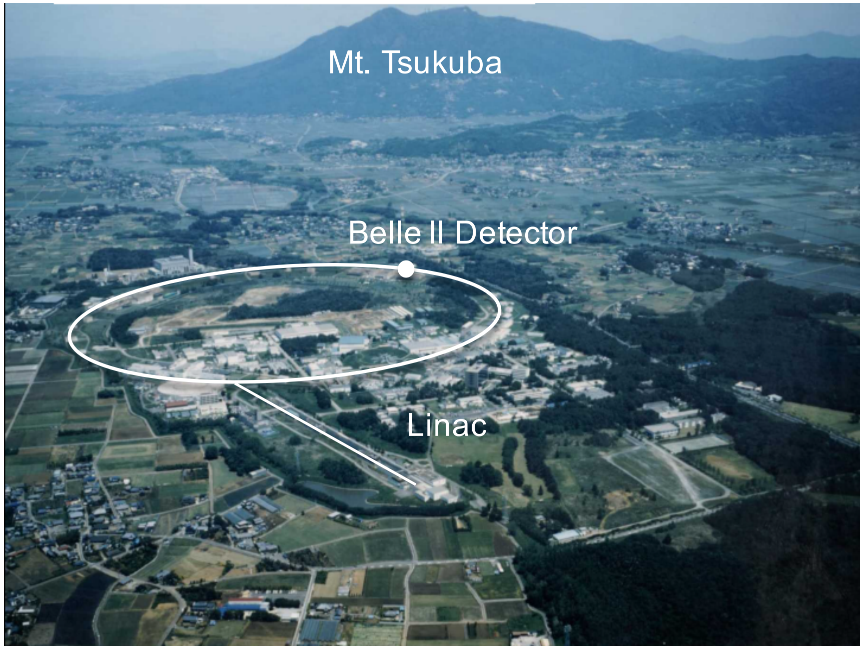
Stato dell'esperimento Belle II a SuperKEKB

Mario Merola (INFN)

Riunione di fine anno 2015

8 gennaio 2016



Outline

- Physics motivations
- Belle II at SuperKEKB
- Physics program
- Status of the project and schedule
- Napoli activities (calorimeter, physics, computing)

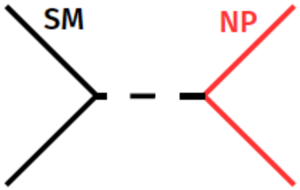
Physics Motivations

Open issues in HEP, related to flavour

- **Baryon asymmetry in cosmology:** new sources of CPV
- **Quark and lepton hierarchy (mass and flavour), 19 free parameters in SM:** GUTs (SUSY) ?
- **Dark Matter:** hidden dark sector ?
- **Finite neutrino masses:** (charged) lepton flavour violation (tau) ?

Search for new physics (NP)

- **Energy frontier:** direct production of new particles - limited by beam energy (LHC - ATLAS, CMS)

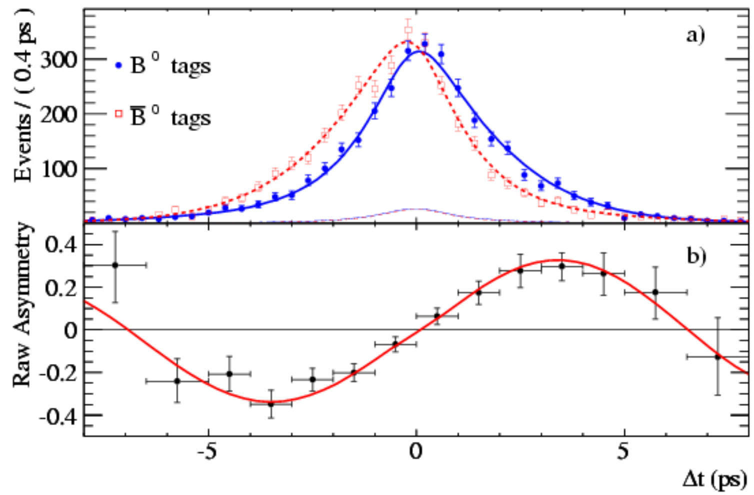


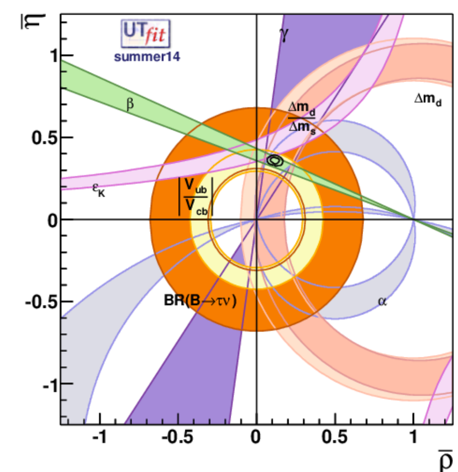
- **Intensity frontier**: new particles in virtual loops, deviation from SM expectations (**B factories**, LHCb)

If NP is found in direct searches it is reasonable to expect NP effects in B, D, τ decays

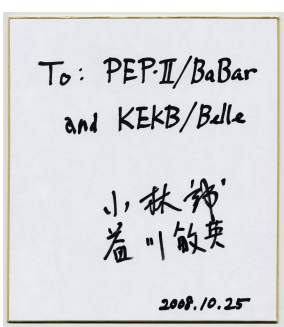
Belle and Babar achievements

- Observation of direct and indirect CP violation
- Precise measurement of CKM parameters





Kobayashi, Maskawa nobel prize in 2008

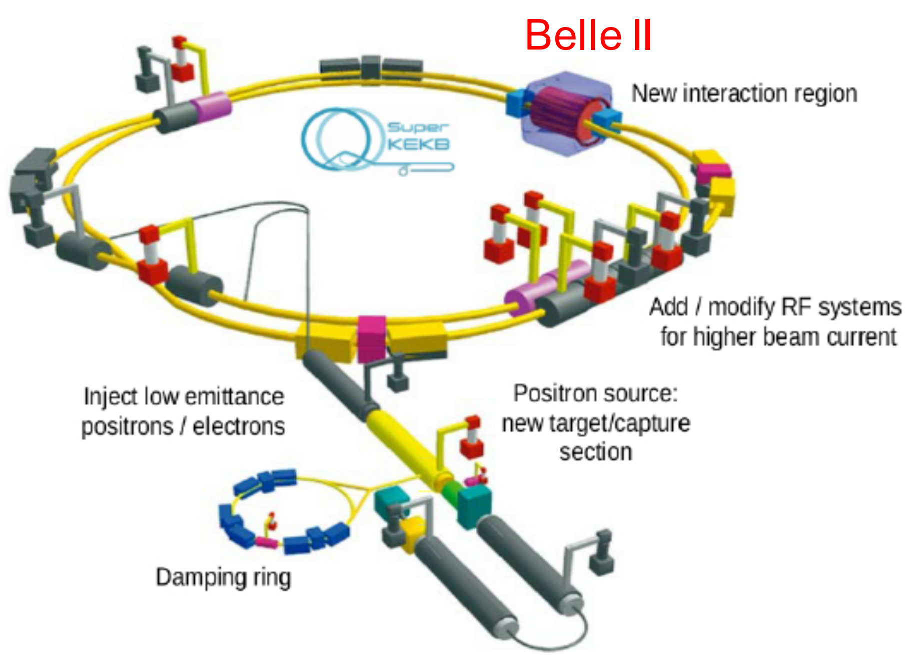


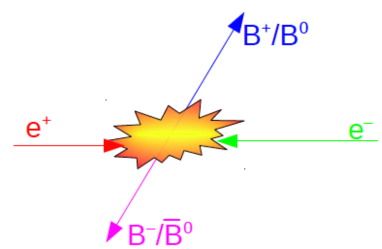
Unique capabilities of B-factories:

- very clean environment
- kinematical constraints
- good detection of neutral hadrons
- hermeticity of the detector

SuperKEKB

- **Electron-positron collider** situated at KEK (Tsukuba, Japan), upgrade of KEKB
- **Construction completed in 2015**
- **$e^+e^- \rightarrow B\bar{B}$** (4 GeV + 7 GeV) mainly at $\sqrt{s_{cm}}$=10.58 GeV (Υ(4S) resonance)



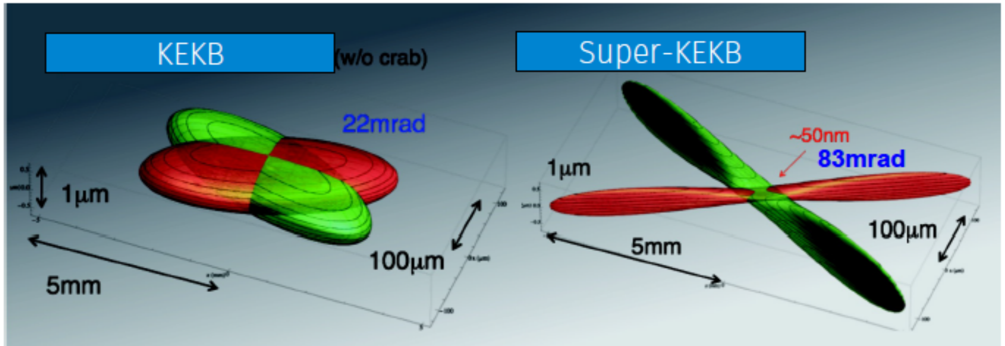


10^{10} B pairs/year

Channel	Belle	BaBar	Belle II (per year)
$B\bar{B}$ Υ(4S)	7.7×10^8	4.8×10^8	1.1×10^{10}
$B_s^{(*)}\bar{B}_s^{(*)}$	7.0×10^6	–	6.0×10^8
$\Upsilon(1S)$	1.0×10^8		1.8×10^{11}
$\Upsilon(2S)$	1.7×10^8	0.9×10^7	7.0×10^{10}
$\Upsilon(3S)$	1.0×10^7	1.0×10^8	3.7×10^{10}
$\Upsilon(5S)$	3.6×10^7	–	3.0×10^9
$\tau\tau$	1.0×10^9	0.6×10^9	1.0×10^{10}

From KEKB to SuperKEKB

Nano-beam scheme firstly proposed by P. Raimondi for SuperB



	E (GeV) LER/HER	β*y (mm) LER/HER	β*x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L (cm⁻²s⁻¹)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

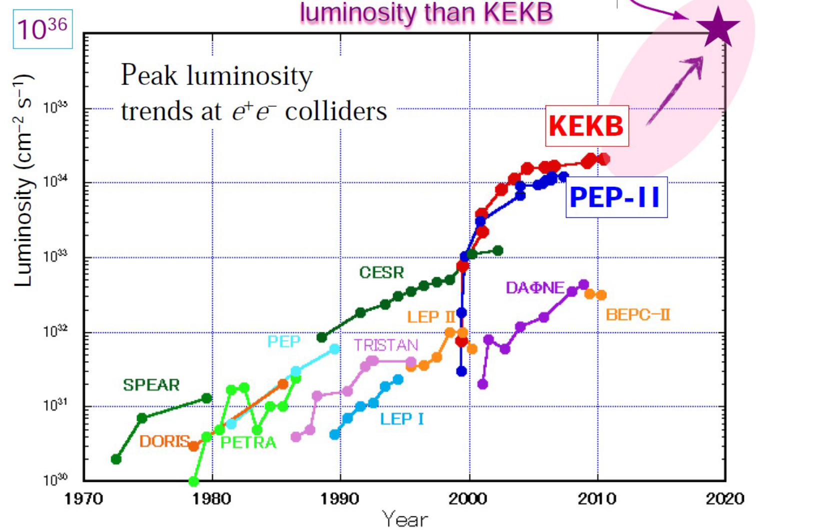
factor 20 factor 2-3

reduced boost

~ 40-50 x

SuperKEKB is the intensity frontier

40x higher instantaneous luminosity than KEKB



Lorentz factor

beam current

Luminosity $$L = \frac{\gamma_\pm}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}}\frac{R_L}{R_{\xi_y}}$$

vertical beta function at IP

Beam size ratio at IP

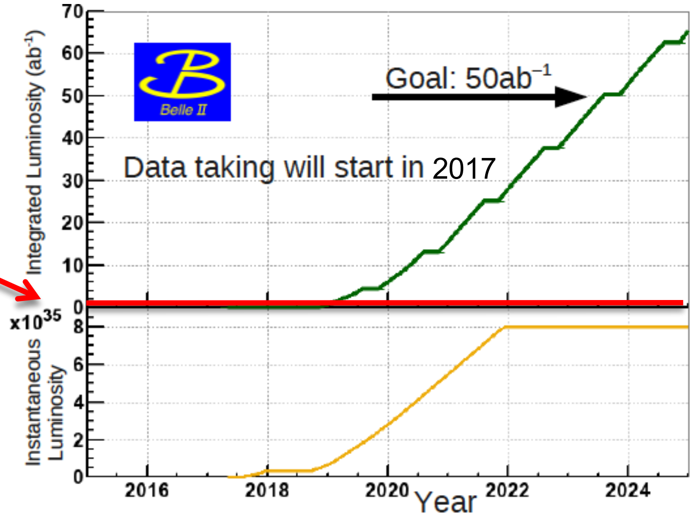
Geometrical reduction factors (crossing angle and hourglass effect)

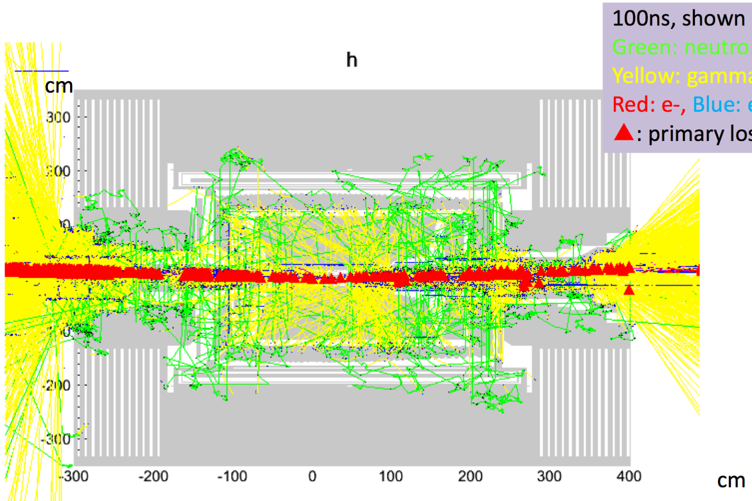
SuperKEKB

Peak instantaneous luminosity: ~0.8×10^{36} cm^{-2} s^{-1}

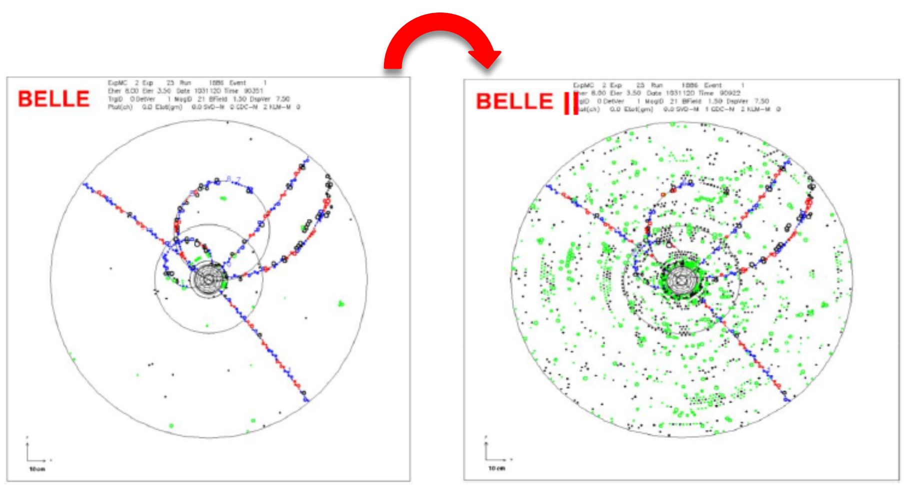
Belle II overall integrated luminosity: ~50 ab^{-1} corresponding to 55 × 10^9 BB pairs (BaBar + Belle ~ 1.5 ab^{-1})

Higher beam background (10-20 x): high detector occupancy, pile-up in calorimeter, radiation damage





Touschek scattering, Bhabha, 2γ



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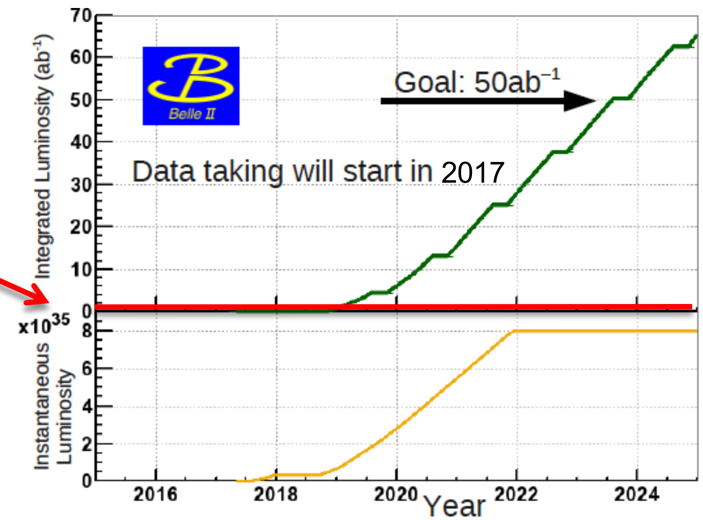
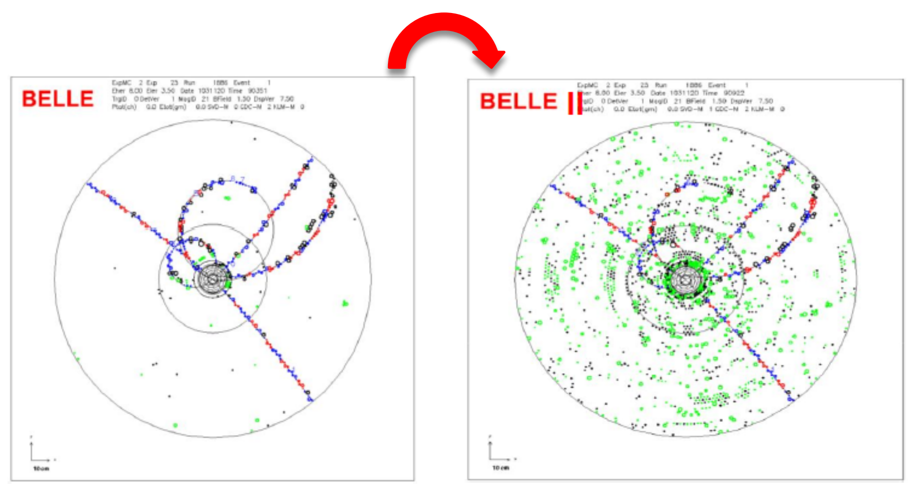


Higher beam background (10-20 x): high detector occupancy, pile-up in calorimeter, radiation damage

Physics process	Cross section (nb)	Rate (Hz)
$\Upsilon(4S) \to B\bar{B}$	1.2	960
$e^+e^- \to$ continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha ($\theta_{\rm lab} \geq 17°$)	44	350 ^{a}
$\gamma\gamma$ ($\theta_{\rm lab} \geq 17°$)	2.4	19 ^{a}
2γ processes ^{b}	$\sim$ 80	$\sim$ 15000
Total	$\sim$ 130	$\sim$ 20000

[a] The rate is pre-scaled by a factor of 1/100.

