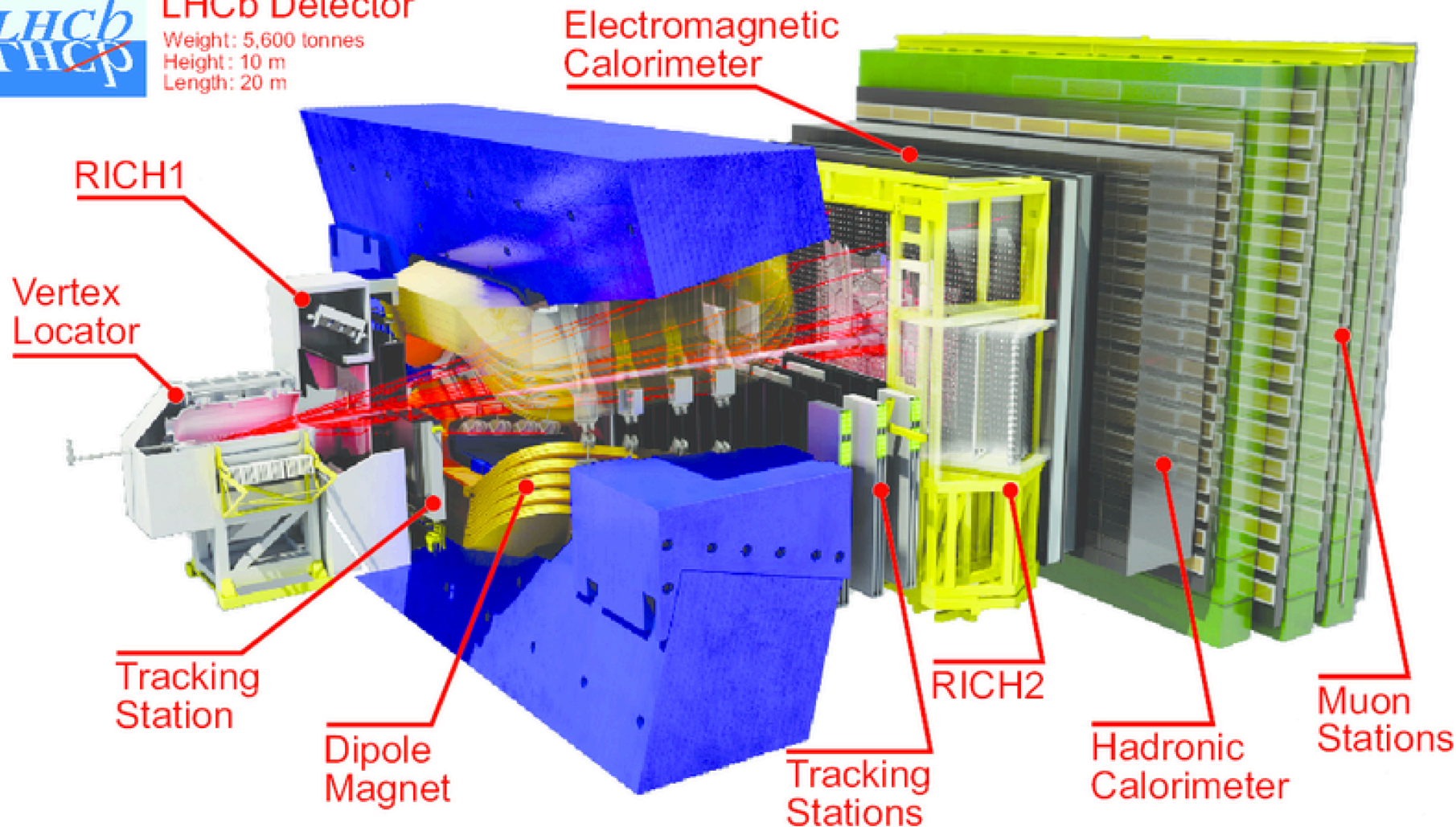




## LHCb Detector

Weight: 5,600 tonnes  
Height: 10 m  
Length: 20 m

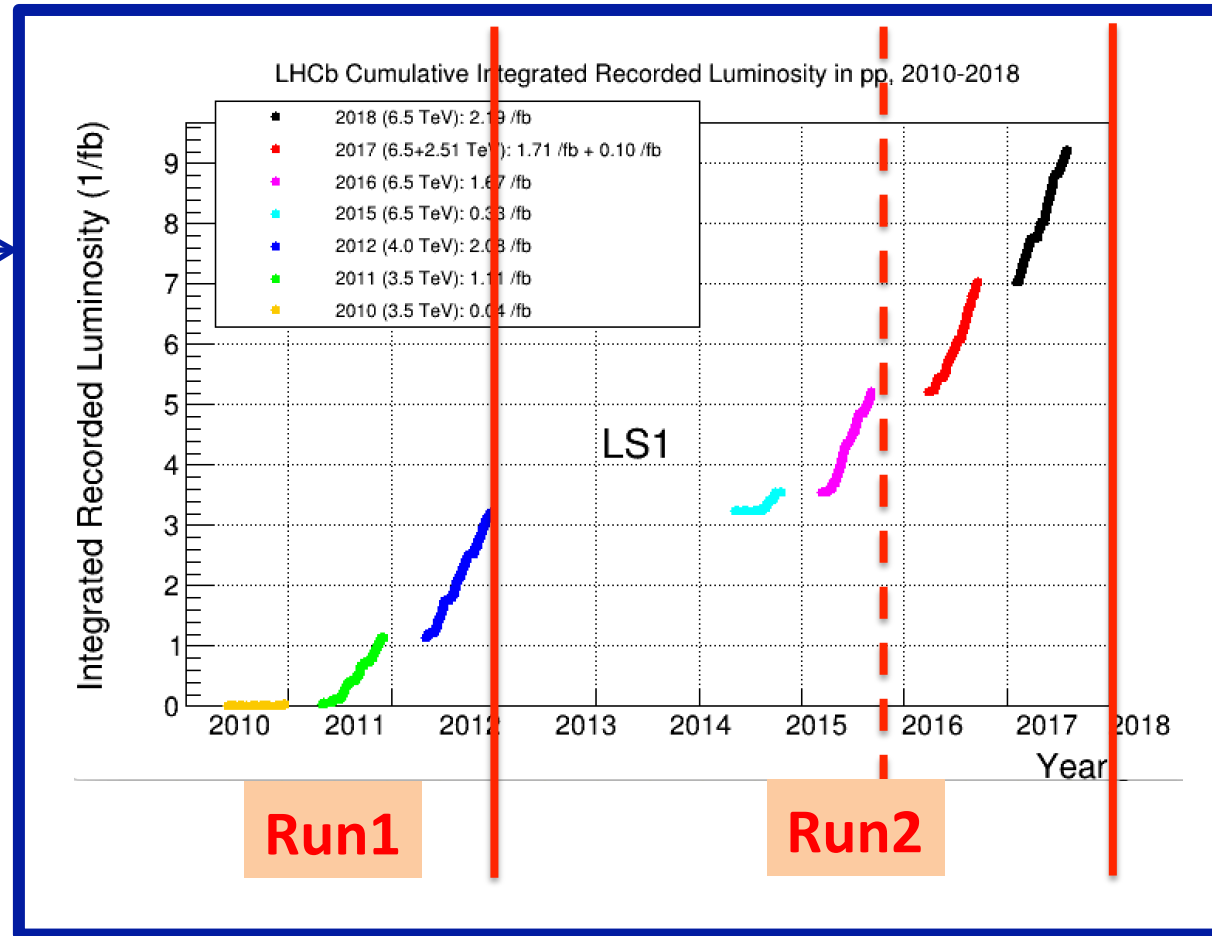


### ***Searching for new physics with a rich physics program:***

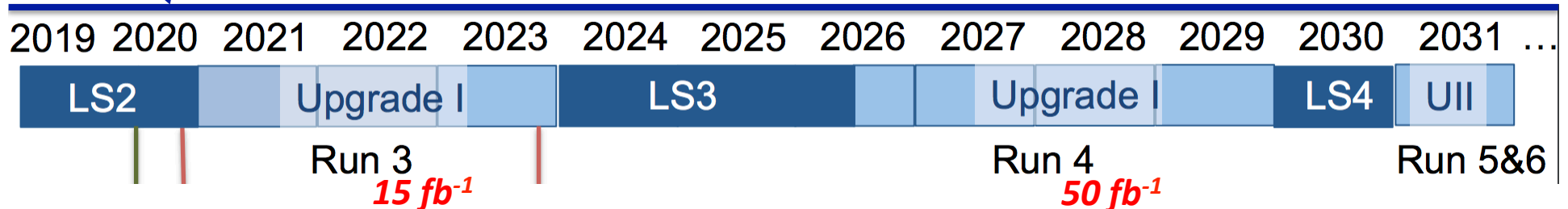
- *Rare B, D, K decays*
- *CP parameters measurements*
- *Charm physics*
- *Spectroscopy and exotic states*
- *Forward electroweak physics*
- *Ion physics*

**Notre perspective à court terme:  
analyser les données collectées et préparer la suite!**

Données collecté

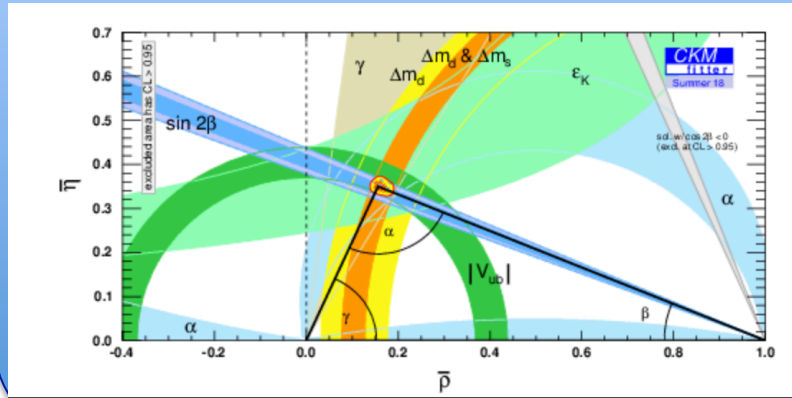


Suite

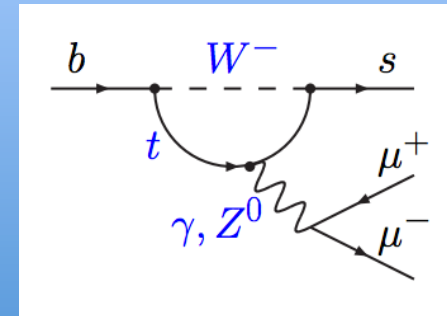


# Activités de notre groupe

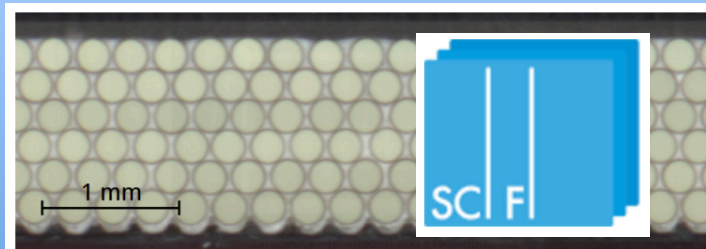
## CP violation



## Desintegrations rares



## Upgrade

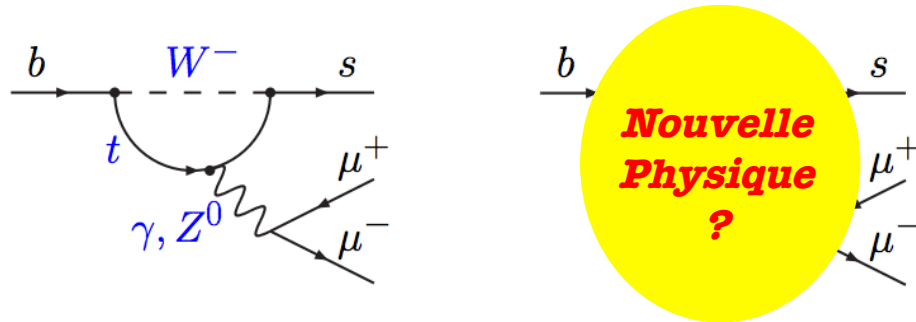


**+ autres contributions (ex: spectroscopie)**

## Depuis la dernière biennale (octobre 2016)...

- **Lepton flavor (universality) violation:**
  - Analyse  $R_{K^*}$  (Run1) publiée: grand impact dans la communauté
  - Analyse combinée  $R_X$  (comprenant  $R_{K^*}$ ,  $R_K$ ,  $R_\phi$ , Run1+Run2) en cours
  - Méthode de mesure de l'efficacité de reconstruction des électrons presque finalisée
  - Analyse  $R_{D^*}(\mathbf{e vs \mu})$  en cours
  - Recherches de désintégrations LFV ( $B \rightarrow K^* \tau \mu$  et  $B \rightarrow K \mathbf{e \mu}$ ) proches à conclusion (thèse de Andrea Mogini, soutenue en Septembre 2018)
- **Charmless decays  $B \rightarrow K_s h h$ :**
  - 6 modes mesurés et une analyse de Dalitz (thèse de Louis Henry)
  - étude phénoménologique sur l'extraction de l'angle CKM  $\gamma$  (thèse Emilie Bertholet)
- **Contribution à d'autres analyses:**
  - Découverte du  $\Xi_{cc}^{++}$
- **Firmware pour SciFi back-end electronics**
- **Tracking et reconstruction pour l'upgrade:**
  - Etudes pour définition de la géométrie du SciFi (thèse de Andrea Mogini)
  - Clustering pour le SciFi
  - Algorithmes de reconstructions des traces
  - Finalisation de la séquence complète de reconstruction sur CPU
  - Reconstruction sur GPU

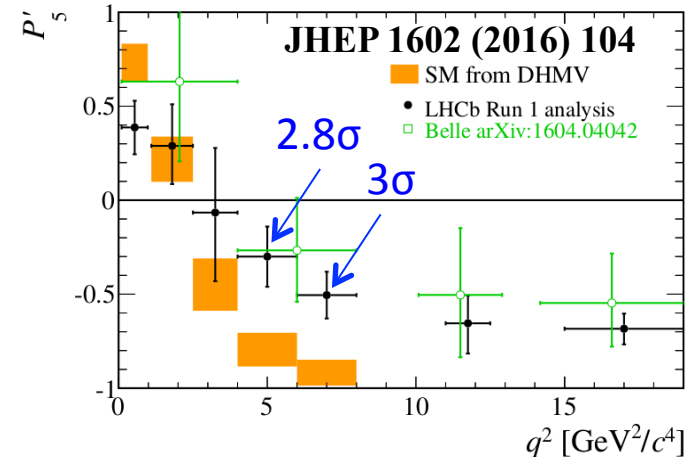
# Transitions $b \rightarrow s$ ( $R_X$ & friends )



