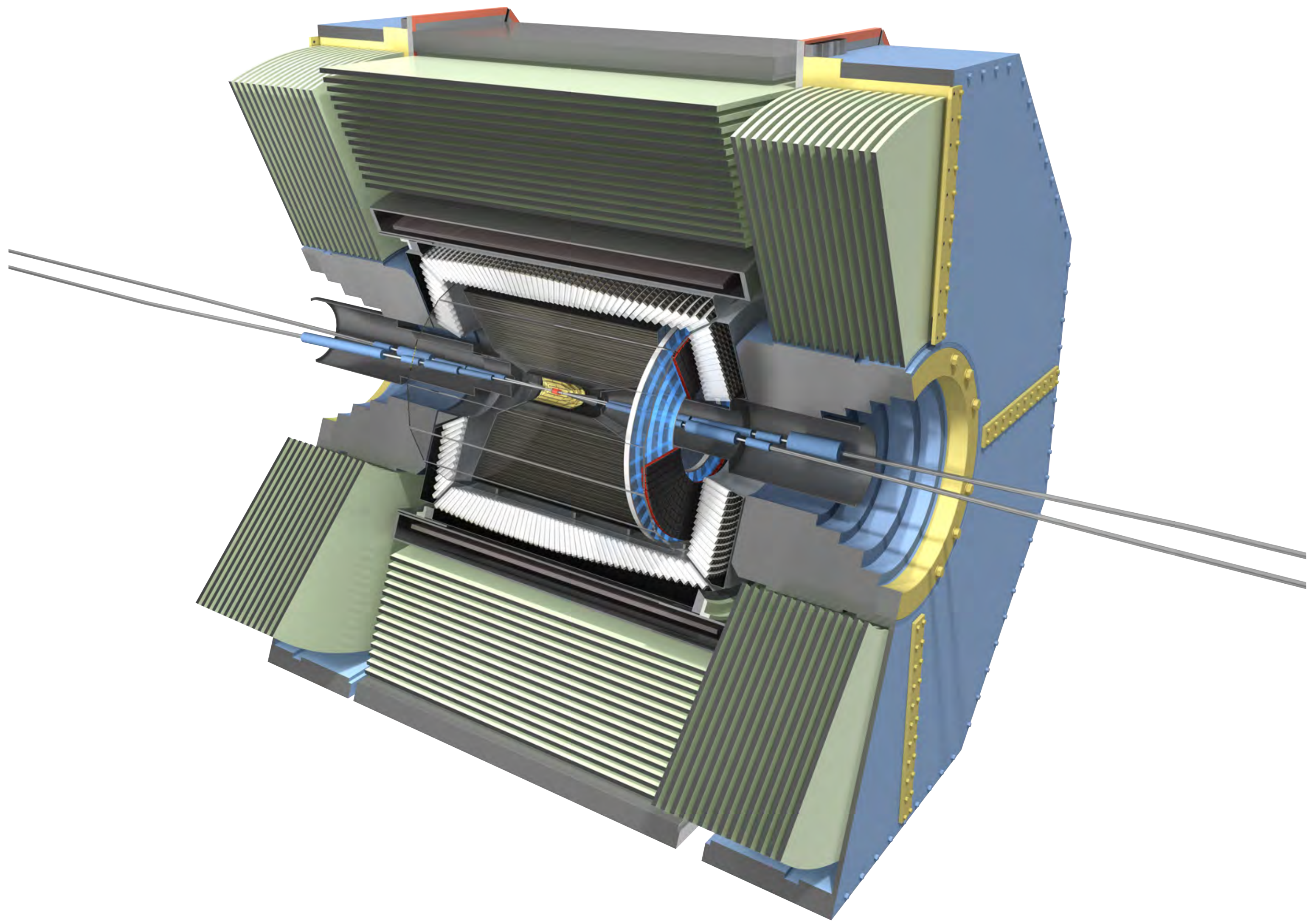
Belle-II Status and Activities



Riccardo de Sangro
Laboratori Nazionali di Frascati
49th LNF Scientific Committee Meeting - May 18th 2015

Outline

- The Belle-II experiment
- SuperKEKB status
- LNF group activities
  - ECL upgrade
    - APD R&D
    - Irradiation Studies
    - BEAST
  - Software

The Belle-II Experiment

- Study flavour physics at Super B Factory built at the KEK Laboratory in Tsukuba, Japan
  - Complementarity with LHC program in search for new physics
    - intensity frontier ⟷ energy frontier
  - Competition with LHCb (upgrade)
    - Largely complementary
    - Independent measurements of many theory parameters, confirmation or else of possible NP observations
- Upgraded e^+e^- collider KEKB → SuperKEKB
- Upgraded detector Belle → Belle-II

Why (still) Flavour Physics?

B Factories

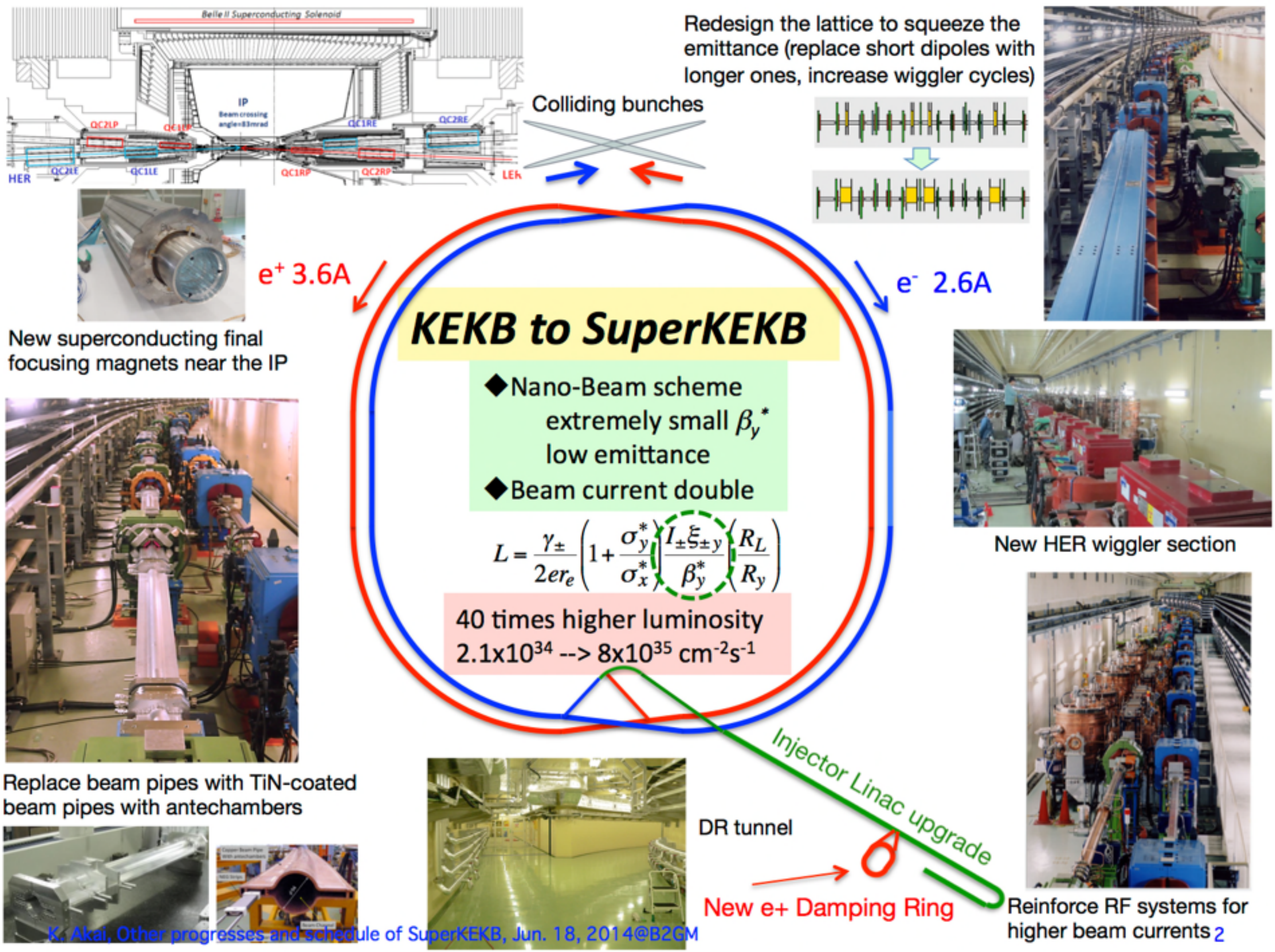
Statistics

- Explore the origin of CP violation
  - Key element in understanding the matter content of our present universe
  - Established in B mesons in 2001
  - Direct CP violation discovered in B mesons in 2004
- Precisely measure the parameters of the Standard Model
  - Elements of CKM matrix
  - Disentangle complicated interplay between strong and weak interaction effects
- Search for the effects of physics beyond the Standard Model in loop diagrams
  - Potentially large effects on rates of rare decays, time dependent asymmetries, lepton flavour violation
  - Sensitive to large New Physics scale, beyond LHC reach, as well as to size and phases of NP coupling constants

Super B Factories

Physics Reach of Belle II and the LHCb upgrade

Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\|V_{us}\|$ $[K \to \pi \ell \nu]$	**	0.1%	K-factory
$\|V_{cb}\|$ $[B \to X_c \ell \nu]$	**	1%	Belle II
$\|V_{ub}\|$ $[B_d \to \pi \ell \nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K_S^0]$	***	$8 \cdot 10^{-3}$	Belle II/LHCb
ϕ_2		1.5°	Belle II
ϕ_3	***	3°	LHCb
CPV			
$S(B_s \to \psi\phi)$	**	0.01	LHCb
$S(B_s \to \phi\phi)$	**	0.05	LHCb
$S(B_d \to \phi K)$	***	0.05	Belle II/LHCb
$S(B_d \to \eta' K)$	***	0.02	Belle II
$S(B_d \to K^*(\to K_S^0 \pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A_{SL}^d	***	0.001	LHCb
A_{SL}^s	***	0.001	LHCb
$A_{CP}(B_d \to s\gamma)$	*	0.005	Belle II
rare decays			
$\mathcal{B}(B \to \tau\nu)$	**	3%	Belle II
$\mathcal{B}(B \to D\tau\nu)$		3%	Belle II
$\mathcal{B}(B_d \to \mu\nu)$	**	6%	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb
zero of $\mathrm{A_{FB}}(\mathrm{B} \to \mathrm{K}^* \mu\mu)$	**	0.05	LHCb
$\mathcal{B}(B \to K^{(*)}\nu\nu)$	***	30%	Belle II
$\mathcal{B}(B \to s\gamma)$		4%	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$		$0.25 \cdot 10^{-6}$	Belle II (with 5 ab^{-1})
$\mathcal{B}(K \to \pi\nu\nu)$	**	10%	K-factory
$\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$	***	0.1%	K-factory
charm and τ			
$\mathcal{B}(\tau \to \mu\gamma)$	***	$3 \cdot 10^{-9}$	Belle II
$\|q/p\|_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II


KEKB to SuperKEKB
◆Nano-Beam scheme
extremely small β_y^*
low emittance
◆Beam current double
$$L = \frac{\gamma_\pm}{2 e r_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$
40 times higher luminosity
2.1×10^{34} --> 8×10^{35} $cm^{-2}s^{-1}$
Belle II Superconducting Solenoid
IP
QC2LP
QC1LP
QC1RE
QC2RE
QC2LE
QC1LE
QC1RP
QC2RP
HER
LER
Colliding bunches
e^+ 3.6A
e^- 2.6A
New superconducting final focusing magnets near the IP
Redesign the lattice to squeeze the emittance (replace short dipoles with longer ones, increase wiggler cycles)
New HER wiggler section
Replace beam pipes with TiN-coated beam pipes with antechambers
DR tunnel
Injector Linac upgrade
New e+ Damping Ring
Reinforce RF systems for higher beam currents
K. Akai, Other progresses and schedule of SuperKEKB, Jun. 18, 2014@B2GM
2

SuperKEKB Status

- The SuperKEKB construction has been fully funded, started in 2010 and is ready to start commissioning
- Funding problems for the operation of the machine, which was foreseen to start in Jannuary 2015, caused a postponement of the commissioning
- After several months of great uncertainty, we now have a firm program to go from today to the first physics run

