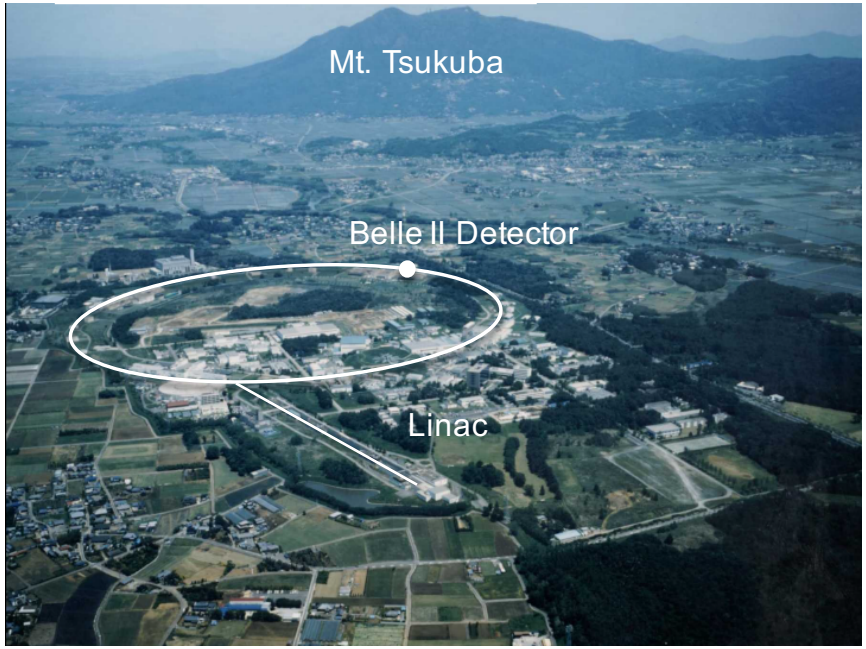
L'esperimento Belle II a SuperKEKB

Mario Merola (INFN)

Riunione di fine anno 2016

19 dicembre 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

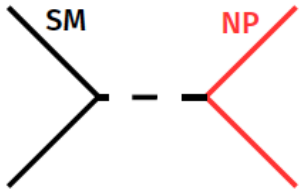
- **Quark and lepton hierarchy (mass and flavour), 19 free parameters in SM:** GUTs (SUSY) ?

- **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)

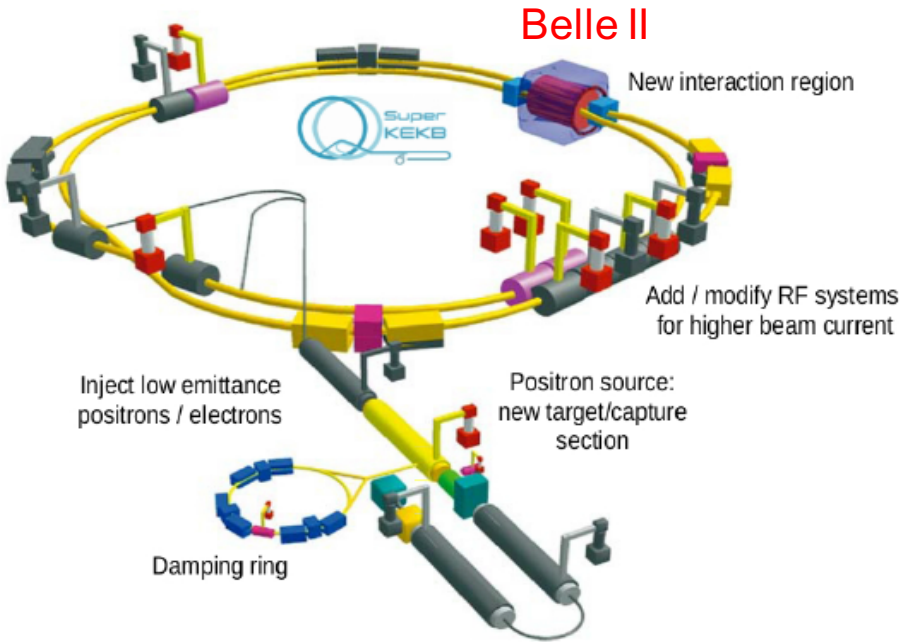


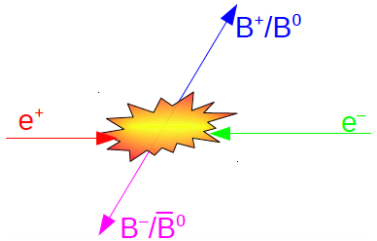
- **Intensity frontier**: new particles in virtual loops, deviation from SM expectations (**B factories**, LHCb)

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

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)



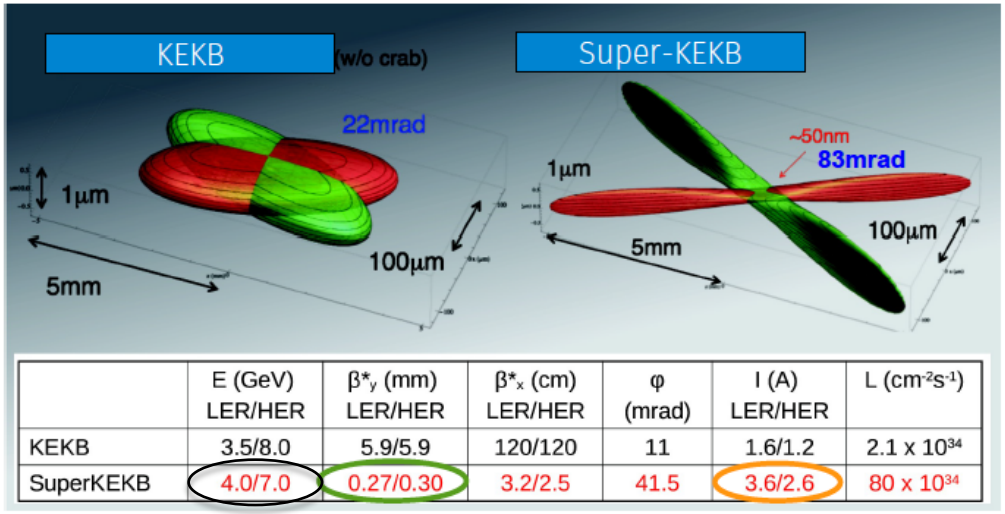


10^{10} B pairs/year

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



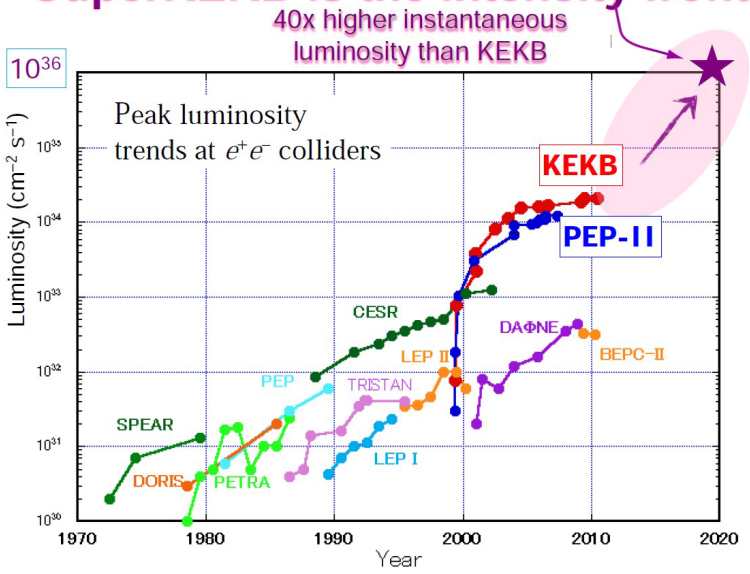
	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

factor 20 factor 2-3

reduced boost

~ 40-50 x

SuperKEKB is the intensity frontier



Lorentz factor

beam current

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

vertical beta function at IP

Beam size ratio at IP

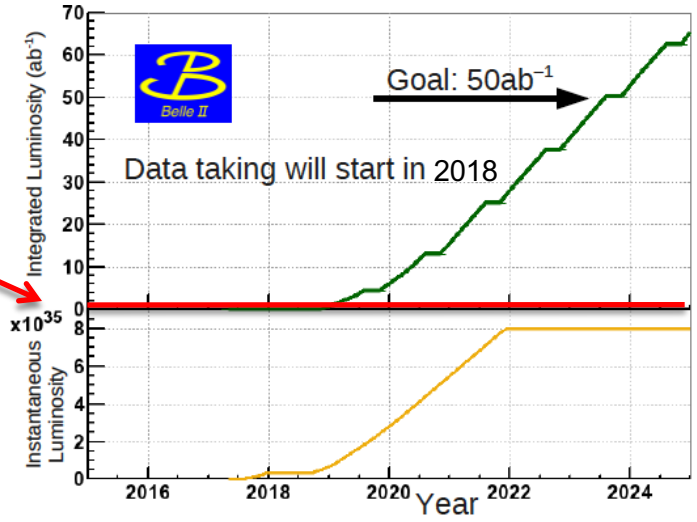
Geometrical reduction factors (crossing angle and hourglass effect)

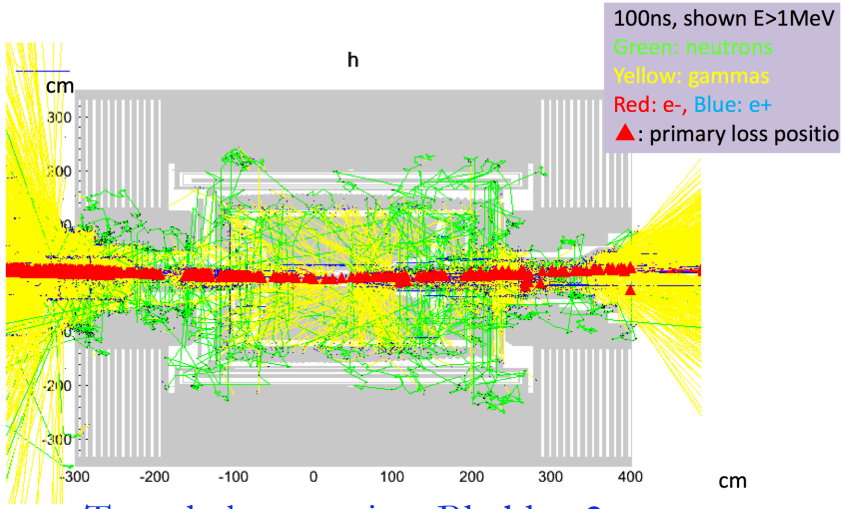
SuperKEKB

Peak instantaneous luminosity: ~8×10^{35} cm^{-2} s^{-1}

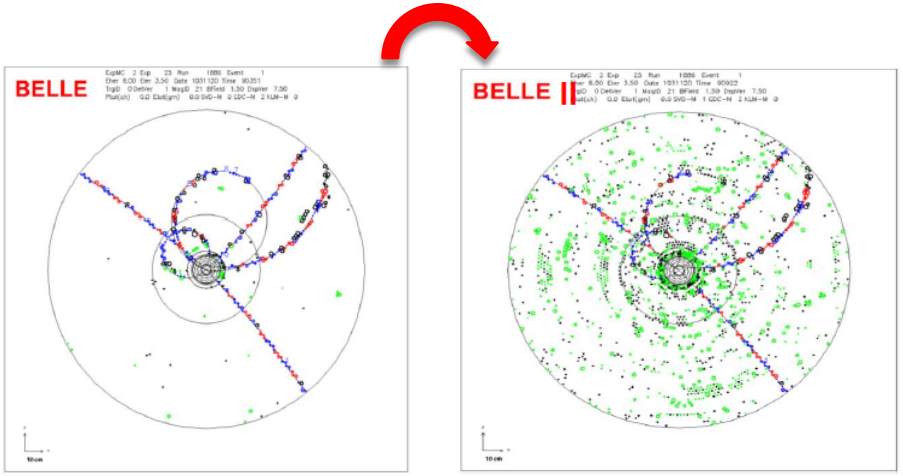
Belle II overall integrated luminosity: ~50 ab^{-1} corresponding to 55 × 10^9 BB pairs (BaBar + Belle ~ 1.5 ab^{-1})