[b] $\theta_{\rm lab} \geq 17°$, $p_t \geq 0.1$GeV/c



From Belle to Belle II

Belle II upgrade:

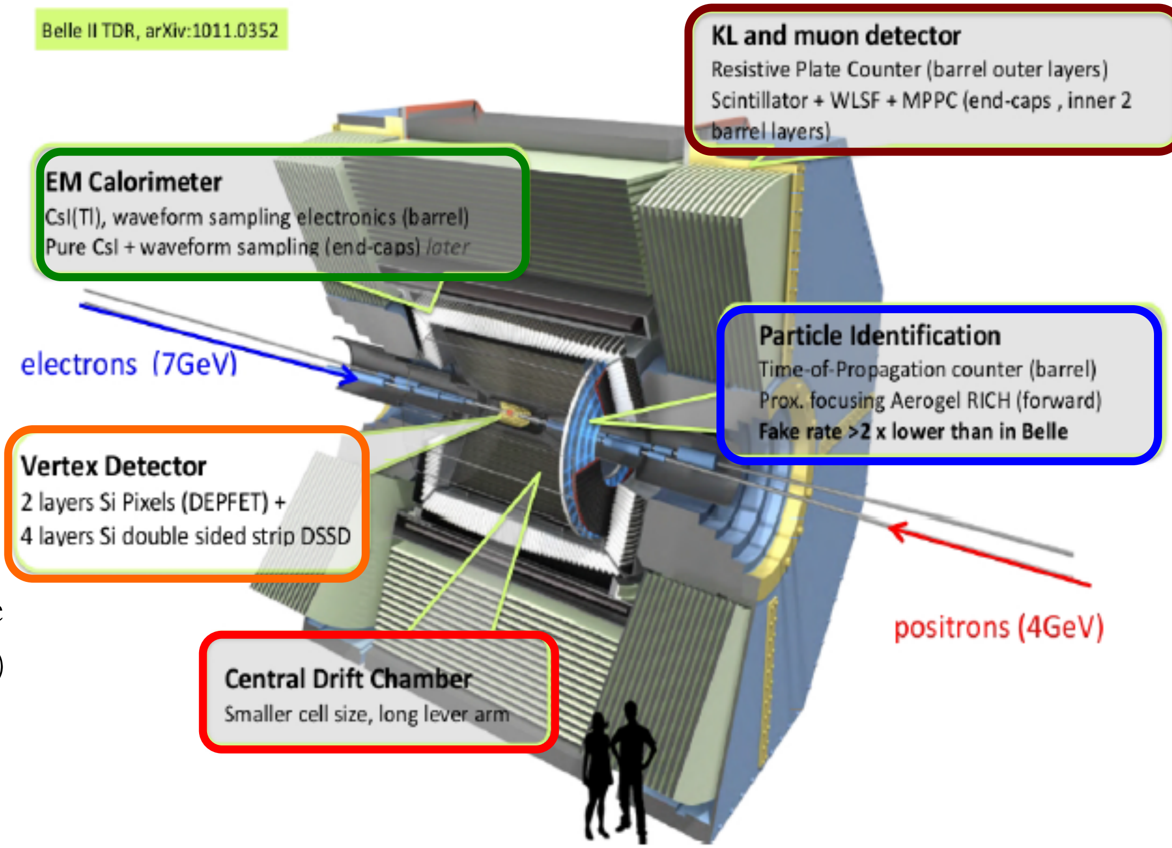
- **Extended VD region** (added pixel detector)

- **Extended Drift Chamber region**

- **New ECL electronics** (waveform sampling and fitting)

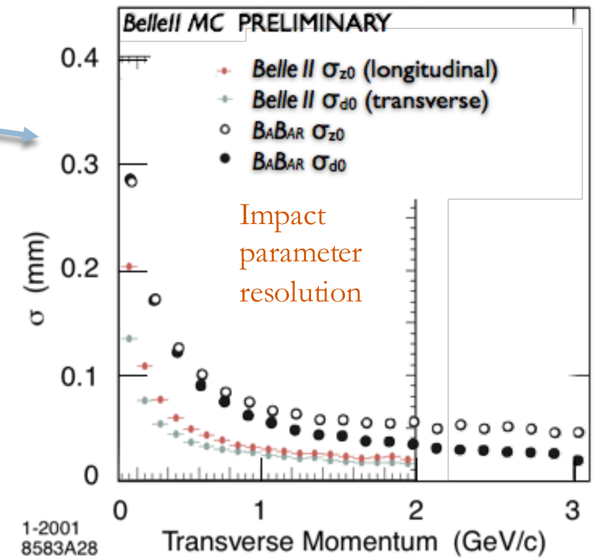
- **Better hermeticity** (additional PID detector in the forward endcap)

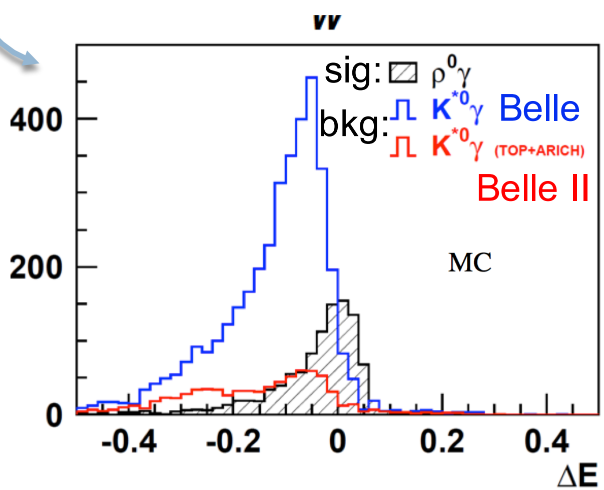
- **High efficiency KLM detector** (some RPCs layers substituted with scintillators)

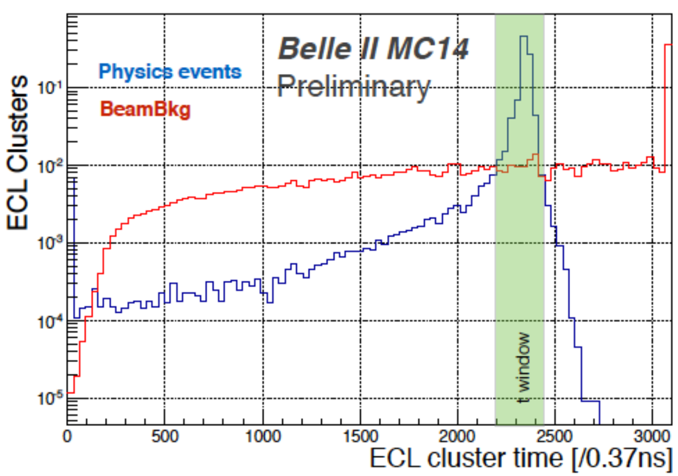


From Belle to Belle II

- Better secondary vertex resolution
- Improved beam background rejection
- Improved K/π separation and flavour tagging
- Increased K_S, π^0 and slow pion efficiency





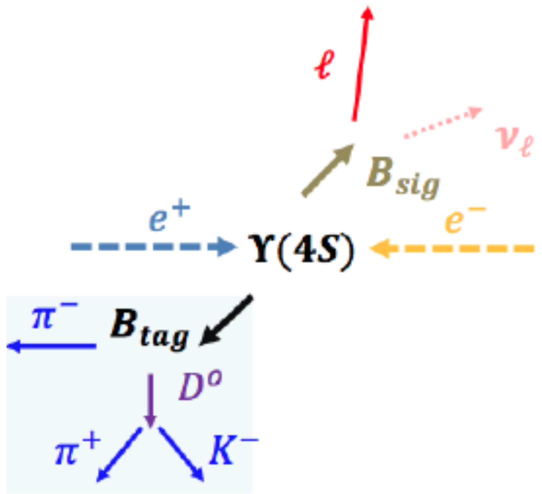


Unique capabilities of e^+e^- B factories - Belle II

1. **Beam energy constraint** and adjusted for different resonances $\Upsilon(nS)$

2. **Clean experimental environment**, low track multiplicity and detector occupancy (w.r.t hadron collider)
   - high B, D, K, tau reconstruction efficiency
   - open trigger ~99% efficient

3. **Full reconstruction of one B (B_{tag})** constraints the 4-momentum of the other (B_{sig})
   - helpful in reconstruction of channels with missing energy
   - opposite side B tagging efficiency: ~30% (~2%@LHCb)



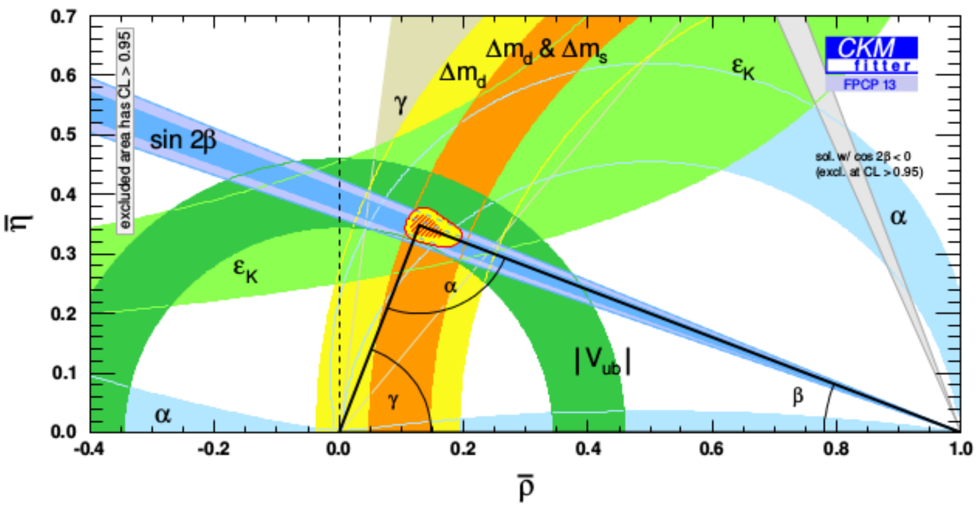
4. **Excellent EM calorimetry performances**
   - high reconstruction efficiency of neutral final states

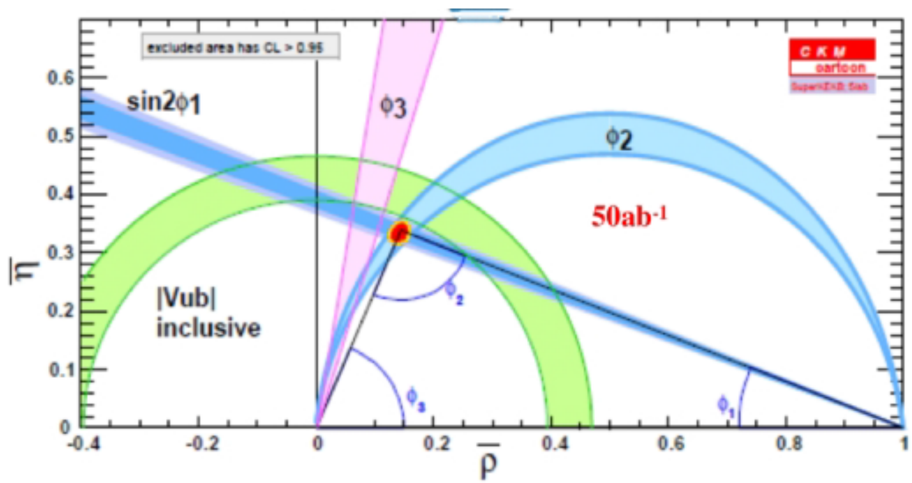
Physics program (1)

- CPV in B decays, CKM angles ($B \to J/\psi K^0, K^0\pi^0\gamma, K\pi$)
- (Semi)leptonic B decays, CKM sides ($B \to D^{(*)}l\nu, \pi l\nu, \tau\nu, \mu\nu$)

projection @ 50 ab^{-1}

Unitarity triangle





Physics program (2)

	Belle	BaBar	Global Fit CKMfitter	LHCb Run-2	Belle II 50 ab^{-1}	LHCb Upgrade 50 fb^{-1}	Theory
φ_1: ccs	0.9°		0.9°	0.6°	0.3°	0.3°	v. small.
φ_2: uud	4° (WA)		2.1°		1°		~1-2°
φ_3: DK	14°		3.8°	4°	1.5°	1°	negl.
$\lvert V_{cb}\rvert$ inclusive	1.7%		2.4%		1.2%		
$\lvert V_{cb}\rvert$ exclusive	2.2%				1.4%		
$\lvert V_{ub}\rvert$ inclusive	7%		4.5%	7.2%	3.0%		
$\lvert V_{ub}\rvert$ exclusive	8%				2.4%		
$\lvert V_{ub}\rvert$ leptonic	14%				3.0%		

Experiment
- No result
- Moderate precision
- Precise
- Very Precise

Theory
- Moderate precision
- Clean / LQCD
- Clean

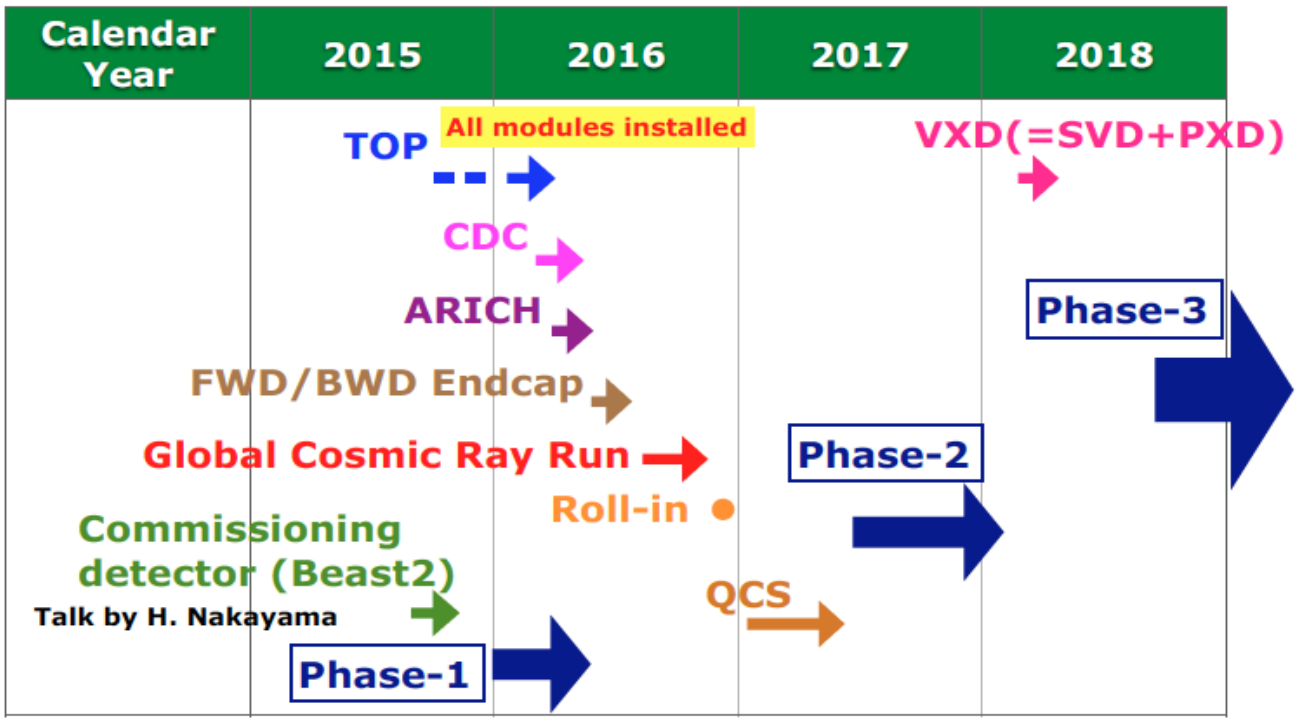
see backup for details on Belle2-LHCb comparison

Programma di fisica include anche:

- Rare B decays ($B \to K^{(*)}\nu\nu$, $X_s\gamma$, $X_s ll$, $\gamma\gamma$)
- Charm physics ($D \to l\nu$, mixing, CPV)
- LFV tau decays ($\tau \to 3l$, $l\gamma$)
- Dark Sector, Spectroscopy

Belle II status and schedule

Belle II schedule: installation and commissioning



BEAST phase 1 (2016): beam, no collisions, cosmics

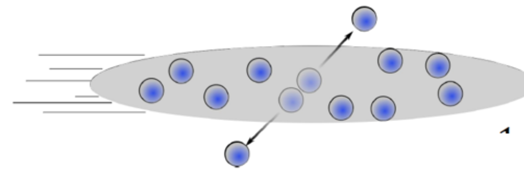
BEAST phase 2 (2017-2018): collisions, complete Belle II detector except for Vertex Detector

Full physics (end 2018-2024): full Belle II detector

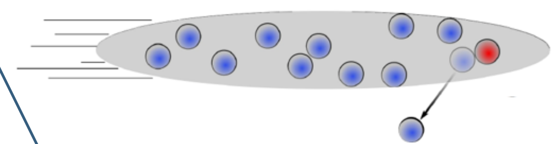
BEAST (**B**eam **E**xorcism for **A** **ST**able experiment): commissioning detector, aimed at studying beam induced backgrounds near the IP

BEAST commissioning detector

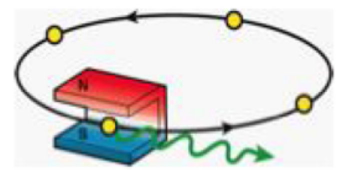
- Among the technical challenges at Belle2, there are beam backgrounds
- In Belle/KEKB, unexpected backgrounds burnt a hole in the beam pipe and damaged inner detectors
- Especially dangerous at SuperKEKB:
  - Temporary damage or faults in electronics
  - Obscure physics processes
  - Fake interesting physics signals
  - Rejecting fake signals also lowers efficiency
- This is where BEAST comes in…



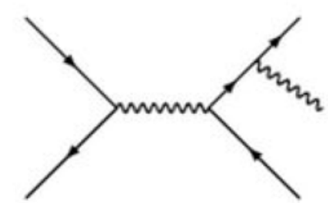
Touschek scattering



Beam-gas scattering



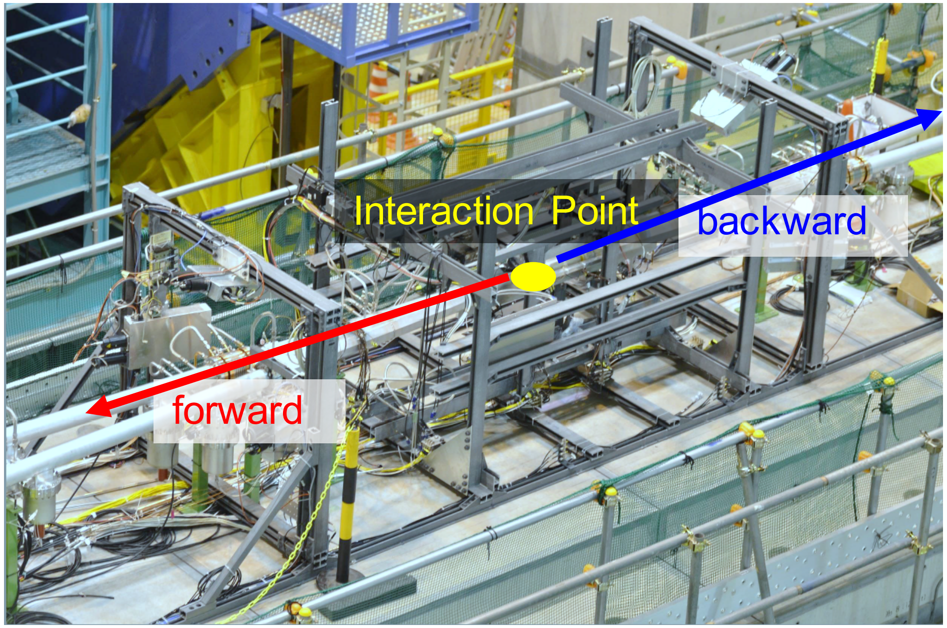
Synchroton radiation



Radiative Bhabha

BEAST Goals

- Instrument SuperKEKB before Belle II is rolled in
- Measure beam backgrounds where BelleII will operate to:
  - Tune simulations in
  - Ensure radiation level is safe for detectors
  - Identify and shield background "hot spots"
  - Test systems that measure radiation levels for feedback to SuperKEKB

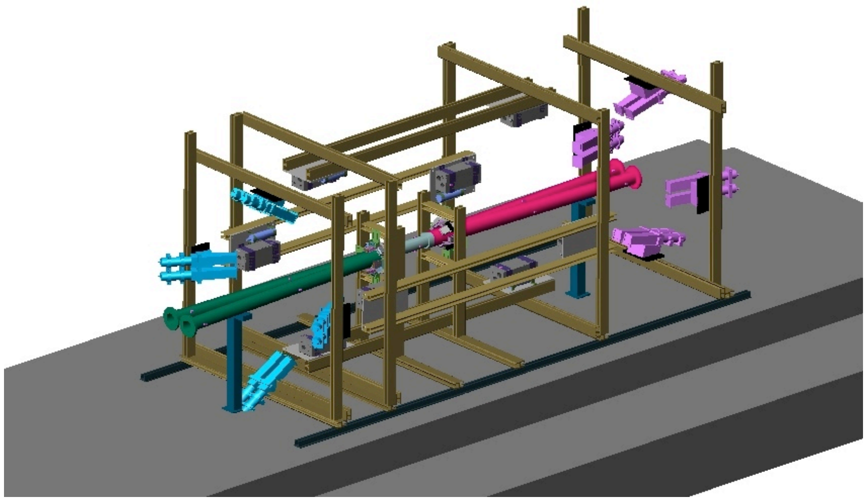


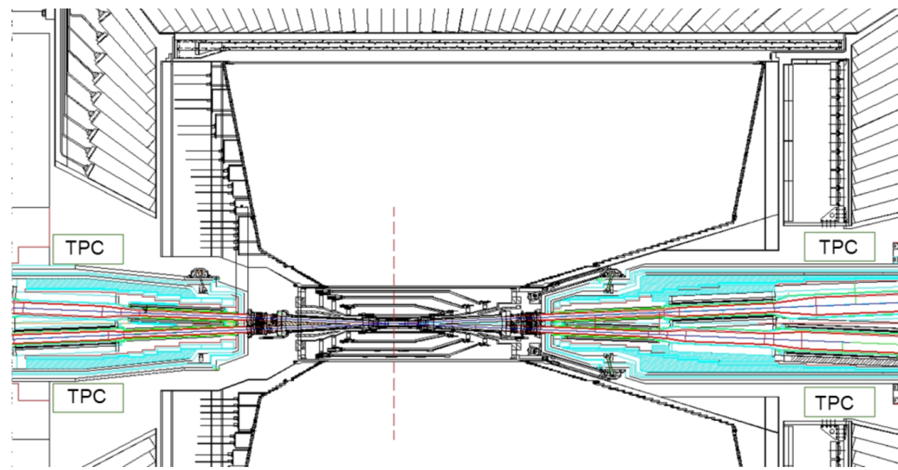
BEAST fiberglass frame supporting background detectors (PIN diodes, TPCs, Diamonds, He3 tubes, BGO, Calorimeter crystals)

BEAST phase I & II

Hardware Installation complete

The suite of BEAST detectors is finalized and detailed design is in progress



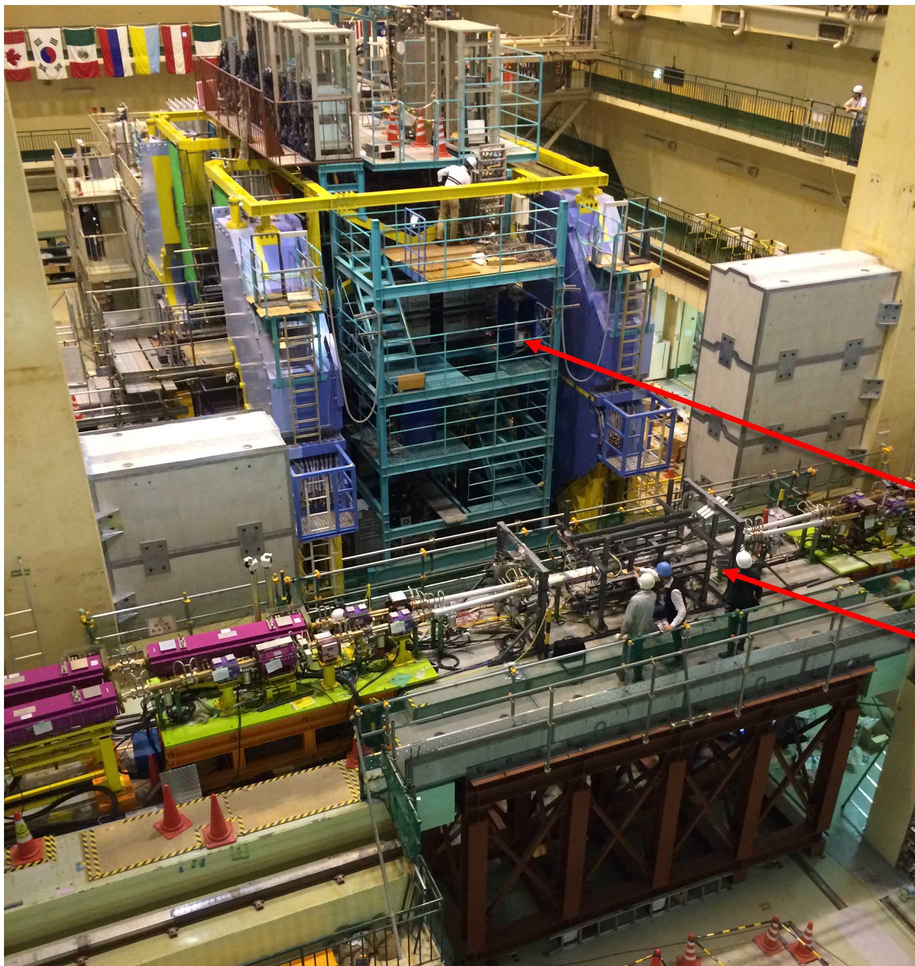


BEAST Phase 1: Feb 2016
- Variety of subsystems on fiberglass support structure
- **No Belle II DAQ, only BEAST DAQ**