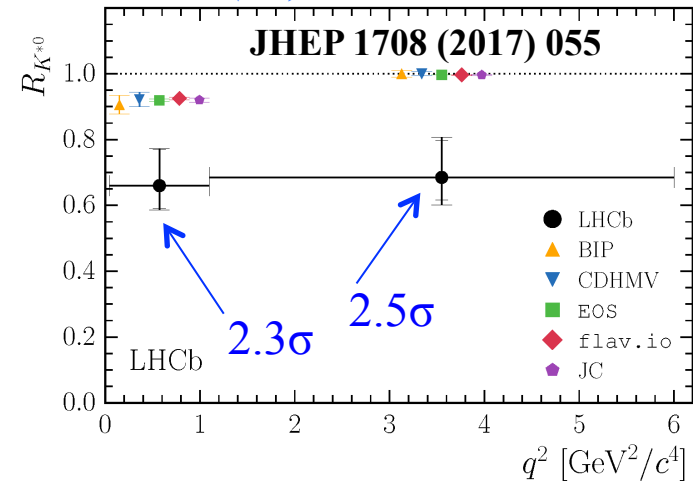
- **Des nouvelles particules pourraient:**
  - Affecter les taux de désintégration
  - Introduire de nouvelles source de CPV
  - Altérer des distributions angulaires
  - Se coupler avec leptons de saveurs différentes
- **Un nouveau résultat sur  $R_K$  a été présenté à Moriond EW 2019.**
- **L'analyse combiné de  $R_{K^*}$  et  $R_K$  est en cours avec une forte contribution du LPNHE**

$$R_X = \frac{BR(B \rightarrow X \mu^+ \mu^-)}{BR(B \rightarrow X e^+ e^-)}$$

## Analyse angulaire $B \rightarrow K^* \mu \mu$

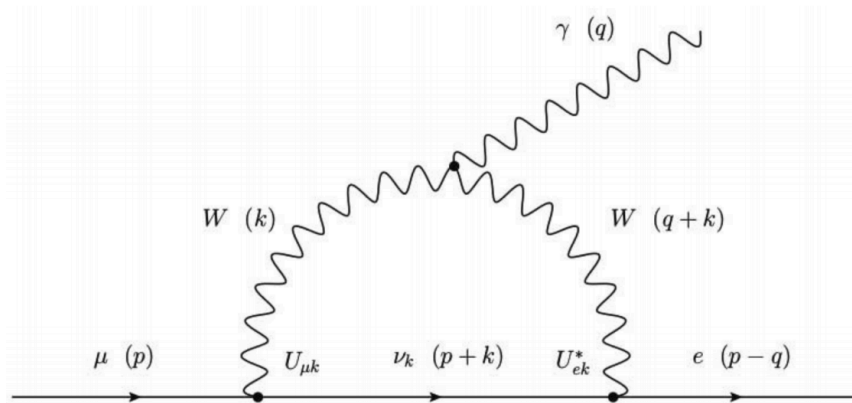


## LFU test $R(K^*)$



## Violation de la conservation de la saveur leptonique (LFV)

- Lepton flavour violation occurs in the Standard Model at very low rate, through neutrino oscillations ( $\text{Br} < 10^{-40}$ )  
 $\Rightarrow$  charged LFV decays in the SM have **rates of the order of  $10^{-54}$  !**



$$\mathcal{B}(\mu \rightarrow e\gamma) \simeq \frac{3\alpha}{32\pi} \left| \sum_{k=1,3} \frac{U_{\mu k} U_{ek}^* m_{\nu k}^2}{M_W^2} \right|^2$$

$$\simeq 10^{-55} - 10^{-54}$$

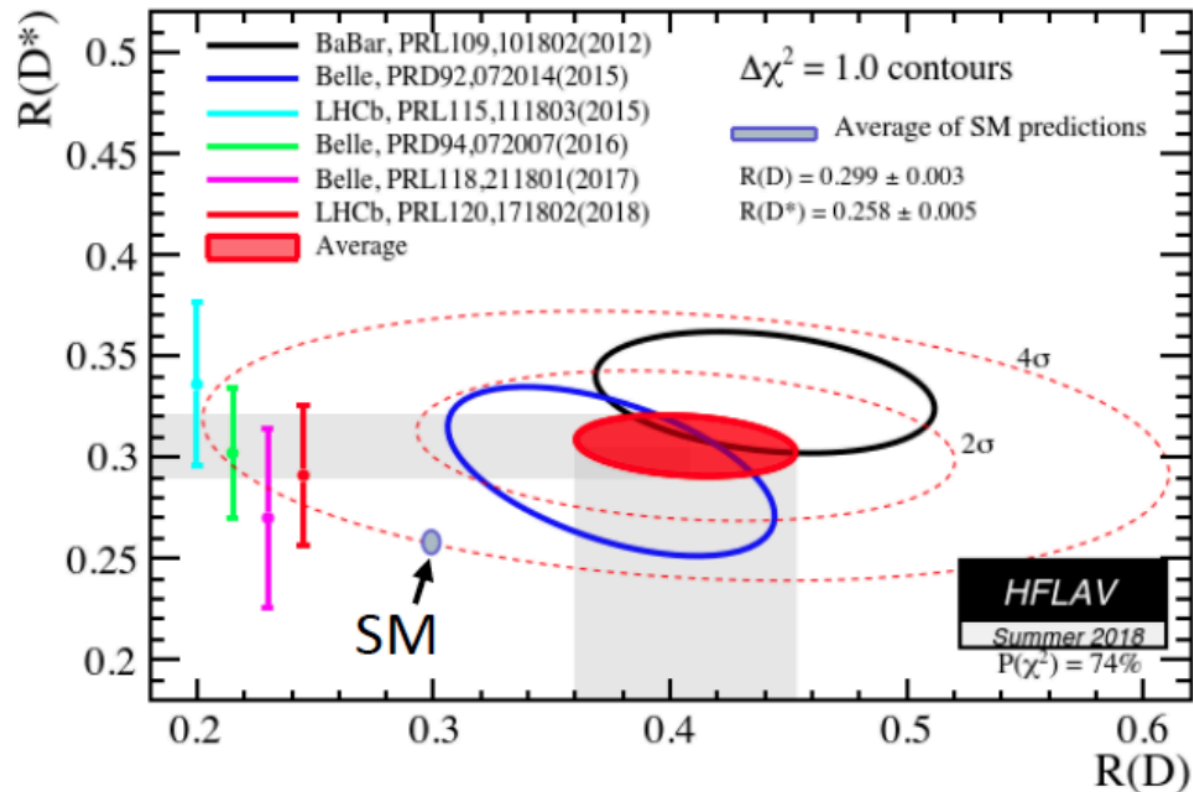
- $\mathcal{B}(B \rightarrow K \mu^\pm e^\mp) \sim 3 \cdot 10^{-8} \left( \frac{1 - R_K}{0.23} \right)^2$ ,  $\mathcal{B}(B \rightarrow K(e^\pm, \mu^\pm) \tau^\mp) \sim 2 \cdot 10^{-8} \left( \frac{1 - R_K}{0.23} \right)^2$ ,  
 $\frac{\mathcal{B}(B_s \rightarrow \mu^+ e^-)}{\mathcal{B}(B_s \rightarrow \mu^+ \mu^-)_{\text{SM}}} \sim 0.01 \left( \frac{1 - R_K}{0.23} \right)^2$ ,  $\frac{\mathcal{B}(B_s \rightarrow \tau^+(e^-, \mu^-))}{\mathcal{B}(B_s \rightarrow \mu^+ \mu^-)_{\text{SM}}} \sim 4 \left( \frac{1 - R_K}{0.23} \right)^2$ .

[Hiller, Loose, Schönwald (2016)]

**Observation of a charged LFV decay would be a striking sign of new physics!**

## Transitions $b \rightarrow c l \nu$ ( $R_{D^*}$ )

$$R_{D^*} = \frac{\Gamma(\bar{B}^0 \rightarrow D^{*+} \tau^- \bar{\nu}_\tau)}{\Gamma(\bar{B}^0 \rightarrow D^{*+} \mu^- \bar{\nu}_\mu)}$$



Objectif: verifier le meme rapport entre etats finals avec electrons et muons.

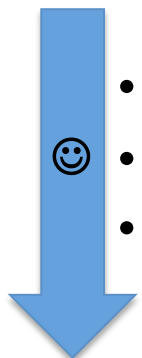
Nouvelle analyse dans le groupe.

# Charmless $B \rightarrow K_s h h'$ decays ( $\beta$ and $\gamma$ )

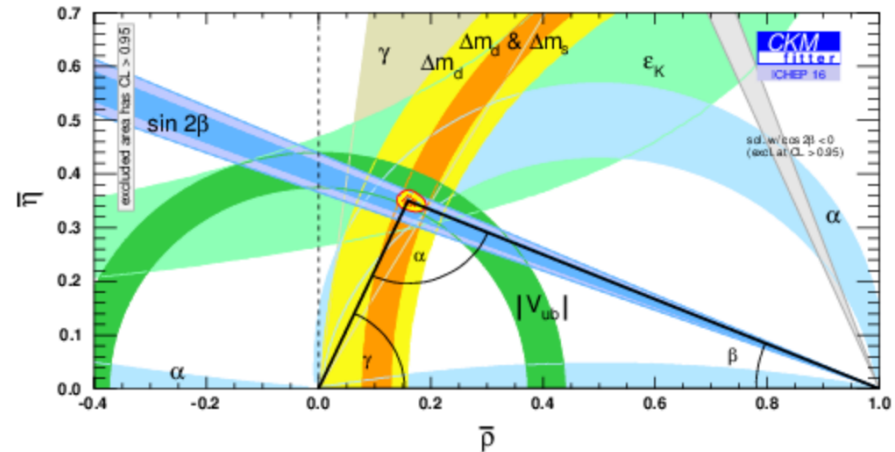
Objectifs:

- mesure de **phases**  $\beta$  et  $\beta_s$  de mésons  $B_d$  et  $B_s$  dans les processus en « boucle »
- Mesure de la **phase**  $\gamma$

**Analyse de complexité croissante**, en lien avec l'augmentation de la taille de l'échantillon collecté :

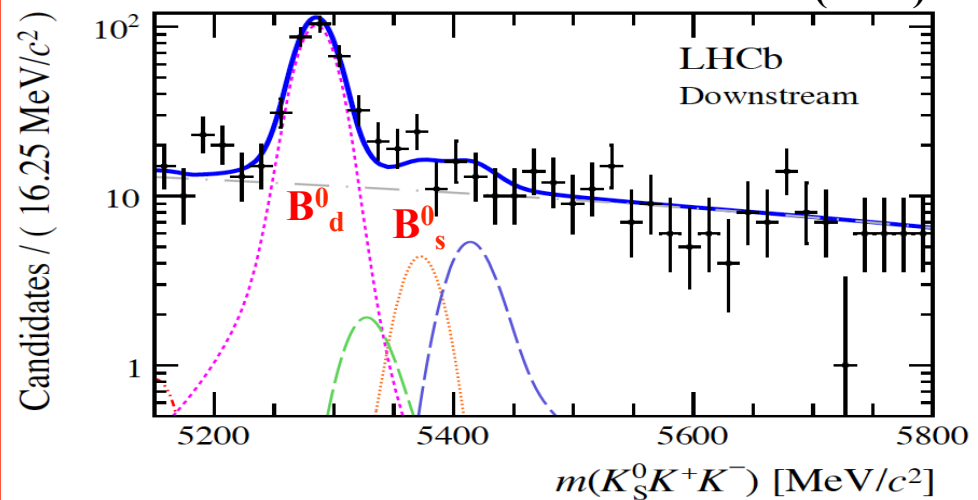


- mesure des BRs;
- analyse en amplitude;
- analyse en amplitude dépendante du temps avec étiquetage de la saveur.



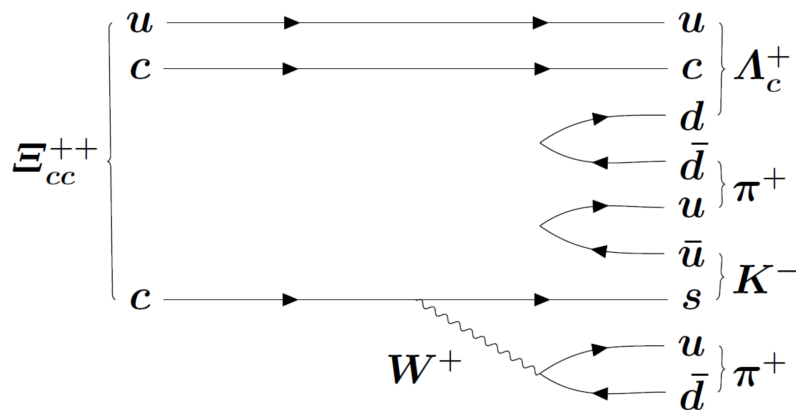
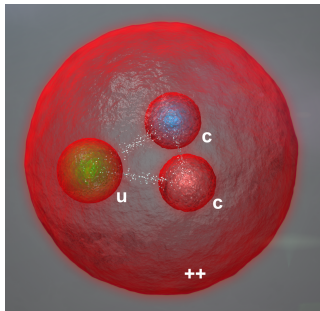
**BR de  $B_{d,s} \rightarrow K_s h h'$  avec  $3 \text{ fb}^{-1}$**

**JHEP 11 (2017) 027**

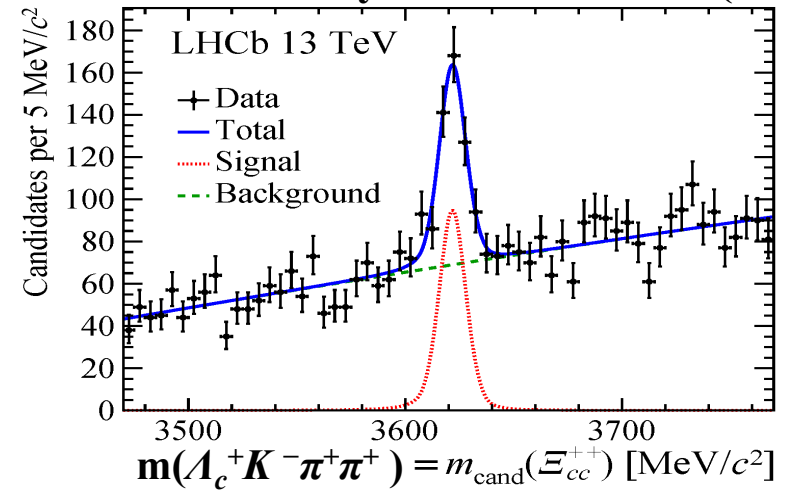




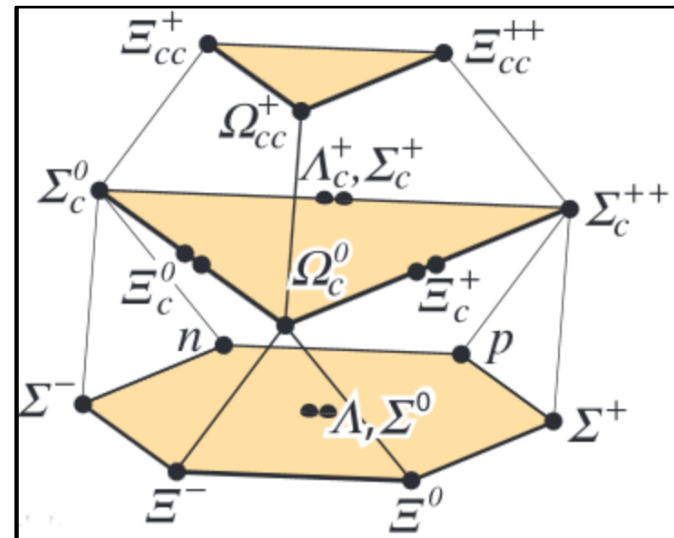
# Spectroscopie



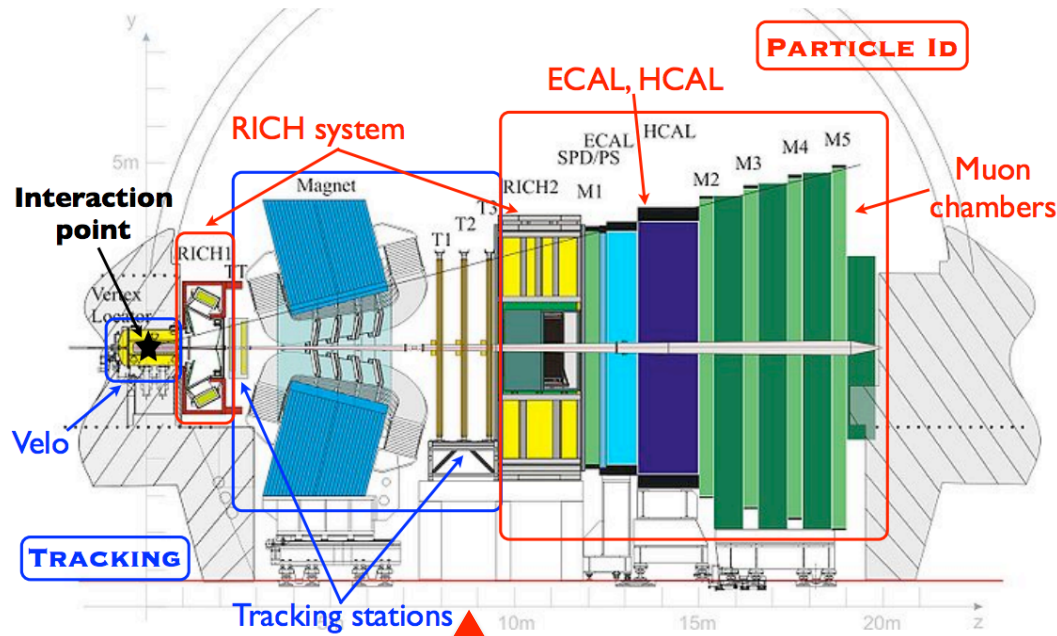
## Découverte du $\Xi_{cc}^{++}$ Phys. Rev. Lett. 119 (2017)



- Premier baryon ( $qqq$ ) avec deux quarks lourds.
- Un nouvel outil pour tester les modèles de QCD !