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





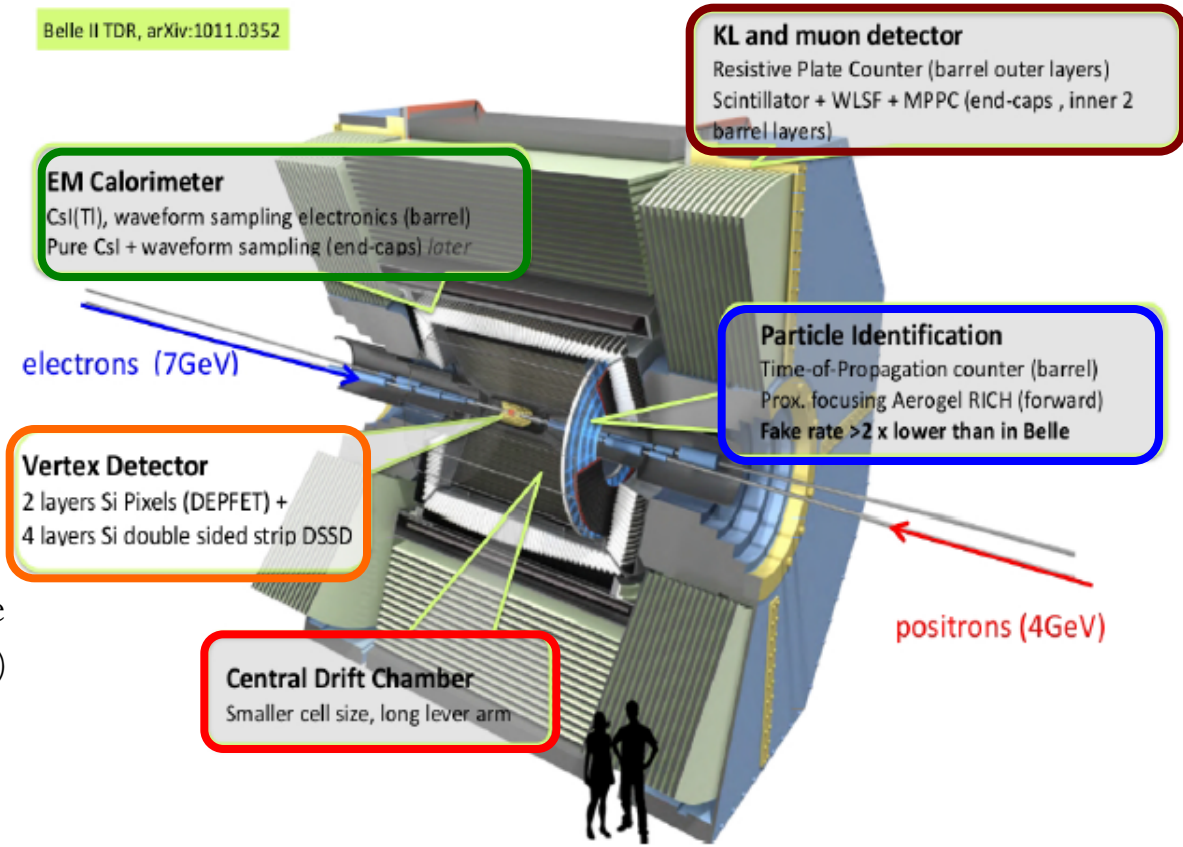
Touschek scattering, Bhabha, 2γ



From Belle to Belle II

Belle II upgrade:

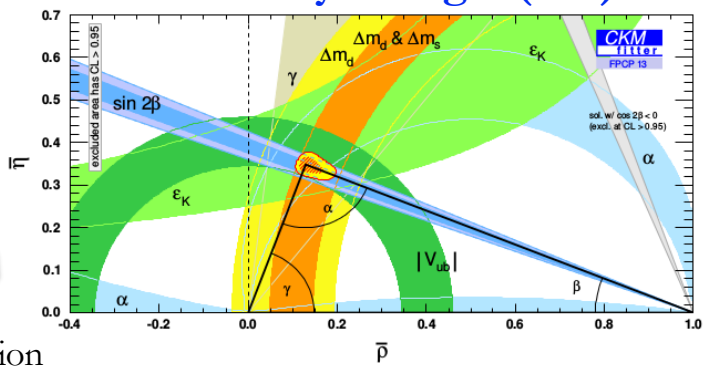
- **Extended VD region** (added pixel detector)
- **Extended Drift Chamber region**
- **New ECL electronics** (waveform sampling and fitting)
- **Better hermeticity** (additional PID detector in the forward endcap)
- **High efficiency KLM detector** (some RPCs layers substituted with scintillators)



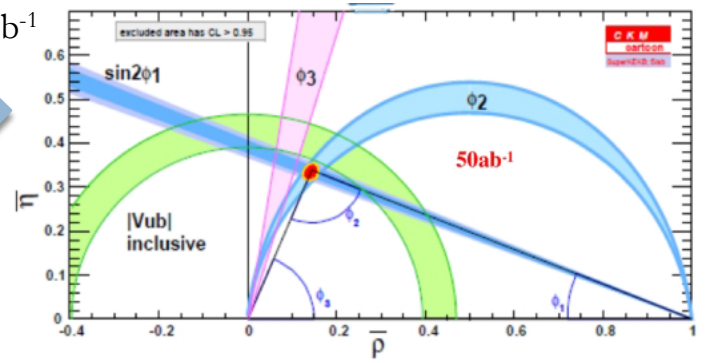
Physics program

- CPV in B decays, UT angles ($B \to J/\psi K^0$, $K^0\pi^0\gamma$, $K\pi$)
- (Semi)leptonic B decays, UT sides ($B \to D^{(*)}l\nu$, $\pi l\nu$, $\tau\nu$, $\mu\nu$)
- Rare B decays ($B \to K^{(*)}\nu\nu$, $X_s\gamma$, X_sll, $\gamma\gamma$)
- Charm physics ($D \to l\nu$, mixing, CPV)
- LFV tau decays ($\tau \to 3l$, $l\gamma$)
- Dark Sector, Spectroscopy

Unitarity triangle (UT)



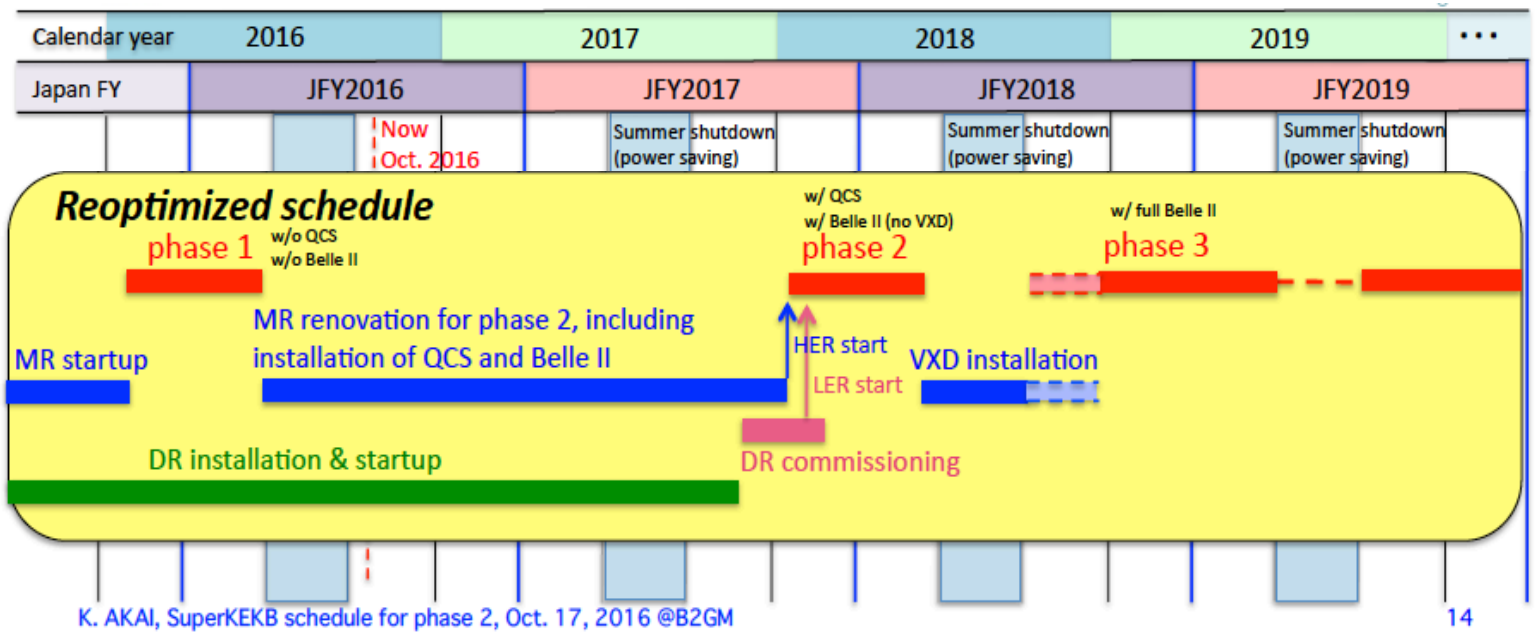
projection @ 50 ab^{-1}



	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.
$\|V_{cb}\|$ inclusive	1.7%		2.4%		1.2%		
$\|V_{cb}\|$ exclusive	2.2%				1.4%		
$\|V_{ub}\|$ inclusive	7%		4.5%	7.2%	3.0%		
$\|V_{ub}\|$ exclusive	8%				2.4%		
$\|V_{ub}\|$ leptonic	14%				3.0%		

Experiment	Theory
No result	
Moderate precision	Moderate precision
Precise	Clean / LQCD
Very Precise	Clean

Belle II schedule: installation and commissioning



Phase 1 (2016): beams, no collisions, cosmics

Phase 2 (2018): collisions, complete Belle II detector except for Vertex Detector

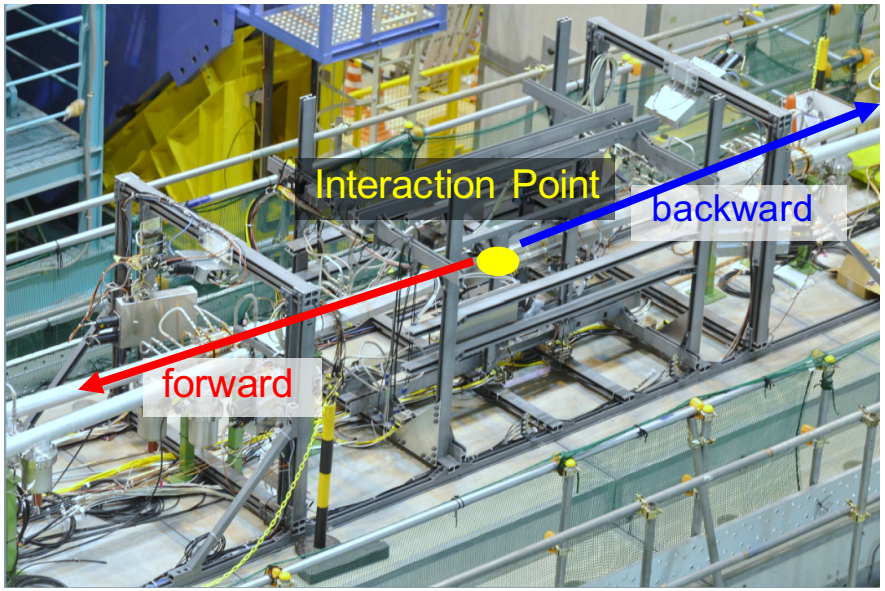
Phase 3 - Full physics (end 2018-2024): full Belle II detector