Commissioning phases

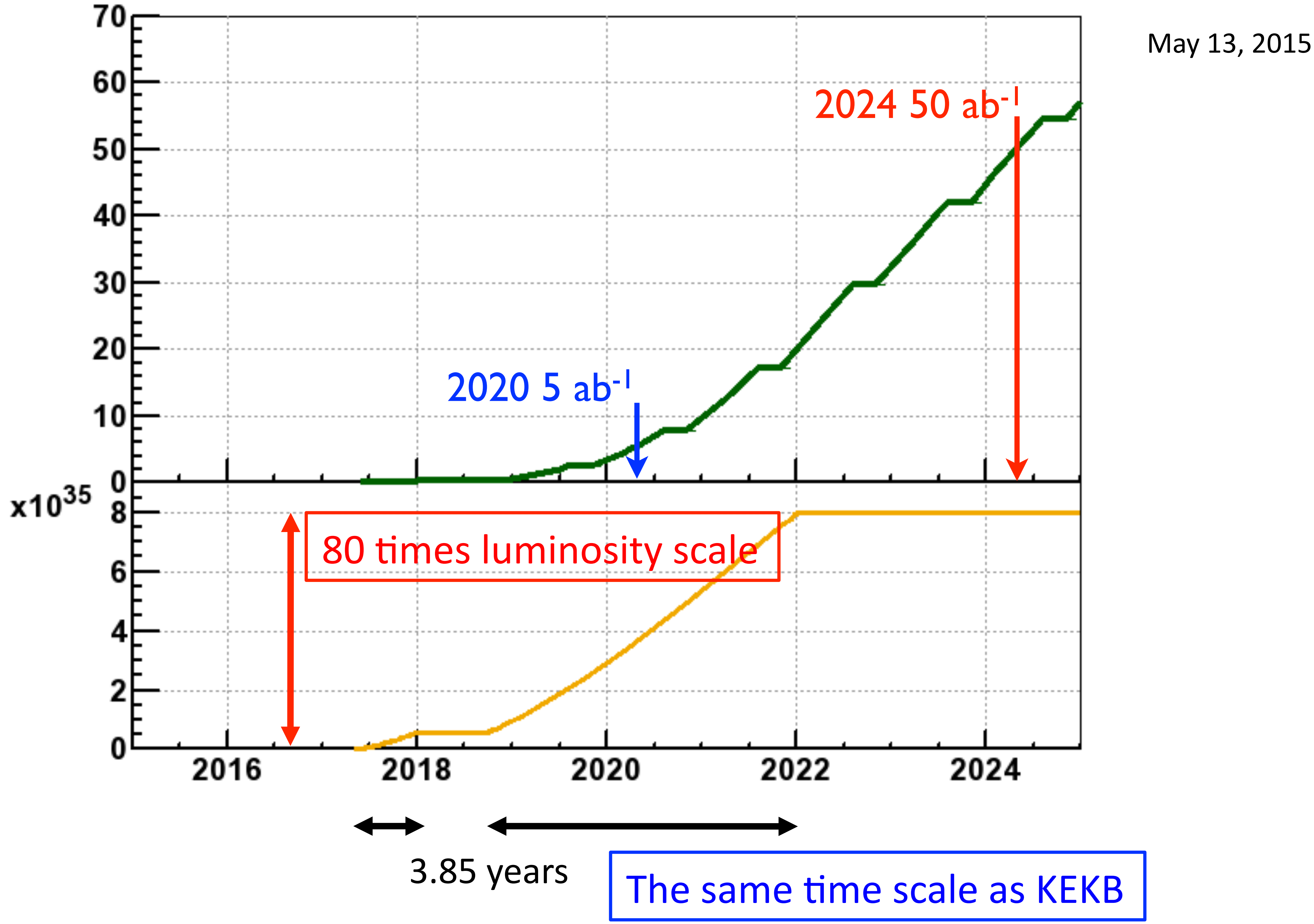
- Phase 1 (5 months) **Jan 2016**
  - No QCS, No Belle II solenoid
  - Basic machine tuning
  - Low emittance tuning
  - Vacuum scrubbing
    - Belle II people request enough vacuum scrubbing in this stage (before Belle II roll in).
    - At least one month at beam currents of 0.5~1A /ring.
  - DR commissioning starts before Phase 2.
- Phase 2 (5 months +3 summer shutdown) **May 2017**
  - with QCS and Belle II (w/o Vertex detectors)
  - Low beta optics tuning
  - Small x-y coupling optics tuning
  - Beam collision tuning
  - Belle II background study
  - Target luminosity at this stage is 1×10^{34} $cm^{-2}s^{-1}$
- Phase 3 **Oct 2018**
  - Physics run (Vertex detectors installed)
  - Increase beam currents
  - Beam tuning continued to increase luminosity

Belle-II *with complete detector* 1 year total delay

K. Akai, Other progresses and schedule of SuperKEKB, Jun. 18, 2014@B2GM

Luminosity Projection SuperKEKB

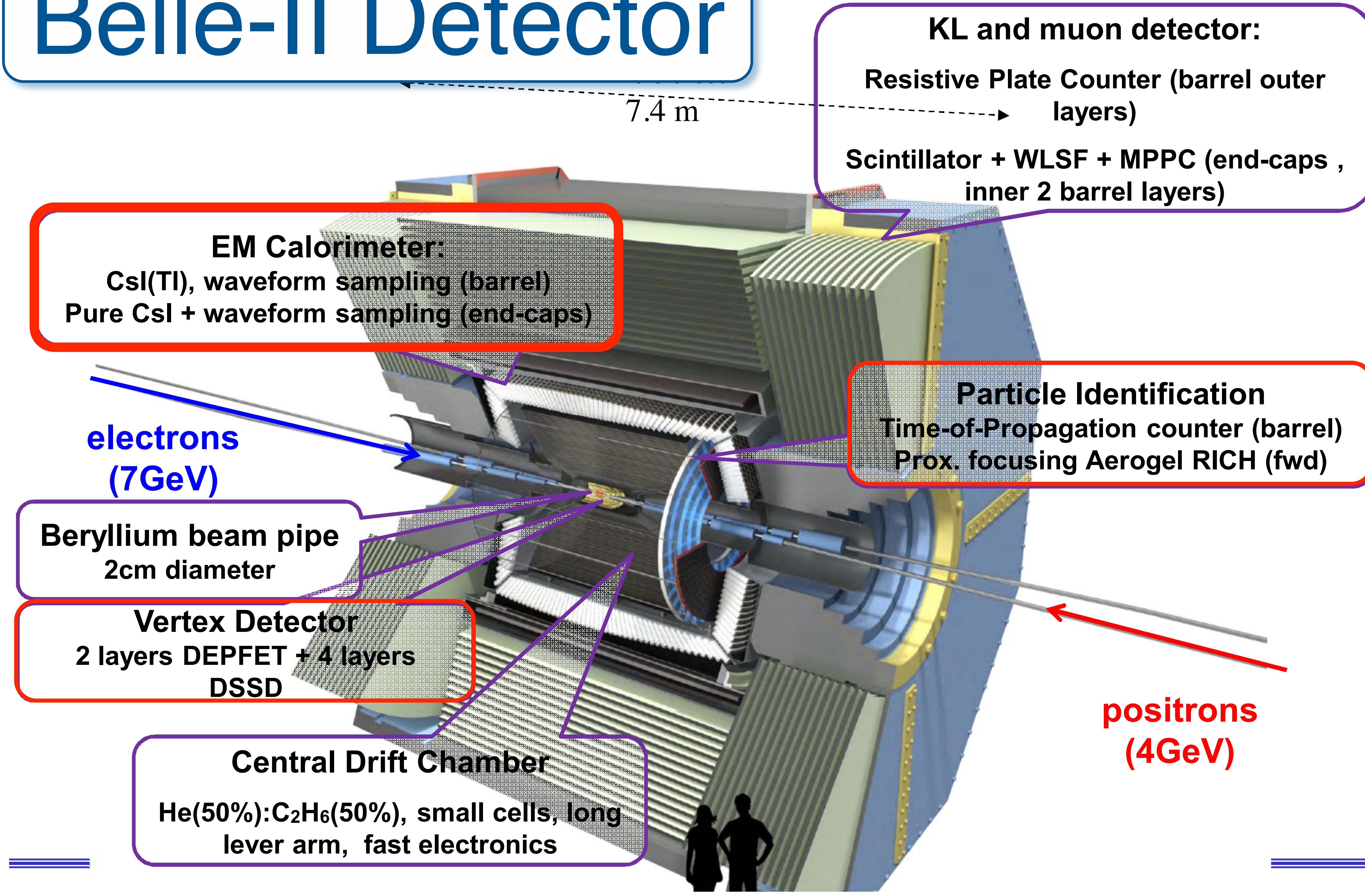
A target luminosity profile of SuperKEKB/Belle II



LNF-KEK Collaboration for SuperKEKB & DAFNE

- The presence of the Frascati group in Belle-II stimulated the revival of a long standing collaboration between LNF and KEK on machine physics
- Collaboration activity on feedbacks started already several years ago, coordinated by A. Drago (LNF)
- Proposal of a collaboration on some topics and for the commissioning stage of SuperKEKB
- Identified topics at the moment:
  - Optics, in particular crab waist option (M. Biagini)
  - Lifetimes and backgrounds studies (M. Boscolo)
  - Injection system studies (S. Guiducci)
- Mutual benefit
  - KEK people to visit LNF to collaborate on DAFNE's commissioning

Belle-II Detector



Contribution of INFN groups

Appendix 2: List of foreseen INFN contributions to detector subsystems

Vertex Detector

Subdetector: SVD
INFN Groups: Pisa, Trieste.

- Contribution to ladder assembly:
  - acceptance and qualification test of a portion of the trapezoidal double-sided microstrip silicon sensors;
  - qualification tests of a sample of the rectangular double-sided microstrip silicon sensors;
  - assembly and qualification of the forward and backward subassembly for Layer 4, 5, and 6, with delivery to the ladder assembly sites;
  - design, fabrication and delivery to the ladder assembly sites of the mechanical tools needed to align the subassemblies.
- Design, procurement, fabrication, deployment and commissioning of the radiation and environmental monitoring systems for the SVD:
  - sensors for radiation monitoring, and the corresponding electronics for digitization, readout, and generation of a beam abort signal;
  - a system of temperature sensors to measure the temperature of SVD ladders, of the cooling system, and of the electronics;
  - a system of humidity sensors to measure the relative humidity inside the SVD volume.
- SVD Power Supplies:
  - procurement and delivery of the low and high voltage power supply system for the SVD ladders
- SVD installation and commissioning:
  - contribution to the equipment needed for the ladder mount operation;
  - manpower contribution to ladder mount, and to SVD installation and commissioning.

PID

Subdetector: TOP
INFN Groups: Padova, Torino.

- Contribution to calibration system:
  - design, fabrication, installation and operation of the timing calibration system for the entire TOP system.
- Contribution to TOP assembly:
  - labor for assembly, installation and commissioning of TOP modules at KEK.

ECL

Subdetector: ECL
INFN Groups: LNF, Napoli, Perugia, Enea Casaccia (Roma1), Roma3.

- Contribution to the refurbishment of the ECL electronics:
  - test of the new collector modules designed to receive the trigger and distribute it to the new shaper boards, designed for the change of the shaping time of the detector;
  - replacement of resistors in the preamplifiers of the forward region to cope with the increase in leakage current of the PiN diodes.