# Happening now: LHCb upgrade



## Higher occupancies and radiation doses:

- 25 ns bunch spacing (50 ns in 2012)
- 2400 colliding bunches at  $\sqrt{s}=14$  TeV
- Luminosity:  $\mathcal{L} = 2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
- Pileup =  $\sim 2.7$  interactions / bunch crossing

## Replace/overhaul several subdetectors:

VeloPixel, Trackers (UT, SciFi), RICH

## Replace readout electronics:

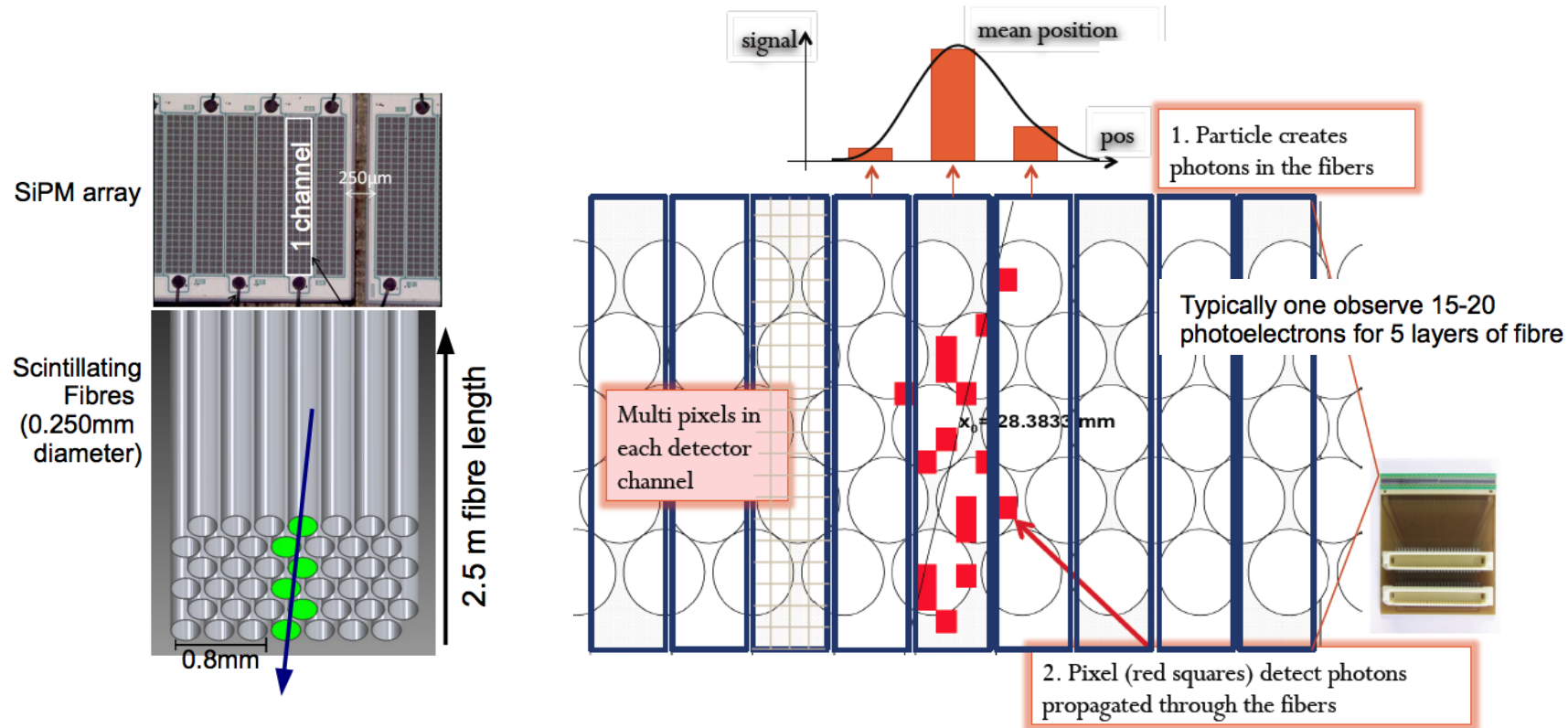
- Readout rate: 40 MHz instead of 1 MHz
- Full software trigger

Target: collect  $50 \text{ fb}^{-1}$  over 10 years after LS2

Nous sommes impliqués dans le  
**Scintillating Fiber tracker (SciFi)**  
(stations de tracking après l'aimant)

Nous sommes aussi impliqués  
dans le projet  
**Real Time Analysis (RTA)**

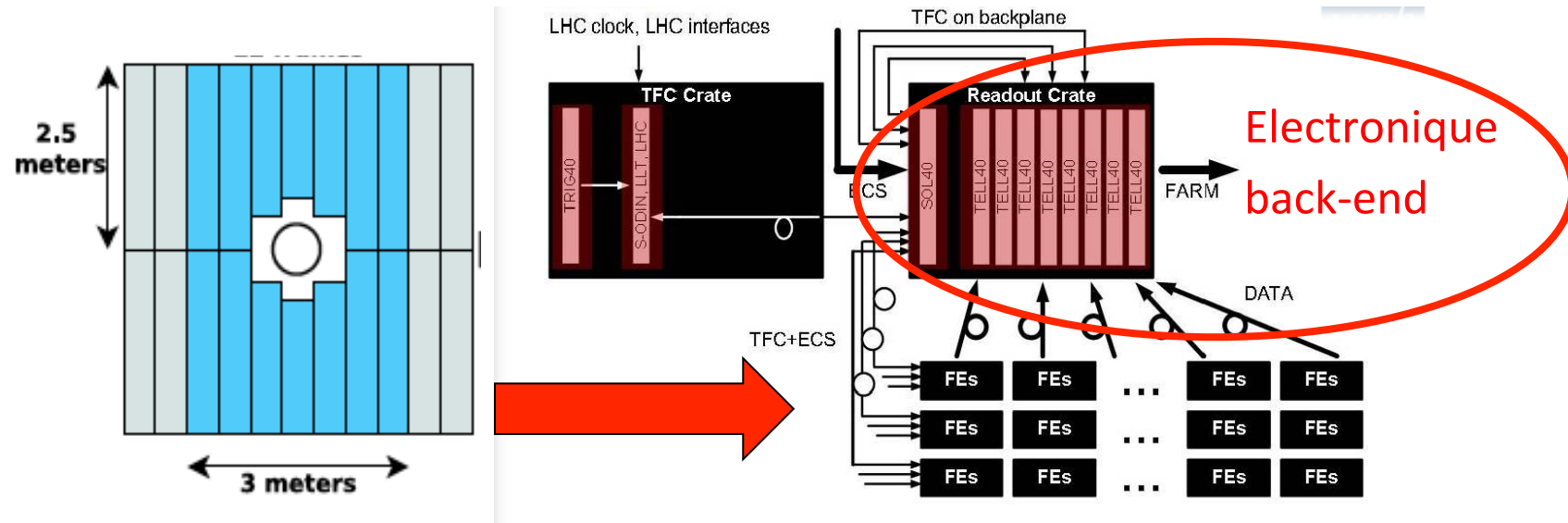
# Le Scintillator Fibre Tracker (SciFi)



**Caractéristiques: résistance aux radiations, granularité, lecture à 40MHz.**

- **3 stations**, each with **4 layers** ( x, u, v, x), each layer divided into **10 (12) fiber modules**.
- **Scintillating fibers: 250  $\mu$ m diameter, 2.5m long**, in multiple planes for improved light collection.
- **Mirror at the center** (beam pipe height).
- **SiPM 128 channels in a 32mm array, 16 SiPM per module**.
- **40MHz front-end electronics**.
- Dead material in the acceptance minimized through **readout at borders**.

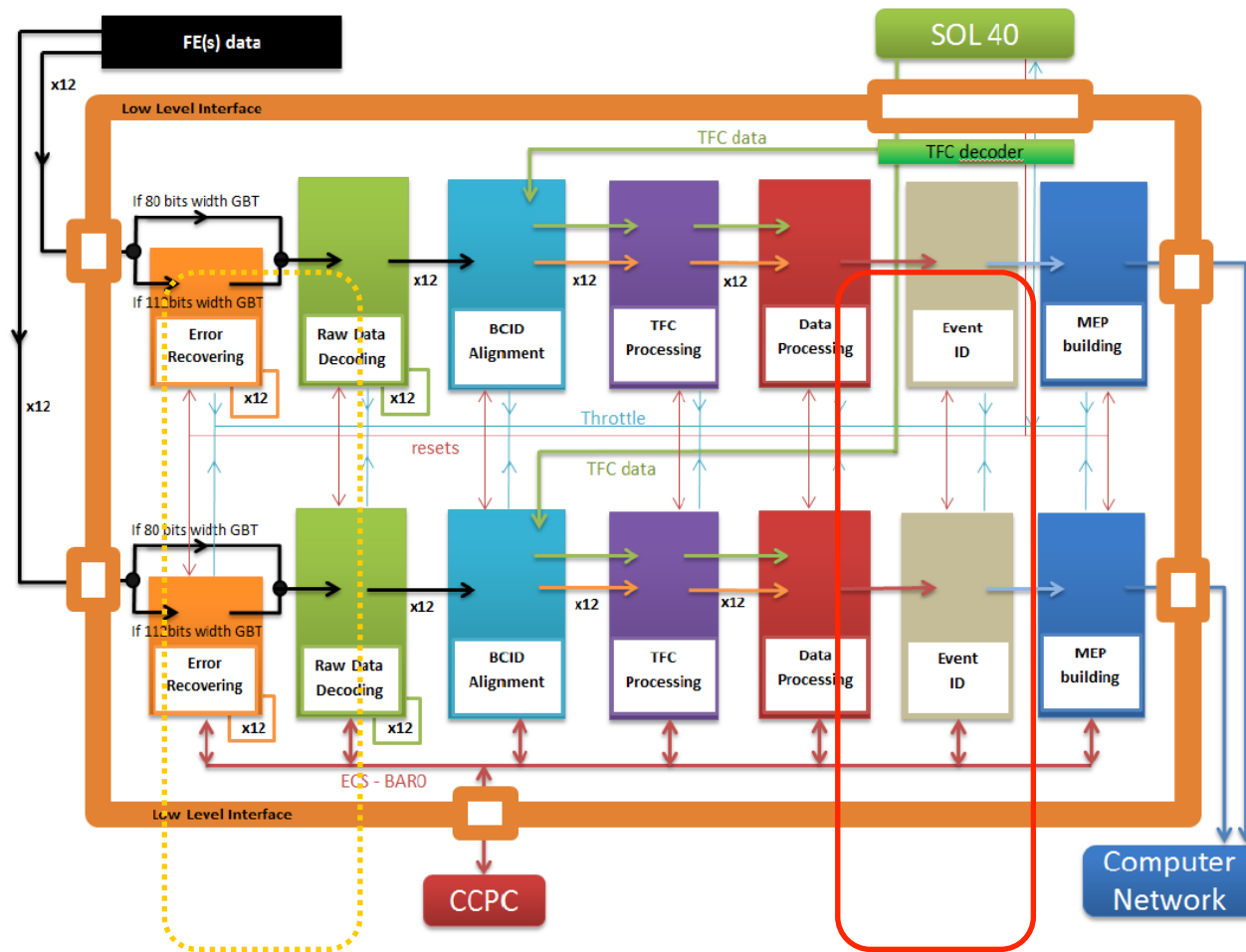
## Notre contribution au SciFi



- Gestion de l'achat des cartes TELL40, format PCIeexpress [2018]
- Développement d'un firmware spécifique [depuis 2015]
- Tests (banc/faisceau) et déploiement du firmware [2015 – 2019]
- Logiciel de pilotage des cartes et interface avec la DAQ [2017 – 2019]
- Installation, commissioning [2019 – 2020 et au delà]

→ **Coordination de l'électronique back-end pour SciFi dans LHCb: Olivier Ledortz**

# Le firmware des TELL 40



MD1: 1 x 24 links

MD2: 2 x 24 links  
2 individual 50 Gb/s  
PCI express output

SciFi case:  
16 links ( SciFi FV )  
or  
2x20=40 links ( FF )

## Réalisations essentielles du groupe:

- Tests et adaptation du firmware générique du back-end
- Définition du format des données de sortie de back-end (firmware spécifique)
- Définition de l'algorithme de « Clustering » (contribution au front-end)
- Support aux tests (Nikhef, C-F, CERN)

# Assemblage des 'C-frames' du détecteur

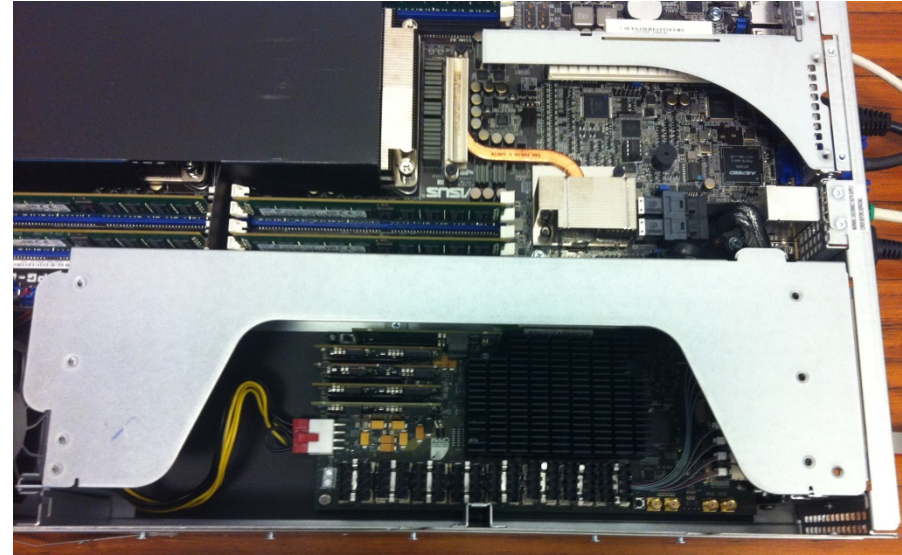
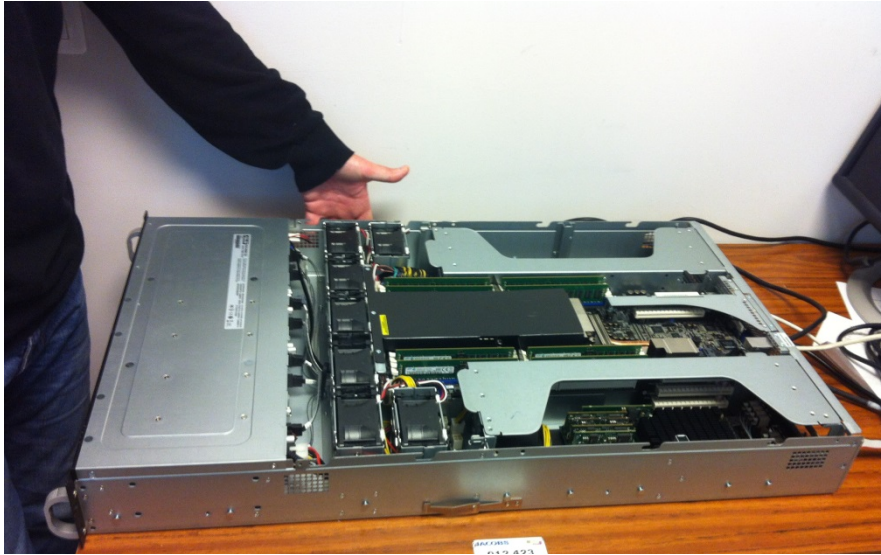
**Vue Globale**



**Fiber Mat + Readout Box**



## MiniDAQ2 setup: commercial server + PCIe40



Functionality	PCIe40 type	Required	Spares	Sub-Total
TELL40_24	24 inputs	48	5	53
TELL40_48	48 inputs	96	10	106
SOL40	48 inputs + 48 outputs	12	2	14
<b>TOTAL</b>		156	17	173