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 (Touschek scattering, beam-gas scattering, synchrotron radiation, radiative bhabha, etc.)
- Instrument SuperKEKB before Belle II is rolled in
- Measure beam backgrounds where Belle II 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

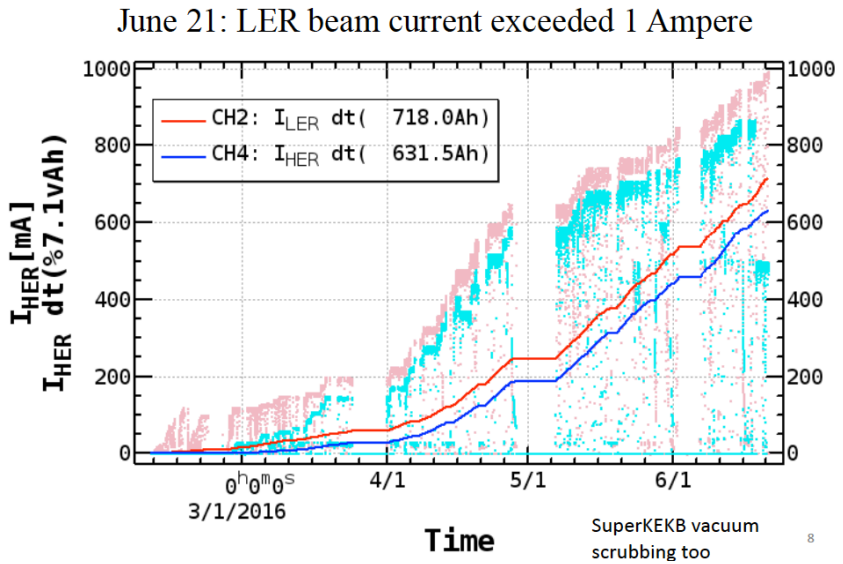
BEAST frame

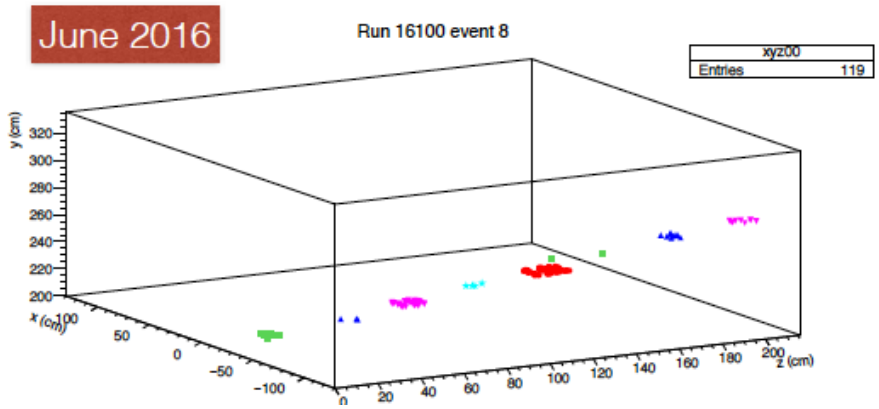


BEAST fiberglass frame supporting background detectors (PIN diodes, TPCs, Diamonds, He3 tubes, BGOs, Calorimeter crystals)

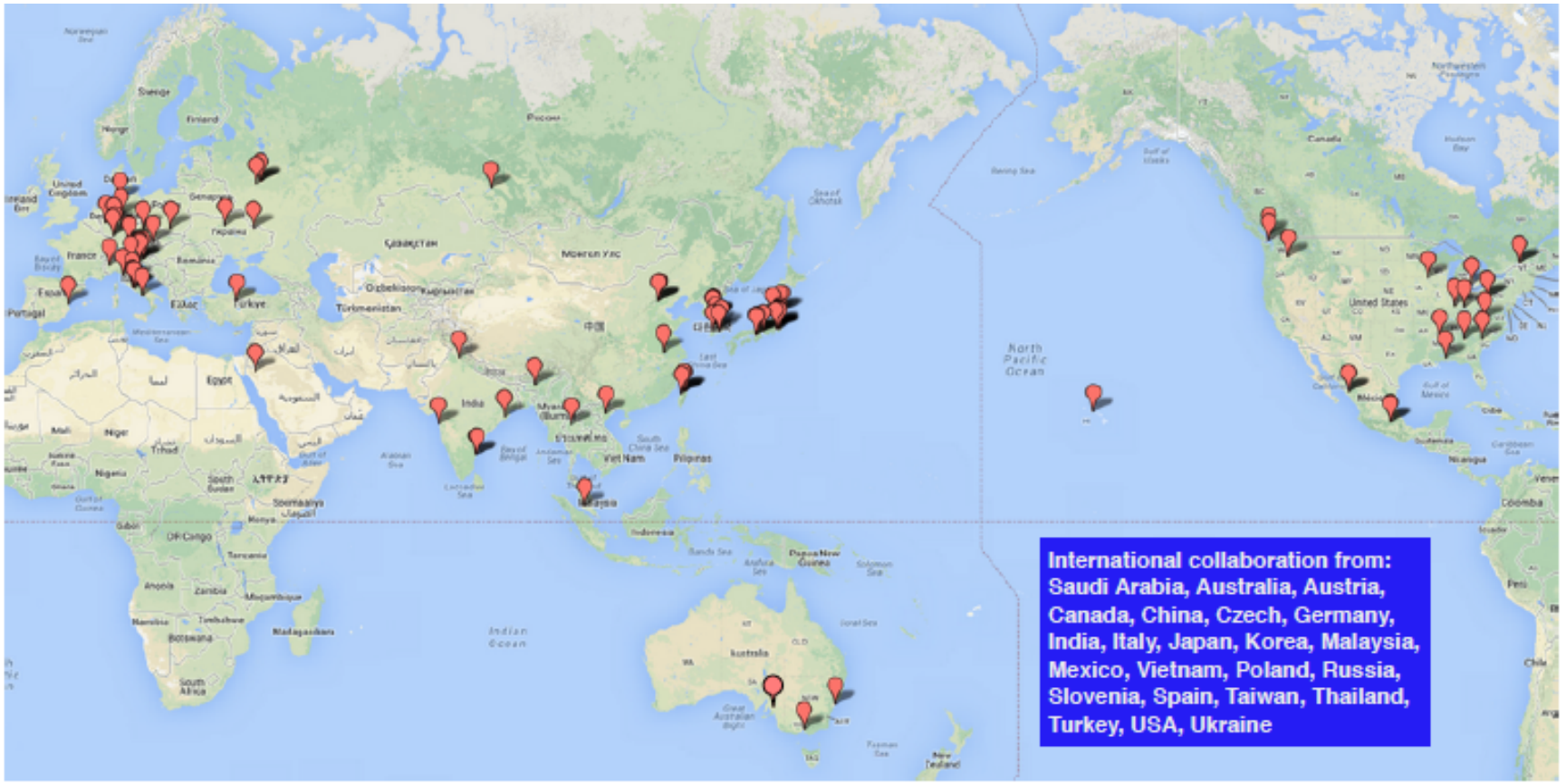
Phase 1 - important milestones

- First beams circulating in SuperKEKB at end of Feb 2016
- June 2016 1 A current achieved
- First cosmics seen in the KLM RPCs





Belle II collaboration



Belle II: ~700 collaborators, 100 institutions, 23 regions/countries

tra cui 9 sezioni infn, 36.7 FTE (N_{tot}=71) nel 2017 rispetto a ~34.9 FTE (N_{tot}=67) nel 2016

Belle II gruppo di Napoli

Nome	Qualifica	FTE (%)
Aloisio	Prof. Ord.	30
De Nardo (Responsabile)	Prof. Ass.	90 (include 10 ReCaS)
Di Capua	RTD A	40
Giordano	RTD A	70
Merola	Assegnista	90
Ordine	Pr. Tecnologo	30
Pardi	Tecnologo	65
Russo	Prof. Ord.	60 (include 10 ReCaS)
Sciacca	Prof. Emerito	0

Principali attività:

Calorimetro elettromagnetico (ECL)

Software e fisica

Computing

FTE totali: 4.7

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

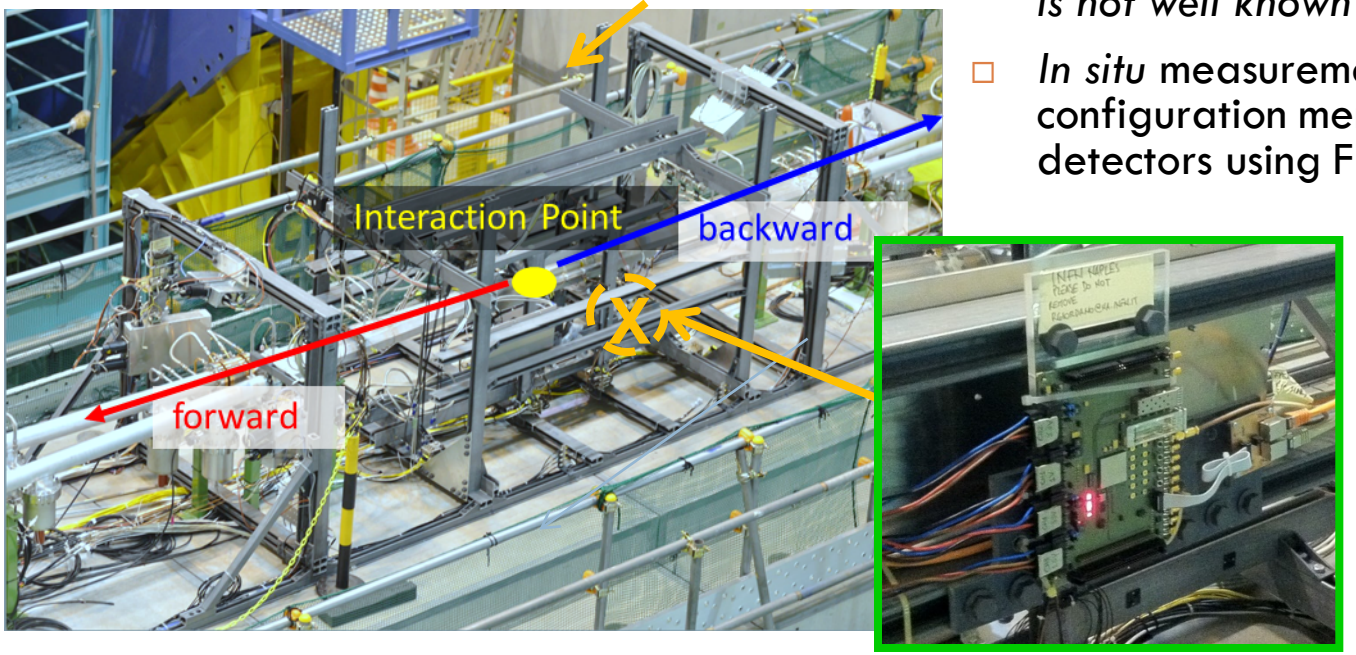
-M. Merola: membro Task Force ricostruzione neutri, responsabile gruppo Belle (con S. Pardi e G. Russo)

-S. Pardi: networking per l'Europa

Attività gruppo di Napoli

- FPGA at BEAST
- uSOP for ECL crystals
- Computing e risorse per Belle II
- Software e analisi

