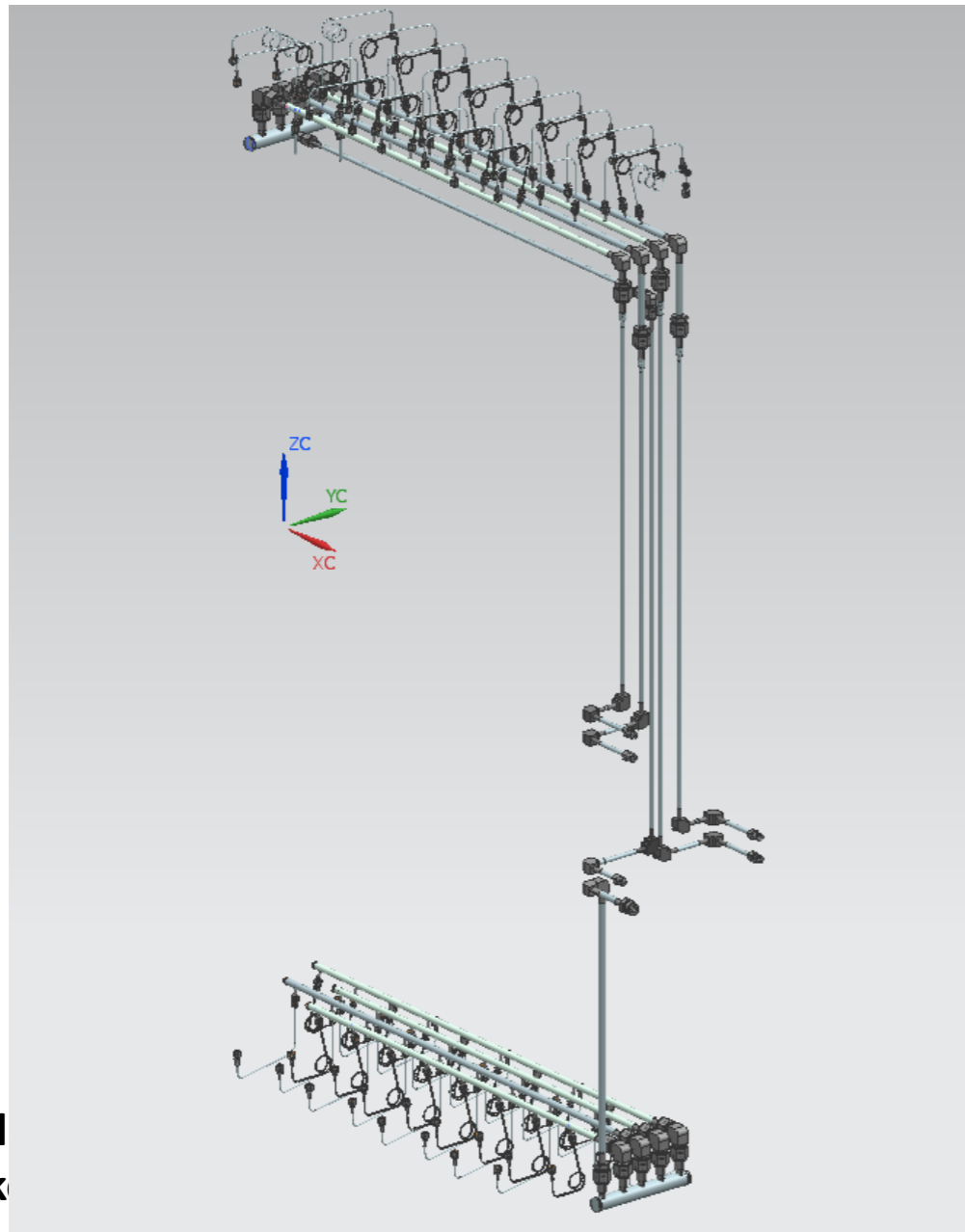


Andreani, Carbone, Citterio, Conti, De Benedetti, Petruzzo, Spadaro Norella

UT CO₂ distribution system

Designed in Milano

Tender process started at CERN



 Project Document N. 1970423 v.1	 Istituto Nazionale di Fisica Nucleare Sezione di Milano Via Celoria,16 20133 Milano, Italy	LHCb UT DETECTOR CO ₂ COOLING DISTRIBUTION PROTOTYPE	
		Created 2018-05-10 Modified: -	Page: 1 of 10 Rev. N. 0

Description document LHCb UT DETECTOR CO₂ COOLING DISTRIBUTION PROTOTYPE		
<p>This document describes the CO₂ cooling distribution system proposed for the UT detector. The design choices and the technological aspects for the manifolds and connection pipes are described. The working drawings for the prototype production are uploaded in the EDMS document.</p>		
Prepared by: Simone Coelli- INFN MI Danilo Trotta- INFN MI	Checked by:	Approved by:
Distribution List		