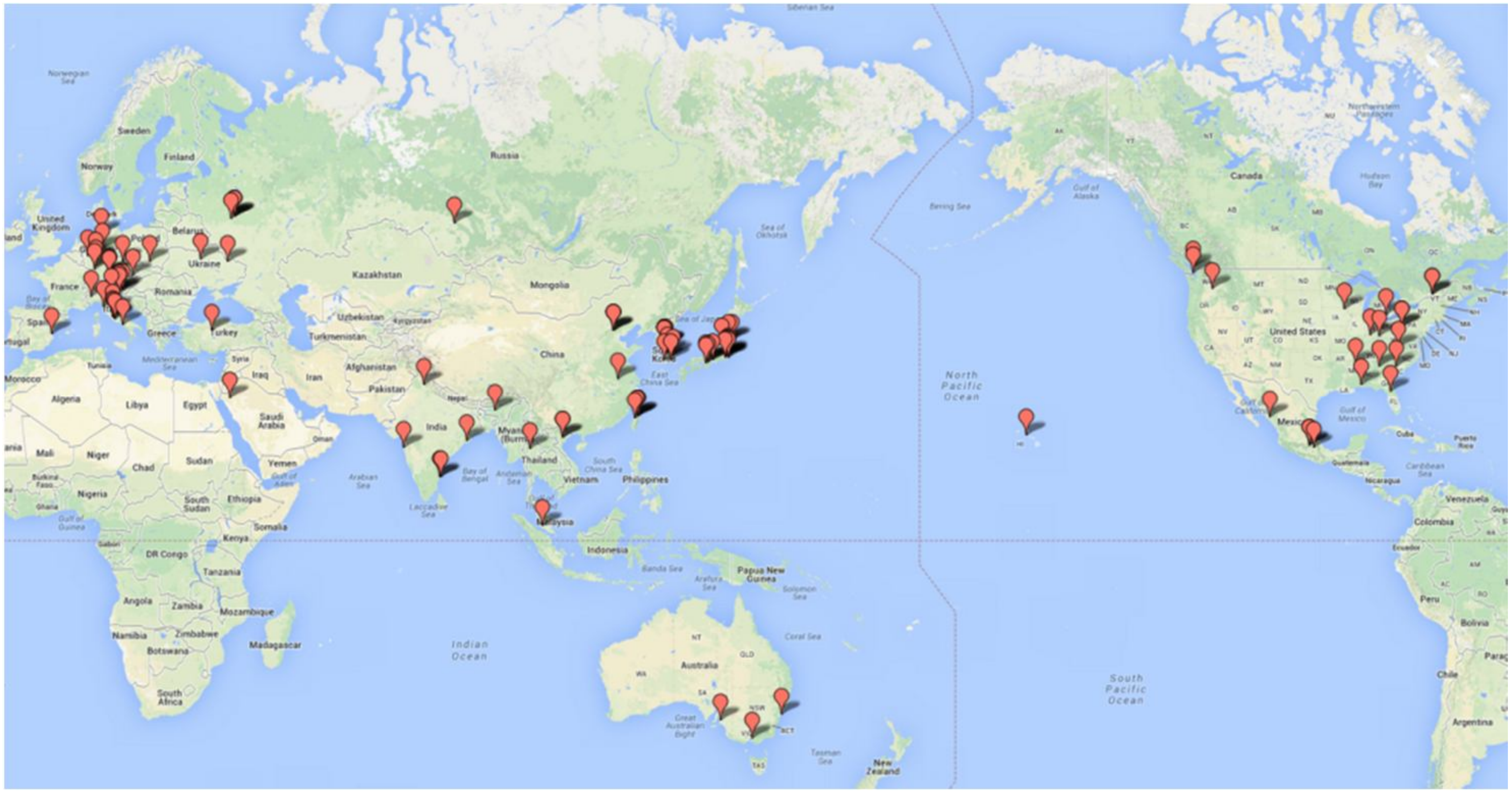
- Contribution to the forward calorimeter upgrade:
  - qualification and radiation tests on CsI and CsI(Tl) crystals for the forward calorimeters;
  - R&D on photo sensors to be used on pure CsI crystals.
- Contribution to the development of slow control system:
  - development, test and construction of a slow control system for ECL, with the possibility of extending it to other subdetectors.
- Software:
  - development of ECL simulation, reconstruction and physics analysis tools

(from the INFN-KEK Mou)

INFN Total

~62 People
~32 FTE
9 Institutions

Belle-II Collaboration



- Belle II (June 30, 2014): ~ 600 scientists, 97 institutions, 23 countries

Hard to find a good time for a phone meeting!

The JENNIFER project

A. Passeri

Japan and Europe Network for Neutrino and intensity Frontier Experimental Research
is a Marie Slodowska Curie RISE project funded by EC under Grant n. 64294.

RISE (Reasearch and InnovationStaff Exchange) action provide support for the research personnel exchange between academia and industry and/or between european instutions and third countries.

JENNIFER network is formed the whole european Belle-II community and most of the european T2K community, together with KEK and with the Tokyo University ICRR.
Its activity includes:

- **Flavour Physics at e+e- machines**
- **Belle-II detector construction and commissioning**
- **Neutrino oscillation physics and T2K data analysis**
- **R&D toward HyperK**

JENNIFER grant amounts to 2.3 M€ in 4 years, supporting european personnel secondments to Japan for a total of 513 person-months.
INFN is the coordinator institution and its share on the budget amounts to 747 k€.

LNF Group Activities

- Forward ECL Upgrade
- ECL Software

E. De Lucia (staff)
R. de Sangro (staff, PI)
*G. Finocchiaro (staff)
B. Oberhof (post doc)
P. Patteri (staff)
I. Peruzzi (associate)
M. Piccolo (associate)
A. Russo (SSE)
A. Zossi (SSE)

7 people
3.9 FTE

(*) Resp. Nazionale Belle-II INFN

Upgrade of the Forward ECL

- High background (and signal) rates @ L=8x10^{35}, bring up two questions for the ECL:
  1. Crystal radiation damage
  2. High pile-up ➜ resolution, combinatorial background
- Solution proposed in the Belle II TDR
  - Substitution of the CsI(Tl) crystal in the forward ECL with pure CsI ones

  ✓ Rad-hard

  ✓ Faster crystal: scintillation time of pure CsI is 6/30 ns vs. 1000 ns for CsI(Tl)

  however…

  ✓ Light yield of CsI ≪ LY of CsI(Tl) and the fast emission component is in the near UV

  ➡ Substitution of the photosensors. Options:

  a) Belle II TDR BASELINE: 2" Hamamatsu photopentode: high S/N, but G(1.5T)~1/4xG(0T)

  b) ALTERNATIVE: Use LAAPD, compact (mechanics), gain independent of B field, redundancy in case of failure (≥2sensors/crystal)

- Proposed contribution from INFN: substitution of ~20% of the forward ECL CsI(Tl) crystals with pure CsI one

  ➡ R&D on photo-sensors and crystals

Forward ECL upgrade task force

- Critical re-evaluation of the conclusions of the Belle-II TDR

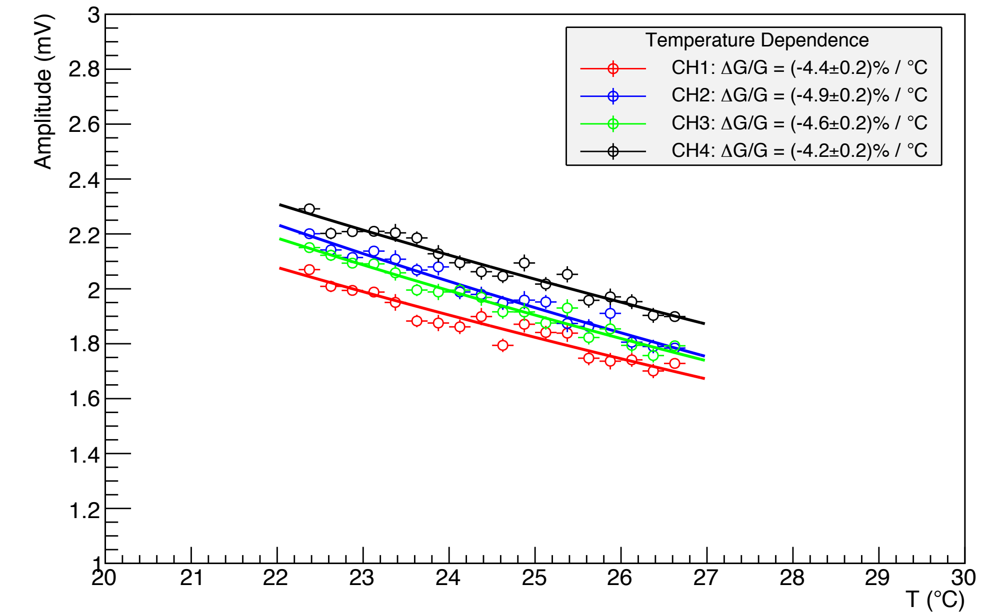
  1. R&D on photo-sensor and crystals (R.d.S., E. De Lucia, G. Finocchiaro, M. Piccolo)
  2. Radiation damage (R.d.S., G. Finocchiaro, M. Piccolo)
  3. Evaluation of the background level to be expected in Belle II and MC validation measuring background rates with BEAST (R.d.S., G. Finocchiaro)
  4. Impact of higher pile-up and hardware performance degradations on actual physics channels (e.g. $B \to K\nu\nu$) (E. De Lucia, B. Oberhof)

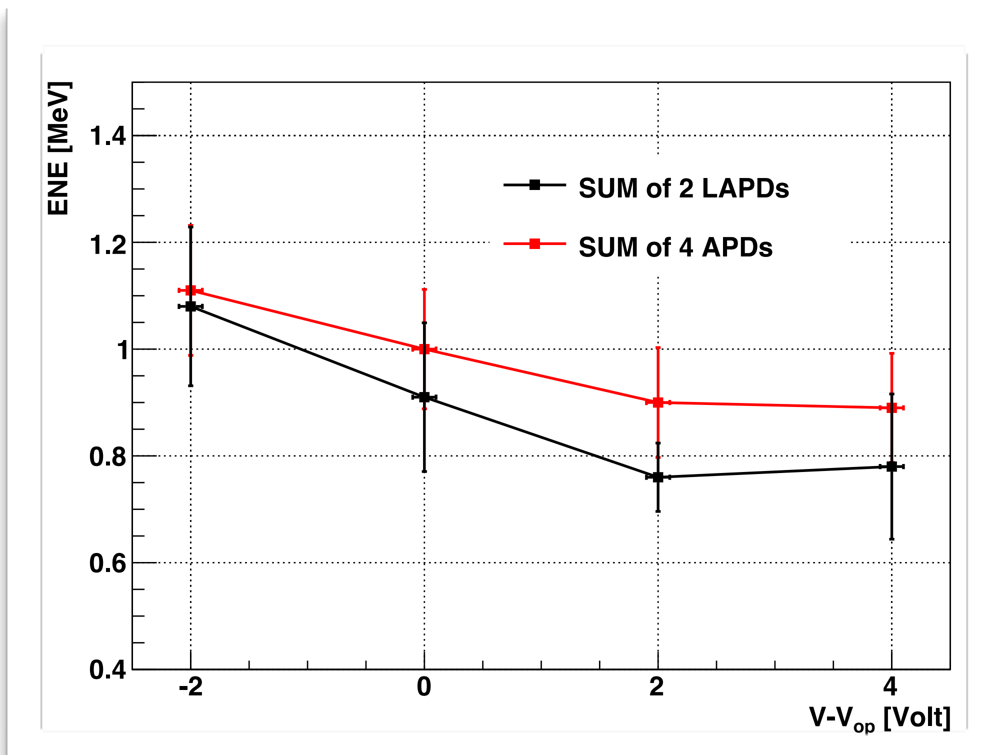
- Take a decision on the upgrade in February 2016