Unit cost estimation:

5.000 EUR

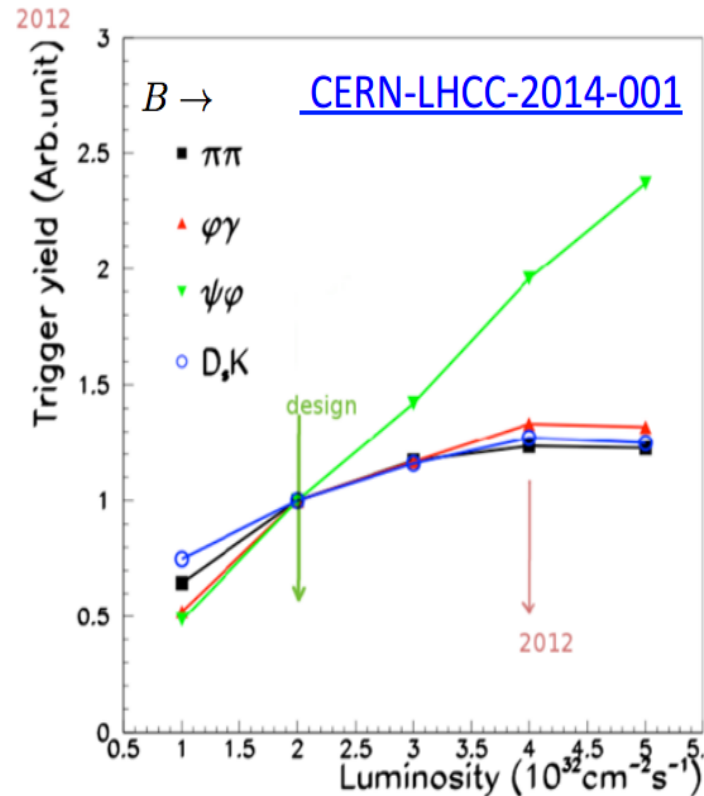
Total cost estimation :

865.000 EUR

# Real Time Analysis: le problème du trigger

Expected luminosity:  $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$  ( $\Rightarrow 5 \text{ fb}^{-1}/\text{year}$ )

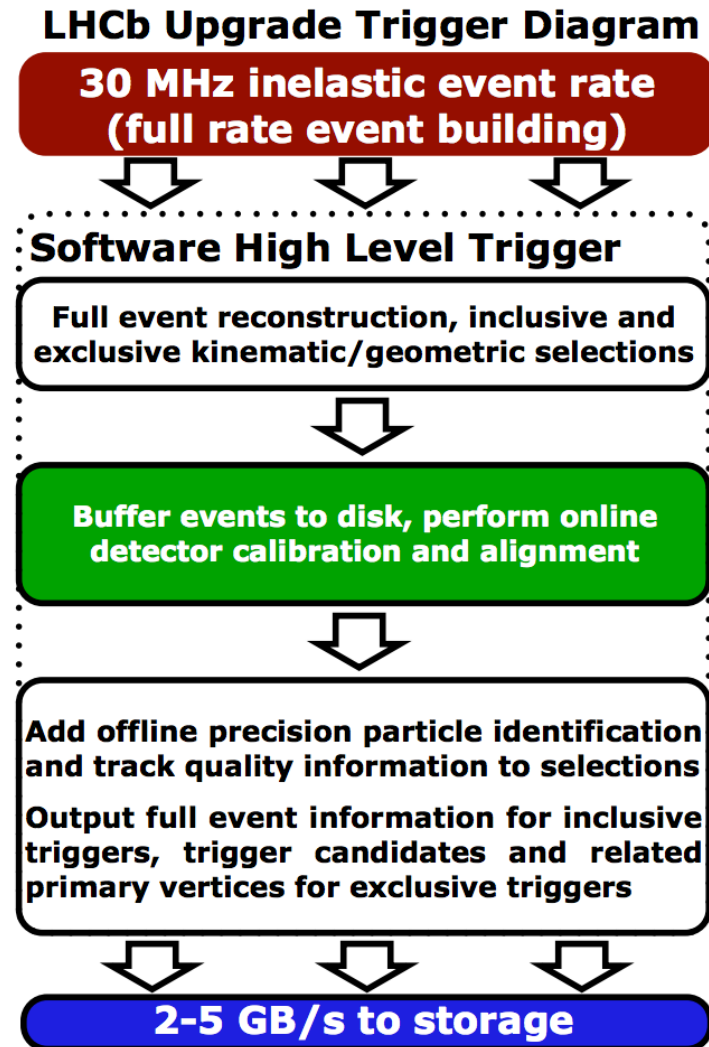
Hadronic channels saturate due to energy cuts in the hardware trigger



Need to move from 1 MHz to 30 MHz read-out rate  
(i.e. reading at the collision frequency of the LHC!)



# Solution: le nouveau software trigger



## Full software trigger: driving criteria

- Much more information at trigger level needed to categorize the more complex event topology
- Essential to be able to:
  - Have the same tracking sequence online as offline
  - Perform the real-time alignment and calibration
- Challenging time constraints for reconstruction:
  - Single CPU timing budget for reconstruction to be  $O(10)$  ms
- To be studied the possibility to optimize the reconstruction as a function of the decay channels

**Run II used as test bench!**

## ***Real Time Analysis: les activités***

- Conception, optimisation et test de l'algorithme de « clustering » pour le SciFi
- **Responsabilité des deux principaux algorithmes de tracking : Velo et SciFi**
- Optimisation de la première étape du trigger :
  - Lancement et pilotage d'un projet pour réaliser sa totalité sur GPU
  - paramétrisation et simplification du « Kalman Filter »
- **Autres études: description du champ magnétique et études d'alignement**

**Proposition et leadership du projet RTA (trigger + reconstruction) : ~50 ETP**

## ***Resumé des perspectives à court terme pour LHCb@LPNHE***

- ***Analyses: profiter des données déjà collecté!***

- ***Charmless*** : un long projet, qui s'effectue par des phases de complexité croissante.

- ***desintegrations rares*** : LFU tests dans les désintégrations  $b \rightarrow sll$  et  $b \rightarrow clv$  et recherches directes de cLFV

- ***Upgrade : assurer son succès!***

- ***SciFi***: installation, commissioning et suivi de l'électronique back-end

- ***RTA***: finalisation du software de trigger et reconstruction

# Groupe Neutrino: Perspectives à 2 ans

- 4 staff
  - Bernard Andrieu (CR), Claudio Giganti (CR/HDR),  
Mathieu Guigue (MdC), Boris Popov (DR)*
- 1 émérite
  - Jacques Dumarchez (DR)*
- 0 postdoc
- 1 visitor
  - Ciro Riccio (INFN) (jusqu'à fin 2019)*
- 1 volunteer
  - Jean-Michel Levy*
- 0 doctorant

## Main responsibilities

Co-convener of T2K beam group

NA61/SHINE analysis coordinator

Co-convener of T2K oscillation analysis

4 PhD theses defended au LPNHE

Institutional Board of representatives

Publication board

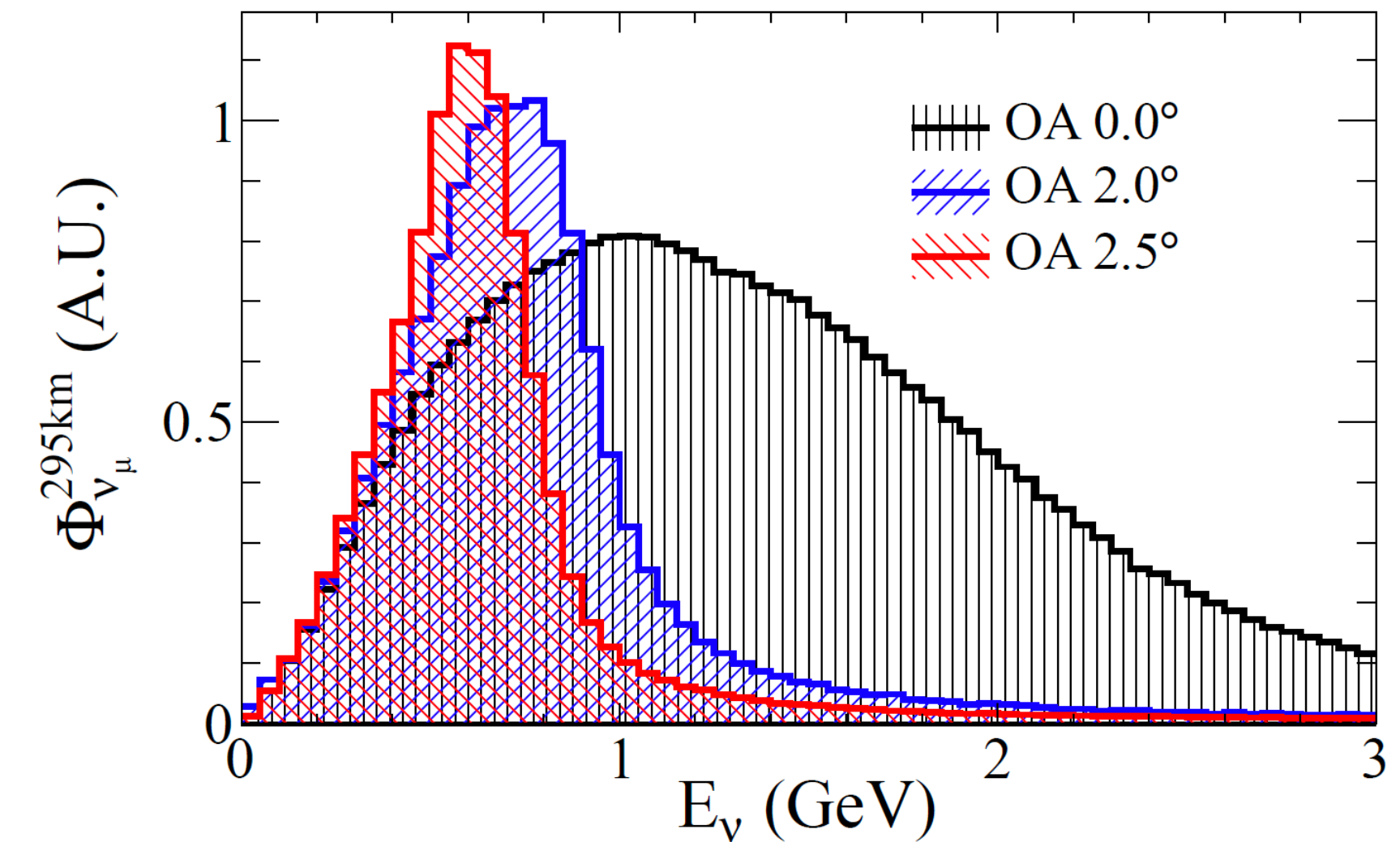
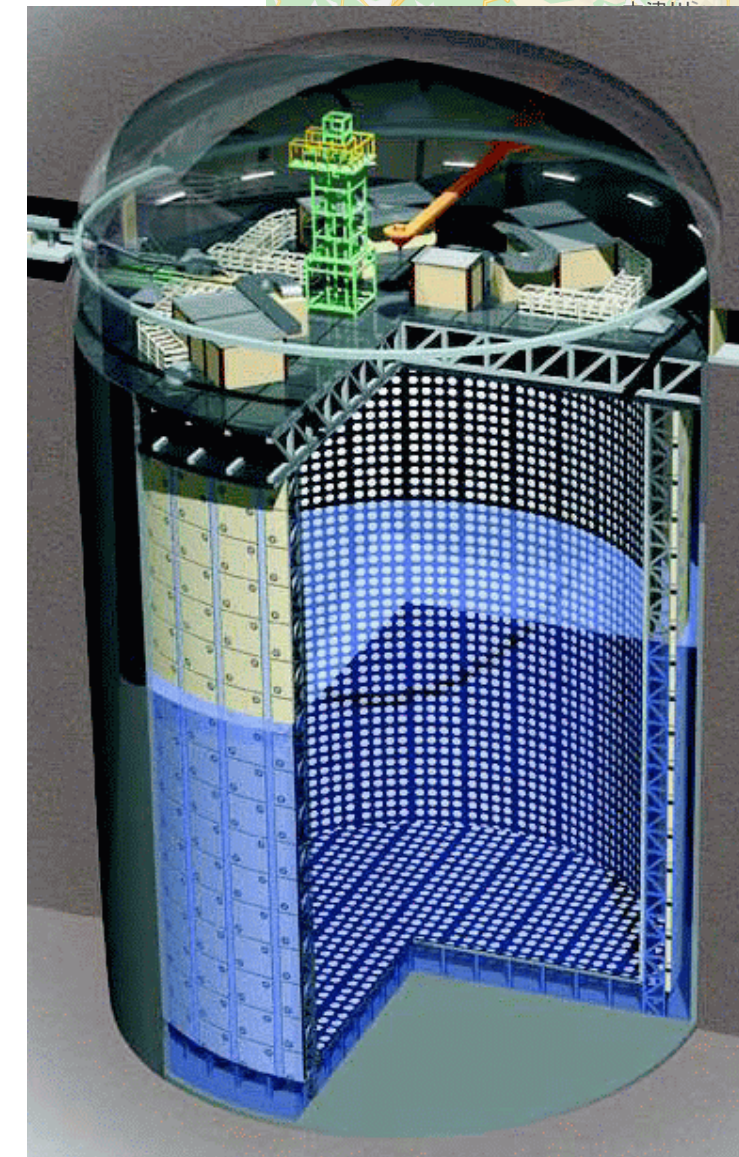
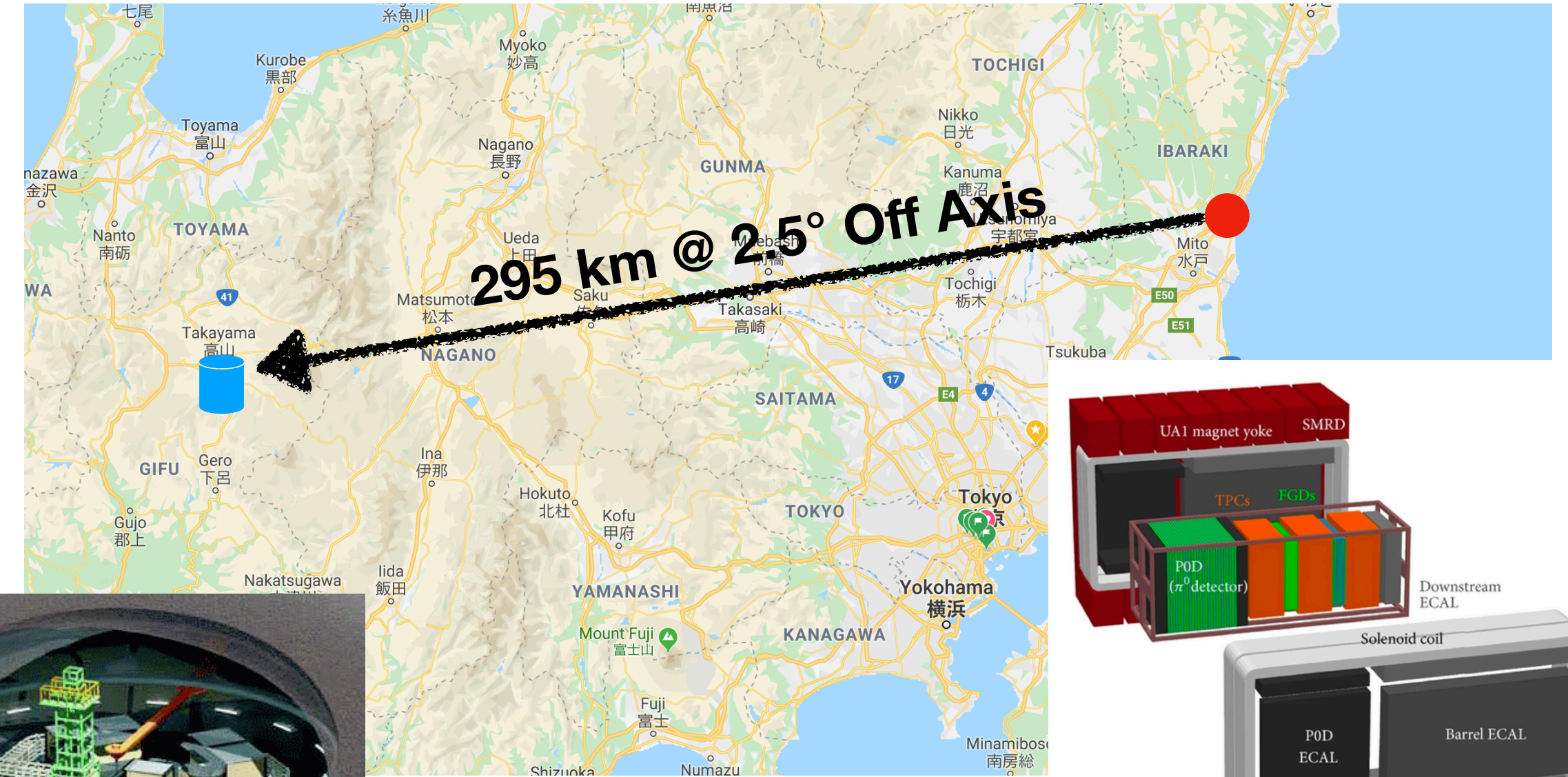
Speakers board