FPGA Setup at BEAST

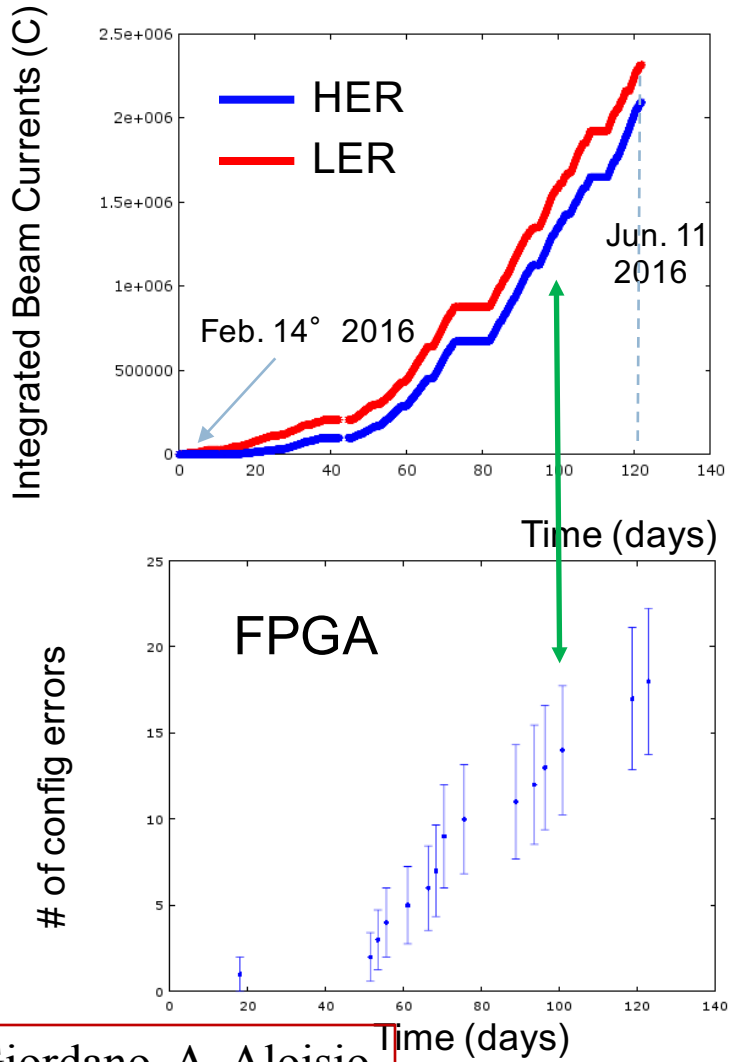


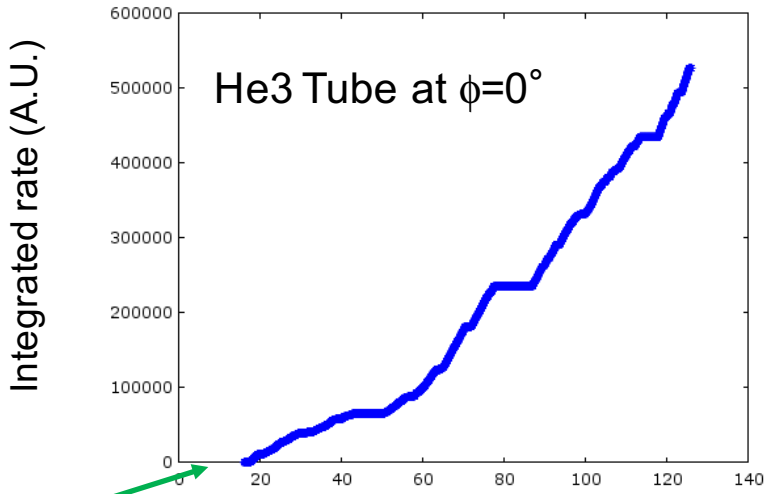
- *The radiation environment at SuperKEKB is not well known*
- *In situ* measurement of upsets* in FPGA configuration memory is interesting for detectors using FPGAs for readout

- FPGA installed on the BEAST support frame (~1 m from the beam pipe)

*change of state due to ionizing particles hitting the device

Configuration Upsets Results



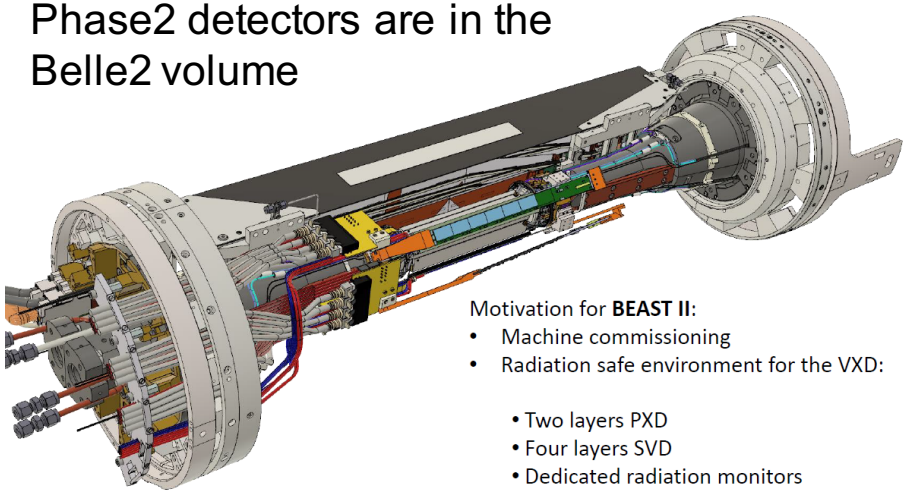


- FPGA upset count is correlated with integrated beam current
- Average rate 0.15 SEUs/day (or 1 SEU every 6.7 days), 18 events
- Negligible variation in currents absorbed by FPGA (< 1mA, i.e. no TID effects)
- Results from PIN diodes at BEAST (M. Nayak, 25th Belle2 General Meeting) => total dose @FPGA < 300 krad, FPGA is still fully functional, no permanent damage
- Beam currents will increase in SuperKEKB phase2 and beams will be focused, FPGA monitoring will continue

R. Giordano, A. Aloisio

BEAST Phase 2

Belle2 detector rolled-in
QCS in place, beams are focused
Phase2 detectors are in the Belle2 volume



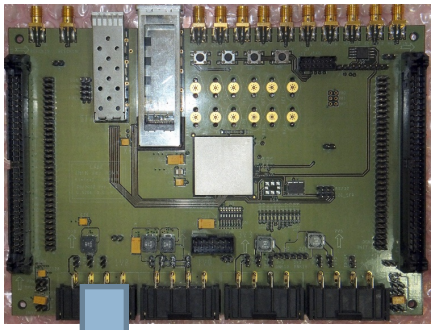
Motivation for **BEAST II**:

- Machine commissioning
- Radiation safe environment for the VXD:
  - Two layers PXD
  - Four layers SVD
  - Dedicated radiation monitors
    FANGS, CLAWS, PLUME

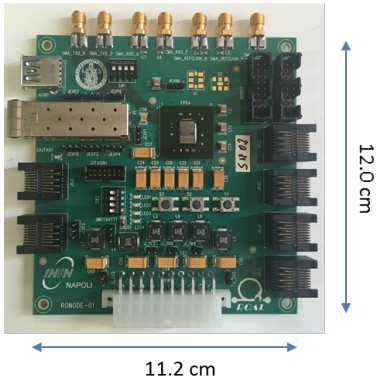
cmarinas@uni-bonn.de

New board for phase 2

Old version



New version



- New FPGA test board ready
- Smaller than previous one, nearly half size
- Board produced and tested
- Successfully employed for testbeam at LNS (Catania)
- It will be installed in BEASTII phase2 together with similar Virtex-5 based board (requested by Belle2)

Sistema di controllo umidità-temperatura ECL

Temperature and humidity effect on the crystals light yield

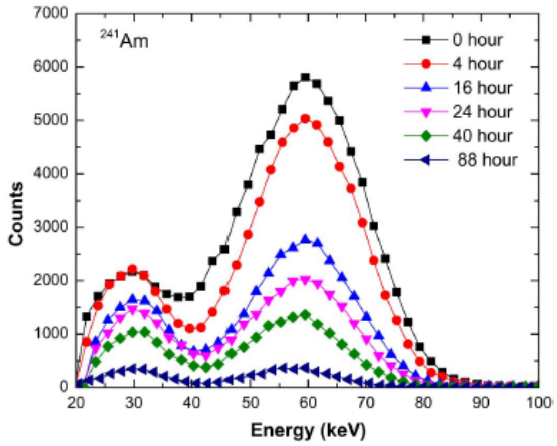


Fig. 2. The changes of pulse height spectrum as a function of time for CsI(Na) sample exposed to 75% relative humidity. An ^{241}Am is used as an ionization source.

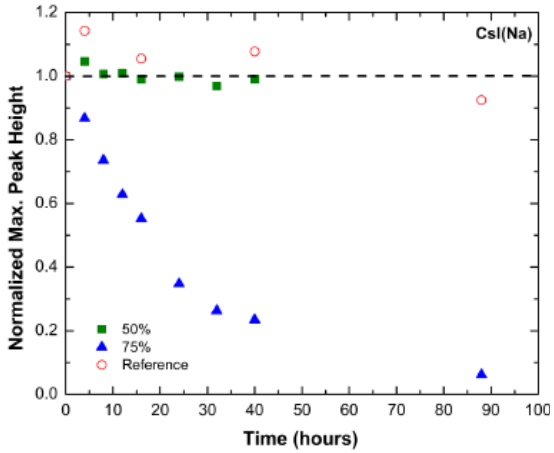


Fig. 3. The changes of the pulse height as a function of humidity and time fo CsI(Na) crystals at room temperature.

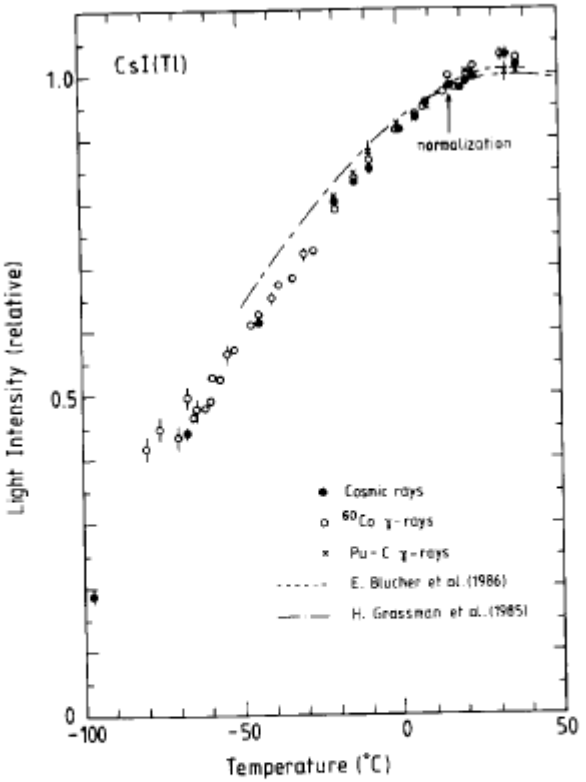
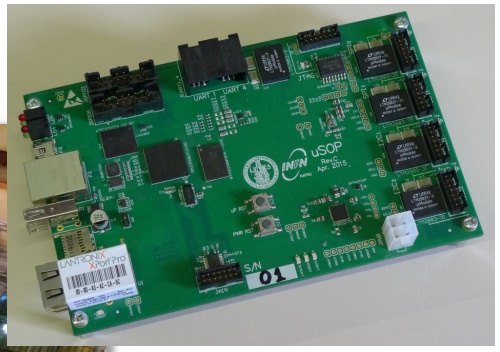