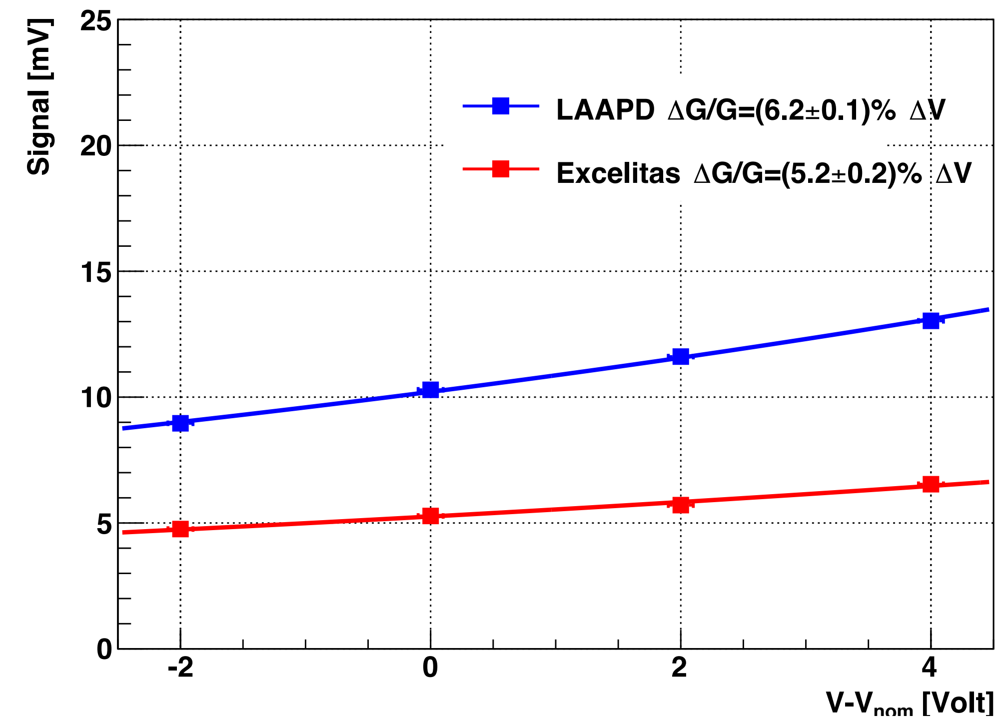
LNF group contributing to all areas

1- R&D on photo-sensors

- Two types of detectors tested: 5.6x5.6 mm^2 APD from Excelitas and 10x10 mm^2 LAAPD from Hamamatsu
- Extensive studies of the pure CsI readout performances of APD in terms of light collection and equivalent noise energy
- Study of gain vs HV and temperature
- Hamamatsu LAAPD selected for beam test study





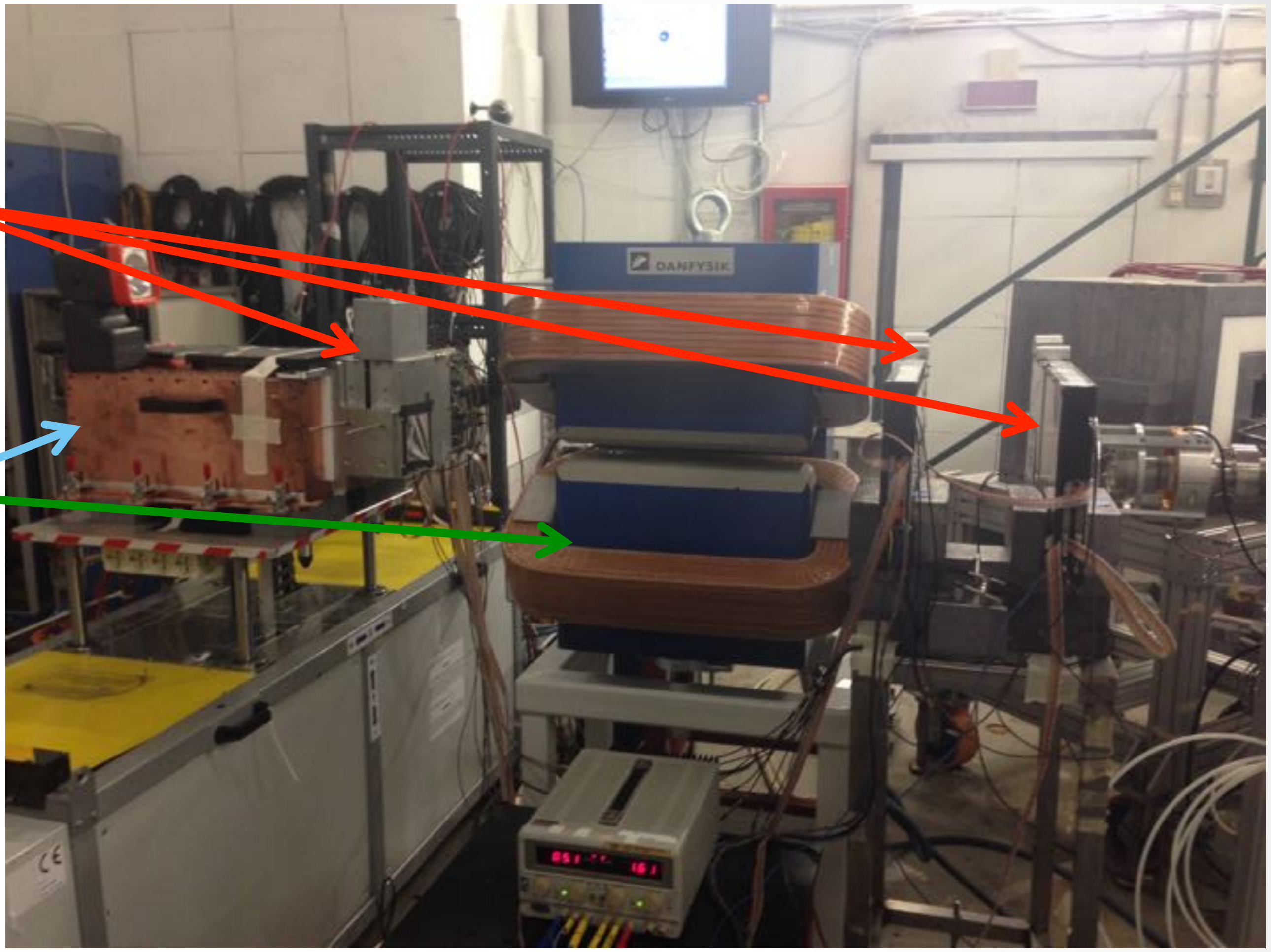


Results presented at TIPP 2014

G. Finocchiaro et al. ``Photodetector R&D for the Belle II Upgraded Forward Electromagnetic Calorimeter'' PoS TIPP2014 (2014) 023

1. Beam test 2014 @ BTF

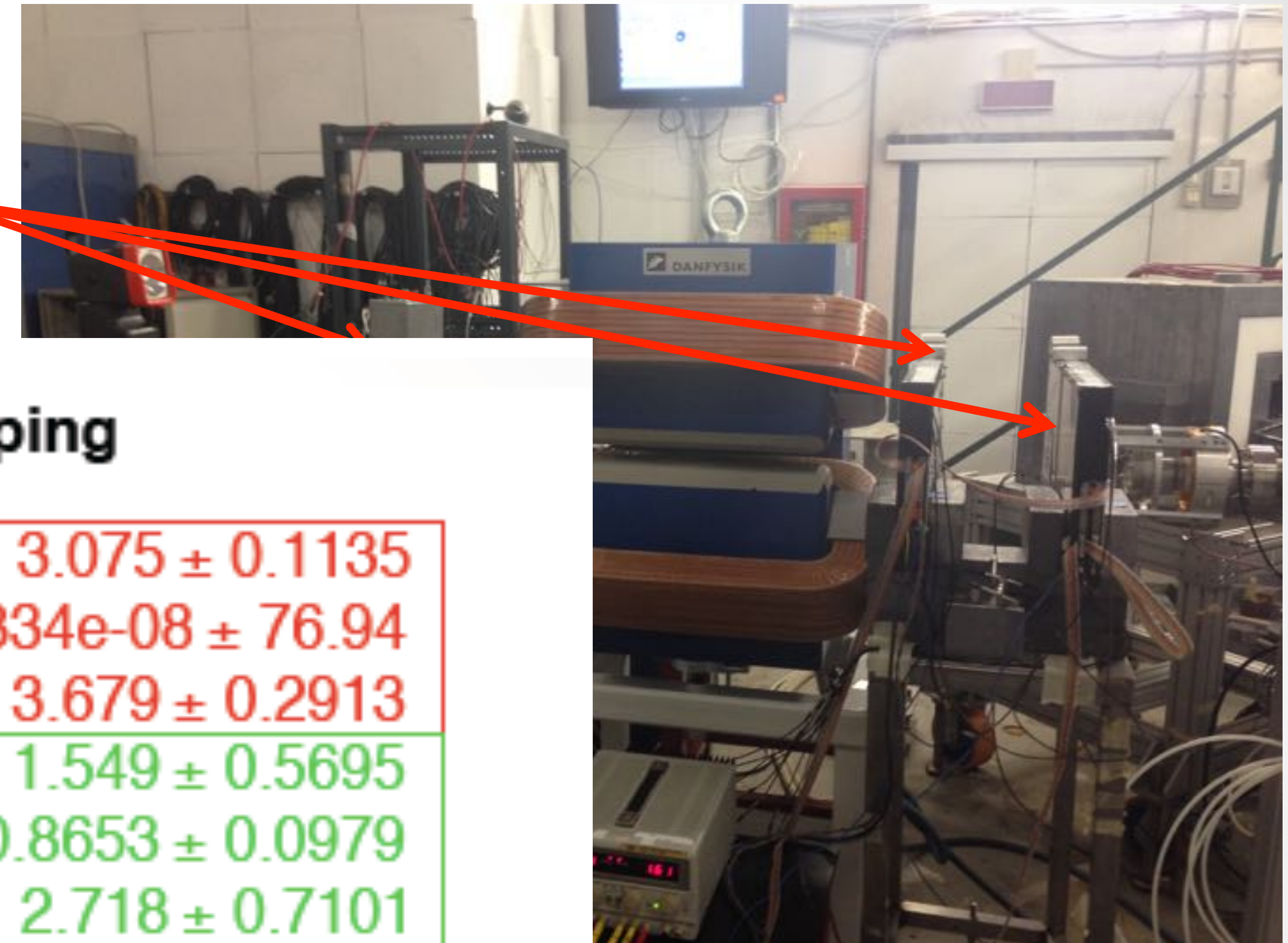
- 8 silicon layers (4 in X and 4 in Y)
  - Pitch 0.228 μ m
  - Depth ~400 μ m
- 1 Bending magnet
- 4x4 CsI pure matrix
  - Each crystal equipped with 2 LAAPD
- 32 custom preamplifier
  - Designed by Roma3
- Each channel temperature and voltage is monitored and readout with slow control process