High intensity  $\sim 600$  MeV  $\nu_\mu/\bar{\nu}_\mu$  beam  
produced at J-PARC  
Neutrinos detected at  
**T2K near detectors (e.g. ND280)**  
**far detector (SuperK)**

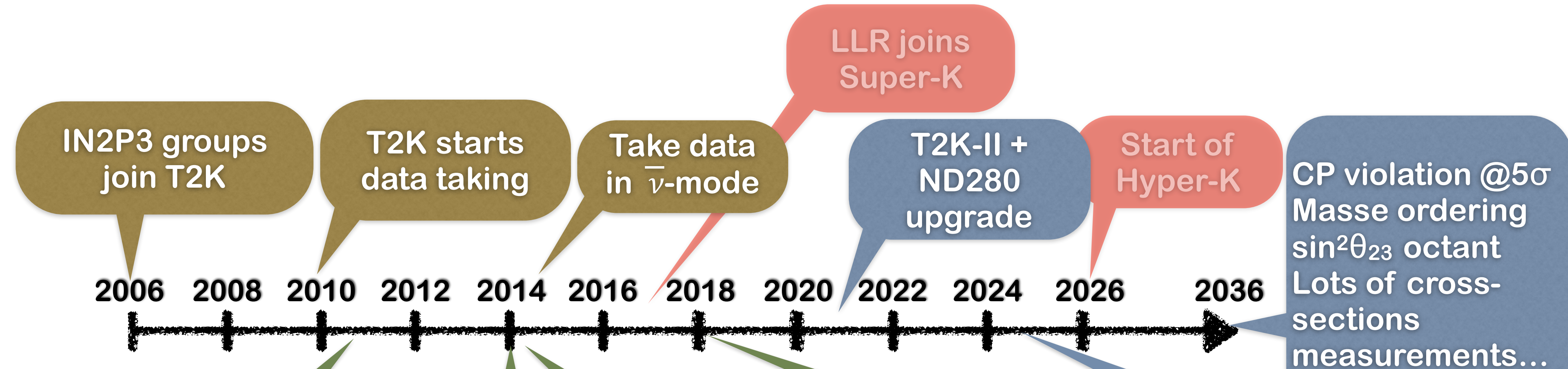
### Scientific goals:

Observation of  $\nu_e/\bar{\nu}_e$  appearance  
Measurement of  $\theta_{13}$  &  $\delta_{CP}$

Precise observation of  $\nu_\mu$  disappearance  
Measurement of  $\theta_{23}$  &  $\Delta m_{32}^2$



# T2K physics program



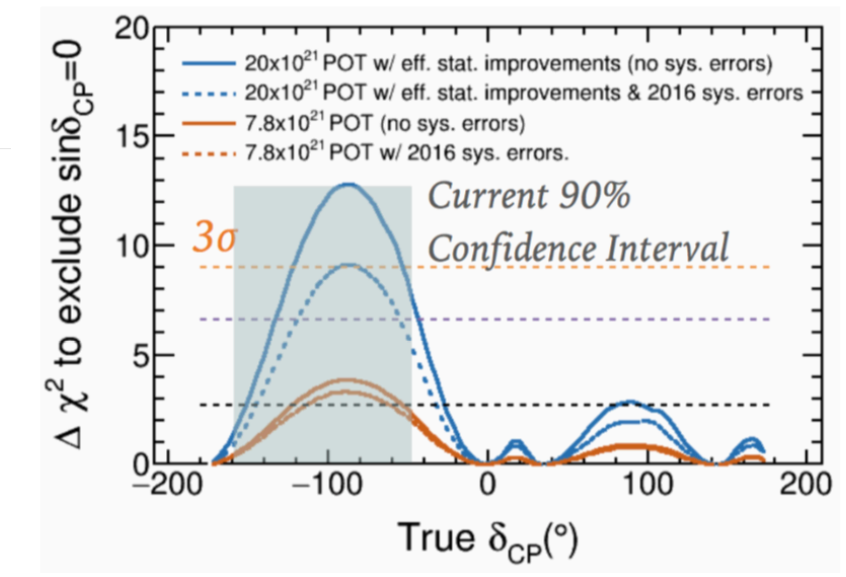
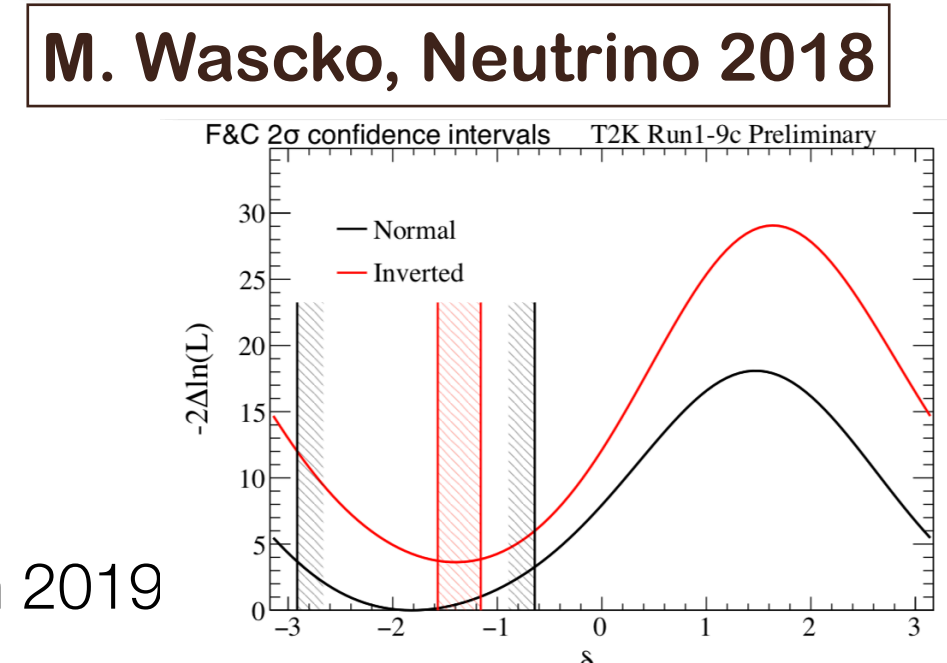
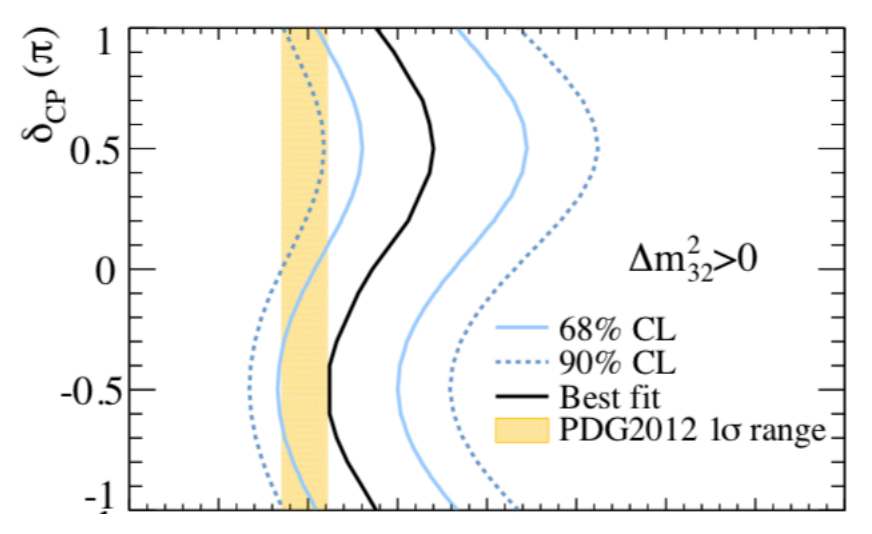
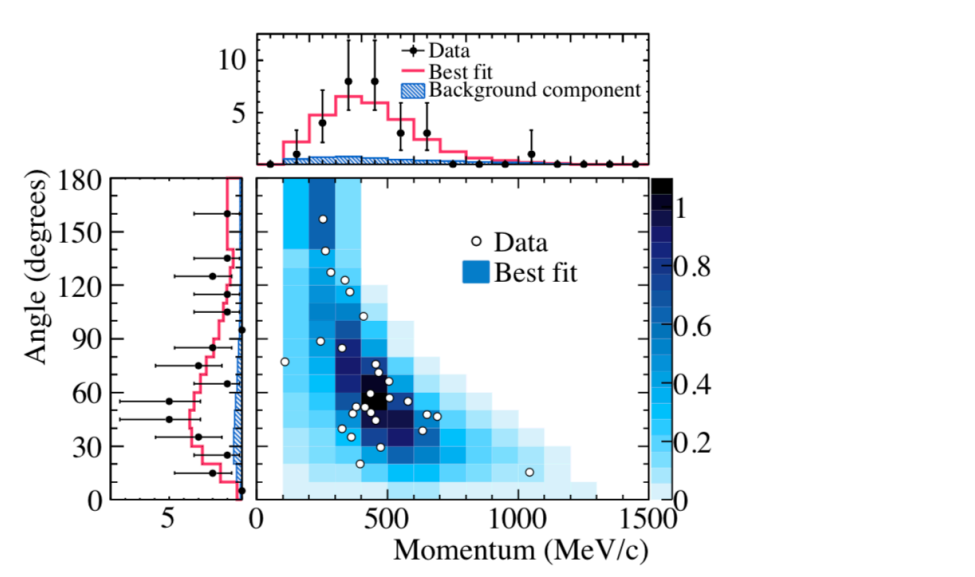
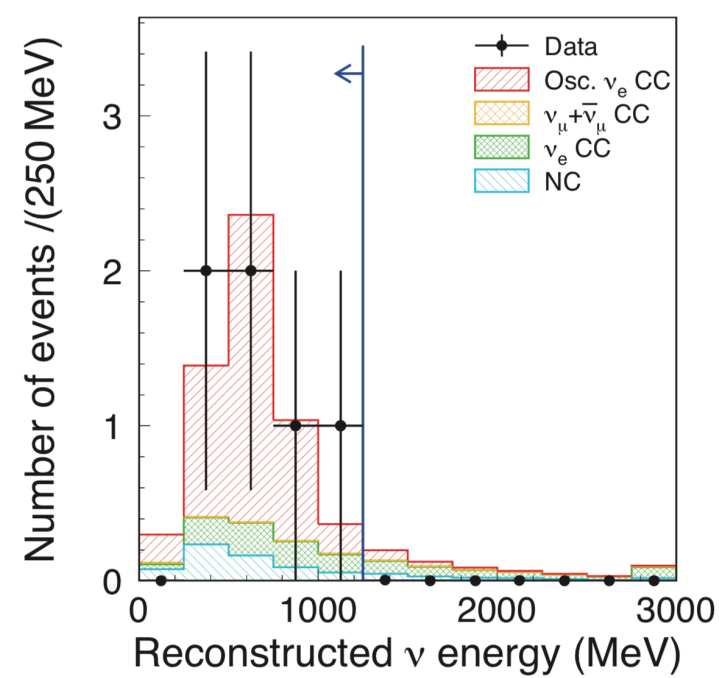
Hints of  $\nu_e$  appearance ( $\theta_{13} \neq 0 @ 2.5\sigma$ )  
PRL 107 (2011) 041801

Observation of  $\nu_e$  appearance ( $\theta_{13} \neq 0 @ 7.3\sigma$ )  
PRL 112 (2014) 061802

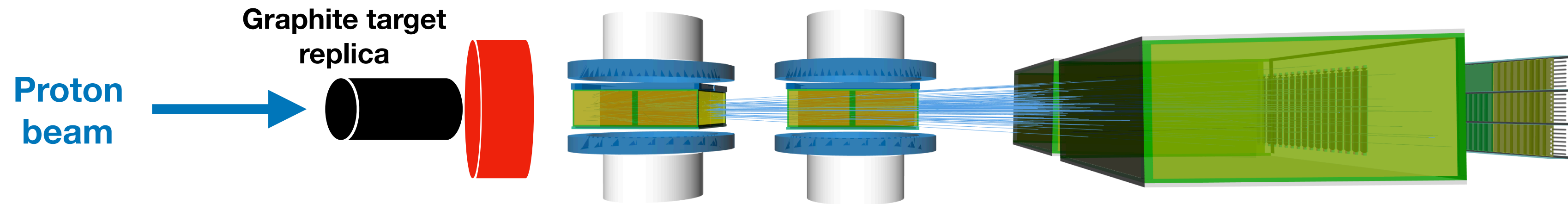
Precise measurement of  $\theta_{23}, \Delta m^2_{32}$   
PRL 112 (2014) 181801

Hints of CP violation  $\rightarrow \sin(\delta_{CP}) = 0$  excluded at 95%  
M. Wascko, Neutrino 2018

CP violation @  $3\sigma$







Measurement of hadron production cross-sections using a thin carbon target and a T2K replica target

Measurement of charged hadron ( $\pi^\pm$ ,  $K^\pm$ ,  $K_s^0$ ,  $p$ ,  $\Lambda$ ) spectra