Coelli, Trotta, Gesmundo

Repl
gask

ts

Conference contributions

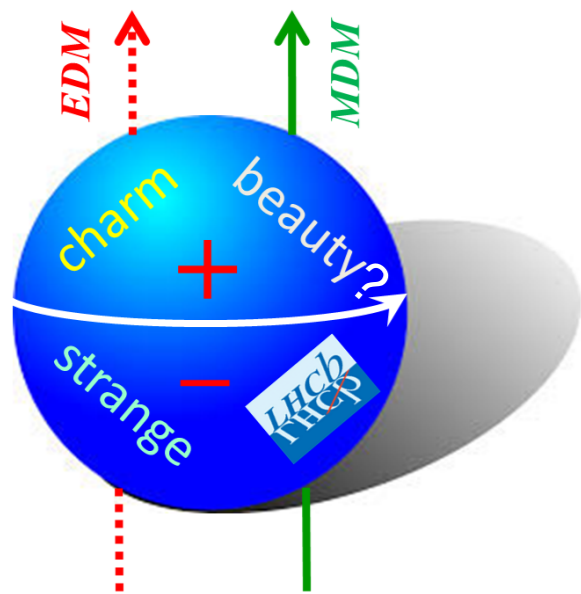
- 1) Lepton Photon, Toronto, Canada, 5-10 Aug 2019, Talk “Prospects for electromagnetic dipole moments of short-lived particles at the LHC”, [N. Neri](#)
- 2) LHCP 2019, Pueblo, Mexico, 20-25 May 2019, Talk: “Recent results on heavy flavour production and spectroscopy with LHCb”, [P. Gandini](#)
- 3) Moriond QCD, La Thuille, Italy, 23-30 March 2019, Talk: “Results from proton-lead and fixed-target collisions at LHCb”, [D. Marangotto](#)
- 4) CLASHEP, Cordoba, Argentina, 13-26 March 2019, Poster: “Search for decays $B(s) \rightarrow J/\Psi p\bar{p}$ ”, [E. Spadaro Norella](#)
- 5) LHCC open session, CERN, 27 Feb 2019, Poster: “Search for decays $B(s) \rightarrow J/\Psi p\bar{p}$ ”, [E. Spadaro Norella](#)
- 6) Kruger, Mpumalanga, South Africa, 12-19 March 2019, Talk: “Heavy flavour spectroscopy at LHCb”, [N. Neri](#)

Conference contributions

- 7) SIF, Arcavacata di Rende, Italy, 17-21 September 2018, Talk: “ Observation of the $B^0(s) \rightarrow J/\Psi p \text{ anti-}p$ decays and precise $B^0(s)$ mass measurement”, **E. Spadaro Norella (First prize for best communication)**
- 8) Hints for New Physics in Heavy Flavour, Nagoya, Japan, 15-17 November 2018, Talk: “Search for CP violation in beauty baryon decays”, A. Merli
- 9) Vertex 2018, Chennai, India, 21-26 November 2018, Talk: “Design and construction of the LHCb Upstream Tracker”, M. Citterio
- 10) Implication workshop, 10-17 November 2018, CERN, Talk: “Ultrapерipheral collisions & Central Exclusive Production”, P. Gandini
- 11) ICHEP 2018, Seoul, Korea, 4-11 Aug 2018. Talk: “CP violation in b-baryon decays at LHCb”, J. Fu
- 12) ICHEP 2018, Seoul, Korea, 4-11 Aug 2018. Talk: “Search for exotic baryonic states at LHCb”, P. Gandini
- 13) ICHEP 2018, Seoul, Korea, 4-11 Aug 2018. Poster: “CP violation in b-baryon decays at LHCb”, P. Gandini

Richieste servizi di sezione

- ▶ Completamento costruzione, test ibridi e spares (versione 4 chip e 8 chip)
- ▶ Installazione, collaudo e messa a punto del sistema di cooling a CO₂
- ▶ Richieste:
 - ▶ 10% FTE Mauro Citterio (10 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 l'anno scorso)**
 - ▶ **In camera pulita UR del 60%-70% in questi giorni. Va risolto urgentemente!**