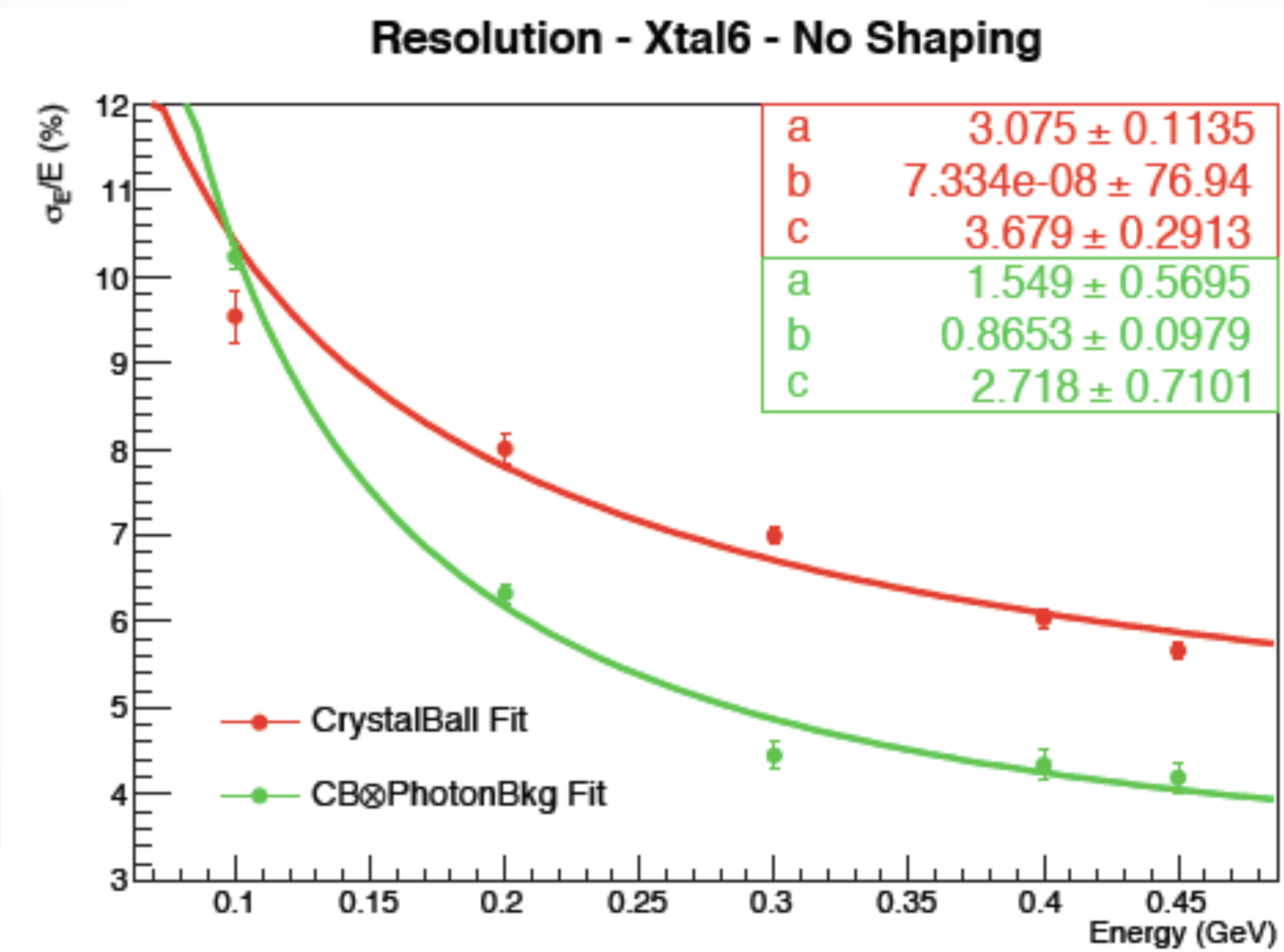


Part of the mechanical assembly built at LNF

1. Beam test 2014 @ BTF

- 8 silicon layers (4 in X and 4 in Y)
  - Pitch 0.228 μm

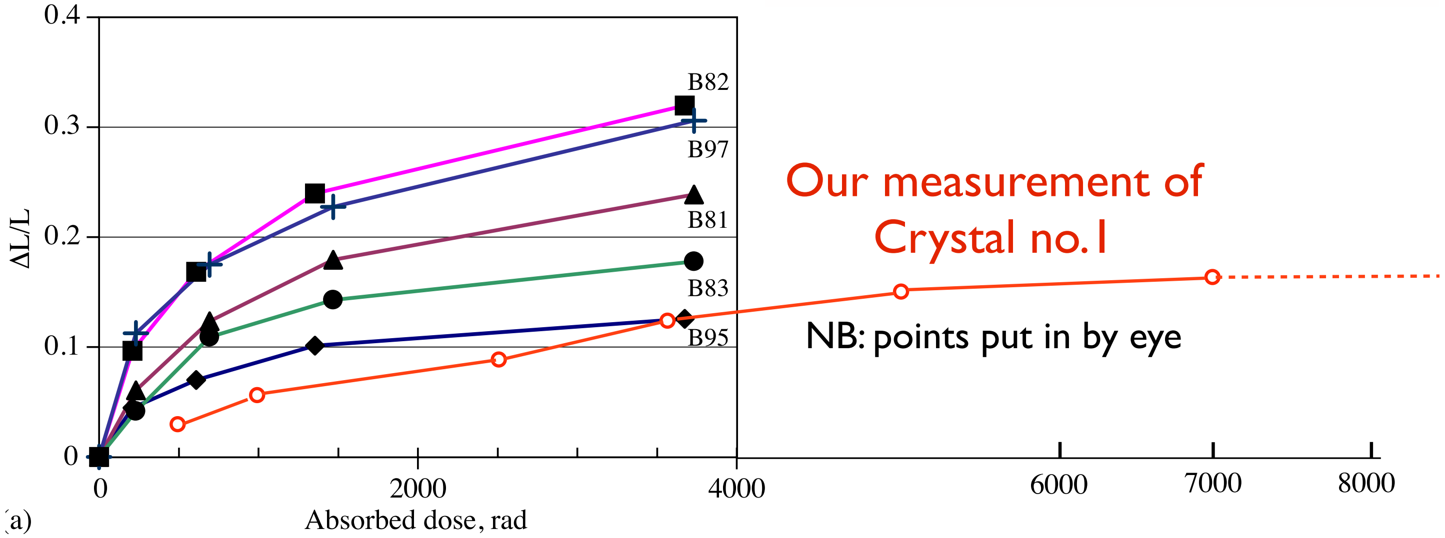




ssembly built at LNF

2. Radiation damage - CsI(Tl)

- Measurements of radiation hardness of CsI(Tl) were made for Belle could not be safaly extrapolated
- Measured amplitude of CR peak in two **CsI(Tl)** crystals from the Belle calorimeter, as a function of the gamma radiation integrated dose (*)



(*) Irradiation tests performed at the ENEA Casaccia Calliope test facility

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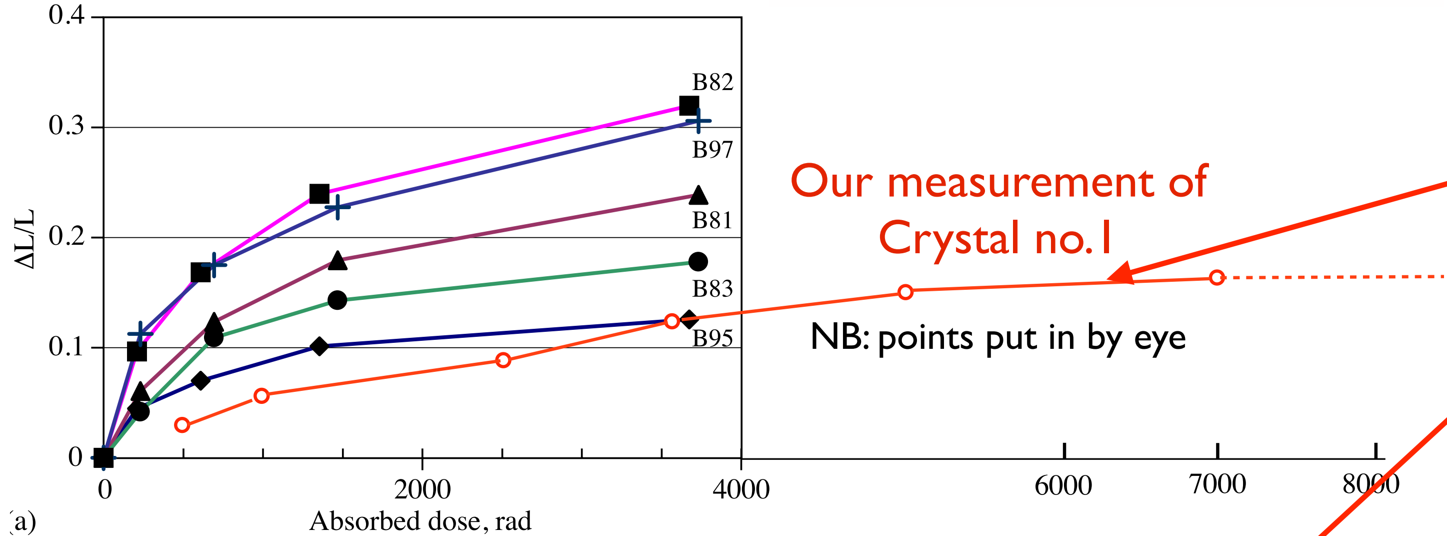
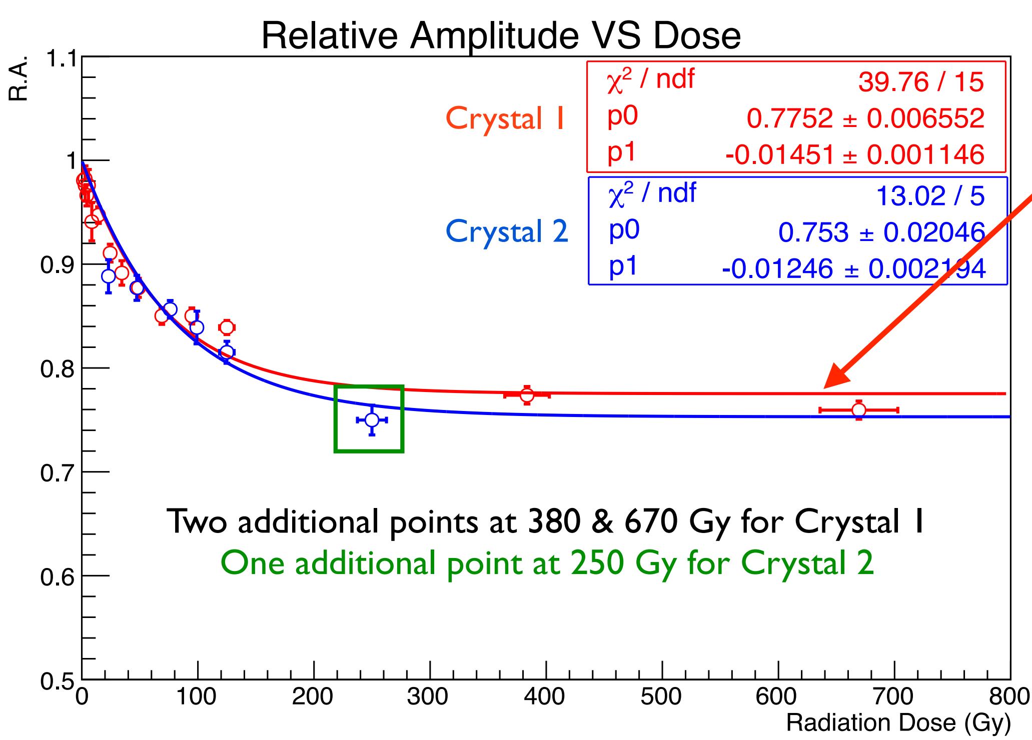
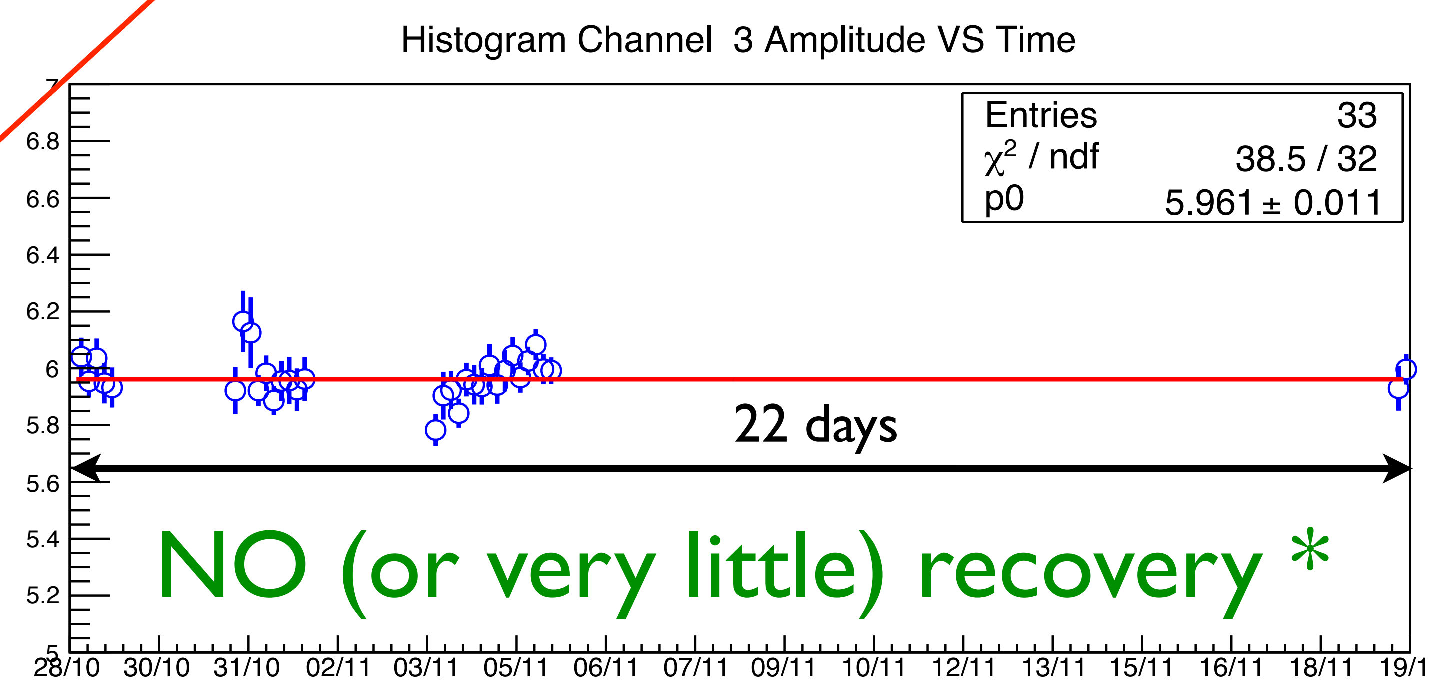