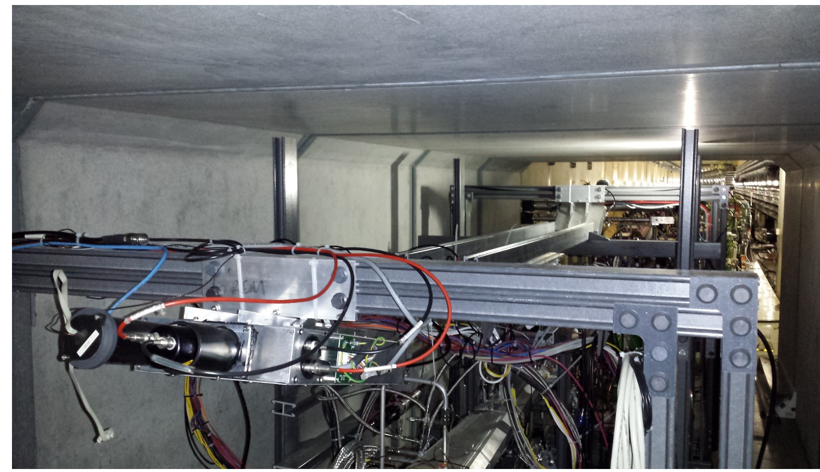
BEAST Phase 2: ~May 2017
- Belle II rolled in.
- VXD BEAST Assembly
- BEAST detectors in dock space
- **BEAST DAQ & Belle DAQ**

Tsukuba hall

End october 2015



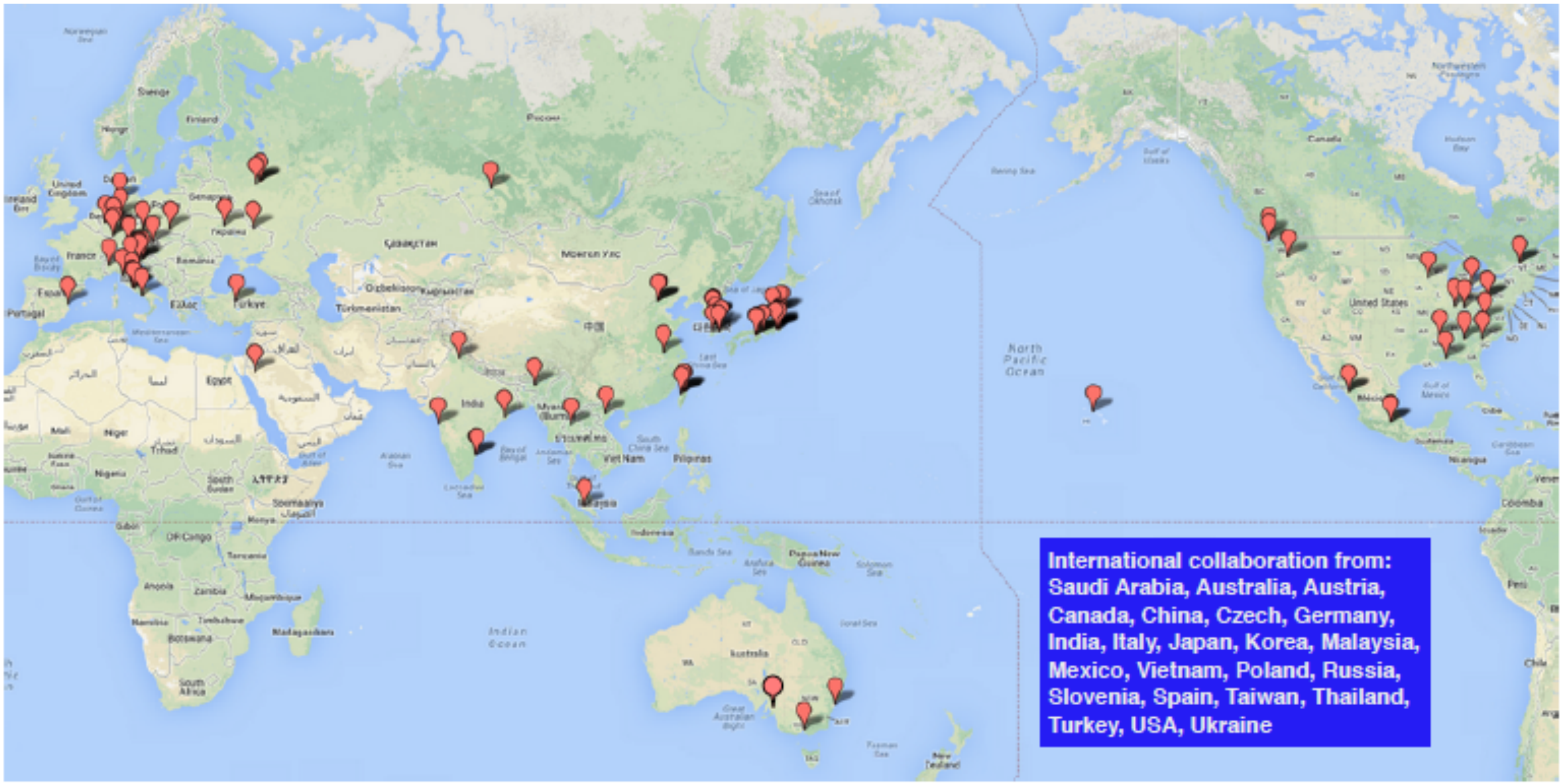
End december 2015



Belle II detector

IR

Belle II collaboration



Belle II: ~650 collaborators, 99 institutions, 23 regions/countries

tra cui 9 sezioni infn, ~36 FTE (67 FIS+TEC) nel 2016 rispetto a ~25 FTE (49 FIS+TEC) nel 2014

Belle II gruppo di Napoli

Nome	Qualifica	FTE (%)
Aloisio	Prof. Ord.	20
De Nardo (Responsabile)	Prof. Ass.	90 (include 10 ReCaS)
Giordano	Assegnista	70
Merola	Assegnista	90
Ordine	Pr. Tecnologo	30
Pardi	Tecnologo	65
Russo	Prof. Ord.	65 (include 10 ReCaS)
Sciacca	Prof. Emerito	0

Principali attività:

Calorimetro elettromagnetico (ECL)

Software e fisica

Computing

Responsabilità ufficiali:

- **G. De Nardo:** identificazione elettroni, convenership gruppo di analisi sui decadimenti del B leptonici, semileptonici e con missing energy, responsabile italiano fisica e software
- **S. Pardi:** networking per l'Europa

Attività gruppo di Napoli sul calorimetro elettromagnetico

(Aloisio, Cavaliere, De Nardo, Giordano, Merola)

	Day I	Day 2
Programma Belle II	Riutilizzo del calorimetro di Belle CsI(Tl) + completo rifacimento dell'elettronica di lettura Sviluppo del software di ricostruzione e PID	Early upgrade degli endcaps per le alte dosi di radiazione. Nuovi cristalli di CsI puro , sensori ed elettronica di lettura. CsI puro già scelto. Opzione sensori ancora aperta
Commitments Napoli	Software di identificazione elettroni e studi di fisica associati (con LNF, RM3) Aiuto nella sostituzione elettronica Barrel: primavera 2014 Endacap: fine 2014	- R&D su lettura CsI puro con Large Area APDs (con PG,LNF,RM3) - Sviluppo sistema di controllo e slow daq (con RM3)

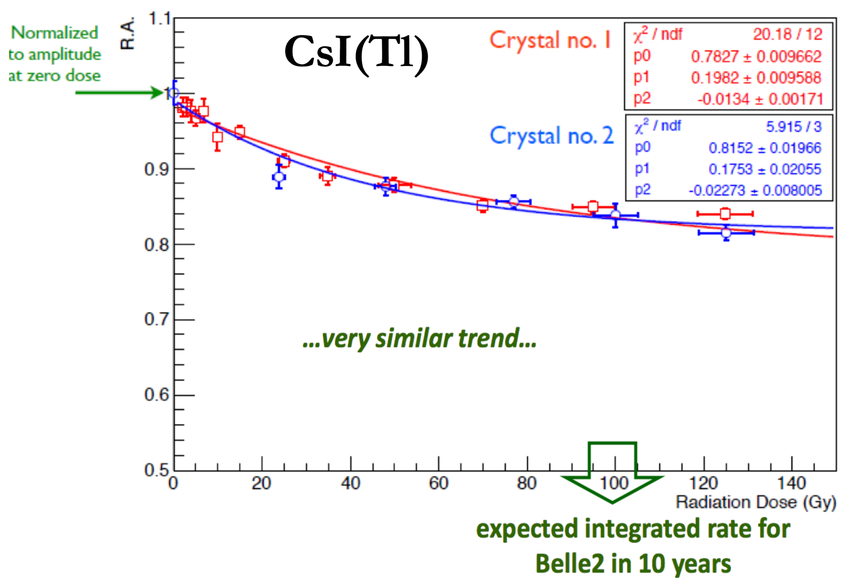
dalla riunione GRI fine 2014

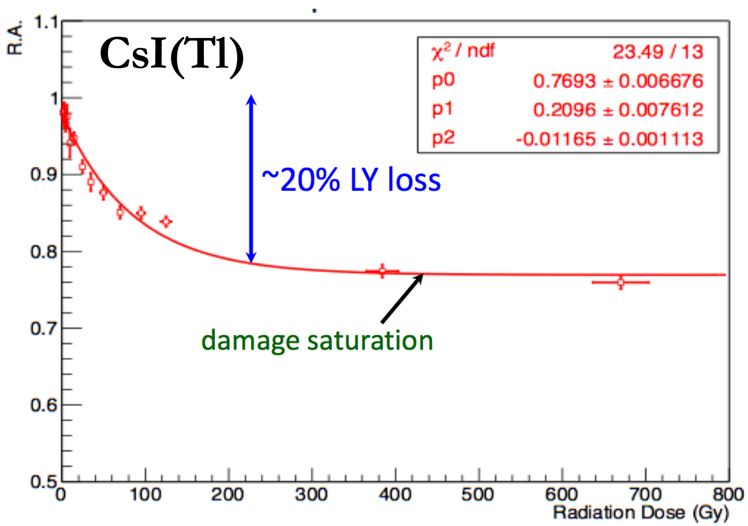
Nelle prossime slides:

- Opzione CsI puro vs CsI(Tl)
- T/Rh monitoring barrel e endcap
- T/Rh monitoring BEAST

Cristalli di CsI puro vs CsI(Tl)

R&D opzione CsI puro: test beam e presa dati con cosmici, test di radiation hardness, caratterizzazione delle colle, studi su wavelength shifters.

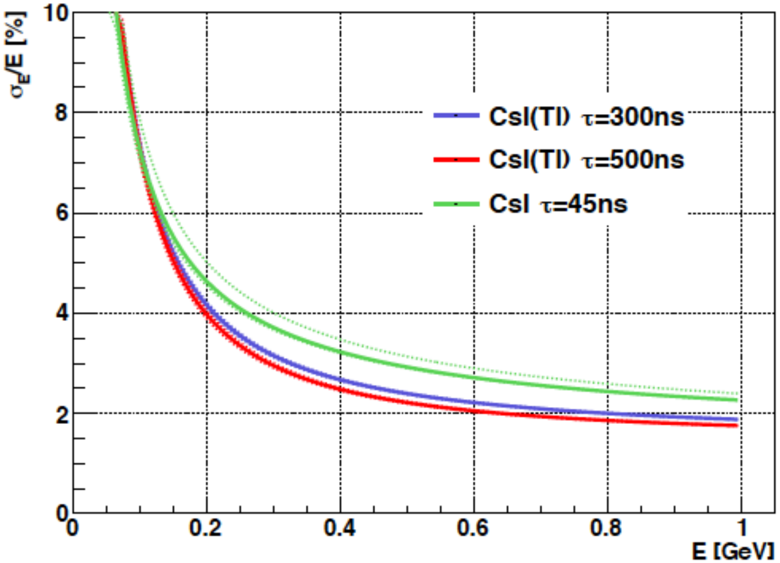




CsI puro più resistente alle radiazioni, CsI(Tl) risultato essere più radiation hard del previsto

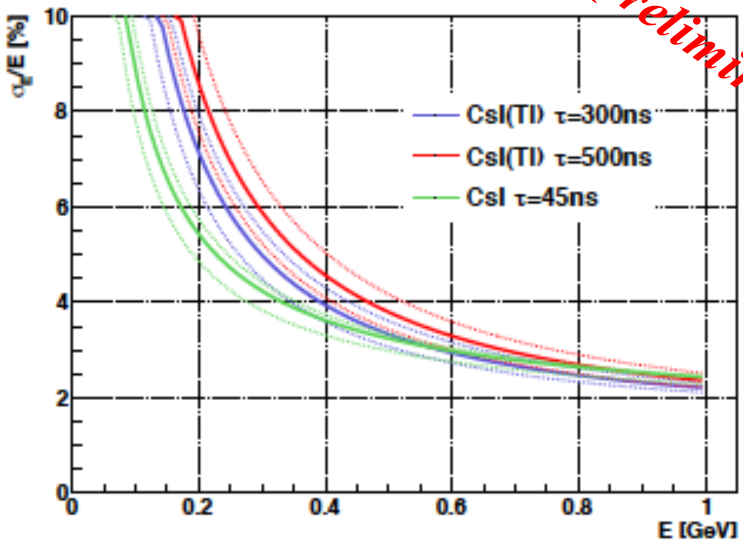
Confronto CsI puro vs CsI(Tl): risoluzione in energia

no pile-up

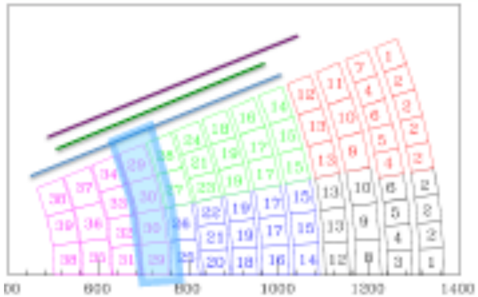


with pile-up safety factor 3x E/μsec

preliminary



Performance del CsI puro marginalmente migliore



Ring 4
sector 1

Pile-up: accumulation of hits in the crystal due to photons from beam background

Opzione CsI puro: conclusioni (preliminari)

- CsI puro ha **maggiore resistenza alle radiazioni** del CsI(Tl), ma deterioramento del CsI(Tl) minore del previsto
- **Risoluzione in energia** per il CsI puro **un po' peggiore** di quella del CsI(Tl) in **assenza di pile-up**
- In condizioni di **pile-up** la risoluzione in energia del CsI è solo **marginalmente migliore** del CsI(Tl)
- Fondamentale è valutare **l'impatto delle diverse opzioni sulla fisica** anche in condizioni più realistiche di pile-up (studiate nelle prime fasi di BEAST)

Sistema di controllo umidità-temperatura ECL

Temperature and humidity effect on the crystals light yield

1026 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 61, NO. 2, APRIL 201

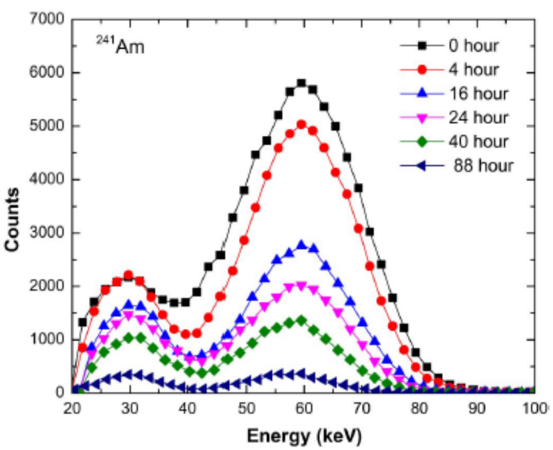


Fig. 2. The changes of pulse height spectrum as a function of time for CsI(Na) sample exposed to 75% relative humidity. An ^{241}Am is used as an ionization source.

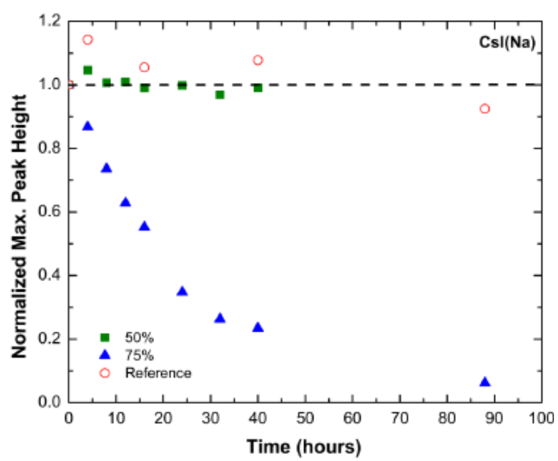


Fig. 3. The changes of the pulse height as a function of humidity and time fo CsI(Na) crystals at room temperature.

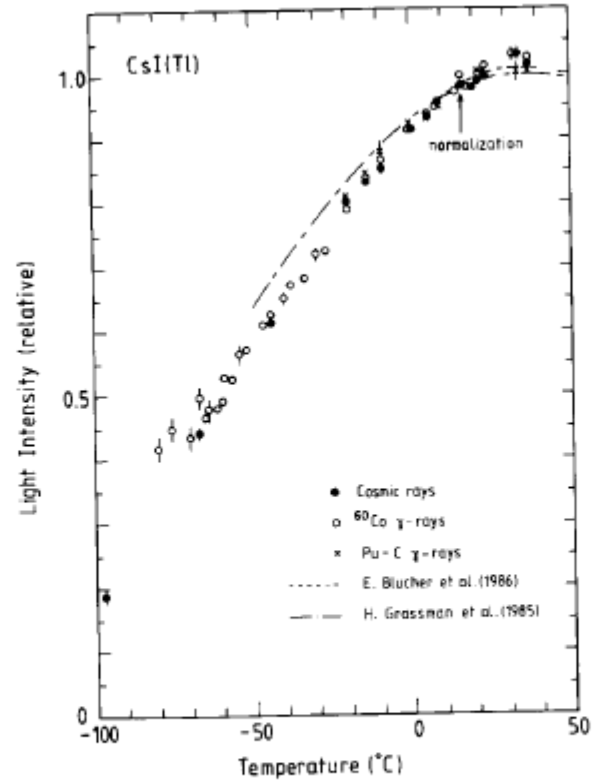


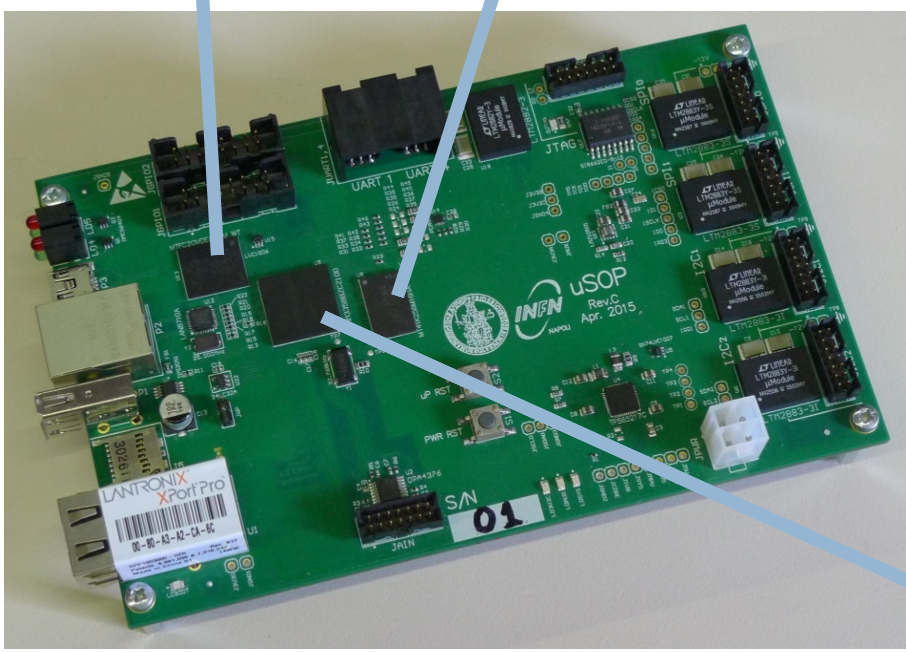
Fig. 4. Relative light intensities from CsI(Tl) measured for cosmic muons, 5 MeV γ-rays from Pu–C and 1.25 MeV γ-rays from ^{60}Co. Data points are normalized to 0.98 at 16.5° C. A few error bars are shown to indicate the error in finding the peak position in the pulse height spectrum. The results from refs. [4,5] are read from the data points in the figures and shown for comparison after conversion to smooth curves.