SELDOM

Search for the electric dipole moment of the strange and charm baryons at LHC



Nicola Neri
Istituto Nazionale di Fisica Nucleare, Italy



Proposal n° 771642 SELDOM
ERC CoG PE2

European Research Council
Established by the European Commission

Electromagnetic dipole moments

▶ Definition $\delta = \int \mathbf{r} \rho(\mathbf{r}) d^3 r$

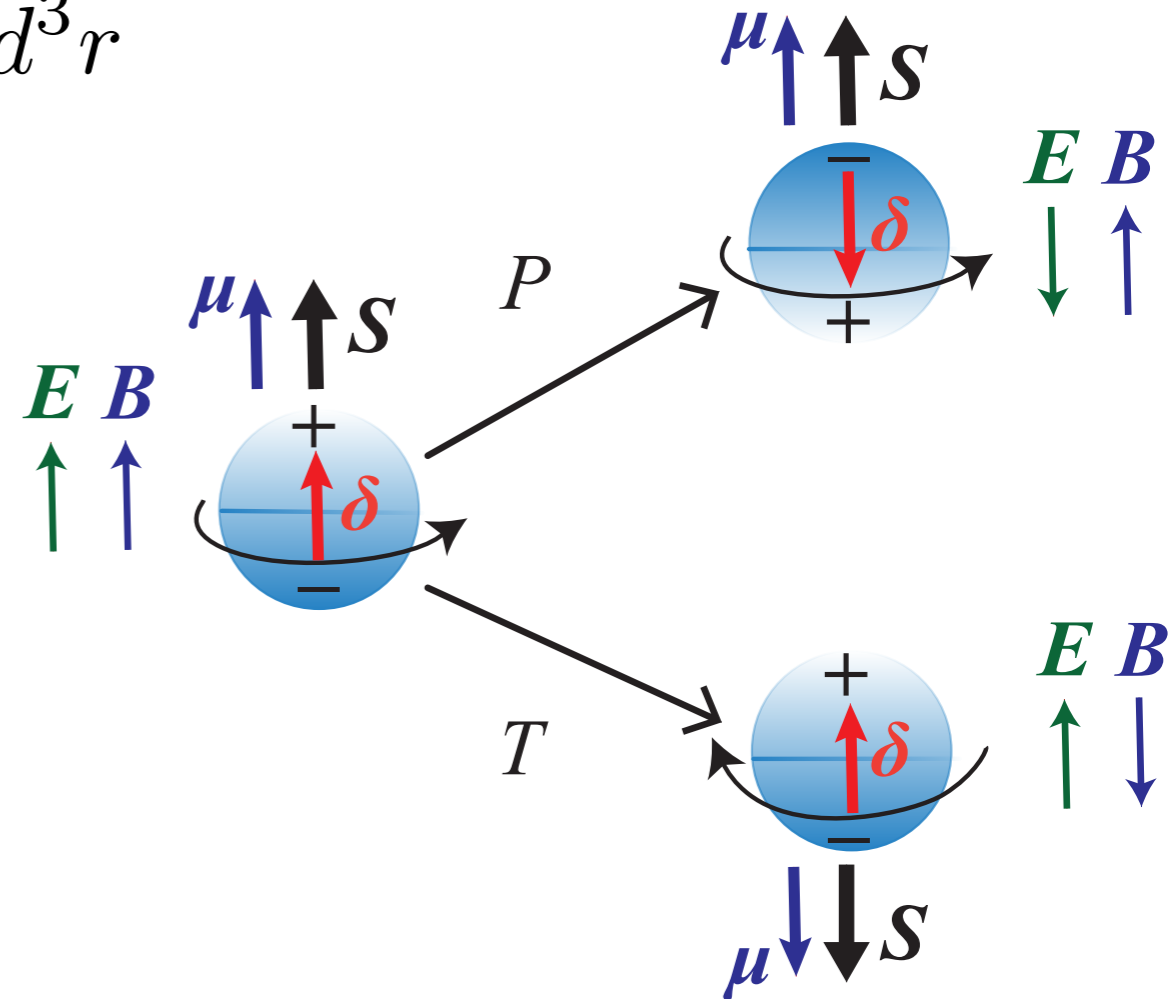
▶ Quantum systems

$$\delta = d\mu_N \frac{\mathbf{S}}{2} \quad \mu = g\mu_N \frac{\mathbf{S}}{2}$$

▶ Hamiltonian

$$H = -\delta \cdot \mathbf{E} - \mu \cdot \mathbf{B}$$

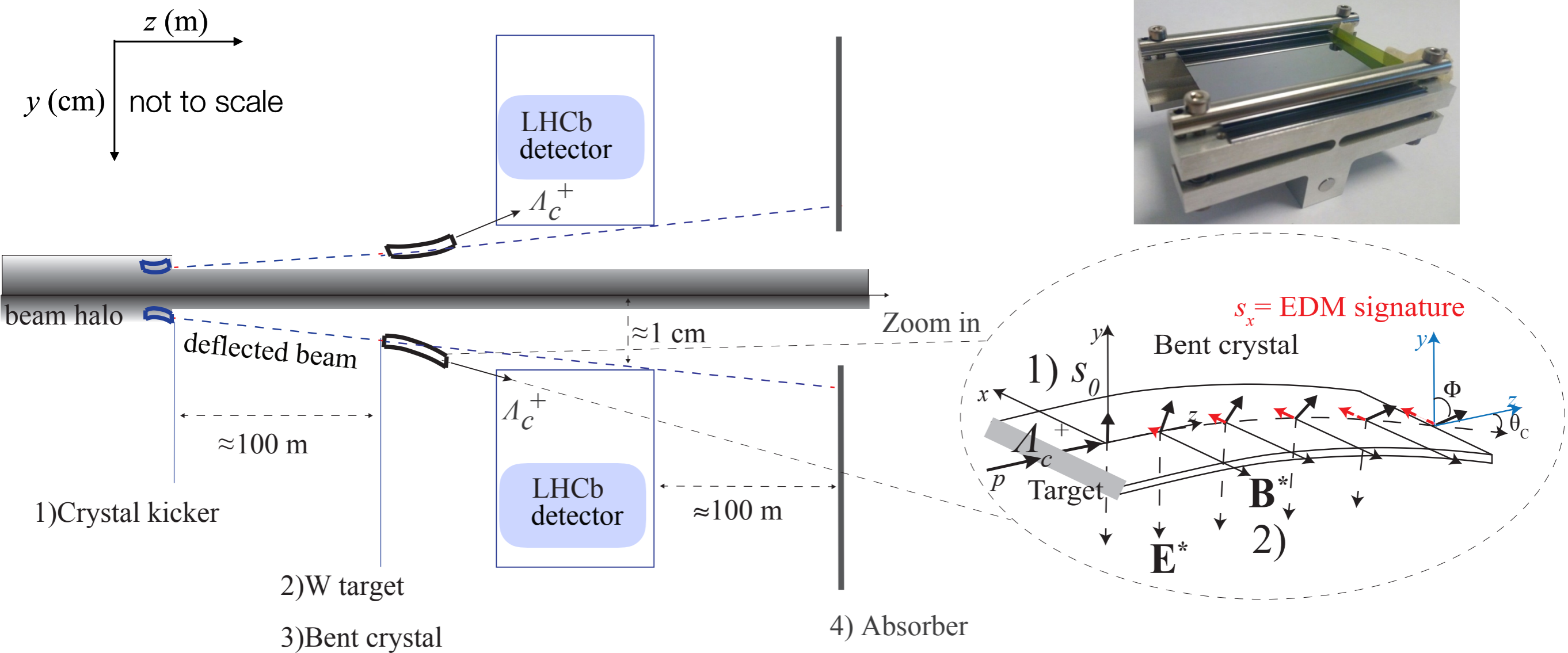
Time reversal, parity: $d\mu_N \frac{\mathbf{S}}{2} \cdot \mathbf{E} \xrightarrow{T,P} -d\mu_N \frac{\mathbf{S}}{2} \cdot \mathbf{E}$