Our measurements

- Confirm existing literature and extend results to higher doses
- Indicate a saturation of the signal loss at high integrated dose rates



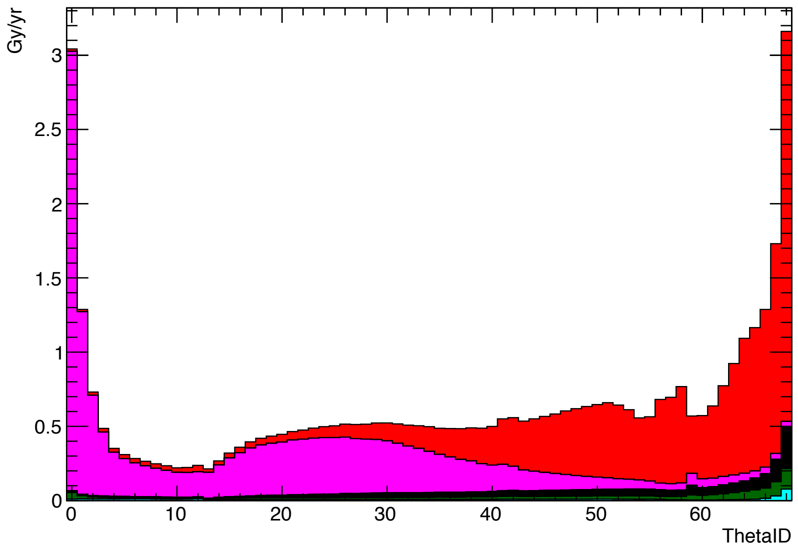


(*) Irradiation tests performed at the ENEA Casaccia Calliope test facility

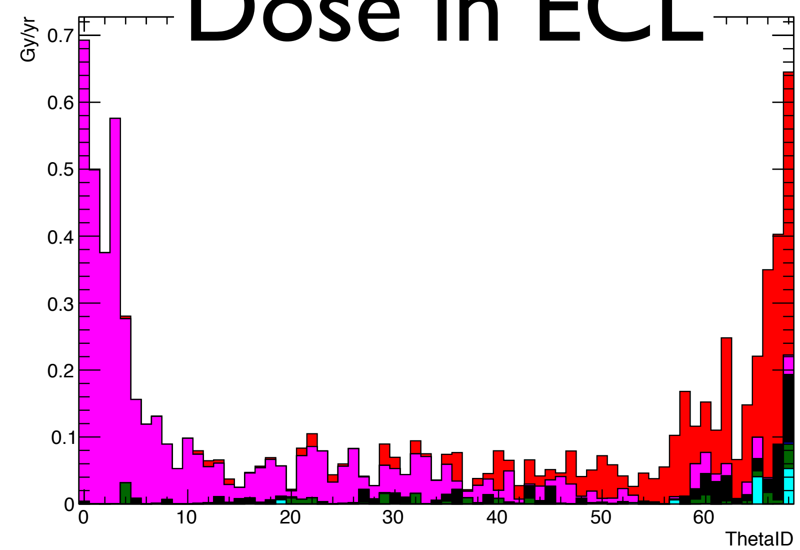
3. Backgrounds

MC Simulation

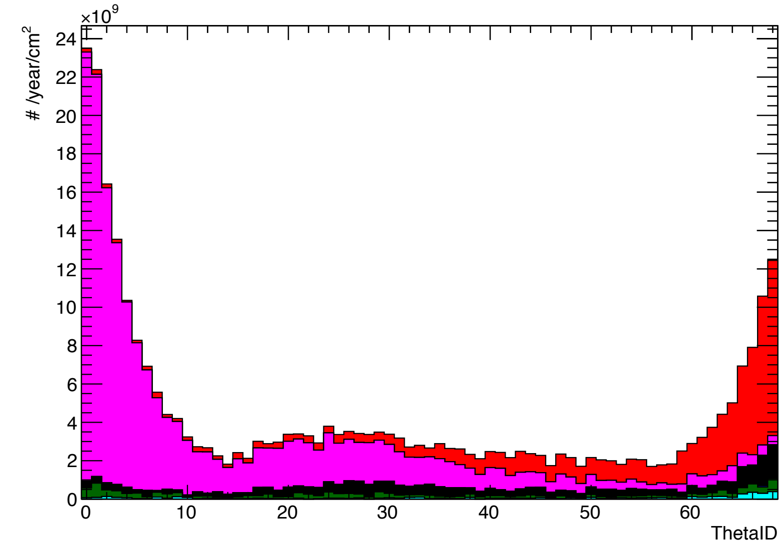
Dose in ECL



Gamma dose in crystals



Gamma dose in diodes



neutron flux in diodes

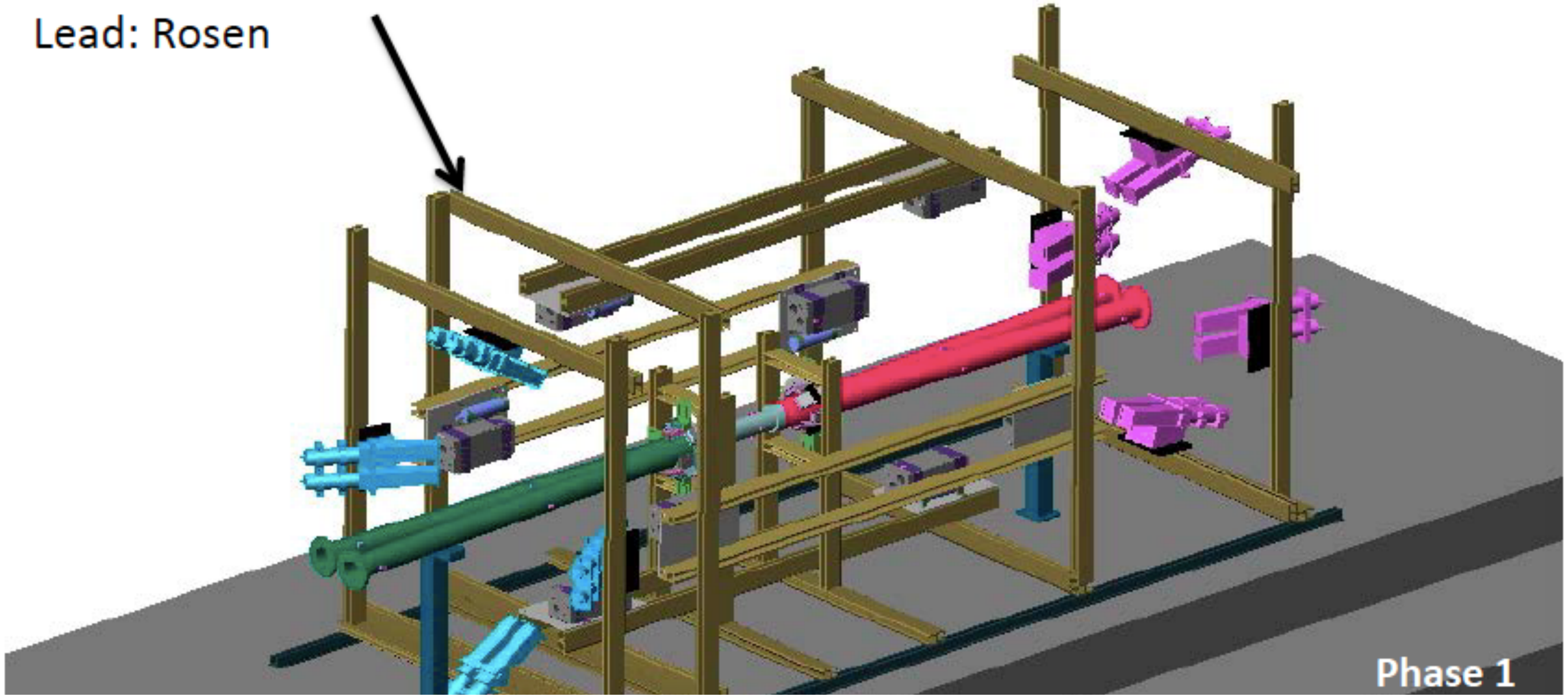
- Rates depend on machine optics details, collimators settings, shields etc.
- To validate this complicated simulation we have proposed to add CsI crystals to BEAST:

BEAST (**B**eam **E**xorcism for **A St**able Belle-II Experiment)

- Consist of a collection of radiation detectors placed around the interaction region and operated during the two phases of machine commissioning
  - Phase I (Jan 2016): no Belle-II detector
  - Phase II (May 2017): Belle-II rolled in without VXD, with a reduced number of radiation detectors in place

Contribution to BEAST phase 1

- Hawaii delivering phase 1 mechanical mounting structure
- Lead: Rosen



BEAST goals:

1. Ensure radiation levels safe before Belle-II roll in
2. Measure individual bem background components
3. System tests (beam abort, VXD occupancy, cooling, etc.)
4. Provide real time feedback to SuperKEKB

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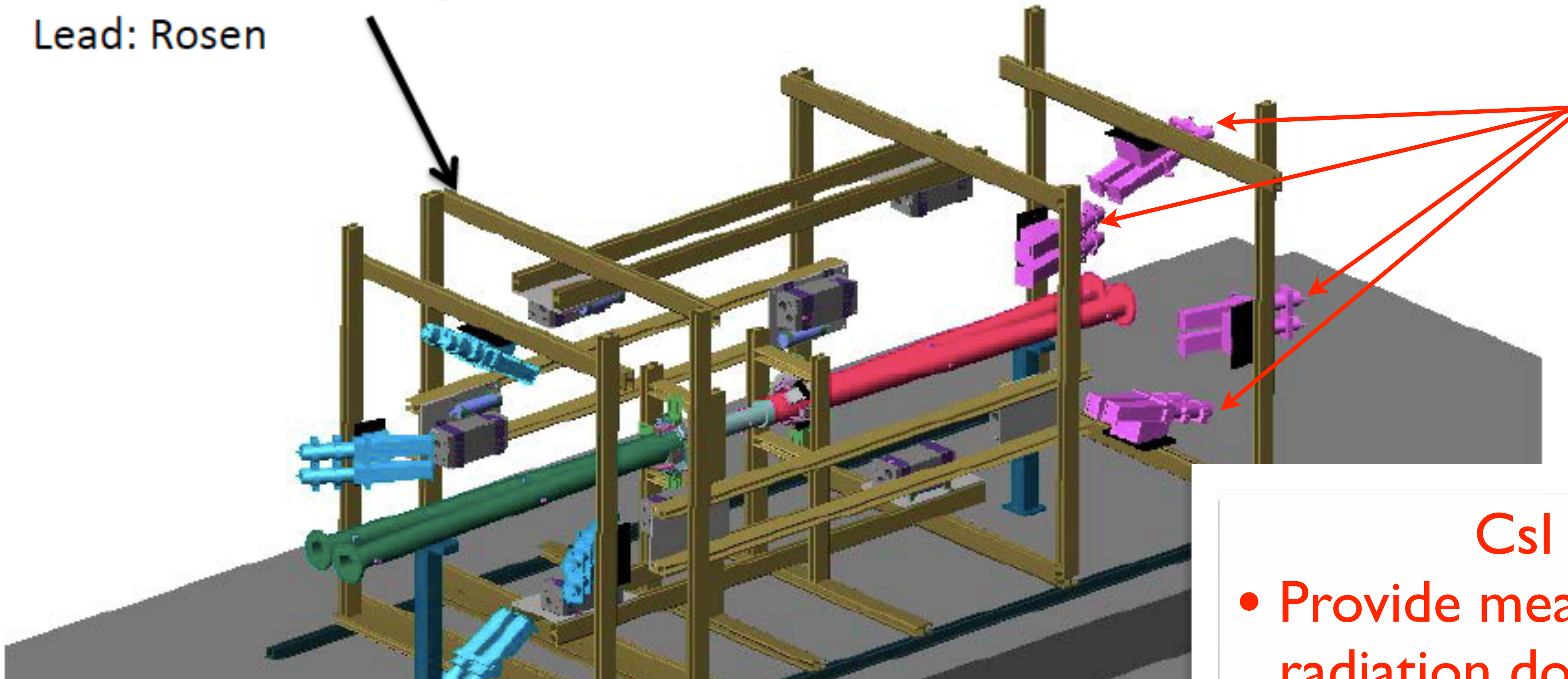