Constraints on neutrino and anti-neutrino fluxes

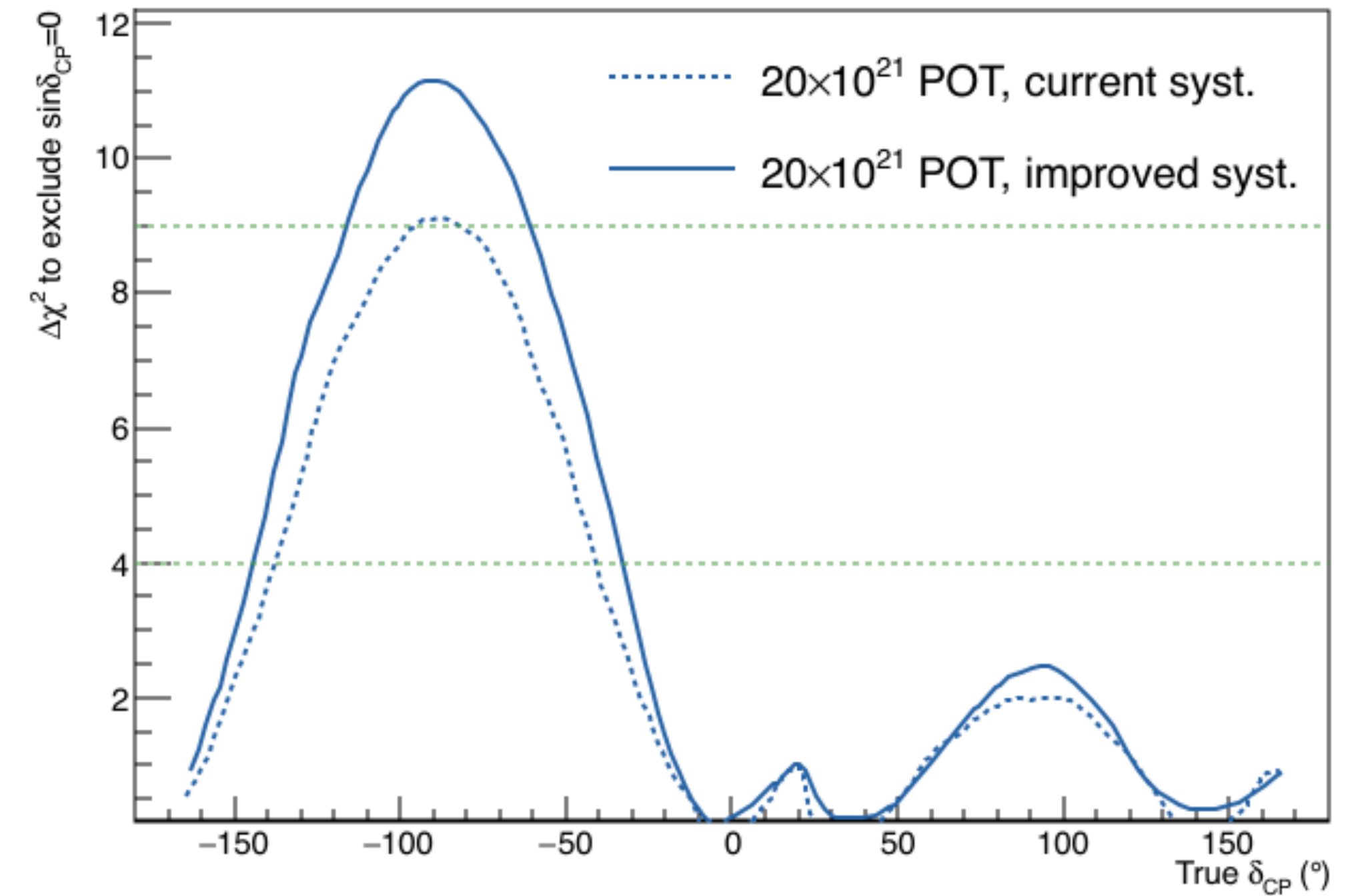
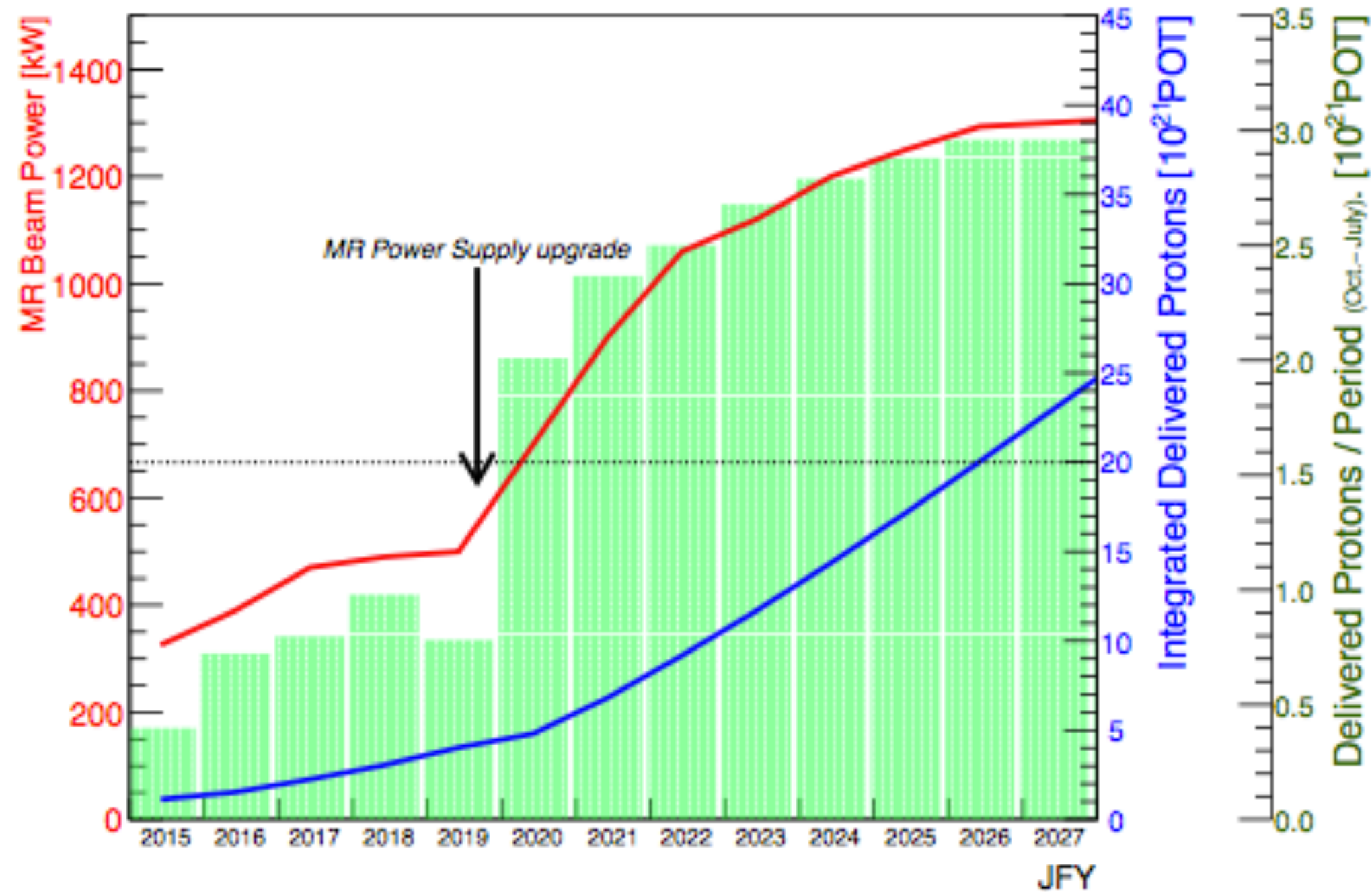
Reduction of flux errors from 25% to 10% using thin target

**LPNHE contributions**

**Analysis coordination**

Statistics increase goal:  $20 \times 10^{21}$  pot  
 Upgrade proton beam intensity: 1.3 MW

T2K-II Protons-On-Target Request



Improvement in  $\delta_{CP}$  sensitivity  
 Exclusion of CP-conservation to  $3\sigma$

Need to reduce systematics  
 Increase near detector angular acceptance  
 Prepare for T2HK

## Super FGD:

2 tons of 1 cm<sup>3</sup> cubes  
 Precise reconstruction of tracks and vertices

## Horizontale TPCs:

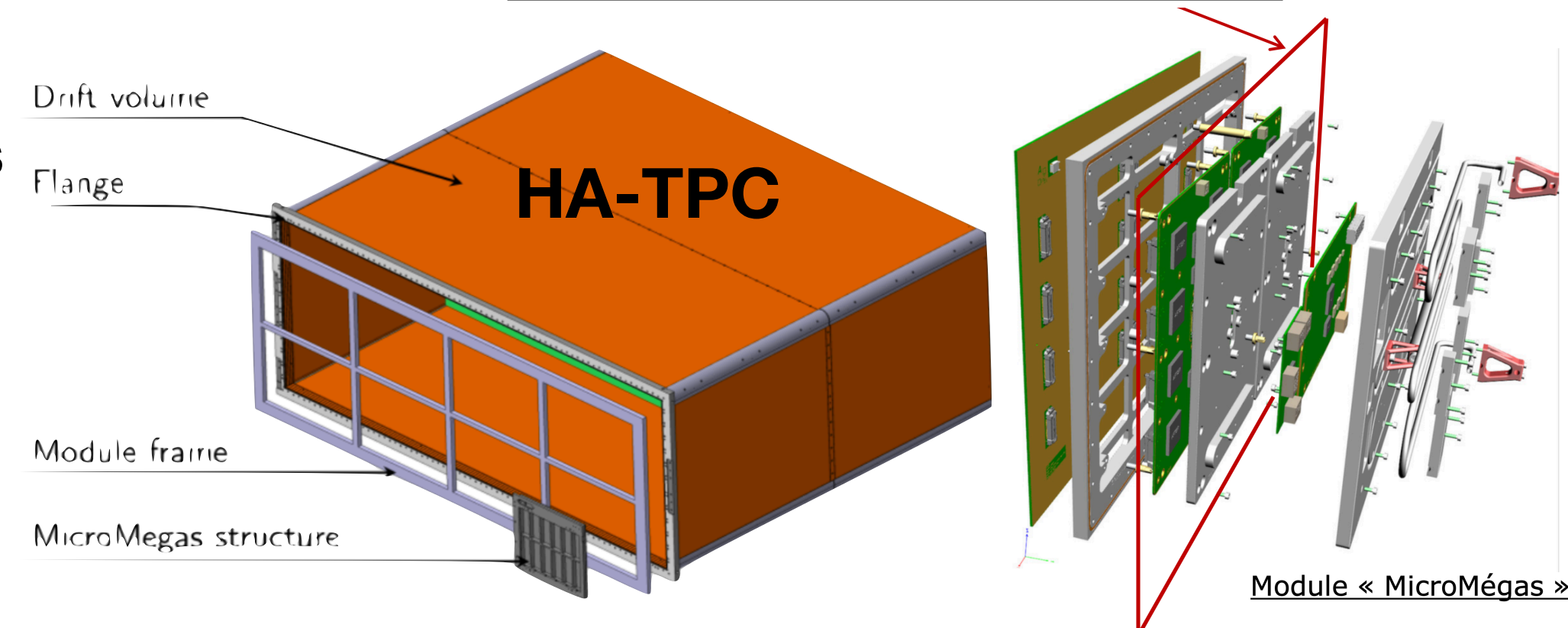
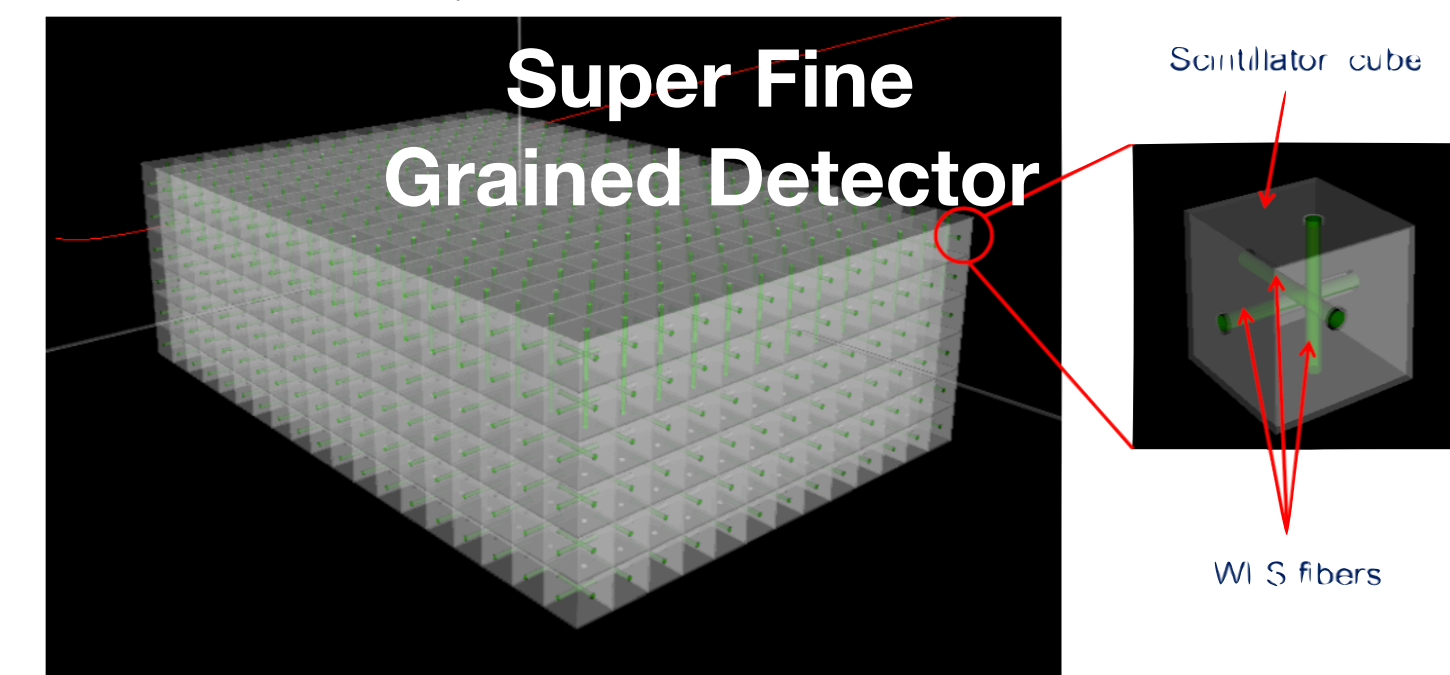
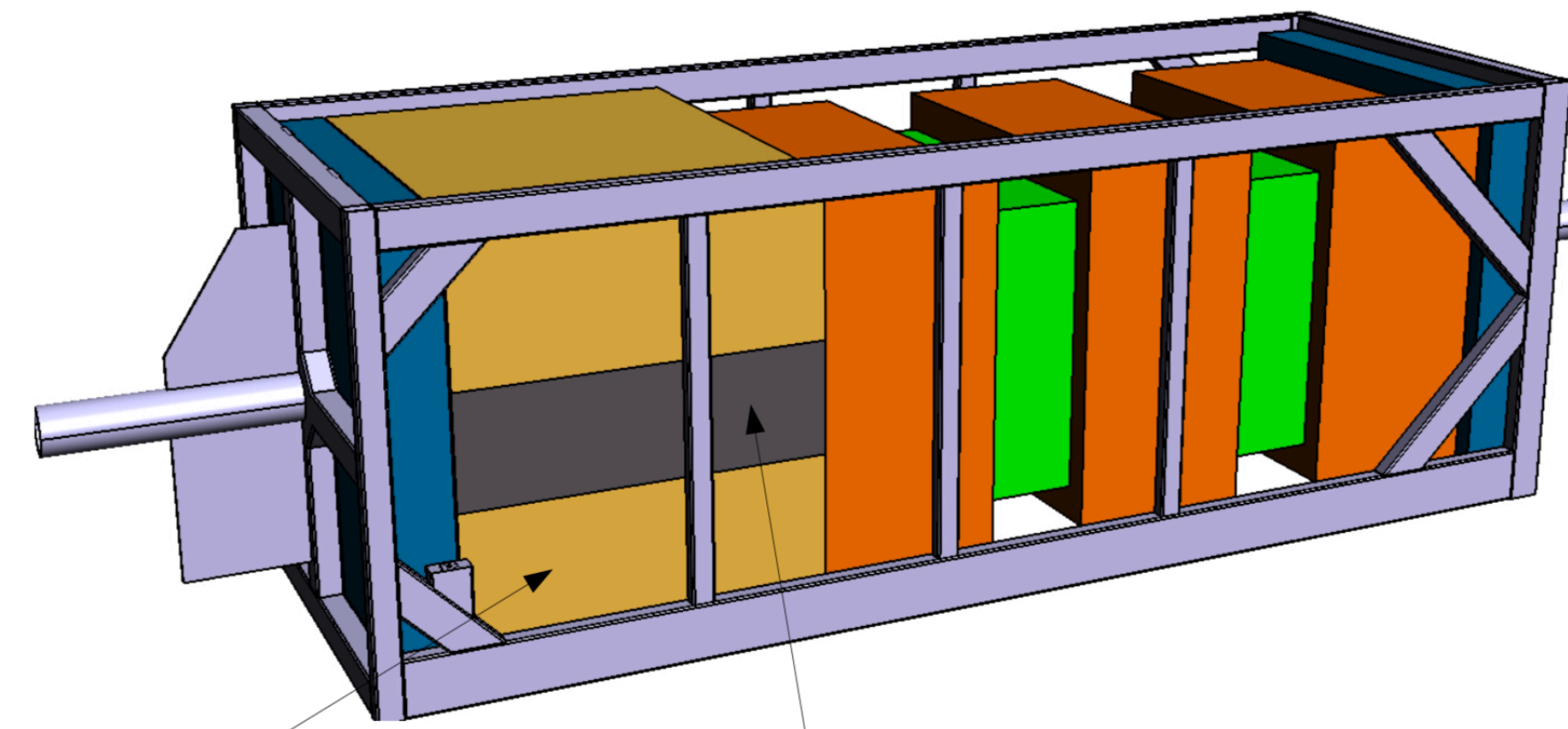
Reconstruction of high angle tracks