The EDM **violates** T and P and via CPT theorem, **violates** CP

Novel fixed-target experiment at LHC for charm baryons

- ▶ EDM/MDM from spin precession of channeled baryons in **bent crystals**

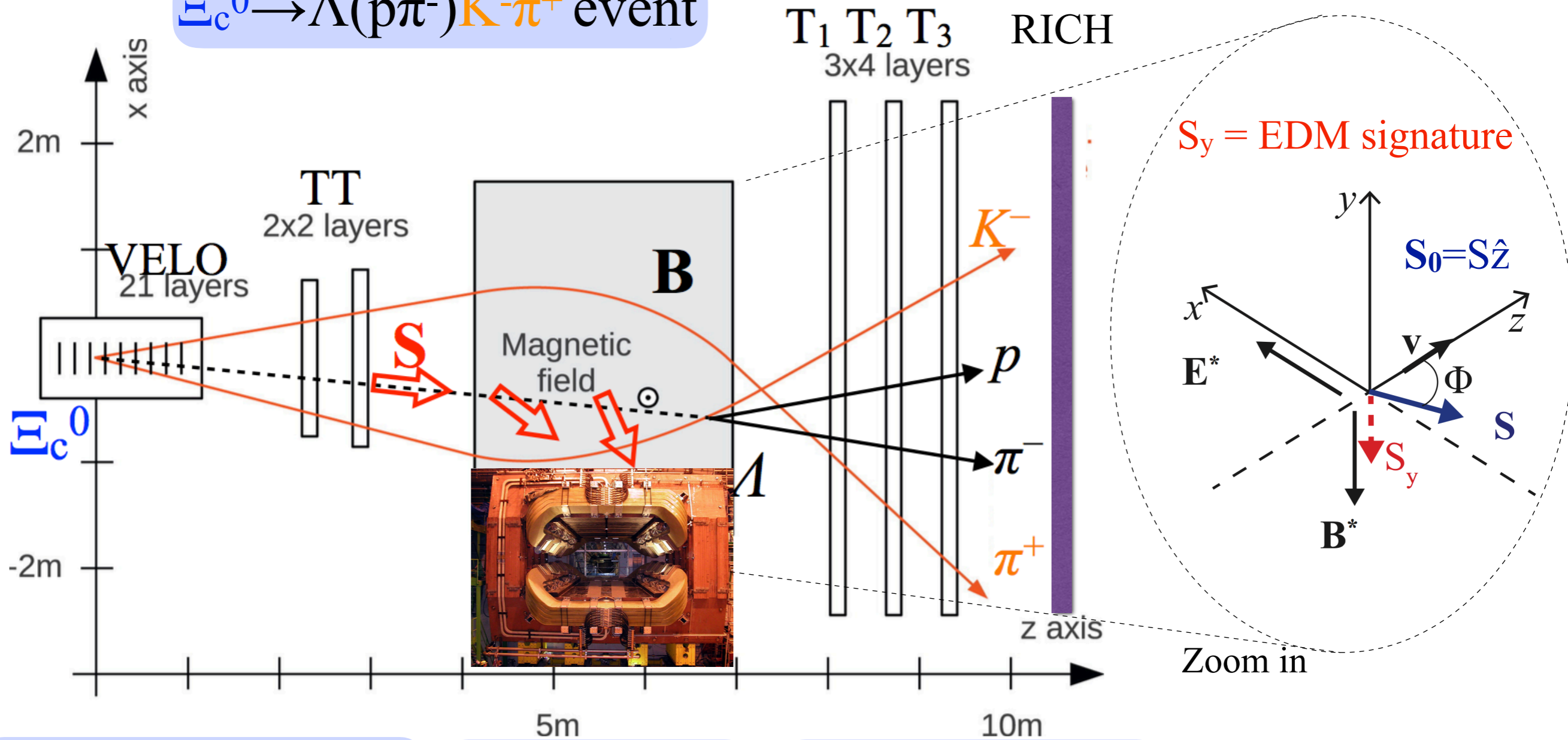


p extraction Λ_c^+ polarised production channeling spin precession event reconstruction

Novel experimental technique for strange baryons

- EDM/MDM from spin precession of Λ baryon in LHCb dipole magnet

$\Xi_c^0 \rightarrow \Lambda(p\pi^-)K^-\pi^+$ event

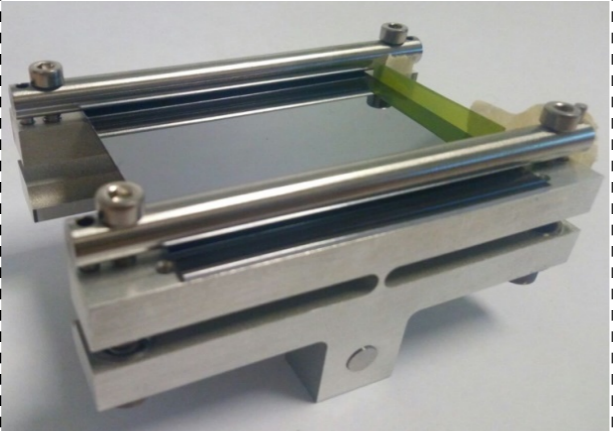
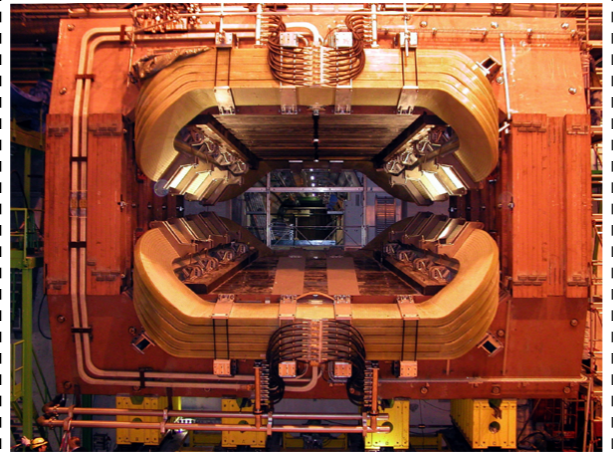