6 boxes each with
1 CsI(Tl)
1 CsI
1 Lyso

BEAST goals:

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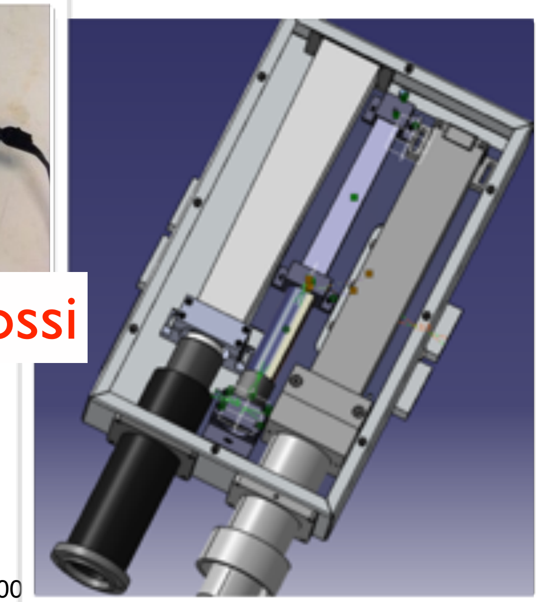
CsI GOALS:

- Provide measurement of radiation dose in crystals to validate MC. **NB:** crucial information needed to decide on the ECL upgrade
- Compare pure VS Thallium doped CsI crystals in high rate environment

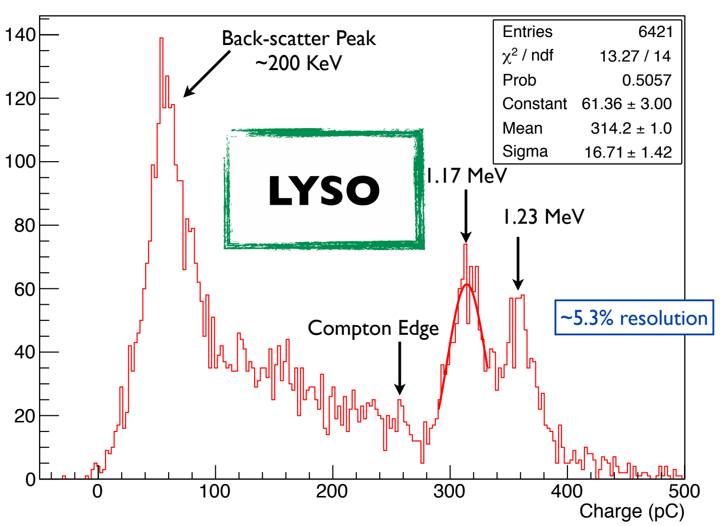
Preparation for BEAST phase I

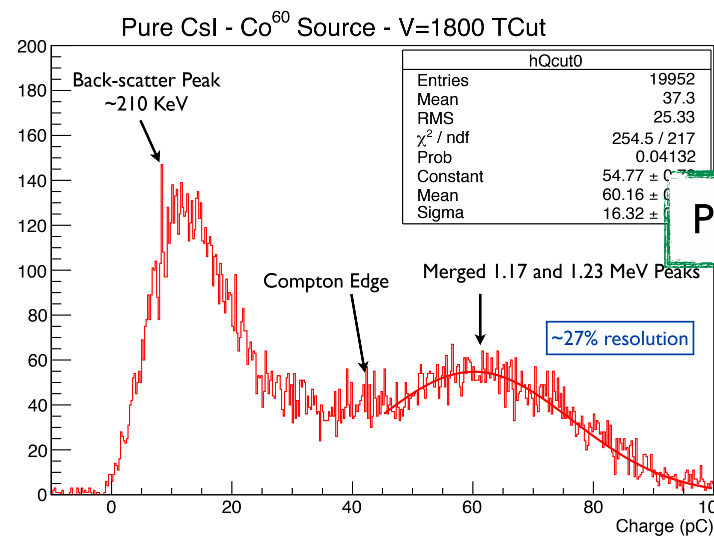
- Mechanical assembly
  - prototype support for 5x5x30cm^3 crystal
  - complete design of dark box + CsI+CsI(Tl)+LYSO crystals +3 PMTs

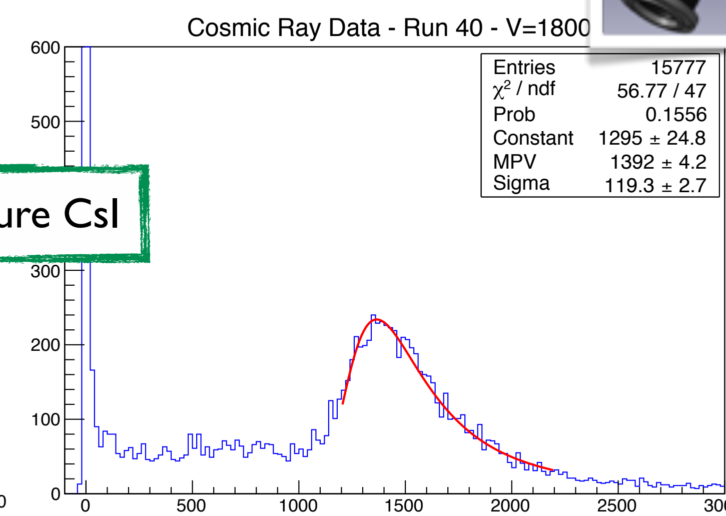


A. Russo, A. Zossi

^{60}Co & CR calibration







Calibration is consistent from 0.2 to 30 MeV

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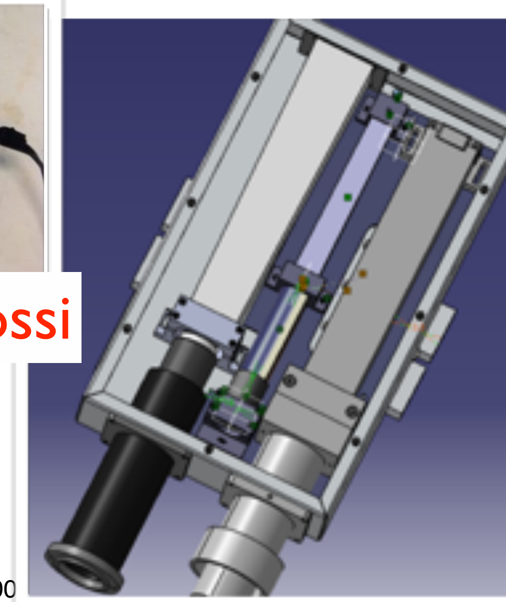
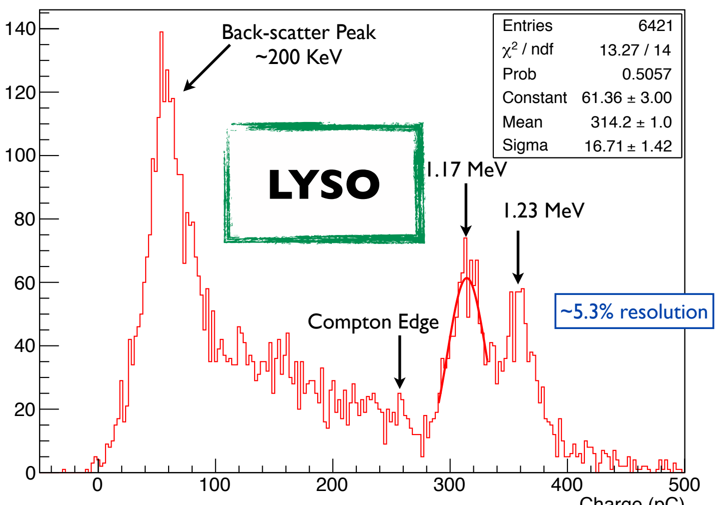
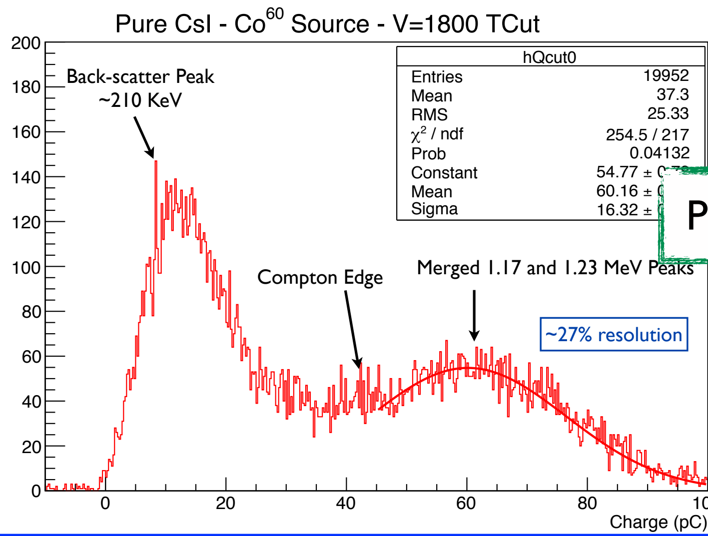
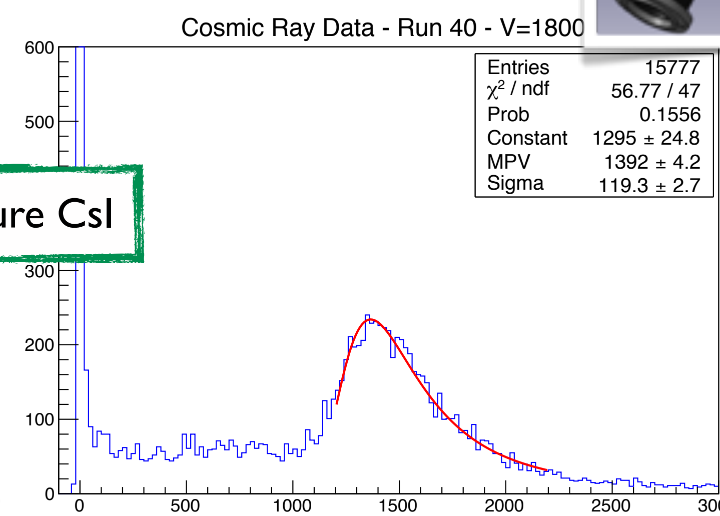