A.Aloisio

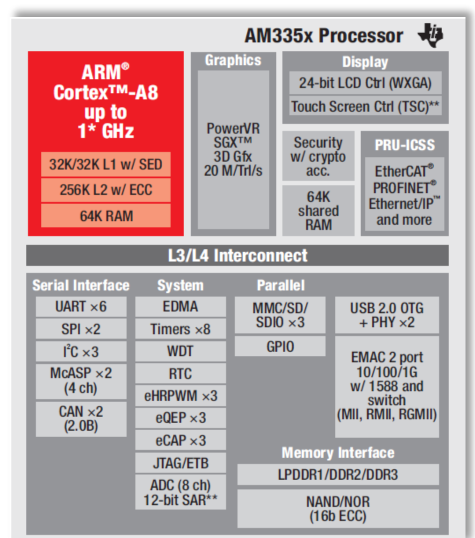
uSOP (Service Oriented Platform)

4 GB Flash eMMC

512 MB DDR3 RAM



- Single Board Computer for embedded applications
- 3U Eurocard form factor, stand alone
- Running Linux OS (Debian)
- Designed as a platform for Belle2 ECL slow-controls

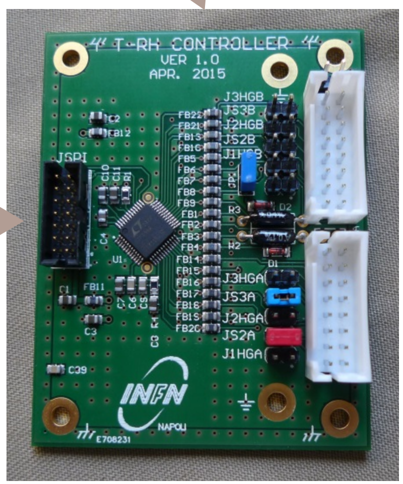


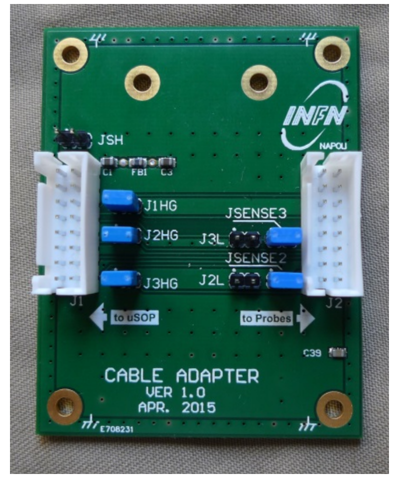
A.Aloisio

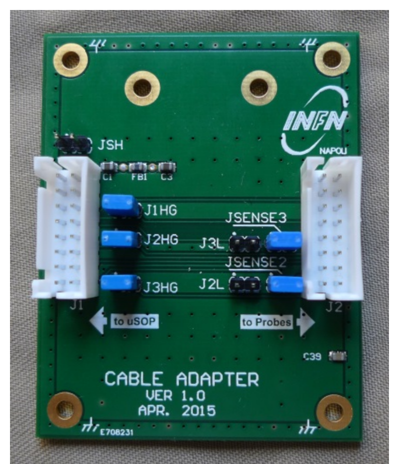
T/Rh readout

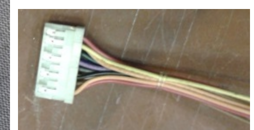
T-Rh Controller

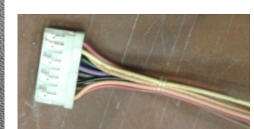
To uSOP

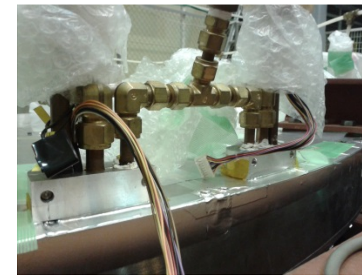


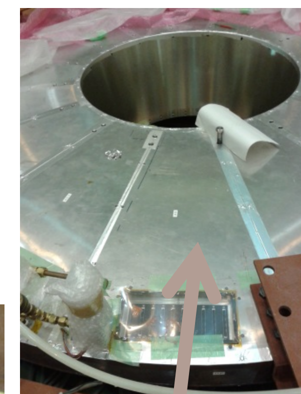












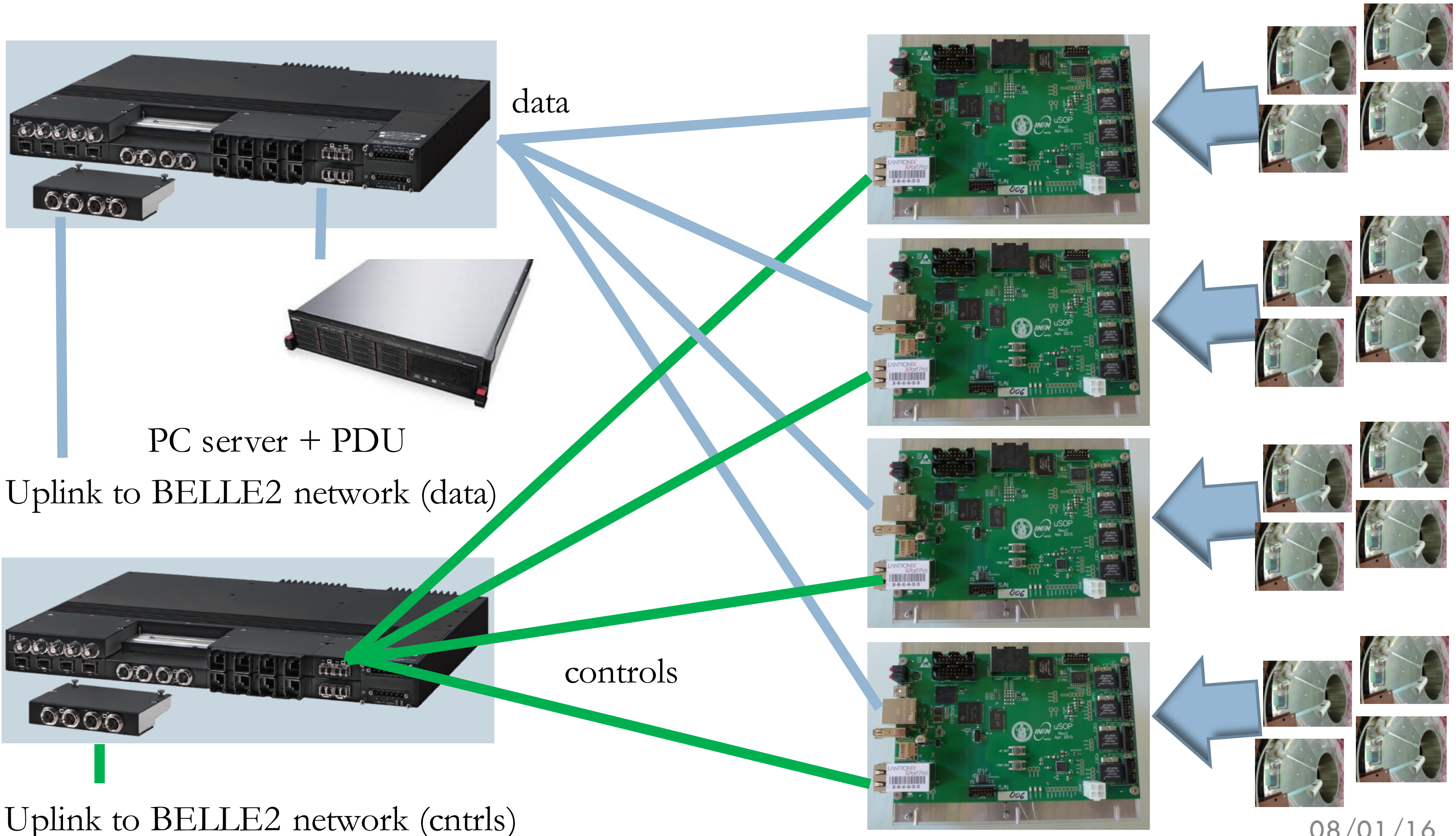
Cable Adapter (passive):

- Selects grounding scheme
- Filters the power to the VAISALA Rh probe
- Sets 2, 3 or 4 wire (Kelvin) read-out

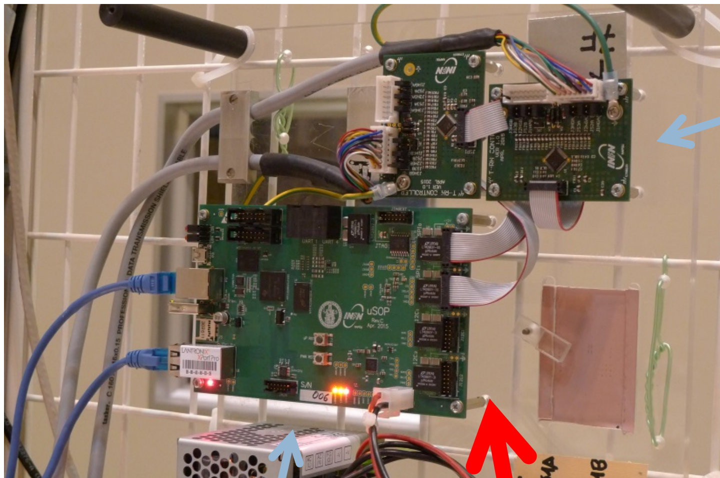
In each sector:

- **3 thermistors**
- **1 VAISALA Rh probe**

Aggregation scheme



uSOP monitoring ECL Forward



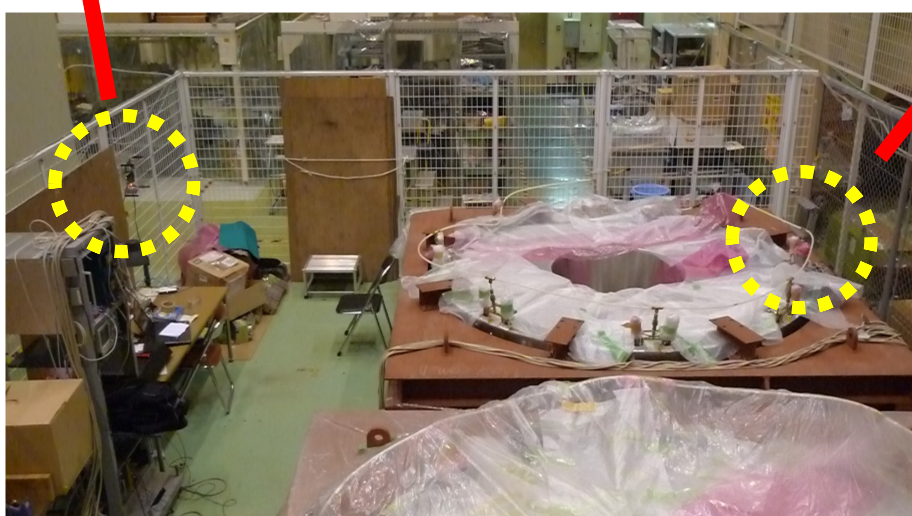
T-Rh Controller

uSOP Rev. C

Cable harness to sectors

Sectors 7F and 8F

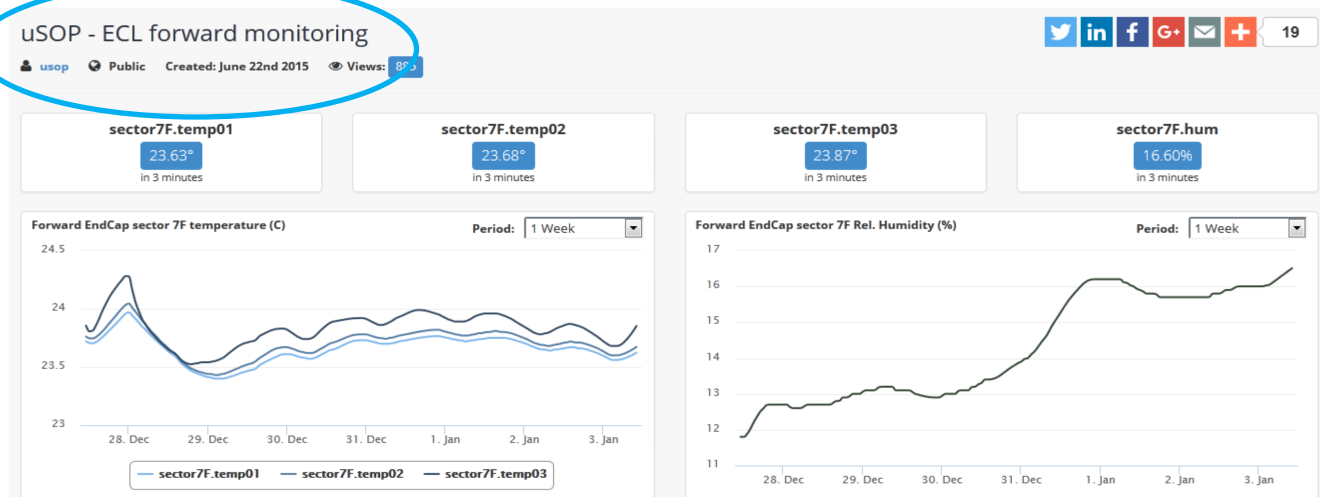
Cable Adapters

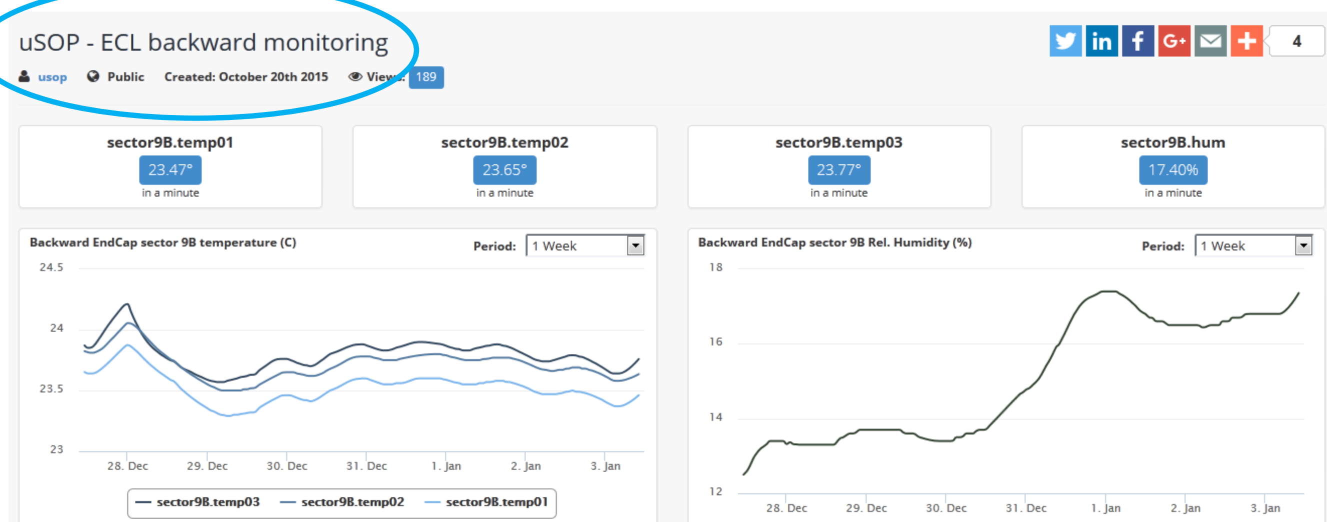


uSOP in the Fuji Hall – CSI booth (Jun. 2015)

A.Aloisio

Live Display

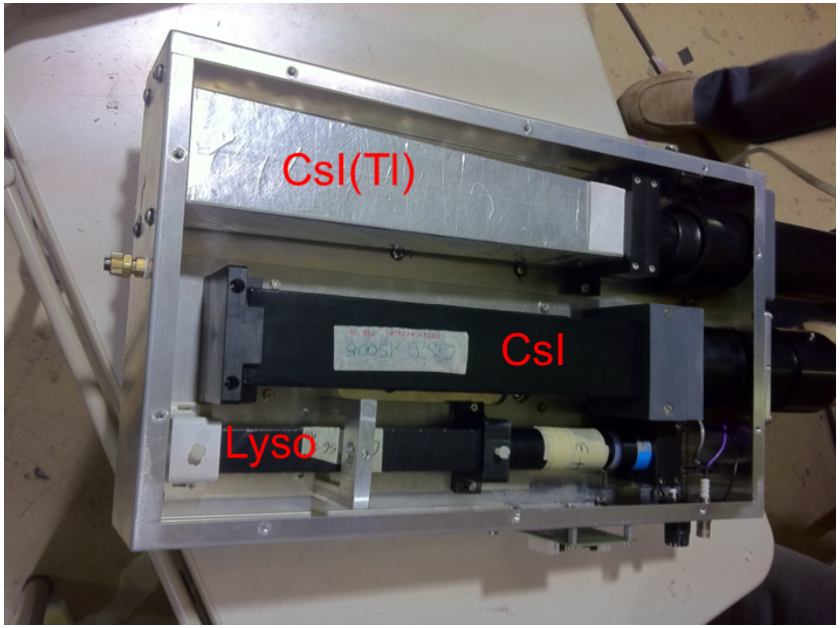




INFN NA contribution to BEAST

Primary detector groups are Belle II collaborators from:
U. Hawaii, Wayne State U. (USA), U. Victoria (Canada), INFN (Italy), U. Trieste (Italy), National Taiwan U. (Taiwan), KEK (Japan), MPP Munich (Germany)

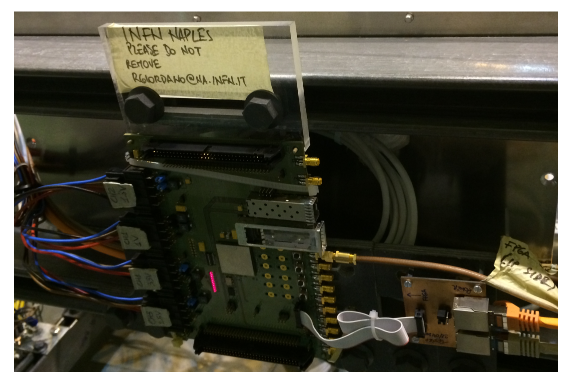
- INFN NA is involved in the calorimeter crystals
- BEAST includes 6 boxes with 3 scintillating crystals each
- Light Yield depends on temperature (T) and relative humidity (RH)
- Dedicated uSOP system monitors T and RH in each box



BEAST ECL

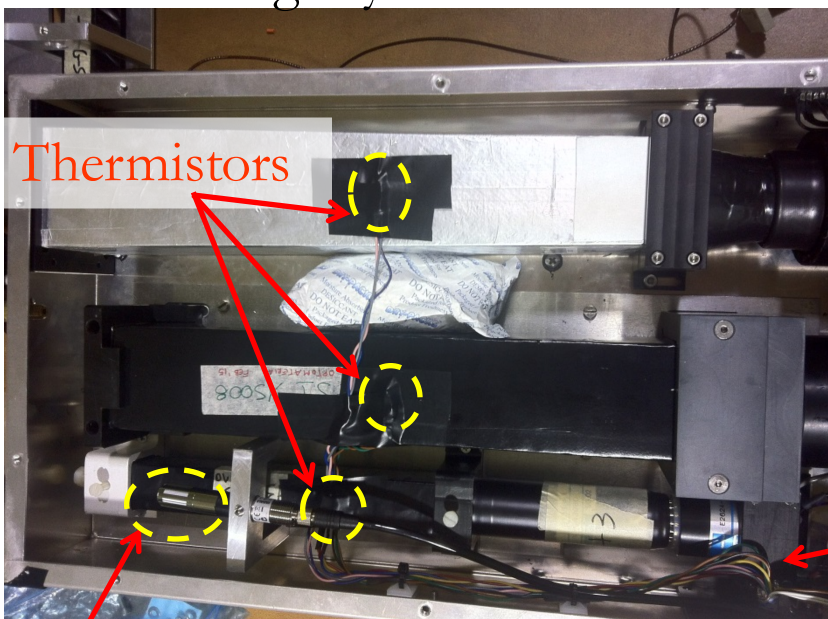
Team

- CANADA
  - U. of Victoria
    - A. Beaulieu
- ITALY
  - INFN - LNF Frascati
    - R.de Sangro, A. Russo (Tech)
  - U. of Naples & INFN Naples
    - R. Giordano
  - U. of Perugia & INFN Perugia
    - A. Rossi, G. Scolieri (Tech)
  - INFN Roma 3
    - P. Branchini

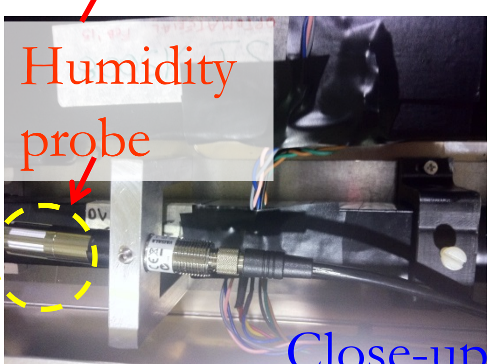


Sensor installation

Box hosting crystals



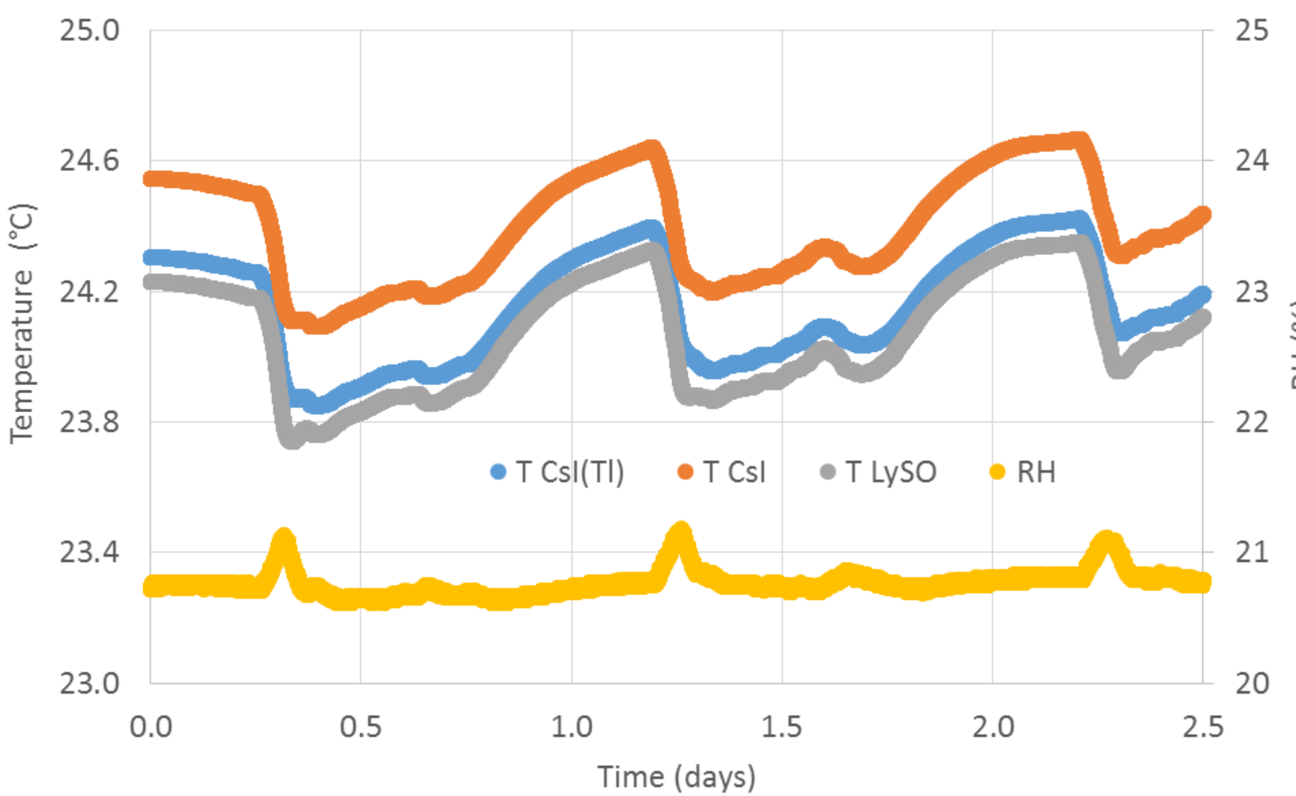
Sensor wiring



- In each box, one thermistor per crystal (Lyso, pure CsI, CsI(Tl)) and a humidity probe
- Cable adapter PCB on the box side
- Sockets/plugs compatible with Belle2 ECL
- Each box is read via a 16-wire shielded cable routed to DAQ room
- 3-wire scheme for thermistor readout