Λ polarised production

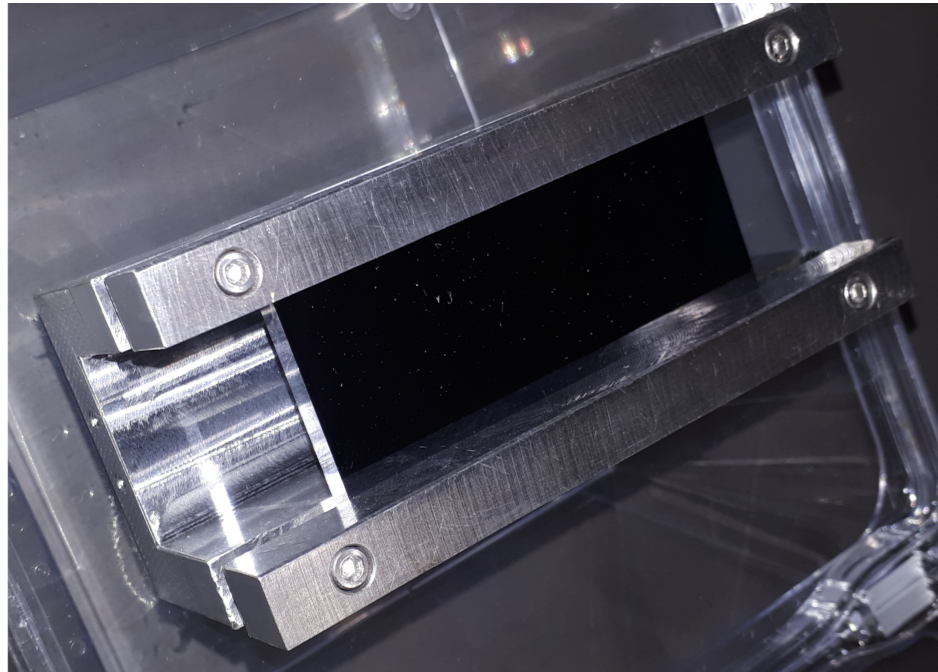
spin precession

event reconstruction

Challenges and preliminary results

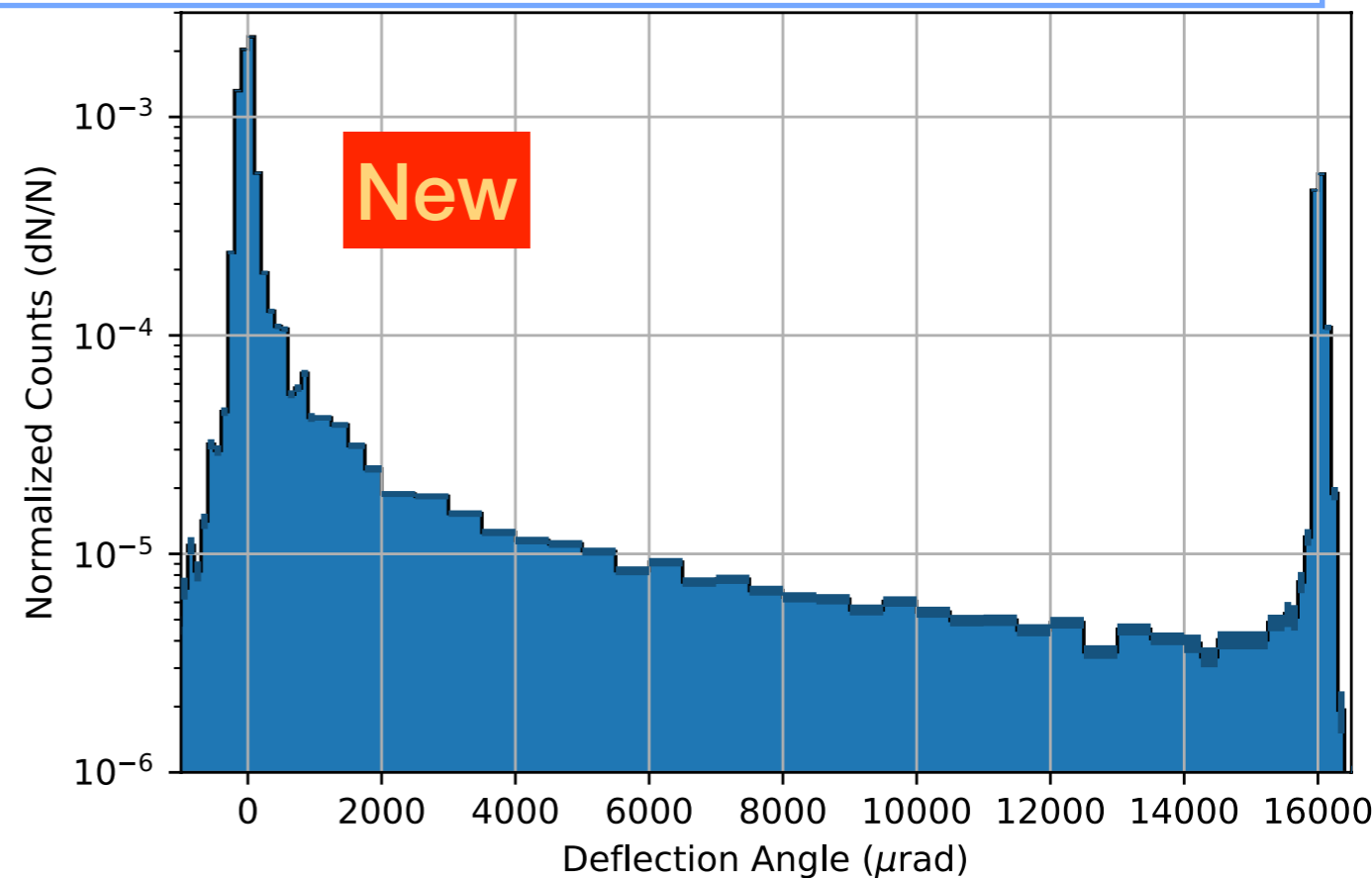
Baryon	Solution	Challenge	Preliminary
<p>Charm Λ_{c^+}, Ξ_{c^+}</p> <p>lifetime $\sim 10^{-13}$ s</p>		<ul style="list-style-type: none"> ▶ Fixed-target setup ▶ Bent crystals with large bending angle (≥ 10 mrad) 	<ul style="list-style-type: none"> ✓ Long bent crystal constructed and tested on beam ✓ Machine layout simulations <p>New</p>
<p>Strange Λ</p> <p>lifetime $\sim 10^{-10}$ s</p>		<ul style="list-style-type: none"> ▶ Reconstruction of long-lived Λ baryons after magnet 	<ul style="list-style-type: none"> ✓ Simulations ✓ Kinematic constraints from entire decay chain ✓ Λ decay vertex