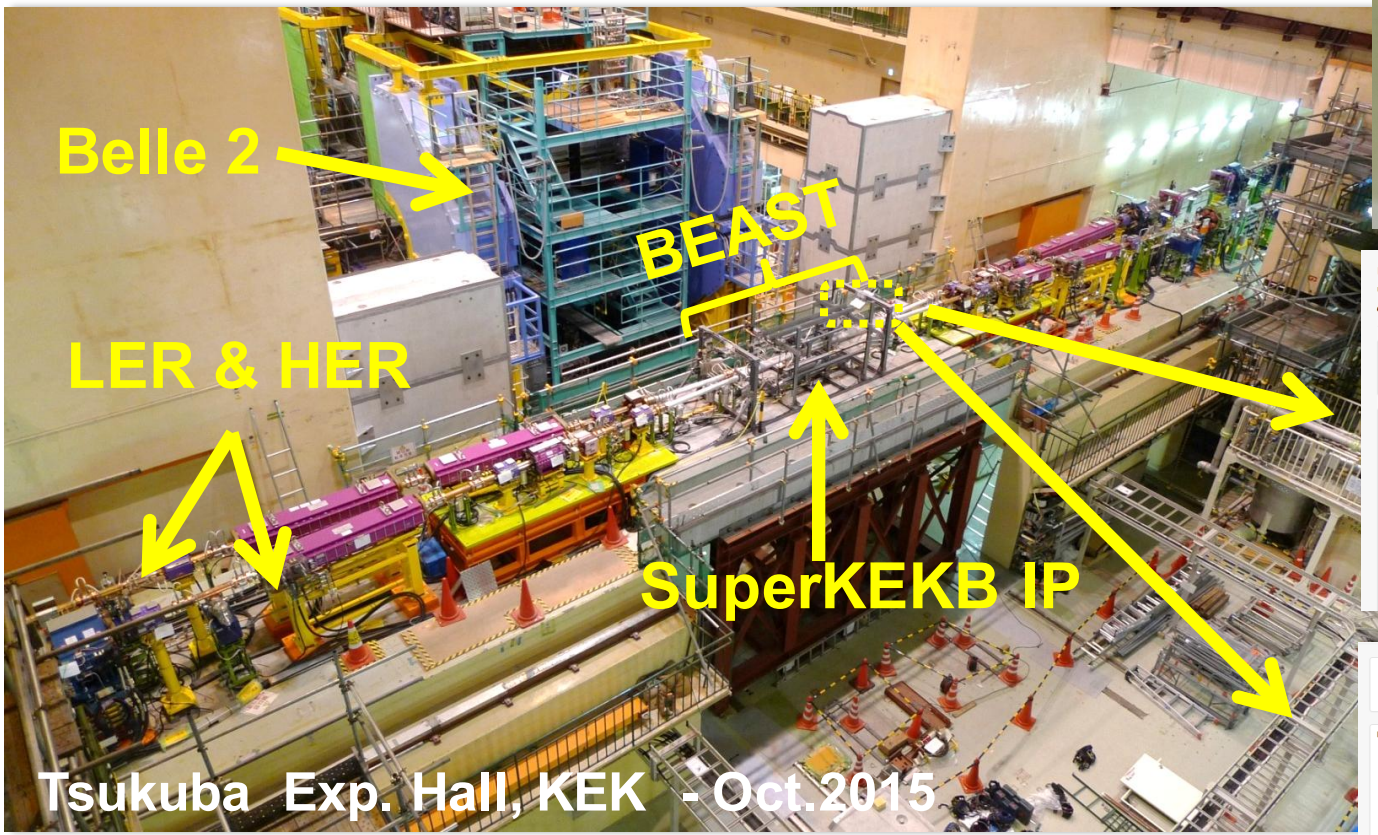
Fig. 4. Relative light intensities from CsI(Tl) measured for cosmic muons, 5 MeV γ-rays from Pu–C and 1.25 MeV γ-rays from ^{60}Co. Data points are normalized to 0.98 at 16.5 °C. A few error bars are shown to indicate the error in finding the peak position in the pulse height spectrum. The results from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

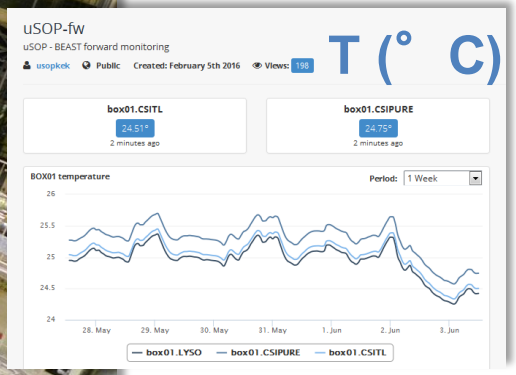
uSOP (micro Service Oriented Platform) @ BEAST

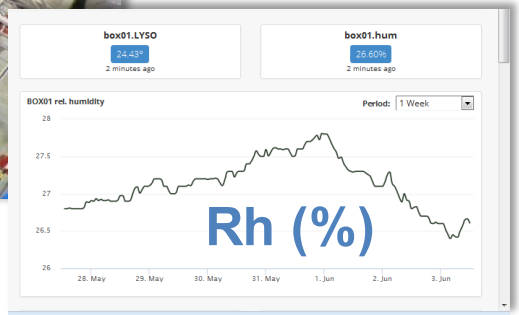
- uSOP has been deployed to monitor T and Rh of the 18 BEAST crystals (LYSO, CsI, CsI(Tl).

uSOP





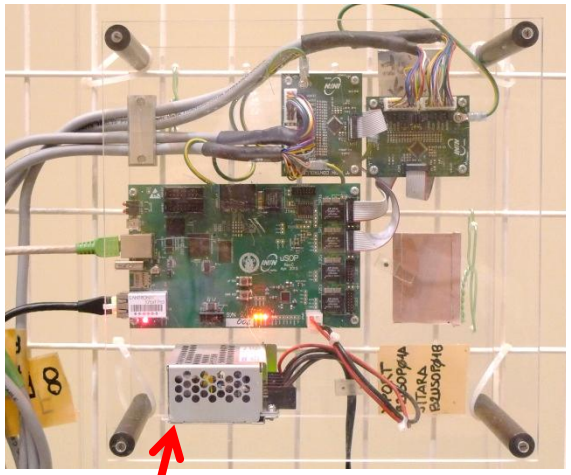




F. Di Capua, A. Aloisio

The ECL EndCap monitoring system 1/2

uSOP



EndCap Sectors 7F and 8F

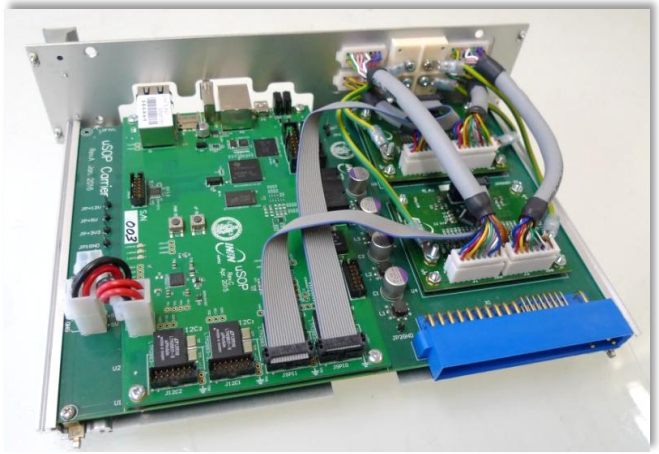
Cable Adapters

EndCap Test Station, Fuji hall, KEK

- Minimal, stand-alone monitoring system at the EndCap ECL test station
- 4 sectors over 32 monitored to control the conditioning system (T, Rh)
- Up-time > 1 year
- Data available via both EPICS and cloud

The ECL EndCap monitoring system 2/2

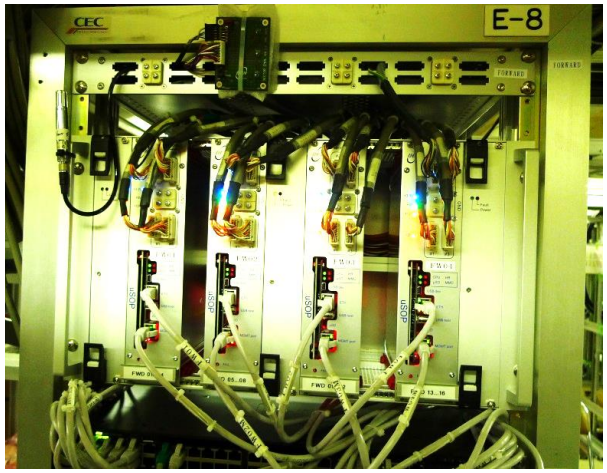
uSOP crate

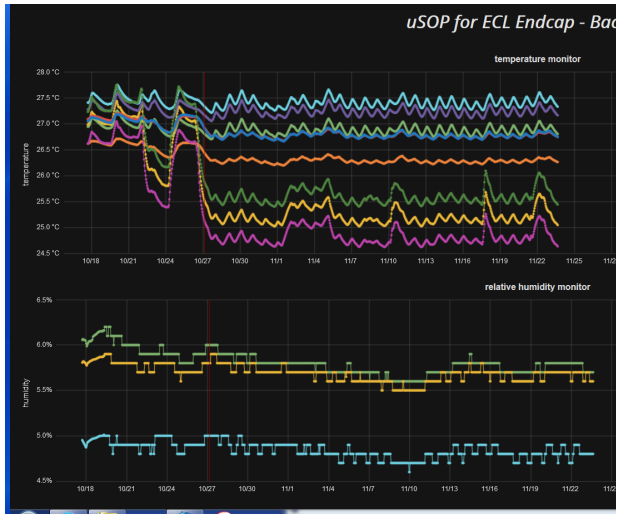


uSOP 6U unit (internal view)

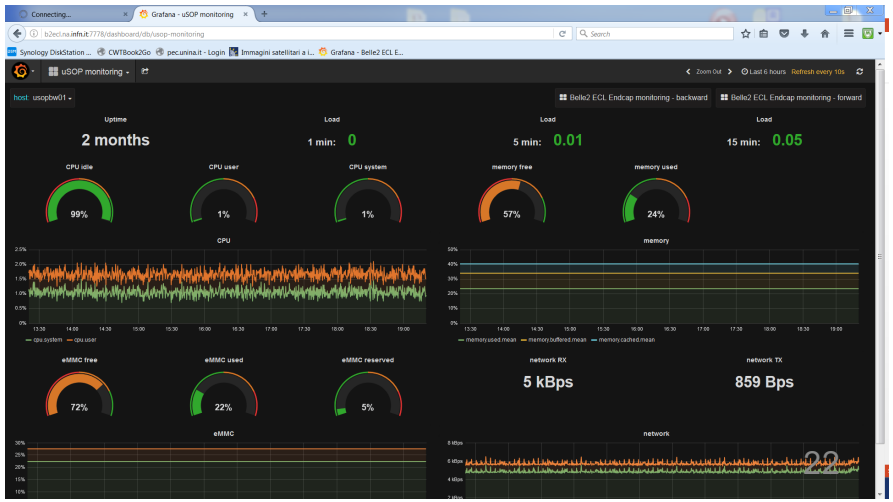
- The final monitoring system will be installed at KEK during 2017
- Forward and Backward ECL:
  - 2112 CsI(Tl) crystals, 32 sectors
  - T and Rh monitor, 128 analog channels (96 thermistors + 32 Rh probes)
- Features:
  - 3-wire read-out to cancel the 40m cable stray resistance
  - Stray thermocouple effects cancellation
  - 8 uSOP boards, 16 ADCs (24 bit)
  - 6U, 12HP form factor, shielded
  - Selective ground scheme to avoid loops
  - Read-out and controls via network