A. Russo, A. Zossi

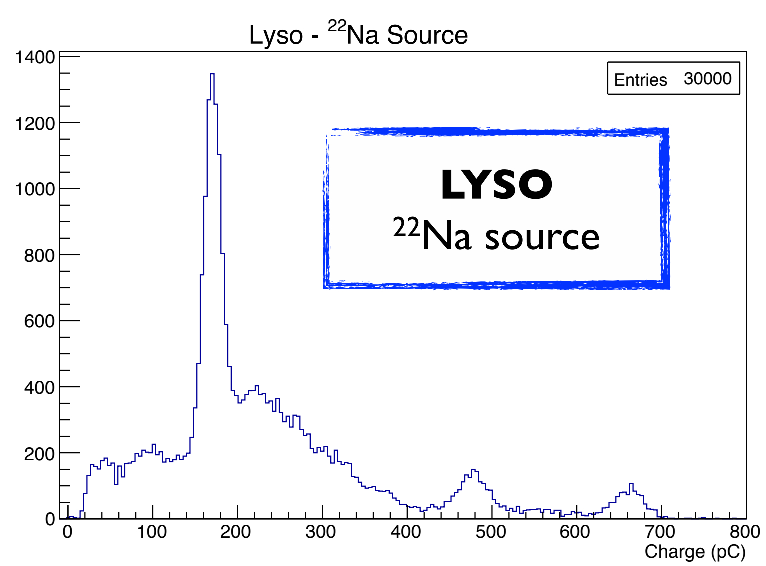
^{60}Co & CR calibration



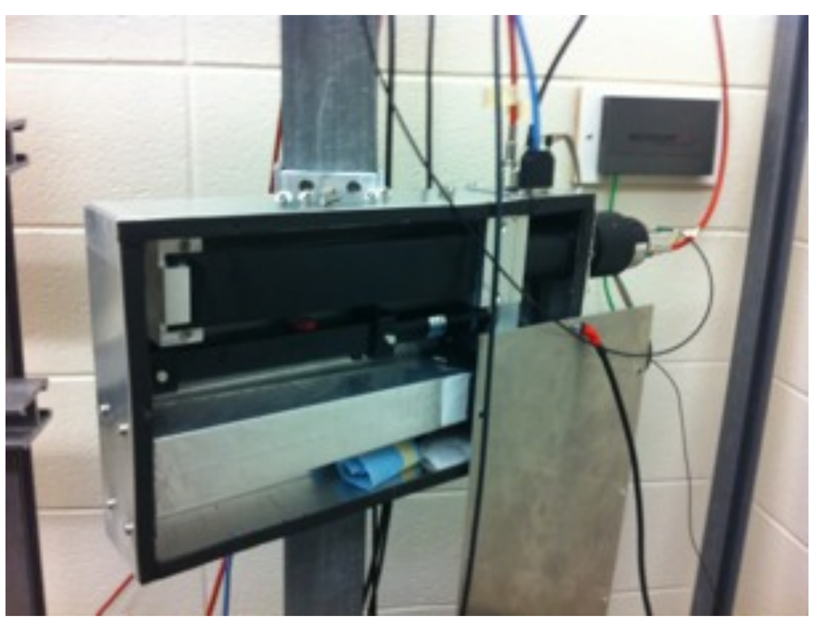




Calibration is consistent from 0.2 to 30 MeV



Mini-Beast, Test @ UH



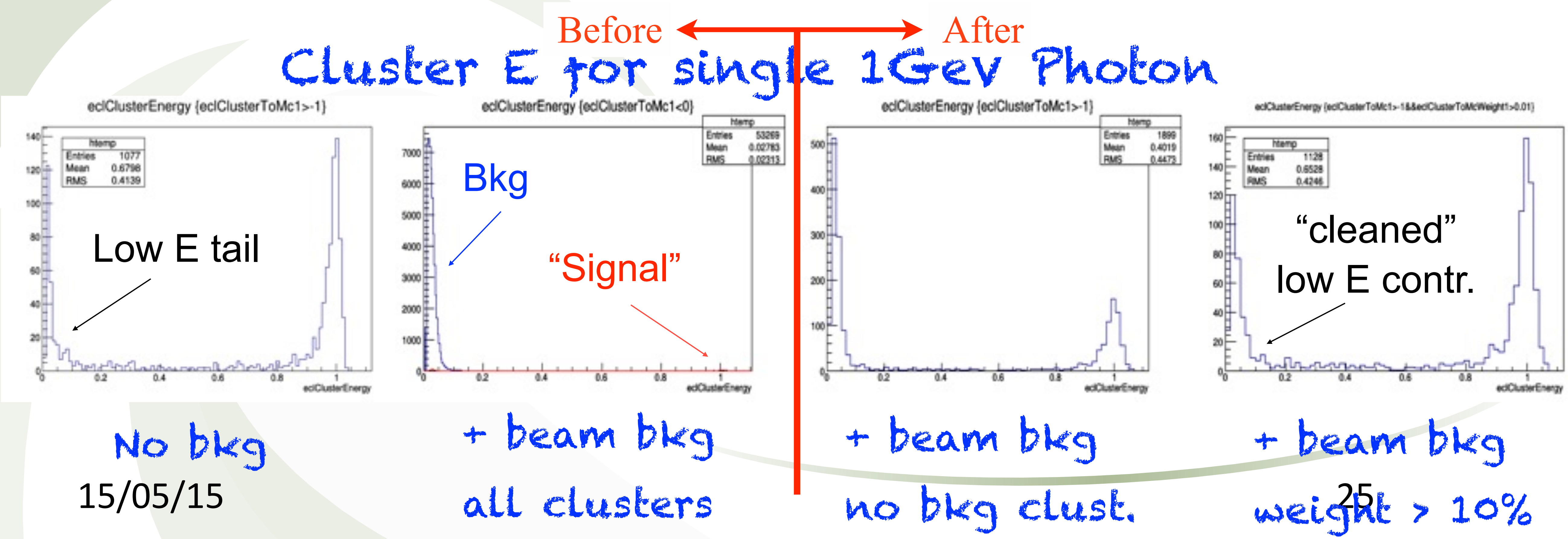
4. Impact on physics of pile-up and radiaton damage

- Study benchmark channels (e.g. $B \rightarrow K\nu\nu$, $B \rightarrow \tau\nu$...) in presence of higher pile-up and degradation of performances
- Need software tools not yet available!
  - Correct simulation of background hits in the calorimeter
  - Fix the ECL $\longleftrightarrow$ MC truth matching in the reconstruction code
  - Implement SW simulation of the digitizer to be able to vary electronics shaping time constants and algorithms
- Work on the ECL software (E. De Lucia, B. Oberhof)

MC-Matching

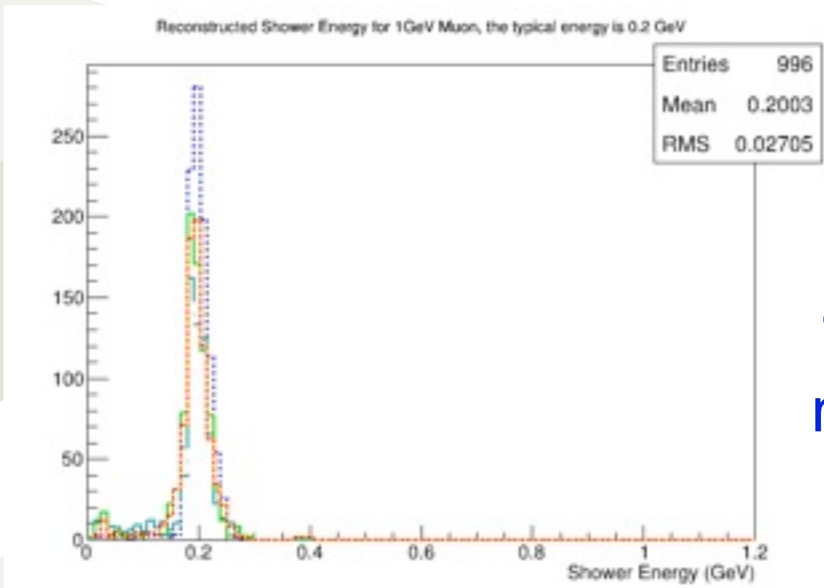
- Various flaws in ECL MC-Matching in old code (now disentagled):
  - no proper treatment of background → bkg clusters associated to MCParticles (+ other complications)
  - no proper treatment of mother-daughter relations → inconsistencies
  - no treatment of multiple-association implemented →
    - impossible to separate bkg and physics contribution in same cluster
    - impossible to resolve overlapping MCParticles in same cluster

- We have introduced a multi-particle weighted matching
  - weights are calculated based on energy release given by GEANT for every MCParticle. Distinction between signal and bkg is based on a Tag

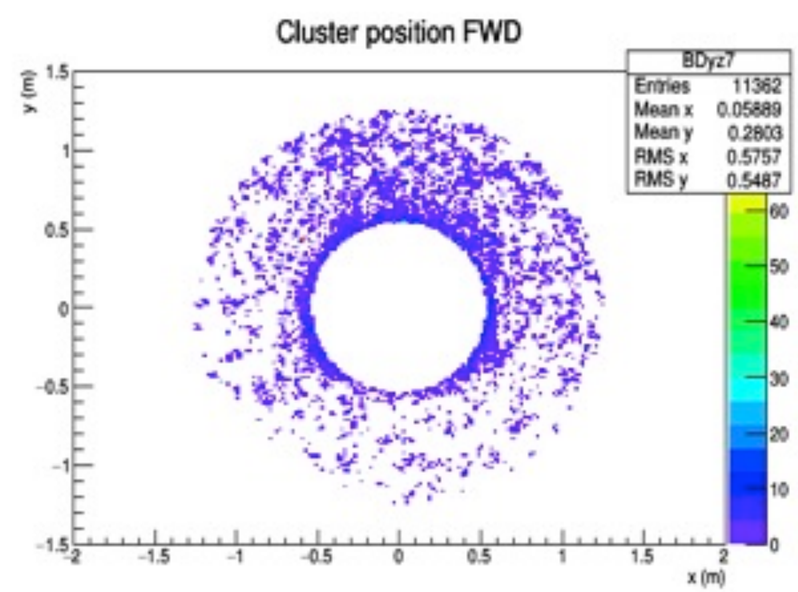


ECL Software - Performance studies

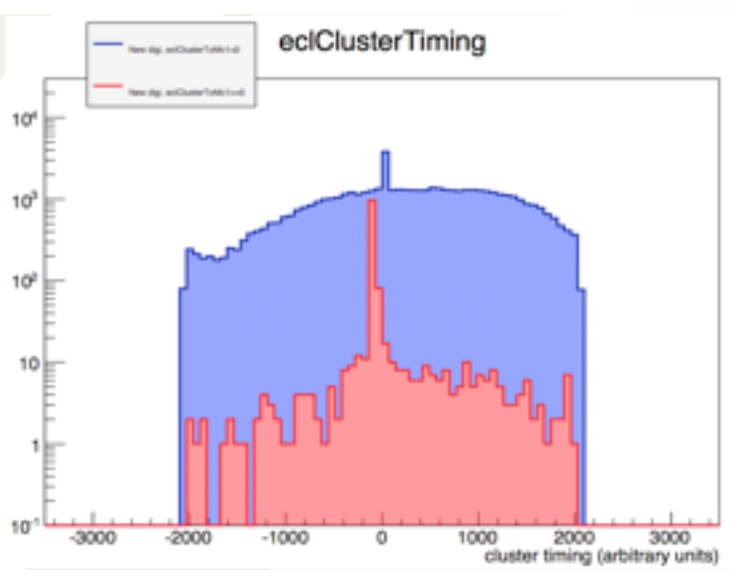
- We have developed various tools to monitor ECL performance
- Validation scripts are run automatically on daily basis to monitor code changes and background conditions
- Studies are now starting to evaluate detector response in working conditions: resolution, pile-up, etc..



Ereco
1 GeV
muons



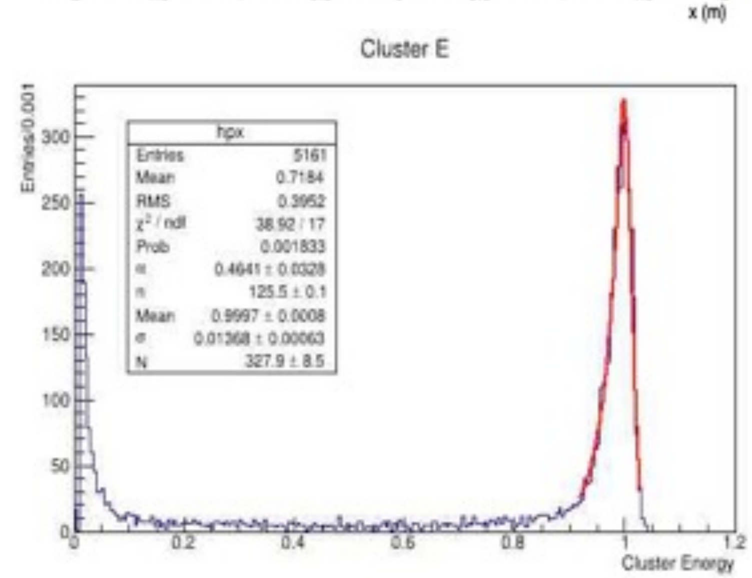
FWD ECL
occupancy



Cluster
Timing

Signal

Bkg



Energy
Resolution

Summary

- The LNF group is involved in all aspects of the studies which will be key for the decision on the upgrade of the forward ECL
- Significant contributions to
  - CsI crystals with APD readout
  - Irradiation studies
  - Background simulation validation with BEAST
  - Software and physics studies
- Active participation to the ongoing commissioning of the ECL