Testbeam in October 2018



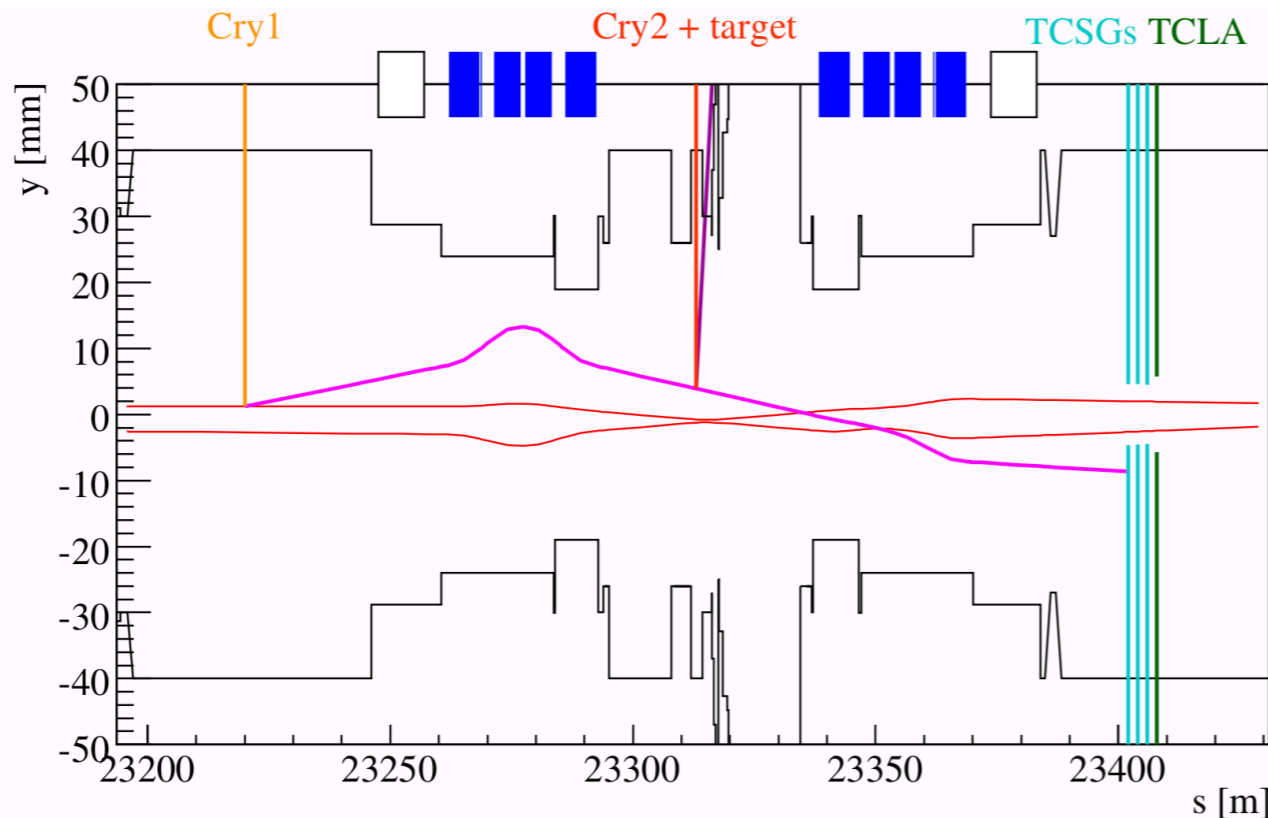
- ▶ Long bent crystal successfully tested at CERN SPS
- ▶ Silicon crystal 8 cm long, bending angle 16 mrad