Waiting for the ECL endcap





- From Oct.2016, continuosly reading 32 sectors of ECL barrel
- Endcap wheels will be installed in 2017
- Monitoring system based on EPICS and Grafana
- We wish to thank Gennaro Tortone and Servizio Calcolo for the tireless contribution



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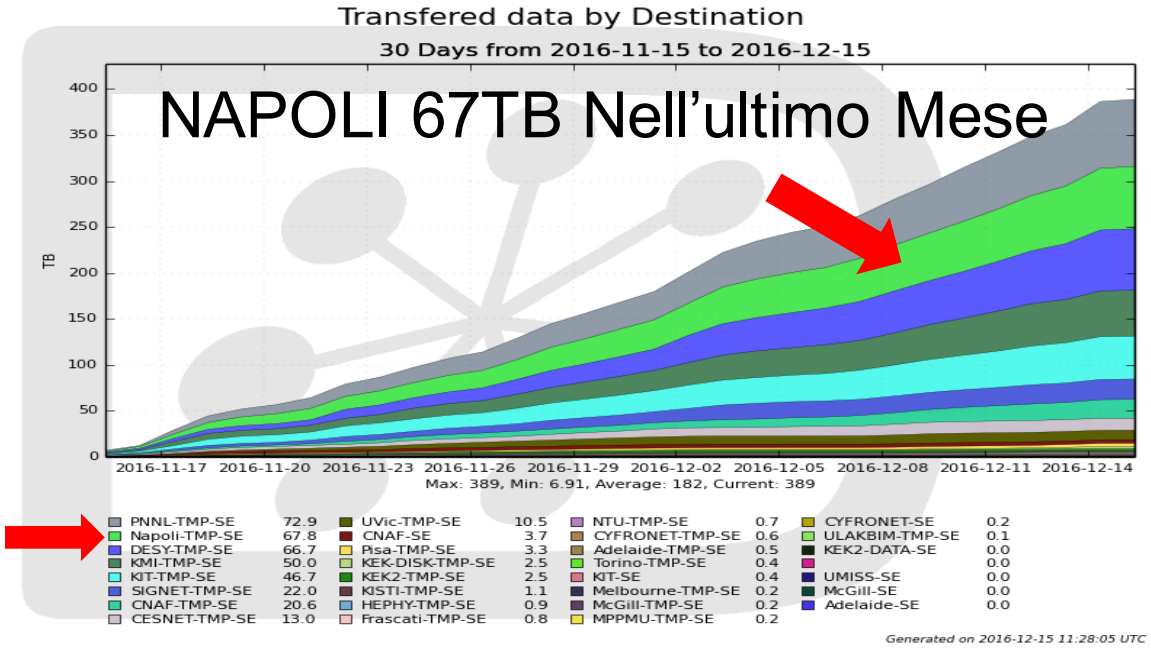
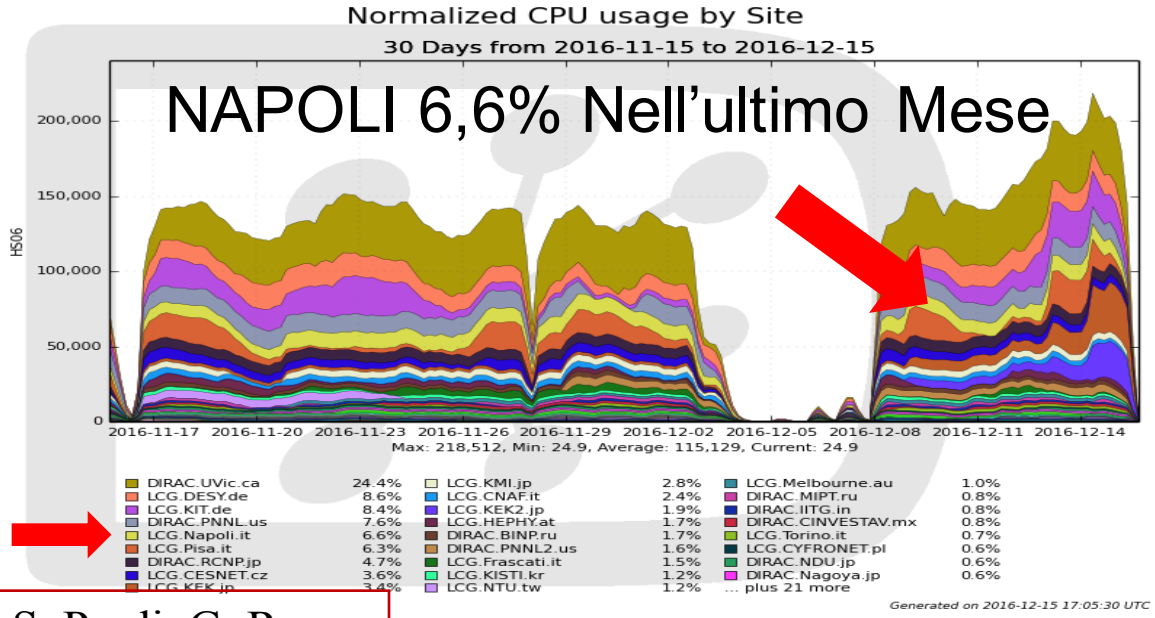
Computing e risorse per Belle II

Computing per Belle II: L'infrastruttura ReCaS





E' in corso la 7° Campagna Montecarlo di Belle II

E' il **2° Sito della collaborazione** per utilizzo di storage.

E' il **Primo Sito italiano per CPU fornite** e il 5° della collaborazione (1700 job costantemente running, 6.6% del totale)

Napoli ha fornito il **36% degli Shift** dovuti dall'italia

ReCaS Ospita un DIRAC Server slave per tutta la collaborazione con funzione di Configuration Proxy.

S. Pardi, G. Russo

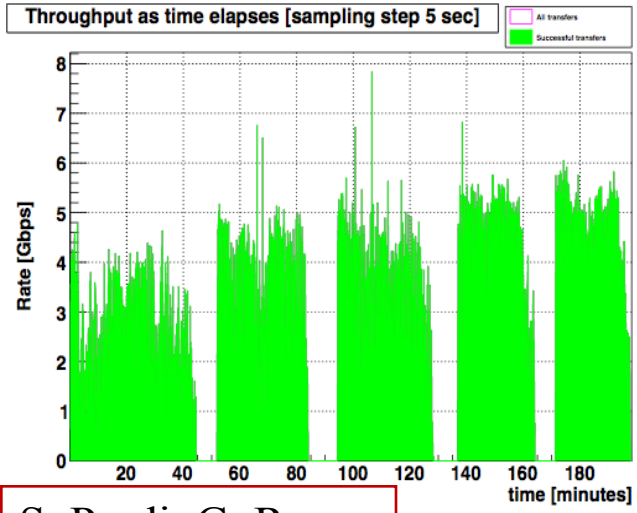
Network Update: NAPOLI ➔ KEK

- Update della rete di interconnessione di KEK vs Europa: Maggio 2016
- Upgrade del link di rete di Recas a 20Gbit/s Settembre 2016
- Update del sito Tier0 di KEK Tsukuba – KEKCC Settembre 2016
- Tuning dello storage di Napoli dedicato a Belle II Settembre 2016

Banda Storage/Storage portata da 5.5Gbit/s –> 13Gbit/s

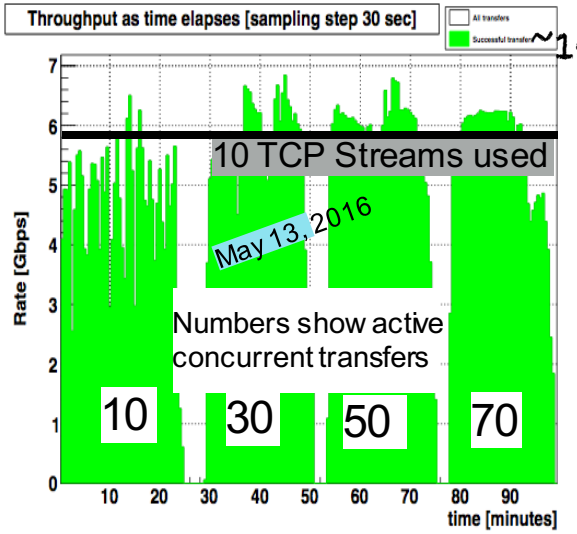
2015 SINET4

NAPOLI ➔ KEK achieved **5.5 Gbps**



Maggio 2016

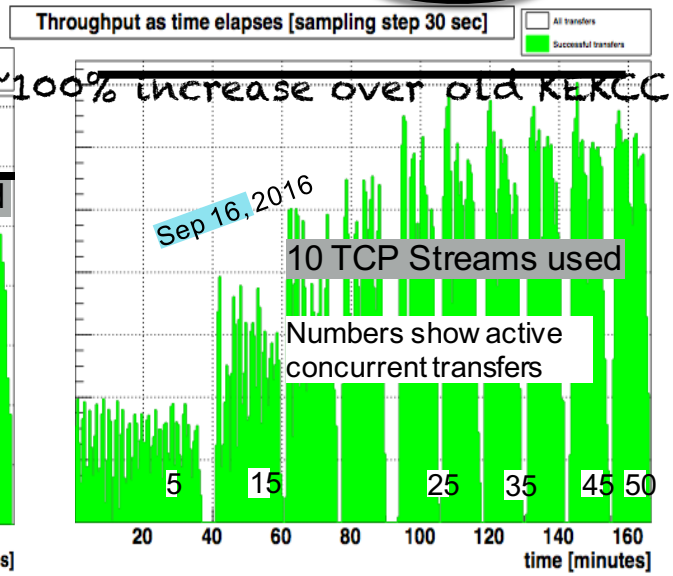
NAPOLI ➔ KEK achieved **6.6 Gbps**



Settembre 2016

NAPOLI ➔ KEK achieved **13 Gbps**

NEW



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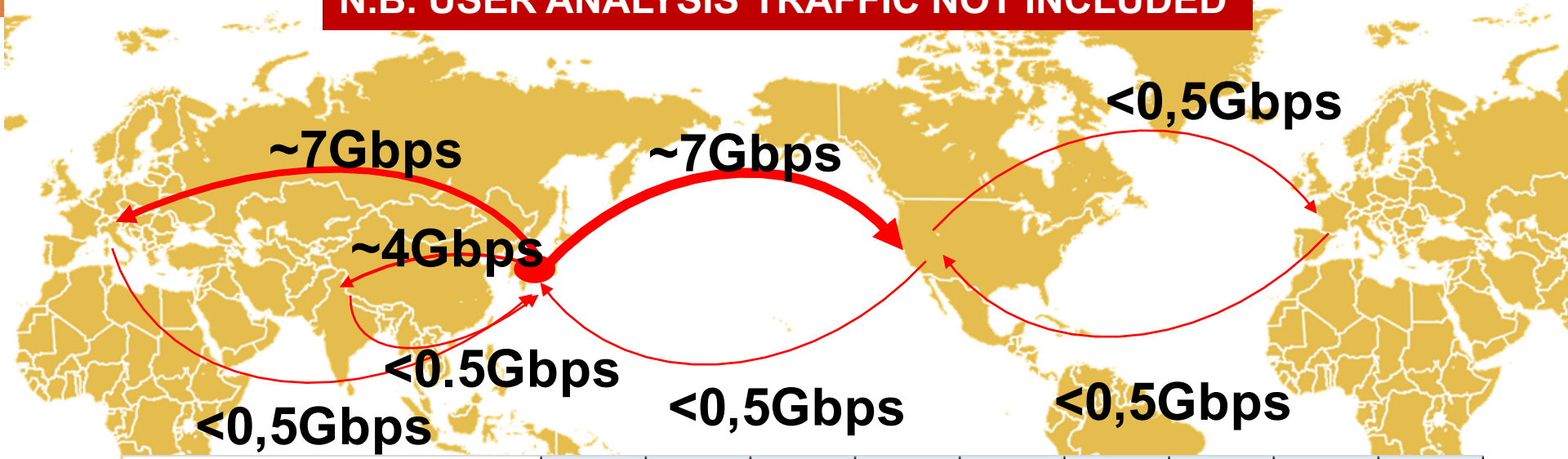
Stima delle risorse di rete necessarie per tutta la collaborazione