R.Giordano

T/RH logs

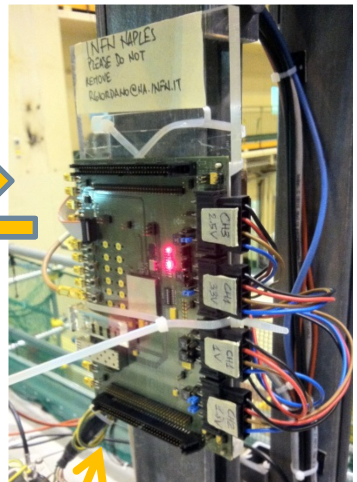


- Each uSOP outputs EPICS PVs over the BEAST network for relative humidity, crystal temperatures and corresponding dew points

- Box is sealed and includes humidity absorber, RH varies mostly due to variation of temperature

Irradiation of FPGA at BEAST

On the back of the strut



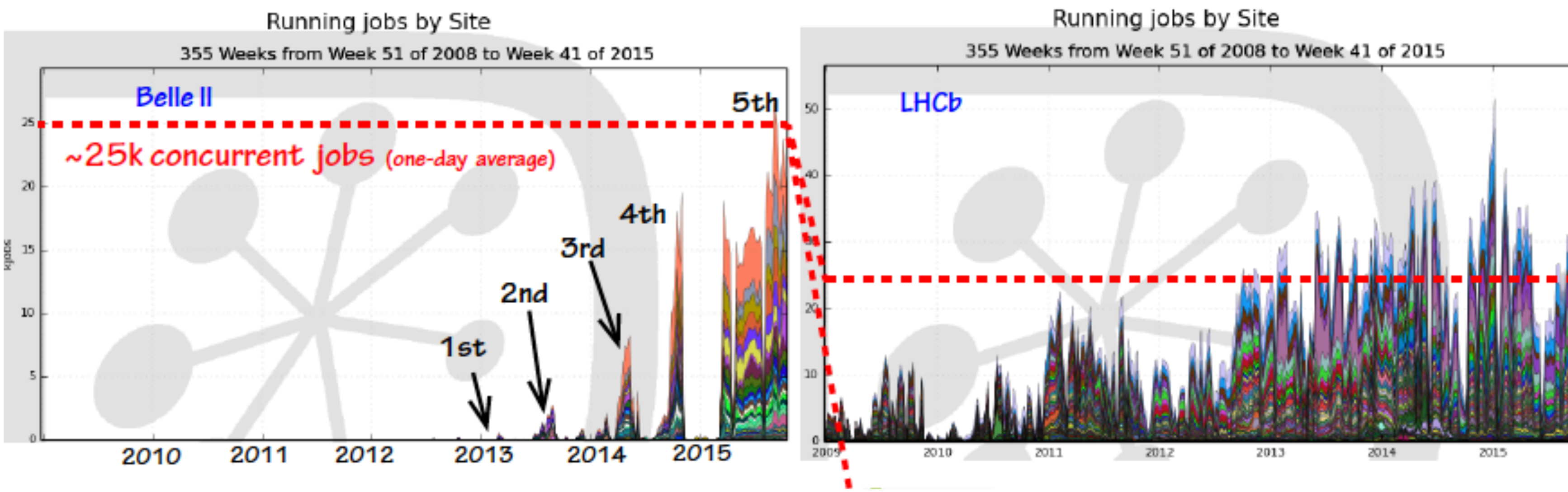
IR forward

- **Activity in the framework of SIR** project "ROAL"
- FPGA board installed on the BEAST structure (behind a TPC)
- Designed for radiation effect studies, only FPGA (Kintex-7 325T) and passives, no active components
- **Readout by uSOP for measuring bit upsets induced by radiation** (JTAG over 40m CAT7 cables)
- External power supplies (4-wire scheme)
- uSOP+ADC(LTC2499) sense voltages at FPGA

R.Giordano

Computing e risorse per Belle II

Impiego risorse BelleII e performance di Napoli



17 countries/region

Australia, Austria, Canada, China, Czech Republic, Germany, India, Italy, Japan, Korea, Mexico, Poland, Russia, Slovenia, Taiwan, Turkey, USA

LCG.DESY.de	18.4%	LCG.CESNET.cz	3.2%	LCG.KISTI.kr	1.4%
DIRAC.PNNL.us	12.1%	ARC.SIGNET.si	3.0%	LCG.Melbourne.au	0.9%
LCG.KIT.de	10.4%	LCG.CNAF.it	2.3%	CLOUD.CC1_Krakow.pl	0.8%
LCG.Pisa.it	7.3%	DIRAC.BINP.ru	2.2%	DIRAC.RCNP.jp	0.6%
DIRAC.UVic.ca	6.8%	LCG.Cosenza.it	2.0%	DIRAC.CINVESTAV.mx	0.4%
LCG.KEK2.jp	5.2%	LCG.Frascati.it	2.0%	LCG.Torino.it	0.4%
LCG.Napoli.it	5.1%	LCG.NCHC.tw	1.9%	LCG.ULAKBIM.tr	0.3%
LCG.HEPHY.at	3.6%	LCG.KMI.jp	1.7%	DIRAC.Beihang.cn	0.3%
LCG.MPPMU.de	3.5%	LCG.CYFRONET.pl	1.7%	... plus 24 more	

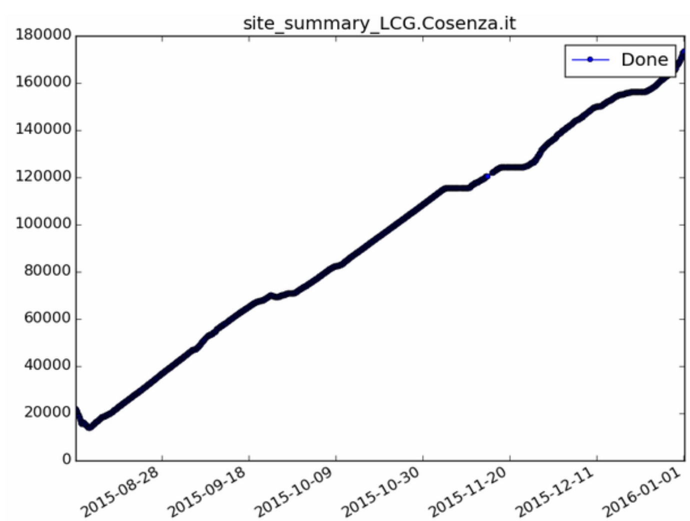
COSENZA E' INSERITA SOTTO IL SITO DI RECAS-NAPOLI

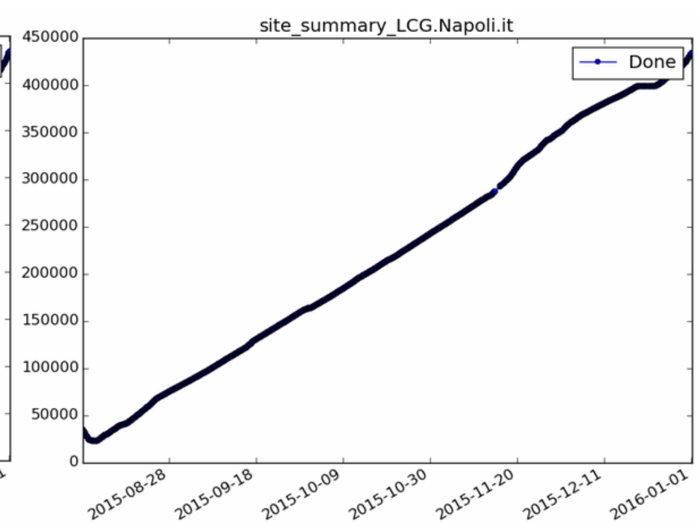
S. Pardi

Risorse di Napoli per BelleII attualmente in funzione

- **Risorse Utilizzate**: ReCaS (700 core) , SCoPE (300 core), Tier 2 (20 core) + 500 core presso la sede di Cosenza gestite dal CE di Napoli.
- Circa **650.000 jobs** eseguiti durante l'ultima campagna Monte Carlo (**MC5**) - circa il 7.1% dell'intera produzione.
- **300TB Storage** messo a disposizione - utilizzato al 45%
- **New**: da dicembre in pre-production **ulteriori 1244 core** sul cluster ReCaS-Unina

(Boccia, Bottalico, Carracciuolo, Doria, Pardi, Russo, Tarasio)





S. Pardi

Networking: stima delle risorse di rete

Attività:

Stima delle risorse di rete che verranno utilizzate dalla collaborazione Belle II nei prossimi anni ed individuazione dei flussi di dati previsti

Data Challenge per il test dello stato attuale della rete

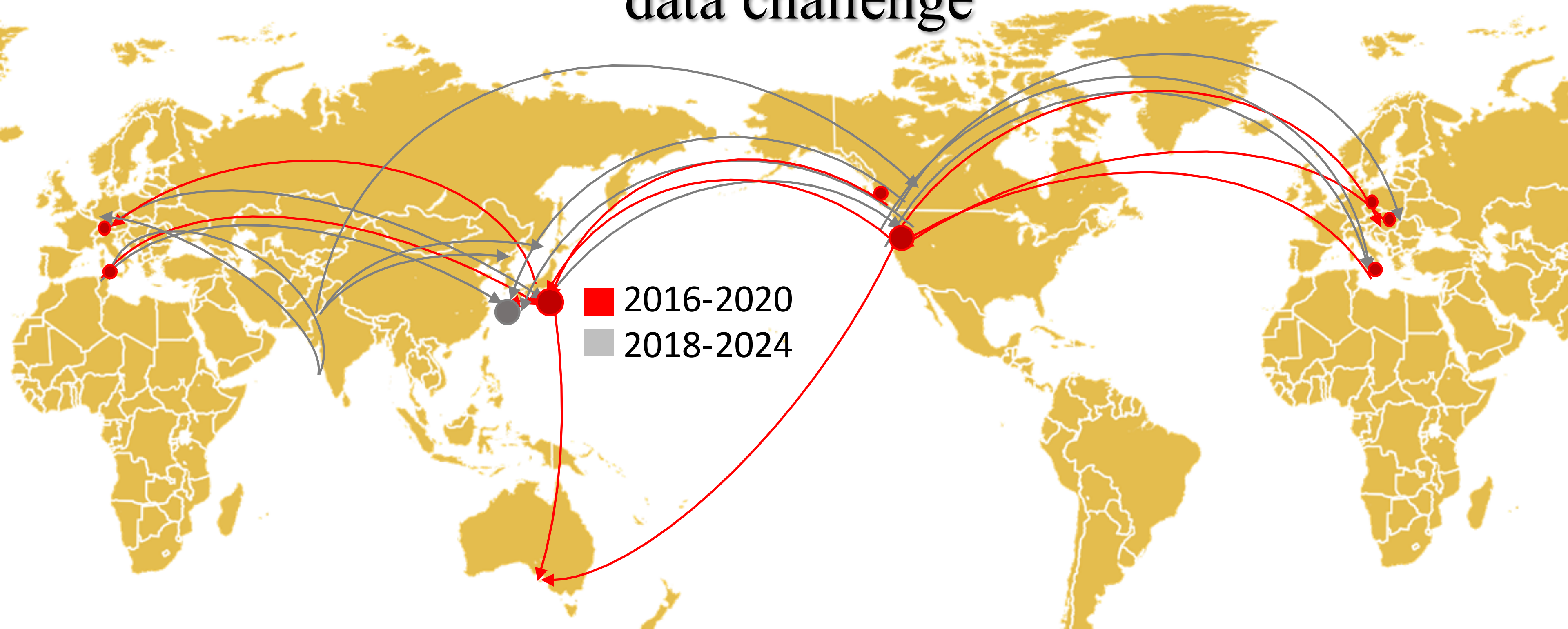
Attività svolta da **S. Pardi** (coordinatore nel network in Europa per Belle II)

Status:

- **Stima numerica effettuata fino al 2018** e individuazione di tutti i flussi di data transfer fino al 2024 sulla base dell'attuale computing model.
- Completata la fase II del data challenge con **risultati per Napoli in linea con le previsioni**
- **Da completare**: stima numerica completa fino al 2024 e stima del traffico dovuto alla user analysis (non è ancora definito il modello di analisi)

S. Pardi

Networking: rappresentazione dei principali flussi individuati per il data-transfer e risultati data challenge



Risultati dei primi test di data transfer tra PNNL, KEK e Napoli (1 TB di dati trasferiti via gridftp)

	2018	2024 (old approx)	2015 Data Challenge Results	Comment
PNNL ➔ NAPOLI	<3Gbps	4 Gbps average	3 Gbps	Goal Achieved
KEK ➔ NAPOLI	1 Gbps	5 Gbps	3 Gbps	Goal Achieved

Storage: gestione delle configurazioni

S. Pardi

Attività:

Napoli ha la responsabilità della gestione delle configurazioni di tutti gli Storage di Belle II (S. Pardi)

Status:

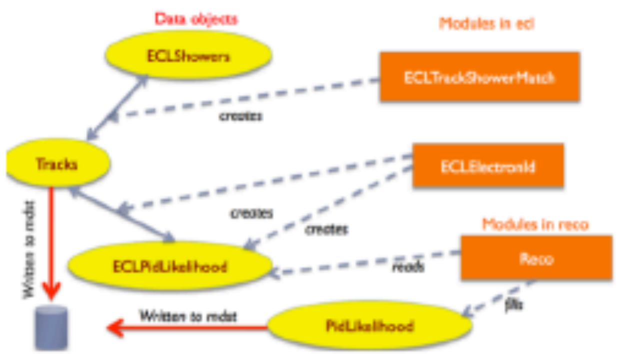
- E' stata completata la **ricognizione, configurazione e certificazione di tutti gli storage della collaborazione** interagendo con i site manager di tutti i paesi (23 storage in totale circa 5 mesi di attività)
- E' stato definito un insieme di storage affidabili (tra cui quello di Napoli) .
- E' stata avviata un'attività di sperimentazione per **l'utilizzo del protocollo http per l'accesso ai dati** coordinata da Napoli che prevede i seguenti punti:
  - Verificare la compatibilità del software di belle II con il protocollo http.
  - Selezionare un set di Storage Element pilota configurati con supporto http
  - Creare una data-federation via http.

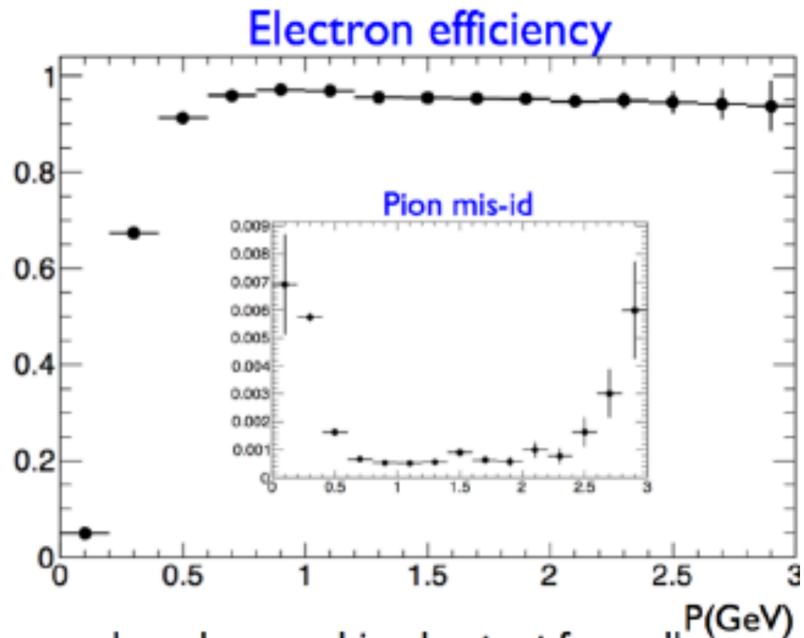
Attività software e analisi

- Identificazione elettroni
- Preparazione di analisi dei decadimenti $B \to \tau\nu$ e $B \to K^{(*)}\nu\nu$

Attività software - identificazione di elettroni

G. De Nardo (responsabile), M. Merola





PID selection base on a likelihood response based on combined output from all Subdetectors capable of PID

e-ID currently uses E/p from ECL and dE/dx from SVD+CDC

Next steps: ottimizzazione variabili per la e-ID, impatto sui canali di fisica

Attività analisi

Ongoing Studies Leptonic, semileptonic and with missing energy B decays working group

Leptonic			
Thomas Keck	Karlsruhe	PhD	B -> tau nu with FEI
Felix Metzner	Karlsruhe	MSc	B -> l nu gamma (hadronic + semileptonic tag) ‡
Mario Merola, Guglielmo De Nardo	Napoli	Staff	B -> l nu tagged
b -> c l nu			
Lucien Cremaldi, David Sanders	Mississippi	Staff	B -> D* mu/e nu
b -> c tau nu			
Abner Soffer	Nagoya Visitor	Staff & students	Vertexing to improve B -> D(*) tau nu and B -> mu nu
Karol Adamczyk	Krakow	PhD	B -> D* tau nu polarisation
Himansu Sahoo, Don Summers	Mississippi	Staff	B -> D(*) tau nu
b -> u l nu			
Alexander Ermakov	Melbourne	PhD	B -> Xu l nu (inclusive)
Matic Lubej, Anze Zupanc	Ljubljana	Staff and students	B -> pi l nu and Bs -> K l nu
Missing Energy			
Elisa Manoni	Perugia	Staff	B -> K(*) nu nu tagged
Johannes Grygier	Karlsruhe	PhD	B -> K(*) nu nu tagged
James Kahn	LMU	PhD	B -> K(*) nu nu tagged
Sasha Glazov	DESY	Staff and students	B -> K(*) nu nu tagged
Gianluca Inguglia	DESY	Staff	B -> nu nu (gamma)

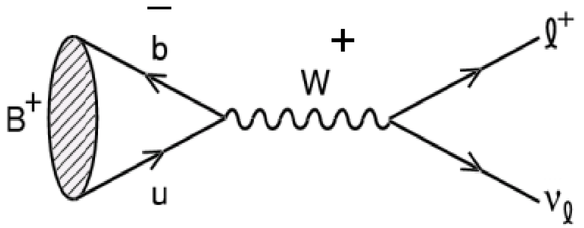
$B \to \tau\nu$

$B \to K^{(*)}\nu\nu$

B leptonic decays ($B \to l\nu$)

- Helicity suppressed

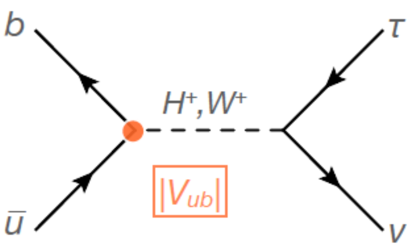
$$BR_{SM}\left(B \to \ell\, \nu\right) = \frac{G_F^2 m_B \tau_B}{8\pi} f_B^2 \, |V_{ub}|^2 m_\ell^2 \left[1 - \frac{m_\ell^2}{m_B^2}\right]^2$$



$\tau:\mu:e \to 1 : 10^{-3} : 10^{-7}$

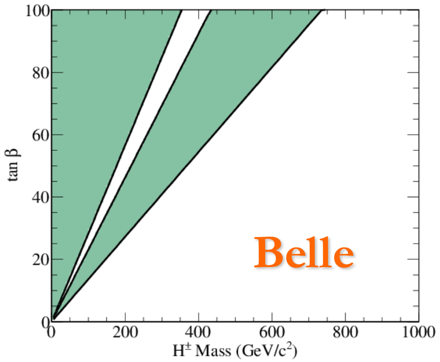
- The SM predicts a branching ratio of $\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = (0.75^{+0.10}_{-0.05}) \times 10^{-4}$

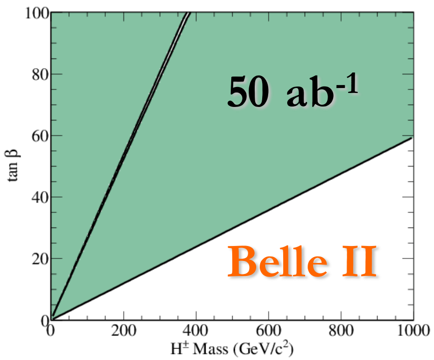
- Higgs doublet models predict interference with SM decay with a modification of the branching ratio



$$B = B_{SM} \times \left(1 - m_B^2 \frac{\tan^2\beta}{m_{H^\pm}^2}\right)$$

ratio of the two Higgs vacuum expectation values

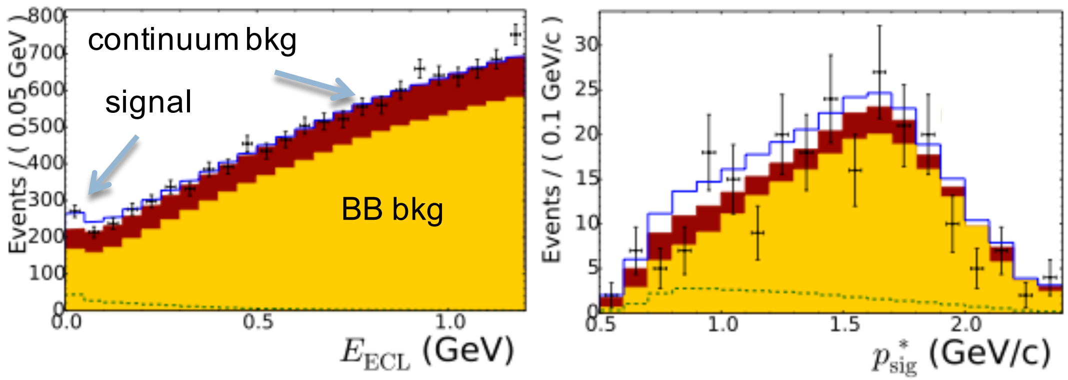




Recent results on $B \to \tau\nu$

- First evidence at Belle (2006) and Babar (2012 - Napoli group)
- Most recent measurement (Belle - 2015):

  - use of multivariate techniques (neural network) to reconstruct the tag side
  - the signal side is reconstructed in four modes: $\tau \to \mu\nu\nu, e\nu\nu, \pi\nu, \rho\nu$
  - the signal is extracted through a two-dimensional maximum likelihood fit to the E_{ECL} and p^*_{sig} distributions



- E_{ECL} is the sum of the energies of clusters in the ECL not associated to reconstructed B mesons
- p^*_{sig} is the momentum of the signal side particle in the CM