Aiola, Fu, Merli, Marangotto, Neri

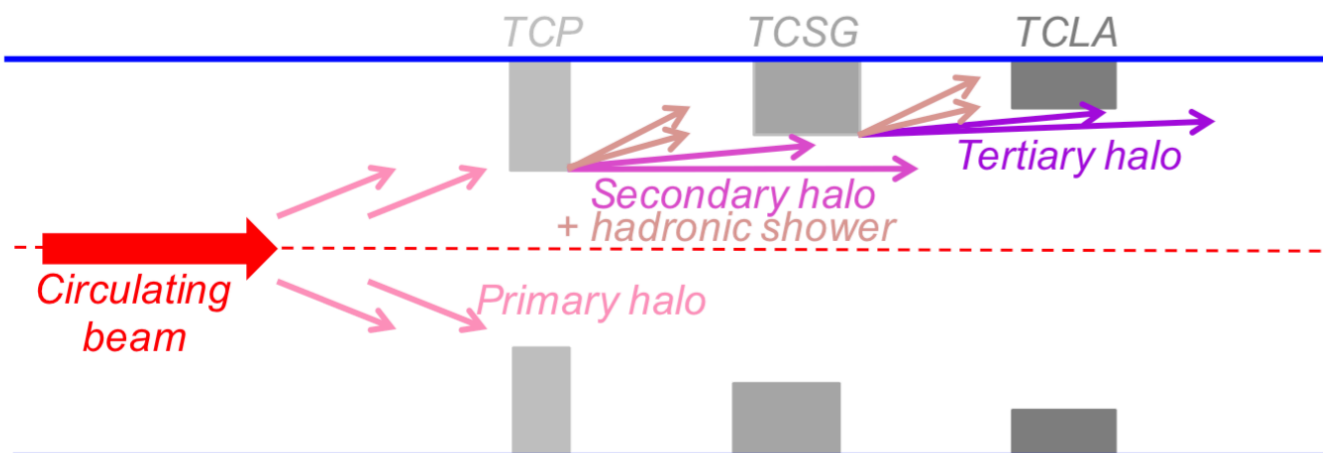


Machine simulations

New



- ▶ LHC machine simulations proved the feasibility of the fixed-target setup with bent crystals
- ▶ Proton flux lower than expected $\sim 10^6$ p/s but still useful for the experiment
- ▶ Studies documented in [arXiv:1906.08551](https://arxiv.org/abs/1906.08551)



Conference contributions

- 1) Hints for New Physics in Heavy Flavour, Nagoya, Japan, 15-17 November 2019, Talk “SELDOM: search for electric dipole moment of heavy baryons at LHC”, [A. Merli](#)
- 2) Physics Beyond Collider Annual Workshop, 16-17 Jan 2019, CERN, Talk: “LHC-Fixed-Target Crystals”, [N. Neri](#)
- 3) Channeling 2018, Ischia, Italy, 23-28 September 2018, Invited talk: “Electromagnetic Dipole Moments of Charged Baryons with Bent Crystals at the LHC”, [N. Neri](#)

Attività' 2020 e richieste servizi di sezione

- ▶ Progetto e costruzione telescopio per caratterizzazione di cristalli curvi su fascio
- ▶ Progetto e costruzione prototipo per camera a vuoto e sistema di posizionamento (goniometro) per cristalli curvi in LHC
- ▶ **Spazio di laboratorio (già richiesto l'anno scorso)**
- ▶ **6 m.u. servizio elettronico**
- ▶ **10% Coelli, 6 m.u. servizio progettazione e officina meccanica**

Composizione gruppo di ricerca 2019

Personale	FTE	LHCb (FTE)	TIMESPOT (FTE)	SELDOM (FTE)	Inquadramento
Aiola	1,0			1,0	AR INFN (UE)
Citterio	0,1	0,1	0,0		Dirigente Tecnologo
Coelli	0,4	0,3		0,1	Tecnologo
De Benedetti				1,0	AR INFN (UE)
De Lorenzo	1,0			1,0	Tecnologo UniMi
Frontini	1,0		1,0		AR INFN
Fu	1,0	1,0			PostDoc UniMi
Gandini	1,0	0,7	0,3		Ricercatore
Lazzaroni	0,1	0,1			PA
Liberali	0,3		0,3		PA
Marangotto	1,0	1,0			Dottorando
Merli	1,0	1,0			AR INFN (UE)
Neri	1,0	0,2	0,2	0,6	PA
Palombo	0,0	0,0			PA in pensione
Petruzzo	1,0	0,7	0,3		AR INFN
Riboldi	0,2		0,2		RU
Shojaii	0,2		0,2		PostDoc
Spadaro	1,0	1,0			Dottoranda
Stabile	0,1		0,1		RTDA
Tot. (FTE)	11,4	6,1	2,6	3,7	

Backup



Progetto call CSN5

Consiglio di Sezione

Milano, 2 luglio 2019

Rad-hard pixel detector for 4D real-time tracking

Main target:

Develop and realize a demonstrator consisting of a complete and simplified tracking system, integrating about 100-1000 read-out channels (pixels), satisfying the following characteristics:

- Space resolution: $O(10\ \mu\text{m})$
- Radiation hardness: $> 10^{16}\ 1\ \text{MeV}\ n_{\text{eq}}/\text{cm}^2$ (sensors) and $> 1\ \text{Grad}$ (electronics)
- Time resolution: $< 100\ \text{ps}$ per pixel (target $\approx 30\ \text{ps}$)
- Real time track reconstruction algorithms and fast read-out (data throughput $> 1\ \text{TB/s}$)

Activities are organized in 6 work packages:

RN: A. Lai Cagliari

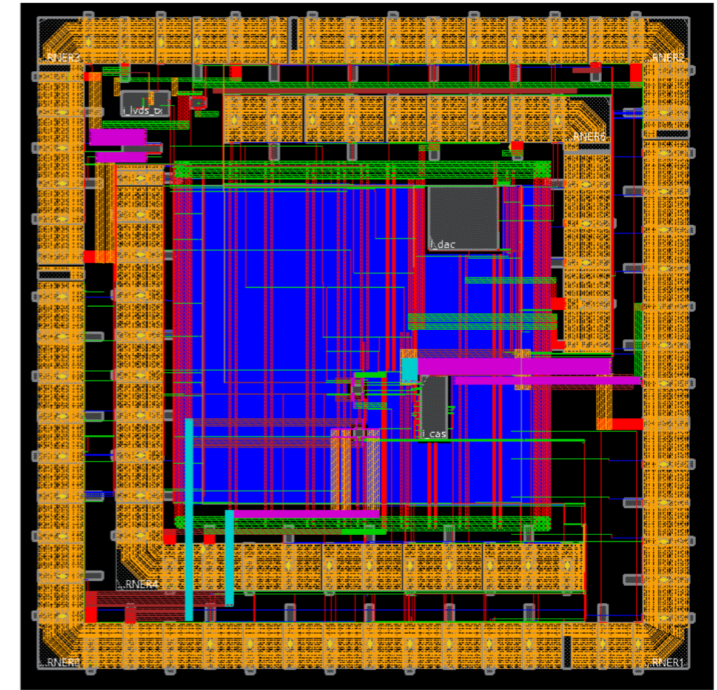
1. **3D silicon** sensors: development and characterization (GF. Dalla Betta Trento)
2. **3D diamond** sensors: development and characterization (S. Sciortino Perugia)
3. Design and test of **pixel front-end** (V. Liberali Milano)
4. Design and implementation of **real-time** tracking algorithms (N. Neri Milano)
5. Design and implementation of **high speed** readout boards (A. Gabrielli Bologna)
6. **System integration** and tests (A. Cardini Cagliari)

Sezioni INFN: Bologna, Cagliari, Genova, Ferrara, Firenze, Milano (+Bergamo), Padova, Perugia, Torino, TIFPA. ≈ 60 heads, ~ 20 FTE. People from **LHCb, ATLAS, CMS + others**

Work in progress in Milano

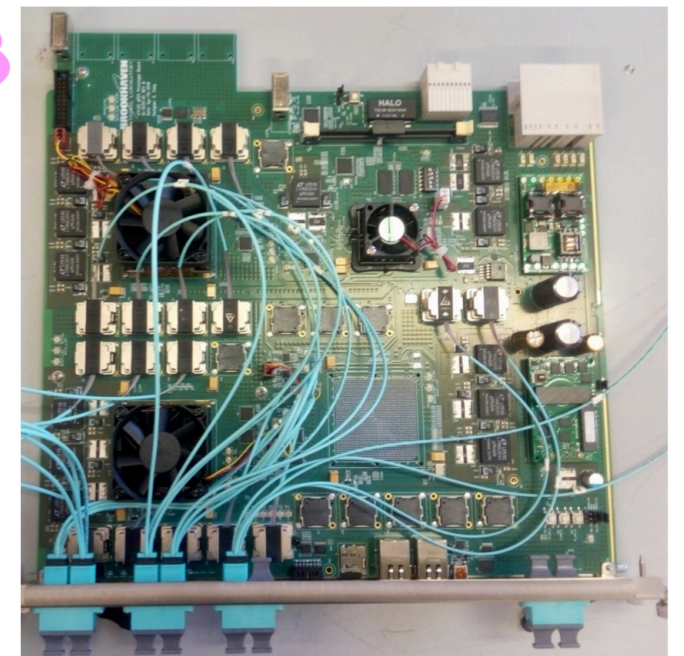
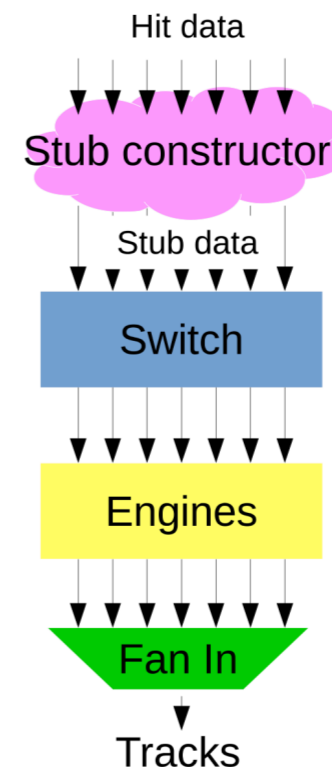
28nm CMOS miniASIC - submitted layout

- ▶ WP3: submission multichannel integrated circuit with full pixel readout foreseen for 01-11-2019 postponed to 01-05-2020 (also financial requests) – Motivation: unavailability of software licence



- ▶ WP4: test using simulated tracks with existing DAQ and Retina boards in progress. Proof of principle in:

- ▶ M. Petruzzo [PhD thesis](#), 23 June 2019: “A 4D real-time tracking device for the LHCb upgrade II”, Università’ di Milano [link](#)



Richieste

- ▶ Mini asic 28nm TSMC (2nd prod), 22 kEuro
- ▶ IC verification at IMEC, 5 kEuro
- ▶ Packaging for standalone IC test, 5 kEuro
- ▶ AR, 23 kEuro
- ▶ DAQ and track-finding board, 20 kEuro
- ▶ Travel expenses, 12 kEuro

Composizione gruppo di ricerca Milano

Personale	TIMESPOT(FTE)	Inquadramento
M. Citterio	0,0	Dirigente Tecnologo
L. Frontini	1,00	AR INFN
P. Gandini	0,3	Ricercatore INFN
V. Liberali	0,3	PA UniMi
N. Neri	0,2	PA UniMi, Resp. Loc.
M. Petruzzo	0,3	AR INFN
S. Riboldi	0,2	Ricercatore UniMi
A. Stabile	0,2	RTDA UniMi
S. Seyedruhollah	0,2	AR Call
Tot. (FTE)	2,7	