N.B. USER ANALYSIS TRAFFIC NOT INCLUDED



	2016	2017	2018	2019	2020	2021	2022	2023	2024
KEK to ASIA	0,1	0,2	0,2	0,1	0,1	2,8	3,4	3,5	3,5
KEK to EU	0,2	0,4	0,4	0,2	0,2	5,7	6,9	6,9	7,0
KEK to USA+CANADA+MEX	0,1	0,4	1,5	3,8	8,4	5,5	6,7	6,7	6,8
EU to KEK	0,2	0,4	0,4	0,2	0,1	0,2	0,2	0,3	0,4
USA+CANADA+MEX to KEK	0,1	0,2	0,2	0,1	0,1	0,1	0,1	0,2	0,2
ASIA to KEK	0,1	0,2	0,2	0,1	0,1	0,1	0,1	0,2	0,2
USA+CANADA+MEX to EU	0,2	0,3	0,4	0,2	0,2	0,2	0,2	0,4	0,4
EU to USA+CANADA+MEX	0,2	0,3	0,4	0,1	0,1	0,2	0,2	0,3	0,4

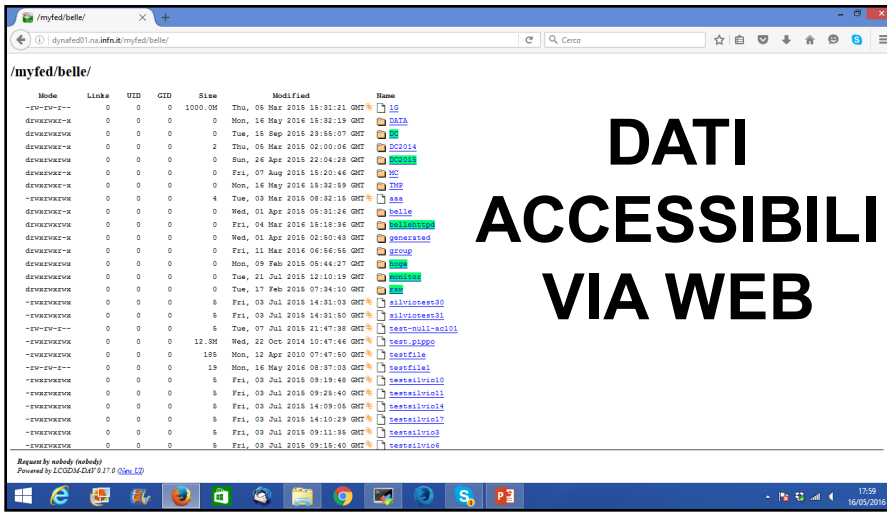
S. Pardi, G. Russo

Computing di Belle II: Sperimentazione HTTP

Coordinamento della sperimentazione per l'utilizzo dei protocolli HTTP e WebDav sugli storage di Belle II in sostituzione dei protocolli attualmente utilizzati.

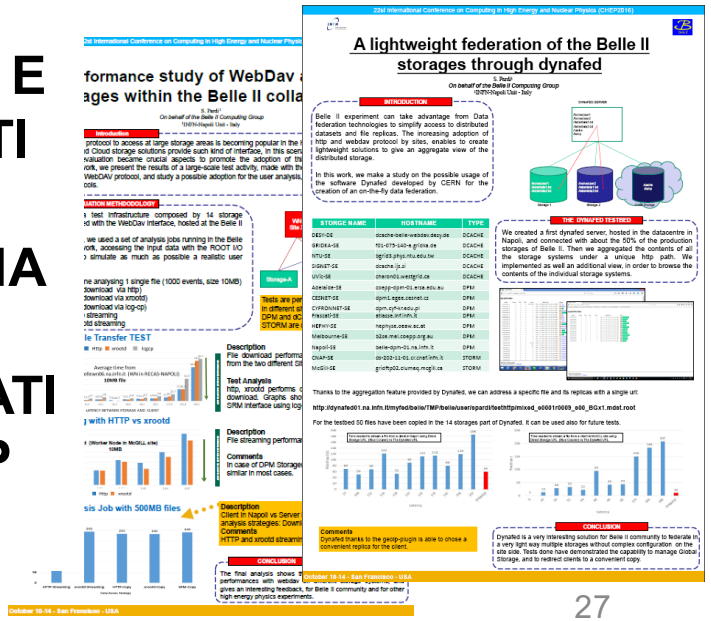
Gestione del server per la federazione di tutti gli storage via HTTP.

Partecipazione per conto di Belle II ai working group internazionali per l'utilizzo di HTTP.



DATI ACCESSIBILI VIA WEB

TESTBED E RISULTATI DELLE PERFORMANCE PRESENTATI AL CHEP 2016



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Organizzazione WLCG Workshop 2017

WLCG Workshop è uno degli eventi centrali per il calcolo distribuito negli esperimenti HEP.

Napoli si è candidata ad ospitare il WLCG-Workshop 2017 su richiesta del Management di Belle II, per il ruolo centrale riconosciuto alla nostra sezione nel computing.

Local Organization Committee (Prof. Guido Russo et al)

Responsabilità:

- Network Representative per l'Europa (Dr. Silvio Pardi).
- Management delle configurazioni degli Storage di produzione.

Presentazioni a conferenze per il 2016

Napoli ha rappresentato il Computing di Belle II in numerosi incontri internazionali

- «Computing in Belle II» - Fermilab - USA
- «Networking in Belle II»- LHCONE Meeting - Helsinki
- «Storage in Belle II» - DPM Workshop Paris
- «Computing in Belle II» – Condor Meeting Bologna -Italy

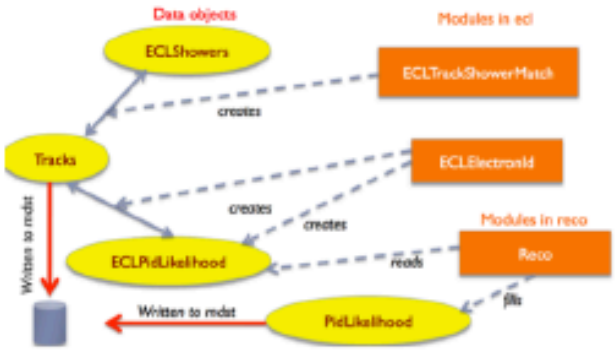
S. Pardi, G. Russo

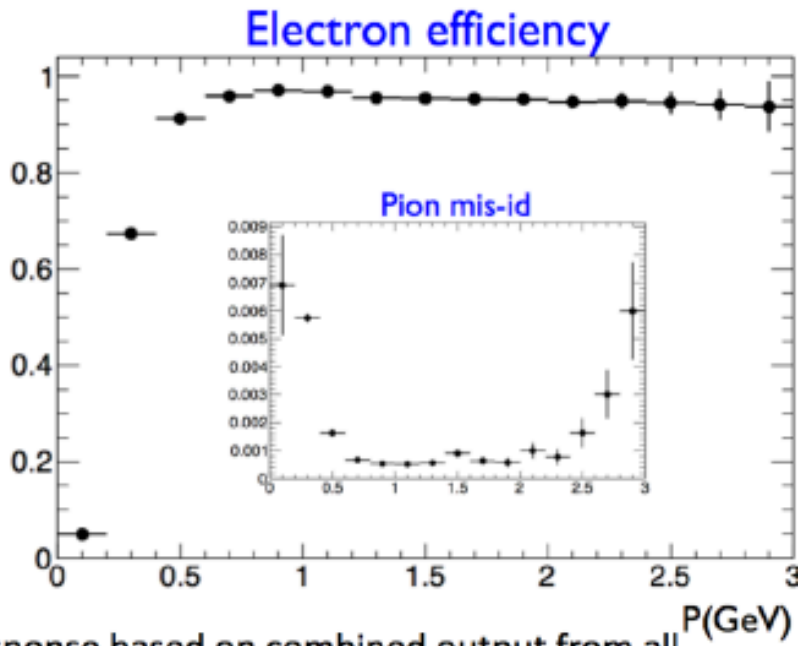
Attività software e analisi

- Identificazione elettroni
- Ottimizzazione ricostruzione neutri
- Primi studi sul decadimento $B \rightarrow \tau\nu$

Attività software - identificazione di elettroni

Responsabilità: Guglielmo De Nardo (NA)





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

Ottimizzazione ricostruzione neutri (fotoni e pi0)

Reconstruction Contacts and Recommendations

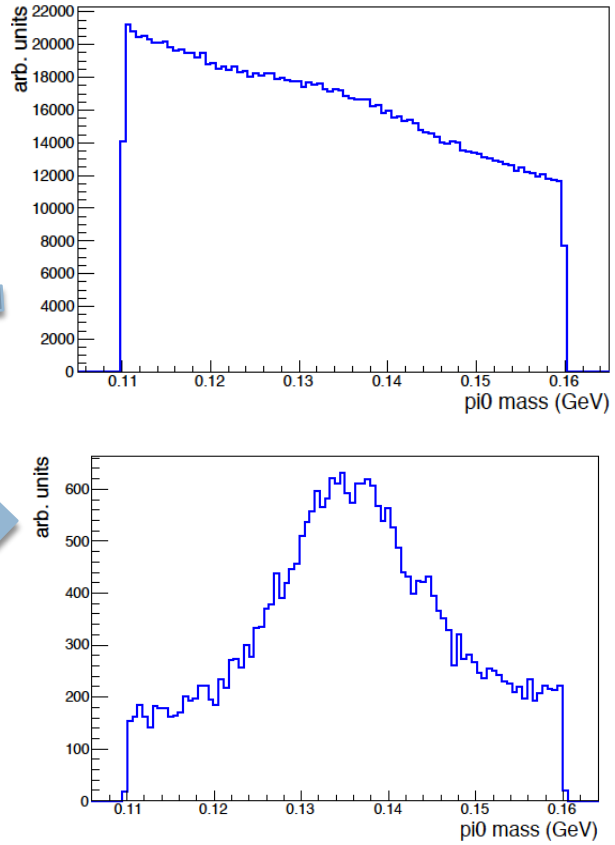
Tracking	@Eugenio Paoloni
ECL	@Torben Ferber
Electron ID	@Guglielmo De Nardo
Muon ID	@Leo Piilonen
K/π/p ID	@Todd Pedlar
K_L ID	@Jo-Frederik Krohn
V^0 reconstruction	@Markus Prim
dE/dx	@Jake Bennett
π^0 reconstruction	@Mario Merola

Neutral Particles and Clustering (@Torben Ferber)

Physics lists:

- Photon physics lists (@Torben Ferber, more people needed)
- Pi0 physics lists (@Mario Merola, @Torben Ferber, more people needed)
- K0L physics list (open, @Jo-Frederik Krohn ?)