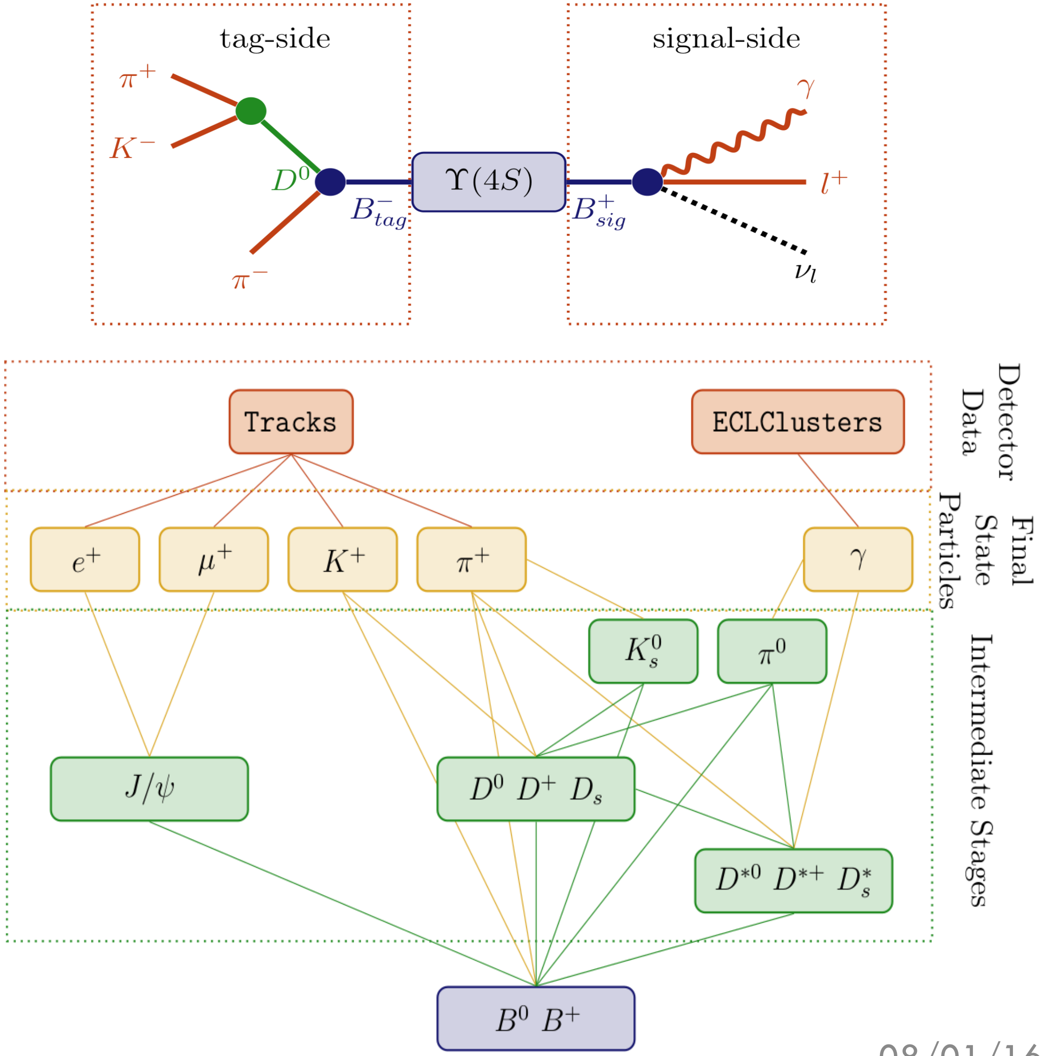
$$\mathcal{B} = [0.91 \pm 0.19(\text{stat.}) \pm 0.11(\text{syst.})] \times 10^{-4}$$ (evidence at ~4.6 σ level)

http://arxiv.org/abs/1503.05613v2

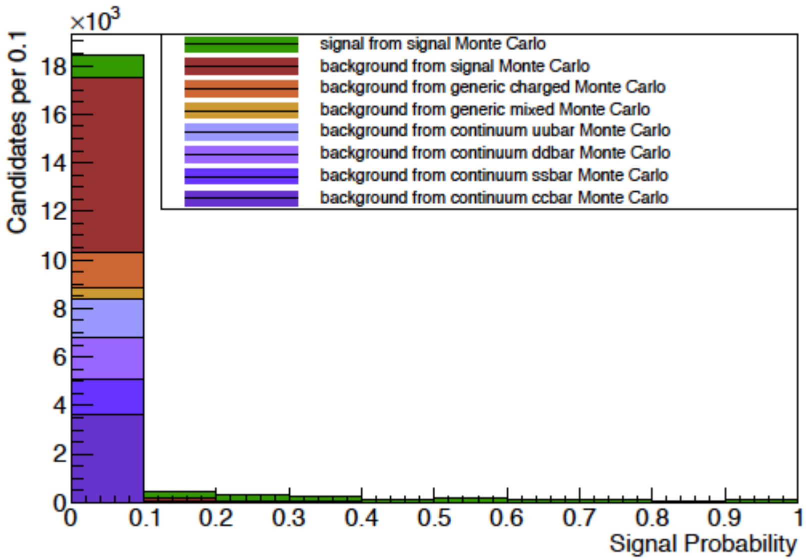
Full Event Interpretation (FEI)

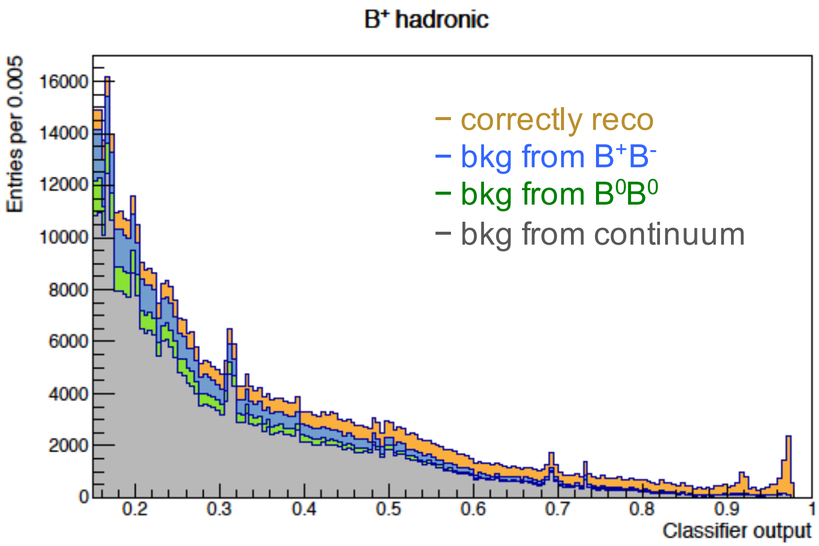
- Developed by Thomas Keck, it's an extension of the Full Reconstruction used in Belle, and uses a multivariate technique to reconstruct the B-tag side through lots of decay modes in an Y(4S) decay.

- Hierarchical approach: first train multivariate classifiers (MVC) on FSP, then reconstruct intermediate particles and build new dedicated MVC. For each candidate a "signal probability" is defined, which represents the "goodness" of its reconstruction.



Full Event Interpretation (FEI) performances





from Christian Pulvermacher PhD thesis

Total reconstruction efficiency compared with Belle I

Belle II

B^+ (hadronic)	0.78 %	B^+ (semileptonic)	1.05 %
B^0 (hadronic)	0.59 %	B^0 (semileptonic)	1.17 %

Belle I

B^+ (hadronic)	0.39 %	B^+ (semileptonic)	0.80 %
B^0 (hadronic)	0.28 %	B^0 (semileptonic)	0.86 %

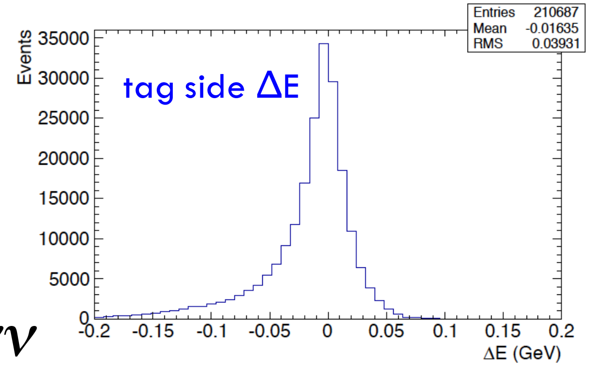
Analysis setup

M. Merola, G. De Nardo, in collaborazione con Perugia

B signal side

$B^+ \to K^{*+}\nu\nu$
- $\to K^+\pi^0$
- $\to K_s\pi^+$
  - $\to \pi^+\pi^-$

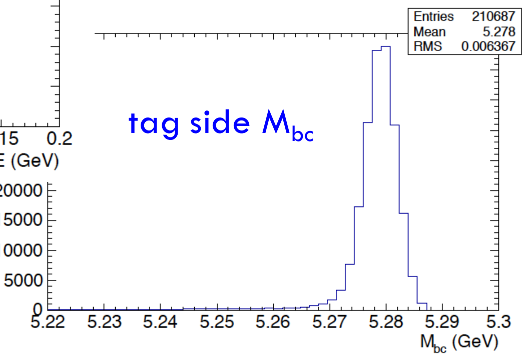
$B^+ \to \tau^+\nu$
- $\to \mu^+\nu\nu$



Differenza tra energia del mesone B e quella dei fasci nel centro di massa

B tag side

Hadronic tag using FEI with tens of decay modes



Massa del B ricostruita con il constraint dell'energia dei fasci nel centro di massa

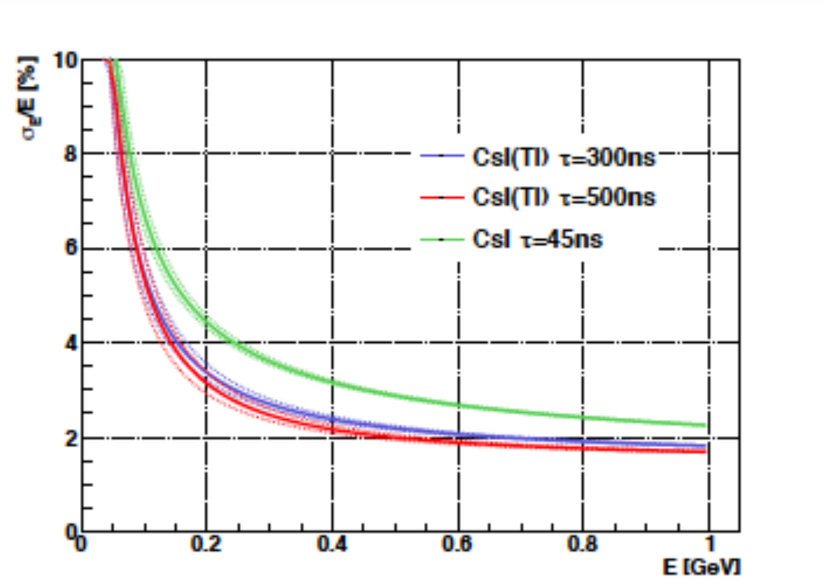
First event pre-selection established and sensible variables look reasonable

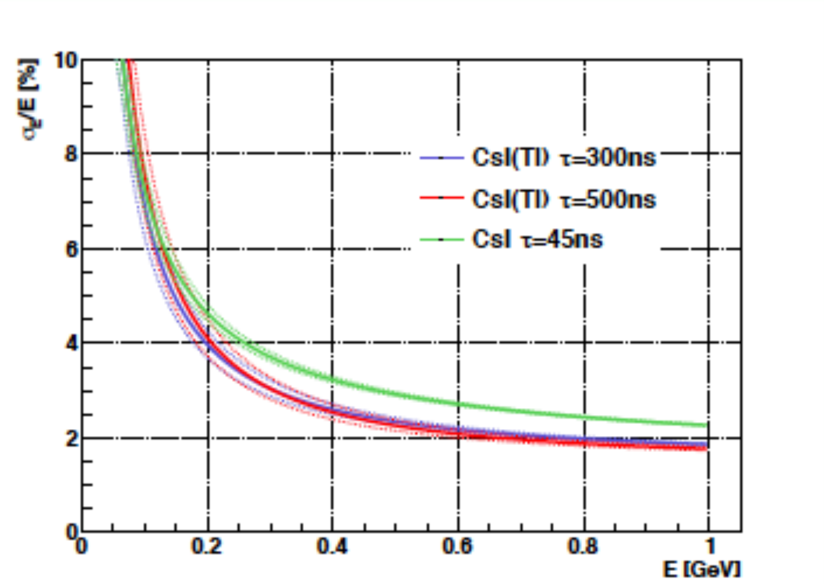
Future plans:

- optimize event selection and add other τ decay modes (e,ρ,π)
- set up an analysis strategy for $B \to \tau\nu$ / $K^*\nu\nu$ (multivariate techniques ?)
- FEI: optimization of input variables, training with beam background

Backup

FONDI ESTREMI - safety factor 3x E/μsec (ring 7 sect 8)



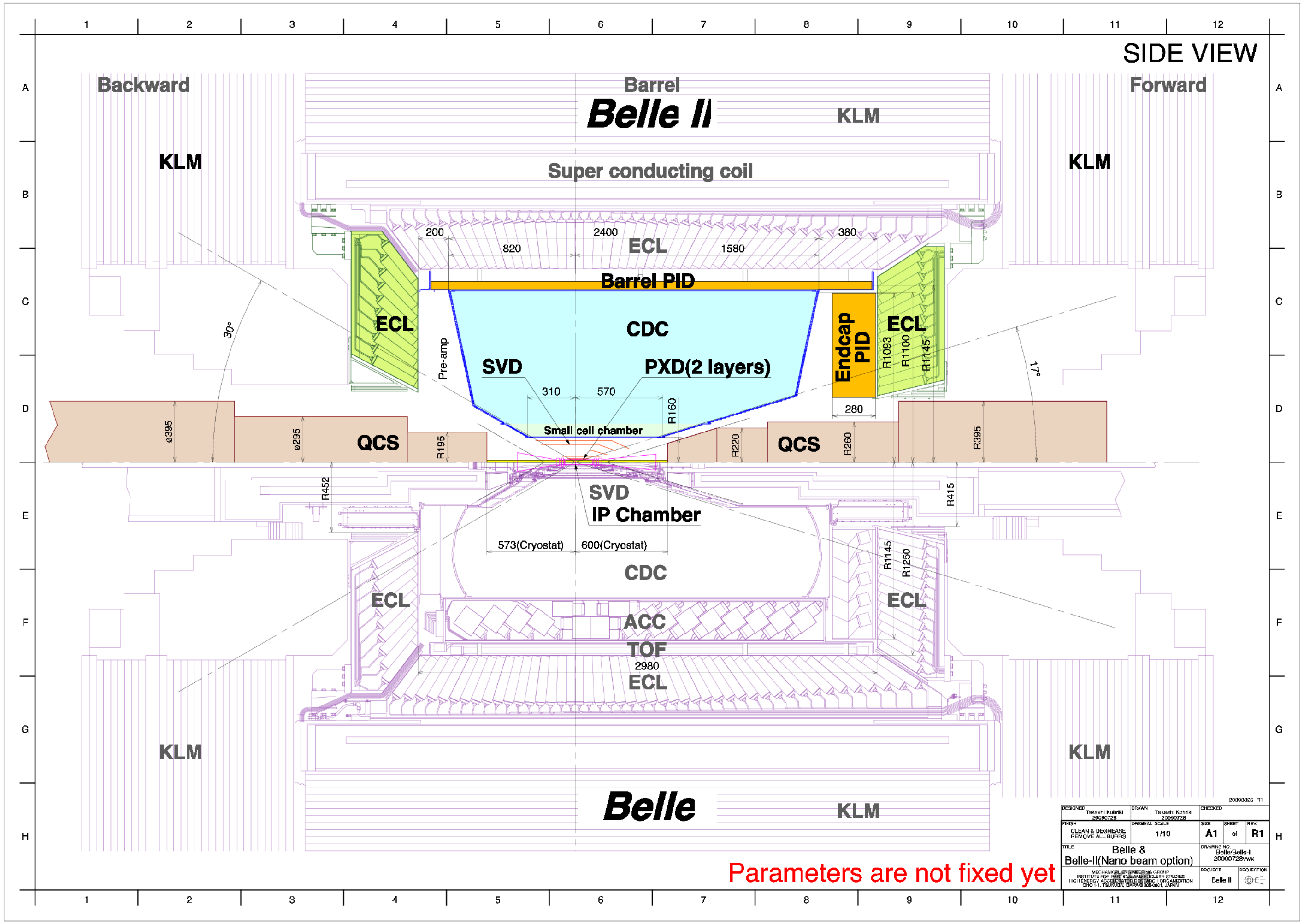


- ✓ E/μsec x 3
- ✓ hit/μsec nominale
- ➡ E/hit x 3

- ✓ E/μsec x 3
- ✓ hit/μsec x3
- ➡ E/hit nominale

- Anche nel limite MC11 con E/hit x 3 il CsI(Tl) appare avere performance migliori

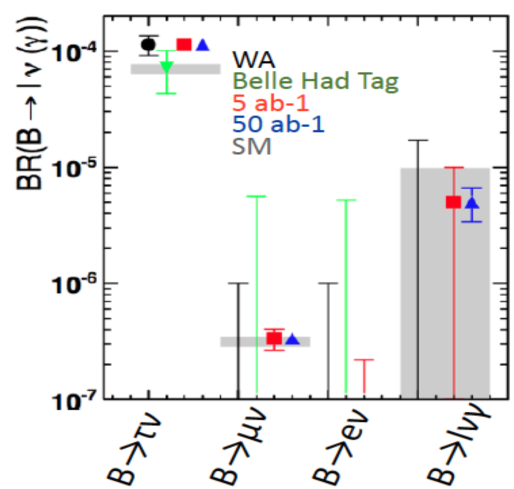
Belle II vs Belle



Physics prospects

	Observables	Belle or LHCb* (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 8 fb^{-1}(2018)	LHCb 50 fb^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012 (0.9^\circ)$	0.4°	0.3°	0.6°	0.3°
	α [°]	85 ± 4 (Belle+BaBar)	2	1		
	γ [°] $(B \to D^{(*)} K^{(*)})$	68 ± 14	6	1.5	4	1
	$2\beta_s(B_s \to J/\psi\phi)$ [rad]	$0.07 \pm 0.09 \pm 0.01^*$			0.025	0.009
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	0.053	0.018	0.2	0.04
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	0.028	0.011		
	$S(B \to K_S^0 K_S^0 K_S^0)$	$0.30 \pm 0.32 \pm 0.08$	0.100	0.033		
	$\beta_s^{\mathrm{eff}}(B_s \to \phi\phi)$ [rad]	$-0.17 \pm 0.15 \pm 0.03^*$			0.12	0.03
	$\beta_s^{\mathrm{eff}}(B_s \to K^{*0} \bar{K}^{*0})$ [rad]	–			0.13	0.03
Direct CP in hadronic Decays	$\mathcal{A}(B \to K^0 \pi^0)$	$-0.05 \pm 0.14 \pm 0.05$	0.07	0.04		
UT sides	$\lvert V_{cb} \rvert$ incl.	$41.6 \cdot 10^{-3}(1 \pm 2.4\%)$	1.2%			
	$\lvert V_{cb} \rvert$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\mathrm{ex.}} \pm 2.7\%_{\mathrm{th.}})$	1.8%	1.4%		
	$\lvert V_{ub} \rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\mathrm{ex.}} \pm 2.5\%_{\mathrm{th.}})$	3.4%	3.0%		
	$\lvert V_{ub} \rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 10.8\%)$	4.7%	2.4%		
Leptonic and Semi-tauonic	$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$96(1 \pm 26\%)$	10%	5%		
	$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7	20%	7%		
	$R(B \to D\tau\nu)$ [Had. tag]	$0.440(1 \pm 16.5\%)^\dagger$	5.6%	3.4%		
	$R(B \to D^*\tau\nu)^\dagger$ [Had. tag]	$0.332(1 \pm 9.0\%)^\dagger$	3.2%	2.1%	...	
Radiative	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%		
	$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	$2.2 \pm 4.0 \pm 0.8$	1	0.5		
	$S(B \to K_S^0 \pi^0 \gamma)$	$-0.10 \pm 0.31 \pm 0.07$	0.11	0.035		
	$2\beta_s^{\mathrm{eff}}(B_s \to \phi\gamma)$	–			0.13	0.03
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	0.23	0.07		
	$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	< 8.7	0.3	–		
Electroweak penguins	$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ $[10^{-6}]$	< 40	< 15	30%		
	$\mathcal{B}(B \to K^+\nu\bar{\nu})$ $[10^{-6}]$	< 55	< 21	30%		
	C_7/C_9 $(B \to X_s\ell\ell)$	~20%	10%	5%		
	$\mathcal{B}(B_s \to \tau\tau)$ $[10^{-3}]$	–	< 2	–		
	$\mathcal{B}(B_s \to \mu\mu)$ $[10^{-9}]$	$2.9^{+1.1*}_{-1.0}$			0.5	0.2

	Observables	Belle or LHCb* (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 2018	LHCb 50 fb^{-1}
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$	2.9%	0.9%		
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$	3.5%	2.3%		
	$\mathcal{B}(D^0 \to \gamma\gamma)$ $[10^{-6}]$	< 1.5	30%	25%		
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ $[10^{-4}]$	$-32 \pm 21 \pm 9$	11	6		
	$\Delta A_{CP}(D^0 \to K^+K^-)$ $[10^{-3}]$	3.4^*			0.5	0.1
	A_Γ $[10^{-2}]$	0.22	0.1	0.03	0.02	0.005
	$A_{CP}(D^0 \to \pi^0\pi^0)$ $[10^{-2}]$	$-0.03 \pm 0.64 \pm 0.10$	0.29	0.09		
	$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.03		
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$	0.14	0.11		
	$y(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$	0.08	0.05		
	$\lvert q/p \rvert (D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$	0.10	0.07		
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm {}^{4}_{5}$	6	4		
Tau	$\tau \to \mu\gamma$ $[10^{-9}]$	< 45	< 14.7	< 4.7		
	$\tau \to e\gamma$ $[10^{-9}]$	< 120	< 39	< 12		
	$\tau \to \mu\mu\mu$ $[10^{-9}]$	< 21.0	< 3.0	< 0.3		