## LPNHE contributions

**TPCs front-end electronics**  
**Detector suspension system**  
**DAQ software**

### LPNHE contributing ITs

Jean-Marc PARRAUD  
 François TOUSSENEL  
 Eric PIERRE  
 Yann ORAIN  
 Julien PHILIPPE  
 Diego TERRONT



Approved by LPNHE and IN2P3 CS

Comparaison between:  
 Far detector data  
 Near detectors predictions

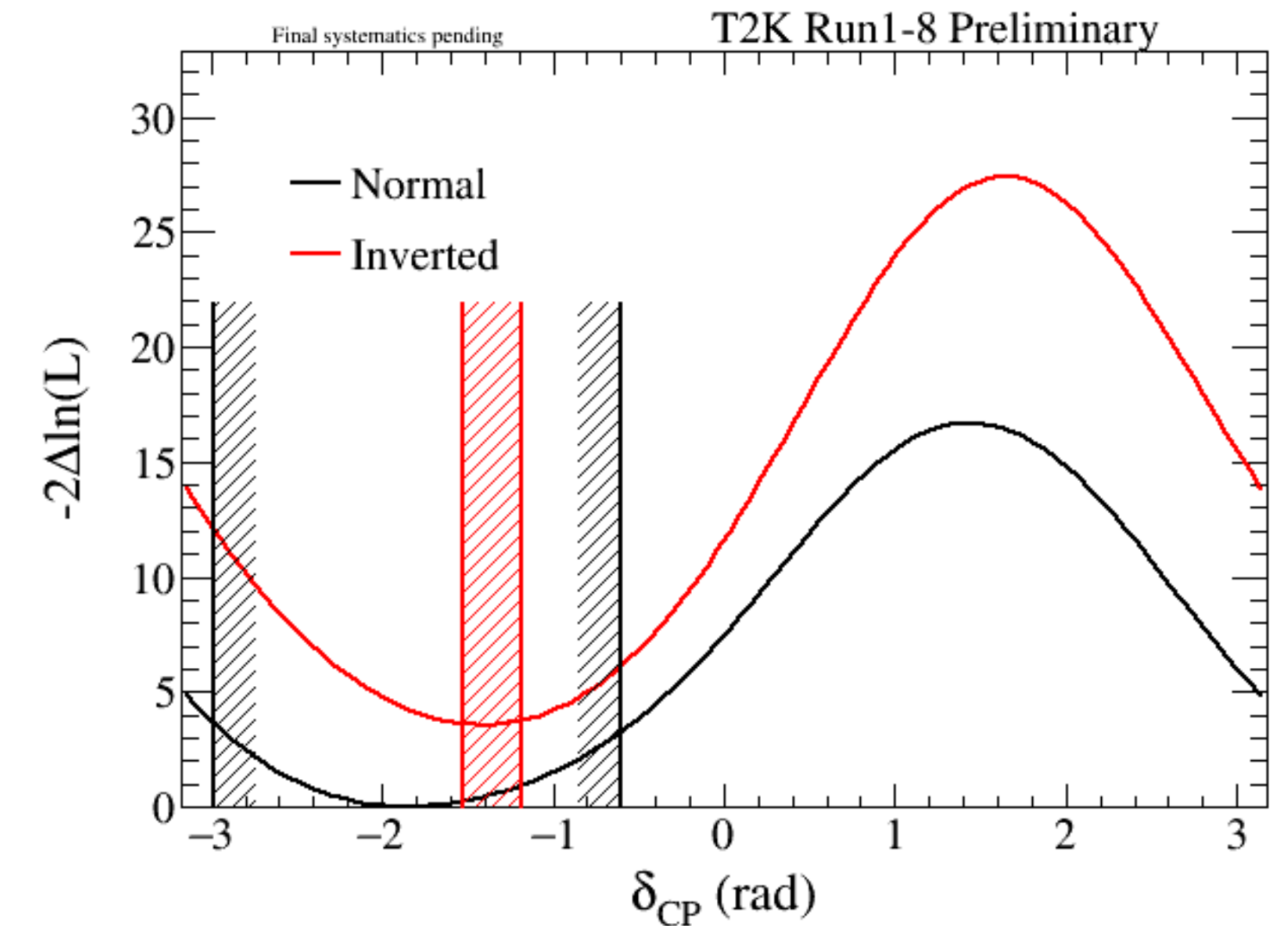
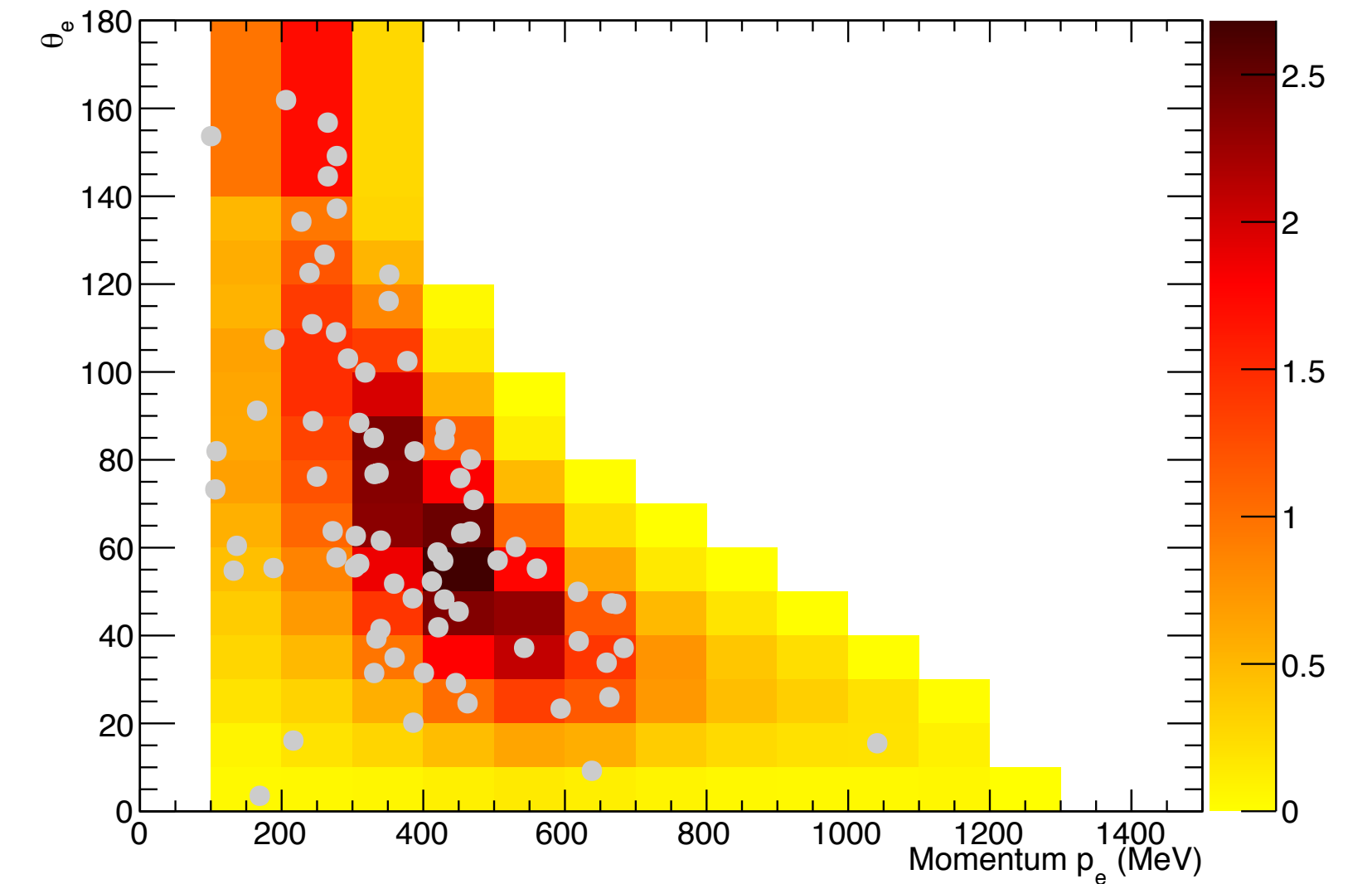
Extraction of oscillation parameters

**LPNHE contributions**

**Oscillation parameters extraction**

**Adding additional data samples**

**Combined T2K-SK analysis**



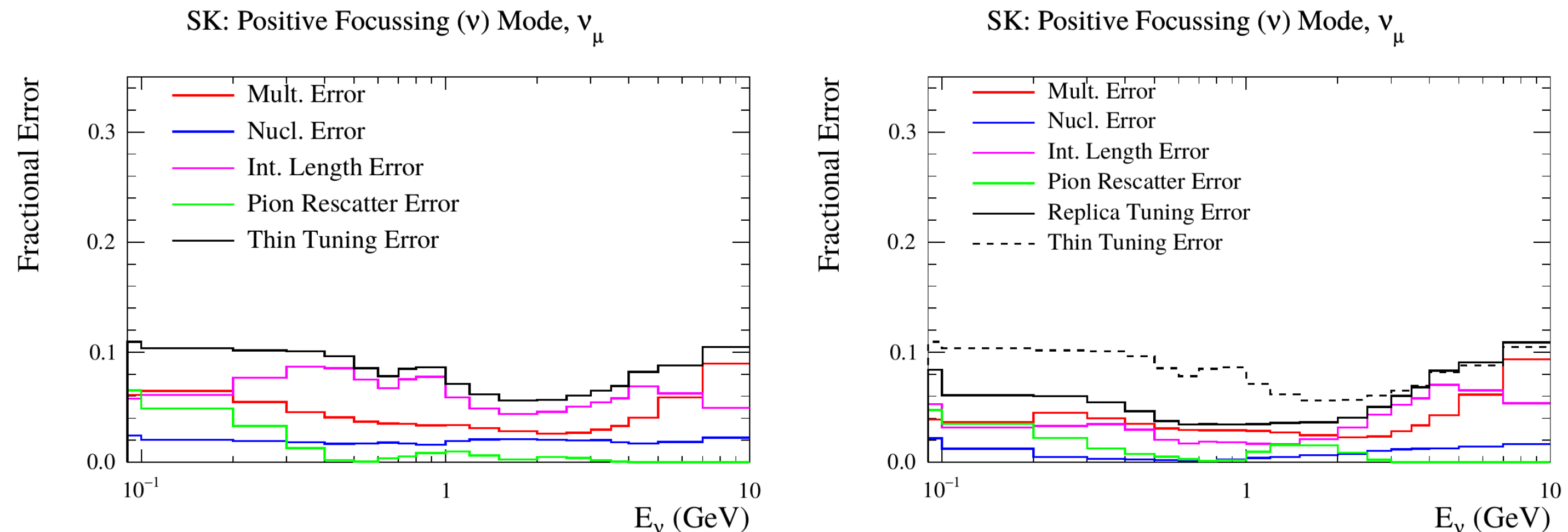
Further reduction of T2K neutrino flux uncertainty down to 5% using published replica-target measurements (in a few months)

Improved measurements with T2K replica target (new target)

Additional tracking detectors

Hadron production with low momentum beam (<10 GeV/c)

Help achieve 3% systematic uncertainty goal for HK



Increase in detector size

Already-proven water Cherenkov technique

8 times larger fiducial volume

40k PMT & 20k+ mPMT

Physics:

Precise measurement of  $\delta_{CP}$

Increased sensitivity to rare events (proton decays, SN neutrinos)

...