pi0 reconstructed mass



Attività analisi

Leptonic, semileptonic and with missing energy B decays working group

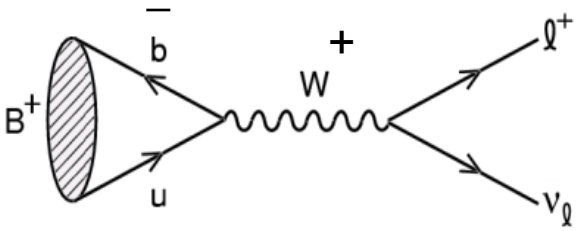
Leptonic			
Thomas Keck	Karlsruhe	PhD	B → τ ν with FEI
Felix Metzner, Moritz Gelb	Karlsruhe	PhD, PhD	B → l ν γ (hadronic + semileptonic tag) ‡
Mario Merola, Guglielmo De Nardo	Napoli	Staff	B → l ν tagged
Chanseok Park	Yonsei	Student	B → l ν with B2BII
b → c l ν			
Lucien Cremaldi, David Sanders	Mississippi	Staff	B → D* μ /e ν
b → c τ ν			
Abner Soffer	Nagoya Visitor	Staff & students	Vertexing to improve B → D(*) τ ν and B → μ ν
Giacomo Caria	Melbourne	PhD	B → D** l ν with FEI
Karol Adamczyk	Krakow	PhD	B → D* τ ν polarisation
Himansu Sahoo, Don Summers	Mississippi	Staff	B → D(*) τ ν
b → u l ν			
Alexander Ermakov	Melbourne	PhD	B → Xu l ν (inclusive)
Matic Lubej, Anze Zupanc	Ljubljana	Staff and students	B → π l ν and Bs → K l ν
Missing Energy			
Elisa Manoni	Perugia	Staff	B → K(*) ν ν tagged
Johannes Grygier	Karlsruhe	PhD	B → K(*) ν ν tagged
James Kahn	LMU	PhD	B → K(*) ν ν tagged
Sasha Glazov	DESY	Staff and students	B → K(*) ν ν tagged
Gianluca Inguglia	DESY	Staff	B → ν ν (γ)
Andrew Duong	Melbourne	student	B → K(*) l τ tagged

$B \to \tau\nu$

$B \to K^{(*)}\nu\nu$
in collaborazione
con Perugia

B leptonic decays (B → lν)

- Helicity suppressed

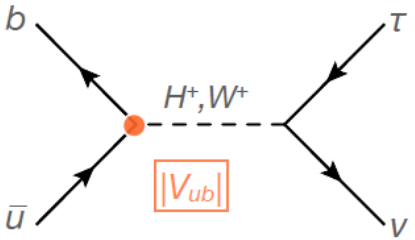


$$BR_{SM}\left(B \to \ell\,\nu\right) = \frac{G_F^2 m_B \tau_B}{8\pi} f_B^2 \,|V_{ub}|^2 \, m_\ell^2 \left[1 - \frac{m_\ell^2}{m_B^2}\right]^2$$

τ:μ:e –> 1 : 10^{-3} : 10^{-7}

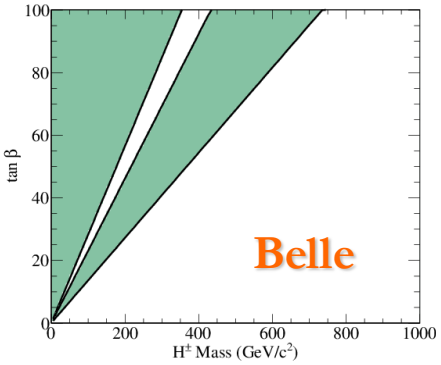
- The SM predicts a branching ratio of $\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = (0.75^{+0.10}_{-0.05}) \times 10^{-4}$

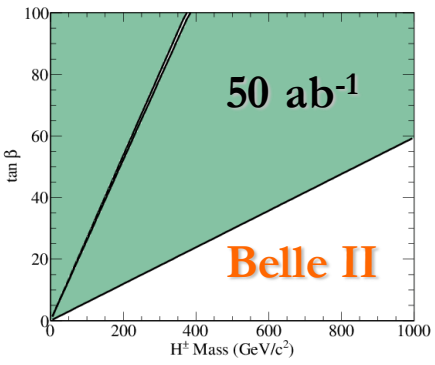
- Higgs doublet models predict interference with SM decay with a modification of the branching ratio



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

ratio of the two Higgs vacuum expectation values

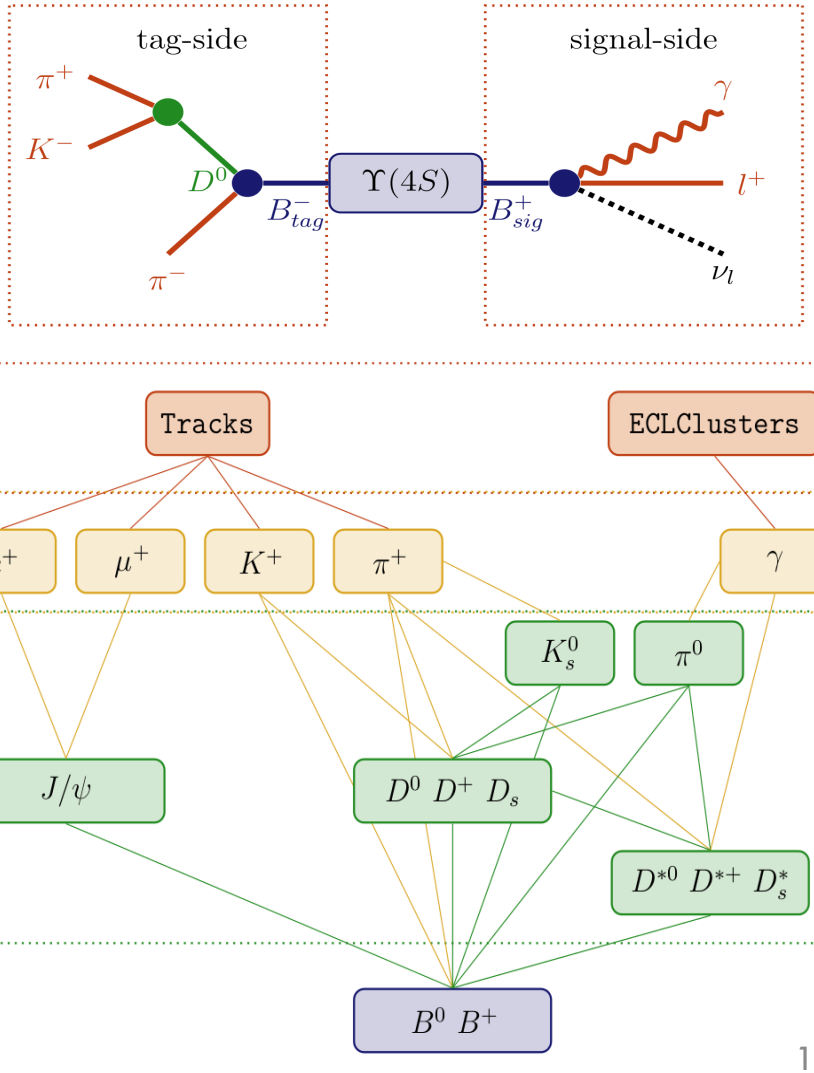




Full Event Interpretation (FEI)

• 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.



Event Selection

B tag side

Hadronic tag using FEI

1) Pre-selection on B-tag kinematics*
2) Cut on FEI output discriminant
3) Pick the highest sigprob B candidate

* Beam-constrained mass: $M_{bc} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$

* Energy difference: $\Delta E = E_B^* - E_{beam}^*$

B sig side

$B \to \tau\nu$

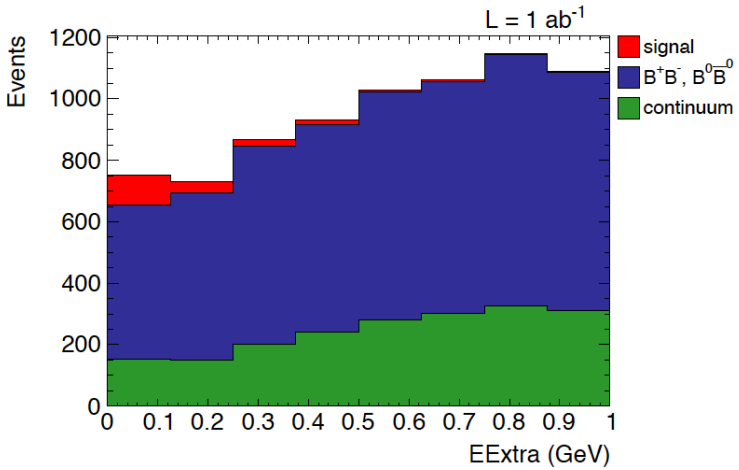
- 4 tau modes: $\mu\nu\nu$, $e\nu\nu$, $\pi\nu$, $\pi\,\pi^0\nu$
- PID, ECL cluster cleaning
- π^0 and ρ mass windows

Require full reconstruction of tag side and only one additional track in the event

- Reiezione eventi di fondo continuo ($e^+e^- \to q\bar{q}$) con tecnica multivariata (BDT)
- Tagli su variabili cinematiche quali la massa totale mancante e l'impulso della traccia dal lato di segnale

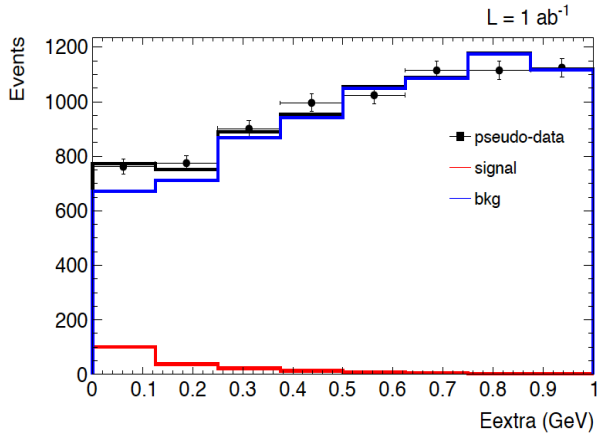
Expected sensitivity at L = 1ab^{-1}

E_{extra} distribution after selection



$E_{extra} < 1$ GeV	Babar PRD 88, 031102 (2013)	Belle PRL 110, 131801 (2013)	Belle II (this analysis)
Signal Efficiency (‰)	**0.72**	**1.1**	**2.2**

Example ML "template" fit to Eextra



- Signal extraction: ML "template" fit to Eextra
- Toy MC with 20000 pseudo-datasets:

$$BR(B \to \tau\nu) = 0.83 \pm 0.24 \times 10^{-4}$$

~30% precision

- Significance of the measurement evaluated with the CLb method: 3.4 σ (stat. only)

M. Merola, G. De Nardo

Questo studio entrerà nel physics book di Belle II

Grazie !

Backup

Belle paper

Belle paper, hadronic tag,
PRL 110, 131801 (2013)

Entire Belle data sample ~ 700 fb^{-1}

TABLE I. Results of the fit for $B^- \to \tau^- \bar{\nu}_\tau$ yields ($N_{\rm sig}$), detection efficiencies (ϵ), and branching fractions ($\mathcal{B}$). The efficiencies include the branching fractions of the τ^- decay modes. The errors for $N_{\rm sig}$ and $\mathcal{B}$ are statistical only.

Submode	$N_{\rm sig}$	ϵ (10^{-4})	$\mathcal{B}$ (10^{-4})
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$	16^{+11}_{-9}	3.0	$0.68^{+0.49}_{-0.41}$
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$	26^{+15}_{-14}	3.1	$1.06^{+0.63}_{-0.58}$
$\tau^- \to \pi^- \nu_\tau$	8^{+10}_{-8}	1.8	$0.57^{+0.70}_{-0.59}$
$\tau^- \to \pi^- \pi^0 \nu_\tau$	14^{+19}_{-16}	3.4	$0.52^{+0.72}_{-0.62}$
Combined	62^{+23}_{-22}	11.2	$0.72^{+0.27}_{-0.25}$

$$\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau) = [0.72^{+0.27}_{-0.25}(\text{stat}) \pm 0.11(\text{syst})] \times 10^{-4}$$

Significance: 3.0 σ