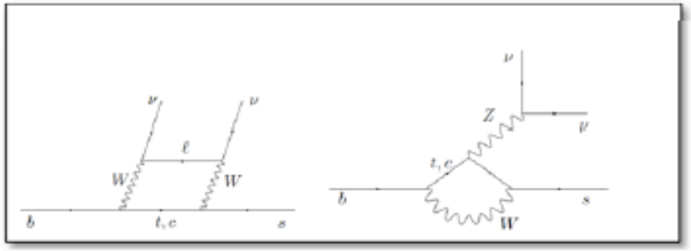
Physics highlights

$B \to K^{(*)}\nu\nu$: theoretical motivations

- SM predictions [JHEP 02 184,2015]:

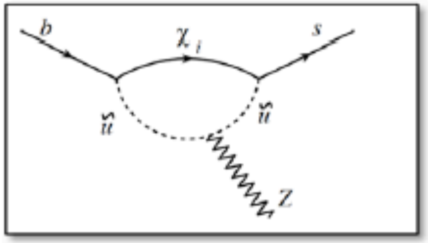
$$\mathrm{BR}(B^+ \to K^+\nu\bar{\nu})_{\mathrm{SM}} = (3.98 \pm \underline{0.43} \pm \underline{0.19}) \times 10^{-6},$$
$$\mathrm{BR}(B^0 \to K^{*0}\nu\bar{\nu})_{\mathrm{SM}} = (9.19 \pm \underline{0.86} \pm \underline{0.50}) \times 10^{-6},$$
$$F_L^{\mathrm{SM}} = 0.47 \pm \underline{0.03},$$

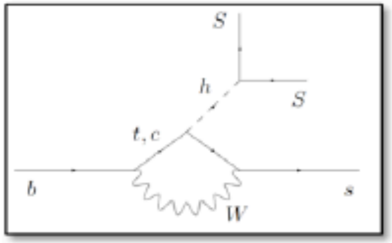
  - form factor error
    parametric error ($|V_{cb}|$-dominated)

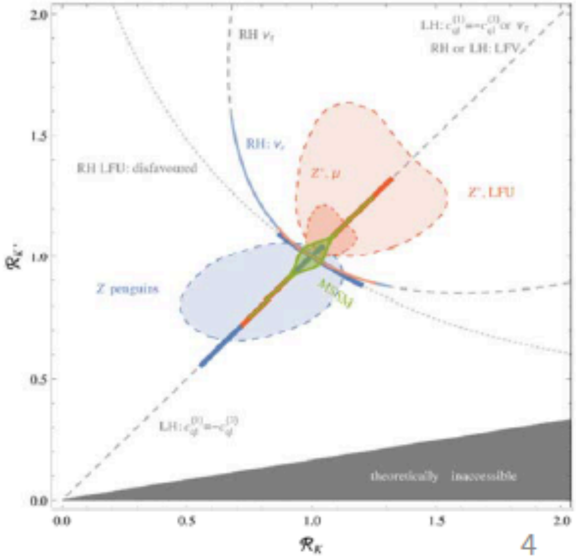


$R_{K^{(*)}}$ = $B \to K^{(*)}\nu\nu$ BR normalized to SM expectations [JHEP 02 184,2015]

- NP effects:
  - non standard Z-couplings
  - new sources of missing energy



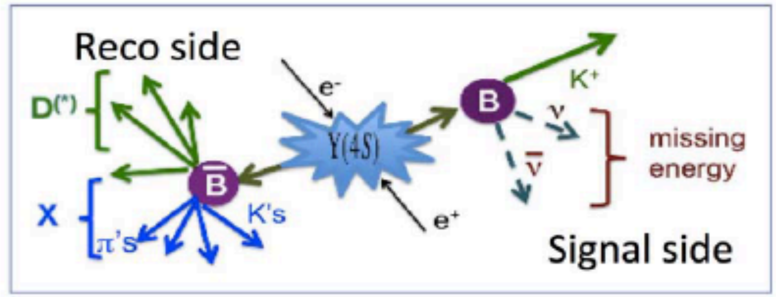




E. Manoni

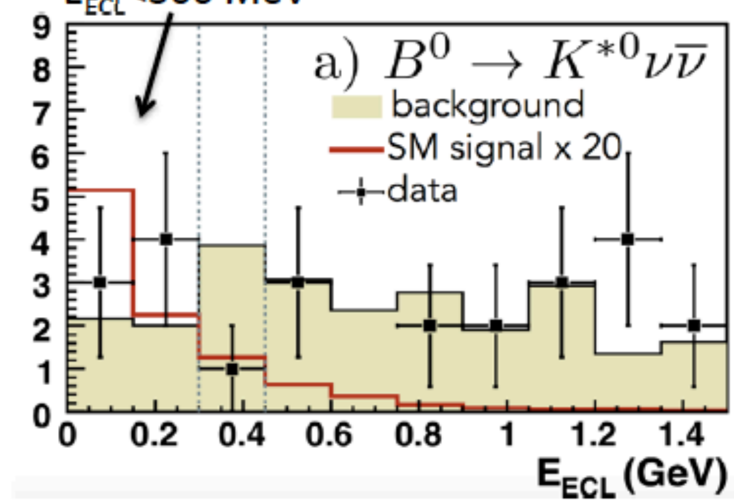
$B\to K^{(*)}\nu\nu$: experimental search (I)

- Recoil method:
  - reconstruct semileptonic or hadronic B decays on one side
  - look for K/K* + missing energy on the rest of the event (and ~ nothing else)



- Suppress qq and combinatoric BB background by using kinematic and event shape variables
- Crucial ingredients:
  - detector hermeticity and performing tracking: veto extra-tracks, low (→0) extra-energy in the calorimeter
  - particle identification: suppression of events with mis-identified K/π on both Reco and Signal sides
- Signal extraction: cut or fit to E_{ECL} distribution (extra-energy in the calorimeter)

here, signal region:
E_{ECL}<300 MeV



[Belle, PRL 99 221802, 2007]

$B \to K^{(*)}\nu\nu$: experimental search (II)

- Most recent experimental results:
  - Belle search for $B \to h^{(*)}\nu\nu$; 0.711 ab^{-1} [PRD RC 87, 111103(2013)]

Mode	Upper limit
$B^+ \to K^+\nu\bar{\nu}$	$< 5.5 \times 10^{-5}$
$B^0 \to K^0_s\nu\bar{\nu}$	$< 9.7 \times 10^{-5}$
$B^+ \to K^{*+}\nu\bar{\nu}$	$< 4.0 \times 10^{-5}$
$B^0 \to K^{*0}\nu\bar{\nu}$	$< 5.5 \times 10^{-5}$

  - BaBar search for $B \to K^{(*)}\nu\nu$; 0.429 ab^{-1} [PRD 87, 112005(2013)]

$BF(B^+ \to K^+\nu\bar{\nu})$	$<$	1.6×10^{-5}
$BF(B^0 \to K^0\nu\bar{\nu})$	$<$	4.9×10^{-5}
$BF(B \to K\nu\bar{\nu})$	$<$	1.7×10^{-5}
$BF(B^+ \to K^{*+}\nu\bar{\nu})$	$<$	6.4×10^{-5}
$BF(B^0 \to K^{*0}\nu\bar{\nu})$	$<$	12.0×10^{-5}
$BF(B \to K^*\nu\bar{\nu})$	$<$	7.6×10^{-5}

~ 1 order of magnitude far from SM expectation

$B \to K^{(*)}\nu\nu$: perspectives at Belle-II

- First extrapolation in BELLE2-NOTE-0021, assuming:
  - similar background to Belle
  - hadronic and semileptonic tag
  - SM prediction [JHEP 04 (2009) 022]:
    - $BR(B^- \to K^- \nu\nu) = 3.6 \times 10^{-6}$
    - $BR(B^0 \to K^{*0} \nu\nu) = 0.13 \times 10^{-6}$

$\mathcal{B}(B^+ \to K^+ \nu\bar{\nu}) = (4.4 \pm 1.5) \times 10^{-6}$	
$0.711\ \mathrm{ab}^{-1}$ [Belle measurement]	$< 5.5 \times 10^{-5}$
$5\ \mathrm{ab}^{-1}$	$< 2.1 \times 10^{-5}$
$50\ \mathrm{ab}^{-1}$	$< 0.7 \times 10^{-5}$
$\mathcal{B}(B^0 \to K^0_S \nu\bar{\nu}) = (2.2 \pm 0.8) \times 10^{-6}$	
$0.711\ \mathrm{ab}^{-1}$ [Belle measurement]	$< 9.7 \times 10^{-5}$
$5\ \mathrm{ab}^{-1}$	$< 3.7 \times 10^{-5}$
$50\ \mathrm{ab}^{-1}$	$< 1.2 \times 10^{-5}$
$\mathcal{B}(B^0 \to K^{*0} \nu\bar{\nu}) = (6.8 \pm 2.0) \times 10^{-6}$	
$0.711\ \mathrm{ab}^{-1}$ [Belle measurement]	$< 5.5 \times 10^{-5}$
$5\ \mathrm{ab}^{-1}$	$< 2.1 \times 10^{-5}$
$50\ \mathrm{ab}^{-1}$	$< 0.7 \times 10^{-5}$

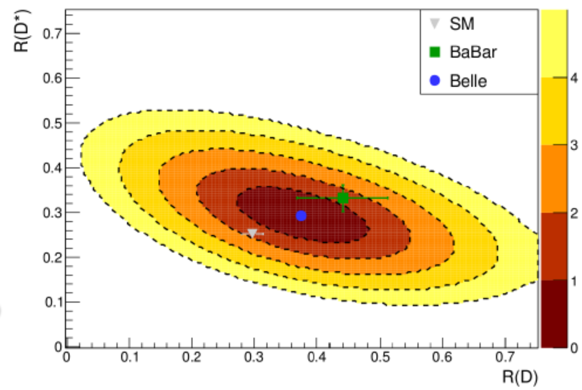
- What's (will be) new:
  - theo side: higher SM expectation for $BR(B^0 \to K^{*0} \nu\nu)$ ($\sim 9 \times 10^{-6}$)
  - exp side: sensitivity study performed with Belle-II full simulation, more reliable estimates of
    - background contamination: e.g. higher pile-up reduced → discriminant power of E_{ECL} (study and optimization of ECL performances ongoing)
    - signal efficiency: lower boost → higher hermeticity (lower bkg, higher eff.), improved tracking and particle identification

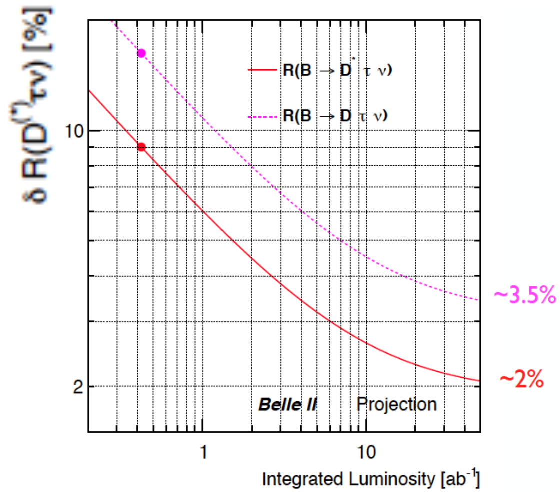
E. Manoni

Semileptonic golden modes

- **$B \to D^{(*)}\tau\nu$**
  - Measurement of $R^{(*)}$ = BR $(B \to D^{(*)}\tau\nu)$ / BR$(B \to D^{(*)} l\nu)$
  - **BaBar**: 3.5 σ far from SM
  - **LHCb**: consistent with SM
  - **Belle**: consistent with both LHCb and BaBar

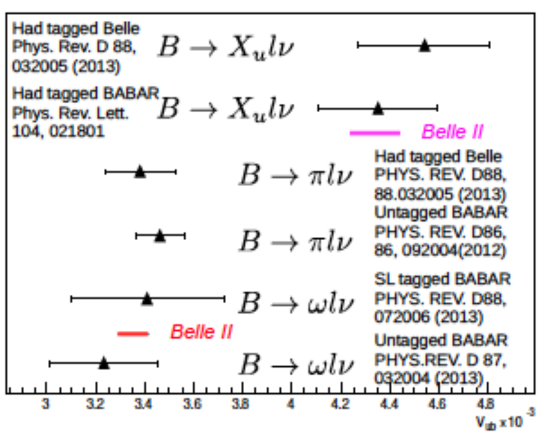
R vs R*

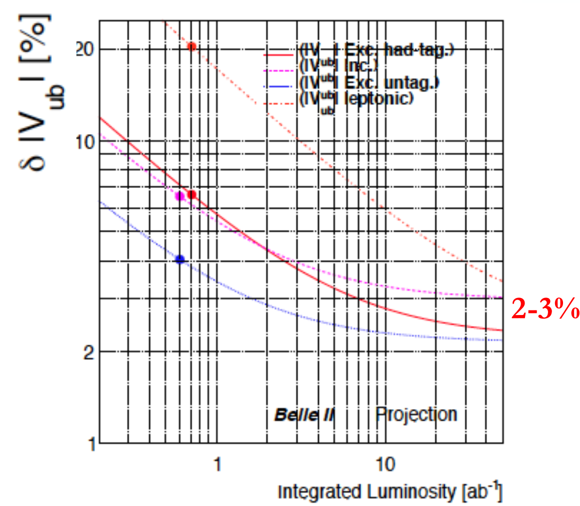




- **$B \to X_u l\nu$**
  - Tension between inclusive and exclusive measurements of $|V_{ub}|$

$|V_{ub}|$



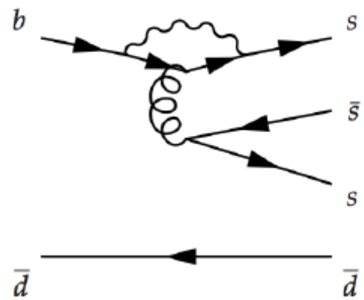


New sources of CP violation in $b \rightarrow s$

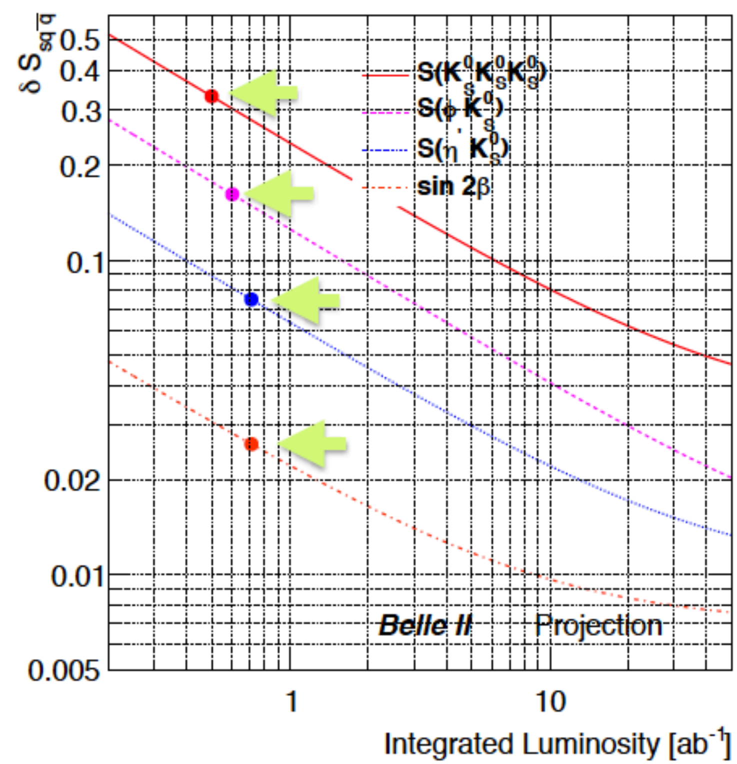
$B^0 \rightarrow \phi K_S^0$

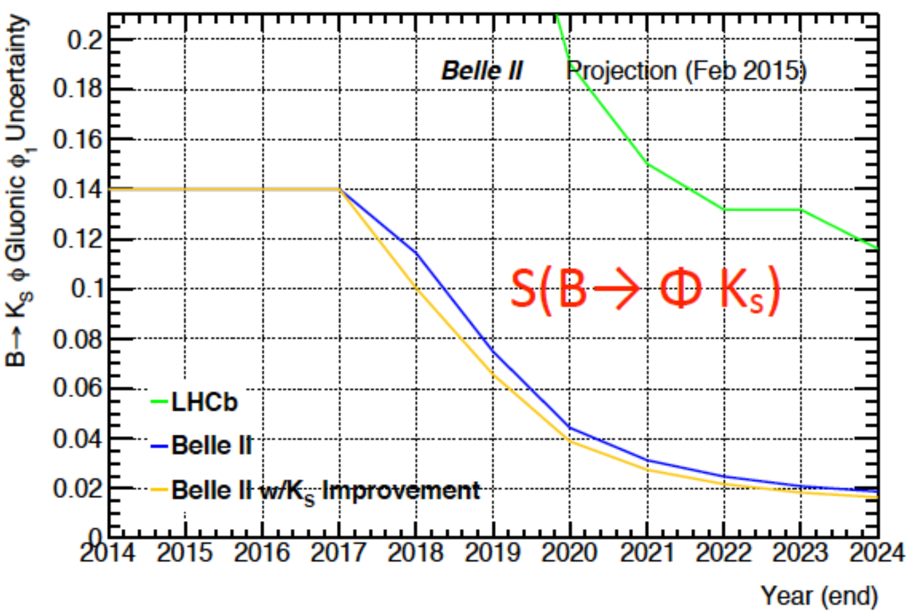
$B^0 \rightarrow \eta' K_S^0$

$B^0 \rightarrow K_S^0 K_S^0 K_S^0$



Belle II projections



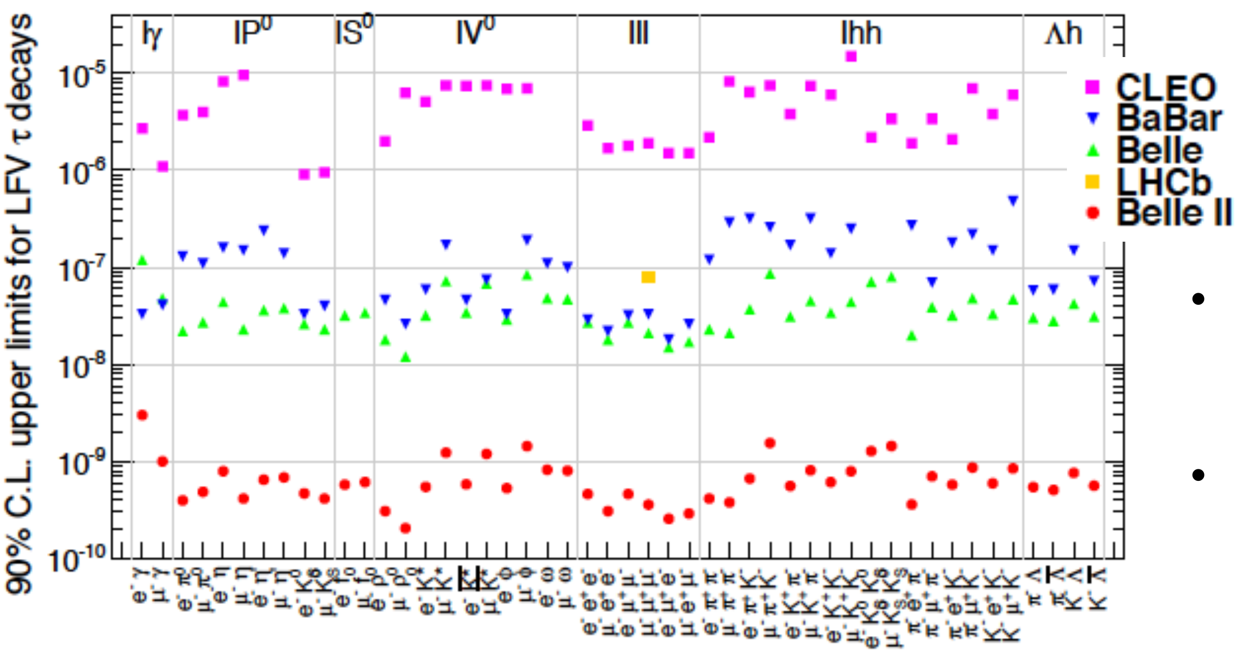


$\delta S(b \rightarrow s) \sim 0.01$ @ 50 ab^{-1}

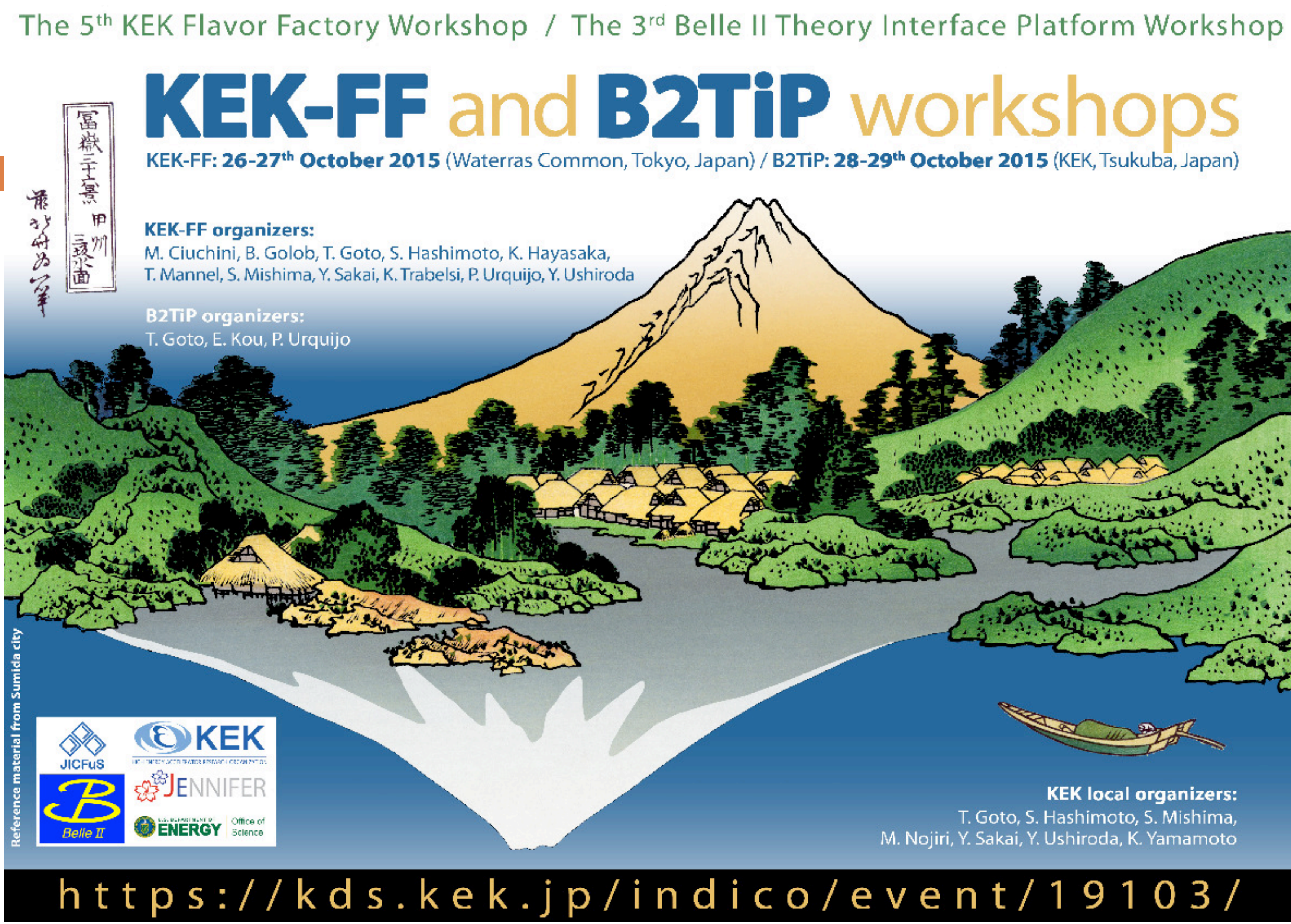
Lepton Flavour Violation in τ decays

- LFV is a **theoretically clean** null test of the SM: BR$\sim 10^{-25}$
- NP may induce LFV

	reference	$\tau\to\mu\gamma$	$\tau\to\mu\mu\mu$
SM + heavy Maj ν_R	PRD 66(2002)034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547(2002)252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68(2003)033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66(2002)115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566(2003)217	10^{-10}	10^{-7}