Project received seed funding from MEXT

**Next milestones:**

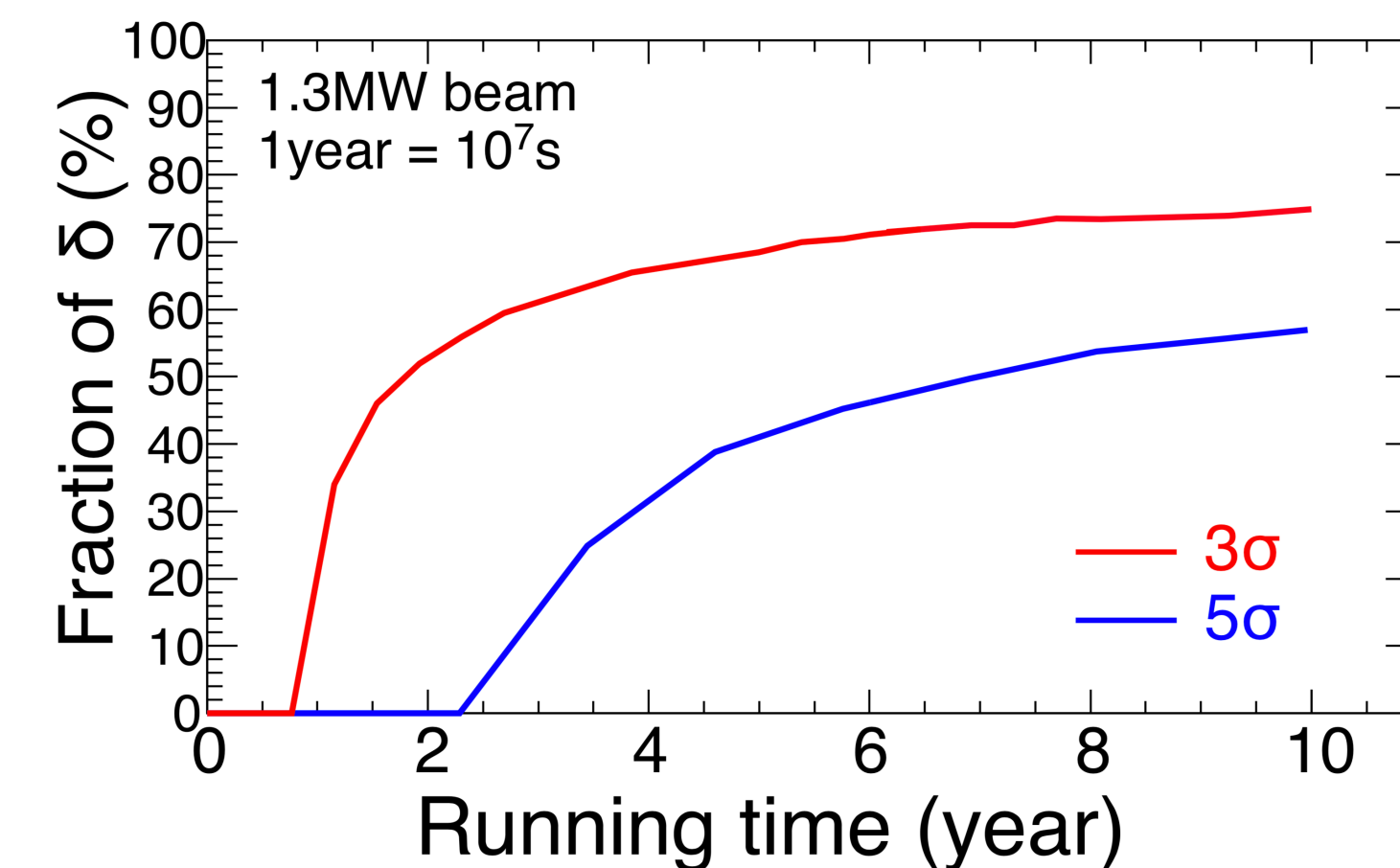
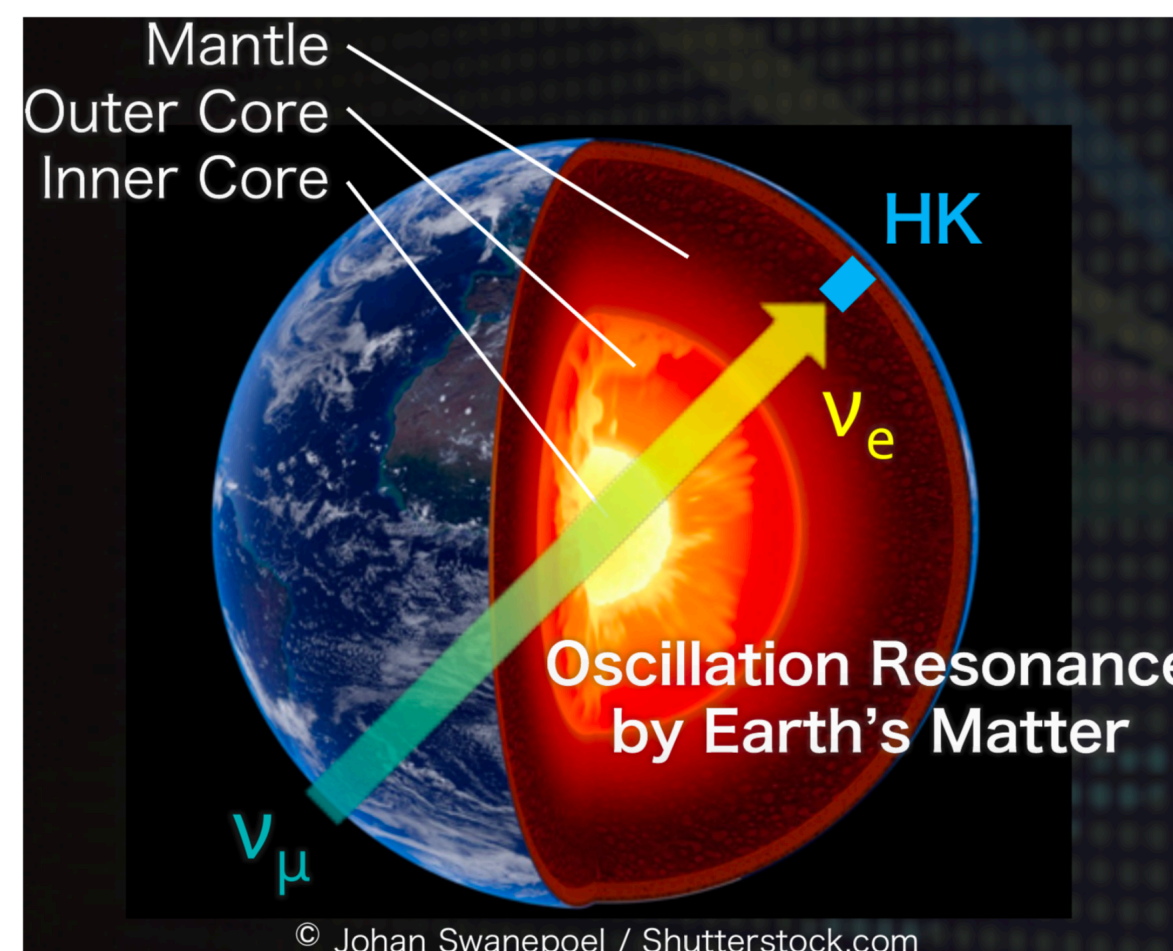
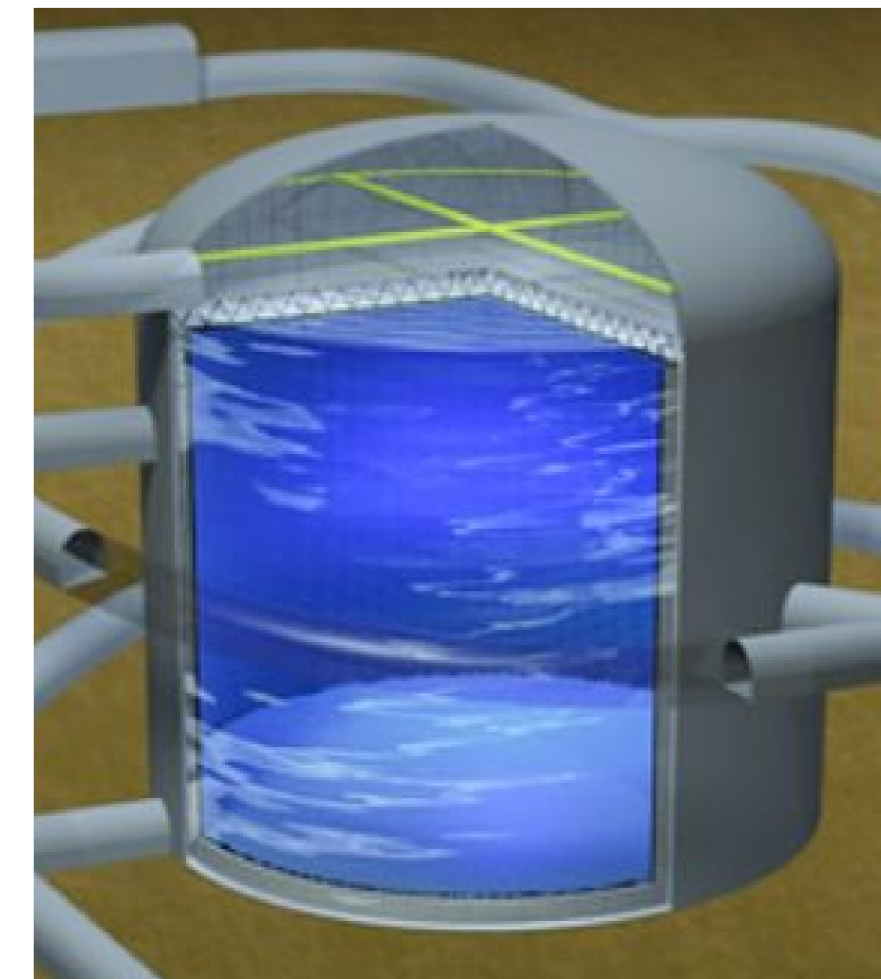
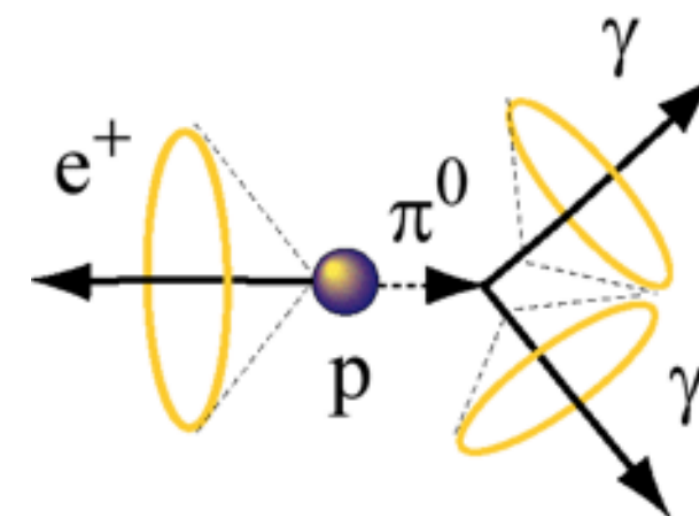
May-June: Technical report

June: 2nd HKFF in Japan

Fall 2019: response from MEXT

R&D over the next couple of years

2027: start data taking



Define LPNHE contributions to the project

Favour common efforts with LLR/CEA

Clock synchronisation

DAQ/electronics?

mPMTs

Computing

Contributing to HK project approval by MEXT

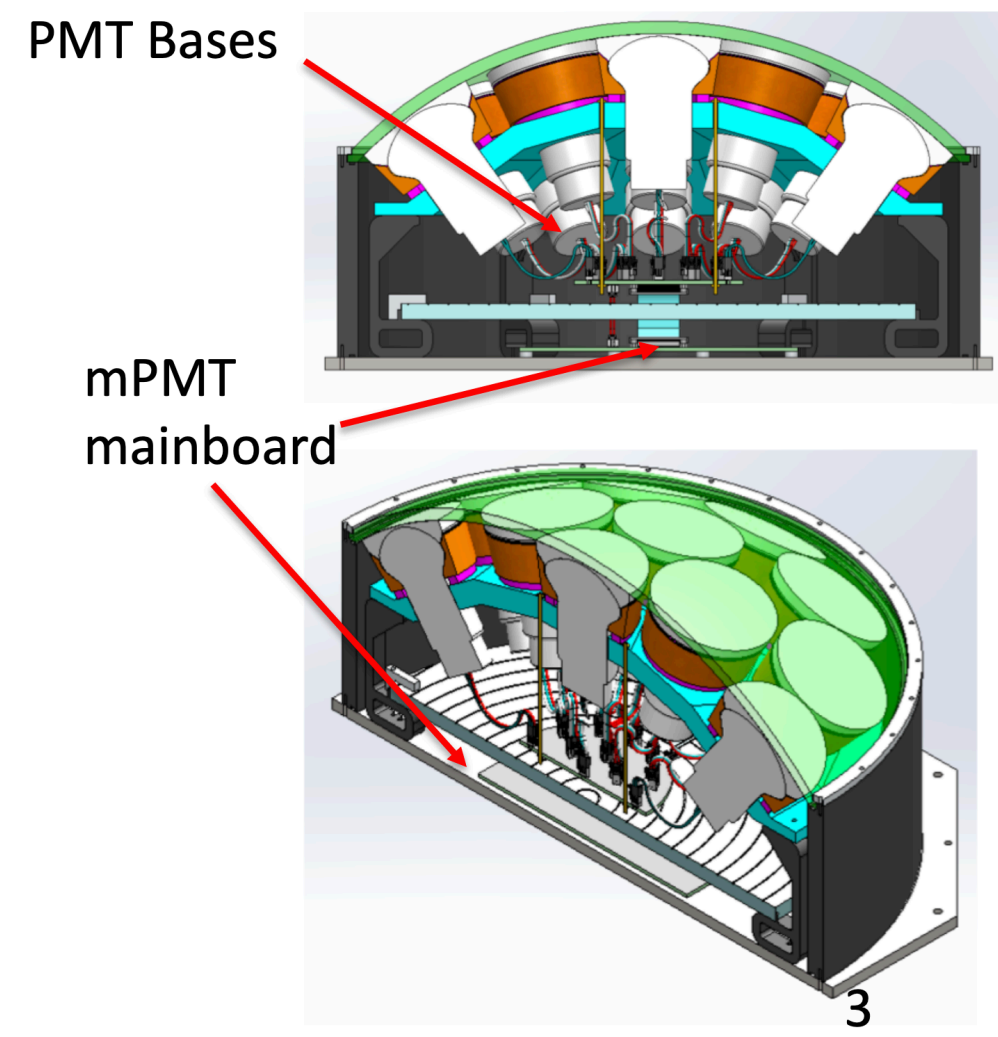
Obtain IN2P3 directorate's blessing...

Collaboration with APC/LLR/INFN/  
IPMU to use *Memphyno* Cherenkov  
water tank

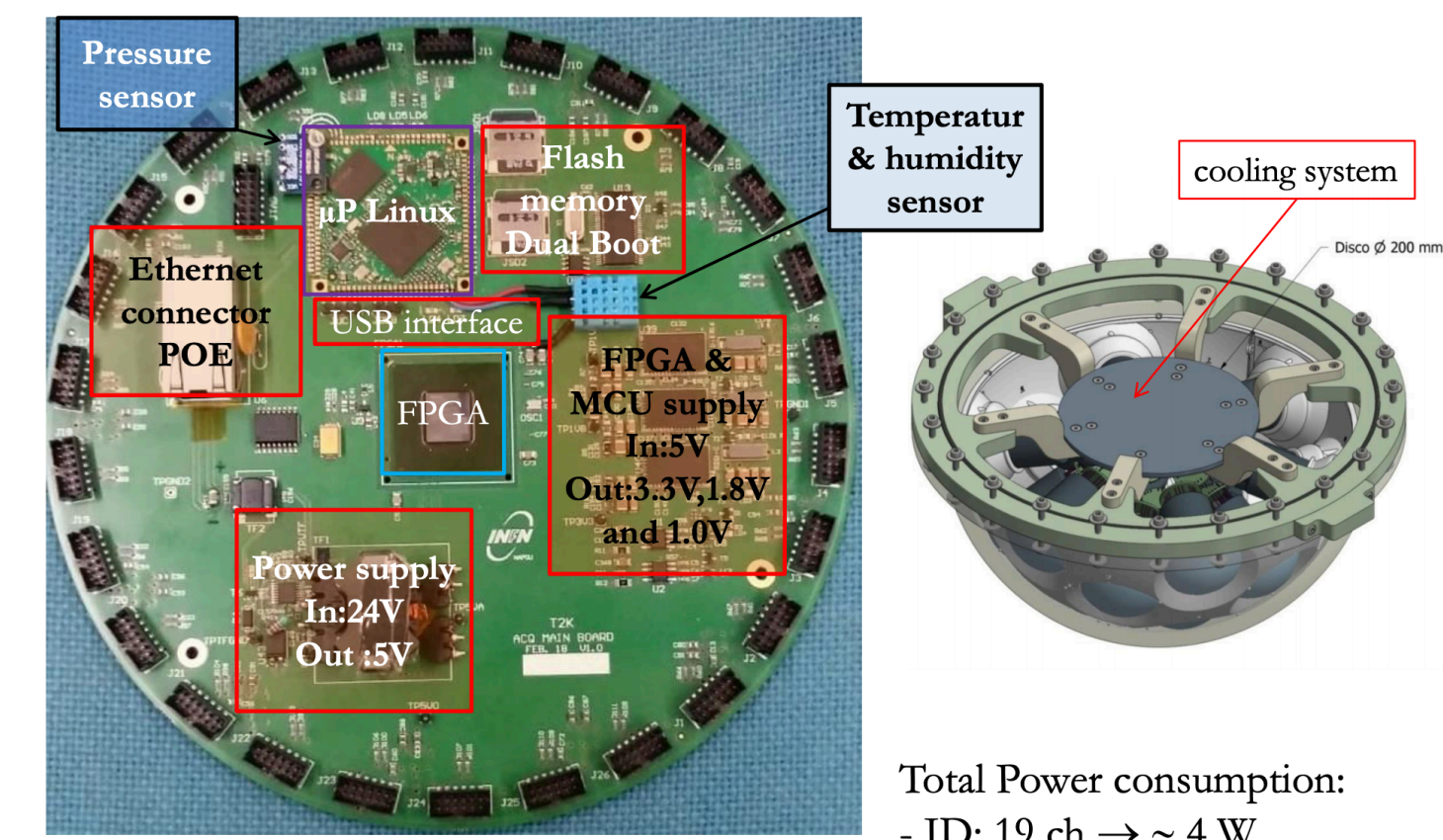
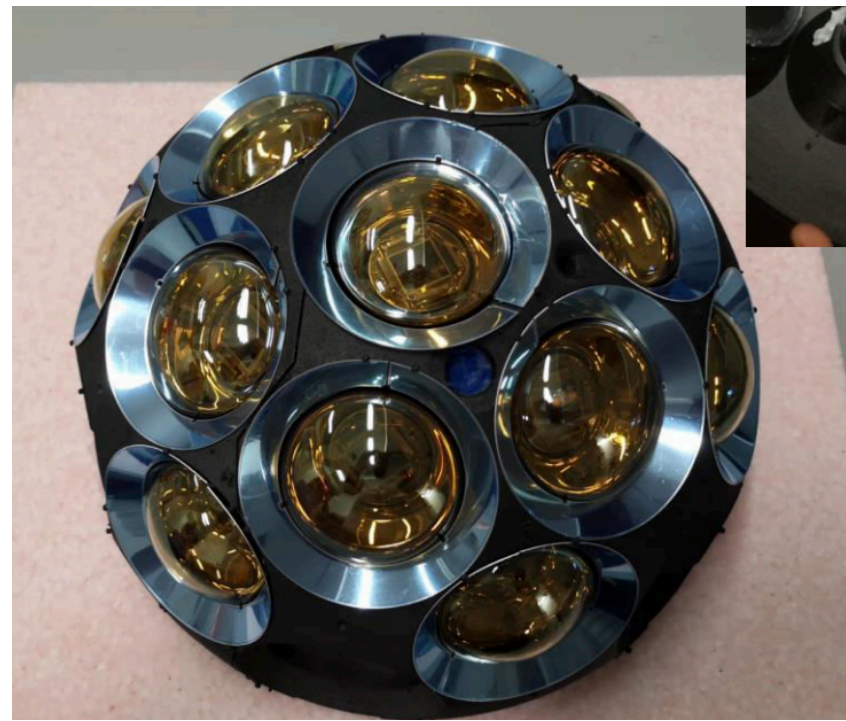
2 scintillator plans for comics trigger

In-water tests of mPMTs Canadian  
and Italian designs (w/ electronics)

**LPNHE contributions/goals**  
**Leading data taking**  
**Develop tools and expertise**  
**DAQ, computing, storage**



INFN mPMT electronics: main board



Total Power consumption:  
- ID: 19 ch → ~ 4 W