- τ decays **studied at B-factories** (hadron machines not competitive)
- **2 orders of magnitude improvement**

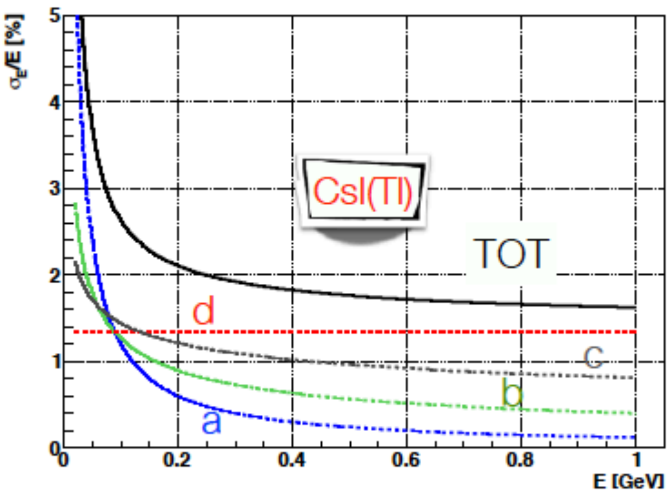


B2TIP: Will include some discussions of physics possibilities during BEAST Phase II

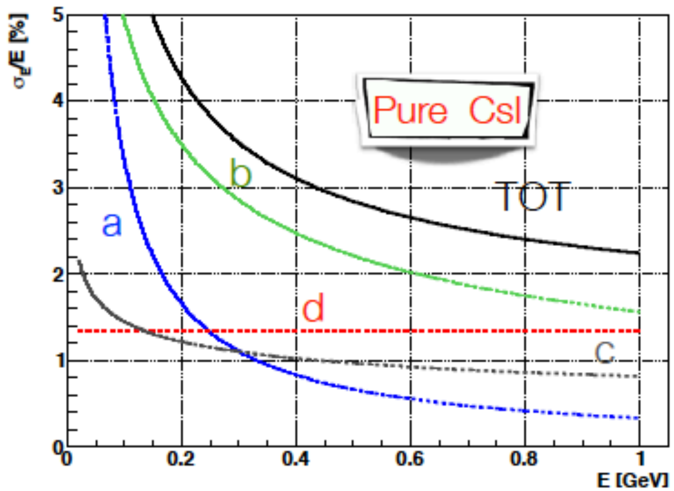
Cristalli di CsI puro: risoluzione in energia

Relative energy resolution

$$\sigma/E = a/E \oplus b/\sqrt{E} \oplus c/\sqrt[4]{E} \oplus d$$



a —> ENE
b —> stochastic
BelleII TDR: **c=0.81%** ~shower shape
d=1.34% ~calibration



The stochastic term **b** in CsI(Tl) is negligible w.r.t. the shower shape fluctuation **c**.
Viceversa in pure CsI.
In the following **c** and **d** (calibration term) *are assumed equal for CsI(Tl)) and pure CsI.*

It is not clear however if one can keep the APD readout stability at the same level of PIN diodes and therefore 1.34% is adequate for APD as well

uSOP peripherals

16 x GPIO

2 x RS232 (*)

JTAG (*)

2 x SPI (*)

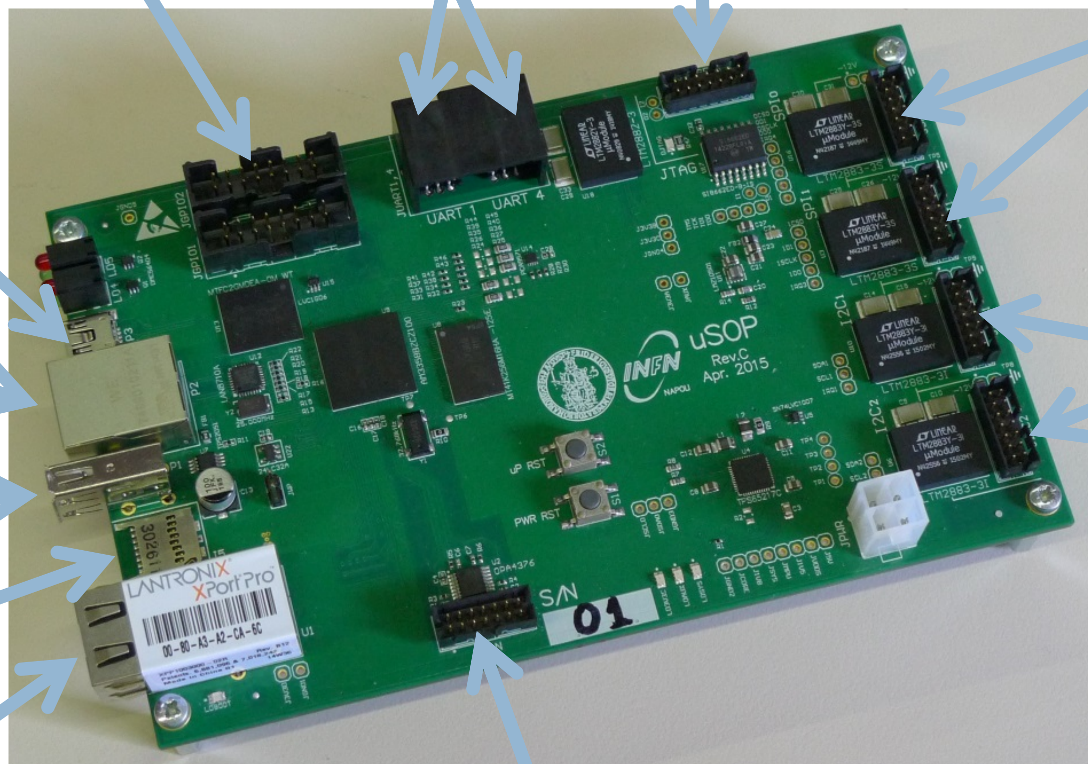
USB device

10/100 Ethernet

2 x I2C (*)

USB host

uSD



10/100 Ethernet (controls and managament only)

4 x AIN (**)

- = fully isolated

** = buffered 12-bit ADC

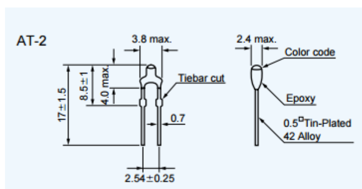
A.Aloisio

Sensors

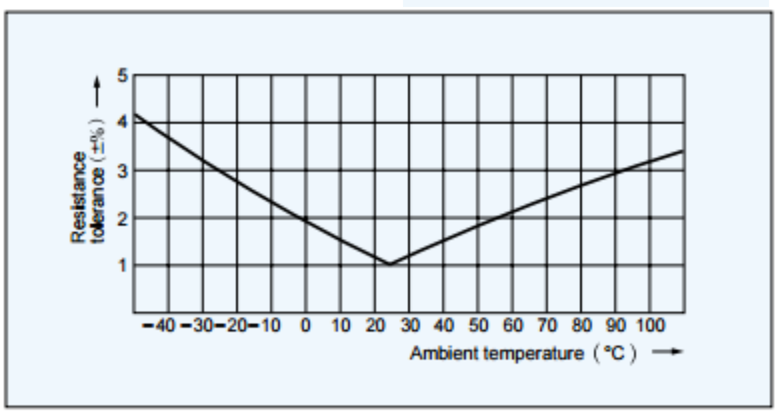
- Same sensors as Belle2 ECL (and same readout scheme)

- 0.3°C uncertainty on temperature
- 3% uncertainty on relative humidity

Thermistor
Semitec AT-2
10 kohm



Resistance tolerance



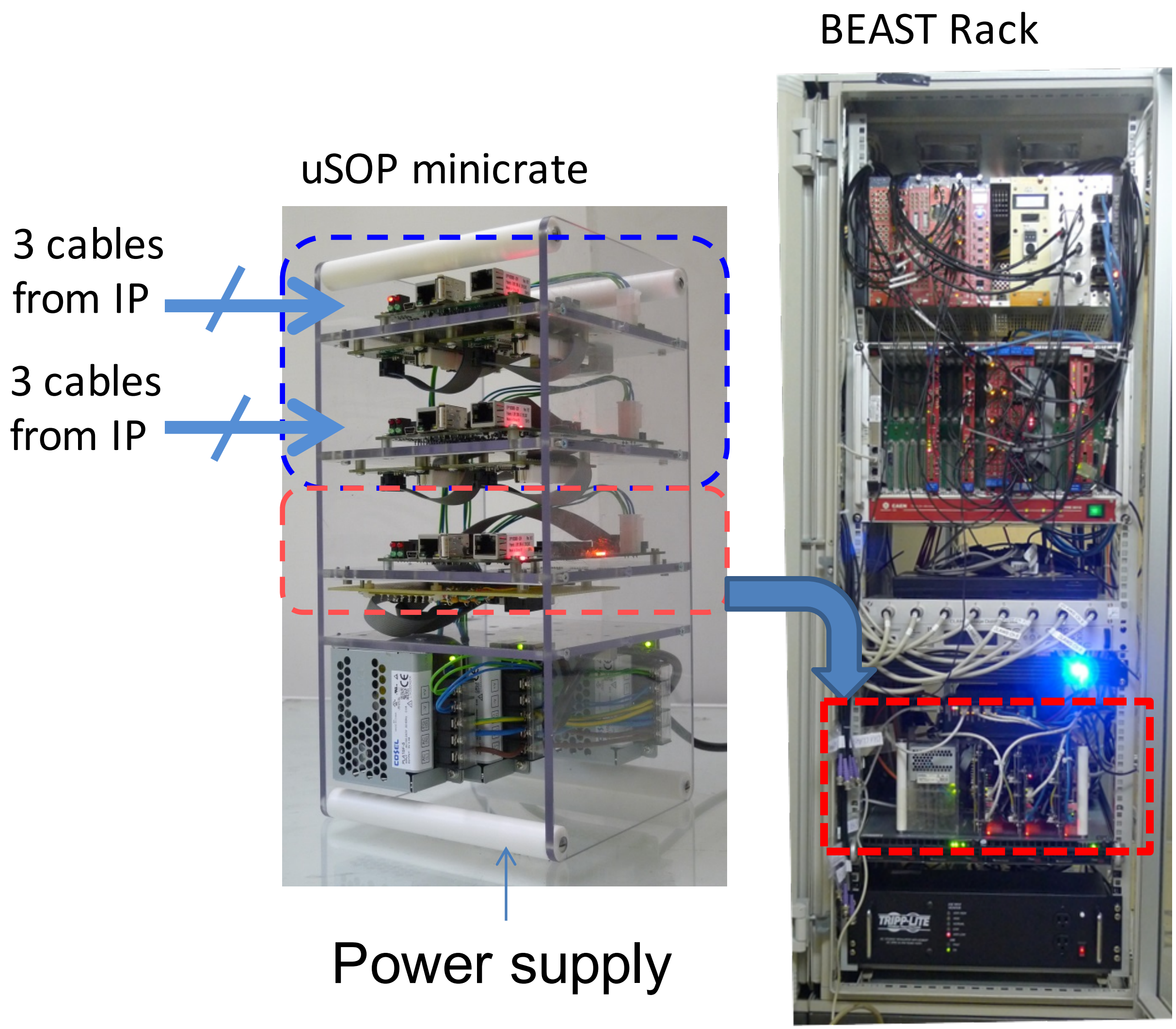
RH probe
Vaisala HMP60

Performance

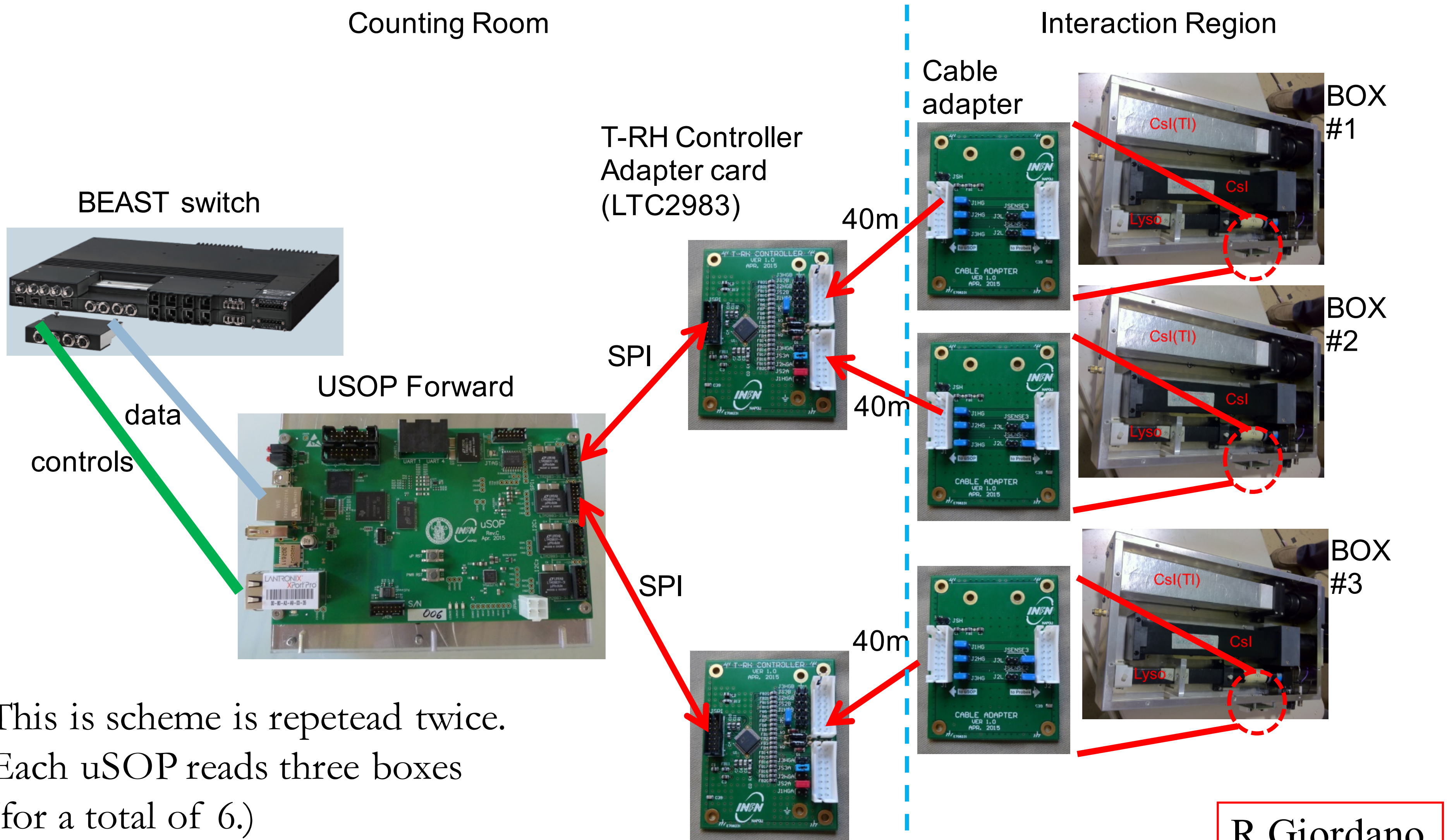
RELATIVE HUMIDITY	
Measurement range	0 ... 100 %RH
Typical accuracy	
temperature range	0 ... +40 °C
0 ... 90 %RH	±3 %RH
90 ... 100 %RH	±5 %RH
temperature range	-40 ... 0 °C, +40 ... +60 °C
0 ... 90 %RH	±5 %RH
90 ... 100 %RH	±7 %RH
Humidity sensor	Vaisala INTERCAP®

In the DAQ Room

- Minicrate with 3 uSOP systems
- 2 uSOPs read 6 boxes
- 1 uSOP for FPGA readout
- Each uSOP has a dedicated ethernet connection for remote power-on/off



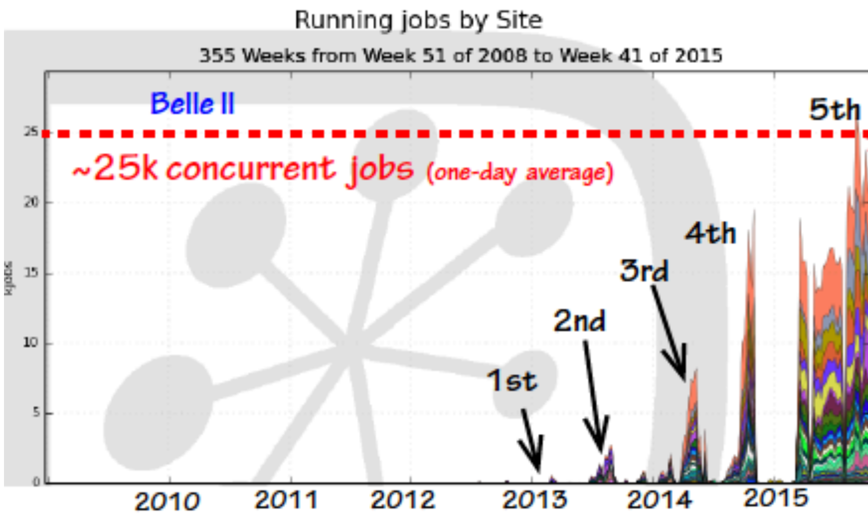
T/RH aggregation scheme

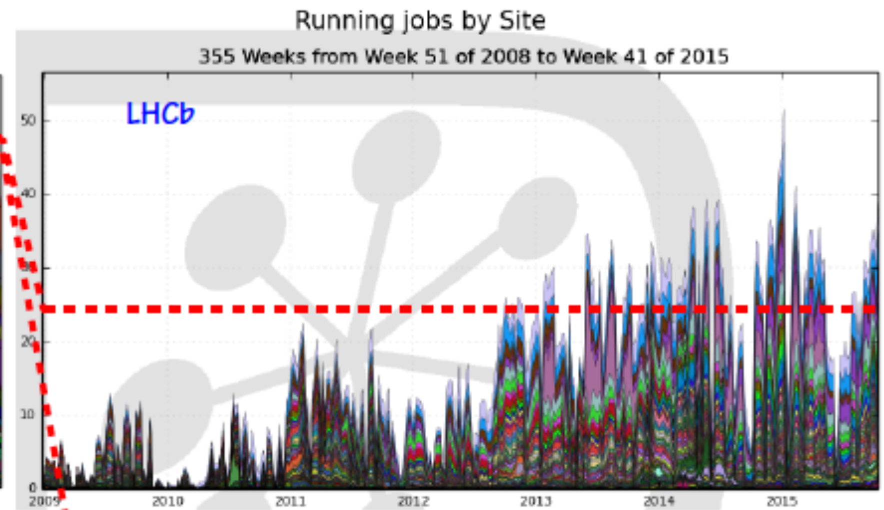


This is scheme is repetead twice.
Each uSOP reads three boxes
(for a total of 6.)

R.Giordano

Impiego risorse BelleII e performance di Napoli





17 countries/region

Australia, Austria, Canada, China, Czech Republic, Germany, India, Italy, Japan, Korea, Mexico, Poland, Russia, Slovenia, Taiwan, Turkey, USA

Need to check the performance under the condition with different type of jobs (MC prod / DST prod / User Analysis in parallel)

Need raw data format from all the detector (DST format)

Networking: risultati data challenge 2015 per Napoli

S. Pardi

- Asia: KEK2 - kek2-se01.cc.kek.jp
- US: PNNL - se.hep.pnnl.gov
- EU: KIT - gridka-dcache.fzk.de
  - NAPOLI - belle-dpm-01.na.infn.it
  - DESY - dcache-se-desy.desy.de
  - SIGNET - dcache.ijs.si
  - CNAF - storm-fe-archive.cr.cnaf.infn.it

- FTS3 configuration (server deployed at PNNL):
  - using 16/10 TCP streams
  - no explicit checksum checks
  - Auto-tuner disabled
  - concurrent file transfers at 5 - 100 (in steps of 5)
  - version : 3.2.32

Site Preparation and data used

- ~100 files with each file ~10 GB. This implies ~1 TB of data.
- Each SE will temporarily take 2 x 1 TB of disk space.
- Each SE has "*-DATA-SE endpoint" + "belle/DC/in and "*-TMP-SE endpoint" + "belle/DC/out"

	2018	2024 (old aprox)	2015 Data Challenge Results	Comment
PNNL → NAPOLI	<3Gbps	4 Gbps average	3 Gbps	Goal Achieved
KEK → NAPOLI	1 Gbps *	5 Gbps	3 Gbps	Goal Achieved

Full Event Interpretation (FEI)

- Input variables used to train the multivariate classifiers:
  - PID, tracks momenta, impact parameters (charged FS particles);
  - cluster info, energy and direction (photons);
  - invariant mass, angle between photons, energy and direction (π^0);
  - released energy, invariant mass, daughter momenta and vertex quality ($D^{(*)}_{(s)}$, J/ψ);
  - the same as previous step plus vertex position, ΔE (B);
  - additionally, for each particle the classifier output of the daughters are also used as discriminating variables.
- Generic training performed on $87*10^6$ B^+B^-/B^0B^0 without beam bkg ~ 80/fb
- The result – analysis independent – is centralized so that all the analyzers can use the same training.